OBSERVATIONS OF PLANETARY ATMOSPHERIC WINDS AND GASES WITH LIDAR

J.B. Abshire (james.b.abshire@nasa.gov)[1], S. D. Guzewich[1], M.D. Smith[1], H. Riris[1], G. R. Allan[2]
[1]NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD, 20771, USA., [2]Sigma Space Corporation, Greenbelt, MD 20771, USA.

Introduction: Winds are the key variable to understand atmospheric transport and answer fundamental questions about planetary atmospheric circulation. On Mars, winds link the three primary cycles of the martian climate: CO_2, H_2O, and dust. The Mars Exploration Analysis Group's Next Orbiter Science Analysis Group (NEX-SAG) has recently identified atmospheric wind measurements as one of 5 top compelling science objectives for a future Mars orbiter [1]. To date, only isolated lander observations of martian winds exist while cloud-tracked winds remain the only data source for Venus and Titan. However, the direct lack of wind observations in planetary atmospheres and imprecise and indirect inferences from temperature observations leave many basic questions about atmospheric circulation unanswered. In addition to addressing high priority science questions, direct orbital wind observations would help validate 3D general circulation models (GCMs) while also providing key input to atmospheric reanalyses.

Additionally, the observation and systematic mapping of trace gas concentrations in planetary atmospheres serves as another diagnostic of atmospheric circulation while also adding insight on chemical processes within the atmosphere and surface-atmosphere exchange.

Lidar Measurement Approach: Orbiting lidar instrument concepts [2] are being designed to observe the atmosphere from a nominally circular polar orbit around Mars. The Mars LIdar for global wind profiles (MARLI) lidar measurement concept is shown in Figure 1. The instrument would be pointed ~30° off-nadir in a cross-track viewing direction. The MARLI lidar will continuously measure dust aerosol backscatter profiles, cross polarized backscatter profiles (for water ice aerosols), the component of the Doppler shift from wind profiles along the instrument's line-of-sight, and the range to the planet's surface. The present MARLI approach uses a Nd:YAG laser and makes measurements at 1064 nm [3] and its measurement types are shown in Figure 2. Vector-resolved winds may also be measured by either using a dual-telescope approach, or by using a single lidar on a movable pointing platform.

Lasers and lidar measurement techniques are also available to measure atmospheric trace gases. Differential absorption techniques use tunable lasers to measure multiple atmospheric gases (e.g., the primary atmospheric gas and the desired trace gas). The lasers are tunable and allow sampling multiple wavelengths within and around the chosen absorption line of the target gas. By precisely retrieving the absorption line shape, and knowing the background atmospheric pressure, a column-integrated trace gas abundance can be retrieved [4]. Range-resolved retrieval approaches may also be used to measure the height resolved profiles of gases, such as water vapor, that have higher abundances.

Lidar Description: The laser backscatter from the Mars atmosphere is weak and is distributed in range and thus a highly sensitive lidar approach is necessary. The present MARLI approach measures the atmospheric characteristics along a single line-of-sight. The MARLI lidar uses a compact efficient ND:YAG laser with flight heritage, a low-mass receiver telescope and photon counting sensitive detectors. For denser atmospheres such as Venus or Titan, reduced lidar power and/or a smaller receiver telescope can be used to retrieve atmospheric gases and winds above the densest and cloudiest regions of the atmosphere (e.g., above approximately 60 km altitude on Venus).

The baseline design of MARLI utilizes a pulsed single-frequency diode-pumped Nd:YAG laser. Its output pulses are wavelength stabilized near 1064 nm. The laser emits ~50 nsec wide pulses at a 1 kHz pulse rate. Nominally, the receiver uses a ~70 cm diameter telescope and splits the returned signal into 3 paths. One path is a cross-polarized channel to allow dust/ice discrimination. The other two paths are used to illuminate an etalon then are refocused onto detectors. This part of the receiver is configured as a double-edge Doppler (optical frequency-shift) discriminator.

Our approach leverages new lidar components developed for NASA, including tunable single frequency lasers and photon-sensitive HgCdTe detectors. Our targeted MARLI instrument size is a ~80 cm cube, comparable to a medium-sized instrument such as the Mars Orbiter Laser Altimeter (MOLA). Nominal payload parameters are < 40 kg, < 90 W, and ~50 Kbits/sec. This approach leverages on measuring terrestrial winds and lidar technology supported by the NASA ESTO Instrument Incubator program.

References: [1] MEPAG: Chaired by B. Campbell and R. Zurek (2015), *Report from the Next Orbiter Science Analysis Group,* http://mepag.nasa.gov/reports.cfm

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[4] J.B. Abshire et al., (2010), A Lidar Approach to Measure CO_2 Concentrations from Space for the ASCENDS Mission, Proc. of SPIE Vol. 7832 78320D-1.

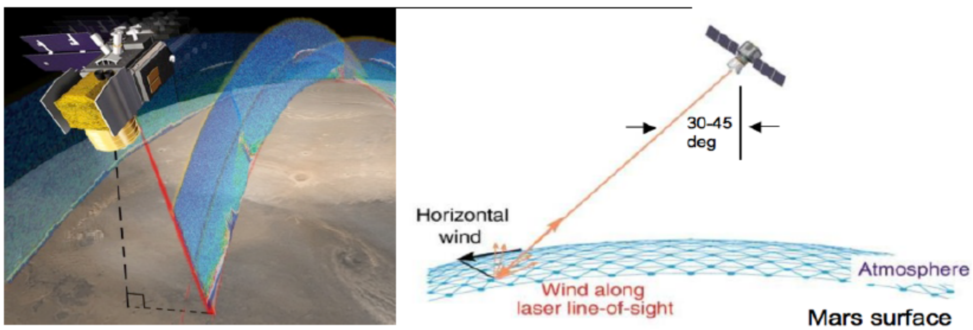

Figure 1. (Left) MARLI measurement approach, which continuously measures the aerosol backscatter profile, the cross-polarized (ice) backscatter profile, the Doppler (wind) profiles, the CO_2 column absorption (surface pressure), and the range to the scattering surface from orbit. (Right) Measurement orientation. Nominally, the lidar is pointed cross-track at ~30° off-nadir to measure the Doppler shift of the wind in the cross-track direction.

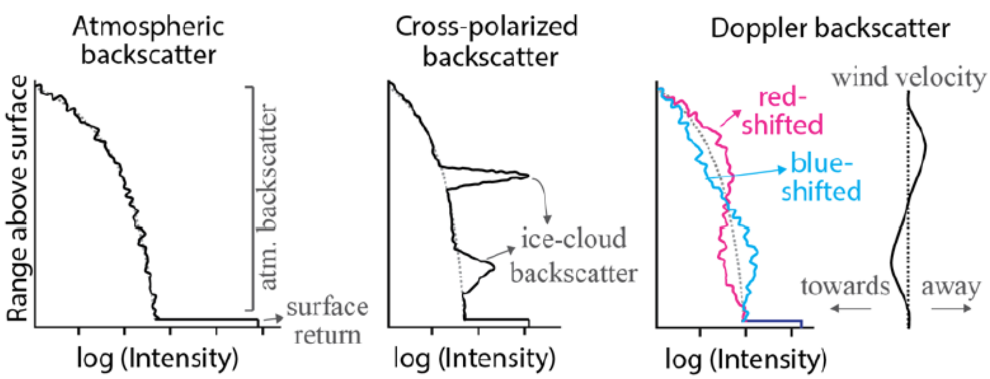

Figure 2. Illustrations of the measurement and retrieval of winds and aerosols. (Left) Range (height) resolved aerosol backscatter profiles. The strong echo pulses reflected from the surface are used for the CO_2 column density measurements. (Middle) Profiles of cross-polarized backscatter, caused by clouds with ice-crystals. (Right) Height-resolved Doppler (wind) backscatter profiles as seen by the two detectors after passing through the double-edged filter. The horizontal wind profile (Far Right) is computed from the scaled ratio (difference/sum) from the detectors after the double-edge filter.