



Wide Band Spectroscopy with FORCAST and FLITECAM

Andrew Helton

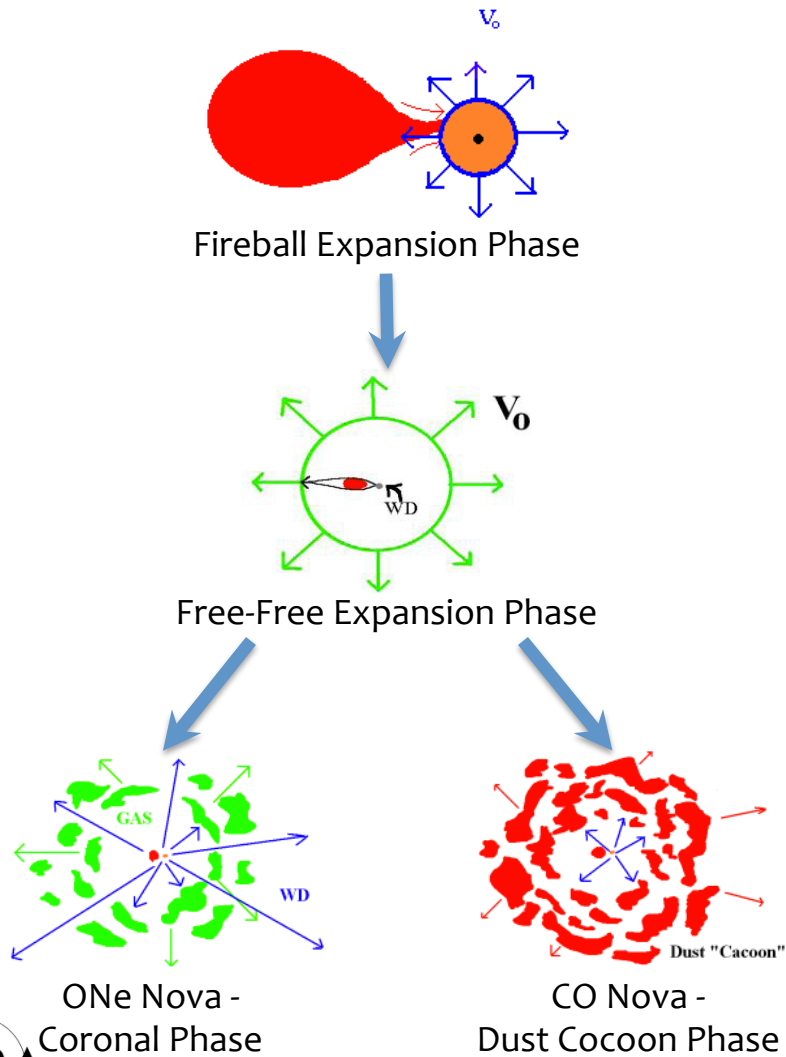
SOFIA Observer's Workshop

Mountain View, CA

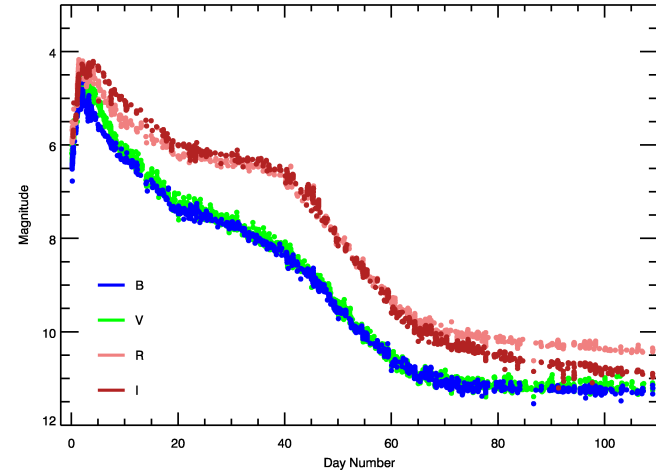
May 20, 2015



What is a Classical Nova?

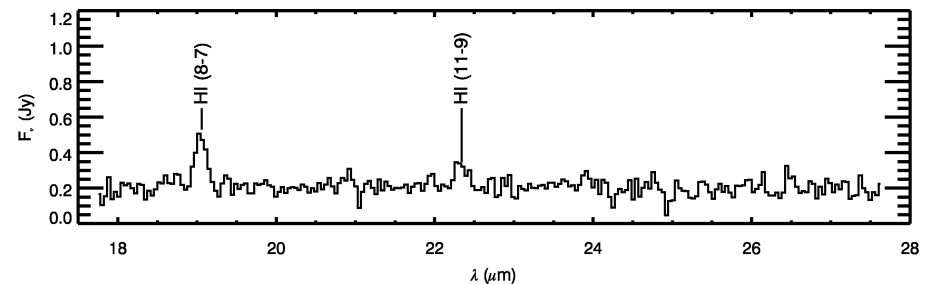
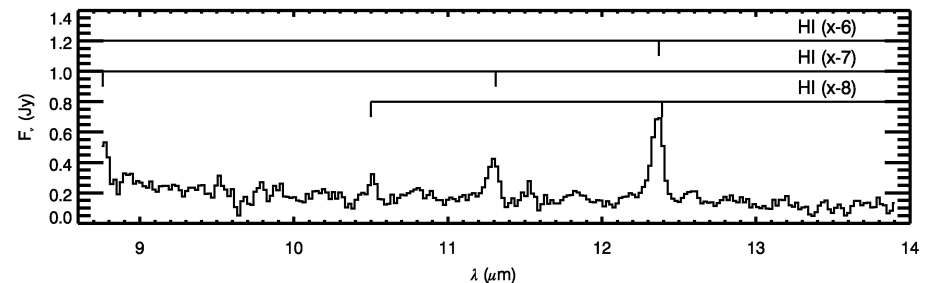
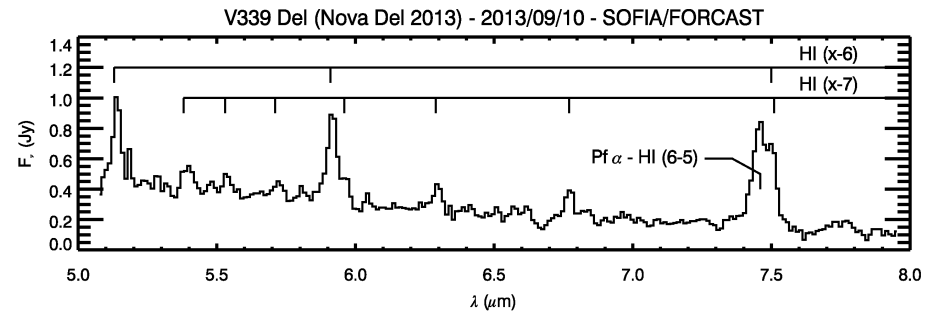


Optical Light Curve of V339 Delphini

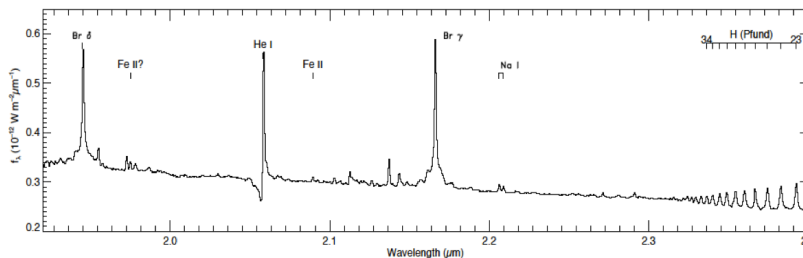
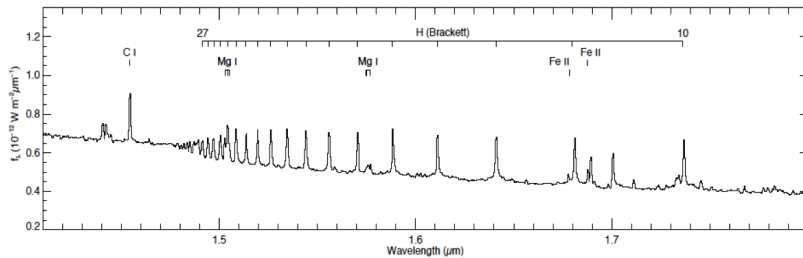
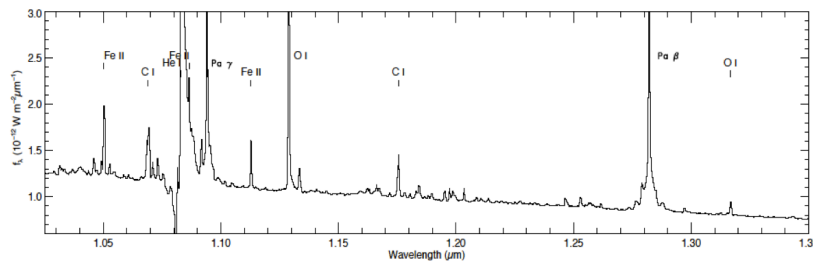
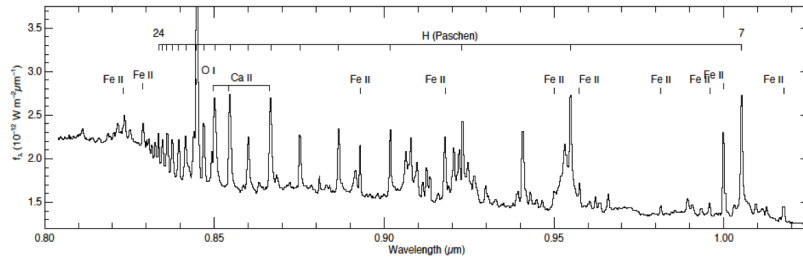


What are the science goals?

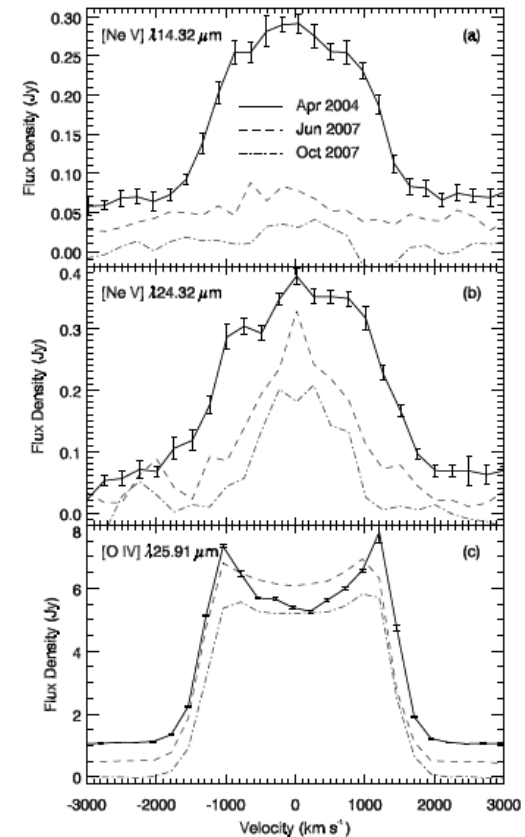
- Identify & measure emission lines
 - Determine physical properties in the ejecta
 - Estimate elemental abundances
 - Calculate ejecta mass
- Characterize emission line profiles
 - Determine ejecta kinematics
 - Characterize ejecta distribution
- Identify dust features (if present)
 - Determine dust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



Observational Properties

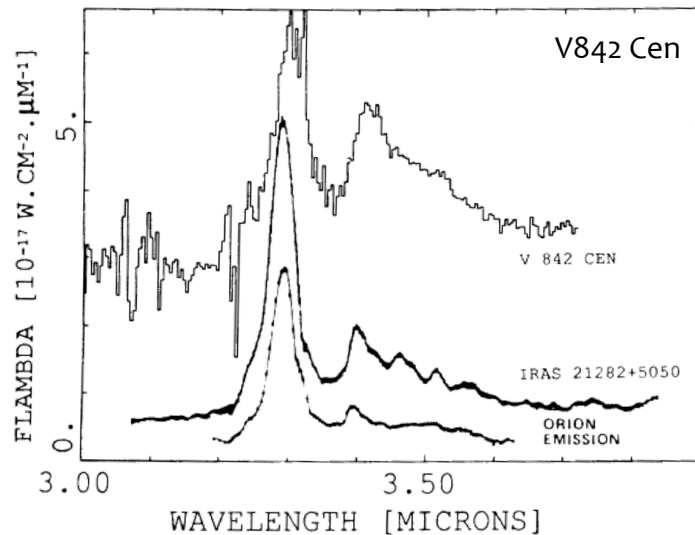


- ← Rich suite of lines throughout the near- and mid-IR
- ↓ Typical line widths range from 500 – 4000 km/s



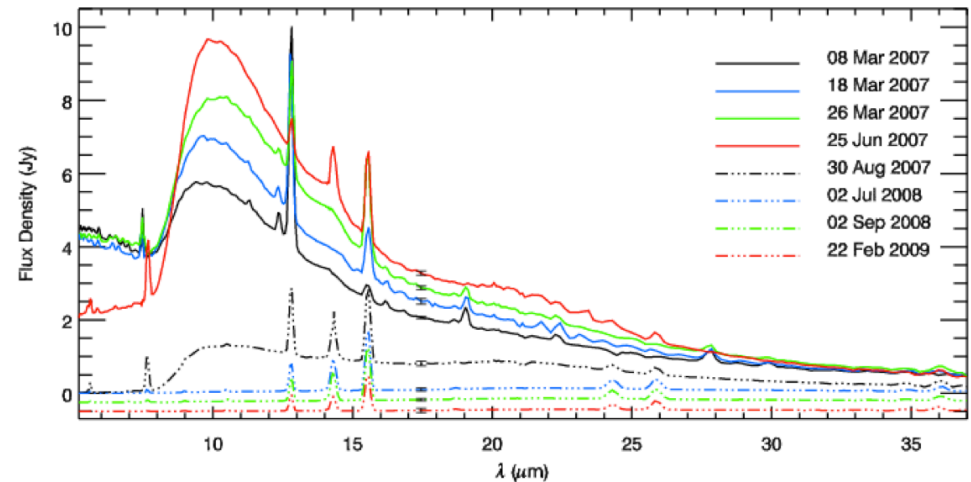
- Dust species include silicates, carbon, silicon carbide, hydrocarbons
- Dust features tend to be broad

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



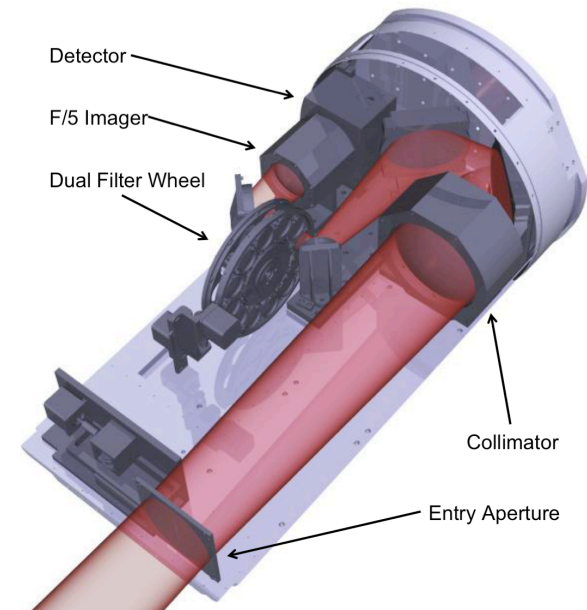
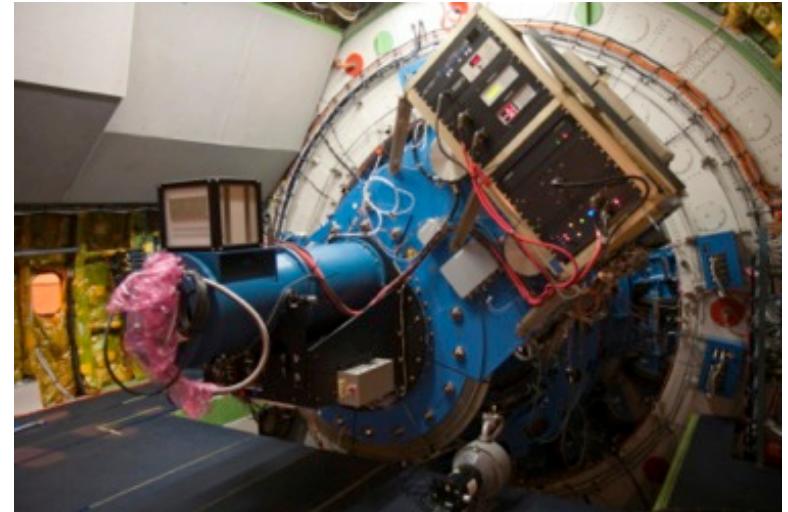
Hyland & MacGregor, 1989

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

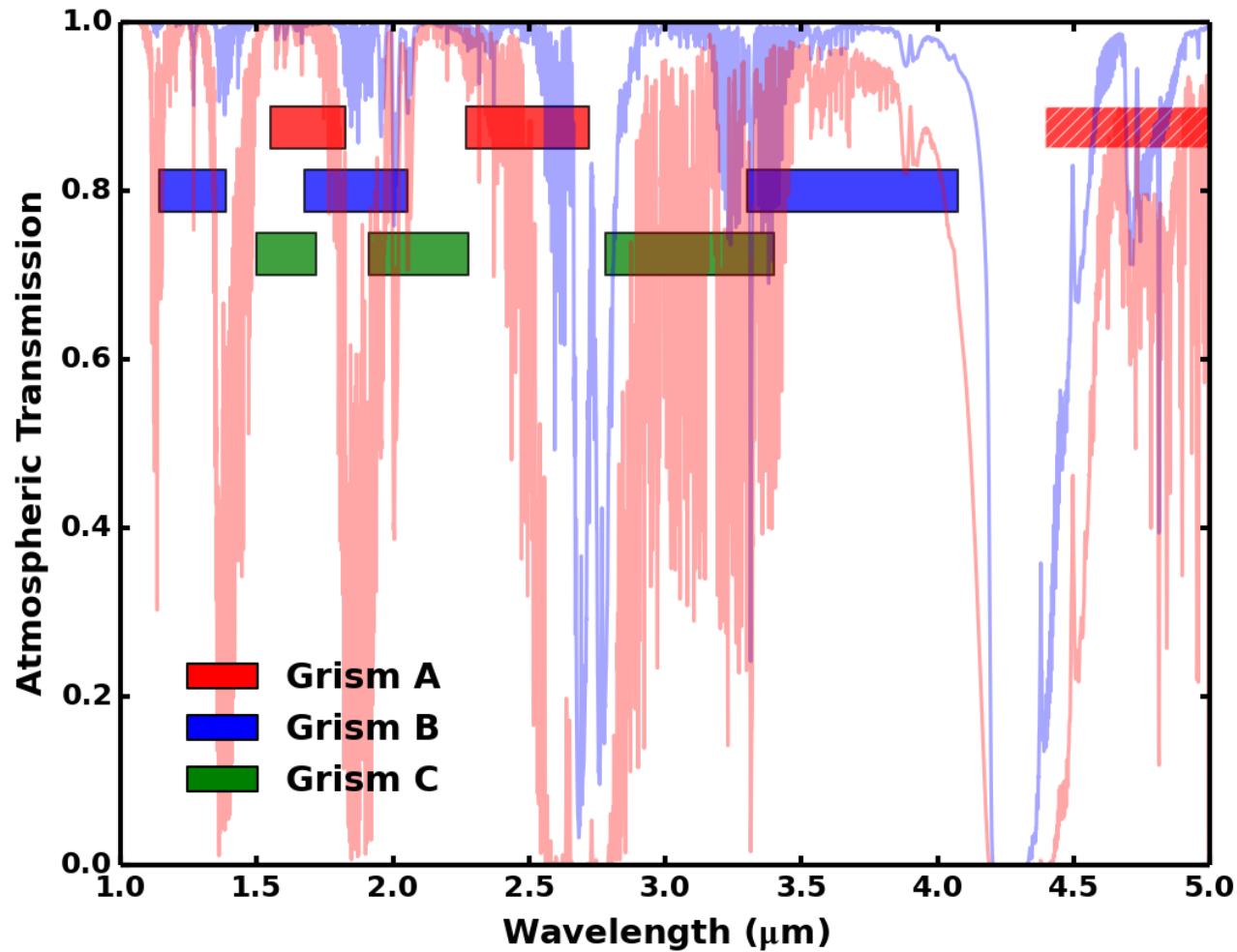


Helton et al. 2010, AJ, 140, 1347

- FLITECAM – **F**irst **L**ight **I**nfrared **T**est **C**AMera
- 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; $R=\lambda/\Delta\lambda$)	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: $\Delta v \sim 210 - 260 \text{ km/s}$

High Res: $\Delta v \sim 170 - 180 \text{ km/s}$





FLITECAM Grism Observations in SPT



Observation 1: V339 Del of Unsubmitted Phase I Proposal (Unsaved)

Instrument: FLITECAM

Target Name: V339 Del

Source Type: Sidereal SIMBAD NED

NAIF ID: NAIF ID Selection List

Coordinates: Galactic RA/GalLong: 20 23 30.68 DEC/GalLat: 20 46 3.80

Proper Motion ("/yr): RA: 0 DEC: 0

Instrument: Configuration: None Selected Spectral Element 1: Slit:

Instrument Mode: Select Mode Overheads - Constant (secs): Select Mode + Factor: Select Mode

Integration Time (secs): Alternate Overhead: Default Overhead: Duration:

Map Area: arcmin X arcmin

Order of Observation:

Priority: Low

Time Critical Observation:

First Critical Time, From: To:

Second Critical Time, From: To:





FLITECAM Grism Observations in SPT



↓ Select the grism from the pull-down menu

The screenshot shows the configuration interface for a FLITECAM observation. The 'Instrument' is set to 'GRISM'. The 'Spectral Element 1' dropdown menu is open, showing a list of grism options: 'None Selected', 'FLT_B3_J', 'FLT_C4_H', 'FLT_A3_Hw', 'FLT_B2_Hw', 'FLT_C3_Kw', 'FLT_A2_KL', and 'FLT_C2_LM'. The 'FLT_C2_LM' option is highlighted with a blue bar and a checkmark. Other fields include 'Instrument Mode' (Select Mode), 'Integration Time (secs)' (with a red X), 'Map Area' (arcmin), 'Order of Observation', and 'Priority' (Low).

↓ Select the slit

The screenshot shows the configuration interface for a FLITECAM observation. The 'Instrument' is set to 'GRISM' and 'Spectral Element 1' is set to 'FLT_C2_LM'. The 'Slit' dropdown menu is open, showing a list of slit options: 'None Selected', 'FLT_SS20', and 'FLT_SS10'. The 'FLT_SS20' option is highlighted with a blue bar and a checkmark. Other fields include 'Instrument Mode' (Select Mode), 'Integration Time (secs)' (with a red X), 'Map Area' (arcmin), 'Order of Observation', and 'Priority' (Low).





Selecting the FLITECAM Instrument Mode

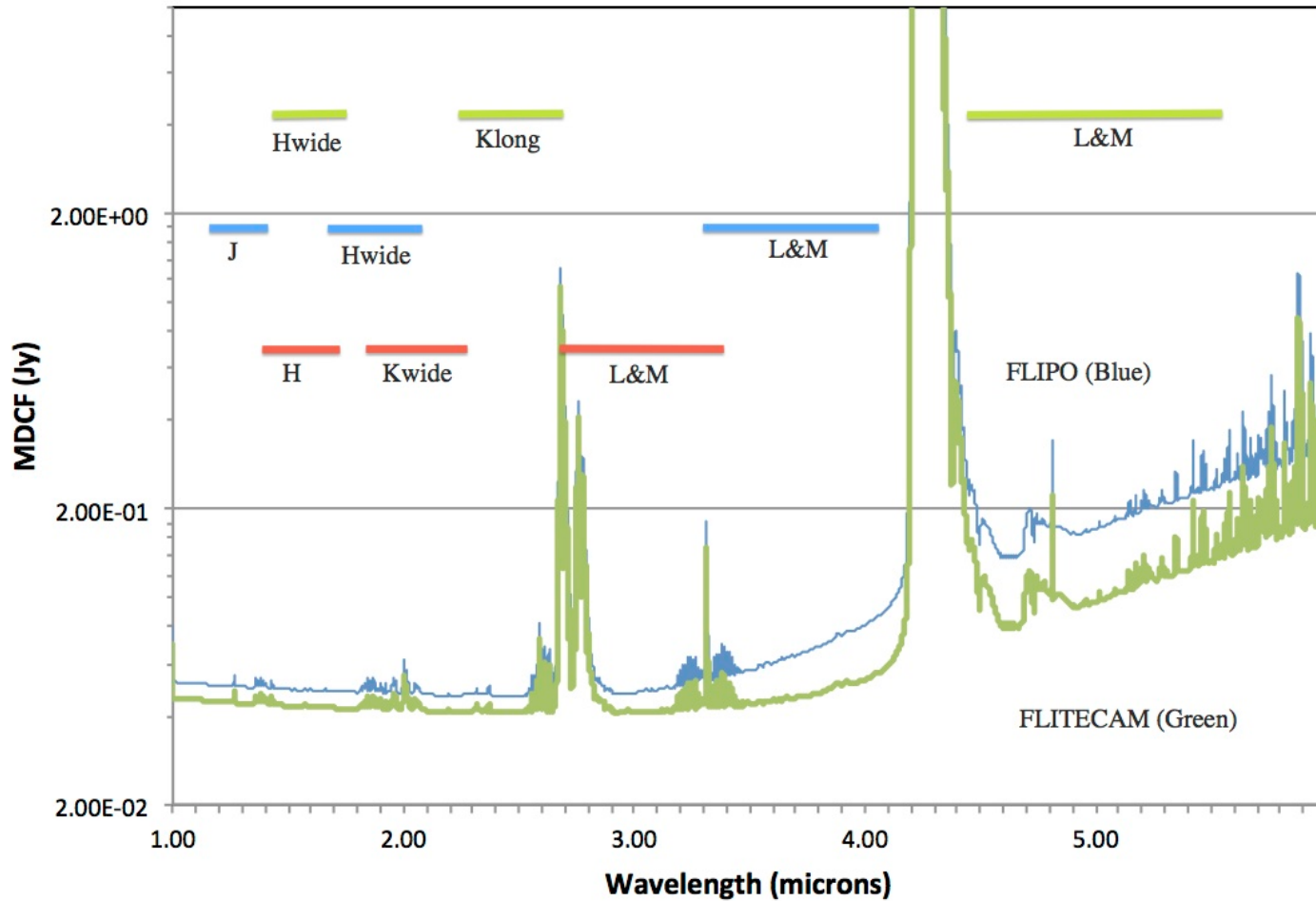


↓ Select the Instrument Mode

The screenshot shows the FLITECAM configuration interface. The 'Instrument Mode' dropdown menu is open, showing three options: 'Select Mode', 'NOD_ALONG_SLIT' (which is selected and highlighted in blue), and 'NOD_OFF_SLIT'. The background configuration fields are partially visible, including 'Instrument: FLT_C2_LM', 'Spectral Element 1: FLT_SS20', 'Integration Time (secs): 300.0', 'Overheads - Constant (secs): 300.0', 'Factor: 1.1', 'Duration: 426.0', and 'Priority: Low'.

- 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







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

Input Observing Parameters

Select the quantity to be estimated:

Choose the instrument configuration:

Choose a slit size (arcsec):

Required Signal-to-Noise ratio:

Single frame integration time (sec):

Total integration time (sec):

Source type:

Source Flux :

Source spectral shape:

Source blackbody temperature (K) or Power Law Index:

- Narrow
- Wide

Signal-to-Noise

FLITECAM

Wide

10

0.5

10

Point Source

5

Jy at 2.2 microns

Blackbody

1500

- Limiting Flux
- Total Integration Time
- Signal-to-Noise

- FLITECAM
- FLIPO

- Point Source
- Extended Source

- Blackbody
- Power Law

Submit Form Clear Form





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](#)

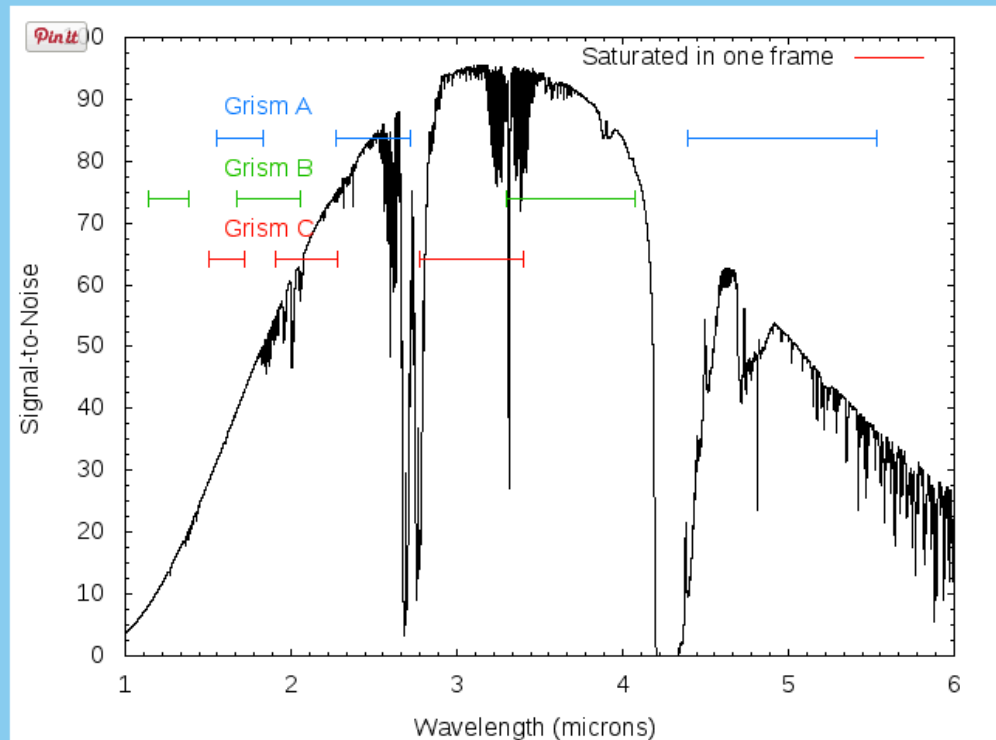
Instrument Configuration: FLITECAM
 Slit size = 1.600 arcsec
 Resolution = 1300.0
 Single frame exposure time = 0.100 sec
 Number of Coadds = 600.000000
 Total Exposure Time = 60.0000000 sec
 Input flux : $0.3097E-11$ W/m²/micron at 2.200 microns

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

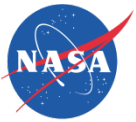
	Configuration	Spectral Element 1	Slit
Instrument:	GRISM	FLT_C2_LM	FLT_SS20
Instrument Mode:	NOD_OFF_SLIT	Overheads - Constant (secs): 300.0	+ Factor: 2.2
Integration Time (secs):	60	Alternate Overhead: 0	Default Overhead: 432.0
Map Area:	arcmin	arcmin	Duration: 492.0
Order of Observation:			
Priority:	Low		

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

Priority *amongst targets* in the program

- Low
- Medium
- High





FORCAST Instrument Overview



- FORCAST - **F**aint **O**bject **i**nfra**R**ed **C**amera for the **S**OFIA Telescope
- Imaging - P.I. Terry Herter (Cornell)
 - Dual Channel, mid-IR (5-40 μm) camera
 - Short Wave Camera (SWC) – Si:As BiB Array – $\lambda < 25 \mu\text{m}$
 - Long Wave Camera (LWC) – Si:Sb BiB Array – $\lambda > 25 \mu\text{m}$
 - 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 $R \sim 200$





Which FORCAST Grisms to Use?



Grism	Coverage (μm)	Resolution (WS/NS) ($R=\lambda/\Delta\lambda$)	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



Observation 2: V339 Del of Unsubmitted Phase I Proposal (Unsaved)

Instrument: FORCAST

Target Name: V339 Del

Source Type: Sidereal

SIMBAD

NED

NAIF ID:

NAIF ID Selection List

Coordinates: Galactic RA/GalLong: 20 23 30.68

DEC/GalLat: 20 46 3.80

Proper Motion ("/yr): RA: 0

DEC: 0

Instrument:

Configuration: None Selected

Spectral Element 1

Spectral Element 2

Slit

Instrument Mode:

Select Mode

Select Dither

Overheads - Constant (secs): Select Configuration/Spectral Element(s)/Integration Time

+ Factor: Select Configuration/Spectral Element(s)/Integration Time

Integration Time (secs):

Alternate Overhead: 0

Default Overhead:

Duration:

Map Area:

arcmin

arcmin

Order of Observation:

Priority: Low

Time Critical Observation:

First Critical Time, From:

To:

Second Critical Time, From:

To:





FORCAST Grism Observations in SPT



↓ Choose the desired grism for the SWC

Instrument:	GRISM	Configuration	None Selected	Spectral Element 2	None Selected	Slit	FOR_LS47
Instrument Mode:	C2N	None	✓ FOR_G063 FOR_G111	Overheads - Constant (secs):	30.0	+ Factor:	2.6023085
Integration Time (secs):	10	Alternate Overhead:	0	Default Overhead:	56.023087	Duration:	66.02309
Map Area:	arcmin		arcmin				
Order of Observation:							
Priority:	Low						

↓ Choose the desired grism for the LWC

Instrument:	GRISM	Configuration	Spectral Element 1	None Selected	Spectral Element 2	Slit	FOR_LS47
Instrument Mode:	C2N	None	None	Overheads - Constant (secs):	30.0	+ Factor:	2.5977144
Integration Time (secs):	10	Alternate Overhead:	0	Default Overhead:	55.977142	Duration:	65.97714
Map Area:	arcmin		arcmin				
Order of Observation:							
Priority:	Low						





FORCAST Grism Observations in SPT

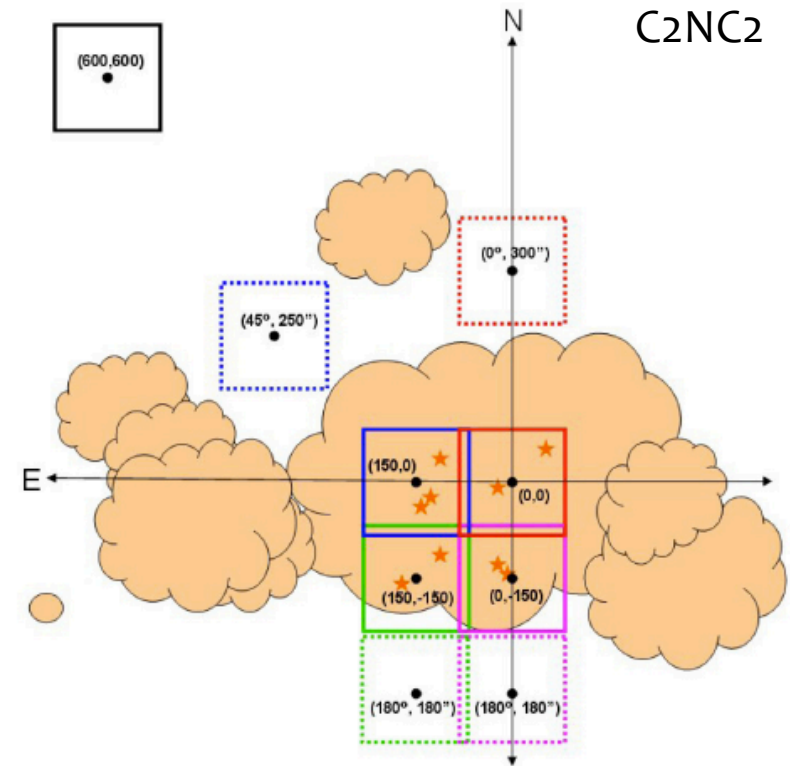


↓ Choose the desired slit width

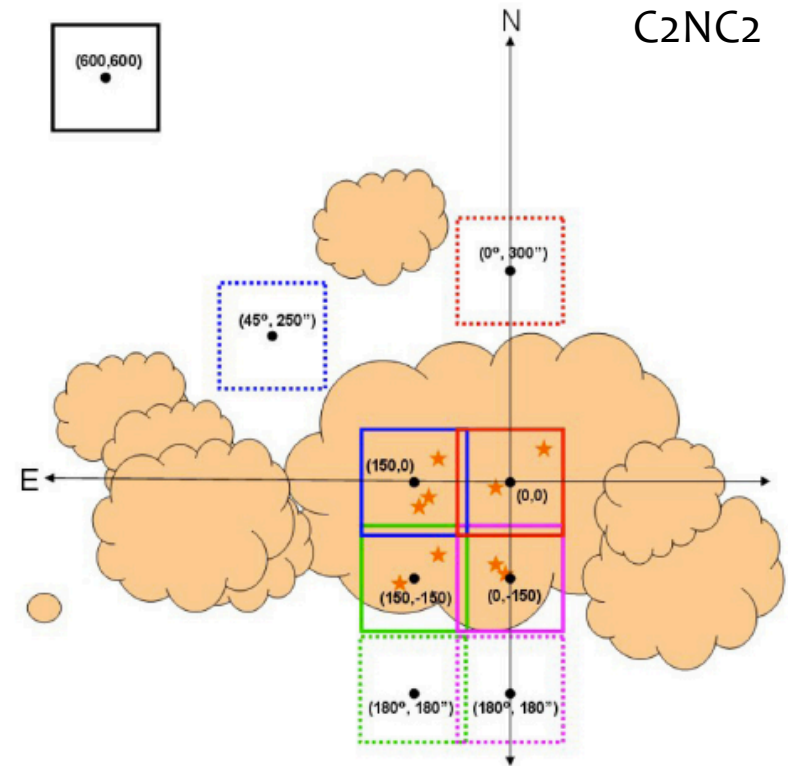
	Configuration	Spectral Element 1	Spectral Element 2	Slit
Instrument:	GRISM	None Selected	FOR_G227	None Selected
Instrument Mode:	C2N	None	Overheads - Constant (secs): 30.0	+ Factor: 2
Integration Time (secs):	10	Alternate Overhead: 0	Default Overhead: 55.977142	Duration: 65.97714
Map Area:	arcmin		arcmin	
Order of Observation:				
Priority:	Low			



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



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



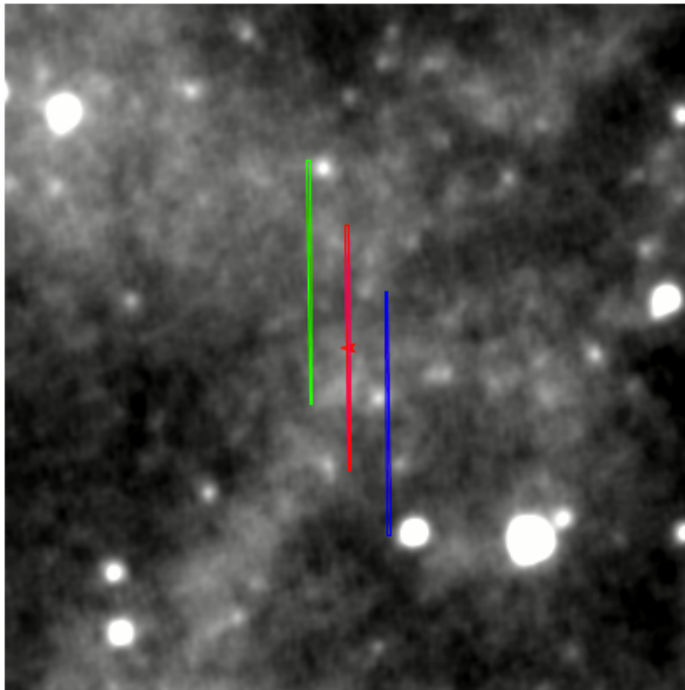
C2N

Nod-Match-Chop

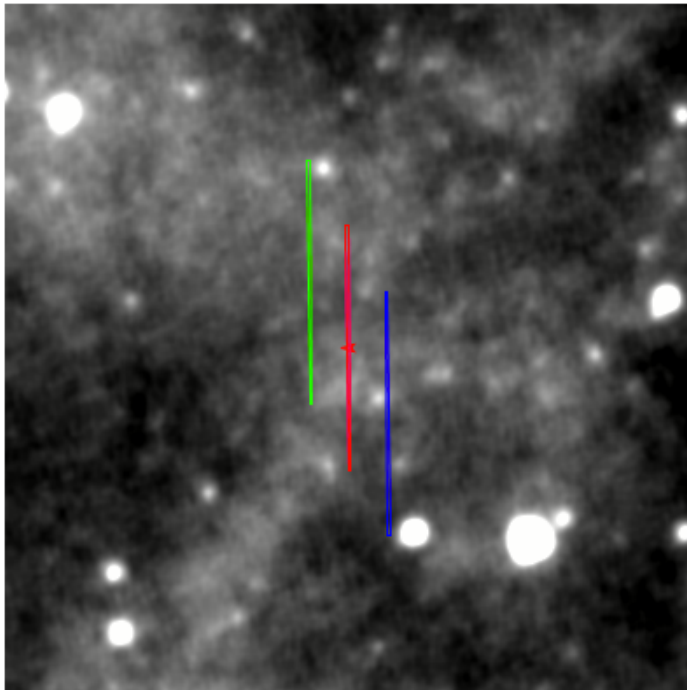
Nod-Perp-Chop

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

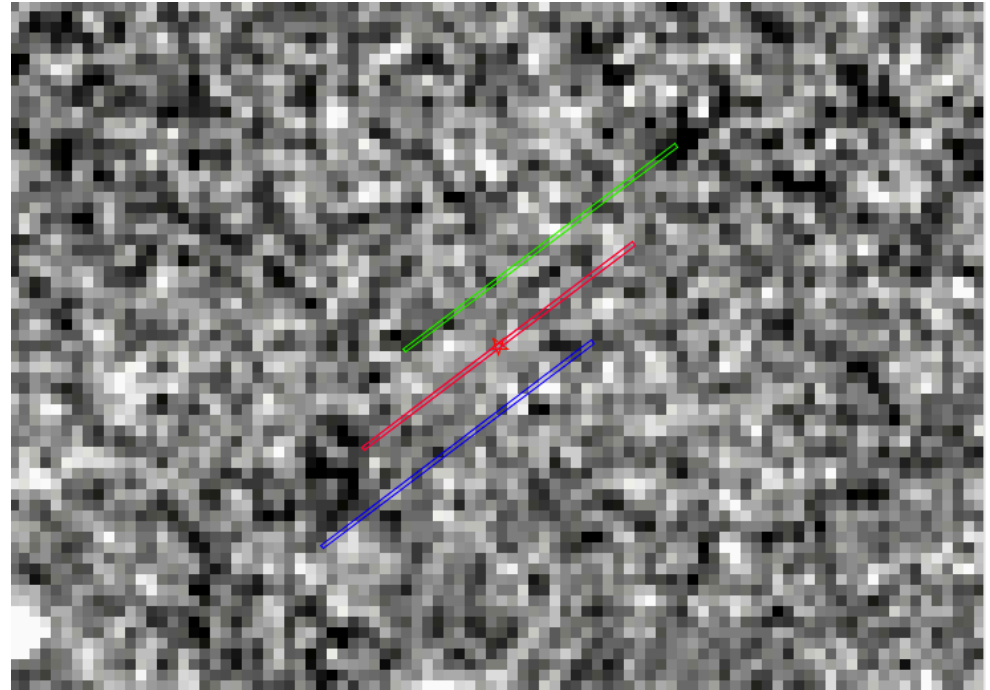
- Check images of the field to see if there is extended emission
 - Download the SSpot tool (<https://dcs.sofia.usra.edu/observationPlanning/installSSPOT/sspotDownload.jsp>)
 - Generate a placeholder grism observation of the target
 - Download an image from the database
 - Overlay the observation on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



- 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
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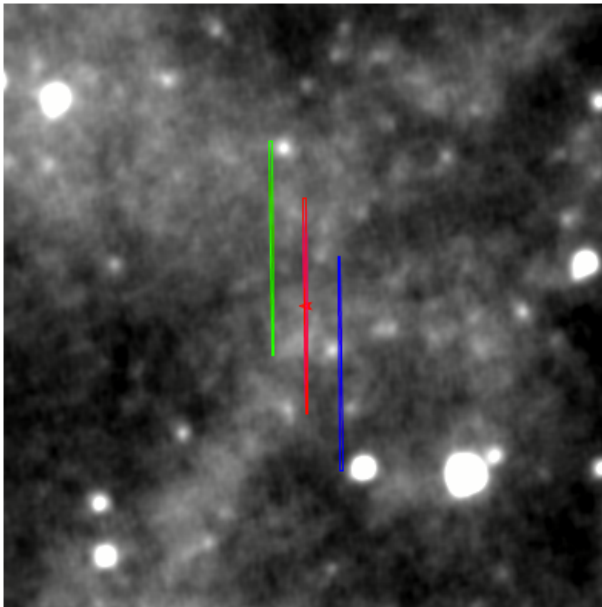


WISE Band 3



MSX-C

- 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



Chop / Nod

Example Rotation Angle (deg)

Chop/Nod Style

Chop Type

Chop Throw (arcsec)

Chop Angle Coordinate

Chop Angle (deg)

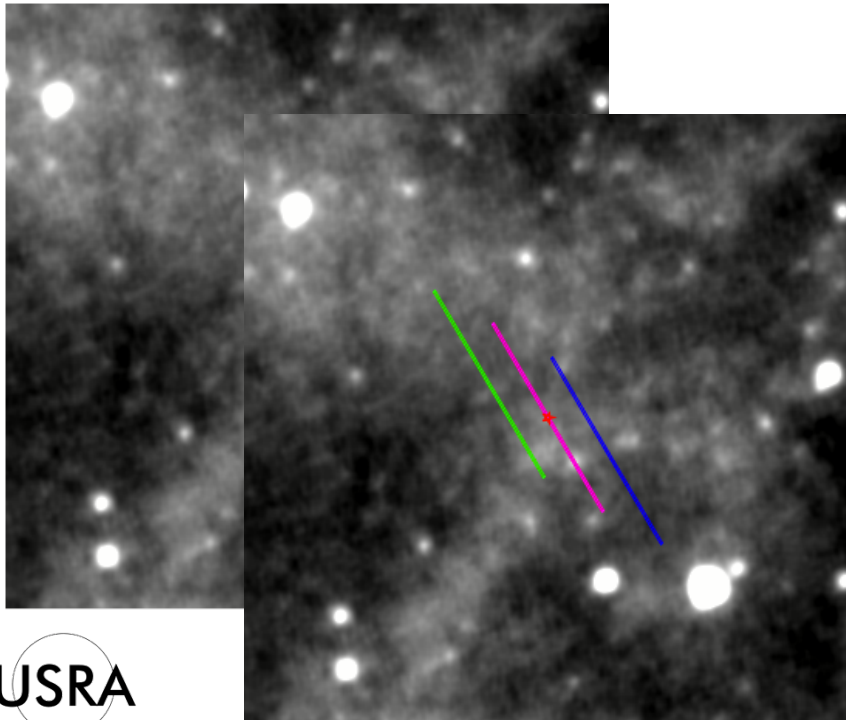
Nod Throw (arcsec)

Nod Angle Coordinate

Nod Angle (deg)

SSpot AOR Definition – Chop/Nod Parameters

- 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



Chop / Nod

Example Rotation Angle (deg) 30.000

Chop/Nod Style Nod Match Chop

Chop Type Sym

Chop Throw (arcsec) 60.000

Chop Angle Coordinate Array

Set Chop Angle Ranges

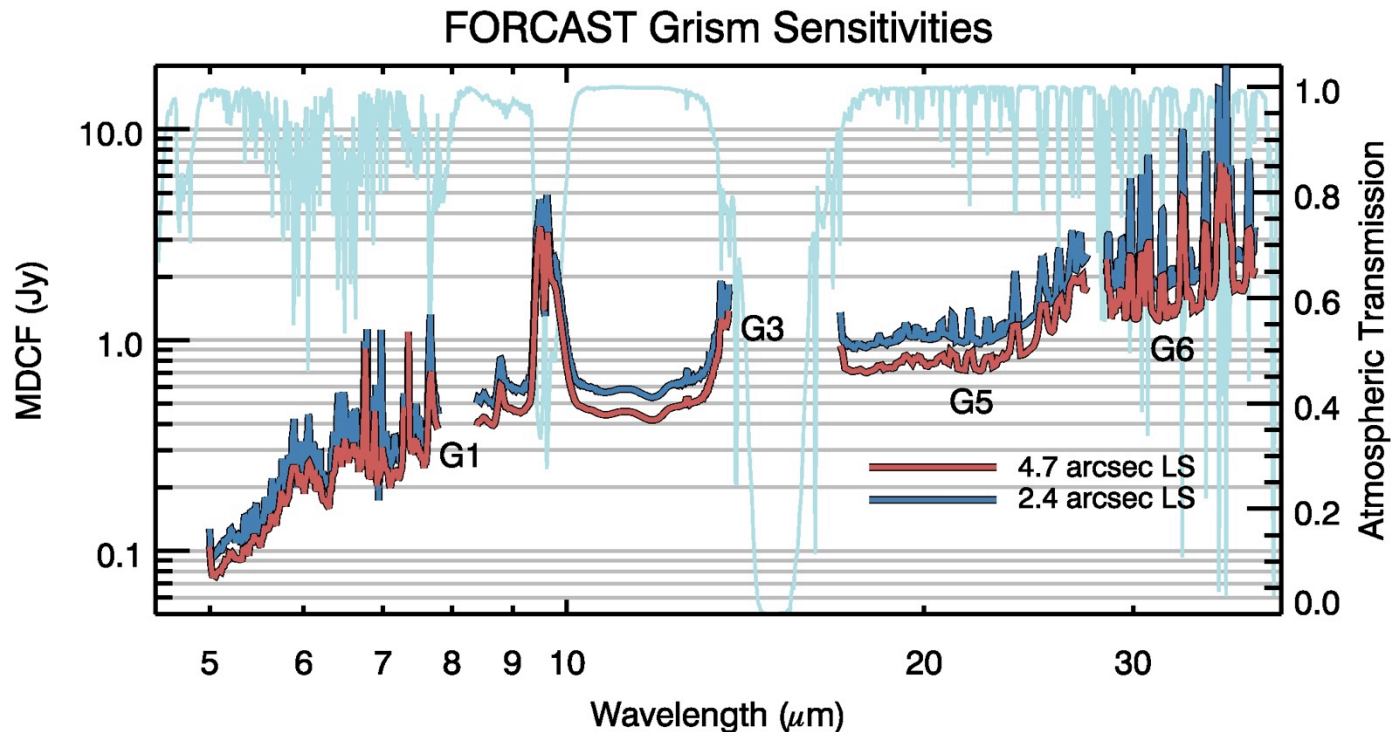
Chop Angle (deg) 30.000

Nod Throw (arcsec) 60.000

Nod Angle Coordinate Array

Nod Angle (deg) 210.000

SSpot AOR Definition – Chop/Nod Parameters



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



- $[S/N]_{req}$ = 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

Input Observing Parameters

Select the quantity to be estimated:

Choose a grism:

Choose a slit size (arcsec):

Required Signal-to-Noise ratio:

Total on-source integration time (sec):

Source type:

Source Flux:

Source spectral shape:

Source blackbody temperature (K) or Power Law Index:

- FOR_G063
- FOR_XG063
- FOR_G111
- FOR_XG111
- FOR_G227
- FOR_G329

Limiting Flux

FOR_G063

2.4

Point Source

Blackbody

W/m²/micron at 10 microns

- Limiting Flux
- Total Integration Time
- Signal-to-Noise

- 2.4"
- 4.7"

- Point Source
- Extended Source

- Blackbody
- Power Law

Submit Form Clear Form





Determining FORCAST Integration Times



FORCAST Grism Calculator Output

Input Parameters

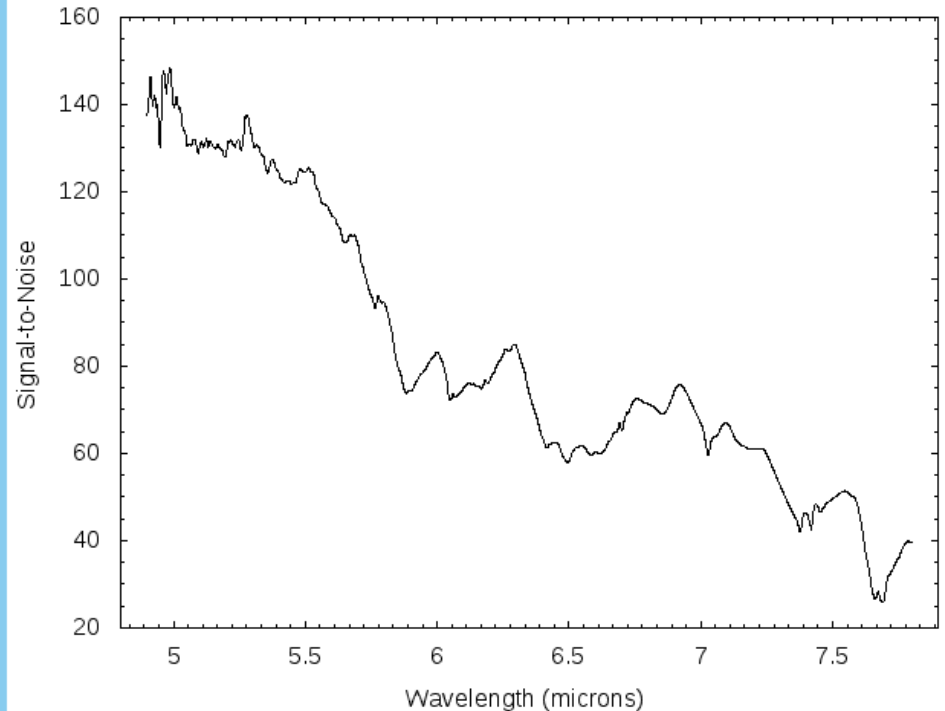
Mode: Signal-to-Noise
Grism: 1
Slit: 4.7 arcsec
Source flux : 1.499e-13 W/m²/micron at 10 microns
Source blackbody temperature: 1500 K
Total exposure time: 60 sec

[View output data file](#)

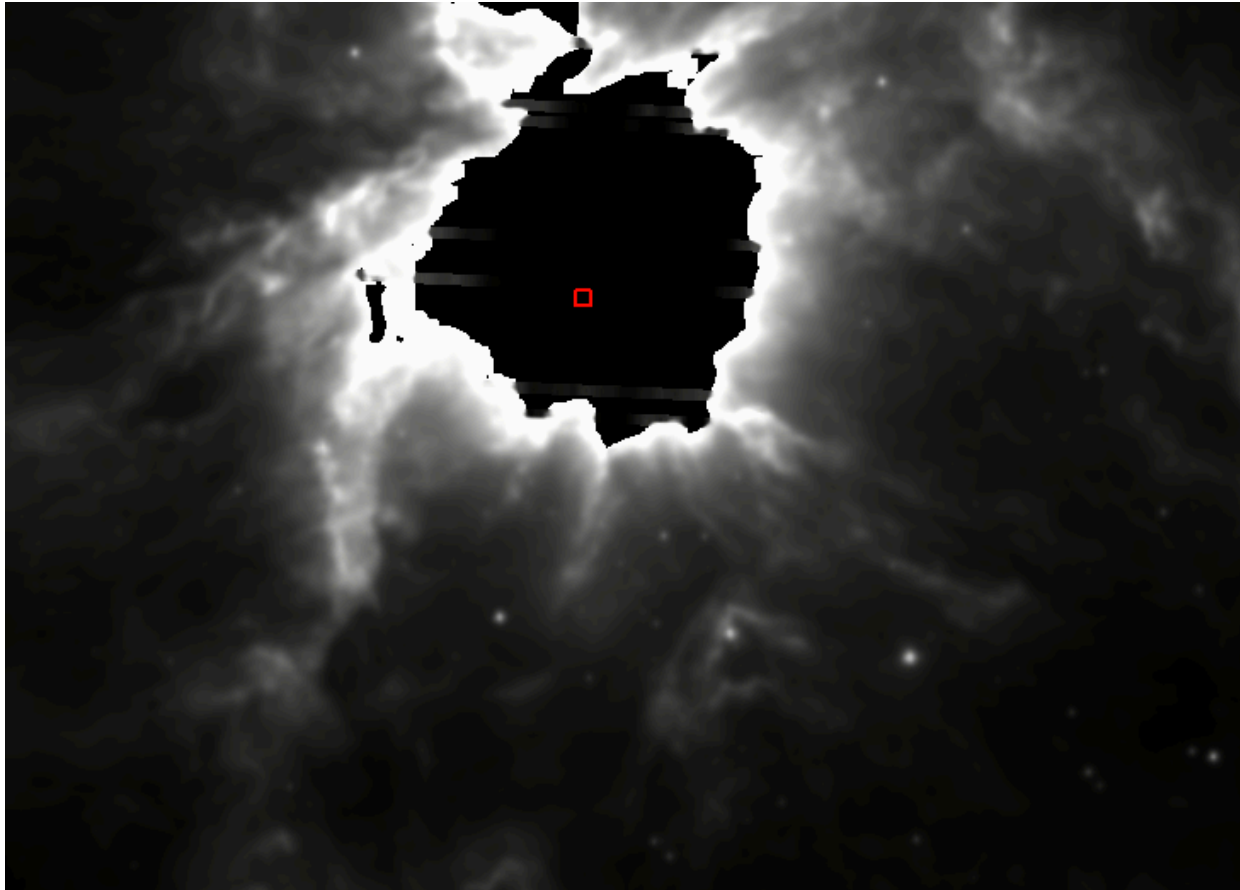
Slit size = 4.700 arcsec
Resolution = 90.0
Single frame exposure time = 0.059570 sec
Frame Rate = 16.787 Hz
Number of Coadds = 1007.00000
Total Exposure Time = 60.0000000 sec
Input flux : 0.1499E-12 W/m²/micron at 10.000 microns

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

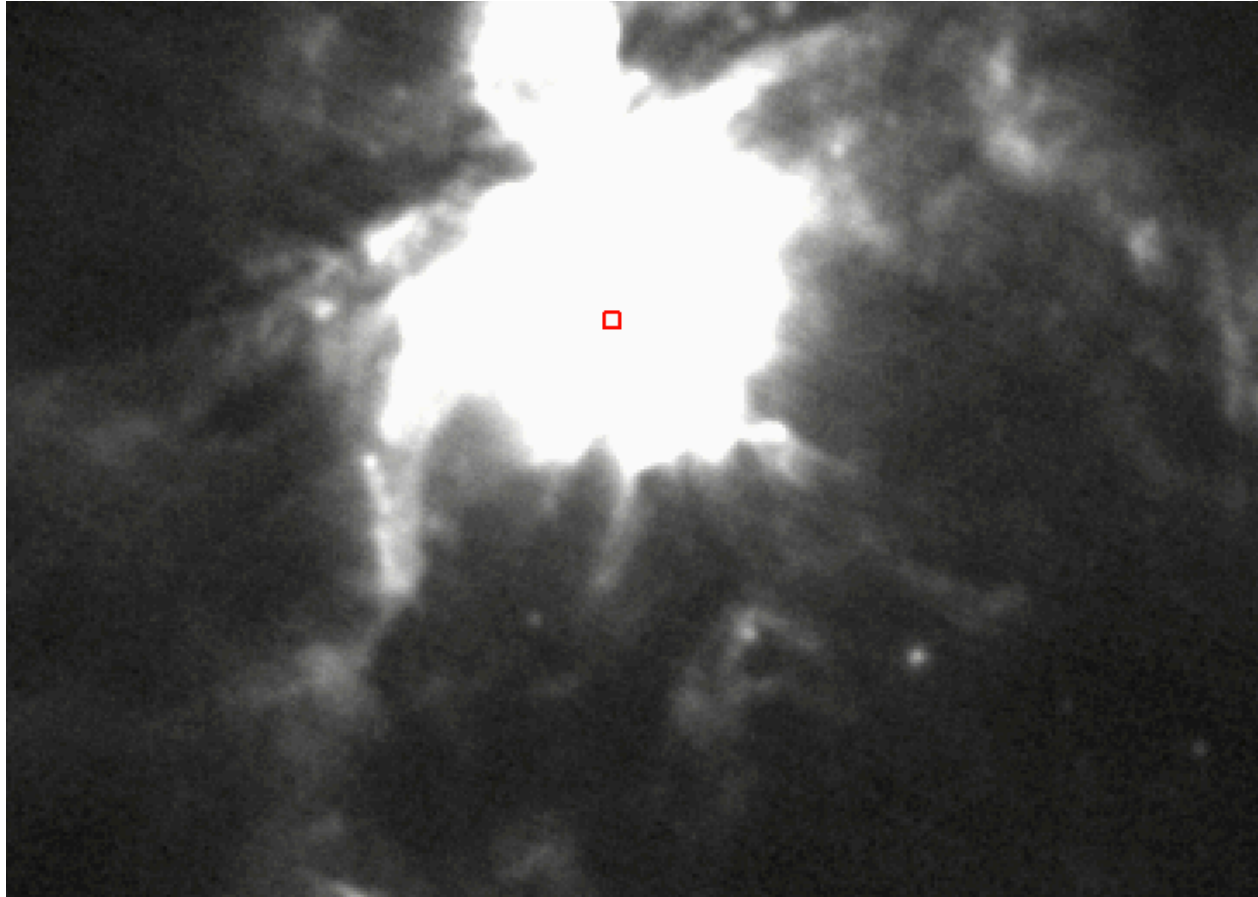


FORCAST Spectroscopy of PAH emission in the Orion-A molecular cloud



Orion Bar – WISE Band 3

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



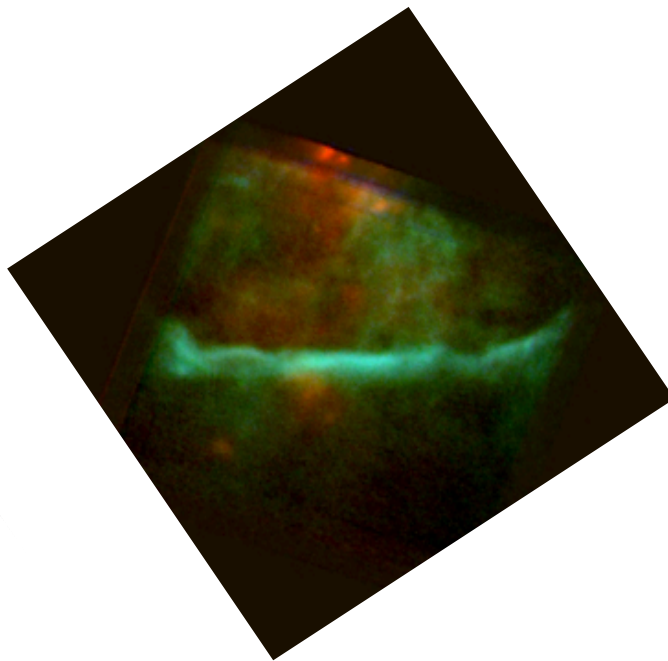
Orion Bar – MSX-C

↓ Choose the desired Instrument Mode

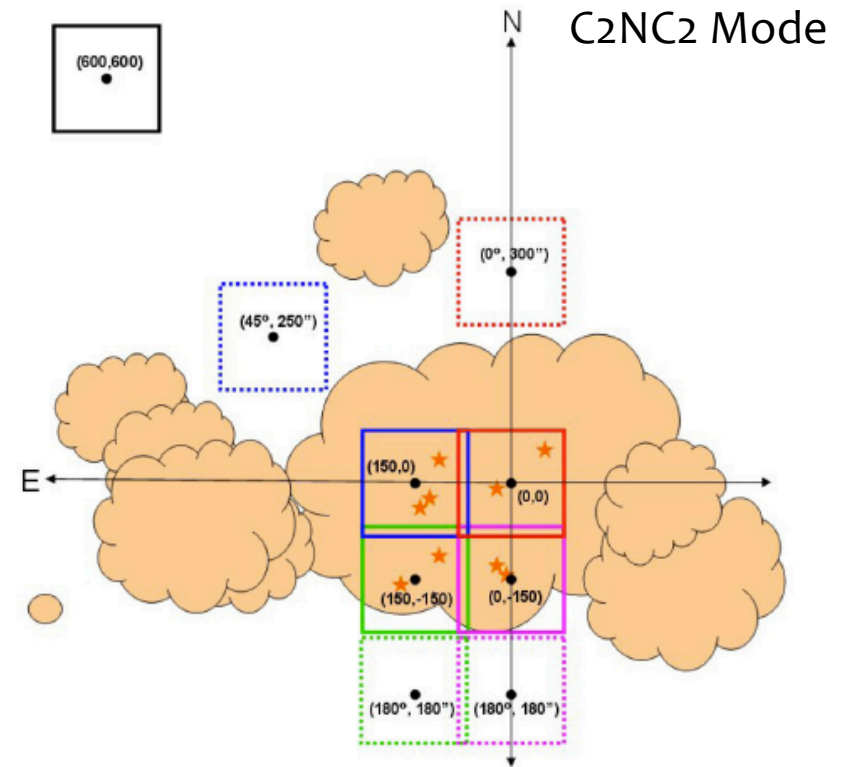
	Configuration	Spectral Element 1	Spectral Element 2	Slit
Instrument:	<input type="text" value="None Selected"/>	<input type="text" value="None Selected"/>	<input type="text" value="FOR_G227"/>	<input type="text" value="None Selected"/>
Instrument Mode:	<input type="text" value="None"/> <input checked="" type="checkbox"/> C2N <input type="checkbox"/> NXCAC <input type="checkbox"/> SLITSCAN	Overheads - Constant (secs):	<input type="text" value="30.0"/>	+ Factor: <input type="text" value="2.5977144"/>
Integration Time (secs):	Alternate Overhead: <input type="text" value="0"/>	Default Overhead: <input type="text" value="55.977142"/>	Duration: <input type="text" value="65.97714"/>	
Map Area:	<input type="text" value="arcmin"/> X <input type="text" value="arcmin"/>			
Order of Observation:	<input type="text"/>			
Priority:	<input type="text" value="Low"/>			

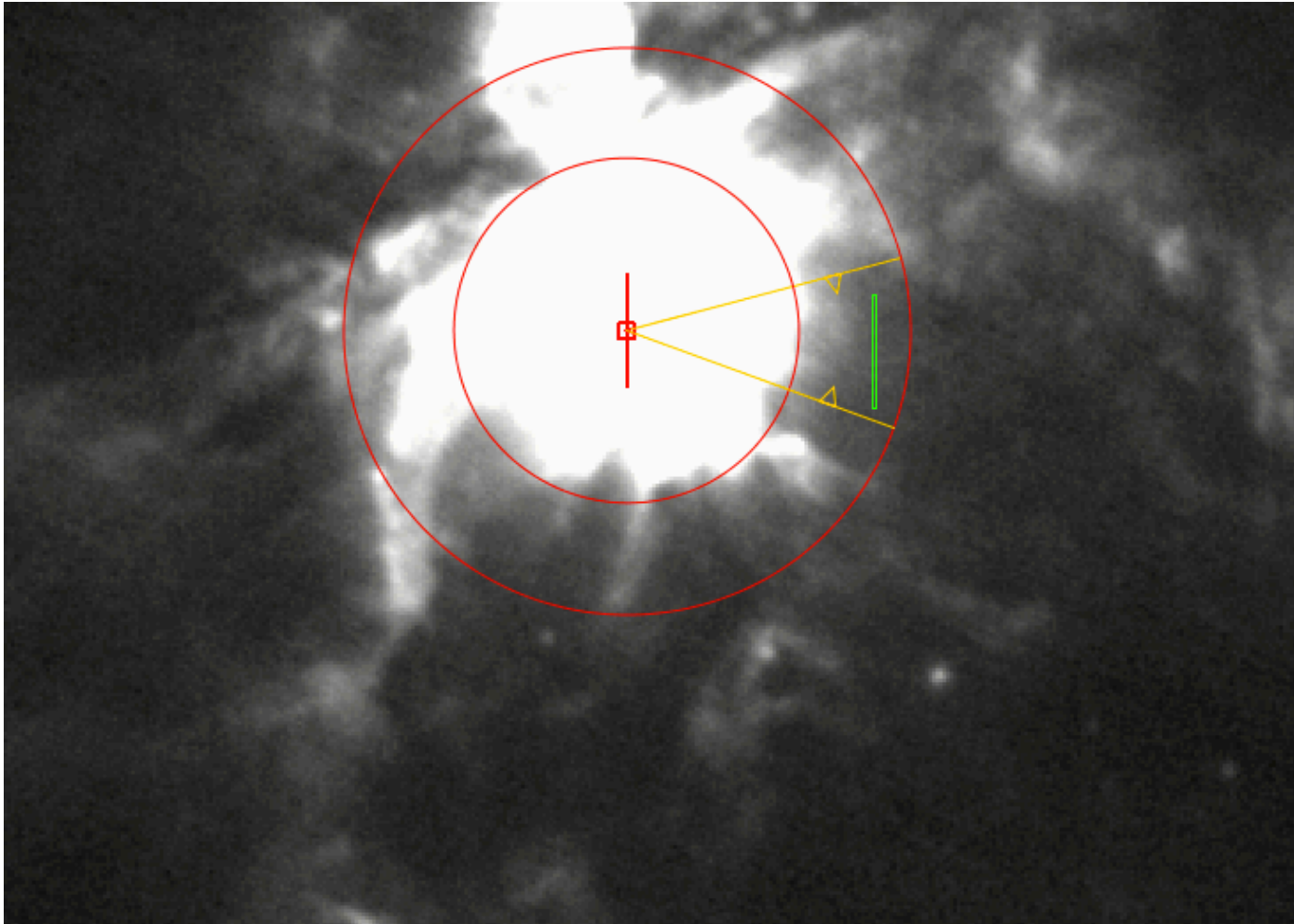
- Three grism observing modes available:
 - C2N – Two Position Chop & Nod
 - Primarily for point sources
 - Low observing overheads
 - NXCAC – Nod Unassociated with Chop, Asymmetric Chop
 - Primarily for extended sources or sources in regions of high background
 - High observing overheads
 - Slitscan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

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

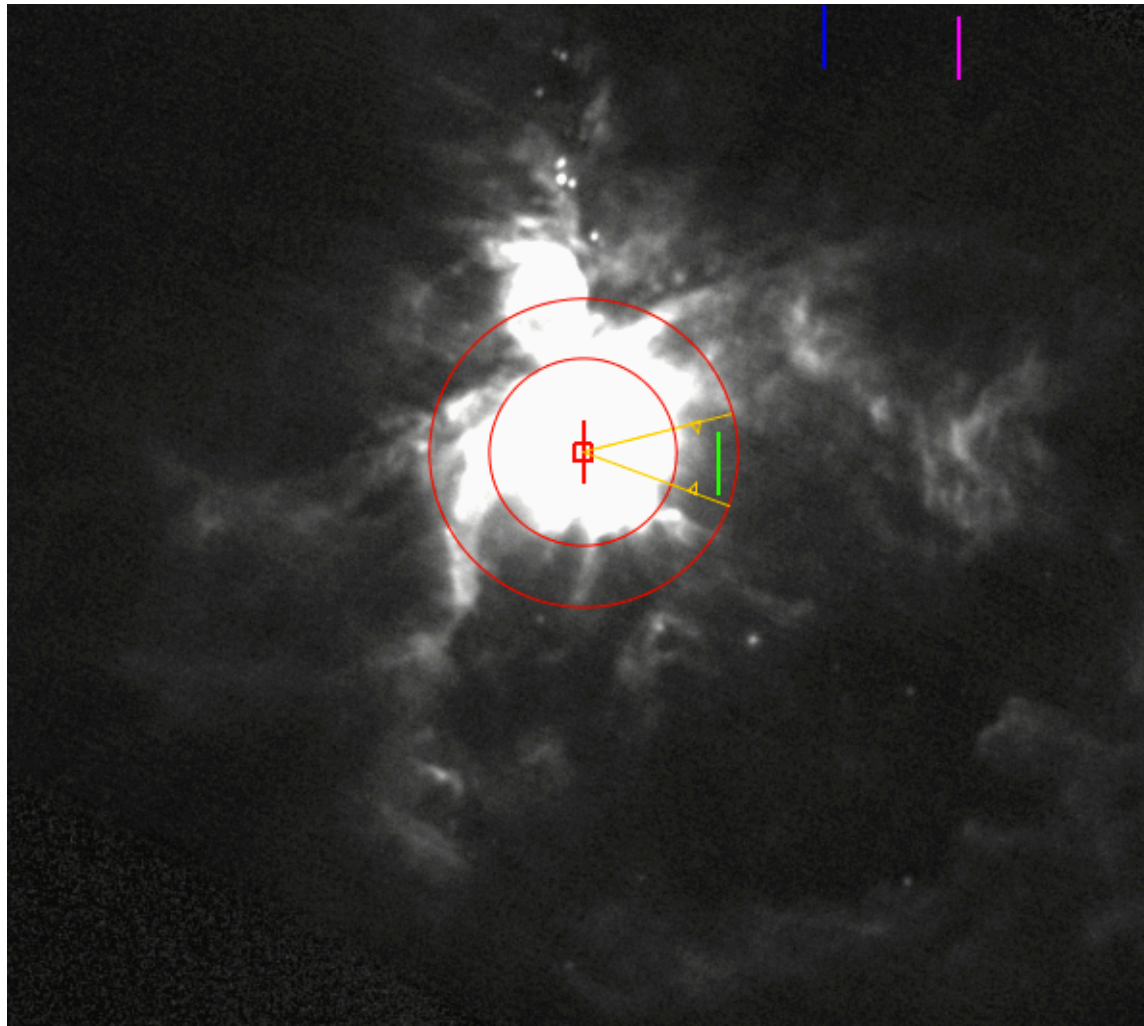


Orion Bar – SOFIA/FORCAST

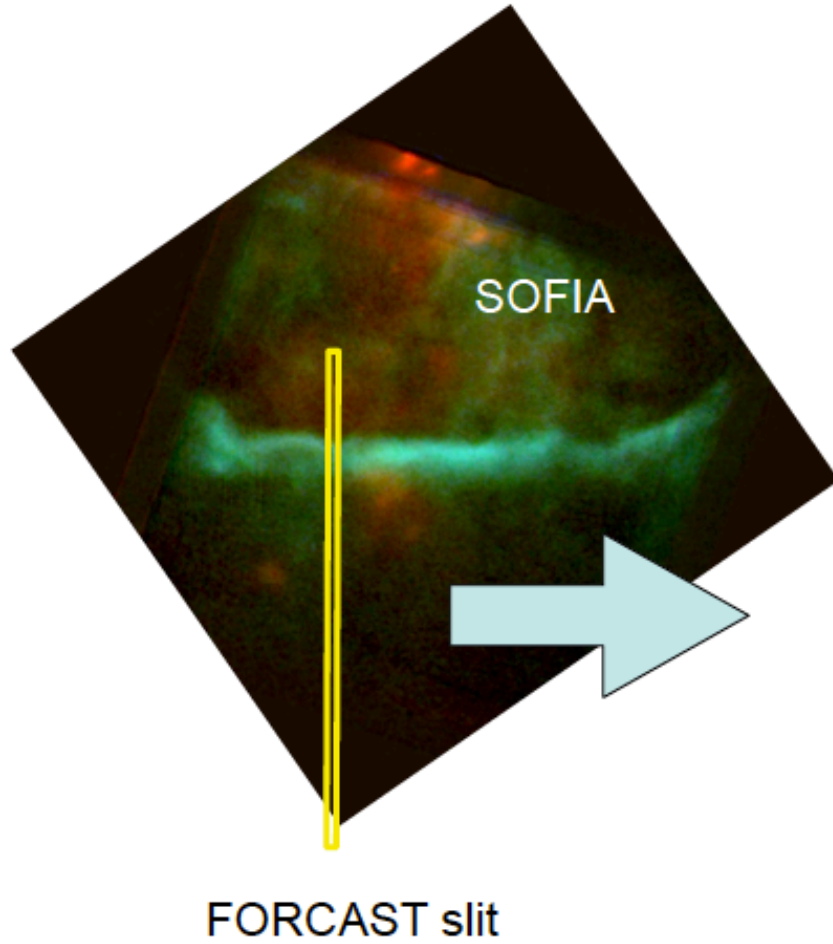




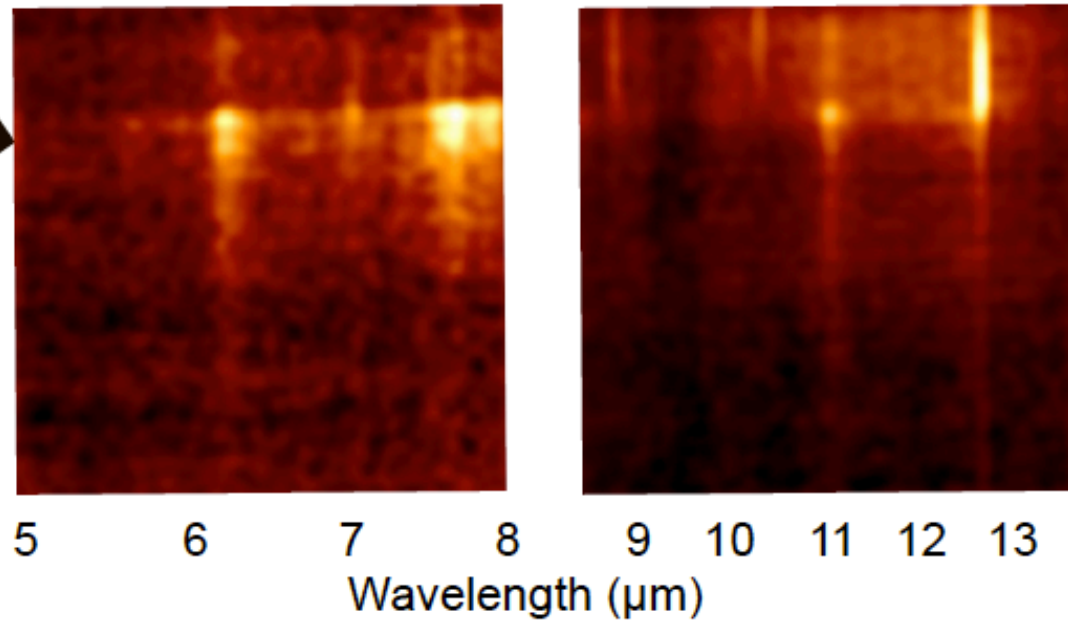
NXCAC setup for Orion Bar observations
Chop Throw: 420"; Chop Angle: 265°



NXCAC setup for Orion Bar observations
Nod Throw: 1500"; Nod Angle: 330°



FORCAST grism spectrum



Keller et al. 2015, in prep

