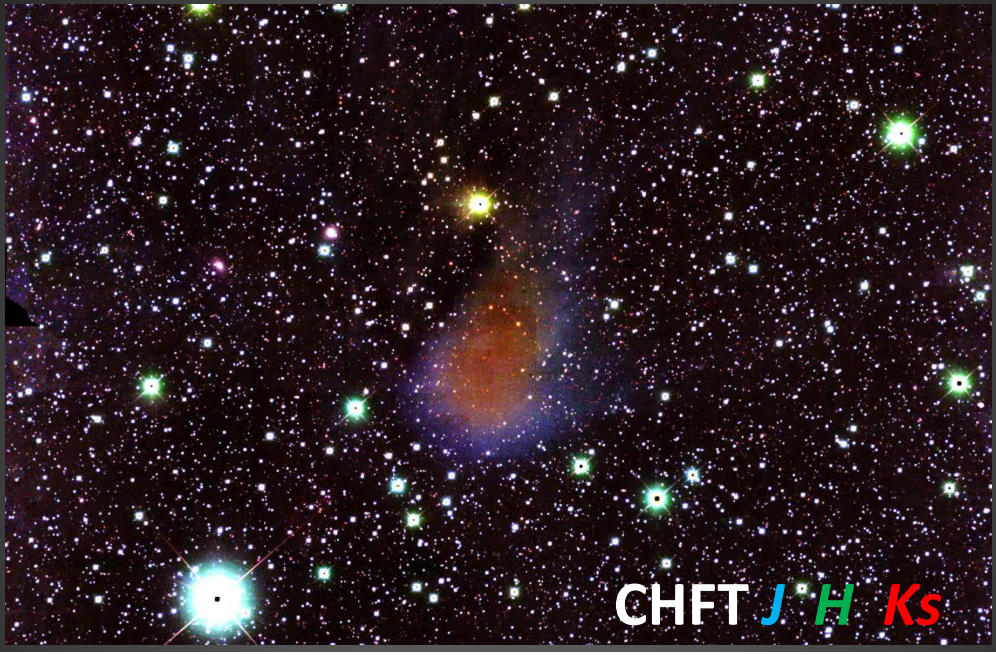
Chemical Modeling of Starless Cores --- L1512



Lin et al. submitted

Sheng-Jun Lin 林聖鈞 [1], Laurent Pagani [2], Shih-Ping Lai 賴詩萍 [1], Charlène Lefèvre [3] , and François Lique [4]

[1]IoA, National Tsing Hua University, Taiwan

[2]LERMA & UMR 8112 du CNRS, Observatoire de Paris, France

[3]Institut de Radioastronomie Millimétrique, France

[4]LOMC-UMR 6294, CNRS-Université du Havre, France

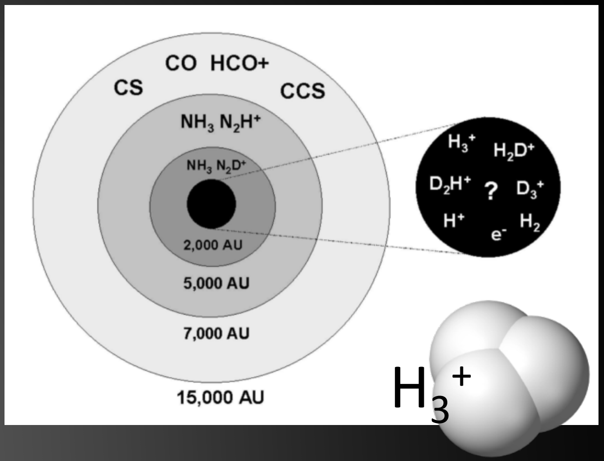
JCMT User Meeting 2019, ASIAA, Taiwan – 2019 Nov 07 – Sheng-Jun Lin

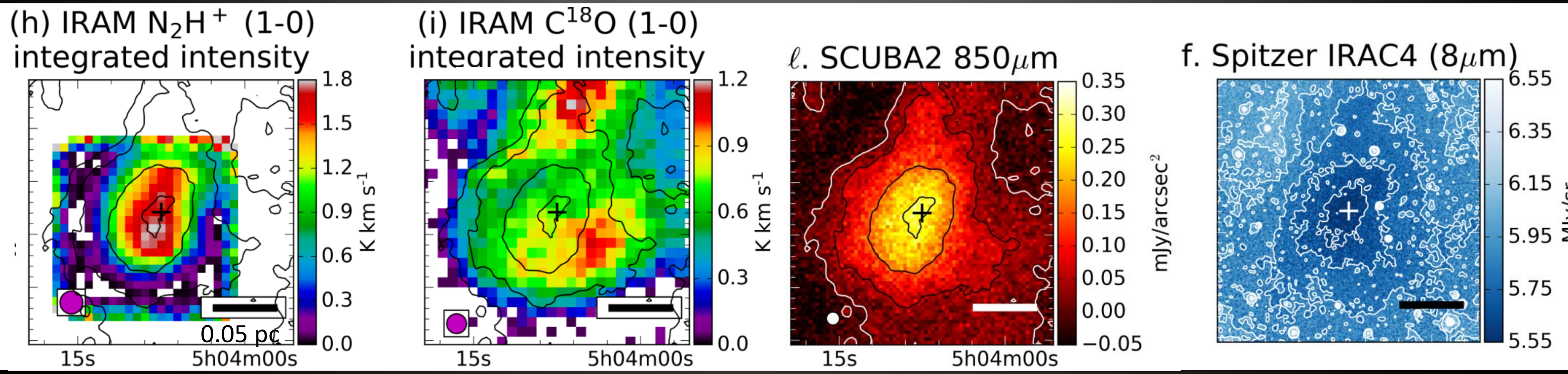
Outline

- Introduction: Starless cores and Formation
- Deuterium Chemistry
- Analysis
- Summary

Starless Core

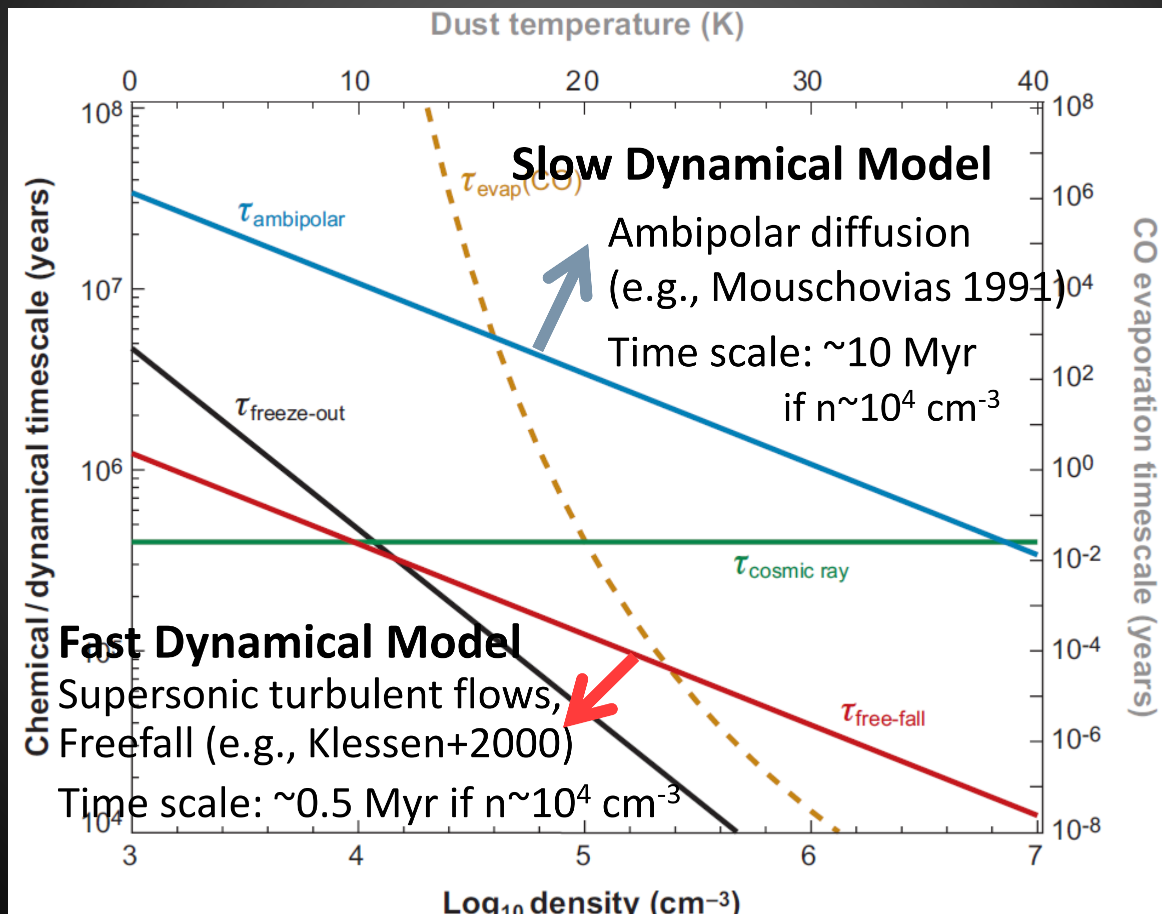
- The earliest phase in star formation
- C-, S-bearing species are depleted
- N-bearing/Deuterated species are abundant
- High **Deuteration** fraction
  - [D]/[H] >> Cosmic [D]/[H] ≈ 3.2 $\times 10^{-5}$





Starless Core Formation

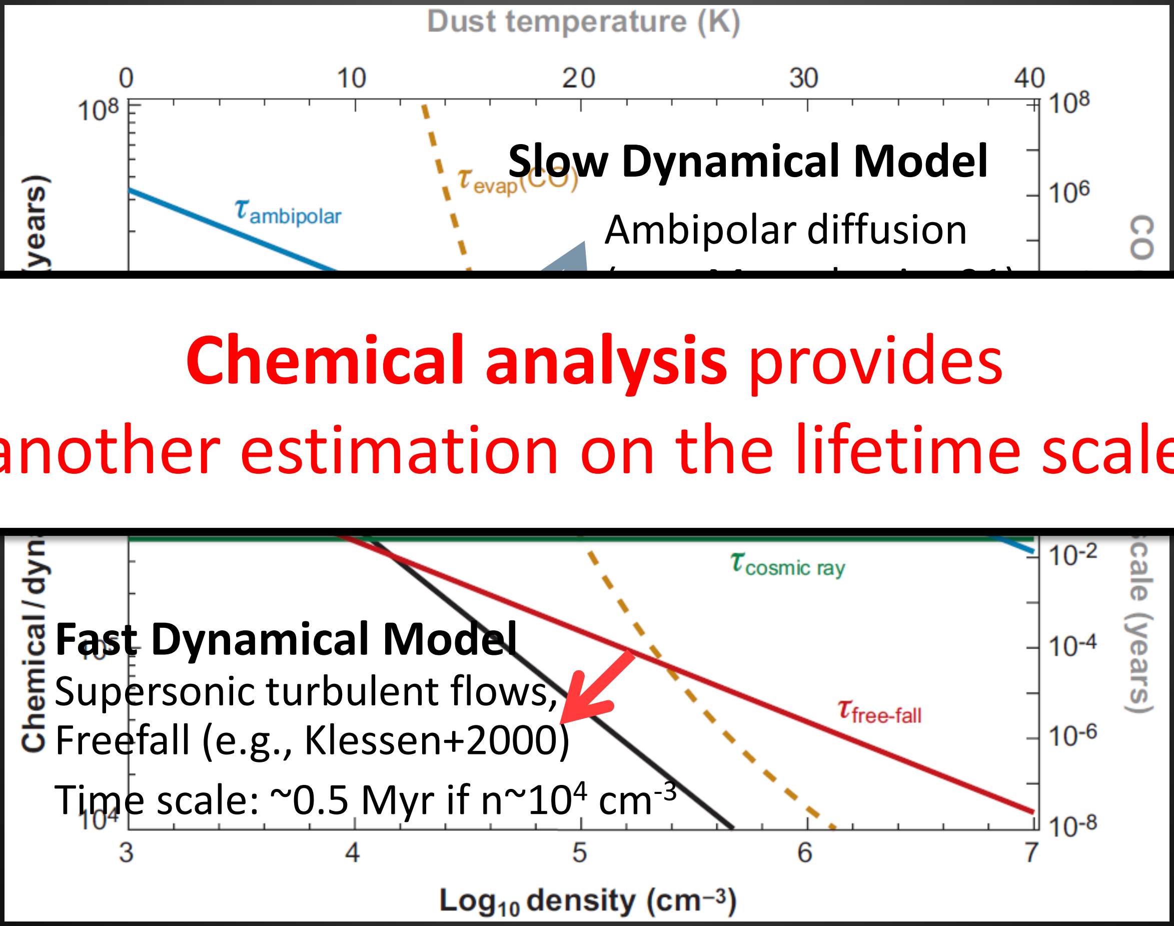
Question: Do starless cores form via slow or fast process?



(Bergin+2006)

Starless Core Formation

Question: Do starless cores form via slow or fast process?



Slow Dynamical Model

Ambipolar diffusion

Fast Dynamical Model

Supersonic turbulent flows,
Freefall (e.g., Klessen+2000)

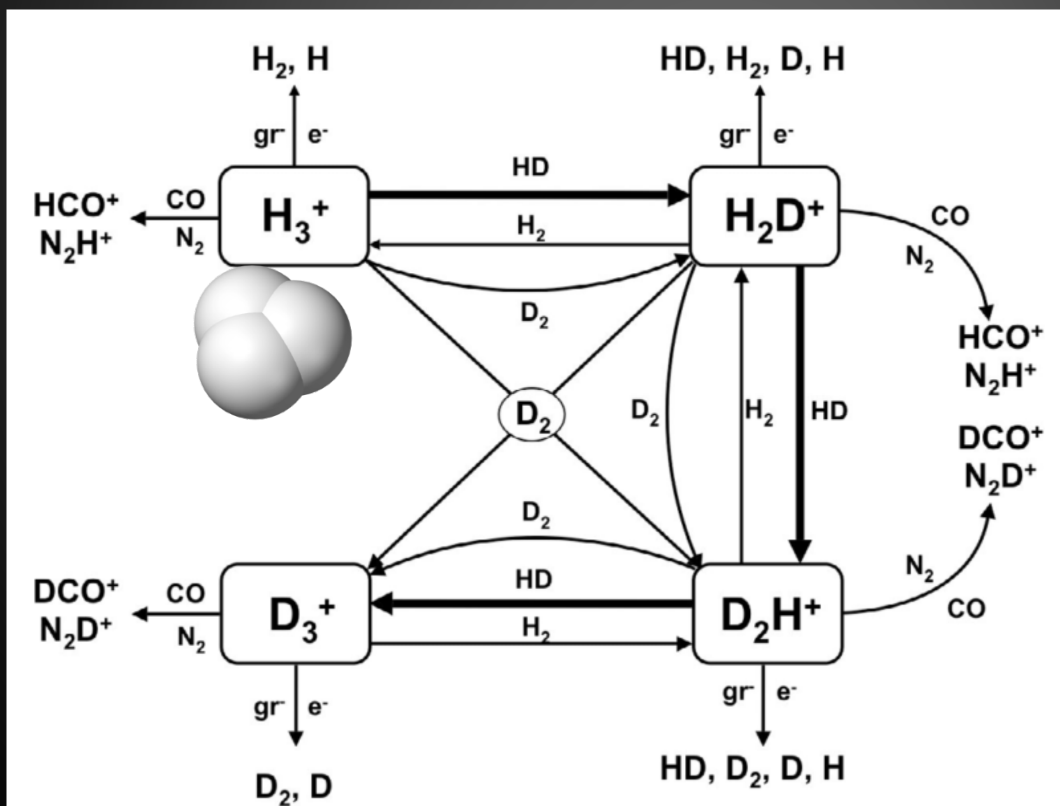
Time scale: ~0.5 Myr if n~10^4 $\mathrm{cm^{-3}}$

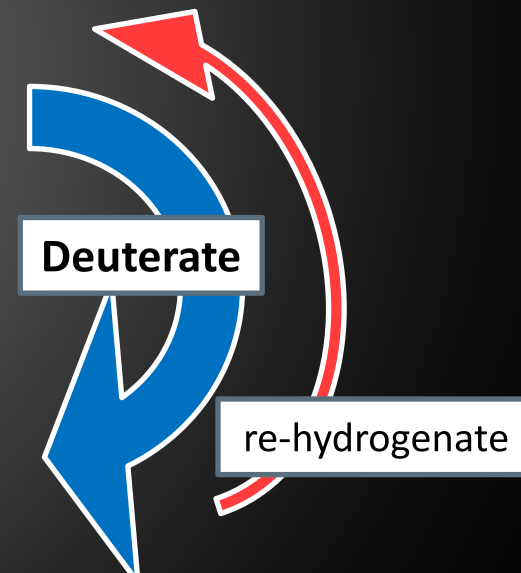
Chemical analysis provides
another estimation on the lifetime scale.

(Bergin+2006)

Deuterium Chemistry

- Starless [D]/[H] >> Cosmic [D]/[H] ≈ 3.2×10^{-5}
- **Deuterium fractionation** is enhanced in the cold environment
- Spin states matter! e.g., ΔE(**o-H_2** - **p-H_2**) = 170 K

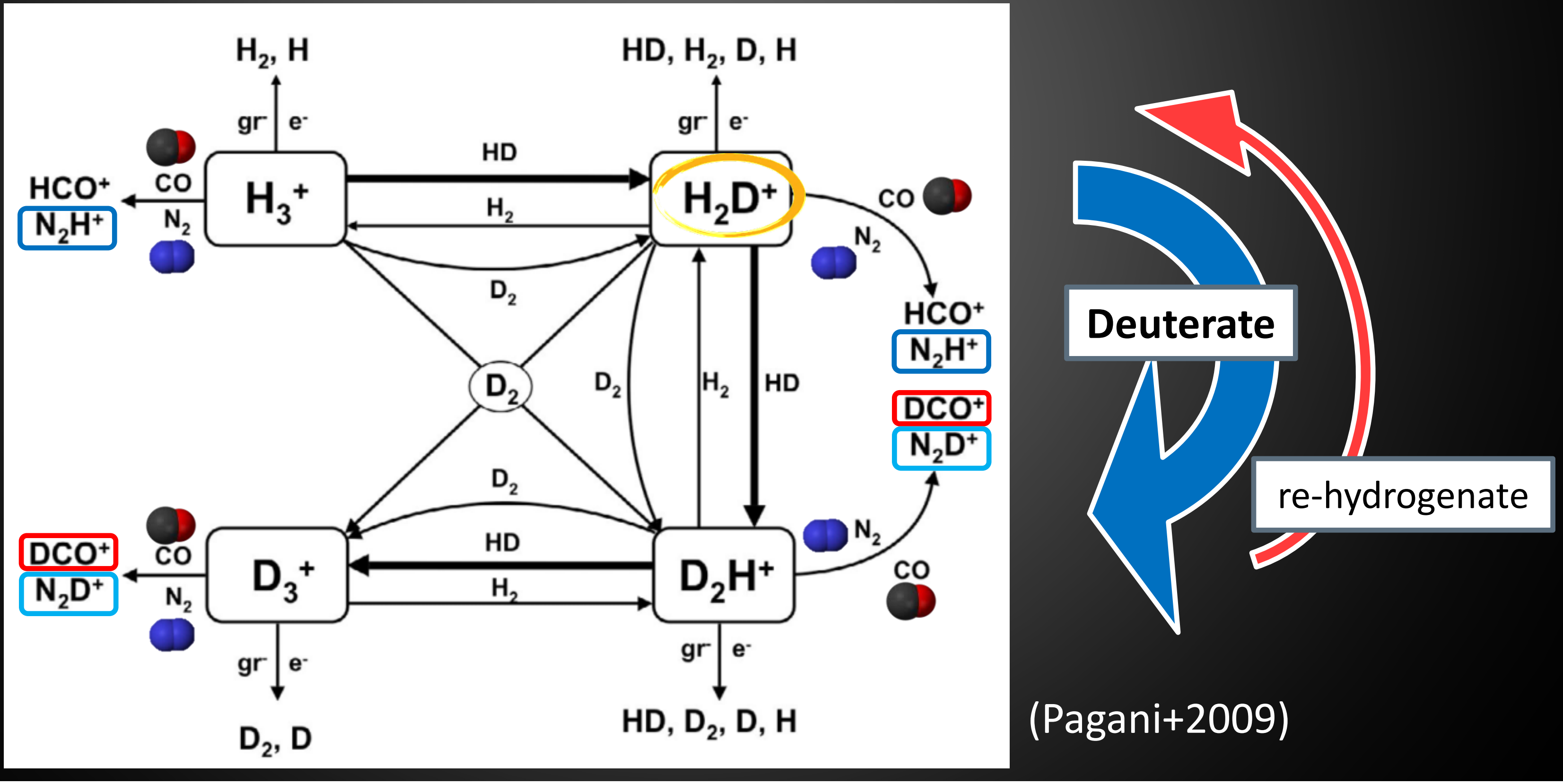




(Pagani+2009)

Solve the Time scale!

- 4 Key cation tracers: o-H_2D^+, N_2H^+, N_2D^+, DCO^+
- The freeze-out process is dominated
- CO and N_2 are depleted and their abundances are constant



(Pagani+2009)

Analysis

Abundance Profiles
(N_2H^+, N_2D^+, DCO^+, o-H_2D^+)

Chemical Modeling with the Deuterium Network

Lifetime of L1512

CO & N_2 Profiles

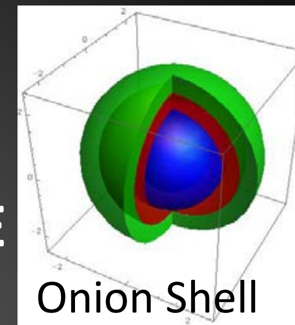
Analysis

Multi-line Obs of the 4 tracers

Density Profile

T_{kin} Profile

1D Spherical Non-LTE Radiative Transfer with an Onion-shell Model



→

Abundance Profiles
(N_2H^+, N_2D^+, DCO^+, o-H_2D^+)

Chemical Modeling with the Deuterium Network

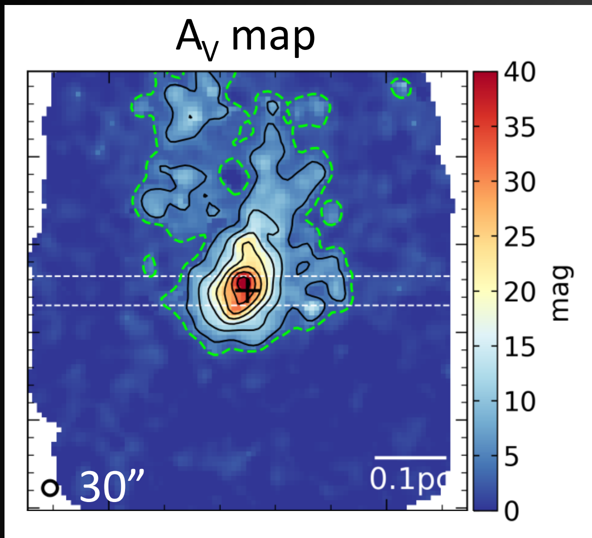
↙

Lifetime of L1512

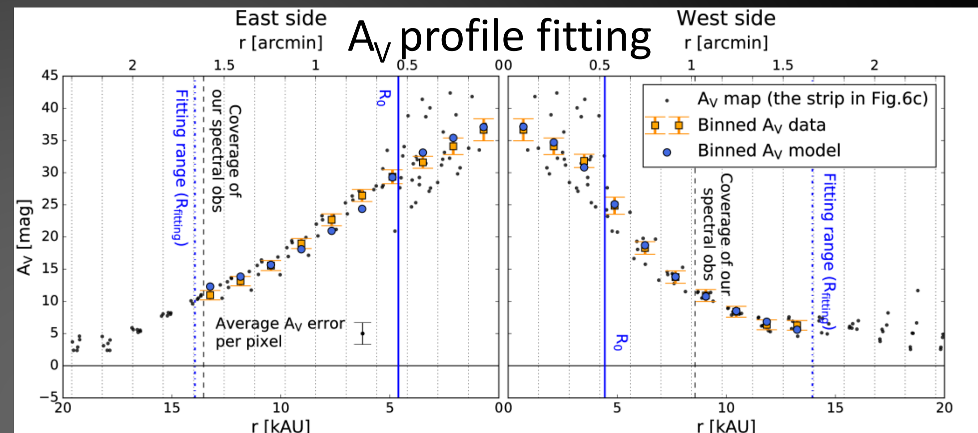
CO & N_2 Profiles

Analysis

Perform a Plummer-like density profile fitting on the extinction map



Azimuthal average



Azimuthal average

A_V model map

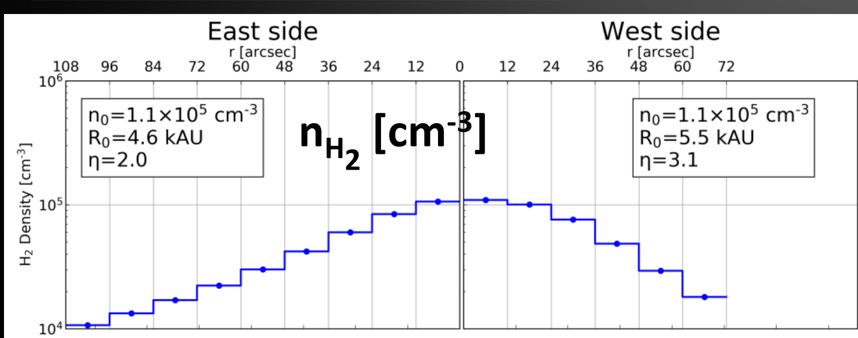
$N_{H_2}/A_V = 5.3 \times 10^{20}$ cm^{-2} mag^{-1}

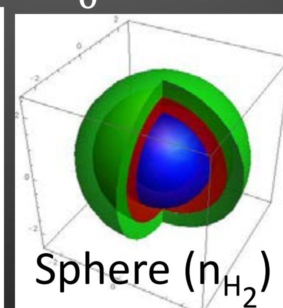
(Bohlin+1978)

N_{H_2} model map

Density Profile

$$n(r) = \frac{n_0}{1+(\frac{r}{R_0})^{\eta}}$$





Analysis: Radiative Transfer

Multi-line Obs of the 4 tracers

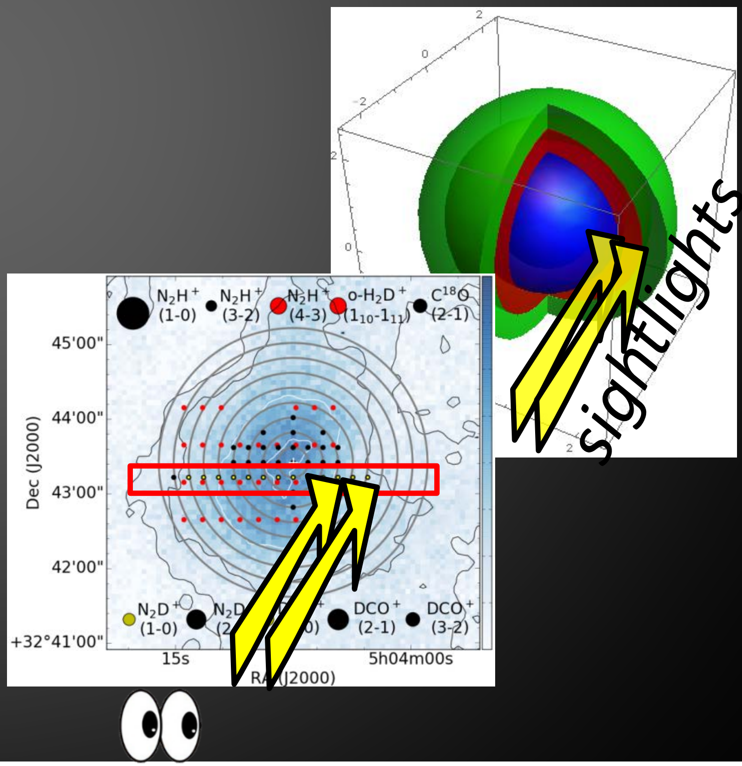
Density Profile

T_{kin} Profile

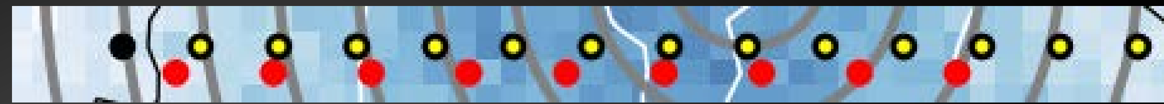
→

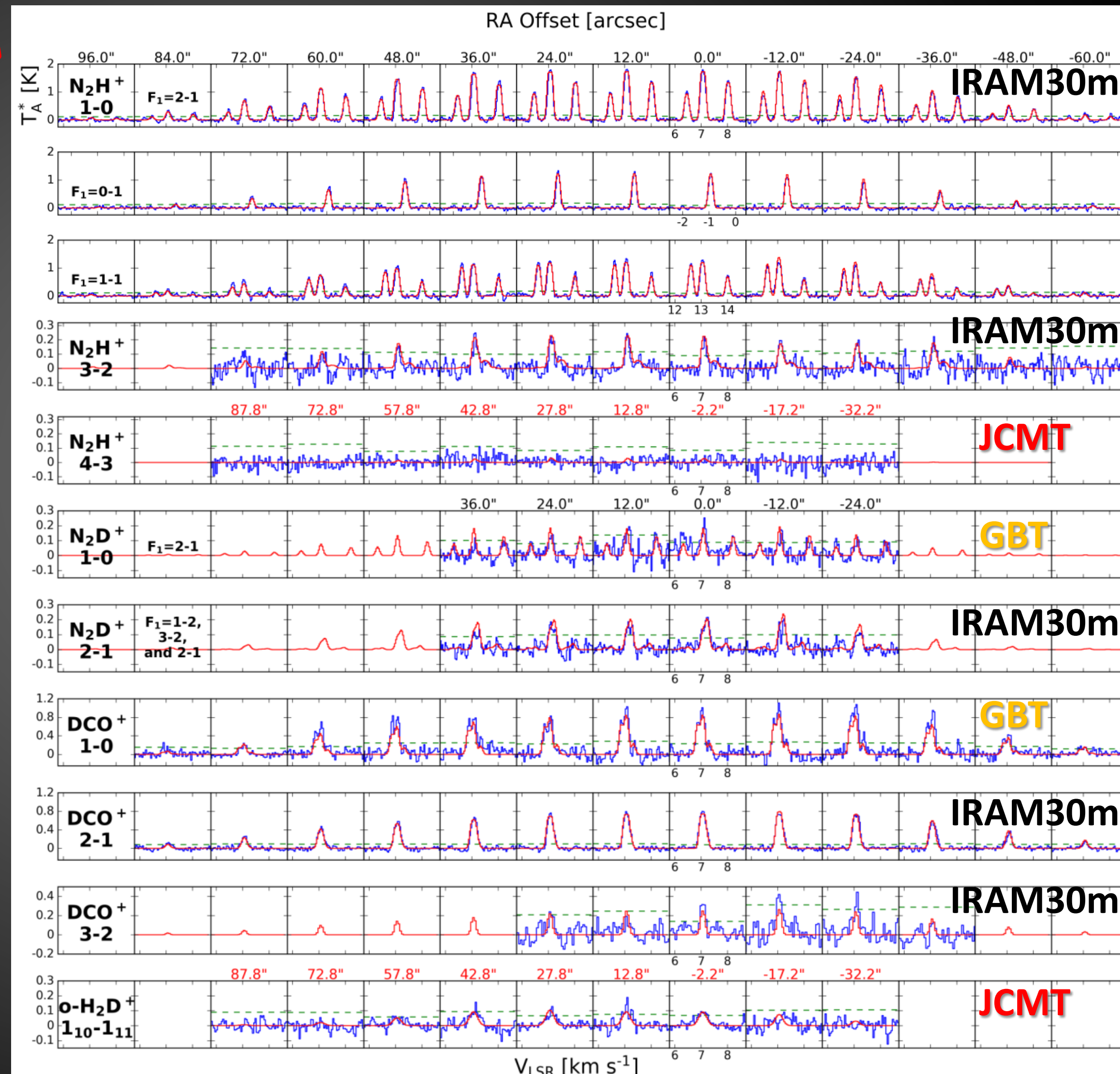
Abundance Profiles
(N_2H^+, N_2D^+, DCO^+, o-H_2D^+)

We used the radiative transfer tool originally written by Bernes (1979) and revised by Pagani+ (2007).

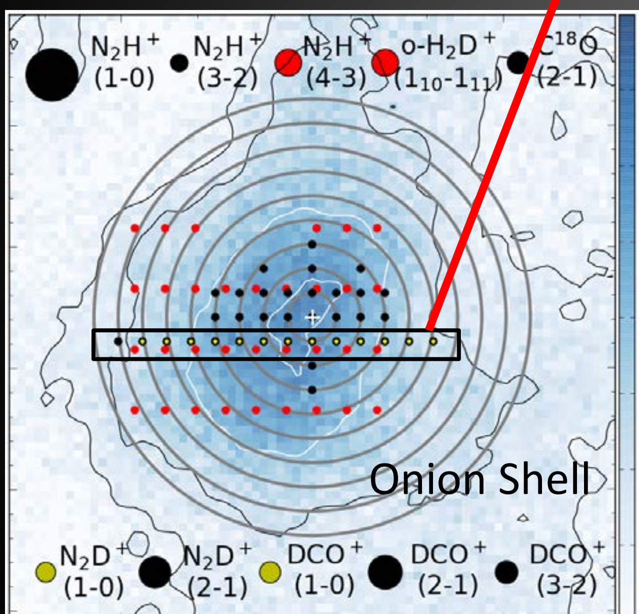


Analysis



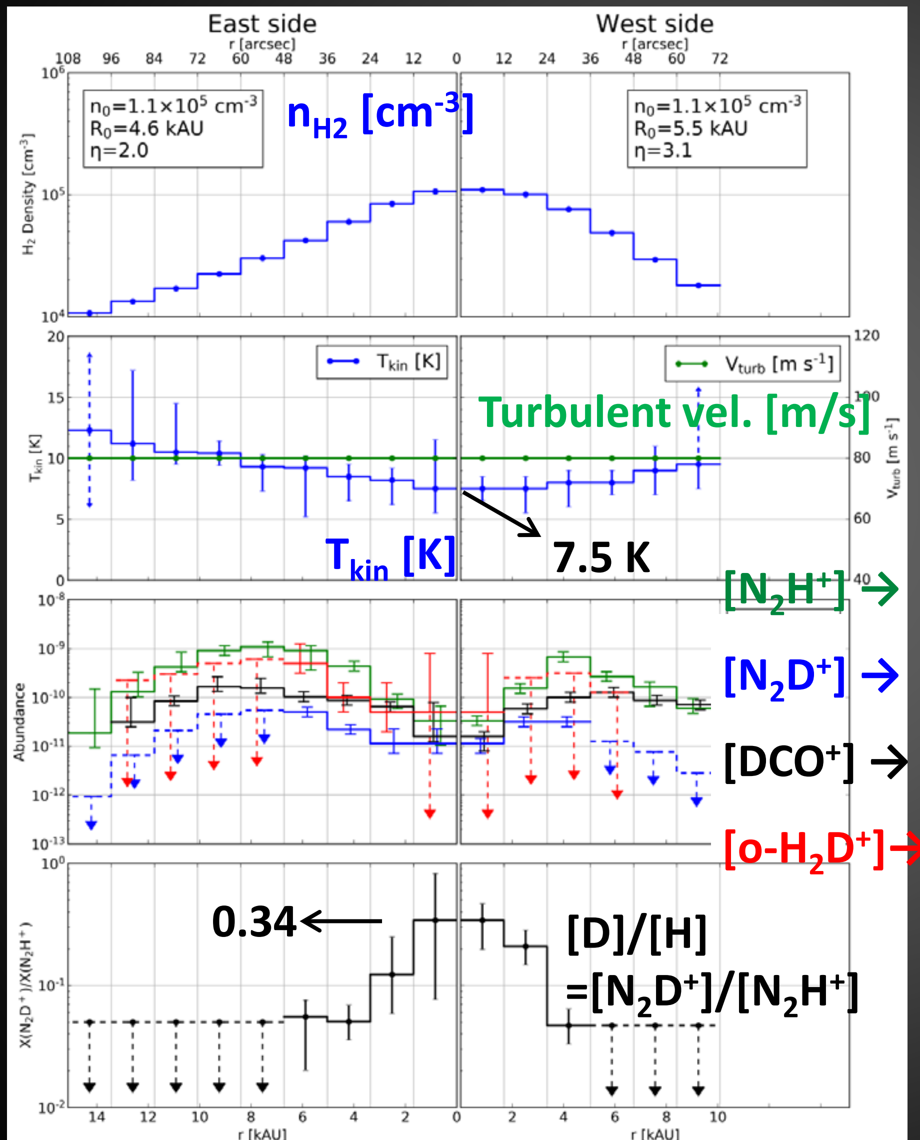


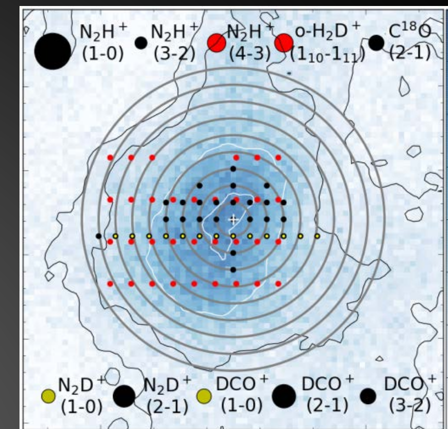
Multi-line Obs
of the 4 tracers



SCUBA2 850um map
& Pointing positions

Profiles of L1512

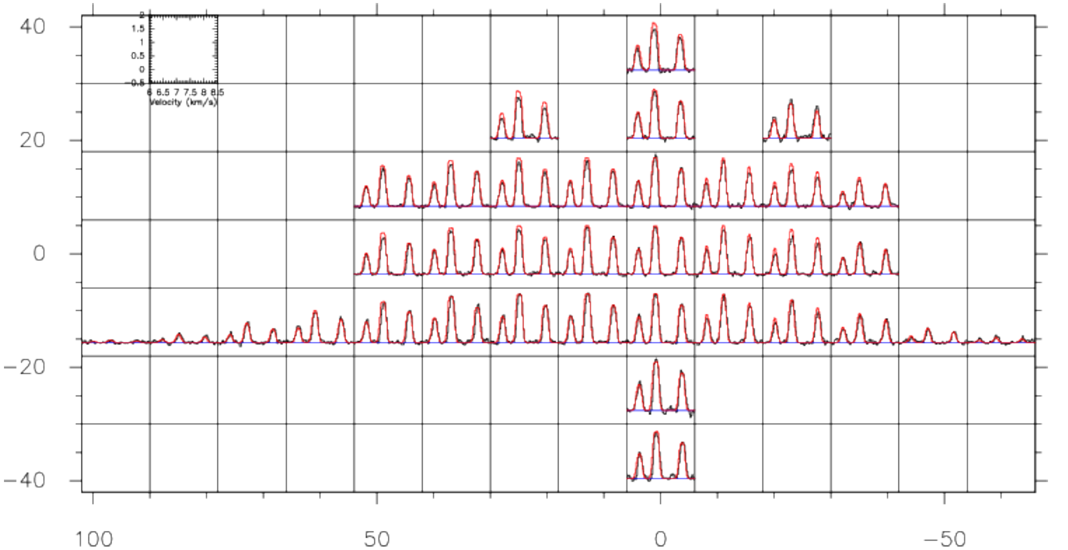


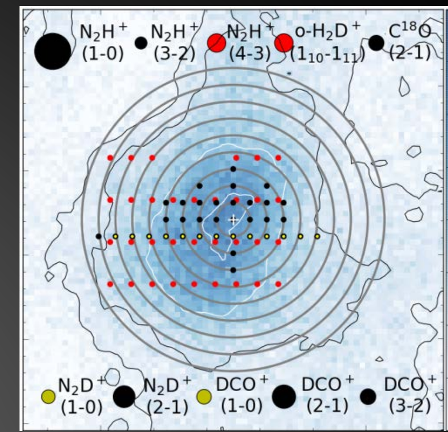


Depletion factor

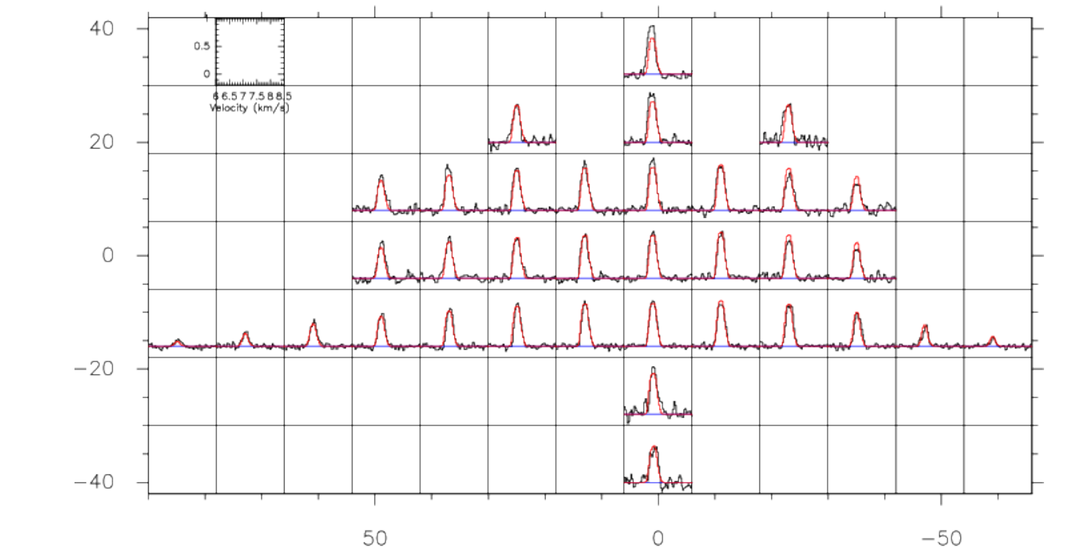
L1512	L183	L1544
27^{+17}_{-13}	6^{+13}_{-3}	>100
4^{+2}_{-1}	2~2.5	~15
9^{+21}_{-3}	>17	~10?
~10	~2	---
This work	Pagani+ 2007, 2009, 2012	Redaelli+ 2019

IRAM30m N_2H^+ J,F_1=1,2-0,1 (central triplet)

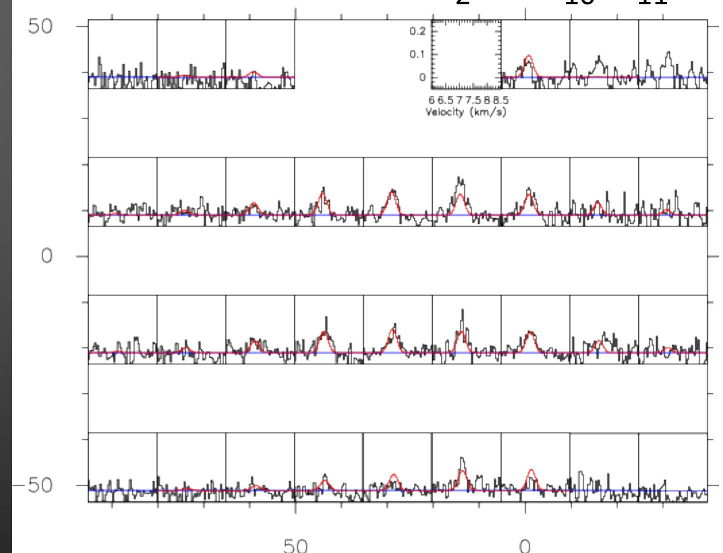




IRAM30m DCO^+ 2-1



JCMT HARP o-H_2D^+ 1_{10}-1_{11}



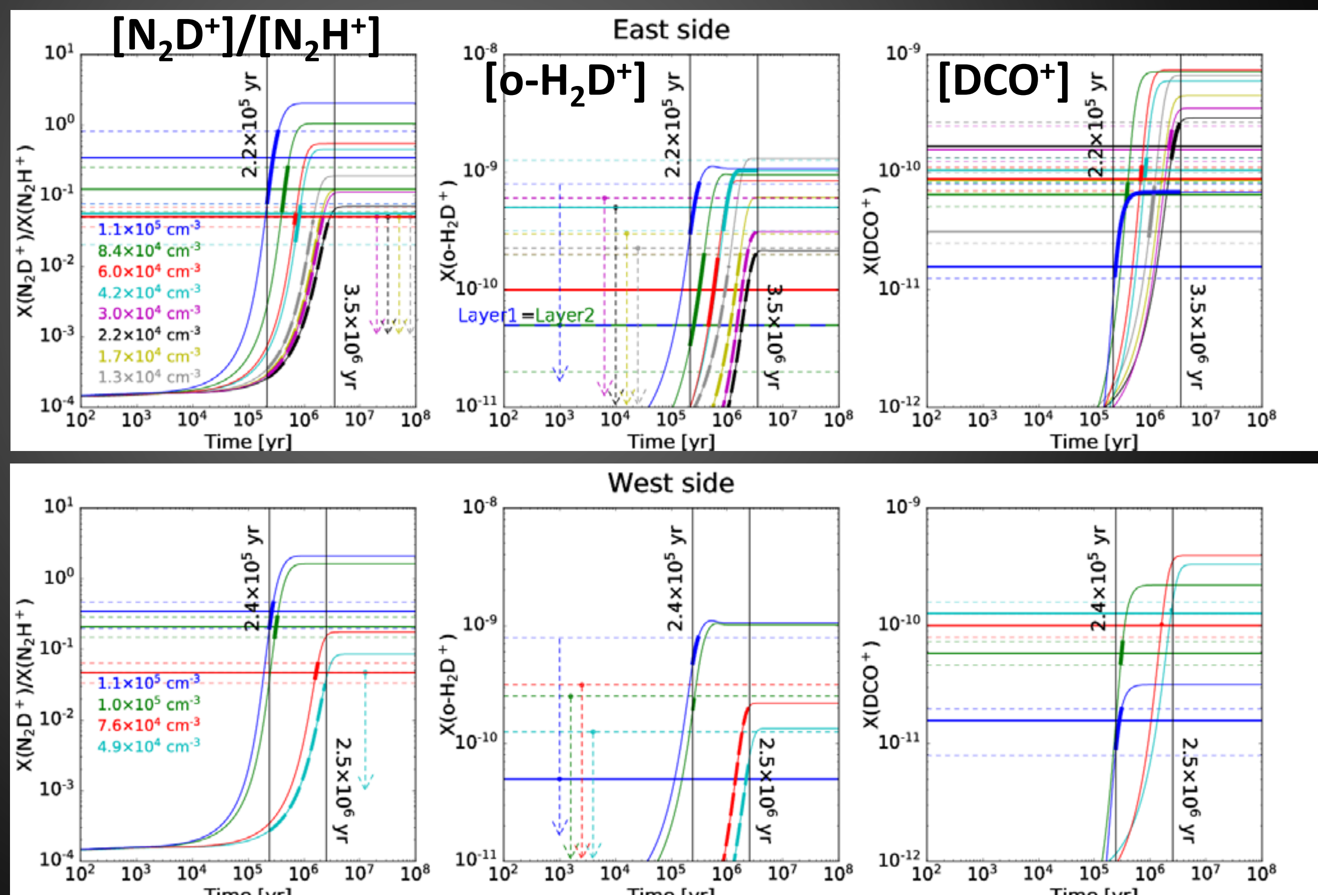
Analysis: Chemical Model

- Pseudo time-dependent NAHOON code (Wakelam 2006) updated with our deuterium chemical network (Pagani+2009)
- The lower limit of the lifetime is **2.5~3.5 Myr**

Abundance Profiles

↓

Lifetime of L1512



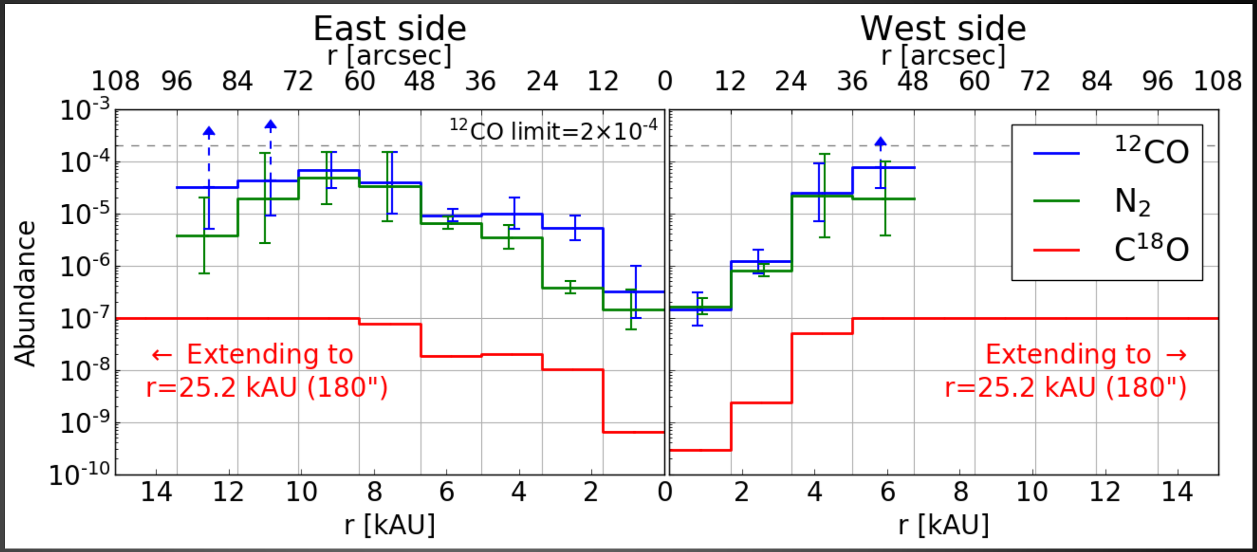
Analysis: Chemical Model

- ^{12}CO and N_2 abundance profiles

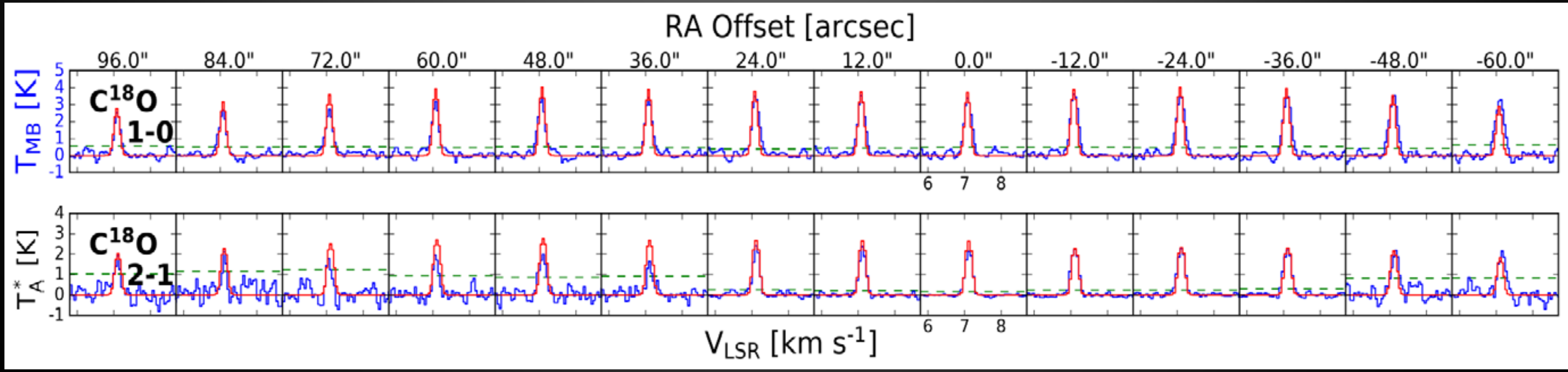
Depletion factor

^{12}CO: ~430–870

N_2: ~300



- Validate with the $C^{18}O$ data by assuming [$C^{18}O$]= [^{12}CO]/500



Summary

1. We find n_{H_2}=1.1×10^5 cm^{-3} and T=7.5±1 K at the center. The depletion factors of N_2H^+ and N_2D^+ are 27^{+17}_{-13} and 4^{+2}_{-1} in L1512, intermediate between the two other more advanced and denser starless core cases, L183 and L1544.

2. We find that CO has a depletion factor of ~430–870 and the N_2 profile is similar to that of CO. Thus, L1512 has probably been living long enough so that N_2 chemistry has reached steady state.

3. N_2H^+ modeling remains compulsory to assess the precise physical conditions in the center of cold starless cores. L1512 is presumably older than 2.5~3.5 Myr, suggesting that the dominating core formation mechanism could be ambipolar diffusion.