Martian Surface with the eyes of Mars Orbiter Mission(MOM)

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India's maiden mission to the red planet,Mars is a milestone for the planetary exploration program of the Indian Space Research Organization (ISRO). The Mars Orbiter Mission, popularly known as MOM with five payloads was launched from Sriharikota using a Polar Satellite Launch Vehicle (PSLV-C25) rocket on November 5, 2013. The details of the payloads are described in this paper. The special attention of this paper is on Martian surface, especially the Valles Marineris region. The dust storm and dust devil observed over Mars by Mars Color Camera (MCC) on orbit 32 and 34 are briefly explained. The optical depth of Martian atmosphere above northern and southern walls of the Valles Marineris is also presented in this article. The large ice cap and mosaic of Martian northern pole captured by MCC is discussed. The importance and future planetary exploration plans of India are briefly mentioned.

I. INTRODUCTION

On December 1,2013 Mars Orbiter Mission(MOM) also called Mangalyaan(Hindi:"Mars Craft") departed from Earth's orbit and after a cruise phase of 300 days in the heliocentric orbit, on September 24, 2014, India become the first country to put an interplanetary space probe around Mars in her first attempt. The first interplanetary mission of India, MOM was launched from Satish Dhawan Space Center using an expanded version of Polar Satellite Launch Vehicle(PSLV-XL) rocket on 5 November, 2013. Then it is moved into what is called geocentric orbit. It would have passed Mars if it had followed the same trajectory. When the maneuver was essential to move the orbiter, so that it would face in a centered direction, an engine burn took place for 24 minutes to slow down Mars orbiter. The length of the orbit increased and it became more and more elliptic in the process. Therefore, it would captured by Mars gravity and continue to circle around Mars. There have been 51 missions for Mars but only 21 of them has been successful. This indicates the complexity of such missions. None of the missions till date had looked specifically for Methane, because the earlier indication was that probably there was no methane on Mars which means no clue for Life on Mars. This is MOM which carries Methane Sensor and came out with the exclusive results. The MOM is driven by key scientific questions such as whether Mars was, is or can be a habitable world. MOM has both technical and scientific objectives[**?**].Technological objectives include the design and realization of a Mars Orbiter with a capability of surviving and perform Earth-bound maneuvers, cruise phase, Mars orbit insertion and on-orbit phase around Mars. Also, deep space communication, navigation, and management were the challenges for the mission. Exploration of Martian surface features and its atmosphere using the five indigenous payloads are the main scientific goal of MOM.

This paper is organized as follows. Section II describes the different scientific instruments which are carried by Indian Mars Spacecraft. The concept of the dust storm and dust devil is defined in section III, along with a brief description of Atmospheric Optical Depth (AOD)in the Valles Marineris region on Mars by MOM data. The polar ice cap is also briefly discussed in the section III. Section IV contains concluding remark.

II. PAYLOADS

Mars orbiter spacecraft carries a suit of five indigenous payloads, namely: Mars Colour Camera (MCC), Methane Sensor for Mars (MSM), Thermal Infrared Imaging spectrometer (TIS), Lyman Alpha Photometer (LAP) and Mars Exospheric Neutral Composition Analyzer (MENCA).

MCC is an electro-optical sensor which provides the images of Mars depending on its position in orbital plane and illumination conditions.MCC uses a Multi-element Lens Assembly of spectral range 400-700 nm for collecting the incident radiation from Mars. Another component Pixel Array Detector with RGB Bayer filter is a 2-dimensional imager capable of storing subsequent frames in less than 0.5 μs [**?**]. It is designed to return 'natural images'(Colours in the image appear the same way as in the object) of Martian surface, its morphological features,especially the events like the dust storm and dust devil. It also provides probing images of two moons of Mars, Phobos and Deimos.

MSM has been developed at Space Application Centre of ISRO to measure the Methane column in the Martian atmosphere from an orbiting platform. This Differential Radiometer has the measurement accuracy of the order of parts per billion(ppb). MSM with its spectral range of 1.64 to 1.66 μm, is able to map the sources and sinks of methane from the apogee of its elliptical orbit of 372 $\times$ 80000 km[**?**].The Methane Sensor for Mars has two channels for calibration, one is methane channel which is sensitive to methane and another is reference channel to measure the background reflectance of Mars at a wavelength of 1.65 μm. Methane is transparent at 1.65μm. The reflectance of Mars in this reference channel is compared to its reflectance in a channel where

methane is opaque to measure the abundance of atmospheric methane.

TIS is one of the five instruments on-board MOM, weighing 3.2 kg. This instrument is operational during both day and night. Using microbolometer device it observes the emitted infrared radiation from Martian environment for minerals reported to exist in Martian surface of spectral range 7-13μm. The scientific goals of TIS are to estimate ground temperature and map surface composition of Mars. The basic physical parameters for thermal emission are temperature and emissivity[**?**]. TIS is being used to study the spatial and temporal variation of surface temperature. During perigee(imaging this instrument is also useful to deduce surface composition and mineralogy which is useful to understand the mineral formation conditions and the process by which they are weathered. The science behind the TIS works using foreoptics, slit, collimating optics, grating, and re-imaging optics.

To understand the evolution of planetary atmosphere of Mars, one has to understand their atmospheric escape process for different kind of gasses.LAP is an absorption cell photometer which measures the relative abundance of deuterium and hydrogen in the Martian upper atmosphere. It is especially useful to understand the loss process of water from the red planet measuring the deuterium to hydrogen abundance ratio(D/H ratio). Being a non-magnetic planet, Martian exosphere is always exposed to solar winds.This causes the photo-dissociation of water which produces hydrogen(H) and deuterium(D). Thus measurement of D/H ratio is important to understand the current escape process. It is also crucial to deduce the loss process of water on Mars.Study the deuterium enrichment in the upper atmosphere of mars is one the scientific objective of LAP on-board Mangalyaan[**?**].

It is believed that Mars have had preliminary atmosphere but is lost to the outer space over the time. Subsequently, Mars developed a carbon-rich secondary atmosphere. In the present day surface pressure of Mars is around 6-7 mbar. Depletion of Martian atmosphere is can be understood by knowing the thermal escape of atmosphere. A simple way to understand the thermal escape is by studying the thermal neutrals in the exosphere. MENCA payload weighing 3.56 kg, is being used in the study of the distribution of the Martian neutral exosphere in the mass range of 1-300 amu in the equatorial and low latitude of Mars. MENCA is a quadrupole mass spectrometer-based experiment[**?**].

MCC and TIS is providing information about martian surface while MENCA is measuring particle environment in exosphere of Mars. LAP and MSM have been providing information about Martian atmosphere. Beside this, MCC,MSM, and TIS are useful in interpreting the data to detect methane as a signal for life(if there were any).But because of the atmospheric scattering, it is difficult to estimate the accurate data by MSM. MCC and TIS both are very helpful to deal with this issue.MCC is used for dust optical thickness estimation to correct atmospheric scattering and TIS is proving information about surface temperature to analyze MSM data for accurate estimation of Methane.

III. MARTIAN SURFACE

Extremely dynamic Martian surface is a topic of deep interest. One of the interesting regions of Martian surface is the Valles Marineris, a region comprising large number of canyon systems.

Valles Marineris : Valles Marineris is a canyon system of Mars. It is the Grand Canyon of Mars, divided into several regions which are called chasma and subdivided into several chasmae. The Valles Marineris is a large tectonic crack which is running upto a length of around 4000 km. It is located near the equator of Mars and it extends from 50^{o}W to 90^{o}W along longitude and 0^{o}S to 15^{o}S along latitude. In multiple observations by MCC this region is found to be hazy and covered with dust. These dust particles play an important role in the energy budget of the martian atmosphere. Since there is an extreme variation of topography, this region often creates its own environment. This makes the Valles Marineris region interesting for the study of the atmospheric behavior of Mars.

MCC observed Valles Marineris on 28 October 2014(the orbit number 32), 5 December 2014 (49) and 13 December 2014 (52). On orbit 32 the valley was found to be hazy. The hazy layer had become relatively thinner from orbit on orbit 49. Thick haze reappeared on orbit 52. The images were taken in the morning at the local time around 9.30 AM. Due to the negligible illumination effect, the comparison among these pictures is not effected. Mars receive 45% more incident radiation during perihelion when Mars is 20% closer to the sun as compared to the aphelion which increases weather activity during the southern mid-spring season.

During Martian summer in the equatorial region of Mars, chances of dust storm increase because of the increase of higher temperature variation. These phenomena are well captured in MCC images and have been studied for dust activity and contrast changes across sharonov crater which is an impact crater on Mars. Contrast computation methodology has been used for computing the contrast using the “bright” and “dark” pixels [**?**]. The “bright” pixels are defined as the intensity at which 10% of the analyzed field pixels are brighter and 90% are darker and vice-versa for the “dark” pixels. Thus, the contrast is given by

$$contrast(I) = 100(I_{bright} - I_{dark})/I_{avg} \qquad (1)$$

Apparent reflectance derived by MSM indicates the presence of dust. The apparent reflectance is the fraction of incident solar radiation reflected by the surface. The average value of apparent reflectance provides an effective spatial resolution of 1^{o} latitude by 1^{o} longitude. The higher difference in apparent reflectance describes the

dust containing region across Valles Marineris (Fig.1). Discarding some constraints, the changes in the values of apparent reflectance deriving dust storm activity indicates the presence of dust in the Valles Marineris region. The dust storm height is found nearly 2.5-3.5 km which is partially local in nature[**?**].

The stereo image acquired by MCC on 5 December, 2014 local time at 70^{o}W longitude has been used for measuring Atmospheric Optical Depth(AOD) over Valles Marineris. The solar angle ranges in between 25^{o} and 30^{o}. Emission angle is found in between 35^{o} and 42^{o}. Phase angle fall between 52^{o} and 53^{o}. The surface elevation of the region at 1 km interval in northern and southern Valles Marineris varies between -6 to 3 km. The contrast for this region is computed using Eq.**??**. Thus the AOD can be written as

$$\tau \approx (\mu_1\mu_2)/(\mu_1 - \mu_2) log\{(I_1)/ < I_1 >][I_2/ < I_2 >]^{-1}\} \quad (2)$$

where μ_1 and μ_2 are the emission angle such that $\mu_1 < \mu_2$ which suggests that μ_1 is more inclined than μ_2. Therefore emission angle μ_1 leads to lower contrast in comparison with emission angle μ_2. This difference in contrast is used to estimate atmospheric Optical Depth. I_1 and I_2 are the two MCC stereo images. $< I_1 >$ and $< I_2 >$ represents the mean image intensity over the analyzed region[**?**]. The observed contrast decreased on orbit 52 because of the large optical depth and the atmospheric hazes appeared brightly. Fig.1 shows the haze inside the valley. From the picture it is easily noticeable that the haze inside the Valles Marineris was relatively thicker than orbit 49. Again eight days after orbit 49, the thick haze reappeared during orbit 52 on 13 December, 2014. Consulting the Global Circulation Region Model, it is found that there is a strong wind in the direction from south-west to north-east which is intersecting the southern wall of Valles Marineris.

Polar Ice Cap : Very recently there has been a work done by Space Application Centre (SAC) under ISRO on the polar ice of Mars. This region is almost 1000 km across. MCC has captured several images of the north pole of Mars. A mosaic is prepared using nine MCC images observed in between 16 December, 2015 and 26 January, 2016 which shows a large cap on the north pole of Mars.The observation had taken place on solar latitude(Ls) from 82^{o} to 100^{o} of 33rd Martian year. The longitudinal position of mars during the orbit around the sun, is used for tracking the time on Mars. That means a system goes from 0^{o} to 360^{o}. Season is tracked by solar latitude. Thus Ls = 0^{o} represents the beginning of the northern spring and Ls = 180^{o} represents the beginning of the southern spring. During the northern winter(Ls - 270^{o}-360^{o})the atmospheric CO_2 freezes and deposits a layer of frozen CO_2 in the area which causes the large expansion in area of polar cap. During the summer, due to the increase in temperature, the dry ice sublimate away,

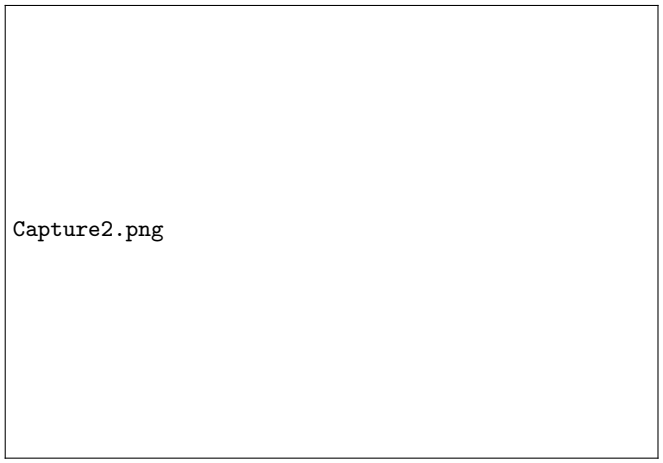

FIG. 1: MCC mosaic of the Martian North Polar Region

results the shrink in the size of the ice cap. The major albedo feature are easily seen in the mosaic. The light brown edge of the ice-cap is surrounded by a series of layers of ice and dust, known as polar layered terrain. Also, the ice cap is surrounded by dark brown sand dunes. The huge canyon, Chasma Boreale almost sliced the ice cap in two regions. The topography and surface albedo is easily visible in the mosaic.

IV. CONCLUSION

MOM has sent some of the most remarkable data in two years. The most remarkable data accumulated by MOM is the proof of watery exercises in its preliminary atmosphere, and the most profound result is the changes in polar ice cap of Mars in summer. Mangalyaan has also evaluated the layers of dust and the atmospheric optical depth on Valles Marineris.
Mangalyaan was a tech demo to see if India could actually get a spacecraft successfully into Martian Orbit. With the success of Mars Orbiter Mission India became the first single nation to enter the orbit of the red planet at its first go, along with the most economical interplanetary mission. Future of MOM is completely dependent on its different components and the life of the components would decide the future of this mission. It is assumed that it could last further in the space at least 5 to 10 years. Mangalyaan was successful to infuse confidence among the countrymen that India was second to none, which can be considered as its greatest achievement. Following the success of Lunar mission 'Chandrayaan-1' and 'Mangalyaan', a discussion is going on the second Mars mission and a possible mission to Venus. Recently ISRO and Indian Air Force(IAF) has signed a MoU for a manned space mission. Hope for the best.

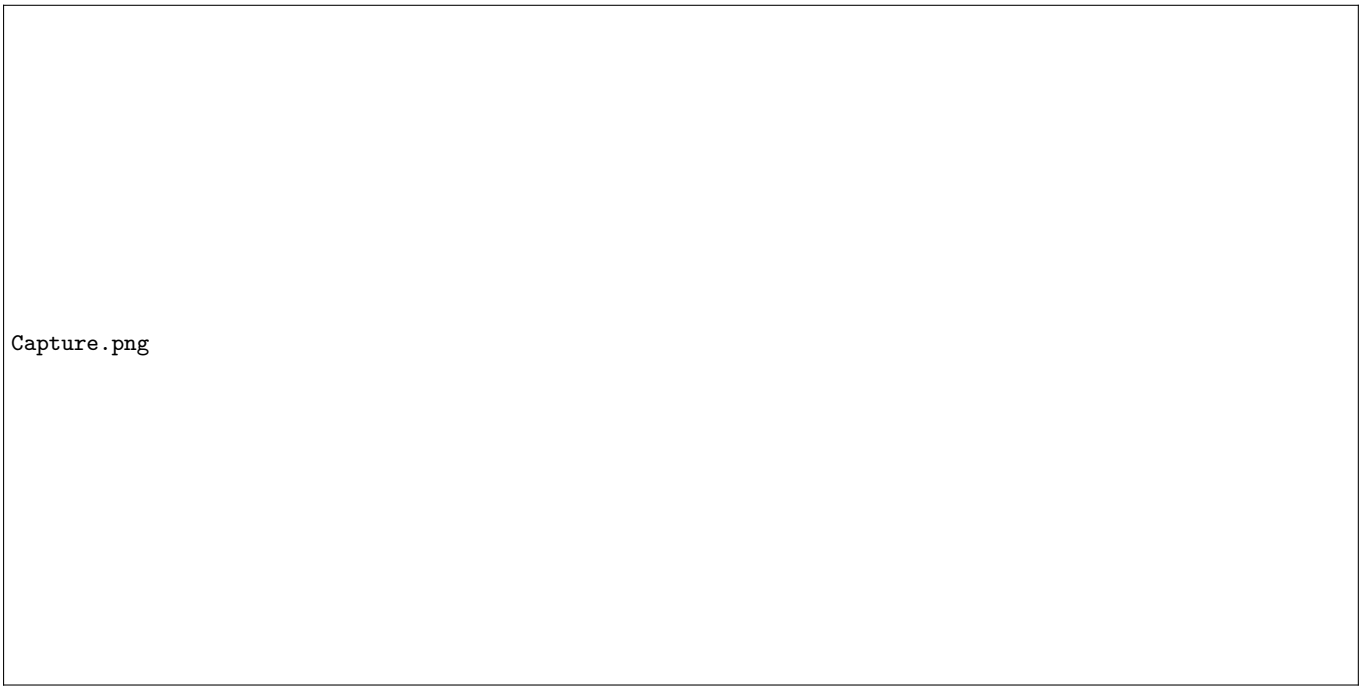

FIG. 2: Natural colour images of Valles Marineris observed on (A) 28 October 2014 (during orbit 34,LT = 9:16), (B) 5 December 2014 (49, 9:48), and (C)13 December 2014 (52, 9:48)[**?**]

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V. REFERENCES

[1] A. S. Kiran Kumar and Prakash Chauhan *Scientific Exploration of Mars by First Indian Space Probe: Mars Orbiter Mission*, Current Science, Vol. 107 -Issue 7: Oct 2014, p1096

[2] Prakash Chauhan and Anil Bhardwaj *Understanding our Celestial Neighbors: An Indian Perspective in Planetary Sciences and Exploration*,Proc Indian Natn Sci Acad**82** No. 3 July Spl Issue 2016 pp. 403-423

[3] Manoj K. Mishra, Prakash Chauhan, and Ramdayal Singh *Estimation of dust variability and scale height of atmospheric optical depth (AOD) in the Valles Marineris on Mars by Indian Mars Orbiter Mission (MOM) data*, Icarus 265 (2016) 84–94.

[4] A. S. Arya, S. S. Sarkar *Mars Colour Camera: the payload characterization/calibration and data analysis from Earth imaging phase(1076)*, Volume 109 - Issue 06 : 25 September 2015

[5] Kurian Mathew, S. S. Sarkar, *Methane Sensor for Mars (1087)*, Volume 109 - Issue 06 : 25 September 2015

[6] R. P. Singh, Somya S. Sarkar *Thermal Infrared Imaging Spectrometer for Mars Orbiter Mission (1097)*, Volume 109 - Issue 06 : 25 September 2015

[7] Raja V. L. N. Sridhar, M. V. H. Rao *Lyman Alpha Photometer: a far-ultraviolet sensor for the study of hydrogen isotope ratio in the Martian exosphere (1114)*, Volume 109 - Issue 06 : 25 September 2015

[8] Anil Bhardwaj, S. V. Mohankumar *MENCA experiment aboard India's Mars Orbiter Mission (1106)*, Volume 109 - Issue 06 : 25 September 2015

[9] Ramdayal Singh and Manoj K Mishra *Identification of Dust Storm and Dust Devil on Mars using Mars Colour Camera onboard Mars Orbiter Mission*,NSSS, 9-12 February 2016