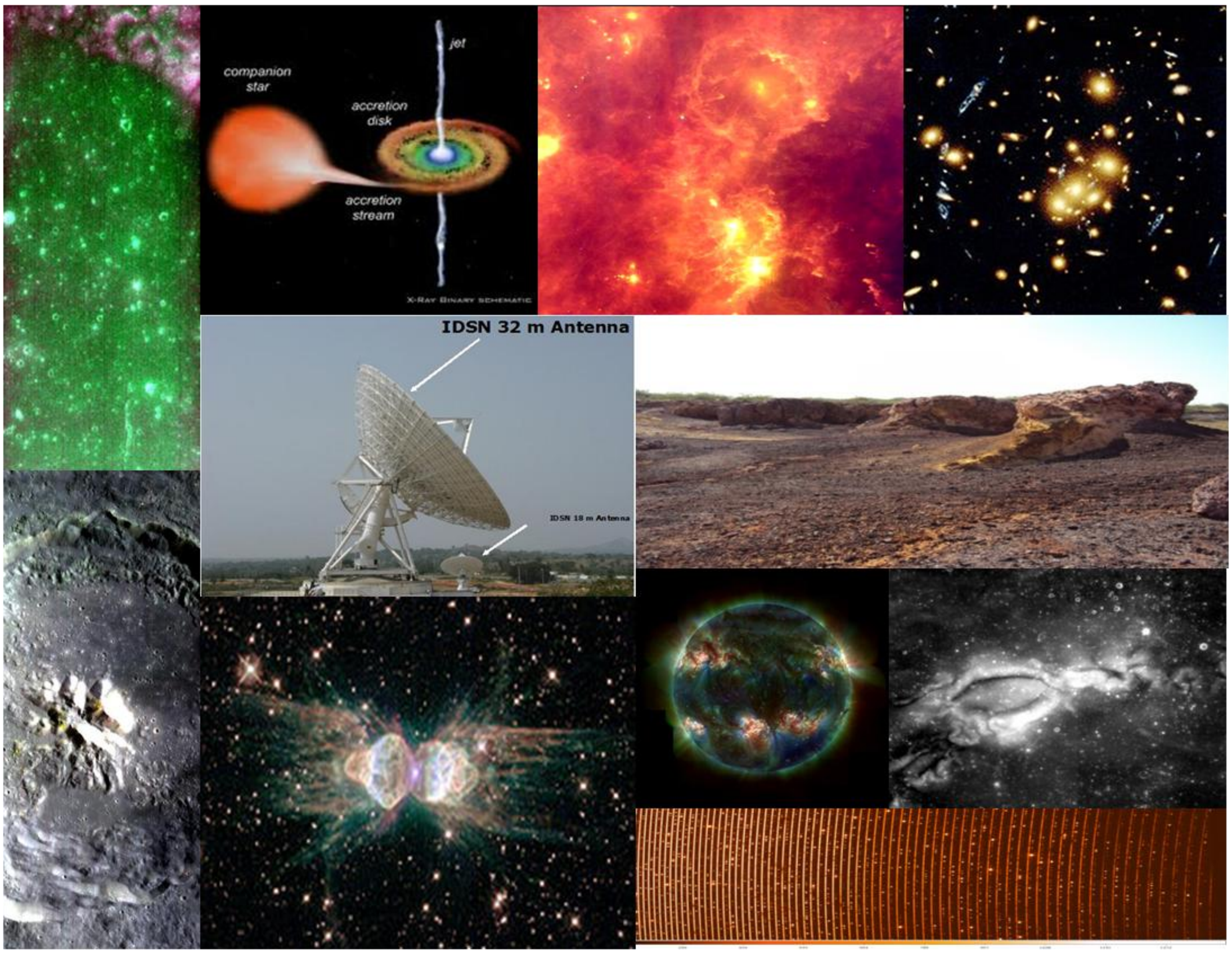
Signatures

Newsletter of the Indian Society of Remote Sensing –Ahmedabad Chapter

Volume: 23, No.4 November-December 2011

Special Issue on

Remote Sensing for Astronomy & Planetary Sciences



A Collage of Images appearing in this issue.

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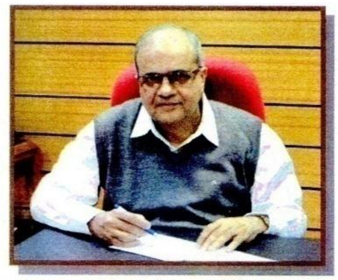

MESSAGE

Observing planets, stars and various other celestial objects, and their movement to understand and seek answers to the fundamental questions about the origin of the universe, evolution and formation of planets, stars and other celestial bodies has been an exciting field of science for the human kind since several centuries. While most of the observations earlier were limited to using earth based instruments, advent of space technology since the second half of the 20th century has made a quantum difference to this quest. Space-based remote sensing with its recent technological advances is playing a key role in looking at these celestial objects from close quarters. The short range photographs, stereoscopic data, measurements in various spectral ranges have given us insight on their mineral composition, surface geology, atmospheric constituents, gravity and even subsurface processes, based on which models of their origin and evolutionary history are being developed. India's first planetary mission Chandrayaan-1, contributed significantly to enhance this knowledge base of the lunar surface. The mission has also successfully ignited minds of younger generation of Indian students, and is hopefully attracting them to pursue this branch of science.

I am glad to know that the Ahmedabad chapter of the Indian Society of Remote Sensing (ISRS) is bringing out a special issue of `Signatures' on the theme of Planetary Sciences and Astronomy. Many articles covering details of results from Chandrayaan-1 mission, proposed missions including Chandrayaan – 2 and Astrosat and exploration on Martial atmosphere and the Sun, are covered in this issue. I am sure, this special issue of `Signatures' will receive very good response from its readers and encourages them to seek more details of new research happening in this exciting field. I wish the issue a grand success.

February 23, 2012

(R. R. Navalgund)

Signatures
Newsletter of the Indian Society of Remote Sensing –Ahmedabad Chapter
Volume: 23, No.4 November-December 2011

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A S Kiran Kumar
Associate Director

MESSAGE

The quest of mankind to understand our universe and in particular our own solar system is not new and since the early 16th century many great scientists have contributed to this desire using Earth based observation systems. However, in the recent times space has become a vantage point to observe the universe and solar system. Many space missions from various space agencies have contributed significantly to our present understanding about our own planet. India has joined the club of space faring nations by sending Chandrayaan-1 to the Moon's orbit and many studies related to Planetary Sciences have been initiated. The eleven instruments of this spacecraft provided excellent data sets on various scientific aspects of the Moon. Today ISRO has definite plans for a follow-on lunar mission and work is in advanced stage for the development of Chandrayaan-2 payloads. Apart from Moon there are plans to study Sun through the Aditya mission and AstroSat satellite will provide vital information about distant celestial bodies. Scientists are also interested to study various science aspects of the Mars. In view of these developments, planetary and astronomical sciences will receive new data from space missions.

I am pleased to note that Ahmedabad chapter of Indian Society of Remote Sensing (ISRS-AC) is bringing out a special issue of their newsletter *Signatures*, on the theme of Remote Sensing for Astronomy & Planetary Sciences. I understand that this issue will have articles related to planetary remote sensing techniques, results on Chandrayaan-1data analysis, exploration of Martian atmosphere and surface etc. Articles are also planned about the future Planetary Science missions in simple and easy to understand language. I am confident that this issue of "*Signatures*" will evoke interest from its readers and will help them appreciate the progress in Astronomical and Planetary Remote Sensing.

(A S Kiran Kumar)

भारतीय अनुसंधान संगठन INDIAN SPACE RESEARCH ORGANISATION

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Volume: 23, No.4 November-December 2011

Inside this Issue

Signatures

Newsletter of the Indian Society of Remote Sensing –Ahmedabad Chapter

Volume: 23, No.4 November-December 2011

Moon Specific

Mars Specific

Sun Specific

General

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From the Chairman's Desk

Dear Readers,

I have great pleasure in reaching out to you all, the members and well-wishers of Indian Society of Remote Sensing – Ahmedabad Chapter once again through *Signatures*. I convey my greetings and best wishes to all of you. The previous issue of *Signatures* was well received by our members. In the intervening period since the last issue was released, we had organized a workshop on Geoinformatics for Urban Planning along with the local chapters of ISG, INCA and IMS Societies, and that received a very good participation from members and students. This issue of *Signatures* focuses on the theme: *Remote Sensing for Astronomy & Planetary Sciences*. Several renowned persons, designers and the scientists who are working in the field of Astronomy & Planetary Sciences have contributed to this special issue through their brief and vivid articles on the focal theme. We had Dr. Prakash Chauhan as guest editor for this issue.

This issue also contains Interviews with Prof J.N. Goswami, Distinguished Scientist, Director, PRL, Ahmedabad and Prof. Carle Pieters, Brown University, USA apart from the regular Chapter news. We have messages from Dr. R R Navalgund, Director, SAC & President, ISRS and Shri. A S Kiran Kumar, Associate Director, SAC. I thank all Authors, Dr. R R Navalgund, Shri. A S Kiran Kumar, Prof. J N Goswami & Prof. Carle Pieters. I am extremely happy to see this current issue in its final form. I am sure that ISRS Members will be immensely benefited from the information given in this issue.

The Jan-March 2012 issue of *Signatures* has been planned to be brought out as a special issue on the theme "**Future Trends in Remote Sensing**". I take this opportunity to invite all of you to actively contribute to the objectives of ISRS by taking part in the Chapter events and contributing to *Signatures*

Wishing you all the very best,

Theme for the forthcoming issue of *Signatures*:

Jan-Mar 2012: Future Trends in Remote Sensing

From the Guest Editor's Desk

The current issue of Signatures is in your hand. This issue is mainly focused on newly evolving remote sensing technologies aimed towards Planetary Exploration and Astronomy and associated scientific results. With successful Chandrayaan-1 mission to Moon and subsequent data analysis from various payloads, Planetary Science studies in India have really emerged in a big way. All the instruments of this spacecraft provided excellent data sets on various scientific aspects of the Moon. Chandryaan-2 is going to be the next excitement and will show case new technologies in the context of Lander/Rover and orbiter configuration. Excellent science results are expected from Chandayaan-2 mission. Apart from Moon, ISRO has definite plans to study Sun through the Aditya mission and distant celestial objects through Astrosat satellite. Today a strong scientific interest exists to study various aspects of the Planet Mars as well. In view of these developments, it is perceived that planetary and astronomical sciences will be the thrust areas in coming times.

Keeping these expectations in mind, this issue of *Signatures* has been brought out as a special issue on the theme of Remote Sensing for Astronomy and Planetary Sciences. This issue contains articles related to planetary remote sensing techniques, results on Chandrayaan-1 data analysis, exploration of Martian atmosphere and surface etc. Some articles cover details of the future Indian Planetary Science and Astronomy missions. All articles of this issue are contributed by eminent scientists and technologists working in this challenging area of remote sensing and are written in simple and in easy to understand language.

I hope that this issue of *Signatures* will be received well by all of you. It will also be helpful in knowing the progress being made in Planetary and Astronomy related Remote Sensing. We are also carrying interviews of two very eminent personalities in this issue. Prof. J N Goswami, Director, Physical Research Laboratory (PRL), Ahmedabad is a well known planetary scientist and his contribution to Planetary Sciences, as Chandryaan-1 Principal Investigator is well recognized. Second interview is with Prof. Carle Pieters of Brown University, USA. She is an outstanding lunar geologist and has contributed to the progress of Lunar geosciences in a significant manner.

Last but not the least, I would like to place my sincere thanks to the editorial committee of *Signatures*, to provide me this opportunity of being a guest editor of this important and interesting issue. Happy Reading.

Prakash Chauhan,
Head, Planetary Sciences & Marine Optics Division,
Space Applications Centre, (ISRO)
Ahmedabad

An Interview with Prof J.N. Goswami, Distinguished Scientist & Director, PRL, Ahmedabad

Signatures : Thank you sir, for accepting our request to give interview on research and development in Planetary & Astronomy sciences. Sir, Can you kindly give a brief summary of the science pursuits in planetary science and astronomy all over the world?

Prof. Goswami: These fields currently cover so many areas of research that an adequate preview or review at the global scale is very difficult. I am not going to talk about Astronomy at length, except the fact that expansion of our universe is not exactly following the Hubbles law, which states that the speed of expansion depends on the distance of a celestial object (star, supernova, galaxy) from the observer. In fact, the universe is found to be expanding at an accelerated pace. The noble prize for Physics in 2011 has been awarded for this discovery that was based on studies of a set of particular type of supernova situated at different distances from us. This result suggests that our universe is dominated by dark energy which is responsible for the observed accelerated pace of expansion. We know that there is non-luminous dark matter in our universe, that we cannot see but could detect based on the gravitational force they exert in galaxies, and with dark energy now accounting for close to 80% of the universe, what we can see and call normal matter constitute only ~5% of the universe.

In planetary sciences, understanding more about the origin and evolution of the solar system, and in particular, exploration of our close neighbors, Moon and Mars, is a major agenda of all the space agencies across the globe. There is a definite thrust to see if we can find any planet other than our own Earth that may harbour any living/fossil form of life. One guiding principle in this effort is to look for presence of water, in extant or extinct form, on any planetary body, as water is considered crucial for evolution of life. NASA has a very strong programme for exploration of possible extant/extinct life forms on Mars.

The other prime targets are pristine solar system objects, the Comets and Asteroids. NASA as well as European and Japanese Space Agencies (ESA and JAXA) have already probed and have ongoing missions and future plans to probe these objects that provide clues for delineating the early history of the solar system.

An Interview with Prof. J. N. Goswami

Exploration of outer planets and their satellites is also important. The satellites in particular have extreme characteristics, from surface covered with ice to active volcanism. NASA and ESA do have major plans for exploring such objects.

We, in India, can meaningfully explore the inner solar system with ISRO capabilities. We have started planetary exploration with Chandrayaan-1 for exploring the Moon and following this with the upcoming Chandrayaan-2. The next obvious target for us will be Mars. We need to develop technologies to meaningfully explore Venus that has a thick and hostile atmosphere or to explore Mercury, which is very close to Sun and this will take its own time. The same is true for exploring outer solar system, where we need more advanced communication facilities because of the distances involved, and more importantly, alternative energy resource for the spacecraft as solar energy will no longer be sufficient at such distances from the Sun. Nonetheless, we can explore asteroids and comets within the inner solar system with our present resources and obviously they will be our targets after exploration of Mars. It is also important for India to develop technologies needed for a mission having a landing module. As you know, in Chandrayaan-2, we are collaborating with Russia who will provide the Lander.

Signatures : What are the major achievements of the scientific community in the field of planetary sciences in the last 10 years?

Prof. Goswami: There are many, the more recent ones include discovery of water on moon by Chandrayaan-1 to presence of methane lakes in Titan and of course growing evidence of presence of water on Mars in the distant and more recent past that raises the question of possible extinct or extant life on Mars. We now have samples returned from Comets by Stardust mission of NASA and from an asteroid by the Hayabusa mission of Japan for laboratory studies. I am sure that the ongoing missions to Mercury, Venus, asteroid and comet by NASA and ESA will provide many new insights about evolution of these objects.

Signatures : The field is exciting and it caught the imagination of the men since ages. We have planetary sciences programmes based on ground based observations, satellite based observations, space probes, interplanetary missions etc. What is the recent progress made in each of the approaches?

Prof. Goswami: Ground and space-based observations complement each other. When our atmosphere acts as hindrance in making ground based observations, we have to depend on space based observations. For any detail studies of the surface of a planetary body, we need a close up view to characterize features at small scale lengths. The case for such a dependency can be seen in the new exciting field of exo-planets, planets in other solar system. The beginning was made in 1995 when European astronomers detected the first exo-planet using ground-based telescope. By 2009, the number of possible planetary systems around sun-like stars has reached a few hundred. The launch of Kepler mission, a dedicated space-based search for exo-planet, a few years back has increased the number of possible exo-planets in other solar systems by a few thousands. However, except in a few cases, the Kepler observations need to be substantiated by ground-based observation to know the details (e.g., the mass of the exo-planets). In fact, we have started a programme at PRL in this direction and the in-house built spectrograph tested recently by integrating it to our Mt. Abu observatory yielded very encouraging results. I feel, in a year or so, we should be able to conduct search for exo-planet in India and also verify some of the Kepler results and provide additional details. Thus, multi-prong approach is essential in planetary research and it includes laboratory studies of planetary samples as well.

Signatures: Can you tell broadly which are the institutes in India who have taken up research in Planetary sciences and in what specific fields?

Prof. Goswami: Until about a decade back, PRL was the only place where planetary science was a major field of research. It had its root during the Apollo era when PRL was one of the NASA approved center for lunar sample studies for delineating past solar and galactic cosmic ray records. These studies were complemented by studies of meteorite samples that are fragments of asteroids. There were sporadic studies of planetary rings, planetary and cometary atmospheres, search for new asteroids etc. at a few other places in the country. However, with the initiation of planetary exploration programme at ISRO, systematic effort has been made to enhance research activities in the field of planetary sciences within the country. At present there are half a dozen institutes and more than a dozen universities that conduct studies on different aspects of planetary science that are supported by ISRO's Planetary Science and Exploration (PLANEX) programme. Following the successful Chandrayaan-1 mission, we now have additional groups involved in analysis and interpretation of data from this mission and also data from US and Japanese lunar missions. Analyzing of data obtained by missions to Mars and Venus has also been taken up by a couple of groups. A majority of the ISRO centers now have a dedicated group involved in analysis and interpretation of data from planetary missions. I am very optimistic about future of planetary science research in India.

Signatures: We have amateur observers with lot of enthusiasm and whether there is any systematic way or mechanism of integrating these studies and put them in better scientific perspective?

Prof. Goswami: It is a difficult proposition. I find that most amateur observers have a reasonable background of the subject. However, in most cases this may not be adequate for a scientific analysis and this can be partially corrected if there is an easy channel for communication with professional researchers. The lack of adequate number of professional researchers (at present) makes this a difficult proposition. However, at individual level many amateur observers do keep contact with professional persons and some of them have also written good scientific articles.

Signature: We have giant telescopes in optical, radiol and other EM waves based all over the world. Do we have such observatories in India? How effective are our ground observation telescopes, so that high quality astronomy and planetary sciences can be pursued in India.

Prof. Goswami: I feel we have reasonable facilities in terms of ground-based observations. We have 1-2 meter class telescopes at Kavalur, Mt. Abu, Hanley (Ladakh), Pune and Nainital (where we will soon have a 3.5 m telescope). We have two radio-telescopes at Ooty and at Pune, the later (Giant Meter wave Radio Telescope [GMRT]) is a unique facility at global level. There are plans to have more improved solar observatories (one is coming up at Udaipur), and also possible participation in large telescope programmes based on international cooperative effort.

Signatures: Do our scientists have working arrangements with world over observatories?

Prof. Goswami: As far as I know only UGC through the Inter University Center for Astronomy and Astrophysics (IUCAA) have a working arrangement for time sharing on a large telescope in South Africa. It is also possible to have observation time elsewhere through collaborations and this is an approach taken by many Indian astronomers. In some observatories, including space-based observatories, time is also allotted to scientists based on proposals made and Indian astronomers have been able to conduct observations through this avenue also. Of course certain observatories charge fee and one can use instruments and facilities available with them for observations.

Signatures: Common man have superstitions about eclipses and they fear of catastrophes/ bad effects associated with eclipses. Scientists look for and wait for eclipses to unravel many truths about Sun and other stars. Can you give a summary of the advances made in scientific analysis during eclipses and how is the preparedness of scientists for the eclipses?

Prof. Goswami: Eclipses, in particular total solar eclipse, provide the best opportunity to study the solar corona, the outermost tenuous layer of the sun, in great detail. Our understanding of many coronal features and phenomena are based on such observations. However, the short duration of the eclipse does not allow an in-depth study to look for time variations etc. Using space-borne instrument one can now create perpetual eclipse condition by masking the light coming from the solar surface. The "ADITYA" mission of ISRO, that is currently being designed, will be based on such an approach to study properties of solar corona and phenomena occurring within it, as close to the solar surface as possible. We can look forward to some interesting novel observations from this mission.

Signatures : India's experience for the first Lunar mission is considered a great success. Sir, you had played a key role in Chandrayaan-1 mission. How could we achieve this? What is the road ahead for Lunar exploration program?

Prof. Goswami: The technological as well scientific success of the Chandrayaan-1 mission was the result of very hard work and dedication of a large group of people who gave their best for a mission that has become a national entity unlike any other mission of ISRO.

Since the mission was mainly conceived as a science mission the decision to take foreign payloads, that are compatible with the pre-defined science goals of the mission, enhanced the science content of the mission. In fact, this was necessary as at that time (in 2003-4) many of the high end detectors made in USA, Europe and Japan and needed for in-depth probing of the lunar surface (e.g., infrared and X-ray detectors) were not made available to India. I may add that the situation has changed by the time we have initiated payload selection and development for the Chandrayaan-2 project and we shall be having only Indian payloads in the Orbiter and Rover. We now have free access to the detectors needed for all the payloads.

Detection of water on lunar surface was the most important new observation from this mission, However, there are also several other firsts, that include possible presence of a very tenuous exosphere with water and carbon-di-oxide molecules, new results on solar wind-lunar surface interactions and observations of new lunar rock types. The impact of science return as well as management of this mission can be gauged from the fact that this mission has received several international honours and has been hailed as a model for international cooperation in planetary exploration in various international forums.

Signatures: How do you see the future of Indian Planetary Science and Astronomy programs and your comments on their effectiveness to attract young talents towards this emerging area.

Prof. Goswami: I feel in both Planetary Sciences and Astronomy, there is a great potential in India and I am optimistic about the future. Yes, attracting young talents towards basic research in the current social and cultural ambience is not as easy as it was several decades back. However, it is not necessary to have a large number; what is needed are a good number of young people committed to research and long-term goals. From my personal experience, I am already seeing a trend amongst young people that is more positive than the scenario about a decade back. I also feel that long term science plans in these fields with well defined targets and timelines are necessary both to attract and engage the young people with challenging and constructive activities. If this can be done I am sure young people will be excited to join an adventure that has challenging goals and well defined timelines.

Signatures: Thank you very much sir, for your valuable time.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures* in their own words, either as a brief survey of state of the art or as articles on novel dream concepts related to the specific theme ***"Future Trends in Remote Sensing"***.

The deadline for inclusion in the next issue is **March 20, 2012.**

- Editorial Team

Astronomy & Planetary Sciences

Planetary Exploration

Prof. Narendra Bhandari, PRL, Ahmedabad

Half a century of planetary exploration, since space age began with sputnik orbiting the earth in 1957, has given us valuable information about all the major bodies of the solar system. Various planetary bodies have been studied using three basic approaches: by remote sensing techniques, by landing instruments on planets to carry out experiments and by laboratory analysis of samples brought back by sample-return missions. Among these methods, remote sensing has played a vital role and the short range photographs have made even far off objects familiar and given us some idea of various processes occurring on their surfaces. Besides, some techniques have given us a good understanding of their chemical and mineral composition, gravity, surface geology, atmospheric constituents and even subsurface processes, based on which models of their origin and evolutionary history have been developed.

The main motivation for exploration of planets is primarily to understand processes leading to the formation of planetary systems, their satellites, rings, comets and asteroids, their atmosphere and environment, how they have evolved over ages and the possibility of life beyond earth. Besides, it is also desirable to determine the possibility of habitability of other planets if we want to nucleate civilizations there. For this purpose planetary resources need to be assessed. The first 100 million years of the history of planets is important if we have to understand their origin and processes which have shaped our solar system. Prime objects where such information is available are comets, asteroids, Kuiper Belt Objects and, of course, meteorites, which nature brings to our doorsteps free of cost. For evolutionary studies we may divide the planets in two groups: the inner rocky planets (Moon, Mercury, Mars, Venus and Earth) and the outer giant gaseous and icy planets (Jupiter, Saturn, Uranus and Neptune). Candidates for life forms existing in the past or present now are Mars and Jovian satellites (Europa, Ganymede and Callisto) where features made by flowing water (rivers, channels, sediment deposits) or water reservoirs in the past (lakes etc) have been found. Water, volatiles, and organics form vital components as resources for human habitation and Polar Regions of Mercury, Moon, Mars, Jovian satellites, Outer planets and satellites (Titan, Enceladus) are primary candidates where some of these may exist.

By now, all the planets and most of their satellites and rings, and minor bodies (asteroids and comets) etc have been photographed from close distance and examined using remote sensing and landing techniques. Most common remote sensing techniques are based on the electromagnetic spectrum. Usually the solar radiation, incident on the object is used as the primary incident spectrum and various features in the returned spectrum produced by the interaction of surface material are used to determine the properties of the material. Sometimes a strong radiation source with known characteristics is also employed for primary incidence. The Ultraviolet, optical, near and far infra red, atomic and nuclear radiations (X rays, alpha and gamma rays), analysed using suitable detectors, allow us to obtain different characteristics of the surface and near surface materials. Absorption of spectral lines gives information about minerals present. Atomic and nuclear properties e.g. characteristic X rays and alpha particles and gamma rays emitted by atoms and nuclides present or induced by energetic solar or galactic particles give information about chemical and radioactive constituents. The detection techniques employ alpha particle detectors or scintillators or semiconductor detectors. These techniques have continuously improved with the development of ever increasing sensitivity and resolution of detectors and have now attained a high degree of perfection. The chemical composition is best determined by analyzing the characteristic X-rays emitted by certain elements (e.g. Mg, Al, Si, Ca and iron) present in the planet's surface material, when excited by solar X rays, specially during strong X-ray flares. Water or ice has absorption features between 1.8 and 3 microns and use is also made of neutron absorption by hydrogen present in water. Neutron detectors have been employed for determining neutron spectrum which may indicate presence of water or ice. Doppler shift measurements enable us to determine gravity fields on different bodies and radar can provide some subsurface information.

The past decade, has seen great strides in planetary exploration. The ***Genesis*** mission brought back the first solar wind sample in 2001, **Hayabusa** brought back the first asteroid samples of Itokawa in 2003 and ***Star Dust*** mission brought back the first comet sample from Wild 2 in 2006. The study of these small but scientifically precious samples led to a deep insight into the way these bodies formed and conditions prevailing in the infant solar nebula. For example the solar particles caught by the silicon wafers on ***Genesis*** showed that the Sun has a higher proportion of oxygen-16 than the Earth. This implies that oxygen-16 from the Sun's protoplanetary disc was depleted prior to the coalescence of dust grains that formed the Earth. Itokawa and Eros both were found to be S type asteroids whose compositions match low iron group stony meteorites. Earlier ***Galileo*** mission had found binary asteroids, a small moonlet Dactyl going around another ,slightly larger asteroid Ida. The ***DEEP IMPACT*** **Mission** impacted on comet TEMPEL and thousands of kilograms of dust and water was ejected due to this impact. Its analysis showed clays, carbonates, sodium and silicate grains and also traces of ethane. There was more dust and less ice than expected, contrary to "the loose dust" model of cometary surfaces. The crater so created by impact became obscure due to the ejected dust and was photographed later in 2007 by another mission, the extended ***Star Dust*** Mission. The samples of comet Wild 2 brought back to earth by ***Star Dust*** showed high temperature minerals like anorthite, calcic pyroxene, spinel and Al-Si rich glass indicating that comets like Wild -2 were not formed in isolation but high temperature material from close to the sun got transferred to the far away comet forming regions. Absence of a short lived radioisotope Aluminum-26 showed that such a transfer took about ~2 million years, during which this radioisotope had decayed. This calls for a revision of the models of exchange of material in the infant solar nebula and formation of comets. An organic compound glycine was also discovered in this comet. Thus important pieces of information were obtained by these missions.

During the past decade remote sensing studies were carried out by orbiters around several planets which included Mercury, Venus and the outer planets. ***Messenger*** which was launched in 2004 arrived on Mercury in 2011 and has already started sending good data which suggest that Mercury was formed in a highly reducing environment. ***Venus Express***, launched by European Space Agency in 2005, was captured in a polar orbit around it in 2006 and has been sending data about Venusian atmosphere all along. The ***Cassini-Huygens*** launched in 1997, explored the outer planets and made many discoveries related to Saturn and Titan. It discovered three new moons of Saturn, subsurface water on Phoebe as it flew past this satellite, and water on Enceladus. ***Huygens*** probe which landed on *Titan* in 2005 discovered large hydrocarbon (ethane and methane) lakes, hundreds of kilometer in size. **NEW HORIZON** was the first *Pluto-Charon* and Kuiper Belt Objects Flyby mission. ***Dawn*** mission, launched in 2007, has already orbited asteroid Vesta and will soon orbit Ceres, making a detailed study by remote sensing techniques. A major breakthrough was attained with discovery of over 1000 Exoplanets outside our solar system in the past two decades

Mars was the center of exploration by NASA and the twin rovers ***Spirit*** and ***Opportunity*** roamed over the martian surface for many years, finding Blue berry like spherules, vugs, and sedimentary mineral e.g.

sulfate, jarosite and hematite, as if salty sea shore existed there. The mission also provided atmospheric temperature profile. The latest addition to the large number of missions is the ***Mars Science Laboratory*** with a highly advanced rover ***Curiosity***, which arrived on Mars only a few weeks ago.

Moon continued to be the prime target for exploration and Japan with ***Selene (Kaguya)***, China with ***Change'-1*** and **2** and India with ***Chandrayaan-1*** became new members of the space club, and with NASA, ESA and Russian Space Agency, there are now six space faring agencies with over 20 nations participating in one way or the other.

One of the significant findings of the past decade is the discovery of water everywhere in the solar system. Now we know that poles and even some deep craters on Mercury, polar regions of Moon, and as **Chandrayaan-1** and **Lunar Reconnaissance Orbiter** found out, environmental, surficial and subsurface water may exist on Moon. Many missions have found evidence of flowing water channels on Mars and sediment deposits bearing testimony to abundant water on this planet in the past and even now in form of ice. The possibility that intense volcanic episodes and some large impacts from the nearby asteroidal belt can dig out sub-surface water and create a temporary atmosphere for thousands of years, in which life can survive or evolve, have revived our interest in finding some extinct or extant life forms there. Several asteroid (e.g. Eros) and many types of meteorites, originating in various asteroids, have shown presence of water or hydrated minerals. Among the satellites, Europa, Ganymede and Callisto have ice on their surfaces and may even have subsurface saline water oceans. As already mentioned active geysers have been found on the saturnian moon Enceladus. Many other satellites or minor planets e.g. Titania, Oberon, Pluto, Triton and Rhea are all good candidates for water and water can as well exist in some atmospheric layers of Jupiter, Neptune and Uranus. Adding to this long list is the hope that many earth- like planets may exist outside the solar system. The ***Kepler*** mission found the planet Kepler 22b which has habitable atmosphere and many more such exoplanets may exist.

Even with this brief and selective summary, it is apparent that the past decade has been an exciting period for planetary exploration . The present decade with Jupiter-Uranus- Neptune orbiter, ***JUNO*** already launched in 2011, Two lunar probes ***GRAIL*** and ***LADEE*** scheduled for 2012, a mission to study Martian Atmosphere and volatile evolution ***MAVEN***, to be followed by ***Exomars*** for Mars landing and subsurface study in 2016, an ambitious Mercury probe ***Bepi Colombo***, two asteroid lander and sample return missions ***Hayabusa-2*** and ***OSIRIS REX*** and ***EPOXI*** for comet Hartley-2 encounter looks even more exciting. To this ambitious program we may add some more moon landers e.g. ***Chang'e-3, MOON NEXT***, Russian robotic moon mission ***LUNNYJ POLIGON***, Jupiter Icy Moon explorer, Titan-Saturn System mission and asteroid and manned Moon missions in another one or two decades. ISRO also has a very ambitious plan of exploring the solar system. After successful completion of Chandrayaan-1 mission, launched in 2008, Chandrayaan-2 mission which will have lander and a rover is in advanced stage. It is scheduled to be launched in 2013. Already a Mars orbiter is being discussed for the next launch window in 2013 or 2016.

All these advancements have become feasible because of developments in robotics, remote sensing and detection techniques. Establishment of a permanent human base on Moon, manned landing on Mars and existence of life elsewhere in our solar system or beyond appears more promising than ever before. The future of planetary exploration indeed looks exciting.

Origin of the Solar System

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Introduction: Not many years ago the beginning of the solar system was thought to be virtually synonymous with the act of creation itself. Even Newton's own calculations on the rate of cooling of a molten iron sphere led him to conclude that the surface of such a sphere would not become inhabitable until after the passage of about 50,000 years. This heretical conclusion, he ultimately rejected himself. It has been recorded that Newton adopted the pious attitude that the issue of the origin of the solar system was beyond scientific discussions. It is said that Newton was perhaps inclined to accept Archbishop Ussher's pronouncement that the Earth was created at 9:00 A.M. on October 26, 4004 B.C. Today, astronomy teaches us that the universe is much, much larger than our solar system. More significantly for the issue of origins, geology, through radioactive dating, teaches us that the solar system is appreciably, but not overwhelmingly, younger than the oldest object in the universe. Thus the solar system must have been formed against the backdrop of an already mature universe, and we can hope to trace our roots to an era where the clues are not hopelessly obliterated by the cleansing fires of the primeval fireball.

The nebular hypothesis: The most widely accepted theory of the solar system formation, known as the nebular hypothesis, maintains that 4.6 billion years ago, the Solar System formed from the gravitational collapse of a giant molecular cloud which was light years across. Several stars, including the Sun, formed within the collapsing cloud. The gas that formed the Solar System was slightly more massive than the Sun itself. Most of the mass collected in the centre, forming the Sun; the rest of the mass flattened into a protoplanetary disc, out of which the planets and other bodies in the Solar System formed. The nebular hypothesis was first proposed in 1734 by Emanuel Swedenborg and later elaborated and expanded upon by Immanuel Kant in 1755. A similar theory was independently formulated by Pierre-Simon Laplace in 1796. The modern version of Kant and Laplace's nebular theory has following main points to note.

1. A rotating nebula forms out of a self gravitating (gravitationally collapsing) cloud of interstellar gas and dust. This collapsing blob of gas and dust spins faster and flattens due to the law of the conservation of angular momentum. Under some conditions, the gas cloud breaks into two or more self gravitating lumps, which subsequently forms a binary or a cluster stars. Under some other conditions, a rotating nebula forms with a central concentration surrounded by a rotating disk of gas and dust (solar nebula).
2. The solar nebula later condenses into many small pieces leading to the formation of asteroids and protoplanets. These protoplanets are self garvitating and grow into full-scale planets by accreting neighbouring piece of material. The formation of the solar system under these dissipative circumstances explains why the planets around the Sun contain 98% of the total angular momentum while 99.9% of the total systems mass resides in the Sun. the laws of dissipation in gaseous medium also explains, why the orbits and spins of the planets are coplanar and aligned, with the orbits being nearly circular.
3. As the outer portion of the cooling solar nebula cools faster, the formation of the Jovian planets (giant outer planets of the solar system i.e. Mars onwards) get a head start, accreting large enough masses of the gases near them and in solar nebula. This explains their giant sizes and the large spacing between these Jovian planets. In the contrary, the terrestrial planets (first four planets close to the Sun) get late start and never acquire a large fraction of the nebular material before the central part collapses to form the Sun and the solar wind sweeps the system clean of gas and small

solid particles. The asteroid belt is all that remains to indicate the larger debris that used to litter much of the solar system.

4. The scaled-down version of this scenario may have led to the formation of satellites around the planets and ring systems of the giant planets. Figure 1 shows various steps that nebular theory proposes.

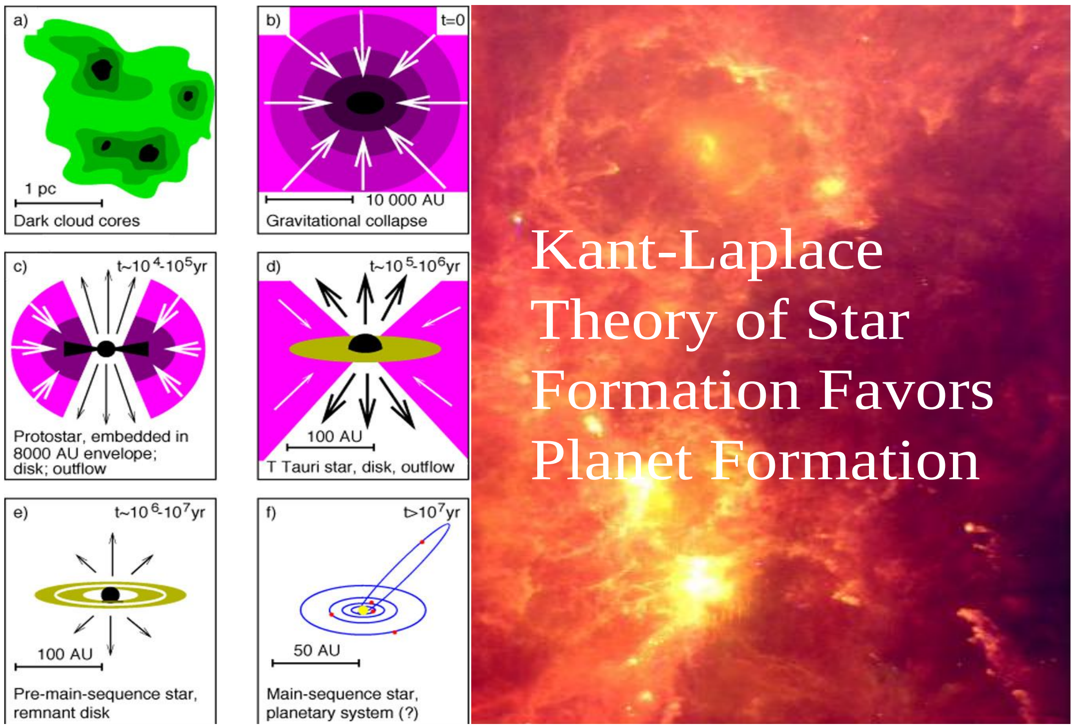

Fig 1 : Various steps required for the formation of planetary system as proposed in nebular theory.

Alternative theories: The nebular hypothesis initially faced the obstacle of angular momentum; if the Sun had indeed formed from the collapse of such a cloud, the planets should be rotating far more slowly. The Sun, though it contains almost 99.9 percent of the system's mass, contains just 1 percent of its angular momentum. In 1978, astronomer A. J. R. Prentice suggested that the angular momentum problem could be resolved by drag created by dust grains in the original disc which slowed down the rotation in the centre.

In 1749, Georges-Louis Leclerc, Comte de Buffon conceived the idea that the planets were formed when a comet collided with the Sun, sending matter out to form the planets. However, Laplace refuted this idea in 1796, showing that any planets formed in such a way would eventually crash into the Sun. Laplace felt that the near-circular orbits of the planets were a necessary consequence of their formation. Today, comets are known to be far too small to have created the Solar System in this way. Tidal theory: Attempts to resolve the angular momentum problem led to the temporary abandonment of the nebular hypothesis in favour of a return to "two-body" theories. For several decades, many astronomers preferred the *tidal* or *near-collision* hypothesis put forward by James Jeans in 1917, in which the planets were considered to have been formed due to the approach of some other star to the Sun. This near-miss would have drawn large amounts of matter out of the Sun and the other star by their mutual tidal forces, which could have then condensed into planets. However, in 1929 astronomer Harold Jeffreys countered that such a near-collision was massively unlikely. Objections to the hypothesis were also raised by the American astronomer Henry Norris Russell, who showed that it ran into problems with angular momentum for the outer planets, with the planets struggling to avoid being reabsorbed by the Sun.

Interstellar cloud theory: In 1944, the Soviet astronomer Otto Schmidt proposed that the Sun, in its present form, passed through a dense interstellar cloud, emerging enveloped in a cloud of dust and gas, from which the planets eventually formed. This solved the angular momentum problem by assuming that the Sun's slow rotation was peculiar to it, and that the planets did not form at the same time as the Sun. However, this hypothesis was severely dented by Victor Safronov who showed that the amount of time required to form the planets from such a diffuse envelope would far exceed the Solar System's determined age.

Protoplanet theory: In 1960, W. H. McCrea proposed the *protoplanet theory*, in which the Sun and planets individually coalesced from matter within the same cloud, with the smaller planets later captured by the Sun's larger gravity. This theory has a number of issues, such as explaining the fact that the planets all orbit the Sun in the same direction, which would appear highly unlikely if they were each individually captured.

Capture theory: The *capture theory*, proposed by M. M. Woolfson in 1964, posits that the Solar System formed from tidal interactions between the Sun and a low-density protostar. The Sun's gravity would have drawn material from the diffuse atmosphere of the protostar, which would then have collapsed to form the planets. However, the capture theory predicts a different age for the Sun than for the planets, whereas the similar ages of the Sun and the rest of the Solar System indicate that they formed at roughly the same time. While the broad picture of the nebular hypothesis is widely accepted, many of the details are not well understood and continue to be refined.

Conclusion and Discussion: The refined nebular model was developed entirely on the basis of observations of our own Solar System because it was the only one known until the mid 1990s. It was not confidently assumed to be widely applicable to other planetary systems, although scientists were anxious to test the nebular model by finding of protoplanetary discs or even planets around other stars.

As of March 2008, the discovery of nearly 280 extrasolar planets has turned up many surprises, and the nebular model must be revised to account for these discovered planetary systems, or new models considered. Among the extrasolar planets discovered to date are planets the size of Jupiter or larger but possessing very short orbital periods of only a few days. Such planets would have to orbit very closely to their stars; so closely that their atmospheres would be gradually stripped away by solar radiation. There is no consensus on how to explain these so-called hot Jupiters, but one leading idea is that of planetary migration, similar to the process which is thought to have moved Uranus and Neptune to their current, distant orbit. Possible processes that cause the migration include orbital friction while the protoplanetary disc is still full of hydrogen and helium gas and exchange of angular momentum between giant planets and the particles in the protoplanetary disc. The detailed features of the planets are another problem. The solar nebula hypothesis predicts that all planets will form exactly in the ecliptic plane. Instead, the orbits of the classical planets have various (but small) inclinations with respect to the ecliptic. Furthermore, for the gas giants it is predicted that their rotations and moon systems will also not be inclined with respect to the ecliptic plane. However, most gas giants have substantial axial tilts with respect to the ecliptic, with Uranus having a 98° tilt. The Moon being relatively large with respect to the Earth and other moons which are in irregular orbits with respect to their planet is yet another issue. It is now believed these observations are explained by events which happened after the initial formation of the Solar System. For instance, the large axial tilts of many planets may be explained by giant impacts with massive planetsmals early in the Solar System's evolution.

Remote Sensing of the Solar System Planets

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Remote Sensing is about getting information or inferring about various objects, may it be a Planet or any Astronomical object, without physical contact with them. One of the earliest example of Planetary remote sensing is the use of a primitive telescope by Galileo for discovering the moon craters and moons of planet Jupiter. Since then we have many observations of our neighbours in the solar system with ground based telescopes and then with the advent of the space age using cameras, scanners, spectrometers on-board orbiting space crafts, flybys, probes etc. Exploration of the solar system planets carried out through remote sensing has brought in a wealth of knowledge giving today's astronomers and planetary scientists remarkable insight into the nature and history of the planets. Principal tools for remote sensing the planetary system and beyond, searching well into outer space, star, galaxies, supernova, use the basic properties of the electromagnetic spectrum. The electromagnetic spectrum characterised by frequency/ wavelength covering a wide range extending from gamma rays ($\lambda \leq 10^{-11}$ m) to radio waves ($\lambda \geq 1$m).

	Wavelength (m)	**Frequency (Hz)**
Radio	$> 1 \times 10^{-1}$	$< 3 \times 10^{9}$
Microwave	$1 \times 10^{-3} – 1 \times 10^{-1}$	3×10^{9}-3×10^{11}
Infrared	$7 \times 10^{-7} – 1 \times 10^{-3}$	3×10^{11}- 4×10^{14}
Optical	$4 \times 10^{-7} – 7 \times 10^{-7}$	$4 \times 10^{14} – 7.5 \times 10^{14}$
UV	$1 \times 10^{-8} – 4 \times 10^{-7}$	$7.5 \times 10^{14} – 3 \times 10^{16}$
X-Ray	$1 \times 10^{-11} – 1 \times 10^{-8}$	$3 \times 10^{16} – 3 \times 10^{19}$
Gamma Ray	$< 1 \times 10^{-11}$	$> 3 \times 10^{19}$

Motivation behind Planetary remote sensing are:

- Understand the working of the Solar System: Detailed study of the leading planets of our Solar System, giant planets and their environments; explore the oldest object of the Solar System: Comets and Asteroids
- The exploration of the Solar System is essential to determine the conditions for life and habitability: achieved through exploration, in situ and by remote sensing activities, of the surface and subsurface of the solid bodies in the solar system; through exploration of the environmental conditions that make life possible
- By studying other planets, like Venus, Mars or Saturn's moon Titan, we can understand the earth system: detailed knowledge of our own solar system would be of great help while interpreting the observation of planets around other stars

How do we characterize the remote sensing of planets?

1. Geophysical investigation allows deciphering the processes leading to the evolution and differentiation of planets, i.e. tracking back their history. This knowledge is needed for planetary exploration
2. Global investigation would try to find the link of the primordial phases of the solar system with sun formation. This knowledge is also required for planetary exploration.
3. Search for the undifferentiated matter, namely the one that still contains tracks of the isotopic composition typical of the interstellar matter from which all bodies were formed and this matter shouldn't be only the solid one but also the "highly volatile stuff" i.e ices and gases.

The remote observations carried out are mainly imaging which provides with the overall geological/geophysical history, the large scale processes characterising the surface and figure, Spectroscopy providing information on composition and mineralogy of the planet, as well as the gas emission-through interaction with ionised particles, Magnetometer / Plasma analyser to measure the internal and external magnetic fields, Radio Science to bring out details on internal structure and Radars providing surface structure and dielectric properties. A few examples of remote sensing techniques used for planetary missions are:

Method	Spectrum	Results/Interpretation	Mission
Gamma-Ray Spectroscopy	Gamma rays	U, Th abundances	Apollo, Venera
X-ray Fluorescence Spectrometry	X-rays	Mineral and chemical composition of surface	Apollo, Viking landers, Venera 13 ,14
Ultraviolet Spectrometry	UV	Atmospheric composition	Mariner, Pioneer, Voyager
Multi spectral Imagers	Visible, UV, IR	Surface feature , composition	All missions
Laser Altimeter	Visible	Surface relief	Apollo, Chandrayaan-1
Polarimeter	Visible	Surface composition	Pioneer, Voyager
Infrared Radiometer	IR	Surface and Atmospheric composition and temperature	Apollo, Mariner, Viking, Voyager
Microwave Radiometer	Microwave	Atmosphere/Surface temperature/structure	
Radar		Study of atmosphere and mapping surface	Cassini, Mars Express , Pioneer,Venus orbiter, Mars Reconnaissance Orbiter, Magellan
Radio Occultation		Composition, pressure and density of atmosphere	Mariner
Synthetic Aperture Radar SAR		Terrain Mapping	Venera 15, 16

Remote sensing has made available a vast knowledge about the Solar system Planets. We will try to provide a brief account of that here.

The planet Mercury is closest to the Sun and the most difficult one to observe from Earth. Compared to other planets little is known about Mercury; ground-based telescopes reveal only an illuminated crescent with limited detail. Only two space probes have visited the planet so far the first was Mariner 10 which mapped about 45% of its surface from 1974 to 1975, the second is the MESSENGER spacecraft (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) which attained orbit around Mercury on March 17, 2011, to map the rest of the planet. Mercury's surface is overall very similar in appearance to that of the Moon. The first orbital image of Mercury was obtained on March 29, 2011. The probe is carrying imaging devices like assorted spectrometers to determine abundances of elements in the crust, and magnetometers and devices to measure velocities of charged particles. The European Space Agency is planning a joint mission with Japan called BepiColombo, which will orbit Mercury with two probes: one to map the planet and the other to study its magnetosphere.Once launched, the spacecraft bus is expected to reach Mercury in

2019. The bus will release a magnetometer probe into an elliptical orbit, then chemical rockets will fire to deposit the mapper probe into a circular orbit. Both probes will operate for a terrestrial year. The mapper probe will carry an array of spectrometers similar to those on MESSENGER, and will study the planet at many different wavelengths including infrared, ultraviolet, X-ray and gamma ray.

Venus has been target of a number of flyby, probe, lander and orbiter spacecraft missions by US and Russia. The microwave and infrared radiometers onboard Mariner 2 revealed that the Venusian cloud tops were cool, the surface was extremely hot—at least 425 °C, and ended any hopes that the planet might have ground-based life. It also obtained improved estimates of its mass, but was unable to detect either a magnetic field or radiation belts. The Venus Express probe designed and built by the European Space Agency successfully assumed a polar orbit around Venus on April 11, 2006. The probe is undertaking a detailed study of the Venusian atmosphere and clouds, including mapping of the planet's plasma environment and surface characteristics, particularly temperatures. One of the first results emerging from Venus Express is the discovery that a huge double atmospheric vortex exists at the south pole of the planet. The mission Bepi Colombo will perform two flybys of Venus before it reaches Mercury orbit in 2020.

Moon – our closest celestial neighbour has aroused curiosity much more than any other object in the sky. Moon is the brightest object in the night sky, fifth largest satellite of the solar system. The end of fifteenth century was apparently the period when scientific study of the moon began. The ushering in of the space era in 1957 opened up the programme for lunar exploration. Luna and Apollo series of missions (orbiter, lander and Manned missions) by then USSR and USA brought out plethora of knowledge about Moon. After a long gap of 20 years since the Apollo missions, moon probes Clementine and Lunar Prospector were launched. A common objective of both Clementine and Lunar Prospector missions was to search for lunar water-ice deposits. Next was another lunar orbiter mission SMART-1 of ESA with high resolution camera, NIR Spectrometer and low energy compact X-ray spectrometer with new technology of swept charge detector. Japan's Selene (Kaguya) mission investigated lunar elemental and mineralogical composition, surface and subsurface structure, remnant magnetic field and gravity field. Chang'e probe from China was launched for mapping its surface and exploring its environment. India's moon mission- Chandrayaan-1 was aimed at high resolution remote sensing of the Moon in visible, near infrared, low and high energy X-rays. The simultaneous photo geological, mineralogical and chemical mapping enabled identification of different geological units to infer the early evolutionary history of the moon. Chandrayaan-1 carried four indigenous payloads Terrain Mapping Camera, Hyper Spectral Imaging Camera, Laser ranging instrument, high energy X-ray spectrometer and a moon impactor. Six payloads from International and Indian scientific community obtained through Announcement of Opportunity are Chandrayaan-1X-ray spectrometer(ISRO ,ESA), NIR Spectrometer (ESA), Sub-keV Atom Reflecting Analyser (ISRO,ESA), Radiation Dose Monitor Experiment(Bulgaria), Mini SAR(NASA),and Moon Mineralogy mapper(NASA).

The most significant result from Chandrayaan-1 is the discovery of the presence of hydroxyl (OH) and water (H_2O) molecules on the lunar surface by the NASA's Moon Mineralogy Mapper (M3) payload. Other important results being the inference of sub surface water-ice deposits in the base of craters in permanent sun shadow by NASA's Miniature Synthetic Aperture Radar (Mini-SAR) experiment and detection of possible existence of water molecules in the lunar environment by the mass spectrometer onboard India's Moon Impact Probe (MIP). Validation of Lunar Magma Ocean hypothesis by the joint analysis of M3, Hyper Spectral Imager (HySI) and Terrain Mapping Camera (TMC); detection of reflection of almost 20% of solar wind protons as neutral hydrogen from lunar surface by Sub-keV Atom Reflecting Analyser (SARA); detection of presence of Mg, Al, Si, Ca on the lunar surface by Chandrayaan-1 X-ray Spectrometer (C1XS);

detailed maps and three dimensional conceptualisation of many lunar crafters of interest by TMC and HySI are other scientific results from Chandrayaan-1.

Mars-the fourth planet from the Sun, with pristine and diverse surface, has a long and fascinating history. We know from orbiting space crafts that Mars has undergone dramatic climatic and geological changes. Water coursing over its surface in distant past left evidences in deeply curved channels and fluvial networks- but now the planet is found cold and dry. Dozens of spacecraft, including orbiters, landers, and rovers, have been sent to Mars by the Russia, USA, Europe, and Japan to study the planet's surface, climate, and geology. With all such missions/ efforts Mars still remains with its mysteries- how did it arrive at its present cold, airless state, did life ever evolved and do these changes experienced by Mars teach us something about the prediction for Earth. The first successful fly-by of Mars was on July 14–15, 1965, by NASA's Mariner 4. The NASA Mars Odyssey orbiter entered Mars orbit in 2001. Odyssey's Gamma Ray Spectrometer detected significant amounts of hydrogen within one metre from the surface regolith on Mars. This hydrogen is thought to be contained in large deposits of water ice. The Mars Express mission of ESA reached Mars in 2003. In January 2004, the NASA twin Mars Exploration Rovers named *Spirit* (MER-A) and *Opportunity* (MER-B) landed on the surface of Mars. Both have met or exceeded all their targets. Among the most significant scientific returns has been conclusive evidence that liquid water existed at some time in the past at both landing sites. On March 10, 2006, the NASA Mars Reconnaissance Orbiter (MRO) probe was put in orbit to conduct a two-year science survey. The orbiter began mapping the Martian terrain and weather to find suitable landing sites for upcoming lander missions. The MRO snapped the first image of a series of active avalanches near the planet's north pole. The Mars Science Laboratory, named *Curiosity*, launched on November 26, 2011, is expected to reach Mars in August 2012.

Jupiter is the largest, and closet to the Sun, of the Gas Giants. It has been visited by a number of missions- two Pioneer missions, Voyagers 1 and 2, and Galileo which has been orbiting the planet since 1995. Cassini is the latest mission to pass near Jupiter, at the end of 2000. All gave better looks at this massive planet than we had before with telescopes. A better understanding of atmospheric composition and circulation came from each. Jupiter has sixteen satellites- four small inner, irregularly shaped ones, four Galilean satellites, four prograde and four retrograde outer satellites. The Voyagers and Galileo missions have also provided tantalizing views of the jovian satellites. NASA currently has a mission underway to study Jupiter in detail from a polar orbit. The spacecraft named Juno launched in August 2011 will arrive in late 2016.

Saturn is the most distant planet in the solar system with spectacular ring system and largest number of satellites compared to any of the gas giant planets. Saturn's rings were first observed by Galileo in 1610 followed by Christian Huygens and Giovanni Domenico Cassini in 1659 and 1675 respectively. Arrival of space age witnessed space missions studying planet Saturn. Pioneer 11 carried out the first flyby of Saturn in September 1979, when it passed within 20,000 km of the planet's cloud tops. Voyager 1 probe visited the Saturn system In November 1980, sending back the first high-resolution images of the planet, its rings and satellites. Voyager 2 (August 1981) continued the study of the Saturn system and acquired more close-up images of Saturn's moons, as well as evidence of changes in the atmosphere and the rings. The Cassini–Huygens space probe launched in October 1997, entered into orbit around Saturn in July 2004.The probe flew by Saturn's largest moon, Titan, and captured radar images of large lakes and their coastlines with numerous islands and mountains. The orbiter released the Huygens probe which descended onto the surface of Titan on January 14, 2005, sending data during the atmospheric descent and after the landing. Cassini has since conducted multiple flybys of Titan and other icy satellites. It found evidence of liquid water reservoirs that erupt in geysers on Saturn's moon Enceladus. In May 2011, NASA scientists reported that Enceladus as the most habitable spot beyond Earth in the Solar System for life. Cassini images provided evidence of hydrocarbon lakes near Titan's North Pole, the largest of which is almost the size of the Caspian Sea. The probe also detected a 8,000 km diameter cyclone-like storm with an eyeball at Saturn's south pole. From 2004 to 2009, the probe discovered and confirmed 8 new satellites. Its primary mission ended in 2008 when the spacecraft had completed 74 orbits around the planet. The probe's mission was extended to September 2010 and then extended again to 2017, to study a full period of Saturn's seasons.

The last two Gas Planets, Uranus and Neptune, are less than half the diameter of Jupiter and Saturn. Both appear a near-sky blue in coloured versions constructed from Voyager 2 images. Uranus has five large satellites (and 17 small ones) and Neptune two, plus 6 small ones discovered by Voyager. Both have ring systems, so that all four Giant Planets possess this feature.

Pluto was discovered by Clyde Tombaugh in 1930. Nearly 50 years after Pluto's discovery Pluto's satellite was discovered by James Christy. Pluto and its satellite Charon is like a double planet system. Mission to Pluto, called *New Horizons* was launched successfully on January 19, 2006. In early 2007 the craft made use of a gravity assist from Jupiter. Its closest approach to Pluto will be on July 14, 2015; scientific observations of Pluto will begin 5 months before closest approach and will continue for at least a month after the encounter. New Horizons captured its first (distant) images of Pluto in late September 2006, during a test of the Long Range Reconnaissance Imager (LORRI). New Horizons will use a remote sensing package that includes imaging instruments and a radio science investigation tool, as well as spectroscopic and other experiments, to characterise the global geology and morphology of Pluto and its moon Charon, map their surface composition and analyse Pluto's neutral atmosphere and its escape rate. New Horizons will also photograph the surfaces of Pluto and Charon.Keeping in mind the wealth of information obtained through remote sensing of solar system planets, one may recommend that Remote sensing is necessary as it gives the basic knowledge of planetary environments; however, alone it is not sufficient and ground truth is required. The ground truth for extraterrestrial planets, asteroids sample return is essential and an unavoidable step in the exploration.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures* in their own words, either as a brief survey of state of the art or as articles on novel dream concepts related to the specific theme ***"Future Trends in Remote Sensing"***.

The deadline for inclusion in the next issue is **March 20, 2012.**

- Editorial Team

Ground Systems for Data Reception, Processing, Archival and Dissemination

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Introduction: The space probes and the space laboratories fitted with suitable instruments, while performing their task in deep space will be engaged in sending the vital science information to the ground receiving systems. These ground stations will perform the process of data reception, processing, archival and dissemination of this science data to scientists on an assured basis. The sensing of the signals arriving from the deep space will be performed by a set of very large diameter, typically 32 m, antennae along with a host of equipments, which help in data volume reduction. The data is processed and the products so obtained are archived in a systematic manner and also disseminated to the users who in turn will analyse and produce results which could lead to path breaking discoveries.

In the Indian context, an effort to build ground systems for deep space missions took shape in the form of indigenous design, development and Operationalisation of a 32m diameter antenna for deep space applications, satellite command and control and science data reception. The Indian Deep Space Network station IDSN is located in Byalalu near Bangalore. Co-located with IDSN is the Indian Space Science Data Centre (ISSDC), which performs the functions of data products generation, archival and dissemination. A set of communication links, both dedicated and public domain are established to provide data transfer. The ISSDC systems are sized for handling large volumes of data, secured data connectivity and transfer in addition to high availability. This article highlights the Indian efforts in handling the science data relevant to astronomy and planetary sciences.

Demands of astronomy and planetary sciences: Astronomy is a natural science that deals with the study of celestial objects such as stars, planets, comets, nebulae, star clusters and galaxies. It is concerned with the evolution, physics, chemistry, meteorology, and motion of celestial objects, as well as the formation and development of the universe. Observational astronomy is focused on acquiring data from observations of celestial objects, which is then analyzed using basic principles of physics. Observational astronomy may be divided according to the observed region of the electromagnetic spectrum.

Planetary science is the scientific study of planets (including the Earth), moons, and planetary systems, in particular those of the Solar System and the processes that form them. It studies objects ranging in size from micrometeoroids to gas giants, aiming to determine their composition, dynamics, formation, interrelations and history. It is an interdisciplinary field, originally growing from astronomy and Earth science, but which now incorporates many disciplines, including planetary astronomy, planetary geology (together with geochemistry and geophysics), atmospheric science, oceanography, hydrology, theoretical planetary science, glaciology, and the study of extrasolar planets. Allied disciplines include space physics, when concerned with the effects of the Sun on the bodies of the Solar System, and astrobiology.

Planetary astronomers have directly observed many of these phenomena through spacecraft and sample return missions. These observations include fly-by missions with remote sensors, landing vehicles that can perform experiments on the surface materials, impactors that allow remote sensing of buried material and sample return missions that allow direct laboratory examination. Planetary scientists are generally located in the astronomy and physics or earth sciences departments of universities or research centres, though there are several purely planetary science institutes worldwide. Hence, it is necessary to have a well equipped ground system to cater to the needs of scientists and astronomers, user demand, operations scheduling, space weather based bulletins and disaster warnings, to support the specific needs of planetary mission like understanding the evolution & origin of planets, evidence of water, methane, biological origin and in-situ observation like drilling for water evidence. Some scientists may have to share the space assets like Hubble, Kepler and Chandra on a pre-allotted time basis in their quest for exoplanets and discoveries of rare celestial phenomena like supernova, stellar collisions and cosmic explosions.

Ground facilities for astronomy and planetary missions: The ground facilities required for astronomy and planetary missions are as follows:

- Deep Space Network (DSN): To provide telemetry, telecommand and tracking support for orbiters, fly-by missions, Landers, rovers, sample and return missions. In addition, payload data reception to be ensured by ground station.
- Science Data center: Acts as repository of all science data, data processing and archival.
- Secured communication network

To have cross-support among the various DSN stations, it is necessary that the ground station has to conform to international standards. Science data center should be able to support the user community through established international standards of data archival and dissemination like Planetary Data System (PDS) standards. ISRO has capability to support near-Earth astronomy missions, deep-space missions and data archival and dissemination of science data. The Indian Deep Space network and Indian Space Science Data center established during Chandrayaan-1 are explained in the sections to follow.

Indian Deep Space Network: Two Antennas, 32m diameter and 18m diameter, in Bangalore support Spacecraft Telemetry and science data reception, command and ranging functions. IDSN Campus also houses a technical complex, facility buildings and power complex in addition to other infrastructure facilities. The ground stations house independent fully redundant electronics for Telemetry Telecommand and Communication (TTC) and Science Data functions. Cryo-Cooled Low Noise Amplifiers (LNA), High-Performance TTC Processors, 20kW S-Band High Power Amplifier (HPA), Maser based/Caesium-Beam based Timing/Frequency Standard Systems, CCSDS compatibility, Station Computers and Space link extension protocols are the highlights of the IDSN. Data service from IDSN is tailored to interface with the supporting agencies interfaces. Figure 1 shows the picture of 32 m antenna at IDSN, Bangalore.

IDSN also hosts an operations facility, which provides for Quick Look Display of Science Data and also supports the payload scientists with instrument data displays. Mission Software, which runs at Spacecraft Control Center (SCC), is operational at IDSN Operations facility. All payload scientists converge on IDSN operations facility during mission operations, instruments turn ON and in-orbit checks. IDSN campus has the infrastructure facilities like electrical supply from service providers, communication links to the external world - both TERRACOM and SATCOM - Internet/e-mail facilities, Air Conditioning Systems, Captive Power, Uninterrupted Power, Guest House, Canteen, Safety and Security Systems.

Fig 1: Image of 32 m antenna at Indian Deep Space Network (ISDN) at Byalalu, Bangalore.

Fig 2: Inside view of ISSDC data archival computer facility.

Indian Space Science Data Centre (ISSDC): ISSDC is the infrastructure, which facilitates science data processing, archival, and dissemination functions for both Indian and Foreign Scientists. The data transfer system at ISSDC, with suitable security systems, provides for distributing science data (as per data policy) to the concerned. The communications infrastructure is elaborate and caters to the needs of Principal Investigators (PIs) and Payload Operations Centres (POCs). ISSDC also interfaces with POCs for routing the operations needs of the instrument to the SCC. Level-0 and Level-1 data products of instruments, as applicable, are routinely produced at ISSDC. Automation in the entire chain of data processing is implemented. Provision is made to host higher-level data products for any instrument as supplied by the PI teams. ISSDC also provides for data archives in Planetary Data Systems (PDS) format, an international standard. The data dissemination will also follow PDS standard. The Computer networking at ISSDC caters to connectivity to the IDSN operations facility, SCC and POCs. The storage and server capacities are built at ISSDC to cater to the needs of Chandrayaan-1 and other science missions to follow. Scalability and high-level availability are given high priority in architectural design. It is also planned to have a help-desk facility at ISSDC to cater to the data needs of National and International Scientists. ISSDC will also host a web site for collecting the observations needs of the scientists and making them available for an apex committee to review for further clearance for operations etc., ISSDC data archival and distribution functions shall follow the data policy guidelines of ISRO. Figure 2 shows the inside view of ISSDC data archival servers.

Data reception, processing, archival and dissemination functions

The Planetary Data System (PDS) as a standard defines how to label data products in order to make them automatically readable and interpretable and how to document the data for future use and reference. Data will be the key in realizing mission objectives and the scientific community is expected to carry out much of the analysis. To maintain a data archive withstanding the test of time such that future generations of scientists can access, understand and use pre-existing planetary data is a tough task. The PDS tries to ensure compatibility of the archive by adhering to strict standards of storage media, archiving formats, and required documentation.

The science data is classified and grouped based on the objectives like:

- Planetary remote sensing
    - Observations that support the planetary characteristics
    - Surface morphology, geo-chemical mapping
- Rendezvous missions like comet flybys, asteroid encounters
- Exo-planet exploration
- Rare celestial events like stellar collision, high energetic cosmic explosions
- Space weather monitoring and solar activities

Facilities like web-based browse application for the users to view the data required, a user account for login and placing the request for the required data, etc are required for data dissemination.

Mission support: Mission support for any planetary and astronomical missions can be classified into the two categories i) **Operations Support**: It involves payload operations planning & execution, Spacecraft operations like orbit & attitude maintenance, thermal & power management, contingency handling, etc. Operations support also includes scheduling of ground station for TT&C support and ii) **Science data processing**: It involves processing of science data from various payloads, archival of all levels of processed data along with meta data and dissemination to end users, following the archival and dissemination policies.

The IDSN and ISSDC supported Chandrayaan-1 mission during its life and today hosts the science data obtained from all eleven instruments flown onboard. Similarly, the instruments data from the ISRO-CNES mission, named Megha-Tropiques, is also being supported. The upcoming missions like ASTROSAT, Chandrayaan-2 and any other deep space or near earth missions will be supported by IDSN and ISSDC. At the end one can summaries that an indigenously built ground facility is available for use by astronomers and planetary scientists of India and abroad.

Planetary Remote Sensing and Gamma Ray Spectroscopy

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Remote sensing by imaging, as applied to Earth, goes back to the middle of the 19th century, when balloonists took the first photos. As applied to the rest of the solar system, Galileo made the first observations in 1610, when he turned a telescope to the heavens and caught a glimpse of the surface complexities on our nearest neighbor, the Moon. Later, he confirmed the Copernican theories with his discoveries of moons, or orbiting satellites, around Jupiter. Since then, we have many observations of our Solar System neighbors, first with telescopes and, after the opening of the Space Age, through remote sensing using orbiting spacecraft and using spacecraft flyby in addition to insitu exploration using probes and lander missions. Nowhere else in the diversified and imaginative programs of NASA and other space agencies from different nations has there been such a plethora of observational and scientific triumphs as the exploration of the planets and the Cosmos beyond. ISRO's Chandrayaan-1 mission to Earth's Moon has also resulted in major discoveries including the presence of water (H_2O/OH) on lunar surface. The Moon Mineralogy Mapper (M^3) on Chandrayaan-1 detected absorption features near 2.8 to 3.0 micrometers on the surface of the Moon, which are attributed to OH/H_2O-bearing materials. These features were observed to be strongest at cooler high latitudes, and at several fresh feldspathic craters.

Most of the same instruments that survey the electromagnetic spectrum (EM) making up the radiation emanating from the Earth have been the principal tools for exploring our planetary associates and beyond searching well into outer space at stars and other members of the Universe.

Choice of Wavelength: Remote sensing observations for the study of planetary geology span a wide variety of interests and applications. The specific object being observed or scientific objective under consideration, drives the choice of which region of the electromagnetic spectrum is appropriate. The electromagnetic environment is created by the incident and reflected UV, visible light, X and gamma rays. Galactic cosmic rays, charged particles from solar wind and solar flares form the particle environment. For example, surface mineralogy can be investigated using spectroscopy from the visible to infrared, because many minerals show diagnostic absorption and emission features at these wavelengths. Geomorphologic information can result from broadband visible orbital imaging in the case of planets with thin to non-existent atmospheres. For planets with atmospheres, consideration must be made of the opacity of the atmosphere as a function of wavelength; in certain cases, such as for Venus which has a thick atmosphere, the only choice for orbital geomorphologic studies is microwave (radar) imaging.

In many cases, the final detailed choice of wavelengths being considered is often constrained by instrumental considerations. Charge-Coupled Device (CCD) cameras, for example, which are now widely available for ground-based and space-based study of the planets, are often limited to operation in the 400 to 1100 nm region. Infrared detector technology is continually improving; however, the range of wavelengths available to an instrument is highly dependent on the composition of the detector and on the ability to cool the instrument below some optimal operating temperature.

***Spectroscopy*:** Spectroscopic remote sensing observations can provide substantially more diagnostic compositional and mineralogic information on planetary surfaces than imaging alone. Essentially three types of spectroscopic observations can be obtained: X-ray and gamma-ray spectra, reflectance spectra, and thermal emission spectra. Each offers specific advantages for answering certain types of questions pertaining to compositional or mineralogical information.

Elemental composition of a planetary surface can be deduced from in-situ measurements or by remote sensing technique or by laboratory analysis of returned samples. These techniques have been applied in the case of the Moon, while study of other planets, satellites and asteroids have been carried out using remote sensing technique except in the case of Mars where in-situ measurements were also carried out. Reflectance spectroscopy, X-ray fluorescence, gamma ray, alpha ray, neutron and neutral atom spectroscopy are some of the basic tools for mapping of the planetary surfaces.

The X-ray spectrum of a planetary surface measured from orbit is dominated by a combination of fluorescent X-rays excited by incident solar X-rays, and coherently scattered solar X-rays from the lunar surface. As soft X-rays are easily attenuated, the XRF technique is limited to planets which do not have an atmosphere. Energetic solar X-ray photons interact with atoms in the top tens of microns of the lunar surface, and produce characteristic K_α X-ray fluorescent lines. This emission is dependent on the chemical composition of the lunar surface and the incident solar spectrum. The intensity of the X-ray K_α line is assumed to be proportional to the concentration of the element.

Planetary surfaces are continuously irradiated with galactic cosmic rays (GCR), mainly protons and alpha particles with energies typically ~GeV/nucleon. In the case of moon, these GCR particles enter the lunar surface and produce a cascade of secondary particles, including ~7 neutrons with energies of ~0.1-20 MeV, per primary particle. Many of these secondary neutrons can produce gamma rays in inelastic scattering (n, xγ) reactions, where x is usually a neutron. Neutrons with energies below the first excited level of target nuclei in Moon can be elastically scattered by nuclei, escape from the Moon (about one third of neutrons), or be captured by nuclei in the (n,γ) reaction when the neutron energy is of the order of ~0.025 eV. Gamma rays can also be produced by the decay of radionuclides produced by such cosmic ray induced nuclear reactions. The gamma rays, thus produced, are transported within the Moon; some of them are absorbed, while others can induce pair production, or are scattered out of the lunar surface. Both the inelastic and the neutron capture gamma ray lines are those classically used in planetary applications. In comparison to X-ray fluorescence spectrometry, compositional data from gamma spectrometry is more representative of the lunar sub-surface as gamma rays come from depths of a few centimetres to tens of centimetres whereas characteristic X-rays have a maximum interaction depth of the order of tens of microns.

X-rays and gamma-rays can be detected by scintillator and semiconductor detectors at gamma-ray energies and gas-filled proportional counters at X-ray energies. These techniques can provide quantitative information on the abundances of many rock-forming minerals (*e.g.*, Na, Mg, Al, Si, P, S) as well as on the abundance of natural radioactive materials (K, Th, U) and hydrogen.

Reflectance spectroscopy provides diagnostic information on the mineralogy and degree of crystallinity of the uppermost few microns of a planetary surface. This technique involves measuring the spectrum of sunlight reflected from a planetary surface, and is thus restricted to the wavelength range where the Sun's flux is highest and where the amount of energy reflected from the object is greater than the amount that is thermally emitted (the typical wavelength range is from 0.3 to 3.5 μm). Many materials, including primary and secondary minerals, exhibit electronic spectral features and vibrational overtone bands at these solar wavelengths. Reflectance spectra reveal absorption features that are characteristic of certain minerals and ices and/or indicate the presence of certain cations. For example, the mineral pyroxene, a common component of basaltic rocks on the Earth, can be detected remotely by the measurement of diagnostic absorption features near 1.0 and 2.0 µm. Variations in the abundances of Fe and Ca in the pyroxene can also be inferred based on subtle shifts in the positions of these bands. Reflectance spectroscopy is currently the most useful technique for remotely measuring the mineralogy of planetary surfaces, and specific minerals have been identified on the Moon, Mars, and a number of asteroids.

Thermal emission spectroscopy also provides diagnostic information on the mineralogy of planetary surfaces, as well as additional information on surface thermophysical properties like temperature and thermal inertia. Most of the major rock-forming minerals exhibit their fundamental molecular vibration spectral features at mid-infrared wavelengths, typically from 3.0 to 25.0 um, where thermal radiation emitted from planetary surfaces at temperatures from 200 to 400 K dominates over reflected sunlight. Unlike reflectance spectra, thermal IR spectra can exhibit features in both emission and absorption, depending on the nature of the planetary environment. Thermal IR spectra are more difficult to interpret, but they also enable one, through radiative transfer modeling, to infer additional information about a planetary surface such as emissivity, particle size and degree of compaction, and the subsurface temperature profile. Thermal emission spectra have been used, for example, to obtain compositional information on variations in terrestrial basaltic lava flows remotely and to constrain the thermal inertia and rock abundance of the Martian surface.

Table shows list of remote sensing methods using EM spectral measurements that have provided exceptional information about planetary surfaces, atmospheres.

METHOD	EM SPECTRUM	INFORMATION	INTERPRETATION
Gamma-Ray Spectroscopy	Gamma rays	Gamma spectrum	Elemental (K, U, Th) Abundances
X-ray Fluorescence spectrometry	X-rays	Characteristic Wavelengths	Surface mineral/ chemical composition
Ultraviolet Spectrometry	UV	Spectrum of Reflected sunlight	Atmospheric Composition: H, He, CO_2
Photometry	UV, Visible	Albedo	Nature of Surface; Composition
Multispectral Imagers	UV, Visible, IR	Spectral and Spatial	Surface Features; Composition
Reflectance Spectrometers	Visible, IR	Spectral intensities of reflected solar radiation	Surface Chemistry; mineralogy; processes
Laser Altimeter	Visible	Time delay between emitted and reflected pulses	Surface Relief
Polarimeter	Visible	Surface Polarization	Surface Texture; Composition
Infrared Radiometer (includes scanners)	Infrared	Thermal radiant intensities	Surface and atmospheric temperatures; compos.
Microwave Radiometer	Microwave	Passive microwave emission	Atmosphere/Surface temperatures; structure
Bistatic Radar	Microwave	Surface reflection profiles	Surface Heights; roughness
Imaging Radar	Microwave	Reflections from swath	Topography and roughness
Lunar Sounder	Radar	Multifrequency	Surface Profiling and imaging;

		Doppler Shifts	conductivity
S-Band Transponder	Radio	Doppler shift single frequency	Gravity data
Radio Occultation	Radio	Frequency and intensity change	Atmospheric density and pressure

Spacecraft remote sensing observations beginning in the mid-1960s expanded our view of the geology of Mars and provided evidence that Mars was once much more geologically and climatically active than it is today. Flybys by the Mariner 4, 6, and 7 spacecraft provided photographic and/or spectroscopic data for parts of the southern hemisphere including the south polar cap. These observations revealed a heavily cratered surface much older than had been expected, and indicated that the seasonal polar ice deposits are dominantly CO_2 rather than solely H_2O ice. Orbital visible and thermal-IR imaging and spectroscopic studies by the Mariner 9 and Viking missions revealed a much more geologically complex surface that has been clearly shaped by volcanic, tectonic, impact, and gradational processes. Perhaps most intriguing was the discovery of ancient, dendritic valley network systems that were caused by the action of liquid water on the surface. The valley networks, along with other morphologic features indicating catastrophic flooding events and changes in erosion rates provides evidence that major climate changes have occurred on Mars. Some of the evidence for climatic variations is quite controversial, such as claims for the existence of Martian glaciers or oceans, and will require additional high resolution remote sensing and *in situ* investigations to resolve them. The experiments aboard the two Viking Lander missions (1976-1980) were primarily designed to search for evidence of organic materials that could indicate the presence of current or past life on Mars.

Geological Investigations: Determining the chemical composition of a planet's surface is an essential part of the investigation of the planet. The abundances of certain elements with different condensation temperatures and with various types of geochemical behavior can provide valuable clues to a planet's origin and evolution. X-Ray and gamma-ray remote sensing observations are important to understand the origin and evolution of the planets. The chemical nature of a planetary surface can be determined from the returned samples or by remote-sensing experiments. Returned samples allow extensive analyses to be performed and surface instruments (on penetrators, rovers, or landers) can provide valuable data, but these results only apply to a localized region. Orbital experiments allow global surveys to be made of a planet's surface, and complement surface measurements, some orbital remote-sensing experiments, such as mass spectrometers and alpha-particle spectrometers, provide only a limited amount of information on surface chemistry.

Gamma-ray spectrometers were carried to the moon on Lunar 10, Apollos 15 and 16 and to Mars on the Soviet Mars-5. The Apollo spectrometers allowed the relative variations of the natural radio elements (K, U, and Th) and certain other elements (such as Fe) to be mapped on a relatively fine scale over 20% of the lunar surface. The abundances of Th, K, Fe, Mg, and Ti were determined for a number of lunar regions overflown by the Apollo Spectrometers by analysis of their gamma ray spectra. The spectrometers flown on these missions used scintillator detectors made of NaI(Tl). Because of the poor resolution of Nal(Tl) detectors, only few gamma ray lines were observable in the Apollo lunar spectra. The idea of using a germanium (Ge) gamma-ray spectrometer with high-energy resolution for a planetary mission was proposed by Metzger. Since germanium detectors can distinguish between gamma-ray lines only a keV in energy apart, they will detect many lines in the energy region of geochemical interest (0.2 to 10 MeV). The first successful planetary mission carrying a Ge gamma-ray spectrometer was Mars Odyssey, which went into polar orbit around Mars in 2001 and was the first to show spectra with many narrow gamma-ray peaks.

The MESSENGER spacecraft to Mercury also carried a Ge gamma-ray spectrometer.

Gamma-Ray Spectrometer (GRS): A gamma-ray spectrometer is a passive sensor that detects gamma rays. The sources for the radiation is are generally upper-soil layers as well as rock layers. The radiation is caused by radioactive decay. Fundamentally, the gamma-ray spectrometer is used to explore mineral deposits.

Chemical elements in soils and rocks emit gamma rays when exposed to cosmic rays (charged particles in space that come from the stars, including our sun) with uniquely identifiable signatures of energy. Gamma rays and neutrons are produced by cosmic rays interaction. Incoming cosmic rays, some of the highest-energy particles, collide with the nucleus of atoms in the soil. When nuclei are hit with such energy, neutrons are released, which scatter and collide with other nuclei.

The nuclei get excited in the process, and emit gamma rays to release the extra energy so they can return to their normal rest state. While some elements like potassium, uranium, and thorium are naturally radioactive and give off gamma rays as they decay, all elements can be excited by collisions with cosmic rays to produce gamma rays. The gamma ray spectrometer looks at these signatures, or energies, coming from the elements present in the target soil.

The interaction is shown in figure 1.

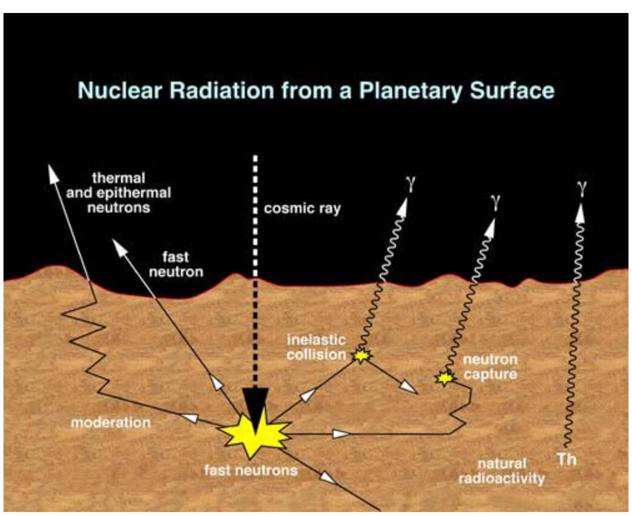

Figure 1 Overview of the production of gamma rays and neutrons by cosmic ray interactions and radioactive decay. Fast neutrons produced by high-energy cosmic ray interactions undergo inelastic collisions, resulting in the production of characteristic gamma rays that can be measured from orbit.

By measuring gamma rays coming from the target body, it is possible to calculate the abundance of various elements and how they are distributed around the planet's surface. Gamma rays, emitted from the nuclei and atoms, show up as sharp emission lines on the instrument's spectrum output. While the energy represented in these emissions determines which elements are present, the intensity of the spectrum reveals the elements concentrations. Spectrometers are expected to add significantly to the growing understanding of the origin and evolution of planets like Mars and the processes shaping them today and in the past. The gamma ray spectrometer looks at these signatures, or energies, coming from the elements present in the target soil.

Some types of scintillation counters can be used as gamma ray spectrometers. The gamma photon energy is discerned from the intensity of the flash of the scintillator, a number of low-energy photons produced by the single high-energy one. Another approach relies on using Germanium detectors - a crystal of hyperpure germanium that produces pulses proportional to the captured photon energy; while more sensitive, it has to be cooled to a low temperature, requiring a bulky cryogenic apparatus. Handheld and many laboratory gamma spectrometers are therefore the scintillator kind, mostly with thallium-doped sodium iodide, thallium-doped caesium iodide, or, more recently, cerium doped lanthanum bromide. Spectrometers for space missions conversely tend to be of the germanium kind.

Due to restrictions on mass, cost, and mission duration in Mars Observer, a passive cooled high-purity Ge detector was used and it was mounted on an extended boom to remove it from the local background radiation of the spacecraft. In the Near Earth Asteroid Rendezvous (NEAR) mission, GRS employs an NaI(Tl) (thallium-activated sodium iodide) scintillator mounted within a cup shield made of bismuth germanate (BGO). The dense BGO cup is itself an active scintillator and thus works to reduce the Compton and pair-production contributions to the unwanted background signal. In addition, it provides direct, passive shielding from the local gamma-ray environment. This design eliminates the need for a boom and allows the detector to be body mounted to the spacecraft.

Gamma ray Spectrometer was flown to investigate lunar surface on Japanese Selene (Kaguya) mission. SELENE was launched by the H-IIA rocket on September 14, 2007. The instrument employed, for the first time in lunar exploration, a high-purity Ge crystal. The Ge detector was surrounded by BGO and plastic anticoincidence shields and cooled by a Stirling cryocooler.

The SELENE-GRS measured gamma rays in the energy range of 200 keV to 12 MeV with high precision to determine the composition of the lunar surface. It was expected to provide data on the abundance of many major elements over the entire lunar surface and possibly on water ice at the polar regions.

The Lunar Prospector GRS produced the first global measurements of gamma-ray spectra from the lunar surface, from which are derived the first "direct" measurements of the chemical composition for the entire lunar surface. The Gamma Ray Spectrometer was a small cylinder which was mounted on the end of one of the three 2.5 m (8.2 ft) radial booms extending from the Lunar Prospector.

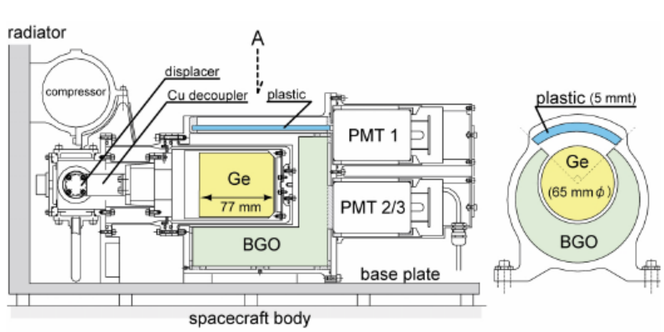

Figure 2 - Schematic drawing of GRD. Incident gamma rays from the Moon come through the plastic scintillator and viewed by a photomultiplier (PMT1). The space around the Ge crystal, the cold-tip of the displacer and thermal link (Cu decoupler), is evacuated. The BGO crystals (BGO1 and BGO2) are coupled with two PMTs.

It consisted of a bismuth germanate crystal surrounded by a shield of borated plastic. Gamma rays striking the bismuth atoms produced a flash of light with an intensity proportional to the energy of the gamma ray which was recorded by detectors. The energy of the gamma ray is associated with the element responsible for its emission. Due to a low signal-to-noise ratio, multiple passes were required to generate statistically significant results.

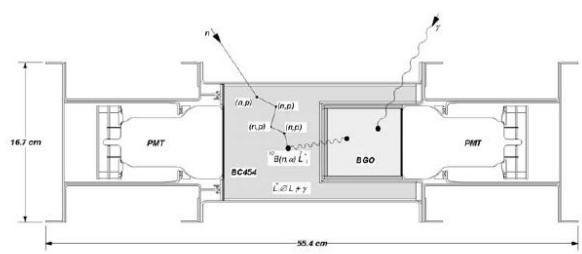

Figure 3 - View of a central cut through the Gamma-Ray Spectrometer sensor. Also illustrated are schematic interactions of neutrons in the borated plastic anticoincidence shield at the left and a gamma ray in the BGO Scintillator.

Future planetary missions will involve landing both stationary and roving probes on planetary surfaces, and will utilize both X-ray and gamma ray spectrometers for performing elemental analyses of surface samples. Such missions will impose constraints on the instruments flown. First, the weights of both instruments must be reduced significantly from those flown on previous missions. Because the instruments for many missions will be exposed to years of cosmic-ray irradiation between the time from launch to rendezvous with the planetary body, the detector systems must be designed to operate reliably under conditions of long-term exposure to this radiation. New technologies must be applied to the design of both X-ray and gamma ray spectroscopy imaging systems. Large area X-ray detectors operating in the 1-10 keV (e.g. of the order of 10's of square centimeters area) domain with both spectroscopic and imaging capabilities are being investigated. Large volume gamma-ray detectors will be of great importance in application to remote and in situ sensing of planetary bodies. Room temperature solid state detectors should be of great importance in the development of planetary remote sensing and in situ analysis systems. These room temperature materials need to be studied relative to their operation and survival in the harsh space flight environment. Their long-term operation during space flight must also be studied. Detector system designs must be developed which are consistent with the very constrained and demanding space flight requirements imposed by the mission.

HISTORICALLY REMOTE SENSING

- In 340 BC, Aristotle described weather patterns in Meteorologica. Theophrastus compiled a book on weather forecasting, called the Book of Signs.
- In 904 AD, Ibn Wahshiyya forecasted the weather by study of atmospheric changes and signs from the planetary astral alterations; signs of rain based on observation of the lunar phases; and weather forecasts based on the movement of winds.
- Initial aerial photographs taken from planes were often highly distorted due to shutter speeds being too slow in relationship to the speed of the plane. By 1920, Sherman M. Fairchild developed a camera with the shutter located inside the lens. This design significantly reduced the distortion problem. Fairchild also designed an intervalometer that allowed photos to be taken at any interval.
- One of the first uses of optical interferometry was the construction of a Michelson stellar interferometer on the Mount Wilson Observatory's reflector telescope in order to measure the diameters of stars. The red giant star Betelgeuse was the first to have its diameter determined in this way on December 13, 1920.
- In the United States, David Atlas developed the first operational weather radars.
- In 1956-1958, W.M. Stinton discovered absorption features in his spectra of Mars that appeared to be consistent with chlorophyll. This was an interesting application of vegetation remote sensing.

Science Instruments & Technologies for Space-Borne Astronomy & Planetary Missions

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1. INTRODUCTION

Exploration of the universe and celestial objects such as stars, planets, comets, etc. has always been fascinating to mankind. Earlier efforts only comprised observation of motion of objects visible to the naked eye. Technological advances during the last six centuries provided more precise observations and theoretical understanding. Dawn of the space age during the last century was a stepping stone in this field as it enabled observation in parts of the electromagnetic spectrum normally blocked by earth's atmosphere and also allowed humans and instruments to physically reach the solar planets.

Space missions for astronomy and planetary sciences are defined as per the scientific objective of the mission. This further leads to the kind of instrumentation for space-flight, observation as well as possible experimentation. Many countries have launched highly sophisticated instruments to achieve various mission objectives. Wealth of scientific data has been accumulated and scientists across the globe are deciphering the data to bring out information which may be helpful for mankind. Even with this it appears to be only a beginning as all these missions have raised more questions than answers. Hence various other missions are lined up for the future. For any future plans, previous experiences play a crucial role in defining mission objectives, designing instrumentation, choice of technologies etc. This article provides an overview of remote sensing missions, science instruments and technologies for astronomy and planetary sciences.

Section-2 provides chronological history of space missions for astronomy and planetary exploration and analyzes this information with respect to development years, type of mission, targeted planets etc. In section-3 typical science instruments, which are part of theses missions are described. In section-4 optical imaging systems flown on various missions are discussed in particular. Also technologies used in realization of these instruments are highlighted.

2. SPACE-BORNE MISSIONS FOR ASTRONOMY AND PLANETARY EXPLORATION

Space age began with the launch of Sputnik-1 in 1957, which orbited the Earth. The first human spaceflight was conducted in 1961. Number of orbiting astronomical observatories was flown beginning 1962. Planetary exploration followed soon after the dawn of space age with particular interest in Moon, Mars and Venus. Various space missions including orbiters, landers, flybys, etc. were flown to understand the topography and composition of these planets. These efforts culminated with the first human landing on Moon in 1969. After this, there were a number of manned missions and sample returns from the Moon. The next two decades saw efforts to explore the outer space including comets, asteroids, Jupiter, Saturn, etc. Ever since the turn of the century, planetary exploration has become a subject of international cooperation with missions planned in a systematic and harmonious manner. The thrust is now more on robotic exploration of the planets, while interest still remains in a future human habitat outside the Earth. Astronomy missions have also furthered the understanding of creation and evolution of the universe through observations made by space telescopes. The most interesting experiments in astronomy are related to extra-terrestrial life detection and search for exoplanets.

Evolution of space missions for astronomy and planetary sciences is shown in Fig. 1, and major milestones are summarized in Table 1.

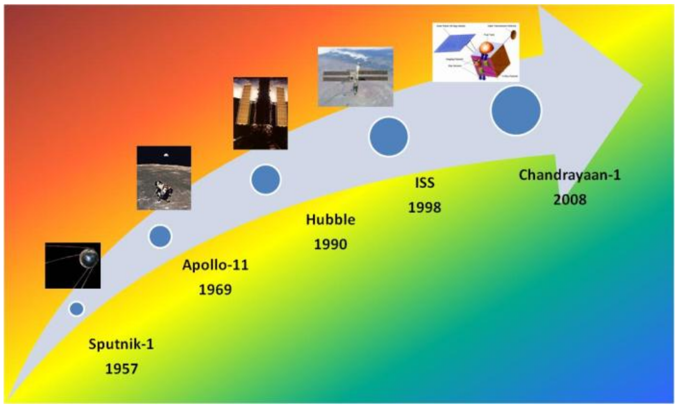


Fig. 1: Evolution of Space Missions for Astronomy & Planetary Sciences

Year-wise number of astronomy and planetary missions is shown in Fig. 2. It is seen that the number of planetary missions was very high during the early stages. This is due to intense competition during cold war era. Subsequently the number of missions started diminishing through mid-70's to early 90's. During the last decade, there is renewed interest in space-borne astronomy and planetary missions through international cooperation and usage of advanced instrumentation technologies. The total number of astronomy missions is about 60 while planetary missions are about 180 in number. Details of some missions flown during last decade are shown in Table 2.

TABLE 1: MAJOR MILESTONES IN SPACE-BORNE ASTRONOMY AND PLANETARY MISSIONS

DATE	MILESTONE	DETAILS
Oct. 4, 1957	First artificial Earth satellite	Sputnik 1
Sept. 14, 1959	First spacecraft to hard-land on another celestial object (the Moon)	Luna 2
April 12, 1961	First human to orbit Earth	Yuri Gagarin on Vostok 1
April 26, 1962	First astronomical satellite	Ariel 1
Dec. 14, 1962	First data returned from another planet (Venus)	Mariner 2
July 14, 1965	First spacecraft pictures of Mars	Mariner 4
Feb. 3, 1966	First spacecraft to soft-land on the Moon	Luna 9
Dec. 7, 1968	First large-scale astronomical mission	OAO 2
Dec. 24, 1968	First humans to orbit the Moon	Frank Borman, James Lovell, and William Anders on Apollo 8
July 20, 1969	First human to walk on the Moon	Neil Armstrong on Apollo 11
Sept. 24, 1970	First return of lunar samples by an unmanned spacecraft	Luna 16
Nov. 10, 1970	First rover	Luna 17
April 19, 1971	First space station launched	Salyut 1
Nov. 13, 1971	First spacecraft to orbit another planet (Mars)	Mariner 9
Dec. 2, 1971	First spacecraft to soft-land on Mars	Mars 3
April 19, 1975	First Indian artificial satellite; objective - astronomy	Aryabhatta
March 13, 1986	First spacecraft to make a close flyby of a comet nucleus	Giotto at Halley's Comet

April 25, 1990	First large optical space telescope launched	Hubble Space Telescope
Dec. 7, 1995	First spacecraft to orbit Jupiter	Galileo
Feb. 14, 2000 Feb. 12, 2001	First spacecraft to orbit (2000) and land on (2001) an asteroid	NEAR at the asteroid Eros
Jan. 14, 2005	First spacecraft to land on the moon of a planet other than Earth (Saturn's moon Titan)	Huygens probe of the Cassini-Huygens spacecraft
Oct. 22, 2008	First Indian planetary mission	Chandrayaan 1
June 13, 2010	First spacecraft to return to Earth with samples from an asteroid	Hayabusa

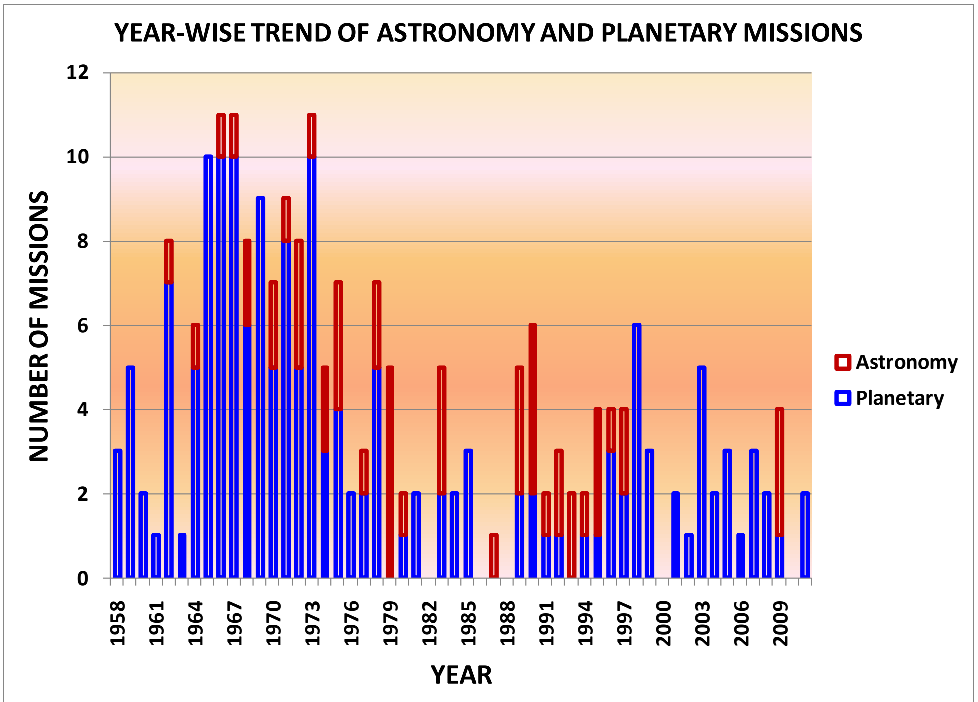


Fig. 2: Year-Wise Trend of Astronomy And Planetary Missions

TABLE 2: ASTRONOMY AND PLANETARY MISSIONS OF 21ST CENTURY

YEAR	MISSION	PURPOSE
2001	Genesis	Collection and sample return of solar wind particles
	Mars Odyssey	Detailed mineralogical analysis of Martian surface, measurement of radiation environment
2003	SMART-1	Lunar orbiter designed to test spacecraft technologies for future missions
	Mars Express	Global high-resolution photogeology, mineralogical mapping and mapping of the atmospheric composition of Mars
	Spirit, Opportunity	Mars rovers

	Hayabusa	Collection and sample return of material from an asteroid
2004	Messenger	Study of characteristics and environment of Mercury (First Mercury orbiter)
	Rosetta	Rendezvous with comet, drop a probe on the surface, study the comet from orbit and flyby at least one asteroid en route
2005	Mars Reconnaissance Orbiter	Reconnaissance and exploration of Mars from orbit
	Venus Express	Study of characteristics and environment of Venus
	Deep Impact	Rendezvous with comet and drop a projectile into the comet nucleus
2006	New Horizons	Observation of Pluto, Charon and Kuiper belt objects
2007	Kaguya	Global survey of the Moon, mineralogy, topography, geology, gravity and plasma environments
	Chang'e-1	Lunar orbiter
	Dawn	Rendezvous and orbit the asteroids Vesta and Ceres to characterize the internal structure, density, shape, size, composition and mass and to return data on surface morphology, cratering, and magnetism
2008	Chandrayaan-1	Topographic and mineralogical mapping of Moon
	Mars Phoenix	Study surface and near-surface environment of a landing site on Mars
2009	Lunar Reconnaissance Orbiter	Map the surface of Moon and characterize future landing sites in terms of terrain roughness, usable resources, and radiation environment
	Kepler	Exploration of Earth-like planets orbiting other stars
	Planck	Observation of anisotropy of cosmic microwave background
	Herschel	Observation in far infrared and sub-mm range for study of formation of galaxies, stars, etc.
2011	Mars Science Laboratory	Exploration of Martian surface

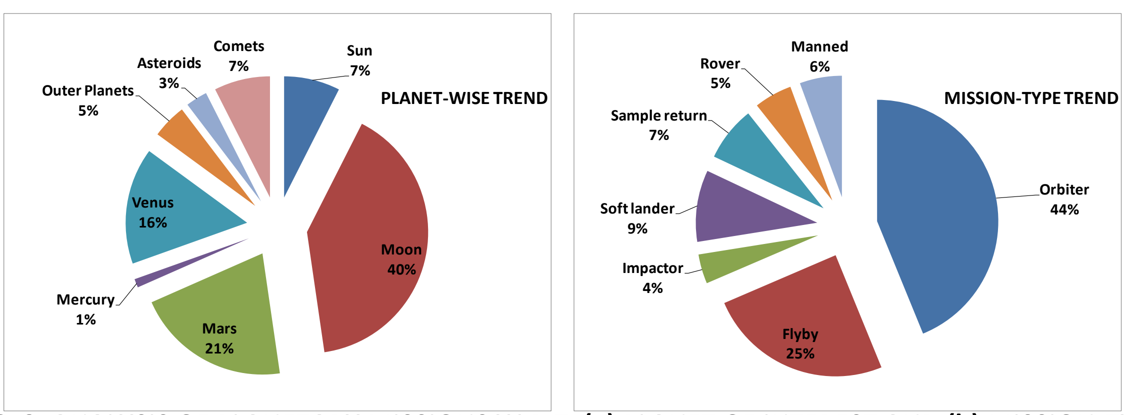


FIG. 3: ANALYSIS OF PLANETARY MISSIONS W.R.T. (a) PLANET OF INTEREST AND (b) MISSION-TYPE

Planetary missions are further analyzed with respect to planet of interest and types of missions and shown in Fig. 3a and 3b. It is seen that Moon has the highest percentage of missions, followed by Mars and Venus. Also, orbiters and flybys are the most common mission-types. Manned missions were prevalent during early stages of planetary exploration, while rovers are more common today.

As we have seen in this section, there is a rich historical heritage of space-borne missions for astronomy and planetary sciences. Technological advances will continue this saga of space exploration in coming years with newer missions expanding the current horizons beyond our solar system to other stellar systems, galaxies, etc. Key to the success of this scientific sojourn is the usage of high-performance, hi-rel, state-of-the-art science instruments that are flown on these missions.

3. TYPICAL SCIENCE INSTRUMENTS FOR ASTRONOMY AND PLANETARY MISSIONS

Space missions for astronomy and planetary exploration carry various types of science instruments for collecting science data. Large missions typically carry a broad suite of instruments for a range of investigations, while small missions are designed around one or two dedicated instruments or smaller suites of focused instruments. In both cases, highly capable instruments are key elements of successful development and operation of high-performance missions for making precise observations. The science instruments flown on various astronomy and planetary missions are broadly classified as shown in Fig. 4.

Also each type of instruments are briefly described with suitable example in this section. As we have seen in the previous section, a plethora of missions for astronomy and planetary sciences have been launched for various mission objectives hence it is quite possible that some instruments might not have found place in this article, however attempt is made to make this list quite exhaustive.

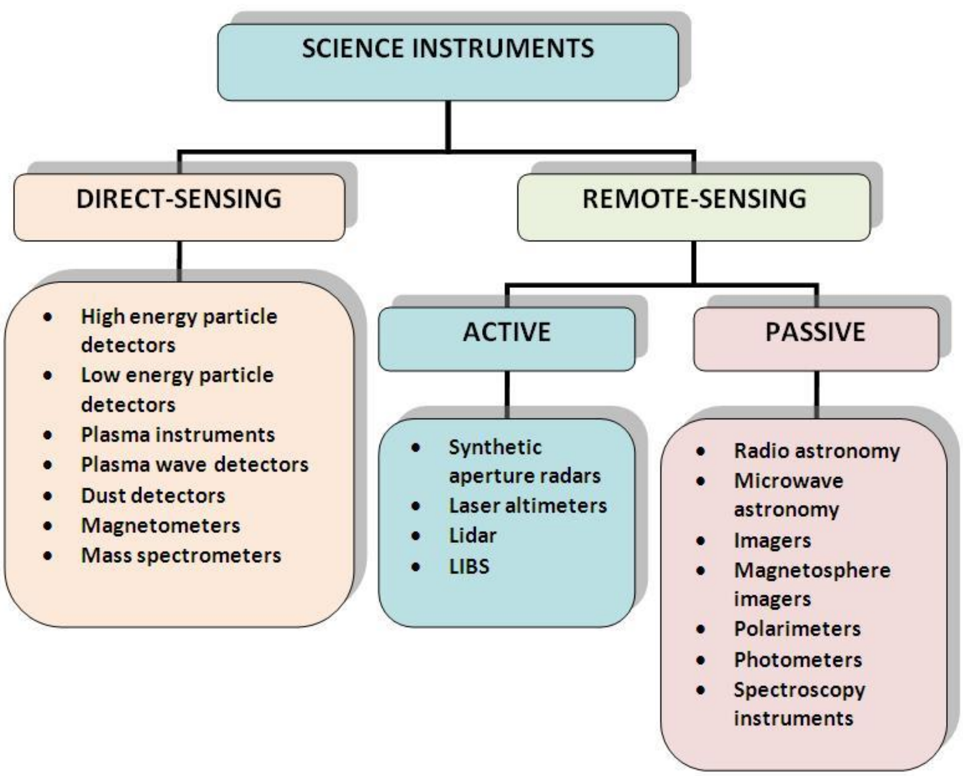


FIG. 4: CLASSIFICATION OF SCIENCE INSTRUMENTS

3.1 Direct-sensing instruments

Direct sensing instruments directly interact with the observable in their vicinity and record their characteristics. Particle detectors, wave detectors, magnetometers and mass spectrometers fall under this category. Galileo's heavy ion counter is an example of direct sensing instrument. Similarly Galileo and Cassini's dust detectors, measure properties of dust such as mass, species, speed and direction etc. Some of the examples of Direct-Sensing Science Instruments are described below:

High-Energy Particle Detectors: High-energy particle detector instruments measure the energy spectra of trapped energetic electrons and composition of atomic nuclei. The Cosmic Ray Subsystem (CRS) on the Voyagers measures the presence and angular distribution of particles from planets' magnetospheres, and from sources outside our solar system. This instrument can measure electrons of 3-110 MeV and nuclei of 1-500 MeV from hydrogen to iron. The Energetic Particle Detector (EPD) on Galileo is sensitive to the same nuclei with energies from 20 KeV to 10 MeV.

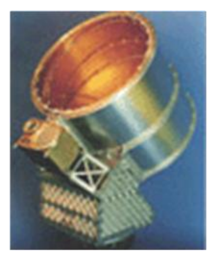
VOYAGER's CRS

CASSINI's CAPS

Low-Energy Charged-Particle Detectors: A low-energy charged-particle detector (LECP) is a mid-range instrument designed to characterize the composition, energies and angular distribution of charged particles in interplanetary space and within planetary systems. The Voyagers' LECPs are sensitive from around 10 keV to the lower ranges of the Cosmic Ray detector.

Plasma Instruments: Plasma detectors measure the density, composition, temperature, velocity and three-dimensional distribution of plasmas, which consist of positive ions and electrons that exist in interplanetary regions and within planetary magnetospheres. The Cassini Plasma Spectrometer Subsystem (CAPS) measures the flux (flow rate or density) of ions as a function of mass per charge, and the flux of ions and electrons as a function of energy per charge and angle of arrival.

Dust Detectors: Dust detectors measure the number, velocity, mass, charge and flight direction of dust particles striking the instrument. As an example, Galileo's instrument can register up to 100 particles per second and is sensitive to particle masses of between 10^{-16} and 10^{-6} gram. Cassini's Cosmic Dust Analyzer (CDA) can determine the species of material in some dust particles as well as the properties mentioned above.



CASSINI's CDA

VOYAGER's MAG BOOM

Magnetometers: Magnetometers are direct-sensing instruments that detect and measure the interplanetary and solar magnetic fields in the vicinity of the spacecraft. They typically detect the strength of magnetic fields in three planes. As a magnetometer sweeps an arc through a magnetic field when the spacecraft rotates, an electrical signature is produced proportional to the strength and structure of the field. The Voyager Magnetometer Experiment (MAG) consists of two low-field magnetometers and two high-field magnetometers that together provide measurement of fields from 0.02 nano-Tesla (nT) to 2,000,000 nT. On the spacecraft, the instruments populate a 13-meter-long fiberglass boom to keep them away from on-board interference. The magnetometers provide direct field measurement of both the planetary and the interplanetary media. It is typical for magnetometers to be isolated from the spacecraft on long extendable booms.

Plasma Wave Detectors: Plasma wave detectors typically measure the electrostatic and electromagnetic components of plasma waves in three dimensions. The instrument functions like a radio receiver sensitive to the wavelengths of plasma in the solar wind from about 10 Hz to about 60 kHz. When within a planet's magnetosphere, it can be used to detect atmospheric lightning and events when dust particles strike the spacecraft. The Voyagers' plasma wave data has produced sound recordings of the particle hits the spacecraft experienced passing through the ring planes of the outer planets.

Mass Spectrometers: Mass Spectrometers, for example the Cassini Spacecraft's INMS, Ion and Neutral Mass Spectrometer, report the species of atoms or molecules that enter the instrument. Huygens' GCMS and ISRO developed CHACE-1 onboard Chandrayaan-1 are another such examples.

3.2 Remote-sensing instruments

Remote-sensing instruments make measurements from a distance without physical contact with the target. In doing so, they form some kind of image or characterization of the source of the phenomena (observables). A camera, also called an imager, is a classic example of a remote-sensing instrument. It records characteristics of objects at a distance by forming an image by gathering, focusing, and recording light. Remote sensing instruments can be broadly classified as **Active and Passive Instruments.**

3.2.1 Passive remote-sensing instruments: Most instruments only receive and process existing light or other phenomena, and they are said to be **passive**. Typical of this type would be an imaging instrument viewing a planet that is illuminated by sunlight. Some of the examples of Remote-Sensing Science Instruments are discussed in more detail below:

Planetary Radio Astronomy Instruments: A planetary radio astronomy instrument measures radio signals emitted by the target such as a planet. The instrument on Voyager is sensitive to signals between about 1 kHz and 40 MHz and uses a dipole antenna 10 m long, which it shares with the plasma wave instrument. The planetary radio astronomy instrument detected emissions from the heliopause in 1993.

Microwave Radio Astronomy instruments: In modern cosmology, Cosmic Microwave Background (CMB) measurements are one of the major pillars to test theories about the birth and evolution of the Universe. The first space-based measurements of the CMB were carried out with NASA's Cosmic Background Explorer (Explorer-66, also called as COBE) satellite. In 1992, it confirmed for the first time that the temperature of the CMB was not identical all over the sky.

This satellite carried an instrument called Differential Microwave Radiometers (DMR), which uses three differential radiometers to map the sky at 31.4, 53, and 90 GHz. Each radiometer employs a pair of horn antennas viewing at 30 deg from the spin axis of the spacecraft, measuring the differential temperature between points in the sky separated by 60 deg. Each radiometer is a microwave receiver whose input is switched rapidly between the two horn antennas, obtaining the difference in brightness of two fields of view 7 deg in diameter located 60 deg apart and 30 deg from the axis of the spacecraft. The instrument weighs 120 kg, uses 114 W, and has a data rate of 500 bps.

Imaging Instruments: An imaging instrument is an optical camera, which provides a 2-D or 3D image of the target. An image provides information about shape, morphology and color of the object thereby indicating origin of the object, surface processes that have occurred/are occurring like impacts, etc. These can be broadly classified as low-resolution, high-resolution, wide-angle, stereoscopic, etc. Technological aspects of optical imagers are covered in more detail in Section 4.

Magnetosphere Imager: Cassini carries a unique instrument that's never been flown before in the outer solar system. The Magnetospheric Imaging Instrument (MIMI) Ion and Neutral Camera (INCA) can form images of the giant magnetic envelopes of Jupiter and its main objective Saturn, as well as fields associated with Saturn's moons. MIMI INCA is more like a particle detector, although unlike most particle detectors, it is actually a remote sensing instrument. MIMI INCA senses ions and neutral atoms that have been flung out of a planet's magnetosphere, forming an image of the source of the particles.

Polarimeters: Polarimeters are optical instruments that measure the direction and extent of the polarization of light reflected from their targets. Polarimeters consist of a telescope fitted with a selection of polarized filters and optical detectors. Careful analysis of polarimeter data can infer information about the composition and mechanical structure of the objects reflecting the light, such as various chemicals and aerosols in atmospheres, rings, and satellite surfaces, since they reflect light with differing polarizations. A polarimiter's function may be integrated with another instrument, such as a camera, or the Voyager photopolarimeter that combines functions with a photometer.

Photometers: Photometers are optical instruments that measure the intensity of light from a source. They may be directed at targets such as planets or their satellites to quantify the intensity of the light they reflect, thus measuring the object's reflectivity or albedo. Also, photometers can observe a star while a planet's rings or atmosphere intervene during occultation, thus yielding data on the density and structure of the rings or atmosphere. One of the three instruments on the Spitzer Space Infrared Facility (SIRTF) is a photometer designed to measure the intensity of stars in the infrared.

Spectroscopic Instruments: Spectroscopy provides a wealth of information for analysis of observed targets. The field of spectroscopy includes methods for analysis of virtually every part of the electromagnetic spectrum. Most are differentiated as either atomic or molecular based methods, and they can be classified according to the nature of their interaction:

- **Absorption spectroscopy** uses the range of the electromagnetic spectra in which a substance absorbs. Signatures of atoms or molecules can be recognized by dips in a spectrum's intensity at specific wavelengths, as light passes through an atmosphere for example.
- **Emission spectroscopy** uses the range of electromagnetic spectra in which a substance radiates. Hot metals, for example, radiate a continuous spectrum of many (or all) wavelengths, while excited gasses emit various discrete wavelengths, giving each specimen a characteristic "fingerprint."

Scattering spectroscopy measures the amount of light that a substance scatters at certain wavelengths, incident angles, and polarization angles.

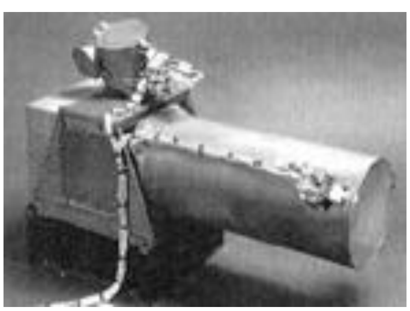
Cassini's ultraviolet instrument is the Ultraviolet Imaging Spectrograph, UVIS. Its infrared instrument is the Composite Infrared Mapping Spectrometer, CIRS. Cassini's Visible and Infrared Mapping Spectrometer, VIMS, produce images whose every pixel contains spectral data at many different wavelengths. It is as though the instrument returns a whole *stack* of images with each observation, one image at each wavelength. Such data units are frequently called "cubes."

Optical imaging spectrometers are discussed in more detail in Section 4.

CASSINI CIRS

Infrared Radiometers: An infrared radiometer is a telescope-based instrument that measures the intensity of infrared (thermal) energy radiated by the targets. One of its many modes of observing is filling the field of view completely with the disc of a planet and measuring its total thermal output. This technique permits the planet's thermal energy balance to be computed, revealing the ratio of solar heating to the planet's internal heating.

Combination instruments: As mentioned above, sometimes various optical instrumentation functions are combined into a single instrument, such as photometry and polarimetry combined into a photopolarimeter, or spectroscopy and radiometry combined into a radiometer-spectrometer instrument. One example is Galileo's Photopolarimeter Radiometer instrument. Another example is the Voyagers' infrared interferometer spectrometer and radiometers, IRIS.

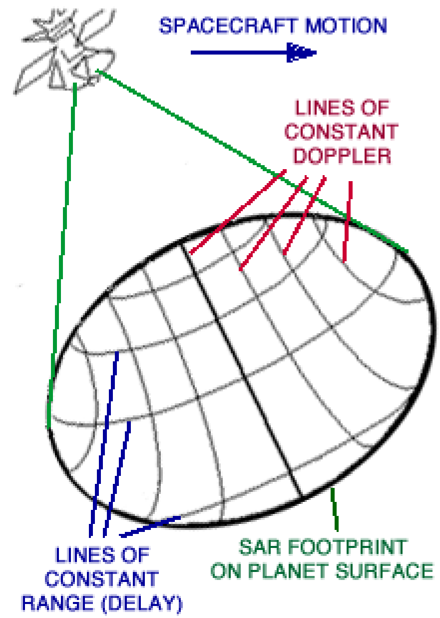


GALILEO PHOTOPOLARIMETER RADIOMETER

Other Instruments: Some of the other instruments flown are Gamma-ray Spectrometer, Neutron Spectrometer, Electron Reflectometer, Alpha Particle Spectrometer, multipurpose instruments etc.

3.2.2 Active remote-sensing instruments

Instruments for active remote-sensing are strategically grouped into radar systems, both full and synthetic aperture (SAR); light detection and ranging (lidar); and laser spectroscopy, including absorption spectroscopy, laser-induced–breakdown spectroscopy (LIBS), and Raman spectroscopy etc. Brief descriptions of few of the instruments are discussed below:



Synthetic Aperture Radar Imaging: Some solar system objects that are candidates for radar imaging are covered by clouds or haze, making optical imaging difficult or impossible. These atmospheres are transparent to radio frequency waves, and can be imaged using Synthetic Aperture Radar (SAR) which provides its own penetrating illumination with radio waves. SAR is more a technique than a single instrument. SAR images are constructed of a matrix where lines of constant distance or range intersect with lines of constant Doppler shift. Magellan's radar instrument alternated its active operations as a SAR imaging system and radar altimeter with a passive microwave radiometer mode several times per second in orbit at Venus.

Altimeters: A spacecraft's altimeter sends coded radio pulses, or laser-light pulses, straight down to a planet's surface (the nadir) to measure variations in the height of the terrain below. The signals are timed from the instant they leave the instrument until they are reflected back, and the round-trip distance is obtained by dividing by the speed of light, and factoring in known equipment processing delays. Dividing by two then approximates the one-way distance between the instrument and the surface. Actual terrain height is then deduced based upon precise knowledge of the spacecraft's orbit. The Pioneer 12 spacecraft and the Magellan spacecraft used radar altimeters at Venus. Laser altimeters generally have a smaller footprint, and thus higher spatial resolution, than radar altimeters. They also require less power. The Mars Global Surveyor spacecraft carried a laser altimeter that uses a small cassegrain telescope. Known as MOLA for Mars Orbiter Laser Altimeter, its technology formed the basis for an experiment flown in Earth orbit in 1997 by the Space Shuttle.

4. REMOTE SENSING OPTICAL IMAGING INSTRUMENTS AND TECHNOLOGIES

Optical imaging instruments are used in various missions for imaging in both visible and IR part of EM spectrum. Main objective of these optical imaging instruments are to generate global map of the surface of planets of interest using panchromatic cameras, generate 3-D images using stereo doublet or triplets, carry out multispectral and hyperspectral scanning (imaging-spectroscopy) of surfaces or environment. Broadly these instruments can be classified in Imagers and imaging spectrometers. These remote-sensing optical imaging systems incorporate relevant optics, dispersive elements, detectors, focal plane and processing electronics and associated spacecraft interfaces.

4.1 Optical Imagers: As discussed in section-3, various types of imaging instruments such as Low-Resolution Video Imager, Low-Resolution Imager, High-Resolution Imager, Wide-angle camera, Wide-Field, High-Resolution Planetary Camera etc have been flown on various planetary missions.

An imaging instrument uses optics such as lenses or mirrors to project an image onto a detector, where it is converted to digital data. Natural color imaging requires taking three exposures of the same target in quick succession or simultaneously through different color filters, typically selected from band pass filters. These imagers either operate in pushbroom or whiskbroom modes. Ground processing combines data from the three black and white images, reconstructing the original color by utilizing the three values for each picture element (pixel). Movies are produced by taking a series of images over an extended period of time. Typical imaging system is shown in Fig. 5. The scan mechanism shown in employed in whiskbroom mode only; pushbroom imagers utilize platform motion for scanning the scene.

Imaging Instrument Technology aspects: In the past, the detector that created the image was a vacuum tube resembling a small CRT (cathode-ray tube), called a vidicon. In a vidicon, signals applied to deflection coils and focus coils sweep an electron beam from a heated cathode (electron source) across a photoconductor coating inside the tube's glass front where the image is focused. Light striking the photoconductor causes its grains to leak their electric charge in proportion to the light's intensity. The sweeping beam's current would vary as it recharges depleted grains' charges to the point they repel the beam's electrons. This current becomes the basis for the digital video signal produced. Viking, Voyager, and Mariner spacecraft used vidicon-based imaging systems. A vidicon requires a fairly bright image to detect.

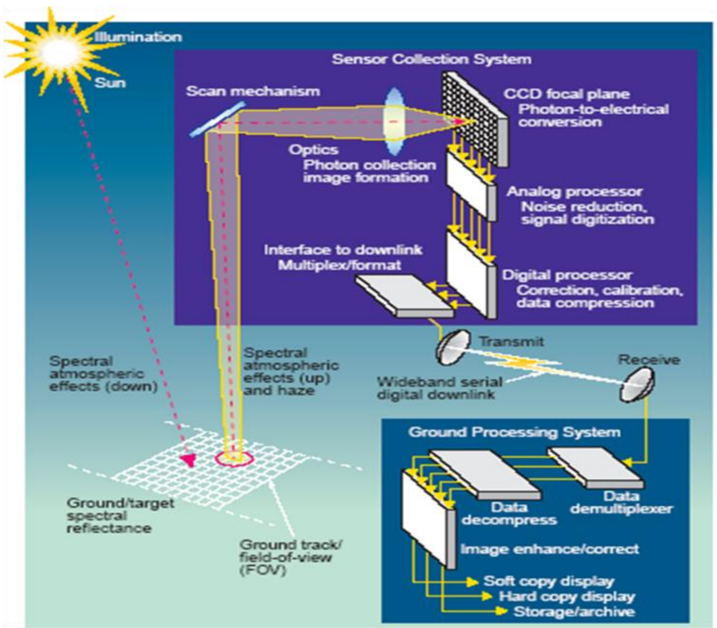
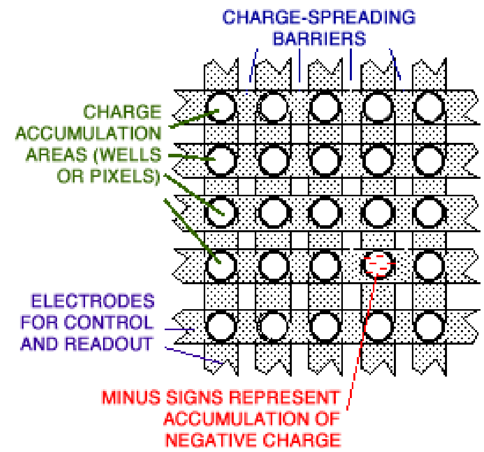


FIG. 5: TYPICAL OPTICAL IMAGING SYSTEM

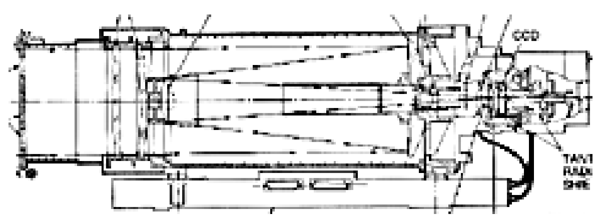
Modern instruments use CCDs, charge-coupled devices. A CCD is usually a large-scale integrated circuit having a two-dimensional array of hundreds of thousands, or millions, of charge-isolated wells, each representing a pixel. Light falling on a well is absorbed by a photoconductive substrate such as silicon and releases a quantity of electrons proportional to the intensity of light. The CCD detects and stores accumulated electrical charge representing the light level on each well over time. These charges are read out for conversion to digital data. CCDs are much more sensitive to light of a wider spectrum than vidicon tubes, they are less massive, require less energy, and they interface more easily with digital circuitry. It is typical for CCDs to be able to detect single photons.

Galileo's Solid State Imaging instrument, SSI, which pioneered the technology, contains a CCD with an 800 x 800 pixel array. The optics for Galileo's SSI, inherited from Voyager, consist of a Cassegrain telescope with a 176.5-mm aperture and a fixed focal ratio of f/8.5. Since the SSI's wavelength range extends from the visible into the near-infrared, the experimenters are able to map variations in the satellites' color and reflectivity that show differences in the composition of surface materials.

The HIRISE instrument, or High-Resolution Imaging Science Experiment, on the Mars Reconnaissance Orbiter (MRO) and TMC camera of Chandrayaan-1 spacecraft has detectors made of single lines of CCD sensors. A two-dimensional image is built up as the image of the planetary surface moves across this one-dimensional detector while the spacecraft moves in orbit. HIRISE often achieves a resolution of less than 25cm per pixel.



DETAIL OF A CCD DETECTOR



GALILEO CAMERA

4.2 Imaging spectrometers: Spectrometers are optical instruments which split the light received from objects into their component wavelengths by means of a diffraction grating. They then measure the amplitudes of the individual wavelengths. This data can be used to infer the composition and other properties of materials that emitted the light or which absorbed specific wavelengths of the light as it passed through the materials. This is useful in analyzing planetary atmospheres. Spectrometers carried on spacecraft are typically sensitive in the visible, infrared and ultraviolet wavelengths. Among various advanced remote sensing methods, visible/IR spectroscopy is a key technology for exploring planetary surfaces and atmospheres. A typical imaging spectrometer is shown in Fig 6.

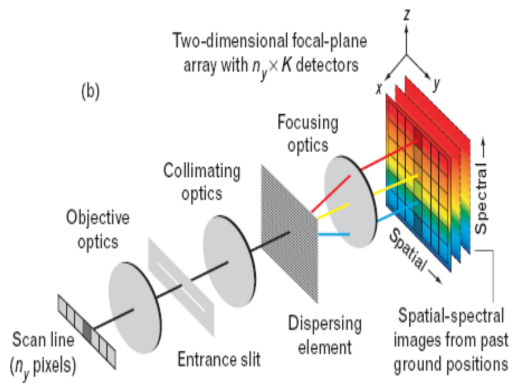


FIG. 6: TYPICAL IMAGING SPECTROMETER

The Moon Mineralogy Mapper (M3) on Chandrayaan-1 mission has moderately fast optics (f/2.5 to f/3.5) and has 600 spatial pixels cross track with 260 spectral pixels per spatial pixel in 10 nm steps in the 430–3000 nm spectral range. Onboard processing is limited to simple summing and compression. Also, the Hyper Spectral Camera (HySI) on Chandrayaan-1 was operated in visible range 400nm to 900 nm, with 80m spatial resolution and 20 nm spectral resolution covering a swath of 20 km on moon surface. Development of optically faster, high uniformity systems approaching f/1 for outer planet missions that enable spectroscopy in the image domain while spanning wide spectral ranges from the UV to the thermal infrared are being developed world wide. Development goals of such spectrometers include low-noise broadband detector arrays with large detector elements and dispersive systems for both high and moderate spectral resolution. Accompanying increased data demands are onboard computing systems that could process and identify spectral signatures and compress information for transmission.

The pushbroom operating sensor VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) on Rosetta mission is used to carry out spectroscopic measurements of comets in 0.25 – 5um spectral range. Mercury Radiometer and Thermal-infrared Imaging Spectrometer (MERTIS) are designed to do spectroscopic measurements of Mercury surface. MERTIS combines a pushbroom IR grating spectrometer (TIS) with a radiometer (TIR) sharing the same optics, instrument electronics, and in-flight calibration components for the whole wavelength range of 7–14 um (TIS) and 7–40 um (TIR). Within the mid-IR range, the instrument will record the temperature, texture, and mineralogical characteristics of Mercury's surface, contributing to a better understanding of the planet's genesis.

Some of the missions incorporate Fourier transform infrared (FTIR) spectrometers that seek trace gases in planetary atmospheres. These spectrometers use onboard Fourier transform calculation to reduce data downlink volume, and have been demonstrated. Also under development are increased array formats to thousands of detectors that provide high system sensitivity in multiple observing bands to take advantage of the large gains possible with cryogenic telescopes.

The main challenges for the above mentioned imaging system development include increasing accuracy while reducing mass, power requirements, and complexity. Some of the major components of these imaging instruments are described below.

Imaging Spectrometer Technology aspects: Detectors, focal plane array (FPA) systems: These are central to scientific measurements across a wide range of the electromagnetic spectrum and generally require optimization for the expected signal frequency wavelength and levels. In astronomy and planetary missions, the signals of interest can be exceedingly weak, barely above noise levels, and these detectors and focal plane arrays must be designed and engineered to reduce noise to theoretical physical limits, maintain sensitivity across the requisite detection bandwidth, and allow precision calibration in the space environment.

Semiconducting detectors include photoconducting; complementary metal-oxide semiconductor; and infrared arrays using quantum wells, wires, and dots and including super lattice and hetero junction structures. A key development in focal plane arrays would include very large focal planes, extending to the gigapixel level, incorporating multiple detector technologies.

General detector development challenges include reducing pixel-to-pixel non-uniformity, noise, and power requirements, as well as improving response uniformity, radiation hardness, spectral range, tunability, and quantum efficiency. Detector systems are required to be developed to operate at higher temperatures with higher signal and polarization sensitivity, as well as having greater array sizes. Additionally, development is under way in multiband field-programmable arrays, avalanche gain devices for particle and photon counting, low-noise electronics, and random-access readouts, buttable arrays for tiling to form large focal plane arrays, three-dimensional packaging structures, and improved detector fabrication processes.

Focal-plane system challenges include developing efficient ways to create very large arrays by optical butting, providing appropriate array thermal control, and developing very low-noise, low-complexity readout electronics. A major new area of opportunity is large-format sensitive detector arrays for wavelengths beyond 40 μm. Longer wavelengths represent a new frontier, and large (kilopixel) arrays with good sensitivity would be required for next-generation flight systems.

Dispersive Elements: Dispersive elements in the imaging spectrometer chain is a very important component and recently have seen great extent of technological development. The filters can be a set of individual elements in a filter wheel, or "they" can be continuously variable as with a circular or linear variable filter—CVF or LVF. Various types of dispersive elements have been flown on various missions like grating, bandpass strip filters Fabry-perot etalons, wedge filters, Fourier transform interferometers, liquid crystal tunable filters (LCTF), acousto-optic tunable filters (AOTF), etc. The filters can be used in the collimated portion of the optics, usually in front of the entrance pupil, or in the convergent beam near the focal plane. The main tradeoffs are size versus the narrowness and spectral shape of the filtration.

5.0 SUMMARY: The universe is very vast and so is this topic, hence it is very difficult to cover all the missions and instruments flown for achieving varied mission objectives at one place. However an attempt is made in this article to present the overview of missions, types of science instruments flown on them with specific coverage on optical instruments. Technological evolutions have propelled the development of spaceborne instruments, which has helped and will be helping in unraveling many mysteries of nature and may culminate in development of human habitat on some planets or finding life somewhere in the universe. Spaceborne optical instrumentations for astronomy and planetary sciences have matured from vidicon imagers to CCD, TDI based imagers and sophisticated spectroscopic imagers. The future missions will see more advancement in these instruments with improved accuracy and measurement capabilities. Robotic exploration will be dominating the future missions for close surface studies and sample returns with more emphasis on fully autonomous and multifunction missions.

Wireless Sensor Networks (WSN) – An in-situ Remote Sensing tool for Planetary Exploration

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1. Introduction: Planetary exploration requires precise data measurements over longer time in a large geographic region of interest. These measurements are normally performed using remote sensing techniques (with instruments on orbiters). But in situ measurements are often necessary for better understanding of various surface/near surface phenomenon concerned with the planet and also to confirm orbiter observations. Normally, this is done by placing sensors in the region of interest to carry out experiments. Results of these experiments will help provide information about the planet and processes occurring therein. So far, Rovers are used for taking such multiple measurements but the data collected is limited to specific number of data points along the rover traverse and one location at a time. Therefore, capturing geographically distinct measurements simultaneously for extended periods of times is challenging. Here we propose "Wireless Sensor Networks (WSN)"- a unique and prospective tool for simultaneous sensing of in situ phenomenon occurring on a remote planetary environment [1].

2. Wireless Sensor Network (WSN):

As shown in Fig 1. , a Wireless Sensor Network (WSN) is a system of intra-communicating spatially distributed network of tiny battery-powered devices [2,3], called NODES, that provide consistent spatio-temporal data useful to monitor and explore remote planetary environments. WSN, in principle offers an efficient way to probe one or a combination of geophysical, geochemical and environmental parameters on a planetary surface, depending on the sensors integrated onto the node. WSNs are potentially powerful tools for planetary exploration missions because of their unique capability of being deployed into an unfriendly and unattended environment for autonomous and remote data gathering tasks.

2.1. Structure and Operation:

2.1.1. Sensor Node structure: The heart of a WSN is a Wireless Sensor Node. Each in-situ sensor node is a tiny, low-power, battery operated embedded device equipped with a suitable sensor that is placed in a region to monitor the specific physico-chemical/geophysical/electrical quantity of interest from that region. Each sensor node will have the capability of sensing (scientific measurement), simple data processing and communication with other nodes. Figure 2 shows the architecture of a typical sensor node. Each sensor node weighing a few grams (Figure 3) with a communication range from meters to a kilometer typically contains a microcontroller, a radio/optical transceiver and one or more sensors. The various components of a sensor node are given below:

Embedded Processor: A microcontroller/ field-programmable gate arrays (FPGAs)-based system collaborates with other sensors and accomplishes data-acquisition, control and communication tasks.

Memory: Local processing and data aggregation is accomplished by a flash memory. Data acquisition, network operation and storage in WSN requires very small amount of memory.

Sensors: The sensor node itself is an integrated probe that contains multiple sensors for scientific measurements like temperature, ambient light, acceleration, volatiles and gas detection, magnetic field etc.

***Wireless Transceiver*:** The wireless transceiver is an RF interface that allows the node to establish communication with the neighbouring nodes. Frequencies used for communication range from few 10s to 100s MHz.

Battery and Power Management: The sensor nodes are equipped with self-contained energy sources such as batteries. Nodes can also use power management hardware as well as solar cells for recharging of batteries. Energy harvesting can be done wherever feasible (eg. Availability of Sunlight).
Individual Sensor Nodes are constructed to accomplish specific tasks like scientific measurement, communication with other nodes, simple data processing, and the ability to be reprogrammed to meet the need of diverse applications. By utilizing a number of sensor nodes it is possible to construct a wireless sensor network using which data can be collected simultaneously from a large area in a given geographical location, rather than a single point on the planetary body. Once deployed, sensors can self-organize into multi-hop adhoc like networks for autonomous data delivery without relying on any fixed communication infrastructure.

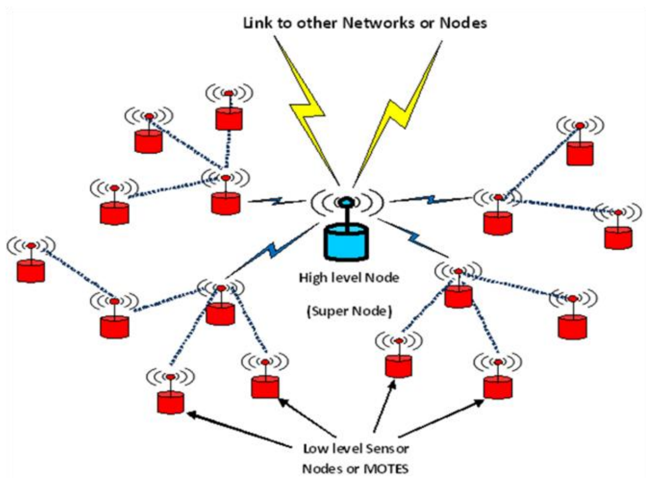

Fig. 1: Wireless Sensor Network

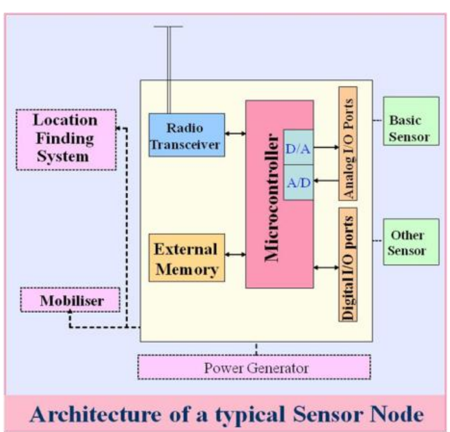

Fig. 2: Architecture of a Sensor Node

Fig. 3: Sensor Node designed at PRL (Mass : ~50 gms)

2.1.2. Operation: Sensor nodes in a WSN can be deployed in many number of ways, simplest of them is to drop these nodes by a descending lander or firing the nodes from the lander. Sensor nodes will be in sleep mode till they are deployed. Once deployed, they are activated and self-organized into adhoc networks and perform autonomous data transmission without relying on any fixed communication infrastructure. Each node performs measurements and then relays data through neighbouring sensor nodes to the base station (lander or rover) thus acting as co-operative clusters by dynamically adapting to sensor node capabilities, events and real-time information. These WSNs have a number of advantages as that they are tiny, consume low power, easily deployable, flexible topology and can handle multiple sensors. The operation of the in-situ sensor nodes have the following different phases:

Deployment: Sensors can be deployed in many number of ways. In general wherever possible, they can simply be dropped by a descending lander, like the Moon Impact Probe (MIP) [4]. Small parachutes or retro-rockets can be used with the nodes to reduce the ground impact. Another option is to drop the sensor nodes using Balloons, on planets having an atmosphere. In the case of moon, the sensor nodes can be fired from a central point (such as a rover/lander) in to the region of interest. The sensor nodes can also be dropped from the rover along its traverse path. Sensor nodes deployed in such a fashion not only collect scientific data but also aid in establishing over-the-horizon communication for the rover.

Activation: Sensor nodes are normally kept in sleep mode until they are deployed. This will reduce the power consumption and RF interference during transit. Once deployed the sensor nodes can use local environment information for activation. On the other hand, the sensor node can be activated by a unique trigger signal. On activation a node will perform BIOS checkup and then bootup, perform preliminary checkup of the surroundings and then start communicating with the central station.

Local Organisation: During the sensor node initialization, it first identifies its neighbouring node and exchange identities after which the network organization proceeds and all the nodes in the network start operating collectively.

Global Organisation : The final phase after activation is to establish a global communication with the central station. The central station may be situated on a lander, or a rover or on the orbiter. Global organisation can be done using either a single-tier or multi-tier architectures having different nodes with varied capabilities and communication range.

3. WSN for Planetary Exploration: Large-scale exploration of planetary bodies such as the Moon, Mars, Venus etc. demand simultaneous and unattended monitoring of various phenomenon occurring on them. Because of the ubiquitous, autonomous and unattended nature of Wireless Sensor Networks, one can think of a large number of applications when exploring these planetary bodies. Some applications of WSN for planetary probing are briefly given below.

3.1. WSN for Lunar Exploration: WSN is a potential tool for exploring the permanently shadowed regions (PSR) of the Moon. Results from recent missions suggest a large amount of water in the cold and dark bottom of impact craters near the lunar poles. Confirmation of these results and further exploration of these dark craters require a Rover or Lander to be deployed in these craters for carrying out in-situ measurements. But the data collected using Rover/Lander missions will be limited to a specific number of data points and one location at a time. Further, the mobility and operation of a Lander or a Rover in PSR is extremely challenging. The overall risk of operating a rover or lander in a permanently shadowed area would also be very high. In this scenario, a WSN is a feasible technique for exploration of such PSRs on the moon. In this case, the Lander/Rover can remain in sunlit areas and the WSN can be deployed to the nearby shadowed regions, thereby alleviating the necessity for the Lander/Rover to be in the shadowed region. Such a network helps in collecting the data simultaneously from a large area of a PSR, as has been recently proposed [5]. An artist impression of a WSN for exploring permanently shadowed regions of the Moon is illustrated in Figure 4. Some other key parameters on the Moon that could be effectively measured by using WSN include ambient light to infer day-night transitions [6], thermal and electrical properties [7], seismic waves and magnetic field to infer sub-surface phenomenon and geophysical properties.

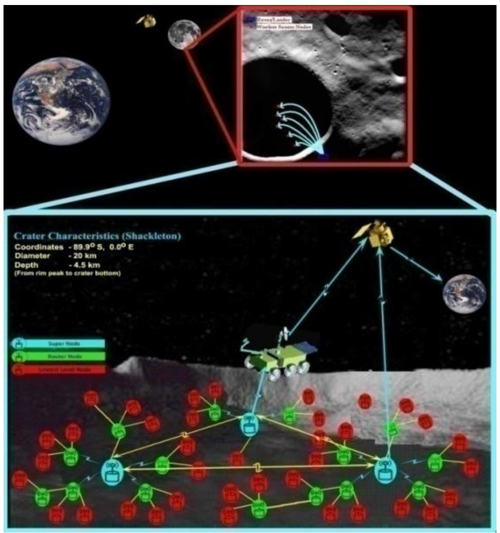

Fig. 4: Scenario of WSN probing PSRs of the Moon Node

3.2. WSN for exploration of Mars and Venus: For planetary bodies with atmosphere such as Mars and Venus, WSN technique can help us in probing various meteorological parameters, surface/sub-surface properties and also detect trace gases in the atmosphere and on surface. WSN can be used on descent platforms such as Balloons for profiling meteorological parameters such as temperature, pressure, density, and also key constituents of the thin Martian and thick Venusian atmospheres. On landing, the same nodes give long-term spatio-temporal observations of these parameters on the surface. Such observations help us in investigating the atmosphere-surface interaction on these planetary bodies. Measurement of ambient illumination on Mars and Venus using WSN helps in estimating their atmospheric opacities. Such measurements also aid in tracking and monitoring dust devils on Mars.

4. Conclusion: Long-term exploration of the Moon and Mars require large-scale in-situ investigations. Wireless Sensor Network (WSN) is a prospective tool that can provide long-term spatio-temporal investigation of their surface and near-surface environment. WSN make it feasible to probe difficult planetary terrains and inaccessible areas which otherwise would not be possible. Recent adavancements in technologies, level of miniaturisation and availability of state-of-art sensing devices can make possible the development of miniaturised sensor nodes for WSN. The applications presented in this article are only a few examples. We can devise numerous ways of using WSN for planetary exploration. Thus WSN can open a new paradigm for in-situ monitoring and exploration of planets using the future lander and rover missions.

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Indian Astronomy Satellite - Astrosat

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1.0 INTRODUCTION

Astrosat is India's first dedicated multi-wavelength astronomy satellite with a capability to observe target sources in wide spectral coverage extending over visible, ultraviolet, soft and hard x-ray regions with co-aligned instruments simultaneously. To understand the nature of cosmic sources, their radiation processes and environment, it is necessary to measure their emissions over the entire electromagnetic spectrum. Since intensity of several classes of cosmic sources varies with time, it is necessary to make simultaneous observations in different wavebands. The Instruments onboard Astrosat provide timing, spectral, imaging and monitoring of different X-ray sources. ASTROSAT is scheduled for launch in 2012 by PSLV. The designed Mission life is about five years.

The payloads of Astrosat are built with collaborative effort of several Indian and international institutions. There are five payloads on ASTROSAT. Three of the payloads viz., Large Area X-Ray Proportional Counter (LAXPC), Cadmium-Zinc-Telluride Imager (CZTI) and Soft X-ray Telescope (SXT) are built at Tata Institute of Fundamental Research (TIFR). The fourth payload viz., Scanning Sky Monitor (SSM) built at ISRO Satellite Centre (ISAC) and fifth payload viz., Ultraviolet Imaging Telescope (UVIT) built at Indian Institute of Astrophysics (IIA). ISRO has partnered with Canadian Space Agency (CSA) to get the photon-counting UV detectors for UVIT. The Focal Plane Camera Assembly (FPCA) of SXT is designed and developed at the University of Leicester (UoL), UK. Besides, these institutions, several centres of Indian Space Research Organization (ISRO) are also involved in the design and fabrication of various components and sub-assemblies of these instruments.

2.0 ASTROSAT SCIENCE GOALS:

a. Multi-wavelength observations

ASTROSAT mission is designed for multi-wavelength astronomy for a wide variety of both Galactic and extra-galactic source types (AGN, binaries, flaring stars, SNRs, clusters.....)

b. Broadband X-ray spectral measurements

- Emission and absorption features with medium energy resolution capability in the 0.3 – 100 keV spectral band with 3 co-aligned X-ray instruments

-Study both non-thermal and thermal components, reflection etc.

c. High time-resolution studies:

-Periodic, aperiodic and chaotic X-ray variability in X-ray binaries

- Detect new accreting milli-sec binaries and AXPs
- Study evolution of pulse and orbital periods.

3.0 ASTROSAT INSTRUMENTS:

There are five payloads onboard ASTROSAT to meet the science goals.

3.1. Large Area X-ray Proportional Counters (LAXPCs):

LAXPCs will be used for the timing and low resolution spectral studies covering broad energy band (3-80keV). This is a cluster of 3 identical co-aligned proportional counters in a multi-layer geometry with 1^o x 1^o field of view (FOV). The X-ray detection volume is 15 cm deep consisting of 60 anode cells each 3.0 cm x 3.0 cm, arranged in 5 layers surrounded on 3 sides with veto cells of size 1.5 cm x 1.5 cm for rejection of non-cosmic X-ray background. The anode wires are made of gold plated stainless steel. Each LAXPC is filled with 90% Xenon and 10% Methane at 1520 torr pressure to provide an average detection efficiency of 100% below 20 keV and 50% in

20- 80 keV. The energy resolution is about 20% FWHM at 6 KeV and 11% at 22 KeV.

A 50 µ thick Mylar film supported against pressure by a honeycomb shape collimator which serves as the X-ray entrance window.

The FOV collimator is made by gluing layers of tin, copper and aluminium. The total effective area of 3 LAXPCs is about 6000 cm^2 below 20 keV and about 5000 cm^2 at 45 keV making it the largest effective area hard X-ray detector ever flown in a satellite mission. This will provide high sensitivity for the timing observations in the hard X-ray band. Fig 1 shows the one of three units of LAXPC payload.

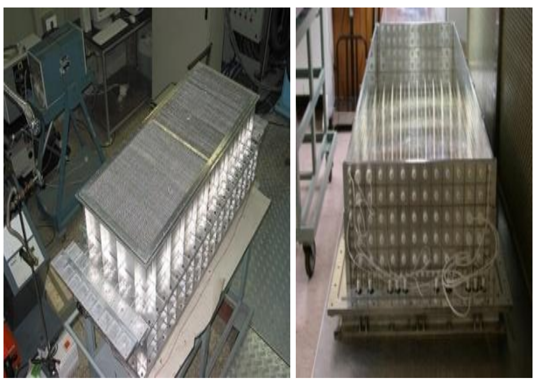

Fig 1. LAXPC payload

3.2. Cadmium-Zinc-Telluride Imager (CZTI): The hard X-ray imager CZTI will consist of a Pixellated Cadmium-Zinc-Telluride detector array. Medium resolution spectroscopy and low resolution imaging (0.1 degree) in 10-100 keV is achieved by CZTI. The CZT array has a geometrical area of 1024 cm^2 made up of 64 detector modules. This will provide position and energy of each detected X-ray. The imaging will be realized by a coded aperture mask (CAM) of tantalum with 17^o x 17^o FOV placed above the CZT plane. The sky brightness distribution will be obtained by applying a de-convolution procedure to the shadow pattern of the coded mask recorded by the detector. The CZT detector will be operated in 0^oC to -20^oC range by passive cooling using a radiator plate of appropriate area.

The CZT has superior energy resolution compared to the LAXPCs, above 40 keV with expected resolution of about 5% at 100 keV. Compton scattering producing background in the CZT will be eliminated to a great extent by using a 2.5 cm thick Caesium Iodide detector immediately below the CZT plane operated in anticoincidence mode.

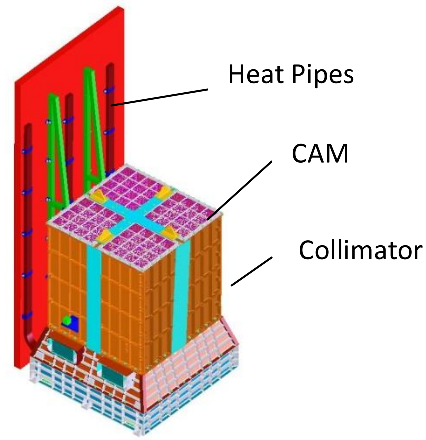

Fig 2 . CZTI Payload

3.3. Soft X-ray Imaging Telescope (SXT):
Soft X-ray imaging Telescope (SXT) being built for ASTROSAT will be sensitive to soft X-rays in the energy range of 0.3 - 8 keV. X-rays in this energy range are amenable to focus and lead to
(a) Nearly 1000 times better sensitivity over non-focusing instruments of similar areas making over 100,000 sources detectable
(b) Separation of confusing sources
(c) Imaging
(d) Spatially resolved spectroscopy
and
(e) Variability studies.
It is based on the use of conical foil mirrors of 2 meter focal length as optics and X-ray CCD as the detector. The gold coated X-ray reflecting mirrors made by nesting 41 conical shells, have been formed by replication process
A Focal Plane Camera Assembly (FPCA) will be mounted in the focal plane and will carry an X-ray sensitive CCD with an optical blocking filter in its focal plane. The CCD, working at -80 degrees C, will provide the highest energy resolution of all the X-ray instruments onboard ASTROSAT, and augment and

extend the energy range of the X-ray instruments onboard ASTROSAT to soft X-rays. It will be sensitive to the energy range where X-ray emission from cosmic X-ray sources is the maximum. SXT will provide medium resolution spectroscopy of soft X-ray emission from cosmic X-ray sources. It will also study the absorption properties of X-ray sources.
The CCD will have an energy resolution of about 130 eV at 6 keV and an effective area of about 200 cm^2 at 2 keV dropping to 25 cm^2 at 6 keV. The expected count rate of SXT is about 1.4 cps per mCrab.

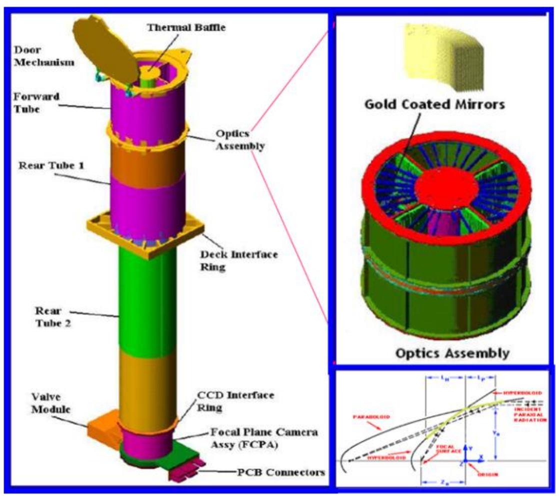

Fig 3. SXT Payload

3.4. The Ultraviolet Imaging Telescope (UVIT):
UVIT observes in ultraviolet and visible bands. All the X-ray telescopes and UVIT can observe simultaneously. UVIT observes simultaneously in FUV (130-180 nm), NUV (200-300 nm), and VIS (320 – 550 nm). The field of UVIT is ~ 29 arcmin circle, and images are made in FUV and NUV with a resolution better than 1.8"; resolution of the images in VIS is ~ 2.2". The instrument will have a temporal resolution of 30 ms for full frame, < 5 ms for small window.

The payload is configured as a twin telescope. One of these makes images in FUV and the other makes images in NUV and VIS. In the NUV/VIS telescope, the radiation is divided between the two channels by a dichroic filter. Each of the two telescopes is an RC configuration, with an aperture of ~ 375 mm and a focal length of ~ 4750 mm.

In each of the three channels a spectral band can be selected through a set of filters mounted on a wheel.

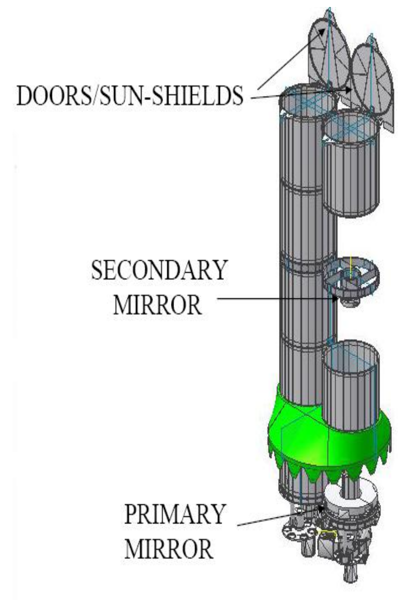

Fig.4 UVIT Payload

It uses three channel plate multiplier and CCD/CMOS3 based photon counting detectors. It will have angular resolution of about 2", a circular field of 0.5^{o}, time resolution of about 1 s and sensitivity to detect a 21 magnitude star in 1000 sec exposure in 50 nm pass band. In addition several filters with pass band of 10 to 50 nm centred at UV lines, will be mounted in a filter wheel in each telescope for narrow band imaging and photometry. The mirrors are made from light weighted Zerodur with aluminium reflecting surface protected by a layer of magnesium fluoride. The telescopes will have suitable baffles above them to reduce background due to stray light. The three Photon Counting Detectors (PCDs), 2 for the 2 UV channels and one for the visible channel, are being made in collaboration with the Canadian Space Agency (CSA). The CCD/CMOS frames are read out at a suitable rate to obtain the position of the photons to construct an image of the sky under observation.

3.5. Scanning X-ray Sky Monitor (SSM):
The Scanning Sky Monitor will consist of three position sensitive proportional counters, each with a one-dimensional coded mask. The SSM has been designed to scan the whole sky to study known bright

x-ray sources for any transient behaviour and to search for new transient sources.

It has a large field of view (~ 11 deg X 90 deg FWHM) to enable the fast coverage of the sky and operates in the 2-10keV range. It has the capability of locating the source in the sky by measuring the energy of x-ray events and the time of occurrence of event using position sensing proportional counter with one-dimensional coded mask as the X-RAY DETECTOR. The SSM has three detectors (SSM1, SSM2, and SSM3 as shown in the Fig No.5) mounted on a rotating platform, which rotates in order that 50% of the sky is scanned by the three detectors. The three detectors are mounted at different angles to cover a large fraction of the sky in the FOV of the detectors. Each rotation is done in step and stare mode and is completed in ~ 6.1 hr nominally, although provision for varying this exists in case necessary. The sensitivity of each detector is 30 milliCrab in one stare. The detector will consist of a single dimension position sensitive proportional counter (PSPC) powered by a high voltage unit. The detector will have two layers, each layer containing 10 anode cells, each cell of cross section 12mm x 12mm. Eight central anodes of the top layer will be made from highly resistive, 25micron diameter carbon coated quartz fibre. These resistive wires will be used to determine the position of a detected X-ray event by means of the charge division method. The two end anodes of the top layer and the bottom layer anodes will be conducting wires, made of gold coated tungsten and will form the veto layer. Cathodes will be made from 75 micron gold coated tungsten wires.

The counters are filled with P-10 or a mixture of Argon and Xenon and methane as quench gas at 800 torr. All the three SSMs are mounted on a platform which has a capability to rotate +/- 178 deg. In normal mode of operations, the platform is made to rotate in step and stare mode. The steering algorithm built makes it to step 10 deg in 30 seconds and stare the sky for 9.5 minutes. This is done to minimise disturbance to the other payloads.

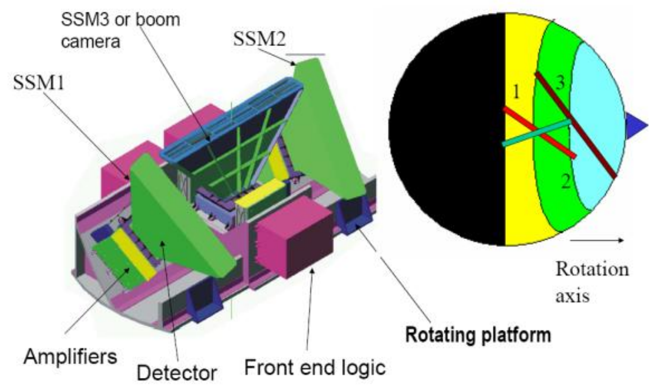

Fig.5. SSM Payload

4. ASTROSAT SATELLITE BUS:

The spacecraft bus configuration and design have the heritage of IRS bus. Astrosat observatory is estimated to be 1530 kg including 855 kg mass of the scientific instruments.

The design considerations of ASTROSAT are based the typical requirements of an Astronomy mission. Design drivers for design of subsystems especially for of power, thermal, mechanism and control subsystems are different. Contamination control is another aspect followed in the building of ASTROSAT spacecraft.

The Payloads are always ON even during eclipse and demand high power. Hence, the power system is sized for these requirements. Two wings of solar panel arrays with two panels each with single axis rotation are used for about 2000 Watt power generation. Two 36 AH batteries support the eclipse and peak power demands. During the full orbit, except for the eclipse period, the panels are always oriented normal to the Sun in order to generate maximum power. Whenever the stellar orientation is changed the panels are reoriented.

As the spacecraft is inertially pointed and changes orientation time to time, the thermal system design becomes a challenge.

The Thermal control system is designed to manage large gradients on instrument- devices, maintain optics and detectors at low temperatures with use of thermal control elements OSR, MLI, paints, thermal tapes, sink plates, quartz wool, heat pipes, radiators and heaters.

The Astrosat is a three axis stabilized satellite and inertially pointed to a target for observation. The orientation manoeuvres and attitude control is done by reaction wheels which will get the torque requirement derived input from 3 gyros and 2 star sensors. Magnetic torquers are used for momentum dumping. The re-orientation involves moving payload view axis from one target to another. The Slew operations, targeting and pointing for observation is managed by a Bus Management Unit (BMU). The BMU is an ASIC based Onboard computer which handles the bus functions of orbit and attitude control, command processing, Housekeeping telemetry, Sensor processing and antenna position processing. During slew and pointing to target, the typical constraints considered are the Solar avoidance: ≥ 45^0, Earth Limb avoidance: ≥ 12^0 and RAM Direction: ~ 11^0 to the view axis of the instruments. The pointing accuracy is 0.03 deg in all axes and the pointing stability is 5×10^{-5} deg/sec.

When targets are selected in the equatorial region, the observations are affected by the earth occultation, bright earth /limb conditions, requiring re orientation of payloads to a safe orientation. Though these reorientations reduce the overall observation time, it is required that the payloads are put to a safe condition. These algorithms are built onboard and also the reconfiguration or orientation may be programmed from the ground based on the prediction of the events.

The four payloads UVIT, LAXPC, SXT and CZT are mounted such that their view axes are along the positive roll axis. The SSM payload is mounted on another face in the yaw-pitch plane and is steered about yaw axis. The motion disturbs the observations of other payloads. So, a special feed-forward compensation scheme is employed in onboard control system which nulls the SSM motion induced disturbance rate and has a near instantaneous settling time.

The satellite has a propulsion system which carries 40 kg of monopropellant hydrazine and 8 numbers of 11 Newton thrusters .The propulsion is planned to be used for removal of initial orbit injection errors and emergency attitude control in orbit like safe hold as when it occurs. The payload data of 30 Gb per orbit will be stored on a solid state recorder and data is downloaded every visible orbit. It is planned to use a 160 Gb solid state recorder to cater to non visible orbits over the data reception centre and some buffer to hold the data for a replay. The data will be transmitted by two X- Band carriers, once in all the visible orbits, at a rate of 105 Mb / sec.

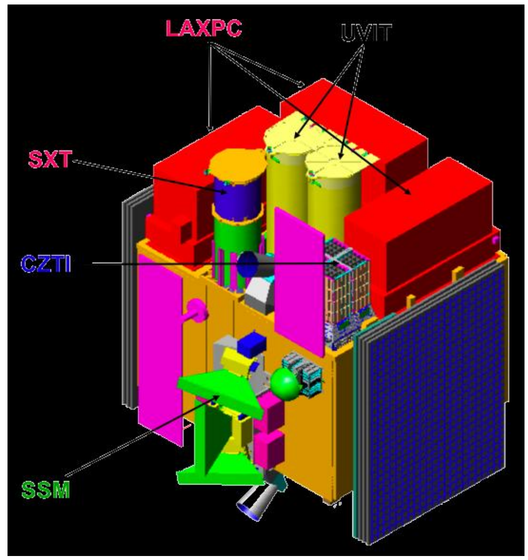

Fig 6. ASTROSAT

4.1 Contamination Control: The UVIT is more sensitive to the contamination. Hence, stringent contamination control practices are employed to control contamination throughout design, development, assembly, handling, storage, packaging and transportation of all the payload instruments and bus systems to avoid cross contamination.

Materials like plastics generating particulate contamination are not used in fabrication. Materials like polymers which have high out gassing are also not used. Baking and cleaning of parts and sub assemblies of instruments is carried out. Only permissible adhesives, epoxies, conformal coating and sealants are used.

Powder free Latex gloves, clean room wipes, swabs which are ESD compatible are used during assembly and testing. Always Nitrogen purging and venting is employed. Special protective covers, double/triple bag assemblies are used for transportation. The assembly of UVIT is instrument is done in clean room of 100 class.

The SXT telescope has a deployable cover at the top which is closed on the ground and helps to protect the telescope from contamination. In-orbit it is deployed by 256 degrees.

Both the telescopes of UVIT also have a deployable covers at the end of external baffle tubes. In-orbit these are deployed by 92 degrees. They also serve as Sun shades.

5.0 ORBIT CHOICE: Based on the requirements of the useful lifetime, low background of charged particles, a 650-Km, 8-deg inclined orbit is chosen. It provides minimum transit time in South Atlantic Anomaly (SAA) region. No orbit maintenance is envisaged for the ASTROSAT in orbit.

6.0 ASTROSAT – GROUND SEGMENT

ASTROSAT Ground Segment comprises TTC and Payload data reception stations, Satellite Control centre, Indian Space Science Data Centre and Payload Operation centres (POCs). All these four operational areas are intimately connected through communication links.

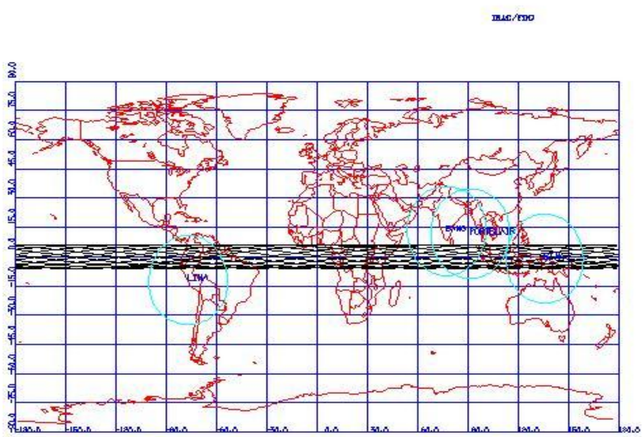

Fig 7. Typical ground traces of ASTROSAT

The ISTRAC TTC network comprising of stations at Bangalore, PortBlair and Biak support ASTROSAT for TTC functions. 10 to11 orbits out of 14 orbits are visible from Bangalore station alone.

ASTROSAT payload Ground station with 11mt antenna, along with the Indian Space Science Data Centre (ISSDC) is collocated in the Indian Deep Space Network (IDSN) Complex, Byalalu, Bangalore. This payload station will support exclusively ASTROSAT payload data acquisition. A standby payload station is also available at SCC, Bangalore.

The ground station transfers the TTC data to the control centre and the exclusive payload data reception station transmits instrument wise de-multiplexed data to Science Data Centre, after due conditioning. Satellite control centre comprises computers, technical facilities, Mission analysis area and dedicated mission control area. At the Satellite Control Centre, the satellite health is monitored; commands are uploaded to satellite towards payload operations and configuration changes onboard. The scheduling for various target observations and operating various instruments is approved by a separate committee identified for this purpose. This centre houses all necessary and approved mission operation software and analysis tools.

The Indian Space Science Data Centre (ISSDC) handles the data ingest, quick look Display (QLD), processing of instrument data (for level-0/1), data archival (all levels, along with the auxiliary data) and dissemination of payload data. It also receives and archives the higher level products generated at POCs. ISSDC also supports Scientists with Payload Facilities and instrument health monitoring.

The Quick Look Data (QLD) output for UVIT will be in the form of image whereas for other X-ray payloads it will be in the form of photon counts, light curves etc.

The Level-0 Processing has two components i) Payload data processing (PDP) and ii) Auxiliary data processing (ADP). PDP extracts the start and end time, segregates the data as per observation ID, formats the data, extracts the orbit, attitude information from SPICE data base and store them in FITS format. ADP separates LBT, AOCS and gyro data and transfers them to SCC, compute start-end time for each separated files, stores orbit and attitude information in SPICE format.

Level-1 Processing: This is reorganized raw data, written in Flexible Imaging Transport System (FITS) format for Astronomical use. All auxiliary information necessary for further processing of this data will be collated at this level and packed along with the respective science data. This data will be released for science use, first to the Payload Managers of the corresponding observing proposal and, after a specified initial lock-in period, to anyone interested in the data. In this processing level the data is validated as per the criteria and is flagged as good or bad, segregation of data as per mode of observation, target, proposal etc, sorting in the order of time line, extraction of instrument details, orbit/attitude details, generation of MKF (make filter file) etc.

Level-2 Processing: Level-2 products contain standard extracted science data from Level-1 like image for UVIT and photon counts, light curves, spectra, histogram for other x-ray instrument . The Level-2 processing applies instrument calibration data. These products are supported at ISSDC. The products are formatted in standard Flexible Image transport System (FITS) and usable as input to Astronomical science data packages for further analysis. The data first made available to Payload manger who submitted the observation proposal and later after the lock-in period to anyone interested.

Payload Operation Centres (POCs) are the instrument wise focal points. They monitor the health of the instruments, coordinate the instrument related operations, plan periodic calibrations and higher level data processing. They receive the processed data from ISSDC and return higher level products generated at POCs for safekeeping at ISSDC.

ASTROSAT Operations Portal handles the reception of proposals, processing, source finalization and sequencing of the same, considering the satellite constraints, geometry, merit / exigency of the proposals.

ASTROSAT Proposal Processing system (APPS) absorbs all the proposals in to its proposal data base and takes up further processing based on the predetermined criteria. It is also interfaced with other planning tools such as Astroviewer and Exposure Time Calculator, along with details of the instruments mode, constraints etc. The source selection and finalization shall be carried out by the ASTROSAT Time Allocation Committee (ATAC- Members are drawn from science and technical areas), assisted by the peer reviewing mechanism that assess all the proposals on their scientific merit and feasibility, and ASTROSAT Technical Committee (ATC- Members drawn from Mission and Operations Team) sequence them in order of priority and allot observation time for the selected proposals. The proposals cleared by ATAC will flow to ATC, which studies the feasibility of observing the sources, meeting all the geometrical and instrument constraints. The decision taken by ATC is the final one and this shall be passed on to Payload Programming System for the generation of time-lined command sequence output to be uplinked to the satellite.

ACKNOWLEDGMENTS: I acknowledge that the aspects discussed in this article are extracted out of Project documents produced by Payload Mangers and project teams of ASTROSAT project.

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The Hunt for Planets around Stars

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Since the discovery of the first exoplanet around the star called 51 Peg in 1995 by Geneva Observatory over 700 exoplanets have been discovered and confirmed to date. Detection and confirmation of the existence of a planet around stars are the most challenging tasks for Astronomers today. Direct imaging of planets against the backdrop of the bright host or parent star is extremely difficult, because the planet will usually be 1 to 10 billion times fainter when compared to the brightness of the host star. It is almost like seeing or imaging the light from a fire-fly against the back drop of a light house. NASA is planning some very radical ideas with the upcoming JWST (James Webb Space Telescope) using a very special coronagraphic – occulting technique to image a planet around a star in the next decade. Therefore, all the existing exoplanet discoveries barring a few either ground-based or space-based are primarily using indirect methods like the Radial-Velocity (RV) technique, Transit technique, or through Gravitational microlensing technique.

The RV technique (which is primarily ground-based) is perhaps the most important method of detecting planets around stars because it is a single method that gives all the dynamical parameters of the planet like mass, semi-major axis, and the period. Thus, RV data is necessary for confirmation even if one detects a planet using the Transit method. Therefore, with the Kepler space satellite detecting around 2000 prospective exoplanet candidates in the Cygnus region, the ground-based RV measurements are needed to verify these results. The only other method that can compliment the RV technique is the space-based astrometry and may require up to 10^{-12} radians (~1 micro arcsec) platform stability along with other technological advancements (for eg: NASA's SIM Lite project which is now abandoned due to lack of funds).

We at PRL have started our own exoplanet program using the technique of precision RV measurements. We have designed and built an optical fiber-fed high-resolution echelle spectrograph. The 1.2m telescope at Mt. Abu typically enjoys about 180 to 220 observable nights in a year, out of which about 120 to 150 are photometric in nature. For our exoplanet program we need about 80 to 90 nights in a year. The project has an acronym PARAS, which stands for PRL Advanced Radial-velocity All-sky Search for detection/confirmation and characterization of exoplanets.

Discovery and characterization of exoplanet systems require high precision RV time-series spanning weeks to decades that can be carried out using a small 1 to 2m aperture telescopes with 0.1arcsec tracking precision and seeing limited aberration free good image quality, and equipped with highly stable fiber fed spectrographs. The full characterization of many exoplanets may be achieved using such long time based observations. None of the exoplanetary systems discovered so far have any similarity with our Solar system. Fundamental questions such as a) the range of planetary system architectures, and when they migrate after formation, b) statistics of planets in the habitable zone and c) formation of planets and planetary systems can be addressed once we began to observe a very large number of stars with planetary systems over a long period of time. The proposed PRL 2.5 m aperture telescope at Mt. Abu if approved, will play a pivotal roll in this regard.

The success of optical high-resolution spectroscopy (~60,000) using 1 to 2m class telescopes for detecting extra-solar planets has been significant over the recent years. It has revived the importance and usefulness of small size telescopes in the age of large and extremely large telescopes. The window for small telescopes relies in the fact that a) a very large number of stars up to 12th magnitude are yet to be monitored with high resolution spectroscopy for exoplanets studies, stellar seismology and pulsations, and other related sciences like abundance measurements, stellar rotational velocities, and b) a very large number of nights that are required for such science endeavors can only be available on 1 to 2m class telescopes. The heart of the of the PARAS project is an optical fiber-fed high resolution cross-dispersed Echelle Spectrograph. It is capable of a single-shot spectral coverage of 370nm to 860nm at R ~ 63,000 and is under very stable conditions of temperature (0.04°C at 24°C). It can be also under pressure control of 0.1mbar, which is achieved by enclosing the entire spectrograph in a low-pressure vacuum chamber. The stability of the spectrograph is required to minimize the instrumental drifts. For instance a change of 1°C in the ambient temperature or 1mbar in the atmosphere may cause instrumental drifts of up to 100m/s in RV. So we limit typical nightly instrumental drifts to less than 20m/s and then using the simultaneous drift corrections from Thorium-Argon spectral lines precision of 1.5m/s to 2.5m/s are obtained. The spectrograph is attached to the Mt. Abu (Rajasthan, India) 1.2m telescope using two 50micron core optical fibers (one for the star and another for simultaneous Th-Ar spectral calibration). Figures below show images of the PARAS spectrograph.

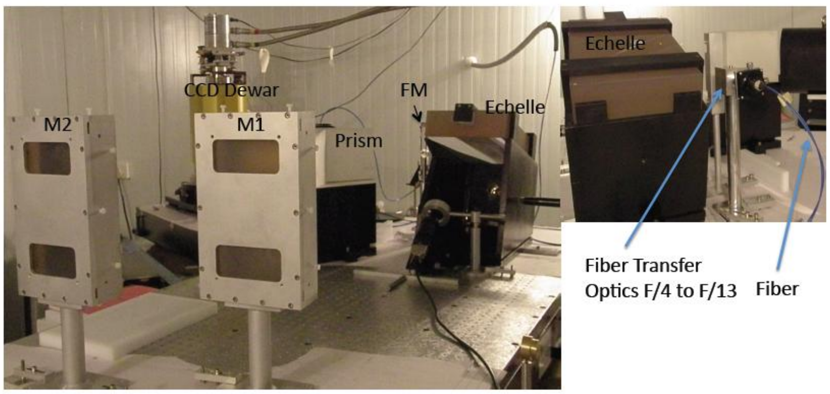
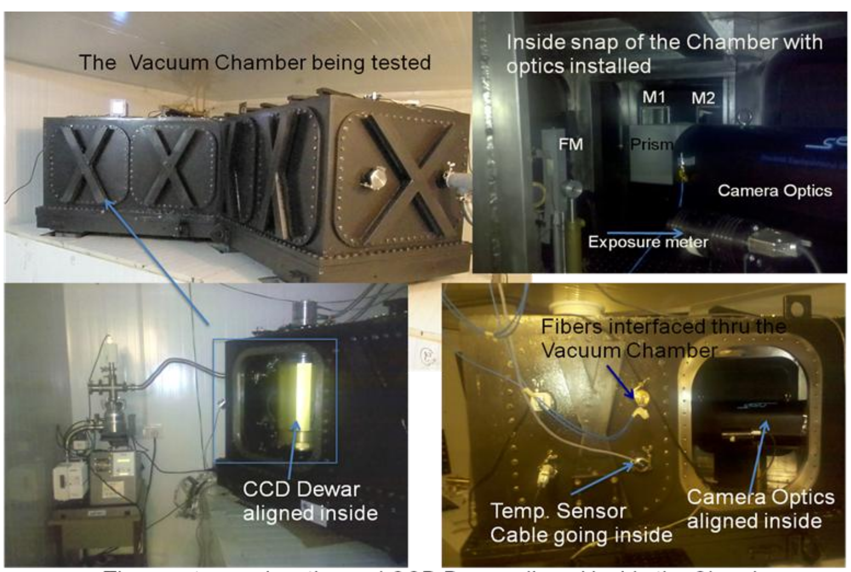


Fig 1. The Echelle spectrograph optics before it was moved inside the Vacuum Chamber. Here it is aligned on the optical bench in a temperature control environment for first light and testing, where M1 & M2 are Off-axis Parabolic Mirrors and FM is the Fold Mirror (Flat). Inset: 2 Fibers (star + calibration) coupling into the spectrograph. The size of the spectrograph is about 2m x 1.5m in a roughly 'L' shaped pattern.



The spectrograph optics and CCD Dewar aligned inside the Chamber

Fig 2. The Echelle spectrograph installed inside the Vacuum Chamber, here M1, M2 and FM carries the same meaning as in figure 1. The Vacuum Chamber is installed inside the temperature control environment.

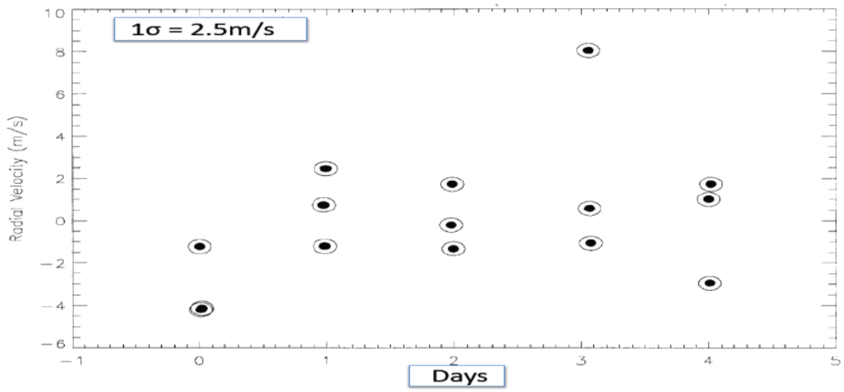


Fig 3. Radial Velocity precision achieved up to over a time-line of 5 to 6 days on the sky. The Radial-velocity measurements were obtained on a RV standard star under temperature control alone.

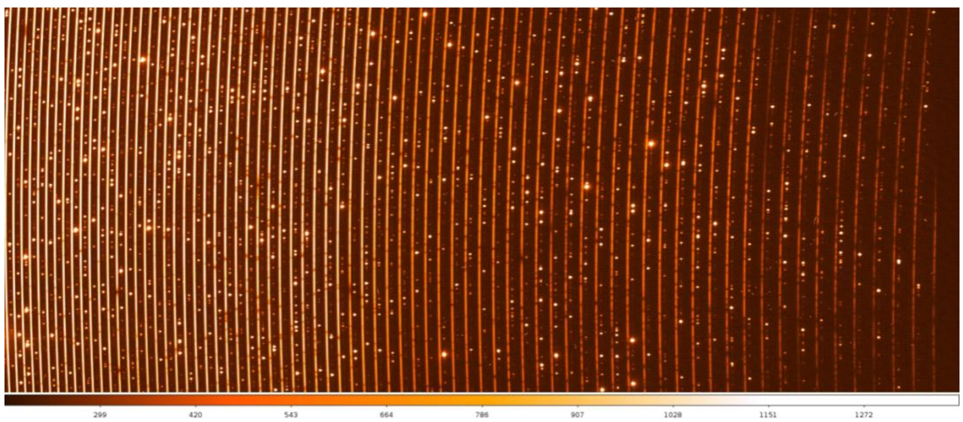


Fig 4. The Star spectra and ThAr calibration spectra recorded simultaneously for precision radial velocity measurements. The continuous lines with absorption features is the star spectra coming from the star fiber and the bright dots represent the Thorium-Argon spectra. Each line represents one Echelle order and the orders ran from 162 (3700A) to order 72 (8500A).

The star fiber can either see the star light or the calibration light (ThAr spectral lamp or Flat lamp), the Calibration fiber always see the calibration beam but can be blocked off using a shutter when required. Thorium-Argon (ThAr) calibration light is required on both the fibers periodically to measure the spectrograph drift during the night of observations and precise radial velocity measurements of the stars from star-ThAr combined spectra (star spectra on star fiber and ThAr spectra on the calibration fiber). Figure 3 shows typical radial velocity precision that PARAS can obtain on the sky of 2.5m/s over a period of 5 to 6 days of time-line. This is measured by observing a radial velocity standard star under temperature control alone and in the near future under pressure control along with temperature control we plan to achieve the same precision of 2 to 3m/s over the time-line of several months. Figure 4 shows a G-type star spectra of ~7th mag along with ThAr spectra.

It took over a year for us to design the spectrograph and another two and half years to build one. Our goal was to create a spectrograph that was of highest possible efficiency and stability given that it would be attached to a small 1.2m telescope aperture and so every photon collected from faint stars is important to reduce the error budget. Equally important was the spectrograph was designed with minimum scattering of light for high spectral purity and RV precision. Therefore, the optical components were polished to micro-surface accuracy of $\lambda/100$ (λ=630nm), and anti-reflection coated to make sure highest possible transmission of 96% through the Camera Lens unit. Further, Finite-Element Analysis was done on the Vacuum Chamber to ensure that under 1atm pressure difference, the chamber does not deform more than 30 microns over its surface. This is to ensure that the optical alignment of the spectrograph remains intact under vacuum.

We also built a special instrument with precision actuators and pellicle beam splitter at the telescope focal plane. This instrument dynamically moves the fiber tip and centroid on the star, correct the flexure between the Primary and the Secondary mirrors of the telescope, and guide on the star. This instrument enables us to take exposure times of several 10s of minutes without the losing the star from the Fiber-tip at the telescope focal plane. We are currently at engineering mode of observations, and actual science observations may begin in a year time from now.

The PARAS program is wholly funded by PRL. We thank the director of PRL for his interest in the program. The PARAS program has collaborations with the Astronomy Department of Penn State University, U.S., and the Geneva Observatory, Switzerland. We also acknowledge the contribution from Mr. D. Subrahmaniyum (SAC, ISRO) and his team members for the initial design analysis and the finite element analysis of the PARAS vacuum chamber.

NATURALLY REMOTE SENSING

- Dolphins can detect electric fields in water using electroreceptors in vibrissal crypts arrayed in pairs on its snout. These electroreceptors can detect electric fields as weak as 4.6 microvolts per centimeter, such as those generated by contracting muscles and pumping gills of potential prey. This permits the dolphin to locate prey from the seafloor where sediment limits visibility and echolocation.

- Slit sensillae of spiders detect mechanical strain in the exoskeleton, providing information on force and vibrations.

- The lateral line in fish and aquatic forms of amphibians is a detection system of water currents, consisting mostly of vortices. The lateral line is also sensitive to low-frequency vibrations. It is used primarily for navigation, hunting, and schooling. The receptors of the electrical sense are modified hair cells of the lateral line system.

- By emitting a train of shrill beeps, a bat deftly avoids the obstacles in its path and unerringly homes in on a succession of tiny nocturnal insects that are its prey.

- The leaves and buds of young sunflowers do exhibit heliotropism (sun turning). Their orientation changes from east to west during the course of a day. The movements become a circadian response.

Signatures in High Energy Astronomy

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1.0 Introduction: The field of observational astronomy is the ultimate in 'remote sensing'. All the science garnered in this field has no 'ground truth' and is based purely on theoretical interpretation of the observed data. Research in astronomy therefore exercises this capability of human ingenuity to interpret the observed data which has to also to stand the test of time as knowledge grows with data from more sensitive instruments and better analysis methods. Astronomy has often led to the observational evidence of theories in core science subjects at extreme conditions of temperature, pressure, gravity, and magnetic fields, not possible to simulate in laboratories on the earth. Although the area of astronomy is as old as that of human life on this planet, the area of space astronomy is relatively new and has blossomed with the advent of space technology since the latter part of 20th century. It covers mainly the UV, X-ray bands and gamma ray and IR wavebands which are not accessible from ground. Space astronomy however now encompasses the optical band also which although accessible from ground, proves better due to the avoidance of disturbances in image quality caused due to the earth's atmosphere as demonstrated by the excellent results from the Hubble Space telescope.

This paper gives a brief outline of what are the signatures which have led to the widespread understanding in the field of high energy astronomy.

2.0 Observational methods and the resulting science

Celestial objects emit electromagnetic radiation in different bands depending on the processes leading to these radiations. In the high energy regime of UV, X-rays and gamma rays, these radiations are often detected as individual photons and their properties like the time of detection, energy and location in the image plane leading to a deeper understanding of the Universe.

Image data can lead to the study of morphology, profile of symmetry, species concentration at specific locations etc. This is specifically applicable for extended objects like supernova remnants, nebulae, interstellar matter and dust. Image data can also be used to study simultaneously a group of target objects like stellar clusters and their individual locations.

Temporal studies of celestial objects are a study of brightness variation as a function of time. Time variability can lead to the measurement of periodic signatures of rotation periods of the object, orbital period if it is in a binary system, quasi-periodic oscillations, power density of any long term data and also aperiodic phenomena like transients. In fact measurement of spin periods of exotic compact objects like neutron stars and black holes is possible in x-ray wavebands by study of timing signatures. Continued studies of these can provide an insight into the evolution of the periods on both short and long time scales, which leads to an understanding of what powers the spin and how it is coupled with other properties like associated matter inflow or magnetic field in the system. Pulsations of specific types of stars like Cepheid, transient phenomena like supernovae outbursts have led to distance estimates of the Universe.

Spectral signatures allow us to study how the flux emitted from the object varies as a function of energy. This can lead to an understanding of the emission process and hence equivalent temperature of the object or the outlying plasma. Spectral line signatures can lead to detection of atomic line features, and the ionisation state of the species. At very high gamma ray energies one can also detect nuclear lines. Deductions from both continuum and line spectra provide an understanding about the nature of the plasma, its optical depth, magnetic field strength, radial velocity etc.

Above signatures individually or together can often lead to the estimate of fundamental parameters like mass, radius, temperature, density, distance, magnetic field, gravity, and composition of the celestial objects. In turn these can also lead to theories on formation, interaction processes, and evolution of these objects over long time scales. Let us see how such fundamental parameters are estimated for a class of objects for example x-ray binaries.

3.0 X-ray binaries: X-ray binaries consist of a compact object like a neutron star or a black hole and a normal star similar to or slightly heavier than the sun. In these systems, the x-ray emission is primarily from/near the compact object which is the neutron star or a black hole. X-ray emission from a normal star is very less compared to the emission from the optical band and occurs mainly from the corona. For example the Sun's total luminosity is 10^{33} erg/s of which the x-ray emission is only about a millionth ~ 10^{27} erg/s. So one may ask the question how do we know that x-ray binaries do indeed garner the exotic objects they are claimed to have. The main proof came from the fact that these are systems emit huge amount of x-rays compared to other known celestial objects ~ 10^{36} to 10^{38} erg/s and that primarily in x-rays. (1, see also recent ref. 2). This emission is interpreted to be due to accretion of matter by the compact object from the outer layers of the companion normal star. (fig.1) This occurs due to the enormous gravity in excess of 10^{14} cm s^{-2}, which these objects possess due to their 'compactness. i.e. A large amount of mass compressed into a small radius. Hence, the mass and radius of these objects are crucial fundamental properties which are responsible for many of the observed phenomena around these objects. We give a brief description of how these are measured using observations primarily in x-rays and other wavelengths. The question may arise-- how do we observe x-rays from black holes –from which even light cannot escape-- we address this question later in this section. Let us first address the 'simpler' neutron stars first.

3.1 Mass and radius of Neutron stars: Neutron stars are expected to have masses of 2-3 times the mass of the Sun, which can be as much as 10^{28} tons, encompassed within a radius of only about 15km.

Mass of any isolated neutron star is extremely difficult to assess. Mass of a neutron star can however be measured in x-ray binary systems called 'accretion powered pulsars' These are objects where the emission from the neutron stars occurs from a very narrow region near the magnetic pole of the neutron stars and the emission is pulsed as a result of the emission region sweeping across the observer's view due to the rotation period of the neutron star. Hence the time period of these pulses directly gives the rotation/spin period of the neutron star which can be folded to show the spin profile as shown in Fig 2.

The arrival time of the pulses varies as the neutron star moves around in the orbit. This is similar to the Doppler shift in the wavelength of spectral lines in optical waveband to study the orbital period of binary stars. In the case of x-rays, the arrival time of the pulses is used and is termed as the cyclical Doppler shift of the pulse period as shown in Fig.3. (4) A study of this shift leads to an x-ray radial velocity curve, estimate of the orbital period (P) of the system and hence mass function of binary system given as

$$P\,(V_x \sin i)^3/2{*}p{*}G = (M_o{*}\sin i)^3/(M_x + M_o)^2$$

where, the subscript 'x' denotes the X-ray emitting neutron star and the subscript 'o' denotes the optical companion star. A similar equation/estimate of mass of companion can be obtained from spectroscopic data of the optical companion when identified. This gives the ratio of masses of the binary. The inclination of the orbit (*i*) with respect to observer's view axis is the most difficult parameter to measure. In eclipsing systems where the sin *i* can be estimated from the depth of the eclipses, therefore, the mass of neutron stars can be determined.

Masses of neutron stars can also be determined in 'binary radio pulsars' which are binary systems consisting of neutron star with a white dwarf or another neutron star as a companion. (5) Again, pulse arrival times are measured in radio waveband, and these are modeled including gravitational effects, to derive the orbital parameters and lead to much more accurate mass estimates of neutron stars.

Radius of a neutron star is estimated in what are termed as x-ray bursters (6). These systems are again binaries which have accretion neutron stars. However these do not have high magnetic fields and so they do not normally pulse. The accreted matter is therefore spread all over the surface of the neutron star. When the layer of accreted matter becomes thick enough, this matter can undergo thermonuclear burning in the form of a burst (like a small fusion bomb). The temperature of the burst is estimated using the spectral emission of the burst. This spherically symmetric emission can be modeled as black body emission at that temperature and hence is an excellent example for application of Stefan Boltzmann law. If we know the distance to these objects, we can then convert the observed x-ray flux into luminosity, and estimate the radius of the neutron star. This method has been used to estimate the radius of several bursters and is found to be in the range of 9-12 km very close to that predicted theoretically.

In the last decade new signatures termed kilo hertz quasi-periodic oscillations have been observed as shown in figure 4, (7) which scientists have modeled to yield results on orbital frequencies and hence limits on mass and radius of neutron stars in systems which are not pulsars. However the interpretations of the QPOs are not yet conclusive.

Now the reader can realise that in case many of the required parameters like distance to the system, properties of the companion, orbital inclination etc are not known, then only estimates of the the parameters can be made based on assumptions.

Methods for determining masses of isolated neutron stars are now underway using multi-wavelength spectral energy distributions of the neutron star and modeling thereof, gravitational lensing methods, etc. It may be noted that thermal emission is difficult to detect because of the extremely small flux received from these objects due to the temperature and small radius of these objects and require therefore extremely sensitive instruments.

The further scientific interest in this area of research is to find which equation of state of these stars fits best the observed data and hence determine what a neutron star is made of and to also to test the theories of gravitation.

3.2 Mass and radius of a black hole

One often reads that nothing can come out of a black hole-- not even light. Then how does one know about the existence of a black hole? Again, black holes in binaries are the systems which have so far provided the maximum observational evidence of black holes. X-ray binaries which have black hole as the compact object (instead of a neutron star) are also profuse emitters of x-rays. The matter accreted from the companion star forms a disc around the black hole and the innermost parts of this disc hurtles into the gravitational potential of the black hole. So all the observed radiation from black holes is what we receive from the innermost stable orbit of the accretion disc, and since the accretion disc achieves temperatures of the order of keV, the innermost stable orbits emit in x-rays. In the case of black holes the mass and radius are related by the equation Rs = 2GM/c**2 for a non-rotating Schwarzschild black hole(ref6). This is the radius of the event horizon beyond which the radiation cannot be observed. The relation becomes more complex for a rotating/charged black hole. It is therefore possible that if we determine the radius of the black hole, the mass can be estimated and vice versa.

The radius of a black hole can be approximately estimated by finding the radius of the innermost stable orbit of the accretion disc. This is made possible by fitting the spectrum of the system, when the the disc is the dominant emitter of the x-rays (see7). The problem is however, difficult because, most black hole binaries are transients, and this state, when the disc is the dominant source of emission and is expected to reach all the way to the innermost stable orbit, is for a short time. The same method can be used for neutron stars too, with a knowledge of how this innermost radius has to be interpreted in terms of the spin and magnetic field the neutron star possesses.

One other signature which can be used to study the innermost stable orbit of the disc, is by detecting relativistic iron line in the spectrum. These lines are believed to originate due to the reflection of hard x-ray photons from the disc. The shape and splitting of the line can be caused due to Doppler and gravitational effects (8). Though Fe lines are observed in neutron stars also as seen in figure 4 (9), the gravitational effects are expected to be predominant in black holes and hence used to estimate the radius and also the spin of the black hole.

The ultimate evidence of black hole is only by estimating the mass of the compact object, and if unequivocally more than 4 times the mass of the Sun, it is considered to be a black hole. Limits of the mass of a black hole in an x-ray binary can be found from deriving the mass function of the optical companion when identified, similar to that of neutron stars, except that in the case of black hole binaries identification of the companion is not based on pulsations but orbital features if any, or due to the brightening of the system in many wavebands during the transient outburst

From the above it is clear that understanding the physics of x-ray binaries involves the observational parameters of the compact object, the companion star, the accretion disc surrounding it, and an interpretation of the observations in terms of the model of the system. In this context, we expect that ASTROSAT will prove very effective with its suite of instruments observing the system in different wavebands.

ASTROSAT is the first Indian satellite earmarked for astronomical studies. Many of the other successful astronomy experiments on Indian satellites like the gamma ray burst (GRB) experiment on SROSS series and the Indian X-ray astronomy experiment (IXAE) on IRS-P3 have been piggy back experiments on platforms with other payloads. ASTROSAT is therefore the first opportunity for the Indian astronomical community to aim at dedicated observations of celestial objects. This is one of the first satellites which will cover a large wavelength band using many large science instruments. This poses advantages coupled with challenges. The advantage is that with one satellite a single target object (star/stellar system) can be observed simultaneously in many wavebands. The main challenge in carrying muti-wavelength experiments from a single platform, is that, the sensitivities of the instruments in the different bands are different and hence the observation time and observation constraints for the different instruments are very different and have to be put together for a mission profile. In addition to multi-wavelength observations, detailed observations of specific targets/field can also be primary observations of individual instruments on ASTROSAT.

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Fig 1

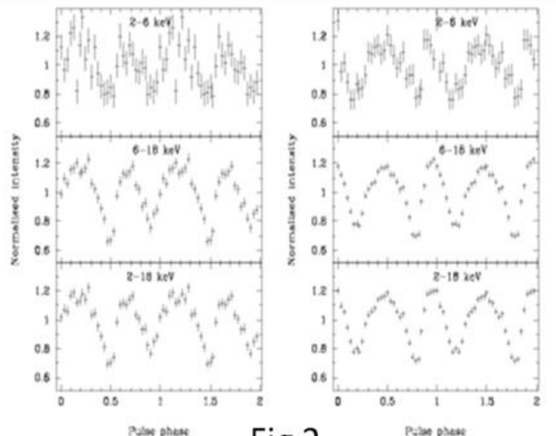

Fig 2

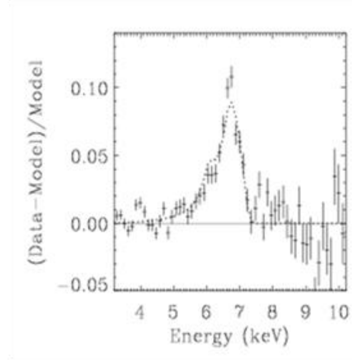

Fig 5

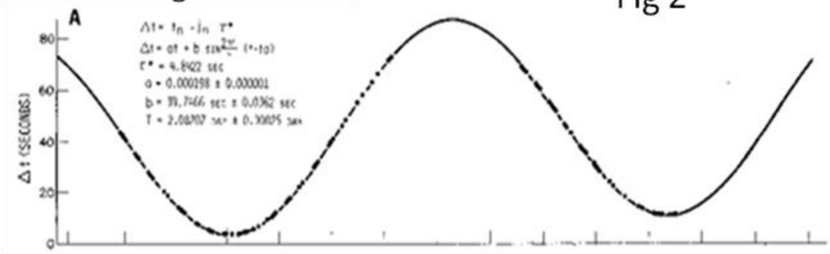

Fig 3

Fig 4

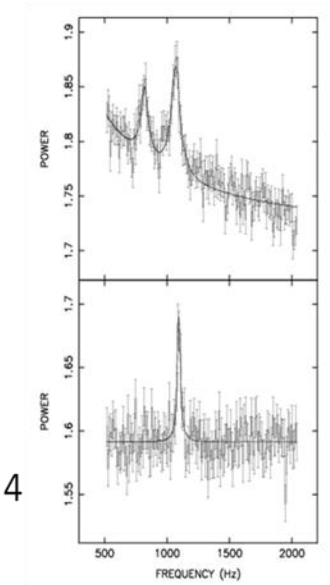

Fig. 1 An artist's impression of an x-ray binary showing its different components

Fig. 2 The folded spin light curve for XTE J1946+274 using data from the Indian X-ray astronomy experiment on IRS-P3 (paul et al., 2001)

Fig. 3 The arrival time profile of Cen X-3 as a function of time, using data from UHURU, the first satellite for x-ray astronomy (Schreier et al, 1972)

Fig. 4 Kilo-Hertz QPOs exhibited by Sco X-1, discovered using RXTE satellite. (van der Kils et al, 1996)

Fig 5. Broad relativistic Fe line observed in Ser X-1. (Bhattacharyya, & Strohmayer, , 2007)

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures* in their own words, either as a brief survey of state of the art or as articles on novel dream concepts related to the specific theme ***"Future Trends in Remote Sensing"***.

The deadline for inclusion in the next issue is **March 20, 2012.**

\- Editorial Team

Remote Sensing Studies of Surface Chemistry of Inner Planets

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Introduction: Our solar system comprising of eight planets, numerous satellites, minor planets, asteroids and comets, got its birth nearly 4.6 billion years ago from the collapse of a dense gas cloud. During its evolution, metals with high melting points coalesced to form metal & rocky rich entities in the inner solar system, whilst the outer solar system exhibits metal-poor large gaseous planets. Using direct studies of meteorites and comets and remote studies of solar system bodies, supplemented with other astrophysical observations of gas disks, star forming regions, etc., models of planetary formation are evolved continuously. However, the picture is still incomplete. The origin of the solar system is one of the important problems of science as it paves the way in understanding where we come from. Understanding the composition of solar system bodies is crucial in determining the various evolutionary processes that led to the present status of our solar system. In spite of all materials originating from the gas and dust in the disk around the young Sun, we see a wide diversity among the planets and their satellites in terms of their composition, atmosphere, magnetosphere, iron richness and so on. Remotely sensing studies of spectral signatures of planets help in understanding these processes.

Solar system exploration had its start during the pre-Pioneer and Voyager series of spacecrafts, where flyby observations were achieved. Subsequently, with the advent of technology our exploration has matured to orbiting missions such as the Luna, Apollo, Viking, Venera, Galileo, Magellan, Clementine, Cassini, SMART-1, Chandrayaan-1, Change-1, Kaguya etc. Remote sensing of planetary bodies is carried out using sensors across the complete electromagnetic spectrum as well as particle detectors (charged and neutral). These studies have enriched our knowledge in understanding of these bodies and also have raised many new questions. Here we focus on chemical composition of planetary surfaces which can be studied through remote sensing at infrared, x-ray and gamma ray wavelengths. X-ray and gamma ray remote sensing can provide elemental composition irrespective of the ionization state of the atom while infrared spectroscopy relies on specific features from elements due to their presence in a particular mineral. Gamma rays emerge from few cm depth of planetary surface whereas X-rays sample only the very upper few tens of microns of the planetary surface. Thus experiments in all three regimes are important for a complete understanding of surface chemistry. Here we shall discuss the role of X-ray observations in deciphering planetary surface chemistry.

Physics of finding the chemistry from X-rays: X-rays, discovered by Wilhelm Rontegen in 1895, was used by Moseley to show that when pure substances are irradiated with a beam of X-rays from an X-ray tube, they produce new X-ray photons with energies characteristic of the substance. When an X-ray photon strikes an atom, it may either get absorbed or scattered. If the energy of the incident photon is greater than the binding energy of an atomic shell, an electron will be ejected by the **photoelectric effect**. The vacancy created thus is then filled by an electron in a higher shell. This electron transition results in the emission of an X-ray photon (**X-ray Fluorescence-XRF**) of energy characteristic of the atom. Since the atomic energy levels of each element in the periodic table are distinct and quantized, the fluorescent X-ray emission from atoms can be used to directly identify the presence of the element. This forms the basis for remotely studies of surface chemistry of airless planetary bodies.

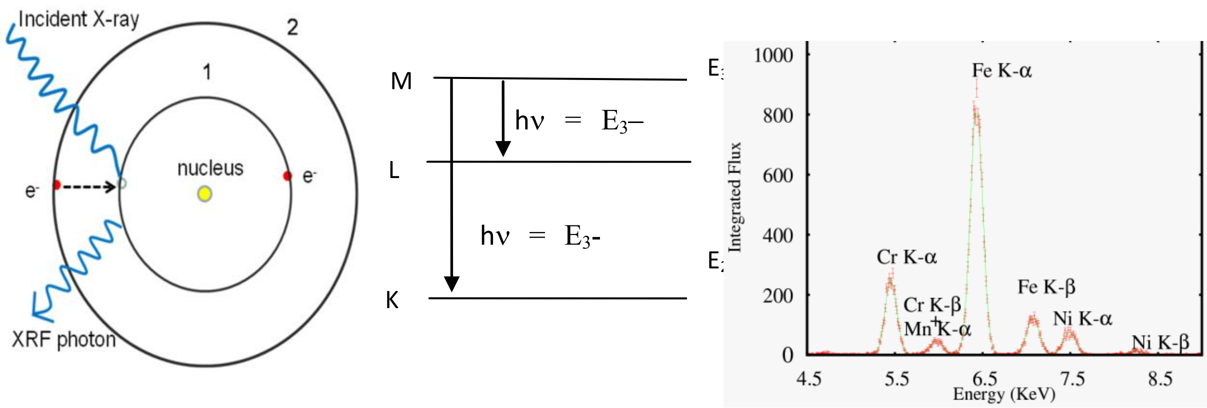


Fig.1(a) decay of excited atom results in emission of fluorescent X-ray photon of a specific energy characteristic to the atom (b) XRF spectrum from a stainless steel plate showing lines from major elements present in stainless steel.

Physics of X-ray emission from planetary surfaces: In the laboratory, X-ray generators or radioactive isotopes are used as sources of x-rays to illuminate the sample under study. But from an orbiting spacecraft, these are too weak to excite x-ray emission from the planetary surface.

On the other hand, the Sun is a source of X-rays. The surface temperature of the Sun is ~ 6000 K, which implies that the resulting blackbody emission is most intense at visible wavelengths and the flux of X-rays emitted is generally low. The solar corona is hot (a few million degrees) but low density and can act as a low-intensity source of X-rays. But, at times, the Sun releases energy explosively, when magnetic configurations rearrange in the chromosphere and/or corona in order to reduce the energy stored in magnetic fields. The excess energy released, often leads to the acceleration of charged particles. Accelerated electrons from the outer layer of the Sun strikes the cool gas atoms in the photosphere of the Sun and radiates energy in the form of X-rays. These events are referred to as solar flares, where the emission of X-rays increases suddenly, reaches a maximum and decays over a time scale of minutes to hours. Solar flares are classified based on the amount of peak X-ray flux reaching the earth as measured by the X-ray detector (1-8nm) in GOES spacecraft. They are termed as A, B, C, M and X class with increasing intensity (see table 1 for details), each class being ten times more intense than the previous. When solar X-ray photons impinge on the surface atoms of the planetary body, XRF photons are emitted from the upper few microns.[1] An X-ray detector on an orbiting spacecraft can then detect them and construct the corresponding energy spectrum.

Table1:GOES classification of Solar flares

Class	Flux (W/m^2) (1-8nm band)
A	$<10^{-7}$
B	10^{-7} to 10^{-6}
C	10^{-6} to 10^{-5}
M	10^{-5} to 10^{-4}
X	$> 10^{-4}$

Elemental composition from XRF spectra: XRF is an efficient technique in providing unmistakable identification of the elements, as the spacing of atomic energy levels in each element is unique. Thus, XRF spectrum measured with a good spectral resolution and well calibrated X-ray detector,

[1] For example in the case of Moon, the upper 2-10µm of regolith is sampled when we map Mg, Al and Si abundance

2 S represents the distribution of photon energies (E) coming from the Sun

provides the elemental makeup of the surface. The abundance of elements can be derived from the strength of x-ray fluorescence signals. However, the conversion of the number of X-ray photons of a given energy (X-ray line flux) into elemental abundances is not a straightforward process. This is because, the observed X-ray line flux from a planetary body depends mainly on:

1. The incident solar spectrum $S(E)^2$: Since X-ray emission from solar flares are dynamic in nature, it is important to continuously measure the solar spectrum.
2. Matrix effects M(S, E): As planetary surfaces are compositionally inhomogeneous, the presence of an element can enhance/attenuate the X-ray line flux of other element which is also termed as inter-element effect.
3. Particle size: In regions where the mean particle size making up the surface is larger than the mean penetration depth of X-rays, particle size affects the XRF line intensity.
4. Geometry of observation: Incident angle (θ) - Angle between solar X-rays and planets' surface, Phase angle (φ) – Angle between the Sun, planets' surface and the detector.

With the above listed dependencies we can define a relationship between observed line flux $I_{obs}(i)$ and corrected line flux $I_o(i)$ {(which can be directly related to the true abundance of i^{th} element) as

$$I_{obs}(i) = f\,(S(E),i)\ \{I_o(i) * M(S(E),E) * P(E, \theta, \varphi,i)\}$$

where f (S(E),i) represents a function of incident solar spectrum S(E) for element 'i'. P(E, θ, φ,i) includes cumulative effects of mean particle size and '*' represents convolution.

Inferences from elemental abundances:

Elements are the building blocks of minerals that make a planetary surface and hence their abundance provides vital clues to decipher its origin and thermal history. Mineral formation depends on the environment in which it crystallizes. For example, early evolution of the Moon included a partial melt phase due to accretion where gravitational potential energy is liberated in the form of heat. After which it gradually cooled and differentiated over time.

The upper layer of this magma which formed the Moon's crust is mainly composed of mineral called plagioclase feldspar. As the magma cools and this mineral crystallized, the early formation seems to have accepted Mg into its crystalline structure while the later ones contain more Fe. Thus, greater the proportion of Mg, more primitive is the rock. Thus the ratio of Mg to Fe is best derived from elemental mapping. The most accepted theory of Moon's origin and the magma ocean hypothesis which tries to explain the dichotomy on the lunar surface is a direct result of mapping the lunar surface chemistry.

XRF experiments in space: It is possible to derive the surface elemental chemistry of solid/rocky solar system objects with no atmosphere (as air absorbs X-rays as in the Earth) through X-ray remote sensing techniques. There have also been XRF experiments on the Mars rovers and Venus landers which did *in-situ* measurements.

It is to be noted that solar X-rays do not provide adequate flux at distances beyond the orbit of Mars and hence orbital elemental mapping using X-rays cannot be performed on outer solar system bodies. Thus we have the Moon, Mercury and Near Earth Asteroids which form ideal examples to carry out such studies.

Mercury: ESA's mission to Mercury, Messenger has reached the orbit and started its operation early this year. XRF spectra from the X-ray spectrometer on board MESSENGER, indicate that the planet's surface chemistry differs in composition from other terrestrial planets [1].

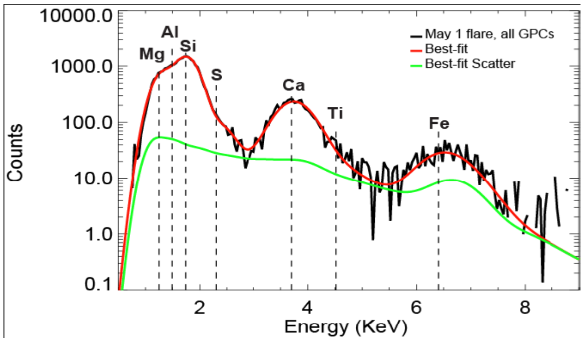


Fig.1: XRF spectrum from Mercury observed by MESSENGER on 1st May 2011 (Nittler et al., 2011)

The Moon: Exploration of Moon in X-rays started with Luna 10 in 1966. Apollo 15 and 16 were the first to successfully establish the usefulness of XRF technique and mapped about 10% of the lunar surface at the equator with the abundance of Mg and Al relative to Si. Subsequent XRF experiments in SMART-1, Kaguya, Change-1 did not perform well as the detectors suffered extensive radiation damage.

Chandrayaan-1 X-ray spectrometer (C1XS) was designed to map the major rock forming elements (Mg, Al, Si, Ca, Ti, Fe) over the lunar surface. C1XS was the best X-ray spectrometer ever flown for planetary studies which achieved good spectral resolution on orbit. C1XS observed clear and direct signatures (fig.3) of major rock-forming elements. It also provided the elemental abundances at some locations on the nearside southern lunar highlands during a C class flare. C1XS analysis results indicate that certain regions in the lunar highland exhibit low Ca abundance and high mafic content compared to what has been perceived so far from Apollo era [2].

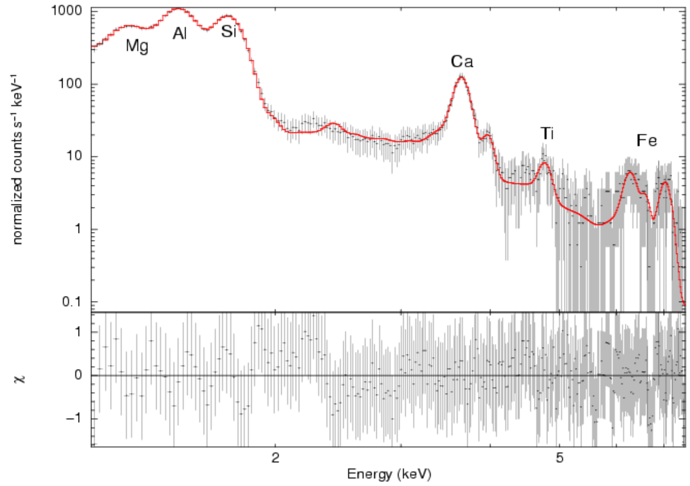


Fig.3. XRF spectrum of a 50 x 50 km region of Moon from C1XS (Narendranath et al., 2011) ; This is modeled and fitted with appropriate function as shown by the red thick line. The bottom panel is the difference between the fitted line and actual data (gives a measures fit quality).

Due to limited solar activity, a complete lunar elemental map could not be generated from C1XS. To fulfill the objective of mapping the lunar surface in X-rays, Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) is being designed at ISRO Satellite Centre, Bangalore.

References:

[1] Larry R.Nittler et al., 2011, The Major-Element Composition of Mercury's Surface from MESSENGER X-ray Spectrometry, Science, 333, 1847

[2] S.Narendranath, P.S. Athiray, P. Sreekumar et al., 2011, Lunar X-ray fluorescence observations by the Chandrayaan-1 X-ray Spectrometer (C1XS): Results from the nearside southern highlands, ICARUS, 214, .53.

Moon Specific

An Interview with Prof. Carle Pieters, Brown University, USA

Signatures: Dr. Carle Pieters (CP), thank you for giving us time for this interview. At the outset, how do you rate the contributions from Chandrayaan - 1 mission to the overall growth of lunar science?

CP: Chandrayaan - 1 mission was extremely important for the India's Space program because it was the first time an Indian spacecraft was being sent beyond the earth's orbit and that is a difficult thing to accomplish, and to accomplish it successfully on the first attempt itself is a wonderful success. So, not only to successfully launch, to successfully send the spacecraft to the Moon, to successfully insert into the lunar orbit and to operate the spacecraft for 10 months was a remarkable success. So there are many successes involved in that and the overall accomplishments demonstrate an excellence in the abilities of the Indian Space Research Organization.

Signatures: Particularly to the overall growth of lunar science?

CP: You probably know lunar science has been a field of activity for decades and Moon was the first non-terrestrial body to be explored as human society ventured into space. So, understanding the Moon had a very important first start but then there was a long period of decades, where no new exploration missions were accomplished. The only new information after the Apollo lunar programs, came from telescopic missions and it wasn't until this last decade that moon missions were again taken up - the Japanese missions, the Indian missions, the Chinese missions & then the US missions. So this new renaissance of lunar exploration, to me as a scientist was thrilling and each of these international activities contributed not only new experiments but the results of those combined together as a body of information have given us a completely new understanding of both the character of the moon and some of the issues that need to be addressed on the moon. And, the Chandrayaan-1 mission is a very important element of that overall growth of lunar science.

An Interview with Prof. Carle Pieters

Signatures: How does the discovery of water through the moon mineralogical mapper M3 of Chandrayaan–1 need to be pursued further and what more needs to be understood on the process of formation of water molecules on moon?

CP: Now, it was a big surprise, I think to everyone, that this surfacial water was discovered on the moon. It was something we have not anticipated but in hind sight now we should have expected perhaps. And, I am sure some people will say they expected it all along but, in my view, one of the important aspects of this is that it demonstrates that airless bodies such as the Moon in the space environment have a character of their own that we really haven't explored extensively; and by that I mean, the current understanding of the origin of this water on the surface of the moon we believe is linked to the fact that the moon is made of rocks – silicates, we call them, that are made out of silicon and oxygen and other elements and the oxygen in these rocks are exposed to space and when you have hydrogen molecules from the solar wind interacting with the oxygen from the silicates, -OH is formed and this appears to be apparently be particularly uncommon on the Moon. So you are exposing new materials; you are breaking soils apart and giving a site where the hydrogen and the oxygen can come together. So this helps us understand the overall character of silicate bodies in the space environment in a way we haven't thought of it before. Now that said, that's the new information. But now it opens many questions that we don't have answers for. What is the real physics of this interaction? What are the requirements in either the temperature or character of the surface to allow this interaction to go on to proceed? Are the molecules of -OH or H2O fixed or are they mobile? And this is a very important question to know the overall character and what these materials will appear like. So, there are now a whole range of questions that we don't have answers for. But we have the questions that we would like to pursue with this new discovery to understand the character of this new information and how it relates to other bodies of the solar system and any long term possible use of this new information.

Signatures: Can you describe other significant results from Chandrayaan – 1 other than the water discovery?

CP: I can only tell you the parts that I personally have either been involved in or am very excited about. One that I am personally involved in that I really enjoyed very much is the discovery of a new rock type on the moon. After all the years that we have been studying the lunar samples, both the returned samples and the meteorites with the new experiments and particularly the Moon Mineralogy Mapper to discover a rock type which to a geologist is called the Magnesium Spinel probably the Magnesium Spinel Anorthosite but is dominated by this one mineral which is Magnesium Spinel and none of our lunar samples have this particular rock type in it. So, it was a thrill to discover this and not so much that it's new but that it means that there are aspects of the moon that we have never seen before and this particular rock type we know from its geologic environment that it originated deep in the lunar crust. And that tells us processes that occur in the formation & evolution of the crust that we did not know before. So that was very exciting. Other significant results, I am thrilled continually by some of the image data that as we look at images with higher resolution with greater detail, we see features that we have not seen before. And this again gives us a broader context of the geology and geologic processes that are occurring across the surface of the Moon and these continue to happen over and over as more data are analysed.

Signatures: What are the pertinent science issues still to be understood even after Chandrayaan, LRO & other recent missions to moon?

CP: There is a range or a family of issues that are still not completely resolved. Most of these, earliest the one I am most involved with, have to do with the understanding the earliest history of the Earth-Moon system; I know the origins of the Earth-Moon system as it applies to the Moon as well as to the Earth but the key is found on the Moon. The Moon retains the history of its first billion years but the Earth does not. These are broad science questions such as what was the early impact history, when did the environment at 1 A.U. become benign and also that life could evolve on the earth and that is related to when this impacts occurred on the Moon, what the sequence was, what the magnitude of these were and that's in the lunar record and we were using the current flux of data to start addressing that but we get little pieces of information. We don't have samples from the key regions on Moon that will help us for example to date some of these events. We know from the examples that I just gave you that we don't have a full specimen of different compositions. So, lot of these issues that have to deal with the earliest events on the Moon are a whole class of very important science issues that really relate to our world's origins. The second family of science issues has to deal with for example the water issues. What is the current history of the space environment around the Moon? One more point directly pertinent is the more recent impact records; how frequent are small craters formed? That's the question that can only be addressed at the Moon and requires a full assessment of the freshest small craters across the surface of the Moon. So those are just some examples that I can think off.

Signatures: What are your comments on Chandrayaan – 2 mission?

CP: I am very eager to hear more about it in coming times. I am generally familiar with the character of the mission and how India and Russia are teaming to have a joint package to go to the Moon and to land on to the surface. I think that's a very important next step. I am excited. I certainly hope that it's completely successful and look forward to seeing it become a reality.

Signatures: Your comments about GRAIL-the new lunar mission of NASA. How will it change our understanding about the Moon?

CP: Well GRAIL is the first experiment to really address some of the detailed geophysics of the Moon in recent days. The first group of missions from Japan, India, China and the US, carried us to a certain level of understanding of the detailed gravity and the topography of the Moon. What GRAIL would do is take it to an order of magnitude of higher understanding about the interior structure by studying the details of the gravity variations across the Moon & this will allow us to look for the aspects of the structure of the crust, the mantle and the core that we have not been able to look at, for the last several decades. So, I look forward to check the results of this mission. I am sure there will be surprises that we cannot anticipate but certainly will lead us to a better understanding of the interior of the moon which sets the stage for the rest of the crust and evolutionary aspects of the Moon that we need to understand as scientists.

Signatures: What are the US plans for future lunar missions & impact of budget cuts for planetary explorations?

CP: Well the scientists have great plans. You may know that NASA and the Science Academy independently on a regular basis evaluate the important science issues and for the last two times, this has been done on a decadal sequence. The Moon has played a very important role in science recommendations. Specifically, the South Pole Atikin (SPA) basin, has been one of the highest science target, to understand the Moon and this involves acquiring a sample from the SPA basin. The reasons for its important is because that the SPA basin which is the largest, deepest and the oldest basin on the Moon will set an important landmark for dating the entire sequence of basin forming events on the Moon and you could only really do that by acquiring a sample in dating the character of the material within the basin. But that has been the high priority but it has not been implemented; it's still a high priority. So, whenever funding is available, we hope that NASA will be able to implement it. Another very strong recommendation that came from the science evaluation this last decadal assessment was for achieve a physical network on the Moon. This has always been a recommendation for an international activity and the key component is that in that is to do it in the most efficient manner you need several stations: seismic stations, heat flow stations. And for one country to do many stations is very difficult and expensive. It's an ideal arrangement to have many countries have their own stations as long as it's coordinated and the data can be integrated. So, that's been a high recommendation, a very strong recommendation especially for international cooperation on activities like that. Some of the areas that we have now found with the current data that we know we have no samples from would be ideal places to complete our sample collection. So, all of these are on our list.

Signatures: How in your opinion, India & US scientists can work together in future for unraveling lunar science questions?

CP: Very well. My experience with the Chandrayaan – 1 has been very positive and highly productive interaction. I would certainly hope that this kind of activity will continue in the next generations of exploration. We show them we can do it very well and have been very successful so I'll certainly like to see that continuing. There are certainly many things that can and should be done. So, I am very positive on this kind of continued cooperation and interaction.

Signatures: What is your opinion on human habitation of Moon & lunar exploration for mineral & other resources?

CP: Human habitation anywhere other than Earth is difficult. That does not mean it shouldn't be accomplished. But there are many issues.

Signatures: About lunar exploration for resources?

CP: Oh resources! The difficulty with resources; everytime I am asked a question like this we need to identify what resources those are?

We currently haven't found gold on the Moon nor have we found diamonds but I am not sure either of those would be resources. Many people then perhaps say, resources are water & habitation, building materials. Those I think we can find on Moon. We know there is water in a variety of different forms. The issues are how are you going to extract it & how are you going to use it? We know we can use lunar materials to build things so, there are resources but if you want to go beyond that well is that copper what resources do you want?

Signatures: what about Helium 3 ?

CP: Well I am not a nuclear physicist so I can't answer the helium3 question.

Signatures: What is your experience with the DAWN mission to explore the VESTA asteroid & what science has comes out of it?

CP: Oh! This is an exciting activity. The DAWN mission to VESTA in many ways is similar to a lunar mission in that it's an airless silicate body however it's located in different parts of the solar system and it's smaller. Those are the two principle differences. However, what makes VESTA very interesting is we know from the meteorite samples that we believe came from VESTA that VESTA is a small body that melted early in its history & after it melted had magma or lava flow on its surface. So, it's a small planetary body. It's doing all the things that a planet does: melting, differentiating, having lava flows – in many ways similar to the moon as a body that melted & differentiated but it's smaller. So, it's the smallest end member of the whole silicate or terrestrial planetary bodies. It's next to the largest asteroids in the asteroid belt & that size gives it the small amount of gravity. So that means it has material on its surface developed into soil & regolith. So that's VESTA as a small terrestrial body is very exciting. And is one of the questions we are currently studying is how VESTA interacted with the space environment? Has it interacted the same way the Moon did or is it different? Impacts of dust in the solar system are less energetic? So, how does VESTA differ from the Moon even though it's a silicate body but it's a different part of the solar system! And we haven't answered that yet. These are some of the questions we are currently studying.

Signatures: Please give your comments on the possibilities of finding life on Mars?

CP: I think there's very low probability. However, I think there is relatively high probability of finding evidence for early beginnings of life. Mars is a special place among the planets and its early history clearly shows it had a very water rich early environment & to have an environment like that must have had not only sufficient water but sufficient atmosphere to retain the water. And those were the conditions under which life began on Earth, so the early conditions on Mars are similar to the early conditions on Earth. So there's a possibility that may be some of the microbes began there as well, we don't know why or when it started on Earth but if anything I would give a relatively reasonable probability of finding fossilized form of early life.

Signatures: What are the science issues that will be addressed during Mars science laboratory mission?

CP: Well Mars science laboratory is currently on its way to Mars. Thank heavens we have launched successfully. It will land with a very intricate sequence this summer and we all hope that'll be successful. Assuming it is, it is a very ambitious program very exciting. It's well instrumented. It's the largest roving laboratory we have ever produced and as you know it costs a lot but it's completed and is on its way to Mars. And it will be able to do some very sophisticate experiments and land in a place and rove over a great diversity, perhaps, addressing some of the issues we were talking about of the earliest history of conditions for life on Mars. I have no idea whether we will be able to answer that question or whether & this is more likely that will reduce more questions about the conditions of that early period? But I as a scientist very excited to see what's going to come out of that and I certainly hope that it have lifetime similarity to the two previous rovers one of which is still very active. So, we have great hopes for the Mars science laboratory and I certainly wish its success and eventful landing.

Signatures: How can you justify the public expenditure of planetary missions & your comments on societal benefits of these missions?

CP: That's a very important question. We all live in a world that now has a lot of not only investment but dependence on technology-technological advancements & how we do things whether its agriculture or medicine & this link of our society to technology is fundamental –its irreversible.

This space program & planetary missions themselves are coupled to that technology & push the bounds of that technology, the achievements of that technology in ways that are intellectually exciting & that creates a momentum that allows an expansion of that technology; expansion of more importantly knowledge whether it's how to do things or the origin of life on earth, on the universe as a whole. So, all these things are intervolving & the planetary part of that to me links to our own origin. I want to know how did our planets formed, how did it evolved if we want to know where it's going what is its future we need to know how its past has made it what it is today. These kinds of issues cannot be separated from each other so because we live on a planet, I believe planetary explorations & understanding of the planets is fundamental to our very existence. Like anything our society does we have to balance expenditures different aspects but we always need some part of commitment to the future t investment to things that are going to assure that we'll be moving forward & that I think fully justifies both the expenditure & the excitement as long as it is always maintained with both commitment & balance within the society.

Signatures: It is related to our recent discovery of Kepler 22B Earth like exo-planet with surface temperature of ~22°C. What is the possibility of existence of the liquid water there? How do you see the explorations for search of lives beyond our solar system?

CP: That's a very good question. I guess my feeling from the involvement being in the planetary science & studying the Moon & Mars & Asteroids & Mercury, Jupiter, satellites of Saturn, what we continually learn is they all are different. Every one of them is different. Everyone one of them had a completely unique history. And we are trying to learn how our solar system evolve the way it did & how we were fortunate to live on Earth or appear to live here? Why are we here? We don't know whether this is a unique absolutely unique & onetime situation or whether anytime you have an object at a certain place in a planetary system at certain temperature! It's going to evolve like the Earth. I suspect not simply because every one of our planets are so different whenever we explore them we make predictions & we find ohhh it's so different. That's not what we thought. So with this new discovery... it's an important discovery there's no question that it doesn't immediately say this is an Earth like planet its saying this is a planet around a star but we know nothing about the history of that system. With our system which is the only system we do know, we know everything is different & this relates to why everything in our system is different. Many of the controlling factors are completely by chance there are some facts that that somebody hit the proto-earth four & half billion years ago & created a moon around the Earth. And this moon around the earth is stabilized the earth's orbital properties such that not only as water stable but it has been stable over four billion years. That's just an accident. Now, it's not predictable. It's just an accident. But I suspect each planetary system is going to have its own set of evidence. And, no evidence happens the same way it.

Signatures: Thank you very much.

Unmixing the Moon – Gaining New Insights into Lunar Evolution

Deepak Dhingra, Geological Sciences, Brown University, Rhode Island, USA

1. Abstract: Newly discovered Mg-spinel-bearing lithology at crater Theophilus has been studied using spectral reflectance datasets from Moon Mineralogy Mapper (M^3) instrument onboard Chandrayaan-1 mission. The extracted spectra have been deconvolved using non-linear spectral unmixing in order to decipher the nature and proportions of the component minerals. Preliminary analyses suggest shocked plagioclase as one of the probable component mineral with Mg-spinel forming about 30% of the rock and the lithology being probably, a spinel anorthosite. This definition of the Mg-spinel-bearing lithology constrains the possible formation mechanisms for this new rock type as well as provides insight into the diversity of the lunar crust.

2. Introduction: Reflectance spectroscopy has been an indespensible tool in the study of rocks both on Earth [e.g. 1] as well as other planetary bodies [e.g. 2]. Several minerals, though not all, have diagnostic absorption bands at VNIR wavelengths making their remote detection possible. This basic information about the mineral assemblage guides the interpretation of the evolutionary history of a planet [e.g. 3]. In the lunar context, high spectral and spatial resolution data from recent planetary missions (e.g. Chandrayaan-1, SELENE) has bridged the resolution gap between remote measurements and laboratory obtained spectra, making them comparable. This advancement has extended the capability from mere identification of minerals to obtaining a first order estimate of the mineral proportions in a rock using appropriate mixing algorithms.

3. Motivation and Scope

The recent discoveries of Mg-spinel-bearing lithology on the Moon [4,5,6,7] occurring on a scale of hundreds of meters to a kilometer have added a new member to the existing inventory of lunar rocks. Earlier studies of lunar samples reported spinel as a minor component in the lunar rock record [8,9]. The recent observations not only differ in terms of detection of spinel-bearing lithology on a large spatial scale, they also indicate a near absence (<5%) of any other mafic minerals (such as olivine, pyroxene) in this rock type. It is therefore important to understand the geological setting of the spinel-bearing region in terms of associated mineralogy, structural setting and presence of any other compositional anomalies.

The present study is focused towards identifying the mineral assemblage occurring with spinel and quantifying the mineral proportions to the first order. We have carried out non-linear un-mixing analysis on Mg-spinel bearing lithology at the lunar near-side crater Theophilus. This exposure was recently identified [5,6] by M^3 instrument based on the presence of a strong 2 μm absorption and a lack of an absorption band at 1 μm. M^3 is an imaging spectrometer operating in the wavelength range of 460-2896 nm with spectral resolution of 10-20 nm & spatial resolution of 140-280 m in the global, coarse resolution mode [10].

4. Methodology

4.1 Background

Rocks are an *intimate mixture* of component minerals where it is hard to separate the components physically at the scale of remote observation. Photons of light (VNIR) falling onto such a target are multiply scattered and in the process interact with more than one type of mineral. The reflected photons received at the detector therefore carry information from multiple components present in the mixture, with individual components contributing to the reflected photons, not in proportion of their abundance but in proportion to the number of times a photon interacted with an individual component. This non-linear nature of photon interaction with the matter makes it difficult to quantify the mineral proportions using linear combination of contributions from individual components. Non-linear mixing models [e.g. 11, 12] provide possible solution to this problem and aid in computing realistic proportions of component minerals in a mixture.

4.2 Approach

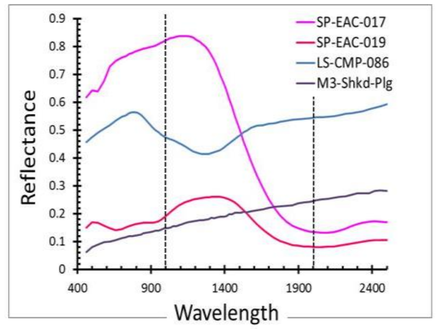
In the present study, we are using Hapke's radiative transfer model [11] to generate a look-up table of reflectance spectra for various mathematical mixtures of probable end-members at viewing geometries similar to the remote measurement. These are generated by first converting reflectance spectra of each endmember into single scattering albedo followed by their linear addition in various proportions. Each remotely obtained reflectance spectrum of the Mg-spinel-bearing lithology to be un-mixed is then compared with available mixture spectra and evaluated for the best matching spectrum. The chosen best match is then inverted in terms of component mineral end-members and their corresponding proportions.

4.2.1 Assumptions: Several assumptions have gone into this effort and need to be explicitly stated for proper interpretation of the obtained results.

(a) Endmembers – RELAB spectra of crystalline plagioclase and spinel (<45 microns) along with a M^3 spectra of shocked plagioclase have been selected as endmembers (Fig.1) for this study based on insights gained from spectral analysis of M^3 data for the Theophilus region [5].

(b) Grain size – The grain size of the end members is assumed to be similar as the target area. Analysis of lunar samples has indicated that the finest fraction dominates the spectral properties of a mineral and therefore the chosen size fraction of <45 µm seems to be appropriate.

(c) Hapke model assumptions - The model assumes that the size of the particles is significantly larger than wavelength of the interacting radiation. Based on the lunar sample analysis, the average lunar soil grain size is between 40-130 µm [13] which is significantly larger than the 0.7 – 2.5 µm wavelength range that is being used in the present study. Apart from this, for simplicity, it is assumed that the target spectra have been obtained from relatively fresh areas and flat terrain. These aspects will be dealt in future efforts.



Endmember	RELAB ID	Origin	Grain Size
Crystalline Plag	LS-CMP-086	Lunar	0-25 µm
Spinel -1	SP-EAC-017	Terrestrial	0-45 µm
Spinel - 2	SP-EAC-019	Terrestrial	0-45 µm
Shocked Plag	M3 Spectra	Lunar	Unknown

Fig.1 Spectra of selected endmembers used in the present study

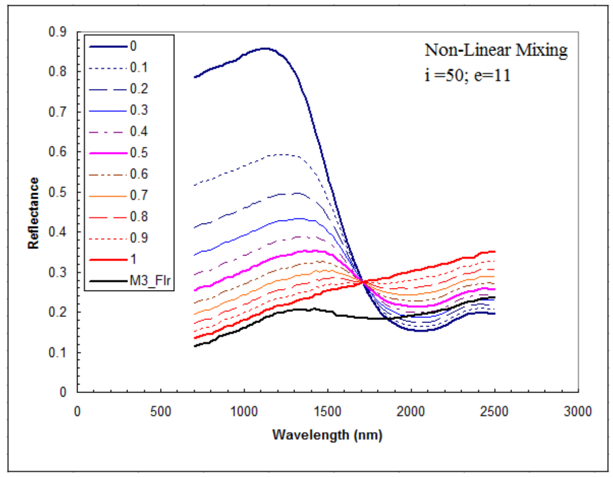
5. Results and Discussion

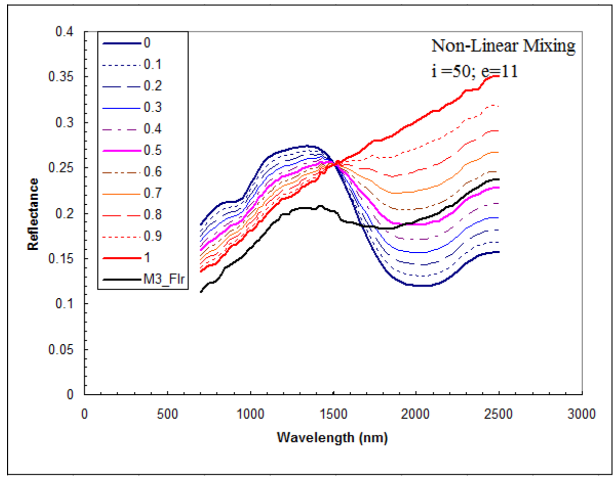
Mathematical mixtures of the selected endmember spectra have been calculated (as described earlier) at 10% increments. Four spectral mixture combinations are thus obtained:

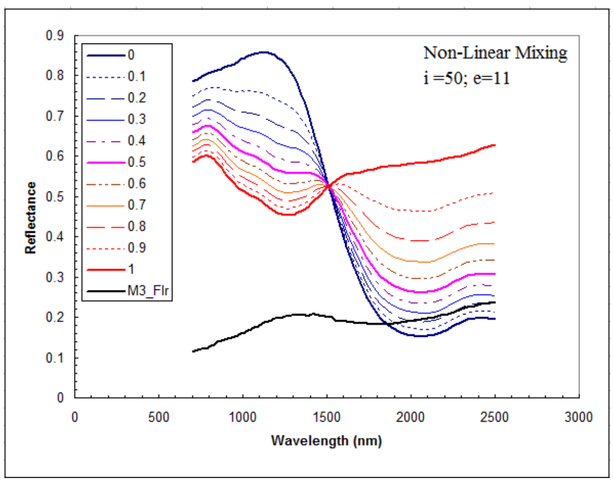
i) Crystalline Plagioclase and Spinel 1 & 2 ; ii) Shocked Plagioclase and Spinel 1 & 2

Spinel 1 and 2 are two different samples. Both the modeled mixture spectra as well as M^3 data have been trimmed at shorter wavelengths due to scattered light issues and at longer wavelengths to minimize the effects of thermal emission in M^3 data, thereby making the modeled mixtures and remotely obtained spectra comparable. It should be noted that no photometric correction has been applied to M^3 spectra that may cause difference in brightness and the overall spectral slope. Such variations, although important, would not affect the interpretations from this study.

Non-linear spectral mixtures of crystalline plagioclase and shocked plagioclase with two different spinel samples shown in Fig. 2 (a-d) provide useful insights into the variation in spectral character both in terms of band shapes and the overall reflectance. Test M³ spectrum (in black) is overlain on all the plots for comparison. While there are several observable differences between laboratory mixtures and the M³ spectrum, the primary purpose of this comparison is to identify probable endmembers. In this context, no combination of crystalline plagioclase with spinel (red through blue spectrum) is found comparable to the test M³ spectrum (black spectrum) in terms of spectral shape. The difference in spectral slope at shorter wavelengths (700 – 1300 nm), lack of any absorption near 1250 nm and an absence of the broad hump around 1300-1400 nm in M³ spectrum suggests that crystalline plagioclase is probably not an appropriate end member. We therefore chose not use it in later analysis.







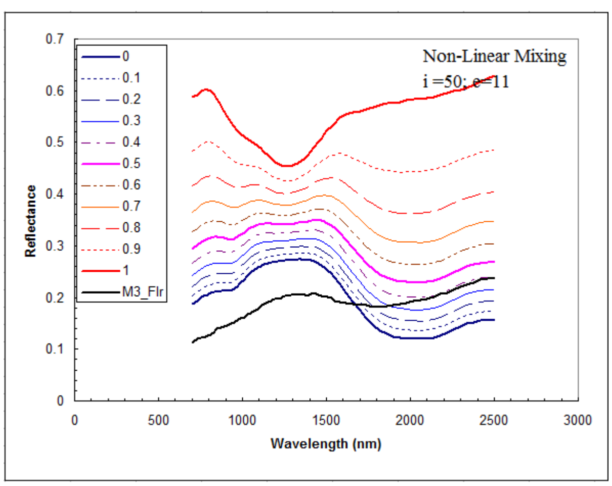
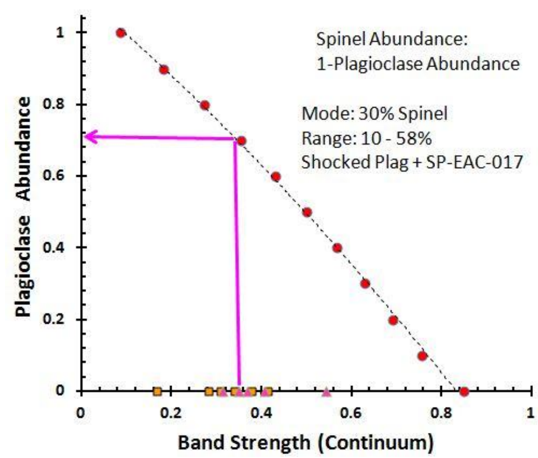


Fig. 2 Comparison of a M³ test spectrum with spectral endmember mixtures: (a) Crystalline plagioclase & spinel 1 (b) Crystalline plagioclase & spinel 2 (c) Shocked plagioclase & Spinel 1 (d) Shocked plagioclase & Spinel 2.



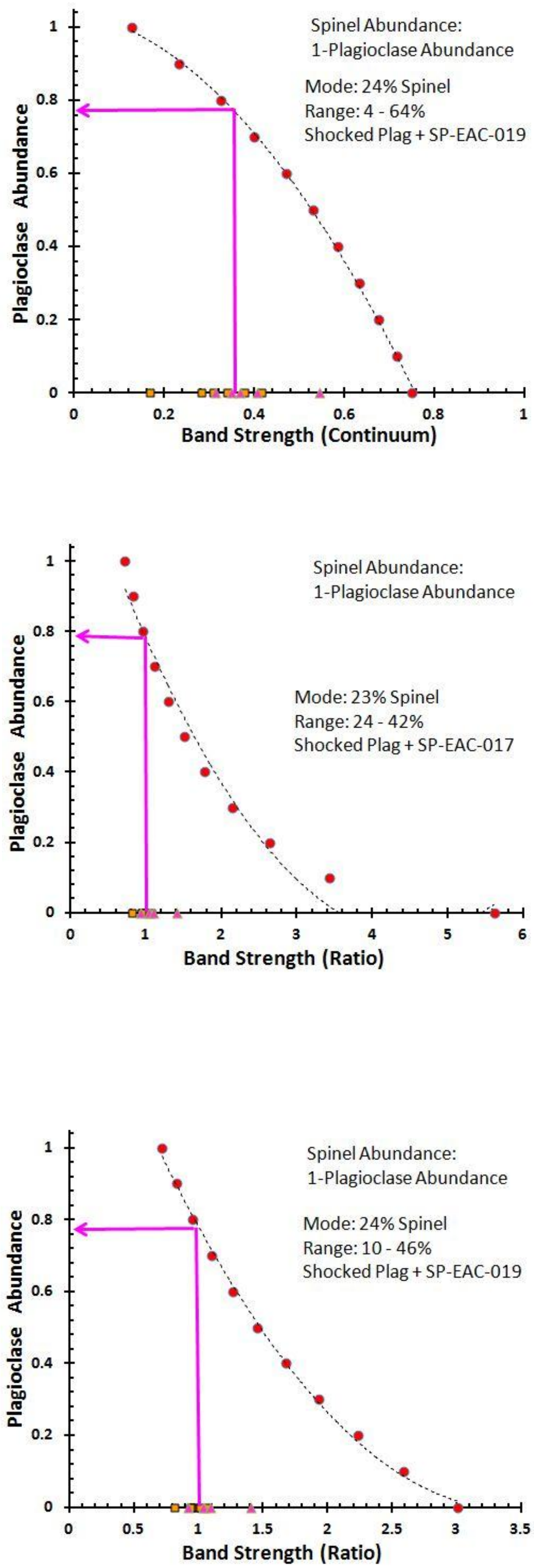


Fig. 3 Band strength estimates (a,b) using continuum method (c,d) using band ratio method.

On the other hand, shocked plagioclase-spinel combination (especially 2d), seems to have similar spectral character as the M^3 spectrum. These endmember mixtures were used in subsequent analysis involving comparison of strength of the 2µm band. Two methods were applied to estimate the band strength, namely continuum removal method and band ratio method. The former method made use of the spectral slope at shorter wavelengths to estimate the value of continuum at 2µm (by extending the spectral slope trend) and then using standard formulation, band strength for both the calculated mixture spectra as well as selected M^3 spectra was estimated. The second method used the ratio of reflectances at 1200 nm and 1900 nm. Results from both methods are shown in Fig. 3(a-d) where plagioclase-spinel mixtures with their proportions are plotted against the calculated band strengths. An estimate of the endmember proportions corresponding to M^3 spectra can then be derived by plotting their respective band strengths.

While the M^3 spectra have a range of band strengths, we focused on spectra extracted from undisturbed locations which might represent in-situ spinel and would therefore provide a more realistic estimate. Based on this criteria, the likely proportion of Mg-spinel is between 20-30%. It is interesting to note that majority of the analysed spectra have abundance estimates falling in the same range. While these estimates are preliminary, given the complexity of issues at hand, they nevertheless indicate Mg-spinel as a dominant component of the lithology, than had been previously known. The high proportion of Mg-spinel with a near absence (<5%) of other mafics provides the necessary constraints on the probable formation mechanisms. It surely has added to the diversity of the lunar crust.

Conclusions: Non-linear spectral mixing analysis suggests shocked plagioclase as one of the probable components in the Mg-spinel bearing lithology and that the spinel proportion in the lithology is around 20-30%. The analysis confirms the high spinel content (interpreted earlier on using qualitative assessment) and emphasizes the crustal complexity that needs to be understood better.

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Call for Articles

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The deadline for inclusion in the next issue is **March 20, 2012.**

\- Editorial Team

The SIR-2 NIR Reflectance Spectrometer on Chandrayaan-1

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Introduction: All the terrestrial planets are surfaced with differentiated crusts. The question whether these crusts have been formed through primordial planetary differentiation or whether they are the cumulative product of a planetary evolution, is still being discussed. The determination of the chemical composition of a planet's crust and mantle is among the foremost important goals of planetary research. UV, VIS, and NIR, as well as x-ray and gamma-ray spectroscopy, provide remote sensing methods to characterize the mineralogical and elemental composition of planetary surfaces. This article is intended to give a short overview of the SIR-2 instrument and discuss some aspects of the progress that the Spectrometer Infrared 2 (SIR-2) on the Indian Moon mission Chandrayaan-1 is making in identifying lunar minerals.

The SIR-2 Instrument: The SIR-2 instrument is a lightweight, modular, grating-based, high-resolution point spectrometer operating in the spectral range 0.9–2.4 µm, with spectral resolution of about 6 nm (256 bands) [1]. The SIR-2 instrument consists of three parts: the telescope, also called the Optical Box (O-Box), the Sensor-Head-Radiator-Unit (SHRU) and the Electronics (E-Box).

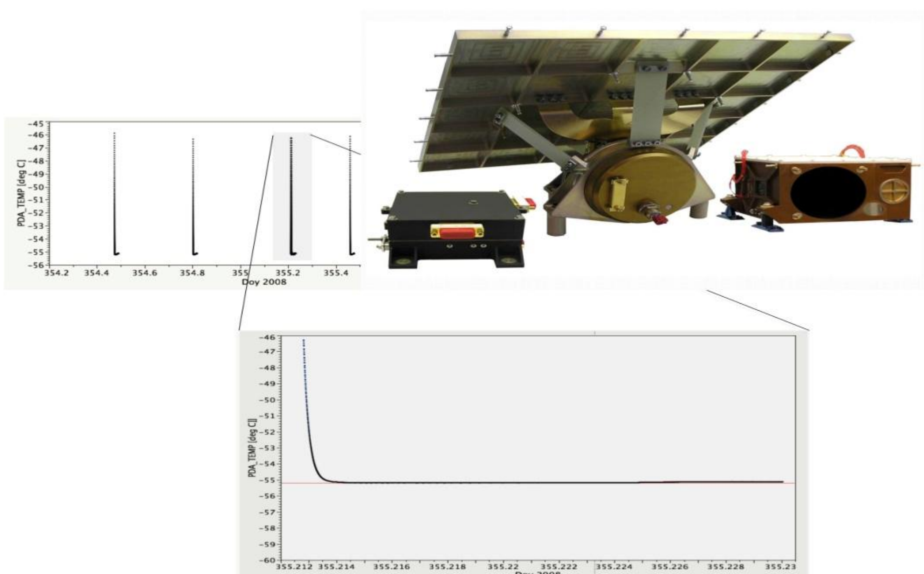

Figure 1. The SIR-2 instrument and its thermal performance. The instrument SIR-2 shown in the upper right part of the image and its constituent units (from left to right, the Electronic-Box (E-Box), Sensor-Head-Radiator-Unit (SHRU) and the Optical-Box (O-Box)). The core spectrometer is part of the SHRU. The diagram shows the temperature of the sensor during several dayside lunar orbits. The enlarged insert displays the performance during the time spectra are taken.

The O-Box, which houses the optics, collects the sunlight reflected by the Moon. The SHRU consists of the spectrometer and the radiator. The spectrometer itself contains a quartz body on which a holographic corrected concave grating has been imprinted, as well as the detector with its analog electronics. The light enters the SHRU through a fiber, which connects the O-Box with the SHRU to allow the accommodation of the O-Box and the SHRU at their designated places on the Anti sunside (ASS) -panel of the spacecraft. The excellent performance of the whole spectrometer is directly related to the thermal stability under which data were taken. While the overall system was passively cooled, an integrated thermoelectric cooler formed together with the instrument radiator a two-stage cooling system which allowed to maintain the operating temperature of the InGaAs detector constant within a temperature range of 1/10 of a degree. The SIR-2 instruments (FM and FS) were calibrated in October 2007 and April 2008 at ISRO's Space Applications Center (SAC) in Ahmedabad, India and in the calibration facility at the Max-Planck Institute for Solar System Research, Germany. Both spectral and radiometric calibrations were performed.

NIR Spectroscopy from Chandrayaan-1 with SIR-2

Although telescopic spectra provide high spectral resolution, the spatial resolution is usually limited to areas of 2-10 km in diameter. Multispectral imaging techniques from space can deliver the spatial resolution to widen the information given by telescopic spectra. The Clementine spacecraft launched in January 1994, acquired images of the whole Moon in the visible to near-infrared range in eleven wavelength bands. Clementine multispectral images provided the increased spatial resolution (in the range of 200 m) compared to Earth-based telescopic observations. With the given spatial resolution Clementine has first opened the possibility to investigate small-scale mineralogical heterogeneities within individual crater areas. While the highly successful Clementine mission reshaped our general understanding of the Moon, one has to admit that up to the launch of Chandrayaan-1 the exploration of the lunar crust in the near-infrared spectral range has been rather limited. The Clementine NIR camera allowed the identification and mapping of the distribution of pyroxene-, olivine- and plagioclase-rich rocks, as well as the mapping of geographic variations in the maturity of the surface regolith at a spatial resolution comparable with ground-based telescopic studies. However, when compared with the Clementine NIR 6 filter camera operating in the 940–2400 nm range, real spectrometers can significantly better discriminate between the different lunar mineralogies, especially with regard to the far side of the Moon, which is not accessible to high resolution spectroscopy from Earth. With this in mind, the SIR-2 spectrometer on Chandrayaan-1 was designed to characterize the mineralogy of lunar surface materials in the near-infrared wavelength range in unprecedented detail with high spectral and spatial resolution. The SIR-2 field of view from 100 km altitude translates into a ground sampling resolution of approximately 220m. The instrument was operational from orbital altitudes of 100 and 200 km between January and August 2009.

SIR-2 is able to discriminate between major crystallized minerals of the lunar surface (ortho- and clinopyroxenes, olivines, plagioclases, Fig.2) and to distinguish and map the petrologic types of mare and highland materials on the surface of the Moon. Further, its high spectral resolution provides the possibility to assess the content of Fe cations in pyroxenes and olivines, and to detect minor mineralogical constituents of lunar materials, e.g. spinels.

Identification of minerals

The theoretical basis for interpretation of visible and near-infrared spectra of minerals was established in a series of papers by Burns, White and Keester, and Bancroft and Burns. Adams presented evidence that absorption bands in the reflectance spectra of planetary surfaces could be used to obtain information on remote mineralogy and petrology. In principle, the strength of an infrared absorption band is a function of the abundance of the absorbing mineral, and the spectra can be used to estimate mineral percentages.

Minerals that make up lunar rocks are with a few exceptions the same as those found on Earth. Constituent minerals are the key to understanding the petrogenesis of rocks since their compositions and distribution reflect the physical and chemical conditions under which the rocks formed, thus allowing us to decipher the history of lunar evolution.

A NIR spectrum of a relatively large geological area represents the sum and complex interactions of individual spectral properties of a heterogeneous admix of different lithologies and mineralogies.

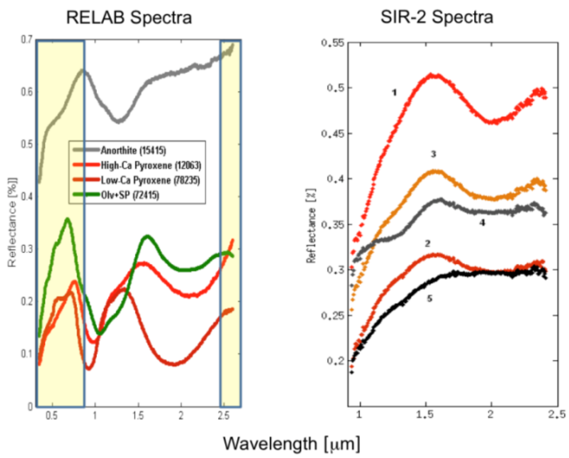

Figure 2. Spectra measured with RELAB (left side) and in-flight spectra measured with the SIR-2 instrument.

There have been several approaches in trying to unscramble and decipher summed spectra ranging from direct spectral characteristics comparisons with laboratory data to sophisticated inverse deconvolution methods. However, in practice, one has to keep in mind that the absorption bands of various mineral components of highland rocks do not combine in a linear fashion. Further on, it has been pointed out often, that it is intrinsically difficult to translate remote sensing spectral parameters into quantitative estimates of mineralogical abundances since soil reflectance characteristics are influenced by several physical variables (particle size, texture, surface texture, etc.) that are challenging to isolate.

Spectral indices have been used to identify spectral shapes by mathematically reducing spectral features of interest to a single number. The pyroxene indexes compare in essence the relative reflectance values of each sample point in key wavelength regions: the '1 μm', NIR albedo (1.329 μm), shifted NIR albedo (1.468 μm), 'typical' opx and cpx band centres (1.814 and 2.067 μm, respectively). The olivine index focuses instead on the lower NIR wavelength centres close to the 1.04-1.10 μm range, the strongest spectral absorption feature of the mineral and its variations in relation to the mid-point wavelength at 1.616 μm. Fig.3 shows the result of one particular study using data from the SIR-2 instrument which investigated the Copernicus crater [2]. Fig.3 displays the olivine and pyroxene index parameters together with some selenographic information. The arbitrary ellipses were drawn to highlight trends and exceptions among the spectral points within geographical variations. Overall the crater floor appears spectrally homogeneous although with a tendency for the southern rim to be cpx-richer than the northern equivalent, and showing a weaker olivine signature too.

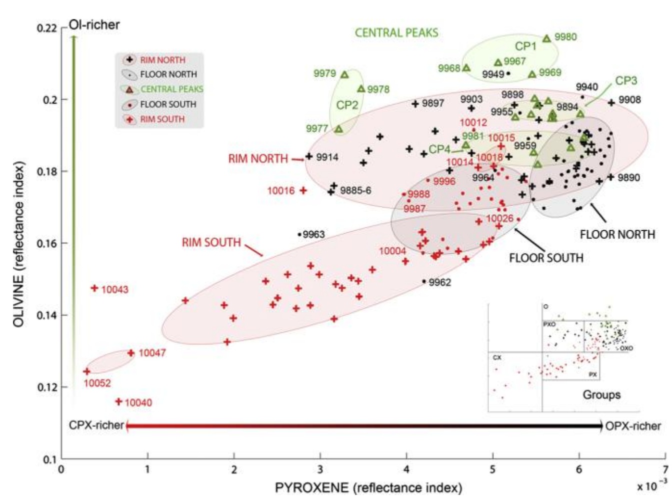

Figure 3. Scatter distribution of pyroxenes and olivine indexes computed for the Copernicus crater. For ease of identification, clouds enclose most samples according to their geographical location within the crater. Inset at bottom right represents an arbitrary classification of spectral types where: O = olivine; PXO=pyroxene–olivine; OXO=orthopyroxene–olivine; PX=pyroxene; CX = clinopyroxene.

The short glimpse on some SIR-2 data, which this note hopefully could provide, should have made clear that the newly acquired data from the SIR-2 instrument allow for a reliable mineral phase detection in exposed lunar materials through diagnostic absorption features in the near-infrared part of the spectrum. While the analysis and the rich harvesting of the scientific dataset returned from Chandrayaan-1 have barely begun, the full potential of this spectrometer will become visible once its data will be combined with the hyper spectral images acquired with Chandrayaan-1's Hyper spectral Imager HySi [40] (400-920 nm).

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NATURALLY REMOTE SENSING

- Insectivorous plant, Venus flytraps detect disturbances to their leaves by means of "trigger hairs" and it closes its trap in about 100 milliseconds. The trigger hairs are located on the trap leaves---there are about 3-5 on each trapping lobe. If these are stimulated twice in rapid succession (within about 30 seconds), the ion concentrations in the leaves increase. This results in an electrical signal that propagates across the leaf. This signal tells cells in certain parts of the the leaf to change size rapidly. This results in the closing of the leaves.

- Mimosa pudica (chui-mui) is well known for its rapid plant movement. Its leaves close under various other stimuli, such as touching, warming, blowing, or shaking. When the plant is disturbed, specific regions on the stems are stimulated to release chemicals including potassium ions which force water out of the cell vacuoles and the water diffuses out of the cells, producing a loss of cell pressure and cell collapse; this differential turgidity between different regions of cells results in the closing of the leaflets and the collapse of the leaf petiole.

Novel Aspects of Solar Wind Interaction with Moon as revealed by the SARA Experiment on the Chandrayaan-1 Mission

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Introduction: Solar wind is a continuous flow of charged particles (plasma) from the Sun. The charged particles are composed of electrons and ions with the typical ion composition of ~96% H+, ~4% He++ and < 1% heavier ions. During its flow from the Sun, the solar wind carries the solar magnetic field along with it. This magnetic field is known as the interplanetary magnetic field (IMF). As the solar wind flows through the interplanetary space, it interacts with various planetary objects-planets, satellites, asteroids, comets and so on- on its way.

Since the interaction involves particles (plasma) as well as magnetic field, the resulting physical processes vary depending on whether the planetary body possesses an atmosphere and a global magnetic field. Moon belongs to the class of planetary bodies which are characterised with a very thin atmosphere (exosphere) and lacks a global magnetic field but has regions of localised magnetic fields scattered on its surface known as `magnetic anomalies'. Due to the lack of atmosphere, the surface of the Moon has been continuously exposed to impact by meteors, asteroids etc. and hence the outermost surface layer has become powdered which is known as regolith.

The Sub-keV Atom Reflecting Analyzer (SARA) experiment on the Chandrayaan-1 had the objective to explore the physical processes happening during the interaction of solar wind with Moon. This is achieved by the measurement of particles {energetic neutral atoms and plasma{which are produced in the interaction and carries the signature of the processes. SARA consisted of two sensors: CENA (Chandrayaan-1 Energetic Neutrals Analyser), and SWIM (Solar Wind Monitor), and a digital processing Unit (DPU) to command and control the sensors. CENA was a neutral particle detector while SWIM was an ion mass analyser, both of which were capable of finding the energy and mass of the particles (Bhardwaj et al., 2005; Barabash et al., 2009). The CENA measured neutral particles in the energy range 10{3000 eV with an energy resolution of 50% and a mass resolution to identify H, O, Na-Mg-Si-Al group, K-Ca, and Fe-group. SWIM had an energy range 100{15000 eV with an energy resolution of 7% and a mass resolution to identify H+, He++, He+, O+, O++ and, > 20 amu. Both the sensors were mounted on the top-deck of the Chandrayaan-1. Both the sensors had fan shaped field of view (FoV). The total FoV of CENA was 160º x 9º and had 7 angular pixels with a resolution of 25º x 9º (FWHM). SWIM had a total FoV of 180º x 7.5º with 16 angular pixels with a resolution of a 10º x 7.5º (FWHM) which depends on the pixel. The mounting along with the field-of-view (FoV) of the sensors is shown in Fig. 1. Chandrayaan-1 operated in a 100 km circular polar orbit for few months and later in an altitude of ~200 km. The orbital period at 100 km was around 118 min.

SARA observations revealed a variety of novel and interesting aspects of the plasma-planetary body interaction.

1. Scattering of solar wind protons as ENAs from the lunar surface

The classical idea was that lunar surface completely absorbs the incident solar wind. Contrary to this, SARA/CENA observations showed that the solar wind protons gets neutralised due to the interaction with the Moon surface and scatters back to space (hydrogen ENAs) with an eficiency of ~20% (Wieser et al., 2009). The energy of the hydrogen ENAs are less than ~50% of the incident solar wind energy and energy spectrum is broader than the incident solar wind protons. This indicates that the interaction with the regolith involves energy exchange resulting in the larger energy spread of the outgoing ENAs. The map of backscattered ENA intensity observed during 3 consecutive orbits is shown in Fig. 2. The dependence of the flux of ENAs on the solar zenith angle (SZA) clearly indicates that the source of these ENAs are indeed the solar wind.

The scattering function of the ENAs will throw light in to the underlying physics of the interaction between the solar wind and lunar regolith. A detailed analysis was carried out to derive the angular scattering function using the full observational data of the ENAs. Around 2,90,000 data points were used for the study so that we get a full coverage for SZA, polar angle of scattering (0 to 90 degree) and azimuthal angle of scattering (0 to 360 degree). The angular distribution of the scattered ENAs were found to strongly depend on the SZA such that as solar zenith angle increases (the angle of incidence of solar wind on lunar surface becoming larger), backscattering is dominant (anti-sunward direction) than forward scattering (sunward direction), which is contrary to what is expected based on laboratory studies.

This indicates that the micro-physics needs to be explored in detail. A mathematical expression which describe the observed angular scattering was derived, as a function of SZA, polar angle of scattering, and azimuth angle of scattering (Schaufelberger et al., 2011). This provides a useful way to represent the scattering function for solar wind produced ENAs from a regolith covered, non-magnetised bodies in the solar system.

The significant amount of the observed ENAs has implications on the solar wind implantation on Moon regolith, space weathering effects and much more.

2. Discovery of Mini-Magnetosphere using backscattered ENAs

As mentioned in the Introduction, lunar surface has patches of localised magnetic fields known as 'magnetic anomalies' of strength few tens of nano-tesla with spatial coverage ranging from few km to few 100 kms across the surface. In the case of Earth, which has a global magnetic field of strength ~35,000 nT on an average, the interaction of solar wind with the geomagnetic field is explained by the fluid dynamic approach of the plasma wherein a bowshock {where the solar wind speed gets reduced from supersonic to sub-sonic speeds, magneopause{where the solar wind gets stopped and detected around, and a magnetosphere are formed. The nature of the interaction of solar wind with a small scale magnetic field was not known although there were speculations that these small areas of locally strong magnetic field would create a mini-magnetospheres that detect the solar wind in the same way that Earth's magnetosphere shields most of the planet from the solar wind.

If the mini-magnetosphere could be formed, which is capable of detecting the solar wind around it, then we expect a difference in the impinging solar wind at the anomaly regions and which will result in a reduced ENA flux from the anomaly regions. SARA has observed for the first time a mini-magnetosphere above the magnetic anomaly region by means of the backscattered ENAs (Wieser et al., 2010). The image of a lunar magnetic anomaly in backscattered hydrogen ENAs for the Crisium antipode anomaly near the Gerasimovic crater is shown in Fig. 3. The ENA ux above the anomaly region indeed showed a decrease compared to the regions which are not affected by the anomaly (undisturbed region). Thus, in the ENA map we can see a `void' at the location of the anomaly. This indeed showed that the small scale magnetic fields are capable of detecting the solar wind and a magnetosphere can be formed. This detection results in more solar wind particles to impinge on the region surrounding the anomaly which results in enhanced ENA emission from those regions which can be seen in the ENA map.

3. Detection of solar wind protons by the Mini-Magnetosphere

It has been observed that when solar wind interacts with the Moon surface, 0.1-1% of the solar wind protons gets reflected (Saito et al., 2008; Holmstrom et al., 2010). Apart from this, SARA has observed that the solar wind protons gets detected back to space by the magnetic anomalies. This population of protons are seen in the viewing directions of SWIM sensor which partly looks at the surface and horizon. The flux of such detected protons are much higher than the normal surface reflected protons.

The detection efficiency averaged over the full far-side hemisphere is ~1%, while over the magnetic anomaly regions alone it is around 10% and over the strongest anomaly it is as high as 50%. The global map of the detection efficiency on the lunar far-side region is shown in Fig. 4

These findings show that the interaction of solar wind with small scale magnetic anomalies are more complicated than envisaged.

4. Modelling of the pickup ion trajectory

The protons reflected from the Moon surface will be influenced by the IMF and the convective electric field (E_{sw}). For an IMF of 5 nT, the convective electric field is in the range 1.5 {5.5 mv m^{-1} for a solar wind velocity (V_{sw}) in the range 300{700 km s□1 (assuming V_{sw} and IMF are perpendicular to each other). Thus, the scattered protons get accelerated by Esw and gyrate around IMF (E x B drift). These can be called as pickup ions. The resulting trajectories can lead them to distances far downstream from Moon and alter the plasma environment there.

A test particle approach and a hydrid model had been developed to investigate the trajectory of these pickup ions, which move under Lorentz force (Holmstrom et al., 2010). The model results showed that the reflected solar wind protons indeed affect the global plasma environment. The results of the model are compared with observations. The model could reproduce the broadening of the energy spectrum of the scattered protons observed by the SWIM. In addition to this , comparison of the modelled trajectories with the Nozomis ion observations showed that the source of the non-thermal protons observed by Nozomi (Futaana et al., 2003) in the lunar vicinity are the indeed the picked up protons.

5. Ions in the near-lunar plasma wake

When the solar wind (as a fluid) flows past the Moon, a cavity is formed behind the Moon roughly at the position of optical shadow. As the thermal velocity of solar wind protons are less (~50 km s^{-1}) compared to the bulk velocity of solar wind (~350 km s^{-1} on an average) entry of solar wind protons to the cavity at closer distance downstream of the Moon is not expected. This cavity, which is devoid of particles is called lunar plasma wake and it gets closed at larger distance downstream of the Moon. But significant proton fluxes were detected by SWIM in the near lunar plasma wake. These protons are of solar wind origin and can be called as 'wake protons'. The energy of these wake protons were slightly higher than of the solar wind. The protons came from just above the local horizon, and moved along IMF in to the wake. The observations were compared with a 1-D analytical model of plasma expansion to vacuum in order to describe the movement of protons parallel to the direction of IMF in to the wake. The comparison showed the observed velocity to be higher than the velocity predicted by analytical models by a factor of 2 to 3 and the observed density to be lower than the model value (Futaana et al., 2010).

Significance of the findings and Discussions

The scattering of ENAs from the Moon surface reduces the implantation of solar wind protons. The implantation of solar wind hygrogen and its subsequent bonding with oxygen in the regolith had considered as potential candidate for the formation of OH/H2O on Moon surface (Pieters 2009, McCord, 2011) which are supported by studies conducted in the lab (Managadze et al., 2011). Thus the ENA scattering of 20% will affect the production of OH/H2O on Moon surface by reducing the implantation rate of hydrogen. The proton scattering from Moon surface as ions also affect the implantation of hygrogen, but the fraction is much lower (0.1-1 %) compared to the ENA scattering. But the proton scattering has higher impact in altering the lunar plasma environment. The presence of the mini-magnetosphere causing lesser ENA scattering at anomaly and higher in the surrounding region, correlates well with the M3

analysis of the spectral features of swirls and off-swirls at Reiner Gamma, Gerasimovich, and Mare Ingenii regions (Kramer et al., 2011a). Their analysis indicated that the swirls are depleted in OH relative to their surrounding supporting that the magnetic anomalies detect the solar wind away from the swirls and onto off-swirl surfaces. In addition to the effect of reduced OH production at magnetic anomaly regions, the detection of solar wind protons affect the spectral properties of the terrain at anomaly regions and also the maturation of the soil which is higher in the region adjacent to the anomaly due to increased flux of protons detected at the swirls. Similar spectral studies of immature craters and surface soils both on and adjacent to the lunar swirls at Mare Ingenii using the Clementine ultravioletvisible and nearinfrared cameras (Kramer et al., 2011b) had also suported this.
As discussed, the trajectories of the scattered solar wind protons can lead to their entry to nightside. The protons in the near wake causes instabilities and wave generation. The existence of ions in deep near-wake indicates that not only the processes which happen in the immediate downstream but also the ones on dayside such as reflection of protons play a role in determining the nature of dynamics in the immediate downstream.

Thus, both the fluid nature (plasma expansion into vacuum) and particle nature of the solar wind (scattered protons reaching the nightside) plays role in the near-wake plasma dynamics.

These all indicate that the interaction of supersonic plasma flow with the planetary body is yet to be fully understood. The nature of the angular distribution calls for the need of investigation of the micro-physics of the plasma-regolith covered planetary body interaction.

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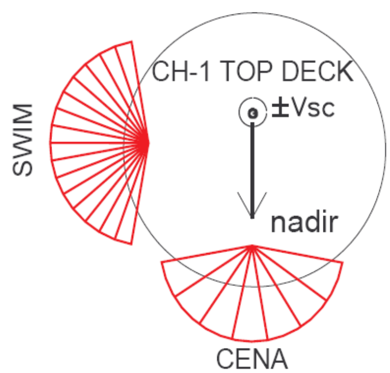


Fig- 1: Mounting of CENA and SWIM on the Chandrayaan-1 along with the FoV. CENA is nadir viewing towards Moon surface and the SWIM was mounted such that few view directions of SWIM looks at the Moon surface. The arrows indicates the nadir direction (towards Moon surface) and the spacecraft velocity vector.

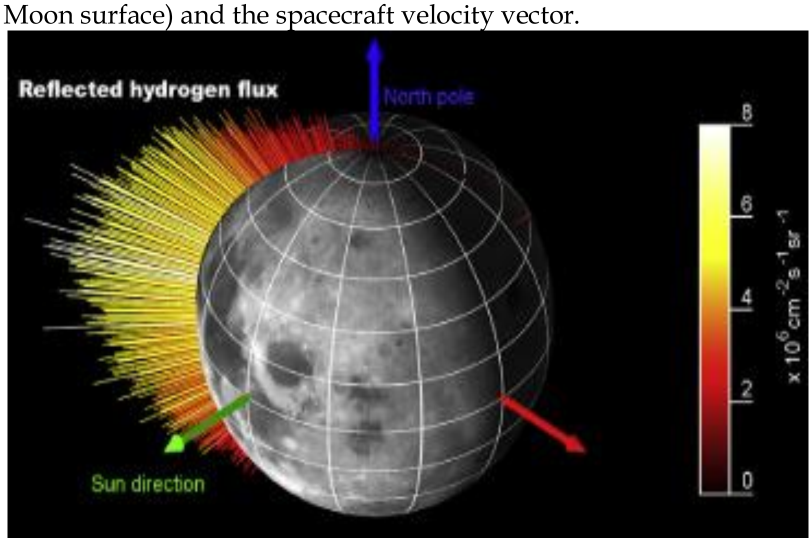


Figure 2: A map of scattered energetic neutral hydrogen atoms as observed by SARA on 6 February 2009. The direction of Sun is indicated by the green arrow. The color and length of the lines indicates the ENA ux. The small flux seen on night-side is due to instrument background. The variation of ENA flux with ZA is seen in the map. The lunar surface map is from Clementine image data (refer Wieser et al., 2009 for more details).

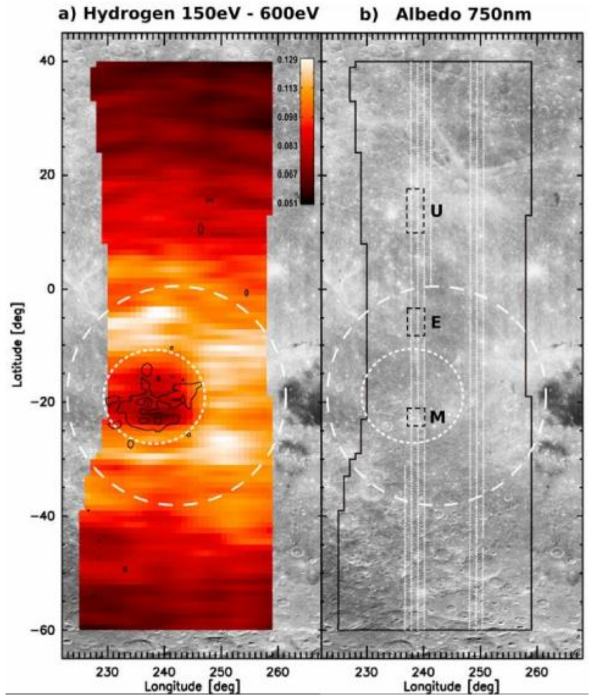


Figure 3: The energetic neutral hydrogen flux from the surface over the magnetic anomaly near 22°S and 240°E on the lunar farside based on the observation on 17 June 2009 from 200 km altitude. The maps show a unit-less reflection coefficient: neutral hydrogen number flux integrated over the specified energy range divided by total solar wind number flux integrated over energy and cosine of lunar latitude in the energy ranges. Black contours in the centre show the magnetic field magnitude at 30 km altitude obtained from Lunar Prospector data, with lines for 5 nT, 15 nT and 25 nT. The dotted circle represents the region of magnetic anomaly and the dashed circle represents the region just surrounding the anomaly. (b) Context image is taken from the Clementine grey scale albedo map where the regions M, E and U indicate 3 sample regions inside the mini-magnetosphere, the enhanced flux region, and the undisturbed region, respectively (refer Wieser et al., 2010 for more details)

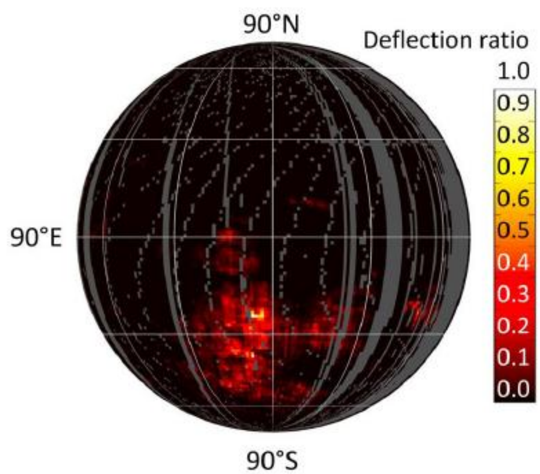


Figure 4: The map of detected solar wind protons obtained by SWIM/SARA observations. Black contours show 2 nT, 3 nT and 5 nT magnetic field strength at 30 km altitude in model by Purucker [2008]. The large anomaly cluster at the Imbrium Antipode (IA), the Serenitatis Antipode (SA) and, the Crisium Antipode (CA) are marked in the figure (refer Lue et al., 2011, for more details).

Identification of Lunar Minerals from Chandrayaan-1 Hyperspectral Data

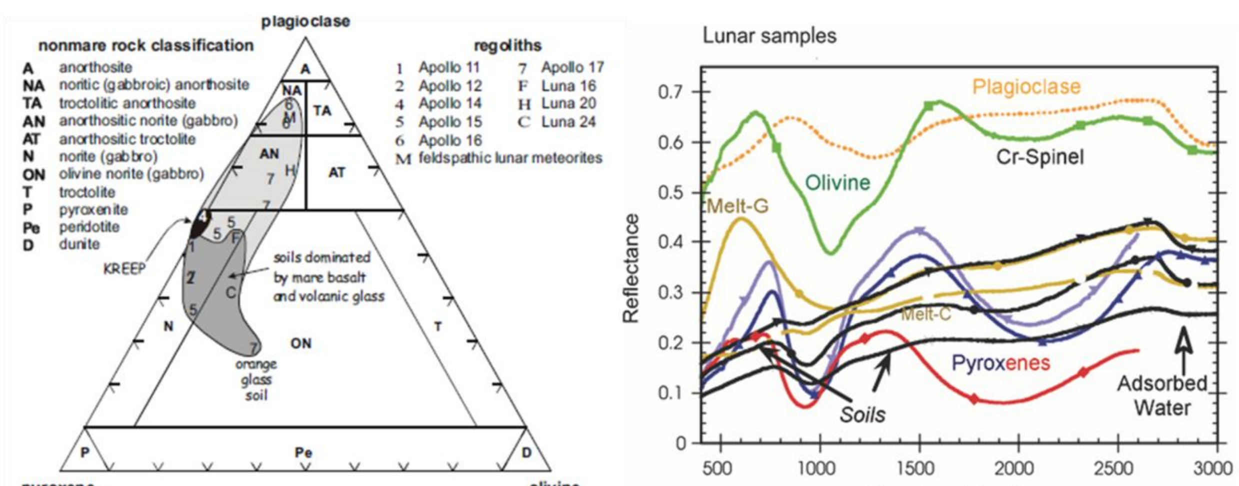
Prabhjot Kaur, Disha Lal and Prakash Chauhan, SAC, Ahmedabad

Introduction: With the launch of Lunar Orbiter missions through 1966 to 1967, techniques for extracting scientific information from the Moon and other remote objects have rapidly evolved. Before the spacecraft exploration lunar mineralogy was untouched by mankind, also speculations about lunar composition and origin were unconstrained. Apollo missions swept away the earlier speculations about the Moon and gave first hands on experience for lunar scientists to analyse lunar samples in terms of petrography, mineralogy, geochemistry and many other interpretations like age. The first lunar sample studied was basalt and led to conclusion that dark plains on the Moon called "Mare" are made up of basalts. Apollo missions lead to a new era of lunar science which results into exploration and understanding of earth's only natural satellite -The MOON. New era of understanding lunar science in unprecedented details has begun now with the recent high spatial and spectral resolution missions like Chandrayaan-1, SELENE/KAGUYA, LRO, Chang'e. Many of these new missions have carried instruments for detection of lunar minerals to understand the evolution of lunar crust.

Lunar Mineralogy: Hyperspectral remote sensing is a major tool to study mineralogy and hence the geology and evolutionary history of any remote sensing object. Minerals form at particular pressure and temperature after crystallisation from the magma and serve as markers to understand thermal history of rocks. Unlike earth, its only natural satellite, the Moon does not have rich mineral diversity. Major minerals of the lunar crust and their reflectance spectra are shown in figure 1. Analysis of these lunar minerals with remote sensing and in laboratory has lead to study of the important key parameters like- temperature, pressure conditions, cooling rate etc. The major minerals on Moon consists of silicates plagioclase $(Ca,Na)(Al,Si)_4O_8$, pyroxenes $(Ca,Fe,Mg)_2Si_2O_6$, olivine $(Mg,Fe)_2SiO_4$ and ilmenite ($FeTiO_3$). Spinel is another important mineral form at high pressure conditions and known to be found at earth's mantle, formed because of phase transformation of olivine to spinel and is recently detected first time remotely on lunar surface by Moon Mineralogical Mapper (M^3) onboard Chandrayaan-1. However, the origin of spinel on the Moon is still not confirmed. Lunar rocks are mainly made up of these major minerals along with other minor/accessory minerals but in different proportions gave rise to different rock types like anorthosite, norites, troctolite, gabbro and dunite. The bright areas of the Moon are composed of anorthosite (95% Ca rich plagioclase) whereas the dark regions are basaltic plains rich in mafic minerals like pyroxene and olivine.

Mineral Detection of lunar surface using Chandrayaan-1 hyperspectral data: Hyperspectral remote sensing uses energy reflected from the objects and translates the same in the form of reflected spectra to obtain mineralogical and compositional information of lunar surface. The visible-near infrared energy offers a rapid and invaluable tool for determining mineralogical information. Chandrayaan-1 has got three hyperspectral sensors: Hyperspectral Imager (HySI) with spectral and spatial resolution from 400 nm to 930nm and 80m/pixel respectively, Moon Mineralogical Mapper (M^3) with and spectral coverage 405 to 3000 nm and spatial resolution140m/pixel (Global mode), Infrared Spectrometer (SIR-2) with spectral range 930 to 2400 nm. The reflectance spectra obtained serve as the fingerprint of minerals and are very peculiar to every mineral owing to their crystal structure and symmetry. The minerals are identified on the basis of absorption feature present in reflectance spectra. The absorption feature produced due to presence of transition elements with empty d-orbital's like Fe^{2+}, Mg^{2+}, Ca^{2+} in the crystal structure of minerals. The interaction of the light with minerals results into excitation of electrons from lower to upper level causing formation of the absorption feature. The shape and wavelength at which these feature will occur is dependent on crystallographic site symmetry of a mineral in which the transition element will enter upon excitation and is explained by crystal field theory. Pyroxenes have absorption feature near 1000 nm and also at 2000 nm. The band center of the absorption feature at 1000 and 2000 nm absorption differs in high-Ca (clino-pyroxene varies from 910-1060 nm and 1970-2350 nm) and low-Ca (ortho-pyroxene 900-930 nm and 1800-2100 nm) pyroxenes. Olivine has a broad absorption feature near 1000 nm formed due to overlapping of three small absorptions. These absorption features are the direct indicators of composition of the minerals. The depth and area together with the band centers (the central wavelength of the absorption feature) of the absorption feature are used to derive compositions of pyroxene and olivine.

One nice case study from Crater Theophilus is of generic interest, where one can find diverse mineralogical variability. Crater Theophilus is a large impact crater with a central peak and a diameter of ~100 Km and located near Mare Nectaris on the near side of the Moon. Figure 2a & 2b shows an RGB (Red-1000nm, Green-1250nm and Blue-2000 nm) image of this crater generated using wavelengths corresponds to specific absorption features of lunar minerals. The anomalous regions are highlighted in yellow, pink and green color in the RGB image. The reflectance spectra collected from the colored regions are shown in figure 2c. A new mineral called Mg-Spinel has been detected first time remotely from this crater by M[3] data based on its prominent absorption feature at 2000 nm and lack of 1000 nm absorption feature. Other minerals detected are: pyroxenes which have absorption feature at both 1000 and 2000 nm and plagioclase which is detected by absorption at 1250 nm. The yellow color in the image corresponds to spinel exposures, the pink color corresponds to crystalline plagioclase and the green color at the rim of the crater is due to mafic mineral pyroxene. The mature floor of the crater doesn't show any absorption feature (see spectra for mature soil) due to loss of absorption feature by space weathering. This effect is termed as optical maturity and increases with soil maturity or surface exposure.



(a) (b)

Figure 1(a): Major mineralogy of Moon expressed in terms of ternary diagram with the plagioclase, olivine pyroxene as end members. (Source: Lucey et al., reviews in mineralogy and geochemistry, 2006) (b). the reflectance spectra of the major lunar minerals measured in laboratory. (Source: Pieters et al., Current Science, 2009)

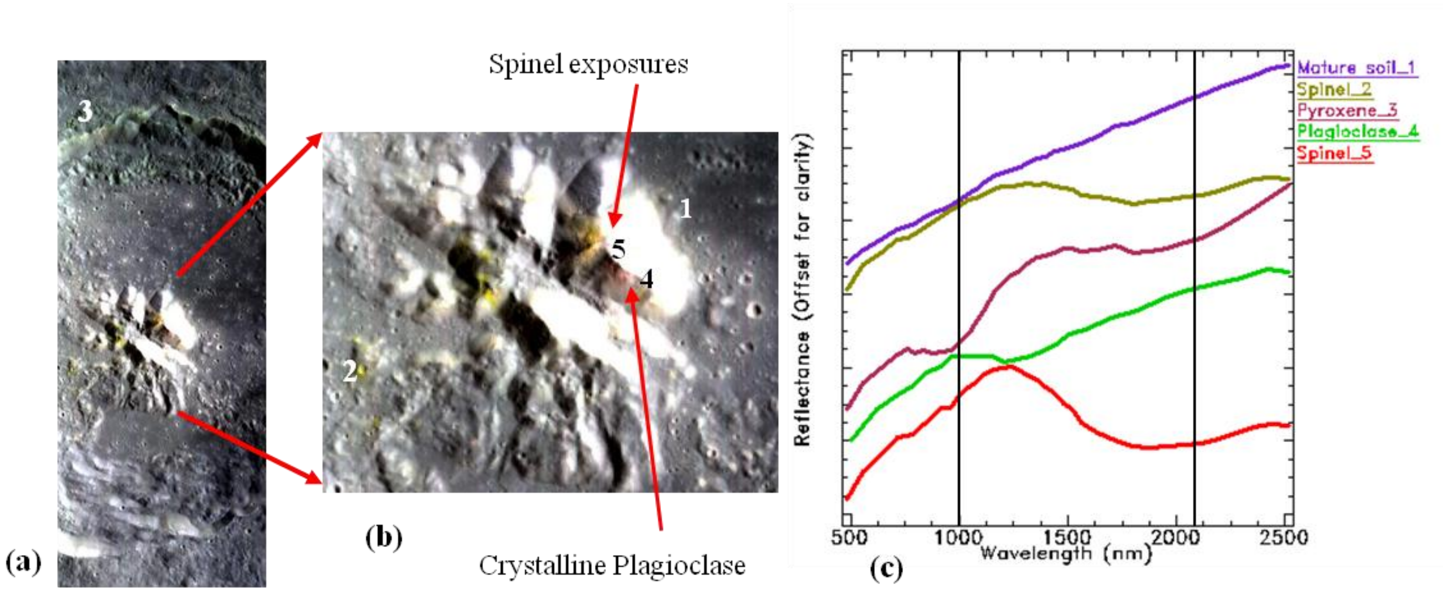


Figure 2(a). RGB image of crater Theophilus generated by assigning red channel to 1000 nm, Green channel to 1250 nm and blue channel to 2000nm. The wavelengths selected are on the basis of absorption wavelengths of lunar minerals. (b). Close view of the central peak of Theophilus yellow color is the exposures of spinel mineral (marked as 2 and 5). Light pink color is crystalline plagioclase marked as 4. (c). Reflectance spectra collected from the marked locations showing the various minerals identified on the basis of absorption feature. The spectra are offset for clarity.

Conclusions: The mineralogy of a planet is an important aspect to understand the formation history of a planet. With the availability of hyperspectral data the derivation of the mineralogical information is much easier now days. This mineralogical information of higher spectral resolution is being complemented by high spatial resolution data (e.g Lunar Reconnaissance Orbiter Camera (LROC), resolution 0.5 m/pixel) provides better understanding of mineralogy with complete morphological details. The reflectance spectra provide direct information about mineral spices, their composition and cooling history. As a result of this high resolution data lunar science has got infinite new questions like presence of water, volcanism on moon, presence of high pressure minerals like spinel and many others to solve. Chandrayaan-1 data analysis has initiated new findings to understand the geologically complex moon.

Observation of Lunar Surface through Mini-SAR Imaging Radar

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Background: The exploration of planetary bodies has always fascinated the mankind. Moon being the nearest planetary body and most distinctly visible from the Earth, has always been in the center of this fascination. Remote sensing observations of Moon can be dated back to early 1960's, when a series of radar images of the Moon's nearside hemisphere were obtained using Earth-based radars at MIT's Lincoln Laboratory, Millstone Hill, Arecibo, Haystack and Goldstone observatory. These Earth-based radars collected much significant information about the lunar surface, one of them being the possible existence of water-ice in the lunar polar region. But systematic observation of lunar surface could only be possible through lunar orbiting satellites, first being NASA's Clementine mission in 1994. Although Clementine didn't carry instruments to specifically look for ice, the mission team improvised an experiment by using the S-band transmitter of the spacecraft, meant for communication to the ground station, to do a bistatic radar experiment to look for ice on lunar surface. Clementine transmitted right circular polarization (RCP) radio signal and the corresponding reflected signals both in right and left circular polarizations (LCP) were received on Earth. The experiment was conducted over two different regions near lunar south pole, one directly over south polar darkness and another, over similar terrain that receives sunlight. An enhancement of circular polarization ratio (CPR), which is the ratio between same and opposite sense circular polarizations, was observed at around 0° bistatic phase angle (which is equivalent to mono-static) over the dark region, but not over the sunlit region, even though both were highland terrains. This relation was interpreted to be caused by the presence of ice in the dark areas near the south pole [1]. Even though this theory was negated by many, including Earth-based Arecibo radar observations, which found enhanced CPR values both in the dark as well as sunlit regions [2], the Clementine experiment, nevertheless, provided an impetus to observe lunar polar region with orbiting Synthetic aperture radar (SAR) with higher resolution and coverage.

MiniSAR Observations of Lunar Surface: MiniSAR imaging radar on board Chandrayaan-1 of ISRO was the first lunar orbiting mono-static SAR, flown in October 2008 with a primary scientific objective to detect water-ice in the permanently shadowed regions on the lunar poles up to a depth of a few meters. Derived its inspiration from Clementine bi-static radar experiment, MiniSAR was operated at S-band (2.38 GHz) frequency with LCP transmission and reception in linear horizontal (H) and vertical (V) polarizations. The returned signal was stored in planetary data system (PDS) format where each pixel in an image strip was represented by the corresponding Stokes' vectors (eqn.1). Several useful quantitative measures derived from Stokes' vector, which are degree of polarization (m), circular polarization ratio (CPR), and relative phase (δ) [Table-1]. The instrument illuminated the surface of the moon at 35° incidence angle, with a ground resolution of 150m and 18km range swath. MiniSAR operated for about 10 months and imaged about 90% of the lunar north and south polar regions, before the termination of Chandrayaan-1 mission. The SAR also acquired few strips of images over lunar equatorial and mid-latitude regions.

$$\begin{pmatrix} S_0 = \langle |LH|^2 + |LV|^2 \rangle \\ S_1 = \langle |LH|^2 - |LV|^2 \rangle \\ S_2 = 2\Re\langle LH \cdot LV^* \rangle \\ S_3 = -2\Im\langle LH \cdot LV^* \rangle \end{pmatrix} \tag{1}$$

where the term '|LH|' denotes magnitude of LCP transmission and H receive signal (complex number); '<>' represents ensemble averaging; '*'

represents the conjugate and '$\Re$' and '$\Im$' are 'real and 'imaginary' parts, respectively, of the complex number.

Data Analysis and few Results: MiniSAR data was analysed using the Stokes' parameters associated with various features, and their distribution on the lunar surface. The investigation showed that CPR, that represents scattering associated with planetary ice as well as dihedral reflections, was anomalously high inside some of the craters in the polar regions [3, 4]. Other stokes parameters such as m and δ also showed distinctly different types of scattering mechanisms inside and outside of the craters on lunar surface [4]. Lunar polar mosaics of intensity and value added products like polarization ratio (indicative of surface roughness), CPR etc. were prepared (Fig.1). The regions of probable existence of water-ice were identified using CPR behaviour and the results were compared with that obtained by NASA. In addition, the scattering characteristics of various morphological features in the lunar non-polar regions were also studied using Mini-SAR data [5]. Table 2 shows the average values of polarimetric parameters for some non-polar craters. Here, the Kopff crater, which is known to be of volcanic origin, is characterized with low LH backscatter and low LH-LV intensity difference. Based on these polarimetric parameters, many useful information about the origin and physical properties of craters can be derived.

Scattering characteristics of lunar morphological features were also studied using MiniSAR data and it was observed that SAR data due to its surface penetration ability and sensitivity to target electrical / physical properties and structure, reveals much more detailed information as compared to optical data (Fig.2). It has also been shown that using polarimetric parameters of Mini-SAR data, it is possible to characterize craters based on their relative roughness and abundance of $FeO+TiO_2$ content [5, 6]. Also, the radar backscatter combined with scattering types of lunar features (obtained by m- δ decomposition of MiniSAR hybrid polarimetric data [5]) were found to be useful in identifying certain targets on lunar surface such as lava melt ponds on the rim of Jackson crater in the lunar mid-latitudes (Fig.3).

While further studies of lunar surface features using MiniSAR data are in progress, it is realized that a dual-frequency SAR observing lunar surface at multiple viewing angles and with higher spatial resolutions will fortify many of the findings of MiniSAR. This can be realized by forthcoming Chandrayaan-2 Dual-frequency SAR.

Table-1 Derived Stokes' parameters and their significance

Stokes' Parameter	Derivation	Significance
Degree of polarization (m)	$m=\sqrt{(S_1^2+S_2^2+S_3^2)}/S_0$	This is an indicator of polarized and diffused scattering; fundamentally related to entropy
Degree of linear polarization (m_L)	$m_L=\sqrt{(S_1^2+S_2^2)}/S_0$	This is an indicator of volume vs subsurface scattering
Circular Polarisation ratio (CPR)	$CPR=(S_0-S_3)/(S_0+S_3)$	This is an indicator of scattering associated with planetary ice deposits and fresh ejecta
Relative LH – LV phase (δ)	$\delta=arctan(-S_3/S_2)$	Sensitive indicator of 'double bounce' scattering

Table 2: Average values of polarimetric parameters for some non-polar craters

Crater Name	*LH σ° in dB*	*LH-LV Diff.(dB)*	*δ*	*CPR*	*Comments*
Taylor (16.7°E, 5.3°S)	-14.2	-14.2	-76°	0.39±0.11	Old Impact crater; Tormented floor; Central mountain
Descartes (15.7°E, 11.7°S)	-14.6	-19	- 65.1°	0.39±0.26	Damaged circular crater; Tormented floor; Crest and rille line
Maunder (93.8°W, 14.6°S)	-13.2	-17.6	- 77.8°	0.60±0.15	M.O. Basin; Old Impact crater; Zone of librations
Kopff (89.6°W, 17.4°S)	-17	-22.4	- 95.6°	0.47±0.24	M.O. Basin; Crater floor flat, filled with lava, Volcanic origin
Olbers (75.9°W, 7.4°N)	-11.7	-15.4	- 82.9°	0.54±0.13	Bright wrecked formation; Crater floor flat, filled with lava

Figures:

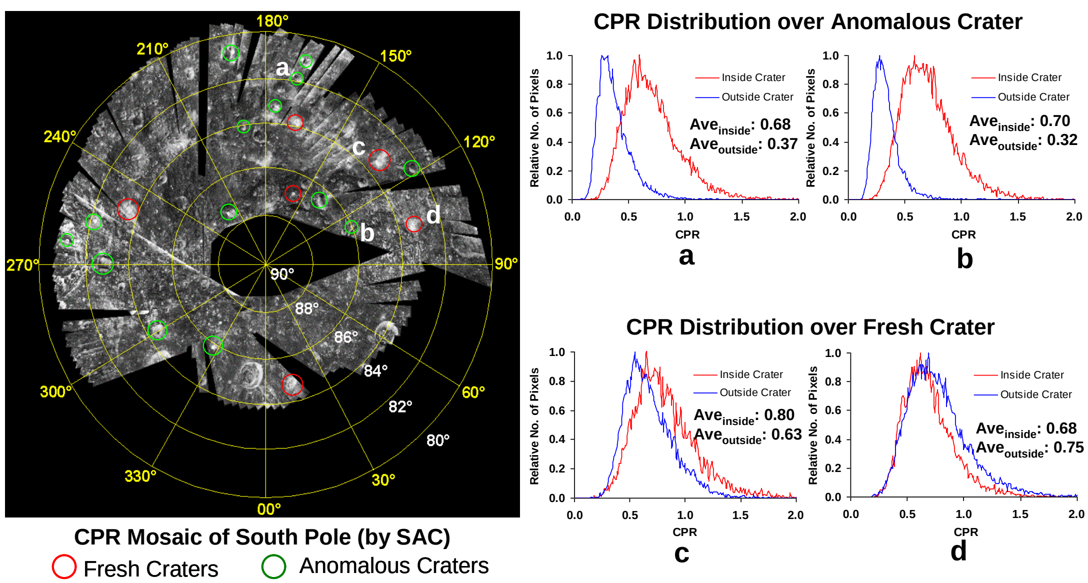

Figure 1: *Left*: CPR map of the South polar region of the Moon. Normal appearing fresh craters are indicated by "Red Circles" while anomalous craters having high CPR in their interiors are shown by "Green Circles"; *Right*: CPR distribution over anomalous ('a' and 'b') and fresh ('c' and 'd') craters. The anomalous craters show distinct 'low' and 'high' CPR values in the outside and inside regions, respectively, of craters, whereas fresh craters are characterized by 'similar' values of CPR both inside and outside of the craters. The results matched well with the same derived by the NASA team.

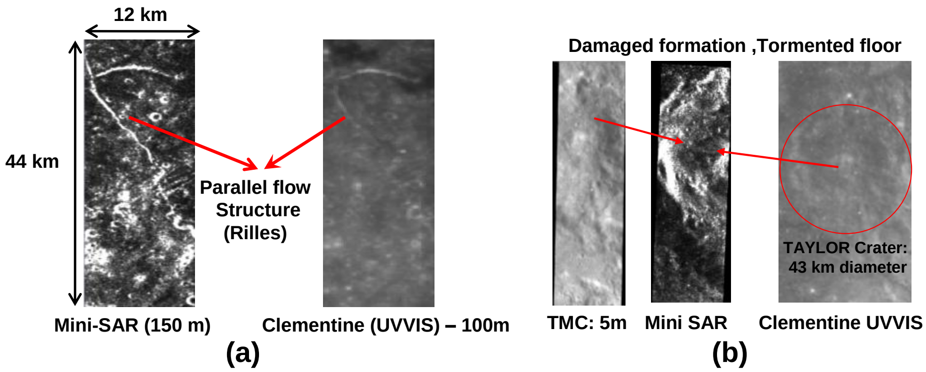

Figure 2: Study of lunar morphological features using MiniSAR data showing advantages of SAR data over optical data (Clementine UV-VIS); (a) surface flow structures (rilles) better visible in SAR data; (b) tormented floor of Taylor crater as visible in MiniSAR data.

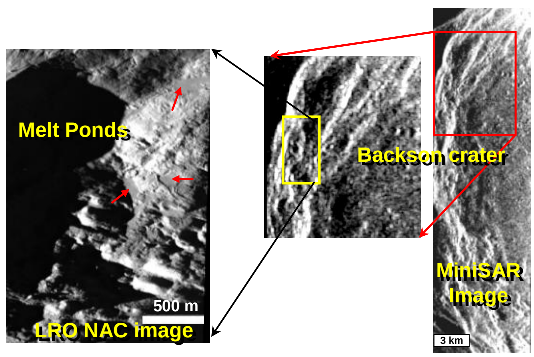

Figure 3: Identification of Lava/melt ponds on the rim of Jackson crater in the lunar mid-latitudes.

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Nature's Graffiti on Moon: The Mysterious Lunar Swirls

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Lunar swirls are strange markings on the Moon surface that resemble the cream in your coffee cup, however, on a much larger scale. These strange looking sinuous features are optically bright and are observed in both the maria and highlands of the Moon. Maria are known as dark colored patches on the Moon made of iron bearing basaltic rocks, whereas, highlands are brighter regions of the Moon. Though generally bright in appearance, lunar swirls often contain lanes of darker material within their looping patterns. Lunar swirls appear to overlay the lunar surface, superposed on top of craters and ejecta deposits, apparently representing diffuse brightening (or darkening) of unmodified terrains. One of the most famous such feature on the near side of the Moon is called as Reiner Gamma formation, which is located in the Oceanus Procellarum region of the Moon, centered around selenographic coordinates 7°30′N 59°00′W7.5°N 59.0°W. It has an overall dimension of about 70 kilometres. The feature has a higher albedo than the relatively dark mare surface, with a diffuse appearance and a distinctive swirling, concentric oval shape. Related albedo features continue across the surface to the east and southwest, forming loop-like patterns over the mare. Figure 1 shows the image of the Reiner Gamma swirl using Clementine and Chandrayaan-1 data.

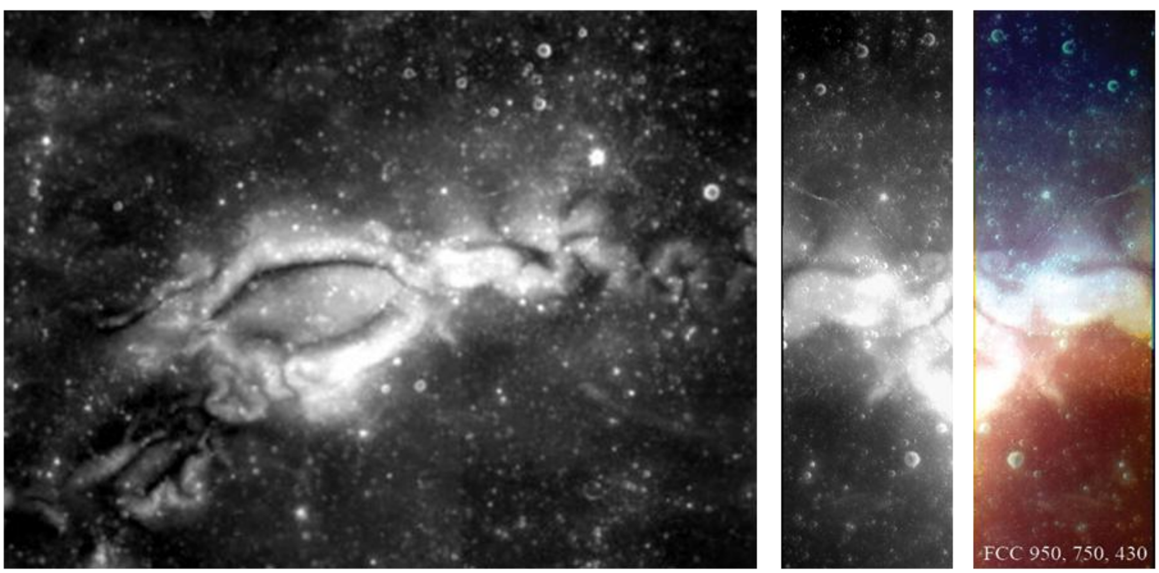
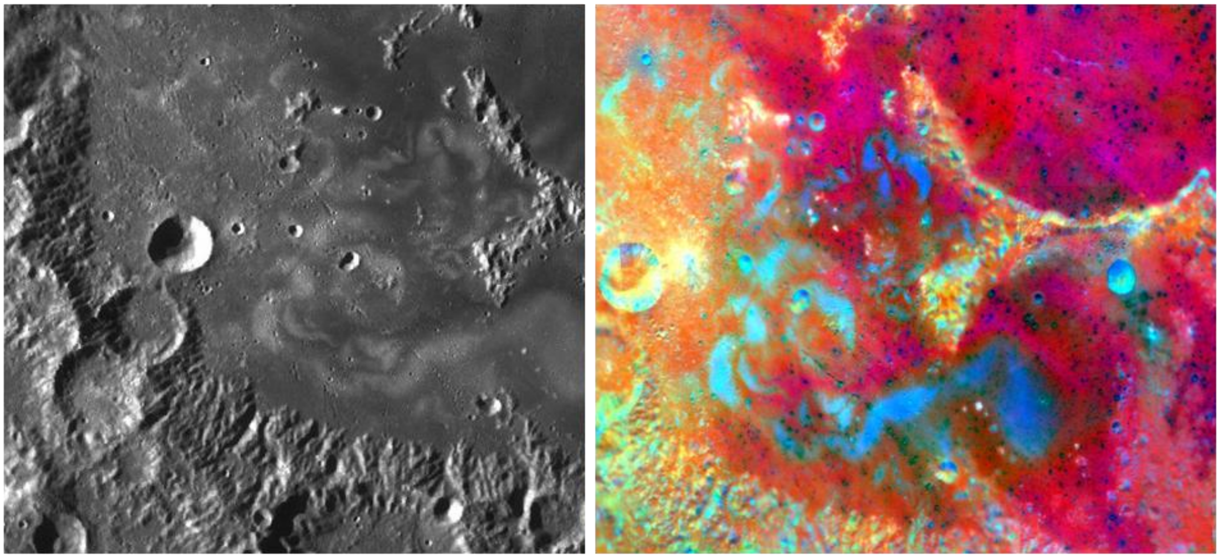


Figure 1: (a) Image of Reiner Gamma swirl as imaged by Clementine senosr, (b) part of Reiner Gamma formation as images by HySI sensor of Chandrayaan-1 and (c) FCC of HySI data. The brighter, sinuous patterns of the image are described as Lunar Swirls against the backdrop of dark coloured mare regions.

As seen from figure 1 Reiner Gamma Formation – is easily distinguished against the dark mare basalt of Oceanus Procellarum. Lunar swirls have been observed in a number of other locales on the Moon, on both the nearside and the farside, in both mare and highland settings. Reiner Gamma is not associated with any particular irregularities in the surface, and so the cause was a mystery until similar features were discovered in Mare Ingenii and Mare Marginis on photographs taken by orbiting spacecraft. The feature on Mare Ingenii is located at the lunar opposite point from the center of Mare Imbrium. Likewise the feature on Mare Marginis is opposite the mid-point of Mare Orientale. Thus it is believed that the feature resulted from seismic energies generated by the impacts that created these maria. Unfortunately there is no such lunar mare formation located precisely on the opposite surface of the Moon, although the large crater Tsiolkovskiy lies within one crater diameter. Figure 2 shows lunar swirls of Mare Ingenii region.



Ingenii swirl: R = 950/750, G = 900 nm, B = 415/750

Fig 2: (a) Albedo image of mare Ingenii swirl and b) multispectral colour ratio composite showing milky blue colour features as Ingenii swirls regions.

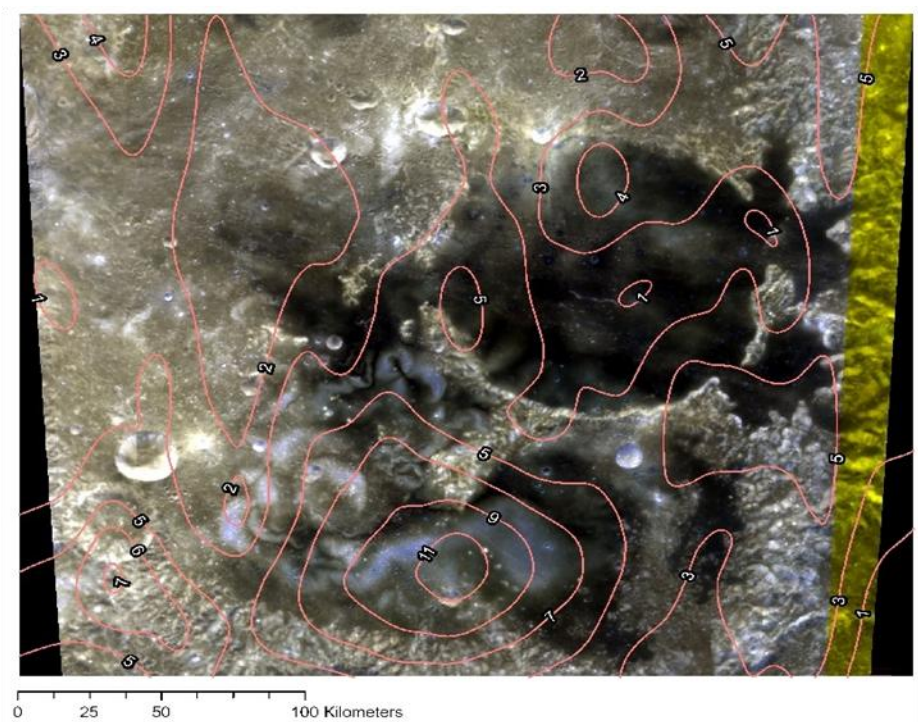


Figure 3: Association of bright albedo features in mare Ingenni region with strong localized (~11 nT) magnetic field.

Lunar swirls tend to be associated with regions of anomalously high crustal magnetic fields. Although not every magnetic anomaly (especially weaker ones) has a visually identifiable swirl. This relationship has led some to speculate that the swirls result from differential space weathering. In this scenario, the magnetic anomaly protects the surface from solar-wind ion bombardment, suppressing the soil darkening caused by exposure to the space environment, and making the swirls appear brighter than the surrounding, unshielded surface. Figure 3 shows association of mare Ingenii swirls with strong localized magnetic anomalies.

Another idea postulates that the magnetic anomalies associated with the swirls lead to the formation of electric fields, due to the differential penetration of solar wind electrons and protons into the magnetic field. These electric fields could then selectively attract or repel fine, feldspar-rich electrostatically levitated lunar dust, creating the characteristic bright and dark lanes of the lunar swirls. Still others speculate that the swirls are remnants of collisions with a cometary coma, disrupted comet fragments, or comet-related meteor swarms. In these comet impact-related scenarios, the impact is proposed to expose fresh material from the top < 1 m of the lunar surface, enhancing the albedo of the area without causing a major change in the topography.

However, the questions such as What are swirls made of? Are they truly flat? How does the cream differ from the coffee? Are being explored using data sets from the recent Lunar missions such as Chandrayaan-1, SELENE and LRO.

One of the recent study using the hyperspectral data from Moon mineralogy Mapper sensor onboard Chandryaan-1 mission suggest that the spectral characteristics of the swirls and adjacent terrains support the hypothesis that the magnetic anomalies deflect solar wind ions away from the swirls and onto off-swirl surfaces. Nanophase iron ($npFe^0$) is largely responsible for the spectral characteristics attributed to space weathering and maturation, and is created by vaporization/deposition by micrometeorite impacts and sputtering/reduction by solar wind ions. On the swirls, the decreased proton flux slows the spectral effects of space weathering (relative to nonswirl regions) by limiting the $npFe^0$ production mechanism almost exclusively to micrometeoroid impact vaporization/deposition. However, still more to be done to know exact formation process of these natural graffiti on the Moon surface, may be returned samples can only solve this enigmatic puzzle.

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- Editorial Team

Lunar Surface Age Determination by Crater Counting Method using Chandrayaan-1 -TMC Data for Apollo 14 Landing Site

A.S. Arya*, R.P Rajasekhar , Ajai & A S Kiran Kumar, SAC, Ahmedabad

Impact craters are the dominant landforms on most of the solid surfaces in our solar system. These impact craters have accumulated on the surfaces over the age of our solar system. Crater counting by itself could be used for obtaining relative ages of the surfaces. The older surfaces accumulate more impacts and hence display a larger number of craters. Thus by knowing the rate of impact, the observed density of craters provides a clue to the age of the surface. The fundamental assumption in the derivation is that the destruction of a crater is slower than its formation.

Apollo 14 landed on Moon on Feb 5, 1971 at 1517 hrs. (Houstan Tx time) about 49.3 km north of the Fra Mauro crater (3^0 7′ S, $17^0$5′W). The area is characterized by ridges a few hundred feet high which radiate from the Imbrium basin seperated by undulating valleys. The ejecta blanket now is buried by younger rubble and lunar soil churned up by more recent meteoroid impacts and possible moonquakes. It therefore serves as a convenient stratiagraphic marker, dividing features that are older than the Imbrium impact from those that are younger. Thus this area is selected for age determination. Several researchers like Haruyama et al., 2009, Hesinger et al., 2000, Neukum et al., 2001 and Ivanov et al., 2000, have established the crater counting technique for Age determination of Moon and other Planetary surfaces

The Apollo 14 mission brought back 43 kilograms of lunar rock, soil, and core samples. Dating of these returned samples has placed creation of the `Sea of Rains' at 3.9 billion years before the present (Merguerian, 1989). In this study we selected the Area around the Apollo-14 landing site for determination of age through crater counting technique using high resolution Terrain Mapping Camera (TMC) data of Chandrayaan-1 mission.

The CHANDRAYAAN-1, launched on October 22, 2009, carried a unique panchromatic sensor called Terrain Mapping Camera (TMC), which viewed the surface of the Moon from 100 kms and returned unprecedented image quality due to its very high spatial resolution of 5 m (Kiran kumar et al., 2009). The imaging is done in strip mode of 20 km swath and each strip has a unique orbit number.

The crater diameters were measured as precisely as possible from the images by counting the pixels. The surface area of the region under consideration was calculated in terms of the pixel size. The cumulative crater frequency N(km^{-2}) for each region was calculated for different diameters of the craters following the lunar chronology curve (Neukum and Ivanov 1994). The crater diameters are plotted as cumulative distributions, i.e., the number of craters divided by the area of the region covered. This gives a complex continuous curve called the `LPF' (LPF).

Neukum and lvanov., 1994 showed that lunar crater distributions measured on geologic units of different ages and in overlapping crater diameter ranges can be aligned along a complex continuous curve, the LPF, by shifting them in log(N_{cum}), i.e., the vertical direction. The LPF is given by an eleventh-degree polynomial:

$$\log(N_{cum}) = a_0 + \sum_{k=1}^{11} a_k \left[\log(D)\right]^k \text{ ------(1)}$$

In (1) the term a_0 represents the time during which a geologic unit was exposed to the meteorite bombardment. The respective cumulative crater densities of geologic units taken at a fixed reference diameter are directly related to the time the units were exposed to the meteorite flux and therefore represent relative age differences of these units. Relative ages or crater retention ages are obtained by a least squares fit of the LPF to the actually measured crater distribution, giving the cumulative crater density at the reference diameter. Heisinger et al., 2000 had compared the ages obtained by crater counting technique to ages obtained by radiometric dating for samples obtained from earlier missions.

TMC Nadir image of orbit no. 760 acquired on Jan 10, 2009 over area around Apollo 14 landing site at a orbit height of 100 km which has been analyzed for the present study. An area of 6000x 4000 pixels around Apollo-14 site was selected for crater counting for age determination. Chain of craters, craters not having complete circular shape and cluster of craters were considered as secondary craters in this study. While crater counting, secondary craters in the study area were avoided to avoid effect of secondary impact events. In this selected crater diameters were in the range of 200 m to 1.3 km. To understand the crater diameters distribution in the area histogram was plotted for crater diameters. Measured crater diameters plotted on to Crater size frequency distribution curve using 'craterstat' IDL subroutine , which contains coefficients for both Moon Chronology and production functions (Neukum et al., 2001 and Ivanov et al., 2000). By fitting the observed points with Lunar production curve as a small segments can give the age of that lunar surface. For this selected area an age of 3.62 Ga was obtained, which falls in upper Imbrian system. This confirms to the geological map of the Moon by USGS (Wilhelms, 1987).

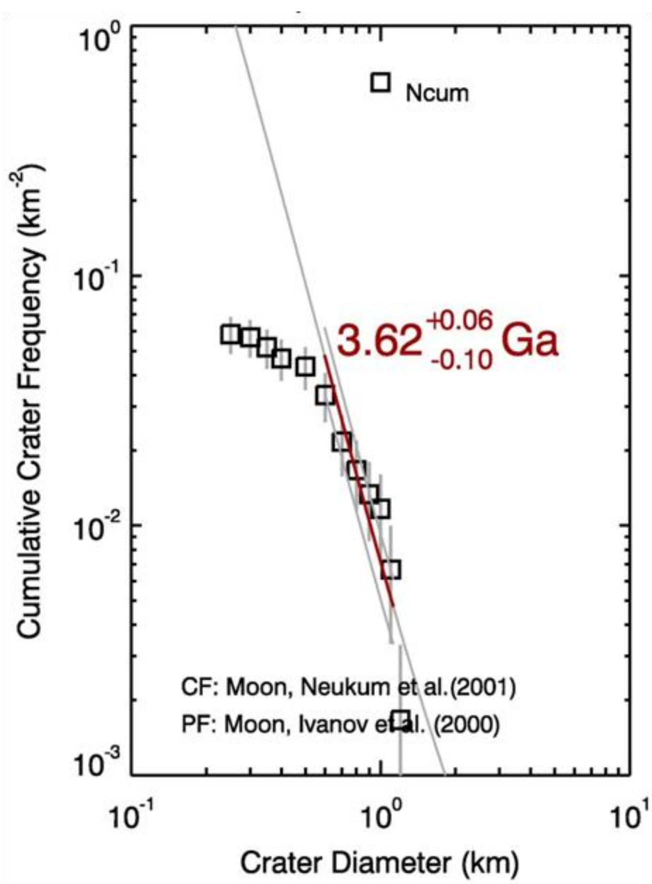

Fig. 2. Cumulative size-frequency distributions of counted craters.

The solid curve is the Neukum's polynomial function fit to the observed CSFD by the least-square method. The model age is 3.62 Ga for the area around Apollo -14 site.

Using high resolution TMC data of Chandrayaan-I of spatial resolution 5m spatial resolution at an orbit height of 100 km., craters of smaller diameters up to few meters can be mapped, which will be useful for precise age determination of lunar surfaces using crater counting technique. In this study attempt has been made to determine the Age of Apollo-14 site using TMC data using above technique and the resultant age obtained is about 3.63 Ga, which belong to the Upper Imbrian system. Above technique can be applied to several other landing sites and other areas for determination ages of lunar surfaces. This confirms to the geological map of the Moon by USGS (Wilhelms, 1987)

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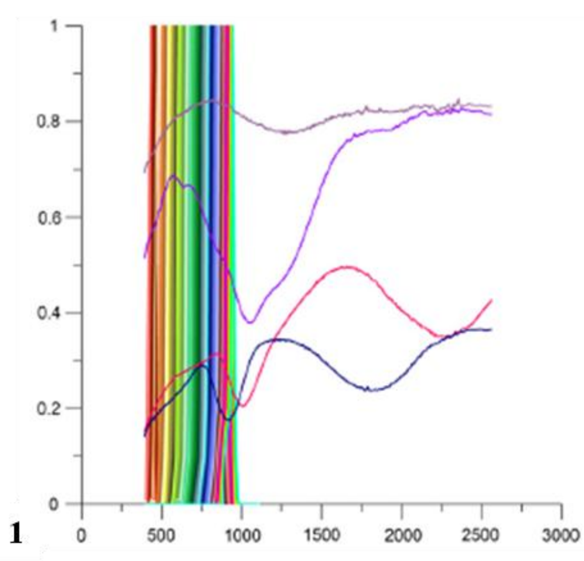
- Editorial Team

New Spectral Band Parameters for Generating Rock-type Composite images using Chandrayaan-1 Hyperspectral Imager (HySI) Data

Satadru Bhattacharya, Prakash Chauhan, Ajai and A. S. Kiran Kumar, SAC , Ahmedabad

Introduction: Compositional mapping of lunar surface on the basis of colour differences and spectroscopy has been carried out since 1960s using remotely-acquired (ground-based or spacecraft) reflectance spectra. It is well known that the analysis of the visible/near-infrared portion (400–2500 nm) of the lunar spectrum is important as this spectral region contains absorption features diagnostic of individual minerals. Pyroxene and olivine are the two most common mafic minerals found in the lunar surface having diagnostic absorption features that vary with composition (Burns, 1993). In spite of limited spectral coverage, Hyperspectral Imager (HySI) can be used to evaluate the strength and the location of the 1000-nm ferrous absorption feature to the first order. Even though the spectral resolution is high in HySI data, its limited spectral coverage inhibits from complete characterisation of the 1000-nm absorption feature and therefore, the variations in 1000-nm absorption feature is only suggestive of local mineralogy as is the case for Clementine UVVIS data. Here, we present a new set of spectral band parameters to generate a rock-type composite of lunar surface using HySI data.

Data Used: HySI data from Chandrayaan-1 mission has been used for the present study. HySI maps the lunar surface in the spectral range of 421–964 nm in 64 contiguous bands with a spectral bandwidth better than 20 nm (Kiran Kumar et al., 2009). The instrument acquires images in push-broom mode with a swath of 20 km from a polar orbit of 100 km altitude.



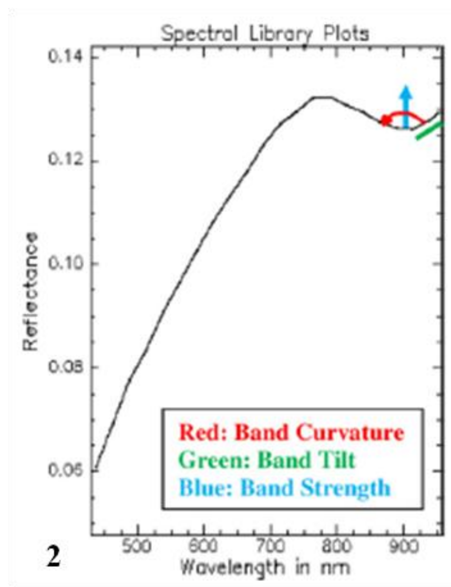


Fig 1. USGS library spectra of major lunar rock forming minerals. Superimposed are the Relative Spectral Response (RSR) data of 64-band HySI filters. 2. Schematic diagram of the three modified spectral band parameters (derived from Clementine UVVIS five-channel data) as per HySI data for characterising the type of mafic minerals present.

Methodology: Compositional mapping of lunar surfaces using spectral band parameters is a standard technique (Tompkins and Pieters, 1999; Pieters et al., 2001; Dhingra, 2008; Isaacson and ieters, 2009). The band parameters are chosen in such a fashion that they could characterise the shape, magnitude and location of the 1000-nm absorption feature diagnostic of mafic rock forming silicates. In the present study, three band parameters, namely, band strength (BS), band curvature (BC) and band tilt (BT) (originally derived for Clementine UVVIS data) have been applied on the HySI data (Bhattacharya et al., 2011) with minor changes depending on the availability of spectral channels that are close to Clementine channels used for deriving the band parameters. The band parameter expressions are presented in the following three equations:

$BS = R_{947.7} / R_{748.3}$ ....(1)

$BC = (R_{748.3} + R_{947.}7)/R_{898.0}$ ....(2)

$BT = R_{898.0}/R_{947.7}$ ....(3)

Band shape comprises of basically three band parameters, namely, band strength, band curvature and band tilt. Tompkins first developed an approach for characterisation of ferrous absorption feature near 1000 nm so that discrimination of mafic bearing lithologies could be possible and therefore, derived two band parameters namely, band strength (''key ratio'' of Tompkins) and band curvature (Tompkins and Pieters, 1999). Later on Pieters et al. (2001) modified this technique by introducing another band parameter which they named as ''Band Tilt''.

Band strength is approximated by the ratio of 947.7/748.3 nm for HySI bands. Areas containing Anorthosites and matured soils lack a prominent 1000-nm absorption feature and therefore have higher values according to this formulation compared to unweathered regions that are rich in mafic minerals with strong 1000-nm absorption feature. This parameter has been assigned a blue channel and therefore anorthosites will appear deep blue and highly matured soils will show a significant blue component in the rock type composite image.

According to the band curvature formulation, high curvature parameter value indicates a shorter-wavelength 1000-nm absorption feature and vice versa (Isaacson and Pieters, 2009). Therefore, the band curvature values will decrease from low-Ca pyroxene (LCP) bearing noritic rocks to high-Ca pyroxene (HCP) bearing gabbroic rocks and the curvature will further decrease for areas dominated by olivine rich rocks (Pieters et al., 2001). For the present purpose, this band parameter is assigned red channel so that areas dominated by LCP bearing rocks appear red in the rock type composite image.

Pieters et al. (2001) defined band tilt as the difference in reflectance at 900 nm and 1000 nm (Fig. 2) and later modified by Dhingra (2008) as the ratio of 900/1000 nm. Due to the unavailability of the 1000 nm channel in HySI, we have used 947.7 nm channel as already mentioned in Eq. (3). Use of 947.7 nm band instead of 1000 nm is not going to change the result as high-Ca pyroxenes and olivine with strong ferrous absorption bands and low curvature have higher reflectance at 898 nm than that at 947.7 nm. For Immature surfaces, having fresh exposed materials, band tilt and band curvature will be complementary to each other in the sense that strong Fe^{2+} absorption without any curvature would exhibit larger tilt (reflectance at 900 nm is greater than that at 950 nm). This parameter has been assigned green channel and thus areas with abundant high-Ca pyroxenes and/or olivine would appear green. But this parameter cannot discriminate between high-Ca pyroxene and olivine.

Results and Discussions: Spectral band parameters, namely, Band Curvature (BC), Band Tilt (BT) and Band Strength (BS) have been derived from HySI data of central part of Mare Moscoviense (a farside mare basin) and crater Le Monnier (a near side mare unit situated at the eastern edge of Mare Serenitatis). Three different mare units, namely, ancient mature mare unit, highland contaminated mare unit and youngest mare unit, with distinct spectral signatures have been identified and mapped on the basis of rock-type composite image and spectral characteristics in the Mare Moscoviense (Bhattacharya et al., 2011). It has also been observed that except for the Im unit which is basaltic in nature (green in rock type composite), all other mare units in Mare Moscoviense are mostly noritic to anorthositic norite in composition and appear in the shades of pink and purple in the rock type composite. Fresh craters from noritic units appear red to orange in the rock type colour composite. Spectral signature of mature highland soils is found to be anorthositic to noritic anorthosite in composition and therefore appears blue to purple in the rock-type composite. The fresh craters and the mature soils within the Le Monnier basin appear green in the rock-type composite indicating high-Ca pyroxene rich basaltic composition. From the present study, it can thus be concluded that the spectral band parameters, as obtained using selective HySI channels, could efficiently be used for lithological mapping of the lunar surface.

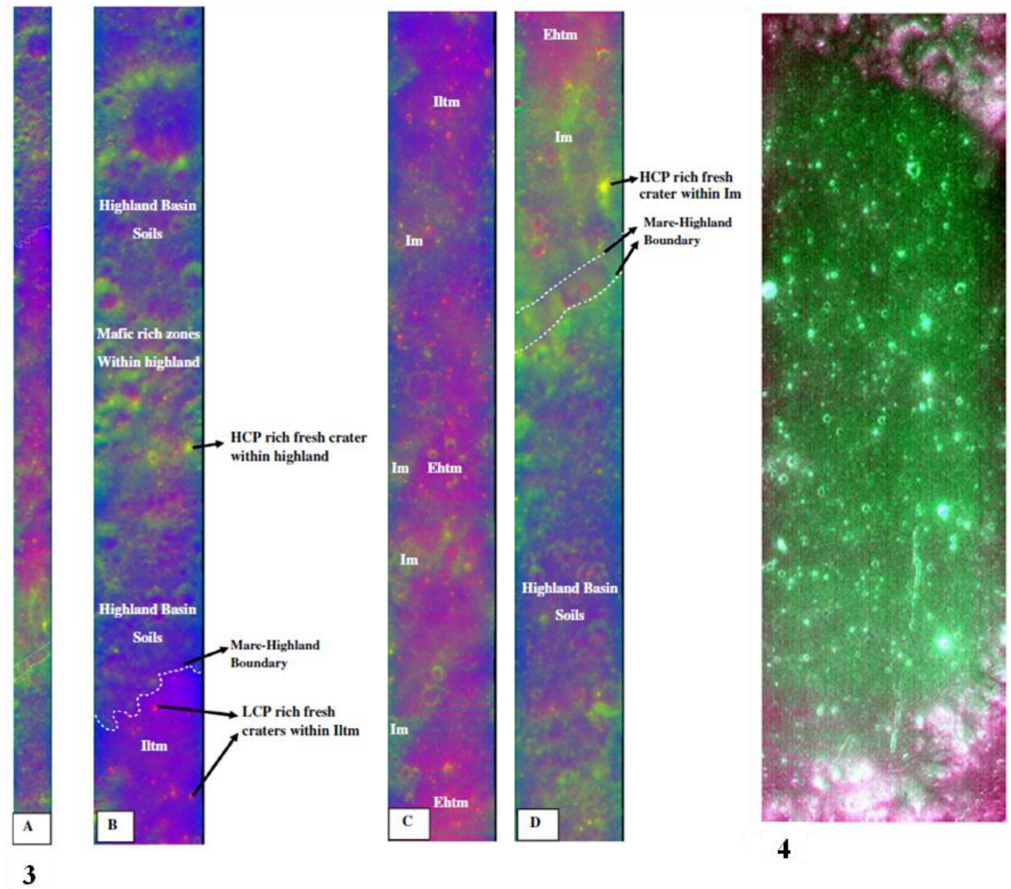


Figure 2(A-D). Rock type colour composite image covering central part of Mare Moscoviense (a farside mare) and 4. Crater Le Monnier (a nearside mare)

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Electro-Optical Imaging Payloads for Chandrayaan-2

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Introduction: India's first planetary mission Chandrayaan-1, to moon, had Indian and International payloads on-board. These instruments collected very significant data over the mission duration. The success of this mission has propelled for the second Indian mission to moon, Chandrayaan-2, with an Orbiter-Lander-Rover configuration. This will be a collaborative mission between the Indian Space Research Organization (ISRO) and Russian Federal Space Agency (Roscomos). ISRO will be responsible for the Launch Vehicle, the Orbiter and the Rover while the Lander will be provided by Russia.

Indian Geosynchronous Satellite Launch Vehicle, GSLV (Mk-II) will place Chandrayaan-2's Orbiter, coupled to the Lander and Rover, in orbit around the Earth. The Orbiter will then boost the orbit to Lunar Transfer Trajectory (LTT). Once on the LTT, the Orbiter and Lander-Rover will separate. The two would then independently reach lunar polar orbit. The Orbiter will be placed in the 200km circular polar orbit and the Lander-Rover module will descend to the lunar surface. After the Lander touched down, the motorized Rover would be released on the lunar surface.

Chandrayaan-2 payloads, five in Orbiter and two in Rover, will carry out a total coverage of the moon with goals supplementing and complementing the measurements carried out by Chadrayaan-1. The orbiter payloads are aimed at mapping the major elements present on the lunar surface and further probe the presence of water and various chemicals. It will also study the lunar exosphere besides preparing a three-dimensional map essential for experiments relating to lunar mineralogy and geology. The two rover instruments will carry out elemental analysis of the lunar surface near the landing site.

The Electro-optical imaging instruments for Chandrayaan-2 mission are -

1) Terrain Mapping Camera-2 (TMC-2)
2) Imaging Infra-Red Spectrometer (IIRS)
3) Rover Imager (RI)

These instruments are being developed indigenously at Space Applications Centre (ISRO), Ahmedabad. The first two instruments, TMC-2 and IIRS are Orbiter payloads and the RI is planned both in Rover and Orbiter.

TMC-2 is continuation of the previous mission to have total topographic coverage of the moon. The images taken by TMC in Chandrayaan-1 are of high quality and detailed topographic mapping of the lunar surface has been undertaken. Also, this data is used by the other instruments for analysis of mineral and chemical composition of the surface. However TMC-1 has mapped only about 45 per cent of the moon surface requiring TMC-2. The challenge in TMC-2 realization is further miniaturization to two-third weight as per mission requirement.

IIRS is an advanced version to the spectrometers (HySI, M-cube and SIR-2) flown in Chandrayaan-1. The spectral range in this instrument is extended upto 5.0µm. The ground sampling will be 80m with swath coverage of 40km. With the extended spectral coverage besides mineralogical mapping of the surface, presence of water discovered by Chandrayaan-1 could be further studied at much higher spatial resolution. Also the higher spectral range will enable understanding thermal inertia of lunar surface, thermal properties of rock types and permanently shadowed areas of Polar regions. Such an instrument will be developed for the first time in ISRO and has lot of design and implementation challenges.

The RI is a miniaturized high-density format colour camera. It will be extremely light weight and low power consuming. It will be there in Orbiter as well as in Rover. In the Orbiter it will be monitoring various events like Lander separation from the Orbiter etc. In the Rover it will view the surface for deciding locations for in-situ experiments by the Rover instruments and panoramic imaging of lunar surface.

Design considerations: The design consideration of these payloads for the lunar mission is to meet the performance requirement in the lunar environment for the mission life of 2 years and 6months respectively for the Orbiter and Rover payloads. The other paramount mission requirement is that the instruments need to be highly compact – low weight and low power dissipation.

For the EO payloads, Sun is the primary source of energy and hence the scene illumination varies as the solar aspect angle goes through a yearly cycle. Limiting the solar aspect angle to ±30° at equator to minimize variation of illumination condition will provide about 2 months of prime imaging periods every six months for the Orbiter payloads. Thus there will be 4 prime imaging seasons during the mission life. During the prime-imaging season regions between 60°N and 60°S will be covered. The solar illumination at polar regions (above 60° latitude) is poor in all seasons and is planned to be covered during the remaining periods termed as the secondary imaging seasons. Continuous imaging in the MIR band of IIRS payload will however be possible. In the VNIR spectral range, the payloads will measure the solar radiation reflected/scattered from Moon's surface. The dynamic range of the reflected signal is quite large, represented by the two extreme targets – fresh anorthosite surface and mature mare soil. The other factors affecting the illumination are the seasonal variation, latitude-longitude of the scene and anisotropic reflectance of lunar surface.

For the 200 km polar orbit, the equatorial shift of the Moon between two orbits is about 34km. The swath for the Orbiter payloads is chosen as 40 km ensuring total coverage of lunar surface at equator with adequate overlap.

Considering the generated data volume of the Orbiter payloads and the download transmission rate, lossless data compression will be carried out before on-board storage and transmission. The RI will have JPEG compression and the data will be transmitted via Lander or Orbiter to Earth.

Terrain Mapping Camera-2 (TMC-2): Like its predecessor, TMC in Chandrayaan-1, TMC-2 is a panchromatic, stereoscopic instrument with three views – fore, nadir and aft. The fore and aft views will be at ± 25° w.r.t nadir view in the along track direction giving a base to height ratio of 1. The three views ensure imaging the entire lunar surface without any occlusion with at least one stereo pair. The along track sampling will be 4.6m and the footprint will be 10m. The swath will be 40km enabling faster coverage for mapping. The ground geometry of the sensor pixel is shown in figure 1.

Though TMC-1 has met all the performance requirements, as already demonstrated by the high quality imageries (figure 2 shows TMC-1 imagery from 200km altitude), further miniaturization is undertaken, in keeping with the mission requirements. Accordingly, new design approaches with innovative usage of new technologies is explored towards meeting the performance requirements with a more compact, lighter system. Towards this new configurations are studied, further optimization of lens weight attempted, new electronic components and new power supply implementation is considered. Table 1 summarizes the key features of the instrument.

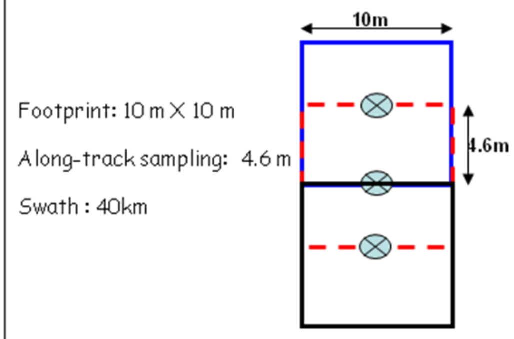


Figure 1 : Ground geometry of pixel

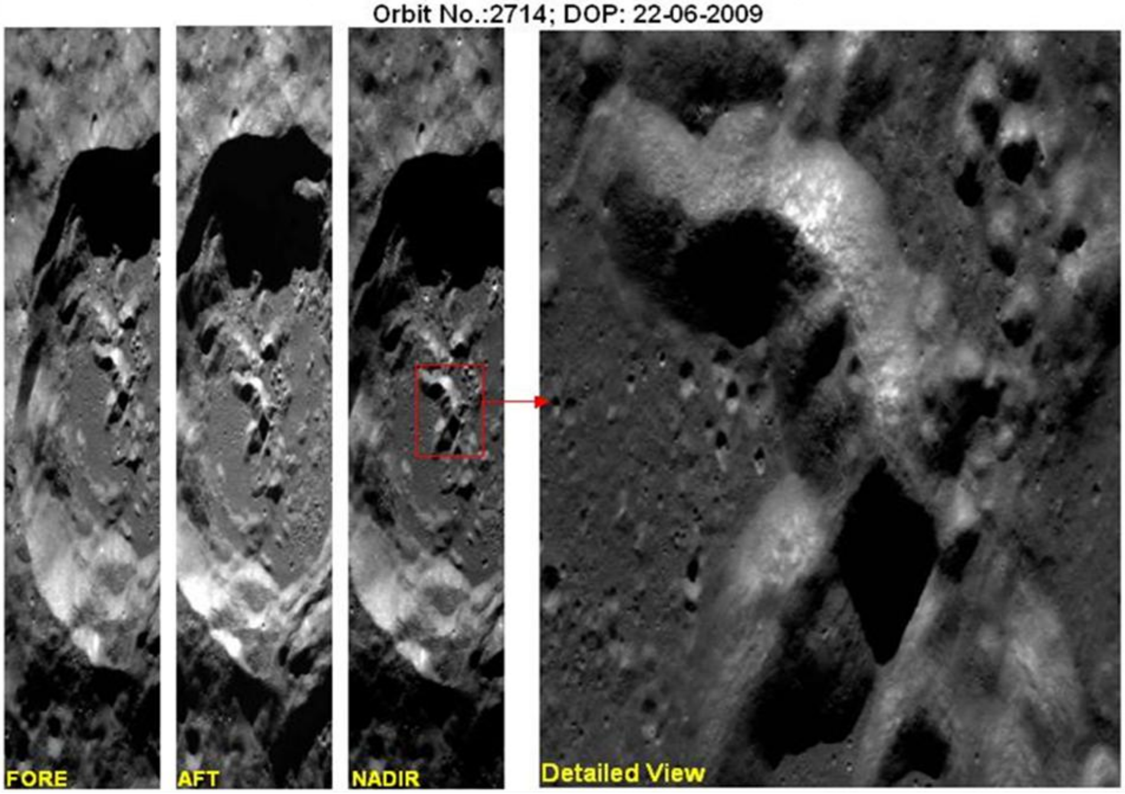
Table-1 Key features of TMC-2

Spatial sampling	Along track 4.6m Across track 10m
Swath	40km
Stereo mode	3-view along track, B/H=1
Spectral range	Panchromatic 0.5-0.85µm
Quantization	12 bit
Datarate	16.2 Mbps/view
MTF	>10%
SNR	>68 @1.2mW/cm²/str/µm) (goal) >300 @14mW/cm²/str/µm)
Power	<5W (Raw)
Weight	< 4 kg

Figure 2

Part of RICCO Crater (North Polar Region) Viewed by Chandrayaan-1 TMC from 200 km

Orbit No.:2714; DOP: 22-06-2009



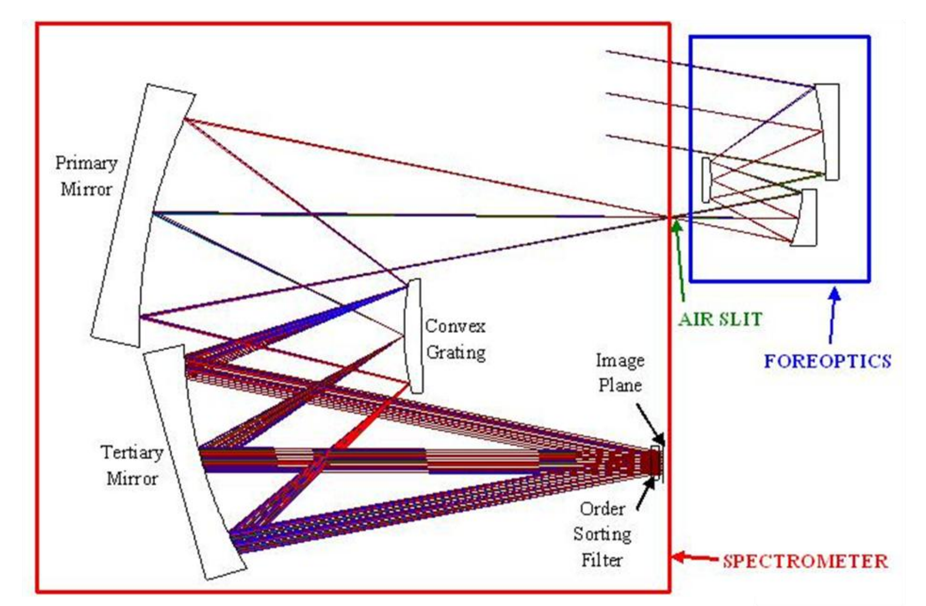


Figure 3 : IIRS Optical Schematic

Imaging Infra-Red Spectrometer (IIRS)

The IIRS instrument operating in NIR and MIR spectral region is planned on Chandrayaan-2 Orbiter. The uniqueness of this instrument will be its capability of mapping in 256 contiguous bands in the spectral range of 0.8 to 5.0 μm with a spectral resolution of better than 20 nm and spatial resolution of 80m. The high spatial and spectral resolution data of IIRS will significantly improve upon the available mineral compositional information, detection of hydroxyl (OH) and water (H_2O) molecules and thermal inertia mapping of lunar surface.

The instrument will map the lunar surface in pushbroom-mode from the polar orbit of 200 km altitude. IIRS will consist of fore optics, dispersing element and imaging instrument. Considering the large spectral range, fore optics is an all reflective design. Convex grating is considered for spectral dispersion. The detector considered is Mercury-Cadmium-Telluride (MCT) area array which is responsive to MIR range. The swath will be collected along one array (columns) of the detector and the spectrum will be along the perpendicular direction (rows). The optical schematic is shown in figure 3. The configuration of the camera electronics is based on the detector and system requirements. The electronics will provide the input stimulus to the detector for its operation and process the detector output. The block schematic of Electronics is shown in figure 4.

IIRS is conceived as a highly compact instrument keeping with the mission requirement of low weight, size and power. The preliminary conceptual instrument view is shown in figure 5 and the features of the instrument is summarized in Table 2. The main challenges in the realization of the instruments are :

- Spectral dispersion for the wide spectral range
- Suitable detector covering the complete spectral range
- Detector cooling requirement; MCT detector demands operation at cryogenic temperature
- Miniaturized electronics for system and detector requirements
- Reduce Background emission effect
- Low weight structure

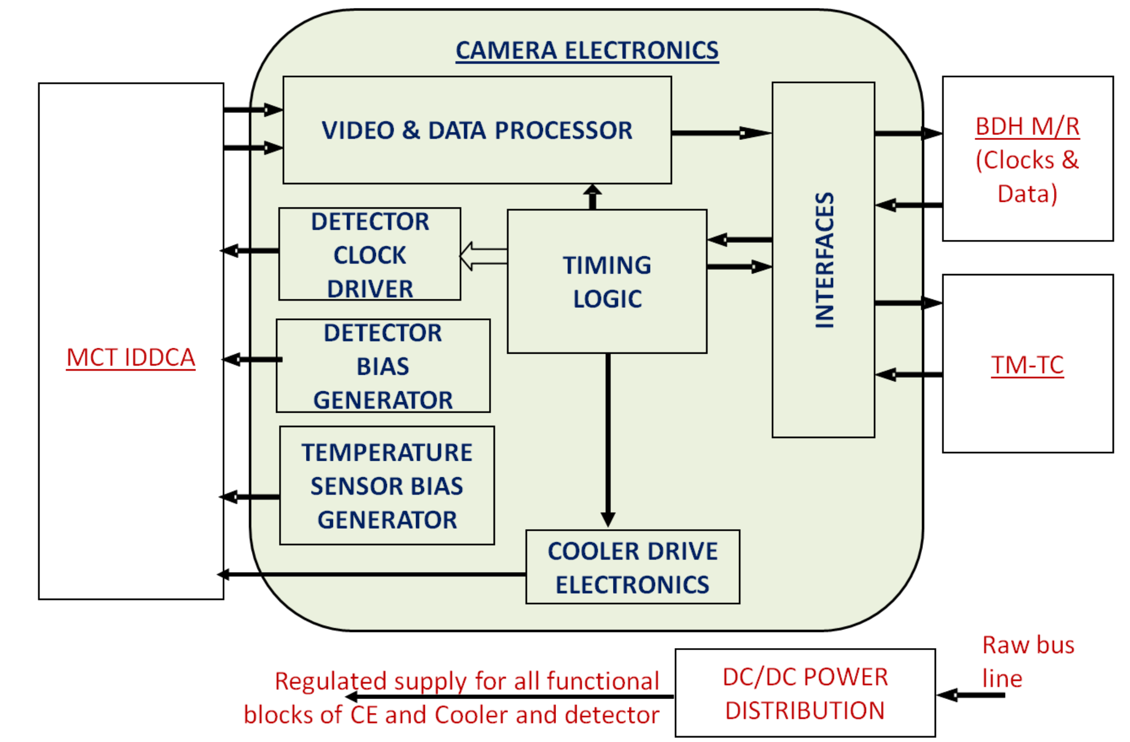


Figure 4 : Block Schematic of Camera Electronics

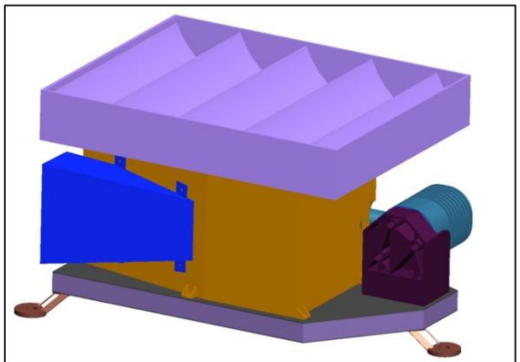


Figure 5 : IIRS Schematic

Table 2 IIRS features

GSD (m)	80
Swath (km)	40
Spectral range (µm)	0.8 to 5
Spectral Resolution (nm)	≤ 20
NEdR ($W/m^2/sr/\mu m$)	≤ 0.05
SNR	500
No. of spectral bands	~ 256
Quantization	12

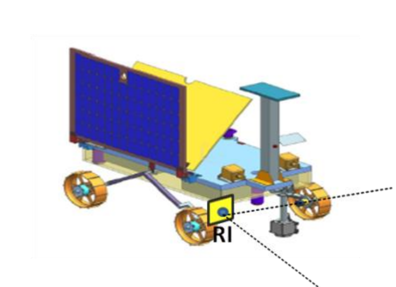


Figure 6 : RI in Rover

Table 3 RI features

Ground sampling	0.6mm@1m (0.6 mrad)
FOV	50 deg.
Frame Size/resolution	HD Format
No. of Bands	Visible with color (RGB) outputs
Storage Capacity	2 Gb (40 raw frames or 2000 compressed frames or 2 min of video)
Output data rate	~ 6.1 Mbps (8-bits Parallel) ~ 146 Mbps (SERDES o/p)
Power	< 2W
Camera head Weight	< 40g

Figure 7 : RI Camera head

Rover Imager (RI): Chandrayaan-2 Rover is configured as a semi autonomous four wheeled vehicle. It will carry two scientific payloads – Laser Induced Breakdown Spectroscope (LIBS) and Alpha Particle induced X-ray Spectrometer (APXS). The Rover Imager (RI) is for the primary objective of:

- Panoramic imaging of the lunar surface
- Video image the rover arm movement
- Collect data for terrain study for comparing with data taken by TMC-1 and TMC-2
- Image Regolith displacement due to the rover movement
- Help deciding locations for in-situ experiments by LIBS and APXS

It can also act as a substitute (redundancy) for the Rover navigation camera, Navcam. Additionally, RI is planned in the Orbiter where it will monitor various events like Lander-Orbiter separation etc. The RI will be a high-density color camera capable of taking images up to 30 fps rate. The configuration of the RI is worked out considering the mission requirement of low weight and power dissipation. The RI will have two units – Camera head (RCH) and Control electronics (RCE). This will facilitate mounting the camera at desired location. In the Rover two RIs are planned one in front and other in rear. Figure 6shows typical location of RI in the front side of Rover. The RI features are given in Table 3 and figure 7 shows the RI Camera head.

Discussion: The development of these payloads is in progress. Though TMC-2 is continuation of TMC-1 but it requires new developmental effort. The wide spectral range IIRS instrument has unique features and its realization and calibration has challenging aspects. The challenge of RI is ultra miniaturization and operation in wide lunar surface temperatures. Realization of these payloads within stringent mass constraint is a challenging affair for which high degree of miniaturization is being adopted.

Acknowledgments: The author acknowledges with thanks the contribution of all colleagues involved in the development. He also gratefully acknowledge the constant encouragement and guidance received from Shri D R M Samudraiah, Deputy Director, Shri A S Kiran Kumar, Associate Director and Dr. R.R Navalgund, Director Space Applications Centre.

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- Editorial Team

Chandrayaan-2 Dual-Frequency SAR: System Configuration

Tapan Misra, Deepak Putrevu and J.G.Vachhani, SAC , Ahmedabad

Introduction: India's second endeavour to moon in the form of Chandrayaan-2 is scheduled for launch in 2013-14. A two-module configuration comprising Orbiter-craft (OC) module and Lander-craft (LC) module (with Indian-Rover) has been finalized for the same. Dual-frequency SAR, identified as one of the payloads of the Orbiter, is being developed in SAC.

Development of Chandrayaan-2 Dual-Frequency SAR promises a new technological milestone in the realm of Microwave Remote Sensing in India. It aims to meet the various science objectives like probing of lunar regolith, water-ice detection & estimation and crater-floor mapping. In the course of this pursuit, Chandrayaan-2 SAR attempts to surpass its predecessor (Chandrayaan-1 MiniSAR) in terms of performance and features. The Dual-frequency SAR (L-band and S-band) has been envisaged to provide continuity to ongoing studies of S-band Chandrayaan-1 MiniSAR data by having an S-band SAR and to cater to further advanced scientific studies by making use of L-band SAR, having capability of better penetration of lunar-regolith.

Major challenges in the development of the system lie in meeting the allocated payload-mass of 14kg by miniaturization of the sub-systems, meeting the raw-power limits of 100W for L & S-band operation (simultaneous) and net data-rate limit of 160Mbps.

System Requirements: Dual-frequency SAR of Chandrayaan-2 aims to address a host of applications to understand the scattering characteristics of lunar surface and subsurface features, based on which the following science goals are targetted:

a) Detection and estimation of water-ice deposits using multi-frequency data.
b) Radio-physical characterization of lunar regolith through dual-frequency full-polarimetric SAR with multiple viewing angles.
c) Dielectric constant and surface roughness estimation over lunar surface using multi-frequency data.
d) Investigation of lunar-geological (selenological) and morphological features especially in the Polar Regions and preparation of seleno-morphological maps.
e) Development of high resolution DEM of lunar polar region and high resolution crater floor mapping.
f) Analysis of high resolution SAR data to find suitable landing sites in the lunar polar region for future lunar missions.

The science objectives given above are translated into the following requirements on system:

1) Full-polarimetric and Circular-polarimetric mode of operation
2) Incidence angle range from 10° to 35°
3) Measurement capability of Sigma-naught better than -20dB (preferably ~ -25dB) with 75m slant range resolution
4) High spatial resolution (2m, 3m) with sigma-naught measurement capability of -10dB or better.

Imaging Geometry: As shown in Fig.1, SAR system has been configured for operation from 9.5° to 35° incidence angles, which corresponds to range coverage from 30km to 125km off-nadir. This would be possible by roll-tilting the spacecraft from look-angle of 8.5° to 31°. The swath-width during a particular imaging session will be 10km, which is obtained from appropriate selection of data window. Coverage area and swath remain the same for L-band, as well as, S-band SAR.

Instrument Description: L-band and S-band SAR have been configured as two independent systems, shared by a common antenna. The planar-microstrip antenna of 1.35m x 1.1m dimensions, common for L-band and S-band SAR, caters to Rover-communications (in S-band) as well. SAR and Rover-communication operations are mutually exclusive, selectable by means of two switches provided in V &

H-polarization paths, shown in Fig.2. A 0°/90° hybrid is used to convert signal from linearly-polarized to circularly-polarized, as required for rover-communications.

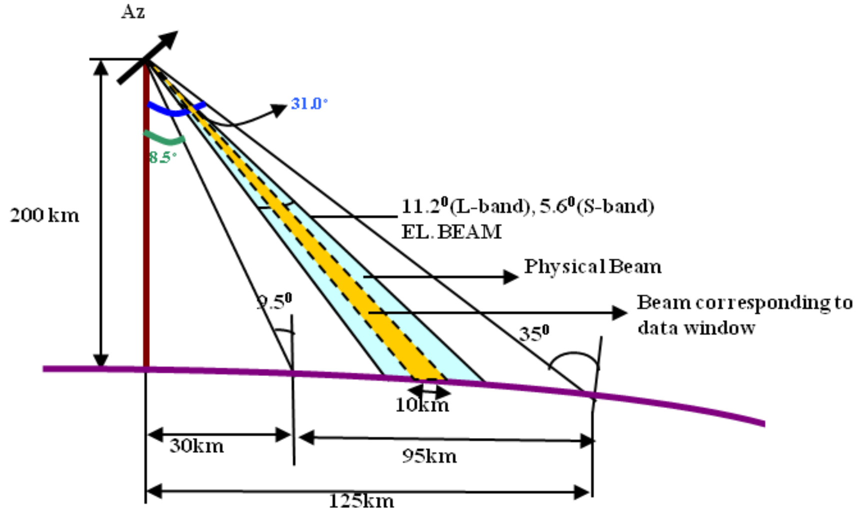

Fig.1: Imaging geometry of Chandrayaan-2 SAR

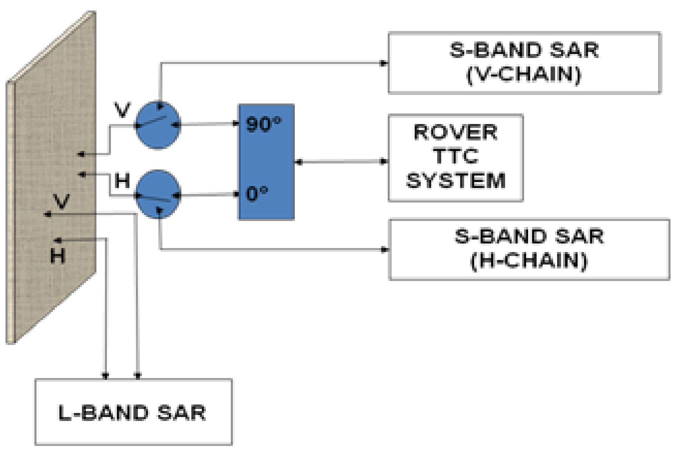

Fig.1: Imaging geometry of Chandrayaan-2 SAR

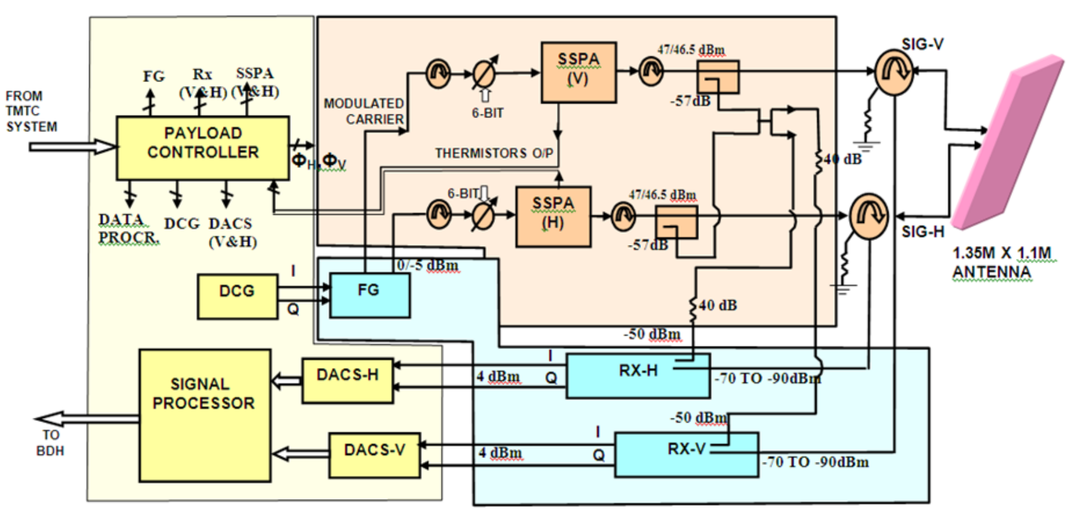

Fig.3: Block schematic of L-band/S-band SAR configuration

In addition to the common dual-band and dual-polarized antenna, mentioned earlier, each SAR system (L-band/S-band) comprises:

i. Digital-Chirp-Generator (DCG) to generated desired Chirp (LFM) signal
ii. Frequency-Generator (FG) to modulate the incoming Chirp to required centre-frequency, viz., 1.25GHz for L-band and 2.5GHz for S-band.
iii. Two SSPA chains (for V & H) with output power of 50W (for L-band) and 45W (for S-band)
iv. Two Receivers (for V & H) to amplify and I/Q demodulate the received signal
v. Two Data Acquisition and Compression Systems (DACS), for V & H polarization chains, for digitization and processing (range-compression and block-adaptive-quantization-BAQ) of the signals, before formatting and sending to Baseband Data Handling (BDH) of spacecraft.
vi. Payload Controller (PLC) is the heart of the SAR system, which generates all the timing signals and commands to all subsystems of SAR. It acts as interface between payload and spacecraft TC/TM system.

Both L & S-band SAR have been configured for Linear (Full) polarimetric and Circular-polarimetric modes of operation. With Full-polarimetric mode of operation, entire 4x4 Stokes' matrix may be derived, whereas with Circular-polarimetry only 4x1 Stokes' parameters may be derived.

The system has been configured for resolution options of 2m to 75m, selectable by means of ground-command for chirp-bandwidth selection, which varies from 75MHz to 2MHz, respectively. Available bandwidth options are 75, 50, 37.5, 25, 12.5, 7.5, 3 and 2 MHz based on which slant-range resolution will be determined.

Major Specifications of the system are given in Table-1 and Radiometric performance in terms of minimum Sigma-naught is given in Table-2.

Salient Features of SAR Development: Microstrip planar antenna of 1.35m x 1.1m dimensions has been designed for dual-band and dual-polarized configuration. The L-band and S-band patches are interleaved on different layers to meet the gain and bandwidth requirements, viz. BW of 75MHz for L-band and 180MHz for S-band (which takes care of the rover-TTC frequencies, as well. The antenna is being realized using light-weight Kevlar honeycomb substrate alongwith great deal of scooping to meet the mass constraints.

Table-1: Major System Specifications for Dual-Frequency SAR

	L-band	S-band
Altitude	200 Km nominal	
Frequency	1.25GHz	2.5GHz
SAR Modes	Circular-Pol, Full-Polarimetric, Single- and Dual-Pol Modes	
Range Swath	10 Km	
Range Coverage	30km - 125km	
Look Angle Coverage	8.5° - 31°	
Incidence Angle Coverage	9.5° - 35°	
Antenna	Dual polarized Microstrip Antenna (Integrated L-band and S-band)	
Antenna Dimensions	1.35 m x 1.1m	
BeamWidth	9.2° x 11.2°	4.6° x 5.6°
Antenna Peak Gain	22 dBi	25 dBi
Transmit pulse width	80 µs - 25µs (For Circular Polarimetric Mode) 50 µs - 25µs (For Full Polarimetric Mode)	
PRF	2600-3000 Hz (for Circular-Pol Mode) 5200-6000 Hz (for Full-Polarimetric Mode)	
SSPA Peak power output	50 W per Polarization channel	45 W per Polarization channel

	(47dBm)		(46.5dBm)	
Slant Range Resolution and Azimuth Resolution after multi-looking	2m	75m	2m	75m
Chirp Bandwidth	75MHz	2MHz	75 MHz	2MHz
Onboard Processing	Range Compression, BAQ			
Data window, after range compression	11-39 µs (nominal)			
BAQ Quantization	2 to 6 bits (I and Q) after range compression			
Data Rate	160Mbps (max) for all frequency and polarization combinations of operation			

Table-2: Min. Sigma Naught corresponding to 75m slant-range resolution

		Circular Polarimetric Mode		Full Polarimetric Mode	
	Off-Nadir(km)	Worst Sigma0 (dB)	Best sigma0 (dB)	Worst Sigma0 (dB)	Best sigma0 (dB)
L-Band	30 Km	-33.5	-35.0	-31.5	-33.0
	125 Km	-26.5	-27.0	-24.5	-25.0
S-Band	30 Km	-29.0	-31.1	-26.9	-29.0
	125 Km	-22.6	-23.3	-20.6	-21.4

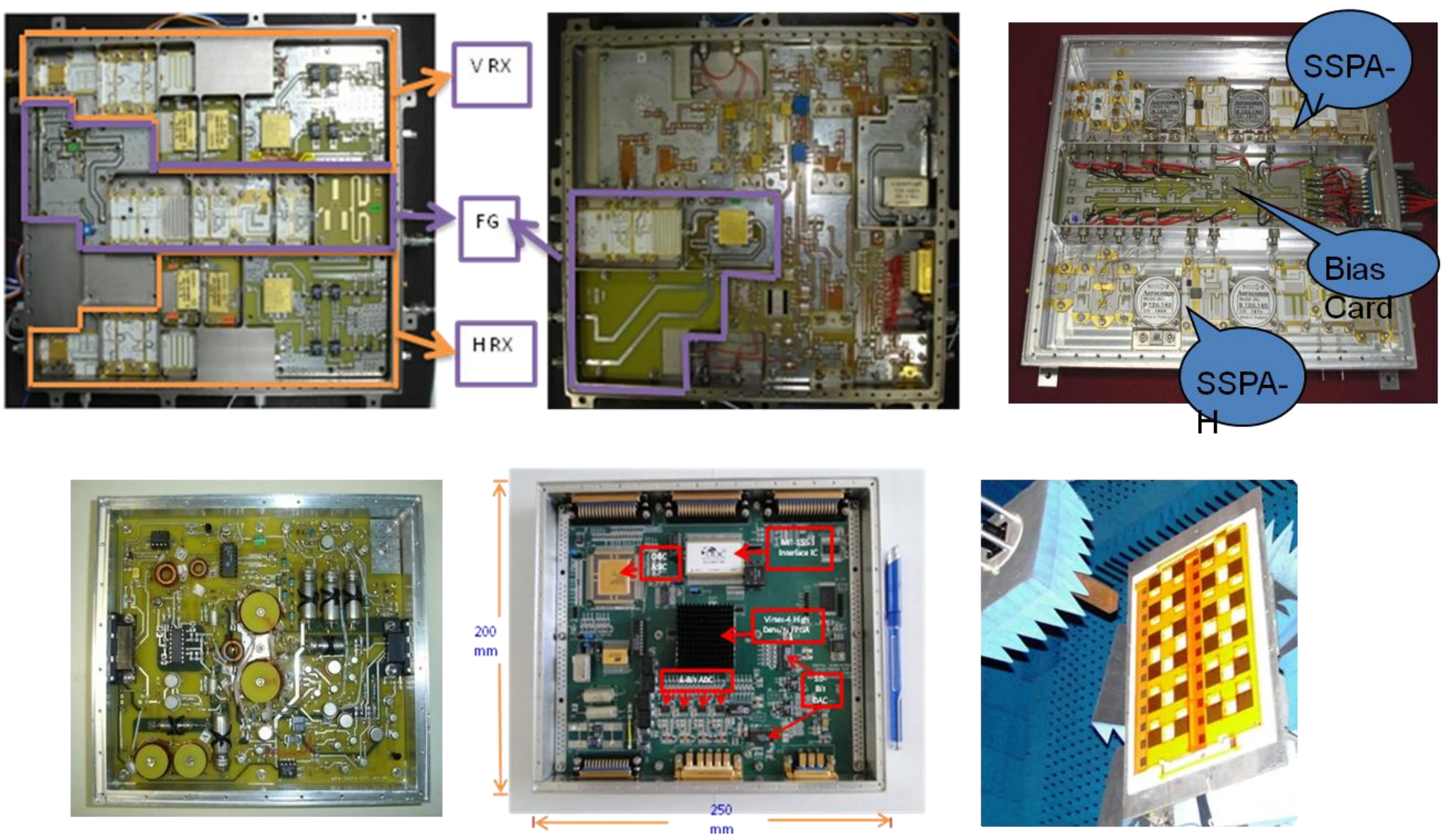

Fig.4(a): Integrated Receiver (V&H) and Frequency Generator for L-band SAR; Fig.4(b): L-band SSPA; Fig.4(c): EPC for L-band SSPA; Fig.4(d): Integrated Digital System; Fig.4(e): Half Antenna (L-and S-band) undergoing tests (In Clock-wise direction)

Transmitter package comprises SSPA(V) and SSPA(H) chains, alongwith its dedicated EPC.

The two chains of SSPAs have dedicated 6-bit phase-shifters to compensate for any undesired phaseimbalance between the two chains. Mechanism for phase-correction due to temperature variations has also been incorporated. For the SSPAa, Class-F design has been adopted using GaN devices in order to improve the efficiency of the transmitter to the order of ~45%. This is critical in view of the maximum raw power availability of 100W, even in the case of simultaneous L & S-band operation.

Two Receivers (V & H) and Frequency Generator have been configured in a single tray using MICs, MMICs and Multichip Modules to meet the miniaturization requirements. The low-noise, high gain receiver chains first take care of the pre-LNA filtering to provide appropriate rejection of the coupled signals from various sources. In particular, sharp-cut-off filters at S-band receiver input are required to provide necessary rejection due to the presence of close-by S-band TTC signals, though at the cost of some Noise-figure.

All the digital subsystems viz., Payload Controller, Digital Chirp Generator and Data Acquisition and Compression System have been configured on a single card, thereby miniaturizing the entire system. Chirp-generation from DCG is programmable based on ground-command selected options of bandwidth (2MHz – 75MHz) and pulsewidth(25µs - 80µs). Xilinx FPGA Virtex-4 based DACS implementation takes care of signal processing as well, which are mainly range-compression (using chirp-replicas from calibration mode) and BAQ (Block Adaptive Quantization) to reduce the data-rate. OBC ASIC-based PLC, in addition to generating the required control and timing signals, also provides synchronization signals required during L & S-band simultaneous mode of operation (In this case, L-band SAR PLC will act as a Master and S-band SAR PLC will be a Slave).

Both subsystems of integrated Receiver-FG and Digital subsystem have a common EPC, sandwiched between these two packages. Both SSPA-EPC and Rx/Digital EPC are pulsed power-supplies to add to the efficiency of the system.

Design Verification Models (DVM) of all subsystems of L-band SAR have been successfully realized and tested. Presently, integration and testing of the same is in progress. Full-antenna (DVM) is expected to be ready by Jan-end of 2012. Some of the realized subsystems are illustrated in Fig.4(a)-4(e).

All in all, each of the Dual-frequency SAR subsystem is representative of unique design and developmental effort which cohesively contributes to aspirations of the first Indian Planetary SAR in terms of performance and usefulness.

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- Editorial Team

Mars Specific

Detection of Methane in Atmosphere of Mars

R.P.Singh* and Rimjhim B. Singh, SAC , Ahmedabad

Introduction: Mankind in pursuit of its needs and quest develops technology to understand the fundamentals of origin and evolution of different geological/ biological systems. Space observations provide unique opportunities in these regards in terms of planetary exploration for understanding the earth like processes in other planets. Study of Mars draws immense attention due to its close proximity to earth. This in turn provides unique opportunity to study its mineralogical and atmospheric composition, weather circulations and its evolution processes.

Evidence from previous missions suggests that the Mars planet was once significantly more habitable than it is today, but it is still unclear whether living organisms ever existed. The existence of life and planet habitability has been the major focus areas of most of the missions. The past flow of liquid water, however, demonstrates the planet's potential for habitability. Recent Reports of methane on Mars have prompted speculations on microbial existence on Mars. Methane concentration of approximately 10 ppb (parts per billion) has been detected by three major group of scientist using Earth based telescopic analysis as well as space based observations from the Planetary Fourier Spectrometer (PFS) onboard Mars Express. Vittorio Formisano and team (Formisano et al. 2004) had detected methane using the PFS instrument. The same was confirmed by Vladimir Krasnopolsky of Catholic University, America through their measurements of 10 ppb of methane on Mars using the Fourier Transform Spectrometer on the Canada-France-Hawaii telescope on Mauna Kea, Hawaii (Krasnopolsky et al. 2004). Mumma et al. (2004) also reported detection of latitudinally varying methane on Mars using NASA's Infrared Telescope Facility (IRTF) on Mauna Kea and the Gemini South telescope in Chile. Additionally they reported enhanced water vapor in the same regions as the methane.

Sources and origin of methane is an important issue in the discovery of spatially varying methane concentration over Mars. Several observers have proposed various methane formation processes having non biological origin (volcanism, hydrothermal processes, water rock interaction as well as biological origin (due to methanogenesis). Yet the issue of methane origin and its sources on Mars remains mystery and needs further investigations.

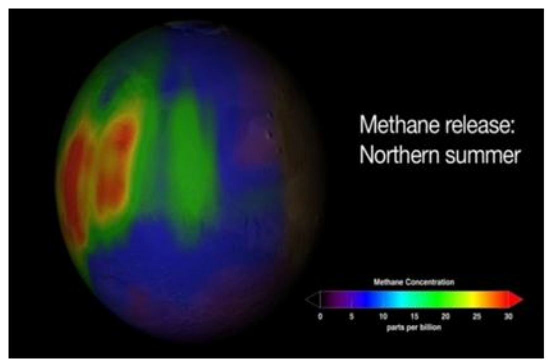

Fig. 1 . Major Spatial distribution of methane as per observations from Mumma et al. (2004).

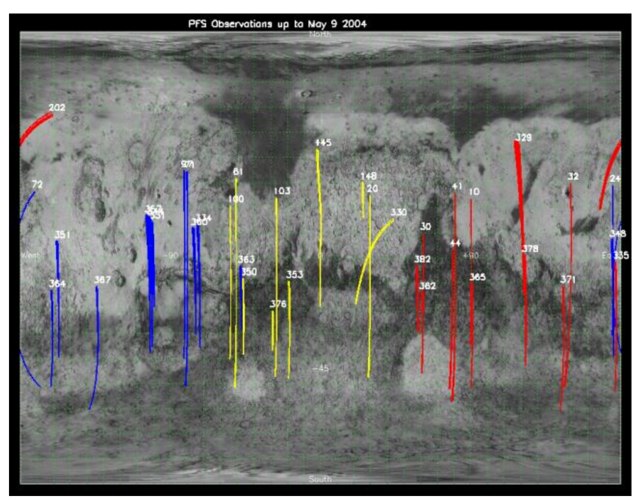

Fig 2. Methane observations from PFS orbit up to May 2004 where Red, yellow and blue orbits with decreasing amount of methane (Formisano et al. 2004).

Spectroscopy of Methane: Methane is a colourless gas and can't be seen by the naked eye. But like all molecules, methane absorbs specific wavelengths of sunlight as they are reflected off the planet's surface to produce a "signature" that can be measured with a spectrometer. A spectrometer is an instrument that separates light at different wavelengths into distinct signals, producing a spectrum. Molecular absorption spectra results from conversion of radiative energy to excitation of the molecules by rotational, vibration or electronic transitions. Absorption occurs when the spacing of available energy levels of the molecule matches with the incident radiation. Rotational energies of the molecule correspond to the far-infrared or microwave region while vibration energies manifest in NIR/SWIR or TIR region. Besides the strong absorption features of methane in the thermal infrared (Green house effect), it also absorb in NIR/SWIR spectral region. Methane molecule is tetrahedral in shape with spherical top molecule having four normal modes of vibration: a non degenerate symmetric stretching mode v_1= 2917 cm^{-1} , a doubly –degenerate bending mode v_2= 1534 cm^{-1} as well as stretching mode v_3= 3019 cm^{-1} and a bending mode v_4= 1306 cm^{-1} . PFS instrument based analysis of methane concentration was carried out near 3019 cm^{-1} wave number as shown in Fig- 3.

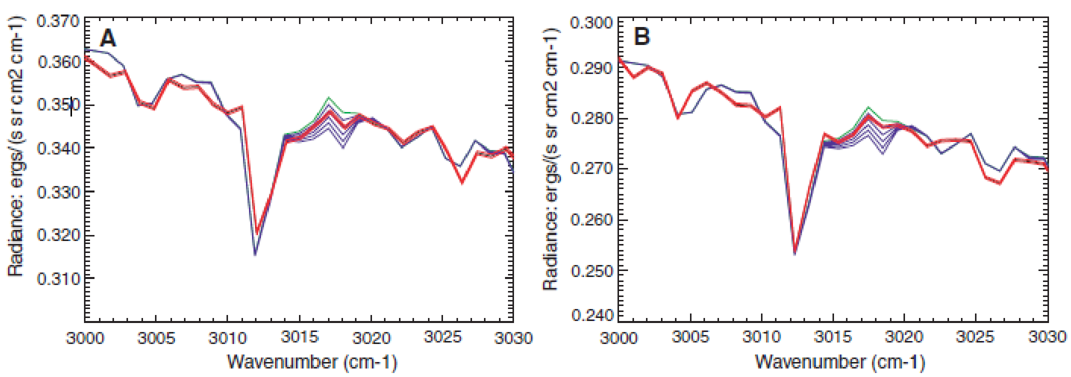

Fig. 3. The synthetic spectra (A) computed for different concentration of methane (10-50 ppbv) and (B) observed PFS mean spectrum analyzed by Formisano et al. (2004) to detect the methane concentration from Mars Express.

Theories of Origin of Methane

Origin of methane on Mars remains a puzzle, although there is considerable work on different theoretical arguments on methane sources of methane emission. Three major sources of methane (1) Biogenic (Microbacteria), (2) Abiogenic (Geological) and (3) Exogenic (Comet, meteorites) have been proposed in literature. Volcanism was earlier thought as possible source of methane in Mars but volcanic out gassing is weaker in mars than that of earth. The youngest lava flows which represent the last case of Martian volcanism are at least 10 million years old which is far greater than the methane lifetime and the released methane should be disappeared at that time. Potential methane production mechanism such as comets, meteorites and volcanic has been generally ruled out by various researchers.

Feasibility of biogenic origin of methane on Mars comes from the fact that 90-95 percent of 1775 ppbv of methane in Earth's atmosphere is directly or indirectly biological in nature. On the other hand, a fraction of the terrestrial methane originates from geological process (Abiotic) such as those found in deep sea "Black Smokers" and "Lost City" vents. The main abiotic process for the formation of methane on earth is hydrothermalism, which leads to the oxidoreduction (redox) reaction between iron-bearing primary silicates (Olivin and Pyroxene) and water to form hydrogen and FeIII-bearing phyllosilicates, a process called serpentinization. Hydrogen, a product of reaction, reacts with CO_2 to form CH_4 in hydrothermal system.

$6Fe_2SiO_4+7H_2O = 3Fe_3Si_2O_5(OH)_4+Fe_3O_4+H_2$

$4H_2+CO_2 = CH_4+2H_2O$

Once methane is formed it can be stored as clathrate in the subsurface and released to the surface via different mechanism.

Methane can also be generated from subsurface microorganism like methanogens in an icy environment (Biogenic source). Substrate provide energy and carbon including CO, CO_2 ,formate methanol and acetate to produce methane.

$CO_2+4H_2=CH_4+2H_2O$ (ΔG^0=-131k)

Bacteria are known to live in liquid veins at triple junctions of grains in polycrystalline ice, where they can extract energy and essential elements from ions in the veins. They are also known to be able to live on mineral grains coated with unfrozen water layers. Montmorillonite, abundance on Mars is favoured as a habitat because it is source of micronutrients and its surface retains sub –nm coating of H_2O that remain unfrozen down to the coldest Martian temperatures. Neither the existing observations nor any modelling studies have satisfactorily addressed the question of sources (origin) of methane on Mars. New information especially on the carbon and other stable gas isotopes at high precision as well as maps of localized sources of methane vents along with mineralogical and environmental data are required to confirm the models.

Future Missions: Major space agencies such as NASA, ESA and ISRO have plans to investigate the sources of methane emission on Mars. Recently launched Science Laboratory rover of NASA (Curiosity) carries suite of instruments such as Sample Analysis at Mars (SAM) which will analyze organics and gases from both atmospheric and solid samples using Quadrupole Mass Spectrometer (QMS), Gas Chromatograph (GC) and Tunable Laser Spectrometer (TLS). QMS will detect gases sampled from the atmosphere or those released from solid samples by heating. TLS will perform precision measurements of oxygen and carbon *isotope* ratios in carbon dioxide (CO_2) and methane (CH_4) in the atmosphere of Mars in order to distinguish between a geochemical and a biological origin . Joint ESA-NASA initiative of Mars Trace Gas Mission (TGM) orbiter to be launched in 2016 will focus on sensitive detection of a suite of trace gases in the Mars atmosphere to better understand the nature of the exchange of trace gases between solid planet and the atmosphere

Reference

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Hydrous Sulfates (Jarosite) on Earth and Mars: Implication for aqueous processes on Mars

Nirmala Jain and Prakash Chauhan, SAC , Ahmedabad

Introduction: Mars may have been, in some ways, similar to the Earth, and this is very interesting to scientists. Even more significant is the possibility that Mars may have had (and might still have) life. Wherever we find water on Earth, we find life! Could the same be true for Mars? Data from the Mars Exploration Rovers and orbiters, such as Mars Odyssey and Mars Global Surveyor, have confirmed evidence of liquid water in its past. Today, the environment on the surface of Mars is harsh and hostile. The atmosphere is very thin, about 1/100th the air pressure on Earth. The surface (including any possible life) is exposed to extreme ultraviolet and space radiation. If liquid water exists, it is may be sparse and seasonal.

Minerals are not only indicators of the physical and chemical settings of the different environments, but they could also play a crucial role for astrobiological study with the possibility of existence of extinct Martian life. Jarosite is the mineral which acts as an important indicator of aqueous and biological processes on Earth and Mars. Water activities may have provided habitable conditions and energy for microbial life on mars. Jarosite is a prime mineral candidate for harboring organic compounds. On Earth, jarosite has been found to form during the oxidation of sulfide minerals and during alteration of volcanic rocks by acidic, sulfur-rich fluids near volcanic vents. Thus jarosite formation requires a wet, oxidizing and acidic environment. Since the discovery of hydrous sulfate (jarosite) minerals on Mars, interest has focused on linking the origin and characteristics of the mineral group to the existence of extinct life on Mars. It is therefore possible that biological fingerprints left over from jarosite formation can be used to identify information about life in the geologic record of Earth and Mars.

Jarosite Discovered on Mars: The Mars rover, Opportunity and OMEGA/Mars Express Data, MRO CRISM hyperspectral imager showed that some rocks contain the mineral jarosite, which is also found here on Earth. This potassium and iron hydrous sulfate and phyllosilicate deposits were discovered previously in most of the places on Mars like, at Mawrth Valli in the northern hemisphere of the Mars and at Endeavour Crater, Meridiani Planum, Candor Chasma in Valles Marineris (Figure 1). Figure 2 shows CRISM-MRO image which has been processed and analysed. The spectral signature indicates the presence of hydrous sulfate (jarosite) and phyllosilicates (clay) in Mawrth valli on Mars.

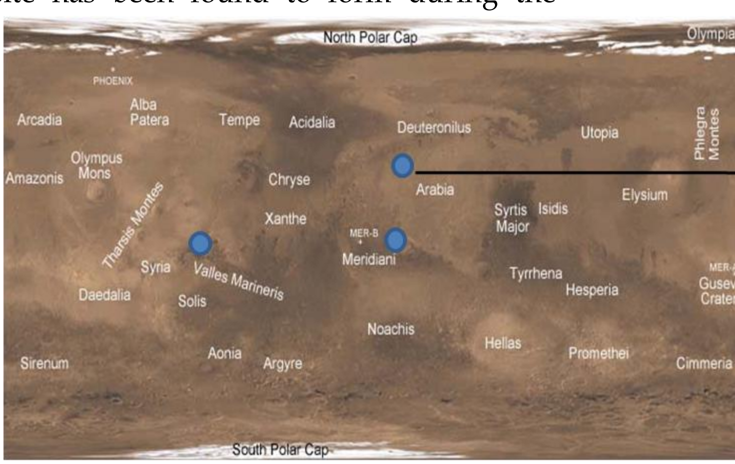

Figure 1: Map of Mars indicating locations of hydrous sulfate (Jarosite)

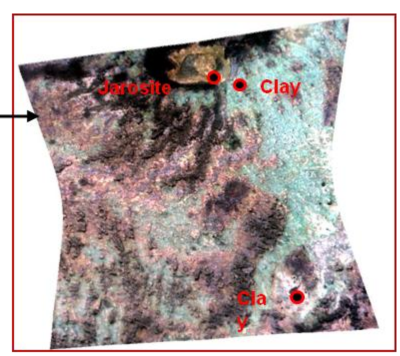

Figure 2: Mawrth Valli on Mars.

Figure 3: Field photo at Martian analogue site at Matanumadh area at Kutch, Gujarat, India.

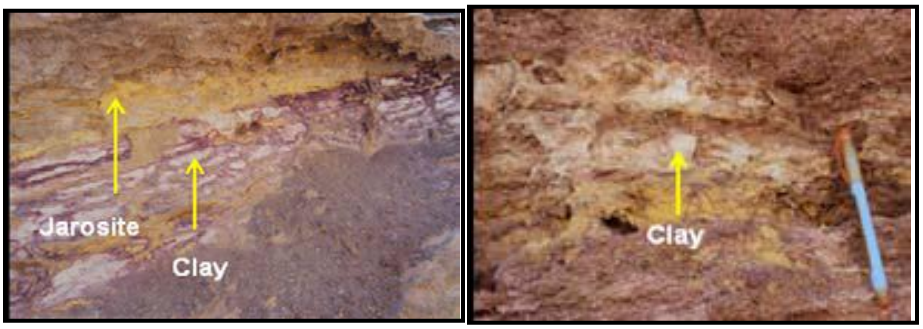

Figure 4: The photo shows the presence of hydrous sulfates (jarosite) and phyllosilicats (clays) study area; Figure 5: The photo shows the sample of hydrous sulfate (jarosite) minerals.

What's so interesting about jarosite and clays? Scientists have concluded that these can only form in the presence of water. Therefore the study of hydrous sulfate and clay deposits can lead in interpreting the environmental conditions on the early Mars. University of Syracuse mineralogists, led by Suzanne Baldwin and Joseph Kula, have been able to determine the age of jarosite here on Earth and the surface conditions under which they were formed. They have established the "diffusion parameters" for argon in jarosite. It means they have discovered a way to use the noble gas argon, which accumulates in jarosite over time, to determine the age of the mineral and the surface conditions under which it formed. According to them " jarosite is a good marker for measuring the amount of time in which water was present on Mars".

Jarosite Discovered on Earth: Scientists world over are busy at work studying features of Mars on Earth. There are places on our planet that can serve as test beds for scientific investigations of Mars. For example, ice covered lake in Antarctica, North Pole dome in Pilbara, Australia, deserts in Australia, impact structures in Canada are few of the many places where scientists are researching in order to understand the geological processes on the Mars. Earth can provide an excellent analogue environment, because it gives the information about the geological processes could have occurred on the Mars in its past.

In India it occurs in Deccan Volcanic Province (DVP) of Matanumadh, Kutch, India, by means of remote sensing techniques and geochemical analyses of field samples. Study of the reflectance spectra of these Martian analogues help in understanding the environmental condition and formation processes of these minerals on Mars. The study of Deccan Volcanic Province (DVP) of Kutch abundant in hydrous sulphate deposits helps in understanding the aqueous alteration processes and fluid-rock interactions associated with gigantic volcanic activities such as the Deccan volcanism. Figure 3 may be considered as a potential Martian analogue site for the study of hydrous sulphates (jarosite-$K_2Fe_3(SO_4)_2(OH)_6$) and phyllosilicates (clay) (Figure 4) in Kutch, India. Here, they have been formed due to the hydrothermal activities associated with Deccan volcanism and hydrous sulphates (natro-jarosite and natro-alunite) may also formed by the process of oxidation of iron sulphide (pyrite-Eocene sediments) which indicate extreme conditions of low pH.

These minerals form commonly when hydrothermal solutions pass through rock bodies that contain pyrite which may then alter to Jarosite or to Limonite (gossan). A similar explanation has been given for the presence of Jarosite at the Opportunity landing site the Meridiani Planum of Mars. These sulfate layers in a study area are white to yellow in colour, up to 1 m thick, and extend laterally for over a kilometer on both sides of Matanumadh area on Lakhpat road, Kutch, Gujarat.

Phyllosilicates (clays) are also found in this study area. These are formed by chemical weathering of rocks by surface or subsurface water on Earth and on Mars. They may have also been formed by alteration of volcanic ash, on Mars. All these processes require water for the formation of these minerals which indicates the water must be present on Mars in its past.

Reflectance spectroscopy has been extensively used as a tool for remote compositional assessment of planetary bodies including the Mars. Spectroscopic and geochemical (e.g., XRD, XRF and SEM) techniques are useful for the study of spectral and geochemical signatures of Martian analogues from the Deccan Volcanic Province of Kutch for characterizing the rocks and minerals. They are also useful to understand their formation processes which can further be linked with the presence of similar kinds of minerals and rocks on Mars. These analogues share certain characteristics similar to environments on Mars. The development of life requires water. To know when and for how long water was present on the Martian surface has implications for the search for life. Jarosite requires water for its formation. Therefore studying jarosite may help answer some of these questions. Bacteria can inhabit practically anywhere and everywhere and a lot of analogue research is going on to understand the environments that bacteria live in.

Clays form from the interaction of water with rock. Different types of clay minerals result from different types of wet conditions. These minerals that contain the same chemical elements as those found in the original volcanic rocks later altered by the water. Clay minerals by OMEGA and NASA's Compact Reconnaissance Imaging Spectrometer (CRISM), instrument on the Mars Reconnaissance Orbiter are giving us the information about presence of these minerals at many locations on Mars.

Conclusions: In future, scientists will be able to study rock and soil samples obtained directly from Mars. Until such a mission is launched and successfully returns back to Earth, analogue studies play an important role to understand Mars. Jarosite from the Earth helps in finding the traces of life on Mars. They offer proof of the presence and action of water at times in the Martian past. But the pH and salinity conditions under which they form are generally too harsh for growing of life. However, on Earth extremophile organisms have been able to exist under similar conditions. It gives the idea about that there was a comparable conditions on Mars for life to start. Evidence of such conditions still is lacking. Discovery of Clay minerals on Mars indicates the planet once hosted warm, wet conditions. If those conditions existed on the surface for a long era, the planet would have needed a much thicker atmosphere than it has now to keep the water from evaporating or freezing. Study of jarosite on Earth as a marker of life on Mars may provide the information of the Red Planet's environmental history. Whether the Jarosite discoveries prove to be an evidence of the possibility of life on Mars remains an open question.

Sun Specific

Remote Sensing of the Sun

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Introduction: One of the major goals of space physics and astrophysics is to understanding the process of particle acceleration and impulsive energy release that occur in active cosmic plasmas at diverse sites throughout the universe, ranging from the planetary magnetosphere to active galactic nuclei. The sun constitutes an unparalleled laboratory for investigating these processes. Its proximity allows the measurement over the entire electromagnetic spectrum to be made on physically relevant scales. At the same time, the system as a whole can be studied, and escaping energetic particles and plasma can be sampled directly. Further the complexity of solar magnetic fields and the solar atmosphere leads to broad range of acceleration phenomena.

The Sun is the most powerful particle accelerator in the solar system, accelerating ions up to tens of GeV and electrons to hundreds of MeV in solar flares and coronal mass ejections (CMEs). Solar flares are the most powerful explosions, releasing up to 10^{32} - 10^{33} ergs in 10^{2}- 10^{3} s. The flare-accelerated ~ 10-100 keV electrons appear to contain a significant fraction ~ 10-50% of this energy, indicating that the particle acceleration and energy release processes are intimately linked. How the Sun releases this energy, presumably stored in the magnetic fields of the corona, and how it rapidly accelerates electrons and ions with such high efficiency, and to such high energies, is presently unknown. In order to address these questions remote sensing of the sun in general and of the dynamic corona in particular is essential, which, however, has been a continuous effort over the globe since 1970s by various countries. The space missions before 2000 *viz.* Skylab, SMM, Yohkoh, SOHO, Ulysses, WIND, ACE, made a remarkable observations over the electromagnetic spectrum and contributed significantly in understanding the various phases and facets of the solar activity. In last decade space missions with better remote sensing techniques and particularly to address the above specific questions have been launched. Among these missions RHESSI, STEREO and SDO from USA, SOXS from India and Hinode from Japan are of specific importance. These missions aim to address such questions. The primary scientific objective of "Solar X-ray Spectrometer (SOXS)" (Jain et al., 2000, 2002, 2005, 2006) and RHESSI (Lin et al., 2002) is to understand the most outstanding question of particle acceleration and explosive energy release in the magnetized plasmas at the Sun, which, however, requires remote sensing of the solar corona with superb spatial, spectral and temporal resolution.

A solar flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released. This energy builds up relatively gradually as the result of deep-seated convective motions that deliver magnetic stress into the corona in the form of non-potential magnetic fields; the twist representing this non-potentiality may reside in an emerging flux system (Jain, 2009). Radio observations from the 1950s, and then X-ray and γ-ray observations from space from the 1970s, revealed that solar flares begin with high-energy processes. The key elements that make the solar X-ray corona very dynamic are accelerated particles, the "evaporation" of large masses of high-pressure plasma into coronal magnetic loops, and magnetic eruptions as frequently observed in a variety of wavelengths. The powerful energy commonly associated with solar flares can take as long as several days to build up, but only minutes to release. Shown in **Figure 1** is evolution of a large X1.0 solar flare in soft and hard X-ray waveband as seen by SOXS detectors on 17 September 2005 (top panel). The flare was observed in H-alpha waveband (middle panel) at National Astronomical Observatory of Japan, revealing multi-ribbon structure. The flare was also seen in very high energy up to 300 keV (bottom panel by RHESSI.

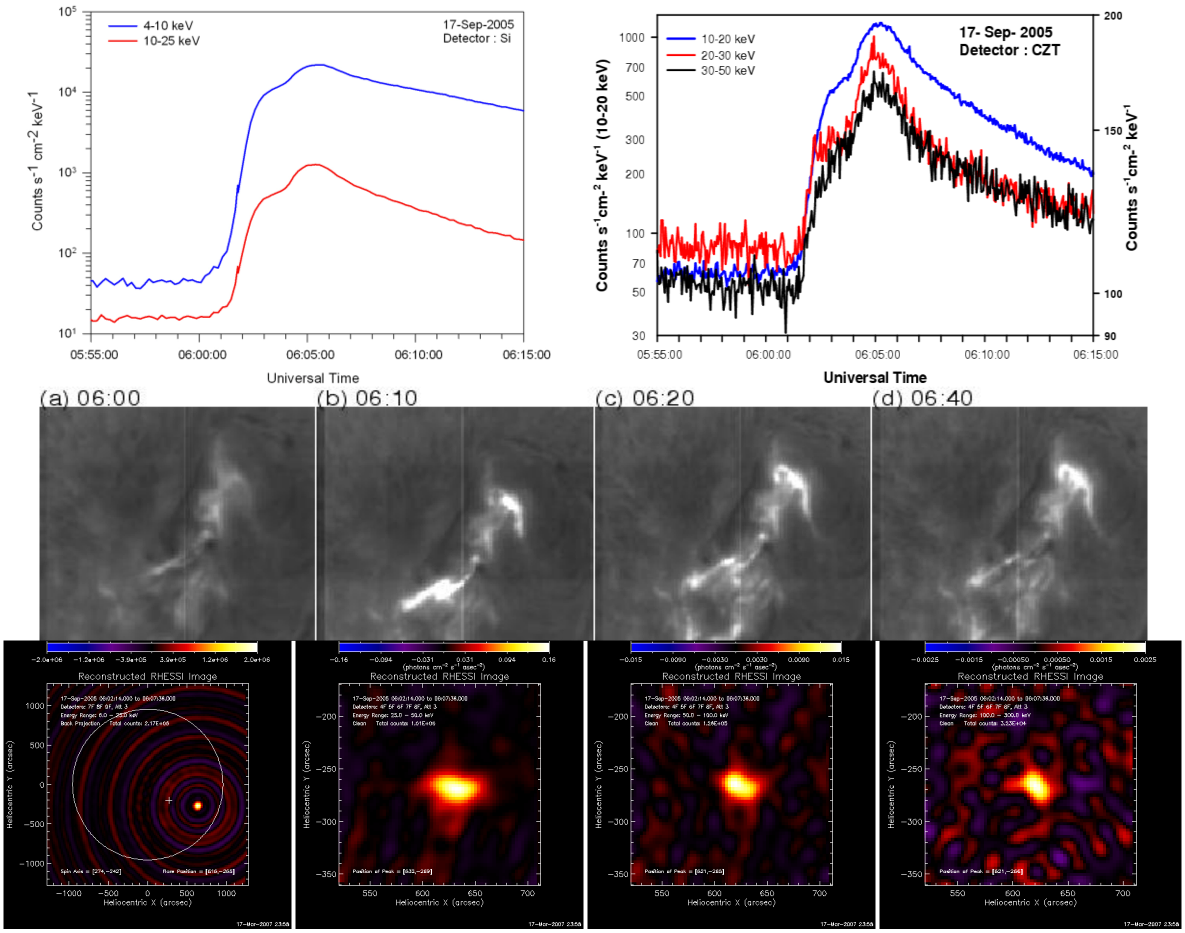

Figure 1: Top: Evolution of large X1.0 extended flare observed on 17 September 2005 by Si and CZT detectors of Solar X-ray Spectrometer (SOXS) mission onboard GSAT-2 Indian spacecraft. The flare was continuing until the instrument was turned off at 06:20 UT. Middle: Sequence of Hα filtergrams of the same flare taken at National Astronomical Observatory of Japan (NAOJ), Mitaka, Japan (Courtesy of Dr. Y. Hanaoka). The flare shows multi-ribbon structure and bright post flare loops starting from 06:20 UT. Bottom: X-ray images of the flare obtained by RHESSI mission, starting from left to right in 6-25, 25-50, 50-100 and 100-300 keV energy bands respectively.

Solar X-ray Spectrometer (SOXS): The first space-borne solar astronomy experiment of India namely "Solar X-ray Spectrometer (SOXS)" was successfully launched by GSLV-D2 rocket on 08 May 2003 onboard geostationary satellite (GSAT-2) of India. The SOXS is composed of two independent payloads *viz.* SOXS Low Energy Detector (SLD) Payload and SOXS High Energy Detector (SHD) Payload. In this article I consider the instrumentation of the SLD/SOXS payload and its in-orbit performance. The SLD payload was designed and developed at the Physical Research Laboratory in collaboration with various centers of Indian Space Research Organization (ISRO). The detector package is mounted on a Sun Aspect System as shown in **Figure 2.** The basic scientific aim of the SLD payload is to observe the solar explosions in in 4-56 keV energy band with high spectral and temporal resolution. To meet these requirements, the SLD payload employs state-of-the-art solid state detectors *viz.* Si PIN (4 - 25 keV), and Cadmium-Zinc-Telluride (4 - 56 keV). The Si detector provides superb high-energy resolution of ~ 0.7 keV, and this feature enabled to remote sensing the flare plasma corona, which revealed, for the first time, iron and iron-nickel complex line features distinctly in the solar flares (Jain et al., 2005, 2006) as shown in **Figure 3**. The details of the instrument and data set can be found at following URL.

http://www.prl.res.in/~soxs-data/. The SOXS worked satisfactorily for almost 8 years (2003-2011) and observed more than 500 flares.

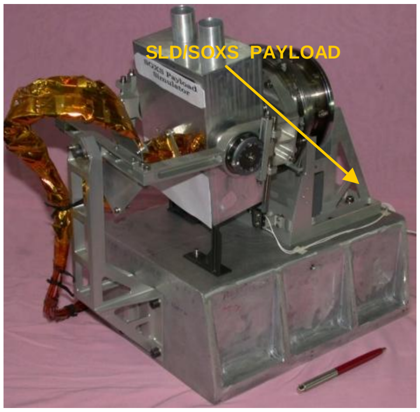

Figure 2: The detector package (see text) mounted on the SOXS Sun Tracking Mechanism (SSTM). The collimators are seen projecting outside. The FOV is 3.4°. The detector package moves in the line-of-sight of the Sun within an accuracy of about 0.1°. The SSTM has only one drive motor for correction in right ascension and declination. The size of the payload relative to pen may be noted.

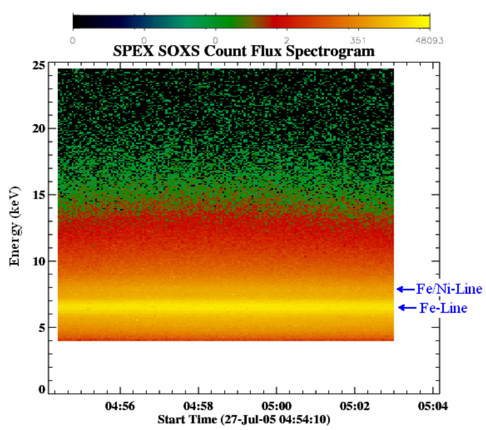

Figure 3: Remote sensing the solar corona by Si detector onboard the SOXS mission. The spectrogram image of the Fe and Fe/ Ni line features made during the flare observed on 27 July 2005.

Remote Sensing the Particle Acceleration and High-temperature Plasma in Solar Flares: SOXS also revealed unambiguously the multi-thermal plasma characteristics during flare evolution in contrast to the concept of isothermal plasma. The high-resolution spectra of solar flares observed by Si and CZT detectors are found to be better fitted with multi-thermal power-law function up to 15 keV and additional broken power-law function until 30 keV. This suggests that the plasma is heated at different temperatures (multi-thermal plasma) over space and time, and therefore the emission measure varies as the function of the temperature (Aschwanden, 2007, 2008, Jain et al., 2008, 2011). This also suggests that flare temporal evolution should be energy-dependent as observed and presented in **Figure 4**. However, there are strong indications that, in many flares the non-thermal component contains a substantial fraction of the total energy (Jain et al., 2000, 2005; Gan et al., 2001; Lin, 2002). The flare-accelerated ~ 10-100 keV electrons appear to contain a significant fraction ~ 10-50% of total energy, indicating that the particle acceleration and energy release processes are intimately linked.

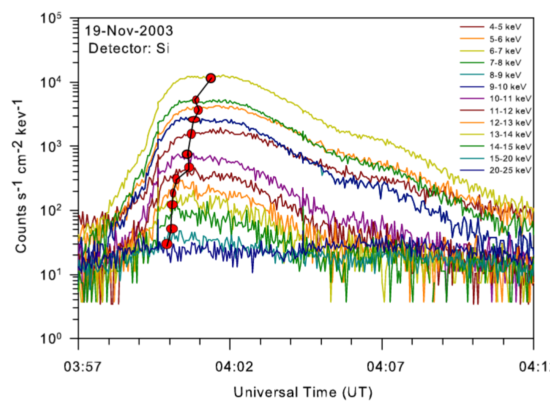

Figure 4: Temporal profiles in 13 energy bands (□ = 4 5, 5-6 …14-15, 15-20 and 20-25 keV) of the November 19, 2003 flare. Each peak time is shown by circle. The curve connecting these circles illustrates the delay in peak time between successive profiles.

The hard X-ray (□ 20 keV) bursts emitted by accelerated electrons colliding with the ambient solar atmosphere are the most common signature of the impulsive phase of solar flare. Provided the electron energy E_e is much greater than the average thermal energy, *kT*, of the ambient gas, essentially all of the electron energy will be lost to Coulomb collisions (Jain et al., 2000). Therefore, the non-thermal hard X-ray fluxes observed in many flares indicates that the energy in accelerated > 20 keV electrons must be comparable to the total flare radiative and mechanical output (Lin and Hudson, 1976). Thus, the acceleration of electrons to tens of keV may be the most direct consequence of the basic flare-energy release process. High-resolution remote sensing of the flare plasma through spectroscopy is the key to understanding the electron acceleration and energy release processes in solar flares. Therefore the precise measurement of low-energy cut-off of non-thermal electron beam is an important quantity: not only is it related to the acceleration mechanism, but it also determines the total number of accelerated electrons and the energy they carry (Gan et al., 2001). Usually low-energy cut-off is assumed to be 20 or 25 keV, which constitutes a main ingredient of the so called standard picture of solar flares. However, the variation in the low-energy cut-off indicates that higher a low-energy cut-off means that the total energy carried by non-thermal electrons is much less than that required to explaining the flare energy budget. But the great decrease of the total number of accelerated electrons seems to explain the number of problems in the standard flare scenario. Thus it would be proper that further studies based on observation with high energy resolution are carried out (Gan et al., 2001). The low energy cut-off of the non-thermal hard X-ray emission commonly taken to be 20 to 30 keV is in fact not known due to the presence of thermal emission, which in extreme cases can extend to energies >30 keV. In order to estimate the break-energy (E_B) between thermal and non-thermal energy release in a solar flare we find that the peak of the observed flare in lower energy band gets delayed from the 24-25 keV Gaussian time profile. However, the delay □ t (*cf.* **Figure 4)** beyond certain energy (break-energy) in the asymptotic limit of cooling time saturates for a given flare event suggesting that the X-ray emission beyond this energy is of non-thermal nature. This break-energy (E_B) point is measured within energy resolution limits of the Si detector (0.7 keV) and found to vary between 17 and 22±0.7 keV (Jain et al., 2011)**.** Previously, Gan et al., (2001) found between 47 and 145 keV, which, however, appears to be much greater then usually accepted 20 keV.

Conclusion: In order to understand the energy build up and sudden release in the solar explosions like flares and CMEs remote sensing of the Solar atmosphere as a function of the altitude is necessary and particularly of the chromosphere and corona. The advance remote sensing technology with the state-of-the-art detectors to imaging the high resolution solar structures as well as the atmosphere and surface of the other astronomical objects in extreme ultraviolet and X-ray may breakthrough to reveal the secrets of the celestial objects.

Acknowledgments: The author expresses sincere thanks to Physical Research Laboratory and Indian Space Research Organization for providing magnificent opportunity to solar physics community to study the space plasma processes taking place on the Sun, a great cosmic laboratory nearest to Earth.

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Exploring Our Nearest Star: The Sun

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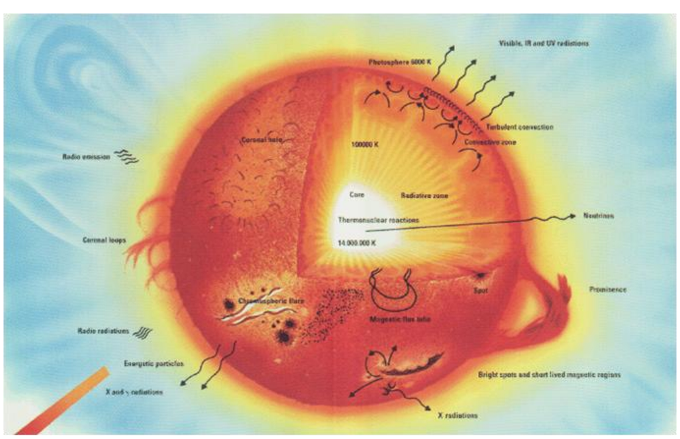
Among the billions of stars in the universe the Sun is moderately sized star, yet it is very near to the planet Earth. The sun provides light and warmth that sustains the life on the planet Earth. The sun governing the seasons, the harvests and even the sleeping pattern's of the creature populating the planet Earth. Being moderate in size, 110 Earth can be accommodated side-by-side across the face of the Sun. Though it is close to the Earth, 100 suns' can be put one next to each other between the Sun and our planet. In one second the light travels 0.3 million km. Being this is the fastest in the universe the light takes about 8 minutes to reach the Earth. So, if you can invent a vehicle that moves at the speed of light then you can reach the Sun only after 8 minutes. Then can you guess how many years it would take if one launches a rocket to reach the Sun ?

Like Earth, the Sun has several different layers. But unlike the Earth, the Sun is completely made up of plasma, a fourth state of matter. Though it is made out of plasma, the temperature, density and pressure changes abruptly in different layers of the Sun. In the core of the Sun's the density is as high as 150 grams per cubic centimeter. On the other hand in the solar corona the density drops to 10^{-15} grams per cubic centimeter. It is close to the vacuum densities in any laboratory on the Earth.



The structure of the Sun with different layers. Courtesy: Calvin J. Hamilton

Broadly, the Sun's layer can be divided into three regions. Those are the solar interior, the surface and the atmosphere. The interior has 3 levels, core, radiative zone and convective zone. The solar interior can't be observed with conventional means. The photosphere is called the surface of the Sun. The solar atmosphere mainly divided into three layers based on the temperature, density and pressure. Those are the solar chromosphere, transition region and corona. The solar atmosphere can be observed from radio frequency to X-ray wavelength regions.

Solar Interior

Core: The Sun's core is made up of ionized particles in which the electrons and protons are wondering at high speeds. The temperature of the core region is about 15 million degree Kelvin. The core of the Sun is responsible for its energy and luminosity. One half of the solar mass is concentrated in core which is just one fourth of the solar radius. The Sun's 99% of the energy is generated here through nuclear fusion reaction. In this process four hydrogen nuclei combine together and form a helium nuclei and in that process it releases enormous amount of energy. The nuclear furnace swallow up 5 million tons of hydrogen every second to generate 4×10^{23} kW of power. Though the sun is burning a large amount of mass but still the Sun can survive another 5 billion years !!

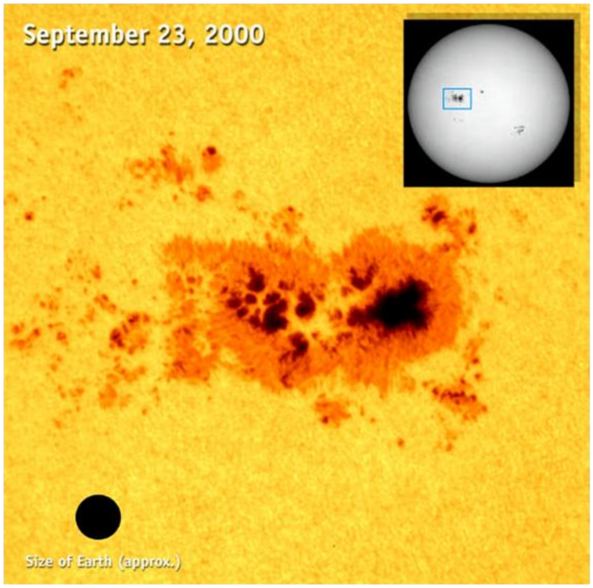
Radiative Zone: The energy generated in the core of the Sun reach the other outer layers of the Sun through radiation zone. There are at least three ways the energy can be transported from one place to the other. A star like the Sun always transport the energy from the inner core to the outer layers through radiation. The temperature in the radiative zone is little less than the core, it is about 5 million degree

Kelvin. The generated energy is transferred by its interaction with the surrounding atoms. The atoms will absorb the radiation, hold it for millionth of a second and then it re emits with different energy and also in different directions. Once again it is absorbed by another atom/ion which is sitting very close to it. The process once again repeats itself. In this way the photons take about 200 thousand years to leave the radiative zone which is about half of the sun radius. In other words the radiation received from the Sun today was generated 200 thousand years ago !!

Convective Zone: Just after three fourth of the radius of the sun the energy is transported to the surface of the Sun through another mechanism. This other way of transporting the energy is required because once the energy crosses the radiative zone its temperature reduces and is about 2 million degree Kelvin. At this temperature the atoms absorbs energy and these densely packed atoms do not release them easily. Consequently, the energy transport by the radiative mechanism slows down. Now the Sun requires another way of transporting the energy to the surface. At this stage the most efficient way of transporting the energy is by convection. In this mechanism the hotter material at the top of the radiative zone rises up and the cooler material from the surface of the Sun sinks down. As the hot material rises up to the surface it transport the energy, cools down and sinks. While sinking again it heats up again and raise. This sets a rolling motion of material just like a boiling water in the vessel. In this way the Sun transport the energy much faster to the surface and more efficiently than the radiation. The convective motion takes a little more than a week to transport the energy to the top of the surface.

Solar Surface

Photosphere: The photosphere is called as the surface of the Sun. The photosphere is the layer you see in the sky when you look at the Sun through a filtered telescope or as a projection on a wall/piece of paper. You should never look at the Sun directly, it can cause damage to your eye.



A full Sun image showing the photosphere. A magnified view of the sunspot is shown. A typical size of the Earth is also shown for comparison.

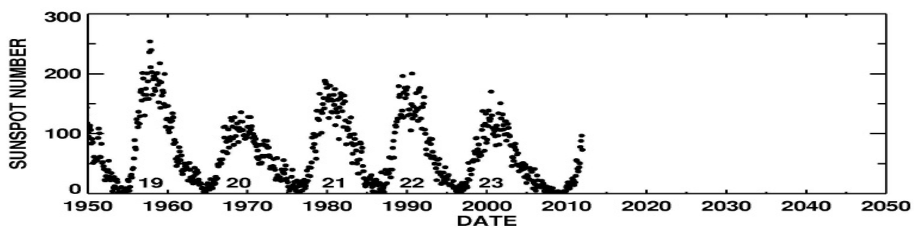
When you project the image on the wall you can see the photosphere and occasionally you will be able to see convective bubbles. These convective bubbles are the patterns of moving hot and cool gases and is called granulation. The pattern can be seen as small pebble like structure in the solar image. The photosphere is cooler than any surface on the Sun. Its temperature is about 6000 degree Kelvin. Once again the energy is transported from the photosphere is by means of radiation. In fact, most of the light that we receive from the Sun on earth is the energy that was released by atoms in the photosphere.

Sunspot: When you look through a filtered telescope sometimes you may see dark spots on the surface of the Sun. Some of the spots are much bigger than the planet Earth. The spots appear dark because they are cooler than the surrounding. A typical sunspot has a temperature of about 4000 degree Kelvin. The sunspots are structured. The inner part of the sunspot is very dark and that region is called umbra. The umbra is surrounded by less dark region called penumbra. The penumbra appears as filamentary type of structure. All the sunspot has magnetic fields and its strength is larger than a small bar magnet.

The sunspot lifetime is ranging from a few hours to several months. The number sunspot seen on the Solar surface follows a regular pattern. They tend to appear large in number on every 11 years, called solar cycle.

Solar Atmosphere

Chromosphere: Above the photosphere there is a thick shell of about 2000 km called chromosphere or sphere of color. In the chromosphere the temperature raises from 6000 degree Kelvin to 20000 degree Kelvin. At this temperature the hydrogen atoms emits light in red color. This color can be seen in prominences that project above the limb of the Sun and are observed easily during the total solar eclipses. In the chromosphere, the hydrogen atoms absorb energy from the photosphere and then emits in red color. Chromosphere accommodates many large scale magnetic features such as plages, filaments spicules etc and most of them are located close to the sunspots.



Sunspot cycle from 1950 to 2010. Courtsey: David Hathaway, NASA/MSFC

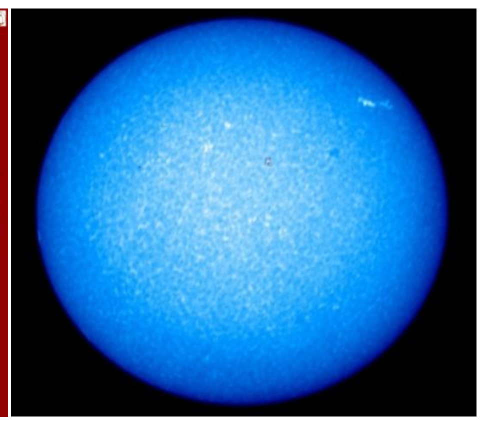



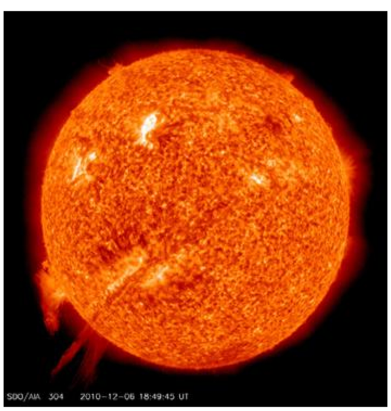
Fig- The image of solar chromosphere as seen in red color of hydrogen absorption line. Black colored regions are solar filaments and white colored regions are plages. Courtsey: BigBear Solar Observatory.

Fig- The image of solar chromosphere as seen in blue color of singly ionized calcium absorption line. Courtsey: Kodaikanal Solar Observatory.

Other than the hydrogen the chromosphere can also be observed in the blue color of singly ionized calcium absorption line. Unlike the image taken in red color of hydrogen, in calcium different structures are seen. On first sight it is easily seen the white colored regions called plages. These regions are brighter than surrounding areas. These regions are the remnants of the sunspots. Other than this there is another type of structure called supergranulation. These structures are about 30000 km in size. Like granulations in the photosphere the supergranulatons are considered as the convective patterns and they originate deep in the convection zone. The borders of these supergranulations appear bright and have intense magnetic field strength of about kilo Gauss. The supegranulation structures are also called as chromospheric network.

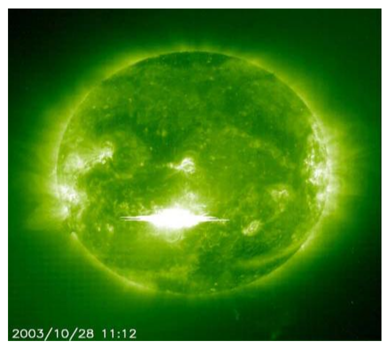
The main solar activity starts in the solar chromosphere. The filament eruptions are observed in the chromosphere. The most powerful event called solar flares are also observed in the chromosphere, though its origin could be in another layer of the solar atmosphere called corona. There are other huge structures called solar spicules observed in the boundary regions of the chromospheric network and is believed to carry a huge mass and energy into the corona at a speed of 100 km/sec.

Transition Region: Above the chromosphere there is a very thin layer of about 100 km thick over which the temperature increases dramatically from 20,000 degrees Kelvin to over 2 million degrees Kelvin in the corona. This region is called the transition region. Most of the elements including hydrogen is ionized at this temperature. This region can be observed in ultraviolet wavelength spectrum and can be seen only from space, since the Earth's atmosphere absorbs most of the ultraviolet radiation emitted by the Sun. Like in chromosphere, in the transition region one can see similar structures. The helium atoms, the second most abundant elements in the Sun starts emitting at transition region temperature. Scientists still do not understand why the temperature in the transition region increases so much as this layer is very far away from the high temperature Sun's core. It is suspected that the complicated structure of the Sun's magnetic field playing a vital role in increase in temperature of this small layer.



The image of solar transition region taken in ultra violet wavelength emitted by ionized helium. Courtesy: SDO/AIA

Solar Flares: A sudden brightening on the solar surface in the vicinity of sunspots are called solar flares. The flares are so powerful that in a matter of a few minutes it heats up the surrounding regions to million degree Kelvin. The energy released in this processes is equivalent to million megatons of hydrogen bomb exploding at the same time. The radiation is emitted across all the wavelength regimes, from Radio to X-ray wavelengths. On many occasions the solar flares are accompanied by the expulsion of huge cloud of hot plasma, called coronal mass ejection (CME). The CMEs are expelled from the Sun at a speed of about 1000 kilometer per second in to the interplanetary media. The CMEs affect the space weather and space climate. The energetic particles from CMEs can damage the satellites, communication systems and power grids. These particles are very hazardous to astronauts and high altitude moving planes.



The solar corona observed in the extreme ultra violet wavelength of ionized iron. The bright white patch seen a little below the center of the solar disk is the large flare that occurred on 28th of October 2003 at 11:12 UT. Courtesy: SOHO/EIT

Scientists are viewing the Sun with several different instruments, each tuned to a particular wavelength of the Sun's energy. Researchers are still using their different instrument along with large telescopes to help look for answers to the many unanswered questions that still surround our dearest star.

The Solar Corona and ADITYA-1 Mission

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The solar corona, the outer atmosphere of the sun can be visually seen during the few minutes of occurrence of a total solar eclipse when the moon comes in between the sun and Earth and covers the Sun fully. The width of the shadow path of the Moon varies between tens of km to couple of hundred of km depending on distances between the Sun, Moon and Earth. Maximum duration for which the solar corona could be observed during an eclipse is about 7 minutes. The disappearance of the sun and visibility of a brilliant hallow around the Sun for few minutes has been seen with awe, fear and excitement in the past. It has generated great interest in the scientists as well as public in general. The beauty of the solar corona leaves lifelong impression in the mind of person who generally travels long distances and number of times to remote places to enjoy the few moments of the visual feast. The scientists have made preparations for months together, carried tons of equipment to remote places, set up camps to conduct the experiments to understand the nature of solar corona.

Now, we know that atmosphere of the sun is very faint compared to the sun, about million times less bright as compared to the brightness of the sun and thus very difficult observe the solar corona against the sky brightness during the day which is about 100 to 1000 times more than the coronal brightness depending on the location (close or away from city) and altitude of the place. In spite of invention of a coronagraph, a special instrument to observe the solar corona, the occurrence of total solar eclipse provides a best view and displays the full glory of the crown of the sun. During the eclipse of 1869 in India at Guntur in Andhra Pradesh, the low resolution spectroscopy of the solar corona showed the existence of an emission line at 5303 Angstrom, popularly known as the green line but could not be attributed to any element present on the earth. Therefore, this was thought to be due to 'coronium' that may exists in the solar corona. The discovery of the green emission line remains unexplained for about 70 years as the atmosphere of the sun was thought to be cooler as compared to the temperature of the sun at that time. In 1940 Edlan identified the green emission line and attributed to the [Fe xiv] ion, that is formed by losing its 13 outer electrons which can happen if the temperature of the atmosphere is very high. Then within couple of years , the other emission lines present in the coronal spectra could be attributed to highly ionized atoms. Following the Saha's theory about abundances of ions as a function of temperature it was realised that temperature of the solar corona should be about 1-2 million degrees. It is confirmed that temperature of the plasma in the solar corona is very high as compared to the surface temperature of the sun which is about 5700 degrees but what causes the plasma temperature to increase to million degrees is still not clear.

The solar corona extends from the surface of the sun to large distances even to the earth and beyond but its brightness (density) decreases exponentially with distance from the sun. It is inhomogeneous and very dynamic. It changes with periods from few seconds, hours, days, months and years. The solar corona displays many features such as prominences consist of cooler plasma about couple of thousands of degrees, transition region coronal features at about a tens of thousands of degree, coronal loops at about million degrees, polar plumes, coronal jets, coronal streamers and solar wind that carries solar plasma and deposits it earth's magnetosphere.

The image of the solar corona (Fig 1) taken in white (continuum) during the total solar eclipse of 2001 shows the broad features of the solar corona as visible with eye during the total phase of the eclipse. Sometimes energetic events such as solar flare and coronal mass ejections (CME's) those influence our space weather can also be seen in the images.

Sometimes large very energetic solar flare can cause communication failures and cause damage to electrical grids and satellites in space. It is very important to predict the occurrence and dynamics of such events to enable the scientists and technocrats to take the precautionary steps in advance.

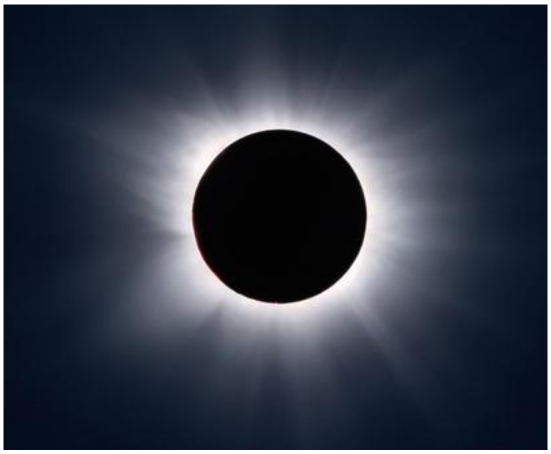

Fig 1. The image of the solar corona obtained during the total solar eclipse of June 21, 2001 by Jay Pasachoff. It appears symmetric because it was taken close to the maximum activity phase of the sun.

The processed image of the solar corona (Fig 2) taken during the total solar eclipse of July 11, 2010 at Easter Island shows more details and some of the fine features such as polar plumes, streamer structures and coronal loops. The image processing is needed to bring out the details because of large variation in intensity in the inner and outer corona.

The shape of the corona varies with the activity phase of the sun. During the maximum phase of the sun when there are large number of sunspots visible on the surface, the solar corona appears circular symmetric and during the minimum phase it appears elongated in the east- west direction of the sun.

The intensity of the solar corona also varies with the phase of the sun and follows a 11-year periodicity as in case of sunspots numbers appearing the surface.

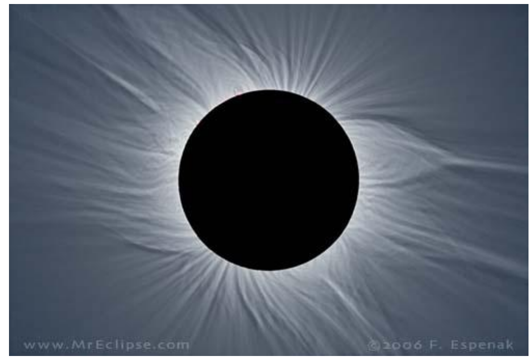

Fig 2. Processed image of the solar corona obtained during the total solar eclipse of March 29, 2006 by F. Espenak showing the polar plumes and details of streamer structures.

Fig 3. The image of the solar corona in the green emission line taken by Indian Institute of Astrophysics, Bengaluru team at Anji, China during the total solar eclipse of July 22, 2009.

The plasma in the solar corona has three components known as emission corona, continuum corona and the Fraunhofer corona. The emission corona is due to radiations emitted by highly ionized atoms at some specific wavelengths, e.g. at 637.4 and 530.3 nm popularly known as the red and green emission lines, respectively. Continuum corona is due to scattering of solar radiations by the electrons moving with high speeds in the solar corona. Because of high temperature of the solar coronal plasma the electrons move with high random velocity and thus absorptions line of the solar spectrum disappear in the spectrum. The third component, Fraunhofer corona arises because solar disk scattered light by the inter-planetary dust particles and shows absorption lines. The Figure 3 shows the image of the solar corona in the green emission line during the total solar eclipse July 22, 2009 at Anji, China by Indian team.

It shows intensity of emission lines decreases at faster rate as compared to the continuum intensity. There are several methods to determine the temperature of the solar corona. The existence of a particular ion indicates an average temperature of the plasma. The ratio of intensity of some of the emissions lines and line widths of emission lines helps in determining the temperature more precisely and temperature variations in coronal structures. In the earlier times when the technology was not advanced, the low resolution spectroscopy was done of the solar corona to identify the coronal line and study intensity ratios as seen in Figure 4 below. The spectrum popularly known as ' Flash Spectrum' shows chromospheric lines as emission lines as well as faint the red and green emission in the inner corona.

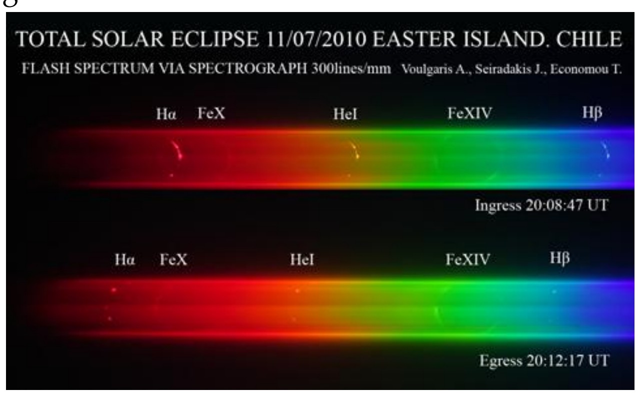

Figure 4. The Flash spectra of the Chromospheres and solar corona just at the beginning and end of the totality on July 11, 2010 at Easter Island by the Greek expedition, courtesy Aris Voulgaris.

Now a days with the advancement in the detector technology it has become possible to take high resolution spectra around the coronal emission line to make a detailed study of temperature and velocity structure of the solar corona. Figure 5 shows the multi-slit spectra around the green emission line obtained during the total solar eclipse of July 11, 2010 by the team from Indian Institute of Astrophysics at Easter Island.

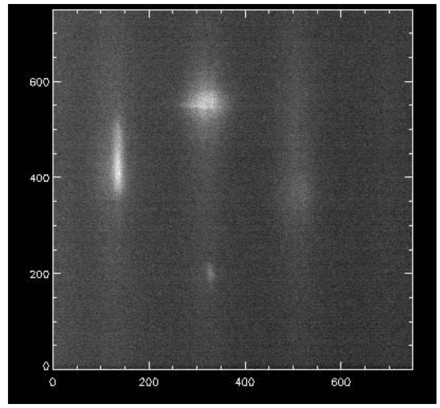

Figure 5. Multi-slit spectra taken around the green emission line during the total solar eclipse of July 11, 2010 by Indian Institute of Astrophysics team at Easter Island.

During the occurrences of total solar eclipses observations can be made only for short duration of few minutes. To overcome this limited duration and study the heating of solar corona we have planned a space based solar coronagraph to take the images of the solar corona in the green and red emission lines, and the continuum simultaneously with high frequency of about 3 Hz. The Figure 6 below shows the optical lay out of the visible emission line corona graph. Various Indian Institutes such as Indian Institute of Astrophysics, Bengaluru; Udaipur Solar Observatory, Udaipur; ARIES, Naintal; RAC, Ooty; LEOS, Bengaluru; ISAC, Bengaluru; and SAC, Ahmedabad are participating in this program. Critical components such as required mirrors with micro roughness of around 0.1 nm will be fabricated at LEOS and high quality detectors will be developed at SAC after a large amount of research and development.

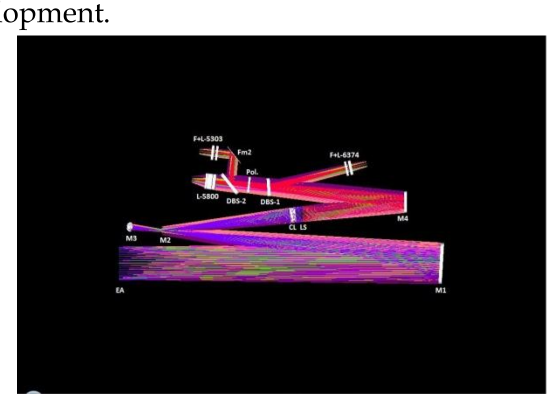

Figure 6. The optical layout of the planned space based visible emission line solar coronagraph.

Declining Solar Activity: Are Sunspots Disappearing?

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Introduction: Early in the 17th Century, Galileo Galilei, the famous Italian physicist, mathematician, astronomer, and philosopher first observed small dark features on the suns photosphere which we now call sunspots and which we now know to be small (earth sized!) regions of intense magnetic concentration and lower than average temperatures. The lower temperatures make sunspots appear dark against the bright solar disk. Since then we have a near continuous record of sunspot activity with systematic daily observations of sunspots being started at the Zurich observatory in 1949 and earlier observations being used to create a continuous record going back to Galileo's first observations in 1610. This record has established that solar magnetic flux varies with time in a periodic cycle that lasts 11 years on average. Near the minimum of the solar cycle, it is rare to see sunspots while during solar maximum, sunspots will visible on the sun almost all the time. However, sunspots are observed to be confined to the solar latitude region of ±35^{o}, first appearing at the start of a new cycle at latitudes of ~35^{o} and then slowly drifting towards the equator as the cycle progresses.

The solar cycle beginning in March 1755 and ending in June 1766, a period of 11.3 years has been designated as the first solar cycle and since then we have completed 23 full solar cycles, with the observed sunspot number count being a good indicator of the magnetic activity on the sun. The sunspot cycle has its origin in a magnetohydrodynamic dynamo operating deep inside the sun which generates and sustains the solar cycle. However, this dynamo is peculiar in the sense that it reverses the suns magnetic polarity at the maximum of each solar cycle, thereby generating a solar magnetic cycle that is twice as long as the sunspot cycle. A key role is played in this field reversal by magnetic flux transport that occurs via meridional circulation, a poleward directed flow that carries background magnetic fields polewards from the solar equator. It is believed that the strength of this background flux that eventually reaches the poles is a key factor that kick-starts a new cycle and sustains the solar cycle.

Solar magnetic fields have a profound and far reaching influence on the earth's near-space environment. With mankind's increased dependence on space based technology, much of which is at risk due to solar activity that waxes and wanes with the sunspot cycle, it is imperative that we understand the solar magnetic cycle and its effects on the near-space environment. In addition, due to the significant anthropogenic influence on climate change in recent times, it is becoming increasingly important to distinguish and delineate the degree to which the solar cycle can affects terrestrial climate. It is known for example (from reliable early records of sunspot activity) that the Sun went through a period of inactivity referred to as the "Little Ice Age or Maunder Minimum" in the period from 1635 to 1715. During this period of solar inactivity rivers that were normally ice-free froze and snow fields remained year-round at lower altitudes. There is also evidence that the sun has had similar periods of inactivity in the more distant past.

The Peculiar Cycle 23 Minimum: The sunspot minimum at the end of solar cycle 23 has been one of the deepest we have experienced in the past 100 years with the first spots of the new cycle 24 appearing only in March 2010 instead of December 2008 as was expected, and roughly 71% to 73% of the days in 2008 and 2009 respectively being entirely spotless. Apart from this, cycle 23 has shown several other peculiarities, like a second maximum during the declining phase that is unusual of odd numbered cycles, a slower rise to maximum than other odd numbered cycles and a slower than average polar reversal. Such departures from ``*normal*" behaviour need to be studied and understood as they could be significant in the context of understanding the evolution of magnetic fields on the sun. Figure 1 shows curves representing the smoothed sunspot numbers for the period 1975 to 2011. Solar cycles 21, 22 and 23 have been demarcated, in Figure 1, by dashed vertically oriented parallel lines. The dashed red line at the bottom is marked at a sunspot number of 20 which is considered to be a very low level of activity for the sun. Compared to cycles 21 and 22 it is apparent that the sunspot numbers stayed at very low levels (below the dashed red line) for an unusually extended period in cycle 23. The green coloured band between December 2008 and March 2010 represents the period between the expected end of cycle 23 and the time when the first new spots of cycle 24 began to appear. The slow rises to maximum, compared to cycles 21 and 22, and the second maximum in the declining phase in cycle 23 are also evident in Figure 1.

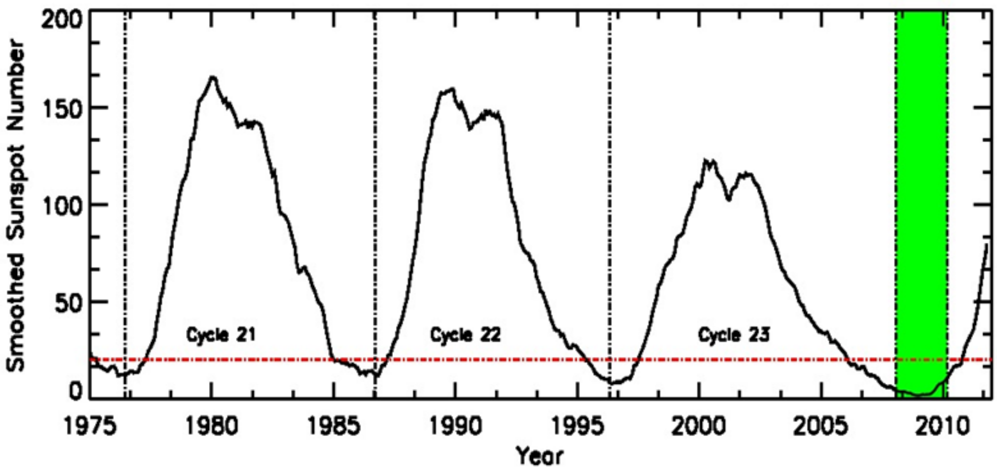

Figure 1: shows the smoothed sunspot numbers as a function of time for the period covering solar cycles 21-23. The dashed red line is marked at a sunspot number of 20, representing very low level of solar activity. The green band represents the period of the extended minimum as described in the text.

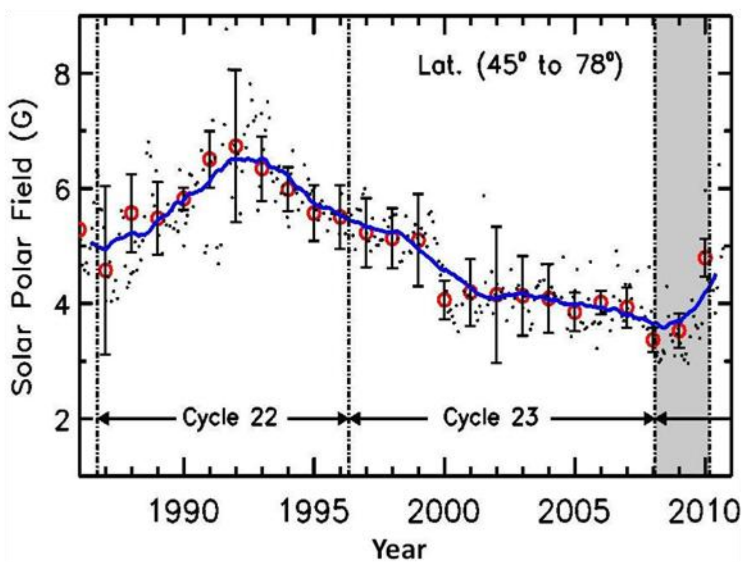

Figure 2: shows the solar polar fields as function of time for solar cycles 22 and 23. The fine filled dots represent the actual data while the blue solid line is a smoothed fit. The open red circles are annual averages. The grey band represents the period of the extended minimum as described earlier.

Solar Magnetic Fields: Solar magnetic-field data are available as standard FITS format files from the National Solar Observatory, Kitt Peak, USA (NSO/Kitt Peak) synoptic magnetogram database (ftp://nsokp.nso.edu/kpvt/synoptic/mag/) and the Vector Spectro Magnetograph (VSM) of the NSO/Synoptic Optical Long-term Investigations of the Sun (SOLIS) facility for solar observations over a long time frame (NSO/SOLIS): (ftp://solis.nso.edu/synoptic/level3/vsm/merged/ carr-rot/). These synoptic maps, each covering one full solar rotation of approximately 27 days, are in the form of 180×360 arrays with a resolution of 1° in both longitude (1° to 360°) and latitude (−90° to 90°). This data can be averaged in longitude to produce a 1° strip of data, for each solar rotation, covering the latitude range −90° ◦ to 90°. Such longitudinally averaged data can then yield the magnetic field in any given latitude range of interest. Figure 2 shows solar fields as a function of time derived by this method in the latitude range 45° - 78° for solar cycles 22 and 23. The solar fields measured in this range of latitudes are loosely referred to as solar polar fields. At the lower limit, this range of latitudes lies well above the sunspot belt while at the upper limit it goes up to the point where the meridional flow is believed to dip below the sun's surface. The fine filled dots in Figure 2 represent the actual data while the blue solid line is a smoothed fit. The open red circles are annual averages. The grey band represents the period of the extended minimum as described earlier. It is easy to see that there is a steady decline in the solar polar fields starting from around 1995.

Microturbulence in the Interplanetary Medium: The twinkling of stars in the night sky is caused by variations in the refractive index in the earth's neutral atmosphere. An analogous effect is caused at meter wavelengths when radio galaxies and quasars are seen to twinkle or "*scintillate*" due to changes or fluctuations in the electron density in the interplanetary medium along the line-of-sight to the radio source being observed. Such observations, called interplanetary scintillation (IPS) provide a good proxy for studying the microturbulence in the interplanetary medium. Interplanetary magnetic fields are known to have a strong influence on the behaviour of solar wind plasma turbulence and since interplanetary magnetic fields are basically solar fields swept out into the interplanetary medium by the solar wind, IPS observations are expected to show signatures of the declining solar fields that began around 1995.

Extensive IPS observations at 327 MHz obtained between 1983 and 2009 from the IPS observatory of the Solar Terrestrial Environment Laboratory in Japan were used to derive the scintillation index (m), a good proxy for microturbulence in the solar wind, and the upper two panels of Figure 3 show plots of m as a function of time in years for a sample of two out of a large number of observed radio sources in the distance range 0.26 to 0.82 AU, where 1 AU is the distance between the sun and the earth. The grey crosses are observations at source heliolatitudes ≤45° while the fine red dots are observations when the source heliolatitudes are > 45°. The open circles are yearly averages by excluding the high latitude observations. The IAU name of each source is indicated at the bottom left in each of the upper two panels. The lower panel in Figure 3 shows only the yearly averages of m for all the radio sources observed. The observed sources were distributed all over the inner heliosphere and show a steady drop in the turbulence levels in the solar wind starting from around ~1995, in keeping with the steady drop seen in solar magnetic fields. This large-scale IPS signature in the inner heliosphere coupled with the fact that solar polar fields have also been declining since ~1995, provide a consistent result showing that the build-up to the deepest solar minimum in 100 years actually began more than a decade earlier.

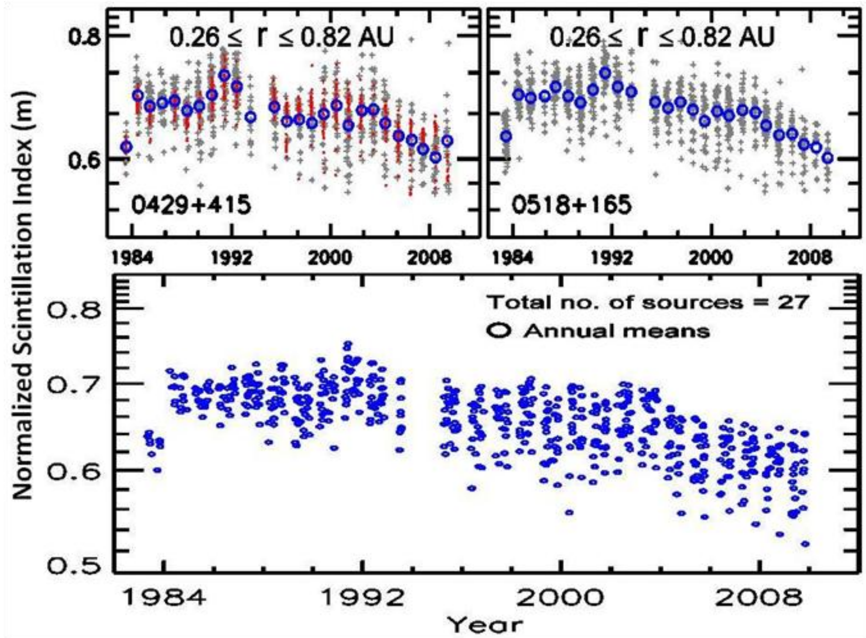

Figure 3. The upper two panels show plots of m as a function of time in years for two out of 27 observed sources in the distance range 0.26 to 0.82 AU. The values of m have been normalized to make it independent of distance from the Sun. The grey crosses are observations at source heliolatitudes ≤45 while the fine red dots are observations when the source heliolatitudes are > 45^0. The open circles are yearly averages by excluding the high latitude observations. The IAU name of each source is indicated at the bottom left in each panel. The lower panel shows only the yearly averages of all 27 sources observed. The steady decline in m starting from ~ 1995 is apparent .

Discussions and Conclusions: In trying to predict the strength of future solar cycles, magnetic persistence or the sun's memory of the polar field strength at minimum in the previous cycle has been postulated as the influencing factor. Some researchers have used this method to try and predict the strength of upcoming of cycles through magnetic persistence or sun's memory. Other researchers have used the strength of the polar fields during the on going cycle minimum and the preceding two solar minima to determine the strength of the next cycle. Later, it was postulated that magnetic persistence is itself governed by meridional flow speed with slower meridional flows resulting in longer memory. In addition, it is believed that a slower meridional flow speed would also determine the cycle period. The observations described above have shown that the deepest minimum of the past 100 years was initiated in the mid 1990's. Observations by other researchers have indicated that sunspot temperatures are gradually increasing while sunspot magnetic fields are gradually decreasing. This raises the all-important question of whether sunspots are disappearing altogether. It is thus apparent that there are a lot of open questions regarding the solar dynamo which governs solar magnetic activity and which makes the sun such a fascinating object of study

It is important to note that it is solar magnetism that gives rise to explosive solar events like solar flares and coronal mass ejections (CME's). During a single CME event, approximately 10^{13} kg of matter can be ejected from the sun at velocities greater than 1000 km s^{-1}. If a CME directly impacts the earth's magnetosphere it can lead to what is known as a geomagnetic storm which, among other things, has the potential to destroy space based satellite systems on which mankind is so dependent. Studies of such related events that affect the near earth environment are known as space weather studies, an increasingly important area of research that had direct implications on the quality of life on earth.

Though a very deep solar minimum, like that just experienced at the end of cycle 23, would imply that space weather events in cycle 24 may be fewer and milder, it still leaves the question of the occurrence of extreme events that can have catastrophic effects on modern technology. There is some indication that such events may actually occur more often in weaker cycles. For example three of the five largest solar energetic proton events and two of the eight strongest geomagnetic storms in the last 150 years occurred during solar cycles 13 and 14 respectively. Both cycles were relatively weak, having sunspot numbers of 88 and 64 respectively. The only clues and insights to this important question can come from looking at the quiet declining phase of cycle 23. In this phase of cycle 23, the largest X-class flare ever recorded (X28) and two of the largest storms of solar cycle 23, associated with two X-class flares (flare class X17/4B and X10/2B), occurred during the period October -- November 2003, when the sun was largely quiet and inactive. In conclusion, weak cycles are important for studying empirical relationships between solar and interplanetary conditions and terrestrial phenomena. Ground based remote sensing methods as described in the text hold the key to understanding such phenomena.

Acknowledgements: The author acknowledges the free data use policy of the National Solar Observatory, USA and the Solar Terrestrial Environmental Laboratory, Japan that enabled such studies to be carried out. The author also thanks Susanta Kumar Bisoi a research student and collaborator in the work described.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures* in their own words, either as a brief survey of state of the art or as articles on novel dream concepts related to the specific theme ***"Future Trends in Remote Sensing"***.

The deadline for inclusion in the next issue is **March 20, 2012.**

\- Editorial Team

On the Estimation of Solar Coronal Magnetic Field Topology Using Green Emission Line Polarization

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INTRODUCTION: Solar coronal magnetic field estimation is one of the most difficult albeit very important problems in solar research. Most of the large-scale (for e.g., active regions and sunspots) as well as small-scale (for e.g., bright points, plages, and faculae) structures seen on the solar atmosphere are nothing but an interplay between magnetic field and plasma motions. Hence, measurement of magnetic field and plasma parameters on the solar structures are considered as one of the most important observational requirements for any solar physics studies. Though the magnetic field measurements on the solar photosphere dates back to one hundred years[1], measurements at higher layers are yet to be established. Also, magnetic fields in the corona is predicted to play a crucial role for the high temperatures (Corona has a temperature of around 2MK in contrast to the photosphere being only around 5800K). The only consistent coronal magnetic field measurement available so far is the spectro-polarimetry using the Zeeman sensitive IR emission line [2]. Most of the Coronal Emission Lines (CEL) are sensitive to coronal magnetic field [3] and hence in principle they can be used to diagnose the vector fields. Due to the low field strengths as well as the low sensitivities of coronal lines, line-of-sight field measurement remains a challenge. However, attempts have been made to estimate the plane-of-the-sky fields especially the topology of the magnetic fields. There still remains a discrepancy between the observational results and theory of emission line polarization [4], [5].

There has been discrepancies in the degrees of polarization estimated by various authors, some have found it to be higher than 25% [6], whereas there are a few series of observations without an eclipse by using coronograph-polarimeter that obtained lower degrees of polarization[7],[8],[9]. Also, theories suggest that the direction of polarization in green line must be perpendicular to that in the white light [10],[11],[12],[13],[14]. However, observational data shows that both the green and white light show the same direction. The reason for this discrepancy between observational and theoretical estimates is ill understood. In this study we aim to understand this problem and analyze observations of coronal green emission line to extract the polarization contribution due to the magnetic field. Here we show the step-by-step procedure for extracting this information using the near simultaneous polarization observations of green and red emission lines.

OBSERVATIONS & DATA REDUCTION: Coronal intensity and polarization data for the coronal emission lines 5303Å (GREEN) and 6374Å (RED) was obtained [15] with FWHM 12Å, during the total solar eclipse on June 21, 2001. To estimate the polarization, digital images were obtained through four positions of a polaroid. We use the following polaroid axis positions in two sets:

Set I - 0, 45, 90,135 degree; Set II - 180,225,270,315 degree

Both green and red line images were processed in a similar way by doing dark subtraction and flat fielding. The pixel size is calculated to be 11.81'' and the field-of-view is 78.5′ ($4.9R_{\odot}$)

Polarization magnitude and position angles using transmission through a polarizer are calculated[16] as follows- :

$$I_{\Phi} = I_u + I_p \cos^2(\Phi - \Theta) \quad \text{where } \Phi = 0, 45, 90, 135°$$

$$I_p = \{(I_0 - I_{90})^2 + (I_{45} - I_{135})^2\}^{1/2}$$

$$\tan 2\Theta = (I_{45} - I_{135}) / (I_0 - I_{90}) \qquad (2)$$

ANALYSIS: In general, total green line intensities can be written as - $I_\lambda = I_E + I_{ph}$

where I_E originates by excitation of FeXIV by electron collision, and I_{ph} from the excitation of ions by absorption of photospheric photons.

In the **absence of magnetic field**, the angular distribution of scattering in the line is analogous to Thomson scattering, so the polarization in the line can be given by [17]

$$\mathbf{p = a(T)\sigma_{5303}\, p_{ph}\, Bwl/(\sigma I_\lambda)} \qquad (3)$$

The inverse relation or anti-correlation between the degree of polarization 'p' and 'I_λ' is evident, Fig.3 & Fig.4 support the same. Hence coronal regions with high intensity show low polarization 'p'. Theoretically, red emission line does not produce any resonance polarization due to its atomic transition [18]. Thus, all polarization observed in this emission line is due to Thompson scattering. Whereas in the presence of magnetic fields, the polarization in green emission line is due to both Thomson as well as resonance scattering. Resonance scattering decreases the degree of polarization and also rotates the plane of polarization. The fact that regions with high intensity have low polarization (regions highlighted in Fig.1) shows that the resonance scattering has modified the degree of polarization. Also from Fig.3 & Fig.4 we see that the slope of line fitted to red data is more compared to green. This is due to the fact that green does not have contribution from Thomson scattering alone,so eq (3) does not hold perfectly true for it.

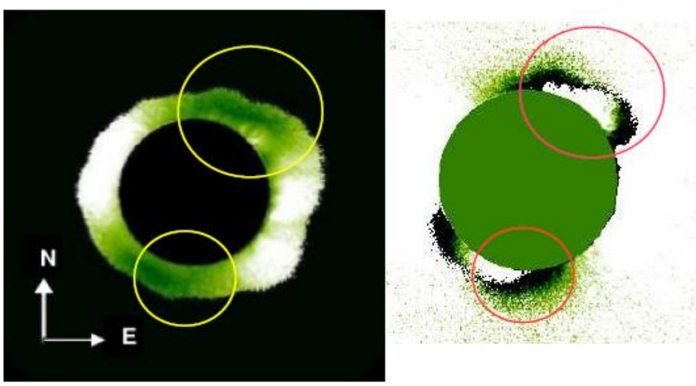


Fig.1 5303 Å Polarization image (Left), tan2Θ (Right)

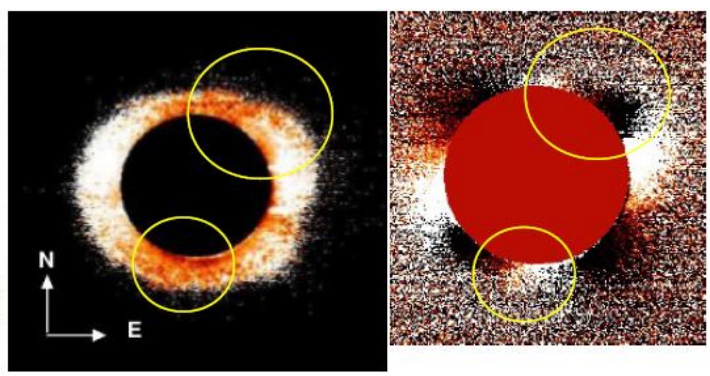


Fig.2 6374 Å Polarization image (Left), tan2Θ (Right)

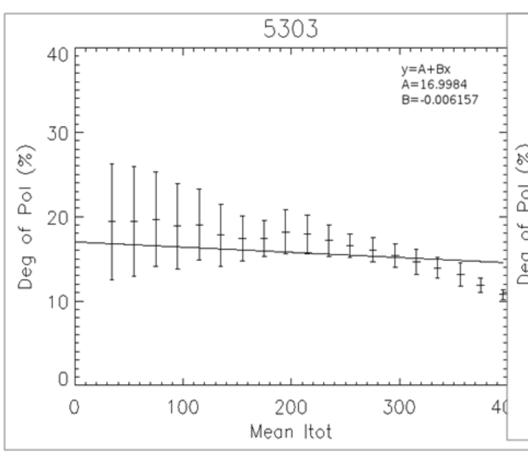


Fig.3 Relation between intensity & polarization(green)

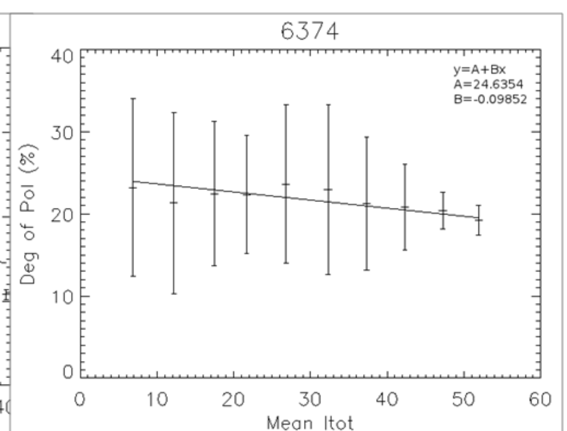
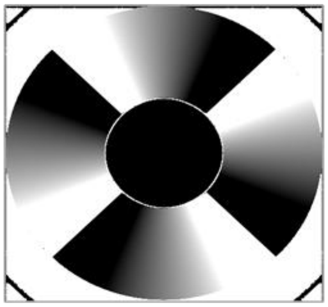


Fig.4 Relation between intensity & polarization(red)

To further substantiate the fact that the polarization observed in red emission line is solely due to Thomson scattering, a simple minded simulation was carried out.

An image was created, with input being completely linearly polarized light (I, Q, U,V=0), where the polarization angle is perpendicular to the radial direction. Since coronal intensity decreases exponentially, an exponential function was used for the intensity variation. These images were then subjected to an analyzer with different angles for its transmission axis, same as that used during observations (0,45,90,135). The resultant images were used to calculate tan2Θ (Fig.5).

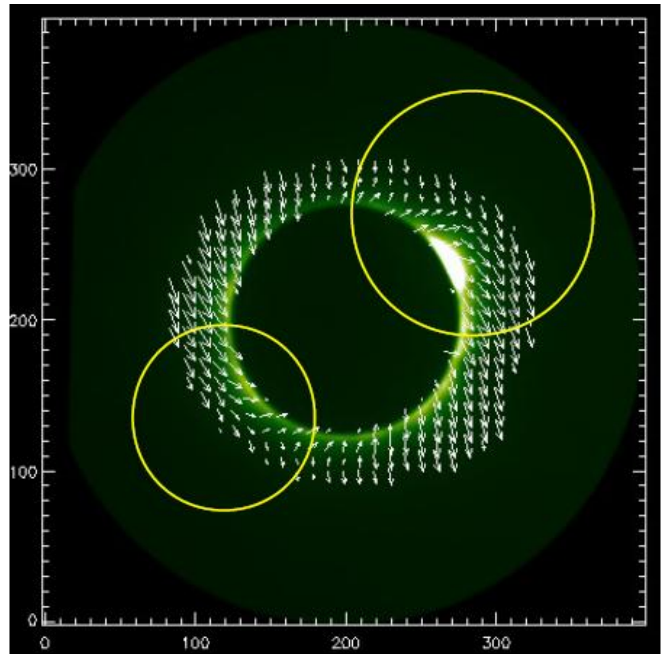


On comparing Fig.5 & Fig.2 (Right), we see that there is a clear similarity in azimuthal angle pattern showing spokes like structures. The polarization due to Thomson scattering is always tangential to the radial vector, which is evident in the simulated and the observed angles. Hence the contribution in red being only due to Thomson scattering and it not being sensitive to magnetic field direction is justified.

Fig.5 tan2Θ image obtained from simulation

The polarization vector fields for green are however not completely tangential, but at different angles, as seen from the azimuthal angle in Fig.1(Right).

Fig.6 & Fig.7 show the linear polarization vectors over-plotted on the total intensity images for both red and green.



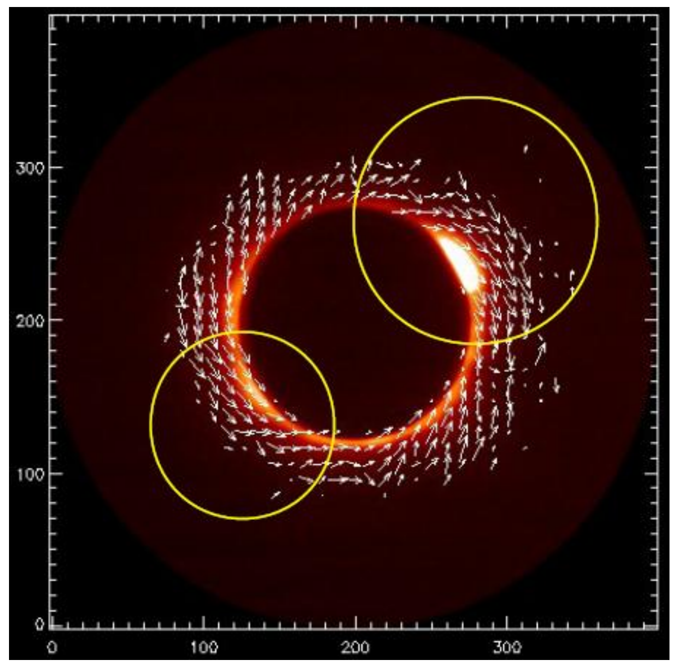


Fig.6 Polarization vector field for green

Fig.7 Polarization vector field for red

It is clear from these images that in the region where magnetic field is present (where degree of polarization has reduced value), the vector angles and magnitude are different from the red line values. This shows that the green line is sensitive to the presence of magnetic fields.

SUMMARY: In order to extract the effect due to magnetic field, red line images need to be subtracted from green line images vectorially. Fig.8 shows the polarization vector after subtraction. It is clear that the polarization vector is non-tangential in places where the magnetic field exists and in other regions they are close to the noise level.

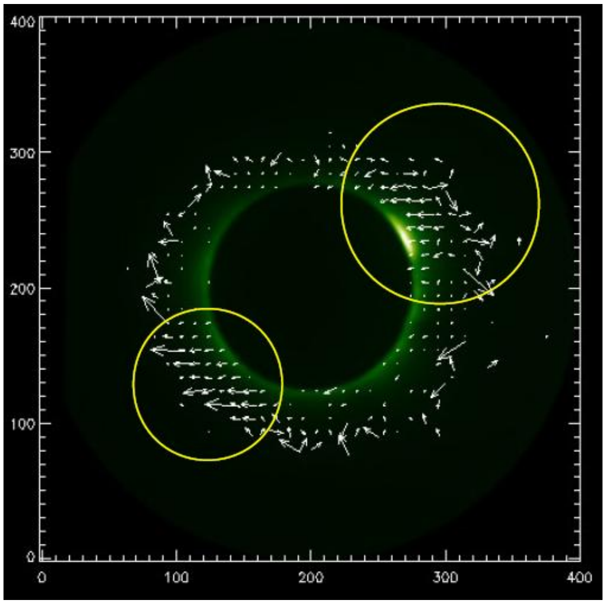


Fig.8 Polarization vector field for (green-red)

However to predict magnetic field topology from these changes requires forward modeling. Since observations are integrated along the line of sight (Plane-of-the-sky), forward modeling is a must to extract the topology information.

To predict magnetic field topology as all the observations are taken using line of sight integration.

A recent paper by Dove et al[19], encourages forward modeling method for predicting the magnetic field, and the same has been verified using Infra-Red observations in the same paper. The retrieval of magnetic field will prove to be a great tool in understanding the coronal processes, which is one of the aim of 'ADITYA-1', the upcoming solar mission of ISRO. The coronagraph planned to be on-board ADITYA-1 will take polarization observations in one particular mode in green emission line and continuum, which will be used for the extraction of magnetic field topology. Such studies will help us understand the corona and the physics of the coronal magnetic fields better.

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General

Earth as a Heavenly Body - Visualizing Earth and the Earth-Moon System in the Vastness of Space

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Man must rise above the Earth, To the top of atmosphere and beyond For only thus will he understand, The world in which he lives- **SOCRATES, 500 B. C.**

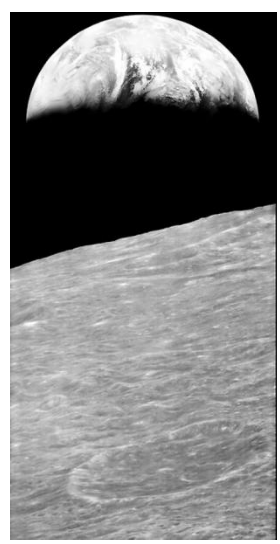
"Once a photograph of the Earth, taken from outside, is available – once the sheer isolation of the Earth becomes known – a new idea as powerful as any in history will be let loose." **- Sir Fred Hoyle -** ***The Nature of the Universe*** **(1950)**

Ask anyone about the planets in the Solar System, and every one would correctly list all nine (now eight, with the ousting of Pluto) planets. But ask them to visualize the planets as heavenly bodies in the night sky, and most would skip the Earth. They would talk about Venus, Mars, Jupiter, Saturn etc., but not Earth. It takes a great imagination to realize that our Earth, on which we all stand, is part of the same dark sky amongst the stars as the other bright planets. And it has taken a long- long time in the human philosophical and scientific journey – from ancient times to Aryabhatta, Copernicus, to Kepler and finally to the heralding of the Space Age - to come to a point when we can create a perspective such that the Earth- our home planet, is seen against the backdrop of the sky.

Ever since photography and imaging of the Earth from elevated platforms (like kites, balloons, and rockets) began, we have been given the opportunity to look at our planet in a new and extended perspective. These pictures captured just parts of Earth, as opposed to a full view of the planet Earth.

However, to see our home planet EARTH in a PLANETARY PERSPECTIVE, our observing platforms and the imaging instruments had to be lofted far far away in space. The first such opportunities, of seeing our planet in full, silhouetted against the sky, were made possible through the Lunar Missions, beginning with Surveyors and finally the manned Apollo missions, which landed a human being physically on the surface of the Moon – the Earth's only natural satellite. Besides giving selected human eyes the first ever direct opportunity to look at the Earth as a celestial object in the sky, the images captured and transmitted back to Earth, gave inhabitants of the Earth a rare view of the Earth is space

On August 23, 1966, NASA's Lunar Orbiter 1 took the first photo of Earth from the Moon's orbit, and it forever changed how we visualize our home planet.



Lunar Orbiter image of the entire Earth in space, with Lunar surface in the foreground

Astronaut photographs taken during the Apollo missions provided full-color images of Earth, and fostered a greater awareness of the need to understand our planet Earth in an integrated manner. It also underscored our responsibility to preserve and cherish perhaps the only home we've ever known."

During 1968, Apollo 8 astronauts captured the Earth as a fragile blue and white sphere, hanging over a barren grey-brown lunar horizon.

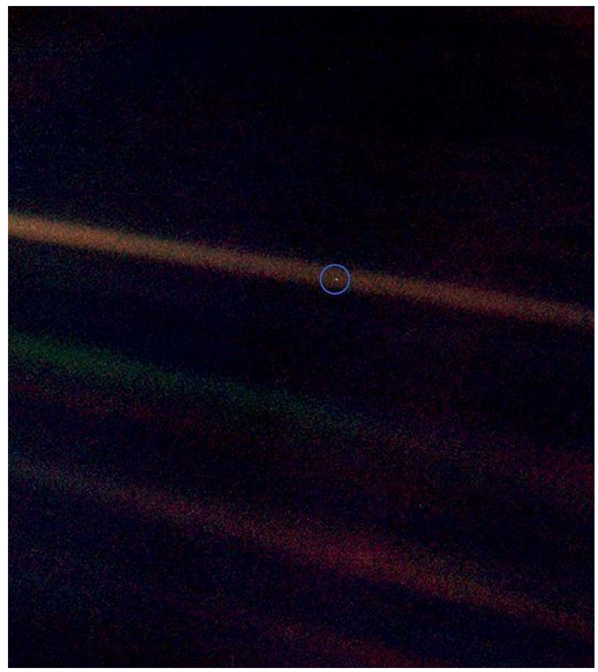
Earthrise- Dec. 24, 1968- Apollo 8

In 1972, from a distance of about 45,000 km, the crew of Apollo 17 took one of the most famous photographs ever made of the Earth.

Earth as "The Blue Marble" from a distance of 45,000 kms.

This snapshot — taken by astronauts on December 7, 1972 — is one of the most widely distributed photographic images in existence. The image is one of the few to show a fully illuminated Earth, as the astronauts had the Sun behind them when they took the image. This original '*Blue Marble*' picture inspired interesting images of the Earth from scores of lunar and planetary space missions that followed - including a few from our own Chandrayaan-1.

In 1990, the picture of the Earth was taken from deep space by Voyager cameras at a distance of 6 billion kms from Earth. In this image, the Earth appeared as a "pale blue dot" surrounded by the vastness of space, like a tiny mote of dust caught in a sunbeam.



The "Pale Blue Dot" image of the Earth taken by the Voyager 1

(the reddish-orange bands are image artifacts due to looking too close to the Sun in the sky)

These missions completely transformed our view of the Earth, and brought home the realization of it being only one of the members of the Solar System family of planets, which itself is a tiny part of the Universe.

Looking homeward, of course, began with the availability of space based platforms in the 1960s. Ever since then, regular imaging and monitoring of the Earth and its environment on a planetary scale has been achieved through a wide network of geostationary and polar orbiting satellites.

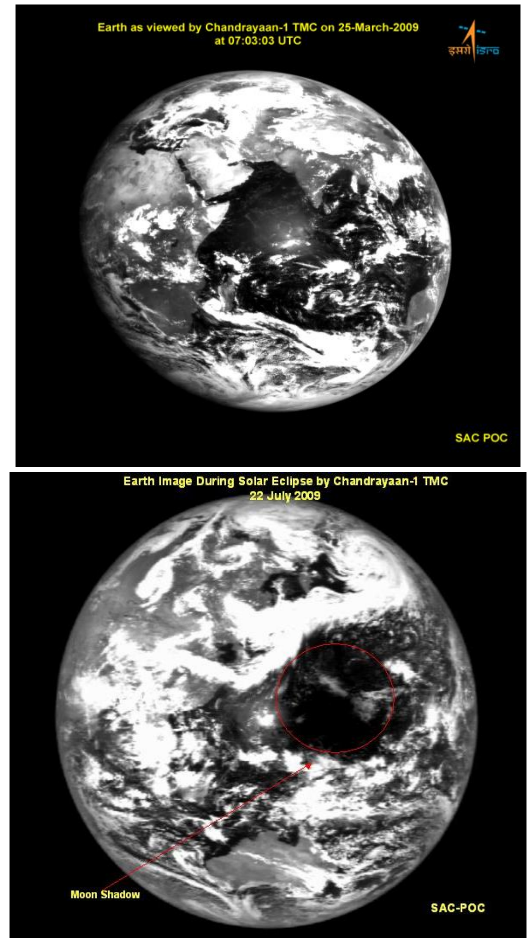
http://www.greenwichschools.org/page.cfm?p=3088

Earth and its celestial neighbor Moon imaged from a vantage point in space.

Imaging from such vantage points far away is space helps us to visualize the Earth-Moon system as being a part of the cosmic environment. With the passage of time, it has been extended way beyond the geostationary orbital altitudes of 36,000 kms to billions of kms now. A distant look-back at the mother Earth has invariably been a part of almost every lunar and planetary mission. Besides its philosophic undertones, such imaging was incorporated as an integral part of testing of the imaging instruments' operational reliability and capability while on their way to the destination.

In the following, we have tried to compile a large variety of Earth images taken from different lunar, planetary and cometary missions over the last many decades. The distances from which our planet has been imaged range from near Earth to a mind boggling billions of kms. The many missions involved have been – Apollo, Clementine, Hayabusa, Kaguya, Mariner, Voyager, Messenger, Rosetta, MGS, Galileo, Cassini,.... - the latest being the Juno mission on its way to Jupiter.

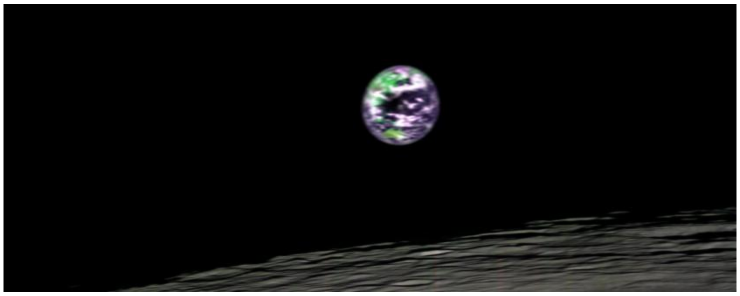
Not to be left behind, India's Chandrayaan-1 imaging cameras in orbit around the Moon, also successfully imaged the Earth in all its majesty, as well as captured the presence of the shadow of Earth's natural satellite (the Moon) over the Pacific Ocean during the unique astronomical event of the Total Solar Eclipse on July 22, 2009.



[Left] - Chandrayaan-1 TMC Vis. Band image – March 25, 2009.

[Right}- Chandrayaan-1 TMC vis. Band image showing the presence of Moon's shadow during a Total Solar Eclipse on July 22, 2009.

A few of the missions also had the capability to image the Earth in more than one spectral bands e.g. the colorful Earth above the Moon's horizon taken by Moon Mineralogy Mapper onboard Chandrayaan-1.



The Earth hanging in Moon's sky as seen by M3 onboard Chandrayaan-1

In addition to increasing our knowledge about the Earth in all its multifarious dimensions, the fast paced development of space technology, has also provided detailed measurements of surface and environmental conditions of the Moon and other planets in the Solar System through orbiters, landers and rovers. Samples have also been successfully collected from Moon and a few other members of the Solar System.

Over the last decade, we seemed to have made some progress in finding other Earth-like planets. A number of possible candidates around other Sun-like stars have been identified. A recent (Dec. 2011) discovery, dubbed Kepler-22b, lying as it is within the so-called 'habitable zone' for existence of life, has raised hopes. However, till we succeed in our dream of finding other Earths out in space, our home planet Earth remains the only planet known in the firmament of the sky to harbor life.

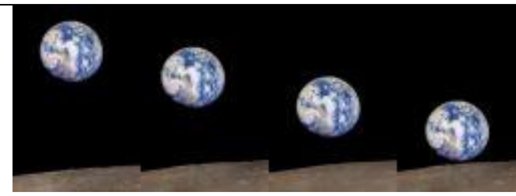
Of course, even before the arrival of technology to reach far out in space to image the Earth in its planetary perspective, powerful human imagination had travelled far and wide. It has Indeed been prophetic on the part of philosophers like Socrates and scientists like Sir Fred Hoyle to have envisaged how looking at the Earth from far away would revolutionize our understanding about our planet and its place in the vastness of the Universe.

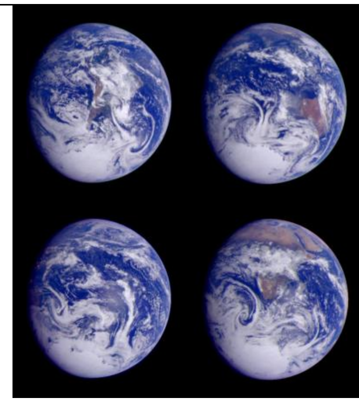
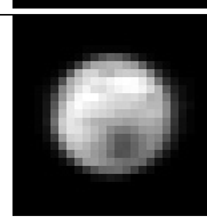
Table below provides some glimpses of the planet Earth in the vastness of space through images taken by a variety of space missions during their journeys to different parts of the Solar System.

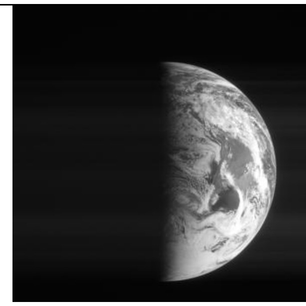
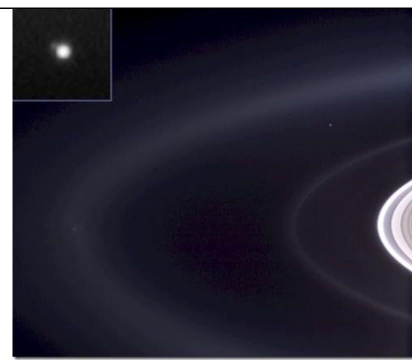
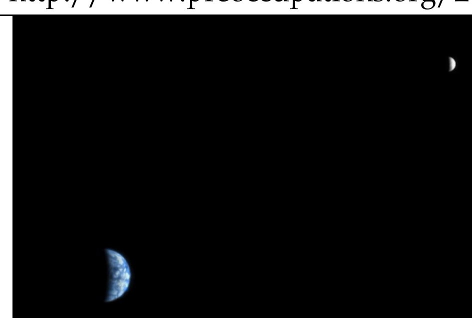
Table -1: Planet Earth a celestial object in the vastness of Space – images by various spacecrafts during their journey through the Solar System

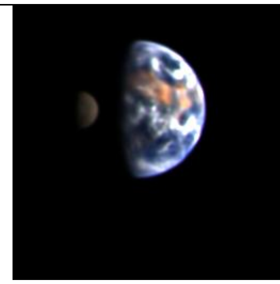
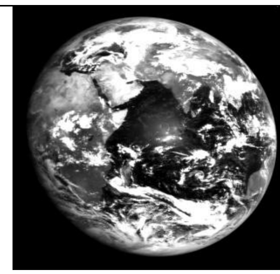
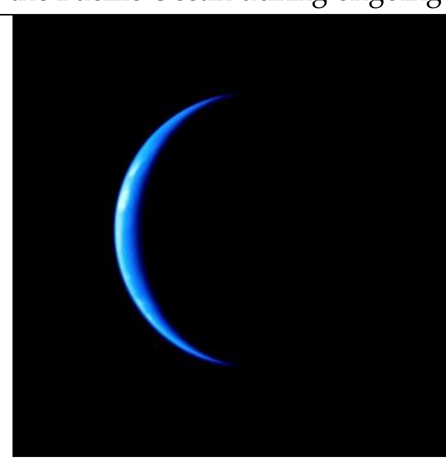
Epoch	Spacecraft and its Distance from Earth at the time of imaging	Image of Earth or Earth-Moon System
1966 Aug. 23	**Lunar Orbiter 1-** from vicinity of the Moon (~ 380,000 Kms)	 First images of Earthrise over the Moon

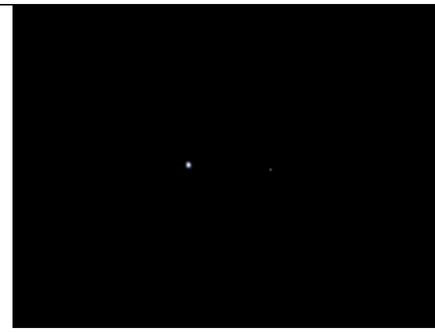
1968 Nov. 14	**Zond 6** - image of Earth from Lunar orbit	
1968 Dec. 21	**Apollo 8** – from Lunar orbit	 The first image ever taken by humans of the whole Earth
1968 Dec. 24	**Apollo 8** – from Lunar Orbit	  The first Earthrise photographed by humans http://en.wikipedia.org/wiki/File: Earth-moon.jpg
1969 July 16	**Apollo 11 -** from Moon	 Earthrise over the lunar horizon

1969 Aug. 09	**Zond 7 -** sequence of images of Earth setting behind the lunar limb	
1972 Dec. 7	**Apollo 17-** Iconic view of Earth from a distance of 45,000 kms	 The original 'Blue Marble' image – Most widely distributed images in existence.
1973 Nov. 3	**Mariner 10 -** Earth and Moon from a distance of 2.6 million Kms	
1977 Sep. 18	**Voyager 1-** Crescent Earth and Moon from a distance of 11.66 million Kms	
1990 July 6	**Voyager 1 -** Pale Blue Dot - from more than **6 billion kilometers**	 Earth is seen as a tiny dot in the vastness of space.

1990 Dec. 11	**Galileo -** Global Images of Earth from a distance of 2-3 million Kms	 RGV color composites
1992 Dec. 16	**Galileo -**Earth-Moon conjunction from 6.2 million Kms	 http://solarsystem.nasa.gov/galileo/
1994 Feb. 11	**Clementine-** Earth crescent from Moon	
2001 Apr. 19	**Mars Odyssey-** from a distance of 3.5 million Kms.	 Earth in thermal IR, dark feature is cool Antarctic continent
2003 May 8	**Mars Global Surveyor -** Earth and Moon from Mars 139 million Kms from Earth	 http://apod.nasa.gov/apod/ap030526.html

2004 May 18	**Hayabusa-** Earth flyby	
2005 Mar. 7	**Rosetta -** after Earth fly -by	
2005 Aug. 2	**MESSENGER -** 102,918 Kms	  Earth in true and false color
2006 Sept. 15	**Cassini - W**ide-angle camera view from a distance of 1.5 billion Kms	 http://www.preoccupations.org/2006/
2007 Oct. 3	**Mars Reconnaissance Orbiter -** Earth and Moon from 142 million Kms	 Earth and Moon as Seen from Mars
2007 Nov.	**Kaguya –** Earth from 110,000 Kms	 HDTV image

2008 Apr. 19	**Kaguya**	 Crescent Earth
2008 May 29	**Deep Impact -** view of Earth and the Moon from 50 million Kms	 Moon transiting the Earth's disk
2009 Mar. 25	**Chandrayaan-1-** Full Earth from Lunar orbit	
2009 July 22	**Chandrayaan-1 -** Earth and the Moon from Lunar orbit	 M3 multi-spectral image of Earth in Moon's sky- Note the Shadow of Moon over the Pacific Ocean during ongoing TSE
2010 May 21	**Dawn- (Akatsuki)** - 250,000 km from Earth	 a sharp and stunning crescent of the Earth in Ultraviolet

2011 Aug. 26	**Juno** - Earth and Moon from ~11 million Kms	

Note: Most of the images above are processed to improve visualization, Useful Reference: http:// www. planetary.org/ explore/topics /earth/spacecraft.html

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Call for Contributions for the Special Issue on Future Trends in Remote Sensing

The Jan-March 2012 issue of *Signatures* has been planned to be brought out as a special issue on the theme "**Future Trends in Remote Sensing**". A list of possible areas, which is not exhaustive, that your articles could cover are:

1. Requirement Scenarios on Remote Sensing for Different Application Domains
2. Remote Sensing of Man Made and Natural Resources
3. Fusion of Space-borne Remote Sensing with Observations made on Ground
4. Future Trends in Microwave/ Electro-Optical Sensor Technologies
5. Computing Systems for Data Processing and Dissemination of Remote Sensing Data Products
6. New Algorithms for Automatic Extraction/ Interpretation of Features
7. Remote Sensing Data Availability/ Accessibility Policies
8. Space-borne/Air-borne/Ground-based/Ship-based Remote Sensing Observation Possibilities
9. Crowd-sourcing Multi-media Applications
10. Dream concepts in remote

    …

We request all the members who are interested to give their article in the issue to kindly intimate a brief outline to me, through email at his email address **nandakumar@sac.isro.gov.in** by **1st February 2012** and Full article in the form of text and/or pictures of size ranging from half page to four pages of A4 size may please be sent directly to the Chief Editor of the Newsletter Dr. R. Nandakumar through email at his email address nandakumar@sac.isro.gov.in preferably before **March 20, 2012.**

Editorial Team

Air Glow Measurements to Study and Understand Terrestrial Upper Atmosphere

Ratan Singh Bisht and P. Narayanbabu, SAC, Ahmedabad

Introduction: The terrestrial upper atmosphere i.e. about 80 km to 1000 km is a closely coupled two component system where the neutrals (thermosphere) and plasma (ionosphere) coexist with linkages to magnetosphere higher above and the lower atmosphere below. This part of the Earth's atmosphere responds sensitively (heating, photo dissociation and photo ionization of the atmospheric species) to the solar radiation and wind reaching the earth through the interplanetary space.

The individual constituents of the atmosphere whether they are atomic or molecular in nature play important role in the process of upper atmospheric energy balance. The lifetime of most of these species, to a large extent, are controlled by the photochemical processes. A number of the atmospheric species get excited and undergo specific spectral transitions as a result of these processes. Consequently, atomic and molecular emissions occur depending on the lifetime of the meta-stable state and the timescale of the ongoing quenching reactions. These atmospheric emissions are known as the `Airglow'. The broad classification of the airglow phenomenon is dayglow, nightglow or twilight-glow depending on the time of the day it is being observed. The phenomenon of excitation and de-excitation over the polar-regions is known as Aurora (Aurora borealis for northern and Aurora australis for southern polar region).

In recent years the need for a comprehensive understanding of the complex processes of the ionosphere-thermosphere system, including its response to the various external forces so as to reach a level of predictive capability, has been felt. The information regarding the thermosphere can be obtained through airglow emissions while ionospheric variabilities can be studied through radio wave propagation characteristics. In this context, satellite platforms provide air glow measurements with global coverage in extended time domains, covering different sessions and different epochs of the solar cycle. This generates the much needed data base to develop upper atmospheric models and achieve the required predictive capability. Measurements in the Earth's limb view mode furnish excellent radiometric resolution and ease to generate vertical density profiles of the air glow emitting species.

Monitoring of the airglow has been a part of many satellite programs initiated across the globe. For instance, NASA's Upper Atmosphere Research Satellite (UARS) had an airglow monitoring instrument called Wind Imaging Interferometer (WINDII) which provided winds and temperatures in the altitude range of 80-300km using some specific airglow emissions in the visible range from the atmosphere. Similarly, the "Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite has an airglow imager operating at the ultraviolet wavelength which has provided information on the distribution of ionization especially over low and equatorial latitudes. However, only a few of the satellite missions so far have tried to measure upper atmospheric airglow intensity simultaneously at wavelengths spanning over the complete visible/near IR spectra. Limb Viewing Hyper Spectral Imager (LiVHySI) onboard YOUTHSAT is performing excellently and generating the above mentioned data base in a wide spectral range.

LiVHySI a unique payload: Traditionally the space-borne airglow experiments have used photometers for the in situ measurements of atmospheric composition, especially the distribution of the emitting species. Some space-borne airglow experiments have made use of the Doppler information of the emission profiles. However, making airglow measurements over a range of wavelengths spanning visible and IR spectrum using a single experiment has never been attempted earlier.

In this context, the LiVHySI is a unique camera. It is a Linearly Variable Filter (LVF) based instrument that is capable of making simultaneous measurements of the intensity of many airglow emission lines and bands covering a wavelength range of 500 – 900nm, altitude range of 80-600km altitude within the limb of earth. The airglow emissions that are covered by this spectral range are given in Table 1.

Table-1

	Wavelength (λ in nm)	Emission Altitude Range (km)	Type of emission
1.	NI 520.0	100-220	Atomic
2.	OI 557.7	90-120 & 150-200	Atomic
3.	NaI 589.0	90-100	Atomic
4.	OI 630.0	160-500	Atomic
5.	OI 636.4	160-500	Atomic
6.	OH 731.6	80-98	Band
7.	OII 732.0	100-200	Atomic
8.	OH 740.2	80-98	Band
9.	O2 762.0	80-100	Band
10.	OI 777.4	250-350	Atomic
11.	OI 844.6	250-350	Atomic
12.	O2 864.5	100-200	Band

Science Objectives, observations and discussion:
Vertical profiles generated by inverting hyper-spectral air glow images furnish altitude wise density distribution of airglow emitting species, chemistry and hence the physical conditions prevailing at these altitudes. This helps in understanding the dynamics of the upper atmosphere at different altitudes. An inverted air glow hyper-spectral image and vertical profiles derived for 630nm OI and 762nm O2 airglow emission from LiVHySI data is shown in Figure 1.

The most dramatic indicator of the internal couplings of Thermosphere and the Ionosphere (TI) is the latitudinal distribution of their parameters over low and equatorial latitudes. A peculiar double-humped latitudinal distribution known as Equatorial Ionization Anomaly (EIA) prevails over these latitudes. Interaction of EIA with other atmospheric processes leads to anomalies in the wind and temperature distribution known as Equatorial Temperature and Wind Anomaly (ETWA).

Further, the ETWA has been identified, among various other factors, as playing a key role in the generation of Plasma irregularities known as Equatorial spread-f (ESF), having significant implications in the satellite-based navigation. LiVHySI is providing systematic latitudinal and altitudinal coverage of thermospheric, ionospheric composition/ energetic/ dynamics through airglow measurements concerning the EIA and ETWA which is very important as, such systematic measurements are still lacking. The Equatorial Ionization Anomaly (EIA) as observed by LiVHySI is shown in Figure 2.

Over low latitudes, an anomalous enhancement in the neutral thermospheric temperature in the midnight sector has been observed which at times is seen to be as high as that during daytime. This is known as the Midnight temperature Maximum (MTM). It has been suggested that the non-linear interaction of tidal winds with ion-drag could be responsible for MTM.

Interestingly over equator, the occurrence of the Counter Electrojet (CEJ) in the dynamo altitudes during daytime has also been associated with the tidal interaction with local wind. The physical mechanisms for the generation of both, MTM and CEJ remain to be explained. LiVHySI through simultaneous measurements of airglow emissions from the mesopause and thermosphere-ionosphere would provide important insight into the generation mechanism of CEJ and MTM and their interrelationship.

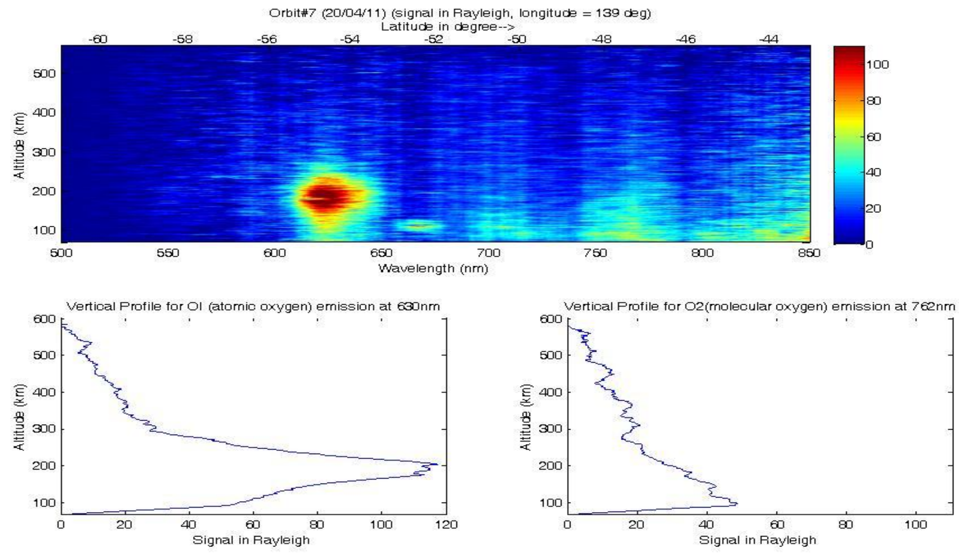


Fig-1

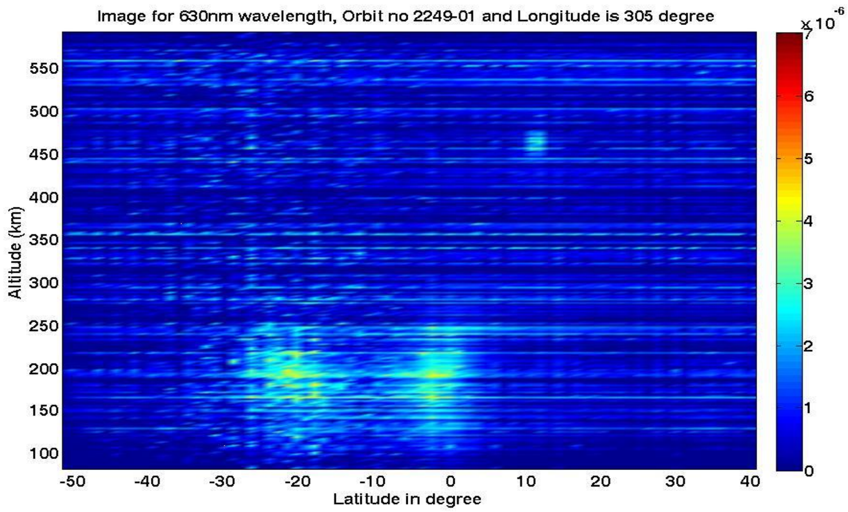


Fig-2

As is known, During Space Weather Events the ionospheric disturbance dynamo (IDD) fields play an important role in the storm-time behavior of EIA and ESF. Two mechanisms are proposed regarding the temporal and spatial variability of IDD fields; (i) that the longitudinal confinement of the thermospheric circulation due to disturbance generated by high latitude heating could cause this variability; (ii) the variation in the duration and amount of excess energy deposited at high latitudes could lead to the observed IDD field changes at any other latitude. The former triggers off Traveling Atmospheric Disturbances (TADs) while the latter alters the global thermospheric circulation.

The neutral atmospheric response to geomagnetic storm/space weather energy input needs to be properly understood. It requires the identification and quantification of the contributions of the internal and external sources to the overall energetics. The low latitude-equatorial thermospheric airglow measurements by LiVHySI along with those at high latitudes would be extremely important in this context. The thermospheric airglow emissions are capable of exhibiting the sudden and periodic changes imposed by the IDD and the TIDs respectively. Therefore, investigation of the spatio-temporal variabilities of these airglow emissions would provide significant handle on this aspect.

Chapter News

Glimpses from Educational Excursion to Jaisalmer & Environs

Prepared By Arundhati Misra & Technical Inputs from Prakash Chauhan

4th November, Night: ***Assemble at SAC Main Gate:*** Members of ISRS, IMSA, ISG, INCA etc and their family, getting started off for Jaisalmer lock, stock and barrel in three luxury buses. A grand start!

5th November, Day-1 : ***Reached Jaisalmer Hotel a little before noon:*** While entering the city, the thing which strikes you is that, this is one place where a 'Horse' is treated more like a Hero, than the Raja himself! So many places are earmarked with the statue of the heroic horse, 'Chetak'. Maharana Pratap Singh's statue is surprisingly missing in most places! The town stands on a ridge of yellowish sandstone, crowned by a fort, which contains the palace and several ornate Jain temples. Many of the houses and temples are finely sculptured. It lies in the heart of the Thar Desert and has a population of about 78,000.

Visit To 'Sonar Kella': Post lunch educational tour took us to the Royal Desert Fort. It reminds us of the famous story and a movie on it- 'Sonar Kella' by late Sri Satyajit Ray. This is a 500 years old fort built by Thakur Bikramsingh. Tour through the fort was a fantastic experience. You have to reach the main Rajdarbar by crossing four gates Suraj pol, Ganesh pol, Bhut pol, and Haoa pol. Within it are many beautiful Havelies and a group of Jain temples dating from the 12th to the 15th centuries. The fort stands almost 30 metres over the city and encompasses an entire living area within its huge ramparts. Walking through the narrow lanes is an experience worth savouring, although the bold cows makes one jittery! People also enjoyed picking up art items, bandni materials, sandstone statues etc, during the walk through the fort.

Young and old, all went up, into the fort, upto the highest point, climbing big steps, manoeuvring dark, narrow, spiralling stairways into the royal chambers of the formidable 'Maharanas' and'Maharanis'. The museum is housed within the fort, displaying the grandeur and might of the Rajput Maharajas of Mewar during that century. When on top of the fort, one gets a breathtaking view of the entire city of Jaisalmer and its surroundings; the landscape encircled by gigantic windmills. You really feel -- 'I am on the top of the world looking down on creation…'.

Fig:1 Golden Fort , Jaisalmer

5th November, Night -2

Boat Ride At Gada Sagar : This tank, once held the town water supply, and was known for providing precious water to the inhabitants of this arid city. There are small temples and shrines even within the lake. However the lake has turned very dirty, and maybe this is the reason why tour operators take us there only after sunset. This filthy lake is an issue which should be taken up by the remote sensing scientists, so that the heritage places can get back their original splendour. The lake needs echo intervention immediately!

6th November, Day-2

1) Visit To Bada Bagh: Another example of a great heritage site, but not well maintained. But people enjoyed going around the cenotaphs of great maharajas. Some of us were also keen in picking up sandstones, resembling gold.

Fig2: Bada Bagh Cenotaphs

2) Visit To Jain Temple: A beautiful temple, and a nice surrounding, with modern camps all around. A local singer enthralled the audience with his beautiful folk songs, and mannerisms. The true sound of the desert!

6th November, Night-2

1) Pack Off For SAM: Post lunch we packed off to SAM, the famous Thar Desert site, very near to Indo_Pakistan border.The majestic sand dunes, the caravan of camels, and the horizon dotted with man made camps and natural acatia trees took us into another world! The sunset across the dunes is in no way inferior to the sunset seen from Darjeeling.

The cultural folk dance, in the SAM camp at night, was another memorable affair which reminded us of our rich cultural heritage. Space technology has taken us to the distant moon, but can we ignore the call of the wild and the nature abundant, on this very earth which has given us our life?

Fig3: Sand Dunes and Camels at SAM

Educational Information: Apart from site seeing around Jaisalmer, participants of the excursion tour received information on the desert formation, geological surroundings of Jaisalmer with special emphasis on sandstone formations in and around city. The process of formation of sandstone, which are the most common sedimentry rocks were explained to participants. The colour of the sandstone of Jaisalmer region is golden-yellow and its main cause the yellow coloured sand found in this region. The participants also saw the samples of fossilised sandstones. It was informed to the participants the during the Jurassic period (~ 180 million years ago) this area was suppose to be having thick vegetative forest cover and proximity to sea, as reveled by fossils found in this region. In the fossil park near Jaisalmer one can find petrified wood fossils carrying signatures of the luxuriant forests in a warm and humid climate, bordering the sea some 180 m.y. ago. The 21 hectare Fossil Park contains about a dozen fossil wood logs lying horizontal in random orientation.

Participants were also taken to SAM sand dunes and a firsthand experience of being in the heart of Thar desert came live to them. They were explained on the processes of the dune formation by wind action and effort being done to provide water through Indira Gandhi Canal in this region. The unique tele-connection of process of desert sand being useful to increase biological productivity in the Arabian Sea was explained to the excursion members. The ironoxide found in the desert sand, when carried through large dust storms, acts as a catalyst to trigger production of oceanic phytoplankton.

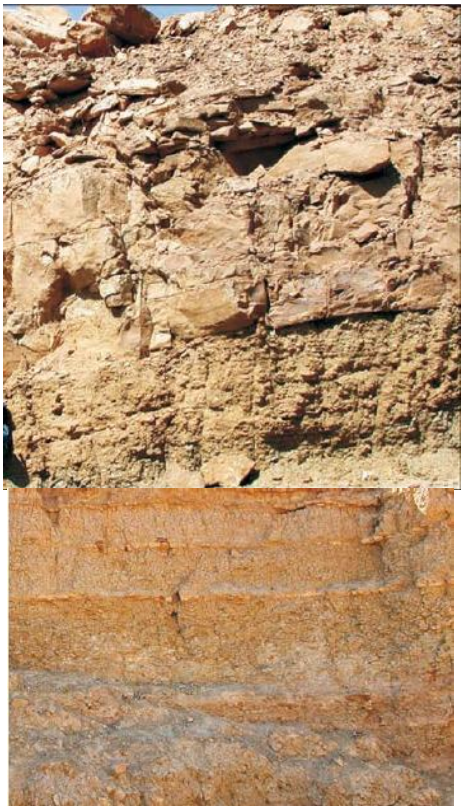


Fig4 : Yellow sandstone formations around Jaisalmer

Fig5 : Desert dust sample being collected in a sand dune

Fig 6: Fossilised sandstone rocks around Jaisalmer. One can see Oyster encrustations and coral fossils in sandstones.

Fig 7: Satellite image showing dust being carried over the Arabian Sea.

Fig: 8 A group photo taken at the SAM Camp before departure to Ahmedabad

7th November, Day-3

Adieu To Thar Desert & Back To The 'Madding Crowd' And Ahmedabad

On the way back, there was stop at a sand dune, which is 30Km from border. Scientists collected data from the dunes for study, shown in Fig 5. Some people had 'joy slip' from the top of the dunes.

Arrival at SAC gate at, 3am, 8.11.11, and back to mundane life.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures* in their own words, either as a brief survey of state of the art or as articles on novel dream concepts related to the specific theme ***"Future Trends in Remote Sensing"***.

The deadline for inclusion in the next issue is **March 20, 2012.**

- Editorial Team

Feedback from Students Nominated by ISRS-AC to ISRS-2011 Symposium and the Pre-symposium held at Bhopal

Quote: I want to thank you for providing me a lifetime golden opportunity to attend the ISRS National Pre-Symposium and Symposium held at Bhopal this year. It was indeed a dream come true for a student like me to have obtained knowledge from very senior scientists having ocean deep knowledge and vast experience in their respective fields.

Learning in such a positive and dynamic environment motivates and inspires students like us to develop skills and start thinking out of the box. The experience I had explained me the meaning of words like discipline, dedication, perfection and management in a much better way than that explained in the oxford dictionary. It was a very pleasant sight to see and experience such senior scientists from ISRO sharing their knowledge with inquisitive students like us in such a humble and polite manner.

I attended the National Pre-symposium tutorial on Satellite Navigation. The tutorial started with a very fundamental note on how has the human navigation evolved from Stone Age followed by Star Age, Radio Age, LORAN Age and the current Satellite Age respectively. To learn how with a GPS device in hand an individual can never be lost on earth irrespective of whichever corner he is in, was very surprising.

Also the knowledge regarding the 'Digital Elevation Model' was indeed mesmerising !

I also learnt about many applications of GPS and was very fascinated to know one of its applications that if we map the errors arising in GPS due to tropospheric region , we can determine the amount of rainfall. Even the errors in GPS can be helpful !

We also went to Kalyanpur, a place for origin of Indian Spheroid and also the place of intersection of GREAT ARC Series , on the second day of pre-symposium tutorial and applied the theoretical knowledge received on first day in class-room in a practical way itself on ground zero there. In the National Symposium on Empowering Rural India through Space Technology we learnt that Remote Sensing has applications in almost every field as for example : Be it a case study on Rural Transport and Rural Tourism, Be it a case study on Development of 3D city models using Geoinformatics Techniques, Be it a case study on monitoring of vegetation using NDVI profiles, Be it a case study on Geo-Visualization in 3D environment, or be it a case study of an entire village in terms of population, type of family- joint or nuclear, source of income , type of houses, etc. Because of this I had a chance to broaden my horizon of thinking and understand in a better way how beneficial is Space Technology and Remote Sensing is in actual means for a vast country like ours !

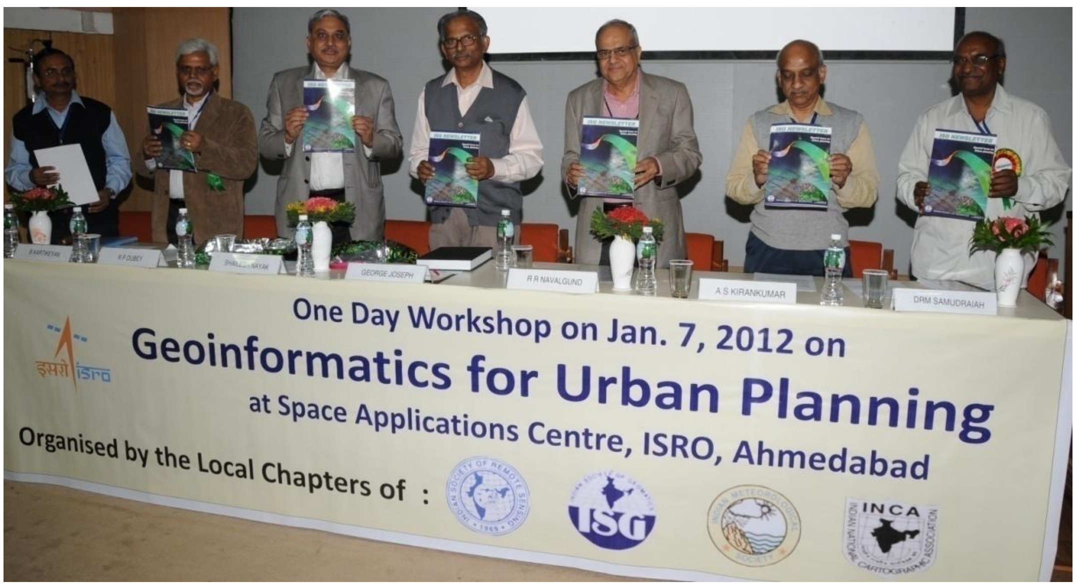
I am greatly indebted to ISRS-Ahmedabad Chapter for selecting me and giving me a chance to attend this ISRS National Symposium-2011. Opportunities like this help a raw piece of carbon mature into a diamond!

Also I will be very grateful if I am blessed with such opportunity in near future. Unquote - **By Kunal K Maheshwari, 5th Semester; ECE, U. V. Patel College of Engineering; Ganpat University.**

Quote: I am very thankful to you that you gave me a chance to attend such a wonderful event. The overall event was fabulous. I never attended such an event before. The arrangements made in the event were very nice and I enjoyed all the events that I attended on all these days. The scientists that came to explain the topics were fabulous and very co-operative with us." Unquote- **By Yash Gorakh**

A Brief Report on Workshop on Geoinformatics for Urban Planning organized by the Local Chapters of ISRS, ISG, INCA & ISG on Jan 07, 2012

Development of metropolis influences the surrounding urban fringe and in a wider sense it affects the activities and economy of the region. The productivity of the region in turn impinges on the economy of the metropolis and as a result, structure of an urban centre develops and provides opportunities for increasing employment, specialized services, and facilities. Hence, it is evident that planning for an urban area cannot be considered in isolation and the physical development should go hand in hand with the changing demands and patterns of activities and functions. In this context, a one-day workshop on the topic **"Geoinformatics for Urban Planning"**, was jointly organised by the Indian Society of Remote Sensing, Ahmedabad Chapter **(ISRS-AC)**, Indian Society of Geomatics, Ahmedabad Chapter **(ISG-AC)**, Indian Meteorological Society, Ahmedabad Chapter **(IMSA)**, and Indian National Cartographic Association, Gujarat Branch **(INCA-GB)**. The invited speakers gave very informative talks related to workshop themes like urban planning, Urban Infrastructure Development and Urban Environmental Assessment. More than **25 posters** were presented during a poster competition and its being an overwhelming response from more than **200 participants**.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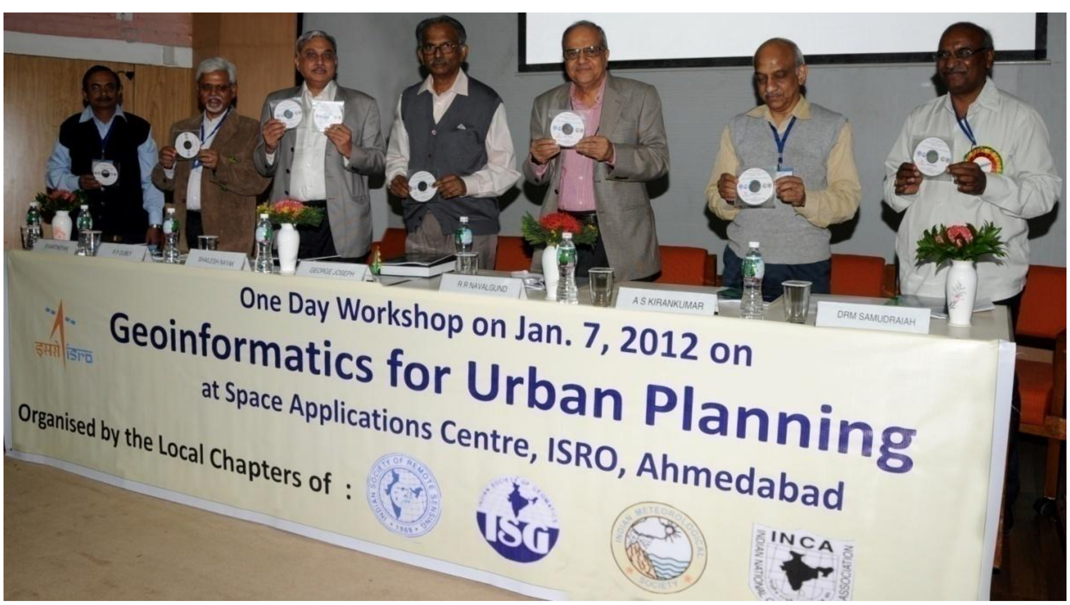
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ROLE OF REMOTE SENSING AND GIS IN URBAN PLANNING


AJAI
SHAILESH NAYAK
One Day Workshop on Jan. 7, 2012 on
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ISG
INCA

Invited Speakers during the Workshop

Readers' Views on Workshop on Geoinformatics for Urban Planning

Quote: Really it's true professionalism & I like to congratulate the organizing team members for conducting the entire workshop so well. *Unquote.* **– Dr. A. K. KANDYA, Professor& Dean, Silver Oak College of Engineering & Technology, Ahmedabad.**

Quote: I have a suggestion to retain this format of one day workshop with a periodicity of once in 2 years to bring all members together and the students pursuing Geomatics and Remote Sensing plus relevant to other Societies for a valuable exchange of wisdom from seniors to the young generation. You may consider forwarding this suggestion to the various societies. There could a possibility to include at least one topic each under the advancement taking place amongst the four professional societies. Last but not the least I enjoyed interacting with the budding professionals and sharing some wisdom. *UnQuote.*- **Aishwarya Narain, Member ISRS-AC, IMS-AC, INCA Gujarat Br., ISG.**

Quote: Congrats! for the successful event. *UnQuote.* **- Kishor G.Domadia, Head, SEPD/ SEDA/SAC**

Quote: It was really a great experience listening all the expert speakers on the subject of "Geoinformatics for Urban Planning". It really helped me to think and develop an interest in some of the subjects discussed in the conference. I am very thankful to all who has organized such an event and gave us the opportunity to present the poster and chance to interact with various professionals working in the field of geoinformatics & urban planning. *UnQuote* **- Utkarsh Shah, JRF, CEPT University.**

Quote: Many thanks to you and all other management committee for providing such a great opportunity to be a part of such a great workshop. I really enjoyed being a part of it. *UnQuote.***- Zia ur Rehman (CEPT Geomatics department), Ahmedabad**

Forthcoming RS related Conferences	
Feb 7-9 2012	**Indian Geospatial Forum**, Gurgoan, Haryana, Web: *www.indiageospatialforum.org/*
Aug 25-Sep 1, 2012	**ISPRS Congress 2012**, Melbourne, Australia, Web: isprs2012.org
Forthcoming Chapter Activities	
Feb 29, 2012	**LN Calla Memorial Lecture** on Antennas for Space Applications by **the distinguished speaker is** ***Dr. S B Sharma,*** **Director, Indus Institute, Ahmedabad.**
March 28, 2012	**28th Annual General Body Meeting along with Elections for ISRS-AC Executive Council 2012-2014** at Space Applications Centre, Ahmedabad

Signing Off

Dear Reader,

The Editorial Team thanks Director, SAC & President, ISRS **Dr. R R Navalgund** and Associate Director, SAC **Shri. A S Kiran Kumar** for writing messages for this special Issue.

We had a Guest Editor **Dr. Prakash Chauhan**, who has compiled a number of articles pertaining to the theme of this issue namely "Remote Sensing for Astronomy & Planetary Sciences" from India and abroad apart from arranging for interviews with two eminent personalities in this field. The editorial team has compiled several chapter related news items and a few general articles. The theme articles have been grouped together under a few sub-topics namely **Astronomy & Planetary Sciences, Moon Specific, Mars Specific and Sun Specific** for the convenience of readers.

We thank a few executive committee members of the chapter namely **Smt. Arundhati Misra** & **Dr. Abha Chhabra** for providing inputs on chapter events. We thank the office bearers and our secretary **Dr. Parul Patel** & Chairman **Shri. DRM Samudraiah** for their active support & suggestions.

We thank **Shri. DNVSSN Murty** and the **Librarian & staff members of SAC Library** for bringing out a few number of copies of this issue in print form.

Each member of the Editorial Team has contributed in some way or the other in bringing out this Issue. Particularly, **Shri. Amit Shukla** has complied the snippets on Naturally & historically remote sensing and **Shri. Yogesh Verma** has supported in formatting this voluminous issue.

The next issue of Signatures is planned to be brought out as a special issue on the theme **"Future Trends in Remote Sensing"**. Each one of you is requested to contribute your pet/dream concepts in Remote Sensing that you wish realised in near future for this forthcoming special issue.

Please send in your contributions for future issues and any feedbacks on the current issue to the email: **nandakumar@sac.isro.gov.in.**

For the Editorial Team,

R. Nandakumar

ISRS

Signatures

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