A search for high-mass pre-stellar cores through observations of N_2H^+ and N_2D^+

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PRE-STELLAR CORES = contracting starless cores

Main physical properties of low-mass pre-stellar cores:

(see e.g. Caselli et al. 2002, Tafalla et al. 2002, 2004, 2006; Crapsi et al. 2005)

1. SED peak in the mm/sub-mm, NO mid-IR emission (STARLESS)
2. Isothermal, low gas temperature T~ 10 K (STARLESS)
3. Centrally-peaked density distribution, $10^6 cm^{-3}$ nuclear density (CONTRACTING)
4. Line widths increasing towards the core center (CONTRACTING)

These properties can be derived from mm/sub-mm continuum emission (cold/warm dust) and cm/mm/sub-mm molecular transitions

Chemical properties of pre-stellar cores

I. $T \sim 10$ K
$+ \, n(H_2) \sim 10^5 - 10^6$ cm^{-3}

→ High CO DEPLETION FACTOR
$f_D = X(CO)^E / X(CO)^O$

II. CO depletion
+ chemical network

→ High DEUTERIUM FRACTIONATION
$D_{frac} = N(D)/N(H)$

In particular:
Cosmic $[D]/[H]=10^{-5}$ (Oliveira et al. 2003)
in low-mass PSCs $N(N_2D^+)/N(N_2H^+)=D_{frac} \geq 0.1$!!! (Crapsi et al. 2005)

If massive pre-stellar cores exist...
They should have high f_D and high $N(N_2D^+)/N(N_2H^+)$!

The search for High-mass pre-stellar cores: Observational problems

$M_* > 8 M_\odot$ → $L_* > 10^3 L_\odot$, $T_{eff} > 17000$ K , short evolutionary timescales

→
- High-mass stars are rare (IMF)
- Typical distances greater than 1 kpc
- Formation in clusters: confusion
- Strong interaction with the parental cloud: environment profoundly altered

To date only few studies of high-mass starless cores (HMSC)
(Sridharan et al. 2005; Beltrán et al. 2006; Pillai et al. 2007)
and NO extensive studies of single HMSC candidates

→ Search for COLD and DENSE SPOTS close to HMPCs, through f_D and $N(N_2D^+)/N(N_2H^+)$!

The search for High-mass pre-stellar cores:
Our approach

Sample: 10 (5 + 5) objects from two samples of HMPCs

(Molinari et al. 1996; Sridharan et al. 2002)

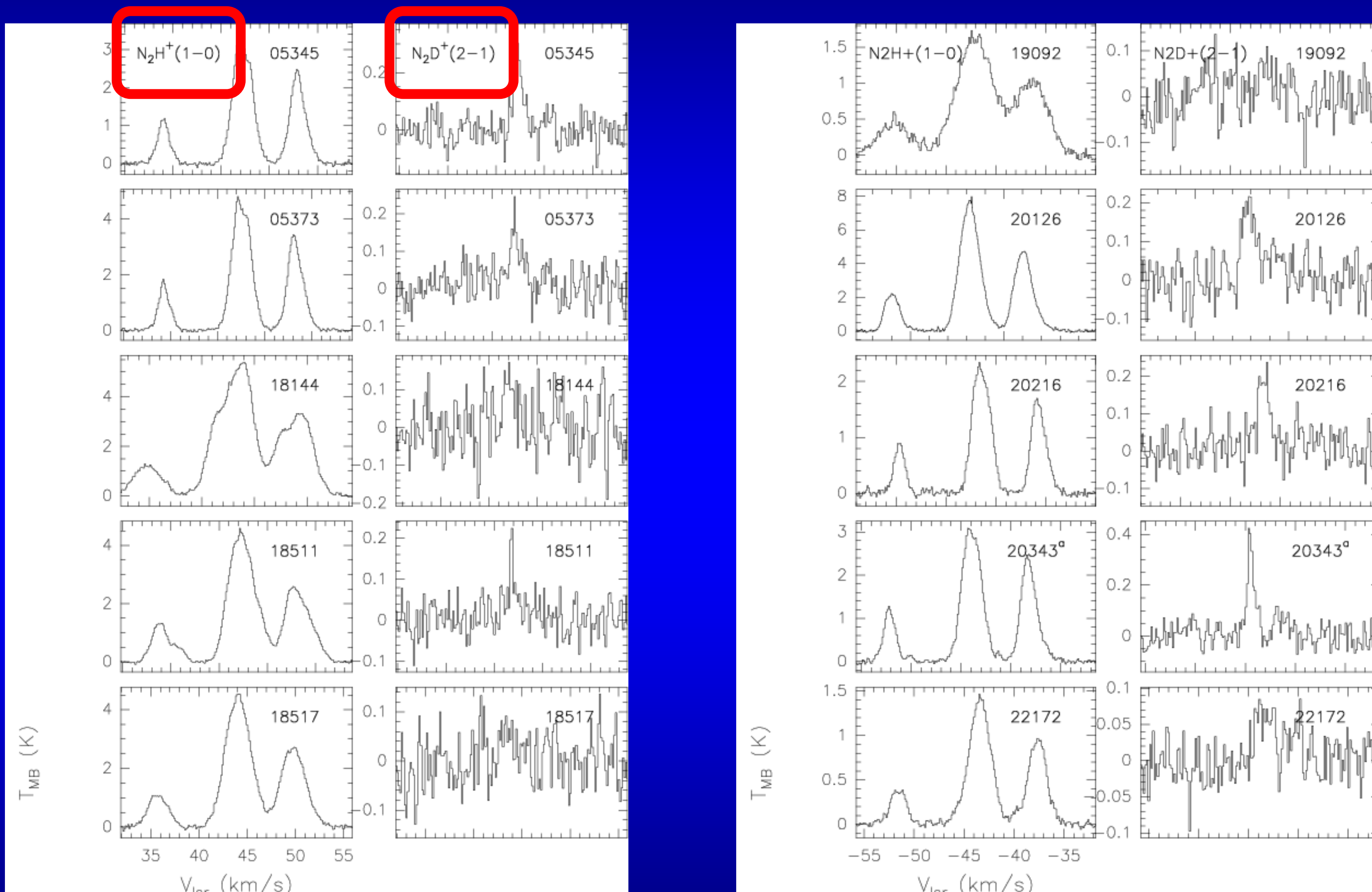
Observations: N_2H^+, N_2D^+, $C^{17}O$, 850μm continuum

IRAM-30m telescope	SCUBA at JCMT
(HPBW 9″ - 26″)	(HPBW 14″)
On-the-fly maps	
and single-point spectra	

Goals: $N(N_2D^+)/N(N_2H^+)$ ➡ Deuterium fractionation

$N(C^{17}O)/N(H_2)$ ➡ CO depletion factor

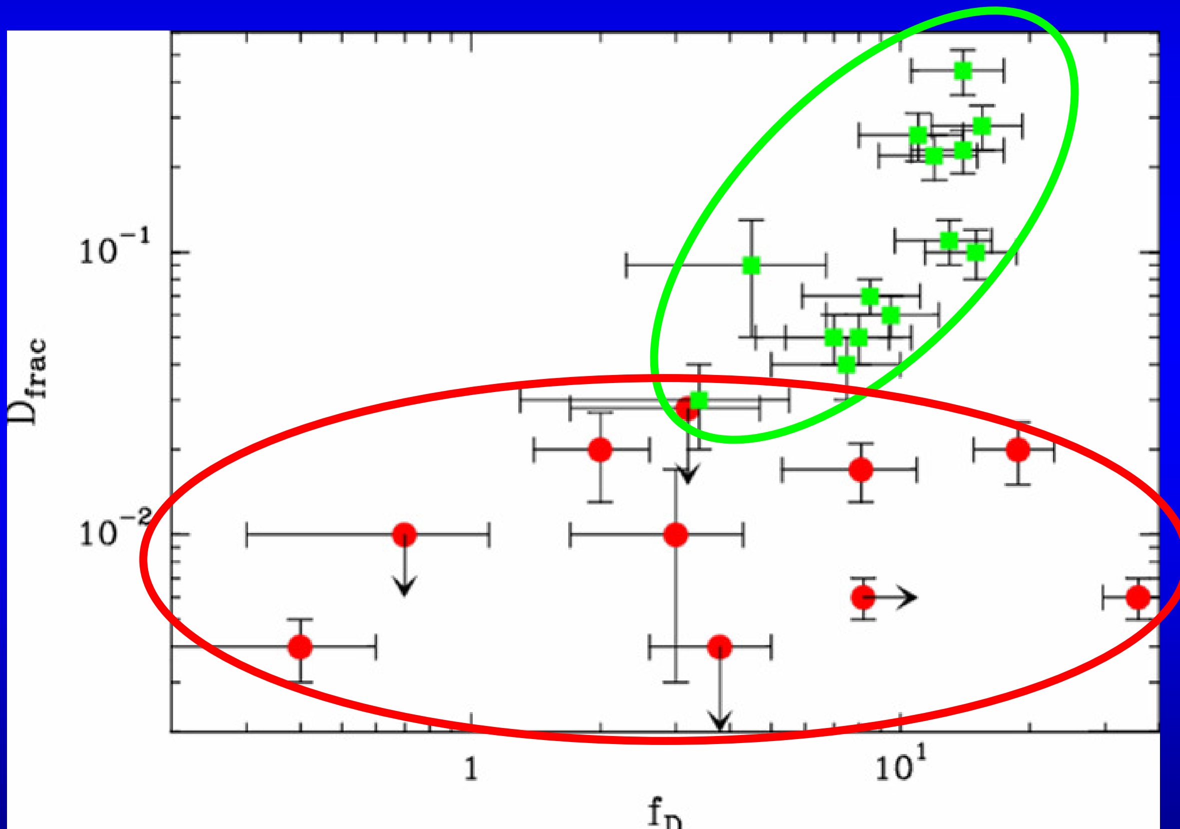
N_2H^+, N_2D^+ spectra at the N_2H^+ peak position



Detection of deuterated gas in 70% of the sources !!

CO depletion and Deuterium fractionation

- $D_{frac} = N(N_2D^+)/N(N_2H^+) = 0.004 - 0.02$, average ~ 0.015
- $f_D = X_{CO}^E/X_{CO}^O = 0.7 - 36$, median ~ 3.2



Low-mass starless cores

High-mass Sources (this work)

(from Fontani et al. 2006 A&A, 460, 709)

CAVEAT:

The angular resolutions (9-24”) are comparable with the sizes of the whole regions

f_D and D_{frac} are *average* values over the sources:

contribution of *non-depleted gas* along the line-of-sight !!

…..where is the cold and dense gas which generates the N_2D^+ emission ?

Possibilities:

High angular resolution observations are needed!

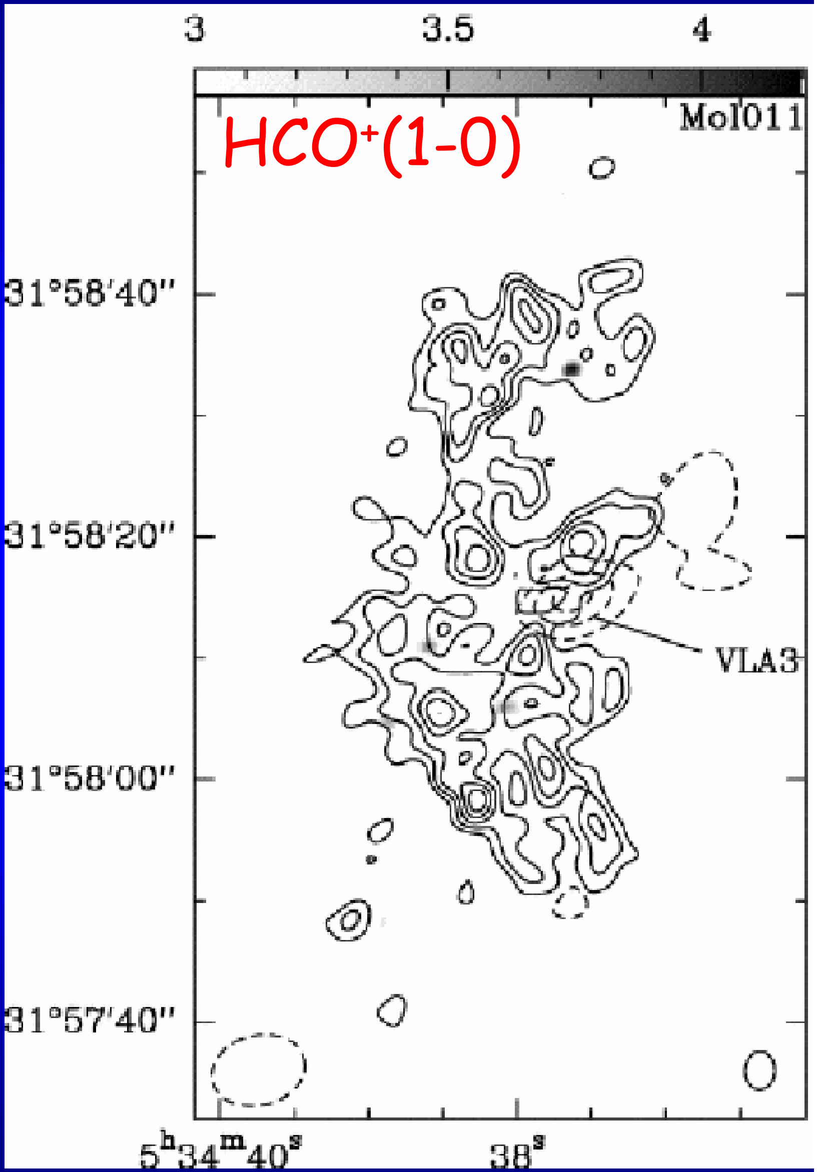
2- in the remnant of the diffuse cold envelope in which the HMPC was born

3-…or in both!

IRAS 05345+3157: DETAILED STUDY

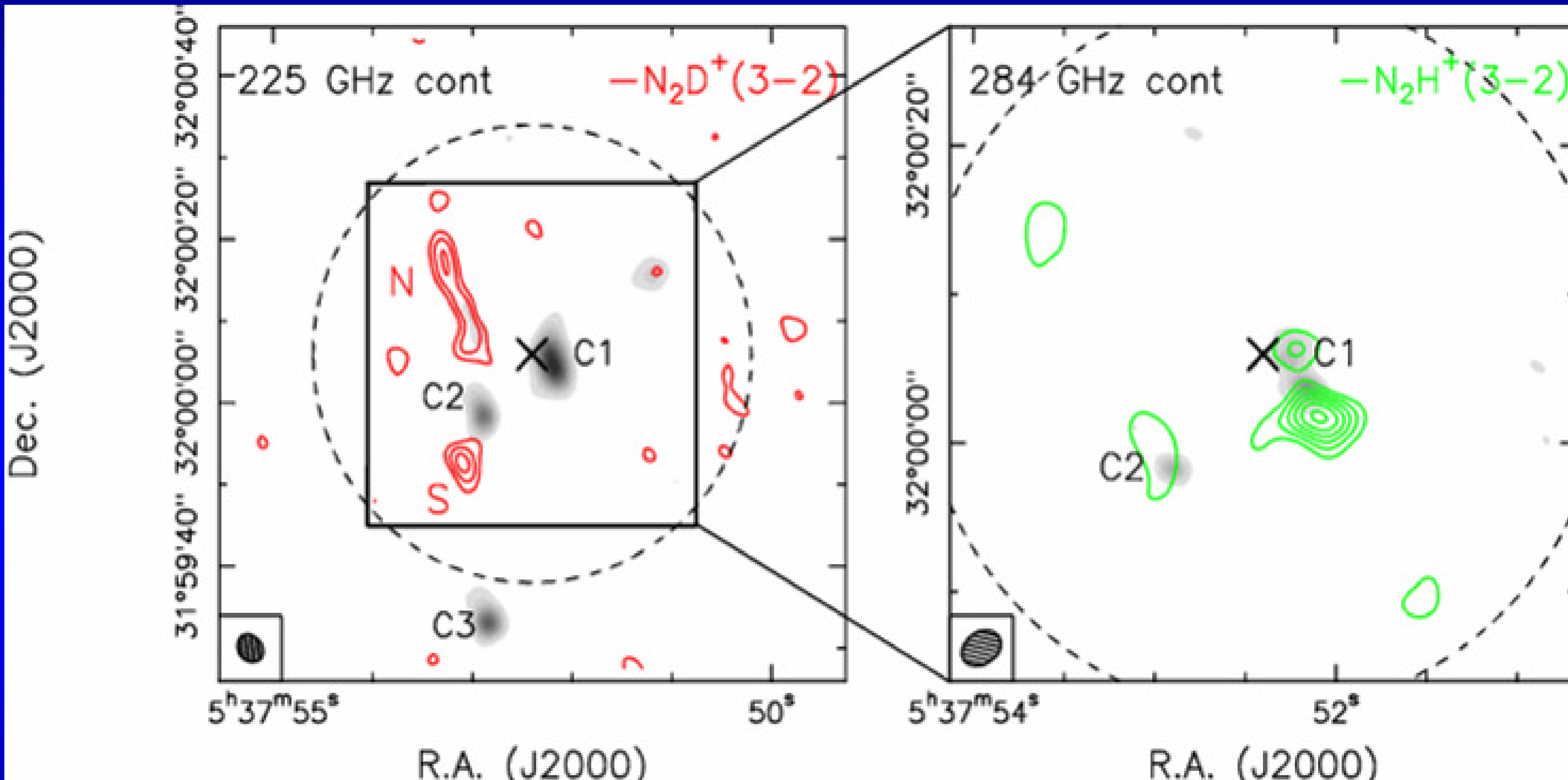
i. Average $D_{frac} \sim 0.01$
ii. Average $f_D \sim 3$
iii. NO MSX 8μm emission
iv. Dust+gas mass ~ 180 M_Θ
v. Clumpy structure

High angular resolution maps (PdBI + SMA) in N_2H^+ and N_2D^+!



(from Molinari et al. 2002)

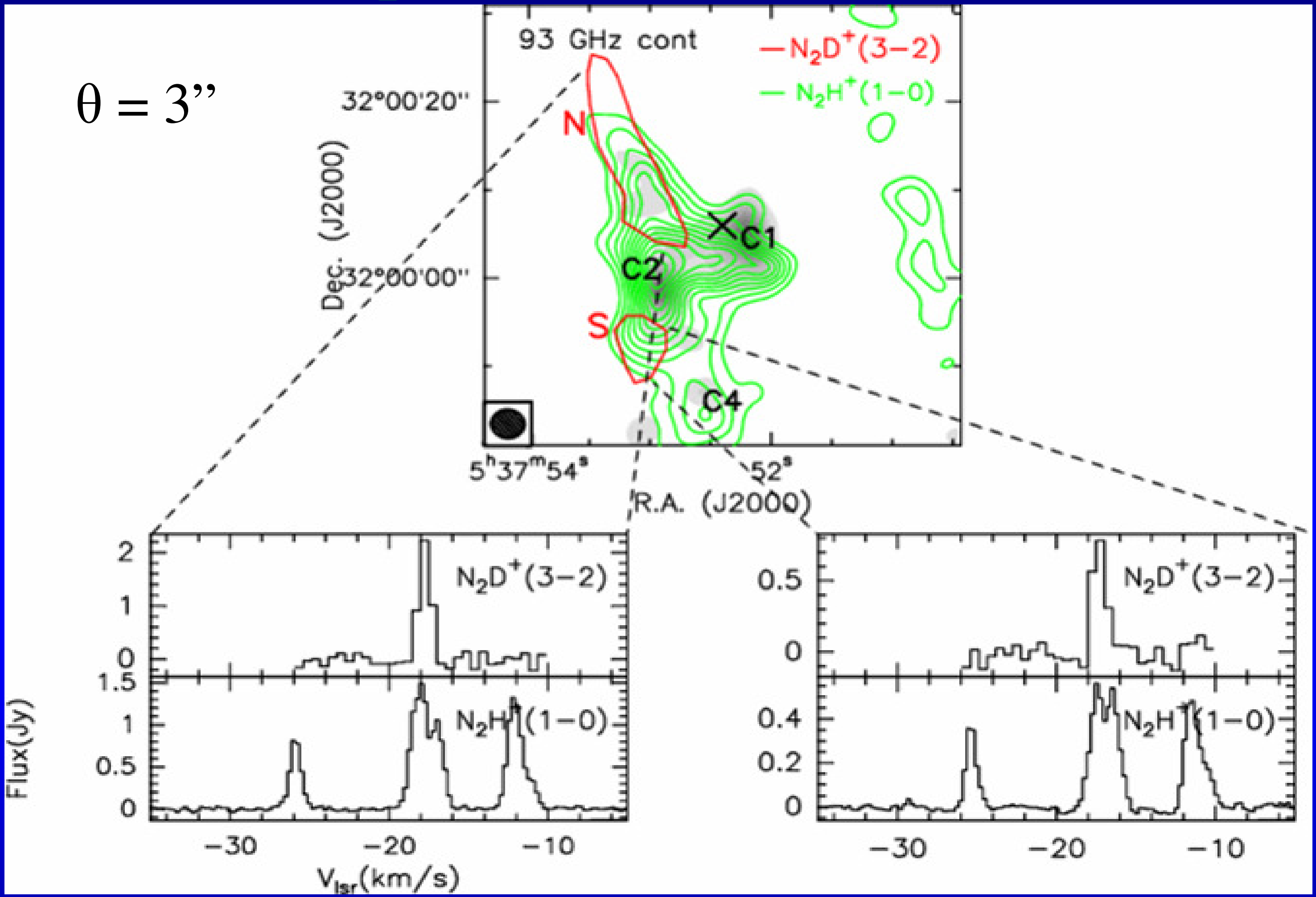
SMA: N_2D^+(3-2), N_2H^+(3-2) and cont. @ 225 and 284 GHz



θ = 3" @ 225 GHz;
2" @ 284 GHz

(Fontani et al., in prep.)

PdBI: in $N_2H^+(1\text{-}0)$ and 93 GHz continuum

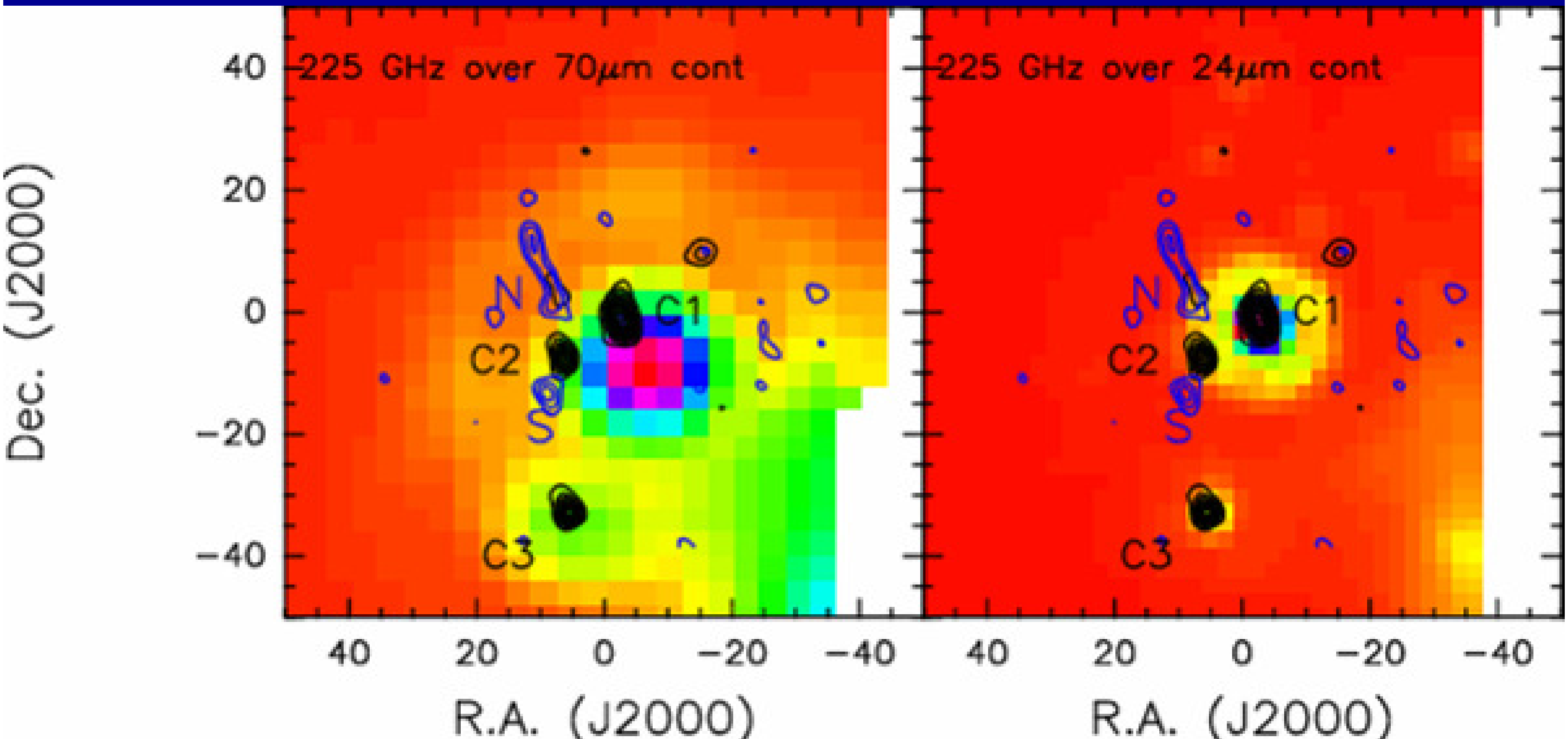


(Fontani et al., in prep.)

N: $D_{frac} = 0.1$
$M_{vir} = 6\ M_{sun}$
$M_X = 9\ M_{sun}$

S: $D_{frac} = 0.1$
$M_{vir} = 2.9\ M_{sun}$
$M_X = 2.4\ M_{sun}$

Spitzer MIPS images



(Fontani et al., in prep.)

SUMMARY and CONCLUSIONS

Search for cold gas in HMPCs

- **Detection of N_2D^+ in 7 HMPCs (70%) !!**
- **Average D_{frac} ~ 0.015**
- **Median f_D ~ 3.2**
- **NO correlation between f_D and D_{frac}**

Detailed study of IRAS 05345+3157

i. **few compact mm continuum sources**
ii. **2 N_2D^+ condensations (N and S), D_{frac} = 0.1 in both N and S**
iii. **N_2H^+ extended and with multiple peaks**
iv. **S = low-mass pre-stellar core**
v. **N = intermediate to high-mass pre-stellar core ..?**

WORKS in PROGRESS

1 Increase the sample of HMPCs: observations of 20 further HMPCs, scheduled @ JCMT, in N2H+(4-3) (HARP) and N2D+(3-2) (WxA)

2 Merging the low- and high-angular resolution maps of N_2H^+ and N_2D^+ in I05345

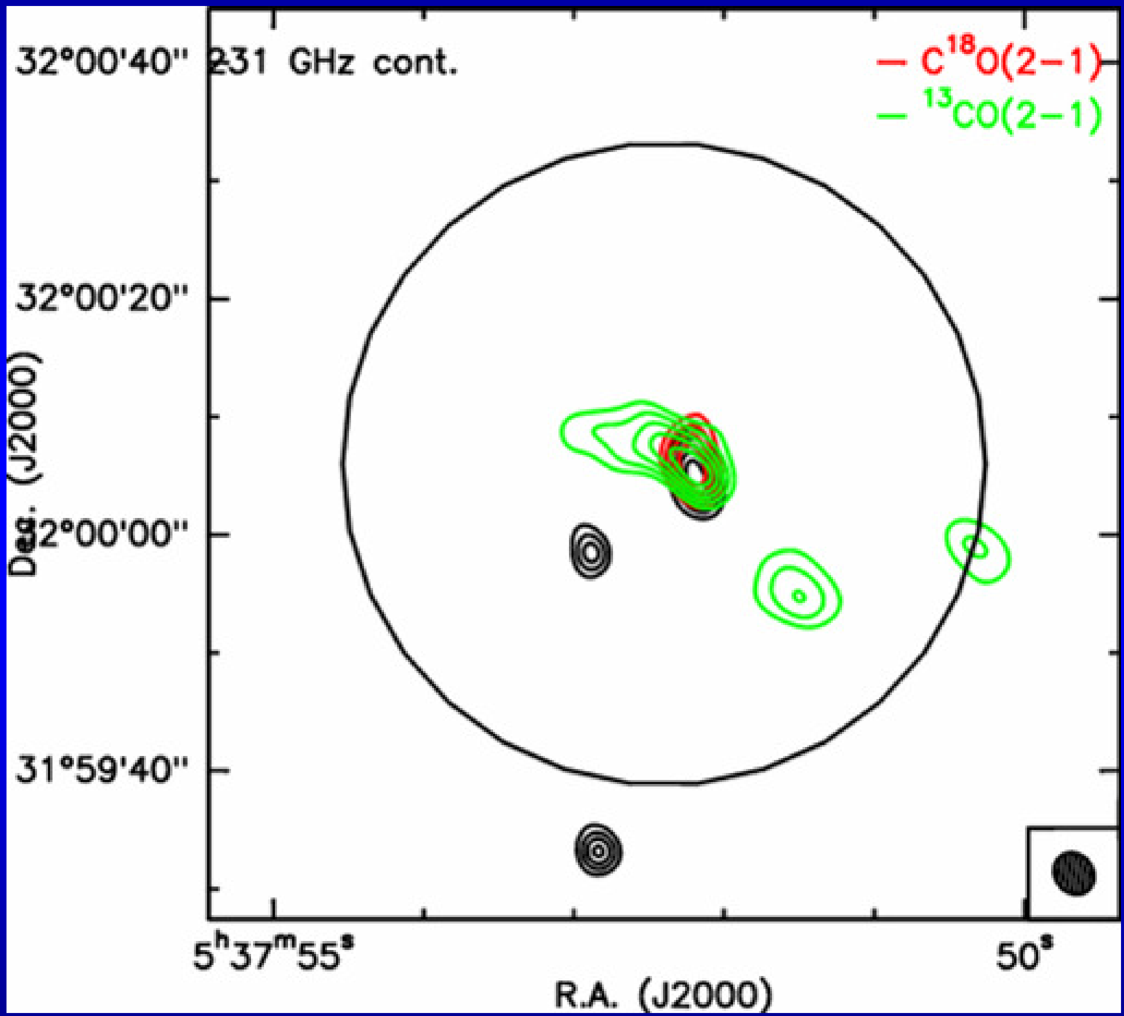
3 Derive the gas Temperature (VLA NH_3 data) in I05345

OUTLOOK

4 Higher-angular resolution study of other sources with high D_{frac} (SMA, PdBI, CARMA, ALMA??)

5 Extend the study to Southern HMPCs (APEX)

CO isotopologues



Chemical properties II - Deuterium fractionation

1. If T ~ 10 K... $H_3^+ + HD \rightarrow H_2D^+ + H_2 + \Delta E$ — H_2D^+/H_3^+ increases

2. If CO depletes...

$\cancel{H_3^+ + CO \rightarrow HCO^+ + H_2}$

$\cancel{H_2D^+ + CO \rightarrow DCO^+ + H_2}$

H_3^+ and H_2D^+ remain abundant

3. If 1 + 2...

$H_3^+ + X \rightarrow XH^+ + H_2$

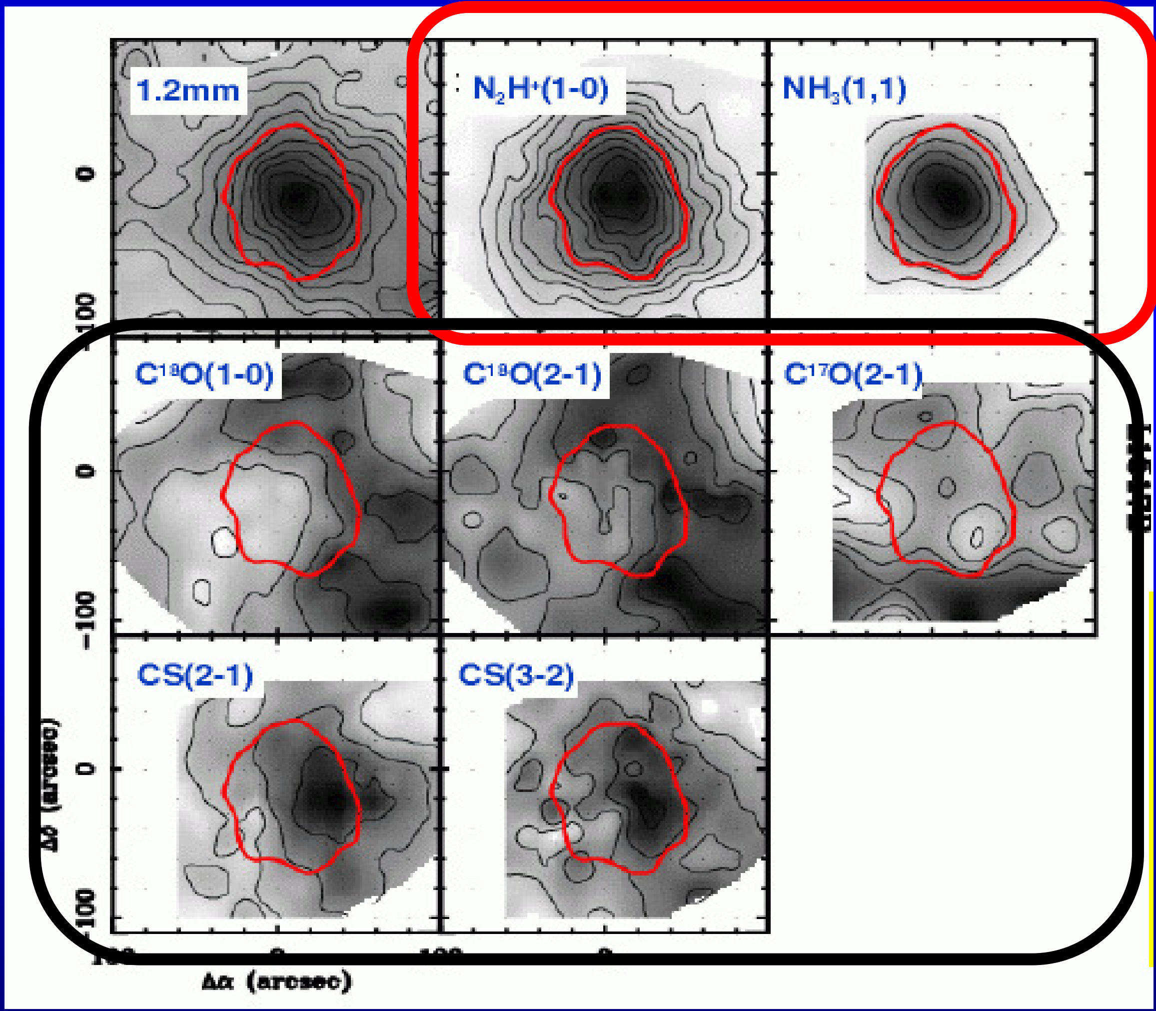
$H_2D^+ + X \rightarrow XD^+ + H_2$

XD^+ and XH^+ abundant and XD^+/XH^+ increases

e.g. Deuterium fractionation from N_2D^+/N_2H^+ excellent to identify pre-stellar cores!
(Crapsi et al. 2005)

Chemical properties I : depletion

An example: L1517B (Tafalla et al. 2004)



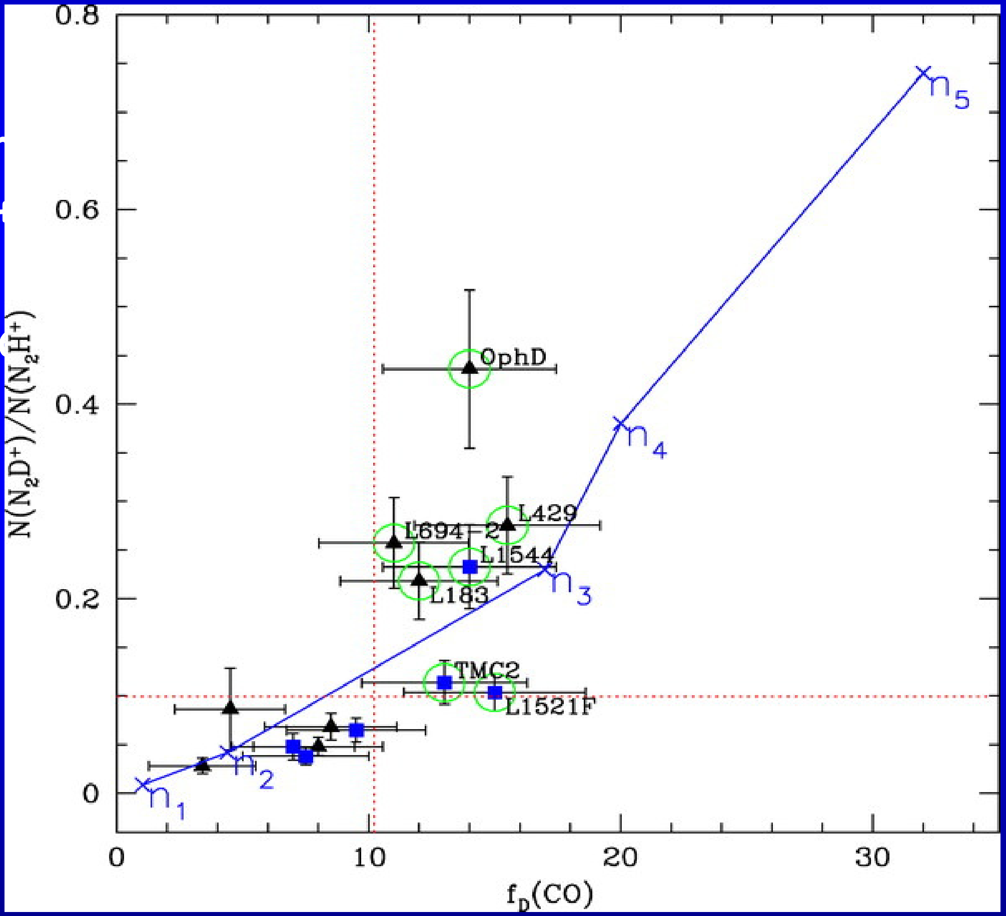
N-bearing species well trace the density profile seen in the dust continuum emission

C-bearing species completely miss the central density peak e.g. N_2D^+/N_2H^+ and CO depletion successfully used in low-mass pre-stellar cores

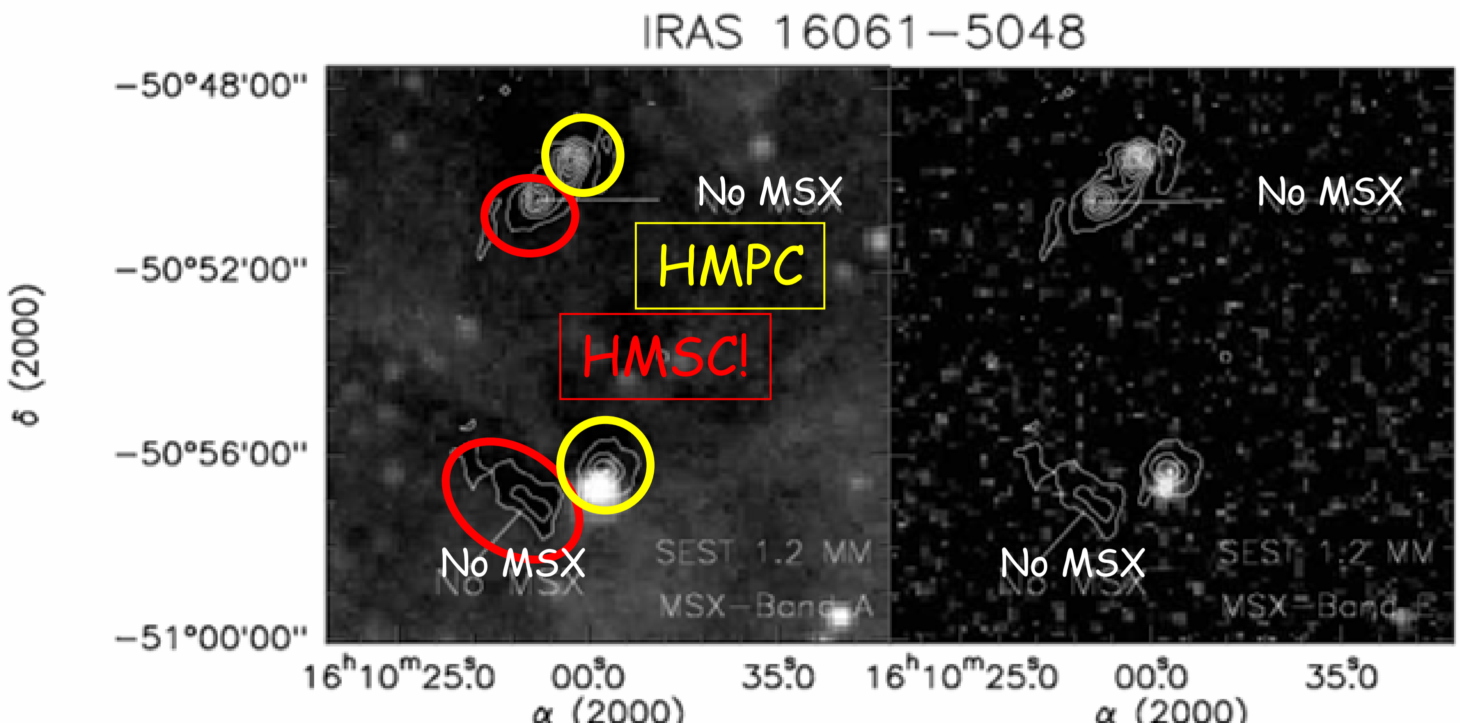
(Crapsi et al. 2005)

- $X_{CO}^{Exp.}/X_{CO}^{Obs.} = f_D \sim 10$
- High deuterium fraction
  N(N2D+)/N(N2H+
- Correlation between f_D

O = pre-stellar cores



High-mass YSOs tend to form in dense clusters



Contours = 1.2 mm (SEST); Grey = MSX @ 8.5μm and 21μm
(Beltrán et al. 2006)

Search for COLD and DENSE SPOTS close to HMPCs, through f_D and $N(N_2D^+)/N(N_2H^+)$!