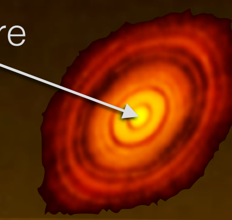
Observing the evolution of exoplanet-forming disks at 0.01-10 au with gas, dust, and wind tracers



Outflows, winds, and disk dispersal

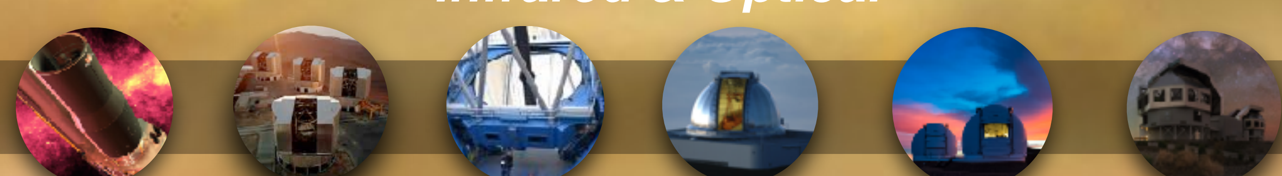
Molecular gas composition & thermo-chemical evolution

Residual gas in inner disk dust cavities at < 10 au

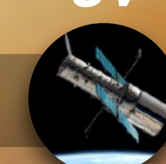
Background artist's impression: Karen L. Teramura, UH IfA

Collaborators: K. Pontoppidan (STScI), Ilaria Pascucci (Un. Arizona), Sean Brittain (Clemson), Ewine van Dishoeck (Leiden), Geoff Blake (Caltech), Colette Salyk (Vassar), Inga Kamp (Groningen), Stefano Antonellini (Belfast), Arthur Bosman (Leiden), Simon Bruderer, Suzan Edwards (Smith College), Uma Gorti (NASA Ames), Min Fang (Un. Arizona), Mario Flock (MPIA), Kevin France (Un. Colorado), Keri Hoadley (Caltech), Madison Walder (Un. Arizona), Mihkel Kama (Cambridge), Antonio Garufi (INAF Arcetri)

Infrared & Optical



UV



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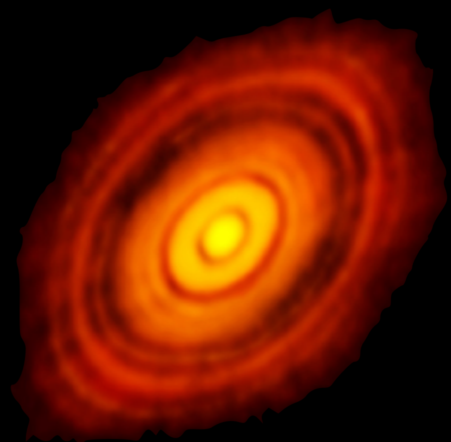
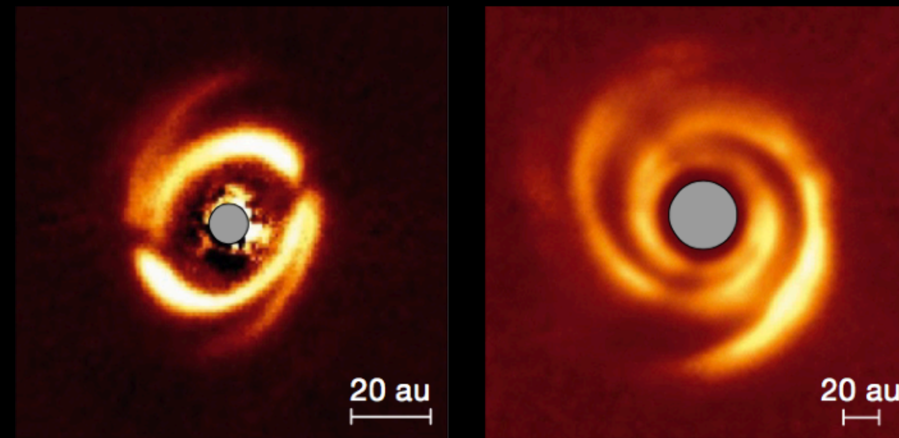
Dr. Andrea Banzatti

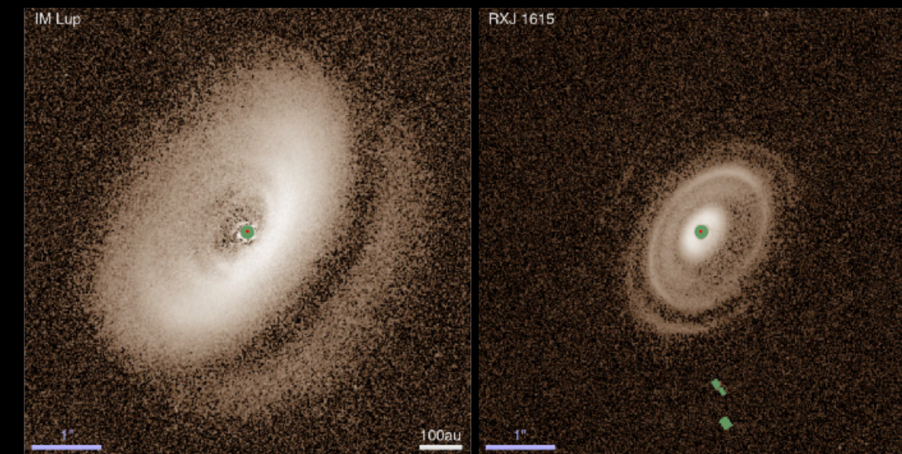
A:



ALMA Partn. 2015



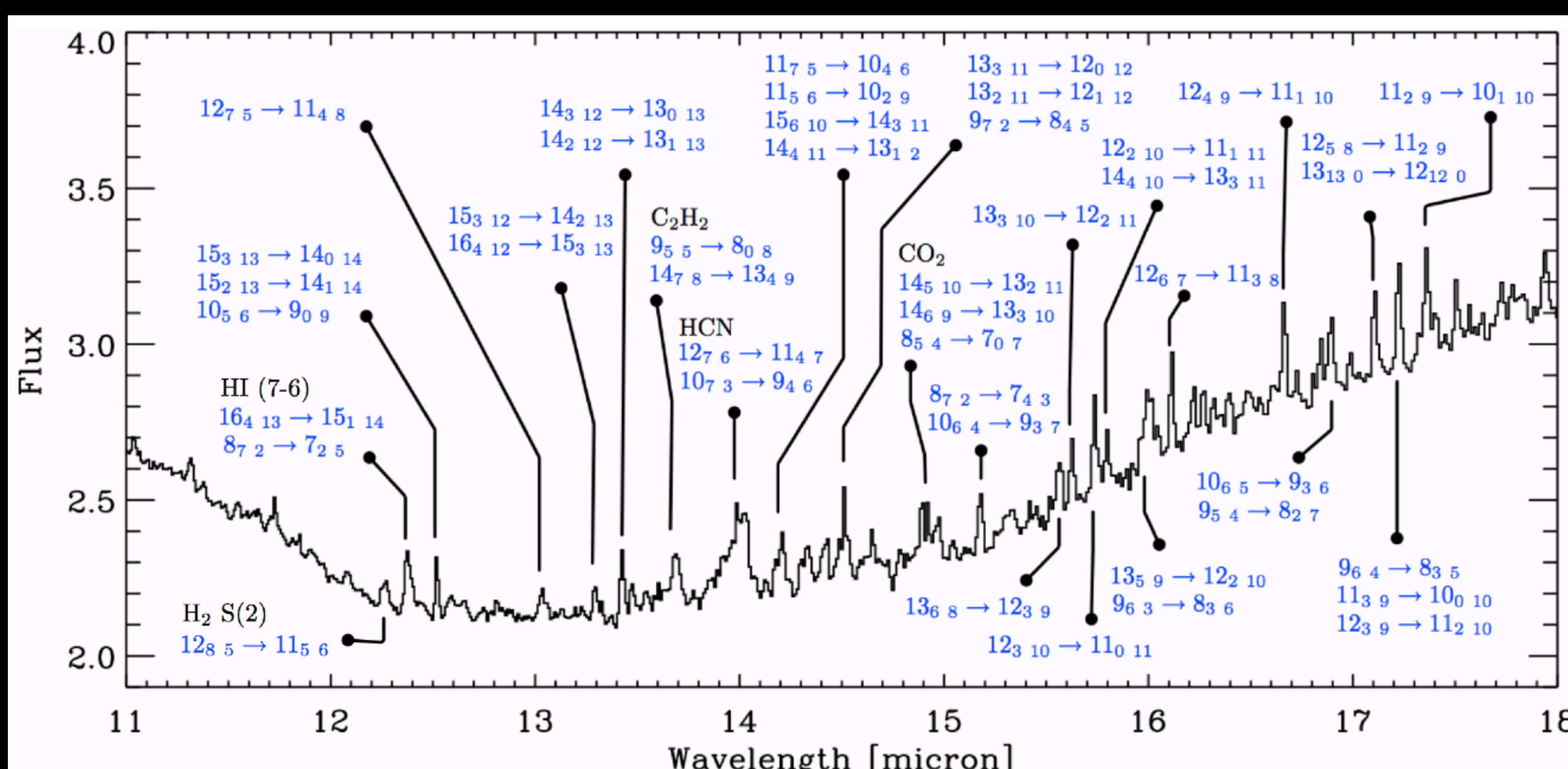
Garufi et al. 2017



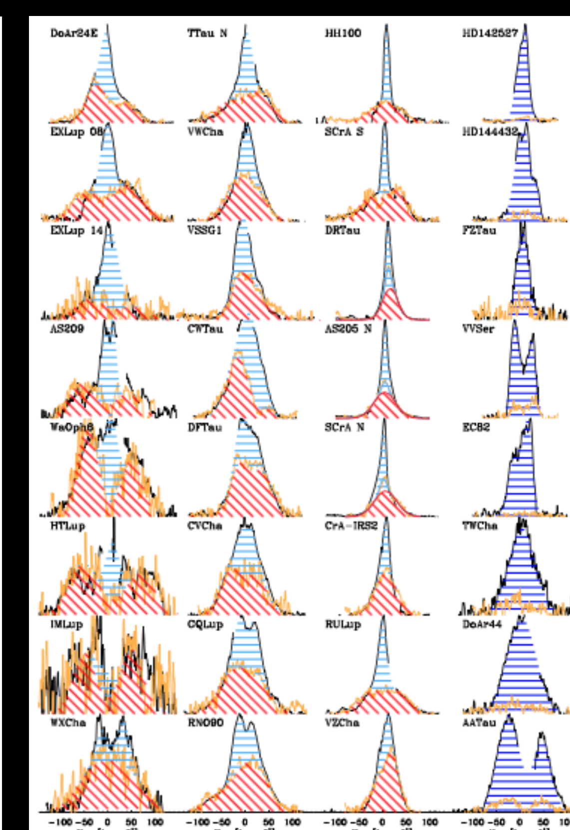
Avenhaus et al. 2018

“If an image is worth a thousand words…
a spectrum is worth a million!”

B:



Pontoppidan et al. 2010



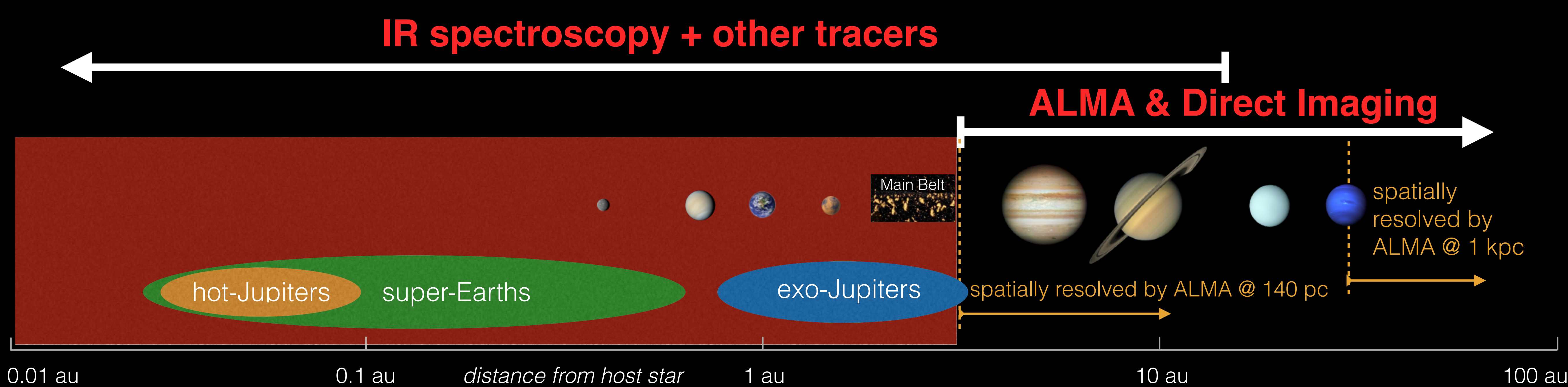
Banzatti& Pontoppidan 2015

Observing the **evolution** of exoplanet-forming disks at **0.01-10 au** with gas, dust, and wind **tracers**

1. **inner disk region**: at 0.01-10 au —> exoplanets, H_2O snow line, winds, cavities, dispersal, accretion, … beyond reach of imagers

2. **synergy of tracers**: multiple molecules, gas + dust , disk + wind , data + models *(doesn't this look like the perfect world to have??..)*

3. **evolution**: you will see in the next slides…



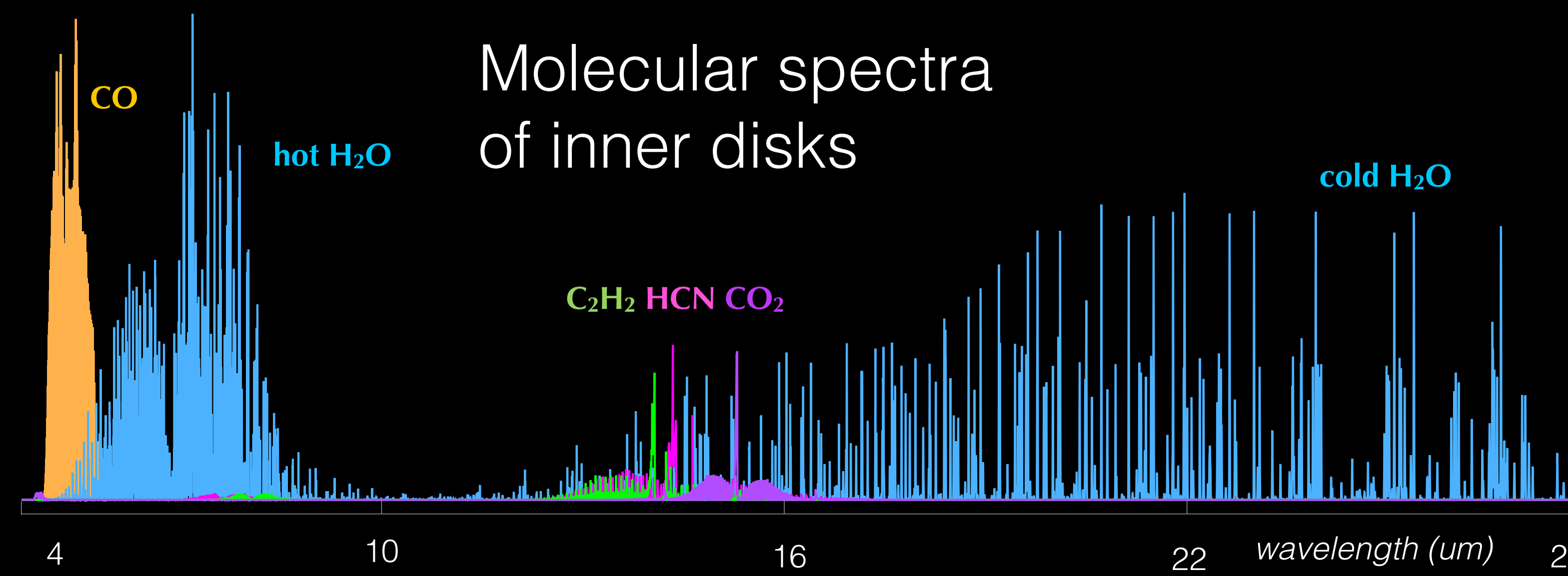
N/MIR molecular spectroscopy to study inner disks

Wavelengths: ~2-40 micron (—> hot gas)

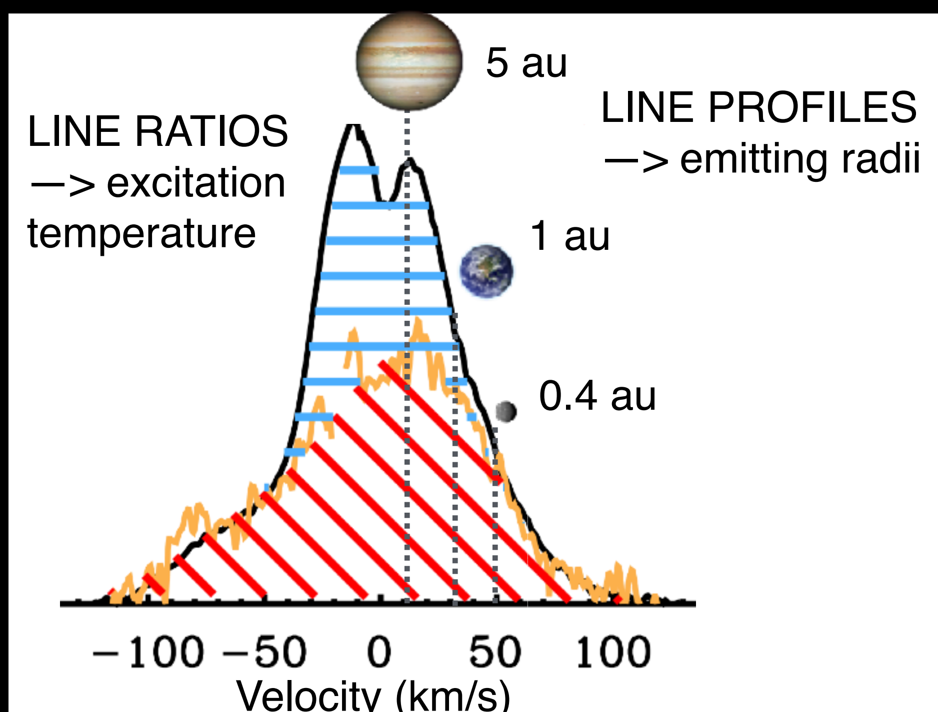
Species: CO, H_2O, OH, HCN, C_2H_2, CO_2, & more

Spectral Resolution: 3-15 km/s (ground)

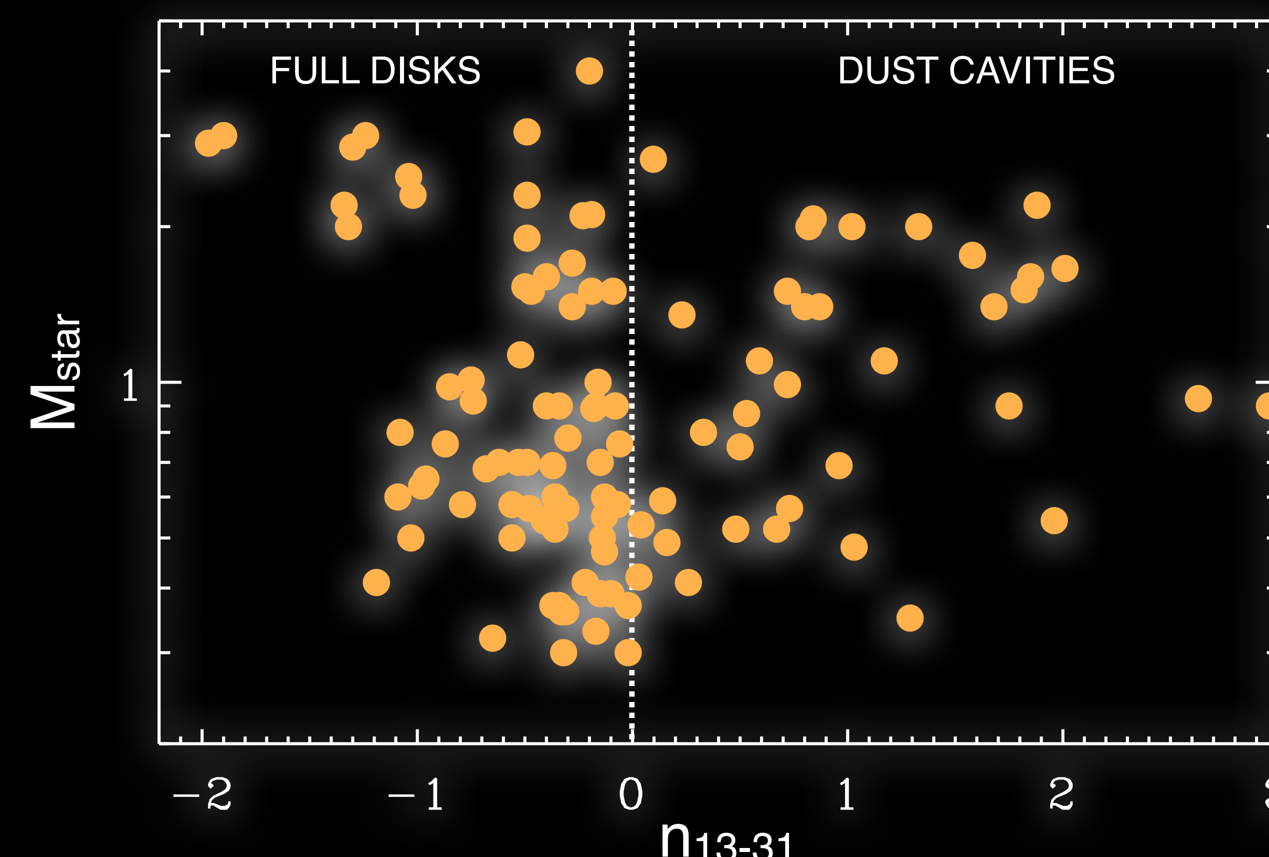
Samples: ~100 disks with multiple tracers, ~ 1000 spectra *(ask about your favorite disk!)*



(e.g. Carr & Najita 2008; Pontoppidan et al. 2010; Salyk et al. 2011; Banzatti et al. 2012, 2017)



Banzatti et al. 2015a, 2017, 2018, Banzatti & Pontoppidan 2015 (Najita et al. 2003, Brittain et al. 2007; Pontoppidan et al. 2008; Salyk et al. 2011, Carmona et al. 2017, …)

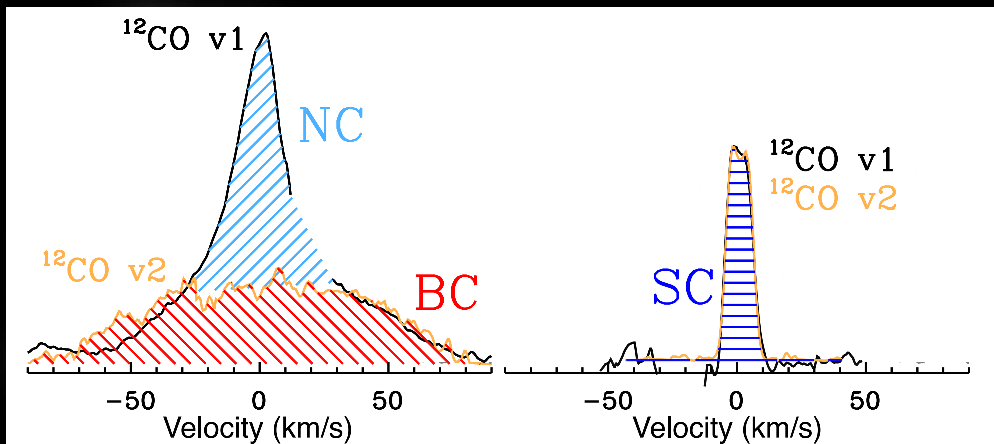


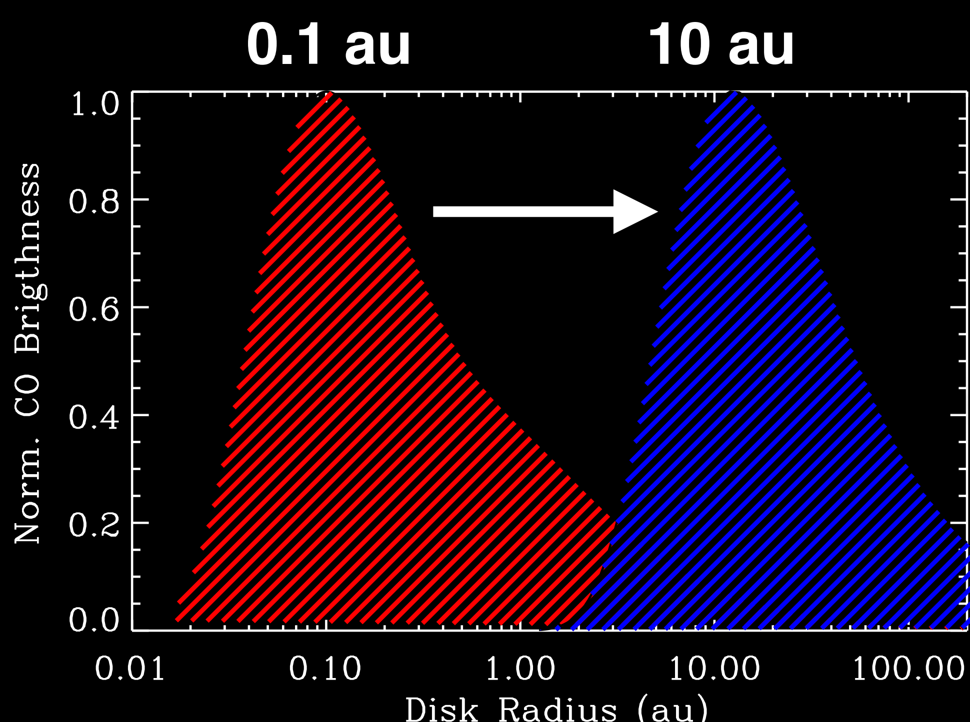
Bottom line: *we probe hot gas, we can access several major chemical species (including water!), and from the line profile we can reconstruct the radial emission at 0.01-10 au*

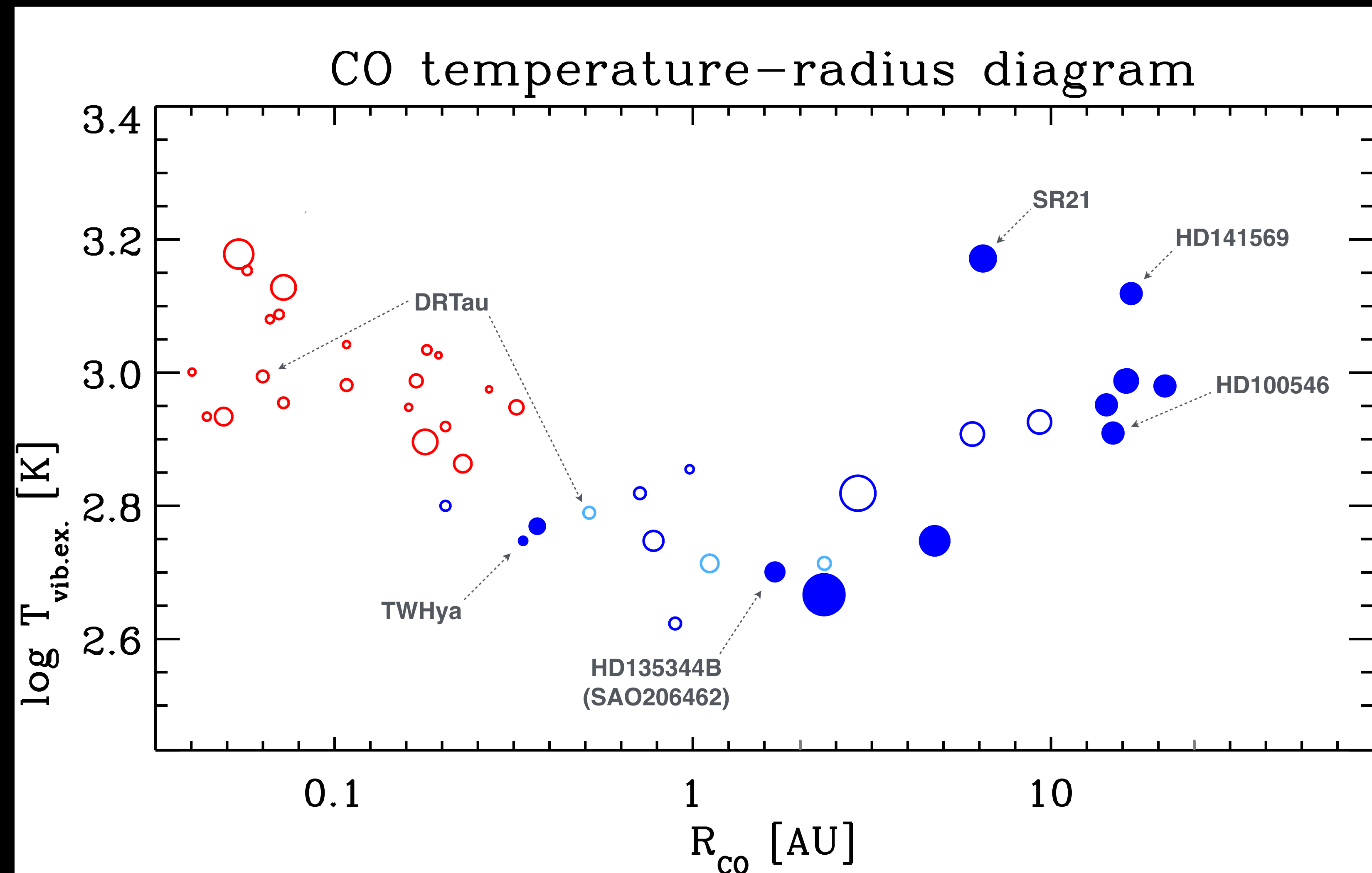
Results: CO as a probe of inner disk cavities (2015)

(Banzatti & Pontoppidan 2015)

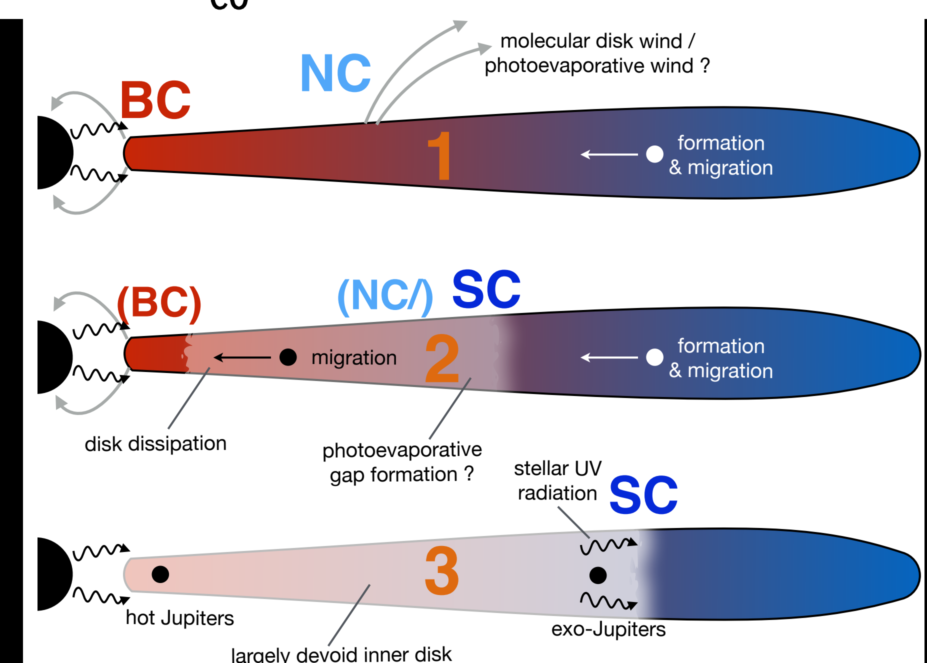
CRIRES survey: Pontoppidan et al. 2011, Brown et al. 2013







(Banzatti & Pontoppidan 2015)



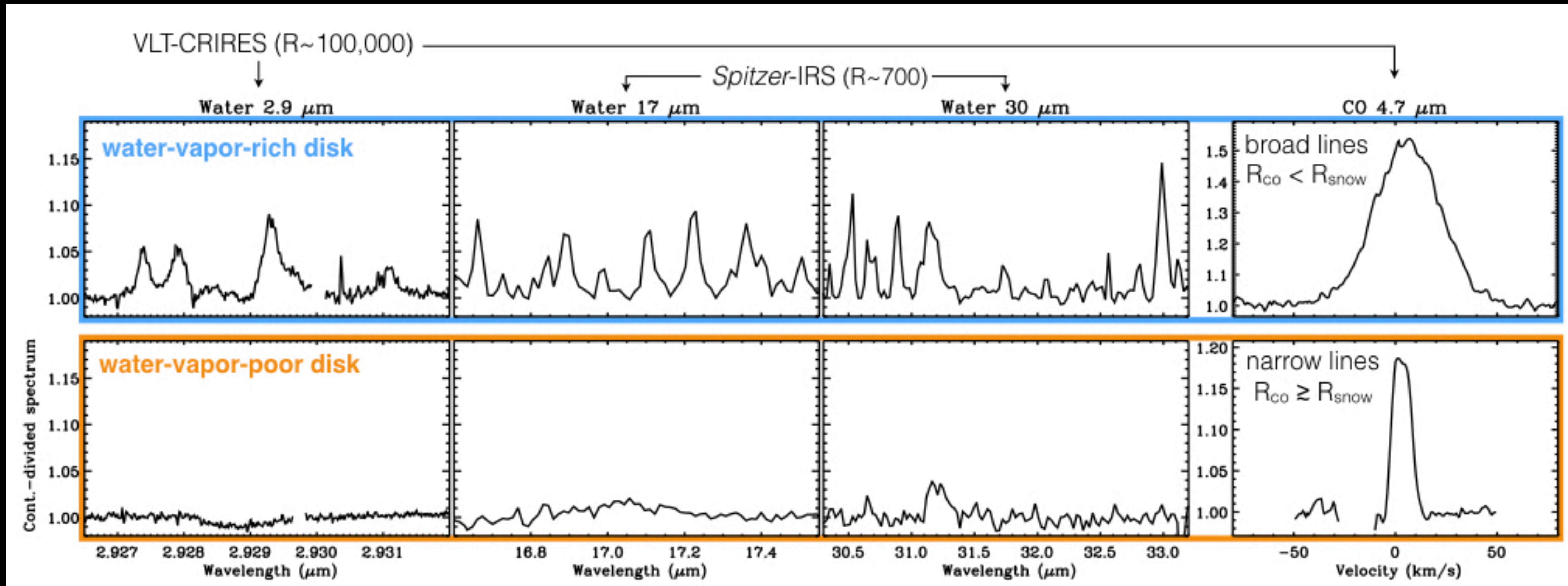
Bottom line: *IR CO emission traces the formation of inner disk cavities, and gives the potential to measure temperature and gas density profiles at < 10 au*

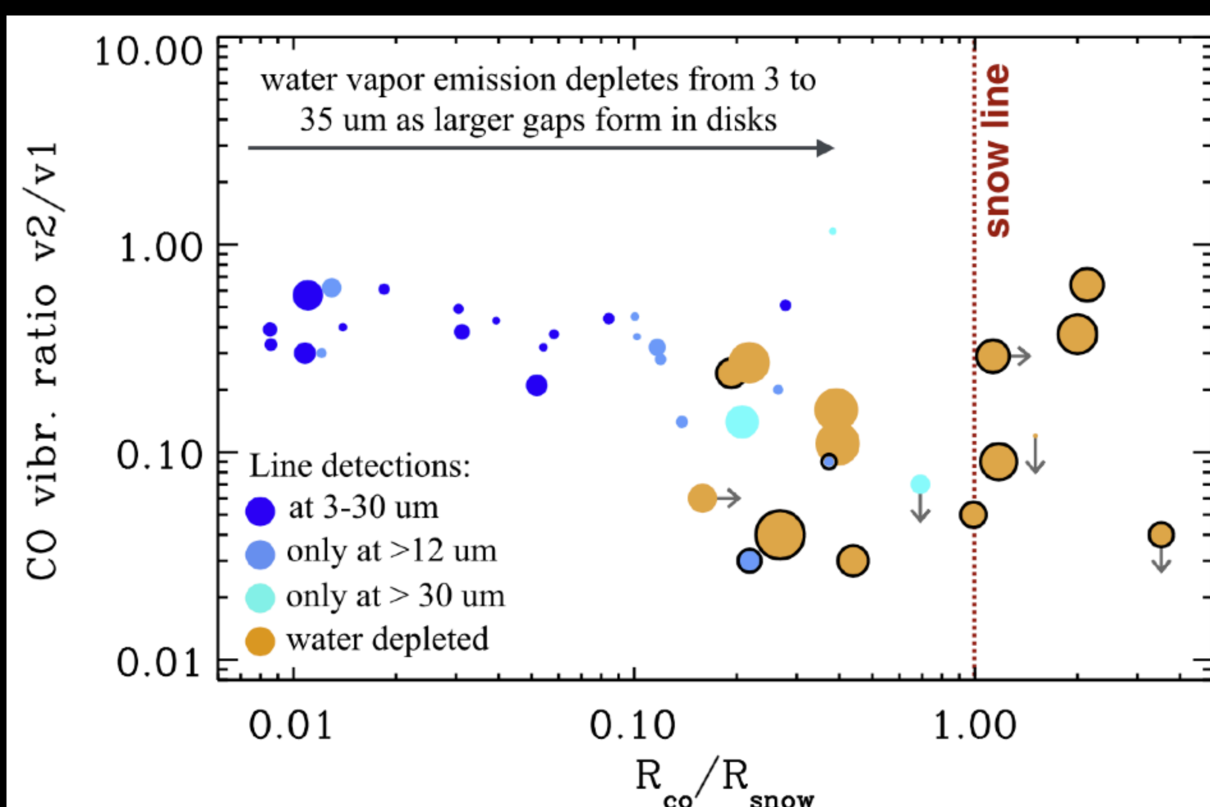
(see also poster by Andres Carmona)

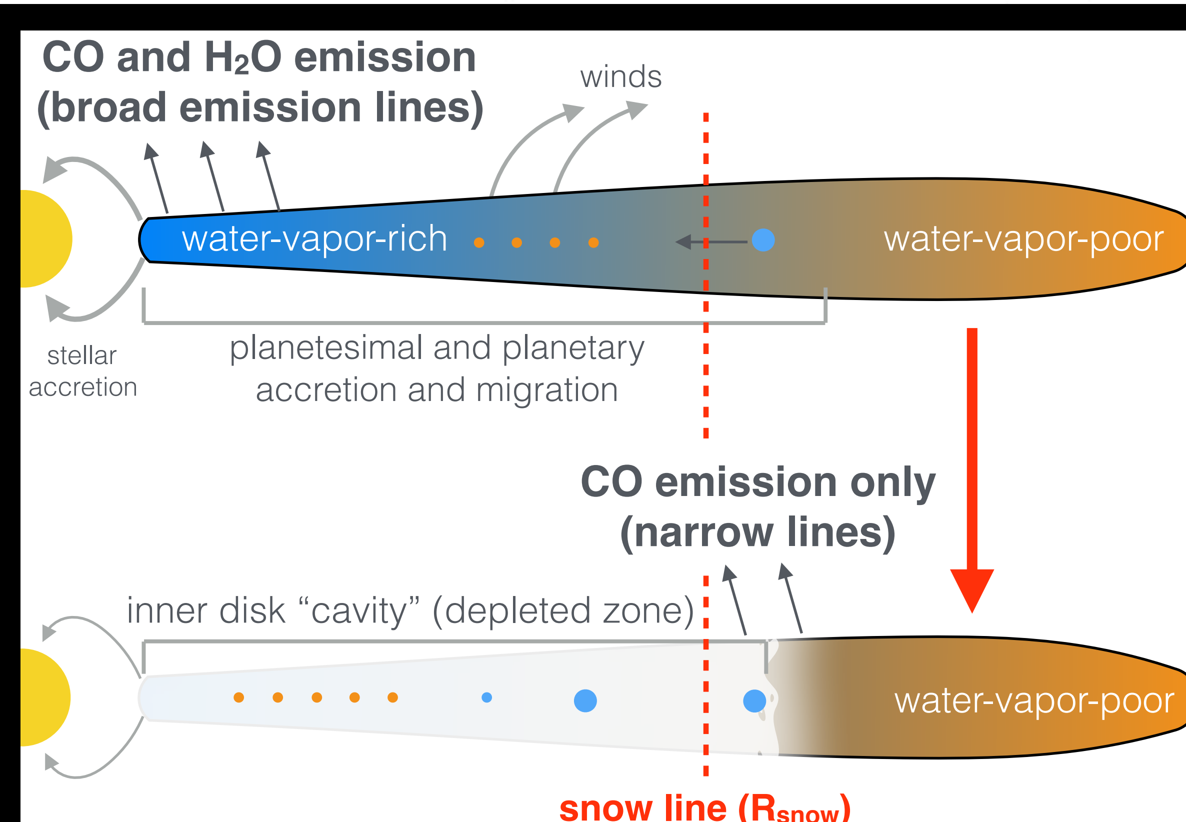
Results: CO + H_2O as a probe of evolving chemistry (2017)

(Banzatti et al. 2017)

CRIRES + *Spitzer* survey of 55 disks with CO, H2O, OH spectra



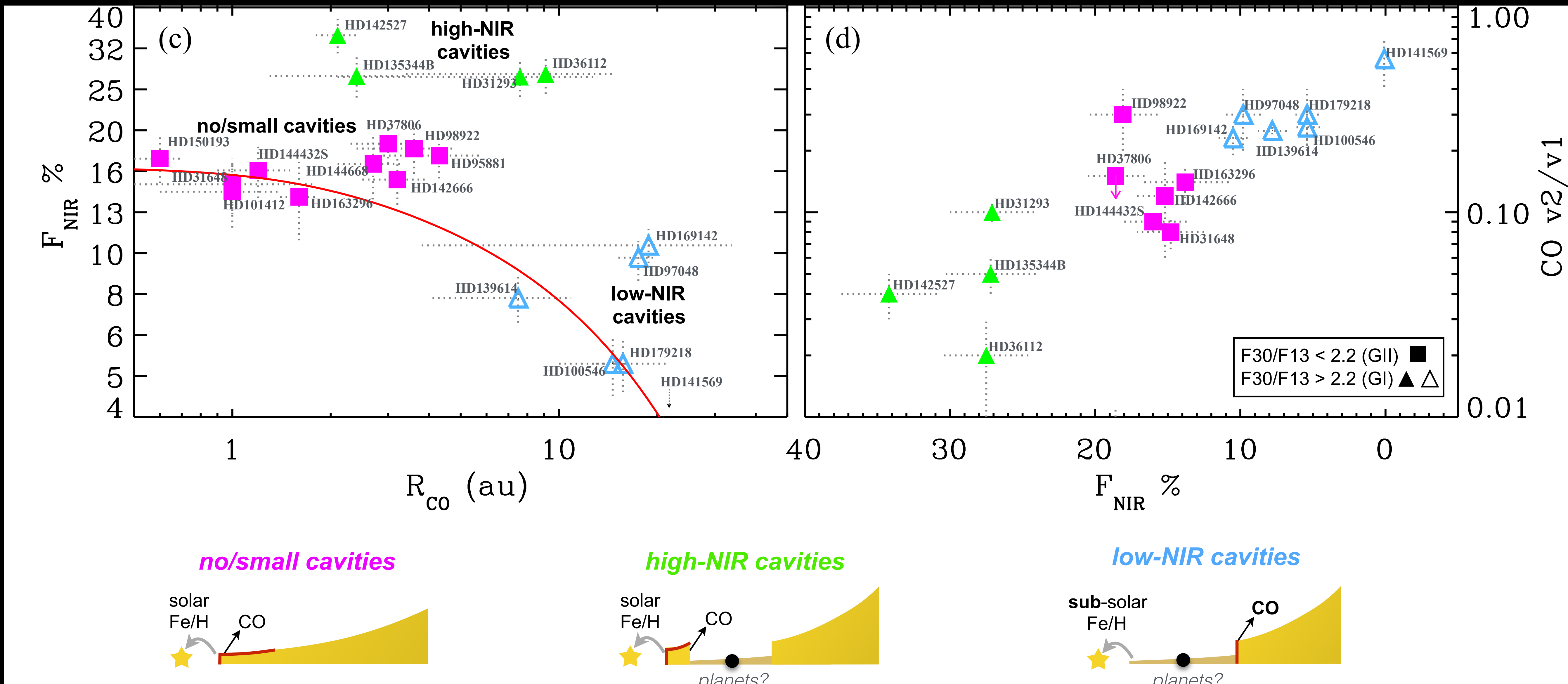




Bottom line: *we can study how inner disks evolve chemically and "dry out" as cavities form*

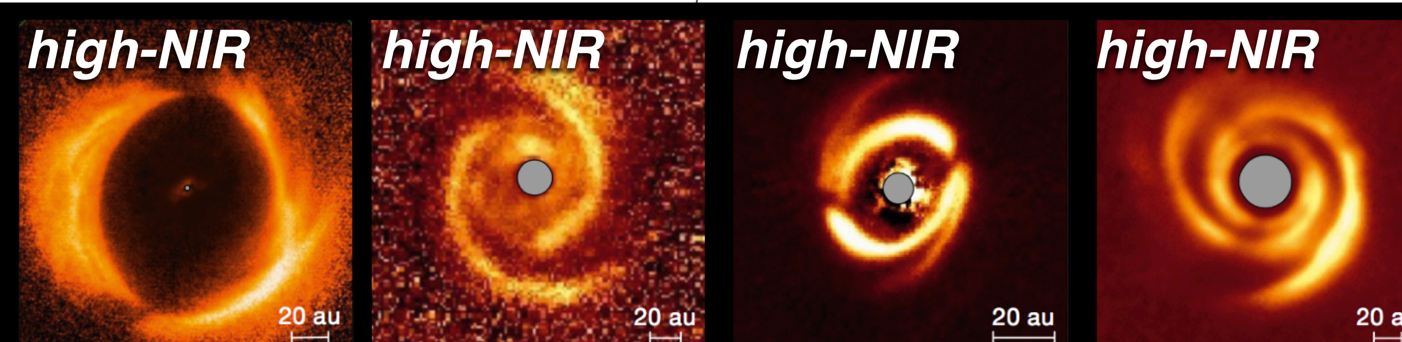
Results: links and co-evolution of CO and dust (2018)

(Banzatti, Garufi, Kama et al. 2018)



Bottom line(s):

1. CO and dust co-evolve in inner disks
2. two types of Herbig inner disk cavities: "high-NIR" and "low-NIR"

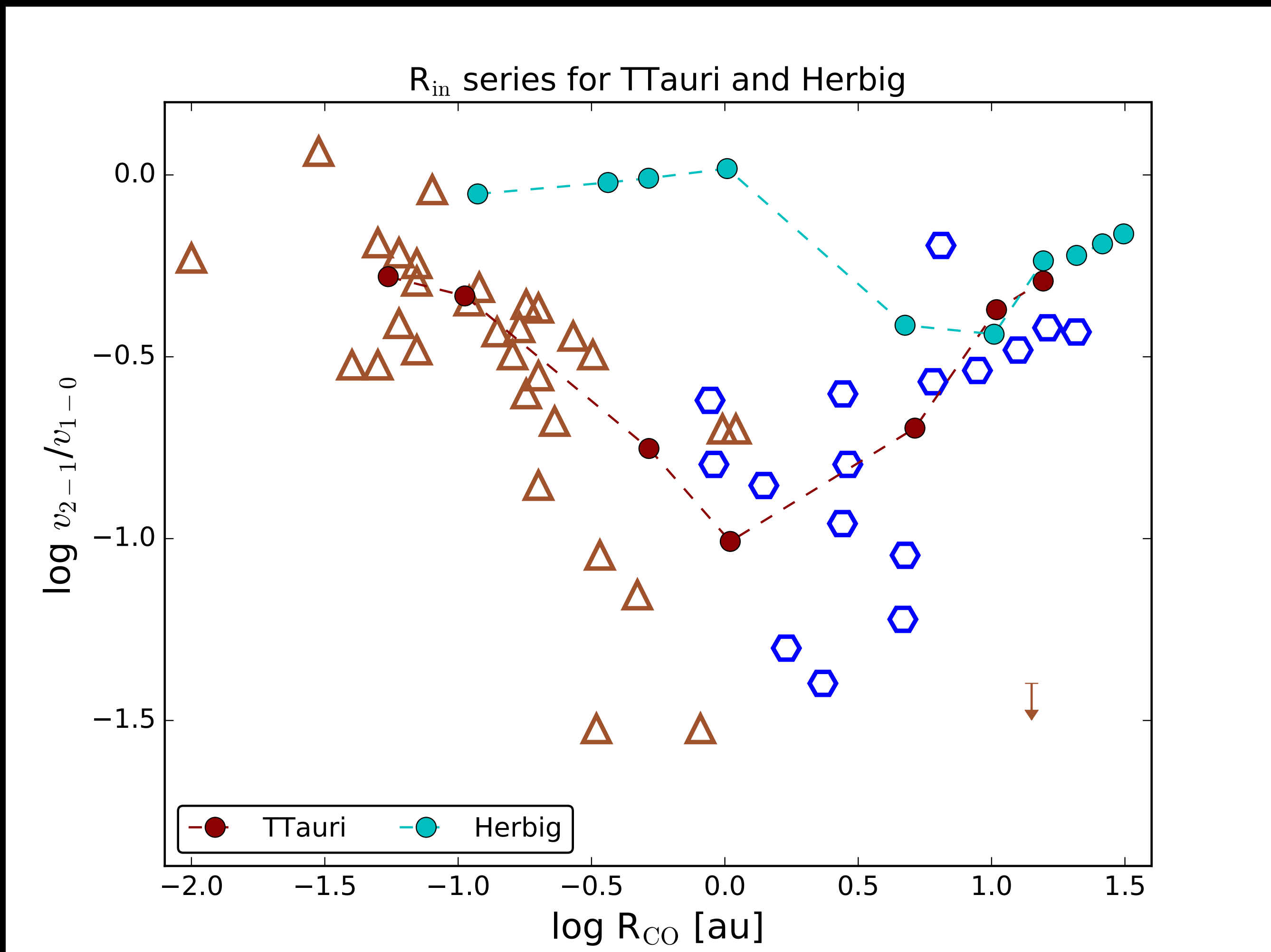


Garufi et al. 2017, 2018

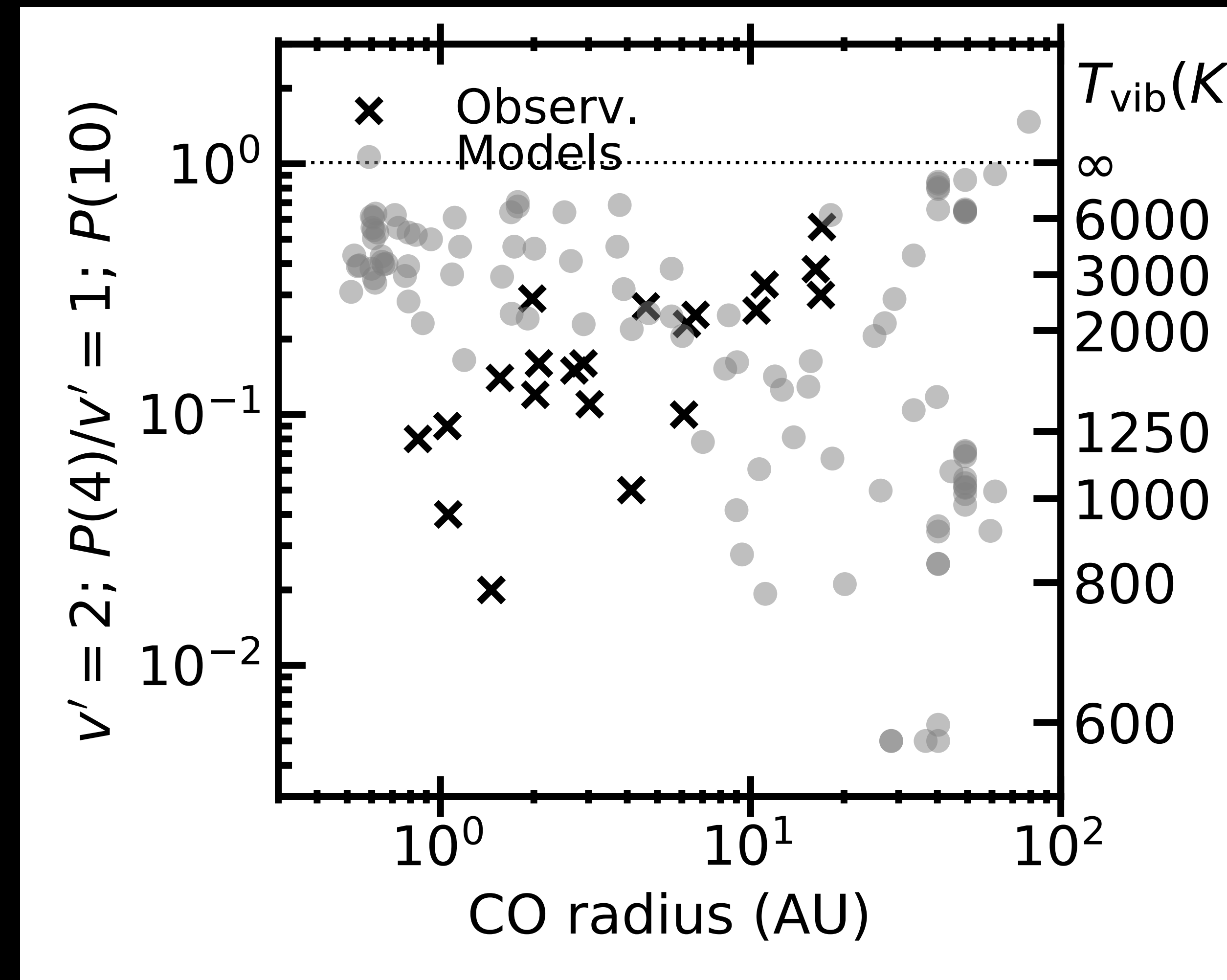
all seem to have shadows/spirals —> misaligned inner disks?

(see also poster by Mihkel Kama, and talk by Antonio Garufi)

Upcoming: CO thermo-physical&chemical modeling



Antonellini et al. 2018, submitted

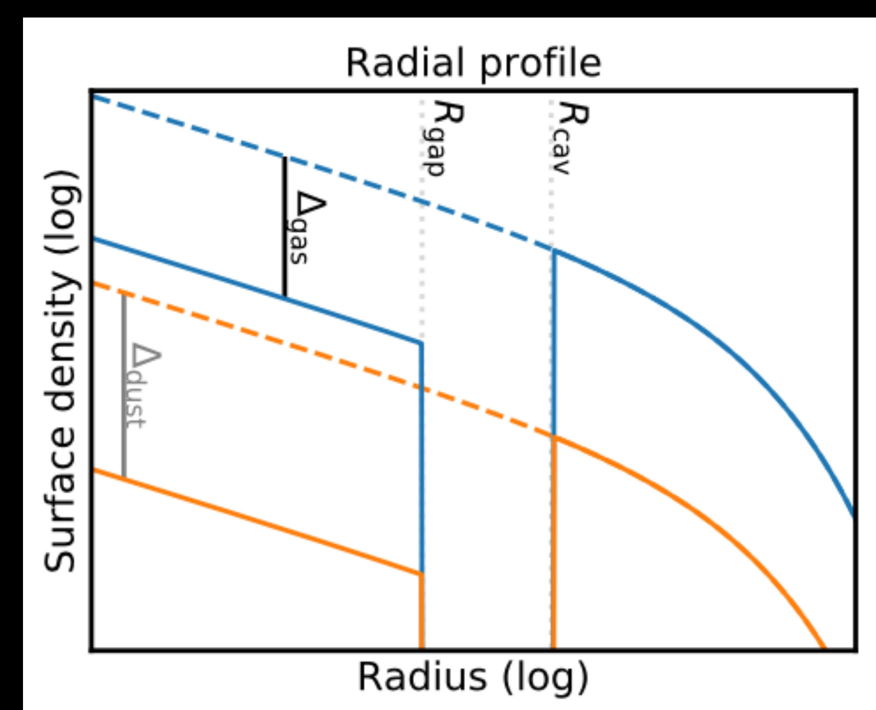


Bosman et al. 2019, in prep

Bottom line(s):

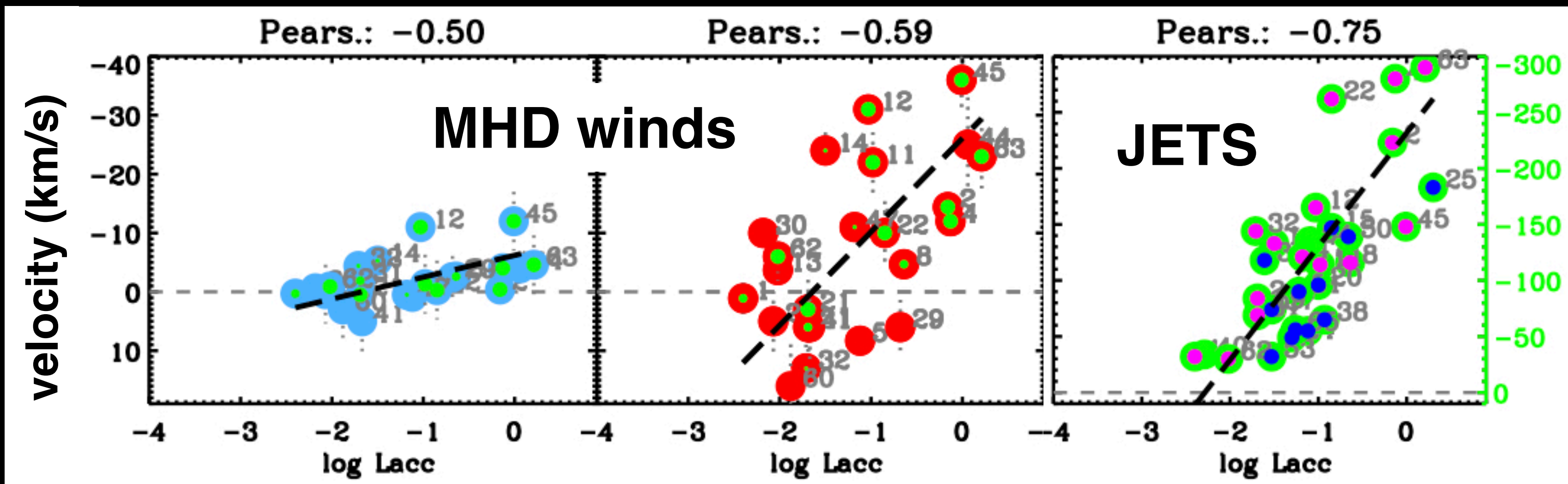
1. Yes, these look like inner disk cavities… but what exactly is their gas/dust structure?

2. toward estimates of inner disk gas and dust depletion at 0.1-10 au, to constrain physical processes (planets, winds)



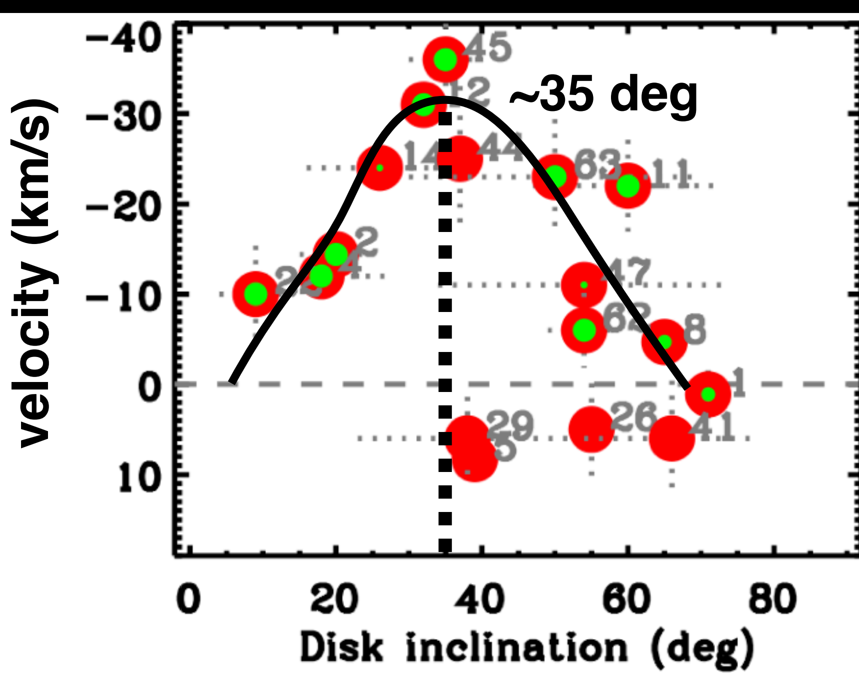
Upcoming: MHD inner disk winds kinematics and co-evolution with disks

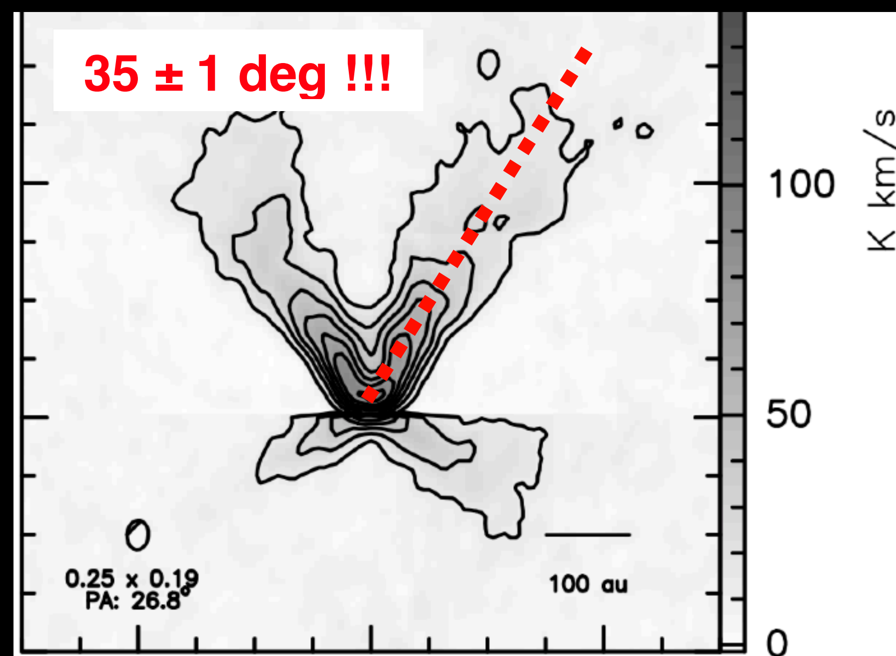
(a survey of high-resolution [OI] emission, Banzatti et al. 2018, submitted)



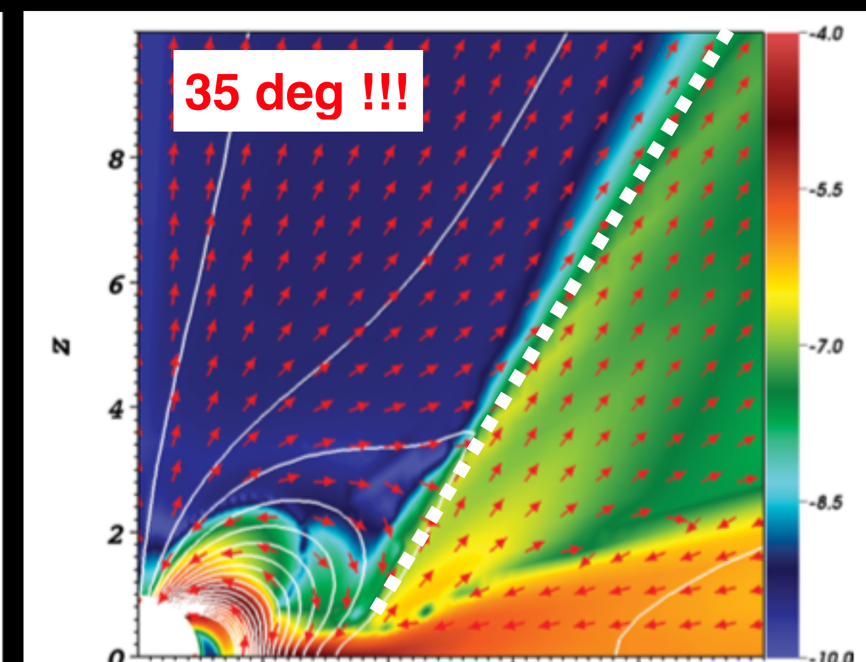
Bottom line (1):

[OI] 6300 A emission probes MHD winds: _kinematically_ linked to accretion and jets, and with ~35 deg semi-opening angle

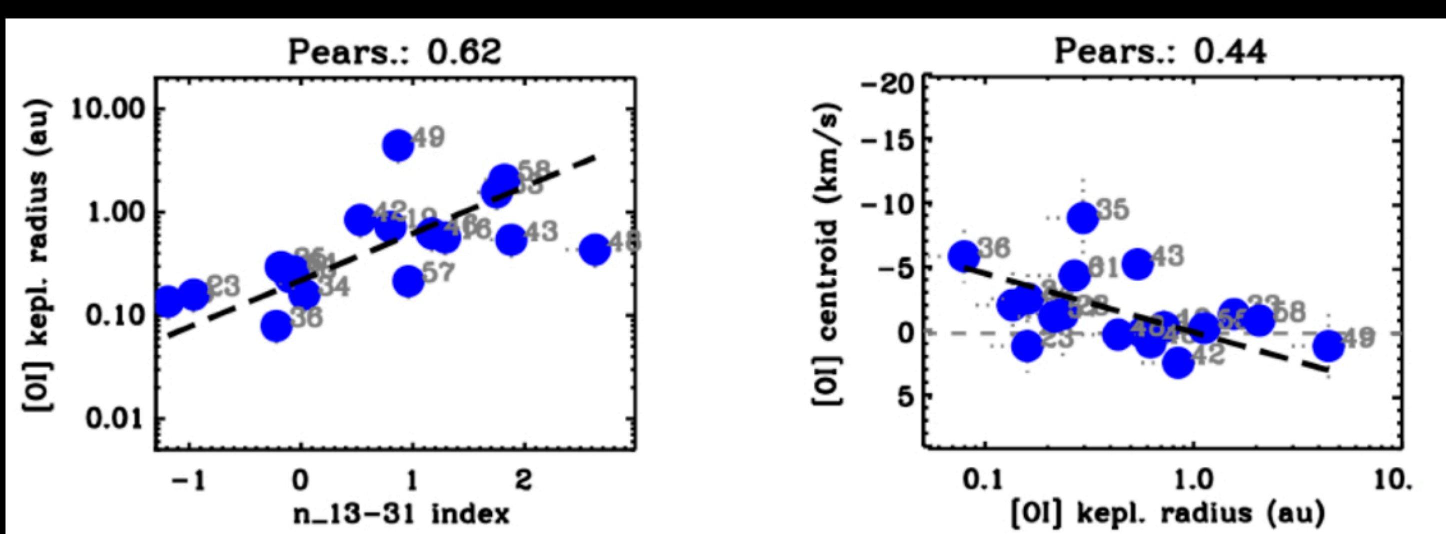




HH30 outflow (ALMA, Louvet et al. 2018)



MHD model (Kurosawa+2012)



Bottom line (2):

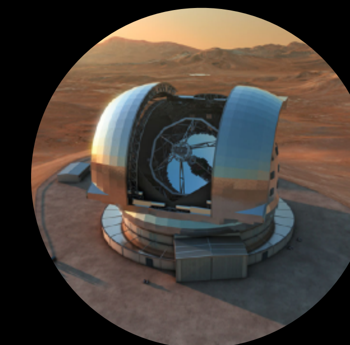
Winds co-evolve with inner disk dust

(see also talks by Pauline McGinnis and Brunella Nisini on Thursday and poster by Suzan Edwards)

Promising future prospects …

New instruments…

…more synergies…



…"To infinity.. and beyond!"

(see talk by Christine Chen tomorrow)

ORIGINS
Space Telescope

The data already available still have an enormous potential…

..let's take a closer look!