DYNAMO, AN IMAGING INTERFEROMETER FOR SATELLITE OBSERVATIONS OF WIND AND TEMPERATURE ON MARS.

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Introduction:

The DYNamical Atmosphere Mars Observer is a low mass field-widened Michelson interferometer designed to measure wind and temperature in the Martian atmosphere. To date there have not been any direct observations of winds on Mars - this instrument is designed to address this gap in our knowledge. This instrument is specifically designed to measure Doppler shifts in emissions in the O2 infra-red atmospheric band at 1.27 microns (although it may be possible to measure other airglow emissions as well). The instrument concept which has been developed has an overall mass of ~16 kg, will require < 10W of orbital average power and will produce ~32 Mbits of data per day. These parameters, including the pointing requirements, are well within the capabilities of typical multi-instrument spacecraft platforms that have been and will be used in Martian orbit.

As in the terrestrial atmosphere, the state of the Martian atmosphere is determined through a complex interplay of chemistry and dynamics. Correct interpretation of data requires inclusion of dynamical and constituent signatures and an understanding of the working of the atmosphere requires consideration of radiative, constituent and dynamical effects. DYNAMO will provide measurements which contribute to several aspects of this investigation. It will provide horizontal winds (using Doppler shifts in the observed emissions), rotational temperatures and the band integrated intensity of the O2 infra-red band from which ozone can be derived. The wind and temperature measurements will allow the zonal mean conditions to be estimated and the large scale wave signatures to be determined. Ozone is implicated in the chemistry of water vapour and its transport. DYNAMO has the potential of making a significant contribution to understanding the operation of the Martian atmosphere

Measurement Principle:

This instrument applies the Doppler imaging technique used for terrestrial applications on the Wind Imaging Interferometer (G.G. Shepherd, P.I, Shepherd et al., App. Opt., 1993) which flew on NASA's Upper Atmosphere Research Satellite. This technique uses a field-widened Michelson interferometer to view natural emissions, selected for their spectral isolation and simple line shape, and measure their Doppler shifts, line widths and mean intensity. Narrow band interference filters are used to isolate the selected emissions passing through the interferometer. Because of prior knowledge of the spectral shape of the line, its properties can be determined by directly examining the interferogram at a single path difference. The interferometer is designed to be field widened at the path difference chosen to optimally view the Doppler shift in the emission. This allows images of the atmosphere to be taken since the variation of optical path is generally less than a wavelength over a field of 4-5 degrees radius.

For observations of wind, temperature and ozone in the Martian atmosphere lines in the 0-0 band of the O2 infra-red atmospheric band at 1.27 microns are proposed. The exact spectral lines chosen are summarized in Table 1. These lines are chosen for their strength (they are among the stronger lines in the band), their relative sensitivity to temperature (they are from different branches in the band and have very different intensity dependencies on temperature thereby allowing an accurate rotational temperature measurement to be made) and their value for Martian chemistry (ozone can be derived from this emission as during the daytime this emission is due to the dissociation of ozone). A similar measurement has been proposed for application on the earth (Ward et al., SPIE Proceedings, Vol. 4550, 2001). These three emissions will be observed simultaneously so that ambiguities which might be introduced by atmospheric variability are minimized.

Table 1: O2 Emission line selection

Line	Wvelgth nm (air)	Rel. Int. (225 K)	dI/dT (225 K) % / K
$^{R}Q(9)$	1264.060	0.019	-1.6E-2
$^{S}R(3)$	1264.277	0.017	-3.4E-1
$^{R}R(9)$	1264.386	0.023	-1.6E-2

On Mars the O2 infra-red atmospheric band extends from ~10 km to ~40 km during the daytime.

The band integrated emission rate varies with season with the emission being most intense during aphelion. Estimates of the velocity uncertainty due to photon noise using intensity profiles of this emission from Krasnopolsky (JGR, 1997) show the maximum uncertainty to take place during perihelion (see Figure 1). A maximum velocity uncertainty of 6 m/s is found.

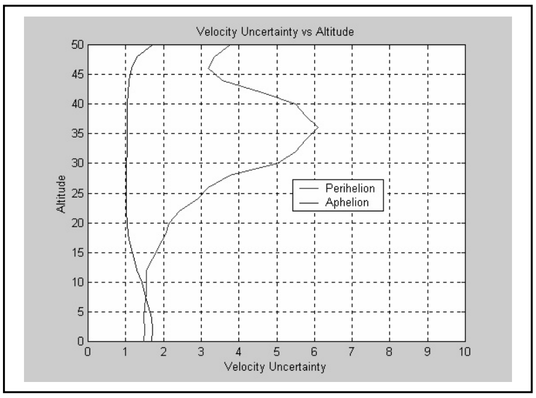

Figure 1, Uncertainties in the velocity derived using intensity profiles from Krasnopolsky **(1997)**

Instrument Design:

The main challenge in sending an instrument to Mars is to reduce its mass, power, volume and data rate sufficiently that it is compatible with the current launch constraints. The emission chosen is very bright so the collecting optics and interferometer can be small relative to the WINDII instrument. In addition since observations are restricted to a single spectral region, the interferometer is not required to be achromatic thereby simplifying the design requirements further. Under these conditions an interferometer could be designed such that one of the arms is a cube. For this circumstance, the arm could be cut along a diagonal without any impact on its function and with a significant reduction in mass. The mass estimate for the concept developed for a Mars mission is 16 kg in a volume less than .05 m^3.

The proposed detector is a HgCdTe 256x256 array detector with a cut-off wavelength of 1.6 microns. These devices have a larger band gap which allows the device to operate much warmer than typical HgCdTe detectors and to have good QE, > 70% at 1.27-mm. For DYNAMO this detector would be run at 180K, a temperature suitable for cooling using radiative means. This detector is available from Rockwell Science Center on a multiplexer, developed for a Pluto flyby mission and has heritage from the detector array in the NICMOS camera on the Hubble Space Telescope.

The data requirements for this instrument are relatively modest. The instrument views the limb with a vertical resolution of 5 km. Winds are estimated every 30 seconds. For each measurement four images and a background measurement are required. This results in a orbit average of 2.5 Mbits and a daily average of 32 Mbits.

The elements requiring power include the processor, readout electronics, piezo-driver, filter wheel, pointing mirror, and spectral lamps. For the operation of these components a peak power of 18 Watts is estimated with an orbit average requirement of 14 Watts.

Since wind measurements are not yet available for Mars, any orbit would be suitable and would return valuable data. However, given the strength of the large scale waves deduced from temperature data, a non-sun synchronous orbit would be preferred. Such an orbit would allow tidal signatures to be more readily resolved.

Two aspects of wind measurements place requirements on the stability and knowledge of the instrument pointing. The first is the fact that this is a limb viewing instrument and the second is that to determine velocity of the atmospheric air, knowledge of the component of the satellite velocity relative to the surface of the planet projected along the line-of-sight of the instrument is needed. Consideration of these requirements for a velocity resolution of 1 m/s and the vertical resolution of 5 km shows that the roll, pitch and yaw all need to be controlled to within .2 degrees. In addition the knowledge and stability of the platform during a measurement must be to within 0.1 degrees for pitch, 0.025 degrees for yaw and 0.1 degrees for roll.

Summary:

To date there have not been any direct global measurements of winds on Mars. Wind measurements are needed to validate the mean winds derived from temperature measurements based on assumptions of thermal wind balance, to determine wave amplitudes and their dissipation and to resolve questions of how constituents are transported on Mars.

DYNAMO is an instrument which is capable of providing these wind measurements. In addition it will provide measurements of the temperature and information on ozone in the height range of 10-45 km. Ozone is thought to be directly linked to water chemistry on Mars and is a constituent whose transport is not well understood. This set of measurements would be a very valuable contribution to our understanding of the Martian atmosphere.

This instrument was proposed for the now postponed CNES Premier mission and is being considered for Canadian contributions toward scientific missions to Mars. Its small size and modest data and power requirements make it an attractive partner for any atmospheric missions to Mars being proposed in the near future.