Near-Infrared Spectral Observations of Mars
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Summary: Near infrared observations of Mars were obtained in August 2003 using the United Kingdom Infrared Telescope (UKIRT) on Mauna Kea, Hawaii. We have used the spectral data to obtain images in the strong 2 _μ_ m CO₂ absorption band. The resulting maps show topographic features that were only first detected by orbiting instruments and that agree well with topographic maps produced by the Mars Orbiting Laser Altimeter (MOLA) on the Mars Global Surveyor (MGS). The CO₂ index ratio is a measure of the absorbing column of CO₂ and is therefore influenced by atmospheric pressure changes as well as topography. Pressure systems on Mars have been measured to have amplitudes as high as 50 Pa in a total pressure of 800 Pa [1, 2]. Preliminary estimates show that our observations are sensitive to 4-5 Pa and can be improved upon by optimising the observing system. This paper outlines a technique by which weather systems might be monitored on Mars from future ground-based or space based instruments.

Keywords: Mars, Near Infrared Observations, Atmospheric Pressure Systems.

Introduction

Observations of Mars as seen at optical wavelengths show variations in albedo due to the composition and texture of the Martian surface. The topography of Mars was relatively unknown, including the large scale features such as Olympus Mons and Valles Marineris, until observations were made by the first orbiting spacecraft CO₂ is the dominant atmospheric component and is ubiquitous in the Martian atmosphere. Topographic observations of Mars can therefore be made by measuring the strength of the atmospheric CO₂ absorption bands. This method was first used by Belton & Hunten [3], Woszczyk [4] and Parkinson & Hunten [5] from ground-based visible light observatories in the 1960s and 1970s. However, much improved results are possible using the strong CO₂ bands in the near IR. Bibring [6] used the ISM instrument onboard the orbiter Phobos 2 to obtain high spatially resolved maps for a small number of equatorial regions on Mars. The observations presented here show that modern ground-based observations can produce relatively detailed topographic maps of Mars.

Observations

Near-Infrared images and spectral observations (0.8 – 3.6 _μ_ m) were obtained using the United Kingdom Infrared Telescope (UKIRT) and the UKIRT Imaging Spectrometer (UIST) on Mauna Kea, Hawaii. The Mauna Kea site was chosen due to its high altitude and therefore excellent seeing. The observations were made in mid-August and early September 2003, taking advantage of the close approach of Mars during the August opposition (in order to optimise the spatial resolution of the observations). Both narrow band imaging and spectral observations were obtained.
Narrow band images were taken as a series of short exposures to optimise the already excellent seeing conditions, and resulted in what could be the highest resolved images of Mars ever taken from a ground-based telescope (Fig. 1). An image scale of 16 km per pixel was attained.

*Fig. 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 resolved image of Mars ever taken from a ground based telescope.*

Spectral observations were obtained by positioning the spectrometer slit on the Martian disk in a north-south orientation and incrementally stepping the slit across the disk in the east-west direction (step sizes of 0.25 and 0.5 arcsec were used) obtaining spectra at each location. Spectral resolving powers of 950-3600 were obtained for differing spectral ranges between 0.8 – 3.6 μm. The data were stored in a three dimensional cube with two spatial axes and a spectral axis allowing spectra to be obtained from any location on the Martian disk and images of Mars to be obtained at any observed wavelength (Fig. 2). Images extracted from these cubes have a minimum spatial resolution of 97 km.

*Fig. 2: Spectral cube. The x axis is the direction of the scan made by the spectrometer slit. The y axis is the length of the spectrometer slit and the z axis is the spectral data for each slit position.*
Standard data reduction has been applied to these observations however they have not been flux calibrated nor corrected for terrestrial atmospheric absorption. As each scan took 51 min to complete the terrestrial atmospheric CO$_2$ absorption is very nearly constant and therefore variations in our image are due to CO$_2$ variations in the Martian atmosphere.

The Martian atmosphere is primarily CO$_2$ (95.3%) and is present in the spectra as a series of strong and weak absorption features. Variations in the strength of these bands are mainly due to atmospheric path length. A colour index can be made by ratioing an image obtained from spectral wavelengths of the deepest part of an absorption feature with an image obtained from spectral wavelengths of the nearby continuum. The 2 $\mu$m absorption band was used as it has the best signal to noise ratio. The resulting images clearly depict the topography of Mars (Fig. 3b and Fig. 3e).

It can be seen that the albedo images (Fig. 3a and Fig. 3d), which depicts surface composition and texture, is clearly different to that of the topographic image produced from the CO$_2$ index ratio (Fig. 3b and Fig. 3e). The topographic map produced shows features on Mars that were only first discovered by orbiting spacecraft, smaller scale features are also seen and confirmed as real by comparison with the MOLA topographic map (Fig. 3c and Fig. 3f). The MOLA/MGS instrument produced the map accurate to 2m vertically and 160m horizontally by recording the return time of a laser pulse. It can be seen that the CO$_2$ index image is highly correlated to the
MOLA map and shows all of the larger scale and some of the smaller scale features. The CO₂ index image does not correlate well with the MOLA map at the North and South poles due to the presence of CO₂ ice in the atmospheric polar hood and ice cap respectively.

**Discussion**

It has been shown that good topographic data can be obtained using modern ground-based telescopes to produce a CO₂ index image. The CO₂ index image depicts the atmospheric path length which is influenced by both the topography and atmospheric pressure systems (i.e. weather). By removing the topographic features it is possible to produce a map of the pressure systems on Mars. Measurements of the surface pressure distribution on Mars are of great interest in testing and constraining general circulation models of the Marian atmosphere [7] and cannot be made with existing spacecraft.

Previous measurements of atmospheric pressure on Mars show a diurnal and pressure system variations on a scale of 50 Pa in a total atmospheric pressure of 800 Pa [1, 2]. We estimated that our data is sensitive to 4 to 5 Pa and with a more efficient observing system, a better sensitivity can be achieved.

A number of problems arise in attempting a true calibration of the data. The removal of terrestrial CO₂ is difficult and requires high resolution radiative transfer modelling of both the Terrestrial and Martian Atmospheres. An accurate relationship between the CO₂ index and the surface pressure depends upon the local atmospheric temperature profile, which has been measured at several specific locations but is not well known over the Martian latitudes. Corrections are needed to reduce the observed surface pressure to a reference altitude (essentially removing the topographic influences), this is difficult for the large altitude range on Mars. Complications also arise from scattering by dust in the Martian atmosphere, however observations at high spectral resolutions will allow comparisons of several resolved strong and weak absorption features which can be used separate the effects of dust opacity and surface pressure.

**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 CO₂ band, once the topographic influence has been removed. Surface pressure changes have been detected with a sensitivity of 4 – 5 Pa with possibilities for improvement. Although accurate calibration is difficult to achieve, better spectrally resolved observations will help to account for contributions by optical density and detailed atmospheric modelling will help to remove the terrestrial atmospheric component. The method outlined here can be used by ground-based or space-based instruments to observe weather systems on Mars.

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References