Deuterium enhancement in H_3^+ in pre-stellar cores

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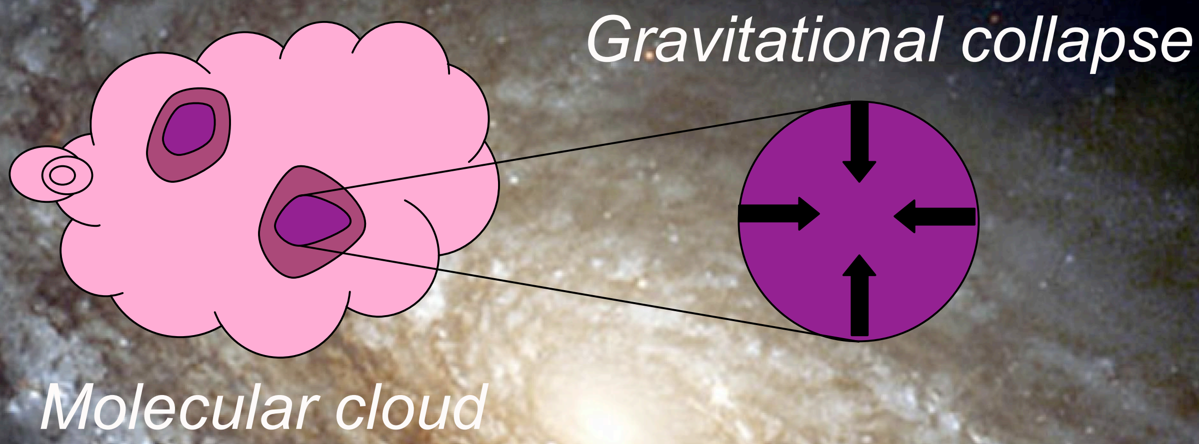
What is a prestellar core?



- ☆ Typical lifetime ~ 10^6 years
- ☆ Strong mm emission, NIR, MIR absorption
- ☆ Very low central gas and dust temperature (< 10 K)
- ☆ High density ($\geq 10^5$ cm^{-3})
- ☆ Enhanced molecular deuteration

Extreme molecular deuteration

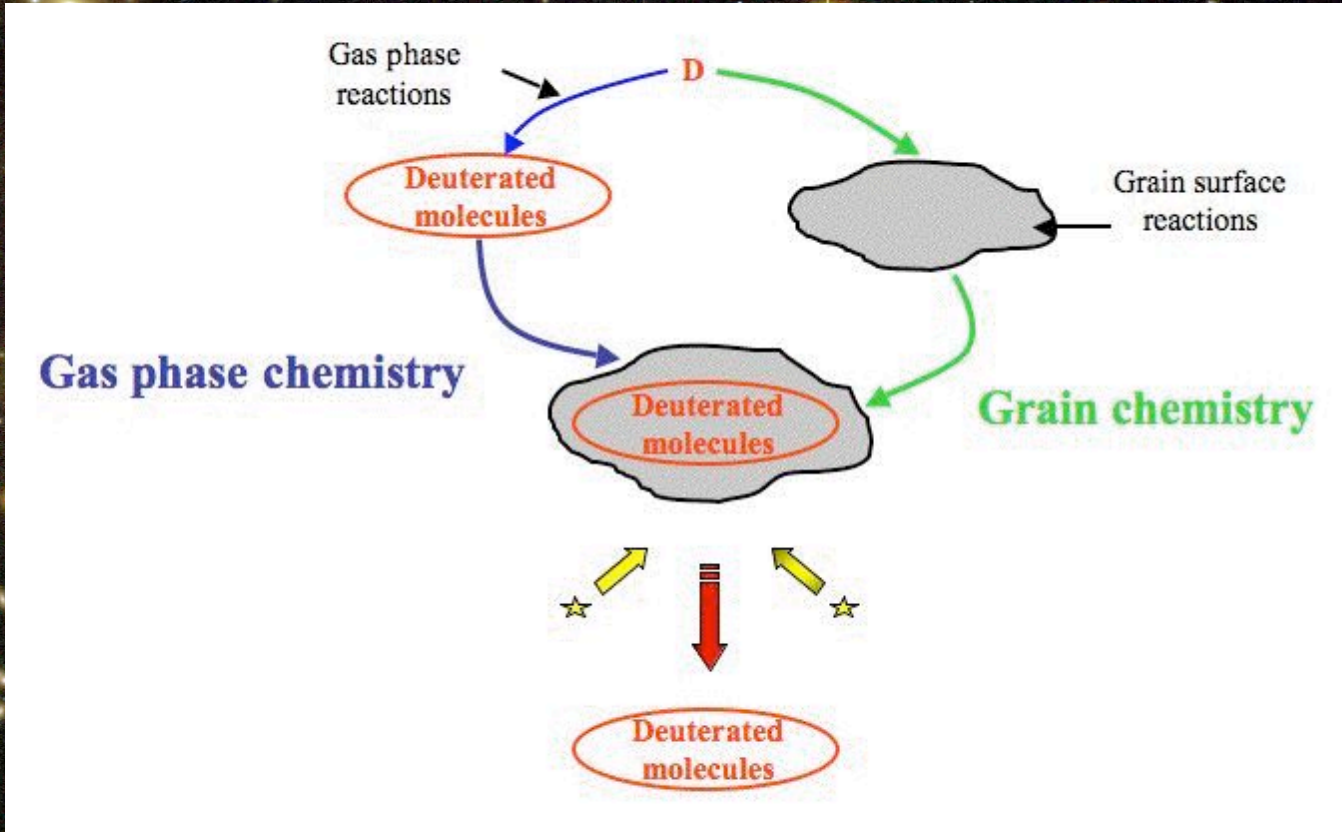
Strong CO depletion in the centre of pre-stellar cores

(i.e. Willacy et al. 1998, Caselli et al. 1999, Bergin et al. 2001, Bacmann et al. 2002, 2003; Pagani et al. 2005).

Depletion of molecules onto dust grains (e.g. Bergin & Langer 1997).
Multiply deuterated species observed in the gas phase:

	$f_d(CO)$	N_2D^+/N_2H^+	DCO^+/HCO^+	D_2CO/H_2CO	ND_3/ND_2H
L1544	~ 10	0.26	0.04	0.04	0.15
16293E	~ 7		0.08	0.4	0.30
L134N	~ 6	0.35	0.18		< 0.032

Chemistry of deuterated species



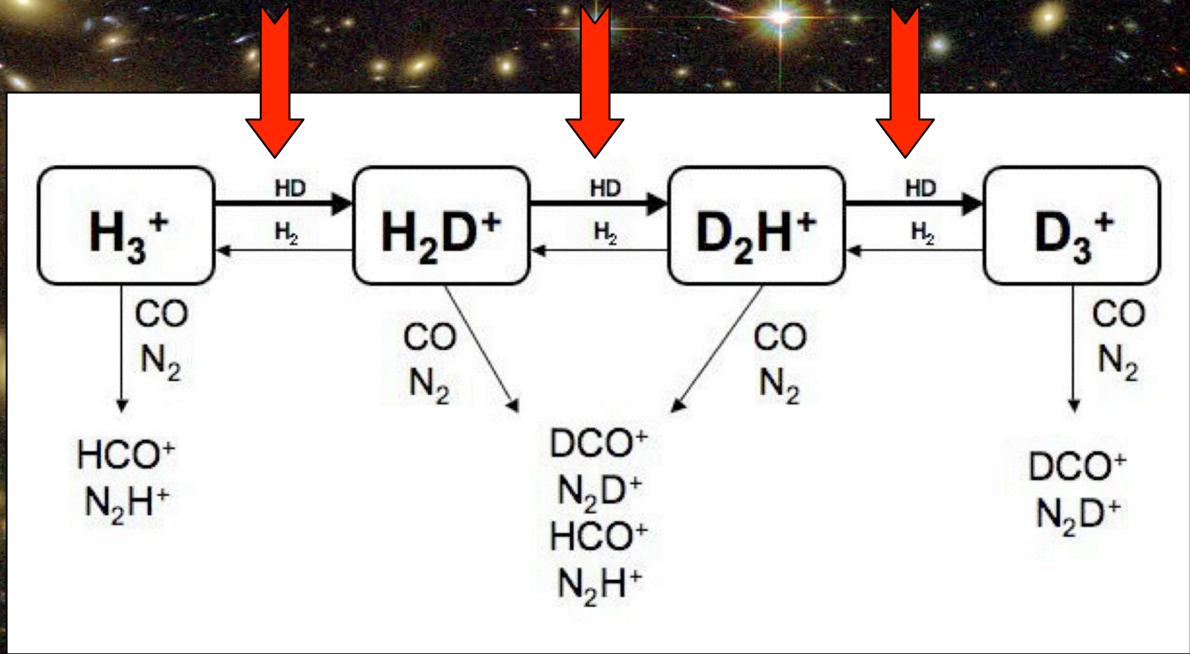
Multiply deuterated methanol (Parise et al. 02)

HDS, D_2S (Vastel et al. 03)

D/H ≥ 0.1 !

Modification of the deuterium chemistry

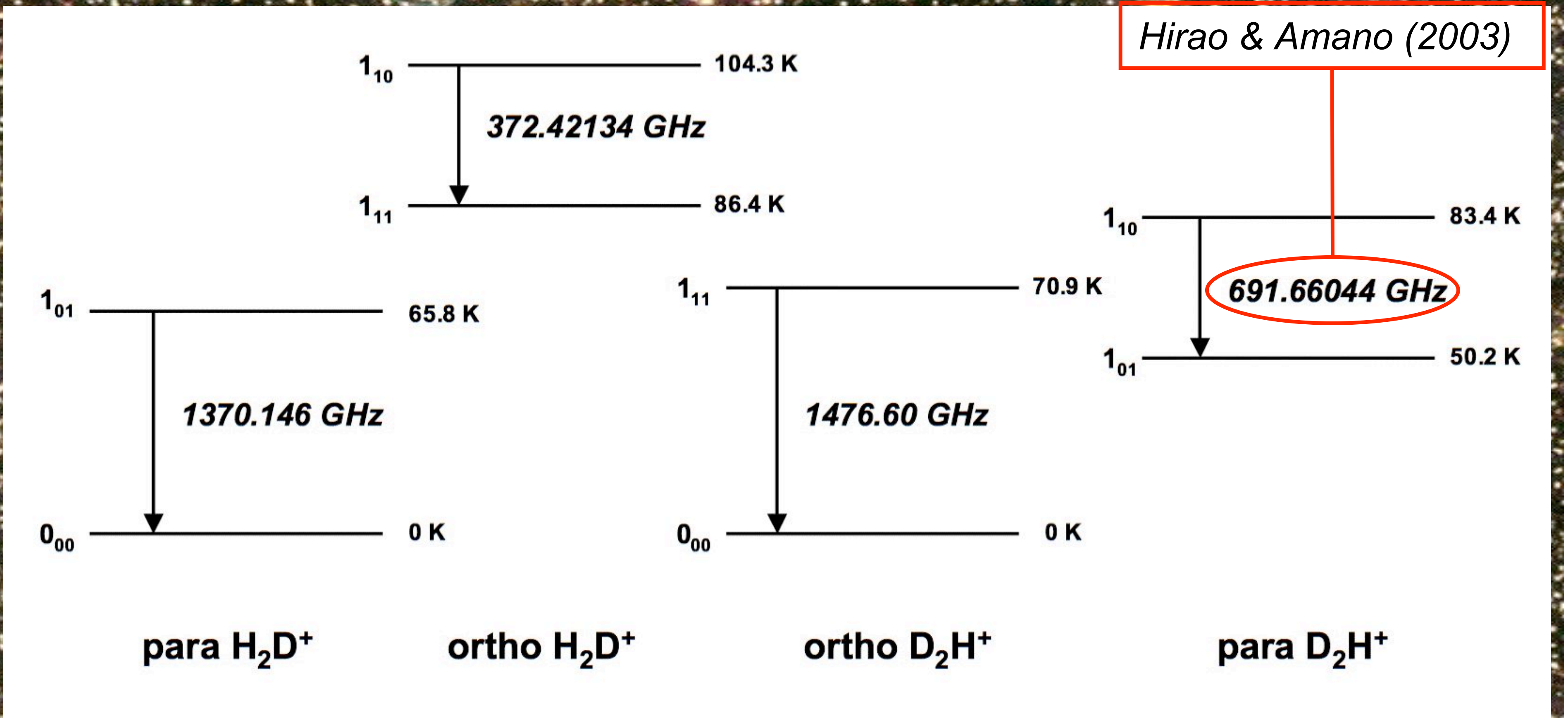
CO depletion



Longtime search for H_2D^+: Phillips et al. (1985), Pagani et al. (1992), van Dishoeck et al. (1992), Boreiko & Betz (1993). Detected by Stark et al. (1999) and Caselli et al. (2003)

→ Search for D_2H^+ starting in 2002

Current and future observations



Caltech Submillimeter Observatory

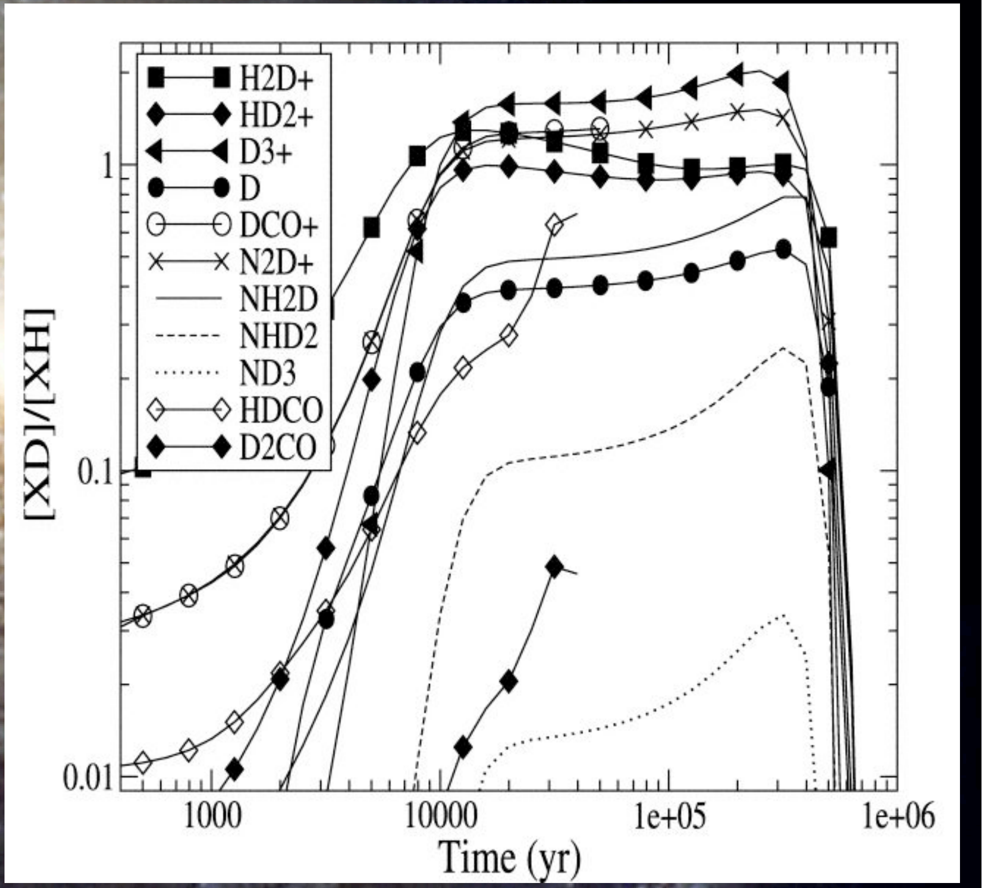
New models

Inclusion of all deuterated forms of H_3^+: H_2D^+, D_2H^+, D_3^+

(Roberts, Herbst & Millar 03)

1) D/H ≥ 0.1

2) $x(H_2D^+) \sim x(D_2H^+)$



Roberts et al. 2003

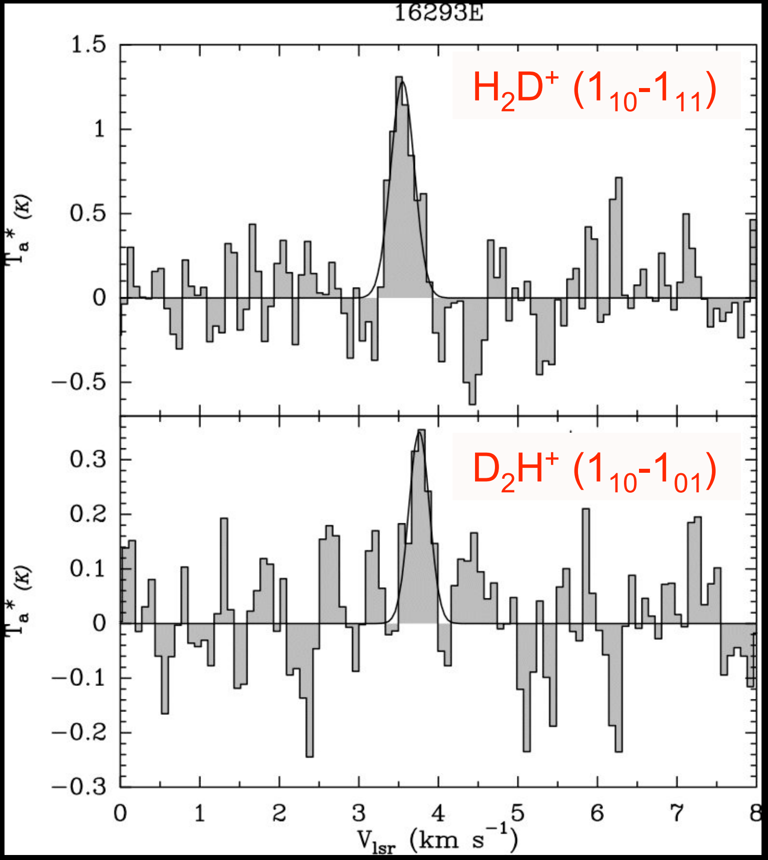
First detection of D_2H^+

☆ **Dense (>10^5 cm^{-3}), cold (<15 K) prestellar core: 16293E**

para-D_2H^+ /ortho-H_2D^+ ~ 0.75 ± 0.37

$x(H_2D^+) \sim x(D_2H^+)=[10^{-10}-10^{-11}]$

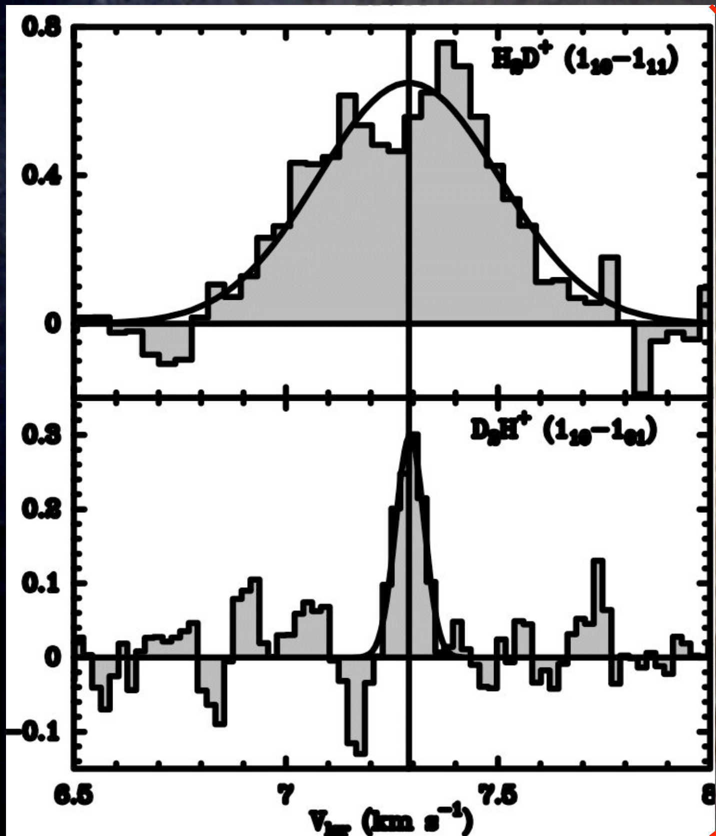
10 K 15 K

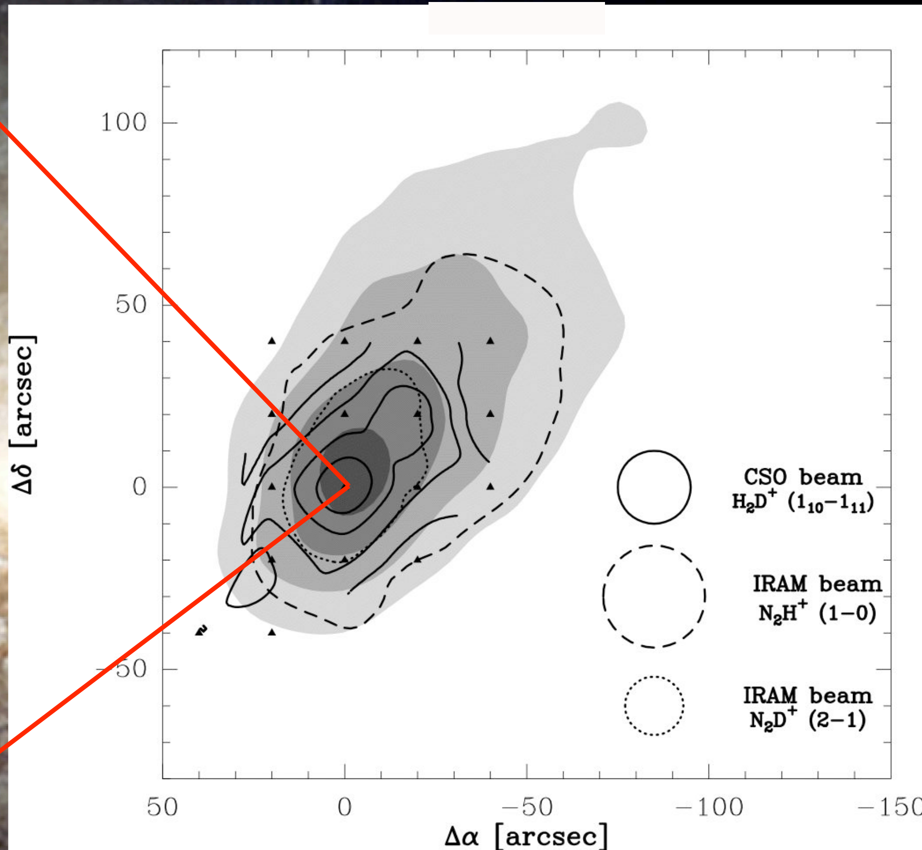


Vastel et al. 2004

ortho/para H_2D^+ and D_2H^+?

L1544



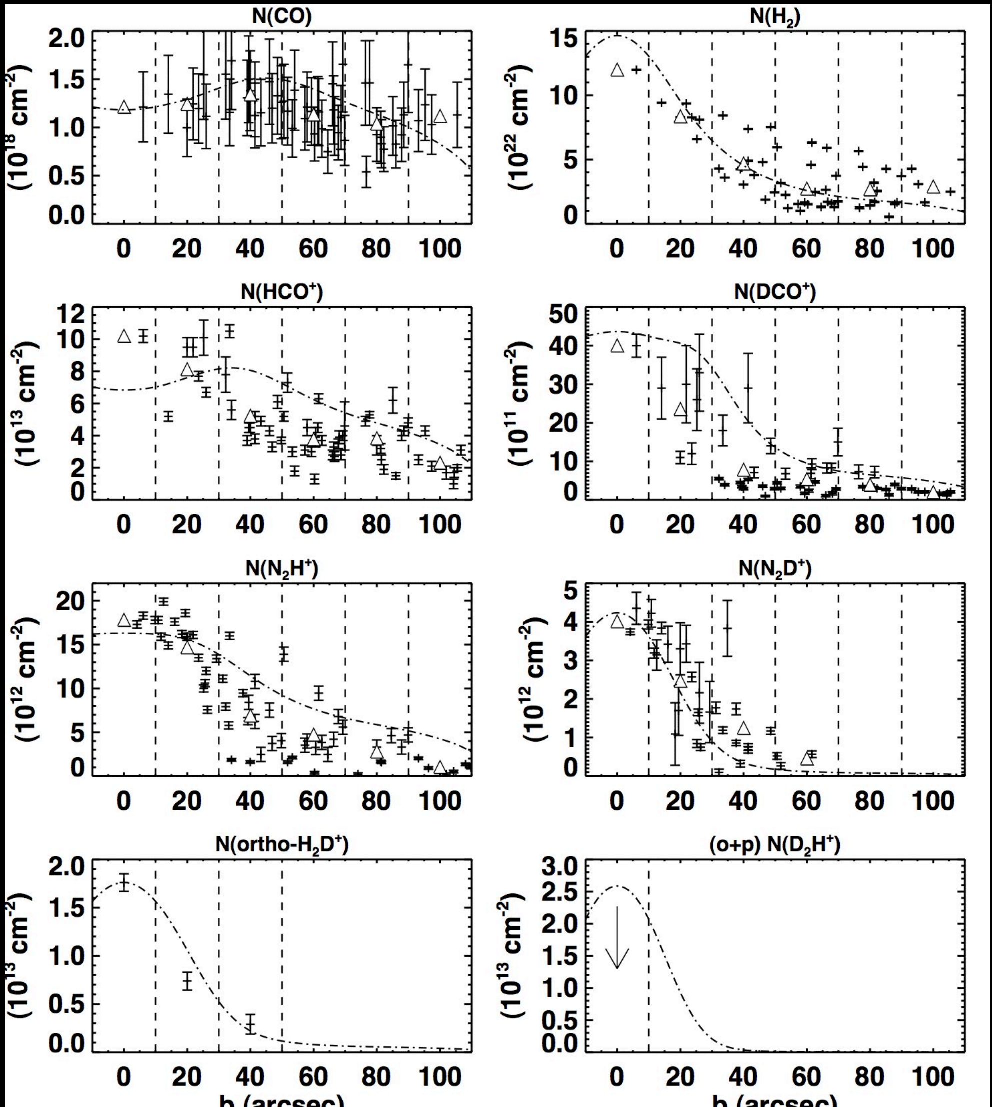


Vastel et al. *in preparation*

Detection of the H_2D^+ $(1_{10}-1_{11})$ line (Caselli et al. 2003)

Analysis of the line shape profile (van der Tak et al. 2005)

Observations



$$H_3^+ + N_2 \rightarrow N_2H^+ + H_2$$

Similar CO and N_2 binding energies

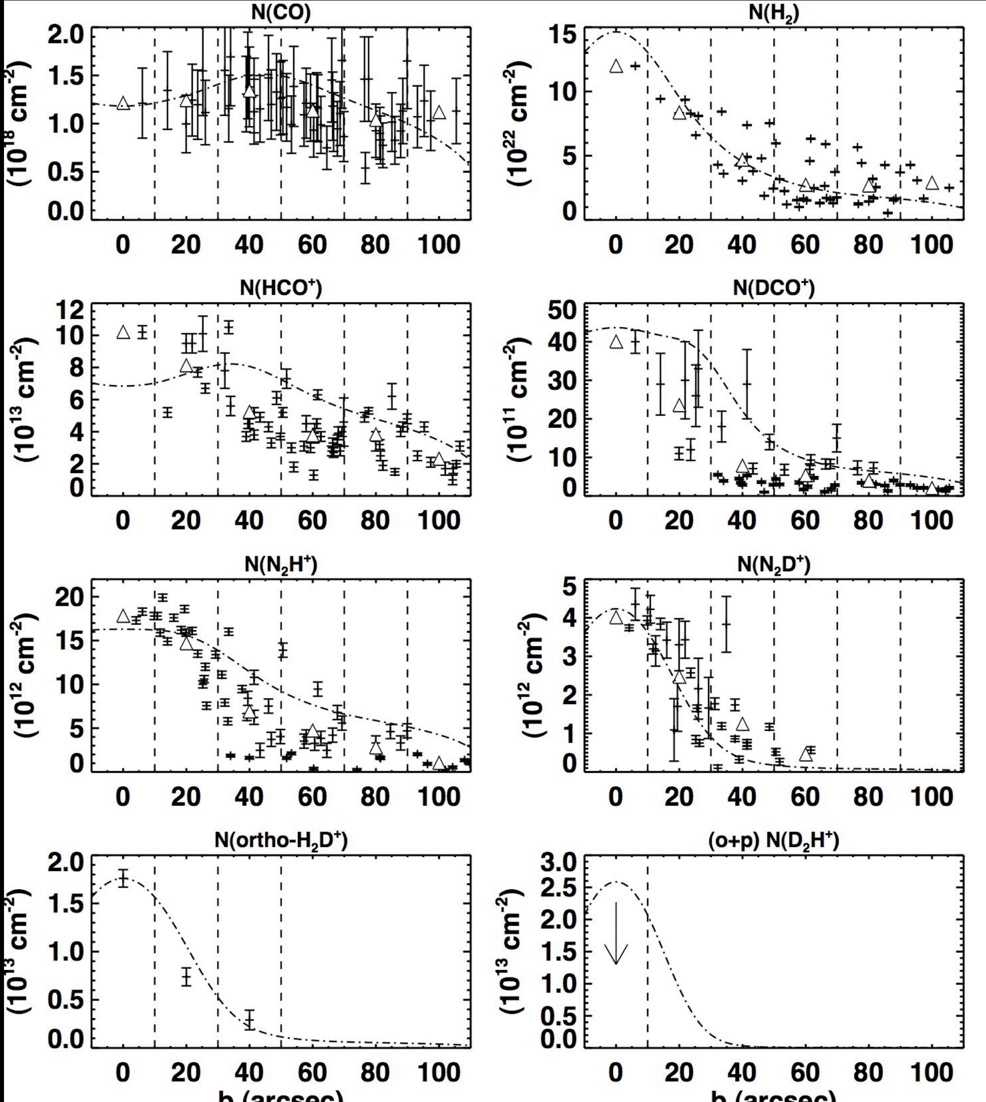
$$N_2H^+ + CO \rightarrow HCO^+ + N_2$$

CO and N_2 freeze out

N_2H^+ observed to survive longer in the gas phase at $n{\sim}10^6$ cm^{-3} compared to CO (10^5 cm^{-3})

Vastel et al. *in preparation*

Observations



$H_3^+ + CO \rightarrow HCO^+ + H_2$

$H_2D^+ + CO \rightarrow DCO^+ + H_2$

CO freeze out

Balanced by the H_2D^+ production rate at the dust peak position

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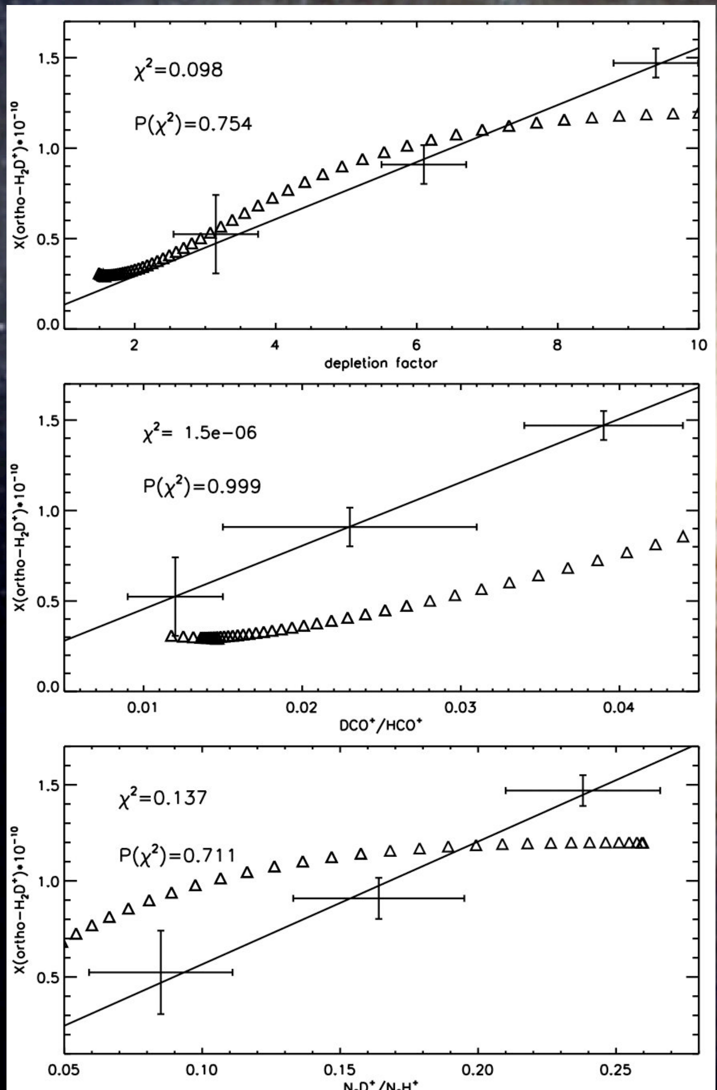
Correlations



- H_2D^+ dominates the fractionation of HCO^+ and N_2H^+
- Main ion in this dense core

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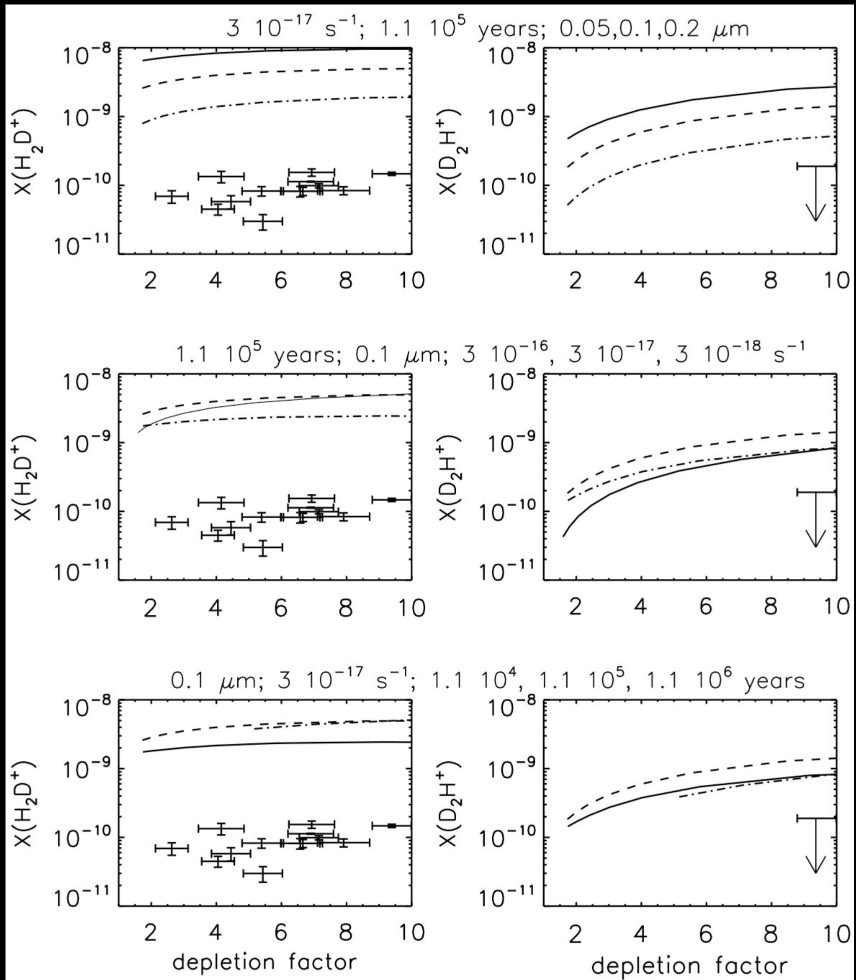
Chemical parameters space exploration



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Ceccarelli & Dominik (2005):

✔ Cosmic ionization rate

✔ Age of the cloud

✔ Grain radius

⇨ <u>cf C. Ceccarelli's lecture</u>

Comparison between the observed o-H_2D^+, p-D_2H^+ and the modelled values for the total (o+p) abundances.

H_2D^+ ortho/para ratio

parameters			$\frac{o}{p}$ H_2D^+	$\frac{p}{o}$ D_2H^+
cosmic ionization rate (s^{-1})	age (years)	grain radius (μm)		
$3\ 10^{-17}$	$1.1\ 10^5$	0.05	0.02	< 1.07
$3\ 10^{-17}$	$1.1\ 10^5$	0.1	0.03	< 0.15
$3\ 10^{-17}$	$1.1\ 10^5$	0.2	0.08	< 0.55
$3\ 10^{-16}$	$1.1\ 10^5$	0.1	0.03	< 0.29
$3\ 10^{-18}$	$1.1\ 10^5$	0.1	0.07	< 0.29
$3\ 10^{-17}$	$1.1\ 10^4$	0.1	0.07	< 0.29
$3\ 10^{-17}$	$1.1\ 10^6$	0.1	0.03	< 0.29
$3\ 10^{-17}$	$1.1\ 10^5$	0.3	0.17	< 0.63
$3\ 10^{-17}$	$1.1\ 10^5$	0.4	0.32	No solution
$3\ 10^{-18}$	$1.1\ 10^5$	0.4	0.33	< 11.81
$3\ 10^{-17}$	$1.1\ 10^4$	0.4	0.33	< 11.81

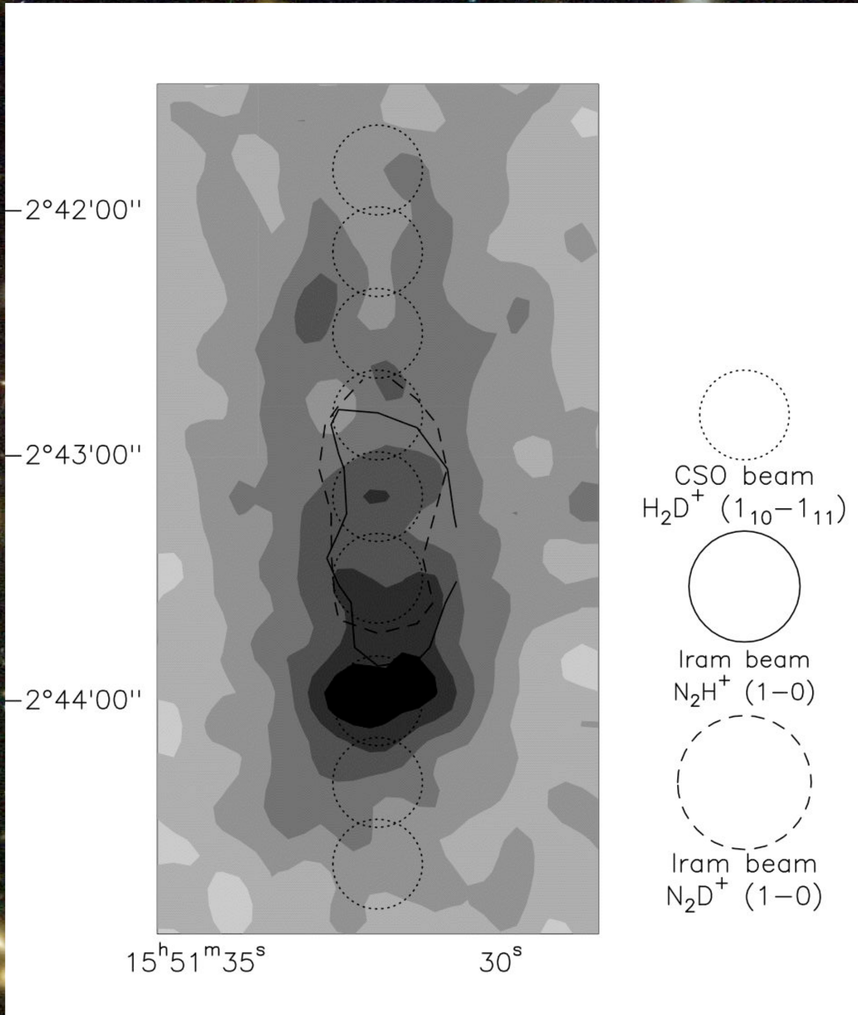
Comparison between the observed o-H_2D^+, p-D_2H^+ and the modelled values for the total (o+p) abundances.

o/p H_2D^+ ≥ 0.3
(Flower et al. 2004)

Grain radius ≥ 0.3 μm

Grain coagulation ?

L134N (=L183)



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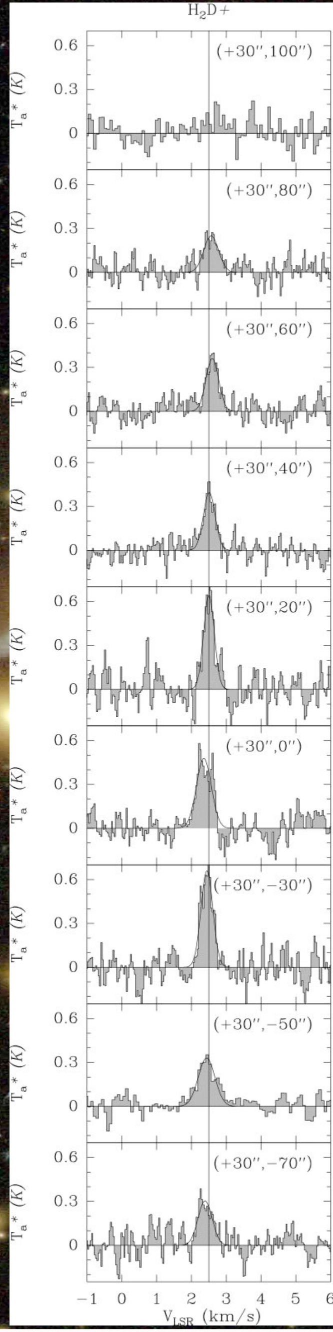

H_2D^+ and D_2H^+ large scale survey

***Collaborators*: C. Caselli, C. Ceccarelli, A. Crapsi,**

F. van der Tak…

Sample of pre-stellar cores and protostars

Detection in 75 % of the pre-stellar cores with

$0.5 \leq T_{mb} \leq 1$ K

Deuterated forms of H_3^+ are unique tracers of the core nucleus, the future stellar cradle.

Unveiling the initial conditions of the star formation processes

Perspectives

Name	Aperture	Platform	Available	H_2D^+		D_2H^+	
				1_{10}-1_{11} (372.4 GHz)	1_{01}-0_{00} (1.37 THz)	1_{10}-1_{01} (692.7 GHz)	1_{11}-0_{00} (1.48 THz)
CSO	**10.4 m**	**Hawaii**	**Y**	**Y**	**N**	**Y**	**N**
JCMT	**15 m**	**Hawaii**	**Y**	**Y**	**N**	**Y**	**N**
SOFIA	**2.5 m**	**Airborne (747)**	**2007**	**N**	**Casimir & GREAT (CONDOR)**	**Casimir**	**Casimir & GREAT (CONDOR)**
Herschel (HIFI)	**3.5 m**	**Space (L2)**	**2007**	**N**	**N**	**Y**	**Y**
ALMA	**50 x 12 m**	**Atacama (Chile)**	**2010**	**Y**	**N**	**Y**	**N**
APEX	**12m**	**Atacama (Chile)**	**2005-2006**	**Y**	**CONDOR**	**Y**	**CONDOR**