Space Debris Sensor Recent Anomaly Attribution Scenario

-or-

A Cautionary Tale of How, While Trying to Measure the Source of One Type of Anomaly, We Ended Up Experiencing Anomalies of a Completely Different Kind…

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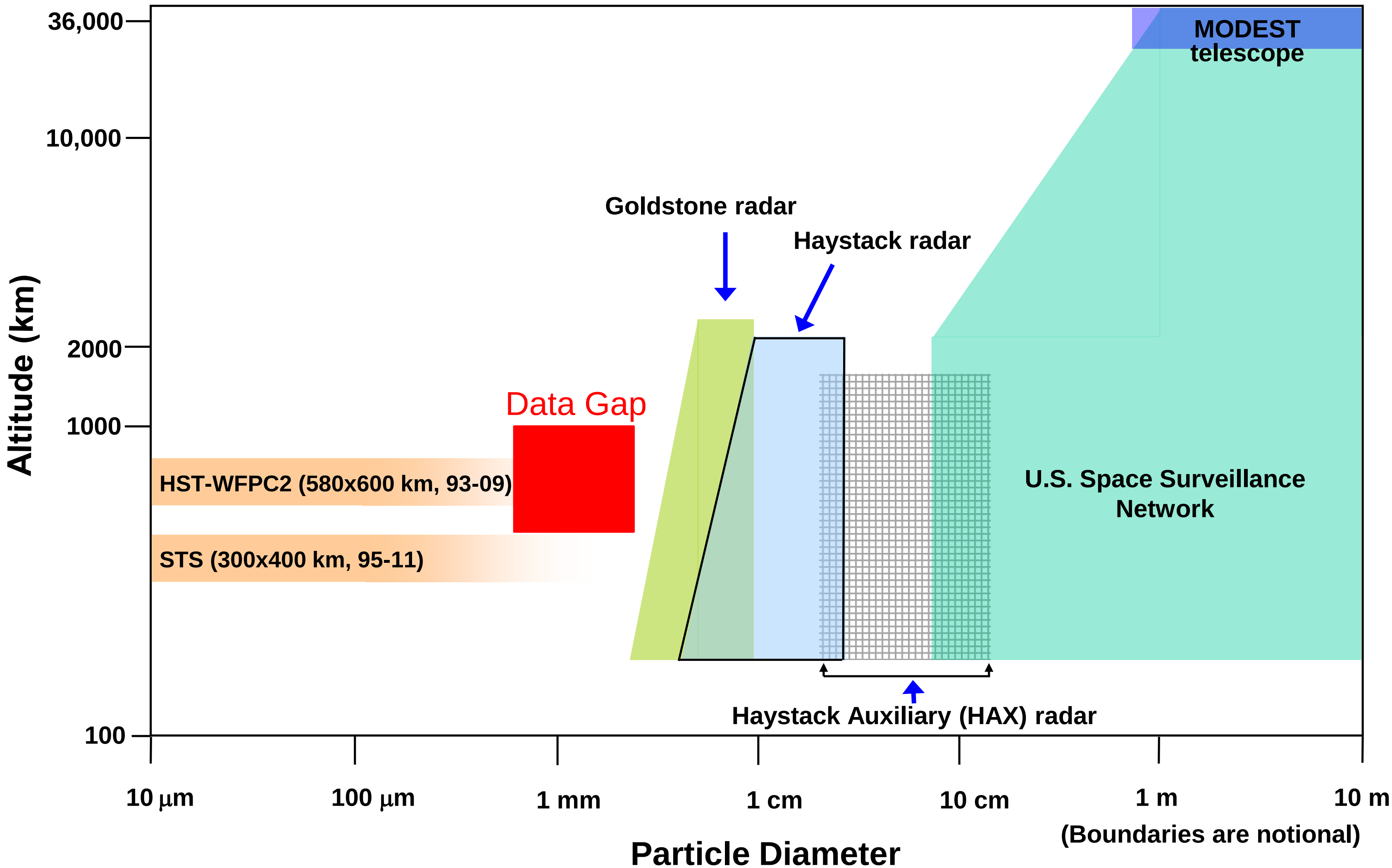
Spacecraft Anomalies and Failures Workshop
11-12 December 2018, Chantilly, Virginia

SDS Introduction

- **The Space Debris Sensor (SDS) is an instrument designed as a part of the DRAGONS program by NASA's Orbital Debris Program Office (ODPO) to provide statistical *in situ* data on the orbital debris population that is too small for ground-based remote sensing**
  - **Information on debris ranging from 50 μm to 500 μm+ in size**
  - **Estimates of this small debris population are currently based on inspection of exposed surfaces returned on Shuttle (retired 2011)**
  - **Technology intended to provide data to be used to update the NASA Orbital Debris Engineering Model (ORDEM)**

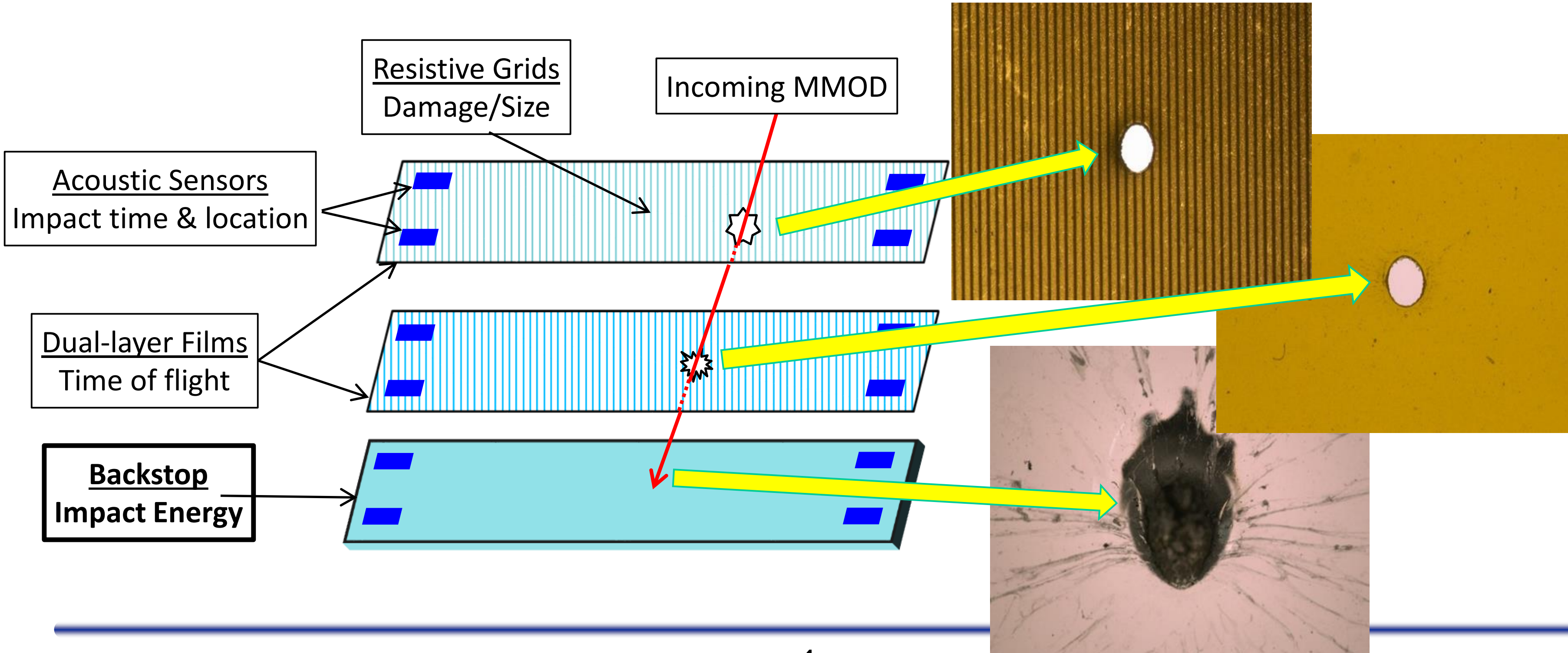
National Aeronautics and Space Administration

Orbital Debris Measurement Coverage: SDS to address Data Gap at ISS altitudes as a technology demonstration



How Does SDS Work?

- SDS combines dual-layer thin films, an acoustic sensor system, a resistive grid sensor system, and sensored backstop to provide real-time impact detection and recording capability
  - Impact event ***observable data*** includes: **Impact times, impact locations, hole size, and backstop energy/impulse**
  - ***Derived data*** includes: **particle size, impact speed, impact direction, and qualitative and quantitative particle mass density**



SDS Introduction and Goals

- First flight demonstration of the Debris Resistive/Acoustic Grid Orbital NASA-Navy Sensor (DRAGONS) developed and matured by the ODPO
  - While other debris sensors have been flown before, this combination of technologies to thoroughly characterize the debris is unprecedented
  - The first flight demonstration in what is hoped to be a new generation of operational sensors flying at higher altitudes to fully characterize the debris environment

SDS Introduction and Goals

- **The Space Debris Sensor (SDS) is a Class 1E NASA technology demonstration external payload aboard the International Space Station (ISS)**
  - Limited budget
  - Accelerated schedule
  - Risk-managed experiment

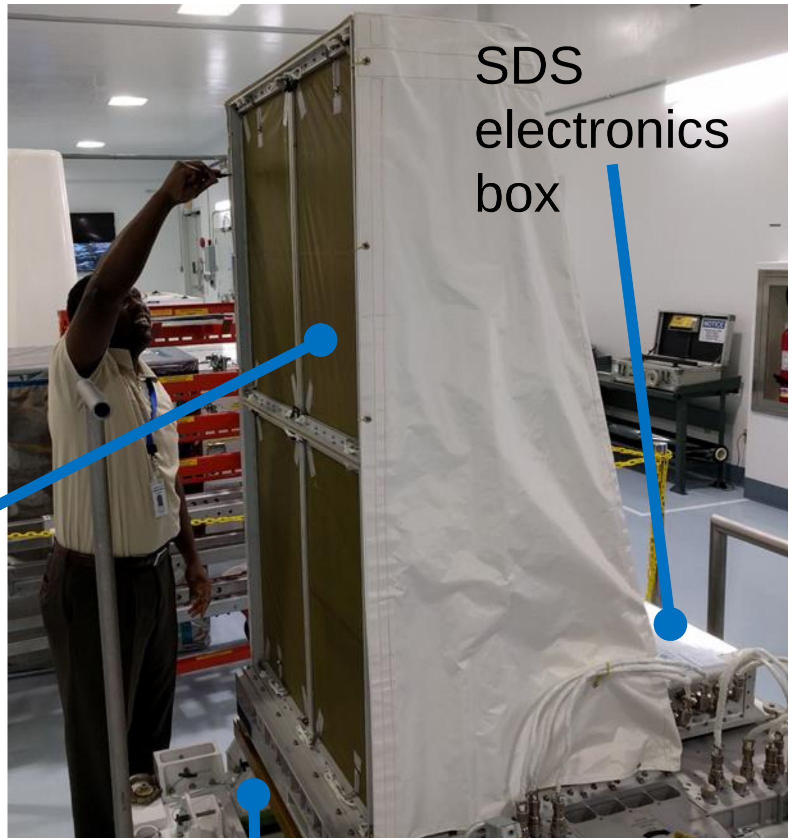
- **Primary goal – Technology demonstration**

- **Secondary goal – Take environment data**

NASA Class 1E Hardware Overview

- "E" for *Experimental*
- New flight hardware classification intended to streamline flight certification
  - All the risk is assumed by the funding authority, in this case, the ISS Program Office (ISSPO)
  - Payload shall not perform mission critical functions
  - Shall not compromise safety of ISS crew or vehicle or SpaceX Dragon launch vehicle
- This hardware classification development and deployment coincident with SDS development life cycle
- Also motivated by NASA *Revolutionize ISS for Science and Technology* (RISE) initiative

SDS Overview
Principal Components & Vital Statistics



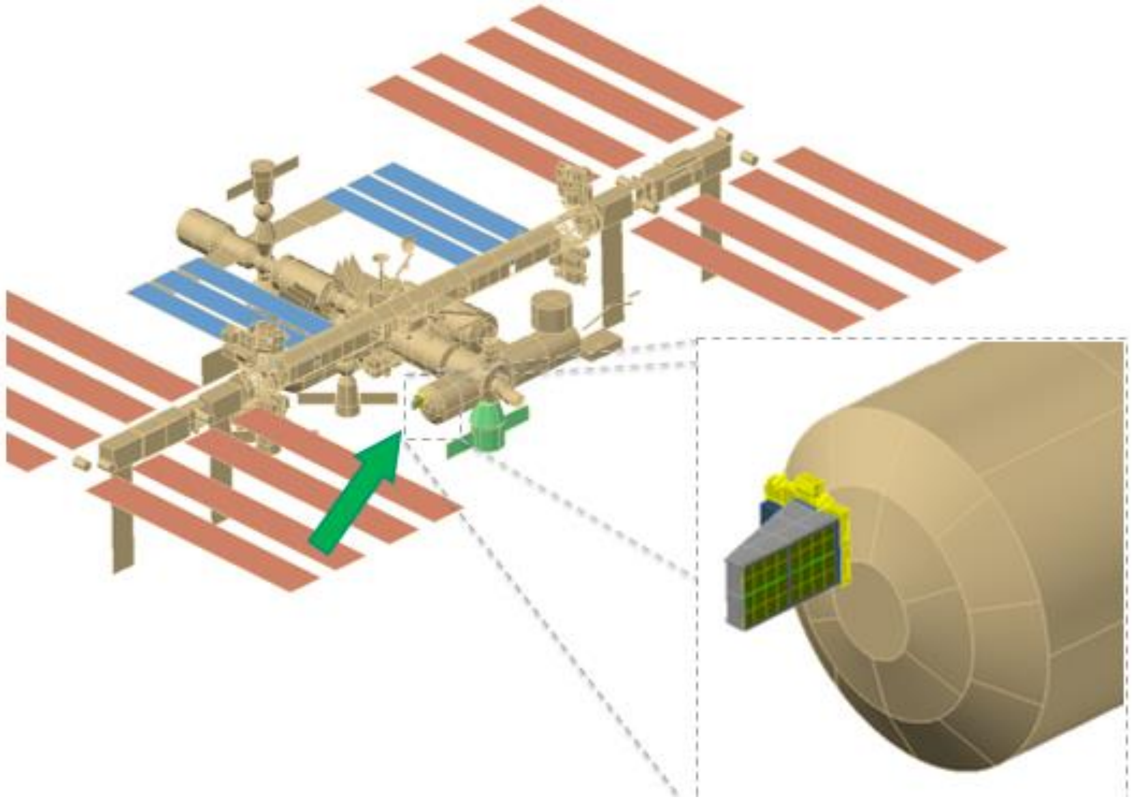
SDS sensor assembly

Columbus External Payload Adapter (CEPA; SpaceX OEM, SDS GFE)

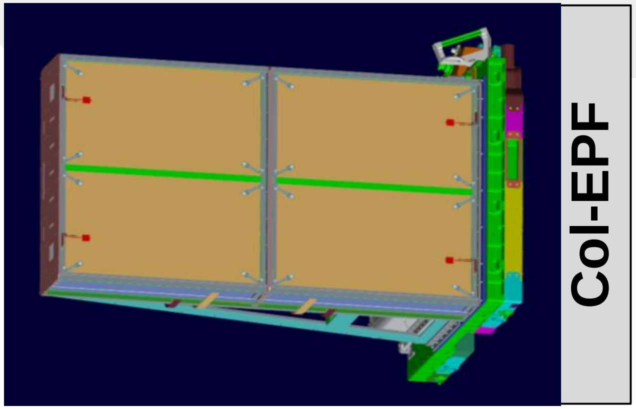
- **Weight:**
  - Total: 267.69 kg / 590 lbs
  - CEPA: 117.94 kg / 260 lbs
  - SDS: 149.75 kg / 330 lbs
- **Size:**
  - External Height: 67.56 inches
  - External Width: 47.92 inches (CEPA with handrails)
  - External Depth: 53.00 inches (CEPA with handrails)
- **Power**
  - 40W: SDS operating without heaters
  - 155W: SDS operating with ISS heaters
  - 100W: SDS non-operating with launch heaters

SDS Installation on ISS

- **SDS launched on SpaceX 13 (Dec. 2017) and was robotically installed on 1 Jan. 2018**
- **Installation on the *Columbus* External Payload Facility (Col-EPF) in the ISS forward-facing (ram) direction**



SDS ISS Orientation

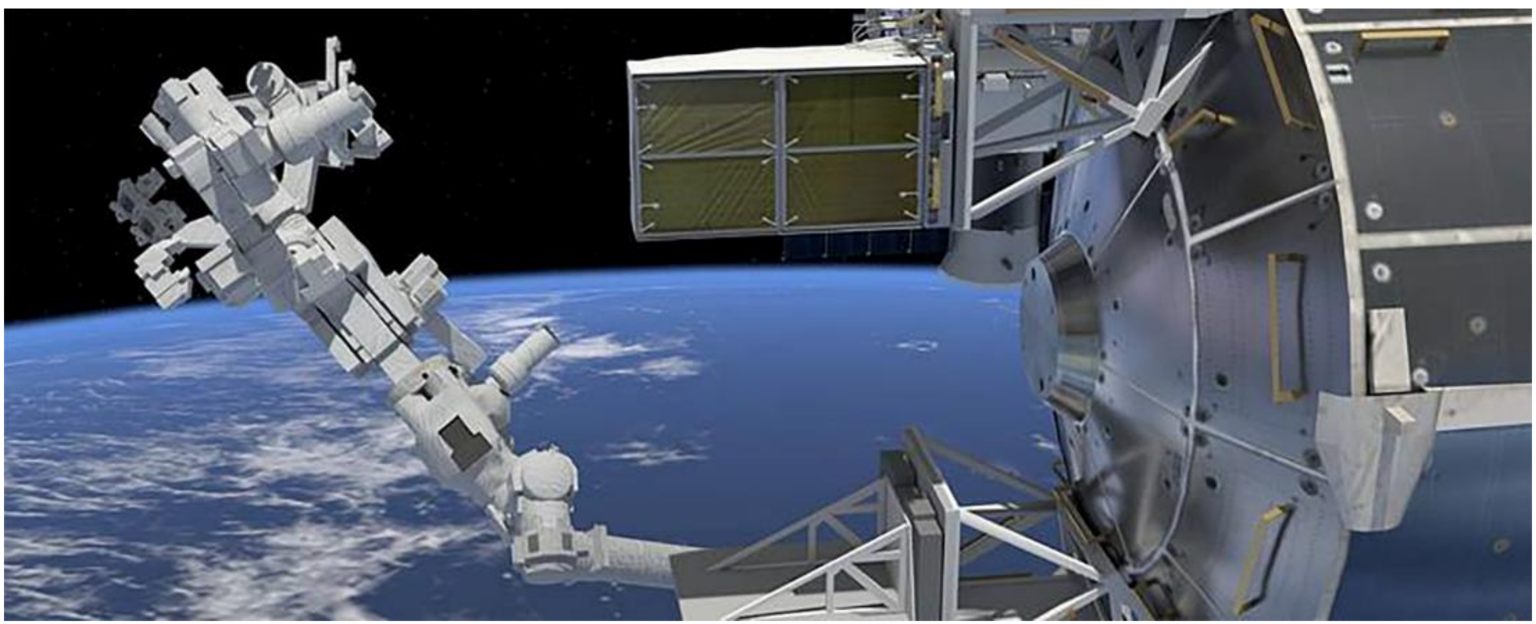


Zenith

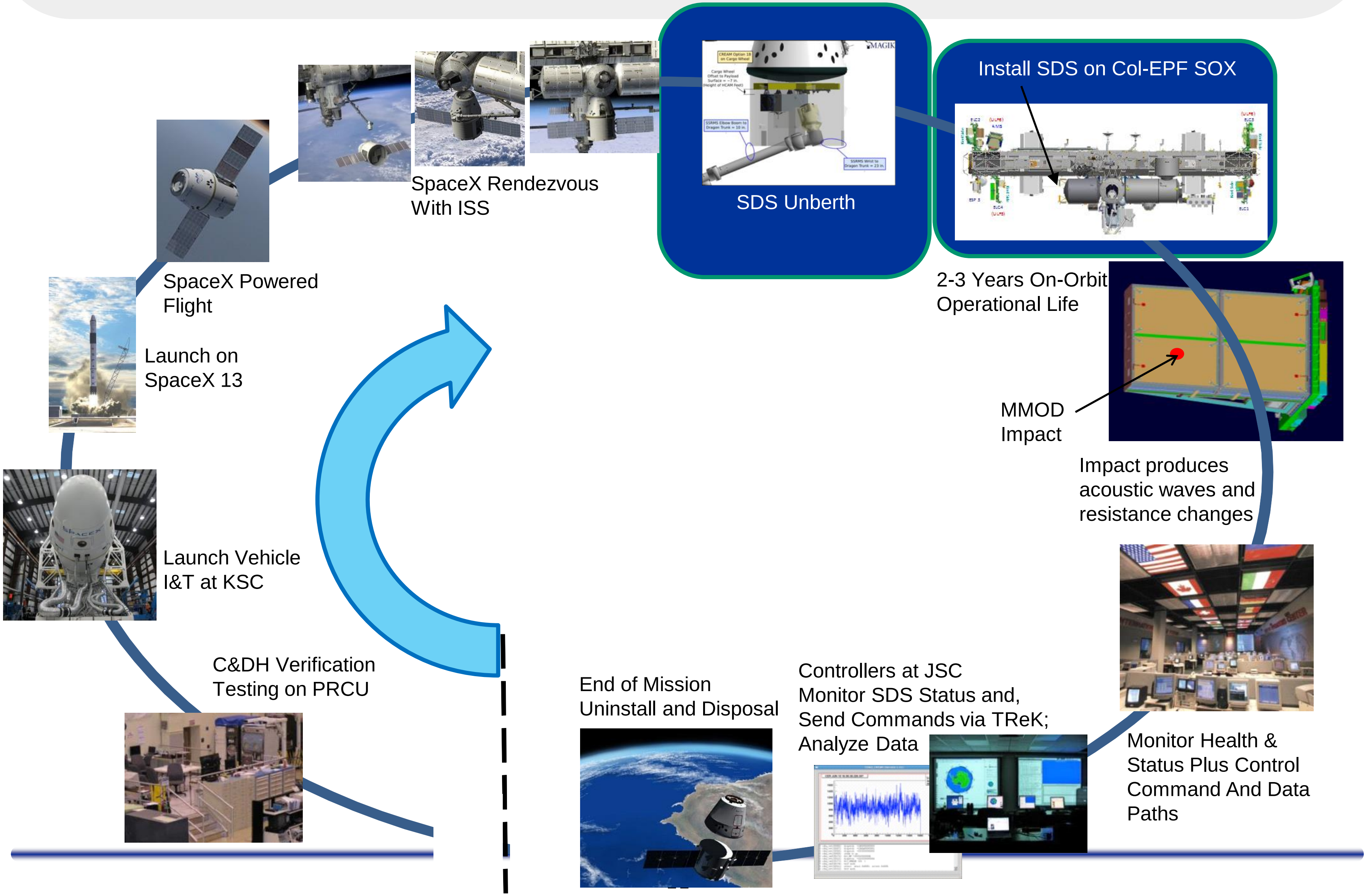
Nadir

Starboard

Port



SDS Concept of Operations



Timeline

- **Initial checkout confirmed that all command and data interfaces were operational**

- **After hours of normal operation, SDS Health & Status data stopped updating and SDS did not respond to commands (Anomaly 1)**
  - **Some of the software was still functional, because packets of information were still coming off of one interface**
  - **However, command and control were no longer functioning**
  - **Did not respond to software reboot commands**

- **The ODPO team determined that the only remaining option was to recycle the power**
  - **A power recycle returned SDS to normal operations**

Timeline

- **We were able to replicate the lockup using the ground unit, and identified it as a software issue**
  - **However, the instrument was not designed for software update**
  - **The original cost estimate to have software configurable was determined not to be within the financial constraints of the program**

- **The partial software lock repeated itself irregularly**
  - **The power recycle was repeated each time the SDS Health & Status data stopped (65 times over 25 days)**

- **Finally, on January 26, 2018, SDS did not recover from three consecutive power recycle attempts (Anomaly 2)**

- **Attempts at power up between February 9, 2018 and June 26, 2018 were also unsuccessful**

Anomaly Resolution

- The initial loss of Health & Status was identified as a partial software locked-up state
- Investigation focused on finding an indicator to preempt the lock-up by issuing a software reboot command
- Software bug was identified in a commercial software module that had passed multiple software tests during development testing
- While final software configuration successfully went through communication and full functional testing, a test of long enough duration to manifest the problem was not repeated for final configuration

Anomaly Resolution

- **There were several attempts to restore functionality, but there was no further response from the instrument**

- **As a direct result of the anomaly investigation (but after the fatal shutdown) a work-around was discovered whereby the software could have been updated in orbit prior to Anomaly 2**
  - **This would have allowed us to correct Anomaly 1, preventing the need for frequent power cycling**
  - **This method could be used in the future on ISS experiment packages using similar communications software**

Summary

- **Efforts through June 2018 were focused on recovery**
  - **Lessons learned being compiled**
  - **Beginning to look into science data – small impacts were seen**
- **SDS experienced two types of anomalies**
  - **Anomaly 1 locked-up the software to a point where commanding and science data collection were not possible until a power cycle reset the payload**
  - **Anomaly 2 is of an unknown cause when SDS failed to reset or respond after an operational power cycle**
- **Other discrepancies have been identified, but it is not clear yet whether they are related**
  - **Only one of the two heater circuits seems to be working**
  - **Heater current draw is less than predicted**
  - **Some wiggles in data telemetry**
- **All 40 acoustic sensors and all 32 resistive grid circuits were functioning and collecting good science prior to second anomaly**

Preliminary Lessons Learned

- **Most probable cause of lost communication (Anomaly 2) was a hardware failure of the memory storage on the main interface processor**
  - **Failure may have occurred due to repeated power cycles or environmental effects (radiation, plasma, etc.)**
- **The software bug in the file management software passed several tests during development. Changes to the software caused the problem to manifest**
  - **Additional long duration software testing pre-launch would have discovered the problem prior to flight**
- **SDS was not designed with a software update capability due to cost**
  - **During anomaly resolution, the team learned that a low cost capability could have been added**

Technology Demonstration Summary (to date)

- **Collected over 1300 acoustic detection files and 26 days of resistance/engineering data**
- **Demonstrated impact detection in the flight environment**

demonstrate the detection component	*ground testing*	*flight experience*
Impact Detection	✓	✓
impact time	✓	✓
impact location	✓	✓
projectile direction	✓	?
projectile speed	✓	?
projectile size	✓	?
projectile density (via impact energy)*	✓	?

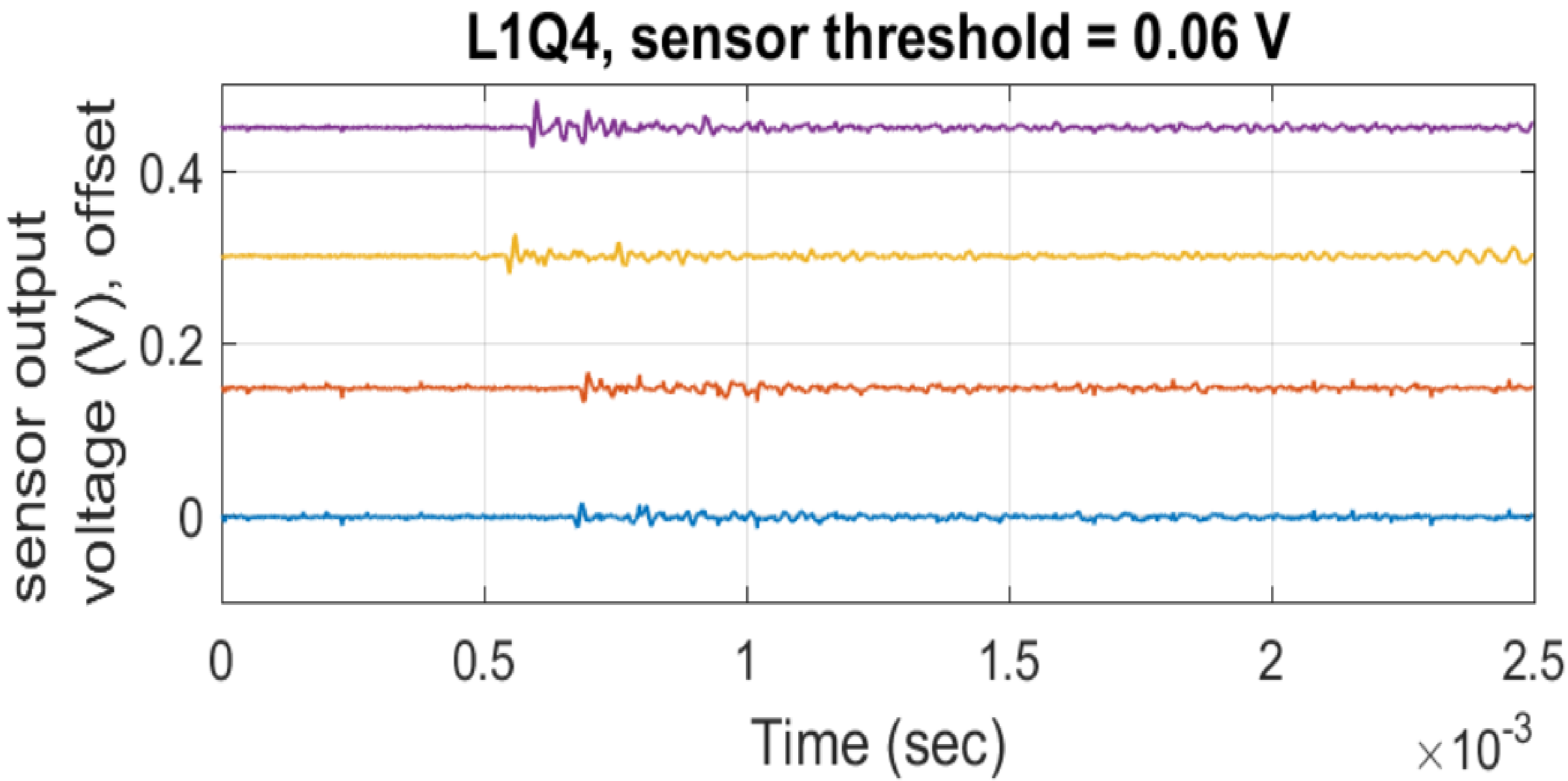
- Because we only had 1 month of data, we have not yet identified any impacts large enough to confirm these capabilities in space

* Projectile density may be demonstrable in a qualitative sense by number of layers penetrated

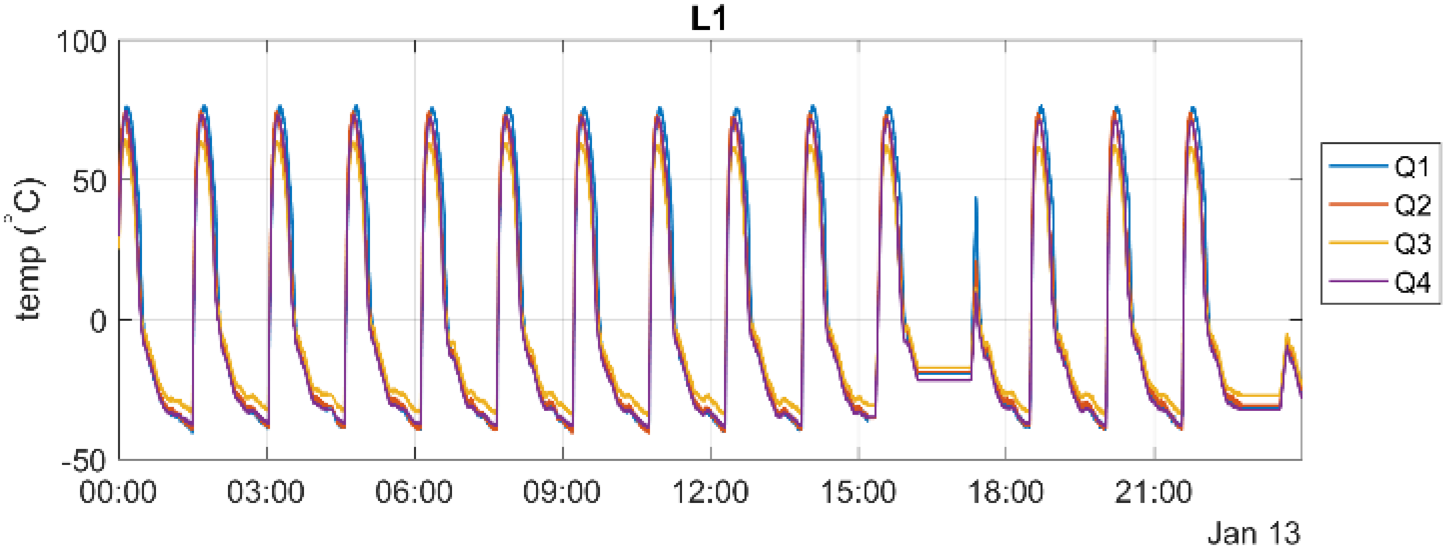
Conclusions

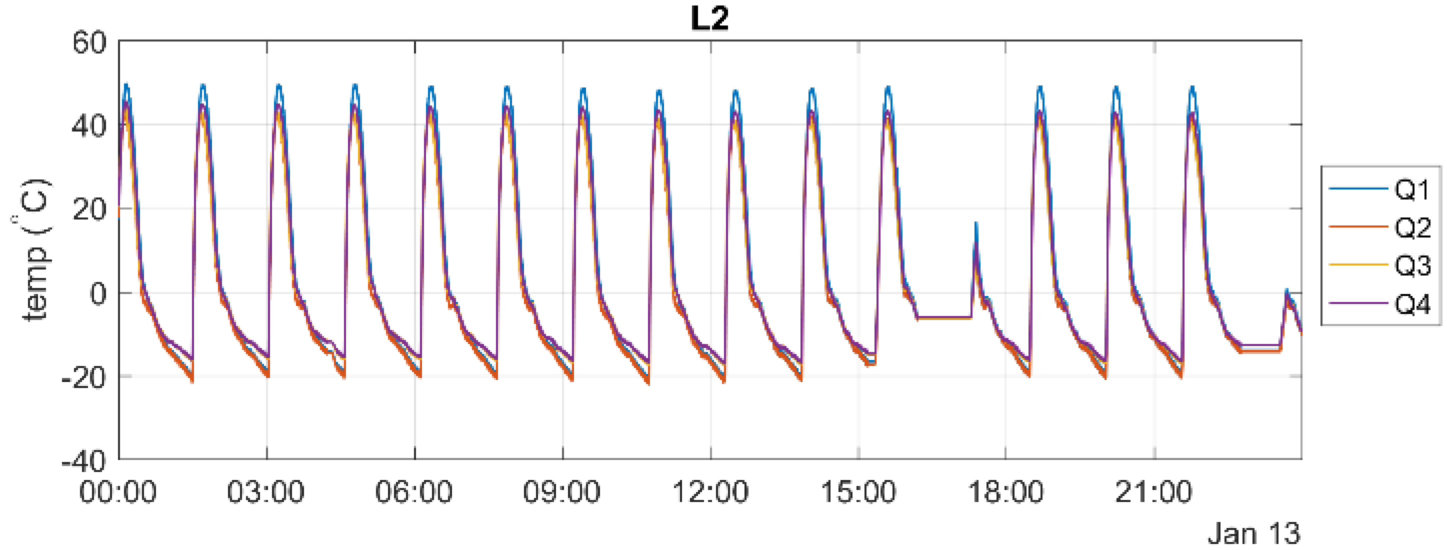
- SDS was a *technology demonstrator* flight payload
  - Demonstrated DRAGONS sensor technology for MMOD environmental measurements
  - Anomaly #1 did not compromise this demonstration
- Analysis of SDS Health & Status and Science data continues to inform
  - Anomaly resolution effort (complete)
  - General sensor-related engineering issues
  - MMOD environmental measurement
- Source of Anomaly #2 is still unknown
  - Possible that power cycling contributed to it, but no way to confirm from available data
  - Plausible environmental factors could have contributed to ultimate failure (e.g., radiation)
- Lessons Learned informs ongoing DRAGONS-type instrument development

Example of Flight Impact Acoustic Data



Example of resistive grid temperatures





Example of potential line break