# Measuring Platform Stability at ELC1 using the Optical Payload for Lasercomm Science (OPALS)


***Matthew Abrahamson***
***David Bayard***
***Jet Propulsion Laboratory***
***California Institute of Technology***


***2016 ISS R&D Conference***
***San Diego, CA***
*July 14, 2016*

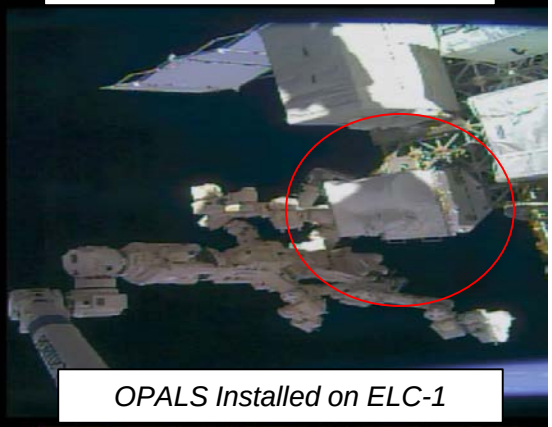
Copyright 2016 California Institute of Technology. Government sponsorship acknowledged.

# Agenda

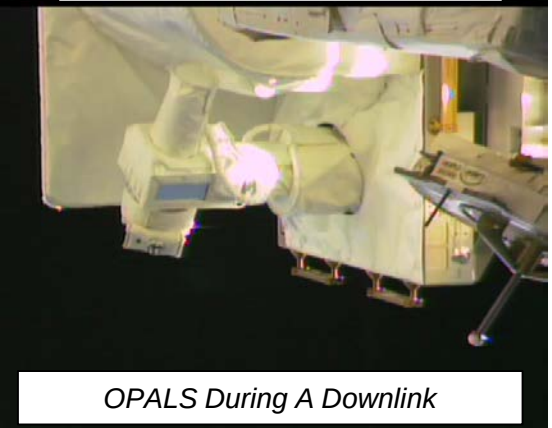
- OPALS Mission Overview
- Platform Stability Experiment Motivation
- OPALS Measurement Overview
- Pointing Approach
- Data Processing Approach
- Results Summary

# OPALS Mission Update

*OPALS in Dragon trunk, as seen from Falcon 9 Second Stage*



*OPALS Installed on ELC-1*



*OPALS During A Downlink*

## OPALS Mission:

Demonstrate the feasibility of space-to-ground laser communications transmissions from ISS

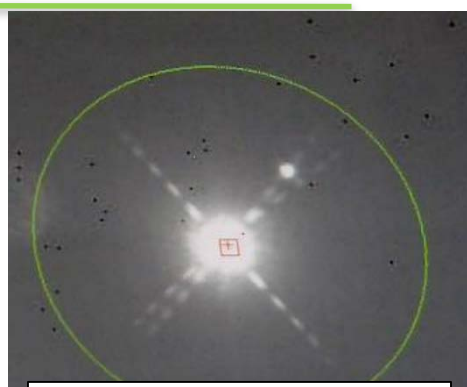
## Prime Mission Milestones:

(Dependent on ISS schedule and TMF Visibility)

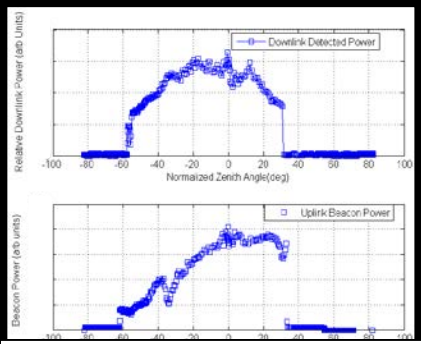
- ✓ Commissioning Phase (May '14)
- ✓ First Official Video Downlink (6/5/14)
- ✓ First Daytime Video Downlink (6/12/14)
- ✓ Low Elevation Transmissions (June '14)
- ✓ Geometry/Pointing Sensitivity Tests (Jul-Aug'14)
- ✓ PN8 and Engineering Data Downlinks (Sep '14)
- ✓ Foreign Ground Station Collaborations (Oct '14)

## Extended Mission Milestones:

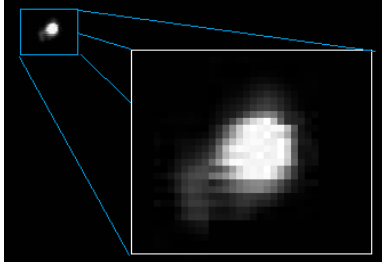
- ✓ Adaptive Optics Tests with Boeing (Jan-May '15)
- ✓ **ISS Platform Vibration Experiment (Jul-Nov '15)**
- Transmissions to DLR (Oct-Dec '15)
- Transmissions to ESA (Jan-Feb '16)
- Transmissions to CNES (Mar '16-May '16)
- Decommissioning (Nov '16)



*First Optical Downlink*




*Optical Link Validation*



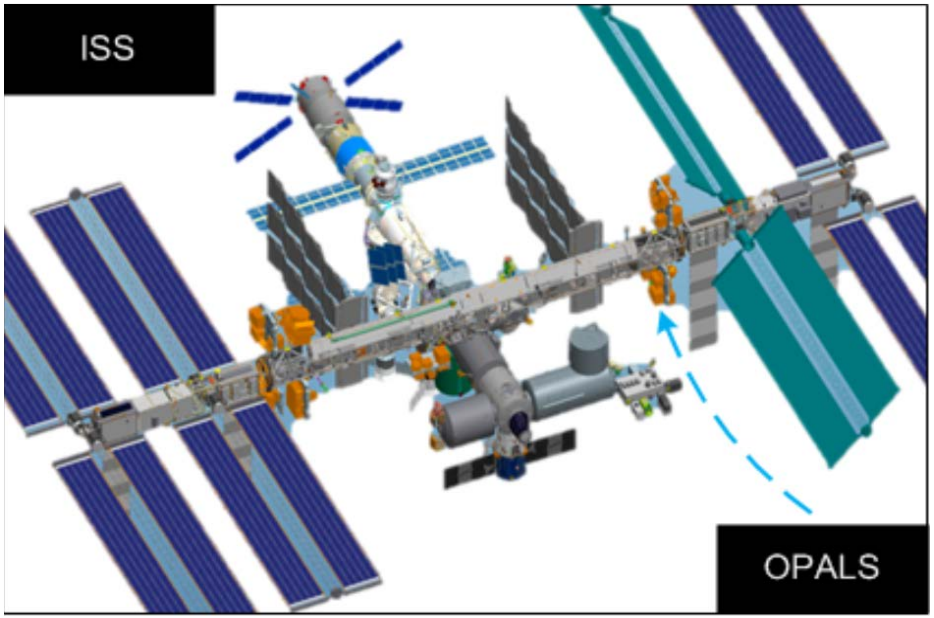
Grey is ISS structure
White is the OPALS Laser

*ESA Signal Acquisition at*

# Vibration Experiment Overview

- Can OPALS be repurposed to measure vibration properties from an external payload site (ELC1 FRAM8)?

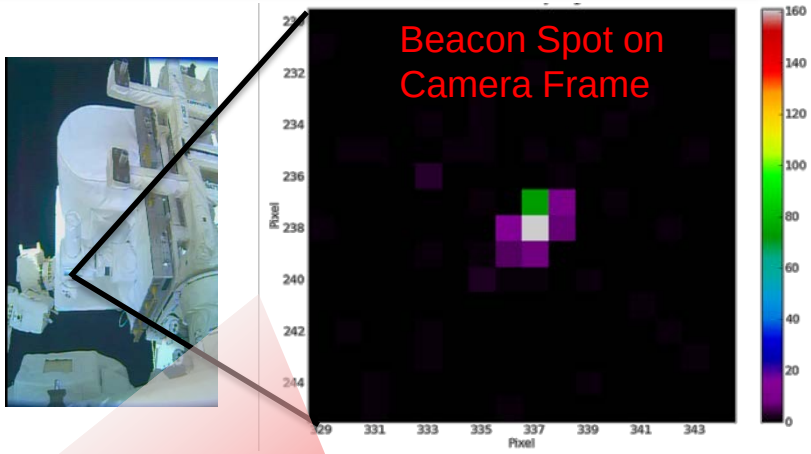
- OPALS capabilities include:
  - 7° by 9° camera with 100 Hz frame rate
  - Two-axis gimbal (Az/El) that can point within 0.25° open loop or <100 μrad (1σ) closed loop
  - Ground-referenced laser beacon



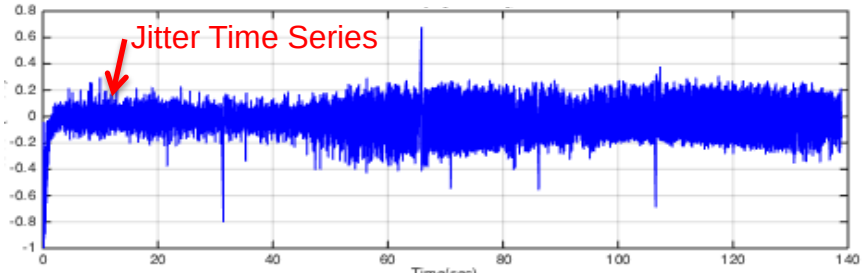

- **Motivation:** External payloads are interested to know the vibration environment experienced on orbit. Existing IMUs are not located at external payload sites; OPALS measurements on ELC1 can serve as a complementary data set
- **Experiment:** OPALS will capture 100 Hz camera imagery of a ground reference beacon; the measured centroid jitter may help characterize the ELC1 platform environment

# Measuring Platform Jitter

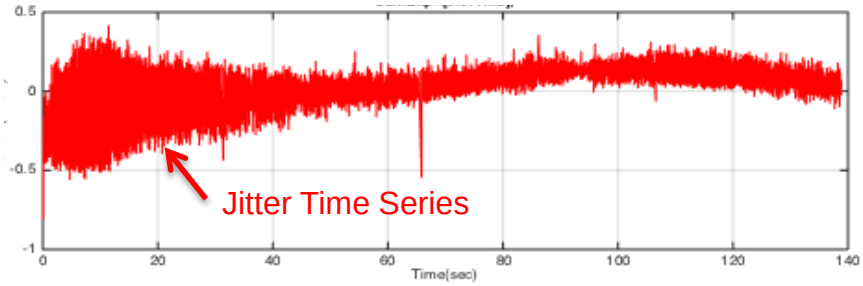
- During a typical OPALS pass:
  - A 976 nm laser beacon is irradiated towards the ISS from the OPALS ground station in Wrightwood, CA
  - The flight camera detects the beacon signal on a 640 x 480 pixel CCD
  - The centroid coordinate of the beacon spot is computed at 100 Hz
  - Pass length is typically ~2-3 minutes



Typical Azimuth Centroid Data



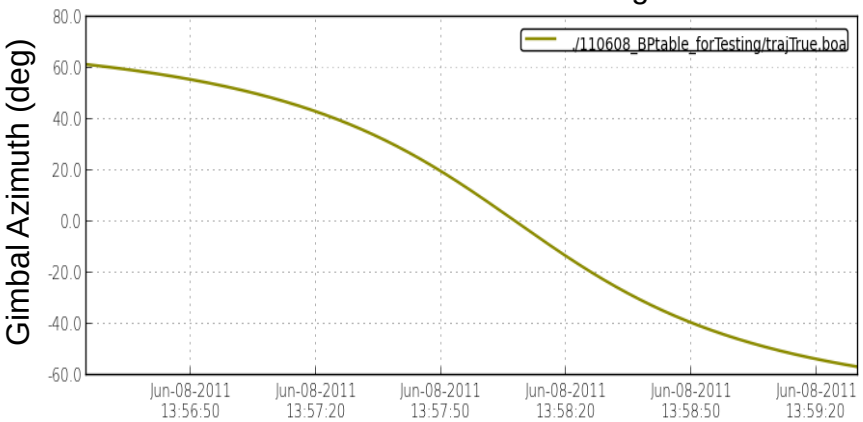

Typical Elevation Centroid Data



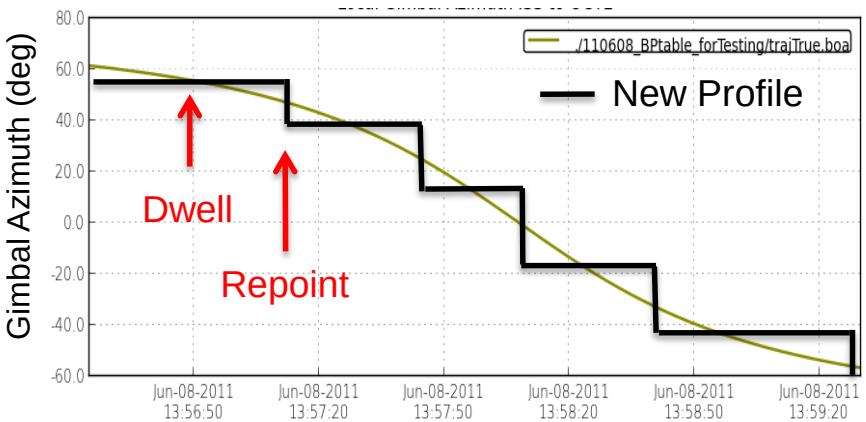
# Step-Stare Pointing Approach

- For this experiment, the gimbal pointing must be fixed during measurement periods
  - Intended to isolate motor vibrations from platform vibrations
  - Periodic repoints must be executed to retain the beacon in the camera FOV
- To isolate the ISS contributions, the following approach is taken:
  - **Propagate** ISS state vector to over-flight segment and **compute** open loop pointing
  - **Modify** the open loop pointing to have a step-stare profile, with multiple dwell periods with no gimbal movement (beacon should move left to right across CCD)
  - **Uplink** the step-stare pointing profile to OPALS for execution
  - Following the pass, **remove** the slew periods and **de-trend** the orbital motion
  - Deliver time series of angular measurements in two axes to ISS Loads & Dynamics

Nominal Commanded Pointing Profile

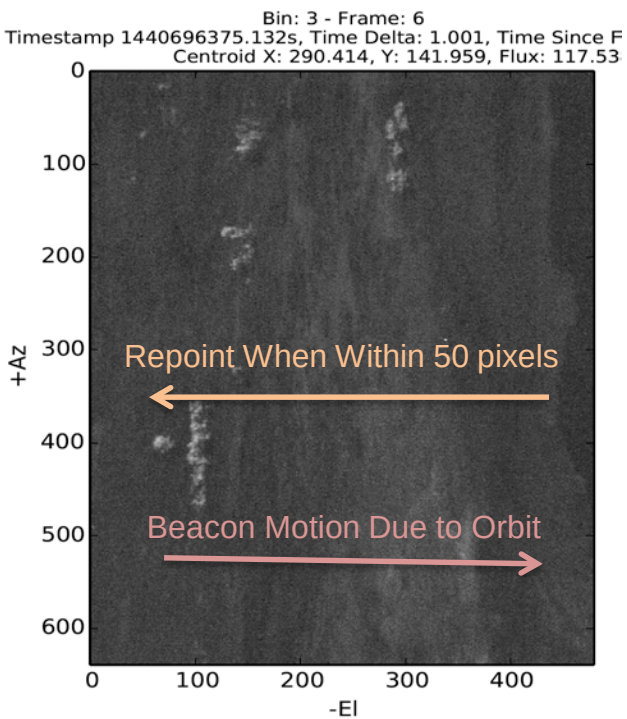



NEW Step Stare Approach

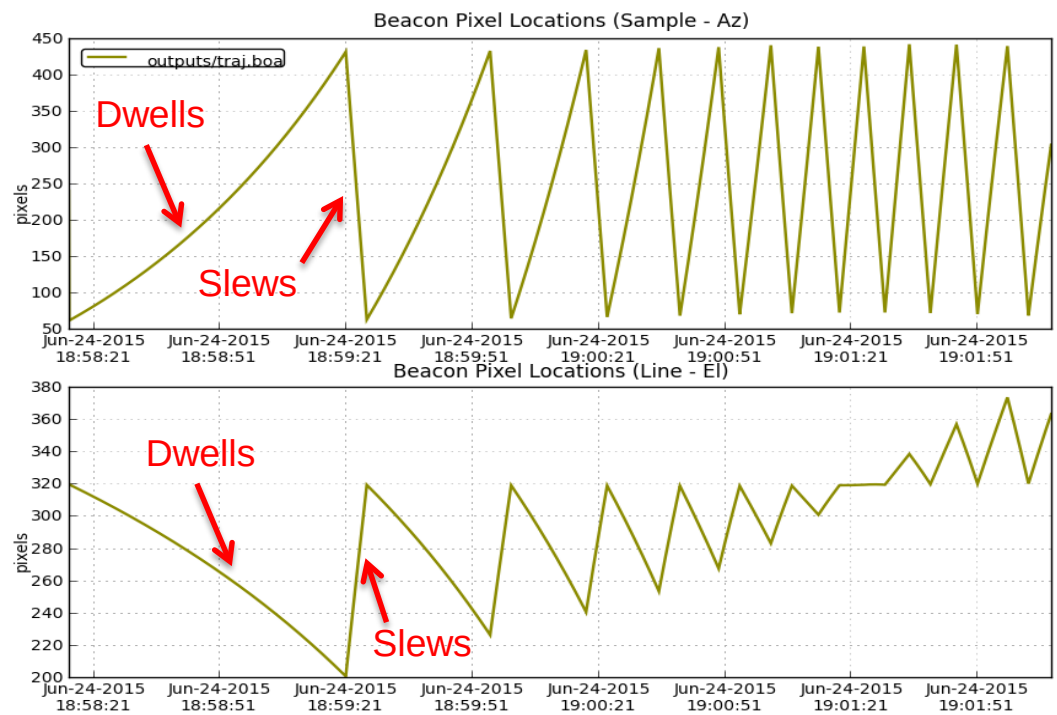


# Computing the Step-Stare Profile

- Assumptions:
  - Begin observations at 10 deg rise above horizon
  - Update pointing any time beacon is within 50 pixels of camera edge (0.75 deg)
  - Look ahead 180 pixels in azimuth (instead of center)
  - Re-center elevation coordinate
  - Assume 5 seconds for pointing update slew
- Dwell characteristics: Longest dwell: 65 sec; shortest dwell: 5.8 sec
  - Tradeoff: Longest dwells have more content, but lower SNR due to greater slant range

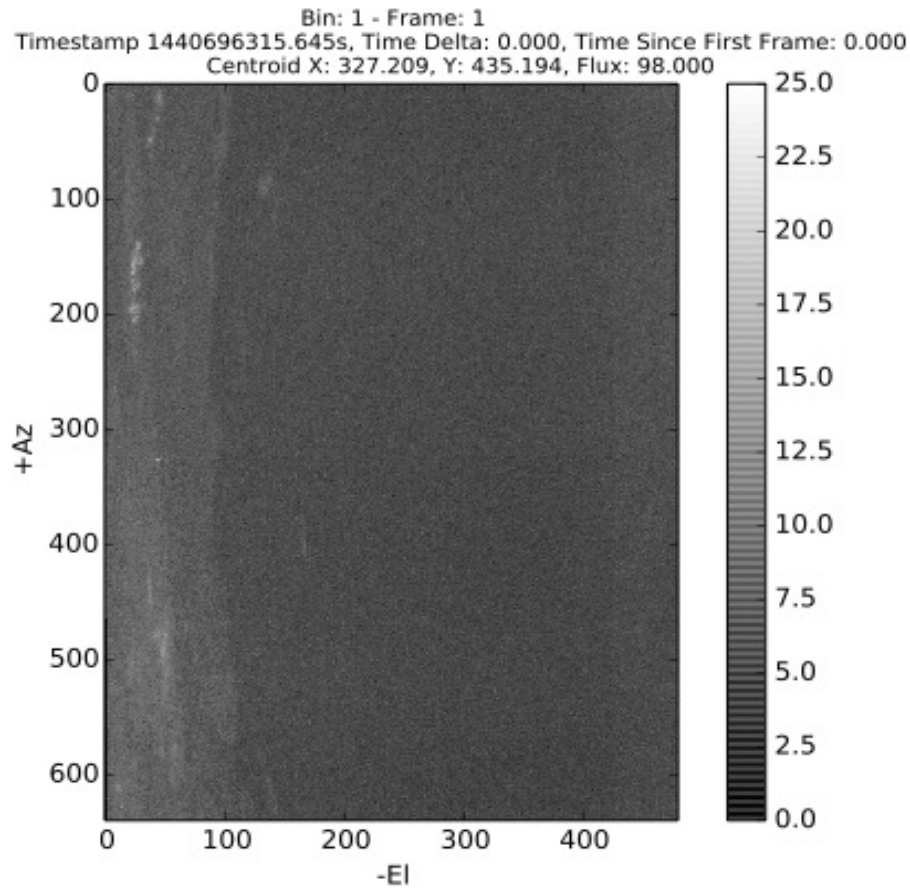


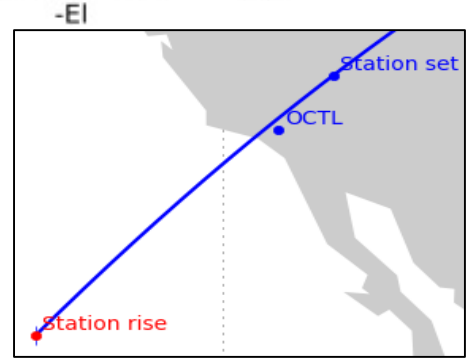

## Predicted Beacon Motion



# Summary of Passes

- Four data takes completed using the OCTL telescope in Wrightwood, CA
  - GMT 239 (Aug 27) @ 17:25 GMT
    - Crew sleep period
    - Daytime
  - GMT 260 (Sept 17) @ 16:35 GMT
    - Crew exercise period
    - Daytime
    - Gimbal driven during second half of pass for jitter comparison
    - Data during gimbal drive determined to be “out of family” with other results
  - GMT 300 (Oct 26) @ 00:59 GMT
    - Crew sleep period
    - Night conditions, high EL pass
  - GMT 096 (April 5) @ 01:15 GMT
    - Crew sleep period
    - Daytime, high EL pass

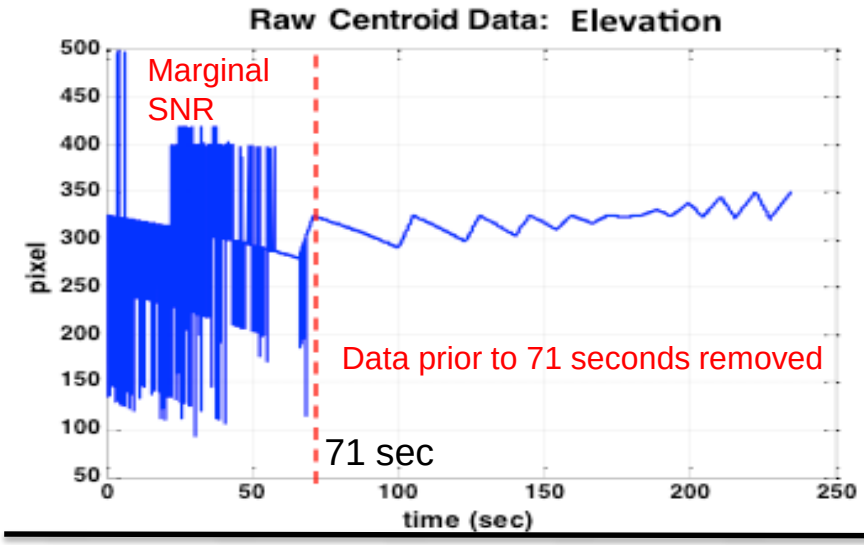


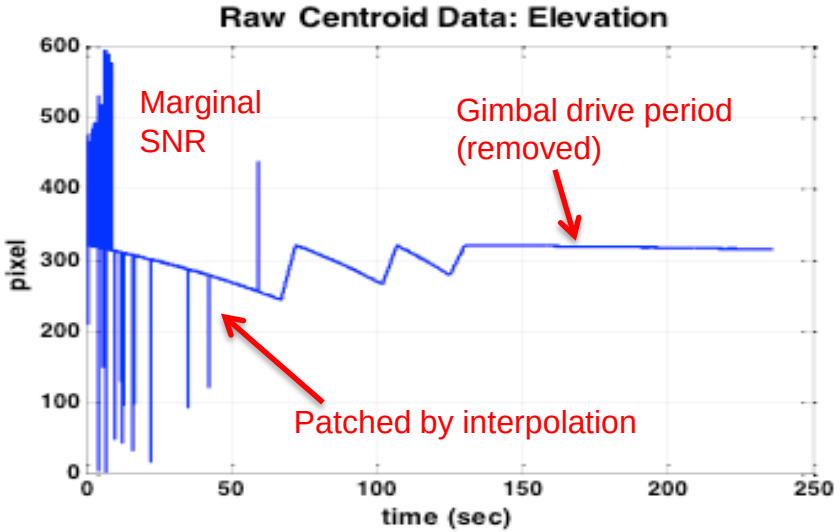

- Due to the short dwell durations near ground station zenith, only the first three dwells are assessed in this analysis

# Raw Optical Centroid Data (EL Axis)

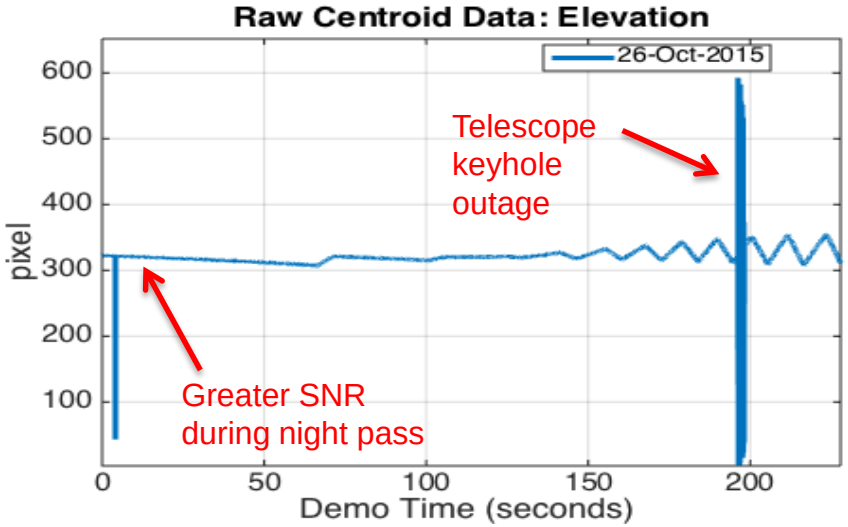
## GMT 239



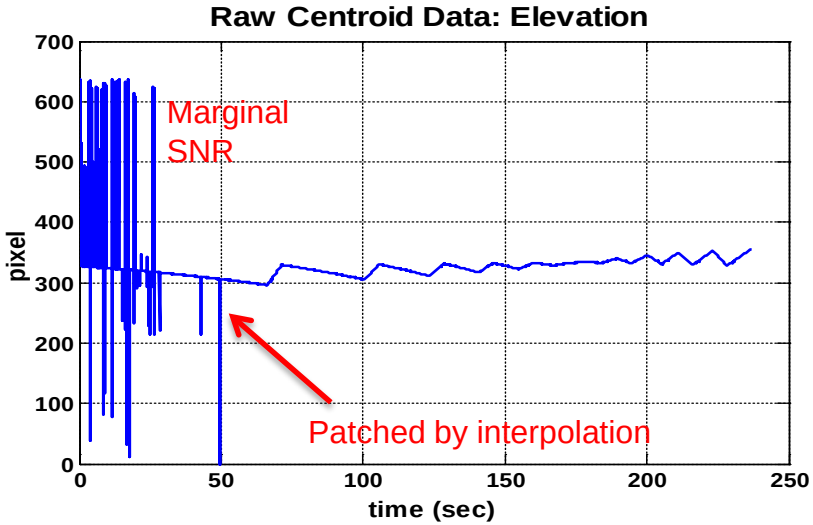

## GMT 260



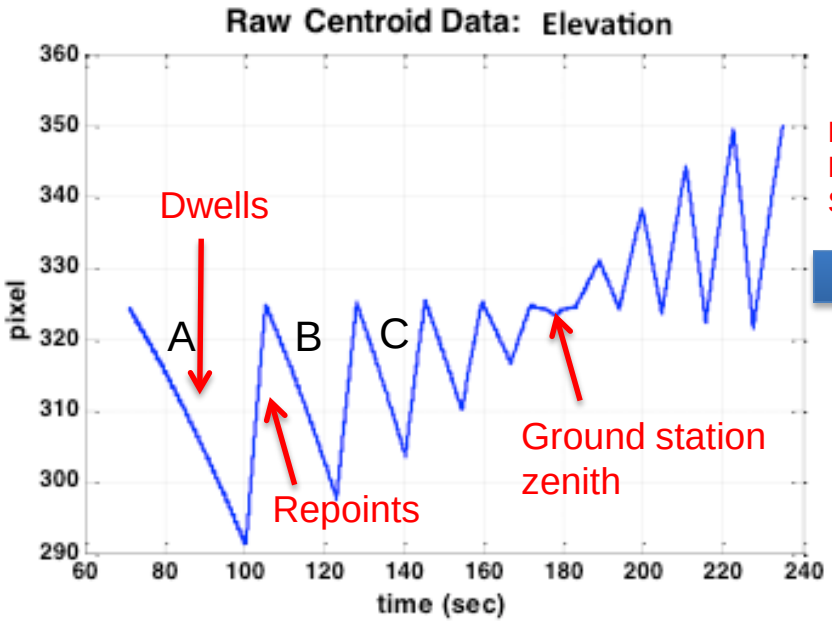

## GMT 300



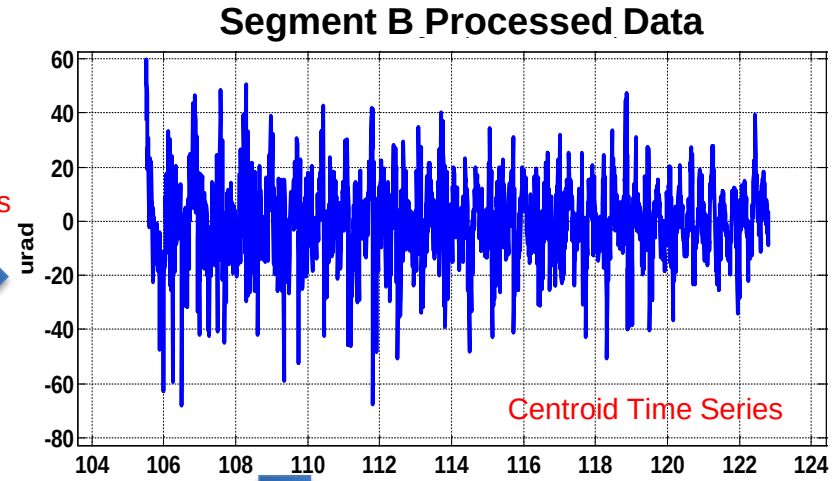

## GMT 096



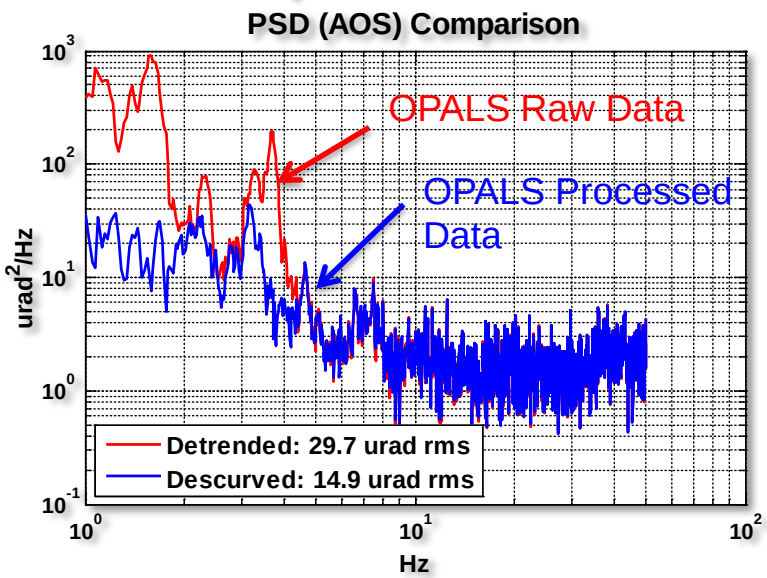
# Data Processing Summary




Detrend / Remove Systematics




Convert to frequency domain

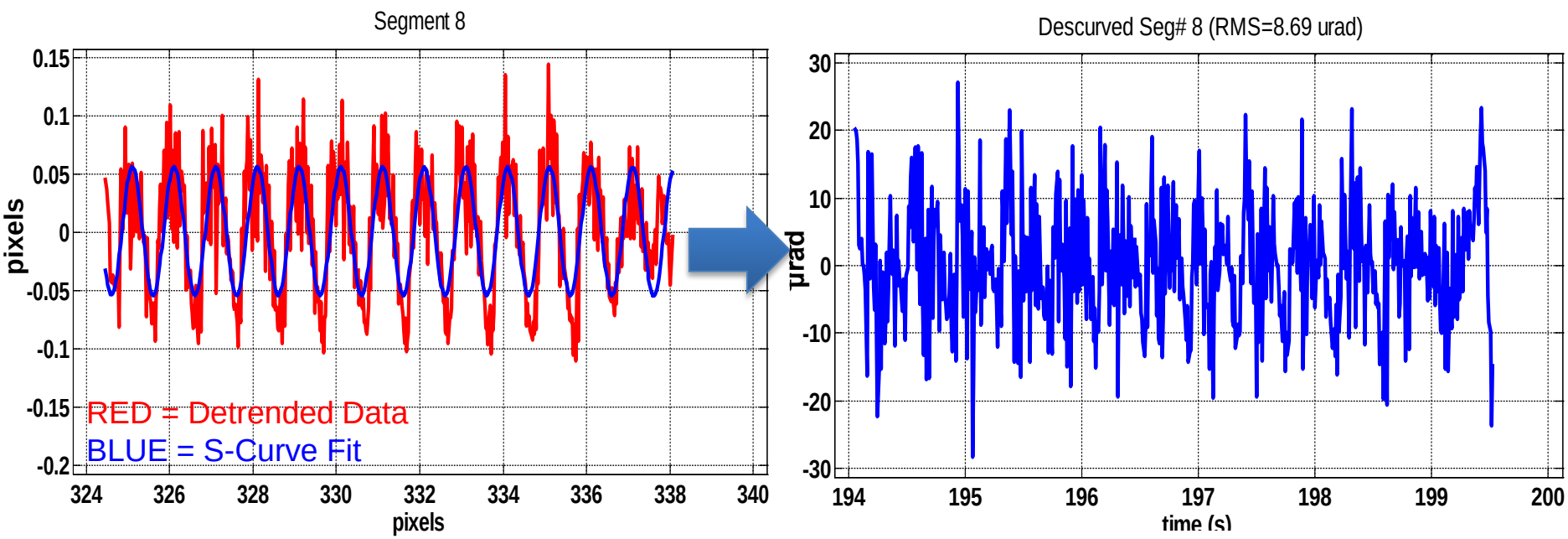



**Processing Approach:**

1. Remove repoint intervals
2. Remove noisy data intervals
3. Detrend orbital motion
4. Compute detrended PSD
5. Remove systematic errors
6. Compute final PSD

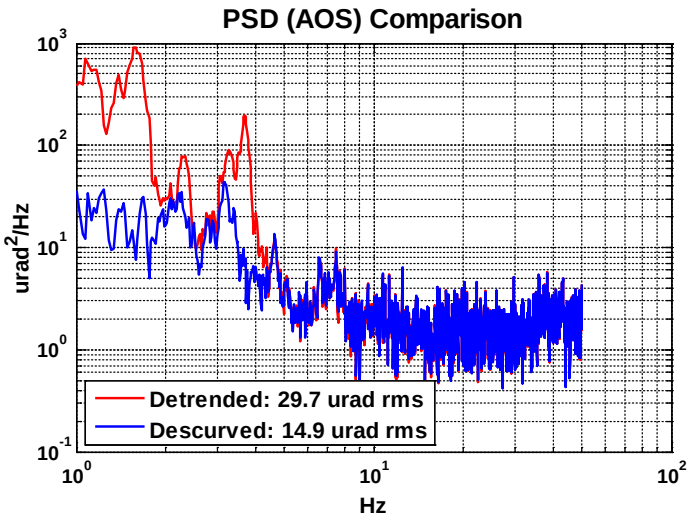
# Data Detrending

1. Data must be detrended for ISS orbital motion
   - Use a 16th order polynomial fit to remove orbital motion and attitude drift
2. A systematic error is present each time a pixel boundary is crossed
   - This can be fit by plotting the detrended data in pixel space and removing the "S-curve"
   - In frequency space, this error is spread across multiple frequencies since the pixel rate is accelerating
   - S-curve systematic error is removed for both same-axis and cross-axis pixel crossings

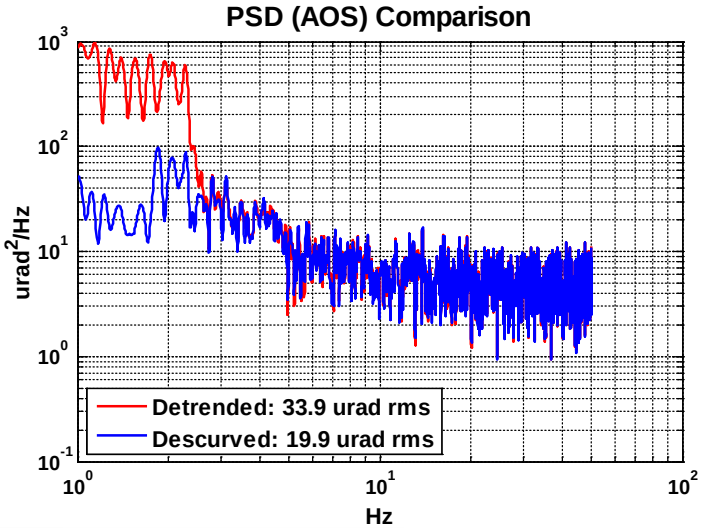


# Processed Power Spectral Density (EL Axis)

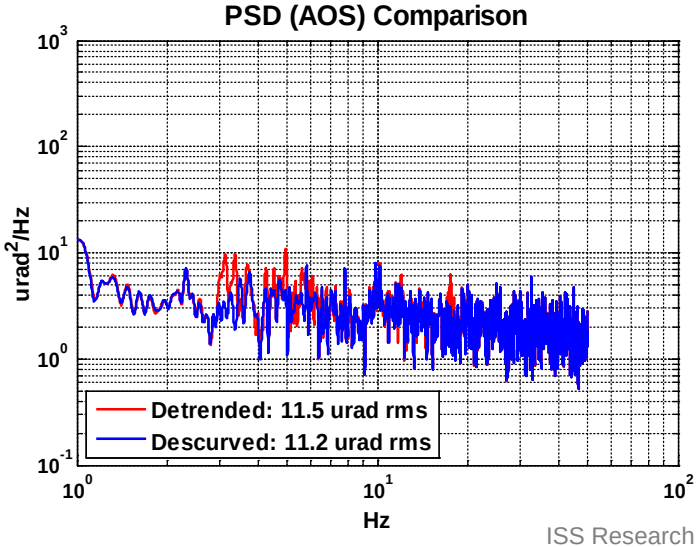
## GMT 239 (Day, Crew Sleep)



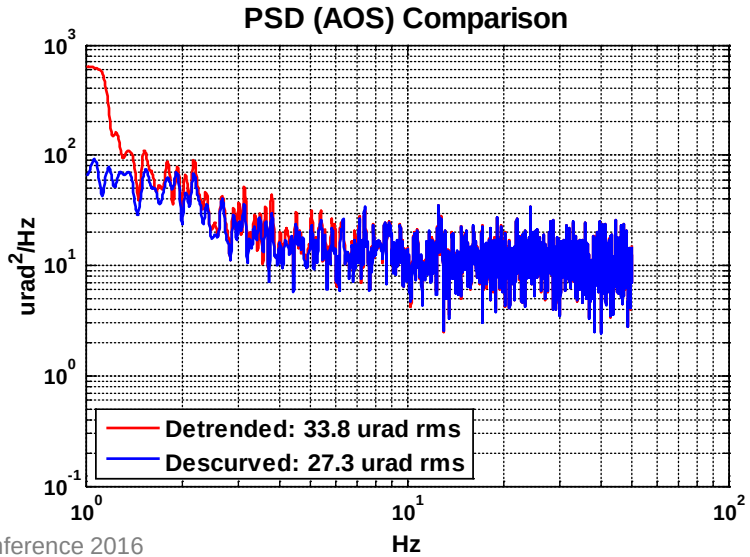

## GMT 260 (Day, Crew Exercise)




## GMT 300 (Night, Crew Sleep)




## GMT 096 (Day, Crew Sleep)



# Results Summary

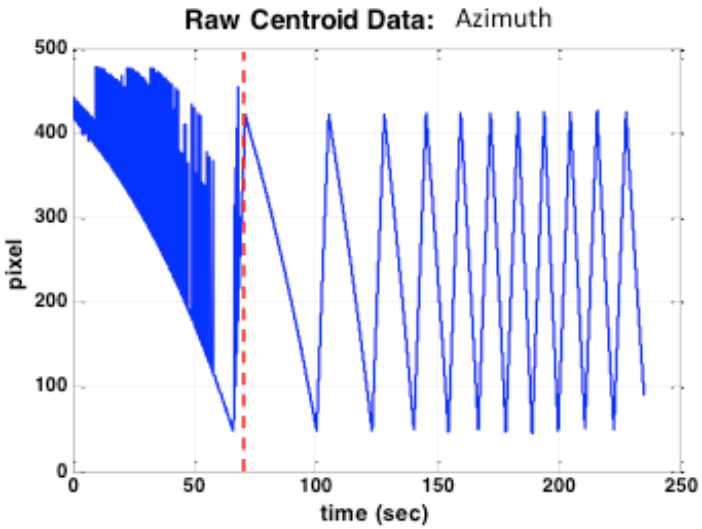
- A new approach to measuring platform vibration using OPALS high-rate optical measurements of a ground reference beacon was demonstrated
  - Complementary to SDMS accelerometer measurements
  - Angular measurements taken from an external payload site (ELC1)
- Jitter analysis was performed on four OPALS centroid data sets
  - Both AZ and EL data analyzed over time window of approximately 125 sec
  - Data segments after 125 sec become shorter and generally less useful for spectral analysis
  - Data was first detrended using 16$^{th}$ order polynomial, and then a double S-curve correction was applied in order to create a jitter PSD
  - Double descurving technique removes *both* same-axis and cross-axis S-curve signatures
- Final RMS Jitter Error is on the order of 20-30 μrad for both axes

| Data Set | Channel | Detrended RMS (urad) | Descurved RMS (urad) | Double Descurved RMS (urad) |
|---|---|---|---|---|
| GMT 096 | AZ | 38.4 | 30.8 | 29.1 |
| | EL | 33.8 | 27.5 | 27.3 |
| GMT 300 | AZ | 30.3 | 21.0 | 21.0 |
| | EL | 11.5 | 11.5 | 11.2 |
| GMT 260 | AZ | 36.2 | 31.2 | 26.8 |
| | EL | 33.9 | 19.9 | 19.9 |
| GMT 239 | EL | 29.7 | 14.9 | n/a |

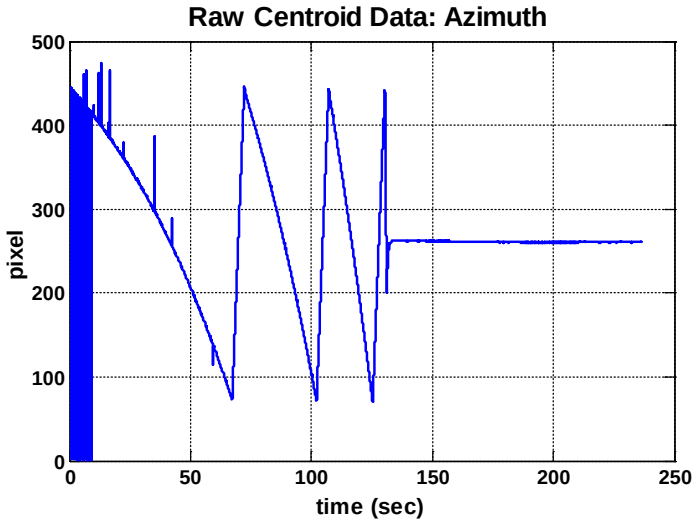
# BACKUP

# Raw Optical Centroid Data (AZ Axis)

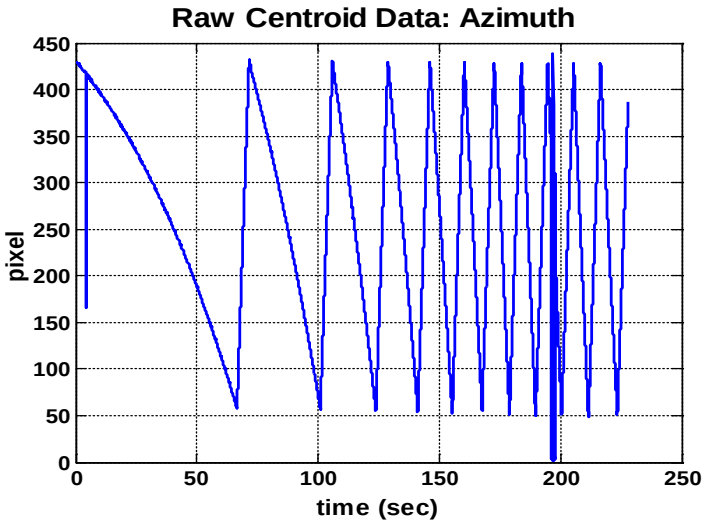
## GMT 239 (Day, Crew Sleep)



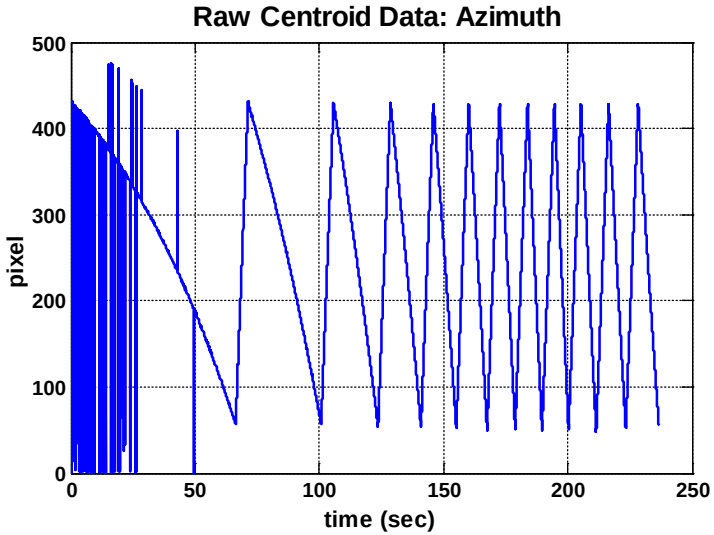

## GMT 260 (Day, Crew Exercise)




## GMT 300 (Night, Crew Sleep)




## GMT 096 (Day, Crew Sleep)

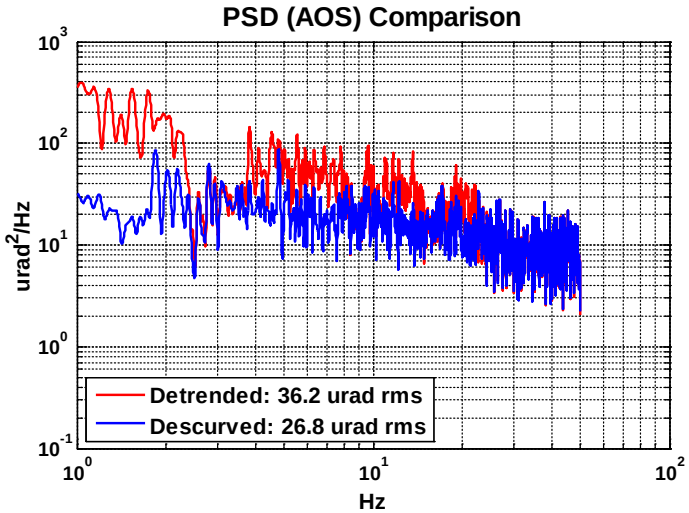


# Processed Power Spectral Density (AZ Axis)

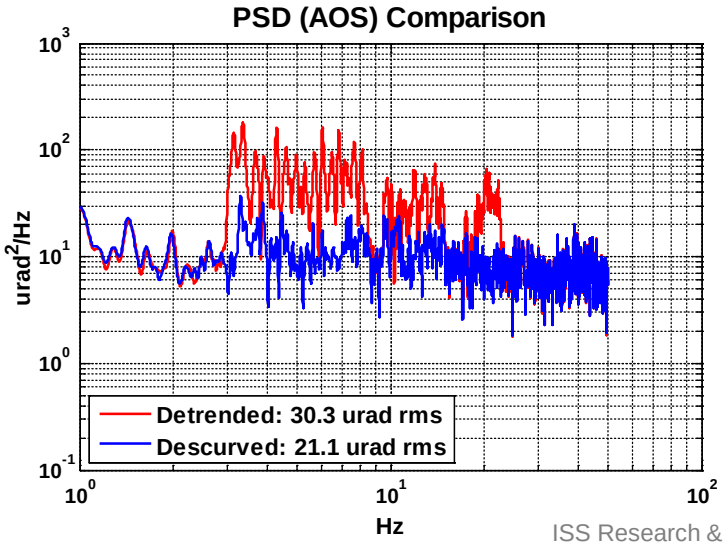
## GMT 239 (Day, Crew Sleep)

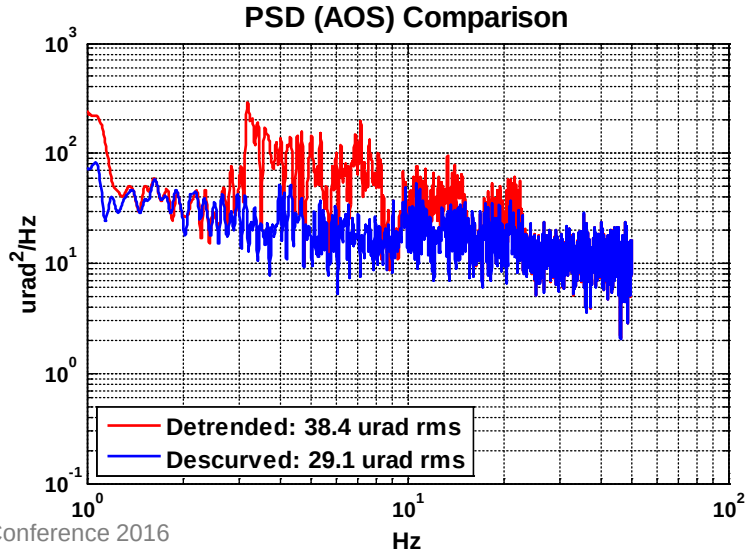
Not Processed

## GMT 260 (Day, Crew Exercise)




## GMT 300 (Night, Crew Sleep)




## GMT 096 (Day, Crew Sleep)