PLANETARY POLARIZATION NEPHELOMETER

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ABSTRACT

We have proposed to develop a polarization nephelometer for use on future planetary descent probes. It will measure both the scattered intensity and polarization phase functions of the aerosols it encounters descending through an atmosphere. These measurements will be taken at two wavelengths separated by about an octave, with one light source near 500nm and another near 1um. Adding polarization measurements to the intensity phase functions greatly increases our ability to constrain the size distribution, shape and chemical composition of the sampled particles. There remain important questions about these parameters of the aerosols on Venus, the giant planets and Titan that can only be addressed with a nephelometer like ours. The NRC Planetary Sciences Decadal Survey has identified probe missions to Venus and Jupiter as a priority. On both of these missions, our proposed instrument would be an excellent candidate for flight. We also expect that future probe missions to Saturn, Uranus, Neptune or Titan would employ our instrument. It could also find use in Earth in situ aerosol studies.

We will use a technique to simultaneously measure intensity and polarization phase functions that uses polarization modulation of a light source. This technique has been implemented in laboratory settings, but not with considerations to the environment on a planetary descent probe. We have proposed to design and build a flexible breadboard nephelometer to test the components and concepts of our approach. We would then test the device against well defined aerosols, ensuring that it accurately measures their expected intensity and polarization phase functions. With the knowledge gained in this flexible design, we would then design and build a breadboard polarization nephelometer more suited to integration on a planetary descent probe. To include traceability in the technical requirements of our device, we would also conduct an Observing System Simulation Experiment. In this study, we would determine what the performance trade-offs are for de-scoping each capability of our instrument. Additionally, it would aid us in optimizing the nominal design parameters to yield the most unambiguous aerosol microphysical information. All of these investigations will be carried out to enhance the likelihood of success and useful data return of our proposed instrument in its descent through a planetary atmosphere. Considerations will also be given to mass, volume, power and cost.

Key words: Aerosols, Instruments, Scattering, Polarization.

1. INTRODUCTION

1.1. Aerosols: Key Observations

The aerosols that reside in the atmospheres of Venus, the giant planets and Titan are the visible faces of these planets, and yet we have quite limited knowledge of them. The impact of this lack of knowledge is significant on our understanding of the composition, structure and dynamics of these planetary atmospheres. We directly address this with our proposed polarizing nephelometer. Our discussion of the scientific relevance of a nephelometer is divided into Venus and Jupiter reasons. However, most of the Jupiter arguments raised apply equally well to the other giant planets and Titan.

1.1.1. Venus

For Venus, we have some detailed knowledge of the cloud layers from remote sensing and also from earlier nephelometers placed in Venus' atmosphere on Russian and American probes. These studies, crudely summarized, have told us that the Venus atmosphere has 3 main cloud decks, extending from about 45km to 70km, with hazes both above, below and between these layers (e.g.,Marov *et al.*, 1980, Ragent and Blamont, 1979 and Gnedykh *et al.*, 1987). The optical thickness of the top-most cloud is dominated by 1 μm spherical aerosols of concentrated sulfuric acid (Hansen and Hovenier, 1974). There are large opacity variations in the middle and lower cloud decks (e.g., Crisp *et al.*, 1991). But in spite of this detailed knowledge of the clouds on Venus, there are still significant questions that can be answered with a nephelometer at Venus.

As a basis for this discussion, we take the goals outlined in the NRC Solar System Exploration Decadal Survey's chapter, "The Case for Venus Exploration." The first topic identified there for which a nephelometer is crucial is the trace gases in Venus' atmosphere. These include sulfur, which plays a key role both in the clouds (via H_2SO_4), and the surface-atmosphere interactions (via volcanic injection and/or surface chemical weathering). If a probe only measured the gas phase abundances of sulfur bearing molecules it would exclude a significant reservoir, namely the aerosols. In the clouds, roughly 1/3 of the sulfur may be in aerosols. Our proposed nephelometer could yield these abundances, completing the trace gas inventories produced by a Venus probe. Furthermore, the debate still continues whether a crystalline "mode 3" family of particles exists in the middle and lower clouds. If these are a distinct material from H_2SO_4, then they represent a significant reservoir of unknown material, and must be accounted for in chemical/aerosol models of the atmosphere. Our proposed instrument could do a good job of determining the size, shape and index of refraction of the aerosols in Venus' atmosphere with little ambiguity, clarifying these outstanding questions.

The second topic concerns the greenhouse effect on Venus. Current greenhouse models still leave open debates about the relative importance of various contributors to the observed temperature on Venus. The clouds represent a substantial absorber of solar and thermal energy on Venus, and defining their microphysical properties and vertical structure is critical in fully understanding the mechanisms that control the greenhouse. A prime example is that the upper cloud has a still unknown blue absorber which is responsible for about 1/4 of all solar energy absorbed by Venus. Identifying this absorber is a task that our proposed polarizing nephelometer would be ideally suited to. Specifying the upper cloud particles' shapes and indices of refraction (for the different modes) may unlock the puzzle of this climatically important blue absorber. Tying back into the previous topic, once this blue absorber is identified, understanding its chemical origin from the trace gases, and the connection with surface processes will be very interesting. Toon *et al.* (1982) have suggested that the blue absorber may be sulfur allotropes, identifiable by their influence on the index of refraction of the aerosols. In this way, Venus may be a proxy for the early Earth. Recent work suggests Earth's early oxygen abundances were so low as to favor SO_2 photolysis proceeding to sulfur allotropes. Producing better constraints on the blue absorber, and possible sulfur allotropes on Venus will add to our understanding of both Venus and early Earth.

The third topic addressed in the decadal survey is the middle atmosphere composition. Chemical cycles between CO_2, CO, O, O_2 are believed to be catalyzed towards CO_2 by heterogeneous chemistry involving sulfur or chlorine molecules. Without this heterogeneous chemistry cycle, the bulk constituent of Venus' atmosphere, CO_2, would rather be in the form of CO and O_2. Once again, understanding the aerosol profiles, and their coupling with the trace gases is key to fully understanding this important atmospheric chemistry cycle. Correlating the (gas phase) trace gas profiles with the aerosol profiles is critical to *fully* understanding the chemistry. Remote sensing observations from orbit will not allow detailed enough specification of the variable aerosol environment to fully understand the observations. The UV contrast on Venus is likely tied to processes where local flows alter both the trace gas abundances and the aerosols. In that sense, this question boils down to one as fundamental as understanding the visible appearance of Venus, in addition to the core questions about the stability of the atmospheric composition.

Other factors to consider that are not specifically called out in the decadal survey include aerosol-dynamic feedbacks and their influence on local trace gas abundances. Nightside near-IR contrast variations suggest that small scale convection patterns occur in the lower cloud while the middle cloud has a global scale (m=1) pattern of cloud opacity variation. The heating caused by these opacity variations is enough to locally influence the buoyancy and circulation, perhaps suggesting a feedback between flow and aerosol opacity. The possibility exists that such feedbacks may be important in controlling the local profiles of trace gases, especially those that have significant vertical variations in the vicinity of the clouds. Obtaining gas phase abundance measurements without placing them in the context of the local heating environment (and thus the local vertical flow) could lead to inaccurate assessments of atmospheric chemical cycles. Thermal structure and accelerometer measurements alone will not reveal the vertical winds that the probe moves through. Measuring the aerosol density is one approach to infer these effects on the rest of the descent probe's observations. Another practical matter involves identifying precisely when an observation from (e.g.) a mass spectrometer may have ingested an aerosol drop, skewing its results. Without a direct measure of the aerosol density, this will leave an ambiguity in the interpretation of gas phase measurements.

1.1.2. Jupiter

For Jupiter, we know even less about the clouds than for Venus. The one descent probe that entered Jupiter's atmosphere, Galileo's probe, entered into an anomalous hotspot location (e.g., Young, 1998). It is generally not believed that the Galileo probe's findings are representative of the cloud structure of a generic region on Jupiter. Remote sensing has revealed significant facts about Jupiter's clouds, but important ambiguities still remain (e.g., West *et al.*, 1986). An example of this is that we do not know the vertical structure of the clouds on Jupiter. For instance, the contrast-bearing cloud deck may be composed of either ammonia or ammonium hydrosulfide aerosols. Remote sensing studies have been unable to agree on this point, with visible wavelengths tending to support ammonia clouds bearing the contrast (e.g., Banfield *et al.*, 1998), and near-infrared wavelengths indicating ammonium hydrosulfide (e.g., Irwin *et al.*, 2001). A side effect of this remote sensing ambiguity is that when we measure cloud-tracked winds on Jupiter, we do not know what level (or levels) they represent. This significant hole in our understanding has propagating effects into dynamical models, limiting their ability to fully understand the driving circulations of Jupiter. A nephelometer on a Jupiter descent probe, entering a representative region of the planet would easily clarify the vertical structure of Jupiter's clouds.

It may turn out that Jupiter's clouds are a more complex mixture of aerosols of water, ammonia and ammonium hydrosulfide than our simple models have suggested. There are several indicators that water vapor is advected up above the top cloud deck (Banfield *et al.*, 1998, Simon-Miller *et al.*, 2000). This certainly raises the issue of how mixed the cloud species are on Jupiter. *In situ* measurement of the optical properties of the aerosols with our proposed nephelometer can yield not only the vertical structure and thicknesses of the clouds, but also some leverage into identifying their chemical abundances.

The deep water abundance of Jupiter, a key quantity in helping to understand the formational scenarios of the giant planets, can also be estimated from the pressure of the water cloud base. While mass spectrometers are an ideal way to estimate this quantity, corroborating evidence from the condensational behavior of water, documented by our proposed nephelometer can help alleviate ambiguities that might arise from contaminated intakes on the relatively complicated mass spectrometers.

If we have the luxury of deploying several entry probes into an atmosphere, spatial perturbations in the cloud structure are indicative of the atmospheric motions. An extreme example of this was the Galileo probe's nearly completely clear atmosphere, which indicated a strong downdraft in the vicinity of the hotspot that it entered. A more representative location may still have some modest vertical winds, which can be inferred by comparing with neighboring probe results. This type of study can greatly add to our full understanding of the dynamics of the giant planet atmospheres.

Another example where nephelometers have significant value addresses the fact that we don't understand what provides the colors of Jupiter. Studies suggest it is blue absorbers located in the upper troposphere (West *et al.*, 1986, Simon-Miller *et al.*, 2001a), and that there are probably at least 2 different coloring agents (Simon-Miller *et al.*, 2001b). Beyond this, little is known about these absorbers. Our proposed instrument should be able to identify the real and imaginary parts of the index of refraction of the aerosols at two different wavelengths. This should give significant leverage in identifying these chromophores. Presumably identifying the chromophores will also have impacts on the photochemical/aerosol models of Jupiter's stratosphere and upper troposphere.

Finally, documenting the aerosol size distributions more carefully, as we could do with our proposed nephelometer, would allow a more accurate assessment of the thermal and radiative balance at varying levels in the giant planet atmospheres to be determined. The thermal infrared flux that is capable of escaping the atmosphere from the layers below the visible cloud deck is poorly constrained, and important for understanding the dynamics in the layers just below the visible cloud deck. There are hints from the water vapor cumulus towers that the dynamics in this region (1-6 bars) might be pivotal in controlling the "weather" on Jupiter. For us to fully understand the role that radiation and convection play in transporting heat through this region, the aerosols need to be well quantified, not only in number density versus pressure level, but also size distribution, shape and albedo. Our proposed nephelometer is the ideal instrument to characterize the aerosols in all these dimensions.

The majority of these areas in which a nephelometer could expand our understanding of Jupiter's atmosphere were specifically called out in the "Decadal Survey." Specifically, the survey's Planetary Atmospheres chapter identifies the measurement of horizontal and vertical variability of aerosols, and scattering properties of the condensed particulates. It also lists needs more indirectly addressed by nephelometer observations including the role of the latent heat of water in Jovian dynamics, deep H abundance, and horizontal winds over several scale heights.

It should be noted that many of the arguments listed above for a nephelometer at Jupiter apply equally well to the other giant planets and some also apply to Titan. In fact, the "Decadal Survey" calls out the need for a multiple probes to Neptune, equipped with a nephelometer.

1.2. Need For Updated Approach

1.2.1. Modernization

The most recently built nephelometer was that for the Galileo Probe. The design of this device dates back to the late 1970's. Modern opto-electronics have advanced considerably since then, with better detectors, solid-state lasers, and high temperature fiber optics as well as all the advances in electronics miniaturization. The net result is that the most recently designed nephelometer is archaic by today's standards. It weighed 4.4kg and used 11W. It's electronics alone measured 19cm in diameter by 16cm tall, while the sensor assembly was over 50cm long (Ragent *et al.*, 1992). Clearly, there would be little to gain by returning to the old design. Mass, volume and power are all precious commodities on an entry probe, and these can certainly be trimmed using modern electro-optic approaches to a nephelometer.

1.2.2. Augmented Capabilities

In addition to obvious gains by updating the technology used in a planetary entry probe nephelometer, there are also compelling arguments to develop a nephelometer with enhanced capabilities. Our proposed nephelometer will measure both the scattered intensity and polarization ratio at several angles from near backscatter to near forward scatter from aerosols it encounters on descending through a planetary atmosphere. It will perform these measurements at two wavelengths separated by about an octave, with one laser near 500nm and another near 1 μm.

Traditionally, a simple nephelometer measures at least the backscatter intensity as an indicator of the backscatter coefficient (roughly speaking, the cloud density) of the aerosols in its vicinity. Some nephelometers (e.g., the Galileo Probe nephelometer) also measure the intensity of the scattered radiation with varying scattering angle. Adding this intensity phase function information gives some information on the particle size, shape and indices of refraction. However, typically these parameters can not uniquely be extracted from the intensity phase function alone, and results are quite model dependent. By also measuring the polarization phase function, we can have a drastically improved metric with which to infer the particle microphysical properties. We can retrieve much more tightly constrained particle size and refractive indices fitting this expanded data set (e.g., Mishchenko and Travis, 1997) (see also Fig. 1). The particular phase angles (defined as 180° minus the scattering angle) at which we intend to measure intensity and polarization phase functions number only about 6. This is the minimum number with which good information on particle size, shape, number density and indices of refraction can be retrieved. The particular angles will include one near direct backscatter (e.g., $\sim 5°$), two near side scattering (e.g., $\sim 60°$, $\sim 135°$, which are most effective for inferring particle shape and refractive index), two near forward scattering (e.g., $\sim 170°$ and $\sim 175°$ which are most effective for inferring particle size) and one scattering angle at which the phase function is most insensitive to particle size, shape and refractive index (e.g., $\sim 15°$ or $\sim 80°$) and which, therefore, can be used to infer the particle number density. The details of these choices will be explored in the Observing System Simulation Experiment described below.

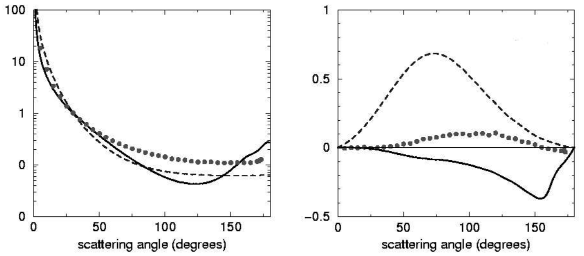

Figure 1. Intensity (left) and polarization (right) phase functions for irregularly shaped volcanic ash from El Chichon (dots), Mie calculations for realistic index of refraction spheres (solid line), and Mie calculations for spheres that best fit only the intensity phase function (dashed line). Note that all three curves are similar in the intensity phase function, but differ markedly in the polarization phase function. This demonstrates the power of the polarization phase function, and its sensitivity to the particle microphysical properties. (from Muñoz et al., 2002)

To further augment the information content returned by our instrument, we intend to measure the intensity and polarization phase functions at two wavelengths separated by about an octave. These functions at only one wavelength allow a good inference of the particle properties under assumptions about the simplicity of their size distribution. Adding information at a second wavelength, which samples the aerosols with a size parameter different by about a factor of two, introduces more robustness into the retrievals in the presence of broader aerosol size distributions. For example, the diffraction feature probed by the two forward-scattering angles can be expected to change quite significantly with a factor-of-two change in the particle size parameter, which provides an additional constraint on the cloud-particle size distribution. Also, the effect of particle shape is expected to change with particle size relative to the wavelength, thereby the measurements are indicative of the presence of nonspherical aerosols. Furthermore, differences in the indices of refraction for the aerosols at the two wavelengths examined can be a strong discriminator for the composition of the aerosols, as was demonstrated by Hansen and Hovenier (1974). We have chosen roughly 0.5μm and 1μm mainly for the range in particle size parameter this achieves and also for the availability of reliable laser sources and receiving optics at these wavelengths. Additionally, it is well known that measurements of light scattering are most sensitive to particle microphysics when the wavelength is comparable to the size (e.g., Mishchenko *et al.*, 2002), so the expected aerosol sizes in planetary atmospheres (0.1μm to 10μm) will be well resolved with laser light at these wavelengths.

1.3. Principles of Polarization Modulation

Our current concept for the design of the nephelometer is based on the technique described in Bohren and Huffman (1983, see sect. 13.7). It has already been successfully applied (by some of our team) in an experimental set–up for measuring intensity and polarization phase functions, located at the AMOLF-laboratory in Amsterdam (www.amolf.nl) e.g., Hovenier, 2000 and Hovenier *et al.*, 2003). A similar device has been developed by workers at Berkeley to characterize diesel exhaust aerosols (Hunt *et al.*, 1998).

Optimally, to extract the most information possible from light scattered from an aerosol, one should measure all elements of the scattering matrix as a function of scattering angle. The scattering matrix (a 4x4 matrix translating the incoming beam's 4-element Stokes vector into an outgoing Stokes vector) has only 6 unique elements for randomly oriented particles with a plane of symmetry. Of those 6 elements, the most important information is contained in the F_{11} function, essentially the intensity phase function, and the F_{12}/F_{11} function, essentially the polarization phase function (e.g., Volten *et al.*, 2001, Mishchenko *et al.*, 2002). Hunt and Huffman (1973) first demonstrated a technique by which these elements of the scattering matrix could be obtained simultaneously from time resolved measurements of the scattered light illuminated by a polarization modulated source. With the correct sequence of static polarizers, quarter wave plates and polarization modulators, any of the scattering matrix elements can be extracted from the time resolved scattered signal. The intensity and polarization ratio are particularly simple to observe, needing no other optical elements than the polarization modulated source. In this case, the intensity phase function will be the DC component of the scattered signal, while the polarization ratio is the amplitude of the signal at the modulation frequency. This is precisely the approach that we plan to take.

1.4. Technical Plan

The design, fabrication, and testing of a hardware prototype nephelometer is proposed to be done by Ball Aerospace & Technologies Corp. in Boulder, Colorado. This device will have the capability for measuring both the intensity and polarization phase functions at multiple wavelengths, using the techniques discussed above. This design effort will occur in two phases: Phase 1 will test multiple design trades (listed below) using a flexible optical breadboard setup. Our evaluation of results from Phase 1 will lead to a more optimal design that will be realized in Phase 2. The end result of Phase 2 will be an optimized breadboard design that has been tested using a variety of aerosol types to demonstrate functionality. The intent is to produce an instrument design that is mature enough to be proposed for a future flight program.

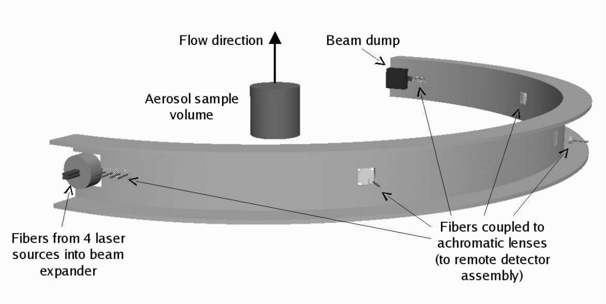

Figure 2. Schematic of nephelometer appendage. This arc extends from the probe body, into the flow. Aerosols passing near the center of the arc are illuminated by the lasers in the base on the left, and the scattered light is sampled by lenses/fibers arranged around the arc.

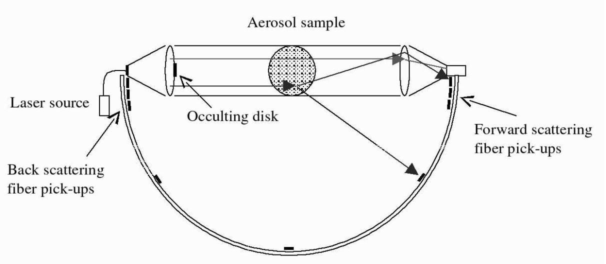

Figure 3. Schematic of baseline optical design. Only light that has been scattered is detected.

A diagram showing our intended baseline approach is shown in Fig. 2. In this design, a set of source lasers and detector elements are arranged around the circumference of a semi-circle, roughly 20cm in diameter, each directed toward the center of the circle. The flow of the aerosol stream is intended to pass through, and perpendicular to, the circle center. Four source lasers, covering two wavelengths and two orthogonal polarizations at each wavelength, will be sequentially strobed into the central aerosol target volume via a fiber optic pigtail. The laser light beam will be expanded to cover a cross section 2-3cm in diameter.

The instrument will detect the scattered light intensity and polarization in three principal angular regions: forward scattering, back scattering, and side scattering. A schematic of this concept is shown in Fig. 3. This schematic serves as a reasonable design point to start from; however, we intend, as part of the effort, to investigate a number of alternative configurations to help optimize the performance against the complexity and resource requirements such as mass, power, and volume. Listed below are several of the design trades that we intend to test:

- Testing a range of different laser sources, from 400nm to 1.55μm, on particle sizes ranging from 0.2 to 5 microns. Laser source intensities and silicon photodiode sensitivities both drop significantly shortward of 500nm, and detector costs can vary significantly over this range; we will try to find a pair of frequencies for the final design that optimize performance against cost.
- CW or pulsed mode for lasers CW, simultaneous use of the laser sources allows us to make concurrent measurements over dual frequencies and polarizations in the same atmospheric sample, and it may have an inherently higher SNR, but the optical design is more complex, requiring polarizing and dichroic beamsplitters and correspondingly more detectors. Pulsed mode (MUX'ed among all 4 modes) might be simplest approach no beamsplitters and a single detector per phase angle is possible. We will test both approaches, and intermediate approaches (e.g., simultaneous wavelengths, but modulating the polarization by strobing pairs of lasers) as part of this effort.
- It is difficult to measure the scattered intensity in the forward (and back) directions without some contribution directly from the source or source reflections from optical surfaces. We plan to include an occulting disk to minimize this component, but a bias subtraction of the intensity with no scatterers present will likely be required. Our intent is to optimize the design to minimize this background bias.

1.4.1. Test Plan

The accuracy of the nephelometer will be tested by performing experiments with spherical particles of known composition and size. The index of refraction will be determined by the measured intensity and polarization phase functions for this aerosol sample using multiple wavelengths. The experimentally determined index of refraction will then be compared to refractive indices found in the scientific literature. Theoretical studies also proposed in this work (see below) will assist in narrowing the breadth of test cases used, and will provide the retrieval algorithms for aerosol microphysical properties.

Testing Apparatus

Testing the accuracy of this nephelometer by comparing experimentally derived intensity and polarization phase function information to theory requires an aerosol sample of known, uniform size and composition. Even the use of commercially available polystyrene latex (PSL) spheres requires the separation of smaller particles produced by the residual surfactants in the solution from the spheres of interest. The proposed testing apparatus, which consists of commercially available components, is shown in Figure 4. The testing apparatus consists of a nebulizer-type aerosol generation system, coupled to an aerosol classification system. The generation system consists of a high-pressure jet of air, which impacts a flow of liquid containing the desired liquid aerosol solution. The resulting aerosol sample is dried and neutralized of any residual charge and drawn into the aerosol classification system. The classifier outputs a monodisperse aerosol sample, while rejecting the rest of the generated size distribution. The monodisperse aerosol sample is directed to the nephelometer test chamber, where the intensity and polarization phase functions are measured by the nephelometer and the aerosol number is measured by a condensation particle counter (CPC).

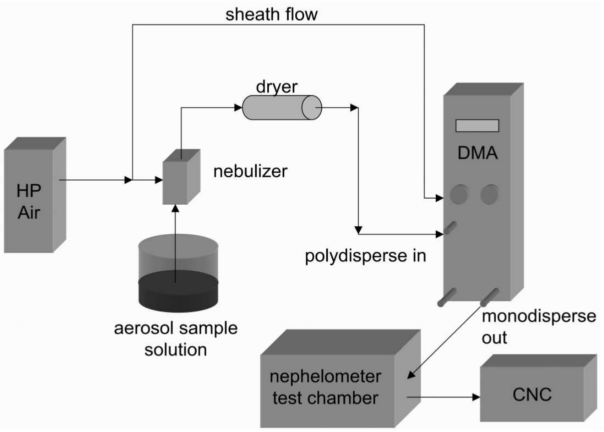

Figure 4. Schematic of aerosol generation system for testing.

This testing apparatus is capable of delivering size-segregated aerosols ranging in diameter from 0.02 to 1.2 μm (larger diameters will be tested using PSL spheres). The range of aerosol composition is practically unlimited as the nebulizer system is capable of delivering liquid spheres as well as solid components that crystallize upon the evaporation of the solvent in the diffusion drier. Having this versatility is advantageous and could be used for future studies of samples more representative of the target planetary atmospheres.

1.5. Observing System Simulation Experiment

This proposed instrument is designed with possible uses at many different planets. Because of this, there are certainly going to be pressures on the design of the instrument to fit into varying requirements for mass, budget or power. Because of the reality of these pressures, we believe it is critical to address system integration and de-scoping issues from the initial phases of the project. To that end, we have identified a study associated with this project. Studies like this are often called "Requirements Flowdown" in the engineering jargon, and essentially will comprise the scientific justification and traceability of requirements for the future flight hardware nephelometer.

1.5.1. Nephelometer Capability Trade-offs

Team members Mishchenko and Liu will perform a study of the trade-offs involved in de-scoping our proposed instrument. There are several approaches that one could take to simplify the proposed instrument, and with the stringent constraints on programs and spacecraft, it would be irresponsible not to systematically address these options. For example, we could choose to fall back to 1 wavelength, or fewer phase angles, or eliminate the polarization information at some scattering angles. The varying results of these instrument performance changes should be identified in detail before firm decisions are made in terms of de-scoping this proposed instrument for a flight project. There are two aspects to the study, first to produce simulated observations, and second to retrieve the aerosol properties that produced the simulated observations.

To produce the simulated observations, we have two options. The first is to compute the scattered radiation for hypothetical aerosols. For this well understood problem, we can use Mie calculations for homogeneous or layered spheres, the T-matrix approach for spheroids or cylinders, and the discrete dipole approximations for arbitrarily shaped particles (e.g., Mishchenko *et al.*, 2000). The second option is to produce real observations comparable to those the final nephelometer would produce using known aerosols in collaborator Volten's laboratory experiment in Holland (e.g., Muñoz *et al.* 2000, Volten *et al.*, 2001, Muñoz *et al.*, 2001).

To retrieve the aerosol parameters, we can use a method akin to that used in Mishchenko and Travis (1997). In that work, they explored the relative merits of using satellite measured intensity phase functions, polarization phase functions and both together to retrieve aerosol microphysical parameters. They effectively used a lookup table method, where they precomputed many models of scattered radiation with varying aerosol parameters and then compared the forward models with the (simulated) observations. Forward models that matched the observations within the error bars then defined the sensitivity of the retrieval in each parameter. Interestingly, they concluded that for satellite observations, polarization phase function has much more leverage on the aerosol's microphysical properties than the intensity phase function. The differences between satellite observations and a descent probe nephelometer warrant performing this type of study again in the current context, but the leverage of polarization ratio is consistent with the claimed strengths of our instrument concept.

2. CONCLUSION

We have proposed to develop a polarization nephelometer for use on planetary atmospheric descent probes. By adding polarization to the capabilities of a nephelometer, we can greatly reduce the ambiguity in aerosol parameters retrieved from the instrument's data. There remain many important scientific questions that are uniquely addressed by such a capable nephelometer descending through a planetary atmosphere. These include the trace gas abundance of Venus ($\sim 1/3$ of which is in aerosols), the source of much of Venus' greenhouse absorption, the identity of the visible clouds on Jupiter, and their coloring agent(s). Opportunities to deploy probes in various planetary atmospheres are likely to emerge in the near future. Technology has advanced to the point that previous designs are severely outdated. Our development program will yield a more capable, significantly smaller, less massive and less power demanding nephelometer than has been flown ever before. We believe that it will be a crucial instrument to include on all future descent probes.

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