# TOPOGRAPHIC AND ATMOSPHERIC PRESSURE MAPPING USING NEAR INFRARED IMAGING AND SPECTRAL OBSERVATIONS OF MARS

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**Introduction:**

Early ground-based observations recorded the visible Martian albedo, displaying variations due to surface composition and texture. However, the topography of Mars, including large-scale features such as Valles Marineris and Olympus Mons remained relatively unknown until the first visiting spacecraft. Concurrently, a technique using ground-based visible observations was being developed to determine the Martian topography by measuring the spatial variation in the strength of the atmospheric $CO_2$ absorption bands. This method was first used by Belton & Hunten (1971), Woszczyk (1971) and Parkinson & Hunten (1973) but resulted in low resolution maps that are inconsistent with current Martian topographic maps. Improved results are possible using the stronger $CO_2$ bands in the near-infrared. Bibring, *et al,* (1991) used the ISM instrument on board the Russian spacecraft Phobos 2, to obtain high spatially resolved maps for a small number of equatorial regions on Mars. The observations presented here use near-infrared ground-based observations to produce relatively detailed topographic maps of Mars that correlate well with topographic maps produced by the Mars Orbiting Laser Altimeter (MOLA) on board the Mars Global Surveyor (MGS).

Measurements of the Martian atmospheric pressure systems are of great interest for testing and constraining general circulation models of the Martian atmosphere (Forget *et al.,* 1999) and cannot be made with existing spacecraft. Past atmospheric pressure measurements on Mars show diurnal and pressure system variations with amplitudes as high as 50Pa in a total pressure of 800Pa (Barnes 1981, Collins *et. al.*, 1996). Here we detail a method by which the weather on Mars can be monitored on a global scale from Earth with a current sensitivity of 4 to 5Pa.

**Observations:**

Near Infrared narrow band images and hyperspectral scans were obtained between the wavelengths 0.9 – 3.6μm using the United Kingdom InfraRed Telescope (UKIRT) and the UKIRT Imaging Spectrometer (UIST) (Ramsay Howat, *et al.,* 1998) on Mauna Kea, Hawaii. The telescope was chosen due to the telescope's recent instrument upgrades (Hawarden, *et al.* 1998), tracking abilities (Bailey and Prestage, *et al.,* 1997), its high alititude and excellent seeing. Seeing was as good as 0.3arcsecs during our observing run. The observations were made during mid-August and early September, either side of the August opposition in 2003 to optimize the spatial resolution of the observations, and to allow Mars to rotate with respect to Earth to obtain observations covering most of the Martian globe.

*Narrow Band Imaging.*

Narrow band images were obtained as a series of 0.09sec short exposures to optimize the already excellent seeing conditions. The resulting images with the best seeing were then selected and stacked resulting in what could be the highest resolution image of Mars ever taken from a ground-based telescope (Fig. 1). An image scale of 16km per pixel was achieved.

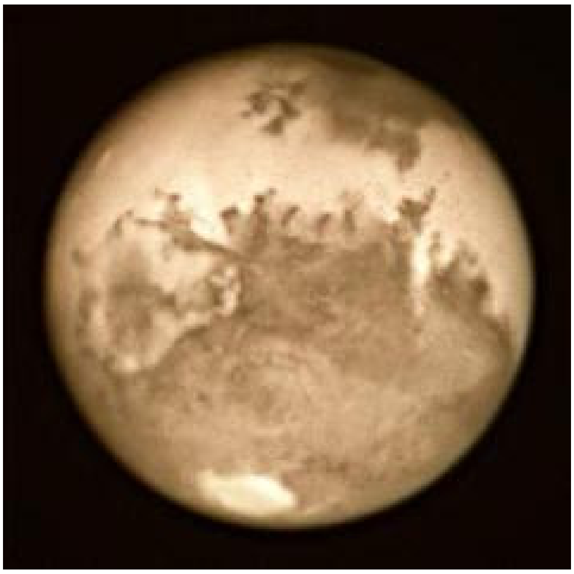

*Figure 1: Narrow band image of Mars obtained on Sept. 4th 2003. The image depicts the Martian albedo at 1.64 μm and is possibly the highest resolution image of Mars ever obtained from a ground-based telescope.*

*Hyperspectral Scans***.**

Hyperspectral scans were obtained by positioning the spectrometer slit in the Martian north-south orientation and incrementally stepping the slit across the disk in the east-west direction, using step sizes of 0.25arcsec. A spectrum was obtained at each location. A resolving power of 950 was obtained for a spectral range of 1.4 – 2.5μm. The data were stored in three dimensional cube with two spatial axes (x and y) and a spectral axis (z) (fig. 2). This is a versatile storage system since spectra can be obtained from any location on the Martian disk and images of Mars can be obtained at any observed wavelength. Images extracted from the data cube have minimum spatial resolution of 97km.

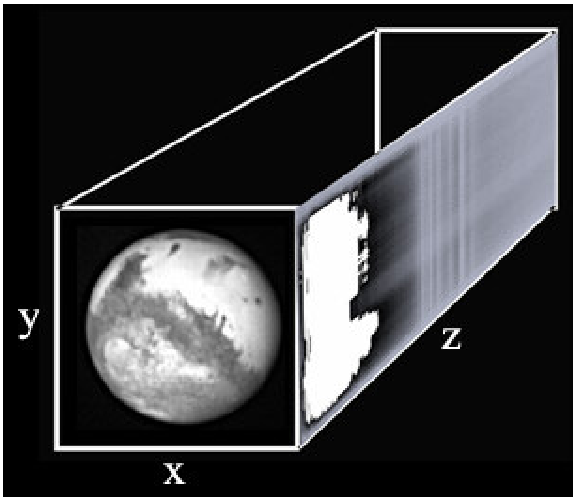


*Figure 2: Spectral Data Cube. The y axis is the direction of the spectrometer slit, the x axis is the direction of the spectral scan and the z axis is the spectral data obtained at each slit location.*

Standard data reduction has been applied to the spectra, however they have not been flux calibrated nor corrected for terrestrial atmospheric absorption. The airmass changed little over the 51min it took to complete each spectral scan, therefore the terrestrial atmospheric $CO_2$ absorption is very nearly constant. All variations in our images should therefore be due solely to $CO_2$ variations in the Martian atmosphere.

*Topographic Images.*

The Martian atmosphere is composed primarily (95.3%) of $CO_2$, which is present in near-infrared spectra as a number of weak absorption features. Variations in the strengths of these absorption features are mainly due to the atmospheric path length which is influenced by the underlying topography. A colour index can be made by ratioing an image obtained from the wavelengths of the deepest part of an absorption feature with an image obtained from wavelengths corresponding to the nearby continuum. The 2μm absorption band was used since it has the best signal to noise ratio.

The $CO_2$ index images detail the surface topography of Mars and are clearly different to the corresponding albedo images which depict the changing surface composition and texture (Fig. 3a and Fig. 3b). The $CO_2$ index image produced from August observations (Fig. 3a) shows large scale features such as the crustal dichotomy (the separation between the brighter highlands in the southern hemisphere and the darker lowlands in the northern hemisphere), Hellas Planitia (the dark low-lying impact region in the southern hemisphere) and Elysium Mons (the bright high-altitude volcano in the northern hemisphere). The $CO_2$ image produced from September observations (Fig. 3b) show large scale features such as Valles Marineris (the dark equatorial canyon system), the Tharsis rise and associated montes (the bright western high altitude uplift region and associated volcanos) and Argyre Planitia (the dark low-lying impact basin in the South).

The MOLA/MGS instrument mapped the topography to an accuracy of 2m vertically and 160m horizontally by recording the return time of a laser pulse (Smith, *et al.,* 1998). This results in a more accurate topographic map than can be produced through atmospheric band strength comparisons from Earth. However it can be seen that the $CO_2$ index images closely correlate to the corresponding MOLA/MGS topographic maps, showing all the sufficiently large features. On comparison smaller scale features can also be identified such as secondary cratering around Argyre Planitia (Fig. 3b) and the small scale crustal fissures associated with the western end of Valles Marineris (Fig. 3b). On comparison the $CO_2$ index image fails to match the MOLA maps near the North and South poles due to the presence of $CO_2$ ice in the atmospheric polar hood and ice cap respectively. The features are also slightly distorted (condensed along the horizontal axis) due to the rotation of Mars during the 51min scan.

**Discussion:**

It has been shown that good topographic data can be obtained using modern ground-based telescopes to produce a $CO_2$ index image. However the $CO_2$ index image is also influenced by atmospheric pressure systems (i.e. weather). By removing the topography, using MOLA/MGS data, it is possible to produce a map of the Martian pressure systems.

These pressure systems are of great interest for testing and constraining current general circulation models of Mars (Forget, *et al.,* 1999) at spectral resolutions not obtainable from currently orbiting spacecraft. An advantage of ground based measurements is that pressure systems can be monitored almost simultaneously across the whole earth-facing disk of Mars. Previous insitu measurements show Mars to have diurnal and pressure system variations of up to 50Pa in a total pressure of 800Pa (Barnes, 1981, Collins, *et. al,* 1996). A rough sensitivity was estimated for our observations by calculating the standard deviation variation across two relatively flat regions at significantly different altitudes on Mars. These were then calibrated against the European Mars Climate Database (Lewis, *et al.,* 1999) surface pressure results for these regions at the same specified solar longitude. An estimate of 4 to 5Pa was reached; however we believe that sensitivities greater than this can be achieved by using a larger telescope,

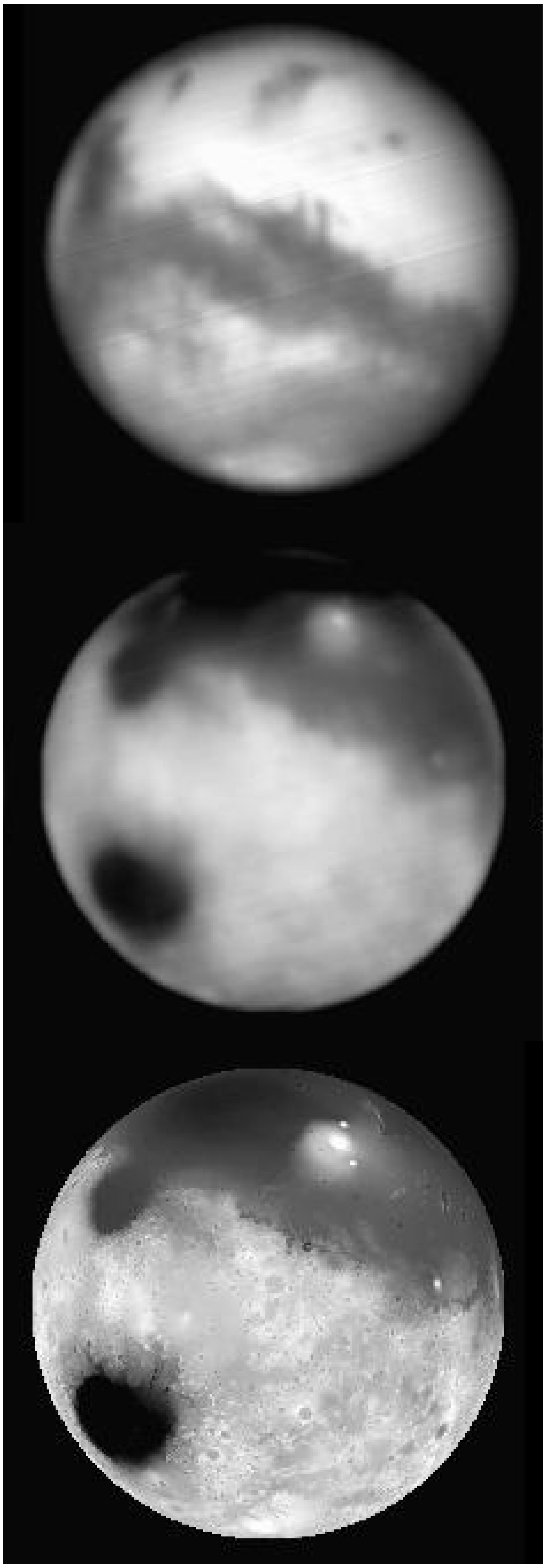

*Figure 3a: Comparison of albedo (top) and $CO_2$ index (middle) images obtained on August 17th 2003 with the corresponding MOLA/MGS topographic map (bottom).*

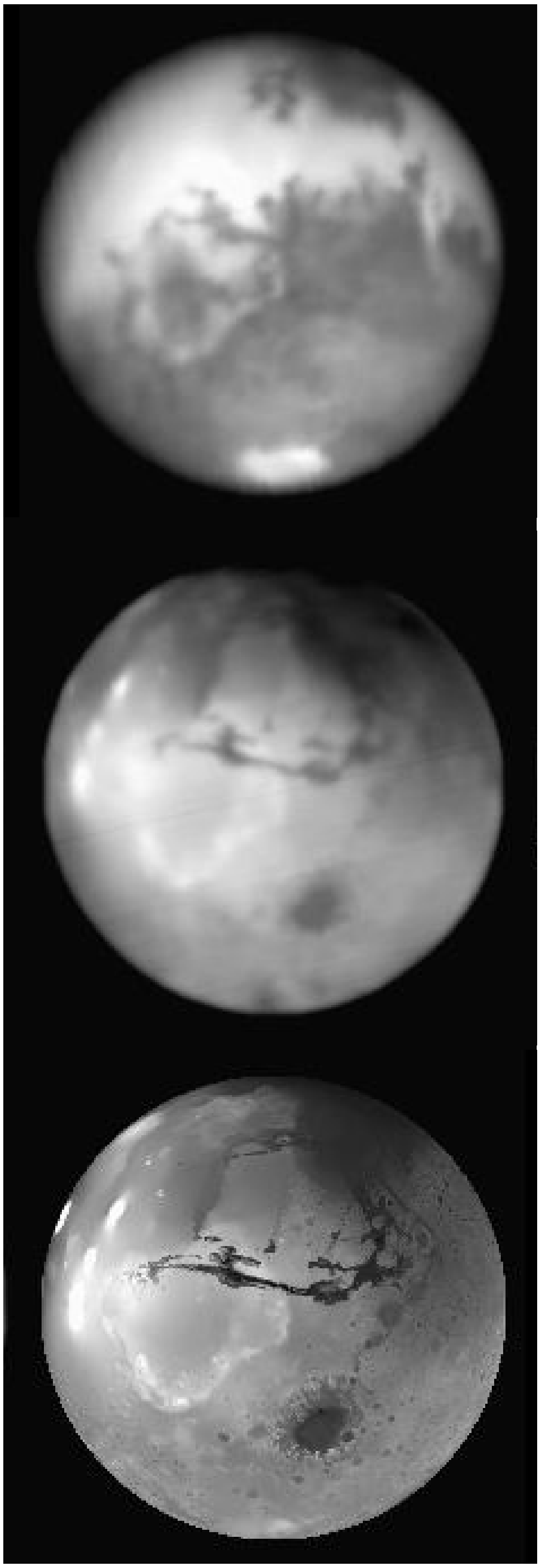

*Figure 3b: Comparison of albedo (top) and $CO_2$ index (middle) images obtained on September 4th 2003 with the corresponding MOLA/MGS topographic map (bottom).*

wider range of $CO_2$ bands and a more efficient observing system (to avoid saturation with UIST we used a narrower than optimal slit, and the shortest possible exposure time, which led to less than 30% of time being spent integrating). Thus pressure sensitivities down to about 1Pa may be possible.

Quantitative data requires a precise calibration between the $CO_2$ index and surface pressure which is difficult to achieve as the relationship depends on the local atmospheric temperature profile. Temperature profiles have only been measured at several specific locations and are not well known over Martian latitudes. Corrections are also needed to reduce the observed surface pressure to a reference altitude (corresponding to sea-level on Earth) that essentially removes the topographic features; this is difficult to do accurately over the topographic variations on Earth (Pauley, 1998) and is therefore a larger problem over the exaggerated topography of Mars.

Errors are produced in the observed atmospheric pressure systems due to the problematic removal of the terrestrial atmospheric $CO_2$ absorptions. This is normally done by dividing the observed spectrum by the spectrum of a relatively featureless standard star observed under similar atmospheric conditions and thereby removing the common spectral component (absorption by the terrestrial atmosphere). This method cannot be used for Mars at these wavelengths, because $CO_2$ absorption is present in both the Mars and Earth atmospheres at similar strengths and is composed of many saturated narrow lines (unresolved at the resolution of our spectra). Once a line is saturated it ceases to behave linearly. The terrestrial absorption will therefore produce a greater absorption in the spectra of the standard star, due to the initial lack of features, than in the Martian spectra which already have strong absorption at these wavelengths. This effect is maximized at opposition due to the lack of relative velocity along the line of sight between the two planets, and would result in removing more than just the terrestrial component of the $CO_2$ absorption (Simpson, *et al.* 2006). The high resolution Spectral Mapping Radiative Transfer (SMART) model developed by Dr David Crisp (NASA, JPL) (Meadows and Crisp 1996) can be used to reduce this problem. Simulated spectra are being produced using different pressures, temperatures and dust optical densities of the Martian atmosphere (taken from the European Mars Climate Database) to investigate their effects on the $CO_2$ index ratio used to create the topographic images. Scattering by dust also complicates the calibration, but independent determinations of surface pressure and dust content might be possible by comparing $CO_2$ bands of different strengths.

**Conclusion:**

Detailed topographic maps of Mars have been obtained from the UKIRT confirming that ground-based observations are still relevant to planetary studies in the modern space-age. The observations correspond very well with highly accurate MOLA/MGS data. It has been shown that atmospheric pressure variations on Mars can be observed by a simple comparison of on and off band images in the 2 µm $CO_2$ band, once the topographic influence has been removed. Surface pressure changes have been detected with a sensitivity of 4 – 5Pa with possibilities for improvement. Although accurate calibration is difficult to achieve, better spectrally resolved observations will help to account for contributions by varying dust optical densities and detailed atmospheric modelling will help to remove the problematic terrestrial atmospheric component.

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