MULTI-FUNCTIONAL LIDAR INSTRUMENT FOR GLOBAL MEASUREMENT OF MARS ATMOSPHERE. Farzin Amzajerdian[1], George E. Busch[2], William C. Edwards[1], Alicia Dwyer Cianciolo[1], and Michelle Munk[1], [1]NASA Langley Research Center (MS 468, Hampton, VA 23681, f.amzajerdian@nasa.gov), [2]Coherent Applications, Inc.

Introduction: NASA has identified Strategic Knowledge Gaps (SKG's) in measurements of Mars atmospheric parameters that can support aerobraking, aerocapture, precision landing, and launch from Mars surface for both robotic and human missions. This abstract describes a laser-based instrument that specifically responds to the Challenge Area 1.6 of the workshop announcement and addresses the Mars atmosphere SKGs. The proposed instrument can provide accurate measurements of winds, densities, temperature, and aerosols. Wind velocity uncertainty is the largest source of landing error as the wind drift can carry the vehicle several kilometers from the target during the parachute descent. Lack of accurate knowledge of density and temperature prevents optimum design of the thermal protection systems, and impacts aerocapture and entry technology selections. When flown on an orbiting asset with sufficient diurnal, seasonal, and latitudinal coverage, the lidar measured parameters will also advance scientific understanding of Mars climate and allow for the development of high-fidelity models that in turn will reduce the risk and cost of future missions to Mars.

Lidar (Light Detection and Ranging) technology can play a key role in addressing the Mars atmosphere knowledge gaps. Lidars using a near-infrared laser offer clear advantages over passive and active radio-wave measurements. These advantages include excellent spatial resolution, high accuracy, operation under any lighting condition, and the ability to aim and scan. This paper proposes a multi-functional lidar instrument that provides major atmospheric parameters while meeting the stringent mass and power constraints of a Mars mission. Taking advantage of relatively low atmospheric density, we have devised an instrument concept that combines the attributes of a "coherent Doppler lidar", a "Differential Absorption Lidar", and an "aerosol backscatter lidar" into a single instrument to provide global profiles of most important Mars atmospheric parameters. In principle, Doppler lidar measures the wind velocity by using the Doppler frequency shift of laser light scattered from suspended aerosols transported by the winds. Differential Absorption Lidar (DIAL) determines the atmospheric constituent concentration by measuring the ratio of transmitted intensities of two different wavelengths emitted by the lidar, corresponding to high and low molecular transmission. Aerosol lidar derives the aerosol concentration by simply measuring the returned signal intensity. Presently, individual lidar systems measuring Earth atmospheric winds and CO_2 exists in the form of ground and airborne-based instruments. Aerosol lidar is more mature as three instruments have been successfully deployed to Earth orbit since 1994.

The multifunctional lidar being proposed combines the functions of each of these individual sensor into a single device resulting in a more robust instrument with fewer components, and thus greater reliability, as well as reduced mass, volume, and power compared with multiple systems to handle each function. The combination of higher aerosol concentration and very low atmospheric absorption compared to the Earth allows the use of a much smaller laser and transmitter/receiver telescope aperture. A novel, highly-efficient, near-infrared laser, optimized for Mars lidar application, is currently under development at NASA LaRC. The efficiency and design of this laser simplifies the instrument's thermal management design and significantly reduces the overall payload mass and power consumption.

Technical Approach: Fig. 1 illustrates the principle of the proposed instrument. The unique feature of the proposed lidar is the precise sequential scan of the frequencies of a set of narrow-bandwidth transmitter pulses over an absorption line of the CO_2 molecule that comprises about 97% of Mars atmosphere. A small fraction of the laser pulse is scattered by the naturally occurring atmospheric aerosols. This back-scattered signal is collected and processed to extract several atmospheric parameters. Since the density of the Mars atmosphere is less than 8 milli-bars, the width of CO_2 molecular absorption is dominated by the Doppler broadening effect which is directly related to the ambient temperature. Therefore the width of the measured CO_2 absorption profile determines the atmospheric temperature, while its strength (area under the curve) is proportional to atmospheric density. The instrument can then determine the aerosol concentration from the returned signal strength at frequencies away from molecular absorption lines. Since optical heterodyne detection is employed, the wind velocity is directly obtained by measuring the Doppler shifts of the received signals. The 3 components of the wind velocity vector are obtained by pointing the laser beam to different directions relative to nadir.

This proposed lidar concept takes advantage of three unique features of the Mars atmosphere to offer a compact and lightweight instrument. These unique features are: 1) dominance of Mars atmosphere by CO_2 molecules that allows for measuring its absorption profile without concerns of contaminations by other molecules, 2) low atmospheric density that eliminates the molecular collision broadening of the CO_2 absorption profile leaving only the temperature dependent Doppler broadening, 3) high aerosol concentration and low laser beam attenuation, compared to the Earth atmosphere, that translates to a stronger lidar signal.

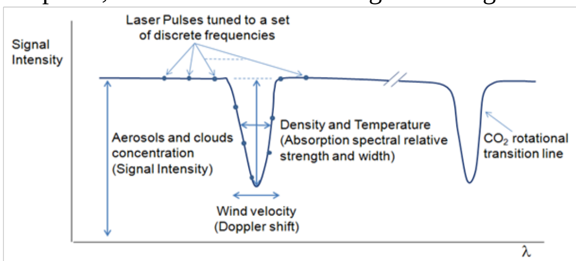

Figure 1. Principal of Mars Multi-functional Lidar.

The mass of this instrument, as described below, is estimated to be between 50 kg to 80kg and its power between 280 W to 330 W, depending on the science versus accommodation trades including measurement precision and orbit altitude.

Instrument Description: Fig. 2 provides a schematic diagram of the lidar instrument. The pulsed transmitter laser, operating in the 1.6-2.0 micron wavelength region, is injection-seeded by a low power, single frequency, continuous wave (CW) master oscillator (MO) laser. Part of the MO laser power output is offset in frequency, by a modulator, before being injected into the transmitter laser. The seeded transmitter laser then generates pulses at the same frequency as the injected laser beam. The modulator tunes the laser frequency such that each pulse is offset by a few MHz with respect to the previous pulse. As shown in Fig. 1, the transmitted pulses completely scan over one of the CO_2 absorption lines.

The resulting transmitter laser pulses are directed toward a beam-expanding telescope. In the design concept of Fig. 2, the telescope is rotated about its axis generating a conical scan pattern in the atmosphere. The telescope's off-axis design allows scanning the laser beam by approximately 30^{o} about the nadir direction. The conical scan allows for determining the wind velocity direction.

The back-scattered signal from the atmospheric aerosols is collected by the telescope and directed toward the detector. The return signal is mixed with a local oscillator (LO) laser beam at the detector generating an electrical signal at the difference frequency between the transmitted and return signal frequencies. The frequency modulator in the LO path varies the LO frequency according to the azimuth angle of the conical scan. This LO offset frequency compensates for the large Doppler shift due to the spacecraft motion, and minimizes the required bandwidth of the detector, the electronic receiver, and the data acquisition system. The onboard signal processer can then provide wind velocity vector and aerosol concentration profiles with a few hundreds of meters resolution from surface up to about 60 km altitude. The atmospheric density and temperature profiles can be provided from about 50 km to 100 km altitudes. Much of the component technologies of this instrument have already been developed by other programs to Technology Readiness Levels (TRL) from 5 to 8, except the pulsed transmitter laser that is at TRL 3 due its specific design for Mars application.

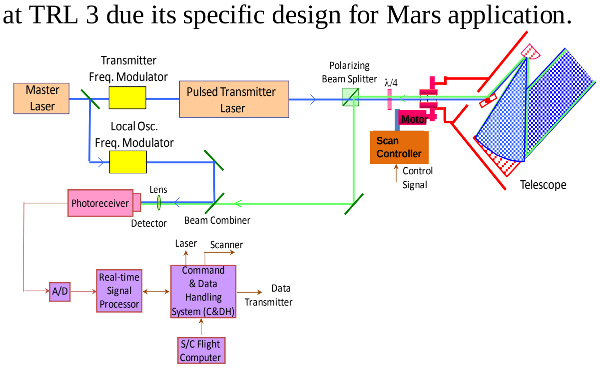

Figure 2. Schematic of Mars Multi-functional Lidar Instrument.

Summary: A multi-functional lidar instrument is proposed that will provide the major Mars atmospheric parameters needed for the development of accurate climate and weather models, and for the design of future missions requiring advanced aerocapture and precision landing. From an orbiting platform, the proposed lidar can profile the atmospheric winds, density, aerosol concentration, and temperature accurately and with high spatial resolution. During its operational lifetime, the instrument will provide a database of atmospheric measurements over diurnal and seasonal cycles on a global scale meeting the needs of both the scientific and entry, descent, and landing (EDL) communities. The proposed Lidar instrument design is based on a novel concept that takes advantage of the low molecular density and the dominance of CO_2 molecules of the Mars atmosphere, and utilizes optical heterodyne detection and a frequency-agile laser transmitter. The lidar concept capitalizes on several cutting-edge component technologies recently demonstrated at NASA LaRC in order to meet the stringent mass and power constraints of a Mars orbiting platform, with an extended lifetime of several years.