FORCAST First Light Experience

TACFL – first light with SOFIA!

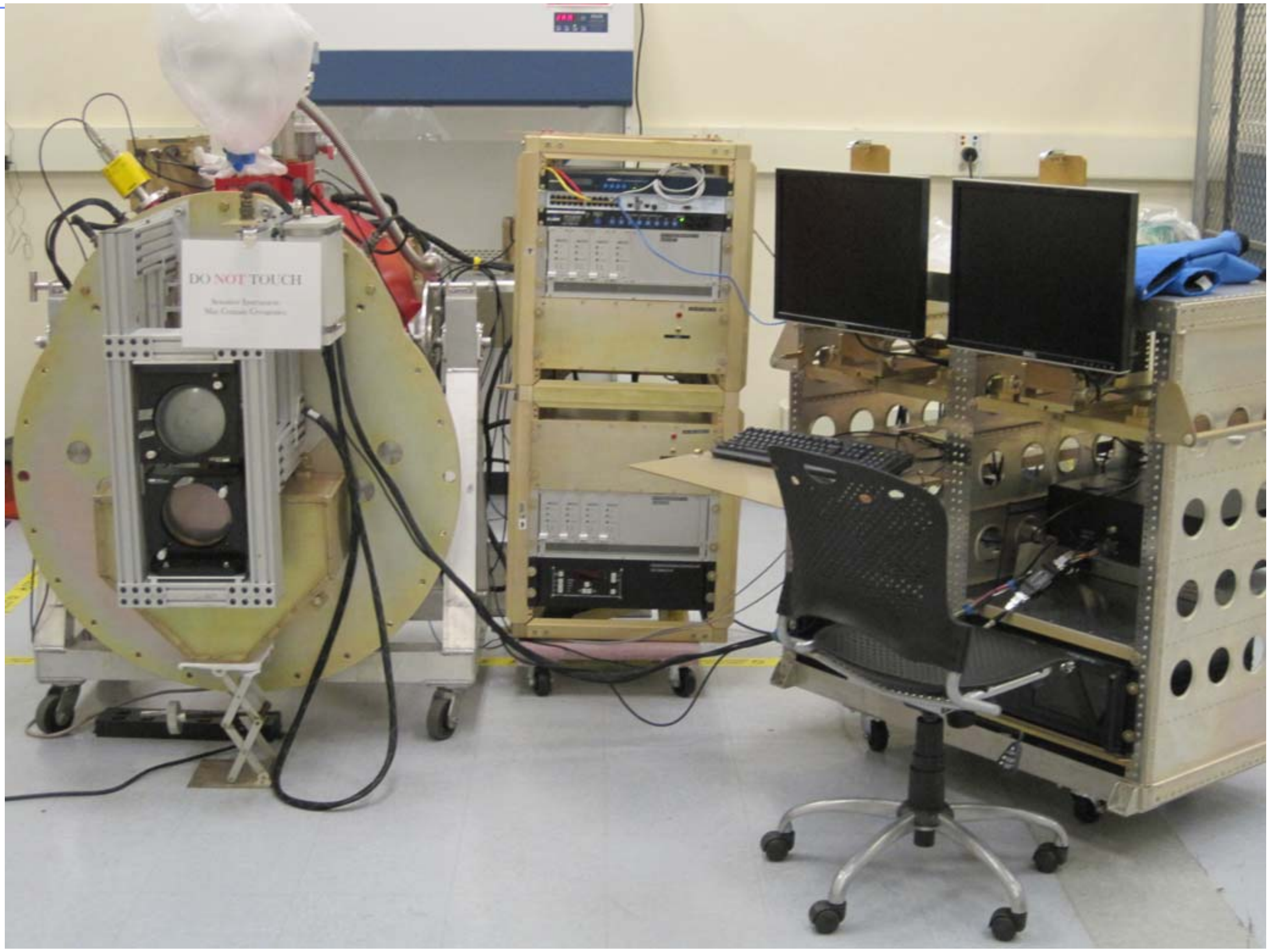
T. Herter and FORCAST Team

TLH: 11-Aug-10

Outline

- Some photos on
  - installation and checkout of FORCAST
  - TACFL flight
- Some results on telescope and FORCAST performance
- FORCAST Team members
  - Joe Adams (Project Scientist), George Gull (Lead Engineer), Justin Schoenwald (Software Engineer), Chuck Henderson (Mechanical Eng), Luke Keller (Co-I)
  - Gordon Stacey (Co-I), Thomas Nikola (Co-I), Keri Hoadley (REU student)

FORCAST in DAOF lab



- FORCAST w/ foreoptics (test equipment), counterweight rack, and PI rack

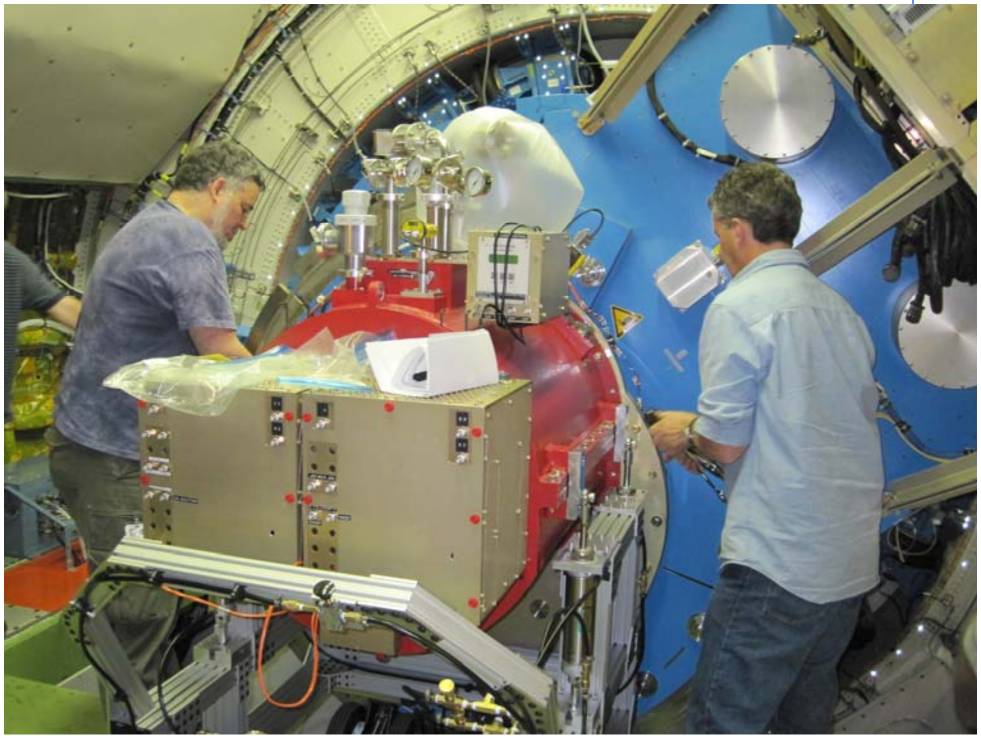
FORCAST & Sky Emissivity Test

Installation on the plane




- Installing PI rack & getting FORCAST into plane

Attaching FORCAST



- George and Charlie positioning FORCAST
- George and Chuck fastening FORCAST to telescope

Cryogen transfers on the plane

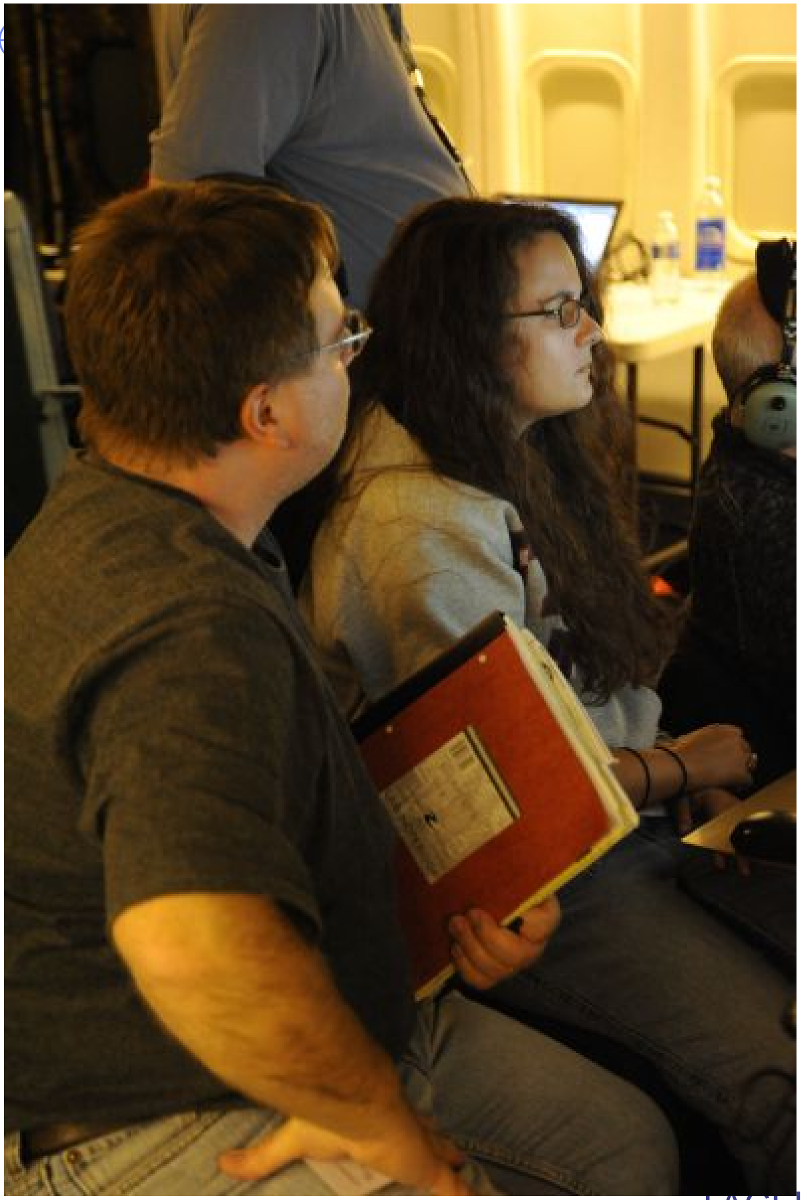
- George and Luke in their Halloween costumes

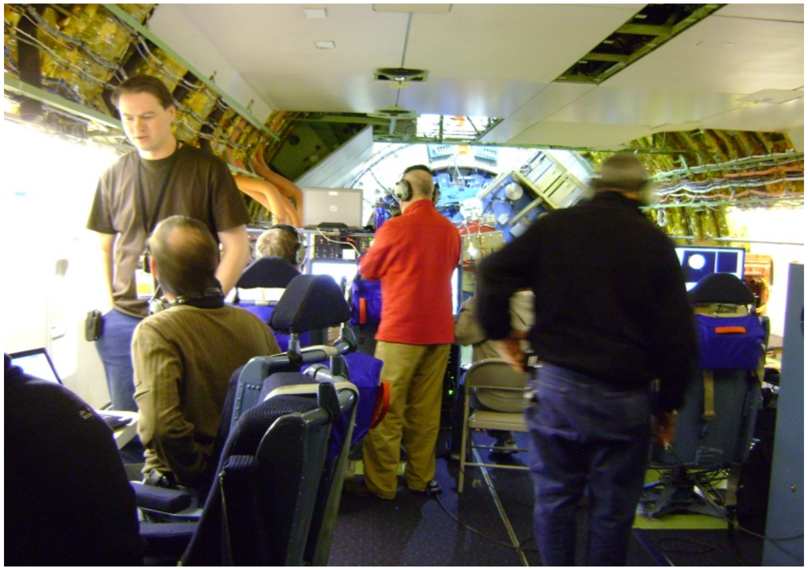
Line Ops

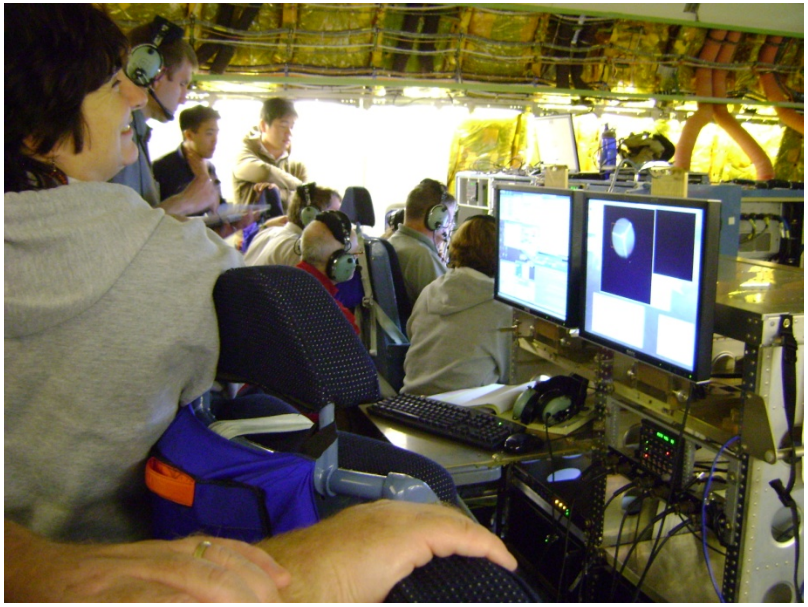
- PI position for flight – my computer screen on top of rack. Keri (seated) and Justin (standing behind PI rack on right)

- Jim, Joe, and Justin looking at data during line operation

Working on Line Ops…







TACFL flight

- Flight to characterize telescope performance, mainly jitter/pointing
  - FORCAST added to get high time resolution image motion data
  - Acquire data at ~ 400 – 500 Hz
  - Secondary goal – IR backgrounds and telescope emissivity
- First light science object goal added
  - M82 and Jupiter selected

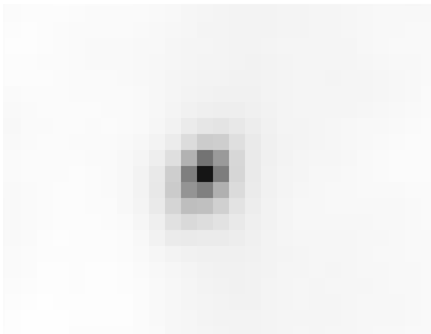
TACFL: In flight operations

- Holgar, Randy, Andy, and Uli at work

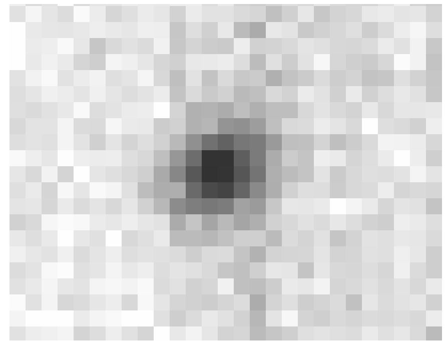
- Jim and Joe (foreground),
- Alan (background)

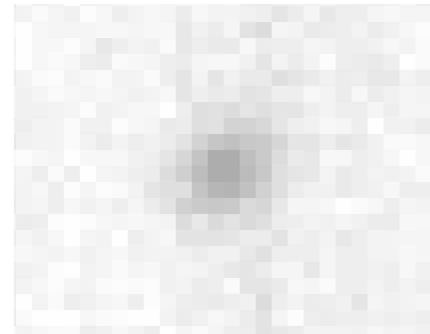
Point Spread Function

Short term

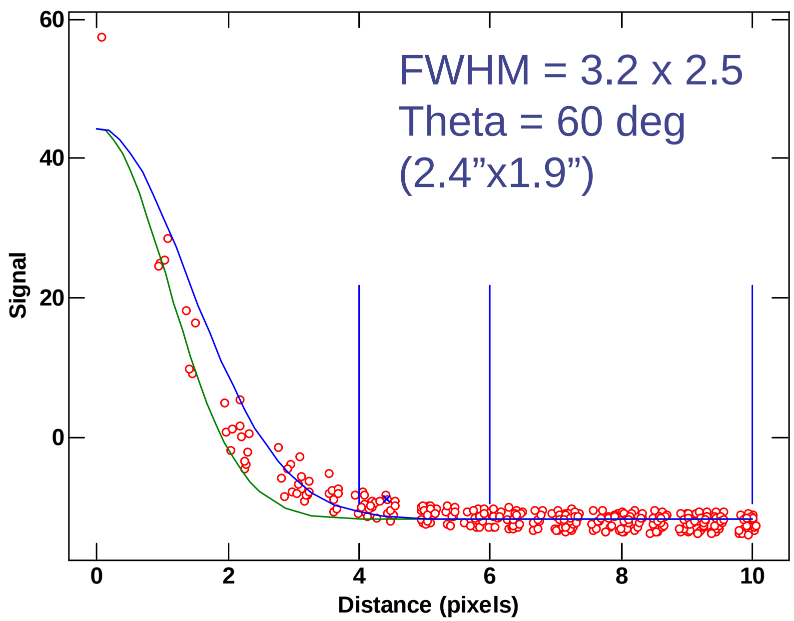


Long term





Scale same as short term



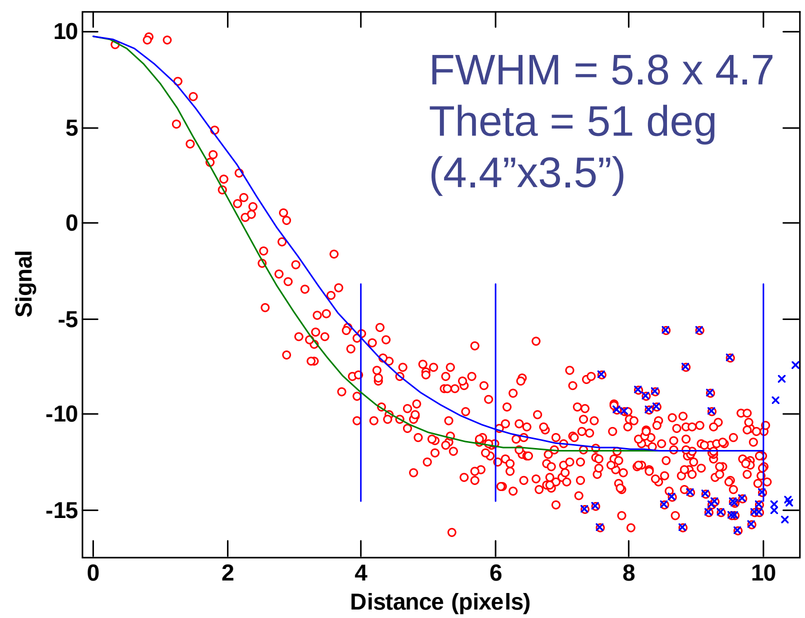
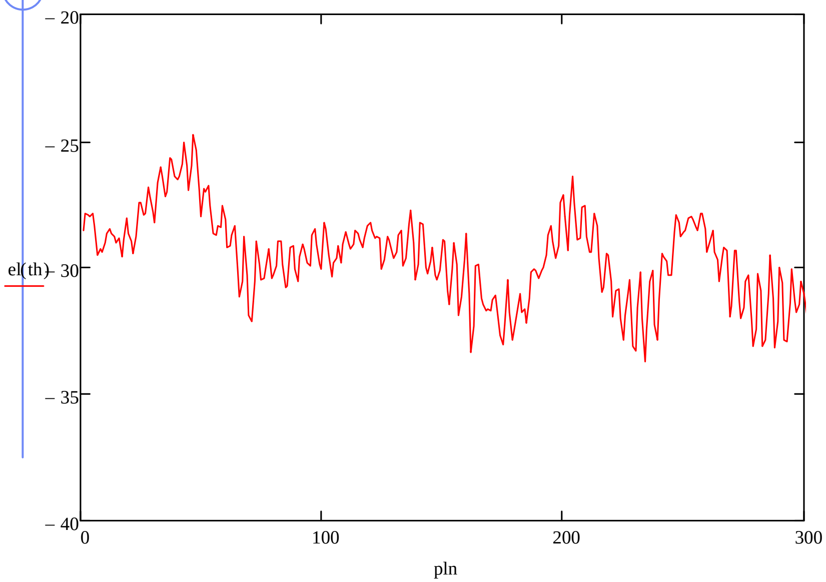
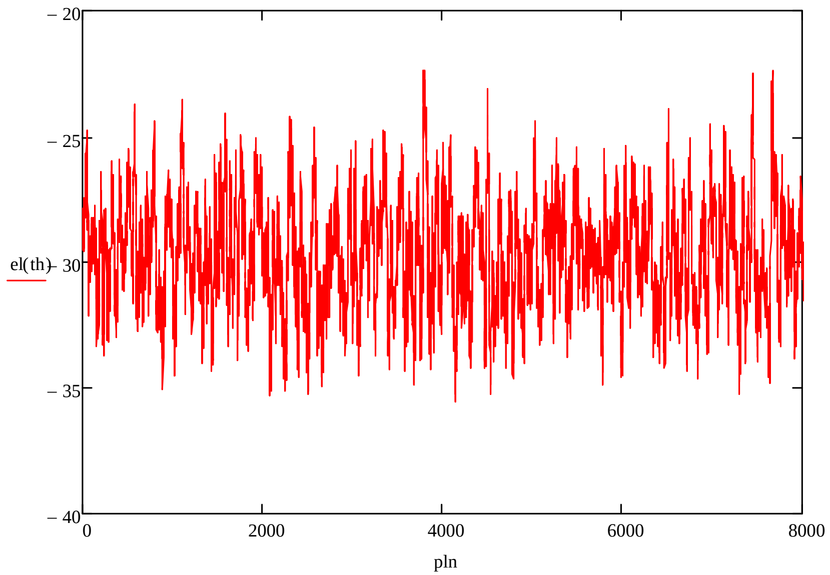


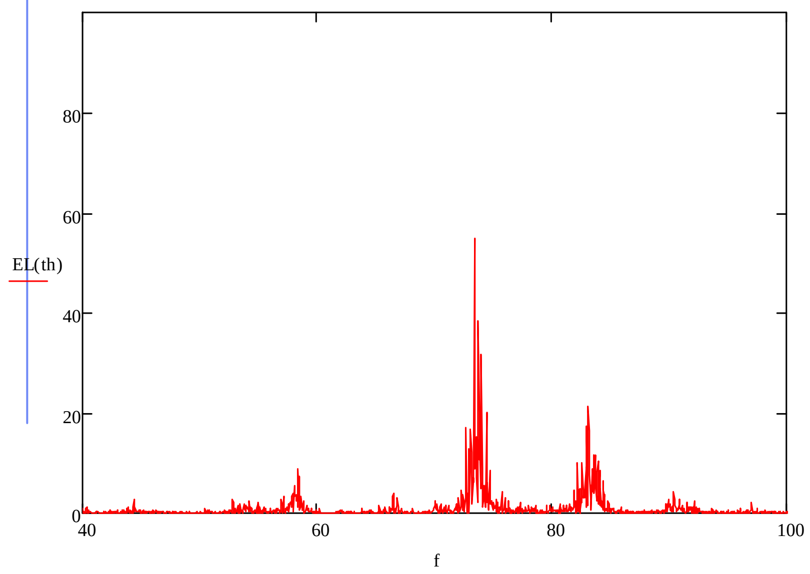
Image Motion

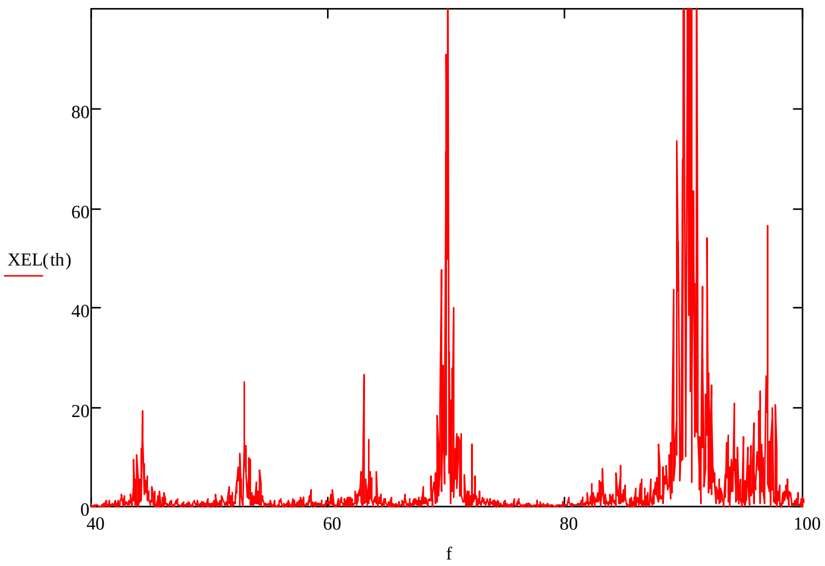




- Image motion in elevation: left - first 300 points, right - full data set, ~ 8000 points
  - Peak-to-peak is 13 pixels (0.75 arcseconds/pixel)
- Axes of FORCAST images rotated by 139 degrees to align measurements with elevation and cross-elevation direction

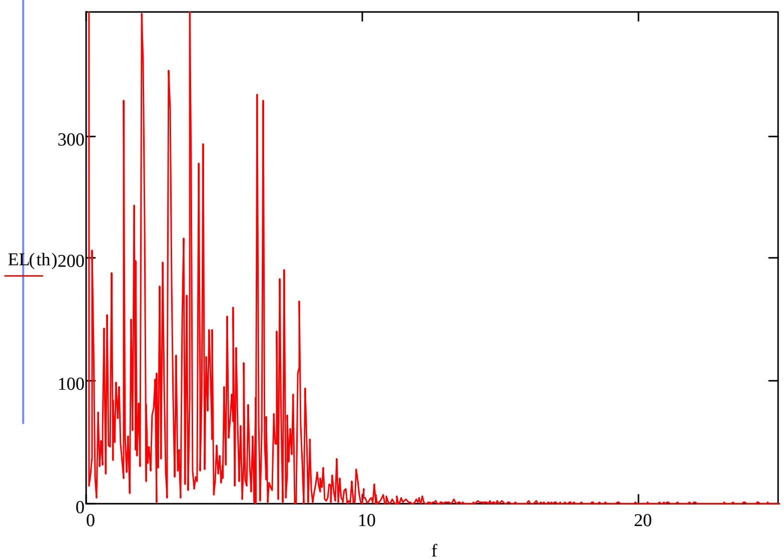
Resonances (40-100 Hz)

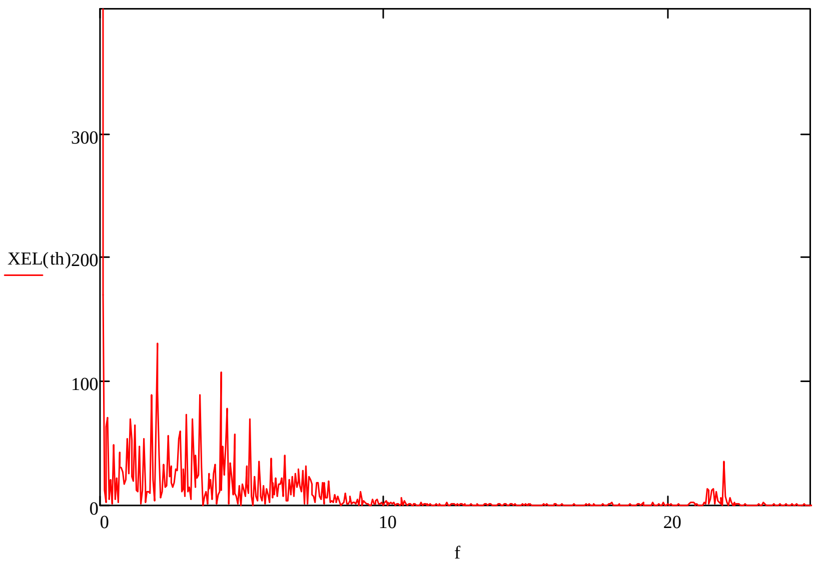




- Transformation of Flow 01 data set
- Axes of FORCAST images rotated by 139 degrees to align measurements with elevation and cross-elevation direction
- Note: This is square of amplitude

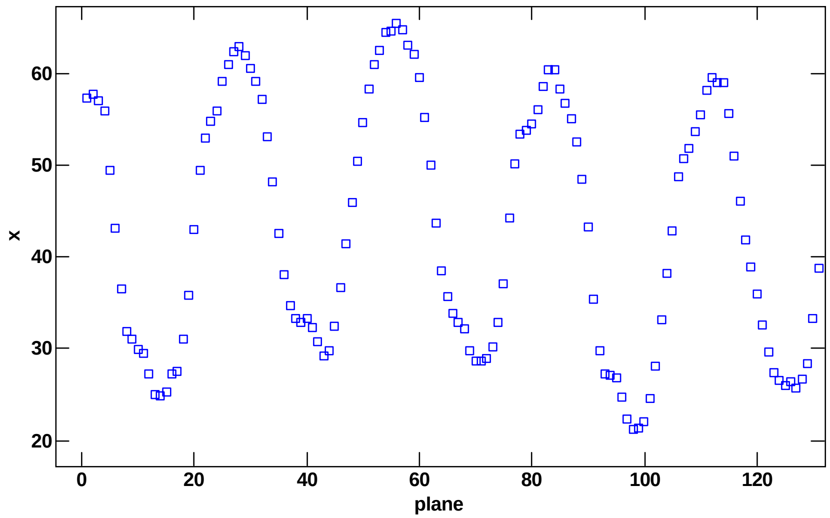
Resonances (< 25 Hz)

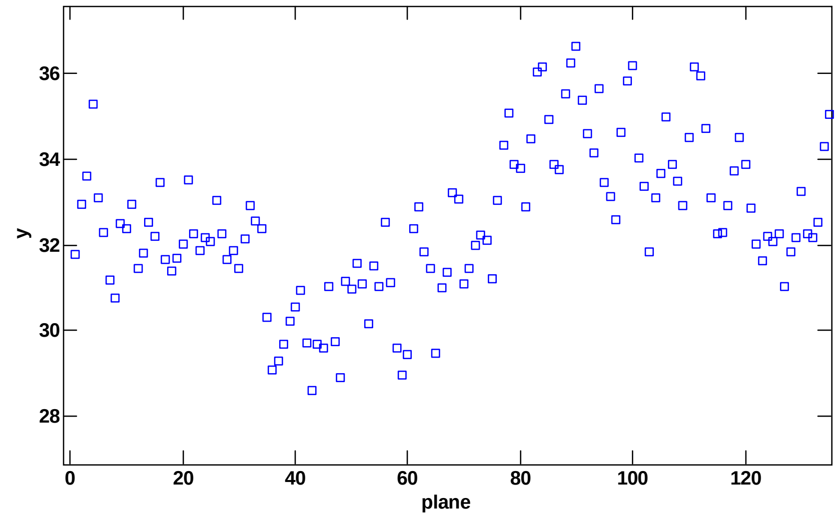




- Transformation of Flow 01 data set
- Axes of FORCAST images rotated by 139 degrees
- Notes
  - These modes have a larger amplitude than the higher frequency ones
  - Again, this is square of the amplitude

Chopper Performance





- Performance of chopper as measured on epsilon Sco
  - Frame rate is 508 Hz, amplitude on vertical axis is pixels
- 30 arcsec chop (in x) at 10 Hz
- Duty cycle very low and position never stabilizes
  - Need to run at much slower chop
  - For 3 arcmin chop 1/2 of time is spent in transition

Background Response modeling

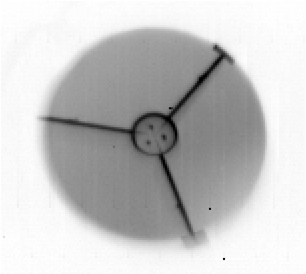
- For a given filter, the photoelectric current in the detector due to the background is given by:

$$PE = A_{tel}\Omega_{pix}\int\left\{\varepsilon_{sky}B_\nu\left(T_{sky}\right)\tau_{tel}\tau_{win} + \varepsilon_{tel}B_\nu\left(T_{tel}\right)\tau_{win} + \varepsilon_{win}B_\nu\left(T_{win}\right)\right\}\frac{\tau_{inst}}{h\nu}d\nu$$

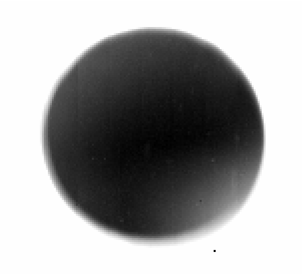
- All emissivities (ε) and transmissions (τ) are frequency dependent (τ here is transmission, not optical depth)
  - The filter and detector response are incorporated into the instrument throughput, τ_{inst}.
  - The sky is assumed to be at a single temperature with an emissivity $\varepsilon_{sky} = 1 - \tau_{sky}$, where the transmission comes from ATRAN.
  - The index of CsI is 1.72 which results in a reflectivity loss from both surfaces is $r_{win} = 0.14$. The total transmission $\tau_{win} = 1 - r_{win} - \varepsilon_{win}$.
  - Estimated window emissivity is ~ 6 %

Blockage/Obscuration

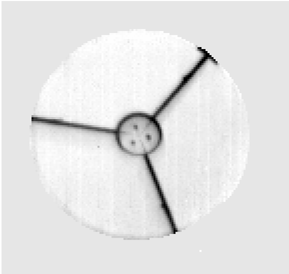
- FORCAST pupil images show the obscured telescope area



5.4 microns, bFT04_0033.fits pupil image from TACFL



11.3 microns, bLP09_0004.fits Image of gate valve from line Ops #1 used as flat



Flatten, normalized 5.4 micron pupil image which gives ~ 6% emissivity contribution

- Neglecting sky emission the integrated pupil signal is proportional to

$$S_{tot} = A_o B_\nu(T_{tel})\tau_{tel}\tau_{win} + A_p \varepsilon_{tel} B_\nu(T_{tel})\tau_{win} + A_p \varepsilon_{win} B_\nu(T_{win}) = A_o B_\nu(T_{tel})\tau_{tel}\tau_{win} + S_{unobs}$$

$$\Rightarrow \quad \phi_o \equiv \frac{A_o}{A_p} = \frac{S_{tot} - S_{unobs}}{S_{unobs}} \frac{\varepsilon_{tel} + \varepsilon_{win}}{\tau_{win}\tau_{tel}}$$

ϕ_p = fractional obscuration, A_p = pupil area, A_o = obscured area. The last step assumes $T_{tel} = T_{win}$

- Subtracting the median from the average over the pupil gives the normalized difference: $(S_{tot} - S_{unobs})/S_{unobs}$ = (average – median) = 0.06
- Taking $\tau_{tel} = \tau_{win} = 0.8$, $\varepsilon_{tel} = 0.2$ and $\varepsilon_{win} = 0.06$ then $\phi_o = 0.06 \times 0.4 = 2.4\%$

Telescope Emissivity

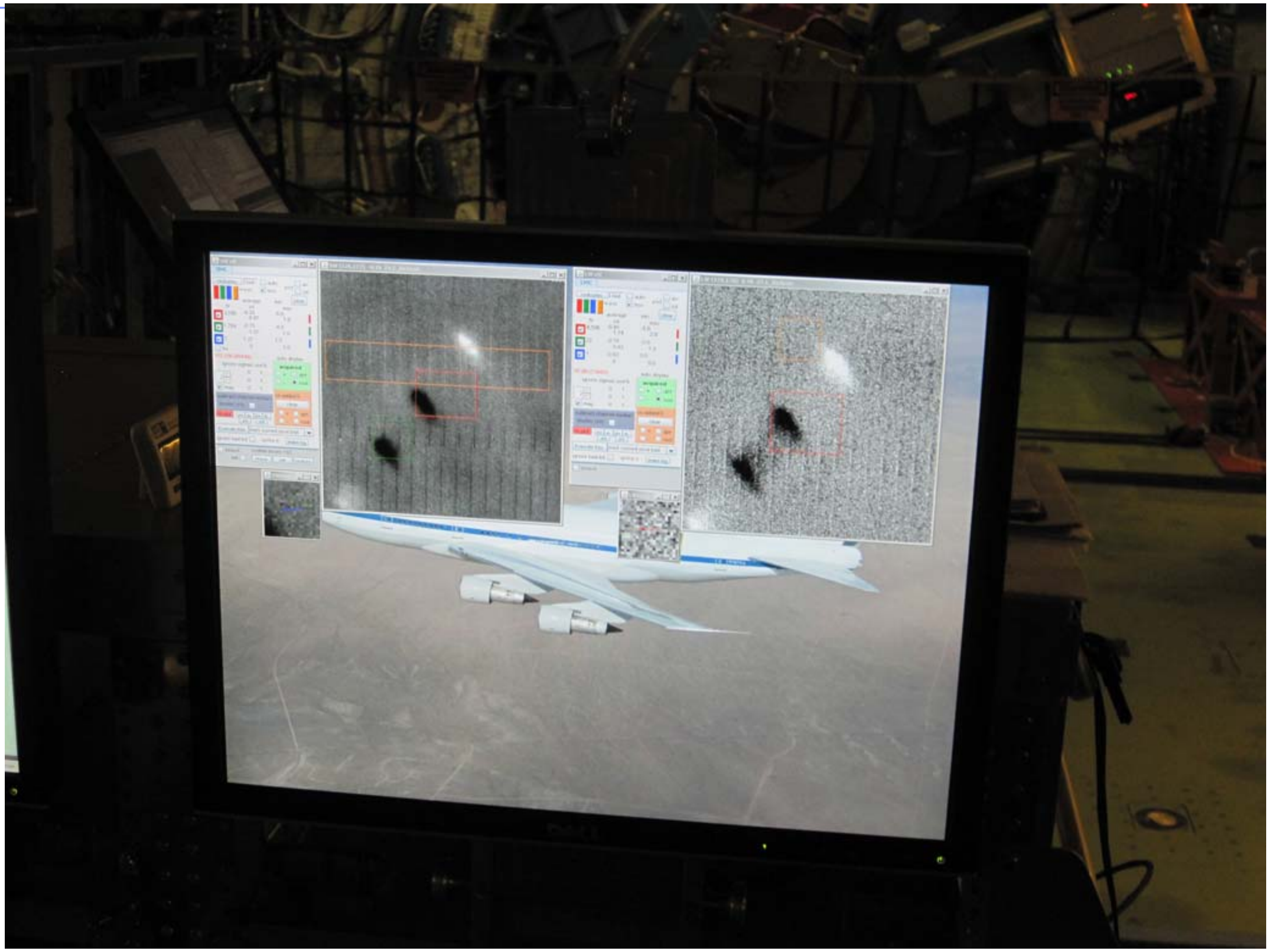
- This is somewhat difficult to pin down
  - Best estimate is between 10 and 20%

- Issues:
  - Difficult to measure from ground due large (and variable) atmospheric emissivity from DAOF tarmac

  - Could not perform sky “dip” during TACFL due to fixed elevation

  - In-flight dewar window temperature is uncertain
    - Estimate is emissivity of ~ 5 – 7 % but if warmer than telescope contributes more signal than expected

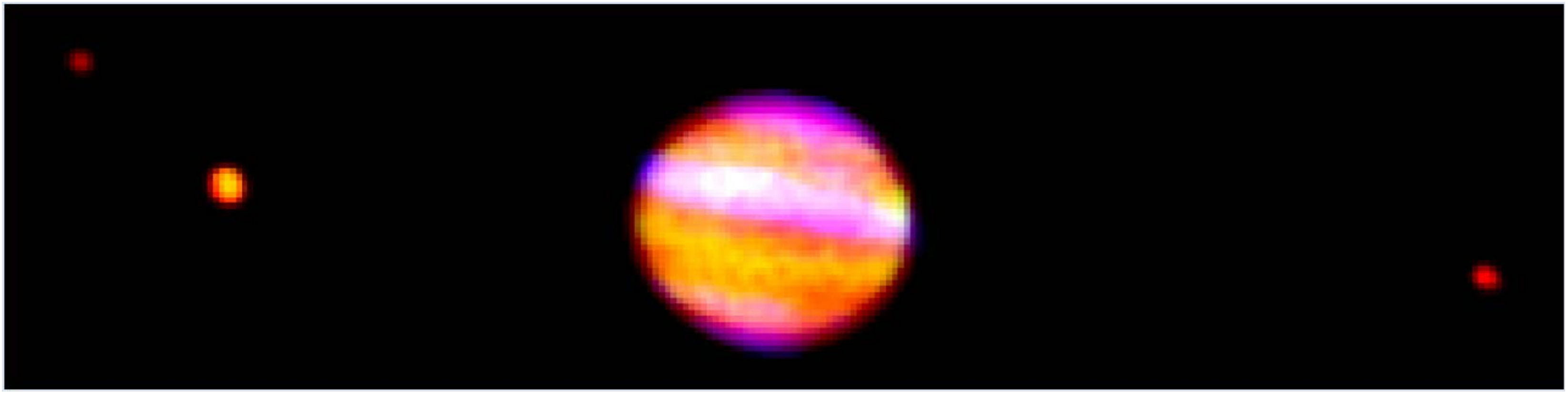
TACFL: First "Science" Integration



- M82 – first chop-nod sequence: 24 μm (left) and 37 μm (right)

FORCAST Calibrations using Ganymede

- Response taken from FORCAST First Light/Flight
  - Jupiter causes detector artifacts
  - Ganymede = “point source” give response
- Photon noise from
  - atmospheric, telescope, and window emission
- Sensitivity models consistent with previous calculations



Jupiter with Europa, Ganymede, Io: 5.4, 24, 37 μm false color image

TACFL Performance

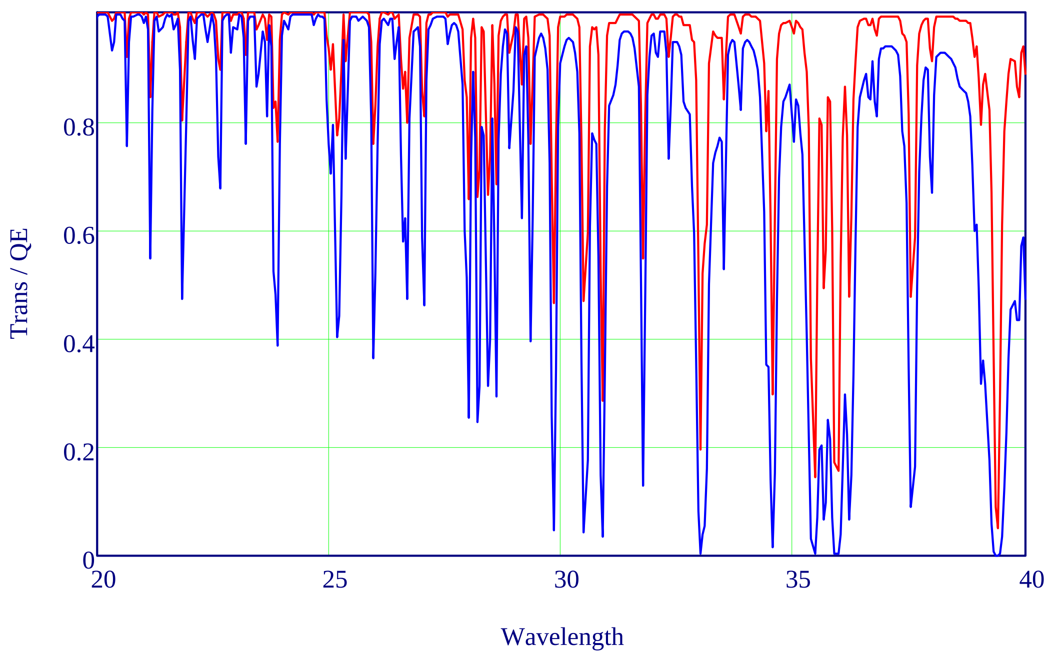
- Use Ganymede for response (e-/sec/Jy)
- Use M82 for noise from background
  - Ganymede compromised because of bright source (Jupiter and possible Ganymede itself)

Filter (um)	Flux (Jy)	Configuration
19.7	0.108	dichroic
24.2	0.135	dichroic
31.4	0.321	dichroic
37.1	0.694	dichroic
31.4	0.238	lwc
37.1	0.468	lwc

Flux for S/N = 4 in 900 seconds assuming 49 pixels used for extraction of (point) source.

Performance is close to SOFIA website sensitivity calculator (SITE) using the same assumptions (35K feet, and 25° zenith angle)

Short Science Sensitivity



Blue: ATRAN transmission model for TACFL flight (altitude = 35K ft, zenith angle = 65°) which has 26.7 μm of precipitable H_20 at zenith

Red: ATRAN transmission model with altitude = 41K ft, zenith angle = 45°) which has 7.3 μm of precipitable H20 at zenith

- Expect up to a factor of 2 – 3 improvement in sensitivity depending on filter for short science flights

TACFL: We've landed

- A nice crowd to greet us at the wee hours of the morning

Summary

- TACFL flight – very successful
  - Able to acquire and detect astronomical sources
  - Telescope performance near nominal
    - Diffraction limited for λ > 50 μm
    - Emissivity reasonable
  - FORCAST within factor of 2 of projected performance

Questions?