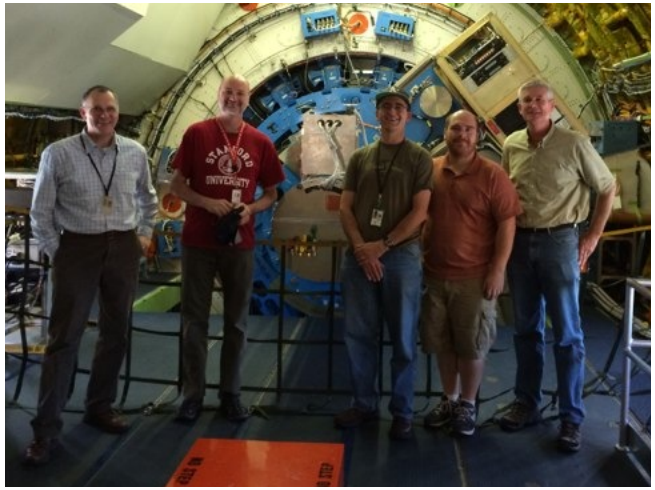
First flights of EXES on SOFIA



Current: Matt Richter (UCD), Mark McKelvey (Ames), Curtis DeWitt (UCD), Mike Case (UCD), Jeff Huang (Ames), Kristin Kulas (Ames), Robert McMurray (Ames), Damon Flansburg (Ames), Jeff Blair (Ames), Emmett Quigley (Ames), Reed Porter (Ames)

Past: Pete Zell (Ames), Andreas Seifahrt (UCD), John Reimer (Ames), Bala Balakrishnan (Ames), Dana Lynch (Ames), John Lacy (UT Austin), Doug Mar (UT Austin), Bill Moller (UT Austin)

Honorary (SOFIA): Melanie Clarke, Bill Vacca, Adwin Boogert

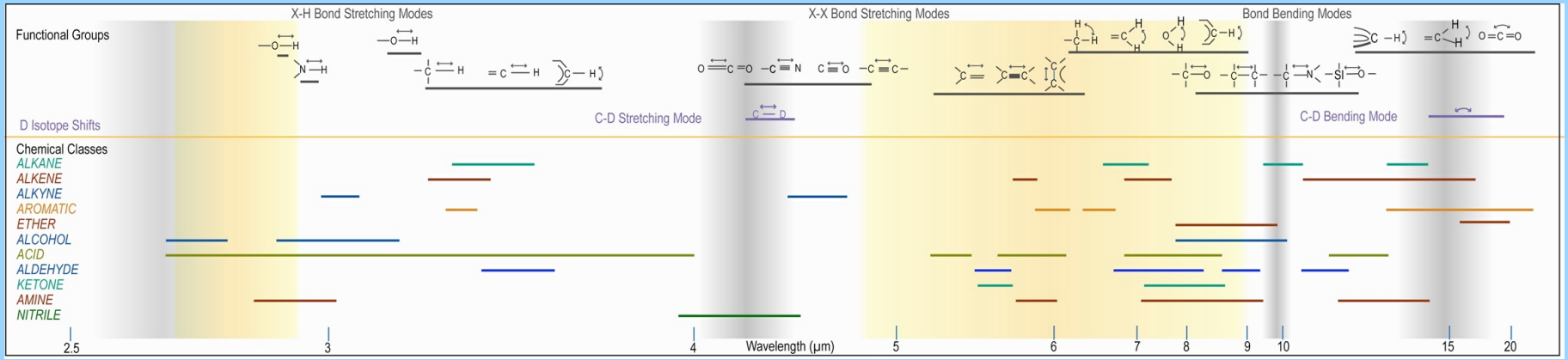
Outline

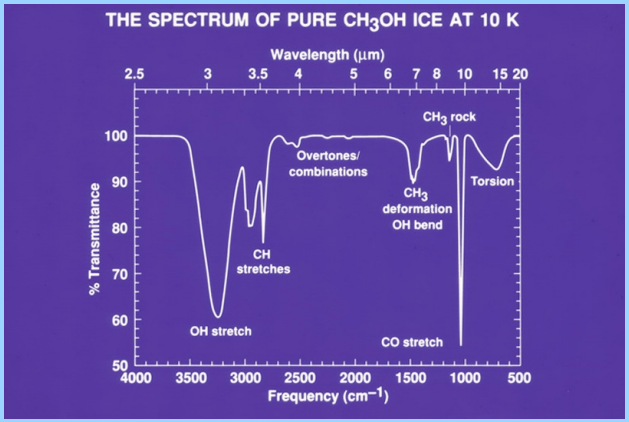
- Mid-IR spectroscopy
  - ♦ features
  - ♦ atmospheric effects
- Importance of high resolution
- About EXES
- Some highlights
- Further information

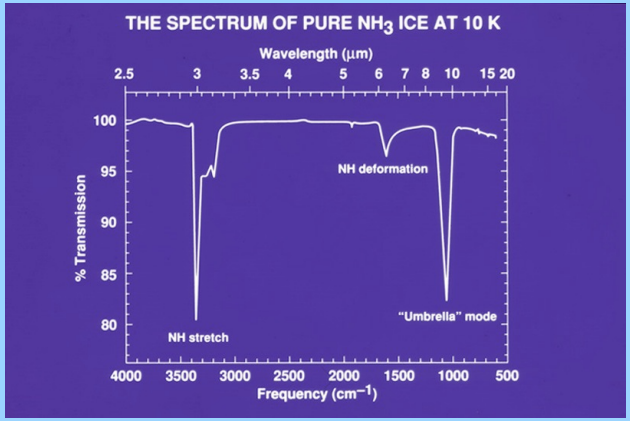
IR spectroscopy, particularly in the 2-40 μm range, can detect and identify many molecular species since different molecules have different IR spectral "fingerprints"

Molecules seen with TEXES

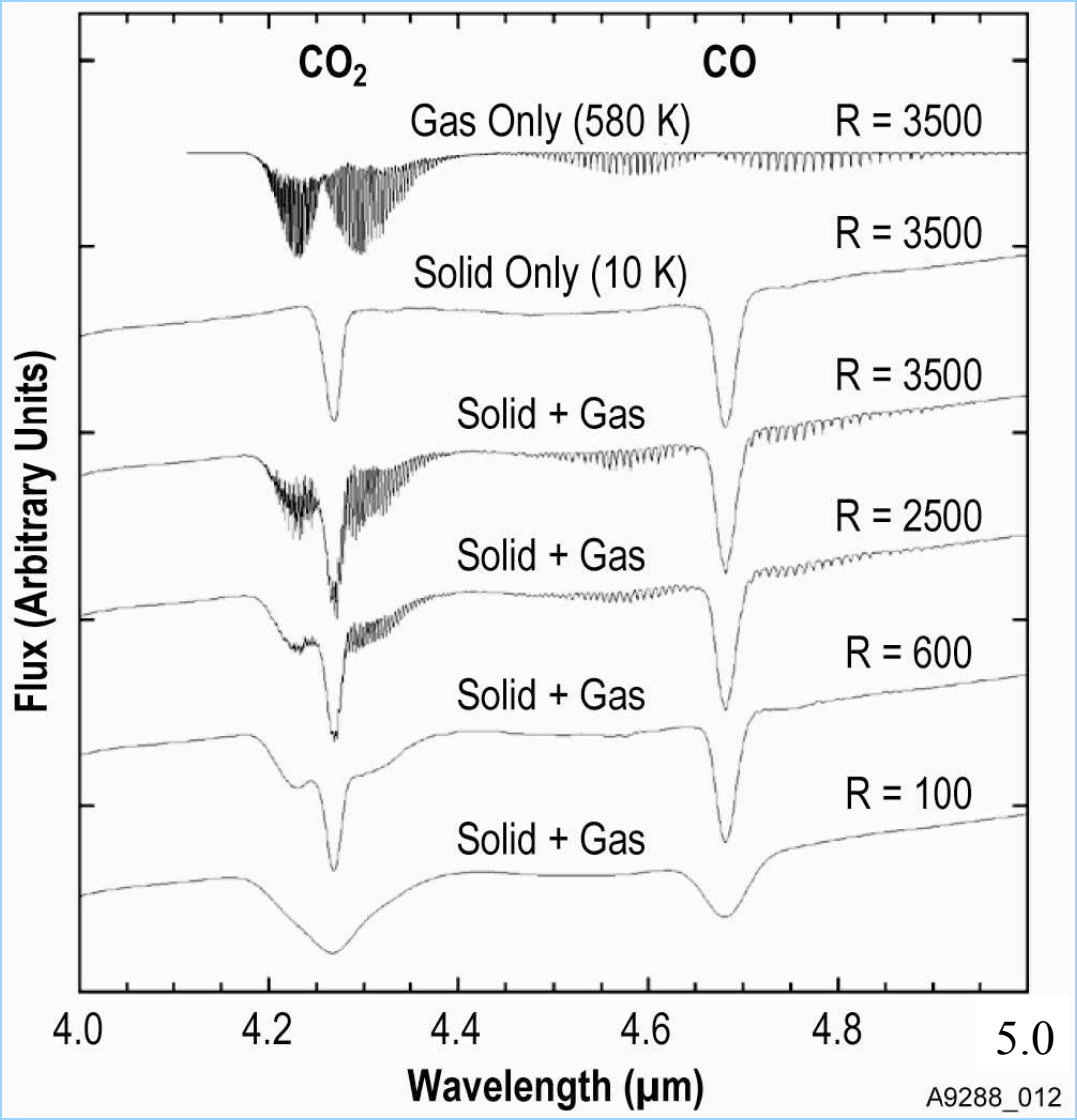
- **without dipole moments: H_2, C_2H_2, CH_4, CH_3**
- **other molecules: H_2O, HDO, HCN, NH_3, SO_2, CO, HNCO, OH, SiO, CS, C_2H_4, C_2H_6, C_3H_4, C_4H_2, C_6H_2, PH_3, CH_3D**







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



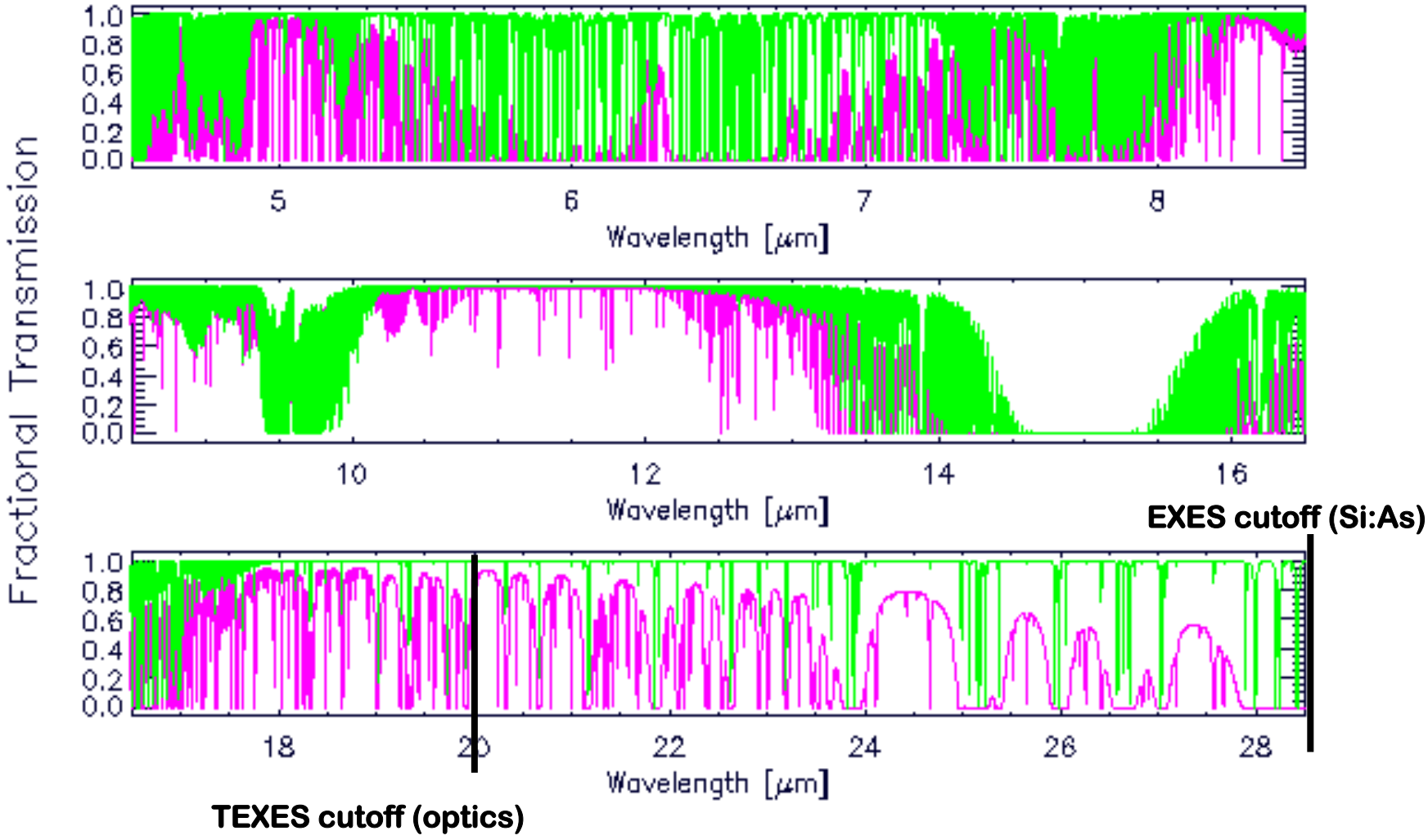
- JWST MIRI (about)
- (T)EXES low
- ISO SWS (about)
- Spitzer IRS High

NOTE: (T)EXES do not observe this full spectral region. IRS did not cover any of this region.

Adapted from Scott Sandford's 2009 teletalk

Atmospheric comparison

SOFIA vs Mauna Kea



Advantage of EXES/SOFIA

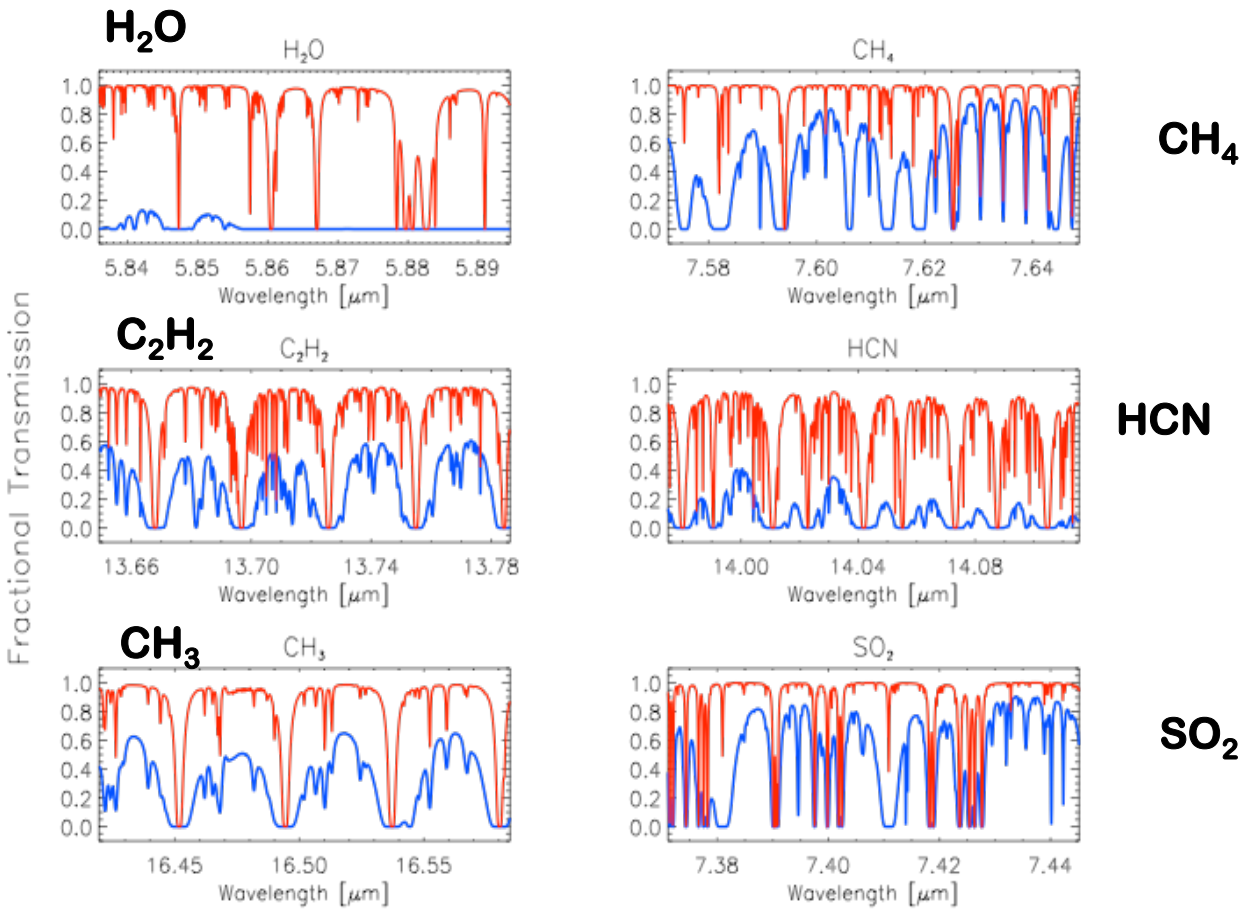
high spectral resolution at wavelengths inaccessible from ground

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

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

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

where:
T is atmospheric transmission
e is system emissivity



CH_4

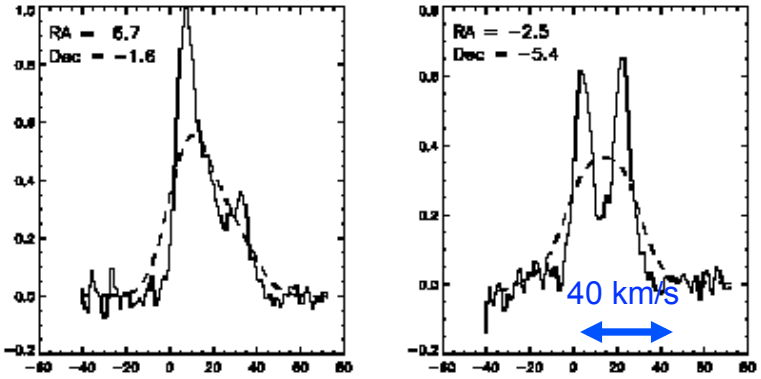
HCN

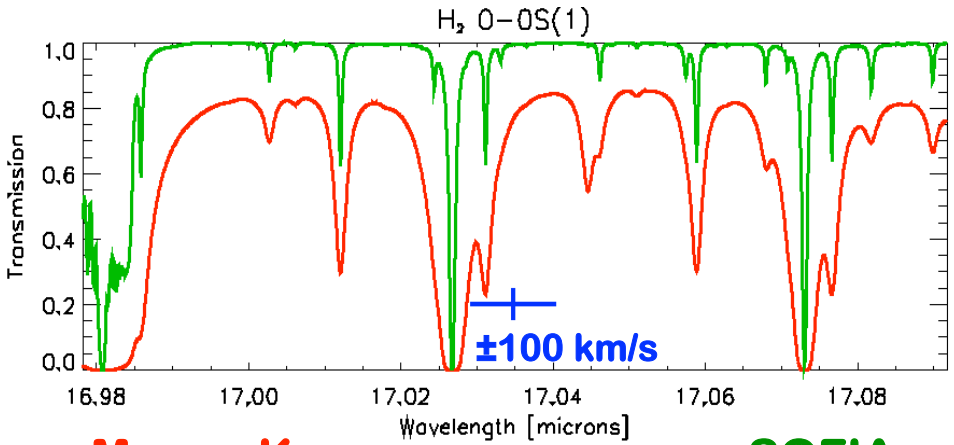
SO_2

High Spectral Resolution

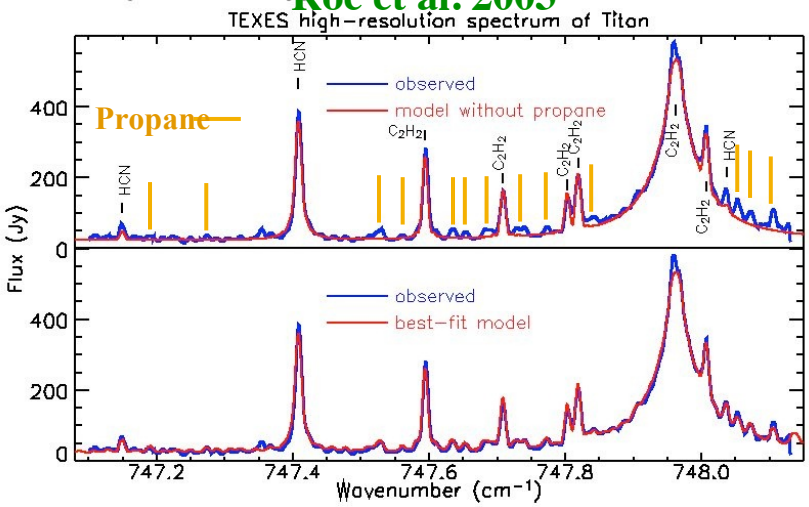
- Line profile information
- Limit confusion
  - other source lines
  - lines from atmosphere
- Maximize sensitivity for narrow lines

Jaffe et al (2003) R~80,000



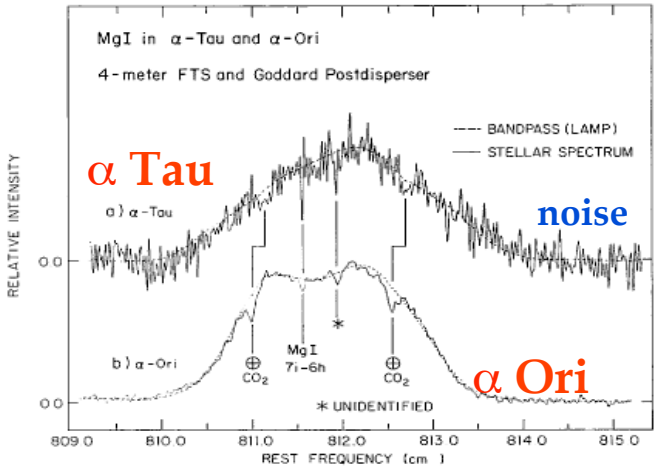


Roe et al. 2003

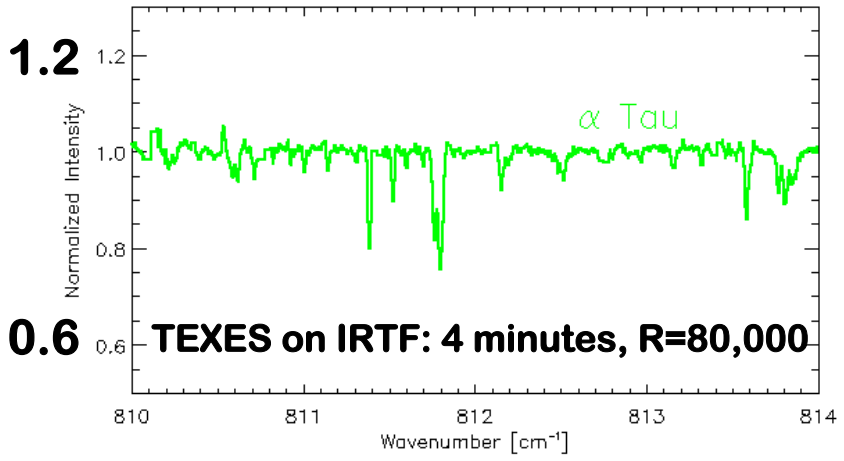


EXES/TEXES niche

- Designed and built to emphasize high resolution
  - ♦ 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

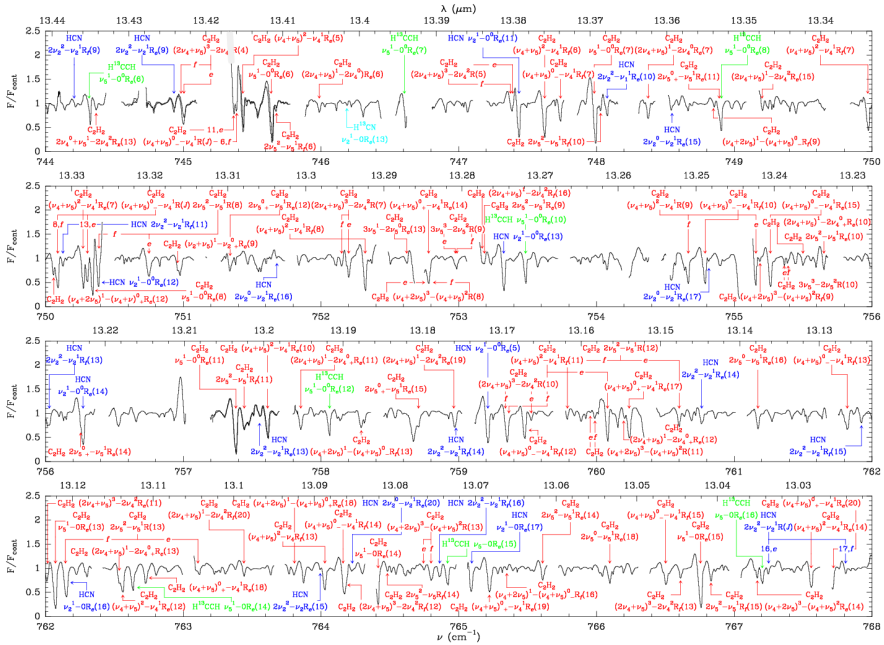


Jennings et al. 1986

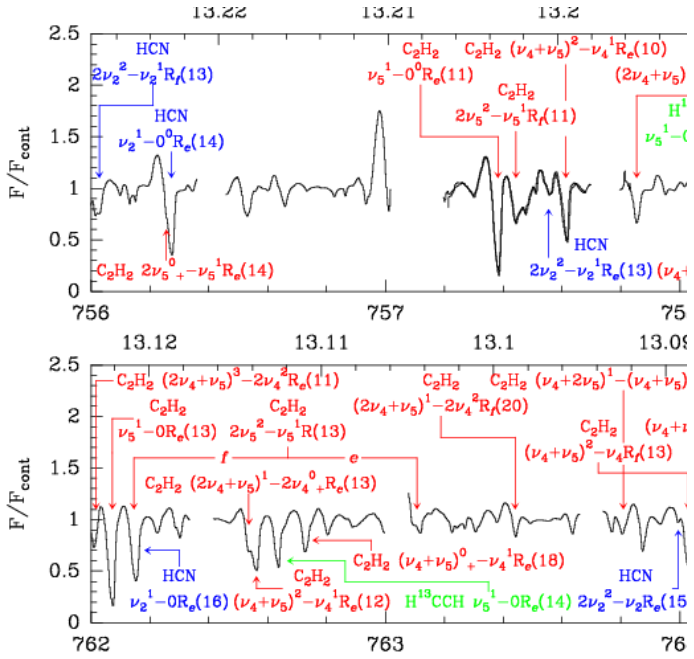


EXES/TEXES niche

- Provide data unobtainable elsewhere
- Complement ALMA, GREAT on SOFIA, Herschel
  - ♦ vibrational transitions
  - ♦ molecules with no dipole moment

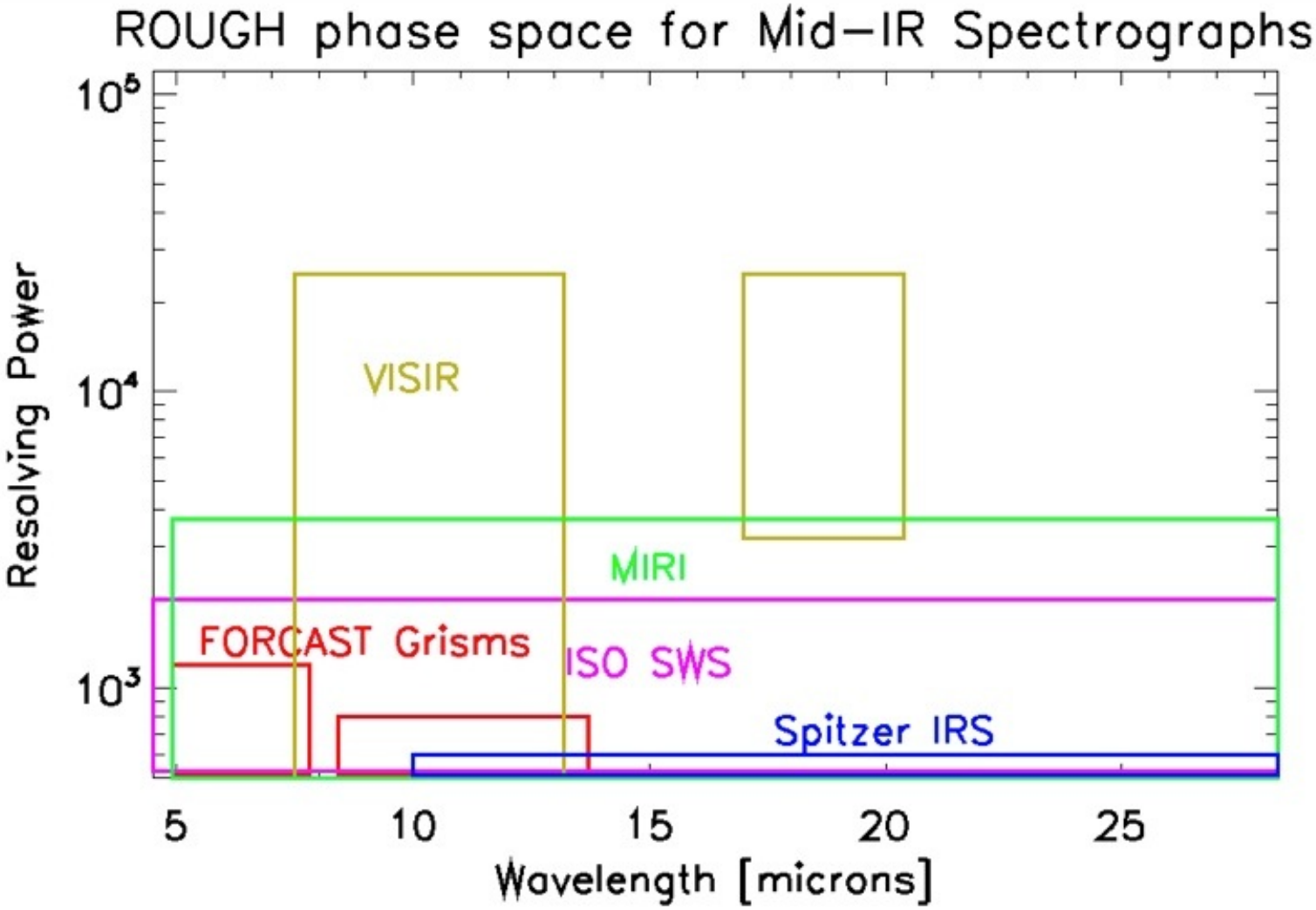


TEXES survey of IRC +10216 (Fonfria et al. 2008)
1 of 6 pages

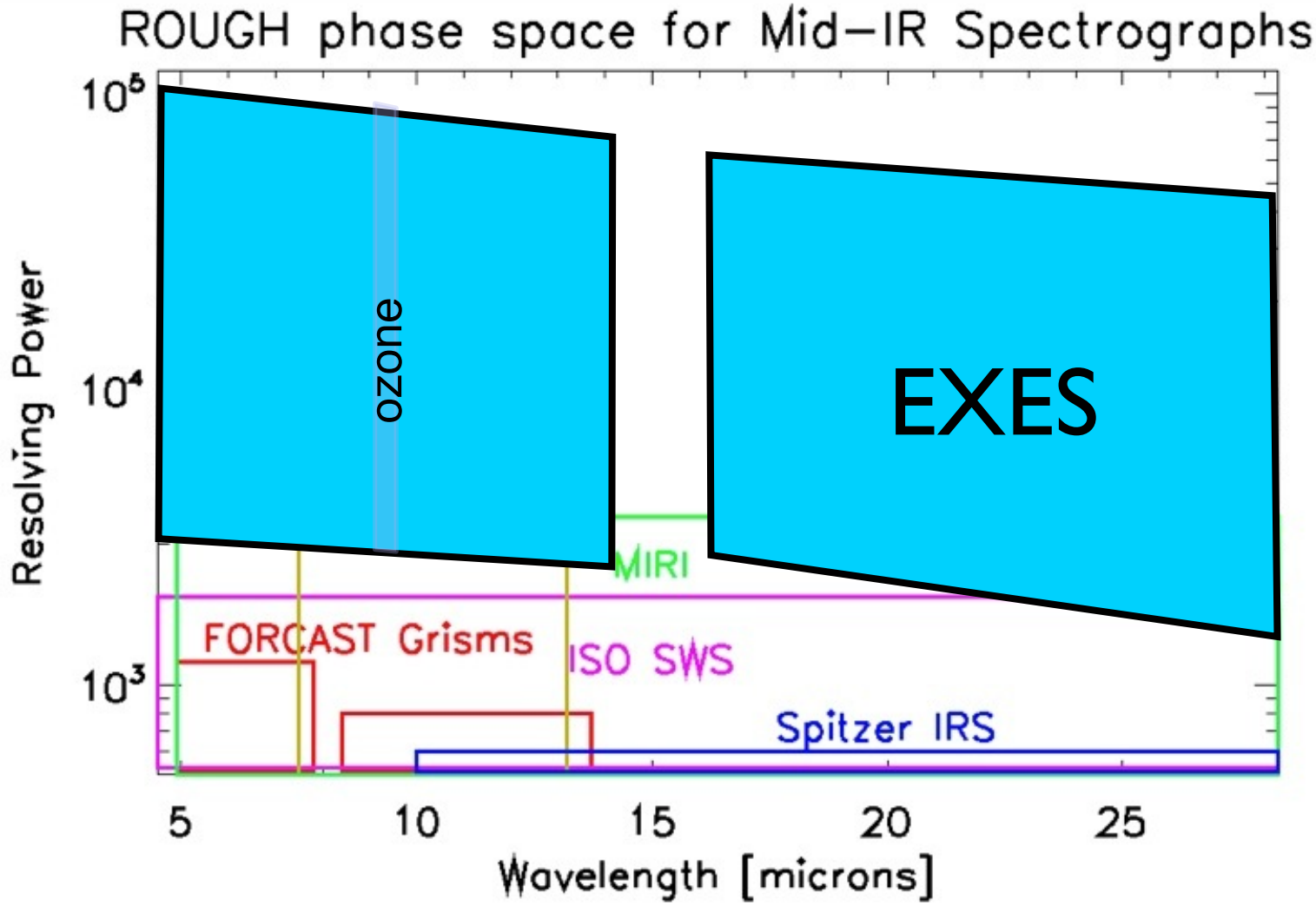


zoom of upper left

Other Mid-IR Spectrographs

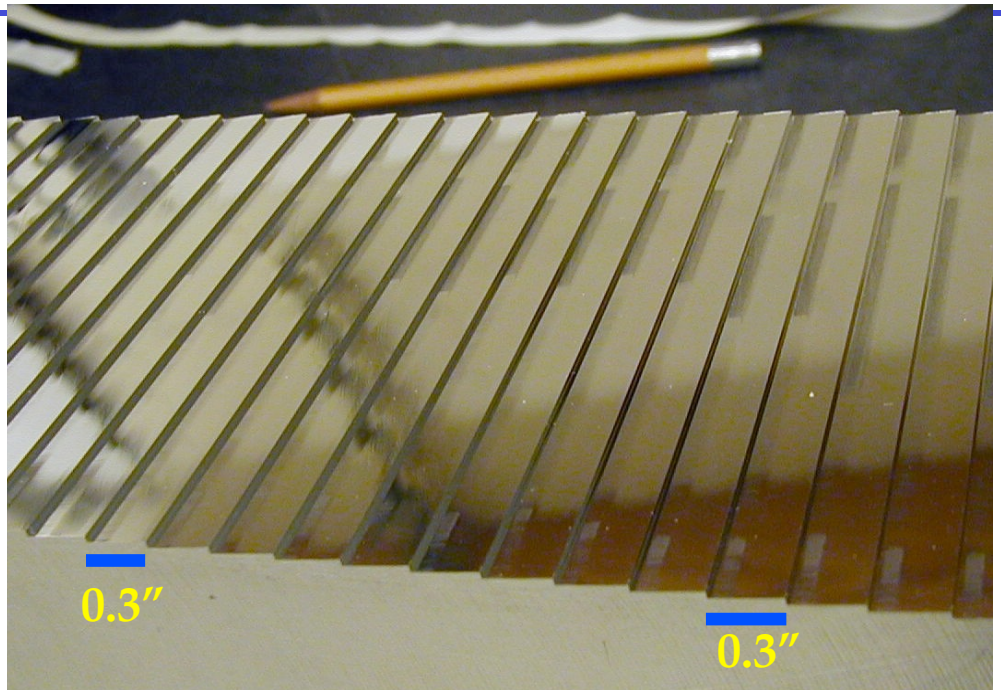


Other Mid-IR Spectrographs



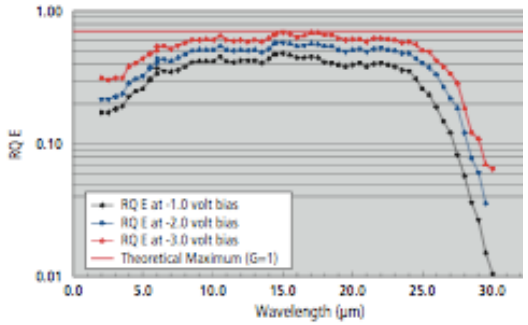
Echelon grating

- 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

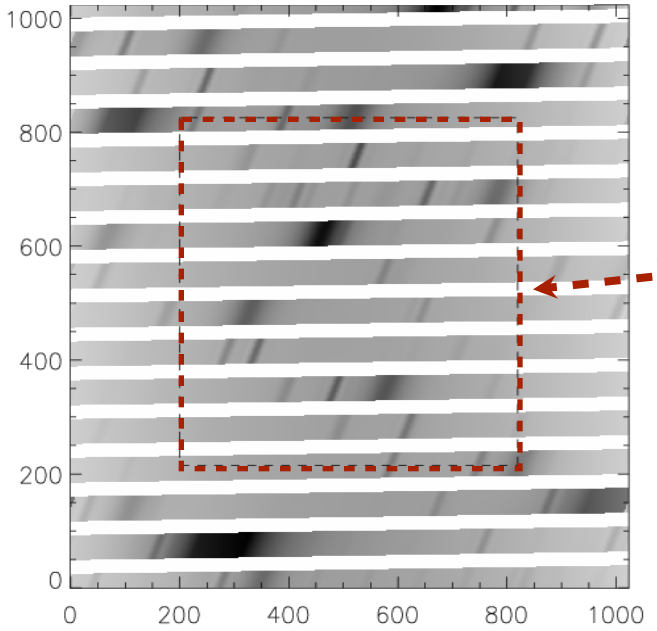


Detectors

- EXES
  - 1024^2 pixels
  - 25 mm per pixel
    - Oversampled
    - 0.38 km/s per pixel
    - 0.21” per pixel
  - 60 e- single sample read
  - matches size of high resolution orders ~19 μm
- TEXES
  - 256^2 pixel
  - focal reduced to 63 mm 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 ~11 μm
- Both:
  - Si:As
  - Optimized for low background (space)
  - shallow wells ~1.e5 e- for <1% non-linear



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

Science configurations

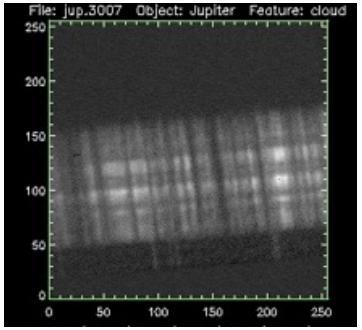
In General

- High resolution modes use ~1m long echelon cross-dispersed by echelle
  - R = 50,000 to 100,000 depending slit width and wavelength
- Single order modes bypass the echelon and use a long slit
- Wavelength coverage set by echelle, 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

Modes

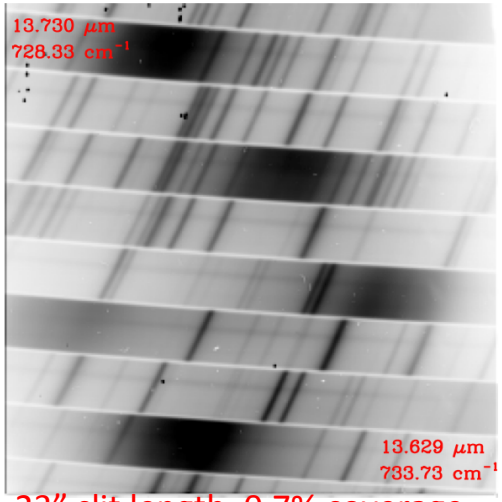
- High-Medium - standard mode
  - echelon plus echelle used in 2nd to 12th order, depending on wavelength
  - can nod on slit for most wavelengths. Most often used for mapping.
- High-Low - spectral survey
  - echelon plus echelle at low orders
  - shorter slit
- Medium mode - just echelle at higher angles
  - R = 5,000 to 20,000
- Low mode - just echelle at lower angles
  - R = 1500 to 4000

High-Medium emphasized
Low untested



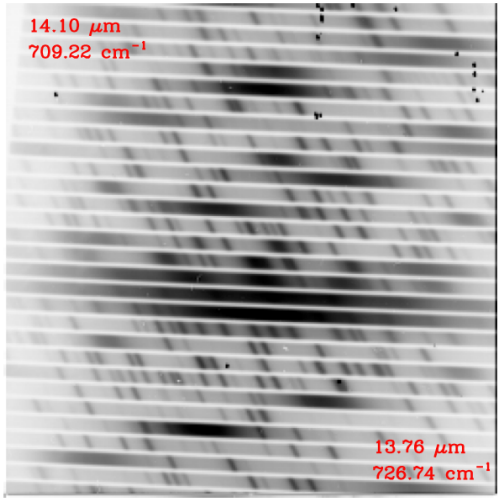
Sky subtracted low mode TEXES spectrum of Jupiter

HIGH_MED Configuration



23” slit length, 0.7% coverage

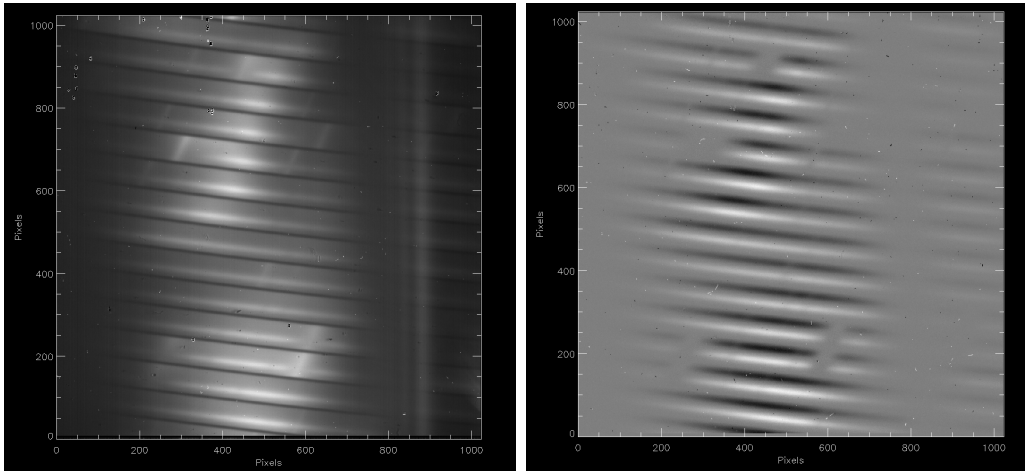
HIGH_LOW Configuration



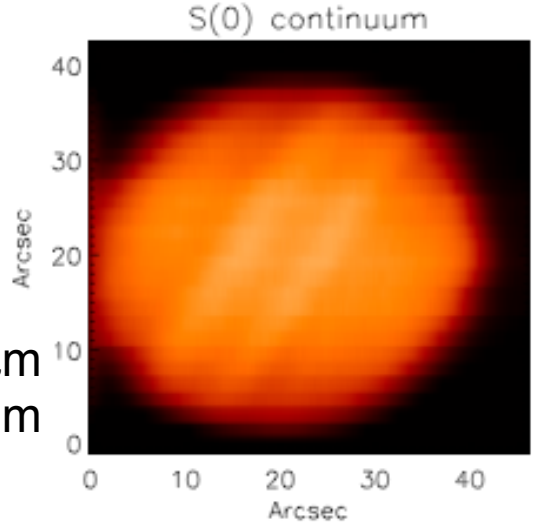
4” slit length, 4% coverage

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 at least the beginning of the map
  - ♦ step size typically half slit width



alpha Tau during nod observation: Left is at one slit position with sky lines and star both visible. Right is after subtraction.



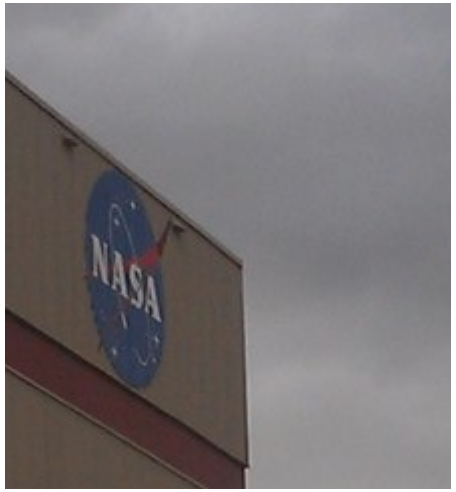
Jupiter at 28 μm continuum

Commissioning Schedule

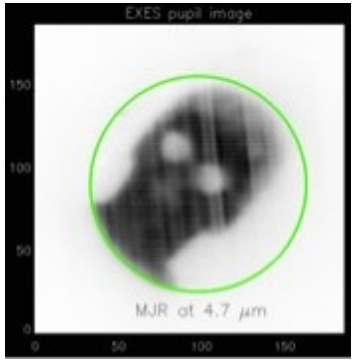
- Arrive DAOF Mar 3
  - ♦ EXES was cold
- Install Mar 31
- Line ops Apr 3 & 4 (clouds)
- Flights Apr 7 & 9 (PDT)

Unloading: Curtis DeWitt and Mark McKelvey

Clouds before the first night

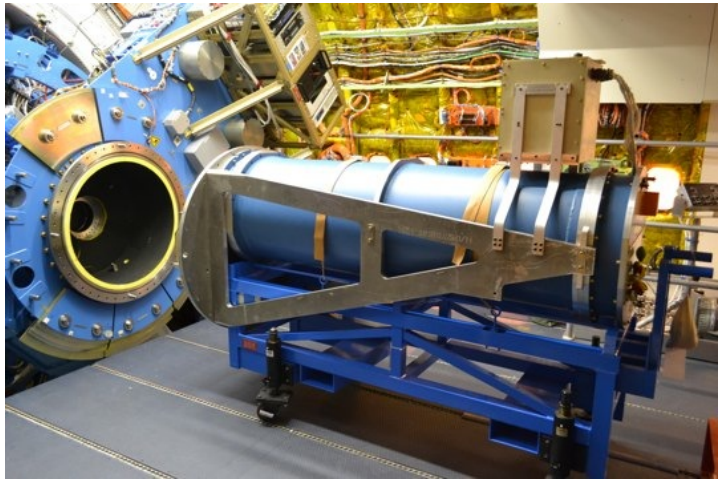


MJR pupil image

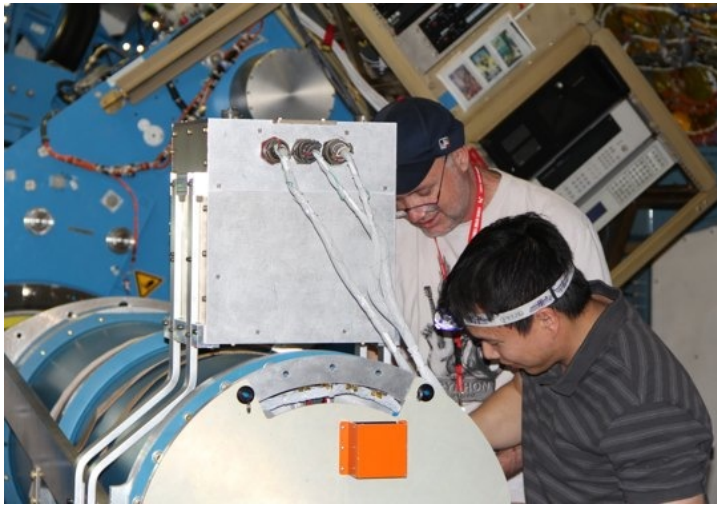


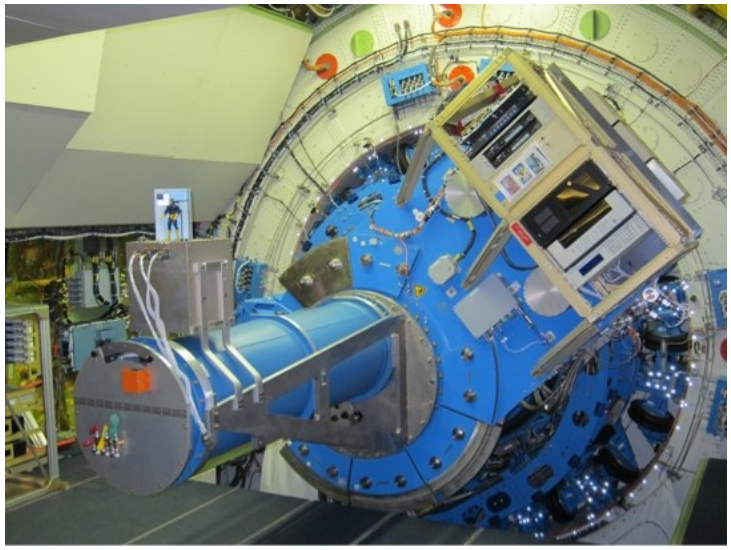
Installation

EXES on cart



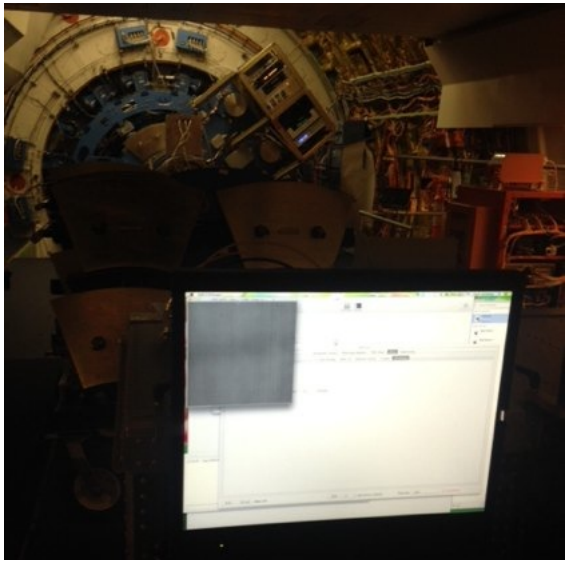
Installation: Mark McKelvey and Jeff Huang



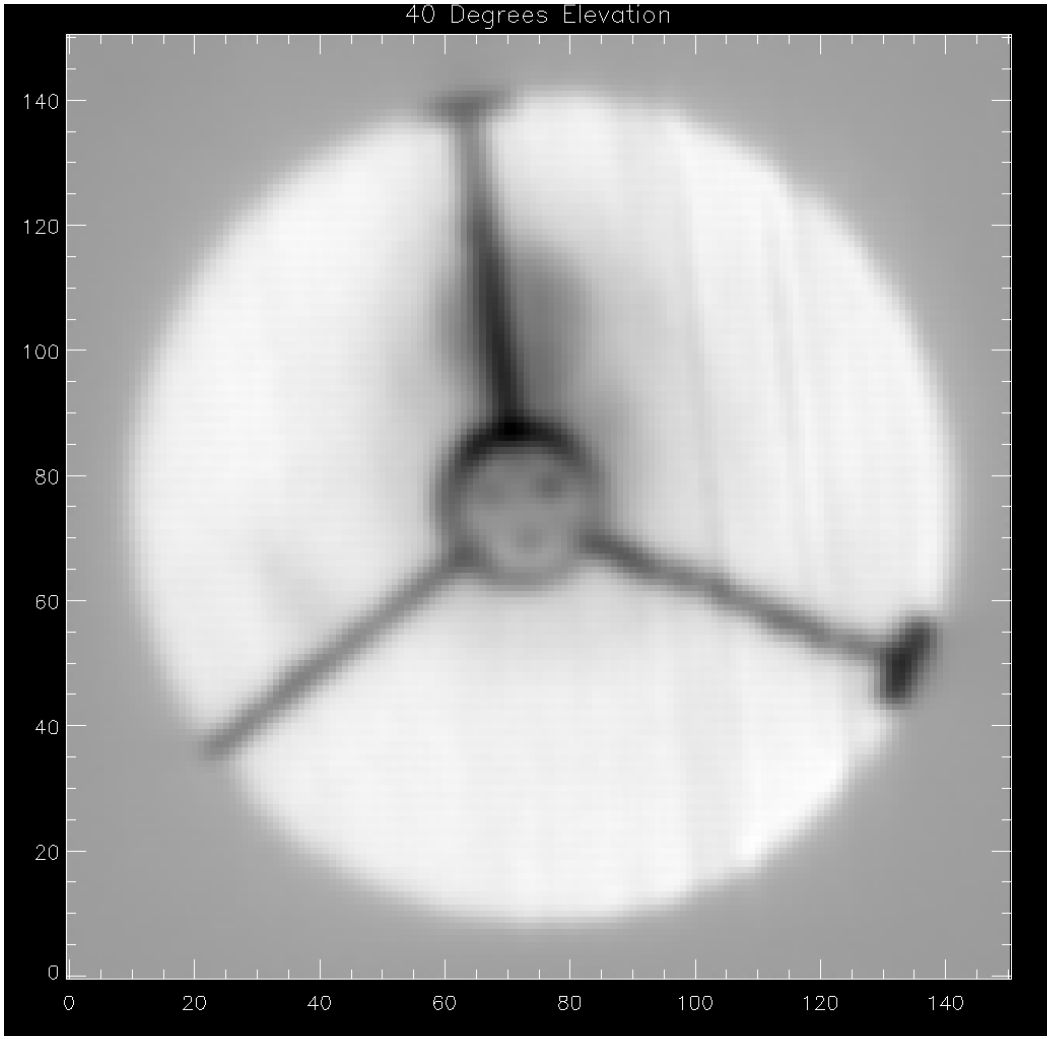


EXES installed

EXES alive



Alignment to telescope



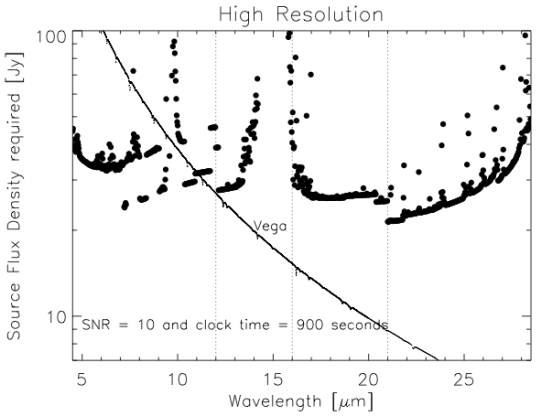
FORCAST Pupil image

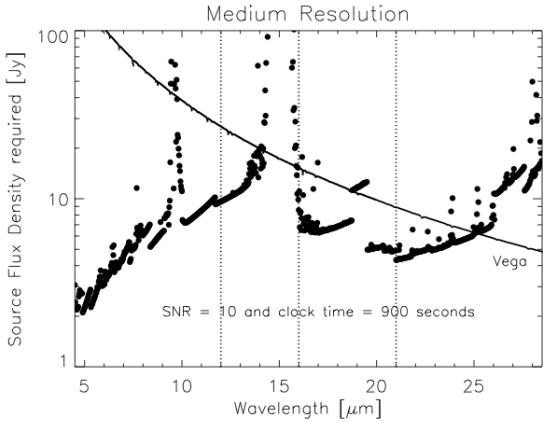
EXES Pupil image

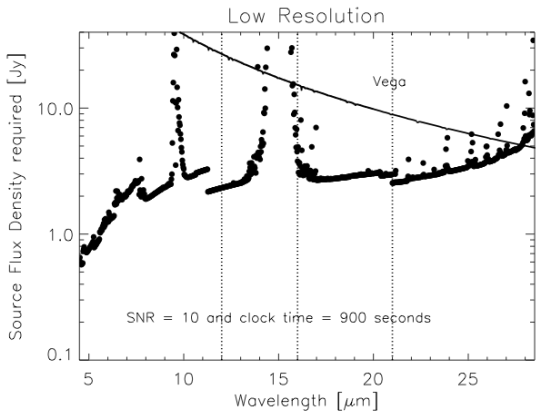
Alignment is good.
Details to be worked out

Sensitivities

- Still to be confirmed. Estimates in Observer's Handbook and Exposure Time Calculator
  - ♦ update expected before SPIE near end of June

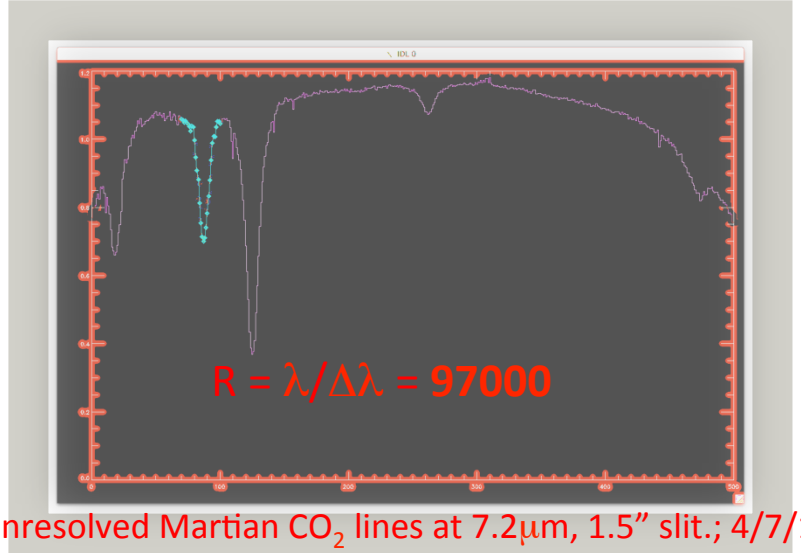




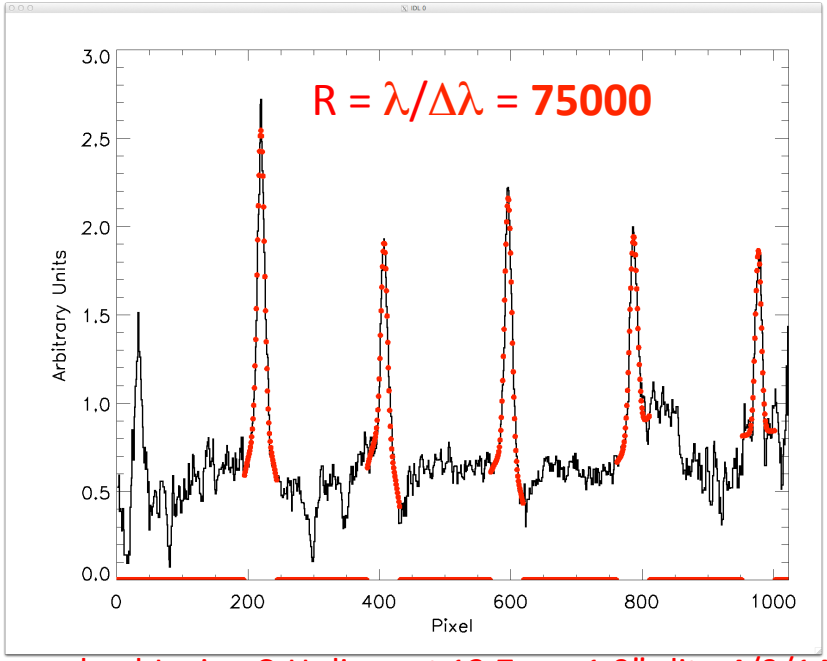


Resolving Power

- Tested using Mars absorption lines, atmospheric emission lines, Jovian emission lines.
- First look indicates
  - ♦ 87% of design for two narrowest slits
  - ♦ 100% of design for widest slit
- Surprising since gas cell before installing looked good. Will have to check

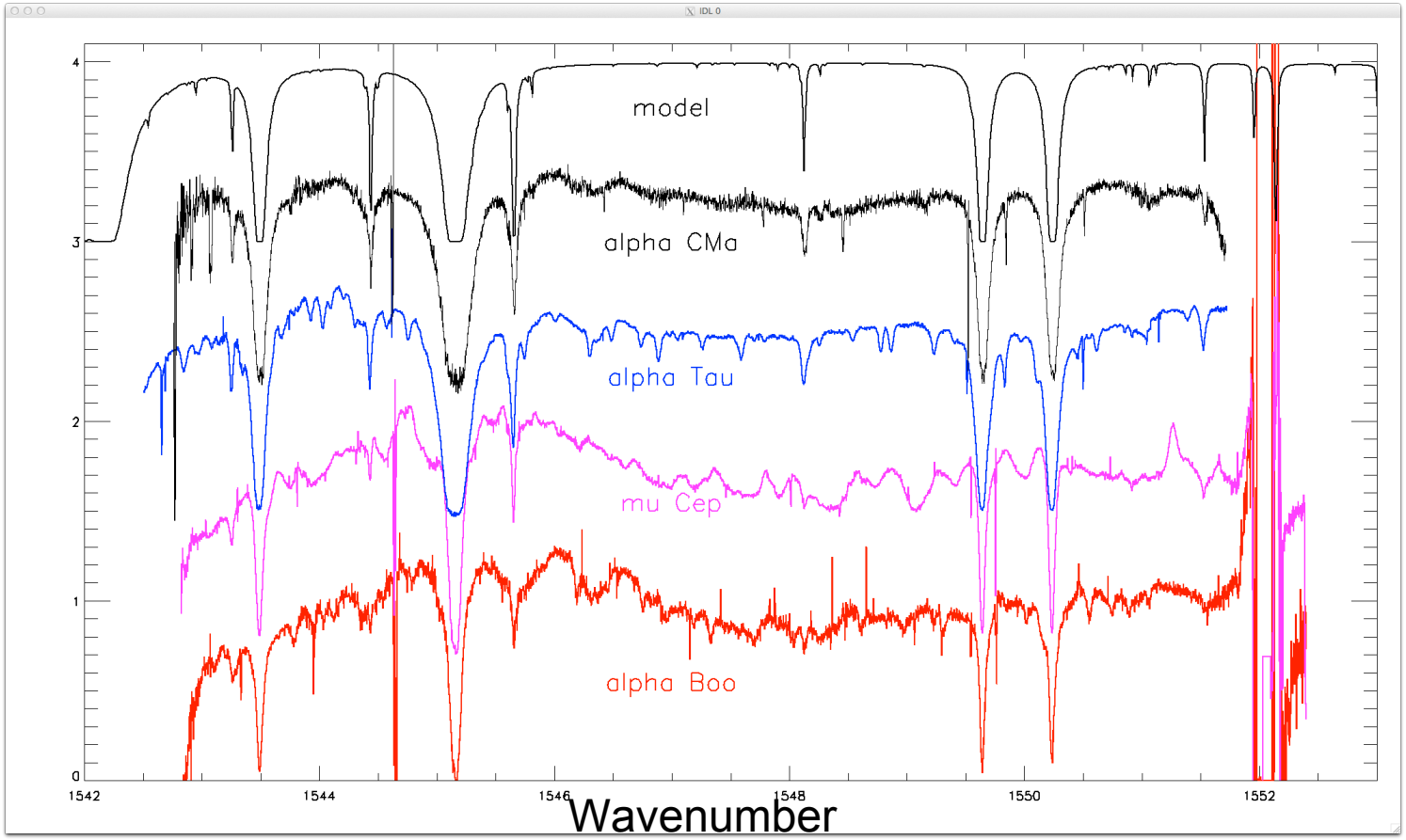


Unresolved Martian CO_2 lines at 7.2μm, 1.5" slit.; 4/7/14



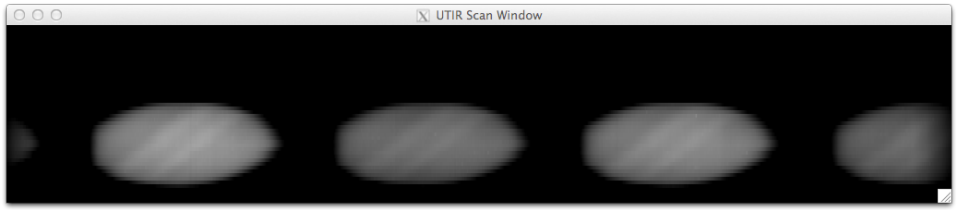
Unresolved Jovian C_2H_2 lines at 13.7μm, 1.9" slit.; 4/9/14

Highlights

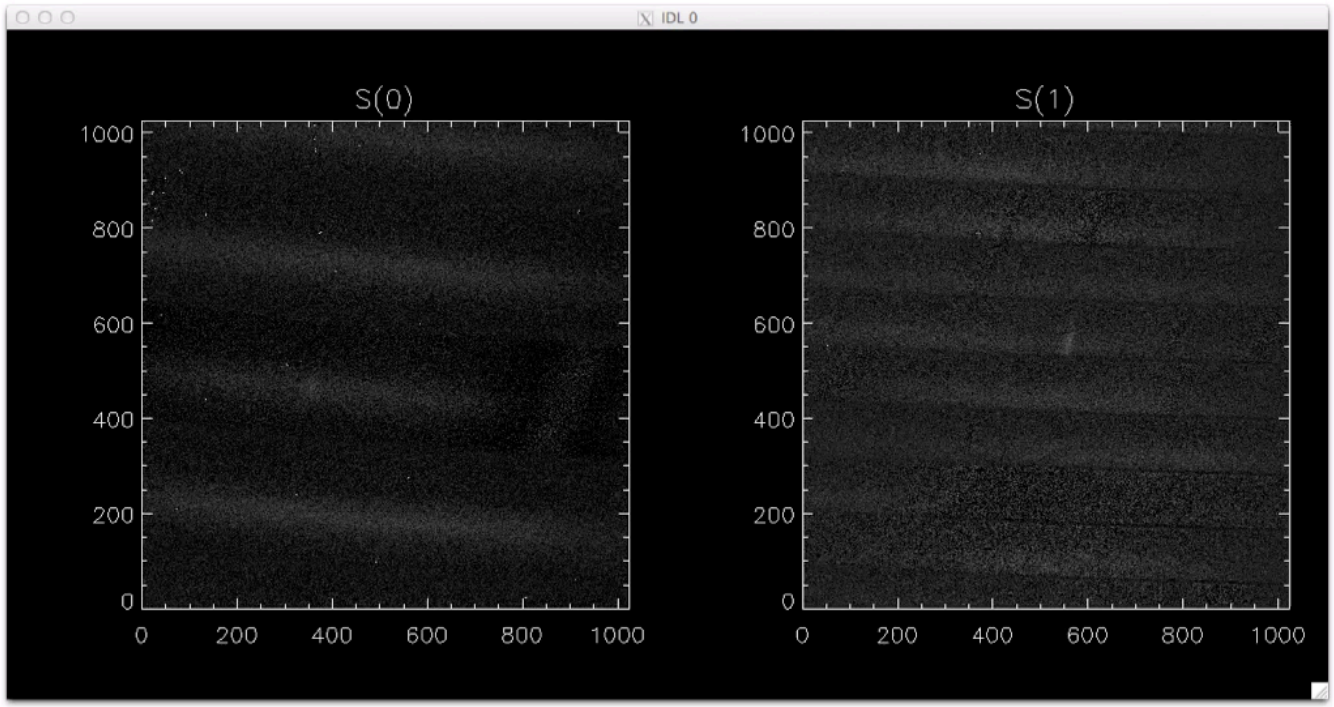


From pipeline: Bill Vacca and Melanie Clarke

Highlights

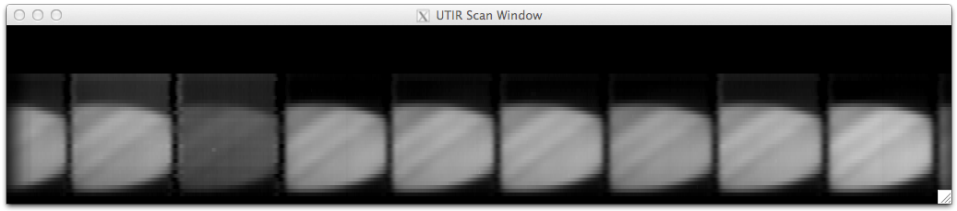


S(0) map from quicklook



Movie showing H_2 emission from Jupiter as slit steps across planet

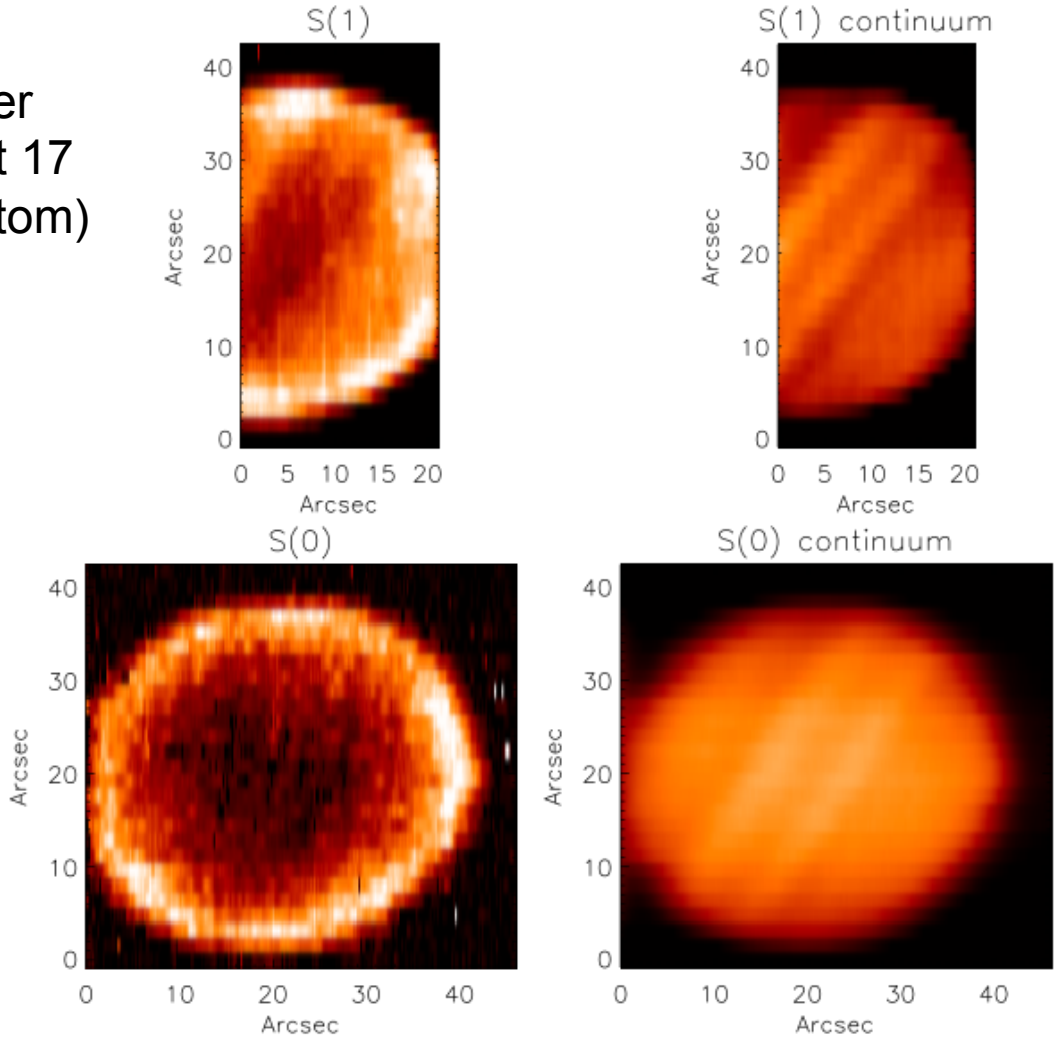
(Note: combines 2 observations)



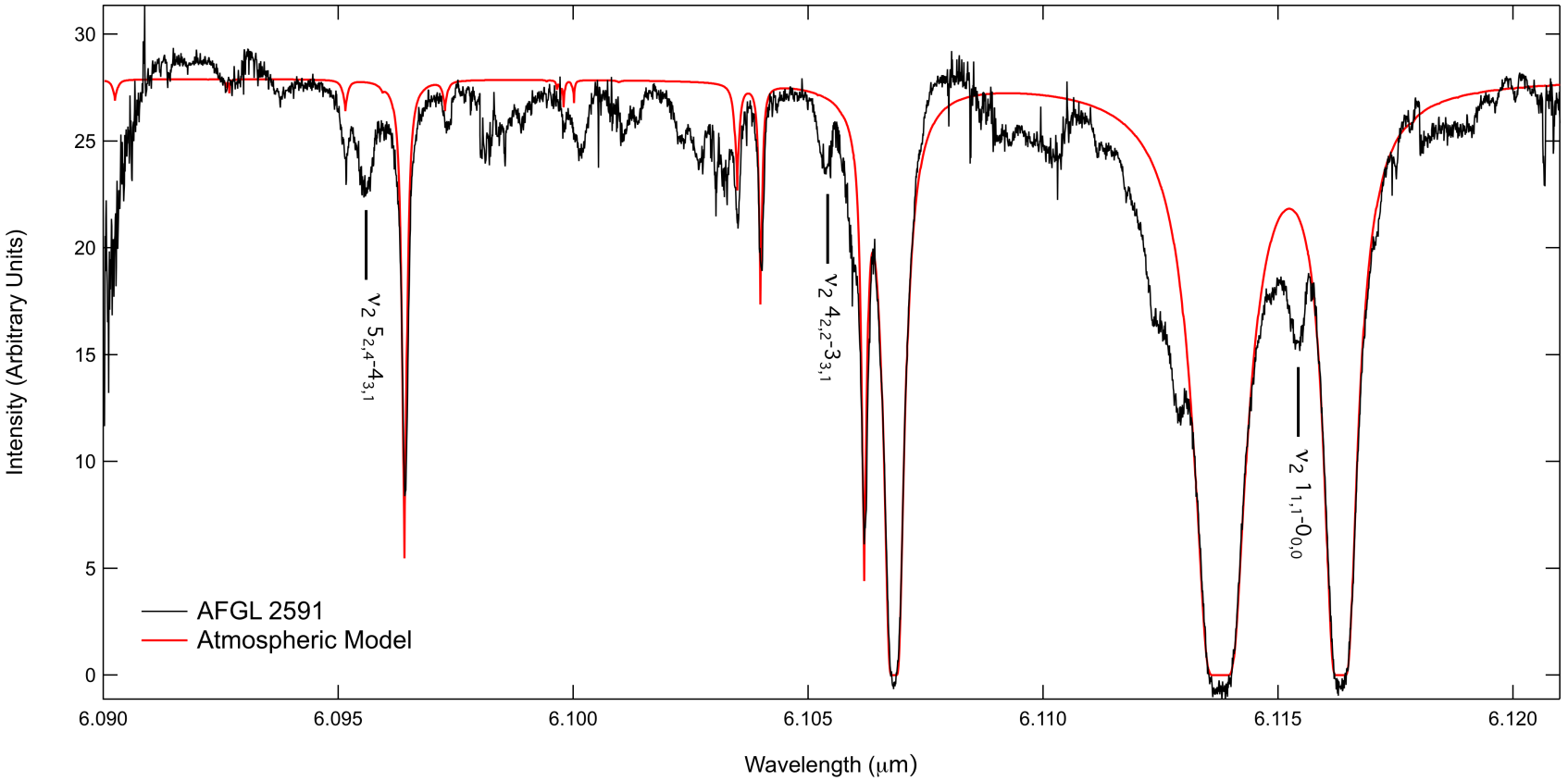
S(1) map from quicklook

Highlights

H_2 maps of Jupiter and continuum at 17 (top) and 28 (bottom) microns



Highlights



H_2O absorption towards AFGL 2591
(Slide courtesy of Nick Indriolo, Johns Hopkins University)

EXES in SOFIA Cycle 3

- Cycle 3 Call for Proposals came out last week
  - ♦ http://www.sofia.usra.edu/Science/proposals/cycle3
  - ♦ Due July 18, 2014
  - ♦ EXES considered shared-risk
    - all modes available - low mode is most uncertain
- Proposal Guidelines
  - ♦ EXES available to entire community (open-skies)
  - ♦ EXES is PI-class, not a facility instrument
  - ♦ 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
- TEXES on Gemini/IRTF
  - ♦ Use for wavelengths that do not need SOFIA (>40% transmission from ground)
  - ♦ Same general guidelines as EXES

Further information

- 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
- http://irastro.physics.ucdavis.edu/exes
  - website still work in progress
  - EXES exposure time calculator:
    http://irastro.physics.ucdavis.edu/exes/etc
- For TEXES on Gemini/IRTF
  - John Lacy (PI): lacy@astro.as.utexas.edu
  - Tommy Greathouse (solar system): tgreathouse@swri.edu
  - Matt Richter (Galactic): mjrichter@ucdavis.edu