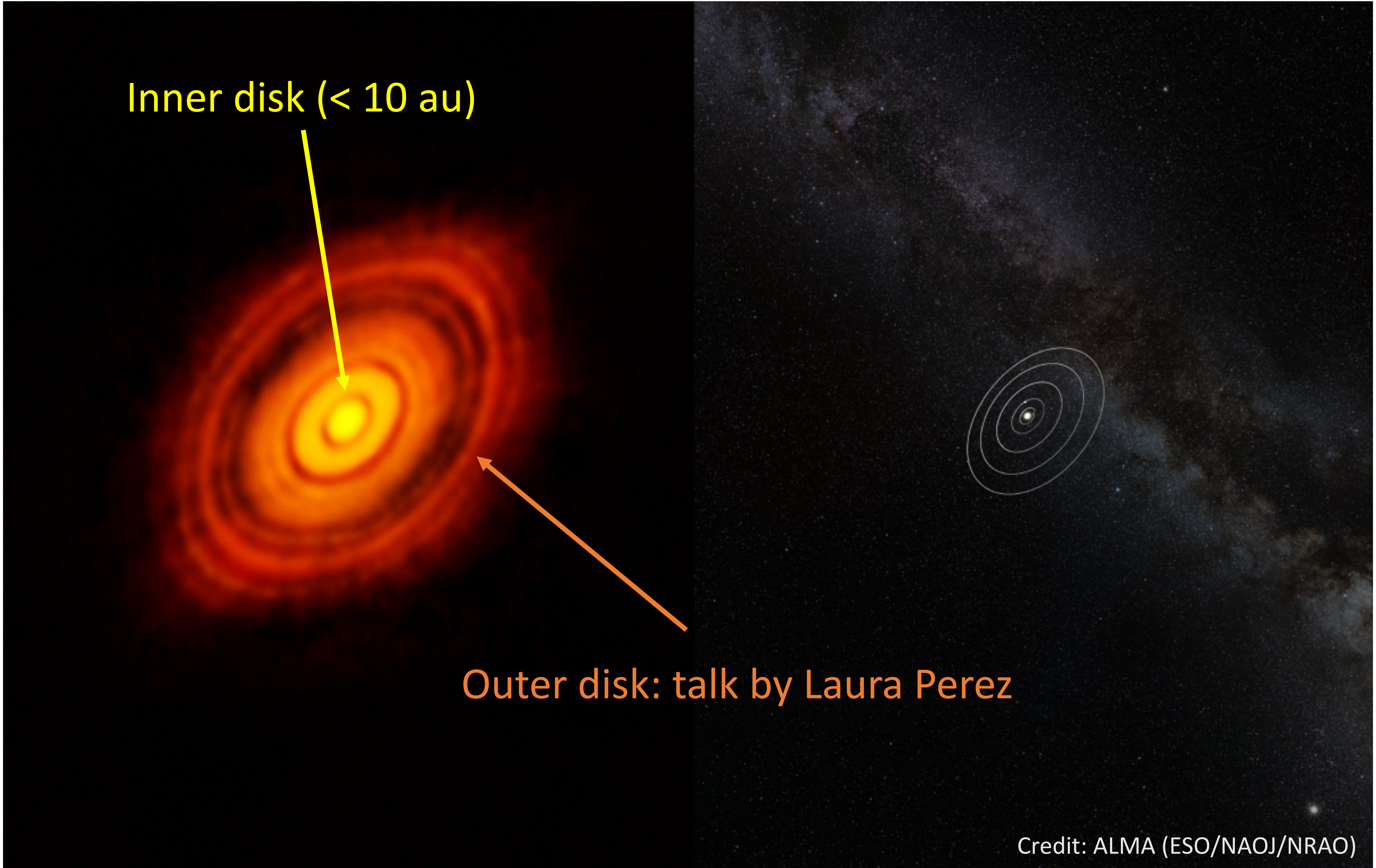
Techniques, Observations, and Diagnostics of Protoplanetary Disks: Inner Disk

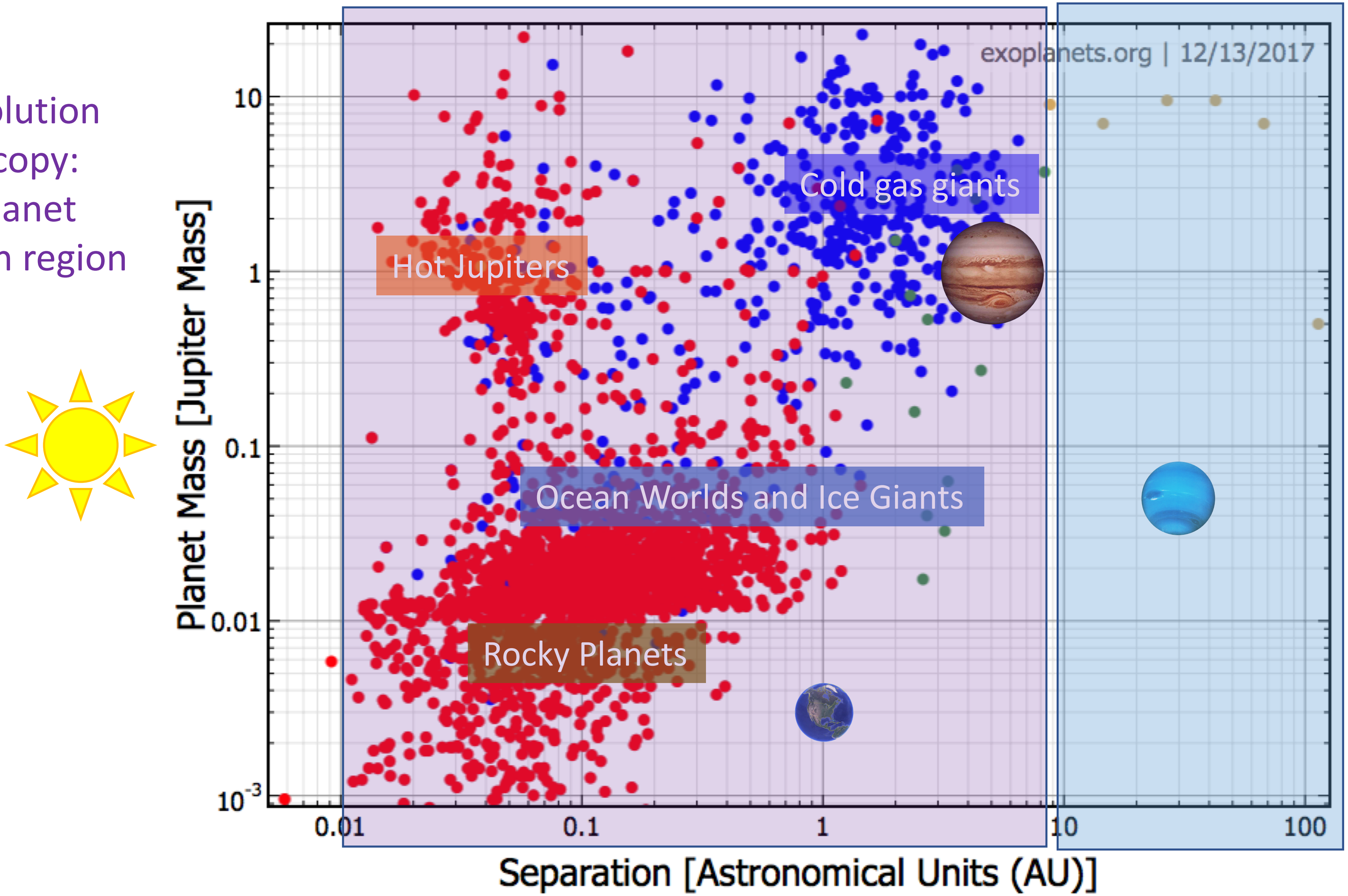
Joan Najita (NSF’s NOIRLab)

2021 Sagan Summer Workshop


Inner disk (< 10 au)
Outer disk: talk by Laura Perez
Credit: ALMA (ESO/NAOJ/NRAO)

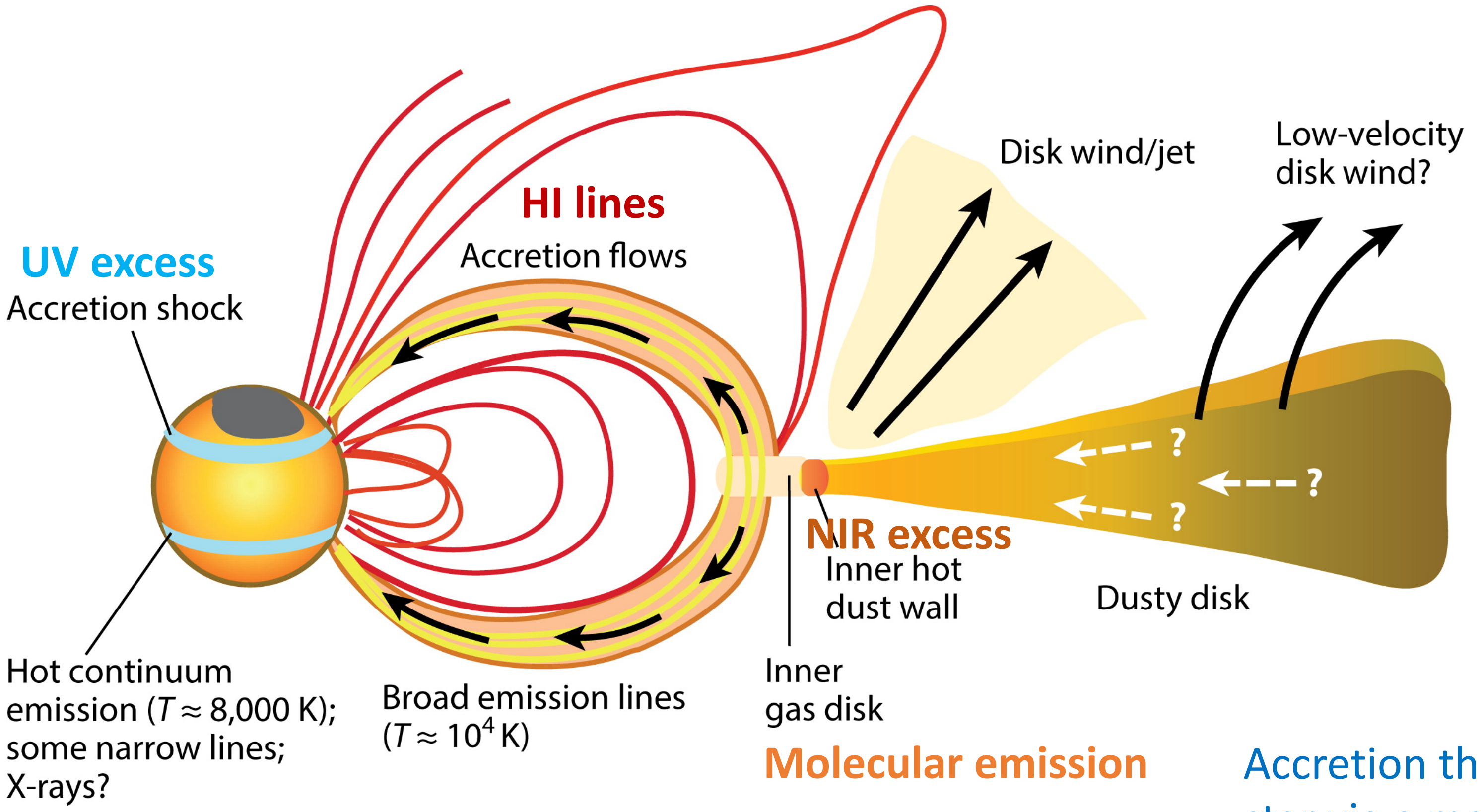
Exoplanet Populations

High resolution Spectroscopy: Probes planet formation region



Imaging: ALMA, high contrast NIR

The near-stellar environment of T Tauri Stars



Accretion through disks and onto star via a magnetosphere

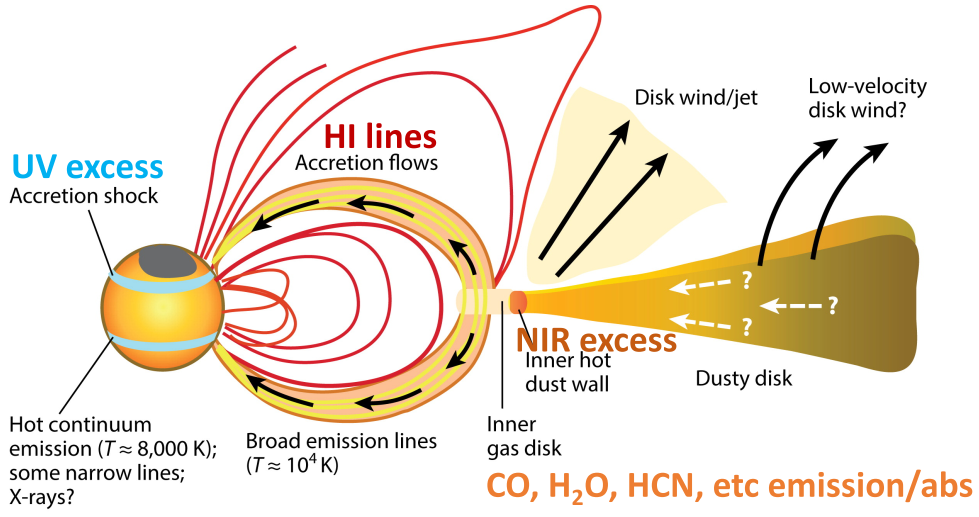
Hartmann et al. 2016

Outline

Rich array of diagnostics from UV to IR

Stellar Accretion:

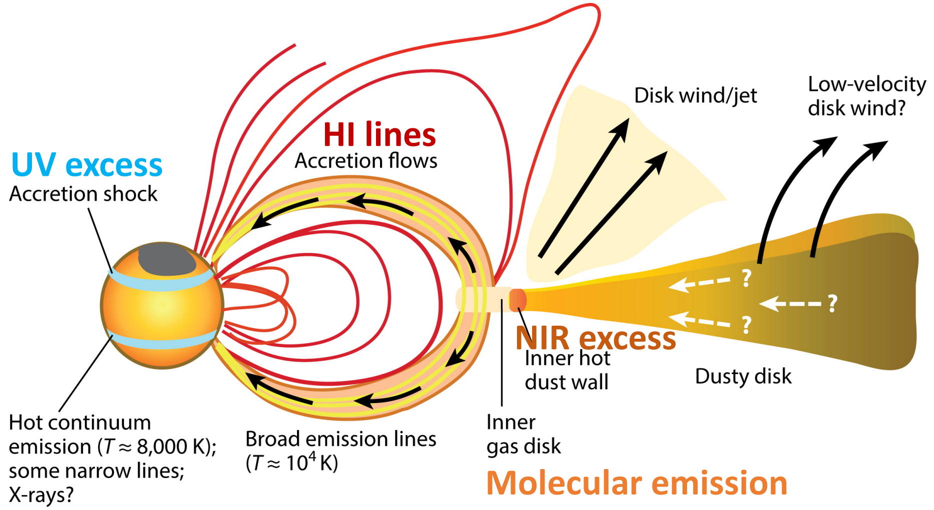
- Inner disk lifetime
- Nature of transition disks

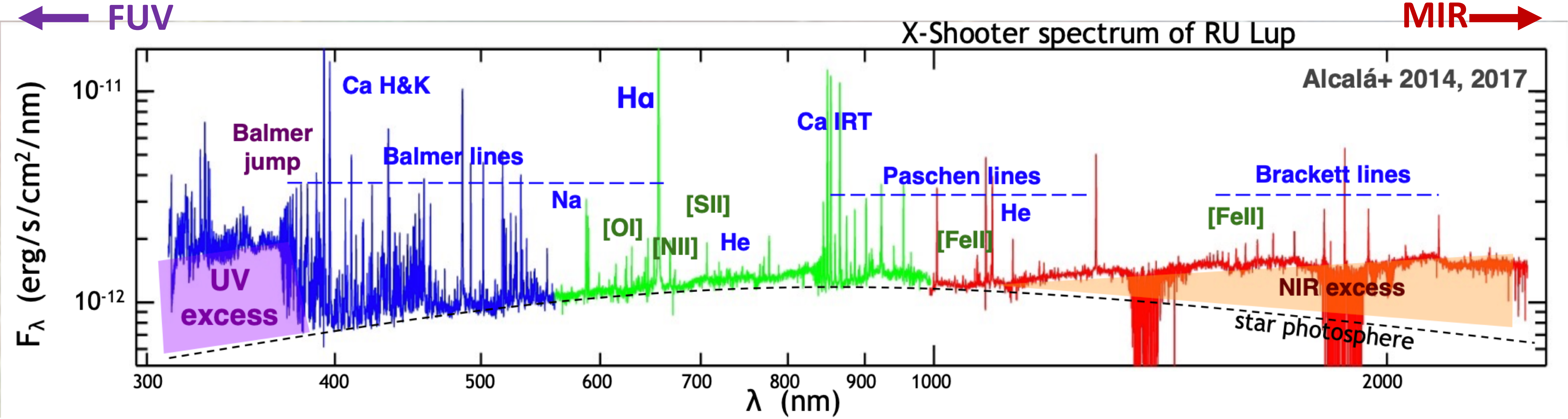


Disk Emission:

- Dynamics—how disks accrete
- Structure—inner radii, circumplanetary disk
- Chemistry—planetesimal formation

NUV/Opt/NIR Diagnostics





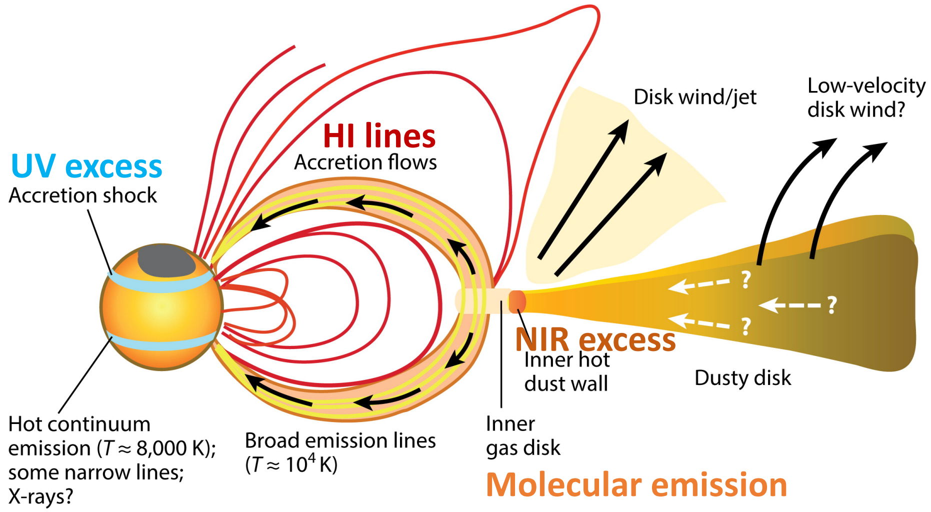
Credit: Alcala in "Accretion & winds/outflows in solar-type YSOs"

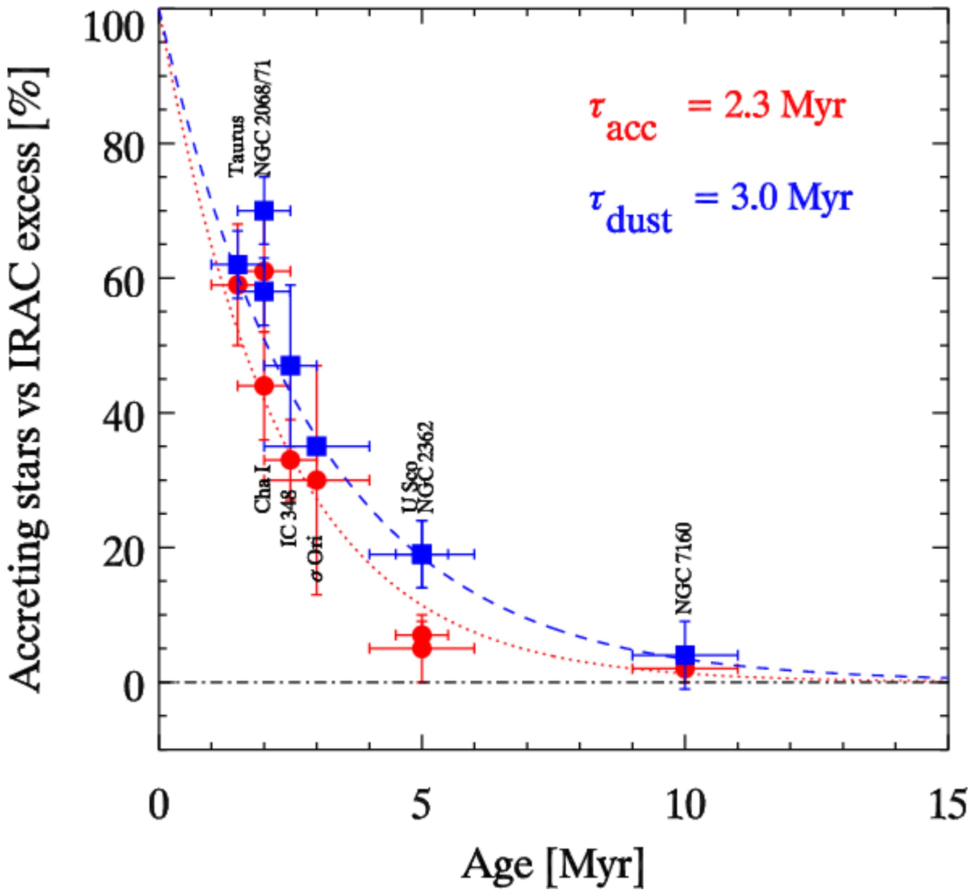
Clues from accretion

Gas disk lifetime, nature of transition disks

Accretion and gas disk lifetime

Fraction of accreting sources in clusters of different ages constrains gas dissipation time of inner disk

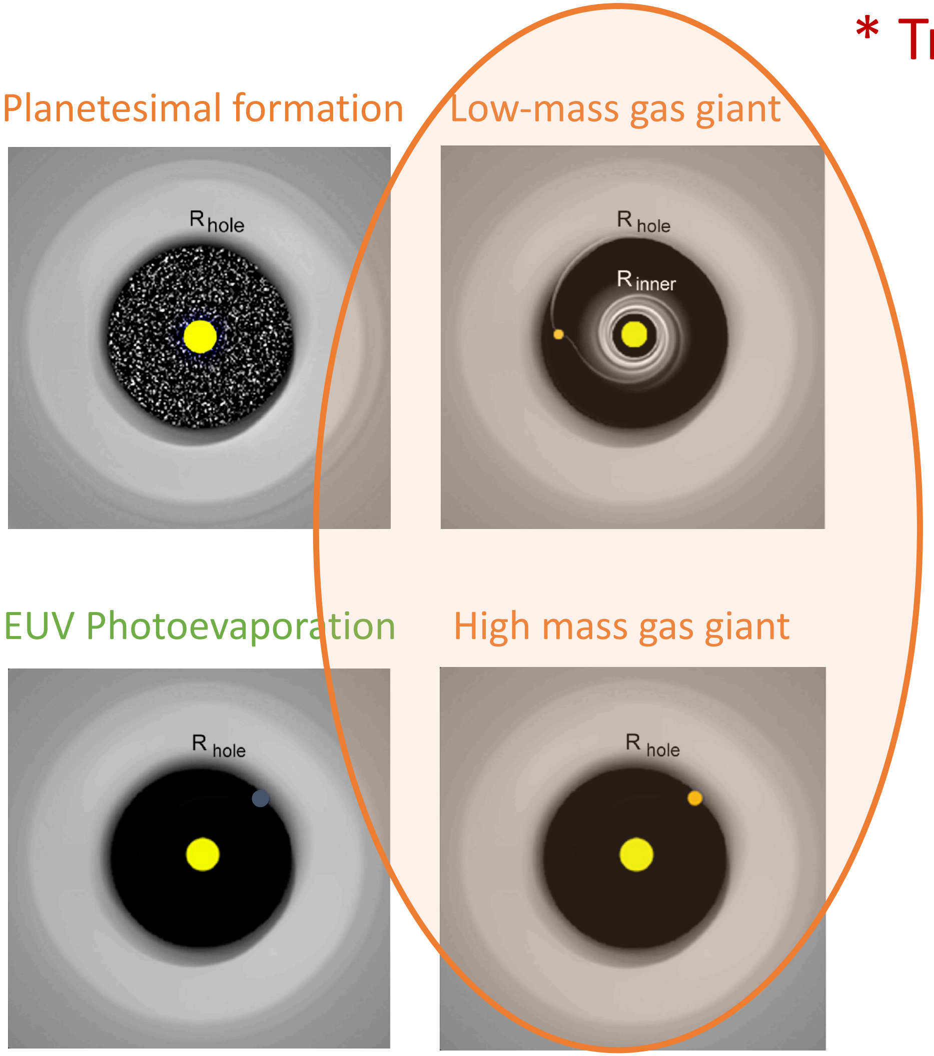


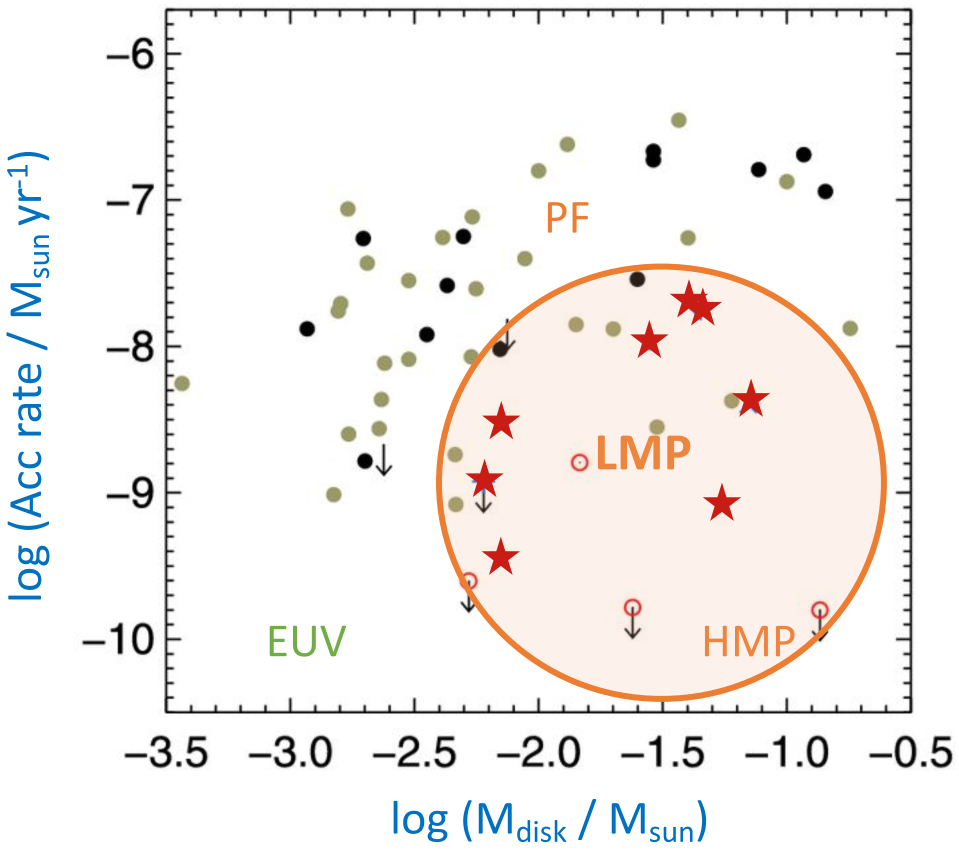


Fedele et al. (2010)

Accretion can reveal planet formation status*

* Transition disk: center is optically thin in continuum



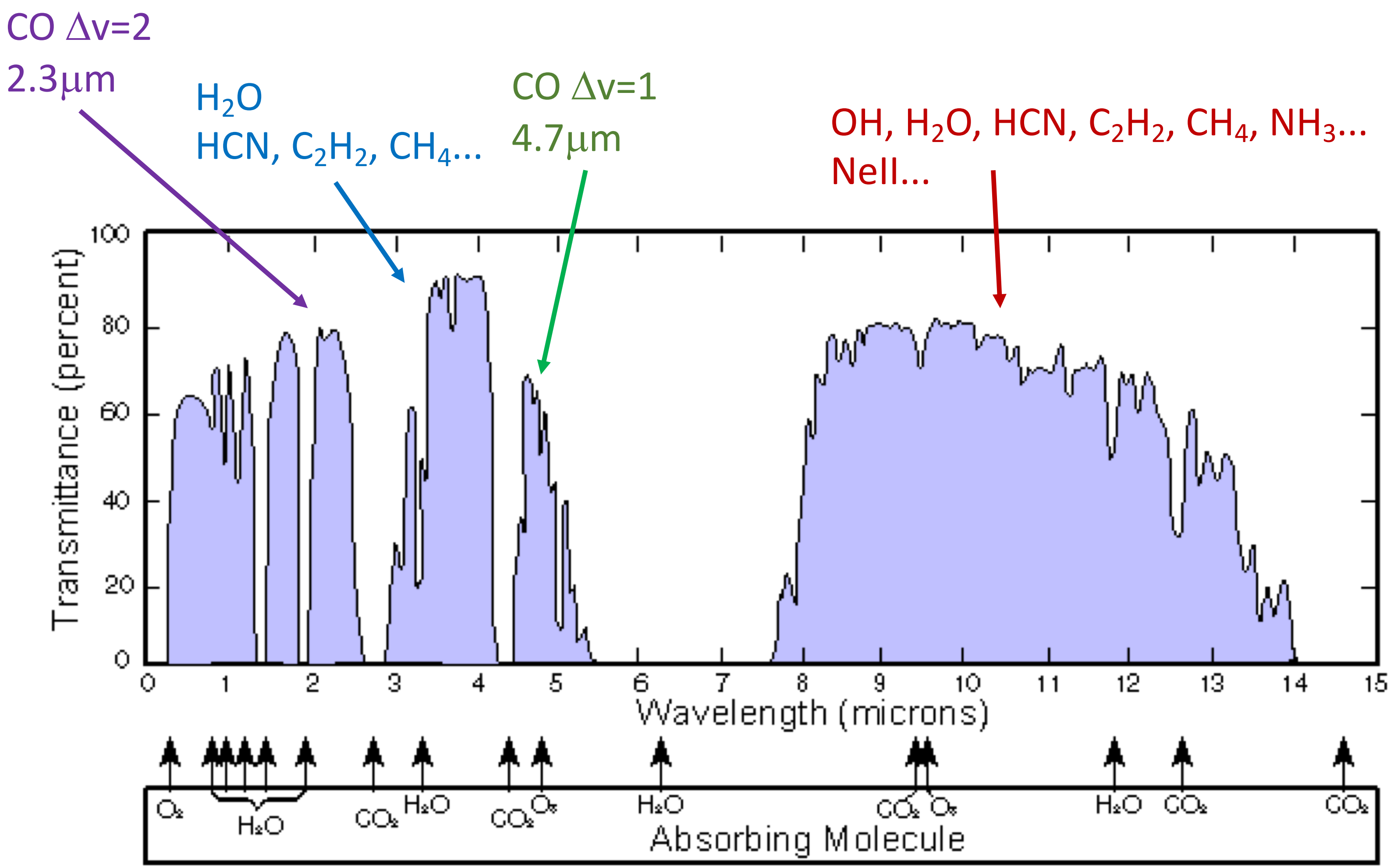


See Najita et al 2008, 2015; Kim et al. 2016

IR Spectroscopy and Disks

Probes of disk

- Dynamics
- Structure
- Chemistry

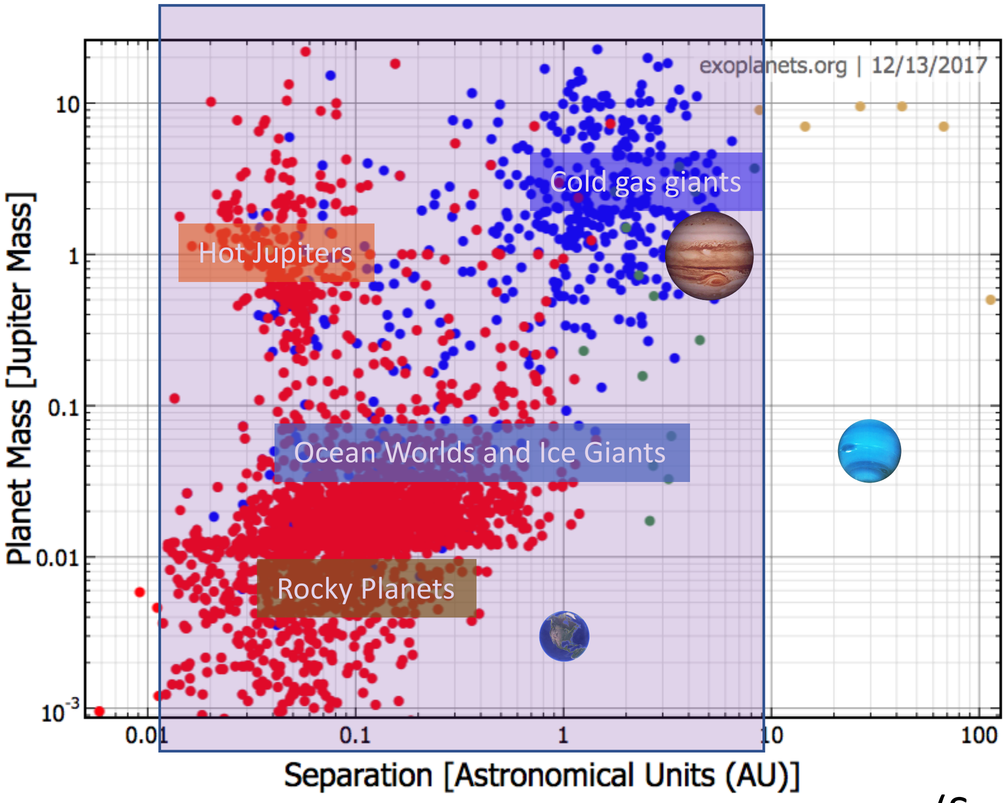


High resolution spectroscopy

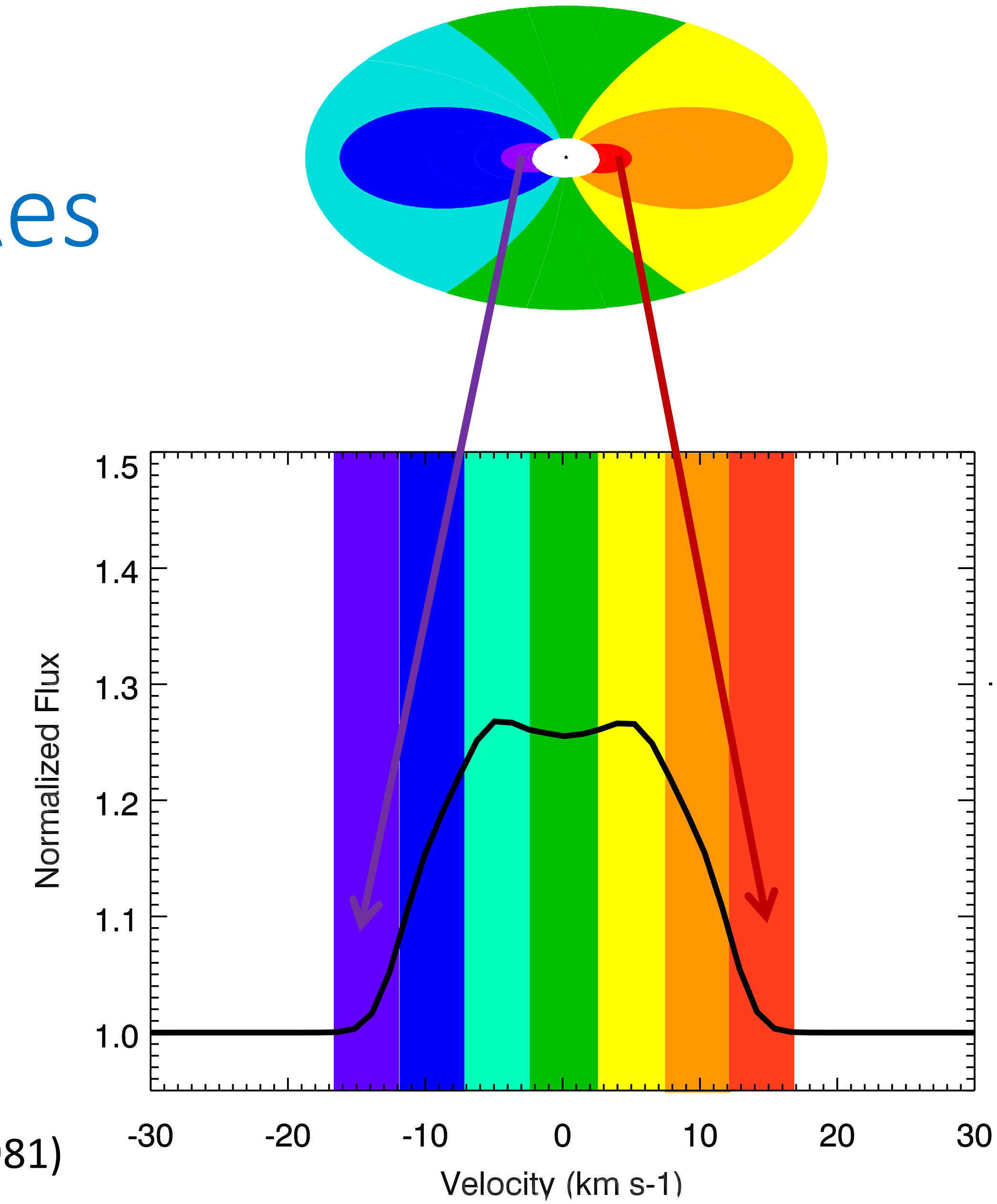
Studying inner disk structure

e.g., Carr 2007; Hoadley et al. 2015

High Spectral Res:
Surrogate for High Ang Res



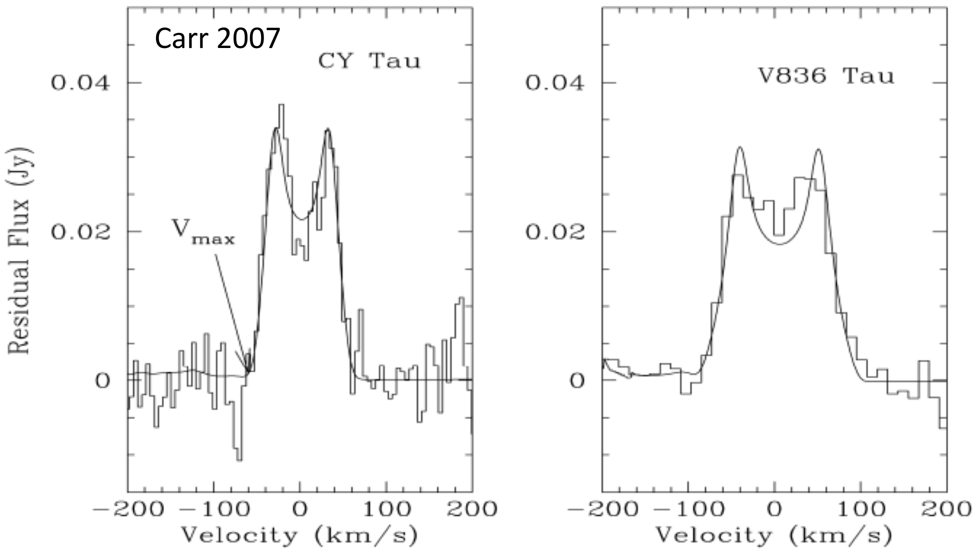
(See Smak 1981)

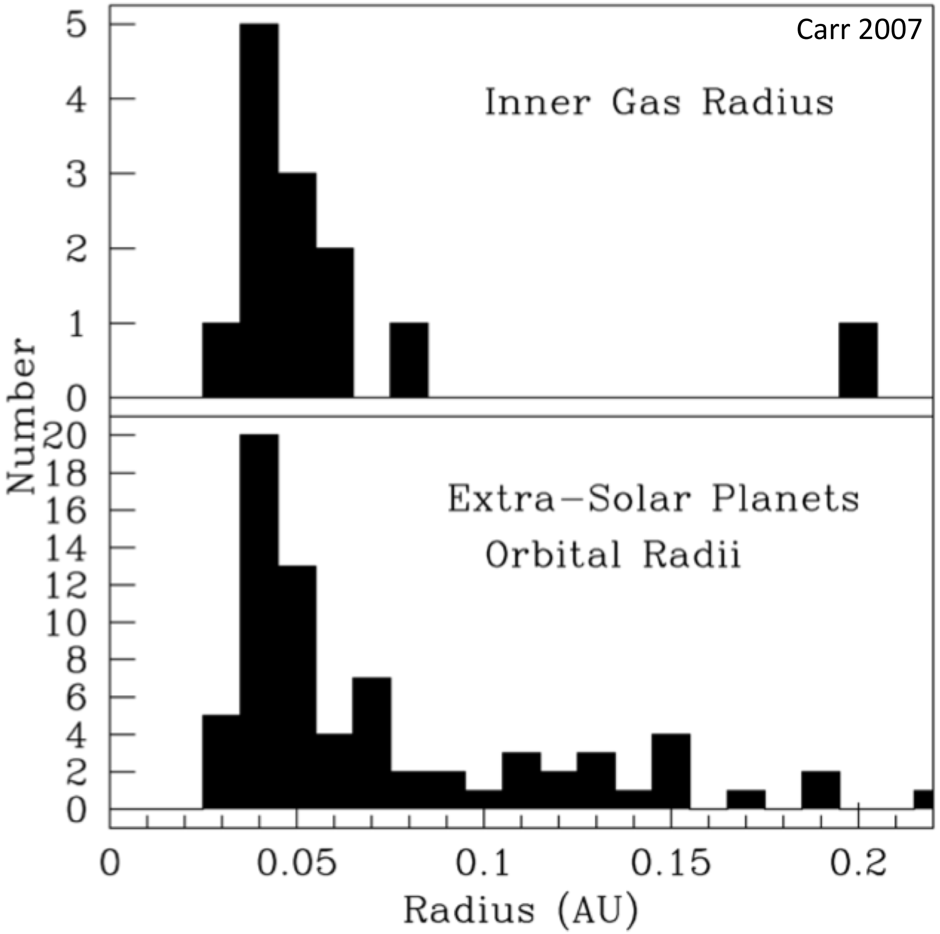


Graphics Credit: Sean Brittain

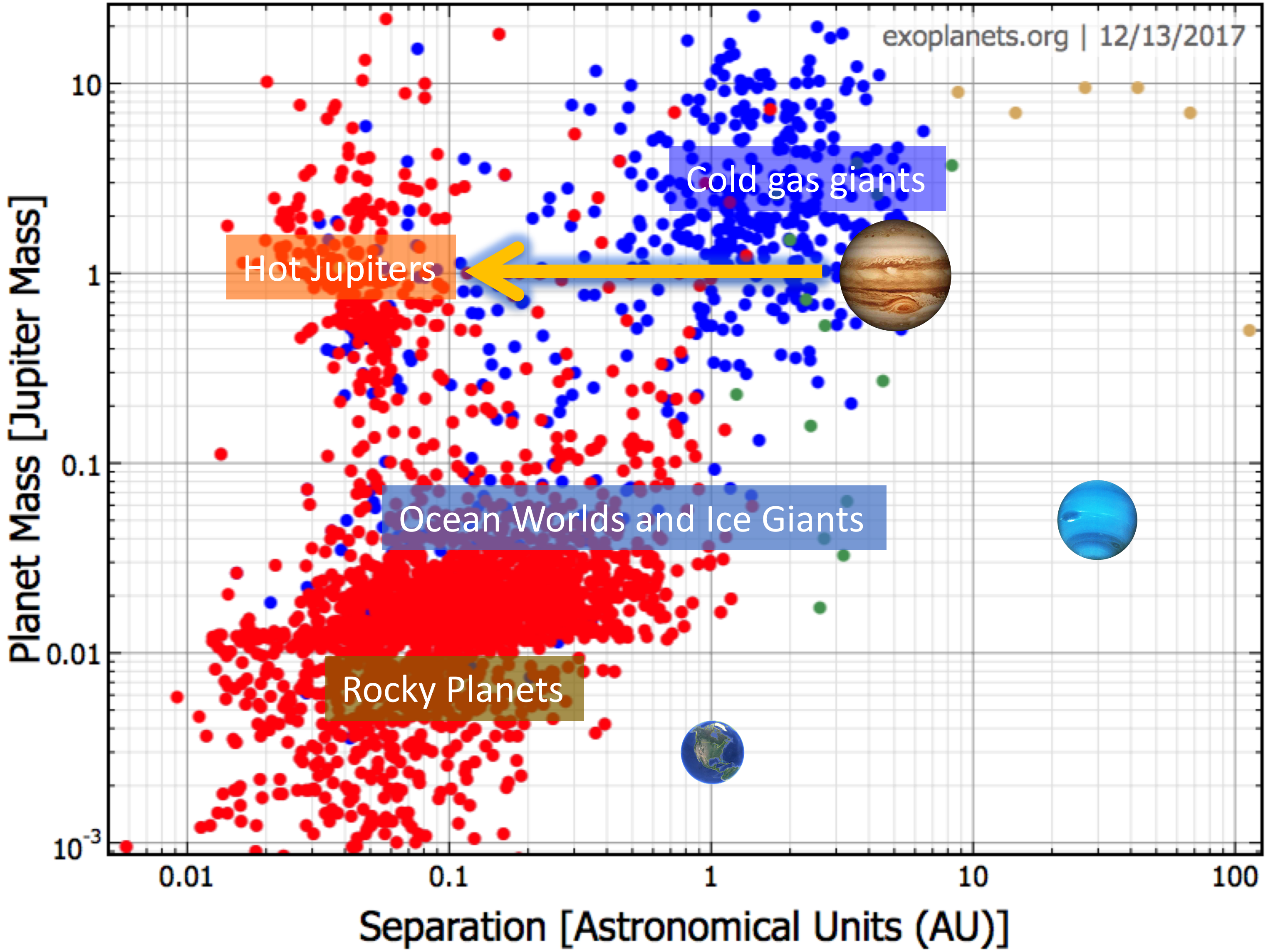
Inner Disk Radii and Exoplanet Orbital Radii

CO fundamental line profiles of Classical T Tauri stars





Exoplanet Populations



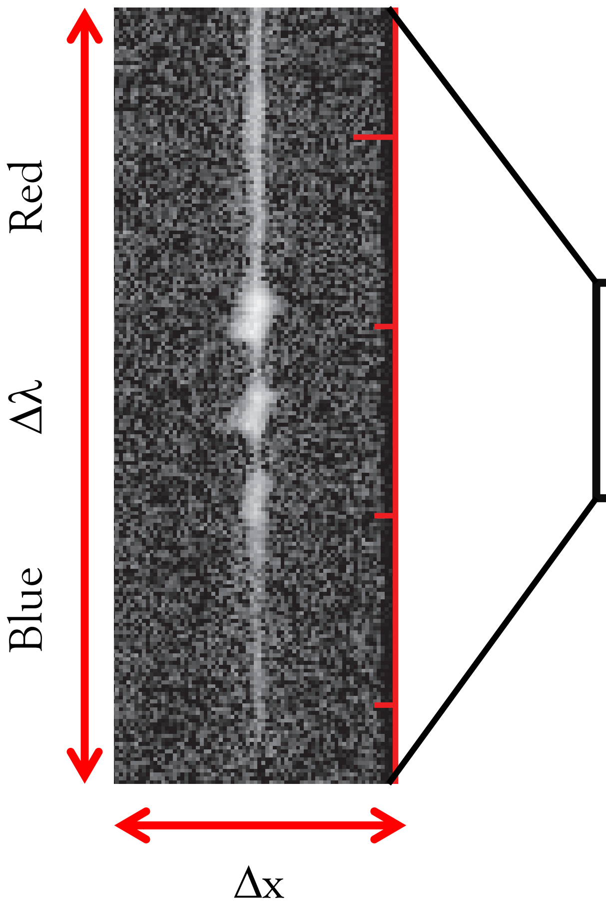
Gas giants can migrate into the inner disk edge

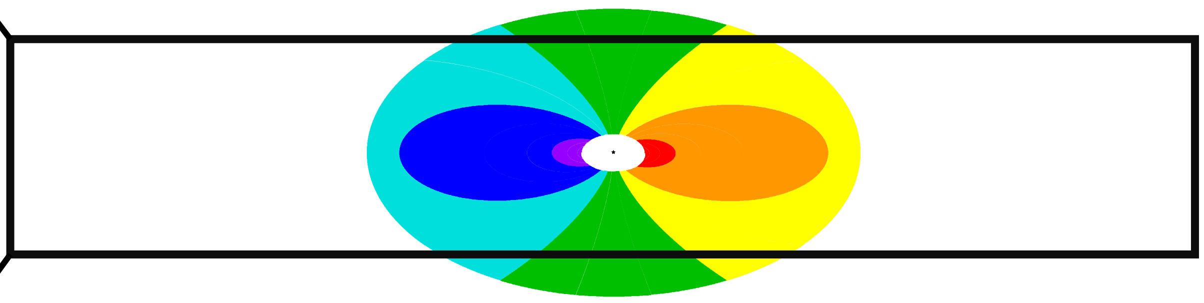
Spectroastrometry

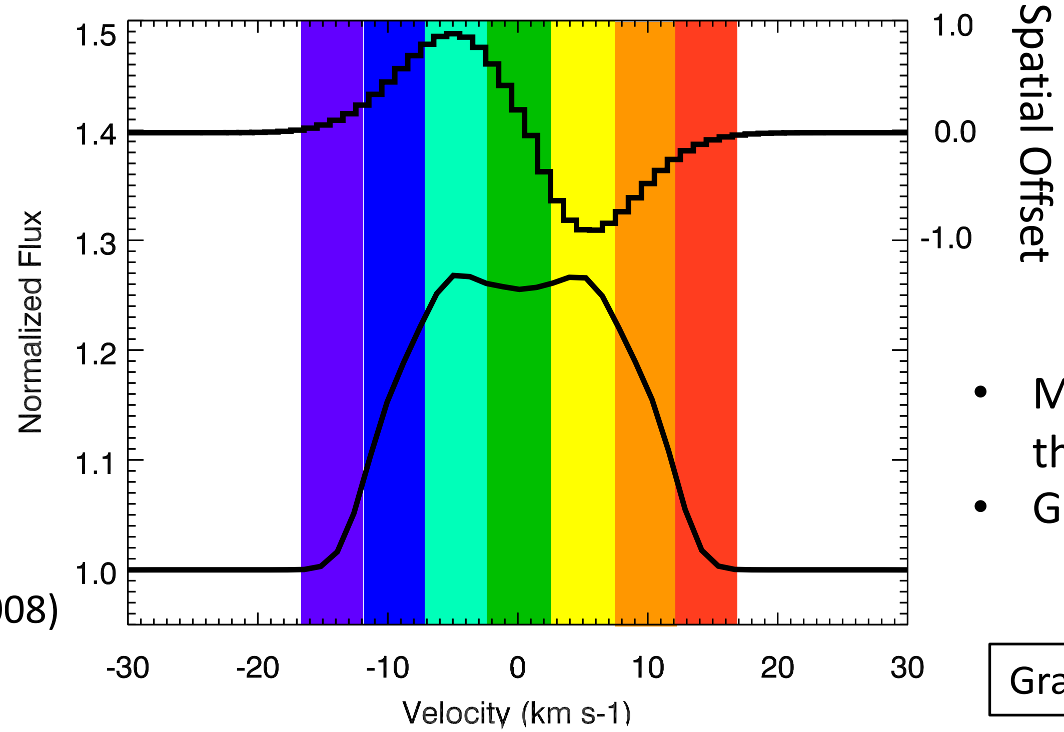
Detecting orbiting circumplanetary disks (birthplaces of moons)

Pontoppidan et al. 2008; Brittain et al. 2010, 2015, 2019; Whelan et al. 2021

Super-Resolution with Spectroastrometry







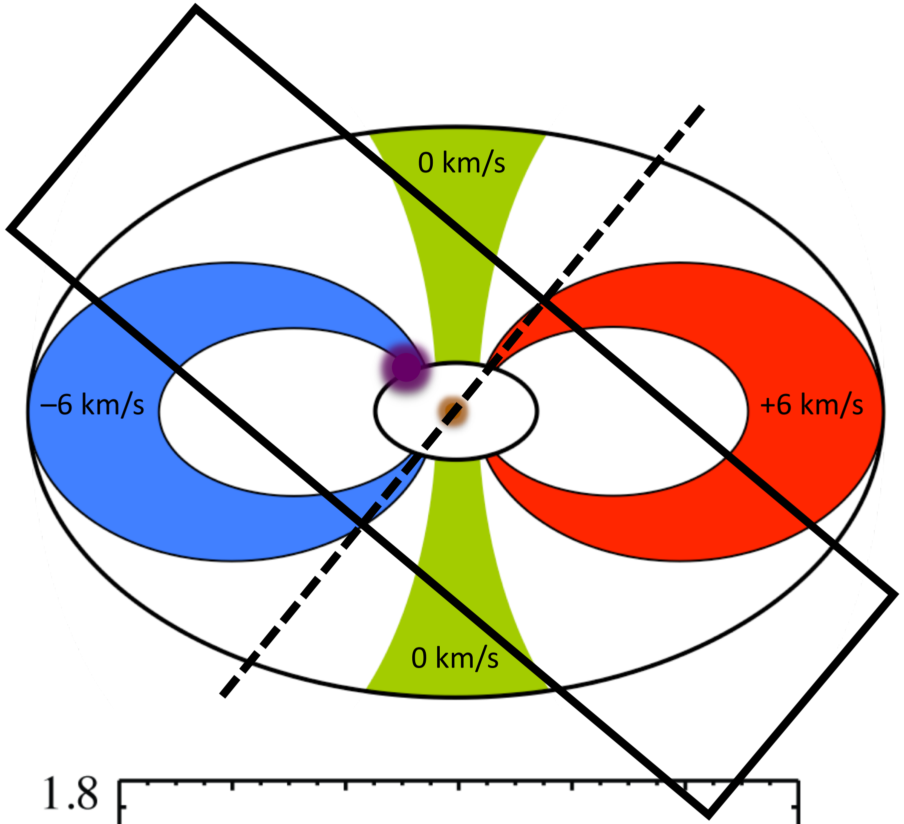
(See Whelan & Garcia 2008)

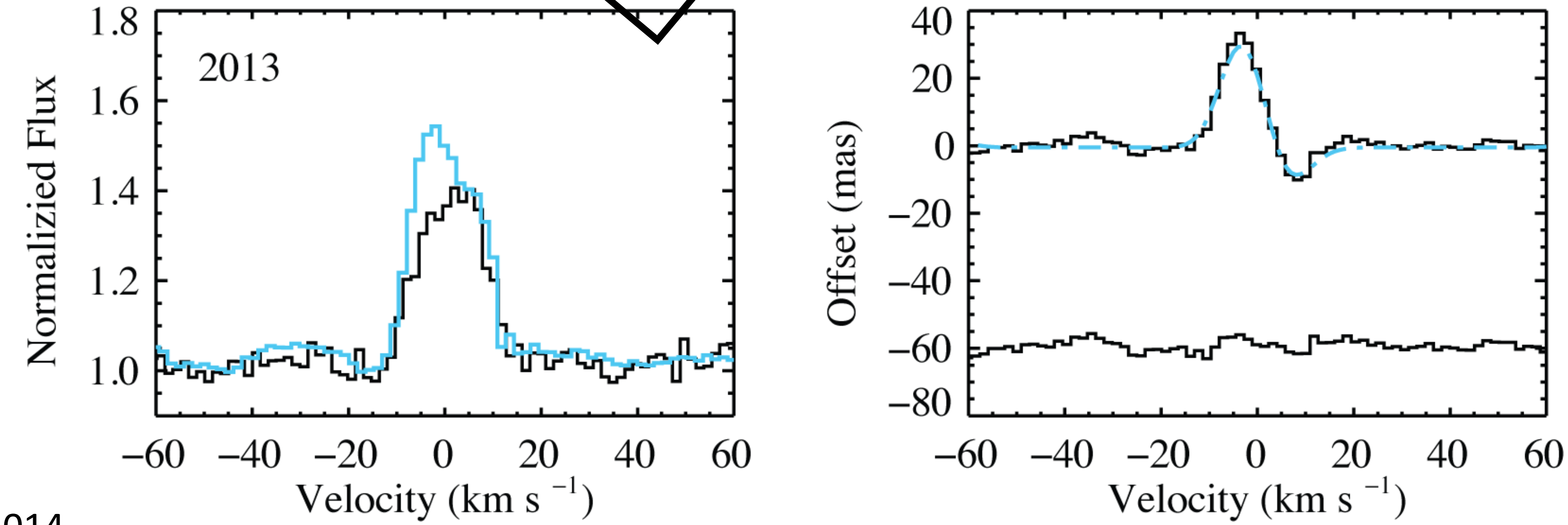
- Magic: spatial centroid more accurate than ang res Δx ~ 0.4 FWHM / SNR
- Good for simple velocity fields

Graphics Credit: Sean Brittain

Spectroastrometry:

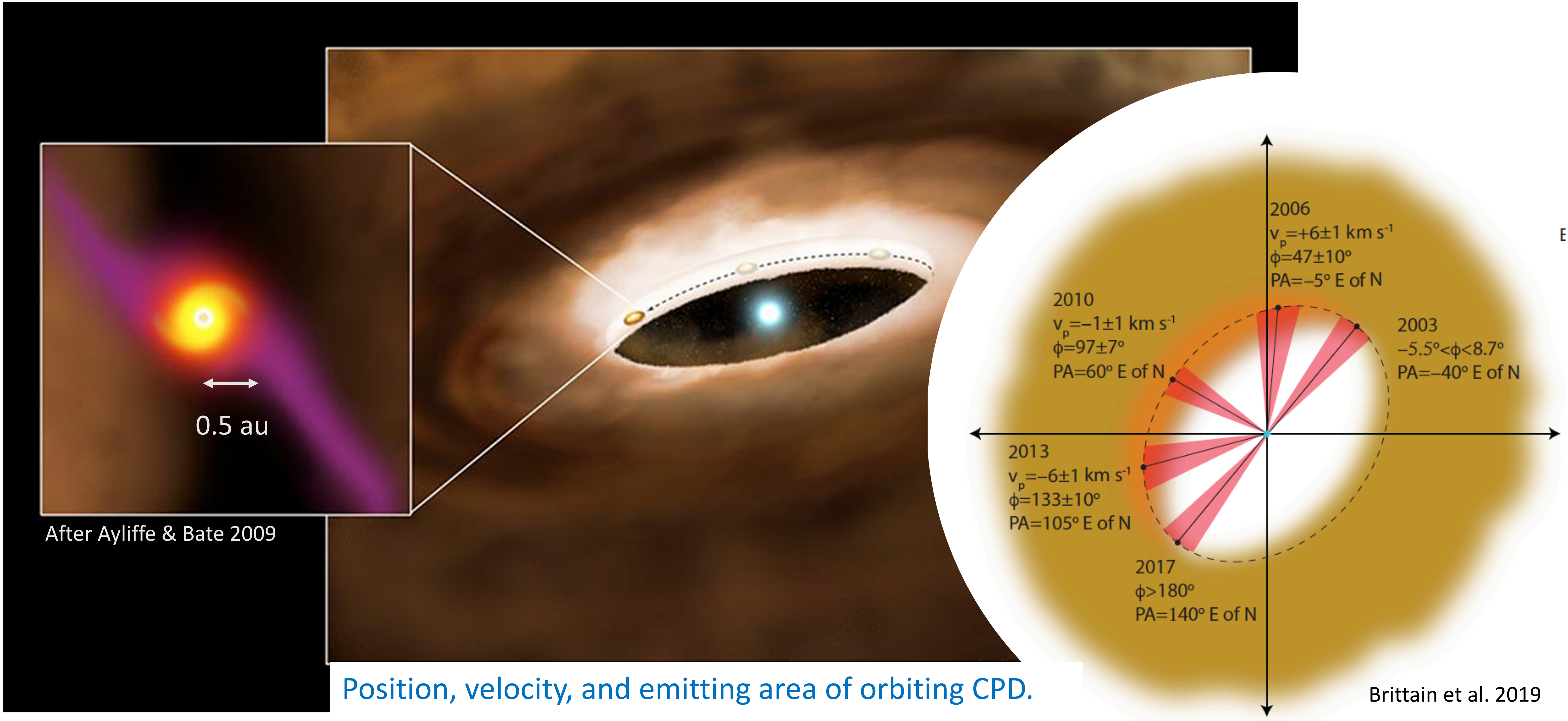
orbiting excess emission source





Brittain et al. 2014

Circumplanetary Disk in HD100546

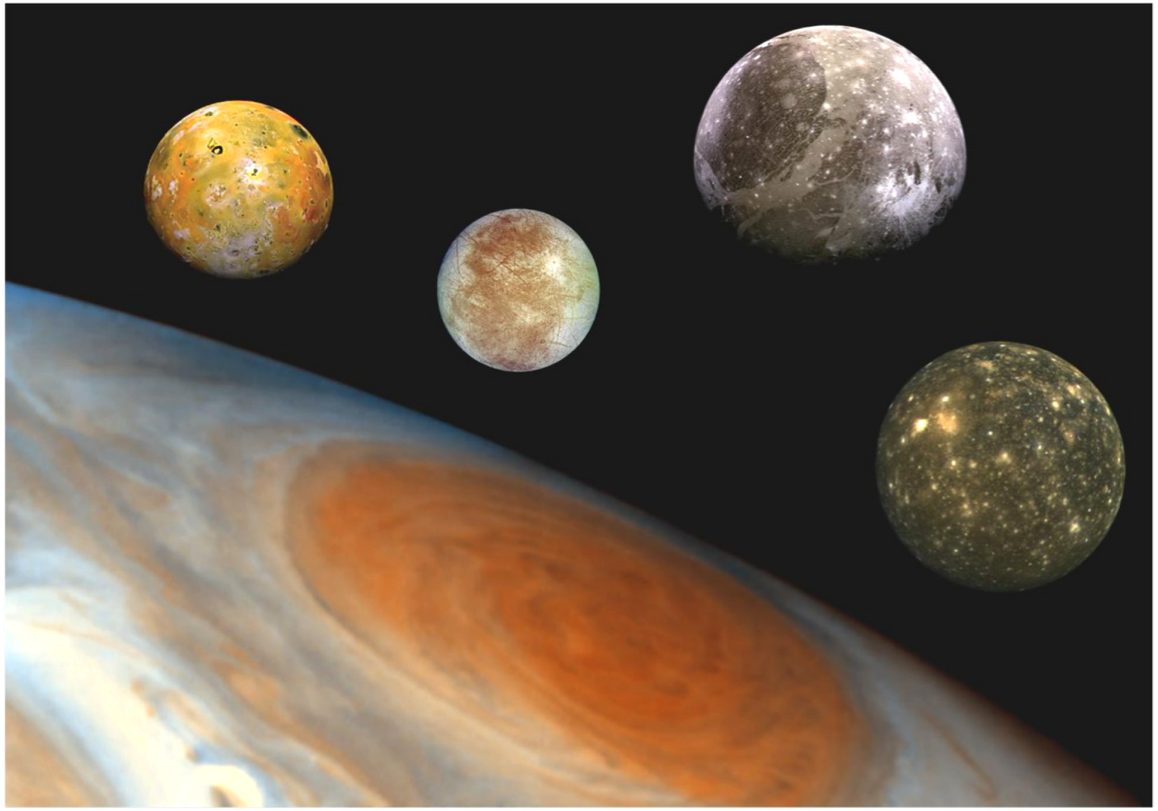


Position, velocity, and emitting area of orbiting CPD.

Spectroastrometry

Enables super-resolution (e.g., to detect orbiting gaseous circumplanetary disk)

- Magic: spatial centroid more accurate than ang res $\Delta x \sim 0.4$ FWHM / SNR
- Good for simple velocity fields

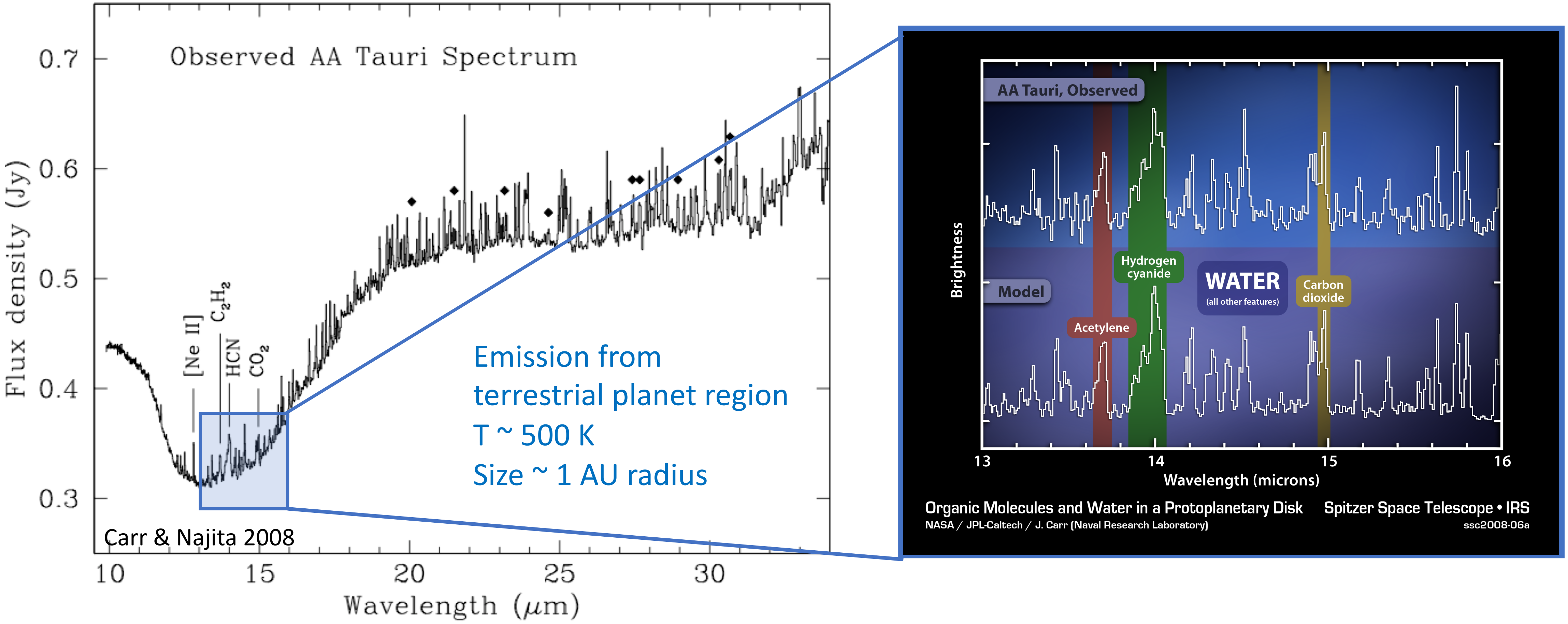


Credit: Galileo Project/Voyager Project/NASA's JPL

MIR molecular spectroscopy

Chemical fingerprint of planetesimal formation

Inner Disk Molecules in Emission

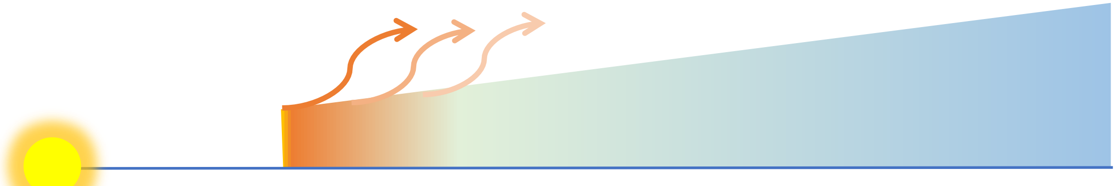


Emission from terrestrial planet region
T ~ 500 K
Size ~ 1 AU radius

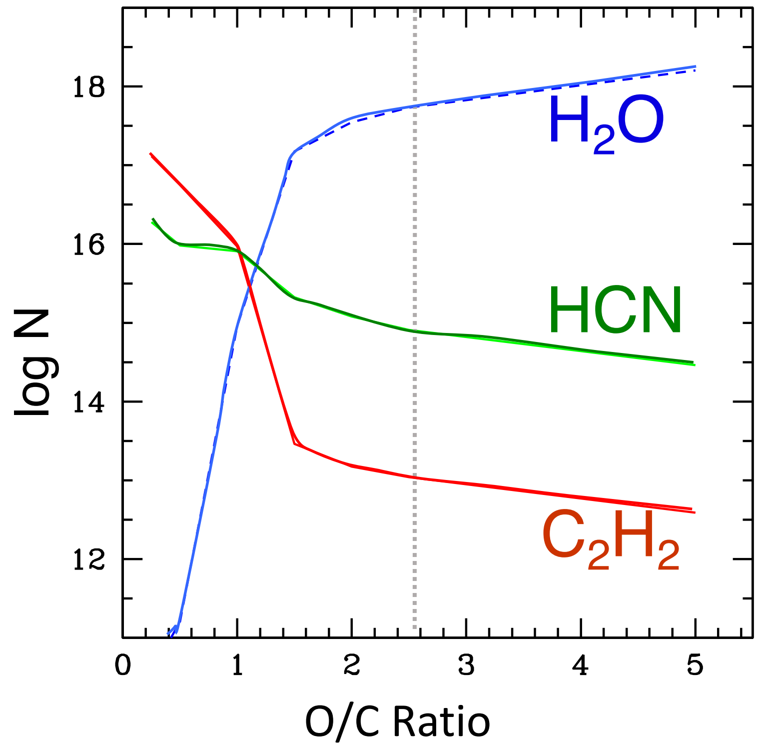
See also Carr & Najita 2011; Salyk et al. 2008, 2011; Pontoppidan et al. 2010

Chemical signature of rising C/O

Warm molecular columns from thermal-chemical models of disk atmospheres at 1AU

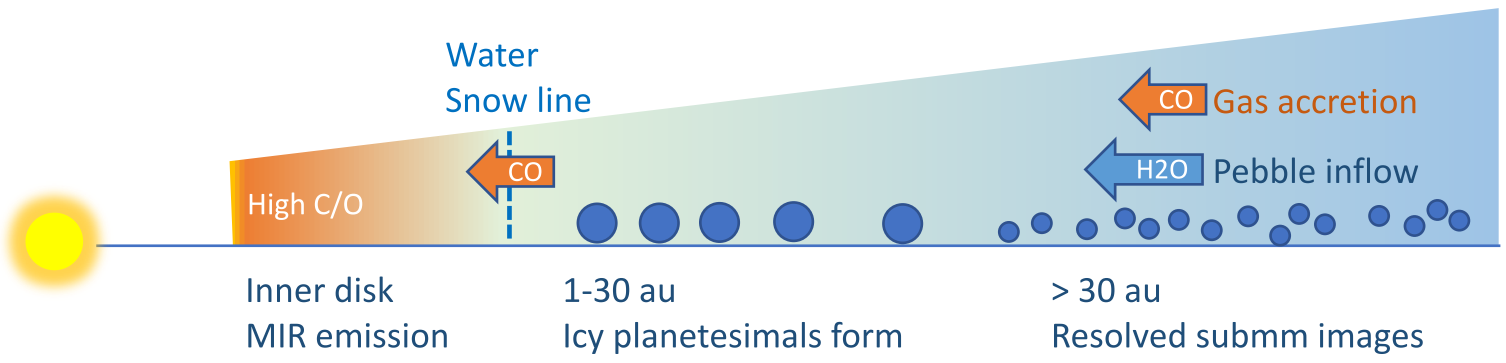


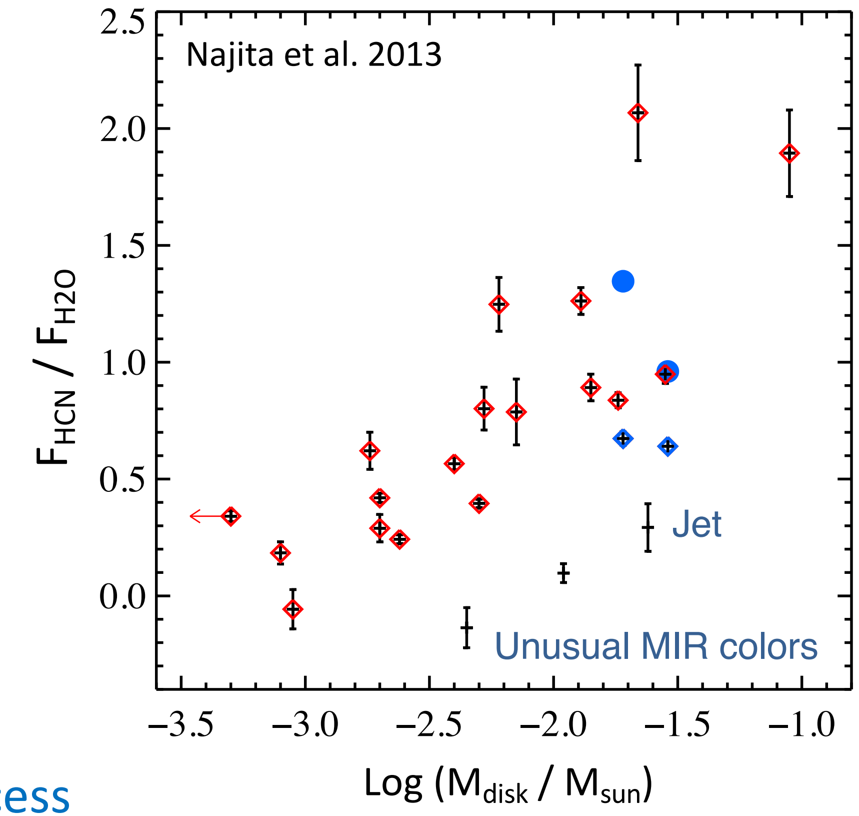
Najita, Adamkovics, Glassgold 2011



Doubling C/O produces 10 fold increase in HCN/H_2O warm column ratio

Chemical signature of planetesimal formation?

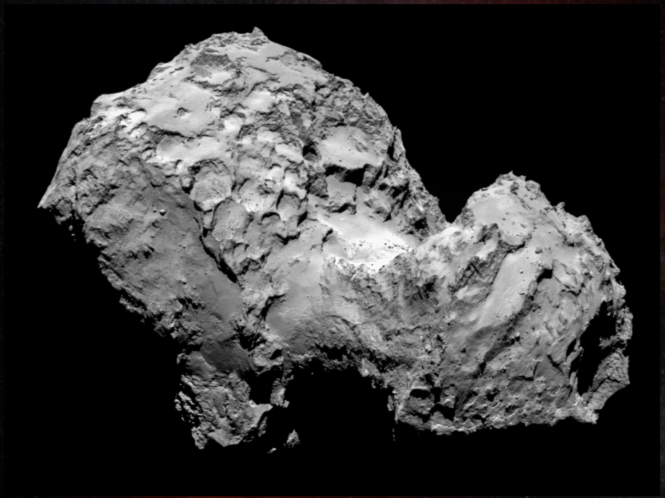




- Icy planetesimals sequester water and O beyond the snow line
- Efficient formation dehydrates inner disk, raises C/O ratio

Chemistry can uniquely illuminate an elusive planet formation process

ALMA Observes HL Tau



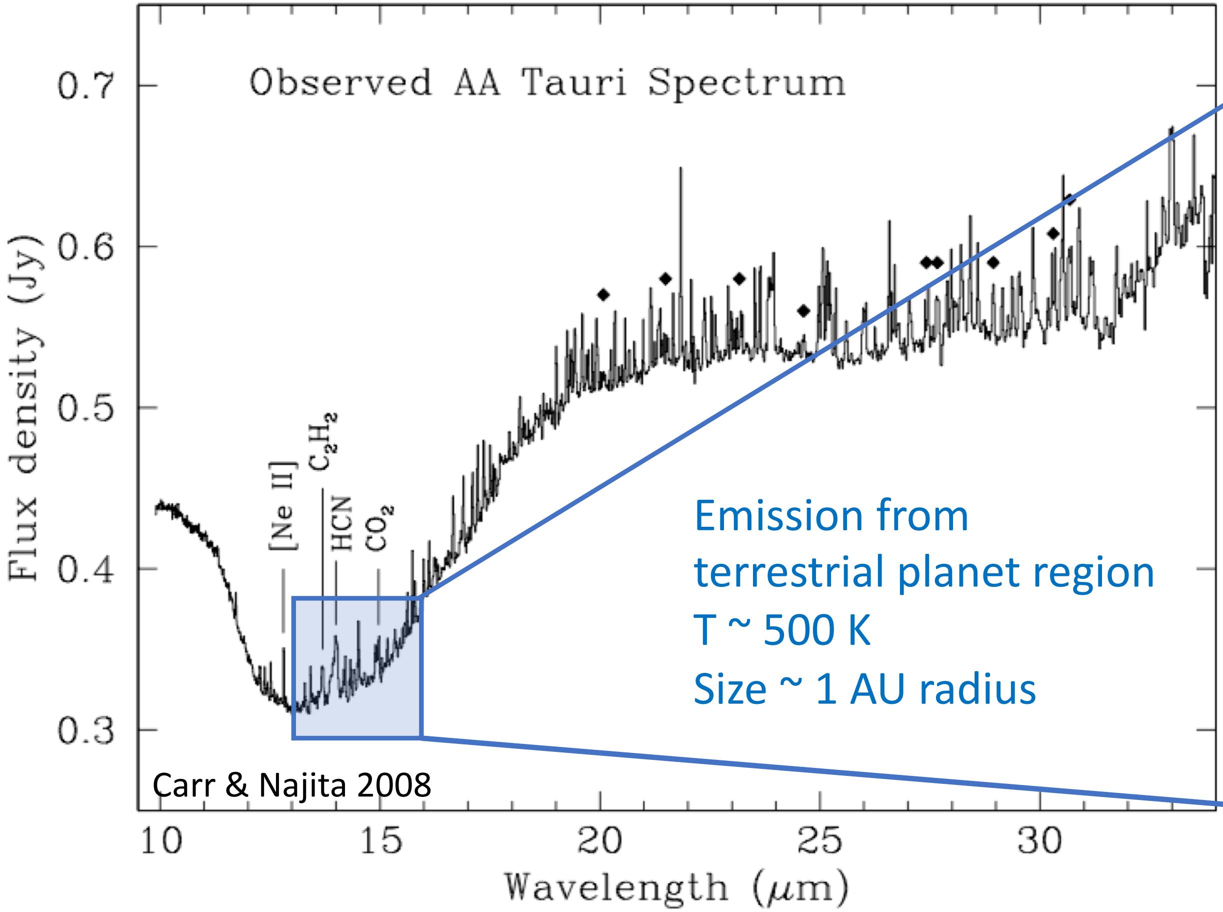
...but observing planetesimals still difficult

Credit: ALMA (ESO/NAOJ/NRAO)

High resolution MIR spectroscopy

Discovery space!

Inner Disk Molecules in Emission



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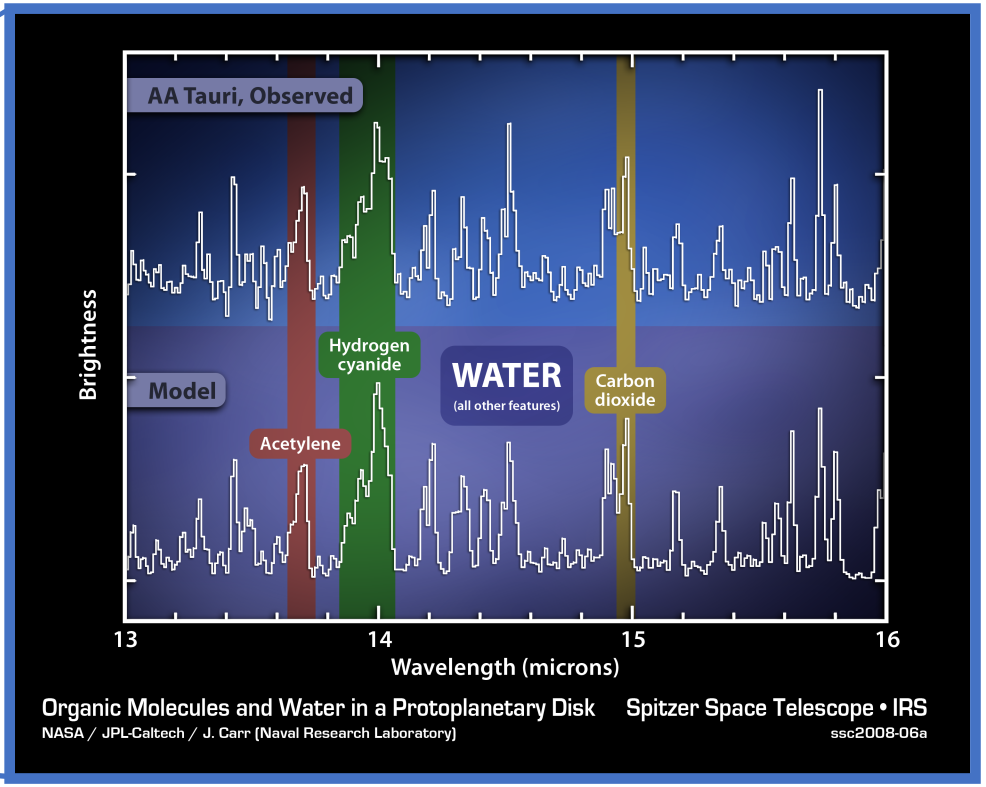
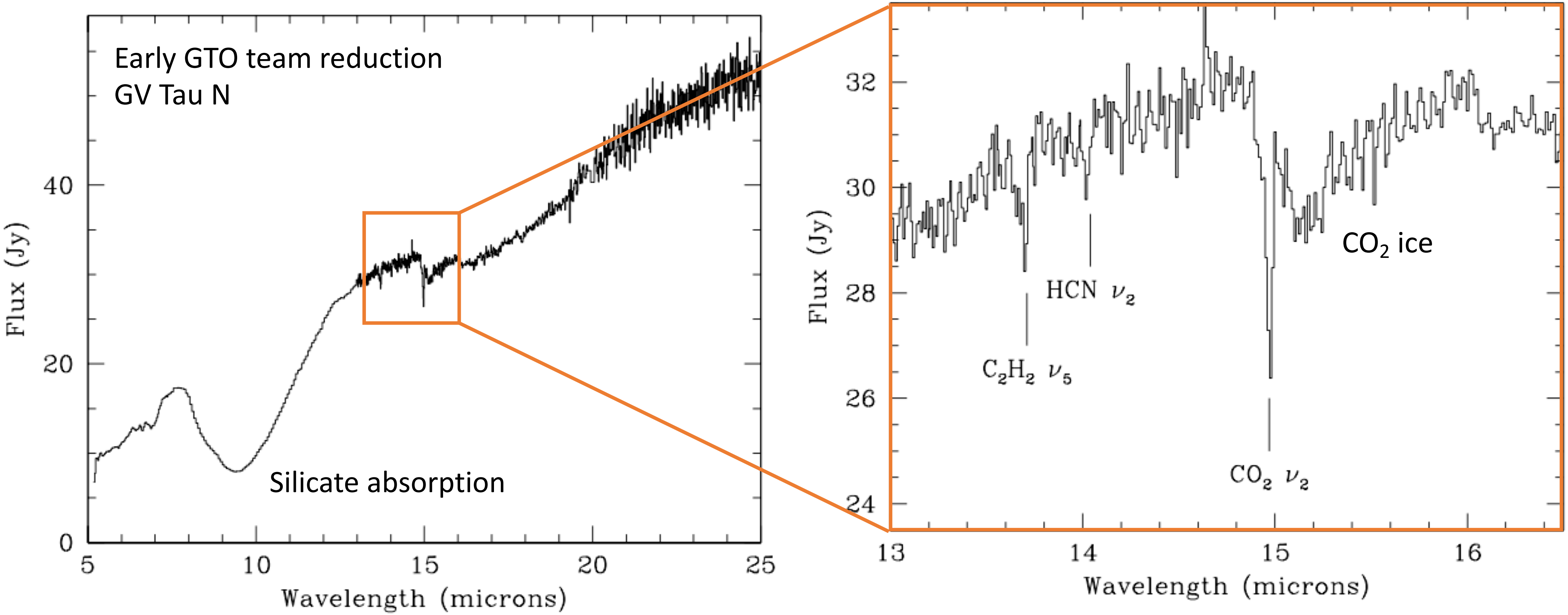


Spitzer/IRS molecular absorption



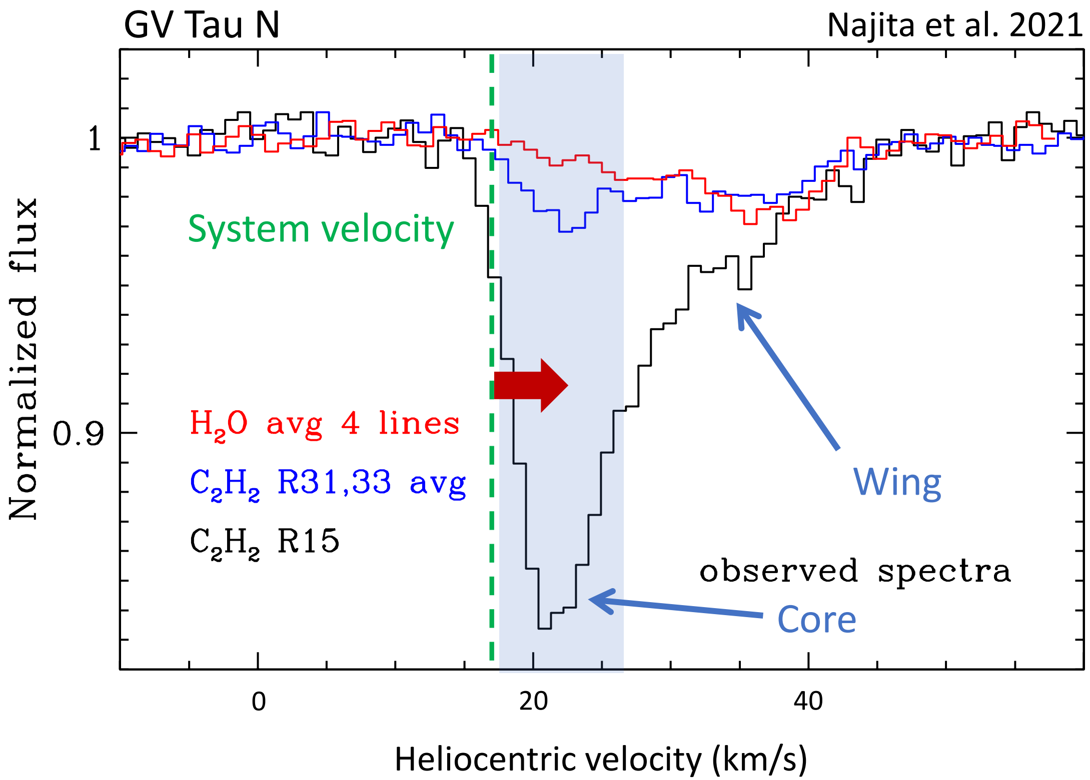
High resolution MIR line profiles

Redshifted line profiles

- 4-20 km/s
- C2H2, HCN, NH3, H2O

Measure component equivalent widths and infer

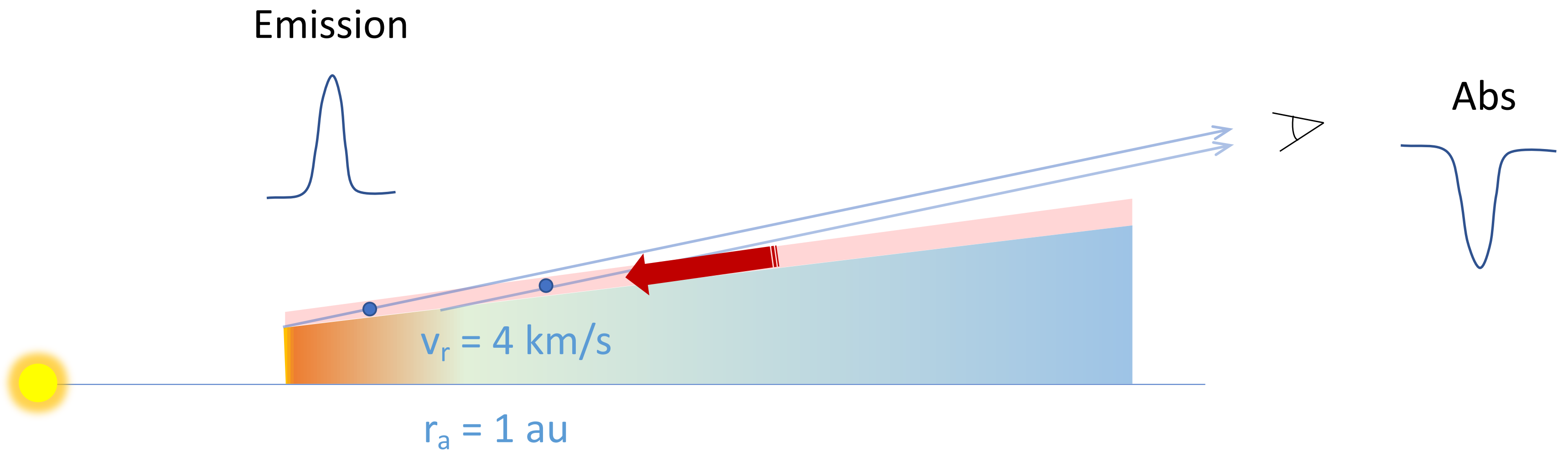
- Temperature T
- Absorption column density N



- Molecular abundances, temperature of inner disks at ~ 1 au
- High column density → disk atmosphere viewed edge on
- Supersonic inflow velocities

Disk accretion in a thin atmosphere

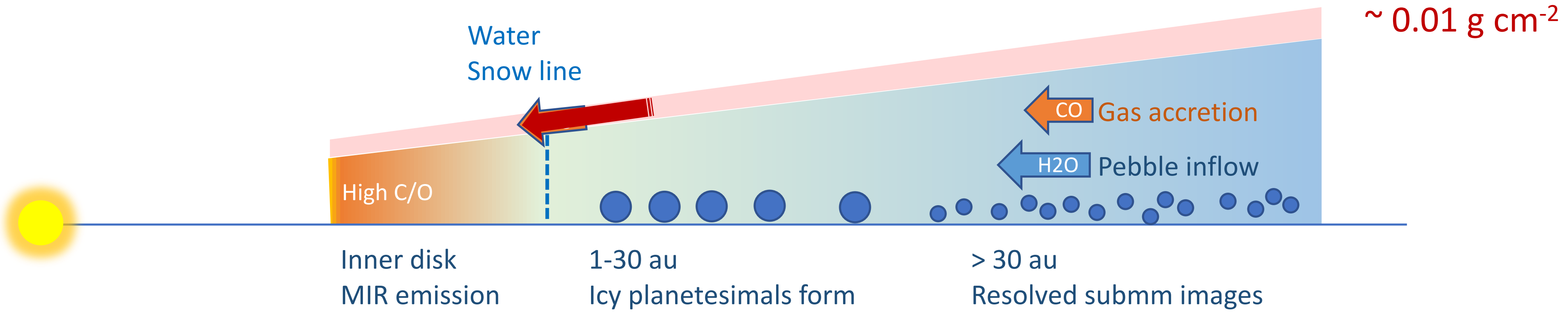
Fast current...overlying a “deep ocean” of the disk...hospitable to planet formation?



Supersonic flow through disk atmosphere at T Tauri stellar accretion rate

Disk accretion in a thin atmosphere

Fast current…overlying a "deep ocean" of the disk…hospitable to planet formation?



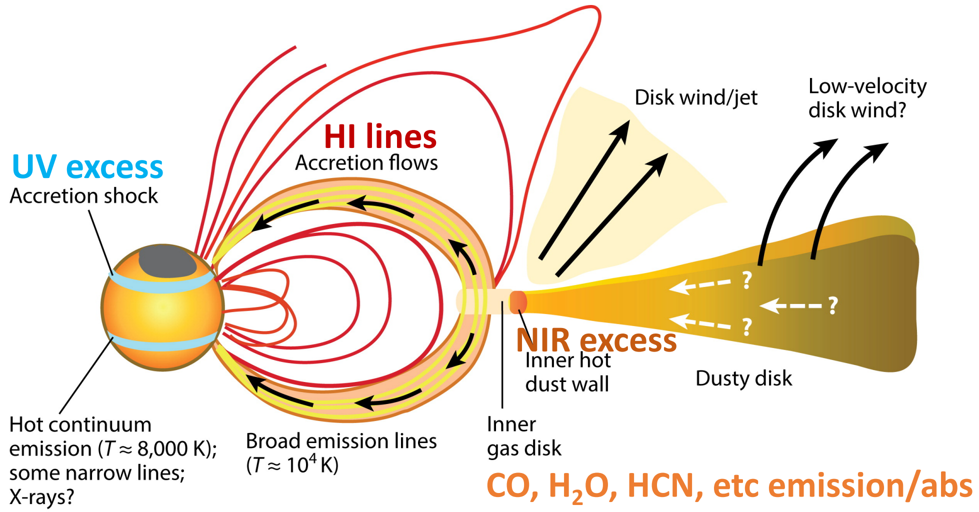
Supersonic flow through disk atmosphere at T Tauri stellar accretion rate

Summary

Rich array of diagnostics from UV to IR

Stellar Accretion:

- Inner disk lifetime
- Nature of transition disks



Disk Emission:

- Structure—inner radii, circumplanetary disk
- Chemistry—planetesimal formation
- Dynamics—how disks accrete