SAGE IV Pathfinder
2019 Earth Science Technology Forum

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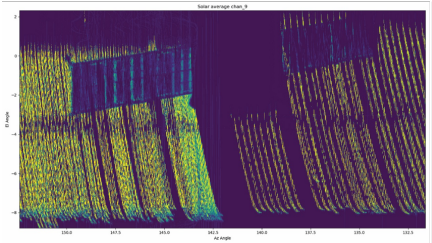
The SAGE III ISS Mission

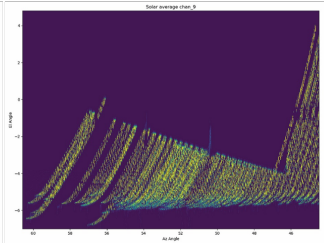
- The Stratospheric Aerosol and Gas Experiment III International Space Station Instrument continues to operate normally on orbit.
- One year and 11 months of Phase E operations/science data collection completed for a nominal 3-year mission.
- As of the week ending 31 May 2019, successful science acquisition is at **85.4%** of all orbit-theoretic occultation opportunities. The baseline science mission success requirement is 75%.
- We have acquired 18,611 solar and lunar occultation events since the start of Phase E. Most events that are missed have been blocked by ISS structures or visiting vehicles.

The SAGE III ISS Mission

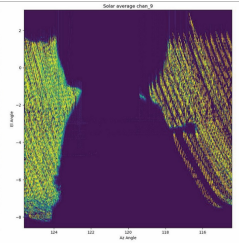
Progress



Dragon

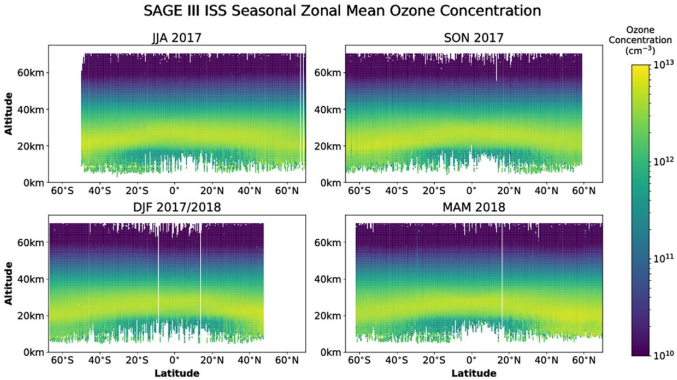


Soyuz



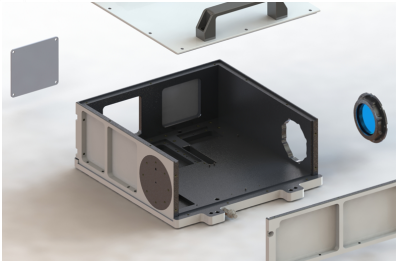
- ISS visiting vehicle blockage can be recognized in the SAGE III data. The usual suspects can be seen in the above azimuth/elevation plots of the SAGE III ISS Channel 9 data.
- Free flying instruments are not susceptible to such blockage.

The SAGE III ISS Mission



- The science community have been looking at the SAGE III ISS science data product release (v5.1) including stratospheric ozone, aerosol, and NO_2 profiles throughout the year.
- Data **have validated very well** with science community measurements. SAGE III ISS captured the August 2017 Pacific Northwest PyroCb event, the largest known such event.

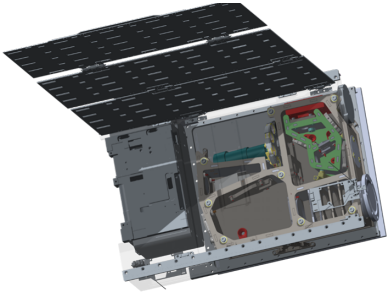
How Does SAGE IV Pathfinder Fit?



- Measuring the composition and state of the stratosphere using solar occultation has been a Langley specialty since 1975.
- The Clean Air Act mandates that NASA monitor atmospheric ozone, which is also identified in the DS Explorer program.

- Accurate records of stratospheric aerosols are a vital piece of the puzzle regarding climate change and are now a **Designated Observable** under the 2017 Decadal Survey.
- SAGE has historically been shown to be one of the best measurement systems for precision and accuracy of stratospheric ozone and aerosol retrievals.
- To keep ahead of technological trends and to bring value to continuing the SAGE data product line, we have been focused on developing a SAGE IV Pathfinder instrument that can produce the same quality measurement but with significant cost and size reduction.

How Does SAGE IV Pathfinder Fit?



- **Solar occultation imager** capable of SAGE-quality ozone and aerosol measurements
- Instrument and spacecraft potentially small enough to fit in a 6U CubeSat form factor
- Enables Sustainability and a constellation for better coverage.
- Future: IR extensibility for better H_2O, gain CH_4, and CO_2
- Future: Possible limb scattering instrument
- Future: Extensibility to Mars and Venus

- Now that data rates from orbit can support an imager for solar occultation, we can realize the benefits of solar imaging: absolute pointing is intrinsic, no assumptions are required for tracking mechanisms, atmospheric refraction is independently retrievable, and the anisotropy of the solar disk is measured.

IIP Goals and 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 with a clear path to flight
- Three Year Plan:
  - PY1: Develop requirements, process major procurements, build and test telescope
  - PY2: Test subsystems, finalize firmware and software, receive detector, integrate
  - **PY3: Test fully integrated system in laboratory environment and Sunlook, use lessons learned to perform mission studies**
- SAGE IV relevance to 2017 Decadal Survey Report
  - Aerosols and ozone are designated as observing system priorities.
  - SAGE IV meets definition of newly-recommended Venture-continuity missions by "bringing forward innovative approaches to sustain measurements at lower costs."

Internal Team

Name	Org	Role
Rob Damadeo	E303	Co-Principal Investigator
Charles Hill	E303	Co-Principal Investigator
Mike Obland	E304	Project Manager
John Leckey	D206	Systems Engineer
Tom Johnson	D207	Avionics & Integration Lead
Stanley Ikpe	D203	Electronics Lead/Detectors
Abou Traore	D211	Optical Eng. Support
Glenn Farnsworth	D211	Optical Eng. Support
Ed Nemie	D202	Mechanical Lead
Mark Banchy	D207	Software Developer
Elisa Leal Acevedo	D207	Software Developer

Name	Org	Role
Tak Ng	D203	Firmware Developer
Benjamin Kempton	D203	Firmware Developer
Meredith Hartzheim	D211	Opto/Elec. Tech
Tory Scola	D206	Thermal Analyst
Bob Wagner	D206	Structural Analyst
John Squires	D203	Electronics Eng. Support
Jon Hicks	D203	Test Operations
Jennifer Esparza	B103	Contract Specialist
Marie Avery	B602C	Program Analyst
Monique Bynum	B602C	Scheduling Assistant
Zain Merchant	D207	SAGE IV Intern

Involved Organizations

- **Quartus Engineering** — SSAI Subcontractor
  - Design and critical stray light analysis/testing of telescope
  - STOP analyses and tolerancing
  - Fabrication of telescope and surrogate chassis
  - Telescope/Electronics Volume Trade Study
- **Teledyne Imaging Sensors** — Partner Org.
  - Fabrication of the detector and its readout electronics
- **Raytheon Vision Systems** — Contractor
  - Loan of ground test detector and study of interfaces with flight detectors
- **Blue Canyon Technologies** — Partner Organization
  - Informs boundary conditions and design constraints
  - Provides interface between instrument and spacecraft
- **NASA Goddard Space Flight Center**
  - Developing integrated detector electronics
- **NASA Langley Research Center** — Funded by ESTO
  - Fabrication/Integration of Filter Wheel Assembly and TEC system
  - Embedded control systems (Firmware and Software)
  - Avionics, support systems, and in-house integration and testing
  - Overall management of work

At each step of development we are cultivating relationships with industry to ensure a viable production path for a future flight model.

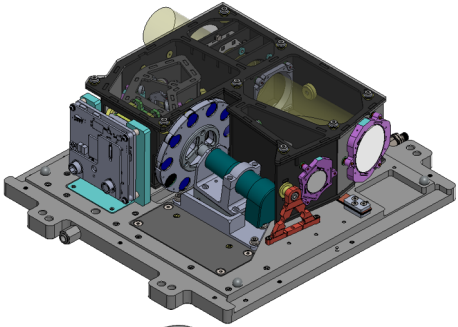
Detectors

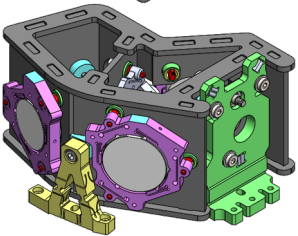
Teledyne HyViSI CHROMA (640 x 480)

- Detector Specifications
  - SiPIN Diode Array
  - Large potential wells for high SNR
  - Low pixel cross talk and no Charge Transfer Inefficiency
  - Individually registered pixels
  - Read noise and dark current are well within acceptable levels at room temperature
- Detector was obtained by the LaRC team from Teledyne Imaging Sensors in mid-March 2019.

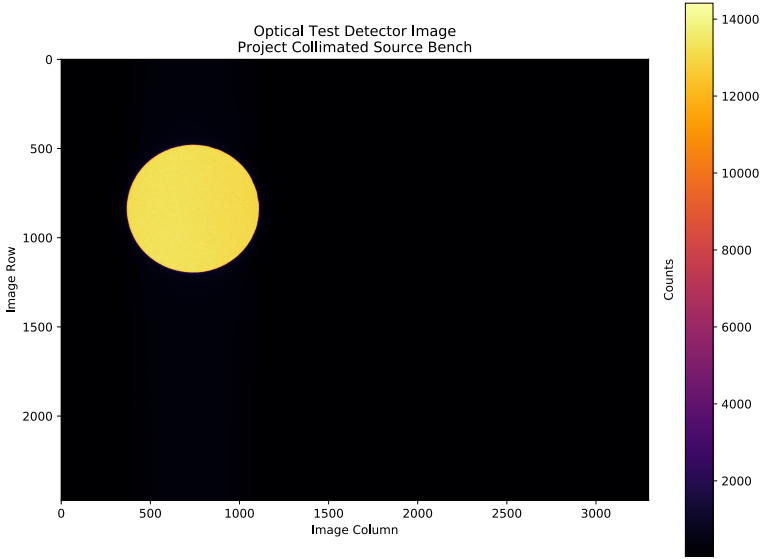
Thanks to supplemental funding from ESTO and the Langley Science Directorate, a contract was awarded to Raytheon Vision Systems on 20 Aug 2018 for loan of a test detector and support for studies of future flight detectors. Langley personal conducted a site visit/tour of Raytheon facilities in March 2019.

SAGE IV Pathfinder IIP Hardware





High-Pixel Density CCD Test Detector (600 nm)



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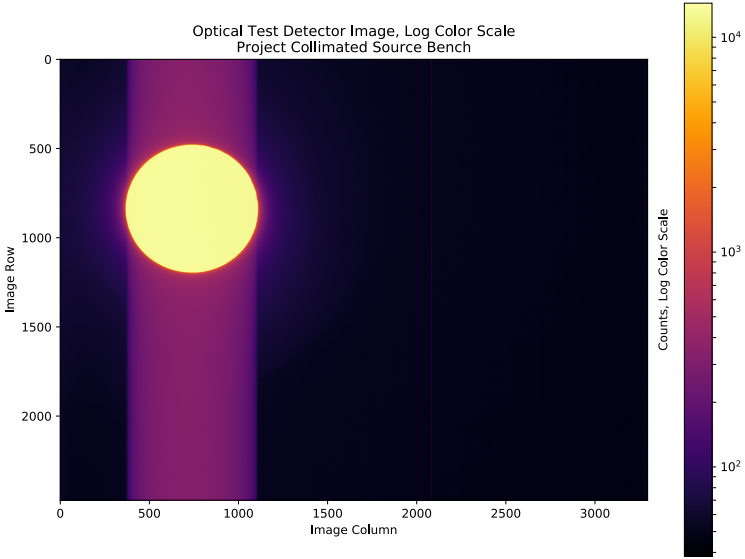

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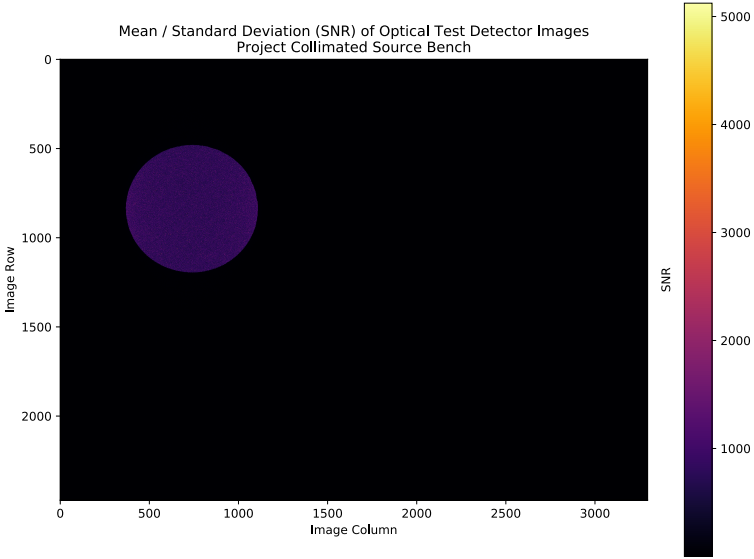
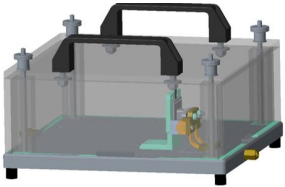


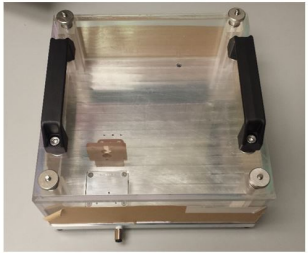
Upcoming SAGE IV Pathfinder Instrument Testing

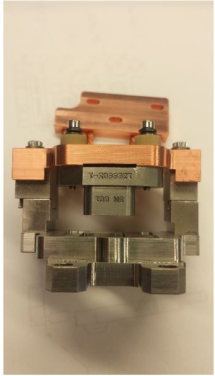
Key testing is planned to qualify the architecture and the design to meet science measurement goals prior to our End-to-End Indoor Test and Sunlook Test.

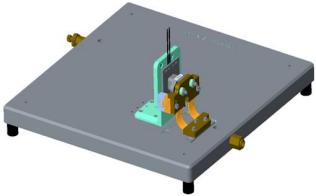
- TEC Model Validation Testing (control & stability)
- Detector Flat-field testing
- Formal Build 5 hardware/software integration test
- Time management and sync verification test
- Equitorial mount commanding test

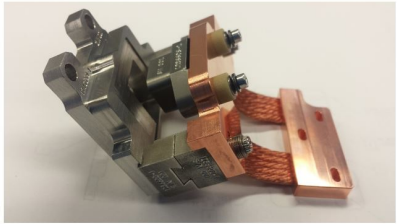
Detector TEC Control Validation Test Fixture











Subsystem Summary

- **Telescope**
  - Built and delivered by Quartus Engineering
  - Performance & stray light testing completed in PY1
- **Filter Wheel Assembly**
  - Fully assembled and integrated with motor/resolver into the surrogate chassis
  - Demonstrated optic replacement
- **Teledyne Detector**
  - Worked with Teledyne to resolve electronics problem in Teledyne FPE
  - NASA Langley Acceptance Testing is complete
  - 99.7% pixel yield and $> 5\ \mathrm{Me}^-$ well depths
  - Detector integration into SAGE IV chassis and focusing is **next**
- **Detector Thermal Design**
  - TEC Controller board was developed
  - TEC Control using firmware controller has been demonstrated
  - Preparing System for TEC System Testing in thermal chamber **to be performed within the month**

Subsystem Summary

- **Integrating Avionics into CubeSat Form Factor**
  - Working with GSFC to develop integrated electronics to incorporate detector electronics into the SAGE IV Instrument Controller
  - GSFC will develop electronics board, LaRC will develop software and firmware to sample data and collect images
  - Board to integrate Motor Controller into existing Instrument Controller firmware was developed
  - Motor Controller Firmware will be moved to the Instrument Controller Fabric
- **System Integraton**
  - Integrated System harness design is complete
  - GSE Chassis design is complete
  - Harness fab and integration is the next step
    (System is operational now, but this will provide ability to move in/outdoors easily)

Subsystem Summary

- **Instrument Controller Software**
  - Ground system via Ball Aerospace COSMOS
  - Motor Controller Board (MCB), Image Processing Board (IPB), Thermoelectric Cooler (TEC), and Equatorial Mount (EQM) interfaces complete
  - Successful demonstration of motor control, raw image downlink, build script integration with the COSMOS ground system for command and telemetry, and Instrument Controller Software and FPE to camera controller interface complete
  - Detector Image Capture via Focal Plane Array/Focal Plane Electronics complete
  - GPS PPS Central Time Management complete
  - Build 5 (final build save for any bug fixes) is expected June 2019 including Pointing Algorithm Control Loop and Science Event Management (Conops Implementation)

Subsystem Summary

- **Optics**
  - SAGE IV modeled in FRED to define the Engineered Diffuser for flat-fielding and for FPA pixel cross-calibrations. Simulations and lab test results agreed for 3 diffusers tested.
  - Bandpass Filters for 6 optical channels characterized and mounted inside SAGE IV filter wheel.

A Pathfinder for SAGE Miniaturization