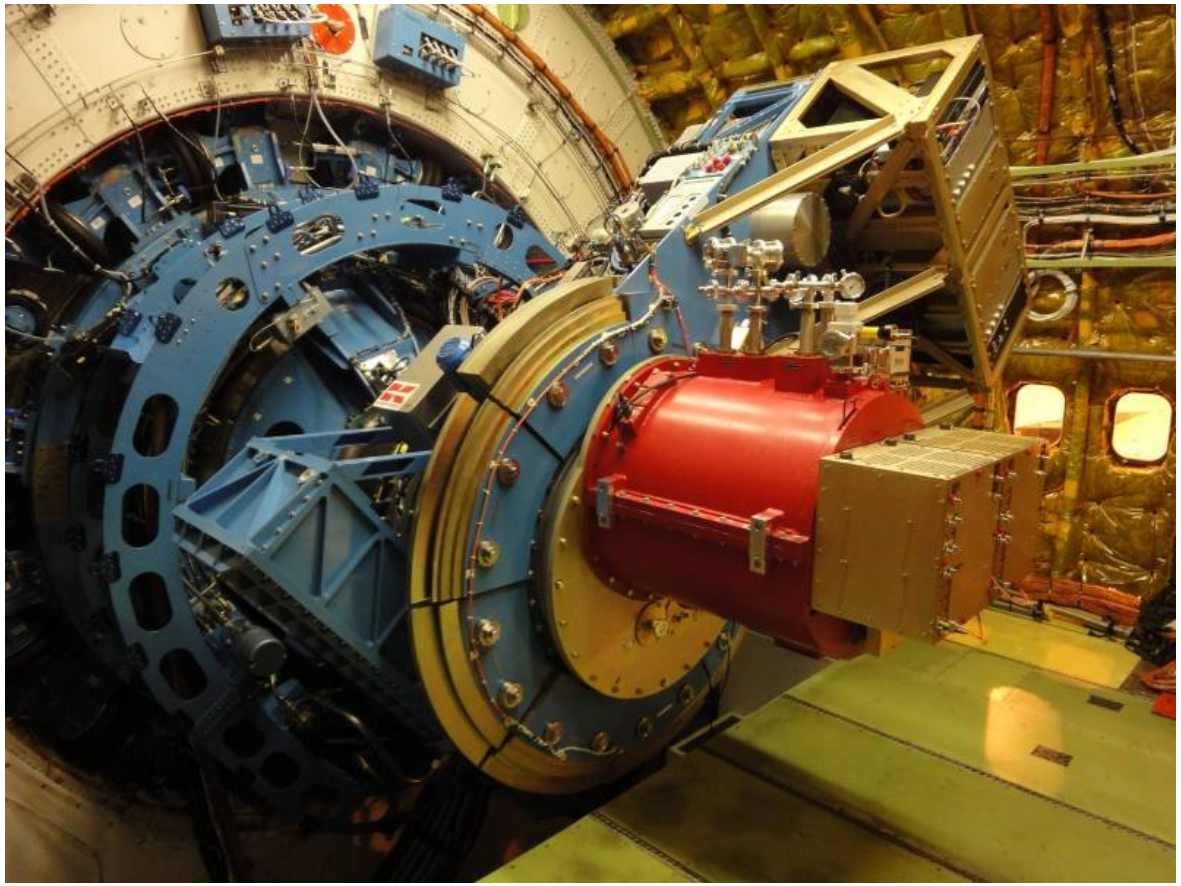
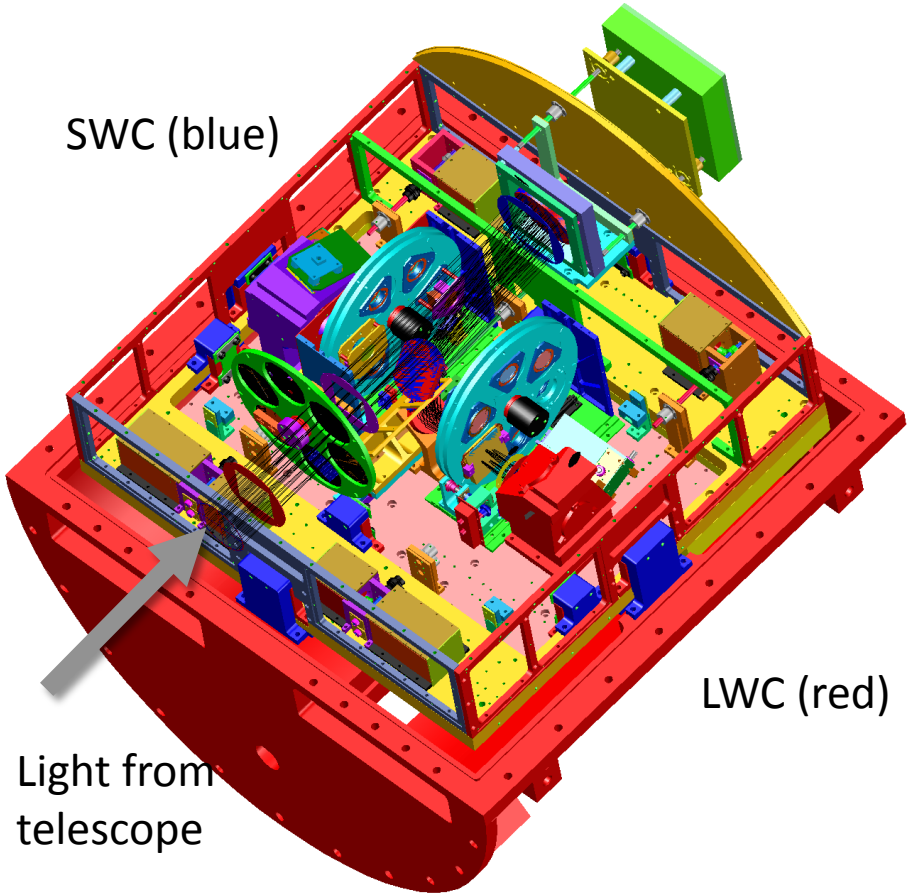


FORCAST: Science Capabilities and Data Products

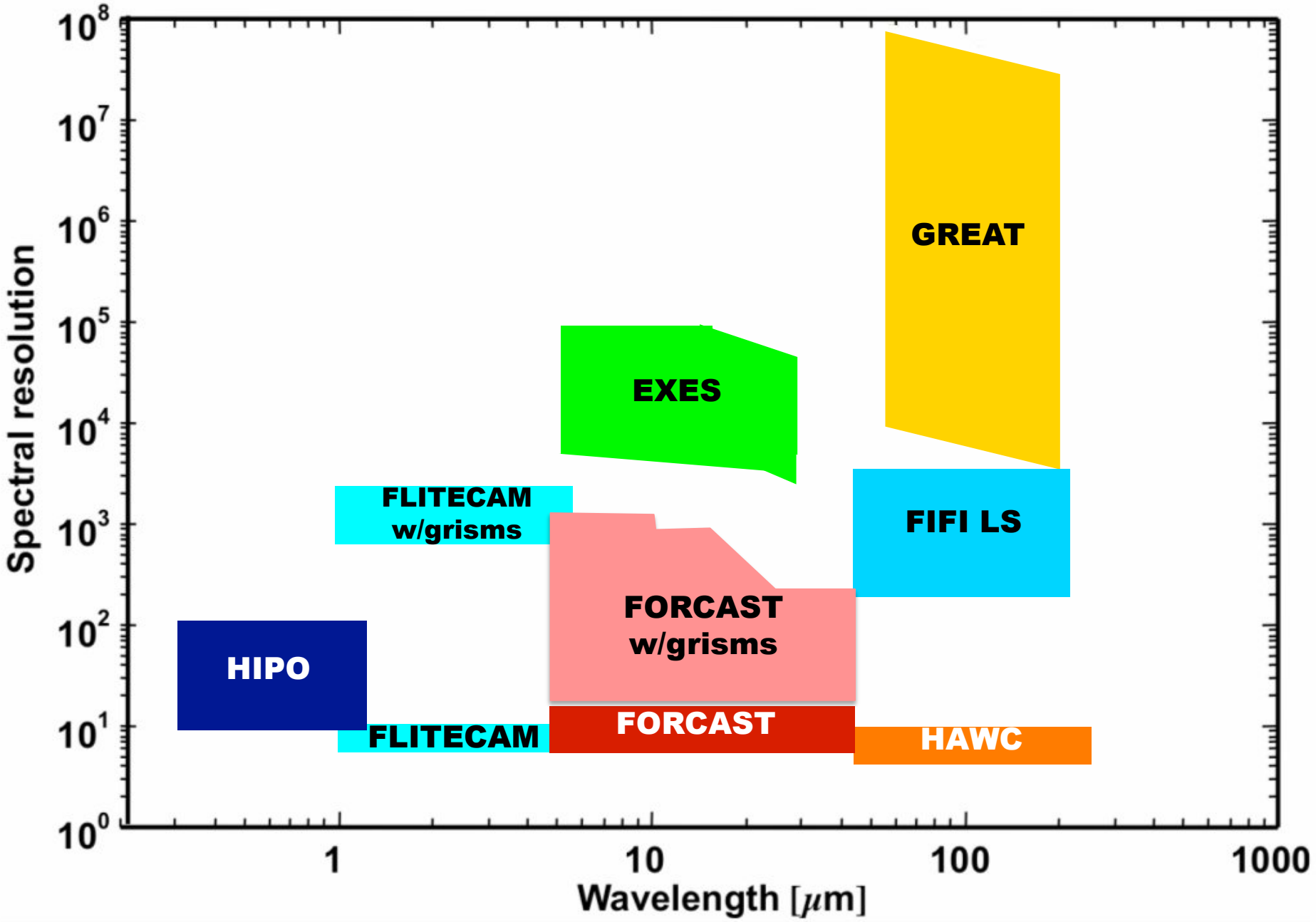
William D. Vacca

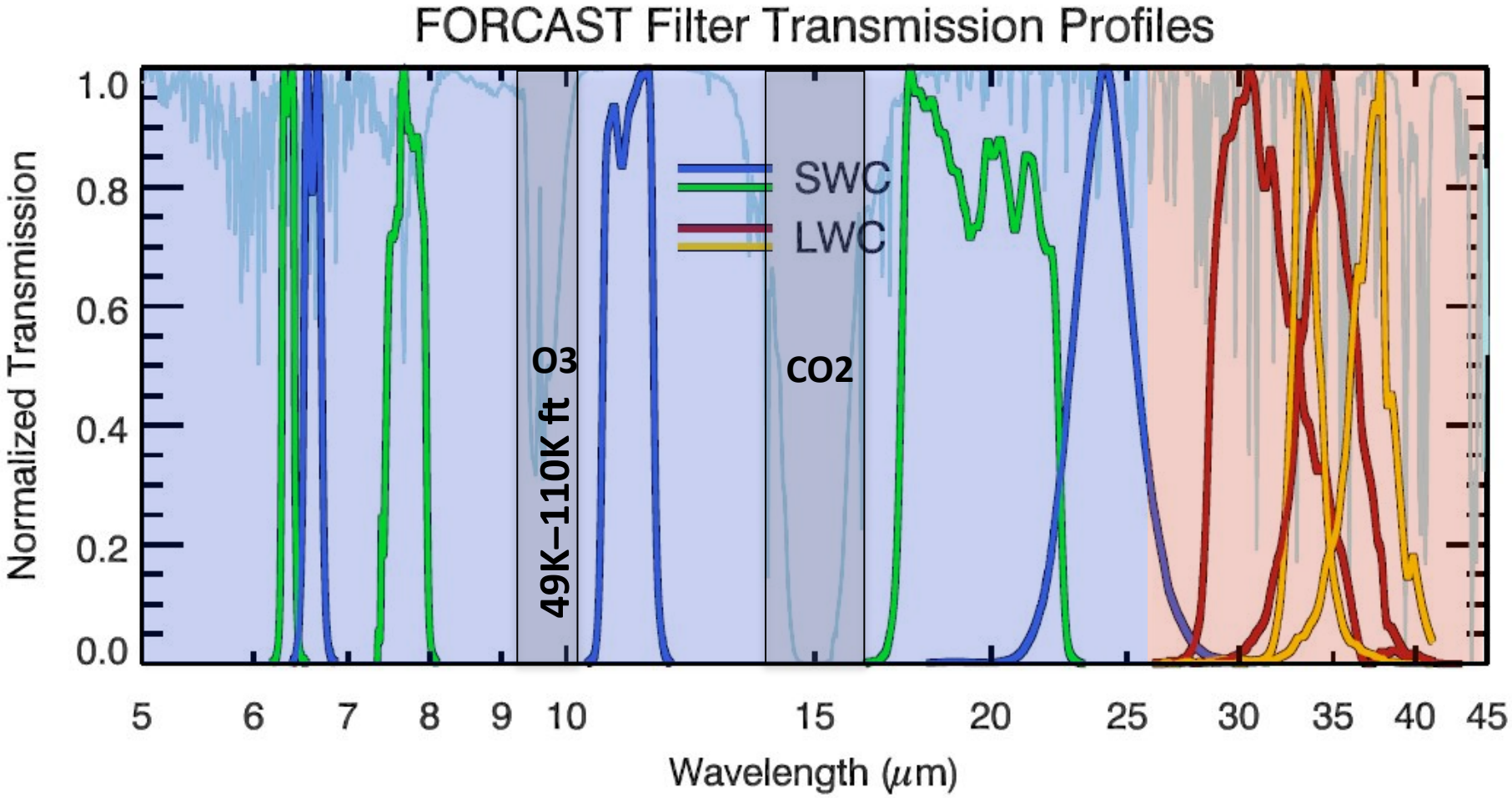
Faint Object infraRed Camera for the SOFIA Telescope (FORCAST)



- Facility Instrument
- PI: Terry Herter (Cornell)
- Wide field (3.4’ x 3.2’ FOV) dual channel 5-40 µm camera and spectrograph
- SWC Si:As BIB 256x256 array for 5-25 µm, 0.79”x0.75”pix, rebinned to 0.768” square
- LWC Si:Sb BIB 256x256 array for 25-40 µm, 0.79”x0.75”pix, rebinned to 0.768” square
- 4 Grisms with 2 long slits provide low resolution (R~70-300) spectroscopy over 5-40 µm
- 2 Cross dispersed grisms with 1 short slit provides moderate resolution (R~ 800-1200) over 5-14 µm

7 First Generation SOFIA Instruments





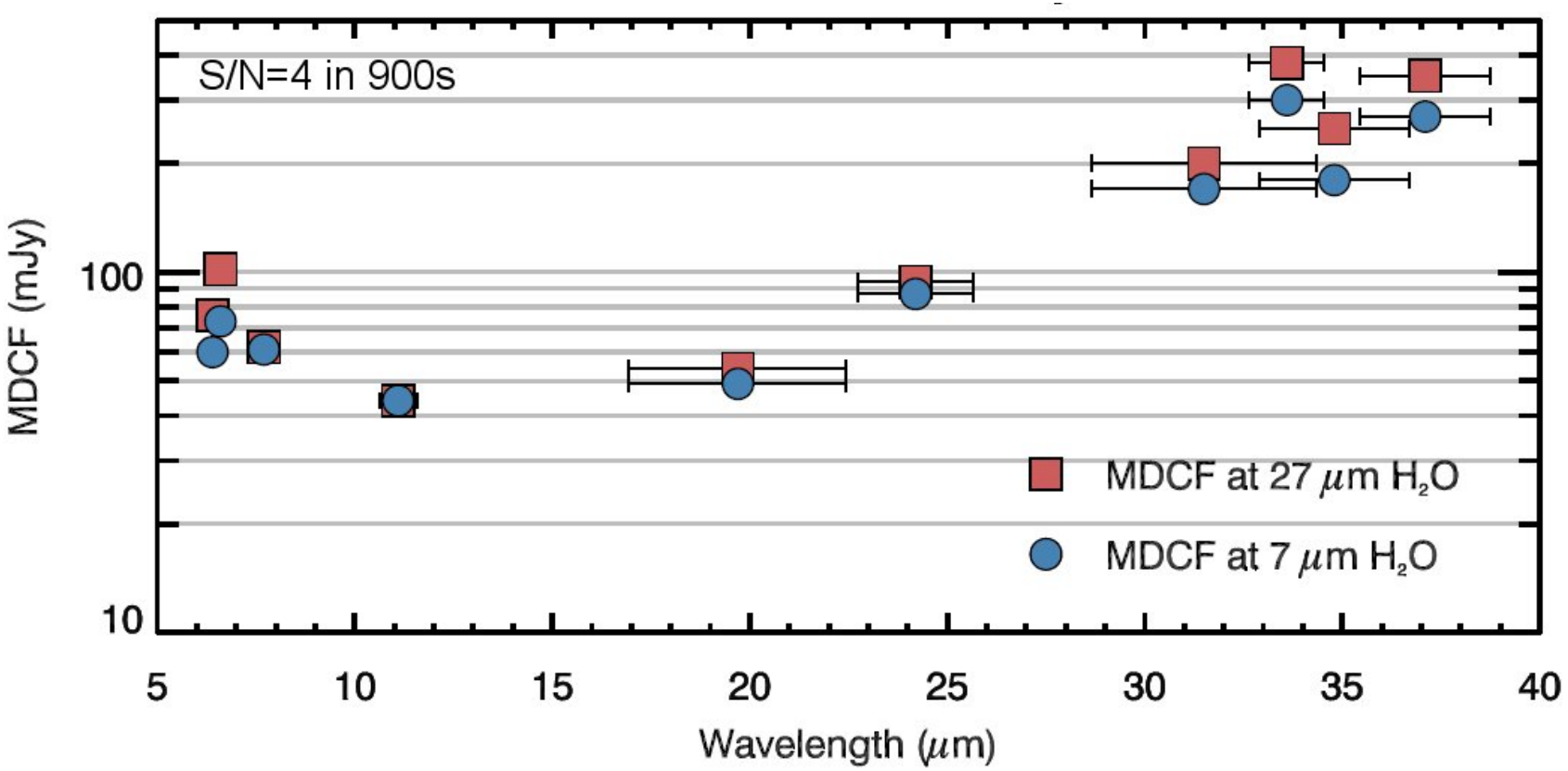
- The dichroic is designed to transmit light at wavelengths greater than 26 microns, and reflect light at less than 26 microns
- Dual channel mode allows simultaneous imaging at two wavelengths
- However, there is decreased throughput compared to single channel mode (60-85% in SWC; 40% in LWC)

Table 2: FORCAST Filter Characteristics

Channel	$\lambda_{\rm eff}$ (μm)	$\Delta\lambda$ (μm)	Imaging FWHM ($''$)		Spectral Features of Note
SWC	6.4	0.14	3.0	3.5	6.3μm PAH feature
	6.6	0.24	2.9	3.5	Continuum reference for PAH
	7.7	0.47	2.7	3.5	7.7μm PAH feature
	11.1	0.95	2.7	3.6	N-band substitute (11.3μm PAH)
	19.7	5.5	2.9	3.8	Q-band sub, Am. Silicate feature
	24.2	2.9	3.3	4.0	24.3μm [Ne V] line
LWC	31.5	5.7	3.4	4.3	
	33.6	1.9	–	4.5	33.5μm [S III] line
	34.8	3.8	3.6	4.5	Crystalline Silicate feature
	37.1	3.3	3.5	4.7	

Meas. FWHM values for 2 values of the telescope pointing stability (jitter): 1.25” and 2.1”

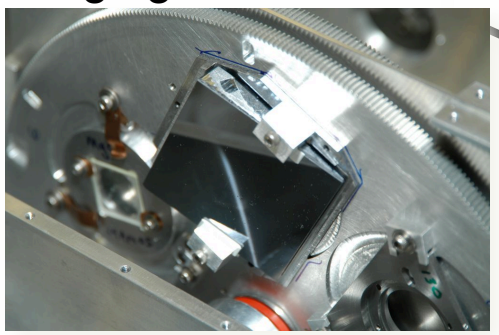
Imaging Sensitivity (present arrays)

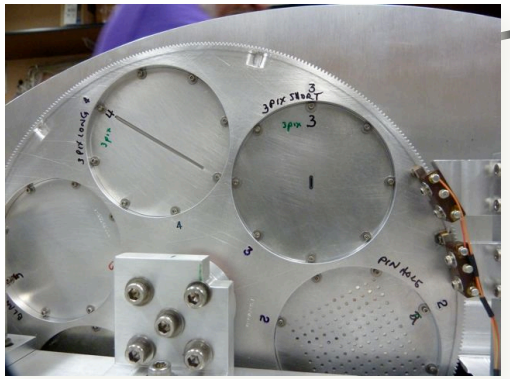


- S/N=4 in 900s, 41000 feet, single channel mode; larger limiting fluxes with dichroic
- Altitude/water vapor affect sensitivity more in the LWC
- SITE, the online integration time estimator, can be used to estimate exposure times

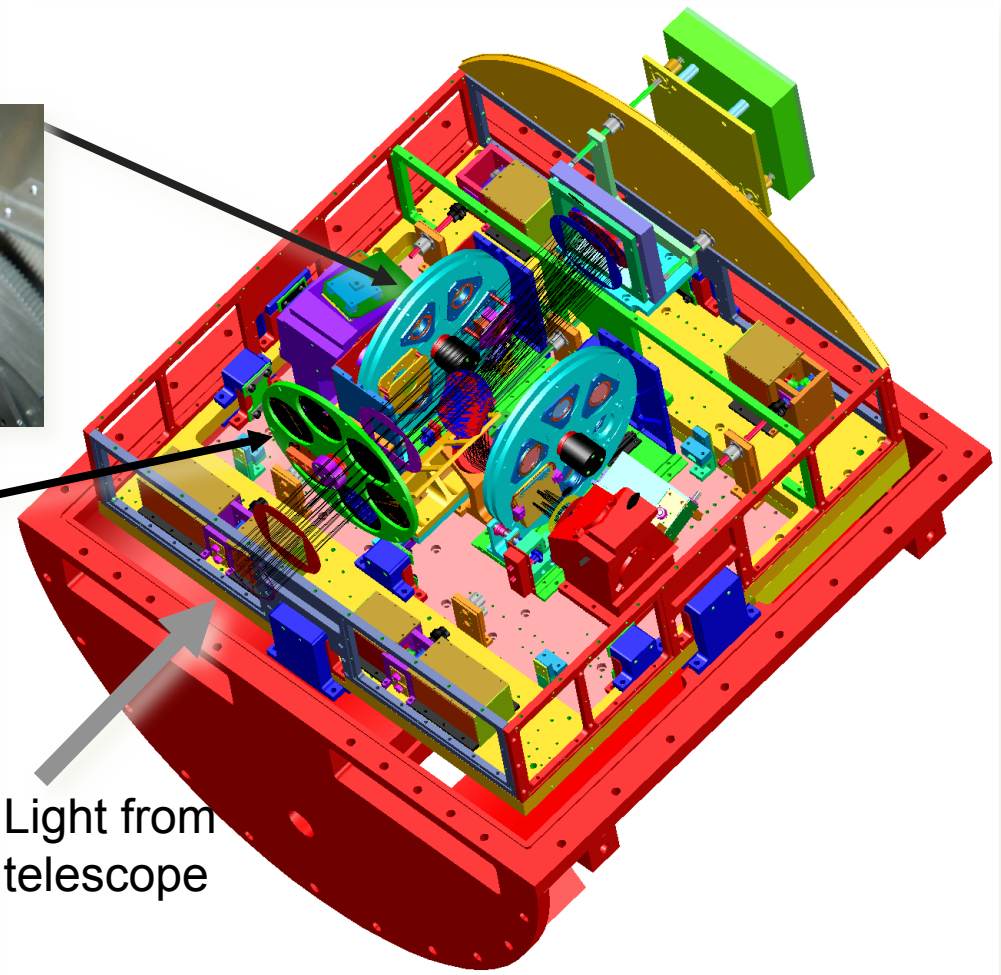
FORCAST grism design overview: layout

Grisms in existing imaging filter wheels





Slits in existing aperture wheel



Light from telescope

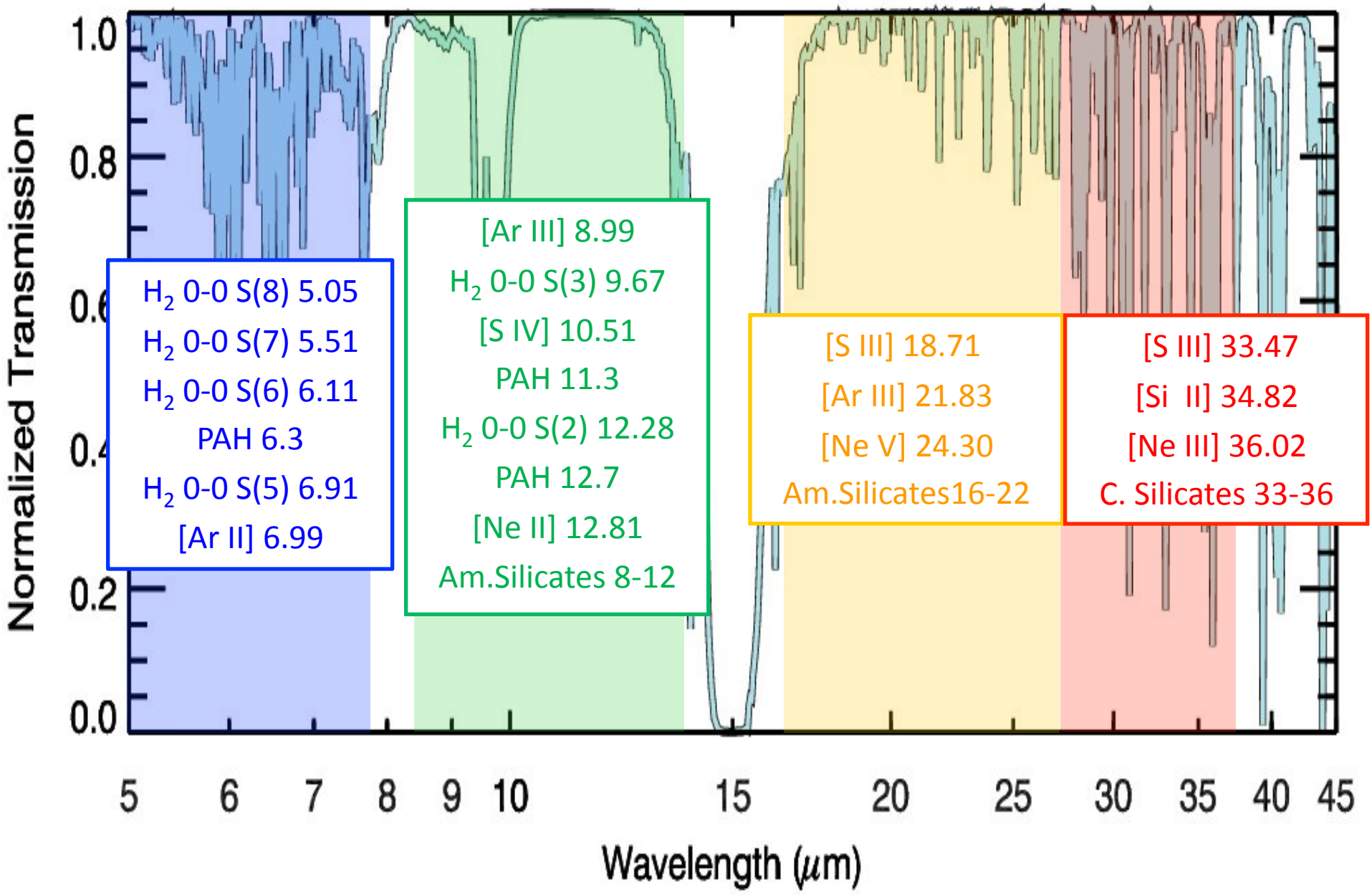
FORCAST Grisms and Slits

Grism	Wavelength	Slit	Resolving Power
Long Slit Spectroscopy in the Short Wavelength Camera			
G1	4.7-7.8 μm	2.4”x192”	200
		4.7” x192”	100
G3	8.4-13.7 μm	2.4” x192”	300
		4.7” x192”	150
Cross Dispersed Spectroscopy in the Short Wavelength Camera			
G2xG1	4.7-7.8 μm	2.4”x11.25”	1200
G4xG3	8.4-13.7 μm	2.4”x11.25”	800
Long Slit Spectroscopy in the Long Wavelength Camera			
G5	17.6-27.7μm	2.4”x192”	140
		4.7” x192”	70
G6	28.7-37.1μm	2.4” x192”	220
		4.7” x192”	110

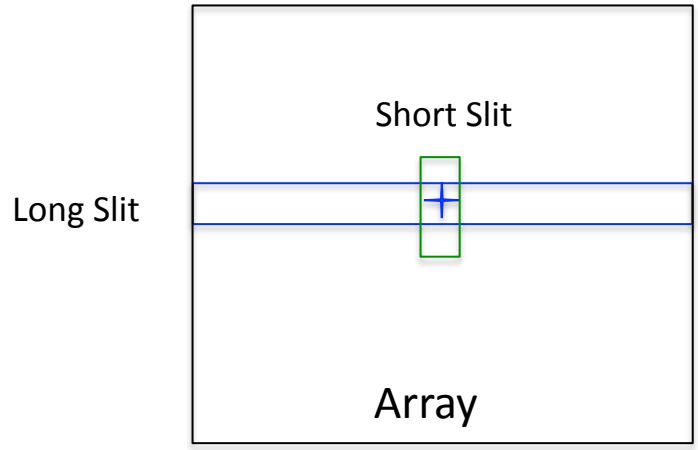
Notes:

- Grisms have not yet been commissioned; Cycle 1 observations are shared risk
- Grism spectroscopy in Cycle 1 available only in single-channel mode
- There is NO field de-rotator, so orientation of slit on sky is dependent on flight plan because SOFIA is an Alt-Az telescope
- Due to limits in telescope rotation, field orientation will rotate between “LOS Rewinds”

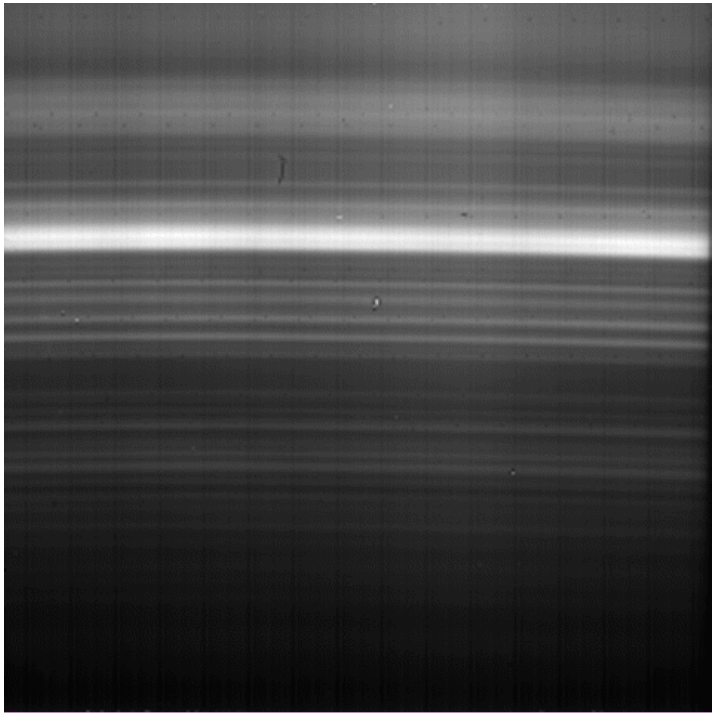
Spectral Features of Interest



Grism spectral formats

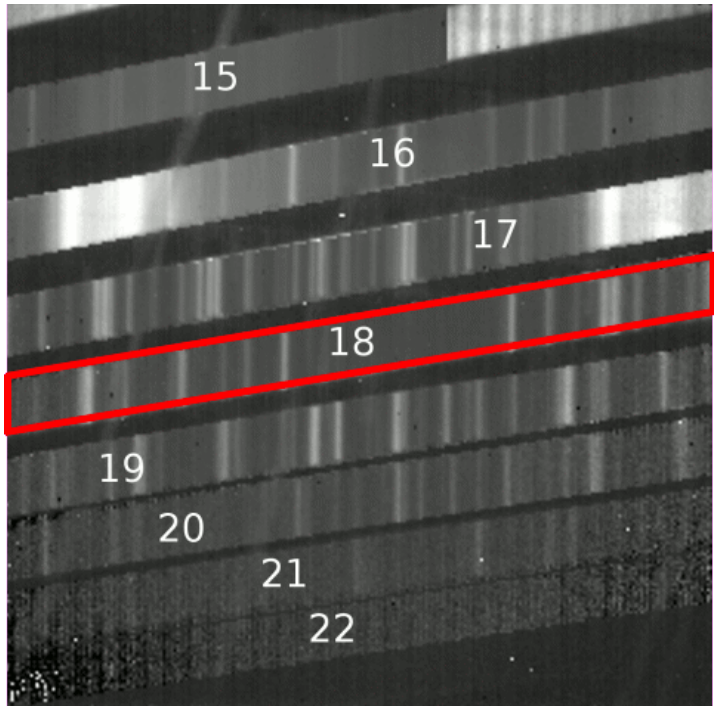


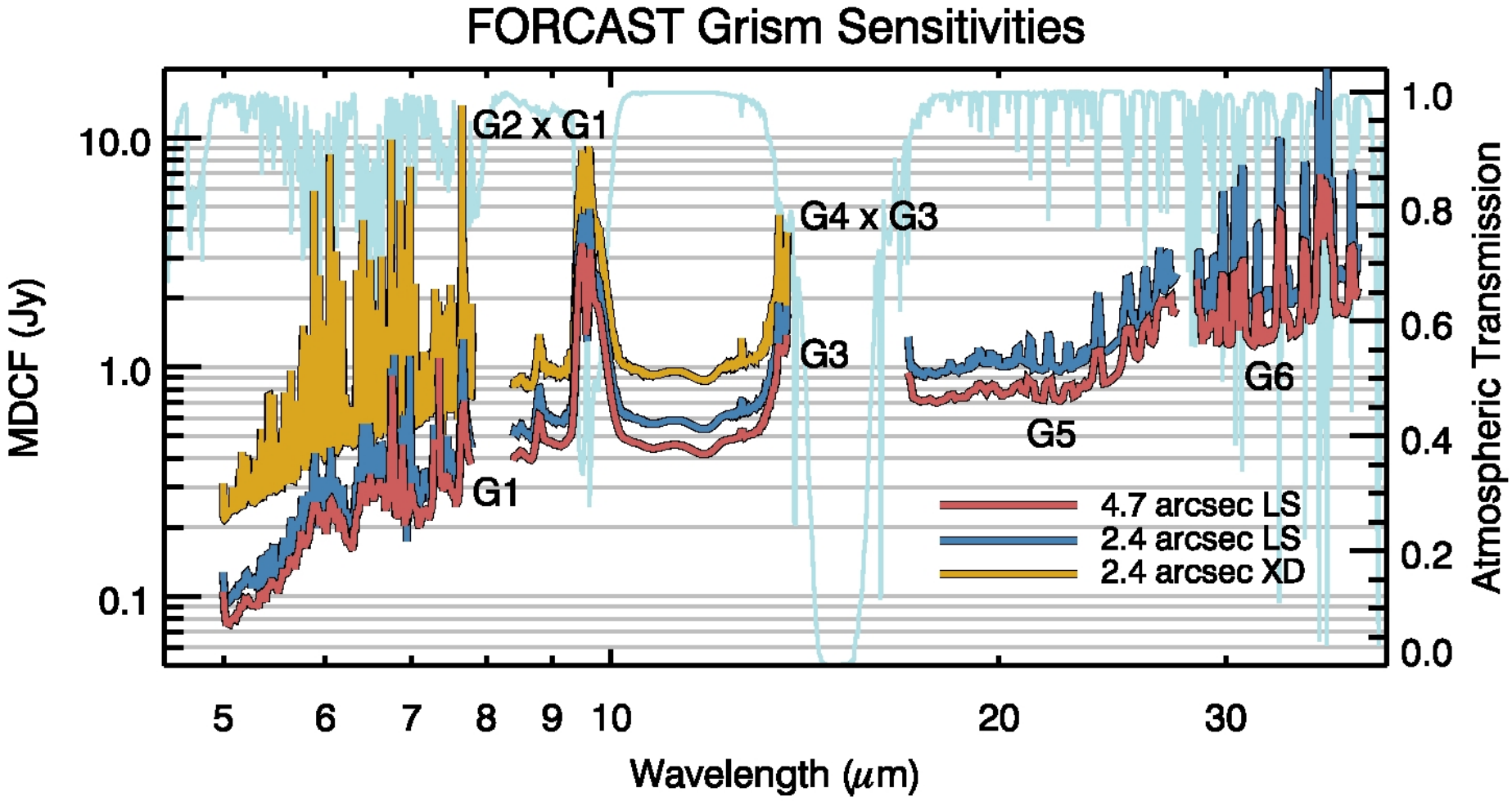
Long slit modes



interference fringes

Short slit (XD) modes



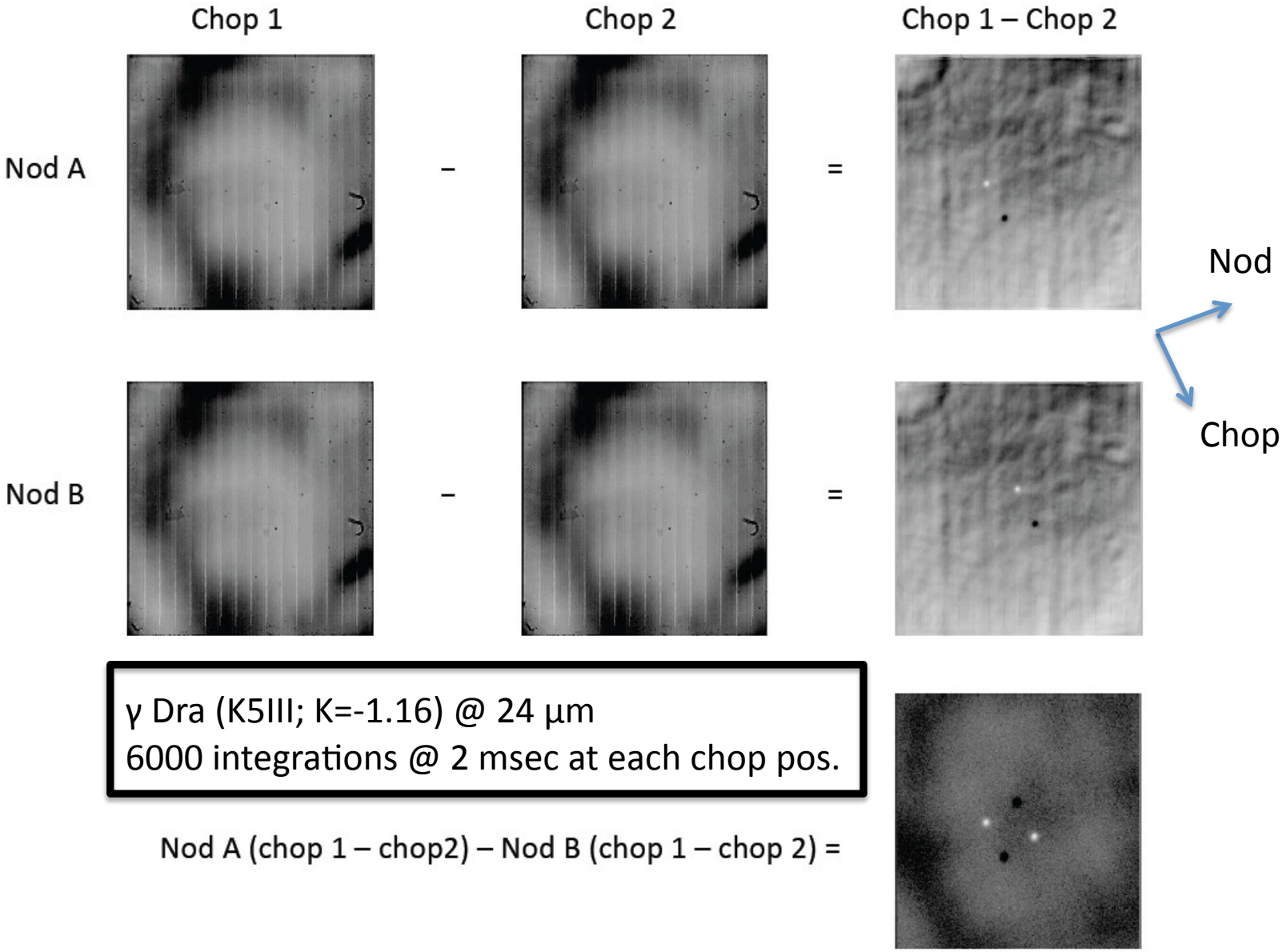


- S/N=4 in 900s at 41000 feet (7μm water vapor)

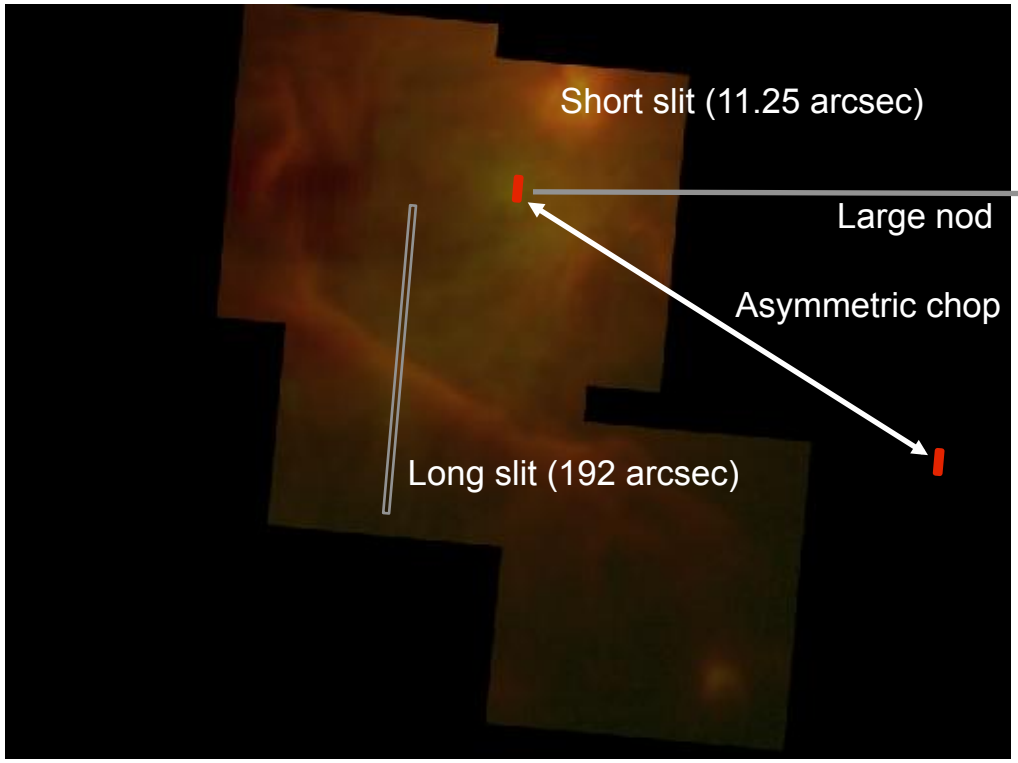
Chop/Nod Technique

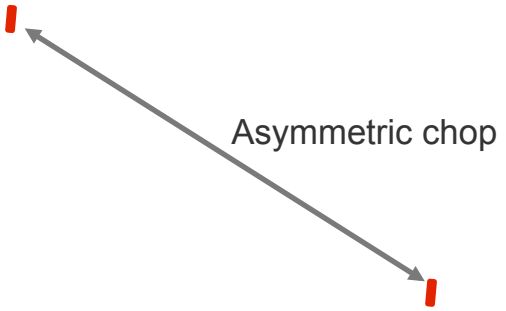
- MIR observations are completely background (sky+telescope+instrument) limited
  - Background can be >$10^{4\text{-}6}$ times brighter than most sources
  - Detector wells can fill in 1-100 msec
- MIR background varies rapidly (order of less than a few sec)
- To subtract majority of the background the secondary is tilted between on-source and off-source positions (chopping) at a rapid rate (~few Hz)
- However, chopping introduces small additional offsets due to the different optical paths for the beams in the two chop positions
- To remove background offset, telescope is moved to another position (nodding) and the chop is repeated
  - Nods on a timescale of ~5-30 sec per nod position
- The two images from the chop positions are subtracted, and the two resulting chop-subtracted images from the two nod positions are subtracted
  - This double-differencing removes all background contributions
- One must ALWAYS chop and nod for FORCAST observations
- There are three types of chop/nod strategies for FORCAST imaging:
  - Nod_Match_Chop (NMC, symmetric)
  - Nod_Perp_Chop (NPC, symmetric)
  - C2NC2 (asymmetric)

Nod_Perp_Chop (Symmetric Chop) Mode:



Pointed observations of extended sources

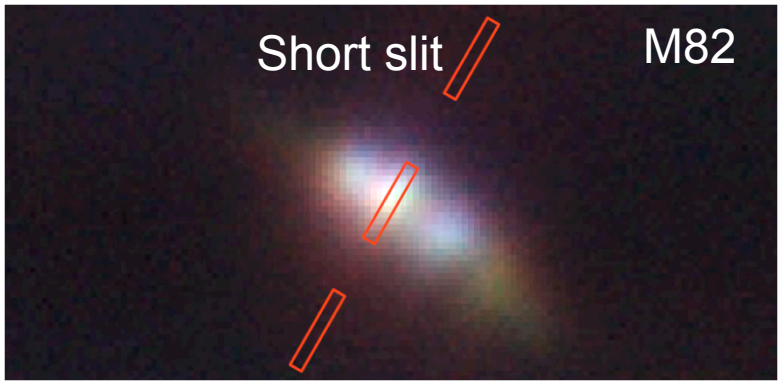




Large HII region example C2NC2 mode

Note: There is NO field de-rotator, so orientation of slit on sky is dependent on flight plan and cannot be specified by observer *a priori*

Galaxy example NMC



Data Reduction Pipeline (DRIP):

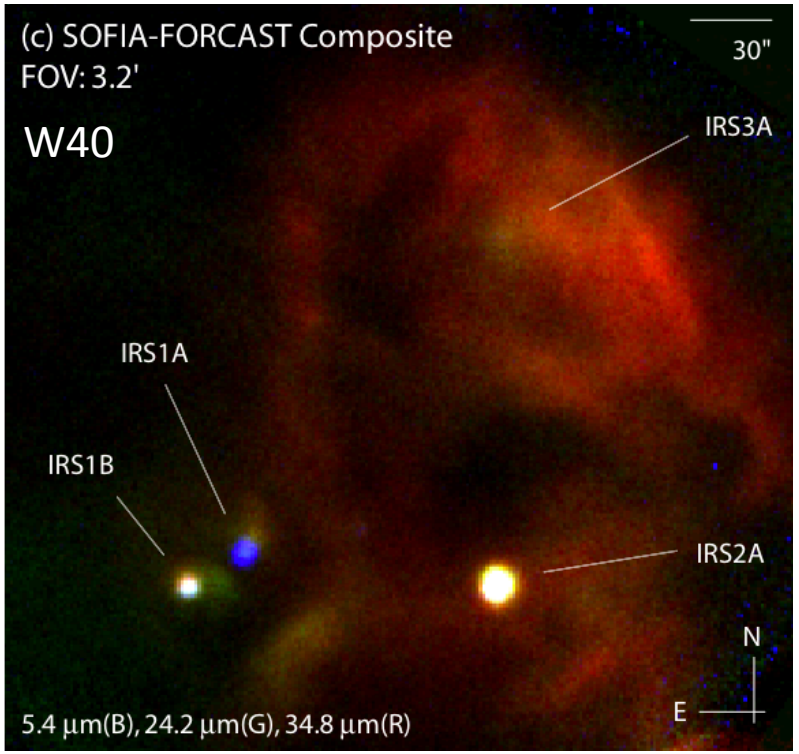
Imaging pipeline:

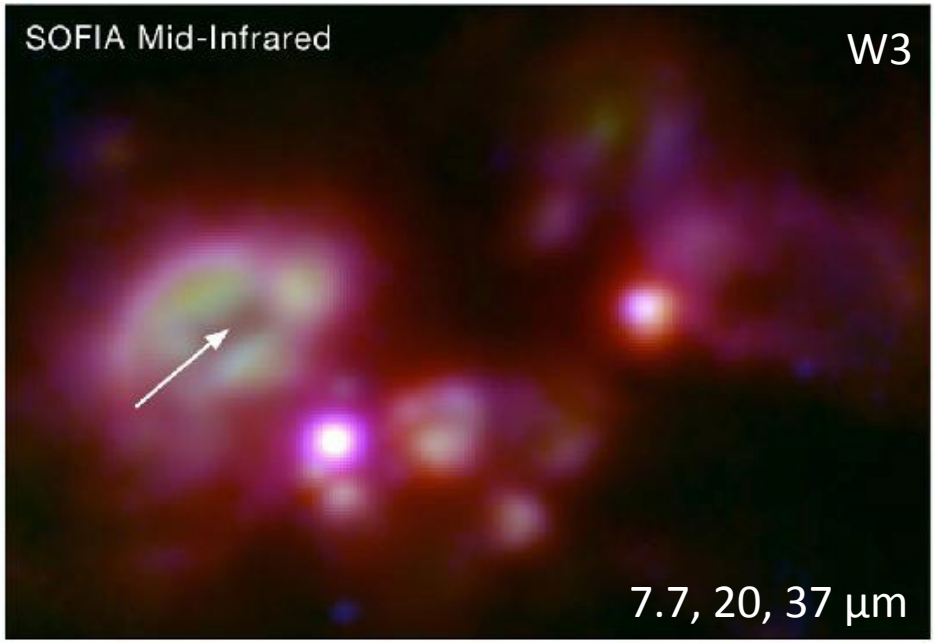
- ***clean***: remove bad pixels
- ***droop***: detector correction for bright sources
- ***jailbar***: remove pattern noise
- ***linearize***: detector non-linearity correction
- ***stack***: background subtraction using chop/nod sets
- ***undistort***: distortion correction and rotate N up, E left
- ***merge***: combine ('fold') stacked frames
- ***co-add***: combine dithered merged frames
- ***fluxcal***: using theoretical spectra of calibration stars, ATRAN models, and instrument throughput curves (good to ~20%)

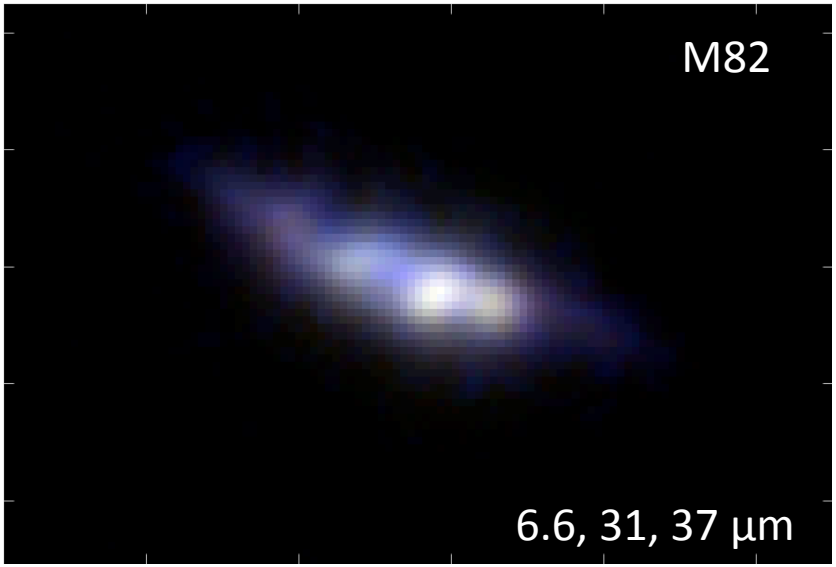
Additional pipeline steps for grism spectroscopy:

- ***spectral extraction***: (optimal or sum columns)
- ***defringe***: if needed after flatfield correction (e.g. low S/N)
- ***wavecal***: apply pre-determined polynomial fit to telluric/nebular lines
- ***telluric***: using observed telluric spectra, pwv data, and ATRAN models
- ***fluxcal***: using observed spectra of flux calibration stars
- ***save***: extracted and calibrated spectra, any specified intermediate data set


Orion Bar
20 & 37 µm

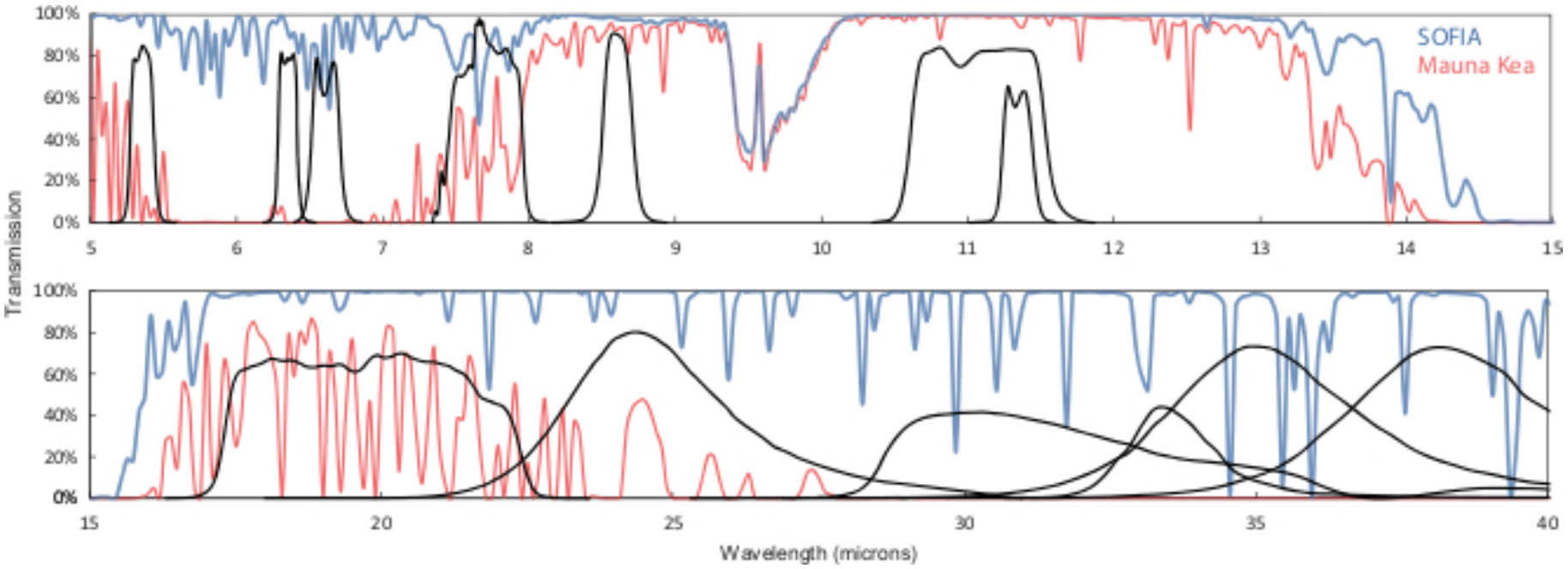

(c) SOFIA-FORCAST Composite
FOV: 3.2'
30"
W40
IRS3A
IRS1A
IRS1B
IRS2A
N
E
5.4 µm(B), 24.2 µm(G), 34.8 µm(R)


SOFIA Mid-Infrared
W3
7.7, 20, 37 µm


M82
6.6, 31, 37 µm

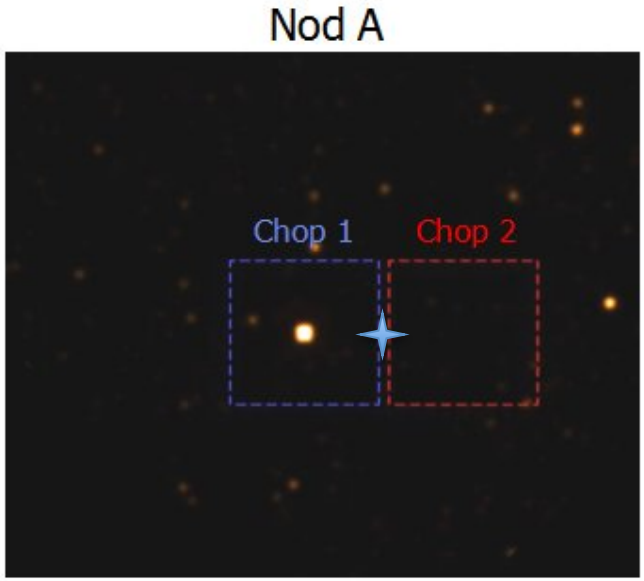
Backup Slides

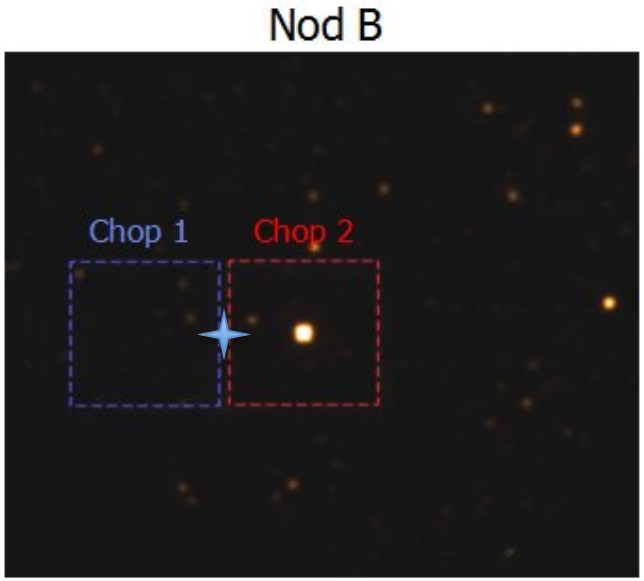
FORCAST Filter Profiles

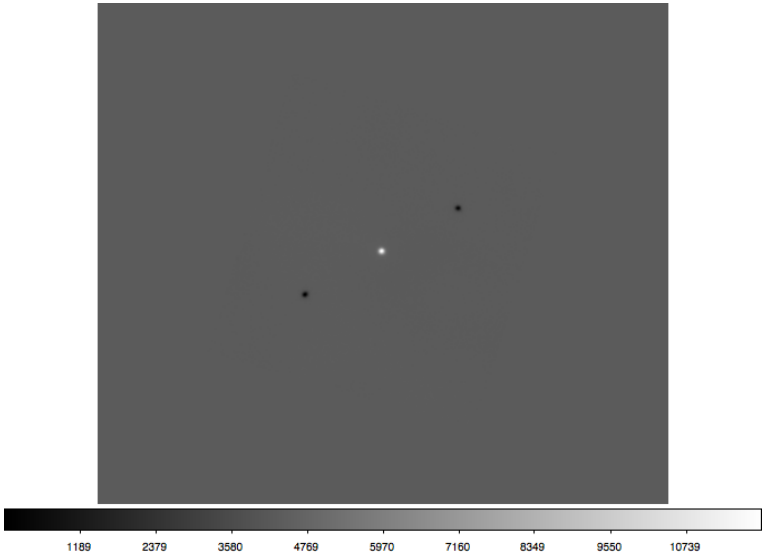


SOFIA : 41000 ft, 7.3 µm PWV, 45° ZA
Mauna Kea: 13800 ft, 3.4 mm PWV, 45° ZA

Nod_Match_Chop (Symmetric Chop) Mode:



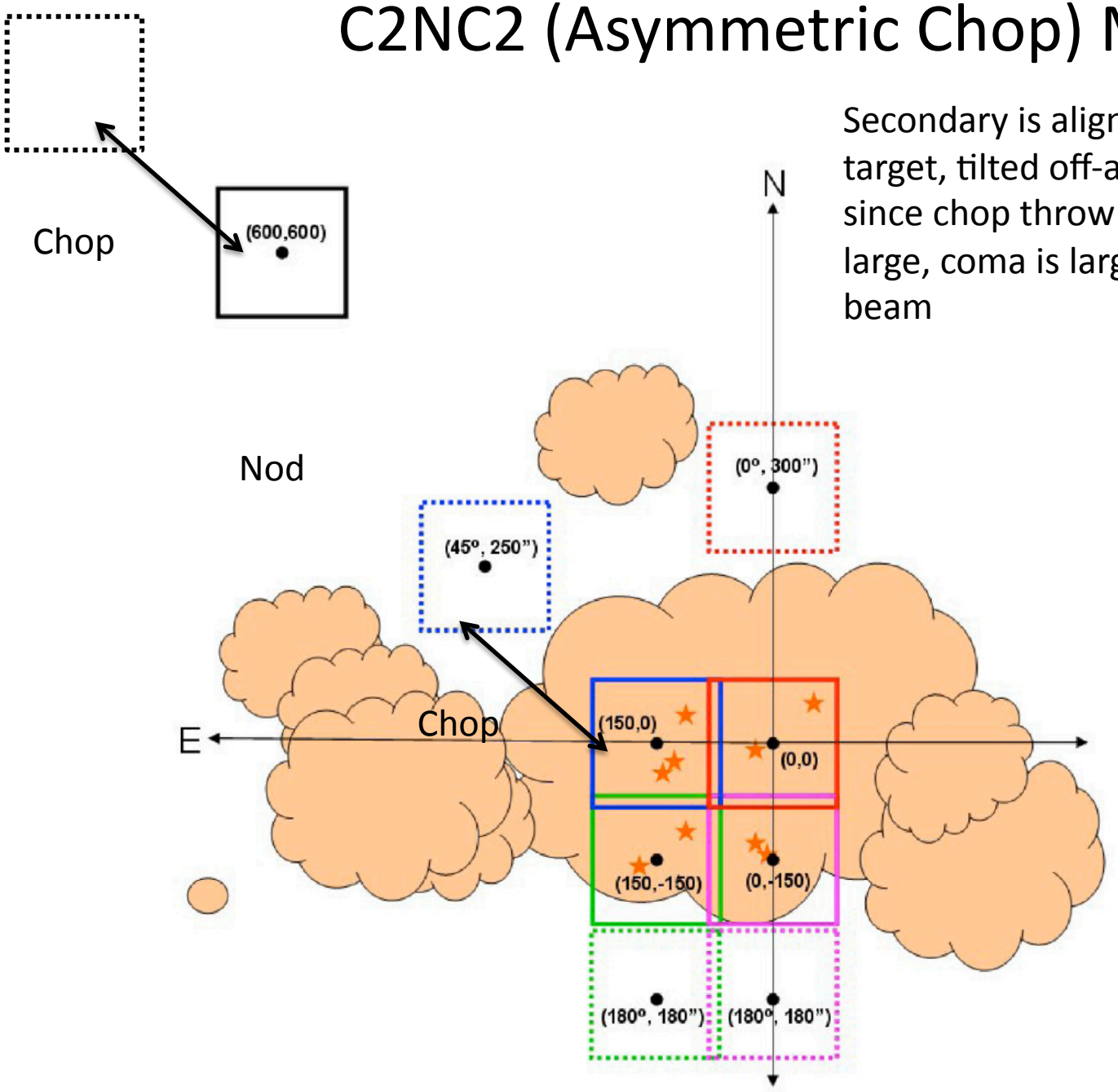




Note:
Chops should be as small as possible due to coma when tilting the secondary (2” per 1’ off-axis tilt); 30” is typical.

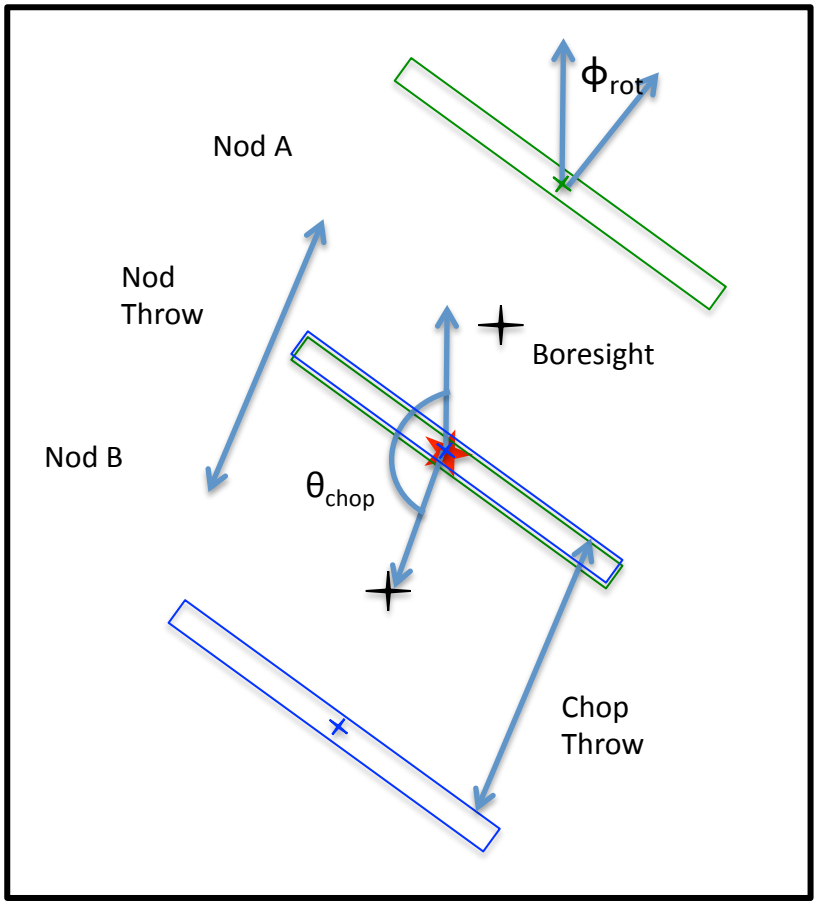
C2NC2 (Asymmetric Chop) Mode:

Secondary is aligned with the target, tilted off-axis for chop; since chop throw is usually large, coma is large in chopped beam

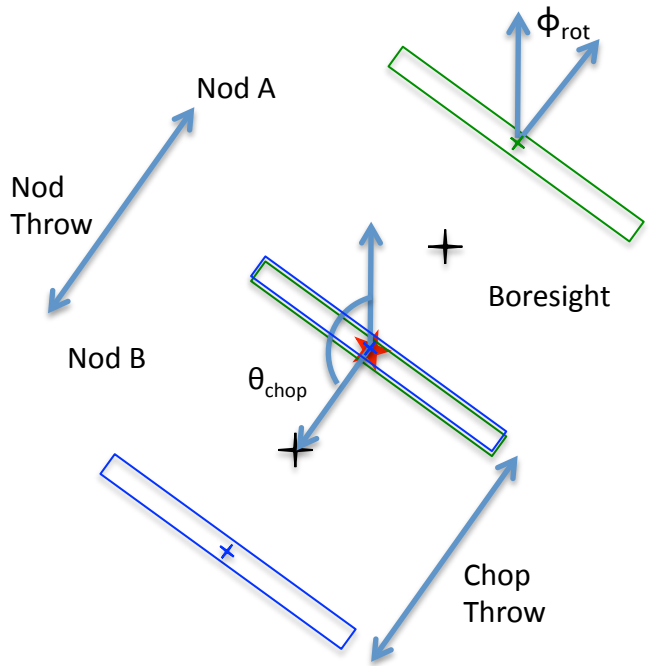


Grism Observing Modes: NMC

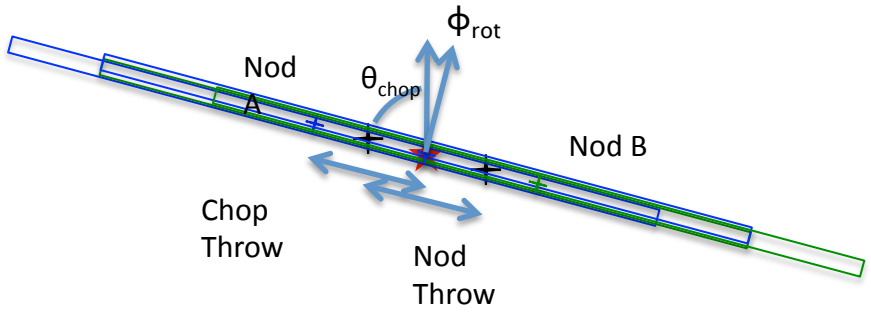
General



Perpendicular

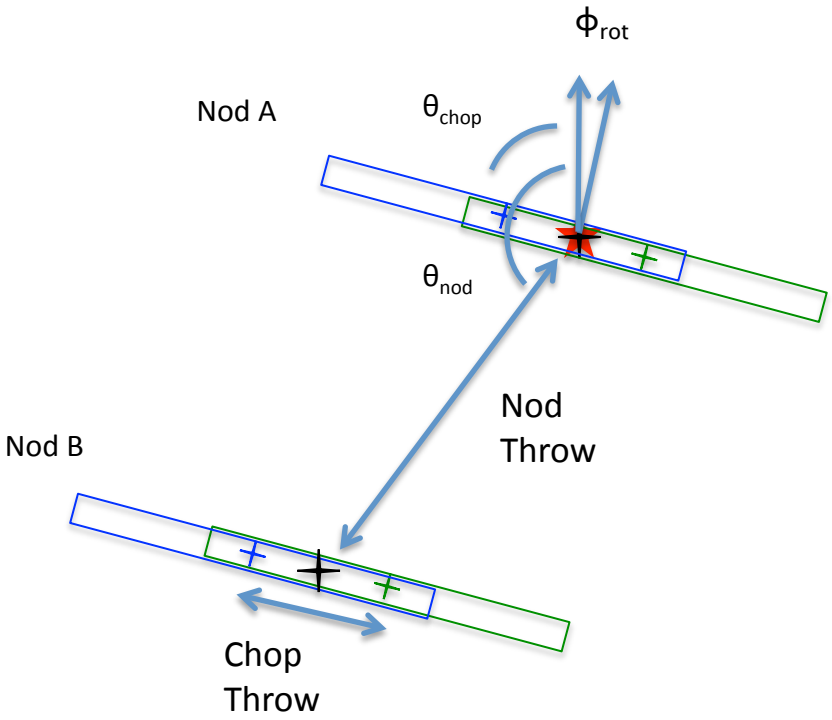


Parallel

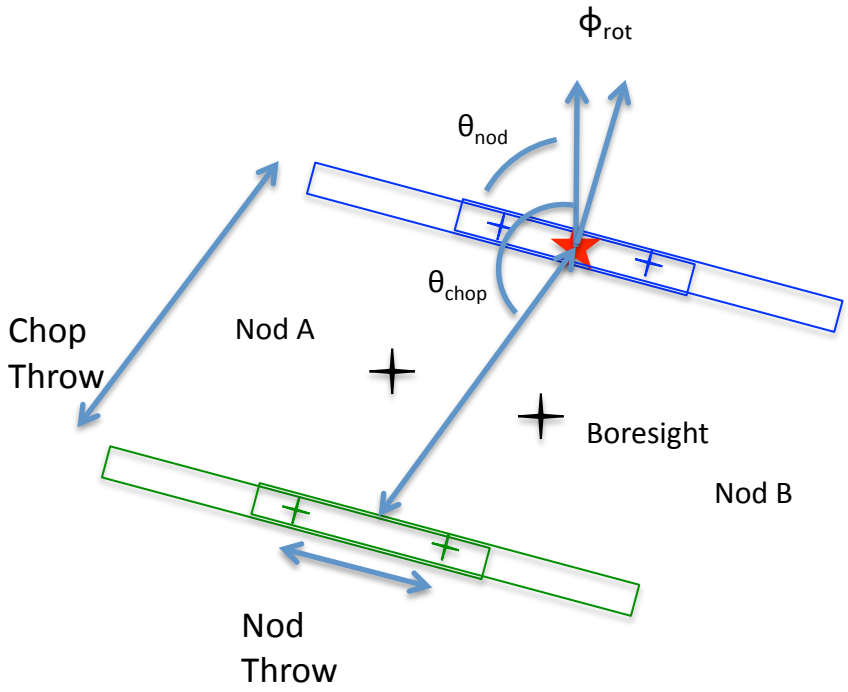


Grism Observing Modes: CAS, NAS

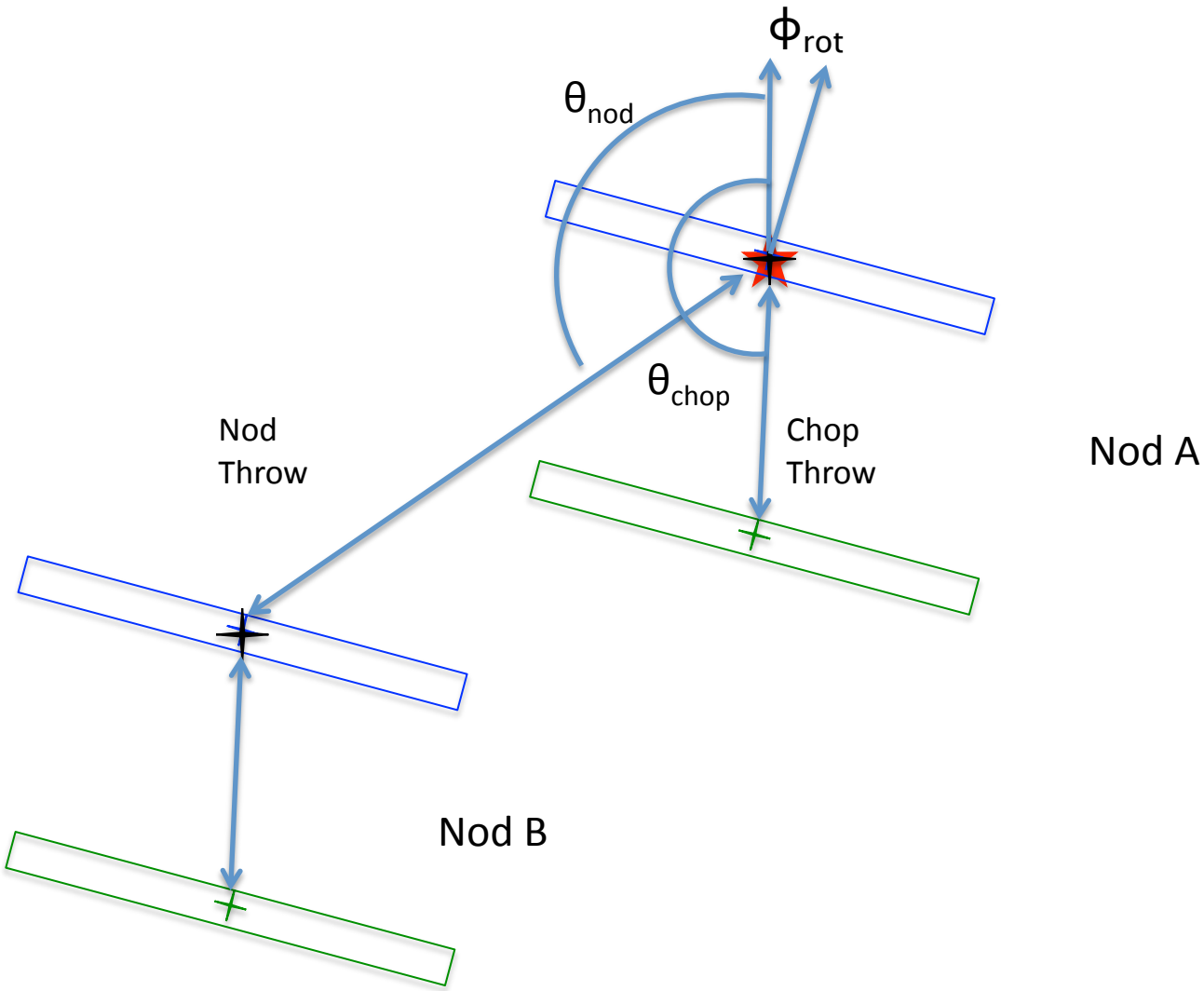
Chop_Along_Slit



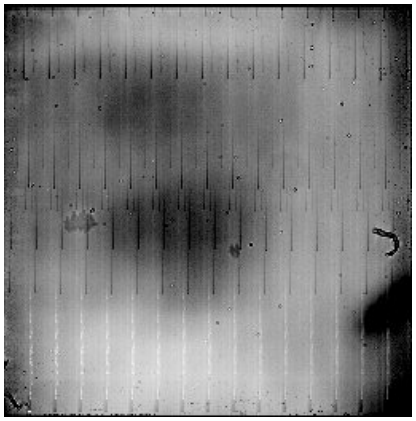
Nod_Along_Slit



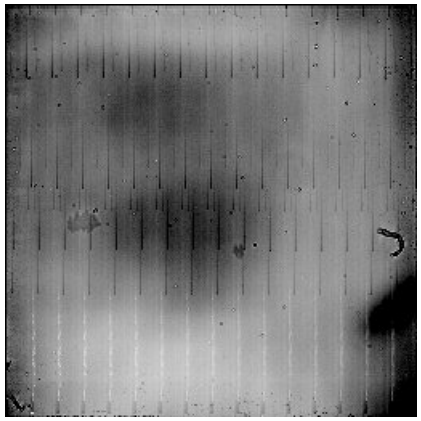
Grism Observing Modes: C2NC2



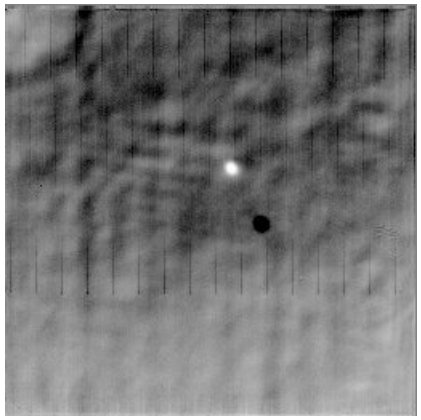
Raw file



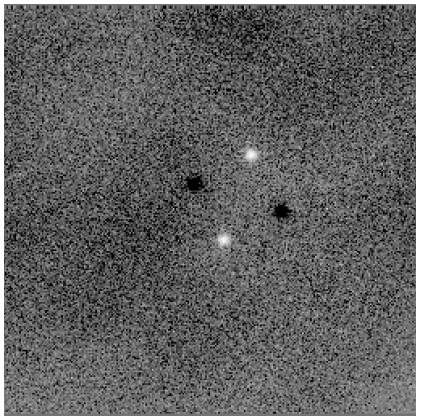
Corrected



Chop subtracted

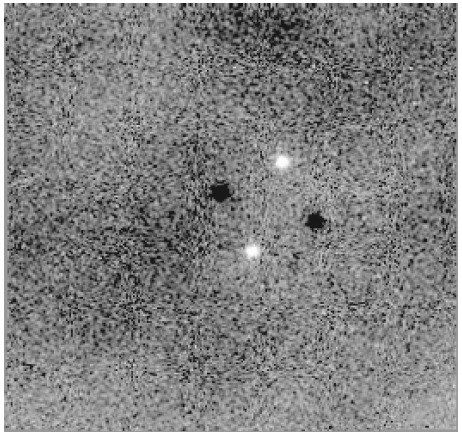


Nod subtracted

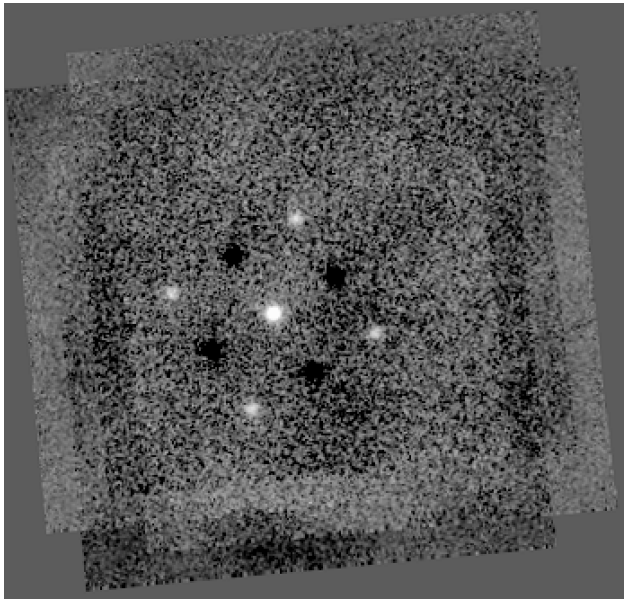


NPC Mode

Undistorted



Merged



Co-added