A 3-D AEROSOL PROFILING LIDAR FOR PLANETARY ROVER MISSIONS

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Introduction: Existing remote sensing techniques provide limited information on vertical profiles of dust and cloud distributions in Martian atmosphere. Lidar on PHOENIX mission to Mars demonstrated high vertical resolution aerosol profiling capability [1]. A conceptual study is presented for an advanced 3-D profiling lidar for aerosols and clouds. This instrument will have a form factor suitable for future Mars and other planetary lander and rover missions. This instrument can be adopted as part of combined surface Raman/lidar active remote sensing system package [2]. It leverages developments of a compact Nd:YAG laser, a photon counting APD detector and other lidar system developments over the past two decades. With a laser output power of more than an order of magnitude greater than the PHOENIX lidar, multi-wavelength (355, 532, and 1064 nm) output, high sensitivity detector, and polarization sensing capability this instrument is suitable to profile aerosol and clouds up to the Martian tropospause and for improved characterization of aerosols and clouds. These capabilities enable new investigations of climate, atmospheric transport and dynamics. The instrument concept, its sensitivity and predicted precision are presented in this paper.

Science Background: Lidar remote sensing provides a unique capability for atmospheric studies involving: 1) ranging, 2) profiling during day and night, 3) spectral selection to avoid absorption due to interfering species, and 4) straight forward inversion without complex data inversion techniques. Precise altitude ranging of aerosol and cloud profiles is the hallmark of pulsed lidar systems. Backscatter lidar data have been used for the retrieval of aerosol extinction profiles that are associated with the development of convective boundary layer, formation of clouds on top of the boundary layer, and many fine scale features in the earth's atmosphere. This capability can be extended to investigate planetary bodies. The lidar on a rover with a robatic arm or a scanning system, will be able to provide 3-D aerosol backscatter and extinction profiles. The combination of three wavelengths (355, 532, and 1064 nm), and aerosol/cloud depolarization at 532 nm will aid in investigating the differences between dust layers, clouds, ice layers and their phases and their optical properties.

Surface-based lidar vertical profiling of Mars dust and ice aerosols should provide the capabilities of 100-500 meter vertical resolutions from the surface to the tropopause for day and night local times. Such a capability would enable a broad range of new climate investigations for Mars lander/rover missions ranging from: 1) dust lifting and transport within small scale (dust devils) to large scale (e.g., global) dust storms; 2) tidal and gravity wave forced vertical variations in water ice cloud formation; 3) dust and water ice correlations within the aphelion cloud belt associated with aerosol microphysics; 4) ice cloud formation associated with water vapor exchange from localized surface sources such as the retreating seasonal ice cap or potential subsurface reservoirs; 5) the detailed ice and dust distributions and surface interactions within synoptic wave fronts at mid-latitudes; 6) the formation of nighttime ground ice fogs at mid latitudes in fall and winter seasons; and (over potential high latitude sites) 7) the formation of CO_2 ice clouds and dust loading levels within the polar winter. Vertically resolved profiling of dust and ice aerosols within the Martian atmospheric boundary layer represents the rare opportunity to discover completely new processes in the Mars climate system, as well as support future Mars landing systems and manned surface operations. These key aerosol measurements in the Mars near-surface environment to be addressed by the lidar instrument would contribute uniquely to unresolved questions in the global transport of dust and water (ice) volatiles in the Mars climate system. They would also serve to constrain dynamical, physical, and radiative characteristics of the lower Mars atmosphere that bear upon future manned exploration and habitability of the Martian surface.

Optical Design: A schematic diagram of the optical design of the system is shown in Fig. 1. It consists of a space qulifiable compact Nd:YAG laser, a 10 cm all metal telescope, and commercially available photon counting Si:APD , and PMT detectors. The basic lidar parameters are provided in Table 1. The laser follows the heritage of successful development of space-qualified Nd: YAG laser for the CALIPSO mission. The laser polarization will be rotated by 90^o on alternate pulses to measure aerosol/cloud depolarization [3]. The rotation of the plane of polarization in the transmitter rather than having a two channel parallel and perpendicular receiver system eliminates the need to acquire data using two channels. This is a simpler design that has the added advantage of avoiding the need to calibrate the two channels in the absence of significant molecular signals such as those in the

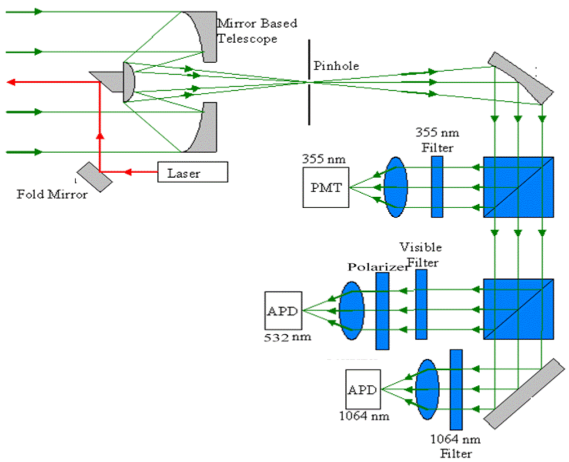

Fig. 1 Schematic digarm of the optical design.

Martian atmosphere and also avoids any cross-talk between the two channels. After beam expansion, the laser beam is transmitted co-axially with the telescope. The lidar system can be easily modified to accommodate operations in surface Raman/lidar modes [2] as has been demonstrated from ground-based systems [4].

Table 1. Lidar Parameters

Component (Parameter)	Description/Value	Unit
Laser Transmitter		
λ's and pulse energies	1064, 532, 355; 12, 16, 12	nm; mJ
Pulse repetition frequency	20	Hz
Detectors,	APD (532 and 1064 nm), PMT (355 nm)	
Single Photon Counting Module (APD)	Model SPCM-AQR-16	
Diameter	175	µm
Dark Count	25	C/Sec
Spectral Range	400 to 1064	nm
Photon detection Efficiency APD	65% (@650nm) and 55% (@532 nm)	
Minimum Signal Detection	45 Photons/Sec or average optical power $2x10^{-17}$ W @532nm	

Lidar Performance: Lidar signals and signal-to-noise ratios (S/N) are calculated at 532 nm for detection of background aerosol layers in the Martian atmosphere are shown in Fig. 2. A background aerosol model with an optical depth of 0.6 at 532 nm is assumed that is consistent with average dust loading observed on Mars. A night background is also assumed. A vertical resolution of 150 m and a 2.5 minute of shot averaging are assumed in the S/N calculations. Because of the high S/N in the boundary layer (>10E3), features of aerosols and clouds can be detected with much higher resolution. High altitude (~20 km) background aerosol layers would require more vertical averaging (500 m). Finer layers of dust, with higher backscattering than that of background aerosols, can be detected to longer ranges and/or with less signal averaging. Narrow-band Fabry-Perot etalon filters and active alignment between the laser and receiver as demonstrated on CALIPSO [5], with appropriate signal averaging, will allow measurements during full day background conditions. A multi-wavelength lidar with polarization detection capability will be capable of exceptional performance beyond what has been demonstrated in detecting and characterizing spatially narrow ice/dust layers and clouds.

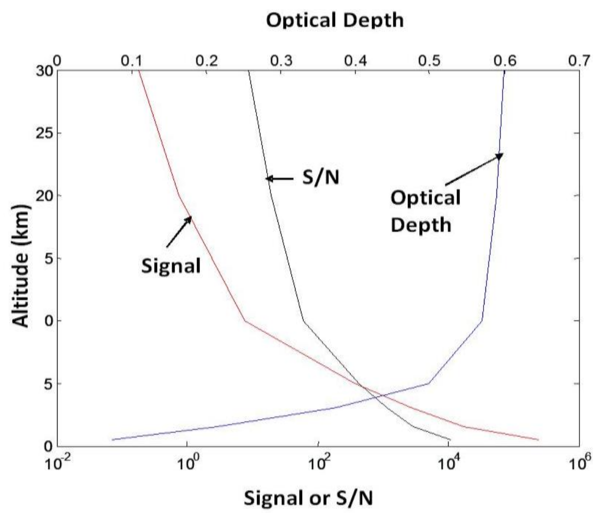

Fig. 2. Aerosol optical depth model, simulated signal at 532 nm (photons/micro sec) and S/N profiles obtained with 300 shot averaging.

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