A LASER NEPHELOMETER FOR DETECTION OF IN-SITU PARTICLES IN PLANETARY ATMOSPHERE.

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Introduction: Proposed Venus and Saturn missions called out in the NASA Decadal Survey include atmospheric observations of clouds and aerosols. Remote sensing techniques to derive cloud properties, including density and particle size, are limited by the optical density of the respective atmospheres.

A nephelometer is an instrument that makes in-situ measurements of the cloud particles it encounters as it descends, using a two-color backscattering process. A new nephelometer (derived from the Galileo version [1]) has been prototyped; the design benefits from lower volume and increased power efficiencies of near infrared diode lasers. This nephelometer measures the laser light scattered off of atmospheric particles. The reflected signal depends on particle density, size, and shape. Using two wavelengths allows discrimination over a range of particle sizes. Typical cloud particle sizes in the upper troposphere of Saturn and below are >1.5 μm [2]. Number density estimates range from ~10^6/m^3 in tropospheric hazes to ~10^9/m^3 in a thick water condensation cloud.

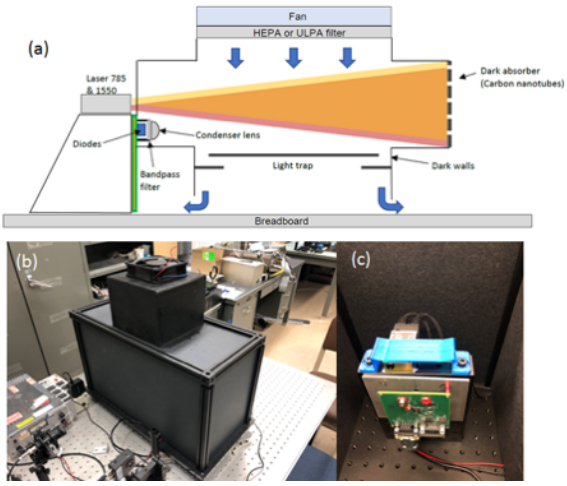


Figure 1a) Diagram of stand-off laser nephelometer instrument in test chamber (b) exterior of test chamber, and (c) laser nephelometer prtotype in test chamber.

The addition of short wavelength filters on the detectors provides a measure of cloud particle single-scattering albedo and Rayleigh scattering. The estimated mass and power for this nephelometer are 1.7 kg and 1.5W, respectively. The system is suitable for a range of in-situ atmospheric missions, including descent probes and landers (NB: Galileo Nephelometer was 4.7kg, and averaged 11W).

Laser and Diode Description: The prototype consists of two diode lasers (785 and 1550 nm), two diode sensors, and control/readout electronics. To test the unit and calibrate sensitivity calculations, a dark air-flow chamber was designed and built. Air is mixed with calibrated particles and flowed through the chamber in the optical path of the sensor, enabling measurements of the sensor response to backscatter from each laser and particle size.

Initial data tests the possibility of operating the lasers in a growing-period pulse mode, allowing for Dynamic Light Scattering approaches to determine the number of particles, and their size distribution.

Measurements: The active laser sensing works independent of lighting conditions at the probe descent location. Two pulsed diode lasers at 785 and 1550 nm, operating at frequencies up to 1.0 kHz, measure backscattered light to characterize cloud aerosol properties and number densities.

Pulsing the lasers minimizes the average power and, along with narrowband rejection filters over the laser detector, minimizes ambient background effects.

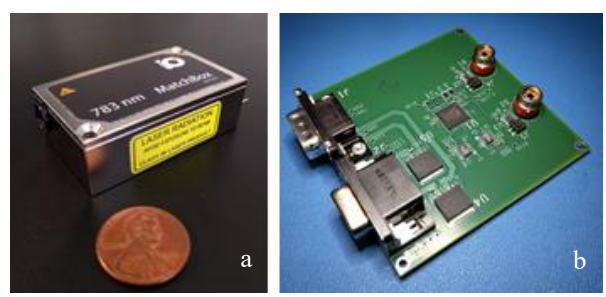


Figure 2a) Diode Laser Module (b) Sensor and laser control board

In-Situ and remote Measurements: We are evaluating a laser-cavity approach for single particle counting and providing scattering phase information. One laser module measures the particles that are outside of the descent probe boundary layer by locating two

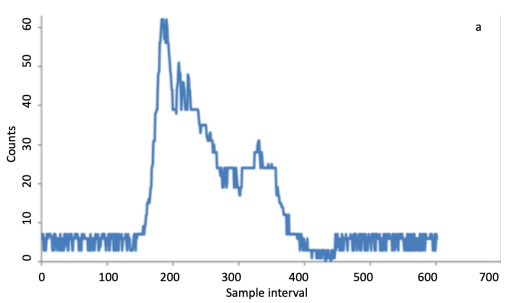
laser apertures at the end of a boom outside of the probe. The other module pulls particles into the probe for single-particle UV detection inside a small reflective cavity. Both techniques have pros and cons, and are complementary; combining the two would provide both ranged measurements and single-particle counting precision.

Results: A Particle Chamber (Figure 1b and c) was constructed and tested that verifies laser control and sensor design and to model sensitivity calculations to verify that the design meets the science requirements for various applications (e.g., Venus, Saturn, and Mars). The test data is used to determine the applicability of Dynamic Light Scattering approaches for determining the particle size distributions.

Dynamic Light Scattering is a technique that takes advantage of the random motion of particles in a medium. Light scattering off these particles is modulated by the random motions. The time-scale of this modulation is a function of the diffusion of the particles in the medium and the size of the particle.

This technique is often used to measure very small particles in fluid suspensions. This is the first known application to atmospheric "cloud" particles using laser scatter.

Figure 3a shows the preliminary results of the backscatter technique; the data was collected with the laser nephelometer prototype. The large peak shape is due to scattering signal from a small cloud of particles passing through the field of view, and then dissipating. The variance in this signal as a function of "lag" time is calculated from raw counts, (Figure 3b). The intensity correlation function for the period during the "cloud" detection (the slope relates to the diffusion of particles in the carrying medium, in this case, air) (Figure 3c) is 0.92, showing strong accuracy. Using this data, predicted particle sizes are on the order of 8 microns. The particles used in experiment were chalk dust which have typical sizes in the range of 5-10 microns, which is consistent with the test results.



Additional measurements are planned with calibration standard to verify sensitivity and SNR calculations.

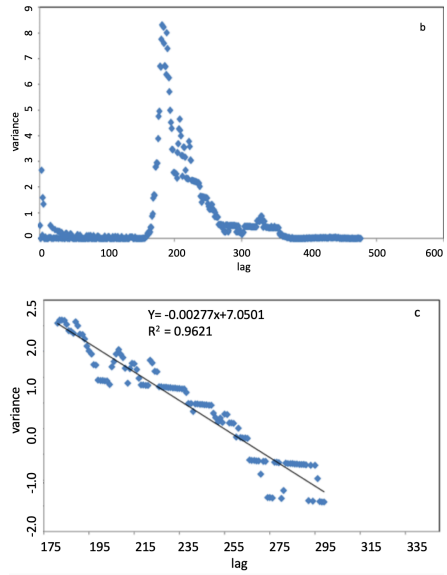


Figure 3a) Plot of particle count vs sample interval (b) Plot of variance vs the lag time and (c) A linear fit, providing an intensity correlation function. The slope of the line is a measure of the particle diffusion.

Future Plans: We have procured a cavity particle counter from Teilch Optical Instruments (TOI). This unit will be used to cross calibrate the laser nephelometer. An improved flow chamber for particle detection with a UV silica window for further precision is being designed. We are working with TOI to evaluate the inclusion of their UV-Cavity particle sensor into nephelometer design, to complement the stand-off approach. A balloon test flight with an integrated engineering unit is planned, bringing the instrument to TRL 5.

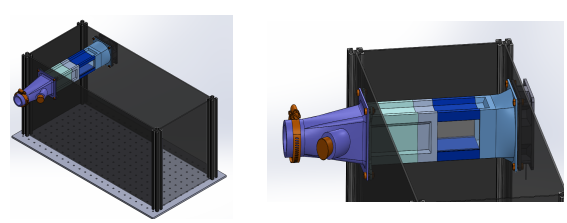


Figure 4a) New detector tube auto CAD drawing enclosed in test chamber (b) Close up drawing of the new detector tube part with inlet for spray can and UV silica window slot in gray and blue

References: [1] Ragent B. et al. (1998) *JGR planet, 103,* 22891–22809. [2] Roman M. T. et al. (2013) *Icarus, 225, 93-110.*