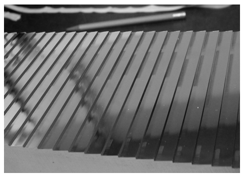
Planning an EXES observation

Curtis DeWitt
SOFIA/USRA Support Scientist

Contents

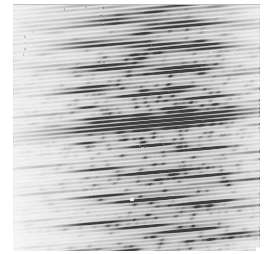
1. EXES instrument overview
    1. Wavelengths
    2. Medium and Low Resolutions
    3. HIGH Resolution Modes
2. Example: Planning a High-Resolution observation of a point source
    1. Atmospheric transmission and Doppler shifts
    2. Using the EXES ETC

EXES, the **E**CHELON **X** (cross) **E**chelle **S**pectrograph



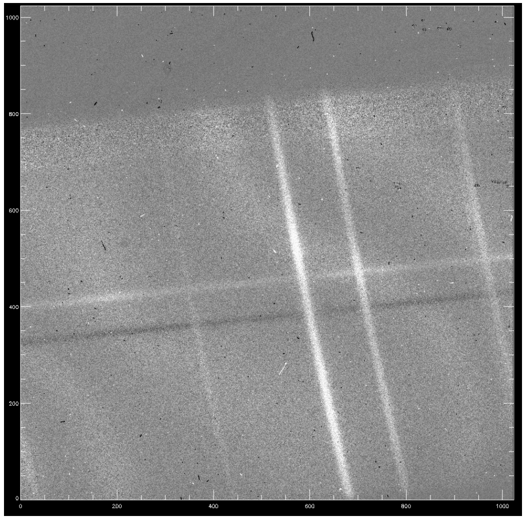
X

=



- Echelon (high resolution) + Echelle (cross dispersion+low resolution)
- R=1,000-100,000, i.e., 3 km/s-300 km/s
- 4.5-28.3 um.
- 4 observing modes: HIGH-MEDIUM, HIGH-LOW, MEDIUM and LOW

Medium and Low modes:



Medium resolution mode

R=8000-25000

~0.7 % coverage

Point source sensitivity:

5-15 Jy for S/N ~50 in 1hr

Low mode example

SHARED RISK in Cycle 9*, due to high background and fringing

R=1000- 5000

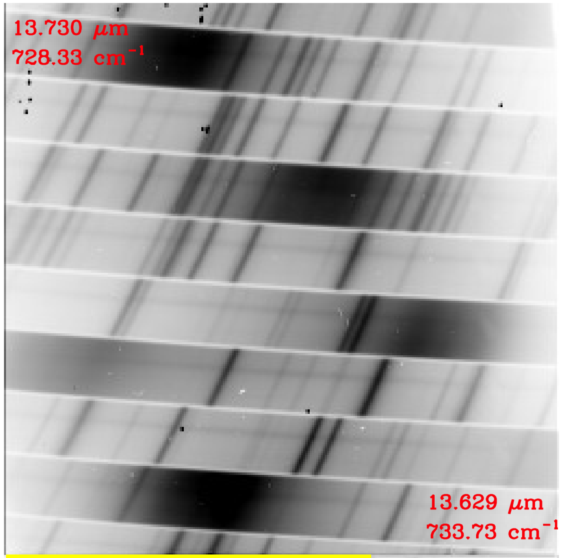
~4% coverage

Point source sensitivity:

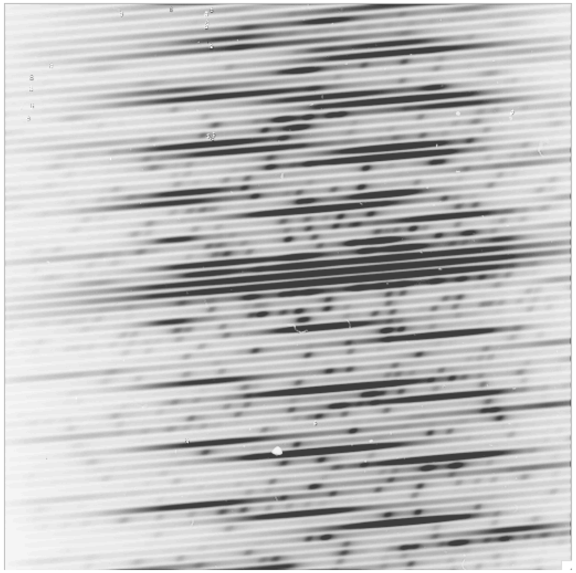
2-10 Jy for S/N ~50 in 1hr

High-medium and High-Low modes

HIGH_MED Configuration



14.27 μm
700.99 cm^{-1}



13.47 μm
742.20 cm^{-1}

(a) HIGH-MEDIUM

In general: R = 50,000-100,000

Point source sensitivity,

20-40 Jy for S/N ~50 in 1hr

Example above: 13.7um, 4th order

20" slit length

R=5.4 cm-1 coverage: 0.7%

(b)HIGH-LOW

In general, R = 50,000-100,000

Point source sensitivity

30-80 Jy for S/N ~50 in 1hr

Example (b):

13.8um

2" slit length (PSF ~ 2.7")

41 cm-1 coverage: 5.8 %

USRA

DSI

Example Observation: Resolve water vapor abs. in a protostar

Example observation:

ISO/SWS detected abundant gas-phase water toward the massive YSO, AFGL 2591

But R ~ 2000

Insufficient for measuring line widths or resolving complex profiles

Resolved line profiles will reveal the location and perhaps the chemical origin of the H2O

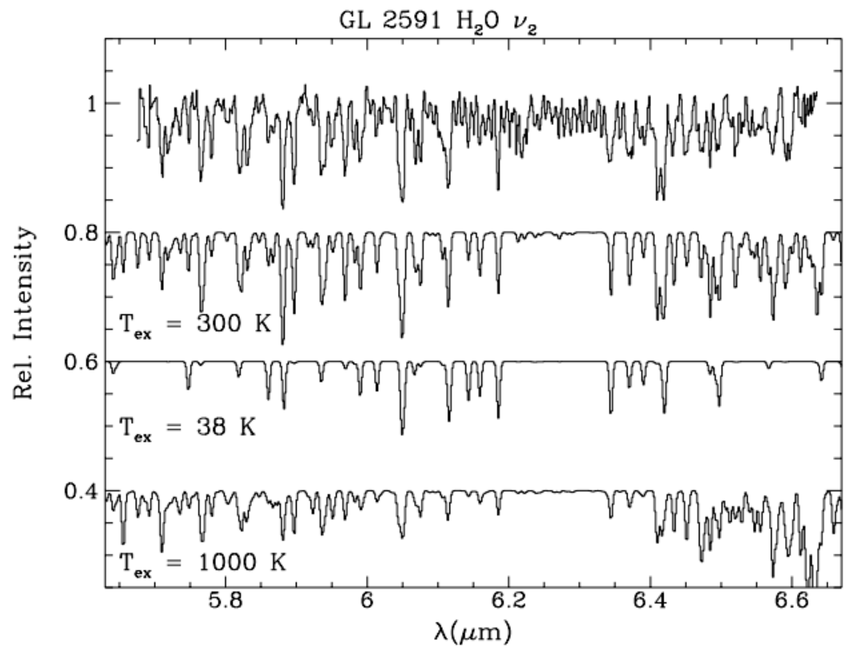


Fig. 2. From top to bottom: Normalized ISO–SWS spectrum observed toward GL 2591; theoretical spectra with T_{ex} = 300 K, b_D = 7.5 km s^{-1}; T_{ex} = 38 K, b_D = 5.3 km s^{-1}; and T_{ex} = 1000 K, b_D = 7.8 km s^{-1}, shifted by −0.2, −0.4, and −0.6 respectively. All model spectra have $N(H_2O) = 2.\ 10^{18}$ cm^{-2}.

(Helmich et al., 1996)

Example observation: resolve H2O toward AFGL 2591

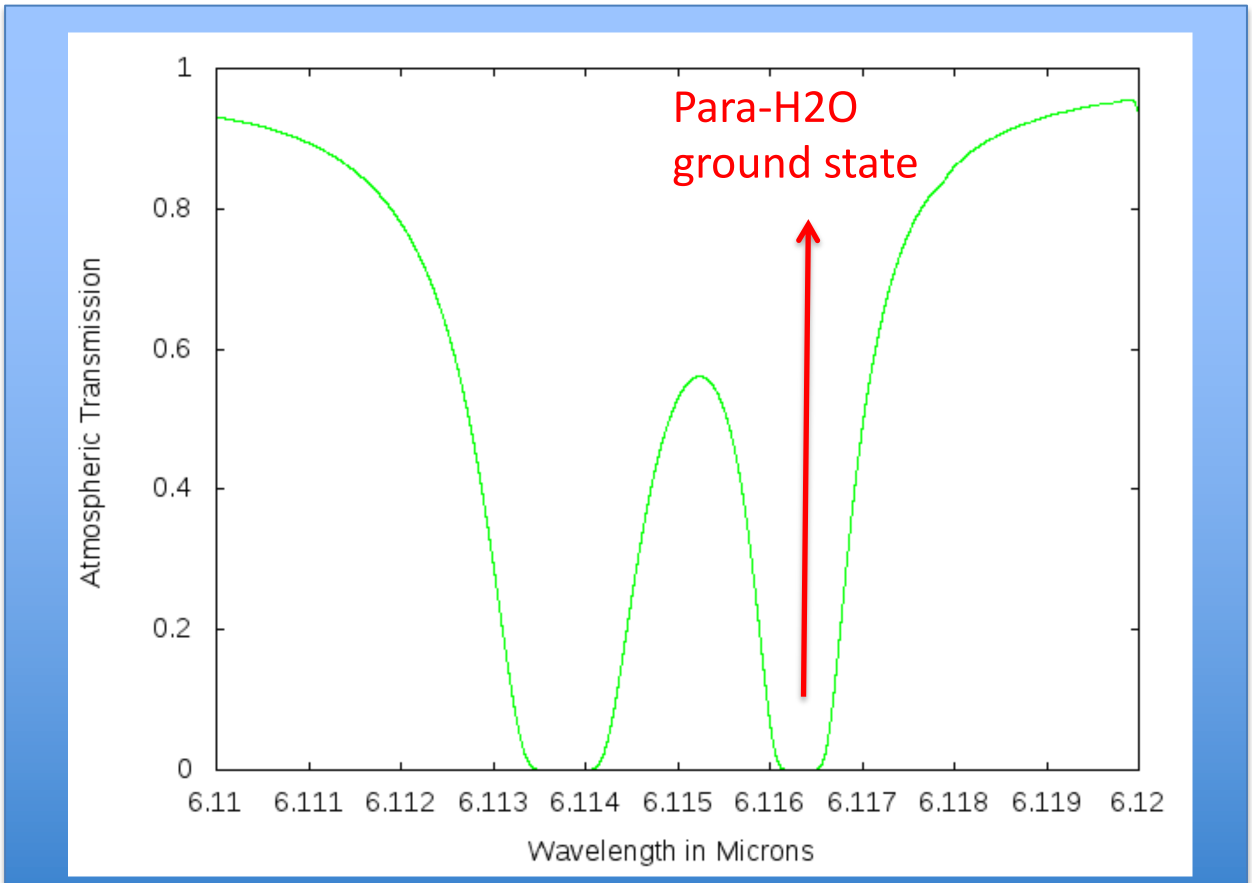
Specific goals:

- obtain S/N~100, R=86,000 spectrum of the massive protostar AFGL 2591 covering 6.07 – 6.12 um. About a strong dozen ro-vib H_2O lines.

- Detect ν_2 $1_{1,1}$-$0_{0,0}$ ground state transition of para-H_2O at 1634.9670 cm-1 (6.1163um) for sensitivity to cold gas

2. Preparing EXES Observation: ATRAN & Doppler Shifts

Use ATRAN: https://atran.arc.nasa.gov/cgi-bin/atran/atran.cgi



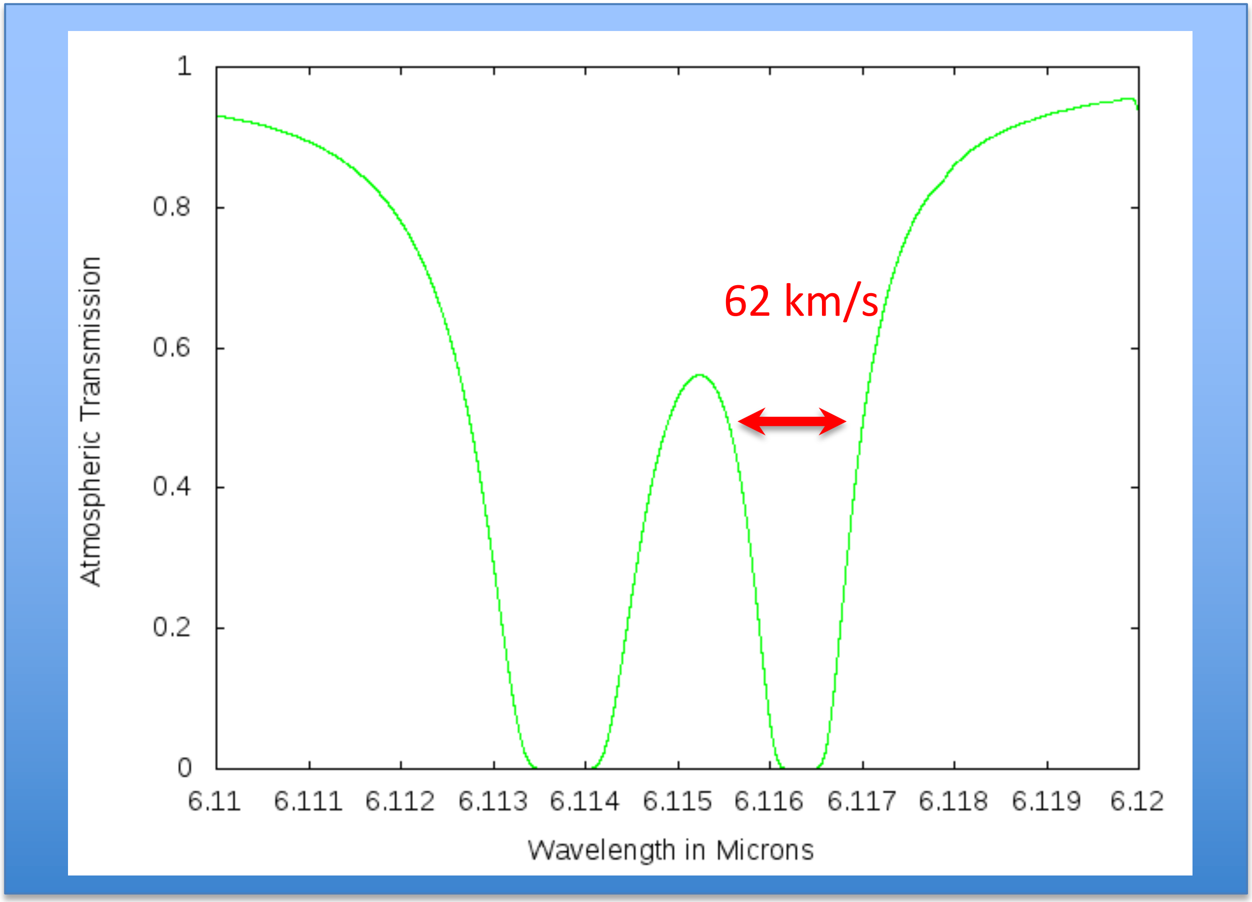
ATRAN: enter typical values
altitude: 41000 ft
Zenith angle: 45 deg

At rest velocity, this is hopeless…

Need a Doppler shift!

2. Preparing EXES Observation: ATRAN & Doppler Shifts

Use ATRAN: https://atran.arc.nasa.gov/cgi-bin/atran/atran.cgi



Telluric line has HWHM~31 km/s

2. Preparing EXES Observation: Doppler Shifts

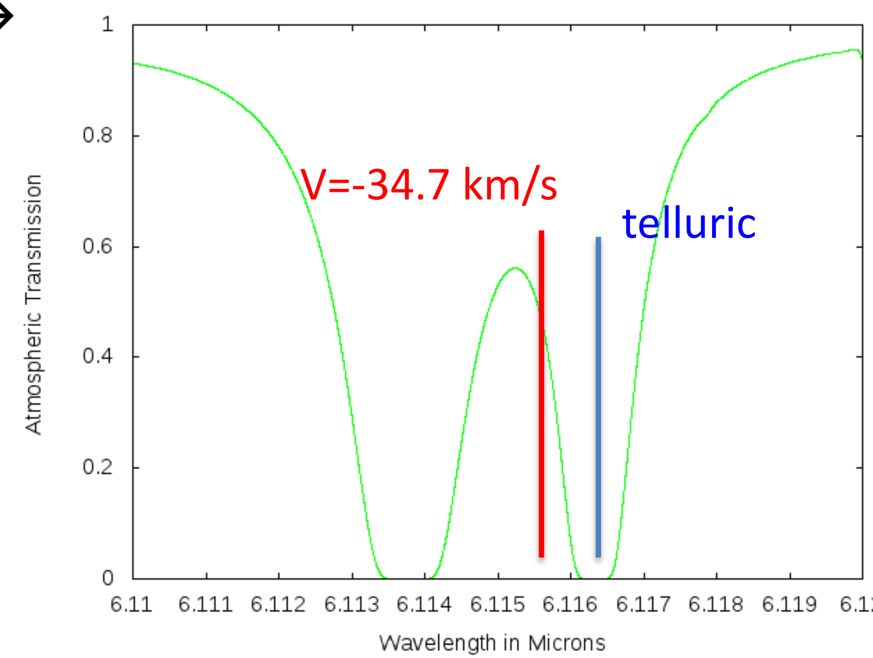
Velocity of line absorption on a given date, V_{DOP}, taking into account velocity AFGL 2591 (V_{LSR} or V_{HELIO}) as well as V_{EARTH} in LSR or HELIO reference frame toward position AFGL 2591. Earth orbital around sun at ~30 km/s.

See details in next slide:

AFGL 2591: V_{LSR}=-5.5 km/s (submm CO lines) →
V_{HEL}=-23.5Km/s

V_{DOP}=-34.7 km/s on April 1 (=0.0007 µm)
=-12.6 km/s on Oct1
Best chance when maximally blueshifted!

Derive acceptable Doppler shift and set time constraints on observation in proposal. Tight constraints limit chances for observation to be scheduled!



Note: if line entirely free of telluric absorption, it may be better done from ground!

2. Preparing EXES Observation: Doppler Shifts

In IDL:

- Example given in baryvel.pro in IDL astronomy library:
  jdcnv, year, month, day, hour, jd ;convert date to Julian date
  baryvel, jd, epoch, vh, vb ;heliocentric velocity of earth for give date in km/s

- project earth velocity toward star. RA and Dec stellar position in radians
  V_{EARTH}=vh[0]*cos(Dec)*cos(RA) + vh[1]*cos(Dec)*sin(RA)+vh[2]*sin(Dec)

- add radial heliocentric velocity of star to radial heliocentric velocity of the earth at that date. The sign of V_{EARTH} is negative!
  $V_{DOP}=V_{HELIO}-V_{EARTH}$

- Note: to convert V_{LSR} to V_{HEL} use helio2lsr.pro
  https://people.ok.ubc.ca/erosolo/idl/lib/helio2lsr.pro)

- AFGL 2591 on April 4, 2014. V_dop = -34 km/s

2. EXES Exposure Time Calculator

The EXES “Exposure Time Calculator” (ETC)
https://dcs.arc.nasa.gov/proposalDevelopment/SITE/index.jsp
http://irastro.physics.ucdavis.edu/exes/etc/etc.html

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

1634.97 cm-1

Enter either the rest-frame wavelength OR the rest-frame wavenumber to be observed: 1634.96 [4.5 - 28.5 micron, or 350 - 2220 cm^-1]

Check here to apply a Doppler shift: ☑ and enter the velocity: -34.7 [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 VLSR to the correction calculated for a given date.

!

-34.7 km/s

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

Configuration: High_Medium

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

Click here for the ETC user manual & documentation.

2. Preparing EXES Observation: Exposure Time Calculator

Slit width sets the resolution. Narrower slits block more star light (SOFIA PSF ~2.7”). Trade off between resolving power and S/N!

Step 4 - Select a slit width

	Slit Width (arcsec)	Ext. Source Aperture (Slit Width x IQ, arcsec^2)	R 6th order	R 7th order	R 8th order	R 9th order
○	1.44	4.77	112000	112000	112000	112000
◉	1.89	6.24	85590	85590	85590	85590
○	2.43	8.01	66667	66667	66667	66667
○	3.23	10.68	50000	50000	50000	50000

2. Preparing EXES Observation: Exposure Time Calculator

Cross disperser grating order sets the echelon order separation, and thus the number of echelon orders (i.e., wavelength coverage) that fit on the array. Slit length is matched to the echelon order separation:

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	32.854	112000	6.06134	6.17088	1620.51	1649.8	3.75	Must be off-slit.
○	7	39.63	112000	6.07295	6.15889	1623.67	1646.65	5.06	Must be off-slit.
○	8	47.192	112000	6.08283	6.14877	1626.34	1643.97	6.9	Must be off-slit.
◉	9	56.118	112000	6.09202	6.1394	1628.82	1641.49	10.01	Must be off-slit.

2. Preparing EXES Observation: Exposure Time Calculator

Cross disperser grating order sets the echelon order separation, and thus the number of echelon orders (i.e., wavelength coverage) that fit on the array. Slit length is matched to the echelon order separation and thus whether on-slit nodding is possible:

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	32.854	112000	6.06134	6.17088	1620.51	1649.8	3.75	Must be off-slit.
○	7	39.63	112000	6.07295	6.15889	1623.67	1646.65	5.06	Must be off-slit.
○	8	47.192	112000	6.08283	6.14877	1626.34	1643.97	6.9	Must be off-slit.
◉	9	56.118	112000	6.09202	6.1394	1628.82	1641.49	10.01	Must be off-slit

2. Preparing EXES Observation: Clock Time and S/N

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

Enter the desired signal to noise ratio:	100

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	400	[Jy]
○ Extended Object		[Jy/arcsec^2]

Note: The source flux or surface brightness entered should be that quantity at the target wavelength.

2. Preparing EXES Observation: Clock Time and S/N

Observation Summary

Signal to noise ratio: (binned to 2 pixels per spectral resolution element)	100
Source type:	Point source
Source flux:	400 Jy
Atmosphere:	41,000 ft altitude, 45 degrees elevation angle

Exposure Time Calculation

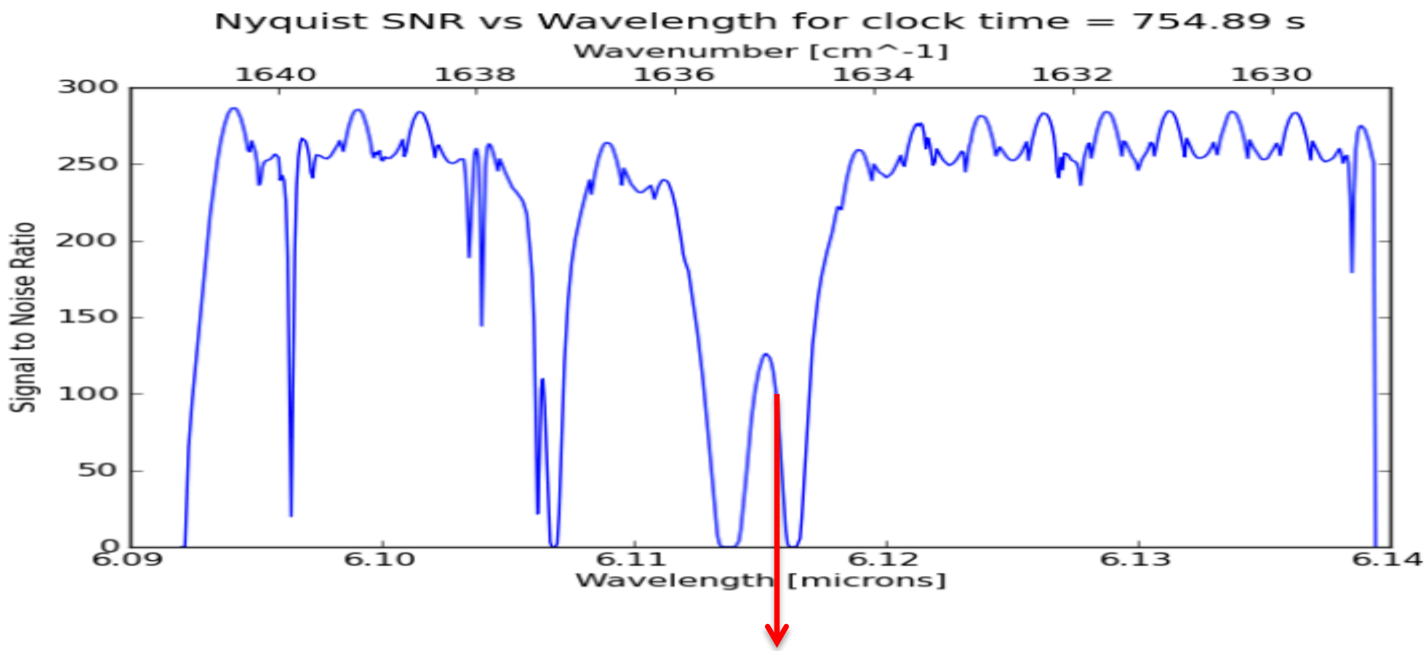
EXES Clock time:	754.89 seconds	Integration efficiency:	0.24
Source count rate (e-/s):	1421	Background count rate (e-/s):	16930

In USPOT, always use **"clock time"**, which includes observing overheads, and including the time spent for off-source sky integration

USPOT will add the calibration overheads (3 min) and appropriate time to acquire and peak up on the target.
(total +5-18 min)

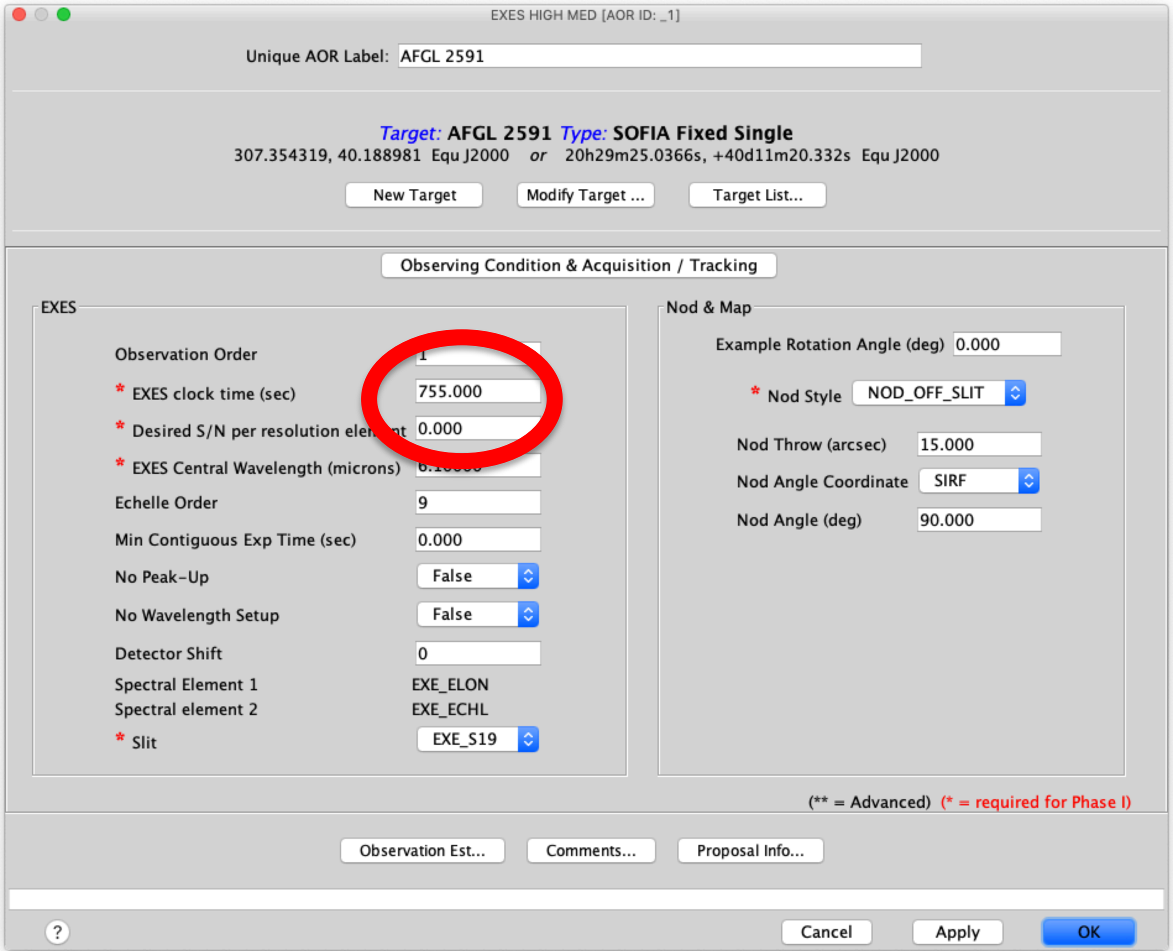
USRA

2. Preparing EXES Observation: Clock Time and S/N

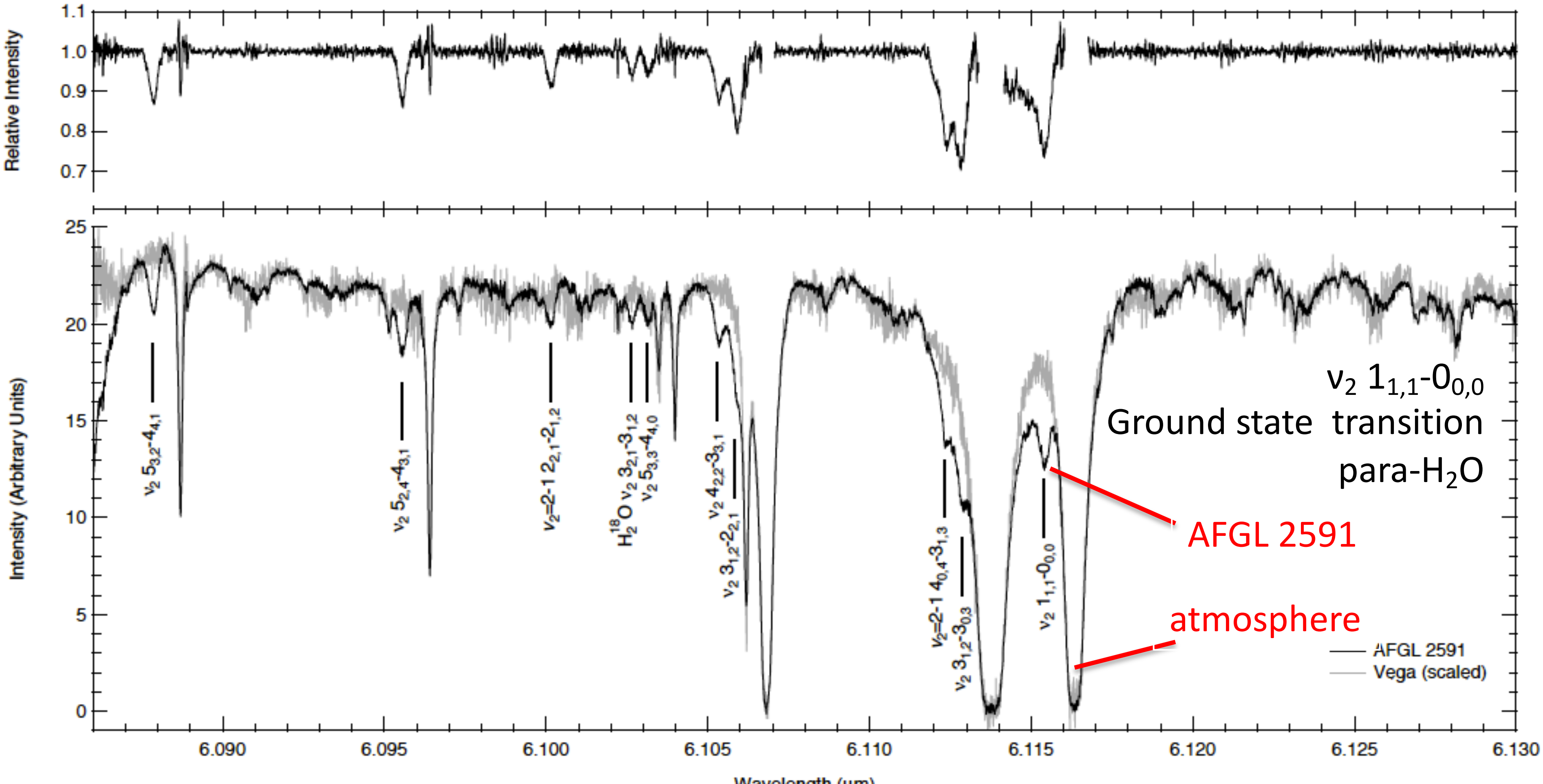


At expected line position, S/N=100; but much better elsewhere.

For AORs in USPOT, enter the clock time



The real data



R=86,000 High_Medium EXES spectrum massive YSO AFGL 2591

Indriolo et al. 2015ApJ...802L..14I

Contact the instrument team for advice…

UC Davis

- Matthew Richter, PI

  mjrichter@ucdavis.edu

USRA/SOFIA support scientists

- Curtis DeWitt

  curtis.n.dewitt@nasa.gov

- Edward Montiel

  emontiel@sofia.usra.edu