Planetary Polarization Nephelometer

D. Banfield (PI:Cornell)
Cornell Astronomy
Ithaca, NY 14853
USA, banfield@astro.cornell.edu

R. Dissly *(Ball Aerospace)*

What are our Scientific Goals?

Clouds & aerosols in planetary atmospheres are clues to the processes occurring there. Many aspects of them cannot be determined through remote sensing. Only an in situ sensor can adequately answer these questions.

Jupiter/Saturn/Uranus/Neptune:

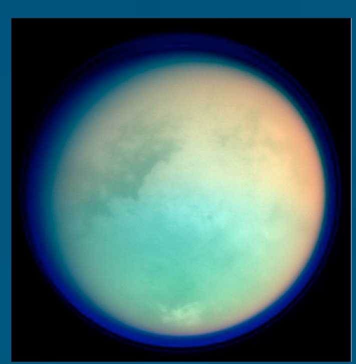
- What are the clouds made of?
- What pressures are they found at?
- What causes the coloration of the clouds?
- What do particle size/shape tell us about dynamics? Is it raining?
- What is the deep water abundance on Jupiter?

Venus:

- How thick are the clouds?
- How much surface Sulphur resides in the clouds?
- What causes the greenhouse regulating blue absorption in the clouds?
- Is there an aerosol/dynamics feedback?

Titan:

- What is the cloud density profile?
- How do cloud particle properties modulate the heat balance to the atmosphere?
- What are the differences between hemispheres?



Others:

- What is the size spectrum of Martian saltating grains/ aerosols?
- What size distribution of grains are lofted in Lunar surface operations?
- What are the properties of particulates in the Earth's Oceans? Europa's Oceans?

What is our Instrument?

•In situ (Descent probe, balloon, lander, aircraft, submarine)

•Active:

•Illuminate cloud with lasers

•Measure scattered light to infer cloud properties

•Measure Intensity phase function

• i.e., scattered light vs. scattering angle

•Information on number density & particle size/shape

•Measure Polarization Ratio phase function

•i.e., polarization ratio of scattered light vs. scattering angle

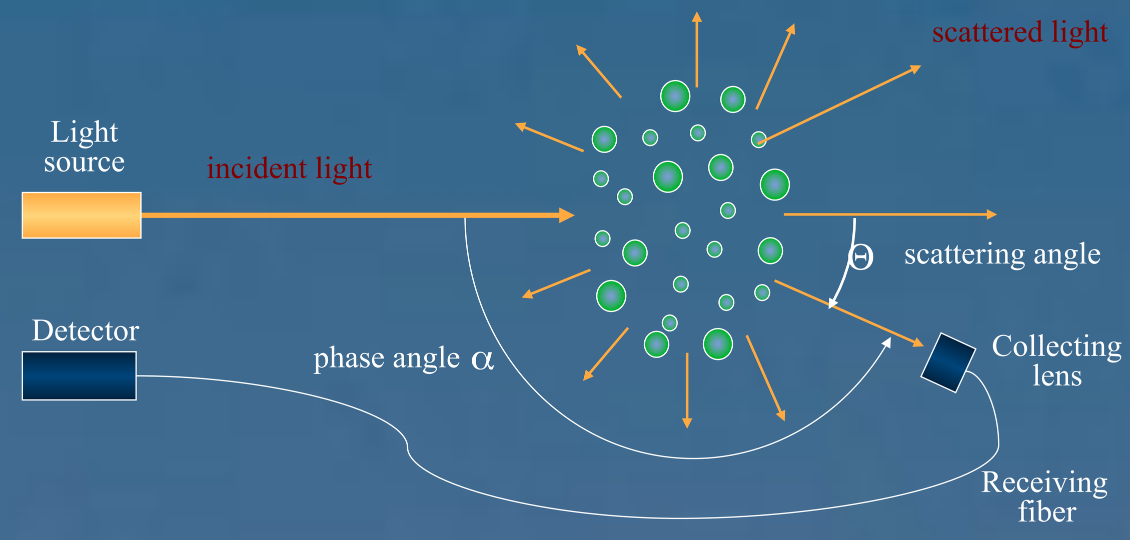
•Adds information on size/shape/index of refraction

•Use multiple wavelengths to study spectral properties

•Single set of optics can support many different wavelength lasers simultaneously

•Lasers separated by an octave give good leverage on particle properties (e.g., 1550nm & 880nm)

Nephelometer (noun): an instrument for measuring cloudiness.
Etymology: 19c: from Greek *nephele* = cloud



Light incident on a sample of randomly oriented particles is being scattered in all directions. That light is being collected and analyzed to infer the character of the aerosols.

How did we Implement our Instrument?

•Use solid state lasers (from Telecom Industry)

•Modulate polarization of illumination:

•Cycle power sinusoidally between 2 orthogonal lasers

•No moving parts!

•Measure intensity relative to modulation cycle

•DC component yields intensity

•AC component yields polarization ratio

•Chopping/blocking filters remove ambient illumination effects

•All sensitive components inside probe hull

•Fiber optics & lenses conduct light in & out.

•Intrinsically robust design for harsh environments!

•Deployed arm to position receiving lenses at many scattering angles

•Before deployment, instrument sees calibration target

How is this Better than its Predecessors?

•By measuring at many angles, we retrieve more than just cloud density as simple backscatter nepheometers are limited to. Backscatter alone is insufficient.

•By measuring polarization ratio in addition to intensity, many ambiguities concerning particle size, shape and index of refraction are removed from the problem. Intensity alone is insufficient.

•With no moving parts and using modern solid state lasers & detectors, instrument can be robust, compact and low power.

What were the Challenges?

•Polarization modulation is not new, but previous instruments used tempermental Pockel's cells which are unsuitable for a flight instrument. Our approach used power modulation of orthogonally polarized solid state lasers. Our main effort was to demonstrate that this would work in a bench-top setting.

•Principle demonstrated using ~5um fiber as a calibration target.

•Aerosols were also used but aerosol generation technology proved too awkward. New aerosol generation equipment recently became available for next steps in development.

•Secondary problems were revealed with fiber interconnects creating undesirable resonant cavities (Fabry-Perot Etalons). This was solved by minimizing unnecessary fiber interconnects, and using angled connections when necessary. Flight designs would use fiber bonding to avoid these interfaces altogether.

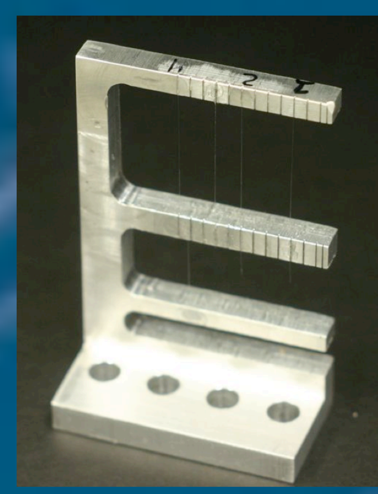
•Coordinated, sinusoidal modulation on all lasers is key, but they have nonlinearities and hysteresis due to thermal effects. We developed an off-line algorithm to identify the proper drive signal to achieve sinusoidal power output. A flight instrument would use an active feed-back loop to achieve this more precisely and robustly.

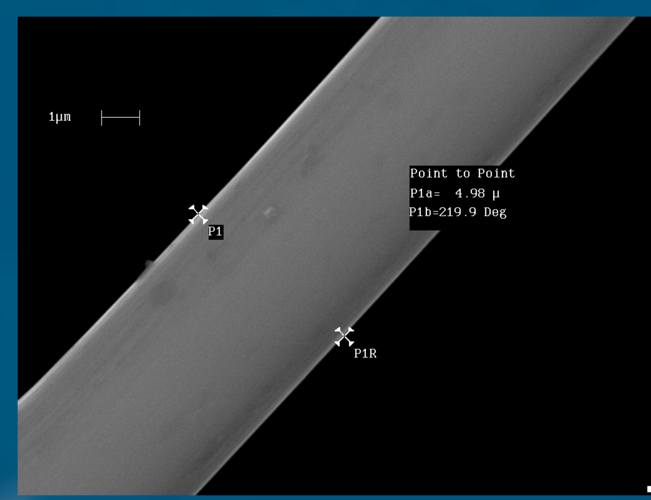
Laboratory Proof of Concept

•Demonstrate measurement of intensity & polarization ratio phase functions using power-modulated orthogonally polarized solid-state lasers.

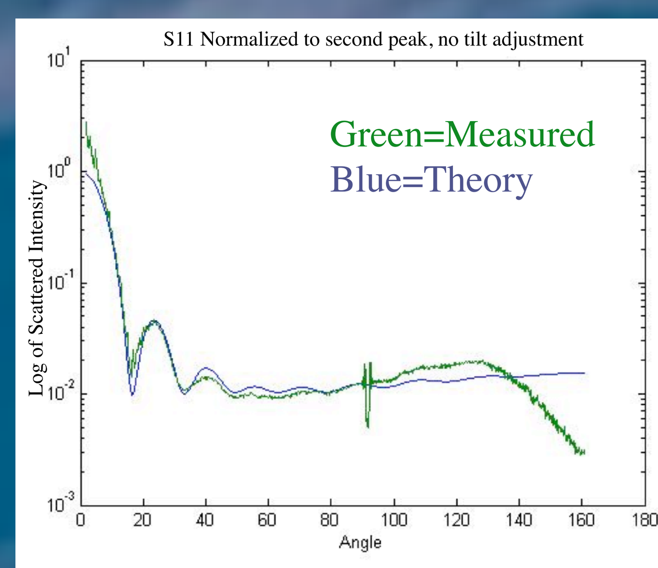
•Using bench-top equipment (not flight configuration)

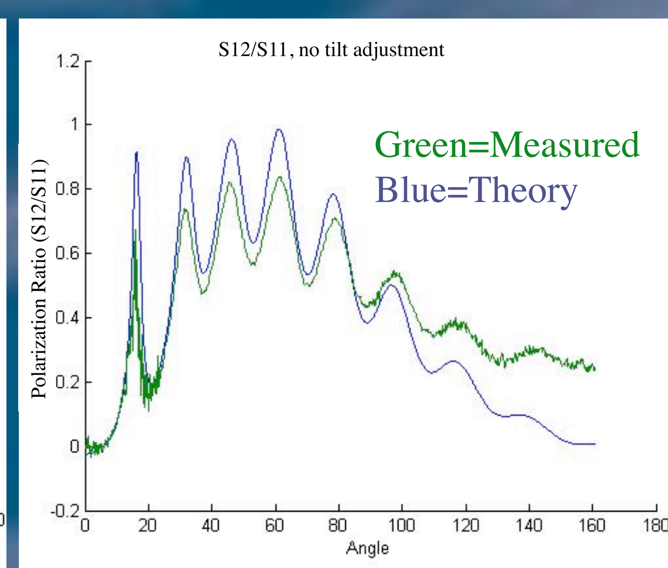
•Calibration target is a 5um Carbon Fiber:





•Measured phase functions match theory for 4.87um carbon fiber cylinder:





•Plots above show the measured (green) and theoretically predicted (blue) intensity (S11) and polarization ratio (S12/S11) phase functions from near forward scattering (~0 degrees) to near backscattering (~180 degrees). Theory is for a perfect cylinder 4.87um in diameter with index of refraction n=2.0+1.22i. This is in excellent agreement with the known properties of the carbon fiber calibration target. **SUCCESS!!!**

•Discrepancies are likely due to oblateness or tilt of fiber, and occulting of beam at 90 dgrees and near backscatter.

What is Next?

•MatISSE proposal to take this from TRL 4 to TRL 6

•Develop optimized lens system for light collection at different scattering angles

•Develop integrated electronics for multiple-angle/multiple wavelength linear array sensor, suitable for flight use

•Develop feedback system for power modulation of lasers suitable for flight use.

•Test system using realistic aerosols (drops, ice, dust)

•Demonstrate full system on stratospheric balloon testing

•Eager to discuss possibilities to include this on missions!

•Already included in EVE (Venus Balloon Mission)

•Eager to find alternative applications!

•Exotic terrestrial aerosol characterization?

•Underwater particle characterization