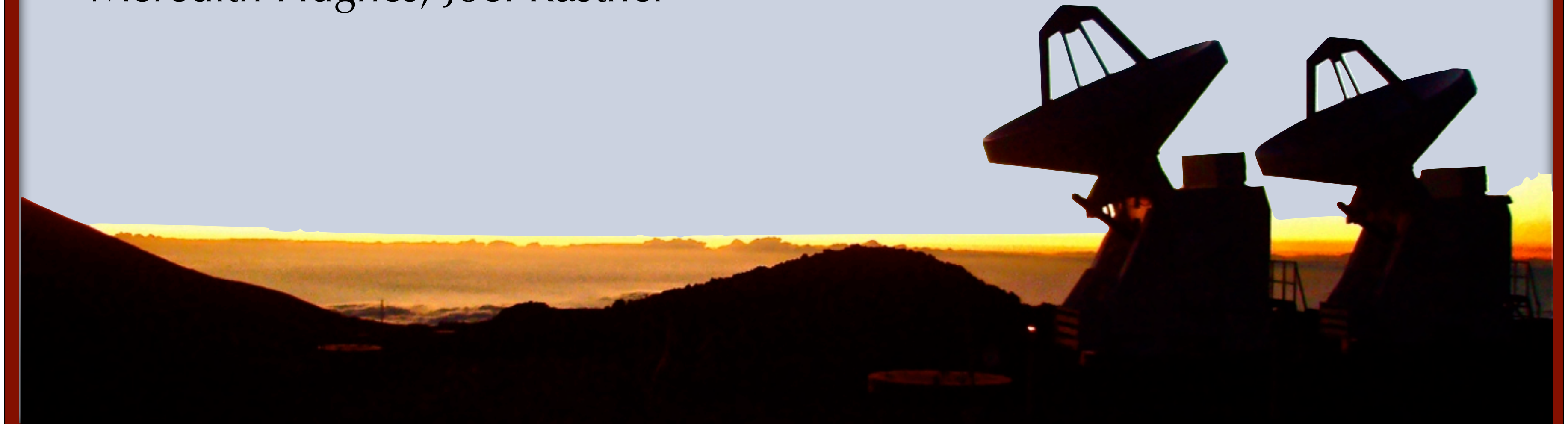
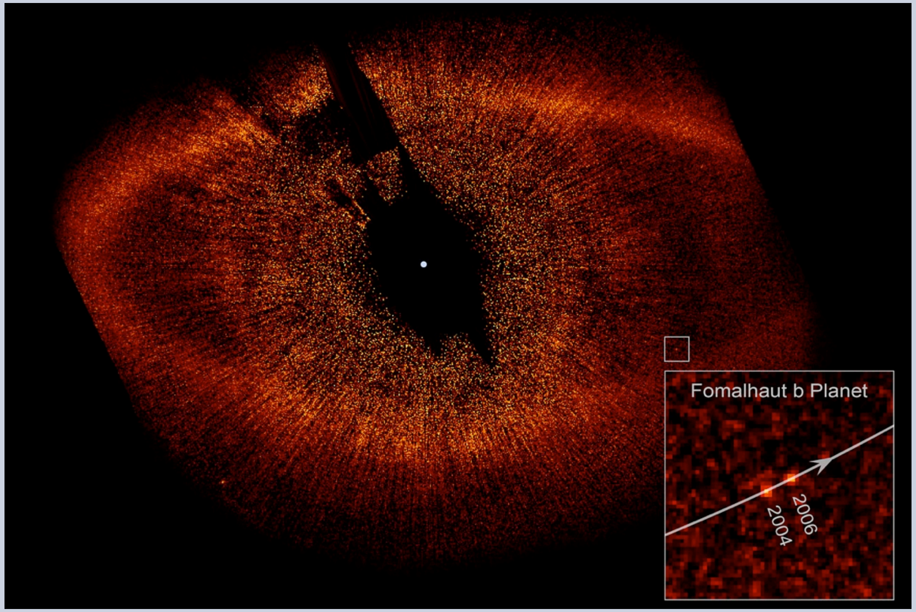
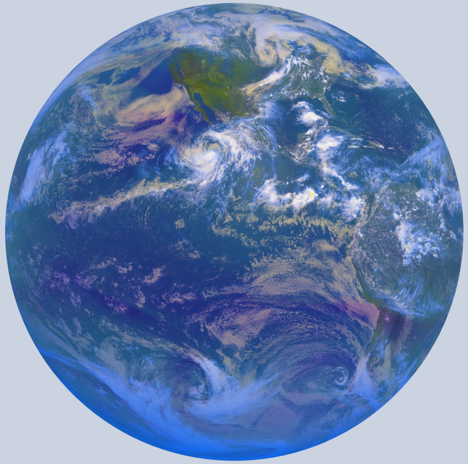
Resolving the chemistry in protoplanetary disks

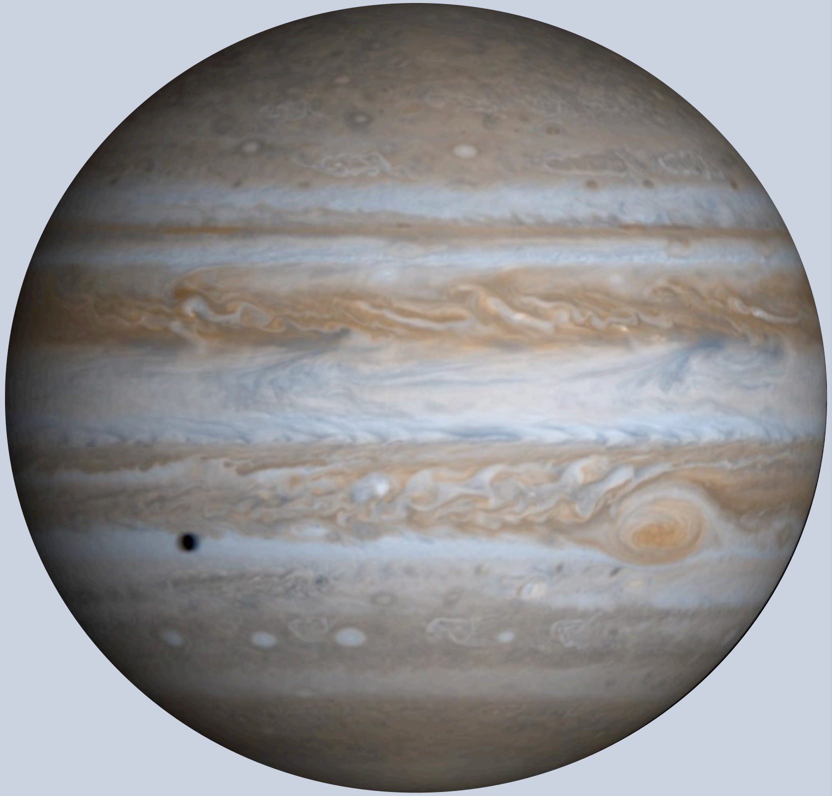
Edwin (Ted) Bergin
and
Karin Öberg

Charlie Qi, David Wilner, Sean Andrews, Catherine Espaillat, Jeffrey Fogel, Ilaria Pascucci, Ilse Cleeves , Brian Svoboda, Christian Brinch, Meredith Hughes, Joel Kastner

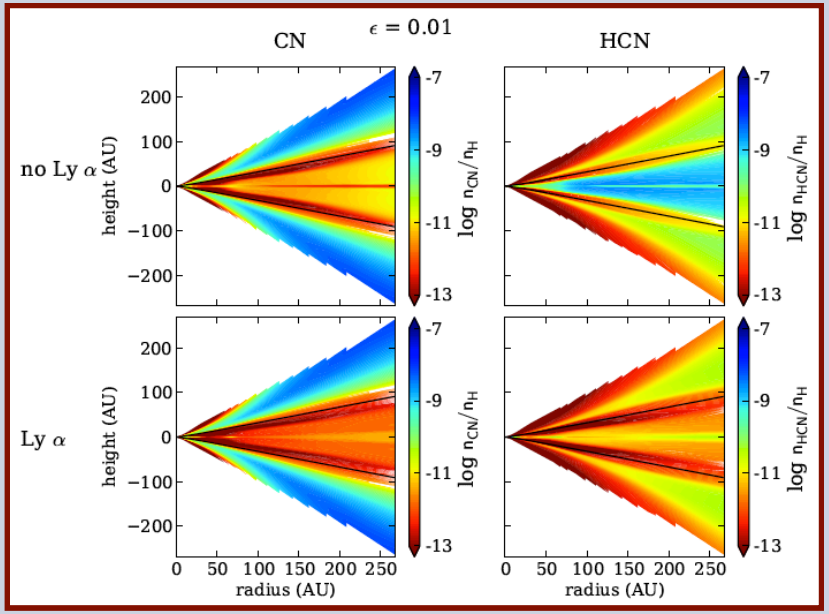


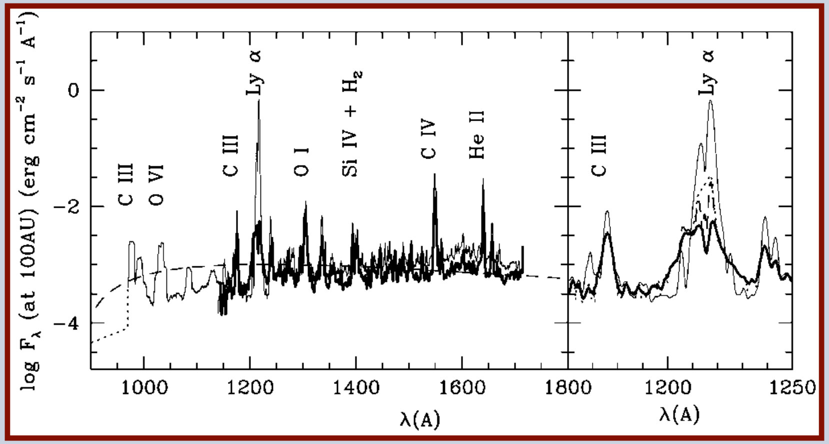

Fomalhaut b Planet
2006
2004





Technical and intrinsic barriers toward disk exploration





Small angular scales and intrinsically low abundances because of strong radiation fields and efficient freeze-out

Extraordinary lack of observational constraints

Lack of experiments on frequency dependent desorption and chemistry → few theoretical constraints

Bergin et al., 2004, Fogel et al. 2010

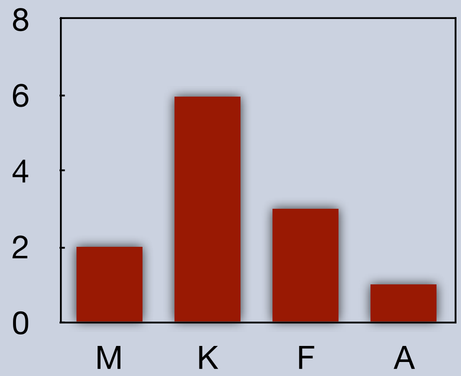
Disk Imaging Survey of Chemistry with the SMA

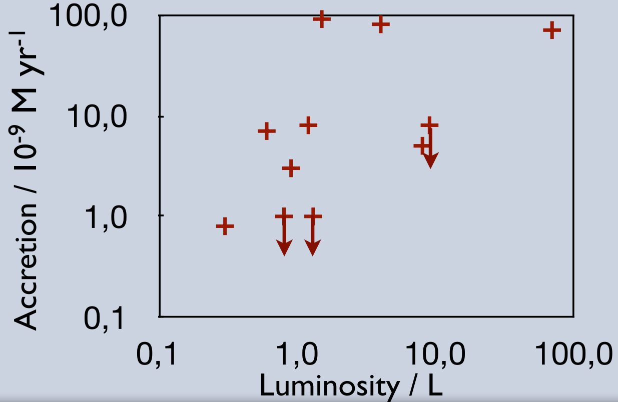
Öberg et al. 2010, Öberg et al. subm.

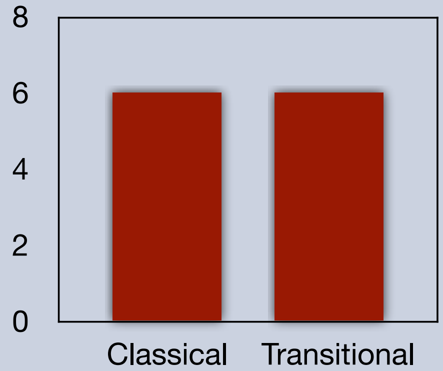
20 track survey of 10 molecular lines toward 12 protoplanetary disks:

CO 2-1, HCO^+ 3-2, DCO^+ 3-2, N_2H^+ 3-2, H_2CO 3-2, 4-3, HCN 3-2, DCN 3-2, CN 2-1

SMA compact configuration ~ 2-3″ resolution ~ 100-400 AU







Connecting disk physics and chemistry

How are radiation fields, disk structure, dust and gas temperature traced by the chemistry?

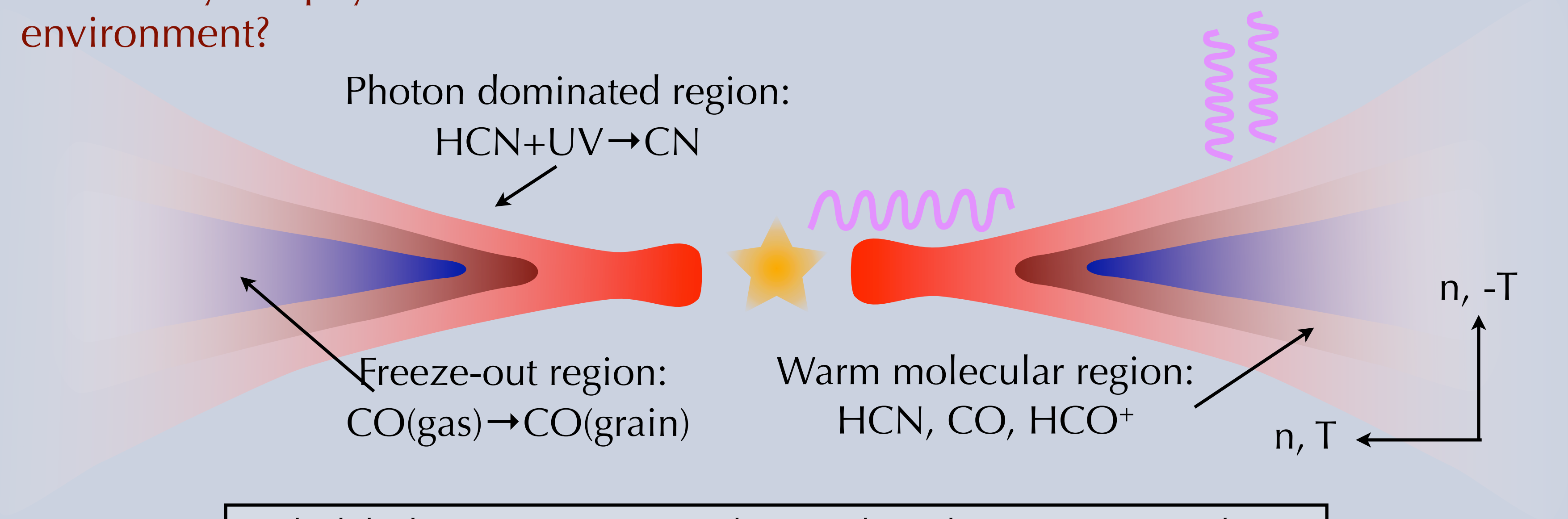
How is the chemical evolution affected by the physical environment?

★ Disk structure: CO, ^{13}CO and HCO^+

★ Radiation: CN/HCN (Bergin et al. 2003)

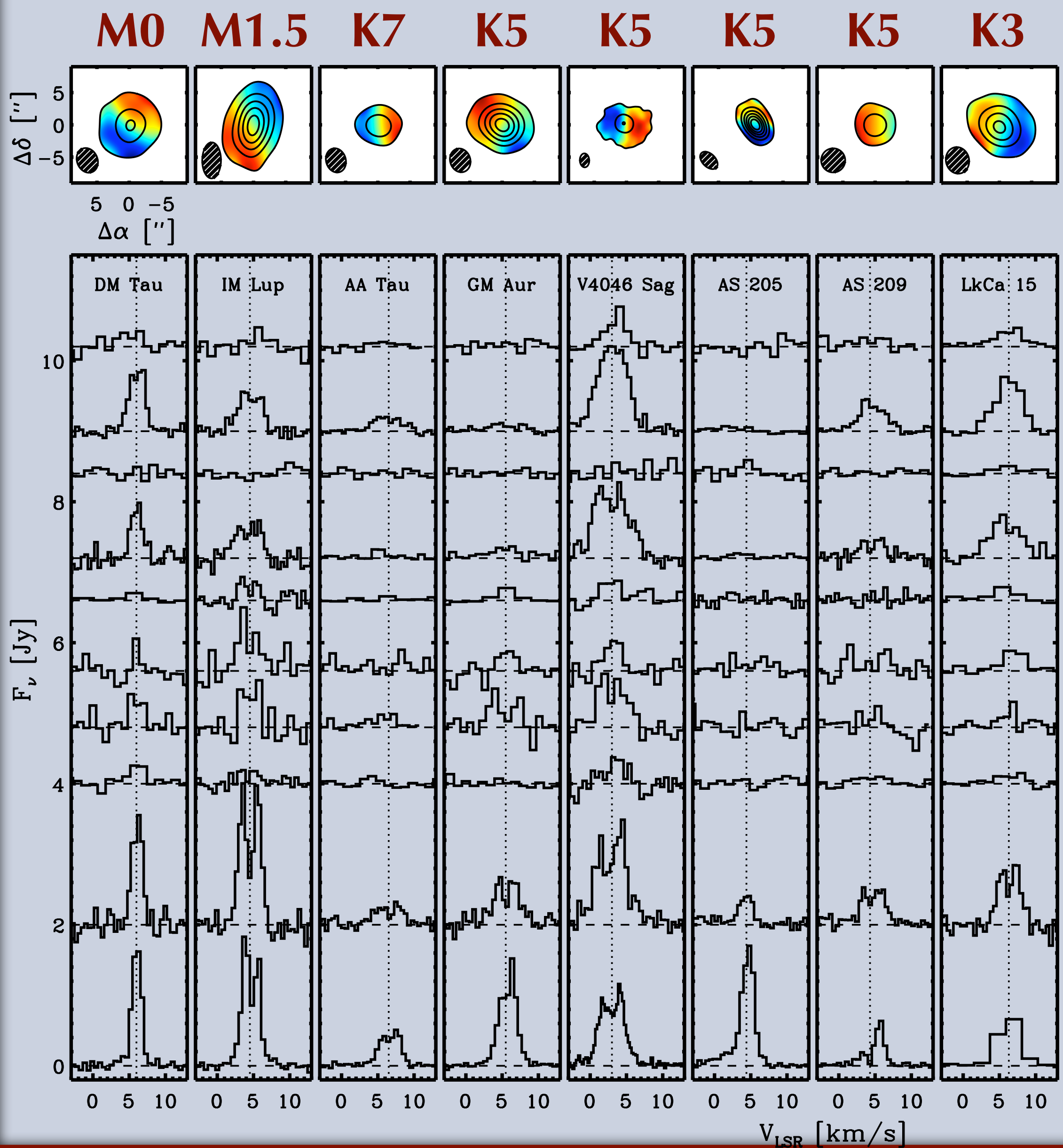
★ Deuteration: DCO^+/HCO^+ and DCN/HCN

★ Cold grains/gas: N_2H^+, H_2CO, DCO^+

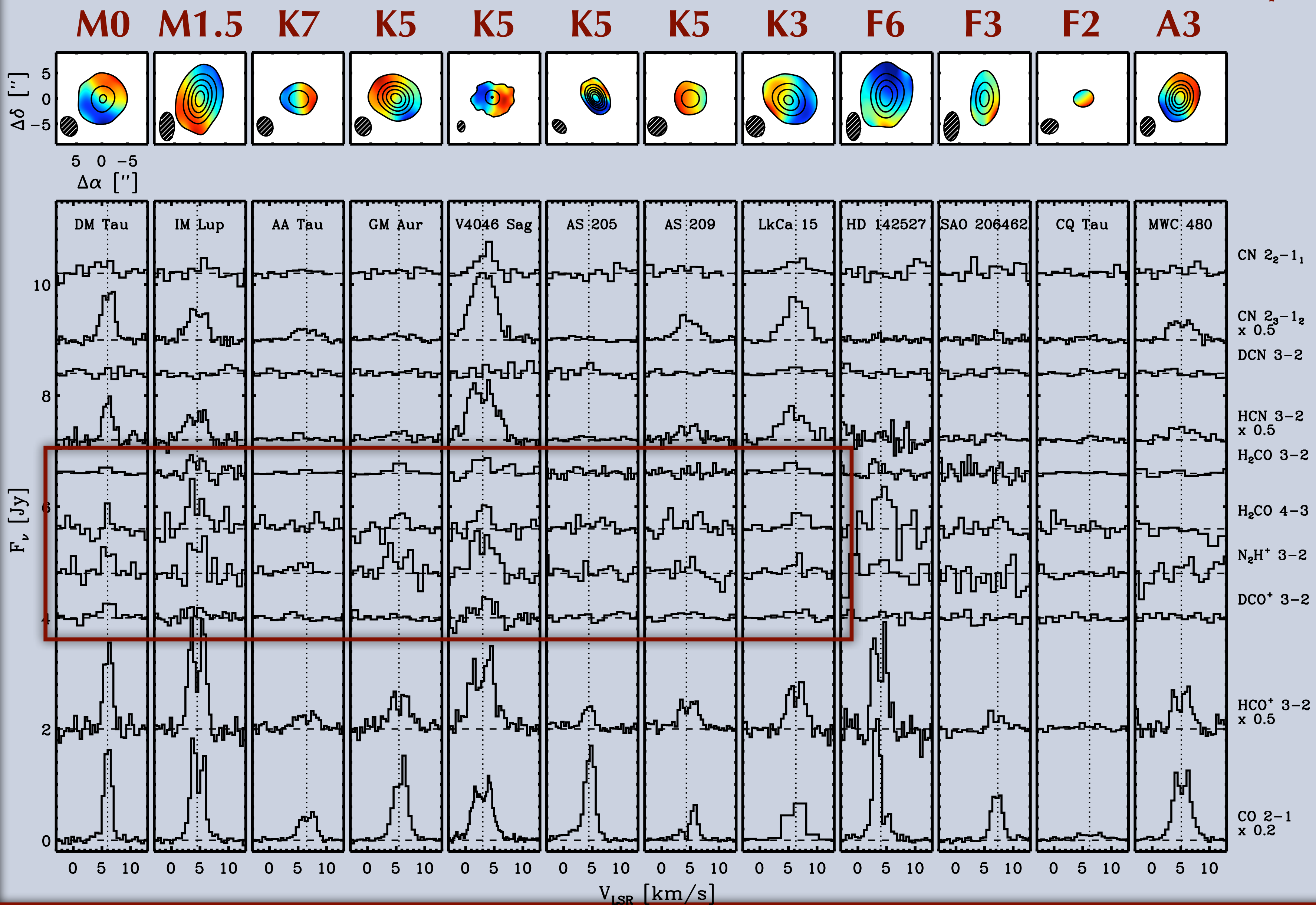


Single dish observations: Dutrey et al. 1997, Thi et al. 2004, Kastner et al. 2008
Resolved observations: Dutrey et al. 2007, Qi et al. 2008, Henning et al. 2010

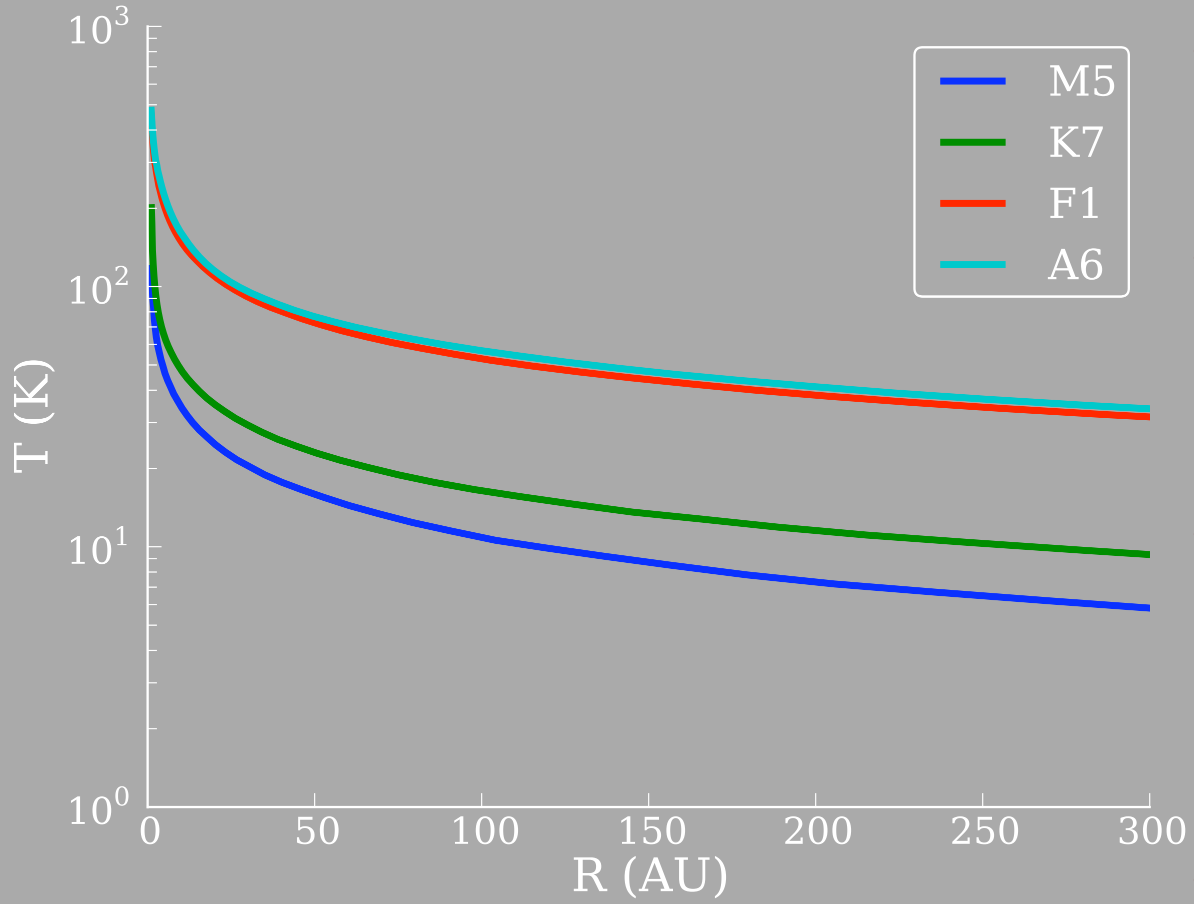
Chemical richness and source variability



Chemical richness and source variability



Warm and Cold Disks

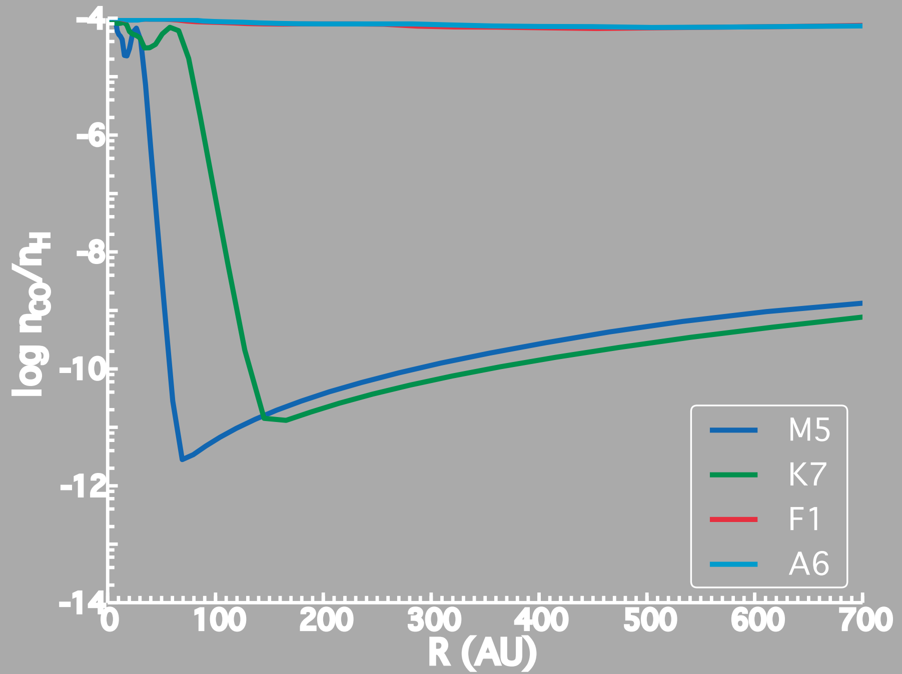


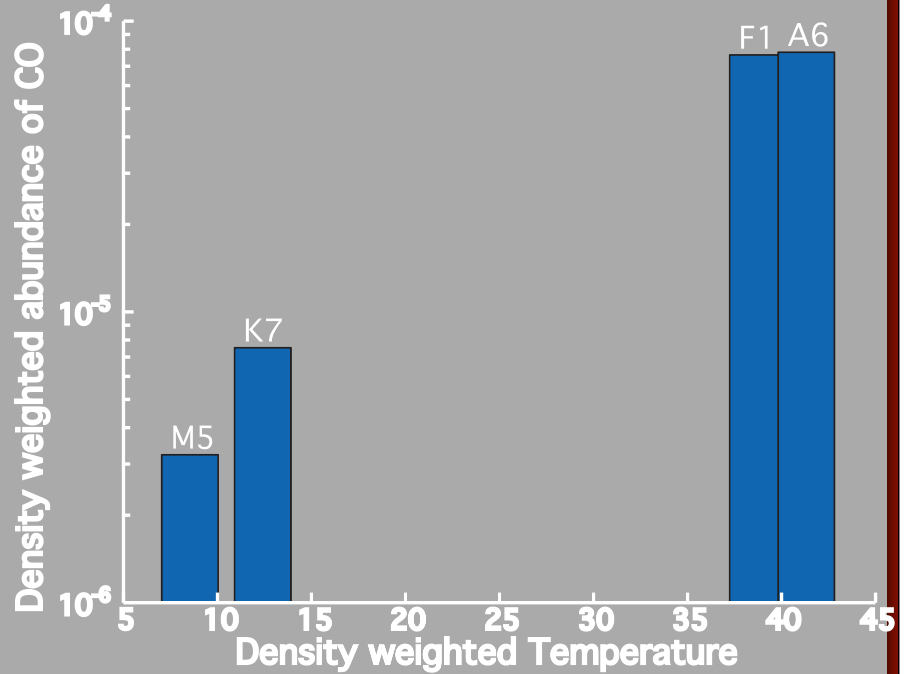
Disk model from C. Espaillat

- Chemical model of Fogel et al. 2011
- Explore molecular distribution in the midplane
- How does chemistry change between warm and cold
- Can this roughly reproduce trends

Warm and Cold Disks

Fogel et al. 2011, in prep.

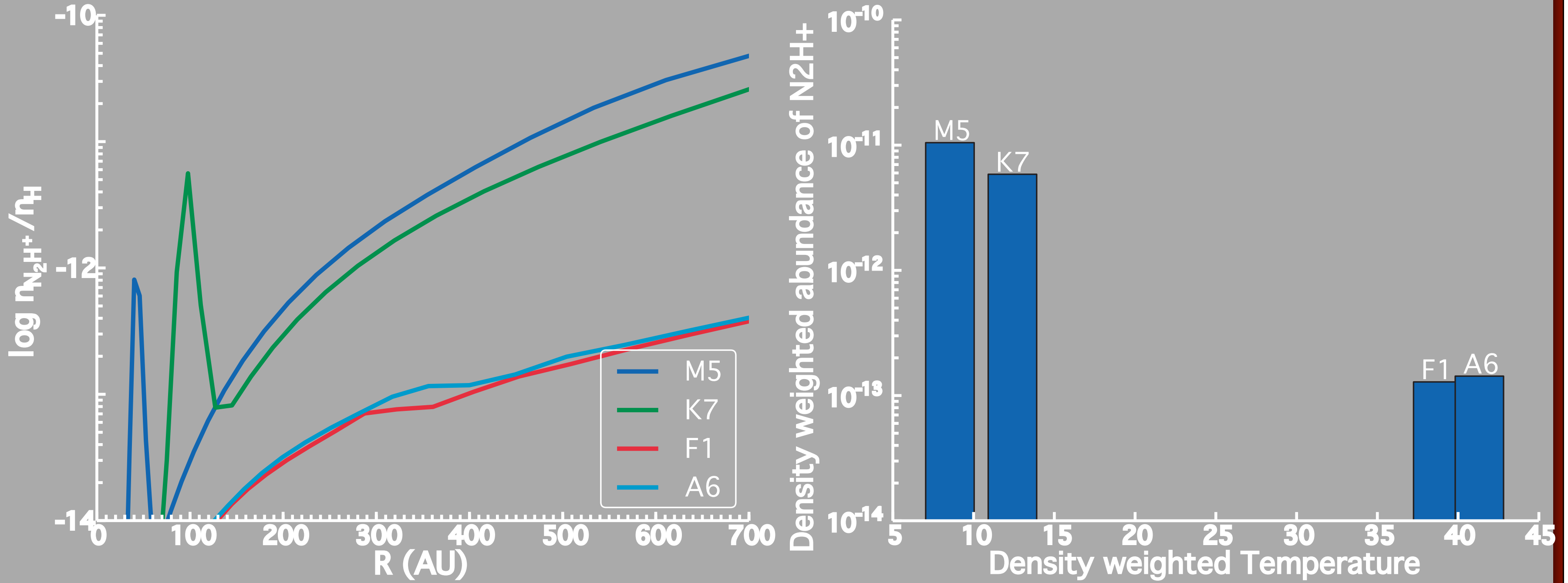




- F and A star (in this model): warm midplane and no CO freeze-out
- M and K star (in this model) have cold midplane with a CO "snowline"

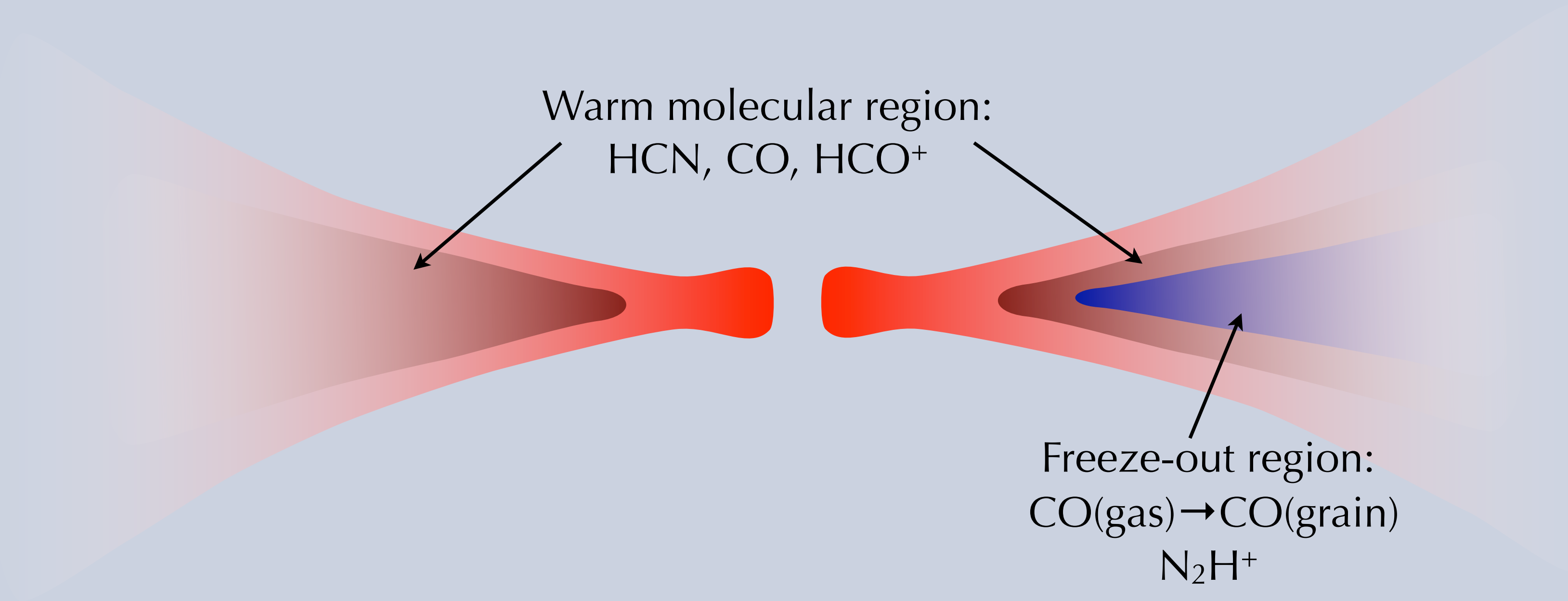
Warm and Cold Disks

Fogel et al. 2011, in prep.



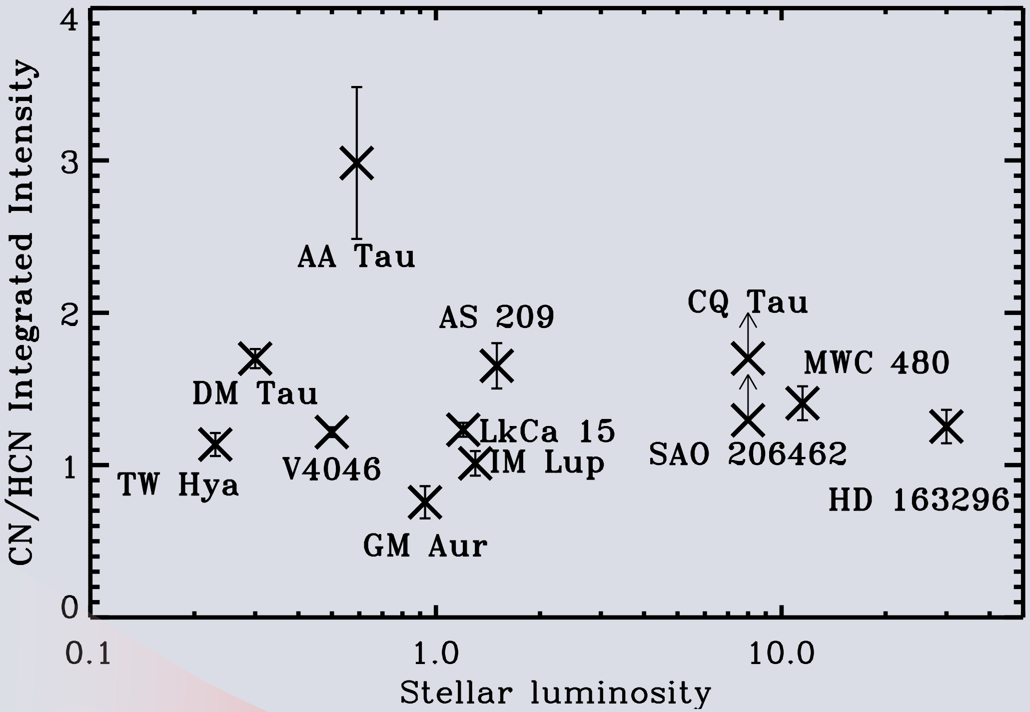
- N_2H^+ forms when CO is frozen - so thrives in a "protected" midplane
- Also predict that there will be sharp gradients near CO snowline

Warm Disks + Cold Disks



- ★ Cold disks have strong CO freeze-out and richer simple chemistry
- ★ Just the beginning of this kind of work....

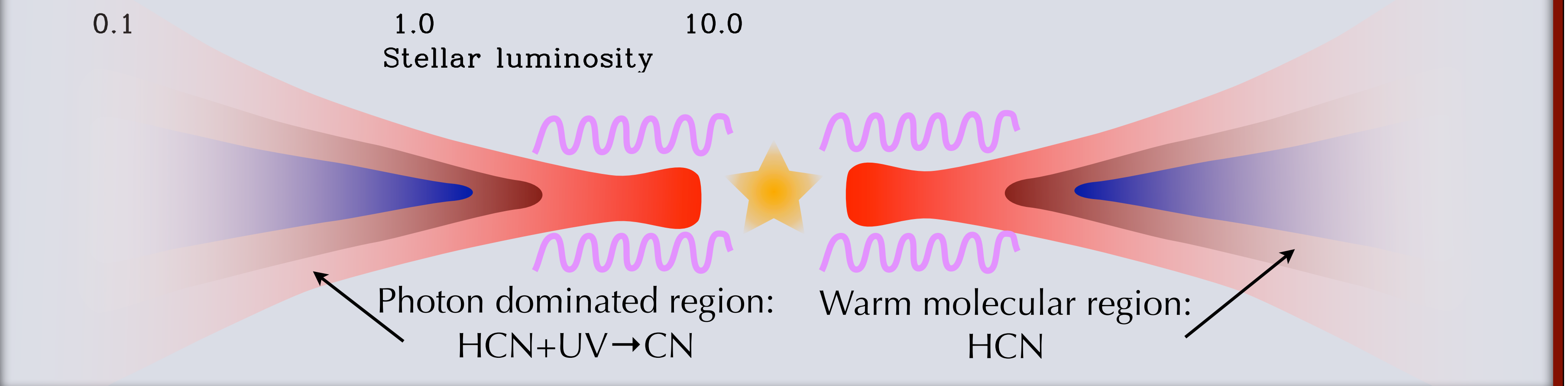
Radiation Chemistry: CN/HCN



★HCN+UV→CN; CN should be abundant at high UV

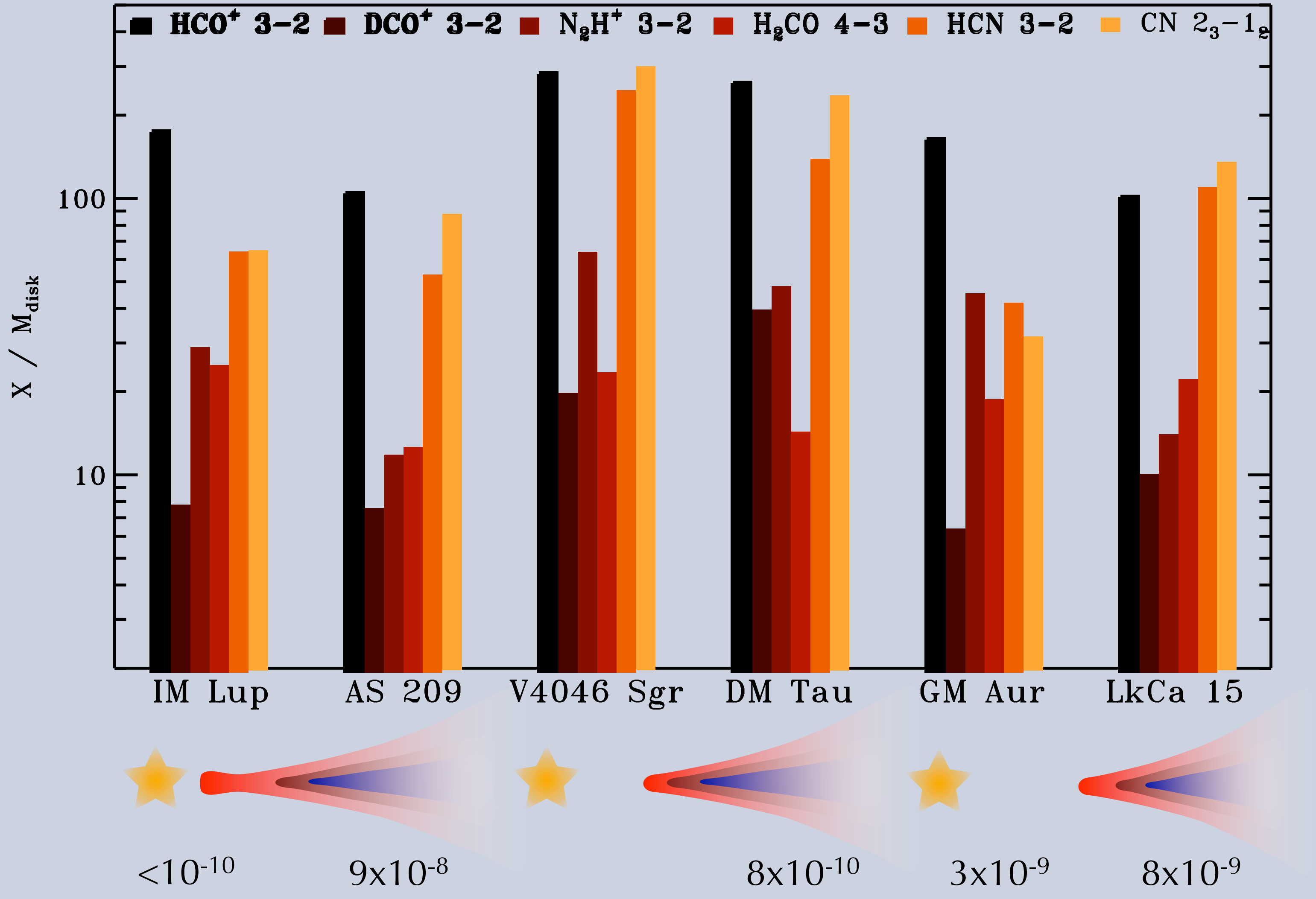
★Surprisingly constant CN/HCN emission ratio

★Disk averaged CN/HCN ratio is NOT a good radiation tracer.

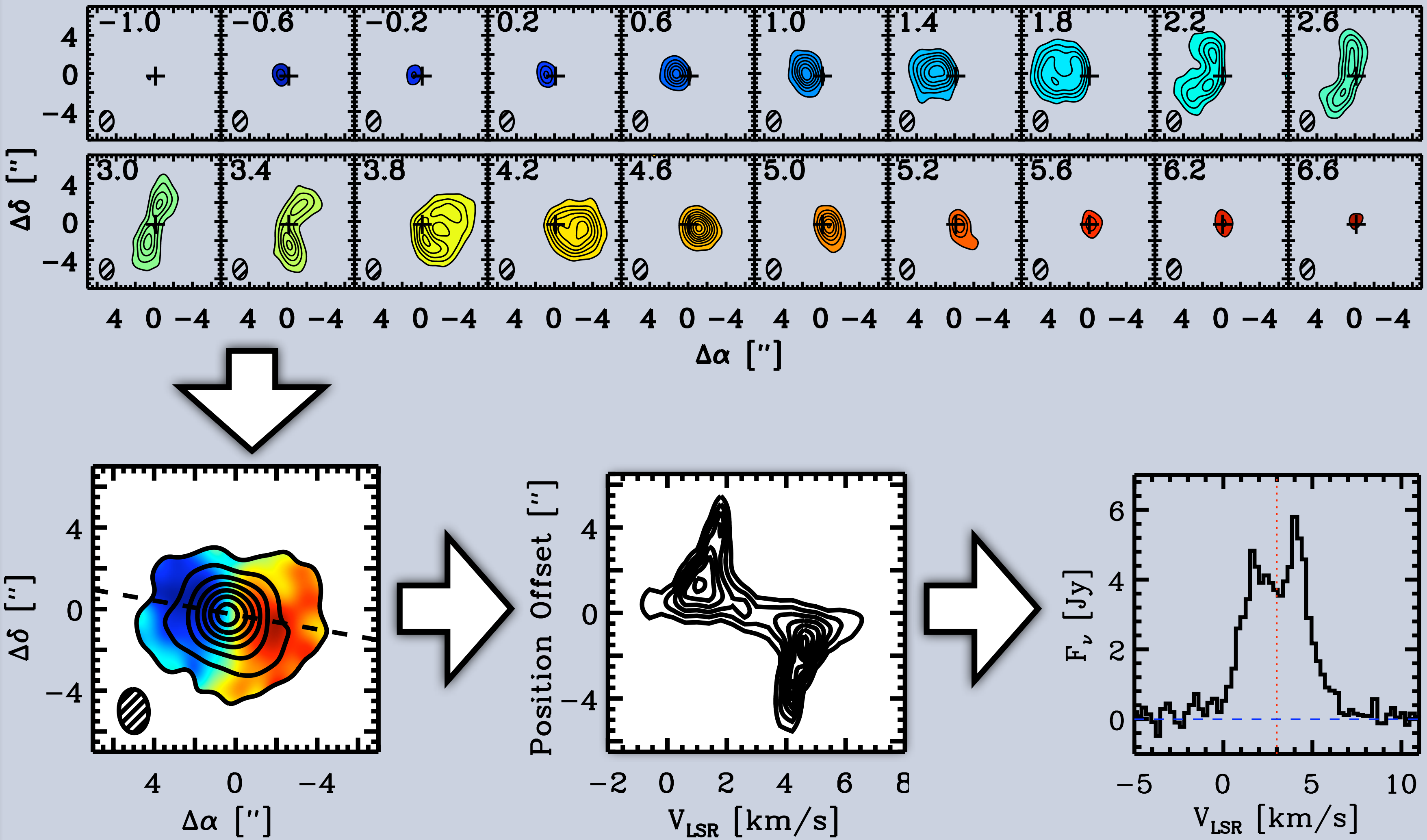


Transition vs. Full Disks:

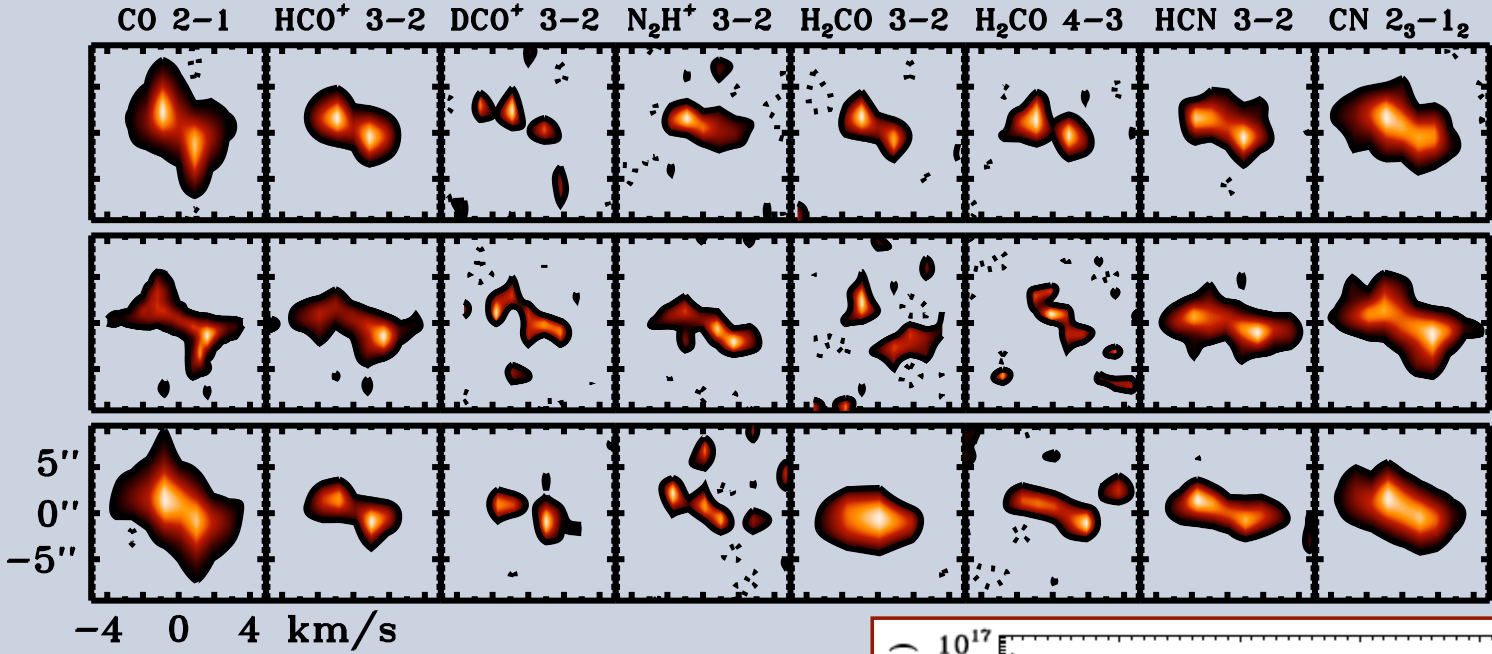
A disconnect between the inner and outer disk



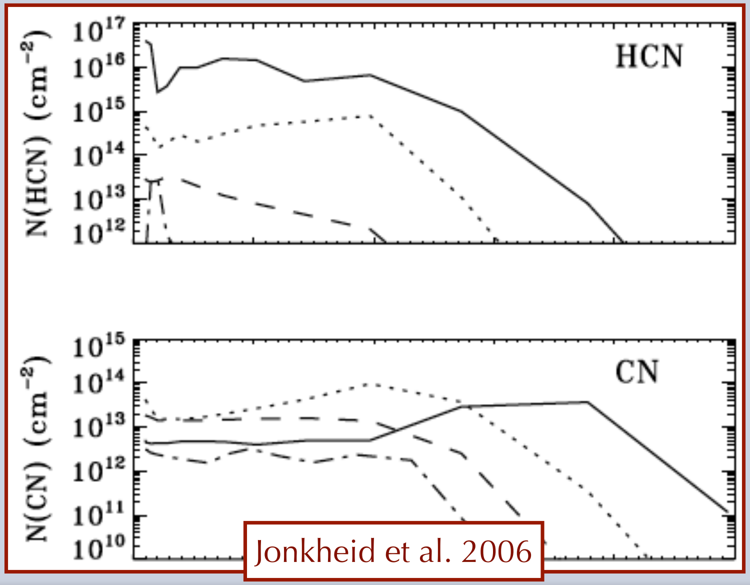
Visualizing spatial distributions: CO in V4046 Sgr



Differences in radial distributions



- ★ Different radial distributions trace combination of radial abundance and excitation dependences:
  - ★ CO/HCO^+ - CO optical depth effect
  - ★ CN/HCN - more photodissociation in low-density outer disk?



DiSCS

- ★ 12 disks observed in 10 lines with a surprisingly high detection rates -- promising to develop molecular tracers for different phenomena
- ★ DCO^+, N_2H^+ and H_2CO common among low-luminosity sources: trace cold midplanes efficiently
- ★ Nearly constant disk-averaged CN/HCN emission ratio, despite orders of magnitude ranges in stellar and accretion UV fluxes
- ★ Radial distributions are promising tracers of the disk environment e.g. DCO^+/N_2H^+, CN/HCN