SMALL LIDAR FOR PROFILING WATER VAPOR, AEROSOLS AND WINDS FROM A MARS LANDER

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Introduction:

The planetary boundary layer (PBL) is the lowest layer of the atmosphere that interacts directly with the surface. Processes within the Mars PBL are very important scientifically because they control the transfer of heat, momentum, dust, water, and other constituents between surface and atmospheric reservoirs [1]. Understanding these processes is critical for understanding the modern climate, including the stability and development of the polar caps [2], how the regolith exchanges with the atmosphere [3], how wind shapes the landscape [4], how dust is lifted and transported [5], and for being able to validate and improve general circulation models (GCMs). The PBL is also important for operations since it is the environment in which landed missions must operate. On Mars the PBL depth varies between roughly 1 and 10 km, depending on time of day, with the deepest layer occurring during the day when convective turbulence is greatest.

The PBL is difficult to observe from orbit, and so detailed observations of it have been mostly limited to those just at the surface from landers. The lack of PBL observations has led to significant gaps of understanding in several key areas. These include diurnal variations of aerosols and water vapor, and direct measurements of wind velocity, the combination of which provides information on the horizontal and vertical transport of water, dust, and other trace species and their exchange with the surface. Because these quantities are interrelated [6,7] and they partially drive the wind fields, it is important to measure the water vapor, aerosols, and winds simultaneously, ideally using a single instrument.

Measurement Approach:

We are developing and plan to demonstrate a breadboard of a small atmospheric lidar to address these needs for a future lander on Mars [8]. As shown in Figures 1 and 2, our new lidar approach is to remotely profile aerosols, atmospheric water vapor and winds using laser wavelengths near 1911 nm. The lidar is designed to measure vertically resolved profiles of water vapor by using a single frequency laser. The laser will be tuned onto and off strong isolated water vapor lines near 1911 nm as shown in Figure 3. The vertical distribution of water vapor will be determined from the on- and off-line backscatter profiles via the differential absorption lidar (DIAL) technique shown in Figure 4. The same laser is used for measuring the aerosol and wind profiles by tuning the laser off-line and resolving the Doppler shift in the backscatter profiles. The laser beam is linearly polarized and a polarization resolved receiver allows separating the backscatter of water ice from dust. As shown in Figure 1, the lidar emits two beams that are offset 30 deg from zenith and perpendicular to one another in azimuth, allowing vector wind profiles to be resolved. Both lidar view directions are otherwise identical and use common lens-type receiver telescopes.

These lidar measurements address important science needs that are traceable to Mars Exploration Program Analysis Group (MEPAG) science goals relating to climate, surface-atmosphere interactions, and preparing for human exploration. Our lidar will measure vertical profiles of water vapor, and dust and water ice aerosols and winds with km-scale vertical resolution from 100 m above the surface to > 15 km altitude. These measurements will directly profile the full planetary boundary layer, which is key for understanding how water, dust, CO_2 and trace species exchange between surface and atmosphere. The lidar will provide observations of these profiles simultaneously during a nominal 4-minute averaging time. A summary of the lidar's calculated measurement performance is shown in Table 1.

Technology and Development Plan:

Our lidar approach shown in Figure 5 utilizes a new laser diode seeded Thulium fiber-based laser transmitter and a highly sensitive HgCdTe avalanche photodiode detector in the receiver. We have procured all components to demonstrate a breadboard version of a single lidar channel. During the next 12 months our plan is to complete testing and assembly of the lidar components to a system TRL 4. We then plan to use the breadboard lidar to demonstrate profile measurements of aerosols, water vapor and wind from the Mauna Kea Hawaii astronomy site where relatively dry atmospheric conditions reduce absorption of the 1911 nm laser signal.

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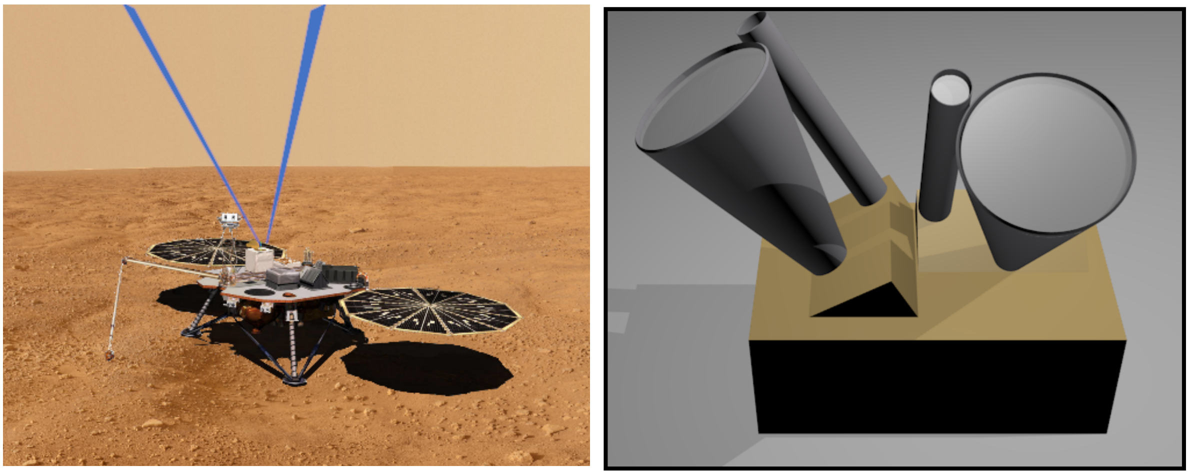

Figure 1. *(Left)* Concept sketch of the two laser beams exiting the small lidar on a lander. The blue color denotes the 1911 nm beams used for the water vapor profiles and vector wind profiles. *(Right)* Solid view of the lidar instrument concept. The approximate dimensions of the box at the bottom are 30 x 18 x 8 cm, and the larger cones are the lidar receiver's lens assemblies. The lidar will measure for the first time vertically resolved water vapor and wind profiles, and aerosol profiles, in the Mars PBL.

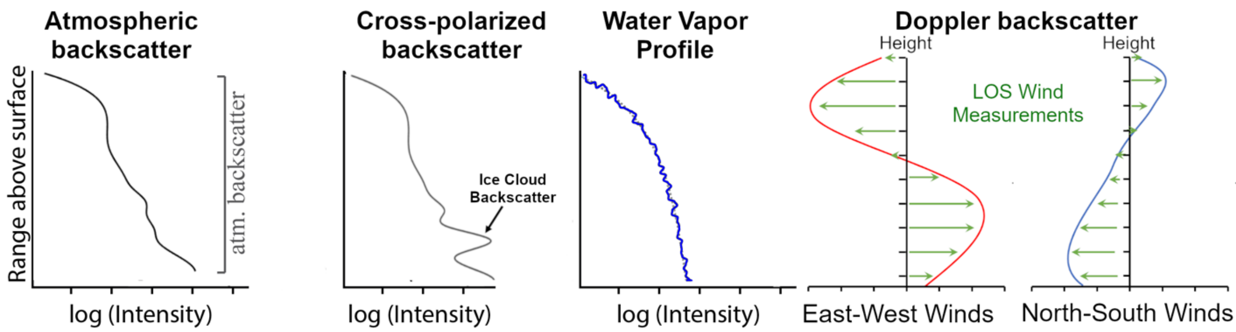

Figure 2. Illustration of the lidar's vertically resolved measurements, made from the surface to ~20 km every ~20 minutes. The lidar will provide, for the first time, vertically-resolved water vapor and wind profiles, along with aerosol profiles, in the Mars boundary layer.

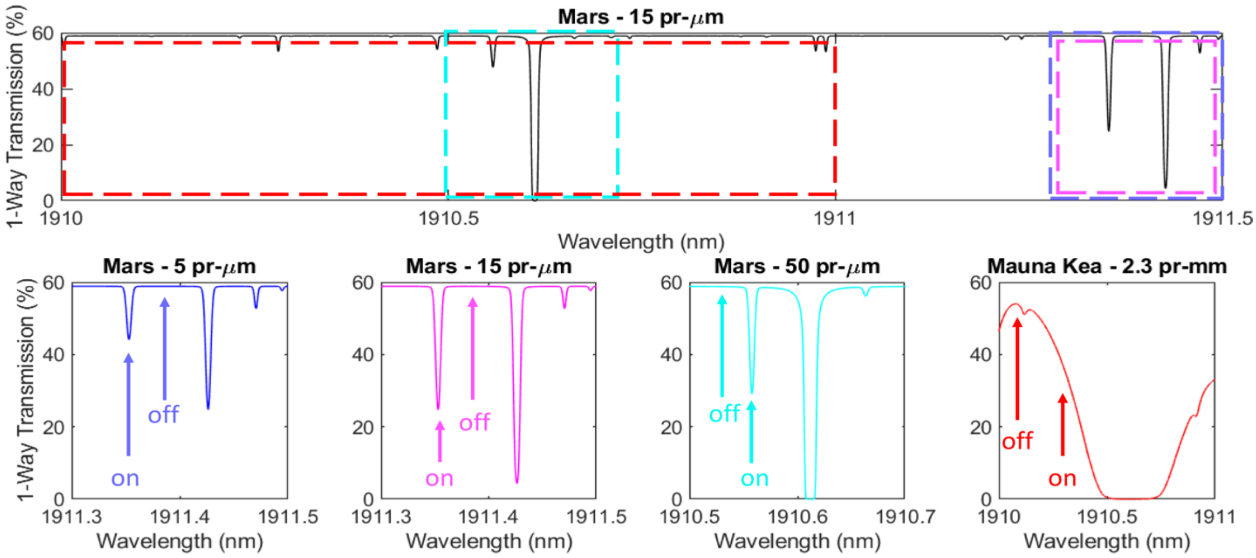

Figure 3. Plots of Mars atmospheric transmission km in 1911 nm region calculated from the surface to 20 km. The dotted boxes correspond to the spectral regions shown in the lower frames. The water vapor absorption lines near 1911 nm are well-suited for DIAL lidar for Mars, and the selected water vapor line is chosen based on abundance, which ranges from 5 to 50 pr-µm. The rightmost plot shows that the 1910.5 nm region may be used for a DIAL lidar demonstration at Mauna Kea to ~ 1-km altitude.

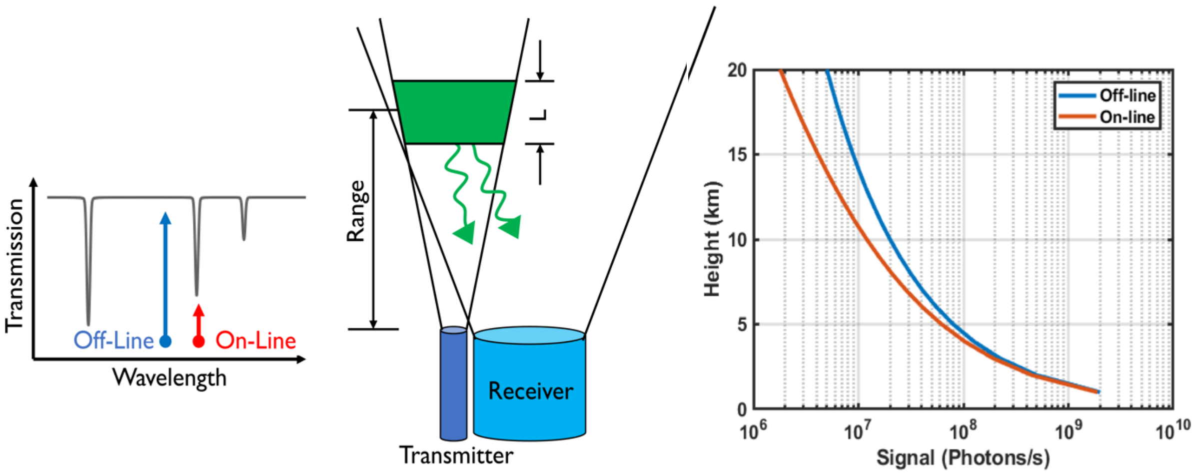

Figure 4. Concept for the DIAL lidar measurement of water vapor profiles showing the stronger backscatter profile for the off-line (blue) wavelength, and weaker profile (due to water vapor absorption) of the on-line wavelength.

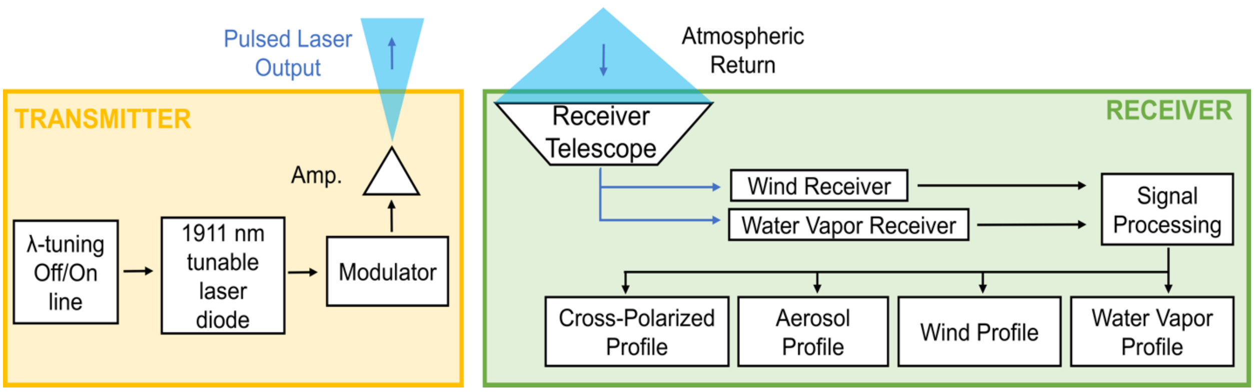

Figure 5. Simplified block diagram of the lidar. The small lidar uses a single-frequency tunable 1911 nm laser and a sensitive 4-pixel detector to measure water vapor, wind and aerosol profiles.

Table 1 - Summary of calculated lidar measurement performance.
These are based on a detailed lidar backscatter measurement model, and are for 250 sec averaging time, 1-km bins, 0.5-W average laser power.

Parameter	*1 km*	*5 km*	*10 km*	*15 km*	*20 km*
Water Vapor rel. error* in alt bin (%)	<0.2	1	15	110	--
Aerosol profile Relative error (%)	<0.02	0.01	0.04	1	3
Horizontal Wind speed error (m/sec)	<0.02	0.1	0.6	2	5
* based on 15 pr-um WV total with uniform mixing ratio from 0-15 km					