Galactic Spectroscopy

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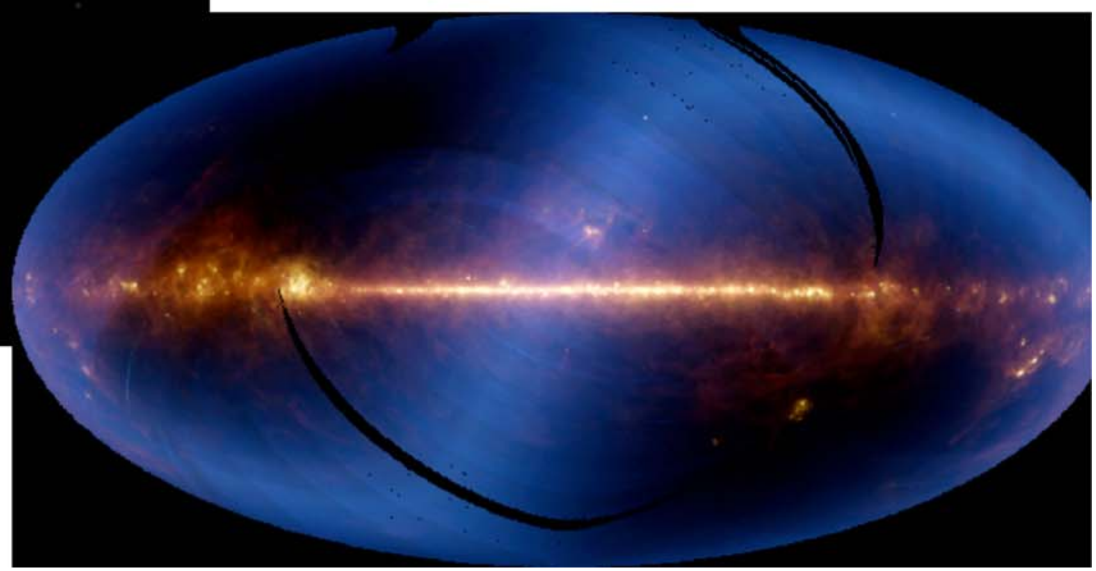


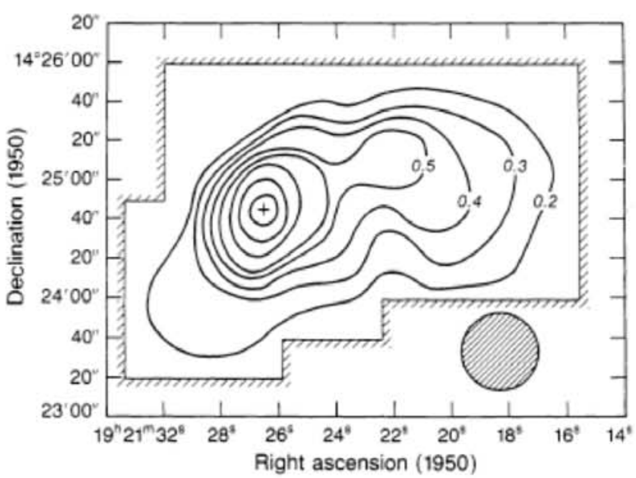
The state of things in 1984

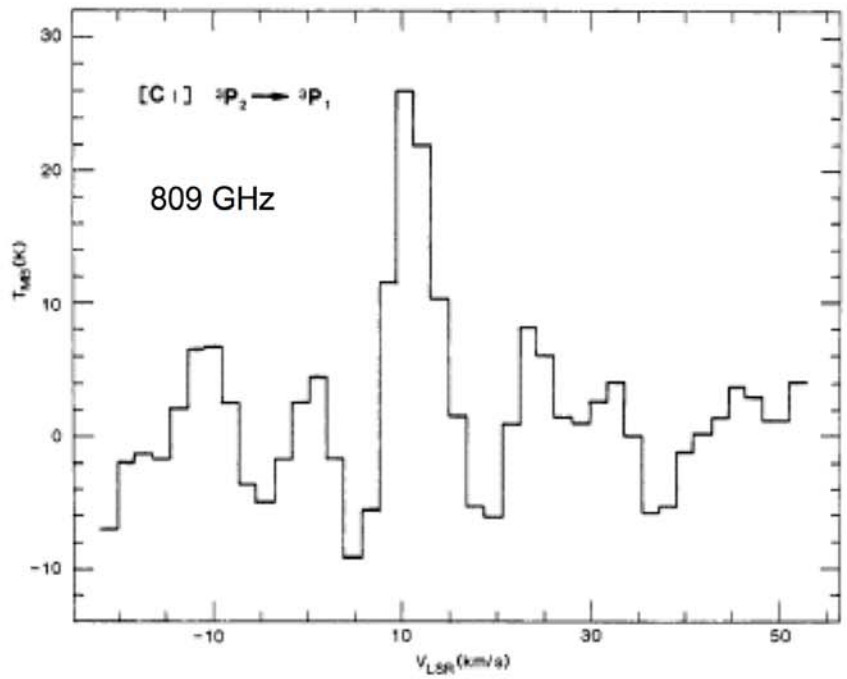
T_{rec}~ 7500 K DSB
A_{tel} ~ 3 m^2

1x1 Bolometer array
42" beam, 50 Jy/$Hz^{1/2}$

W51 at 400 μm

Jaffe, Becklin, & Hildebrand 1984





Jaffe et al. 1985

Molecular Clouds in Galaxies (yesterday)
Global Star Formation (yesterday and Paul Goldsmith))
Dense Hot Cores (Juergen Stutzki started this)
Individual Clump/Star Formation (now and Darek Lis)
Planet Formation (now)

At every stage of the evolution from diffuse ISM to planetary bodies, there is a winnowing of material that is paralleled by a physical and chemical evolution. CCAT can help determine what fraction goes where and the physical and chemical state of the 'leftover' material.

CCAT can contribute by:

Large Focal Plane Arrays	Surveying large areas while preserving good spatial resolution (important for first problem) Giving context to compact sources
Small Arrays	Filling in zero spacings
Large bandwidth	Surveying large spectral regions
Good surface, better receivers	Pushing to highest frequencies
A gift of filled apertures	Looking at lower excitation material that is somewhat more extended by separated kinematically Behavior at edges
Good sensitivity and spatial discrimination	As a companion to IR absorption studies.

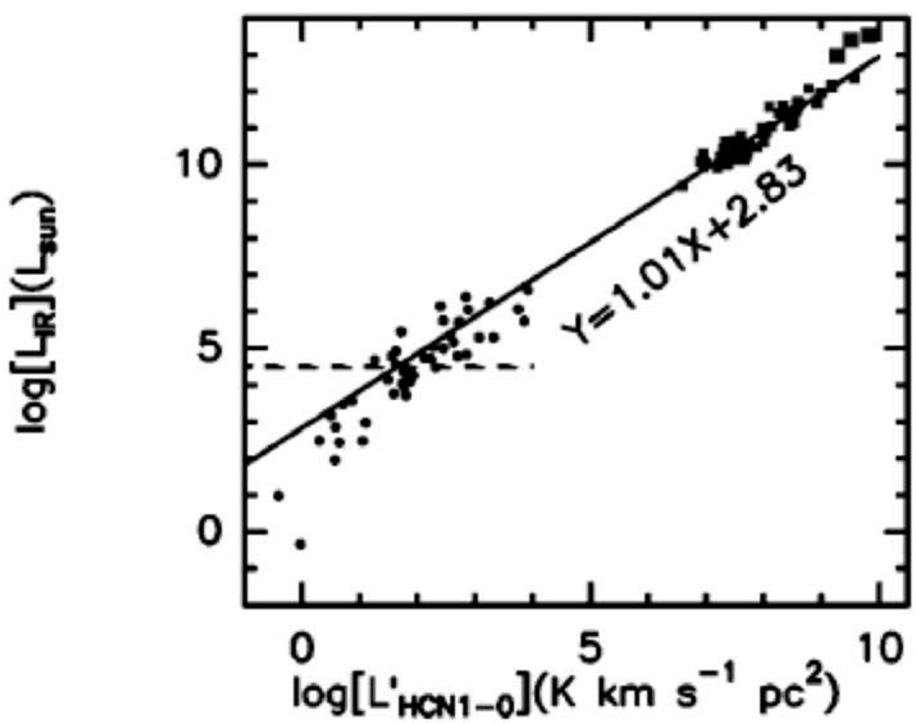
Gas Participation Fractions for

Molecular Clouds in Galaxies

What fraction of the ISM is bound up in molecular gas?

This is really a problem for cm/mm spectroscopy

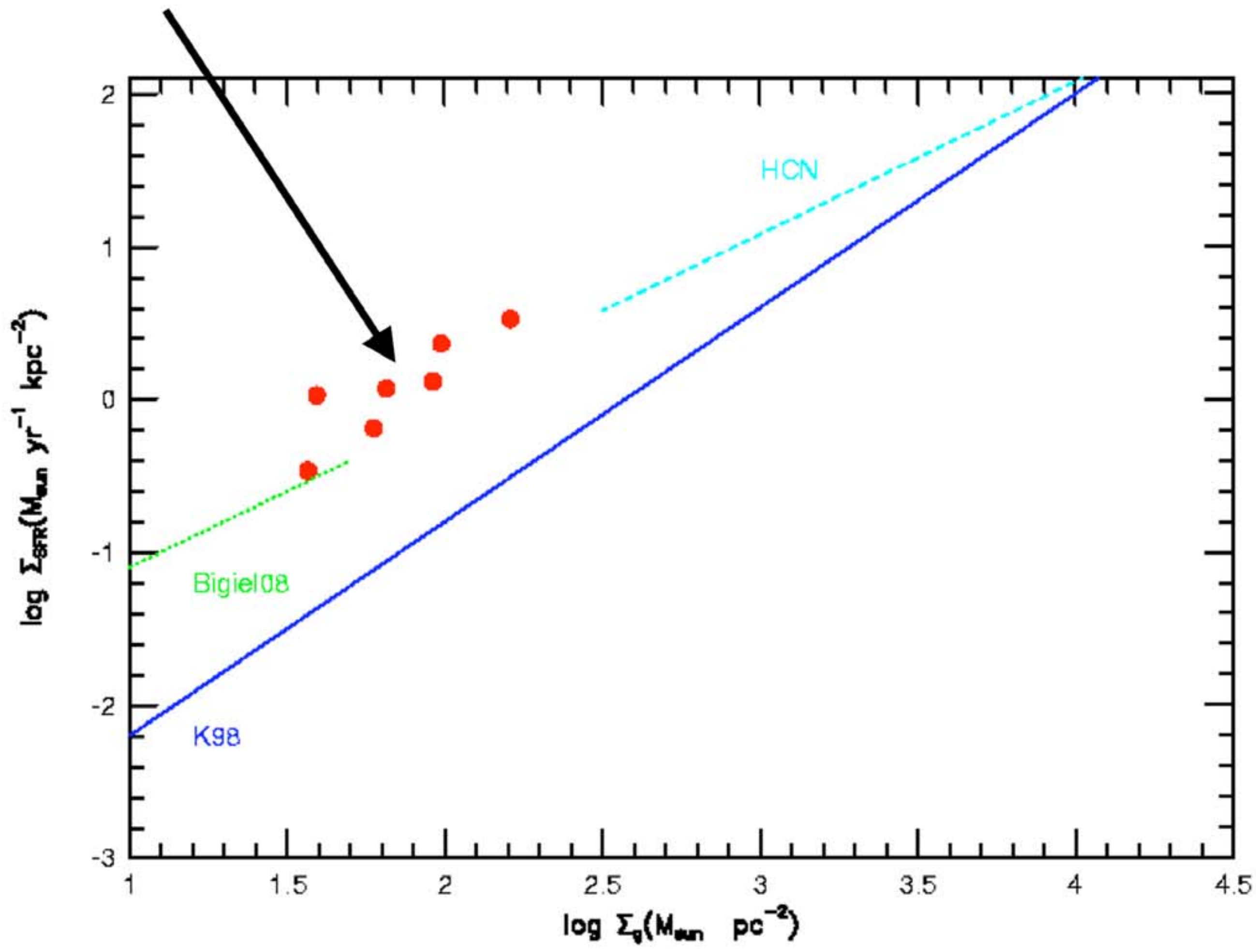
The strong relation between amount of <u>dense</u> gas and star formation can be elaborated and explained by mapping galaxies and galactic cores in higher J states of molecules with high n_{crit}.



Wu et al. 2005

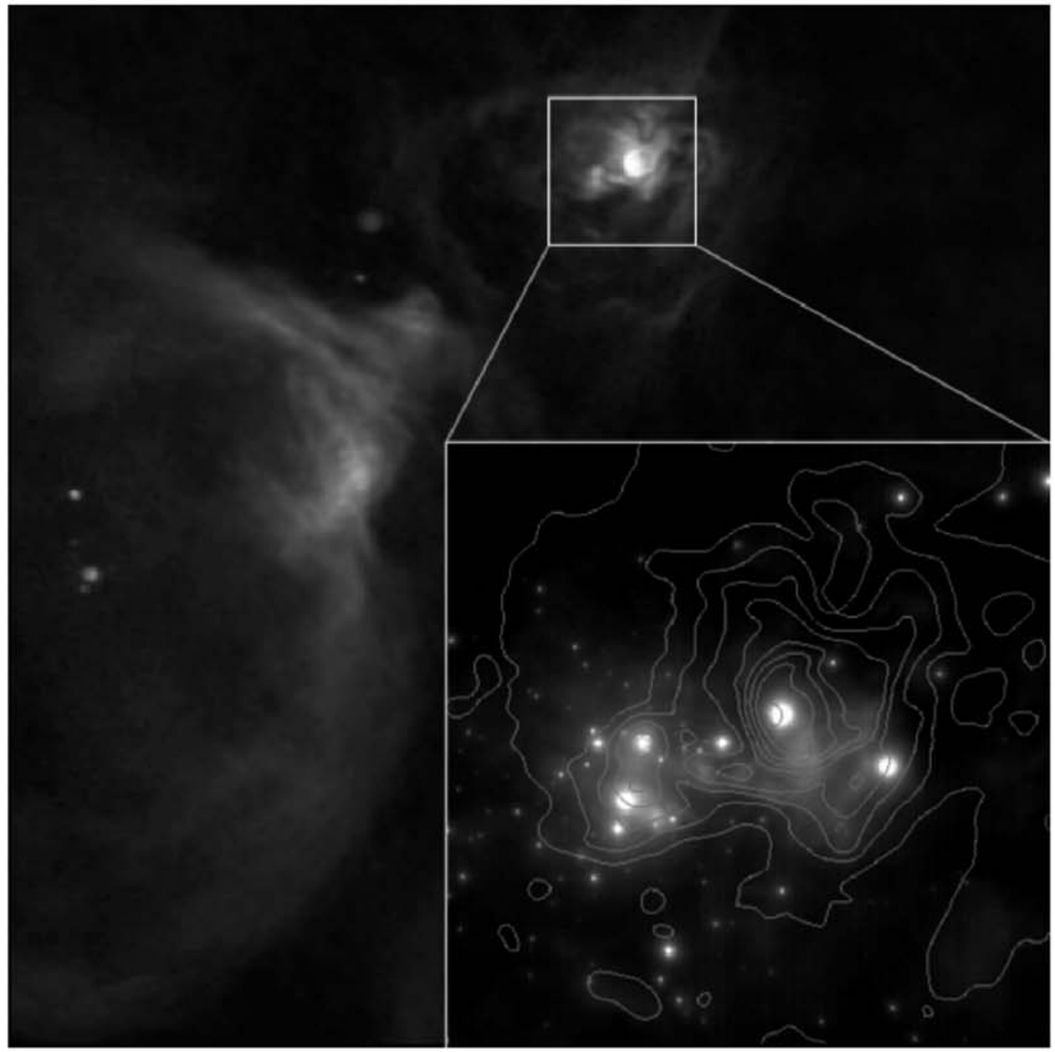
Star formation scaling law is different than for CO.
What will happen if you select even denser/warmer gas?

c2d results on Perseus cores



Gas Participation Fractions for

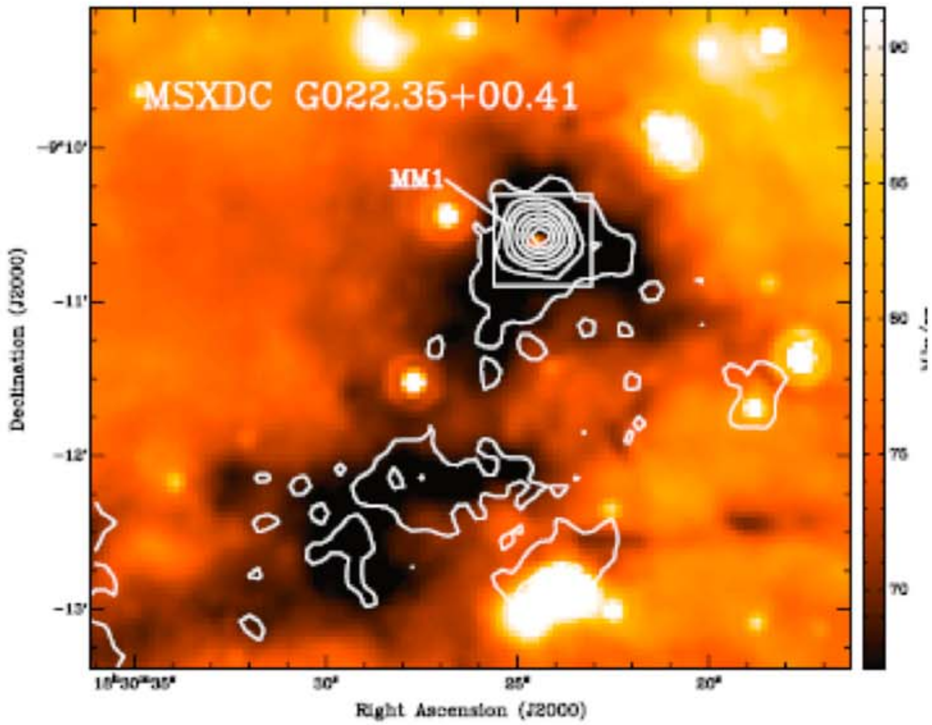
Dense Hot Cores:
In high mass star forming regions, what fraction of the mass is in the very dense, hot regions and what is the physical and chemical (also dynamical) state of the rest of the material?



1 arcmin

Lacy et 2007

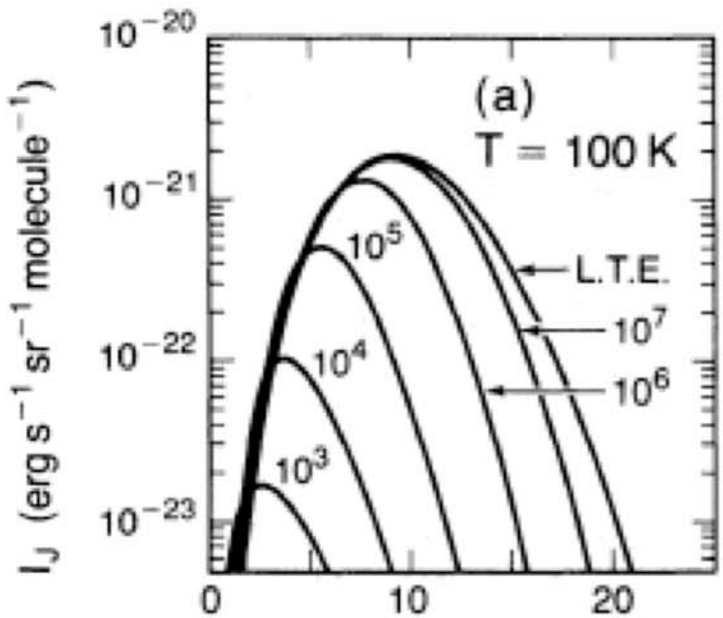
Massive cores start out with large amounts of very dense, fairly cool gas. How much of this remains unaffected by star formation once it gets going?



Rathborne, Simon, & Jackson 2007

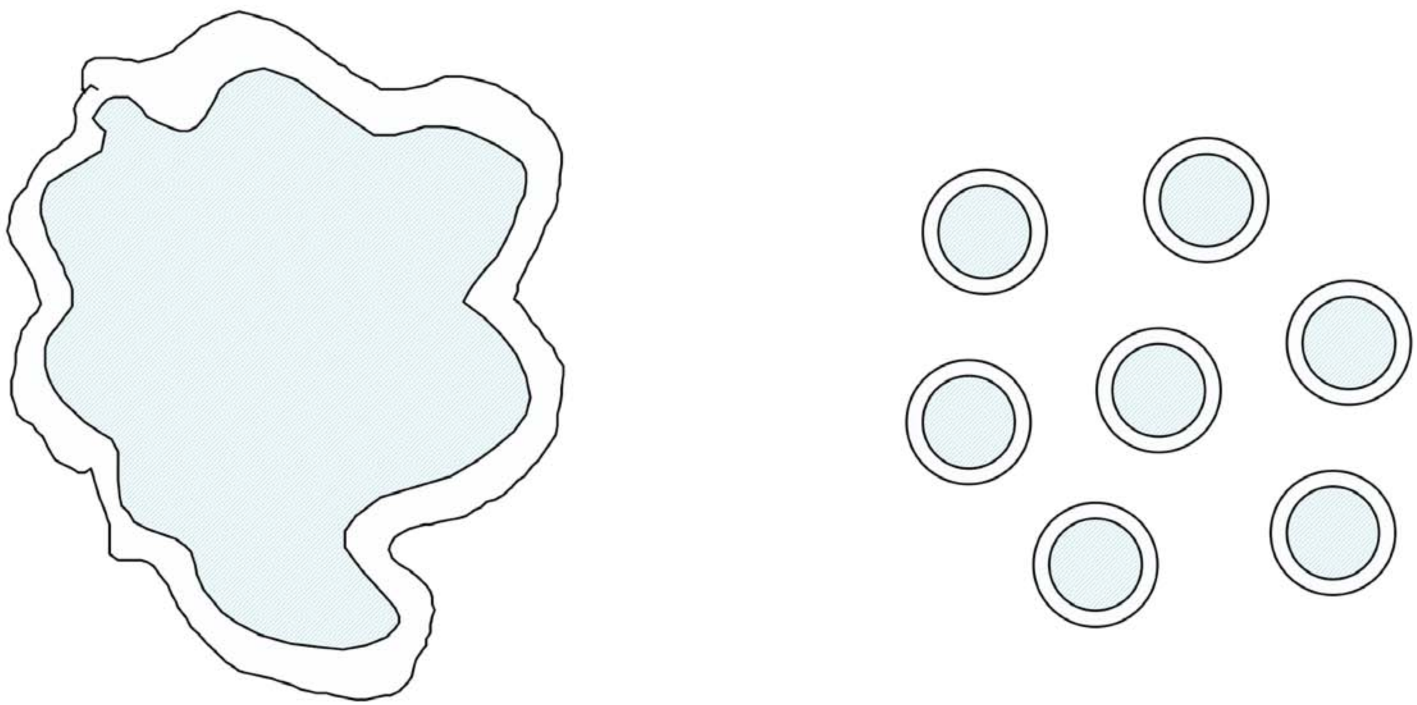
What is the nature of all that stuff in the periphery of the core or in the “missing flux”?

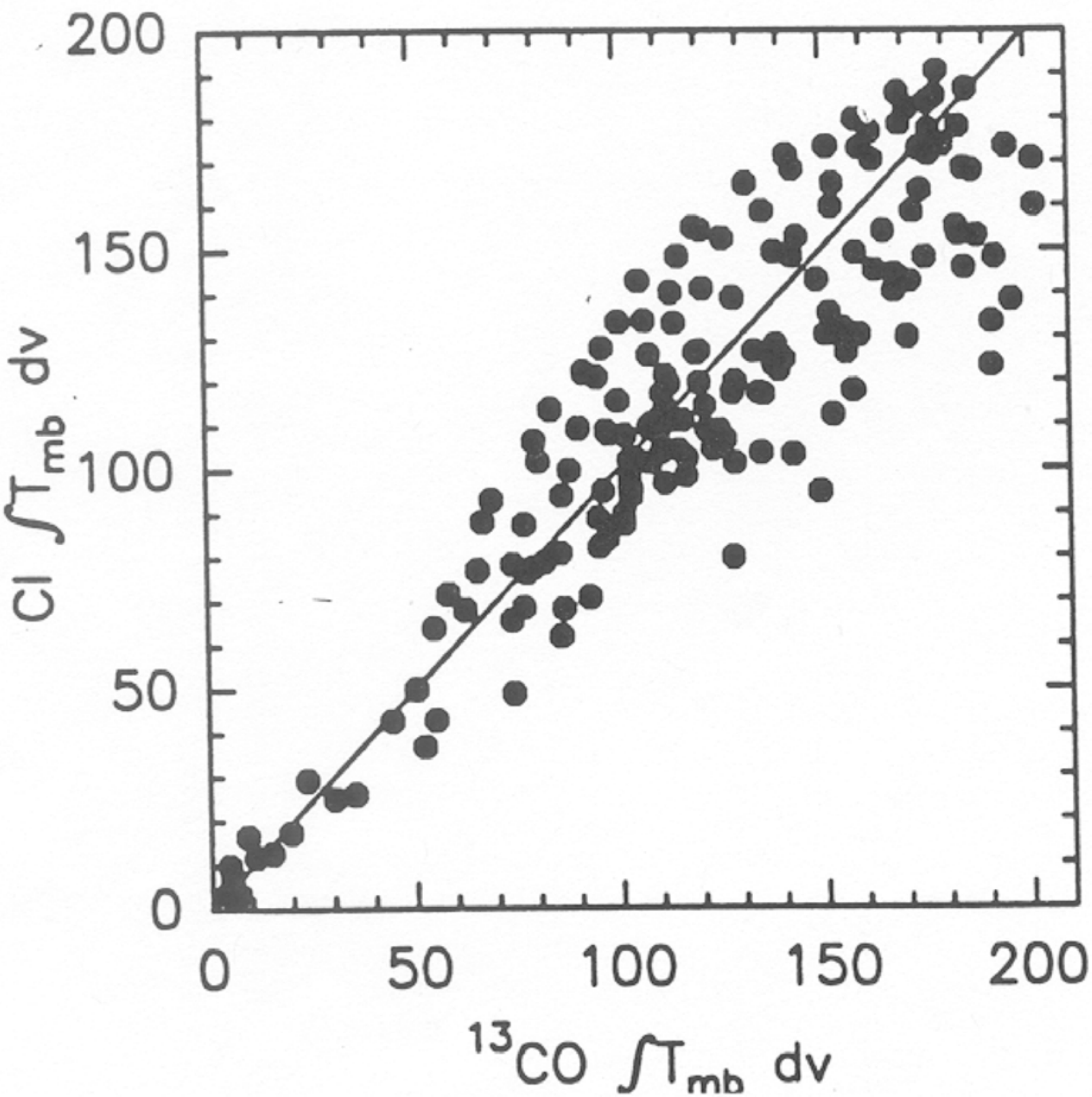
A combination of chemistry, excitation, and kinematics is the key.



Mckee et al. 1982

PDR's, Clumpiness, and the chemical structure of massive Star forming regions.





CI ∫T_mb dv
¹³CO ∫T_mb dv
0
50
100
150
200
0
50
100
150
200

Gas Participation Fractions for

Individual Clump/Star Formation

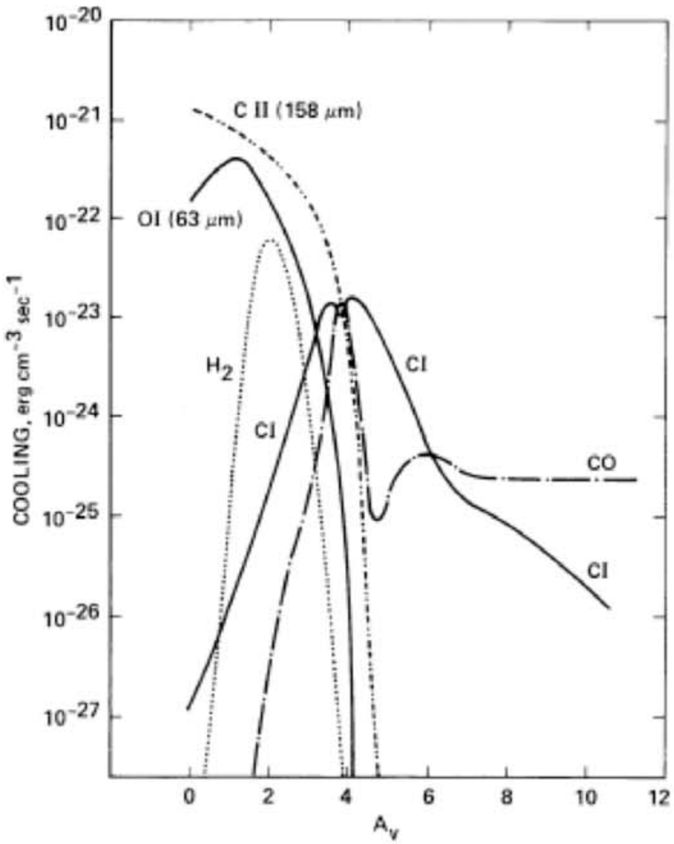
For solar-mass stars, what defines the boundary between material participating in collapse and what remains?

How does the position of the boundary and the mass fraction that remains differ in isolated and cluster formation?

What is the physical and chemical nature of the remaining material?

Extended edges will be a strength of CCAT

at $n=3\times10^4$ cm^{-3} and 140 pc, 10^{21} cm^{-2} corresponds to 16 arcsec



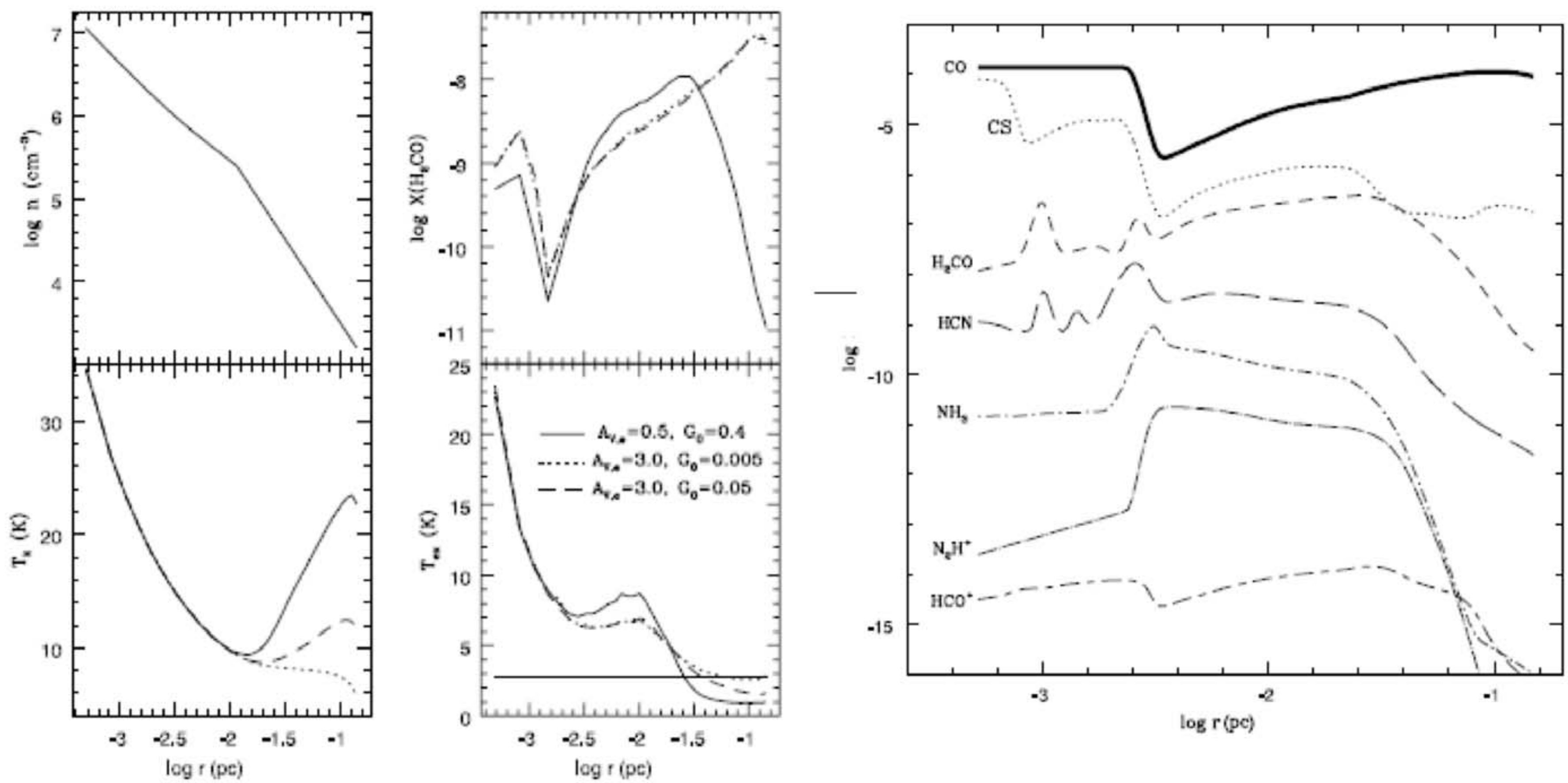
Hollenbach, Takahashi, & Tielens 1991

Why do you better in low G PDRs? Closer 3x, density lower 10x
=> 30x better “resolution”

Within the cores themselves,

the evolution of star forming cores involves the on-again off-again relationship of gas and dust

Lee, Bergin, & Evans 2004, 100,000 years

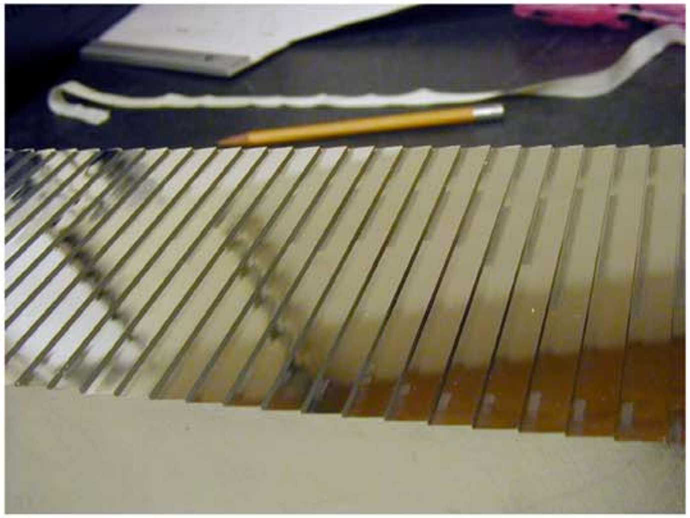


CCAT and the upcoming revolution in IR spectroscopy

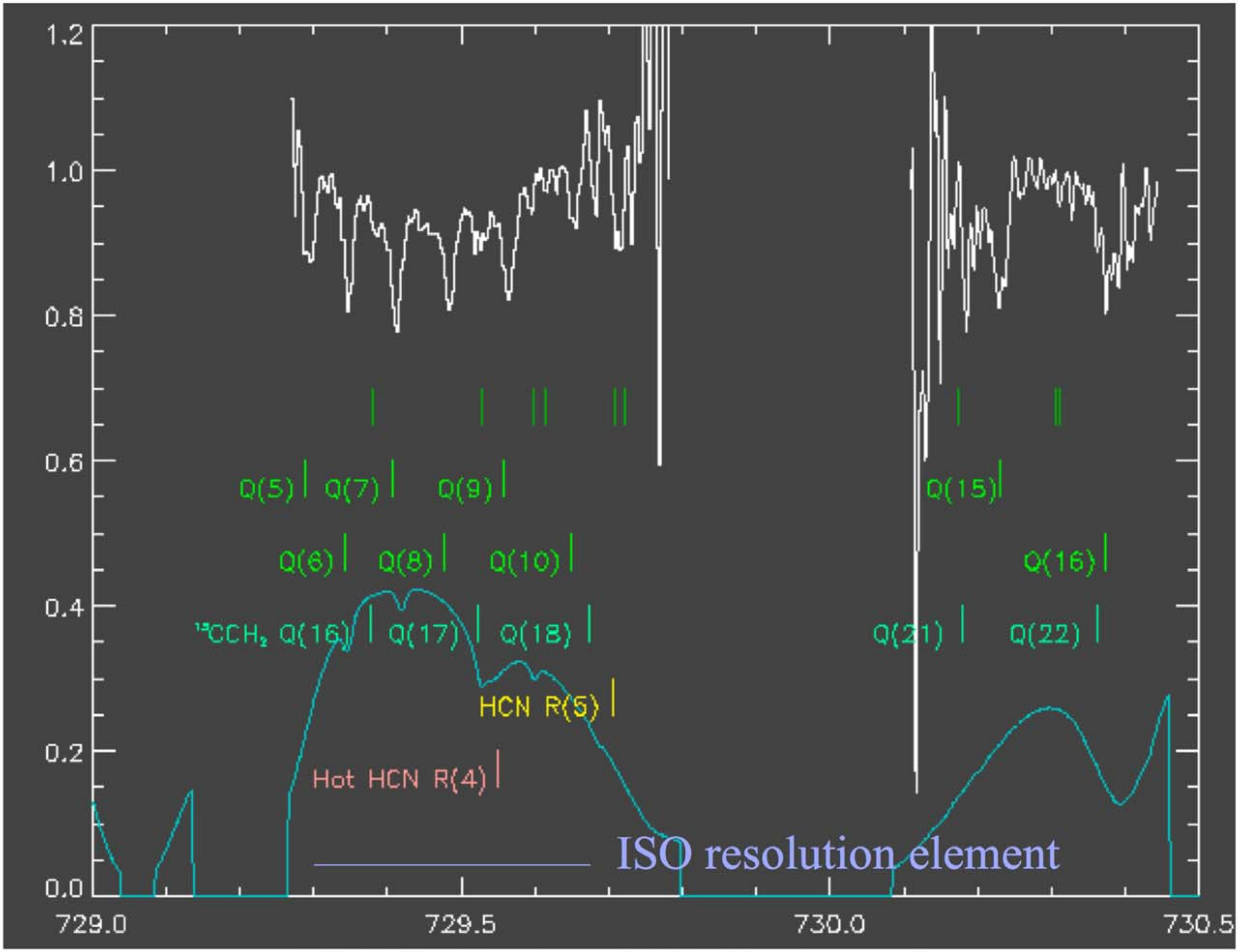
Solid state features with JWST

Gas absorption with TMT/GMT/ELT and next generation IR spectrographs

Texes 0.9m grating
(Lacy et al. 2003)

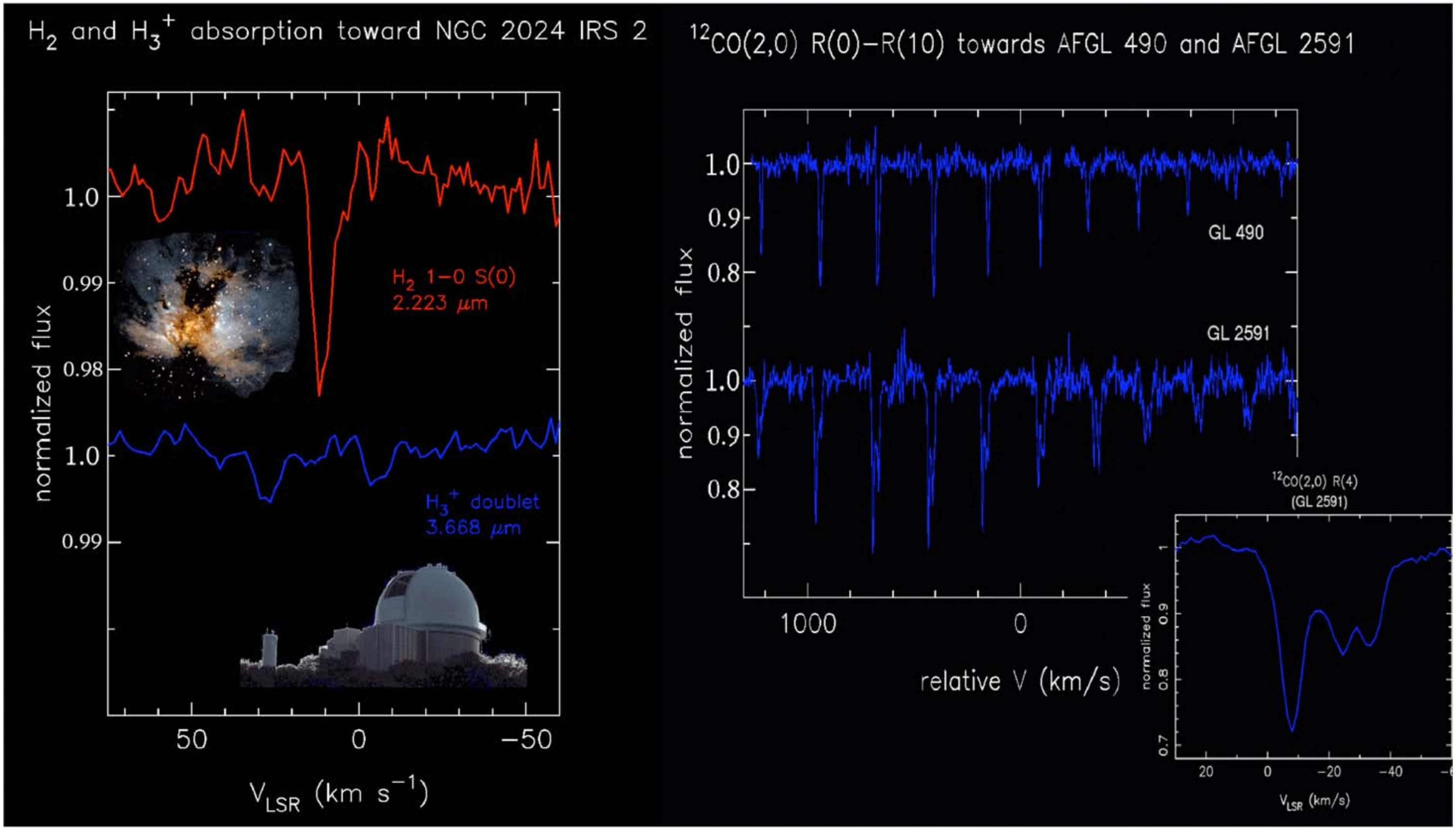


Some molecules are only accessible in the IR



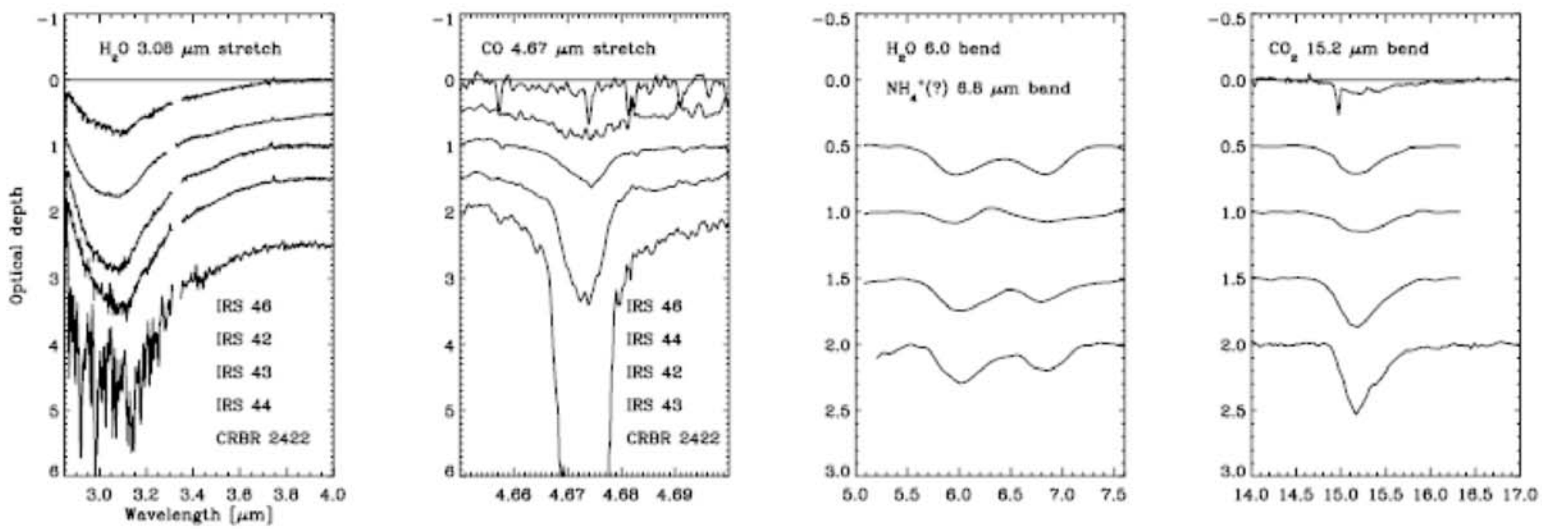
TEXES Data: C_2H_2 Q - branch

IR spectra also give you many transitions along a single line of sight.



First detection of H3+ and H2 in same source (Phoenix at KPNO)
Courtesy Craig Kulesa (U. Arizona)

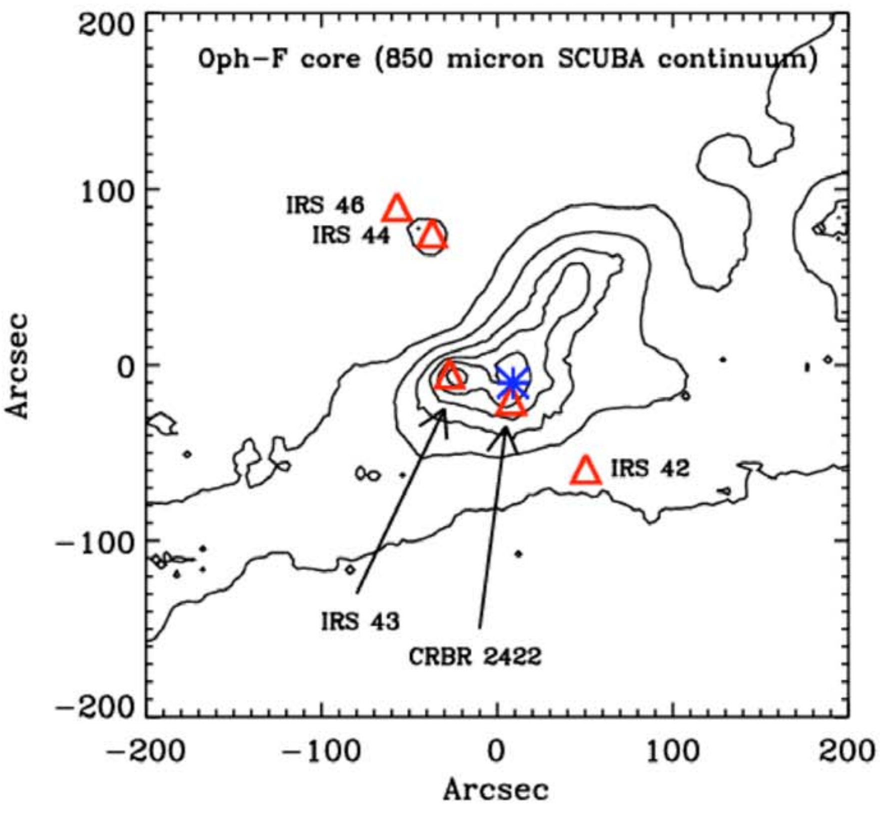
Mid-IR Ice bands in the ρOph Core (Pontoppidan 2006)

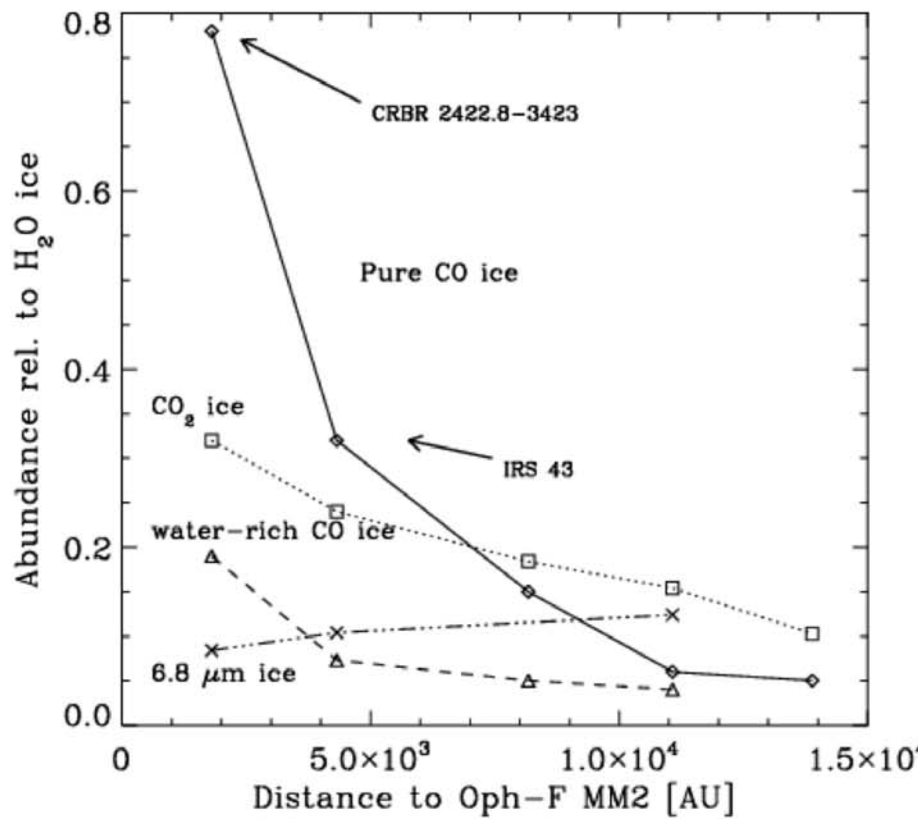


CCAT can probe gas chemistry and excitation along these same lines of sight. ALMA cannot.

Mapping ice/gas properties in protostellar cores

Pontoppidan (2006)





The improvements in infrared sensitivity and wavelength coverage will allow us to probe numerous lines of sight through a given cloud core in absorption.

Probing these same lines of sight in emission brings us a whole host of other molecules and allows us to probe the evolution of dust/gas chemistry.

Gas Participation Fractions for

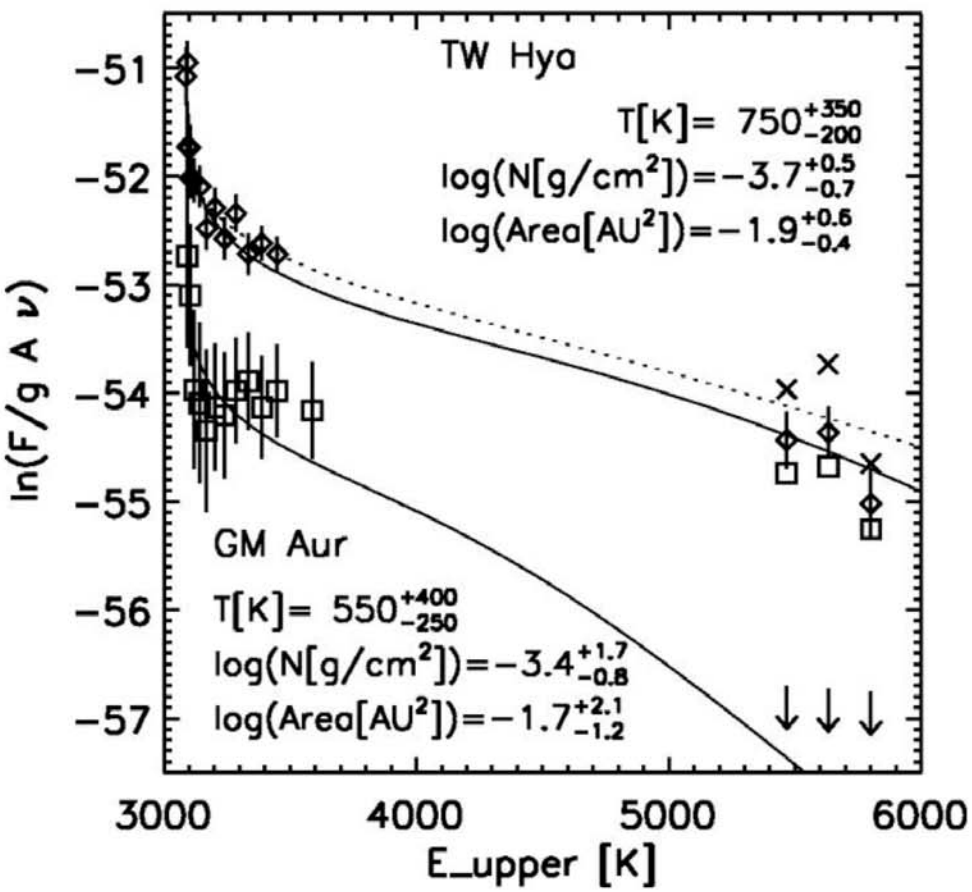
Planet Formation

Planetary bodies have a hard time assembling very close to or very far from the parent star. Infrared spectroscopy can sample the inner transition very effectively. Submillimeter spectroscopy can allow us to probe the outer transition.

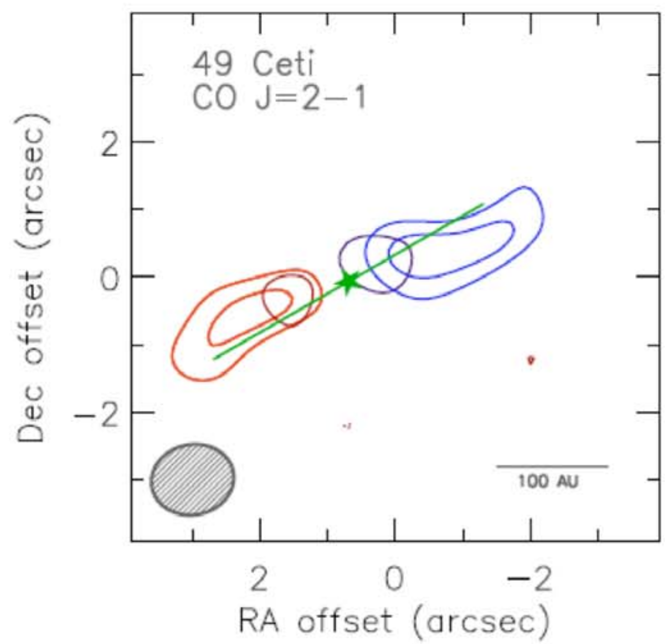
CCAT can (1) tell us which transitions are important
(2) Probe transitions at the highest frequencies

Infrared probes the inner few AU, millimeter on scales of 100 AU. In between, you pass through the snow line and out of the region where planets form.

Salyk et al. 2007



Hughes et al. 2008



There may be many lines revealing different aspects of the disk physics and chemistry.
Ceccarelli and Dominik (2005)

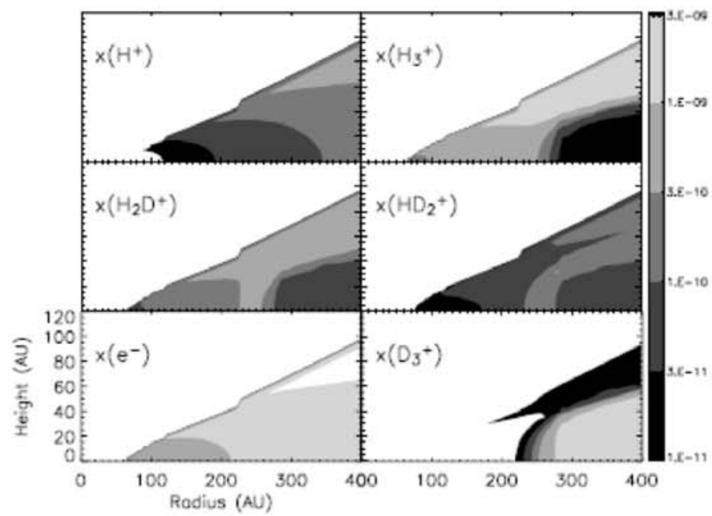
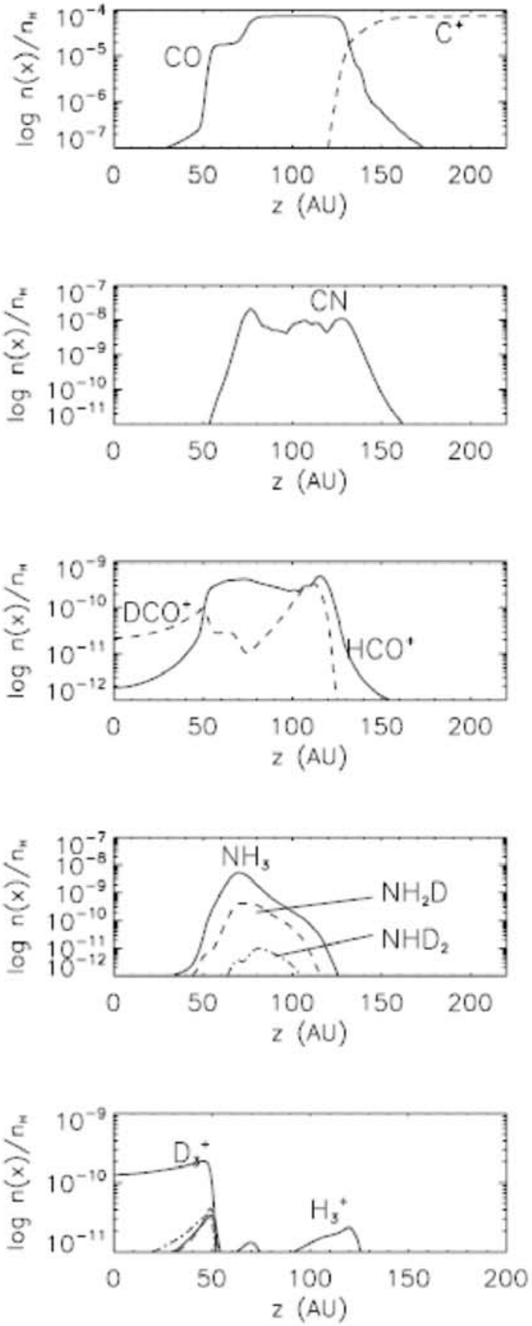


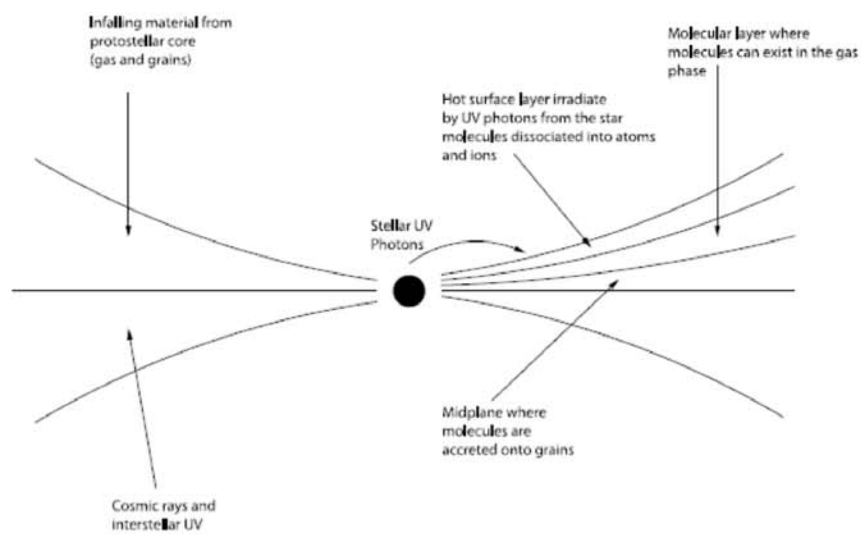
Table 3. Line fluxes of the ground transitions of the ortho and para form of H_2D^+ and the HD_2^+ respectively, for the standard case. The velocity-integrated line intensities, expressed in main beam temperatures, $T_{mb}\Delta v$ are computed assuming observations at CSO and JCMT of the o-H_2D^+ and p-HD_2^+ transitions respectively.

	o-H_2D^+	p-H_2D^+	o-HD_2^+	p-HD_2^+
Transition	$1_{1,0}-1_{1,1}$	$1_{0,1}-0_{0,0}$	$1_{1,1}-0_{0,0}$	$1_{1,0}-1_{0,1}$
ν (GHz)	372.4	1370.1	1476.6	691.7
Flux erg/s/cm^2	8.2e–18	1.0e–16	5.7e–17	2.6e–18
$T_{mb}\Delta v$ (mK km s^{-1})	18.8[a]	–	–	4.8[a]

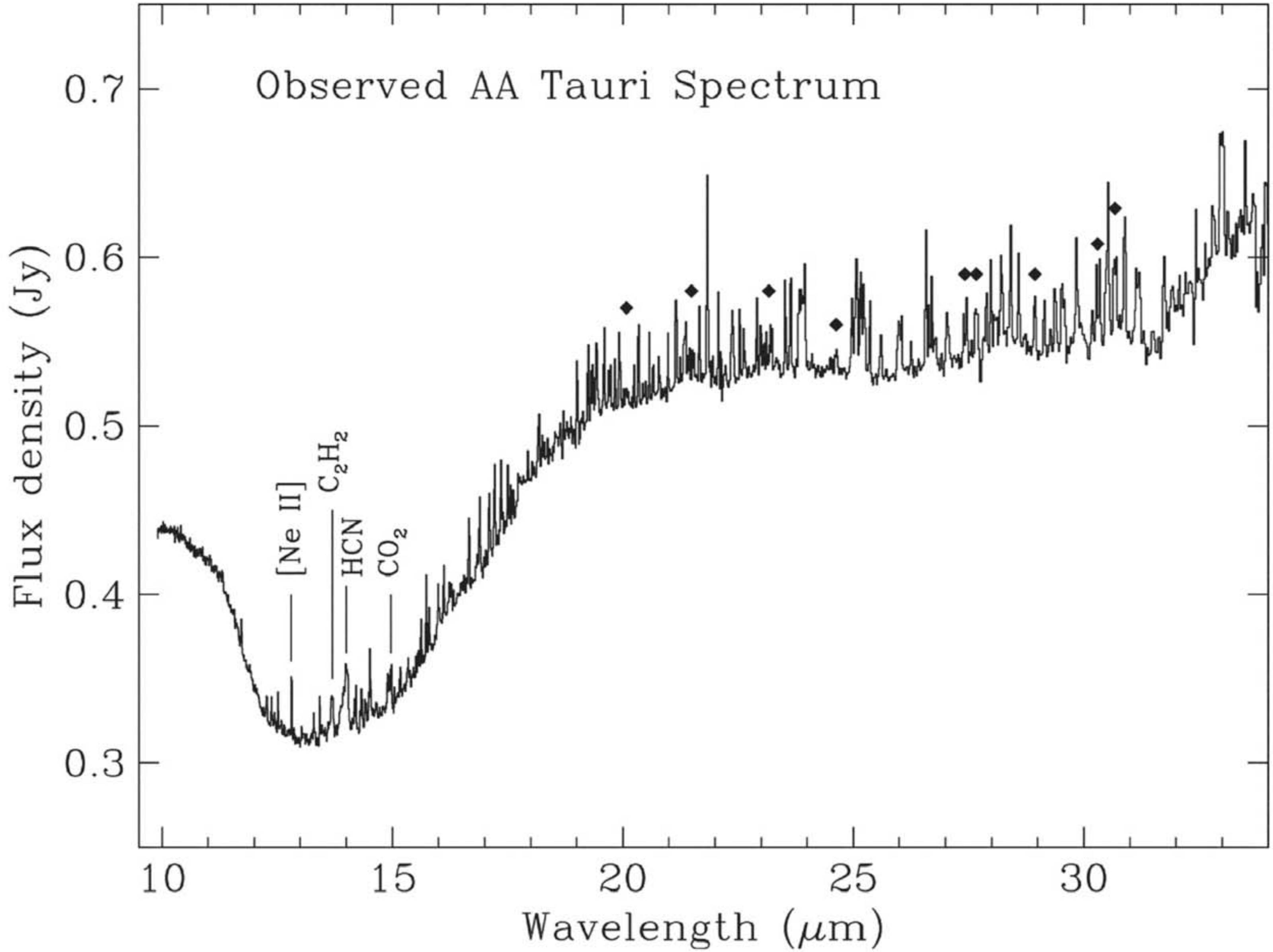
[a] Note: the main beam efficiency is assumed to be 0.6 at CSO and 0.3 at JCMT.



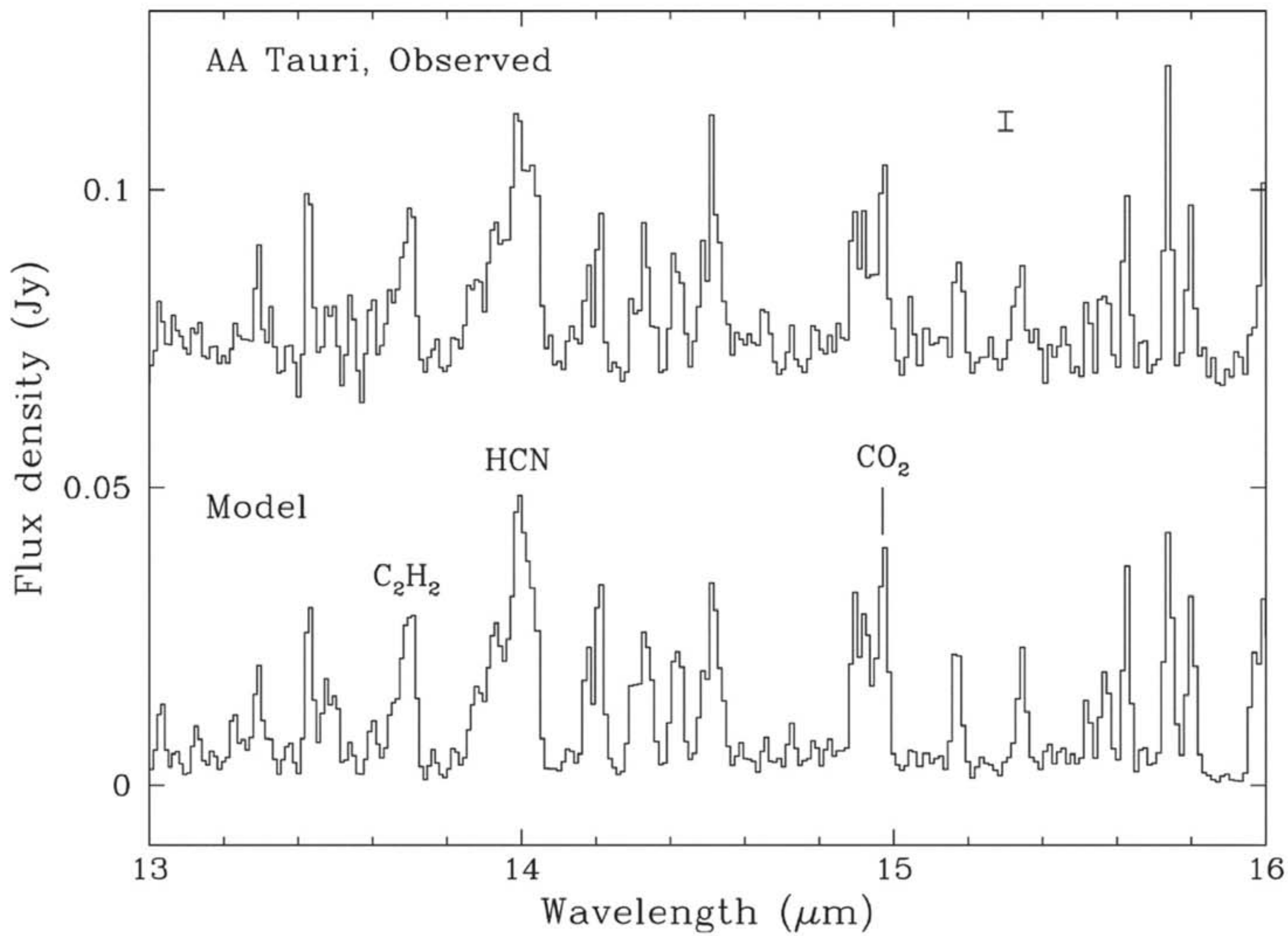
Willacy (2007) vertical distributions in protostellar disks.



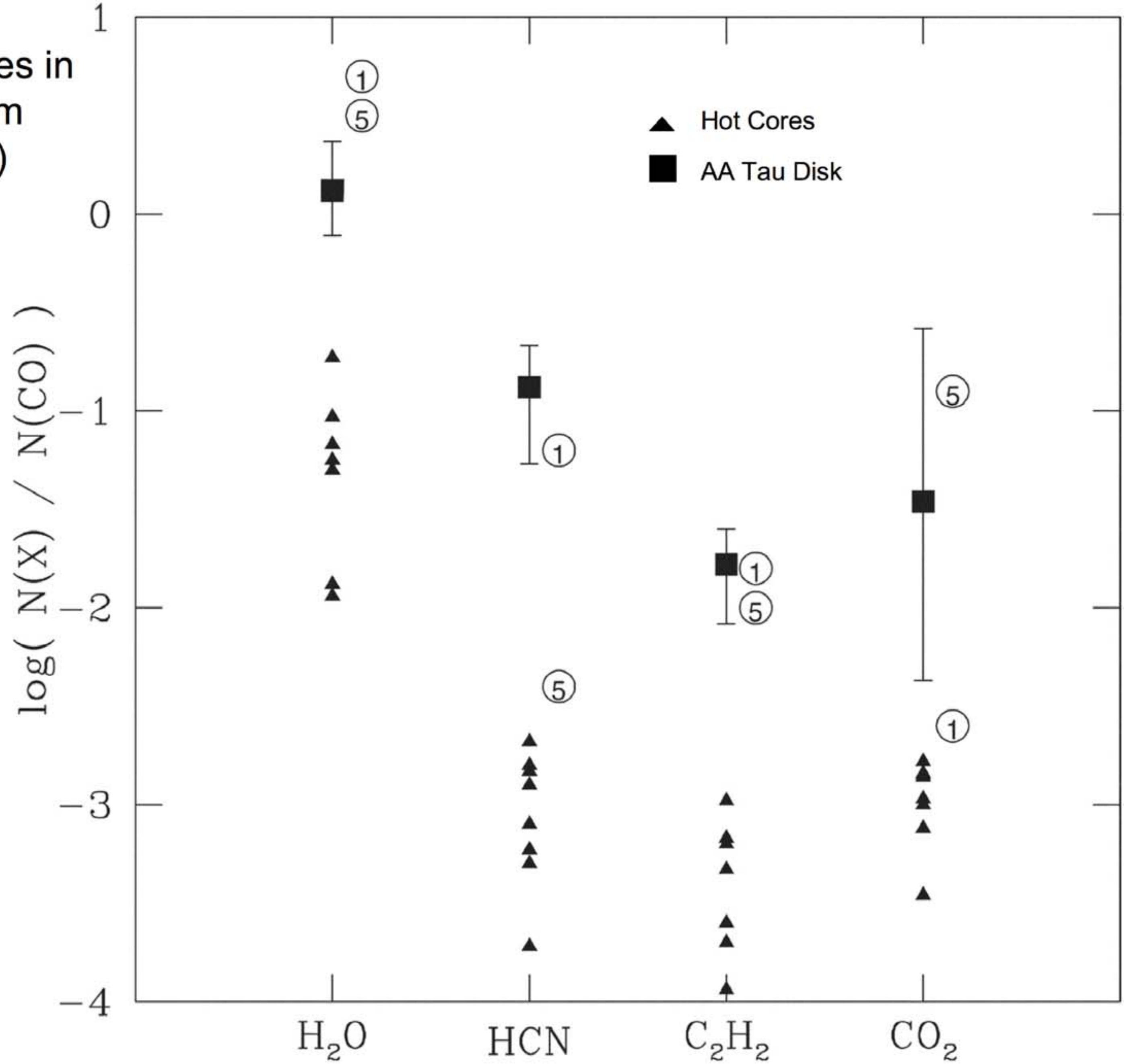
Carr and Najita 2008. Q branches of major molecules labeled. Diamonds show water lines.



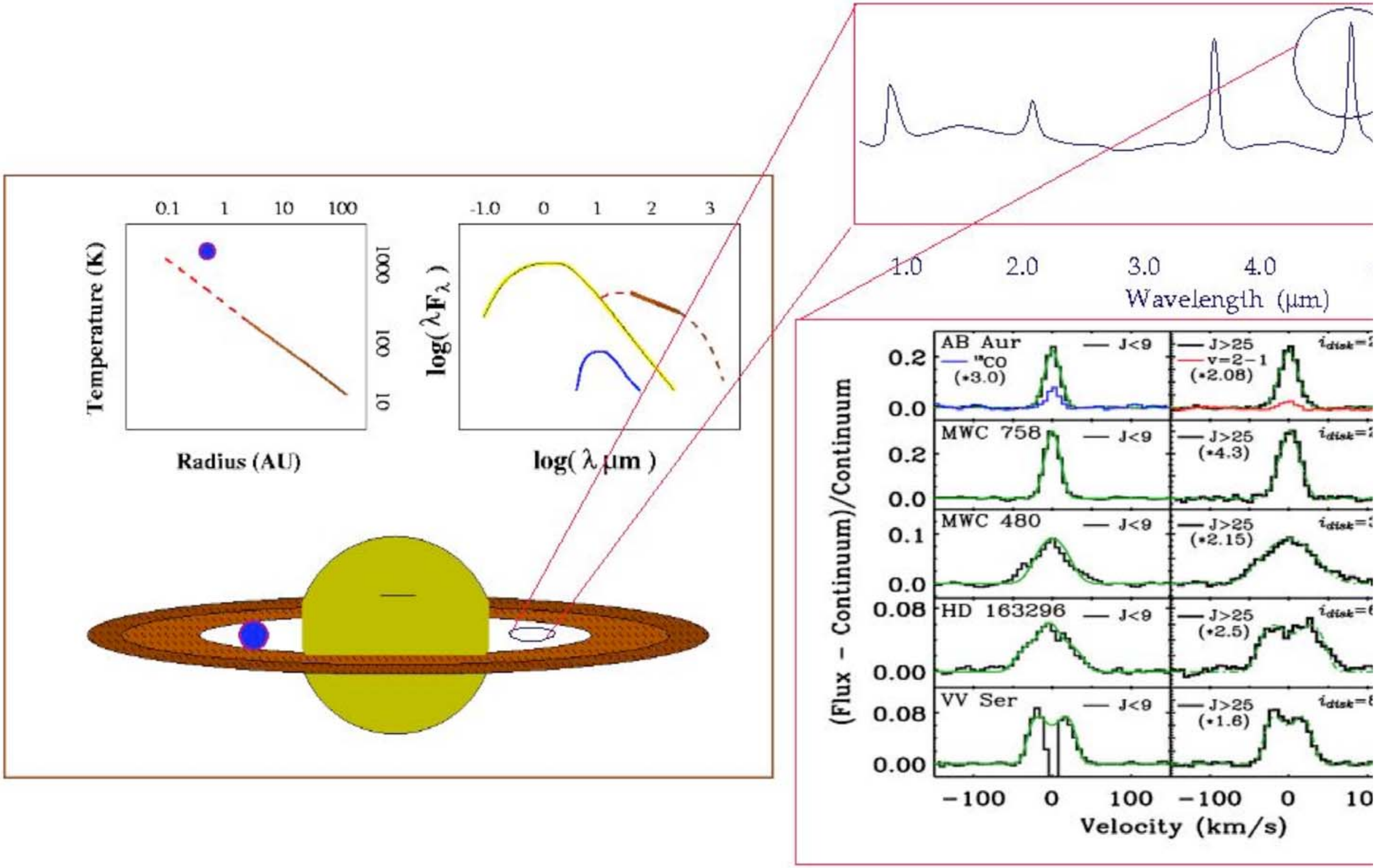
Carr & Najita (2009) Unmarked features are water



Chemical abundances in the AA Tau disk from Carr & Najita (2008)

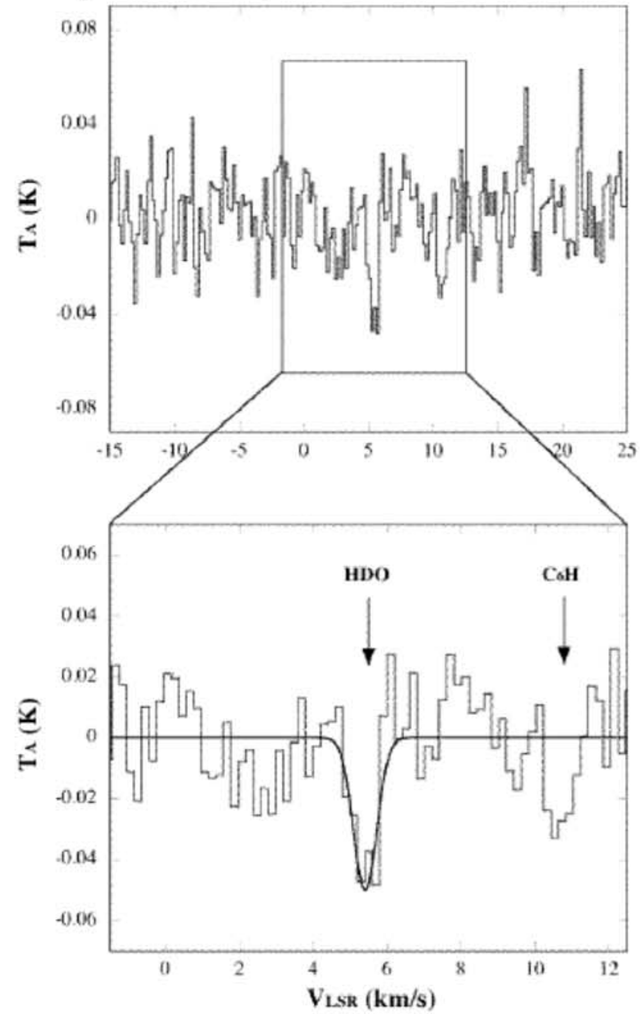


Gas content as a function of radius and age.



CCAT, by virtue of its high frequency capability, can do a good job of filling the gap between the millimeter and IR studies and, at the same time, probe one of the most important parts of the disk.

DM Tau at 464 GHz
Ceccarelli et al. 2005



Thanks!