

On-Orbit Performance of the Moon Mineralogy Mapper Instrument

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ABSTRACT

Launched on India's Chandrayaan-1 spacecraft on October 22, 2008, JPL's Moon Mineralogy Mapper (M3) instrument has successfully completed over six months of operation in space. M3 is one in a suite of eleven instruments, six of which are foreign payloads, flying onboard the Indian spacecraft. Chandrayaan-1, managed by the Indian Space Research Organization (ISRO) in Bangalore, is India's first deep space mission. Chandrayaan-1 was launched on the upgraded version of India's Polar Satellite Launch Vehicle (PSLV-XL) from the Satish Dhawan Space Centre, SHAR, Sriharikota, India. The primary science objective of the M3 instrument is the characterization and mapping of the lunar surface composition in the context of its geologic evolution. Its primary exploration goal is to assess and map the Moon mineral resources at high spatial resolution to support future targeted missions. M3 is a cryogenic state of the art "push-broom" near infrared imaging spectrometer with high signal to noise ratio and spatial and spectral uniformity. The mission lifetime for the instrument is 2 years with 3 months of primary science imaging every 6 months.

Thermal control makes use of passive cooling to provide three temperature zones needed for efficient cryogenic staging, namely 150 K, 170 K and 210 K. A three-stage passive cooler provides cooling for the low temperature zones while a flat plate radiator provides 300 K cooling for the electronics. M3 contains a single mercury cadmium telluride focal plane array cooled to near 150 K by means of the passive cooler 3rd stage. The passive cooler 2nd stage cools the spectrometer optics bench to 170 K while the 1st stage provides cooling to a thermal shield at 210 K surrounding the optics bench. Aluminum

flexible thermal straps connect the detector and optics bench to the passive cooler stages. In survival mode, the instrument is off and survival heater power is used to maintain non-operating allowable flight temperatures.

At launch plus 2 hours, M3 survival heater power was enabled and the detector decontamination heater was powered on 6.5 hours later. The spacecraft trajectory required five liquid apogee motor burns at perigee to place the spacecraft into the lunar transfer trajectory. Lunar orbit insertion occurred at launch plus 17 days and 5 days later a stable 100 km circular orbit was achieved. India's Moon Impact Probe was first powered on and successfully released after achieving a stable orbit. M3 was powered on November 18, 2008 after 27 days in decontamination mode. Two days after M3 was powered on, the detector was sufficiently cold to begin acquiring science data. This paper provides a brief overview of the overall thermal control approach, reviews the on-orbit instrument performance and identifies important lessons learned.

INTRODUCTION

The M3 instrument, designed and built by the Jet Propulsion Laboratory for NASA under the Discovery Program, is currently flying onboard the Chandrayaan-1 spacecraft in a near polar orbit at a nominal 100 km altitude. M3 is one of two NASA payloads of opportunity instruments flying onboard Chandrayaan-1 (Ref. 1).

Spacecraft communications during Earth Transfer Orbits and Lunar Transfer Trajectory relied on ISRO's telemetry, tracking and command (ISTRAC) network stations. ISTRAC's network include stations in Bangalore, Lucknow, Sriharikota, Thiruvananthapuram,

Mauritius, Bearslake Russia, Biak Indonesia, Brunei, Trivandrum and Port Blair (Ref. 2).

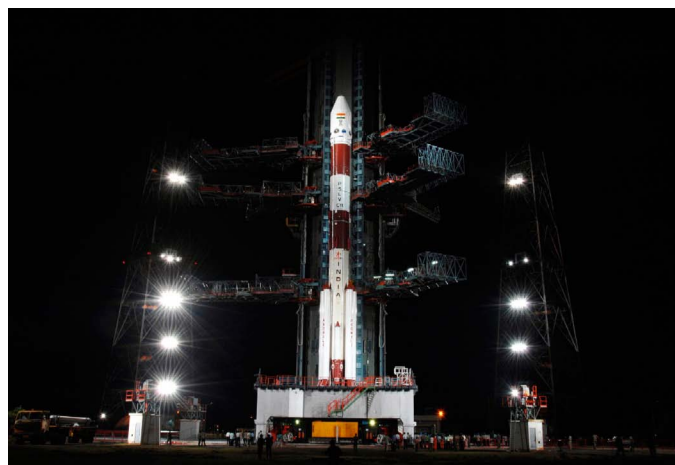


Figure 1. Chandrayaan-1 spacecraft on top of the launch vehicle at SHAR

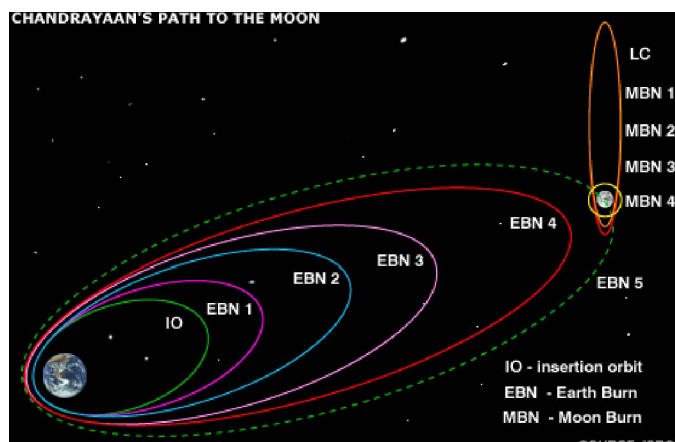


Figure 2. Chandrayaan-1 mission trajectory to the Moon

The Chandrayaan-1 mission ground segment consists of the Ground Station Network including the Indian Deep Space Network (IDSN), Mission Operation Complex (MOX) and the Indian Space Science Data Centre (ISSDC). The ground segment is responsible for all spacecraft communications, orbit maintenance, attitude control, payload operations, and also has responsibility for making the science and auxiliary data available to the payload scientists. The IDSN consists of an 18m and 32m antennae located in Bialalu, a suburb of Bangalore. The 32m antenna was built specifically to support this mission. The ISSDC along with the 18m and 32m antennae are located at the Bialalu Campus. The network is augmented with Deep Space Networks from JPL and the Applied Physics Laboratory (APL) in addition to a 64m antennae in Bearslake, Russia. These network stations extend the visibility for launch and early orbit phase operations in addition to near continuous visibility during normal operations phase. The ISSDC is a new ISRO facility which serves as the primary data center for the payload data archives for Indian space

science missions. The MOX, located within the ISTRAC campus in Peenya, north of Bangalore, serves as the control center for the Chandrayaan-1 mission. It is responsible for all spacecraft operations for all mission phases including monitoring the health of the spacecraft and all payloads.



Figure 3. Chandrayaan-1 spacecraft at the vehicle assembly building prior to integration on the launch vehicle

Chandrayaan-1 was launched on October 22, 2008 at 00:52 UTC and achieved operational orbit 22 days later. The Chandrayaan-1 spacecraft on top of the launch vehicle prior to lift off is shown in Fig. 1. A schematic of the trajectory with the five transfer trajectory Earth Burn Numbers (EBN) and four Moon Burn Numbers (MBN) after lunar capture is illustrated in Fig. 2. During launch and the subsequent three week journey to the Moon, the payload teams were located at either MOX or ISSDC. After reaching the Moon operational orbit, each payload team was required to be present at MOX to support their instrument initial power on commanding. Payload commissioning was started on November 15, 2008 with the Moon Impact Probe (MIP) instrument being the first and subsequent payloads were typically allocated 1 day for commissioning.

At launch plus 8.5 hours, the M3 instrument was in survival mode with the decontamination heater powered on and remained in this configuration until power on about 4 weeks later. M3 integrated on the spacecraft awaiting to be installed on the launch vehicle is shown in Fig. 3.

After the completion of all environmental tests at ISRO'S Satellite Centre (ISAC) in Bangalore, the spacecraft was transported, on September 16, 2008, to the Space Processing (SP-1) at SHAR, about 500 km away, for final preparations prior to launch. Chandrayaan-1 in the SP-1 facility at SHAR undergoing final preparations for launch is shown in Fig. 4. The spacecraft was moved from SP-1 to SP-2 at SHAR on October 10, 2008 for integration on the launch vehicle.

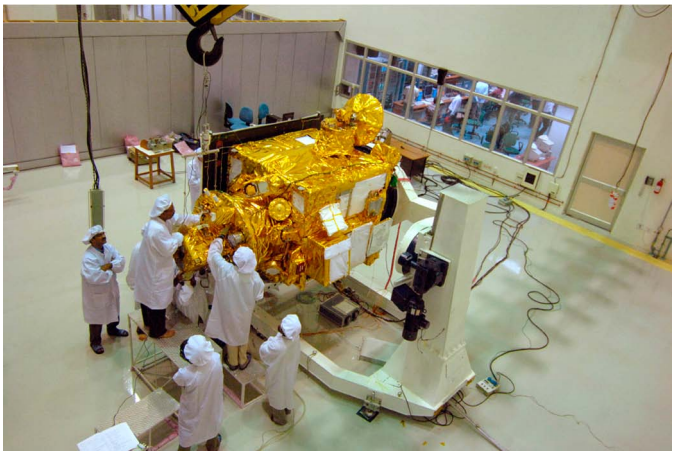


Figure 4. Chandrayaan-1 spacecraft at SHAR in SP-1 being readied for launch

INSTRUMENT THERMAL CONTROL

M3 makes use of reflected sunlight to provide day coverage of the Moon's surface. Primary science imaging is planned for a two-month period over six-months where the sun is within ± 30 degrees from the orbit plane (± 30 deg. beta angle). M3 can make use of science imaging data from extended coverage up to ± 60 degrees.

The low lunar orbit planned for this mission is nominally circular, polar and very nearly perpendicular to the ecliptic plane. The orbit plane is inertially fixed due to the small oblateness of the Moon. The solar incidence angle, with respect to the surface normal, changes at about 1 degree per day. Therefore, the primary imaging periods, where the sun vector is within ± 30 degree from the surface normal, will take place during the two months centered on the noon/midnight orbit. The extended coverage up to ± 60 degree provides an additional two months of science observations although with reduced lighting conditions. Imaging within the ± 60 degrees will take 120 days to complete and will repeat every six months. The orbit path will change direction from pole to pole every six months.

	Allowable Flight Temperatures (AFT) ⁽¹⁾				
	Operating				Non-operating
	Science min/max	Power-on/ Startup	Orbit Variat ⁽²⁾	Spatial Grad	Survival
Integrated Electronics Assembly (IEA)	5/35	-40/35			-40/50
Focal Plane Array (FPA)	140/155K	135/300K	± 0.4 K		135/325K
Fan-out Board	-10/10	-40/35			-40/50
Spectrometer	165/195K	n/a	± 0.5 K	5K	155/350K
Telescope	165/295K	n/a			155/150K
Thermal Shield	180/250K	n/a			170/350K
Passive Cooler Structure	180/250K	n/a			170/350K

1. All temperatures in Celcius unless noted.

2. Variation per orbit for the entire orbit.

Table 1. Allowable flight temperature requirements (Refs. 4-5)

The lunar surface temperature varies from 380 K at the equator and drops to ~ 100 K on the night side (Ref. 3). Due to the low altitude, this surface temperature variation results in a significant infrared heat load orbital variation which has potential for severely impacting the passive cooler performance.

The temperature control requirements are listed in Table 1. During normal operations, the instrument remains in imaging mode throughout the orbit, but only collects data during the day-side of the orbit. This helps to minimize the orbital temperature variation due to changes in detector power dissipation.

The survival heater power allocation is only 13 W average and 20 W peak. The peak allocation is defined as the maximum power draw at 35V. Survival heater power uses the spacecraft raw bus power and the heaters were designed for a range of 35-42 V.

The instrument is comprised of the Optical Bench Assembly (OBA) and the Integrated Electronics Assembly (IEA). The optics bench temporal temperature stability requirement is ± 500 mK over an orbit. The OBA envelope is 0.5 m by 0.5 m by 0.3 m and the IEA is 0.3 m by 0.3 m by 0.1 m. The total instrument measured mass is 8.0 kg. Additional information on the instrument can be found in Refs. 4-5. The passive cooler is an integral unit that mounts on top of the thermal shield and provides cooling for the three low temperature zones. Each of the stages provides a flexible thermal link to the zones requiring cooling.

The heart of the M3 instrument is a mercury cadmium telluride (HgCdTe) focal plane array cooled to ~ 150 K by means of the passive cooler third-stage. The detector temporal temperature stability requirement is ± 400 mK over an orbit. The spectrometer optics is maintained at ~ 170 K by means of the passive cooler second stage.

The passive cooler first-stage cools a thermal shield which intercepts parasitic heat leaks from the surrounding environment. Fig. 5 shows a schematic of the instrument temperature zones with the major assemblies. Additional information on the passive cooler can be found in Refs. 4-6.

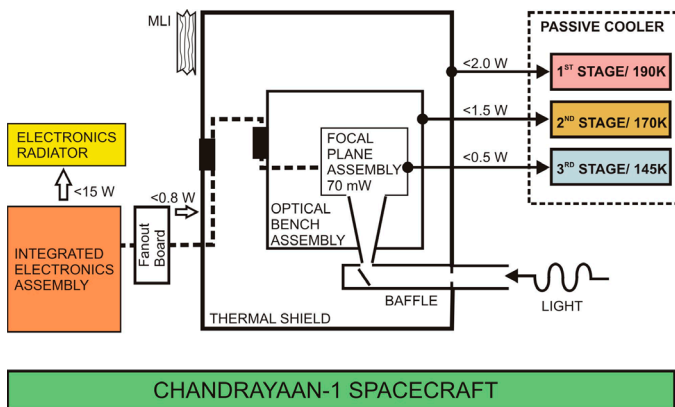


Figure 5. Instrument thermal schematic diagram with passive cooler (Refs. 4-5)

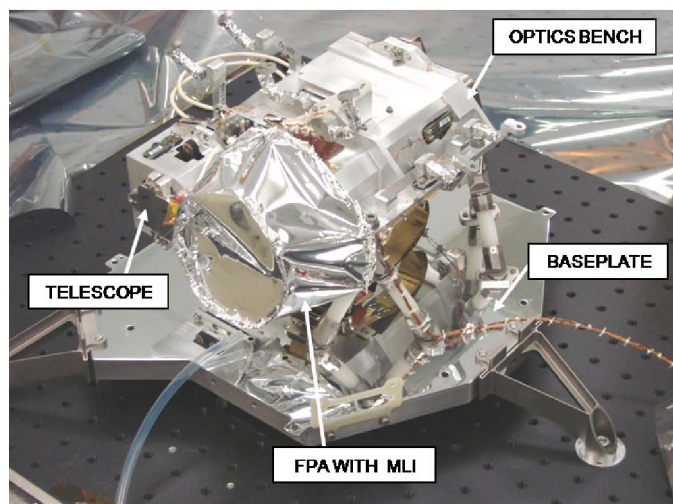


Figure 6. Optics bench assembly mounted on the flight support structure (Ref. 5)

Multi-Layer Insulation (MLI) blankets and low conductance mounts are used to provide thermal isolation to the spacecraft interface. The IEA waste heat is rejected to space via the chassis top surface serving as a room temperature radiator. In survival mode, the instrument is off and survival heater power is used to maintain non-operating Allowable Flight Temperature (AFT) limits. A focal plane decontamination heater is used to raise the detector temperature when in survival mode to near 250 K to de-ice the detector.

Fig. 6 shows the thermal shield base with the three low thermal conductance kinematic mounts for attaching to the spacecraft. The optical bench is mounted to the thermal shield base with six struts (three bi-pods). An MLI blanket completely surrounds the thermal shield

including the passive cooler exterior. Fig. 7 shows the assembled optical bench with telescope and detector without passive cooler, while Fig. 8 shows the assembled instrument with MLI blankets.

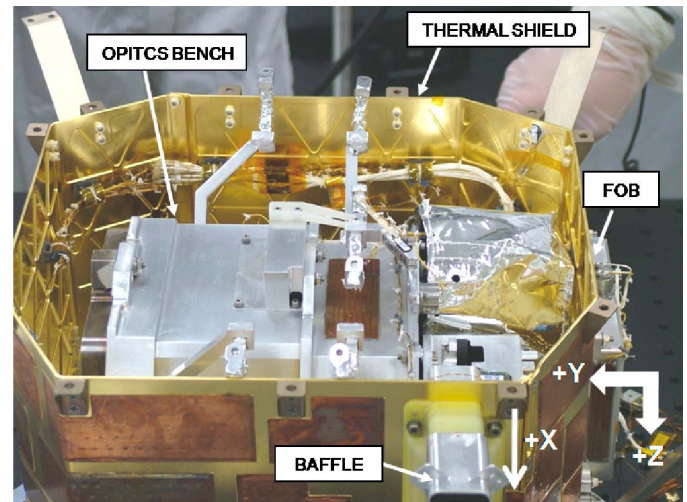


Figure 7. Optics bench assembly with thermal shield mounted on the flight support structure (Ref. 5)

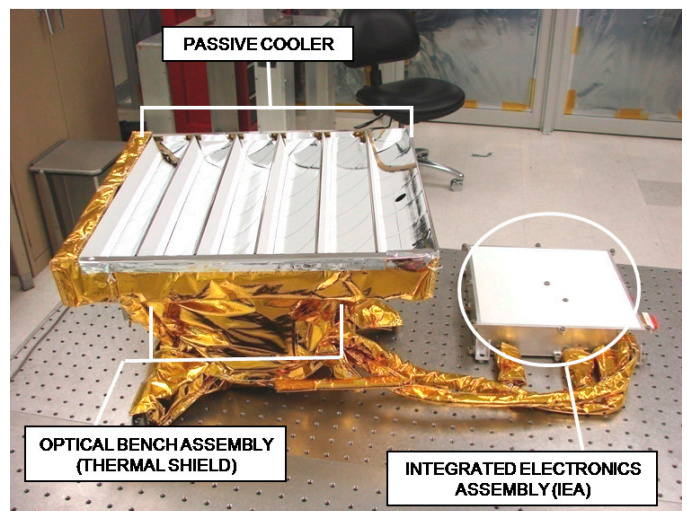


Figure 8. M3 Instrument in flight configuration (missing IEA MLI) (Ref. 5)

ON-ORBIT PERFORMANCE

IN TRANSIT TO THE MOON

In transit to the Moon, the M3 instrument remained in survival mode with the focal plane decontamination heater powered on. The decontamination heater is located near the detector and when powered on, it raises the detector temperature to near 250 K. During the initial outgassing of the spacecraft and payloads, water vapor is the main outgassing product and, it is typically a significant source of cryocontamination for a long period of time, often times lasting for many months. Multi-layered insulation and carbon composite structures