One-year completion of Chandrayaan-2 Lunar orbit insertion (August 20, 2019)

Chandrayaan-2 completes a year around the Moon

The Moon provides the best linkage to understand Earth's early history and offers an undisturbed record of the inner Solar system environment. It could also be a base for future human space exploration of the solar system and a unique laboratory, unlike any on Earth, for fundamental physics investigations. In spite of several missions to the Moon, there remains several unanswered questions. Continued high resolution studies of its surface, sub-surface/interior and its low-density exosphere, are essential to address diversities in lunar surface composition and to trace back the origin and evolution of the Moon. The clear evidence from India's first mission to the Moon, Chandrayaan-1, on the extensive presence of surface water and the indication for sub-surface polar water-ice deposits, argues for more focused studies on the extent of water on the surface, below the surface and in the tenuous lunar exosphere, to address the true origin and availability of water on Moon.

With the goal of expanding the lunar scientific knowledge through detailed studies of topography, mineralogy, surface chemical composition, thermo-physical characteristics and the lunar exosphere, Chandrayaan-2 was launched on 22nd July 2019 and inserted into the lunar orbit on 20th August 2019, exactly one year ago. Though the soft-landing attempt was not successful, the orbiter, which was equipped with eight scientific instruments, was successfully placed in the lunar orbit. The orbiter completed more than 4400 orbits around the Moon and all the instruments are currently performing well.

Science payloads and its unique capabilities:

1.	Terrain Mapping Camera – 2 (TMC-2)	High resolution topographic maps and Digital Elevation Models (DEM) of the lunar surface.
2.	Orbiter High Resolution Camera (OHRC)	Highest resolution optical images ever (~30 cm) from a lunar orbiter platform.
3.	Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS)	Highest resolution surface composition study of Moon using X rays – generation of global elemental maps. Monthly studies of geotail at the Moon – high time resolution particle spectrum and flux mapping

4.	Solar X-ray Monitor (XSM)	Highest time cadence and resolution solar flare spectrum for supporting CLASS and for independent studies of the solar corona.
5.	Imaging Infra-Red Spectrometer (IIRS)	Mapping minerals in 0.8 to 5.0 micron with a focus on extracting clear signature of surface presence of hydroxyl and/ or water.
6.	Dual frequency Synthetic Aperture Radar (DFSAR)	First full polarimetric measurements of permanently shadowed regions. First L-band observation of Moon and along with S-band, provides better identification of sub-surface water.
7.	Chandra's Atmospheric Composition Explorer – 2 (CHACE-2)	Study of neutral species in the exosphere and its spatial and temporal variations.
8.	Dual Frequency Radio Science Experiment (DFRS)	Lunar charged and neutral environment studies using the radio occultation technique.

Mission management and Operations:

The spacecraft is healthy and performance of subsystems are normal. The orbiter is being maintained in 100 +/- 25 km polar orbit with periodic orbit maintenance (OM) maneuvers. So far, 17 OMs are carried out since achieving 100 km lunar orbit on 24th September 2019. There is adequate onboard fuel to remain operational for about seven years.

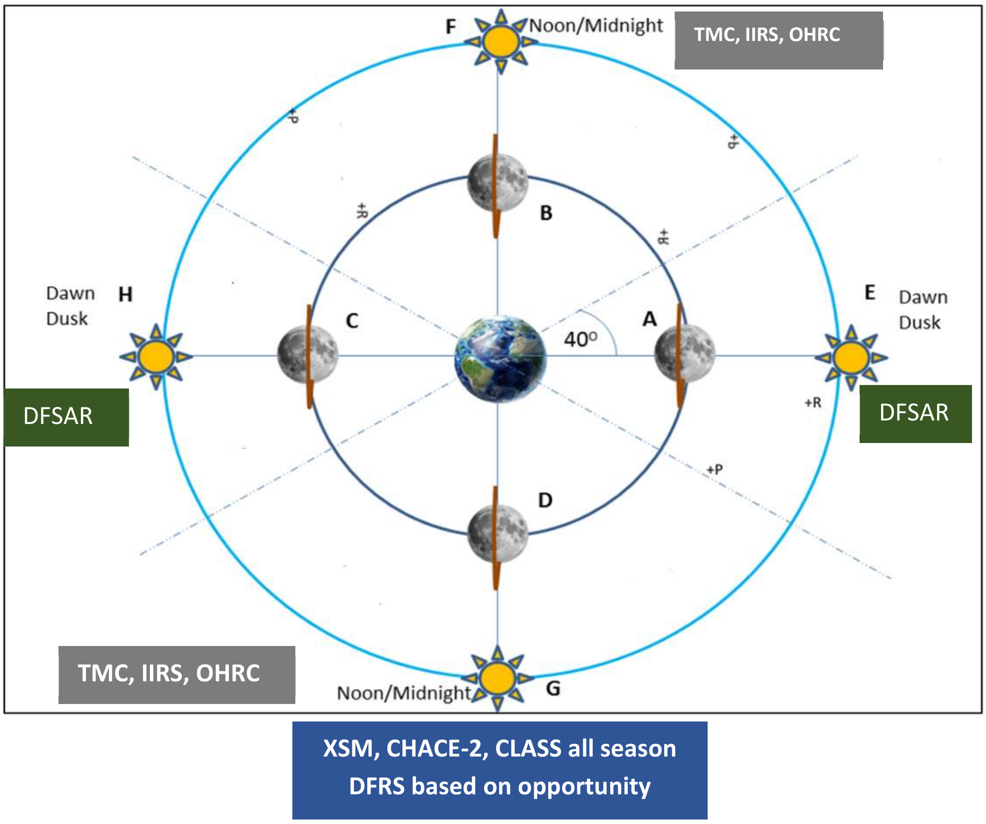


Fig.1: Payload operations with respect to seasons

During the course of a year, the Sun-aspect angle (angle made by Sun to zenith of local lunar point) varies giving rise to extreme variations in illumination (Dawn-Dusk orbit to Noon-Midnight orbit). Hence payload operations are planned optimally as follows: during the Dawn-Dusk season (i.e Sun angle w.r.t orbital plane > 40 deg.) SAR payload is operated. During Noon-Midnight Season (i.e Sun angle w.r.t orbital plane < 40 deg.), optical payloads such as TMC-2, IIRS are operated. CLASS, XSM and CHACE-2 are operated in all seasons. DFRS is operated as and when opportunities arise (Fig.1). IDSN-18m antenna and JPL DSN stations support S-Band telemetry and X-band payload data dumps. Downloaded data are transferred to ISSDC for processing, archival and dissemination (Fig.2).

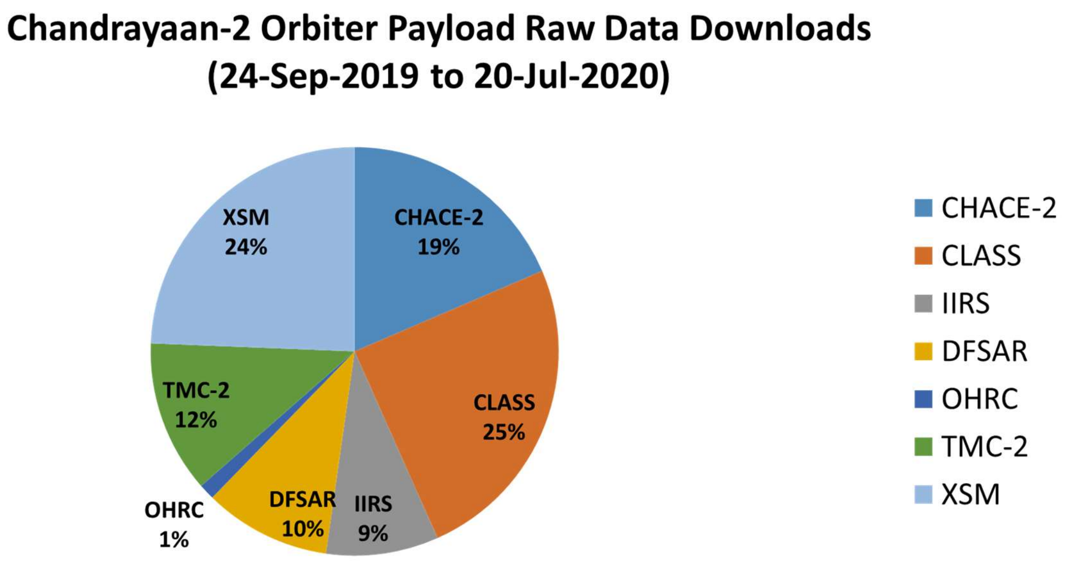


Fig.2: Payload data downloaded at ISSDC

Salient results from one-year observations

TMC-2 acquired images during 220 orbits consisting of nearly 4 million sq. km area and generated DEM and Ortho-images. Coverage map is shown below (Fig.3). Green stripes show observed regions.

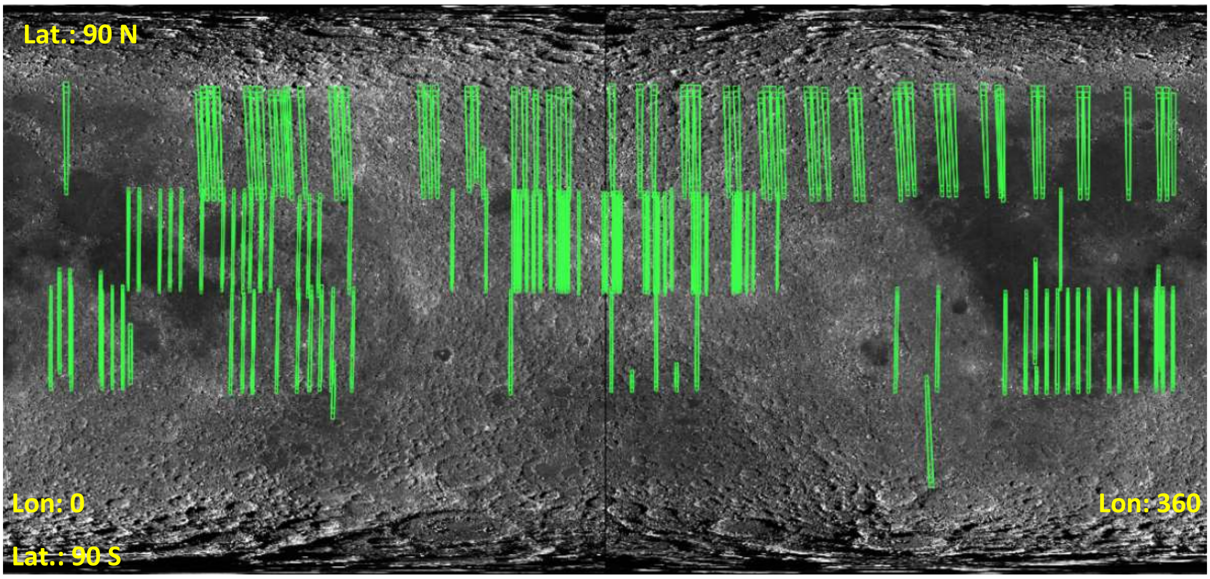
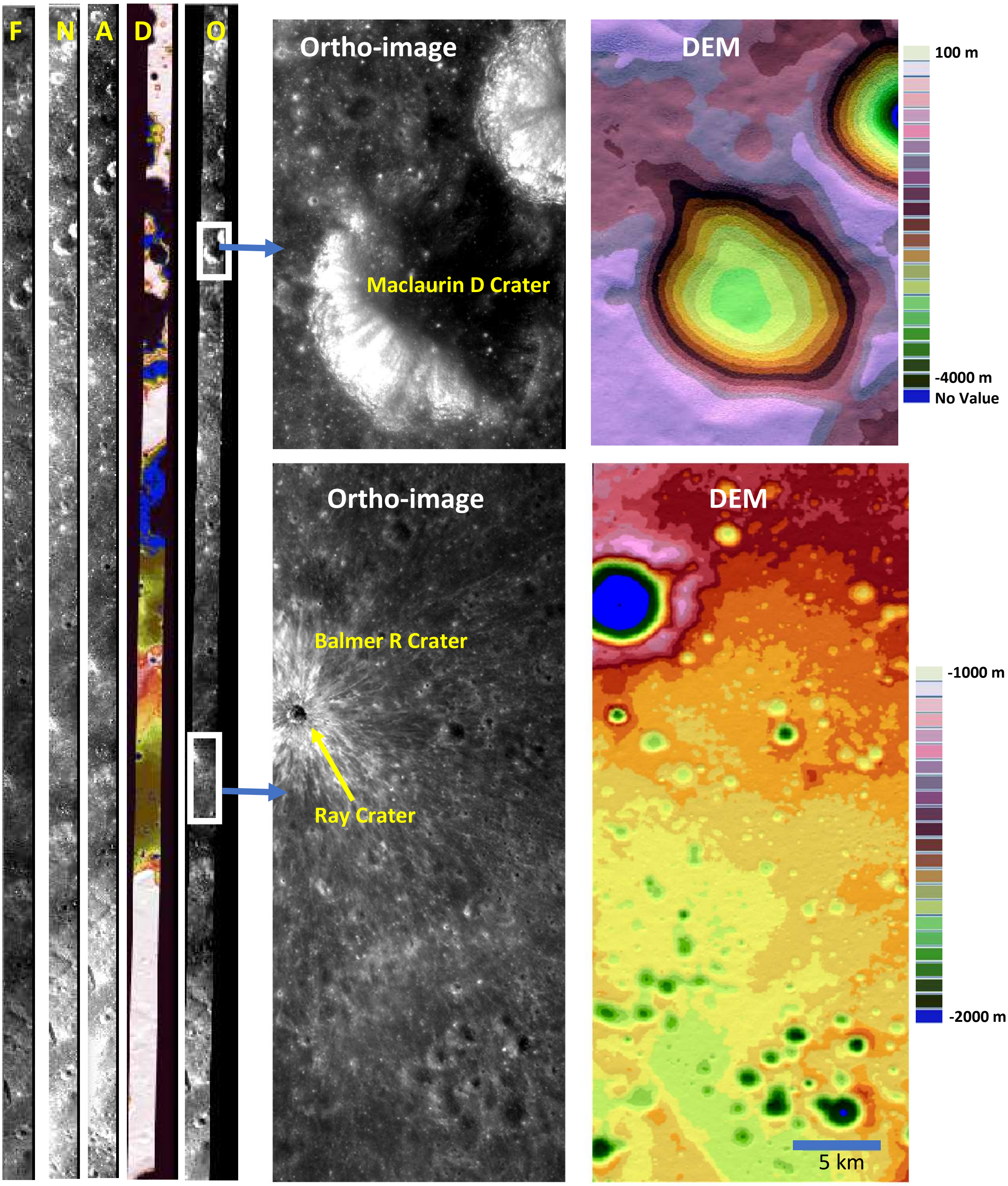


Fig.3: TMC-2 Image acquisition coverage plotted over LRO-WAC image *(Courtesy: NASA / LRO project)*



Fore (F), Nadir (N), Aft (A), DEM (D) and Ortho-image (O) of orbit 1945, Date of Pass-31 Jan.2020 and Zoomed view of a portion of Ortho-image and DEM.

Fgi.4: Balmer-Kapteyn (B-K) basin region. The scene center of the DEM and ortho-images are 69.386 E longitude and 14.473 S latitude.

B-K basin region is located on the east limb of the moon in the near side close to Mare Fecunditatis. It is a pre-Nectarian impact structure, which contain two rings of approximately 225 km and 450 km in diameter. This area is of scientific importance as it contains a type of light plains deposit that appears to lie on the top of an ancient basaltic surface. The image shows Balmer 'R' and Maclaurin 'D' craters. The one km diameter ray impact crater system is clearly visible in the image (Fig.4). The Digital elevation Model (DEM) has been generated from the stereo triplets (Fore, Aft and Nadir camera images).

Lunar lobate scarps are relatively small-scale tectonic landforms which are low angle thrust faults, believed to be young lunar landforms. Due to their small size they are not easy to detect. However, in lower sun angles the subtle variations in topography is enhanced by the corresponding shadows. One such scarp was detected on 15-10-2019 during low Sun elevation angle (15^0) from an altitude of 100 km in the Mare Fecunditatis region (fig.5).

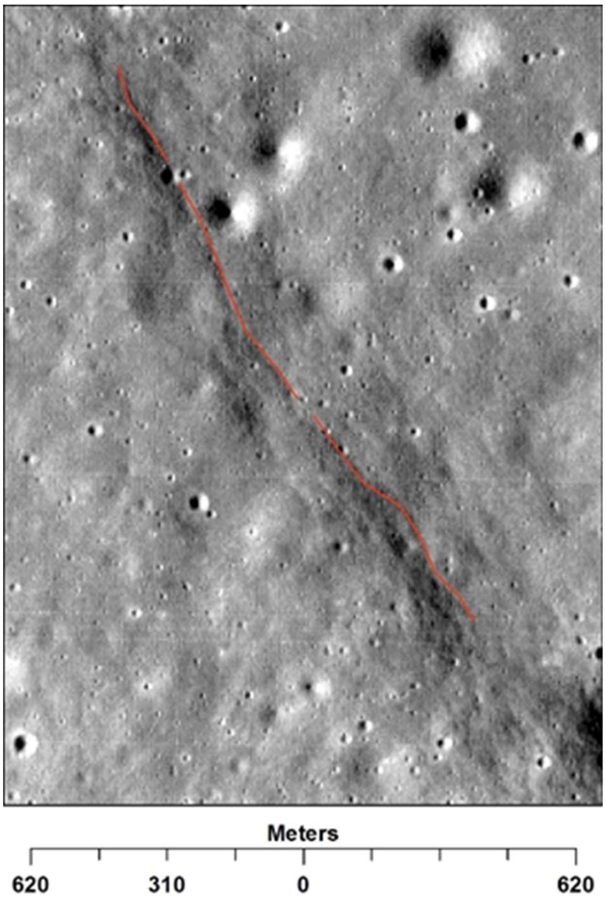


Fig.5: Lobate Scarp in the Mare Fecunditatis Region

Slope map indicates that the length of the scarp is 1416m and average relief variation across the scarp is 24m. This lobate scarp could have been formed in the Copernican period.

OHRC has acquired 22 orbits images of lunar surface consisting of nearly 1056 sq. km area. It is also used to characterize landing sites for future missions.

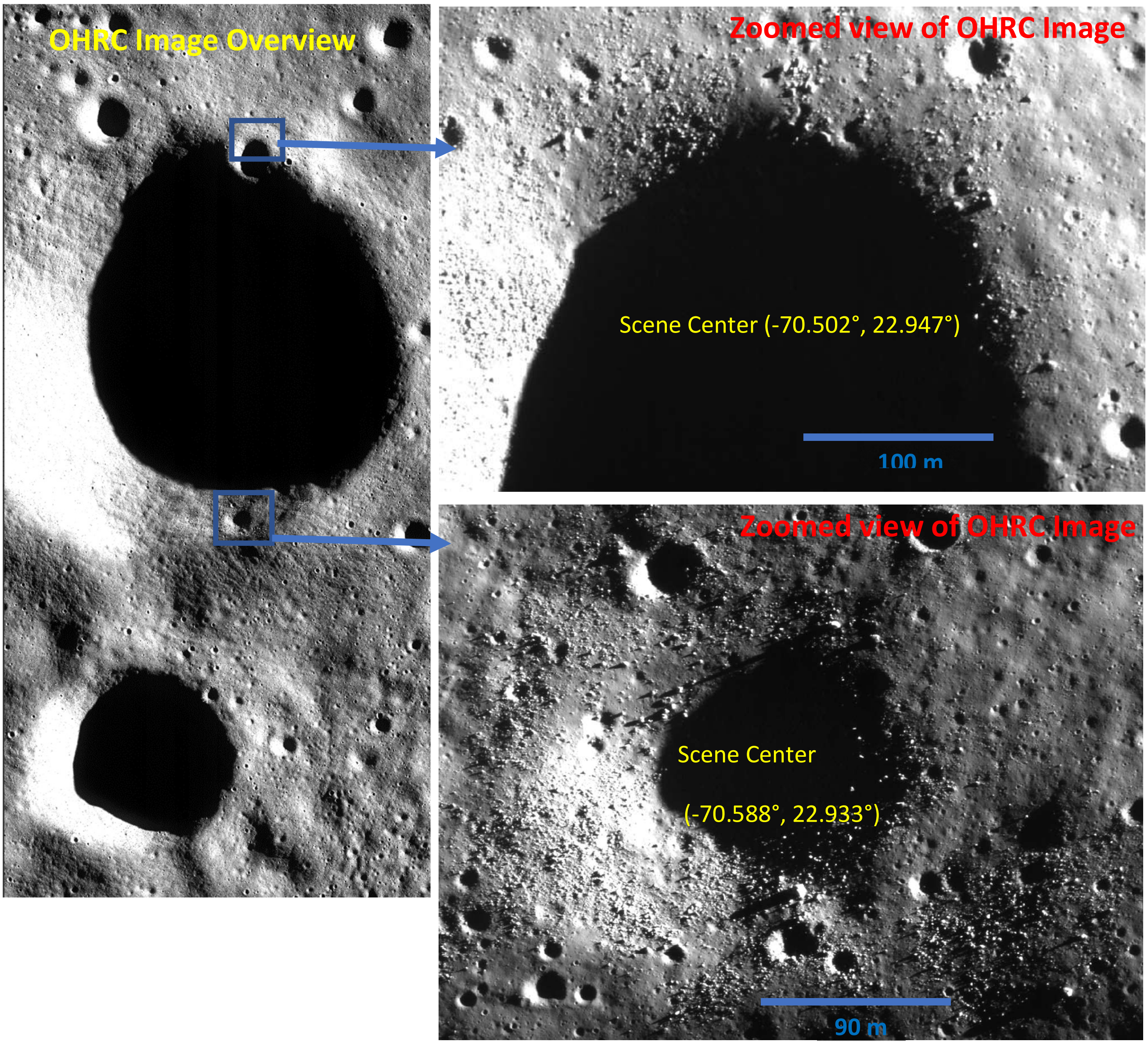


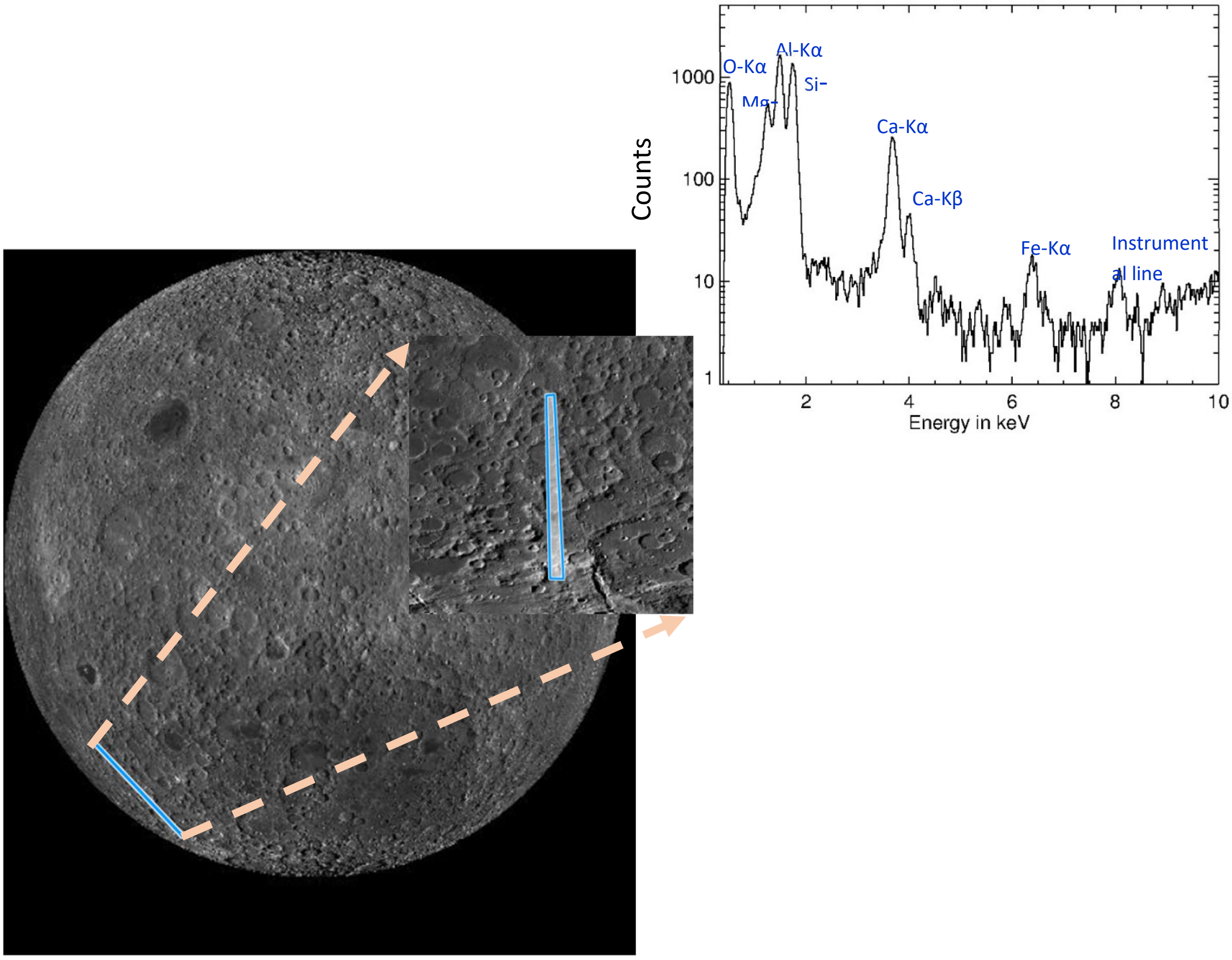
Fig.6: OHRC image covering the region between Manzinus C and Simpelius N acquired on 02nd March 2020

Boulders can be easily identified using OHRC images due to its very high spatial resolution. Hundreds of boulders, ranging from 1m to 50m in diameter, are distributed within an ejecta close to the crater rim. These boulders represent the deepest material excavated during crater formation. Boulders on the Moon surface are often found around young impact craters. Apart from characterizing the landing sites, the OHRC images allow scientists to study boulder populations in the region of interest and help them interpret geologic features and derive geologic history for a region.

CLASS: The Moon uniquely reveals the surface elemental composition during solar flares, resulting in the incidence of X-rays on the sunlit lunar surface. CLASS, an X-ray spectrometer on the Chandrayaan-2 Orbiter, has been measuring the resulting X-ray fluorescence photons since September of 2019, unveiling new elemental maps at kilometer scales like never before.

On 29th of May, the Sun flared to a level of C9.3, the second strongest flare of 2020 and CLASS caught secondary X-rays from fluorescence on the Moon as the orbiter flew over the rugged southern farside highlands. The X-ray spectrum shows direct and clear spectral signatures of major refractory elements (Aluminium and Calcium) from the highland region with additional evidence for lower amounts of Mg and Fe (Fig.7).

The far side hidden from Earth's view is quite different from the side we can see. Most of the lunar mare volcanism is confined to the nearside. All of the returned samples collected by the Apollo missions are from the nearside equatorial region which serve as a calibration standard for remote sensing measurements. However, we know today that the highland compositions are more diverse than what is represented in the returned samples. X-ray spectroscopy being one of the most direct approaches, CLASS delivers the promise of higher spatial resolution global maps for major elements on the lunar surface, the first of its kind.



Courtesy: LROC Quickmap

Fig.7: X ray fluorescence spectrum from Moon measured in CLASS from an area in the southern farside highlands (~ -35 to -66 lat, 121 long)

XSM: Solar X-ray Monitor *(*XSM) has been operational in-orbit from September 2019 and has observed several flares, including many low-intensity events. Modeling these spectra with theoretical models help us in understanding the evolution of physical properties of the Corona during solar flares.

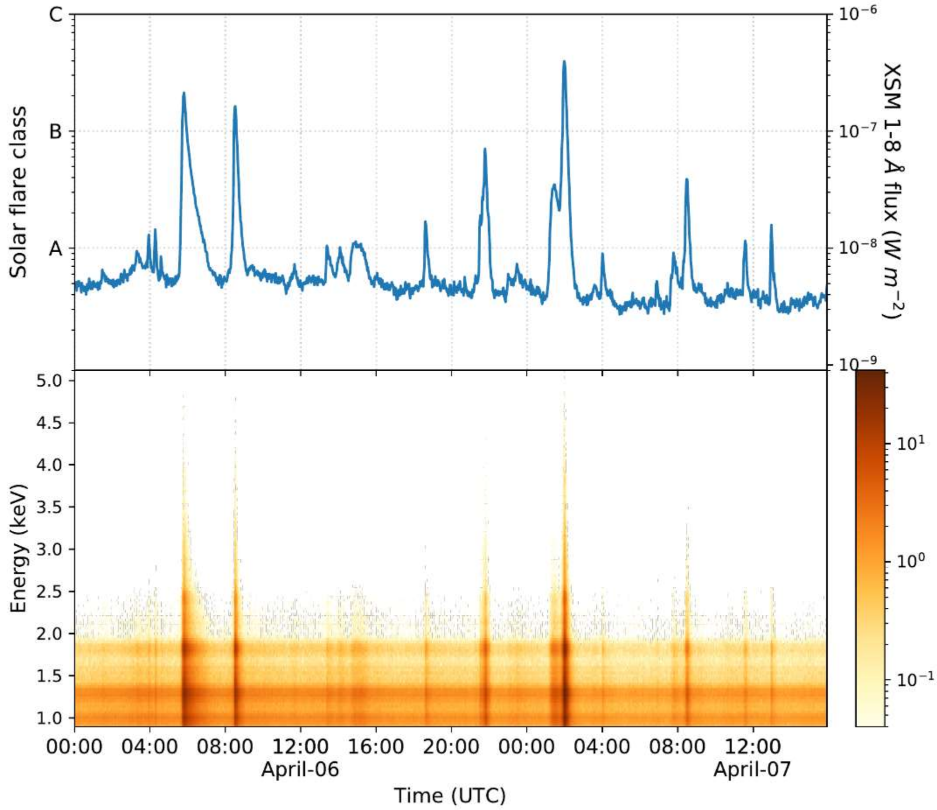


Fig.8: X-ray flux measurements (top panel) from XSM during 06-07 April 2020, when a series of flares were detected, including three B-class flares. The bottom panel shows the dynamic spectrum (spectrum measured for every point in the top panel, plotted along the vertical axis) during the same period.

DFSAR: Previous observations of lunar poles carried out with ground-based radars as well as orbital-based SAR data from Mini-SAR (Chandrayaan-1) and Mini-RF (Lunar Reconnaissance Orbiter) yielded ambiguous results on the possible presence of water ice in the permanently shadowed regions. These observations were constrained by limited viewing geometry and polarization measurements of aforementioned radar instruments. Chandrayaan-2 DFSAR, with its capability to acquire images at multiple incident angles with multiple polarization modes, has been imaging the lunar surface at both L and S-band wavelengths. In addition, full-polarimetric imaging capability of

DFSAR will provide new insights into the nature and distribution of lunar water-ice deposits.

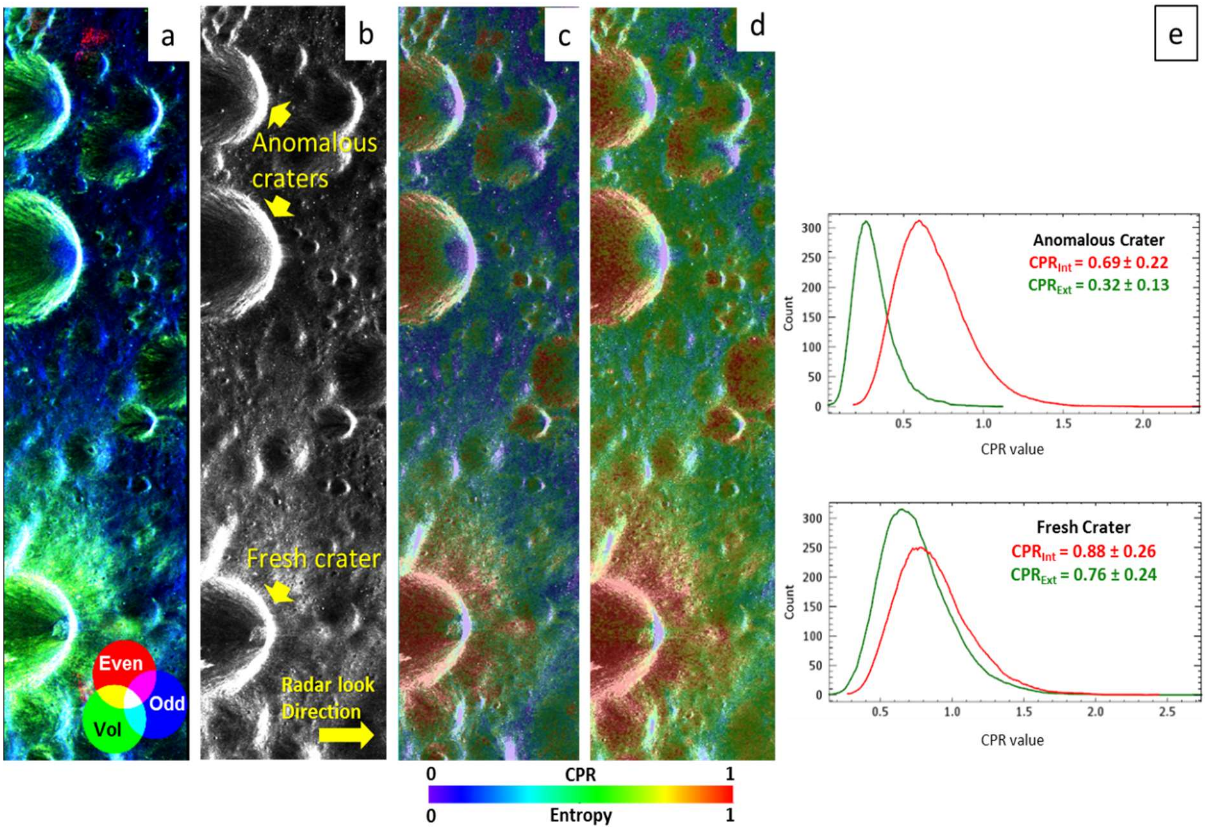


Fig.9: L-band polarimetric SAR image of a part of Peary crater (88.6° N, 24.4° E) in the lunar north pole (a) Yamaguchi decomposition image showing even-bounce, odd-bounce and volume scatterers in the RGB planes; (b) total backscatter intensity image; (c) circular-polarization ratio (CPR) image overlaid on intensity image, (d) polarization entropy image overlaid on intensity image and (e) distribution of CPR in the interior and exterior of fresh and anomalous craters.

Above figure.9 shows images of various radar parameters over a part of Peary crater lying within a permanently shadowed region (PSR) in the lunar north pole, derived from DFSAR L-band polarimetric data. The analysis of the radar parameters shows that some of the secondary craters within Peary have anomalous circular polarization ratio (CPR) values associated with anomalous scattering entropy and volume scattering within the crater interiors, and are ideal candidates for bearing water-ice. Craters with similar values of CPR in both interior and exterior regions can be interpreted as fresh craters with the presence of wavelength scale rock fragments and not water-ice or other volatiles.

SAR backscatter intensity is highly influenced by small-scale surface roughness and dielectric constants of lunar regolith. These two parameters are also crucial for identification of regions with probable presence of lunar volatiles such as water-ice.

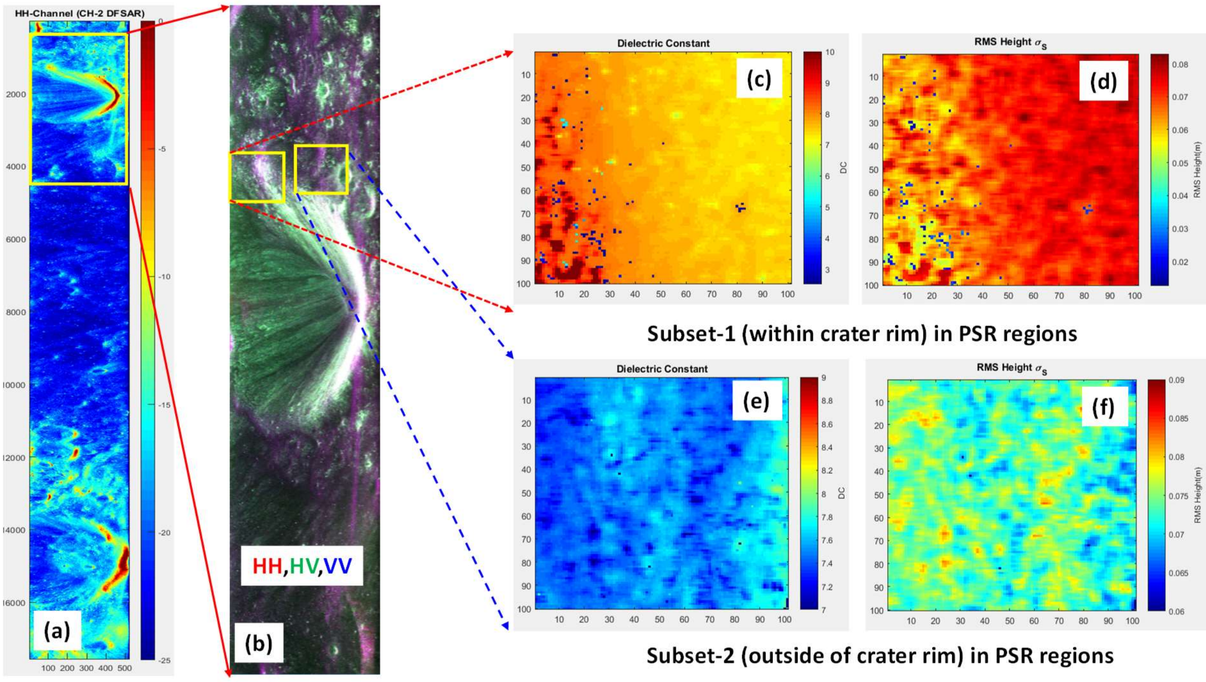


Fig.10: Images showing regolith dielectric constant and surface roughness estimated from L-band polarimetric SAR data in the permanent shadow regions near Haworth crater in the lunar South Pole acquired on 19th Oct, 2019. (a) SAR backscatter (HH polarization) image (b) False colour composite image with HH, HV and VV pol data in the RGB planes, respectively (c) dielectric constant and (d) RMS height images retrieved over subset-1; (e) dielectric constant and (f) RMS height images retrieved over subset-2. The regions with blue dots in figures (c) & (d) show low dielectric values and low surface roughness and are indicative of regolith with water-ice.

The figure.10 shows an example of retrieval of surface roughness and dielectric constants of lunar regolith at 25m spatial resolutions around an unnamed crater within permanently shadowed region (PSR) near Haworth crater in the lunar South Pole. Two sub-images were considered, one from the crater rim (subset-1) and other from outside the crater (subset-2). These images are used to retrieve the dielectric constant and surface roughness using L-band polarimetric data acquired on Oct 19, 2019 using two-layer scattering model. From the model inversion, it is observed that within the crater rim, a sub-set of pixels show very low dielectric constant and low surface roughness, most likely suggesting the presence of water-ice. There were no pixels with low dielectric constant, outside the crater rim. Further analysis is in progress and regions identified to hold water-ice, will be confirmed with the help of other radar parameters from DFSAR.

CHACE-2 has detected signatures of Argon-40 at 100 km altitude. Over the 6 months, CHACE-2 had observations in different orbit geometries covering dawn-dusk and noon-midnight sectors so that the local time variation could be addressed.

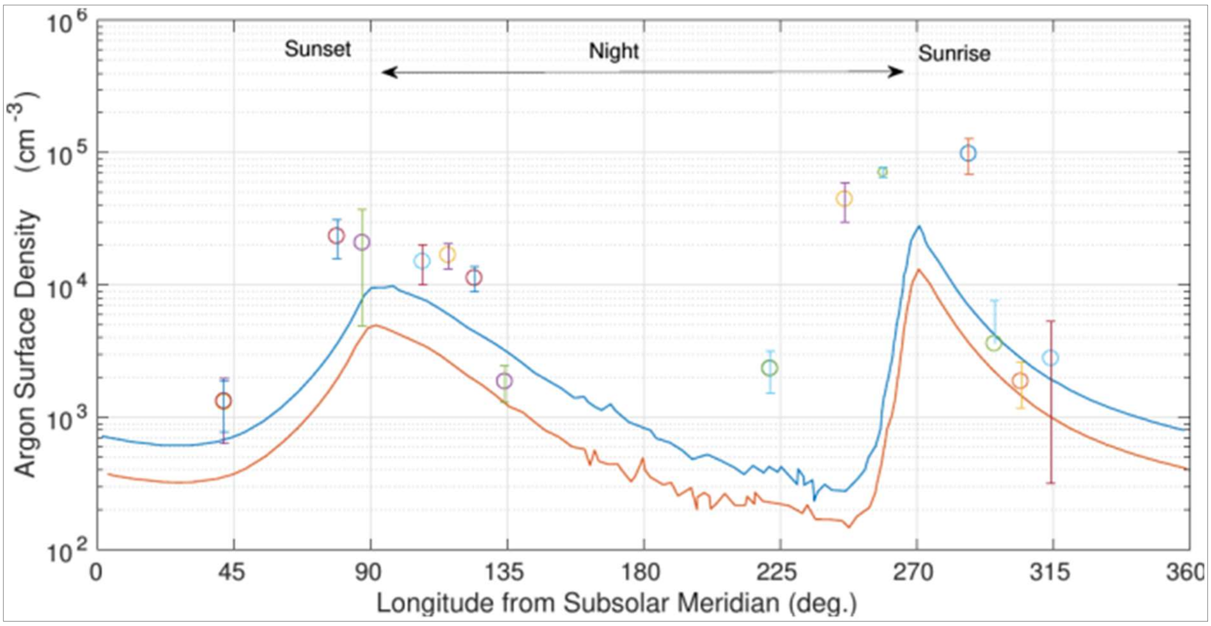
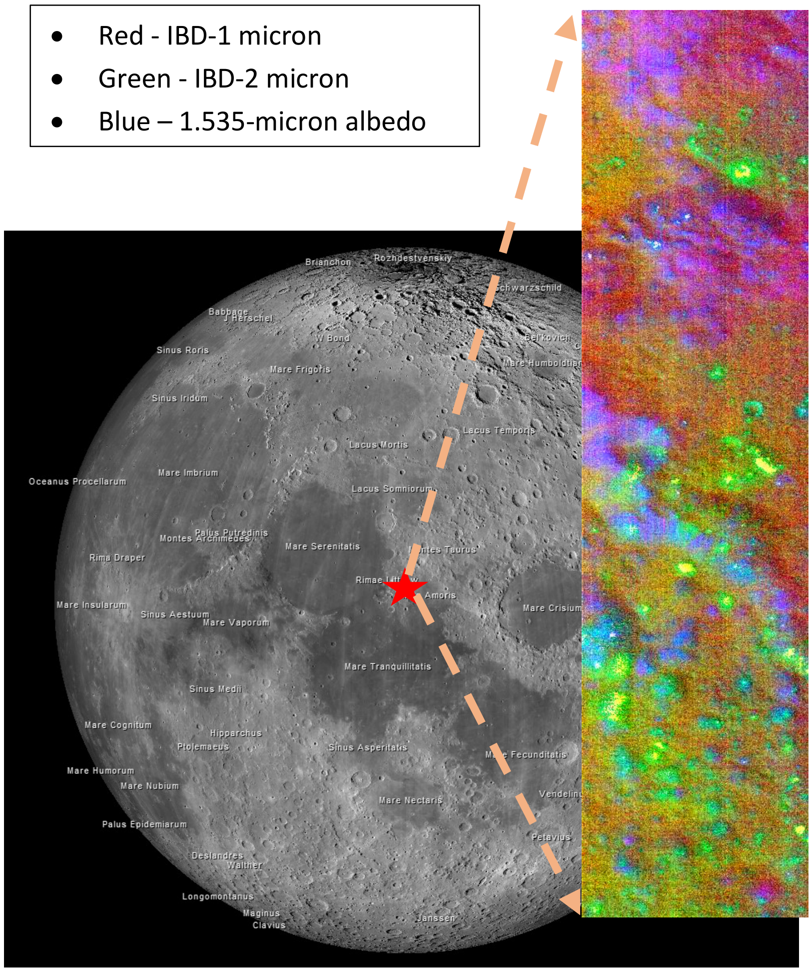


Fig.11: Variation of surface density of Argon-40 with local time near the equator. The horizontal axis is the longitude from subsolar meridian, such that zero represents subsolar point, 90º represents dusk/sunset, 180º represents midnight and 270º represents dawn/sunrise. The solid curves are from LACE/Apollo (Hodges, 1975) for 2 lunations. The open circles represent CHACE-2 observations.

After applying instrument calibration factors and the additional correction factor suggested by Sridharan et al (2015), the argon densities agree with the previous observations by LACE/Apollo. The primary Sunrise peak and the secondary peak during Sunset are represented. These are CHACE-2 observations from low-latitude region (<30°) with favorable roll-angle. These results confirm the day night variations observed by Apollo surface instrument locally. CHACE-2 is designed to generate global distributions for the first time.

IIRS: The lunar surface minerology is best captured in the near-infra red wavelengths. In addition, clear signatures of hydroxyl and water also exist at these wavelengths that would continue the study initiated by the Moon Minerology Mapper on Chandrayaan-1. The Imaging Infrared Spectrometer (IIRS) has been mapping the mineralogy in the 0.8-5 µm. Figure.12 shows an example of the mineralogical diversity of lunar highland crust at the mare-highland transition zone of Mare Tranquilitatis. The false colour composite (FCC) is generated by assigning the integrated band depth at 1 µm as Red channel, 2 µm as Green and the 1.535 µm albedo as Blue channel. In such FCC, the dark-coloured minerals enriched exposures appear in green to yellow to orange, whereas the matured highland soil and mafic-free plagioclase-bearing anorthositic rocks appear in blue to purple.



Courtesy: LROC

Fig.12: False color composite showing the compositional diversity at Mare Tranquilatis imaged by IIRS (80 m/pixel). The bluish regions are anorthositic (light-coloured plagioclase-bearing monomineralic rock) in nature and the areas highlighted in yellow-green are the exposures enriched in dark-coloured minerals (mostly silicates).

DFRS: Radio Occultation is a widely used technique for sounding the atmospheres of planets. The dual frequency radio science experiment uses X and S band to sound the ionosphere of the Moon assisted by the radio receiver at the ground station IDSN. The refraction of the radio signals measured from multiple occultation events, can provide evidence of the presence of steady or time-dependent changes in the neutral and ionized components above the surface.

Some of the salient science results are presented here. Public data release is planned by end of this year, after validation by a formal peer review. The first-year observations from Chandrayaan-2 demonstrate the in-orbit performance of payloads, strongly indicating its ability to contribute significantly to lunar science. The anticipated long life of this orbiter can contribute much to the current resurgence of interest among the global scientific community for a sustained presence on the Moon.