# Get ready, get set.....

## Mid-IR spectroscopy with EXES on SOFIA and TEXES on Gemini North


**Matt Richter – UC Davis**

*and*

**John Lacy - UT Austin (EXES and TEXES)**

**Tommy Greathouse (mostly TEXES)**

**Mark McKelvey – NASA Ames (EXES)**

**Curtis DeWitt - UCD (mostly EXES)**

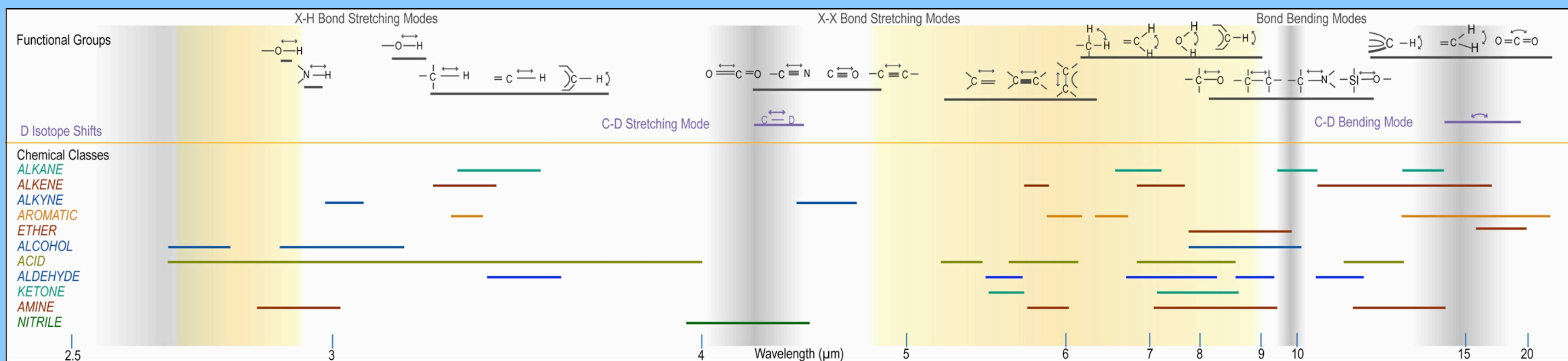
# Outline

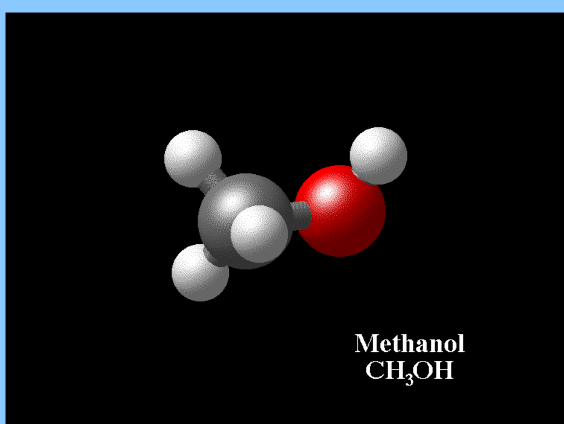
- Quick primer on mid-IR spectroscopy
  - features
  - atmospheric effects
- Importance of high resolution
- EXES and TEXES
  - relative to other instruments
  - detectors
  - instrument science configurations
  - observing modes
  - sensitivities
  - software
- Schedule: proposal and observing
- Further information

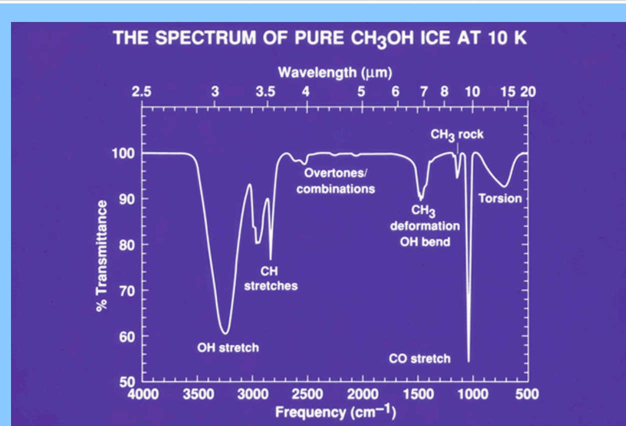
## IR spectroscopy, particularly in the 2-40 μm range, provides an ideal way to detect and identify many molecular species since different molecules have different IR spectral "fingerprints"

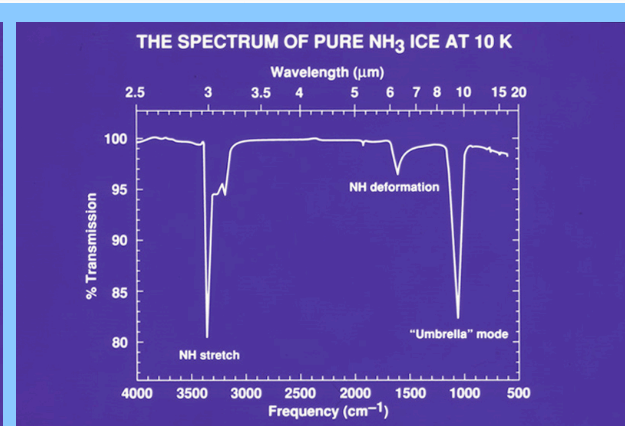
### Molecules seen with TEXES

- **without dipole moments: $H_2$, $C_2H_2$, $CH_4$, $CH_3$**
- **other molecules: $H_2O$, HDO, HCN, $NH_3$, $SO_2$, CO, HNCO, OH, SiO, CS, $C_2H_4$, $C_2H_6$, $C_3H_4$, $C_4H_2$, $C_6H_2$, $PH_3$, $CH_3D$**



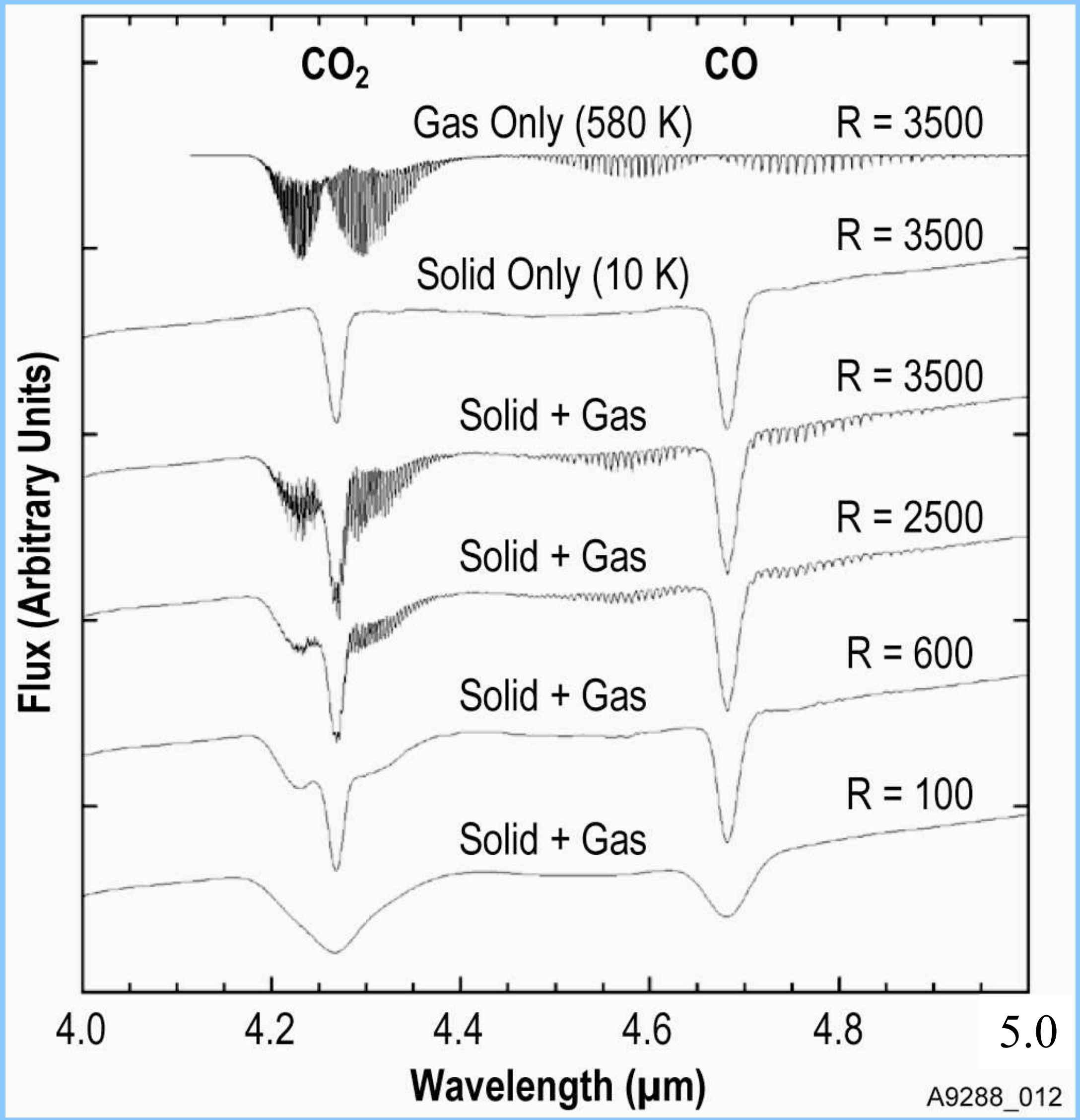




Adapted from Scott Sandford's 2009 teletalk

## Armed with the appropriate spectral resolutions, one can also distinguish between solids and gases




JWST MIRI (about)
(T)EXES low

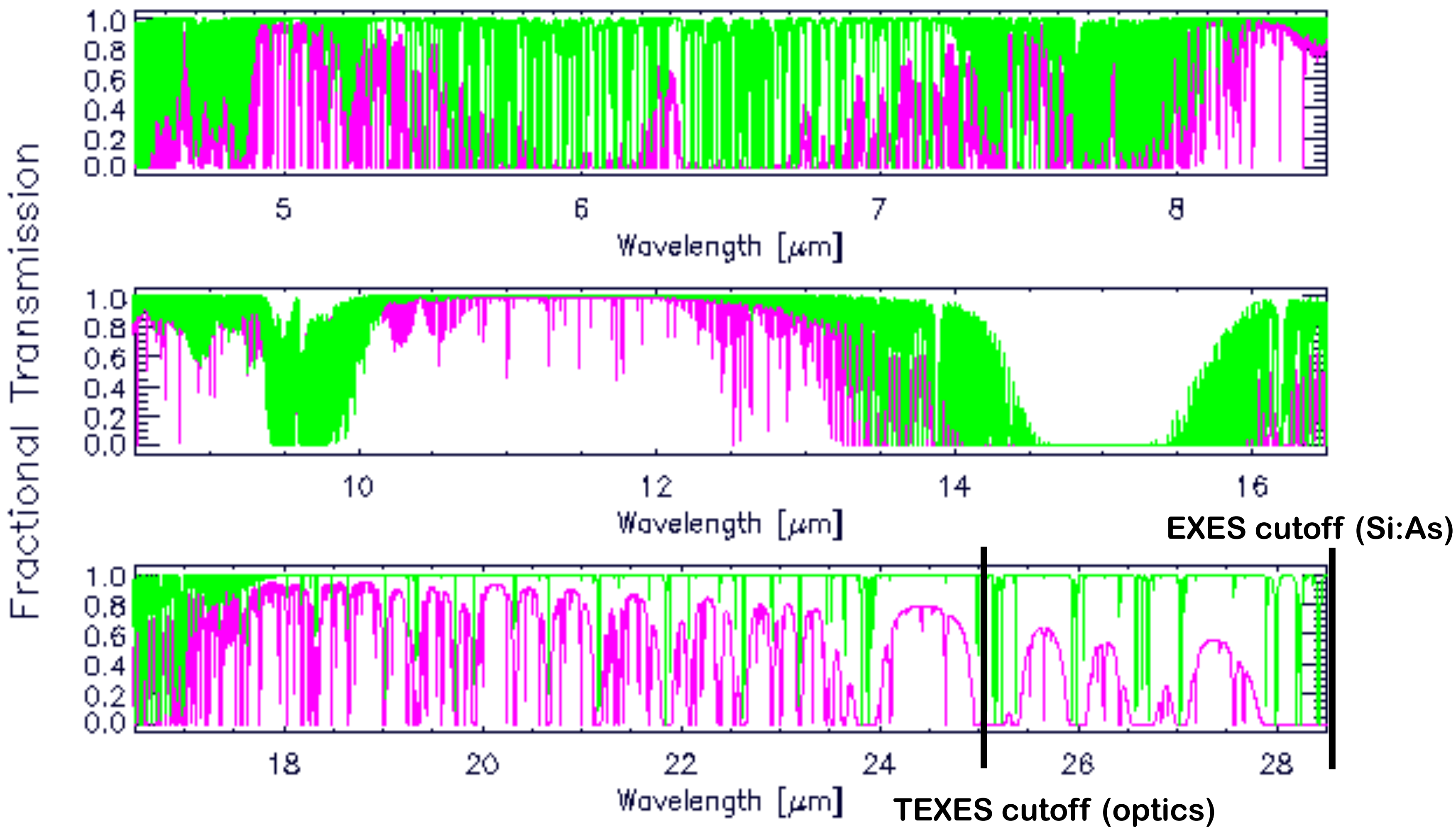
ISO SWS (about)

Spitzer IRS High

Adapted from Scott Sandford's 2009 teletalk

# Atmospheric comparison

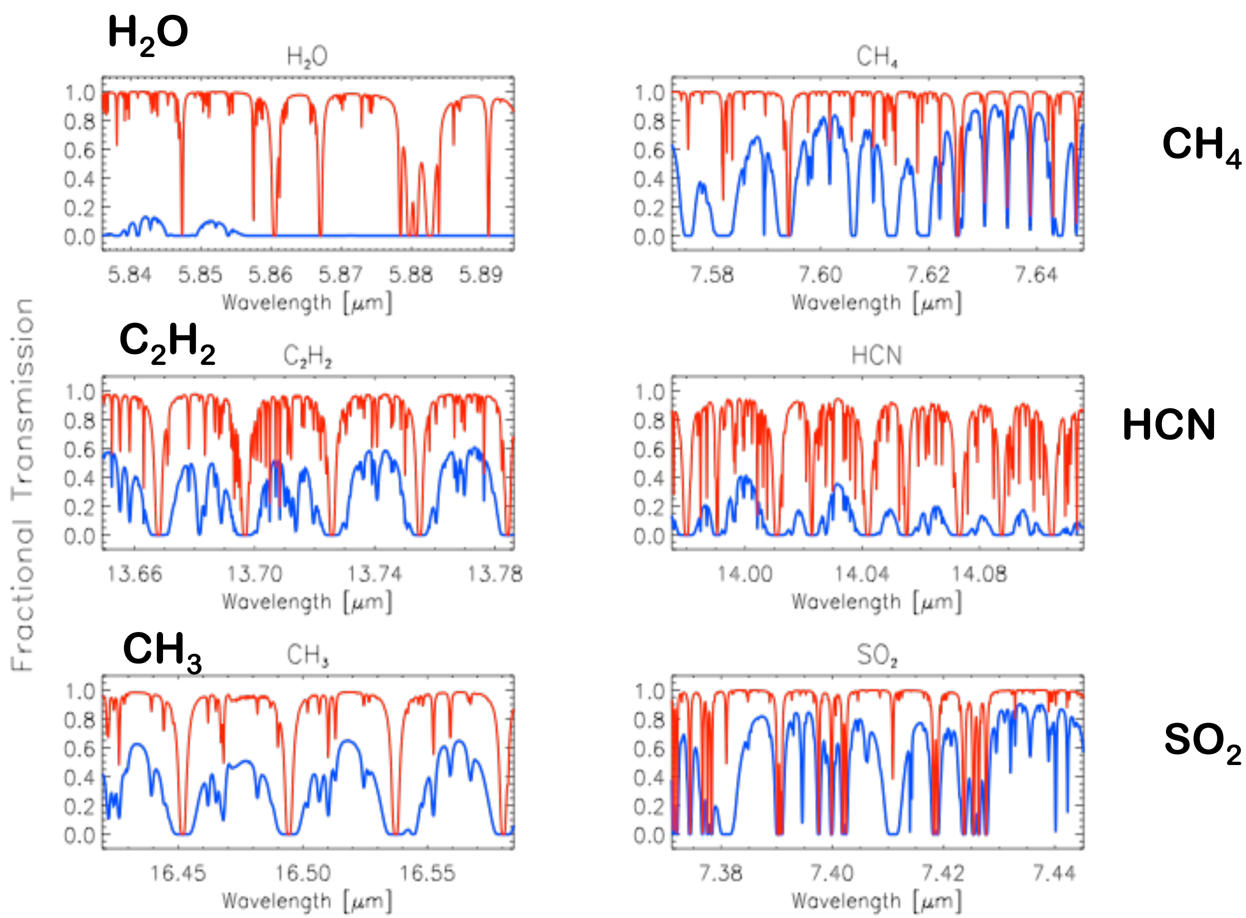
SOFIA vs Mauna Kea



# Advantage of EXES/SOFIA

## high spectral resolution at wavelengths inaccessible from ground

Comparison of transmission from SOFIA and Mauna Kea for some important molecules




Effect of atmosphere in background limit
(Mason et al 2008)

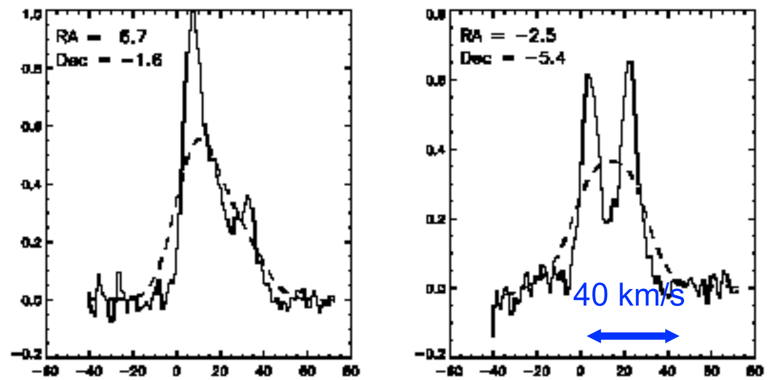
$$S/N \propto T / ( (1-T) + \varepsilon )^{0.5}$$

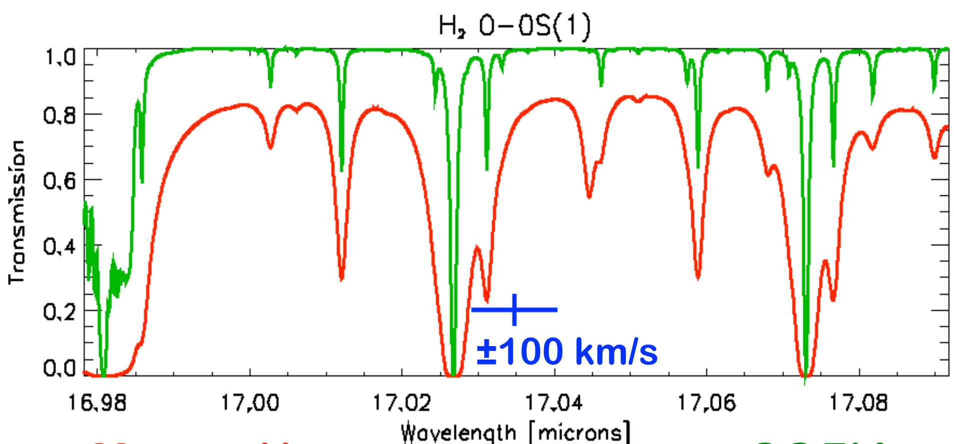
where:
$T$ is atmospheric transmission
$\varepsilon$ is system emissivity

# High Spectral Resolution

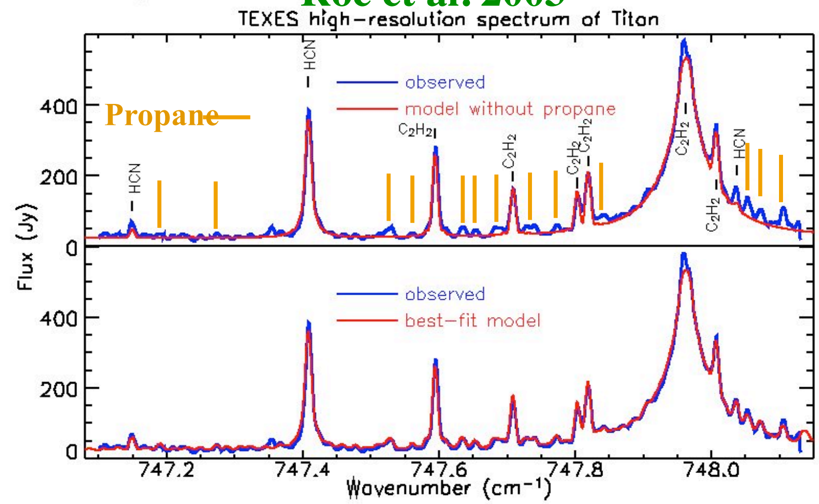
- Line profile information
- Limit confusion
  - other source lines
  - lines from atmosphere
- Maximize sensitivity for narrow lines

Jaffe et al (2003) R~80,000



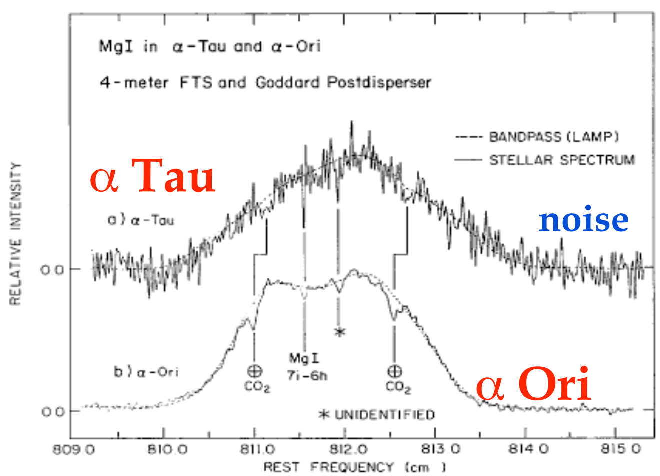




Roe et al. 2003

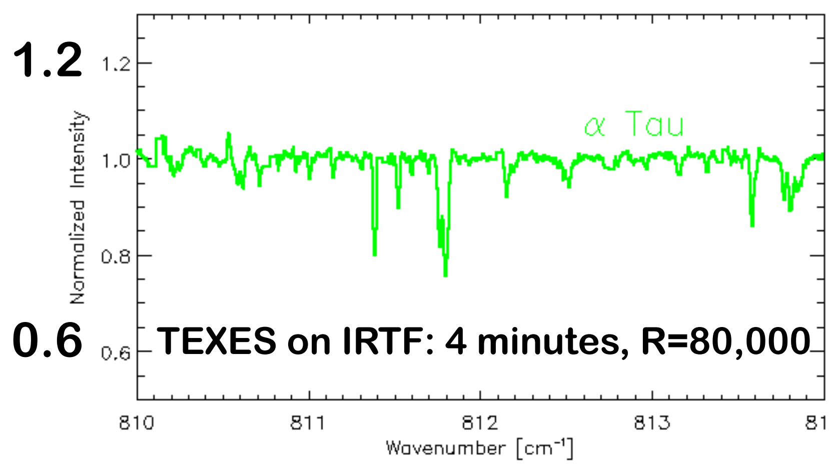


# EXES and TEXES niche

- **Both designed and built to emphasize high resolution mode**
  - Evolution from J. Lacy work with Irshell, R=10,000 grating spectrograph
  - Higher resolving power than other mid-IR grating and FP instruments
  - Higher sensitivity than FTS or Heterodyne

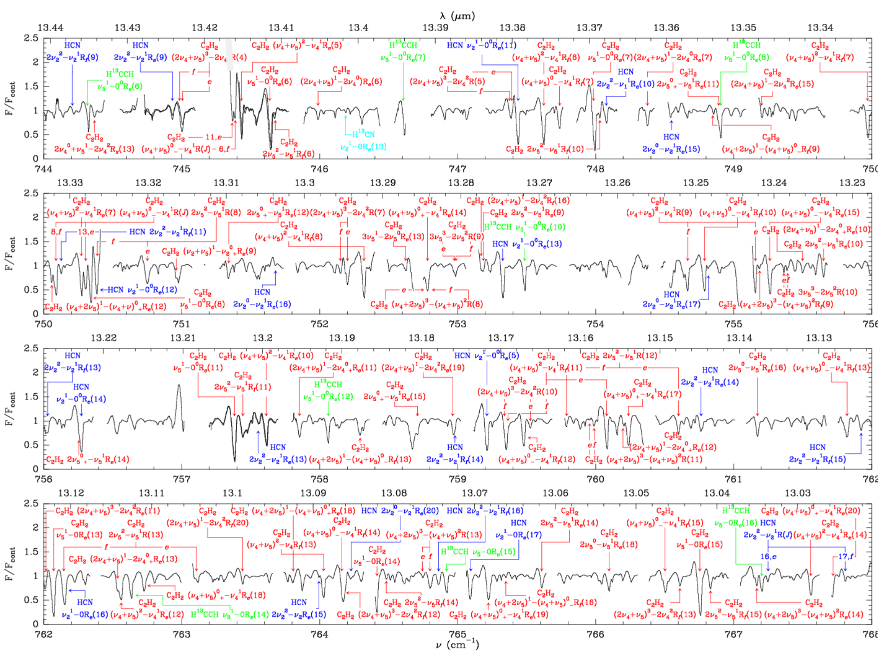



Jennings et al. 1986

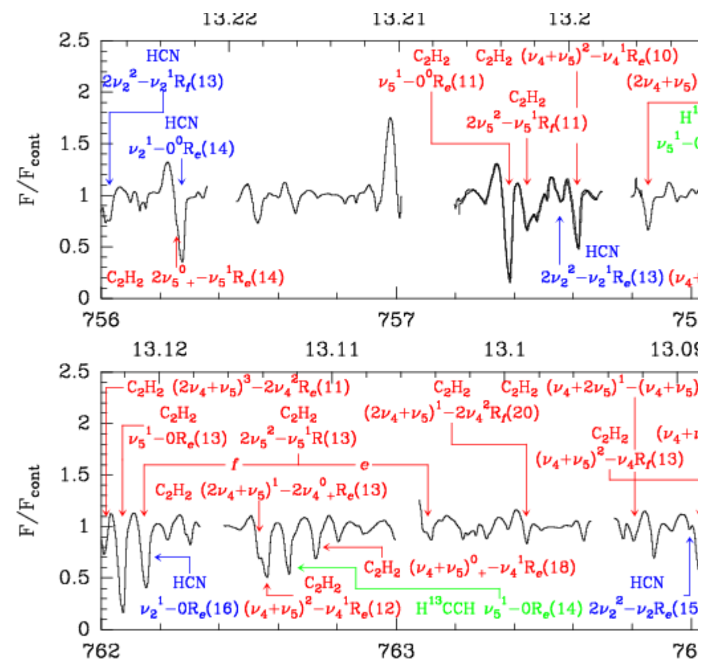


# EXES and TEXES niche

- **Provide data unobtainable elsewhere**
- **Complement ALMA and Herschel**
  - vibrational transitions
  - molecules with no dipole moment

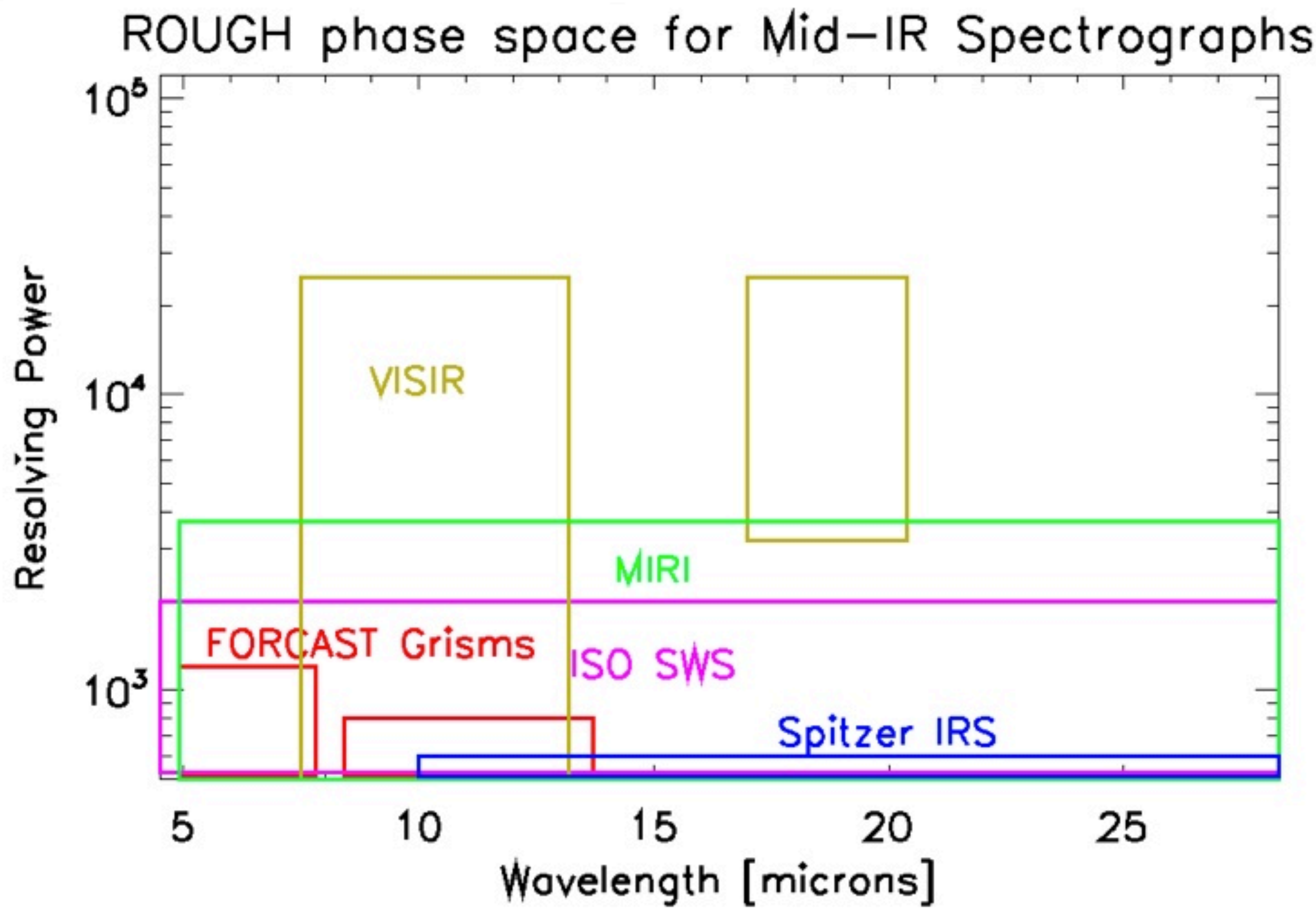



TEXES survey of IRC +10216 (Fonfria et al. 2008)
1 of 6 pages

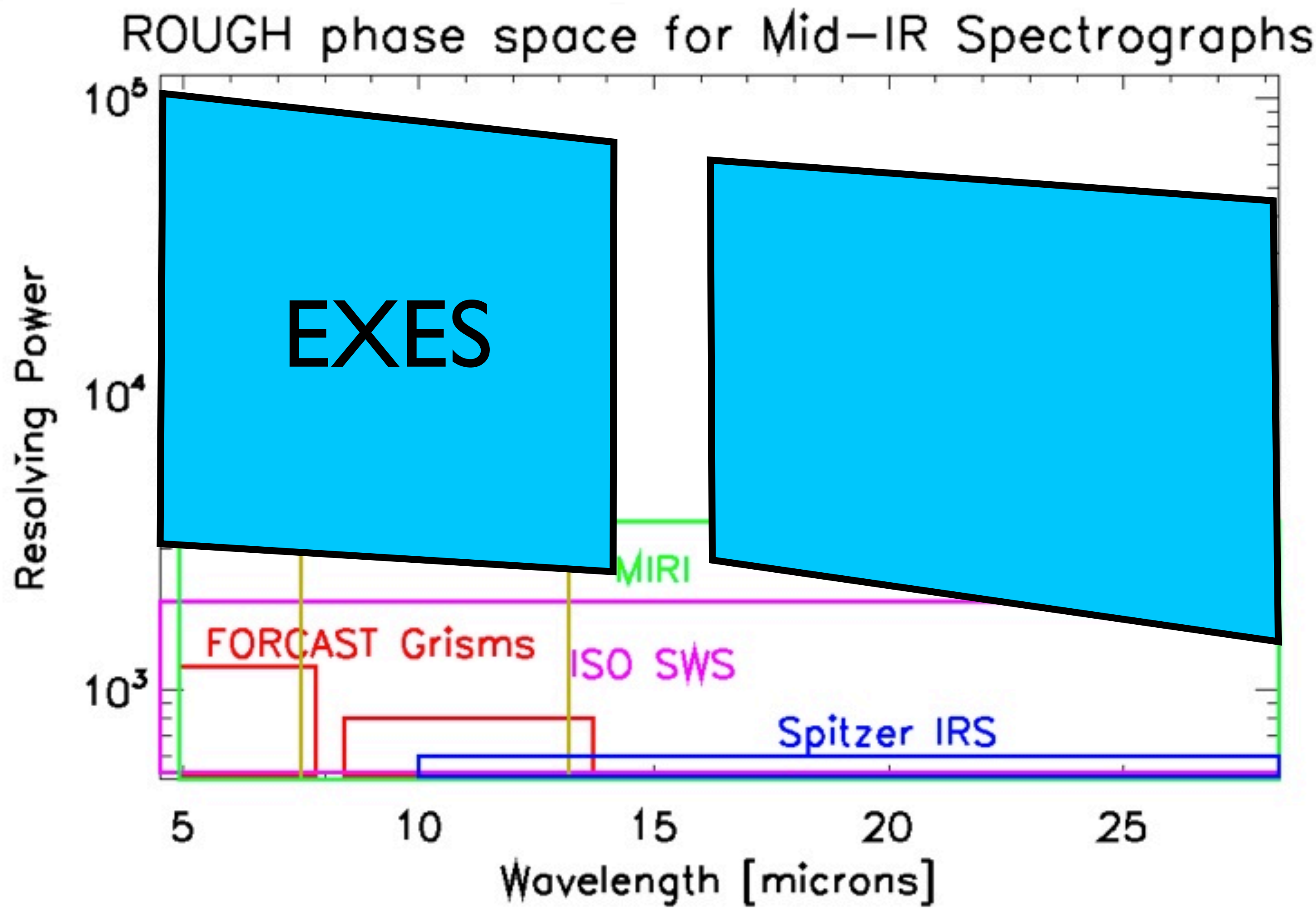



zoom of upper left

# Other Mid-IR Spectrographs

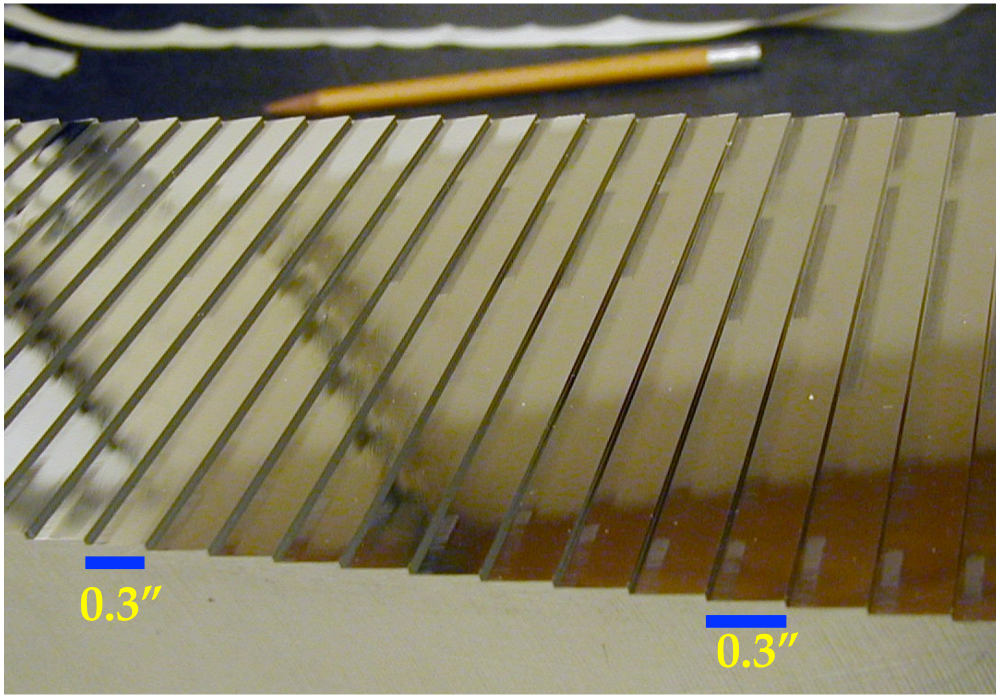


# Other Mid-IR Spectrographs



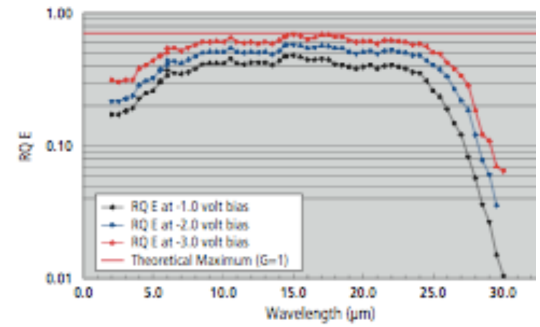
# Echelon gratings

- 36” and 40” long
- 0.300” groove spacing
  - 0.131 grooves/mm
- 84.2 degree incidence angle
  - 0.03” groove height
- Diamond machined Al 6061
  - Hyperfine Inc

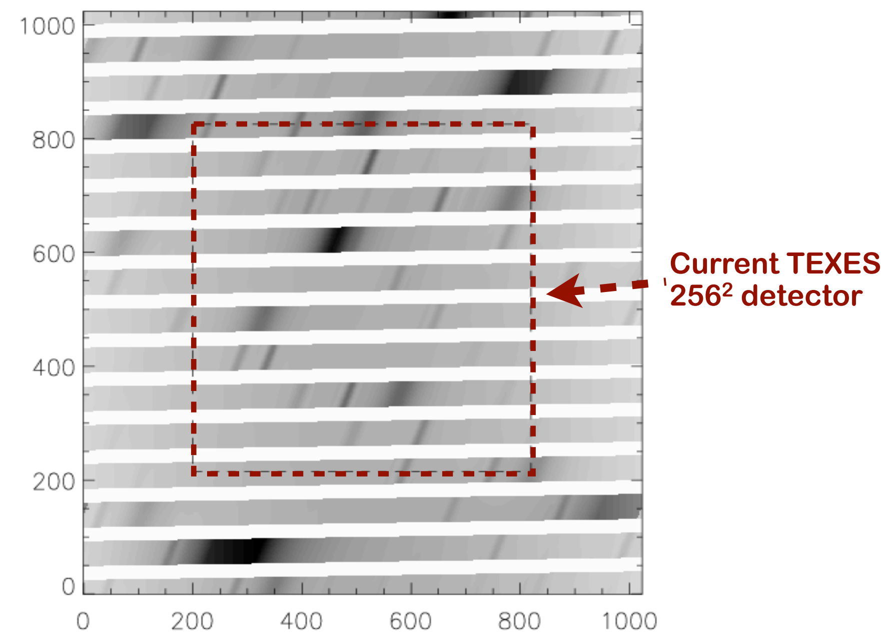



# Detectors

- Both:
  - Si:As
  - Optimized for low background (space)
  - shallow wells ~1.5e5 e-
- EXES
  - $1024^2$ pixel
  - 25 $\mu$m per pixel
    - Oversampled
    - 0.38 km/s per pixel
    - 0.21” per pixel
  - 60 e- single sample read
  - matches size of high resolution orders around 19 $\mu$m
- TEXES
  - $256^2$ pixel
  - focal reduced to 63 $\mu$m pixels
    - 0.97 km/s per pixel
    - 0.13” per pixel on Gemini
  - 30 e- single sample read (IRAC array)
  - matches size of high resolution orders around 11 $\mu$m




Raytheon Si:As RQE

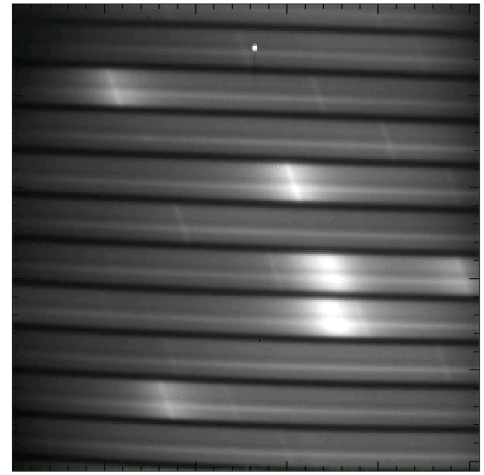



Model atmosphere showing TEXES high-medium mode if it had $1024^2$ pixels and no focal reducer

# Science configurations

## In General

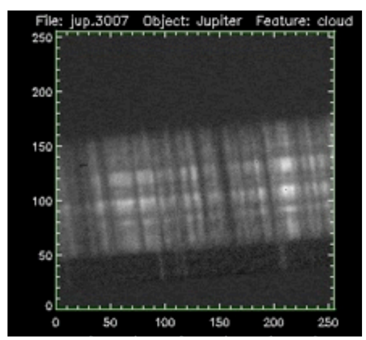
- High resolution modes use ~1m long echelon cross-dispersed by another grating
  - R = 50,000 to 100,000 depending slit width and wavelength
- Single order modes skip the echelon and give a long slit
- Wavelength coverage set by echelle/low order grating, not echelon
  - coverage in medium is same as in high-medium
  - coverage in low is same as in high-low
- Order sorting filter required for all modes
- No on-instrument slit rotation possible



Raw high-medium spectrum of $\beta$ Gem

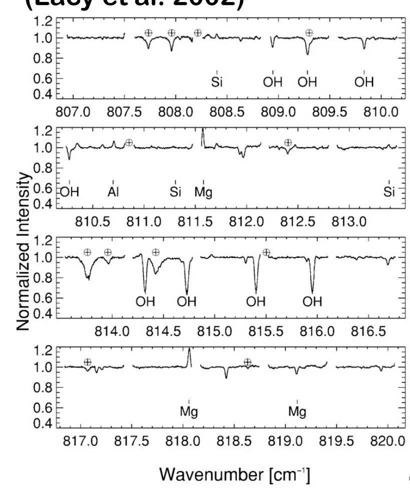
## Modes

- High-Medium - standard mode
  - echelon plus echelle used in 2nd to 12th order, depending on wavelength
  - can nod on slit for most wavelengths.  used for mapping.
- High-Low - spectral survey
  - echelon plus low order grating
  - single aperture on sky
- Medium mode - just echelle
  - R = 10,000 to 20,000
- Low mode - just low order grating
  - R = 1500-4000



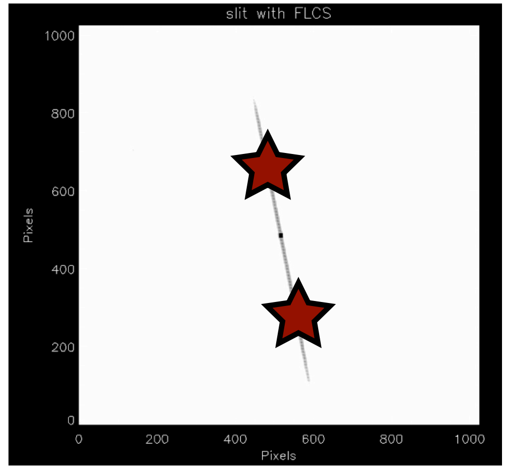

Sky subtracted low mode spectrum of Jupiter

High-Low 1D extracted spectrum (Lacy et al. 2002)



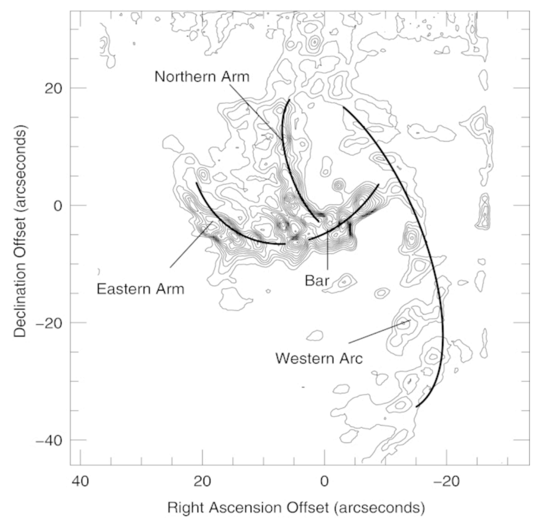
# Observing Modes

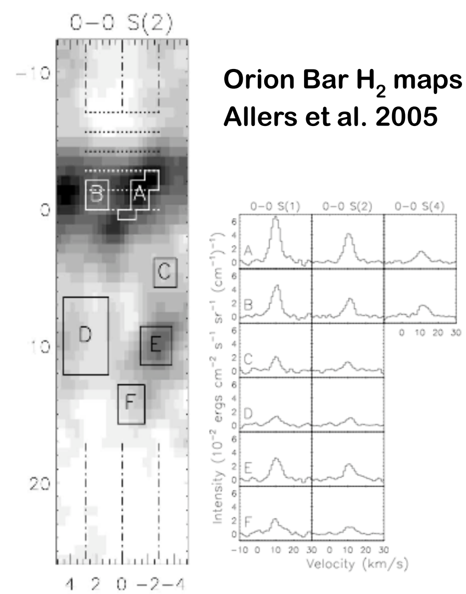
- **Nod mode**
  - on-slit: source moved between two points along slit for sky subtraction
  - off-slit: source moved off slit for sky subtraction
- **Map mode**
  - stepped maps with sky subtraction from <u>at least</u> the beginning of the map
  - step size typically half slit width
    - detectors have rolling readout so spatial information is smeared




EXES on Ames Telescope Assembly Alignment Simulator with approximate boresight

Nod on-slit: object alternates between two positions.




Orion Bar $H_2$ maps
Allers et al. 2005

<u>Figure 1 from Irons et al. 2012 ApJ 755 90</u>
Map of [NeII] emission in Galactic Center

# Sensitivities

- **TEXES on Gemini**
  - S/N = 5 in 3600 seconds clock time (includes overheads)
  - per resolution element
  - does not include atmosphere

| Resolution Mode | Resolution | Point source flux density (mJy) | | Point source magnitude | | |
|---|---|---|---|---|---|---|
| | | 10 $\mu$m | 20 $\mu$m | 8 $\mu$m | 12 $\mu$m | 20 $\mu$m |
| low | 0.003 $\mu$m | 30 | 60 | 8.5 | 7.2 | 5.5 |
| medium | 24 km/s | 70 | 140 | 7.6 | 6.3 | 4.6 |
| high | 3.6 km/s | 250 | 500 | 6.2 | 4.9 | 3.2 |

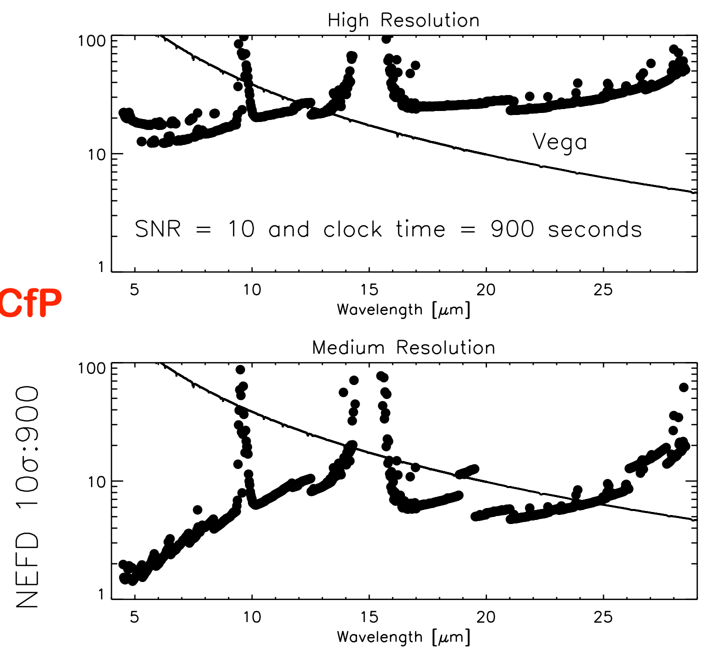
- **EXES on SOFIA**

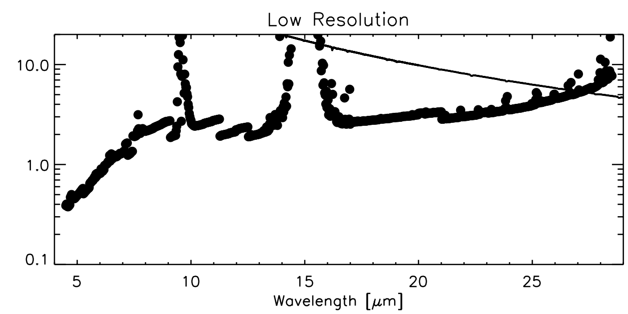
– S/N = 10 in 900 seconds clock time (includes overheads)

– per resolution element

– includes median atmosphere

**TO BE REVISITED before CfP**



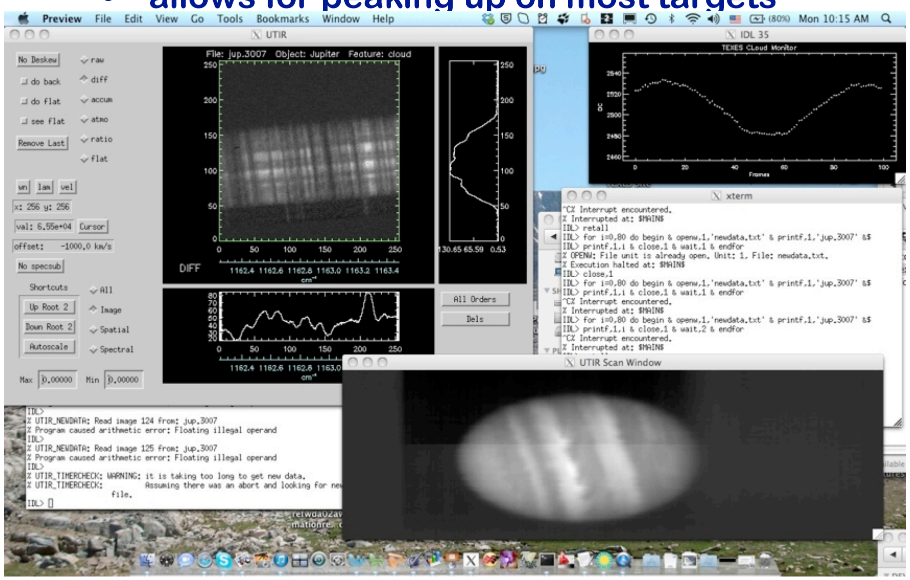



# Software

- TEXES software mature, but still improving
- EXES to be adapted from TEXES, but non-trivial task

## Quicklook data reduction

- At telescope (each disk write)
- interactive GUI
- combines files
- allows for peaking up on most targets

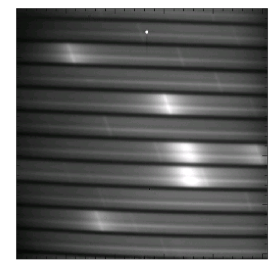


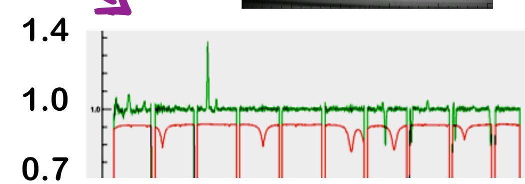

Screenshot of quicklook halfway through scan of Jupiter

## Pipeline data reduction

- near real time (1 file behind: about 5 min)
- interactive or script
- combines files
- close to final version at telescope
- Scripts rerun at home later

Changes this to THIS






$\beta$ Gem (Sundqvist et al 2008)

# Current Schedule

- TEXES on Gemini
  - On telescope Oct 2013 for up to 11 nights
    - http://www.gemini.edu/sciops/observing-gemini/2013b-call-proposals
  - NOAO proposals due Mar 28
    - http://www.noao.edu/gateway/gemini/
  - TEXES will return to IRTF in 2014A and back to Gemini in 2014B
- EXES on SOFIA
  - To be included in Cycle 2 as shared-risk
    - only high-medium and medium modes available
    - only available to General Investigators in Nov/Dec 2014
      - After commissioning flights
    - http://www.sofia.usra.edu/Science/proposals/index.html
  - Call for Proposals will go out in April 2013 with proposals due June 2013
  - Ground tests on airplane currently scheduled for Jan 2014
  - Two sets of commissioning flights: March 2014 and October 2014
- Proposal Guidelines
  - Both instruments are PI-class, not facility
  - Both are open to entire community (open-skies)
  - Both request at least 1 member of instrument team on proposals and publications.
    - This is a request, but cannot be a rule
    - Team member(s) will help with proposal and any Phase II, conduct observations, and reduce data

# Further information

- For TEXES on Gemini or IRTF:
  - John Lacy (PI): lacy@astro.as.utexas.edu
  - Tommy Greathouse (solar system): tgreathouse@swri.edu
  - Matt Richter (Galactic): mjrichter@ucdavis.edu
- For EXES on SOFIA
  - Matt Richter (PI): mjrichter@ucdavis.edu
  - Mark McKelvey (Co-I): mark.e.mckelvey@nasa.gov
  - Curtis DeWitt (postdoc): curtisdewitt@gmail.com
- Instrument websites in progress....