MARLI: MARS LIDAR FOR MEASURING GLOBAL WIND AND AEROSOL PROFILES FROM ORBIT

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Abstract:

NASA's Mars Exploration Analysis Group's Next Orbiter Science Analysis Group (NEX-SAG) identified atmospheric wind measurements as one of most compelling science objectives for a future Mars orbiter [1]. To date, only very few direct observations of Mars winds exist. Winds are the key variable to understand atmospheric transport and answer fundamental questions about the three primary cycles of the Mars climate: CO_2, H_2O, and dust. However, the lack of direct observations and imprecise and indirect inferences from temperature observations leave many basic questions about the atmospheric circulation unanswered. In addition to addressing high priority science questions, direct wind observations from orbit would help validate 3D general circulation models (GCMs) while also providing key input to atmospheric reanalyses.

The dust and CO_2 cycles on Mars are partially coupled and their influences on the atmospheric circulation modify the global wind field. Dust absorbs solar infrared radiation and its varying temporal and spatial distribution forces changes in the atmospheric temperature and wind fields. Hence it is important to simultaneously measure the height-resolved wind and dust profiles. NASA Goddard Space Flight Center is developing the MARLI lidar to provide a unique capability to observe these variables continuously, day and night, from orbit.

Measurement Approach:

The MARLI lidar [2-3] is designed to observe the atmosphere from a nominally circular polar orbit around Mars. The lidar measurement concept and an instrument illustration are shown in Figure 1. The simplest version of the instrument would be pointed ~30° off-nadir in a cross-track viewing direction. The lidar will continuously measure dust aerosol backscatter profiles, cross-polarized backscatter profiles (to identify water ice aerosols), the component of the aerosol Doppler shift from wind profiles along the instrument's line-of-sight, and the line-of-sight range to the planet's surface. These measurement types are shown in Figure 2. The MARLI development is being supported by the NASA ROSES PICASSO and MatISSE Programs.

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 height-resolved atmospheric characteristics along a single line-of-sight. The lidar uses an efficient pulsed Nd:YAG laser with flight heritage, a low-mass receiver telescope, a direct detection receiver with an etalon-based Doppler discriminator, and a photon-sensitive detector.

The MARLI design, shown in Figure 3, utilizes a pulsed single-frequency diode-pumped Nd:YAG laser. The optical emission frequency of the laser is locked to a single frequency non-planar ring oscillator seed laser. The laser emits linearly polarized ~40 nsec wide pulses at a nominal 1 kHz pulse rate. The lidar receiver uses a ~50 cm diameter telescope and its optics split the returned signal into 3 paths. One path is a cross-polarized channel to allow discrimination of dust and ice in the laser backscatter profiles. The other two paths are used to illuminate a 5 cm diameter etalon at different angles that are then focused onto separate detector pixels. These receiver elements are configured as a double-edge Doppler (optical frequency-shift) discriminator for the aerosol backscatter profiles.

The MARLI approach leverages several new lidar components developed for NASA, including a new single frequency seed laser developed for the Laser Interferometer Space Antenna (LISA) mission, a single frequency ring laser developed by Fibertek Inc. and a photon-sensitive HgCdTe APD from Leonardo DRS Technologies. Our targeted instrument size is a ~70 cm cube, comparable to a medium-sized instrument such as the Mars Orbiter Laser Altimeter (MOLA). Nominal payload parameters are 40 kg, < 90W, and ~50 kbits/sec at 100% duty cycle. Our approach leverages our work on measuring terrestrial winds and lidar technology supported by the NASA ESTO IIP program.

Development status & plans:

We have developed all components and demonstrated many aspects of the measurement with an instrument breadboard. A brassboard version of the lidar is being completed during spring 2022 and is shown in Figure 4. It uses flight-like components and will be used demonstrate measurements from the ground to thin cirrus clouds.

Calculated Measurement Performance:

We have calculated the expected performance of MARLI using lidar measurement models that we developed as part of this project. For the Mars atmosphere we selected several cases that represent the atmosphere under a range of atmospheric aerosol (dust and water ice) loading. To date the bulk of current spacecraft observations of the global Mars atmospheric state have come from the Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) spacecraft, which show large temporal variations in the amount and vertical distribution of dust and ice aerosols and water vapor. For this work we extracted aerosol profiles shown in Figure 5 using extinction profiles (version 5.2.4) from the Mars Climate Sounder (MCS) on the MRO [6-8]. The MCS extinction retrievals were then scaled to the MARLI wavelength of 1064 nm. Since the Mars atmospheric pressure is low, we chose to neglect molecular scattering.

The MARLI lidar will obtain atmospheric profile measurements at a rate of ≥ 2 Hz with nominally 150 m vertical resolution. The lidar measurement performance depends on the orbit altitude, laser pulse energy and pulse rate, telescope diameter, the atmospheric vertical bin depth and averaging time. The vertical and time averaging will be performed on the ground, so are adjustable during data analysis. The performance plots in Figures 6 and 7 were calculated assuming averaging over 40 seconds (~2° latitude for a nominal 400 km polar orbit) with 2 km thick vertical bins.

Details of the instrument and its planned measurements will be shown in the presentation.

References:

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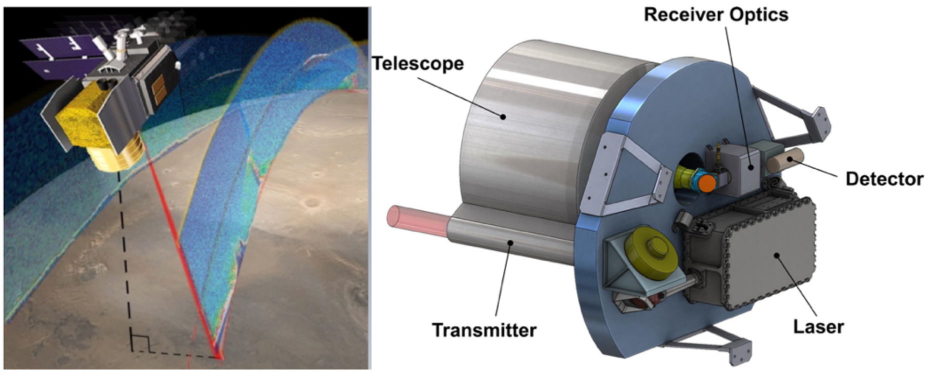


Figure 1. *(Left)* The MARLI approach continuously measures the aerosol backscatter profiles, the cross polarized (ice) backscatter profiles, and the Doppler (wind profiles), Nominally the lidar is pointed cross-track at ~ 30 degrees off nadir, to measure the Doppler shift of the wind in the cross-track direction. *(Right)* Drawing of MARLI from an engineering study. The telescope diameter is ~ 50 cm and other components are labelled.

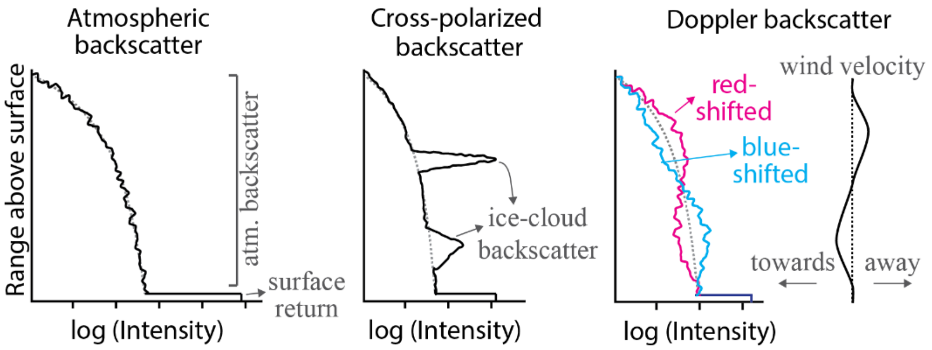


Figure 2. Illustrations of the MARLI measurement types. *(Left)* Range (height) resolved aerosol backscatter profiles. *(Middle Left)* Profiles of cross-polarized backscatter, caused by ice clouds. *(Middle Right)* Height resolved Doppler backscatter profiles as seen by the two detector channels after passing through the etalon used as the double-edge filter. *(Right)* The horizontal wind profile is computed from the detected signal ratio after the double-edge filter.

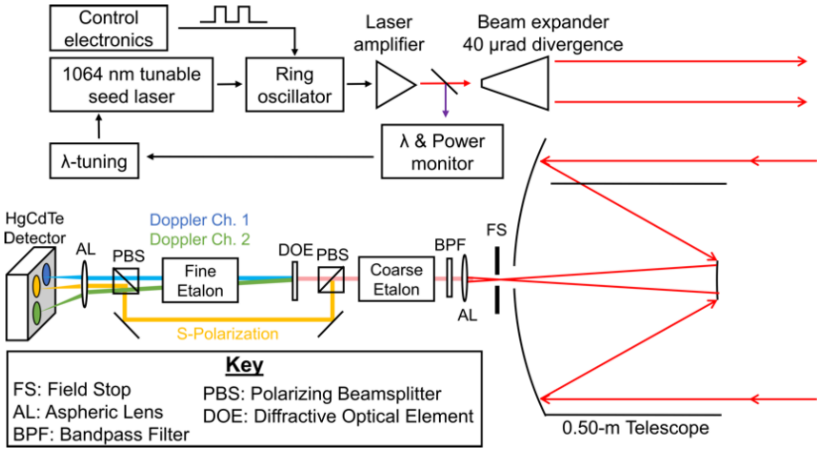
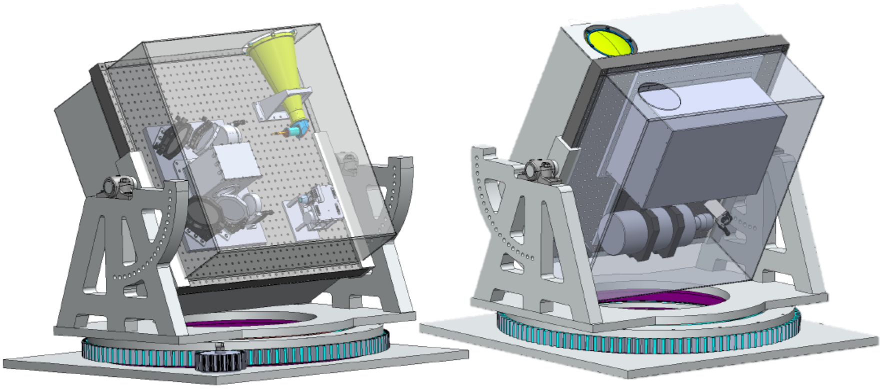


Figure 3. Block diagram of the MARLI lidar showing major components and subsystems.



Receive Side

Transmit Side

Figure 4 - Drawing of the MARLI brassboard lidar assembly. This will be used to demonstrate measurements from the ground at NASA Goddard Space Flight Center. The lidar brassboard uses a smaller 14 cm diameter receiver lens instead of the 50 cm diameter flight telescope. The brassboard is being assembled during spring 2022 and will be used to demonstrate aerosol backscatter profile measurements and measurements to wind-blown thin cirrus clouds.

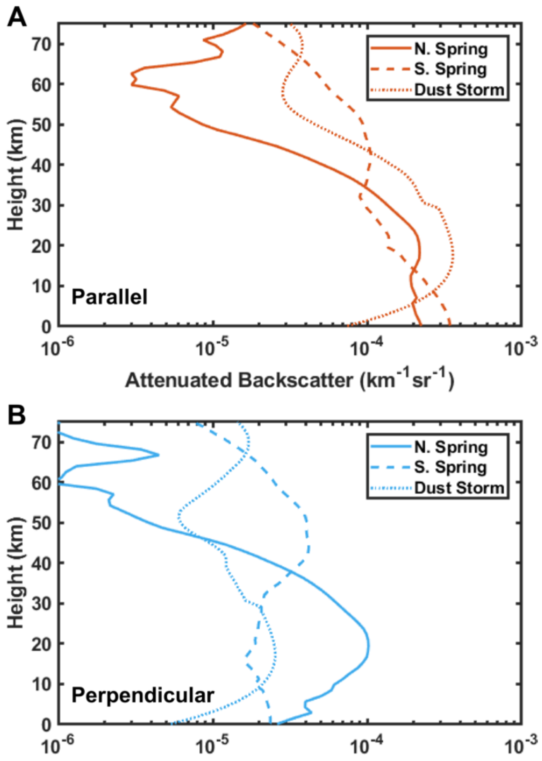


Figure 5 - The Mars atmospheric backscatter profiles used to predict MARLI measurement performance were computed from MCS retrievals:

(A) Attenuated backscatter (βT^2) with polarization parallel to the transmitter for the three atmospheric test cases as a function of altitude.

(B) Attenuated backscatter with polarization perpendicular to the transmitter for the same three cases.

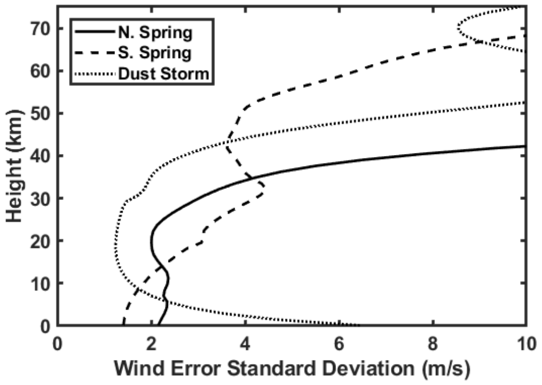


Figure 6 - The RMS wind-speed uncertainty from the MARLI instrument model computed as a function of altitude from the surface for the case of a uniform cross-track horizontal wind speed of 18 m/s. The performance was calculated assuming averaging over 40 seconds (~2° latitude for a nominal polar orbit) with 2 km thick vertical bins.

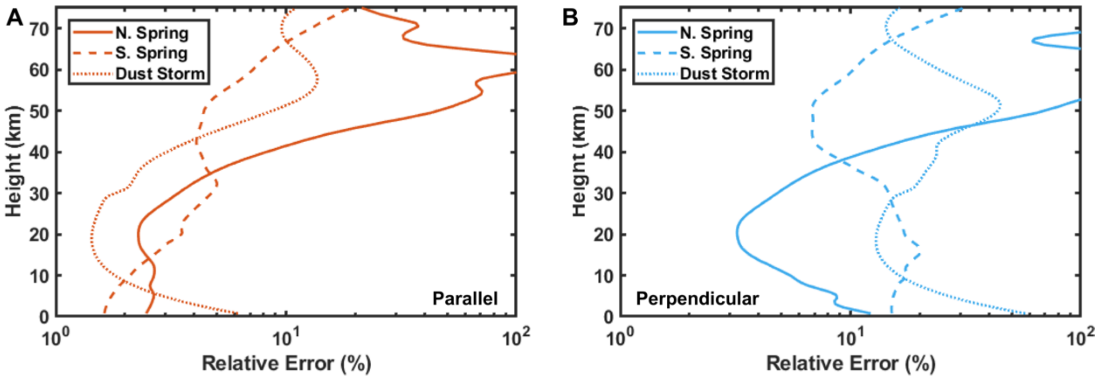


Figure 7 - Calculated relative error as a function of height for the MARLI atmospheric backscatter profile measurements in the parallel (A) and cross polarization (B) channels. The relative errors are plotted on a log scale. The performance was calculated assuming averaging over 40 seconds (~2° latitude for a nominal polar orbit) with 2 km thick vertical bins.