SOFIA Observatory Characterization And Improvements

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OUTLINE

- Image Quality vs. Time
- Improvements since Early Characterization Flights
- OCF & SCAI Flights : HIPO – FLITECAM – FORCAST image size
- Latest Image Quality Improvements: AMD
- Plans for next year

Performance Improvement Timeline relative to Requirements

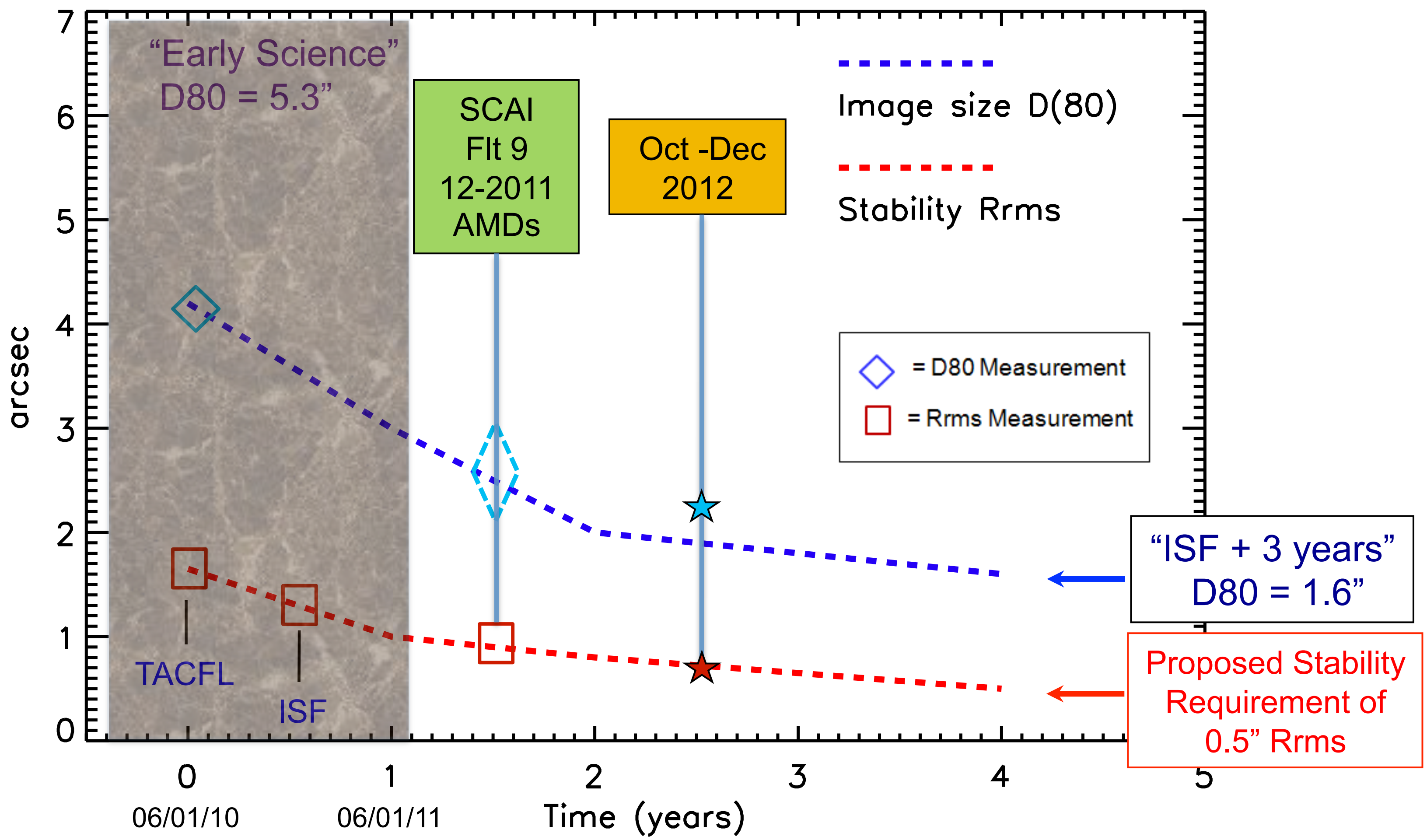


Image Quality – TACFL & OCF

TACFL

- First light opportunity for SOFIA (May 2010)
  - FORCAST
  - Limited MCCS capabilities (Door control)
  - TA elevation and Aperture Assembly angle was limited to 23 degrees
- Flew within 200miles radius from Base, mostly over ocean

Observatory Characterization Flights (OCF) 2 and 3:

- characterize the pointing stability of the observatory at low, medium, and high elevation angles.
- study effects of cross-elevation and line-of-sight angle variations.
- Investigate the effect of altitude changes. Data at 35kft and at 42kft.
- Implement an improved algorithm for the feed forward of Fine Drive (FD) control deviations to the Secondary Mirror Tilt-Chop-Mechanism (TCM).

- Most of the test points were performed on inertial point sources with visibility both in the infrared and at visible wavelengths.

- Data was taken (in most cases) with FORCAST instrument at 5.4 or 11 μm, and with DSIs Fast Diagnostic Camera (FDC), which was mounted in place of the Focal Plane Imager camera (FPI) during OCF 2.

Image Quality – TACFL & OCF

- On **TACFL** (May 2010) Image Quality (neglecting diffraction and shear layer seeing) was about 4.3 arcsec (D80) with rudimental TCM Feed Forward. It was dominated by image jitter. Main contributors have been:

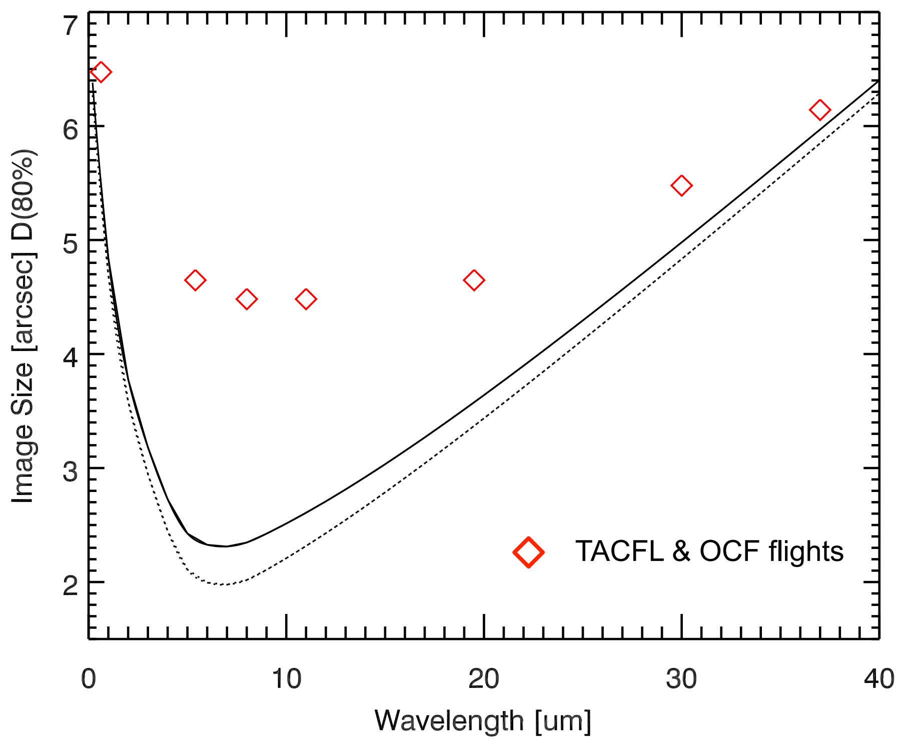
a) 1 to 10 Hz residual motion in the Fine Drive, mainly in EL (~1.2 rms jitter)
b) 89 Hz fwd-aft motion in the secondary spiders, mainly in XEL (~ 0.4” rms)
c) 69 and 73 Hz PM Rocking excitation (~ 0.25” rms in EL, ~0.15“ rms in XEL)

- Between TACFL and OCF2 the TA team has worked on the lower frequency problems:
- **Quasi-static FBC** (<3Hz) for compensating low frequency bending of the TA due to g-vector changes (turbulences, EL changes) by using accelerometer signals only.
- **TCM Feed Forward** (<10Hz) to compensate rigid body deformations caused by windloads by feeding forward Fine Drive control deviations (accelerometer and gyro signals) to the Secondary Mirror Tilt-Chop-Mechanism (TCM).

- On **OCF2** an improvement of ~20% (~1.0 rms jitter) in EL was realized by increasing the speed of the TCM Feed Forward algorithm.

- <u>Remark:</u>
  Though both **TACFL** and **OCF2 Pointing & Control** measurements took place in 35 kft, OCF2 Image Quality numbers are difficult to compare with TACFL numbers, because data from TACFL are with EL=23°, and from OCF2 data are with EL=30°-40°.
- **At higher EL angles flexible modes are more excited**.

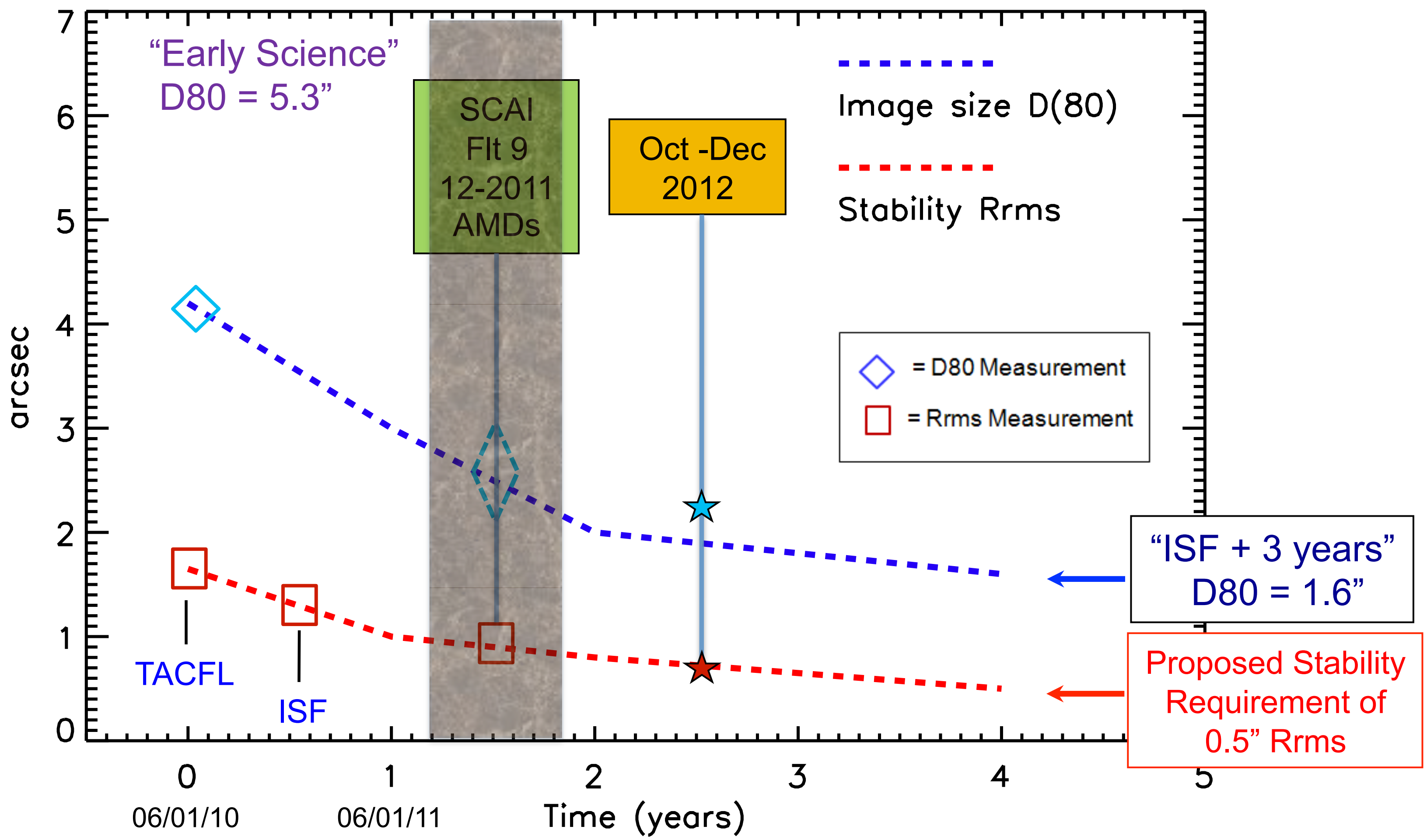
D80 vs. Wavelength



Total image size, including diffraction and anticipated jitter and shear layer seeing, as a function of wavelength.

- Image jitter dominates image quality at this point.
- Additional effects are significant as well, but they have not been studied yet.
- De-focus image size was probably contributing to the image quality
- Chopper jitter is also another component in the Image quality (under ~1 arcsec FWHM).
- FORCAST camera design is not optimized for best image quality at ~5um microns)

Performance Improvement Timeline relative to Requirements



SOFIA Characterization And Integration (SCAI)

TA Improvements and engineering work

- Flexible Body Compensation (FBC), Dynamic FBC, Fast Diagnostic Camera (FDC), SFDC, Secondary Mirror Assembly (SMA) …

TA V&V

- How reliable is blind pointing? Nods? Differential flexure? SMA stability? Focus drift? Differences between TA-native & MCCS?

Observatory Performance and Characterization

- AMD System, Image jitter
- Cavity seeing, shear layer disentanglement
- Check for engine exhaust plume background
- Understand thermal effects on focus and alignment
- Calibrate WVM

SI Commissioning (HIPO, FLITECAM, and ‘FLIPO’)

- (HIPO, FLITECAM, and ‘FLIPO’)

SOFIA Flights: Characterization, Verification and Validation, SI Commissioning , and TA Improvements

August Activities:

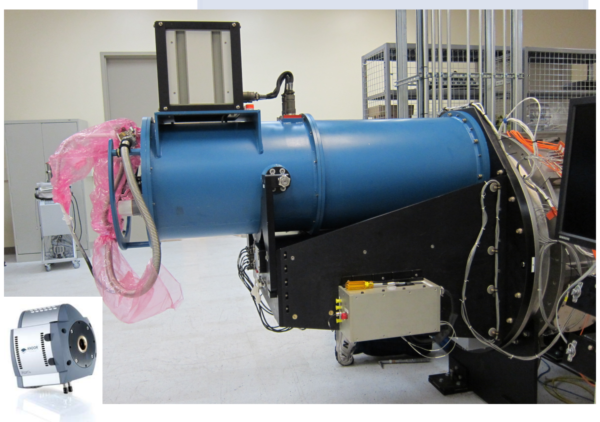
- 2 flights in the HIPO + FDC configuration

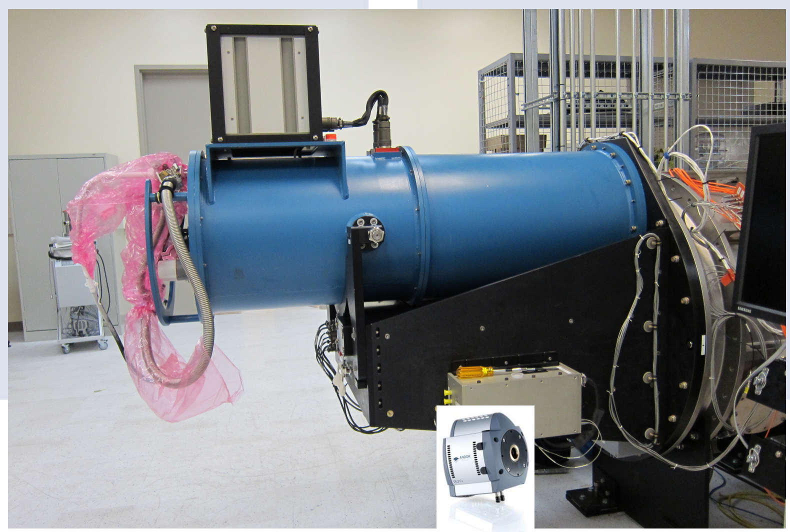
Fall Activities:

- 3 flights in the FLIPO + FDC configuration

Fall Activities:

- 2 flights in the FLIPO + SFDC + AMD configuration





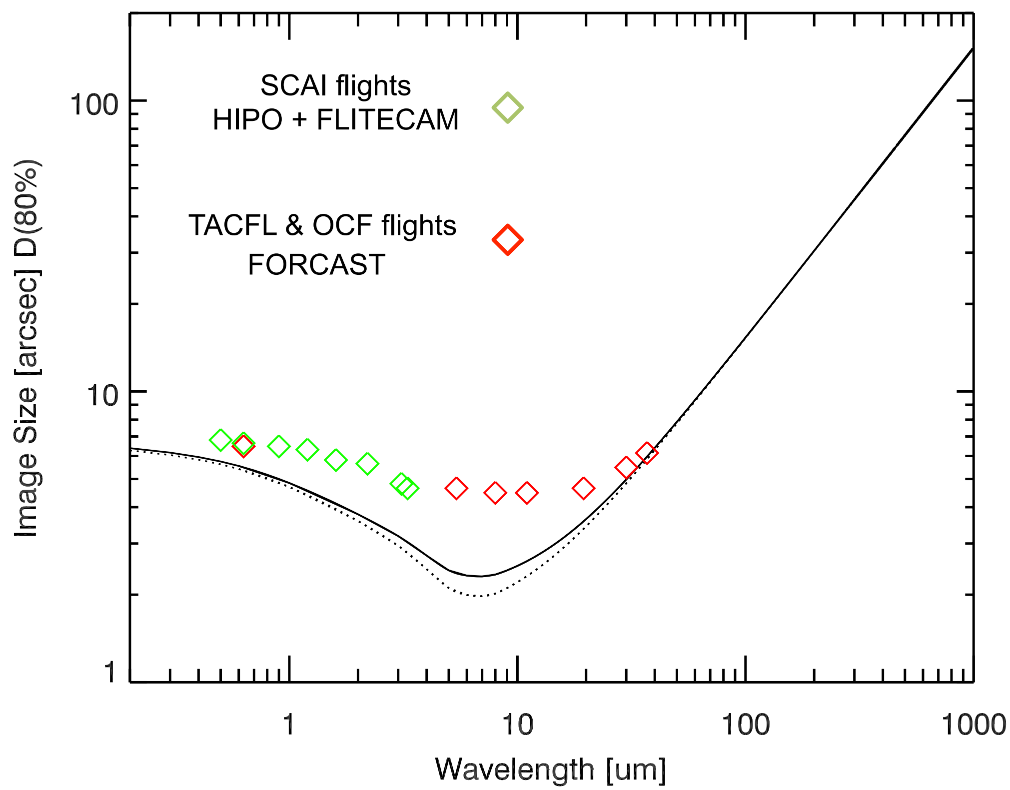
SCAI Flights for Shear Layer and Cavity Seeing Using Image Quality

- On four SCAI Flights, both HIPO and FLITECAM were mounted together in the so called FLIPO configuration.

- This allowed us to measure both the infrared 1.25 to 3.6 micron image quality (FLITECAM) and the optical 0.3 to 1.0 micron image quality (HIPO), at approximately the same time and under the same conditions.

- We have some preliminary data from the nights of 14 Oct, 18 Oct and 24 Oct 2011. All data were at about 41,000ft.

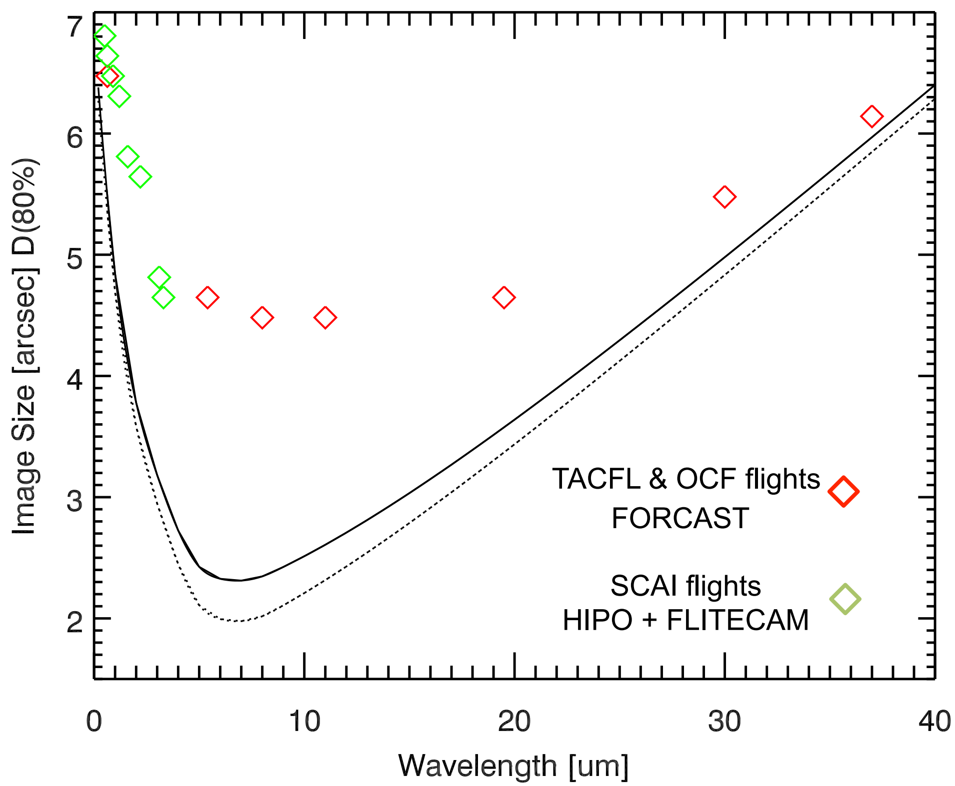
D80 vs. Wavelength



Total image size, including diffraction and anticipated jitter and shear layer seeing, as a function of wavelength.

- **HIPO and FLITECAM images sizes:**
- SCAI flights show the evidence for the wavelength dependence of Shear Layer and Cavity Seeing
- There is a clear trend that shorter wavelengths have larger image size.
- The effect can be seen in individual images
- The 1.25 image is larger and rounder
- The 3.6 image is sharper and elongated in the cross elevation direction (90 Hz spider motion)

D80 vs. Wavelength



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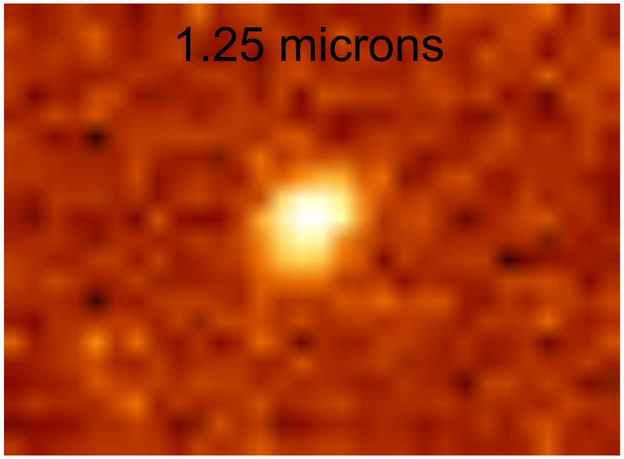
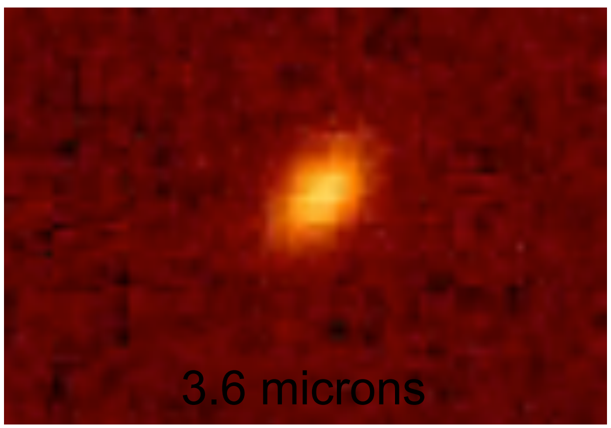
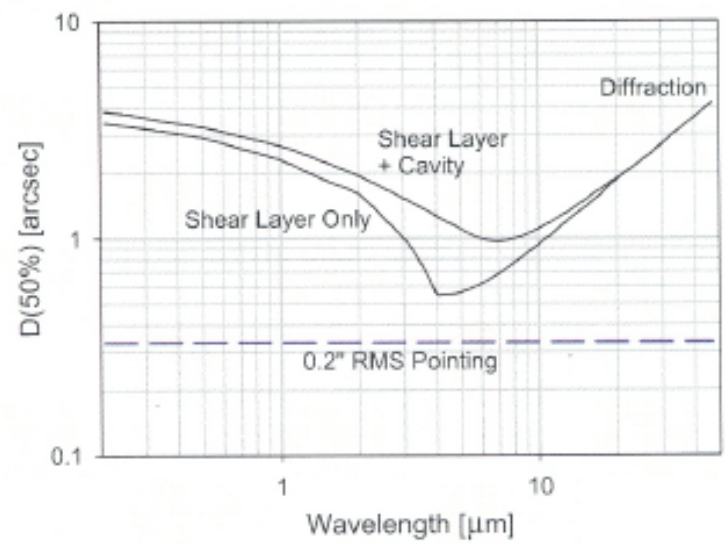
FLITECAM Images





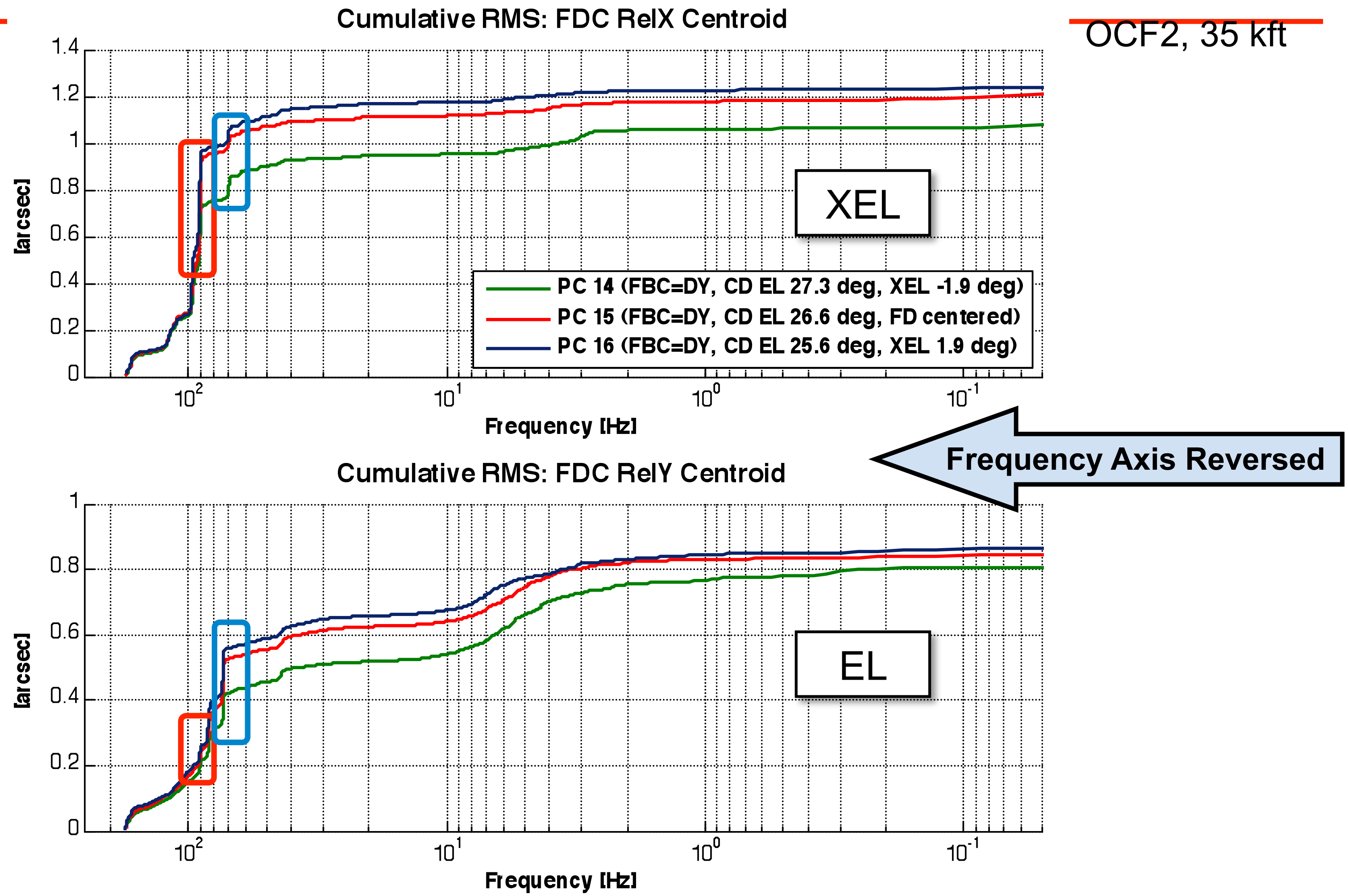


- When a 1.4 arcsec rms Jitter has been removed from each measurement, the resulting curve is similar to what was expected for Shear Layer plus Cavity seeing.
- From 2.15 to 5.4 microns the images have hit a floor of about 2" FWHM
- This is larger than expected especially at 3.6 and 5.4 microns and is presently unknown what is the cause.

Image Quality Improvements: AMD

- Image jitter is fairly well known, and with the Reaction Mass Actuator System we will be able to control it over a wide frequency range.
- Use of Active Mass Dampers (AMD) on the topside of the SMA housing and the Baffle Plate to suppress the 89 Hz Spider/Baffle Plate. The 89 Hz spider excitation is the largest one of several noted error contributor. A significant response reduction (40% to 85%, depending on disturbance location) in the 89 Hz mode was demonstrated during ground test.
- Use of AMDs in damping of 6 different PM modes (rocking and bending) Successfully ground tested. Very well suppresses the 70 Hz and 175 Hz modes; control law developed.

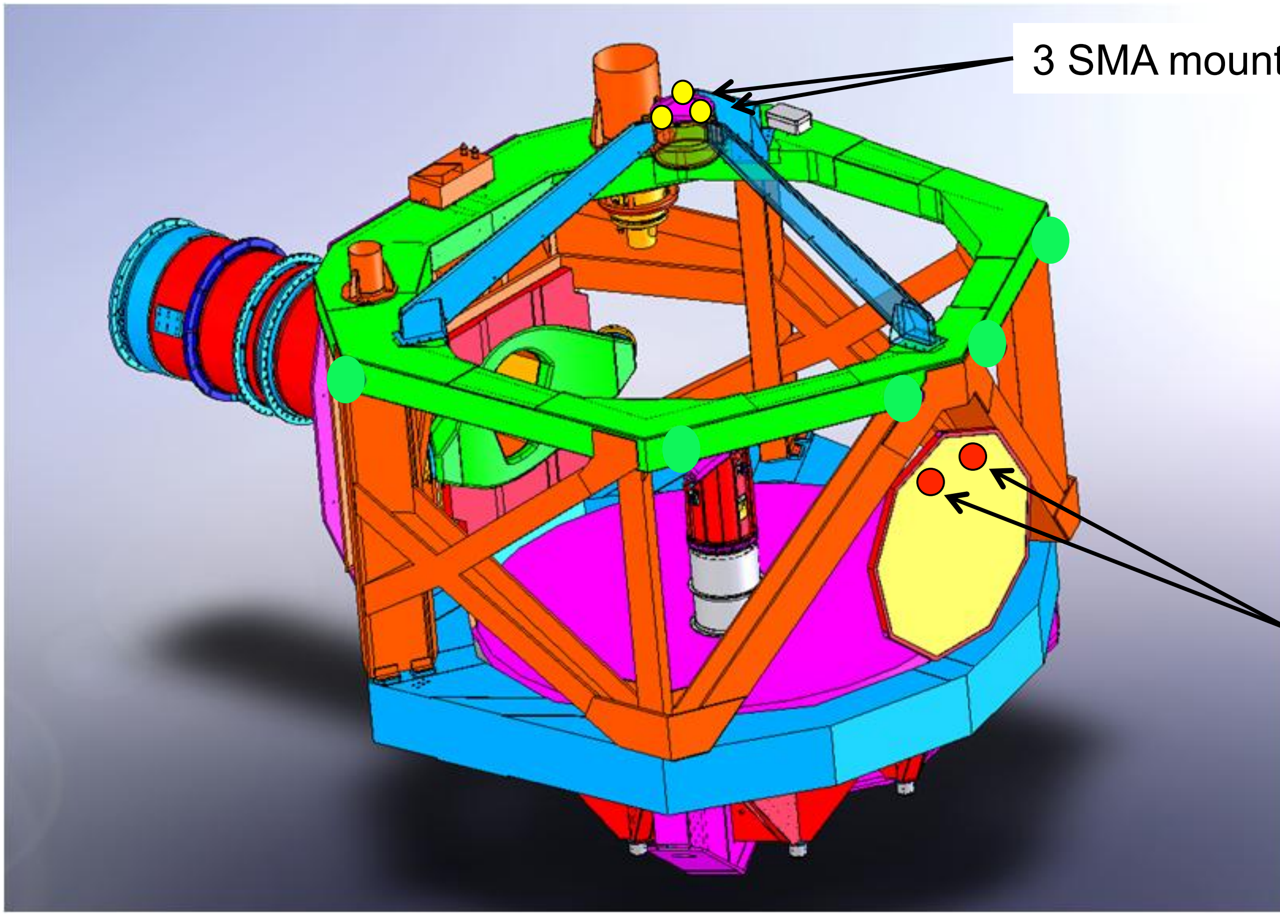
Main Stability Error Contributors



➔ **89 Hz spider excitation is the main error contributor in XEL** (~ 0.4” in XEL)

➔ **69 & 73 Hz PM excitation is the main error contributor in EL** (~ 0.25” in EL)

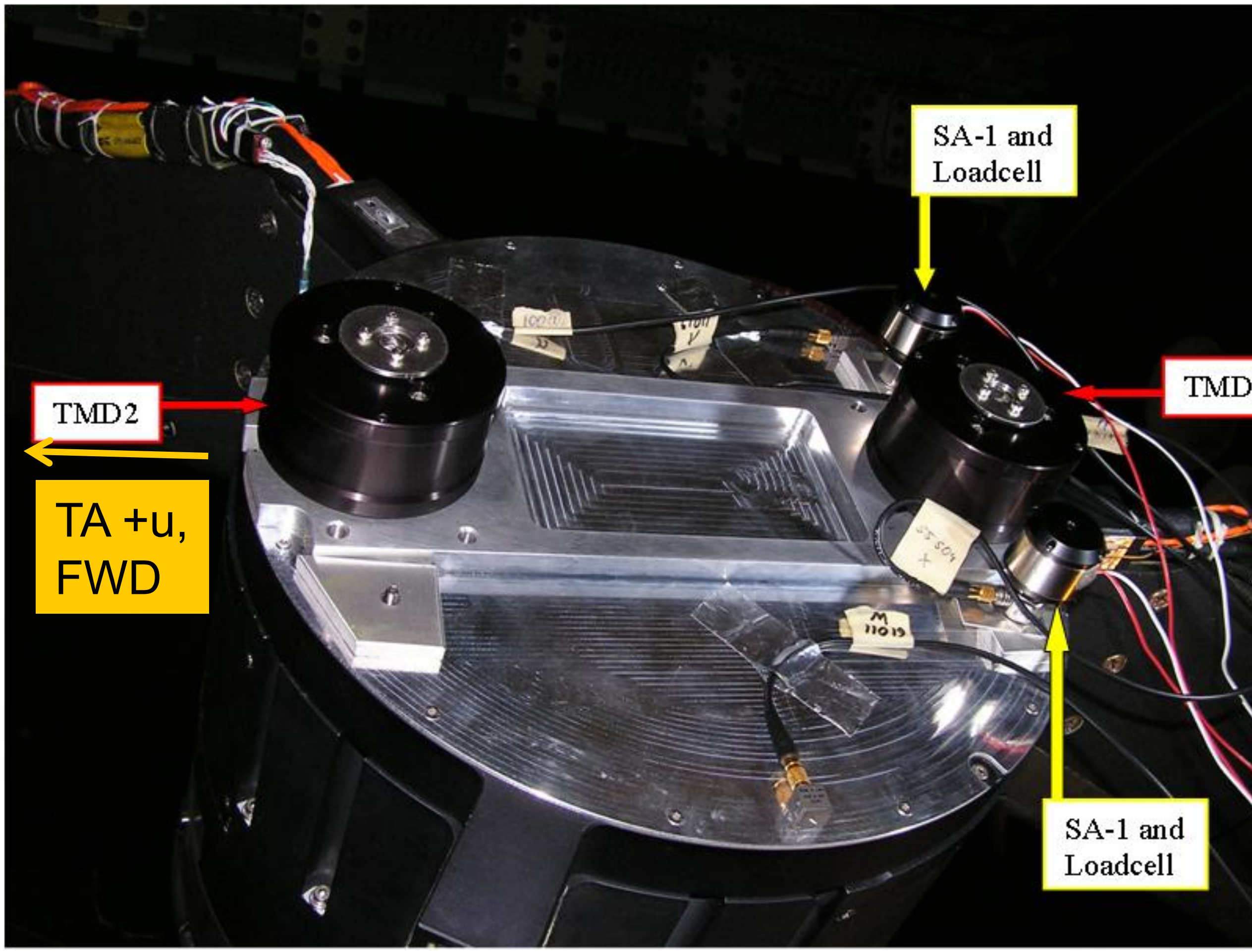
89 Hz Spider Mode Damping
SMA and Baffle Plate AMD Locations



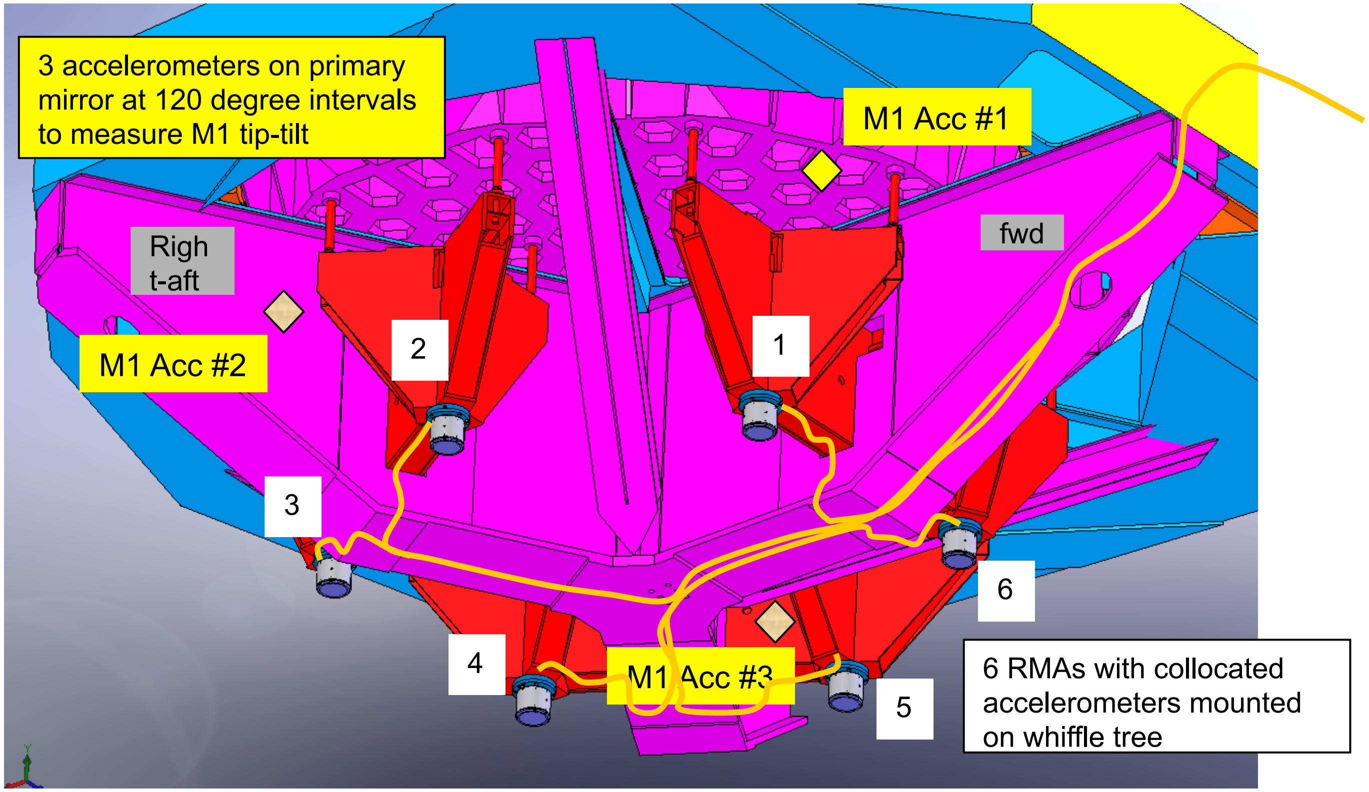
There is a strong coupling between the Spider mode and a Baffle Plate mode
→ 3 SMA and/or 1 (or 2) Baffle Plate mounted AMD’s needed to address the Spider 89 Hz image jitter contribution plus other contributions

SMA Mounted AMD's (TMD test shown)

- Three SA-1 AMD's (<0.5 lbm each) will be mounted to the top side of the SMA with a modified design cover plate (similar to ground test, shown below) to actively dampen the 90 Hz mode as well as other SMA/spider modes



PMA AMD System

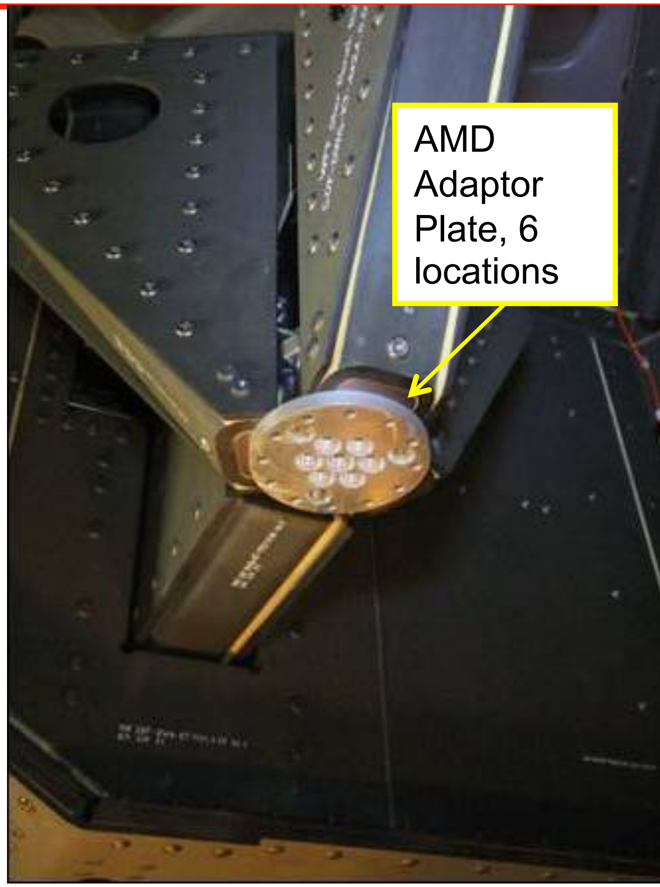


6 PM Whiffle Tree mounted AMD's

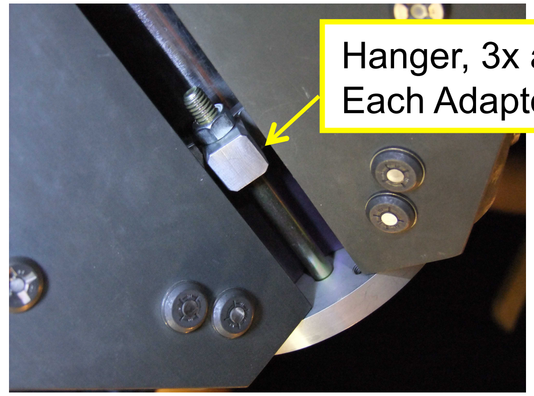
- To attenuate PM rocking modes and PM Bending modes
- Uses locations and control laws developed in ground test

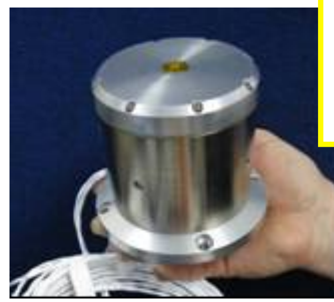
PMA Active Mass Damper Mounting

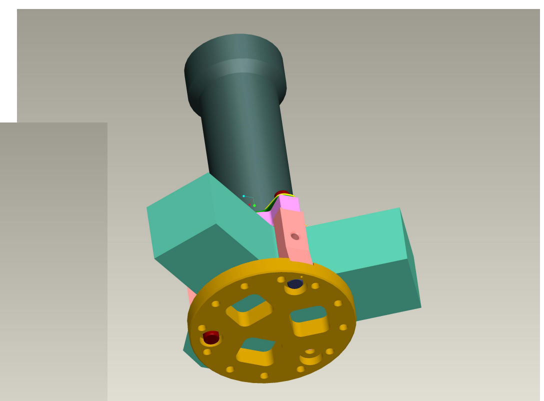
Ground Test approach but with enhancements

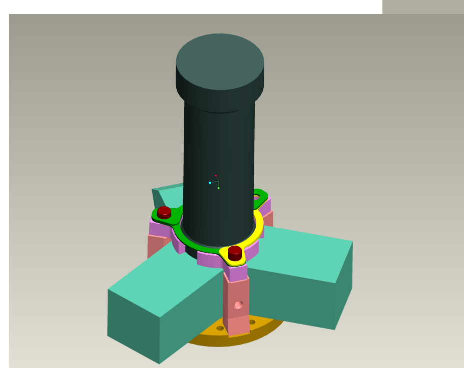


PM Whiffle Tree Mounted AMD's
(ground test mounting hardware shown)

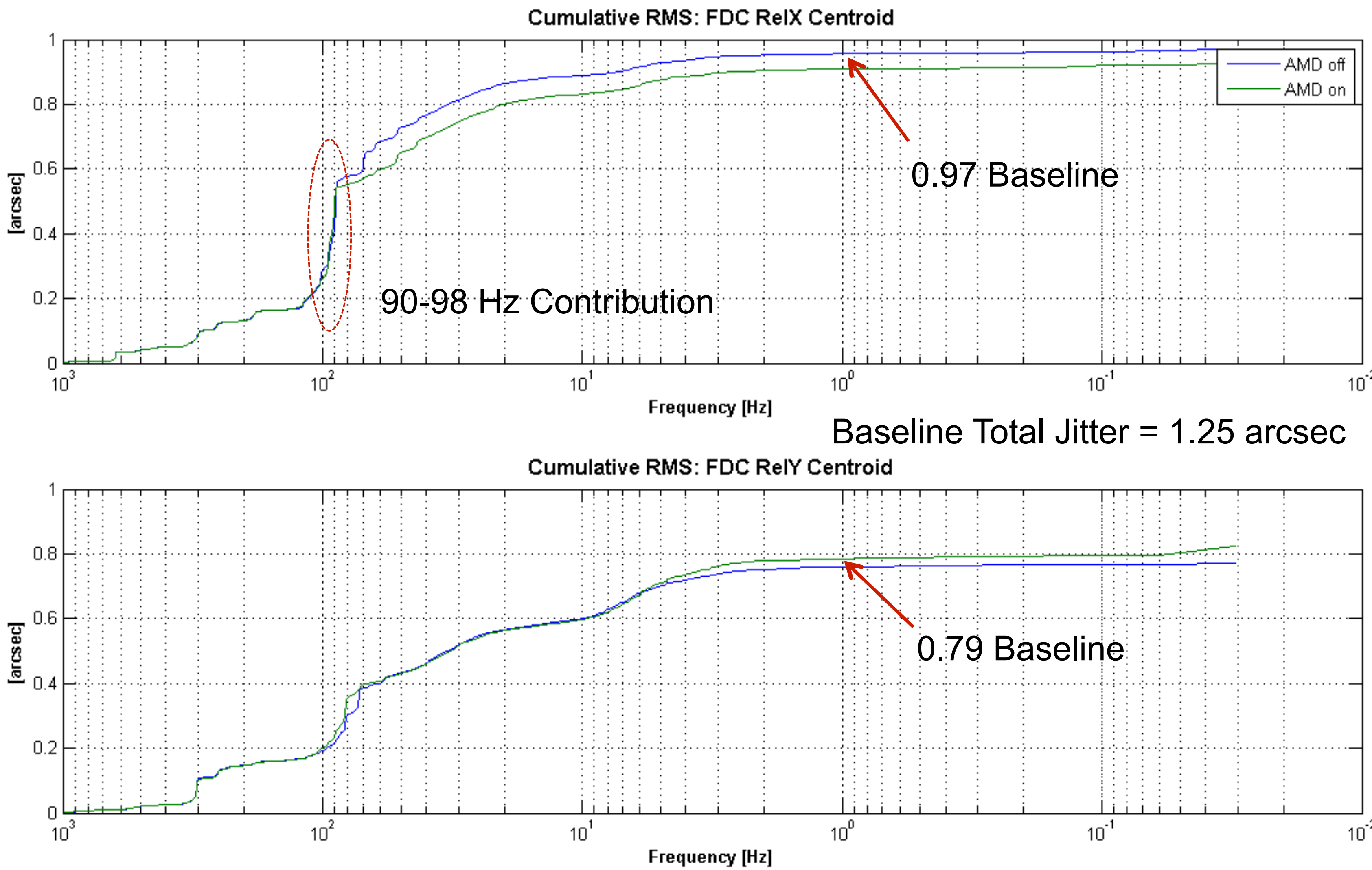






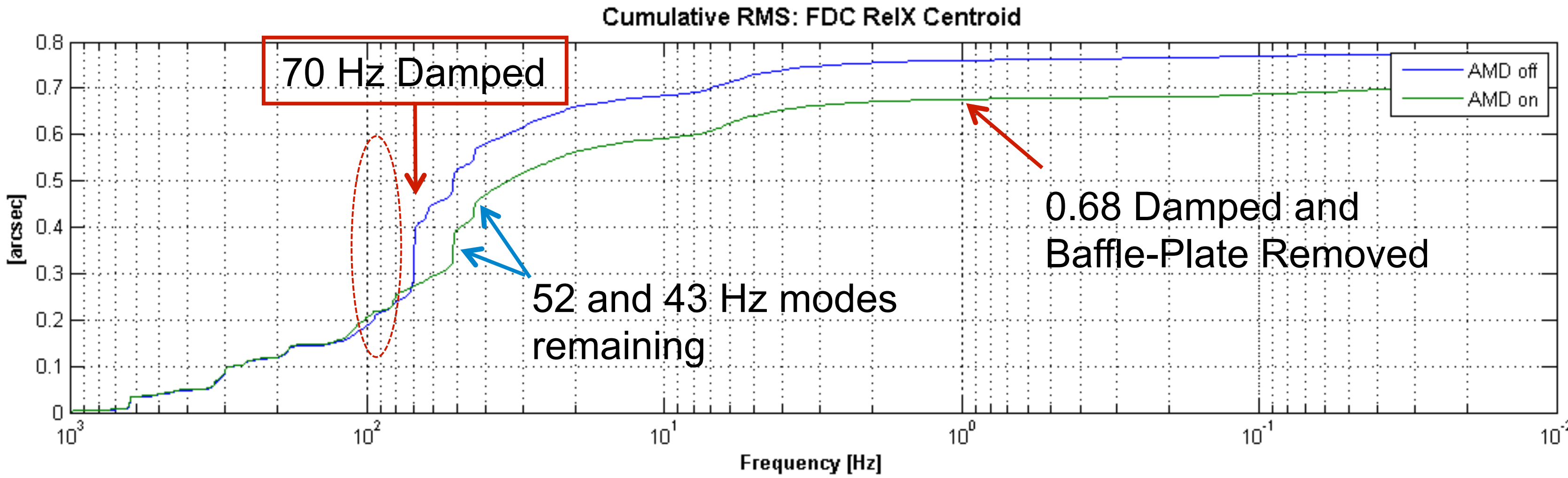


AMD Test Results SCAI 7
SFDC Data, 41k ft, Low Elevation 31˚

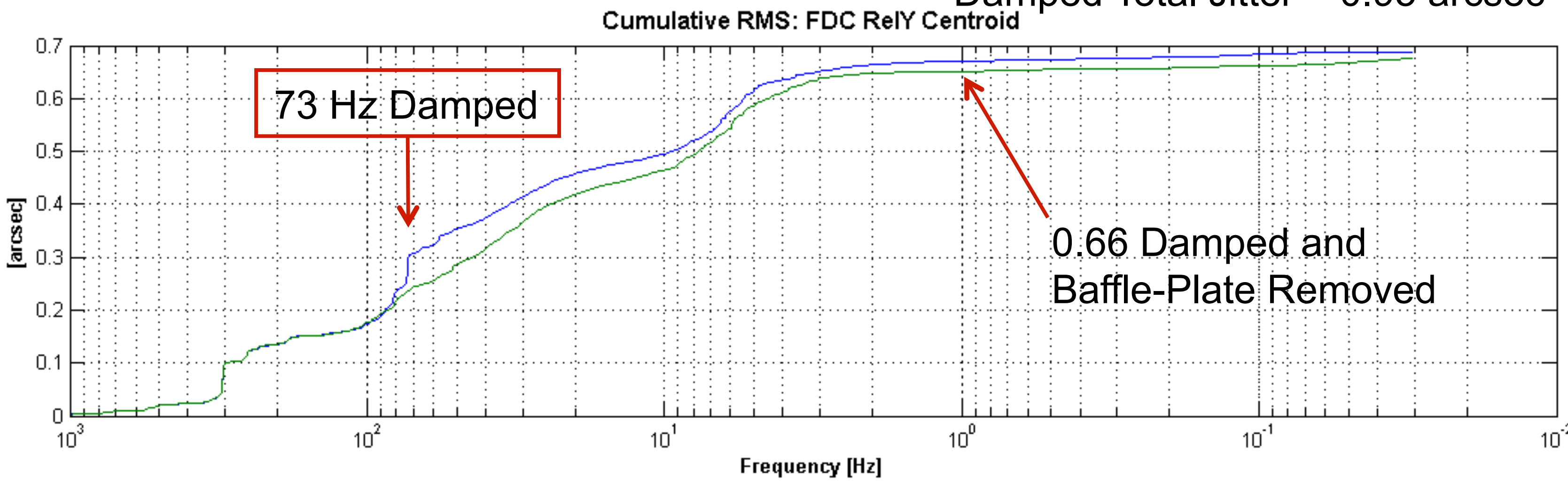


TA AMD Flight Test Results

AMD Test Results SCAI 9
SFDC Data, 41k ft, Low Elevation 25˚

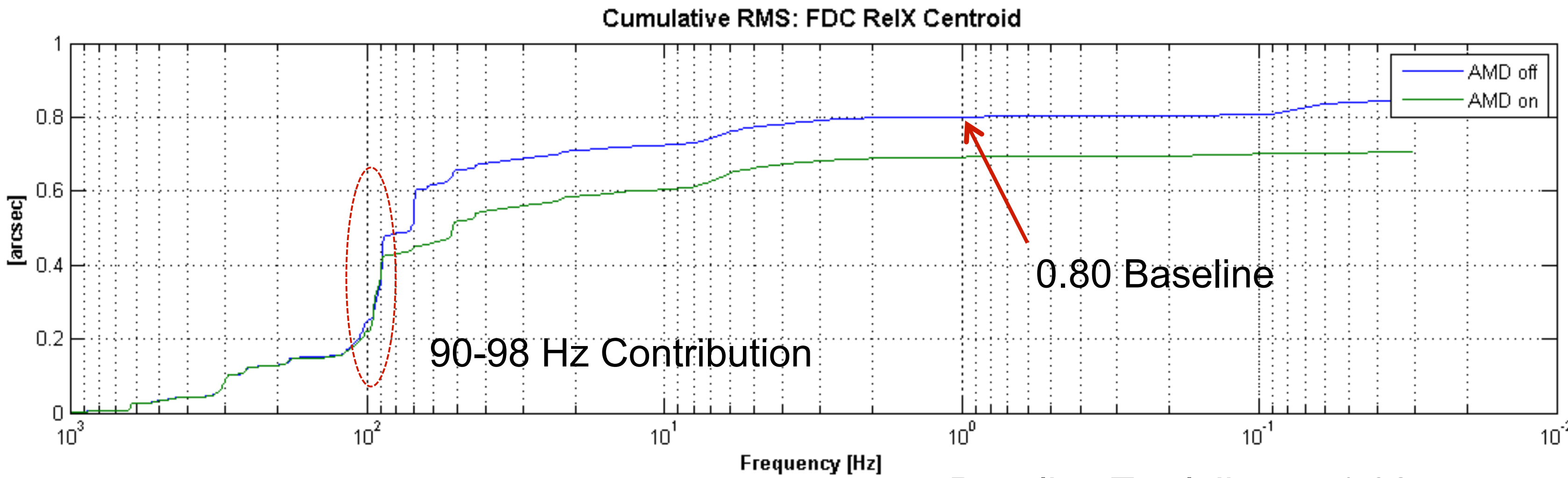


Damped Total Jitter = 0.95 arcsec

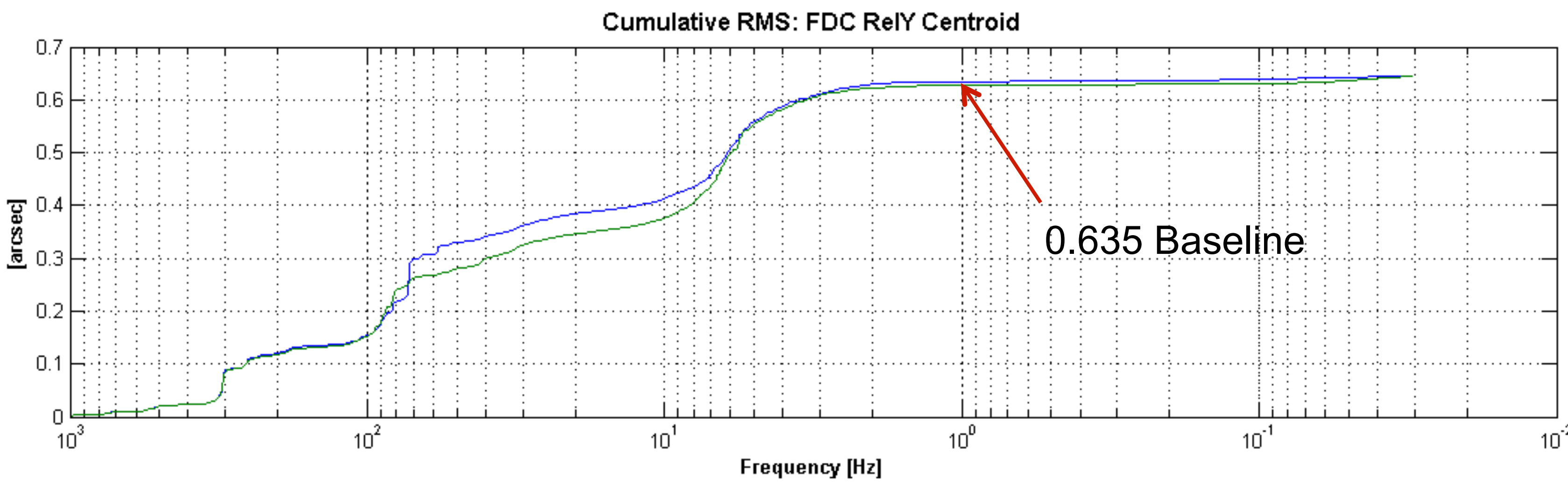


TA AMD Flight Test Results

AMD Test Results SCAI 7
SFDC Data, 45k ft, High Elevation 59°

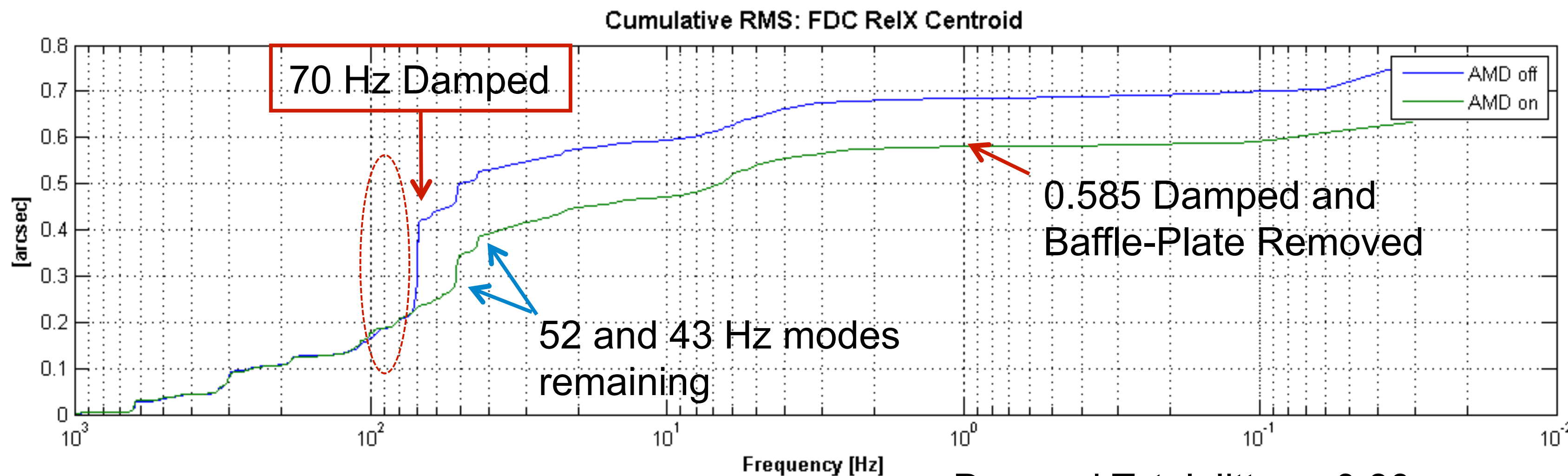


Baseline Total Jitter = 1.02 arcsec

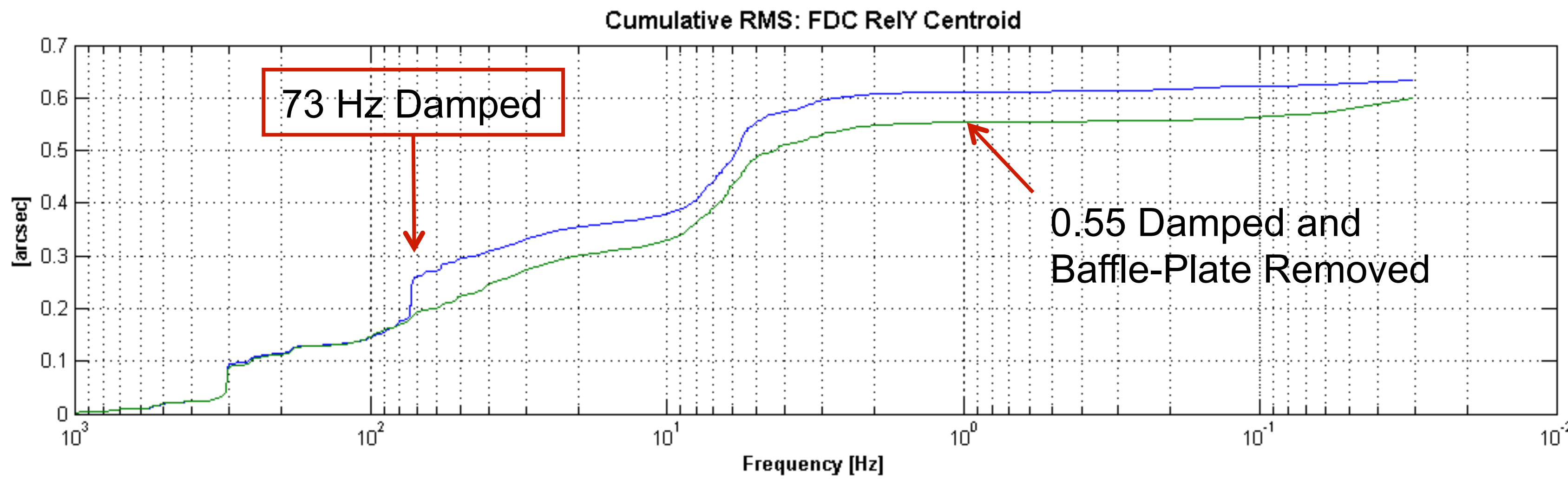


TA AMD Flight Test Results

AMD Test Results SCAI 9
SFDC Data, 45k ft, High Elevation 59˚

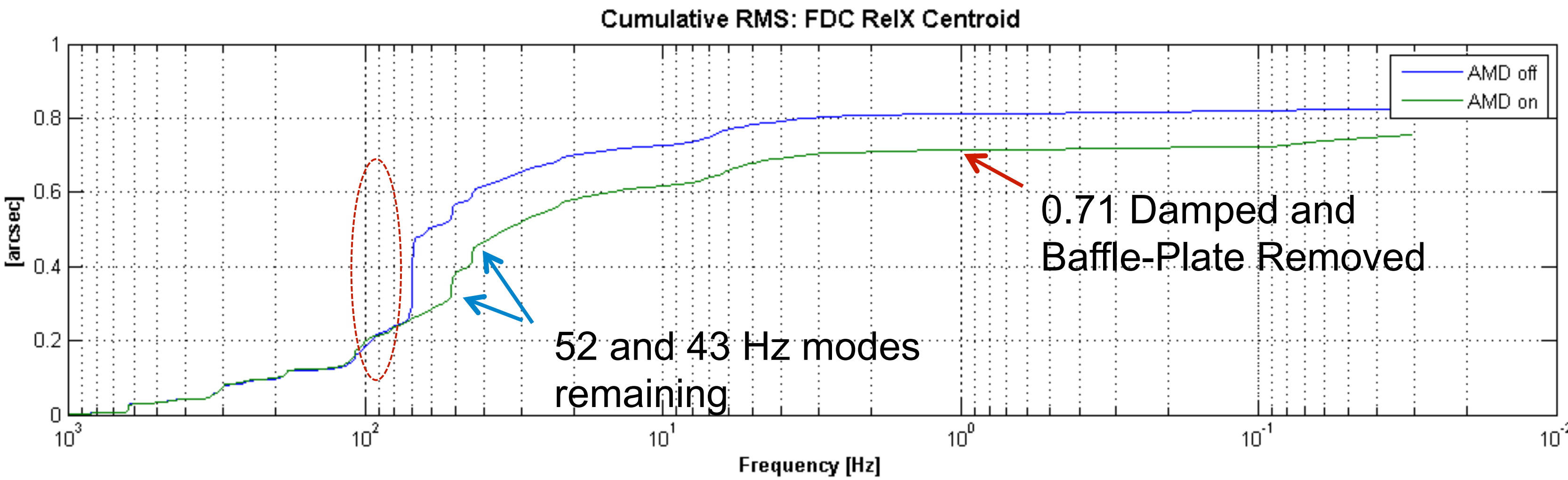


Damped Total Jitter = 0.80 arcsec

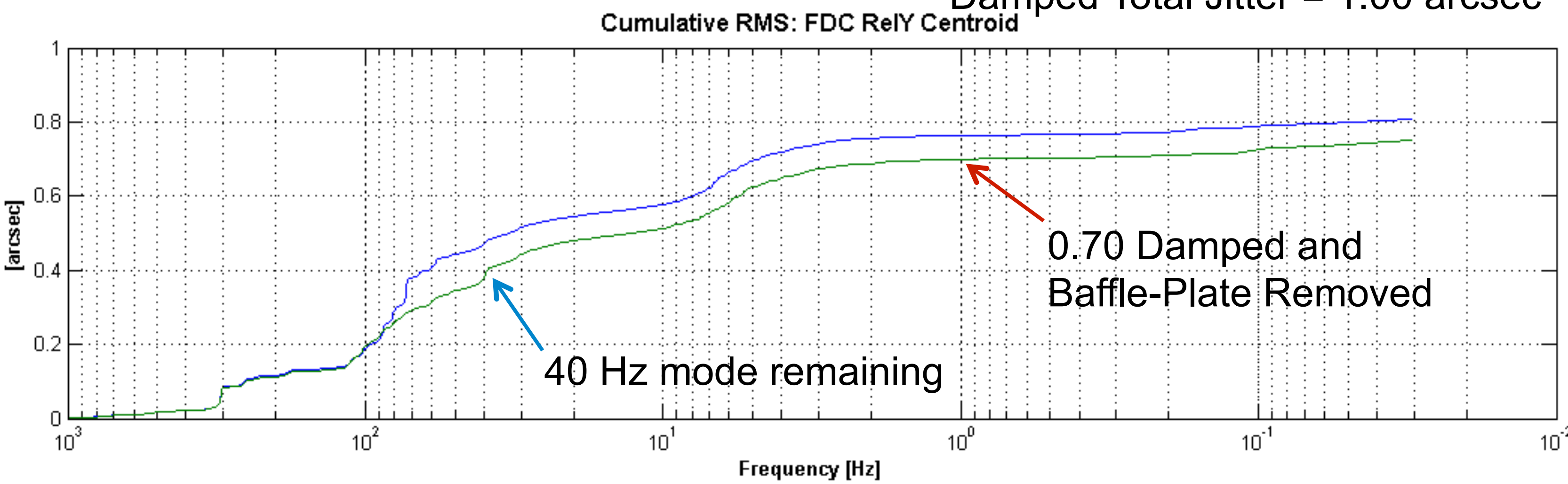


TA AMD Flight Test Results

AMD Test Results SCAI 9
SFDC Data, 45k ft, Mid Elevation 37°



Damped Total Jitter = 1.00 arcsec



AMD - Summary

- Cumulative jitter, Rrms, reduced by ~0.3 arc seconds (from 1.25 down to 0.95 for 41k feet and low elevation); ~ 2/3 of this from the baffle-plate removal

- Removal of the baffle-plate dramatically reduces the jitter contribution seen between 90 – 98 Hz

- SMA dampers were not sufficient in size and lack sufficient moment arm to well dampen the jitter energy coming in from the baffle-plate

- PMA dampers are very effective in damping the modes targeted thus far (the 70 Hz, 73Hz, 173 Hz and 175 Hz modes. Additional PM rocking modes at 52 Hz, 57 Hz and 40 Hz remain to be addressed in future control law implementations.

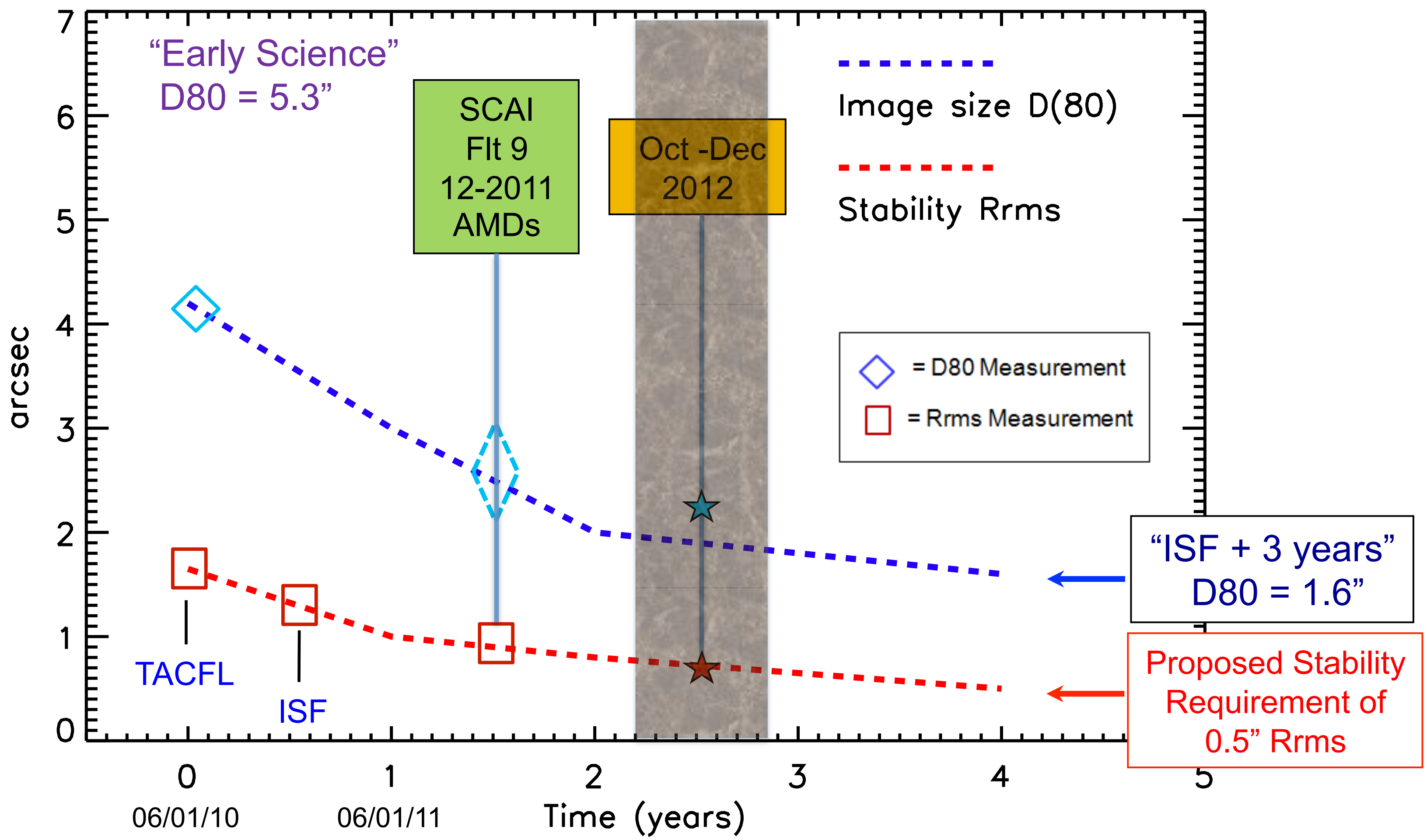
- Baseline jitter varies with altitude from about 1.0 to 1.25 arc seconds.

- Jitter seen to be lessened at high elevation relative to mid-elevation

- From preliminary review to date, best case of 0.8 arc seconds observed at 45k ft and high elevation (SCAI 9, baffle-plate removed)

- Options to the baffle-plate present design/mounting need to be considered

Performance Improvement Timeline relative to Requirements



Further improvements

- Goal for 2012: to reduce the cumulative jitter, Rrms,
    - from 1.25 down to 0.9 for 41k feet
    - to best case of 0.7 arc seconds for 45k ft

- Implement the removal of the baffle-plate as a science-flight configuration option
- Develop options to the baffle-plate present mounting and re-design/rework the mounting
- Potentially redesign the baffle-plate to reduce aero-disturbance and introduce passive damping into the baffle-plate and TA structure

- Work towards a flight certified AMD system
    - The hardware installation is flight-worthy and can be retained on-board as is
    - The software needs to be verified/validated to allow continuous operation
        - Achieve full time availability of PMA damper suite, which are very effective in damping the modes targeted thus far (the 70 Hz, 73Hz, 173 Hz and 175 Hz modes)

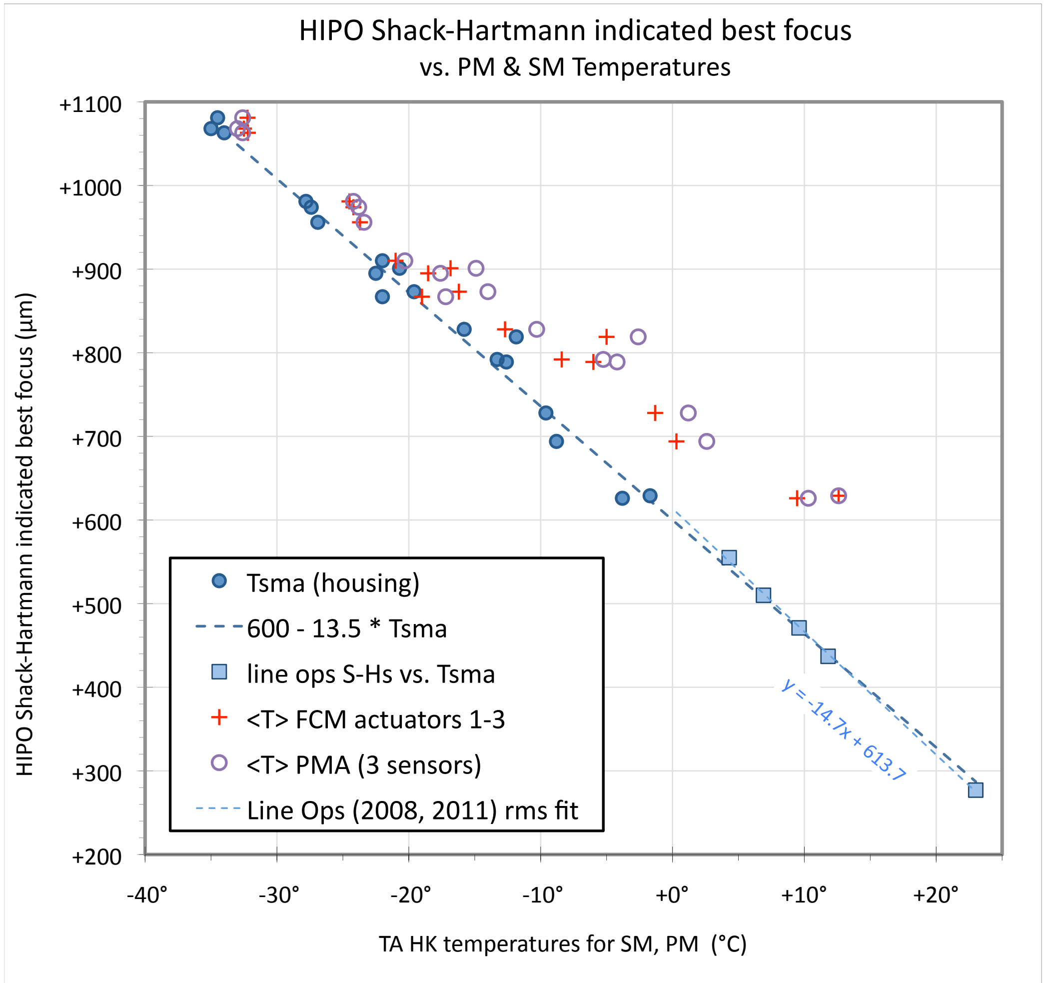
- Expand the PM damper suite control law set to dampen additional PM rocking modes at 52 Hz, 57 Hz and 40 Hz.
- Evaluate further PM mode (43 Hz pumping) and TM tower modes for damping

- Further study SMA/spider modes and damping options

Further improvements

- The **SOFIA Characterization And Integration (SCAI)** flight series will Plan and Execute In-Flight Observatory Characterization
- Need to shift toward mid- and long term Observatory performances and requirements. Characterization data give us the integrated system performance needed
- We are working on a roadmap for the Long Term Observatory improvements (image quality and pointing stability)
- Will keep working on TA controller improvements including SMA controller
- Will replace the Focal Plane Imager (FPI) with a newFPI based on the experience of the DSI Fast Diagnostic Camera. It will be fully integrated by the end of the year.

Focus vs. Temperature



Dec. 08 and June 2011 line operations Shack-Hartmann results included. This suggests that SMA housing temperature is the best, based on consistency with the line operations results at warm temperatures.

Two levels of semi-automation of focus control are under investigation:

1. Allow the MCCS to change FCM t in the background as the measured relevant cavity temperature changes

2. Implement an FPI autofocus capability that evaluates a visible source in FPI images