Deuterium Fractionation in Massive Star Forming Clumps in Infrared Dark Clouds

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in collaboration with
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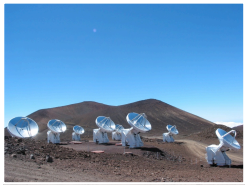
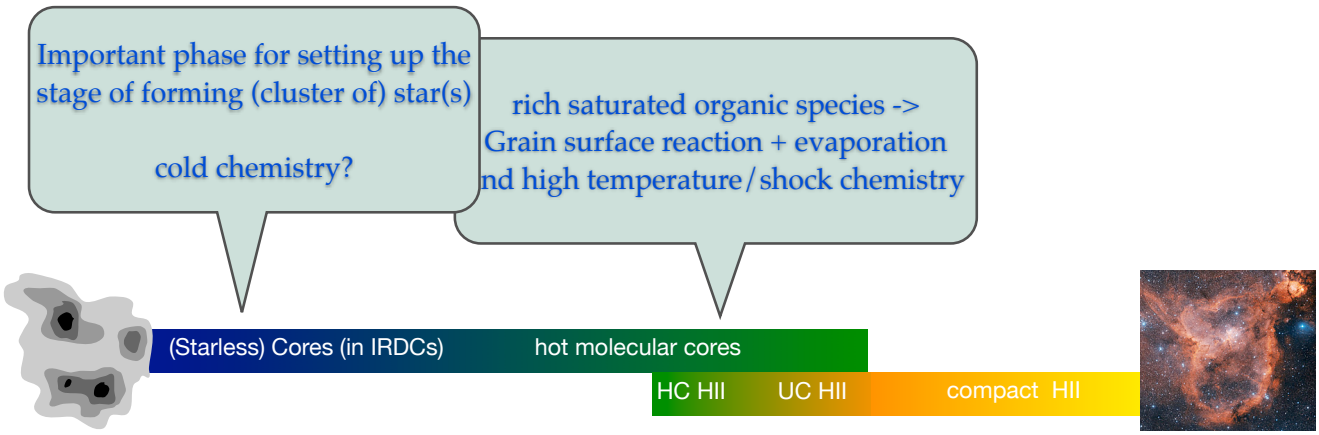


Massive Star Formation



$n(H_2) \sim 10^2$ cm^{-3} $n(H_2) \sim 10^{4\text{-}5}$ cm^{-3} $n(H_2) \sim 10^{5\text{-}7}$ cm^{-3}

$M \sim 10^5$ Msun T~10-20 K T>100K

$L > 10^3$ L_{sun}

(Courtesy of J. Rathborne)

Cold Dense Cores and Deuterium Fractionation

- Deuterium fractionation -

gas phase	grain surface
e.g. Roberts and Millar (2000, 2005)	e.g. Tielens (1983)
$H_3^+ + HD \leftrightarrow H_2D^+ + H_2 + \Delta E$	enhanced atomic D/H ratio (adsorbed from gas phase) + lower activation barriers in reactions involving D
root reaction that propagates D to other molecules, While CO being the main destroyer of H_2D^+	

common required/favored condition : low temperature + (CO) depletion

- often observed XD/XH >> [D]/[H] ~ a few $x10^{-5}$
- may be used as an indication of gas thermal history

deuterium fractionation in low mass star forming cores

- Examples of deuterium fractionation
  - D_2CO/H_2CO [(~0.003 in Orion (Turner 1990), ~0.05 in IRAS 16293 (Ceccarelli et al. 1998)]
  - $DCO^+/H^{13}CO^+$ [(Shah & Wootten 2002)]
  - CH_2DOH, CH_3OD, CHD_2OH, CD_3OH [in IRAS 16293 (Parise et al. 2002, 2004)]
  - ND_2H, ND_3 [in B1, LDN 1544, LDN 1689N (Lis et al. 2002, 2006)]
- Deuterium fractionation and star formation history/stages (N_2D^+ v.s. N_2H^+ often used)

prestellar cores —evolution→ protostellar cores (class 0, class I)

increasing central concentration
increasing CO depletion $f_D(CO)$
increasing infall linewidth/profile asymmetry
increasing deuterium fractionation ratio

increasing (dust) temperature
decreasing CO depletion $f_D(CO)$
decreasing deuterium fractionation ratio

DEUTERIUM FRACTIONATION IN LOW MASS STAR FORMING CORES

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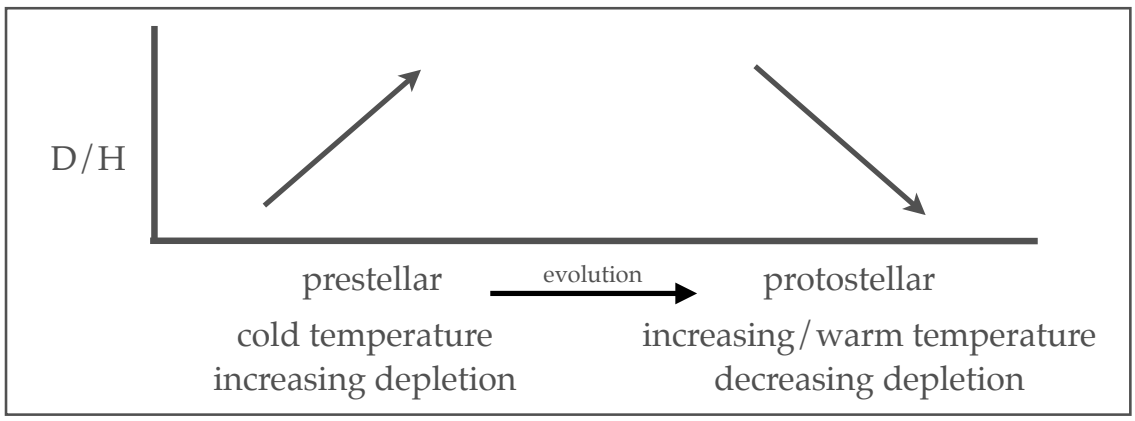

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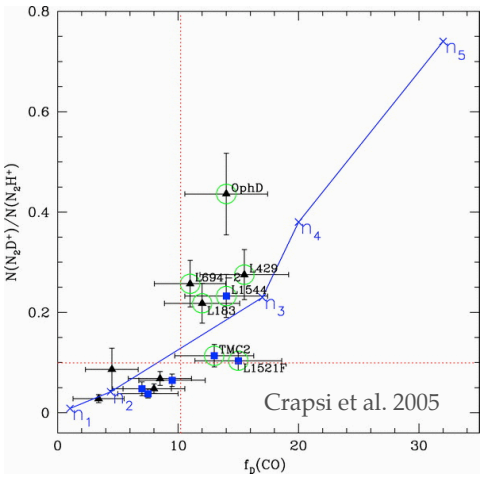
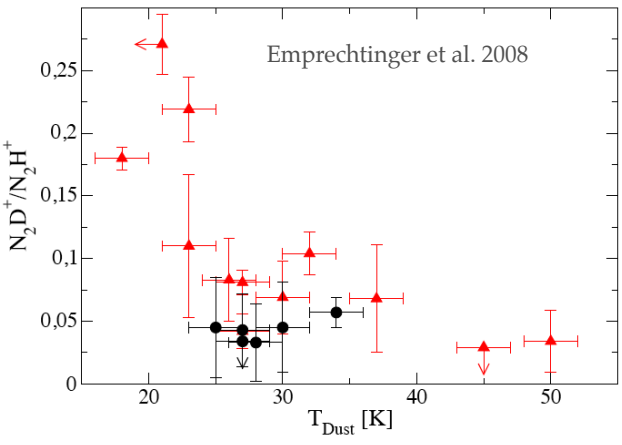
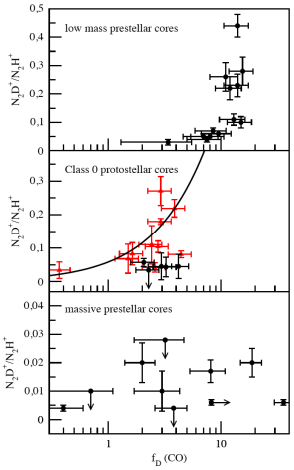


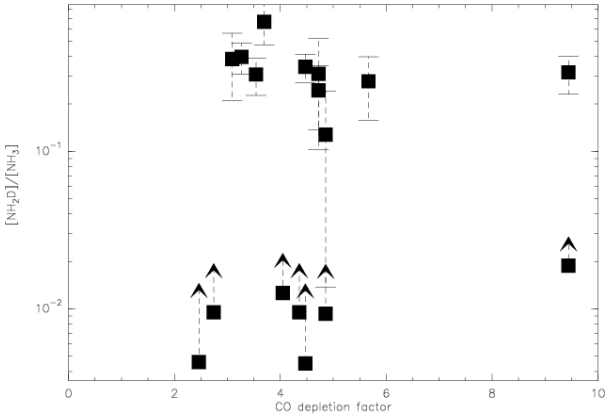


DEUTERIUM FRACTIONATION IN MASSIVE STAR FORMING CORES/CLUMPS

- Massive star forming regions?
  - Enhanced deuterium fractionation (D/H ratios) were also found (e.g. Hatchell et al. 1998, 1999; Fontani et al. 2006; Pillai et al. 2007)
  - typical range (a few % to 10s%)
  - No clear correlation found in D/H with physical parameters so far, but an underlying correlation was not ruled out

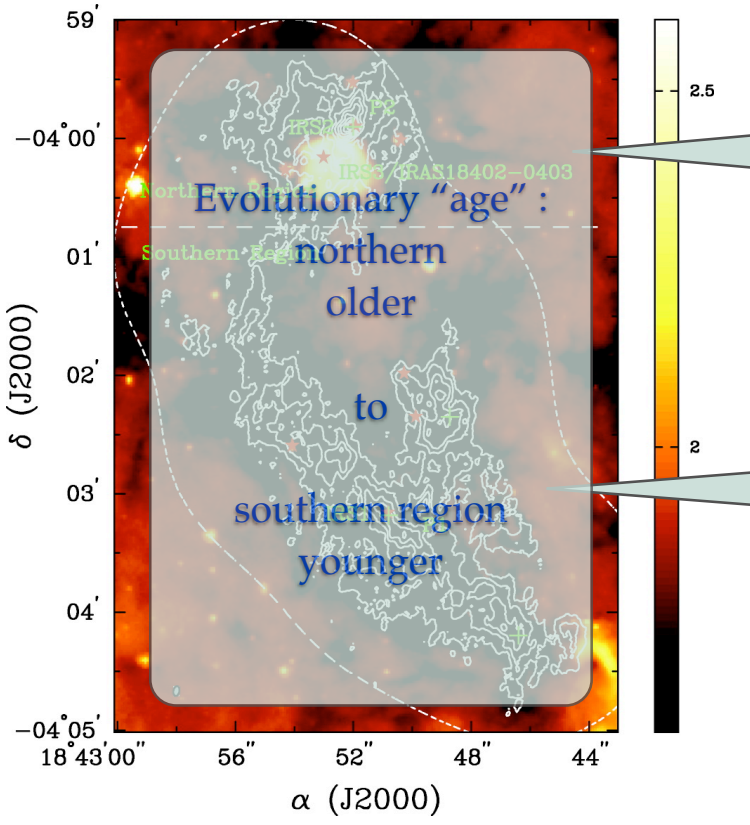


Emprechtinger et al. 2008 / Fantani et al. 2006



Pillai et al. 2007

CASE STUDY WITH SMT: IRDC G28.34+0.06



- D ~ 4.8 kpc (beam ~ 0.5pc)

Northern Region :
IRS 3; IRAS 18402-0403; 10^3 L_{sun};
associated with UCHII region
IRS 2; dust cont. P2; 10^3 L_{sun};
associated with NH_3, H_2O maser

NH_3 with VLA(+ 100M)
P2 with T_K ~ 30K
linewidth > 3 km/s

Southern Region :
IRS 1; dust cont. P1; 10^2 L_{sun};
associated with NH_3, H_2O maser

NH_3 with VLA(+ 100M)
P1 with T_K ~ 20K
linewidth ~ 1.8 km/s

(Wang et al. 2008)

Case Study with SMT: IRDC G28.34+0.06

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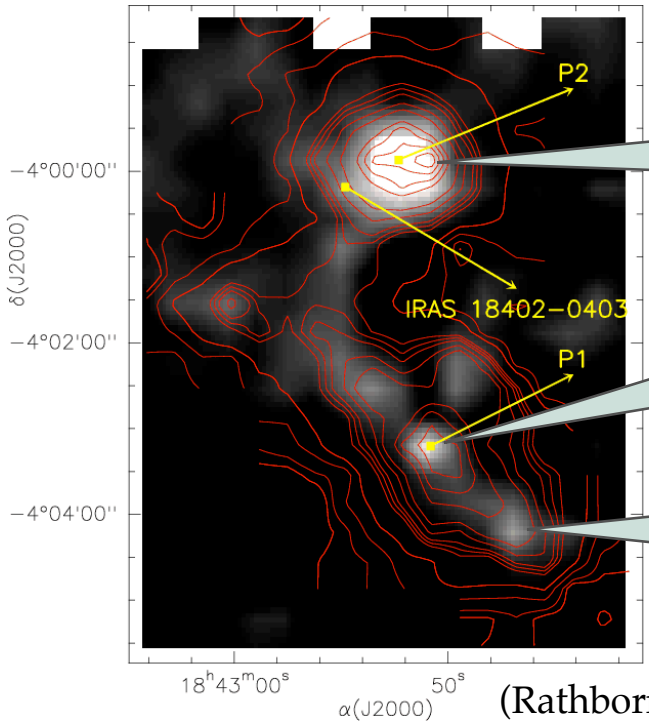


P2; a.k.a MM1
T_K~ 16 K (NH_3)

P1; a.k.a MM4
T_K~ 17 K (NH_3)

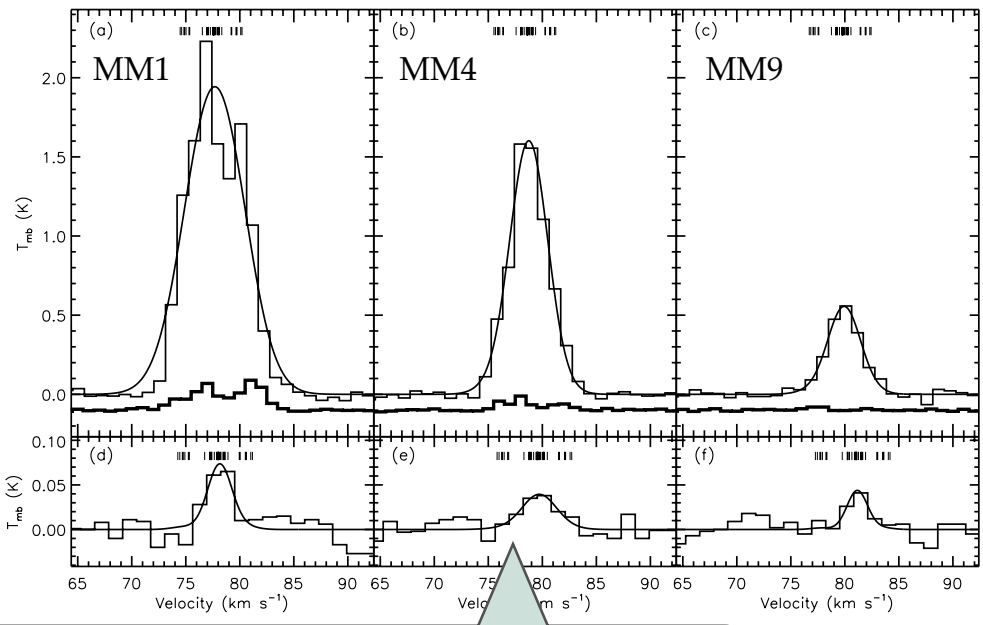
P3; a.k.a MM9
T_K~ 13 K (NH_3)

(Rathborn & Jackson 2006; Pillai et al. 2006)

Case Study with SMT: IRDC G28.34+0.06

N_2H^+ (3-2)

N_2D^+ (3-2)

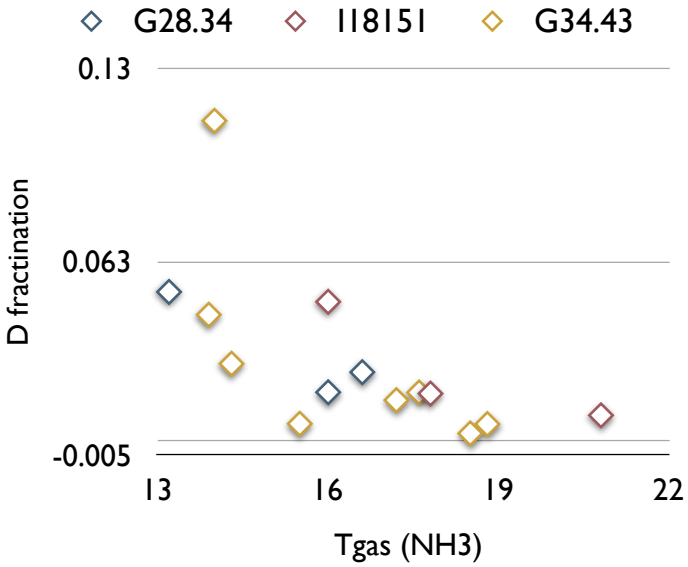


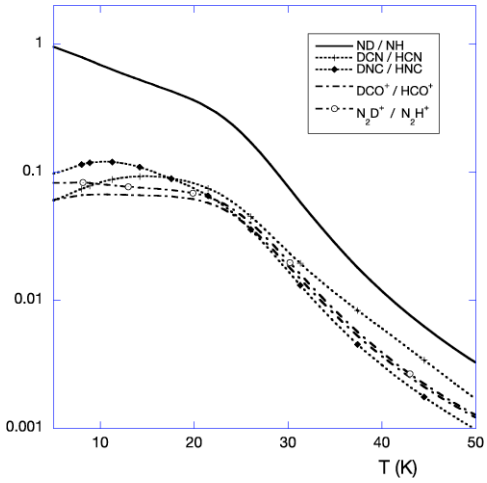
D/H : 0.016 (MM1) < 0.023 (MM4) < 0.051 (MM9)

Large enhancement of D/H as seen in other massive SF regions
Moderate decreasing trend from MM9, MM4, to MM1

(Chen et al. 2010)

Correlation with any physical parameter??



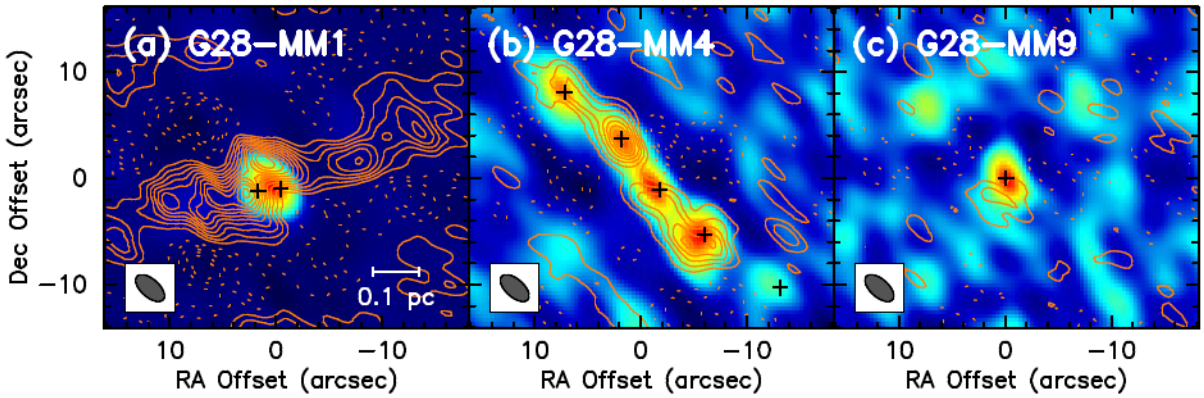


Roueff et al. 2005

- telling? or fortuitous given that
  - N_2H^+, N_2D^+ and NH_3 are assumed to coexist in LTE
  - the temperature is averaged over the beam area
- need to spatially resolve the emission

Study with interferometers

- Examples include :
  - Fontani et al. (2008) : $N_2D^+/N_2H^+ \sim 0.1$ in IRAS 05345+3157
  - Busquet et al. (2010) : $NH_2D/NH_3 \sim 0.1$-0.8 in IRAS 20293+3952
  - Chen et al. (2010) : N_2H^+,N_2D^+ in G28.34+0.06 with SMA

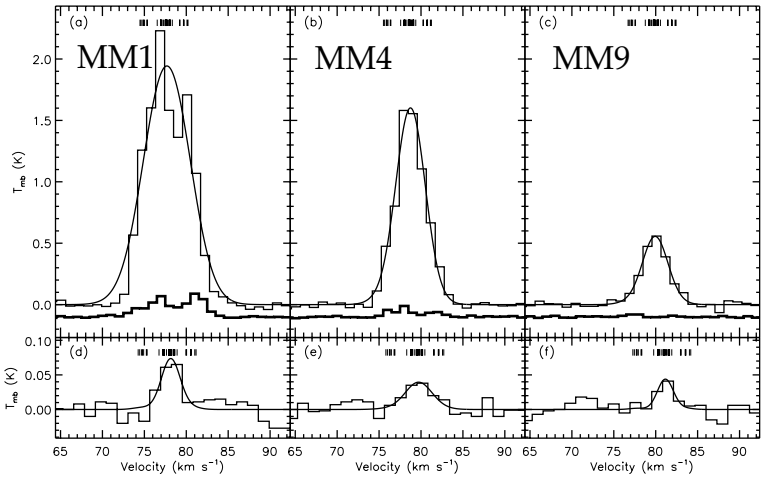


- N_2H^+ emission in avoidance of dust continuum and ^{13}CO emission, indicative of heating and evaporation of CO in the (hot) dust core
- N_2D^+ not detected/imaged by the SMA

Study with interferometers

- Chen et al. (2010) : N_2H^+ in G28.34+0.06 with SMA

N_2H^+ (3-2)



  - Most N_2H^+ emission as well as N_2D^+ emission are extended, indicative of (clumpy) dense cold gas at larger scale

Summary

- A significant enhancement of D/H ratios via N_2H^+/N_2D^+ observations are detected and a moderate decreasing trend of D/H are found to correlates with the (averaged) gas temperature in massive dense molecular clumps. This is resembling the case in low mass protostellar studies, and could probably be resulted from evolutionary effects.
- Future sensitivity high angular resolution observations in [N_2H^+,N_2D^+] (or other deuterated species) with ALMA will help to spatially resolve and further refine the D/H variation in massive star forming regions from clump down to core scales.