SAGE III ISS Operations: A Two-Year Perspective on Operating on the ISS

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Abstract

The Stratospheric Aerosol and Gas Experiment III (SAGE III) was delivered to the International Space Station (ISS) on 23 February 2017. The SAGE III payload was robotically installed on EXPRESS Logistics Carrier-4 (ELC-4) on the S3 Truss and began acquiring science measurements on 17 March 2017. The SAGE III telescope and instrument assembly employs the methods of solar occultation and lunar occultation to retrieve near-global vertical profiles of atmospheric ozone, water vapor, nitrogen dioxide, multi-wavelength aerosol extinctions, and other gaseous species and atmospheric state parameters.

The activities on the ISS contribute to a dynamic operational environment. The attitude changes, EVAs, and the arrival and departure of vehicles require continual consideration when operating.

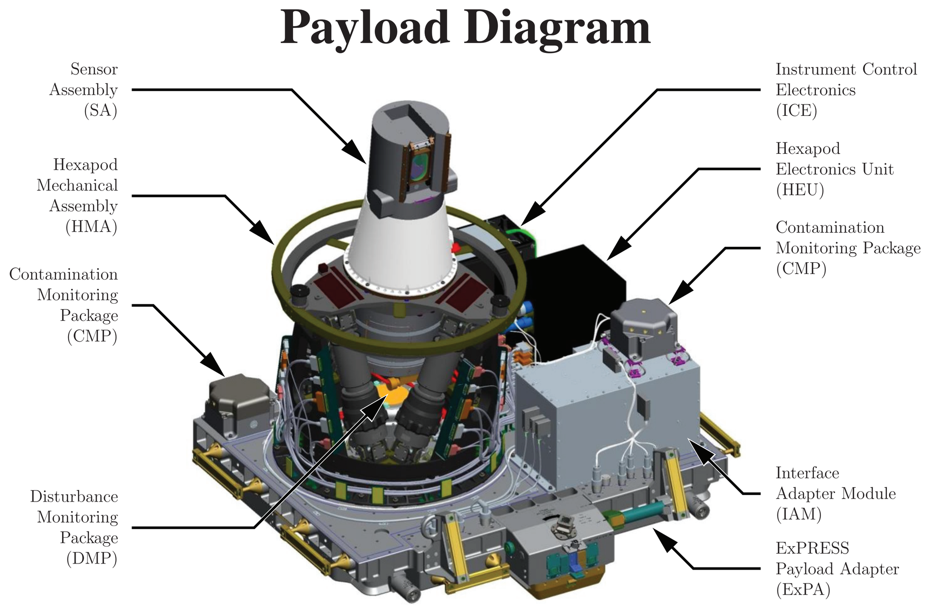
After operating for two years, the SAGE III payload has planned over 20,000 occultation events and acquired approximately 17,000. A significant number of the missed events were because of visiting vehicles blocking the field of view. Using instrument data from these blocked events, the SAGE III team has mapped the structure of the ISS from the perspective of the instrument.

Error Correction and Detection (EDAC) methods are necessary to preserve the functionality of the instrument software. On SAGE III the Hexapod Electrical Unit (HEU), which controls the orientation of the telescope, reports whenever an EDAC occurs. By analyzing the EDAC messages in the HEU telemetry, information concerning the orbital environment of the ISS can be obtained.

To be presented is a summary of operational considerations when working on ISS along with how instrument data can be used to map the structural and electromagnetic environment of ISS.

SAGE III Payload

Payload Diagram



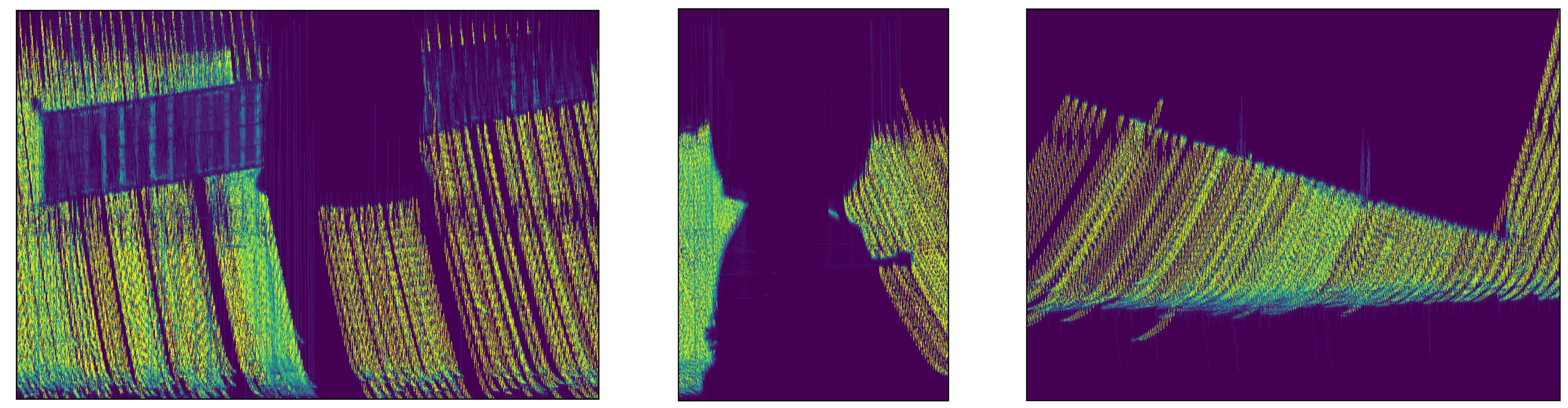
The SAGE III on ISS is comprised of five subsystems: the Sensor Assembly (SA) and its electronics unit, the Hexapod Mechanical Assembly (HMA) and its electronics unit, the Disturbance Monitoring Package (DMP), two Contamination Monitoring Package (CMP)s, and the Interface Adapter Module (IAM) flight computer.

SAGE III Science Measurement

All possible measurements that SAGE III can perform in an orbit.

SAGE III measures vertical profiles of the atmosphere using occultation through the atmosphere. In addition to the capability of performing solar and lunar occultation, SAGE III can take limb scattering measurements on the daylit side of the orbit, measuring the light scattered by the atmosphere.

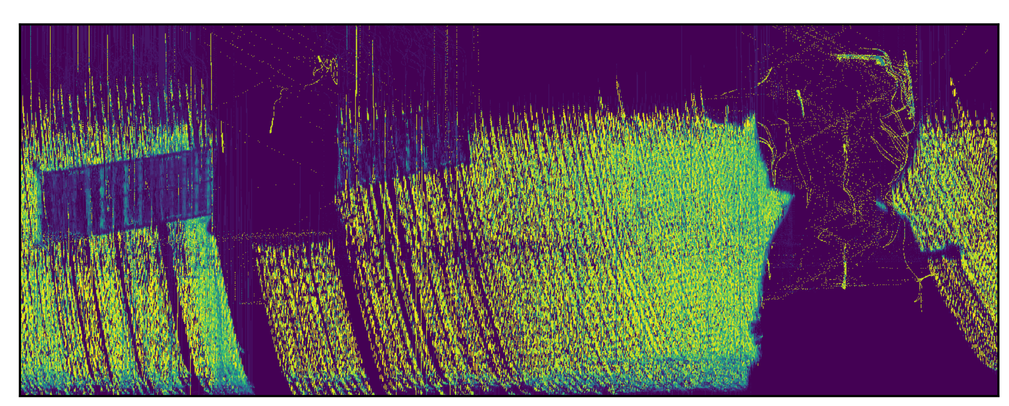
ISS Structural Blockages



Progress, Soyuz, and Dragon as seen by SAGE III

Approximately 43% of failed or incomplete events are caused by obstructions, affecting 6.6% of all events. By utilizing pointing telemetry and the intensity of the light seen by the SA for an event and overlaying several events, a picture of the instrument's field of regard can be created. Using only blocked events produces an image of the obstructing object. These images are composed of several dockings of each vehicle.

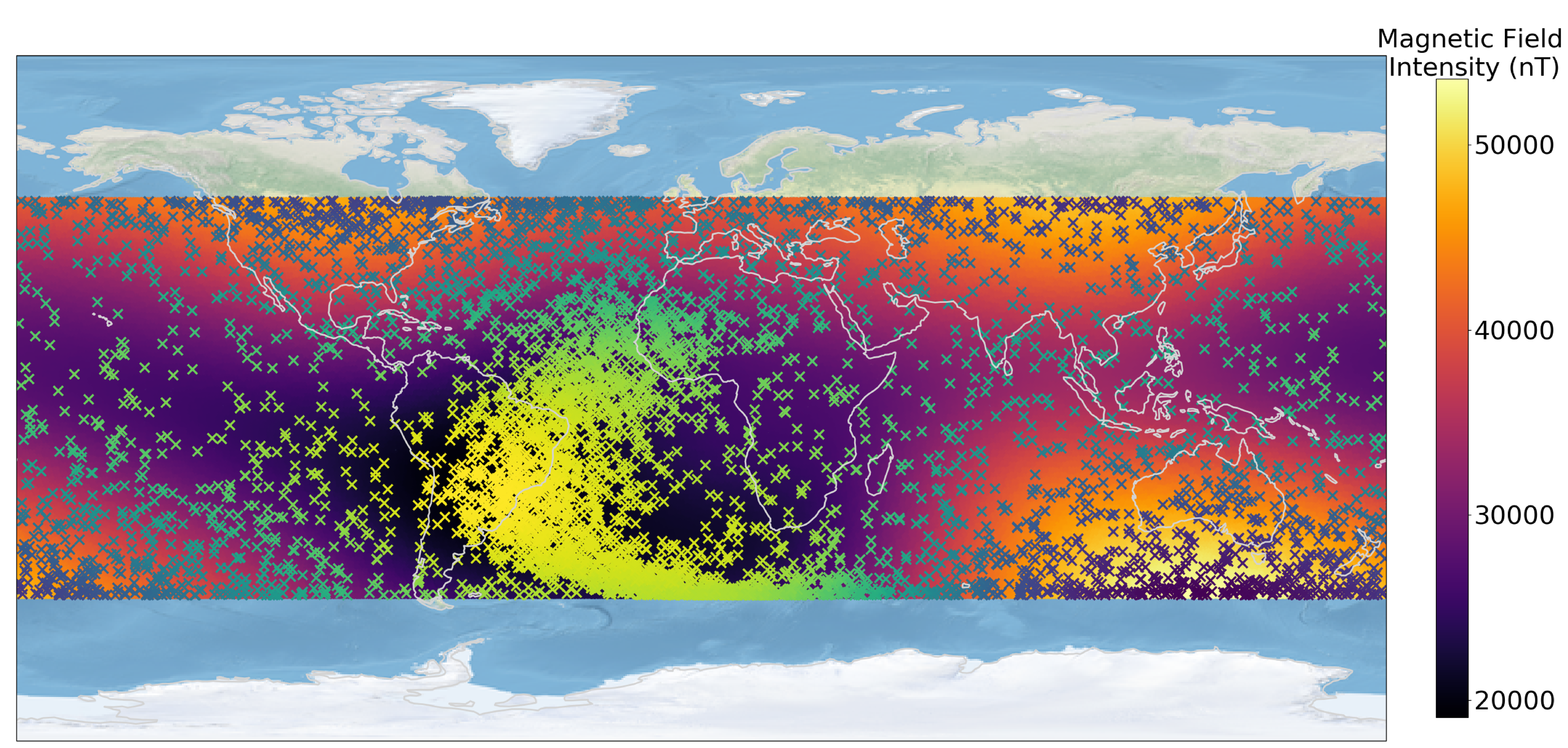
- Progress: The outline of the vehicle and it's solar arrays. Rather than completely obstructing the sun, the SA is able to track the sun through the individual panels on the array.
- Soyuz: The body of the vehicle and the periscope are clearly defined.
- Dragon: The downward sloped straight line in the middle of the image is produced by the bottom edge of the vehicle's solar panels, which are more opaque than those on Progress.



Progress and Soyuz visualized using failed solar and lunar events

Lunar occultation events operate without the attenuator in the optical path. Without the attenuator the instrument is more sensitive to stray light. As a result 18% of lunar events have locked onto glint off of Progress and Soyuz, which can be seen in the image to the left, or tracked reflections in the ISS solar arrays.

HEU EDAC Trending



HEU EDAC message locations plotted over the magnetic field intensity at the altitude of ISS (the color of the markers is solely for contrast).

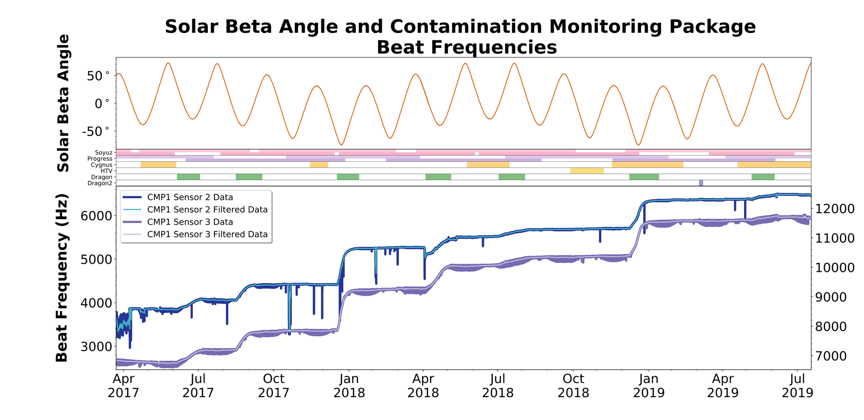
The SAGE III HEU telemetry provides operators with information about error detection and correction for single bit errors in the memory. These single bit errors are generally the result of an energetic particle hitting the memory of the HEU. Between April 2017 and February 2019 the HEU reported 4,258 EDAC messages.

SAGE III operations can use the information in the EDAC messages to trend the health of the memory in the HEU and to find the location of ISS at the time of the error to create a geographical map of where these EDACs are occurring. The map of EDACs shows a high density around the South Atlantic Anomaly (SAA).

The SAA is an area where the Inner Van Allen Radiation Belt is closest to earth and the magnetic field is the weakest. This leads to an increased flux of particles, especially above an altitude of 200 km. The ISS is heavily shielded to protect the astronauts inside, however external payloads are exposed to these energetic particles and can be affected by it.

The SAA is the most prominent single factor to the occurrence of these single bit errors and nearly 50% of all EDAC messages reported by the HEU occur in or shortly after passing through the SAA. Of the other 50%, a portion occur in the auroral zones with the remaining points randomly distributed over the globe.

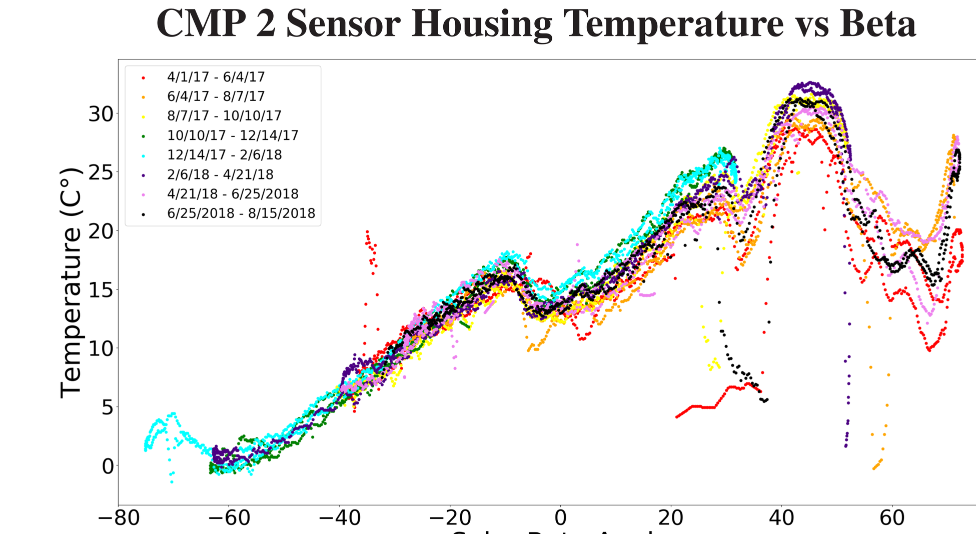
Operational Considerations



- Contamination - The SAGE III instrument is sensitive to molecular contamination. Eight Mark 24 TQCM sensors made by QCM Research monitor the contamination environment around SAGE III. Thruster firings and out gassing from vehicles are the primary sources of contamination. To protect the optics, a quartz contamination window, which is normaled open during events, can be commanded to remain closed during periods of high contamination. The window has a negilegable effect on the data from events taken during these periods.
- Thermal - The temperature of SAGE III is highly correlated with solar beta angle. At beta angles below negative 70, operations has to power off the SA to keep the temperatures below limits.
- OPM/Attitude Changes - SAGE III can only operate when ISS is oriented in positive XVV or negative XVV. In all other configurations, SAGE III is in SAFE mode to protect the instrument.
- Reboost - After determining that there were no contamination concerns, no actions are necessary from the operations team. One event has failed when a reboost occurred in the middle of it causing the motion of the sun to be faster than the instrument could track.
- EVA - Unless the EVA is out on the S3 Truss where SAGE III is located, no action is required.
- Docking/Undocking - Similar to a reboost, the docking or undocking of vehicles present little contamination and does not require any action from the operators.
- Data downlink - Occasionally not all of the instruments telemetry and data is transmitted by ISS to the ground, in this case the data has to be read again from the solid state memory on board SAGE III.

Overall there have been no appreciable impacts on the SAGE III instrument or the science measurements.

CMP 2 Sensor Housing Temperature vs Beta



Scan Head Temperature vs Beta