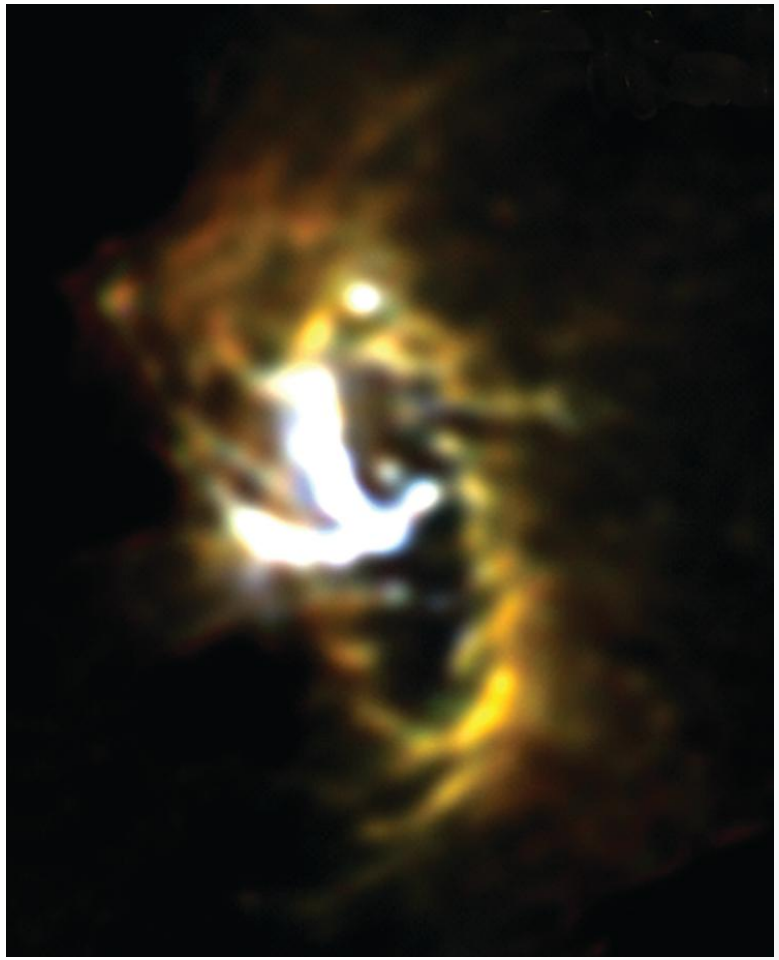
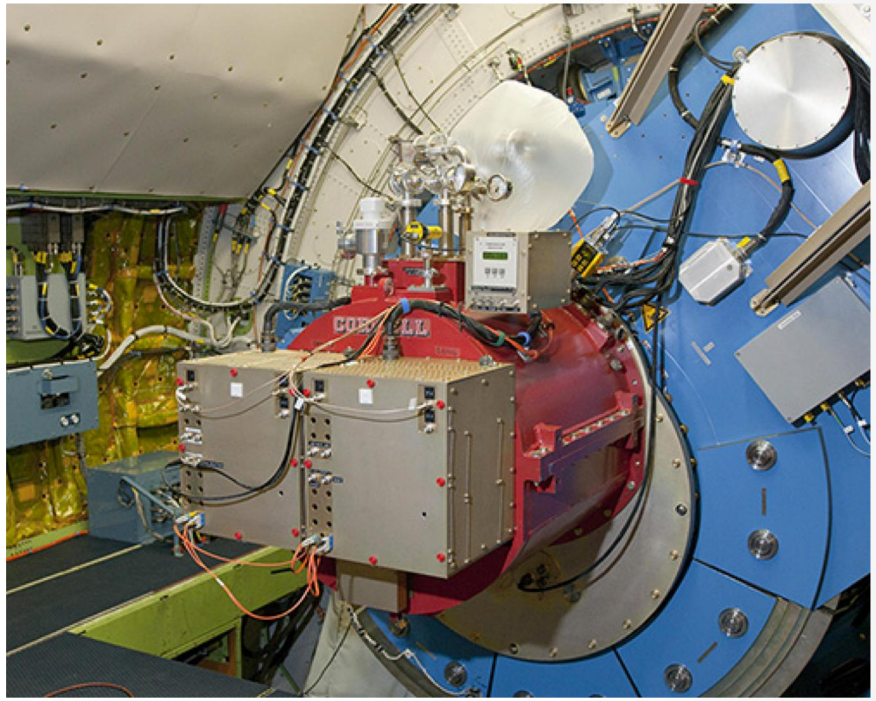
Mid-IR imaging and spectroscopy with FORCAST



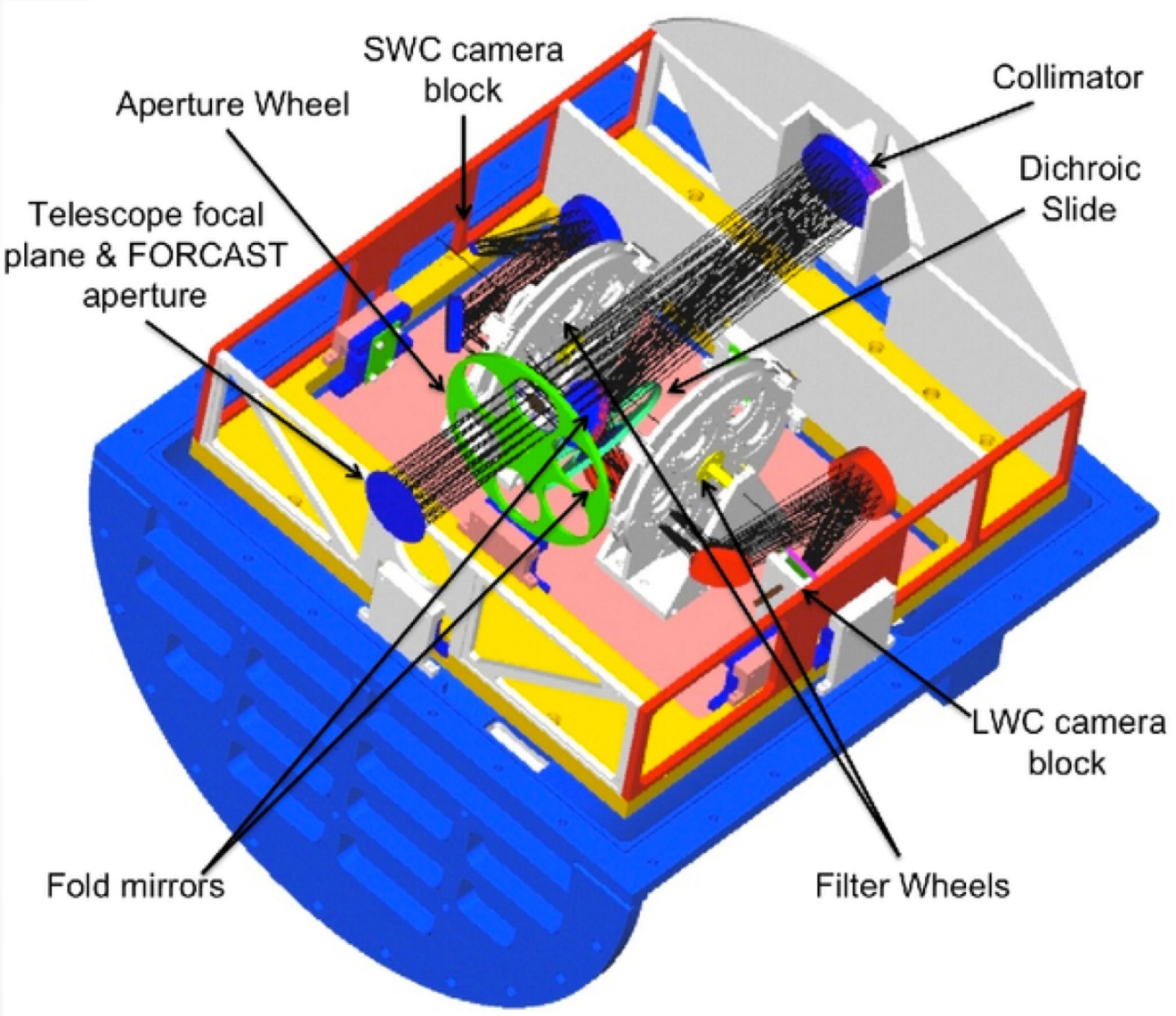
The galactic center with FORCAST
(NASA/DLR/USRA/DSI/FORCAST Team/Lau et al. 2013)

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, re-binned to 0.768” square
- LWC – Si:Sb BIB 256x256 array for 25-40 µm, 0.79”x0.75”pix, re-binned to 0.768” square
- 2 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

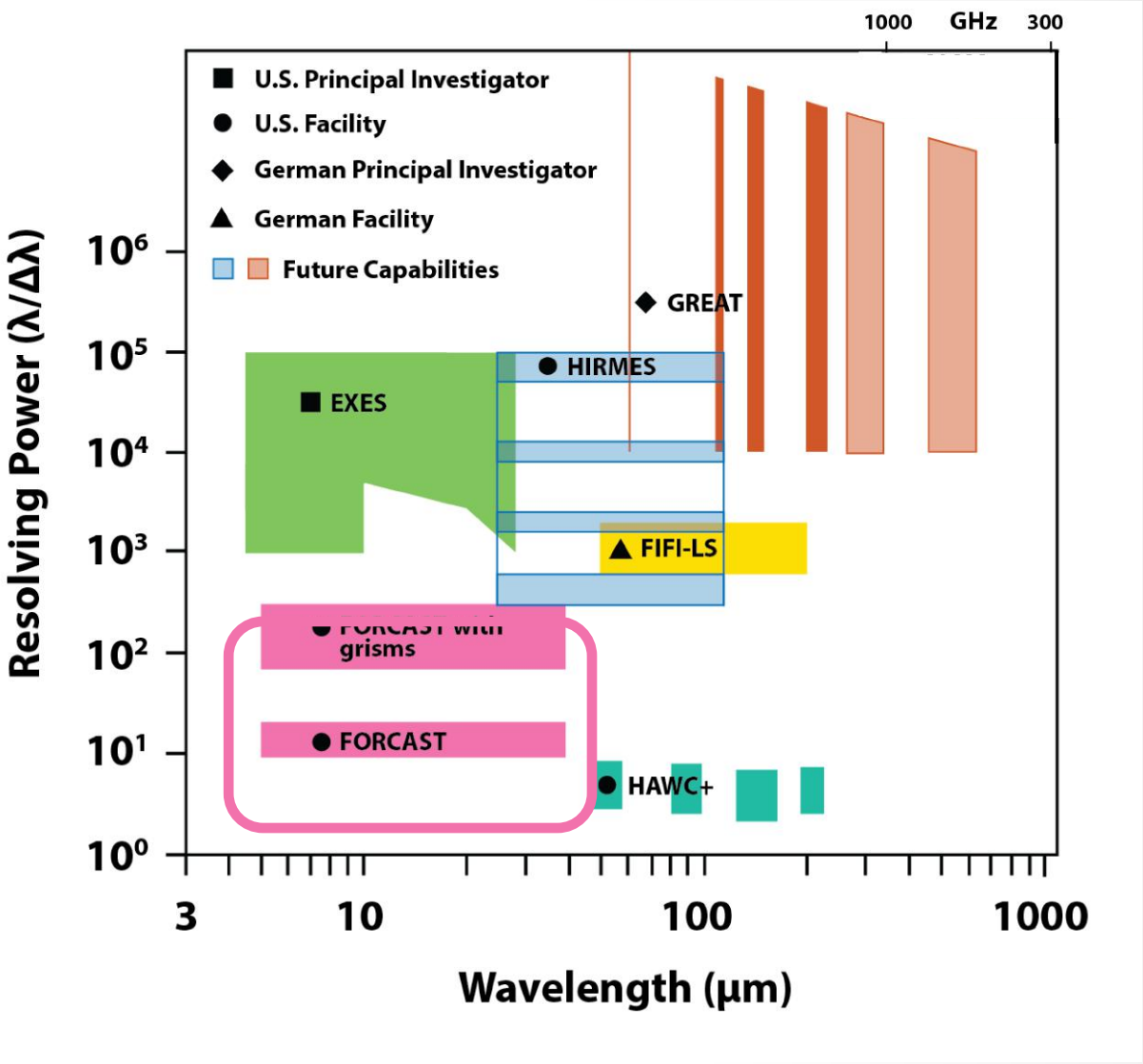
Filters and grisms

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		

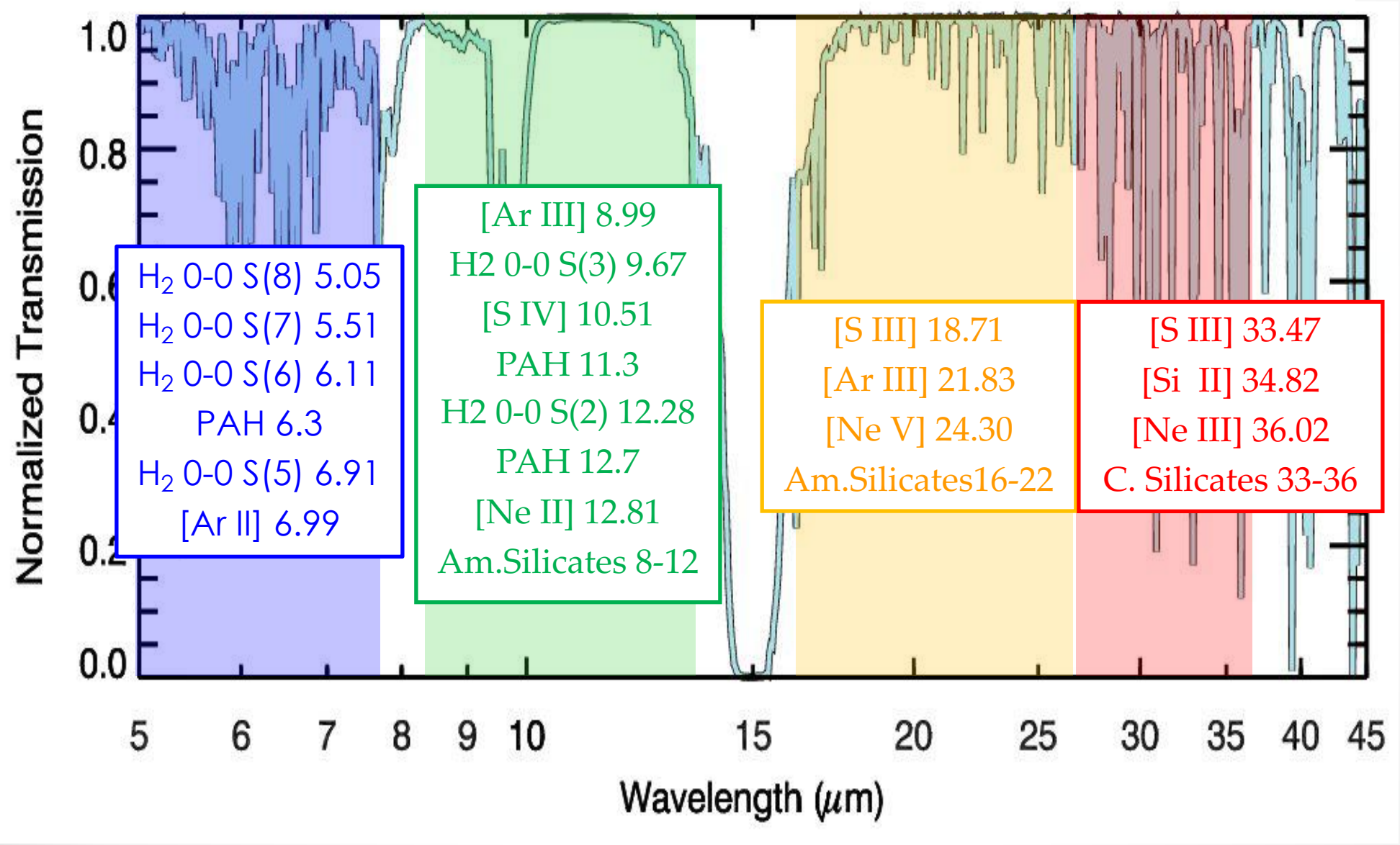
Grism Details

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]



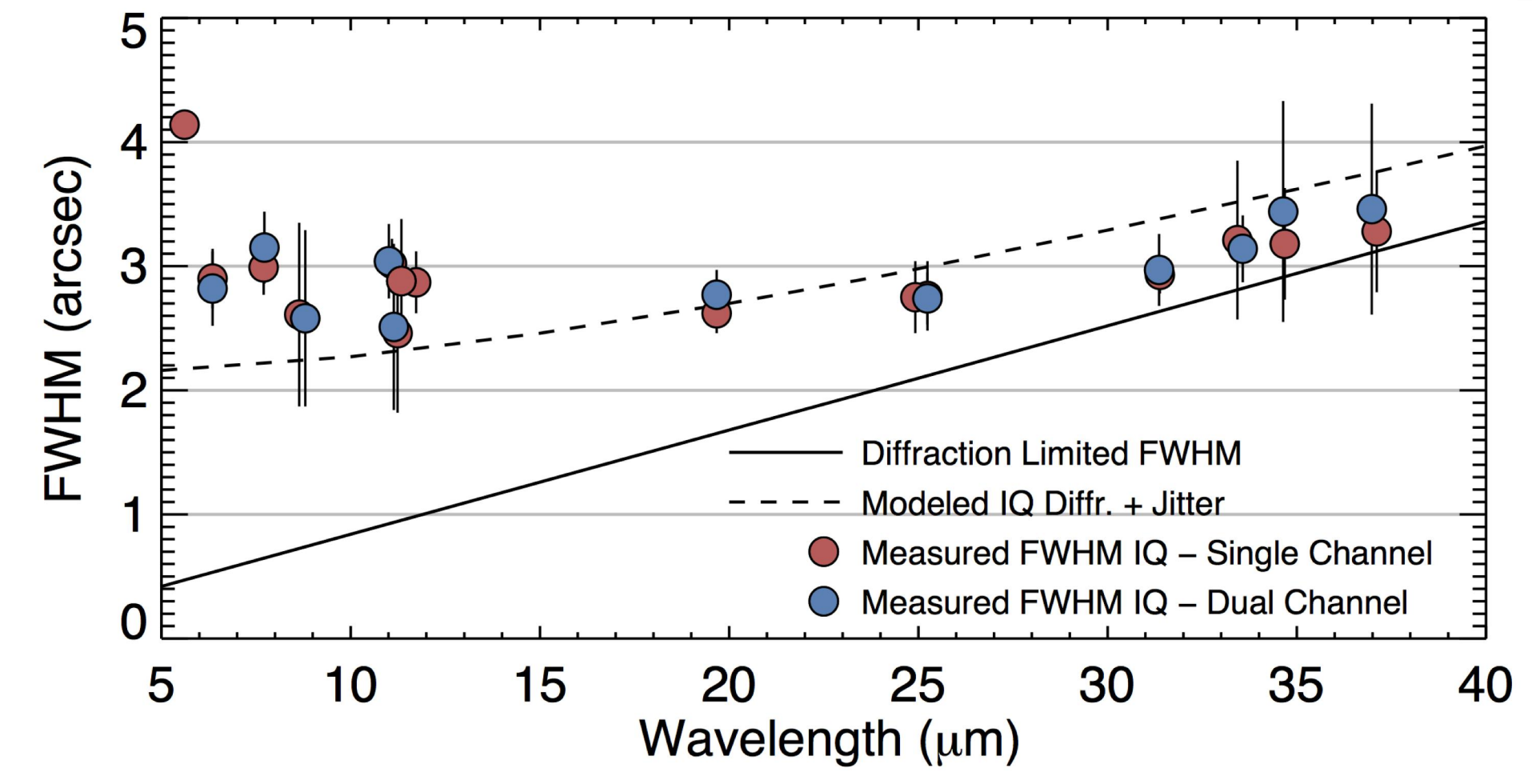
Filter, Grism, & Slit defined in header with keywords:
SPECTEL1, **SPECTEL2**, & **SLIT**

Spectral features of interest



SOFIA
2018 Community Days Workshops
NASA
USRA
DLR
DSI

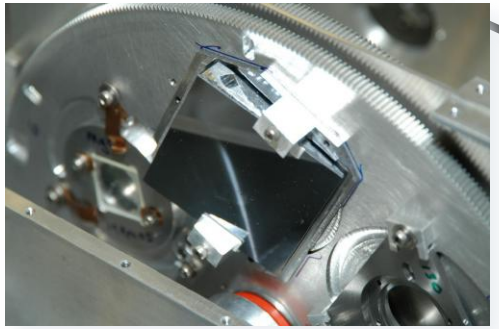
FORCAST Imaging Resolution

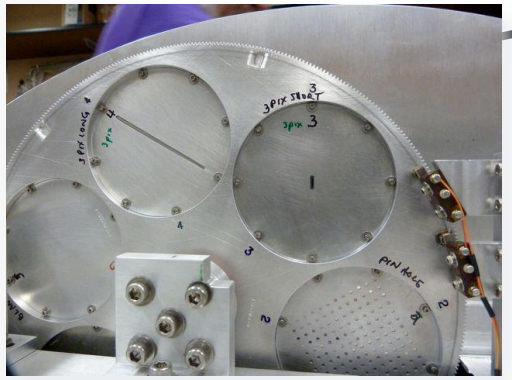


For comparison, Spitzer resolution of ~ 6'' @ 24μm

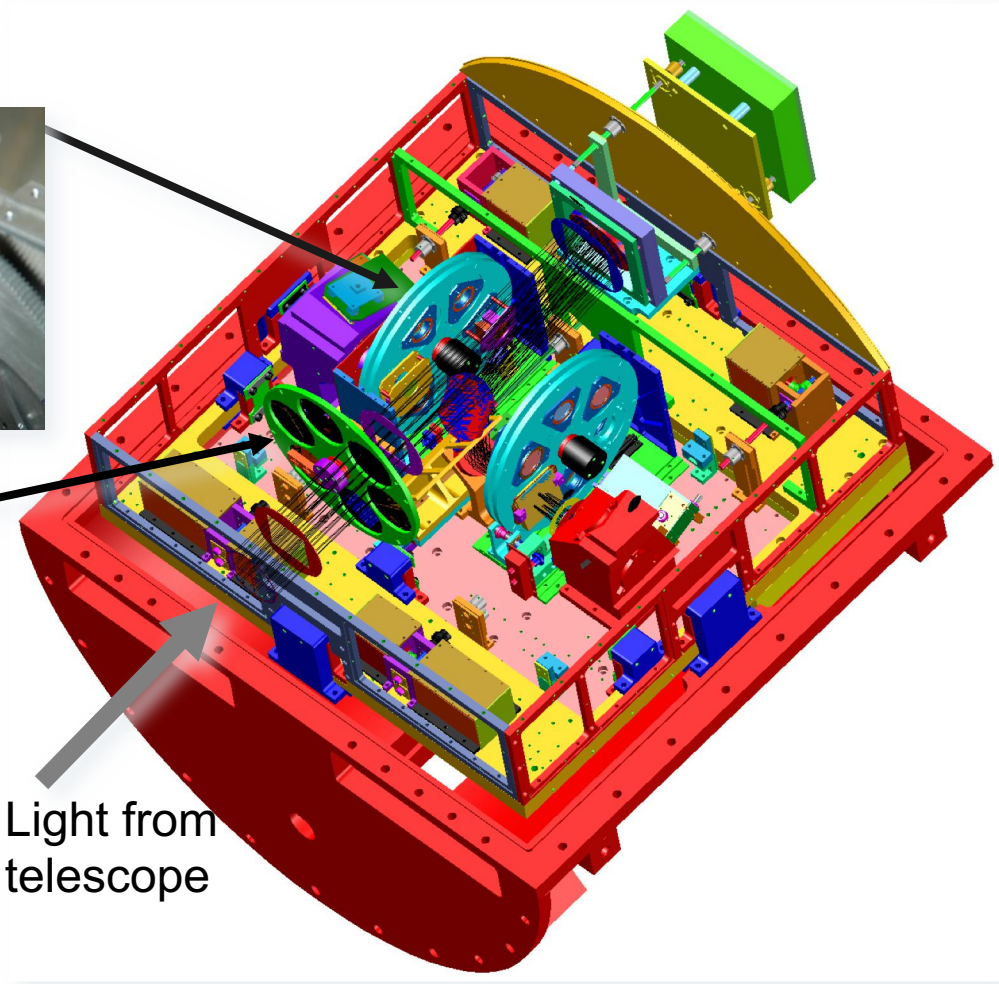
FORCAST grism design overview: layout

Grisms in existing imaging filter wheels



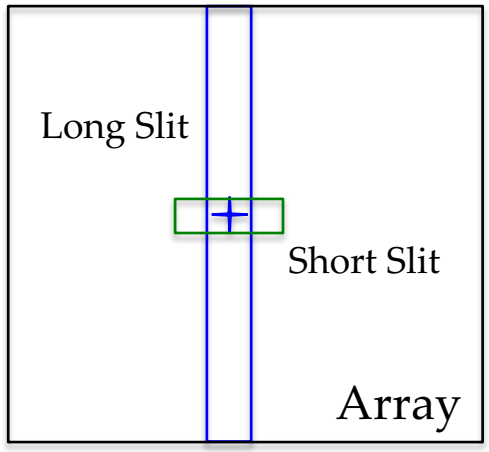


Slits in existing aperture wheel

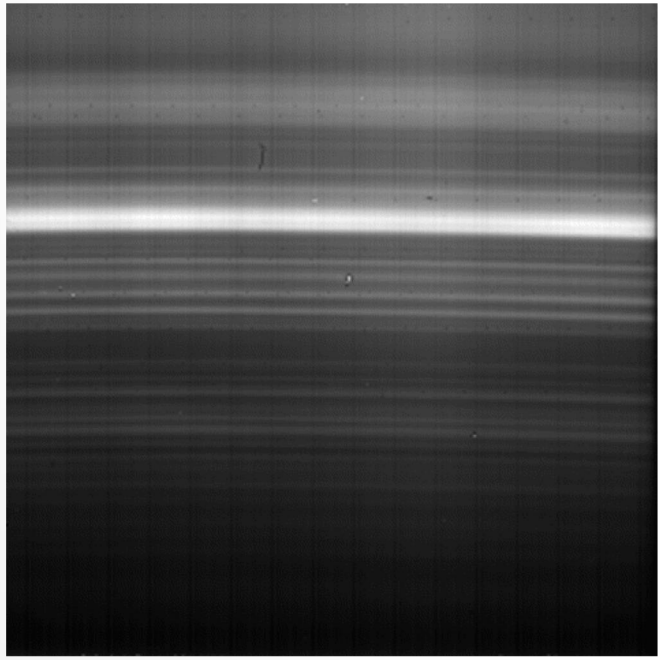


Light from telescope

Grism spectral formats

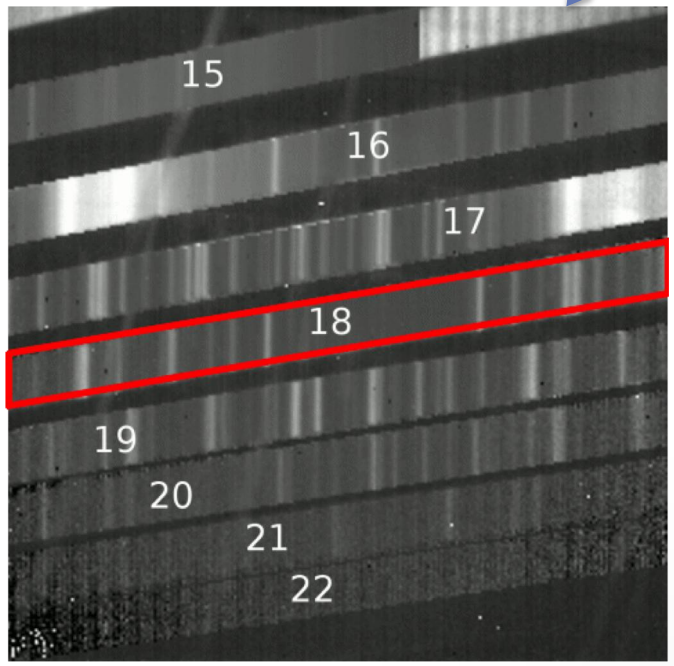


Long slit modes

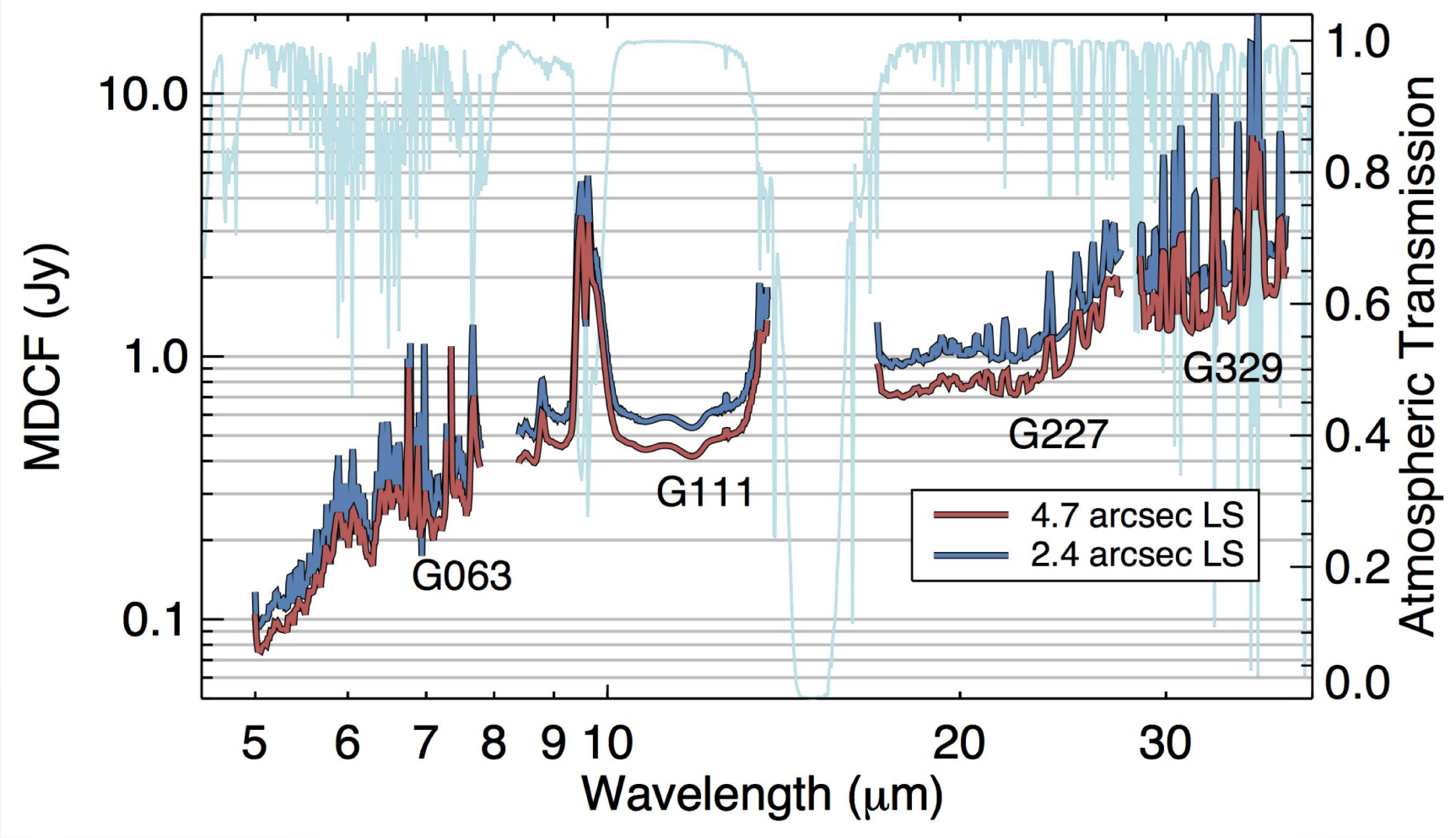


Short slit (XD) modes

interference fringes



Spectroscopic Sensitivity

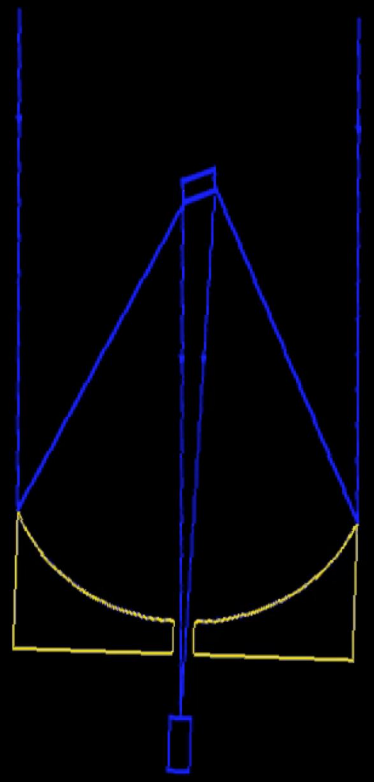


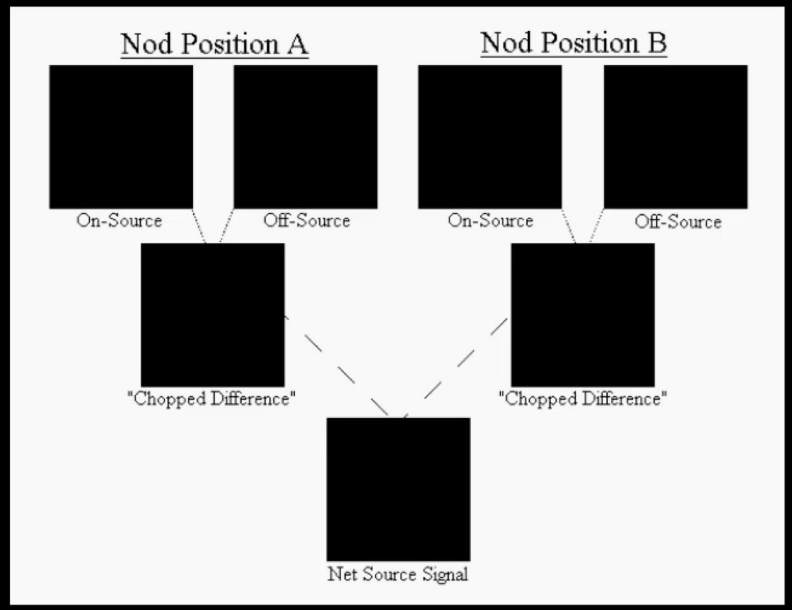
- S/N=4 in 900s, 41000 feet, single channel mode ***only***
- Altitude/water vapor affect sensitivity more in the LWC

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

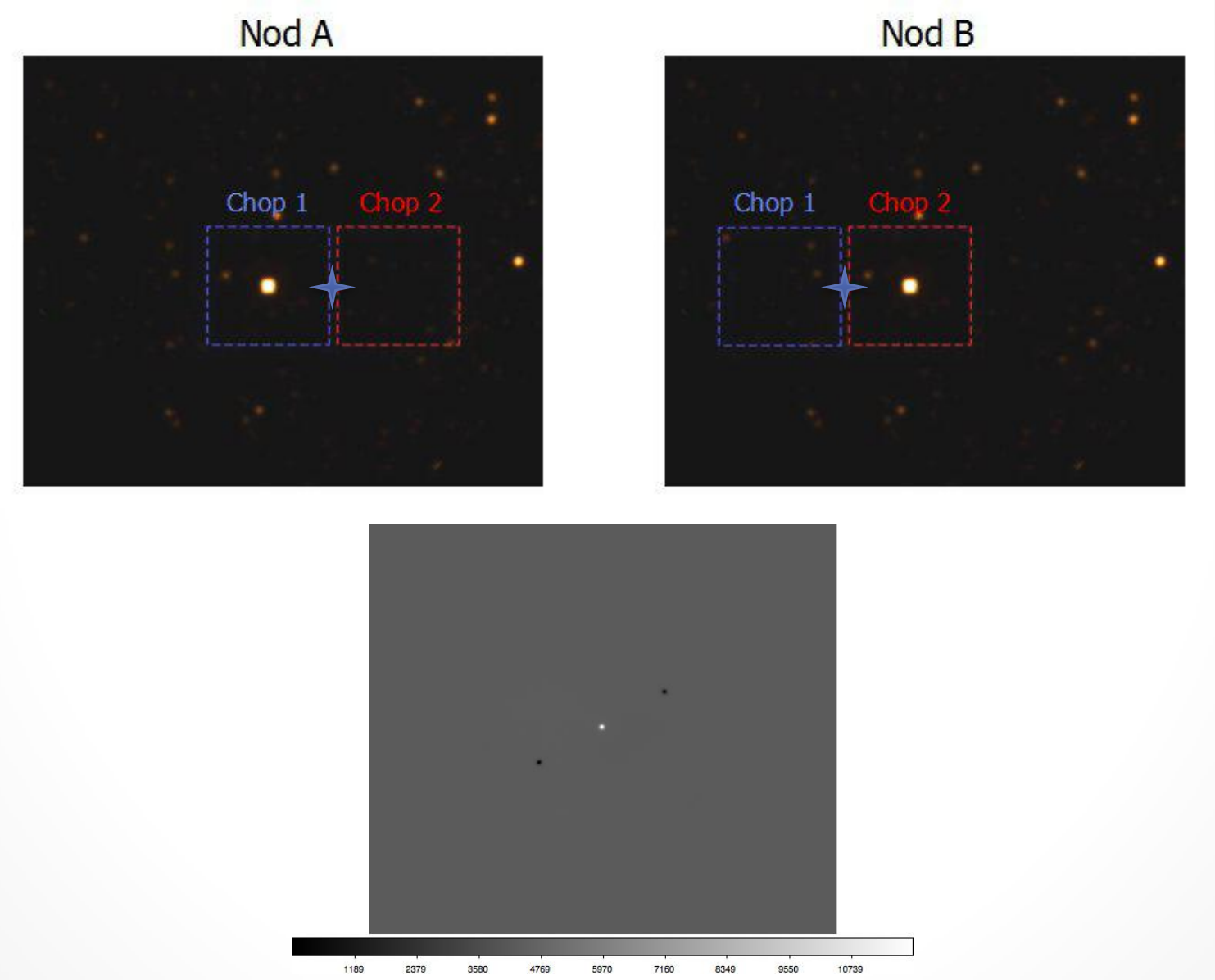
Nod Position A

Plus Beam

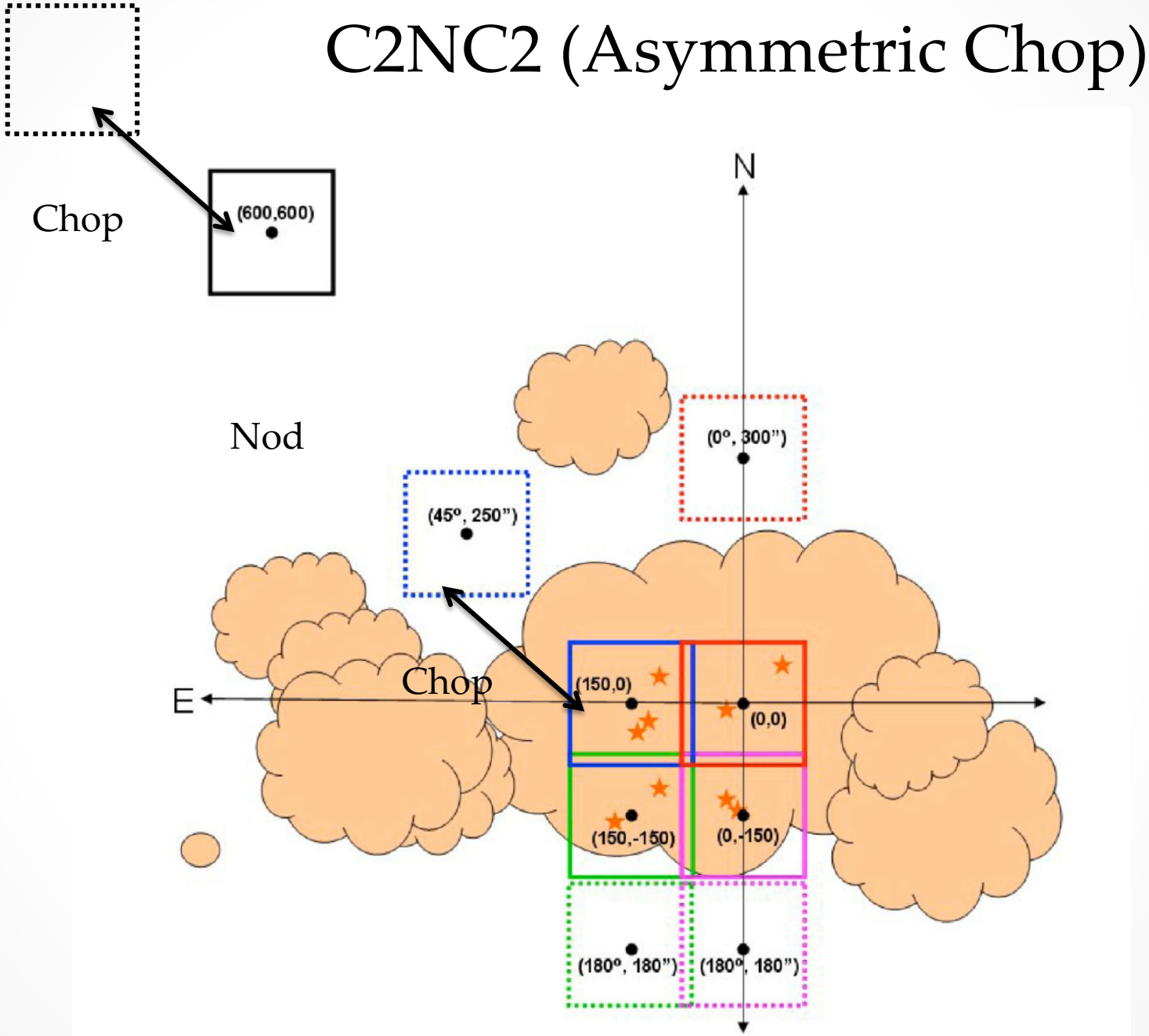
Source+Sky+Tel$_+$

-(Sky+Tel$_-$)

Nod_Match_Chop (Symmetric Chop) Mode:

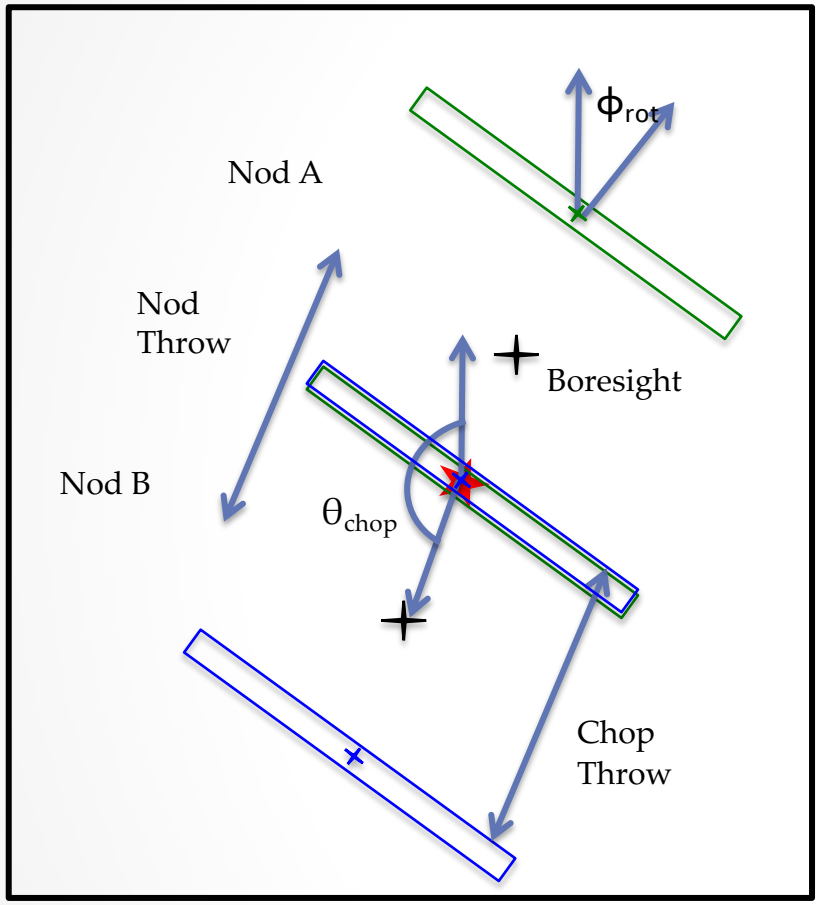


C2NC2 (Asymmetric Chop) Mode:

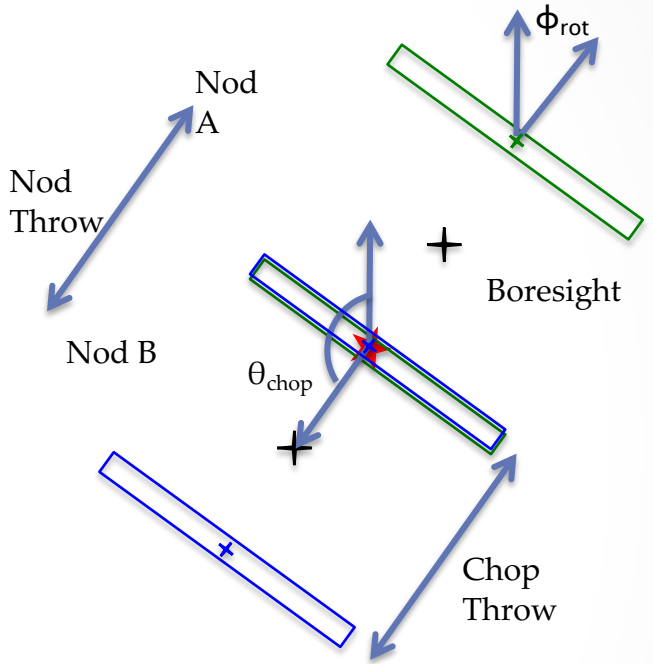


Grism Observing Modes: NMC

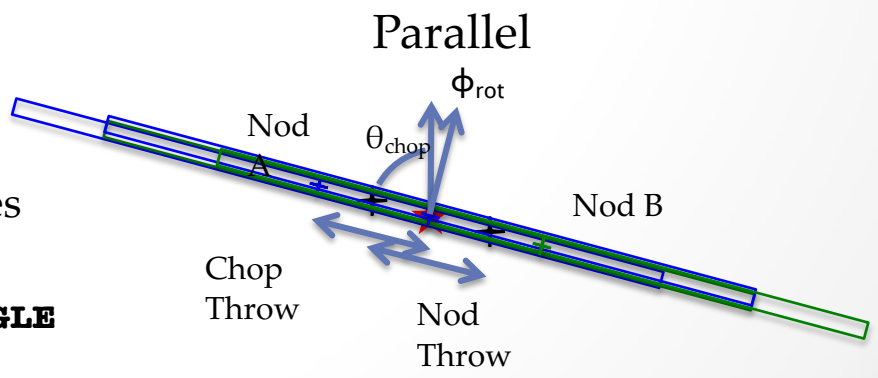
General



Perpendicular



Parallel



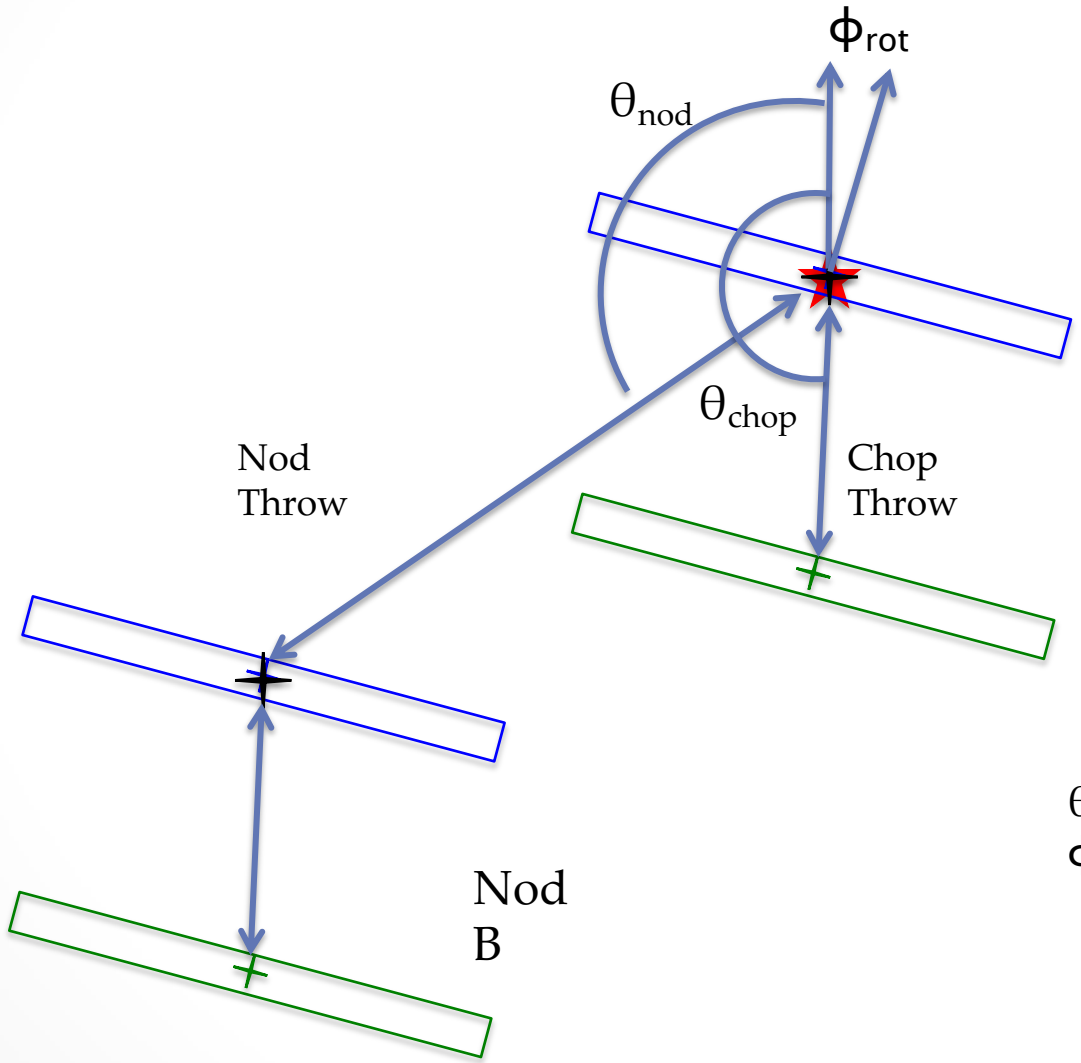
Default is a chop angle of 30˚ and a nod angle of 210˚, but the angles can be chosen by the user. Indicated by header keywords:

Chop Parameters: **CHOPSYM**, **CHPCRSYS**, **CHPAMP1**, **CHPAMP2**, & **CHPANGLE**

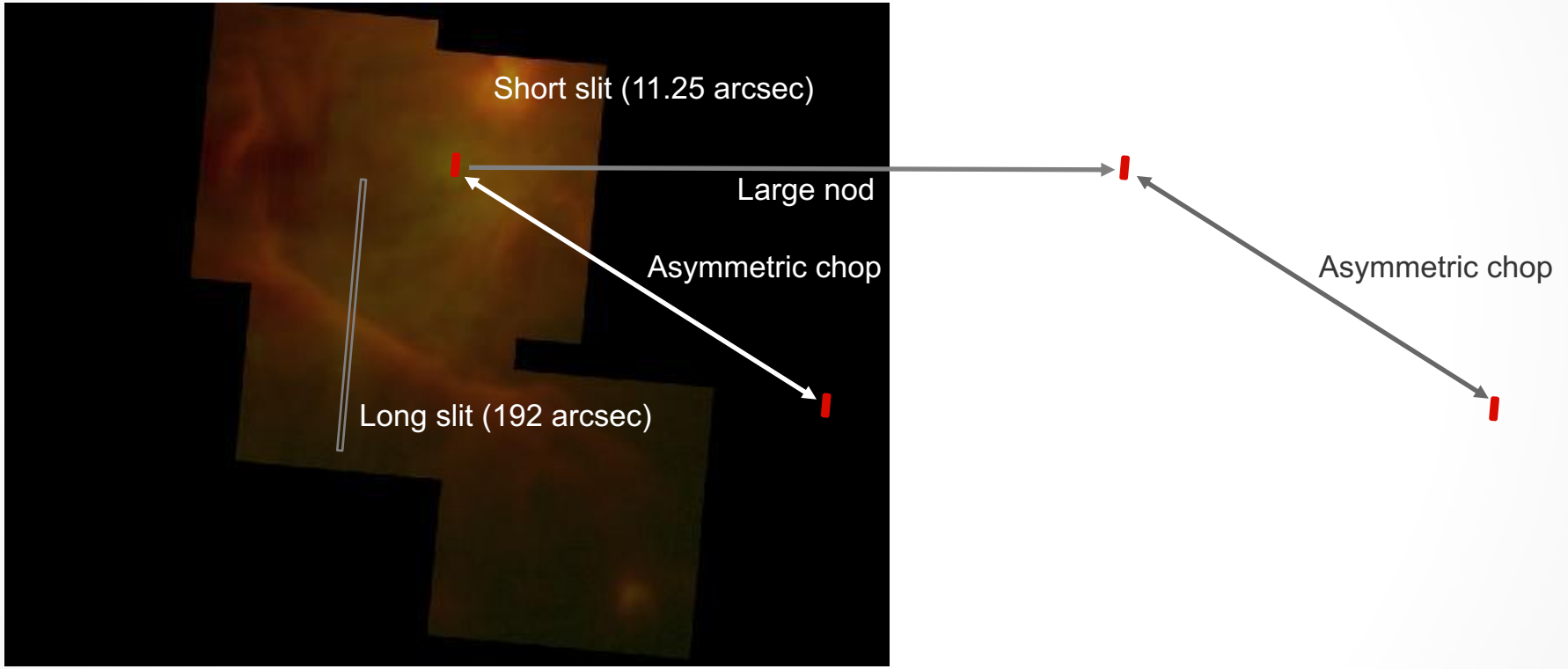
Nod Parameters: **NODSTYLE**, **NODCRSYS**, **NODAMP**, & **NODANGLE**

Grism Observing Modes: NXCAC

(similar to C2NC2 for imaging)



Pointed observations & mapping in extended sources

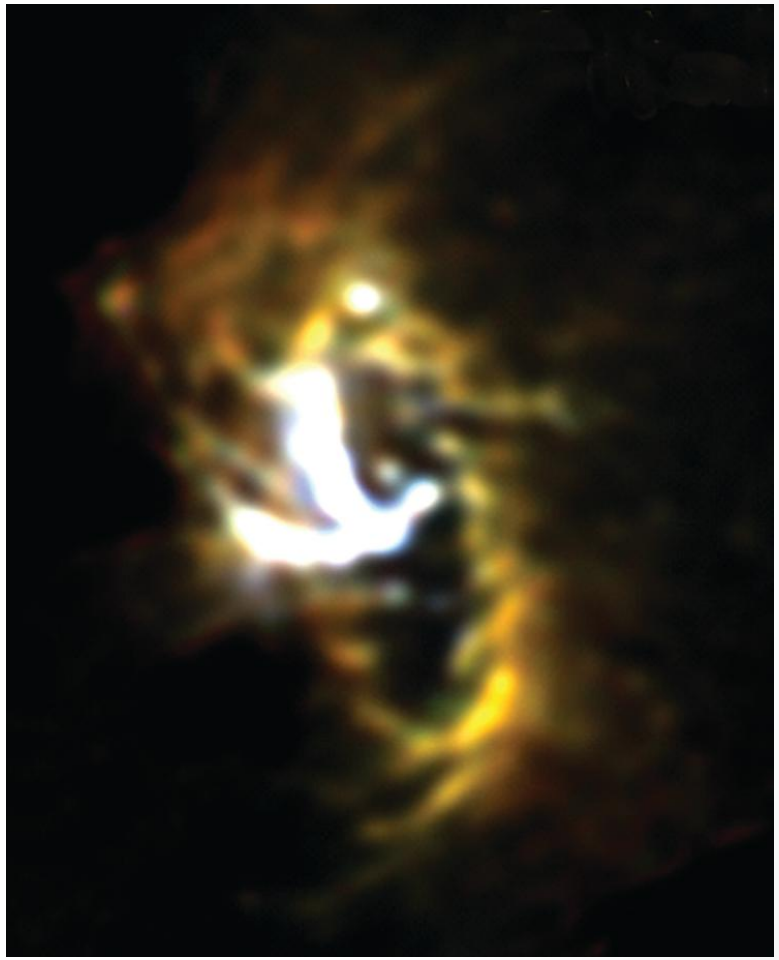


Large HII region example NXCAC mode

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

Bonus Slides:



The galactic center with FORCAST
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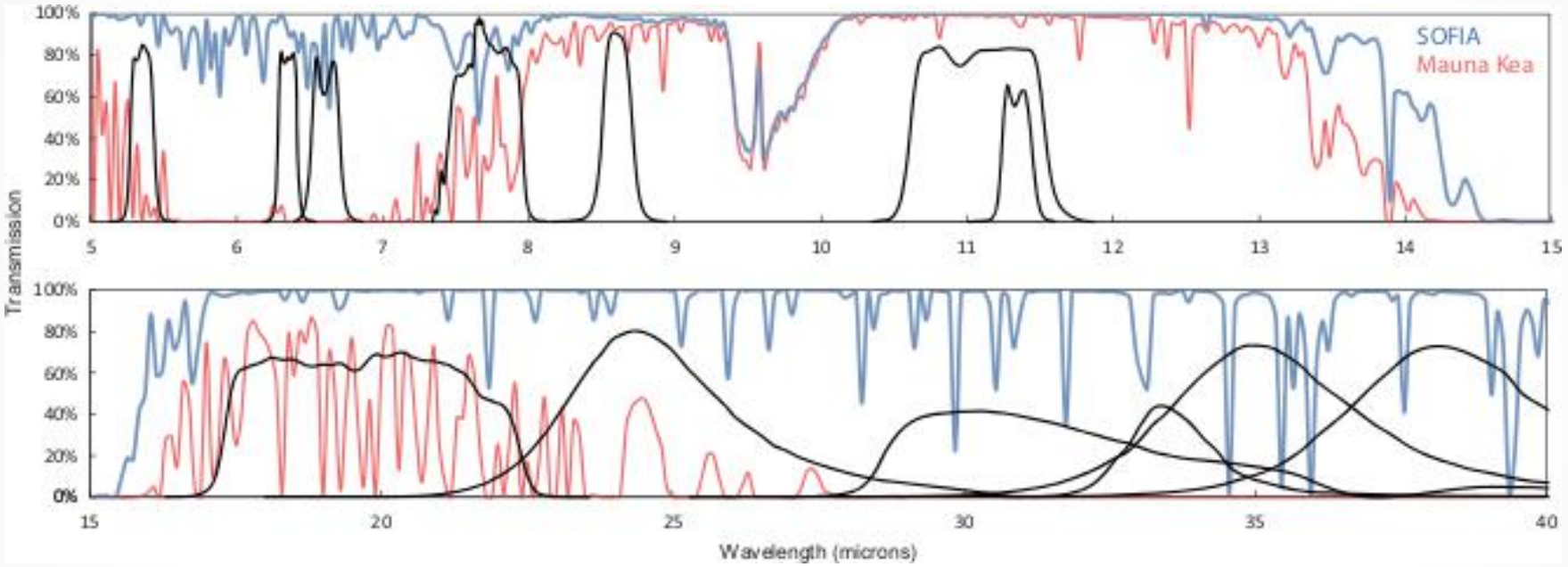
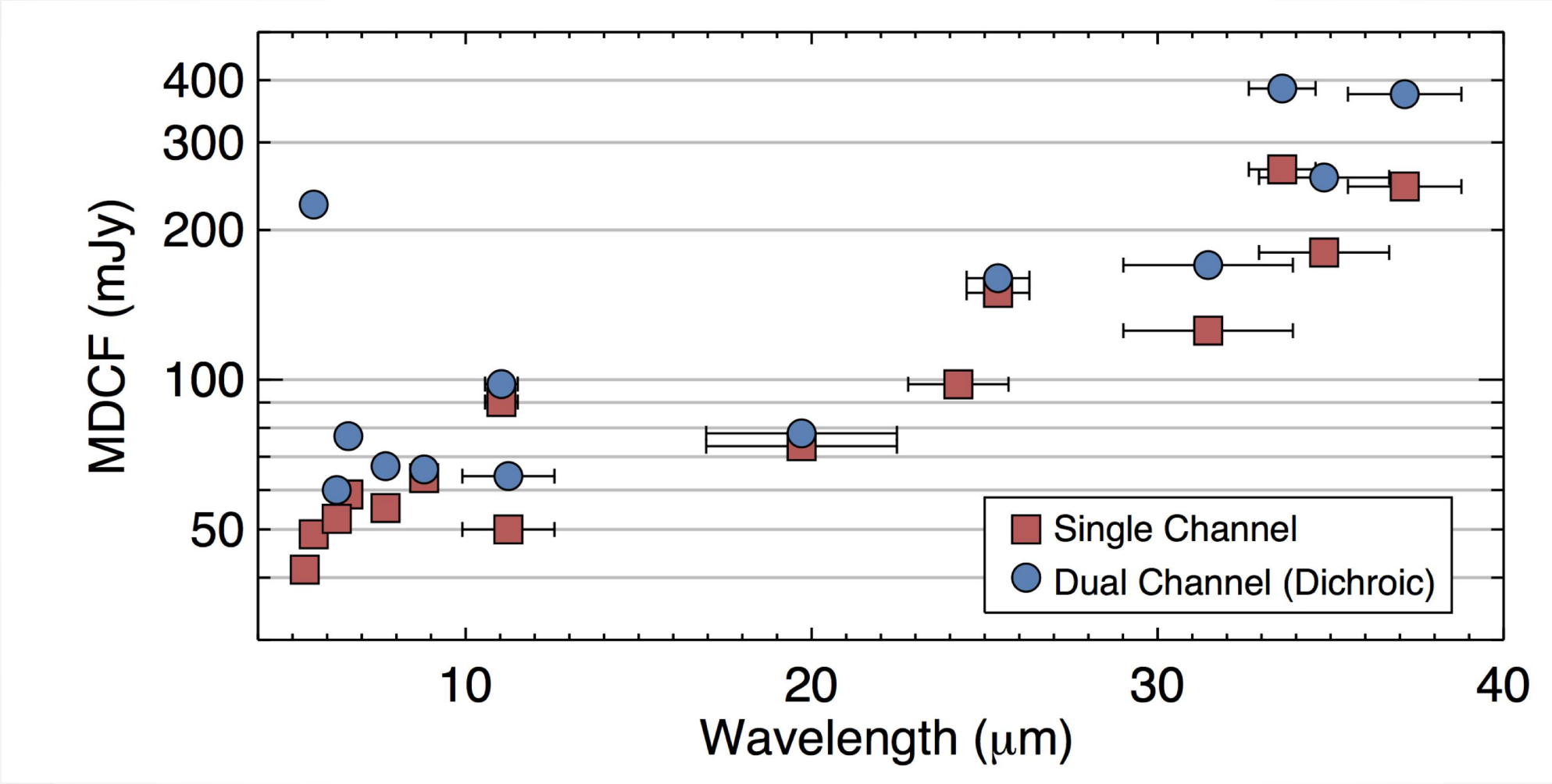
FORCAST Filter Profiles



SOFIA : 41000 ft, 7.3 µm PWV, 45° ZA

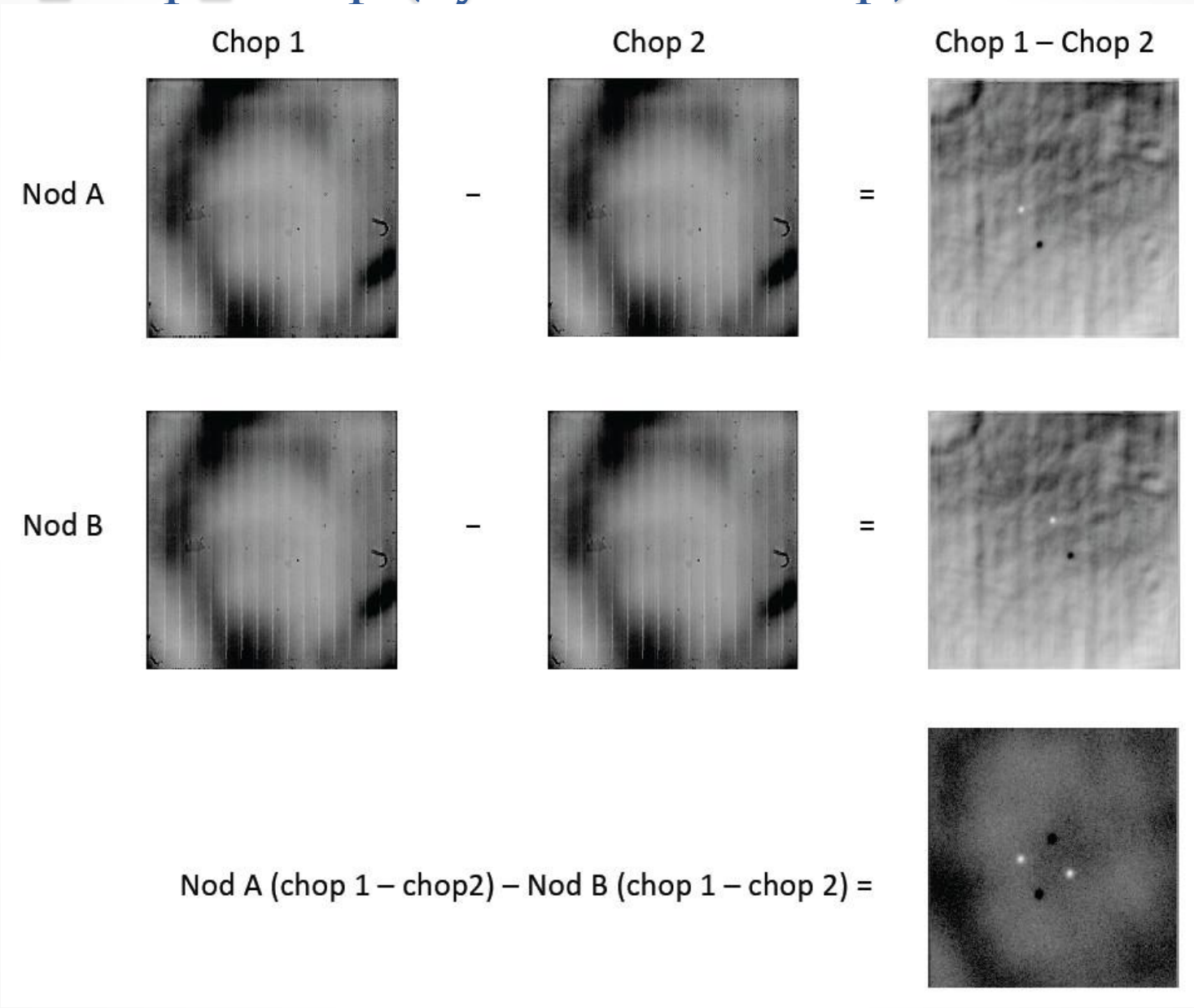
Mauna Kea: 13800 ft, 3.4 mm PWV, 45° ZA

Imaging Sensitivity



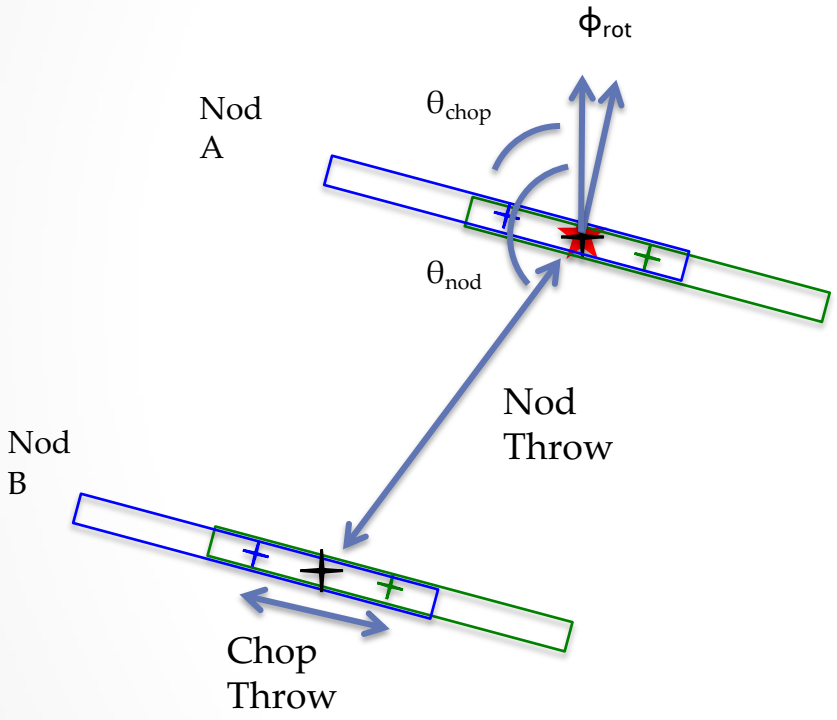
- S/N=4 in 900s, 41000 feet, single channel mode; larger limiting fluxes with dichroic
- Altitude/water vapor affect sensitivity more in the LWC
- In preparing your FORCAST observations, you can use SITE, the online integration time estimator

Nod_Perp_Chop (Symmetric Chop) Mode:

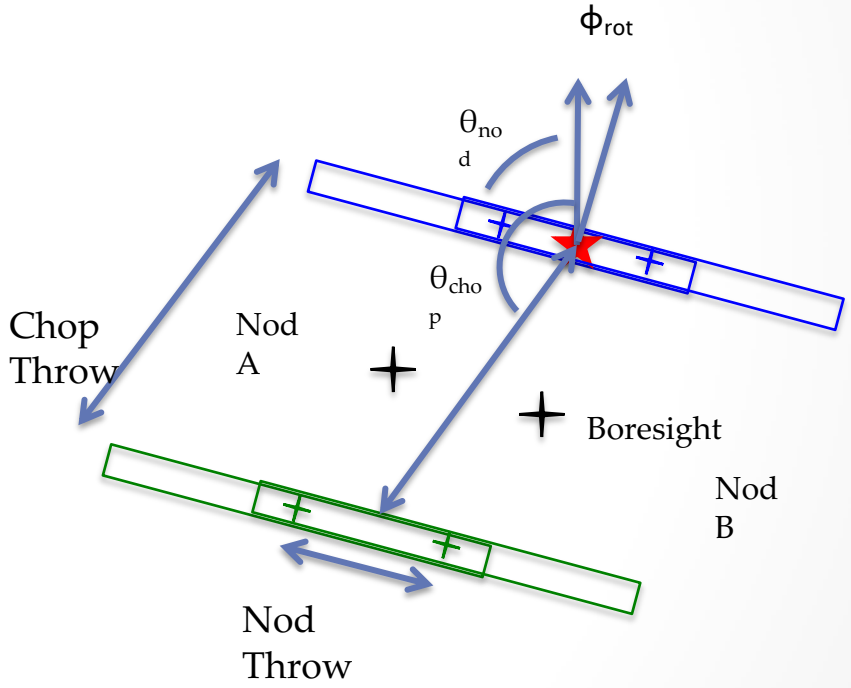


Grism Observing Modes: CAS, NAS

Chop_Along_Slit



Nod_Along_Slit



FOCAST Grism Data: Pipeline and Products

AAS SOFIA Data Workshop

R. Y. Shuping

Observatory Scientist

USRA-SOFIA/SSI

FORCAST Data Reduction Pipeline

Level 1 raw FITS files
Clean bad pixels
Droop correct
Nonlinearity correct
Stack
Jailbar correct
Grism?
yes
no
Grism?
yes
no
Extract
Merge
Flux Calibrate
Combine
Undistort
Merge
Register
Telluric Correct
Coadd
Flux Calibrate
Level 3 flux-calibrated FITS file
DCS
Archive
Quality Assurance
Guest Observer
Archive Investigator
SOFIA Science Center

FORCAST Grism Data Products

STEP	Description	LEVEL	DCS PRODTYPE	Product ID	Size
Stack Chop/Nods	Chop/nod correction	2	stacked	STK	256x256x2
Extract Spectra	Rectified image produced during extraction.	2	rectified	RIM	*X* x *Y* x 4
Extract Spectra	Raw extracted spectra	2	spec	SPC	*X* x 4
Flux Calibrate	Flux calibrated spectra	3	calspec	CAL	*X* x 5
Combine Spectra	Combined spectra	3	combspec	CMB	*X* x 5

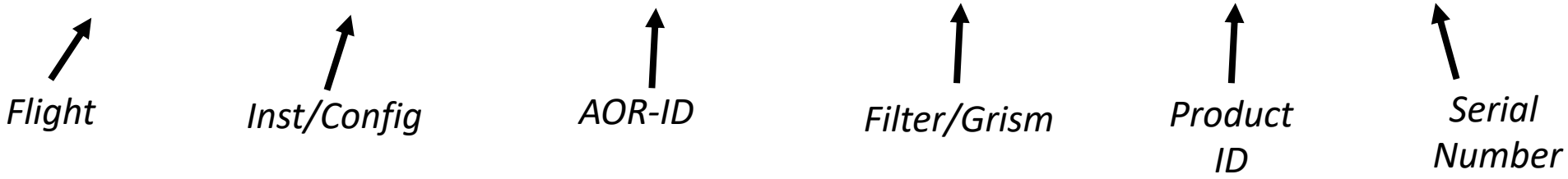
These are generally the products of interest for most GOs and archive users.

FORCAST Grism Flux Calibration

- Extracted spectra are corrected for instrumental response…
  - Determined empirically from observations of calibrators (standard stars and asteroids).
- …then corrected for telluric absorption using standard model atmosphere.
  - Best fit determined from grid of ATRAN models.
- Adopted telluric model and instrumental response are included with the final spectrum.
- Overall absolute calibration accuracy is 5 – 10%, but…
- ***Data can be affected by systematic uncertainties, e.g. variable slit losses***.
  - If you need absolute spectrophotometry, consider additional imaging observations for final calibration.

File Naming Conventions

F0428_FO_GRI_0500637_FORG111_RIM_0177.fits

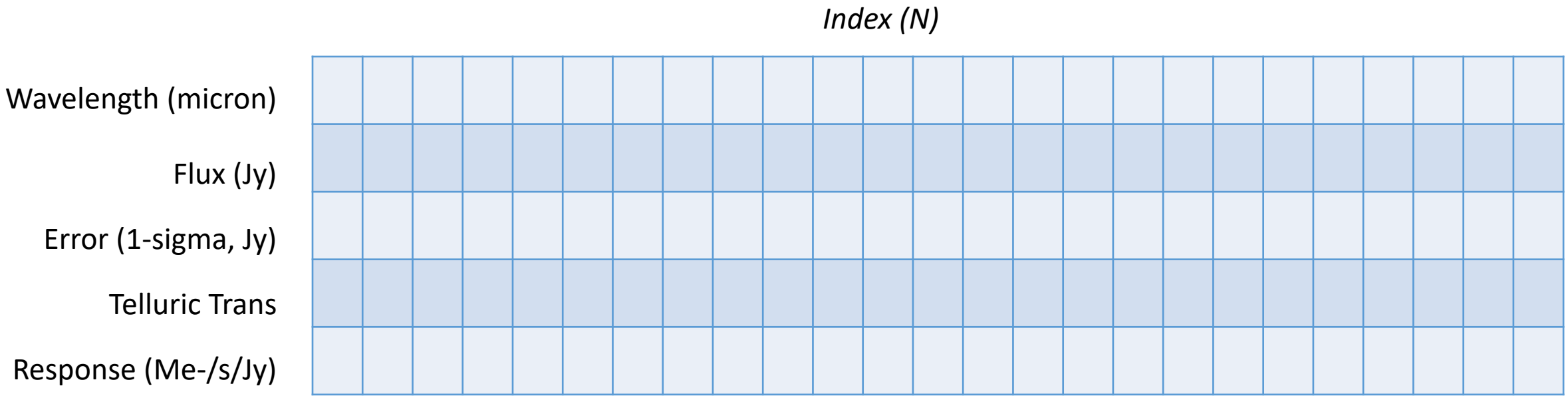


F0428_FO_GRI_0500637_FORG111_CAL_0177.fits

F0434_FO_GRI_0501381_FORG063_CMB_0228-0229.fits

Data Format: Flux Calibrated Products (L3)

Flux Calibrated products delivered as *N* x 5 array, one per FITS file.



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Level 3 flux-calibrated FITS file
DCS
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Quality Assurance
Guest Observer
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SOFIA Science Center

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Extract Spectra	Raw extracted spectra	2	spec	SPC	*X* x 4
Flux Calibrate	Flux calibrated spectra	3	calspec	CAL	*X* x 5
Combine Spectra	Combined spectra	3	combspec	CMB	*X* x 5

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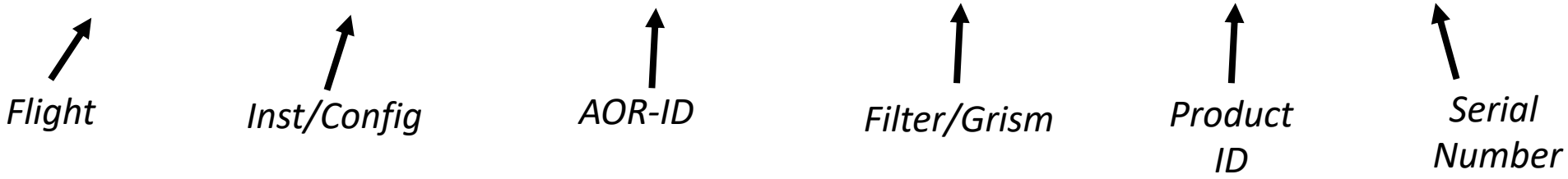
File Naming Conventions

F0428_FO_GRI_0500637_FORG111_RIM_0177.fits



F0428_FO_GRI_0500637_FORG111_CAL_0177.fits

F0434_FO_GRI_0501381_FORG063_CMB_0228-0229.fits

Data Format: Flux Calibrated Products (L3)

Flux Calibrated products delivered as *N* x 5 array, one per FITS file.