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MOLECULAR FRACTIONATION IN LOW-MASS STAR FORMING REGIONS

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DEUTERATION MAPS OF N_2H^+ AND HCO^+ IN L1544

Redaelli et al. (2019)
arxiv: 1907.08217

DEUTERATION: WHY?

1) Diagnostic indicator of star formation process

2) Used to understand the origins of the different materials in the Solar System

3) Good tracer of dense and cold gas

DEUTERATION: THE THEORY

Ceccarelli&Caselli(2014)

Fractionation: substitution of an atom with an isotope in a molecular compound

Deuteration: $\mathrm{H} \rightarrow \mathrm{D}$

Elemental abundance:

$$\frac{\mathrm{D}}{\mathrm{H}} = 1.5 \times 10^{-5}$$

Linsky+(2003)

DEUTERATION IN THE COLD ISM

Key reaction

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

Low temperature

Further enhancements

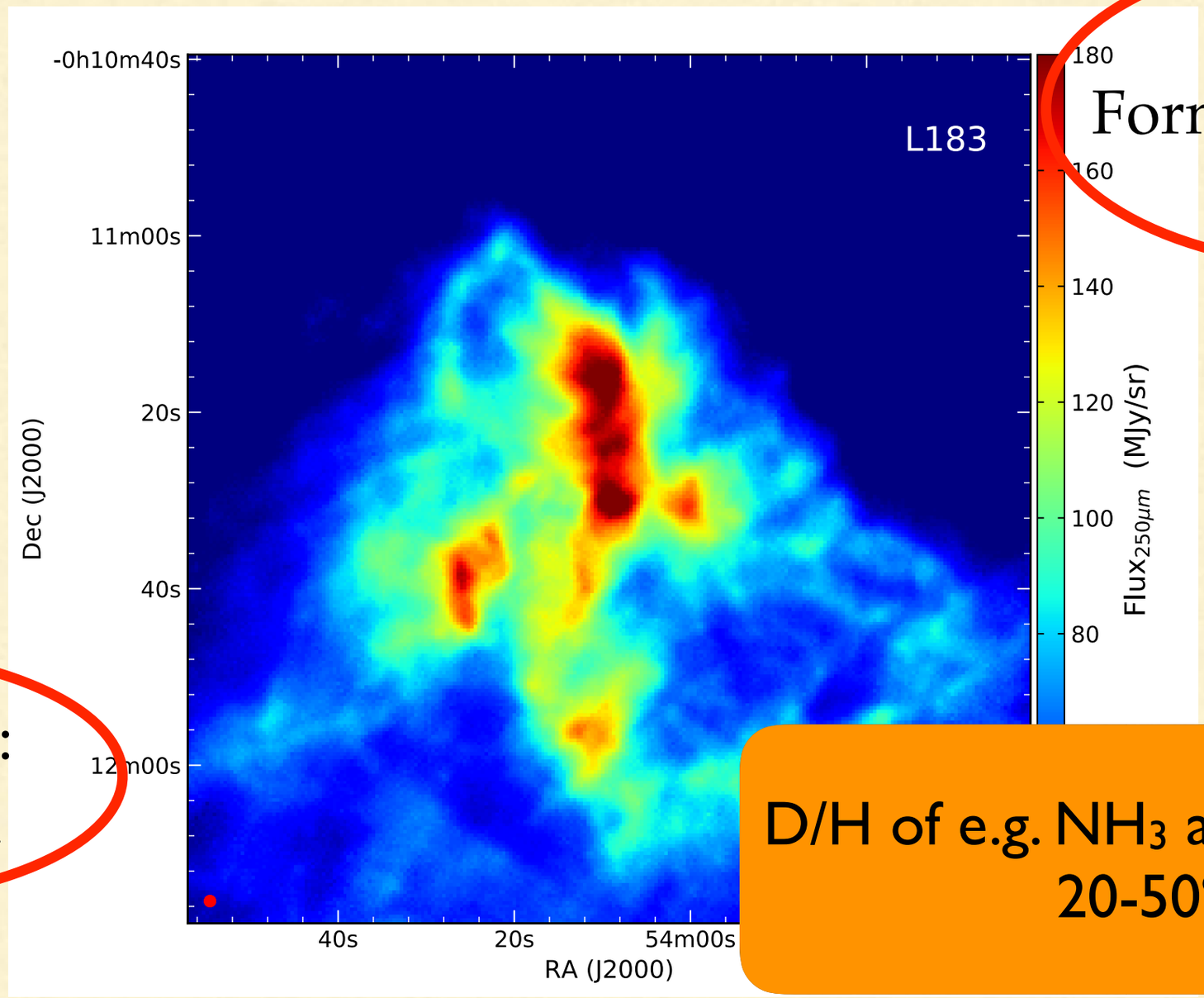
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

High density

Dalgarno&Lepp(1984)

PRESTELLAR CORES

"Deuteration factories"



Low T:
Formation of H_2D^+ favoured

High density:
CO depleted

D/H of e.g. NH_3 and N_2H^+ up to 20-50%!!!

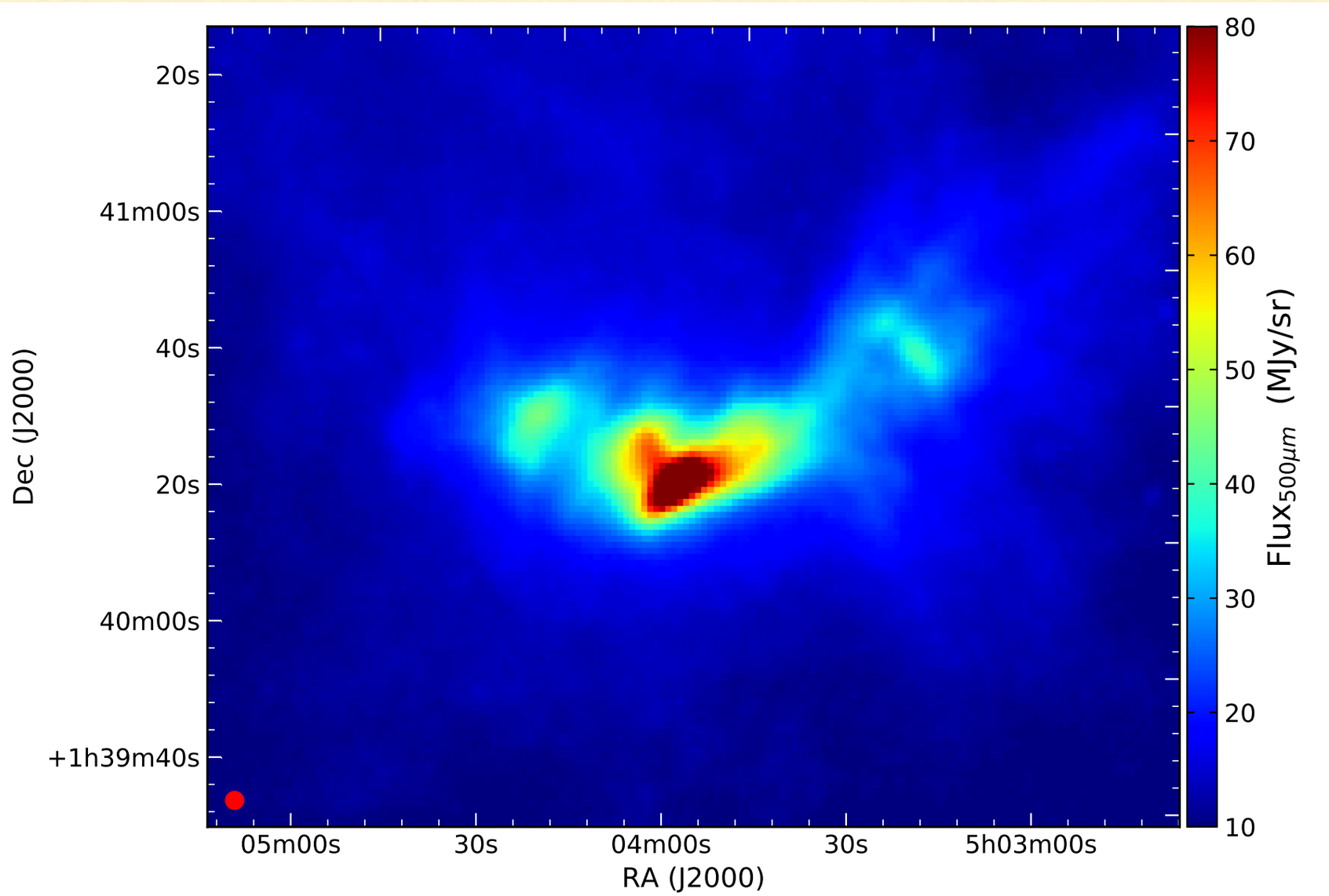
THE PROJECT OBJECTIVES

- Use recent high sensitivity data to investigate the **deuterium fraction distribution** of abundant ions in a well-known source

- Use state-of-art chemical code to **investigate the chemistry** of L1544

- Step II: investigate the **spatial variation of the ionisation fraction**

THE SELECTED SOURCE



- Close (d~135 pc)
- Isolated
- ~10 $M_\odot$
- Many observational/ theoretical studies

THE OBSERVATIONS

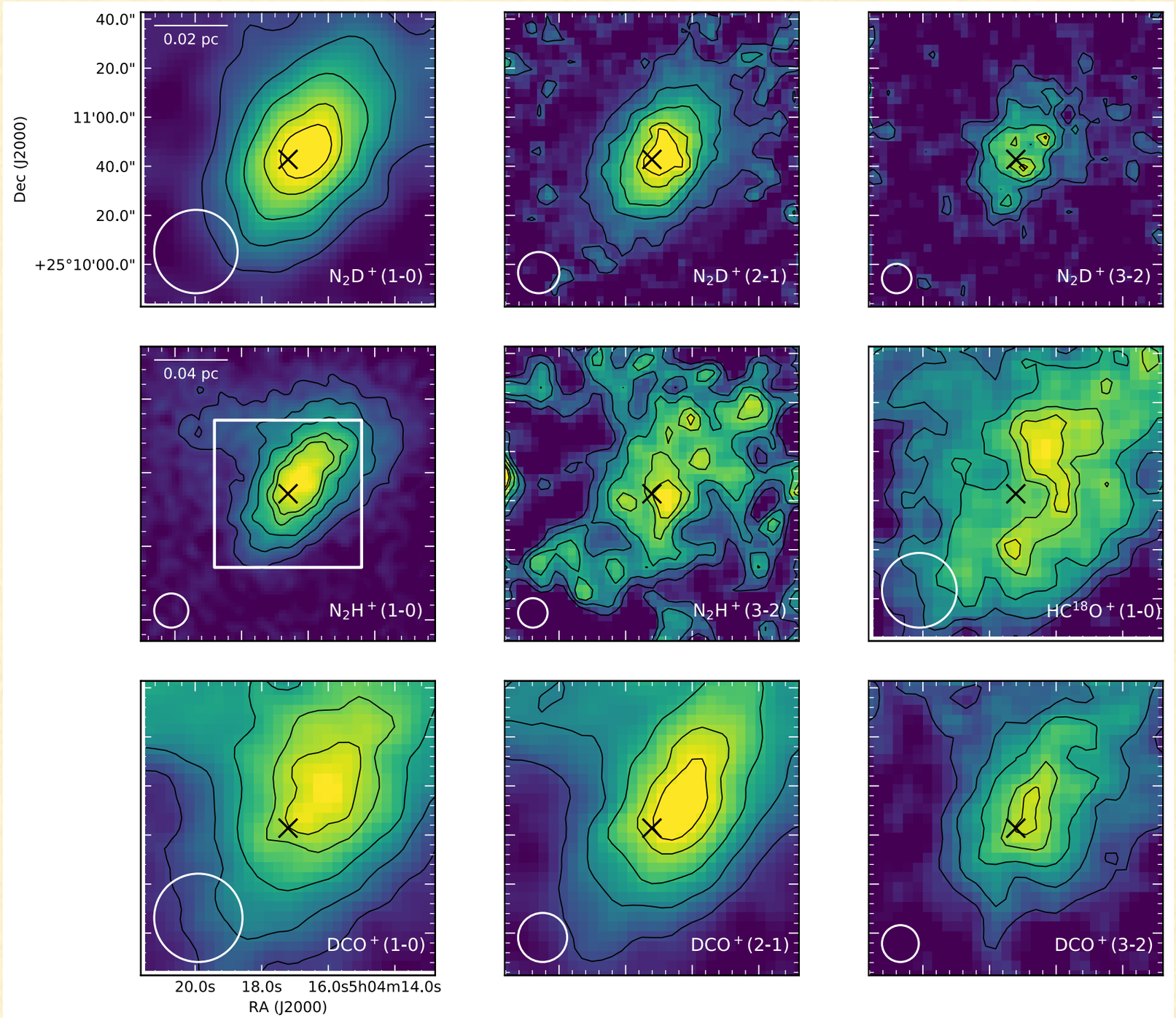
The collected data:

- N_2H^+ (1-0), (3-2)
- N_2D^+ (1-0), (2-1), (3-2)
- $HC^{18}O^+$ (1-0)
- DCO^+ (1-0), (2-1), (3-2)

Resolutions:

- Angular: 12″-36″ (from 230 to 80 GHz)
- Spectral: 20kHz (0.02-0.07 km/s)

INTEGRATED INTENSITY MAPS



DERIVING COLUMN DENSITIES

The 'usual' approach: LTE analysis

Radiative transfer equations:

Observed

$$T_{\rm MB} = \eta_{\rm bf}\left[J_\nu(T_{\rm ex}) - J_\nu(T_{\rm bg})\right]\left(1 - e^{-\tau_\nu}\right)$$

$$\tau_\nu = \sqrt{\frac{\ln 2}{16\pi^3}}\frac{c^3 A_{\rm ul} g_{\rm u}}{\nu^3 Q(T_{\rm ex})\Delta V} e^{-\frac{E_{\rm u}}{k_{\rm B}T_{\rm ex}}}\left(e^{\frac{h\nu}{k_{\rm B}T_{\rm ex}}} - 1\right) N_{\rm col}$$

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Known from spectroscopy

Assume T_{ex} constant for different transitions

DERIVING COLUMN DENSITIES

The main issue is that different transitions of the same molecule are **not in LTE**, i.e. they present different T_{ex}

A non-LTE approach is needed!

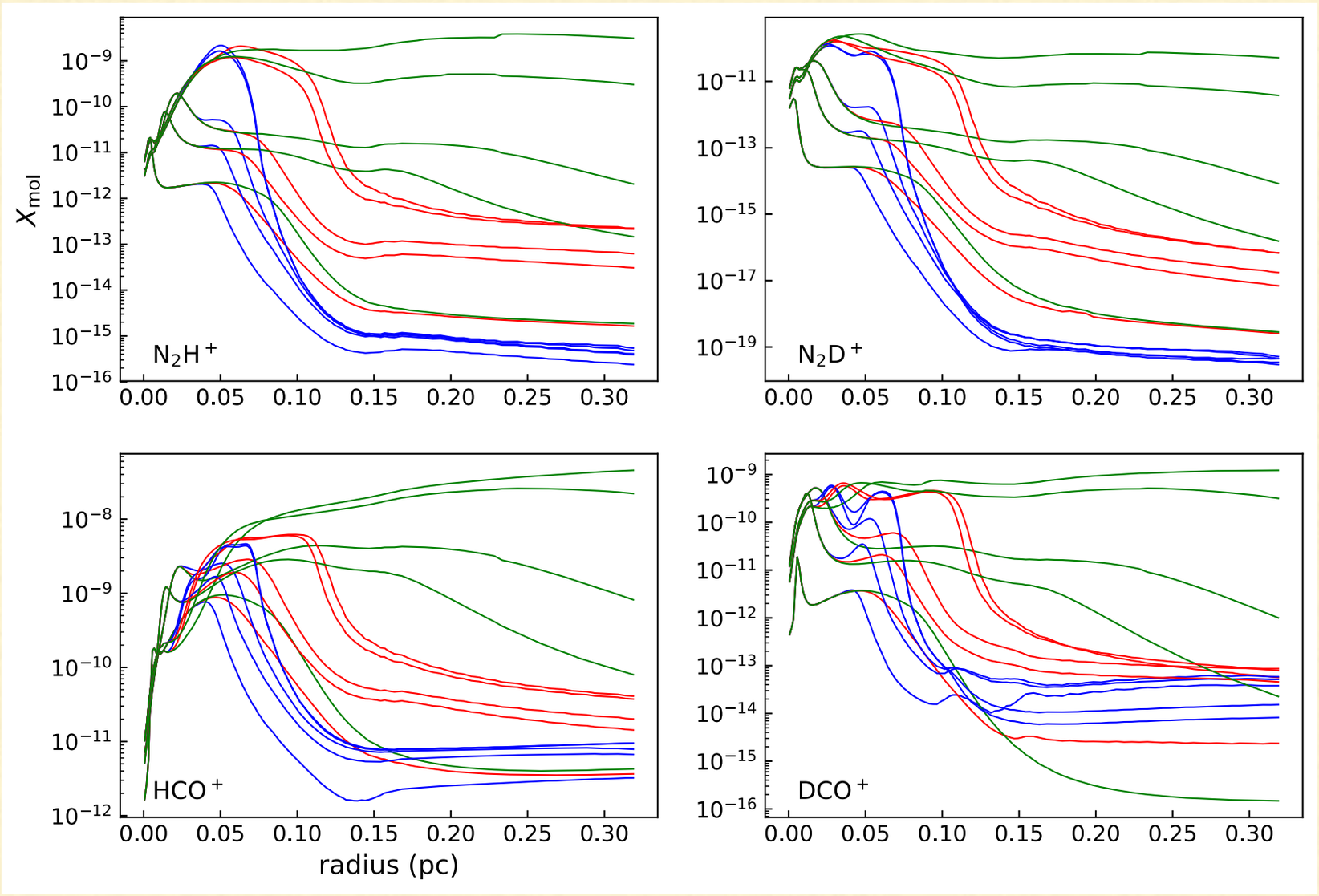
Limited to the centre due to spherical symmetry

NON-LTE APPROACH

- Performed with MOLLIE (Keto+1990)
- We used the most recent available collisional coefficient
- The model of the source is from Keto & Caselli (2015), a QE-BE sphere
- We tested the chemical models developed by Olli Sipilä (Sipilä+ 2015a,b)

CHEMICAL MODEL

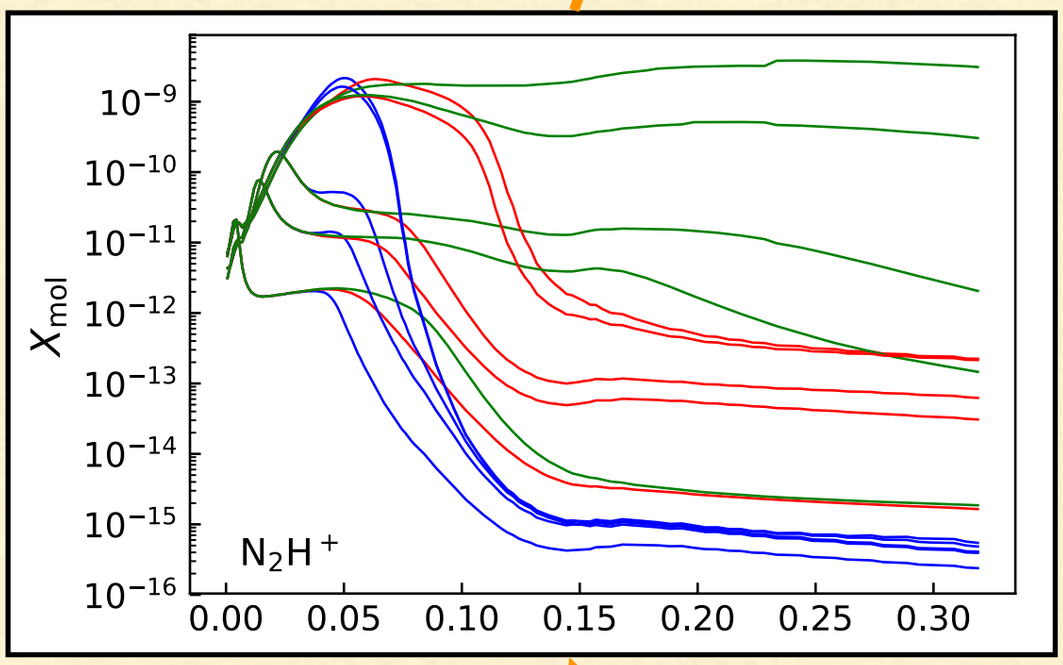
Abundance profiles



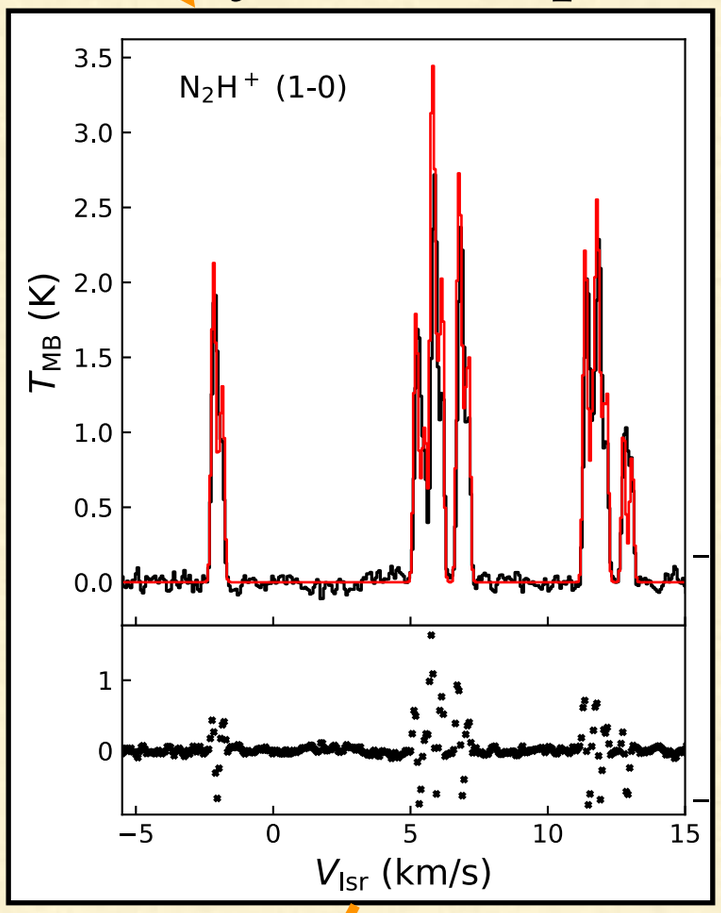
MODELLING THE DUST PEAK

MOLLIE

Abundance profiles

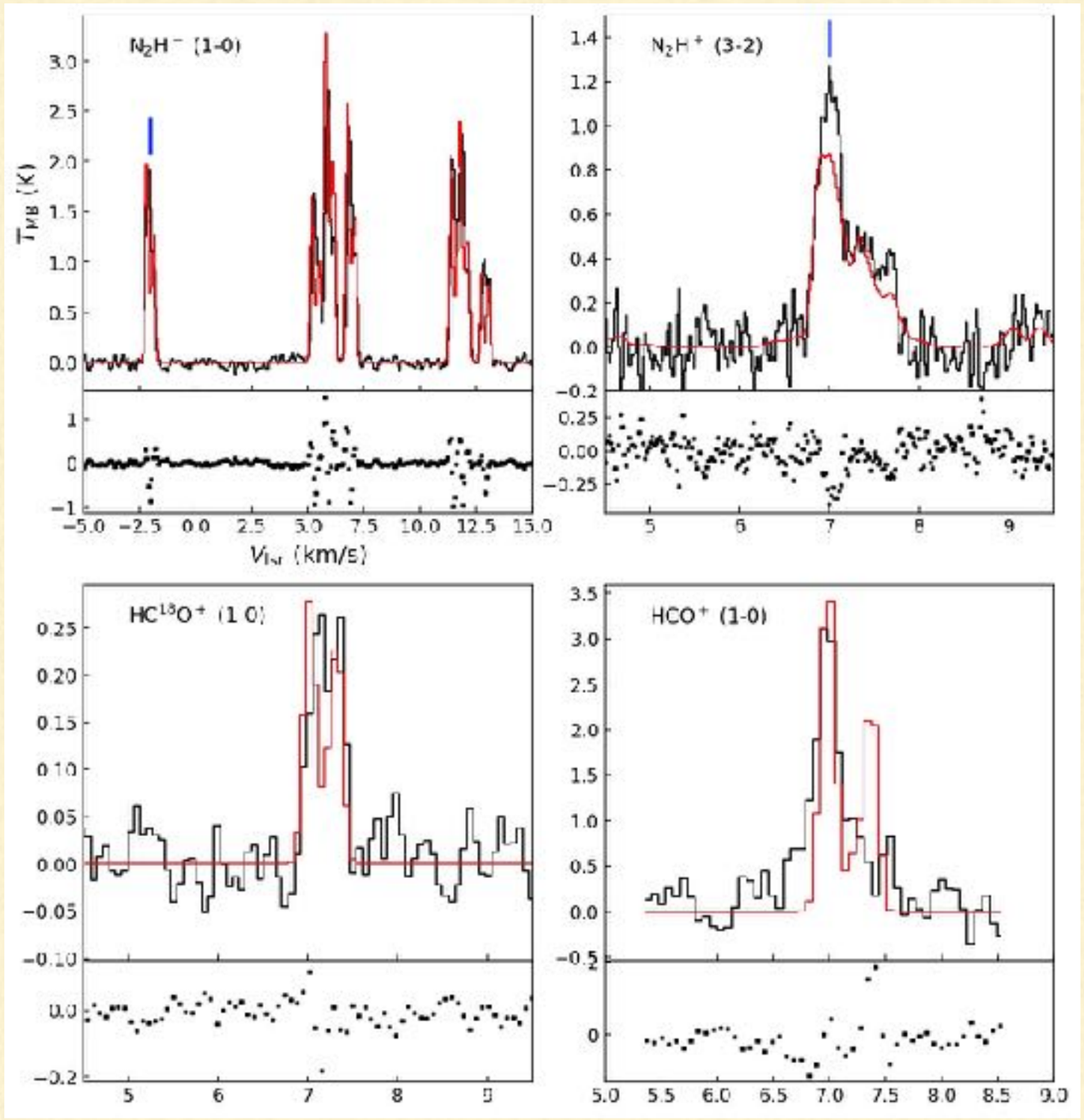


Synthetic spectra



Match the observed spectra

THE BEST FIT SOLUTIONS



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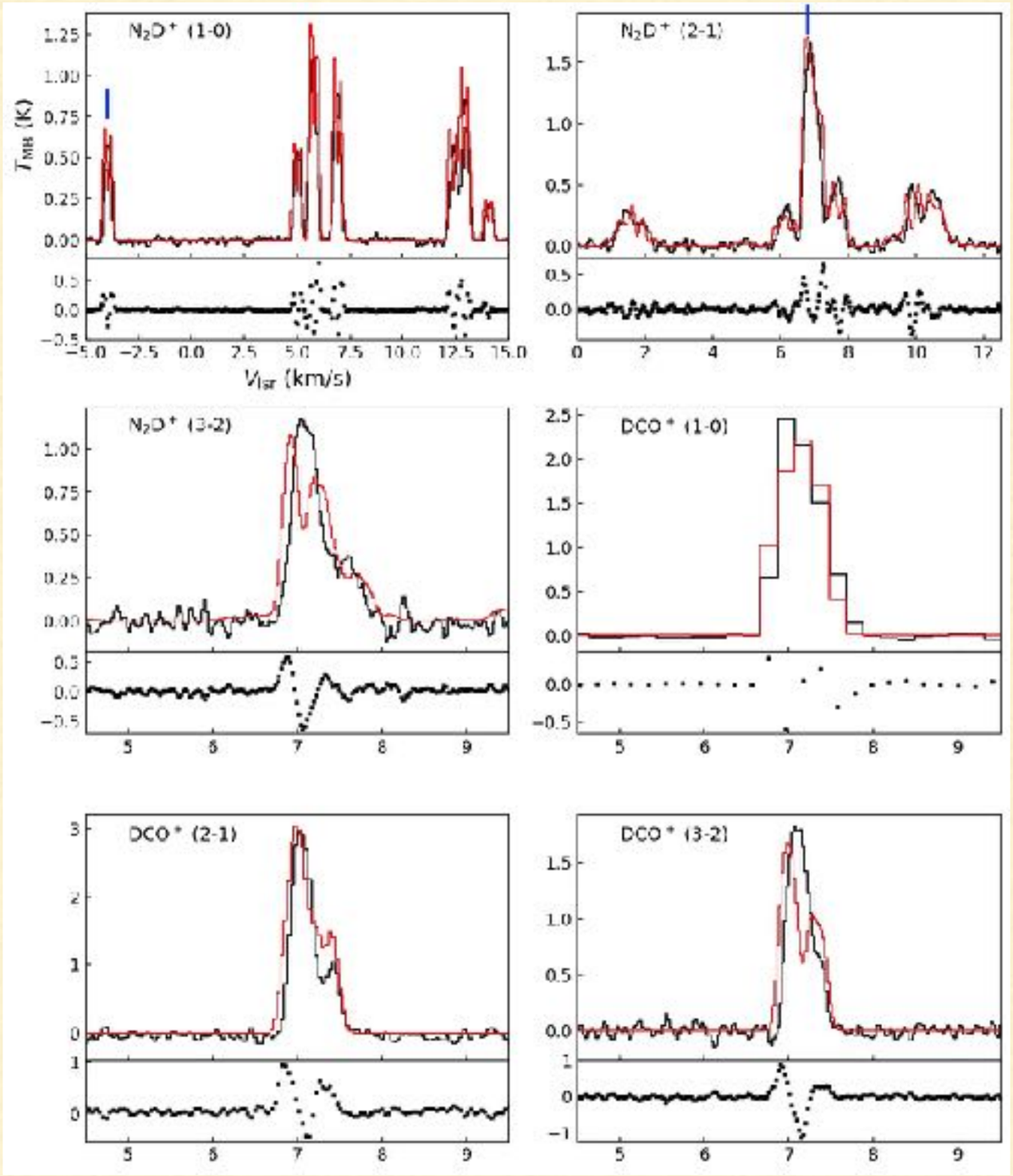
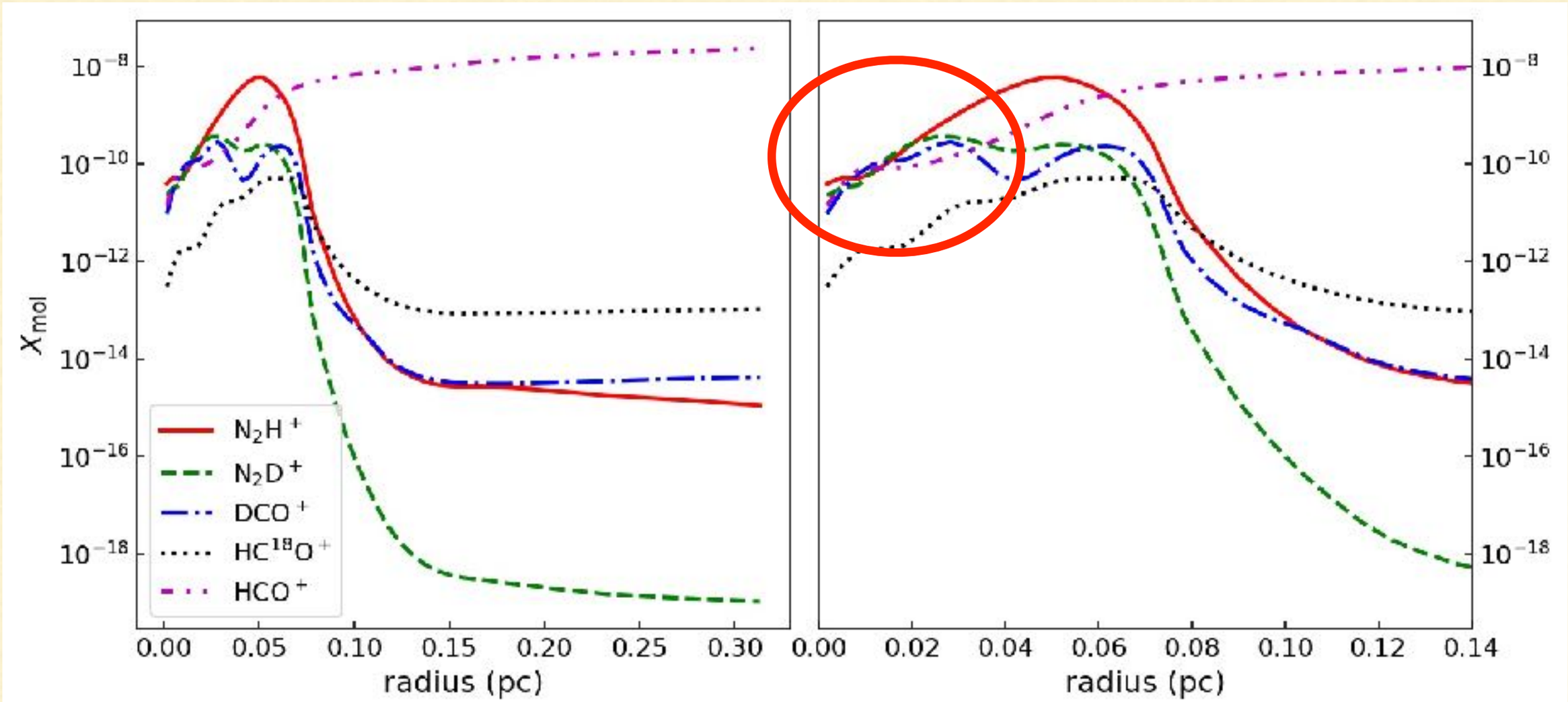


FINAL ABUNDANCE PROFILES



$t = 10^6$ yr

$A_v = 1$ mag (but HCO^+)

Depletion of all molecules

MOLECULAR COLUMN DENSITIES

With MOLLIE results, I can derive
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Radiative transfer equations:

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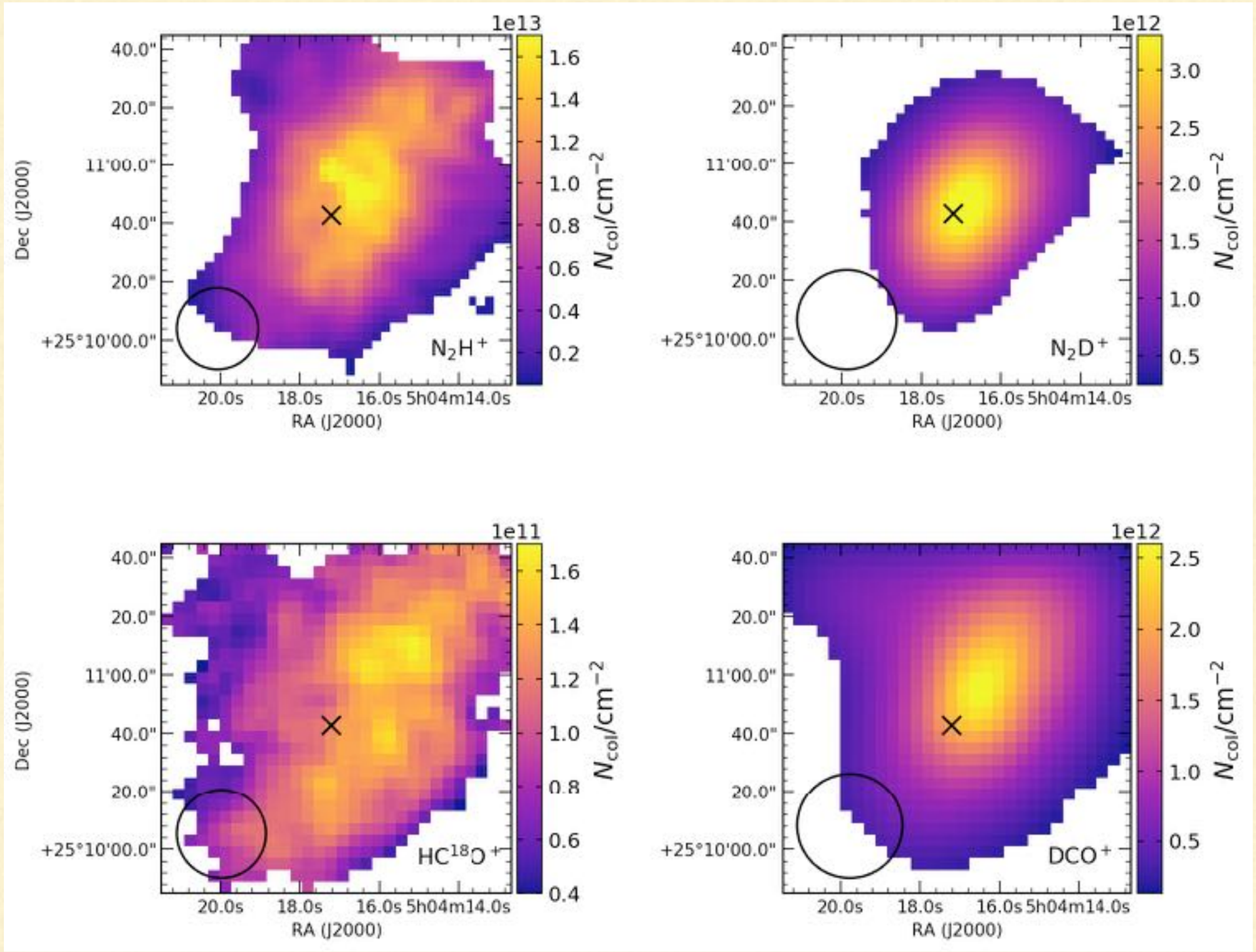
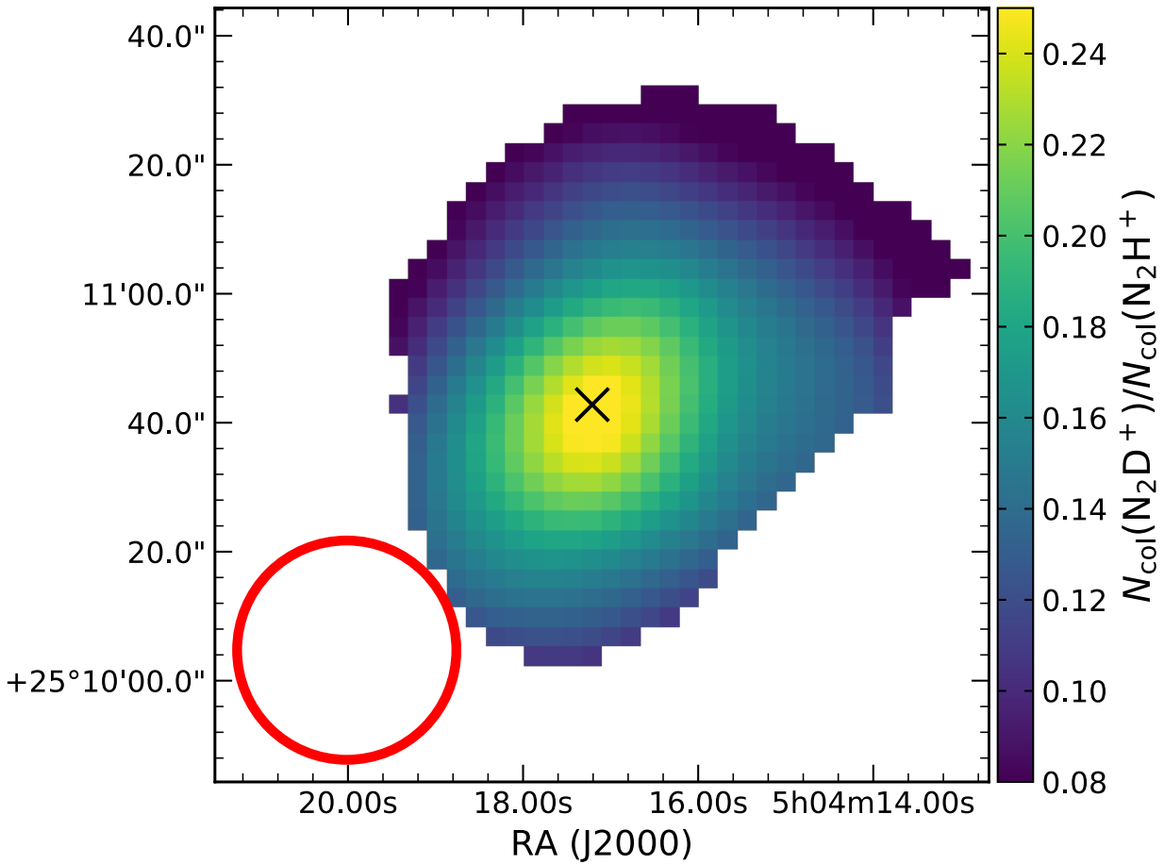
FINAL N_{COL} MAPS

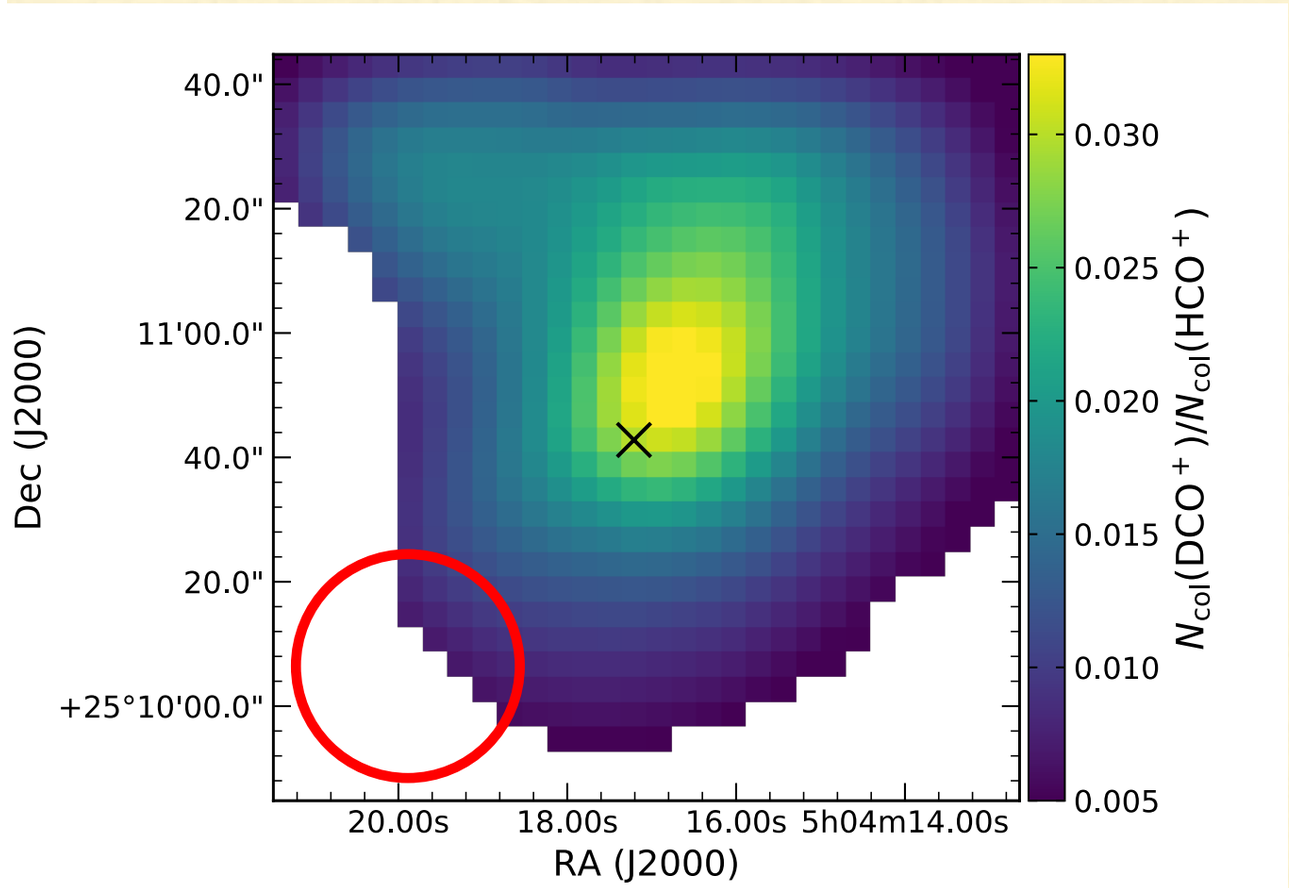


DEUTERATION MAPS



$$\mathrm{D/H_{N_2H^+}} = 0.26^{+0.15}_{-0.14}$$

$$\mathrm{D/H_{HCO^+}} = 0.035^{+0.015}_{-0.012}$$



CONCLUSIONS

- All molecules, including N_2D^+, experience depletion to some extent at the core centre

- Different J transitions do not share the same T_{ex}

- HCO^+ is significantly less fractionated than N_2H^+

THANKS FOR THE ATTENTION!

…Questions??