Wide Band Spectroscopy with FORCAST and FLITECAM

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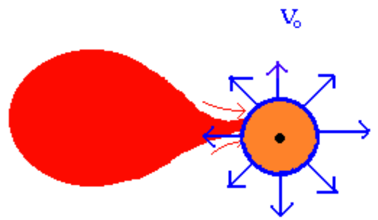
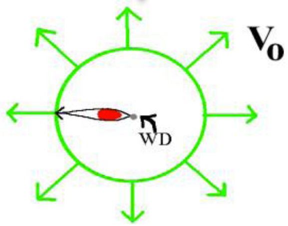
SOFIA Observer's Workshop
Mountain View, CA
May 20, 2015

Observations of Classical Novae in Outburst

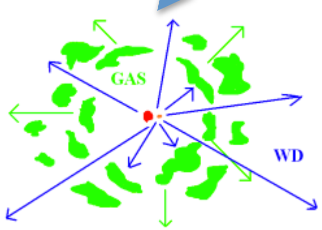
What is a Classical Nova?



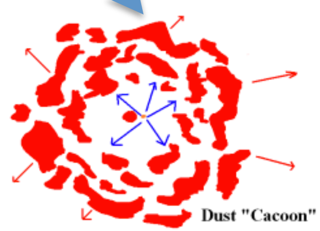
Fireball Expansion Phase



Free-Free Expansion Phase

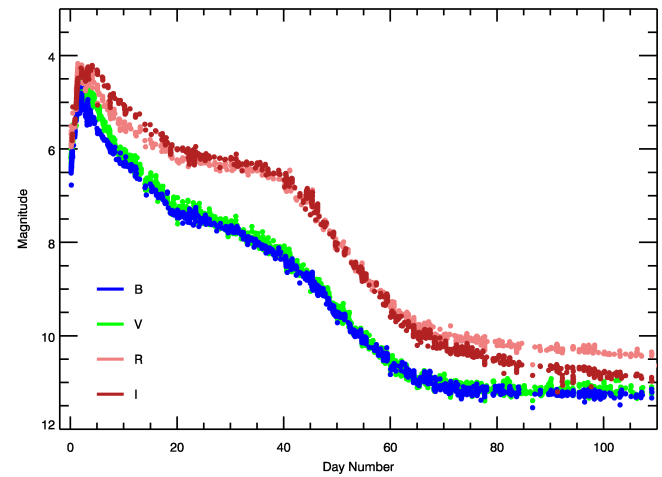


ONe Nova -
Coronal Phase



CO Nova -
Dust Cocoon Phase

Optical Light Curve of V339 Delphini

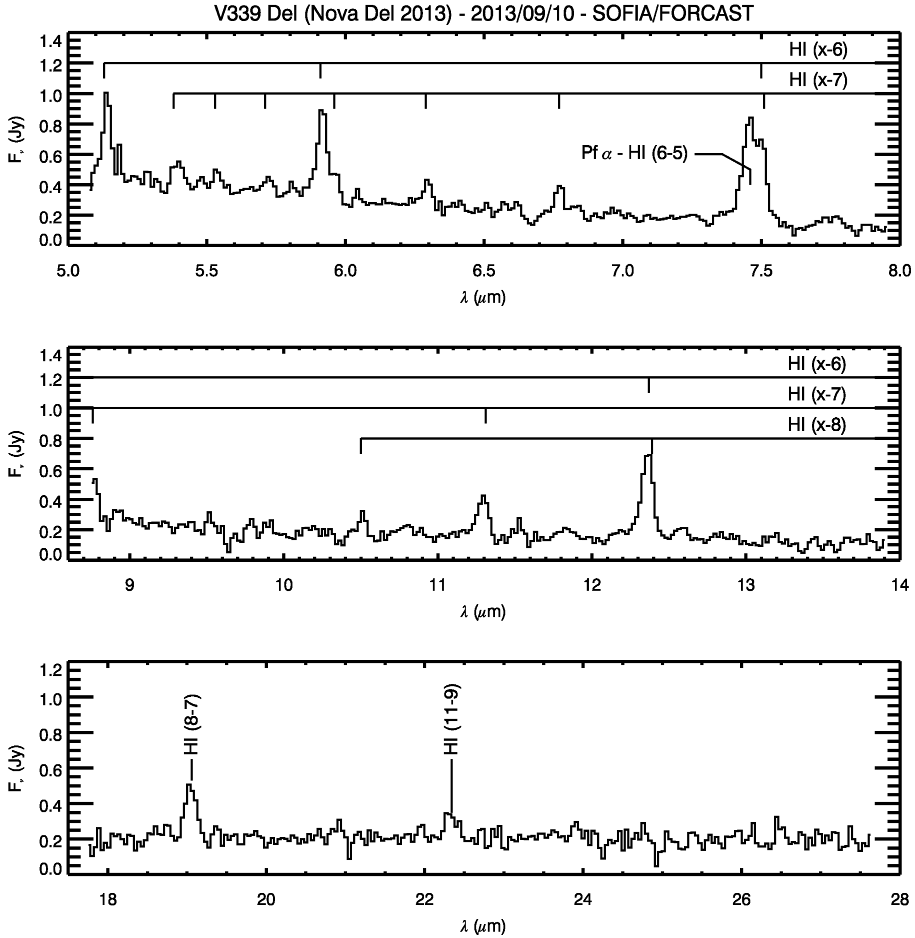


USRA

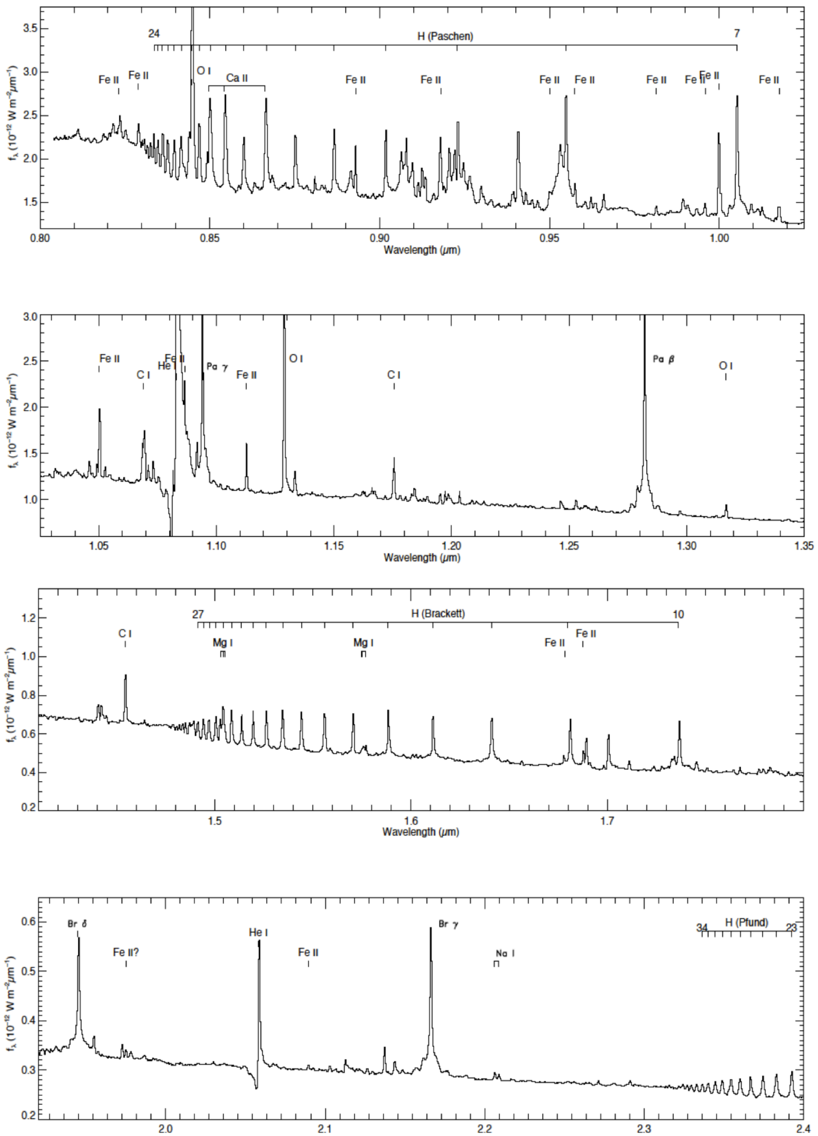
Observations of Classical Novae in Outburst

What are the science goals?

- Identify & measure emission lines
  - Determine physical properties in the ejecta
  - Estimate elemental abundances
  - Calculate ejecta mass
- Characterize emission line profiles
  - Determine ejecta kinematics
  - Characterize ejecta distribution
- Identify dust features (if present)
  - Determine dust species, e.g. silicates, hydrocarbons, etc.
  - Examine the processes of molecule formation, dust grain growth, and dust processing

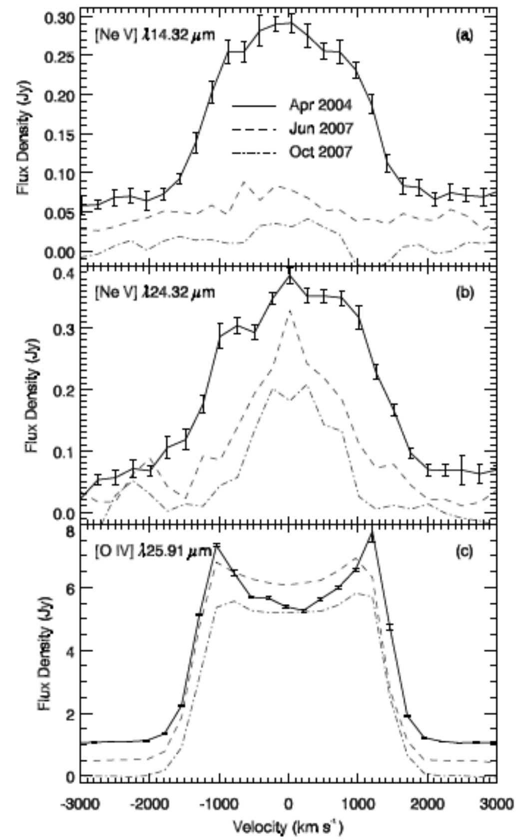


Observational Properties



Helton et al. 2015, in prep

- Rich suite of lines throughout the near- and mid-IR
- Typical line widths range from 500 – 4000 km/s

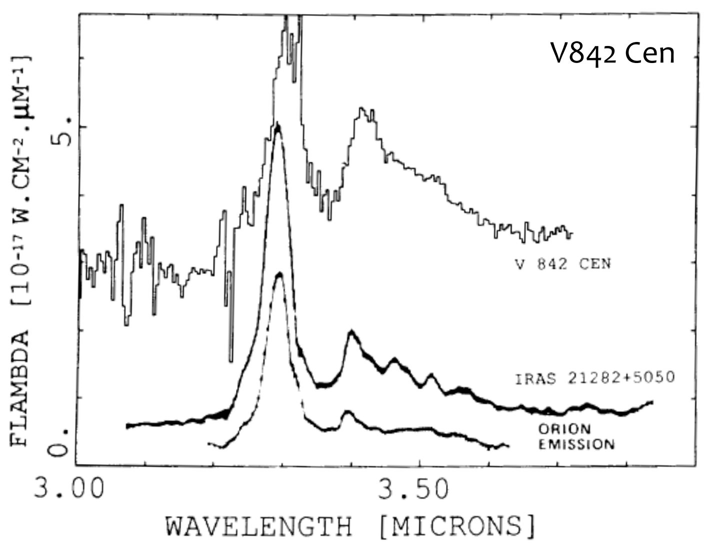


Helton et al. 2012, ApJ, 755, 37

Observational Properties

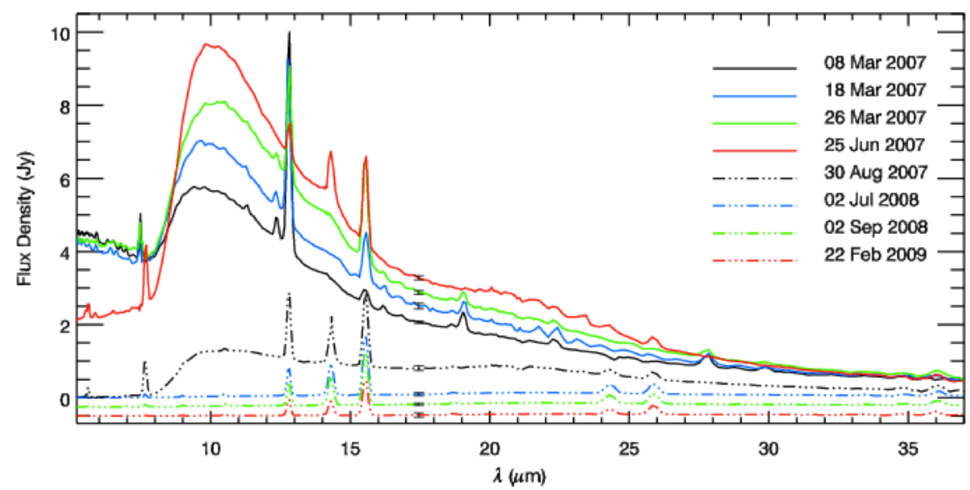
- Dust species include silicates, carbon, silicon carbide, hydrocarbons
- Dust features tend to be broad

⬇ Strong aromatic features at 3.3 μm and possible aliphatic features from 3.4 – 3.55 μm



Hyland & MacGregor, 1989

⬇ Silicates, silicon carbide, and a broad complex of hydrocarbons appear in the mid-IR

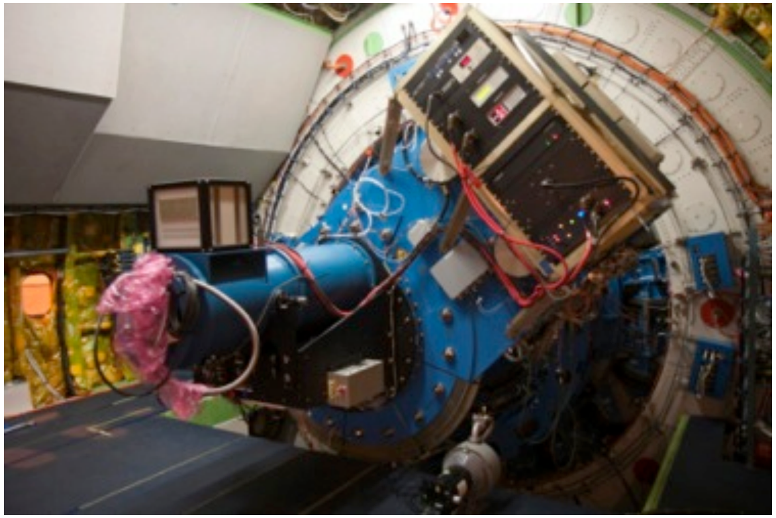


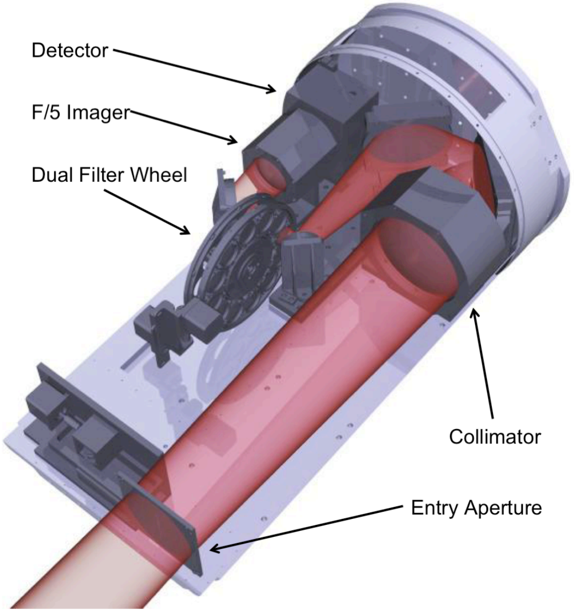
Helton et al. 2010, AJ, 140, 1347

FLITECAM Instrument Overview

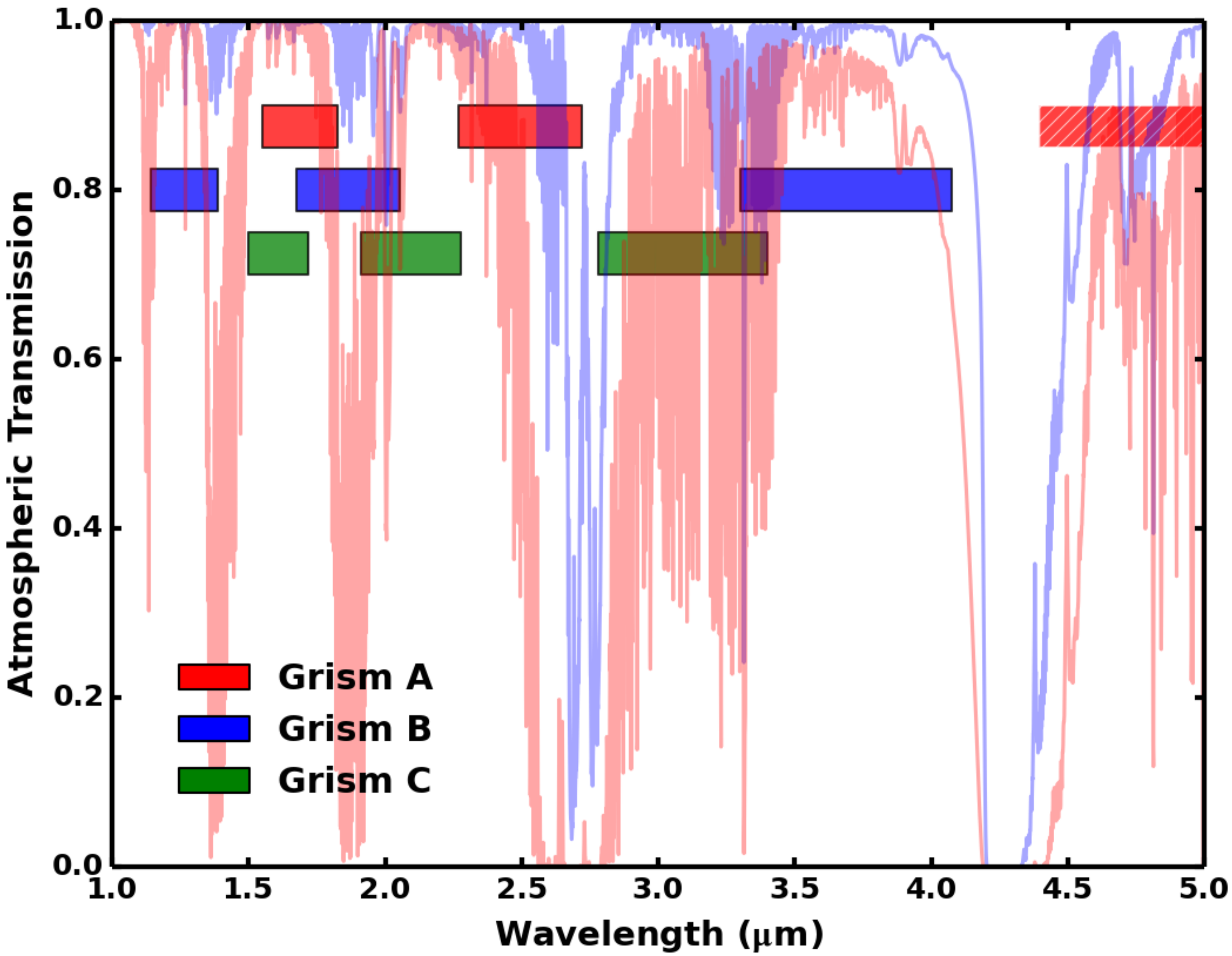
- FLITECAM – **F**irst **L**ight **I**nfrared **TE**st **CAM**era

- P.I. Ian McLean (UCLA)
  - Near-IR (1.0-5.5 μm) camera
    - 1024 x 1024 InSb Array
    - 8' x 8' FOV with 0.475" square pixels
  - Grism Spectrometer
    - 2' slit length
    - Dual width, 2" and 1" – R ~ 850 and 1700 respectively





Which FLITECAM Grisms to Use?



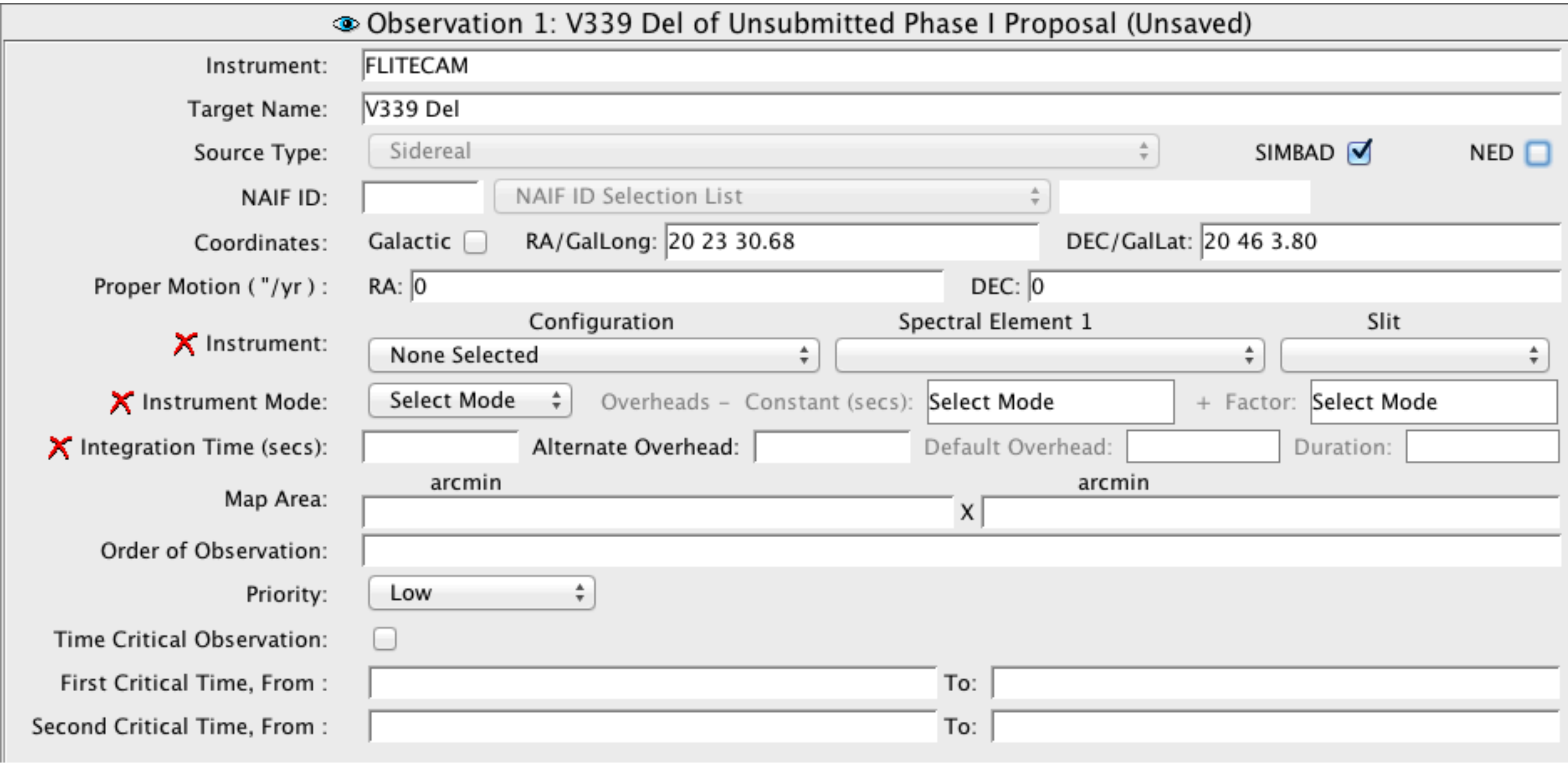
Which FLITECAM Grisms to Use?

Grism	Coverage (µm)	Resolution (WS/NS; R=λ/Δλ)	Features of Interest
FLT_B3_J	1.14-1.39	1425/1720	**O I**, **C I**, Fe II
FLT_C4_H	1.50-1.72	1400/1640	Mg I, Fe II
FLT_A3_Hw	1.55-1.83	1290/1710	Mg I, Fe II
FLT_B2_Hw	1.68-2.05	1320/1750	**He II**, Fe II
FLT_C3_Kw	1.91-2.28	1390/1650	Fe II, Na I
FLT_A2_KL	2.27-2.72	1140/1690	
FLT_C2_LM	2.78-3.40	1300/1670	Aromatics
FLT_B1_LM	3.30-4.07	1200/1780	Aromatics + Aliphatics
FLT_A1_LM	4.40-5.53	-/-	

Low Res: Δv ~ 210 – 260 km/s

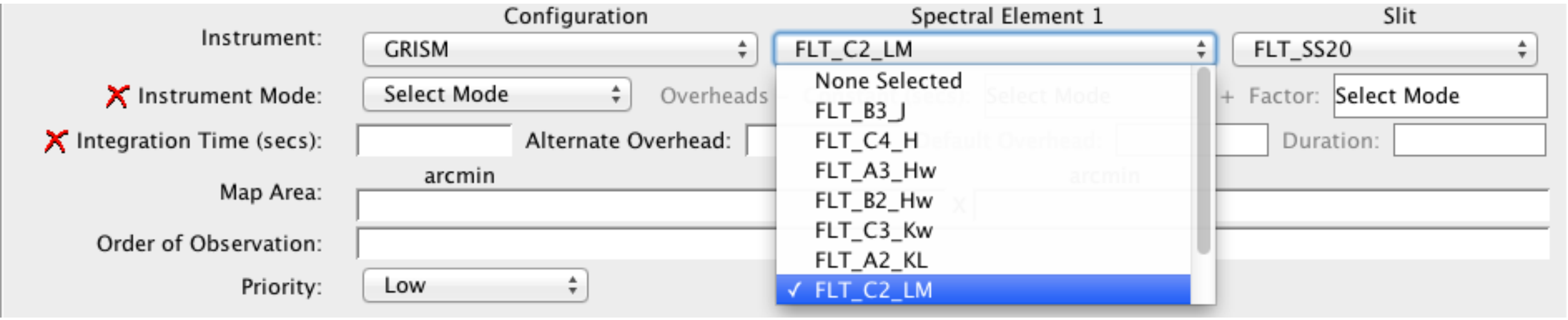
High Res: Δv ~ 170 – 180 km/s

FLITECAM Grism Observations in SPT

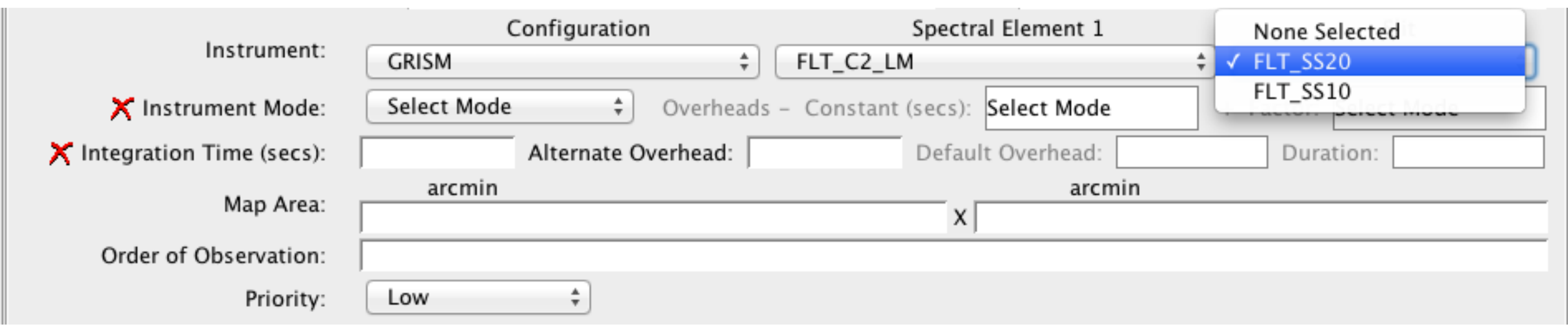


FLITECAM Grism Observations in SPT

- Select the grism from the pull-down menu

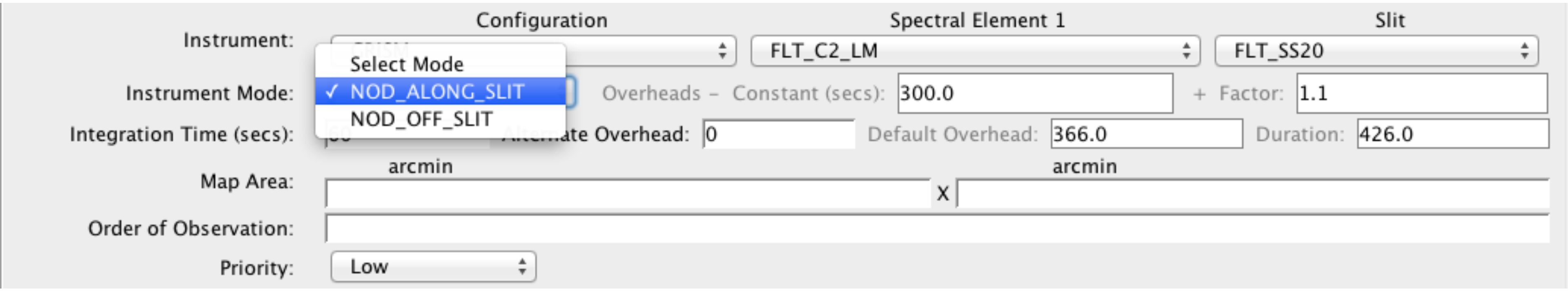


- Select the slit



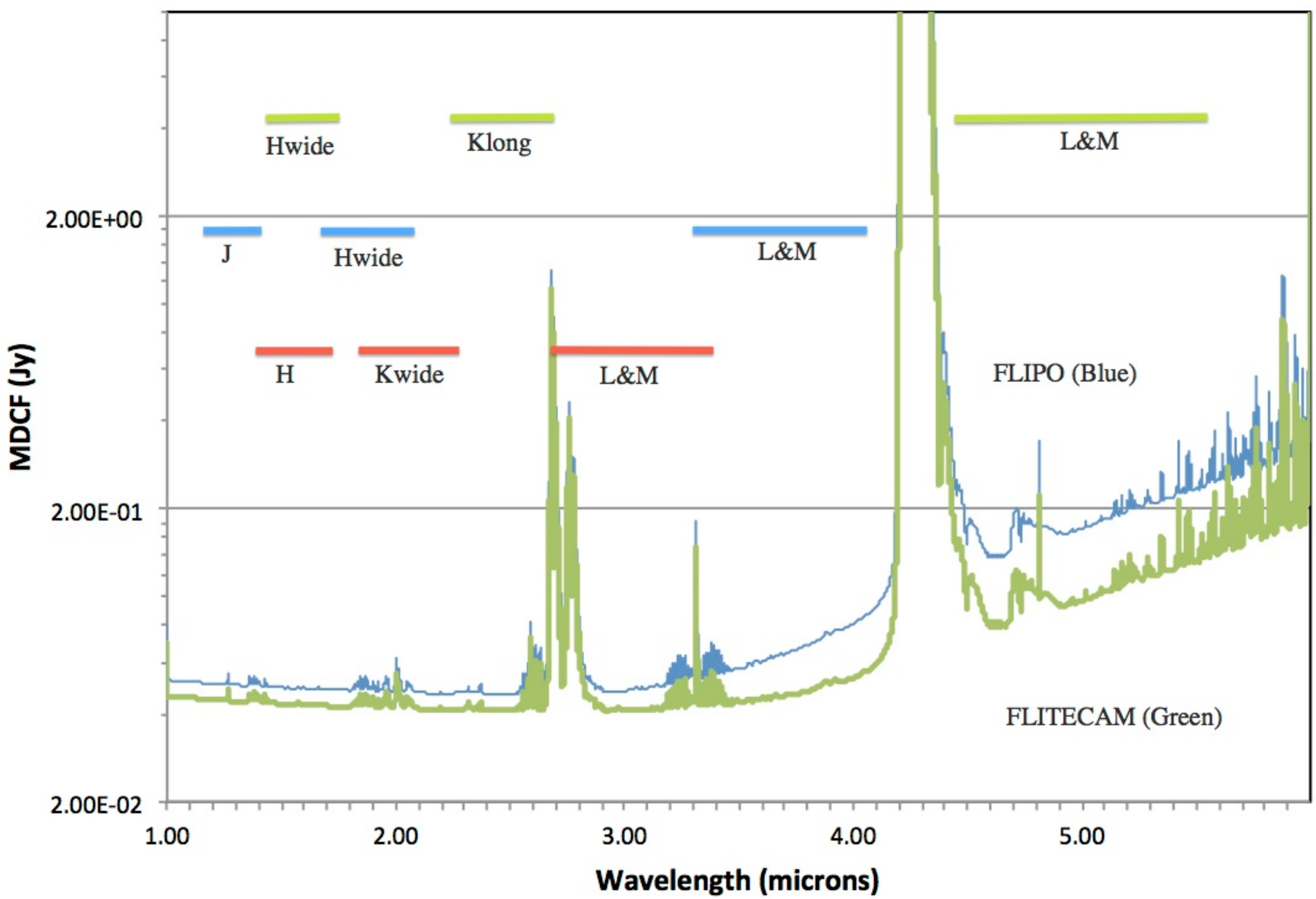
Selecting the FLITECAM Instrument Mode

⬇ Select the Instrument Mode



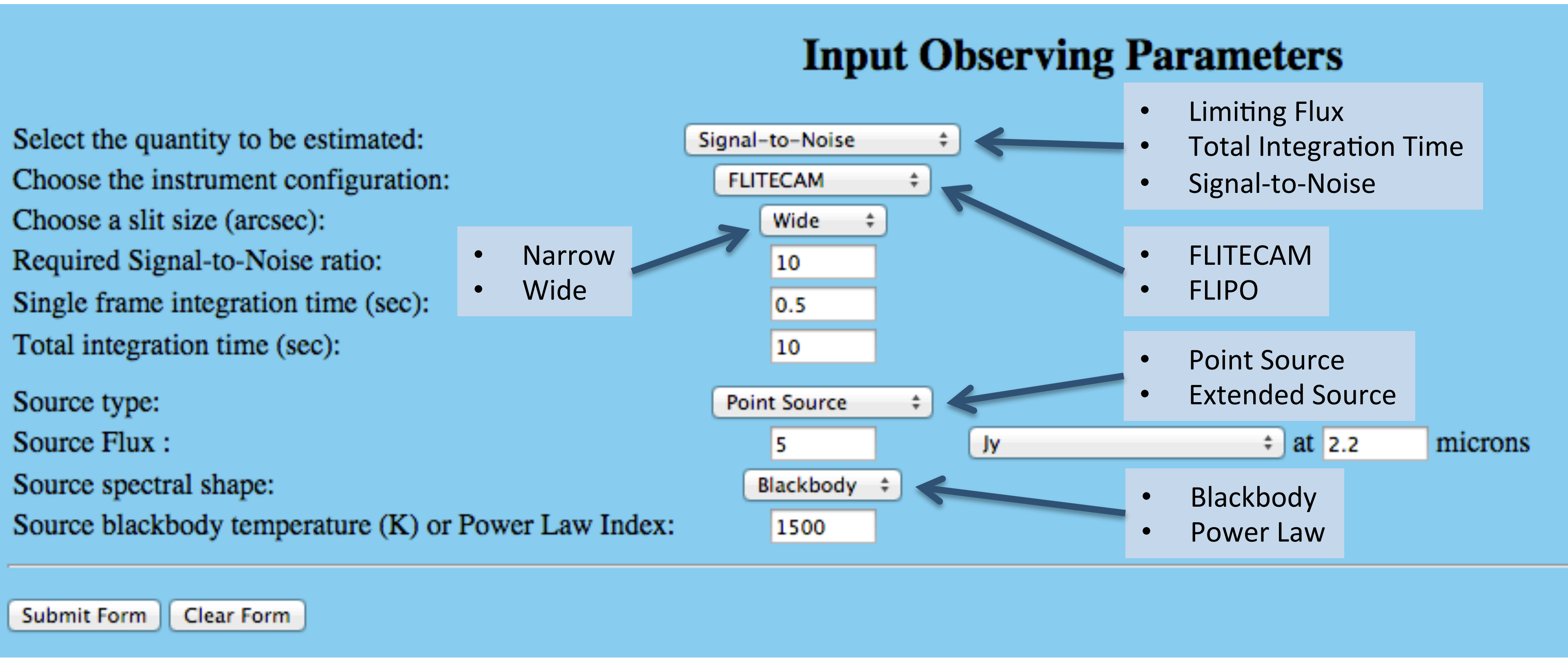
- Two grism observing modes available:
  - Nod-Along-Slit
    - Primarily for point sources
    - Low observing overheads
  - Nod-Off-Slit
    - Primarily for extended sources
    - High observing overheads

FLITECAM Grism Sensitivities



Determining FLITECAM Integration Times

- Estimate the source flux & enter into the FLITECAM on-line exposure time estimator
  - https://flitecam.sofia.usra.edu/cgi-bin/flitecam/flitecam_calc3.cgi



Determining FLITECAM Integration Times

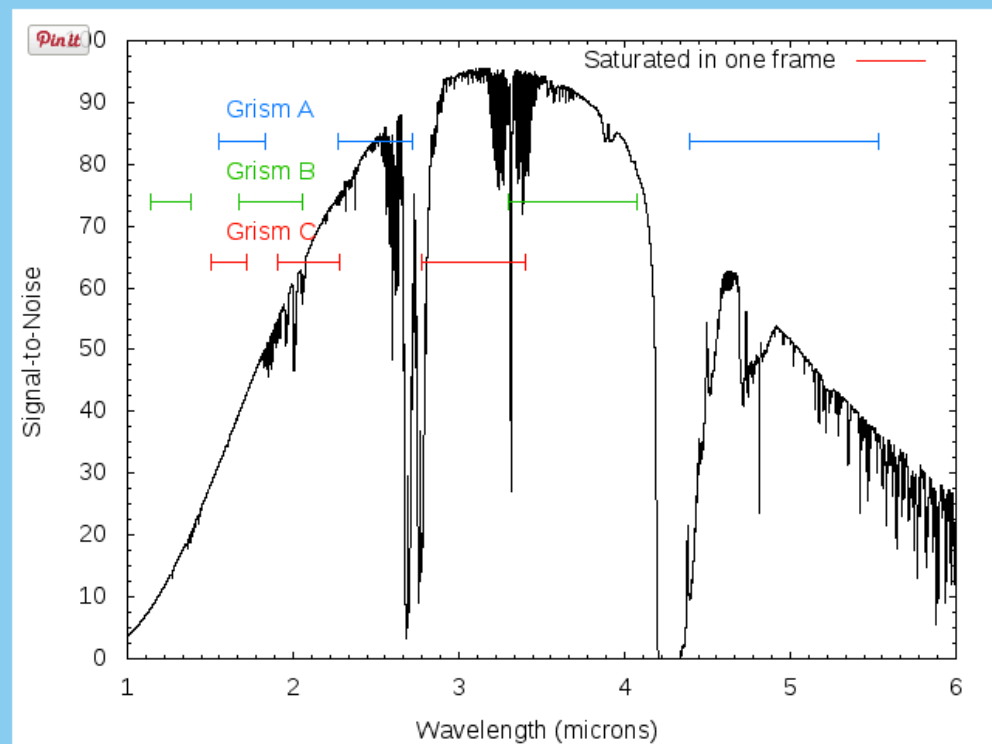
Input Parameters

Mode:	Signal-to-Noise
Configuration:	FLITECAM
Slit:	1.6 arcsec
Single frame exposure time:	0.1 sec
Total exposure time:	60 sec
Source flux :	3.097e-12 W/m2/micron at 2.2 microns
Source blackbody temperature:	1500 K

View output data file

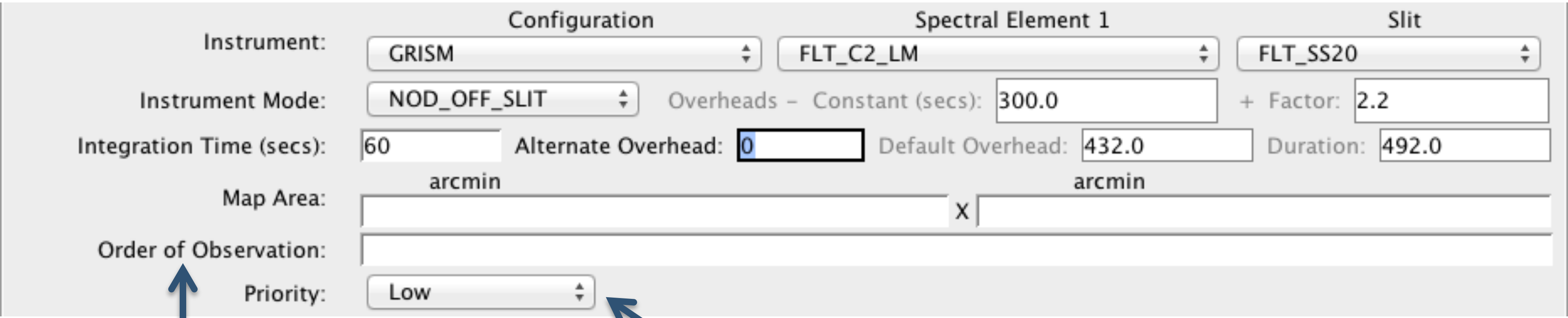
```
Instrument Configuration: FLITECAM
Slit size  =  1.600 arcsec
Resolution = 1300.0
Single frame exposure time =    0.100 sec
Number of Coadds           =    600.000000
Total Exposure Time        =    60.0000000      sec
Input flux : 0.3097E-11 W/m2/micron at  2.200 microns

Wavelength (microns)       FWHM (arcsec)       Fractional Slit Transmission
--------------------       -------------       ----------------------------
   1.250                      3.60                     0.34
   1.650                      3.50                     0.35
   2.200                      3.42                     0.35
   3.550                      3.37                     0.36
   3.760                      3.37                     0.36
   4.750                      3.38                     0.36

Signal-to-Noise Ratio
---------------------
J        :     13.136
H        :     38.088
K        :     70.499
L        :     93.145
Lprime   :     90.654
M        :     47.201
```

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



FLITECAM Grism Observations in SPT

- Input the desired On-Source Integration Time



Priority *amongst targets* in the program
- Low
- Medium
- High

Order of Observation *between* the different *Instrument Configurations* in the program

FORCAST Instrument Overview

- FORCAST - **F**aint **O**bject infra**R**ed **CA**mera for the **S**OFIA **T**elescope

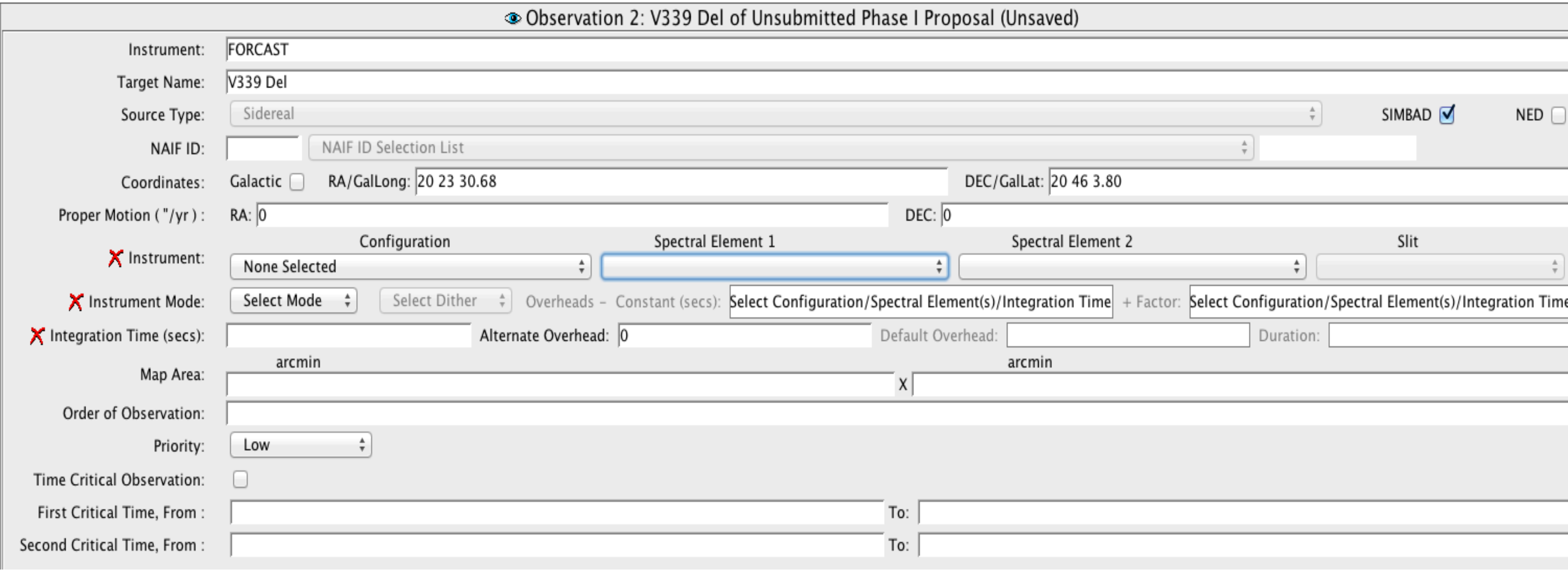
- Imaging - P.I. Terry Herter (Cornell)
  - Dual Channel, mid-IR (5-40 µm) camera
    - Short Wave Camera (SWC) – Si:As BiB Array – $\lambda < 25$ µm
    - Long Wave Camera (LWC) – Si:Sb BiB Array – $\lambda > 25$ µm
    - 3.4’ x 3.2’ FOV with 0.768” square pixels

- Spectroscopy – P.I. Luke Keller (Ithaca College)
  - Grism Spectroscopy
    - Low Resolution from 5-40 µm at R ~ 200

Which FORCAST Grisms to Use?

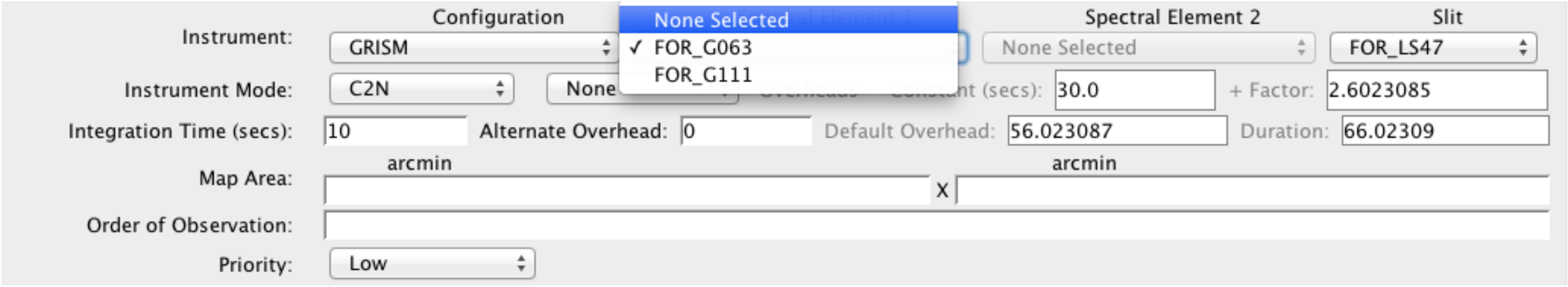
Grism	Coverage (µm)	Resolution (WS/NS) (R=λ/Δλ)	Resolution (WS/NS) (Δv [km/s])	Features of Interest
FOR_G063	4.9-8.0	90/180	3000/1670	[Mg V]; [Mg VII]; [Ne VI]; [Ar II] PAHs
FOR_G111	8.4-13.7	150/300	2000/1000	[Ar III]; [S IV]; [Ne II] PAHs, Silicates, SiC
FOR_G227	17.6-27.7	70/140	4290/2140	[S III]; [Ne V]; [O IV] Silicates
FOR_G329	28.7-37.1	110/220	2730/1360	[S III]; [Ne III]

FORCAST Grism Observations in SPT

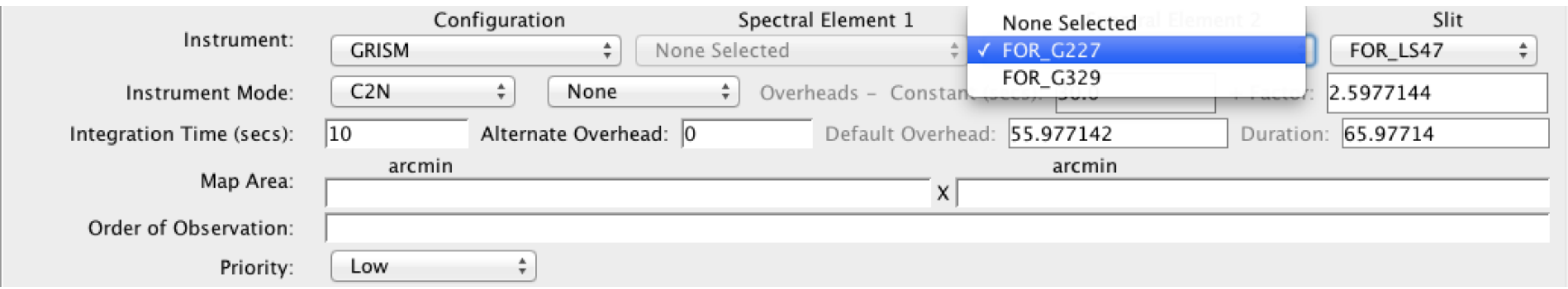


FORCAST Grism Observations in SPT

- Choose the desired grism for the SWC

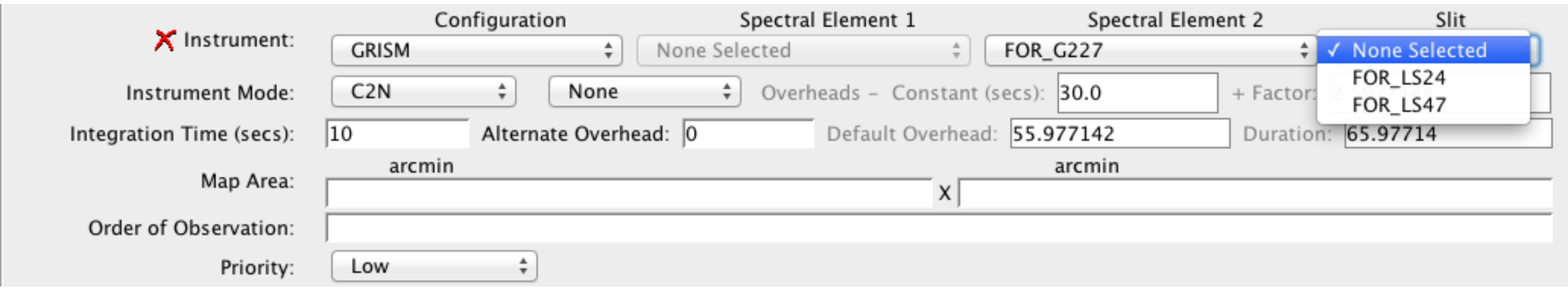


- Choose the desired grism for the LWC



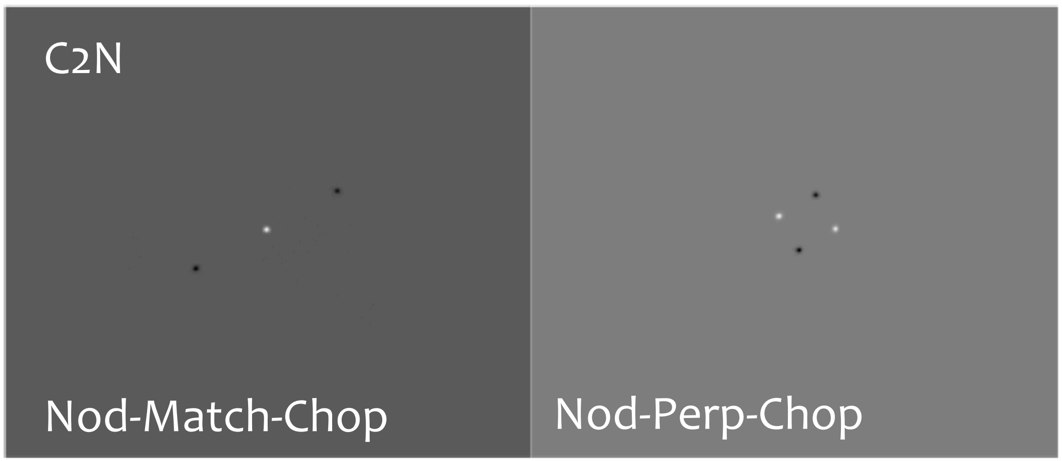
FORCAST Grism Observations in SPT

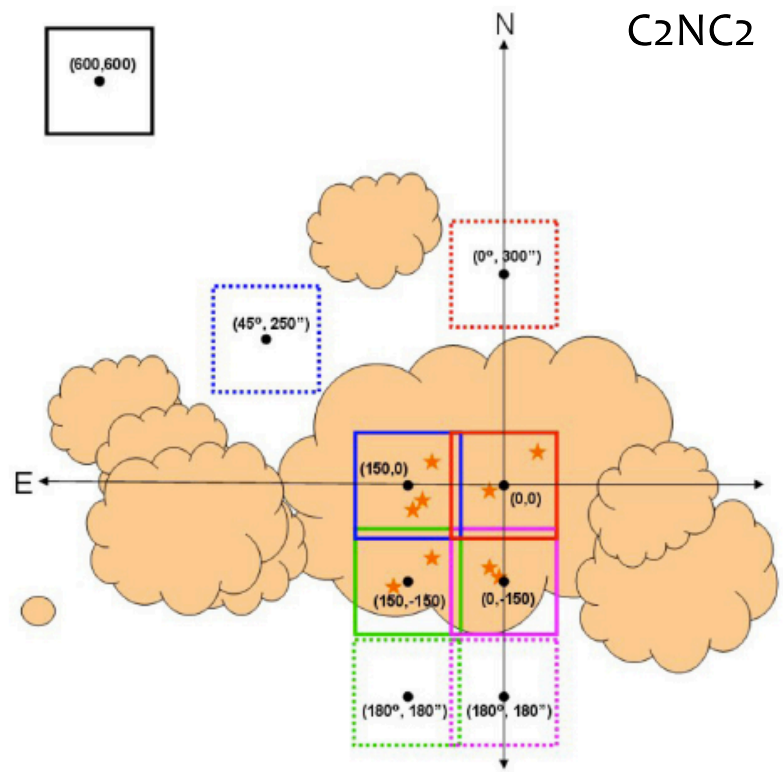
- Choose the desired slit width



FORCAST Observing Modes

- Observing Modes - Imaging
  - 2 Position Chop and Nod (C2N)
  - 2 Position Chop / Offset Nod (C2NC2)





FORCAST Observing Modes

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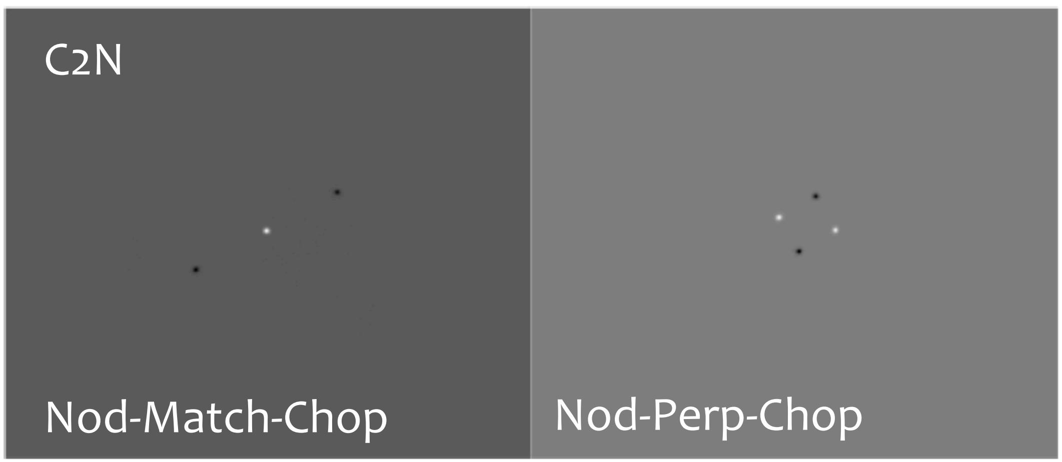
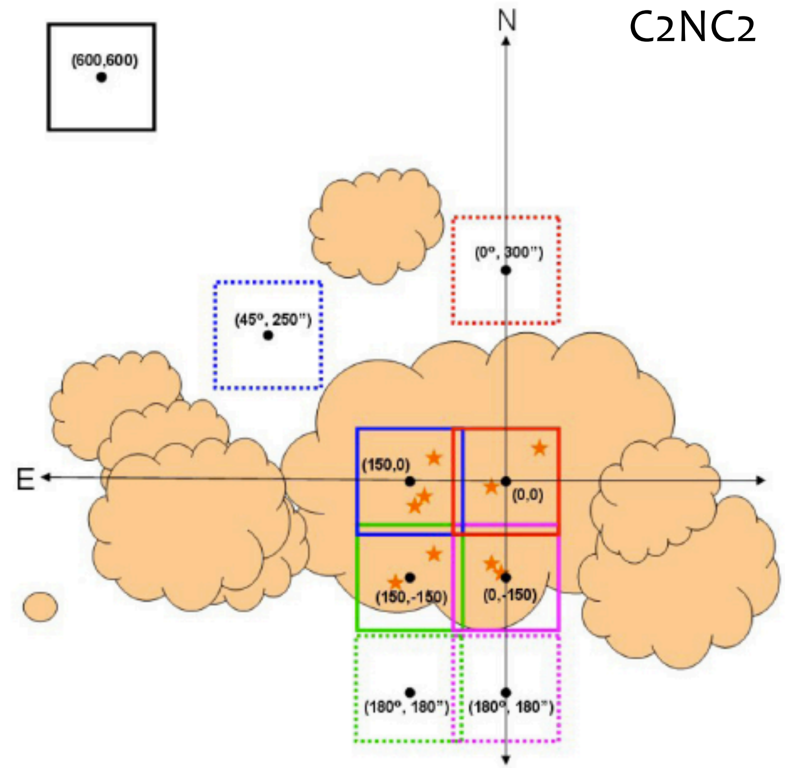


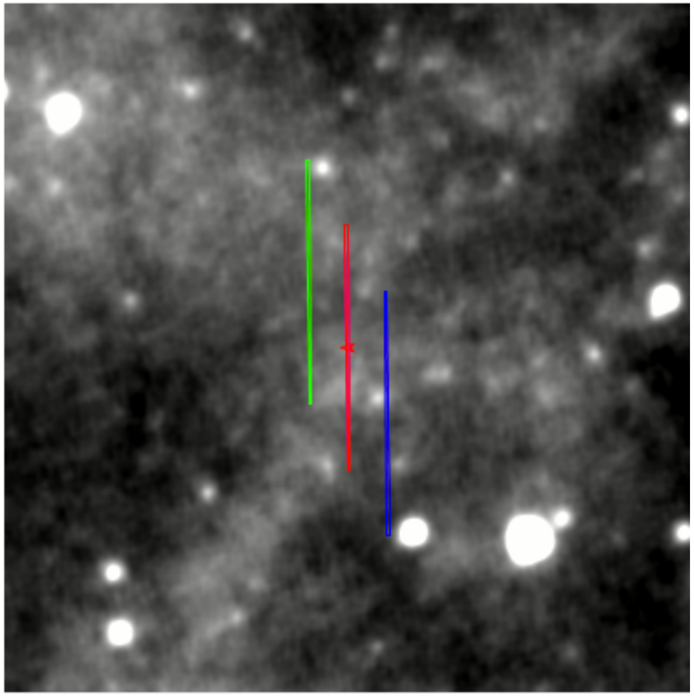
C2NC2



- Observing Modes – Grism Spectroscopy
  - 2 Position Chop and Nod (C2N)
  - Nod Unassociated w/ Chop, Asymmetric Chop (NXCAC)
    - Conceptually very similar to C2NC2

FORCAST Instrument Mode – C2N or NXCAC?

- Check images of the field to see if there is extended emission
  - Download the SSpot tool (https://dcs.sofia.usra.edu/observationPlanning/installSSPOT/sspotDownload.jsp)
  - Generate a placeholder grism observation of the target
  - Download an image from the database
  - Overlay the observation on the image



WISE Band 3

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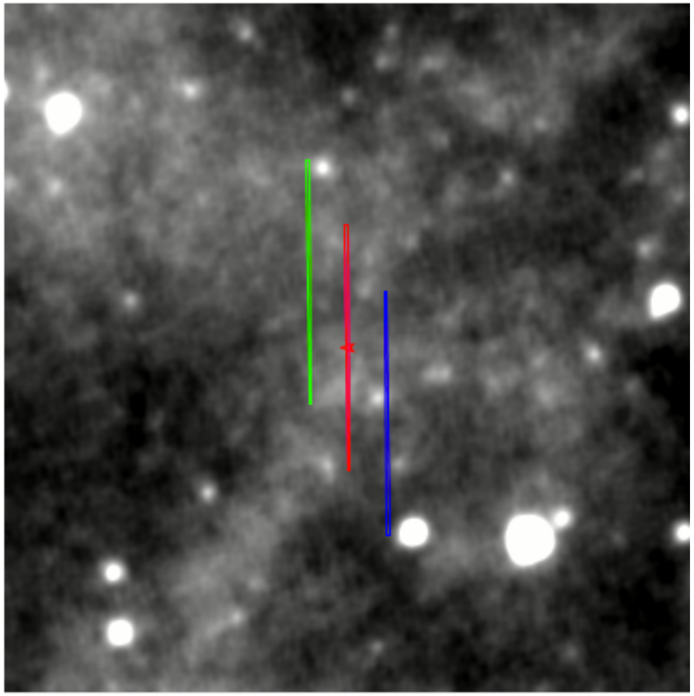
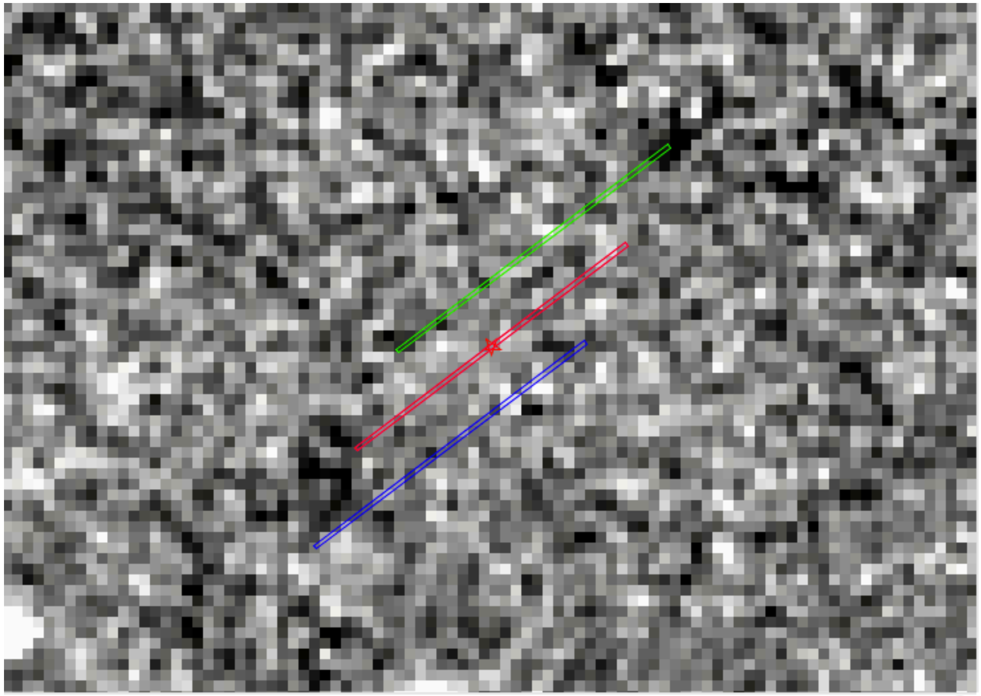
  - Generate a placeholder grism observation of the target
  - Download an image from the database
  - Overlay the observation on the image



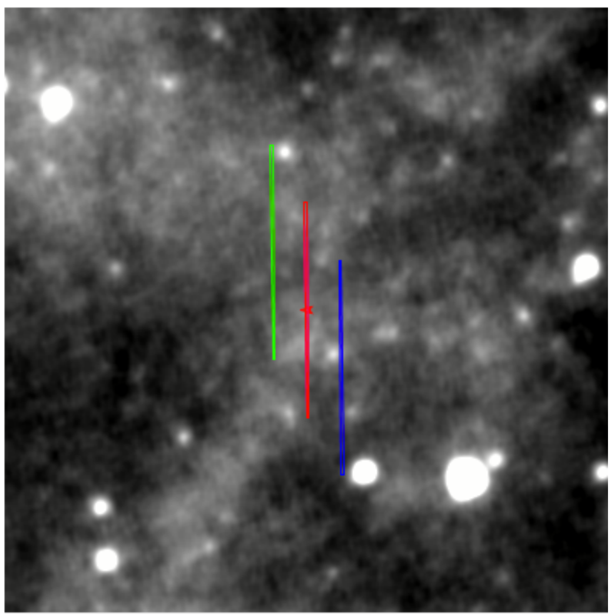
WISE Band 3

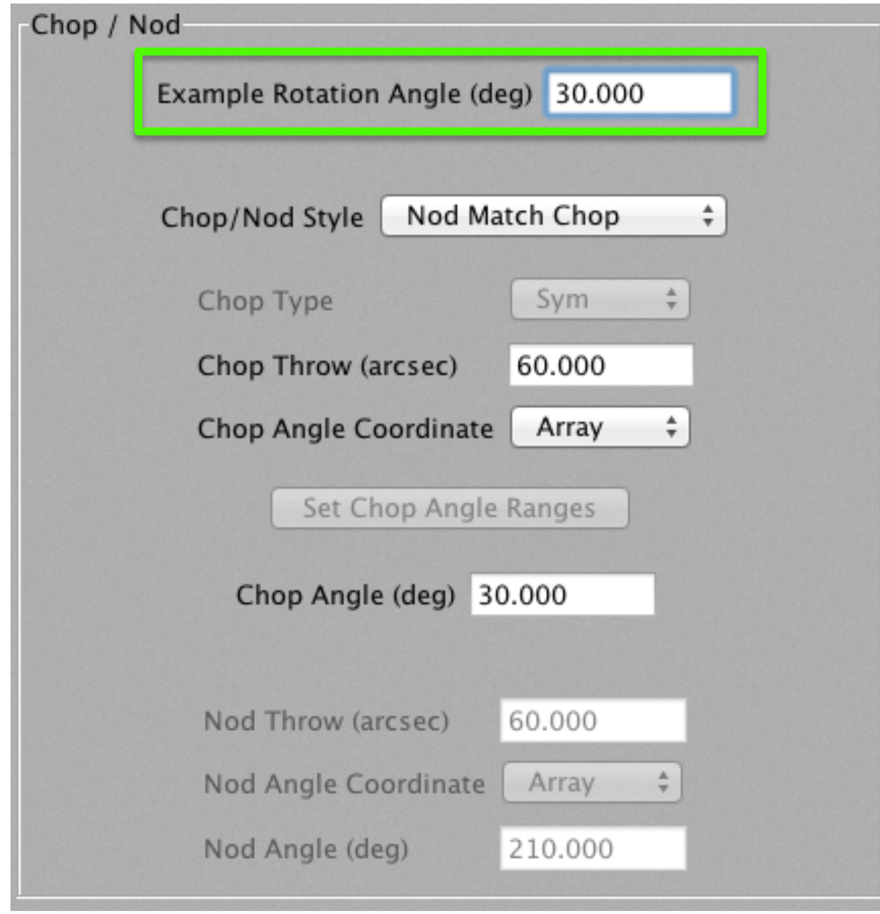


MSX-C

Other Considerations – Slit Orientation

- The SOFIA telescope does not have an instrument rotator
- Neither FLITECAM nor FORCAST have a field rotator
- The rotation of field cannot be known *a priori*, but only after flight planning
  - Default is 0° rotation





SSpot AOR Definition – Chop/Nod Parameters

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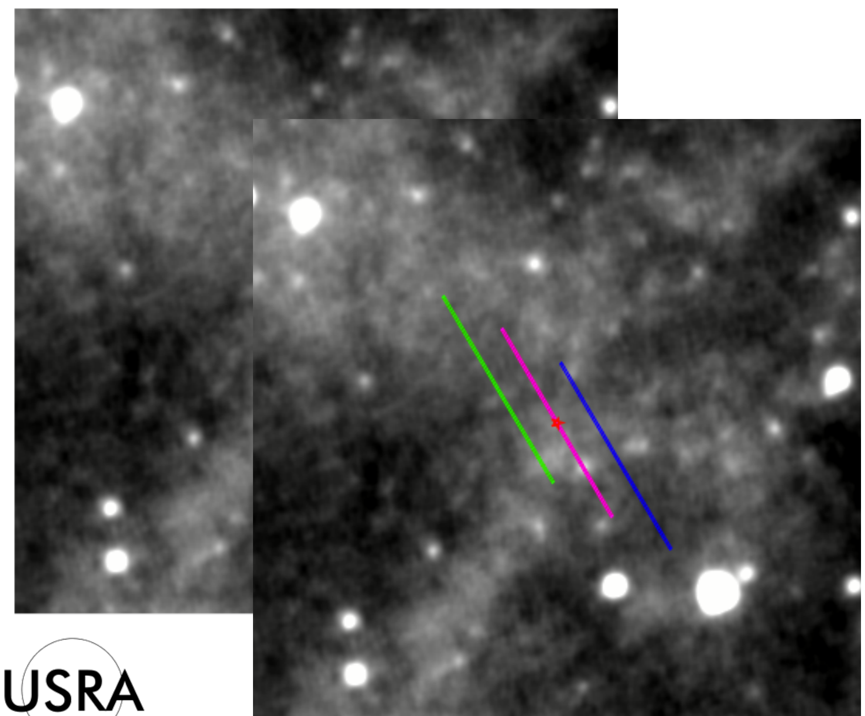

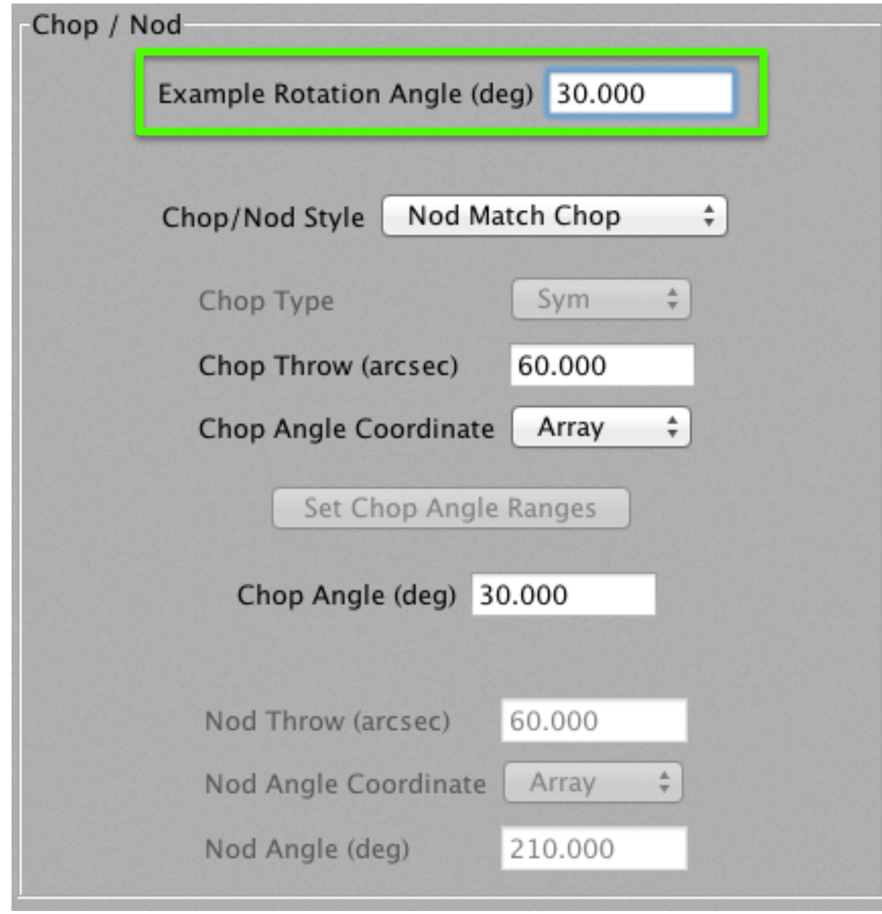

SSpot AOR Definition – Chop/Nod Parameters

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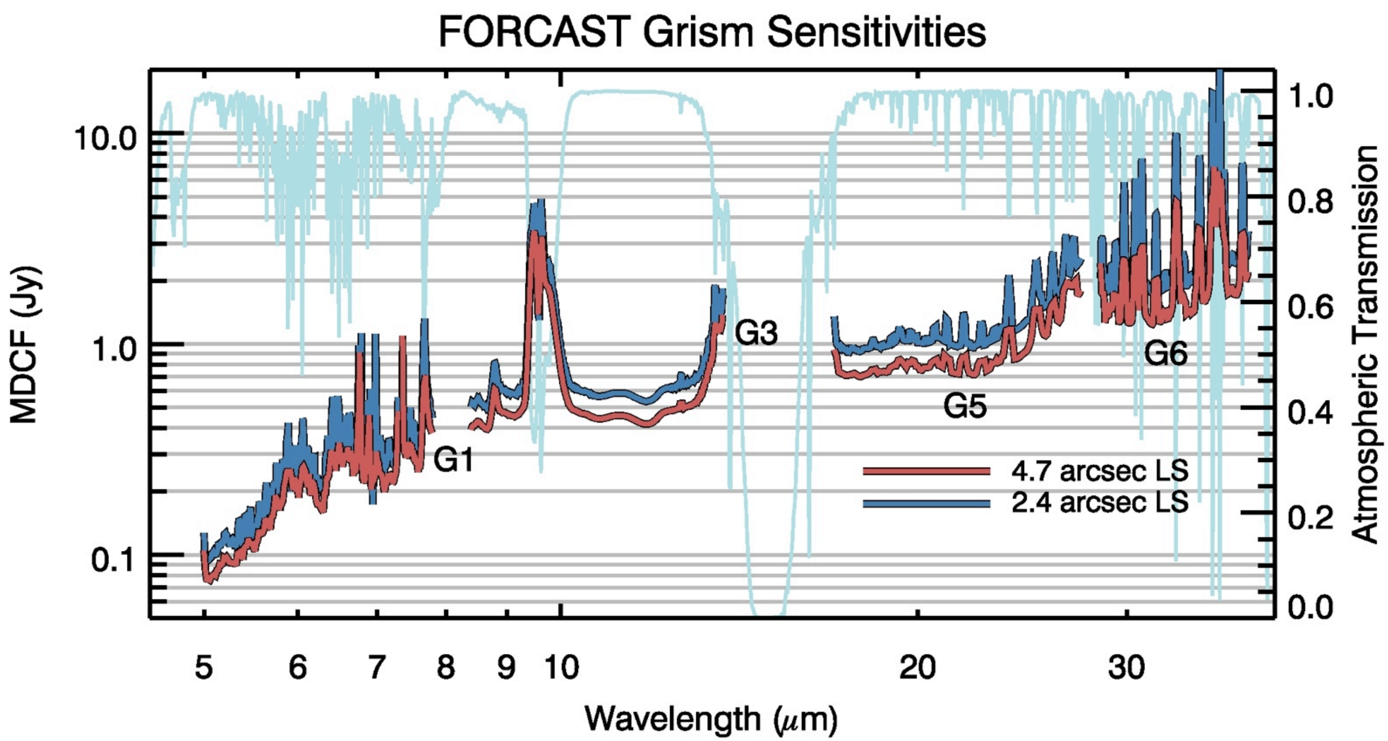
FORCAST Grism Sensitivities

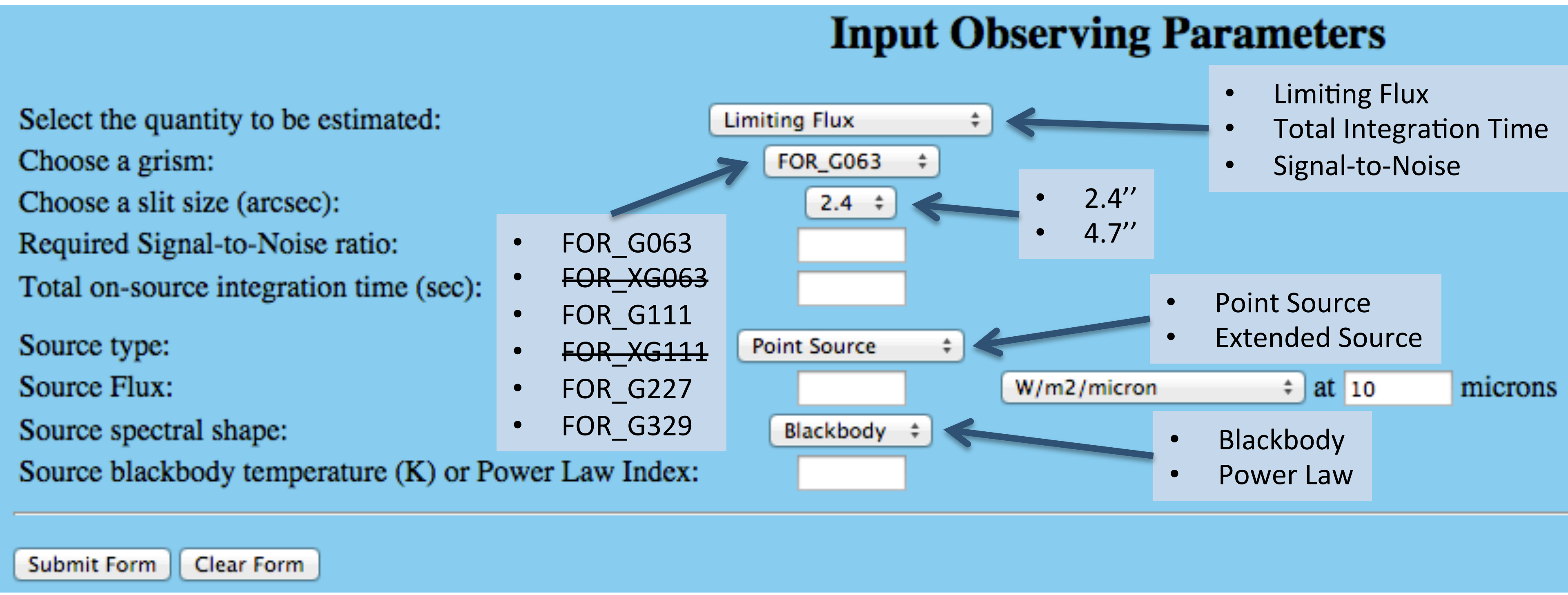


$$\frac{[S/N]_{req}}{4} = \frac{F_{src} \cdot \sqrt{t_{exp}}}{MDCF \cdot \sqrt{900}}$$

- $[S/N]_{req}$ = required S/N
- F_{src} = source flux
- t_{exp} = on-source exposure time
- *MDCF* = minimum detectable continuum flux

Determining FORCAST Integration Times

- Estimate the source flux & enter into the FORCAST on-line exposure time estimator
    - https://forcast.sofia.usra.edu/cgi-bin/forcast/forcast_grisms_calc.cgi



Determining FORCAST Integration Times

FORCAST Grism Calculator Output

Input Parameters

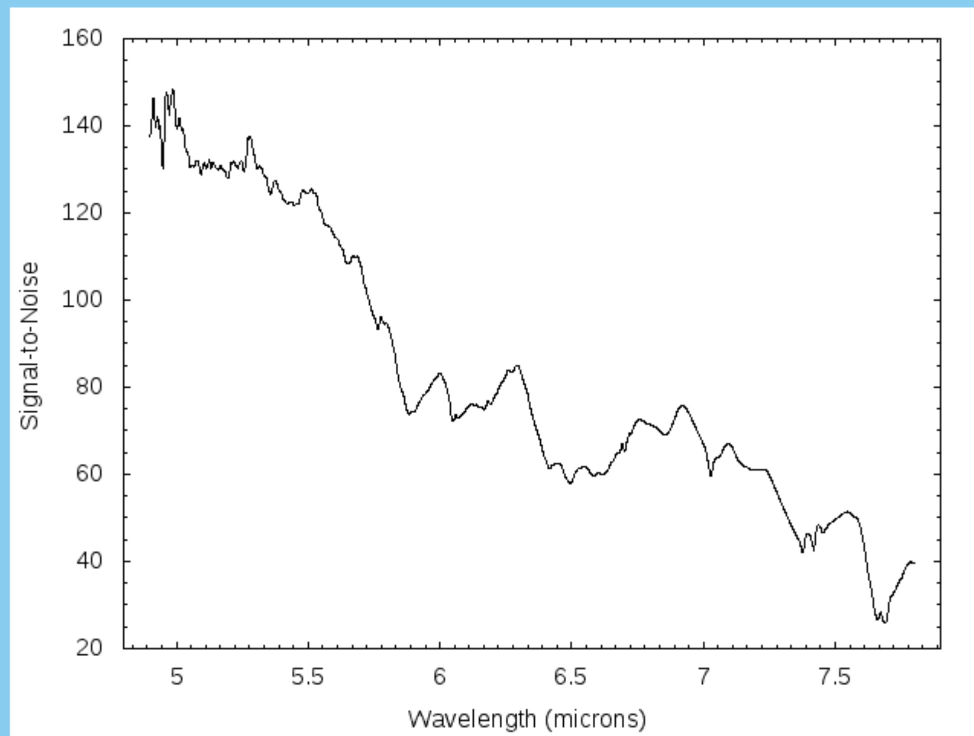
Mode:	Signal-to-Noise
Grism:	1
Slit:	4.7 arcsec
Source flux :	1.499e-13 W/m2/micron at 10 microns
Source blackbody temperature:	1500 K
Total exposure time:	60 sec

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
```

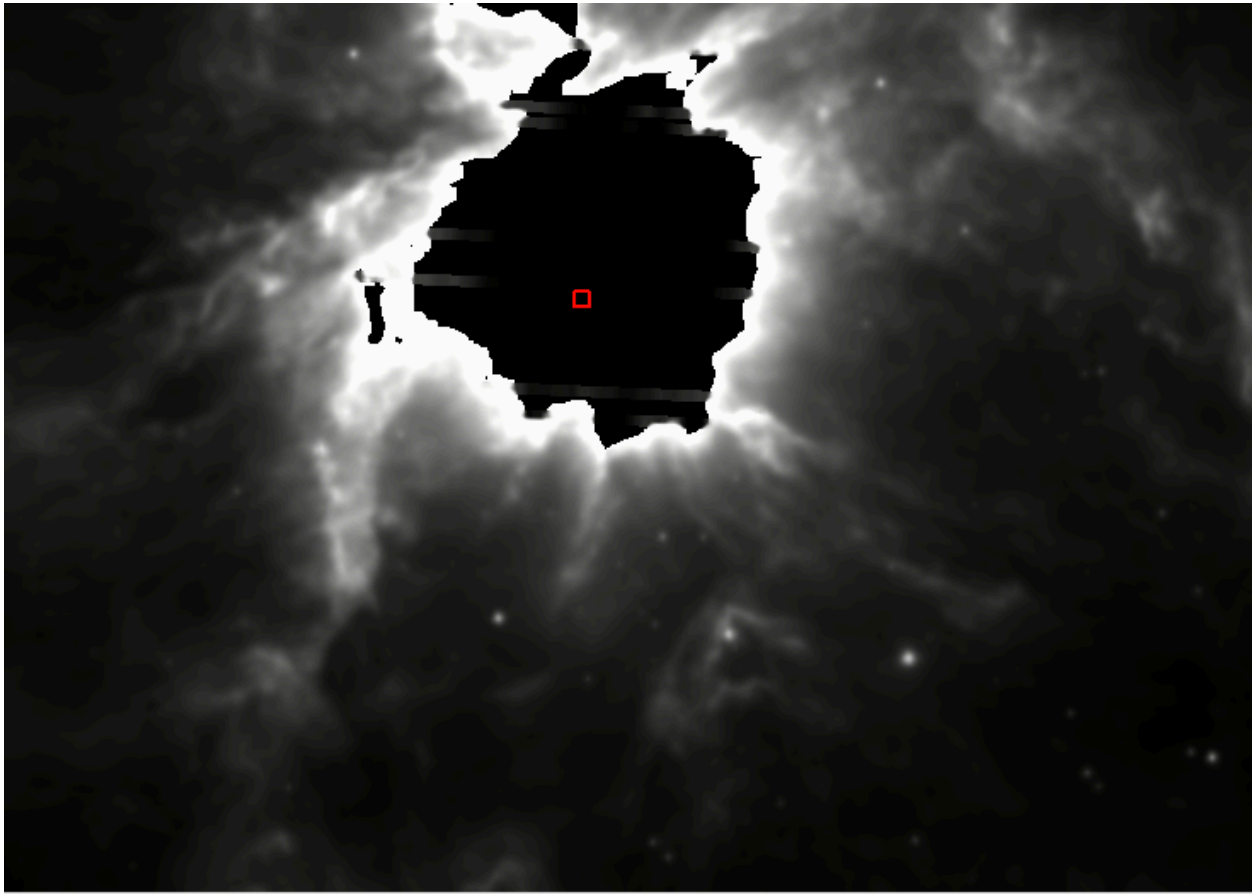
Plot of Signal-to-Noise as a function of Wavelength



USRA

Other Considerations – Extended Emission

FORCAST Spectroscopy of PAH emission in the Orion-A molecular cloud



Orion Bar – WISE Band 3

Other Considerations – Extended Emission

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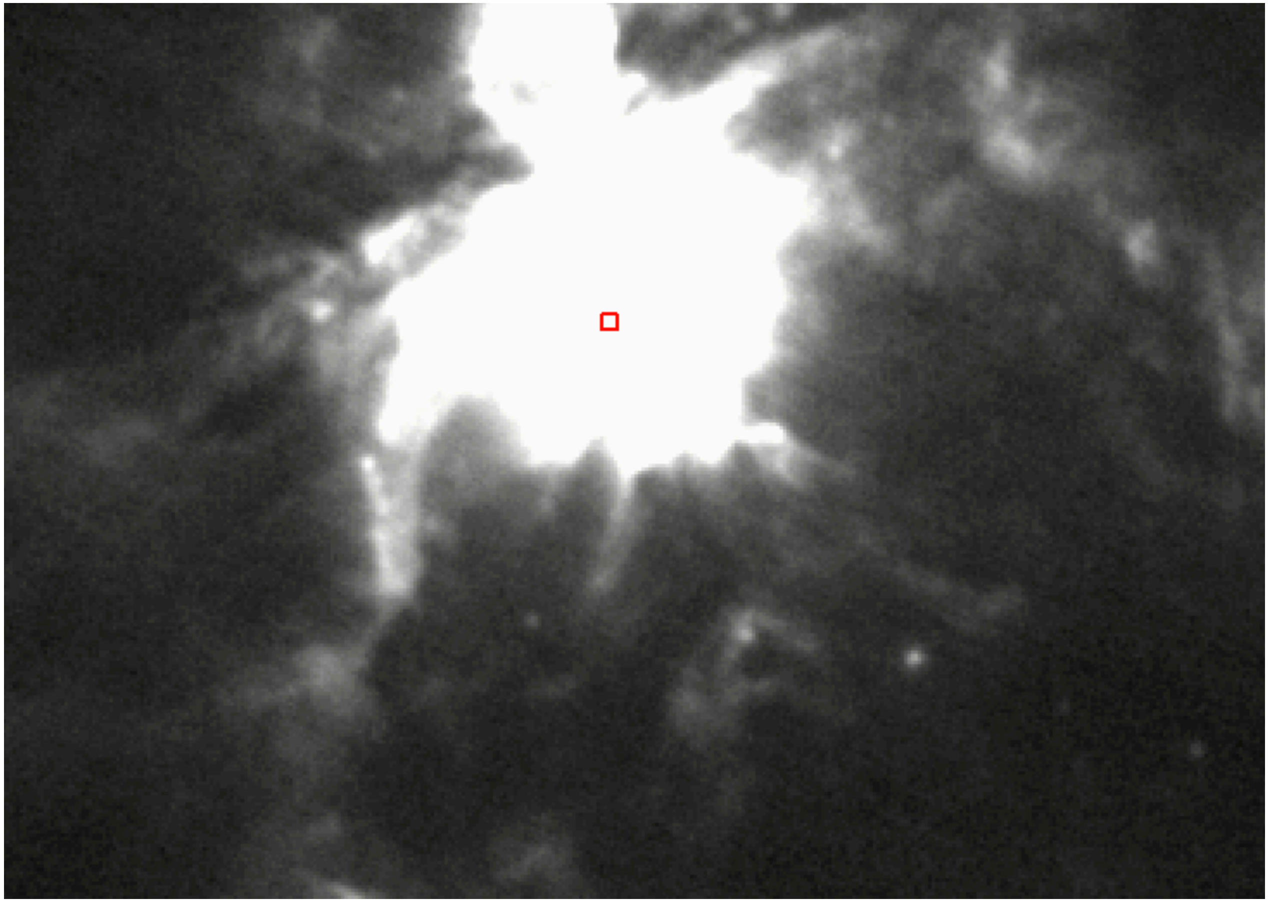
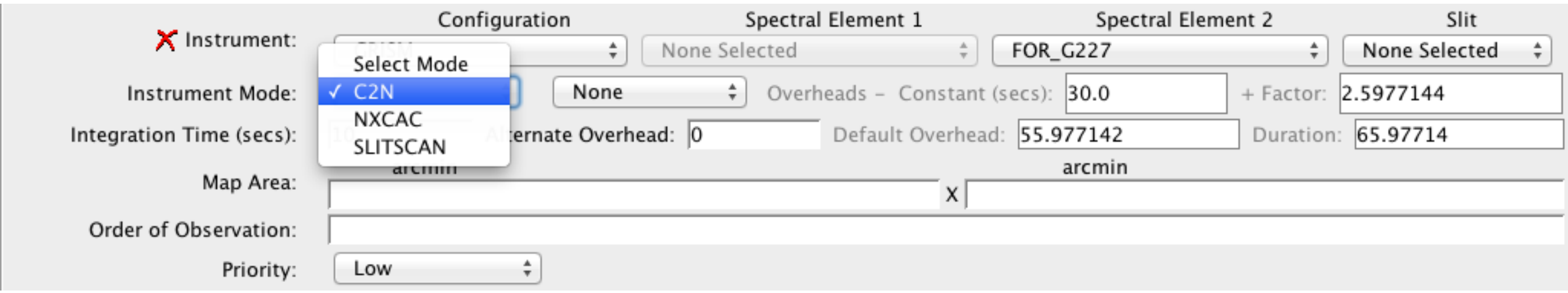


Orion Bar – MSX-C

Other Considerations – Extended Emission

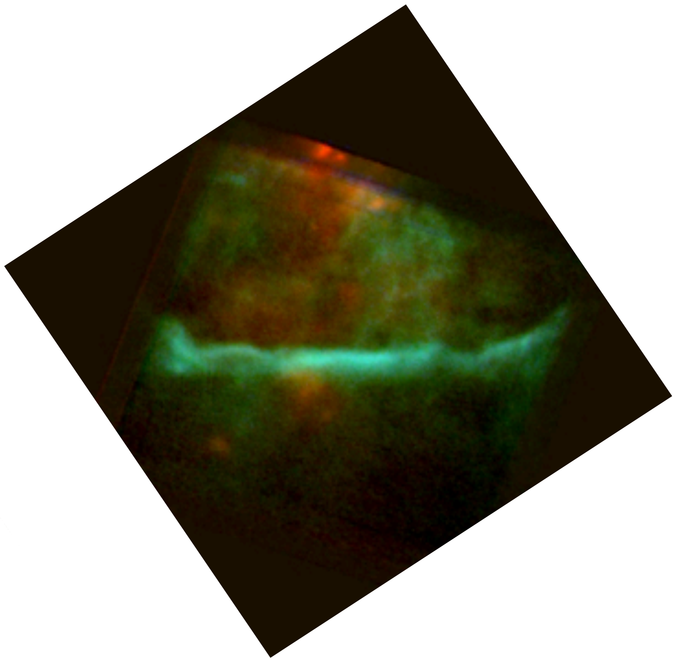
Choose the desired Instrument Mode



- Three grism observing modes available:
  - C2N – Two Position Chop & Nod
    - Primarily for point sources
    - Low observing overheads
  - NXCAC – Nod Unassociated with Chop, Asymmetric Chop
    - Primarily for extended sources or sources in regions of high background
    - High observing overheads
  - Slitscan
    - Series of observations dithered perpendicular to the slit length
    - Allows spectral mapping of extended regions

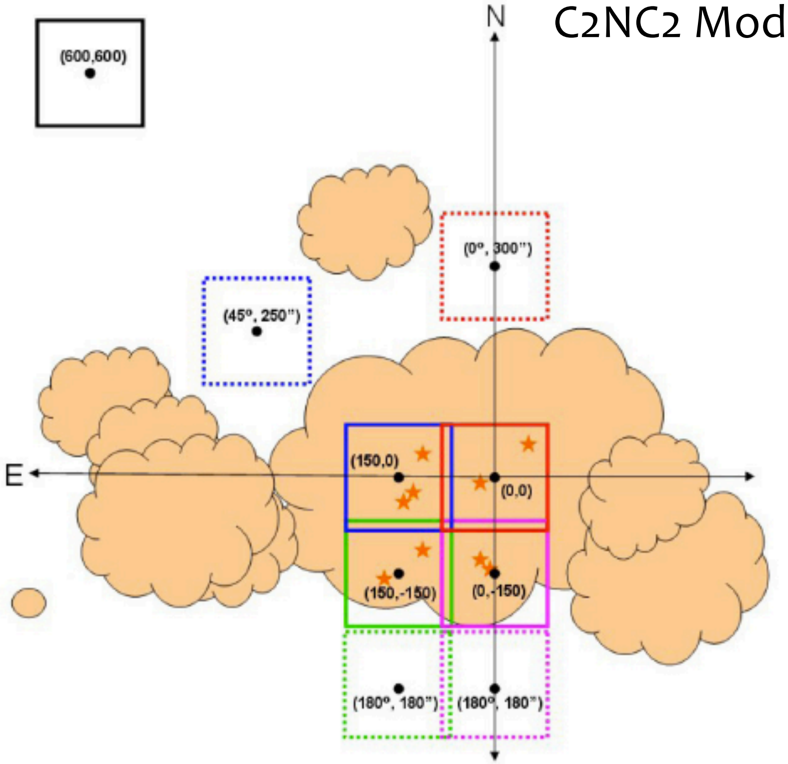
Other Considerations – Extended Emission

FORCAST Spectroscopy of PAH emission in the Orion-A molecular cloud

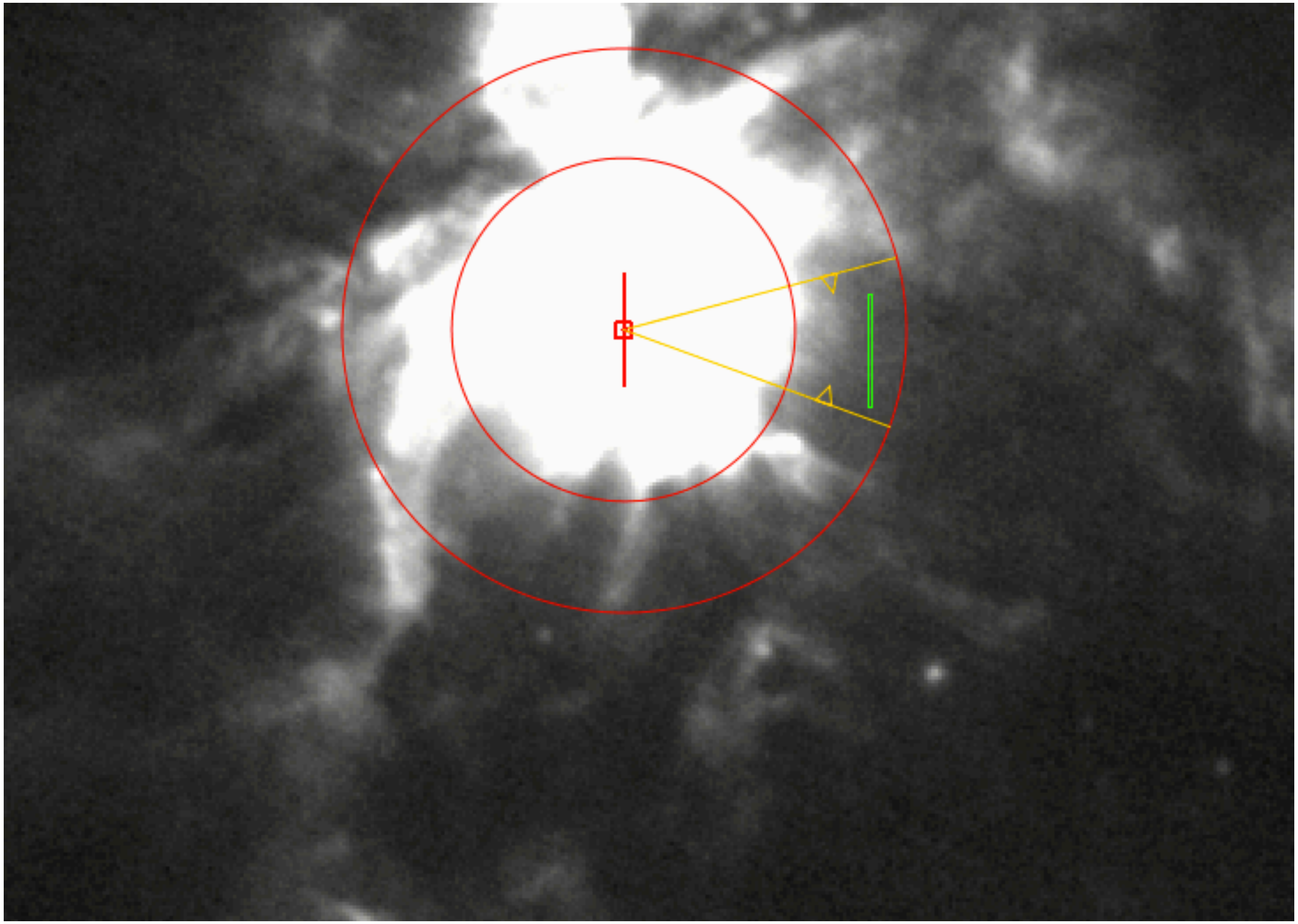


Orion Bar – SOFIA/FORCAST

C2NC2 Mode



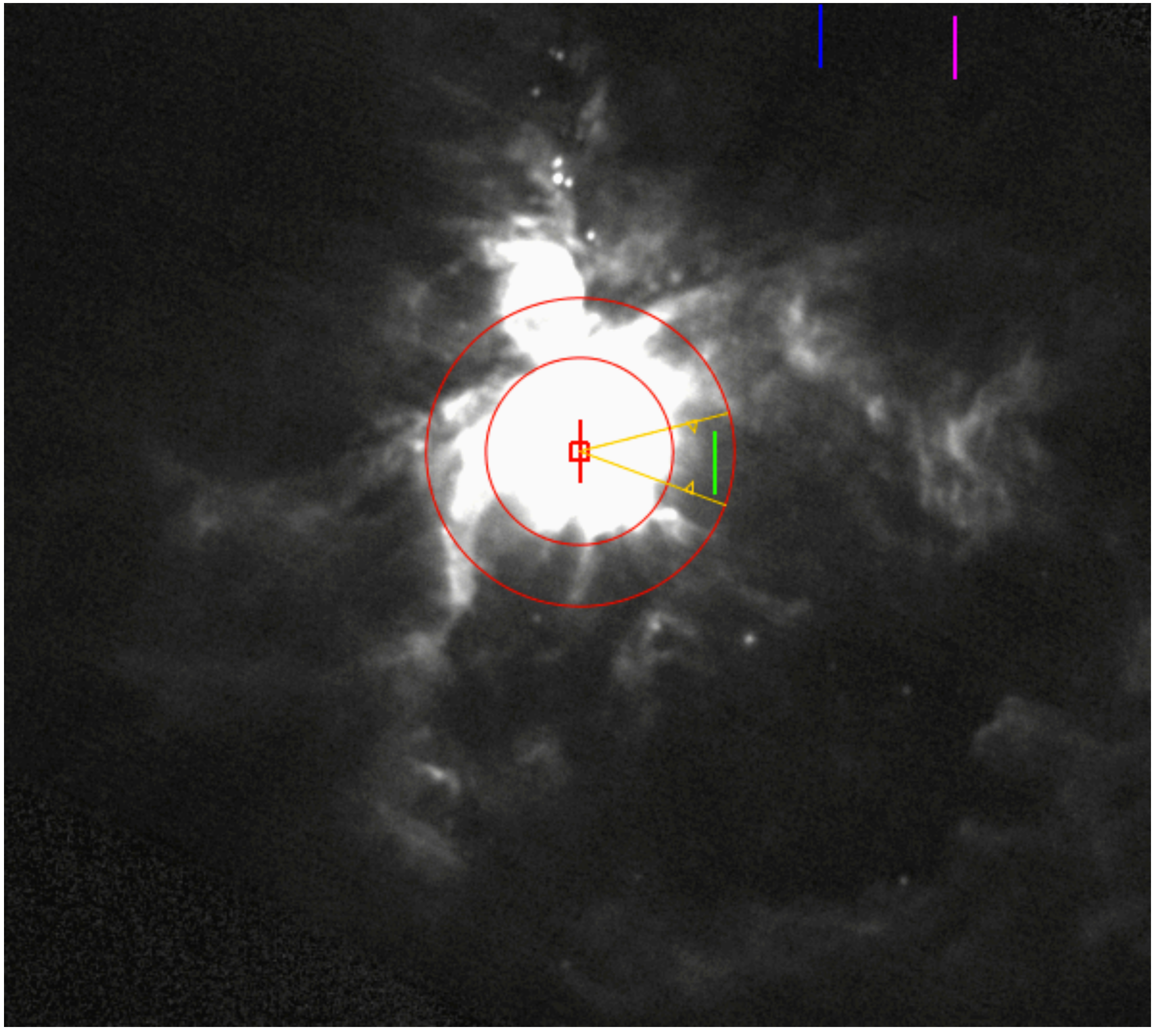
FORCAST NXCAC Mode



NXCAC setup for Orion Bar observations

Chop Throw: 420”; Chop Angle: 265°

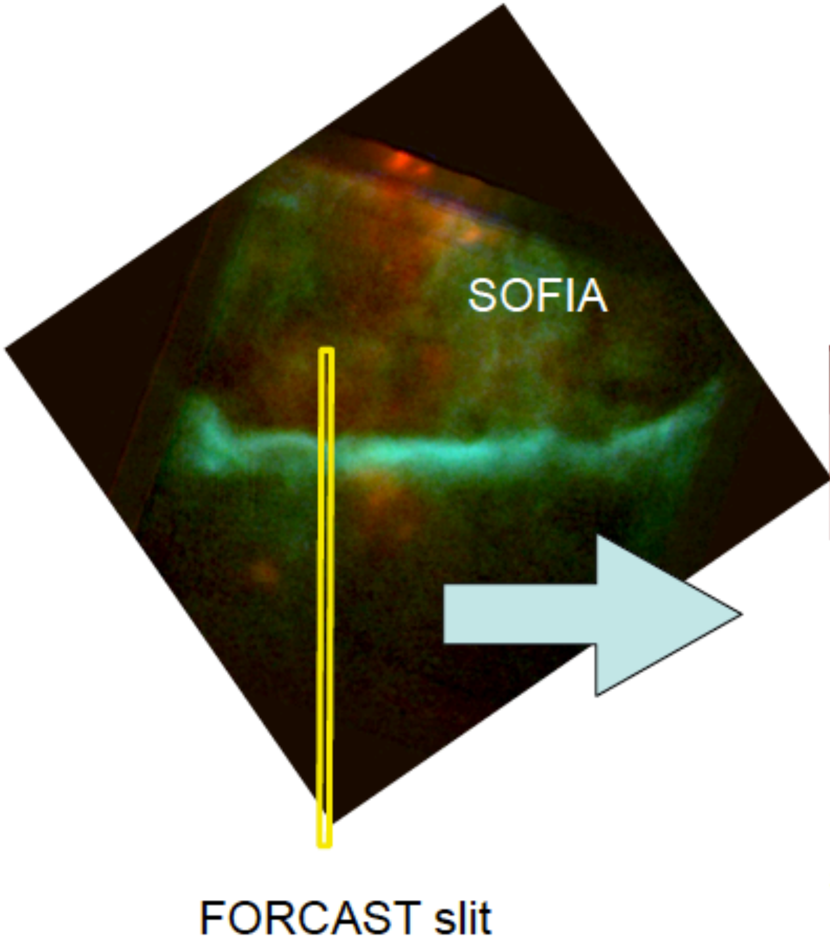
FORCAST NXCAC Mode

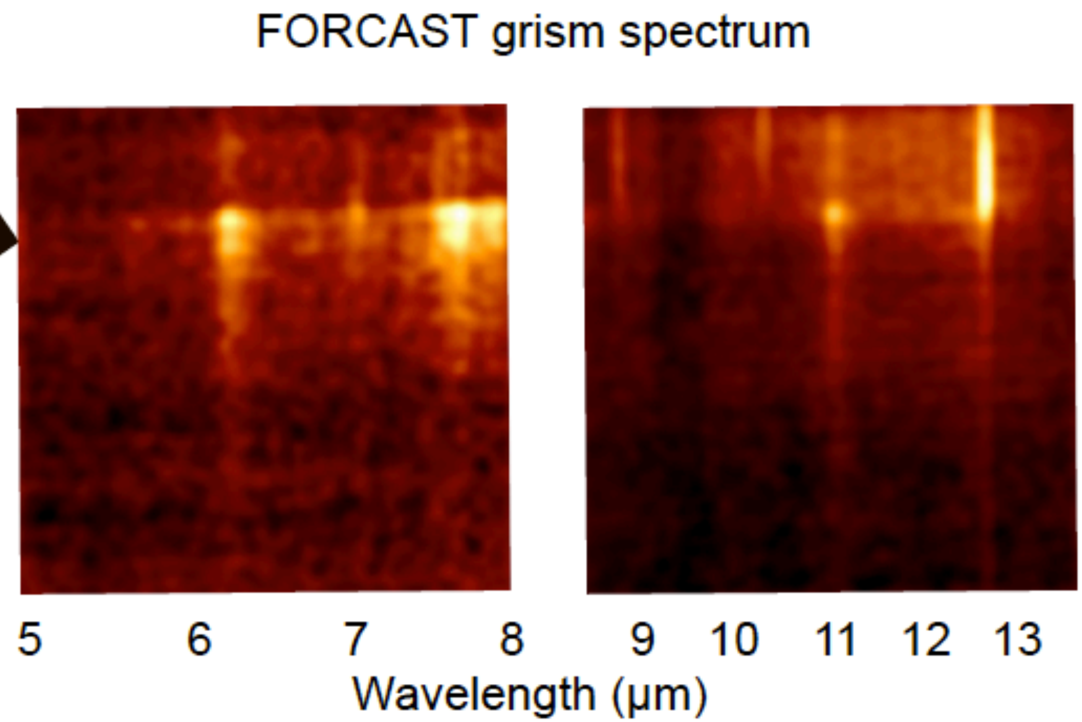


NXCAC setup for Orion Bar observations

Nod Throw: 1500”; Nod Angle: 330°

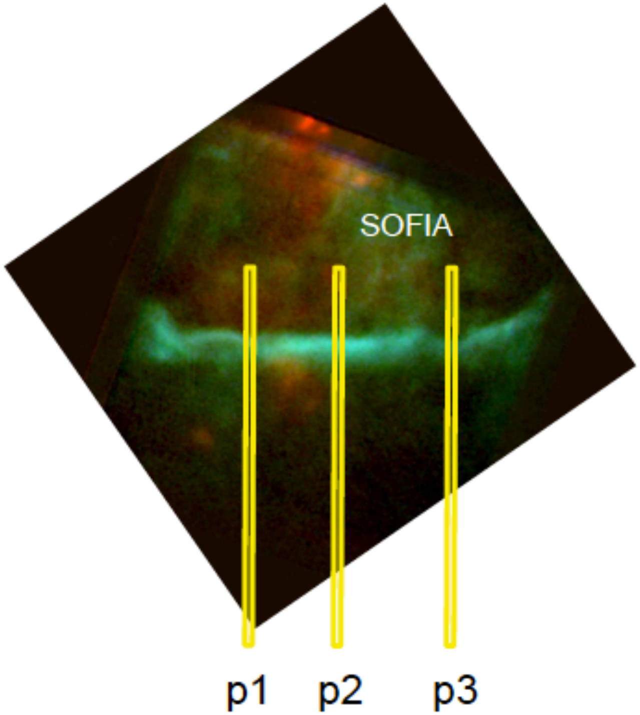
FORCAST NXCAC Mode



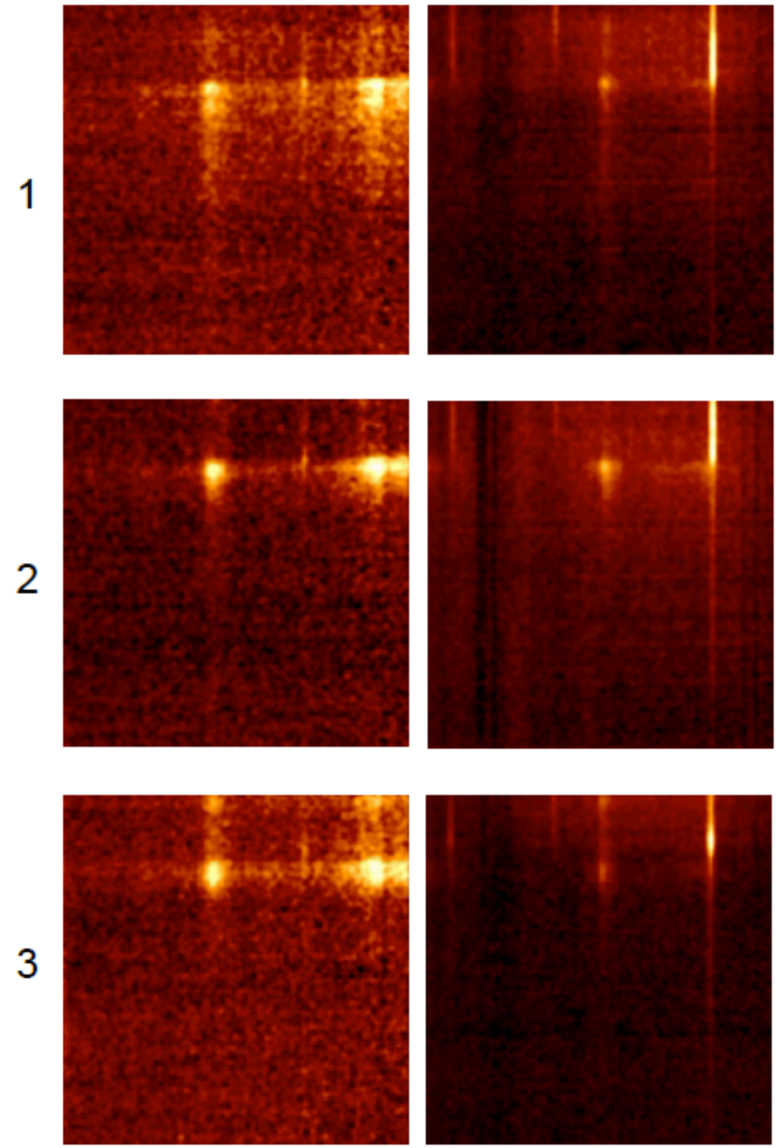


Keller et al. 2015, in prep

FORCAST NXCAC Mode

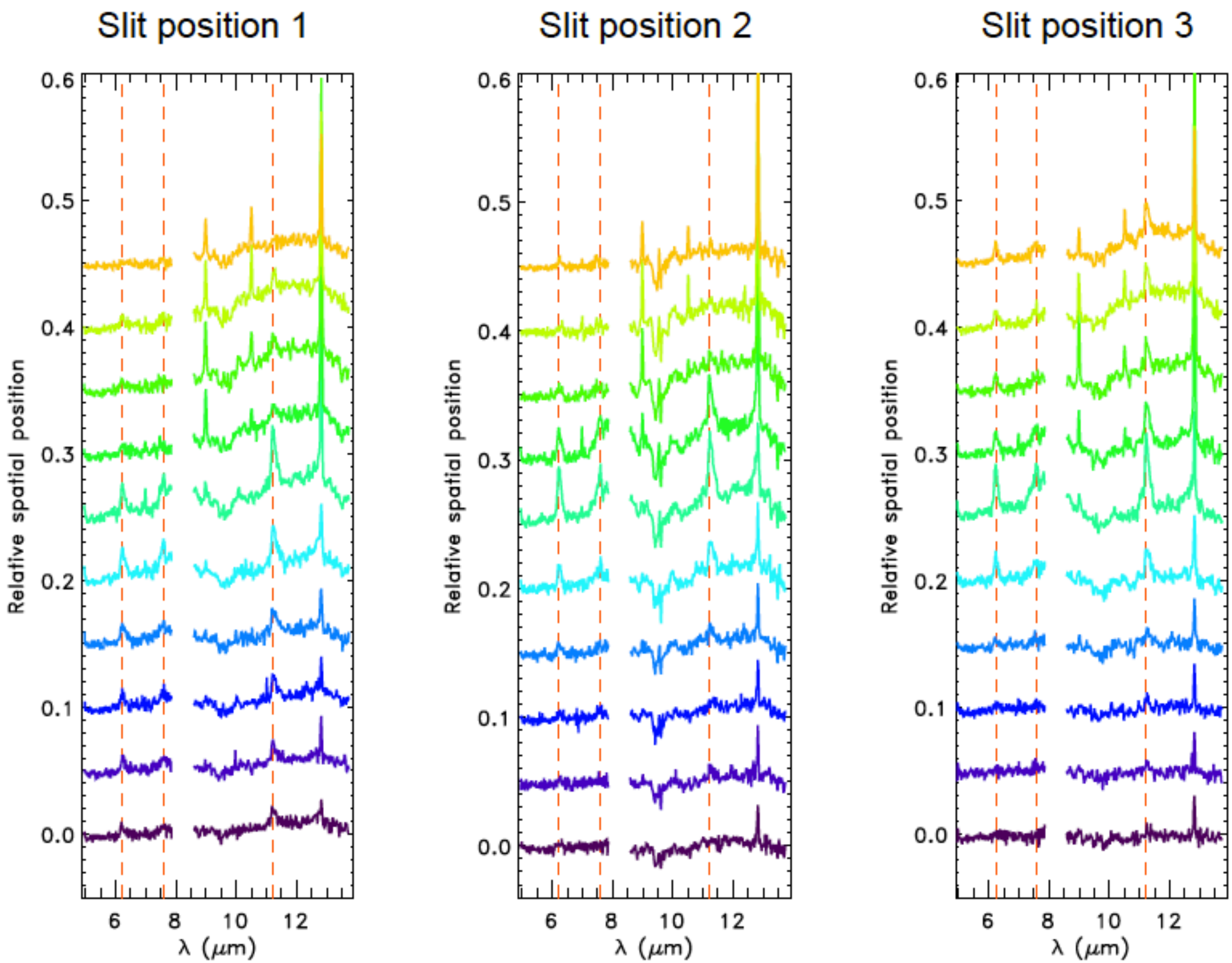


3 slit positions
along bar



Keller et al. 2015, in prep

FORCAST NXCAC Mode



Keller et al. 2015, in prep