deuterium fractionation in a cluster-forming dense core

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low-mass star-forming cores

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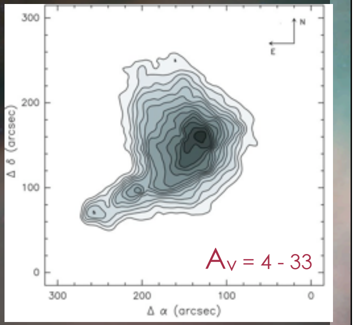
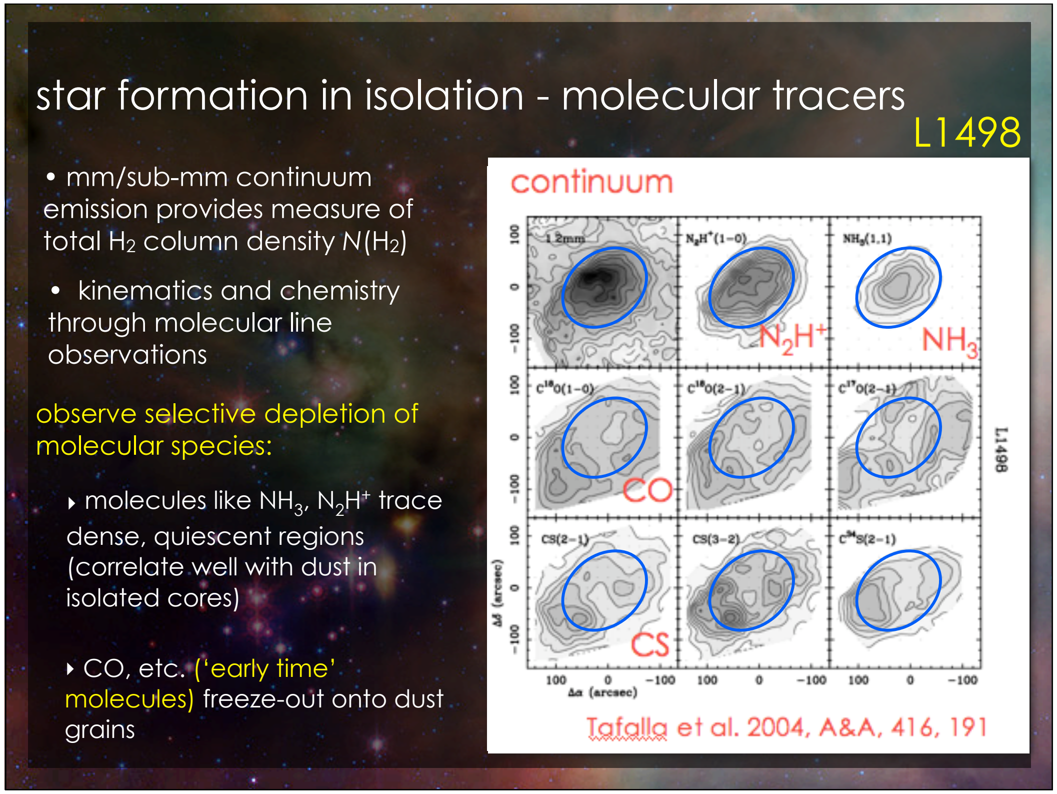
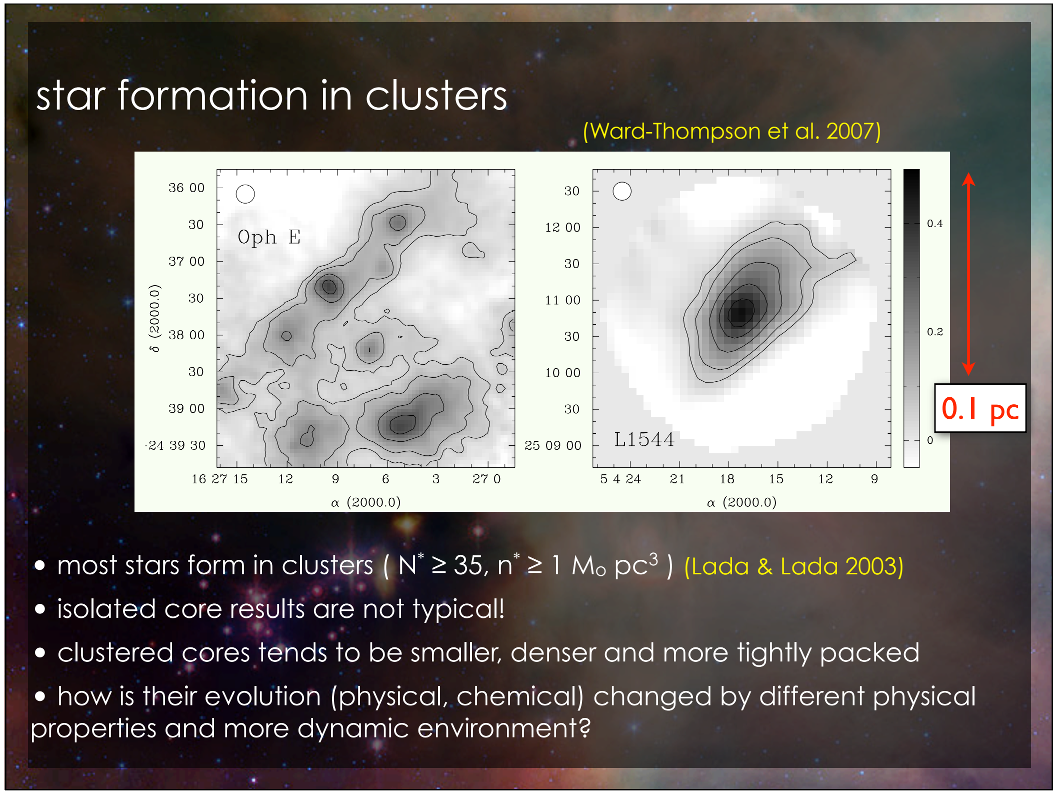


Alves et al. 2001

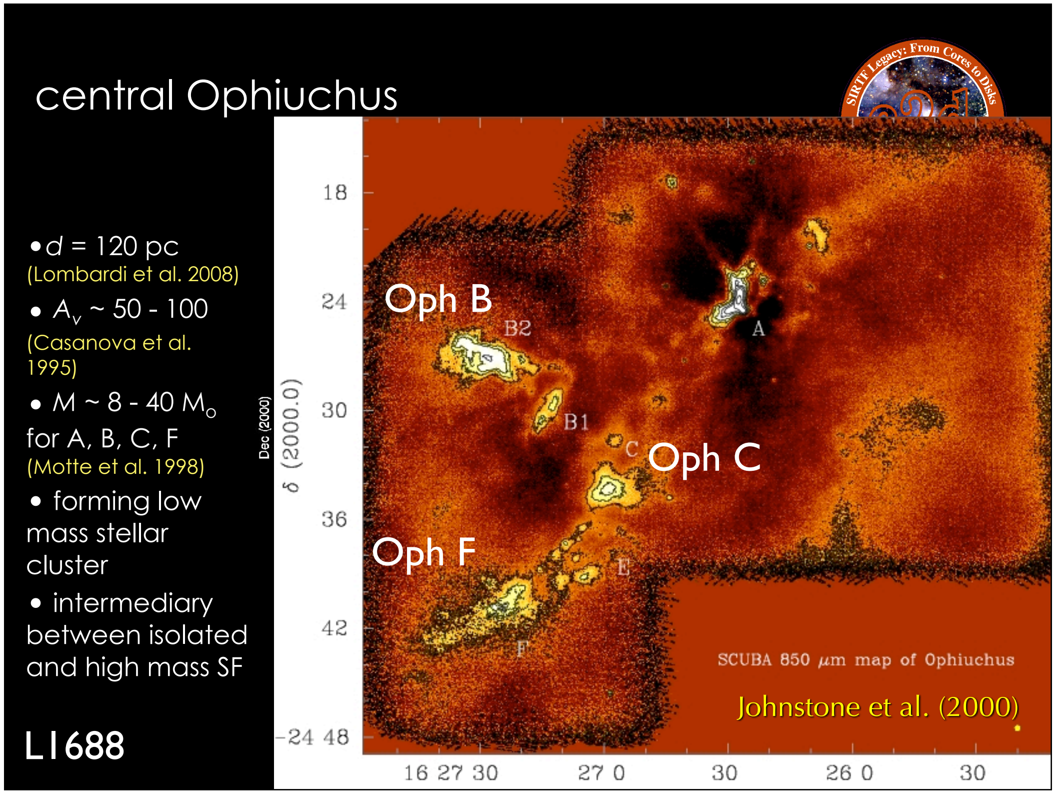
- dense cores of interstellar gas are the formation sites of stars in nearby molecular clouds
- isolated cores characterized by n ~ 10^4 cm^{-3}, d ~ 0.1 pc, T ~ 10 K
- relatively simple structure characterized by (sub) millimeter dust continuum or extinction measurements



- this has been presented yesterday, so just to reiterate - N2H+, NH3 tend to trace continuum emission, quiescent regions well; CO and C-bearing molecules deplete onto dust grains

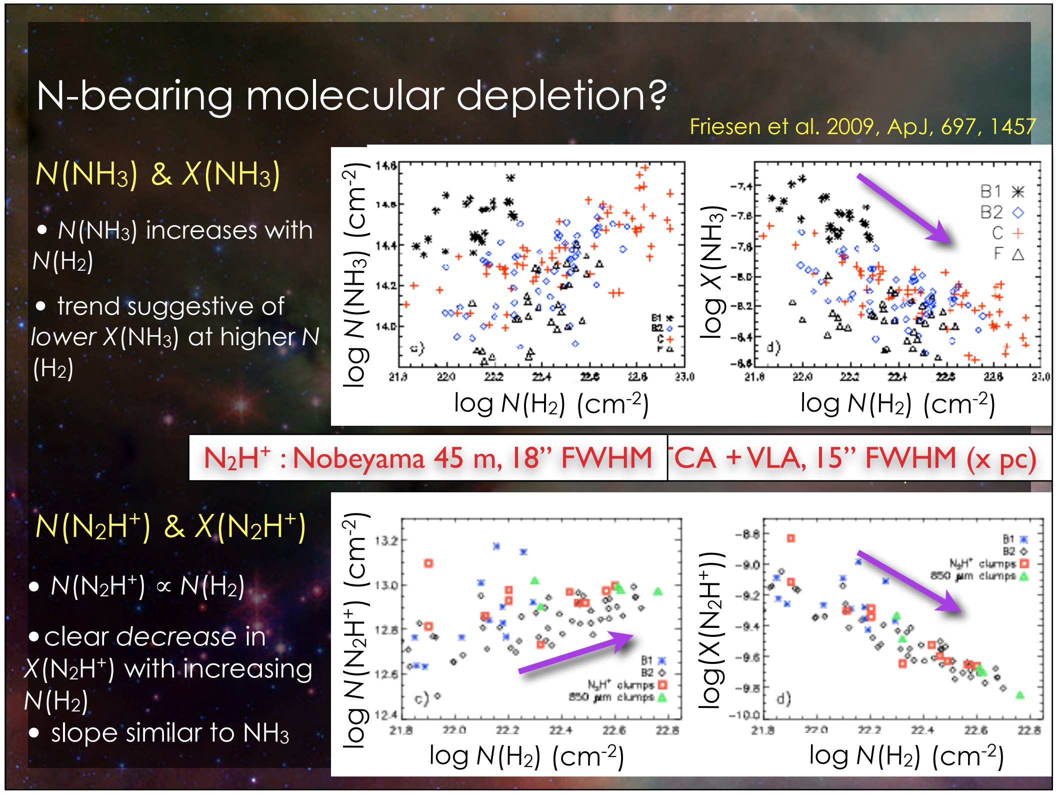


it has also been noted that most stars form in clusters, so these isolated results are not typical. clustered cores tends to be smaller, denser and more tightly packed. we need to think about how their evolution (physical, chemical) is changed by their different physical properties and their more dynamic environment



to begin to answer this question, we looked at NH3 and N2H+ emission in the Ophiuchus molecular cloud

- properties
- nearby cloud forming a low mass stellar cluster - an intermediary between isolated low mass star formation and more distant, more massive clustered star formation



- we mapped NH3 at the GBT, ATCA and VLA towards three Oph cores.. da da da
- similarly, N2H+ mapped at the Nobeyama 45 m telescope towards Oph B only showed...

high density probe: deuterated species

- need better molecules to trace the high density gas in more complicated cores

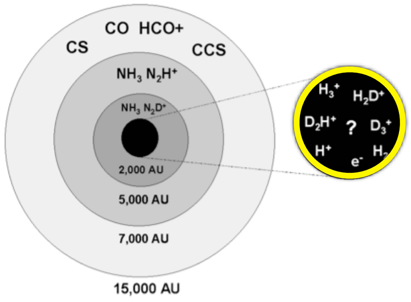
Deuterium fractionation in dense cores initiated by the reaction

$$H_3^+ + HD \leftrightarrow H_2D^+ + H_2 + \Delta E$$

$$\Delta E = 230 \text{ K}$$

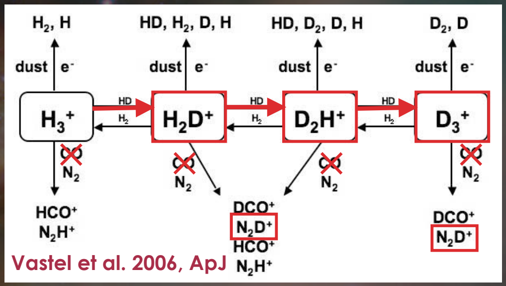
- low energy barrier: reaction proceeds in both directions unless $T \leq 20$ K
- expect deuterated species to selectively trace conditions at high n, low T

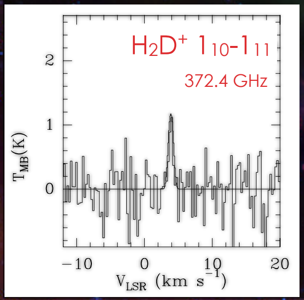
Di Francesco et al. (2007)



deuterium fractionation at low temperatures

- $H_3^+ \rightarrow H_2D^+$ at low *T*
- depletion of CO limits destruction pathway
- mechanism to propagate deuteration to other molecular species, i.e $N_2H^+ \rightarrow N_2D^+$

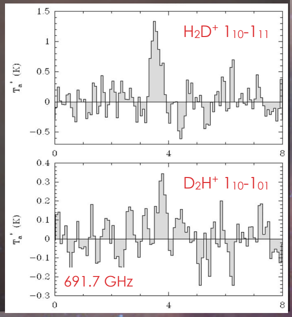




- resulting deuterium fractionation of a molecule orders of magnitude > ISM $[D]/[H] \sim 10^{-5}$

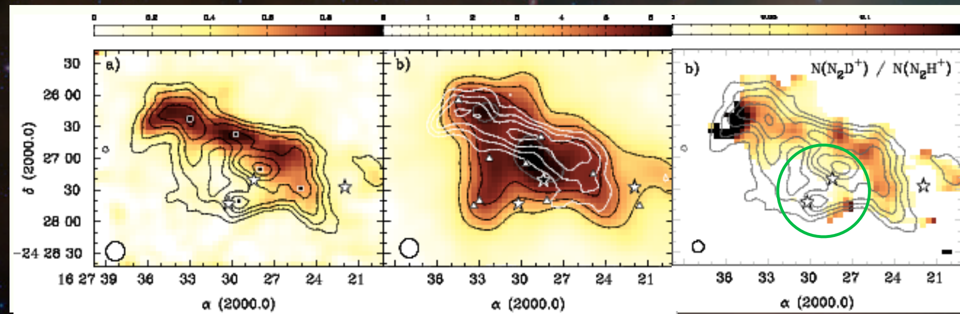
ie. $X(H_2D^+)/X(H_3^+)$

Stark et al. 2004, ApJ



Vastel et al. 2004, ApJ

deuterium fractionation in Oph B2: N_2D^+



N_2D^+ 3-2 @ 231.321 GHz, IRAM 30 m
850 μm contours

integrated intensity
contours over N_2H^+

$R_D = N(N_2D^+)/N(N_2H^+)$
(assume same T_{ex})

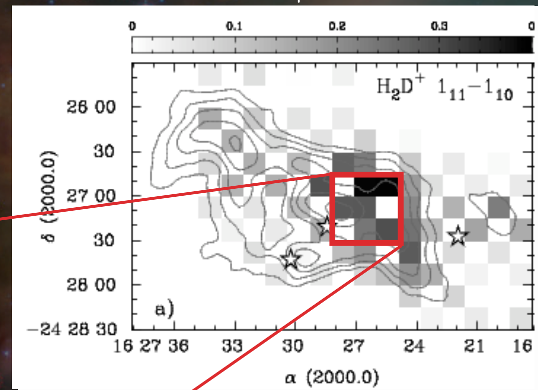
- extensive N_2D^+ emission, small scale features with enhanced R_D
- average R_D ~ 0.03 - low end of observed range in starless cores, still large compared with interstellar D/H
- avoids entirely embedded protostars
- not abundant at continuum peak

Friesen et al. 2010b, ApJ, 718, 666

deuterium fractionation in Oph B2: H_2D^+

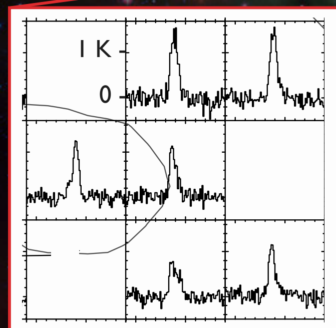
- o-H_2D^+ 1_{10} - 1_{11} (372.4 GHz) lies at the edge of an atmospheric water line - requires very low pwv
- JCMT HARP - 4 footprints of 4 x 4 pixels across Oph B2
- find similar distribution to N_2D^+ 3-2

850 μm continuum contours

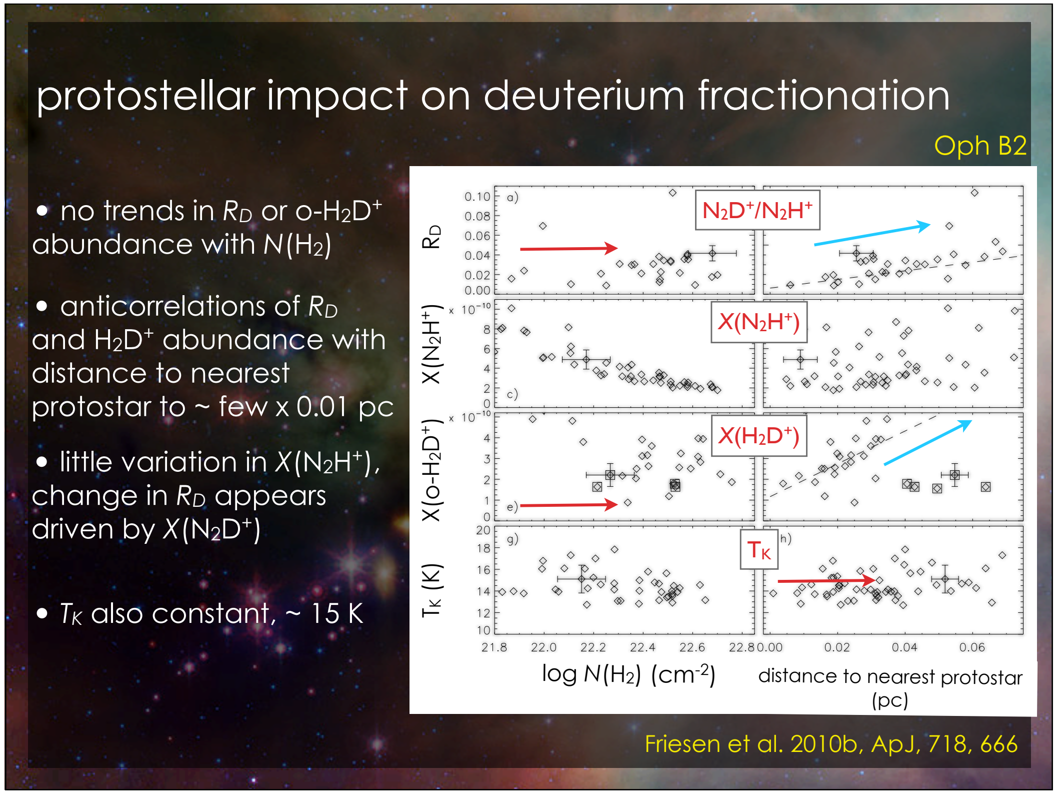


Friesen et al. 2010b, ApJ, 718, 666

integrated o-H_2D^+ intensity



sample of line profile variations,
transsonic line widths

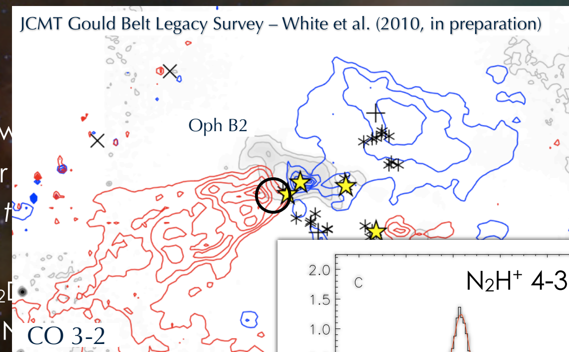


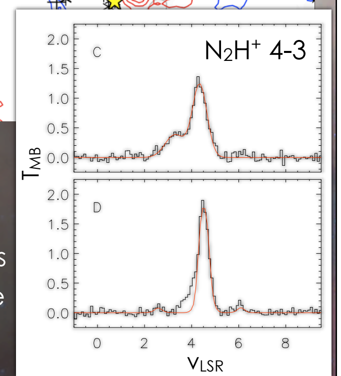
to quantify trends in deuterium fractionation, H2D+ abundance

protostellar impact on deuterium fractionation

ways to reduce R_D

- Heating of gas to T > 20 K
  - $H_3^+ + HD \leftrightarrow H_2D^+ + H_2 + \Delta E$ now
  - limits production of H_2D^+, other
  - **but** T_K < 20 K across Oph B2 as t
- Heating of dust to T > 18 K
  - CO evaporates, reacts with H_2D
  - T as above, also should see N(N
- Outflows
  - CO evaporated close to star, mixed into core gas
  - or, shocks locally heat grains, liberate CO
  - some evidence for impact of outflow on dense gas
  - analysis of CO/shock tracers needed to investigate
- Increased ionization from YSOs?
  - little evidence for increased X_e in literature





deuterium fractionation: ionization

- In absence of CO, deuterated molecular abundances can be depressed by greater electron fraction (Caselli et al. 2008)

x-rays from young protostars

- ROSAT observations of Oph B protostars find L_x = 30.7, 29.2 erg s^{-1} (Casanova et al. 1995)
- at a few x 0.01 pc and n ~ 10^5 cm^{-3}, this is sufficient to increase x(e) beyond cosmic ray value (following Silk & Norman 1983)

directly measuring x(e)

- x(e) determined usually with HCO^+, DCO^+; t
use N_2H^+ and N_2D^+ instead, i.e.:

  - x(e) > X(N_2H^+) + X(N_2D^+) + X(H_3^+) + X(H_2D^+)

ALMA: will enable high-resolution data of N_2H^+, N_2D^+ (many lines!) and H_2D^+ at 372 GHz
ALMA will also observe D_2H^+ at 692 GHz

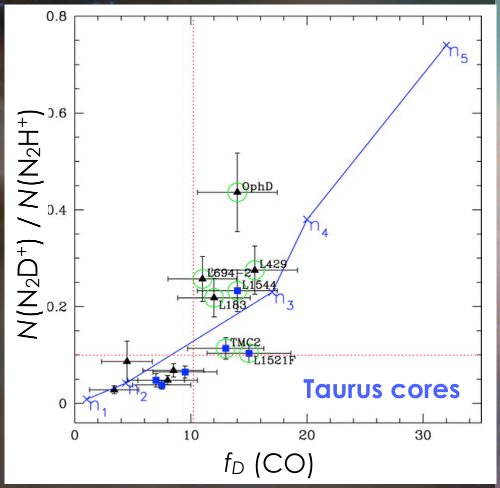
caveats: o/p H_2D^+ ratio, multiply-deuterated H_2D^+

summary

- what are good dense gas tracers in clustered environments?
  - large-scale depletion can occur, even of ‘late type’ molecules such as NH_3 and N_2H^+
  - distribution of species not simple
  - appears dependent on local environment
- in particular, deuterium fractionation in molecules can be significantly impacted by protostars - even in low mass environments. What is the dominant mechanism?
- in clustered environments, high resolution/wide-field data will be needed
- ALMA - wealth of cold chemistry species visible, “will observe the molecular ring like Taurus and Orion” - and Ophiuchus

deuteration surveys

- large-scale studies are lacking for low T, high n deuteration
- results of smaller surveys suggest environmental impact on measured trends
- SMT/12m study: pointed survey of N_2D^+/N_2H^+ towards a large sample of cores in Taurus (~30) & Perseus (~65) + Kirk, Shirley, ++
- complimentary to COMPLETE data, NH_2D/NH_3 survey (Shirley+)
- will probe deuteration in starless/ protostellar cores & isolated/ clustered environments, evolutionary status



Crapsi et al. 2005, ApJ

f_D = integrated CO depletion factor

spherical models of increasing central concentration