QOS 2021

October 3 (Sunday) - 9 (Saturday), 2021

Online Meeting

QUADRENNIAL OZONE SYMPOSIUM

[E_12] The Stratospheric Aerosol and Gas Experiment (SAGE) IV Pathfinder

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What is SAGE?

The Stratospheric Aerosol and Gas Experiment is a series of space-based Earth remote sensing instruments

- SAM (1975): Proof of concept of solar occultation for atmospheric remote sensing
- SAM II (1978–1993): Single photodiode measuring aerosol extinction at 1 μm
- SAGE I (1979–1981): Four channels measuring aerosol, ozone, and NO2
- SAGE II (1984–2005): Seven channels measuring aerosol, ozone, NO2, and H2O
- SAGE III: Changed to CCD spectrometer, added lunar occultation and limb scattering
- Meteor-3M (2002–2005), ISS (2017–Present), FOO (laboratory test setup)

These instruments have contributed to decades of critical science and discoveries

SAGE III/ISS is primarily a science continuity mission

- Interconnected stratospheric constituents: aerosol, O3, H2O, NO2

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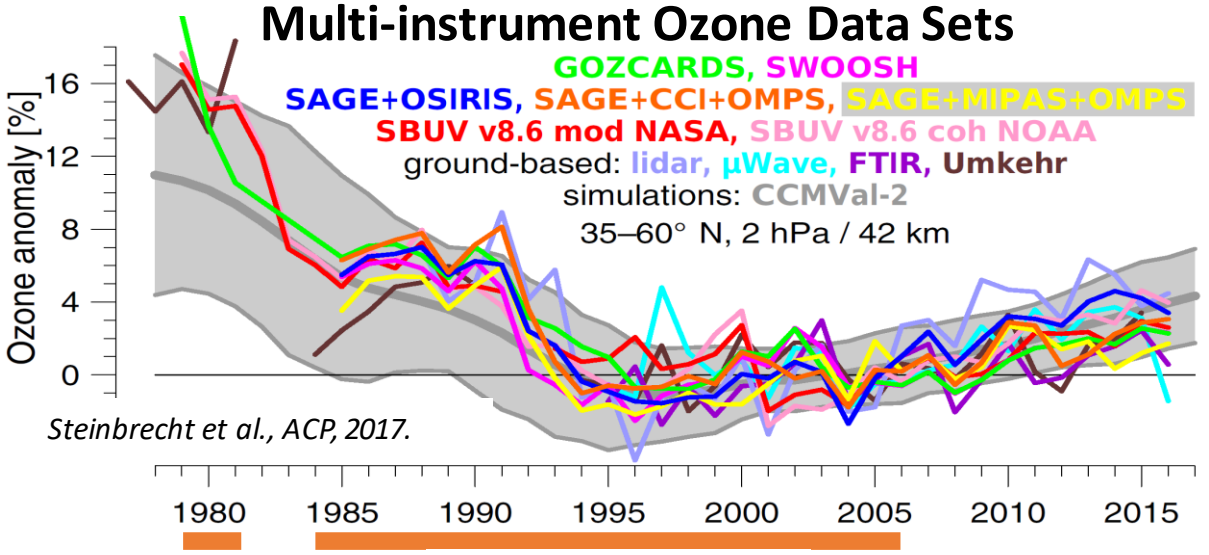
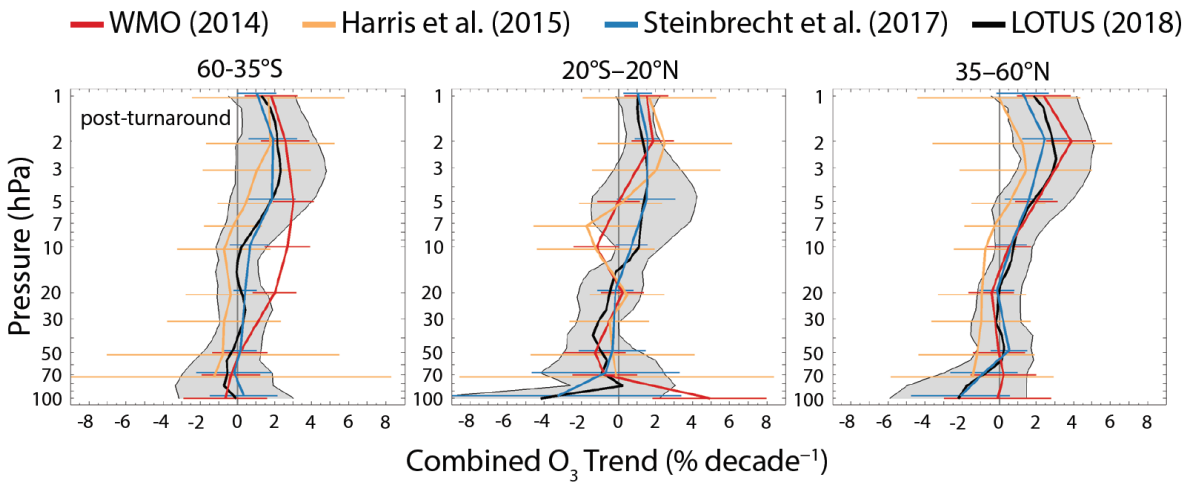
Stratospheric Ozone

The multi-decadal SAGE data sets have undergone intense scrutiny and have become the international standard for accuracy and stability.

SAGE ozone data has been used to monitor the effectiveness of the Montreal Protocol.

Current results show signs of recovery in the upper stratosphere from decreasing ODSs but a continual decline (uncertain) in the lower stratosphere from increasing GHGs. Continued observations are necessary to improve uncertainties.



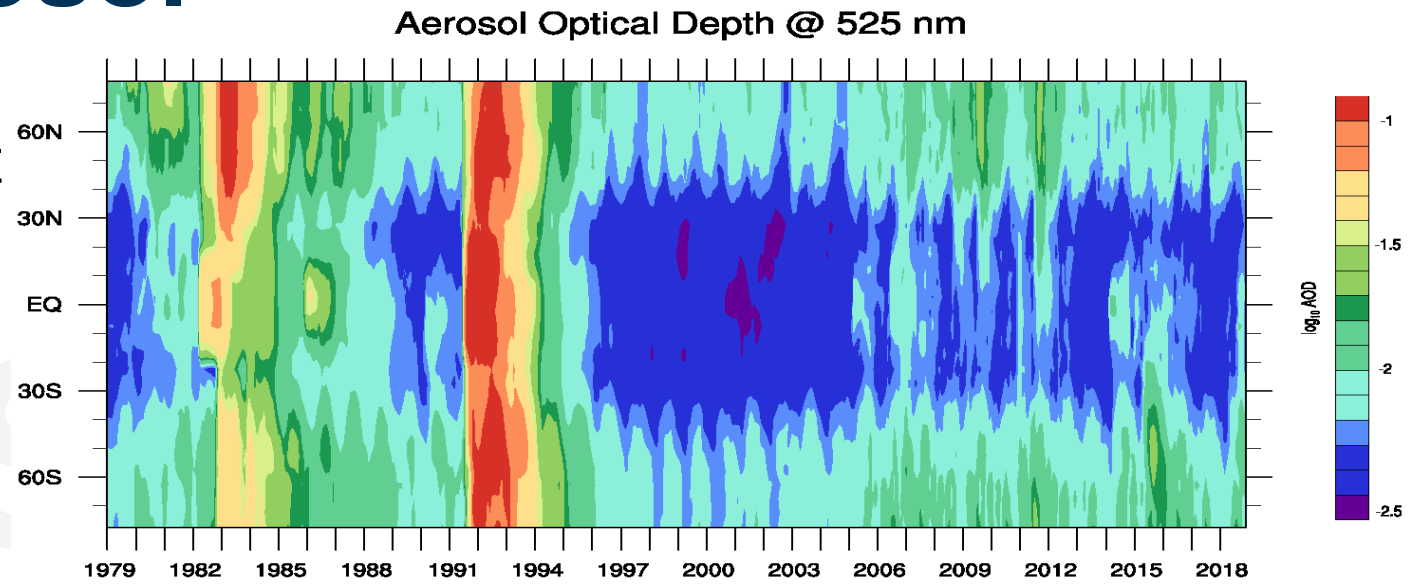


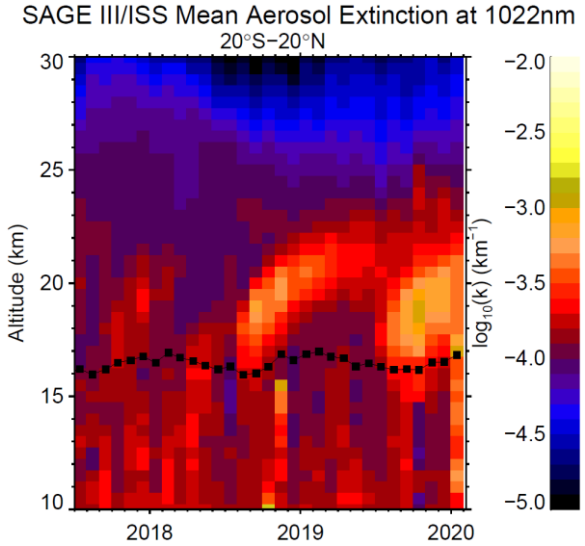
Stratospheric Aerosol

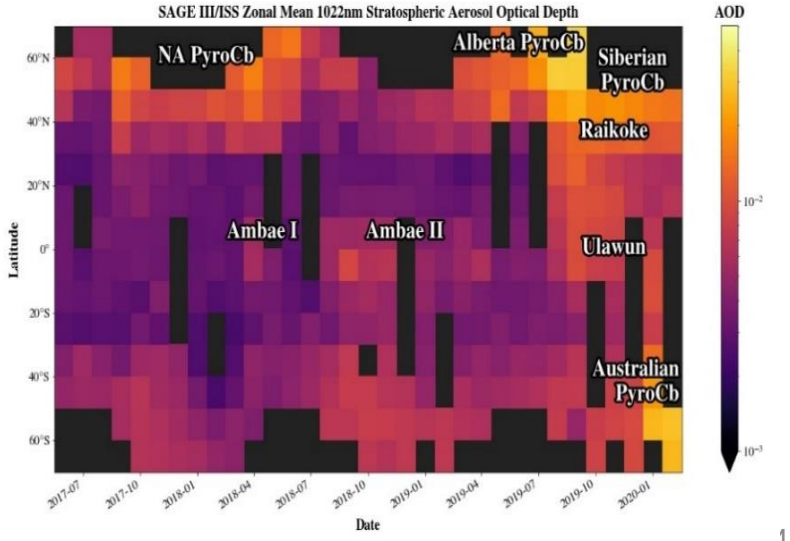
SAGE aerosol data has been recognized as a critical measurement for long-term climate studies

SAGE III/ISS data is providing data continuity and improving the merging of previous records

The last three years have seen several small volcanic eruptions and the two largest PyroCbs ever recorded





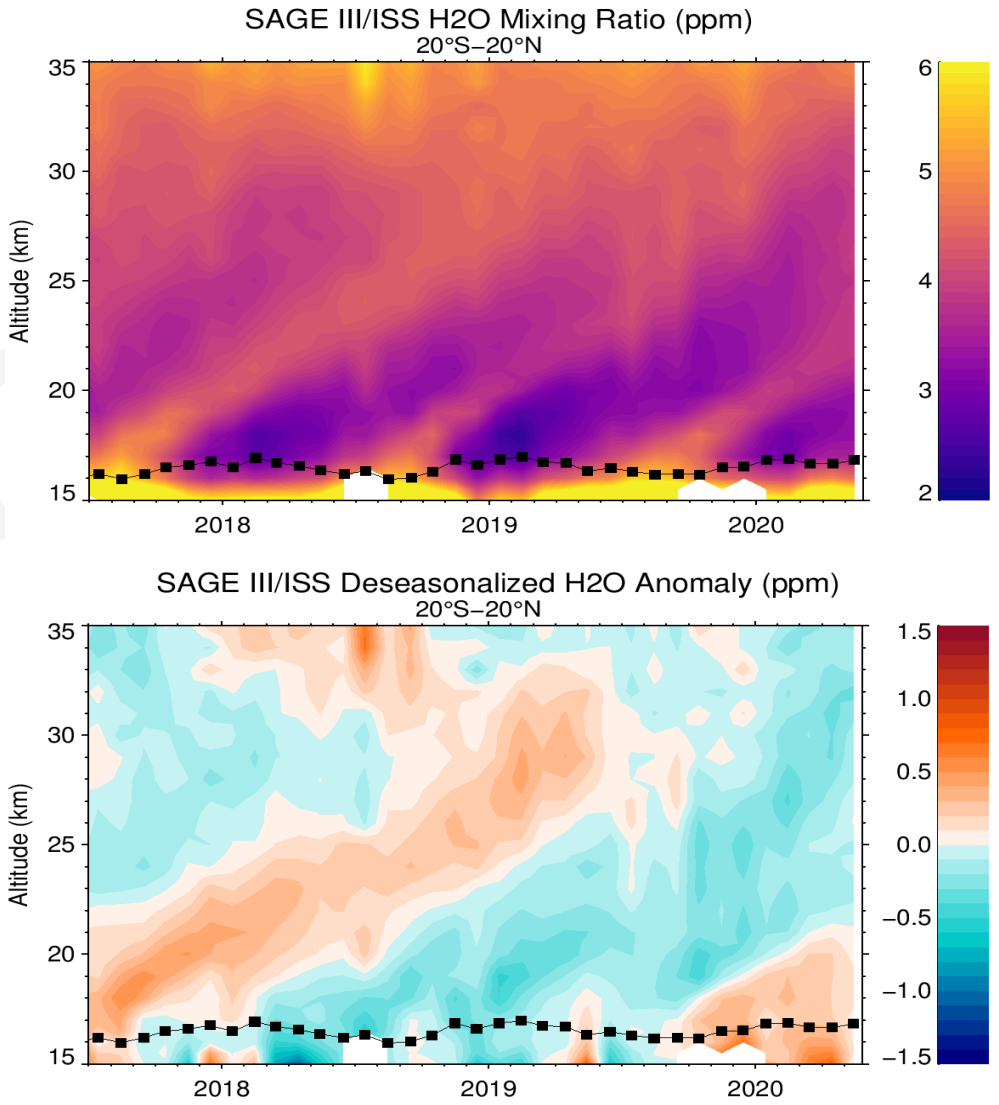


Stratospheric Water Vapor

Water vapor plays important roles in stratospheric chemistry and Earth's radiation budget and is a useful transport tracer

SAGE data is a core component of the combined satellite record of water vapor such as the Stratospheric Water and OzOne Satellite Homogenized (SWOOSH) data set (Davis et al., 2016)

SAGE III/ISS is the only instrument under 15 years old currently providing measurements of stratospheric water vapor



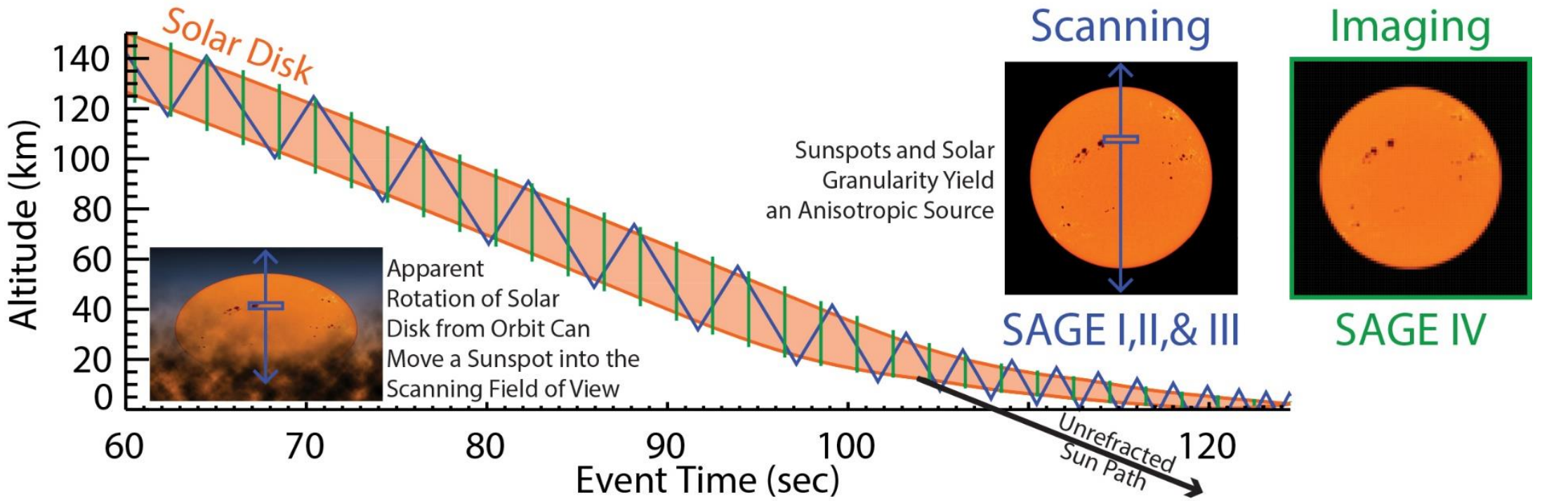
What have we learned from SAGE so far?

Over four decades of experience with solar occultation have taught us how to optimize the measurement for the next generation system.

Lessons learned from SAGE I/II/III Scanning Technique:

- When using a scanning spectrometer, pointing knowledge becomes critical and subsequently requires heavy (~350 kg) and expensive mechanisms.
- Assumptions must be made about the instrument's mechanical stability during an event.
  - Linearity of scan mirror motion
  - Azimuthal tracking expects a uniform image
  - Non-orthogonal transient behaviors
- External meteorological data are required to compute refraction for tropospheric and lower stratospheric pointing.
- Radiometric symmetry of the solar disk must be assumed while scanning.

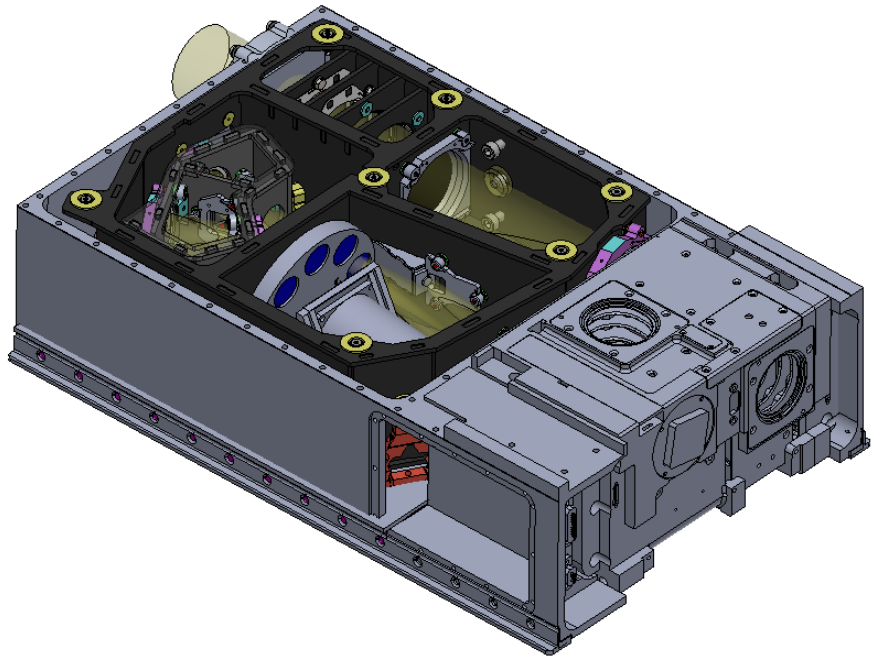
What are we doing different?: Solar Imaging



- Absolute pointing is intrinsic to solar imaging
- No assumptions are required for tracking mechanisms
- Atmospheric refraction information is independently retrievable
- Anisotropy of the solar disk (e.g., sunspots and granularity) is measured

What is the SAGE IV concept?

- SAGE IV is a solar occultation imager capable of meeting or exceeding SAGE-quality ozone and aerosol measurements
- Instrument and spacecraft small enough to fit in a 6U CubeSat form factor for a significant size and cost reduction
- Enables cost-effective sustainability of measurements
- Accelerated schedule that ensures measurement validation by operating concurrently with SAGE III
- Simple design offers extensibility for greater utility:
  - Constellation for better coverage
  - IR extensibility for better H_2O, gain CH_4 & CO_2
  - Expansion to 12U to include spectrometer
  - Solar occultation at Venus or Mars



What have we been working on?

SAGE IV was funded in 2017 via NASA Earth Science Technology Office's Instrument Incubator Project (IIP) for a three-year technology development program.

Objectives:

Develop a laboratory SAGE IV prototype enabling a follow-on transition to a low-risk flight mission

- Demonstrate the radiometric performance of the system through laboratory and Sunlook testing
- Utilize commercially available parts to the extent possible (i.e., no R&D) with a clear path to flight

IIP completed in late 2020 (with some delays from COVID-19)

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SAGE IV Pathfinder Instrument Design

Telescope:

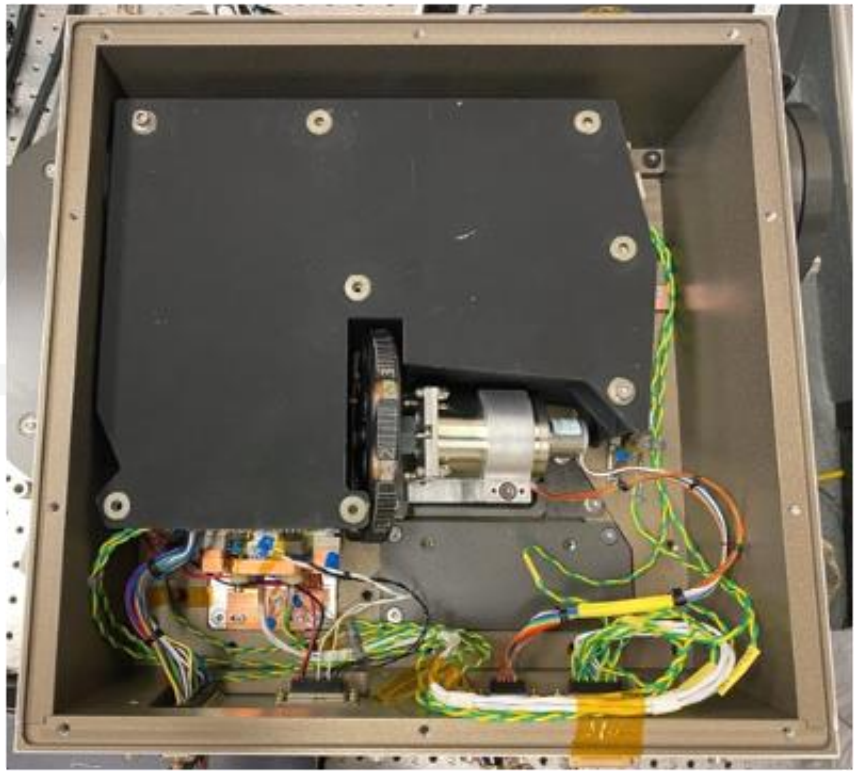
- Compact (<20x20x10cm), state-of-the art fabrication
- Excellent stray light mitigation demonstrated by testing at SDL
- Low- and matched-CTE materials meet requirements over potential CubeSat temperature ranges

Detector:

- 2D array for instantaneous spatial imaging
- Deep-well photodiode array for high-SNR in shot noise regime
- Silicon spectral range (UV/Vis/NIR) for low dark noise and simple temperature control (i.e., TEC instead of cryo-cooling)

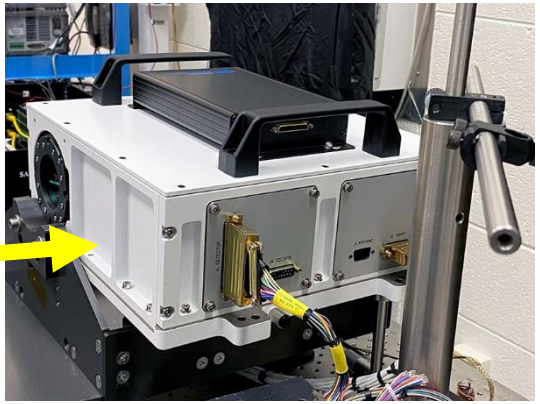
Filter Wheel:

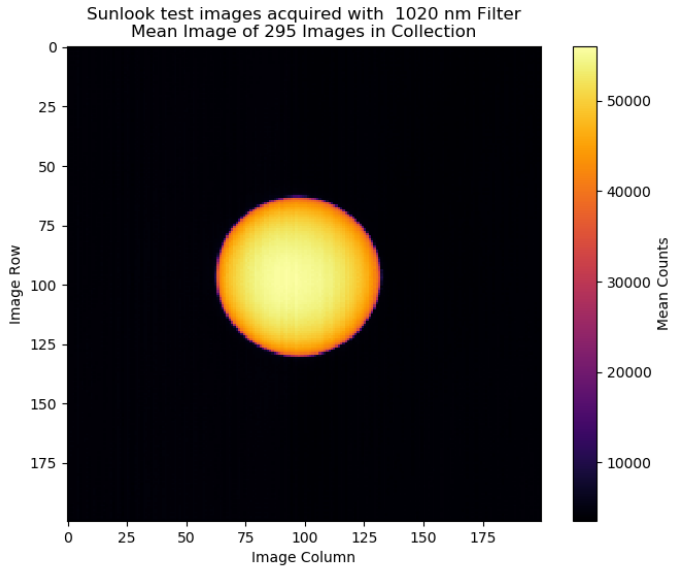
- Contains 7 science channels (similar to SAGE II)
- Enables on-orbit characterization during active science events
- Low motor speed / torque required (30 rpm)



Instrument Testing

- SAGE IV prototype integrated into surrogate chassis for testing.
- Extensive system testing and characterization performed in laboratory clean room with calibrated light source.
- Sunlook testing occurred outdoors with instrument surrogate chassis positioned on equatorial mount.
- Closed-loop control of the system maintained the Sun in the instrument FOV.
- Laboratory and Sunlook testing successfully assessed the integrated system performance.





SAGE IV is a pathfinder for affordable science continuity