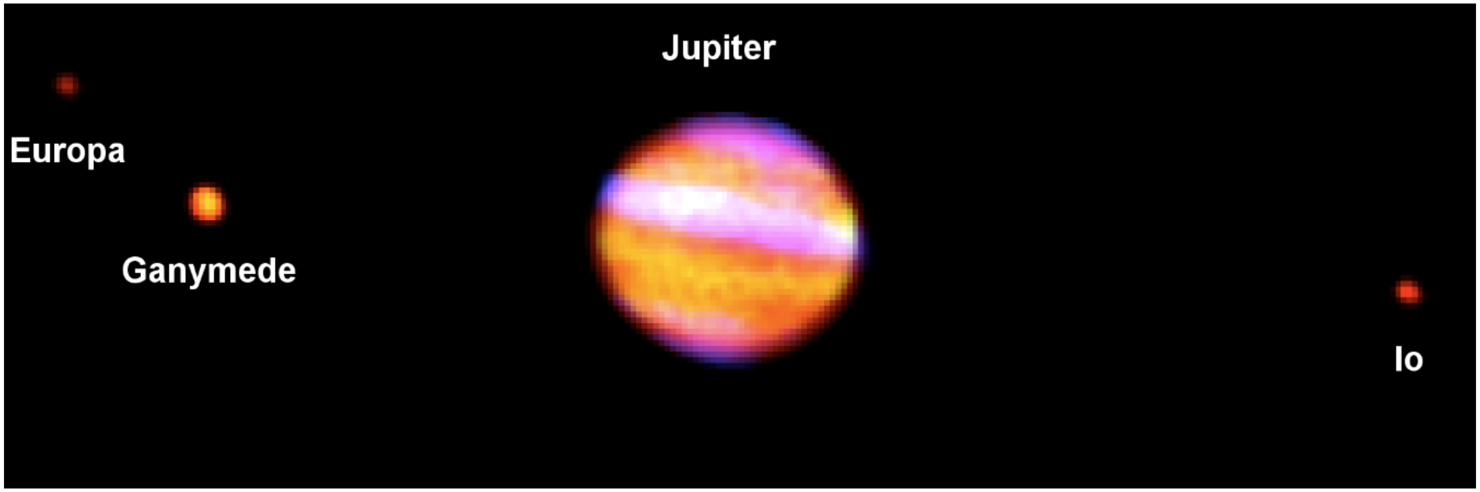


SPOT Meeting # 7 Overview and Summary

SOFIA USERS GROUP Sept 17, 2012

Eric Becklin and Pasquale Temi

Outline

- SOFIA Pointing Optimization Team (SPOT) Overview
- Tracking and Pointing.
- Guide Camera Upgrades
- Chopper Issues
- Image Quality
- Summary

SOFIA Pointing Optimization Team (SPOT)

- Formed in 2009 by DSI to oversee SOFIA Pointing, Tracking, Image Quality and other Telescope Assembly (TA) issues.
- Membership, Charter and previous meetings reports and slides are on the Wiki site at: https://wiki.sofia.usra.edu/twiki/bin/view/SPOT/WebHome
- It is co-chaired by Hans Kaecher MTM (Father of the SOFIA telescope) and Joerg Wagner DSI (Professor of Engineering at Stuttgart)
- Science members are Eric Becklin, Pasquale Temi, Ted Dunham, Juergen Wolf and Alfred Krabbe.
- The SPOT is a major communication tool as well as bring together engineering and science expertise on SOFIA.
- It meets twice a year for two days at the DAOF, Ames or Stuttgart. The last meeting (#7) was 20, 21 Aug at the DAOF

Tracking and Pointing

- Over the last year, a major emphasis of the SPOT has been the tracking and pointing of the TA on SOFIA.
- By tracking I mean the ability to stay on a celestial target to a given accuracy (such as 0.5 arcsec rms) over a given time (such at half an hour).
- Pointing is the ability to move from one point on the sky to another point on the sky to a certain accuracy.
- The SPOT has built on other efforts such as the SCAI flights, the OPT, the many MCCS efforts, the various line ops in the area of tracking and pointing and especially work by K-T and DSI (H. Jakob)
- For me the past meeting provided a good summary of the status of the Observatory in Tracking and to a lesser extent Pointing.

Summary of Pass Through on Axis Tracking with the FPI

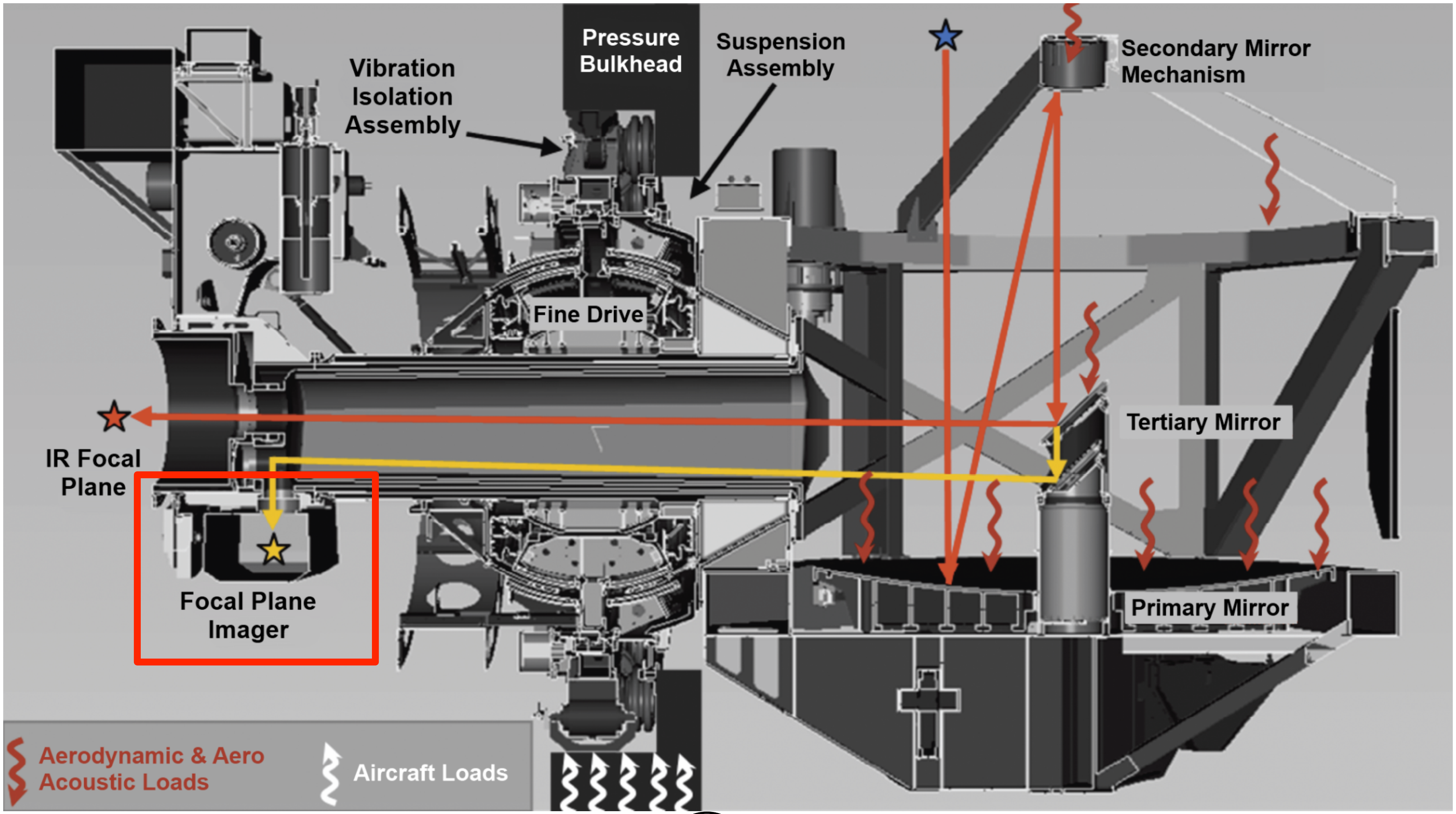
- Data from a test and a report put together by Walt Miller

- The test was accomplished by tracking Polaris in the Focal Plane Imager (FPI) with a Field of View of about 10 arcmin (0.55arcsec/pixel) for 17 minutes.
- The MCCS was not in the loop and only pass through commands were used.

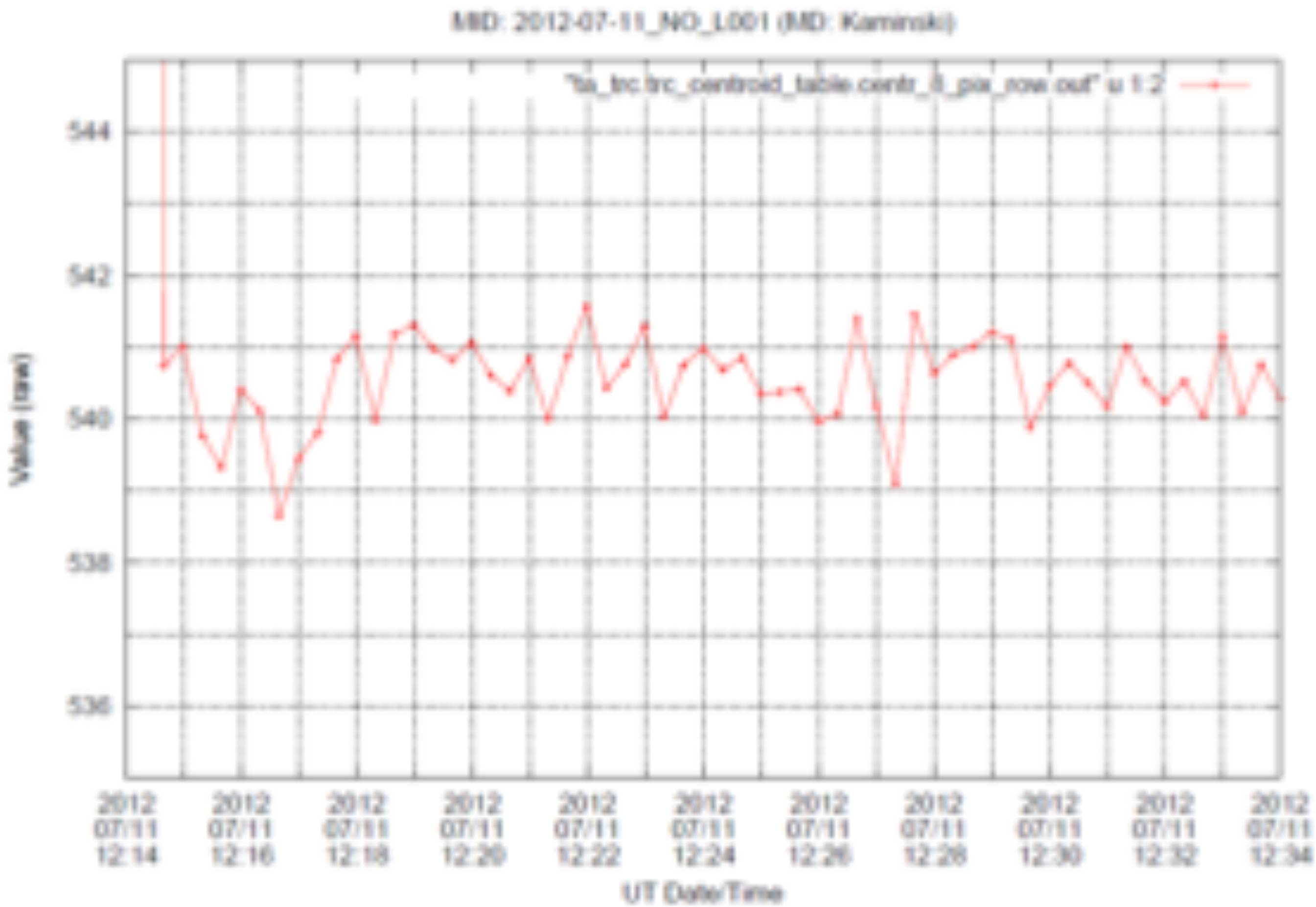
- The Telescope Assembly had been aligned and the latest K-T tracking algorithms were employed.

- The output was the position of Polaris in rows and columns on the FPI as a function of time.

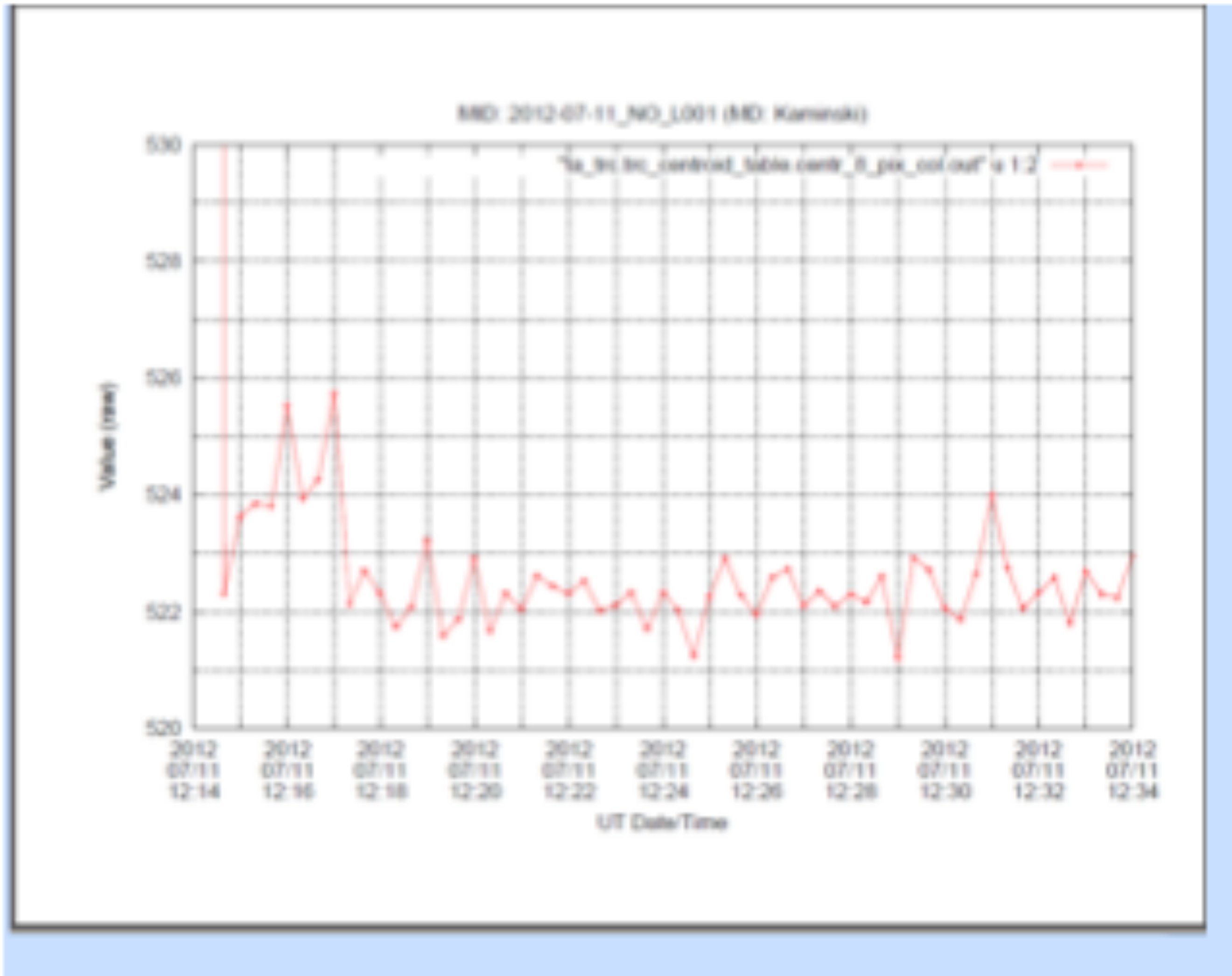
SOFIA Telescope Assembly



Pass Through tracking on Axis (Row)



Pass Through Tracking on axis (Column)



Summary of Pass Through on Axis Tracking with the FPI

- For the 17 minutes the peak to peak tracking in both rows and columns is a bit larger than 1 pixel which is 0.55 arcsec

- The data show that the rms tracking was 0.29 arcsec in the rows and 0.27 arcsec in columns, for a radial tracking of r_{rms}= 0.40 arcsec.

- Much better than I expected at this point.

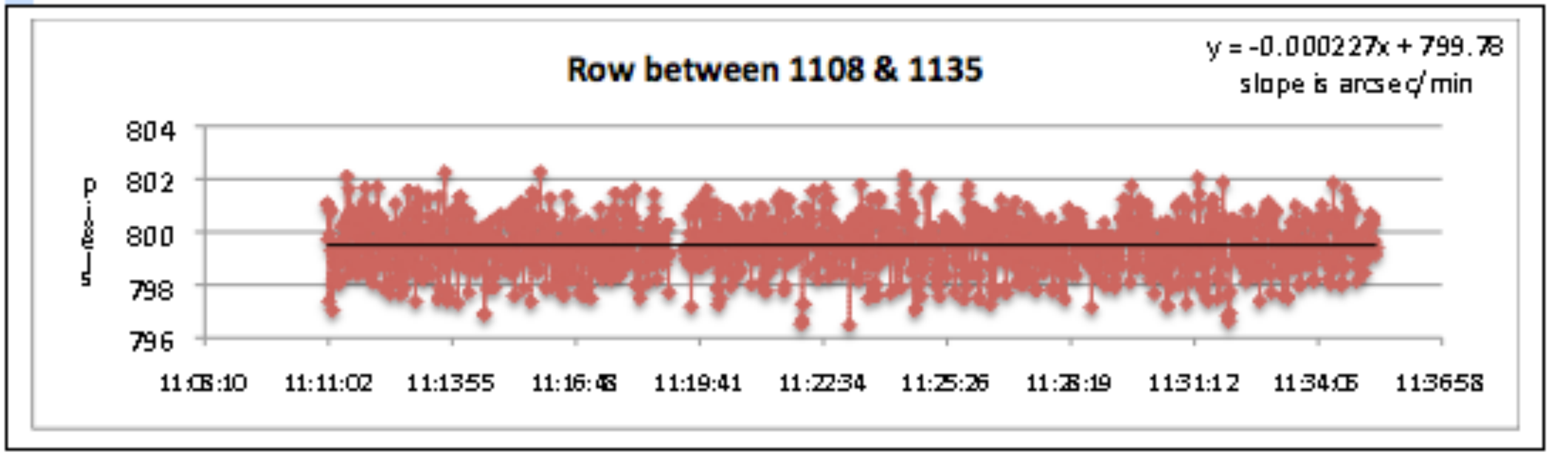
- This is only one test on Polaris on the Ground.

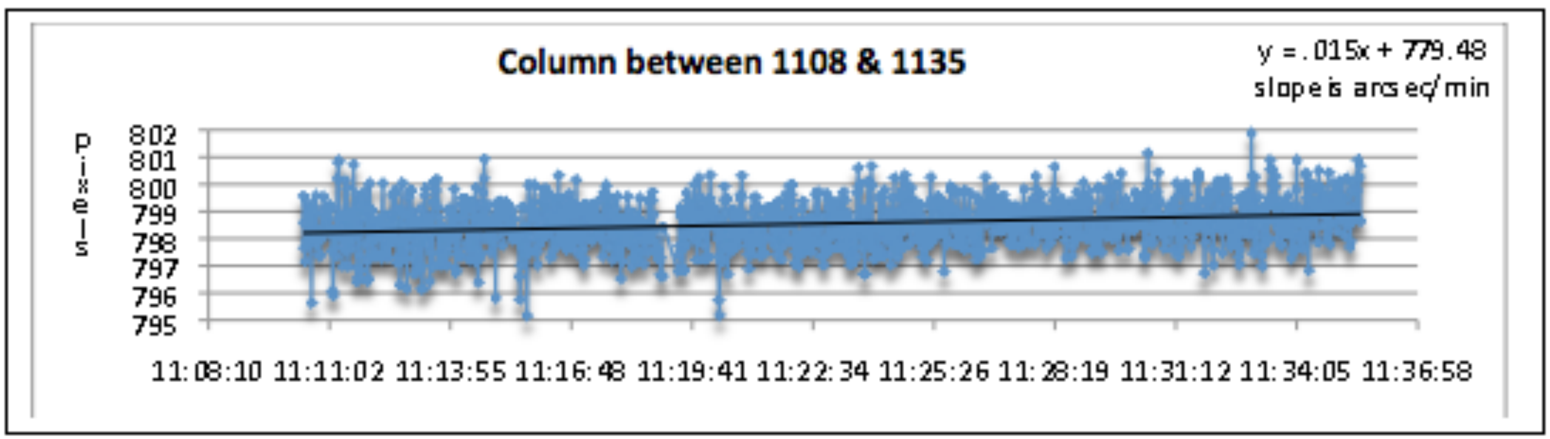
- However, it is very encouraging.

Offset Tracking in the FPI

- This test was also put together and reported by Walt Miller.
- Two stars were observed separated by about 4 arcmin.
- Guiding was done on one of the stars near the center of the FPI.
- The second star (surrogate target) was measured and the position was recorded in both rows and columns
- Both stars were about 6th mag and data were taken for about 30 min. Two LOS rewinds were taken during the data set. The MCCS was now in the loop.

Outline


Row between 1108 & 1135
y = -0.000227x + 799.78
slope is arcsec/min
pixels
804
802
800
798
796
11:08:10
11:11:02
11:13:55
11:16:48
11:19:41
11:22:34
11:25:26
11:28:19
11:31:12
11:34:05
11:36:58


Column between 1108 & 1135
y = .015x + 779.48
slope is arcsec/min
pixels
802
801
800
799
798
797
796
795
11:08:10
11:11:02
11:13:55
11:16:48
11:19:41
11:22:34
11:25:26
11:28:19
11:31:12
11:34:05
11:36:58

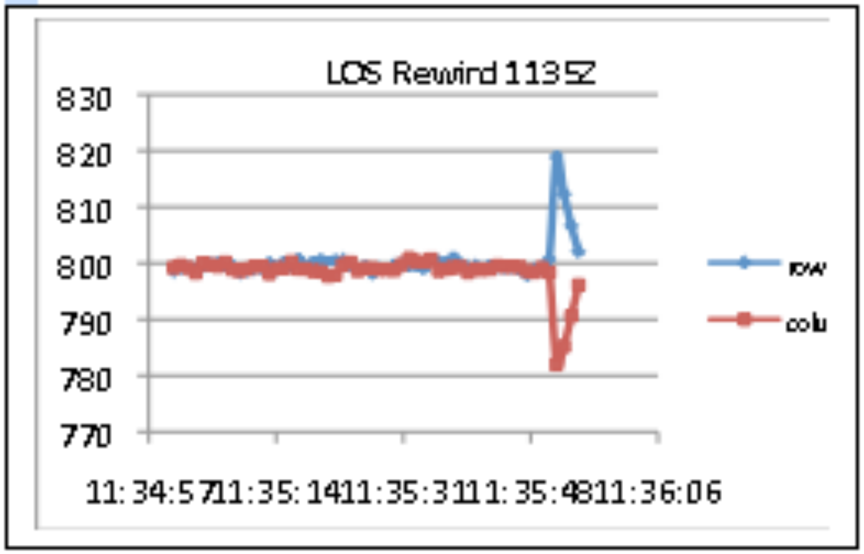
Results of Off Axis Tracking in FPI

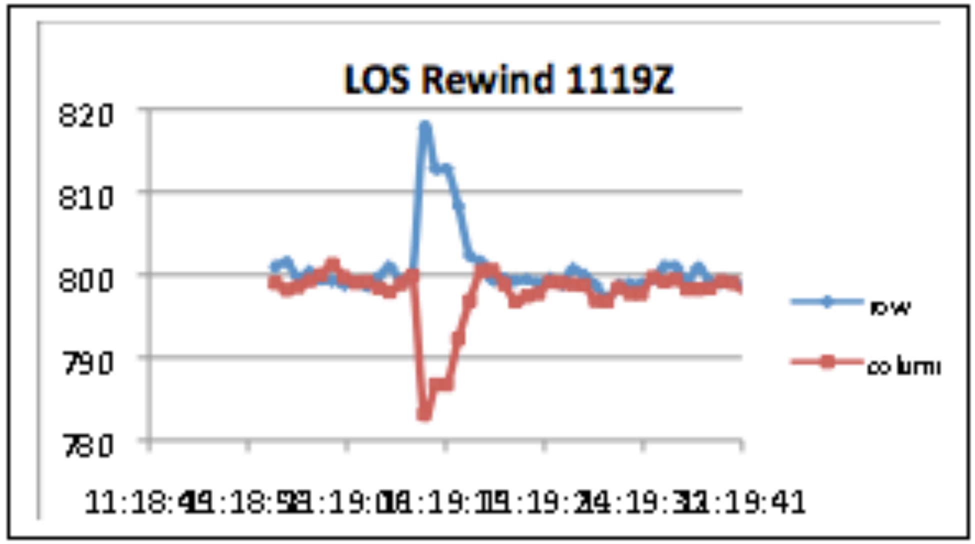
- Tracking noise is about 5 pixels peak to peak in both rows and columns.
- This corresponds to an RMS tracking of about 0.7 arcsec for 30 min.
- There is a drift of about one pixel or 0.5 arcsec in the column direction over the 30 minutes of time of the test.
- No good explanation why RMS tracking is worst than the pass through on axis. Fainter stars?,
- The column drift could be the LOS gyro drift error, scale factor error, differential refraction or something else. However, it does appear linear and could be corrected for.

LOS resets

- Two LOS resets were performed during this offset tracking test.
- Offsets motions of the target star were seen from errors in the bore site relative to the LOS turning point. (~20 pixels in both rows and columns or about 15 arcsec total)

Outline


LOS Rewind 1135Z
830
820
810
800
790
780
770
11:34:57
11:35:14
11:35:31
11:35:48
11:36:06
row
colu


LOS Rewind 1119Z
820
810
800
790
780
row
column

LOS resets

- For this size of motion, the TA tracker makes a correction to the position of the guide star derived from the rotation point provided by the MCCS, and within 5 to 10 seconds of time the surrogate target was back on the SI bore site!!

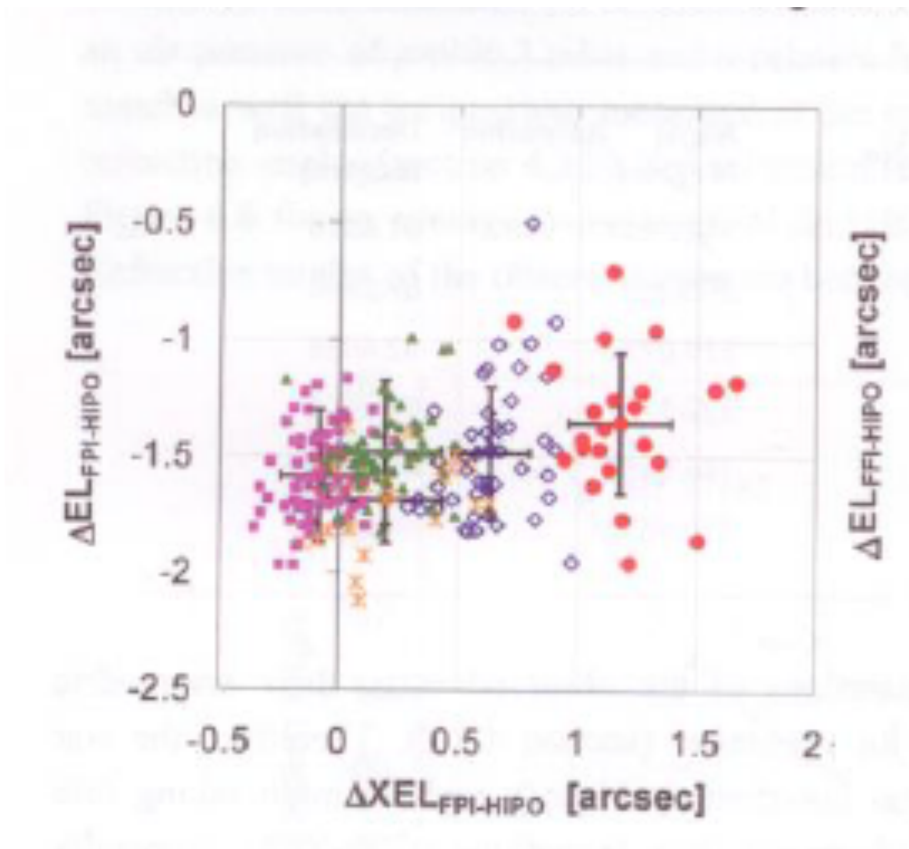
- Major accomplishment of TA, MCCS and Walt!!

Issues with FPI tracking

- In this series of tests no instrument was on the telescope to determine what actually happened to the instrument bore site.
- Previous measures with HIPO over the years indicates that the motion between the FPI and the HIPO bore site is about 1 arcsec (See page 115 of F. Harms Thesis)
- This issue will be tested in the coming line ops and flight test for Observatory V and V (003) this Oct, Nov.

- The present un-cooled FPI camera has very high dark current and low QE.
- A new FPI camera with 30 times larger S/N will be installed in January 2013 and will be discussed later.

FPI to HIPO Bore Site Harms Thesis page 115



DSI

SETI Institute

FFI tracking and the GREAT Bore Site

- The fine field tracking camera (FFI) has a ~40 arcmin Field of View.
- Tracking with the FFI is not as good as the FPI, because:

  1) There is variable flexure between the Main telescope bore site and FFI on the head ring. Static FBC does correct, but probably not better than a few arcsec

  2) The Secondary mirror does have motion (with hysteresis) that is not yet been fully characterized nor has a way of centering been determined.

  3) Offset guiding has a longer lever arm, so LOS errors and LOS rewinds have a larger effect.

- That being said, it does appear that if you check the bore site on a bright star, and do not do an LOS reset, the tracking is accurate to a few arcsec over times as large as 30 min, much less than the 16 arcsec GREAT beam.

Pointing with the FPI and FFI

- Pointing while tracking on a guide star in the FPI, it now appears to be better than 1 arcsec, and probably is a small as 0.5 arcsec. (based on material just presented)

- Pointing while tracking on a guide star in the FFI, I personally have not direct data.   Based on what I think I have heard and following the problems in Basic Science which have been improved on, it appears to be better than 2 arcsec for motion less than 10 arcmin movement.   Good enough for the GREAT matched chop nod of 10 arcmin for their 16 arcsec beam.

Blind Pointing under gyro control

- Test where done by Pasquale and results shown in the backup
- Linear offset in elevation of about -1 arcsec per deg.
- Cross elevation offset vs elevation 40 arcsec and a very strange curve that is presently not understood.
- Blind tracking with gyros shows p to p of 2 arcsec after 3 min and 6 arcsec after 10 min.

Universities Space Research Association

SOFIA Imager Upgrade
Status & Outlook

J. Wolf, M. Lachenmann, E. Pfüller, M. Wiedemann, DSI

DAOF
SPOT Meeting, August 20/21, 2012

FPI Upgrade

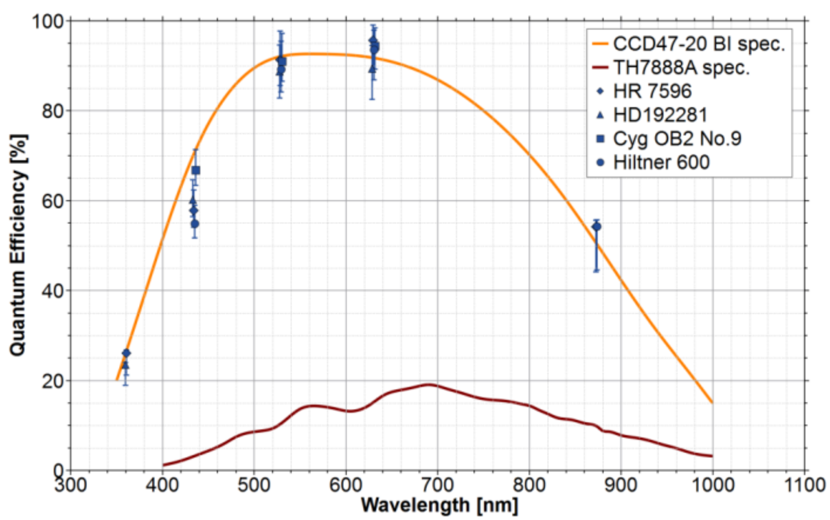
- Fast Diagnostic Camera (FDC) will become the new FPI
- KT (camera controller, s/w), DSI (filter wheel, environmental tests) work in progress
- Shipment to DAOF September 18, 2012
- Ready for integration ~ Oct. 01, 2012
- NASA schedule for integration planned for Jan 13.
- Demonstrated tracking on Pluto during the Occultation flights

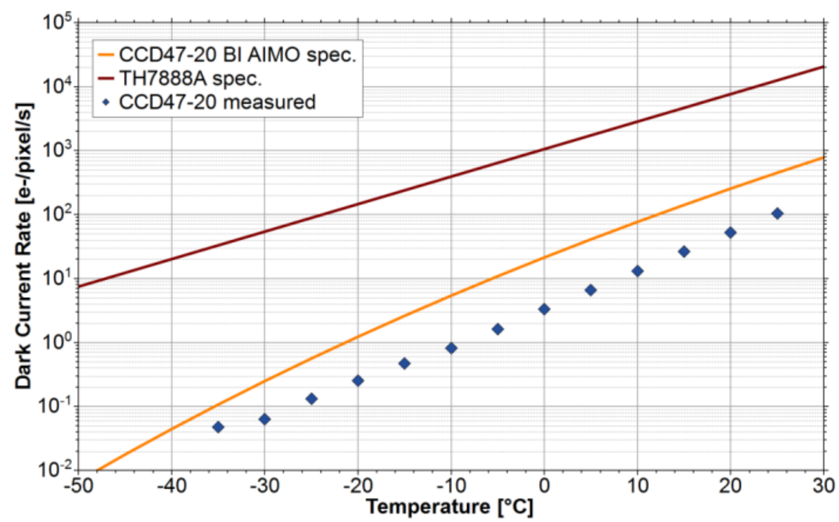
Motivation for the Imager Upgrade

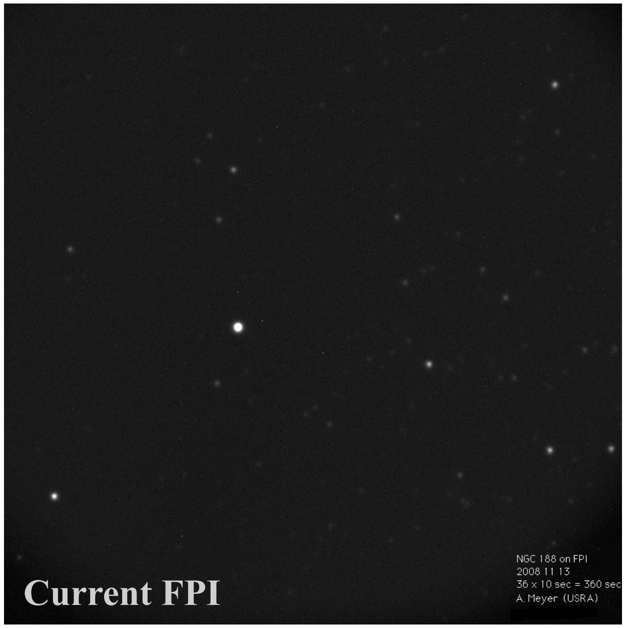
Present SOFIA imagers are too insensitive for efficient observatory operation.
Use of a modern, back-illuminated high sensitivity CCD sensor will help.

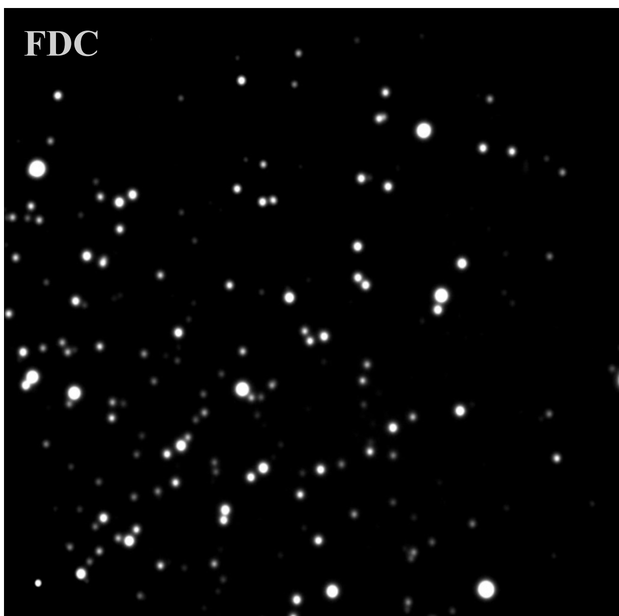
	SOF-1011	Current FPI	New FPI
Sensitivity	m_v = + 16^{mag} Shall be usable for tracking	m_v = + 16^{mag} Not usable t_{exp} = 1 sec $^S/_N$ = 4	m_v = + 16^{mag} OK t_{exp} = 1 sec $^S/_N$ = 70
Tracking Accuracy ≤ 0.5 arcsec	Shall be possible with m_v = + 16^{mag}	Needs m_v = + 13^{mag}	OK with m_v = + 16^{mag}

For more details see M. Wiedemann: Fulfillment of the SOF-1011 requirements with the new FPI based on Andor iXon cameras



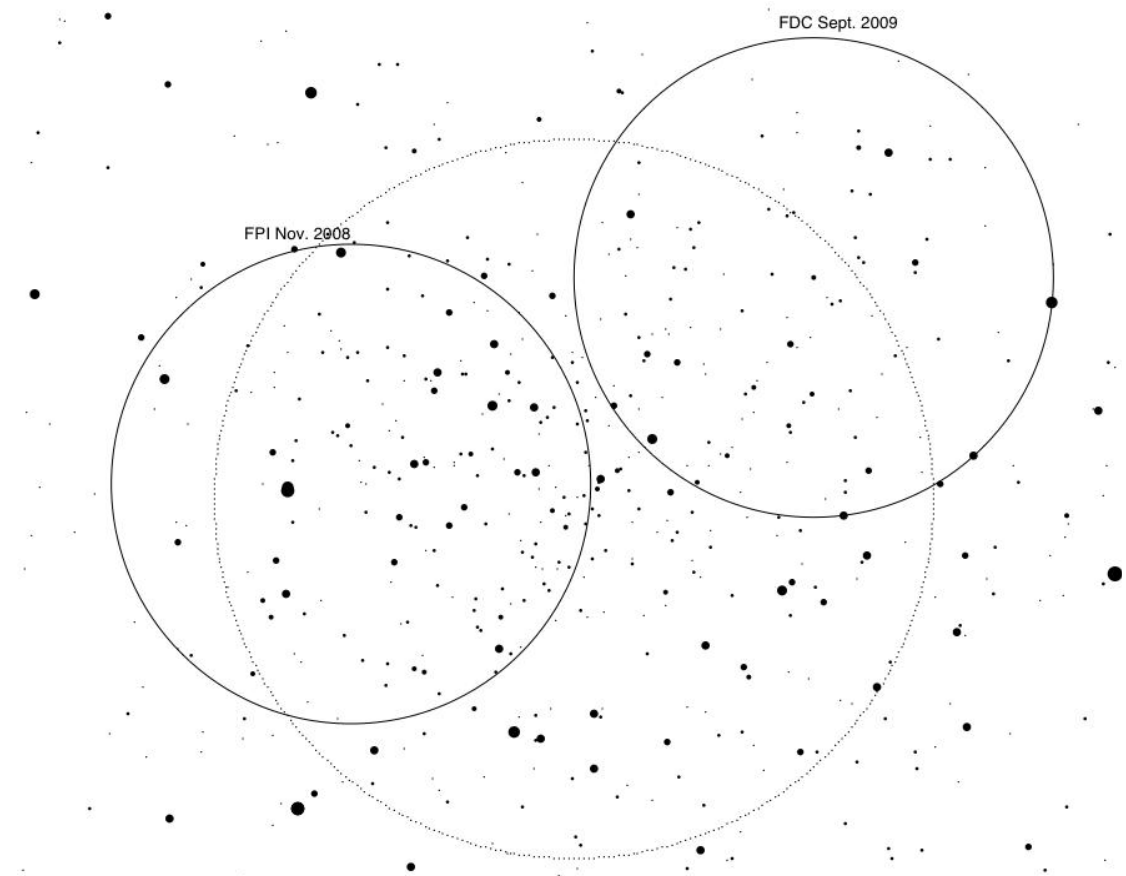






Result after the Upgrade

Star fields in NGC 188 with comparable exposure times taken during Line Ops in the current FPI and the FDC (FPI: 36 x 10 sec = 360 sec, FDC: 22 x 16 sec = 352 sec)



Chop Matched Nod

- Present measurements of Chop Nod with 2 arcmin p to p amplitude needed for GREAT show that it is accurate to better than 1.5 arcsec. (report of Jeff Van Cleve)
- Chop Nod with 1 arcmin amplitude for FORCAST is accurate to better than 1 arcsec.
- Chop Nod was demonstrated by the MCCS control to basically work and make the appropriate corrections even through an LOS rewind.
- Holger did find that the three position chopper was not symmetric around the center. Error of 10 arcsec for max 8 arcmin chop throw. Needs to be calibrated on a bright star for a new chop direction, until fixed.

TCM Alignment

- D

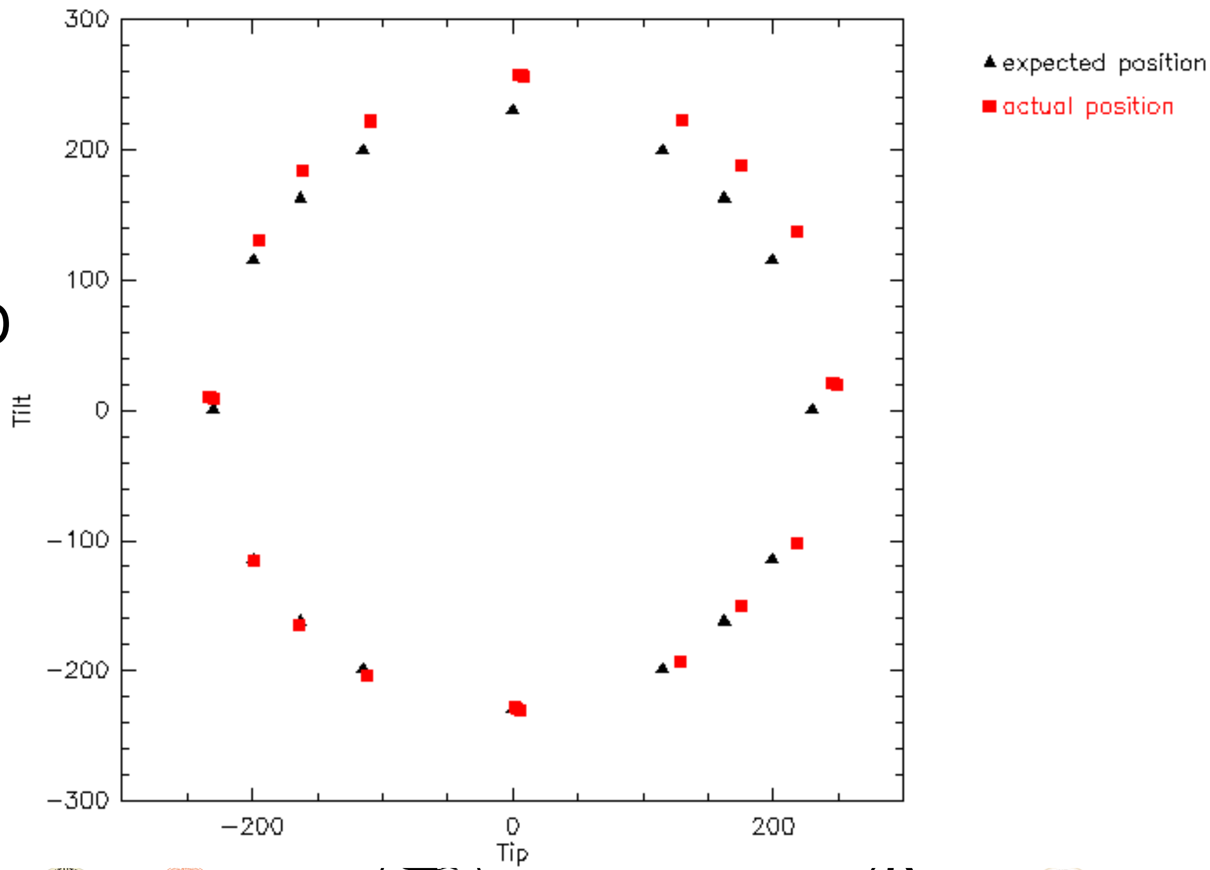
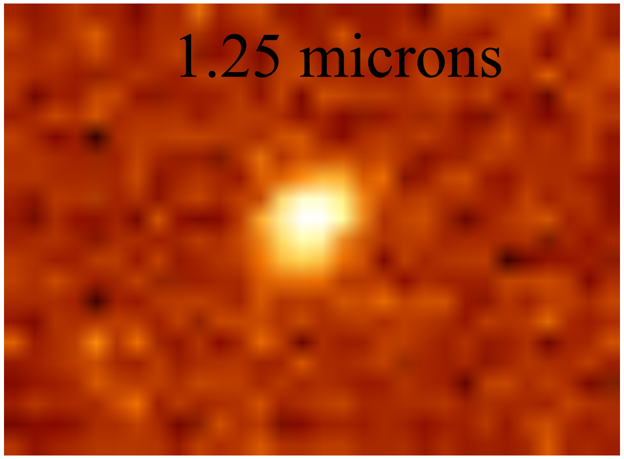
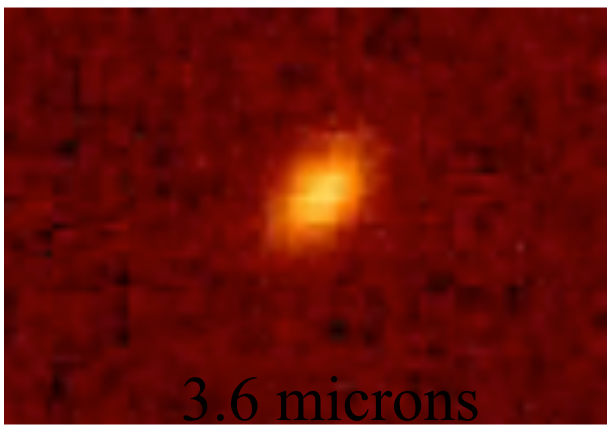


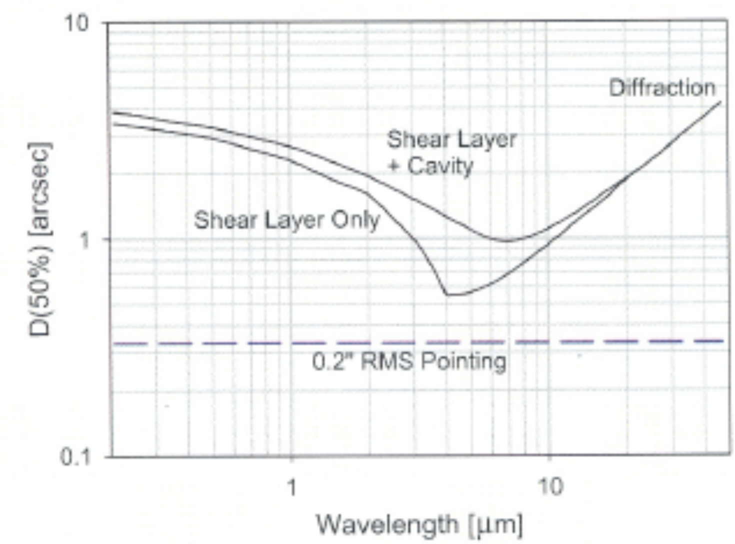
Image Quality

- Covered by Pasquale at the last SUG (see backup slides)
- Nothing has changed.
- Will get an symmetric image with a FWHM of about 2 arcsec if we remove the baffle plate. (RMS ~1.1 arcsec)
- This is now the configuration and will be checked with GREAT on an engineering flight in Nov.
- AMD's on the primary will become part of the configuration, but do have a relatively minor effect of the present image size.

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.

Summary

- Major progress in understanding the tracking and pointing of the SOFIA telescope using the various guide cameras, gyros and the MCCS have been made.
- Pointing and tracking with the FPI has been demonstrated under 1 arcsec rms for half an hour.
- The up graded FPI will allow use over more than ~98% of the sky.
- Use of the FFI tracking and pointing for GREAT will be better than ~2 arcsec, much smaller than their 16 arcsec beam.
- LOS rewinds still have some issue, but can now be quickly corrected for.
- Continued progress and understanding will be made in the up coming line ops and V and V flights with HIPO.   This progress will continue through the life of the program.

Backup

30

Units used to measure image size

- There are a number of ways that are used to describe the image size.
-
- When talking about telescope motion, we usually use the rms motion in the focal plane. This motion is a function of frequency, but astronomers are usually most interested in the integrated motion at all frequencies. RMS (i.e. R_{rms})
- When specifying optical design one usually uses 80% enclosed energy at a given wavelength usually optical. Theta (80%)
- When talking about data in the science instrument we usually refer to the full width at half maximum. FWHM (i.e. X_{FWHM})

Summary of Units and equations

- FWHM= 1.67 R_{rms}
- Theta 80%= 2.54 R_{rms}
- Theta 80%= 1.5 FWHM
- Theta 50% ~ FWHM

Note: These are approximate and valid for Gaussian type distributions.

Pasquale's Blind Pointing Tests

33

MCCS Pointing Accuracy Test

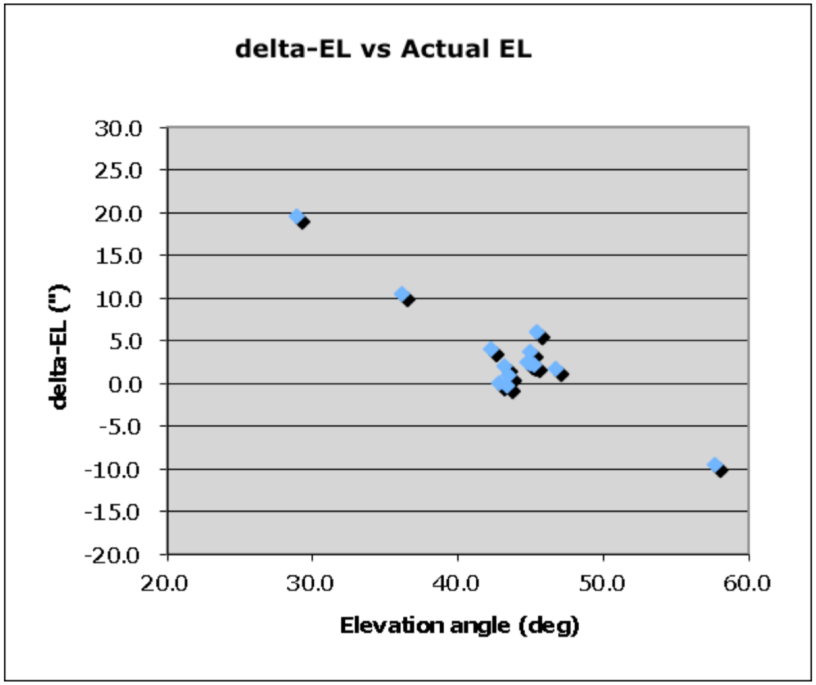
Objective: Evaluate the TA "blind pointing". This test measure the ability of the TA to acquire stars under gyro control and also show the degradation in pointing accuracy over the time taken for the test.

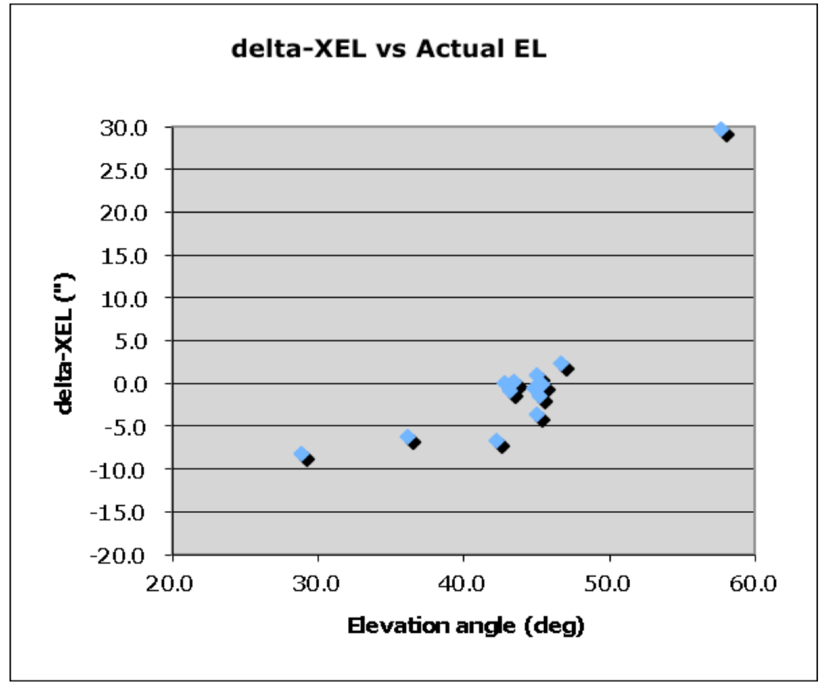
The telescope was set on a known star and the coord_correct procedure was done to calibrate the TA inertial reference frame (IRF) to the sky coordinate system (ERF) at that time.

Tracking was then turned off and the TA was commanded to move under gyro control to a number of stars within a narrow XEL range but over a wide EL range.

The position was measured and compared to the initial star position immediately after the coord_correct was done.

MCCS Pointing Accuracy Test



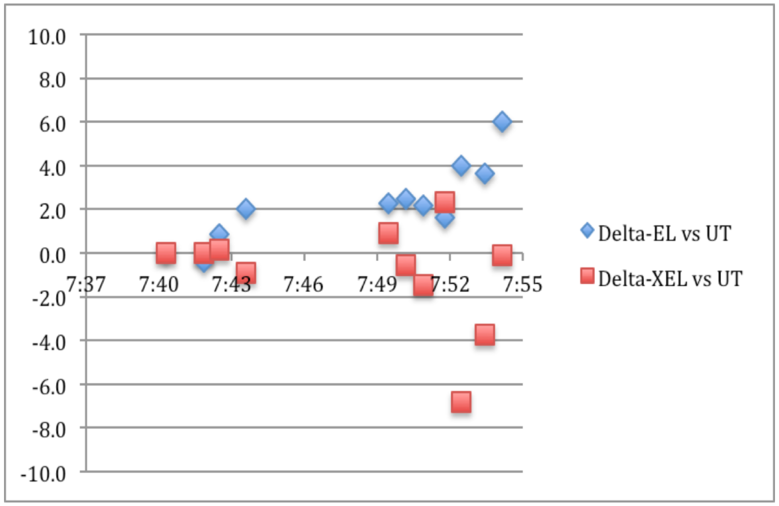


Dependence of elevation offset (left) and cross-elevation offset (right) on elevation angle

- The elevation difference shows a clear linear trend with a linear least-squares fitted slope of -0.96 arcsecond of pointing error per degree of elevation. The cross-elevation offset vs elevation angle is not so clear.

- The tight clustering of points around zero offset and 45 degrees elevation are the Plieades points. This shows the good

MCCS Pointing Accuracy Test



Position offsets plotted against UT showing the degradation in pointing accuracy with time.

Elevation and cross-elevation differences for those positions in the vicinity of the Plieades as a function of UT.

The positions clearly degrade with time over the ~15 minute duration of the test.

Conclusions

- There is a clear linear relationship between the elevation error and elevation angle with a slope of -0.96 arcsecond per degree.
- There is a dependence of cross-elevation with elevation but this cannot be determined with the data at hand.
- The pointing accuracy degraded with time to about 6” maximum over the 15 minute duration of the test.

Image Quality

SPOT 7

Pasquale Temi

August 20, 2012

			Error contribution		Statistic	Verifiation Method
			arcsec		(RSS)	
			visible	~4 μm		
Aero-optical						
	Free atmosphere		small			
	Shear layer		2.5 rms	small		FDC measurement
	Cavity seeing					
		Nasmyth tube	??	??		
		"tub"	??	??		
Optics						
	Diffraction		small	0.2 rms	0.2	
	Optical quality		tbfi	better than visible	0.2	REOSC Acceptance test
	Stressed optics					
		Mounting	small ??			TD ??? If any
		Coating				
	Alignment and focus		0.2 rms ?	0.2 rms ?	0.2	HIPO/SCAI
		Chopper coma	.8 arcsec/arcmin ?	.8 arcsec/arcmin ?		
Image motion						
	Telescope tracking					
		< 0.5 Hz	1.0 rms		1	
	Telescope disturbance				0.9	
		Controller Regime	.6 rms			
		AMD Regime	.6 rms			
		Blur	.3 rms			
	Chopper jitter					
	Chopper overshoots					
Instrument						
	Optical quality					
	Stiffness					
	Detector details					
Sum					1.4	

Static Pointing:

1. Static pointing requirements require a (static) pointing stability of ~0.2” rms over a 30 min. period.
2. Is this in our reach with the current system?
3. Need to identify areas of improvements and a path to get there

Image quality improvements:

Image quality improvements (including Static contribution) are relevant for wavelengths short of 40um.

Given the SOFIA Capabilities they are both needed for observation in imaging as well as in spectroscopy mode

Image quality improvements:

AMD: for cycle 2 obs. AMD system should be routinely used in science flights

In one year from now the system should have passed all the design reviews and airworthiness.

See next slide for goals of the current AMD system.

Need to find opportunities of testing the system on a non-intrusive basis before the beginning of Cycle 2 Obs.