The CHESS spectral survey of pre-stellar cores

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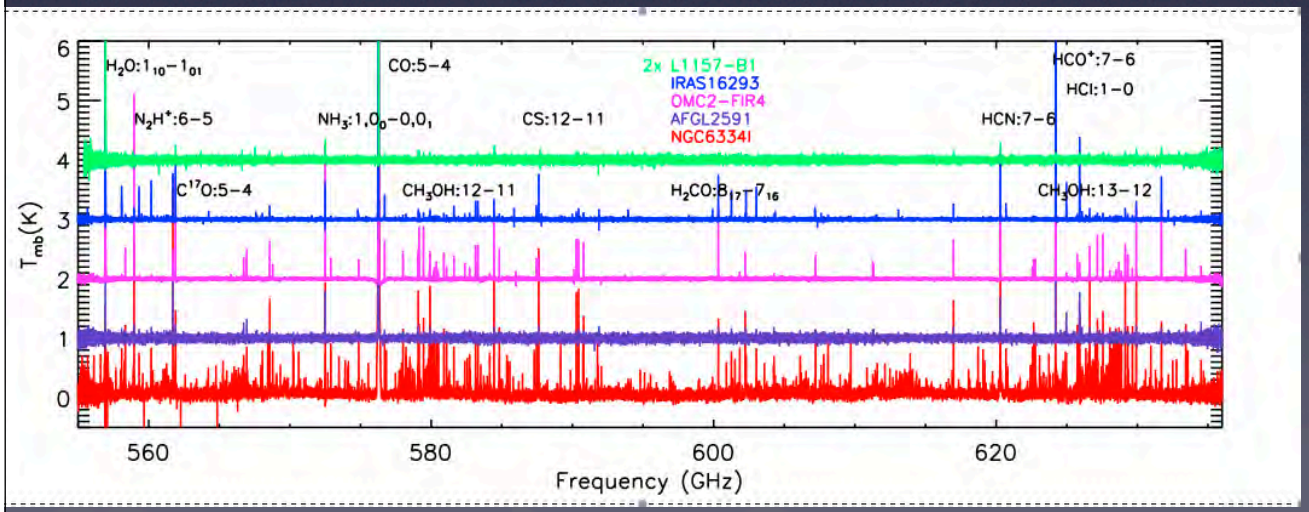
CHESS

Chemical HErschel Surveys of Star forming regions

Herschel/HIFI GT Key program (PI: C. Ceccarelli)

(Mostly) Unbiased spectral surveys of young stellar objects of different evolutionary stages and of various masses

Aim: characterise their chemical contents, its evolution in the star formation process, reconstruct gas physical structure



Ceccarelli et al. (2010)

→ talk by Cabrit, posters by Lefloch, Codella, Vasta, Busquet

→ talk by Bottinelli, posters by Taquet, Coutens

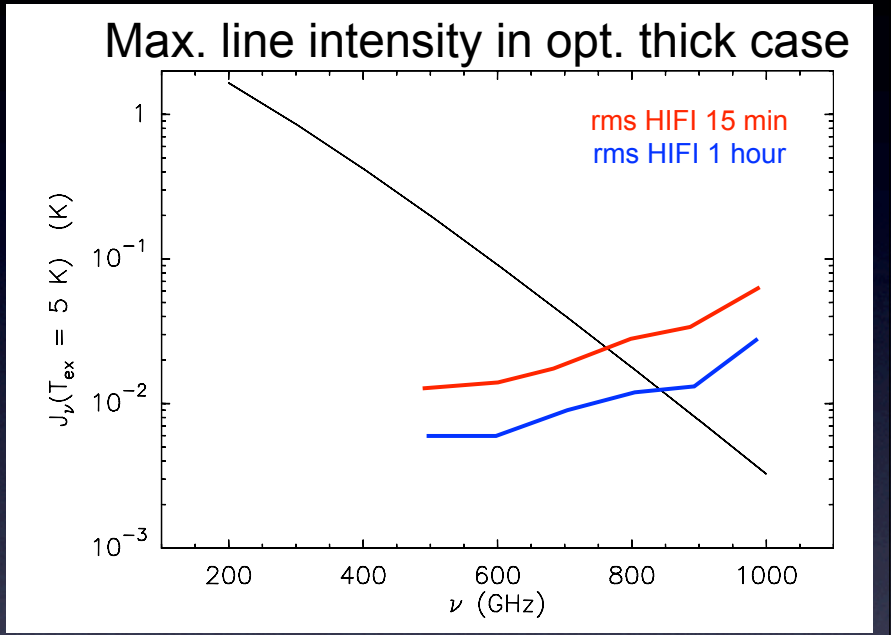
→ posters by Kama, Lopez-Sepulcre

→ poster by Kazmierczak

Pre-stellar cores

- Challenging observations:
  T ~ 10 K, n ~ 10^5 -10^6 cm^{-3}
  - at Herschel frequencies:
    - fundamental transitions of light molecules (high Aul)
    - high energy transitions of large molecules

    ➔ low excitation temperatures
  - low continuum: difficult absorption measurements



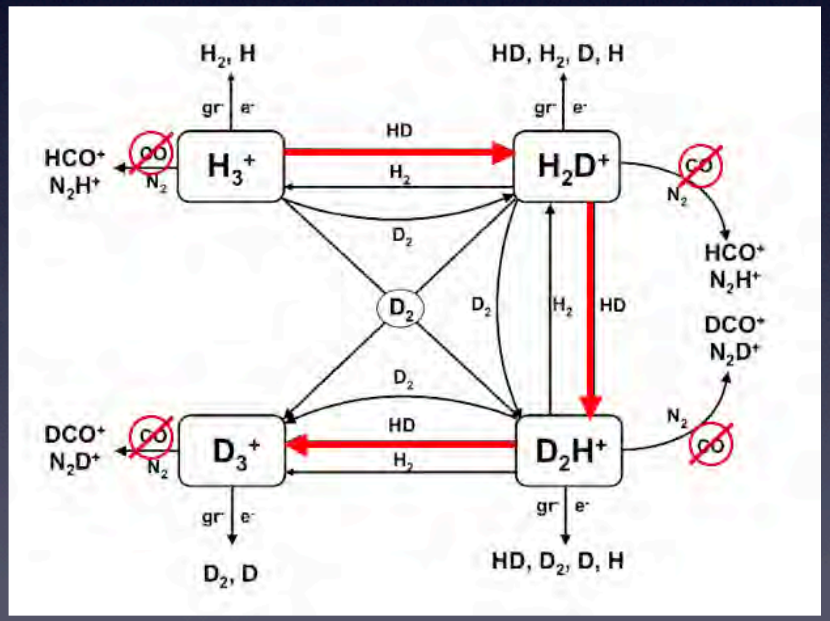
- biaised spectral survey with Herschel/HIFI: at the lowest frequencies
- only possibility to study spectrum at high frequencies

Chemical characteristics of pre-stellar cores

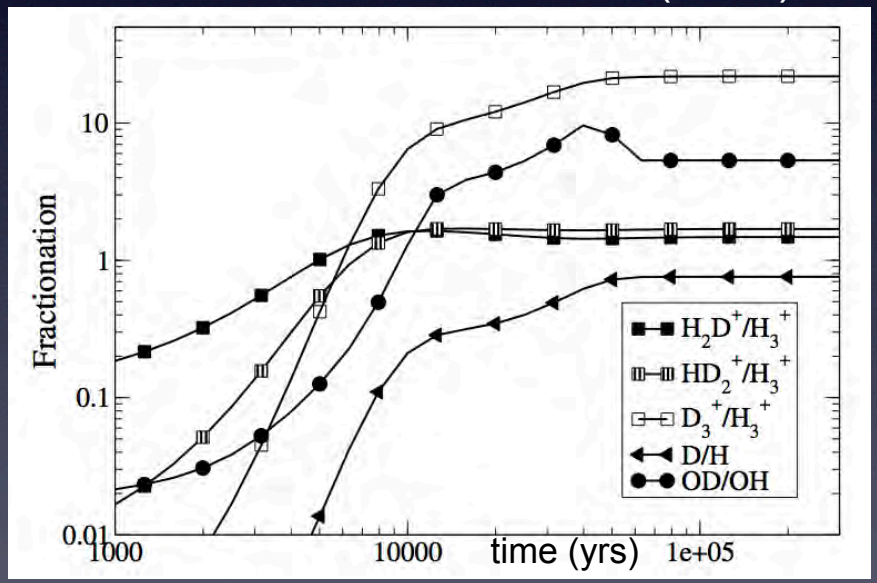
high depletion
high deuterium fractionation

$H_3^+ + HD \rightarrow H_2D^+ + H_2$

reverse reaction inhibited at low temperatures

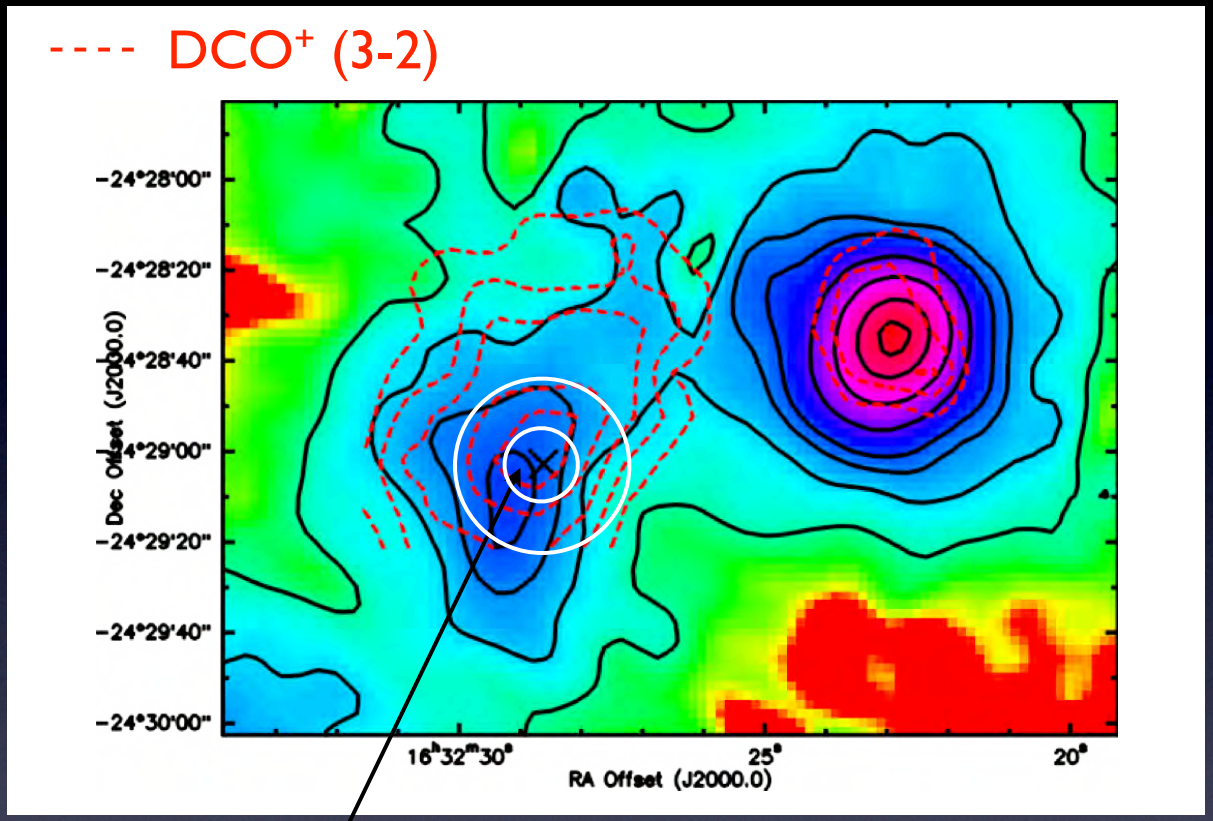


Roberts & Millar (2004)



CO depletion: strong increase in H_2D^+/H_3^+, etc.
Important role played by H_2D^+, D_2H^+, D_3^+

Source: IRAS16293E



HIFI integration position

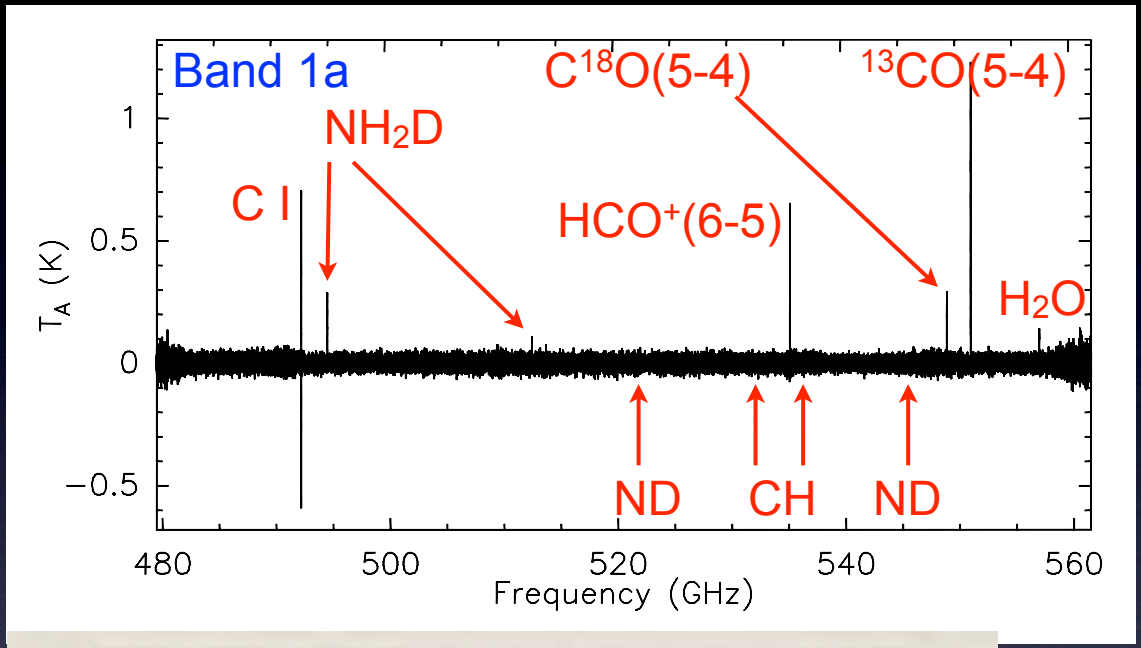
- o-D_2H^+ integration at 1476 GHz
- band 1 (480 - 640 GHz) survey

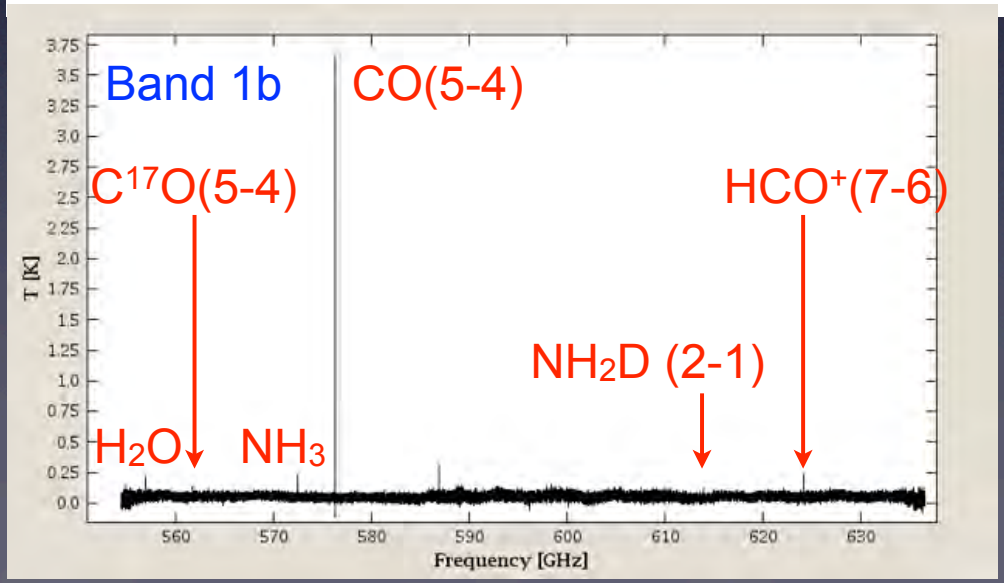
one of the few sources with D_2H^+ detection (Vastel et al. 2004)

strong deuteration D_2CO/H_2CO ~ 40% Loinard et al. (2001)

warmer than typical pre-stellar cores: T_d ~ 15 K (Stark et al. 2004)

Spectral survey of band 1: 16293E





low line density

deuterated molecules:
NH_2D, ND

ortho-H_2O
NH_3
CH

+ Dedicated deep integration
NH at 974 GHz

Continuum ~ 0.1 K
(11 mK in L1544 - Caselli et al. 2010)

N Hydrides

NH_3 ubiquitous in dense pre-stellar cores

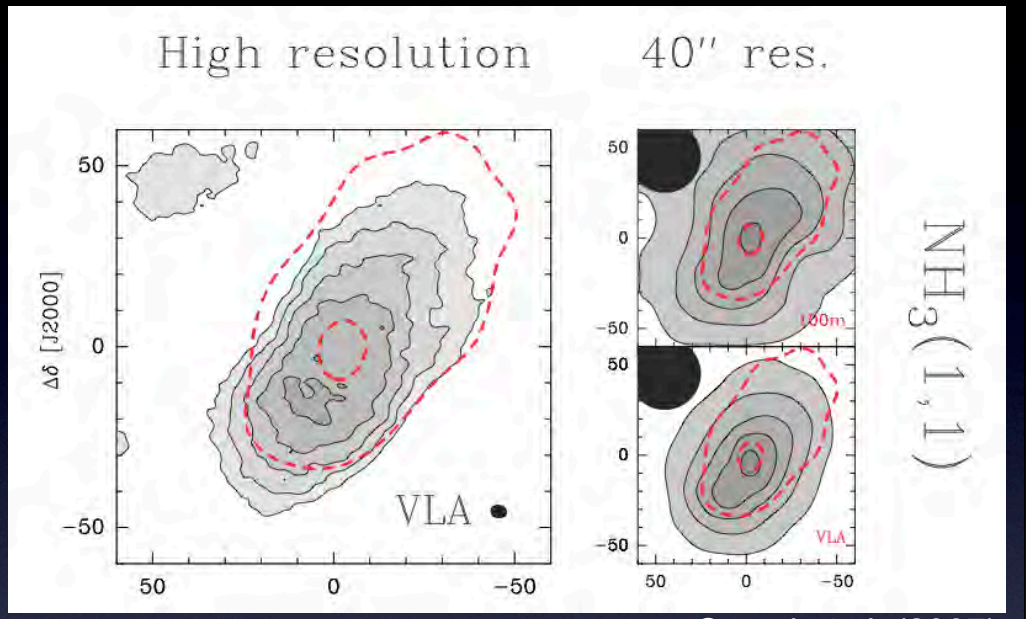
e.g. Benson & Myers (1989)

highly fractionated in D: NH_2D, NHD_2, ND_3

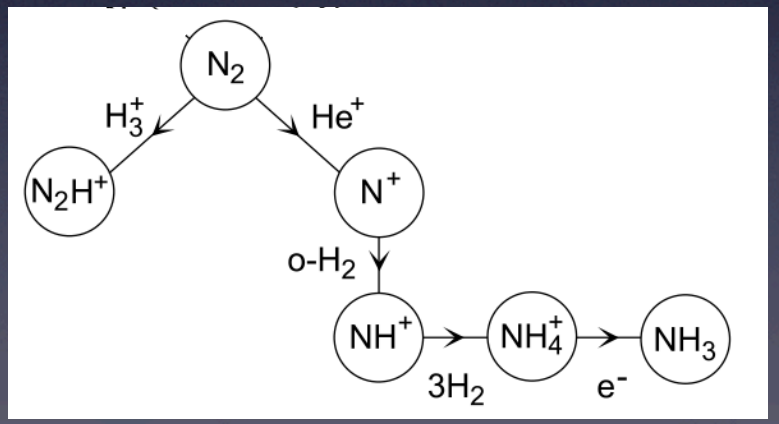
Tiné et al. 2000, Roueff et al. 2000, van der Tak et al. 2002, Lis et al. 2002

NH, NH_2: important intermediates for NH_3 synthesis in the gas-phase

NH formation:
DR of N_2H^+
DR of NH_2^+ and NH_3^+

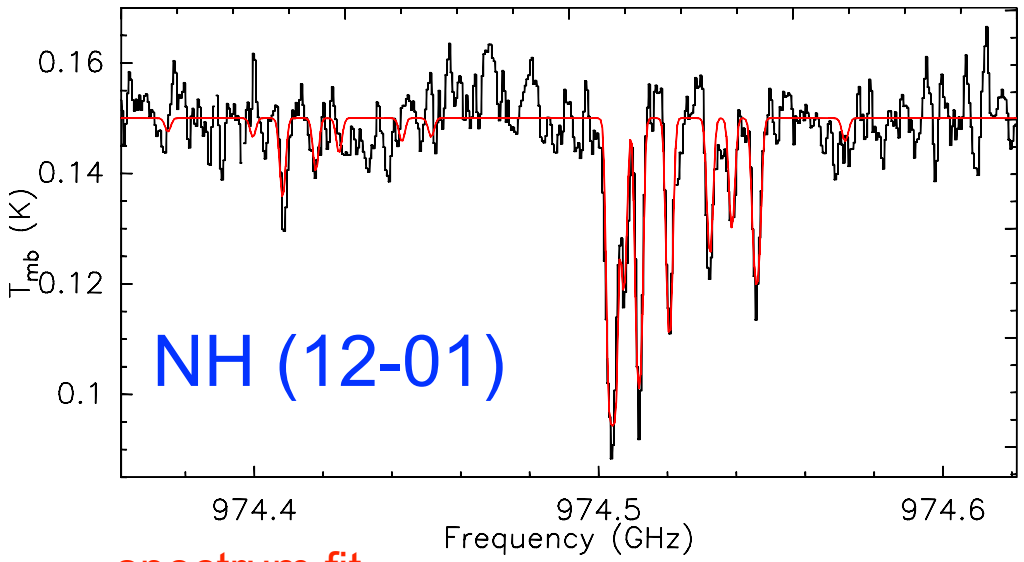


Crapsi et al. (2007)

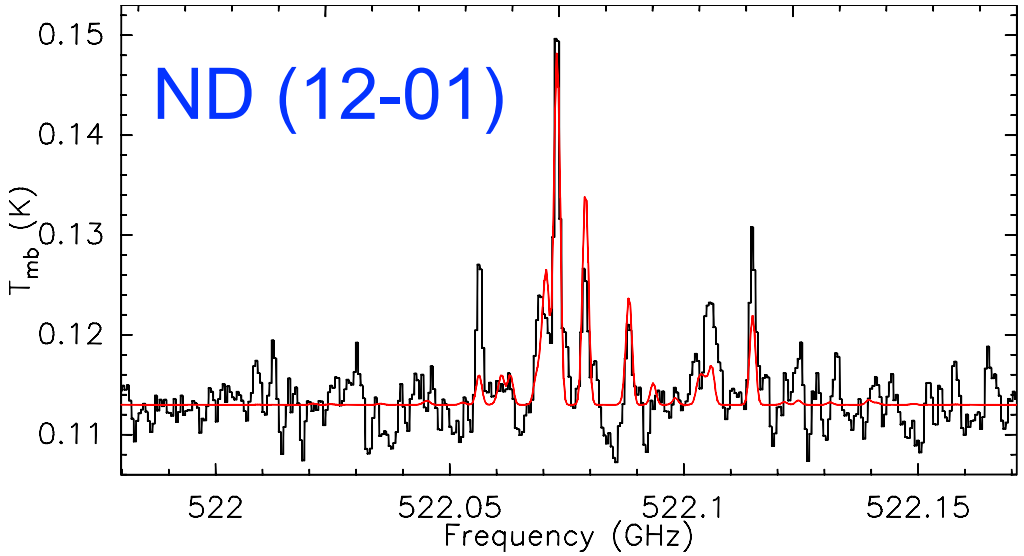


adapted from Hily-Blant et al. (2010)

N Hydrides



— spectrum fit



Deuterium fractionation

ND/NH ~ 20 % (3 - 40%)

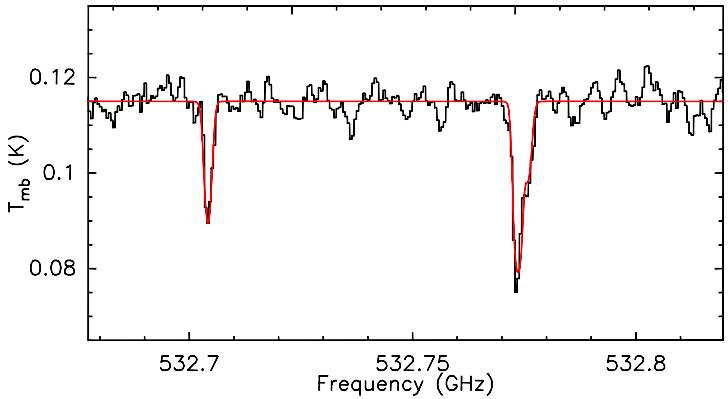
In IRAS 16293-2422

ND/NH ~ 70 %

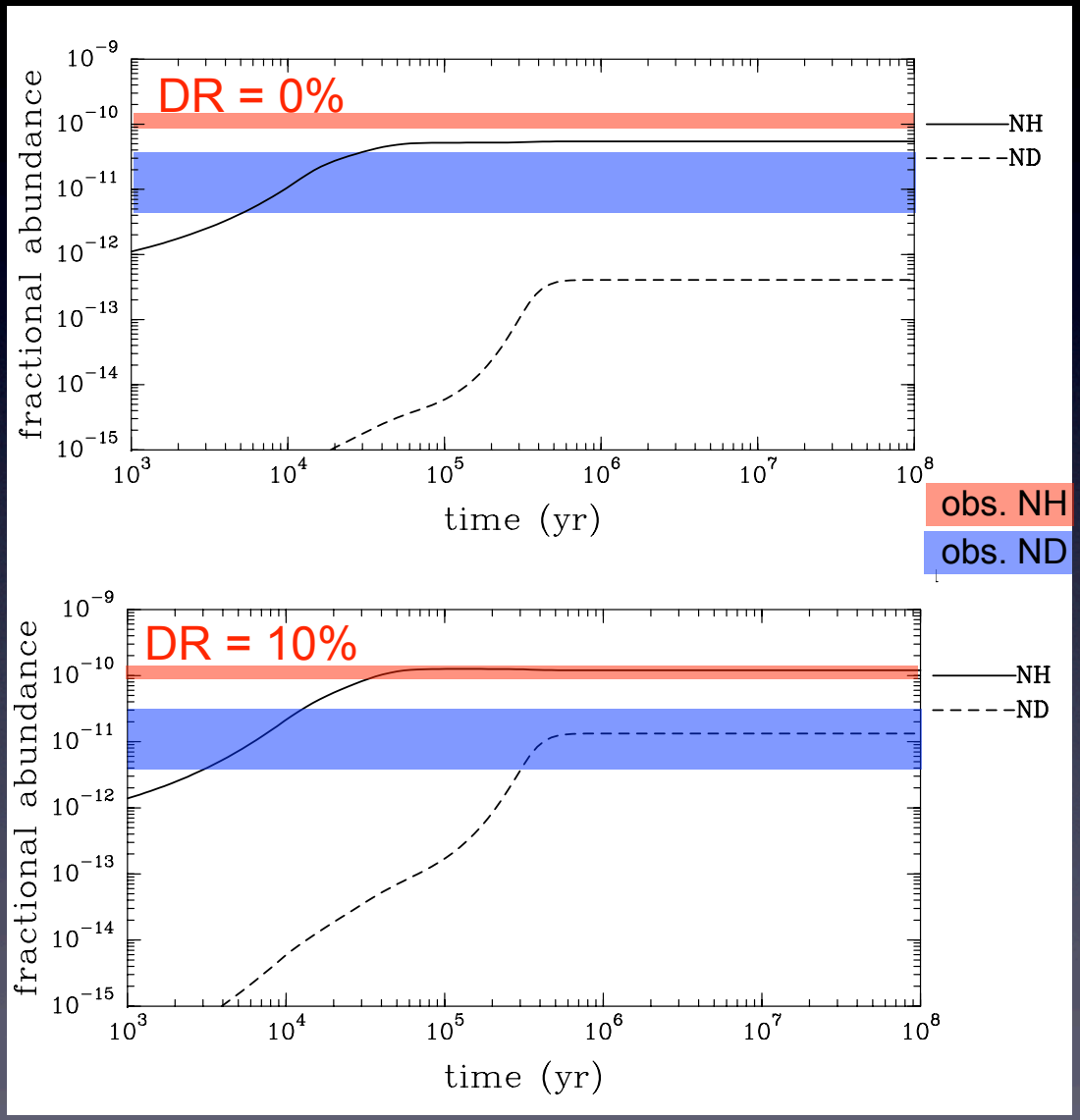
(Bacmann et al. 2010)

ND in emission

CH in absorption



Modelling



gas-phase
chemical network

$N_2H^+ + e^- \rightarrow NH + N$

$\rightarrow N_2 + H$

Molek et al. (2007)

good agreement for DR ~ 10%

Hily-Blant et al. (2010)

Deuteration

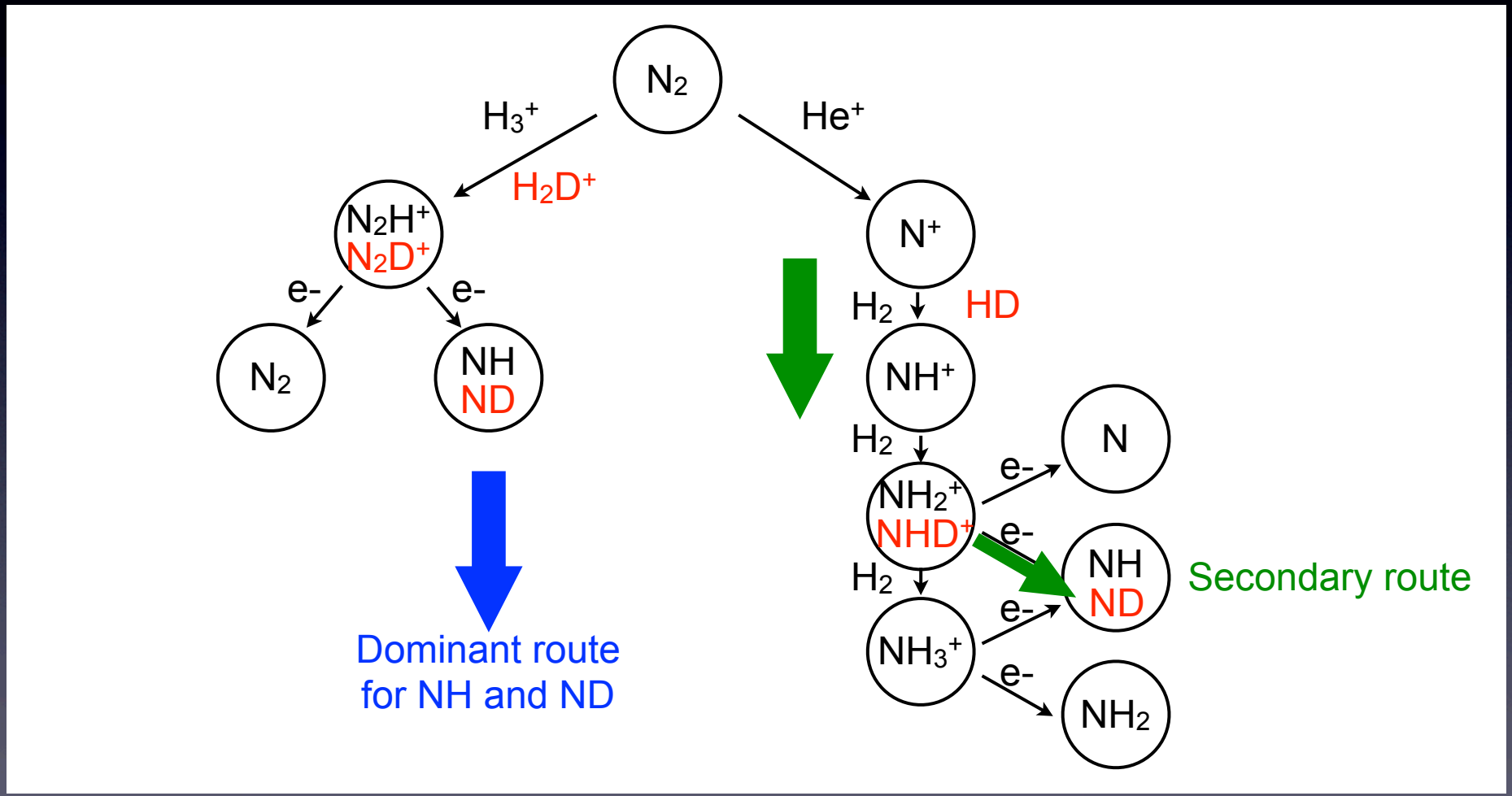
main formation route for ND

$N_2D^+ + e^- \rightarrow ND + H_2$

$o\text{-}H_2/p\text{-}H_2 \sim 5\ 10^{-4}$

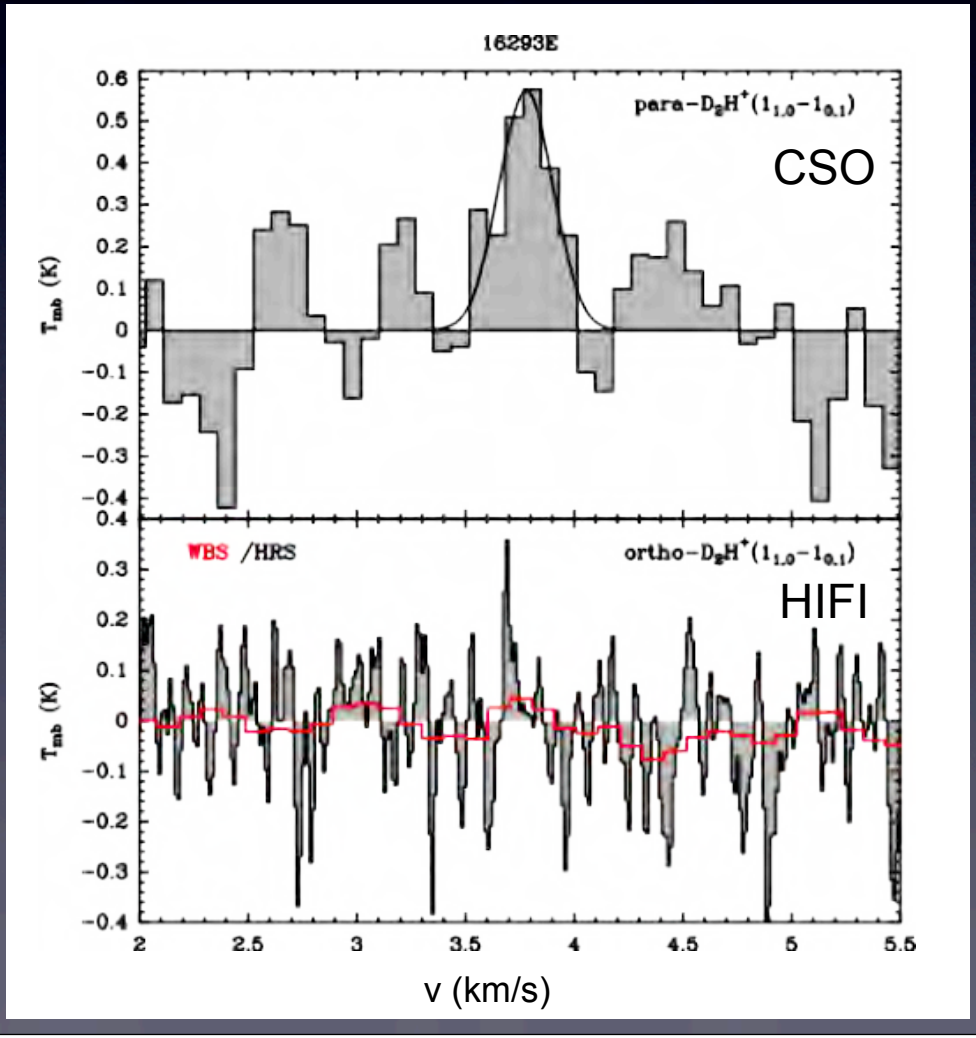
cf. Dislaire et al. (2012)
see poster by R. Le Gal

NH and ND formation routes



D_2H^+

Large interest for deuterated isotopes of H_3^+



- non depleted kinematics tracers
- chemistry

Detection of p-D_2H^+ (and o-H_2D^+)

Vastel et al. (2004)

Search for o-D_2H^+ in 16293E

Upper limit on o-D_2H^+

Vastel et al., in prep

$H_3^+ + HD \leftrightarrow H_2D^+ + H_2 + 230\ K$

$H_2D^+ + HD \leftrightarrow D_2H^+ + H_2 + 180\ K$

$D_2H^+ + HD \leftrightarrow D_3^+ + H_2 + 230\ K$

$o\text{-}H_2D^+ + o\text{-}H_2 \rightarrow H_3^+ + HD$
86 K 170 K

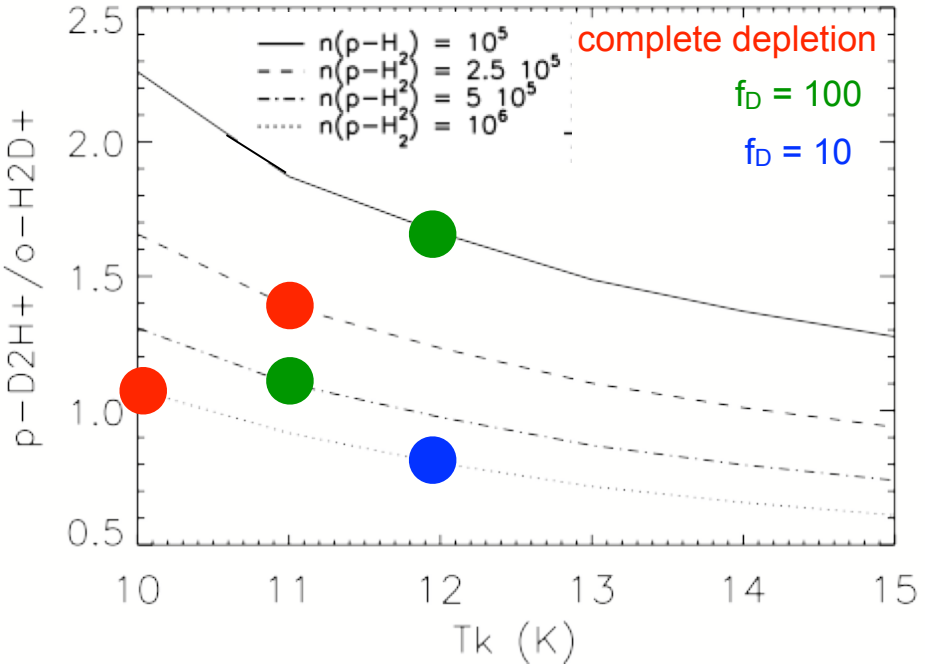
$p\text{-}D_2H^+ + o\text{-}H_2 \rightarrow H_2D^+ + HD$
50 K 170 K

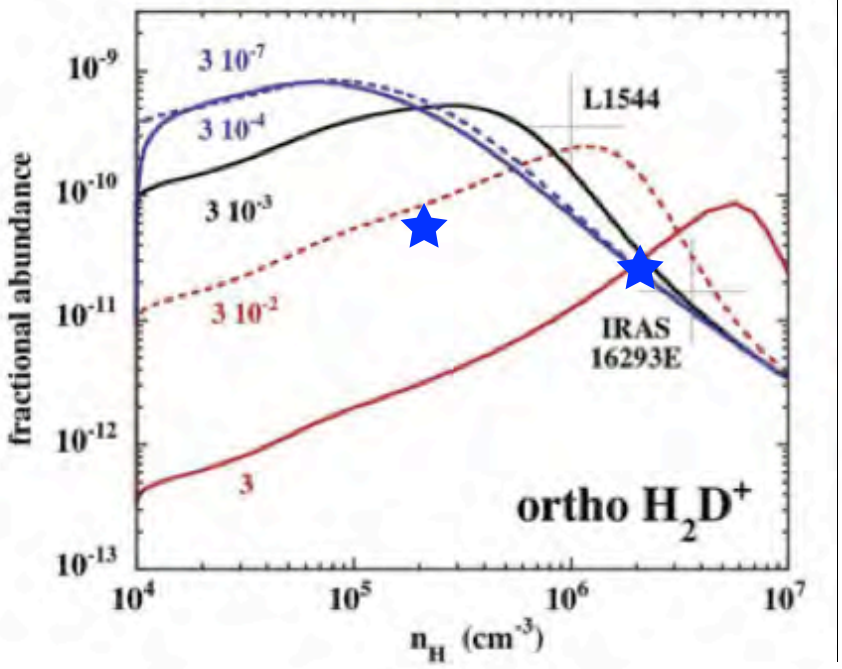
o/p H_2 ratio: limiting factor for deuterium fractionation of the H_3^+ ion
Pagani et al. 1992, Gerlich et al. 2002

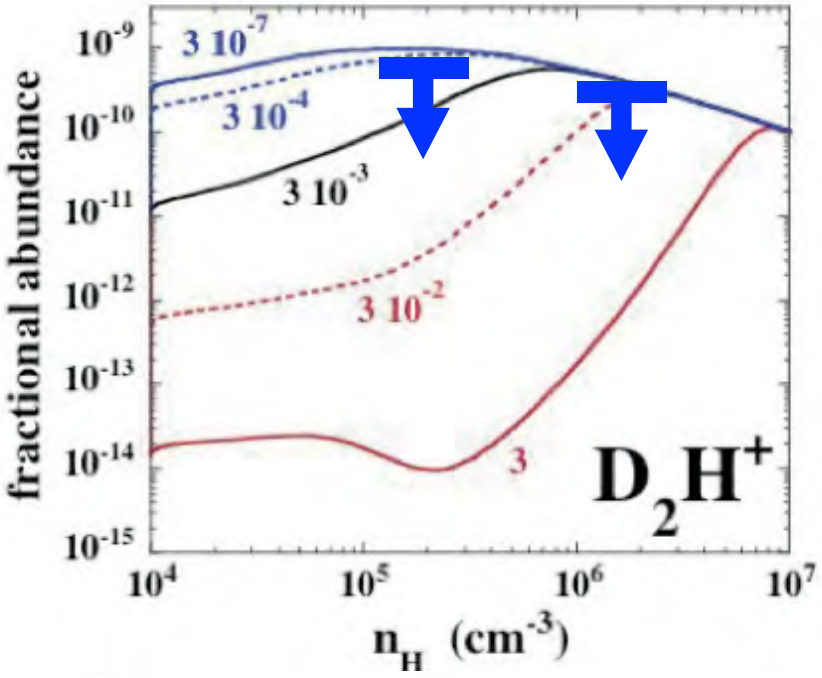
detailed modelling of H_2D^+ and D_2H^+ emission

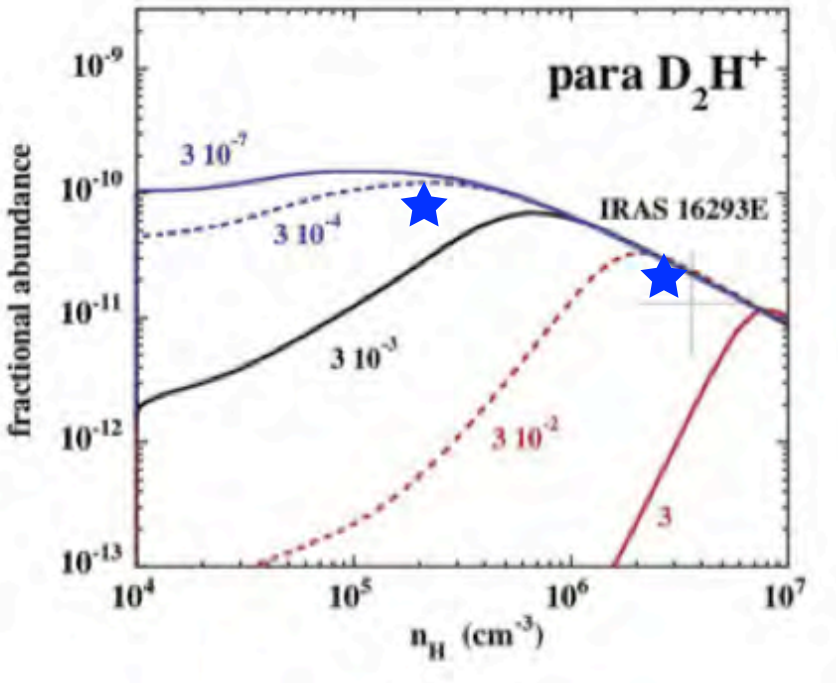
LVG calculations

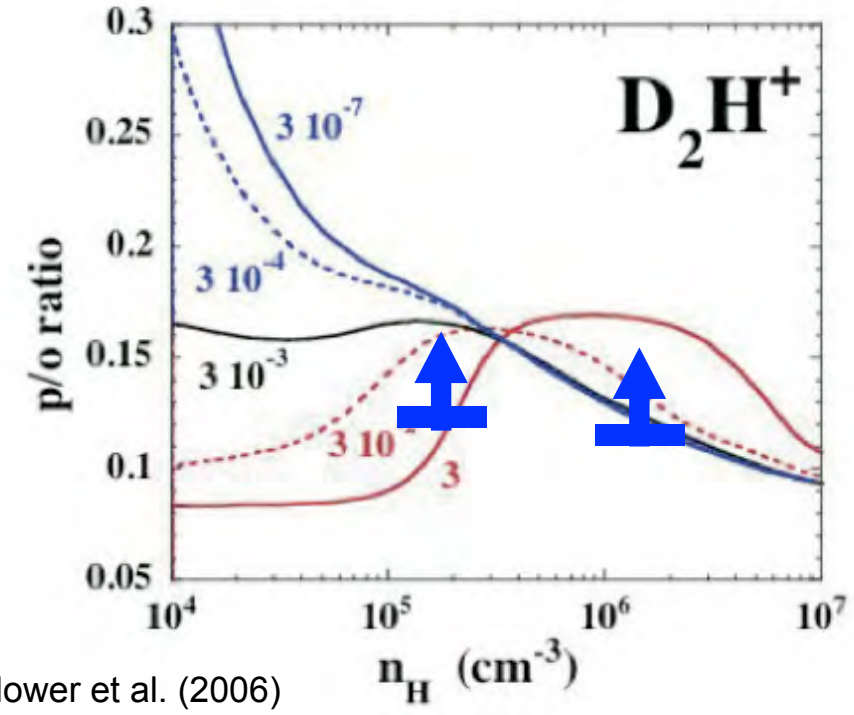
Collisional rates: Hugo et al. (2009)







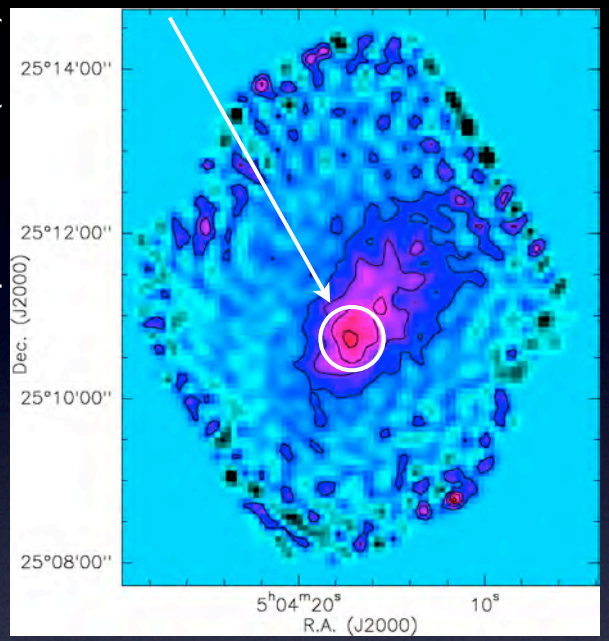




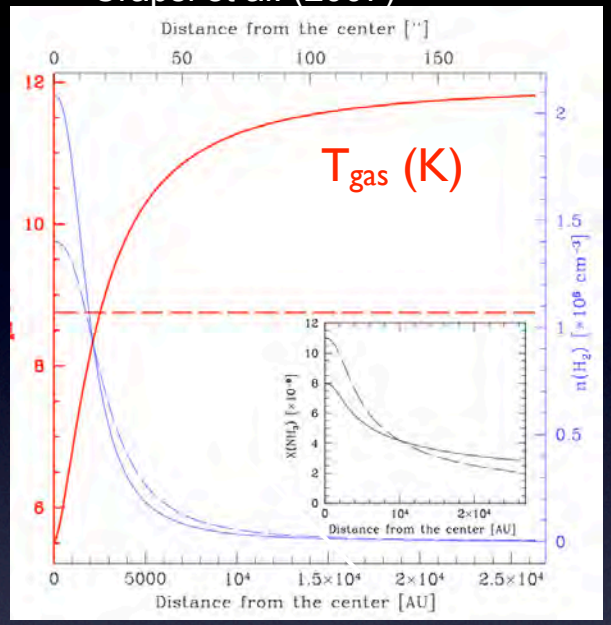
Flower et al. (2006)

Source : L1544

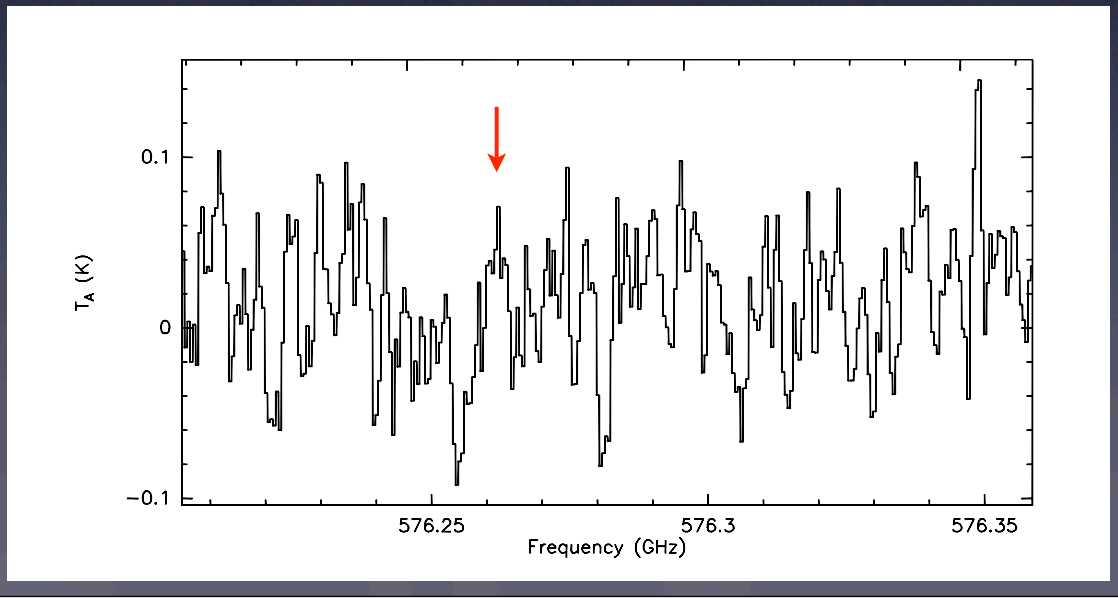
HIFI beam at ~550 GHz



Crapsi et al. (2007)



"typical" prestellar core

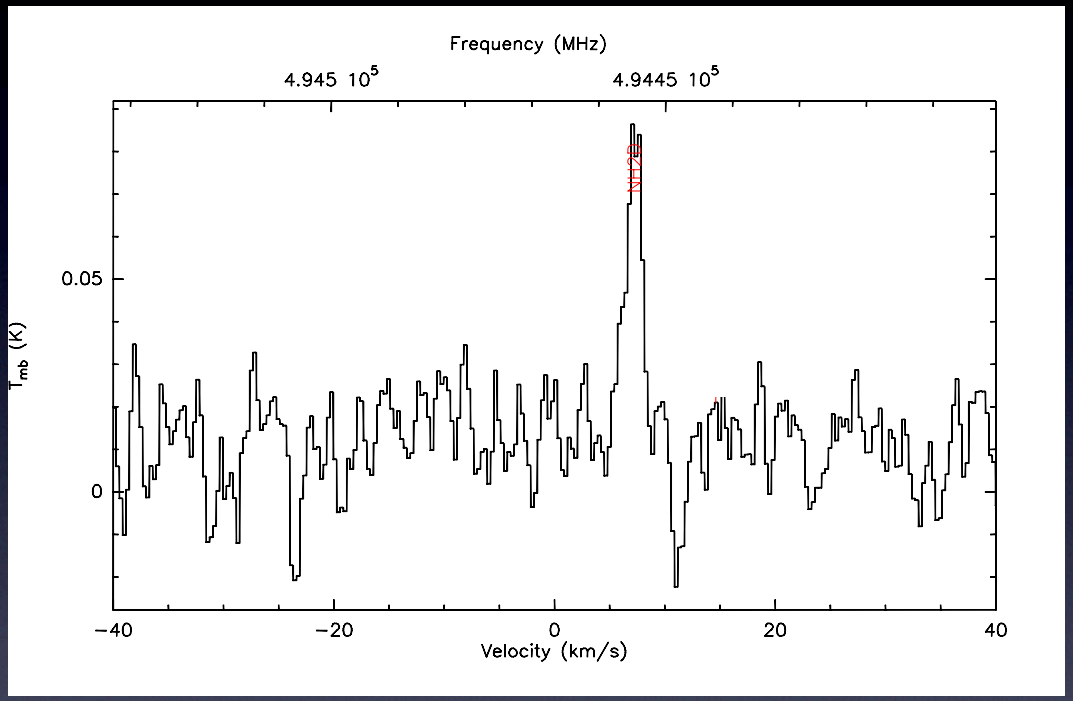


No detection of $^{12}CO(5\text{-}4)$

LVG Modelling
(Radex, van der Tak et al. 2007)

CO depleted at densities > 5 10^3 cm^{-3}

Ammonia in L1544



Detection of NH_2D
@ 494 GHz

+ Detection of NH_3
@ 572 GHz
(WISH KP)

high critical density transitions

10^7 - 10^8 cm^{-3}

traces core centre

Conclusions

- CHESS: Spectral survey of Band 1 in 16293E + o-D_2H^+, dedicated lines in L1544
- only simple molecules detected: hydrides, CO
- high abundance of deuterated molecules: indication for cold chemistry
- models can reproduce deuterium fractionation in NH and NH abundance: dominant route to form NH via N_2H^+, ND via N_2D^+
- need for a comprehensive model including NH_3 and NH_2D, accounting for both D_2H^+ and N hydrides observations

CHESS posters

- Herschel-PACS full spectral range spectrum of the B1 shock in the L1157 outflow: Gemma Busquet
- Where is Chlorine? The missing HCL emission in the protostellar shock L1157-B1: Claudio Codella
- Peering into the protostellar shock L1157-B1: Bertrand LeFloch
- The Herschel-CHESS unbiased search for N-bearing species in the chemically rich outflow L1157: Magda Vasta

- Study of deuterated water in the low-mass protostar IRAS16293-2422: Audrey Coutens
- Herschel CHESS search of ozone and molecular oxygen in the solar type protostar IRAS16293-2422: Vianney Taquet

- The HIFI spectral survey of the protostar OMC2-FIR4: Mihkel Kama
- Detection of OH+, H2O+ and HF towards the intermediate-mass protostar OMC-2 FIR4: Ana Lopez-Sepulcre

- CHESS observations of high-mass protostellar object AFGL 2591: Maja Kazmierczak