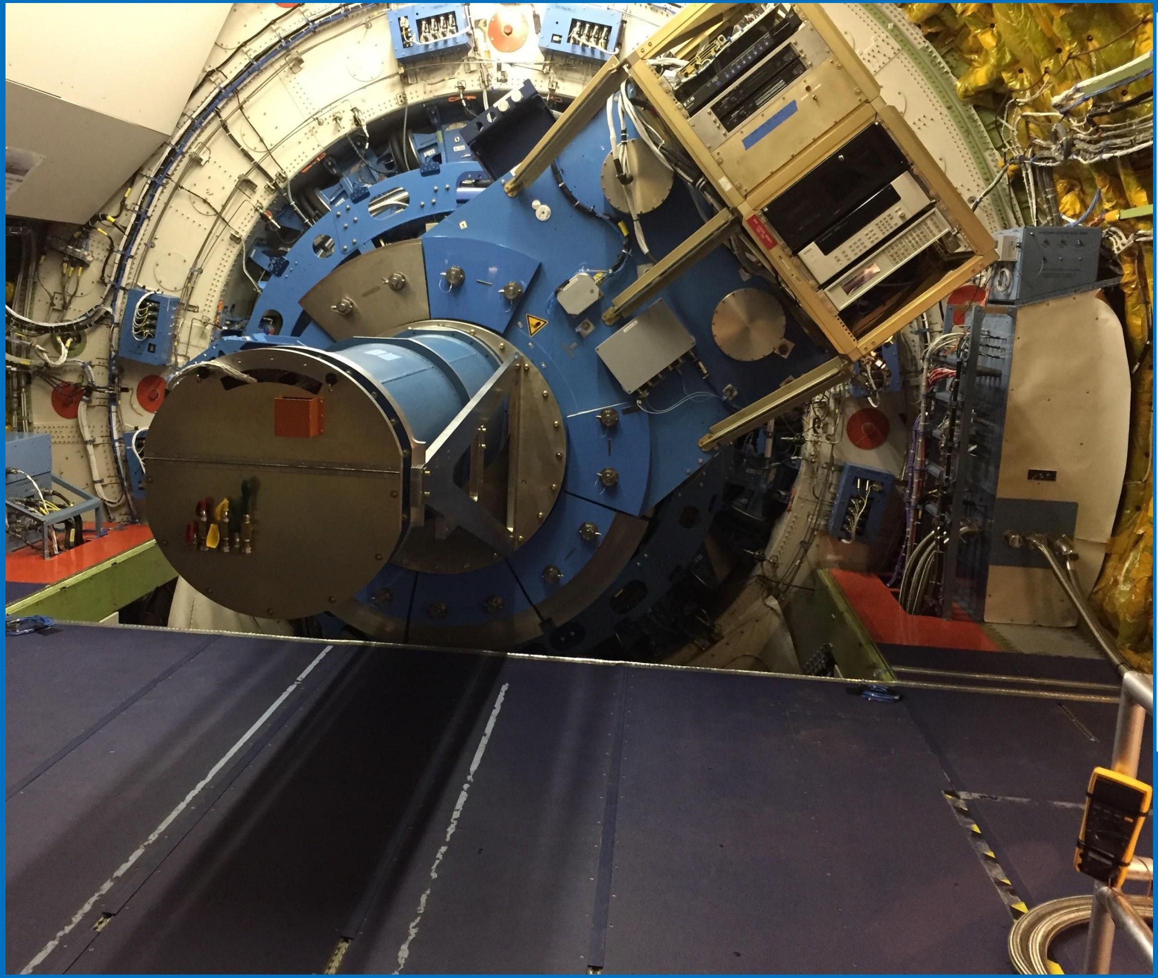
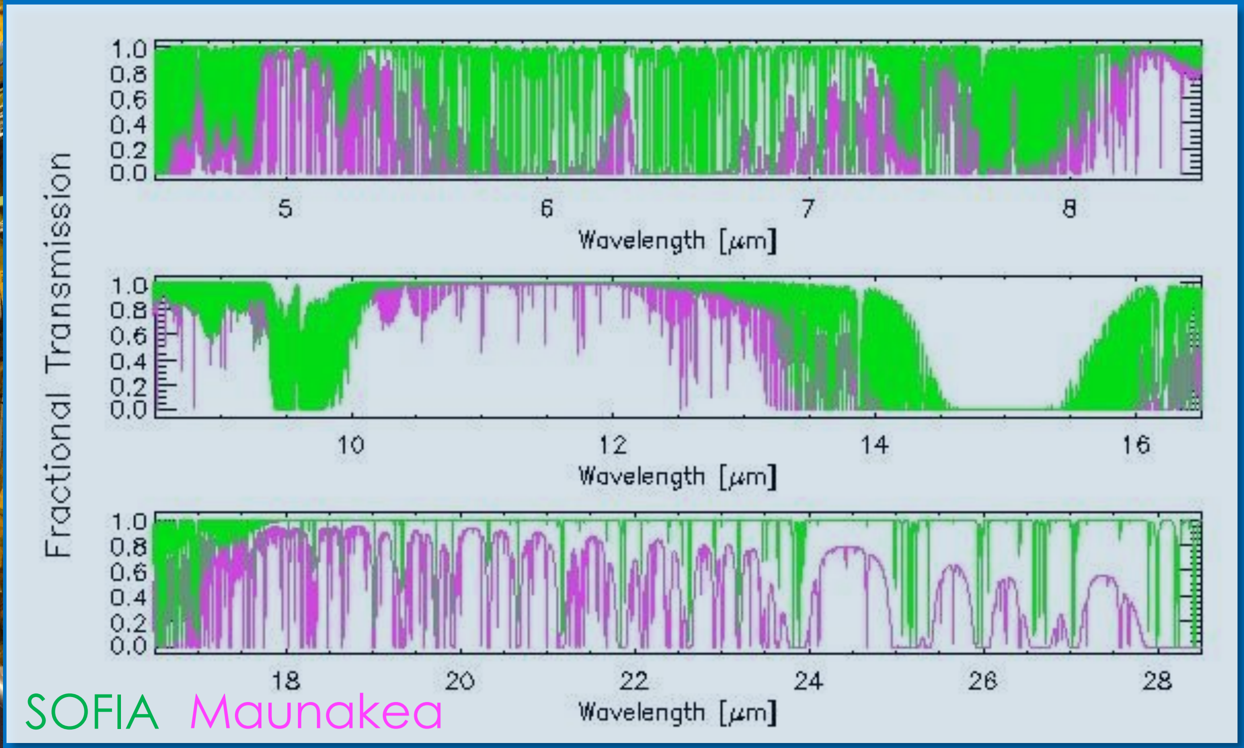
Southern Sources with EXES/SOFIA: A Community Chat





UC Davis

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Maisie Rashman

USRA

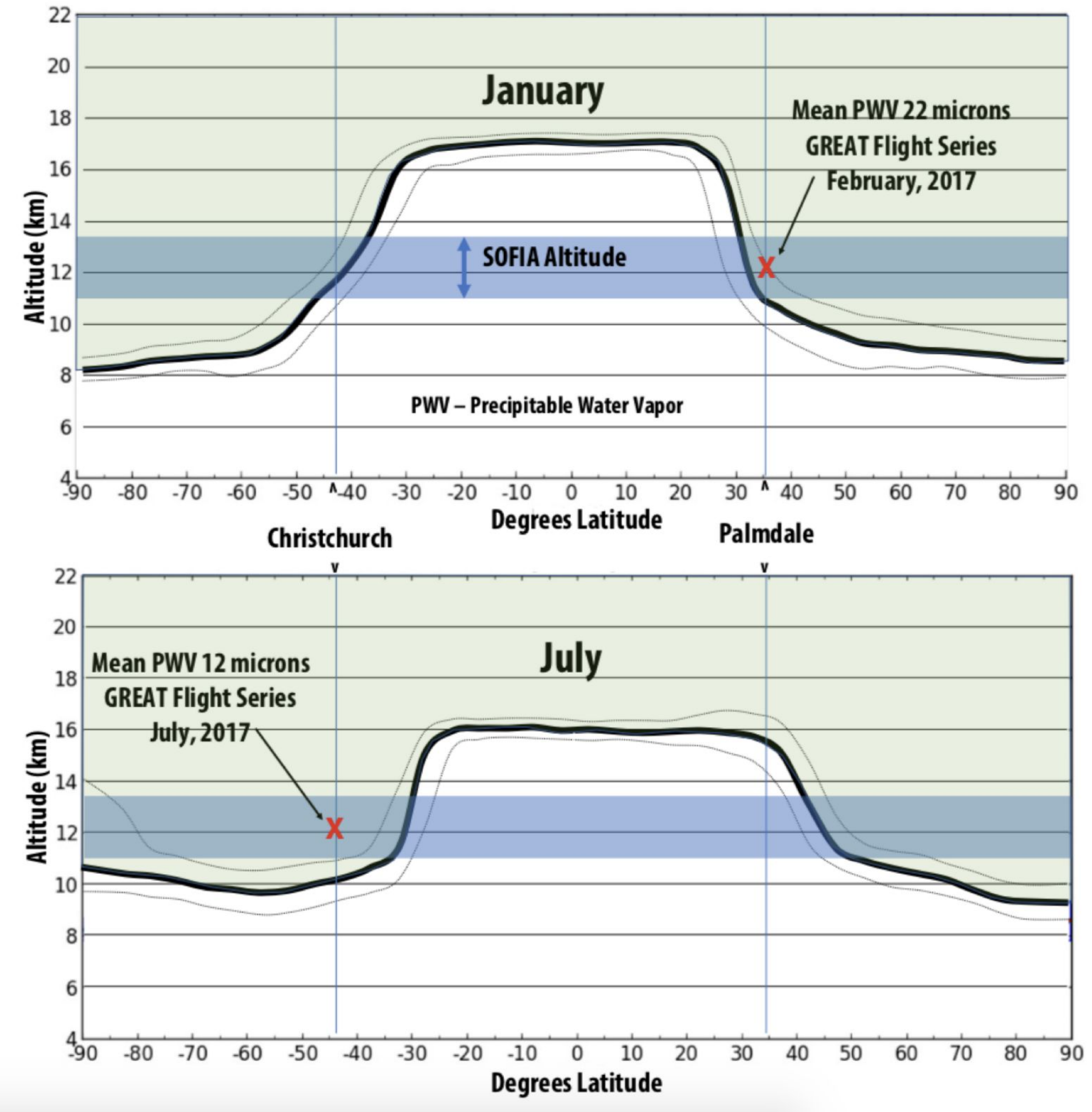
Curtis DeWitt
Edward Montiel

30 March 2021

Context

Context of this webinar

- Flights from the Southern Hemisphere can allow to access to sources with declination < -36 degrees, and often observe with much lower water vapor
  - enabling detection of fainter sources / transitions
- In previous (2 -- 9) proposal cycles, the demand for EXES Southern observations judged to be way too low for a Southern campaign [but that may be affected by self-selection, and pre-selection of instruments]
  - Only instrument that did not go to the South
- A Southern campaign on SOFIA needs some community coordination ahead of next/future Call for Proposals. If there is scientific value and interest, a campaign may happen

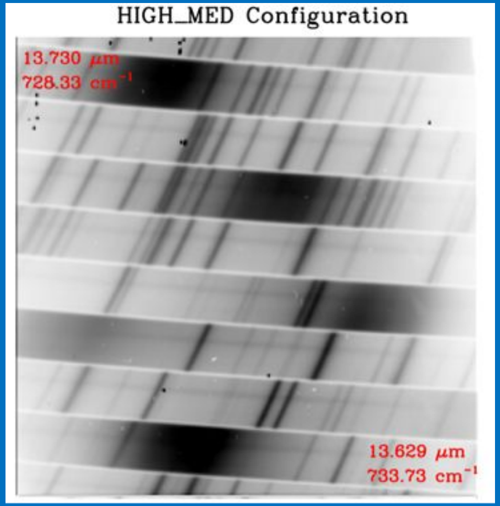


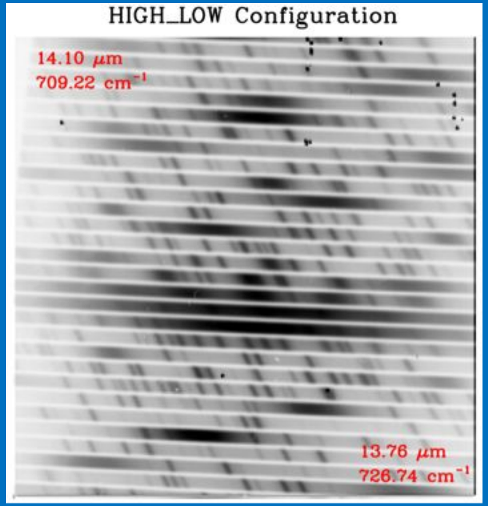
"SOFIA's Vision for the Future" H Yorke 4 Sep 2019

How to contribute to the process

- Participating today! Feel free to unmute and ask questions at any time. Arielle will watch the time for us.
- Google doc (https://docs.google.com/document/d/1YwMOyqT7pJC_JXjVon4tWKVixuS8doUVaTtoeYCJQr8/edit?usp=sharing)
  - email us if you want permission to edit
- Direct email to us - good if you want your idea kept more private
- EXES team will lead production of a document to be passed to the SUG and SOFIA leadership. We will welcome help.
- The focus will be on what science will be enabled by observing southern sources with EXES

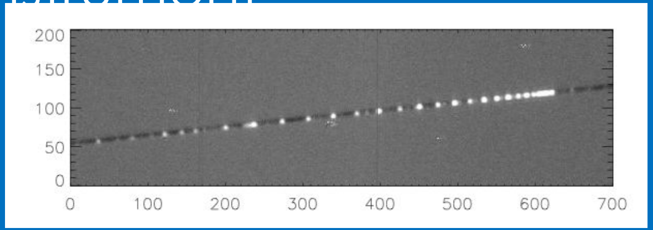
EXES in a Nutshell


HIGH_MED Configuration


HIGH_LOW Configuration

- Operates from 5 to 28.3 μm
- 1024 x 1024 detector
- High spectral resolution (R = 60,000 to 100,000) using a 1m long grating
- Cross dispersed
  - lower resolution modes use just the cross disperser
    - R ~ 10,000 and R ~ 3000 depending on wavelength, mode and slit width
    - low resolution often results in too high a photon flux for the low background detector. Generally safe for λ < ~7 μm
- Wavelength coverage depends on wavelength, mode, and cross-disperser angle.
- EXES Exposure Time Calculator helps illustrate possible instrument configurations

MEDIUM mode (pinhole)



EXES compared to other facilities

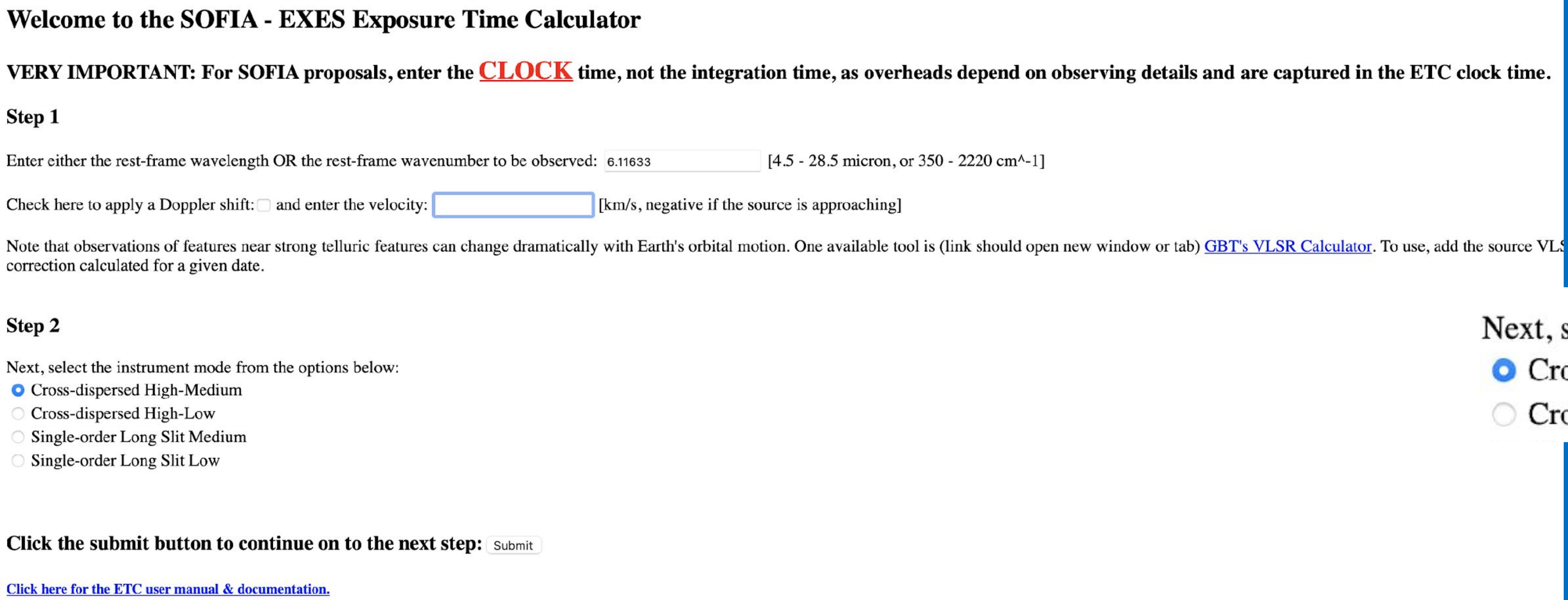
- JWST MIRI
    - same wavelength region (same type of detector)
    - Continuum sensitivity far beyond SOFIA/EXES
    - R=3000 (=EXES low)
    - much higher spatial resolution (~0.2" vs 2.5")
    - integral field
- ESO-VLT
    - CRIRES: R=100,000 for 1-5.5 µm
    - VISIR: R=30,000 in 8-13 µm (best with narrow band filter near [NeII])

EXES Exposure Time Calculator (ETC)

- Exposure time calculator (ETC) helps illustrate options. Note that ETC has some simplifications and oddities so we recommend working with EXES team for proposals and observing configurations.
- Current URL is http://irastro.physics.ucdavis.edu/exes/etc/
  - it will be moving to a USRA server before Cycle 10.
- User enters information on first two pages
- Final page summarizes entries and provides time estimate for a given S/N
- Give quick example here. Feel free to talk to us later as needed.

EXES ETC example (page 1)

- Observing H2O absorption out of ground state



Welcome to the SOFIA - EXES Exposure Time Calculator

VERY IMPORTANT: For SOFIA proposals, enter the CLOCK time, not the integration time, as overheads depend on observing details and are captured in the ETC clock time.

Step 1

Enter either the rest-frame wavelength OR the rest-frame wavenumber to be observed: 6.11633 [4.5 - 28.5 micron, or 350 - 2220 cm^-1]

Check here to apply a Doppler shift: ☐ and enter the velocity: [km/s, negative if the source is approaching]

Note that observations of features near strong telluric features can change dramatically with Earth's orbital motion. One available tool is (link should open new window or tab) GBT's VLSR Calculator. To use, add the source VLS correction calculated for a given date.

Step 2

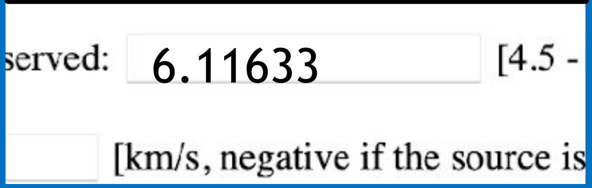
Next, select the instrument mode from the options below:

● Cross-dispersed High-Medium
○ Cross-dispersed High-Low
○ Single-order Long Slit Medium
○ Single-order Long Slit Low

Click the submit button to continue on to the next step:

Click here for the ETC user manual & documentation.

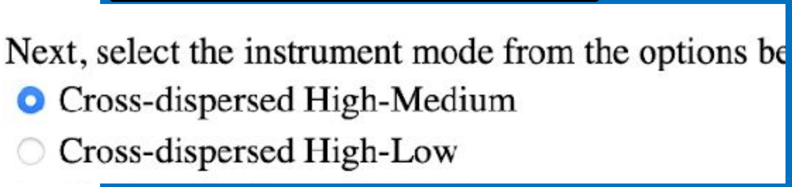
Step 1: enter wavelength or wavenumber at center



served: 6.11633 [4.5 -

[km/s, negative if the source is

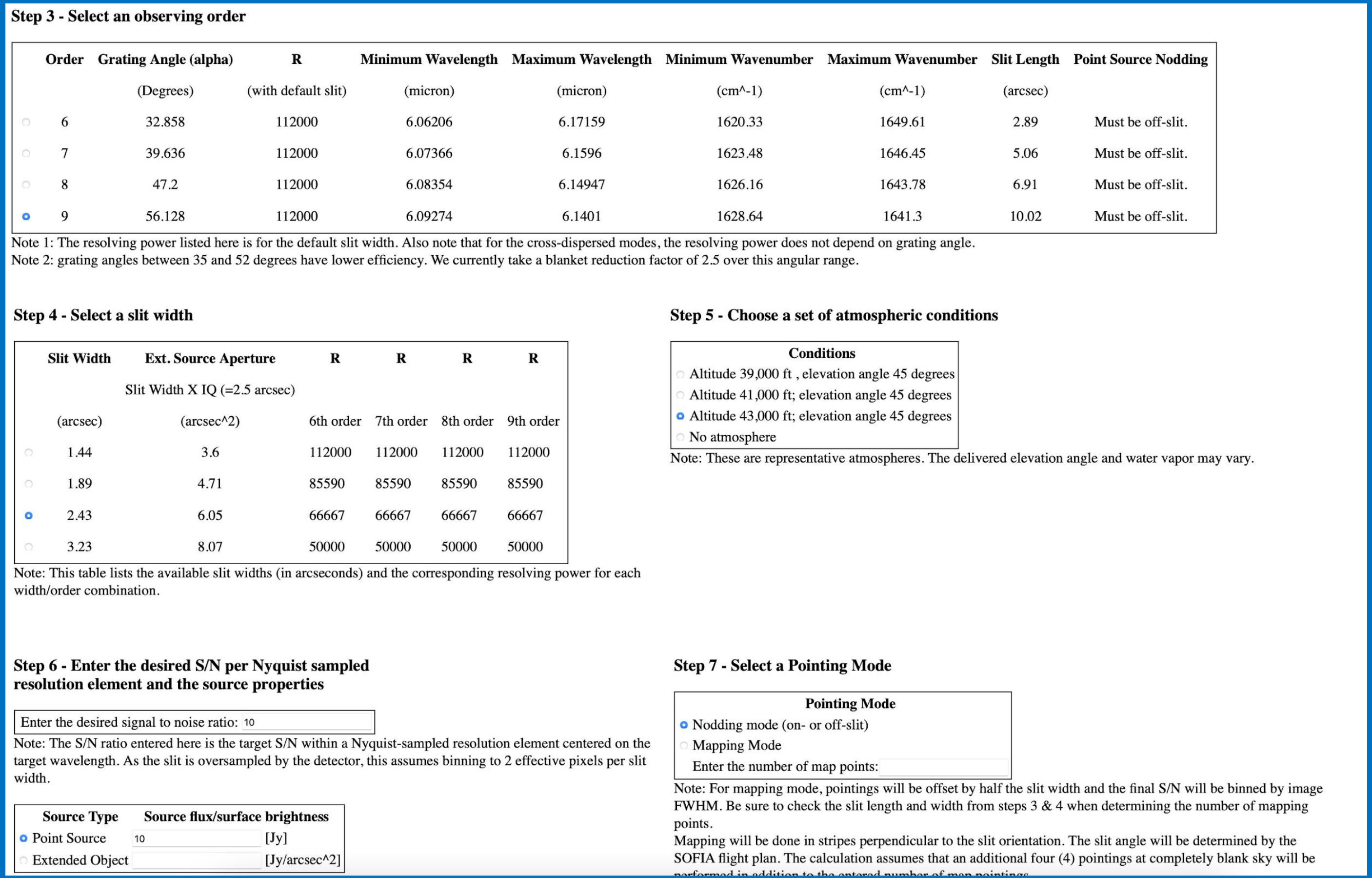
Step 2: Choose mode



Next, select the instrument mode from the options be

● Cross-dispersed High-Medium
○ Cross-dispersed High-Low

EXES ETC example (page 2)



Step 3 - Select an observing order

	Order	Grating Angle (alpha)	R	Minimum Wavelength	Maximum Wavelength	Minimum Wavenumber	Maximum Wavenumber	Slit Length	Point Source Nodding
		(Degrees)	(with default slit)	(micron)	(micron)	(cm^-1)	(cm^-1)	(arcsec)	
○	6	32.858	112000	6.06206	6.17159	1620.33	1649.61	2.89	Must be off-slit.
○	7	39.636	112000	6.07366	6.1596	1623.48	1646.45	5.06	Must be off-slit.
○	8	47.2	112000	6.08354	6.14947	1626.16	1643.78	6.91	Must be off-slit.
●	9	56.128	112000	6.09274	6.1401	1628.64	1641.3	10.02	Must be off-slit.

Note 1: The resolving power listed here is for the default slit width. Also note that for the cross-dispersed modes, the resolving power does not depend on grating angle.
Note 2: grating angles between 35 and 52 degrees have lower efficiency. We currently take a blanket reduction factor of 2.5 over this angular range.

Step 4 - Select a slit width

	Slit Width	Ext. Source Aperture	R	R	R	R
		Slit Width X IQ (=2.5 arcsec)				
	(arcsec)	(arcsec^2)	6th order	7th order	8th order	9th order
○	1.44	3.6	112000	112000	112000	112000
○	1.89	4.71	85590	85590	85590	85590
●	2.43	6.05	66667	66667	66667	66667
○	3.23	8.07	50000	50000	50000	50000

Note: This table lists the available slit widths (in arcseconds) and the corresponding resolving power for each width/order combination.

Step 5 - Choose a set of atmospheric conditions

Conditions
- ○ Altitude 39,000 ft , elevation angle 45 degrees
- ○ Altitude 41,000 ft; elevation angle 45 degrees
- ● Altitude 43,000 ft; elevation angle 45 degrees
- ○ No atmosphere

Note: These are representative atmospheres. The delivered elevation angle and water vapor may vary.

Step 6 - Enter the desired S/N per Nyquist sampled resolution element and the source properties

Enter the desired signal to noise ratio: 10

Note: The S/N ratio entered here is the target S/N within a Nyquist-sampled resolution element centered on the target wavelength. As the slit is oversampled by the detector, this assumes binning to 2 effective pixels per slit width.

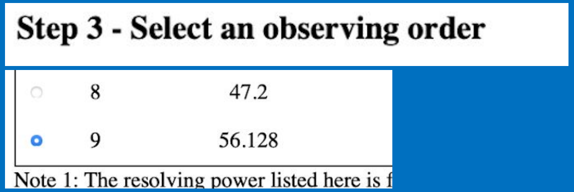
Source Type	Source flux/surface brightness	
● Point Source	10	[Jy]
○ Extended Object		[Jy/arcsec^2]

Step 7 - Select a Pointing Mode

Pointing Mode
- ● Nodding mode (on- or off-slit)
- ○ Mapping Mode

Enter the number of map points:

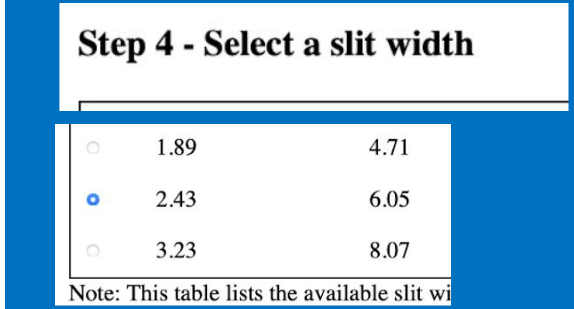
Note: For mapping mode, pointings will be offset by half the slit width and the final S/N will be binned by image FWHM. Be sure to check the slit length and width from steps 3 & 4 when determining the number of mapping points.
Mapping will be done in stripes perpendicular to the slit orientation. The slit angle will be determined by the SOFIA flight plan. The calculation assumes that an additional four (4) pointings at completely blank sky will be



Step 3 - Select an observing order

○	8	47.2
●	9	56.128

Note 1: The resolving power listed here is f



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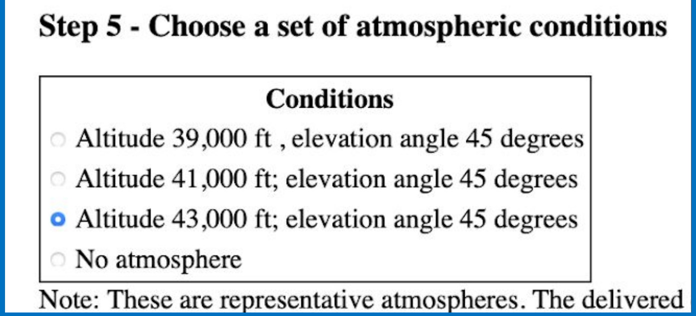

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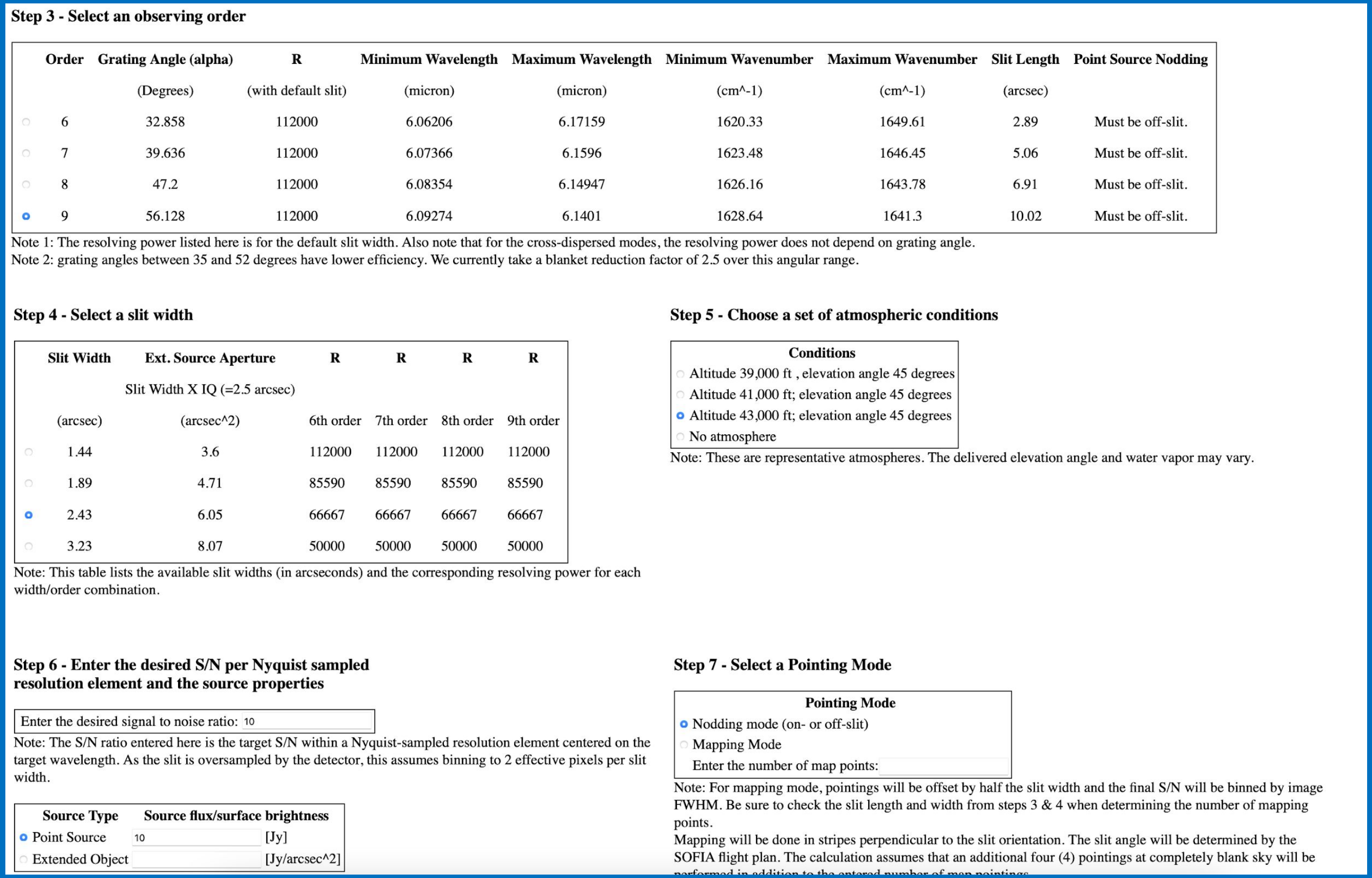
EXES ETC example (page 2 cont'd)



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	Source Type	Source flux/surface brightness	
●	Point Source	10	[Jy]
○	Extended Object		[Jy/arcsec^2]

Step 7 - Select a Pointing Mode

Pointing Mode
● Nodding mode (on- or off-slit)
○ Mapping Mode
Enter the number of map points:

Note: For mapping mode, pointings will be offset by half the slit width and the final S/N will be binned by image FWHM. Be sure to check the slit length and width from steps 3 & 4 when determining the number of mapping points.
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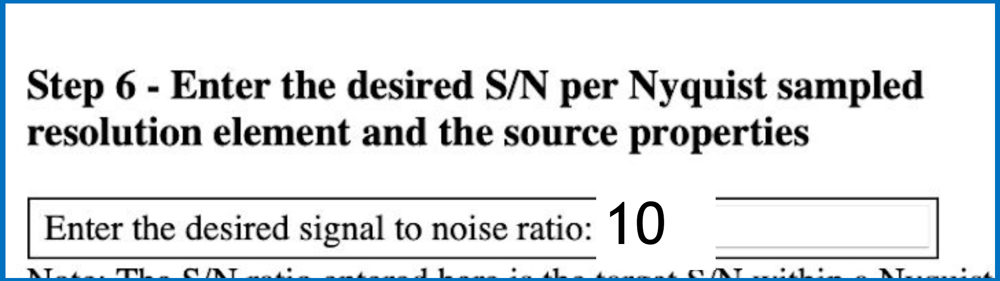

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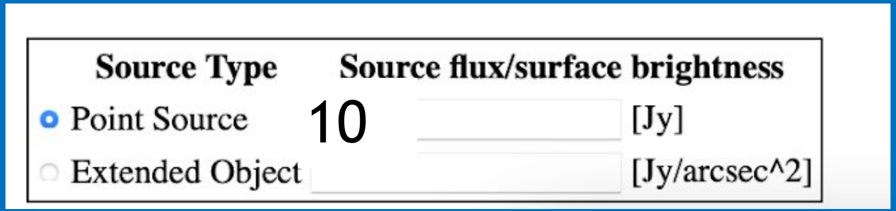

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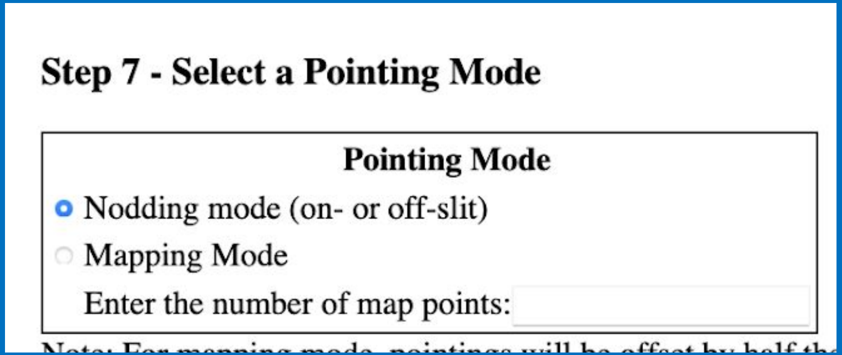
●	Point Source	10	[Jy]
○	Extended Object		[Jy/arcsec^2]



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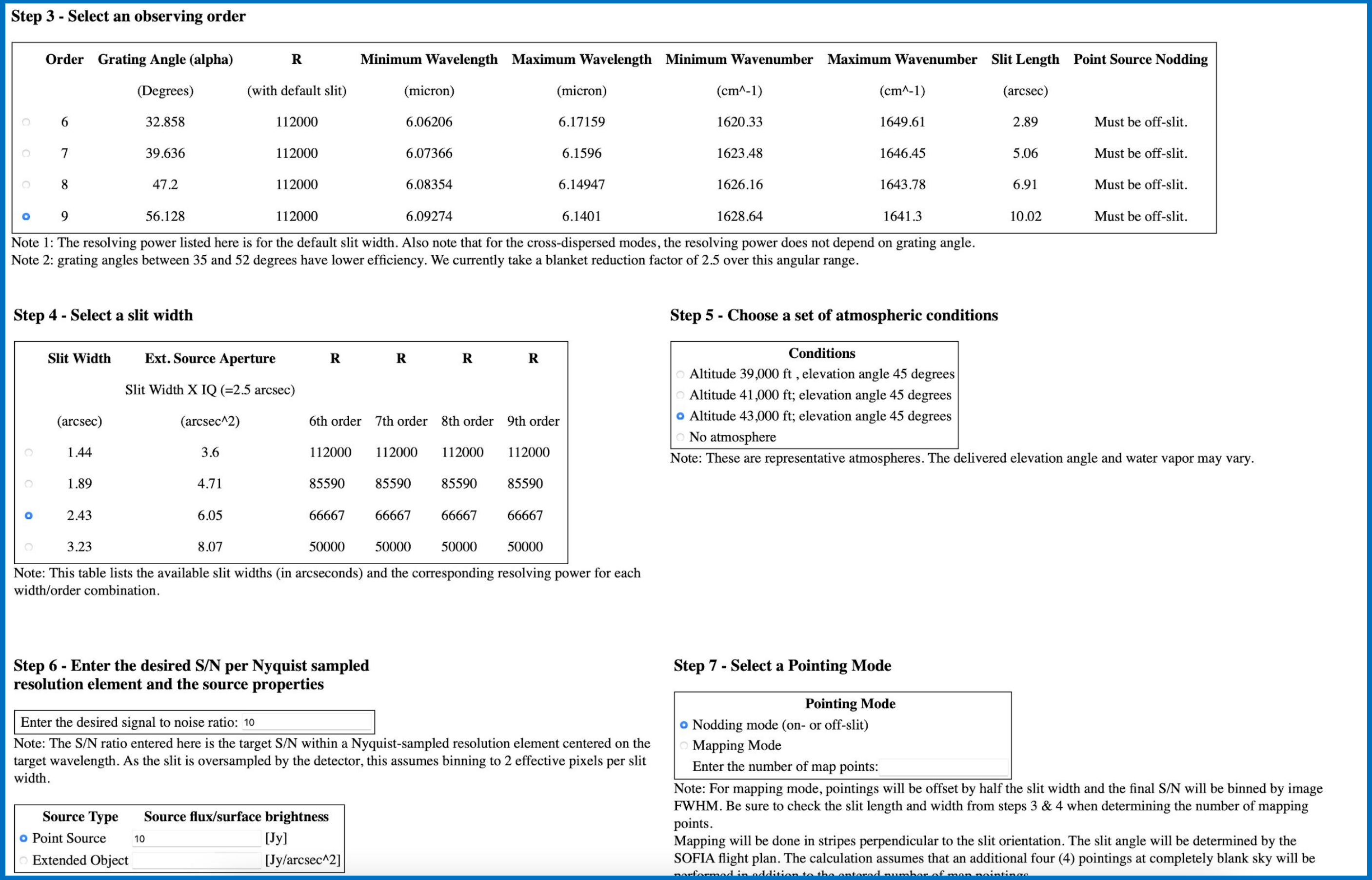
EXES ETC example (page 2 cont’d)



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○	8	47.2	112000	6.08354	6.14947	1626.16	1643.78	6.91	Must be off-slit.
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Step 4 - Select a slit width

	Slit Width (arcsec)	Ext. Source Aperture Slit Width X IQ (=2.5 arcsec) (arcsec^2)	R 6th order	R 7th order	R 8th order	R 9th order
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Source Type	Source flux/surface brightness	
● Point Source	10	[Jy]
○ Extended Object		[Jy/arcsec^2]

Step 7 - Select a Pointing Mode

Pointing Mode
- ● Nodding mode (on- or off-slit)
- ○ Mapping Mode

Enter the number of map points:

Note: For mapping mode, pointings will be offset by half the slit width and the final S/N will be binned by image FWHM. Be sure to check the slit length and width from steps 3 & 4 when determining the number of mapping points.
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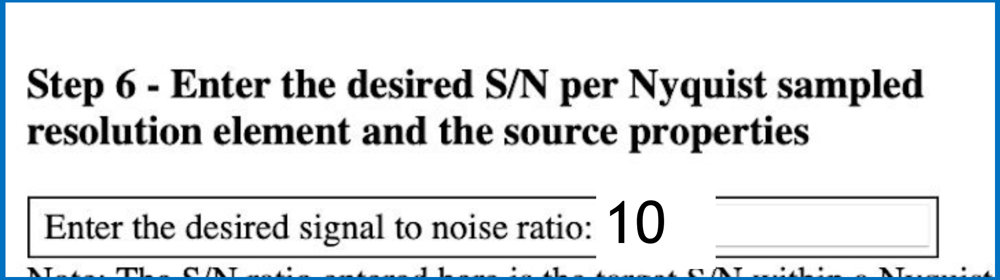

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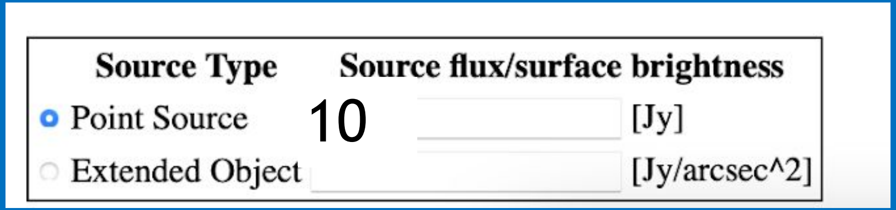
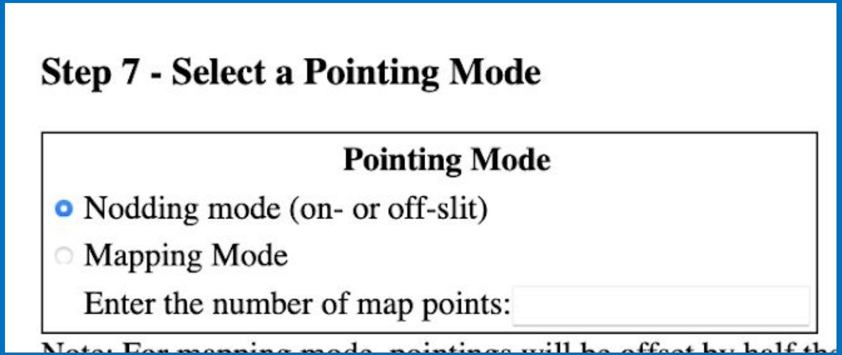


Source Type	Source flux/surface brightness	
● Point Source	10	[Jy]
○ Extended Object		[Jy/arcsec^2]

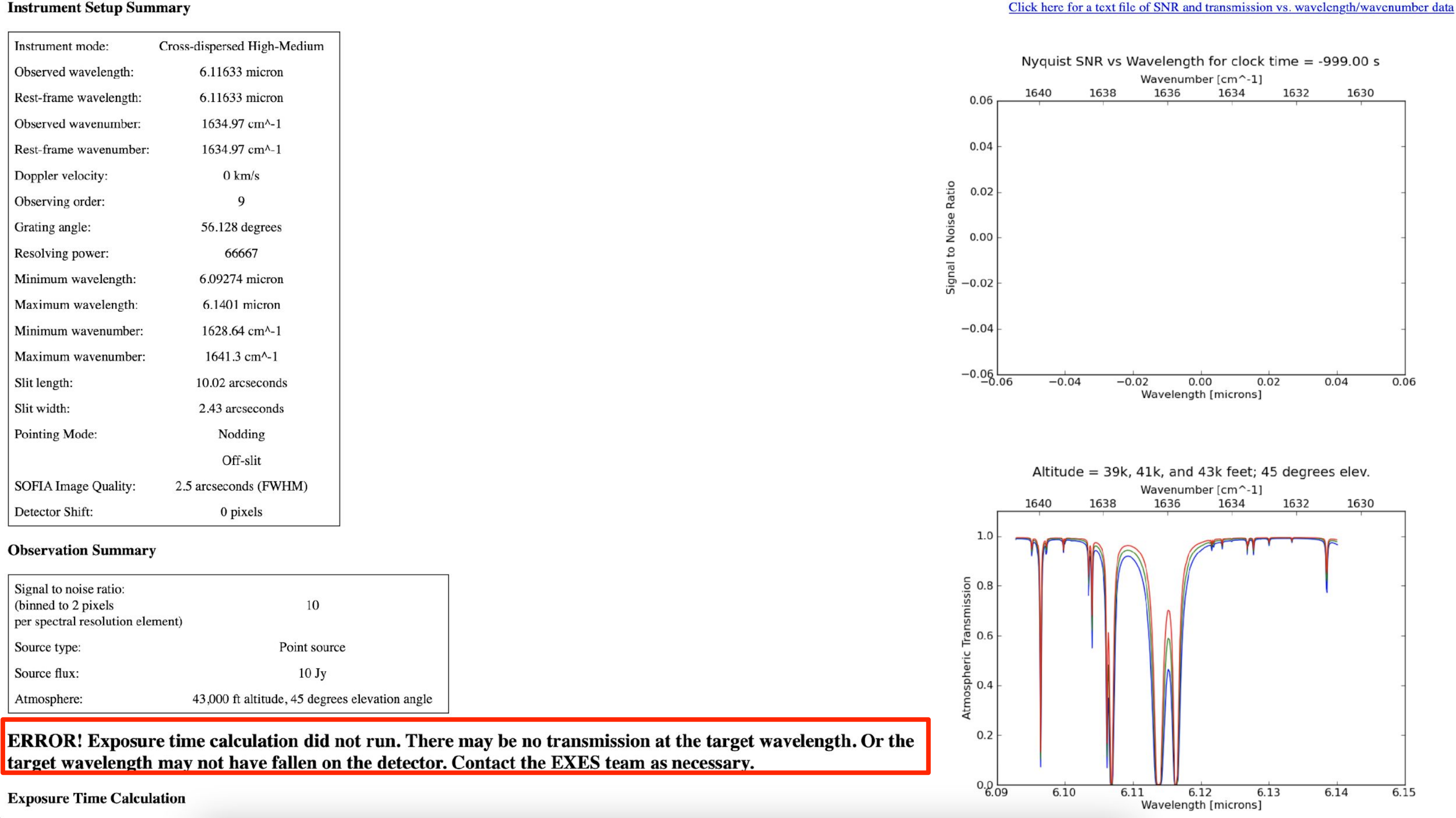


Step 7 - Select a Pointing Mode

Pointing Mode
- ● Nodding mode (on- or off-slit)
- ○ Mapping Mode

Enter the number of map points:

EXES ETC example (page 3 - ERROR)



Instrument Setup Summary

Click here for a text file of SNR and transmission vs. wavelength/wavenumber data

Instrument mode:	Cross-dispersed High-Medium
Observed wavelength:	6.11633 micron
Rest-frame wavelength:	6.11633 micron
Observed wavenumber:	1634.97 cm^-1
Rest-frame wavenumber:	1634.97 cm^-1
Doppler velocity:	0 km/s
Observing order:	9
Grating angle:	56.128 degrees
Resolving power:	66667
Minimum wavelength:	6.09274 micron
Maximum wavelength:	6.1401 micron
Minimum wavenumber:	1628.64 cm^-1
Maximum wavenumber:	1641.3 cm^-1
Slit length:	10.02 arcseconds
Slit width:	2.43 arcseconds
Pointing Mode:	Nodding Off-slit
SOFIA Image Quality:	2.5 arcseconds (FWHM)
Detector Shift:	0 pixels

Observation Summary

Signal to noise ratio: (binned to 2 pixels per spectral resolution element)	10
Source type:	Point source
Source flux:	10 Jy
Atmosphere:	43,000 ft altitude, 45 degrees elevation angle

ERROR! Exposure time calculation did not run. There may be no transmission at the target wavelength. Or the target wavelength may not have fallen on the detector. Contact the EXES team as necessary.

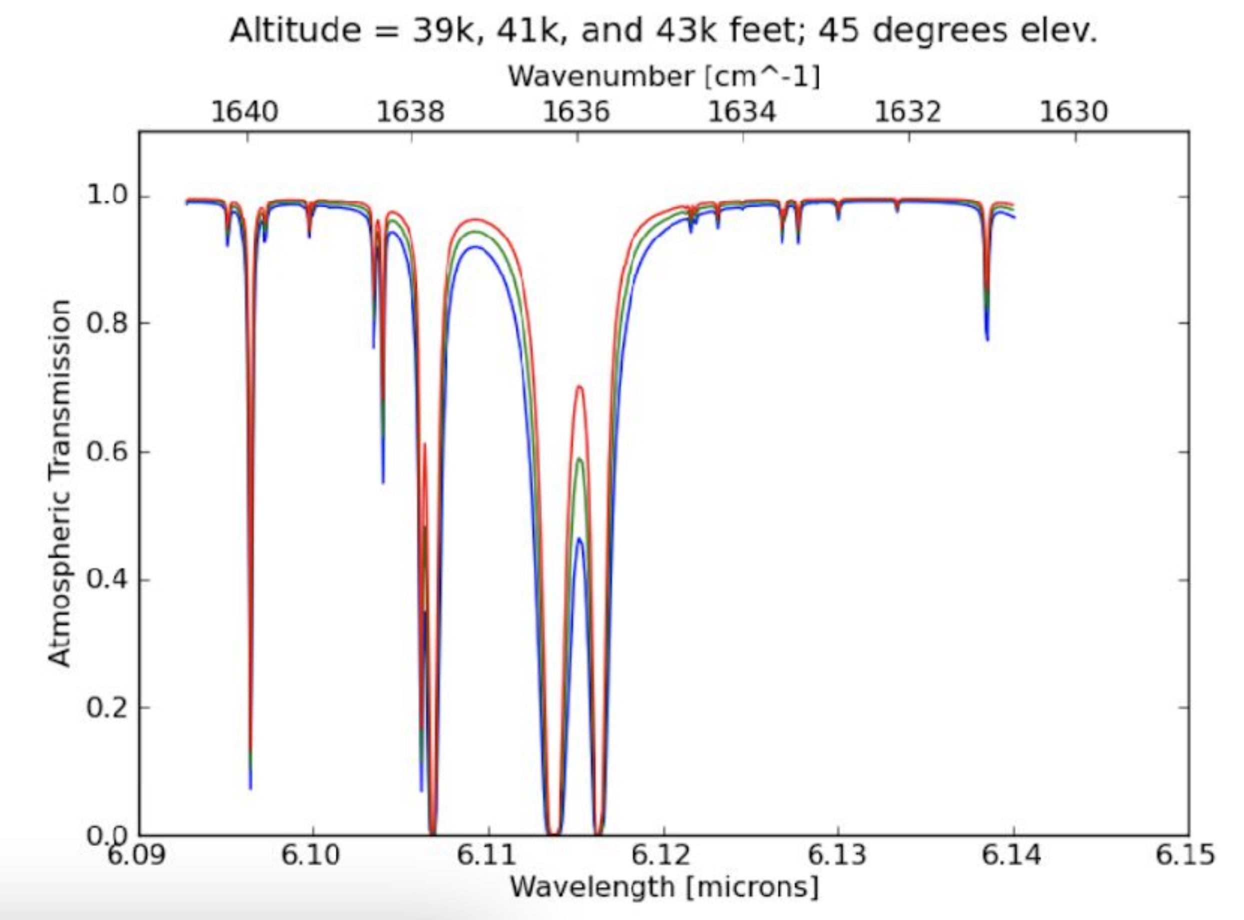
Exposure Time Calculation

SNR vs Wavelength plot is blank

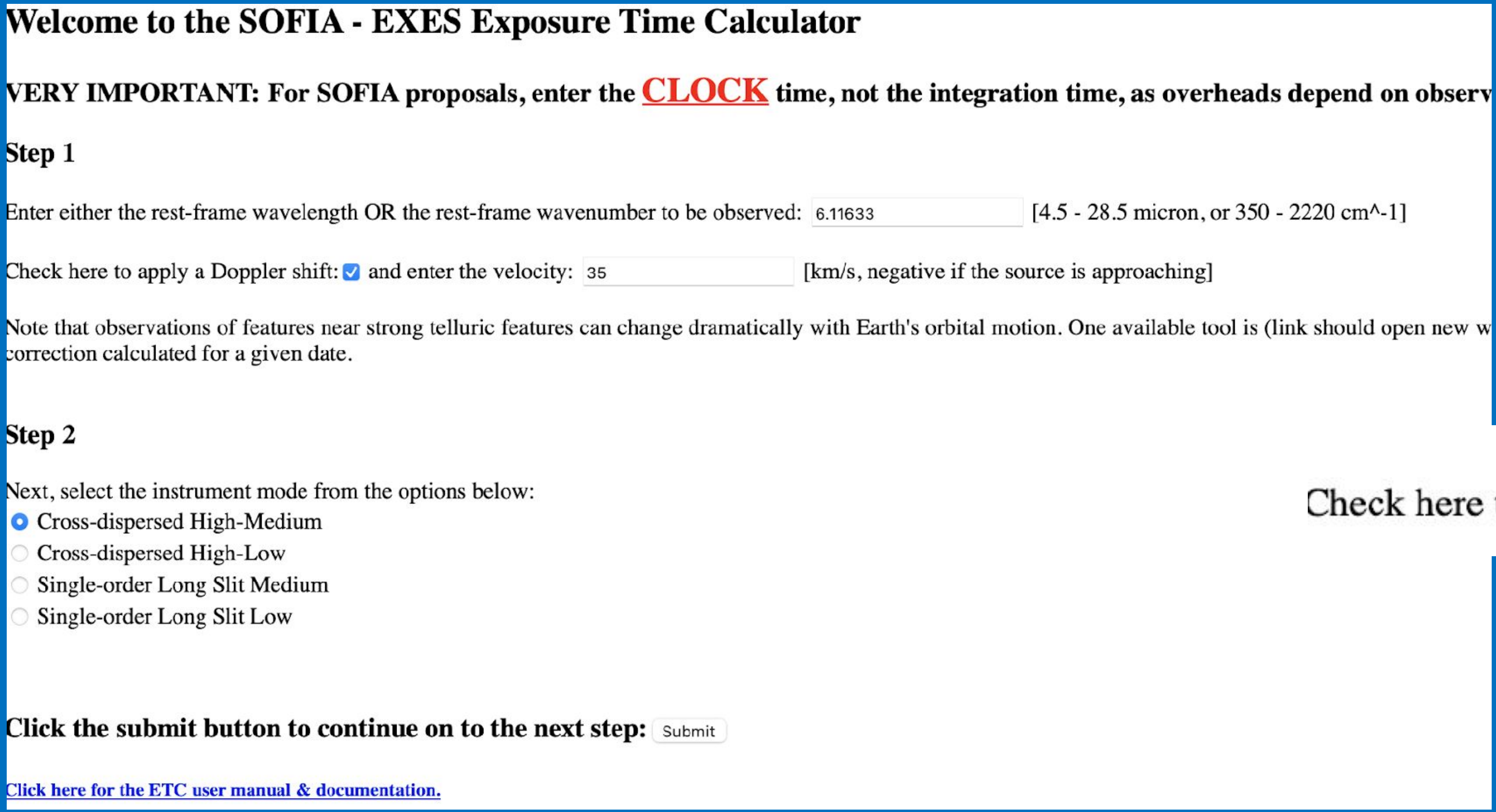
Clock time is -999

Error caused because we are at strong atmospheric line

EXES ETC example (page 3 - Atmosphere)



EXES ETC example (with 35 km/s redshift)



Welcome to the SOFIA - EXES Exposure Time Calculator

VERY IMPORTANT: For SOFIA proposals, enter the CLOCK time, not the integration time, as overheads depend on observ

Step 1

Enter either the rest-frame wavelength OR the rest-frame wavenumber to be observed: 6.11633 [4.5 - 28.5 micron, or 350 - 2220 cm^-1]

Check here to apply a Doppler shift: ☑ and enter the velocity: 35 [km/s, negative if the source is approaching]

Note that observations of features near strong telluric features can change dramatically with Earth's orbital motion. One available tool is (link should open new w correction calculated for a given date.

Step 2

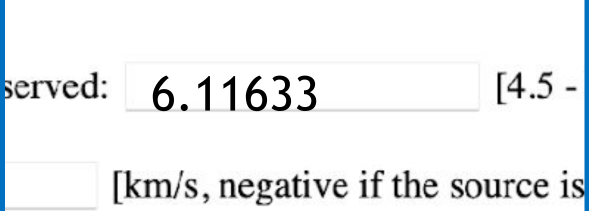
Next, select the instrument mode from the options below:

● Cross-dispersed High-Medium
○ Cross-dispersed High-Low
○ Single-order Long Slit Medium
○ Single-order Long Slit Low

Click the submit button to continue on to the next step: Submit

Click here for the ETC user manual & documentation.

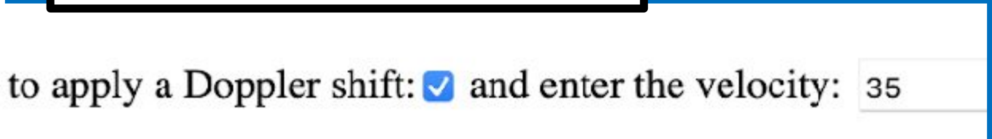
Step 1: enter wavelength or wavenumber at center



served: 6.11633 [4.5 -

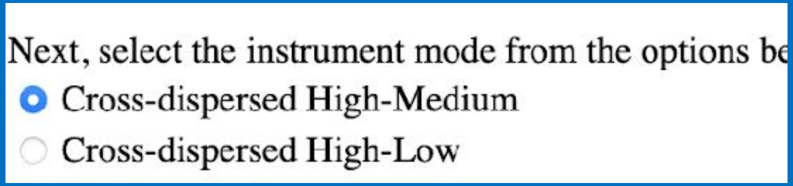
[km/s, negative if the source is

Step 1a: add Doppler shift



Check here to apply a Doppler shift: ☑ and enter the velocity: 35

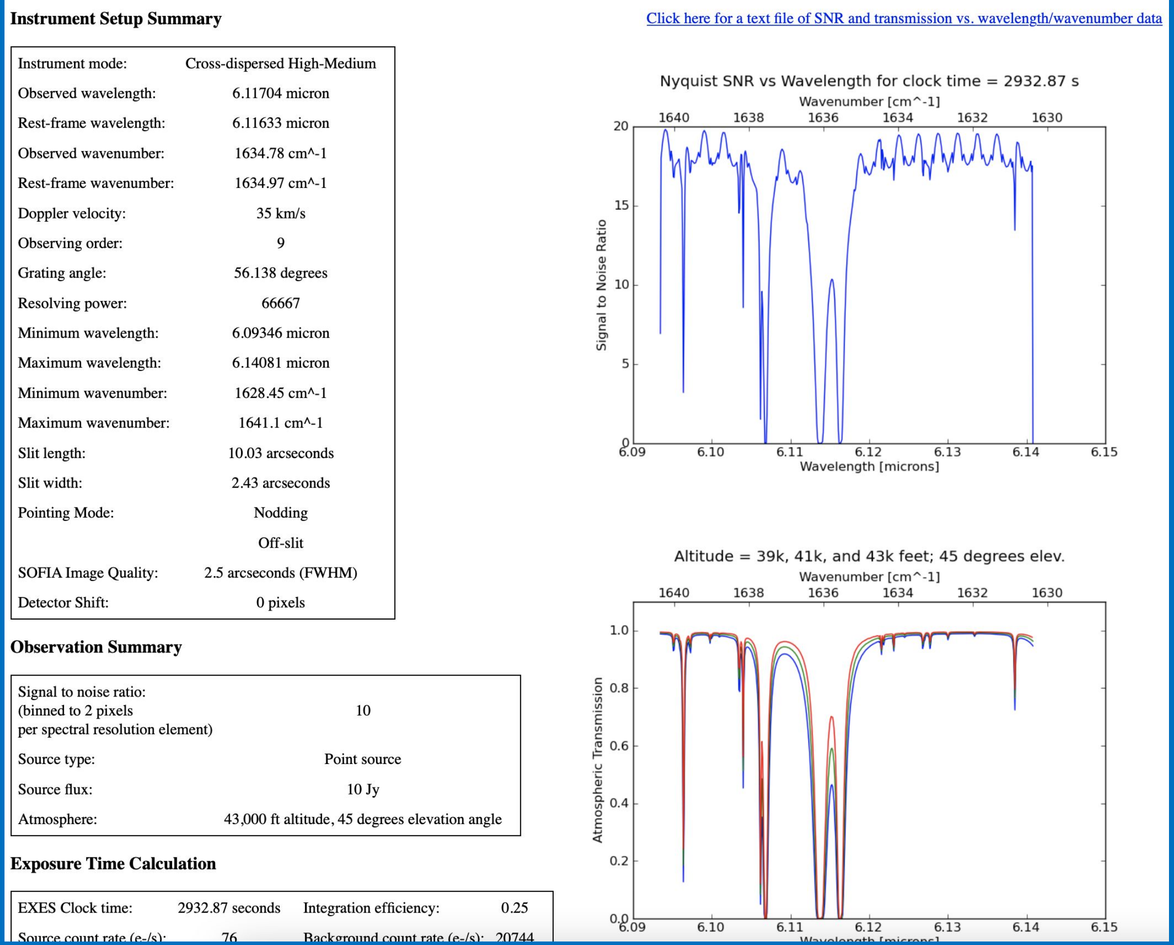
Step 2: Choose mode



Next, select the instrument mode from the options be

● Cross-dispersed High-Medium
○ Cross-dispersed High-Low

EXES ETC example (pg 3 with redshift)



Instrument Setup Summary

Click here for a text file of SNR and transmission vs. wavelength/wavenumber data

Instrument mode:	Cross-dispersed High-Medium
Observed wavelength:	6.11704 micron
Rest-frame wavelength:	6.11633 micron
Observed wavenumber:	1634.78 cm^-1
Rest-frame wavenumber:	1634.97 cm^-1
Doppler velocity:	35 km/s
Observing order:	9
Grating angle:	56.138 degrees
Resolving power:	66667
Minimum wavelength:	6.09346 micron
Maximum wavelength:	6.14081 micron
Minimum wavenumber:	1628.45 cm^-1
Maximum wavenumber:	1641.1 cm^-1
Slit length:	10.03 arcseconds
Slit width:	2.43 arcseconds
Pointing Mode:	Nodding Off-slit
SOFIA Image Quality:	2.5 arcseconds (FWHM)
Detector Shift:	0 pixels

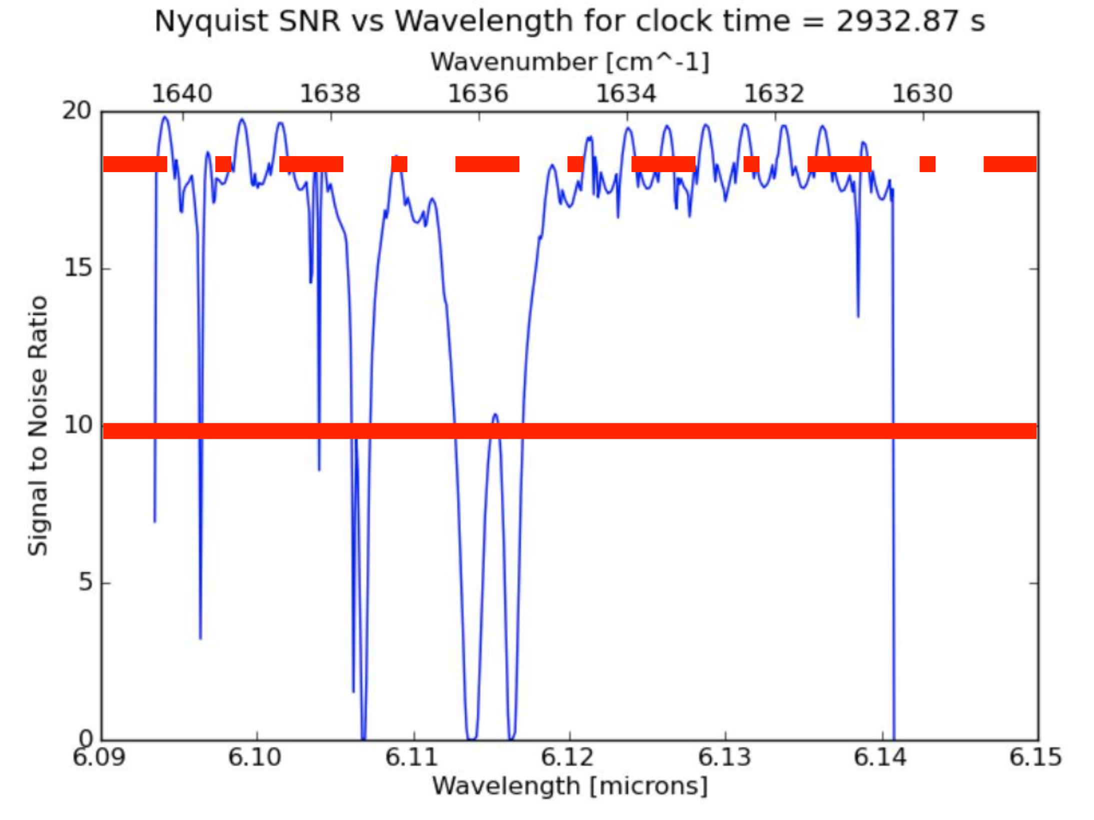
Observation Summary

Signal to noise ratio: (binned to 2 pixels per spectral resolution element)	10
Source type:	Point source
Source flux:	10 Jy
Atmosphere:	43,000 ft altitude, 45 degrees elevation angle

Exposure Time Calculation

EXES Clock time:	2932.87 seconds	Integration efficiency:	0.25
Source count rate (e-/s):	76	Background count rate (e-/s):	20744

Clock time = 2932.87 s

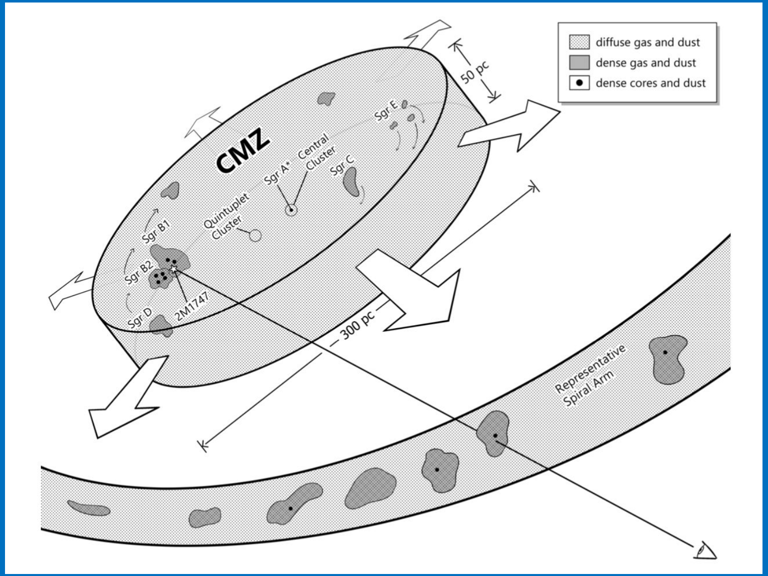


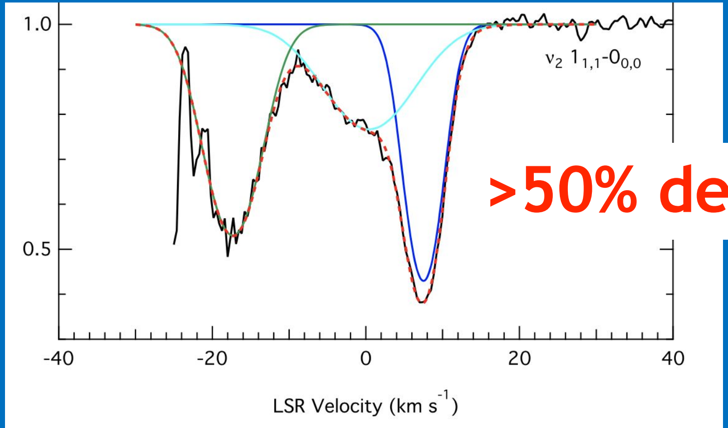
Galactic Center

Absorption Lines in the ISM

Molecular absorption toward GC (Tielens)

- Use background continuum source to probe molecules along line of sight (Geballe et al 2021 for H_3^+ - arXiv:2103.06514)
- Due to likely time required, target particular lines
  - H_2O, CH_4, C_2H_2, HCN, HNC, SO_2
- For very cold gas, H_2O absorption out of ground state
  - Example: BN (Indriolo et al 2018)



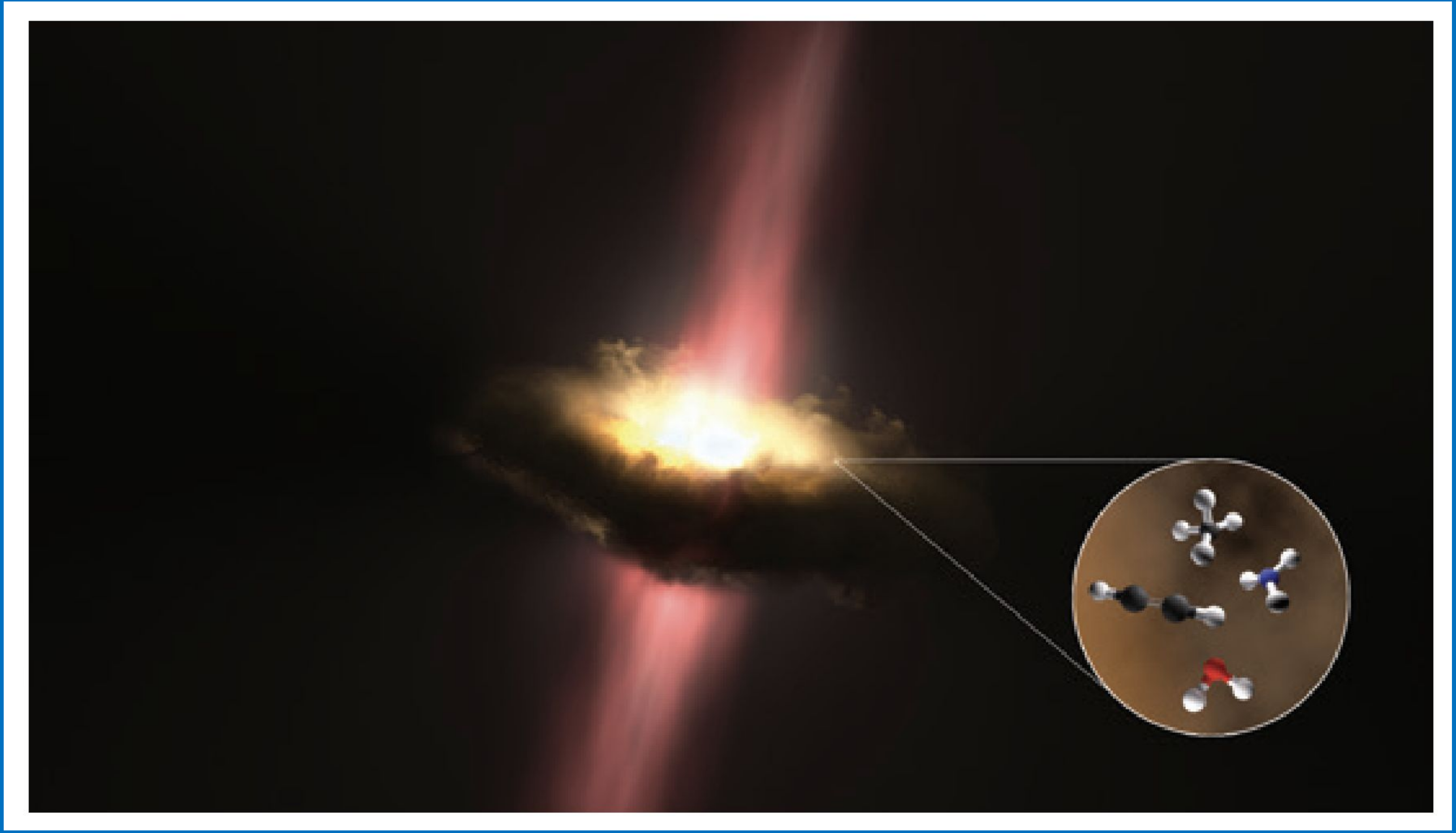


>50% deep!

With proper Doppler shift, even 10 Jy source would be possible with 3000s

Protostars and Hot Cores

Protostars Part 1– absorption lines toward Massive YSOs



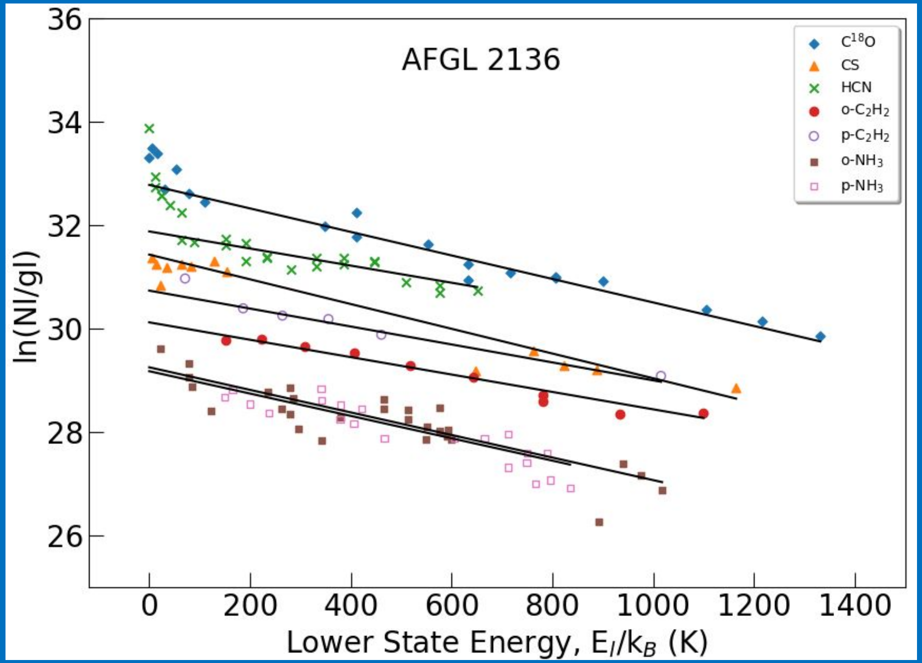
NASA / Ames Research Center / Daniel Rutter

Case for the South: Diversity of Massive YSO disks

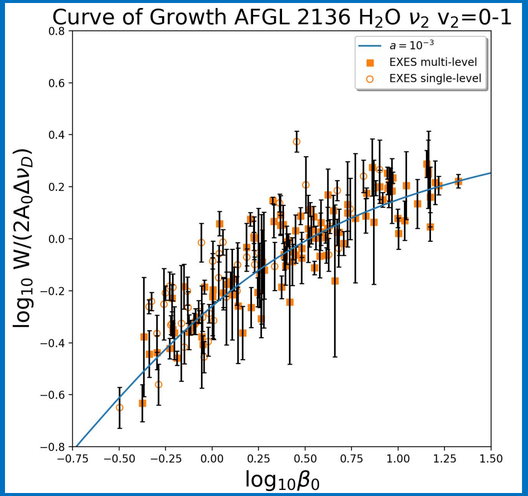
(on behalf of Xander Tielens)

- 5.3-8 um, R=60000 absorption line surveys probing the chemistry, kinematics and structure of HMYSO disks.
- Completed for AFGL 2136 & AFGL 2591
- Molecule networks and disk chemistry not directly probed by submm
- The C.O.G of 100s of H2O lines assessed with stellar atmosphere theory gives dT/dz – and the M-dot at the midplane
- What is the impact of M-dot, evolutionary age, disk inclination, radiation environment, binarity?

Need absolute source numbers!



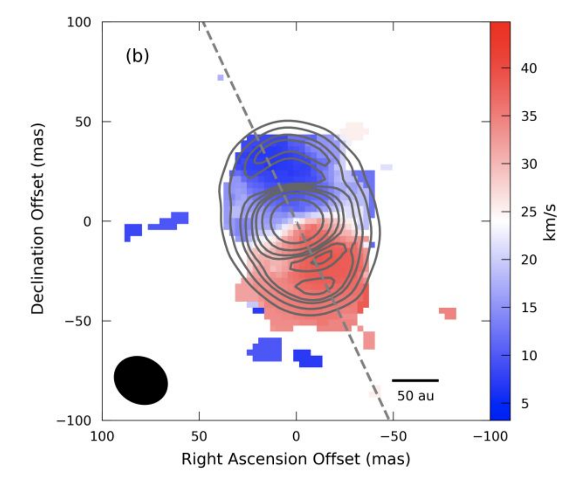
Barr et al 2020



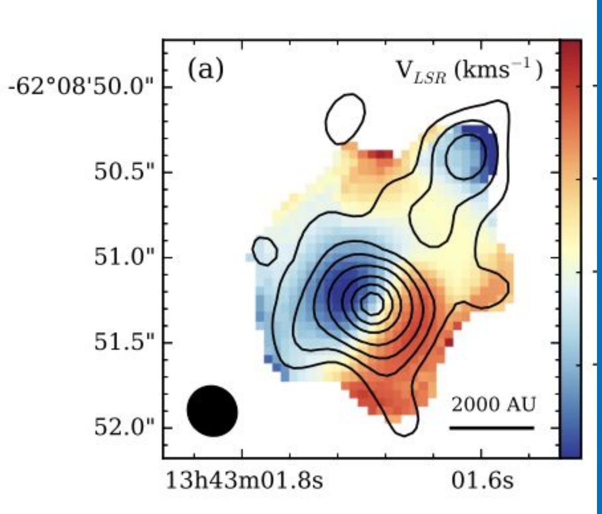
Barr et al 2021 *(submitted)*

Case for the South: Diversity of Massive YSO disks

- 5-8um took 16 grating settings and about 10-15 hrs each to compete (it's faster now..)
- Targets need to be about 100 Jy for practical survey speed
- 5-ish good ones above dec -30 deg
- Another 3 good ones in the South, < -30 deg
- Showcase source, AFGL 4176, dec = -62



AFGL 2136 IRS 1 (North)
Maud et al. 2019



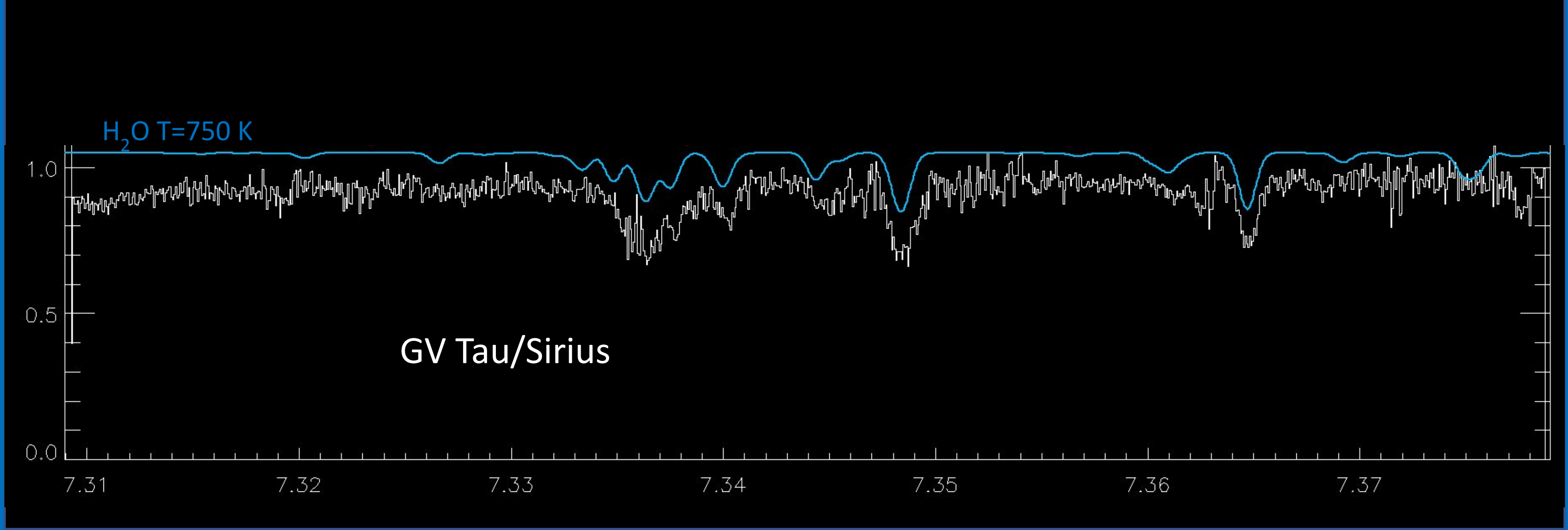
AFGL 4176 *(South)*
Johnston et al. 2015

✓ ISO/SWS shows warm gas phase absorption
✓ Flux 150-300 Jy
✓ ALMA sees a disk in Keplerian rotation

Protostars Part 2– Can EXES do low mass protostars?

- Low Mass YSOs are faint by EXES standards
- Programs GV Tau (8 Jy) (Carr et al, in prep), *MEDIUM Resolution*, ~23 km/s

- 09_0197, 09_0003 will also target brighter TTs and FU Ors, in medium res mode.
- Need > 2 Jy continuum for absorption lines, S/N ~ 50, in an hour for medium mode



GV Tau / Sirius, Program 05_0097

Or, use the EXES resolution advantage on emission lines

- T-Tauris in the MIR usually have emission lines
- Few T-Tauris have resolved MIR molecular emission line
- Options from the ground very limited, 12um

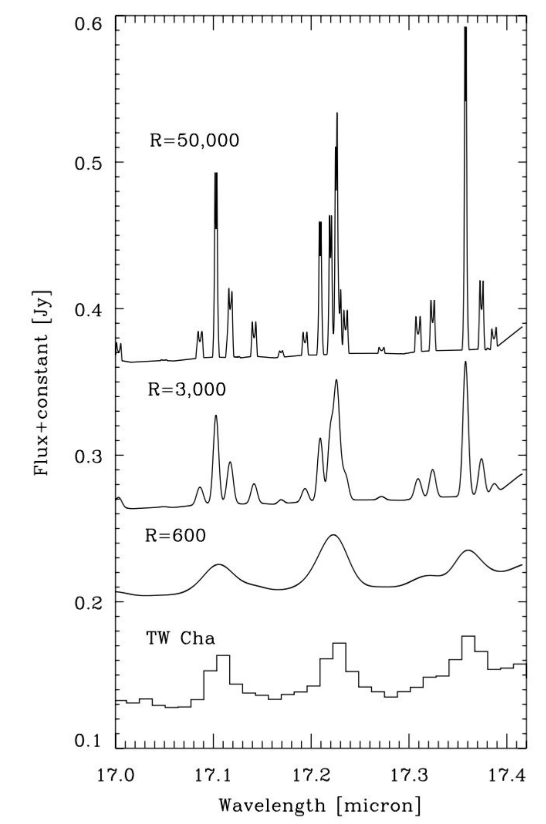
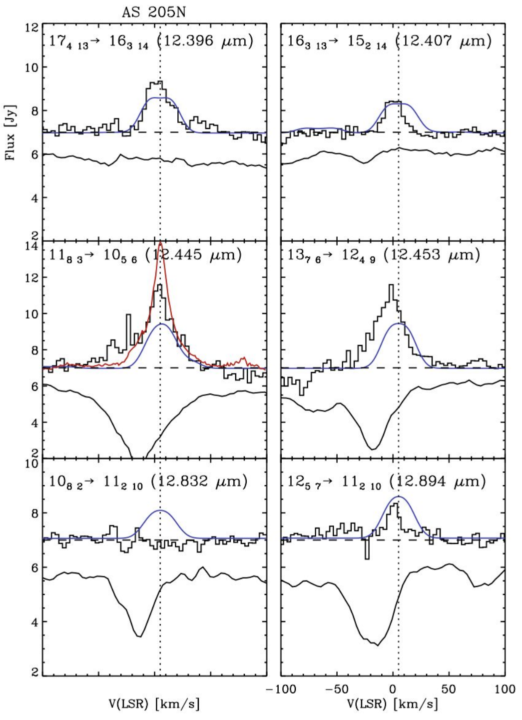


Figure 5. LTE disk model showing how the 17.22 μm H_2O line complex breaks up into many individual lines at higher spectral resolution. Model spectra with resolving powers relevant for both *Spitzer*-IRS ($R = 600$) and JWST-MIRI ($R = 3000$) are shown. Note how JWST-MIRI is expected to resolve the water line complexes (but not the individual lines). The lower curve is the spectrum of TW Cha, shown for comparison. The model is taken from Pontoppidan et al. (2009).

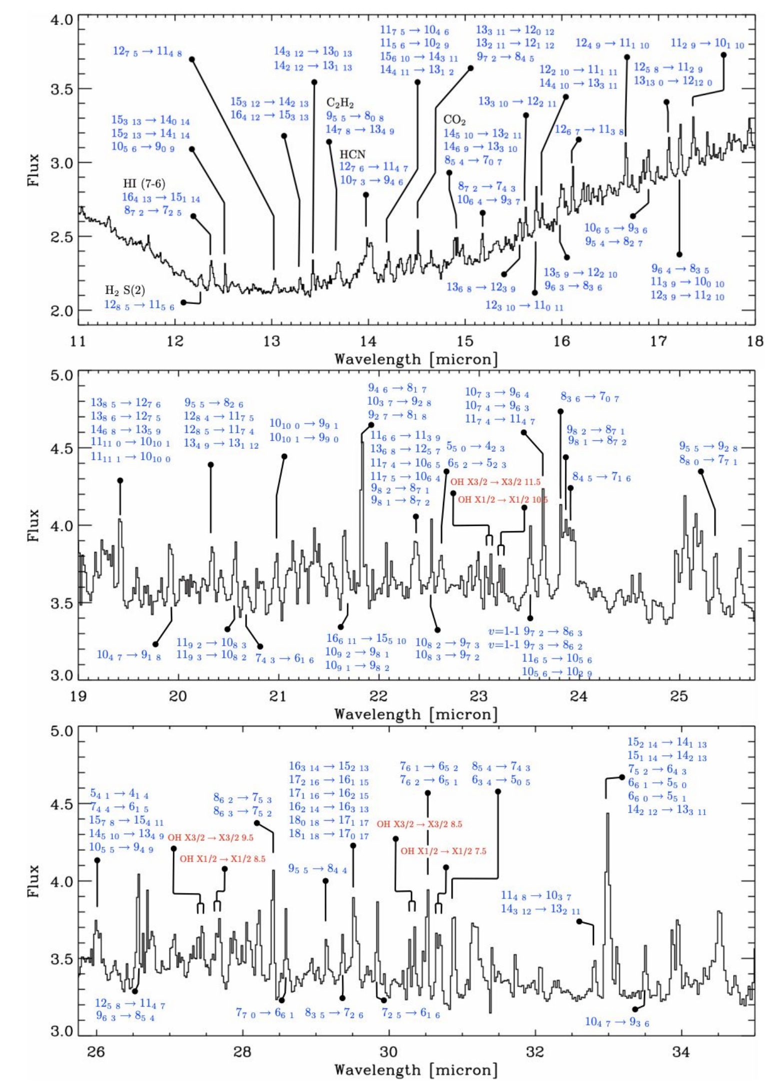
Pontoppidan et al. 2010a



Pontoppidan et al. 2010b

Or, use the EXES resolution advantage on emission lines

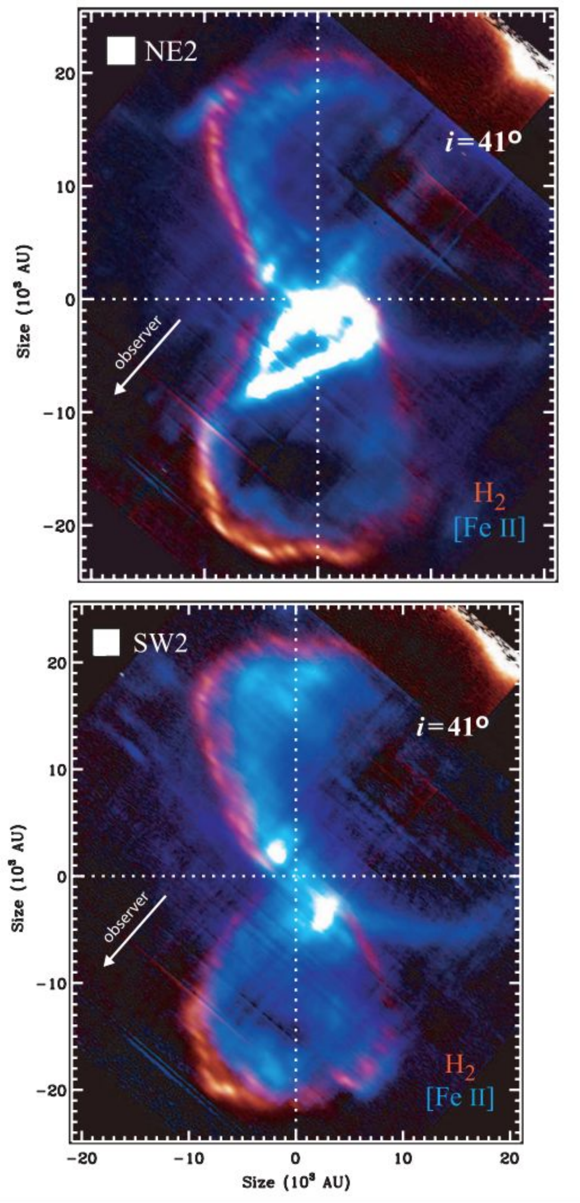
- Line peaks to EXES (R=50000) will be a factor of [(500 km/s)/ FWHM_line] larger.
- Practical observing times for line peaks with >5-10 Jy (S/N ~10, a few hours)



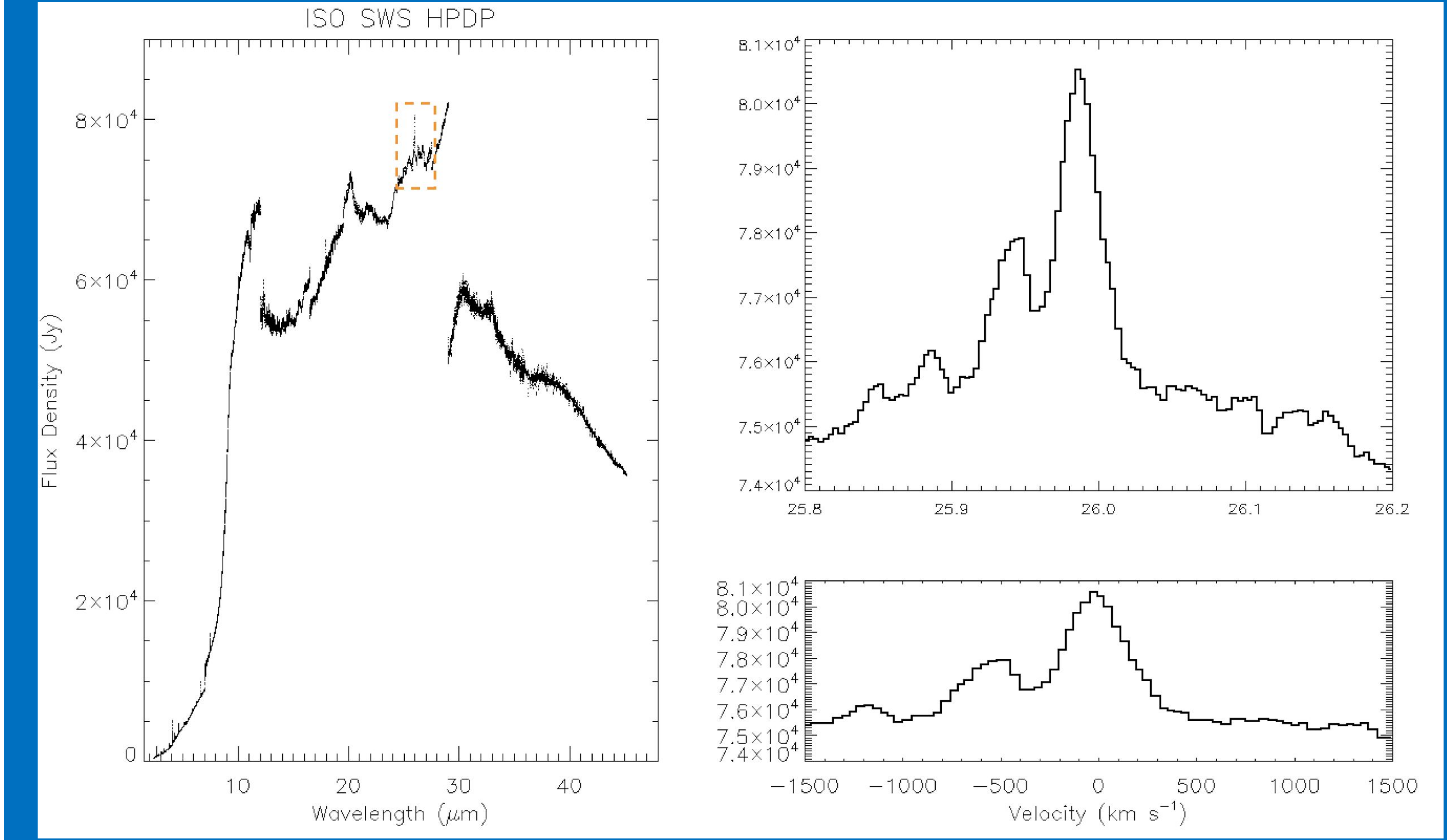
T-Tauri star RNO 90 with IRS Spitzer, Pontoppidan et al. 2010a

Homunculus Nebula/eta Carinae

Tracing [Fe II] Emission in the Mid-IR with EXES

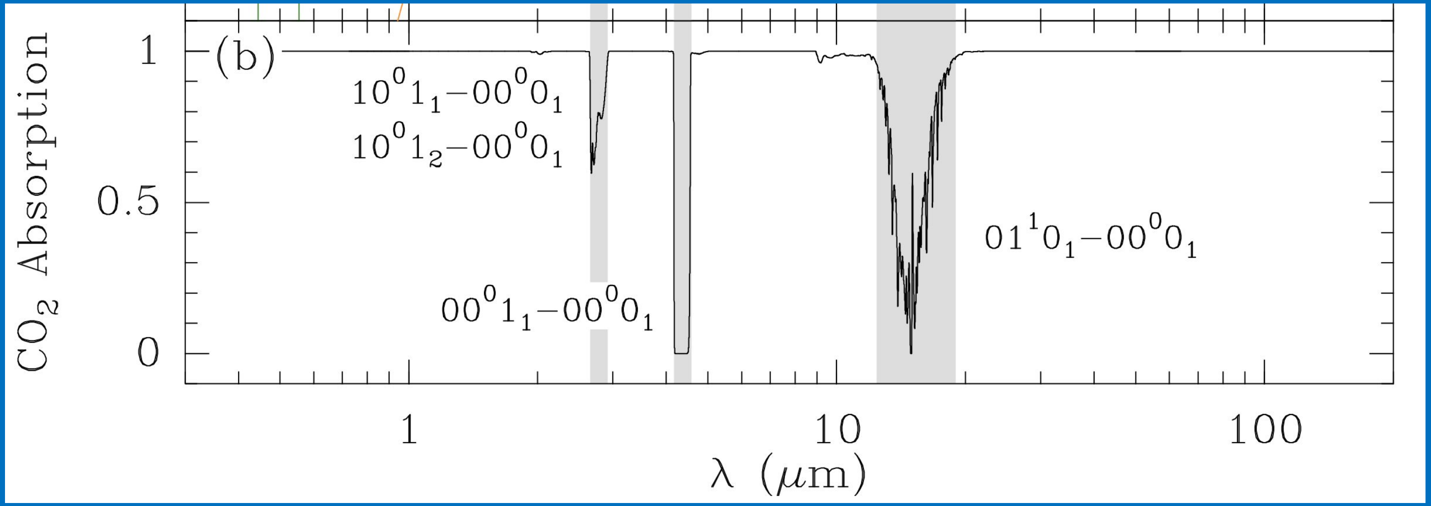


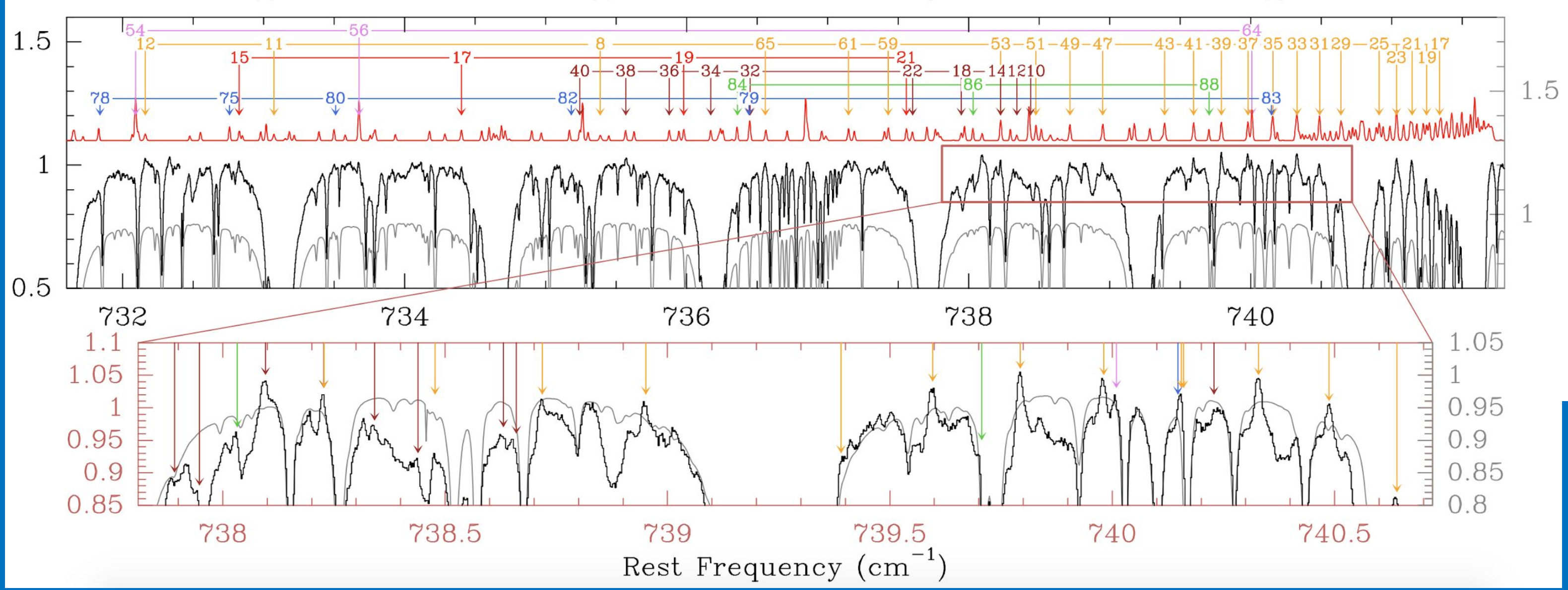
Smith (2006)

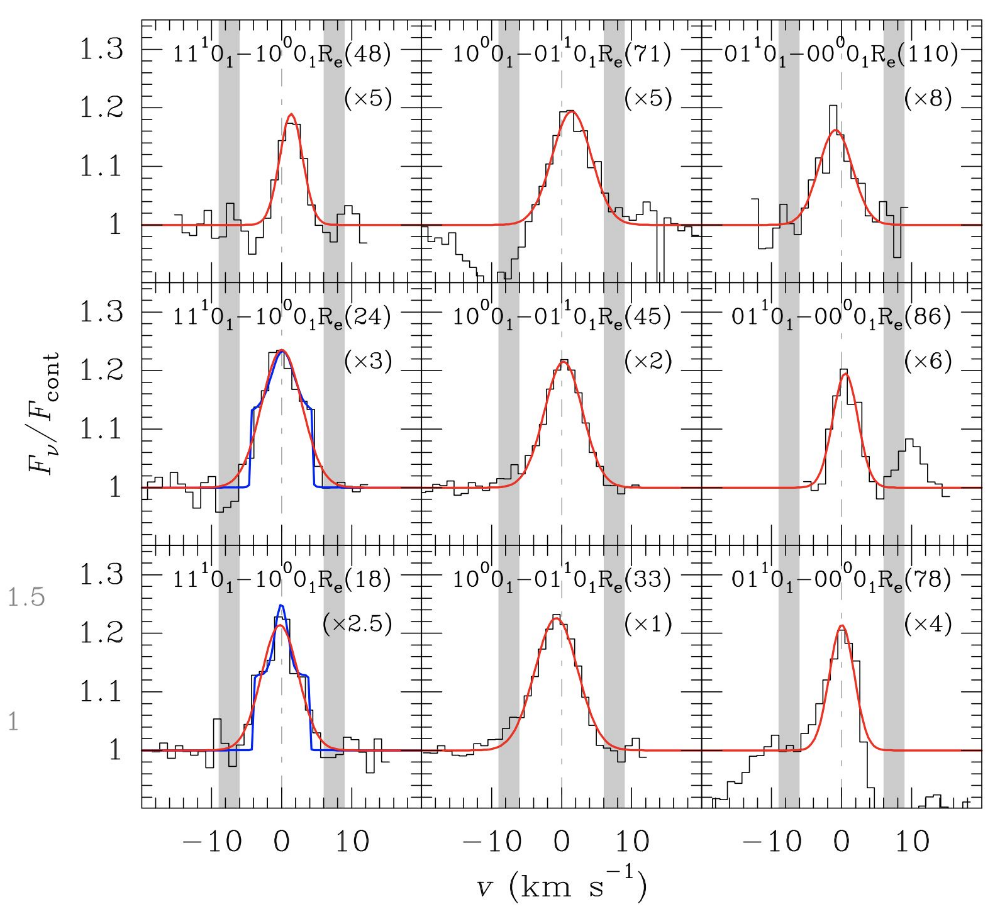


Evolved Stars

Fonfría et al. (2020, A&A, 643, L15)







Potential Southern Targets and Science with EXES

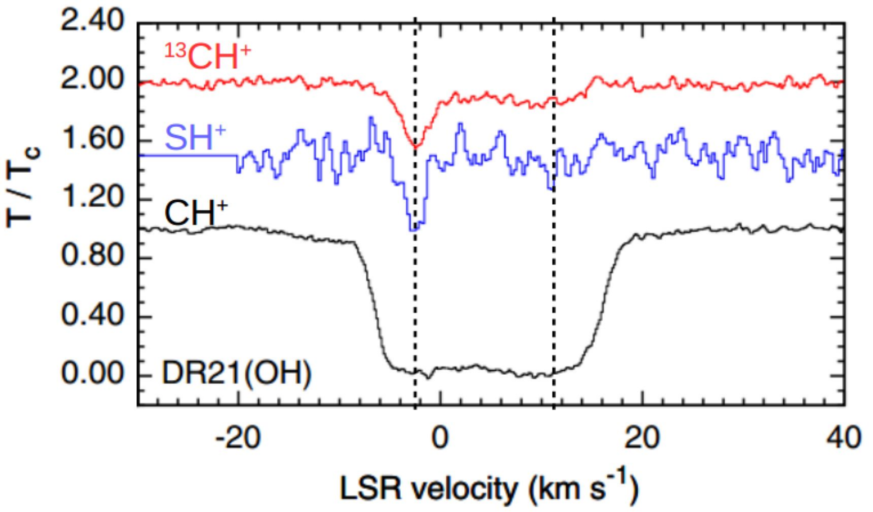
- AGB Stars
  - R Dor (M-type; O-rich), RAFGL 4211 (C-type), π^1 Gru (S-type)
- Spectral type M Stars (RGB, AGB, RSG stars)
  - ɣ Cru, 2 Cen, NU Pav
- Surveys and/or targeted molecules
  - e.g. 02_0004+05_0073, 06_0056, 06_0144, 09_0227, 09_0233
- Similar to protostars and hot cores: increased diversity of sources leads to better models

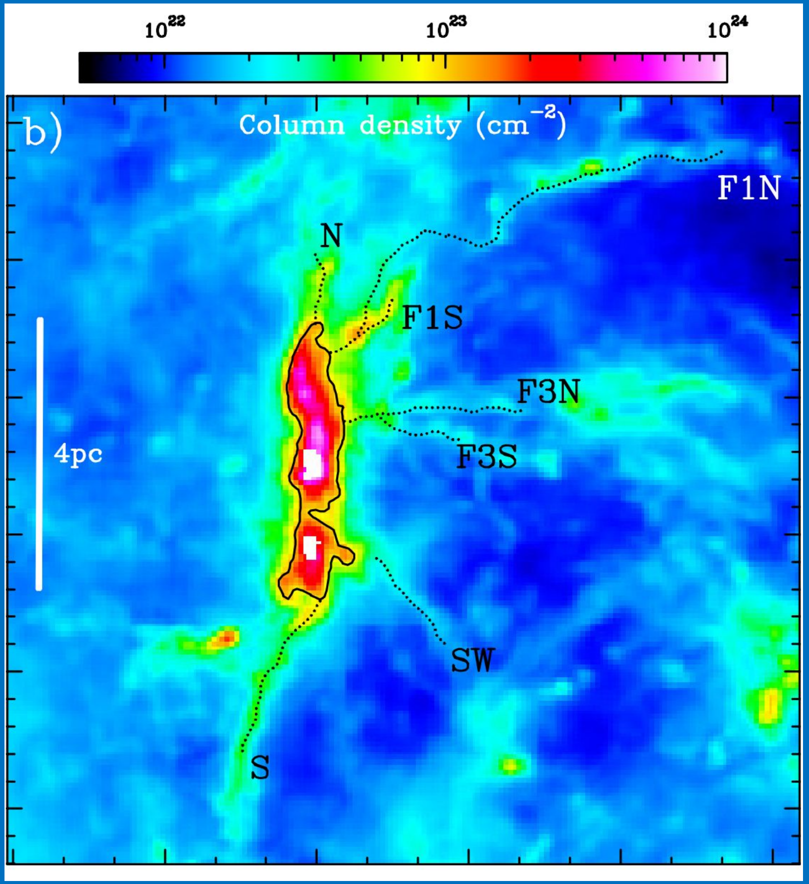
Shocks & PDRs

Observing H_2 0-0S(1) towards the DR21 ridge

- The DR21 ridge (located in Cygnus-X) is one of the most active high-mass star forming regions within 2 kpc.
- Several indications that a cloud-cloud collision formed the DR21 ridge. (Dickel et al. 1978, Dobashi et al. 2019, Bonne et al. in prep.)
- Such collisions predict the presence of shocks.
- Herschel CH^+ absorption indicates the presence of shocks in the region.
- EXES should be able to detect and spectrally resolve the heating from the shock with H_2 0-0S(1) (e.g. Draine et al. 1983; Lesaffre et al. 2013)

Godard et al. 2012





Hennemann et al. 2012

EXES observations to probe shocks and PDRs

- EXES has an excellent spectral resolution (< 6 km/s) + the sensitivity to detect shocks in 0-0S(1) starting around v > 10 km/s and $n_{preshock} > 10^3$ cm^{-3} (e.g. Draine et al. 1983; Lesaffre et al. 2013)

  -> For brighter shocks, other H_2 transitions can also be detected with EXES

  -> See e.g. Neufeld et al. 2019, for an interesting application
- EXES can also probe the hot gas structure in PDRs (see 09_0211, PI Soam)
- There are large grids of irradiated shock models (e.g. Godard et al. 2019)

- Potential targets with strong FUV irradiation and possible shocks:

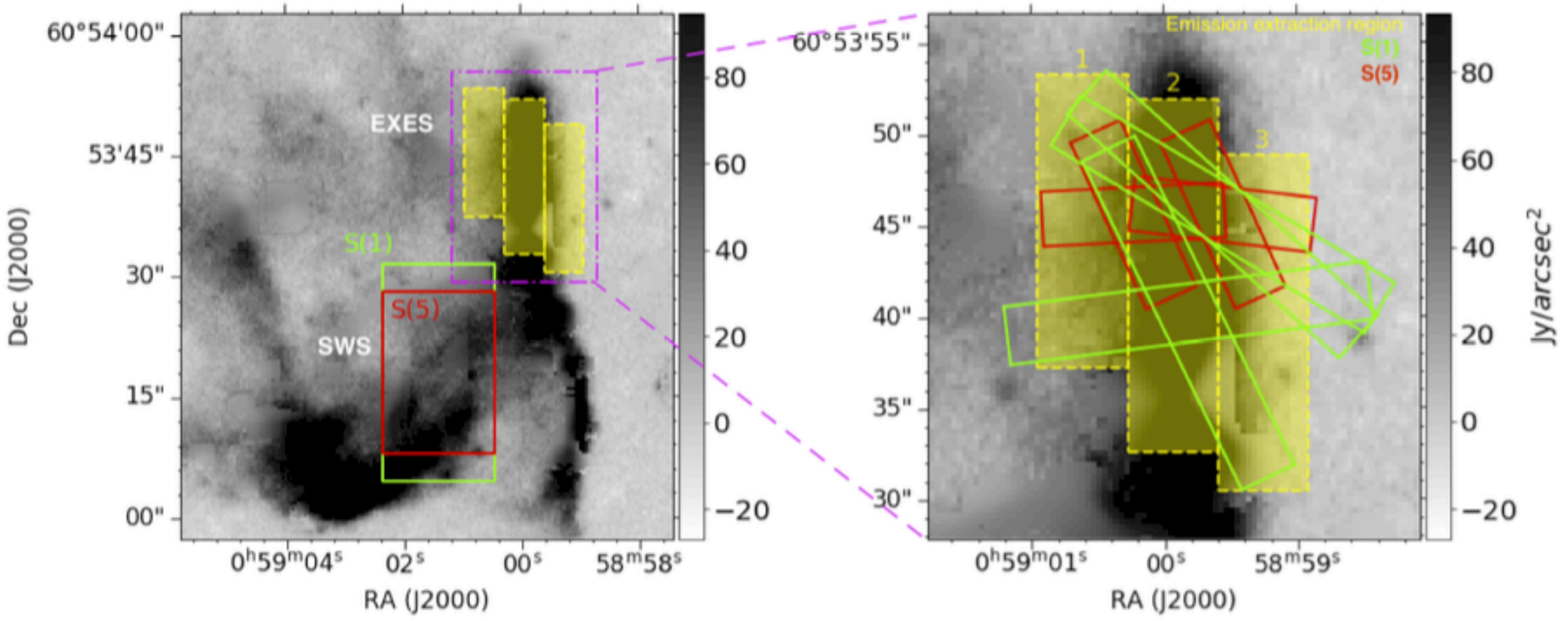
  - 30 Doradus: Indications of the presence of shocks (Lee et al. 2019)

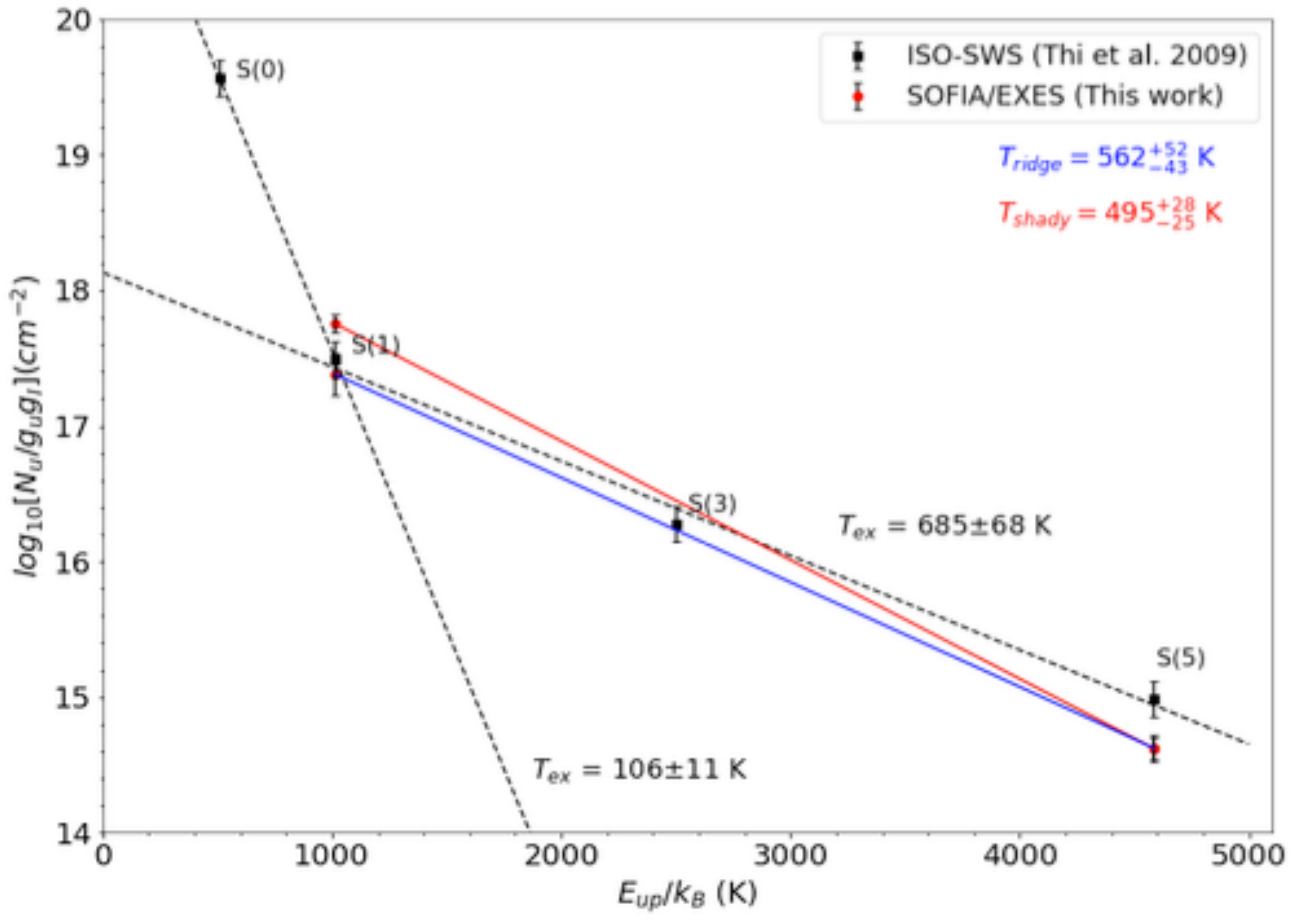
  - M16: Shocks could be responsible for the pillar formation (Pattle et al. 2018)

- EXES can be complementary with high-J CO observations from 4GREAT

Spatially varying temperatures in the IC 63 PDR from pure rotation excitation of molecular hydrogen

Archana Soam, B-G Andersson, Curtis DeWitt, J. Karoly, Matt Richter





We reinvestigated temperature of IC 63 PDR using pure rotational molecular hydrogen observations of S(1) and S(5) using EXES.

Similar investigation was done by Thi et al. (2009)

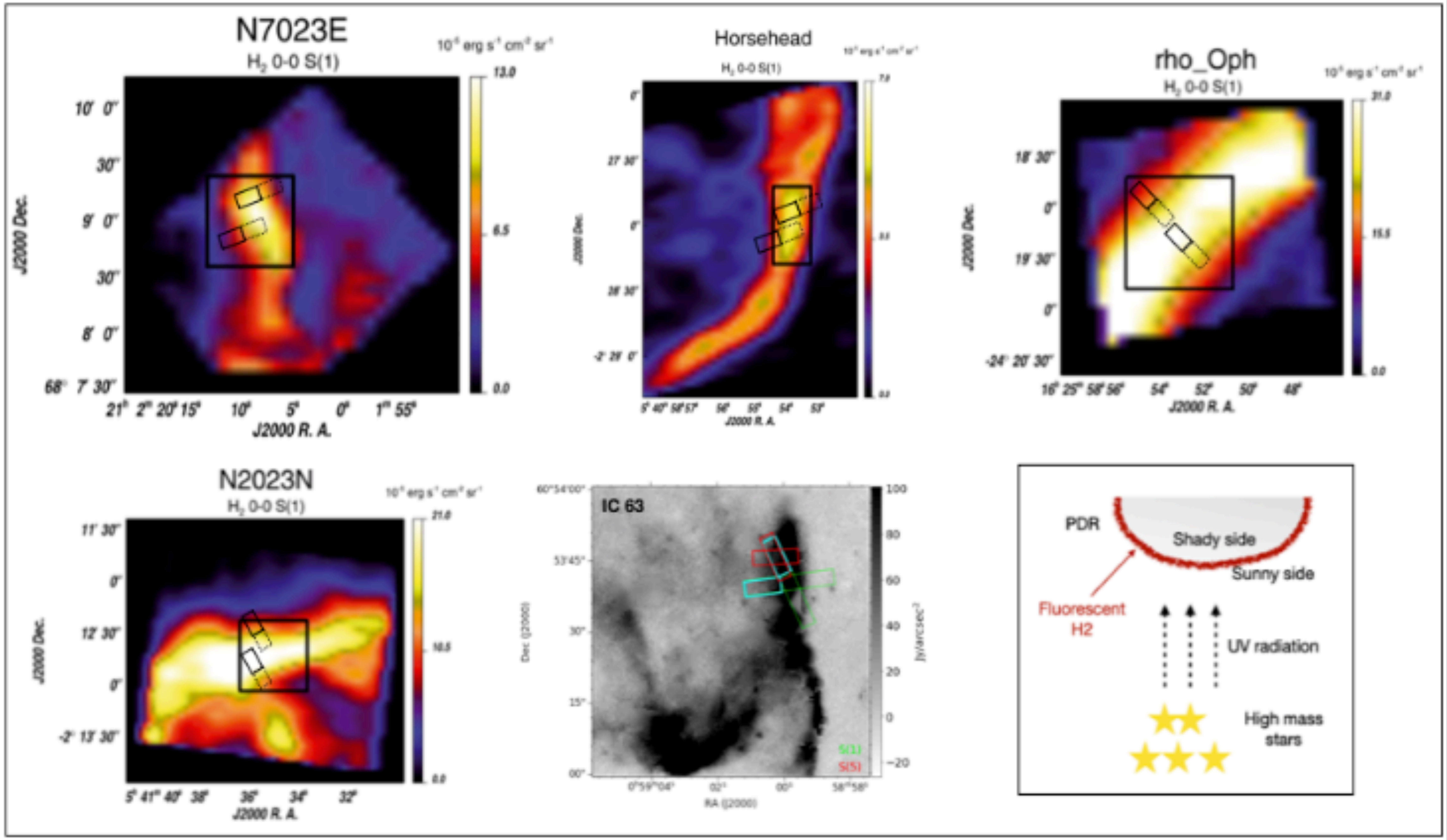
in this nebulae using lower resolution ISO/SWS observations. They found warm components at Tex=106±11K and hot gas component is seen at Tex=685±68 K.

We divided IC 63 PDR into "shade", "ridge" and "sunny" sides for our investigation. We obtained temperature of

T =562+/-50 K towards the "ridge" and Tex=495+/-30 K in "shady" side

The higher spatial resolution of EXES over SWS enables us to spatially resolve temperature in this PDR.

INSPIRE: INvestigating Spatially varying temperatures in PDRs from pure-rotational excItation of moleculaR hydrogEn



Panel show the H_2 0-0 S(1) emission images of various PDRs (adopted from Habart et al. 2011). Lower right most panel shows the cartoon of a PDR with definitions of ‘sunny’ and ‘shady’ regions, locations of ionizing source and fluorescent H_2 region.

Archana Soam, B-G Andersson, Curtis DeWitt, J. Karoly, Matt Richter, Kyle Kaplan

Accepted in cy 9

Suggestions for Southern sky: 30 Doradus

Naslim et al. 2015

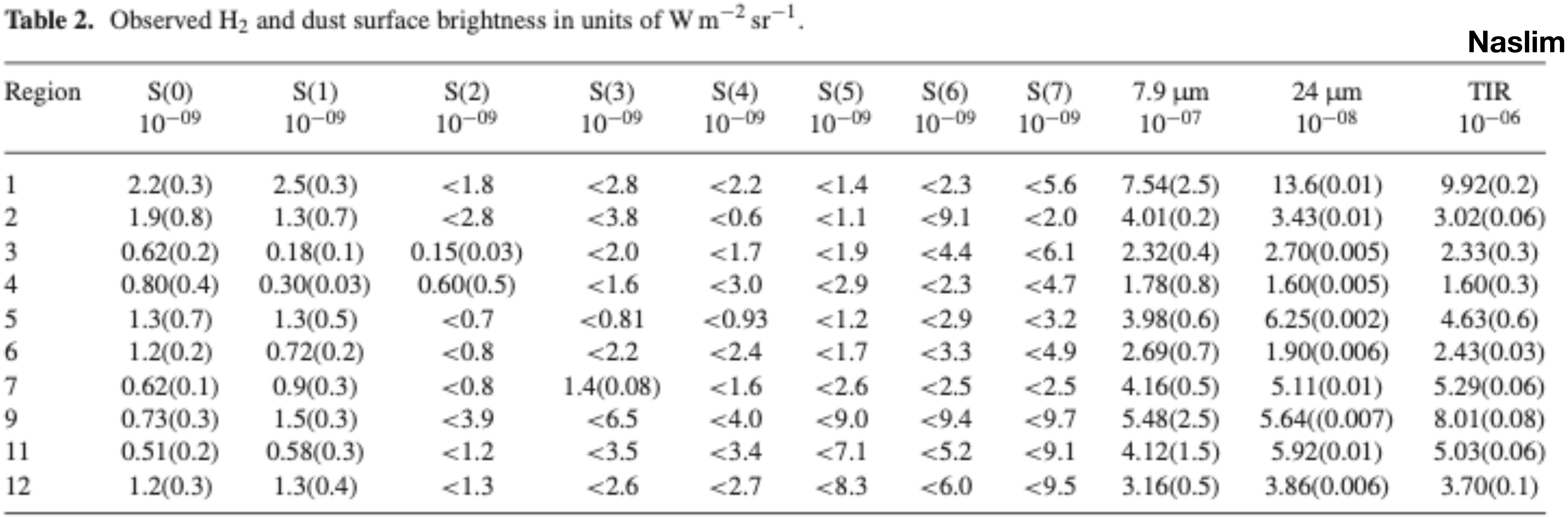


Table 2. Observed H_2 and dust surface brightness in units of W m^{-2} sr^{-1}.

Region	S(0) 10^{-09}	S(1) 10^{-09}	S(2) 10^{-09}	S(3) 10^{-09}	S(4) 10^{-09}	S(5) 10^{-09}	S(6) 10^{-09}	S(7) 10^{-09}	7.9 μm 10^{-07}	24 μm 10^{-08}	TIR 10^{-06}
1	2.2(0.3)	2.5(0.3)	<1.8	<2.8	<2.2	<1.4	<2.3	<5.6	7.54(2.5)	13.6(0.01)	9.92(0.2)
2	1.9(0.8)	1.3(0.7)	<2.8	<3.8	<0.6	<1.1	<9.1	<2.0	4.01(0.2)	3.43(0.01)	3.02(0.06)
3	0.62(0.2)	0.18(0.1)	0.15(0.03)	<2.0	<1.7	<1.9	<4.4	<6.1	2.32(0.4)	2.70(0.005)	2.33(0.3)
4	0.80(0.4)	0.30(0.03)	0.60(0.5)	<1.6	<3.0	<2.9	<2.3	<4.7	1.78(0.8)	1.60(0.005)	1.60(0.3)
5	1.3(0.7)	1.3(0.5)	<0.7	<0.81	<0.93	<1.2	<2.9	<3.2	3.98(0.6)	6.25(0.002)	4.63(0.6)
6	1.2(0.2)	0.72(0.2)	<0.8	<2.2	<2.4	<1.7	<3.3	<4.9	2.69(0.7)	1.90(0.006)	2.43(0.03)
7	0.62(0.1)	0.9(0.3)	<0.8	1.4(0.08)	<1.6	<2.6	<2.5	<2.5	4.16(0.5)	5.11(0.01)	5.29(0.06)
9	0.73(0.3)	1.5(0.3)	<3.9	<6.5	<4.0	<9.0	<9.4	<9.7	5.48(2.5)	5.64((0.007)	8.01(0.08)
11	0.51(0.2)	0.58(0.3)	<1.2	<3.5	<3.4	<7.1	<5.2	<9.1	4.12(1.5)	5.92(0.01)	5.03(0.06)
12	1.2(0.3)	1.3(0.4)	<1.3	<2.6	<2.7	<8.3	<6.0	<9.5	3.16(0.5)	3.86(0.006)	3.70(0.1)

In IC 63 fluxes, mean EXES fluxes are:

S(1) = 5.3 x10^{-5} erg/s/cm^2/sr, S(5) = 2.5 x10^{-5} erg/s/cm^2/sr

Spitzer flux in region 12 averaged over 30”x30” region

S(1) = 1.3 x10^{-6} erg/s/cm^2/sr, S(5) = 0.8 x10^{-5} erg/s/cm^2/sr

We think, it is reasonable to find a sub-region with flux 5~ 10 times the above mentioned flux which can be detected by EXES.

The higher spatial resolution of EXES over *Spitzer* enables us to spatially resolve temperature in this PDR.

Discussion

Summary

- EXES is the only instrument that has not been on a Southern Deployment
- Currently no similar instrument/facility exists on the ground or in space
    - even JWST/MIRI won't reach same spectral resolution
- High spectral resolution and wavelength coverage provides opportunity for unique science
    - e.g. non-polar molecules
- Need community input
    - Keep contributing to the Google Doc
    - Send us an email
        - mjrichter[at]ucdavis.edu, curtisdewitt[at]gmail.com, emontiel[at]sofia.usra.edu

Thanks to:

Arielle Moullet
Leslie Proudfit
Jim Jackson
B-G Andersson

Archana Soam
Lars Bonne
Le Ngoc Tram