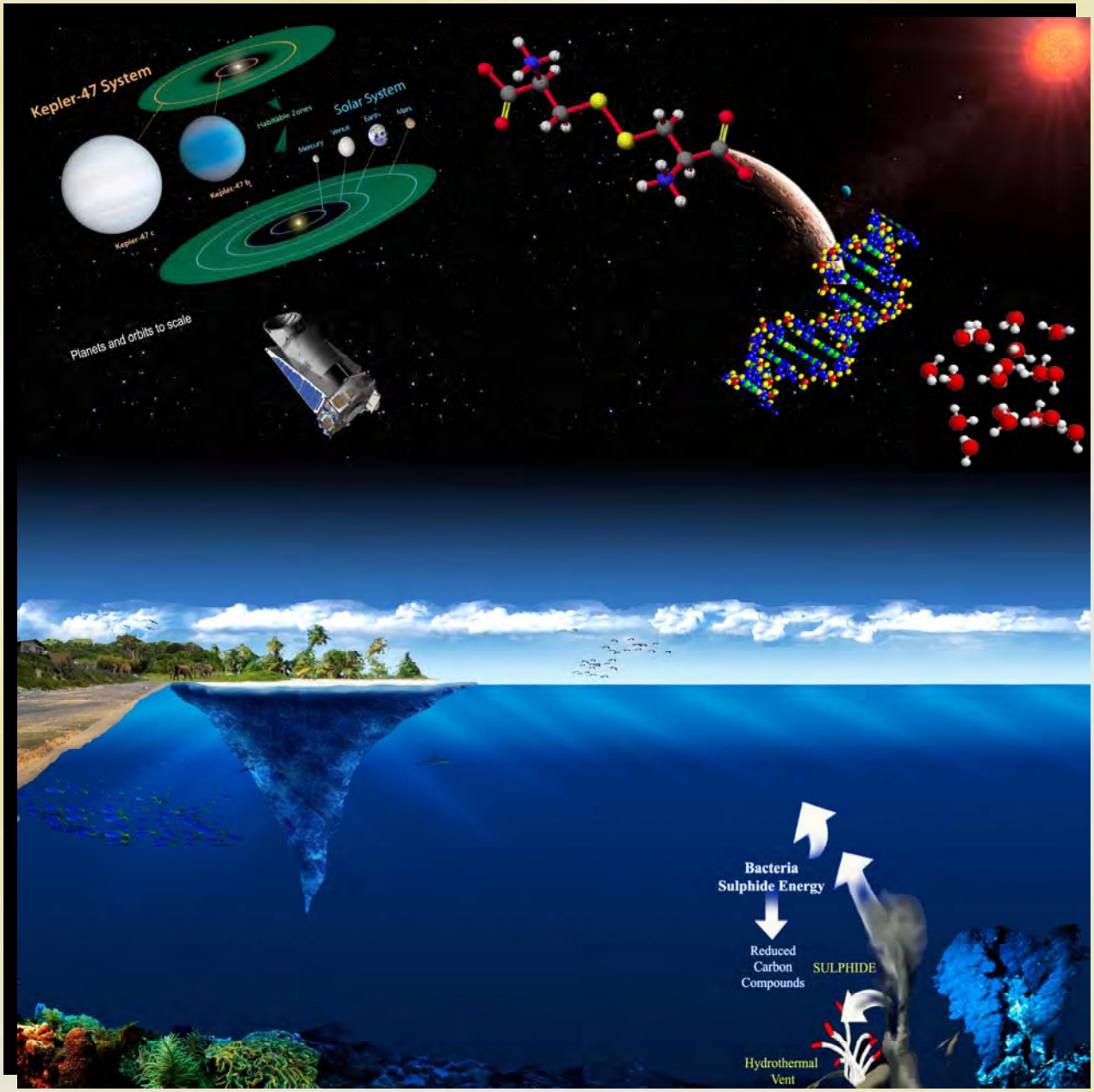
PLANEX

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Planetary Sciences and Exploration Programme

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Newsletter



PLANEX

PLANEX has initiated a quarterly magazine "PLANEX Newsletter" aimed towards popularizing planetary science and exploration among the populace. It has evoked a lot of interest amongst the readers.



The newsletter aims to increase awareness and popularise latest research and technological activities being undertaken in the field of Planetary Sciences and Exploration through publication of inspirational excerpts, popular scientific and technological articles, latest News Highlights, Planetary Mission Stories and Updates, available research opportunities for blooming researchers and so on.....

Submission of Articles

Articles related to Planetary Sciences and Exploration and its allied fields for publication in PLANEX Newsletter are solicited. The article will be published after successful completion of a review process. For further details related to article submission, its length and format etc., please contact at the following E-Mail IDs

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planexnews.prl@gmail.com

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PLANEX

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COVER PAGE

The theme shown on the **Cover Page** (not to scale) portrays life and habitability in our universe. Possibility of life exists anywhere from deep ocean floor on Earth to inter stellar space. Unlike photosynthetic life, complex chemosynthetic life is also possible. Kepler's hunt for habitable planets so far discovered 3845 planet candidates of which 961 are confirmed. Kepler-47 is one such planetary system discovered by Kepler mission which is shown on top-left. The Kepler Spacecraft is also shown. A potentially habitable Gliese 581 zone is shown at top-right. Search continues for detecting life-supporting molecules in extra-terrestrial environments. Related news items and articles about "life on a tidally locked planet" and "Chemosynthesis" are covered in this issue.

(**Image Credits:** kepler.nasa.gov ; http://en.wikipedia.org/wiki/File:Blacksmoker_in_Atlantic_Ocean.jpg ; http://www.nasa.gov/images/content/59094main_DNA_Molecule.jpg ; http://burnlipo.com/wp-content/uploads/2013/04/Deep-Sea-1920x1080-Wallpaper-HD.jpg ; http://www.pmel.noaa.gov/eoi/nemo/education/images/chemosynthesis.jpg)

Cover Design: Durga Prasad Karanam

EDITOR'S DESK

Are the earthlings alone in the universe? This eternal inquisitiveness to know more about those mystery species sharing the cosmos with us has been the driving force for several of our planetary endeavors. The current issue of the newsletter delves into astrobiology with interesting conceptual and informative articles exploring, extra terrestrial life. Related news highlights summarize recent advancements in our search for water in the outer space, a mandatory prerequisite (…considered by many) for sustainance of life anywhere.

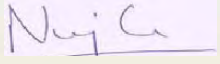
For long, the Moon's tidal locking with the Earth is understood to be responsible for our own survival. Prof. A. K. Singal of PRL, brings out an idea sharing article elaborating this concept in the wider perspective i.e. relating life to the tidal locking of planets with their stars.

After familiarizing with a bit of astronomical concepts, but naturally, it would be stimulating to know the processes which can be expected to support life in the outer space. Dr. Anindita Das and her team from NIO, Goa attempts to relate life in deep seas here to the ones expected on Mars, through chemosynthetic mode of survival. Seasoning the issue are the next two articles discussing specific advantages of RADAR technology, which has been extensively used to detect water in permanently shadowed regions of the Moon, and suitability of Commercial-Off-The-Shelf (COTS) components in space applications.

One of the noticeable events in lunar exploration during recent times was robotic landing on the Moon after a hiatus of around four decades - by Chinese mission Chang'e – 3 on Dec. 14, 2013. The Mission story column compiles relevant details of Chang'e - 3 such as geological context of the landing site, science goals and payload inventory of the mission. Mission updates cover the most awaited successful launch of GSLV-D5 with indigenous cryogenic stage, health of MOM along with accomplishments and plans of other space agencies.

The events briefed in the issue include 'From Mantle to the Moon' – a scientific meet in memory of Prof. D. Lal (at PRL), NSSS 2014 (at Dibrugarh university), 14th PLANEX workshop (at DDU Nadiad), and PLANEX Projects progress review meeting (at PRL). Before signing off, it's my pleasure to inform you that we have recently launched a new reader-friendly website, which can be accessed at: http://www.prl.res.in/~planex/planexnews/

Keep smiling and as always
Happy reading ☺



Neeraj Srivastava



READER'S COLUMN

"…..It is nice to see all the volumes of PLANEX newsletters. It gives me immense pleasure to see the rise of this unique newsletter, and makes me proud to be a part of this newsletter….."

- Diganta Kumar
Department of Geological Sciences,
Gauhati University, Guwahati

"…..Congratulate you for the newsletter. It shares a lot of information, thank you great job! Updating my knowledge through these newsletters...Thank you once again!....."

- R.S. Aarthy
Department of Geology,
Anna University, Chennai

"…..We are very happy to get the PLANEX newsletters. It is very informative. We wish to receive the newsletters in future also….."

- Darshana Pandya
Community Science Centre, Vallabh Vidyanagar

"…..Thanks for the wonderful issue. Great coverage on Mars….."

- T Parimalarangan
ISTRAC-ISRO, Bangalore

"…..Congrats, really a super issue. For a person like who has been involved with MOM right from the beginning it is a collector's item. A great issue! Thanks a tonne for it….."

- Srinivas Laxman
Space Journalist

"…..Thanks for an awesome issue. Thank you for keeping us all in loop and getting engaged. I look forward to many such fruitful issues from PLANEX team….."

- Pillutla Radha Krishna
Pondicherry University, Pondicherry

NEWS HIGHLIGHTS

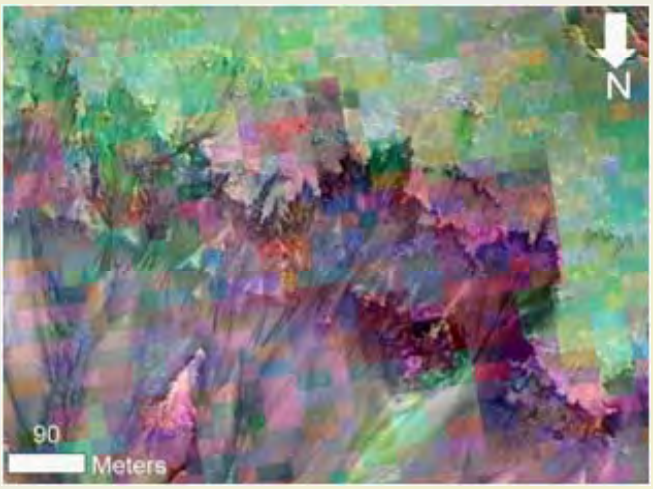
Volatile and Organics in Gale Crater

On its way before exploring Mount Sharp, Curiosity investigated some of the right rocks within Gale crater that may ultimately determine whether Mars ever had an early environment supporting water and habitability. At Gale, the rover examined the drilled powder samples from two lowest stratigraphic units (John Klein and Cumberland; ~3m apart) within Yellowknife Bay formation, unofficially referred as the Sheepbed member. Yellowknife Bay was chosen as the first scientific exploration target for Curiosity as there are evidences for presence of fluvio-lacustrine depositional systems. It is believed that the exposed strata may have locked evidence of ancient habitability, if any, linked within its elements and compounds. The extracted powders (gray in color) were delivered to the Sample Analysis at Mars (SAM) and Chemistry and Mineralogy (CheMin) instruments. From both the drilled units, almost similar amount of evolved H_2O gas was detected, whereas O_2 gas abundances released from Cumberland were nearly eight times the release from John Klein. The typical sources for release of H_2O gas at low temperatures (<300˚ C) are H_2O adsorbed as thin film on surfaces and internal surface H_2O associated with exchangeable cations in 2:1 phyllosilicates (e.g., smectite). The dehydroxylation of the octahedral layer of a 2:1 phyllosilicate (e.g., smectite) is connected to the high temperature (450˚-835˚ C) release of H_2O gas. The decomposition of perchlorate or chlorate salts is inferred to be the source for released O_2 gas. The CO_2 releases from the samples have shown peak values at temperatures below 300˚ C and further analysis of the gas has shown that additional C sources are required to explain the evolved CO_2. Overall, the probable CO_2 sources include combustion of terrestrial organics dwelled in SAM (for a small portion of the evolved CO_2), low-temperature acid dissolution of Martian carbonates, and combustion of indigenous and/or exogenous organic materials. SO_2 and H_2S also released from both the units during SAM analysis, and both reduced and oxidized S volatiles were detected that suggests possible presence of both the oxidized and reduced S species in all the samples. Detection of evolved H_2S was found consistent with high temperature H_2O and evolved SO_2 had peak detections at 600˚-625˚ C. Pyrrhotite and probably pyrite are regarded as candidate S sources for the SO_2 and H_2S releases from both the units. SAM detected the abundance of several N-bearing compounds from both the units that include NO, HCN, CH_3CN, ClCN, CF_3CN, and $C_3H_4F_3NO$. Among organic compounds, SAM detected certain presence of chloromethane and dichloromethane in samples from both the units. In comparison to Rocknest windblown materials, large quantity of chlorinated hydrocarbons in the mudstone was detected by Curiosity that indicates possible preservance of indigenous Martian or meteoritic organic carbon sources within mudstone. Apart from this, it is definite that at least the carbon source for chlorinated hydrocarbons is not of Martian origin.

Source: http://www.sciencemag.org/content/343/6169/1245267.abstract

A revisit to water-like flow features on Mars

The mysterious flow-like feature named Recurring Slope Lineae (RSL) gained attention when HiRISE camera onboard MRO revealed that these linear flow features appear and disappear on Martian surface. These flows are observed to form and grow during warm seasons, and fade or completely disappear in cold season. A closer look at this phenomenon, mainly for analyzing the spectral signatures around RSL's during its growth and lightening, has been taken to understand how convincingly water or briny water may be at work in forming such season-linked flows. Over 13 confirmed sites of RSL were investigated by CRISM for detecting spectral signatures coupled with water or salts. During the initial investigation of these RSLs three years back, no chemical sign of water appeared which was obvious due to quick evaporation of water. Instead, a flow instigated by briny water was speculated that might adjust grains or alter surface irregularity in a way that darkens the form. Another likely explanation could be that the marks have darkened due to moisture, whilst an increase in the more oxidized component of the minerals - which may together suggest that water has indeed played a role. In the latest CRISM analyses, distinct spectral signatures of ferric and ferrous minerals over most of the RSL sites



Seasonal dark flows on a Martian slope. Refer to the source for understanding colors associated with these flows

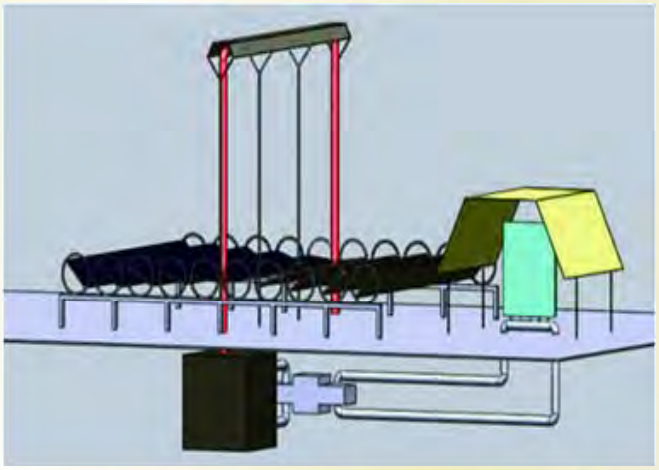
were detected, whose spectral strength was found varying in a similar pattern as that of RSLs. Despite geomorphic, visual and temporal data supporting the liquid hypothesis for RSL, CRISM IR water-related diagnostic absorption features (at 1.4 & 1.9 µm) were not detected at any of the RSL sites. The absence of water-related absorptions also rules out hydrous ferric salts as a spectrally dominant phase on the RSL slopes, regardless of their presence in the subsurface throughout the southern mid-latitude soils of Mars. The observed spectral fluctuations could be possibly attributed to removal of a fine-grained surface component during RSL flow, precipitation of ferric oxides, and/or wetting of the substrate.

Source: http://onlinelibrary.wiley.com/doi/10.1002/2013GL057893/abstract

Night time exploration of Moon seems easier now

Beside some lunar polar craters, all parts of the Moon see around 14.77 days of sunlight followed by 14.77 days of night. This calls upon the need for carrying heavy batteries or the use of nuclear energy to provide energy to vehicles/rovers and/or astronauts/crew during lunar nighttime. A team of researchers has thus explored two options of storing energy on Moon during daytime, which can be used later during the nighttime investigations. The overall system comprises of series of mirrors arranged in a manner so that it can converge daytime sunlight over a thermal mass, such that it transmits the required energy for the rovers and/or equipment to operate during night. Within the first system, the reflected daytime light using a system of mirrors heats the thermal mass, which is originally made from modified fragments of regolith or typical lunar soil. The generated heat would be stored and could be used during the nighttime operations. In the second system, a complex arrangement of mirrors and heat engine is utilized. The solar rays are concentrated using these mirrors (Fresnel reflectors), which then heats the fluid filled within a tube. As a result, the fluid is converted into gas that heats the thermal mass. Thereafter, during the lunar night, this heat is transferred to a Stirling engine that produces the required amount of electricity to drive the equipments. The focus of both these systems is to solve the needs for greater energy, such as in manned mission, where nights have to be spent on the Moon.

Source: http://www.sciencedirect.com/science/article/pii/S0094576513002567



Novel system for producing electricity on Moon

New insights on the compositional properties of the surface materials of Phobos and Deimos

Understanding the composition of a planetary body provides key insights on the properties and origin of that specific body. Researchers are thus trying to study the compositional properties of two asteroid like small sized moons of Mars; Phobos an ancient body ~4.3 - 3.7 Ga and Deimos. This attempt would eventually lead us in deciphering it clear whether these bodies are made up of materials from Mars or they are pointing towards any possible primitive material derived from other parts of our solar system. Earlier, from the limited available data, it was thought that these moons of Mars were irregular, small sized, less denser dark bodies generating almost no spectral features in the visible-ultraviolet wavelength range. With the advent of new datasets, it could be further established that Phobos is composed of heterogeneous surface with two spatially coherent components; one, a more or less flat spectrum: also referred as blue unit, and another with a spectrum in which the slopes are steeper towards the NIR, also referred as red unit. The spectrum of Deimos was found to be more closely related to red unit. Phobos was thus found to be spectrally diverse and having higher density than Deimos and favoring much of porous material. Recent multispectral imaging data from HRSC onboard Mars Express, HiRISE onboard Mars Reconnaissance Orbiter (MRO) and NIR-VIS spectroscopic data obtained by OMEGA onboard Mars Express and CRISM onboard MRO have largely helped in characterizing major units on Phobos. The studies shows that both the moons are more or less low albedo bodies and visibly brighter than few C-type asteroids. They do not display any amount of prominent absorptions of ferrous minerals such as olivine and pyroxene and neither any other diagnostic spectral features are observed. Few localized matter on Phobos

present a distinct "blue" unit or flatter continuum and the spectra's from red unit of both Phobos and Deimos are roughly similar. Further, using the colour data, it has been observed that the surficial properties of Phobos are not identical. Since, different sides of the moons will have an effect of varying environments. It has been suggested that the moon's surface are possibly covered by fine grained regolith material. Presence of dust rings is also envisaged; however, detailed studies are required to further elaborate on this aspect. A thorough understanding on the compositional properties and detailed sample analysis is still a need in order to identify the nature and geology of various materials as well as for achieving an in depth knowledge on the origin of Phobos and Deimos.

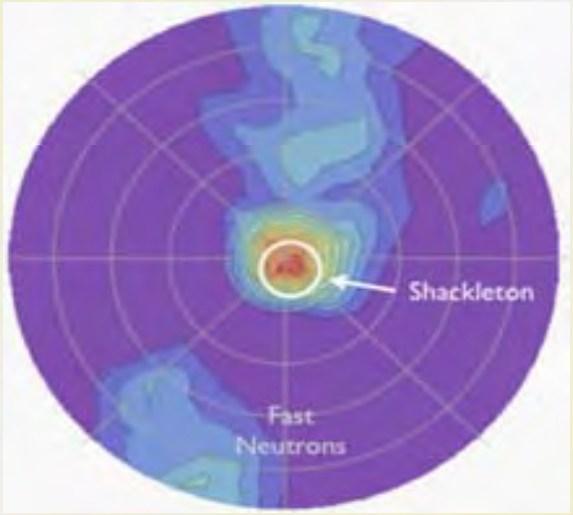


Visible/NearIR color composite images of Phobos from MRO HiRISE

Source: http://www.sciencedirect.com/science/article/pii/S0032063314000439?np=y

Detection of enhanced surface hydrogen within the Moon's Shackleton Crater

NASAs Lunar Prospector and Lunar Reconnaissance Orbiter derived lunar neutron datasets have provided key insights on the presence of enhanced hydrogen abundances and its distribution over lunar Polar Regions. The permanently shadowed regions on the Polar areas have always been the potential zones for surveys, since the cold traps present here could be an important possible volatile reservoirs. Orbital neutron spectroscopy is the most accepted method as it is capable of providing hydrogen concentration measurements as well as stratigraphic variations within few meters of the surface. Hydrogen enhancement analysis through epithermal neutrons presented a highly asymmetric distribution on the poles with an average abundance of 106 ± 11 ppm H. On contrary, analysis using independent fast neutron data illustrated a single, localized and statistically important element spatially coincident with Shackleton crater. Neutron suppressions within epithermal and fast region point towards possible hydrogen enhancements. Earlier studies were confined to few specific circumpolar latitude bands outside the Polar Regions. Due to the absence of permanently shadowed areas on the lunar mid latitude regions presence of widespread volatile compounds are not much expected. Although, all the regions cannot be ruled out, since the lunar mare regions which are higher in Fe, Ti, Gd and Sm can have an effect on the neutron count rates at different energy regions. Thus, in order to reduce this influence, researchers selected the mid latitude highlands. In the entire analysis a parameter "λ" was employed to identify the statistically important feature and to differentiate the consistency between the acquired neutron data and the hydrogen poor hypothesis. Count rate data was used to understand whether the pixel value relates with enhancement or deficit. Through the analysis of maps it was observed that the epithermal neutrons presented a circumpolar distribution till the Cabeus region wherein the fast neutrons exhibited the feature that was spatially coincident with Shackleton crater. On analysing the water content distribution it was seen that the statistics is directly correlated with the hydrogen abundance. Composition of regolith is assumed to be ferroan-anorthosite. Neutron count rates from varying neutron energy ranges were compared to obtain an understanding on the hydrogen burial depth. Through this analysis, fast neutron discrepancy in a specific zone was observed near Shackleton crater pointing towards bulk hydrogen enhancement.



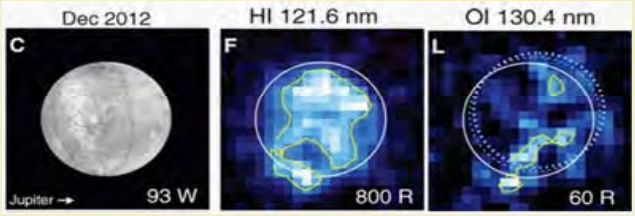
Enhanced bulk surface hydrogen concentrations within Shackleton crater

Source: http://www.sciencedirect.com/science/article/pii/S0019103514000840

NEWS HIGHLIGHTS

Water Vapor over Europa's South Pole

Jupiter's sixth closest moon, Europa, is the sixth-largest moon in the Solar System. Earlier, magnetometer measurement has confirmed the existence of liquid water under the icy crust of Europa. This thrust the researchers to look at Europa by using Space Telescope Imaging Spectrograph onboard the Hubble Space Telescope under optimum timing conditions (Dec., 2012); when maximum variation of Jupiter's magnetic field is orientated towards Europa. This configuration offers spatially homogeneous, yet time variable emissions originating from the periodically changing magnetospheic conditions on Europa. In addition, this causes an aurora over the Europa's South Pole. During the 7 hours observations of this event HST recorded faint ultraviolet emitted light. The observation was focused over the limb of Europa, where the surface reflectance is marginally influenced. Excited atomic oxygen and hydrogen produce this aurora glow and detectable OI 130.4-nm and Lyman-α emissions were persistently found above the southern limb of Europa. The possible explanation that stems out is that, when Jupiter is further away from Europa (apocentre), the long surface cracks called 'linea' on Europa might be venting water vapour plumes into space. The linea experience differential surface stresses and open the fissures when Europa is unsqueezed at apocentre. The vents are narrowed/closed when Europa is closest to the Jupiter. Based on the studies from future HST observations, Europa would become the second moon in the solar system known to have water vapour plumes; however, the crown remains with Saturn's moon Encleadus.

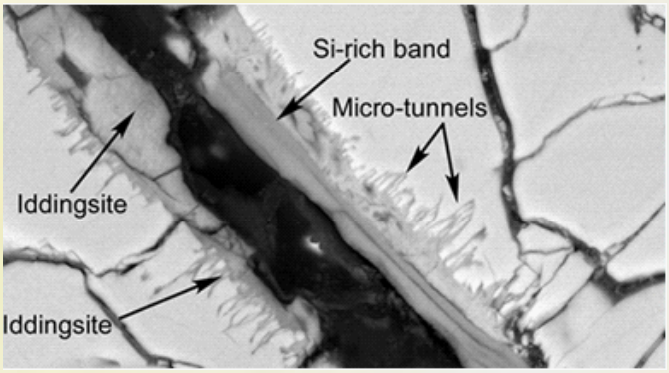


Eruption of Europa's south pole water vapor plumes

Source: http://www.sciencemag.org/content/343/6167/171.full

Martian Meteorite Yamato: Recorded history of Mars!

Mars was continuously under surveillance to understand its ancient water activity through orbital based images and/or by thin sectioned meteorite images. The major difference between them is, the former maps the surface of Mars in few 10's of meter to understand the present state, whereas the later uses meteorite samples and scan in few 10's of micrometer level to look at the past records. Researchers from Jet Propulsion Laboratory, peep inside an ancient Martian meteorite named Yamato (Y000593), which was found on the Yamato Glacier in Antarctica in 2000. This meteorite belongs to the nakhlite classification, a subgroup of Martian meteorites. The Martian meteorites are distinguished by the composition of oxygen isotopes within the silicate minerals and trapped Martian atmospheric gases. Two distinctive sets of features associated with Martian-derived clay are found using the scanning electron microscope image. First, throughout the olivine crystals in sample, tiny tunnels and micro-tunnels structures displaying curved and undulating shapes were observed, which is consistent with bio-altered textures observed in terrestrial basaltic glasses. Second, nanometer- to micrometer-sized spherules sandwiched between layers within the rock, distinct from carbonate and underlying silicate layer. Yamato 000593 reveals unique features, viz. evidence of aqueous alterations as seen in the clay minerals and the presence of carbonaceous matter associated with clay phases. These substantial signatures reveal that water reservoir were active during the early history of Mars.



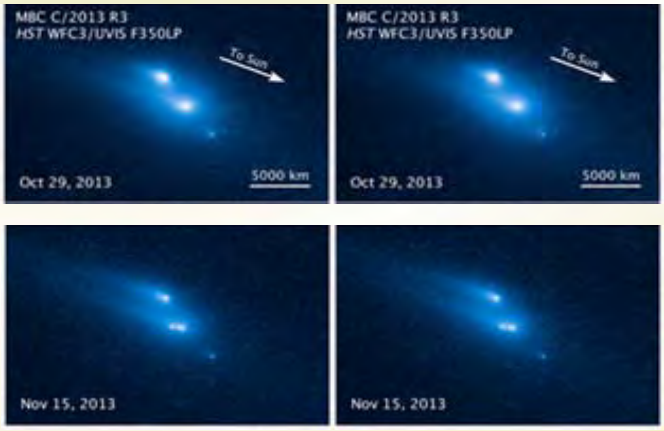
Thin section of Y000593 showing micro-tunnel

Source: http://www.jpl.nasa.gov/news/news.php?release=2014-065

Spectacular disintegration of Asteroid captured by HST

One of the advanced electronic eyes Hubble Space Telescope (HST) is orbiting above the Earth's atmosphere to explore the universe. Until now, HST has seen the closest and farthest objects in the universe, but on late 2013, it witnessed one of the spectacular events i.e., disintegration of an asteroid in the asteroid belt. Based on the observations from Keck Telescope, Hawaii, the HST was made to focus its attention to observe the crumbling asteroid named P/2013 R3. The HST observation showed nearly 10 embedded objects, each with their own comet-like dust tails.

Among these fragments, four are ~350m in size, whereas the smallest fragment size ~180m. They are drifting away from each other at 1.5 km/h. The asteroid is disintegrating due to subtle effect of sunlight that causes the rotation rate to slowly increase over time and pull apart due to centrifugal force. This scenario is called YORP effect and this is the first time it was observed using images. The P/2013 R3 breakup may be caused due to weak, fractured interior, which probably resulted from numerous non-destructive collisions with other asteroids in the belt sometime in the last billion years. The disintegrated asteroid in the future will provide a rich source of meteoroids; most of them plunge into the Sun. But, some of the small fractions of the debris may blaze our skies as meteors and finally land in enthusiast meteorite researcher's hand.

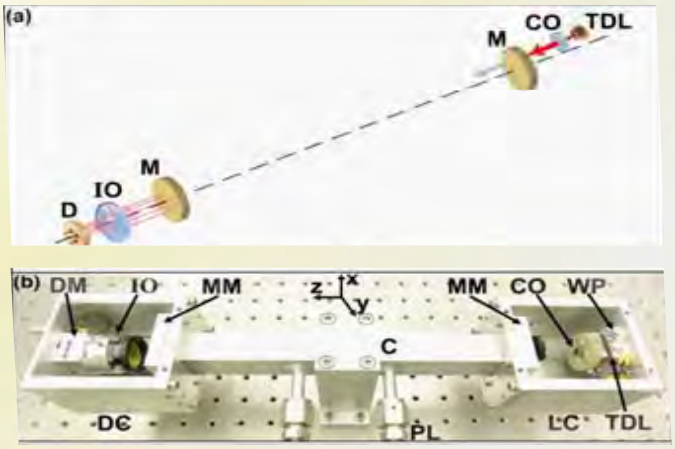


Asteroid fragments after breakup are up to ~350m

Source: http://hubblesite.org/newscenter/archive/releases/2014/15/full/

Advanced laser techinque in 1881 nm region for in-situ detection of H_20

Recent advances in the instrumentation and sensor capabilities have made it possible to extract significant evidences on various science issues that were mystery in the past decade. Recently, researchers have studied and analyzed how an extremely sensitive prototype tunable diode laser spectrometer is efficient in identifying water vapor and its isotopologues in 1881 nm region. The instrument design is based on wavelength modulated Cavity Enhanced Absorption Spectroscopic (CEAS) measurements. This instrument is highly sensitive in obtaining its measurements from few kilometer long absorption path lengths. This has been made possible by multi passing of laser light that can be tuned in a small sized confocal optical cavity. Though few km long path lengths are not difficult to be acquired through CEAS, the instrument detection capability is still lessened due to the reduction in the signal to background ratio. This is because, during the measurements, due to the overlap in the circulating laser light that produces optical interference fringes large amount of undulations takes place in the cavity transmission spectrum. In order to cope up with this problem, the instrument is designed in such a way that the light is infused in an off-axis direction. Later, by advanced Wavelength Modulation (WM) techniques, the remaining oscillations are smoothened. This technique is advantageous, as it primarily helps in reducing the noise produced by lasers and detectors and later helps in increasing the signal to noise ratio. In addition to this, the detection of very weak absorption features is possible. ~1881 nm region was selected for the studies due to the presence of various absorption lines of water isotopologues such as $H_2{}^{16}O$, $H_2{}^{18}O$, $H_2{}^{17}O$ and HDO. Similar other detailed analysis and studies using laser spectroscopy will definitely provide us key insights on understanding and obtaining substantial measurements on water present in the atmosphere, surface, near or subsurface reservoirs.



Layout of the single-channel spectrometer

Source: http://www.sciencedirect.com/science/article/pii/S0032063314000130

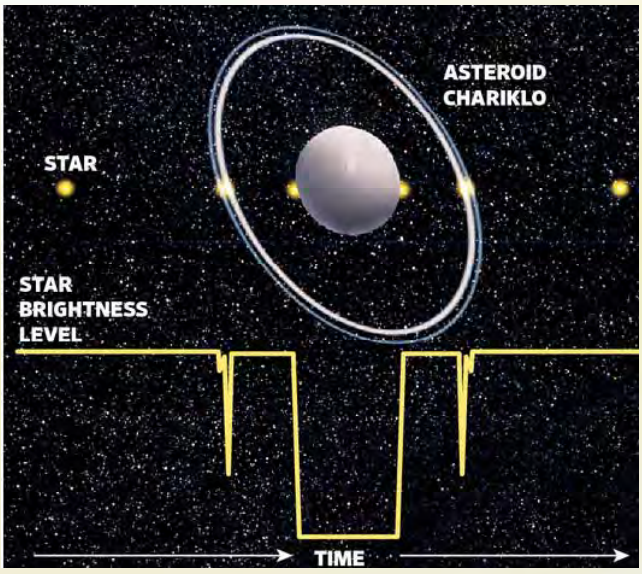
Eureka! Rings around an asteroid

Among the four Jovian planets, Saturn has the most spectacular ring systems than Jupiter, Uranus and Neptune. Till now there are no reports of rings around any other planetary bodies or asteroid. But, for the first time, astronomers have observed two rings around an asteroid named Chariklo, which is orbiting between Saturn and Uranus, whose size is 124 ± 9 km only. On June 3, 2013 Chariklo passed in front of a distant star, creating a dip in observed light from the star, which was observed using telescopes at seven different locations. Astonishingly the

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NEWS HIGHLIGHTS

astronomers observed two unexpected dips in recorded starlight, which came before and after the dimming caused by Chariklo itself. On careful observation of these complementary dips provided by Chariklo occultation, it was found out that they are two closely spaced but distinct rings surrounding the asteroid. Thus, a multi-chord stellar occultation revealed the presence of two dense rings around Chariklo, whose widths are about 7 km and 3 km with an orbital radius of 391 and 405 km, and they are separated by a gap of 9 km. The formation of rings is yet to be solved, but one possibility is that, an impactor that excavated icy materials from Chariklo's outer layer and created disk of debris around Chariklo, and formed into rings. The sustainability of the ring around Chariklo speculates that the impact might have occurred at very-low speed for the particles to remain in the orbit. This finding has proved that the ring formation was possible from minor bodies like asteroids, earlier rings had been found only around the largest planets. This created an open challenge to the researchers, to think about the ring formation by smaller bodies likes asteroids, which are predominant in our Solar System.



Asteroid with two rings detected by dip in observed brightness level

Source: http://www.nature.com/nature/journal/vaop/ncurrent/full/nature13155.html

FLASH NEWS

» Erupted plume height at Grimsvotn Volcano correlated with magma pressure change
Link: http://www.nature.com/ngeo/journal/v7/n3/full/ngeo2044.html

» Another planet with water in its atmosphere
Link: http://www.sciencedaily.com/releases/2014/02/140225101737.htm

» Map of Moon's north pole stitched by 10,581 LROC images
Link: http://lroc.sese.asu.edu/gigapan/

» Mercury contracted far more than previous estimates
Link: http://www.nature.com/ngeo/journal/vaop/ncurrent/abs/ngeo2097.html

» Gas stations in space
Link: http://www.sciencedaily.com/ releases/ 2014/ 03/140306112307.htm

» Recent gully activity on Mars
Link: http://www.jpl.nasa.gov/news/news.php?release=2014-086

» Mars may had fresh liquid water four billion years ago at Endeavor crater
Link: http://www.sciencemag.org/content/343/6169/1248097

» Exploring habitability at simulated Mars
Link: http://scitation.aip.org/content/aip/journal/rsi/85/3/10.1063/1.4868592?TRACKPRESS=BARDI

» Evidence for post-Noachian insitu alteration on Mars
Link: http://onlinelibrary.wiley.com/doi/10.1002/2013JE004602/abstract

» Exploring existence of habitats in Earth-like planetary systems
Link: http://www.sciencedirect.com/science/article/pii/S0032063314000610

Life on a Tidally-Locked Planet

Introduction:

A tidally-locked planet in its orbit around a star keeps the same face towards the star. This happens when the rotation period of the planet around its own axis becomes equal to its revolution period around the star. The rotation and revolution periods, even if initially different, could get synchronized over time due to tides on the planet because of the gravitational effect of the star, hence the term tidal-locking. Of course instead of a planet and star it could be any other gravitationally bound pair of astronomical bodies, like Earth and Moon.

Moon keeps the same face turned towards Earth at all times. This is the effect of the tides that might have been caused on Moon due to the gravity of Earth. Over time Moon's rotation period has become synchronized with its period of revolution around the Earth. Tides caused by both Moon and Sun are slowing down Earth's rotation too and the day is lengthening day-by-day. In a very far-off distant future the day would become much longer, first a month-long, when Earth gets tidally locked to Moon and then perhaps a year-long, when Earth becomes a tidally-locked planet with its rotation period equal to its revolution period around Sun. Not infrequently, a leap second has to be added in the standard time keeping, based on atomic clocks, to keep in synchronism with this slow lengthening of the day.

Tidal locking will do a number of things to Earth's ecosystem as the front side starts getting all the sunlight, and the back side slowly freezes. In fact an extremely important question that comes to mind in this connection is - could life be sustained on such a planet which has one side always facing the Sun (temperatures much above 100° C, the boiling point of water) and the other darker side (howling winds at below −100° C)? We do not discuss here the miniscule probabilities or even the mere possibility of life ever starting or evolving on such a planetary system. But suppose life does form and evolve to higher forms, what would it be like to live on such a planet? We could rephrase the question: what sort of life we could expect to live if we were transported to such a planet. Of course such an interstellar travel being not really possible, it will have to be only in our imagination (a fantasy - Ooh La La!).

What gives rise to a tidal locking?

The gravitational force of Moon raises a tidal bulge in the oceans on Earth, in general there being two tidal bulges on opposite sides of Earth. The bulges are there because of the differential gravitational force of Moon. The oceans at points closer to Moon experience a larger gravitational force than Earth's centre, and hence feel a larger attraction and the water is pulled away from the Earth towards the Moon, thereby producing a bulge on the near side. On the other hand, the bulge on the opposite side arises, because the water on that side is pulled towards the Moon less than the Earth's centre. Therefore, the water on that side moves relatively away from the Earth's centre. Therefore, as Earth rotates, a given point on the surface will experience two tides in a day. Because of friction there is a delay in Earth's response, causing the tidal bulge to lead the Earth-Moon axis by a small angle. The Moon exerts a torque on the tidal bulge that retards Earth's rotation, thereby increasing the length of the day. This slowing down mechanism has been working for billion of years, since oceans first formed on the Earth. There is geological and paleontological evidence that the Earth rotated faster and that Moon was closer to Earth in remote past. Tidal rhythmites are alternating layers of sand and silt laid down offshore from estuaries having great tidal flows. Daily, monthly and seasonal cycles can be found in the deposits. The geological records are consistent with this that 620 million years ago the day was 21.9 ± 0.4 hours and there were 400 ± 7 solar days/year. Extrapolated backwards, the day was even shorter, with a year having perhaps more than a thousand days, during Earth's first billion years. Of course it is not the actual duration of the year that has changed, it is only the number of days that decreases, with the duration of each day becoming longer with the passage of time.

We have leap second once or twice a year (on June 30 or Dec. 31). The day lengthens by a second every 40,000 years. It may not seem much, but when linearly extrapolated it becomes substantial. The slowing rotation of the Earth results in a longer day as well as a longer month. The torque that Earth's tidal bulge exerts on the Moon leads to an acceleration of the Moon's orbital motion, causing the Moon to recede from Earth at an average

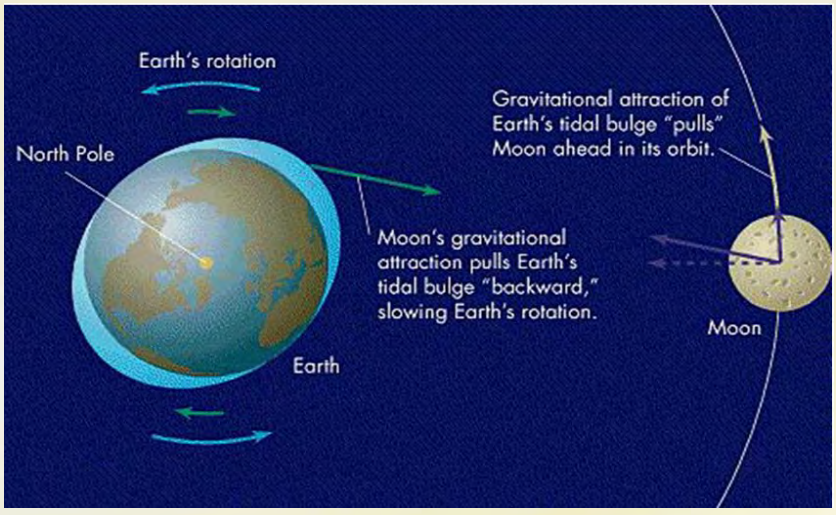


Figure 1: The slowing down of Earth's rotation due to tides caused by Moon's gravitational pull and the accompanying acceleration of Moon's orbital motion due the pull of Earth's tidal bulge

rate of about 2 cm/year. The size of the orbit changes in such a way so as to conserve angular momentum for the system. If the Earth and Moon still continue to exist, the Moon's distance would have finally increased to about 1.35 times its current value by the time the length of the day equals the length of the month and the lunar tidal friction mechanism will cease. Earth will be then tidally locked to Moon. That has been projected to happen, once the day and month both equal about 47 (current) days, billions of years in the future. Tides due to Sun will be still there, though the effect of the Sun on Earth tides is less than half that of the Moon. Eventually the rotation period of Earth might become equal to its revolution period around the Sun. The day-night cycle would having ceased, with one side of Earth always facing the Sun and the opposite side of Earth in a perpetual dark, and Earth thus getting tidally locked to Sun. Perhaps the time required for such a thing to happen may be too long and much before that Earth and Moon might get eventuality swallowed by Sun when it turns a red giant. But one can still imagine the possibility of such a tidal-locking to occur, if not here on Earth, may be elsewhere on another planet around some other star.

Are there any tidally-locked planets somewhere?

Within the Solar system, apart from Moon there are many other satellites tidally locked with their primaries. Pluto and Charon are both tidally locked to each other. Close binary stars throughout the universe are expected to be tidally locked with each other. An unusual example is Tau Boötis, a star tidally locked by a planet. The time taken for a tidal locking actually depends on things like orbital distance, masses of both bodies, and the malleability of the orbiting objects. Generally, closer objects are more likely to experience tidal locking. For planets orbiting M-type stars, which are slightly smaller than our Sun, the region where planets become tidally locked overlaps with the so-called habitable zone, where water can remain as a liquid on a planet's surface. For such stars, we would expect that a lot of the planets in the habitable zone would be tidally locked.

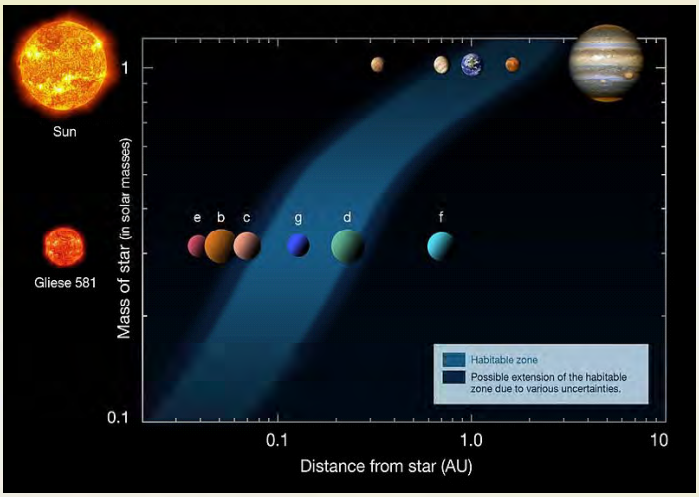


Figure 2: Planetary habitable zones of the Solar system and the Gliese 581 system compared

We now know that there are planetary systems around other stars, and already about a thousand or so such exoplanets have been found. There is evidence that some of them are tidally locked to their companion star. Zarmina is an extrasolar planet around Gliese 581, an M3V red dwarf star approximately 20.5 light years away from Earth in the constellation of Libra. The planet lies near the habitable zone of its parent star, and the presence of liquid water is considered a strong possibility and is believed to be the most Earth-like planet, and the best exoplanet candidate with the potential for harbouring life found to date. There might be a finite possibility of life on such a planet. However, Zarmina is tidally locked to its star. The immediate disadvantage of a tidally-locked planet is obvious. One side of the planet cooks while the other freezes, playing havoc with the atmospheric system of the planet.

Atmospheric system of a tidally-locked planet:

On a tidally-locked planet, a single region is consistently close to the star. Known as the sub-stellar point, this region continuously receives more direct starlight, and thus more heat. Water on one side may be in a vapour form while on the other side it may be frozen into ice. Strong constant heating of a planet on one side can change or even control how much weathering occurs on the planet, which can lead to significant and even unstable climate changes. These dramatic climate effects could make a planet that otherwise has the potential for life to instead be uninhabitable. An unstable climate on a tidally-locked planet could create a runaway greenhouse effect that could result in an atmosphere like that of Venus.

And it's not just the extreme temperatures. Permanently devoid of the heat of the star, the atmosphere on the dark side would first turn into a denser gas, then condense into a liquid, and then perhaps further condense into solid form. Meanwhile, air that is constantly exposed to light — or that is heated by a ground that is constantly exposed to light — will heat up and expand. Although it is doubtful whether the atmosphere on the dark side of the planet would get to solid form, it would certainly keep condensing and leaving a vacuum to suck in the expanding hot air from the other side. This might make for circulation of atmosphere that would make the planet liveable, but it will also lead to hellish storms, as the atmosphere from the light and dark side of the planet essentially switched sides continually. The presence of an atmosphere can help distribute the heat across the planet, equalizing the temperatures. But tidal locking could result in wide climate variations, a result that could threaten the evolution of life on the surface of these planets.

The far side of the planet would be frigid, since it would never see the star. Its only source of warmth would be winds from the warmer half of the planet. If there was no heat transport from the hot side to the cold side then we could expect the temperatures to be below −100° C on the

cold side, and more than 100° C on the hot side. However, if the planet has an atmosphere then it will transport heat from the hot side to the cold side, and this might make the temperature difference much more moderate.

Perhaps some of the water could be found in a liquid state near the boundary between the hot and cold regions and one could expect some kind of water cycle, with something like glaciers being continually melted by the warm air blowing in from the hot side, with the melted water flowing in gigantic rivers to the hot side, where it evaporates and cycles back around to fall as snow on the cold side.

Could life be sustained on a tidally-locked planet?

Consider what life would be like for those living on a planet tidally locked to its star where while one side is permanently bright and boiling hot, the other side is permanently dark and freezing cold. The lit side of the planet will be stripped of its oceans and made to face burning star and scrubbing hot winds all the time, while the dark side will be covered with frozen oceans and biting cold winds howling all the time. There would never be any relief from the extreme temperatures so it may be difficult to sustain life on such an inhospitable world. There would be zones of different climates, in concentric rings, depending upon how far it is away from the sub-stellar point. In the centre there would probably be scorching hot deserts but farther away from the sub-stellar point, as the star would get lower in the sky, there would be gradually cooler climates. Different places on the planet would be confined to either day or night, or even dusk at regions in between. However at a given place any change from day to night or vice versa will not occur.

Life, if it manages to struggle along on such a planet, will be very hard or perhaps be underground. More likely a circular belt between the two sides - a sort of "twilight zone" - could be the place for life to evolve and flourish. In this dusk band around the planet, where star will be permanently hanging very low near the horizon or perhaps the stellar disc partially peeking above the horizon, with an ever-colourful red, yellow sky due to scattered light, the temperatures would be more moderate, right in between the hot and cold sides. However the heat on one side would cause the air to rise, creating a low pressure system, while the cold on the other side would cause the air to sink, creating a high pressure system. This would cause the planet to experience a constant and violent circulation of air, or, essentially a planet-wide hurricane. The constant air circulation would actually circulate the temperatures extensively and extremes in temperature would mitigate. Water cycles with huge rivers crossing from cold to hot side might make living there possible.

One important issue is the concept of time. With no day-night cycles, concept of time will be difficult to come. On Earth right from birth, we notice that many phenomena in nature are repetitive. This is due to our most basic natural clock, viz. the rotation of the Earth, causing the rising and setting of the Sun, giving rise to alternative periods of light and darkness. All human and animal life has evolved accordingly, keeping awake during the day-light but sleeping through the dark night. Even plants follow a daily rhythm. Of course some crafty beings have turned nocturnal to take advantage of the darkness, e.g., the beasts of prey, blood–sucking mosquitoes, thieves and burglars, and of course astronomers.

At least there might be no astronomers on a tidally-locked planet, as starry sky may not be known (except for some rumours about it by adventurer fellows daring to venture deeper into darker side of the planet). Secrets of the universe − planets, stars, Milky-way, other galaxies − all these might remain very difficult, if not outright impossible, to unravel. Just imagine, it took thousands of years for us to figure out that a few "wandering stars" are heavenly bodies (planets) in just our neighbourhood and all this happened in spite of the fact that a starry sky is daily visible in most places for about half of the time (night). How will the inhabitants of a tidally-locked planet ever know about it when their everlasting "hot summer afternoons" never turn into cool evenings and dark nights?

A "day" in the life of a denizen of a tidally-locked planet:

On Earth, early humans noticed that over a certain period of time, seasons changed, following an almost fixed pattern. Near the tropics - for instance, over most of India – a burning hot season gives way to torrential rains, in turn followed by months of bitter cold, then a couple of months of a pleasant weather springing up before the heat sets in again; the time period of this repetitive cycle defines a year. One would expect that on a tidally-locked Earth there would be no seasons. The only change in the amount of sunlight would come from the slight variation in distance from the Sun due to Earth's orbit being slightly elliptical. Certainly that would be the case if the axis of Earth were not inclined to the ecliptic. So one could ask, will there be sort of seasons if the axis of a tidally-locked planet were tilted to its orbital plane like in case of Earth. Though there would be no day-night cycle on such a world, yet if the axis of the planet were inclined to its orbital plane around the star, there would be cycles of variation of temperature accompanying star's height over the horizon. This cycle would be the most natural clock for the denizens of this tidally-locked planet and thereby would define day on such a planet, regulating the daily life-cycle of the denizens of the planet. Then a "morning" will begin with a cold Winter, followed by a pleasant Spring and then a hot Summer afternoon, with the Fall falling in the evening, followed again by a Winter morning starting the next (year-long) day. Depending upon the latitude of the place there might occur a completely dark night in between or there might be no night ever.

Of course depending upon the width of the inhabitable belt, as the day will pass the temperature will vary, perhaps much more than what we are used to between various seasons on Earth. To escape the rising heat or the impending cold, the population would be forced to migrate towards darker or brighter sides, depending upon the time of the day, perhaps for hundreds or thousands of kilometres, depending upon the temperature variations and the size of the planet and width of the dusk band. We on Earth have day-night cycle with working or sleeping hours. With no day-night cycle, denizens of the tidally-locked planet would perhaps not evolve with sleep as a necessary ingredient of their daily life. Even on Earth there are perhaps many species, e.g., ants, which never sleep and work ceaselessly. May be denizens of the tidally-locked planet will also work incessantly their whole lives, migrating from one place to another without pause or stop. Rest assured there might be no rest for the whole day on such a plant. With no day-night cycle, no sleeping and waking hours, no office or school going daily routines followed by leisurely weekends, with perhaps hardly any diversions and adding to it the drudgery of restless migrations from one place to another, the life might sound dull to us denizens of the present-day Earth, but to the denizens of the tidally-locked planet it might not sound so boring as they would have evolved within a very different system with a very different "life-style".

Further Reading:

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Chemosynthesis in Deep-Sea Red-Clay: Linking Concepts to Probable Martian Life

Introduction:

Chemosynthetic microbial activity could share similarities between Martian and Earth systems. Recent discoveries on Earth suggest that wherever there is organic matter, water and energy, there is also life existing over a broad range of temperature, pressure, pH and other environmental conditions. As these factors are also common in space, it is possible that there is life in the outer space [e.g., 1]. Mars, the planet that most closely resembles Earth, shows evidence for water, past or present, and could be the focus of searching for life in the form of prokaryotes. Besides, the red colour of the planet is attributed to the dominance of oxidized Fe content. On Earth red clays are believed to be aeolian (wind-borne) Fe-rich dust deposited over geological time on land or on the sea-floor. Similar situation may be expected on Mars. However, more details can be known after mission data like that of Curiosity and our very own Mars Orbiter Mission (MOM) is examined. The greater part of Mars is arid and shows evidences for volcanic activity [2]. Some of the other characteristics that could resemble life on Mars include oligotrophy and chemosynthesis based on redox chemistry of metals in Central Indian Basin (CIB) sediments. The surface of Mars at present may be too harsh and this UV-bathed surface may be microbially sterile. Signatures if any could be only belonging to microbial fossil relicts here. However, deeper below, away from sunlight microbial life may still be persistent in case free-water or mineral-bound or chemically bound water is available. It is to be recalled that life on Earth exists in the deep-biosphere thousands of meters below land surface or the deep-sea floor. In such locations chemosynthetic mode of survival is the one way of life that has been understood so far. The present study therefore examined the patterns of distribution of chemosynthetic bacteria in the deep-sea red clay sediments of CIB along with chemosynthetic rates and Adenosine Triphosphate Profiles (ATP) and sediment properties as a prelude to drawing parallels between Earth and Mars systems as and when samples from Mars missions would be made available.

Chemolithoautotrophy and Martian Life:

Chemolithoautotrophs are those microbes capable of fixing inorganic carbon, CO_2 into living material by means of energy produced from an oxidation reaction of an inorganic compound. On Earth, there are many groups of such microorganisms. Some respire aerobically using O_2, but many operate anaerobically using NO_3 as a terminal electron acceptor in respiration instead of O_2. Other kinds of bacteria can also use sulphate, carbonate/carbon dioxide and carbon monoxide, or oxidised iron or other metals as terminal electron acceptors in respiration [3]. In order to test the possibilities suggested by hypothetical scenario for extant or relatively recently extinct Martian life two sets of

information may be required. First, we need more information bearing on the likelihood of geothermal or volcanic activities on Mars. Second, the Observer Missions should provide us with further information on the presence of near surface water. In addition, we need information on the water content of the deeper subsurface of Mars. Such information may not be available until actual on-site drilling takes place during a rover or other sample return mission [3].

Central Indian Basin sediments as potential Martian Analogues:

It may be difficult to get identical Martian analogues on Earth especially under the deep-sea in the first instance. However, the argument that Earth and Mars had similar origin and hence there could be similarities in the chemical composition of the two systems cannot be ruled out. Consequently, there could be similarities in the early life viz. microbes if existing on Mars. The following conditions make deep-sea pelagic red clays of CIB a potential Martian analogue:

» Abundance of CO_2 below calcite compensation depth
» Net upward thrust of fluid flow in seabed resembling subsurface flow in Mars
» Temperature gradients in waters especially during volcanic explosions
» Iron in oxidized state
» Saline condition of at least 35 ppt or more
» Very low organic matter < 0.1% of total sediment weight

The Approach:

Our present approach is to consider the possibilities of defining and quantifying analogous microbes and their processes among the presently available deep-sea data and the little currently available Martian data [4, 5, 6; Das, unpublished;] and to continue comparison with the on-site Martian exploratory data in future. For this futuristic approach it is necessary to re-analyse the Microbial Ecology, Genetics and Energetics data of CIB and maintain these Earth-Analogue Data Archives for comparing with actual Mars On-site Data as and when it would be made accessible. This would be done in the following two steps in the first phase of Earth-Analogue Data Archiving Process:



Figure 1: The Fe^{3+} dominated Red Sediments on (a) Earth [Red Clay Area (RCA) of Central Indian Ocean Basin, Courtesy: Polymetallic nodules- environmental impact assessment program, NIO-Goa, India] and (b) Mars [Courtesy: Google images]



Figure 2: Images of the deep-sea sediment of the Central Indian Ocean Basin

» Decipher patterns of genetic and biogeochemical constitutions of deep-sea red clays
» Strengthen base reference in present CIB for comparison with Mars samples in future

In the second phase of actual Mars On-site Data Generation (possibly during future Rover Missions) these archived data could be useful for first order comparison:

» Find analogy between present deep-sea data archives and future Martian on-site revelations
» Draw plausible parallel between two planetary systems in future missions
» Throw light on universality/commonality of Origin of Life on the two sister planets

Parameters examined in red clays to be extended to analogous processes on Martian planet:

The following parameters crucial for analysis of microbial biogeochemistry are used in the present deep-sea analogue studies and would be implemented for actual Martian soil samples in future:

» Microbial abundance in terms of total counts
» Diversity of culture dependent and independent Chemosynthetic bacteria
» Dark fixation of CO_2 as proxy for microbial chemosynthetic activity
» Community composition RFLP/ DGGE/ 454 pyrosequencing
» Energy flow in terms of ATP (Adenosine triphosphate)
» System sustainance in terms of heat-photon flux calculation

Salient results towards the analogue studies:

Chemosynthetic bacteria in CIB red clays: Some of the cultured isolates showing potential chemosythetic activity from the red clays showed affiliation to Halomonas sp. W7-7 (99%), Halomonas sp. MAN K46 (99%), Halomonas sp. EB 312 (99%), Uncultured bacterium clone 24B33 (96%), Uncultured actinobacterium CN-1 SL2_EO5 (98%), Dietzia sp. WR-3 (96%), Dietzia sp. ice-oil-71 (99%), Dietzia sp. Mali 88-02 (98%), Dietzia sp. (84%), Dietzia sp. (96%), Haererehalobacter sp. (96, 94%), Halomonas sp. (98, 94, 90%), Salinicola sp. (93, 97%), Brevibacterium frigoritolerans (98%), and Bacillus sp. (98%). The values in the parentheses indicate the percentage similarity of genetic code of the sample bacteria of CIB to the genus name available from genomic databases.

» *Chemosynthetic activity:* Prima facie results show highest carbon fixation (C-Fixation) in the pelagic red clays upto 10-10,000 nmol g^{-1} dry wt day^{-1}. These observations could be indicative of enhanced chemosynthetic activity in the organically deplete but volcanically active area [4]. The only data available on chemosynthesis at present for comparison is the famous Viking I radiolabelled experiment data which was much disputed three decades ago. Carbon uptake of CIB red clays shows 100-100,000 radioactive counts. The same for Mars soils done earlier by Viking I robots [5, Bianciardi et. al, 2012]] recorded 10,000 counts. This result is pretty striking and indicates huge possibility of detecting Martian microbial life. The apparent "life-less" red planet shows more activity than the lowest readings in the deep-sea microbial activity on Earth.

» *454 pyrosequencing:* Our pyrosequencing studies suggest that heat and light liberated in the process of the hydrovolcanic alterations could have supported even photosynthesis [Van Dover, 2000]. This inference is linked to the presence of high numbers of tags belonging aerobic anoxygenic phototrophic bacteria. Other rare genera which are believed to have shaped the planetary processes included psychrophilic, mesophilic (eg. Flavobacterium) and thermophilic (eg. unknown Thermomicrobia) forms. In the pyrosequence, data fragments of genomic sequences or tags are detected and matched with available databases to find out the taxomonic identity of a microbe. In Fig. 3, many cases show that the detected microbial sequences can be indentified up to phylum or order or family level but the genus or species may be new or unknown as yet. These sequences are labelled as unknown and the percentage of tags belonging to such unknown genera or species are plotted in Fig. 3.

» *Evidence of methane and sulfur bacteria:* Presence of Desulfuromonas and Methylobacterium could indicate traces of processes involving the sulphur and methane cycles as they could occur in Martian surface/ subsurface. Their presence could indicate that either there could be a diffused flow of hydrothermally influenced fluids at present in these deep sea clays or they are remnants of once dominant genera during volcanic eruptions or micro-ecological successions following responses to post eruption geochemical processes.

» *Adenosine Triphosphate (ATP):* Anomalously high ATP in the range 100-10,000 ng g^{-1}. ATP is the universal energy currency of all living forms and profiles show its ubiquitous presence in CIB pelagic red clays.

» *Numerical simulations:* Explicit finite difference model showed microbial nitrification-denitrification couple and enhanced chemosynthetic activity in the pelagic red clays in response to chemical phase changes due to hydrovolcanic alterations. Alterations could have occurred between 100-1000 year time scales before present. A focused jet of initial mass and heat flow could have got converted to a diffused flow with passage of time [Das et. al, 2011].

» *Heat-photon flux:* A question arises as to what supports the microbial biome in organically deplete red clay. Moreover why are there phototrophs in completely dark realms? We hypothesize that heat generated from hydrothermal crust cooling can linerate enough energy to support phototrophic microbes. This is a current subject of our research and we hope to come out with established formulations soon. The inhabitants of extreme environments like acidophiles in acid mine drainages, thermophiles in hot vents; psychrophiles in ice sheets are well-known and easily explainable. But microbes are also known to be strange inhabitants of the most unlikely environments like the phototrophs in dark realms. Such existence has been speculated by Van Dover (2000). However, these existences are not illogical but throw light into life's most uncanny secrets. Similarly unlikely analogues and anomalous populations in Martian and Earth environments may expose some hitherto unforeseen clues to the "Origin of Life" in planetary systems.

Discussion:

A fine time when India has successfully launched MOM, it is most appropriate for the scientific community besides space scientists to contribute towards finding suitable analogues of Martian soils, sediments and rocks. In a series of discussions with eminent scientists and scholars we realize that in this nascent phase of inter-disciplinary research many definitions and understanding are largely obscure to most of us. For example, sometimes even the term "Martian analogue" appears ambiguous. Many peers have often criticized the concept of "Martian analogues in deep-sea sediments".

It possibly might appear to readers that we are trying to search Martian particles/ debris/ life units etc. (like the well known SNC (Shergottites, Nakhlites, and Chassigny) meterorite that had fallen from Mars to Earth, in the abyssal depths of deep-sea floor. Therefore questions arise about the elusiveness of the concept, the flaws in the preservation of the fallen debris and other associated ambiguity. We clarify that deep-sea clays could act as some sort of proxy for Martian red soil just as for example any mammalian carcass could serve as a proxy for human body for a start. The present hypothesis states that the deep-ocean red clays could be suitable Martian analogues. We don't imply that we are searching for any Martian debris in the deep abyss. Earlier, researchers have used many terrestrial analogues like Atacama Desert (Chile), Death Valley (CA), and the California Coast [Bonaccorsi et. al, 2010] for comparability with Mars soils. Many others have concentrated on under-sea volcanoes and vents and proposed them as extra-terrestrial analogues [Prieur, 2005]. But, to the best of our knowledge none have ventured so far into the extensive expanse of red clays in the sea floor which is intriguing. However, this is not surprising because largest amount of research energy was concentrated in vents or to coastal

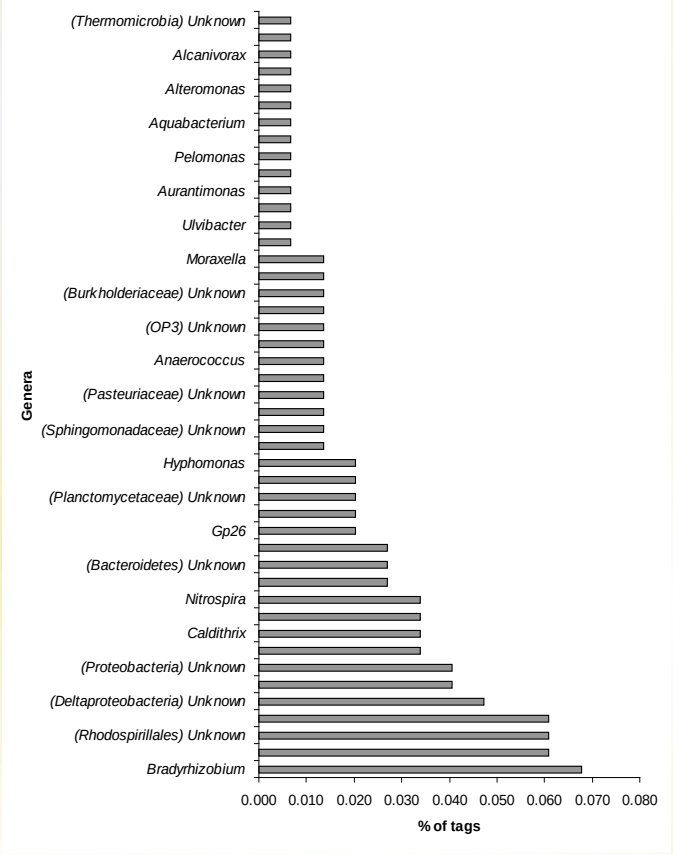


Figure 3: Rare bacterial genera of hydrovolcanically altered red clays of CIB. Note the presence of hyperthermophilic Thermomicrobia and anaerobic Anaeococcus in permanently cold and present aerobic environment, indicative of past geological events and activity

oceans as the red clays are far from the continents and not always logistically accessible. In fact the study of chemosynthesis in the red clays itself is very new [Das et. al, 2011]. To add an extra icing on the cake we also have a few low-temperature hydrothermally altered red clays [Nath et. al, 2008] from the CIB, making it convenient to analyze the microbial processes in red clays with and without volcanic signature. It would be pertinent here to mention that pressure is a significant parameter especially in the deep-sea due to the high hydrostatic load. However two things should be remembered with regards to microbial life under pressure. Microbial life per se is rather more dependent on molecular diffusion and other small forces rather than big forces like gravity and high hydrostatic pressure. So as such it could be a flawed criticism that a microbial cell would explode or implode due to hydrostatic pressure. A sub-micron level cell is too small to physically realize the effect of pressure unlike a fish or a blue whale or a human. However, what matters is the effect of pressure on enzymatic reactions which involve a series of changes in volumes of products and reactants that are in other words inversely related to pressure. Some reactions like first order reactions and radio-active decay are totally independent of pressure [Macdonald, 1975]. Thus the concept of pressure is far more complex and needs to be addressed according to which enzymatic reactions are involved. Therefore for the first order detection pressure is less crucial, unlike temperature which directly influences rates of molecular diffusion and thereby the entire microbial life.

Another important proxy parameter is ATP, which is the biological currency of energy. It is the form of energy that most living forms use. However, some primitive microbes could survive on pyrophosphate molecules for their energy requirement. Detection of such molecules could be a proxy or signature of extant (presently alive) and active microbial life. Thus ATP measurement could be very crucial. In addition, the ability of technology to enhance the detection limits would enable researchers to detect sub-pico-molar range of ATP, a range more suitable for Martian environment. Thus, we would have in our data sets details of both hydrothermally altered and unaltered red clays. Upon analyses of the MOM data and comparison with the "Deep-Sea Analogue" experiments data and data from literature, the following new knowledge may emerge:

» Low-temperature mineral fluid inclusions precipitated in the presence of microorganisms extinct or extant [Parnell et. al, 2002]
» Potential autochthonous (unique to) aerobic or anaerobic chemolithoautotrophic inhabitants of Mars that survive through the oxidation of inorganic compounds and fixation of carbon dioxide [Cousins, 2010]
» Possibility of numerous chemosynthetic pathways due to the disequilibrium and reduced chemical species that result from the mixing of high- and low-temperature fluids [Cousins, 2010 , Gaidos and Marion, 2003]
» Mars-specific chemolithotrophic metabolism - Theoretical possibilities and constraints to calculation [McCollom and Shock, 1997]
» Geo-chemical models to evaluate the amounts of chemical energy available in potential biological environments like Martian hydrothermal systems [Vamed et. al, 2003]

Conclusion:

To conclude we may say that a large amount of geothermal energy is possibly getting converted to ATP during microbial redox reactions. Hydrothermal activity and associated rock alteration processes may be highly relevant in these deep-sea sediments and planetary systems like Mars. The high chemosynthetic potential could be attributed to reported volcanic activity in the vicinity of the pelagic red clay realm in the CIB. Red clays of CIB are possibly one among the nearest analogues to Martian systems, on Earth.

Future scope:

The analogies with deep-sea sediments aim at understanding:

» The fundamentals of evolution of life on Earth and allied systems and possibility of extant life on Mars
» Therefore it seeks the co-operation and collaboration with the payload projects of MOM especially the Mars Colour Camera (MCC), Thermal Imaging Spectrometer

(TIS), and Methane Sensor for Mars (MSM)

» It requests links to future space sample-return missions to Earth [Das et. al, 2011, Das et. al, 2012]

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Recent Advances in Polarimetric Radar Imaging of the Moon

Introduction:

Radar is a useful remote sensing tool for studying planetary geology because it is sensitive to the composition, structure, and roughness of the surface and can penetrate most of the surface materials to reveal information about buried rocks or potential layering. Many of the planetary bodies of our solar system including Venus, Mars, Moon, Saturn's icy satellites, the icy Galilean satellites Europa, Ganymede and Callisto were studied using ground-based radio telescopes and orbital radar systems. For example, early work at Arecibo and Haystack Observatory in the 70's & 80's provided almost full nearside coverage of the Moon at 7.5 m, 70 cm, and 3.8 cm wavelengths. Observations of the icy Galilean satellites conducted during 1987-1991 with the Arecibo 13 cm - system and the Goldstone 3.5 cm system yielded significant improvements in our knowledge of the satellites' radar properties.

Radar polarimetry has the potential to provide additional information about surface physical properties beyond what can be obtained from single polarization backscatter measurements. Recent polarimetric imaging using Arecibo and Green Bank telescopes has included Venus and the Moon. Much interest in polarimetric studies of the lunar surface has been generated with the availability of data from two orbital polarimetric radars since 2009. In this article, starting with a brief background on the theory and observations, some of the unique and interesting results obtained from the polarimetric radar studies of the Moon are discussed.

Polarimetric radar:

The simplest form of imaging Synthetic Aperture Radar (SAR) transmits on one polarization, and receives on the same (like) polarization, like the radars on the Magellan and Cassini missions. Conventional dual-polarized radars transmit on one polarization, and then receive simultaneously on two polarizations, one being the same as that which was transmitted, and the other its orthogonal counterpart, known respectively as the like- and cross-polarized channels (Raney et al., 2011). In both of these cases, the primary data products received can be generally termed as 'images' since they do not include the relative phase between the two receiver channels. As a result, analysis of such datasets has to be carried out using minimal options like simply using the ratios or differences of their respective images. For instance, the radar on the Magellan mission to Venus measured only horizontal (H) polarization, except for a few orbits where the spacecraft was rotated to measure the vertical (V) polarization. The Cassini radar also operated in single polarization to probe the properties of Saturn's icy satellites.

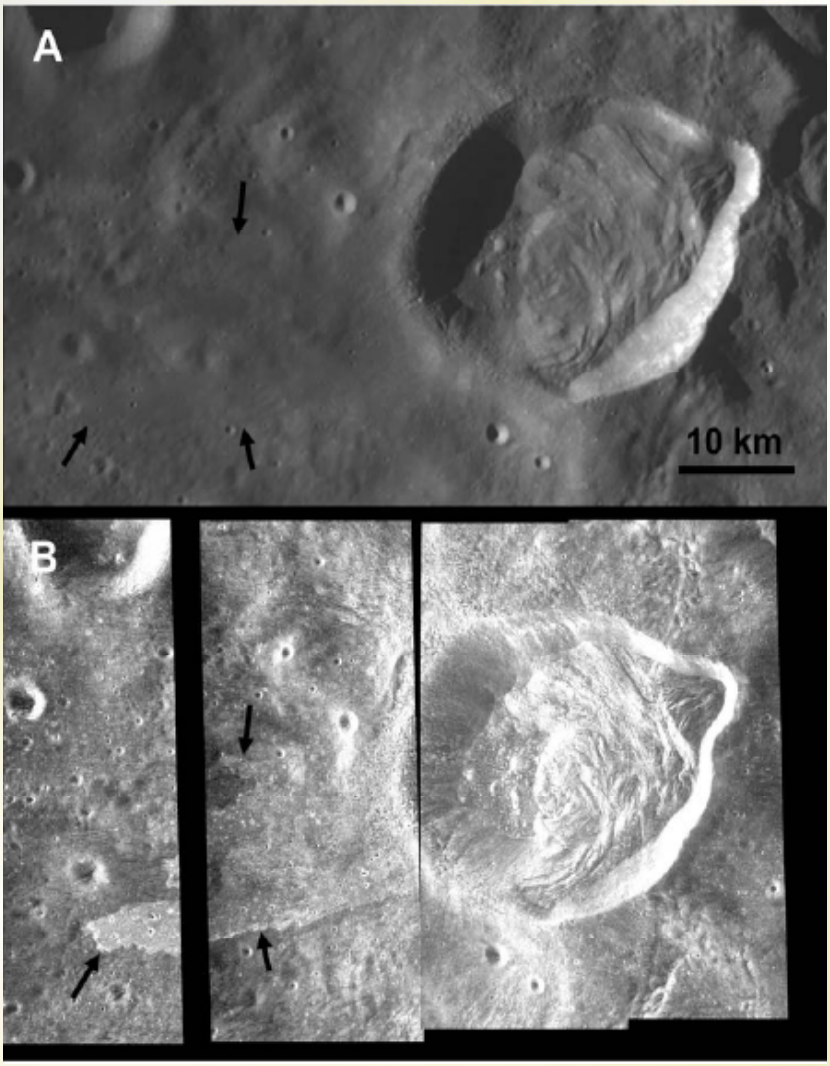


Figure 1: Impact melt flows west of the crater Gerasimovich D. (a) An LROC Wide-Angle Camera image of the crater and surrounding area. The impact melt flows are visible in some places, but are generally covered by regolith. (b) Mini-RF total backscatter power images. Radar illumination is from the left. The radar wave penetrates through thin regolith cover to reveal the flow outlines (Carter et al., 2012)

If relative phase is retained between the two received polarizations, then the received data could be termed as 'polarimetric'. The polarimetric data support certain quantitative measurements that are beyond the limited capabilities of simpler imaging radars as explained above. In particular, this data allows for the construction of the Stokes polarization vector. From the Stokes vector, daughter products such as the Degree of Polarization (m), Circular Polarization Ratio (CPR), Degree of Linear Polarization (DoLP) and Relative Phase (δ) could be generated which provide invaluable insights into the geophysical properties of the surface.

A fully polarimetric SAR system transmits the EM energy and coherently receives the backscattered waves in two orthogonal polarizations (Horizontal 'H' & Vertical 'V', in general). A 4 × 4 scattering matrix of each resolved element in the scene could be generated from the data received from such a SAR system. Compact polarimetry covers those options that fall between fully-polarized and dual-polarized SARs. Compact polarimetric radars transmit on only one polarization, and receive on two orthogonal polarizations coherently, i.e., they retain the relative phase between them. The major motivation for compact polarimetry is to achieve quantitative backscatter classifications of the same level as those from a fully polarized system. The principal constraints of planetary missions like mass, power, and limited coverage associated with a fully polarimetric SAR could be avoided utilizing the compact polarimetric radar techniques. A comprehensive description of the advantages of a fully polarimetric SAR over a compact polarimetric SAR is beyond the scope of this article.

Radar polarimetry at the Moon: Polarimetric radar data resources of the Moon can be broadly classified into two groups: observations from ground-based radar telescopes and lunar orbital-SAR observations. Since the 1960's, traditional radar astronomy has been based on analysis of the four-element Stokes vector that characterizes the radar backscatter observed from selected bodies, such as the Moon or Venus in response to circularly polarized transmissions. Standard practice for such large radar astronomical telescopes is to use circular polarization for both transmit and receive signals. Observations have also been made in which the same circular polarization was received as was transmitted. Since this component should contain no energy in the case of an ideal reflector, this component has been termed as "depolarized" (Evans and Pettengill, 1963). The Arecibo Radio Telescope (300m-diameter) in Puerto Rico can hardly claim to be compact radar, yet it is by far the best established example of compact polarimetry (Raney et al., 2011) which employs the same technique. During the Clementine mission in 1994, a bistatic radar experiment measured the magnitude and polarization of the radar echo versus bistatic angle for selected lunar areas (Nozette et al., 1996). These Clementine bistatic radar measurements also utilized circular polarization both on transmit and receive with a sole objective of determining the presence of water ice in the Permanently Shadowed Regions (PSRs) of the lunar poles. The recent Mini-RF radars on Chandrayaan-1 (Mini-SAR) and the Lunar Reconnaissance Orbiter (Mini-RF), using a hybrid-polarimetry architecture (Raney, 2007) to generate the Stokes vector, mark the first time that polarimetric radar data have been obtained from a planetary mission. In contrast to the existing methods, hybrid dual-polarimetric architecture receives orthogonal linear polarizations, while transmitting circular polarization. This hybrid polarimetric architecture is based on the classical physical optics theory

that the values of the Stokes parameters obtained from the elements of the covariance matrix are independent of the particular polarization basis in which the data are observed (Greens, 1968). In case of the dual-circular and hybrid-polarimetric radars, the representation of Stokes parameters of the backscattered field and several useful products derived from them is different and has been explained in detail by many researchers (Campbell et al., 2010; Carter et al., 2011; Raney et al., 2011, 2012).

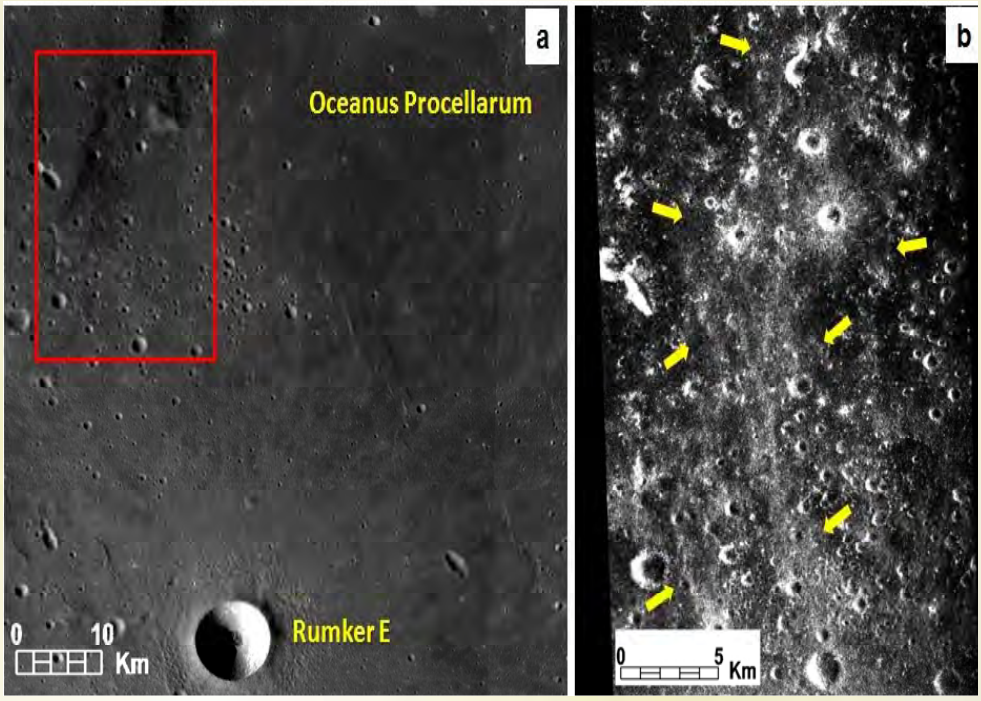


Figure 2: (a) LROC WAC mosaic showing a part of Oceanus Procellarum near the Rumker E crater. The red box indicates the extent of Mini-RF backscatter image on the right. (b) Mini-RF total backscattered power image. Radar illumination is from the right and the approximate extent of the material that is not observed in optical images is shown by arrows. The radar wave penetrates through the regolith

Polarimetric radar studies of the Moon:

(i) Earth-based radar studies: Radar remote sensing has long been used to study the dielectric and physical properties of the lunar regolith. The following examples describe some of the works carried out till date using radar observations of the moon and this list is not exhaustive. The most credible interpretations of the backscatter characteristics of the lunar surface started from 1961 using the data from Millstone-Hill radar system (Hagfors, 1961; Pettengill & Henry, 1962). Evans and Pettengill (1963) measured the total lunar cross sections in the wavelength region from 8 mm to 22 m, which could be interpreted in terms of electrical properties of the surface material based on various models of the lunar surface. Using the images obtained from ground-based radars that operated in the wavelength ranges of 3 cm to70 cm, several studies related to the scattering properties of the lunar regolith and impact craters were carried out during 1965-1997 (for e.g., Hagfors et al., 1965; Zisk et al., 1974; Thompson et al., 1981; Zisk et al.,1987; Campbell et al., 1997). The results obtained from these studies suggested that Earth-based radar observations can be used to augment spectroscopic data to differentiate certain chemically distinct units, in addition to their utility for characterizing variations in regolith physical properties.

With further improvements to the ground-based observatories like the Arecibo and Green Bank telescope, full Stokes vector radar imaging of the Moon at much higher resolutions has been possible since the beginning of 21st century. Since 2003, most of the near side of the moon has been studied in detail at 70 cm & 12.6 cm wavelengths. Some significant studies include the investigation of radar dark haloes, the geology of South Pole, mare backscatter properties, distribution and extent of pyroclastic deposits, etc.(for e.g., Ghent et al., 2005; Campbell and Campbell, 2006; Spudis et al., 2008; Campbell et al., 2009; Carter et al., 2009; Campbell et al., 2010).

(ii) Orbital radar studies: All of the above mentioned results were obtained from ground-based radar observatories which could only map the near-side of the Moon due to the Earth-Moon rotation system. The first ever polarimetric radar images of both the poles and far side of the Moon were obtained from Mini-SAR, the imaging radar that was launched on India's Chandrayaan-1 in Oct, 2008. The Mini-SAR mapped over 95% of the lunar poles (beyond 80° latitudes) and acquired very limited data from equatorial region at 150 m radar resolution (Spudis et al., 2010). The Mini-RF radar onboard the Lunar Reconnaissance Orbiter (LRO) that was launched in 2009 was the first orbital radar to provide the 4-element Stokes vector at two different wavelengths (S and X bands) and at two different resolutions (150 m and 30 m). The Mini-RF radar has almost entirely mapped the lunar surface including both the poles and far side. The orbital radars Mini-SAR and Mini-RF are collectively referred to as the "Mini-RF radars" by some authors (Raney et al., 2011). Even though the main objective of the Mini-RF radars was to resolve the longstanding issue of detecting the water ice in the PSRs near the lunar poles, the data obtained from them has been utilized in several ways as complimentary information to the observations from optical and infrared region. Some of the significant results include the detailed investigation of lunar

swirls, developing theoretical models for radar scattering from the lunar regolith and analysis of several new impact melt flows (Fig.1) that were not observed in prior radar imaging, etc. (for e.g., Neish et al., 2011; Fa et al., 2011; Raney et al., 2012; Saran et al., 2012; Carter et al., 2012).

New results:

Surface roughness mapping: Traditional polarimetric radar astronomy is based on analysis techniques that use Stokes or child parameters individually, such as total power (S_0) or the CPR. In contrast, polarimetric analysis in quantum physics and related fields has developed a mature alternative technique known as decomposition, in which two or more suitably selected parameters are used jointly to classify fundamental characteristics of the observed field (Raney et al., 2012). A new decomposition technique was introduced by Raney et al. (2012) derived from the classical Stokes parameters for analysis of polarimetric radar astronomical data. This decomposition is based on m (the degree of polarization) and chi (the Poincaré ellipticity parameter). Analysis of the crater Byrgius A demonstrated how m-chi can more easily differentiate materials within ejecta deposits and their relative thicknesses. Goldschmidt crater at the lunar north pole was analyzed to demonstrate how m-chi can differentiate coherent deposits of water ice. Goldschmidt crater floor was found to be consistent with single bounce Bragg scattering suggesting the absence of water ice. The m-chi decomposition and color-coding described in Raney et al. (2012) has been found to be a useful analysis tool for a variety of lunar investigations. The m-chi is a complementary product to CPR that permits a rigorous quantification of surface scattering properties and does not need to be combined or overlaid on S0 maps for morphological information in the same manner often required for CPR maps. The morphology

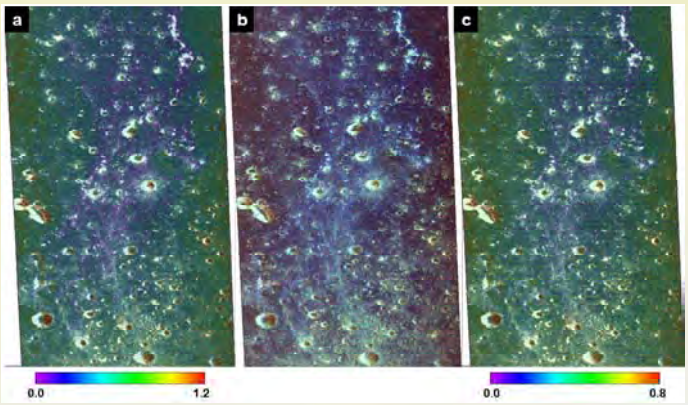


Figure 3: (a) CPR (b) m-chi decomposition and (c) DoLP images of the region shown in Figure 4b. The CPR and DoLP images are stretched to a color scale and overlaid on the total backscattered power image shown in Figure 4b. The m-chi decomposition shows 'double-bounce', 'volume' and 'surface' scattering contributions in red, green and blue respectively. Note the relatively lower values of the sub-surface feature in CPR image in contrast to that as observed from the DoLP image

and surface roughness of volcanic cones and lobate lava flows in the Marius Hills was analyzed in detail using this method (Lawrence et al., 2013). Comparisons between optical, Thermal Infrared and Mini-RF observations confirmed that volcanic domes in the Marius Hills are composed of rough, blocky lava flows which are not enhanced in silica relative to the surrounding mare basalts.

Subsurface mapping: Apart from the above discussed studies, one of the clear advantages of polarimetric radar data over optical/infrared observations lies in its subsurface imaging illustrated by an example here. The linear-polarized component of the received echo can be used to infer the presence of subsurface scattering expressed in the form of Degree of Linear Polarization (DoLP). For subsurface scattering, the direction of the linear polarization will be parallel to the plane of incidence and reflection and the linear polarization angle will change as the surface tilts in the azimuth direction with respect to the radar (Carter et al., 2011). The value of DoLP depends on surface physical properties, the radar viewing geometry with respect to the surface topography (incidence angle), and the amount of spatial averaging across surfaces with differing amounts of radar penetration.

A comparison of variations in CPR and DoLP values can be used to infer differences in the surface and subsurface materials and structure at a given region. Fig. 2a shows part of an LROC WAC mosaic of Oceanus Procellarum region near the Rumker E crater. The corresponding S band Mini-RF backscatter image of the area outlined in Fig. 2a is shown in Fig. 2b. Streaks of bright material which are not visible in the LROC WAC image are clearly visible in the backscatter image. In order to verify that the radar is seeing the surface beneath the thin regolith cover, the polarimetric radar products CPR, DoLP and m-chi decomposition images of the scene were generated as shown in Fig. 3.

This radar bright region shows relatively higher DoLP values (in the range of 0.2-0.5) and very low values of CPR (in the range of 0.1-0.3) and the m-chi decomposition indicates that surface scattering is the dominant scattering mechanism within this region. In this case, the radar wave is most likely penetrating the surface and reflecting from a buried layer with a higher dielectric constant than the surface giving rise to quasi-specular scattering from subsurface. Also, the low CPR values indicate that the surface is relatively smooth at Mini-RF wavelength scale. Thus in cases where the observed CPR and DoLP values can be combined with information about the geologic setting derived from other sources like optical and infra-red images, it is sometimes possible to make reasonable assumptions about the types of scattering present in a given region.

Rock abundance mapping: Since LRO has almost mapped the entire lunar surface, quantitative estimates for surface

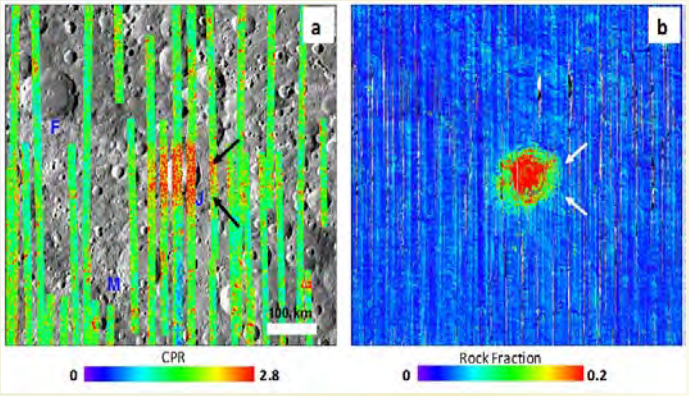


Figure 4: (a) Circular Polarization Ratio (CPR) and (b) Rock concentration image mosaics of Jackson crater region stretched to color scale and overlaid on LROC WAC global mosaic for shading. The craters Jackson (J), Fitzgerald (F) and McMath (M) are labeled in (a). The approximate extent of the continuous ejecta blankets in the eastern hemisphere of the Jackson crater region is indicated with arrows in (a), which are found to be absent in (b). The images show that CPR is sensitive to both surface and sub-surface rocks at radar wavelength scale and can provide additional information on distribution of rock fragments

rock abundances have been possible using the datasets from Mini-RF and Diviner radiometer. The radar parameter CPR was found to be well correlated with surface-subsurface rock abundance and can potentially be used for qualitative rock abundance mapping of lunar surface. Recent studies on comparison of thermal infrared (LRO-Diviner radiometer data) derived rock abundance and CPR sensitivity to surface-subsurface roughness due to presence of radar wavelength-scale rock particles revealed that CPR is not only sensitive to surface rock particles but also provides information on existence of sub-surface rock particles (Fig. 4). Synergetic use of thermal infrared and SAR data helped preparation of rock concentration maps of some of the lunar non-polar regions having a relatively homogeneous terrain (Saran et al., 2013).

Mass movement along slopes: Recent studies have also shown evidences of mass movements along the crater slopes on lunar surface (Senthil kumar et al., 2013). Observations on movements of dry granular matter along the slopes of some of the craters in lunar low-latitude regions have provided significant insight to the processes of degradation of material inside the craters. Polarimetric SAR data have been found to provide significant information about the nature of impact melt-flow materials along crater slopes (Fig. 5).

Characterizing ejecta fields & Impact melts: Mapping ejecta blankets help us to better understand the physics of impact cratering. Both the continuous and extended ejecta blankets of several lunar craters have been detected that are not visible in optical images, due to the subtle variations in surface roughness associated with them (Campbell, 2012). One such example is shown in Fig. 6. The Mini-RF onboard LRO has afforded new views of lunar impact melt flows, allowing for a reassessment of their global distribution (Carter et al., 2012). Lunar impact melts have been primarily studied at optical wavelengths, but complementary information can be obtained by observing impact melts at radar wavelengths. Since radar data is sensitive to surface and sub-surface roughness, it can be used to identify rough impact melt deposits, even when they are not easily seen in optical data. Since 2010, several new impact melt flows were mapped using the S-band Mini-RF data.

Water ice at lunar polar regions: The Clementine bi-static radar experiment detected elevated CPR values in the south pole of the Moon, suggesting the presence of patchy ice deposits in the permanently shadowed areas of Shackleton crater (Nozette et al., 1996). This was later questioned by further studies using ground-based Arecibo observatory and Green Bank Telescope (GBT) at a bi-static angle of 0.37°, by suggesting that high CPR values observed near the south pole are caused by surface roughness of the rugged inner walls of Shackleton crater and proximal ejecta of impact craters (Campbell et al., 2006). However, with the availability of data from the hybrid polarimetric orbital radars around the Moon, the Mini-SAR (Ch-1) and the Mini-RF (LRO), Spudis et al. (2010,2013) showed the anomalous behavior of polar craters which are under

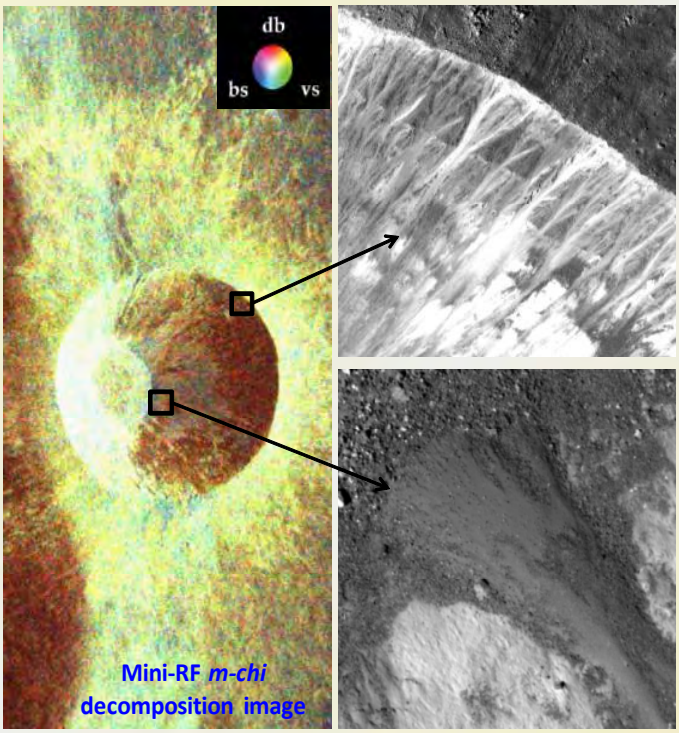


Figure 5: Are there landslides on the Moon? Left- Characterization of impact melt flows in Eimmart A crater through m-chi decomposition of Mini-RF data. Right- Alcove-channel-fan morphology visible from high resolution LROC NAC images. The figures show that SAR decomposition parameters such as smooth or rough surface scattering provide additional tools to characterize impact melt-flow materials

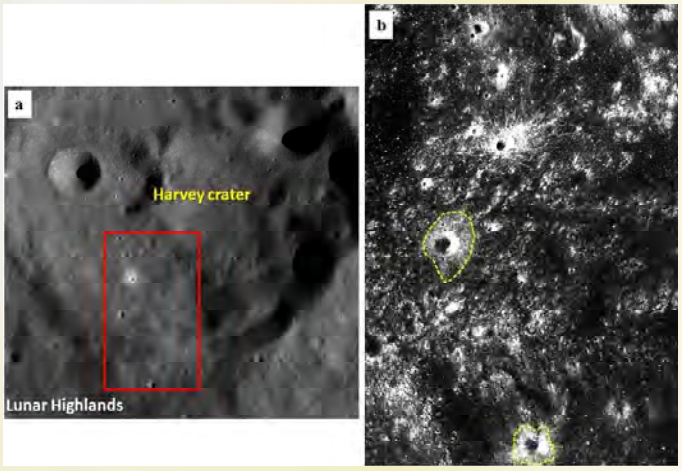


Figure 6: Mini-RF can see ejecta fields that are not visible in optical images. This could be because the extended ejecta causes subtle variations in surface roughness or that Mini-RF is detecting subsurface effects. (a) Harvey crater as seen from part of an LROC WAC mosaic. The red box indicates the extent of Mini-RF image on the right. (b) Mini-RF total backscattered power image. Radar illumination is from the left and the bright, continuous ejecta boundary of two Harvey secondary craters is outlined in yellow dotted lines, which is not visible in the WAC image

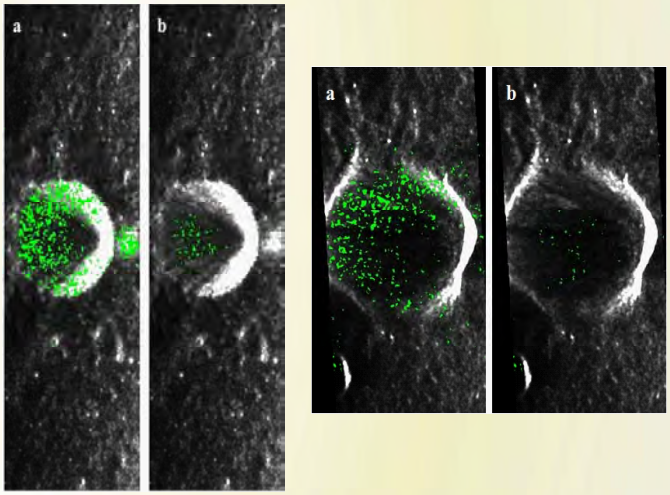


Figure 7: Regions of volume scattering (in green) overlaid on total backscattered power images (S_0) using (a) existing method (regions of CPR > 1) and (b) the algorithm developed by Mohan et al. (2013). Left: Small crater on the floor of Rozhdestvensky and Right: Whipple crater. Both these craters are located at the lunar north pole

permanent sun shadow, i.e., elevated CPR values in their interiors, but not exterior to their rims. Application of scattering models developed previously by Thompson et al. (2011) suggests that these anomalously high-CPR deposits exhibit behavior consistent with the presence of water ice. Also, Spudis et al. (2013) indicated that multiple lines of evidence including lighting, temperatures, neutron flux, UV, and S-band radar data when interpreted in combination suggest that these deposits are likely to be water ice. Fa et al. (2011) developed a theoretical model for radar scattering from the lunar regolith using the Vector Radiative Transfer (VRT) Theory for random media in order to aid in the interpretation of data from the Mini-SAR & Mini-RF. Both polarized and depolarized radar backscattering coefficients and the CPR were calculated as a function of incidence angle, regolith thickness, surface and subsurface roughness, surface slope, abundance and shape of buried rocks, and the FeO + TiO_2 content of the regolith. Since multiple scattering between buried inclusions has not been considered in this study, the VRT model could not account for any Coherent Backscatter Opposition Effect (CBOE). Despite not taking into account multiple scattering, this study suggested that it will be very difficult for the Mini-SAR and Mini-RF radars to detect ice mixed into the regolith. Fa et al. (2011) suggested that to improve the ability to detect concentrations of ices, both the radar backscattering coefficients and CPR should be analyzed simultaneously (as opposed to solely the CPR, as in the work of Campbell et al. (2006) and Spudis et al. (2010)). Such a study was carried out by Fa and Cai (2013) by studying the influences on CPR caused by surface slope, rocks, and dielectric constants which are quantitatively analyzed using high-resolution topography data and optical images. Statistical results showed that there is almost no apparent difference in CPR characteristics between the polar and nonpolar anomalous craters, or between the polar and nonpolar fresh craters. The enhanced CPR in the interior of anomalous craters is most probably caused by rocks that are perched on lunar surface or buried in regolith, instead of ice deposits as suggested in previous studies. A two-component mixed CPR model developed in this study suggested that to detect ice deposits unambiguously, rock abundance and dielectric properties for the interior region of permanently shadowed craters should be further investigated. A new technique for improved mapping of water-ice deposits in the polar cold traps of the moon was developed by Mohan et al. (2013). This study is based on the idea that additional information related to geological setting and roughness patterns should also be considered while identifying the regions containing water-ice deposits. Based on the signatures of diffuse scatterers and radar backscattering coefficient, a scattering mechanism-based algorithm was developed, which has the advantage in classifying regions showing elevated CPR due to surface and double-bounce scattering effects. The algorithm was then tested using Mini-SAR data which showed promising results (Fig.7) for identifying craters with water-ice deposits and separating them from young, fresh craters with elevated CPR values.

Summary:

Radar studies of the Moon are of particular interest as it is the only method for probing to depths beyond a few centimeters (the range of thermal infra-red variations), and for their sensitivity to the bulk geochemical properties and rock abundance of the lunar regolith. Some of the results described here indicate the importance of radar data in providing new information and opening new insights into

the lunar surface. In particular, radar polarimetry of the Moon has been proved as an efficient technique to understand its surface texture, composition and structure. Such studies can be used to quantitatively estimate dielectric constants, make depth estimates for mantling deposits, investigate the amount of surface versus subsurface scattering, and search for areas that are rock poor at the radar wavelength scale. For improved detection of water ice at the lunar poles, fully polarimetric radar scattering theory might be an alternative to detect ice since it contains all the scattering information for any arbitrary polarization state (e.g., circular, linear and hybrid modes), which also contains more information than a single parameter of the CPR. This objective will be served by the L & S-band radar which is going to be launched on the Chandrayaan-2 mission that will have fully polarimetric imaging modes at both the frequencies. Also, a test of the CBOE model could be observations of the bistatic scattering properties of the lunar surface such as by using a radar transmitter in lunar orbit in combination with a terrestrial receiver (which is in progress now). In summary, radar polarimetry has established its capability to better distinguish between different types of surface and subsurface physical properties as compared to single-polarization radar data.

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COTS for Space Application

Introduction:

The drive to use Commercial Off-The-Shelf (COTS) components in the space industry is growing since these parts are required to obtain higher performances. The existing space-level radiation-hardened components and technology cannot match the requirements of high-performance spacecraft which could otherwise be realized with the rapid development of microelectronics technology. Also due to cost pressure, COTS components are widely being favoured in some space missions in order to achieve high performance. However, COTS components are designed for working in terrestrial operating conditions while the electronic components used in spacecraft usually have a much higher reliability and suitability requirement because of the harsh ambience encountered by the space missions. Therefore, the use of COTS components in space applications is closely related to reliability and suitability issues, which have to be considered before their use.

Commercial-Off-The-Shelf components or COTS as they are more commonly called (sometime referred to as Off-The-Shelf (OTS)) represent those used in commercial applications and in normal terrestrial environments. It is defined as a technology which is ready-made and available for sale, lease, or license to the general public. It refers to hardware systems or computer software and may also include free software with commercial support. The use of COTS has been mandated across many government and business programs; as such products may offer significant savings in procurement, development, and maintenance for ground based applications.

The reason to use COTS components is not only due to cost pressures, but also the desire on the part of designers to gain access to advanced technology providing higher processor performance and greater logic and memory density than parts designed specifically for use in military or space systems. According to Moore, the number of transistors incorporated in a chip will approximately double every 24 months (Fig. 1). Technology is also evolving by his law till today. Since price is a major factor, technology performance improves initially for COTS only. But devices designed to have a terrestrial lifespan of a few years do not have the detailed attention to reliability and extensive testing needed to ensure reliable operation for about 20 years in the harsh environment of space. Improved performance COTS have also been used for space applications [1].

Earlier, a significant proportion of probes and satellites have failed in their mission. A survey conducted by Canadian Space Agency in 2008 showed that failures of more than 150 Earth-orbiting satellites, almost half were due to electrical failures, with 40% of all failures occurring during the first year of the mission mostly due to space envi

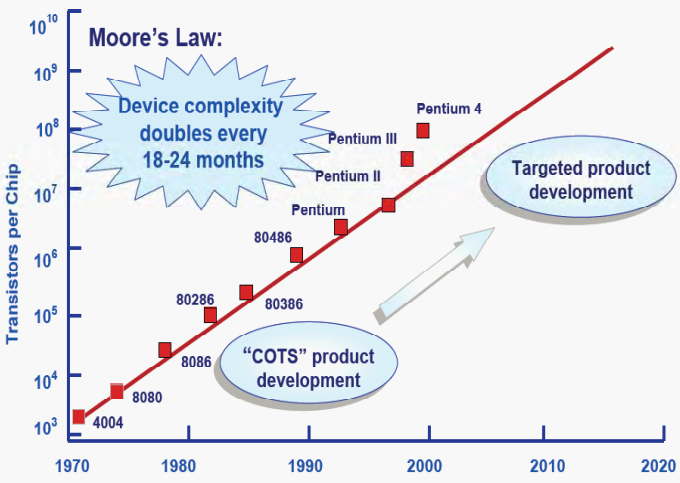


Figure 1: Microprocessor complexity (Source: James, Boeing Sr. Tech Fellow)

ronment [2]. The study concluded that better testing, redundancy and flexibility provide the keys to more reliable satellite operation. Due to the use of very reliable components, the twin Voyager 1 and 2 spacecraft continue exploring where nothing from Earth has flown before. In the 36th year after their 1977 launches, both spacecrafts are still sending scientific information about their surroundings through the Deep Space Network (DSN). These two Voyager spacecrafts were originally expected to last long enough to capture images of the outer planets, and have operated longer than almost any other space probe. However at that time, COTS were not even in conceptual stage.

In space applications, reliability has always been a key requirement. The failure of a single component in a vehicle subsystem can endanger an entire mission, resulting in the loss of hundreds of years of man-effort and tens or hundreds of millions of dollars. However, use of COTS components are still gaining importance in some quarters of the space industry.

The life duration and usage cycle of equipments on a spacecraft is significantly different from typical commercial applications on the ground. For the commercial world, if a COTS component fails on ground, a new one could be replaced. On the other hand for space missions, it is impossible to get back the non-functioning COTS component for replacement. Since COTS components are not governed by strict military standards that require inspection of the die for workmanship flaws and the performance of burn-in on each device to remove early random failures, reliability issues become important. COTS vendors typically employ various sample-based techniques for calculating reliability. So, it is not prudent to rely solely on invalidated reliability data from COTS vendors. Sammy [3] provides a description of common reliability and qualification practices and methods related to the utilization of COTS microelectronics in critical space applications. COTS components could not be used in military and space missions for many years due to above limitations. The scenario has changed in recent times. The utilization of COTS components for space applications is becoming necessary in order to achieve the high performance of space systems. There are many projects (e.g. in NASA and Surrey Satellite Technology Limited) using COTS components, such as SREREO, ST-5, TIMED, GLAST, SWIFT and MLA [4].

In order to use COTS components for the intended space application, special consideration and characterization may be necessary to determine the suitability of these parts. It is necessary to verify their reliability under the particular harsh operational conditions (radiation, temperature cycle, vibration) present in a space environment before its application to space. Because the reliability and space suitability are unknown and no radiation data are available for the COTS components, the only way to get the information is to test the COTS components and evaluate their suitability. With the introduction of a stringent methodology for selection, procurement, product assessment and testing (screening and qualification), COTS can provide a solution when space level parts are neither feasible nor available for the intended application.

Major issues and suitability of COTS in space applications:

There are few very important issues which need to be addressed before using COTS components for space applications.

» *Thermal environment:* Planetary bodies for in-situ exploration interest may have extreme conditions in terms of temperature and its variation. For example, Venus has mean temperature as high as 462° C. Moon has almost no atmosphere and temperature variation from -173° to +117° C The temperature variation at Mars is -140 to +20° C and for Mercury is 175° to 425° C. COTS components have a relatively small operating temperature range. The temperature range of space/military parts is typically from -55° to +125° C, while COTS components are designed to meet the commercial temperature range from 0 to +70° C or the industrial temperature range from -40° to +85° C.

» *Radiation environment:* The main source of radiation in space environment consists primarily of high-energy electrons, protons, alpha particles and heavy ions. Continuous exposure to radiation can shift the threshold voltages which can make transistors to switch easier or with difficulty. Radiation may also increase the leakage current, causing the on and off states of the transistors to become less distinguishable. Either effect can ultimately cause circuit failure. The most common radiation requirement in the aerospace design community is Total Ionizing Dose (TID), also known as total dose. Total dose irradiation is primarily caused by electrons and protons that penetrate into the silicon and can result in

device degradation and/or device failure. Charge build-up affects the current-voltage characteristics of transistors used in semiconductor circuits. Single Event Effects (SEEs) are caused by a single, energetic particle, and can take on many forms. Single Event Upsets (SEUs) are soft errors, and non-destructive. They normally appear as transient pulses in logic or support circuitry, or as bit flips in memory cells or registers. Several types of hard errors, potentially destructive, can appear: Single Event Latchup (SEL) results in a high operating current, above device specifications, and must be cleared by a power reset. Other hard errors include Burnout of power MOSFETS, Gate Rupture, frozen bits, and noise in CCDs. No radiation data is available for COTS components. Total Dose susceptibility of COTS parts varies from < 5 to > 100 krad (Si). Generally one uses the test data from published sources to reduce the cost or screen parts using a Co-60 γ-ray cell. For untested COTS parts, 5 krad (Si) is taken as the dose limit.

» Generally commercial manufacturers routinely change their manufacturing processes, shrink layouts and modify circuit designs, which may cause significant or catastrophic radiation degradation. So, the test results from the qualification of the COTS components are related to the specific lot of the COTS component. Unlike the military high-reliability system, users of COTS have little visibility into commercial manufacturers' proprietary design, materials, die traceability, and production processes and procedures.

» *Moisture absorption:* COTS components are typically more frail and susceptible to moisture absorption [5]. COTS generally are Plastic Encapsulated Microcircuits (PEMs), rather than the hermetically sealed ceramic-packaged integrated circuits which are used in space/military and are susceptible to moisture absorption. COTS however can be used with proper testing and qualifications. First is to house the component or sub-assembly in a moisture-sealed enclosure, perhaps with a desiccant. Good engineering practices can overcome many of the limitations inherent in these less expensive packages, but designers must well understand the behaviour of PEMs in the intended applications.

These issues have to be addressed during the stage of designing a space product with COTS components. Reliability, suitability analysis and evaluation are required for COTS components.

It is common practice within NASA/ISRO/ESA/space agency to test electronic parts at the manufacturing lot level to demonstrate, statistically, that parts from the lot tested will not fail in service using generic application conditions. The test methods and the generic application conditions used have been developed over the years through cooperation between NASA, Department of Defence (DoD), and industry in order to establish a common set of standard practices. These common practices, found in MIL-STD-883, MIL-STD-750, military part specifications, EEE-INST-002, and other guidelines are preferred because they are considered to be effective and repeatable and their results are usually straightforward to interpret.

Reliability analysis: Reliability analysis includes a series of screening tests such as radiography test and burn-in test, Destructive Physical Analysis (DPA), reliability calculation and assessment. A reliability program can be roughly partitioned into three testing phases: Mechanical, Environmental and Electrical. Mechanical testing involves testing the mechanical integrity of a product's packaging, including wire bond attachments, termination integrity and solderability, just to name a few by Destructive Physical Analysis (DPA). Environmental testing places devices under stressful conditions that accelerate the so-called "life" of a device in order to provide reasonable data to calculate failure rates and other important reliability characteristics. Burn-in, thermal cycling, moisture absorption are some of the test in this category. Finally, electrical testing is used to verify a product in its intended-operating environment. Testing programs are developed as a way of characterizing all of the DC specifications, and timing characteristics that a device must operate under.

Suitability analysis: Space suitability analysis is also important for the application of COTS components at the upper limit of their space environmental tolerance capabilities.

Evaluation: Based on the results of general reliability and suitability analysis to a COTS part, the need for an evaluation usually arises due to general concerns about the reliability of the component in specific space application. The usage of COTS component is permitted on space projects, provided the usage is thoroughly evaluated for thermal, mechanical including shock and vibration, vacuum and radiation environments of the specific space application and found to meet the mission requirements.

Thermal environment: The operating temperature range of most of COTS components is small. However with the development of the semiconductor industry in recent years, some of them can meet the military temperature standard. During the design stage of a space product with a COTS part, it is necessary to analyse the space suitability in thermal environment according to the temperature requirement of the specific mission and the operating temperature range of the selected COTS component, and the result of the thermal cycle test would decide on the qualification of the COTS component.

Radiation environment: One of the major concerns is the radiation issue for the Electronic, Electrical & Electromechanical (EEE) components in designing an instrument for space. Radiation data for COTS is not available as com-

pared to space/military components,. However this does not imply that it is not possible to use COTS parts. One of the most difficult obstacles for wider utilization of COTS components in space systems is the large variability in response to the effects of radiation. Analysis of the response of COTS component to the radiation environment anticipated during a particular space mission based on radiation test is of paramount importance.

Radiation test: The radiation tests should be done at component level, including Total Ionizing Dose (TID) test and Single Event Effects (SEE) test. The devices are electrically tested before irradiation, with parametrics recorded and data logged for later comparison. Devices are electrically biased in specialized fixtures within the radiation chamber and exposed to a predetermined radiation level. They are then electrically tested after irradiation to determine if degradation or device failure has occurred. If no measurable degradation has occurred, the devices are irradiated again at a higher dose level and tested once more. This process repeats until the devices fail or reach the maximum predetermined radiation level.

Radiation hardness: In general, COTS used in space missions need to be radiation hardened against the Total Ionizing Dose (TID) and Single Event Effects (SEE), resulting from the space radiation environment. In order to increase the radiation tolerant ability, radiation hardness can be achieved by many ways, such as using the shell of the spacecraft, increasing the shell of the instruments, adopting shielding board and local shielding.

Vibration and shock environment: The vibration and shock environment relates primarily to the vibrations and shocks during the launch phase. It is very severe compared with other commercial applications on the ground. Experimental techniques can be utilized to determine suitability of the COTS component to the specific launch environment. The mechanical environment tests include vibration test and acceleration shock test. For a specific space project, the selected COTS component must pass these tests at unit and or at system level.

Vacuum environment: To ensure that the instrument will survive in space vacuum environment, the experiment in vacuum condition must be done at unit level and at system level for several days, respectively. During the vacuum environment experiment, functional test needs to be done to ensure that the unit or the system is working normally and that no failure has occurred.

Suitability evaluation: To properly evaluate the space suitability of the selected COTS component, the radiation (TID and SEE) tests and hardness should be performed prior to tests in thermal environment, vibration and shock environment and vacuum environment. Based on to the analysis results of these space environments, once radiation hardened in effective ways and having passed all the tests, the instrument built with COTS component may be said to have qualified for use in space.

Conclusions:

COTS components offer designers access to the latest commercial technology. However they do not contain such fine-grained protection against SEU and SET events. On the other hand, it is still feasible to use high-performance COTS components on space flight applications provided they are thoroughly evaluated with thermal, mechanical and radiation requirement of the specific application and guaranteed to meet mission requirements. But, the successful utilization of COTS part in space is tightly related to reliability and suitability issues. Due to these constraints, the use of COTS components is still very limited at the moment.

However the use of COTS is increasing particularly when they provide system-level performance that their Hi-Rel/ Rad-Tol counterparts cannot achieve, and/or where there is a substantial quantity effect (e.g., memory components for mass memory units, or high speed serial links, where thousands of components are required). Nevertheless, it is still unusual for COTS components to be chosen in space avionics especially in projects that have strong quality assurance requirements, particularly in critical applications.

Further Reading:

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MISSION STORY - CHANG'E-3

After Chang'e-1 and Chang'e-2 missions, Chang'e-3 became the first Chinese mission to achieve a soft landing on the Moon. Chang'e-3 carries an orbiter, a lander, and a rover, 'Yutu'. The scientific goals of the mission include topographic, geological and mineral mapping, study of space environments, Sun-Earth-Moon and their relationship and conduct astronomical observations from the Moon. In addition to its scientific objectives, the mission mainly aimed at realizing difficulties in soft landing and roving on the lunar surface.

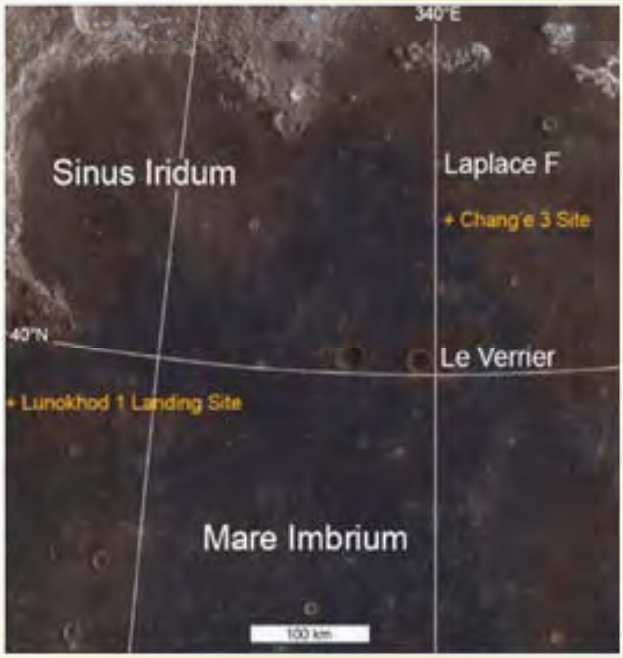


Source: CCTV
(http://english.cntv.cn/special/lunarmission/)

Launch and operations:
Chang'e-3 was launched onboard by Long March-3B carrier rocket from Xichang Satellite Launch Center, China, on Dec. 2, 2013. It entered the lunar orbit on Dec. 6, 2013 with an altitude of 100 km from the lunar surface. The lander softly touched the lunar surface (at the east of Sinus Iridium) on Dec. 14, 2013, followed by the successful deployment of its rover "Yutu" on Dec. 15, 2013.



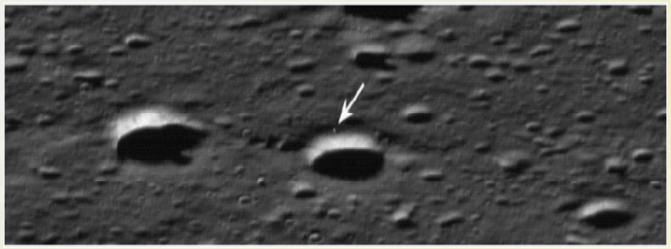
Source: www.news.cn (Xinhua/Li Gang)



LROC WAC image highlighting the proximity of the Chang'e 3 landing site (Source: Robinson et al., 2014)

Landing Site:
The lander touched the relatively flat ejecta blanket of the CE3 crater having diameter of 450 m (44.12°N, 340.49°E, DEM elevation: -2640 m). Particularly, it landed on the young high-Ti mare basalt (having the age of 3 Ga) of the Imbrium Basin. The investigation of this region will help lunar scientists to understand the mare filling and emplacement styles of these basalts, their composition and the physical factors affecting the lithospheric deformation due to lava loading. Both the lander and the rover will go into "sleep mode" during every 14 - day long lunar nights. Both the lander and rover utilise Radioisotope Heater Unit (RHU) for heat supply during night survival. These RHUs provide thermal energy to these systems but not electricity.

Lander:
Chang'e-3 lander weighs ~1200 kg, (body 2.5 m across; leg diameter 4.8 m) and carries seven scientific instruments. The expected operational lifetime is one year.



Caption: NAC east-to-west oblique view of Chang'e-3 site (M114268234). Arrow denotes landing site, north is to the left. (Source: Robinson et al., 2014)



China's Chang'e-3 lander and Yutu rover. Credit: Chinese Academy of Sciences

The scientific instruments carried by the Lander include:

Lunar-based Ultraviolet Telescope (LUT): A 5.9 inch Ritchey–Chrétien telescope (in UV band of 245-340 nm) for lunar-based astronomical observations with a capability of observing celestial objects with magnitudes as low as 13. Such stationary telescope allows scientists for long exposure and continuous observations of the target celestial system.

Extreme Ultraviolet (EUV) Camera: The 30.4 nm camera is used for the study of structure and dynamics of the Earth's plasmasphere. It helps in understanding the effects of solar activity on the Earth's atmosphere.

Lander cameras: Three panoramic cameras facing different directions acquire images of the Earth and other celestial bodies.

Soil probe: This soil probe will conduct simple soil analysis.

Rover:
The six wheeled "Yutu" rover (body 1.5 m across) with a total mass of 140 kg is a proficient and integrated robot built to withstand huge temperature variations (100 K at night and 400 K at day) on the lunar surface. Several RHUs are used to keep the electronics of the rovers in optimal temperature during cold lunar nights. Since its deployment, 'Yutu' travelled a total distance of atleast 100–110 m on the Mare Imbrium from its landing site. The rover had suffered a mechanical abnormality caused by harsh lunar environment on Feb. 13, 2014 and is currently in an immobile condition. However, the instruments on the rover appear to be normal.

The scientific payloads weighing 20 kg carried by Yutu are:

Ground Penetrating Radar (GPR): For in-situ measurements of the subsurface structure of the lunar crust down to several hundreds of meters.

Spectrometers: *Alpha Proton X-ray Spectrometer (APXS)/ Active-Particle-X-ray-Spectrometer* will study and analyze the elemental composition of the lunar regolith. *An infrared spectrometer* will analyze the mineralogy.

Stereo cameras: Two hazard avoidance cameras are mounted on the lower deck of the rover (1.5 m above ground) while two navigation cameras provide stereo vision to aid navigation.

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MISSION UPDATES (Source: Websites of various space agencies, press releases and published articles)

GSLV-D5 with indigenous Cryogenic stage launched successfully

The most awaited ISROs GSLV-D5 (carrying GSAT-14) with indigenous cryogenic upper stage was launched successfully from SDSC-SHAR, Sriharikota on Jan.15, 2014. After perfect execution of all the stages of launch as planned, within 17 minutes 5 seconds of liftoff GSAT-14 has been placed precisely in its initial orbit. On Jan.18, 2014 it was placed in its final designated orbit.

ISROs MOM celebrated its 100 days journey

MOM spacecraft is heading towards Mars in heliocentric orbit. After six successful maneuvers, the spacecraft is now on its cruise towards Mars. The health of all scientific payloads is in normal condition. As on Feb.11, 2014, MOM is ~160 million km away from earth.

NASAs CASSINI and HUBBLE captured Complete Auroras of Saturn

Two independednt spacecrafts, Cassini orbiting the Saturn and Hubble space telescope orbiting the earth, captured the complete view of auroras of Saturn. These observations provide information of motion of auroras and their effects on Saturn's magnetic environment.

Rosetta came out of Hibernation and its payloads are ready for science

After ten years of cruise in space, Rosetta came out of hibernation on Jan. 20, 2014. The post wake-up period for the mission has been scheduled for the payload check-up to keep them up in commissioning phase. According to the mission team, health of all the payloads and spacecraft systems are in normal condition and they are currently in commissioning phase.

Curiosity is on new strategy to protect wheels on its cruise

Curiosity wheels are getting damaged because of sharp rocks on its way to Mount Sharp. To tackle this, the mission team has activated reverse drive to protect wear and tear of wheels. Now curiosity is heading towards Kimberly, a science way point with diverse rocks, for sample collection. Later, Curiosity will take off to its final destination. Assessments are being made to evaluate the safest route to Mount Sharp.

ESAs Exo-Mars obiter scheduled for launch in 2016

ESAs Exo-Mars orbiter with the Trace gas orbiter accompanying the Entry, Descent and Landing Demonstrator Module (EDM) is scheduled for launch in the Jan. 7-27, 2016. The spacecraft will be launched by proton rocket and expected to reach the red planet in Oct., 2016 after 9 months cruise.

NASA Cassini finishes the 100th flyby of Titan

NASAs Cassini Spacecraft has successfully accomplished its 100th flyby of Titan. The spacecraft radar revealed many secrets of the Titan and provided lot of information regarding the Titan's atmosphere and about its seas. Its mission team is planning to measure the depth of the seas of Titan using present radar with innovative technique.

NASAs LADEE detected the dust levitated during the descent of Chang'e-3 Lander

LADEE mission team planned to analyze the data obtained during the descent of Chang'e-3 and quick deployment of its rover Yutu. Initially, LADEE instruments found no signatures of dust, during Chang'e-3 decent. However, different procedures to analyse the data before and after deployment yielded some interesting but complex results.

NASAs ORION is getting ready for the flight test

Orion is a multi-purpose crew vehicle being built by private aerospace agency for the NASA and ESA for the human exploration of different destinations in solar system. The future vehicle for the astronauts is ready for initial testing. The first flight test will be the Exploration Flight Test-1 (EFT-1), where all the systems will be tested in the space and will be back to earth after rendezvous with ISS.

LADEE may impact the Moon around Apr. 21, 2014

LADEE mission has been approved for extension of 28 days. Since the spacecraft systems are in perfect condition, propellant is still there to conduct science experiments for one more lunar cycle. So now LADEE may impact lunar surface around Apr. 21, 2014 based on the final trajectory.

Yutu can't move but can do Science

China's Moon rover Yutu stopped moving on Lunar surface because of some mechanical failure in Jan., 2014, but its communication with the earth station is intact. Its APXS has analysed the data at different sites when it was moving but now it cant take data at different locations. The purpose of the rover is completely lost.

14TH PLANEX WORKSHOP



The Indian Space Research Organisation (ISRO) has embarked on an exciting planetary exploration program. After the successful Chandrayaan-1, the first Indian mission to Moon, Mars Orbiter Mission was launched Nov. 5, 2013, and Chandrayaan-2 consisting of Orbiter, Lander and Rover is scheduled to follow soon. Exploration of asteroids and comets will be a near future objective. With the aim of creating awareness amongst students and research scholars, particularly in the universities and other research laboratories and academic institutions and to attract bright talented students to take up research work in the challenging area of Planetary Science and Exploration, the PLANEX programme of ISRO has been organizing periodic workshops and training programmes. The 14th Workshop in this series was organised by Prof. S.V.S. Murty, PRL, Ahmedabad along with Prof. H.S. Mazumdar, Head, R & D center, during Jan. 6-10, 2014 on the theme "Instrumentation for Planetary Exploration" at DDU, Nadiad, Gujarat.



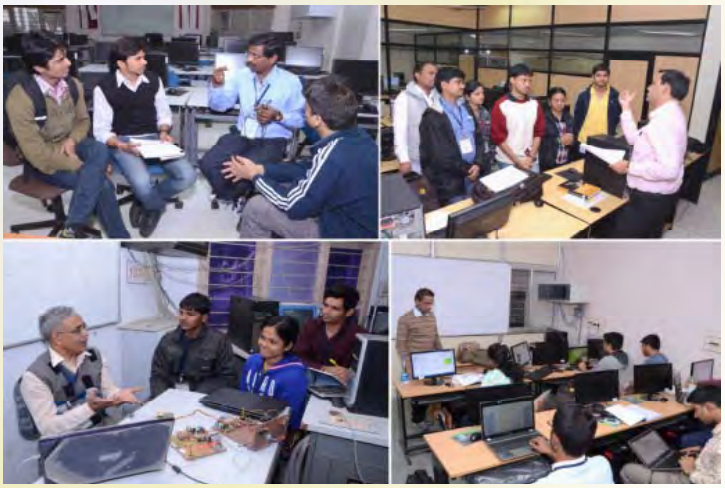
On the back drop of the successful launch of GLSV-D5 on Jan. 5, 2014, the workshop was started with the talk by Prof. J.N. Goswami, Director, PRL, giving a global view of planetary science and stressing the importance of indigenous development of important technologies.

The workshop consisted of lectures by subject experts, drawn from PRL, ISRO centers and DDU. Broadly, the talks were organised in four sessions, covering our present knowledge about the solar system gained through exploratory efforts by ISRO and other space agencies and the need for further exploration. Special lectures focusing on the important and upcoming traditional technologies like robotics and wireless sensors and the specific requirements of space instrumentation; like miniaturisation in size, mass and power requirements without compromising the sensitivity and accuracy in performance were delivered. The recent missions of ISRO, Chandrayaan-1 and Mars Orbiter Mission and the upcoming Chandrayaan-2 and their onboard instruments were also detailed for the benefit of the students.



A unique feature of the workshop was a short project work done by the participants in teams. Seven projects, mentored by faculty of DDU and PRL on aspects related to vairous technologies/ concepts of exploration provided an opportunity for the students to work in a team and engage their minds to think and put their ideas in to actions. It was amazing that the end product of these

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short projects was spectacular and satisfying to both the mentors and the students.Midway through the workshop, the participants were taken to a sightseeing trip to the garden city, Vadodara, to provide the necessary relaxation, away from the hectic work.

A special session for students presentations were also included on each day, in which all the participants gave one short presentation of about 10 minutes on the topic of their own interest. Participants from different academic and research fields chose emerging topics for their presentation, following which experts gave their suggestions in view of bringing out the novelty in their research work. On the last day of the workshop, a committee of experts was constituted to interview students about their respective fields and research plans. Based on their performance, 5 students were selected to pursue their career as a project associate at PLANEX for one to two years. Every year, PLANEX workshops are organized during January for which notification comes in Sept/Oct of the previous year. PLANEX encourage young minds to take part in the workshop and explore the mysteries in the field of planetary science by an active participation. Thirty one students at post graduate level, with science and engineering backgrounds, research scholars, teachers and scientists from universities and research institutes from all over the country had attended the 14th PLANEX workshop. The workshop concluded with the distribution of certificates to all the students and mentors by Prof. Desai, VC of DDU.



PLANEX PROJECTS PROGRESS REVIEW MEETING



A two-day PLANEX project review meeting was organized in Physical Research Laboratory, Ahmedabad during Mar. 28-29, 2014 to discuss the progress of projects funded by PLANEX programme. Around fourteen Principal Investigators (PIs) participated in this meeting to briefly summarize the outcomes, present status and future goals of their projects. Prof. S.V.S. Murty, Co-ordinator PLANEX gave a brief report of status of the projects and about inclusion of new projects in his introductory remarks. To assess the progress of PIs he had invited a group of experts from PRL and SAC, Ahmedabad. Director, PRL delivered the welcome address where he stressed on focusing specific science goals in the field of Mars and Moon related researches. He also encouraged PIs to suggest new research activities using the datasets going to be acquired by ISROs Mars Orbiter. The presentations given by PIs during meeting sessions included topics related to early evolution of solar system bodies, remote sensing studies of solar system objects, impact cratering, geological investigation of Mars and Moon analogs, development of tools and techniques for analysis of planetary datasets and payload development for future planetary missions. The review committee critically assessed the quality of work completed by PIs and offered several suggestions to bring out the novelty of their results. Overall, a great progress was observed in the quality of presentations and awareness of the PIs towards the emerging and ongoing researches across the globe in the field of planetary sciences. The meeting concluded with feedbacks from experts where PIs were praised for the quality of results and meticulous presentations.

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NATIONAL SPACE SCIENCE SYMPOSIUM - 2014



Indian space programme has gone aboard those steps where excellence and pride pursue each other. With a goal to converge different fields of space science research under one hood and discuss on their exciting results, every alternate year ISRO organizes a National Space Science Symposium (NSSS) where participants across the country take part. This year, during Jan. 29 - Feb. 1, ISRO has organized the 18th NSSS in Dibrugarh University, Dibrugarh, Assam. Dibrugarh, a city well known for its unique cultural and religious diversities welcomed nearly 400 participants from the areas of atmospheric science, space science, planetary science and astronomy and astrophysics. Dibrugarh University, one of the 8 universities of India selected by ISRO ADCOS for support under its Space Science Promotion Scheme provided the optimal facilities and hospitality for excellent functioning of the symposium.



Overall, the symposium comprised of one popular lecture, three Inter-disciplinary Lectures (invited talks), three Special Plenary Sessions (SPS, invited talks) and five Parallel Sessions (contributory papers both oral and poster presentations). The popular lecture was delivered by Prof. J.N. Goswami, Director, PRL Ahmedabad on the first day of symposium on the topic "Origin and Early Evolution of Solar System". He briefed the key results related to birth and evolution of our solar system in such a manner that ignited sparks within many school students and young researchers who are yet to choose their path to traverse. The special session on Mars Obiter Mission (MOM) provided an excellent account on the challenges met by ISRO team in putting MOM in Mars transit orbit, in addition to providing science objectives and the technical details





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of the payloads in achieving these objectives. Adding to this, ISRO had set-up an exhibition for the young minds to motivate and feel proud of our national achievements in space, where real size models and scaled down models of launch vehicles and satellites, posters, and summary of results from long-term researches were displayed.



From PLANEX group and Planetary Science division at PRL, 16 members participated, contributing 19 abstracts to the parallel session PS5. This session was further subdivided into 5 sub-sessions covering topics related to planetary geosciences and terrestrial analogues, small bodies in the solar system, lunar science results from Chandrayaan-1, planetary atmospheres, space weather and solar studies, and planetary data processing and future planetary instrumentation under which the presentations were scheduled. The lead talks in PS5 session were given on recent finding of enhanced hydration signatures on Moon, trapped gases in the meteorites, a new view of solar wind interaction with the Moon from Ch-1 SARA, atmospheric dynamics of Mars and processing the datasets of ISROs MOM. In this session, contributions from PLANEX group were focused on remote sensing studies of Mars and Moon, model based simulations and analytical studies of meteorites and rock samples. During their oral and poster presentations, several important issues and new ideas, viz. thermal behavior of top lunar soil, difference in aqueous/ non-aqueous morphology on Mars, GEANT4 simulations for Ch-2 APXS, and new litho-types of Mars were explored and discussed. Overall, major focus was given for introducing and sharing with other co-participants the various types of quality researches that can be done in this emerging field of scientific exploration. The performance of PLANEX members were recognized through first prize in poster presentation and second prize in oral presentation in PS5. PLANEX had also set up a desk where its quarterly published newsletters were displayed for enrolling new subscribers for distribution of the e-copies as well as hard copies on demand.



During the last day of the symposium, a panel of experts summarised their key observations of the symposium and embarked on giving several recommendations with respect to the scientific content briefed under different sessions. They discussed on several issues and obtained feedbacks from the participants that may help in future to improve the quality and standards of symposium and to ensure that the participation in the symposium should increase by at least two folds. A dazzling dance program treated the participants on the second day of the symposium that portrayed the Northeast culture. The symposium wrapped up with a sincere vote of thanks by Dr. S. Seetha, PD, SSPO, ISRO and the symposium convener Prof. P. K. Bhuyan, Department of Physics, Dibrugarh University, who concreted their and efforts of many other associates to make NSSS 2014 a well-organized and fruitful symposium.



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EVENTS

A SCIENTIFIC MEET IN THE MEMORY OF PROF. DEVENDRA LAL

A two-day Scientific Meet "From Mantle to the Moon" was organised in remembrance of Prof. Devendra Lal, a renowned Scientist and former Director, PRL, during Feb. 14-15, 2014 at Physical Research Laboratory, Ahmedabad. The meeting was organised as a mark of tribute to the great person. The meeting provided a glimpse of reminiscences of the Life and Science of Prof. Devendra Lal. The two-day meet comprising seven sessions together presented a glance of different facets of Prof. Lal's Life and his contributions. Eminent personalities, associates and students of Prof. Lal shared their scientific memoirs during the meeting. Prof. J. N. Goswami, Director, PRL, presented the welcome address which was followed by an inaugural talk by Prof. U.R. Rao. In his talk, Prof. Rao highlighted all the important events and happenings of Prof. Lal's 85 years of journey. Some of them are - the discovery of ^{10}Be, Prof Lal's shifting from TIFR to PRL, getting moon samples to India and so on. Prof. Rao described Prof. Lal as a person full of energy and appealed to pay homage through good deliberations during the meeting.



Prof. Devendra Lal *(1929 - 2012)*



Session-1 of the meeting was on "Prof. Lal: TIFR, PRL, Scripps Connections". During first talk of the session by Prof. B.V.Sreekantan, he described Prof. Lal's inital phase of research including his first meeting with Lal in TIFR library. He emphasised upon the pioneering work done by Prof. Lal on Cosmic Rays. He also recollected some memories related to the popularity of Lal, Pal, Pieter's paper. Prof. Ray Wiess described about 56-year chronology of Prof. Lal at La Jolla. According to Prof. Wiess "Passion" is the word that can best describe Prof. Lal - a great man with a common touch. Prof. R.K. Varma described about Prof. Lal's 25 years trip of cosmogenic nuclides in geology. Prof. Varma also mentioned that Prof. Lal had a good sense of humour and also was fond of toys. Prof. Bhandari, the first student of Prof. Lal described him to be interested in everything and anything. He narrated some of his experiences with Prof. Lal as a student and also as a colleague. Prof. Bhandari mentioned that Prof. Lal made his every student feel that he is fully working with him. Prof. Abhijit Sen narrated about the support and encouragement provided by Prof. Lal for experimental activities in plasma physics.



EVENTS



Session-2 and Session-3 were general sessions on "Earth and Planetary Sciences" and "A glimpse of Science at PRL". Talks on various aspects such as Plate tectonics on Earth, AMS Applications, Role of nano-particles on atmosphere, interesting viewpoints of planetary sciences and exploration were delivered by experts in Session-2. A glimpse of various Science activities being carried out at PRL was presented in Session-3. Topics in this session included Science at Mt. Abu Observatory, Solar Physics at USO, Early Solar System Evolution, Atmospheric dynamics and coupling, Mud volcanism, Biogeochemistry of Indian Ocean.

Sessions 4 and 5 were essentially a recollection of memories of Life and Science of Prof. Lal in the words of his close quarters. These sessions were conducted in a rather informal way where Prof. Lal's colleagues/ close associates from TIFR, PRL and Scripps narrated their association and experiences with him.

There were two sessions on the second day of the meeting on "Current trends in Earth Solar System Processes". In the first talk of the session Prof. J.V. Narlikar shared his personal experiences with Prof. Lal. He mentioned that his association with Prof. Lal was very fruitful and in an unexpected way helped him in solving his own problems. Prof. Kumar Chitre in his talk highlighted some unresolved issues in Solar Physics. There were a series of talks related to diverse aspects such as - Dark matter, Paleo-monsoon research,



Cosmogenic isotopes in Geomorphology and archaeology, Exhumation and Denudation history of Himalayas and Progress in Luminescence dating.

The concluding remarks of the meeting were presented by Prof. Krishnaswami who cited that the meeting has indeed brought all facets of Lal's life and everyone will truly miss him a lot. He later thanked all the participants who came from far and wide. The meeting was successfully concluded with the words of Prof. Goswami "We don't know whether he heard us or not, let us hear him now....." followed by a video streaming of Prof. Lal's recent interview that was recorded earlier.

ANNOUNCEMENTS AND OPPORTUNITIES

» Meeting on "***Electrification in dusty atmospheres inside and outside the solar system***" will be organized during Sep. 8-11, 2014 at the Scottish Highlands, Pitlochry, Scotland. Last date for submission of abstracts is June 15, 2014.
For more details, visit:- http://leap1.sciencesconf.org/

» "***14th International Earth and Space Conference***" will be organized during Oct. 27-29, 2014 at the St. Louis, Missouri, USA. The last date for submission of abstracts is Apr. 14, 2014.
For more details, visit:- http://earthspaceconf2014.mst.edu/

» "***24th Meeting of Earth Sciences***" will be organized during Oct. 27-31, 2014 at Palais Beaumont, Pau. The last date for submission of abstracts is May 15, 2014.
For more details, visit:- http://rst2014-pau.sciencesconf.org/

» "***CoRoT Symposium 3, Kepler KASC-7 Joint Meeting***" will be organized during July 6-11, 2014 at Espaces Vanel, Toulouse, France. The last date for submission of abstracts for posters is May 15, 2014.
For more details, visit:- http://corot3-kasc7.sciencesconf.org/

» Workshop on "***The Study of the Ice Giant Planets***" will be organized during July 28-30, 2014 at Johns Hopkins Applied Physics Laboratory, Laurel, Maryland. The workshop is open for abstract submission.
For more details, visit:- http://www.hou.usra.edu/meetings/icegiants2014/

» "***8th International Conference on Aeolian Research (ICAR VIII)***" will be organized during July 21-25, 2014 at Lanzhou, China. The last date for submission of abstracts is Apr. 15, 2014.
For more details, visit:- http://www.2014icar8.com/

» "***Saturn Science Conference***" will be organized during Aug. 4 – 7, 2014 at Pyle Center, University of Wisconsin-Madison. The last date for submission of abstract is June 1, 2014.
For more details, visit:- http://www.ssec.wisc.edu/meetings/21st_saturn/

» "***77th Annual Meeting of the Meteoritical Society***" will be organized during Sep. 7 - 12 at Casablanca, Morocco. The last date for submission of abstracts is June 24, 2014.
For more details, visit:- http://www.metsoc2014casablanca.org/whene_and_where.php

» Workshop on "***Planet Formation and Evolution***" will be organized during Sep. 8 - 10, 2014 at Kiel University, Kiel, Germany. The last date for submission of abstracts is June 20, 2014.
For more details, visit:- http://www1.astrophysik.uni-kiel.de/~kiel2014/main/

» The " ***European Planetary Science Congress 2014***" will be organized during Sep. 7-12, 2014 at Centro de Congressos do Estoril, Cascais, Portugal. The last date for submission of abstracts is May 6, 2014.
For more details, visit:- http://www.epsc2014.eu/information/general_information.html

» International conference on "***Living Together: Planets, Host Stars and Binaries***" will be organized during Sep. 8 - 12, 2014 at Litomyšl, Czech Republic. Last date for submission of abstracts is Aug. 1, 2014.
For more details, visit:- http://astro.physics.muni.cz/kopal2014/

WELCOME

1. Mr. Mani Teja V.	–	Project Associate
2. Ms. Aarthy E.	–	Project Associate
3. Ms. Mariammal M.	–	Project Associate
4. Mr. Ricky Wilfred G.	–	Project Associate
5. Mr. Shyamal Kishore	–	Project Engineer
6. Mr. Manish N. Sanghani	–	Project Associate
7. Mr. Subhadyouti Bose	–	Project Associate

FAREWELL

1. Mr. Arunsenapathy R.	–	Project Associate
2. Mr. Ranjith Kumar P. M.	–	Project Associate

AWARDS AND HONOURS

1. **Mr. Rishitosh Sinha** got selected to attend the COSPAR Capacity Building Workshop on "Atmospheric Correction of Earth Observation Data for Environmental Monitoring: Theory and Best Practices" which was held in Bangkok, during Nov. 4 - 8, 2013.



2. **Ms. Indhu Varatharajan** awarded first prize for best Poster entitled "Systematic mapping of exposed units in Mawrth Vallis and Hellas Planitia: Attempt for geomorphic characterisation of hydrated and anhydrous regions on Mars" by Indhu V., Rishitosh K. Sinha, Vijayan S., and S. V. S. Murty during the NSSS 2014 (Jan. 29 - Feb. 1, 2014) at Dibrugarh, in the session PS5.



3. **Dr. Vijayan S.** awarded second prize for best Oral Presentation entitled "Inversion of Lunar regolith layer thickness using simulated Chandrayaan-2 passive microwave brightness temperature" by Vijayan S., Shiv Mohan, and S.V. S Murty during the NSSS 2014 (Jan. 29 - Feb. 1, 2014) at Dibrugarh, in the session PS5.



14TH PLANEX WORKSHOP- GROUP PHOTO



MY ASSOCIATION WITH PLANEX

With the association with PLANEX, I have achieved a strong background to become a planetary science research student. I joined PLANEX as a Project Associate in Nov., 2010, to work with Prof. S. V. S. Murty, with an objective to study the evolutionary processes of iron meteorites through noble gases and nitrogen. The experience on noble gas mass spectrometry has given opportunities to understand and realize the challenges and possibilities of experimental research. Due to the association with Prof. S. V. S. Murty and the experimental guidance by Mr. Ramakant Mahajan, I gained a confidence to become a planetary science researcher. The interaction with Prof. Murty, inculcated an inspiration to move further in the field of noble gases in planetary materials. The learning experiences in the PLANEX noble gas lab helps me very much in my current research.

Even though I could measure noble gases and nitrogen from different types of meteorites, my specific work was mainly on iron meteorites, to understand the formation and evolutionary processes of non-magmatic iron meteorites. These experiences helped me to get familiar with different types of planetary materials and the relevance of studying them. Fortunately, during my tenure, PLANEX had conducted many national and international conferences to popularize planetary science and to participate in planetary exploration programs by ISRO. These programs helped me to get in contact with the planetary science community in the country and to evolve myself as a planetary science student. At present, I am in the process of extending my noble gas and nitrogen studies to understand planetary evolution, through meteorites.

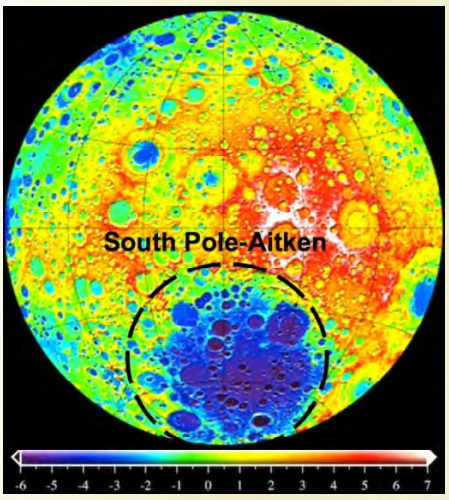
I am very happy and proud of the PLANEX newsletter crew, for their immense service to the planetary science community all over the world. I am very much thankful to all PLANEX members, who motivated and supported me for my higher studies.

I wish the PLANEX newsletter could ignite many more young minds in future, who are interested in involving in planetary science research.

Ranjith Kumar P. M.
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South Pole-Aitken basin : The largest impact crater on the Moon



The South Pole-Aitken (SPA) basin is the largest, deepest and the oldest recognized impact basin lying on the far side of Earth's Moon. Roughly 2,500 kilometres in diameter and 13 kilometres deep than the surrounding highlands, it is one of the largest known impact craters of the Solar System. SPA is thought to have formed about 4.3 billion years ago, just a few hundred million years after the formation of the Moon itself. The basin was named for two features on opposing sides; the crater Aitken on the northern end and the southern lunar pole at the other end. When there's favorable libration at the Moon's southern limb, it is sometimes possible to see the outer rim of this basin from Earth as a huge chain of mountains located on the lunar southern limb, often referred as "Leibnitz mountains".

The existence of a giant far side basin was suspected as early as 1962 based on early probe images (namely Luna 3 and Zond 3), but global photography by the Lunar Orbiter Program in the mid-1960s confirmed its existence. The first complete geologic map showing the confines of this basin was published in 1978 by the United States Geological Survey. Little was known about the basin until the 1990's, when the spacecraft Galileo and Clementine started geologic exploration of the Moon. Multispectral images obtained from these missions revealed that this basin contains more FeO and TiO_2 than typical lunar highlands, and hence has a darker appearance. The topography of the basin was mapped in its entirety for the first time using laser altimeter data and the analysis of stereo image pairs taken during the Clementine mission. Most recently, the composition of this basin has been further constrained by the analysis of data obtained from a gamma-ray spectrometer that was on board the Lunar Prospector mission.

Possibilities for the distinctive chemical composition of SPA, in having elevated abundance of iron, titanium and thorium compared to the highlands are: the presence of unusual rock types, widespread distribution of ponds of iron-rich basalts like those in the lunar maria, exposure of lower crustal rocks with a different bulk composition from the surface, or the presence of rocks dug up from the lunar mantle.

Simulations of near vertical impacts show that this basin should have dug up vast amounts of mantle materials from depths as great as 200 kilometers below the surface. However, observations do not favor a mantle composition for this basin, and crustal thickness maps constructed using the Moon's topography and gravity field indicate the presence of about 10 kilometers of crustal materials beneath this basin's floor. Thus it has been suggested that the basin was not formed by a typical high-velocity impact, instead formed by a low-velocity projectile that hit at a low angle (about 30 degrees or less), and hence did not dig very deeply into the Moon.

SPA is interesting, as the deepest lunar crustal materials should be exposed here. Several craters in this area have permanently shadowed regions that may contain deposits of hydrogen or water ice, as indicated by observations from the Lunar Exploration Neutron Detector (LEND), an instrument onboard the Lunar Reconnaissance Orbiter (LRO). Conversely, nearby areas of higher elevation receive constant illumination by the Sun; this makes them useful for harnessing solar energy for future robotic or human explorations. Also, SPA is known to be scientifically rich destination for future exploration by landed and sample return missions because being the oldest basin on the Moon, it has the importance of recording the chronology of major impact events in the early solar system that might help in the understanding of lunar history, structure and giant impact processes.



Image of the Aitken basin taken by the Apollo 17 crew

Image source : www.spaceanswers.com
Text Source: www.psrd.hawaii.edu, the-moon.wikispaces.com, www.lpi.usra.edu, sservi.nasa.gov, en.wikipedia.org.

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