DiSCS:

A spatially and spectroscopically resolved survey of chemistry in protoplanetary disks

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Collaborators:
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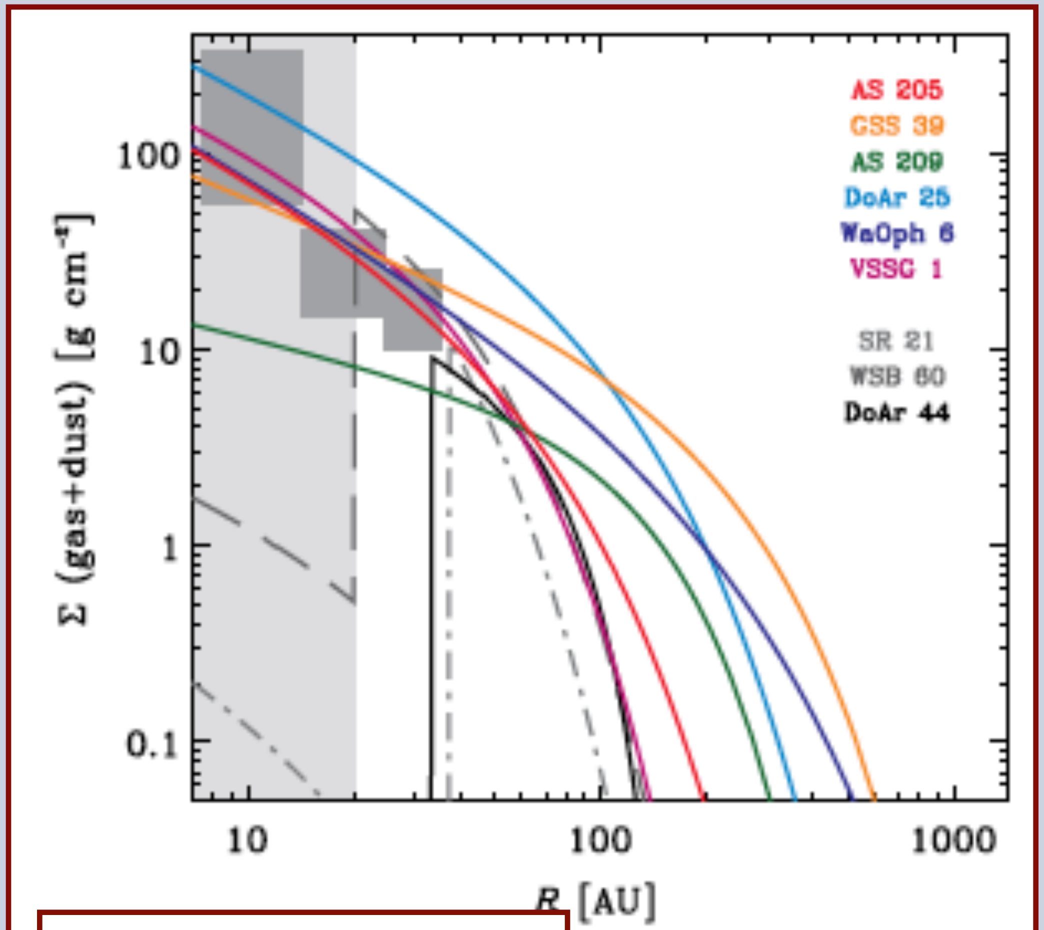
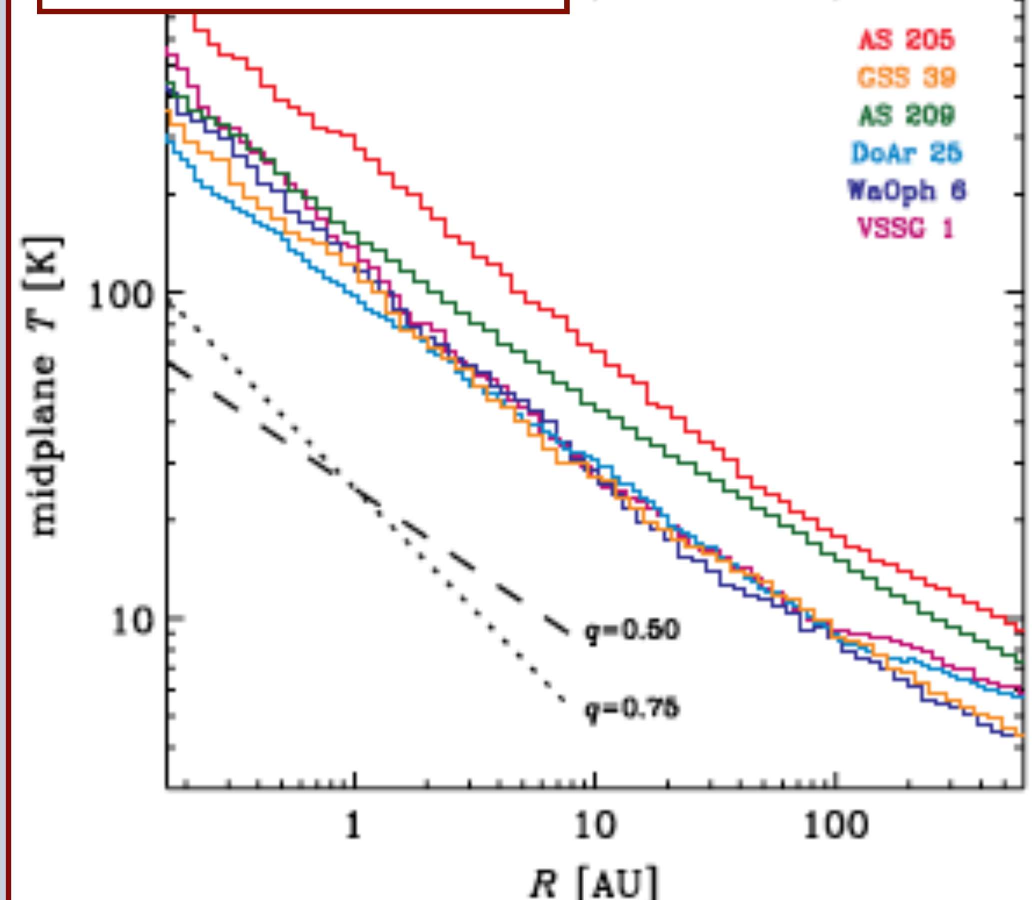
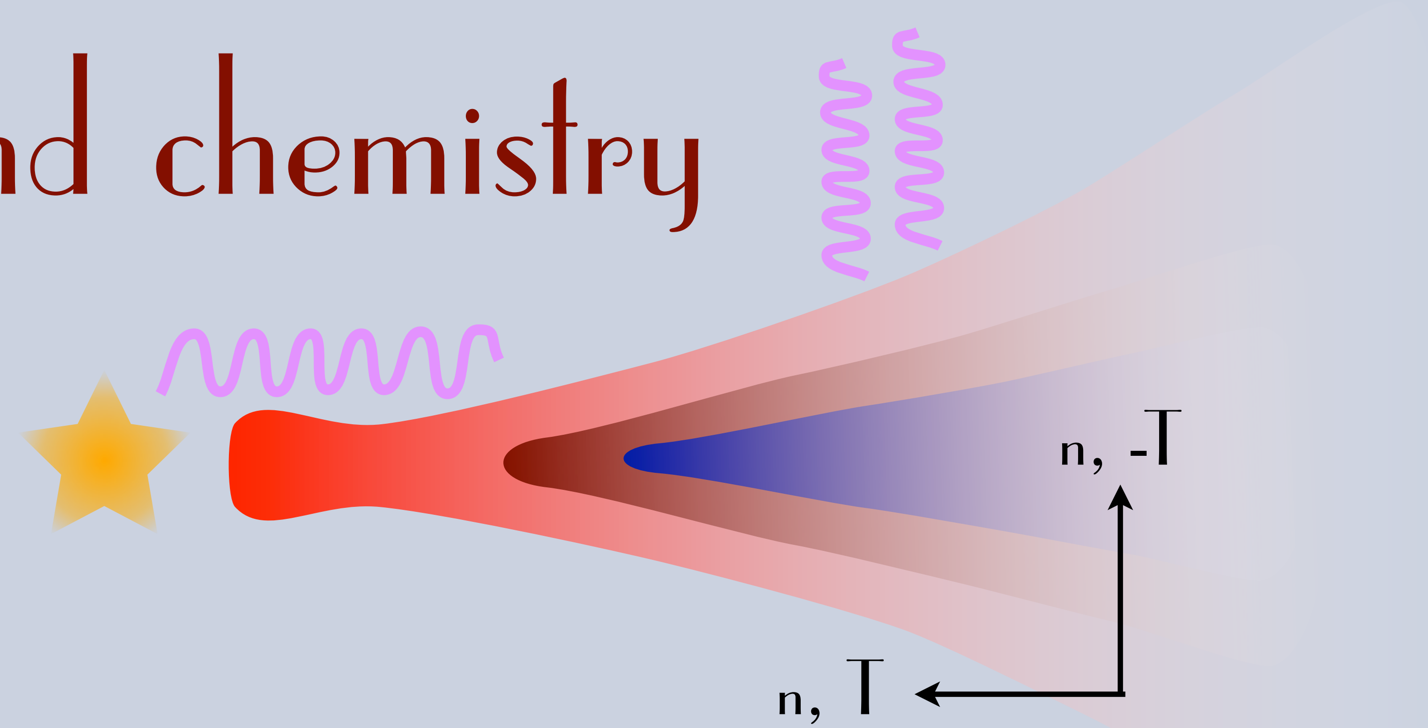
Connecting the physics and chemistry



Andrews et al. 2009





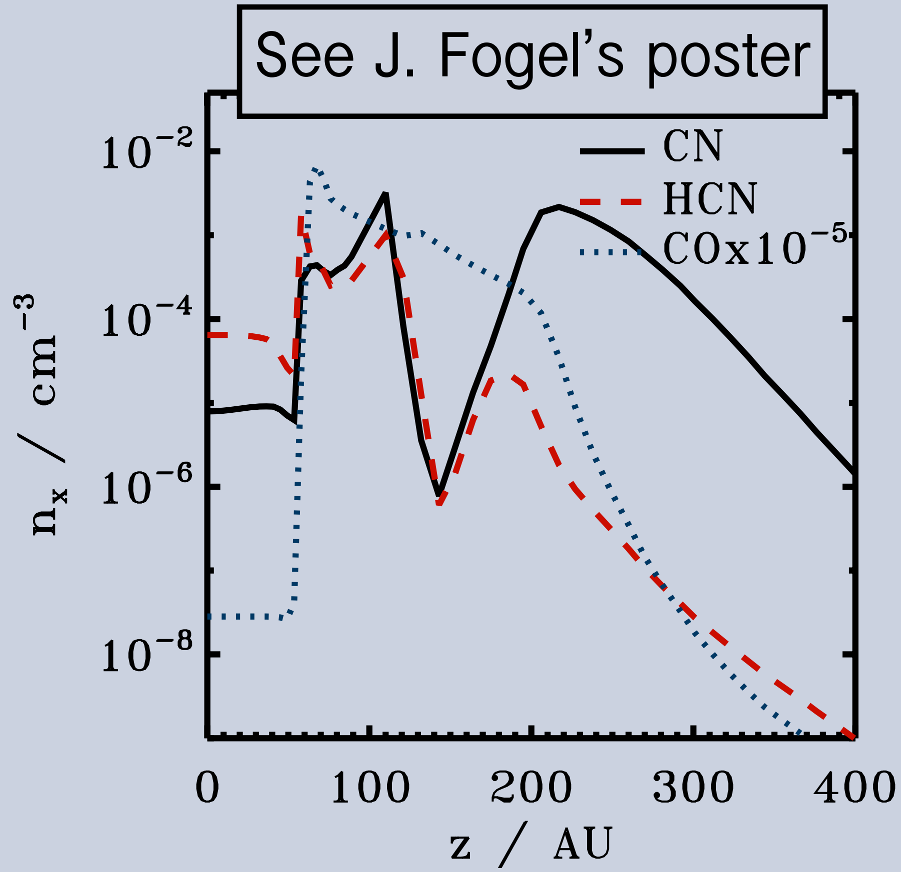
Resolved dust studies and SEDs have revealed variation in density profiles, dust settling and growth (e.g. Andrews et al. 200x, Espaillat et al. 200x)

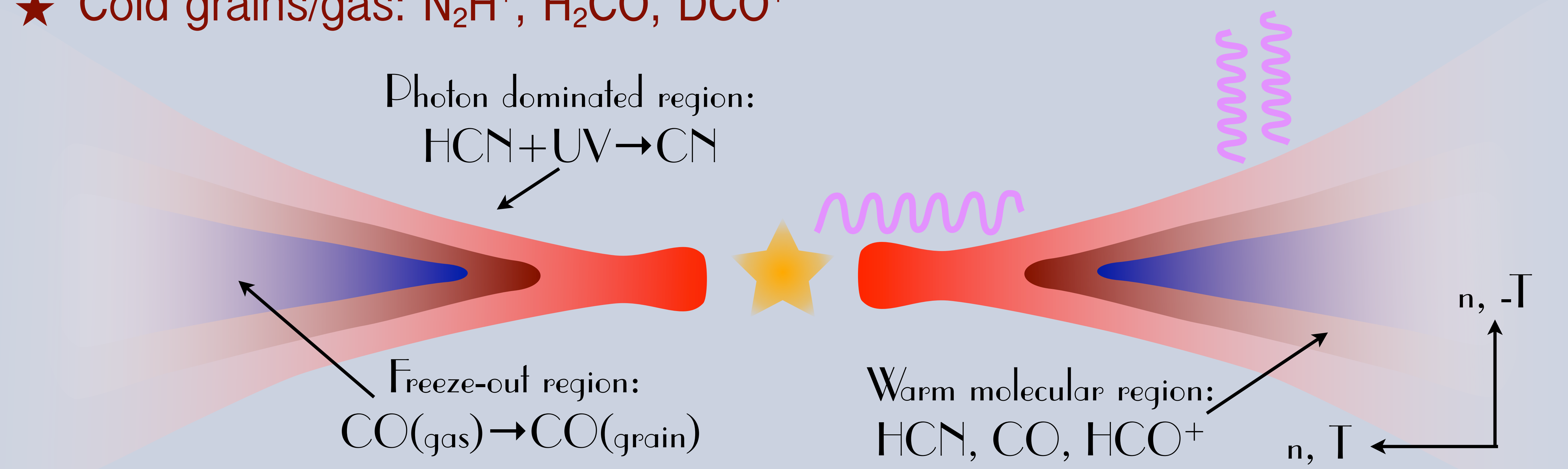
Optical, UV and X-ray measurements give order of magnitude variations in radiation fluxes and accretion rates (e.g. Calvet et al. 2004)

DISCS: How is the physics traced by the chemistry? How is the chemical evolution affected by the physics?

Molecular Targets

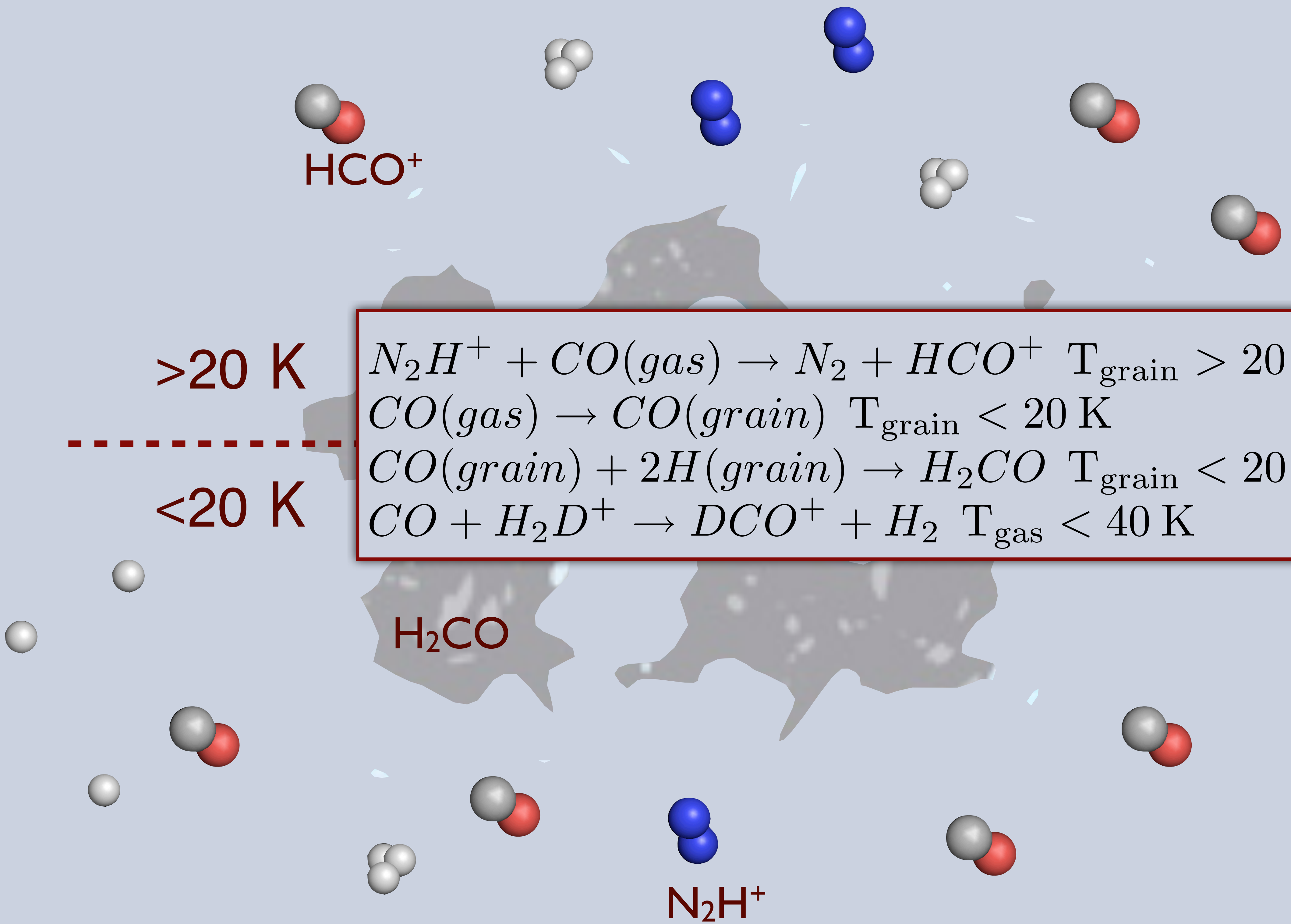
- ★ Disk structure: CO, ^{13}CO and HCO^+
- ★ Radiation: CN/HCN (Bergin et al. 2003)
- ★ Deuteration: DCO^+/HCO^+ and DCN/HCN
- ★ Cold grains/gas: N_2H^+, H_2CO, DCO^+





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

Grain temperature dependent chemistry



$N_2H^+ + CO(gas) \rightarrow N_2 + HCO^+ \;\; \mathrm{T_{grain}} > 20\,\mathrm{K}$

$CO(gas) \rightarrow CO(grain) \;\; \mathrm{T_{grain}} < 20\,\mathrm{K}$

$CO(grain) + 2H(grain) \rightarrow H_2CO \;\; \mathrm{T_{grain}} < 20\,\mathrm{K}$

$CO + H_2D^+ \rightarrow DCO^+ + H_2 \;\; \mathrm{T_{gas}} < 40\,\mathrm{K}$

Source Sample

	Spectral type	Luminosity / $L_\odot$	Accretion / $10^{-9}\ M_\odot$	Hole
DM Tau	M1	0.3	0.8	y
IM Lup	M0	1.3	<<	n
AA Tau	K7	0.6	7	n
GM Aur	K5	0.9	3	y
V4046 Sgr	K5	0.5+0.3	<<	y
AS 209	K5	1.5	90	n
AS 205	K5	4.0	80	n
LkCa 15	K3	1.2	8	y
HD 142527	F6	69	70	y
SAO 206462*	F3	8.0	5	y
CQ Tau	F2	8.0	<8	n
MWC 480	A3	11.5	…	n

*HD 135344B

Disk Imaging Survey of Chemistry with the SMA

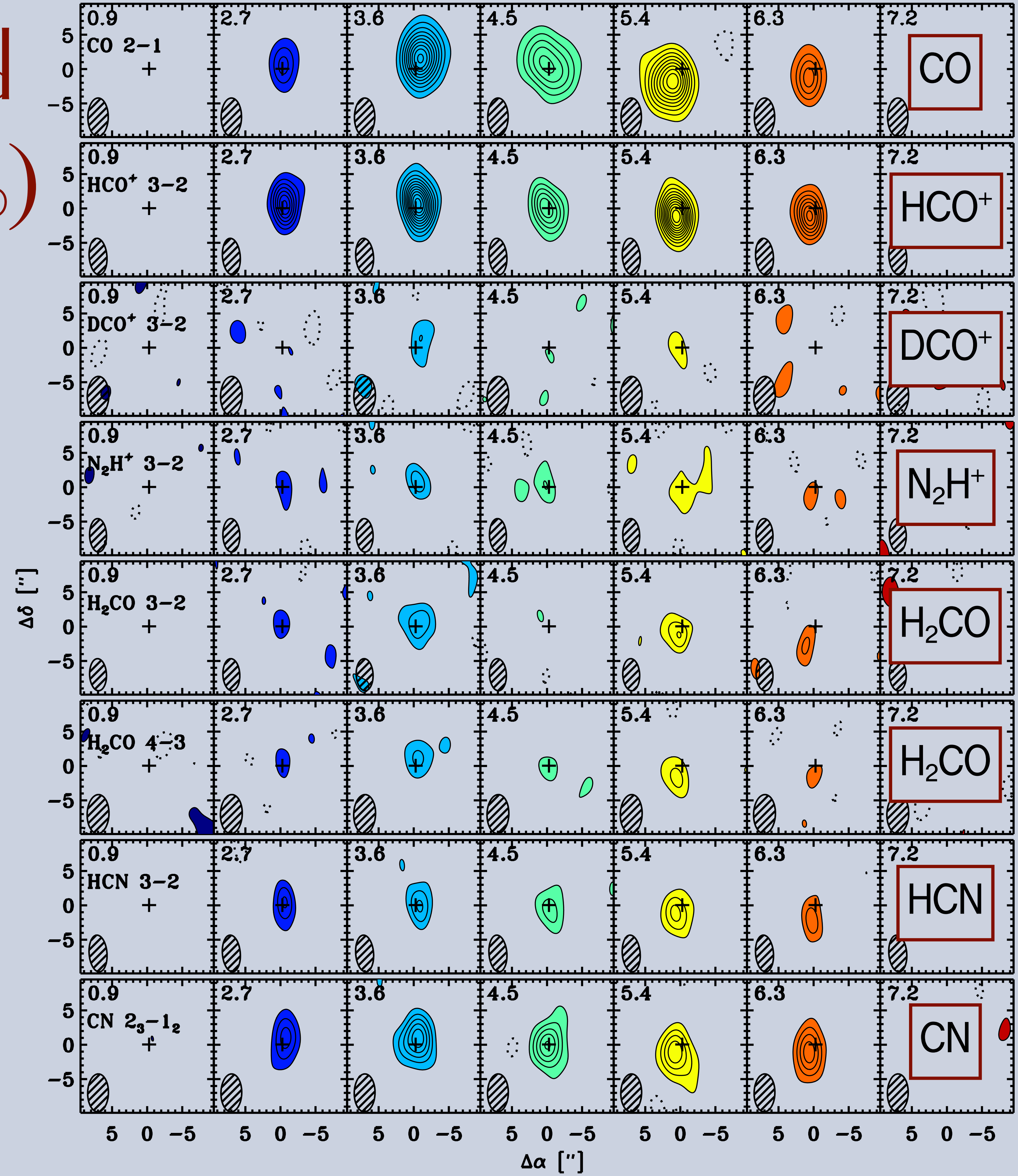
20 track survey of 10 molecular lines toward 12(14) protoplanetary disks: CO 2-1, HCO^+ 3-2, DCO^+ 3-2, N_2H^+ 3-2, H_2CO 3-2, 4-3, HCN 3-2, DCN 3-2, CN 2 x 2-1

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

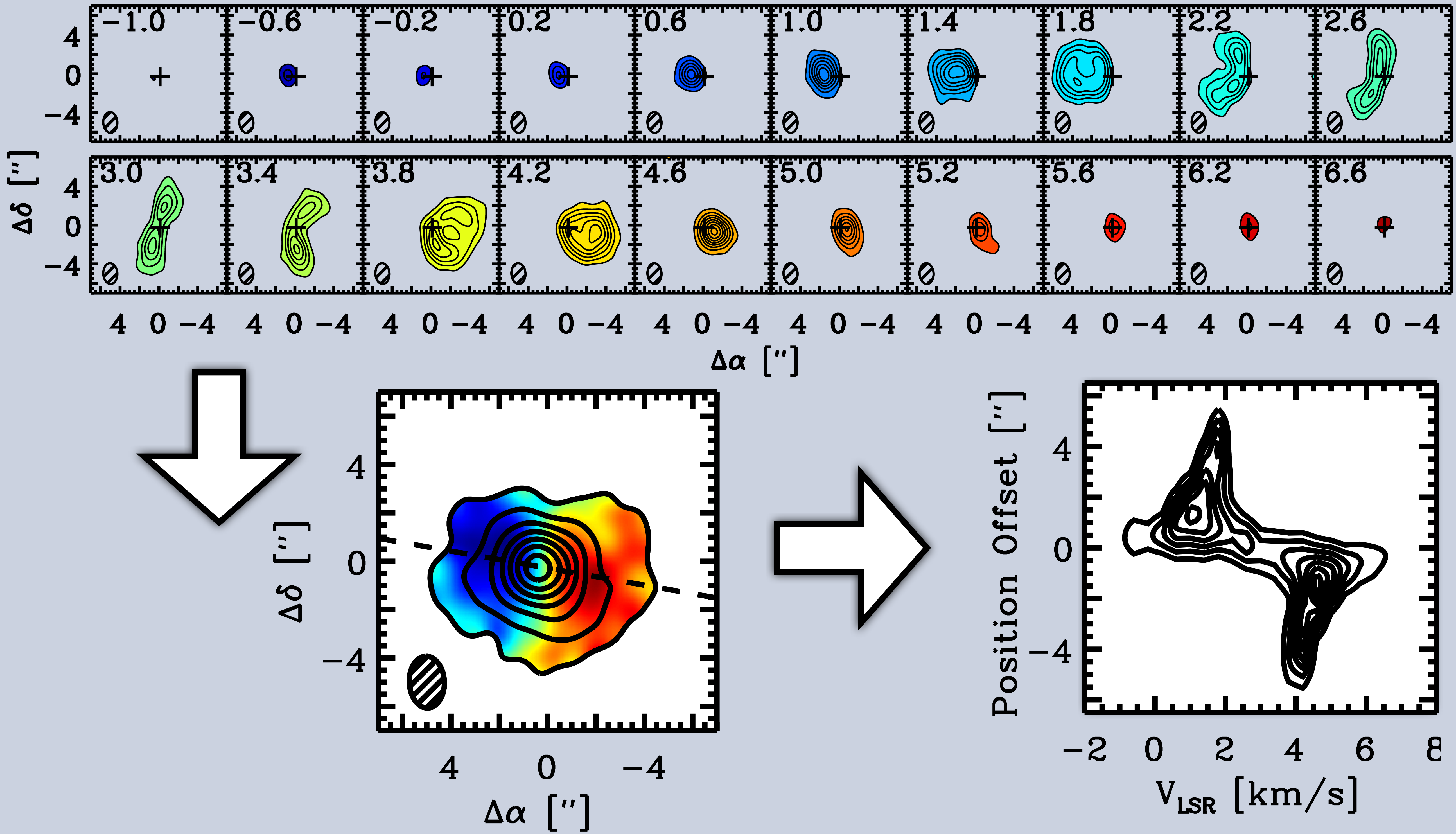
4 extra compact and extended tracks on V4046 Sgr (PI J. Kastner)

A spatially resolved chemistry (IM Lup)

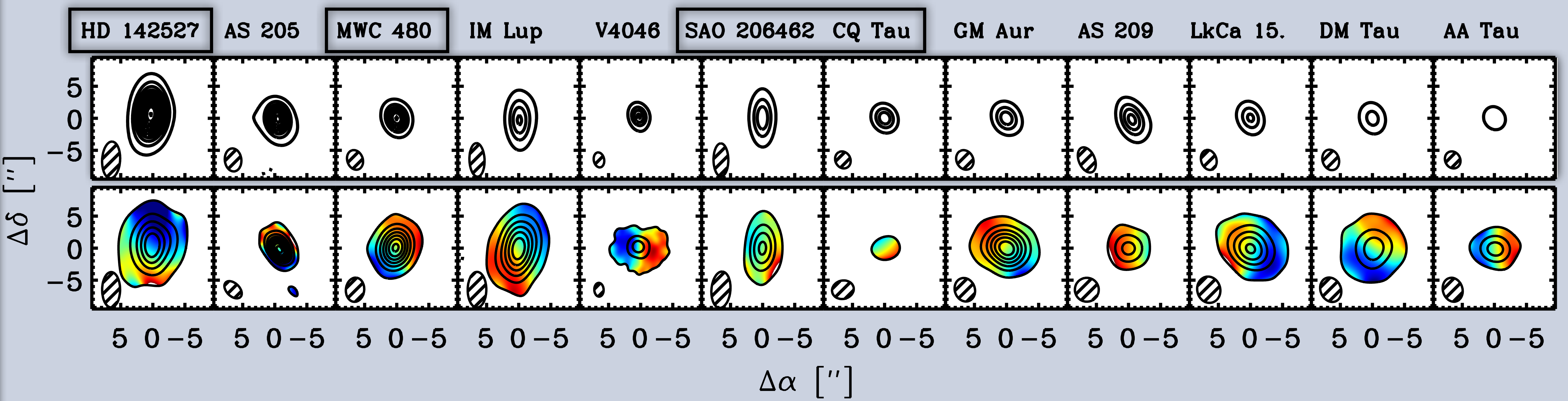
- ★ Needed to derive accurate abundances
- ★ Info on radial chemistry changes
- ★ Can be used to derive disk structure to be compared with dust-disk models
- ★ 12 disks x 3-10 lines x 5-20 velocity channels



Visualizing spatial distributions: CO in V4046 Sgr



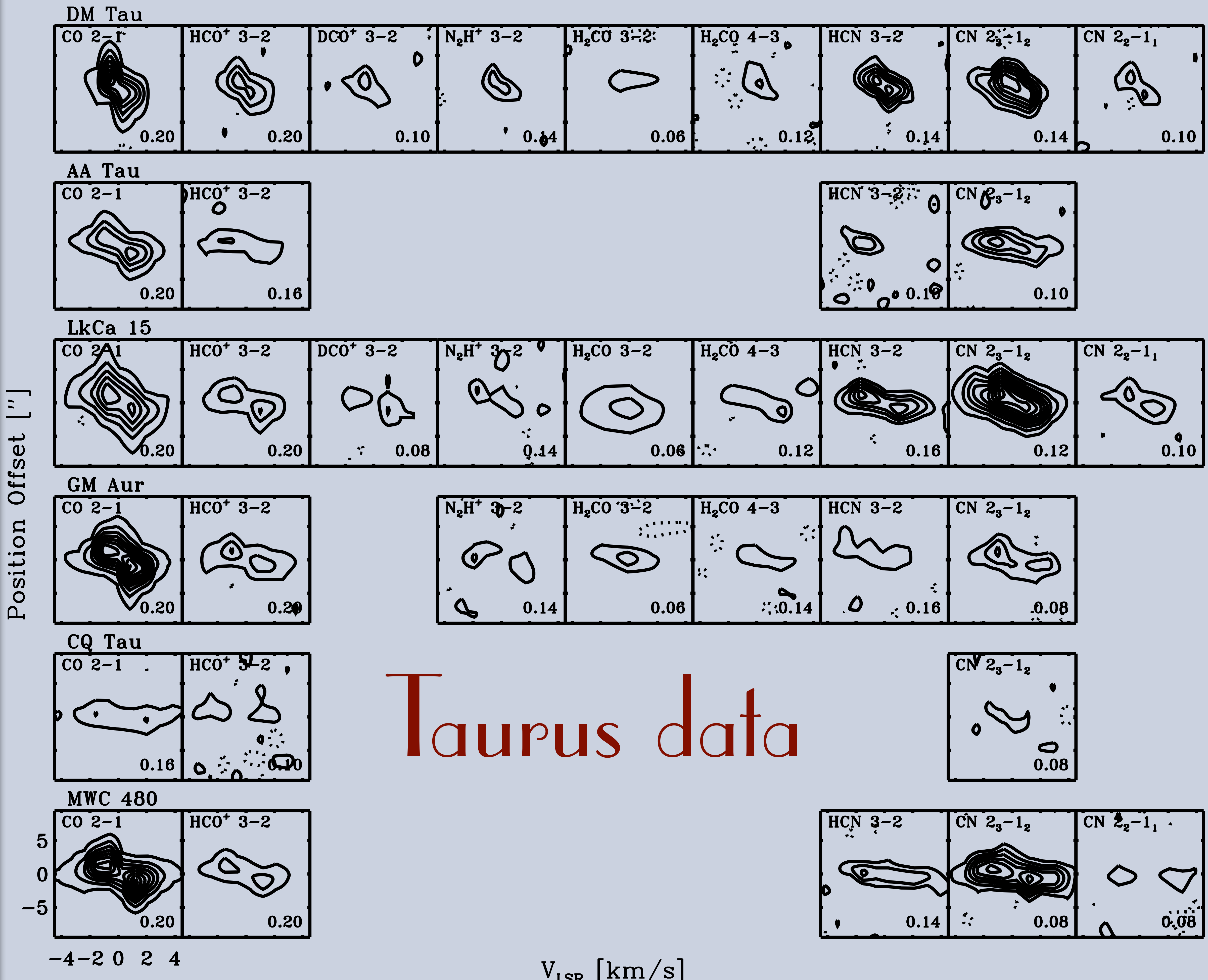
Dust vs. gas



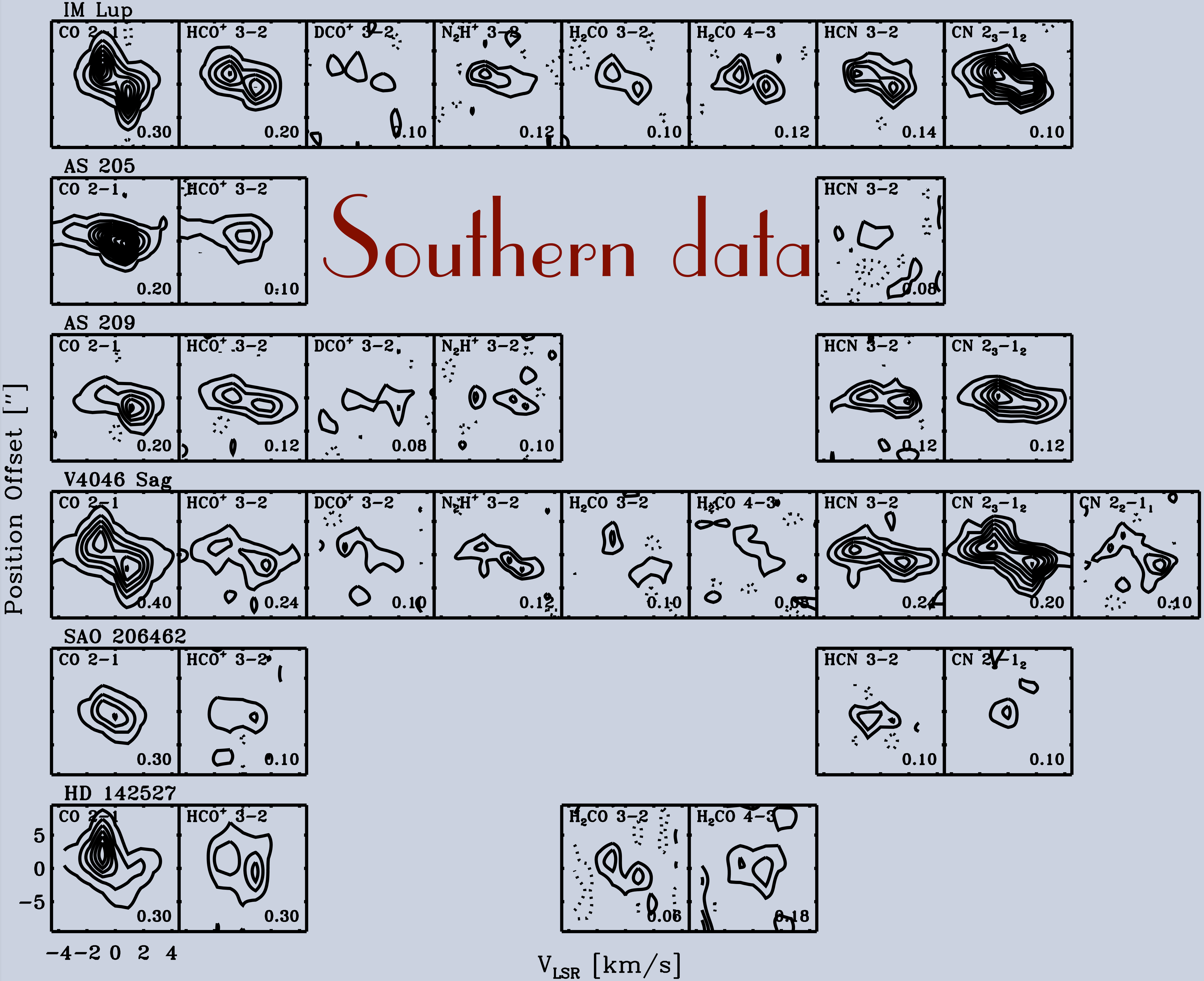
No obvious correlation between 1 mm dust continuum and CO 2-1 emission (nor between CO 2-1 and the molecular inventory)

No obvious difference between Herbig Ae and T Tauri disks

Taurus data

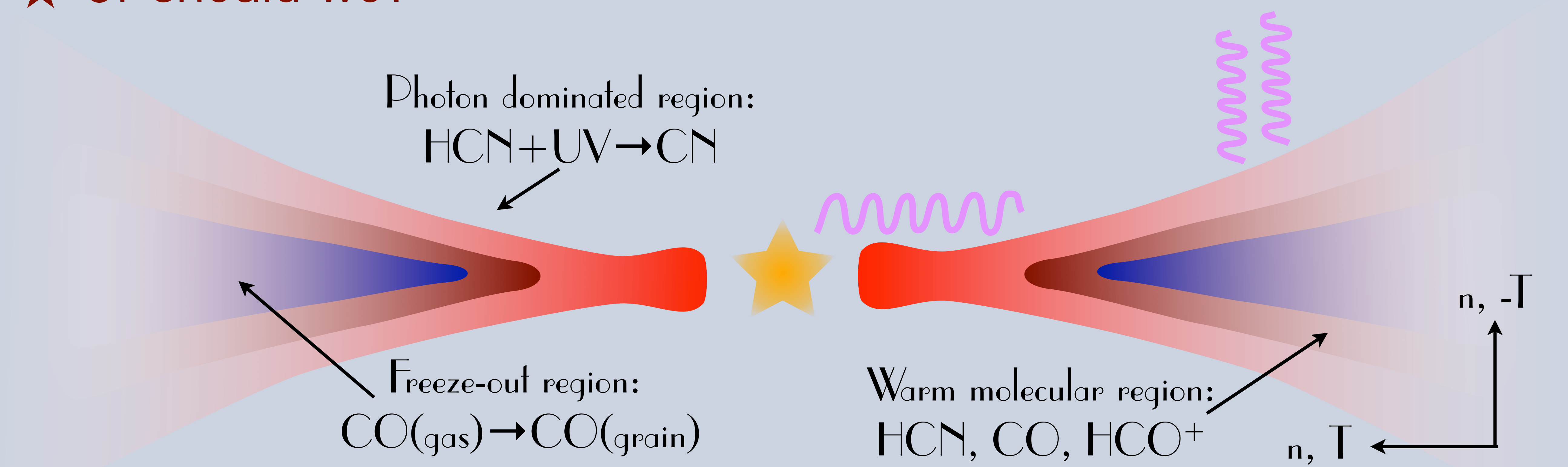

DM Tau
CO 2–1
HCO+ 3–2
DCO+ 3–2
N2H+ 3–2
H2CO 3–2
H2CO 4–3
HCN 3–2
CN 23–12
CN 22–11
0.20
0.20
0.10
0.14
0.06
0.12
0.14
0.14
0.10
AA Tau
CO 2–1
HCO+ 3–2
HCN 3–2
CN 23–12
0.20
0.16
0.10
0.10
LkCa 15
CO 2–1
HCO+ 3–2
DCO+ 3–2
N2H+ 3–2
H2CO 3–2
H2CO 4–3
HCN 3–2
CN 23–12
CN 22–11
0.20
0.20
0.08
0.14
0.06
0.12
0.16
0.12
0.10
GM Aur
CO 2–1
HCO+ 3–2
N2H+ 3–2
H2CO 3–2
H2CO 4–3
HCN 3–2
CN 23–12
0.20
0.20
0.14
0.06
0.14
0.16
0.08
CQ Tau
CO 2–1
HCO+ 3–2
CN 23–12
0.16
0.10
0.08
MWC 480
CO 2–1
HCO+ 3–2
HCN 3–2
CN 23–12
CN 22–11
0.20
0.20
0.14
0.08
0.08
Position Offset ["]
5
0
−5
−4 −2 0 2 4
VLSR [km/s]

Southern data

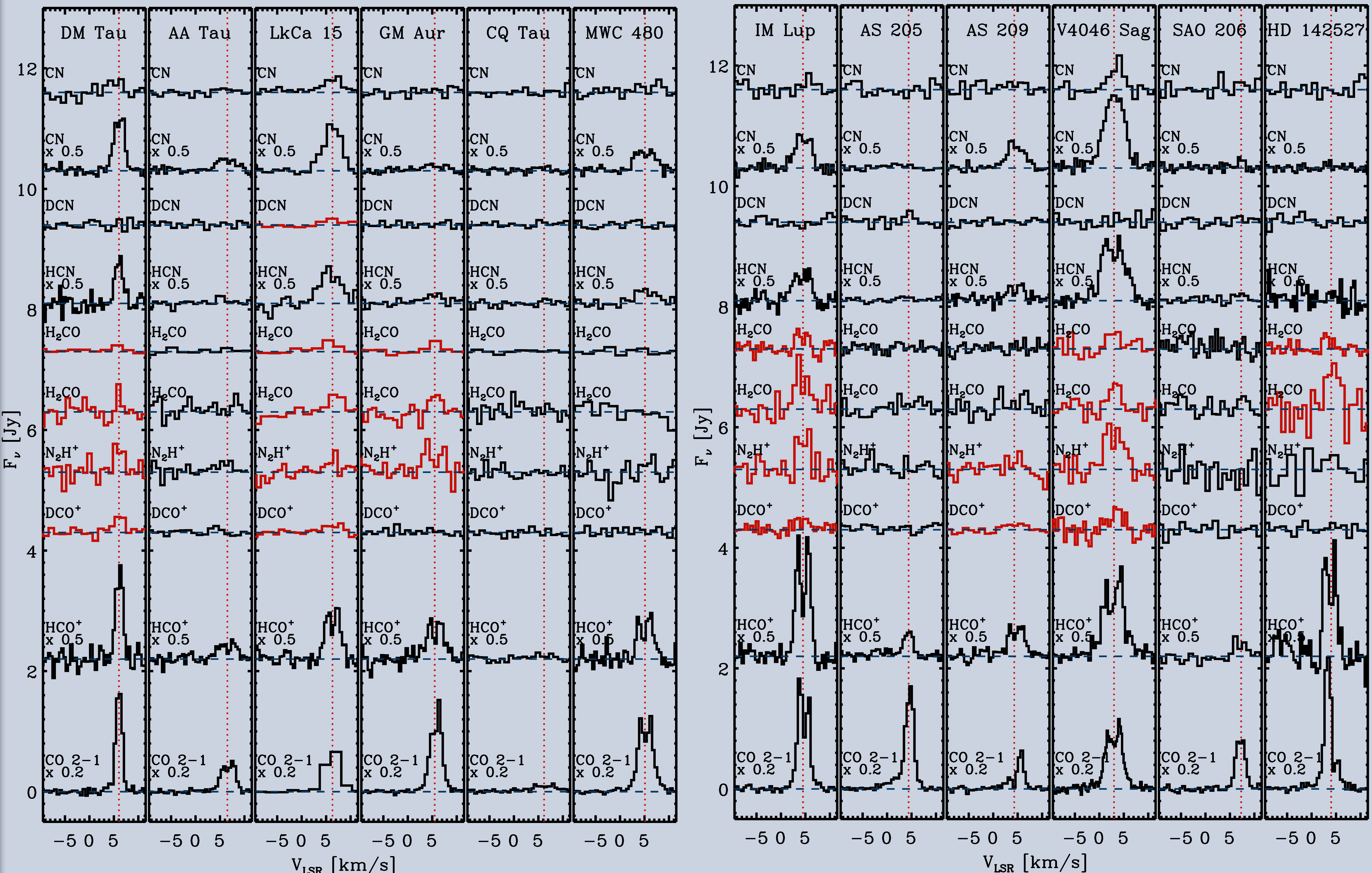


Disk-averaged trends across the survey

- ★ Orders of magnitude range in stellar luminosity and accretion luminosity and different stages of grain settling.
- ★ If radiation drives chemistry (through heating or direct photochemistry) we should see disk averaged differences across the sample.
- ★ Or should we?

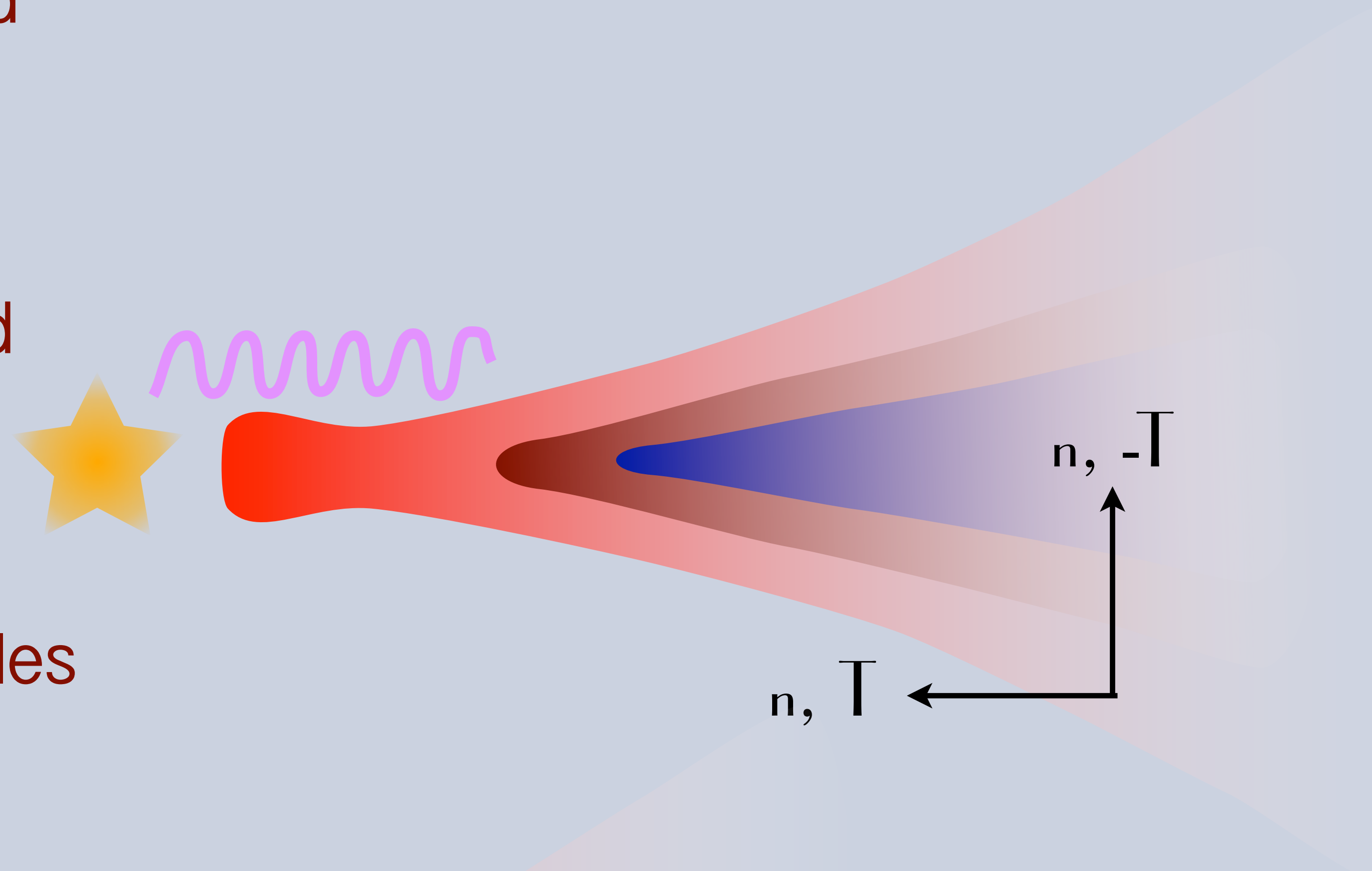


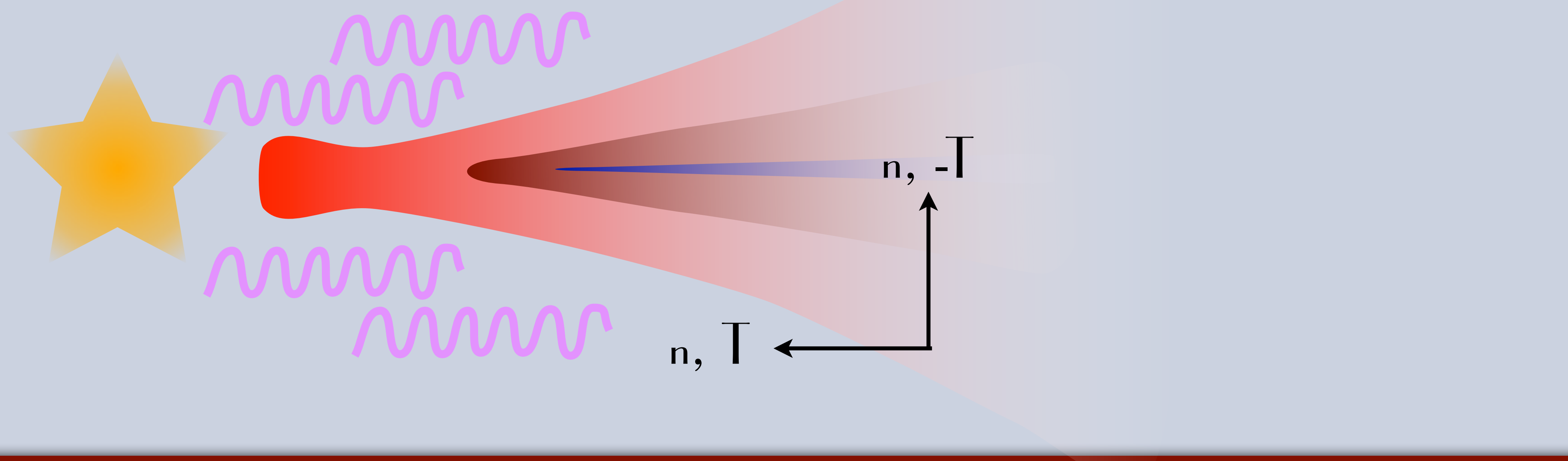
DISCS Detection Rates



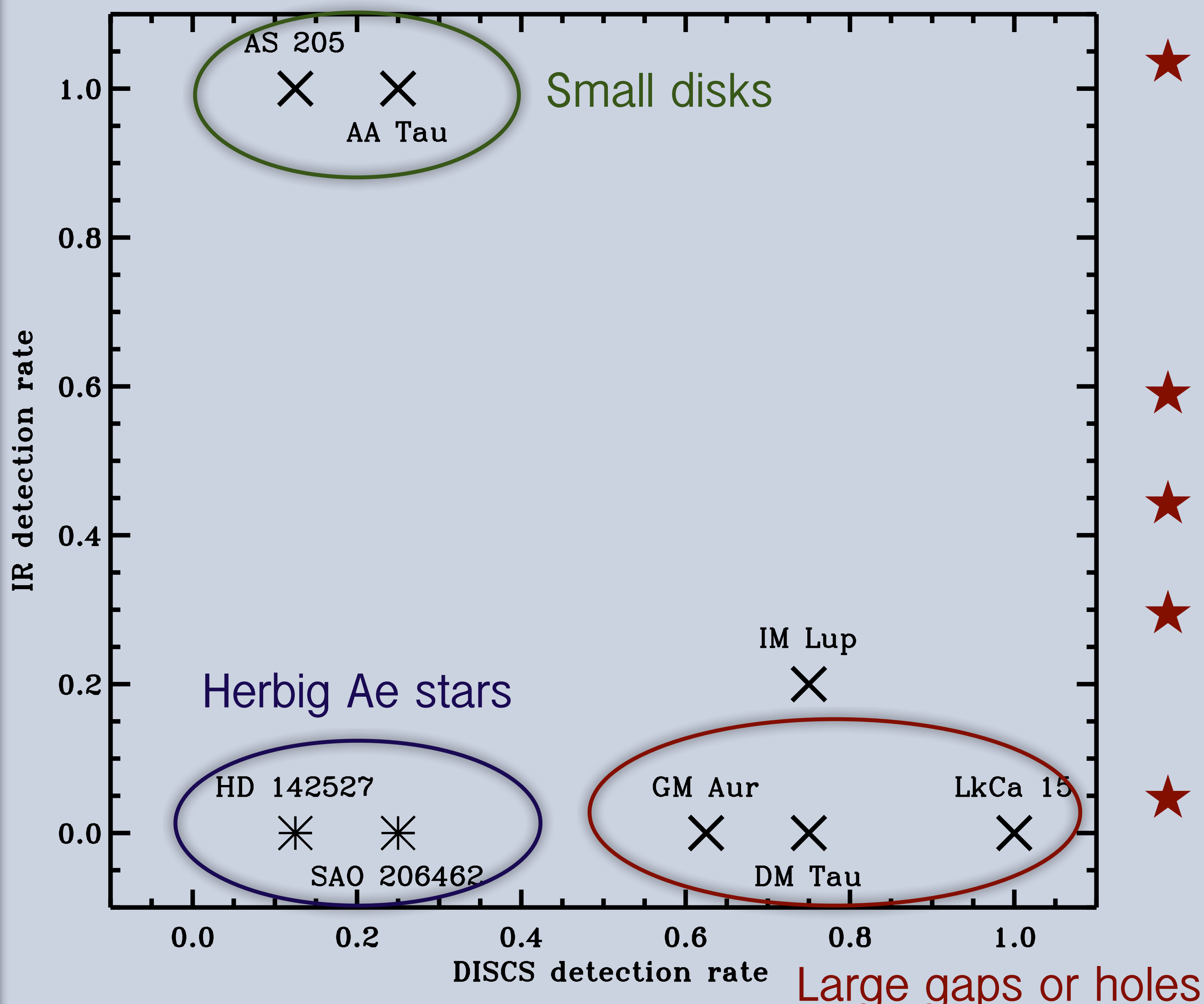
Rich T Tauri and poor Herbig Ae disks?

- ★ N_2H^+, H_2CO, DCO^+ generally detected toward T Tauri disks and lacking toward Herbig Ae disks
- ★ Good tracers of cold material toward disk midplanes
- ★ Most Herbig Ae disks lack protected midplanes for long enough time scales and chemistry is reset compared to protostellar phase?



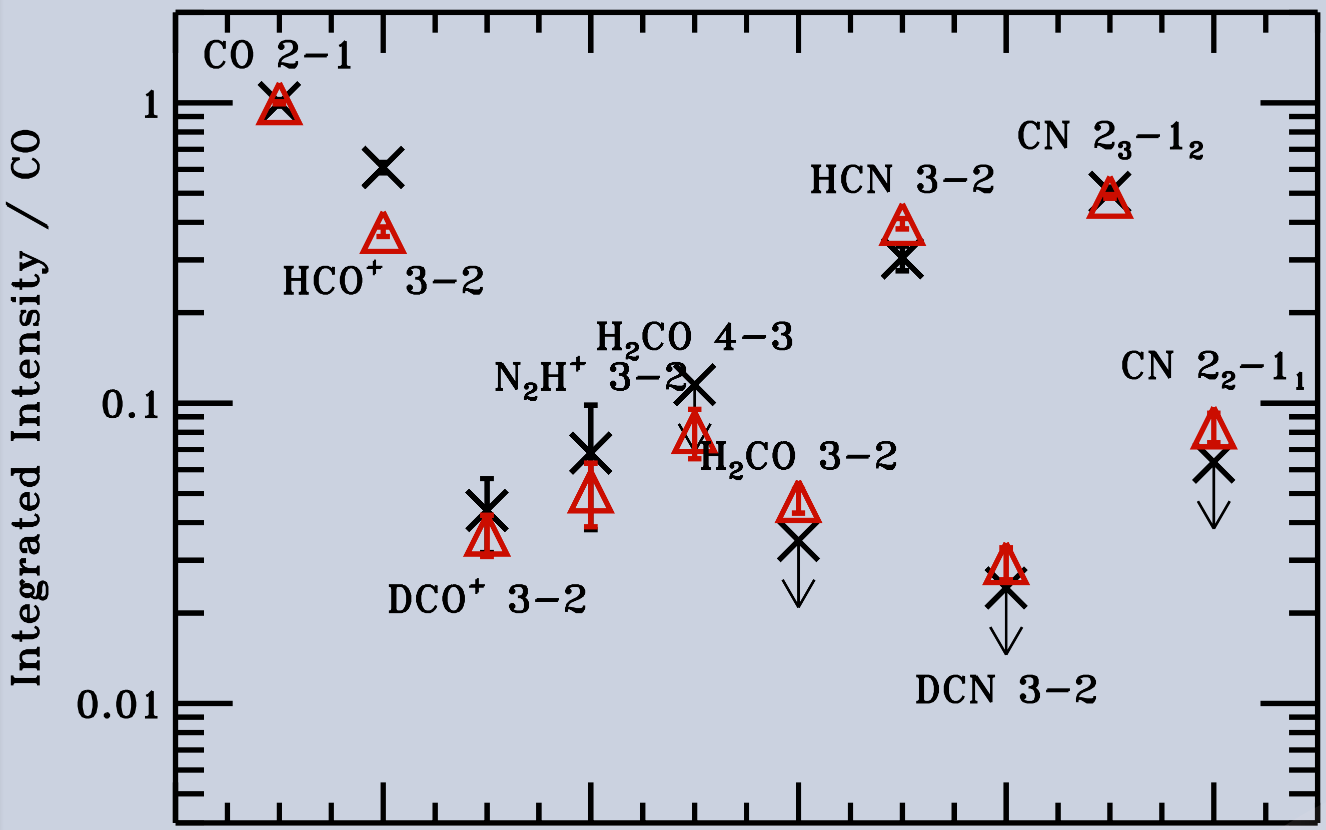


Inner vs. outer disk chemistry

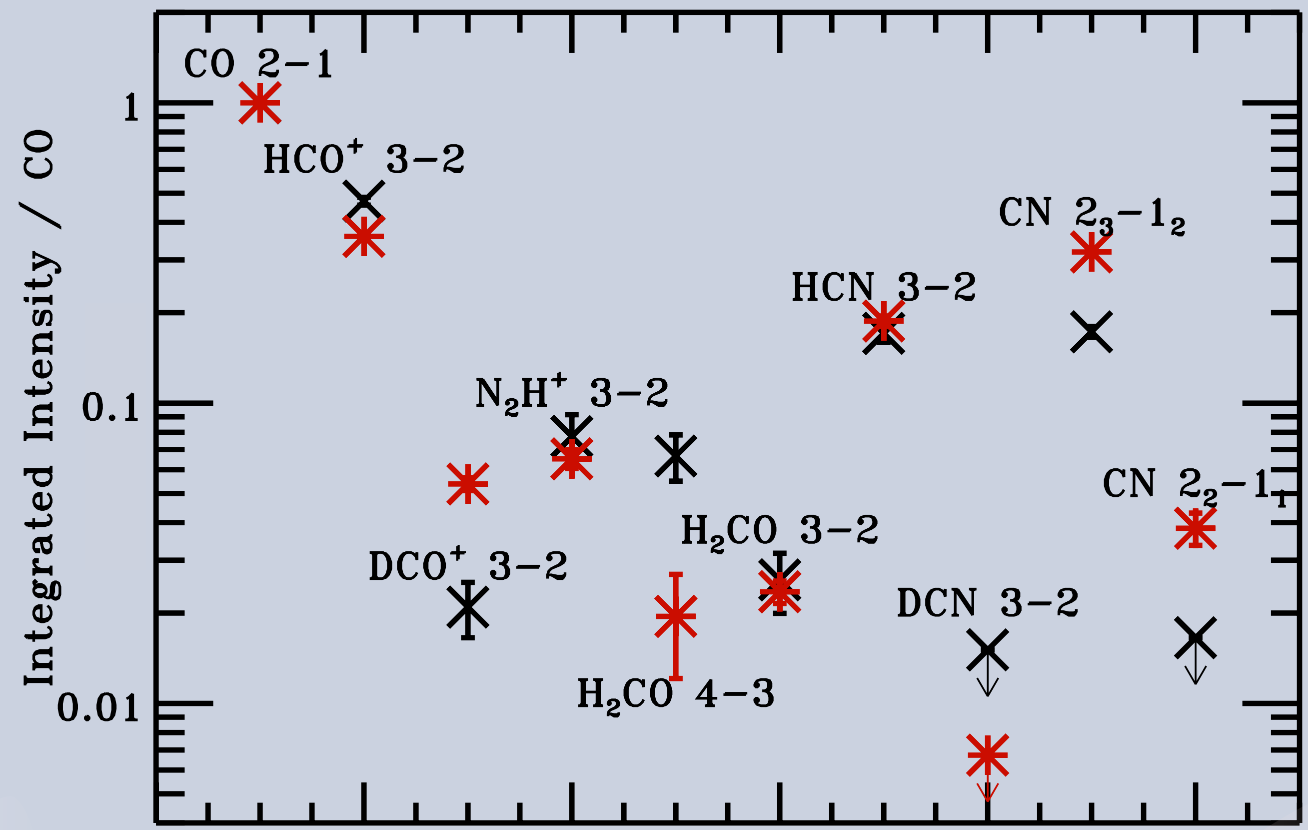


- ★ 67% source overlap between DISCS and infrared chemistry surveys (Pascucci et al. 2008, Pontoppidan et al. 2010)
- ★ IR R<10 AU
- ★ DISCS R>100 AU
- ★ Few molecules in Herbig Ae disks in both regimes
- ★ No positive correlation; boring anti-correlation?

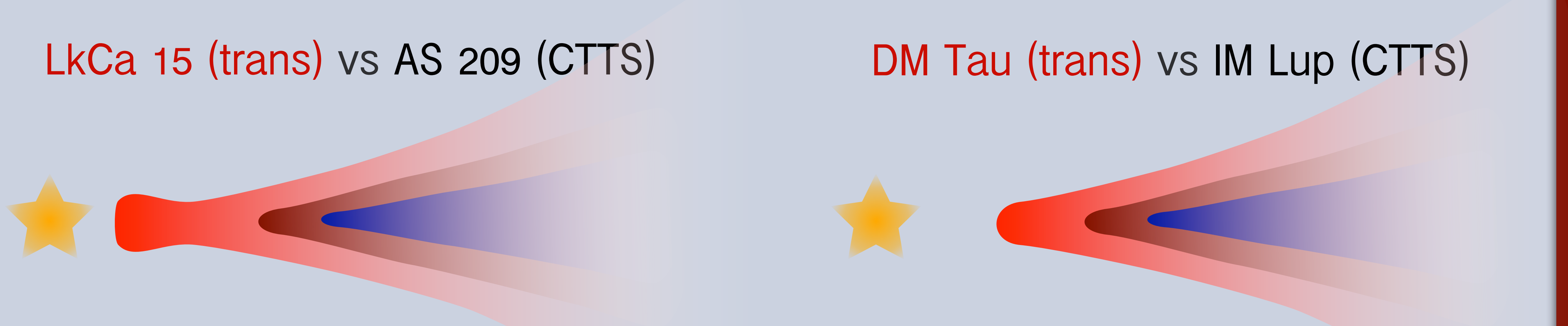
Transition disks vs classical T Tauri disks



LkCa 15 (trans) vs AS 209 (CTTS)



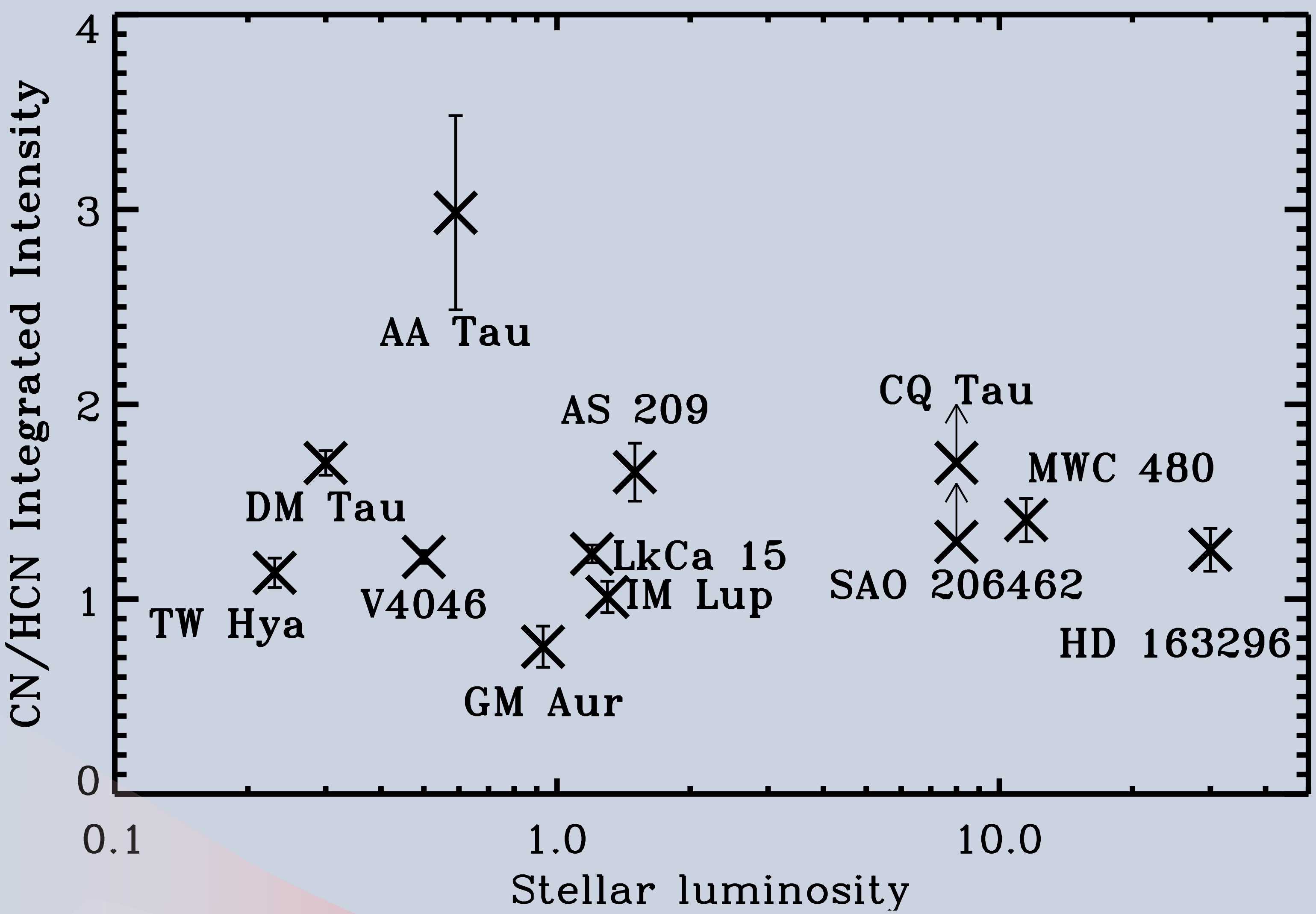
DM Tau (trans) vs IM Lup (CTTS)



Outer disk chemistry oblivious of inner disk physics:

holes, gaps, accretion

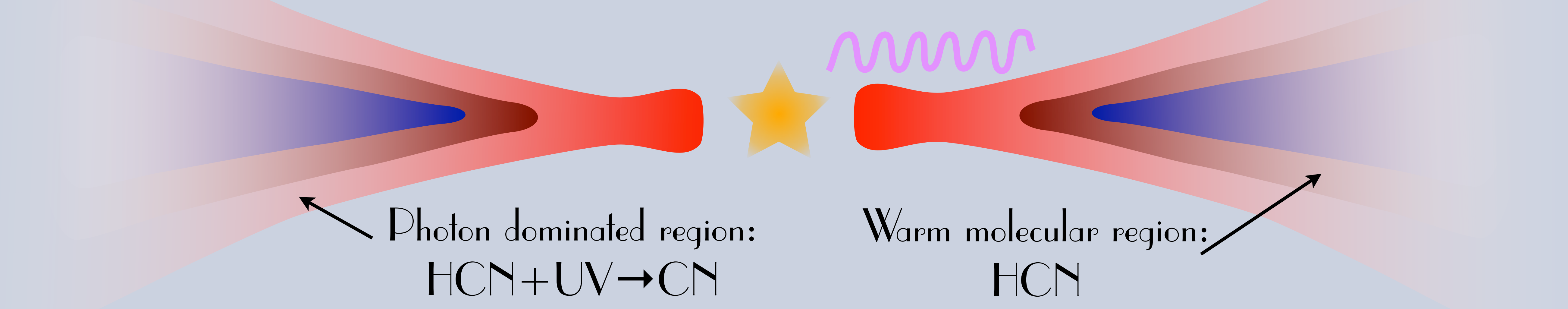
Radiation Chemistry: CN/HCN



★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.



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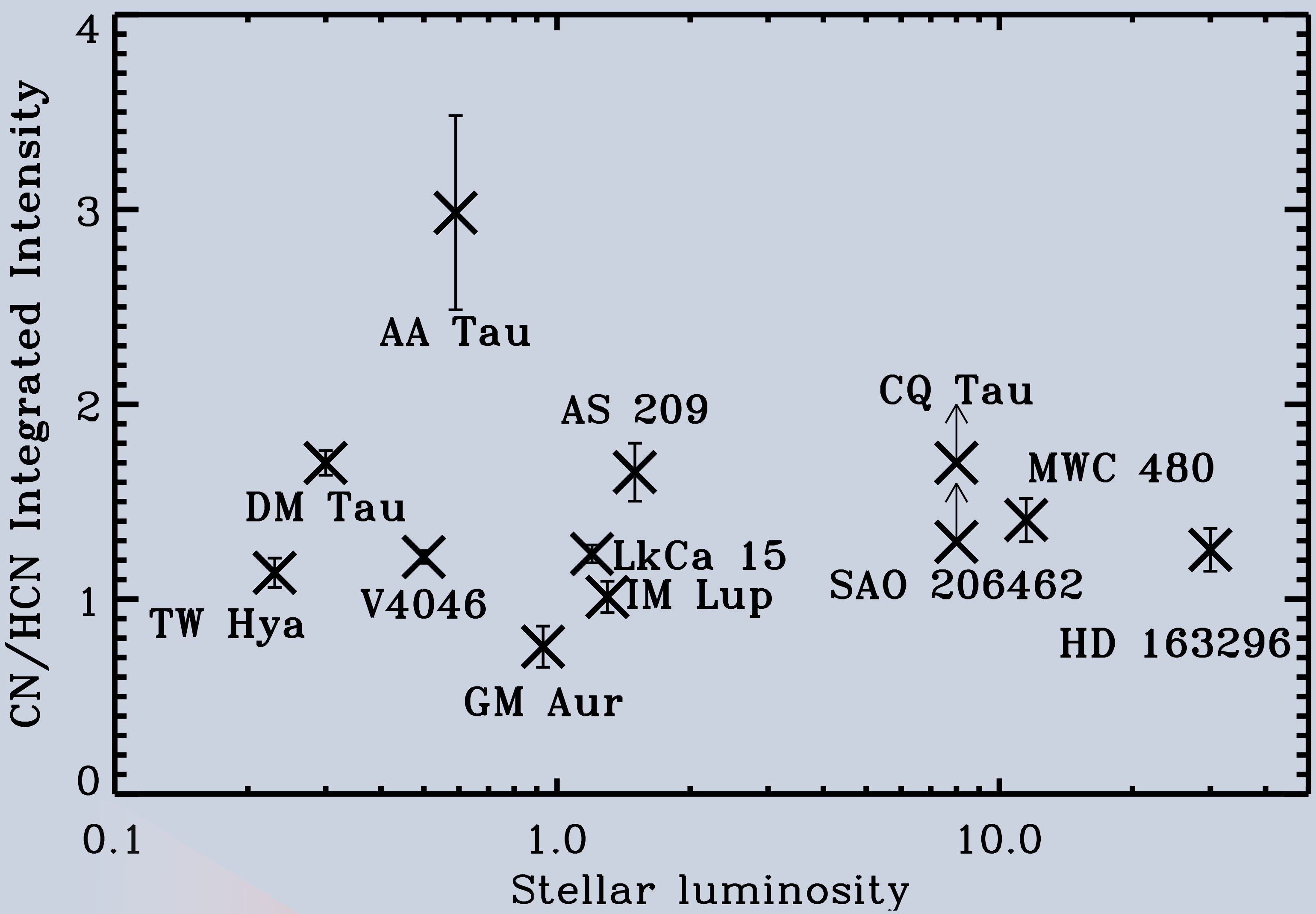

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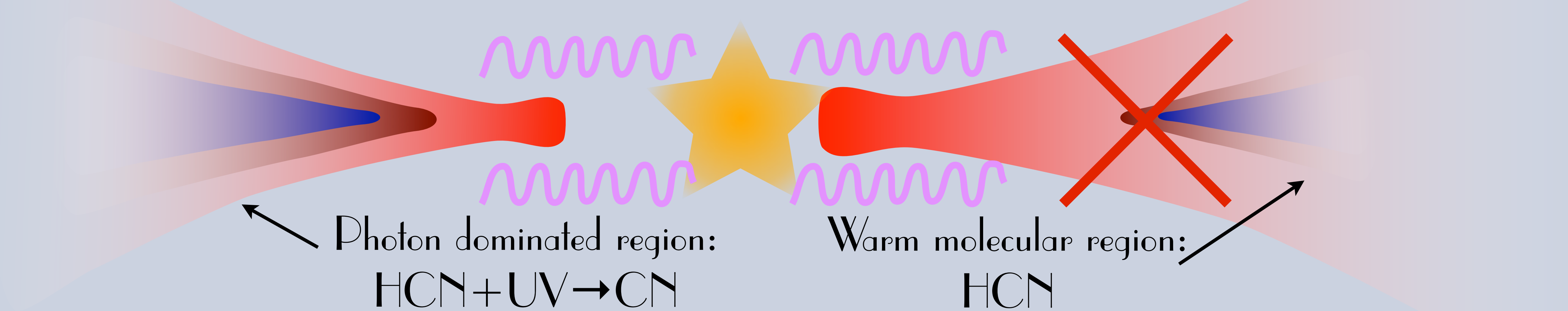
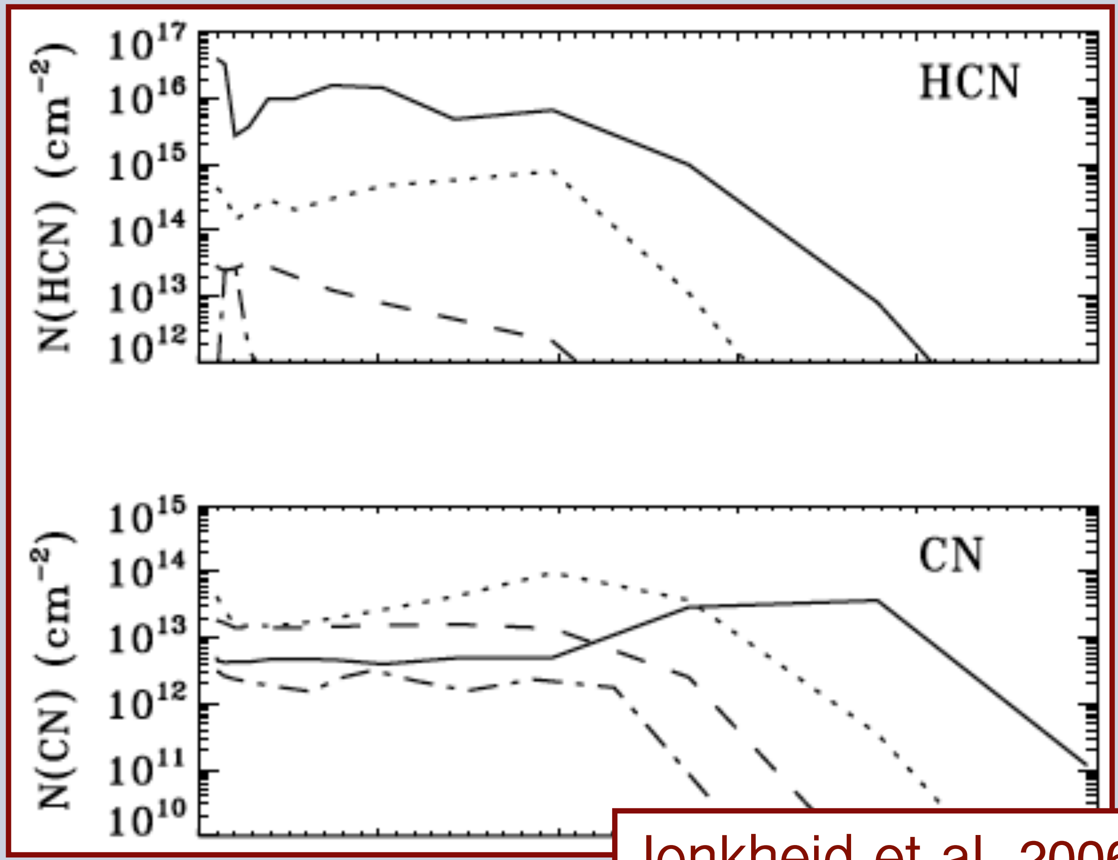


CN vs. HCN emission regions

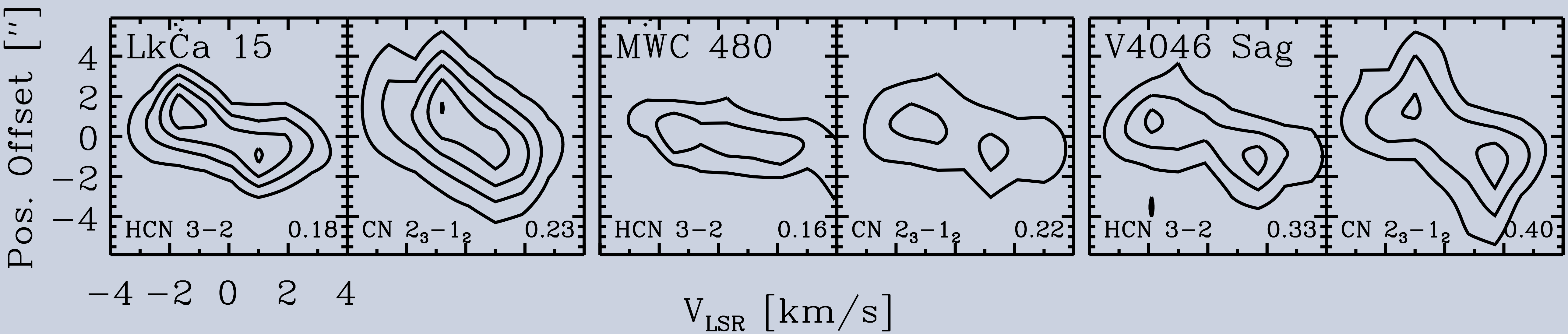
Within disks the CN/HCN ratio is variable

CN emission often originates further out in the disk

Supports models of higher CN abundances in outer disks because of density tapering

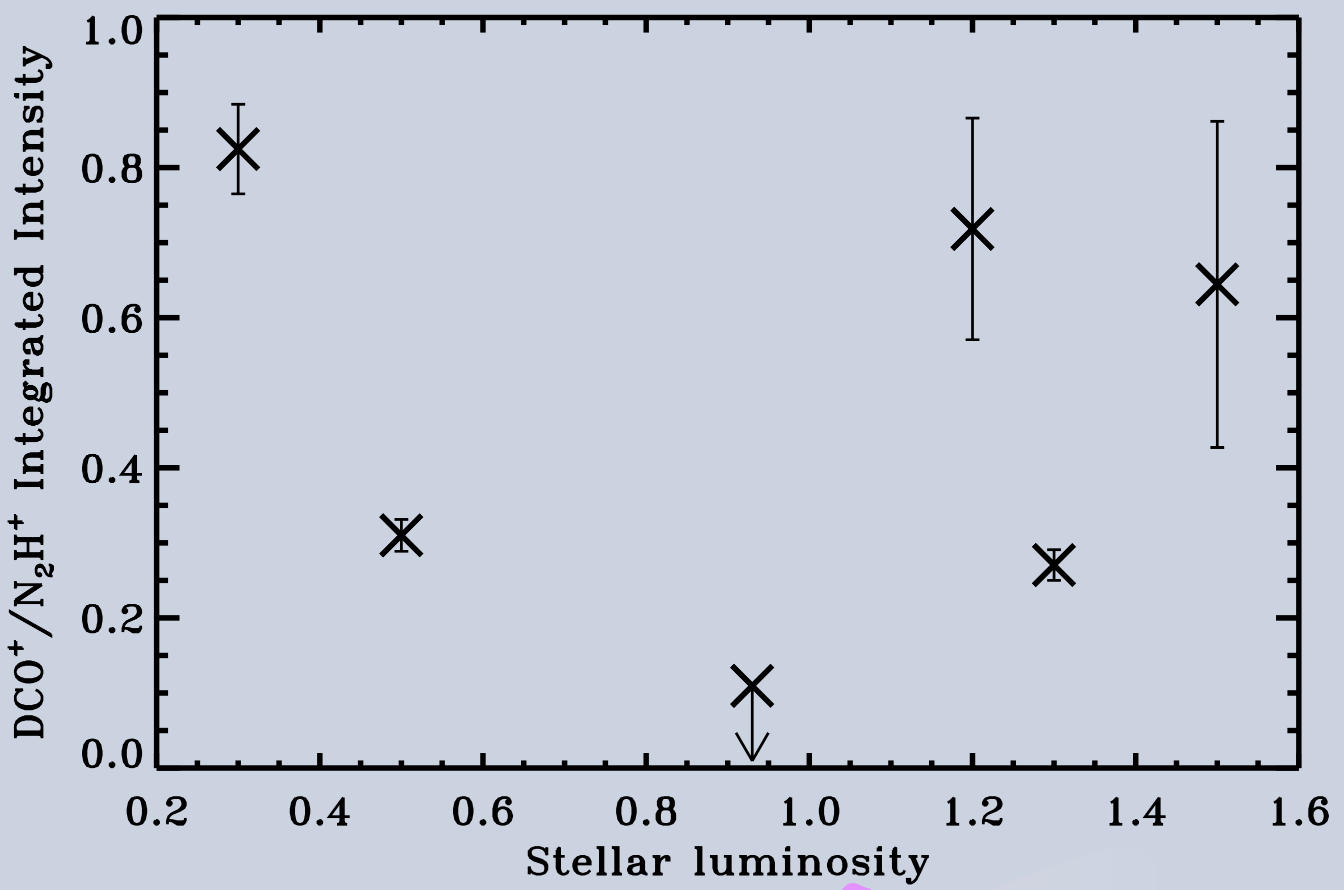


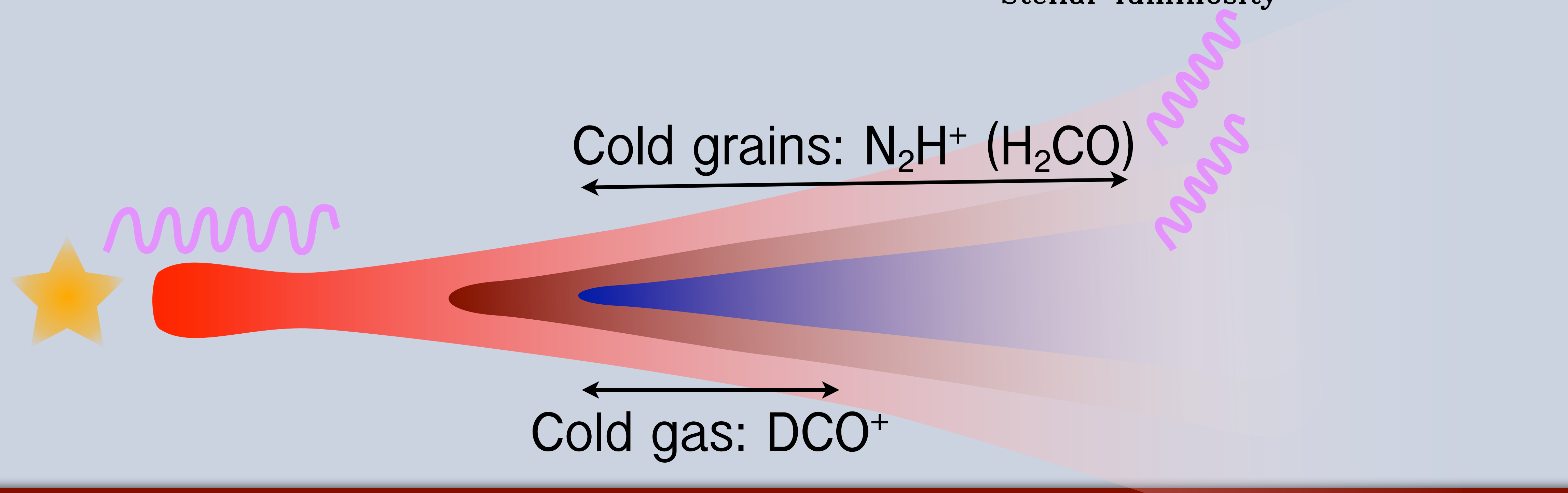
Jonkheid et al. 2006



Different cold chemistries?

- ★ N_2H^+ and DCO^+ not correlated across the sample
- ★ Order of magnitude range in DCO^+/N_2H^+ ratio suggests different emission conditions
- ★ Cold grains and cold gas not always coinciding?





IM Lup as a model test case

1. Grid of tapered disk models with 5 disk parameters and 2 geometric parameters (e.g. Hughes et al. 2008)

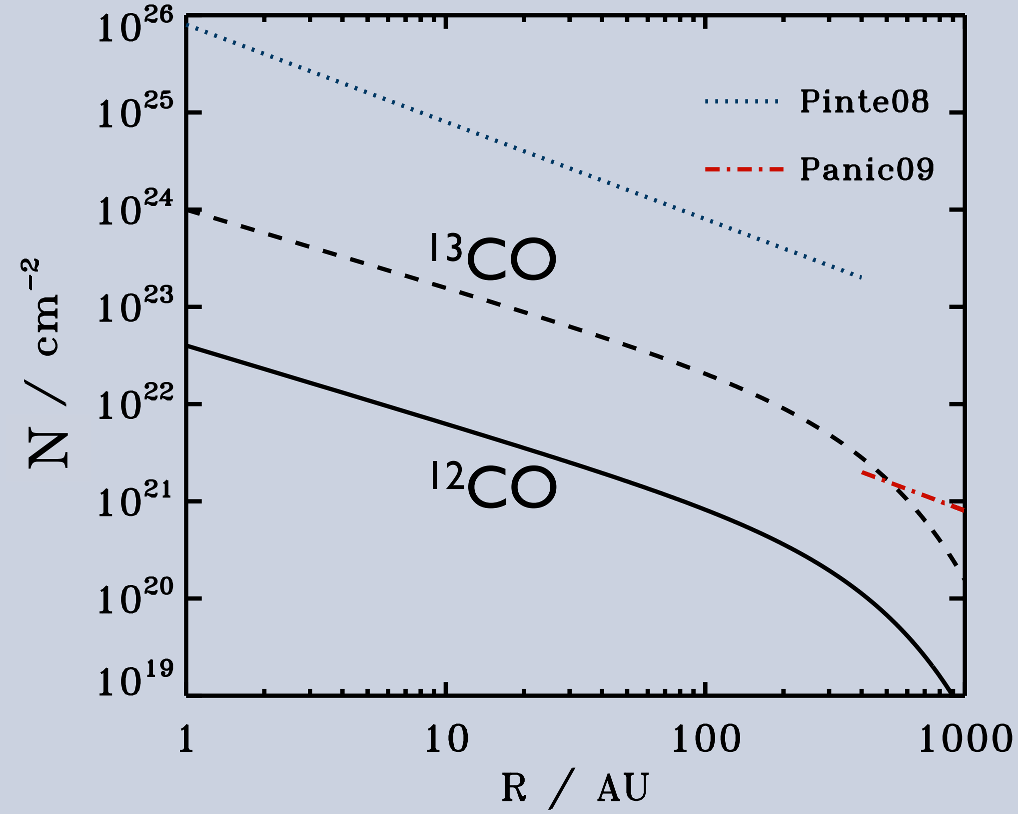
$$\Sigma = \frac{c_1}{R^\gamma} exp\left[-\left(\frac{R}{R_C}\right)^{2-\gamma}\right] \qquad T = \left(\frac{T_{100}}{R}\right)^q$$

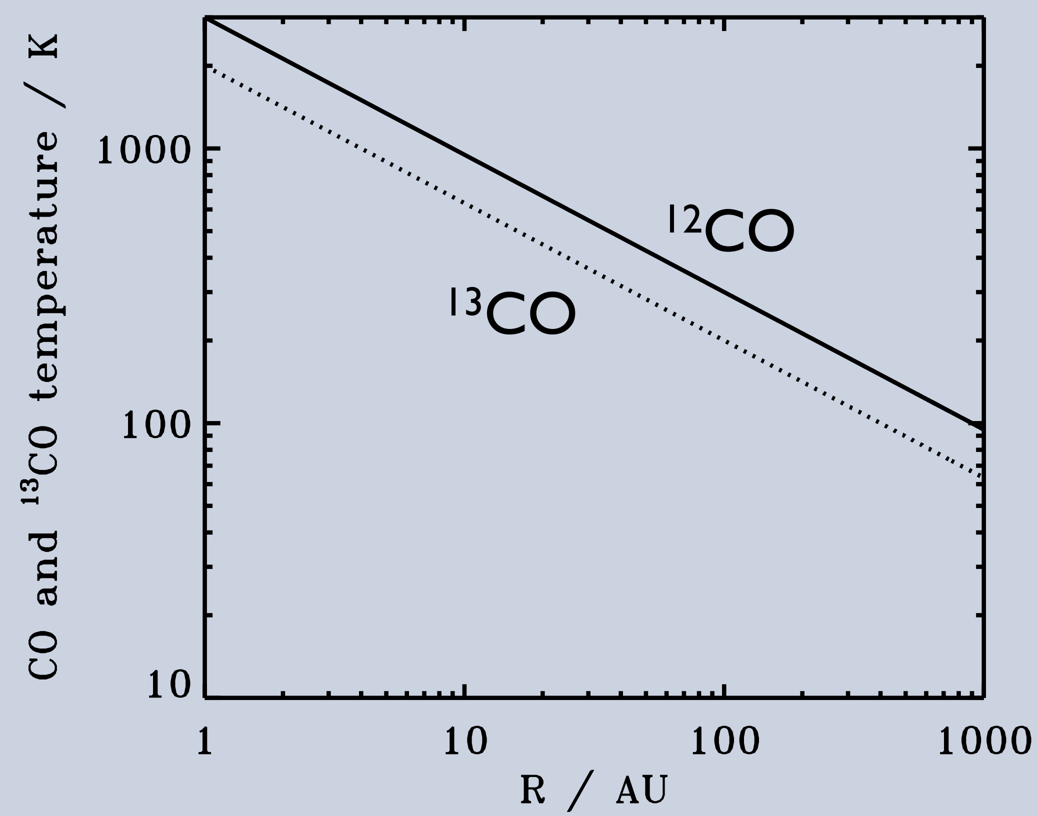
2. LIME radiative transfer of CO and ^{13}CO emission lines (Brinch and Hogerheijde 2010)
3. χ^2 optimization between observed and model visibilities
4. Use best-fit model to constrain emission lines of cold chemistry tracers

Fixed: M=1 $M_\odot$, q=0.5, γ=0.9, [CO]=10^{-4}, [^{13}CO]=1.4x10^{-6}

From Panić et al. 2009 and Pinte et al. 2008: i, P.A., v_{lsr}

Free parameters: T_{100}, c_1, R_C





CO and ^{13}CO results

CO 2-1

T_{100} = 300 / 200 K

c_1 = 4x10^{22} / 1x10^{24} cm^{-2}

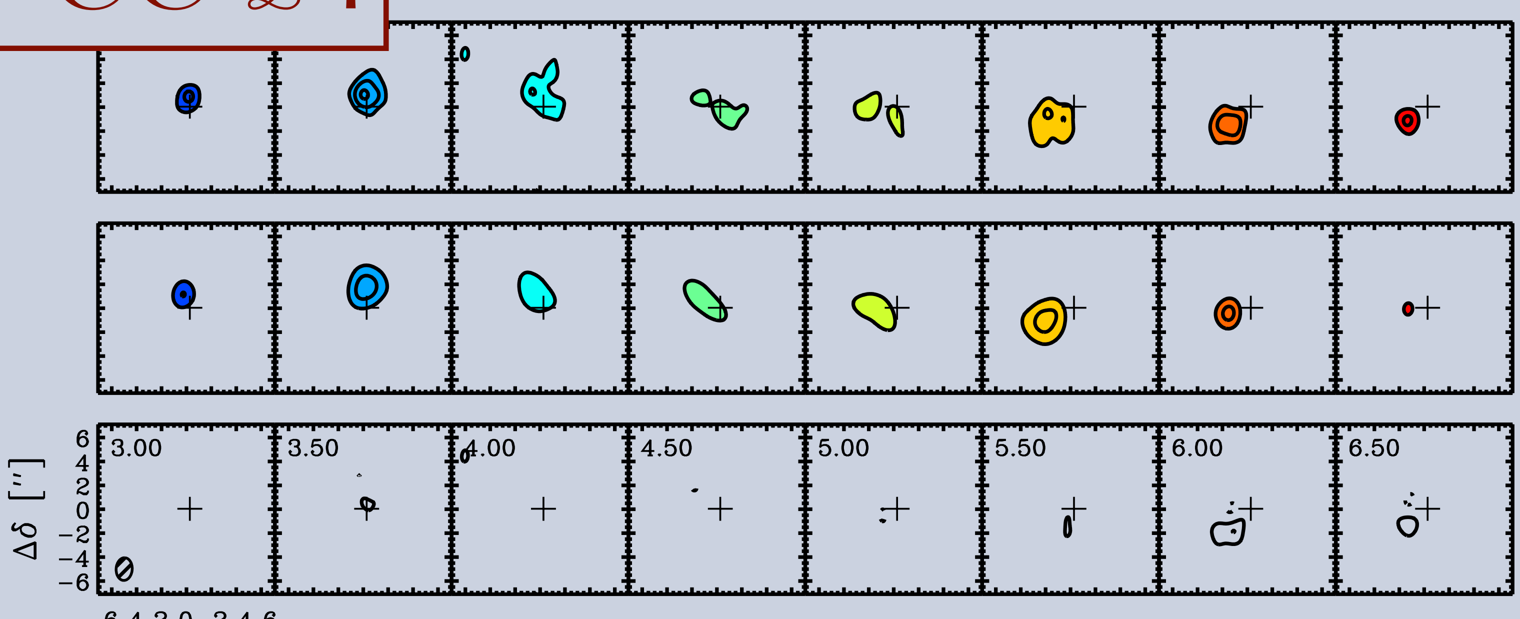
R_C = 375 AU

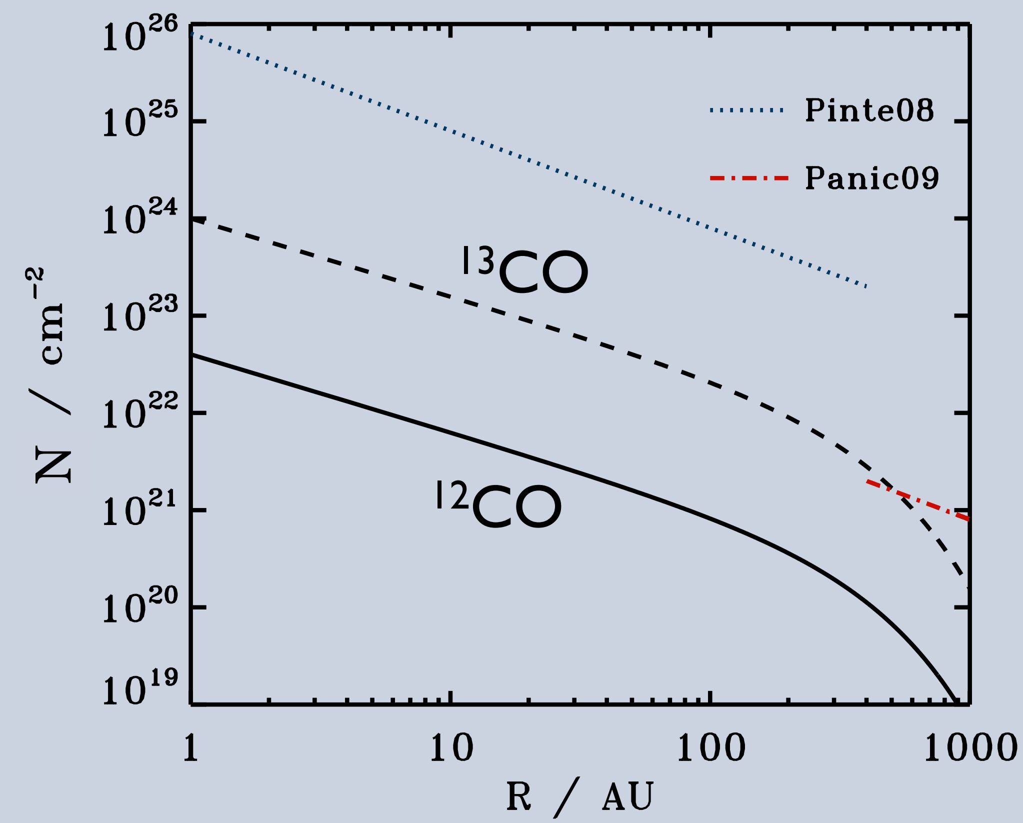
i = 53°

P.A. = 310°

v_{lsr} = 4.4 km s^{-1}

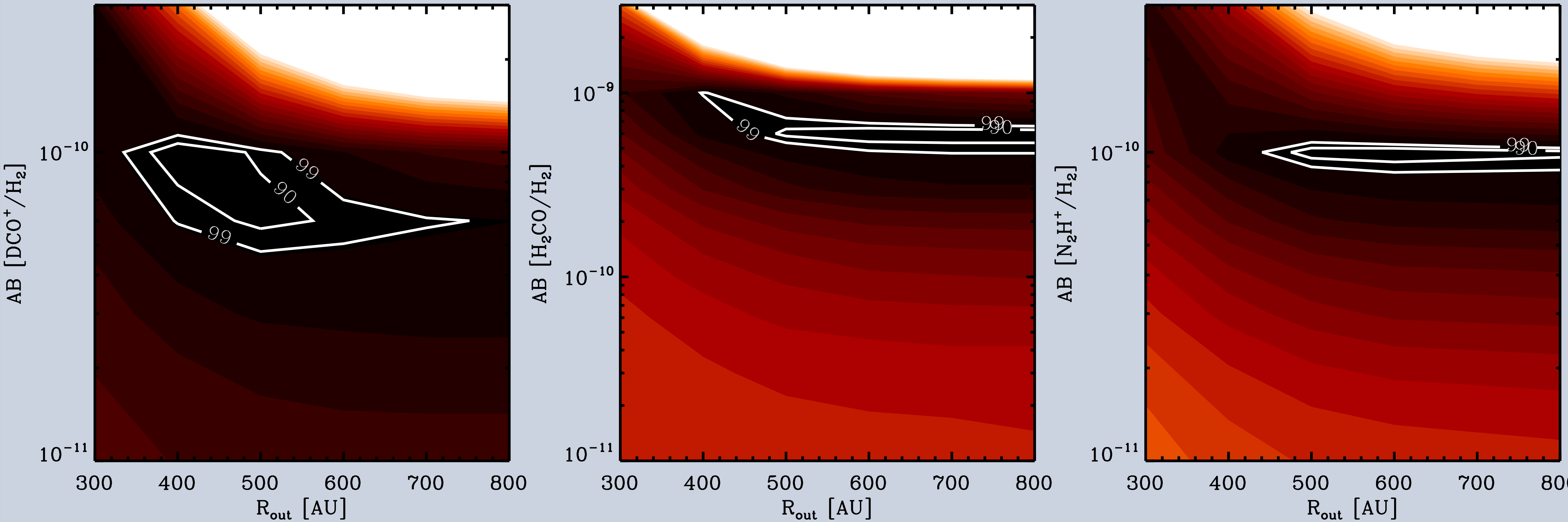
^{13}CO 2-1

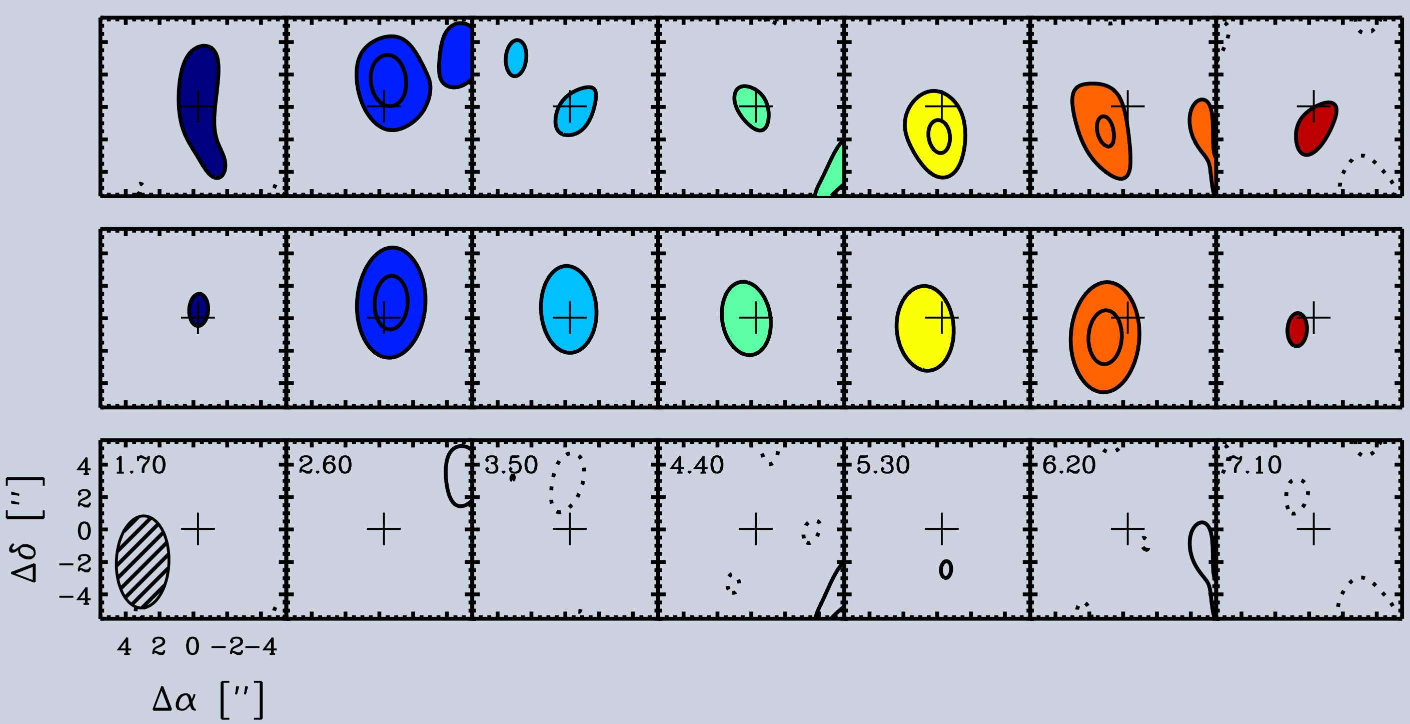


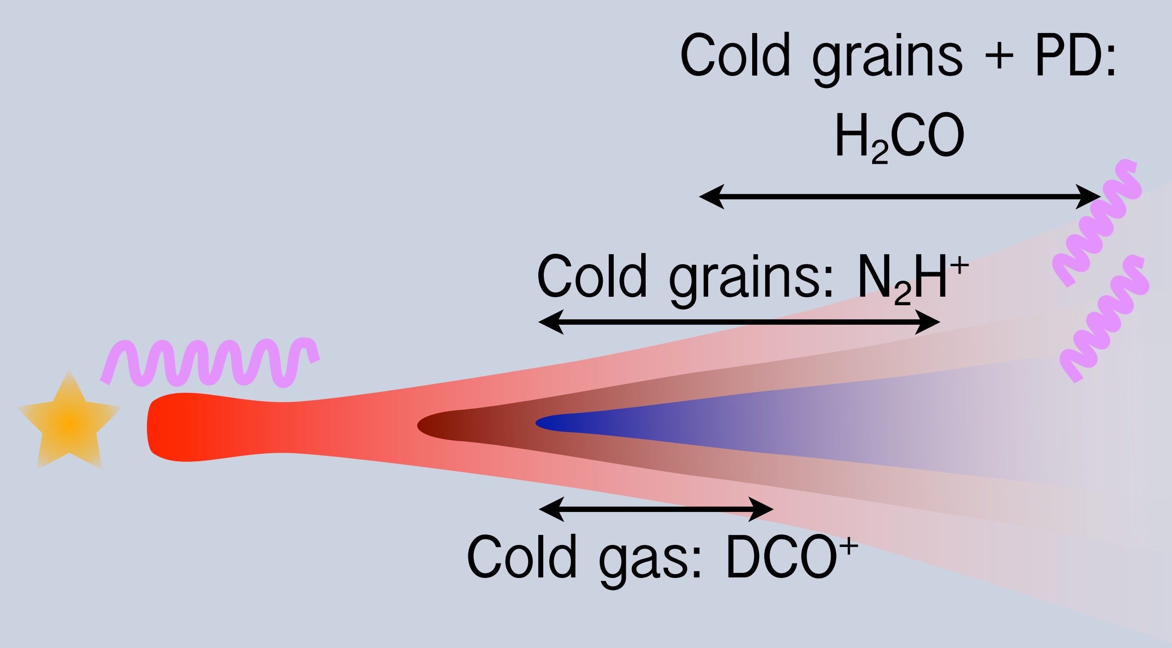


^{13}CO and CO data presented in Panić et al. 2009

IM Lup DCO^+, N_2H^+ and H_2CO results







DiSCS conclusions (so far)

- ★ High detection rates of small molecules toward disks around low-luminosity stars - low detection rate toward high-luminosity stars: DCO^+, N_2H^+ and H_2CO require cold midplanes to be abundant
- ★ Chemical disconnect between inner and outer disk
- ★ The averaged CN/HCN emission ratio is constant across the sample, despite order of magnitude differences in radiation fluxes; the radial distributions of molecules in individual disks are potential tracers of disk physics e.g. CN/HCN and DCO^+/N_2H^+ radii