SAGE III ISS
Environment Characterization Products

Payload Operations Integration Working Group External Splinter

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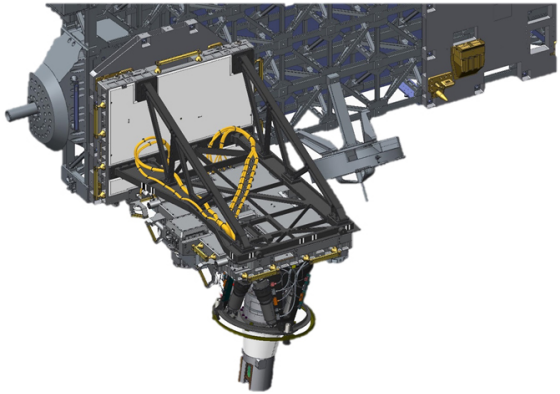
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23 October 2018

SAGE III ISS Environment Characterization Products
Amy Rowell
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Who Cares?
Instrument
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How Do They Work?
Observations
Disturbance Monitoring Packages
What is it?
Observations
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Payload Overview



The Stratospheric Aerosol and Gas Experiment (SAGE) III is an external payload on the International Space Station (ISS) launched on SpaceX CRS-10 on 19 February 2017 and robotically installed on ExPRESS Logistics Carrier-4 (ELC-4). First light was acquired on 17 March 2017.

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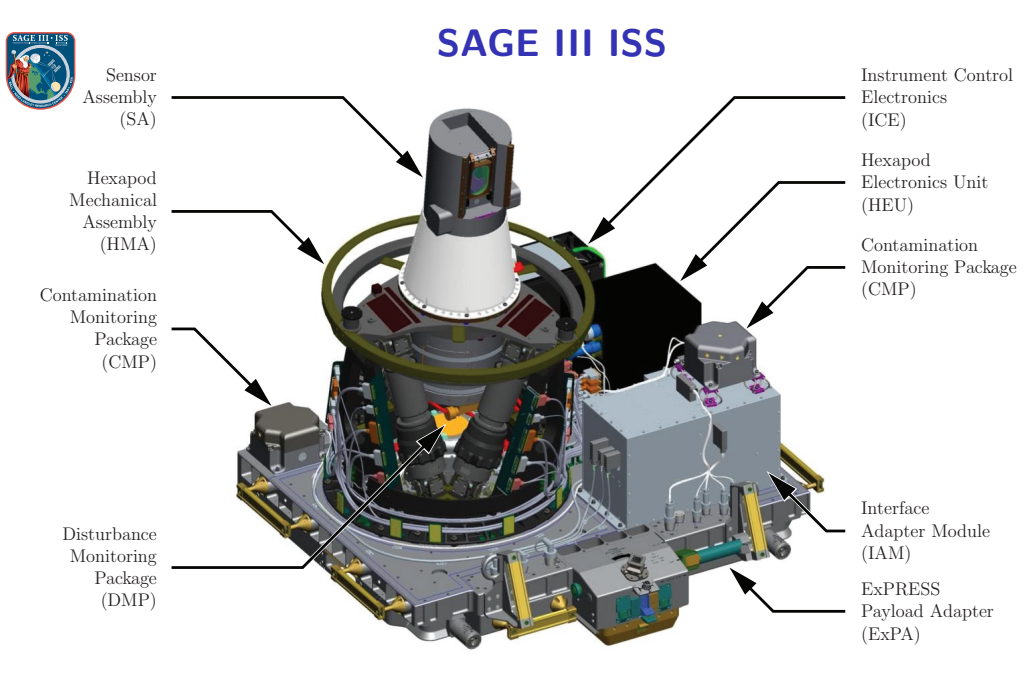
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SAGE III ISS



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Why are these Measurements Important?

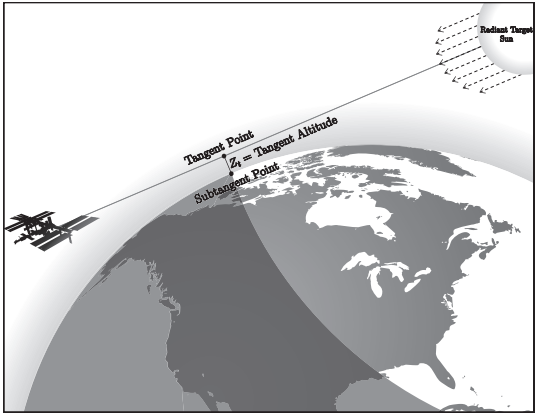
- The Clean Air Act mandates that NASA monitor atmospheric ozone.
- Accurate records of stratospheric aerosols are a vital piece of the puzzle regarding climate change.
- SAGE has historically been shown to be one of the best measurement systems for precision and accuracy of stratospheric **ozone** and **aerosol** retrievals.



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SAGE III Instrument

- Occultation: Measures the light transmitted through atmospheric gases, clouds, and aerosols using emissive target (Sun or Moon)
- Passive remote sensor
- Can reliably measure vertical profiles of aerosols and trace gases in the stratosphere and upper troposphere



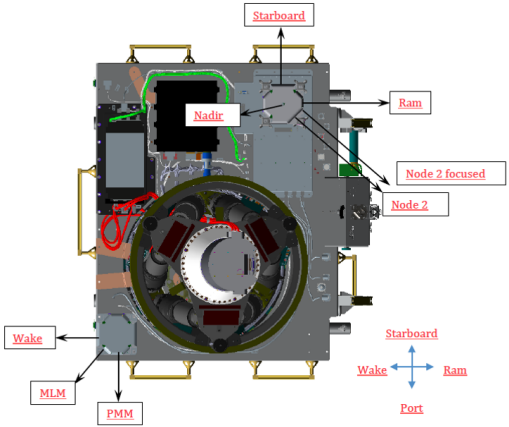
- The SAGE series of instruments is considered the international standard in **ozone** and **aerosol** for accuracy and stability.

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SAGE III Contamination Monitoring

- Why does SAGE III conduct contamination monitoring?
  - The instrument optics are susceptible and sensitive to contamination.
  - The goal of the Contamination Monitoring Packages (CMPs) is to aid in Fault Detection Isolation and Recovery (FDIR) efforts to minimize contamination impacts to the payload and by extension the science data product.
- The instrument contamination window exists to protect the telescope.
  - The flight computer FDIR system monitors CMP telemetry and has the ability to automatically close the contamination window if necessary.
  - The window can be manually commanded to close.
- CMP measurements aid the SAGE III team to determine where to stow the instrument scan head away from contamination sources.

Contamination Monitoring Package (CMP)s



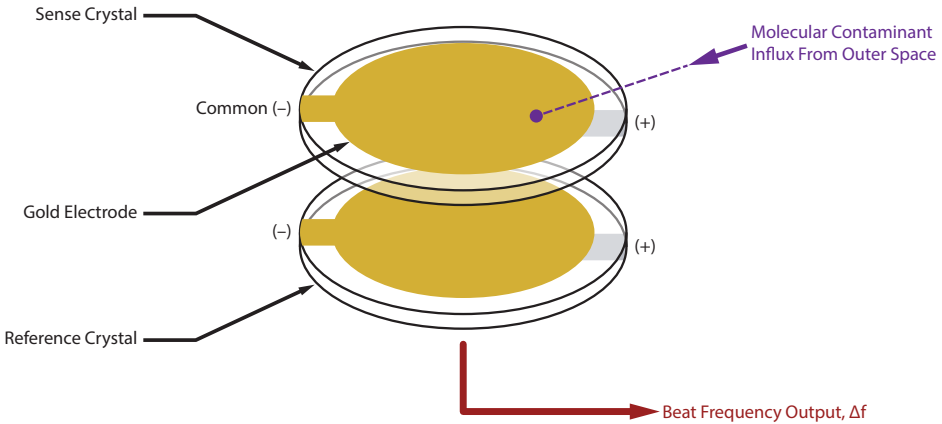
- Two CMPs monitor particulate contaminant flux in the 2π steradian solid angle on the payload side of the ExPRESS Payload Adapter.
- The packages are comprised of eight Quartz Crystal Microbalance (QCM) sensors.

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SAGE III Contamination Environment

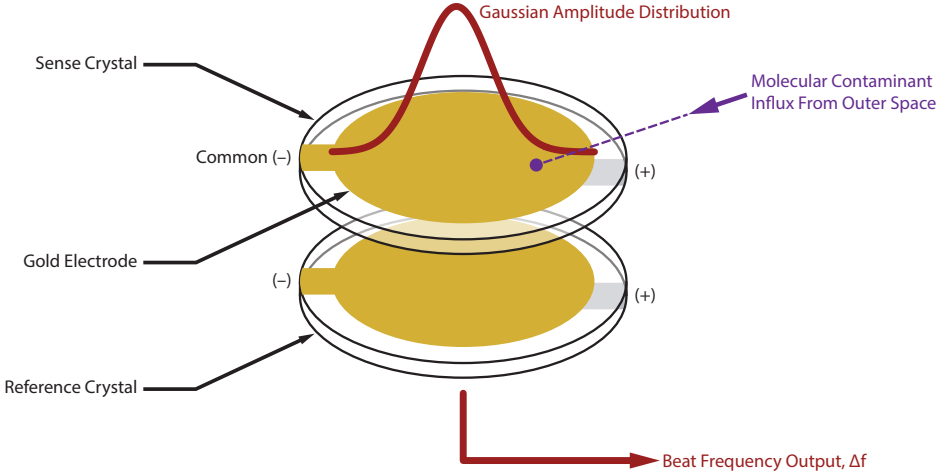
CMP, Sensor	Half Angle	Direction of View	Field of View
CMP1, Sensor0	70.3°	Starboard	ELC-4
CMP1, Sensor1	70.3°	Ram	N2 Zenith and Nadir, partially N2 Fwd
CMP1, Sensor2	50°	Node 2 Focused	N2 Zenith and Nadir, possibly N2 Fwd
CMP1, Sensor3	70.3°	Node 2 Broad	N2 Zenith and Nadir, N1 Nadir, possibly N2 Fwd
CMP1, Sensor4	70.3°	Nadir	N2 and N1 Nadir depending on vehicle, MRM1
CMP2, Sensor0	70.3°	Wake	MRM1, MRM2, DC1, SM Aft
CMP2, Sensor1	70.3°	PMM	N2 Zenith and Nadir, N1 Nadir, MRM1, MRM2, DC1, SM Aft, possibly N2 Fwd
CMP2, Sensor2	70.3°	MLM	MRM1, MRM2, DC1, SM Aft, slightly N2 Nadir

How Quartz Crystal Microbalances Work



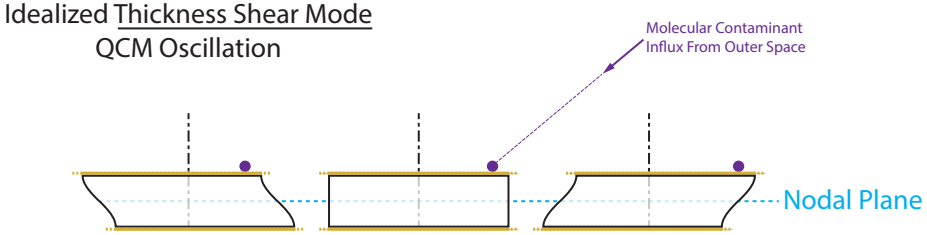
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How Quartz Crystal Microbalances Work



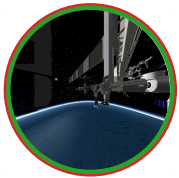
How Quartz Crystal Microbalances Work

- Two Sunwise-cut quartz crystals vibrate in resonance and a resulting beat frequency is telemetered at 1 Hz.
- The SENSE crystal is exposed to the environment and the REFERENCE crystal is shielded below.
- The electrode configuration is designed to apply acoustical "energy trapping" causing the vibration amplitude Gaussian shape.
- Voltage is applied to the crystal by the electrodes inducing the piezoelectric effect of quartz, vibrating the crystals in thickness shear mode.

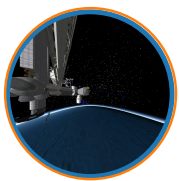


Thermoelectric Quartz Crystal Microbalance (TQCM)

- Mark 24 Thermoelectric Quartz Crystal Microbalance (TQCM)s purchased from QCM Research
  - Maximum beat frequency in the linear range is conservatively about 150kHz.
  - Crystal temperature is controlled by a single-stage Peltier heat pump.
  - Temperature range: $-25°C$ to $+80°C$
  - Burnoffs raise the TQCM temperature to $80°C$
  - Active surface area is 0.317 cm^2
- Contaminants are **ad**sorbed on the gold electrode covering the sense crystal.
- Solar Flux Effect
  - QCMs are sensitive to solar radiation. The resulting temperature gradient causes a stress-induced frequency change.
  - The amplitude of frequency change induced by thermal radiation is dependent on the solar beta angle.
  - The Sun-wise cut crystal reduces internal stresses and drastically reduces solar-flux-induced frequency change.



MLM FOV



Node2 FOV

Solar Beta Angle and Contamination Monitoring Package Beat Frequencies

Solar Beta Angle

50 °
0 °
-50 °

Soyuz
Progress
Cygnus
HTV
TGA
Dragon

Beat Frequency (Hz)

0
1000
2000
3000
4000
5000

Relative Mass Deposition Per Sensor Surface Area (ng/cm²)

2000
4000
6000
8000
10000

CMP1 Sensor 2 Data
CMP1 Sensor 2 Filtered Data
CMP2 Sensor 2 Data
CMP2 Sensor 2 Filtered Data

Apr 2017
May 2017
Jun 2017
Jul 2017
Aug 2017
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Surface Chemistry

The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption or chemisorption.

Physisorption

- Characteristic of weak Van der Waals forces
- Example: Water condensing on a window
- Reversible chemical reaction that is not highly surface-dependent
- Adsorbed constituents can be burned off, scrubbed by atomic oxygen in low Earth orbit (as seen on our Ram-facing sensor), or may spontaneously desorb.

Chemisorption

- Characteristic of covalent bonding
- Example: Rust on an iron nail
- Irreversible surface chemistry reaction
- UV photofixation can encourage chemisorption
- Unable to burnoff our two Node 2-facing sensors

Mass and Thickness Calculations

TQCMs are highly precise and accurate for rigid, homogeneous thin films. However, when these assumptions are not met viscoelastic effects come into play and Sauerbrey calculations are precise but not accurate.

"Sauerbrey Mass"

Mass per unit area,

$$\Delta m = \frac{-A\sqrt{\rho_q \mu_q}}{2{f_0}^2}\Delta f, \qquad (1)$$
$$= -S \cdot \Delta f.$$

"Sauerbrey Thickness"

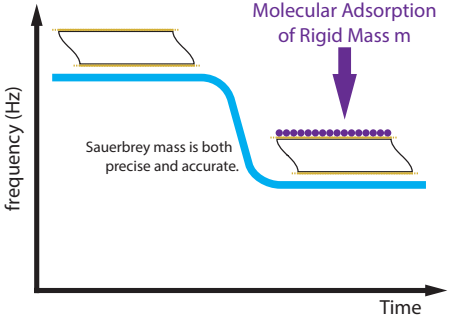
Thickness for a known contaminant density,

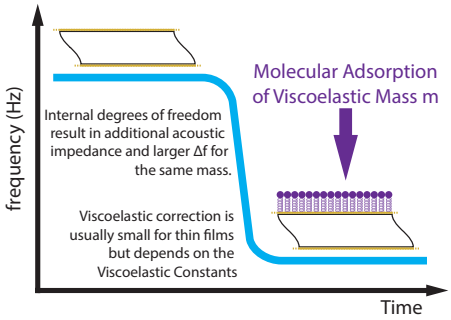
$$d_f = \frac{-S}{\rho_f}\Delta f. \qquad (2)$$

A = active surface area (cm^2),
μ_q = quartz shear modulus ($\frac{g}{cm \cdot s^2}$),
Δf = change in frequency (Hz),
ρ_q = quartz density ($\frac{g}{cm^3}$),
f_0 = resonant frequency (Hz),
and ρ_f = film density ($\frac{g}{cm^3}$)

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Mass and Thickness Calculations





- The Sauerbrey mass is the maximum possible mass deposition.
- The Sauerbrey mass sensitivity constant is $S = 1.965 \frac{ng}{Hz \cdot cm^2}$ for a 15 MHz Sunwise-cut quartz crystal.

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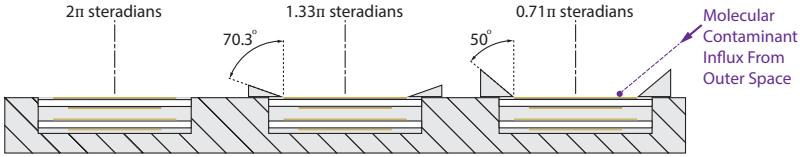
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Field of View Considerations

For 15 MHz Crystals



Clausing Conduction Factor	1.00	1.00	1.00
Effective Sauerbrey Sensitivity	1.96 ng / $cm^2 \cdot Hz$	1.96 ng / $cm^2 \cdot Hz$	1.96 ng / $cm^2 \cdot Hz$

Geometry dictates that a Clausing conduction factor be applied to the crystal Sauerbrey sensitivity based on the sensor field of view.

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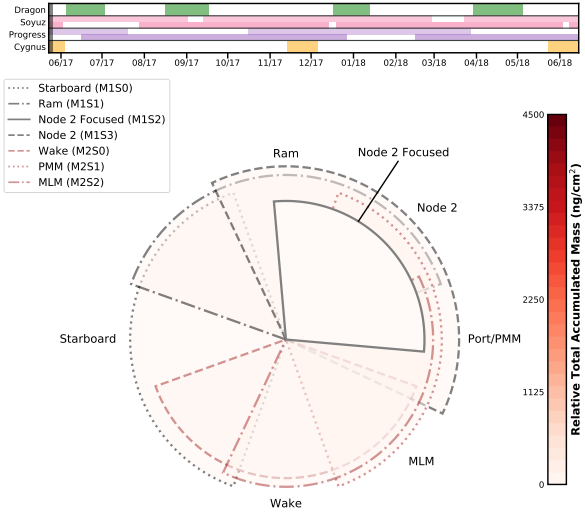
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SAGE III ELC-4 Observed Contamination Deposition

Contamination Heat Map



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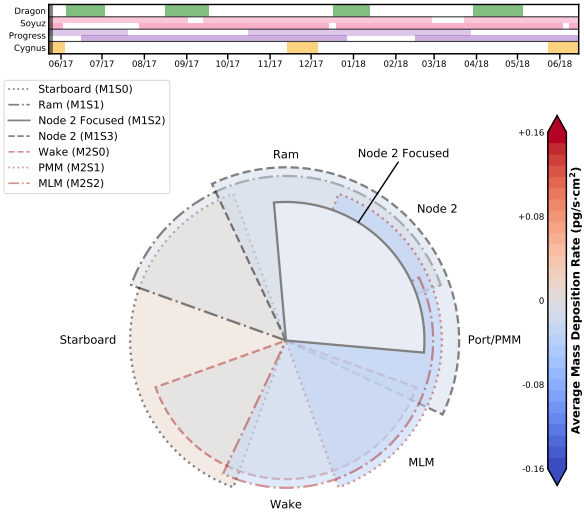
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SAGE III ELC-4 Observed Contamination Rate

Contamination Heat Map



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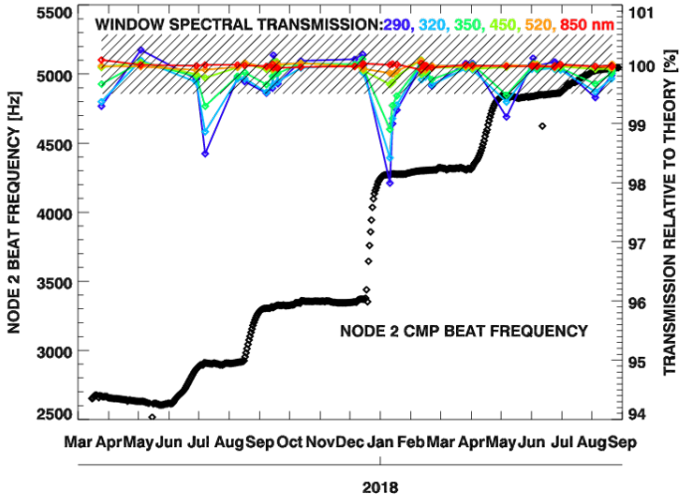
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SAGE III Contamination Window Transmission



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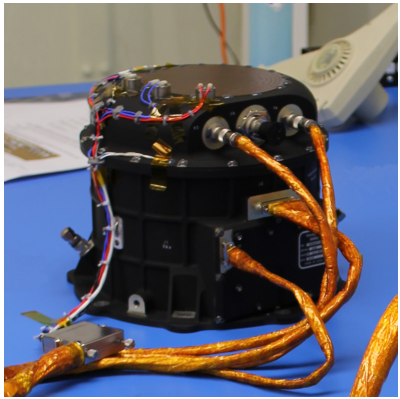
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Disturbance Monitoring Package (DMP)



- The DMP is a Honeywell Miniature Inertial Measurement Unit comprised of three orthogonal ring laser gyros to measure angular rates in three orthogonal axes.
- The SAGE III science retrieval algorithm requires precise pointing knowledge with respect to Earth and the radiant target.
- The DMP's primary requirement is to flag periods when vibration conditions can negatively impact the science data product.

Disturbance Monitoring Package (DMP)

Additional analyses in-work from the DMP

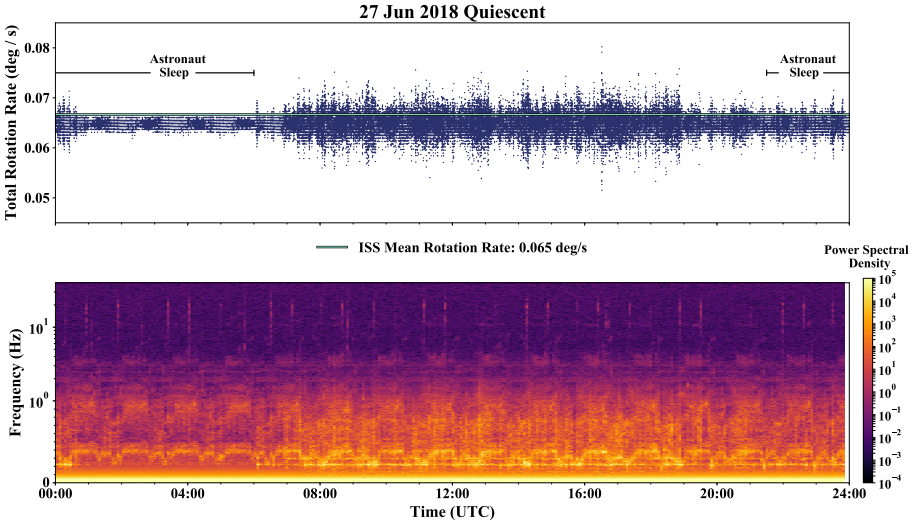
- Corrections for jitter in science data products
- Better accounting of spacecraft attitude changes
- Improve data usability lower into troposphere where solar geometry is obscured



- Creates applicability to new data users which expands existing user community
- Absolute attitude product
  - Improved latitude/longitude/altitude registration for limb scattering measurements
  - Payload vibration environment at ELC-4 beneficial to ISSP and external payload community

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Quiescent Day



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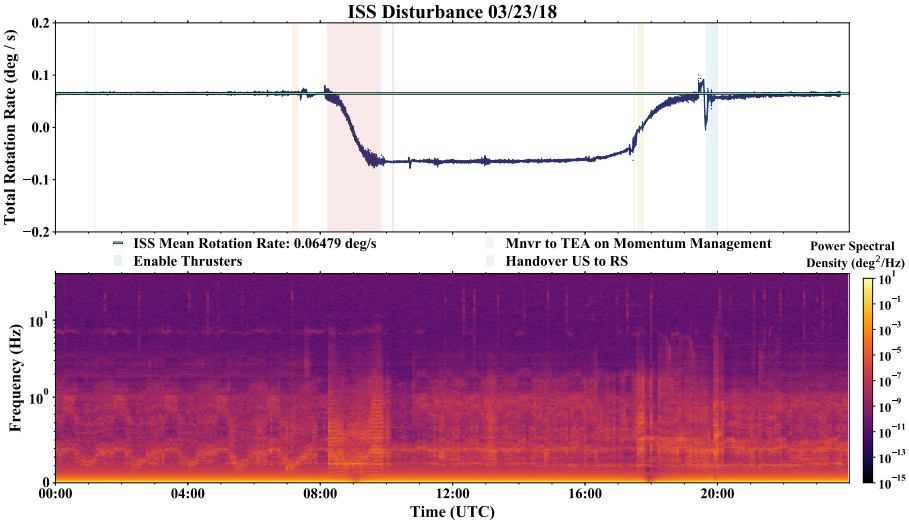
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Soyuz Docking



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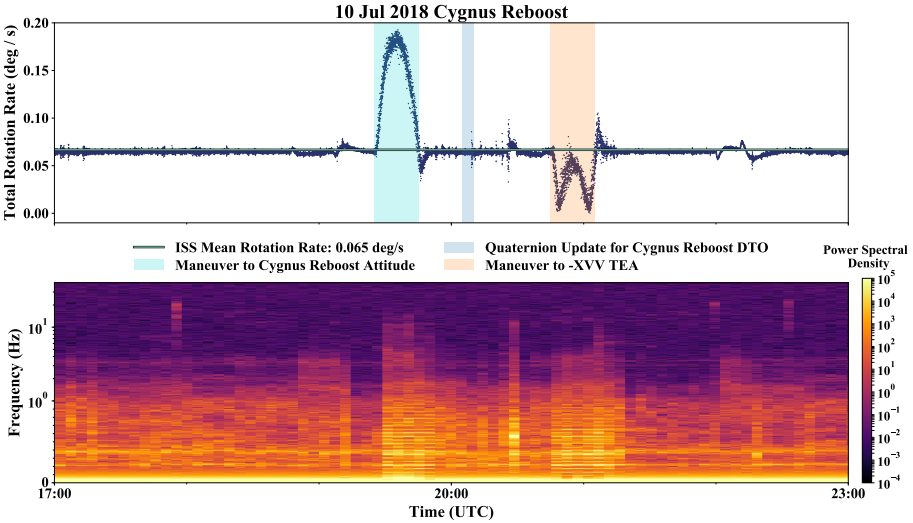
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Cygnus Reboost



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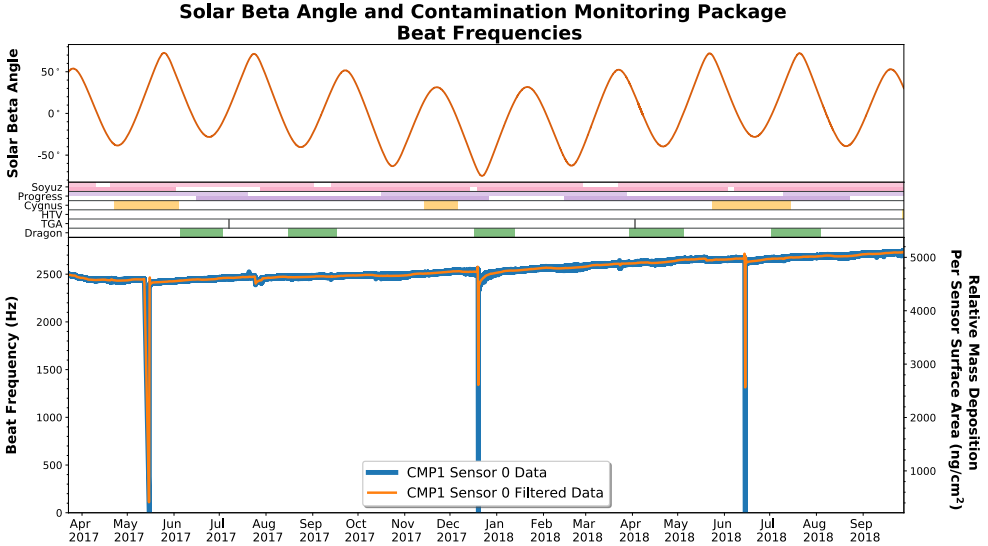


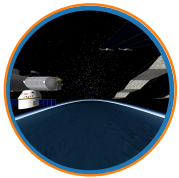
Image Credit: NASA Astronaut Ricky Arnold



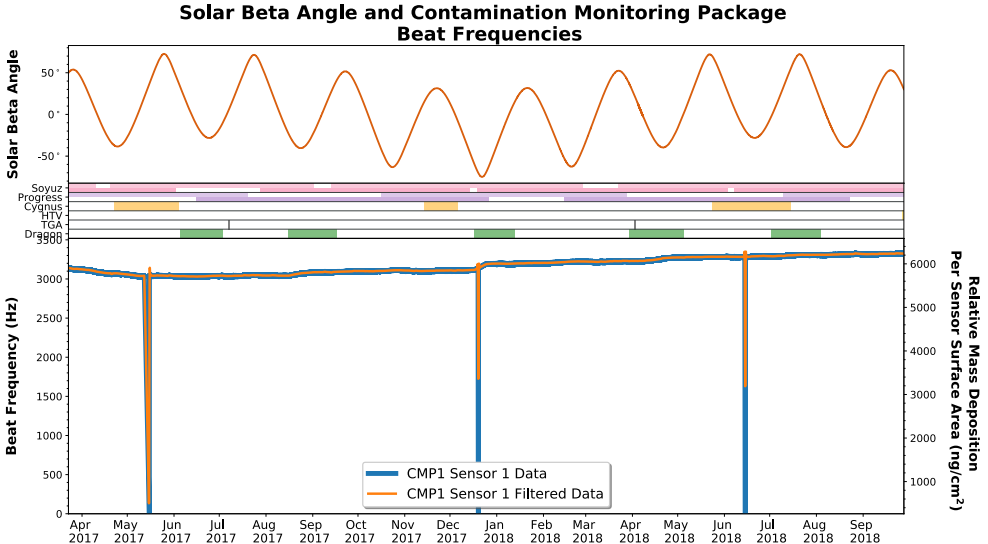


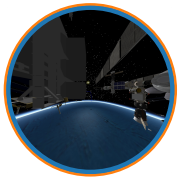
Backup


Solar Beta Angle and Contamination Monitoring Package
Beat Frequencies
Solar Beta Angle
50°
0°
-50°
Soyuz
Progress
Cygnus
HTV
TGA
Dragon
Beat Frequency (Hz)
2500
2000
1500
1000
500
0
Relative Mass Deposition
Per Sensor Surface Area (ng/cm²)
5000
4000
3000
2000
1000
CMP1 Sensor 0 Data
CMP1 Sensor 0 Filtered Data
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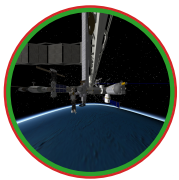


Ram FOV

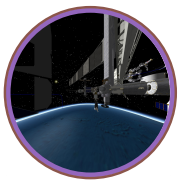

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Solar Beta Angle
50°
0°
-50°
Soyuz
Progress
Cygnus
HTV
TGA
Dragon
Beat Frequency (Hz)
3500
3000
2500
2000
1500
1000
500
0
Relative Mass Deposition
Per Sensor Surface Area (ng/cm²)
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Wake FOV



PMM FOV



MLM FOV

