Status of the Multi-Angle Stratospheric Aerosol Radiometer (MASTAR)

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Introduction

- Stratospheric aerosols (15-30 km) include a naturally occurring background component (magnitude varies with latitude and time), as well as transport of anthropogenic sources from the troposphere and impulsive injections from volcanic eruptions.
- Cooling caused by stratospheric aerosols (reflection of incident solar radiation) can offset some of the warming caused by increasing greenhouse gases.
- Monitoring stratospheric aerosols requires satellite measurements with good temporal sampling, spatial sampling, vertical resolution.
- **Limb scattering observations** (looking horizontally at the Earth's atmosphere, measuring scattered sunlight) can satisfy these requirements.

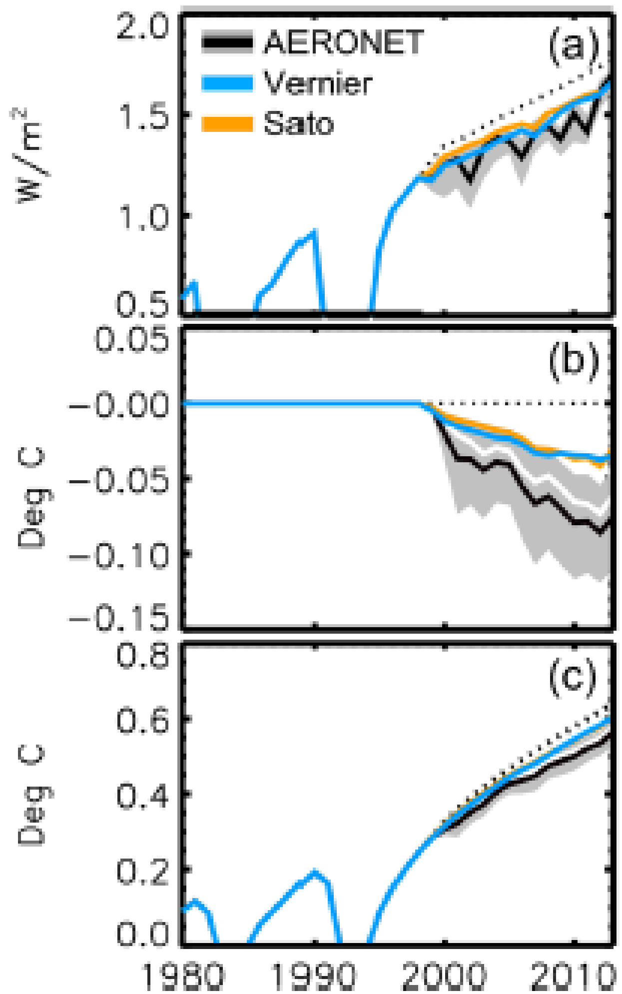
Uncertainty in Radiative Forcing

- Previous scenarios (*e.g. SPARC* [2006]) assumed no change in stratospheric aerosol after 2000 (dotted line in figures).
- Stratospheric aerosol optical depth (SAOD) data sets from AERONET, SAGE+GOMOS [*Vernier et al*], OSIRIS [*Sato et al*] all show increases in SAOD since 2000.
- Climate model calculations show resulting impact on radiative forcing and temperature.
- Uncertainty in radiative forcing term is still significant [*e.g.* -0.19(±0.09) W/m^2 using AERONET data]

Global mean radiative forcing

Temperature anomaly

Global temperature change



Ridley et al. [2014]

Volcanic Plumes and Air Traffic

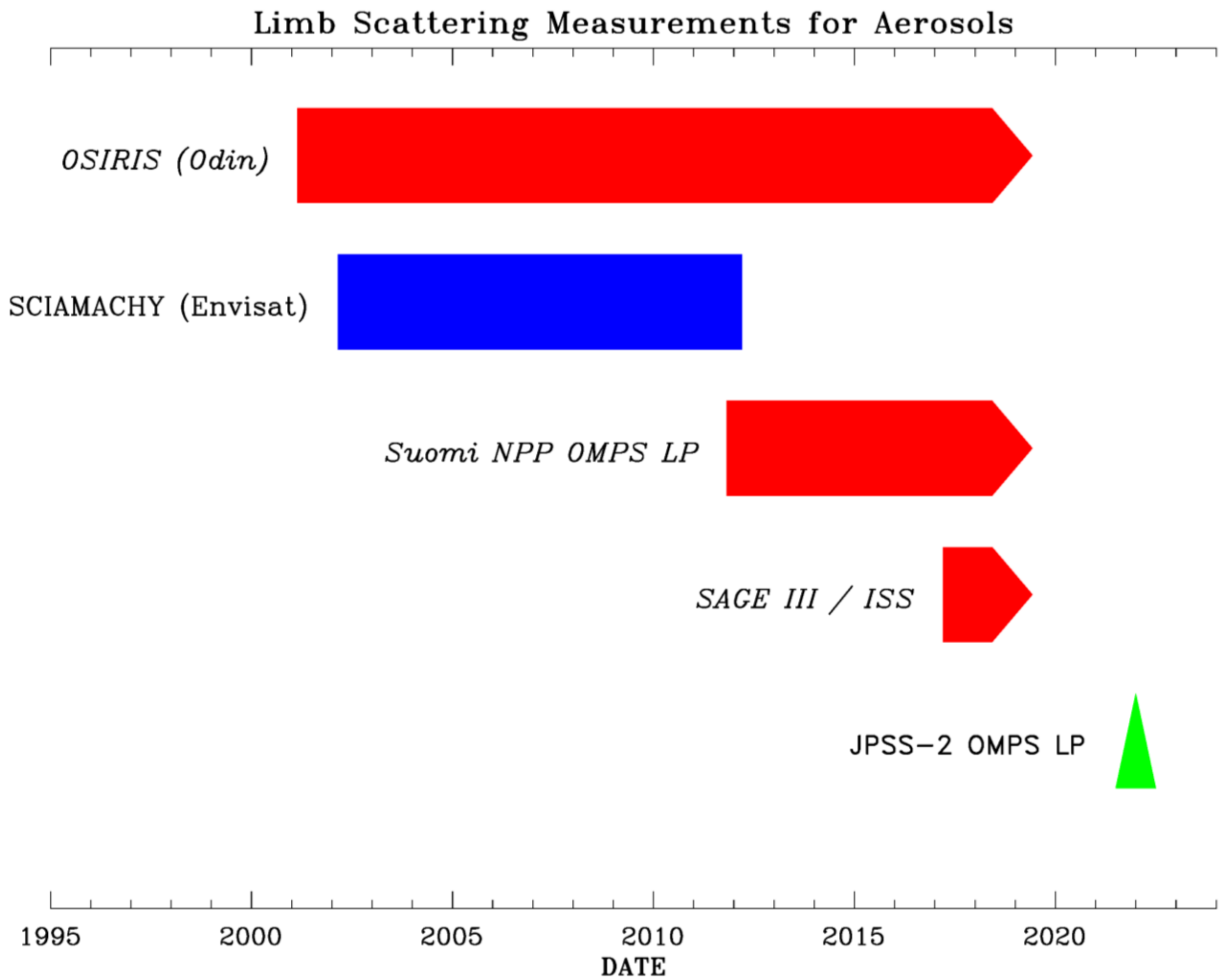
- Many commercial jets cruise at 10-12 km altitude → accessible to eruption plumes.
- Volcanic ash increases wear on engine compressor blades, reducing efficiency.
- Ash particles can melt and re-solidify inside engine, causing a loss of power during flight.
- Estimated cost of cancelled or rerouted flights during Eyjafjallajökull eruption was $2.6 billion.
- Near-real time knowledge of plume location and altitude would improve predictions of future behavior.

Pavlof eruption plume/CBS News

Eyjafjallajökull eruption plume/Getty Images

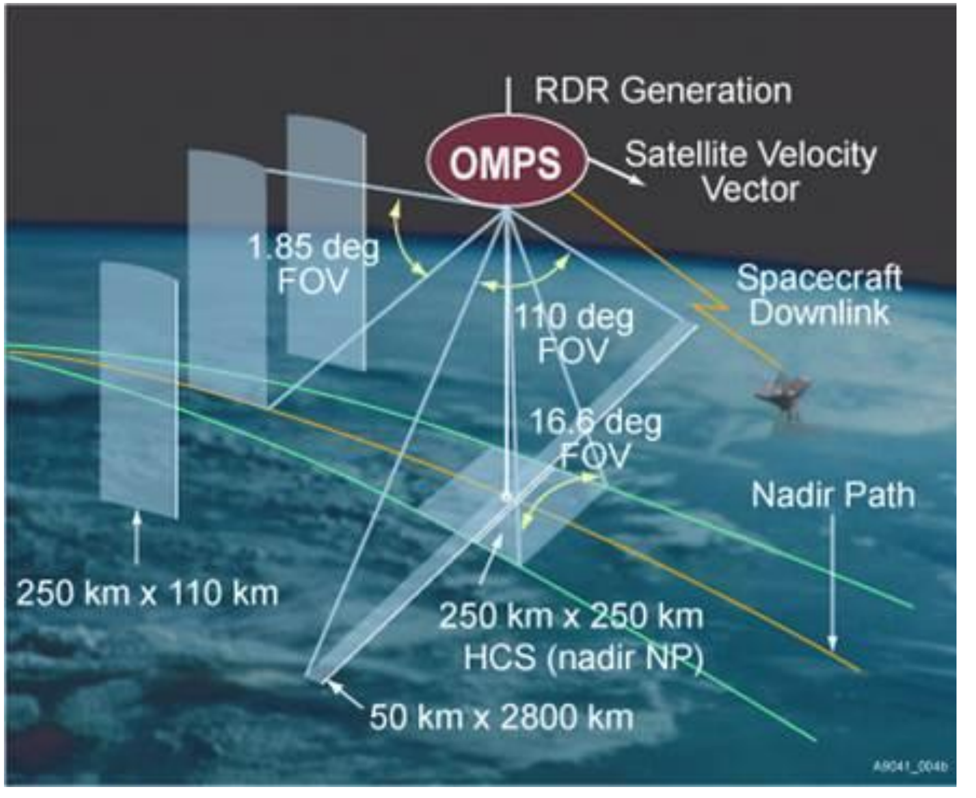
Recent Limb Scattering Measurements

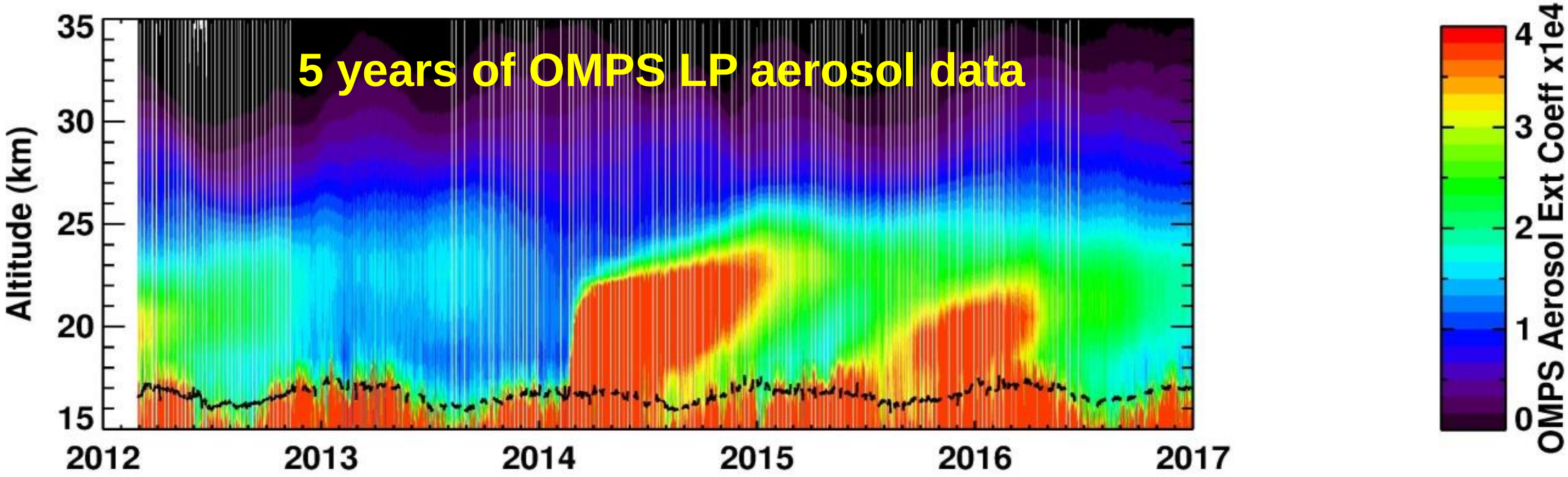
- SCIAMACHY data end in March 2012 (Envisat failure).
- OSIRIS is operating, but has orbit drift and power issues.
- SAGE III is now operating on ISS. Collects both limb scatter and occultation data, but spatial coverage limited by ISS orbit.
- OMPS LP operating regularly on Suomi NPP since April 2012.
- Next LP instrument will not be launched before 2022.



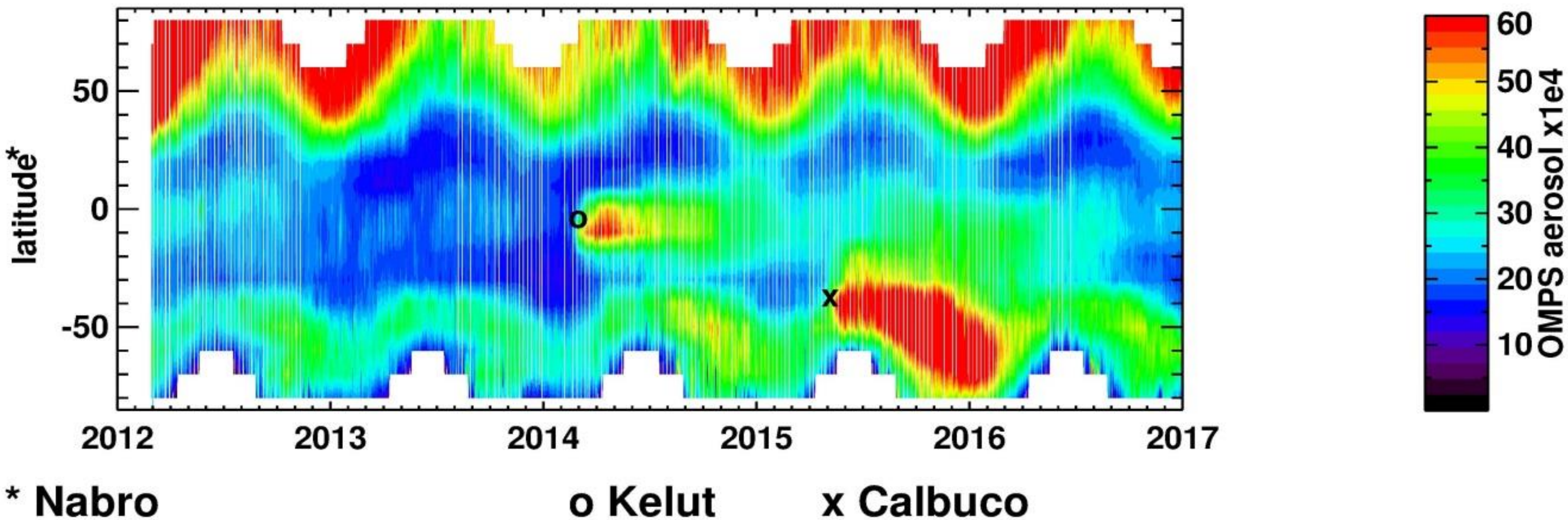
OMPS Limb Profiler (LP)

- Ozone Mapping and Profiling Suite (OMPS) Limb Profiler (LP) launched on Suomi NPP satellite on 28 October 2011.
- Limb scatter measurements look backward along the orbit track with three slits (center, ±4.25° to each side = 250 km horizontal separation at tangent point).
- Hyperspectral CCD collects simultaneous data over 0-80 km altitude (1 km sampling) and 290-1000 nm (spectral resolution = 1-35 nm).
- Retrieval products include ozone profile, aerosol extinction coefficient profile, cloud top altitude.





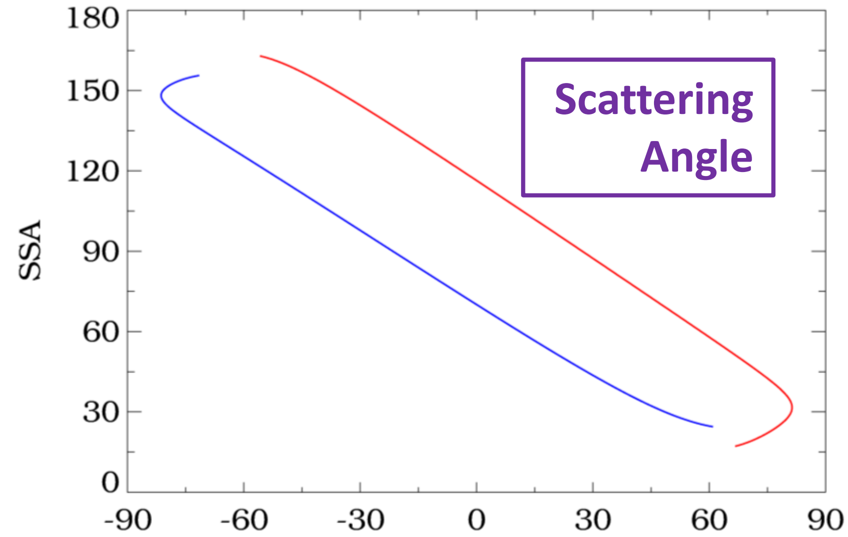
Suomi NPP LP AER675 extinction coefficient time series. The figure shows daily zonal mean profiles averaged over 0°-10°S latitude. The dashed line shows tropopause altitude.

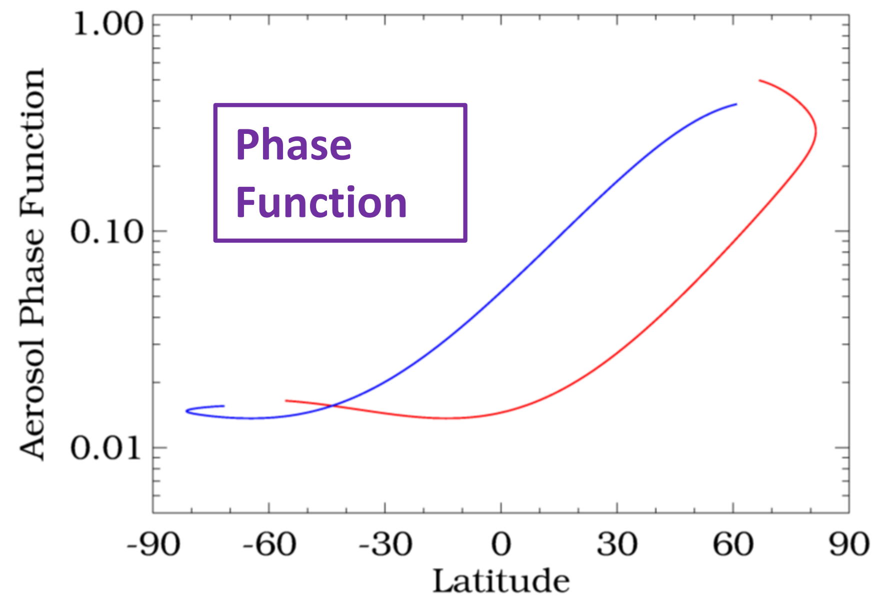


LP AER675 stratospheric optical depth time series. Extinction coefficient profiles are integrated from the tropopause to 35 km and averaged over 10° latitude bins. Symbols show the approximate location and date of recent volcanic eruptions: Nabro (June 2011), Kelut (Feb 2014), Calbuco (Apr 2015)

LP Scattering Angle Sampling

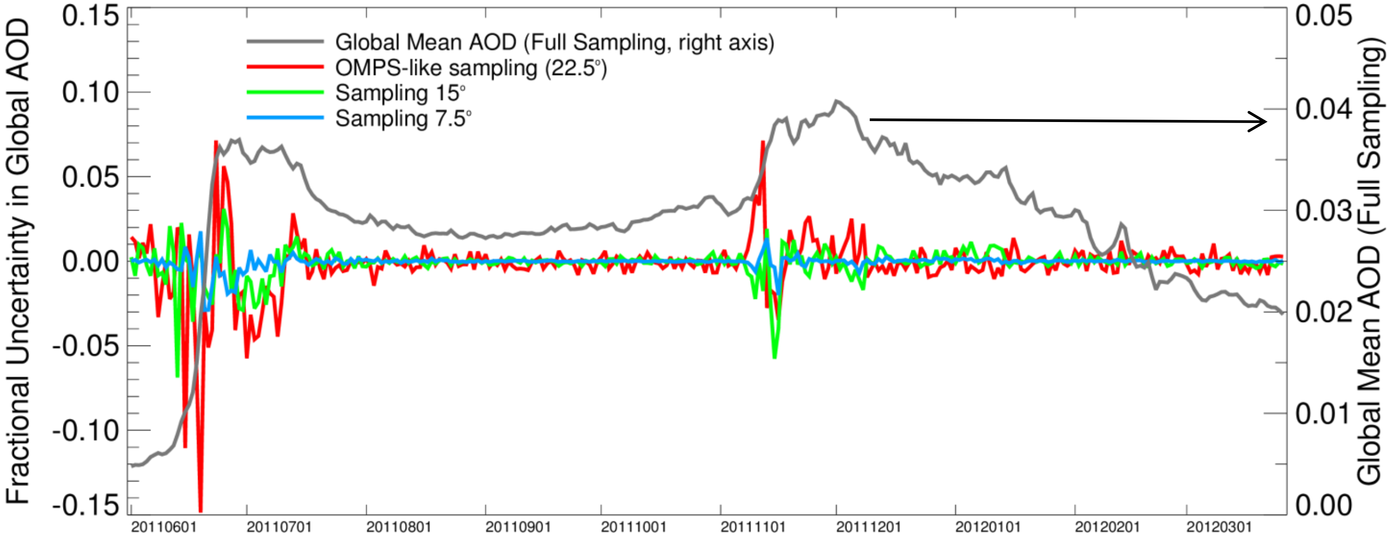
- **Red** = OMPS LP sampling for June 22, **Blue** = LP sampling for December 22.
- High scattering angle values observed in Southern Hem., low values observed in North. Seasonal shift in absolute values at single latitude.
- Large phase function variations are seen for forward scattering geometry (θ < 90°) with nominal aerosol size distribution.
- **LP sensitivity to aerosols varies by factor of 30 from SH to NH during each orbit.**





Spatial Sampling Study

- We conducted a spatial sampling study using output from the GEOS-5 atmospheric model. GEOS-5 included a representation of stratospherically produced aerosols and perturbations from large volcanic eruptions.



Aerosol loading increases by a factor of 3–4 following a volcanic perturbation. The uncertainty in estimated global mean aerosol loading decreases from 15% for OMPS-LP like sampling ***(red)*** to 3–5% for 3x denser sampling in longitude ***(green)*.**

Multi-Angle Stratospheric Aerosol Radiometer (MASTAR)

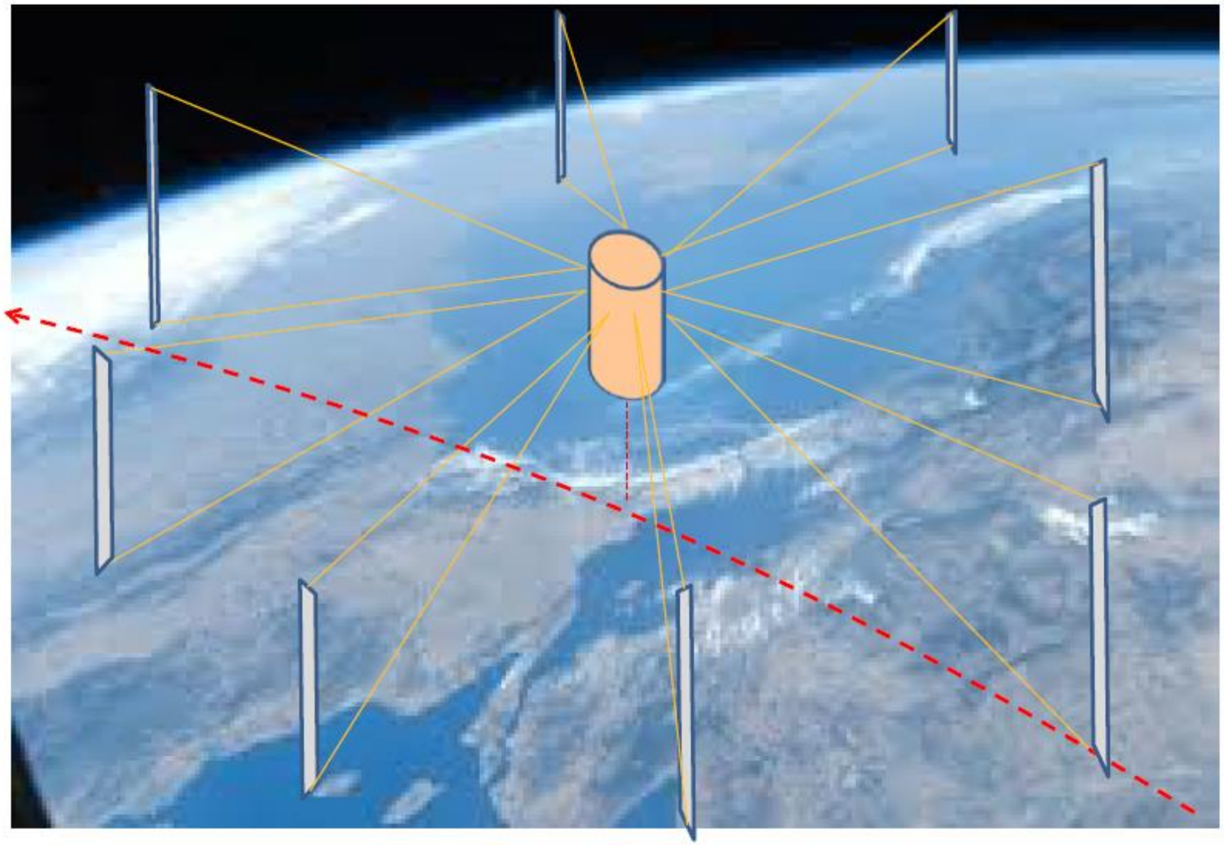
- Guiding principles for MASTAR design:
  - Target **Cubesat size range** to force simple design, allow rapid development, enable multiple instruments for future constellation.
  - Keep OMPS LP measurement approach (**limb scattering**) for best spatial sampling along orbit.
  - **Add viewing directions** to help balance scattering angle sampling between hemispheres. Additional directions can give increased spatial sampling between orbits and aerosol phase function information.
  - Use **simple wavelength selection**: 675 nm and 850 nm for aerosol profile, 350 nm for altitude registration
  - **Reduce stray light** concerns for incoming signals with large dynamic range.

MASTAR History

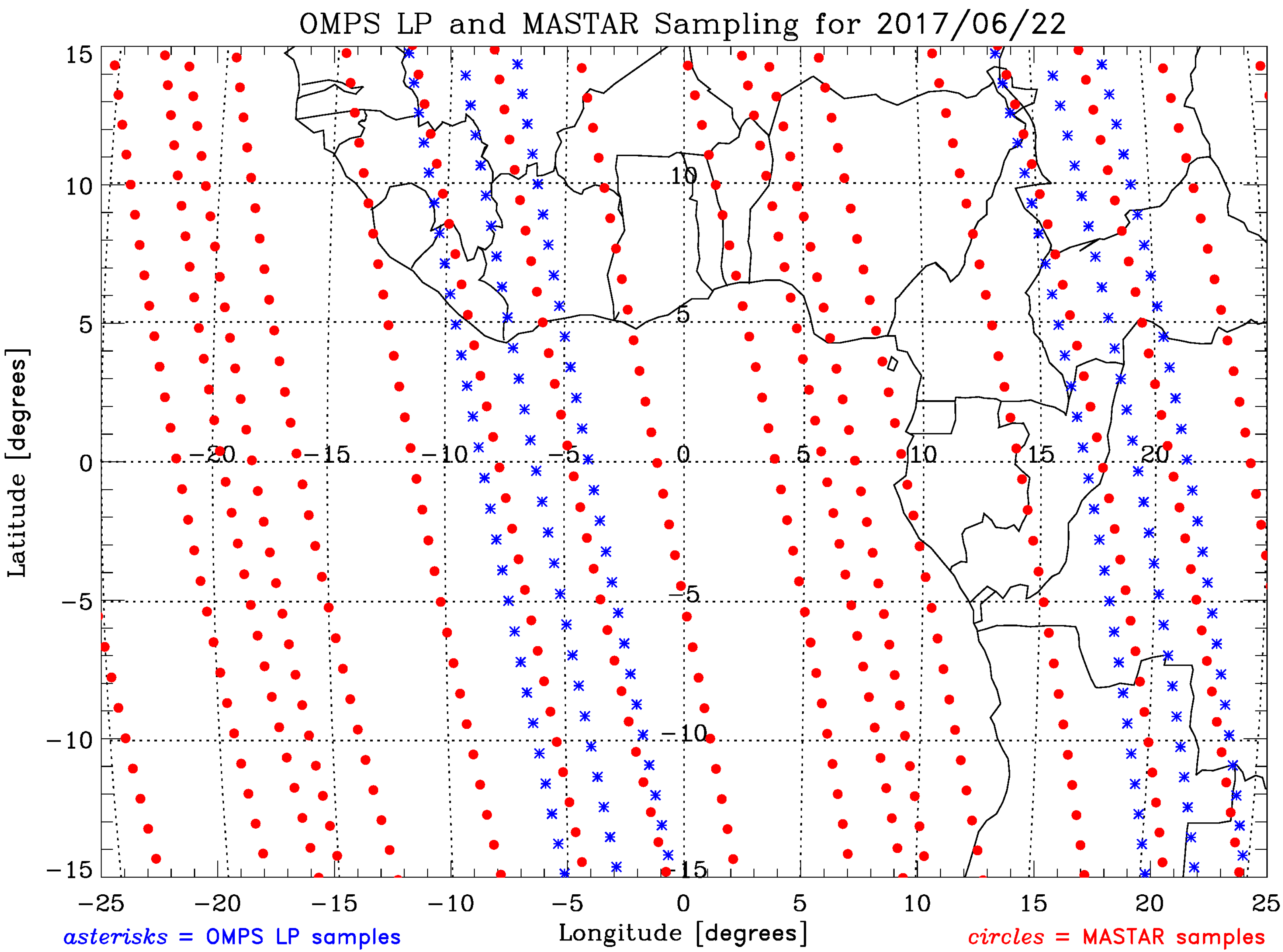
- Proposed as Global Aerosol Measurement System (GAMS) to GSFC study of small satellites constellations in April 2015.
- Development funded by GSFC IRAD awards in FY16 and FY17. Additional support from GSFC Code 610.
- Proof-of-concept system constructed using (primarily) COTS parts in summer 2016.
- Follow-on MASTAR project supported by IIP Instrument Concept Demonstration award (18-month duration) in November 2016.
- Add second science wavelength in near-IR (850 nm) to GAMS design to improve aerosol retrieval capabilities in upper troposphere and lower stratosphere (UT/LS).

MASTAR Measurement Concept

- Satellite flies with long axis normal to orbit.
- Vertical slits cover 0-60 km (minimum) at Earth limb.
- Tangent point is ~2200 km from spacecraft (using 400 km altitude from ISS launch).
- Aerosol measurement is flexible in terms of orbit altitude.
- Multiple satellites would improve spatial and temporal sampling.

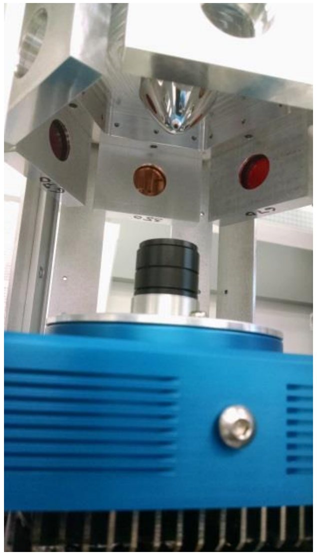


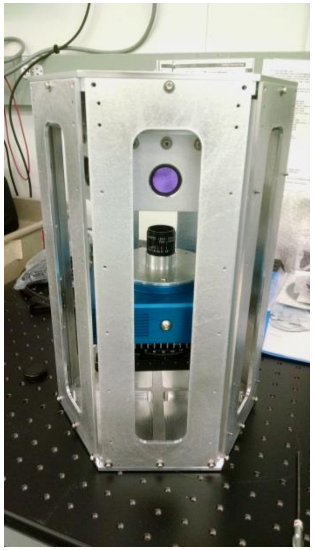
MASTAR Sampling vs. OMPS LP



GAMS - Prototype

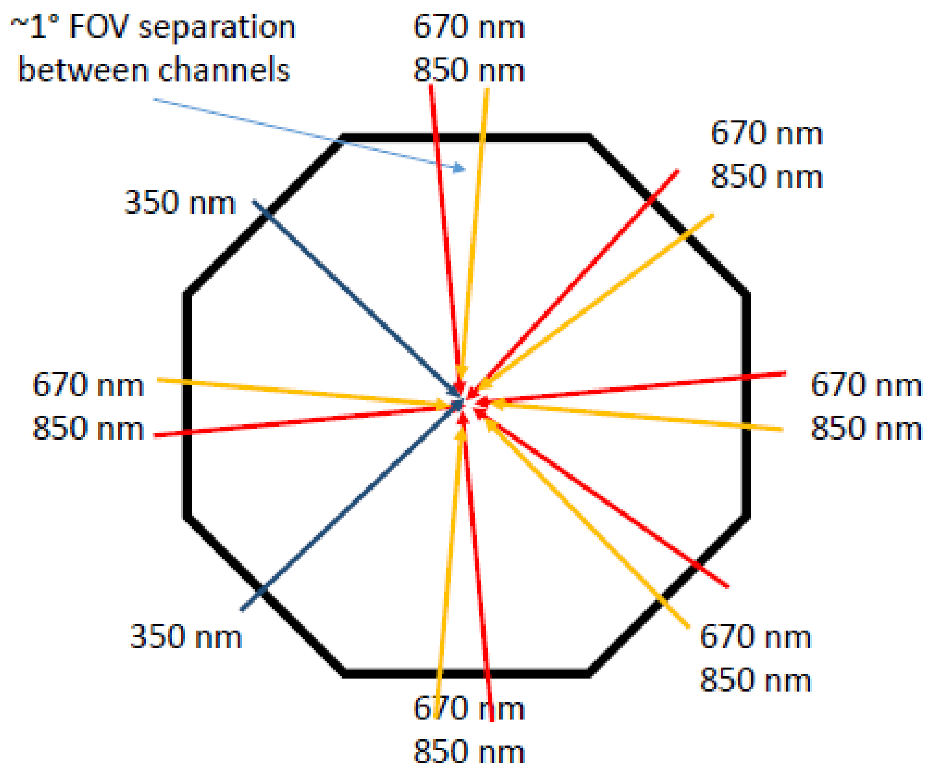
- Development funded by GSFC IRAD awards in FY16 and FY17, with additional support from GSFC Code 610.
- Proof-of-concept system constructed using (primarily) COTS parts in summer 2016.
- Use hyperbolic mirror (fabricated at GSFC) to provide simultaneous multi-directional viewing.
- Spectral filter choices include four at 670 nm for aerosol science, two at 350 nm for altitude registration using Rayleigh scattering (supplement to spacecraft attitude control capability).





MASTAR - Top View

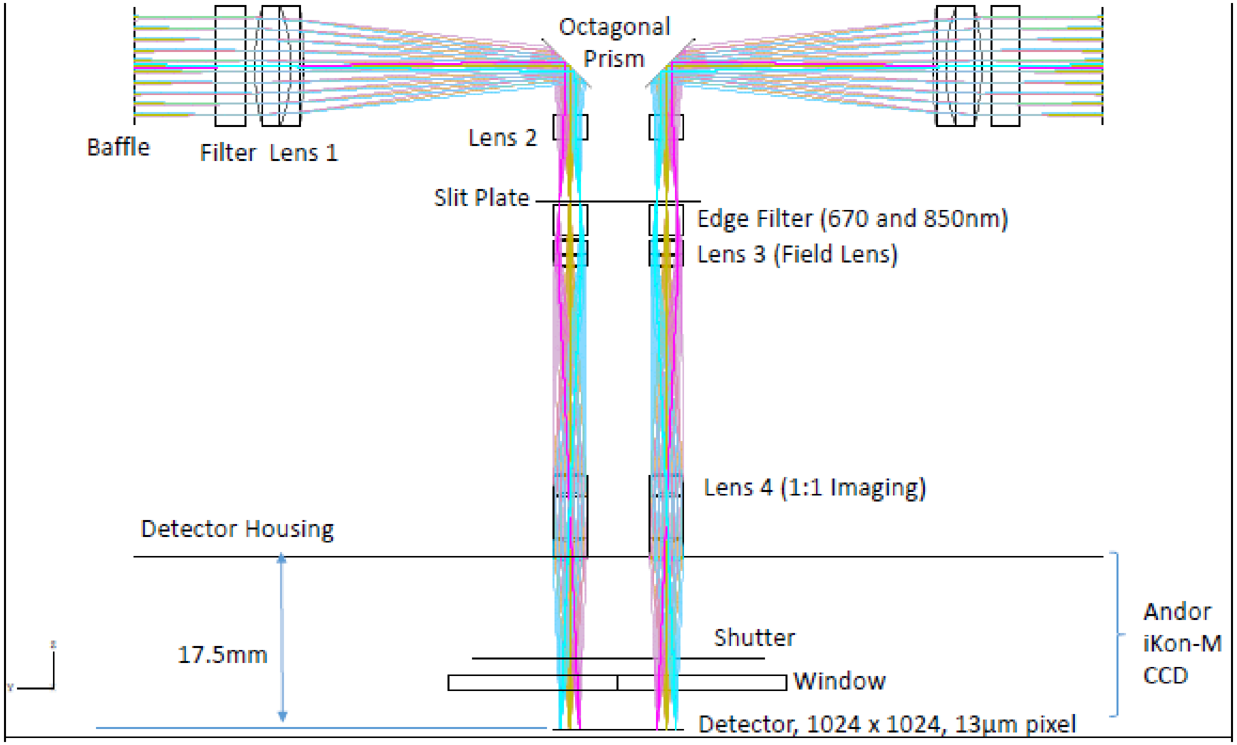
- Most viewing directions use two wavelengths (670 nm, 850 nm) to provide best vertical coverage for aerosol retrieval.
- Azimuthal pointing difference of 1° for paired wavelengths gives ~40 km horizontal separation for aerosol profiles at tangent point.
- Measure 350 nm radiance profile at two orthogonal directions to use RSAS method for validation of altitude registration from satellite attitude control system.



MASTAR Octagon

MASTAR Design – Side View

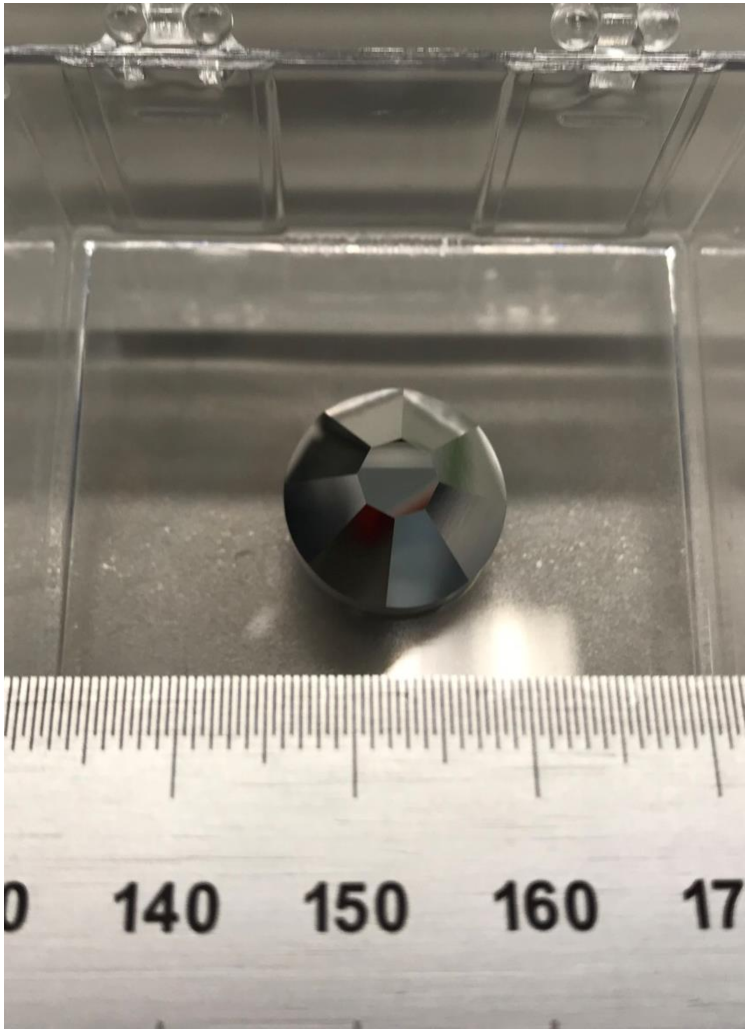
- Light enters from side of instrument (top of Cubesat frame) and multiple directions at once.
- Direct light down to CCD using octagonal prism.
- Focusing lenses create image of each slit on CCD.



- Slit images are inverted on CCD to put low altitude samples (bright signal) towards outside of CCD, which should help reduce stray light contamination from "cross-talk" between different slits.

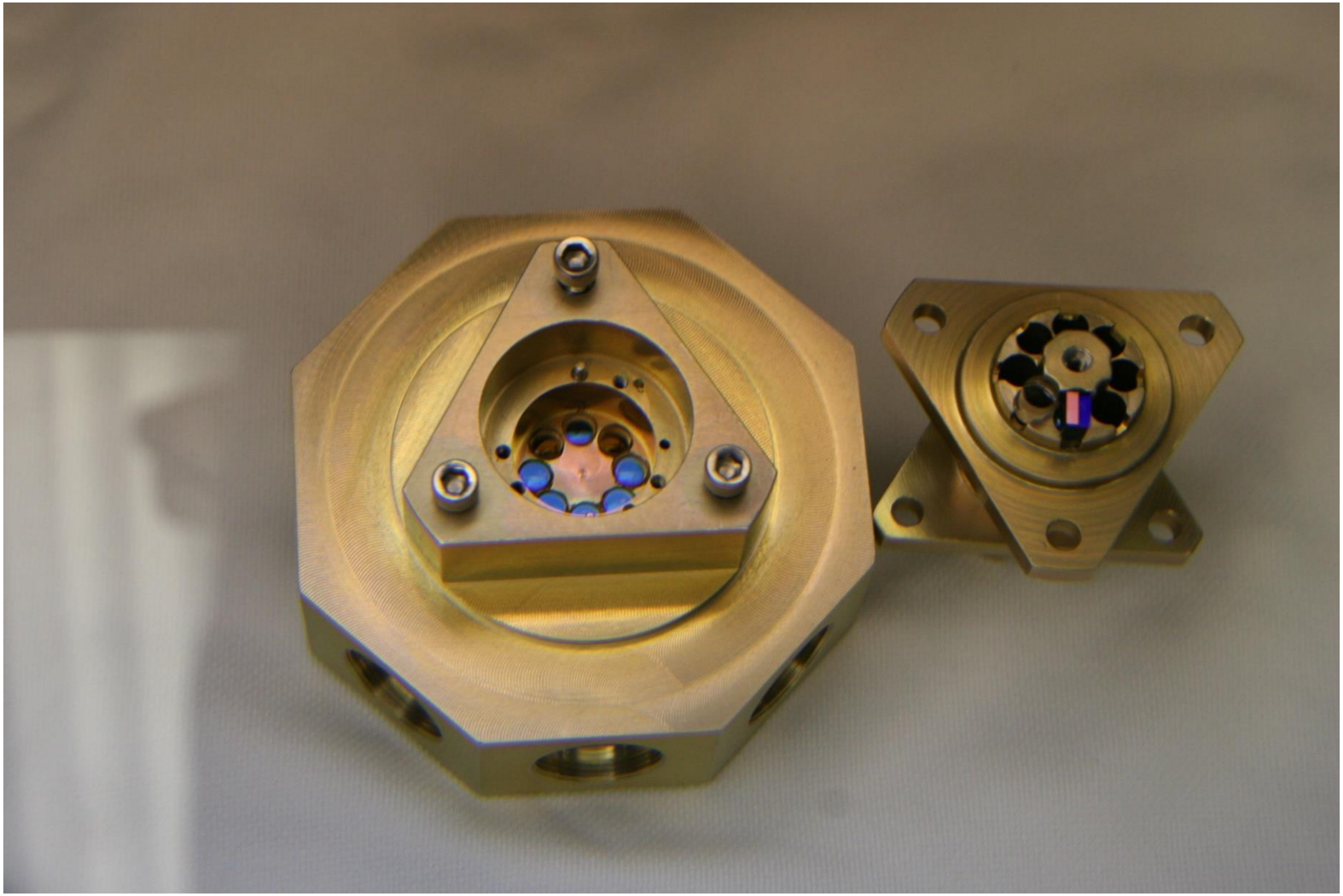
MASTAR Optical Elements - 1

- Ray tracing analysis based on science requirements showed that hyperbolic mirror would give too small image size on CCD.
- Changing design to flat-sided prism simplifies fabrication, enables creation of "clean" slit images.
- Completed prism is 12 mm in diameter.



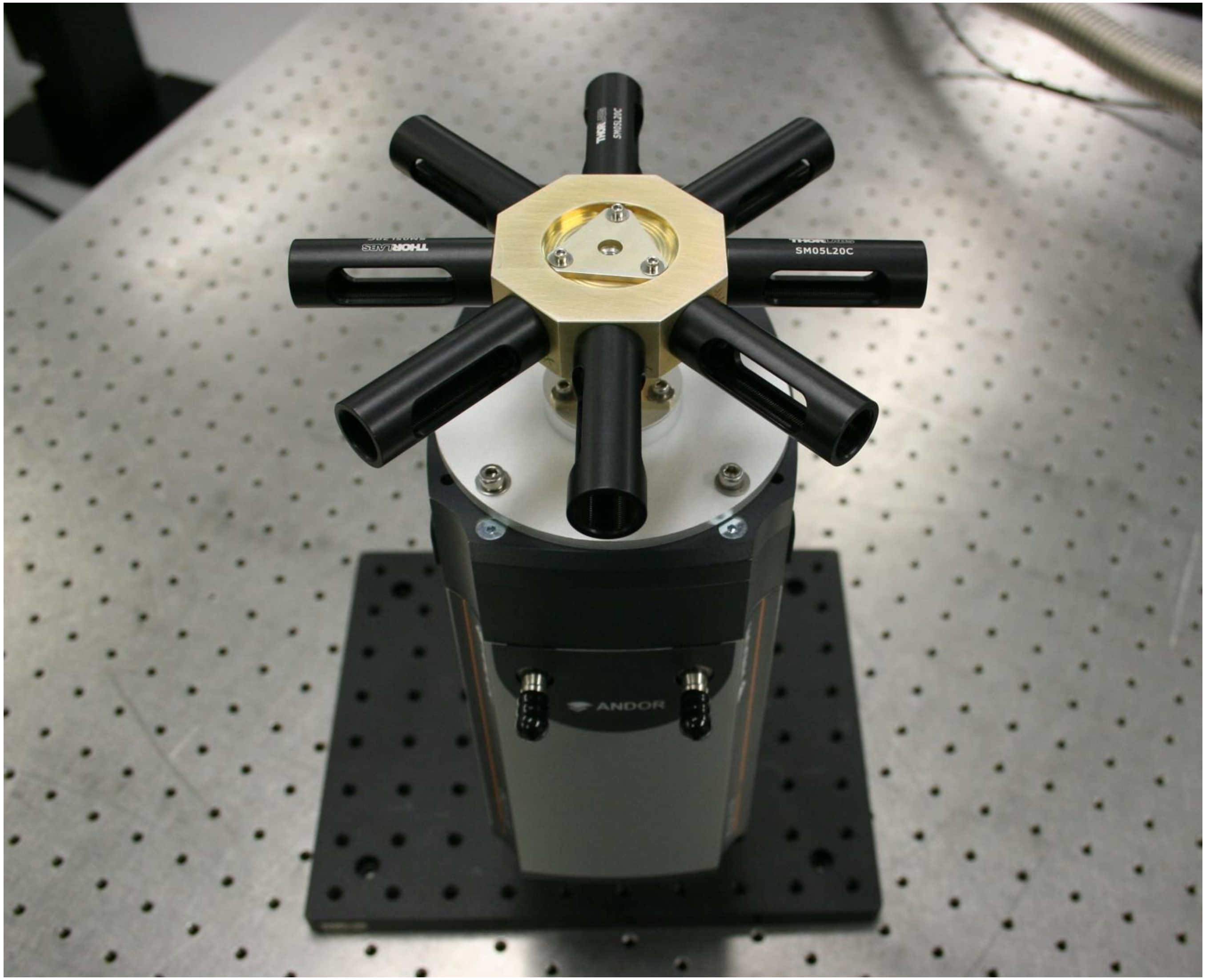
Octagonal Prism

MASTAR Optical Elements - 2



LEFT = Prism assembly, lens 1 (both not visible), lens 2. Blue = 670/850 nm, dark = 350 nm. Assembly is inverted. RIGHT = Assembly for 1:1 reimaging optics (lens 3, lens 4).

MASTAR Optical System - Assembled



6/6/2018: Optical assembly integrated with viewing apertures and mounted to CCD detector.

Future Activities for MASTAR

- Test integrated optical system in laboratory (in progress).
- Procure and integrate subsystems (*e.g.* onboard data processing, power supply, thermal control) to create functional prototype.
- Test completed prototype outdoors (building roof at GSFC) in summer 2018.
- Model optical performance response to intra-orbit thermal variations.
- Develop modified slit plate and detector combination for improved performance.
- Submitted proposal to NASA ROSES InVEST program for development of next-generation instrument.

ARGOS (Aerosol Radiometer for Global Observation of the Stratosphere)