Thermal Infrared Imaging Spectrometer Onboard Mars Orbiter Mission

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(*Submitted* 28-09-2015)

Abstract

Thermal Infrared Imaging Spectrometer (TIS) on-board Mars Orbiter Mission (MOM) is a grating based spectrometer which measures thermal infrared radiation emitted from Mars environment in 7-13 µm spectral range. Observations from TIS help in estimating brightness temperature of Mars surface and in knowing the composition of the surface. TIS is made up of light weight miniaturized components (total weight 3.2 kg) and has power requirement of 6W and uses un-cooled micro-bolometer array for detection.

1. Introduction

Knowledge of Spatial and seasonal behavior of planetary surface temperature is required to understand various thermo-physical processes and associated weather systems. The satellite based observations of surface temperature provides an important boundary conditions for global circulation modeling. Satellite based measurements in thermal infrared spectral region have been used to characterize atmospheric properties, surface composition and detect the surface temperate variability[1-7].Many Thermal infrared spectrometers (IRS, IRIS, ISM, IRTM, TES, THEMIS) onboard different spacecrafts have been flown earlier to Mars to study the thermal ambience and surface composition. The initial infrared spectrometers based experiments were carried during Mariner 6 and Mariner 7 Flybys. In 1971, Mariner 9 began orbiting Mars, and its infrared interferometer spectrometer (IRIS) returned many valuable spectra. Later distinct absorption in the 9 and 20 um spectral regions were observed in Viking Infrared Thermal Mapper (IRTM) data which confirmed basalt like sand surfaces in dark region. It was followed by French built Imaging Spectrometer for Mars (ISM) on the 1989 Russian Phobos 2 flight. In 1997, the Mars Global Surveyor arrived at Mars, carrying the Thermal Emission Spectrometer (TES) and global mineralogical mapping was carried out. The TES was followed by another specialized thermal radiometer (THEMIS) on board Mars Odyssey Mission which is also functioning till date and provided data for more than 12 years. In spite of years of telescopic study from earth and the flights of many spectrometers orbiting around Mars, many processes are still unknown, particularly causes of surface temperature variability and physics of associated dust storm activities on Mars. Thermal Infrared Imaging Spectrometer (TIS) onboard Indian Mars Orbiter Mission (MOM) provides newer opportunity to observe Mars disk as well as specific sites in thermal infrared spectral region from unique elliptical orbit.

2. TIS Configuration

TISis one of the five instruments on board MOM. TIS is designed to detect thermal emitted radiation from Martian environment in 7-13 μm infrared spectral region using micro bolometer detector. The TIS is a plane reflection grating based infrared spectrometer with all refractive optical elements. The spectrometer consists of fore optics, slit, collimating optics, plane reflection grating and focusing optics.

TIS consists of f/1.4 fore optics lens assembly with a focal length of 75mm and a field of view (FOV) of ±3.18°. The f-*number* is an important parameter for any imaging system. The *f-number* is the ratio of the effective focal length to the entrance pupil diameter. The *f-number f/1.4* means that the entrance pupil diameter of fore optics is $1/1.4^{th}$ of the focal length. The irradiance at the image plane is inversely proportional to the square of the *f/no.*

A collimating lens allows the incoming beam of light collected from fore optics and passing through a slit (that defines the input to the spectrometer) to fall on plane reflection grating which then disperses the incident energy into different wavelengths. The first order spectrum of the dispersed emitted Martian infrared radiation is refocused by a focusing optics on 160 x 120 pixels micro-bolometer based area array detector.

A detector is a device that produces an output which depends on the amount of radiation falling on the active area of detector. Thermal detectors make use of heating effect of the electromagnetic radiation. In bolometer type of detector, the change in temperature caused by the radiation changes the electrical resistance. The semi-conductor based bolometer exhibits a much more pronounced resistance variation with temperature change as compared to metals.

The instrument was spectrally calibrated using tunable lasers. The longer axis of the detector is aligned in the cross-track direction. So, 160 detector elements in the cross-track direction define the swath coverage of the sensor while 120 elements in the along track direction define the spectral range. By binning pixels in the along track direction, it is possible to select the required spectral sampling interval as well as number of spectral bands. It is operationally planned to have TIS imaging with 12 bands (Mode-3). The analog current signal from the detector is converted into a voltage signal, which is amplified and digitized subsequently. Digital signals received from TIS is corrected for the drifts due to changing thermal ambience and processed to know the emitted thermal infrared radiation from Mars using prelaunch and earth bound phase calibration studies.

Specific absorption features of surface mineral composition and atmospheric conditions (Aerosol Optical Thickness) manifest in thermal emission spectra observed from TIS. An optical schematic showing the imaging chain of TIS is given in Figure 1and verification and flight model of TIS is shown in Figure 2 and Figure 3 respectively. Table1 shows the important sensor specifications of TIS instrument.

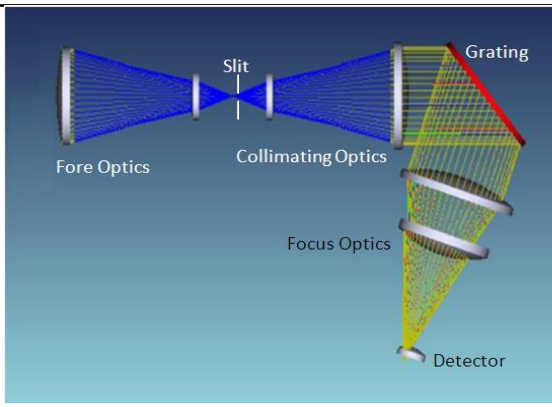

Figure1: Schematic diagram of TIS imaging chain.

Table1: Thermal Infrared Imaging Spectrometer (TIS) Characteristics[8].

Parameter	Value
Spatial Resolution	258m @ Periareion (372km) 55 km @ Apoareion (80000km)
Foot print(Coverage)	41km x 258 m @ Periareion 8800km x 55km @ Apoareion
Spectral range	7µm – 13µm
Spectral resolution	~500 nm (12 bands)
NEDT (Radiometric performance)	< 1K @300K
Data rate	6.56 Mbps
Mass	3.2kg
Power	6W

The thermal imaging spectrometer for such a large span of spectrum in a compact way was designed maximally utilizing the in-house available materials / components and also using COTS (commercial off the shelf) components[8].Signal was maximized by (a) optimizing the signal collection efficiency, (b) maximizing grating efficiency over preferred wavelength region, (c) longer dwell time etc. Back ground was minimized by reduction of stray emissions, tight control of temperatures of sensitive optical and electro-optical components.

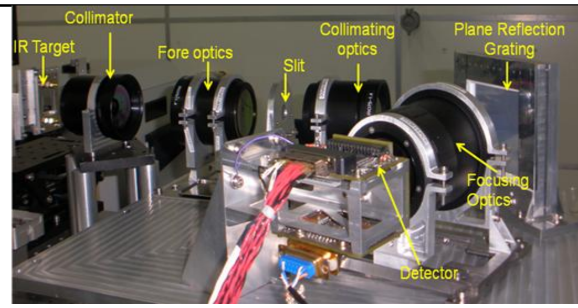

Figure 2: Verification Model of Thermal Infrared Imaging Spectrometer (TIS) instrument showing arrangements of different optical components.

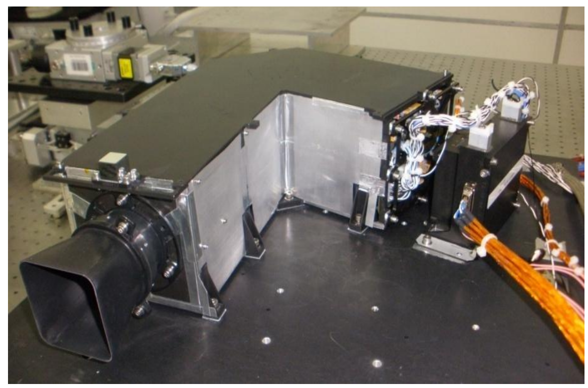

Figure3: Flight Model of Thermal Infrared Imaging Spectrometer (TIS) instrument

3. Measurement Principle

As mentioned earlier, TIS is an un-cooled micro-bolometer detector based spectrometer which uses grating as dispersive element. Emitted thermal infrared radiation from martian surface is collected through fore optics of TIS. Incident thermal infared radiationafter passing through collimated optics in the form of parrallel raysgetsdiffracted and dispersed by reflecting grating.The dispersed spectrum of infrared energy from reflected grating is further refocused by a focusing optics on the micro-bolometer based area array detector. Observed signal at detector is converted into spectral radiance through process of Analog to Digital conversion and calibration.

The diffraction grating is a device which essentially consists of a large number of equidistant lines with separation d. The plane reflection grating with 12 grooves/mm was used in TIS instrument. The following grating equation is used to study the dependence of angle of diffraction (θ) on the wavelength (λ).

$$d \sin\theta = m\lambda; \quad m = 0,1,2 \ldots$$

where m is the order of diffraction.The zeroeth order of diffraction corresponds to principal maximum occuring at θ=0 irrespective of the wavelength. The first order spectrum of the dispersed beam from grating was refocused on the micro-bolometer area array in TIS. For m=1, the angles of diffraction are different for different wavelength and it is the reason why energy received by TIS in different wavelengths appears at different positions of the micro-bolometer array detector. Tunable laser was used for spectral calibration of the instrument. It may be noted that the energy received from Martian surface at different wavelengths is recorded as a spectrum.

Spectral radiance observed by TIS consists of contribution of surface emitted radiance as well as atmospheric emission which are coupled with atmospheric transmittance. Emitted radiance from any surface depends on the surface temperature and the surface emissivity. The emissivity depends on the composition, surface roughness, and physical parameters of the surface.

Thermal emission radiance received at satellite sensor in given bandwidth (L_{sen} or L_i) can be written as

$$L_{sen} = L_i(T_B) = \varepsilon_i B_i(T_s).\tau_i + L_i \uparrow + (1-\varepsilon_i) L_{DWR}.\tau_i$$

where T_B is the at sensor brightness temperature, τ_i is atmospheric transmittance, $L_i \uparrow$ is upwelling path radiance, ε_i is surface emissivity, B_i (Ts) is Planck radiance at surface temperature T_s and L_{DWR} is down-welling sky irradiance. Here all quantities refer to spectral integration over bandwidth of channel 'i' and depend on the view zenith angle. According to Planck's Law, the spectral radiant exitance (W m^{-2}, um^{-1}) is expressed as

$$B_i(T_s) = \frac{c_1}{\lambda_i^5\left(e^{\frac{c_2}{\lambda_i T_s}} - 1\right)}$$

c1 and c2 are the Planck's radiation constants, with values of 1.19104×10^8 W. $\mu m^4 m^{-2}$ and 14387.7 μm.K, respectively. The λ is the wavelength in microns.Spectral radiance received by TIS is modeled to estimate the surface temperature and emissivity. The retrieved spectral signature (in terms of emissivity) helps to know about the composition of different minerals as well as atmospheric turbidity.

4. Post-Launch Observations

Mars Orbiting Mission was launched on 5 Nov. 2013 from SDSC Sriharikota, India. Orbit raising manoeuvres were carried out during Earth orbiting phase before MOM was injected in heliocentric orbit towards mars on 1 Dec. 2013 (Figure 4).The TIS instrument was operated during Earth bound phase[9-11] on 23rd November 2013.The imaging session involved one minute observations of space count, preceded and followed by ten minute observations of Earth surface over Libyan Saharregion. The imaging was carried out at 0900 UTC, at the altitude of 21335.4 km with the Solar Elevation of 52.84 degree. Figure 5 shows the coverage of TIS instrument and Figure6 shows the thermal infrared radiance observed in different bands over Sahara region projected on Mars Colour Camera (MCC) image.

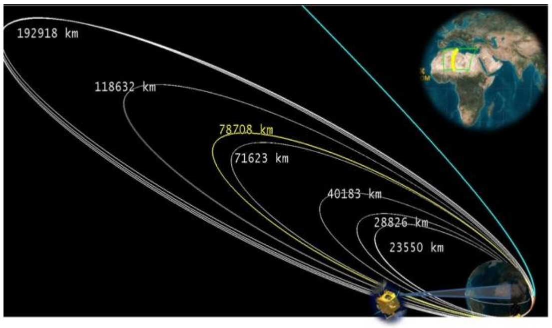

Figure 4: Orbit raising manoeuvres during earth bound phase and TIS imaging of 23rd November, 2013 over Sahara region.

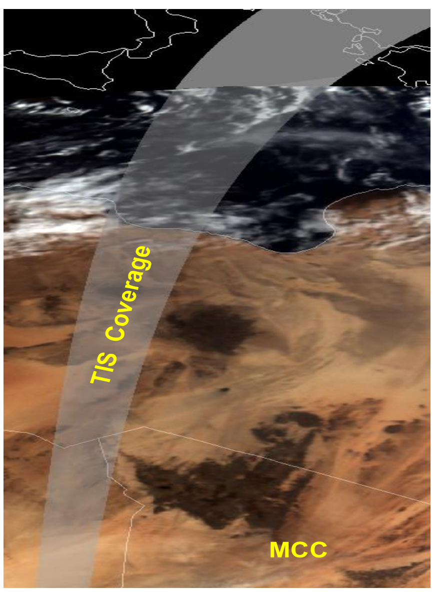

Figure 5: TIS coverage of 23rd November, 2013 over Sahara region shown on Mars Colour Camera (MCC) image

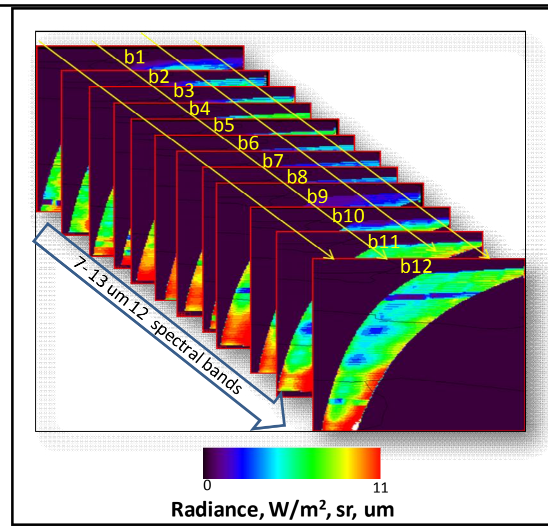

Figure 6: Stack of 12 bands (7-13 µm) spectra of TIS observed radiances on 23rd November, 2013 over Sahara region during Earth imaging

TIS based observations of Martian surface is being collected from 28thSeptember 2014 (solar longitudes (Ls) 204^0) from apoapsisas well as periapsis positions in elliptical orbit (Figure 7). Observations have been taken from satellite altitude varying from 76694 km to 386 km in different imaging sessions. Elliptical Orbit of MOM provides opportunity for scanning of full Mars disk from apoapsis at coarse spatial resolution (Figure 8) as well as site specific surface imaging at relatively high spatial resolution in push broom mode from periapsis (figure 9).

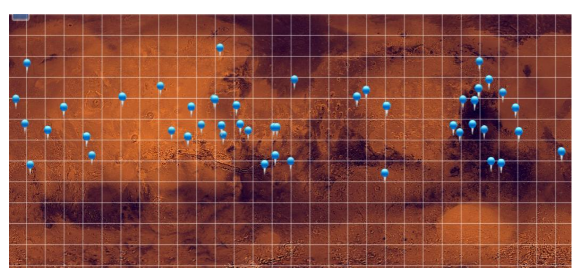

Figure 7: Imaging sessions (between solar longitude Ls 204^0-340^0) of TIS instrument showing the central latitude and longitude of

the different scenes (Source SAC MOM POC Archive)

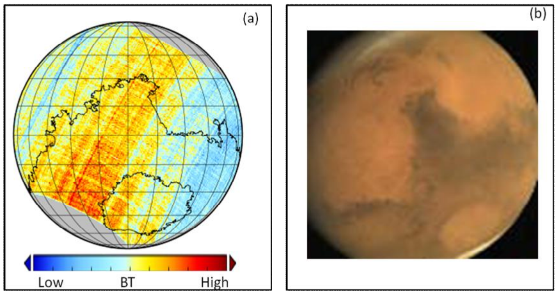

Figure 8: Observations of (a) Brightness Temperature (BT) observed from TIS instrument on 9 Oct. 2014 (Ls=210.7 degrees) in 12.25 um spectral band and (b) corresponding Mars Color Camera (MCC) image taken during same imaging session

The performance of the TIS instrument in Earth-imaging phase, Cruise phase and Mars Orbiting phase have been found in agreement with the laboratory-measurements.

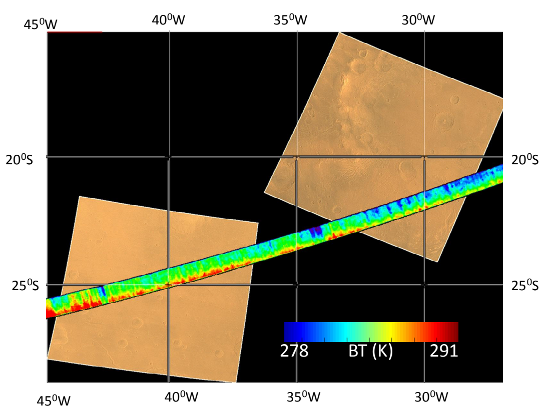

Figure 9: Brightness Temperature (BT) variability as observed from push broom imaging from TIS instrument near Holden Crater on 27 Feb. 2015 (Ls=299.2 degrees) in 10.25 µm spectral band from the altitude of 386 km. TIS observations are draped on background of MCC data.

5. Conclusions

TIS instrument on-board Mars Orbiter Mission is agrating based spectrometer aimed to detect thermal infrared emission from Mars surface in 7-13 µm range and infer thermo-physical characteristics of planet.Elliptical Orbit of MOM provides unique opportunity for scanning full Mars disk from apoapsis as well as site specific surface imaging at relatively high spatial resolution in push broom mode from periapsis. Observed brightness temperatures were found related with surface temperature and solar zenith angle, viewing geometry and atmospheric conditions.

Acknowledgement:
The authors wish to thank all the team members involved in the design, realization, test & evaluation, data product generation and scientific analysis of TIS instrument. The support provided by Director, Space Applications Centre, Ahmedabad and Program Director, Space Science Programme Office, ISRO, Hq. Bangalore is gratefully acknowledged.

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