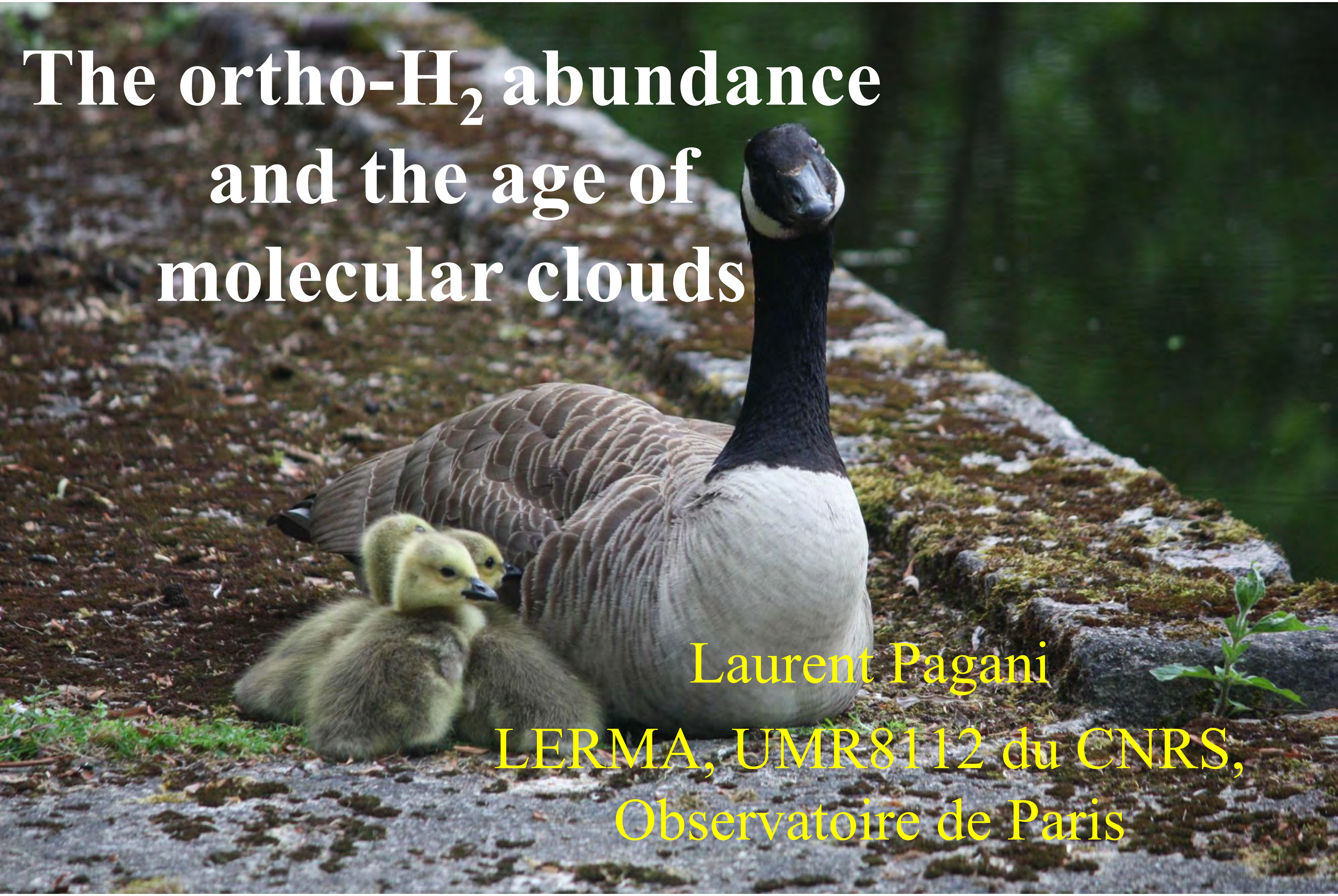
The ortho-H_2 abundance and the age of molecular clouds



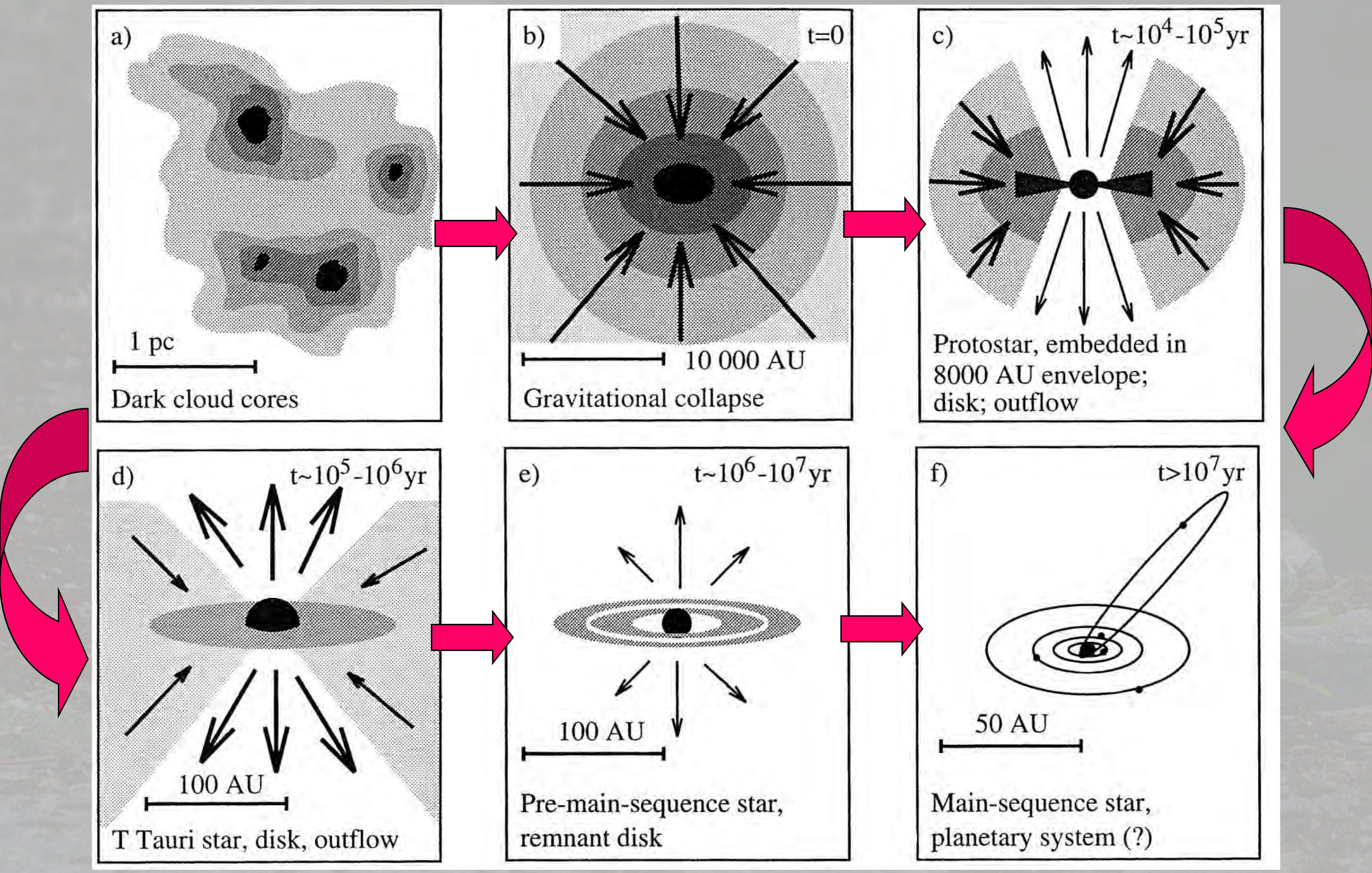
Laurent Pagani

LERMA, UMR8112 du CNRS,
Observatoire de Paris

This talk :

- Low mass star formation
- Ortho-H_2 :
  - its role in deuteration control
  - formation and destruction
- Deuteration amplification needs CO depletion – a myth ?
- How old is a cold cloud ?

Low mass star formation



Low mass star formation

- Prestellar cores form either slowly:
  - Turbulence dissipation (Nakano 1998)
  - Ambipolar diffusion (Mouschovias 1991, Ciolek & Basu 2000, 2006,...)
- or fast :
  - Supersonic turbulent flows -> local density enhancements (Klessen et al. 2000, Larson 2007, Hennebelle et al. 2007, 2008…)

Ortho H_2 : deuteration control

- $H_3^+ + HD \rightarrow H_2D^+ + H_2 + 232$ K ???

  $pH_3^+ + HD \rightarrow pH_2D^+ + pH_2 + 232$ K

  $pH_3^+ + HD \rightarrow oH_2D^+ + pH_2 + 145$ K

  $pH_3^+ + HD \rightarrow pH_2D^+ + oH_2 + 62$ K

  $pH_3^+ + HD \rightarrow oH_2D^+ + oH_2$ **- 25 K**

  etc.

- $pH_2D^+ + oH_2 \rightarrow oH_2D^+ + pH_2 + 83$ K

ortho - H_2 > 1 % $\Leftrightarrow$ no H_2D^+

Pagani et al. 2009

Ortho H_2 : deuteration control

- $CH_3^+ + HD \rightarrow CH_2D^+ + pH_2 + 375$ K
- $CH_3^+ + HD \rightarrow CH_2D^+ + oH_2 + 205$ K
- $C_2H_2^+ + HD \rightarrow C_2HD^+ + pH_2 + 550$ K
- $C_2H_2^+ + HD \rightarrow C_2HD^+ + oH_2 + 380$ K
- etc.

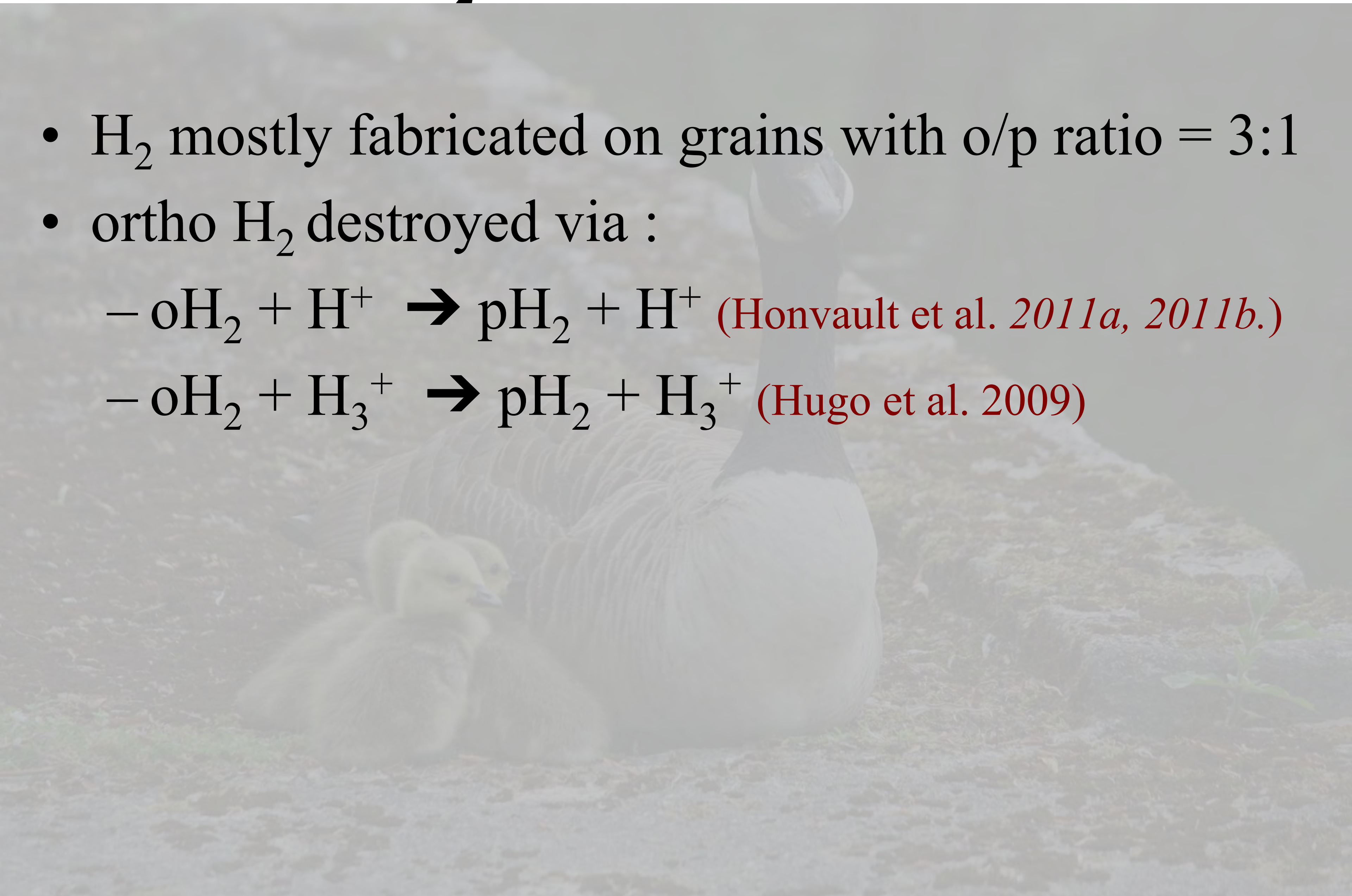
↪ no ortho-H_2 control !

↪ allows deuteration in warm regions (Parise et al. 2009)

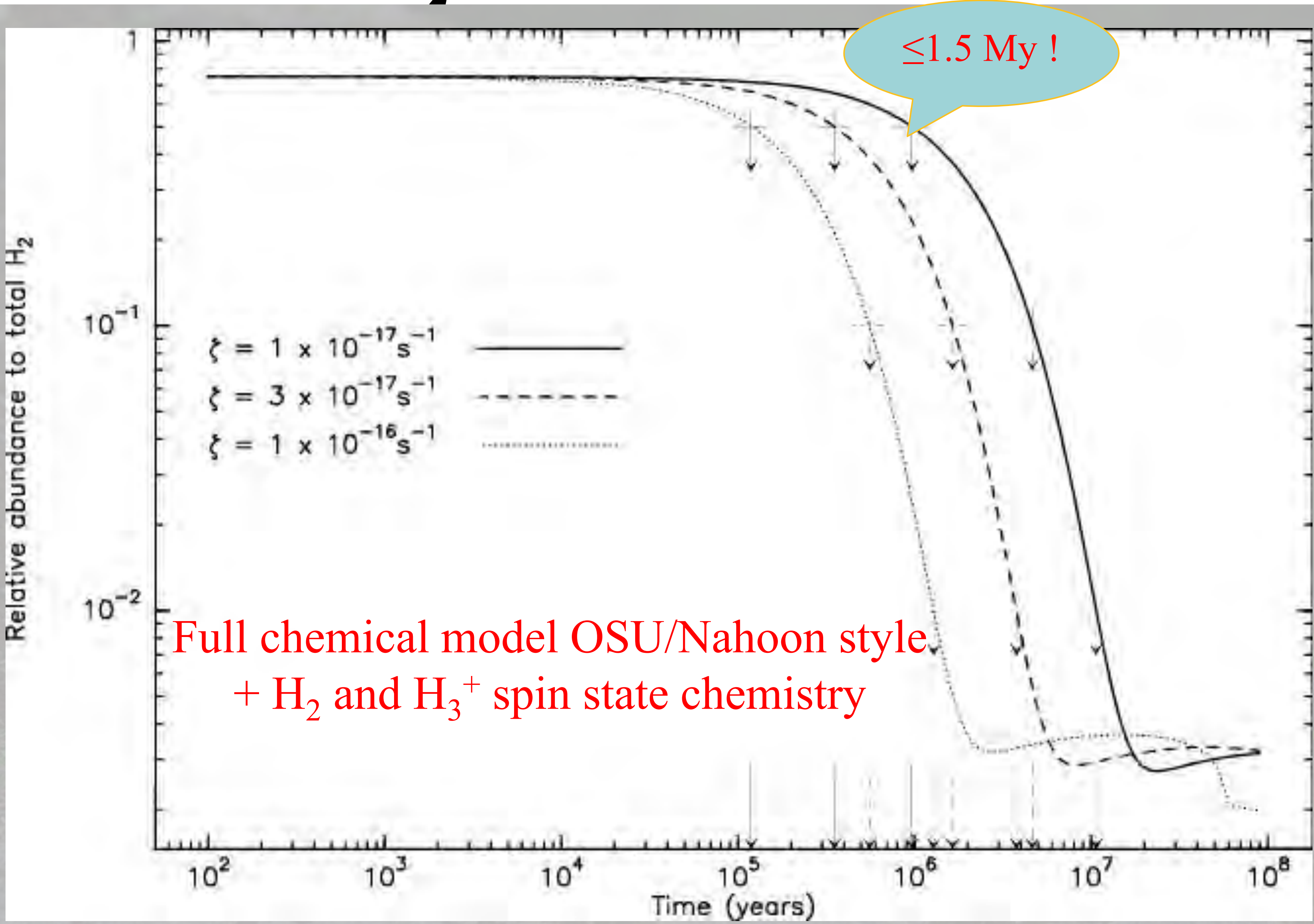
… and in cold regions too!

Ortho H_2 : fabrication/destruction

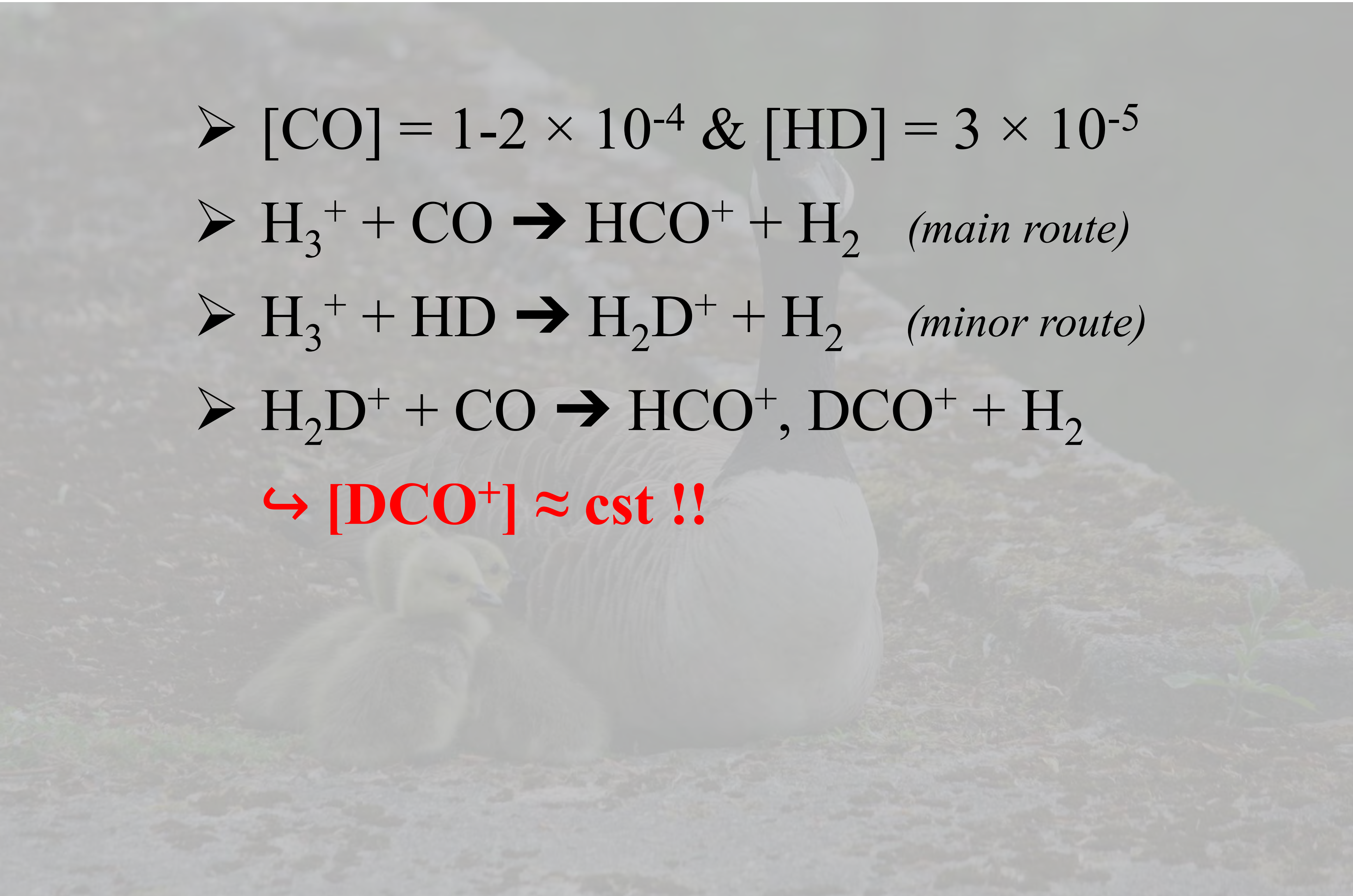
- H_2 mostly fabricated on grains with o/p ratio = 3:1
- ortho H_2 destroyed via :
  - $oH_2 + H^+ \rightarrow pH_2 + H^+$ (Honvault et al. *2011a, 2011b.*)
  - $oH_2 + H_3^+ \rightarrow pH_2 + H_3^+$ (Hugo et al. 2009)



Ortho H_2 : fabrication/destruction



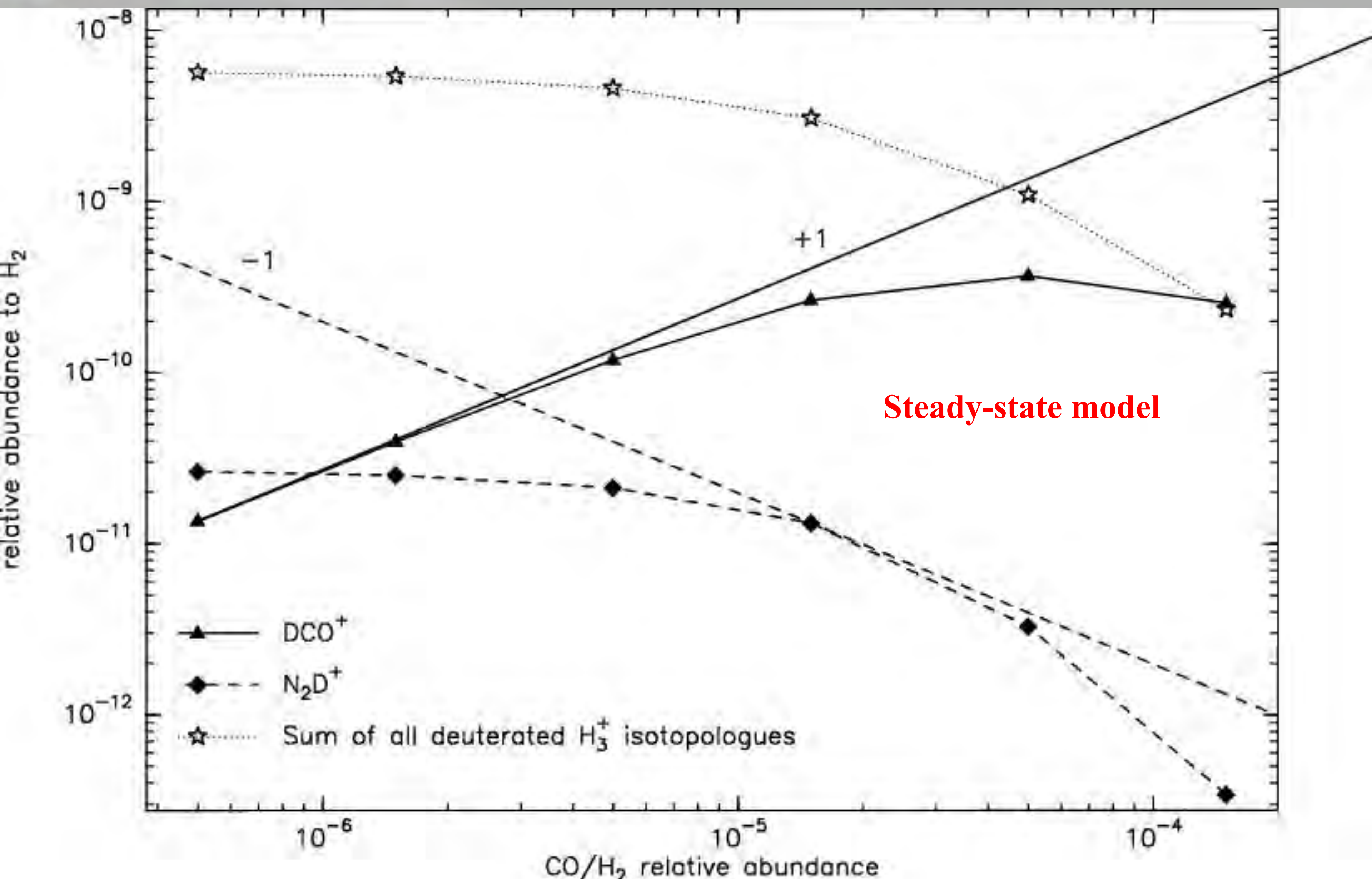
Do we need CO depletion to deuterate ?



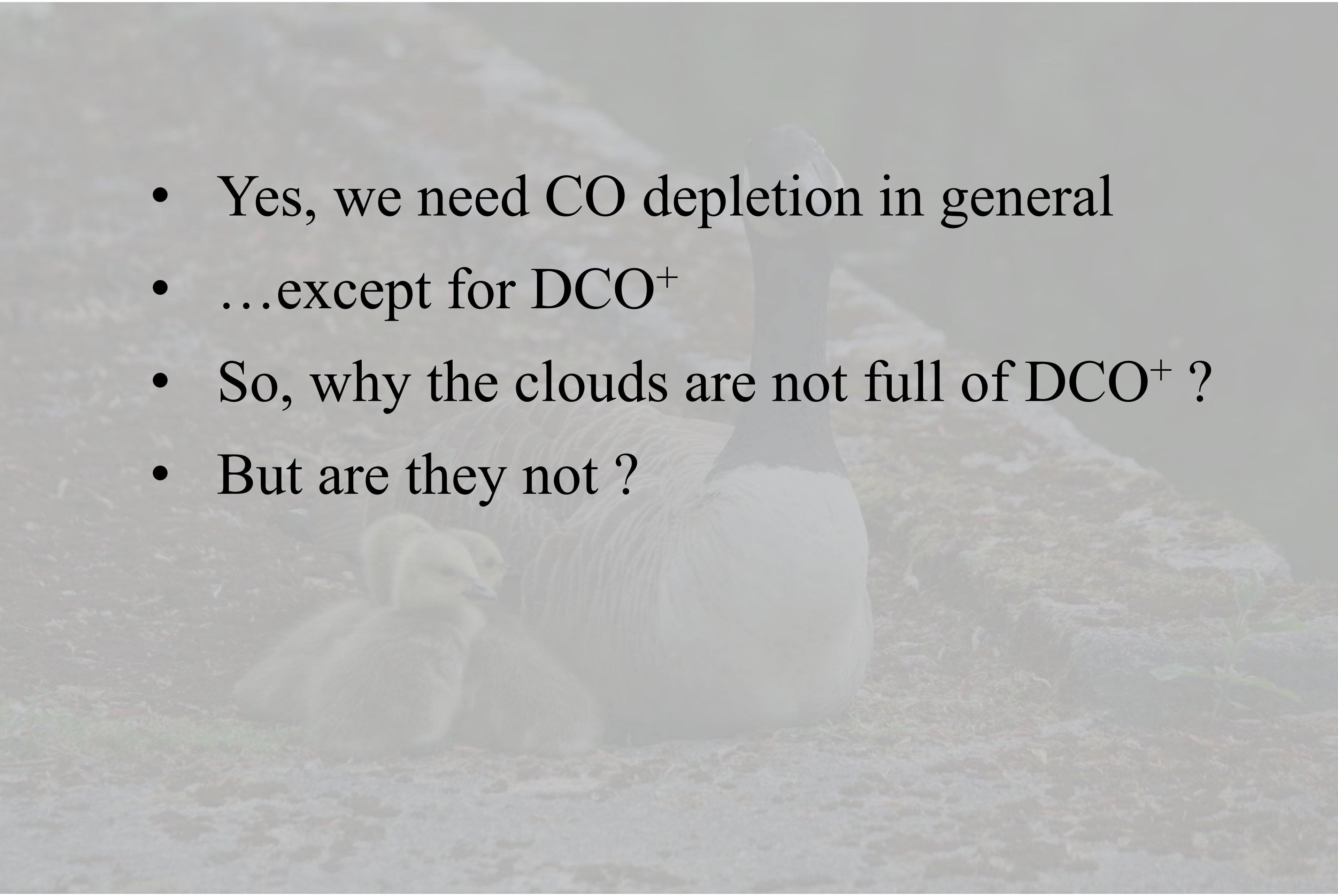
- $[CO] = 1\text{-}2 \times 10^{-4}$ & $[HD] = 3 \times 10^{-5}$
- $H_3^+ + CO \rightarrow HCO^+ + H_2$ *(main route)*
- $H_3^+ + HD \rightarrow H_2D^+ + H_2$ *(minor route)*
- $H_2D^+ + CO \rightarrow HCO^+, DCO^+ + H_2$

↪ **$[DCO^+] \approx$ cst !!**

Do we need CO depletion to deuterate ?



Do we need CO depletion to deuterate ?



- Yes, we need CO depletion in general
- …except for DCO^+
- So, why the clouds are not full of DCO^+ ?
- But are they not ?

Do we need CO depletion to deuterate ?

212 BUTNER, LADA, & LOREN Vol. 448

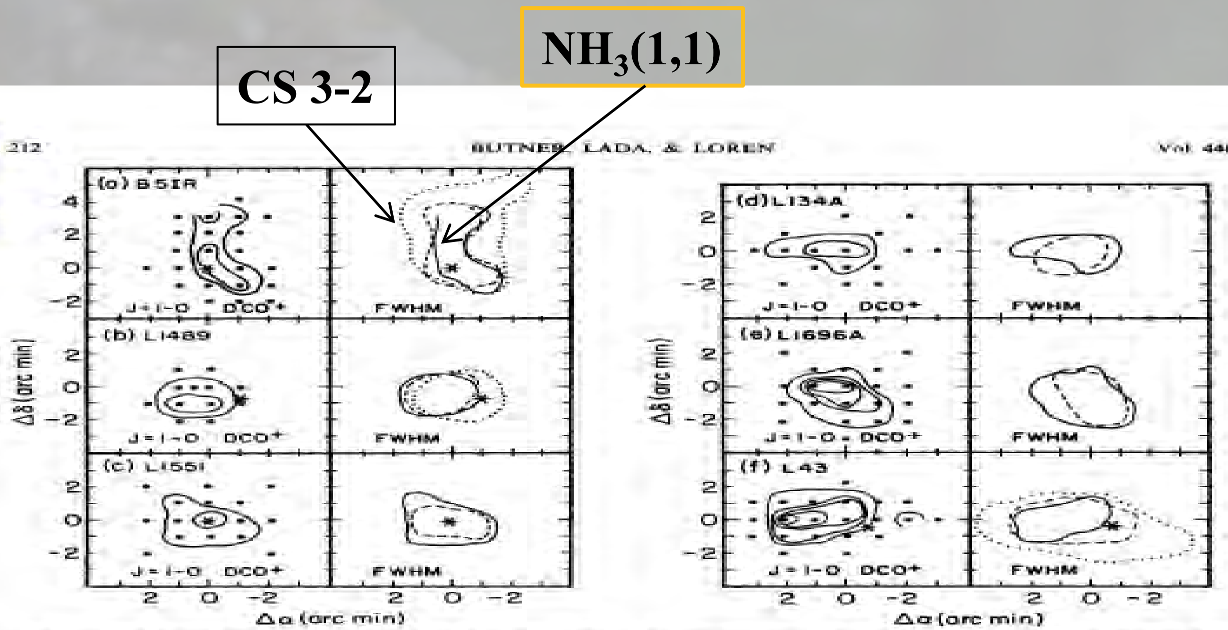


FIG. 2.—(a) The left-hand panel is the contour plot of the DCO^+ map for B5-IR. The lowest contour is 1.2, the steps are 0.5 K. Units are T_R. The right-hand panel is a comparison of the full width half-maximum (FWHM) maps of NH_3 (1,1) (*dashed line*), DCO^+ ($J = 1 \rightarrow 0$) (*solid line*), and CS ($J = 3 \rightarrow 2$) (*dotted line*). The NH_3 map is taken from Benson & Myers (1989), the CS map is taken from Zhou et al. (1989). (b) Same as (a), for L1489. The lowest contour is 2.3 K, steps of 0.7 K. (c) Same as (a), for L1551-IR. The lowest contour is 1.5 K, steps of 0.6 K. (d) Same as (a) for L134A. The lowest contour is 0.9 K, steps of 0.4 K. (e) Same as (a), for L1696A. The lowest contour is 1.4 K, steps of 0.4 K. (f) Same as (a), for L43. The lowest contour is 1.7 K, steps of 0.5 K. (g) Same as (a), for L234A. The lowest contour is 1.5 K, steps of 0.5 K. (h) Same as (a), for L234B. The lowest contour is 1.5 K, steps of 0.5 K. (i) Same as (a), for L1262. The lowest contour is 1.4 K, steps of 0.4 K.

DCO^+ abundance. They found good agreement with the temperature/abundance predictions of Herbst.

Additional reactions suggested by Dalgarno & Lepp (1984) and revised H_3^+ recombination rates (Smith & Adams 1984) have complicated the simple picture developed by Herbst (1982). In addition, our knowledge about possible reaction networks has increased dramatically in the past 10 years. There has also been increased interest in the possible time-dependent variations of molecular abundances (Millar et al. 1988). However, there have been few attempts to incorporate deuterium chemistry in the new reaction models. For this reason, Millar et al. (1989) calculated the expected relative abundance for a number of deuterated molecules over a range of physical conditions, including those found in TMC-1 (cold, $T_k \sim 10$ K; dense, $n \sim 10^4$–10^5 cm^{-3}). They used a reaction network based on the models of Millar, Leung, & Herbst (1987), which describes the chemistry of dense molecular clouds using a pseudo–time-dependent model. In cores with physical conditions similar to TMC-1, Millar et al. (1989) predicted that the DCO^+/HCO^+ ratio should be between 0.02 and 0.05.

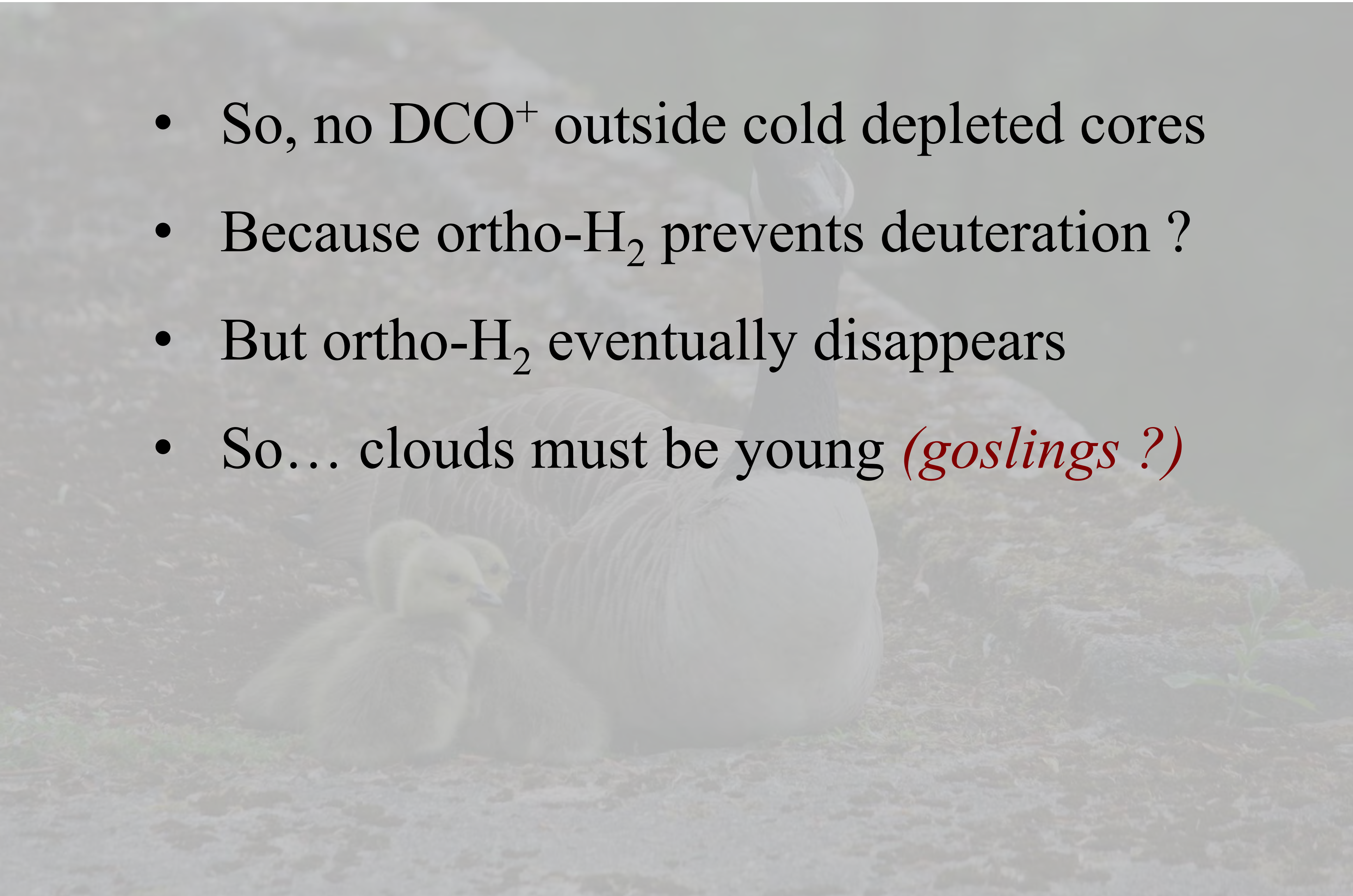
The dense cores identified in the Myers & Benson (1983) NH_3 survey provide an excellent laboratory to measure the amount of deuterium fractionation and thereby to better constrain the chemical models. The cores all have similar density and temperature ($n \sim 10^4$–10^5 cm^{-3}, $T_k \sim 10$–15 K) to TMC-1.

To estimate the DCO^+/HCO^+ ratio, we use the column density derived from the DCO^+ and the $H^{13}CO^+$ $J = 1 \rightarrow 0$ observations with the assumption that $T_{ex} = T_k$. The simple LTE excitation calculation is used instead of more sophisticated multitransitional line transfer models since only one $H^{13}CO^+$ transition was observed. [Using a multiple transition line analysis, however, we find good agreement with the LTE estimates for $N(DCO^+)$ and $\tau_{J=1\rightarrow 0}$ (§ 6)]. $H^{13}CO^+$ was observed instead of the more abundant HCO^+ because the HCO^+ $J = 1 \rightarrow 0$ transition is expected to be optically thick in most cases. The $H^{13}CO^+$ abundance is converted to an HCO^+ abundance by assuming that the $HCO^+/H^{13}CO^+$ ratio equaled the $^{12}C/^{13}C$ ratio [$^{12}C/^{13}C = 76 \pm 7$ (1 σ) in the local interstellar medium; see Wilson & Rood 1994 and references therein]. Since the typical optical depth of the $H^{13}CO^+$ $J = 1 \rightarrow 0$ line is ~ 0.2, the corresponding typical HCO^+ $J = 1 \rightarrow 0$ line would have optical depths in excess of 10, justifying our choice of $H^{13}CO^+$. The DCO^+ and $H^{13}CO^+$

(Butner et al. 1995)

How old is a cold cloud ?

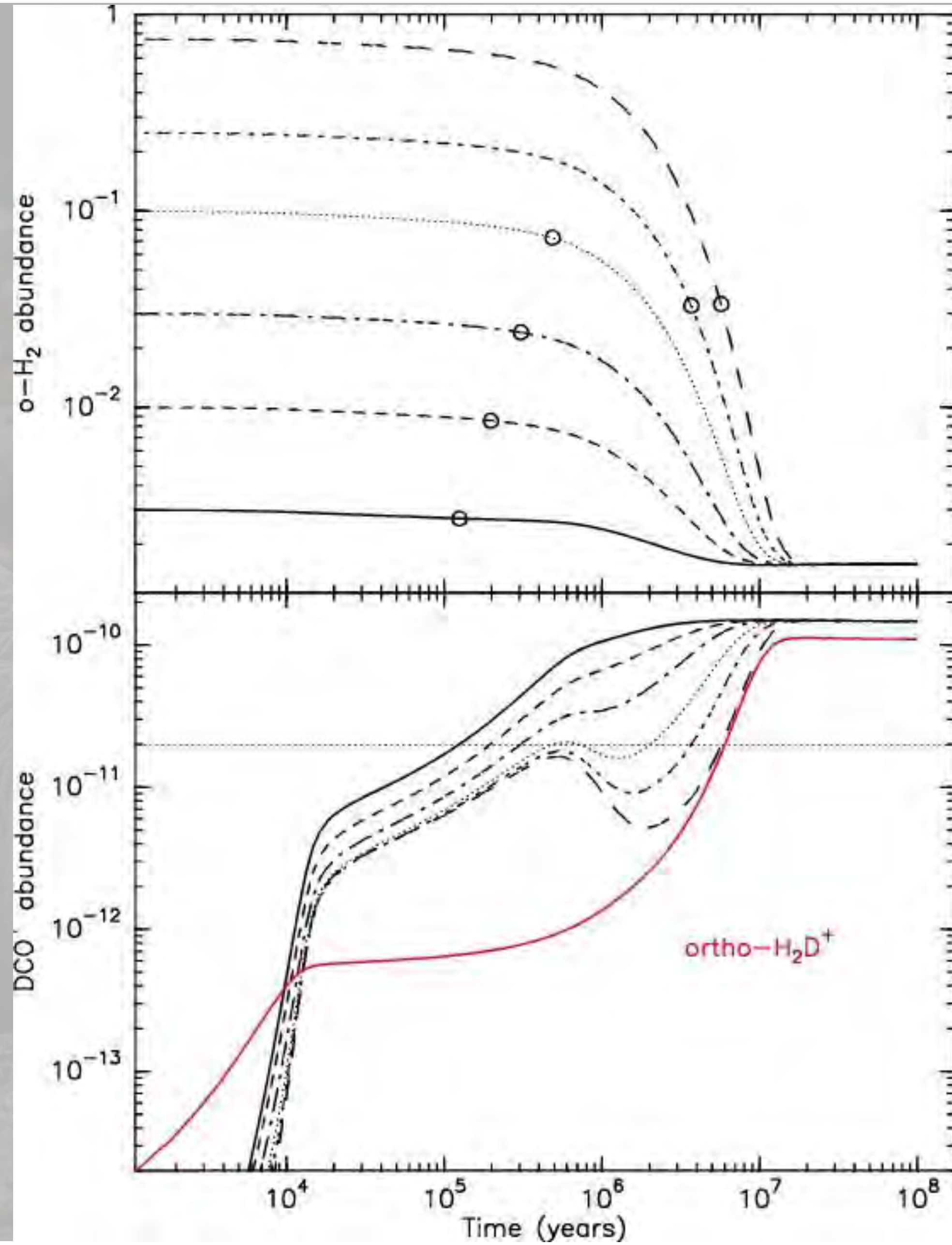
- So, no DCO^+ outside cold depleted cores
- Because ortho-H_2 prevents deuteration ?
- But ortho-H_2 eventually disappears
- So… clouds must be young *(goslings ?)*



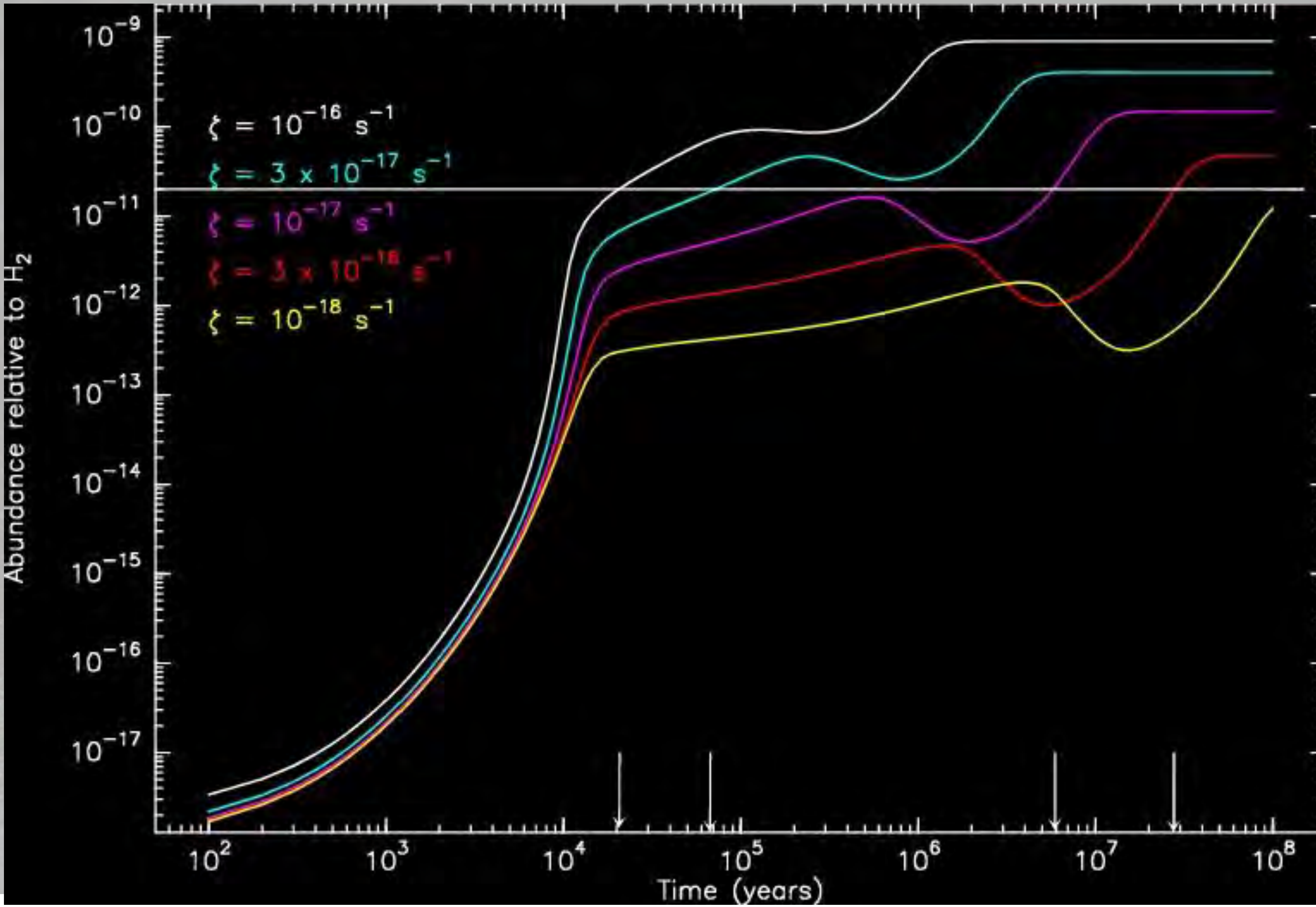
How old is a cold cloud ?

- ❖ Deuteration model (Roueff et al. 2005)
- ◆ + ortho/para spin state H chemistry (Hugo et al. 2009)
- ◆ + DR rates (Pagani et al. 2009)
- ◆ + corrections (CD + oH_2,…)
- ✧ Undepleted
- ✧ $\zeta = 10^{-17}$ s^{-1}
- ✧ metallicity = 3.4×10^{-8}
- ✧ T_{kin} = 10 K
- ✧ $n_H = 2 \times 10^4$ cm^{-3}

- ❖ Detection limit :
  0.1 K in 0.5 km/s
  (DCO^+ J:1-0)
- ❖ Column density :
  10^{22} H_2 cm^{-2}



How old is a cold cloud ?



Dependence on Cosmic Ray Ionization rate

Conclusions

- Deuterium chemistry seems to say that prestellar cores and clouds are young :
  - clouds < 6-7 My (for normal CR rates and Metallicity)
  - clouds + prestellar core < 1.5 My (*subm. A&A*)
- Role of C-bearing Deuterium chemistry needs clarification
- Watson scheme is too simplistic : $DCO^+ \not\Leftrightarrow [e]$
- high Cosmic rays ionization rates impossible in dark clouds ?