Cloud Measurement Solutions

Deducing the Composition of Venus Cloud Particles with the Autofluorescing Nephelometer (AFN)

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The Science Driving the Technology

Single particle measurements were made in Venus clouds during the Pioneer mission with an optical spectrometer that was designed and developed by Robert Knollenberg.

The measurements from the AFN will build upon, complement and fill some gaps in those results.

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The Clouds of Venus: A Synthesis Report

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The Microphysics of the Clouds of Venus: Results of the Pioneer Venus Particle Size Spectrometer Experiment

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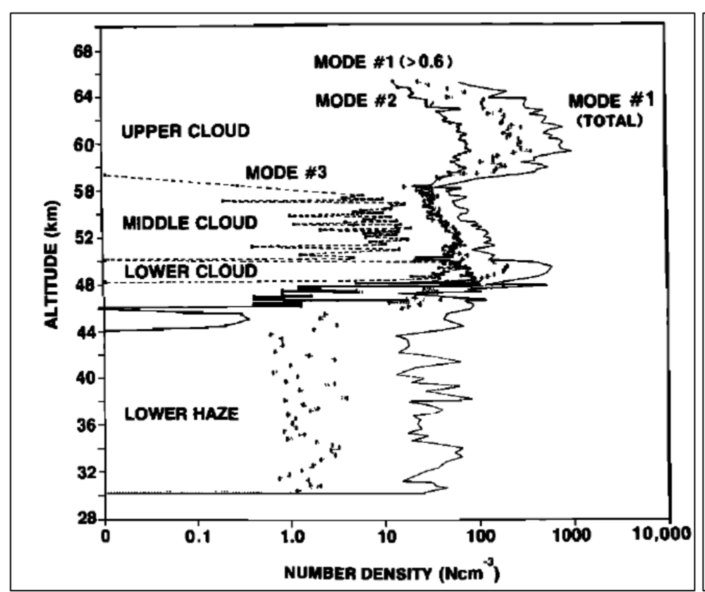
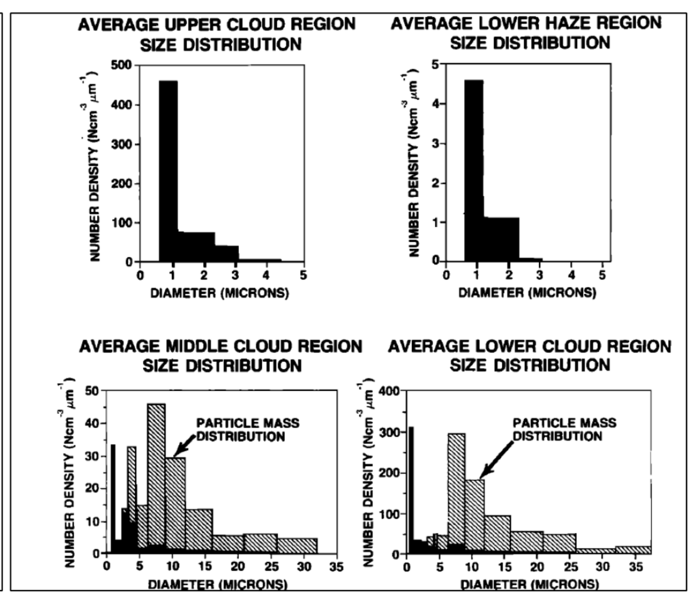
Modes Identified in the Size Distributions
Upper Cloud Layer (2); Middle Cloud Layer (3); Lower Cloud Layer (3); Lower Haze Layer (2)





Knollenberg Et Al. Proposed the Possible Composition and Phase Of Venus Cloud Particles

TABLE 1. Summary of Venus Cloud Properties

Region	Altitude, km	Temperature, °K	Optical Depth τ	Average Number Density N, cm^{-3}*	Mean Diameter, µm	Composition†
Upper haze‡	70–90	225°–190°	0.2–1.0	500	0.4	H_2SO_4 + contaminants
Upper cloud	56.5–70	286°–225°	6.0–8.0	(1) 1500 (2) 50	Bimodal 0.4 and 2.0	H_2SO_4 + contaminants
Middle cloud	50.5–56.5	345°–286°	8–10	(1) 300 (2) 50 (3) 10	Trimodal 0.3, 2.5, 7.0	H_2SO_4 + crystals
Lower cloud	47.5–50.5	367°–345°	6–12	(1) 1200 (2) 50 (3) 50	Trimodal 0.4, 2.0, 8.0	H_2SO_4 + crystals
Lower haze¶	31–47.5	482°–367°	0.1–0.2	(2) 20	0.2	H_2SO_4 + contaminants
Precloud layers¶	46 and 47.5	378° and 367°	0.05 and 0.1	50 and 150	Bimodal 0.3 and 2.0	H_2SO_4 + contaminants

TABLE 4. Summary of Real Refractive Indices Assuming all Particles are Spherical Refractive Indices

Region	Pioneer Venus	Venera 9
Upper haze	1.45 ± 0.04	
Upper cloud region	1.44 ± 0.01	1.46 ± 0.02, 0.01
Middle cloud region		
55 km	1.42 ± 0.02	1.42 ± 0.015
51–54 km	1.38 ± 0.02	
Lower cloud region		
49 km	1.32 ± 0.03	1.33 ± 1.38
48 km	1.44 ± 0.02	1.42 ± 0.02
Upper precloud	1.46 ± 0.01	
Lower precloud	1.50 ± 0.01	
Lower haze		

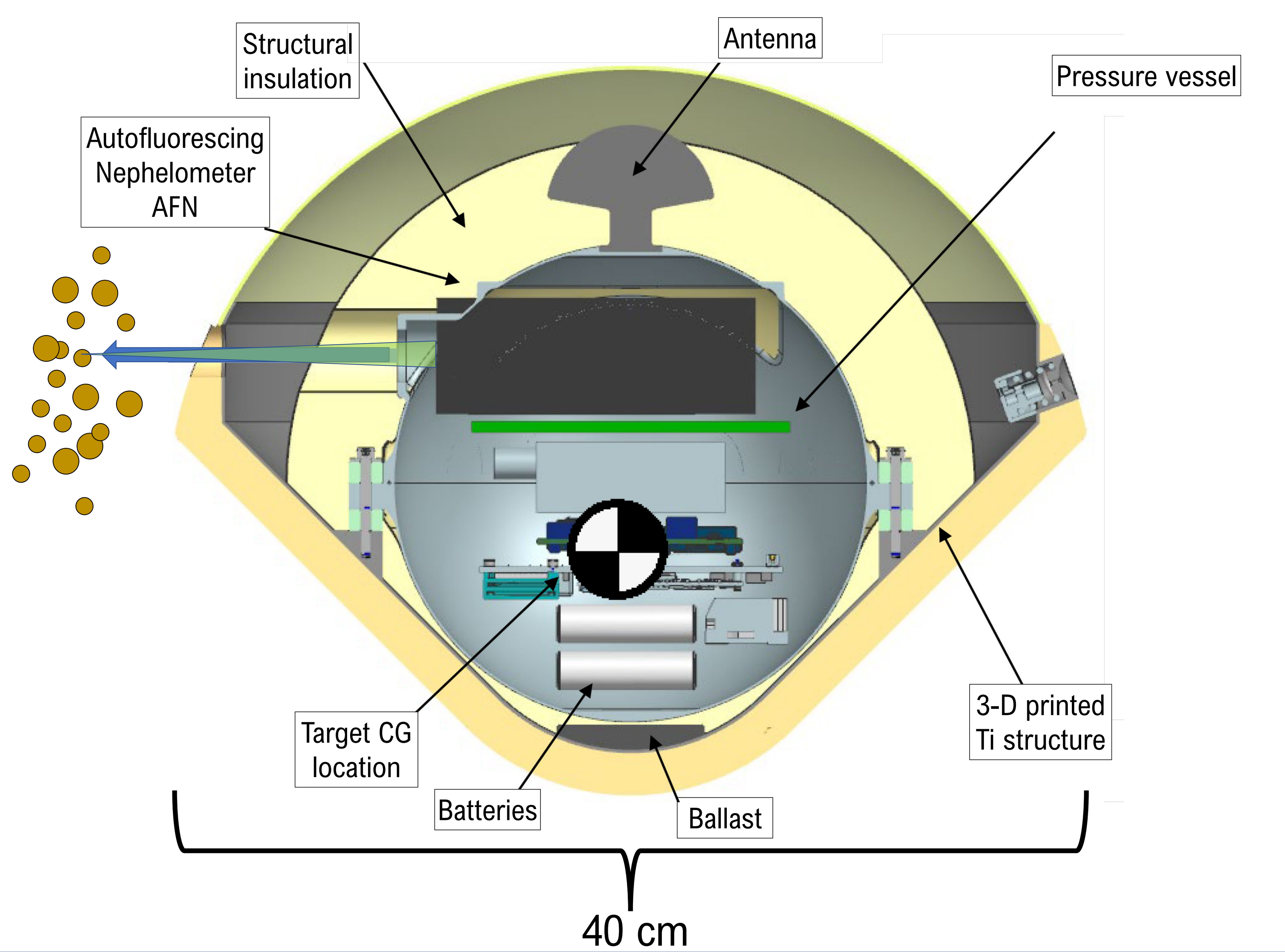
Knollenberg Et Al. Also Proposed that Venus particles had compositions with a range of Refractive Indices

The AFN Design Criteria is Based on the Results of the Pioneer Mission And the Aims to Address Questions that Were Raised by Them

- Detection and derivation of the equivalent optical diameter (EOD) of individual particles from 1 – 10 µm with an accuracy of ±20% (limited by uncertainties in refractive index).
- Derivation of particle number concentration < 5000 cm^{-3} over the specified size range with an accuracy of ±30% (limited by uncertainties in particle velocity) .
- Derivation of particle asphericity with an accuracy of ±30% (limited by uncertainties in orientation and shape of non-spherical particles).
- Direct measurement of fluorescence at the wavelength band between 470-520 nm with an accuracy of ±10% (limited by background light, mass of organic material and fluorescence efficiency at the excitation wavelength of 440 nm).

Venus Probe with AFN - **Actual Size**

Launch date – May 2023



Laboratory Studies

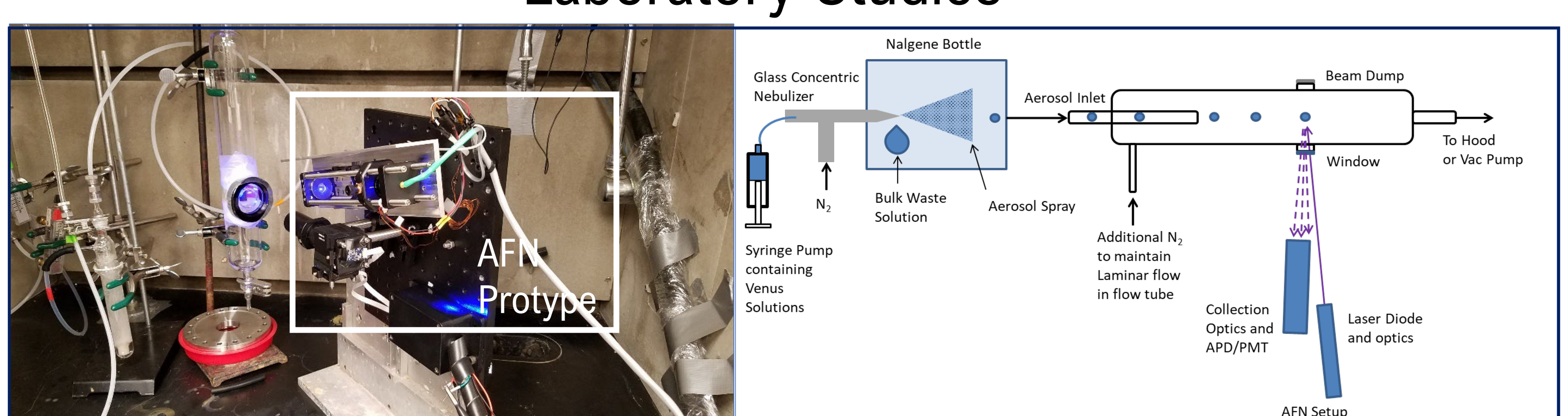


Figure 5. A breadboard prototype of the AFN was evaluated in the laboratory using six weight percent concentrations of H_2SO_4: 70%, 75%, 80%, 85%, 90% and 95% mixed with 0.0, 0.1 and 1.0 mg/ml of formaldehyde nebulized to create a polydisperse mist.

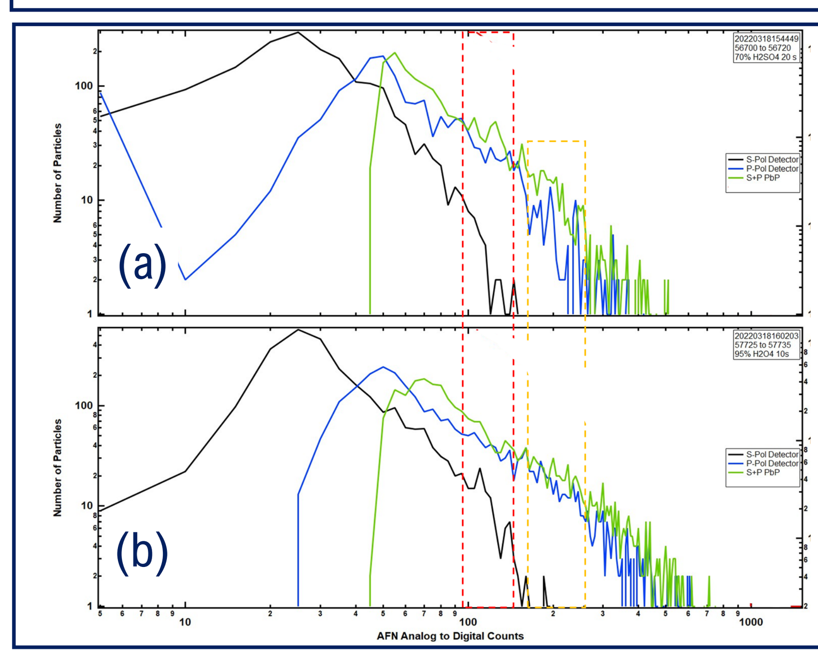


Figure 5. The number of detected particles, detected by the AFN, drawn as a function of the polarized light scattering intensity, is shown here to illustrate how the Mie oscillations can be observed in these frequency distributions.

The AFN detects scattered light, polarized in the same plane as the illuminating light (P-polarization, blue curve), and scattered light in the plane perpendicular to the incident light (S-polarization, green curve).

The vertical dashed lines highlight several of the regions of the distributions where the droplets with an acid concentration of 70% (Fig. 5a) have peaks and valleys at scattering intensities different than those droplets with 95% acid concentration.

The refractive indices are extracted by analyzing these features and relating them to theoretical and laboratory distributions.

The Theory and Technology

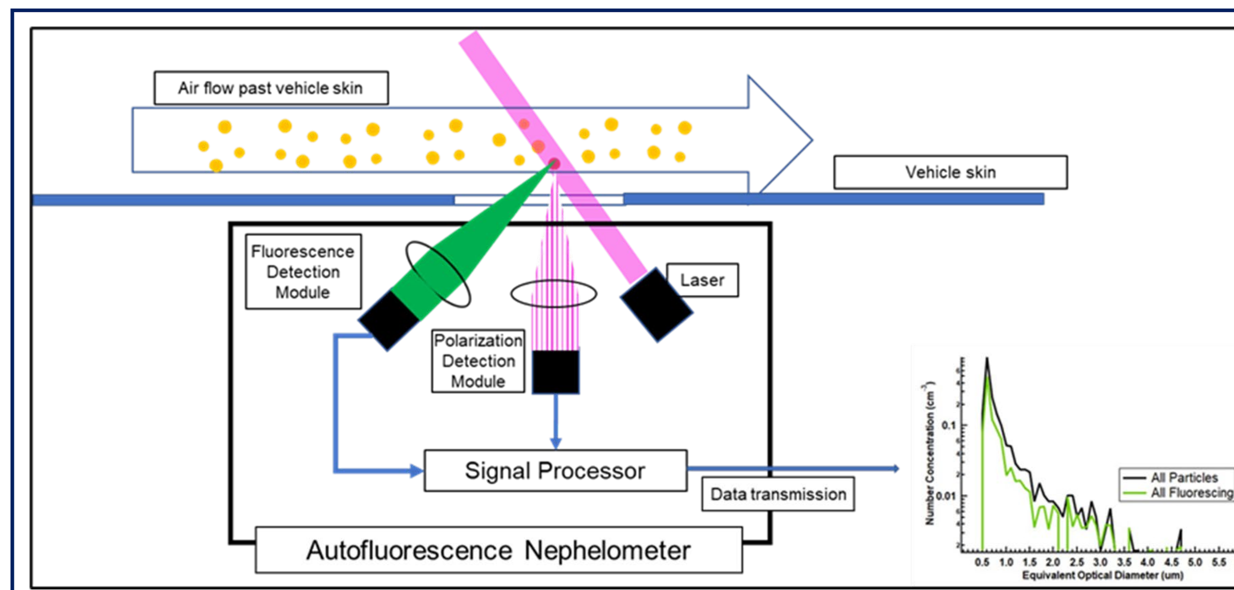


Figure 1. A 440 nm diode laser projects a focused beam out a window into the air-stream where it is intercepted by individual cloud droplets. Droplets that have no organic carbon (OC) in them will only scatter light, which is collected by the AFN optics. Emitted light from fluorescing droplets, that contain even small amounts of OC, will also be measured by the AFN, along with their scattered light.

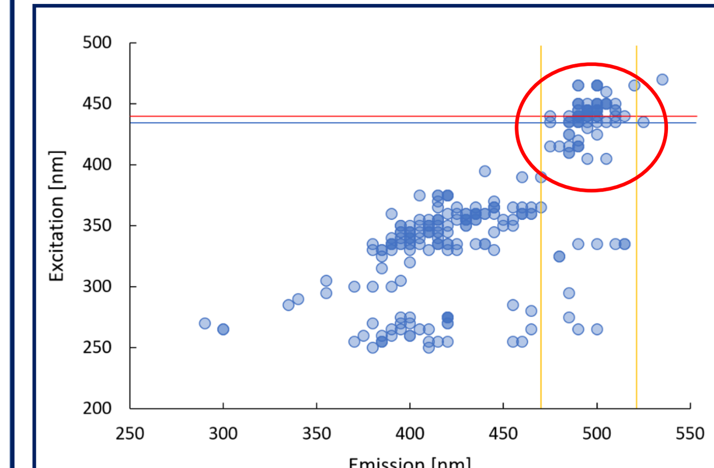


Figure 2. The excitation and emission wavelengths chosen for the AFN were motivated by laboratory work performed by Firebird Biomolecular Sciences who demonstrated that a wide variety of OC, reacted with sulfuric acid, will fluoresce when excited over a large range of UV excitations.

The availability of small, high-powered UV diode lasers led us to choose 440 nm.

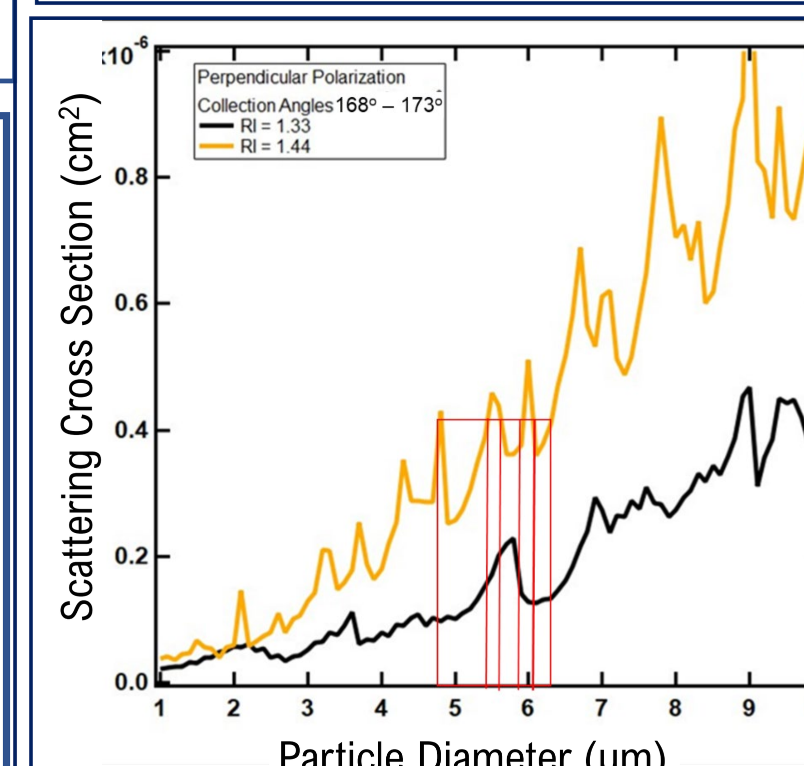


Figure 3. The relationship between the light scattered by an illuminated single particle, as a function of size, is non-monotonic and highly sensitive to the refractive index of the particles, as highlighted by the vertical red lines.

The refractive index of the Venus droplets will be extracted by exploiting these oscillating features.

The extraction algorithm uses machine learning trained by theoretical calculations and laboratory evaluations.

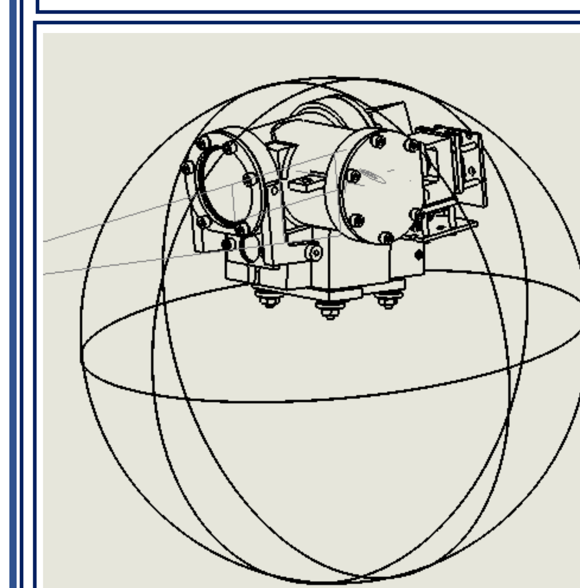


Figure 4. Solidworks® model of the mission-ready AFN in pressure vessel

Current Status of the AFN

- Laboratory studies of a prototype AFN have been completed that demonstrate that polarized, scattered light and fluorescence emissions from single particles > 1 µm can be detected at a distance of 20 cm from the sensors.
- The mission-ready AFN's opto-mechanical and signal processing design is completed (Fig. 4), and all parts will be in-house ready for assembly by early June 2022.
- The mission-ready AFN will be delivered to Rocket Lab for integration by June 30, 2022.

Acknowledgements

The authors would like to express their appreciation to Rocket Lab for providing the vehicle that will carry the AFN to Venus and deploy the AFN's capsule in the planet's atmosphere. We especially thank Christophe Mandy for the drawing of the capsule shown in this poster.

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