Science Operations for SOFIA: The FORCAST Experience

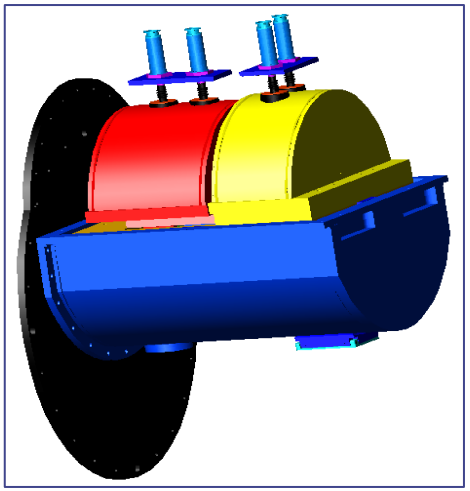
Herter: 10-Aug-11

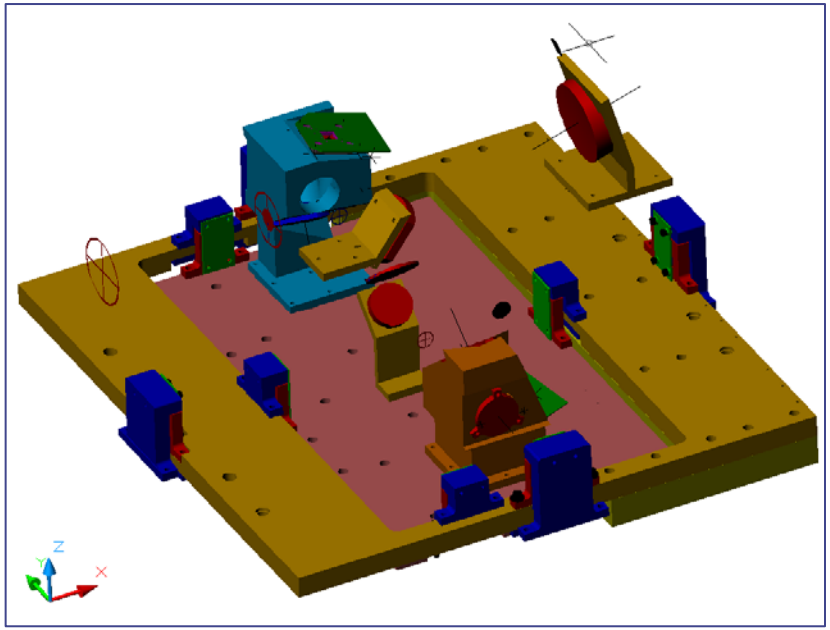
Experiences flying on SOFIA

- It has been both challenging and rewarding
  - We are part of a making a highly complex system work
  - But, of course, that is the point (to push new boundaries)
- At every stage things have worked better than (I) expected
- Observatory performance is quite good
  - Would like continued image quality improvement
- Great team effort by everyone

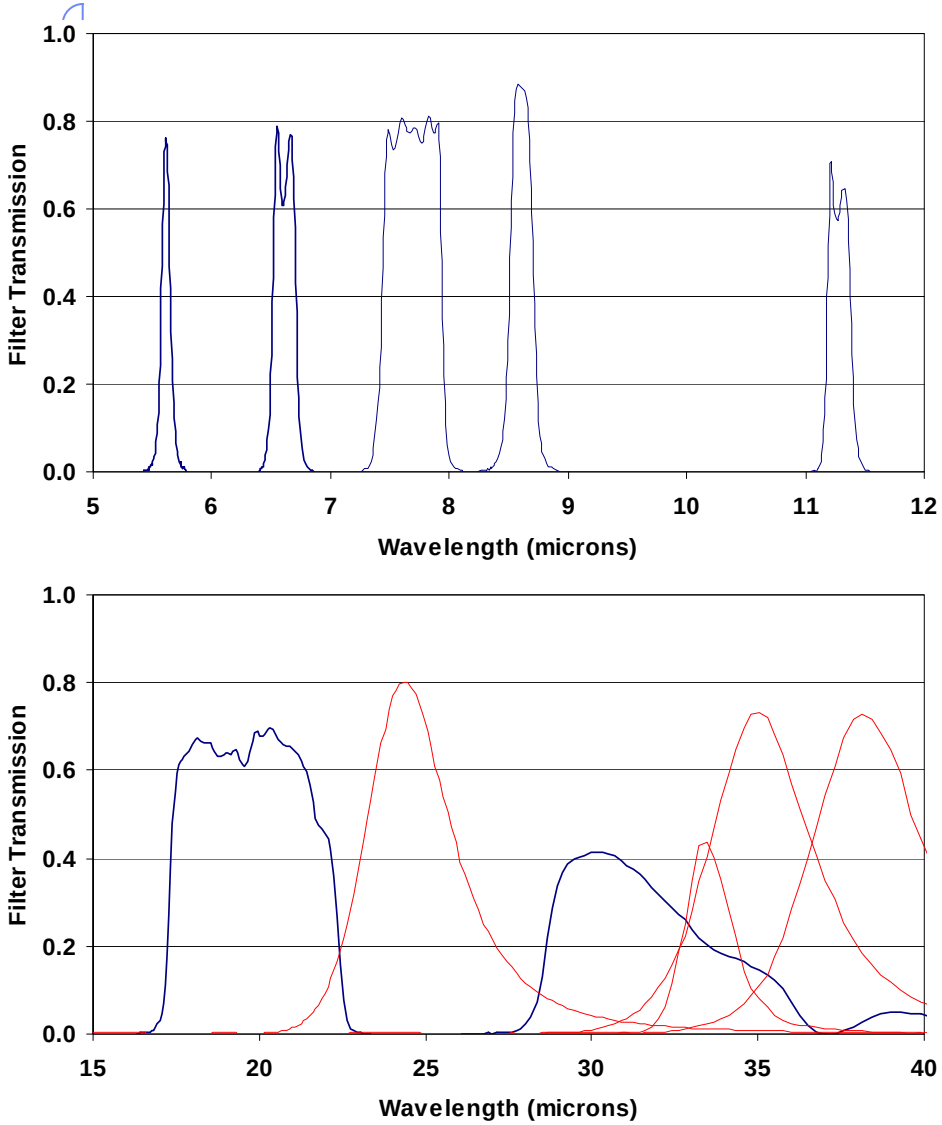
Instrument Overview

- Facility Instrument
- Dual-Channel 256x256 Camera w/ Si BIB arrays
  - 5-25 μm with Si:As array
  - 25-40 μm with Si:Sb array
- Field of View
  - 0.75"/pixel giving a 3.2'×3.2'
- Designed for diffraction-limited imaging for $\lambda > 15$ μm
- Selectable Filters in 5-40 μm range
- Can easily accommodate grisms for spectroscopic capability





Filters for Basic Science



Filter (μm)	R (λ/Δλ)
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37.1	8.8

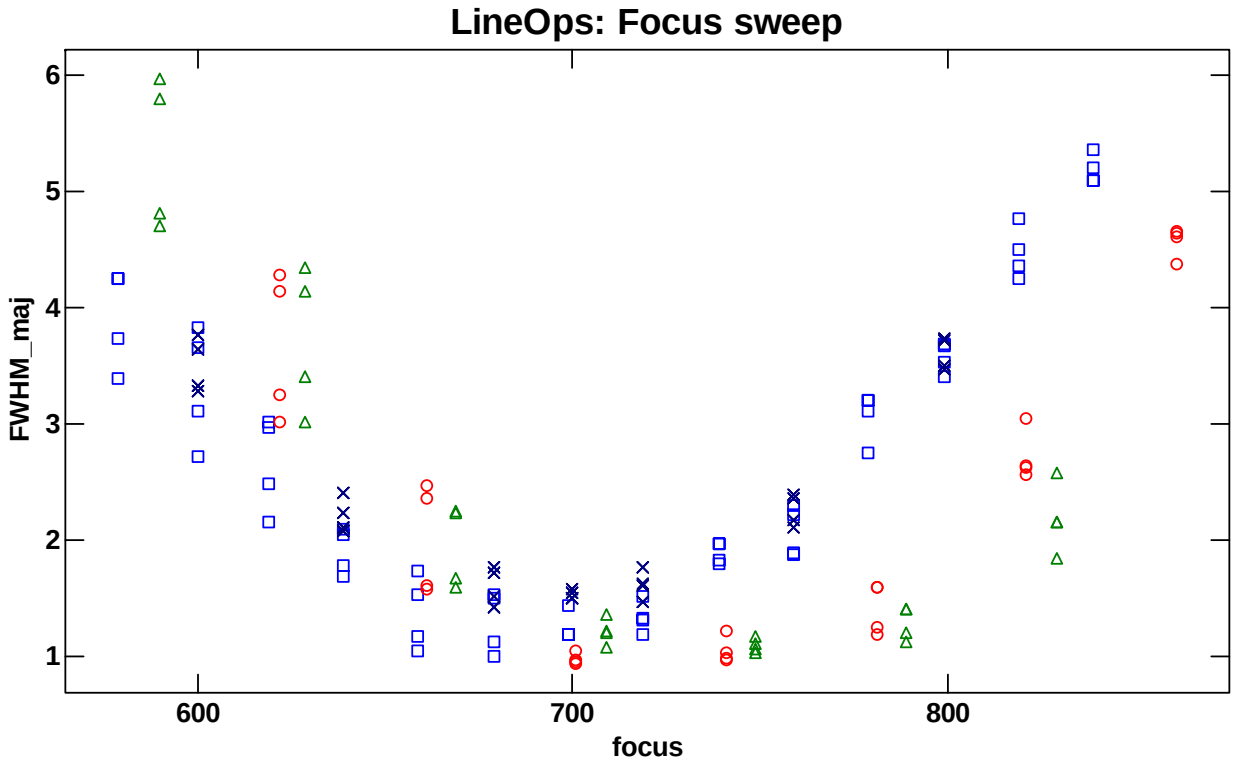
Left: representative FORCAST filter curves (not including atmospheric transmission or detector response).

The Observing Experience

Preparation and flights consisted of the following:

- LineOps (Line Operations, 19 in total)
  - Park plane on tarmac and look at stars
  - Allowed end-to-end testing of H/W & S/W
  - This provided extremely important practice
- Observatory characterization flights
  - 25-May-2010, 10-Nov-2010, 18-Nov-2010
    - Observatory operational and performance checkout
    - High speed “jitter” measurements of bright stars
    - Also measured primary-secondary telescope emissivity
- Short Science flights
  - 30-Nov-2010, 03-Dec-2010, 07-Dec-2010
    - Observed Jupiter, Comet Hartley 2, M42, W3, M82 + calibrators
- Basic Science flights (support of guest investigations)
  - 10 flights: 05-May through 07-Jun-2011

FORCAST LineOps PSF Size



Key:

- 5.4 μm
- 8.6 μm
- 11.1 μm
- 24.2 μm

FWHM of major axis of gaussian 2D fit in arcseconds.

- Focus sequence showing FWHM of star measured during LineOps
  - 24.2 μm filter is actually responding at ~ 5 μm due to light leak and atmospheric transparency.
- FWHM at best focus < 1.4 arcseconds

Line Ops PSF measurements

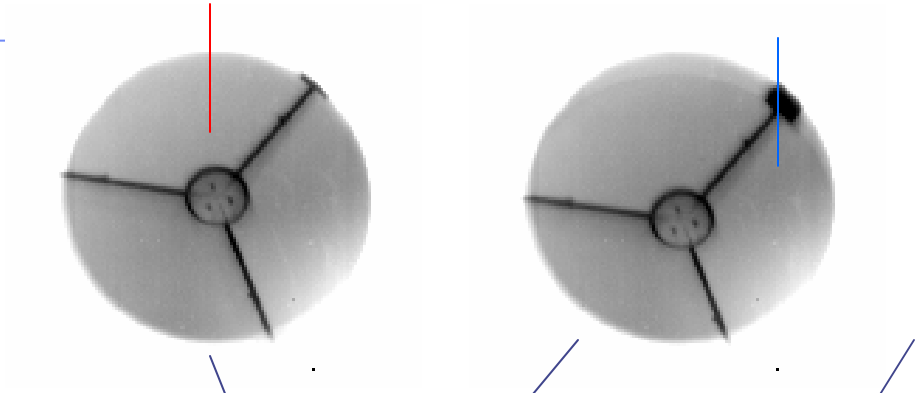
Source	Lambda (μm)	Focus Major Axis	Focus Minor Axis	FWHM Major (arcsec)	FWHM Minor (arcsec)	T_exp (sec)	Files
RX Boo	11.1	745	740	1.5	1.1	5	54-60
	19.7	735	735	2.0	1.8	30	47-53
Alpha Boo	5.4	695	690	1.3	1.0	5	22-35
	8.6	735	725	0.9	0.7	5	15-21
	11.1	745	745	1.1	0.8	5	8-14

Observations made with SOFIA parked on tarmac at Dryden Airborne Operations Facility (DAOF) in Palmdale.

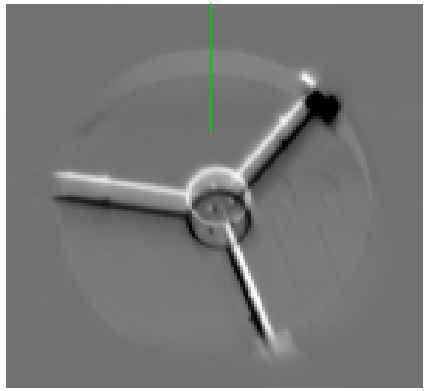
Basic Science Configuration

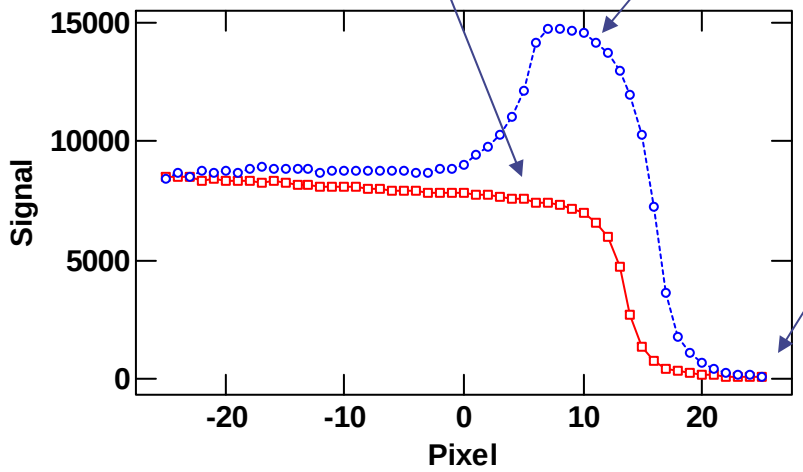
- Chop configuration
  - Two position chop with nodding
- Observing Modes
  - Symmetric chop
    - Chop symmetrically about nominal optical axis
  - “Asymmetric” chop
    - Area of interest observed on-axis
    - Maintains image quality
    - Only 1 in 4 frames contain the source
- Channel Readout
  - SWC, LWC, or both
  - Performance penalty for LWC when both are read simultaneously.

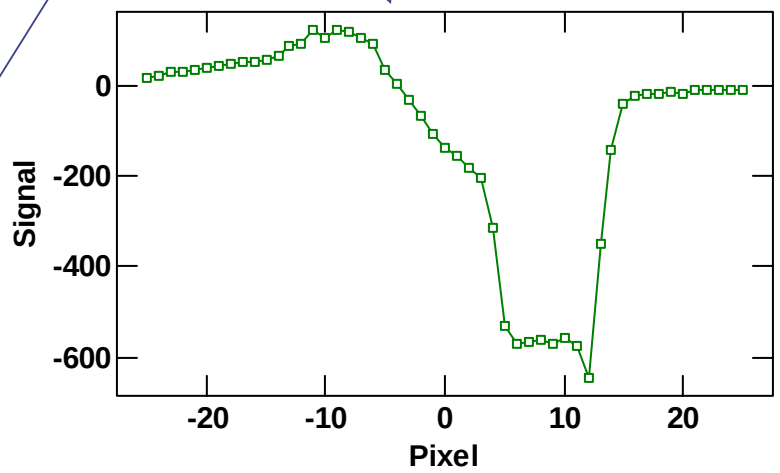
Primary-Secondary Emissivity



difference



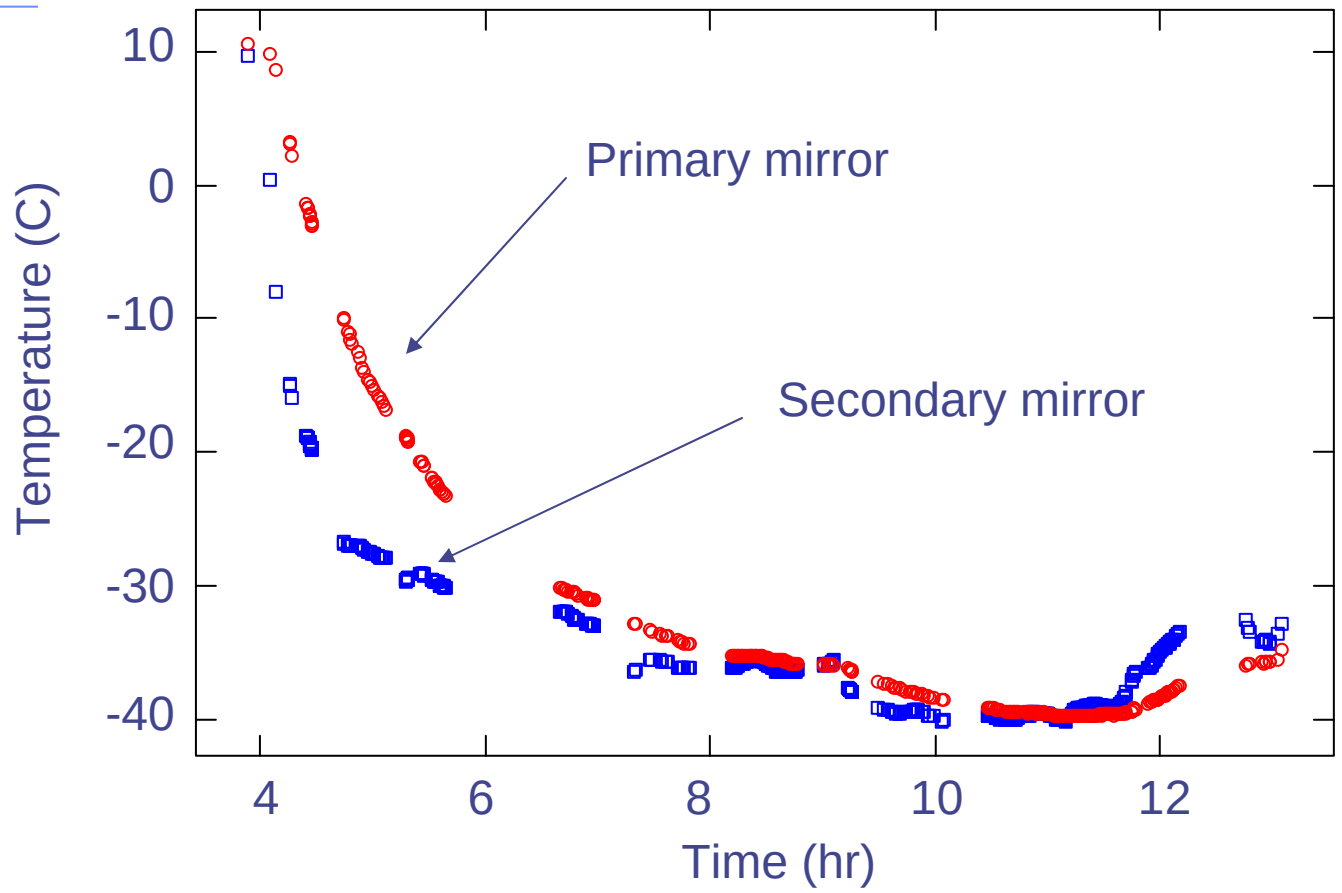




- bLE01_0039-41.fits, FR = 102 Hz, 11.3 μm
- Coll_LL = 539/639
- S_{blk} = 14700, S_{on} = 6580, ΔS_{off} = 570

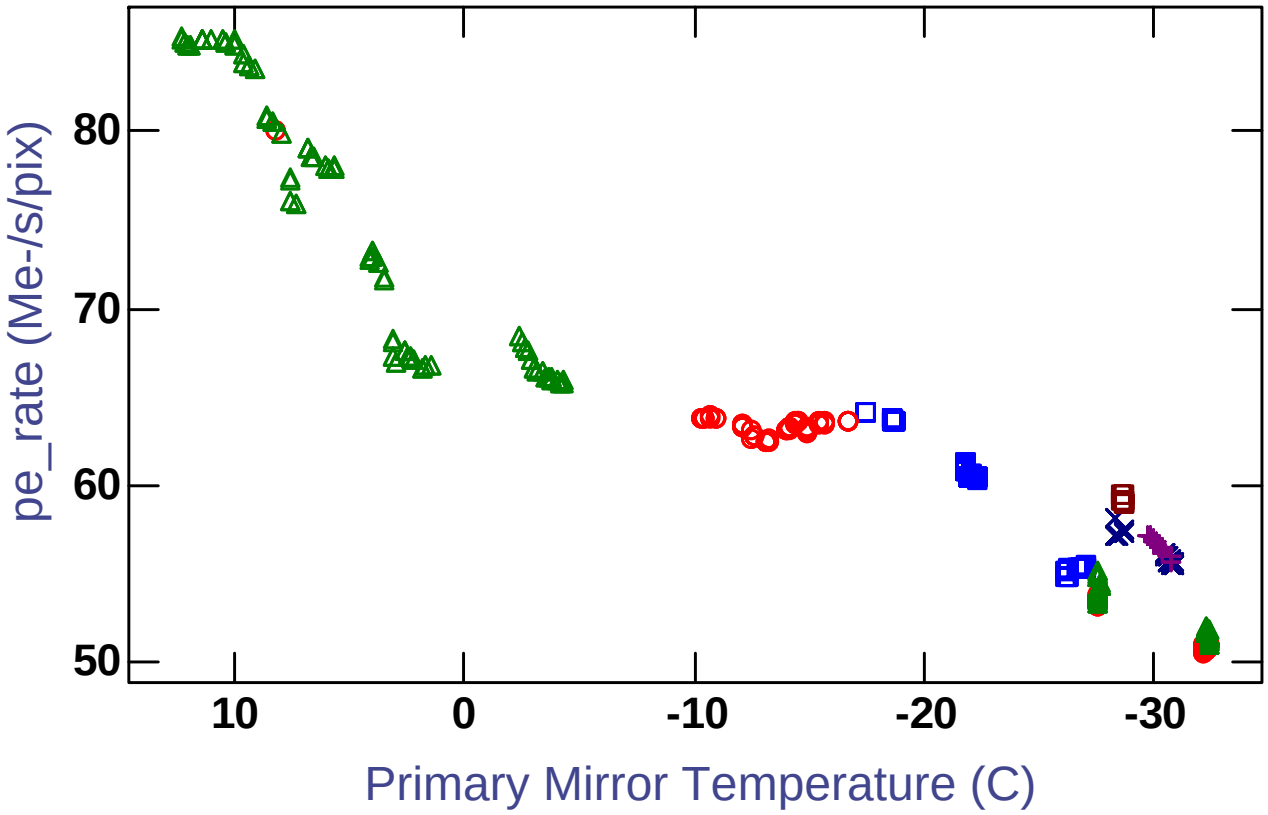
$$\varepsilon_{ps} = \frac{S_{on} - S_{off}}{S_{blk} - S_{off}} = \frac{570}{8690} = 6.6\%$$

Telescope Temperature vs. time



- TA primary (red) and secondary (blue) temperatures vs. UT for short science flight #1

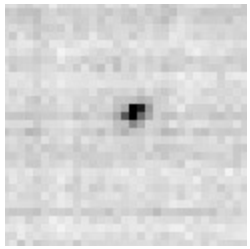
Telescope Temperature vs. time

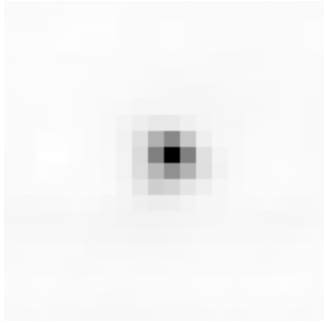


- FORCAST/SOFIA background (photoelectron rate per pixel) at 37 μm (with dichroic) for short science flight #2. Symbols indicate different zenith angles.

PSF comparisons

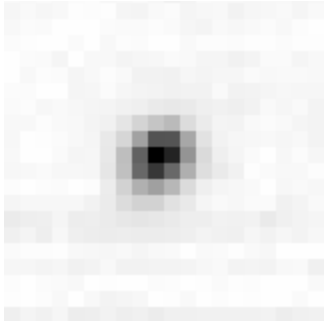
Short term



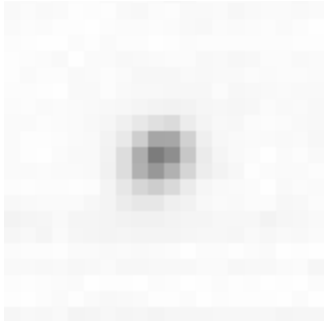


align & add

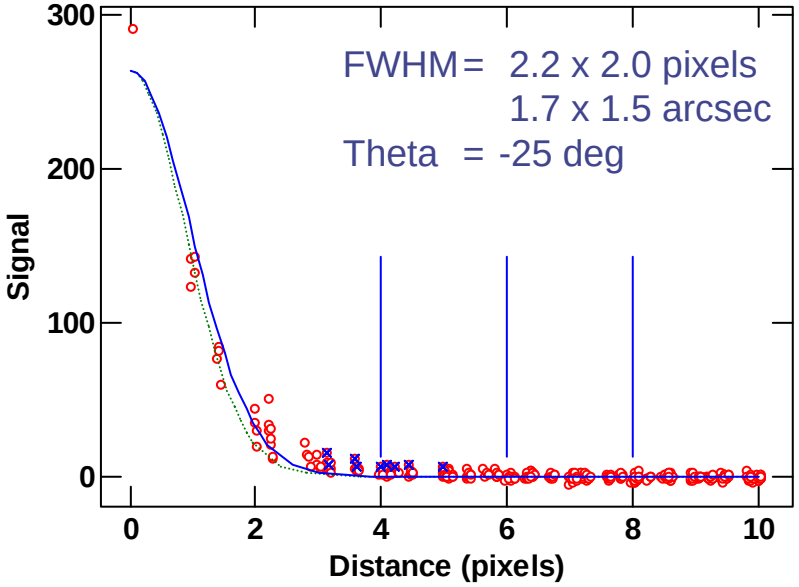
Long term

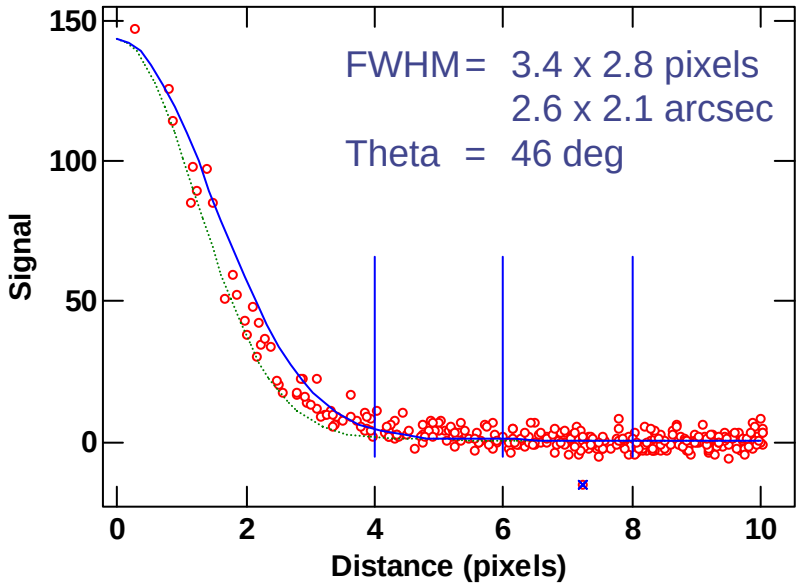


straight addition



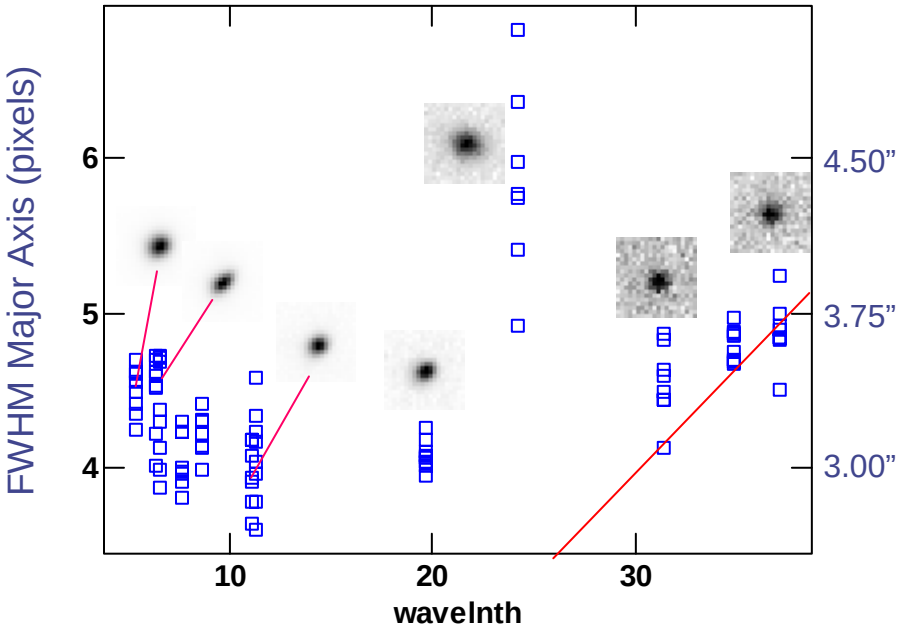
Scale same as short term

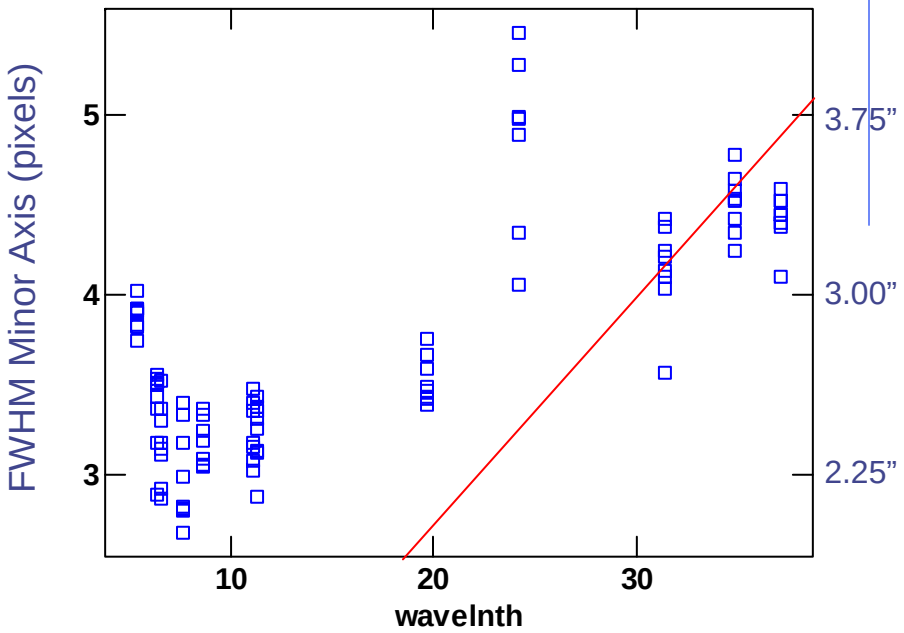




From 500 Hz sampling at 11.1 μm, coadded 2500 exposures, from OCF#3

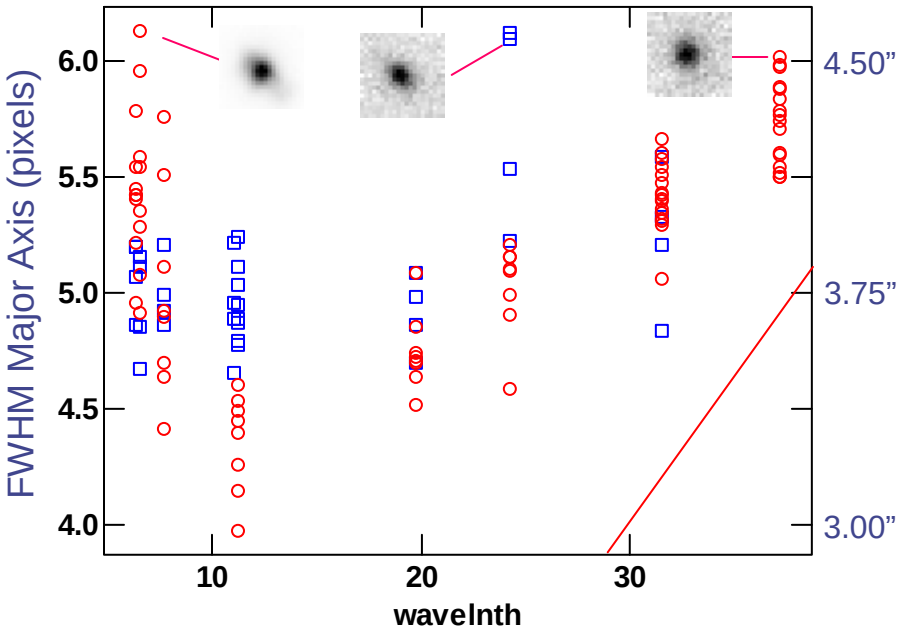
Image Quality – OCF#3

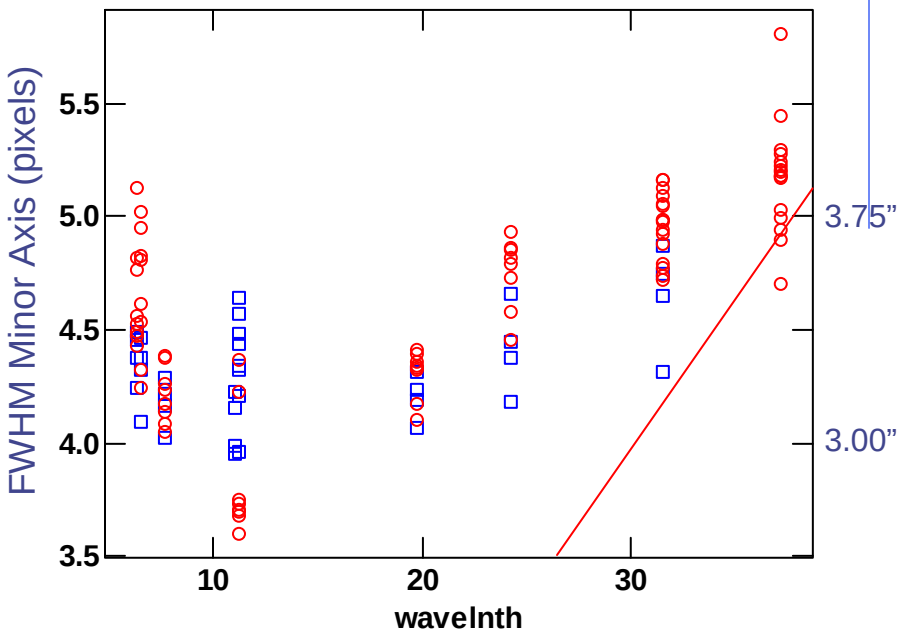




- FWHM of PSF major axis vs wavelength from OCF #3 at altitude ~ 43k feet from Beta And. Pixels are 0.75 arcseconds. Exposure time = 5 seconds, except for 34.8 & 37.1 μm which is 30 seconds. Red line is diffraction limit.

Image Quality – SS#3





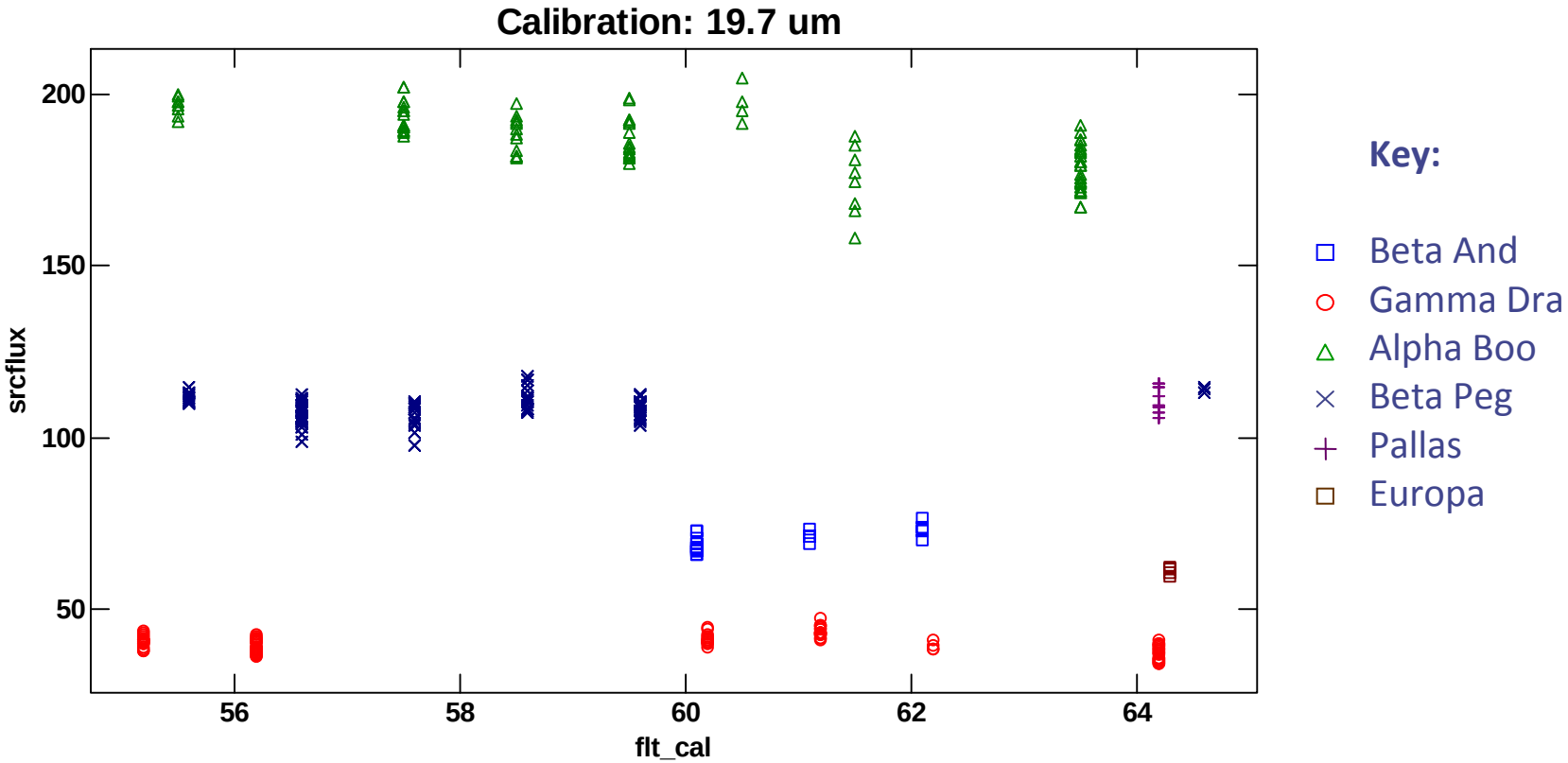
- FWHM of PSF vs. wavelength for SS#3 for mu Ceph (red, at 41k) and Sirius (blue, at 43k). Pixels are 0.75 arcseconds. Exposure time is 5 seconds for mu Ceph and 10-30 seconds for Sirius. Red line is diffraction limit.

FORCAST Science Observations

- Short Science sample images
  - Orion and W3
- Basic Science sample images
  - Pistol/Sickle region of Galactic Center
  - Circumnuclear disk around Sgr A*

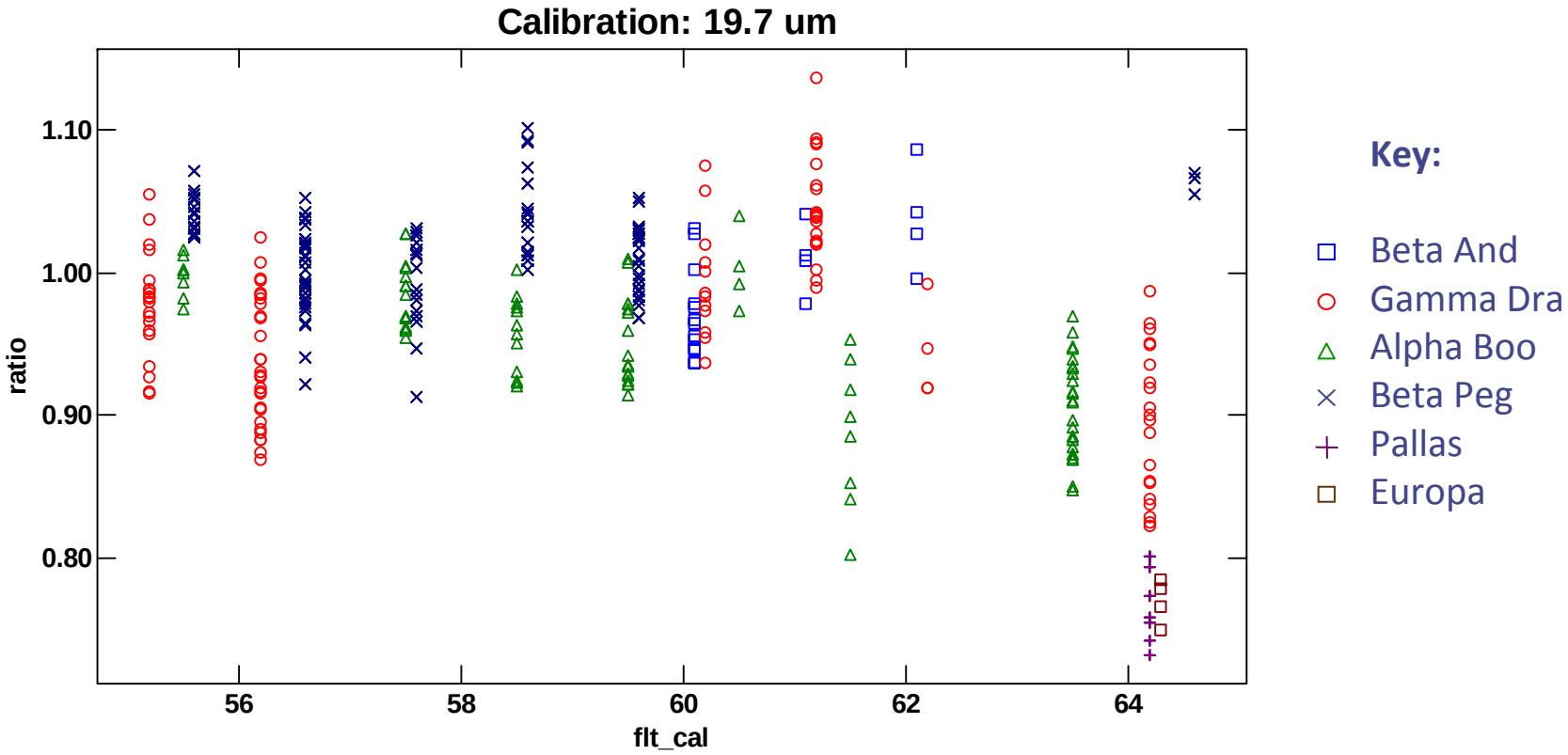
- But first
  - A word on calibration …

Calibrator consistency



- Calibrator flux at 19.7 microns derived from “standard” (preliminary) calibration for Basic Science flights (numbered as SOFIA flights 55 – 64)

Calibrator consistency

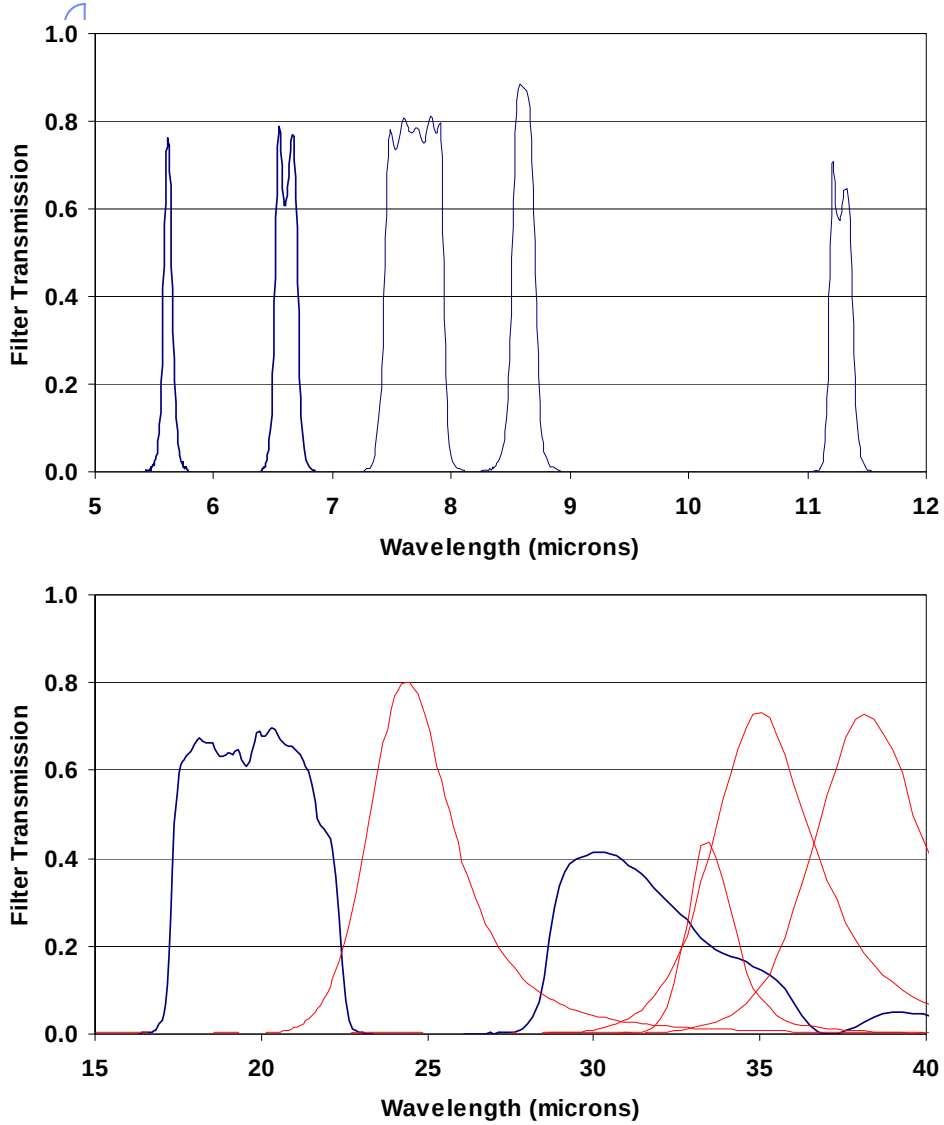


- Ratio of calibrator flux derived from “standard” (preliminary) calibration relative to “actual” flux at 19.7 microns for Basic Science flights
- When flight based correction corrections applied should be better than 20% and likely better than 10% (rms).

SOFIA: Orion Image

- Left: Visible (HST, O'Dell and Wong),
- Middle: Near-IR (McCaughrean),
- Right: SOFIA 19.7 μm (green) + 37 μm (red) image

Filters for Basic Science



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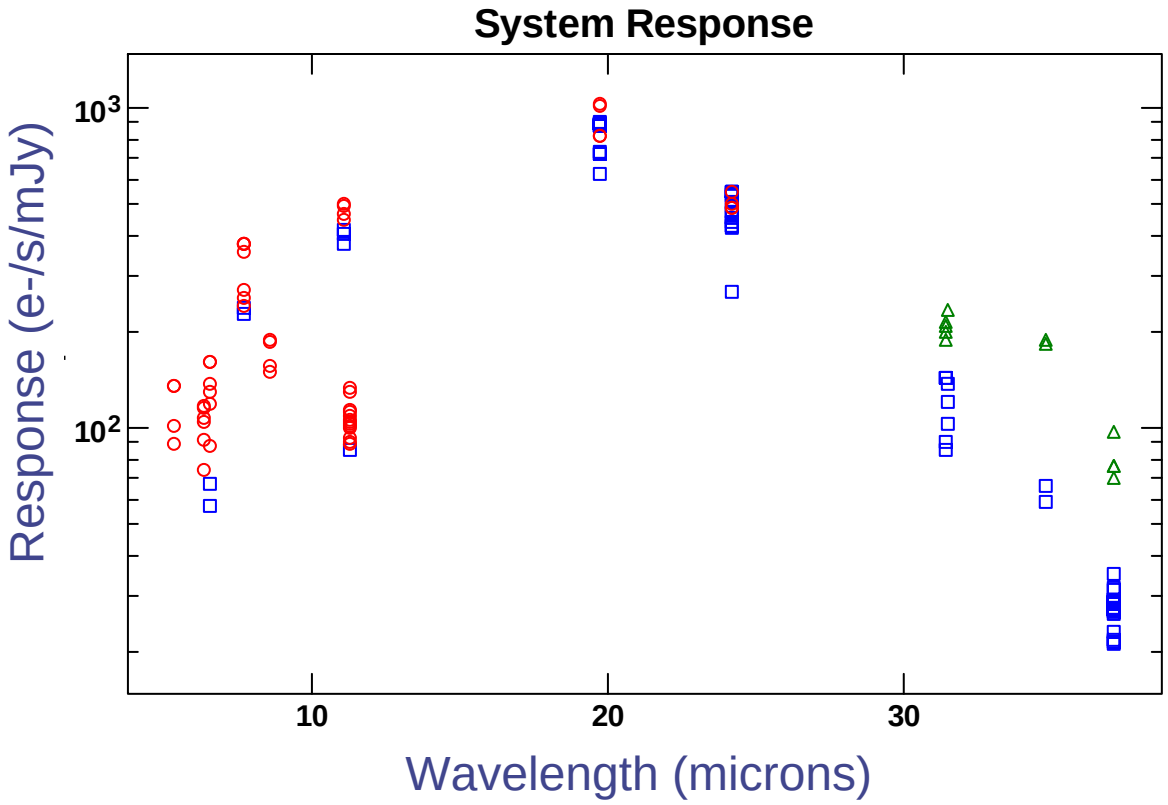
FORCAST Response



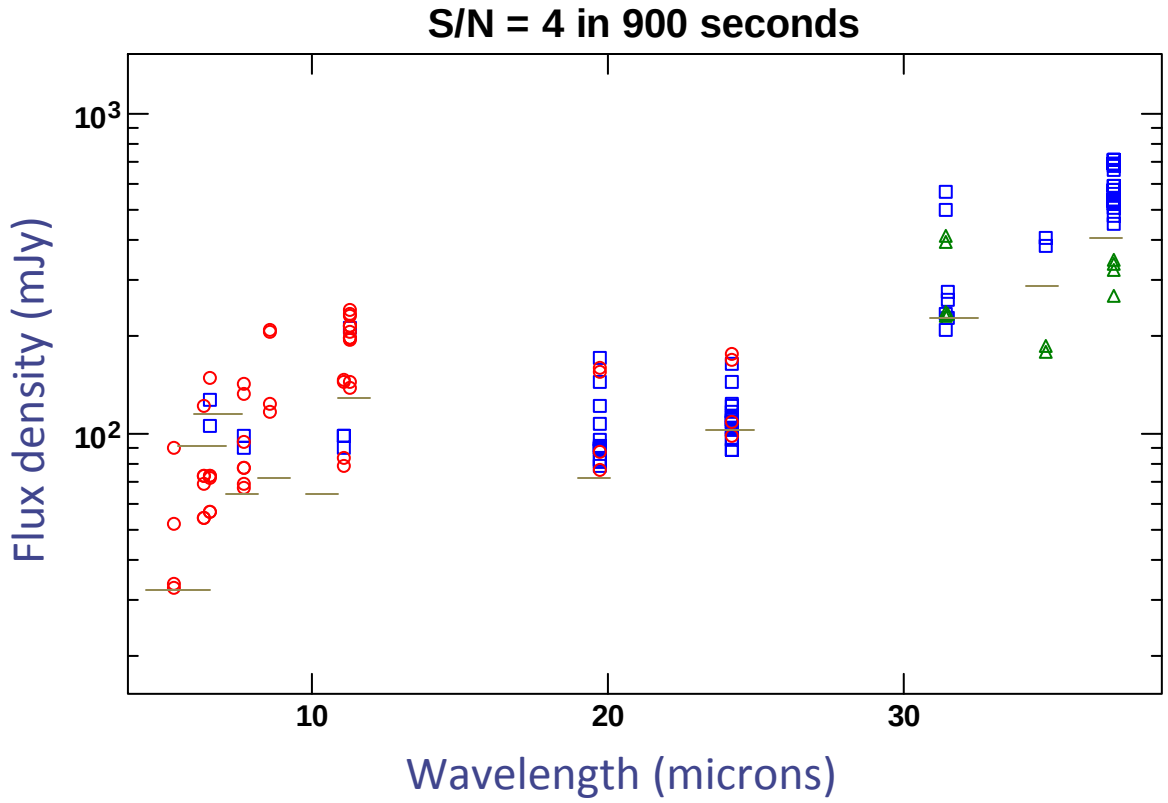
Key:

SWC - red circles
LWC - green triangles
Dichroic blue squares

29 pixels for extraction

- FORCAST spectral response from OCF#3 and short science calibration data.
- Variability is due to altitude, elevation, and presence of dichroic.

FORCAST Sensitivity



Key:

SWC - red circles
LWC - green triangles
Dichroic blue squares
Sens model (no dichroic)

29 pixels for extraction

Assumes source is in all 4 chop/nod images (chop & nod on-chip)
- Factor of 2 worse otherwise

- Estimated flux density of a point source for signal-to-noise ratio of 4 in 900 seconds based on calibrator images from OCF#3 and short science flights.
- Variability is due to altitude, elevation, and presence of dichroic.

Summary

- Science flights have been highly successful.
  - 3 Short Science and 10 Basic Science have lots of publishable results
- Science breadth
  - Wide range of programs covering planetary science, star formation, stellar evolution, the interstellar medium, and others.
- FORCAST niche will be
  - Spatial resolution & wavelength coverage
  - Grisms spectroscopy (to be commissioned next year)