SOFIA Pointing, Tracking, and Image Quality Improvement

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SUG Meeting
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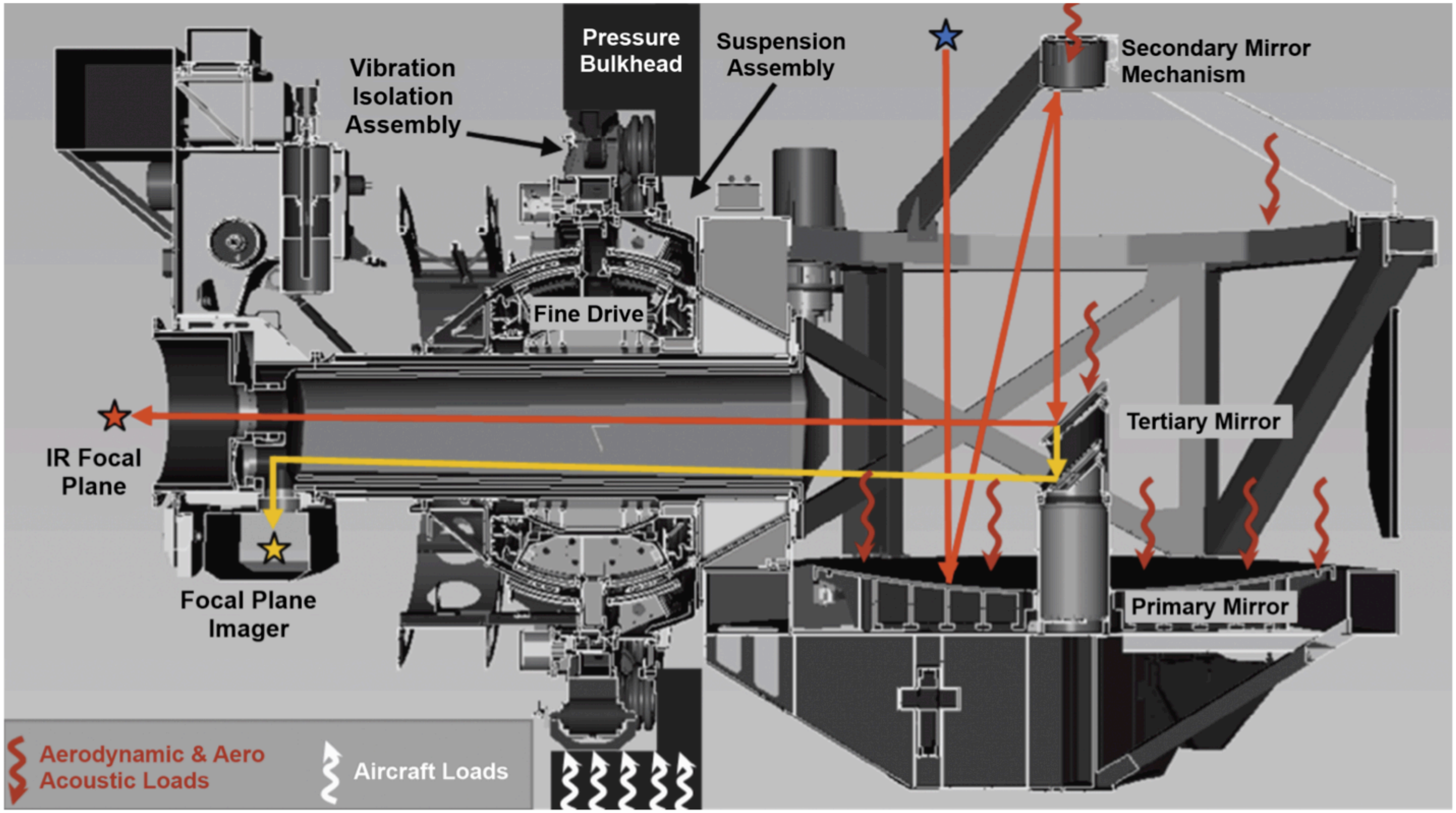
Outline of Material

- The New FPI Camera
- Tracking while Guiding
- Image Quality

New Focal Plane Guide Camera


Pressure Bulkhead
Vibration Isolation Assembly
Suspension Assembly
Secondary Mirror Mechanism
Fine Drive
IR Focal Plane
Tertiary Mirror
Focal Plane Imager
Primary Mirror
Aerodynamic & Aero Acoustic Loads
Aircraft Loads

Background on new Focal Plane Imager

- The Focal Plane Imager that came with the SOFIA Telescope had major problems
  - Very low Quantum Efficiency (QE)
  - Very high Dark current because operated warm (~25C)
- Use of Camera on bright sources V~11th mag only. Therefore not useful for most 8 arcmin fields even in the galactic plane.
- Use of larger field guide cameras on the telescope structure had flexure problems for most observations. (FFI and WFI)
- During 2012 down time the magnitude and cause of this flexure was determined but no simple solution is possible. (to be discussed later)

New Focal Plane Imager for SOFIA

- During 2012 DSI and Kayser-Threde under the leadership of Juergen Wolf provided a new Guide Camera and associated electronics for the SOFIA telescope
  - Based on previous work over the last several years using ANDOR cameras. (known in the project as the Fast Diagnostic Camera, FDC)
  - Major support from DSI students Manual Wiederman, Enrico Pfuller and most recently Michael Lachenmann
- CCD detector is an ANDOR iXon DU 888 camera with with electron multiplication gain, very high QE~90%, very low read noise and fast read out.
- It is a 1024 by 1024 pixel detector and optics that provide a ~0.5 arcsec per pixel scale (Field of View ~8 by 8 arcmin).

FPI Upgrade Overview

Early 2012 KT & 4DE were contracted to design new FPI camera controller and software. DSI started with design of new filter wheel

June Design Review for the FPI Upgrade

Sept. Hardware was delivered and environmental testing began

Jan. 2013 Start of FPI+ integration at DAOF

Feb. 6/7 FPI+ Integration Line Ops (~1 ½ nights lost due to weather)

Feb. 12/14 FPI+ Integration Flights (2 half flights)

FPI+ Integration Line Ops & Flight

Preliminary results:

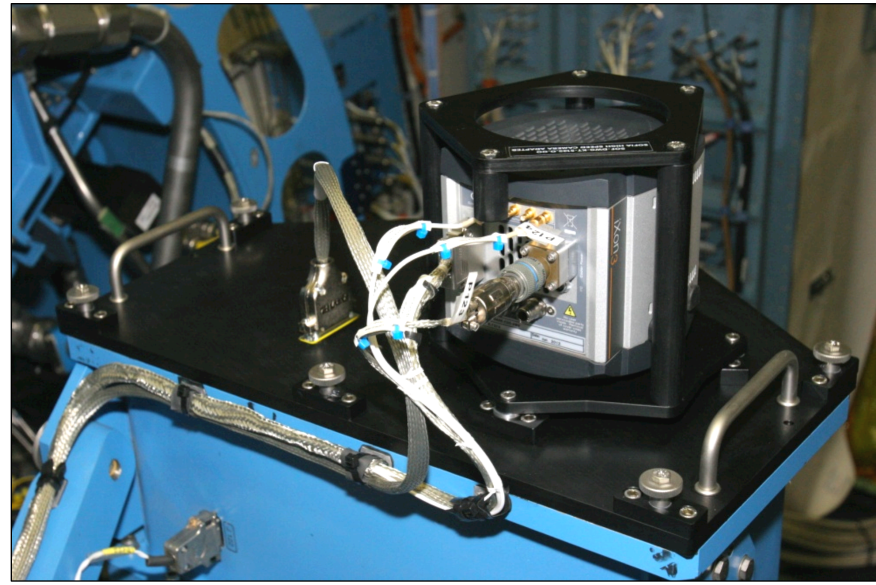
- The camera performed as expected and the team were able to track on V ≈ 16 mag stars with t_{exp} = 2.0 s; Signal to noise of about 50:1. Star images during flight due to share layer seeing were about 5 arcsec FWHM.

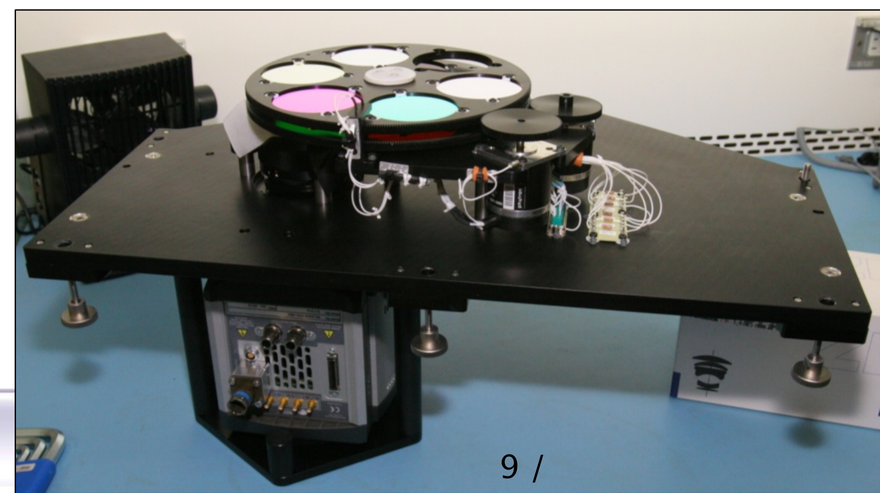
There are still improvements to be made:

- Trigger modes for Secondary Mirror (ie chopper) synchronization need to be optimized.
- Tracking on Sub-Frame Images
- Improvements to "Diagnostic Laptop GUI"
- …

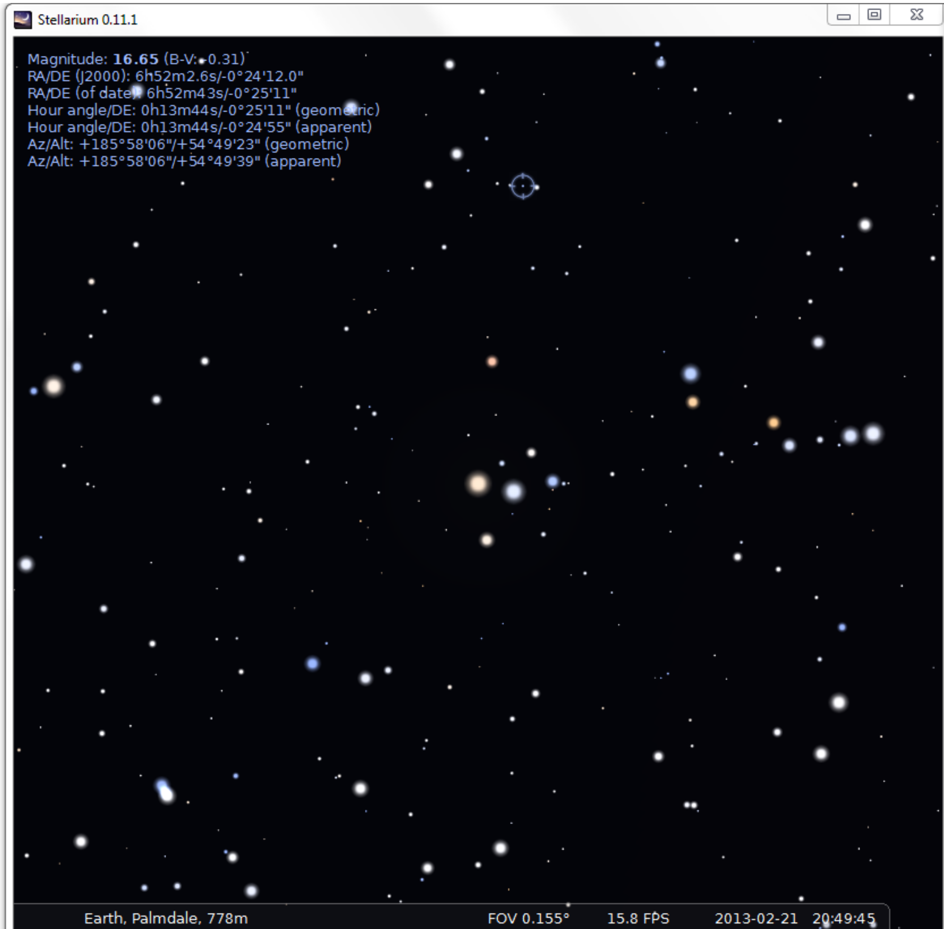
FPI+ Camera & Controller

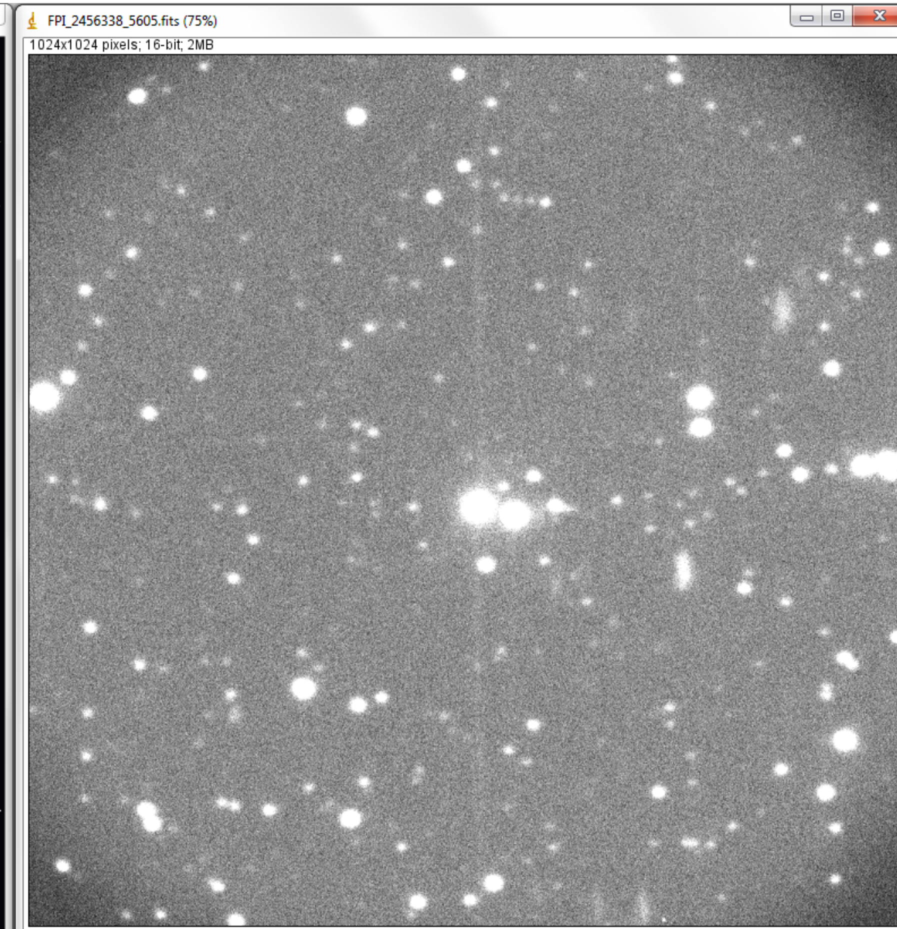
All hardware was environmentally tested by DSI at NASA Ames





FPI+ with a 10th Mag star in center





$t_{exp} = 0.5$ s

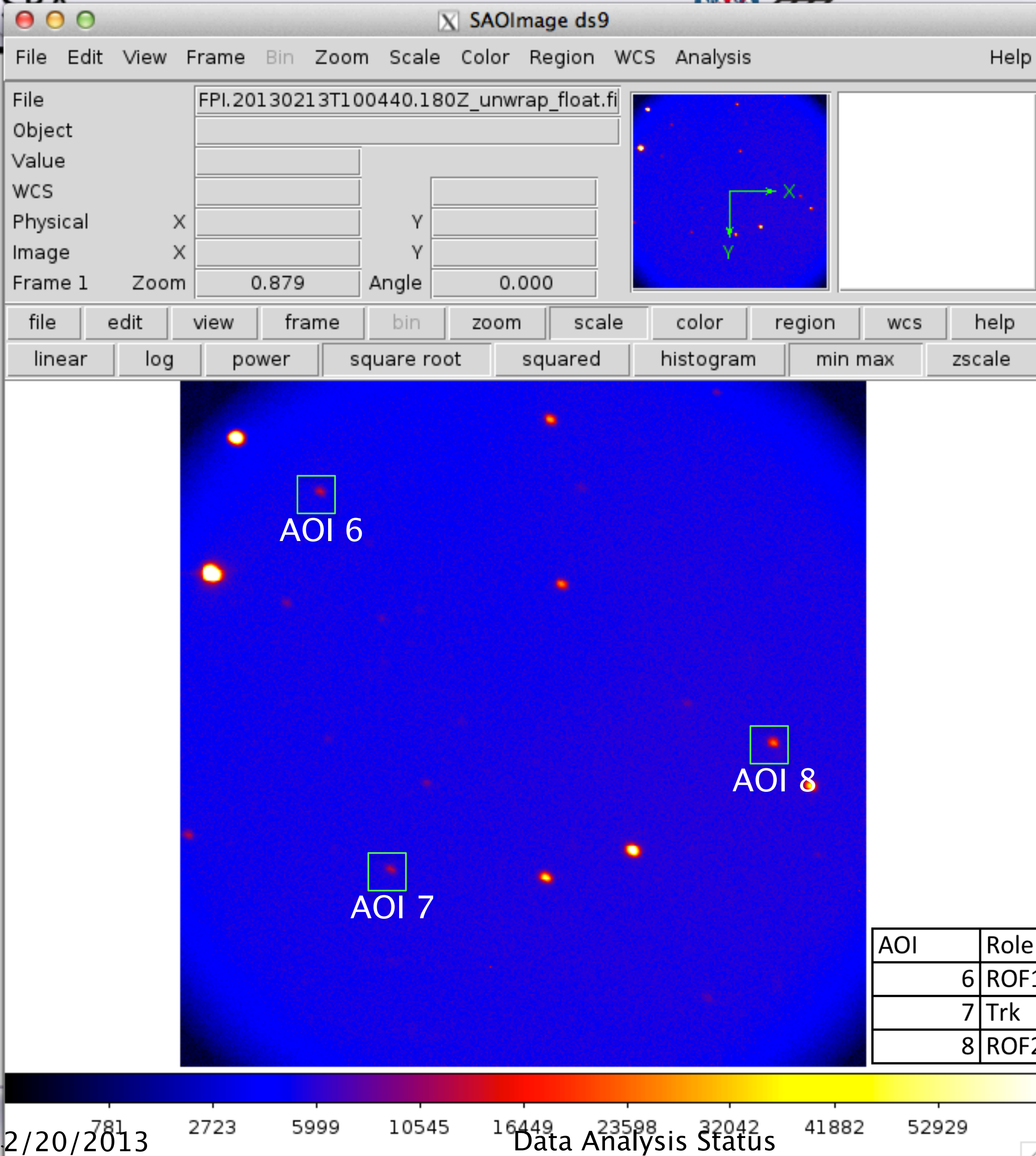
Summary on New Focal Plane Imager

- Camera works as expected. (~a factor of 100 improvement in S/N!!)
- Can now successfully guide on >95% of the fields. (see study by Jeff Van Cleve In the Back-up)
- Neutral density and near IR (~1 micron) filters allow Bright star, Lunar and day time tracking (Still to be demonstrated)
- Might also be used for some science??

In Flight Results with the New FPI Camera and MCCS and TA Improvements

- Two flights were made in Feb 13 to test tracking with the new FPI and other improvements with the TA and MCCS. HIPO also flew.
  - The results were very encouraging
  - There were some communication issues that slowed things down.

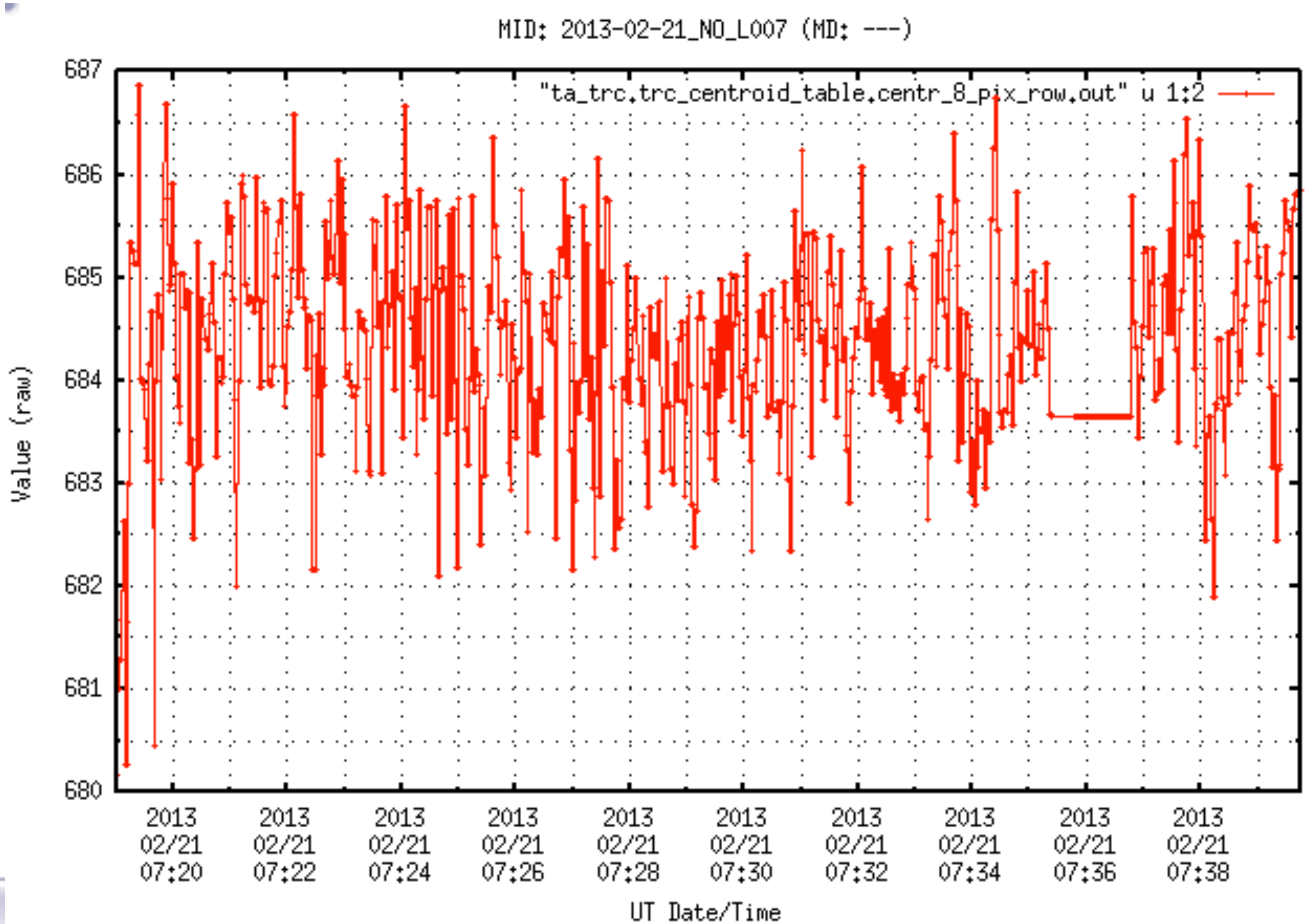
Faint Star Tracking
FPI+ test 3.1 Image



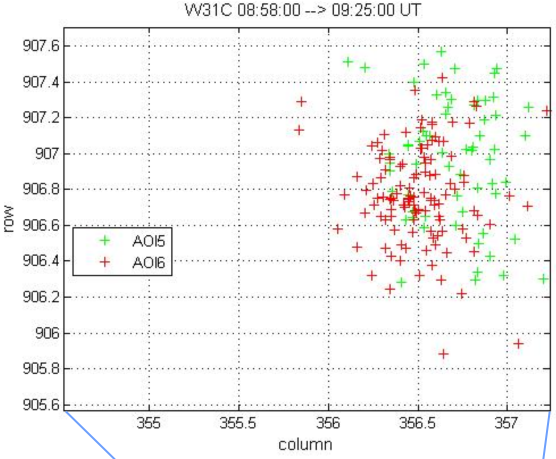
- Unwrap DNs (see later)
- Identify AOIs from HK
- Identify stars from Simbad and Aladin
- 2s integration
- 2x2 binning
- SIBS (259.61, 272.70) not at a visible star

AOI	Role	Rmag
6	ROF1	15.5
7	Trk	15.5
8	ROF2	14.7

Offset guiding in the FPI Camera for 18 min including LOS rewinds



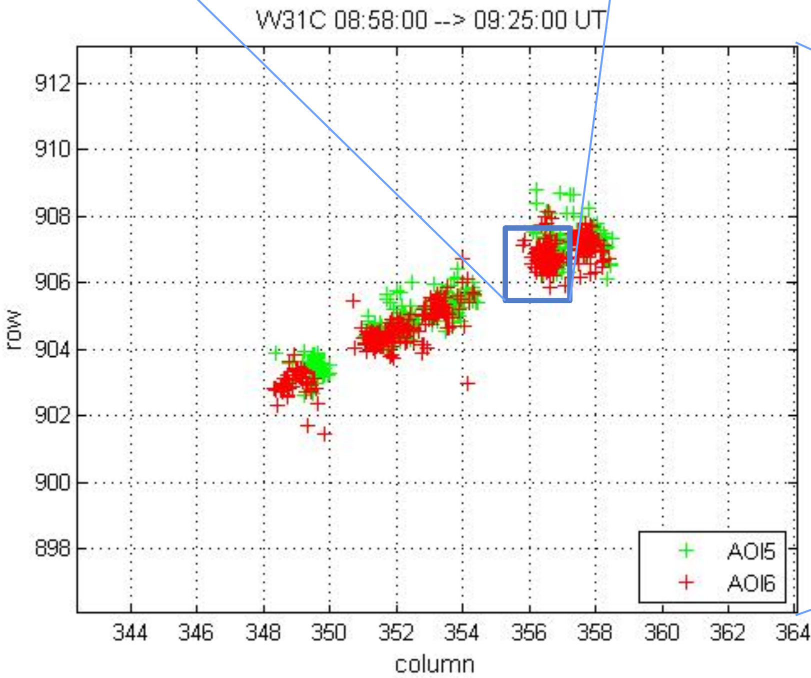
Leg 11: DBS – W31C

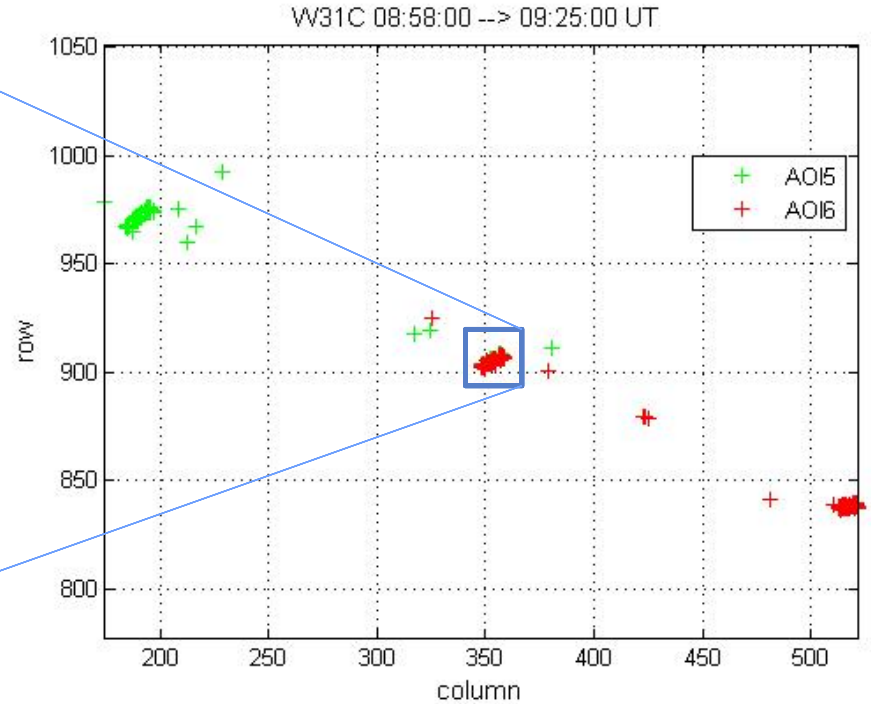


	1
Distance b/w Mean AOI Positions (")	0.1494

	AOI-A	AOI-B
Ellipticity	0.3196	0.1991

	AOI-A row	AOI-A col	AOI-B row	AOI-B col
Mean Position (pixels)	906.9677	356.6969	906.7765	356.5040
Std Dev (pixels)	0.3411	0.2321	0.2749	0.2202
Std Dev (")	0.1876	0.1276	0.1512	0.1211



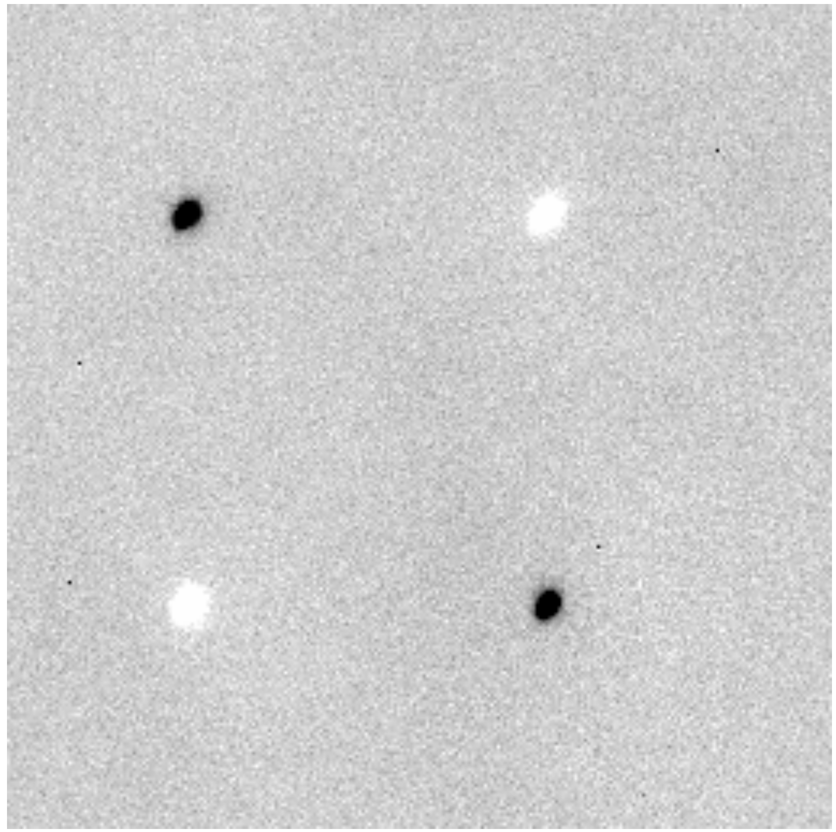


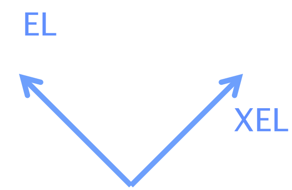
Alpha Tau 11.3

Image Quality*

PA= –45.5°
$FWHM_{maj}$=3.90”
$FWHM_{min}$=2.85”
Eccentricity=0.269

TA Elevation=31°





39,000 ft
Leg 6

*averaged over all four sources

Summary of Results on Tracking

Line operations and V&V flights demonstrated excellent telescope pointing stability when all tracking was performed in the FPI.

- We expect to perform both centroid and ROF tracking using 2 or 3 trackable stars in the FPI, which will be available over >92% of the sky when FPI+ gives us 100x as many guide stars.
- Two-star tracking observations with the old FPI, using bright star clusters and a recently developed algorithm for real time chop-nod matching, suggest that the absolute pointing, image stability over 30 min, LOS rewind errors, and chop-nod matching are each about 0.4 arcsec or better.
- Use of the other guide cameras for centroid tracking and ROF stabilization give typical results of 2" absolute pointing, 3"/hr image stability, and 1" chop-nod match error per 1 ' of chop throw, though the Mission Operations staff can reduce these errors by a factor of 2 at the time expense of frequent imager and chopping secondary alignments and calibrations.
- Errors are 1-sigma radial, assuming Gaussian statistics.

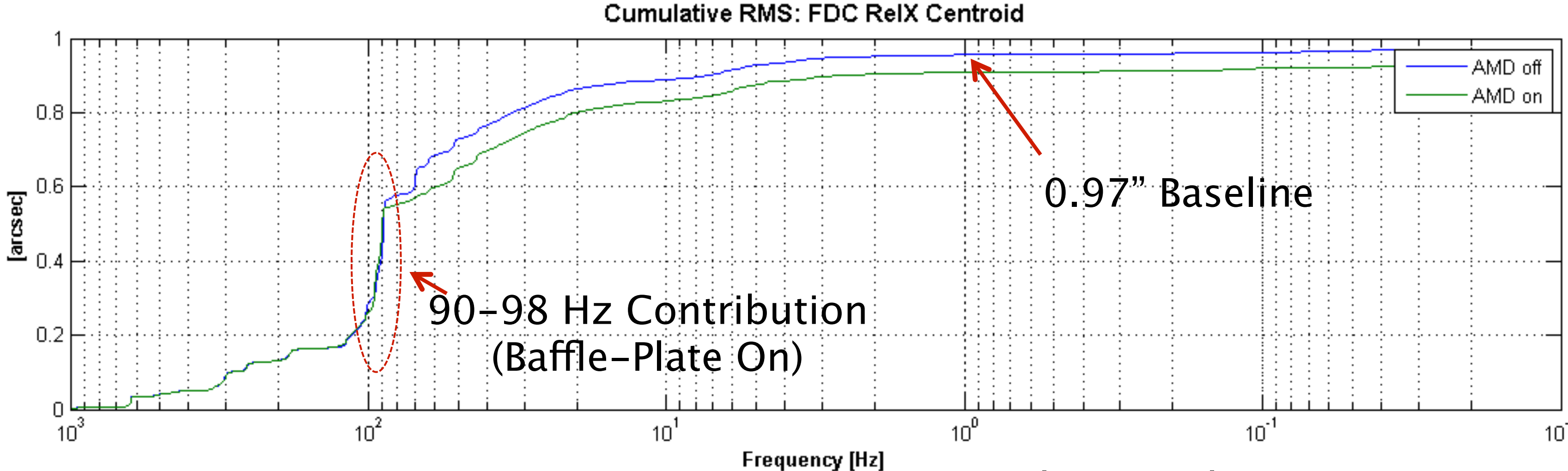
Image Quality

- Image quality of the SOFIA telescope is presently primarily limited by:
  - Diffraction for wavelength greater than ~40 microns
  - Jitter of the telescope for wavelengths between 3 and 40 microns
  - Shear layer seeing for wavelengths between 0.3 and 3 microns.

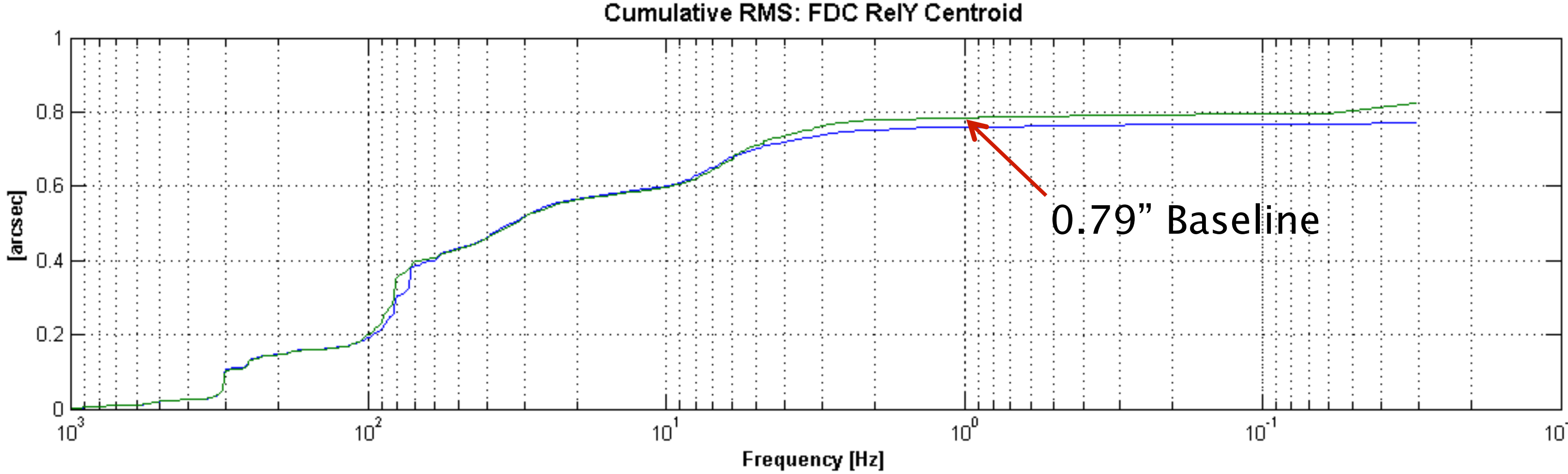
- Jitter of the telescope is improving. When the baffle plate was removed in Dec 2011, the jitter at 90 Hz was completely removed. Active Mass Dampers on the primary also improved things, and will be placed in operation later in the year. In 2011 early science flights we had a jitter of about 1.6 arcsec rms (~2.5 arcsec FWHM). It is now about 1.0 arcsec rms (1.5 arcsec FWHM).

AMD Flight Test Results (Dec. 2011)

SCAI 7 SFDC Data, 41k ft, Low Elevation (31°, file 55v56)

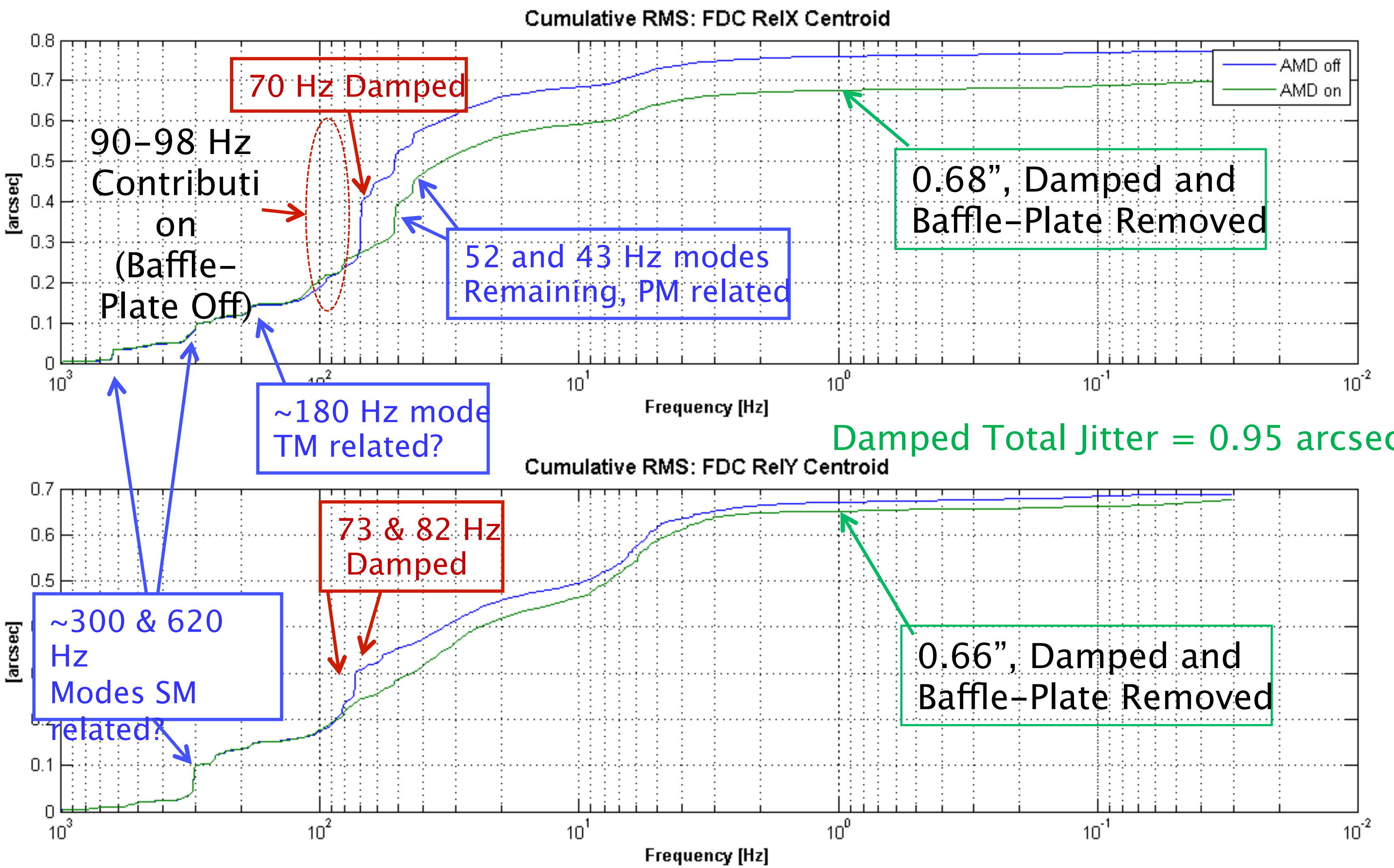


Baseline Total Jitter = 1.25 arcsec



AMD Flight Test Results (Dec. 2011)

SCAI 9 SFDC Data, 41k ft, Low Elevation (25°, file 250v251)



Shear Layer Seeing

- Shear Layer seeing is very strong for the shortest visible wavelengths and gets less into the Infrared.
  - Visible FWHM~5arcsec completely dominated by Shear Layer.
  - 2.2 micron Image quality is about FWHM~3 arcsec and shear layer is estimated to be about 2 arcsec when jitter is removed.
  - Close to theory and models.

- Improvement in the shear layer seeing will be very difficult but not impossible.

- More study is in progress.

Image Quality Summary

- For most of our science we are diffraction limited (Lambda >40 microns)

- Jitter improvements are most important in the 3 to 40 microns region and good progress is being made. Future improvement have been identified. Passive damping will help as will a better controller and a faster response of the secondary mirror. Reduction of the air flow unto the TA probably will also help.
- Improvements in the Shear Layer and Cavity Seeing should be driven by science

Path to improve Image Quality

- **AMD system (active + Passive) development**
- Tune-up of current AMD
- Implement Passive damping systems (damping material on PM whiffle trees and SM bipods).

- **Wide band disturbance, disturbance feed forward**
  - Wide band disturbance will be the remaining main pointing error contributor after the narrow band disturbances are solved.
  - Disturbance feed forward is means to handle this
  - Ongoing work with more sophisticated and aggressive controllers

- **Cavity acoustics, shear layer measurements**
  - Cavity aerodynamic model project
  - Differential pressure measurements on headring etc
  - Investigation of deflector plate to reduce downwash on headring and primary mirror.
  - Investigation of damping acoustic noise by “Helmholtz resonators” (existing holes in Lower Flexible Door).
  - Instrumentation plans. May be a means to reduce wide band disturbance on pointing.