OBSERVING MARS WITH LARGE GROUND-BASED TELESCOPES USING ADAPTIVE OPTICS.

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Introduction:

Observations of Mars from ground-based telescopes have, until recently, been limited by the effects of "seeing" in the Earth's atmosphere to relatively coarse spatial resolutions of around 200km or larger. However, the situation is changing with the development of adaptive optics systems on large telescopes. Systems available now use natural guide stars to achieve correction of wavefront distortions introduced by the atmosphere such that it is possible to achieve diffraction limited spatial resolution at near infrared wavelengths. Adaptive optics systems are available or being developed for the Keck 10m telescopes, and the ESO Very Large Telescope (VLT), Gemini and Subaru 8m telescopes. On such a telescope the diffraction-limited resolution at 2µm wavelength at a favourable opposition of Mars such as that occurring in August 2003 is about 16km.

The current generation of natural guide star adaptive optics systems will be followed by improved systems using laser guide stars, and by multi-conjugate adaptive optics (MCAO) using multiple laser guide stars to provide improved levels of adaptive correction (Ellerbrook & Rigaut 2000). These sophisticated adaptive optics systems are also fundamental to the current plans for extremely large telescopes (ELT's) with ~30m apertures, and ESO's overwhelmingly large telescope (OWL) of 100m aperture. With such a telescope observations of Mars with resolutions of better than 1km at short infrared wavelengths should be possible.

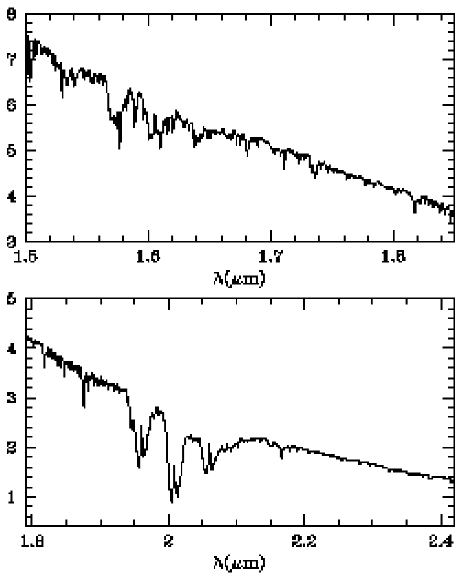
Possible Observations:

To observe Mars with the current generation of adaptive optics systems requires a "reference star" close to the planet that can be used to sense the wavefront distortions. In the case of Mars the satellites Phobos and Deimos are bright enough and close enough to the planet to be used for this purpose. Phobos reaches magnitude 10.4 and orbits the planet with a period of 0.319 days. Deimos is magnitude 11.5 and has a period of 1.26 days. Using a moving satellite as a reference object is possible with systems such as CONICA/NAOS on the ESO VLT using tracking tables to correct for the changing separation of the satellite from the planet (Brandner et al. 2002).

Adaptive optics works best at near infrared wavelengths (1–2.5µm). At shorter wavelengths current systems do not provide adequate correction, while at longer wavelengths the diffraction limited resolution is reduced and the gains from adaptive correction are smaller. Spectroscopy at these wavelengths could be a very valuable probe of the surface and atmosphere of Mars. To perform spectral mapping across the disk of Mars there are two possible modes of observation. The data can be obtained using a slit spectrograph, and the slit scanned across the disk of Mars to build up a spectral imaging data set. One way of doing this is to fix the spectrograph slit, and allow the rotation of the planet to build up the scan. An alternative approach would be to use a tunable filter instrument, which can image the whole planet and build scans by scanning in wavelength. The latter approach is potentially more efficient if specific features are being targeted so that relatively few spectral points are required.

The near IR wavelength region has not yet been extensively studied using spacecraft The ISM instrument on Phobos-2 mapped a small part of the equatorial region of Mars at spatial resolutions of 7-25km before the probe failed. Interestingly this is about the same spatial resolution that could be achieved with a diffraction limited 8m ground-based telescope. The OMEGA instrument on Mars 96 returned no data as the spacecraft was lost soon after launch.

Near infrared spectral mapping instruments are planned for two forthcoming Mars missions: OMEGA on Mars Express (2003 launch) and CRISM on Mars Reconnaissance Orbiter (2005 launch). While these instruments will offer higher spatial resolution than is possible from ground-based telescopes their spectral resolution is much lower. Low resolution may be sufficient for the broad features due to surface minerals that are a key goal of such projects. However, higher spectral resolutions (~1000 or more) are desirable to study the narrower atmospheric absorption features.



The figure shows a simulated Mars spectrum at a resolution of 1000 calculated using a radiative transfer model for the Mars atmosphere. The features are mostly CO_2 bands. From observations of the distribution of such spectral features over the surface of Mars it is possible to study the distribution and optical properties of the airborne dust in the Martian atmosphere. It is also possible to construct the first spatially-resolved description of the ambient atmospheric pressure at the Martian surface.

Data reduction:

The data obtained from such observations will present a number of challenges in data reduction. In addition to the standard astronomical data reduction processes such as flat-fielding and wavelength calibration, the data need to be corrected for various effects arising from the partial correction of the adaptive optics and for extinction in the Earth's atmosphere. Adaptive optics systems give images with a point spread function (PSF) that contains a diffraction limited core, surrounded by an uncorrected halo of the original seeing disk size. The degree of correction of the adaptive optics is measured by the Strehl ratio, which is defined as the height of the peak of the PSF as a fraction of a perfect diffraction limited image. Typical Strehl ratios of current systems are 50% or less, and the Strehl ratio will decrease as the distance from the reference star increases. Hence both the spatial and spectral PSF will vary across the image.

The light being observed will have passed twice through the Mars atmosphere and once through the Earth atmosphere. The standard method of correcting astronomical spectra for extinction in the Earth's atmosphere is by dividing the observed spectrum by one of a nearby standard star. However, this technique is unlikely to be adequate for the high S/N we would like to achieve in such observations since it is subject to errors due to airmass mismatch and different PSFs for the star spectrum and that of Mars. We suggest that the correction should be based on transmission determined from a radiative transfer model for the Earth's atmosphere. The model would be adjusted to fit standard star observations, by varying parameters such as the amount of H_2O and CO_2 (the main absorbers in the near IR), and the PSF until a good fit is achieved. The same model with only the PSF adjusted and transmission recalculated for a different airmass would then be used to fit the Mars spectra. It is important that the CO_2 absorption in the Earth atmosphere is accurately removed in order to make reliable measurements of the CO_2 bands in the Mars atmosphere.

The corrected Mars spectra thus obtained would also be fitted using a radiative transfer model. The model for the Mars atmosphere must take account of multiple scattering effects as well as transmission. These model fits can be used to both constrain atmospheric properties and to determine the surface reflection spectrum which contains information on mineral composition.

Conclusions:

Large ground-based telescopes using adaptive optics systems have the potential to make detailed observations of the surface and atmosphere of Mars, which can complement the data obtained from spacecraft. Near IR spectral mapping with spatial resolution of about 16km should be achievable with the current 8m class telescopes. Resolutions of 1km or less could be achieved with even larger telescopes currently being planned. To fully exploit such observations, new data reduction techniques need to be developed based on radiative transfer models for the Earth and Mars atmospheres.

References:

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