A SUBMILLIMETER SOUNDER FOR MEASURING MARTIAN WINDS WATER VAPOR AND TEMPERATURE.

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Introduction:

The winds on Mars are almost completely unknown, yet are critical for understanding fundamental Martian processes, such as the dust and water cycles, and for ensuring safe landing of robotic and human spacecraft. Previous Martian surface wind measurements are limited to the Viking, Pathfinder, Phoenix and Curiosity landed missions; all single locations with only the Vikings operating contemporaneously. Indirect wind measurements have been made through application of techniques such as thermal wind balance, and through examination of wind generated features on the surface, and cloud motions. A few Earth-based observations of winds have been made, but they are severely limited in time and represent averages over very large regions of the atmosphere. Given this dearth of measurements, most studies of Martian winds are model-based in nature and only limited validation has been possible for the conclusions drawn.

The need for a global, long-term wind measurement set is great, as discussed by NASA's Next Orbiter Science Analysis Group [NEX-SAG; 1]. This group was chartered by the Mars Exploration Program Analysis Group in 2015 to evaluate the science priorities for a potential Mars orbiter envisioned to launch as early as 2022. One of the five compelling science objectives noted was to *"Measure winds and characterize transport and other dynamic processes to understand current climate, water, and dust cycles, with extrapolation to past climates"* and a Finding was *"Observation of wind velocity is the single most valuable new measurement that can be made to advance knowledge of atmospheric dynamic processes. Near-simultaneous observations of atmospheric wind velocities, temperatures, aerosols, and water vapor with global coverage are required to properly understand the complex interactions that define the current climate."* The NEX-SAG further identified that a long-wavelength atmospheric sounder could meet this objective.

Science Motivation:

The various Mars orbiting spacecraft that have been flown to date have characterized the Martian atmosphere fairly well in terms of temperature, pressure, dust and ice aerosols, and column water vapor amount. The ExoMars Trace Gas Orbiter will measure profiles of the abundance of many key trace gases, and MAVEN is studying the upper atmosphere and its interaction with the space environment.

However, fundamental questions regarding the nature of the current and past Martian climate remain. Addressing these questions requires an understanding of the atmospheric general circulation and its variability, for which global wind measurements are necessary, and have remained and missing piece in basic atmospheric characterization. Further, measurements of temperature, aerosol and water vapor are needed simultaneously with any wind measurements, to fully understand the impact of thermal forcing on wind, and the consequences for aerosol/vapor transport. Specific science examples, relating to key questions involving two major cycles operating in the Martian atmosphere, are discussed below.

Winds, Temperature and the dust cycle. Dust storms (Fig. 1) are a major part of the Martian climatology, and affect the atmospheric state on local to global scales. However, their genesis and evolution are not well understood, particularly with regard to the generation of global dust storms. At the most basic level, it is still not understood why some storms become global while others remain regional or local. Intriguingly, a "flushing" storm originating in the northern hemisphere and migrating southwards was seen just prior to the 2007 global dust storm [2], providing a possible mechanism for the incitement of the global dust storm. However, a similar flushing storm in a later Mars year did not lead to a global dust storm. What was different about the circulation in those two cases? Why was the response to the first storm so much different? **Measurement of the winds and associated atmospheric temperatures are essential for enhancing understanding of dust storm progression, and variability.**

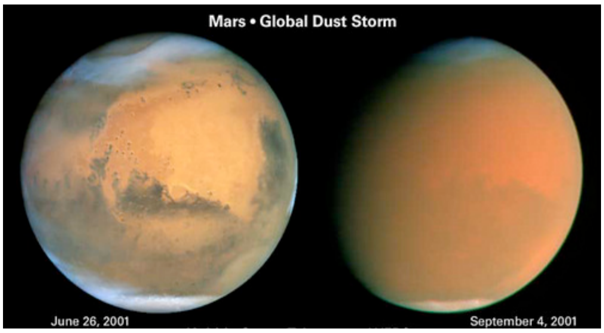

Figure 1: An example of a global dust storm on Mars (this one in 2001). Image credit: HST.

Winds and the water cycle. One of the biggest mysteries on Mars is when, and under what conditions, was there sustained surface water. Given that such flow is not sustained today, although geomorphic and geologic evidence shows clearly that it was in the past, the question then becomes, how and when did the Martian climate change? Simultaneous measurements of the vertical profile of wind and water vapor abundance are essential for understanding how much vapor mass is transported by the atmospheric circulation. Key questions include: is there net cross-hemisphere transport today and is transport influenced by seasonally or orbitally forced behavior of possible sources and sinks (e.g., polar cap and high-mid latitude regolith)? Further, understanding behavior in today's climate is critical for understanding climate change and the rate thereof.
Recent assimilation of TES temperature and water vapor data [5] indicate net northward transport of water, contrary to many other studies. However, they acknowledge that the vertical water vapor distribution may be incorrect, as TES only provided column abundances. Further, the polar winter vortex may influence the transport of water and CO_2. The nature of the polar jet is being modeled and is apparently sensitive to both CO_2 condensation [6] and dust loading [7]. Measurements of winds and water vapor vertical profiles will enable a greater understanding. **Measurement of winds and water vapor vertical profiles as a function of season is essential for quantifying transport and validating models. This in turn can be used to gain insight into the current climate and climate history of Mars**.

Engineering Motivation:

Wind profiles are critical for entry, descent, and landing to, and in the future ascent from, the surface of Mars. Currently, un-validated model output (from usually ≥2 models to guard against potential errors) is used to provide guidance for spacecraft design and landing parameters. This may result in over-design of spacecraft or, at worst, mis-prediction of the wind field leading to failure. **Global wind measurements are needed for guiding appropriate spacecraft design.**

Sub-millimeter Instrument Design Concept:

A passive submillimeter limb sounding instrument is ideally suited to provide the needed wind, water vapor, and temperature profile measurements. The technique has high heritage in Earth-science, and dramatic advances in associated technology in the past decade (driven in part by the communications industry) enable significant reductions in needed power, mass and complexity. Such an instrument can make measurements both day and night, and in the presence of atmospheric dust loading. Per the NEX-SAG report, our instrument design will be optimized to deliver measurements of winds, temperature, and water vapor between 0–80 km, at ~5 km vertical resolution.

Our concept for such an instrument builds on prior JPL-led instruments such as the Microwave Limb Sounder currently flying on EOS *Aura* [8], and the MIRO instrument aboard *Rosetta* [9]. The instrument would employ a single, steerable antenna (~23 cm diameter), and observe a diverse set of spectral lines, both weak and strong, from multiple species to cover the full range of altitude desired. The antenna would be 2-axis gimbaled for steerable limb and near-nadir views, enabling continuous instrument operation during spacecraft maneuvers for special campaign observations, or as the spacecraft orbit changes. Fig. 2 shows a block diagram of the instrument.

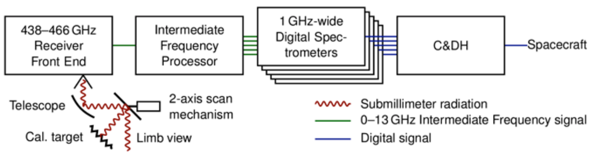

Figure 2: Block diagram of instrument

Performance Analysis. Initial simulations have been undertaken to show performance of our notional sub-mm sounder (Fig. 3). These simulations employed algorithms and software developed for Aura MLS (suitably adapted to the Martian atmosphere) to model performance of the instrument under conditions taken from the Mars Climate Database.

References:

[1] MEPAG NEX-SAG Report (2015), Report from the Next Orbiter Science Analysis Group (NEX-SAG), *Chaired by* B. Campbell and R. Zurek, 77 pages posted December, 2015 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.nasa.gov/reports.cfm.
[2] Wang, H. and Richardson, M.I. (2013) *Icarus*.
[3] Piqueux, S. A. *et al.* (2014) *Icarus*.
[4] Cantor, B. A., et al. (2010) *Icarus* 208, 61–81.
[5] Steele, L. et al., Icarus 237 (2014) 97–115
[6] Toigo, A. et al., 6th Mars Polar Conference, abstract #6030
[7] Guzewich, S. et al., 6th Mars Polar Conference, abstract #6007
[8] Waters, J.W. *et al.* (2006) *IEEE Trans. Geosci. Remote Sensing 44*, 1075–1092.
[9] Gulkis, S. et al. (2007), *Space Sci Rev*, *128*(1-4), 561–597.

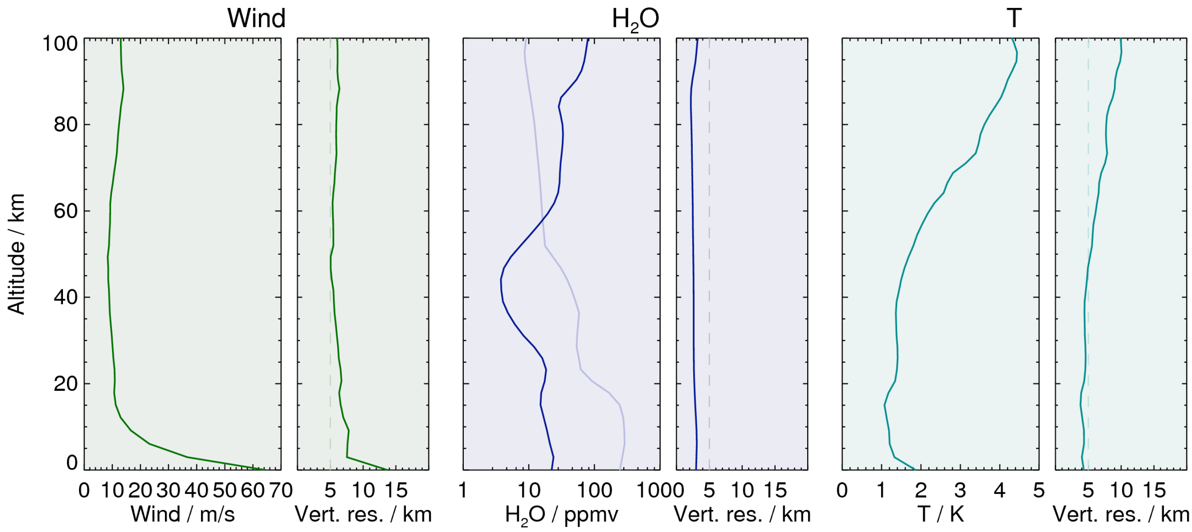

Figure 3: Example preliminary results from simulated retrievals, showing estimated precision and vertical resolution for line of sight wind, water vapor and Temperature from a 450 GHz submm limb sounder.