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

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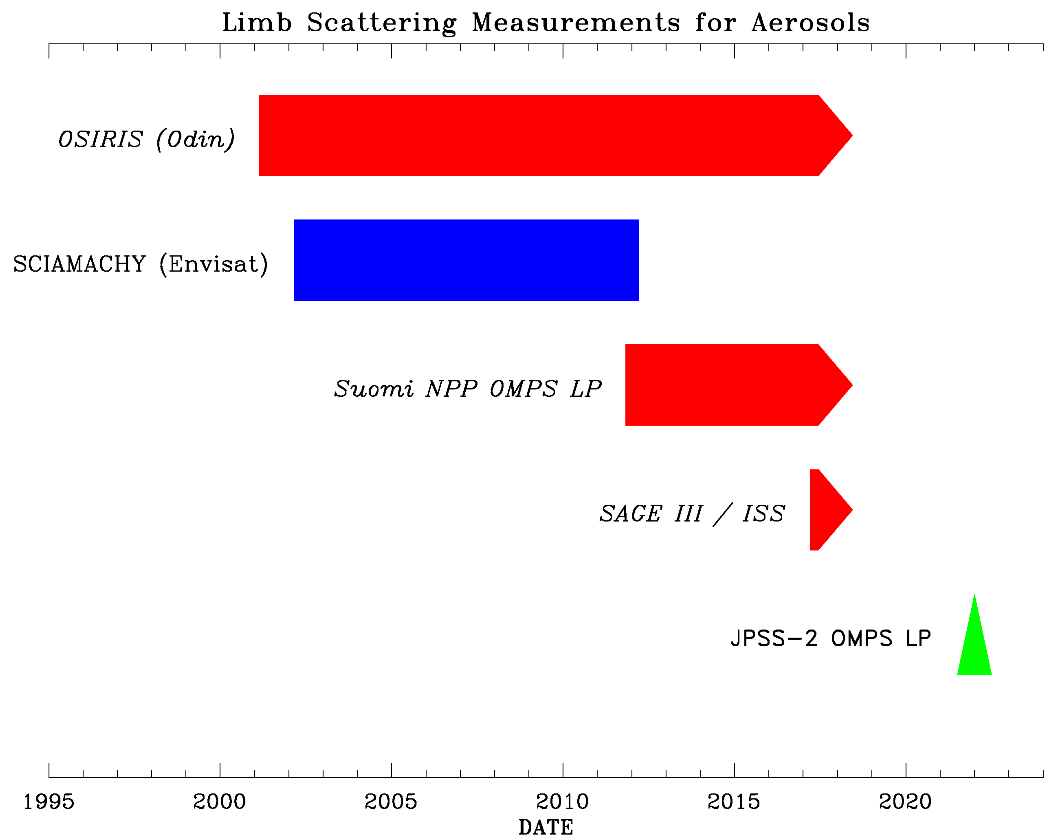
Introduction

- 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.

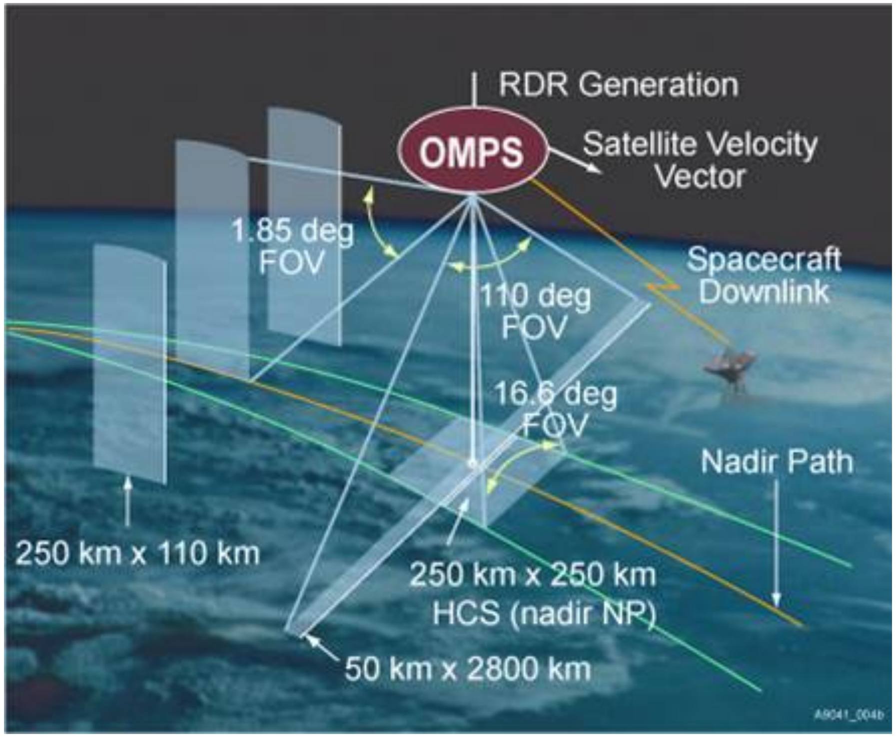
Recent Limb Scattering Measurements

- SCIAMACHY stopped working in March 2012.
- OSIRIS is operating, but has power issues.
- SAGE III recently launched to ISS. It will collect both limb scatter and occultation data (but distribution of measurement options not yet determined).
- OMPS LP operating on Suomi NPP since April 2012.
- Next LP instrument will not be launched before 2022 → possible data gap?



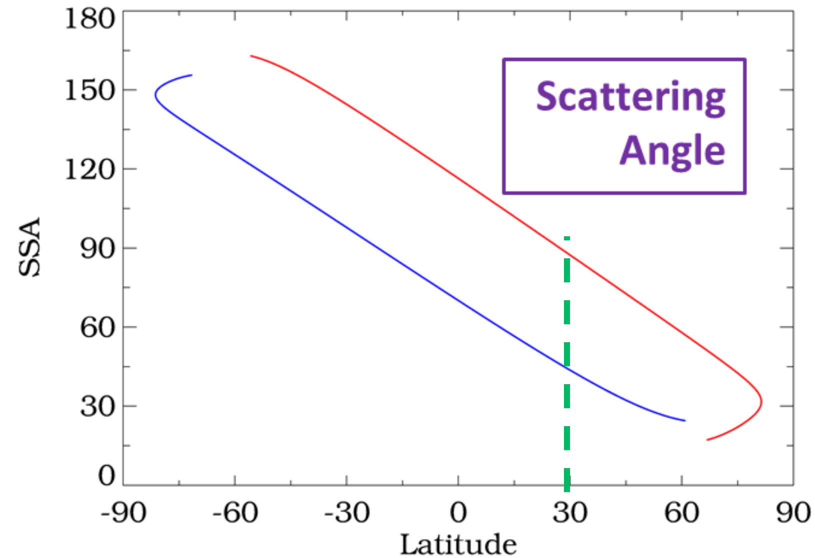
OMPS Limb Profiler (LP)

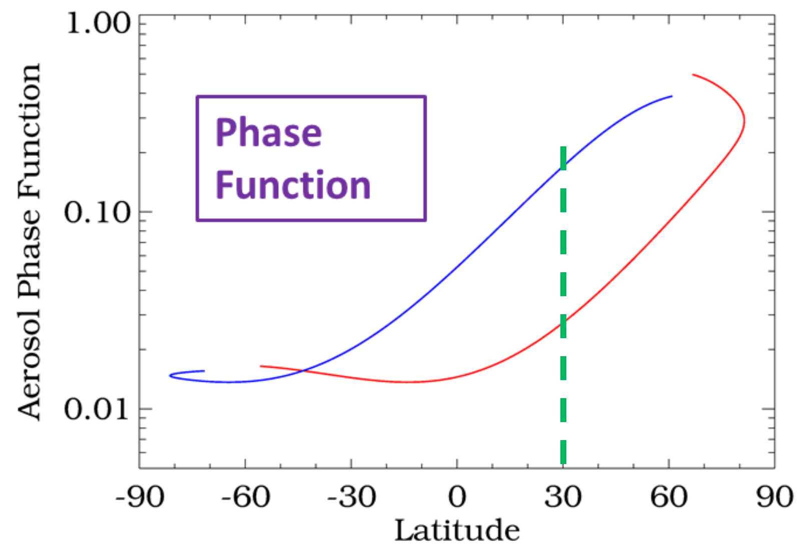
- Ozone Mapping and Profiling Suite (OMPS) Limb Profiler (LP) launched on Suomi NPP satellite on 28 October 2011.
- Limb scatter measurements are made looking backward along the orbit track with three slits (center, ±4.25° to each side = 250 km separation at tangent point).
- Hyperspectral CCD collects 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.



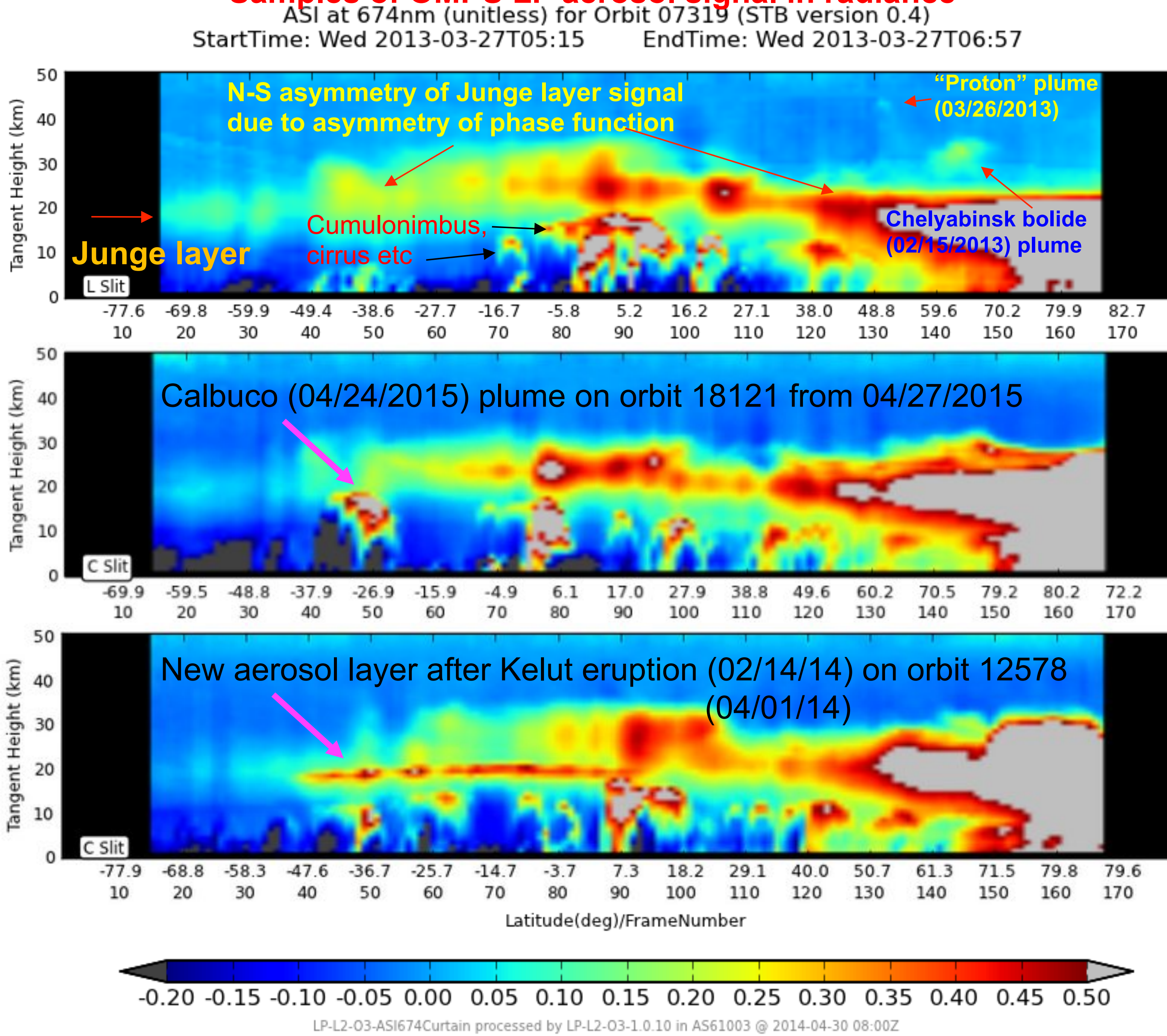
LP Observing Geometry

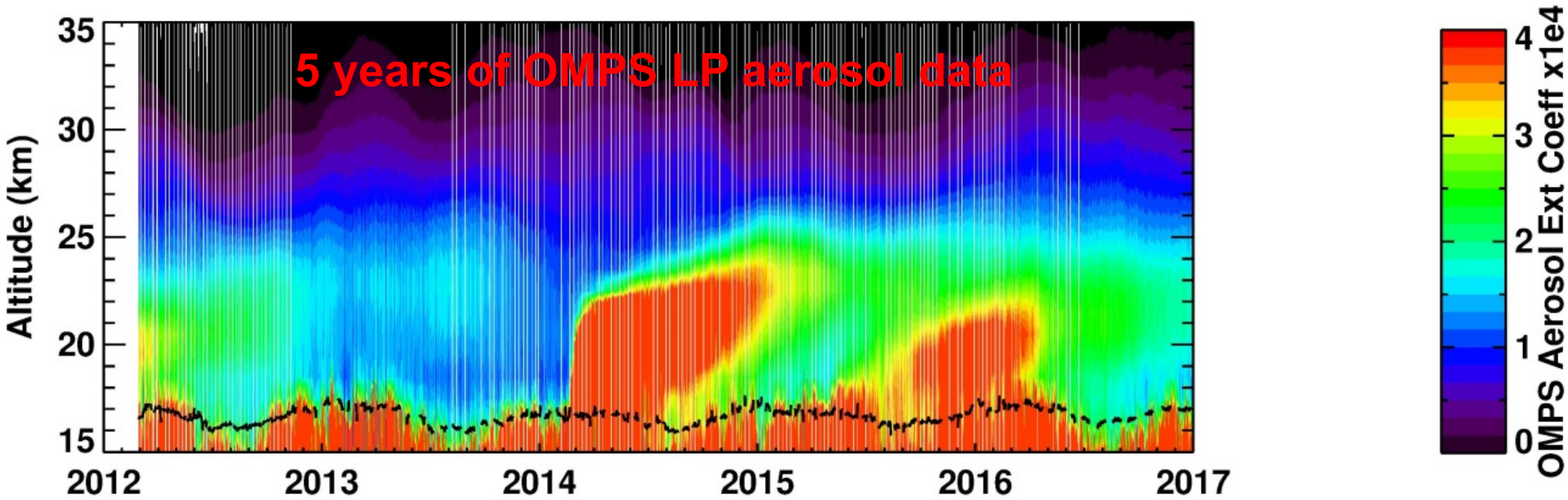
- LP viewing geometry (backwards along orbit track) produces high scattering angles in SH, low scattering angles in NH.
- When combined with typical aerosol phase function, this yields a factor of 30 difference in sensitivity over the latitude range of the orbit.
- Seasonal variations in scattering angle [*red = June 21, blue = December 21*] also cause a factor of 7 variation in phase function at 30°N.



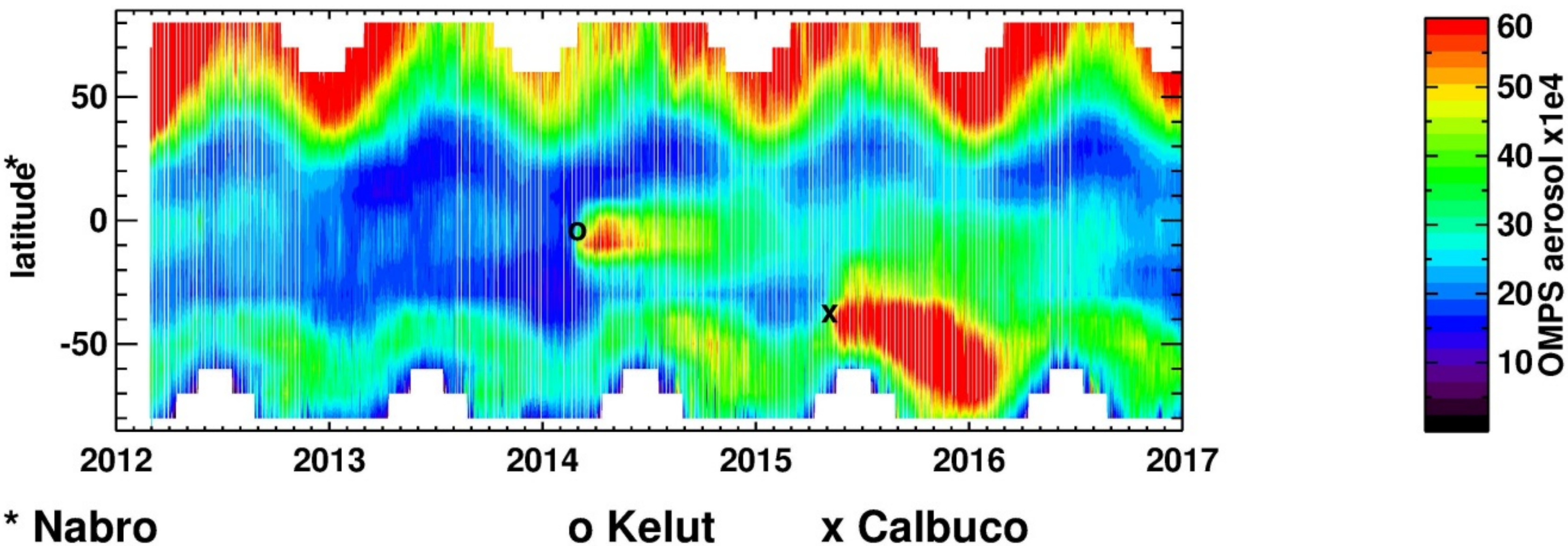


Samples of OMPS LP aerosol signal in radiance





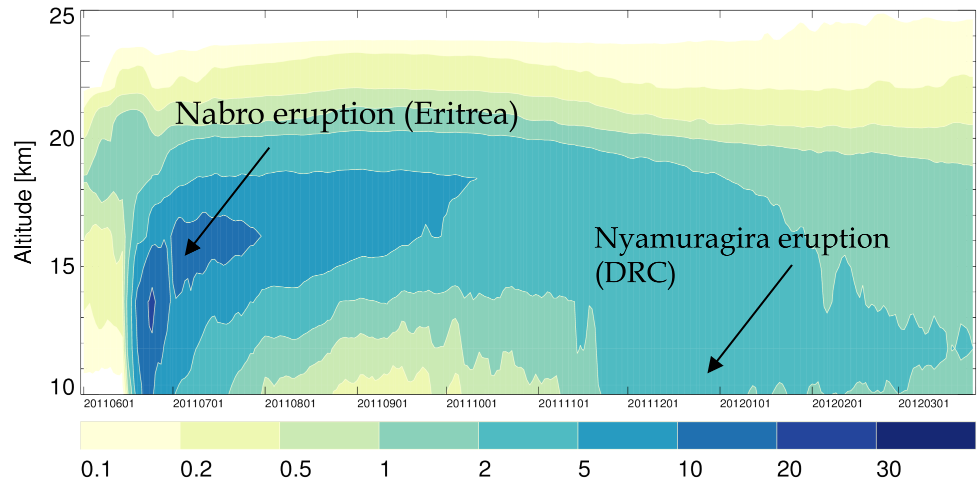
Suomi NPP LP AER675 extinction coefficient time series. The figure shows daily zonal mean profiles averaged over 0-10°S latitude. The dashed line shows tropopause altitude.

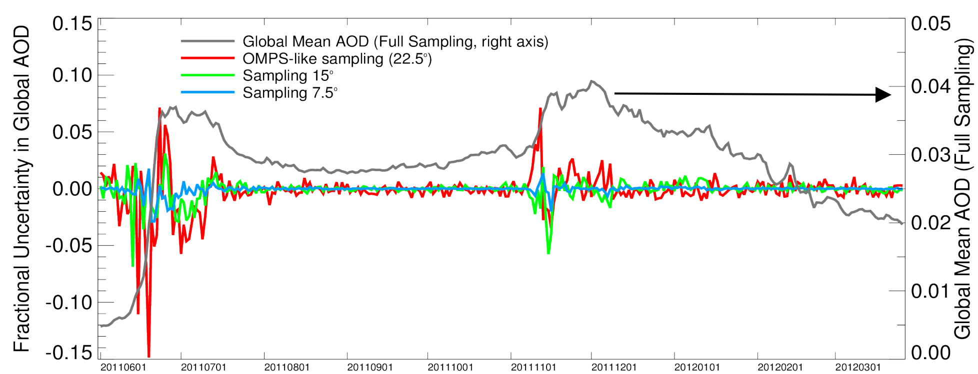


LP AER675 stratospheric optical depth time series. Extinction coefficient profiles are integrated from the tropopause to 35 km and averaged over 10° latitude bins. Symbols show the approximate location and date of recent volcanic eruptions: Nabro (June 2011), Kelut (Feb 2014), Calbuco (Apr 2015)

Spatial Coverage

- Use aerosol abundance produced by GEOS-5 atmospheric transport model to examine evolution of stratospheric aerosol load following Mt. Nabro eruption in 2011.
- OMPS LP sampling along sun-synchronous orbit produces >15% uncertainty in global mean aerosol loading following eruption.
- Increasing cross-track sampling by 3x (filling gaps between orbits) reduces calculated uncertainty to < 5%.



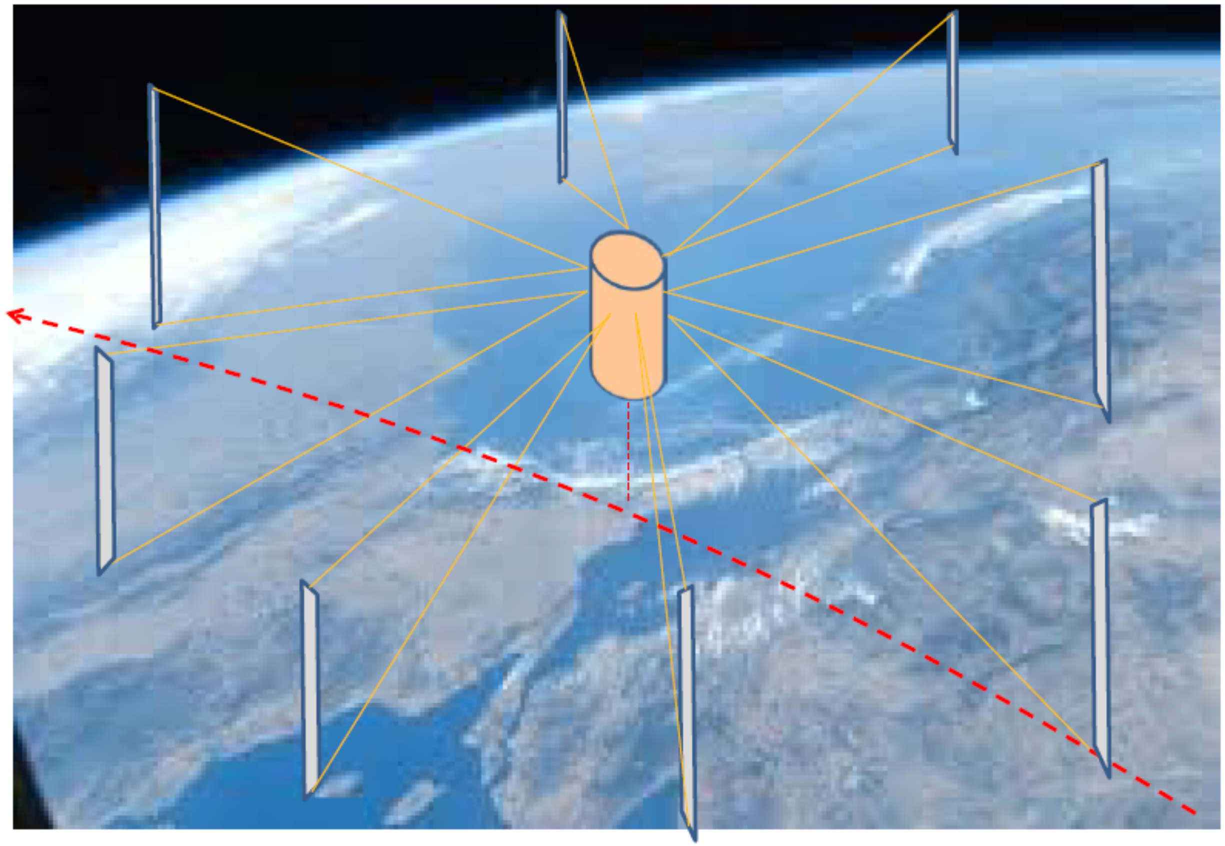


Global Atmospheric Monitoring System (GAMS)

- Create simplified version of OMPS LP instrument to expand coverage, increase overall sensitivity.
- View in multiple directions simultaneously to balance scattering angle sampling, collect more spatial locations.
  - Side benefit is better characterization of particle size distribution.
- Reduce wavelength coverage to selected choices (filters) to enable smaller instrument size.
- Project history:
  - Apr 2015: White paper for GSFC CubeSat/SmallSat constellation call.
  - Sep 2015: FY16 GSFC internal funding for construction of laboratory prototype (GAMS).
  - Jul 2016: Bench testing with single wavelength instrument.
  - Sep 2016: FY17 GSFC internal funding for optical design analysis, addition of second science wavelength
  - Oct 2016: IIP award for development of Multi-Angle Stratospheric Aerosol Radiometer (MASTAR) instrument
  - May 2017: Revised optical design complete, mechanical design under way

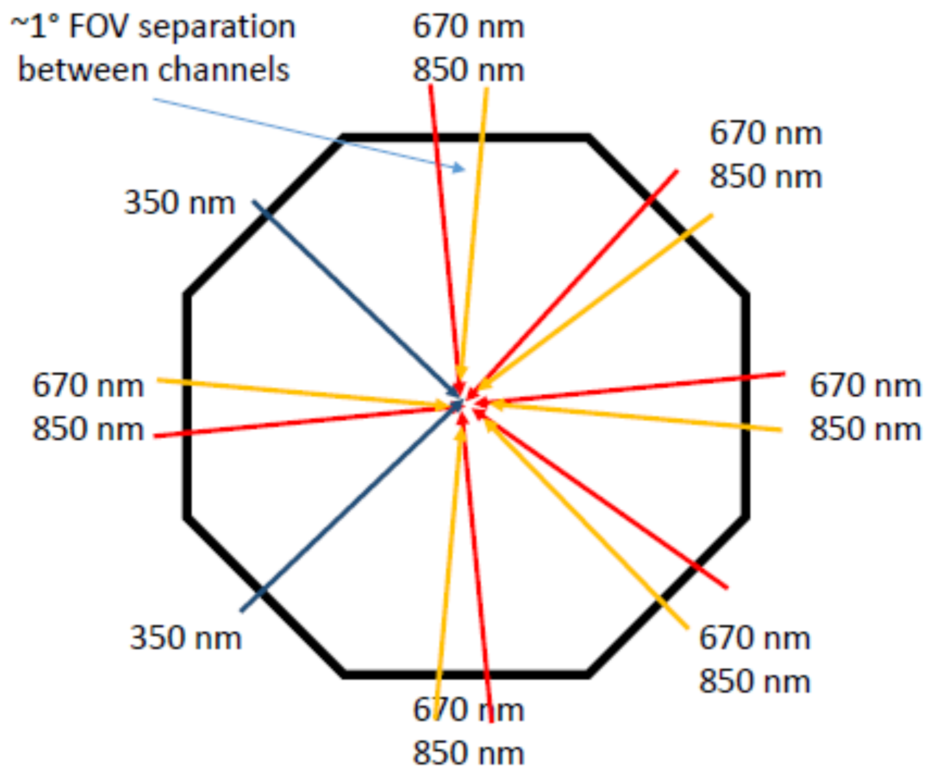
MASTAR Measurement Concept

- 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 - Top View

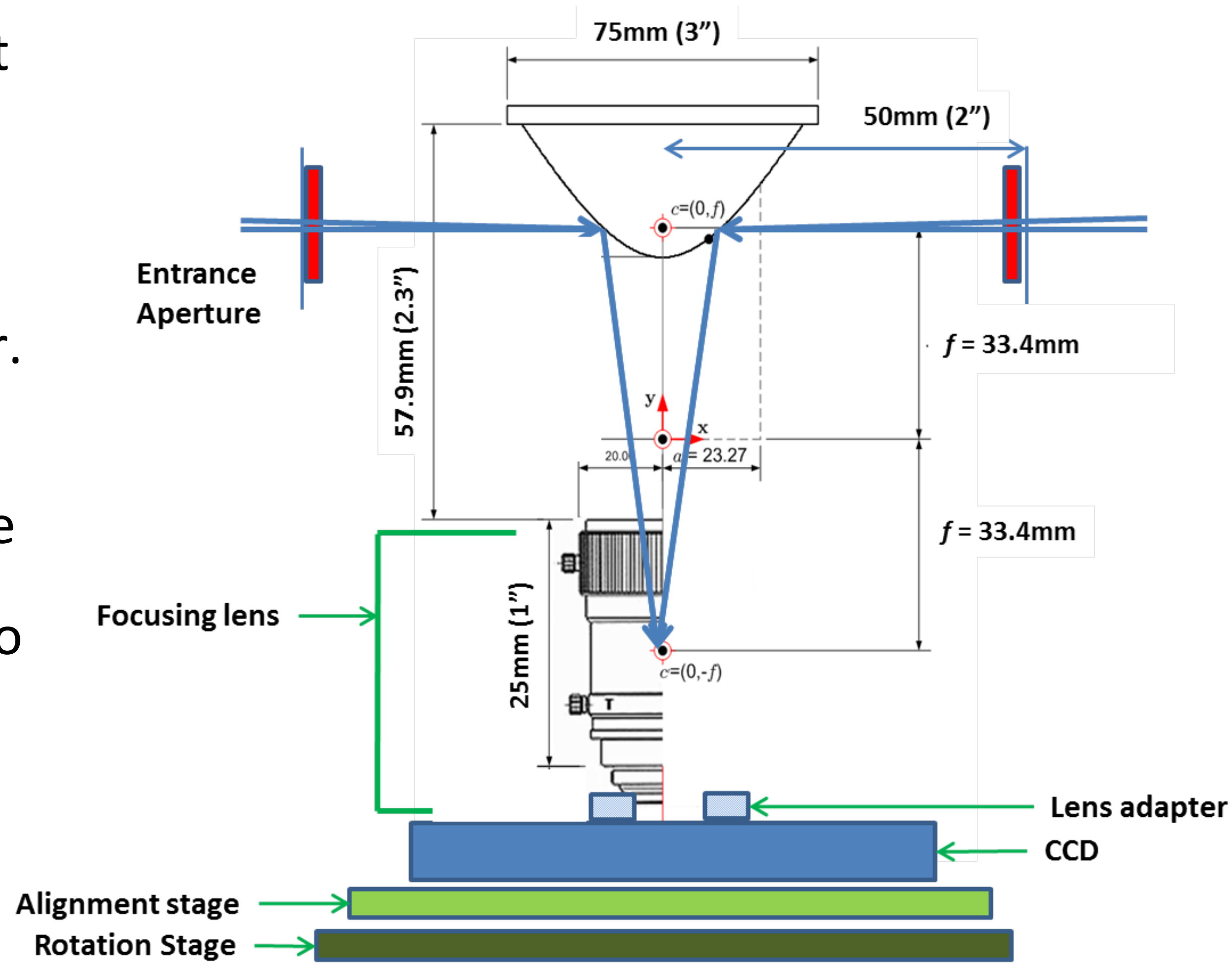
- Most viewing directions have two wavelengths (670 nm, 850 nm) to provide best vertical coverage for aerosol retrieval.
- Pointing difference of 1° for paired wavelengths gives ~40 km horizontal separation for aerosol profiles at tangent point.
- Measure 350 nm radiance profile at two orthogonal directions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



MASTAR Octagon

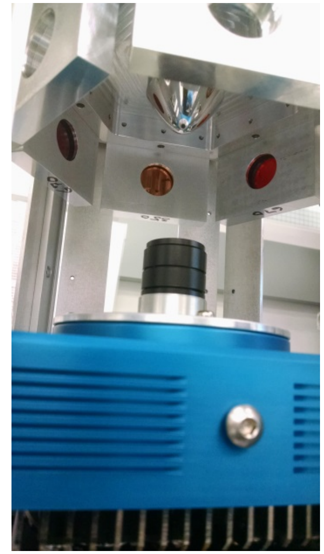
MASTAR – Side View

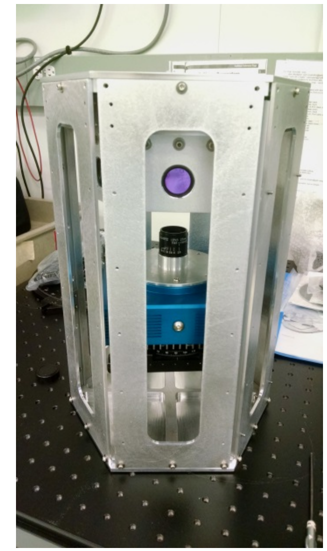
- Light enters from side of instrument (top of Cubesat frame).
- Direct light down to CCD using multi-sided mirror.
- Slit images are inverted on CCD to put low altitude (bright signal) towards outside to reduce stray light contamination from “cross-talk”.

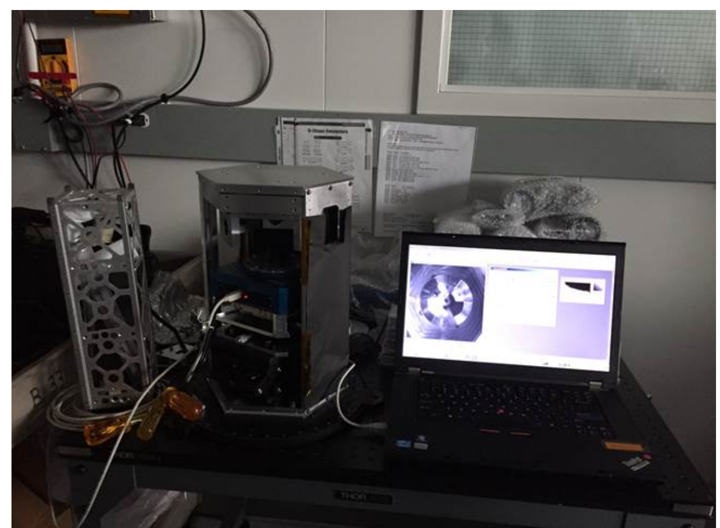


Laboratory Bench System

- Initial system constructed with mostly COTS parts in fall 2016.
- Hexagonal configuration is approximately to 3U Cubesat scale.
- Illuminate system to collect basic data for evaluation of optical design.

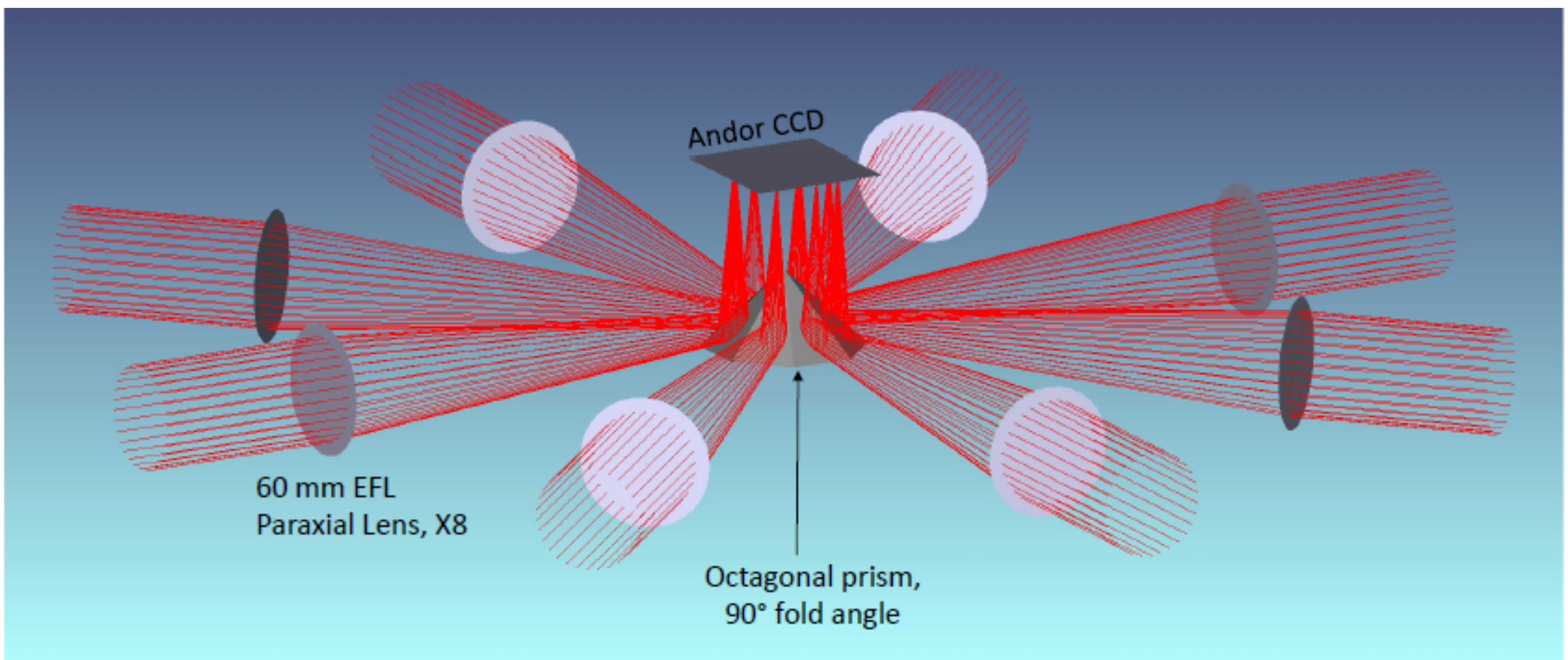






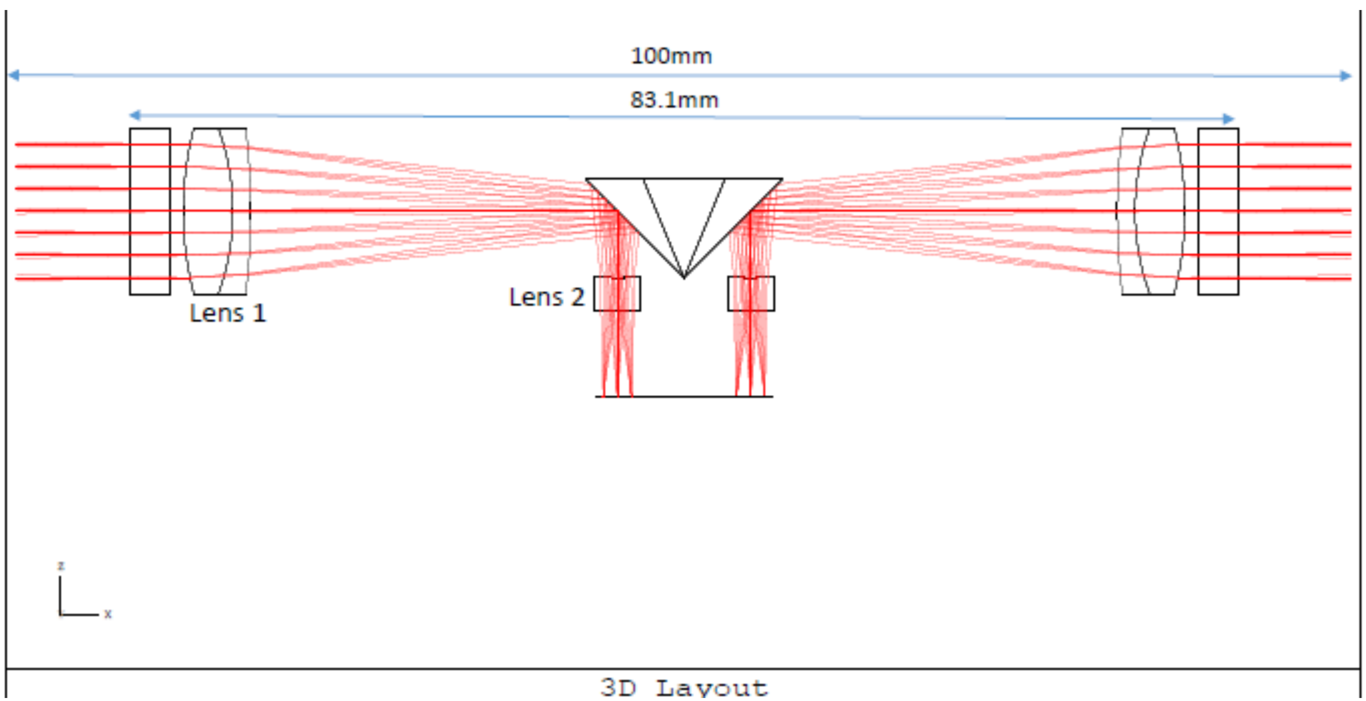
Optical Design - 1

- 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, produces “clean” slit images.



Optical Design - 2

- Telephoto system (negative focal length intermediate lens) allows multiple view directions with desired effective focal length to fit within Cubesat frame (horizontally).



Next Steps for MASTAR

- Procure and design hardware to construct revised optical system.
- Define additional systems (on-board data processing, power supply, thermal control) to create functional prototype.
- Use NASA GSFC models of aerosol distribution to help define necessary performance.
- Adapt current OMPS LP aerosol extinction retrieval algorithm to use MASTAR input data.
- Test completed system outdoors (GSFC building roof?) in summer 2018.