MEASUREMENT OF MARS ATMOSPHERIC WINDS WITH INTERFEROMETRY

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Introduction: Global high-resolution measurements of wind in Mars' atmosphere remains a void and high priority in our scientific understanding of the Martian climate according to MEPAG[8] and wind remains a loosely constrained hazard in the entry, descent and landing (EDL) of spacecraft.

Existing direct measurements of Martian winds are limited to landers isolated spatially and temporally from one another (e.g., Viking[10], Pathfinder[11] and Phoenix[6]) and Earth-based measurements of the Doppler-shift of spectral features (e.g., CO lines) at very coarse resolution[9]. Winds have been inferred from the large database of atmospheric temperature measurements from instruments like the Thermal Emission Spectrometer [12] and Mars Climate Sounder[7], however inferred winds differ between the two datasets at levels of tens of m/s. Additionally, the assumption of gradient wind balance necessary to produce those derived winds breaks down near the equator, precisely where most spacecraft perform EDL. Simulated winds from general circulation models also differ from the observations.

Several Earth-orbiting spacecraft have successfully measured stratospheric and mesospheric winds through high-resolution optical spectroscopy[4][5]. Using a Fabry-Perot interferometer, this same technique could provide global wind measurements on Mars, filling this void in our scientific understanding of the Martian climate and significantly reducing error bars on wind's impact to spacecraft EDL.

Scientific Rationale: Decades of space-based obsrevations of the Martian atmosphere has greatly illuminated our understanding of its climate and processes. But, this understanding remains constrained by the lack of direct observations of winds. Observations of water vapor, dust and trace species indicate substantial transport of species on timescales ranging from diurnal to inter-annual (Figure 1), but knowledge of their sources and sinks can only be indirectly inferred without measurement of wind, since winds are transporting the aerosols and trace gases.

Direction measurement of winds will help close the question of coupling between radiative and dynamical interactions in the Martian climate and improve understanding of the feedback between dynamical transport of aerosol and trace gas species and their impact on those dynamics through radiative heating.

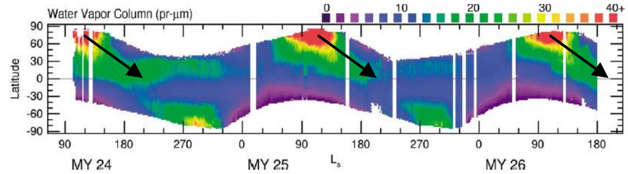

Figure 1. TES water vapor column abundance over 3 Mars years suggesting substantial meridional transport of water vapor off the winter polar cap in spring (indicated by arrows). Adapted from [13].

Measurement Technique and Requirements:

Measuring the vertical profile of horizontal (zonal and meridional) winds from space requires viewing the atmospheric limb from two near-perpindicular angles so the correct wind vector can be decomposed. This is accomplished by an instrument with either multiple telescopes or a single telescope with azimuthal slewing capability. Accuracy of the measurements depends on both instrument properties and careful selection of spectroscopic features to observe.

Near-infrared emissions lines from O_2 near 1.27 μm represent an ideal spectral signature to map winds for the bulk of the atmospheric volume above 35 km altitude. This O_2 atmospheric IR ($X^3\Sigma_g$-$a^1\Delta_g$ 0-0) band airglow is produced by the photolysis of ozone and has been used to map the global distribution of ozone on Mars[3]. Below 35 km, increasing dust optical depth masks this spectral feature and prevents wind measurement, particularly for long-path limb measurements. To counter this effect, sub-limb measurements of CO_2 spectral features can be employed. Absorption of solar backscattered radiation near 1.45 μm by CO_2 viewed in a sub-limb (e.g., 60° observer zenith angle) configuration can provide wind measurements to the lowest scale height of the atmosphere at slightly-degraded vertical resolution.

This combination of limb and sub-limb observations by a space-based Fabry-Perot Interferometer would provide global wind measurements with uncertainties <10 m/s from the surface to the middle atmosphere (Figure 2), meeting the criteria of the Mars Science Orbiter Science Assessment Group[2].

Interferometer wind measurements can be accomplished from a variety of orbits, including sun-synchronous orbits that have been typical of recent missions, as well as precessing orbits. Precessing orbits able to sample the atmosphere at multiple local times are particularly useful for identifying atmospheric waves, such as tides, with periods of fractions of a sol.

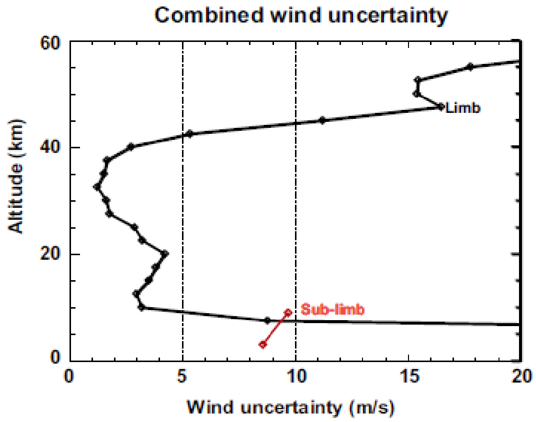

Figure 2. Wind uncertainty of the concept Mars Atmospheric Wind Insturment (MAWI)[1].

Concept Instrument: MAWI, a conceptual Mars atmospheric wind interferemoter[1], was designed in preparation for the 2013 Mars Science Orbiter mission definition[2]. This concept builds on the successful flights of three Fabry-Perot interferometers on Earth-observing satellites (e.g., the TIMED Doppler Imager[5]) and inherits many of their technical specifications.

The MAWI concept is a two-telescope tunable multiplexed double-etalon Fabry-Perot interferometer. The telescopes would be mounted at azimuthal angles of 45° and 135° off the satellite's velocity vector, allowing limb and sub-limb scanning of the atmosphere from the surface to near 80 km. Both telescopes would have an azimuthal scan range of 27°. The optics system includes a radiatively cooled (to ~150 K) HgCdTe detector and both a high and low-resolution etalon enabling detection of narrow spectral lines. The low-resolution etalon is tunable to allow measurement of multiple spectral lines.

Each combination of limb and sub-limb measuremetns take approximately 1 minute. Therefore, in a nominal 70° inclination 400 km circular orbit, measurements would be taken every 200 km (~1.5° latitude near the equator). Vertical resolution is near 2.5 km, which would allow MAWI to observe expected small scale variations in wind profiles with height, particularly near the top of the planetary boundary layer.

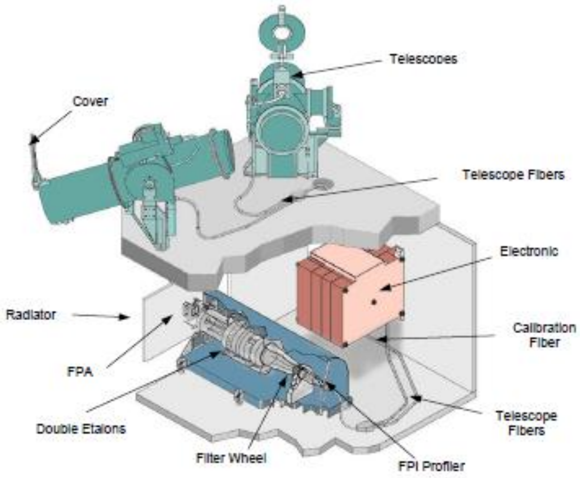

Figure 3. MAWI concept.

Conclusions: Global direct measurement of Mars atmospheric winds is a critical scientific and engineering need that can be filled with flight-proven space-based measurement techniques. Wind measurements are needed to answer outstanding scientific questions about transport of aerosols and gases and their impact on the Martian climate system. Accurate direct wind measurements would reduce risks and targeting uncertainties in spacecraft EDL.

Measurement of winds could be accomplished by imaging spectroscopy of Doppler-shifted emission and absorption lines from O_2 and CO_2, respectively, using a Fabry-Perot interferometer. This would allow a vertical profile of wind from the near-surface to ~80 km, even during periods of high dust loading in the lower atmosphere.

A concept Mars Fabry-Perot interferometer, the Mars Atmospheric Wind Interferometer, has been designed and would make an ideal candidate for flight on the next Mars orbiter mission.

References: [1] Boldt, J. et al. (2006) *AGU*, P51C-1207. [2] Calvin, W. et al. (2007) *Report from MSO-SAG2*. [3] Federova, A. et al. (2006) *JGR*, *111*, E09S07. [4] Hays, P.B. et al. (1993) *JGR, 98*, 713-723. [5] Killeen, T.L. et al. (1999) *Proc. of SPIE, 3756,* 289-315. [6] Holstein-Rathlou, C. (2010) *JGR, 115*, E00E18. [7] McCleese, J.D. et al. (2010) *JGR*, *115*, E12016. [8] MEPAG (2010) *Mars Science Goals*. [9] Moreno, R. et al. (2009) *Icarus, 201*, 549-563. [10] Murphy, J.R. et al. (1990) *JGR, 95*, 14555-14576. [11] Schofield, J.T. et al. (1997) *Science, 278*, 1752-1758. [12] Smith, M.D. et al. (2001) *JGR*, *106*, 23929-23945. [13] Smith, M.D. (2003) *Icarus, 167*, 148-165.