Probing the inner protoplanetary disk physics and chemistry with the E-ELT

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Physique et **C**himie du **M**illieu **I**nterstellaire

CNRS INSU Observer & comprendre

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DiscAnalysis DIANA

SEVENTH FRAMEWORK PROGRAMME

Questions that could be answered using E-ELT observations

- What is the gas and solid(ices) composition of the inner disk material (where the telluric planets form)?
  - What kind of chemistry occurs there?
- What is the structure of the inner gas/dust disk?
- What is the interplay between disk accretion/ ejection/evolution?

Disk gas line emissions

Gas lines in emission (1-5 micron) probe <20-30AU

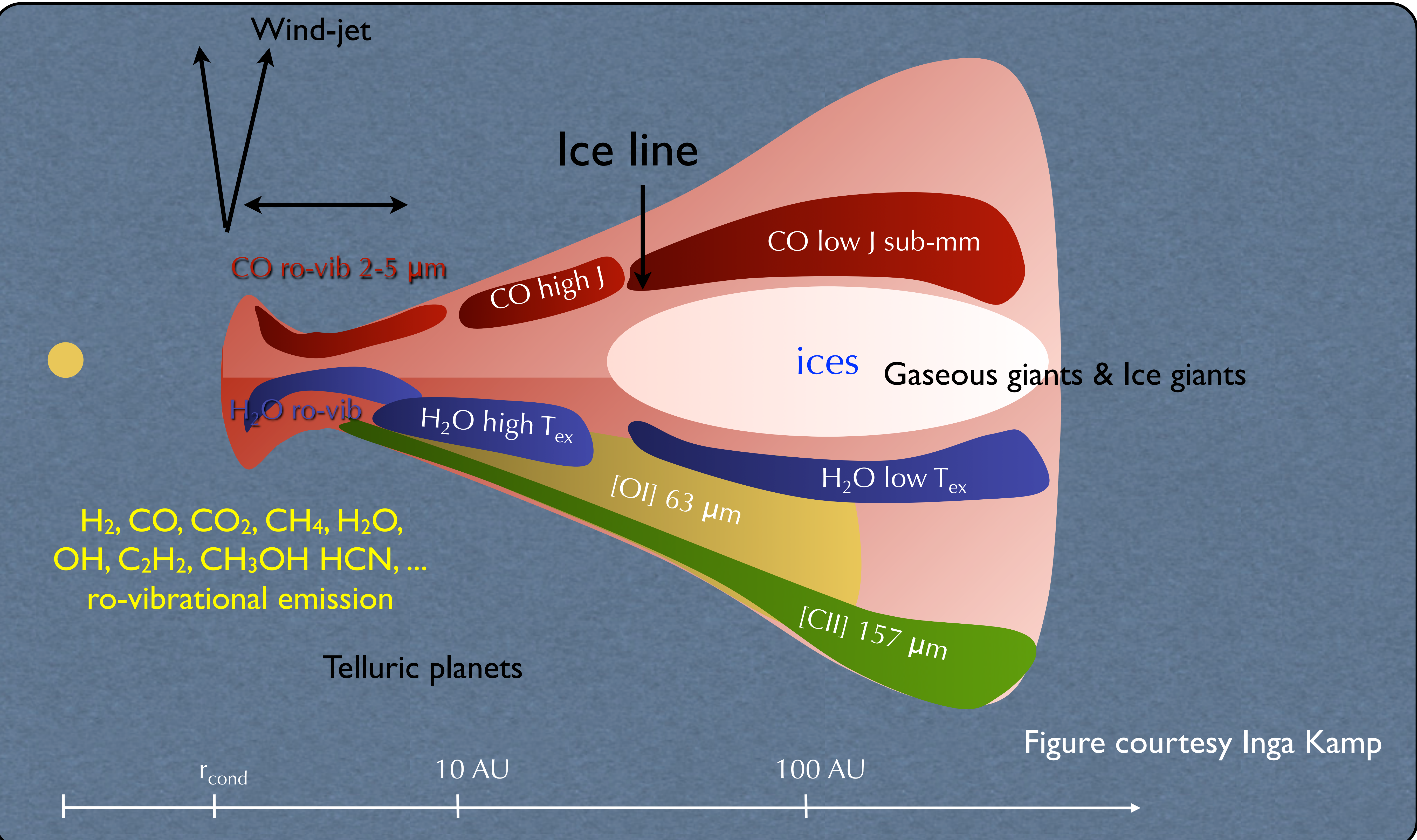
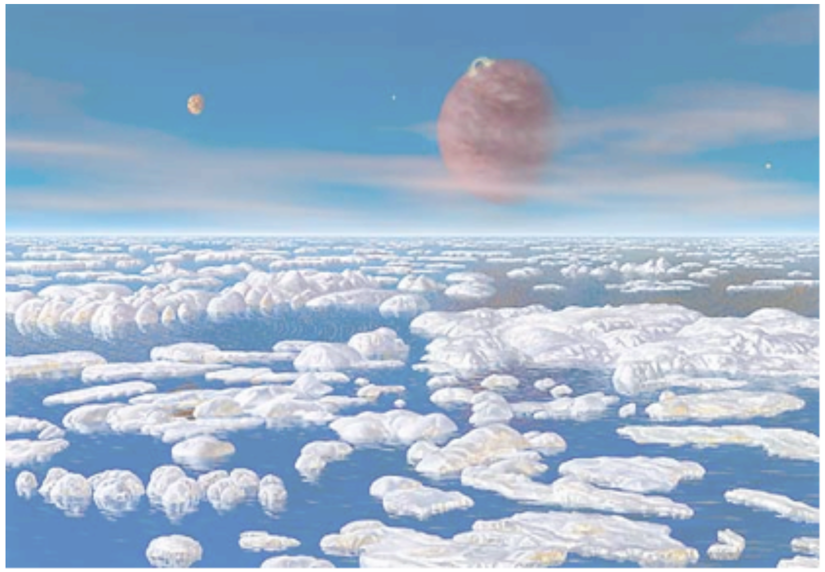
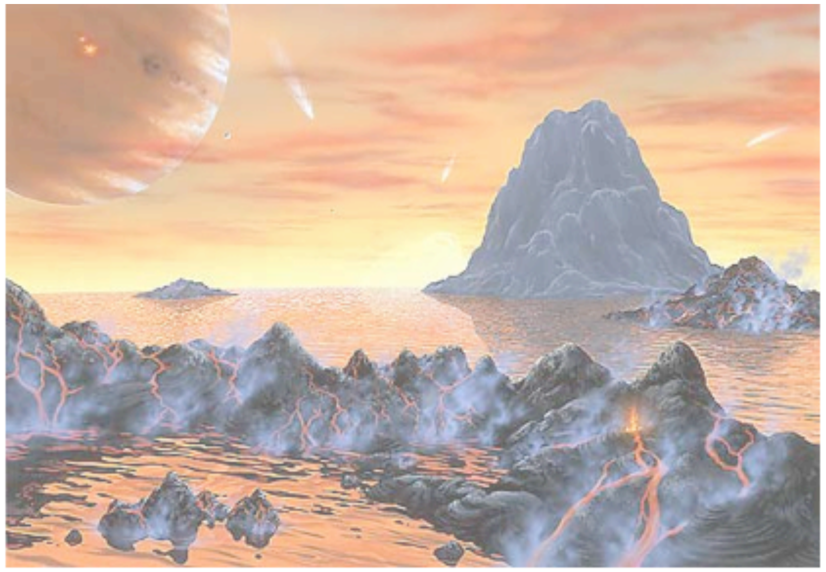


Figure courtesy Inga Kamp

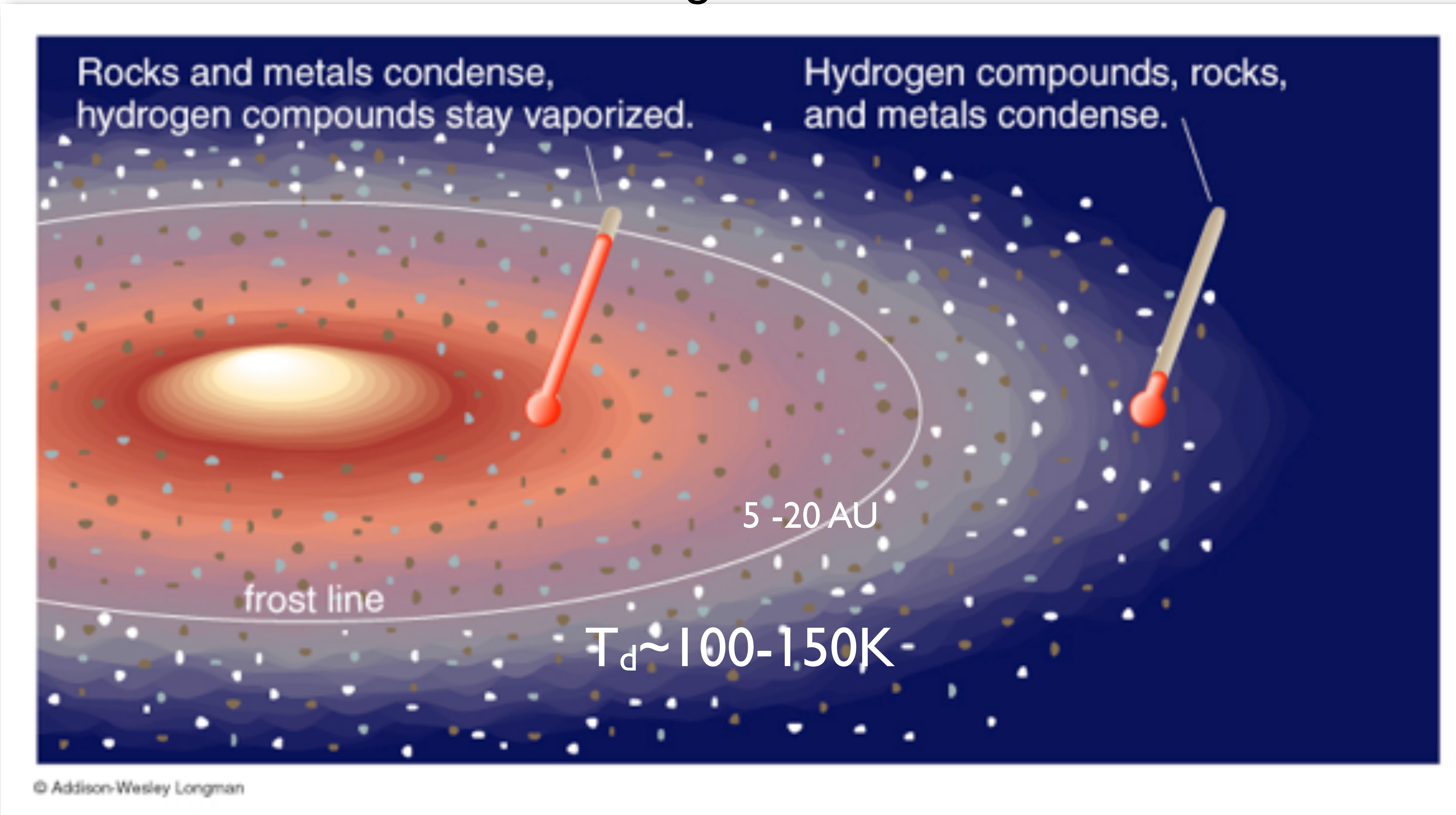
Water: one of the most interesting molecules

- How much water is in discs?
- What is the main reservoir of water in discs? Ice or vapour?
- Where is the cold/warm/hot water located? (core-collapse planet formation theory requires icy grains to work efficiently)





The *Snow/Ice line* is located at the distance from the Sun where the dust *T* is low enough for water ice to condense



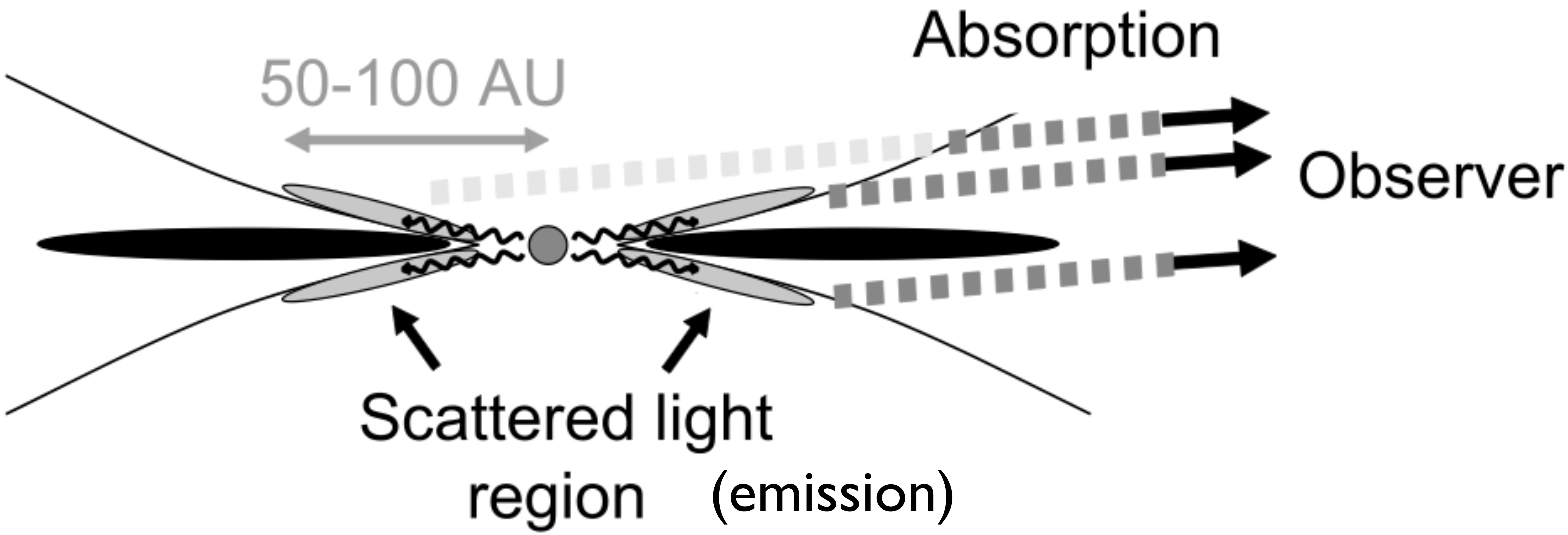
Icy grains stick more easily to each other than silicate grains: faster grain growth

Current state-of-the-art observations: water ice observed in edge-on disks with Subaru

- Water ice is the main ice component of grains outside the freeze-out zone: important for the coagulation of grains
- Absorption studies only possible for (almost) edge-on disks
- near-IR fluxes are lower than face-on disks
- A handful of cases with 8-m telescopes

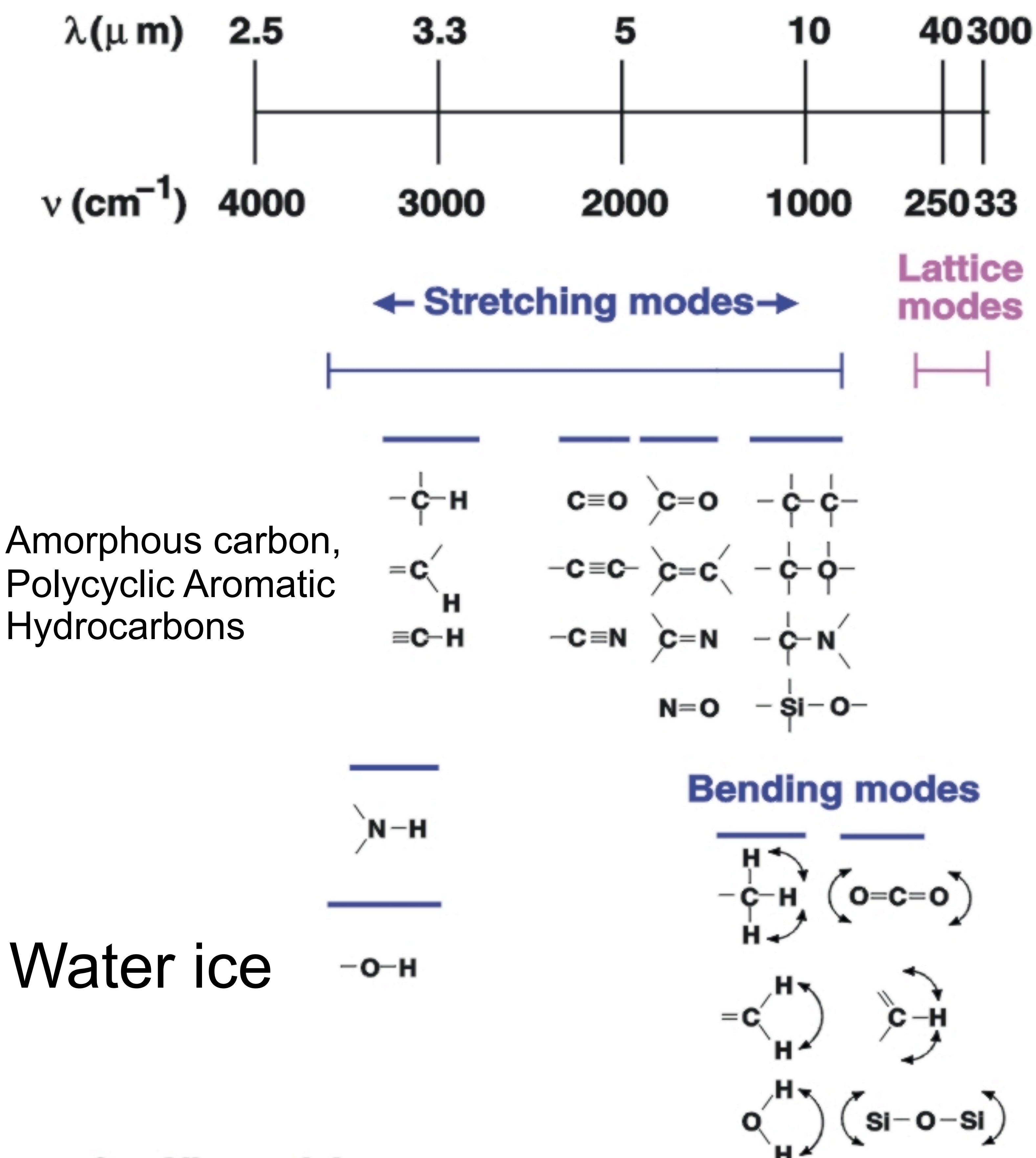
Water ice

- Inner hot dust grains (and cold gas) act as "background" source against which the ices can absorb



Terada & Tokunaga 2012, ApJ 753, 19

Molecular Vibrations in the Infrared

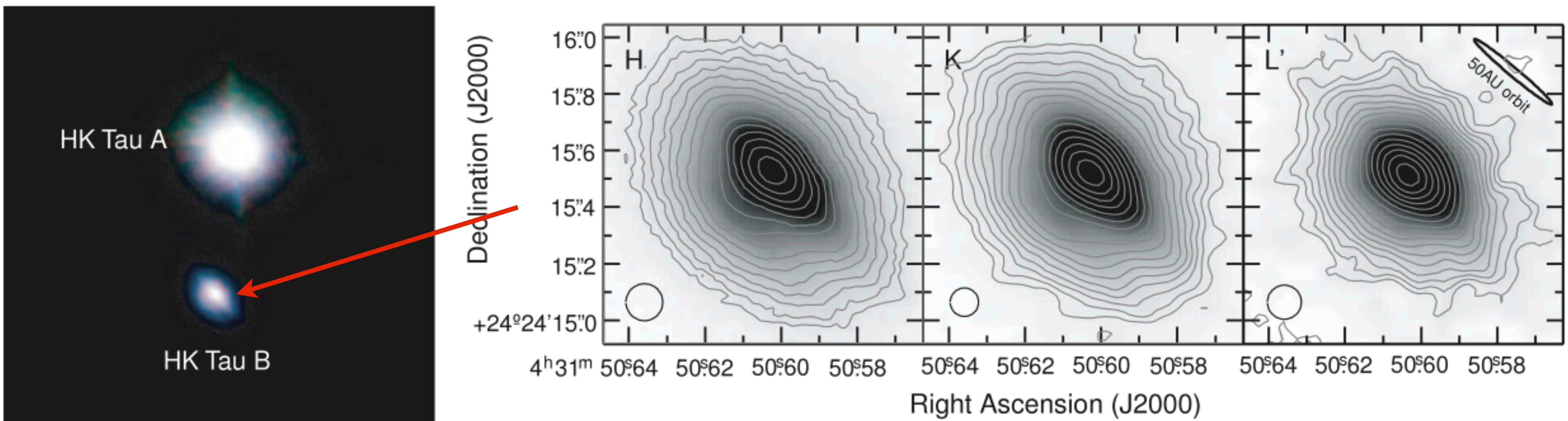


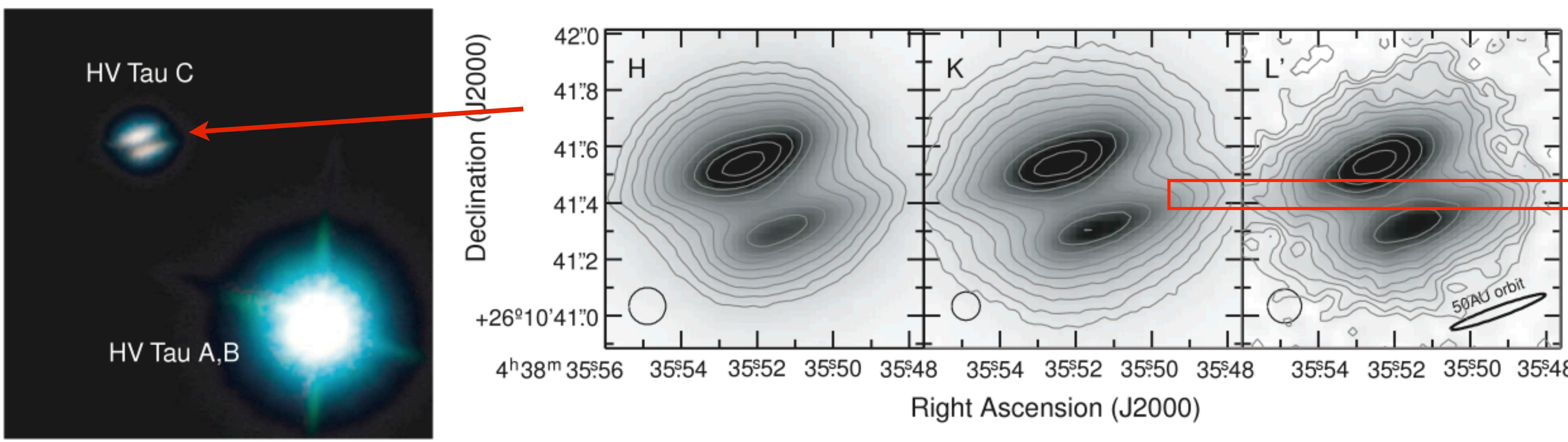
after Allamandola

- Stetching & bending modes occur in both amorphous and crystalline solids
- Lattice modes exist only in crystalline solids

Example: HK TauB & HV Tau c edge-on disks

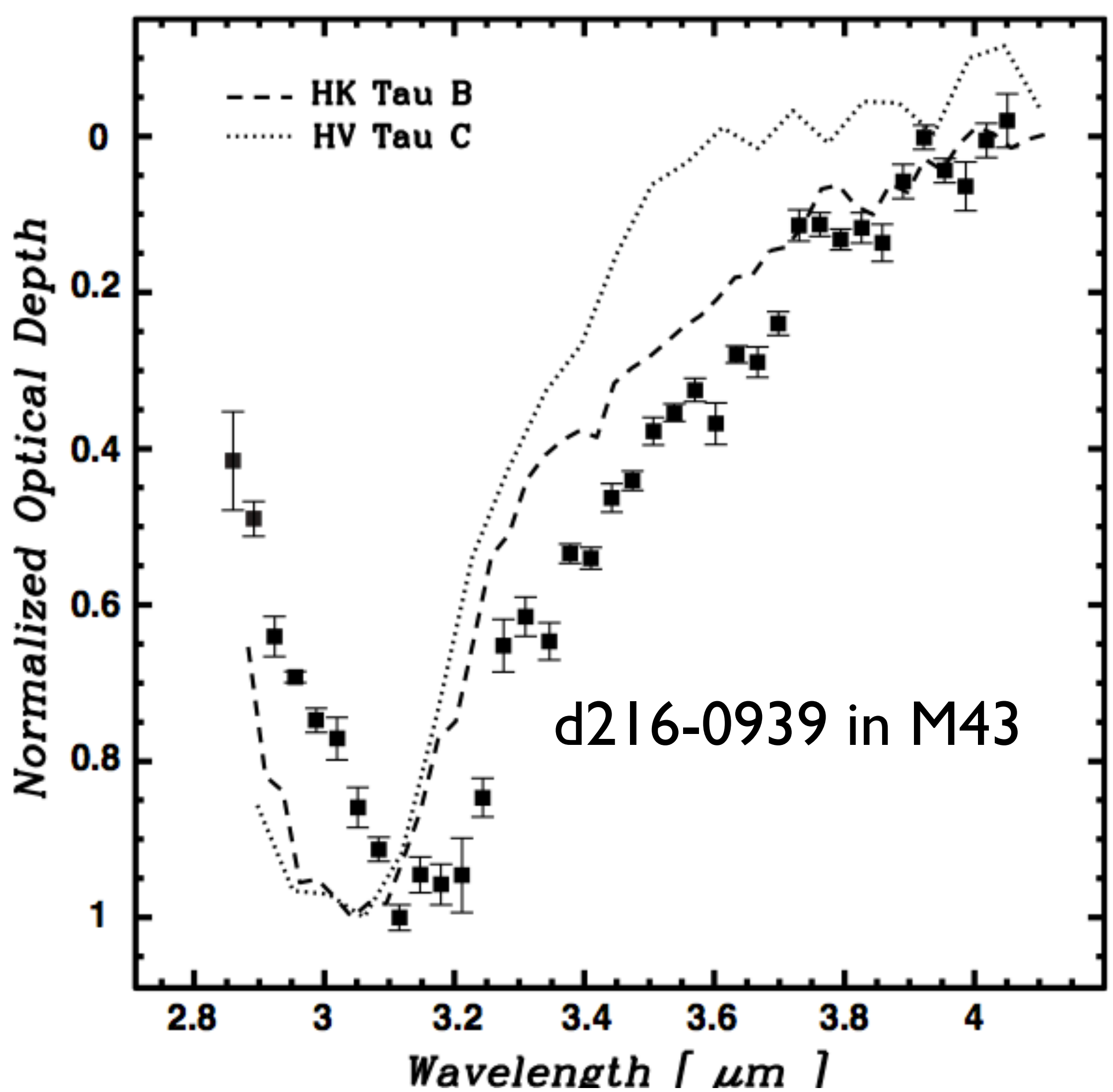
Terada et al. 2007, ApJ 667,303

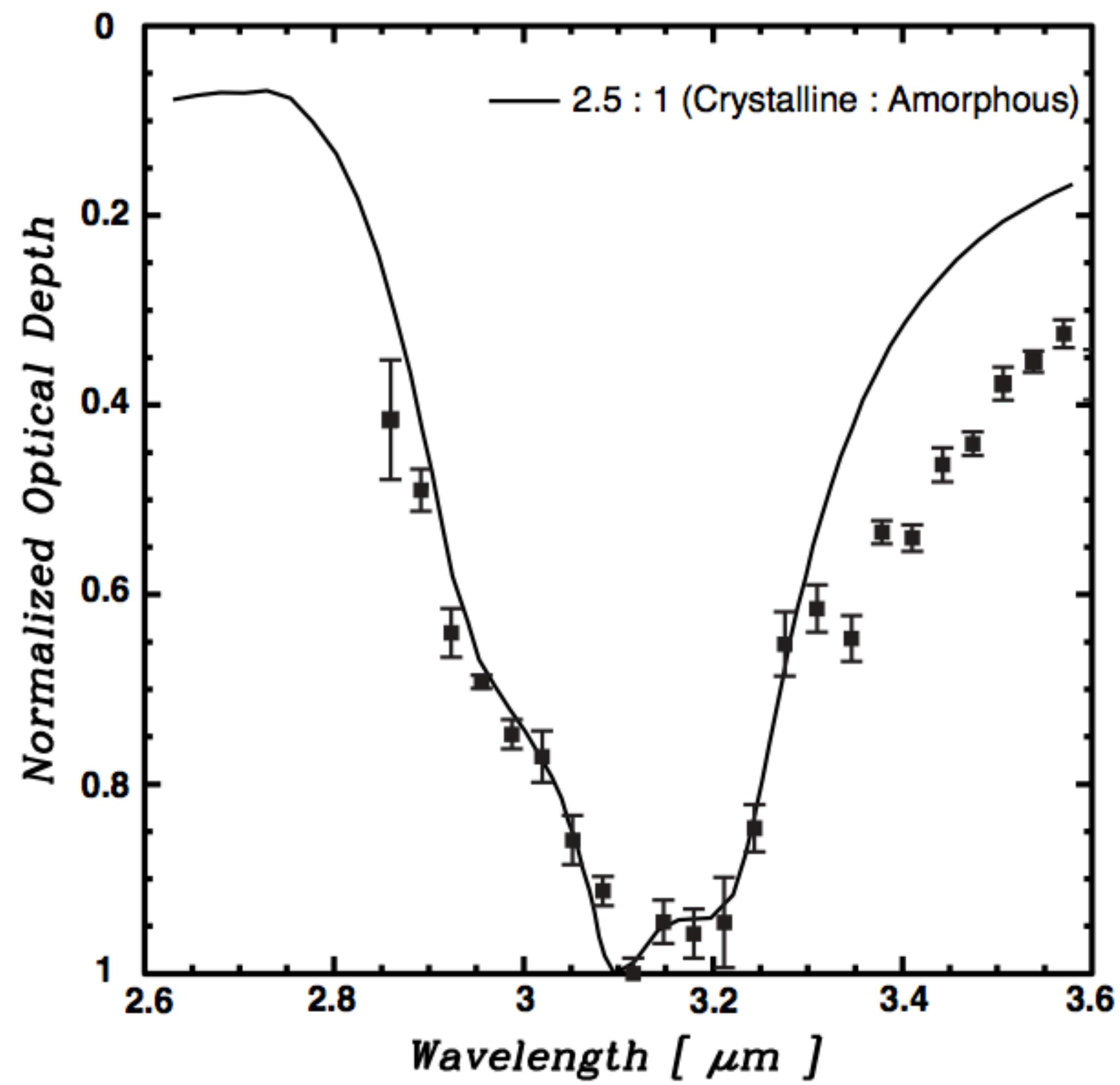


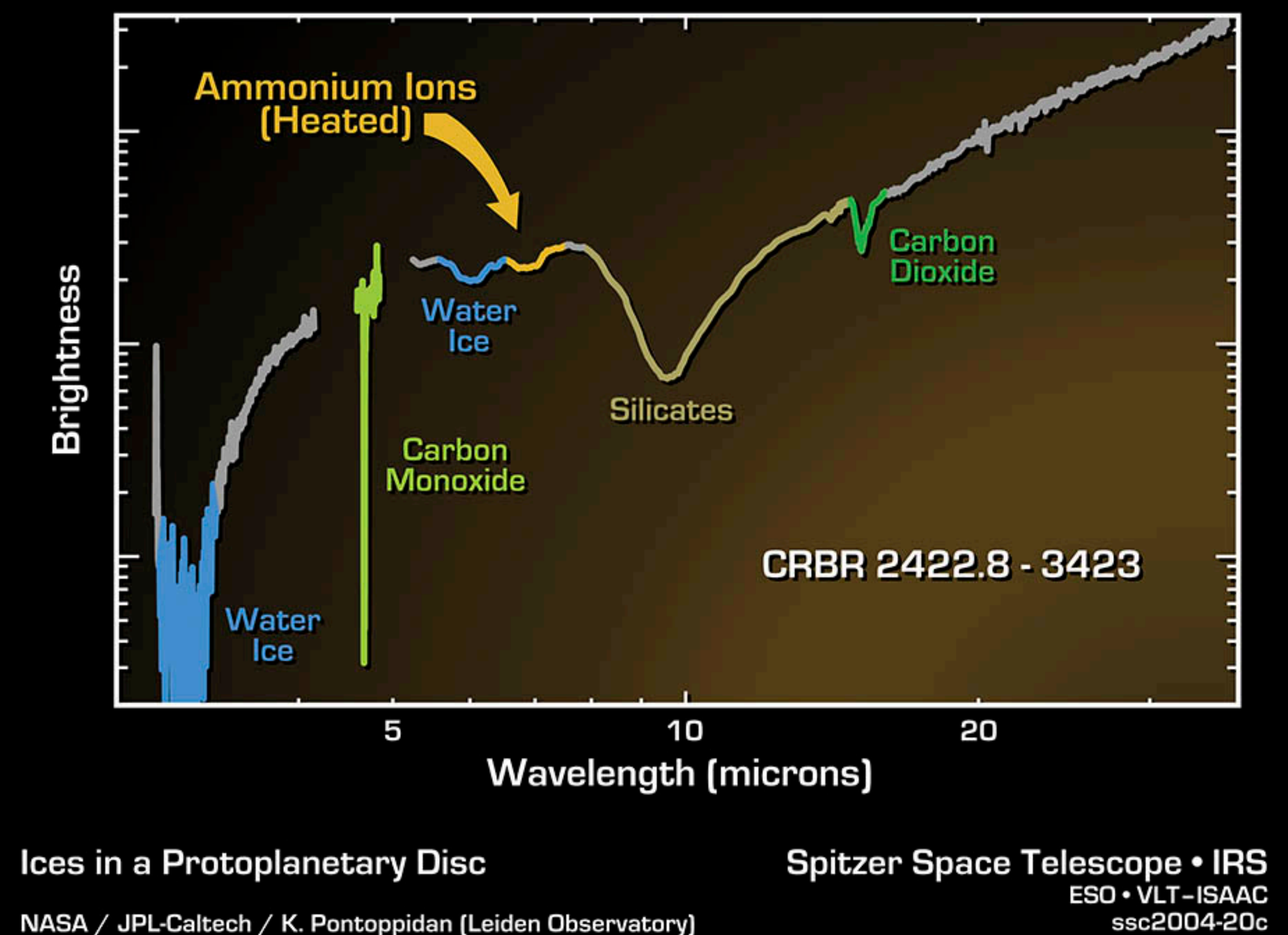


Ice spectroscopy gives an idea on the composition and origin of the ices

- Amorphous ice: remnant from envelope (unprocessed)
- Crystalline ice: the ice has been heated?





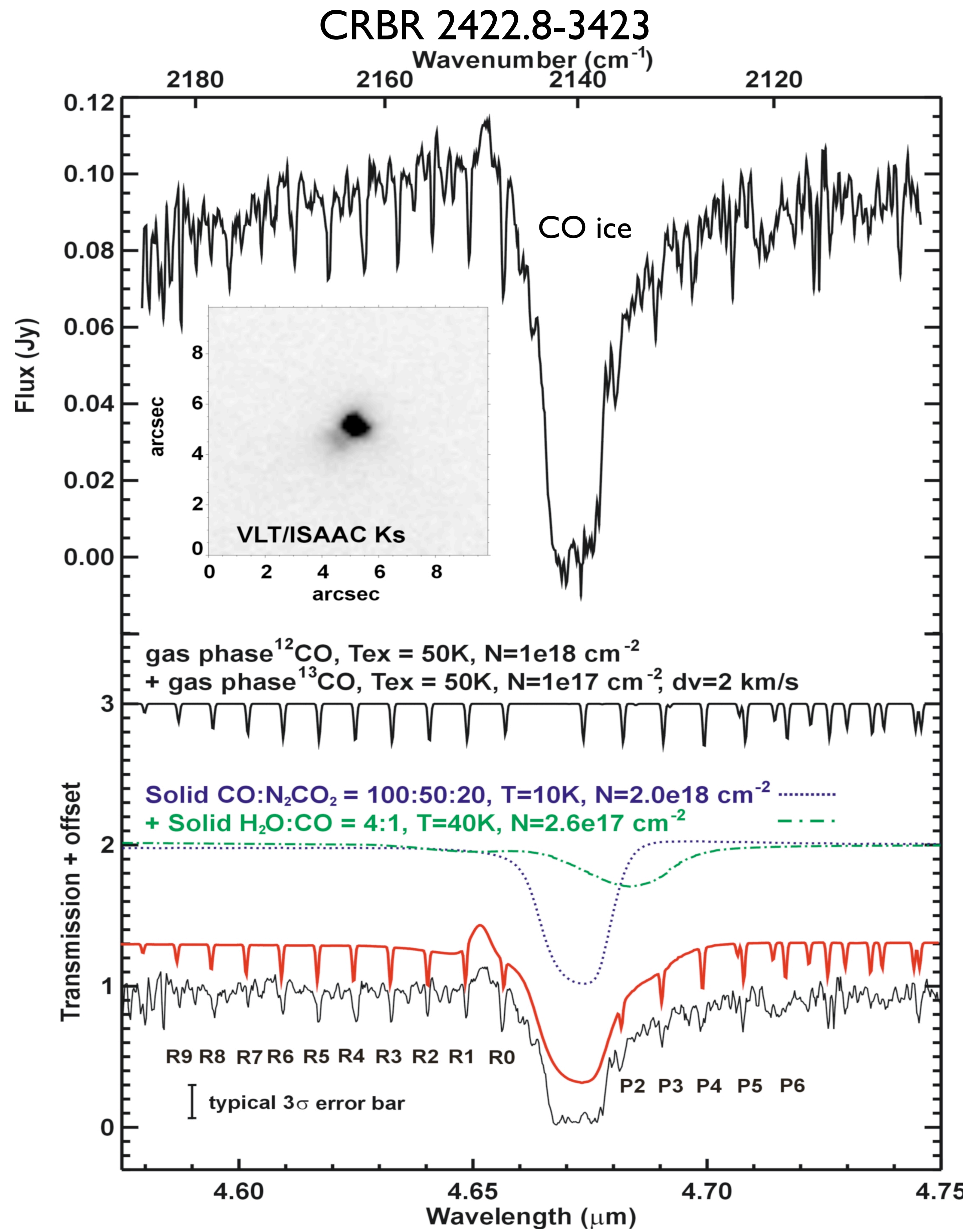


Pontoppidan et al. 2006

CO gas & ice in absorption

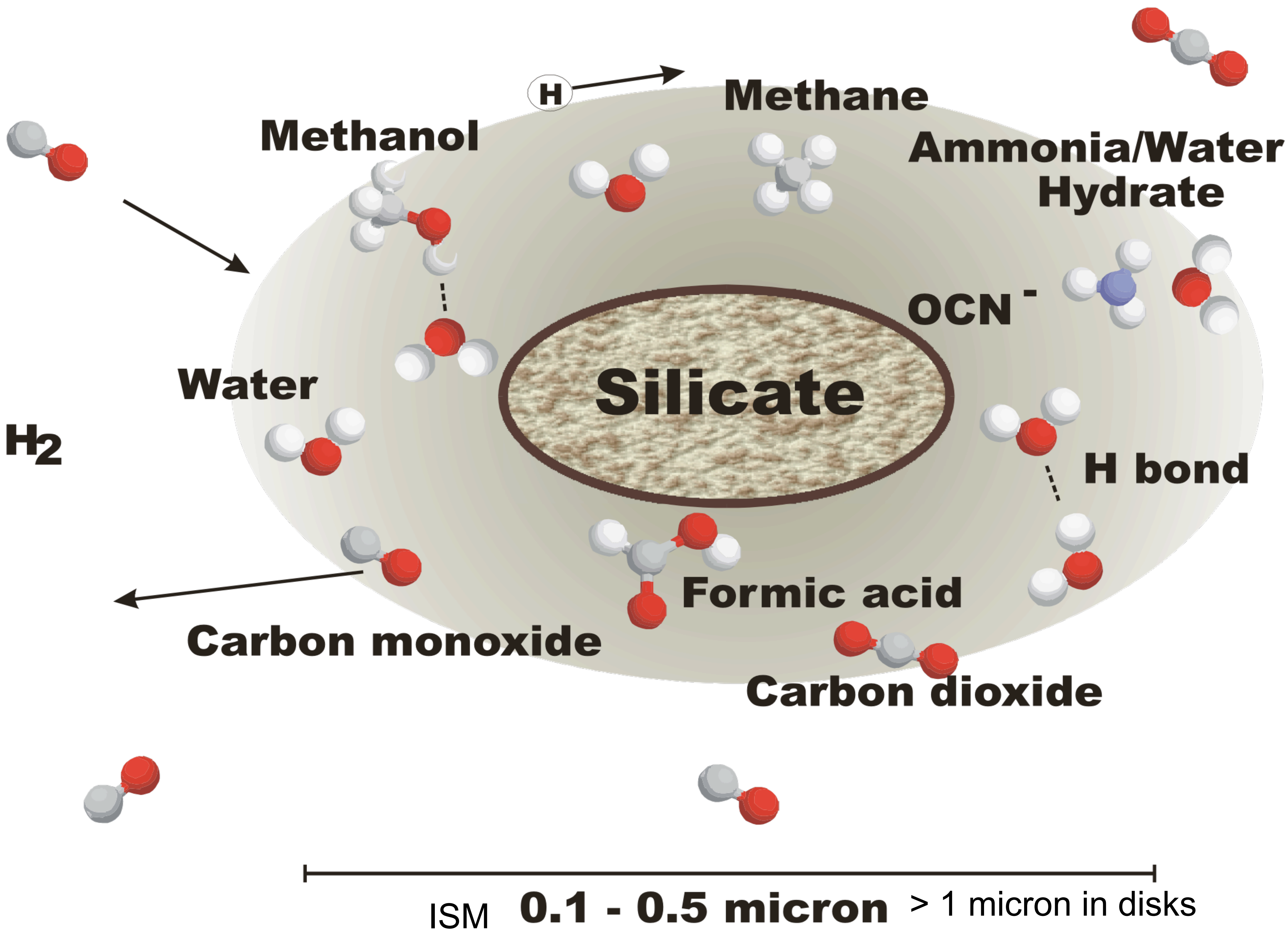
VLT-ISAAC R=10,000, t=36 min, S/N~20 (continuum)

N(CO ice)/N(gas)~1



Thi et al. 2002, A&A 394, L27; Pontoppidan et al. 2005, ApJ 622, 463

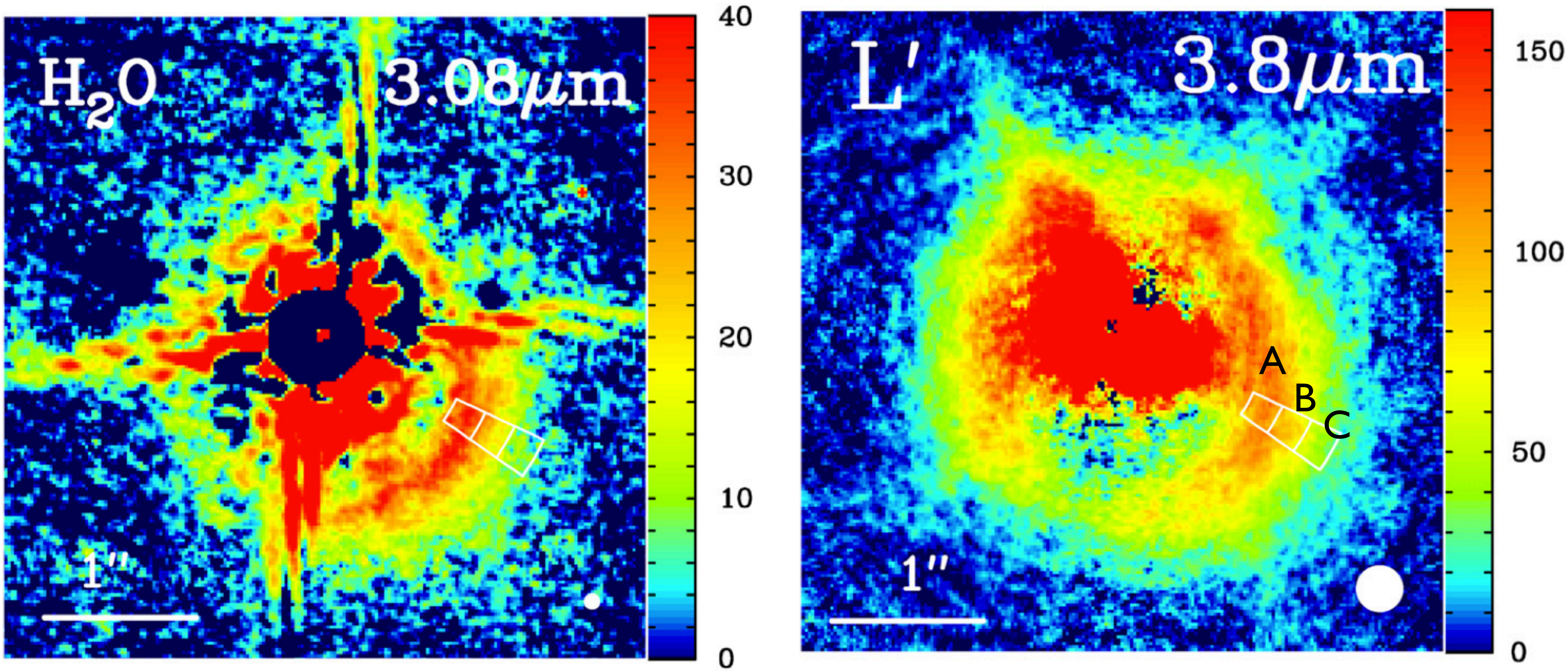
Relations between disk and cometary ices



Ice observation in "face-on" disks: use of narrow band filters

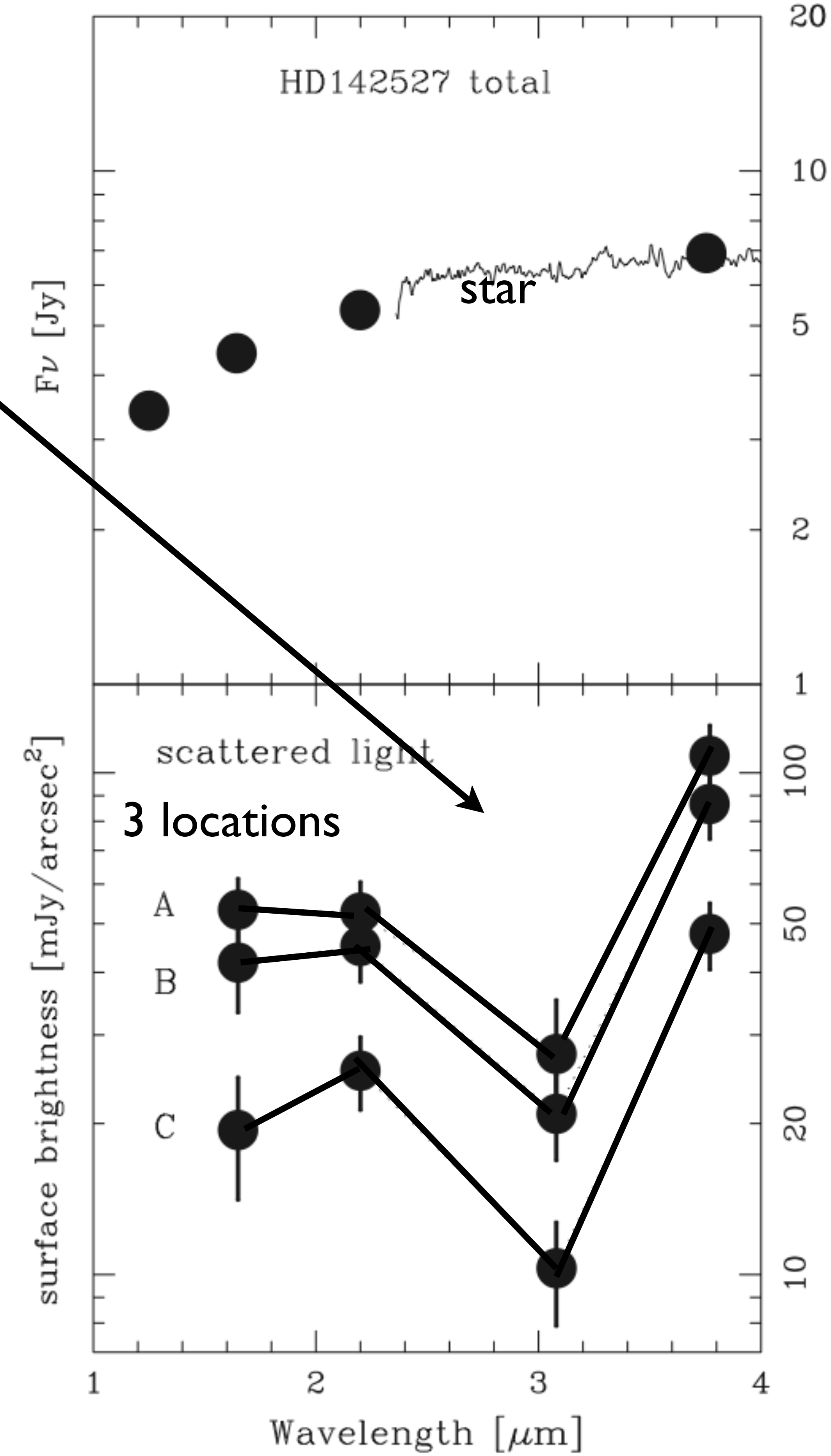
- Narrow-band filter around the water ice feature

- HD 142527 with Subaru



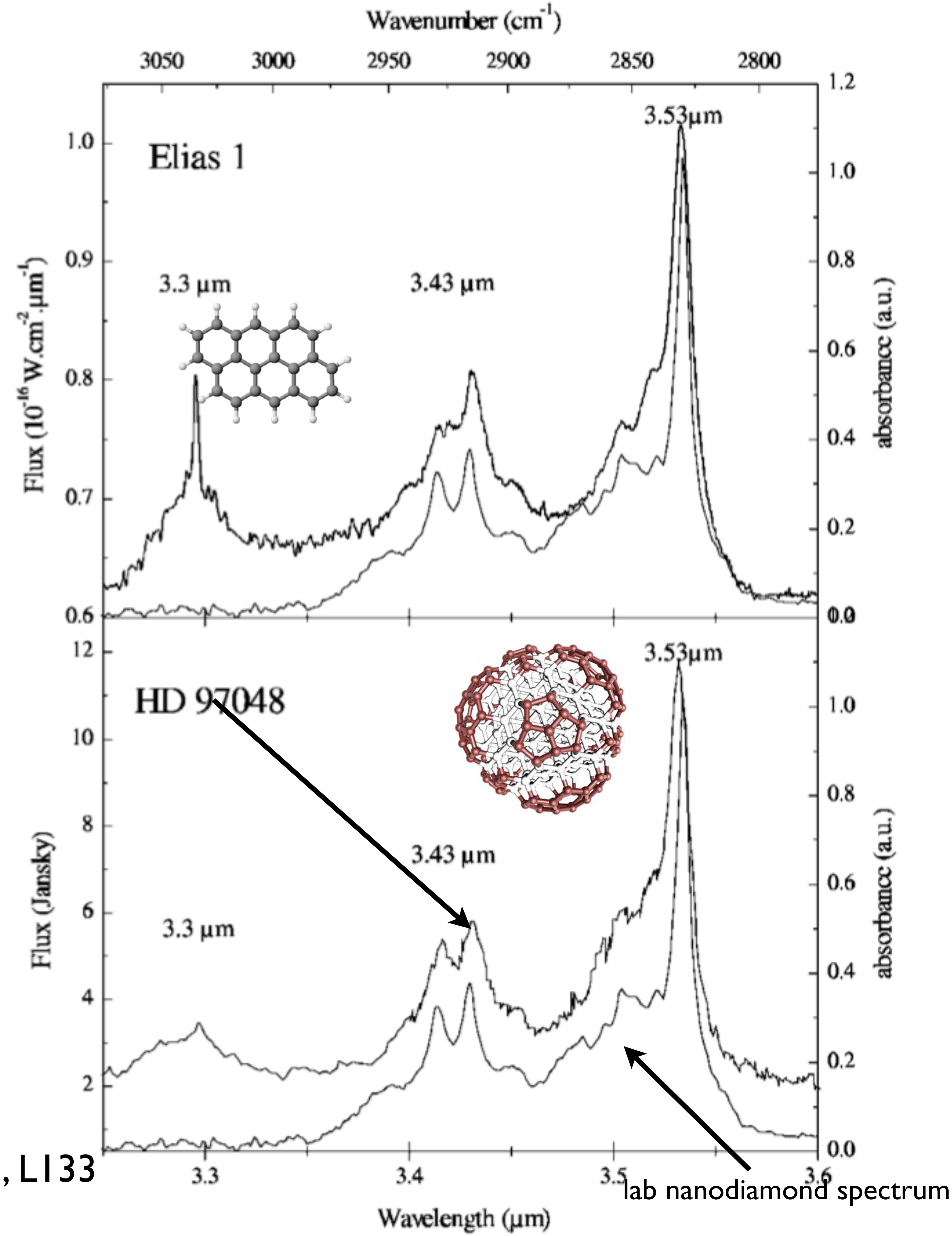
Honda et al. 2009, ApJ, 690, 119

- less scattered-light in the narrow-band
- Advantage:
  - no need to have the disk seen edge-on
  - can determine the size of the ice-emitting area and non-axisymmetric emissions
- Disadvantage: no actual spectra are taken (narrow-band filters)
- With E-ELT, could we detect the ice line? IFU can give spatial and spectral information



Nanodiamonds detected in two HerbigAe disks

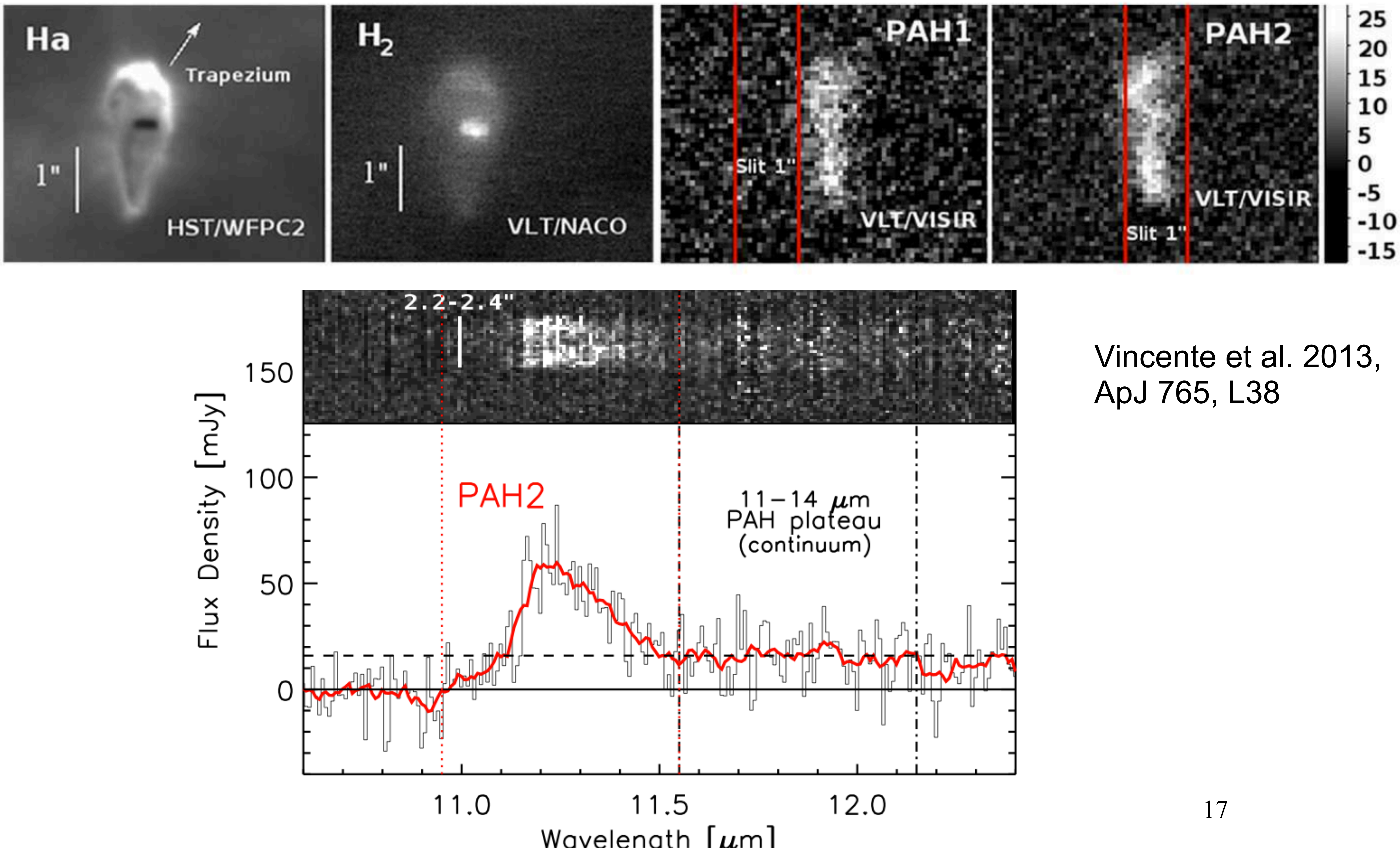
- Polycyclic Aromatic Hydrocarbons (PAHs) seen in many disks around HerbigAe
- No PAHs detected from TTauri disks (not enough UV photons to excite them)



Guillois 1999, ApJ 521, L133

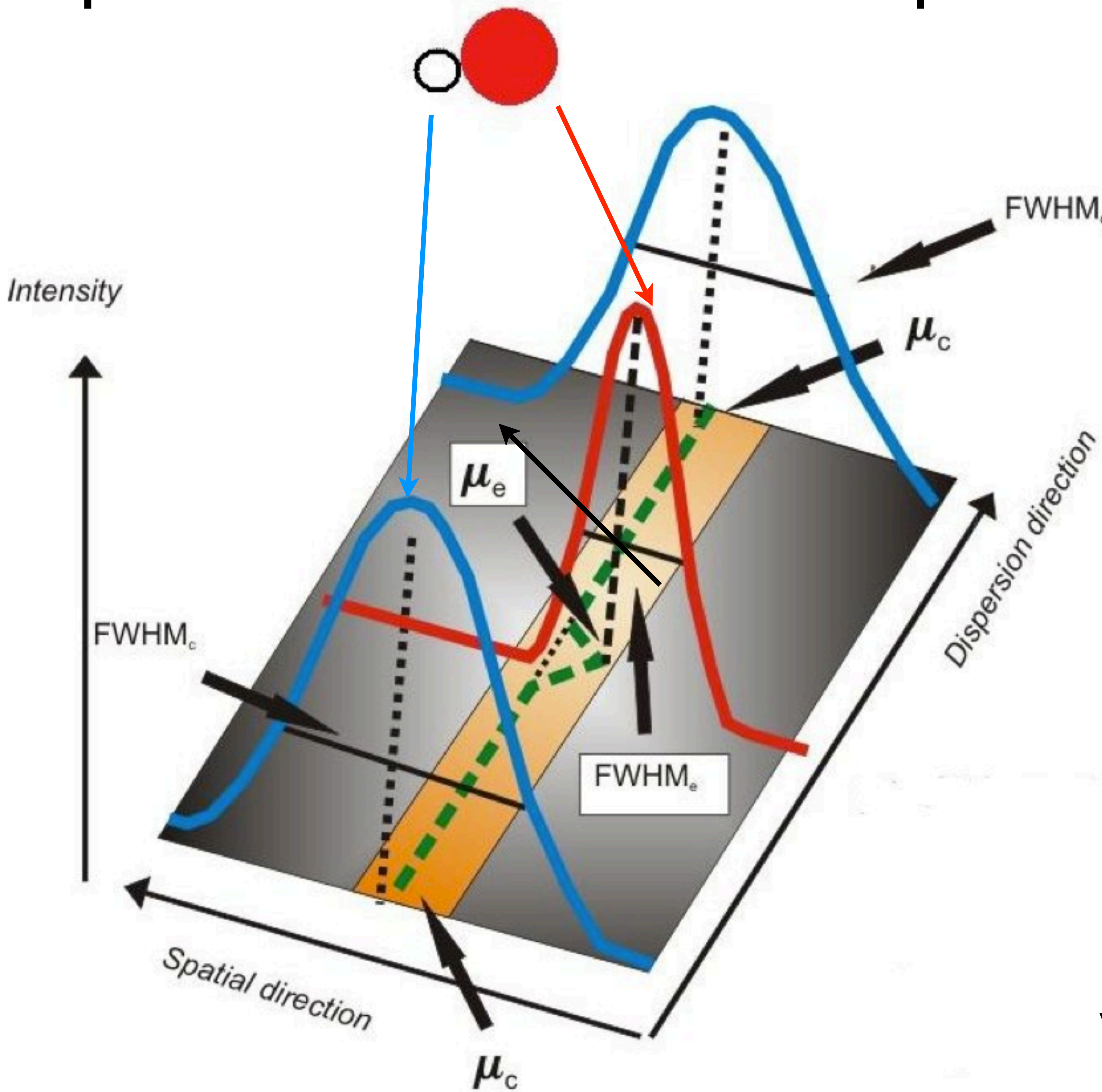
PAHs in disks illuminated by external OB stars

PAHs in the evaporating disk



Vincente et al. 2013, ApJ 765, L38

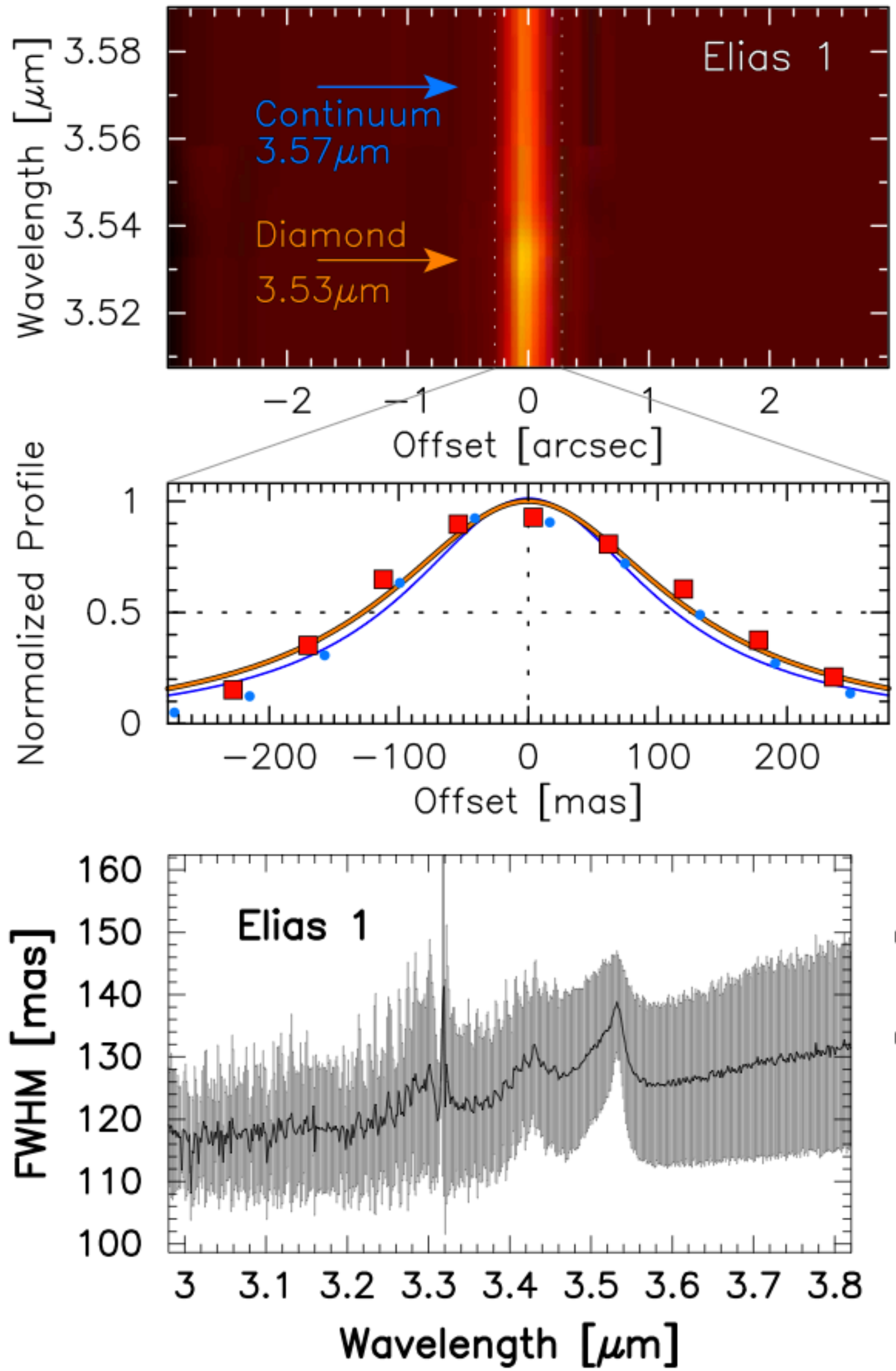
Spectro-astrometric technique



Wheelwright

Spectro-astrometric observations

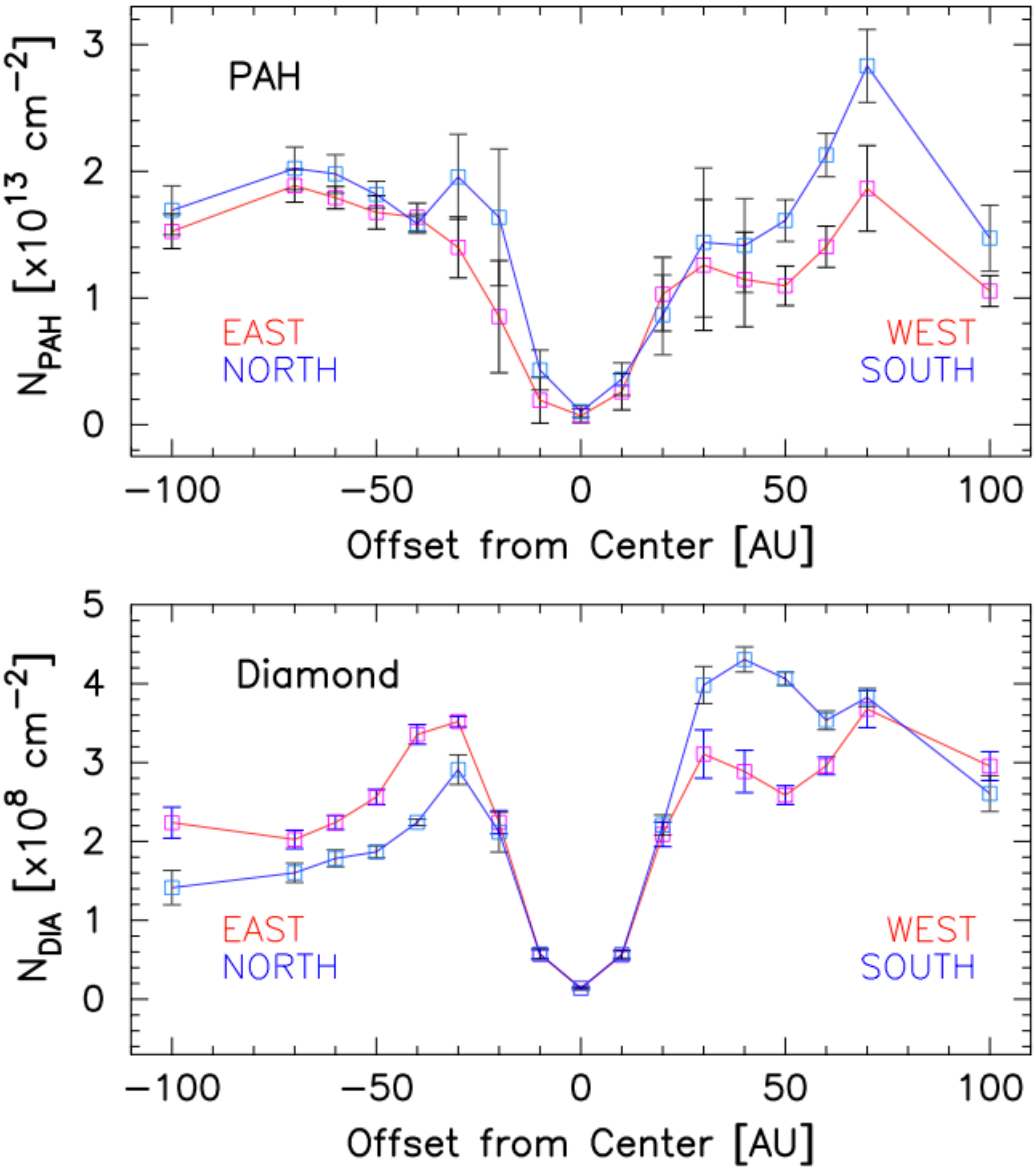
- Diamond emission is shifted compared to the continuum emission
- 50 mas "resolution"



Goto 2009, ApJ 693, 610

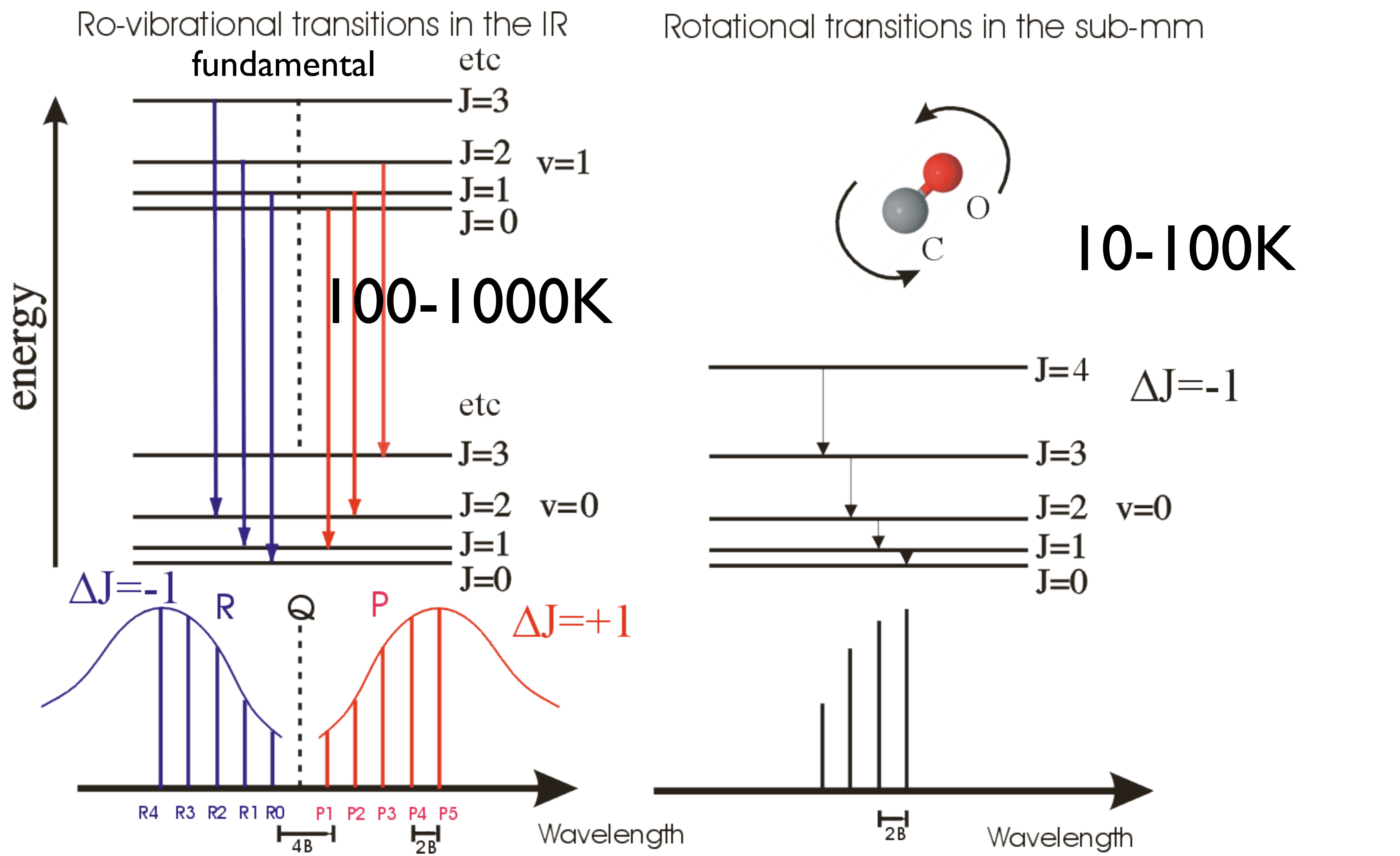
Spatially-resolved spectra

- PAHs and Nanodiamonds do not have the same spatial variations
- Spatial information in one-direction only
- Need to detect the features in more objects!



Goto 2009, ApJ 693, 610
(see also Habart et al. 2004)

CO ro-vibrational lines



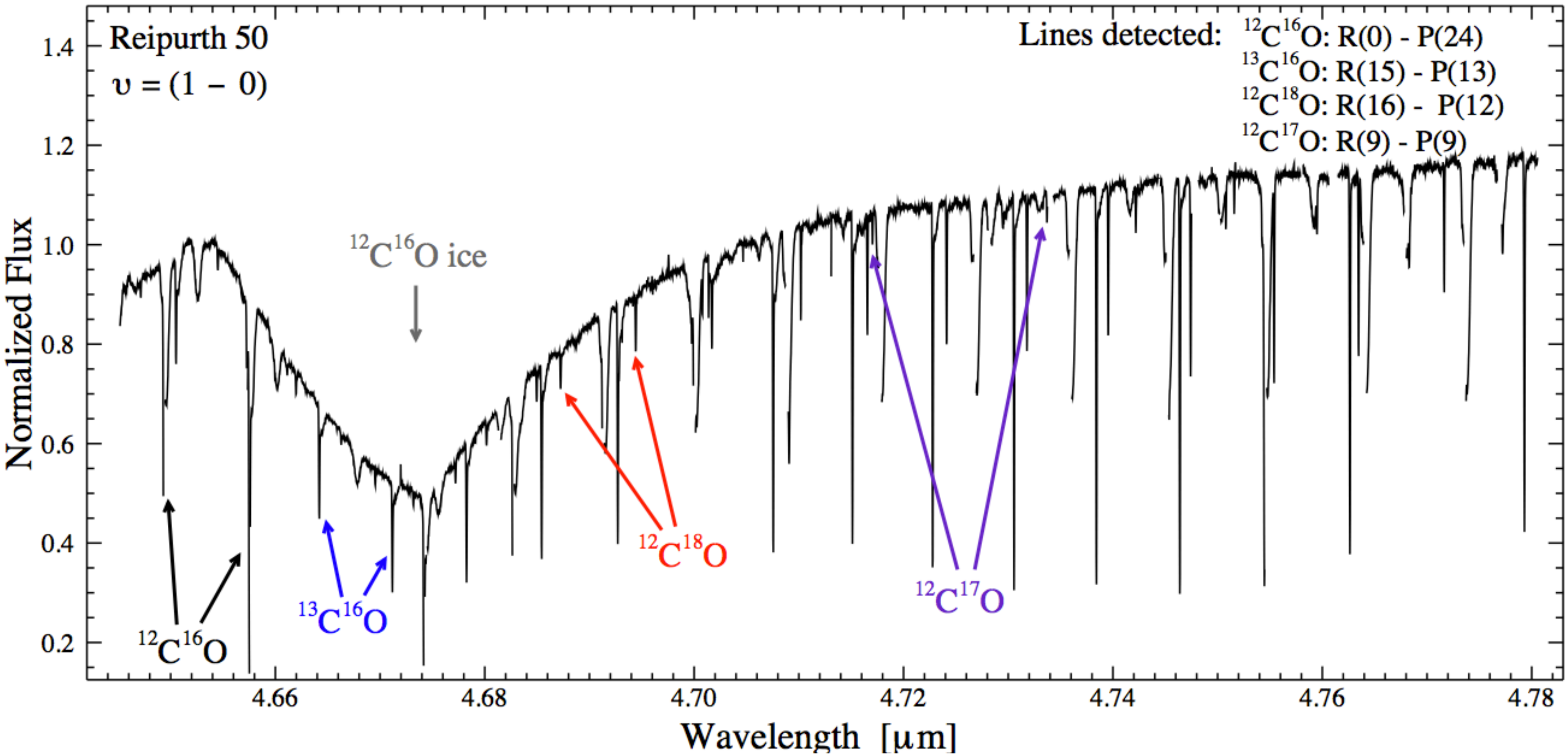
CO ~ 4.5-5.0 micron

Thi et al. 2013

CO fundamental emission observed at high spectral- and spatial resolution

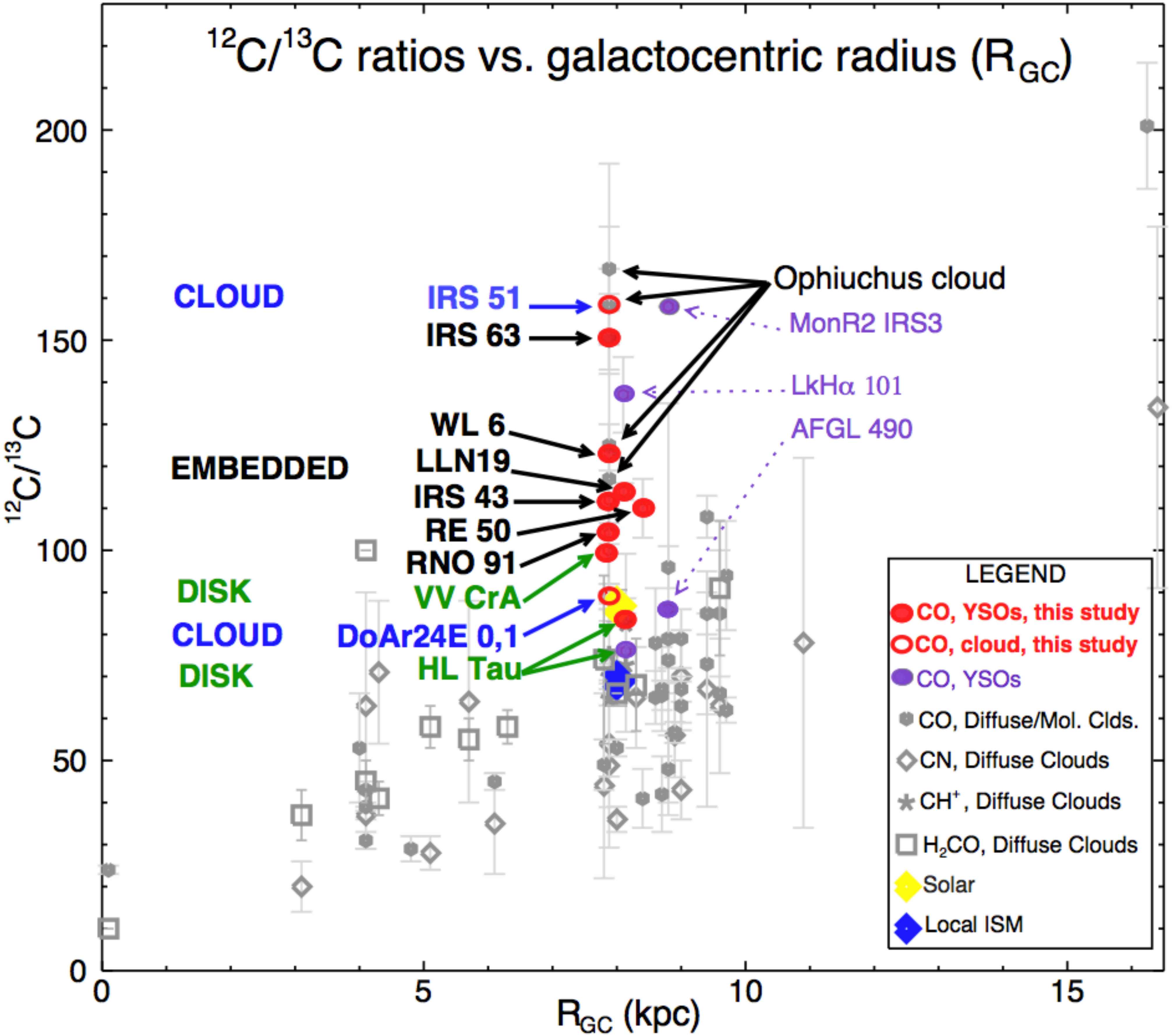
- probes the inner molecular disk (require high-spatial resolution: d=140 pc, 0.01"=1.4 AU)
- profile constrains the gas kinematics of the inner disk:
    - disk wind/jet
    - funnel flow/accretion flow
    - Keplerian rotation (emission from disk material)
- Precise interstellar composition: example carbon isotopic ratio ^{12}C, ^{13}C, ^{16}O, ^{17}O, ^{18}O

Determining Carbon and Oxygen isotopic ratios in the envelope around a young stellar object



VLT-CRIRES

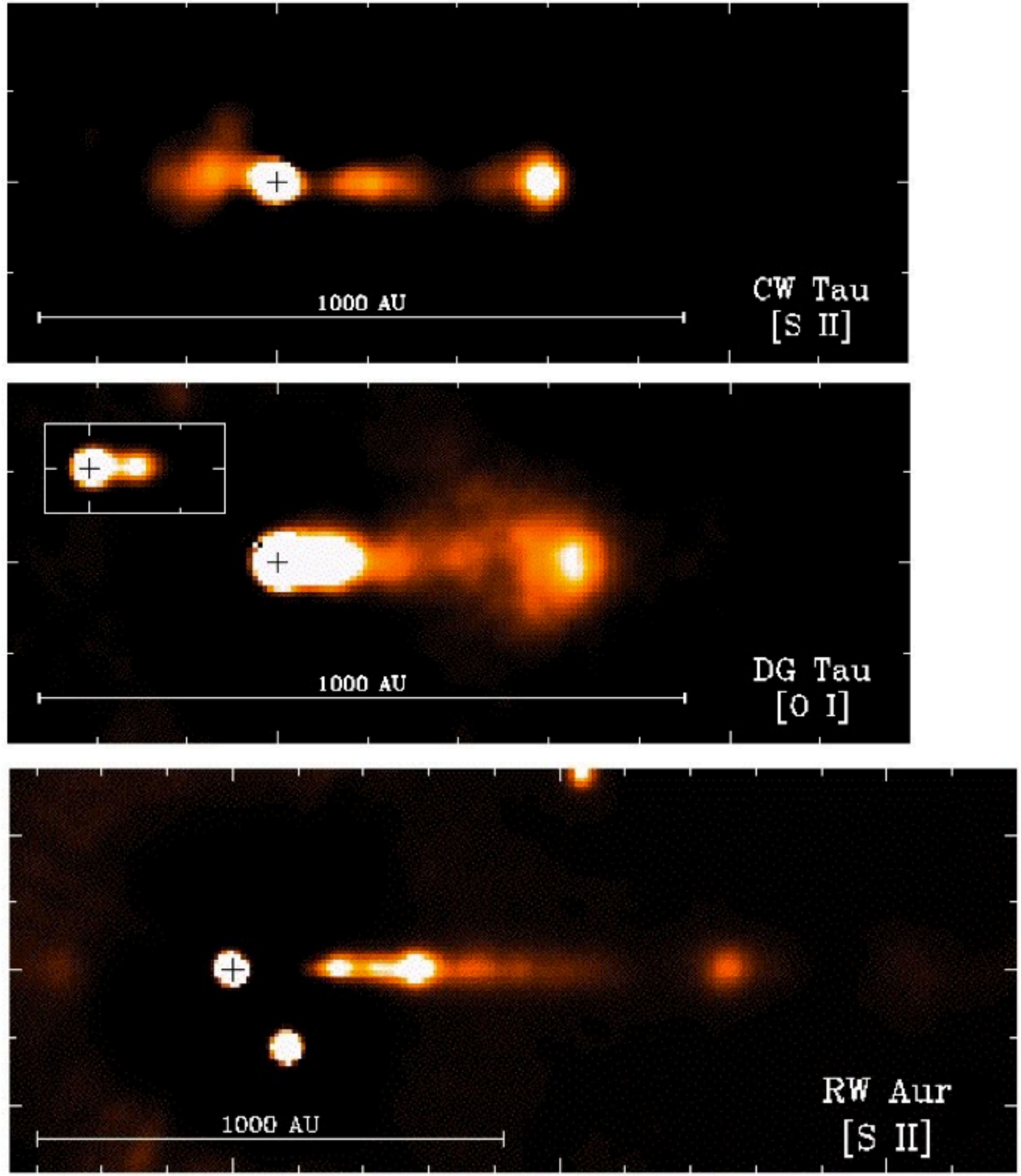
Smith R. et al. 2010



R. Smith, PhD thesis

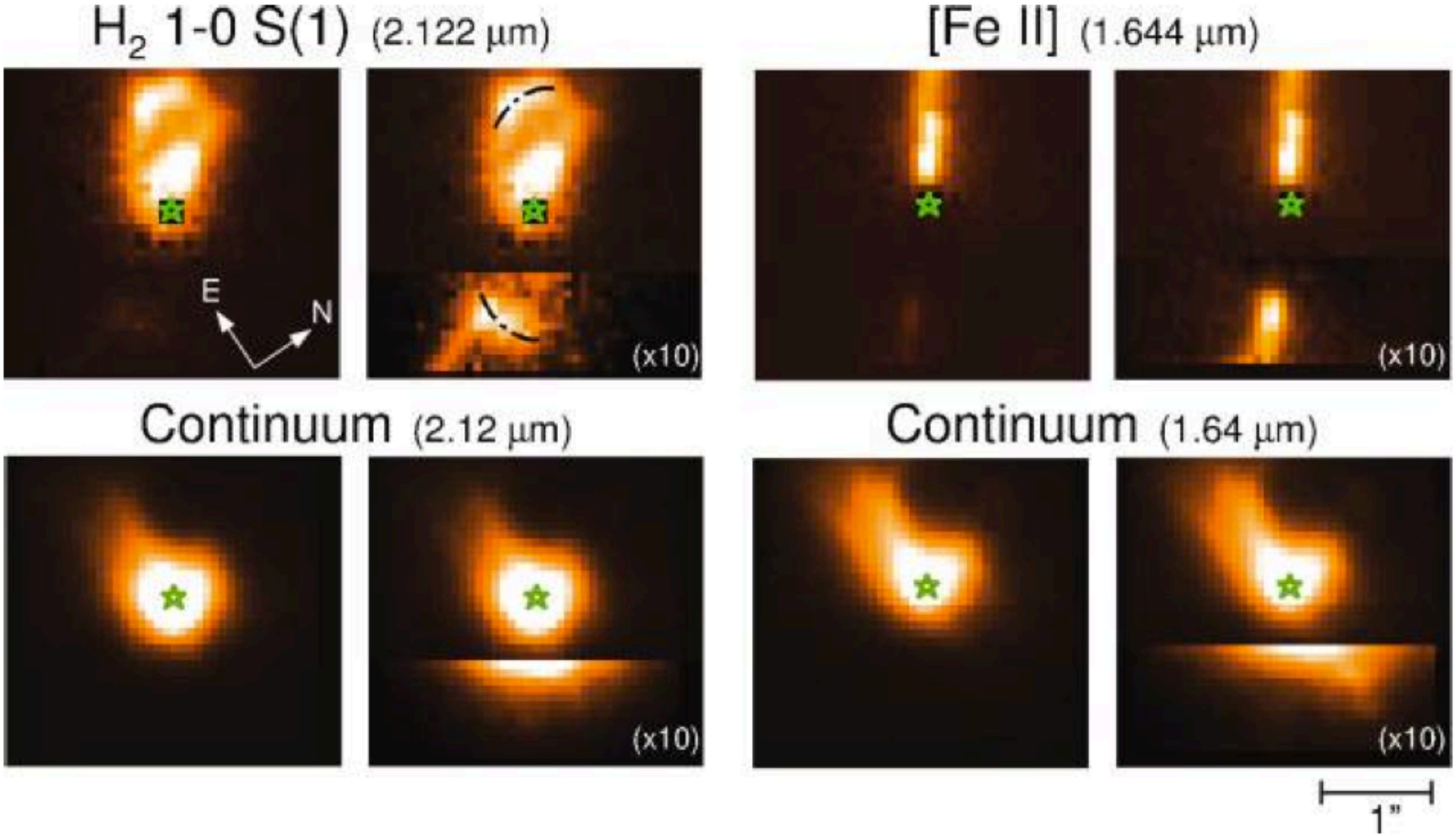
Microjets from T Tauri stars

- PUEO @ CFHT
- FWHM 0.1” = 14AU



Dougados et al 2000, A&A 357 L61

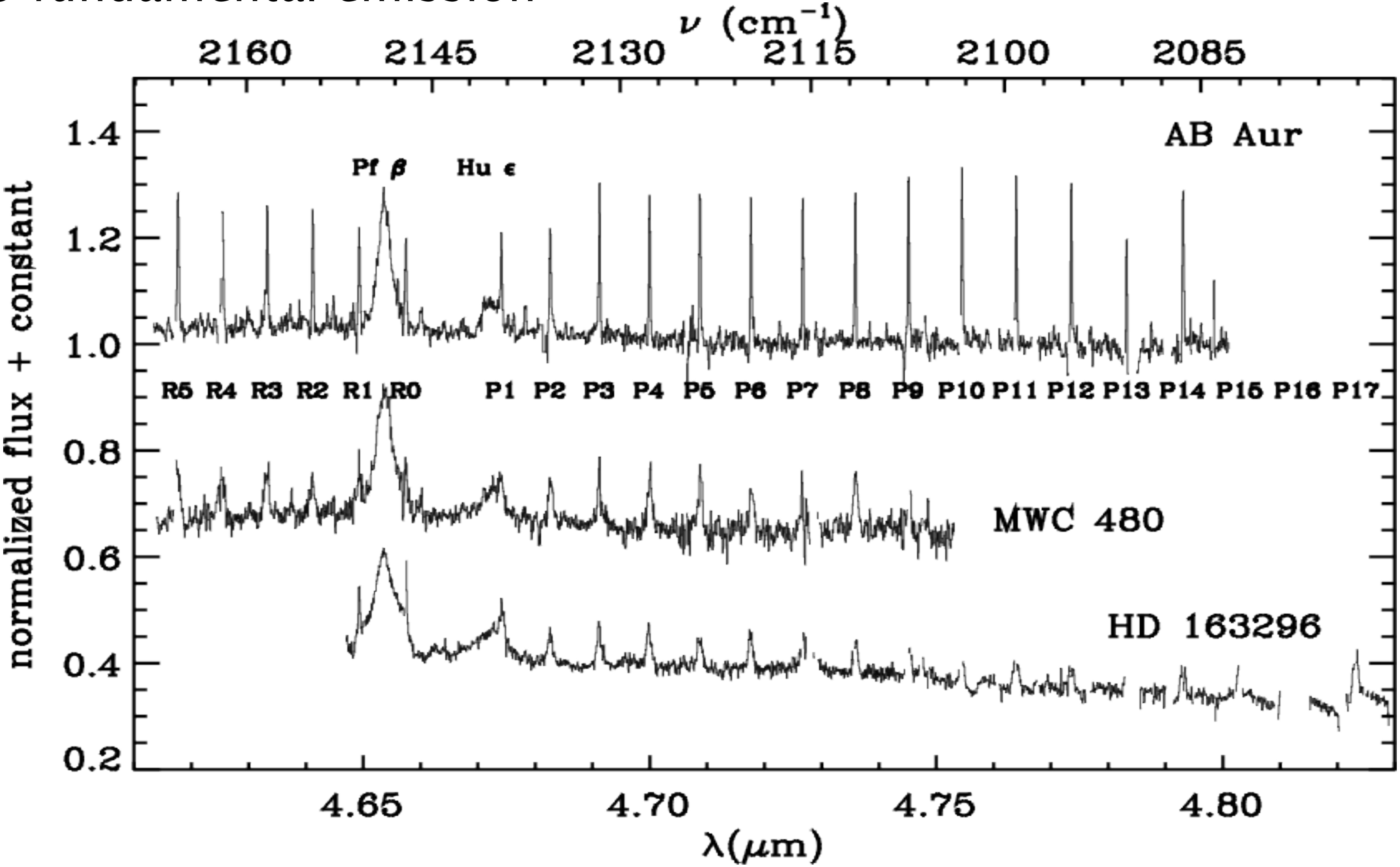
HL Tau microjet with Gemini



Takemi et al. 2007 (Gemini)

- [FeII] sensitive to depletion

CO fundamental emission



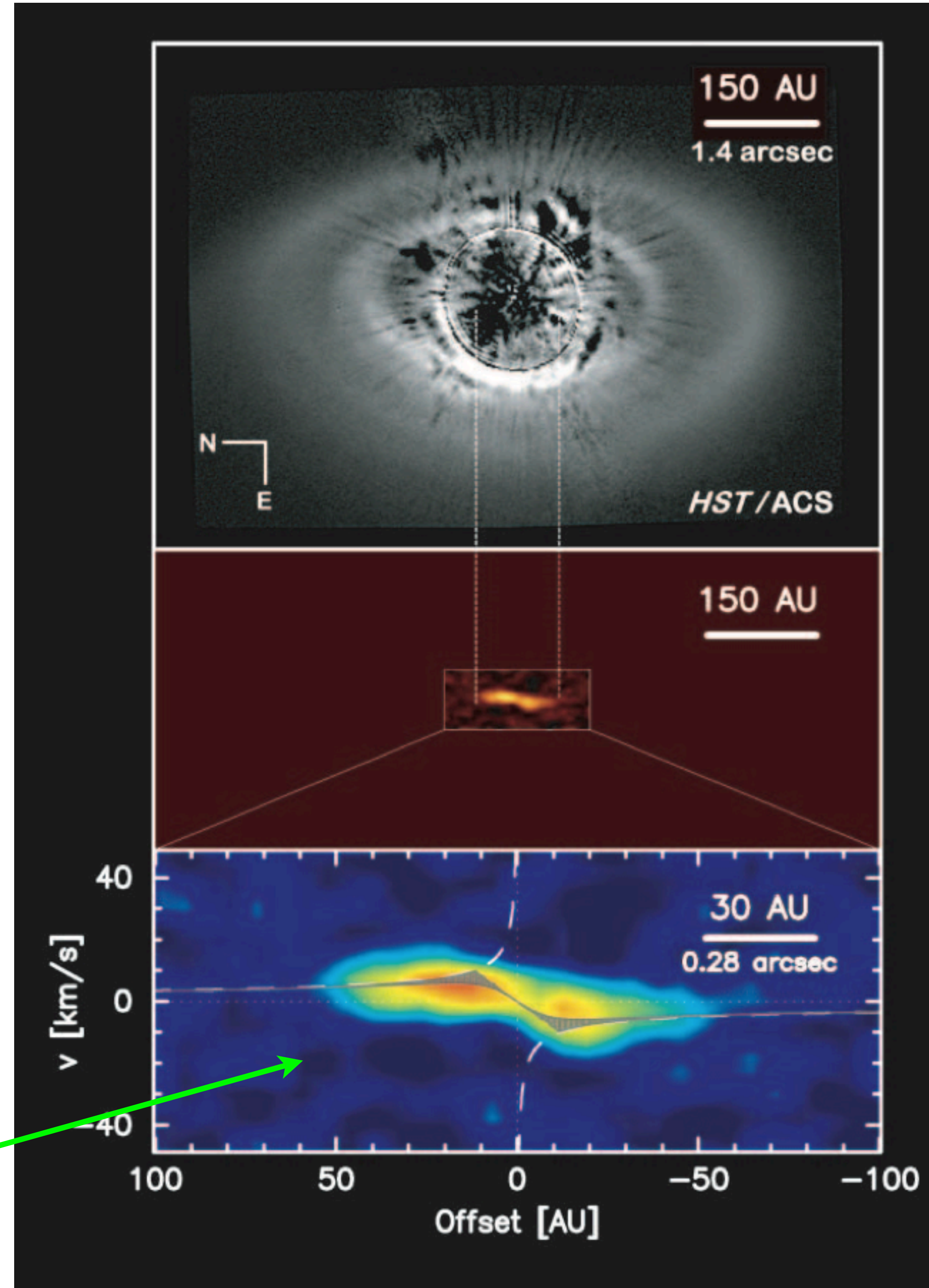
Blake & Boogert 2004

Other groups: Pontoppidan, Salyk, Brittain, Goto, Carmona, Najita, Gibb...

Spectro-Astrometric (SA) observations

- CO rovibrational emission (~4.5-4.9 micron)
- HD 141569A (~1E-4 M_{Sun} disk)
- Subaru, spectrograph IRCS. R~20,000

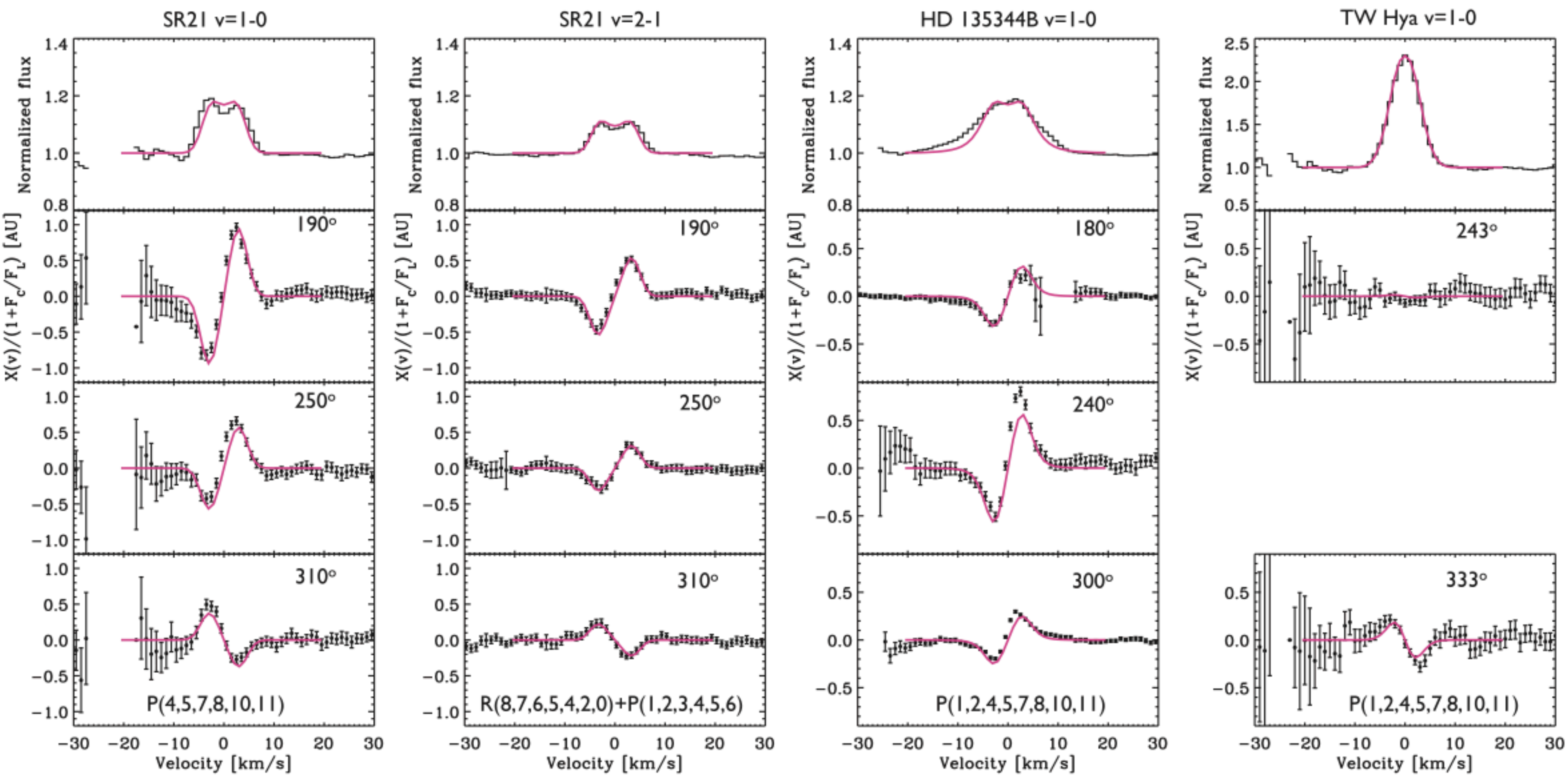
Keplerian rotation pattern



Goto 2006, ApJ 652, 758

SA at the VLT with CRIRES

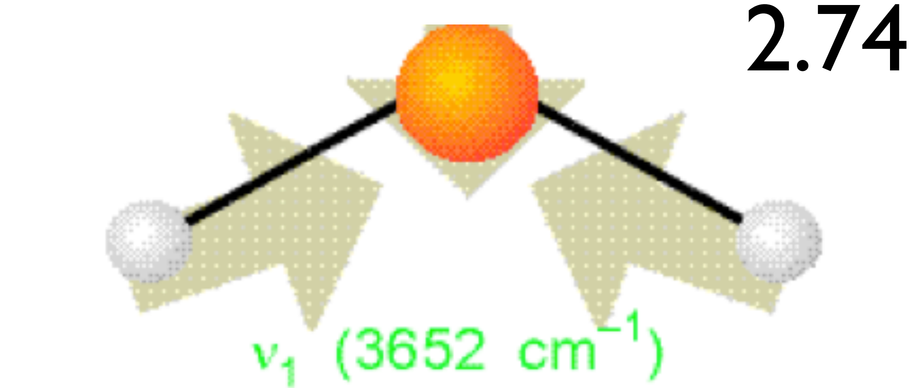
- Derive the size of the CO emitting area



Pontoppidan 2008, ApJ 684, 1323

~1.5 mas "spatial resolution" (error bars)

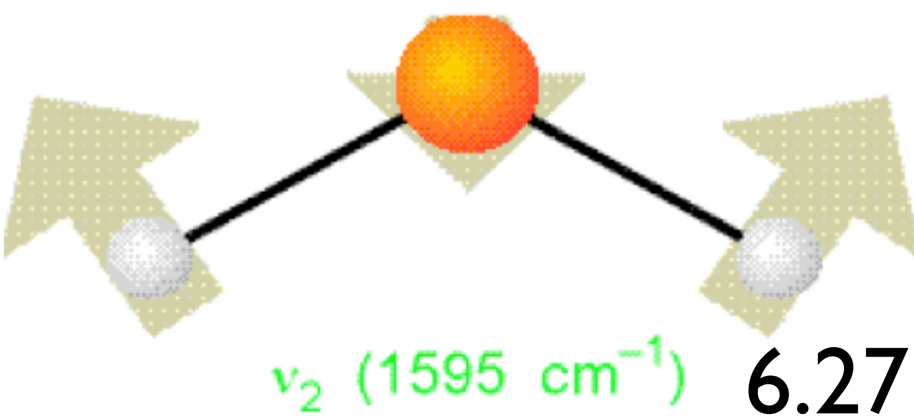
Three vibrational modes of an isolated water molecule



2.74 microns

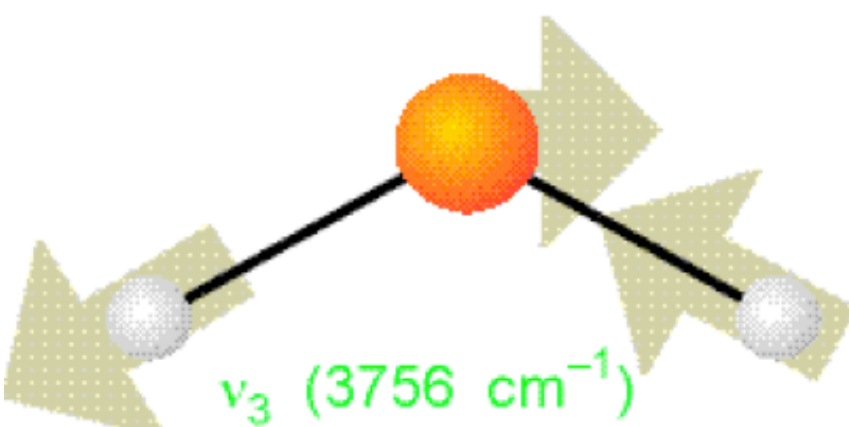
Symmetric vibrations

$1\ \text{cm}^{-1} = 1e4/\ \mu\text{m}$



Bending motions

6.27 microns

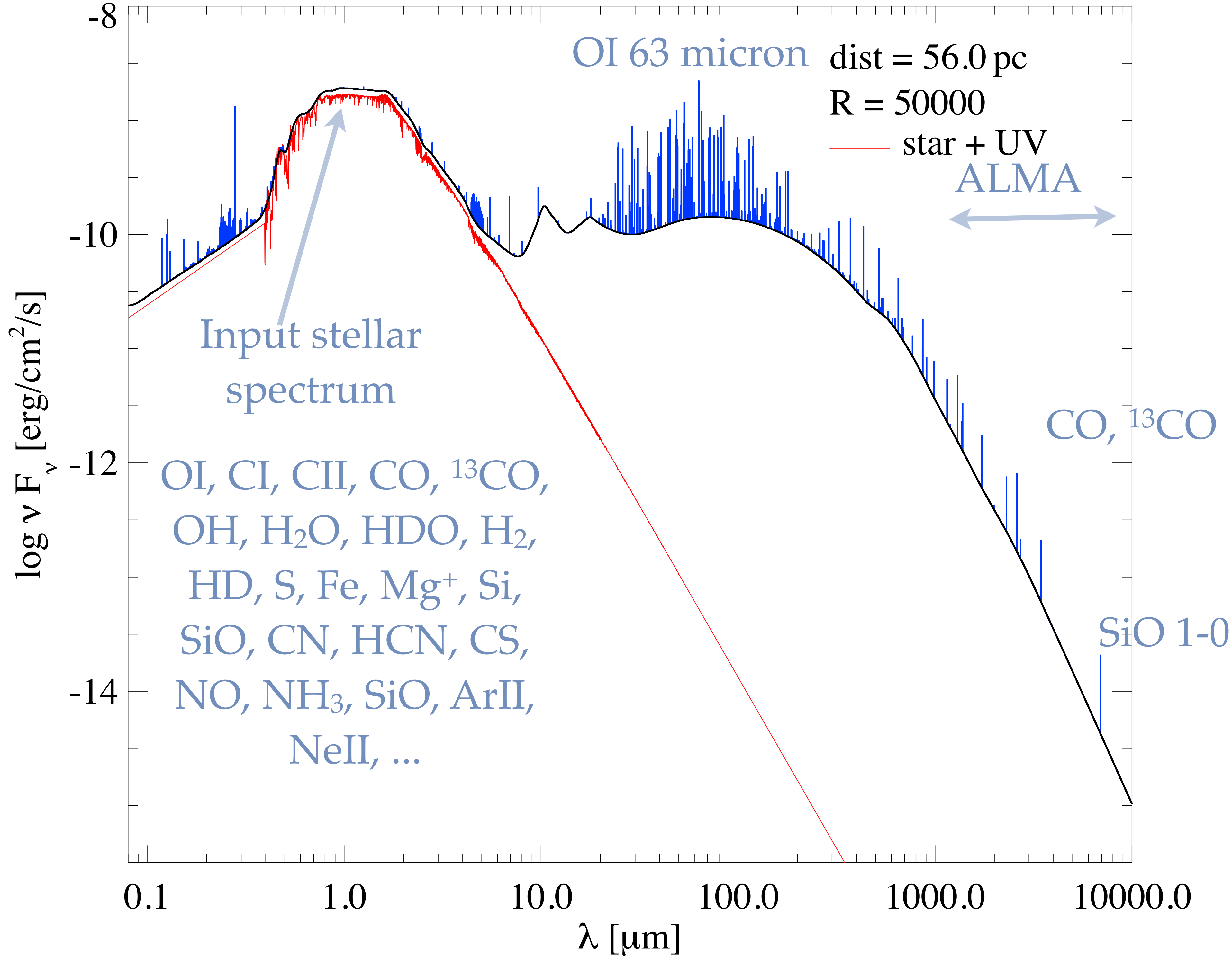


Anti-symmetric vibration

2.66 microns

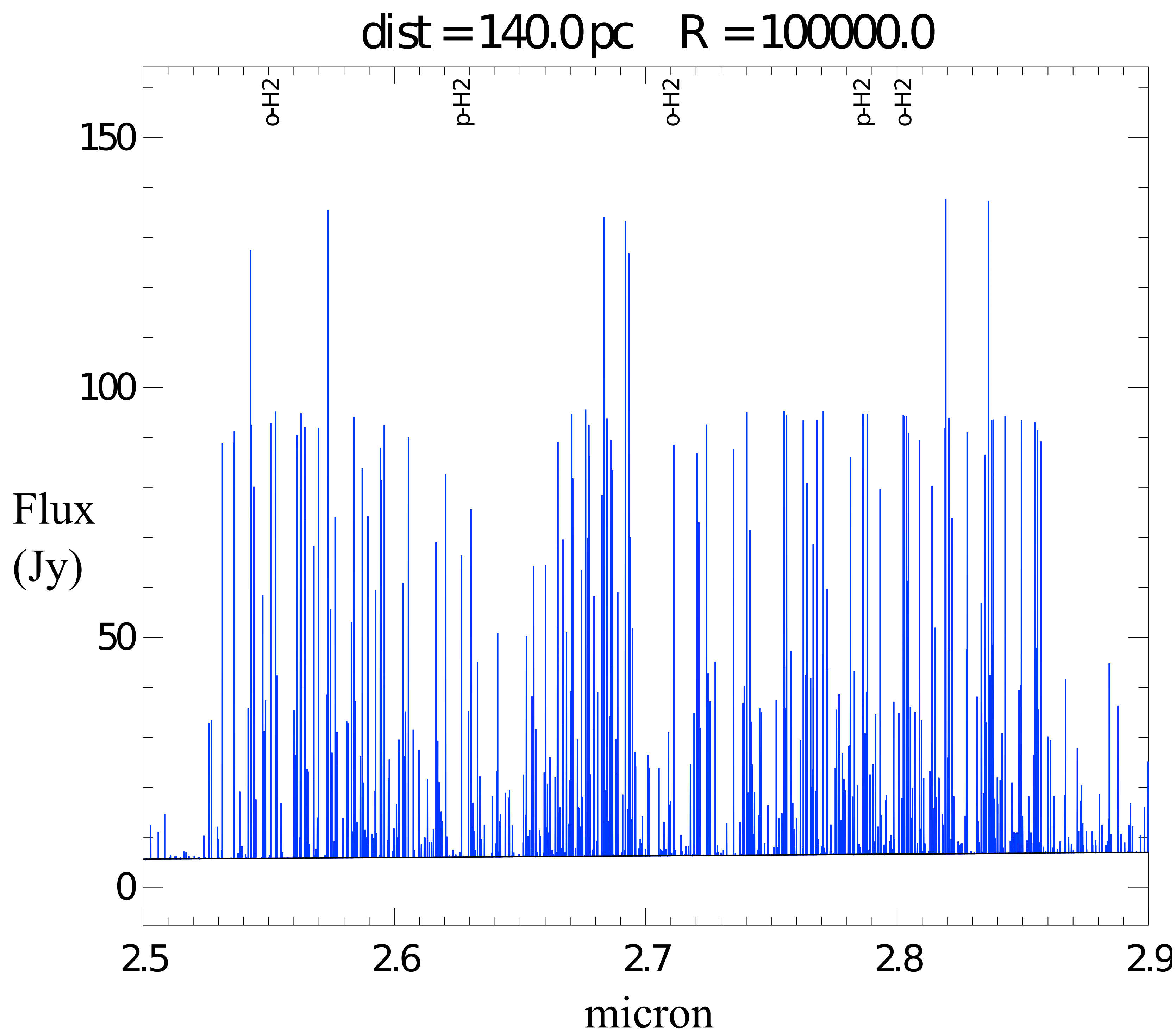
9 degrees of freedom: few millions lines in the IR

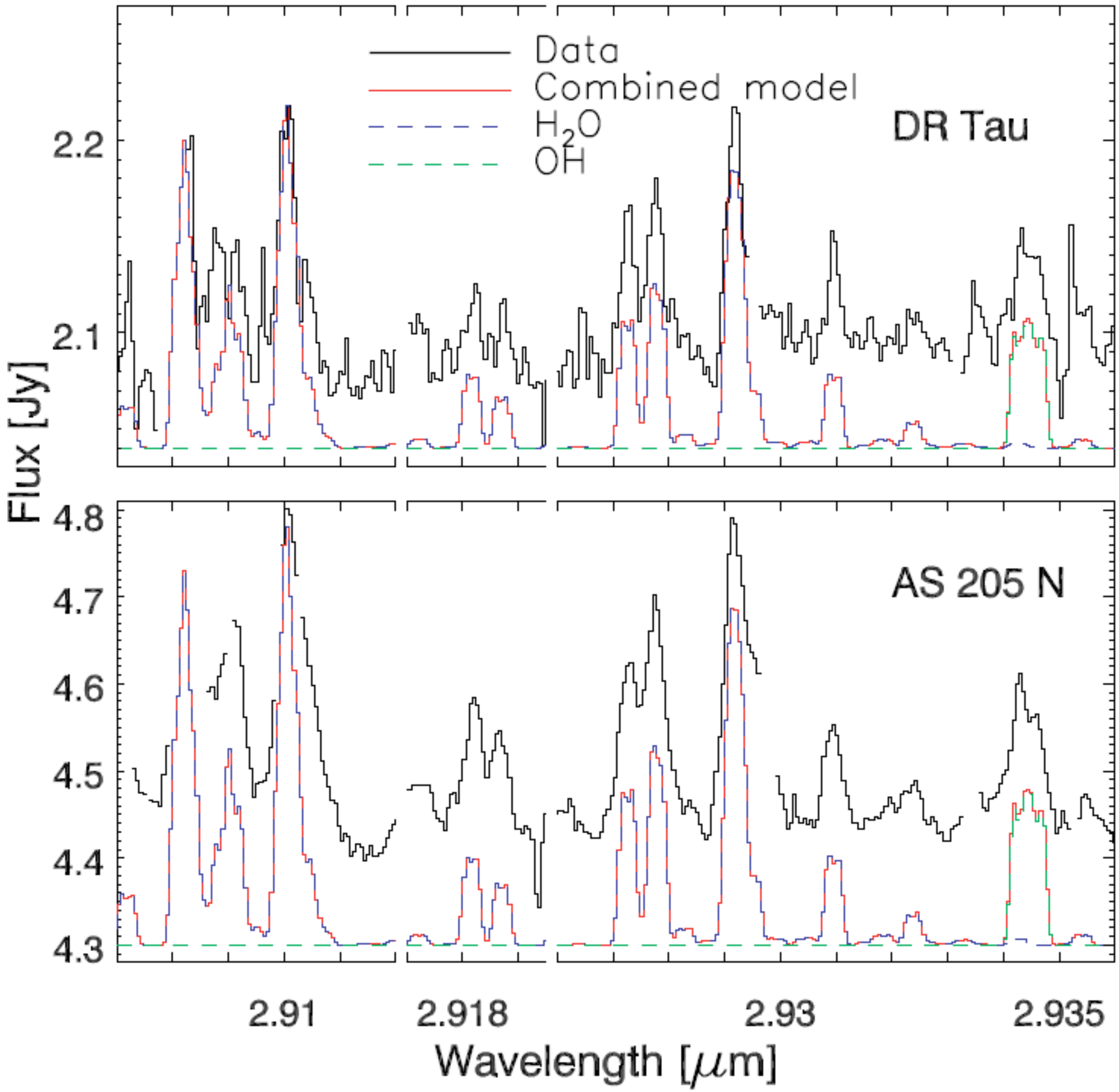
ProDiMo model ~30,000 lines



Models are now capable to "predict" hot water and CO line fluxes

- Model-prediction for a 0.01 MSun disk (ProDiMo Woitke et al. 2010, Kamp et al. 2011, Thi et al. 2011, 2013)
- Hot water lines dominate the near-IR





Hot OH and H_2O

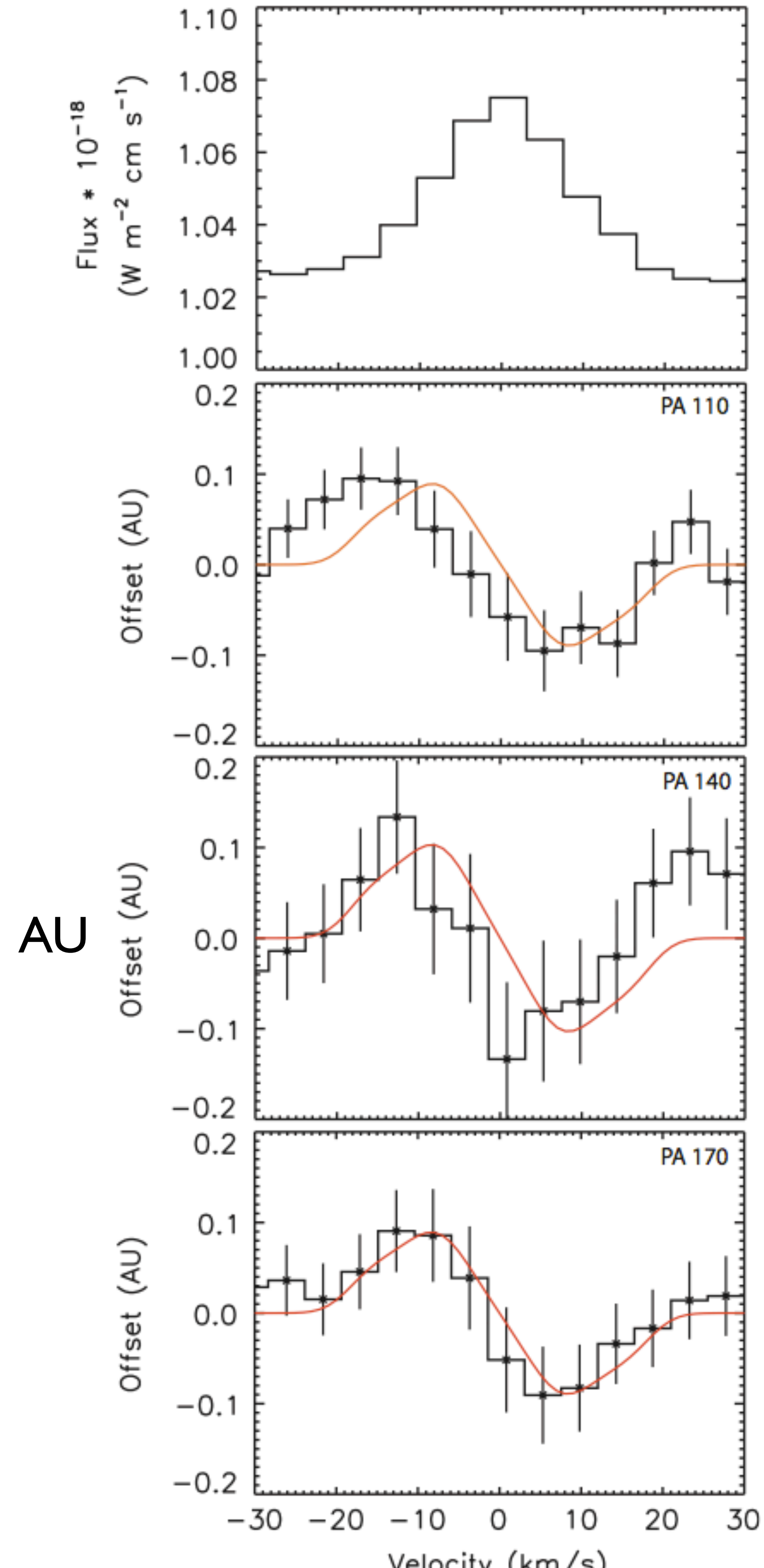
Keck-NIRSPEC
dv=35 km/s

Salyk et al. 2008

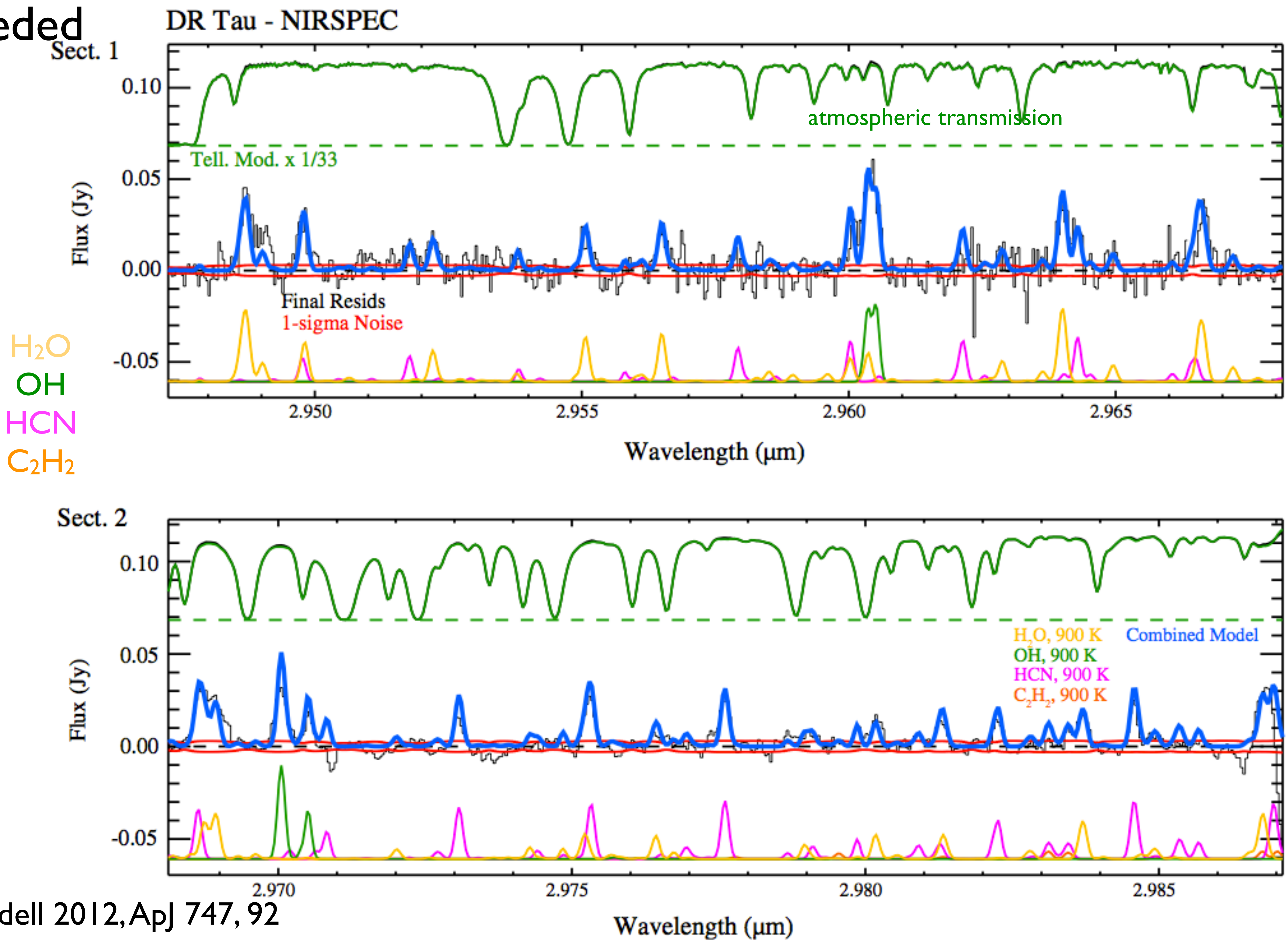
Spectro-Astrometric observation of water lines

- DR Tau, d=140 pc
- Keck R=25,000
- average emission profile and spectro-astrometric signature of 3 strong water 001-000 vibrational lines (2.91869, 2.92782, 3.01063 micron)

Brown L. R., 2013, ApJ 770, L14



Other molecular emissions: careful knowledge of the atmosphere needed

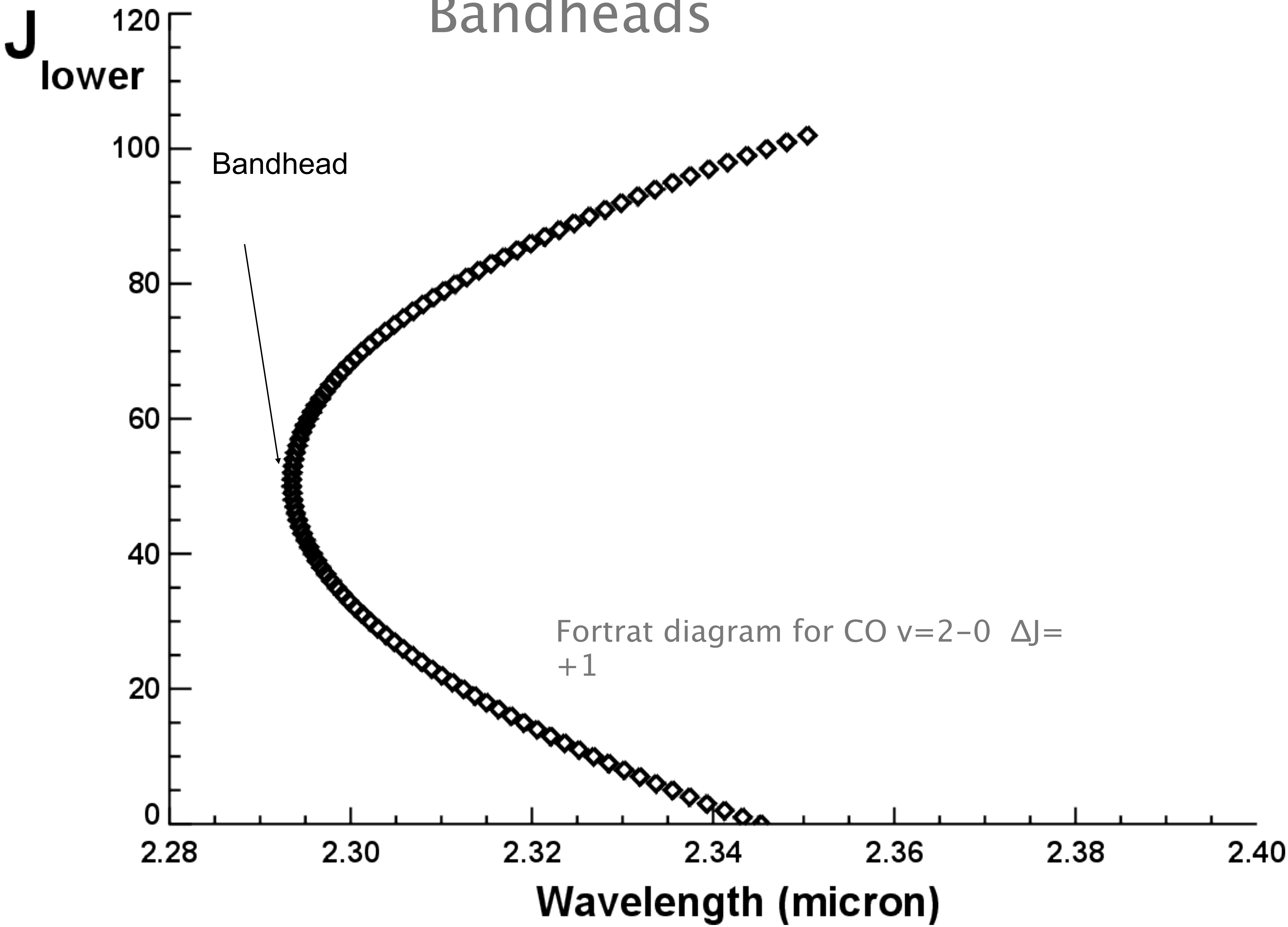


Mandell 2012, ApJ 747, 92

Summary

- Possible aims of disk chemical studies with the E-ELT (beyond current works with 8-m class telescopes):
  - High spatial- and spectral-resolution observations of hot gas phase lines: derive kinematics (disk, wind, accretion flow, ...). With an Integral-Field-Unit, there is no need to perform multi-slit position astro-spectroscopic observations
  - High sensitivity to detect (new) lines and weak solid-state features in a larger number of objects than possible so-far.
    - CRIRES mag(M)=8, 1h, 5 sigma: F~1.5e-19 W/m^2 (METIS planned ~100 times more sensitive).
    - ELT allows to study fainter objects (disks around young Brown Dwarfs or exo-cometary emissions)

Bandheads



Fortrat diagram for CO v=2-0 ΔJ= +1