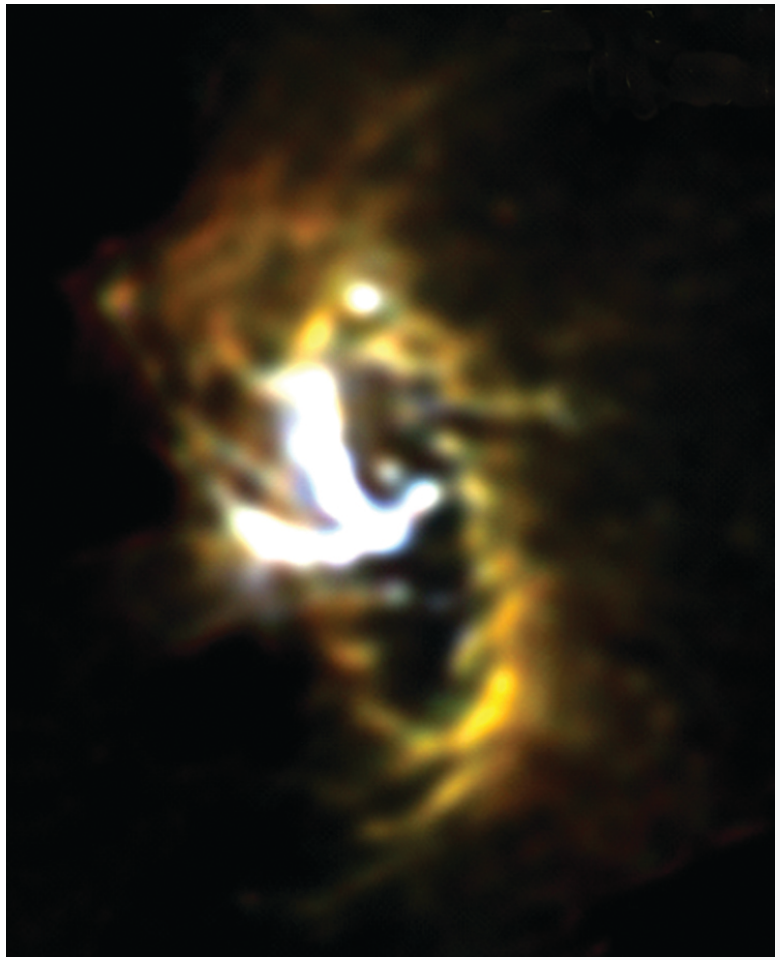
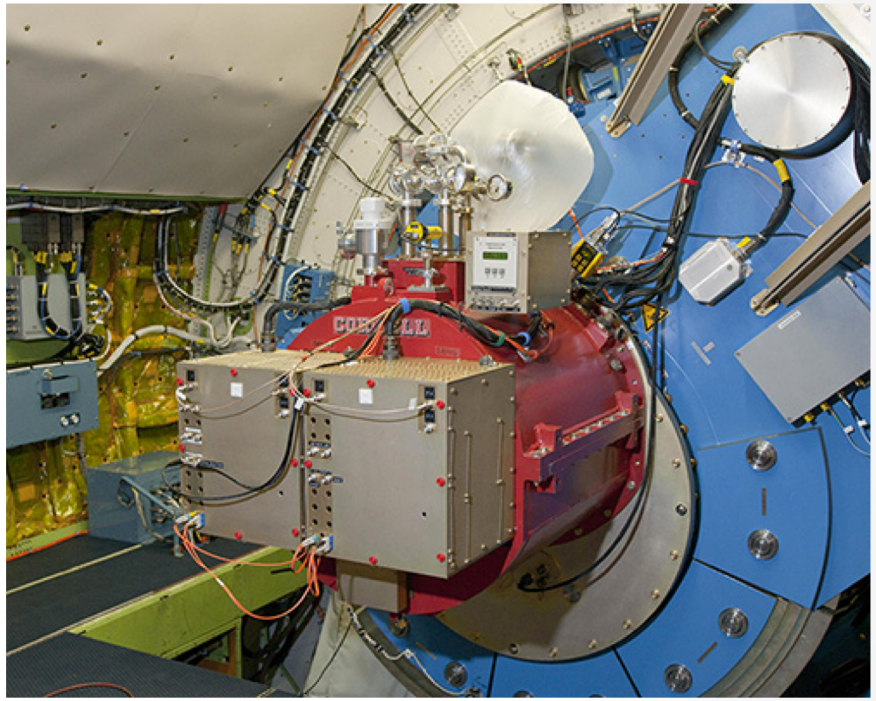
Mid-IR imaging and spectroscopy with FORCAST



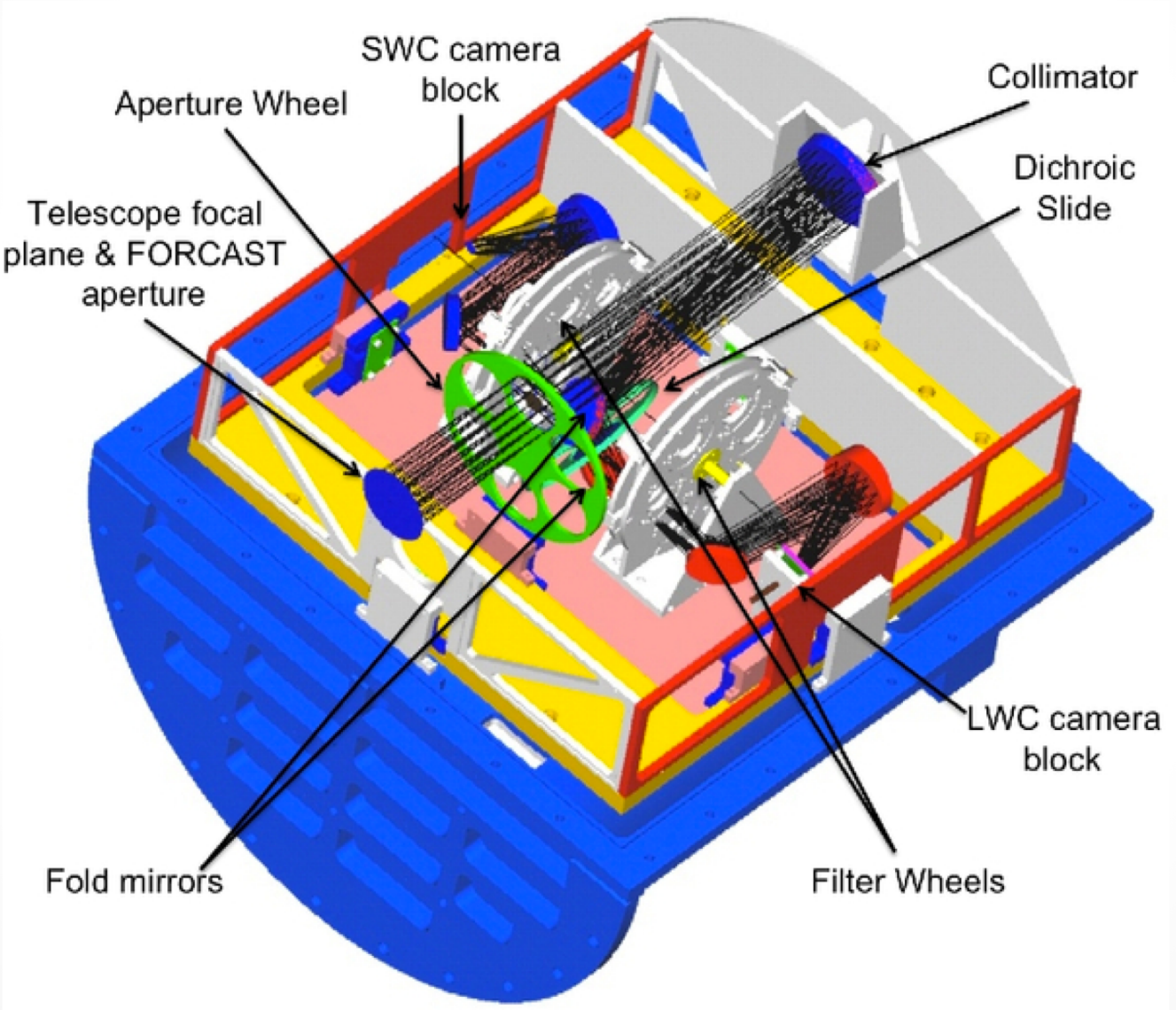
The galactic center with FORCAST
(NASA/DLR/USRA/DSI/FORCAST Team/Lau et al. 2013)

Faint **O**bject infra**R**ed **CA**mera for the **S**OFIA **T**elescope

- 2-channel mid-IR camera and grism spectrometer
- 1st Gen Instrument
- PI T. 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 + 2 long slits provide low resolution (R~70-300) spectroscopy over 5-40 µm



Schematics


SWC camera block
Aperture Wheel
Collimator
Dichroic Slide
Telescope focal plane & FORCAST aperture
LWC camera block
Fold mirrors
Filter Wheels

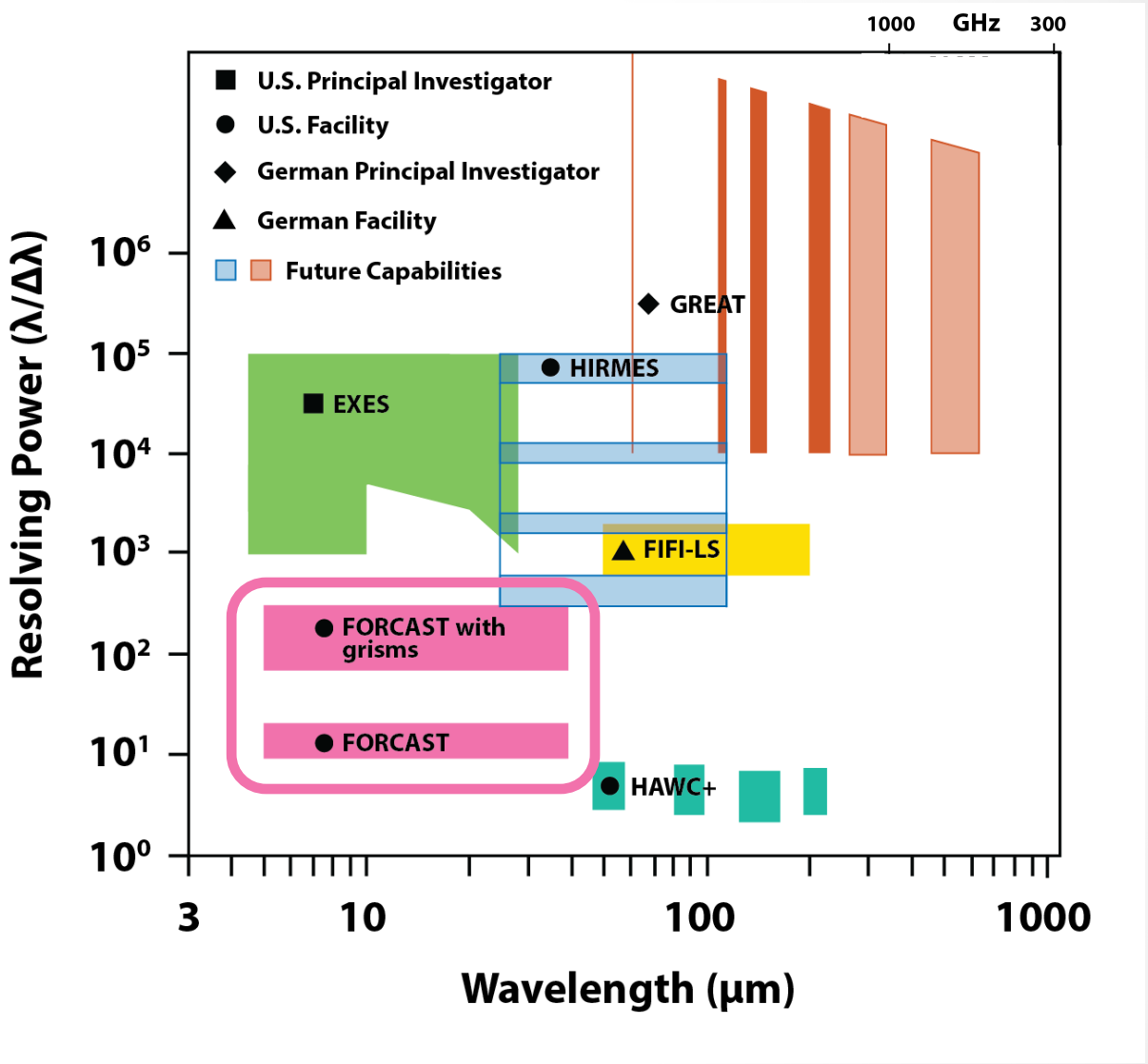
Filters and grisms

Filter Parameters

SWC Filters		LWC Filters	
λ_{eff} (μm)	Δλ (μm)	λ_{eff} (μm)	Δλ (μm)
5.4	0.16	24.2	2.9
5.6	0.08	31.5	5.7
6.4	0.14	33.6	1.9
6.6	0.24	34.8	3.8
7.7	0.47	37.1	3.3
8.8	0.41	A subset of these will be chosen each cycle as the nominal set.	
11.1	0.95		
11.2	2.7		
11.3	0.24		
11.8	0.74		
19.7	5.5		
25.4	1.86		

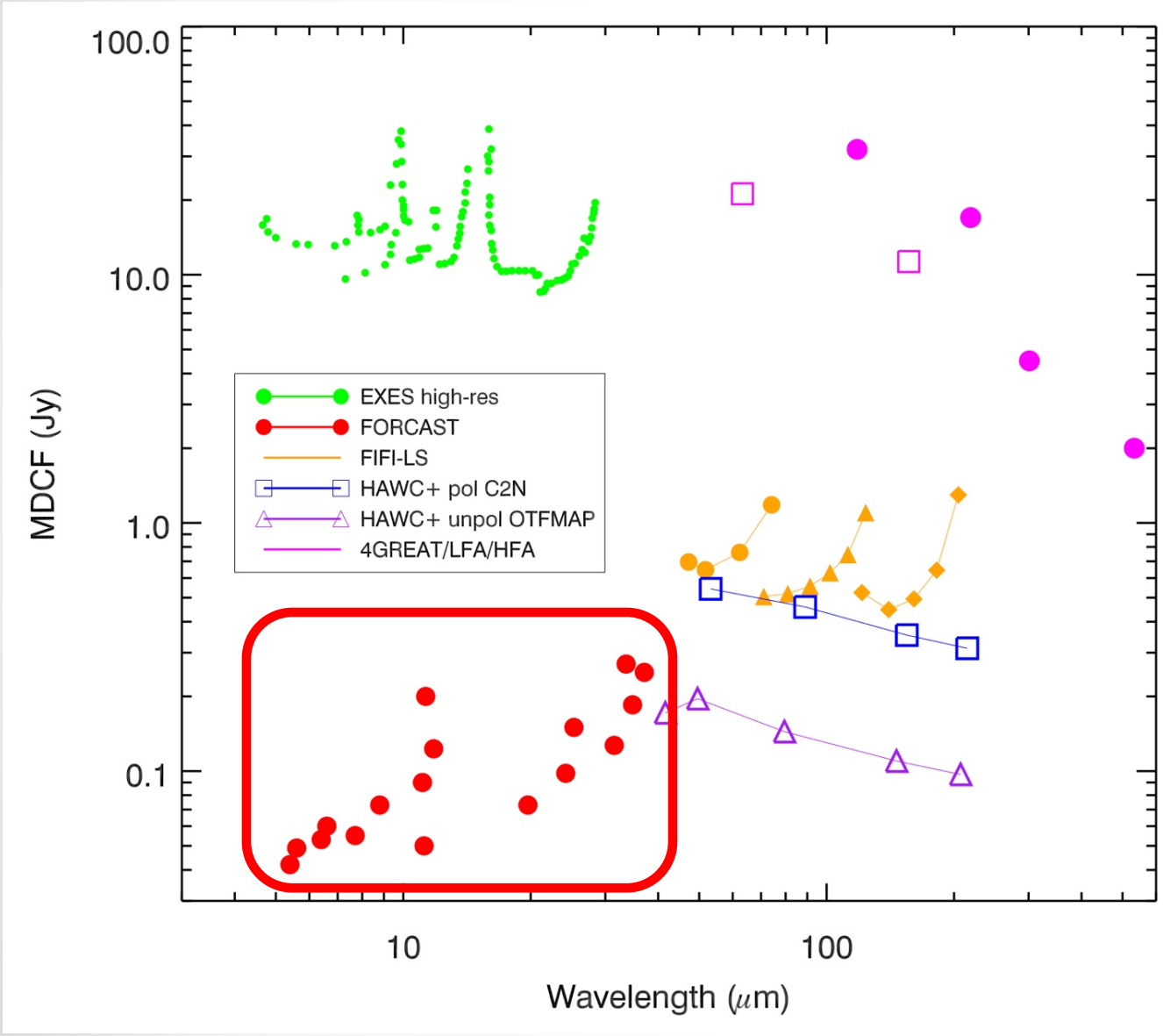
Grism Details

Grism	Coverage (μm)	R (λ/Δλ)[a]
G063	4.9–8.0	120[c]/180
G111	8.4–13.7	130[c]/260
G227	17.6–27.7	110/120
G329	28.7–37.1	160/170[b]



2018 Community Days Workshops

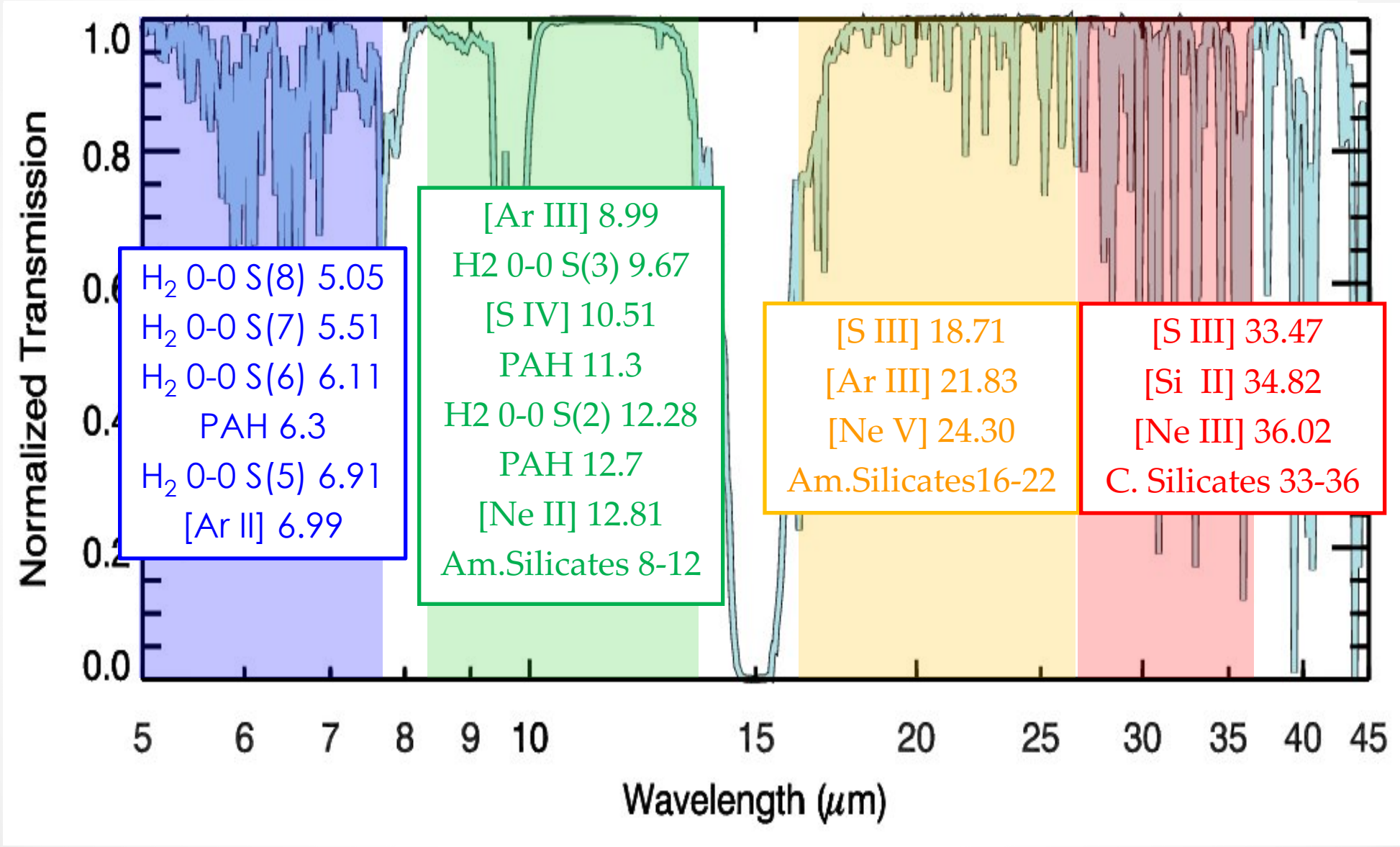
Range and continuum sensitivity



4-σ MDCF for point sources (Jy) for 900 s of integration time.

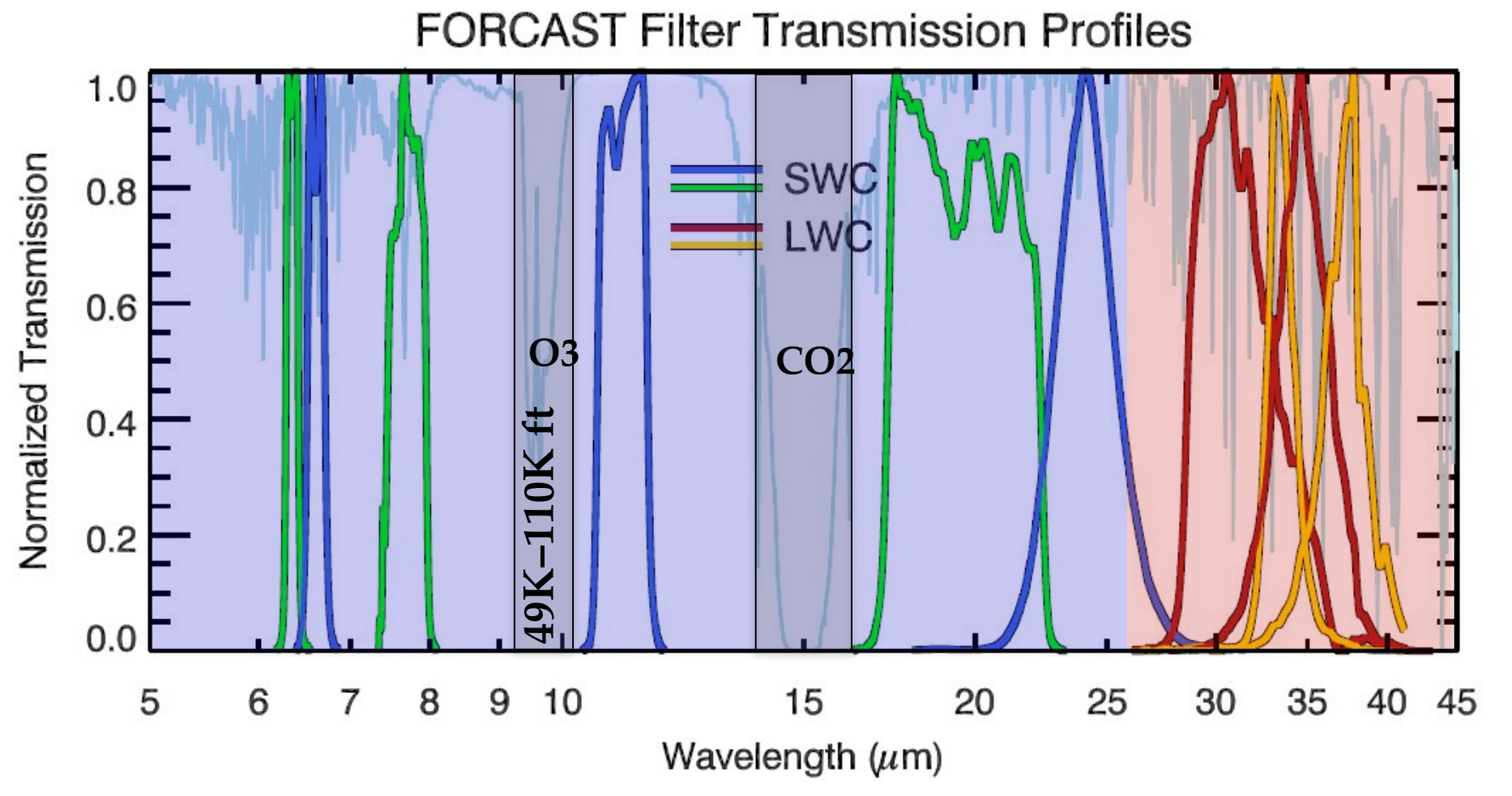
"Review: Far-Infrared Instrumentation and Technology Development for the Next Decade"
Farrah, D. et al, 2017, JAI

Spectral features of interest



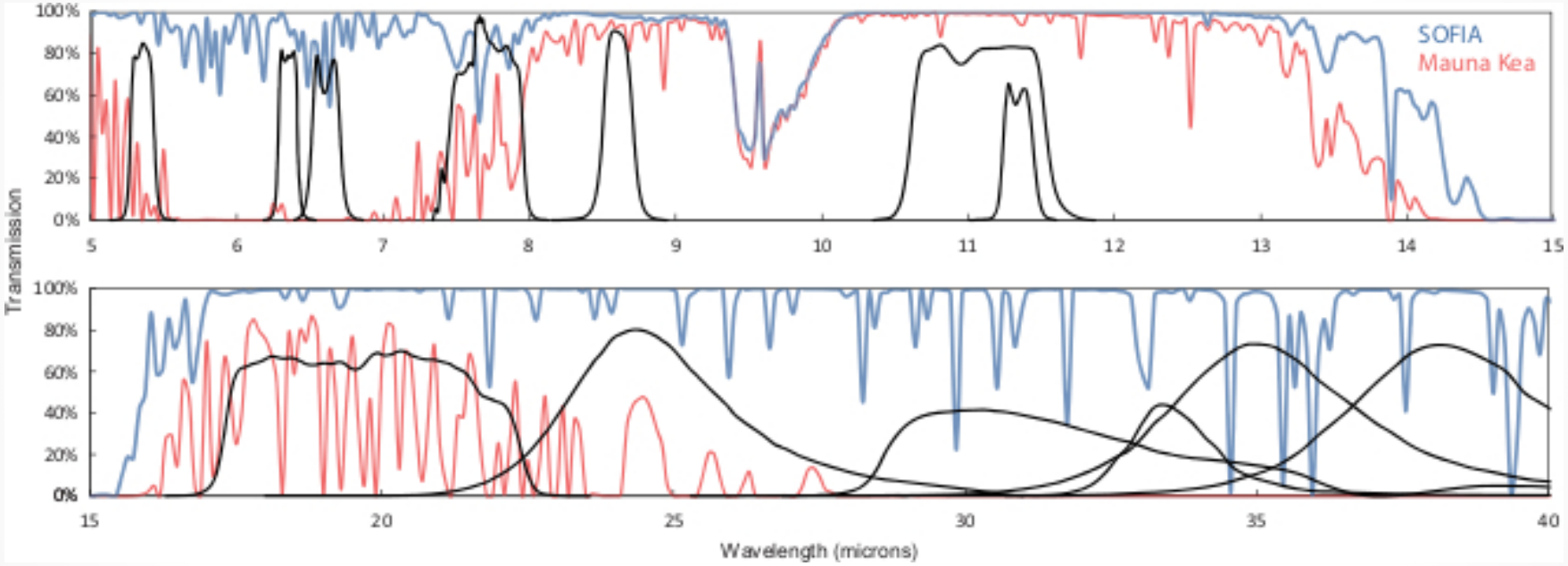
SOFIA
2018 Community Days Workshops
NASA
USRA
DLR
DSI

Filters



The dichroic is designed to transmit light at wavelengths greater than 25 µm, and reflect light less than 25 µm.

FORCAST Filter Profiles



SOFIA : 41000 ft, 7.3 µm PWV, 45° ZA

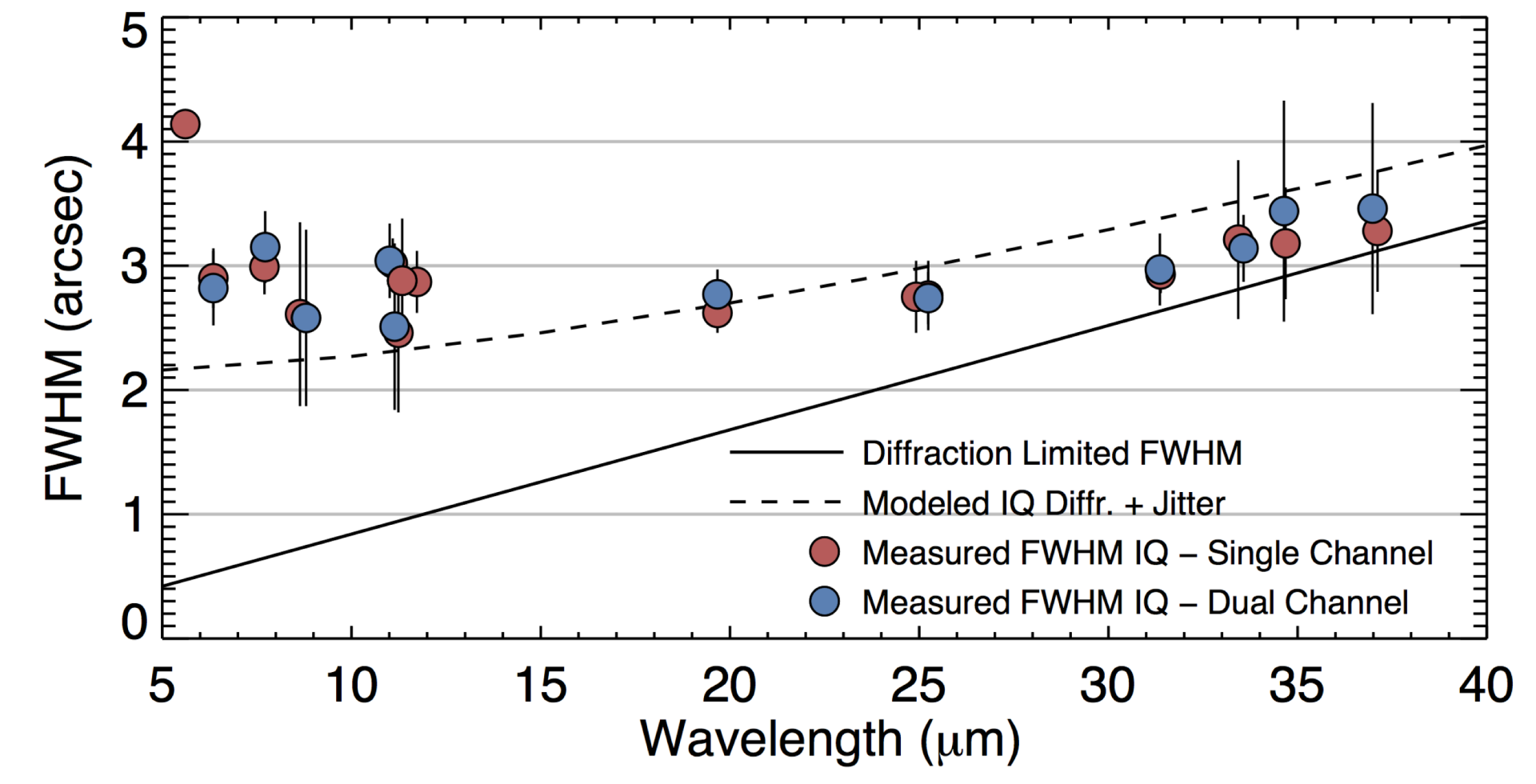
Mauna Kea: 13800 ft, 3.4 mm PWV, 45° ZA

Filters and dichroic

Channel	λ_{eff} (μm)	$\Delta\lambda$ (μm)	
SWC	6.4	0.14	
	6.6	0.24	~60%
	7.7	0.47	
	11.1	0.95	
	19.7	5.5	~85%
	24.2	2.9	
LWC	31.5	5.7	
	33.6	1.9	~40%
	34.8	3.8	
	37.1	3.3	

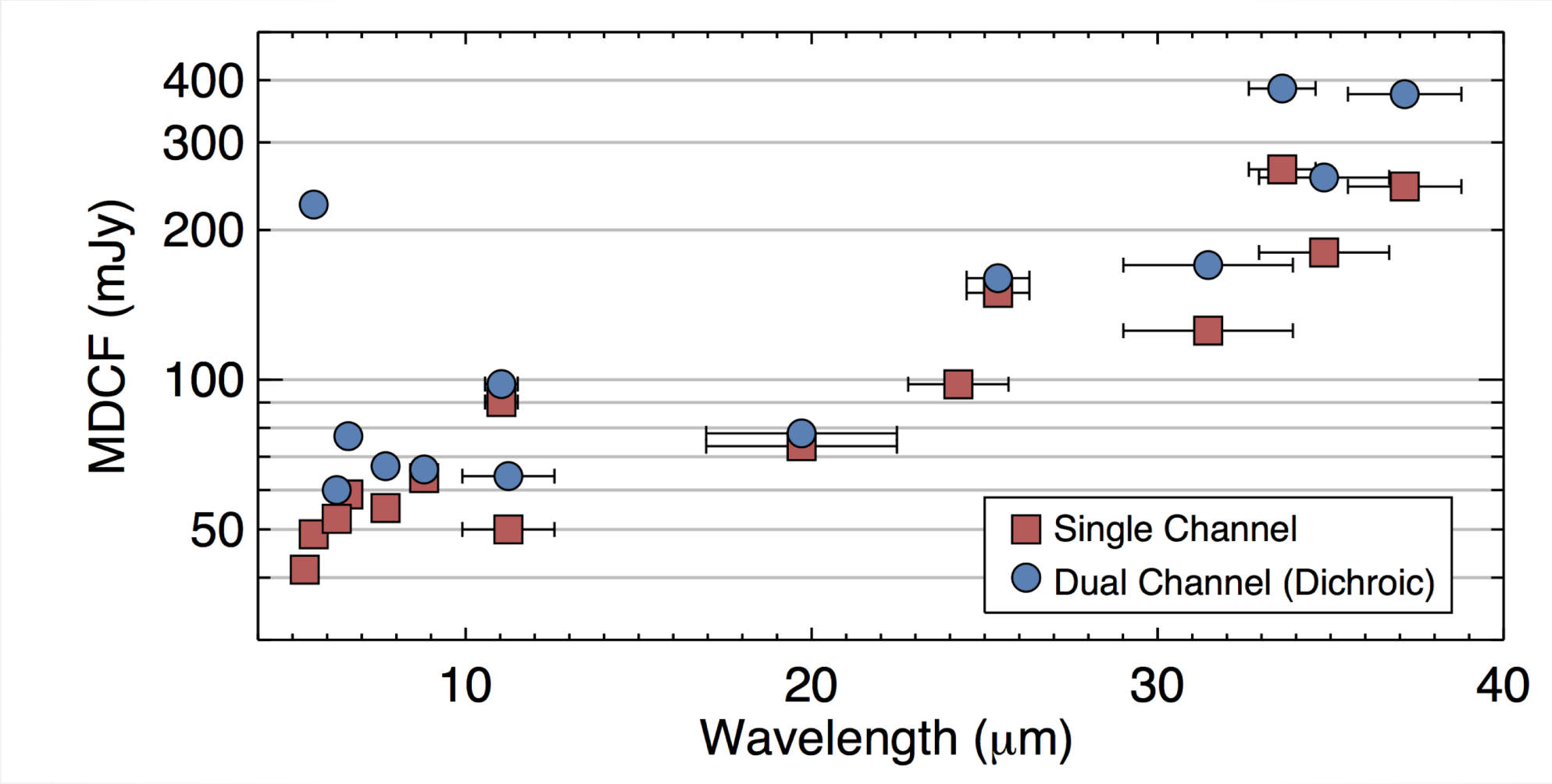
- Dual channel mode allows simultaneous imaging at two wavelengths
- ***However, there is decreased throughput compared to single channel mode***

FORCAST Imaging Resolution



For comparison, Spitzer resolution of ~ 6'' @ 24μm

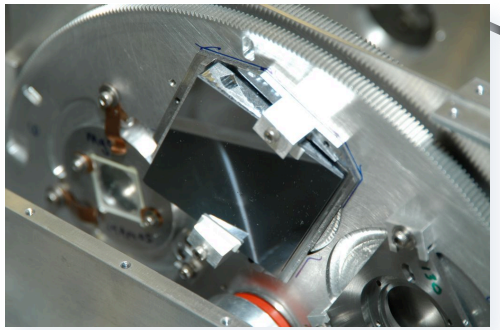
Imaging Sensitivity

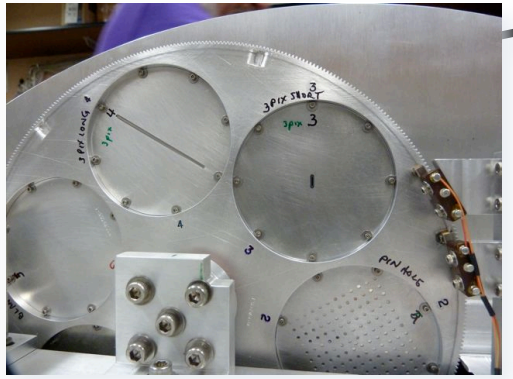


- S/N=4 in 900s, 41000 feet, single channel mode; larger limiting fluxes with dichroic
- Altitude/water vapor affect sensitivity more in the LWC
- In preparing your FORCAST observations, you can use SITE, the online integration time estimator

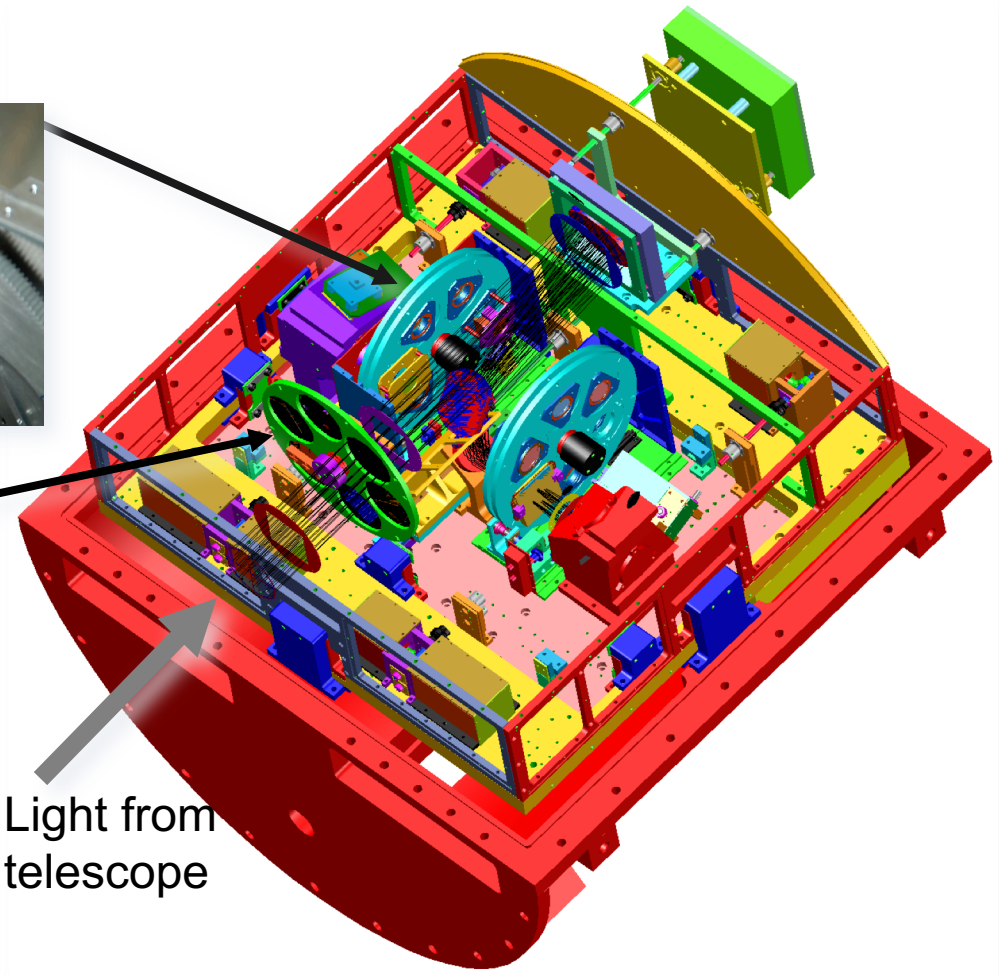
FORCAST grism design overview: layout

Grisms in existing imaging filter wheels



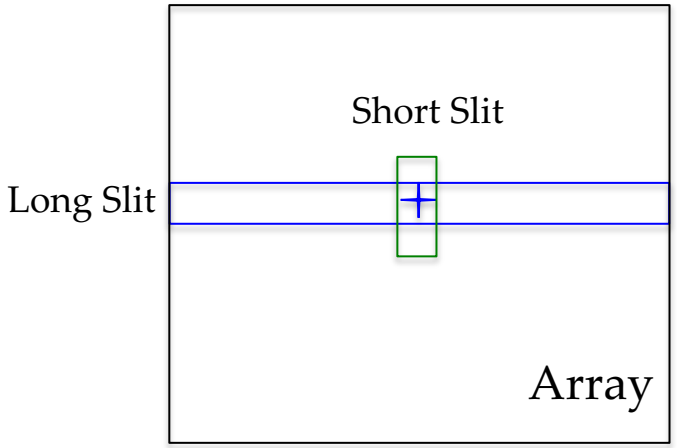


Slits in existing aperture wheel

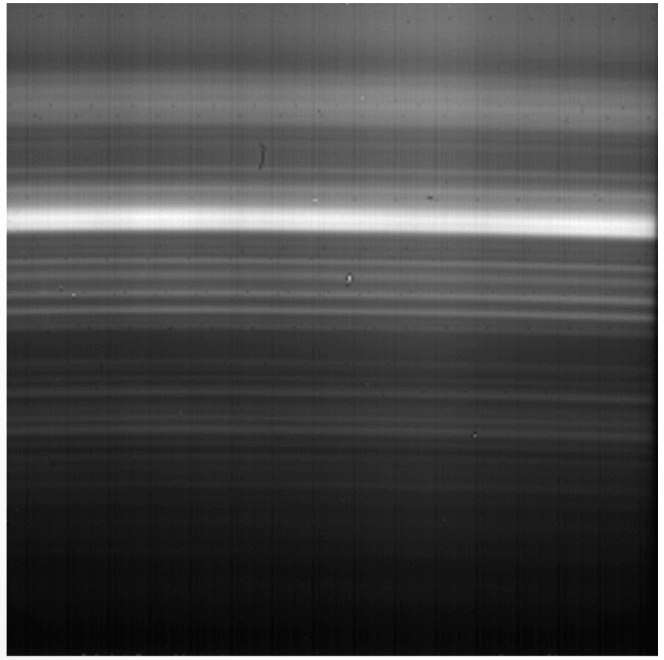


Light from telescope

Grism spectral formats

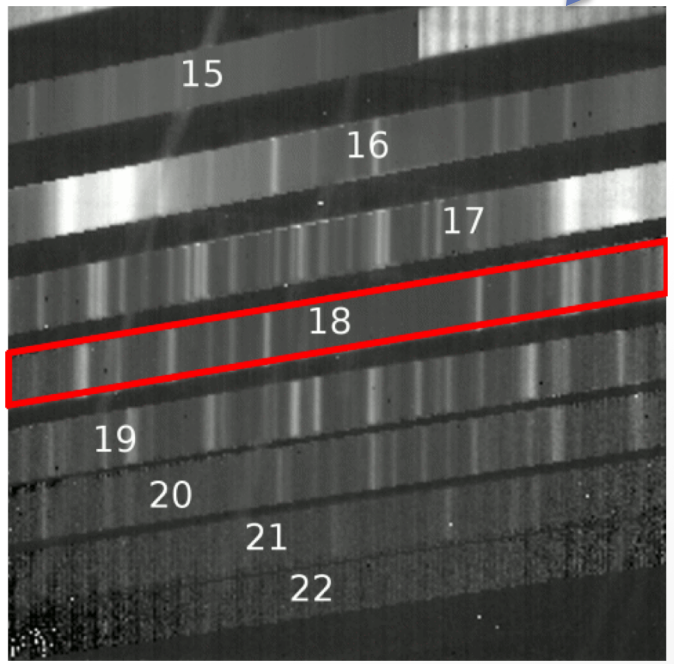


Long slit modes

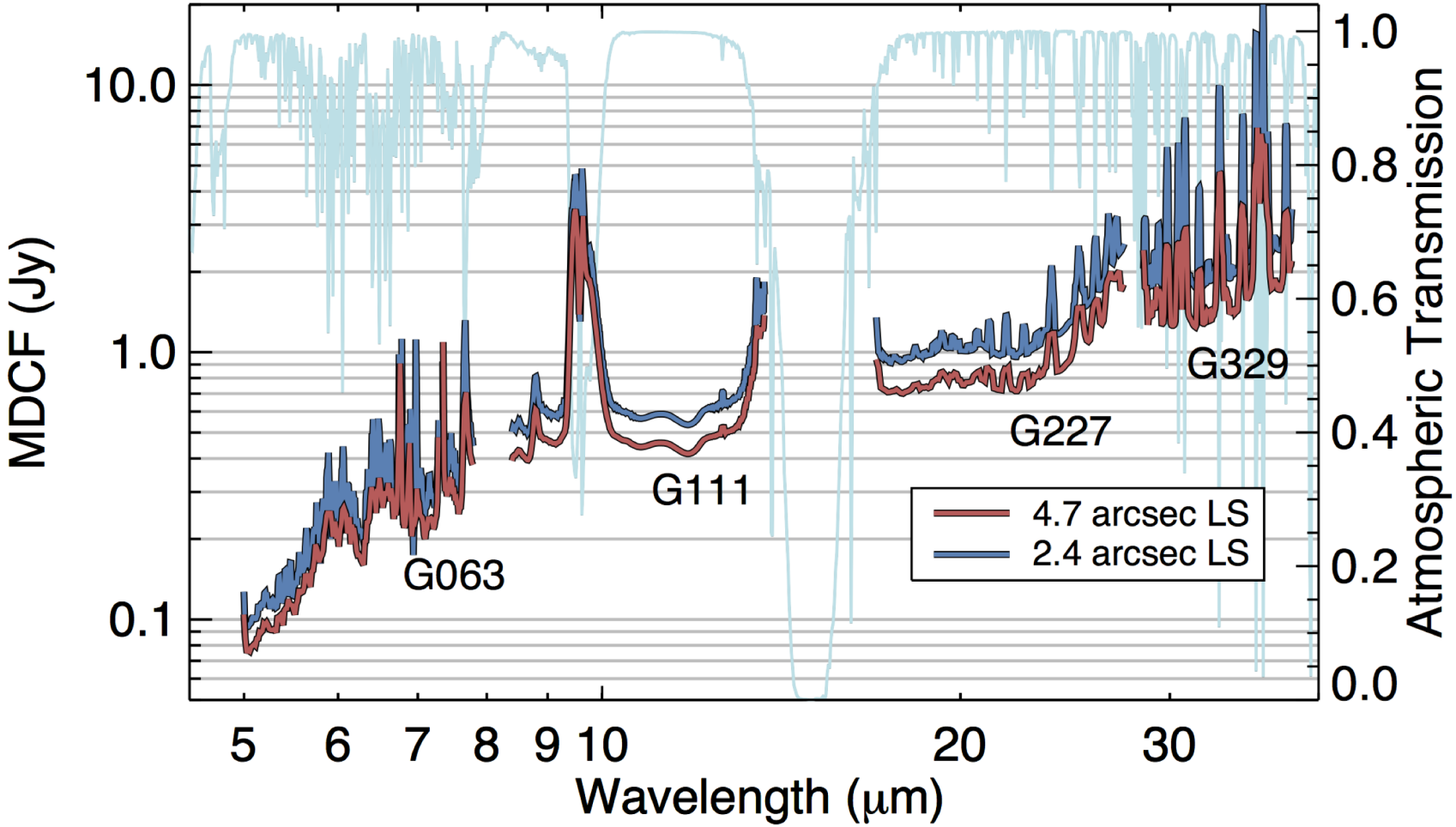


Short slit (XD) modes

interference fringes



Spectroscopic Sensitivity

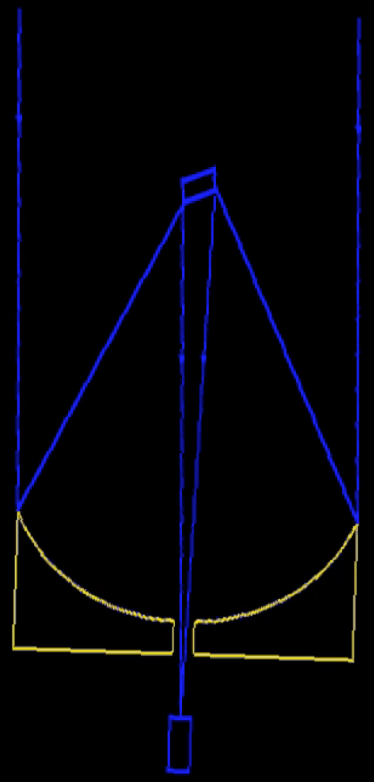


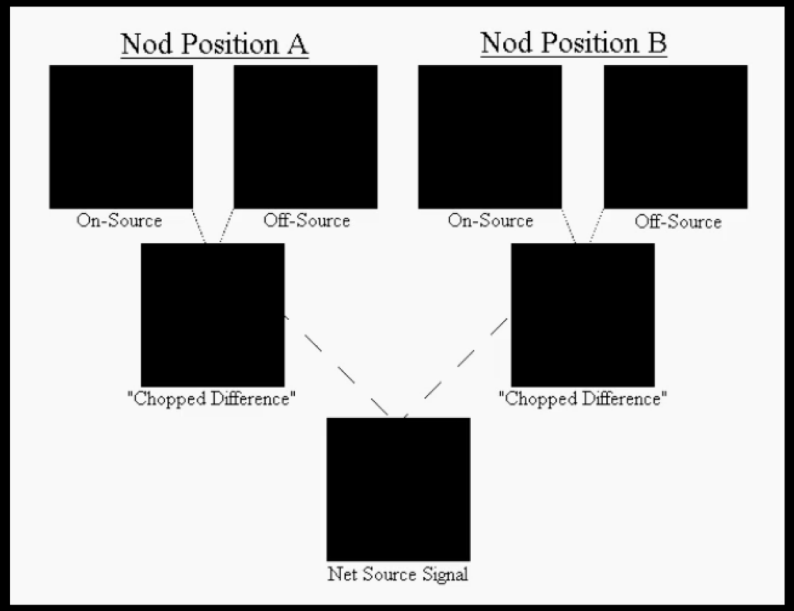
- S/N=4 in 900s, 41000 feet, single channel mode ***only***
- Altitude/water vapor affect sensitivity more in the LWC
- In preparing your FORCAST observations, you can use SITE, the online integration time estimator

Chop/Nod Technique

- MIR observations are completely background (sky+telescope+instrument) limited
  - Background can be >10^6 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 ~30 sec,
- 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

Chopping & Nodding





Chop Nod Animation

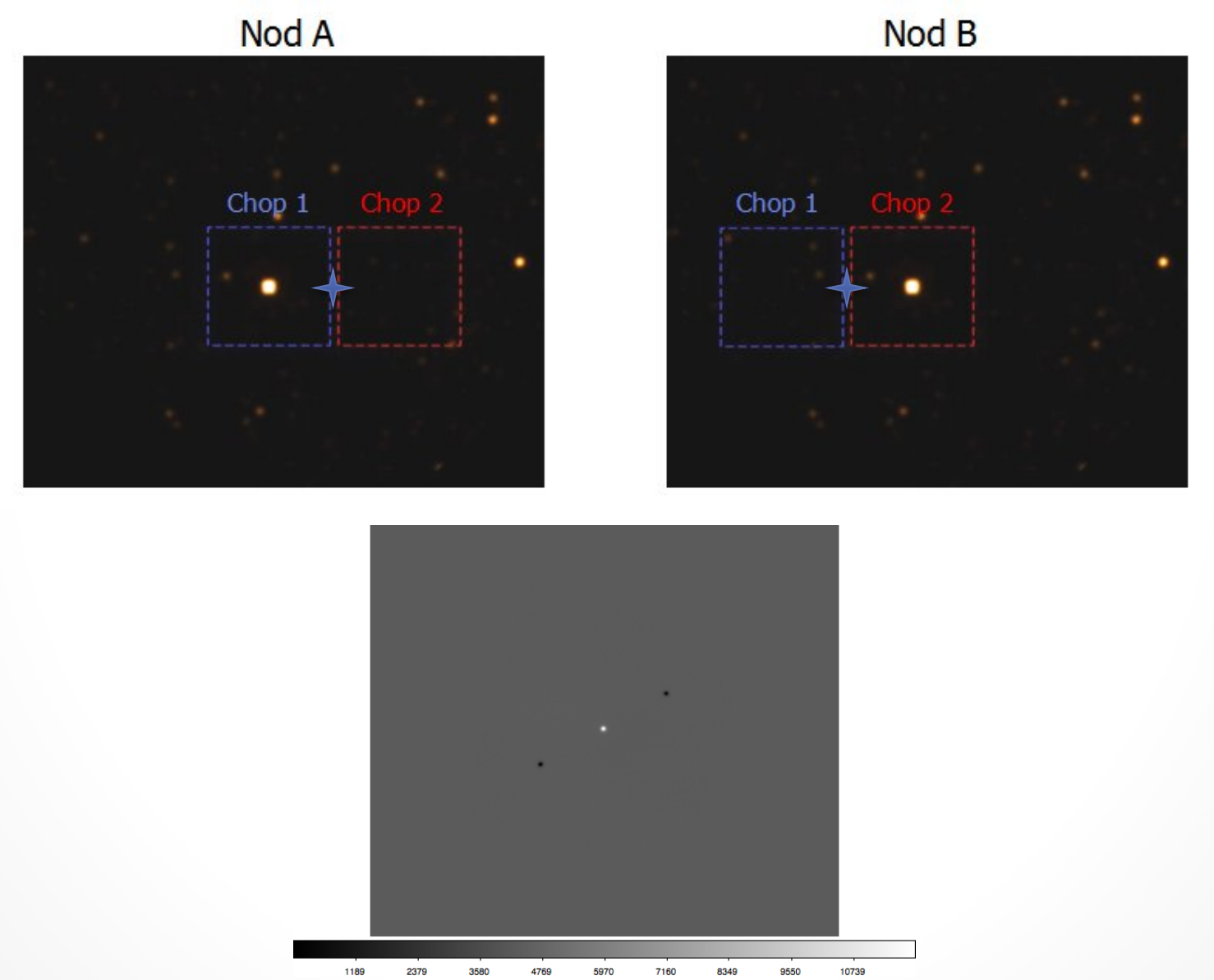
Nod Position A

Plus Beam

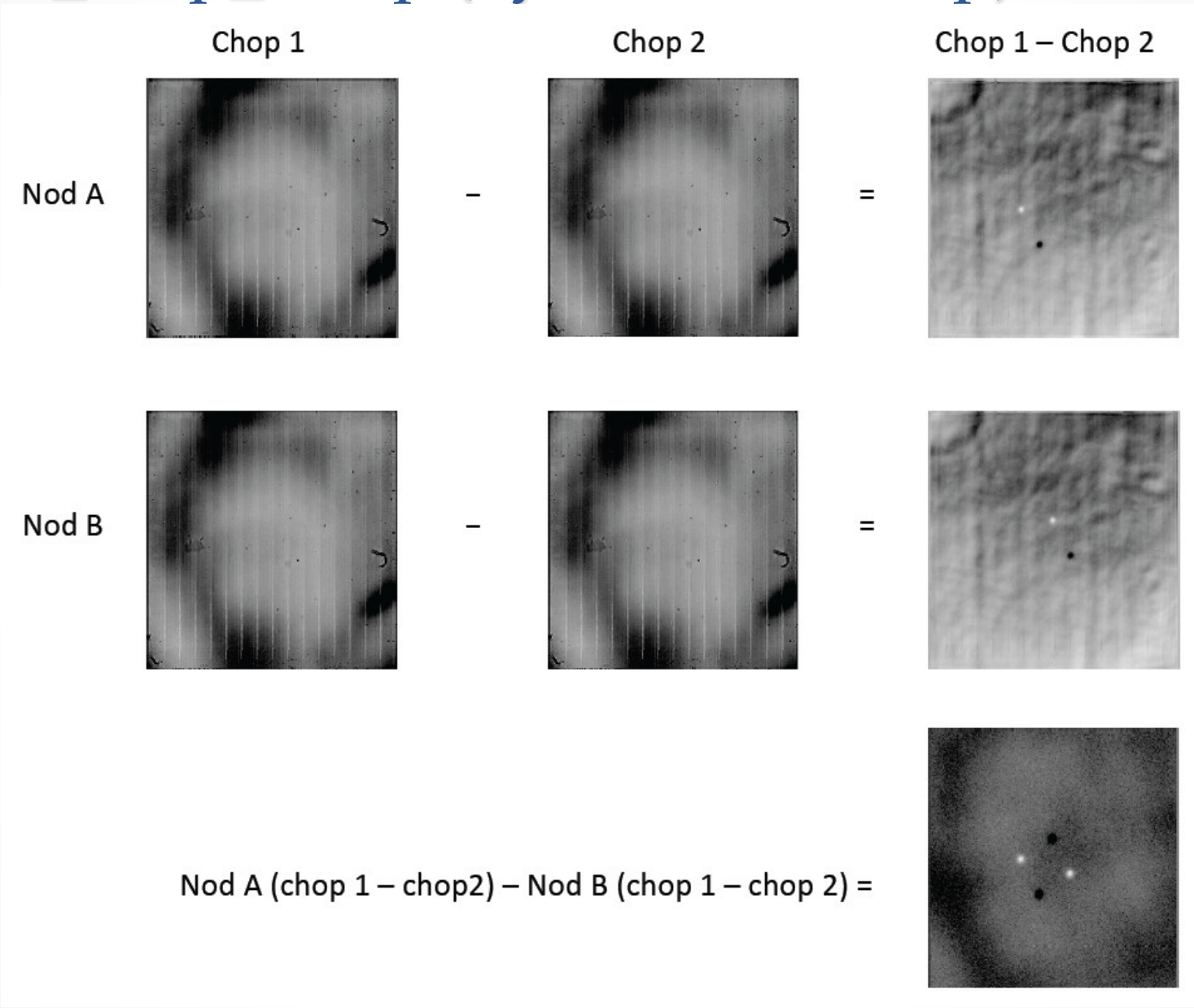
Source+Sky+Tel$_+$

-(Sky+Tel$_-$)

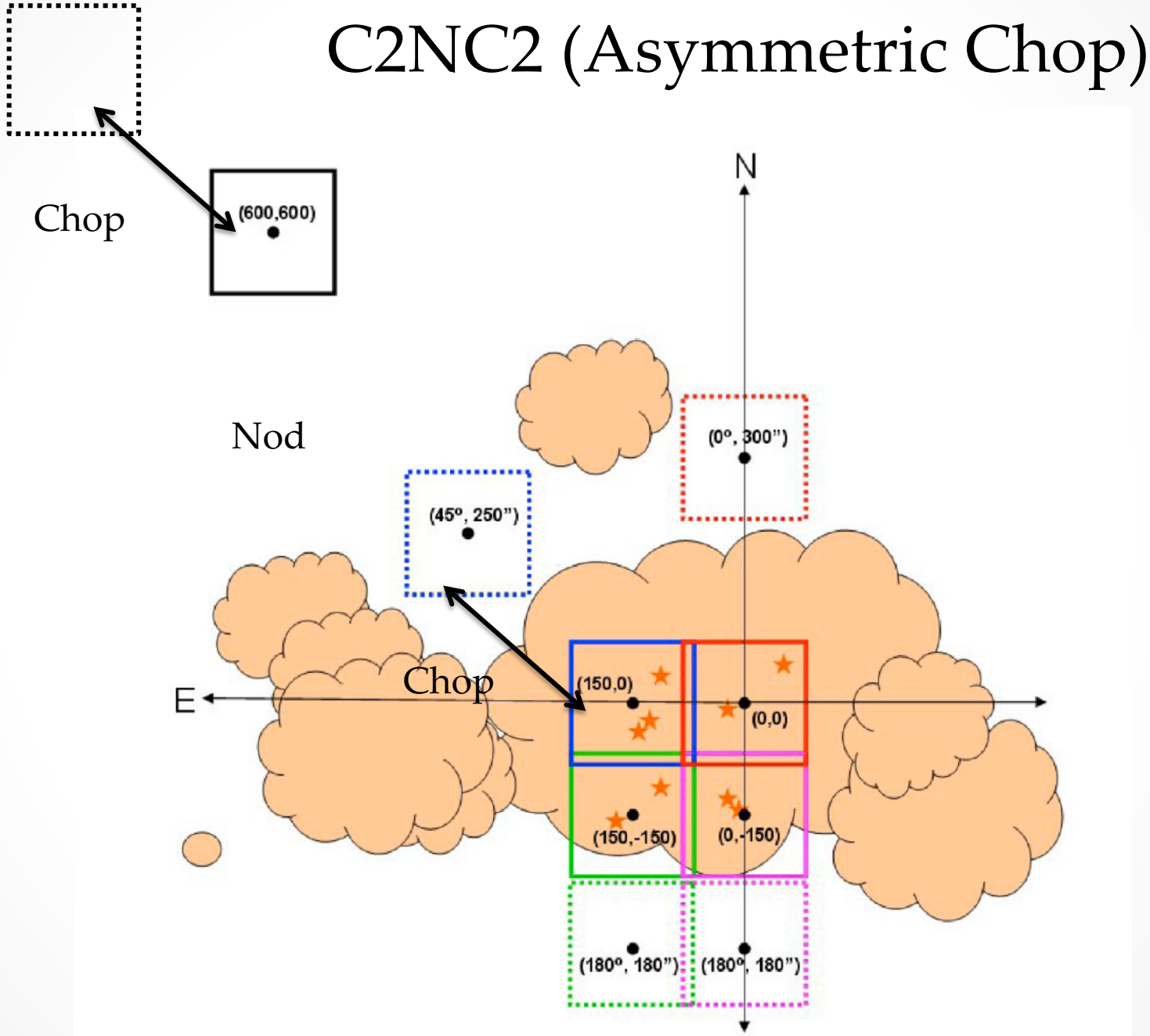
Nod_Match_Chop (Symmetric Chop) Mode:



Nod_Perp_Chop (Symmetric Chop) Mode:

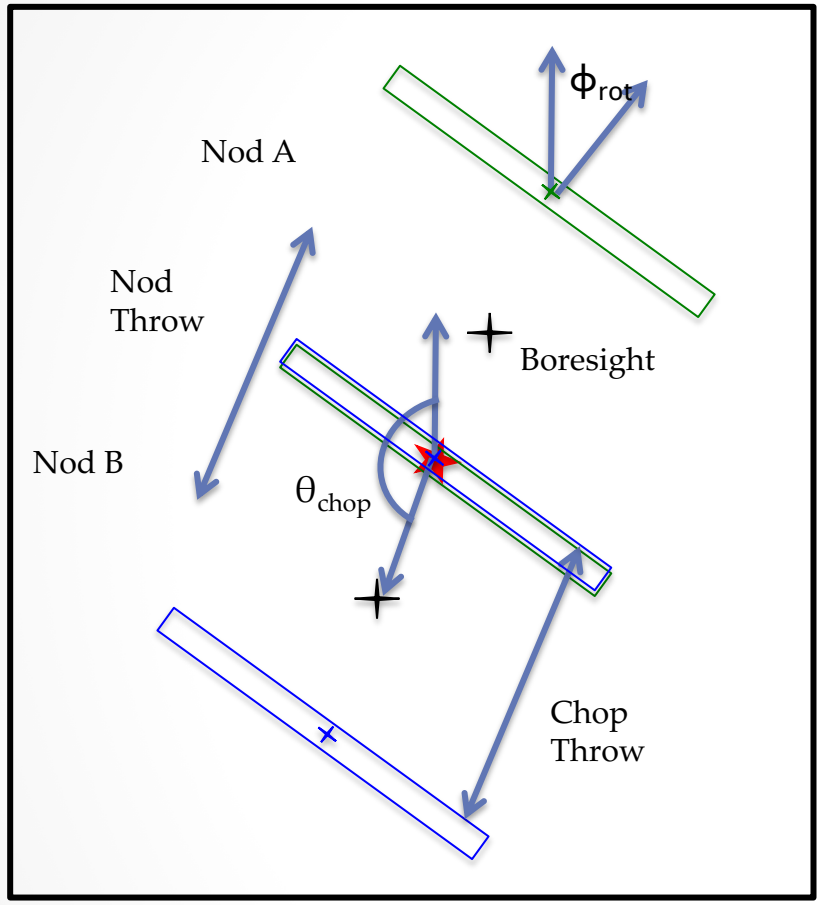


C2NC2 (Asymmetric Chop) Mode:

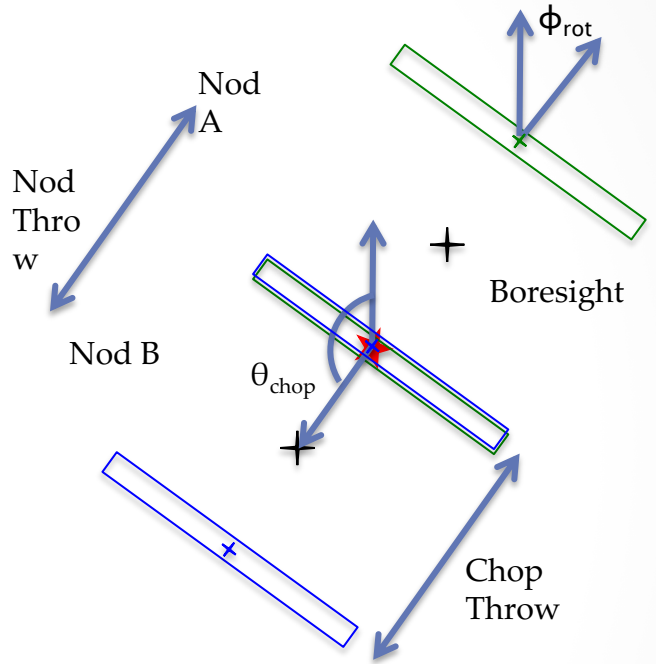


Grism Observing Modes: NMC

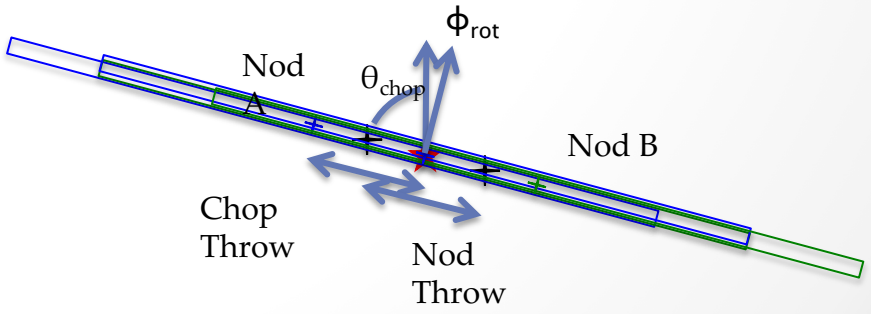
General



Perpendicular

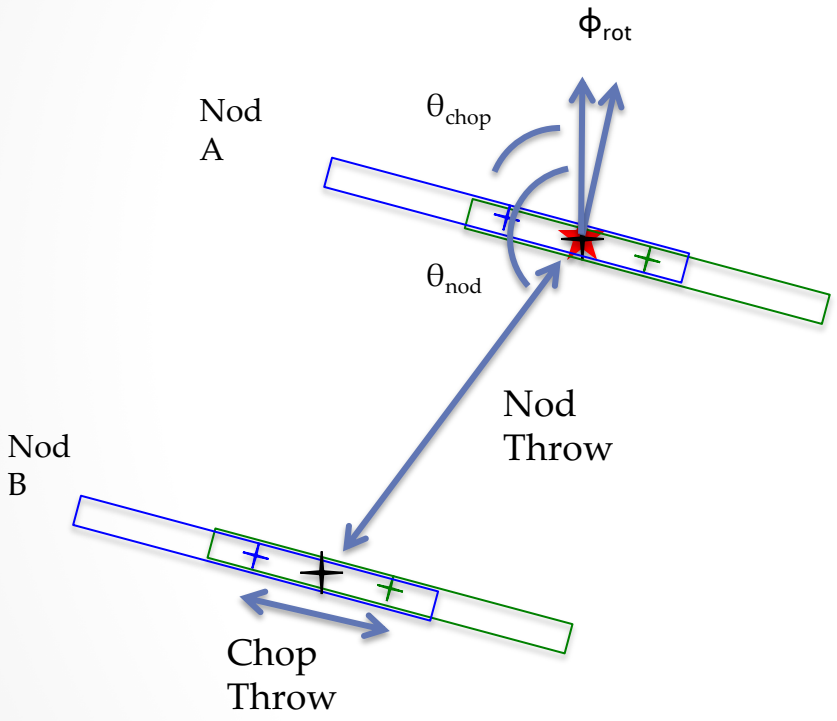


Parallel

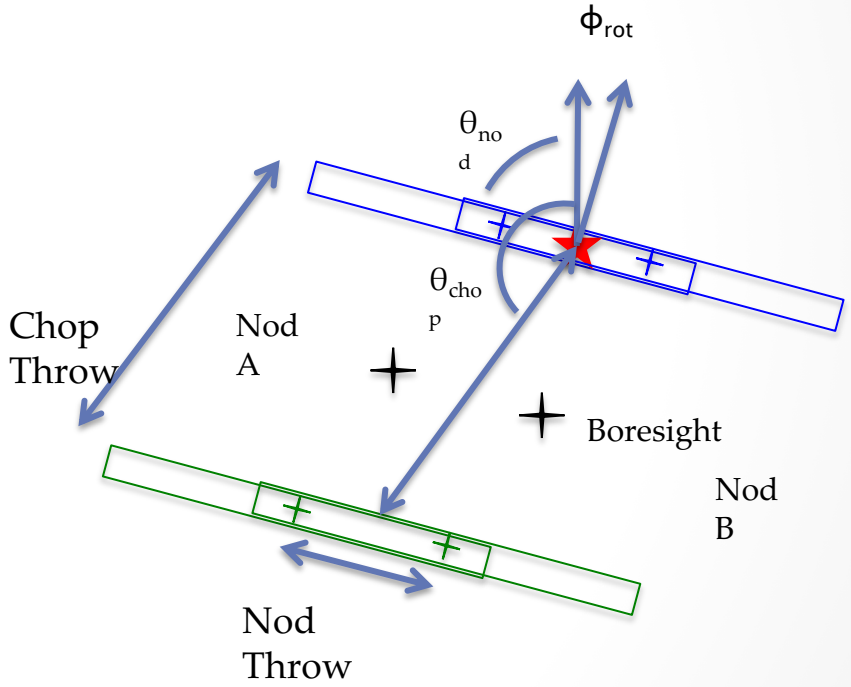


Grism Observing Modes: CAS, NAS

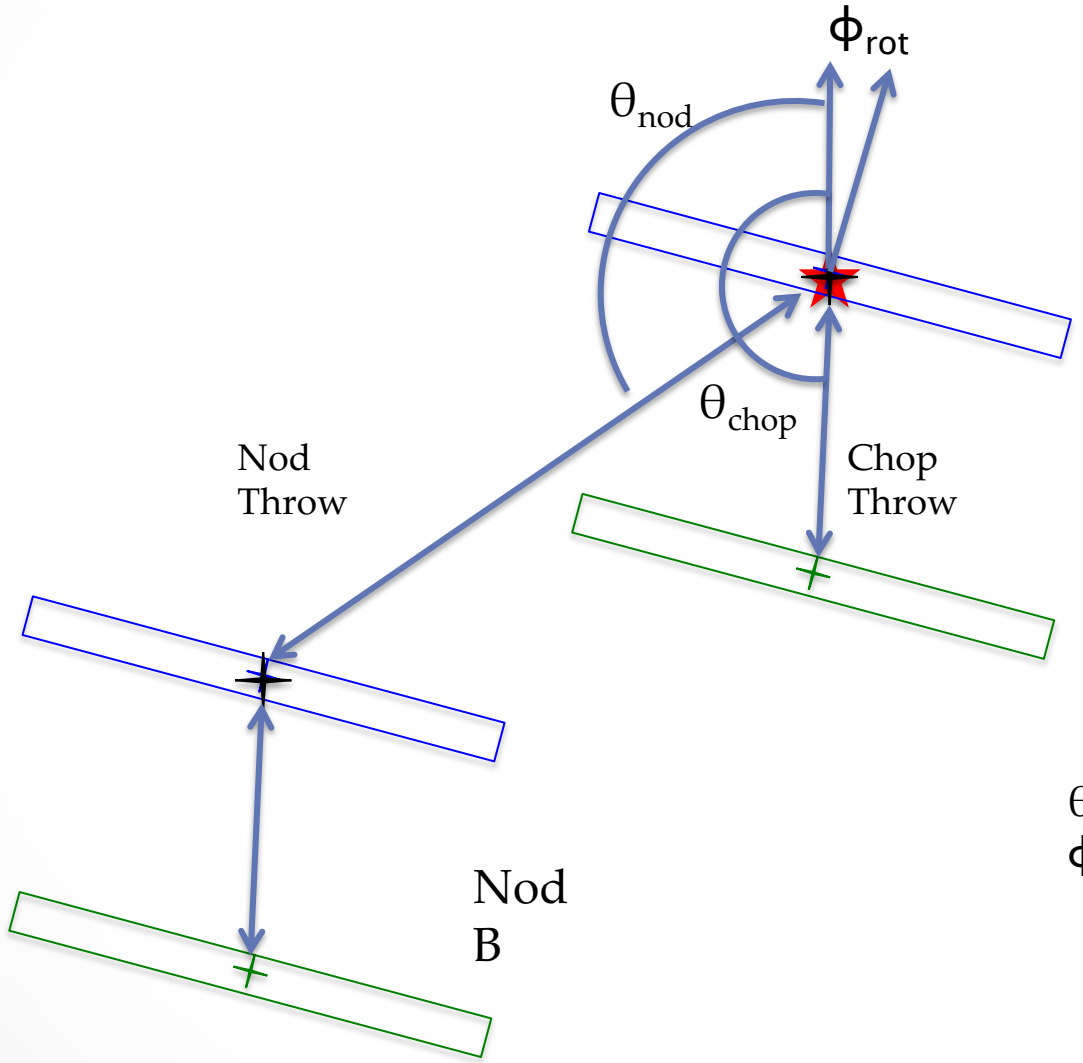
Chop_Along_Slit



Nod_Along_Slit

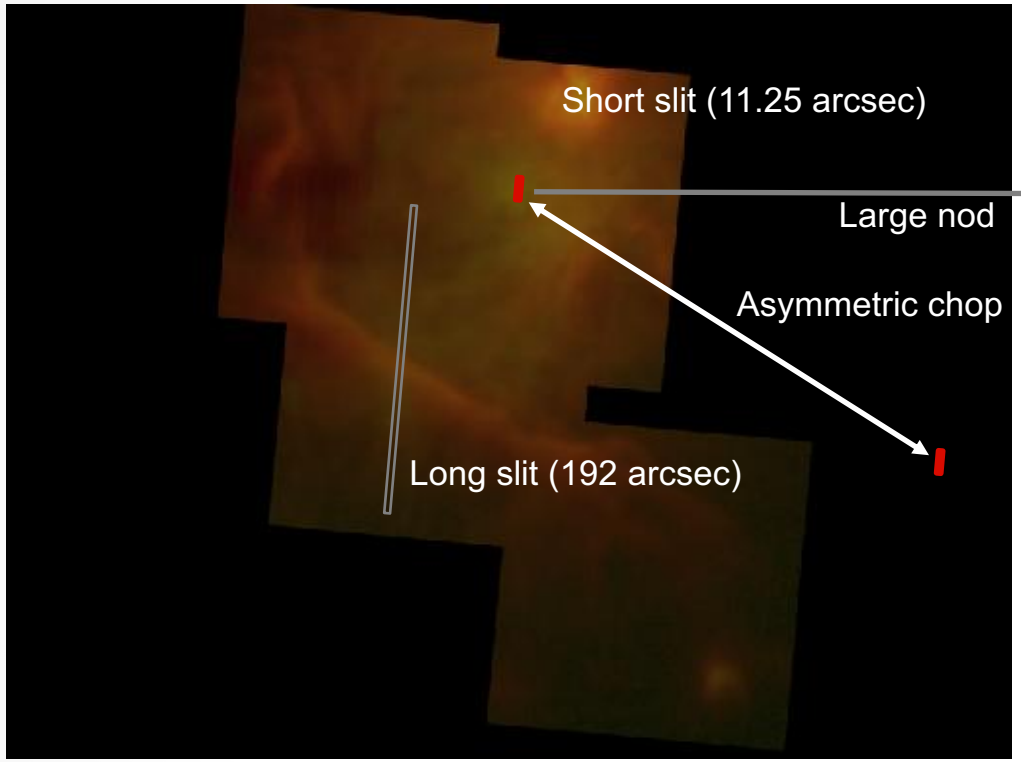


Grism Observing Modes: C2NC2

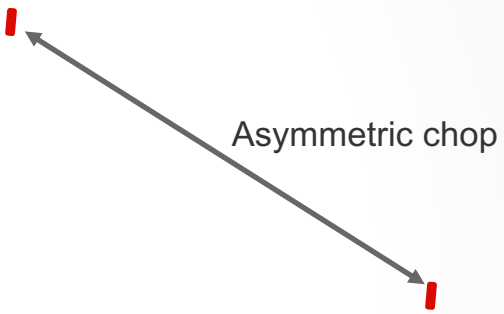


$\theta_{dither} = 90 + \Phi_{rot}$

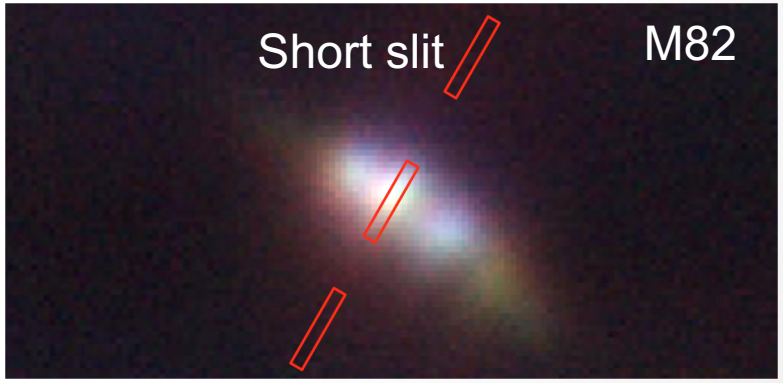
Pointed observations & mapping in extended sources



Large HII region example C2NC2 mode

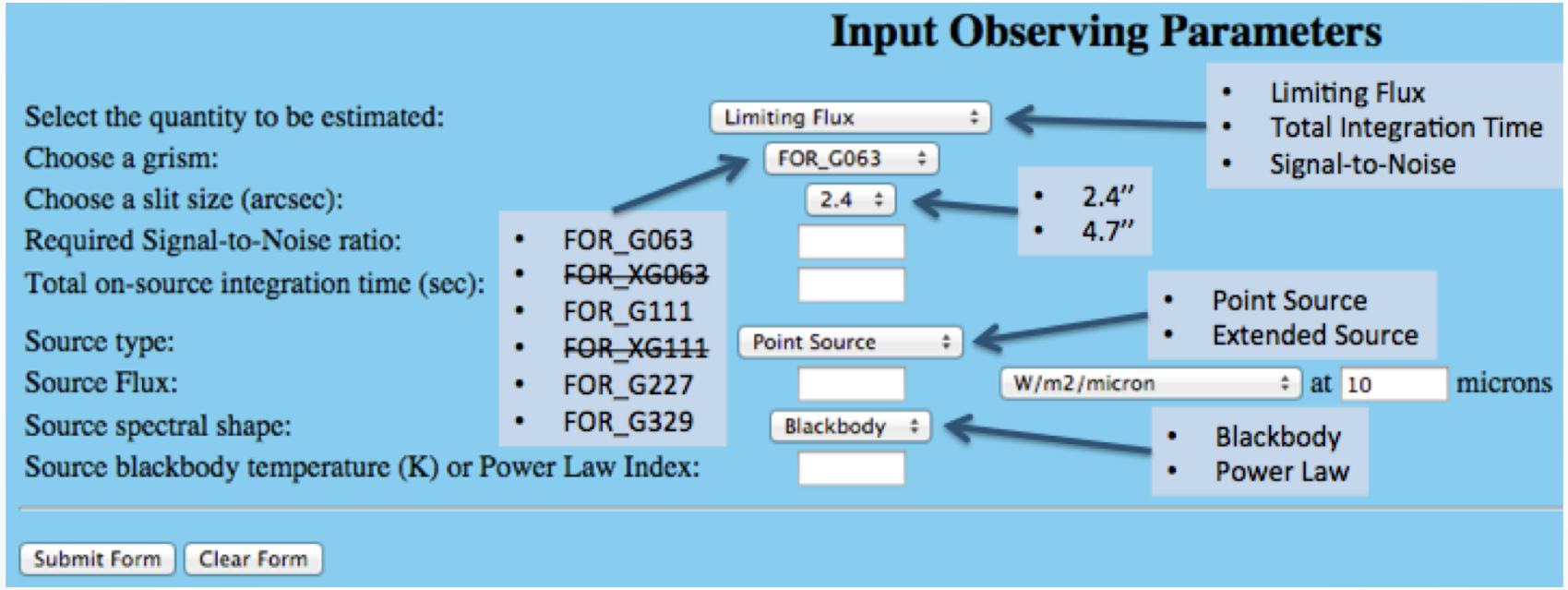


Galaxy example NMC



FORCAST Exposure Time Calculator

FORCAST ETC found on the DCS web pages:
Imaging: *https://dcs.sofia.usra.edu/proposalDevelopment/SITE/index.jsp*
Grisms: *https://forcast.sofia.usra.edu/cgi-bin/forcast/forcast_grisms_calc.cgi*



FORCAST Exposure Time Calculator

FORCAST Grism Calculator Output

Input Parameters

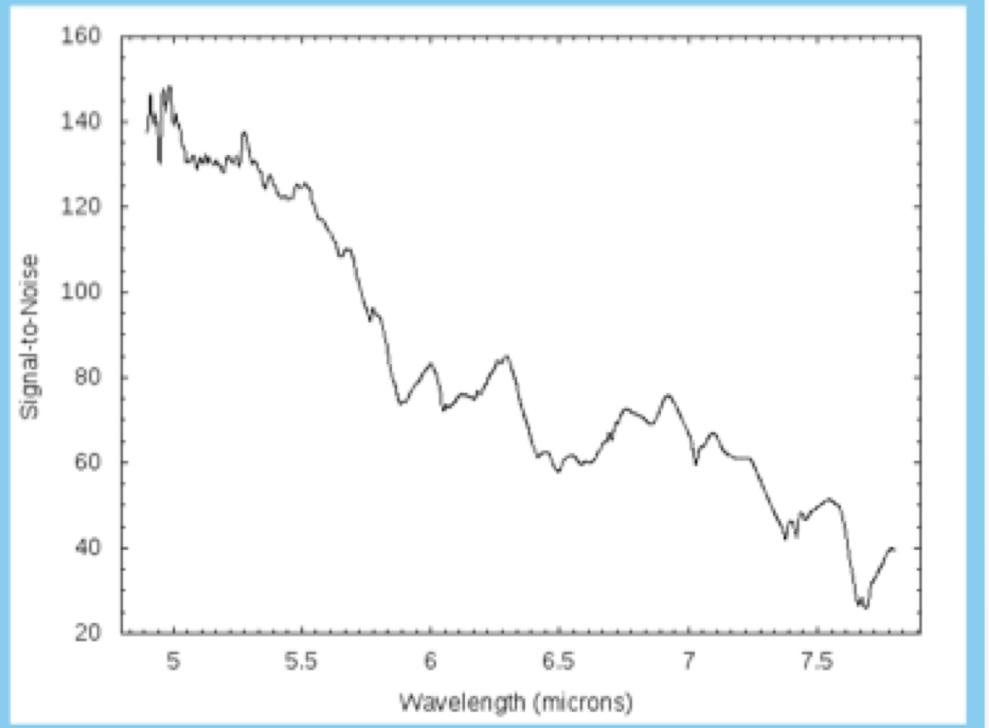
Mode:	Signal-to-Noise
Grism:	1
Slit:	4.7 arcsec
Source flux :	1.499e-13 W/m2/micron at 10 microns
Source blackbody temperature:	1500 K
Total exposure time:	60 sec

View output data file

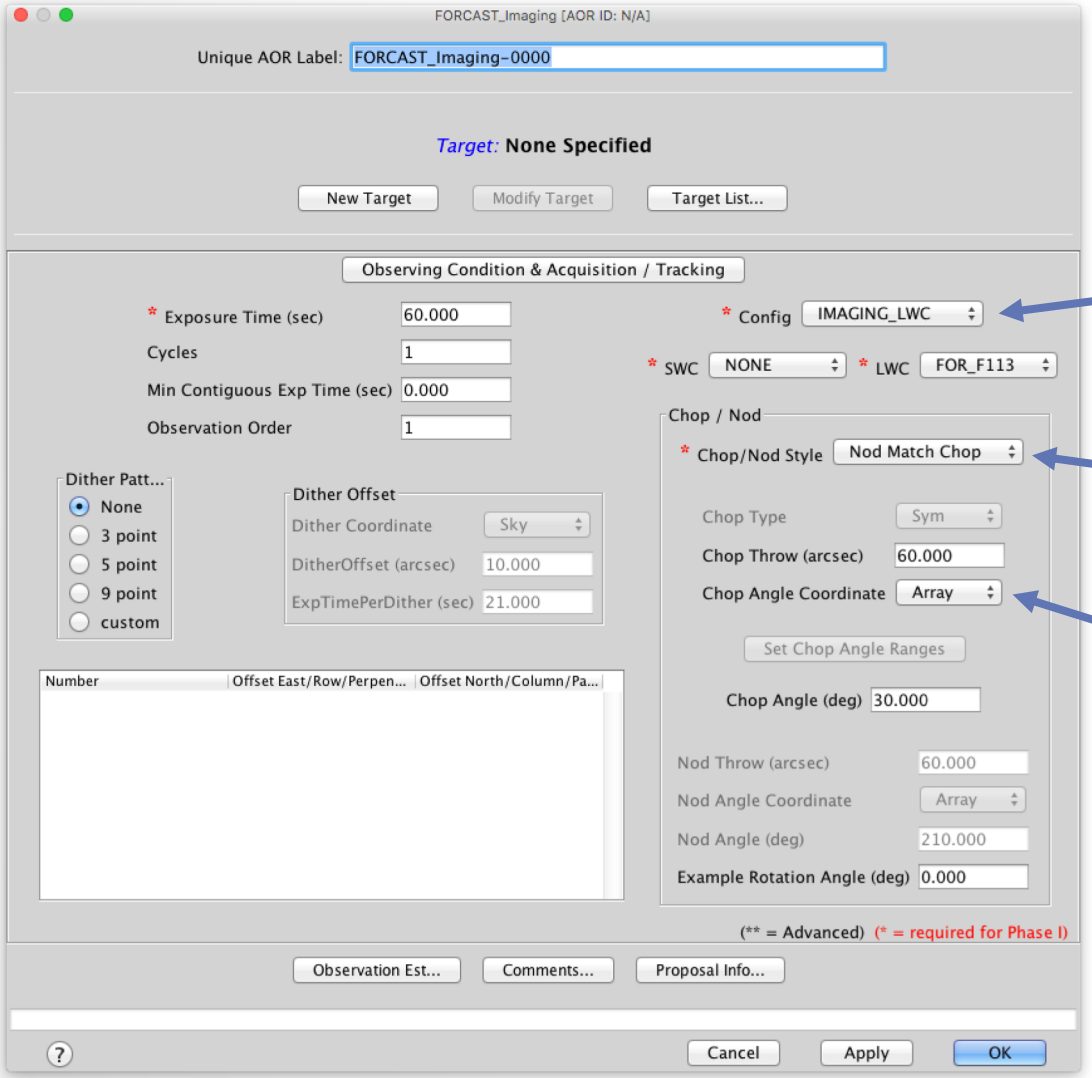
```
Slit size  =  4.700 arcsec
Resolution =   90.0
Single frame exposure time =   0.059570 sec
Frame Rate =   16.787 Hz
Number of Coadds          =    1007.00000
Total Exposure Time       =    60.0000000      sec
Input flux : 0.1499E-12 W/m2/micron at  10.000 microns
```

Wavelength (microns)	FWHM (arcsec)	Fractional Slit Transmission
5.000	3.51	0.75
6.350	3.53	0.74
7.700	3.54	0.74

Plot of Signal-to-Noise as a function of Wavelength



FORCAST in USPOT



FORCAST Imaging

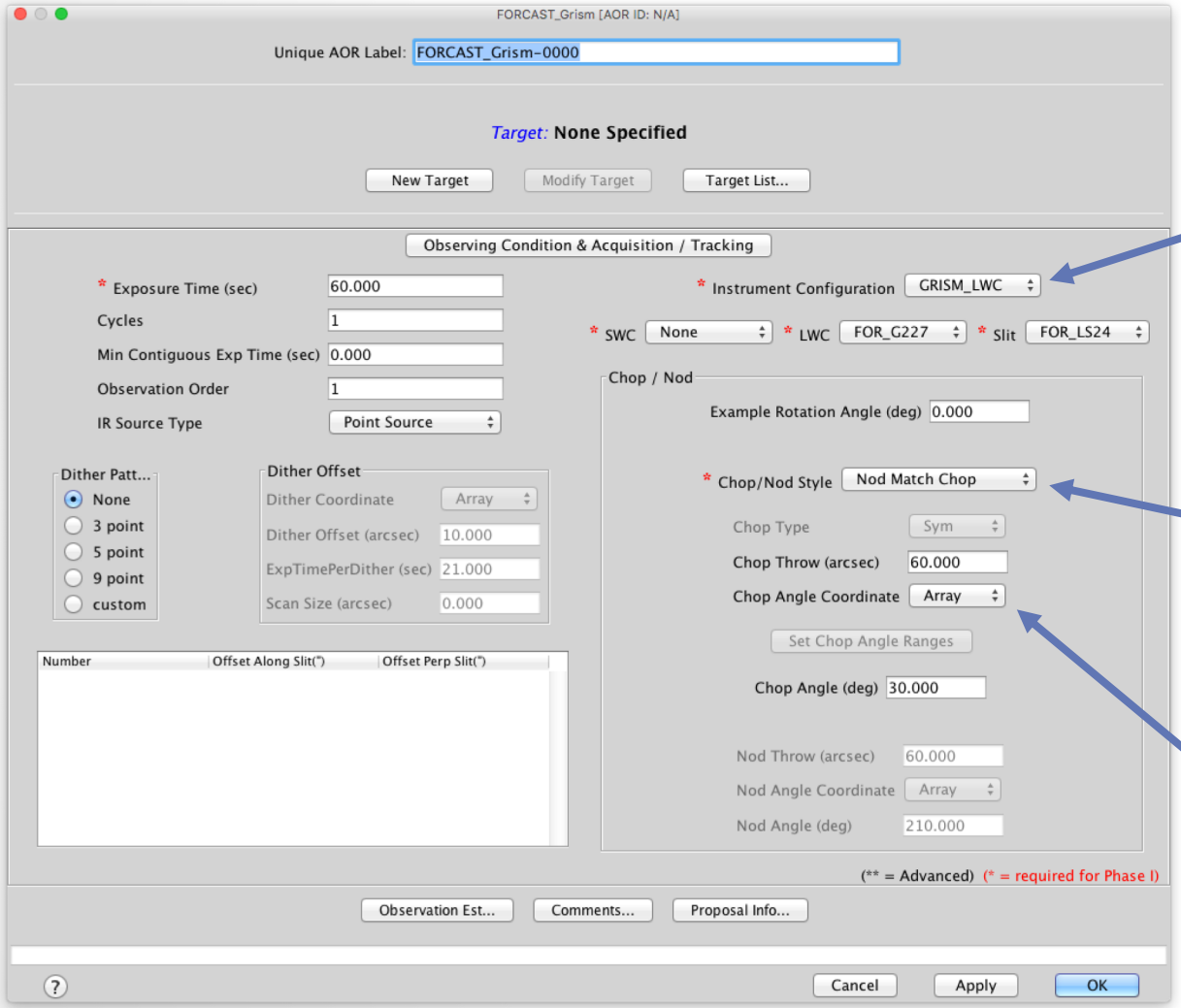
IMAGING_DUAL
IMAGING_SWC
IMAGING_LWC

Nod Match Chop
Nod Perp Chop
C2NC2

Array
Sky

- ETC provided on-source integration time to achieve a specific S/N.
- Enter on-source integration time in USPOT. Then USPOT will add overheads.

FORCAST in USPOT



FORCAST Grism Spectroscopy

GRISM_SWC
GRISM_LWC

Nod Match Chop
Nod Perp Chop CAS
Nod Perp Chop NAS
NXCAC
SLITSCAN

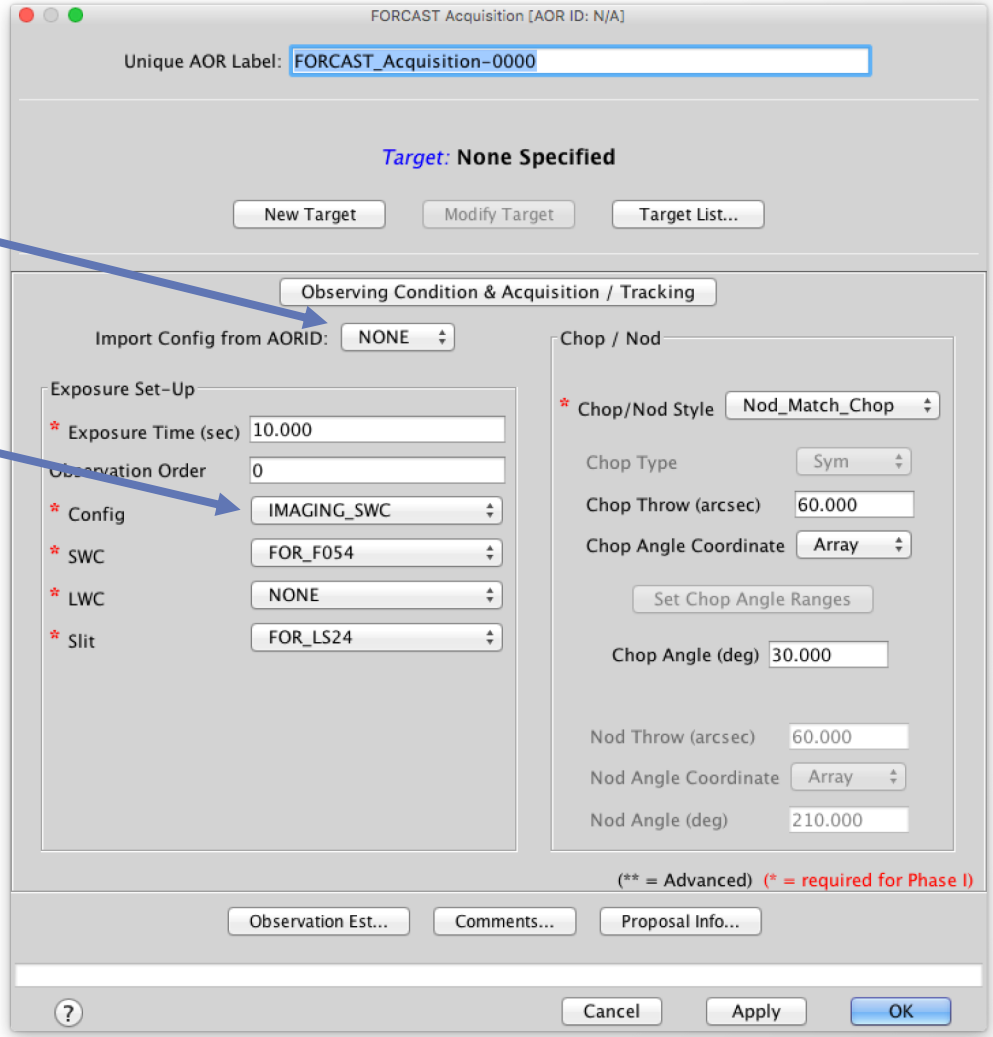
Array
Sky

FORCAST in USPOT

FORCAST Grism Acquisition

Match Grism Configuration

IMAGING_SWC
IMAGING_LWC



Include two acquisition AORs, each of which will achieve S/N>5. Integration time for most observations <60s. Details can be worked out in Phase II, but it is important to create AORs in Phase I to reserve time for it, typically a total of 3 minutes per acquisition.

FORCAST Data Products

- Once flight series is complete, data are pipelined, flux calibrated, and archived in the SOFIA Data Cycle System (https://dcs.sofia.usra.edu), usually within a month.
- GOs are then notified via email and provided links for data retrieval.
- ***Proprietary period is typically 1 year from completion of pipeline processing and calibration.***
- Pipeline processing removes instrumental artifacts and sky/telescope background.
- Telluric correction is applied using a grid of ATRAN models.
- Flux calibration is applied using response tables/curves derived from observations of standard sources (stars/asteroids).
  - ***Flux calibration uncertainty: 5 – 10%***
- See ***FORCAST Data Handbook*** and Cookbook Recipes for more information:
  - https://sofia.usra.edu/science/proposing-and-observing/data-products

Resources online

- FORCAST observer manual
  https://www.sofia.usra.edu/science/proposing-and-observing/sofia-observers-handbook-cycle-6/5-forcast

- FORCAST time estimator (grisms)
  https://forcast.sofia.usra.edu/cgi-bin/forcast/forcast_grisms_calc.cgi

- FORCAST time estimator (imaging)
  https://dcs.sofia.usra.edu/proposalDevelopment/SITE/index.jsp