

Get ready, get set.....

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

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and

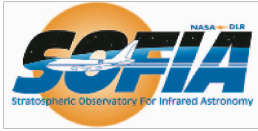
John Lacy - UT Austin (EXES and TEXES)

Tommy Greathouse (mostly TEXES)

Mark McKelvey – NASA Ames (EXES)

Curtis DeWitt - UCD (mostly EXES)

SCTF Telecon 3-13-13



Outline

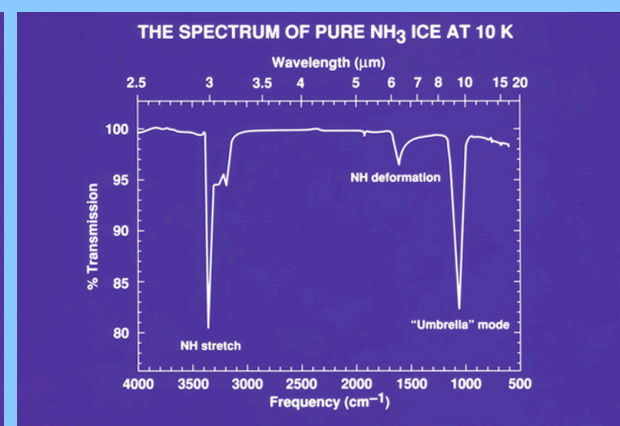
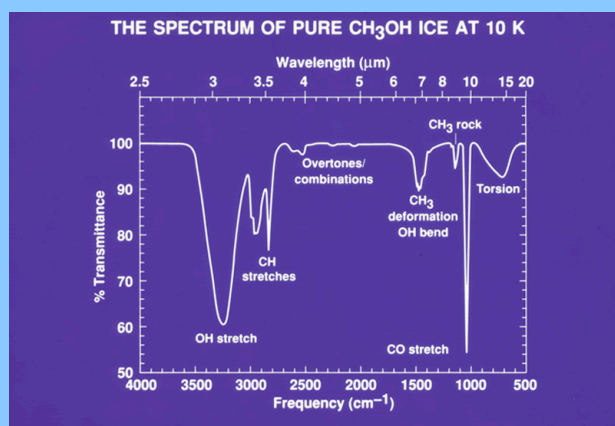
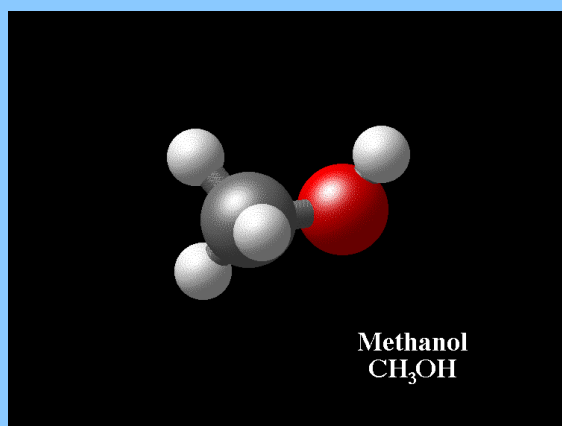
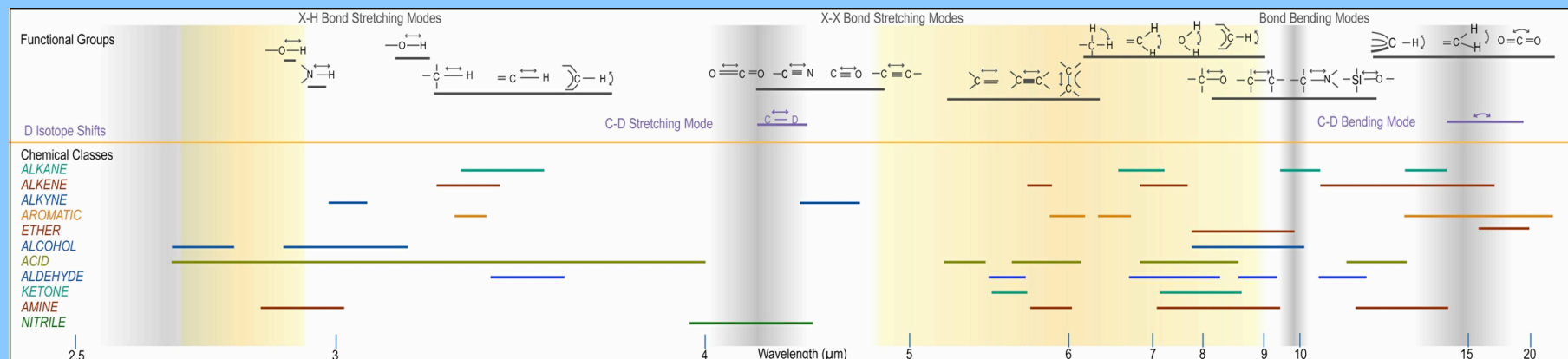


- Quick primer on mid-IR spectroscopy
 - features
 - atmospheric effects
- Importance of high resolution
- EXES and TEXES
 - relative to other instruments
 - detectors
 - instrument science configurations
 - observing modes
 - sensitivities
 - software
- Schedule: proposal and observing
- Further information

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”

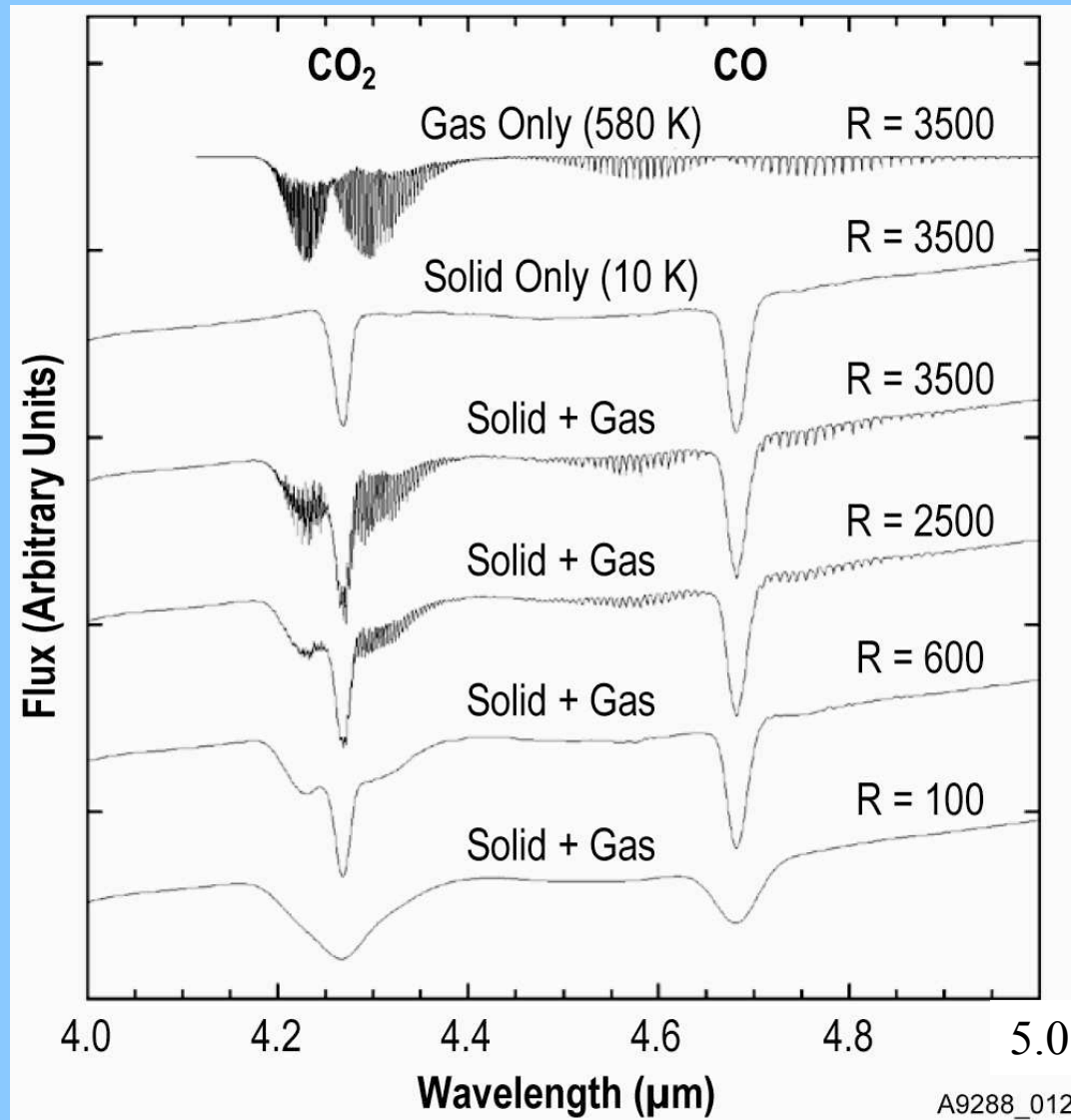
Molecules seen with TEXES

- 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

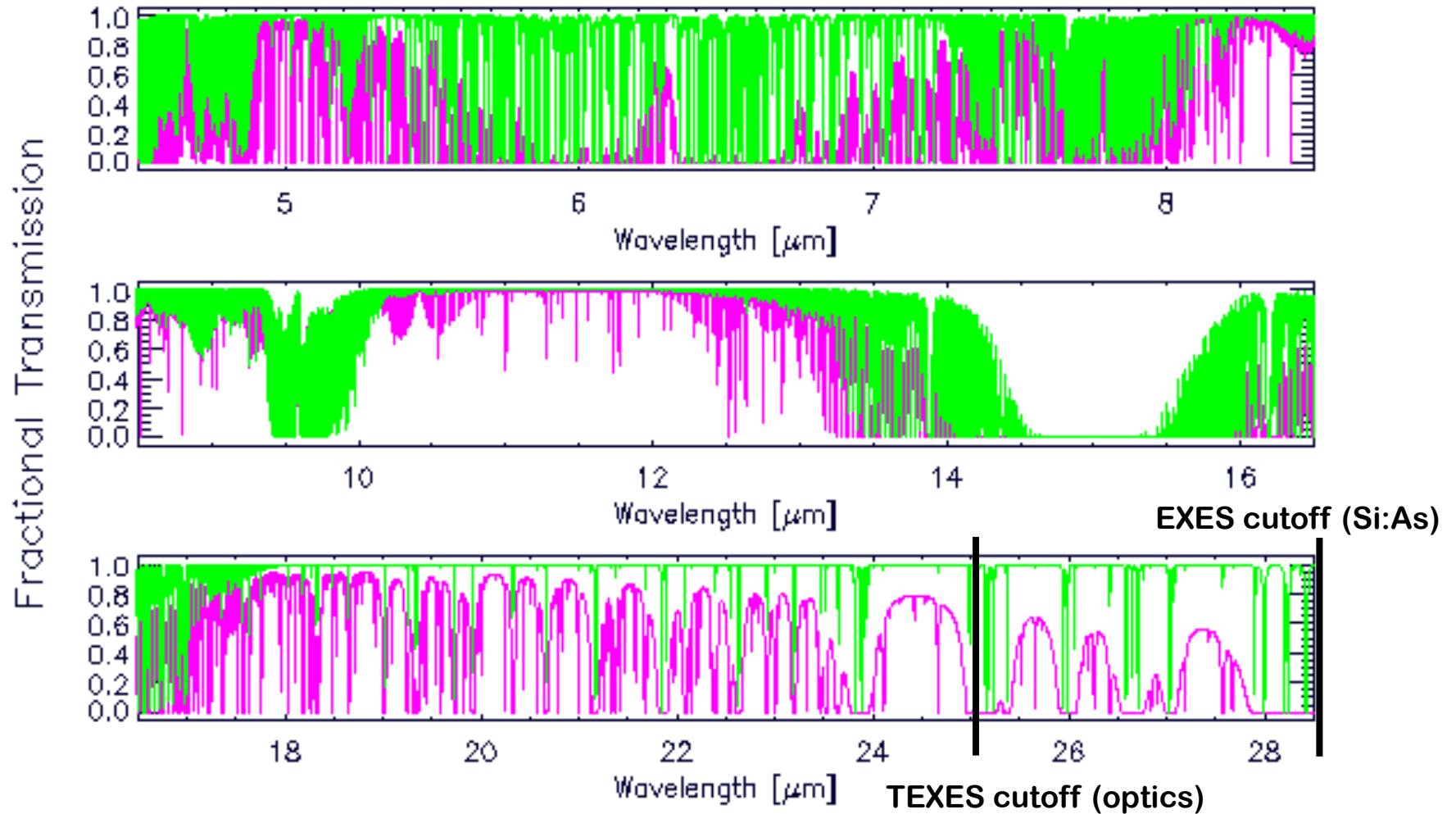
ISO SWS (about)

Spitzer IRS High

Adapted from Scott Sandford's 2009 teletalk

Atmospheric comparison

SOFIA vs Mauna Kea



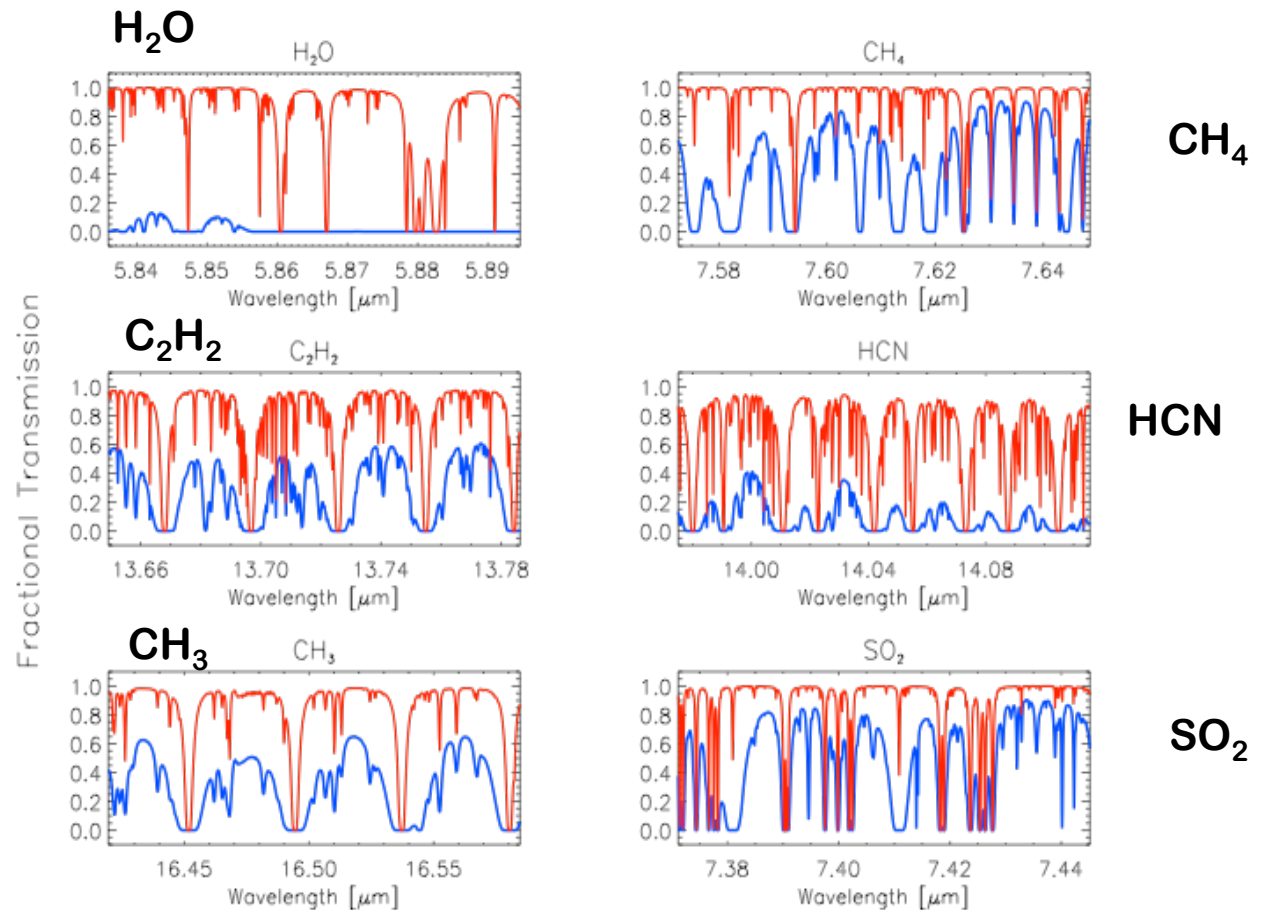
high spectral resolution at wavelengths inaccessible from ground

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

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

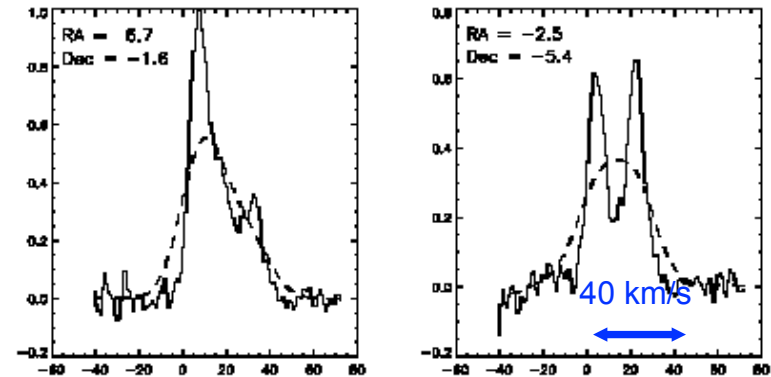
$$S/N \propto T / ((1-T) + \epsilon)^{0.5}$$

where:
T is atmospheric transmission
ε is system emissivity



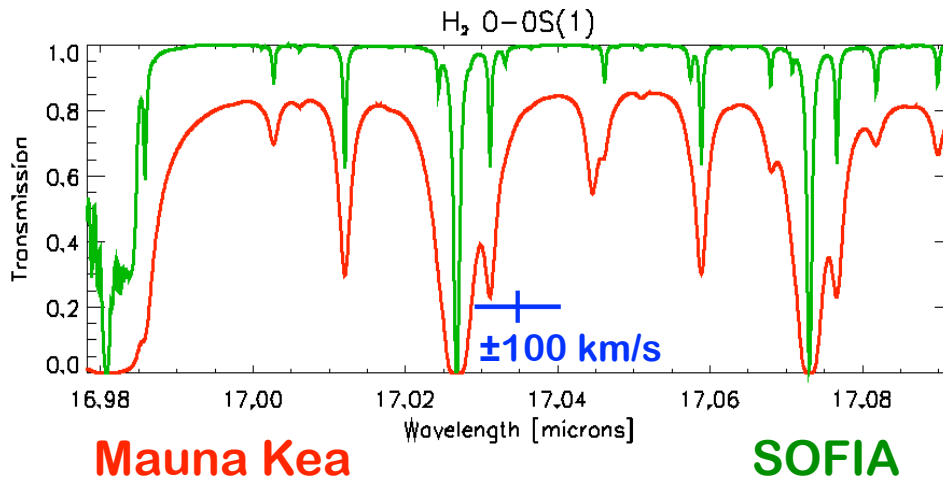
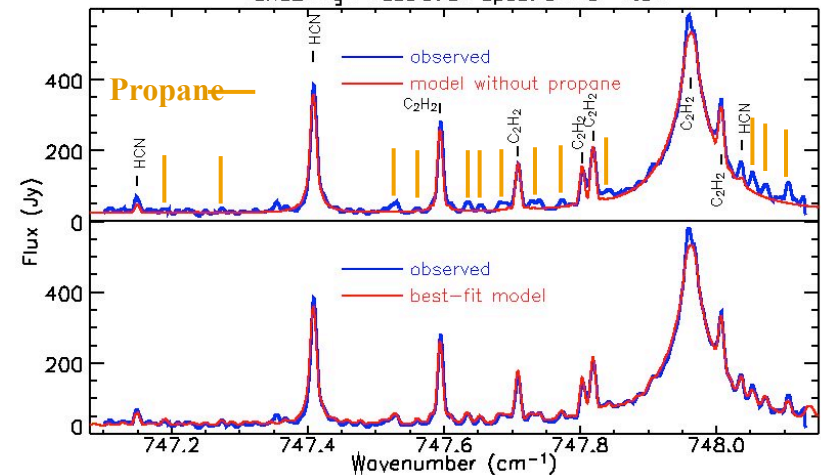
- Line profile information
- Limit confusion
 - other source lines
 - lines from atmosphere
- Maximize sensitivity for narrow lines

Jaffe et al (2003) R~80,000

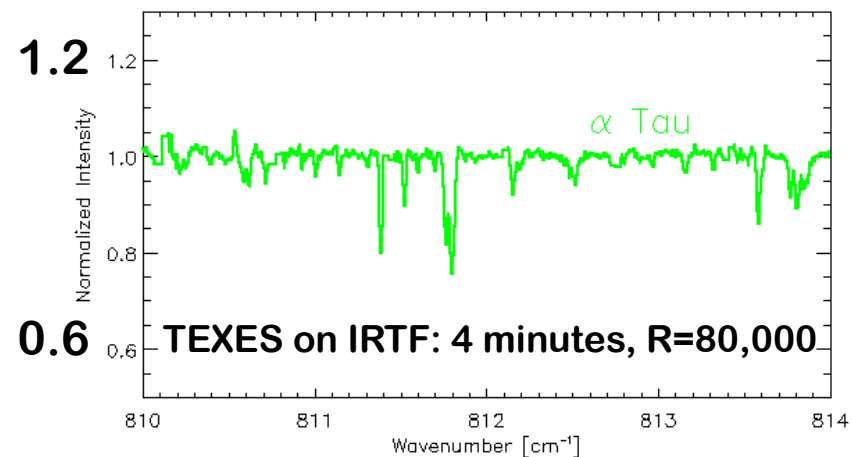
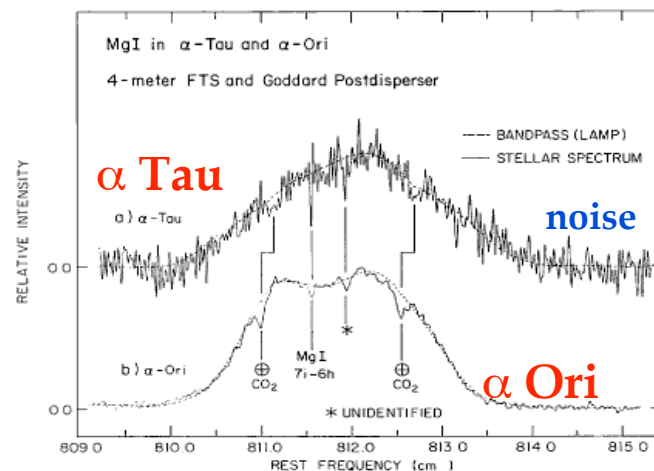


Roe et al. 2003

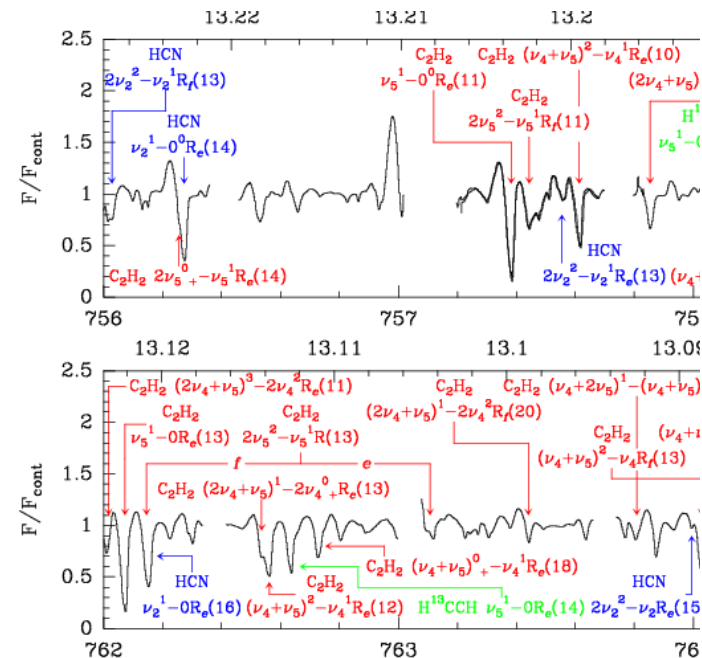
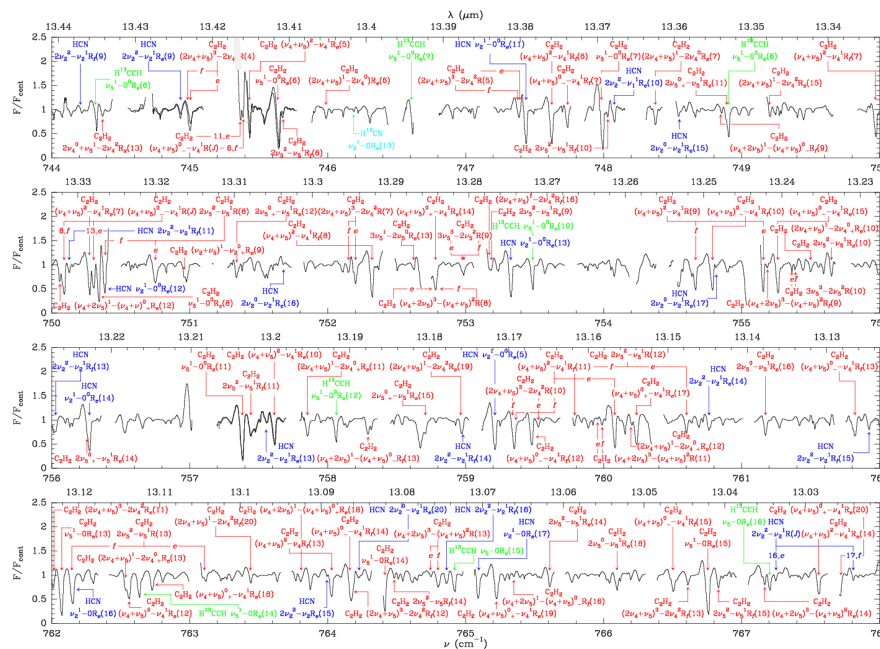
TEXES high-resolution spectrum of Titan



- 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



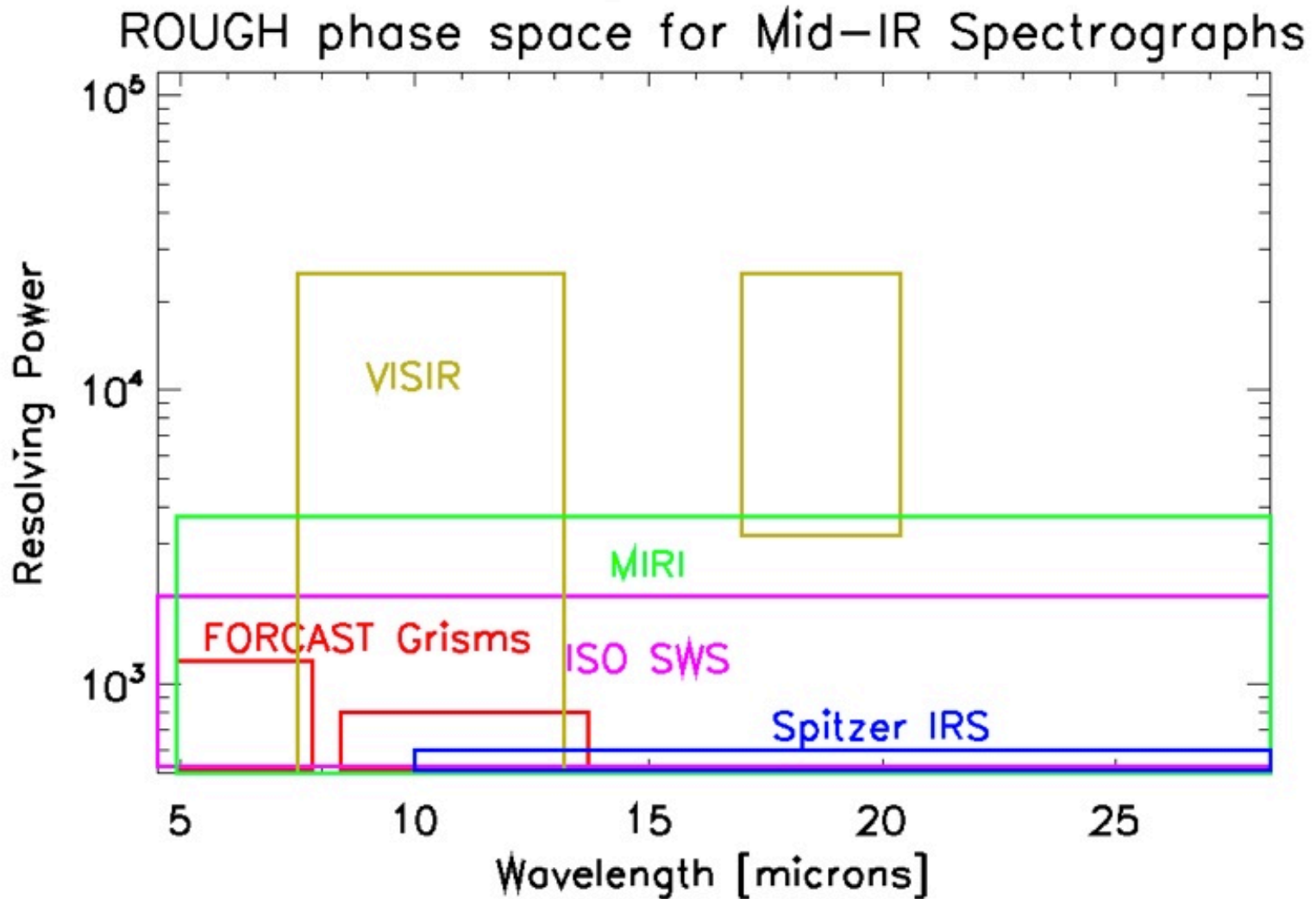
- Provide data unobtainable elsewhere
- Complement ALMA and Herschel
 - vibrational transitions
 - molecules with no dipole moment



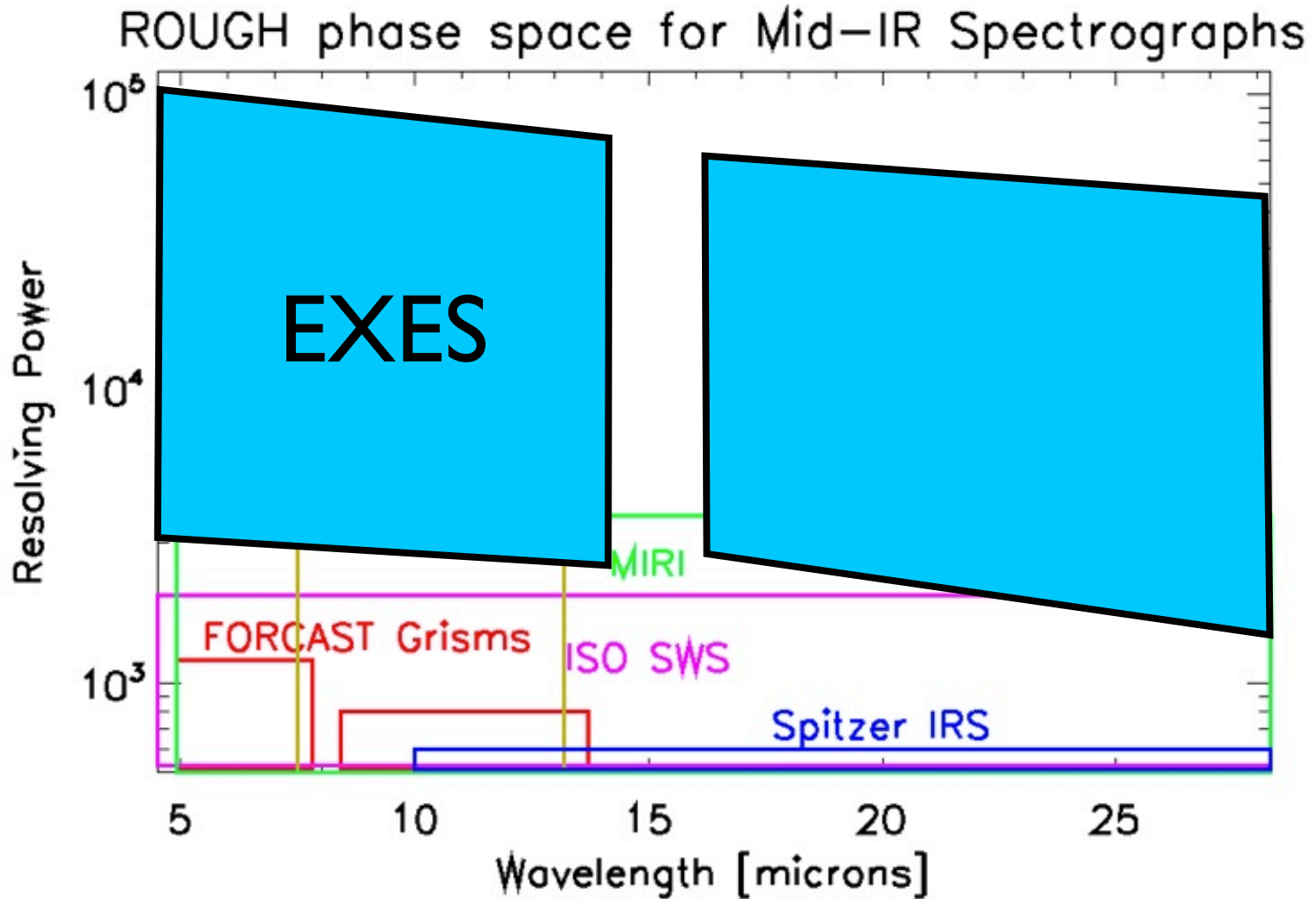
TEXES survey of IRC +10216 (Fonfria et al. 2008)

zoom of upper left

Other Mid-IR Spectrographs

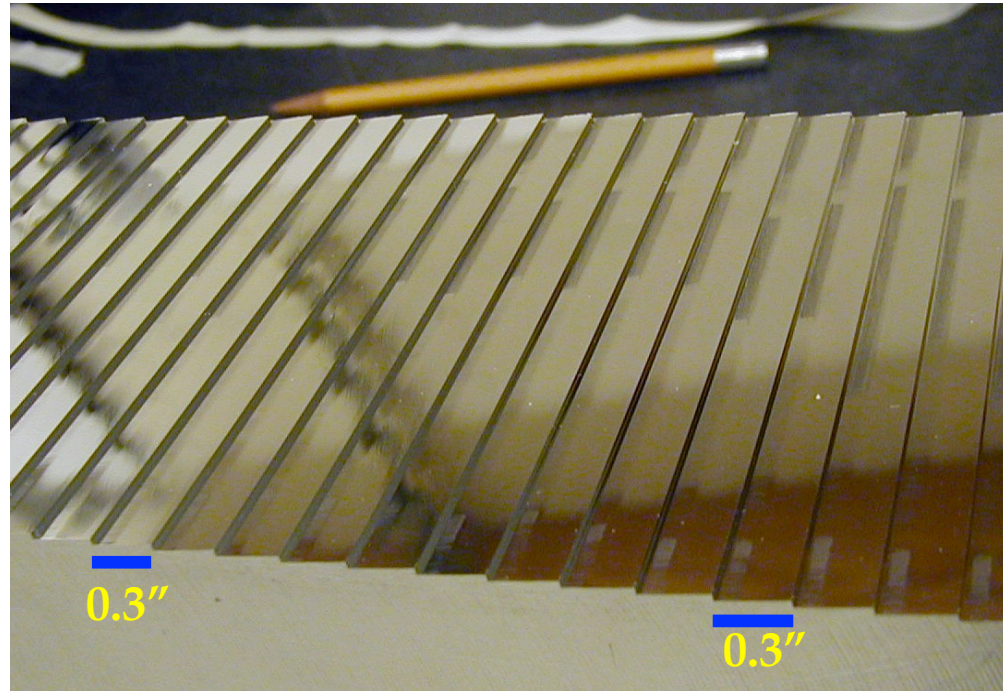


Other Mid-IR Spectrographs

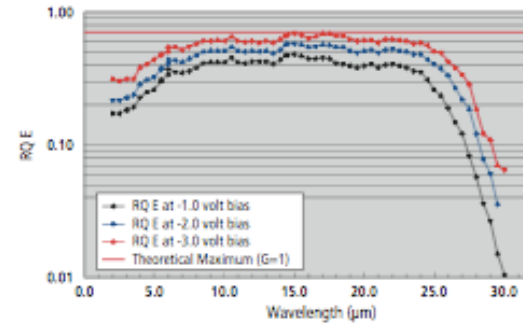


Echelon gratings

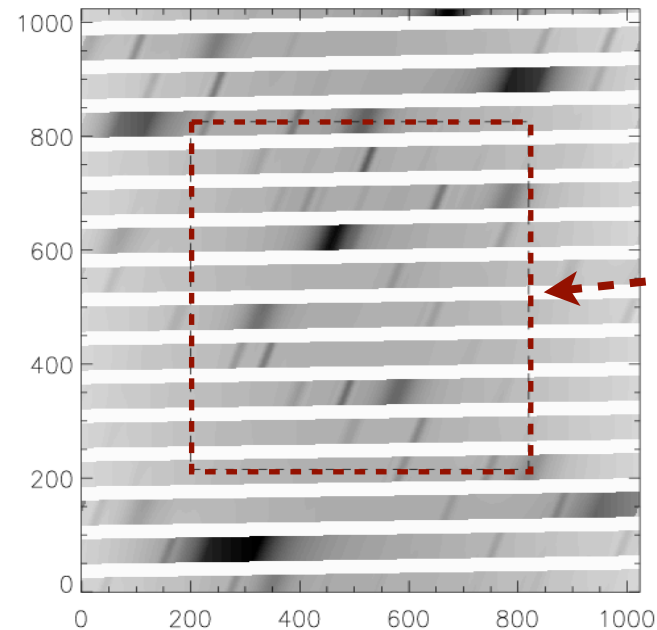
- 36" and 40" long
- 0.300" groove spacing
 - 0.131 grooves/mm
- 84.2 degree incidence angle
 - 0.03" groove height
- Diamond machined Al 6061
 - Hyperfine Inc



- **Both:**
 - Si:As
 - Optimized for low background (space)
 - shallow wells $\sim 1.5e5 e^-$
- **EXES**
 - 1024^2 pixel
 - $25 \mu\text{m}$ 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 $19 \mu\text{m}$
- **TEXES**
 - 256^2 pixel
 - focal reduced to $63 \mu\text{m}$ 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 $11 \mu\text{m}$



Raytheon
Si:As RQE

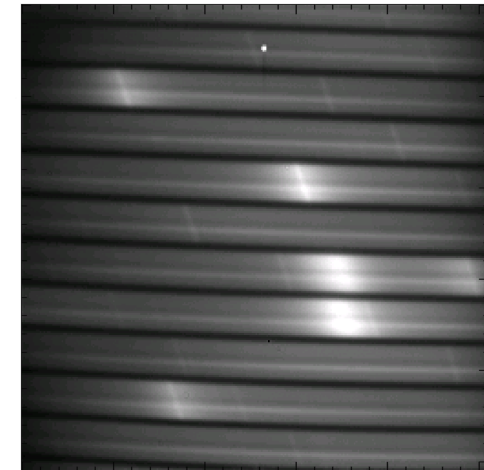


Current TEXES
 256^2 detector

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

In General

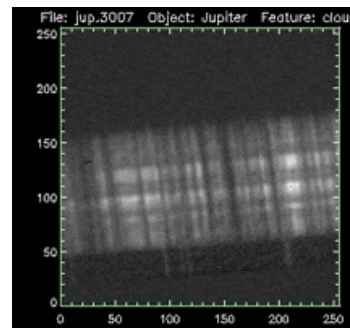
- High resolution modes use ~1m long echelon cross-dispersed by another grating
 - $R = 50,000$ to $100,000$ depending slit width and wavelength
- Single order modes skip the echelon and give a long slit
- Wavelength coverage set by echelle/low order grating, not echelon
 - coverage in medium is same 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 β Gem

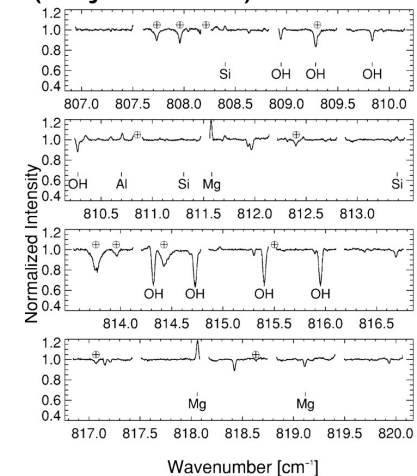
Modes

- 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

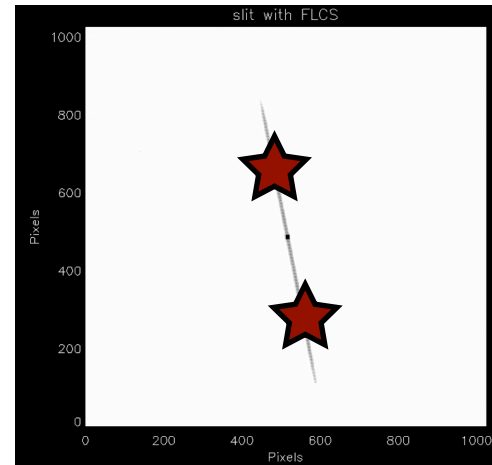
High-Low 1D extracted spectrum (Lacy et al. 2002)



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

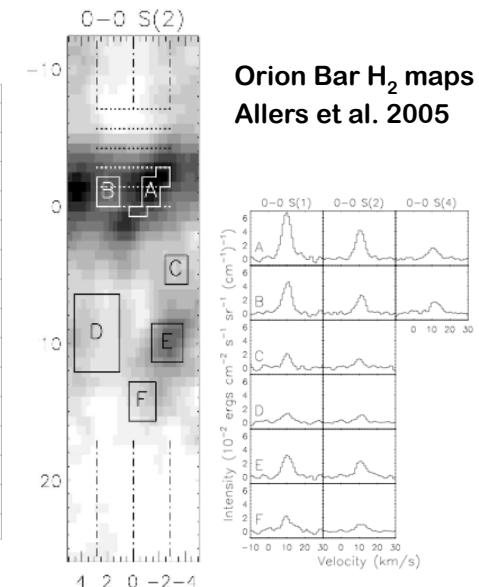
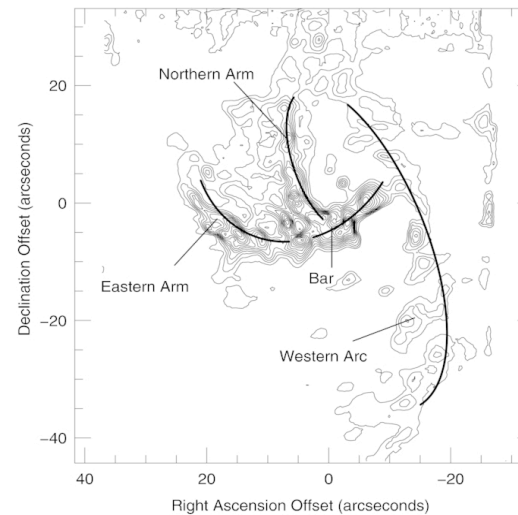


EXES on Ames Telescope
Assembly Alignment
Simulator with approximate
boresight

Nod on-slit: object alternates between two positions.

- **Map mode**

- stepped maps with sky subtraction from at least the beginning of the map
- step size typically half slit width
 - detectors have rolling readout so spatial information is smeared



Orion Bar H₂ maps
Allers et al. 2005

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

- **TEXES on Gemini**

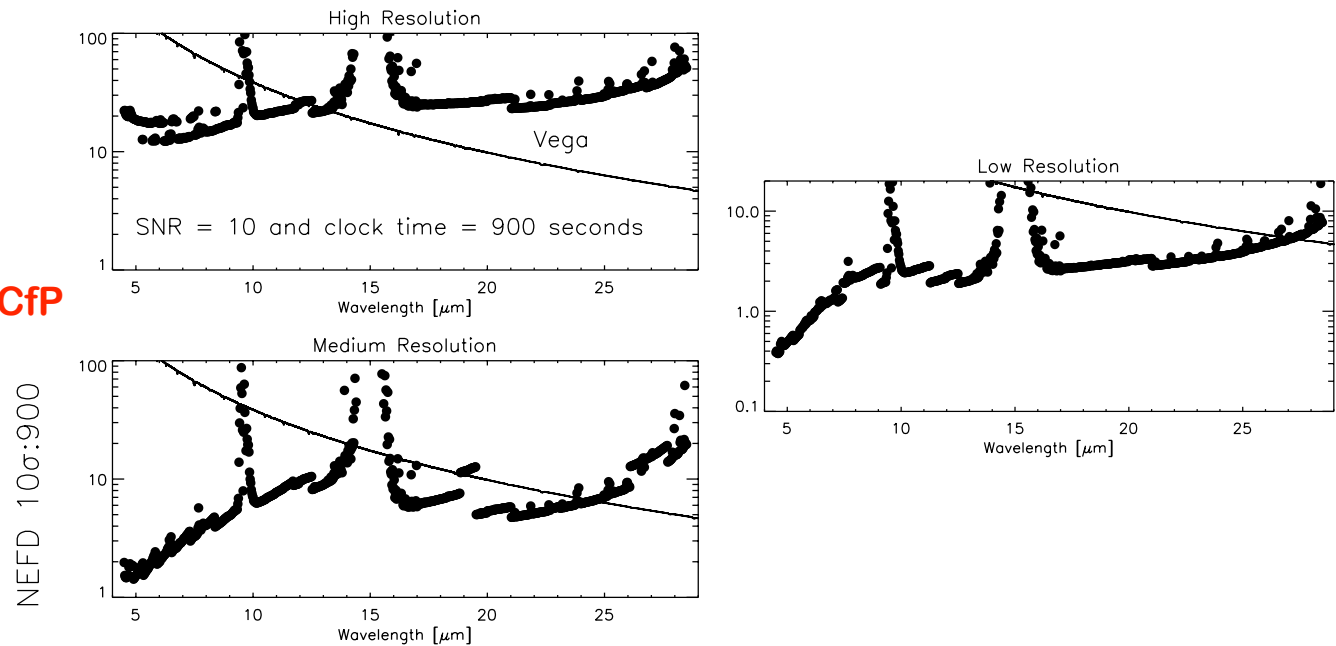
- S/N = 5 in 3600 seconds clock time (includes overheads)
- per resolution element
- does not include atmosphere

Resolution Mode	Resolution	Point source flux density (mJy)		Point source magnitude		
		10 μm	20 μm	8 μm	12 μm	20 μm
low	0.003 μm	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

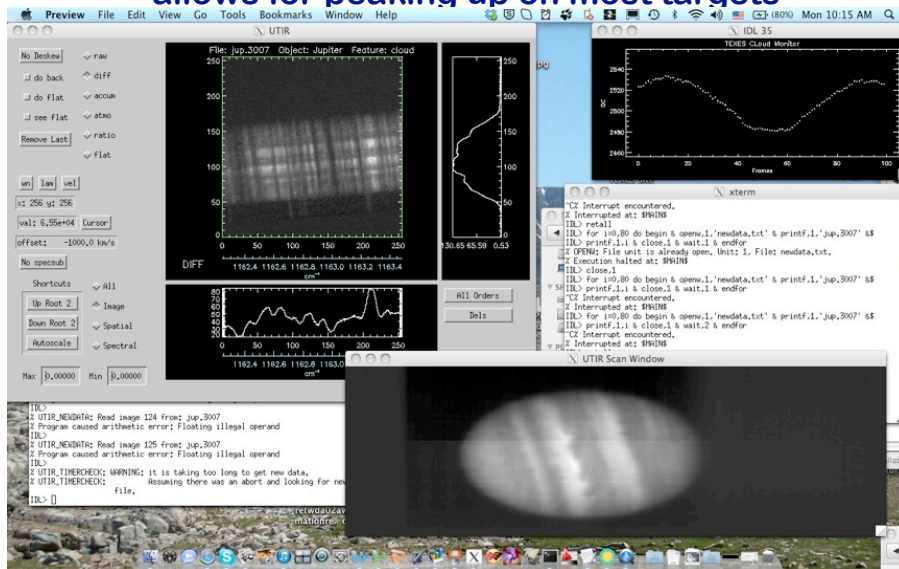
TO BE REVISITED before CfP



- **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**

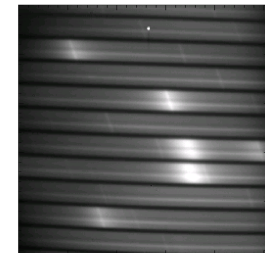
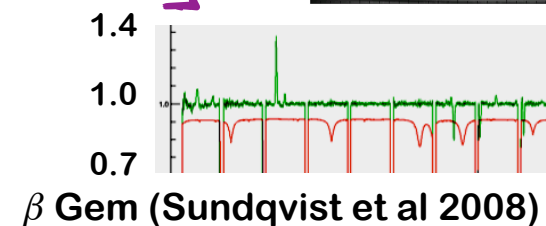


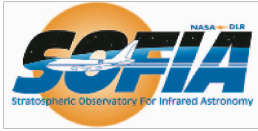
Screenshot of quicklook halfway through scan of Jupiter

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**

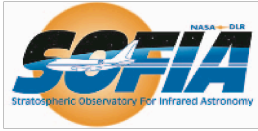




Current Schedule



- **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): curtisde Witt@gmail.com
- **Instrument websites in progress....**