Cosmic Rays 2

09 November 2022

The cosmic-ray ionisation rate in the prestellar core L1544

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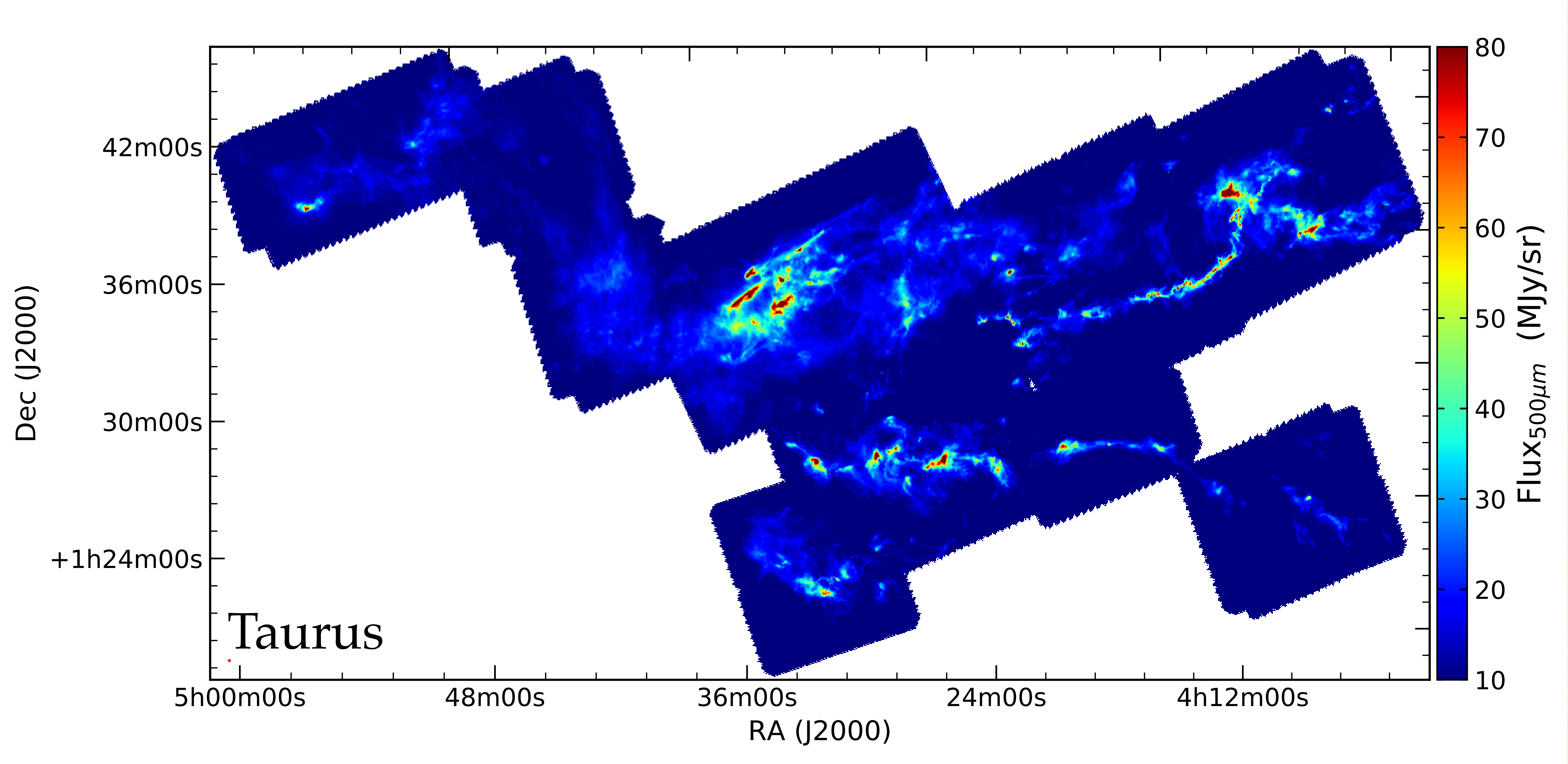
CR IN MOLECULAR CLOUDS



At A_v>1, UV photons are absorbed ⟶ CRs only ionising agents!

CR IN MOLECULAR CLOUDS

CRs only ionising agents!

$$\mathrm{CR} + \mathrm{H}_2 \rightarrow \mathrm{H}_2^+ + \mathrm{e}^- + \mathrm{CR}$$

$$\mathrm{H}_2^+ + \mathrm{H}_2 \rightarrow \mathrm{H}_3^+ + \mathrm{H}$$

<u>Ionisation fraction</u>

Fundamental for coupling B-fields to the matter

<u>Ion chemistry</u>

(in space, ion+neutral reactions are dominant)

DEUTERATION

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

Precursors of all deuterated species (in the gas phase)

OBSERVING THE CRIR

CR play a key role for the dynamics and chemistry of star forming regions

How can we derive it observationally?

Not an easy task

THE MOST "DIRECT" METHOD

Based on the detection of H_3^+, which has a simple chemistry

$$\mathrm{CR} + \mathrm{H}_2 \rightarrow \mathrm{H}_2^+ + \mathrm{e}^- + \mathrm{CR}$$

$$\mathrm{H}_2^+ + \mathrm{H}_2 \rightarrow \mathrm{H}_3^+ + \mathrm{H}$$

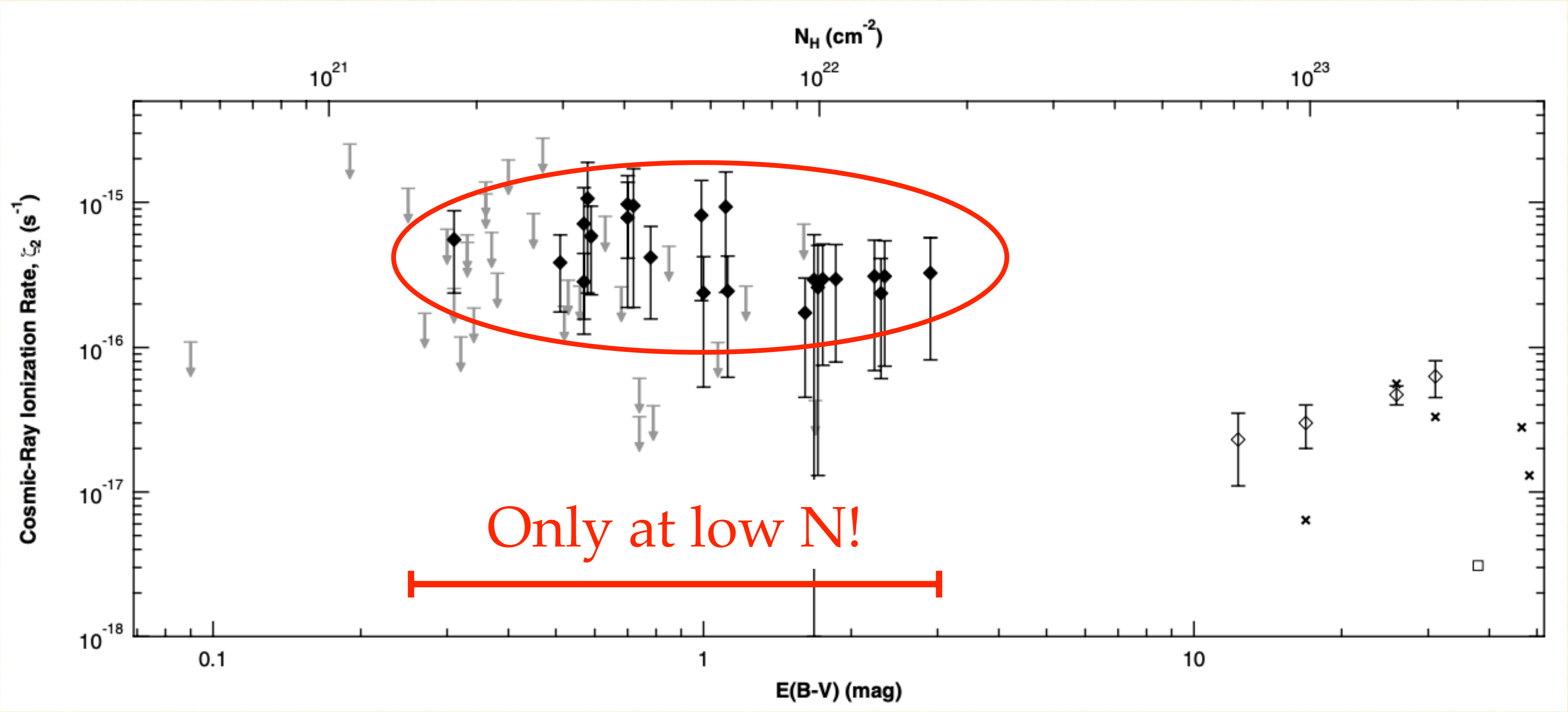
$$\mathrm{H}_3^+ + \mathrm{e}^- \rightarrow \mathrm{H}_2 + +\mathrm{H}$$

$$\mathrm{H}_3^+ + \mathrm{CO} \rightarrow \mathrm{HCO}^+ + \mathrm{H}_2$$

Balancing formation and destruction,
one derives CRIR

Indriolo et al. (2007, 2012)

THE MOST "DIRECT" METHOD

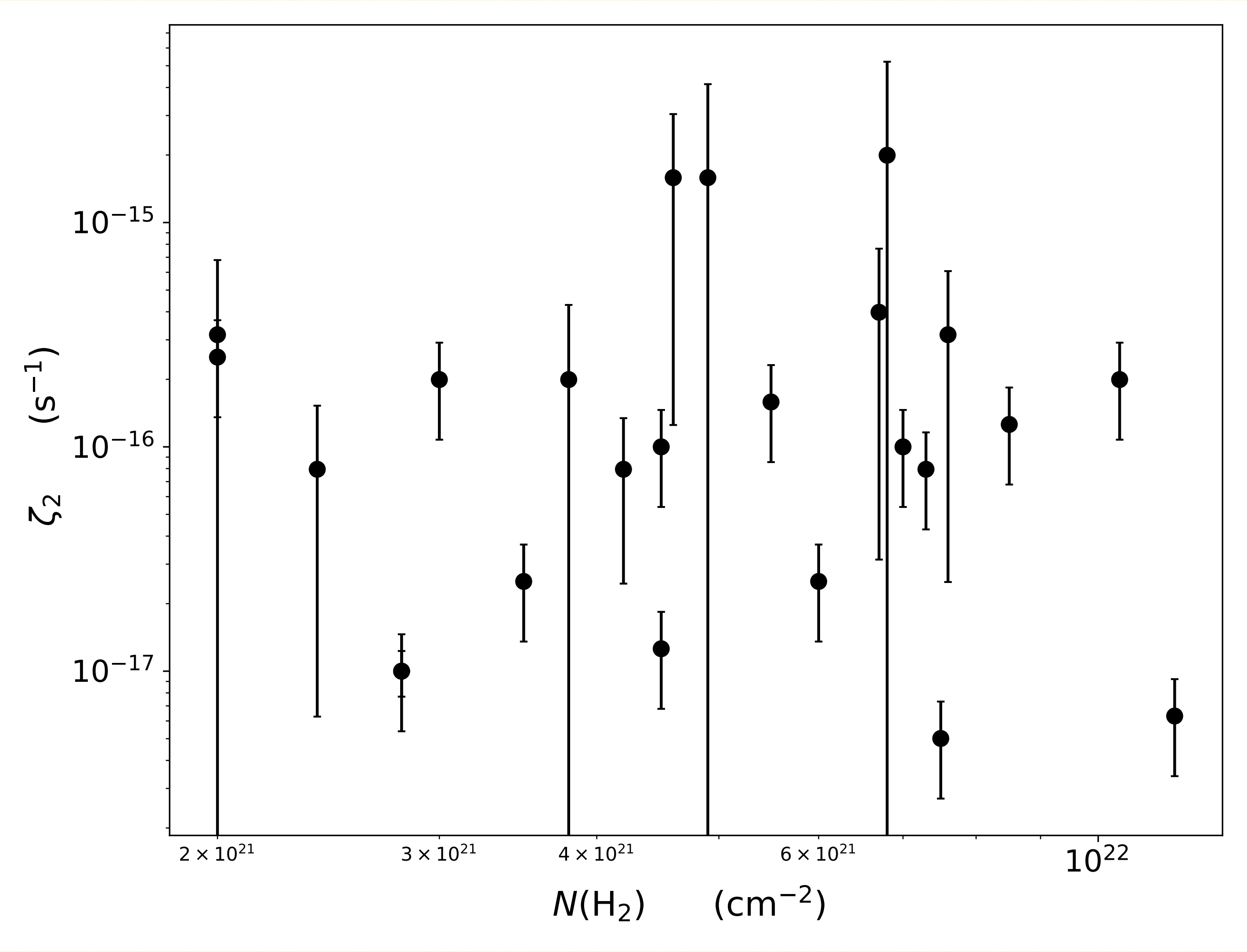


Indriolo et al. (2012)

AT HIGHER DENSITIES

Things become more complex…

Some sort of underlying chemical model is needed

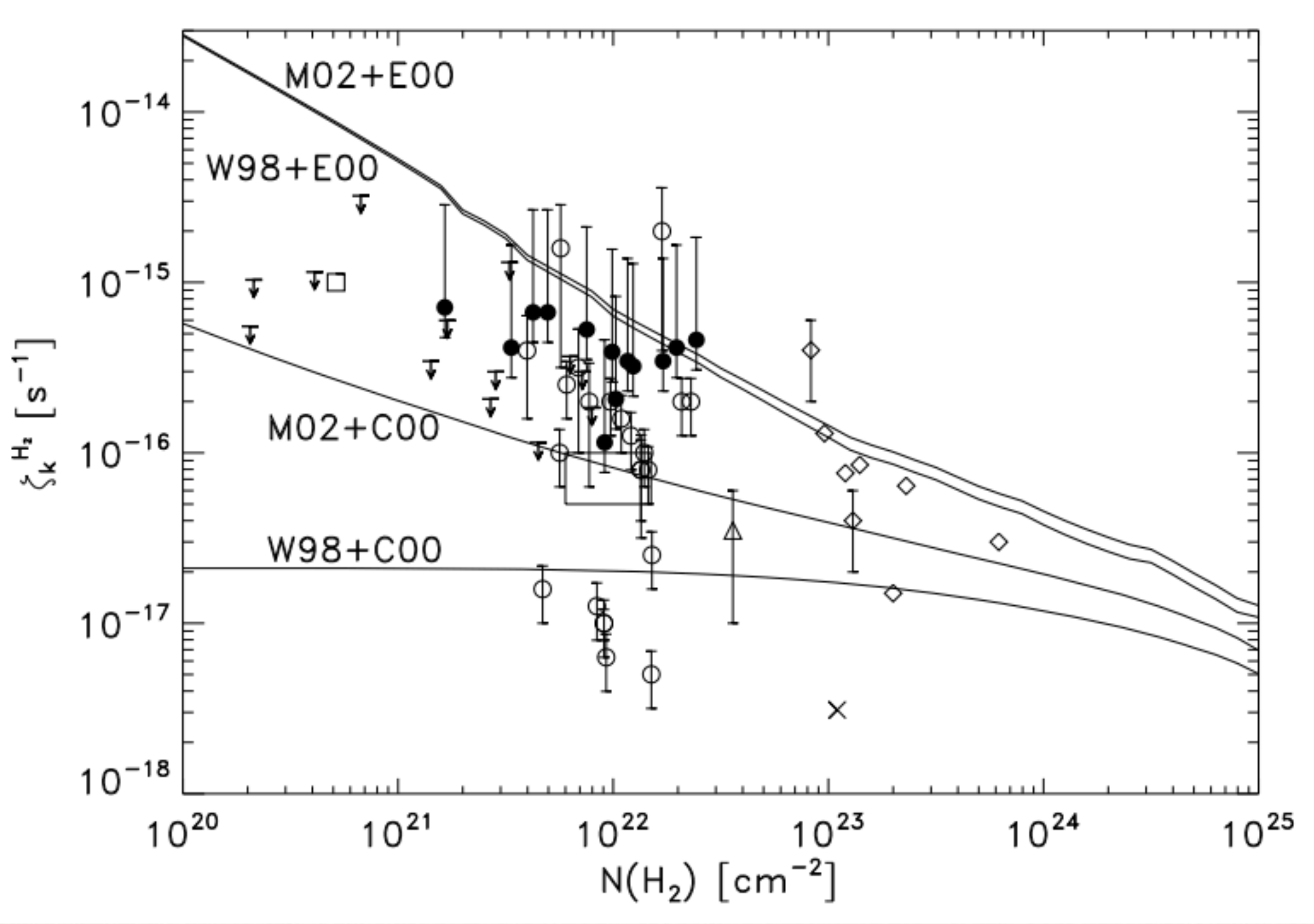


Pioneering work: Caselli et al. 1998

- Used DCO^+, $H^{13}CO^+$, $C^{18}O$ data
- Simple steady-state chemistry
- Strongly dependent on depletion, metal abundance,…

CR ATTENUATION

Primary CRs interact with the ISM and loose energy



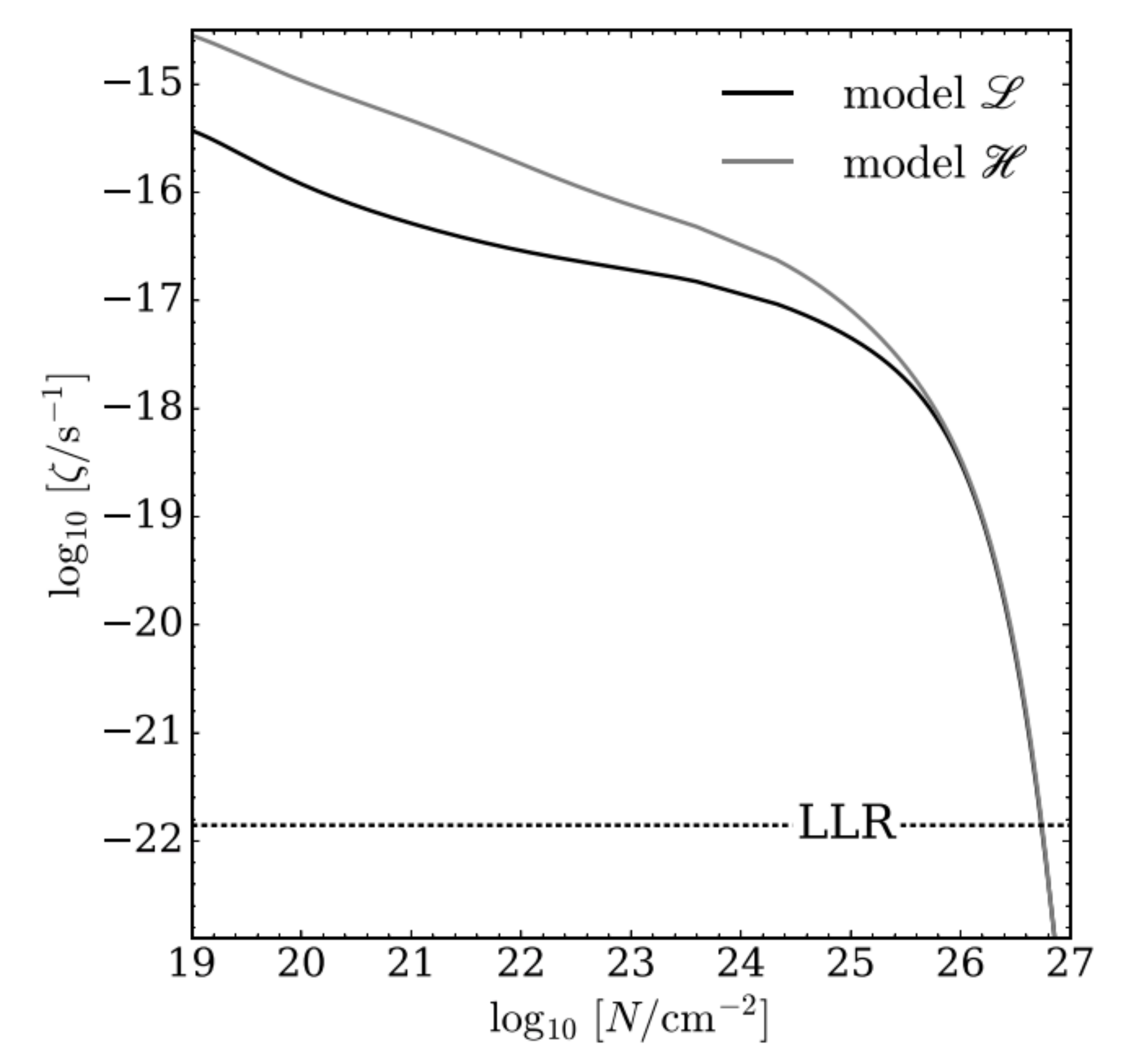
Padovani et al. (2009):

- Losses due to interactions with H_2
- Continuous slowing down approximation
- Various model for the CR spectra at low energies

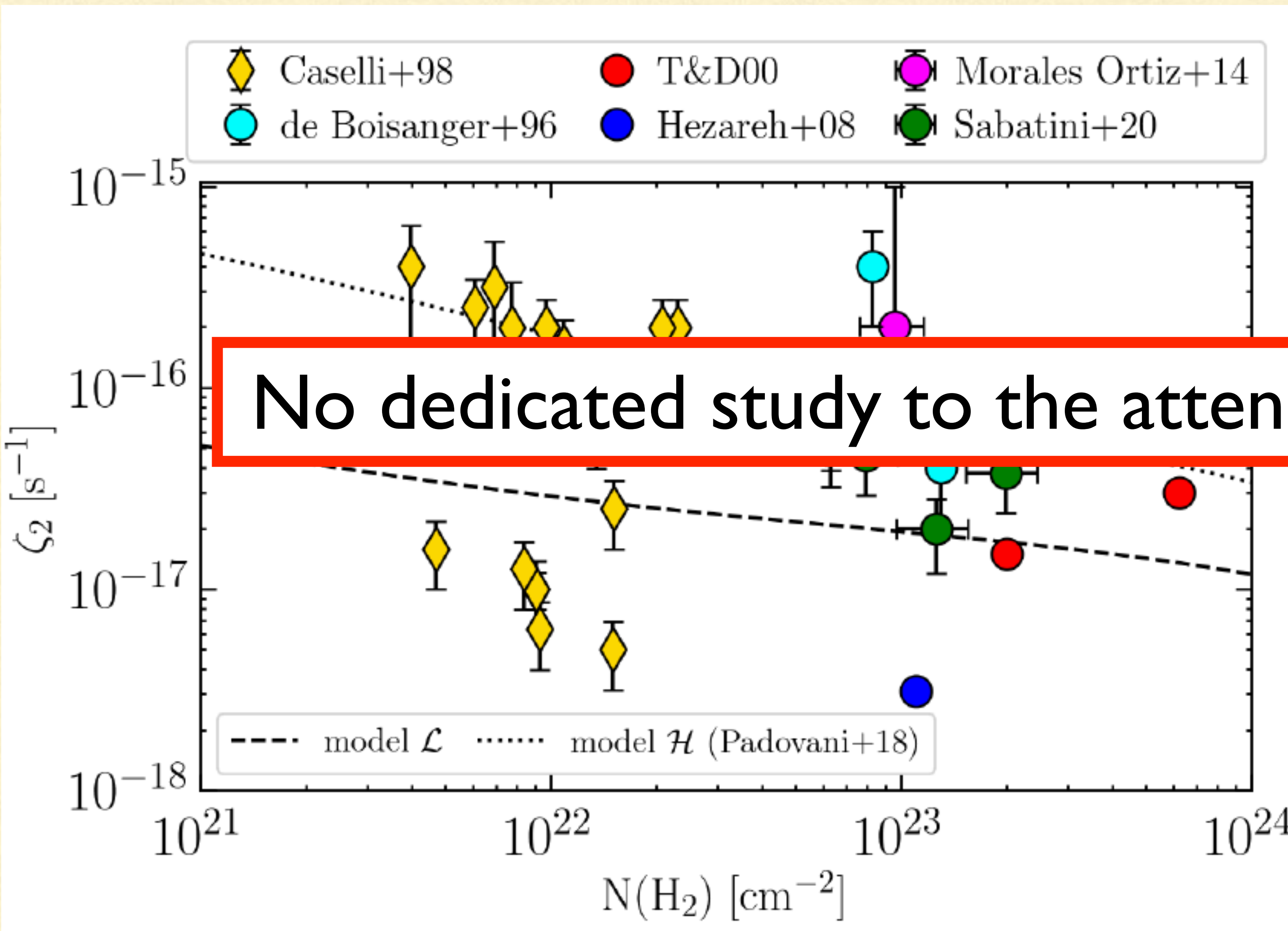
CR ATTENUATION

Padovani et al. (2018):

- Expanded the work at higher N
- Two models: “High” and “Low” (from Ivlev et al. 2015)



CR ATTENUATION: OBSERVATIONS?



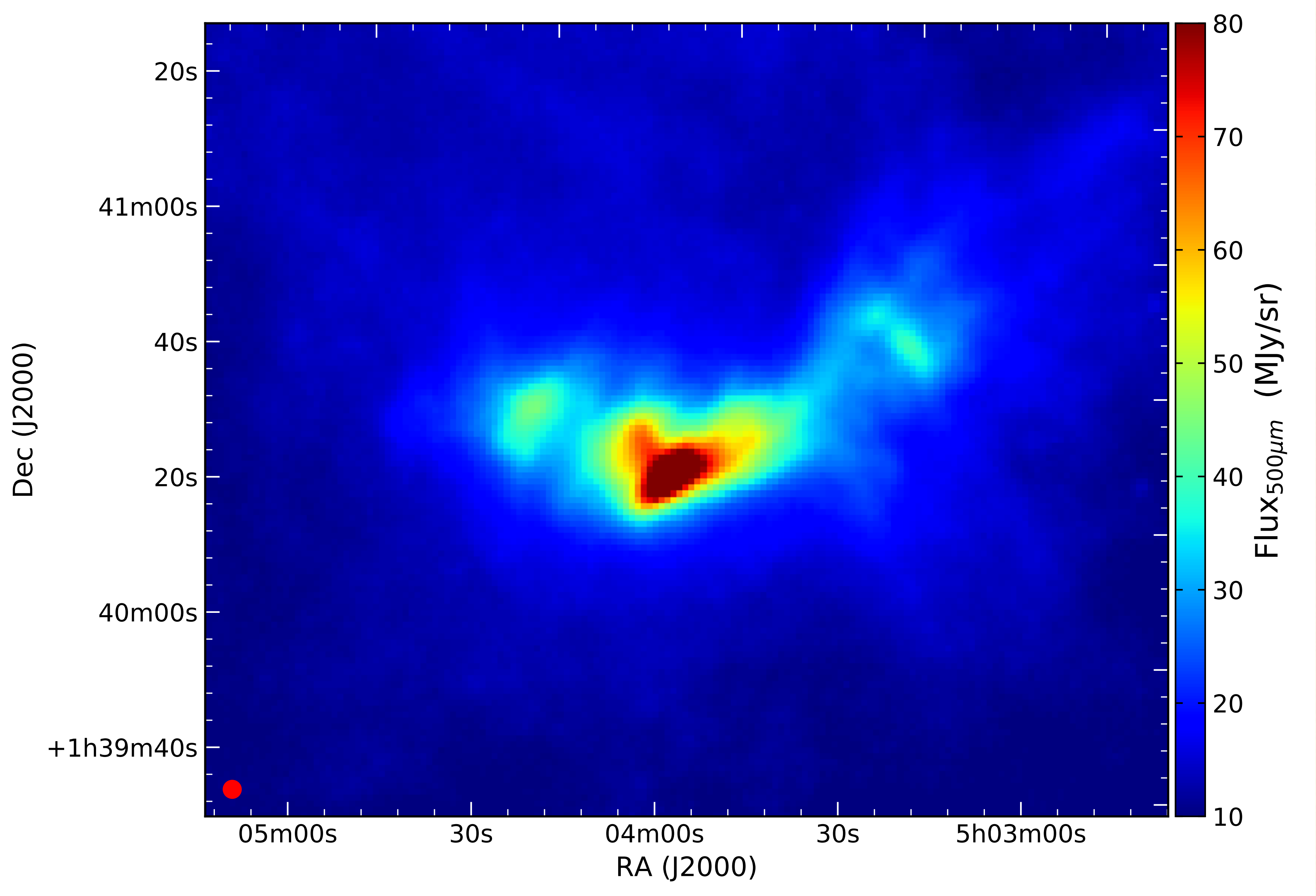
No dedicated study to the attenuation in one source

Based on the method from

It uses observations of H_2D^+, $C^{18}O$, $H^{13}CO^+$, DCO^+

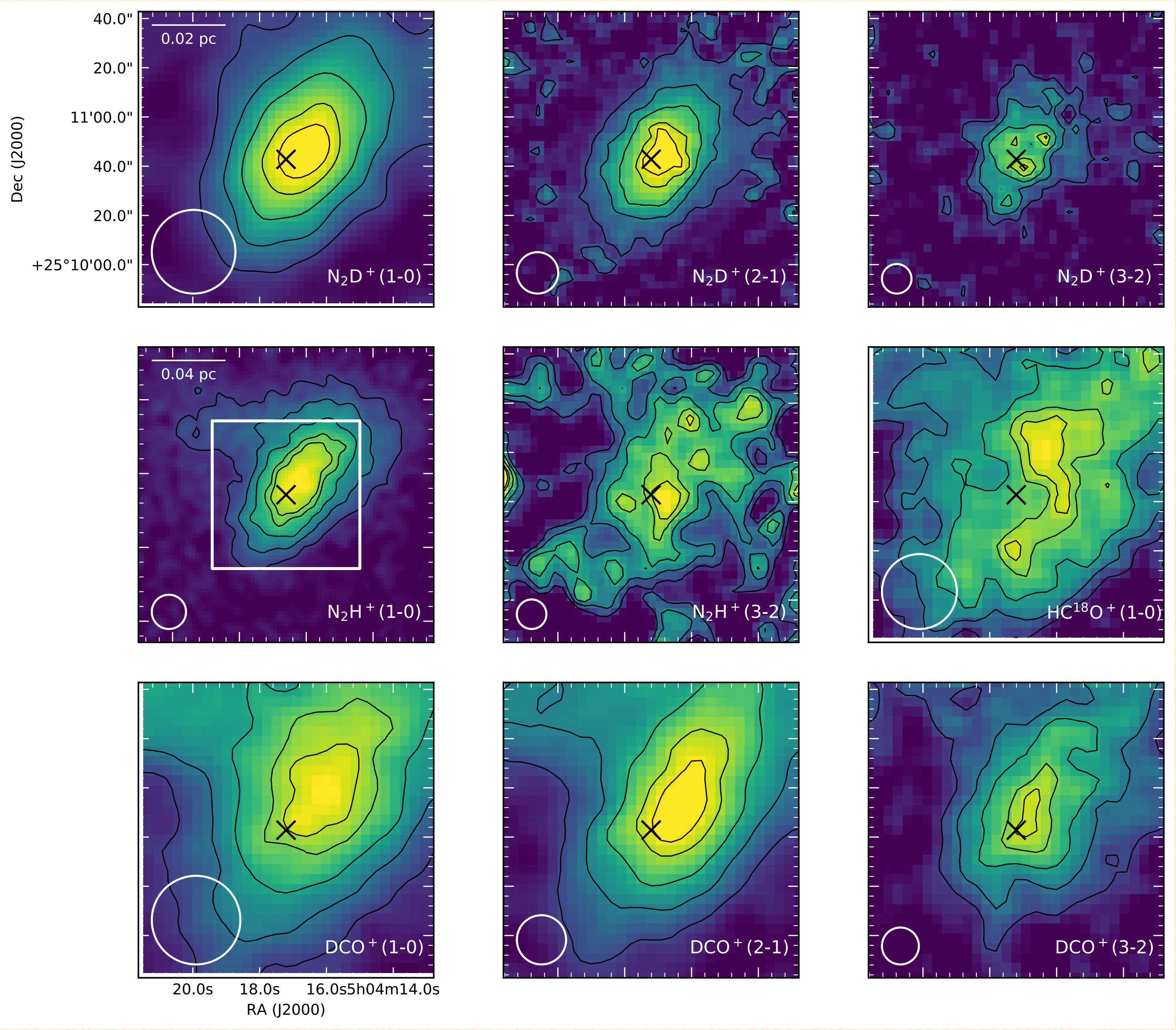
Sabatini et al. (2020)

CRIR IN L1544



- Close (d~170 pc)
- Isolated
- ~10 $M_\odot$
- Many observational/theoretical studies

INTEGRATED INTENSITY MAPS

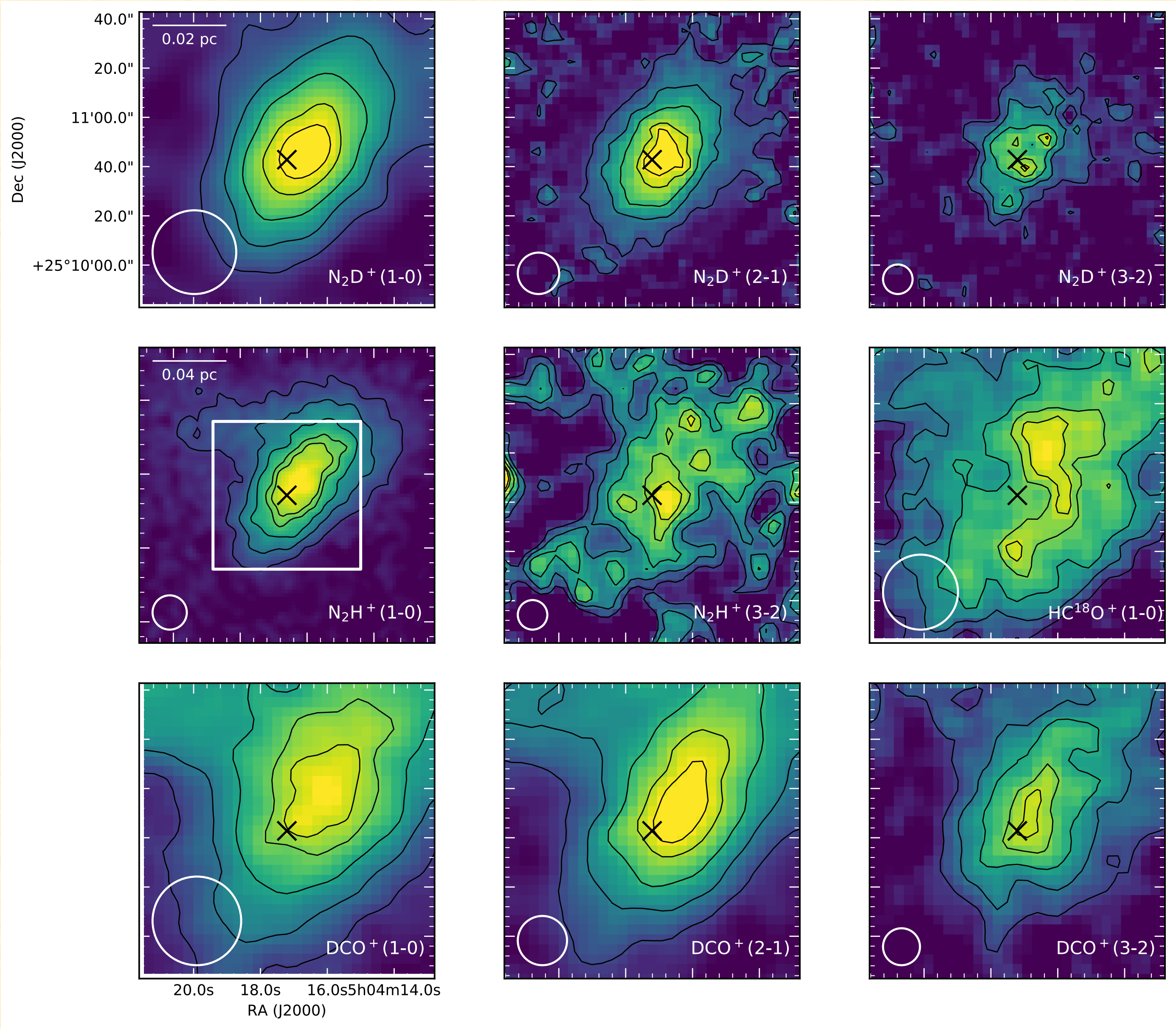


The collected data:

- IRAM 30m
- High spectra resolution
- Multiple transitions of 4 species

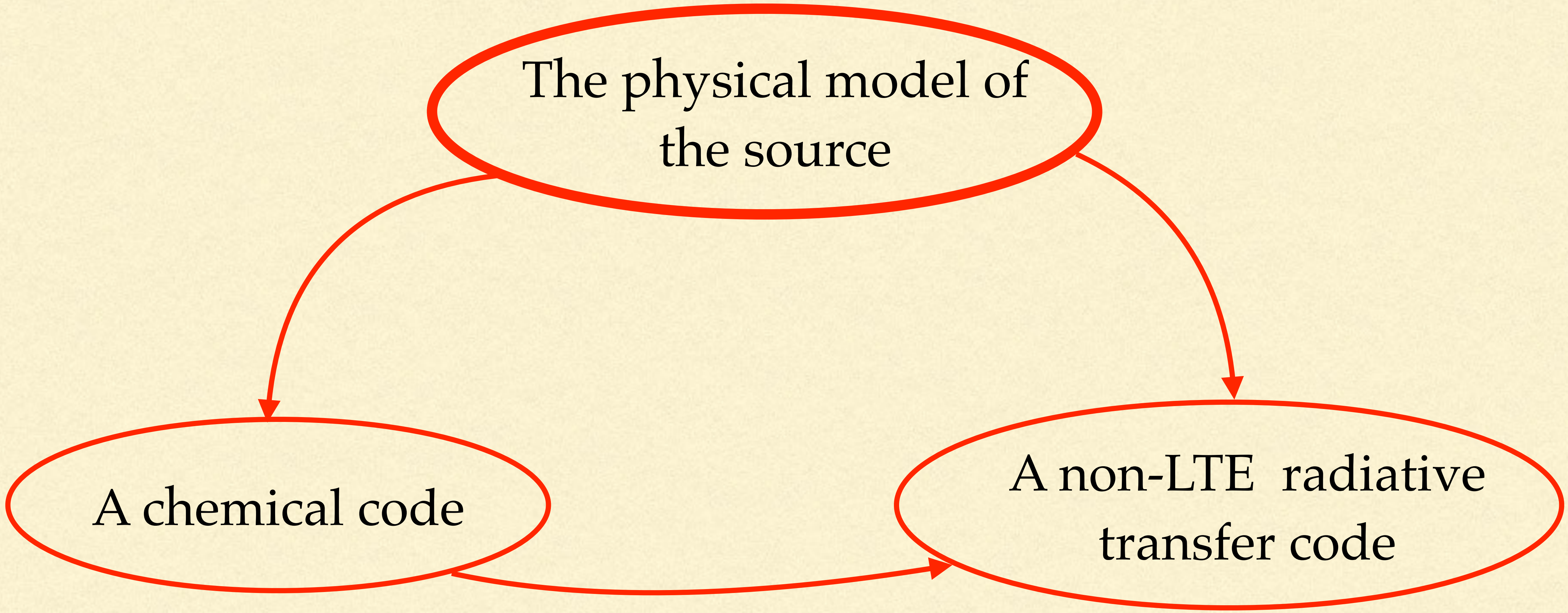
Redaelli et al. (2019)

INTEGRATED INTENSITY MAPS



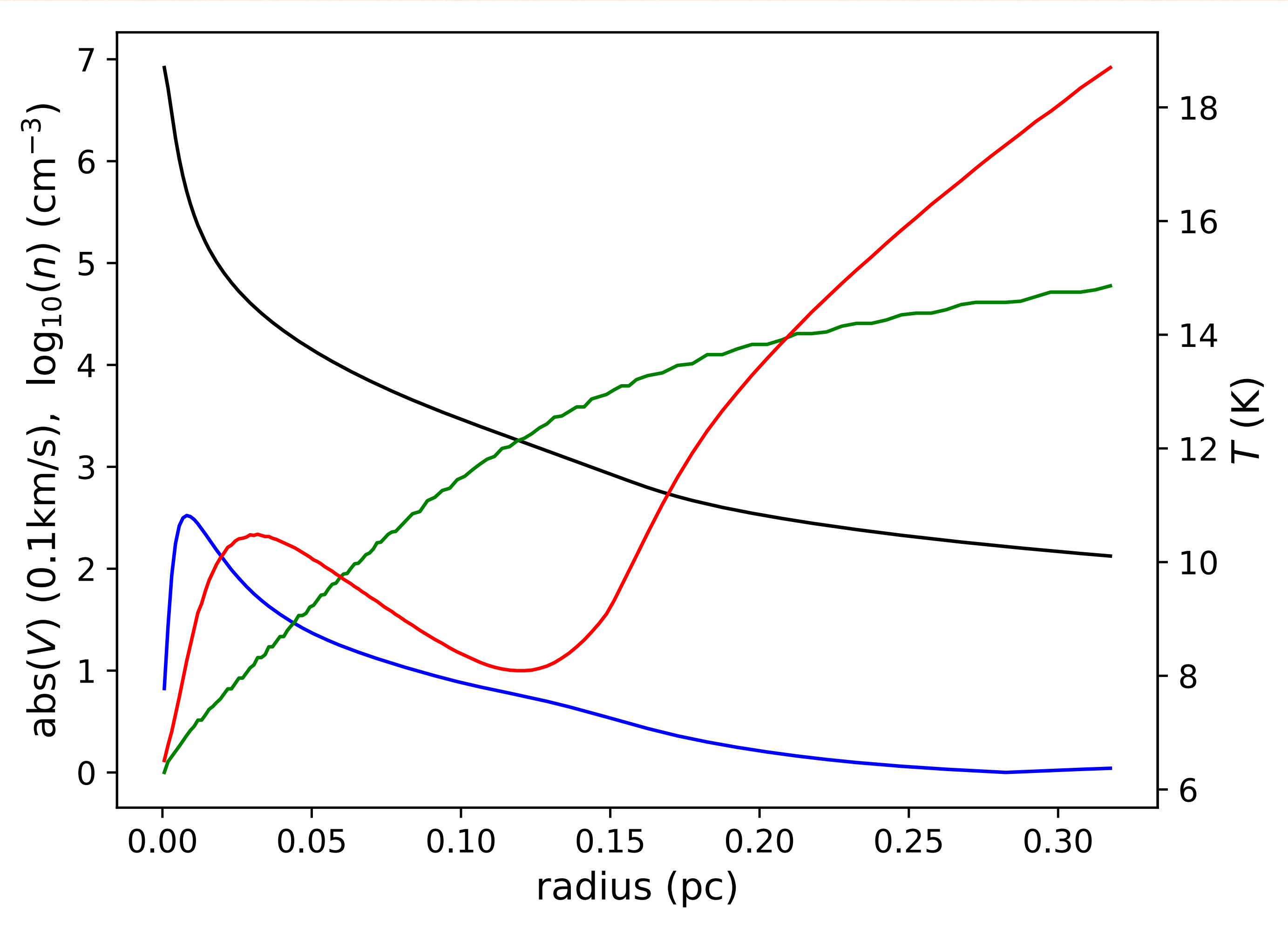
We can use these data, together with a chemical code, to investigate the CR ionisation properties of L1544

THE “INGREDIENTS”



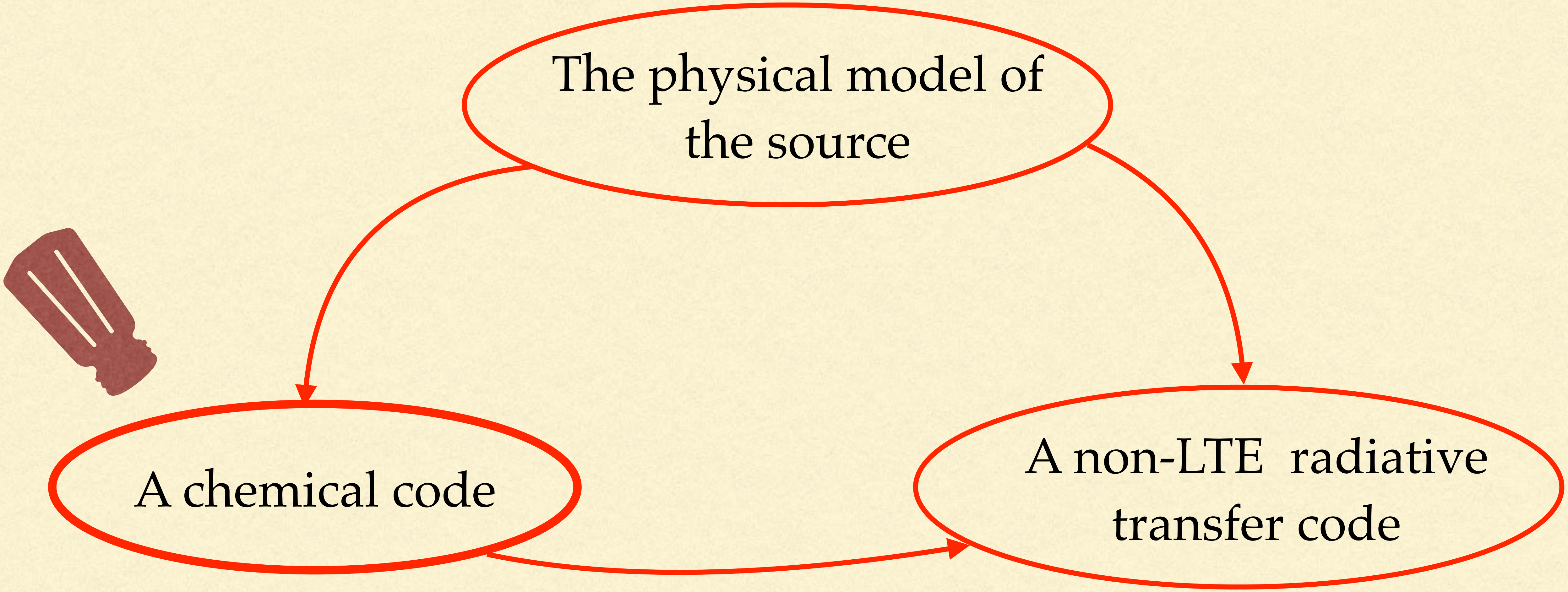
THE "INGREDIENTS"

The physical model of the source



Keto&Caselli (2015)

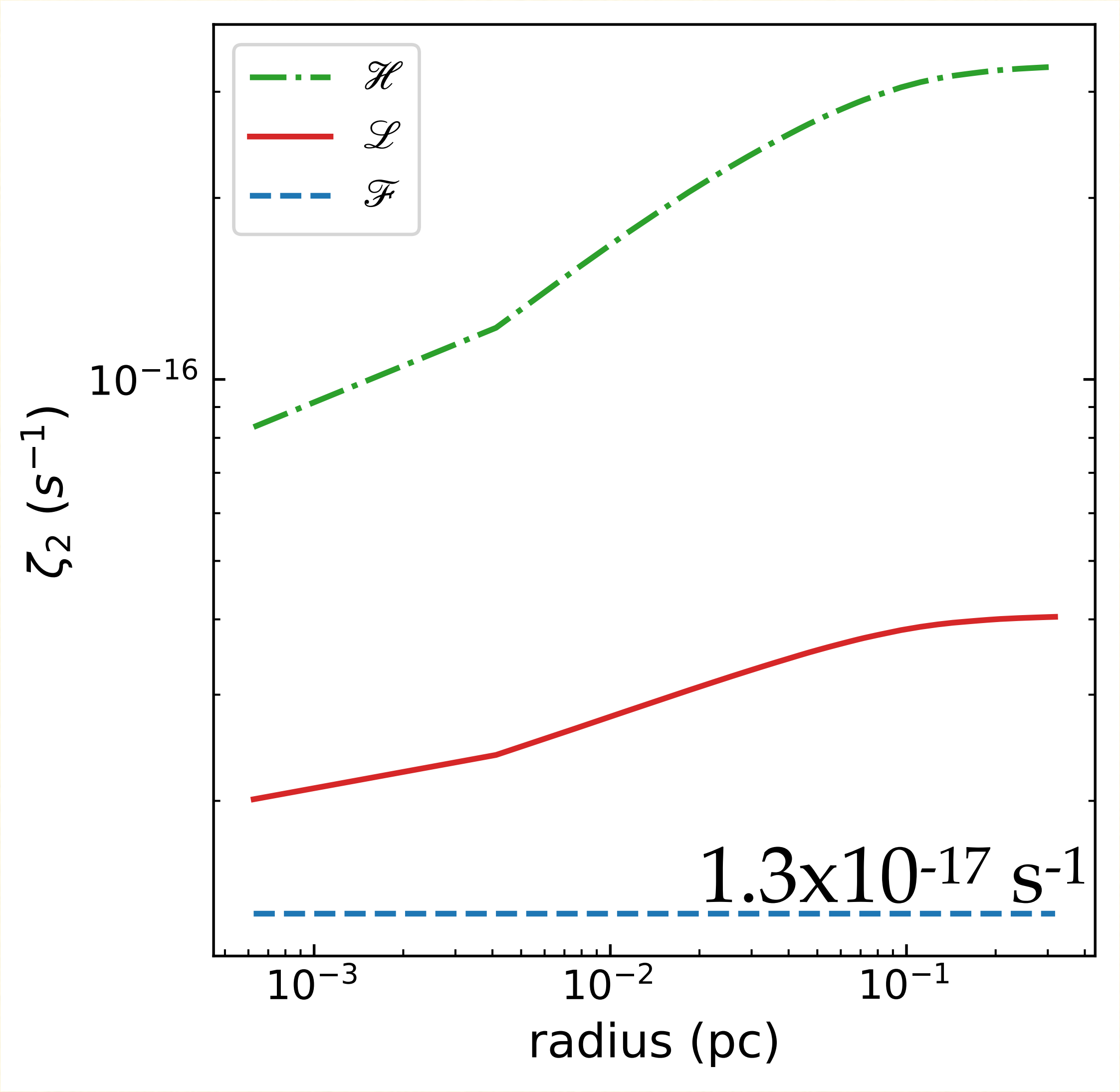
THE "INGREDIENTS"



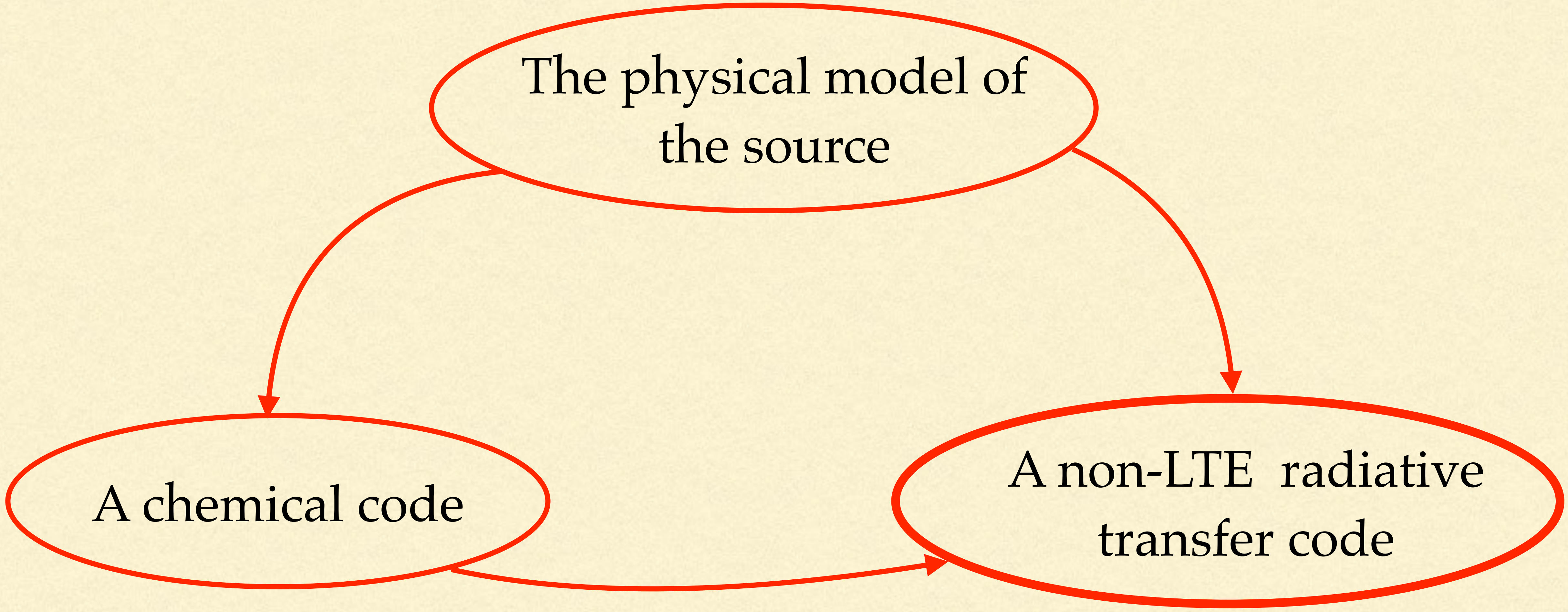
THE "INGREDIENTS"

A chemical code

- Gas-grain chemical code from Sipilä et al. (2015a, 2015b, 2019)
- Spin-separated for deuterium
- Run "statically"
- It accepts profiles for CRIR



THE "INGREDIENTS"

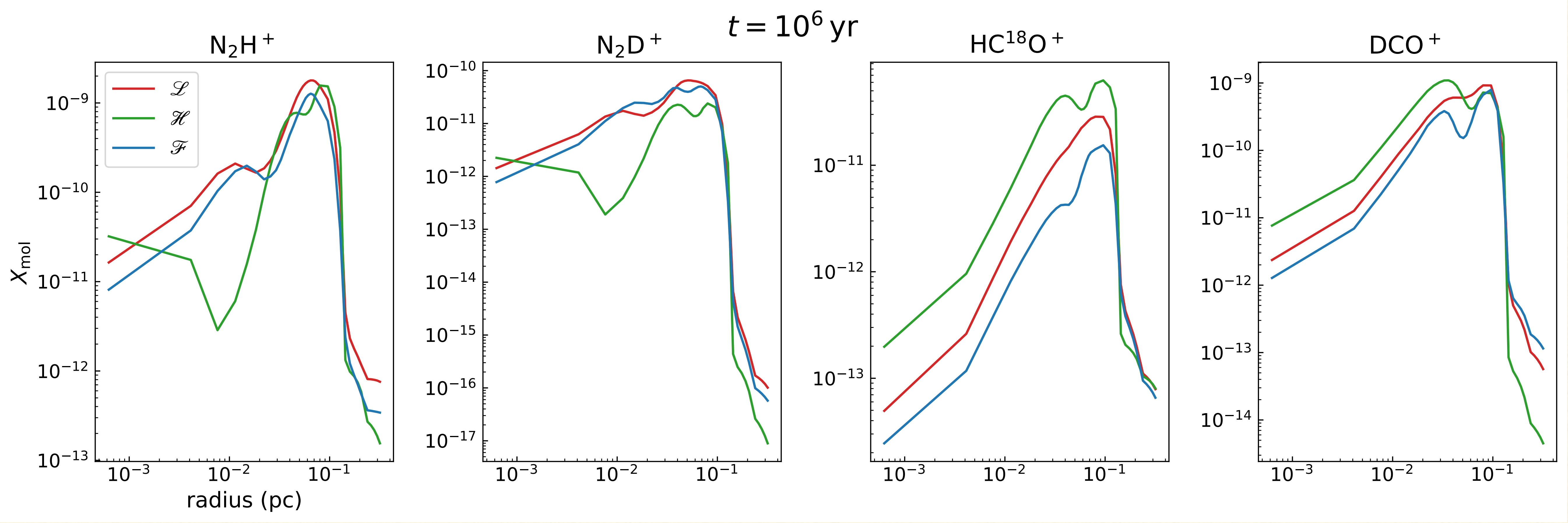


THE "INGREDIENTS"

A non-LTE radiative transfer code

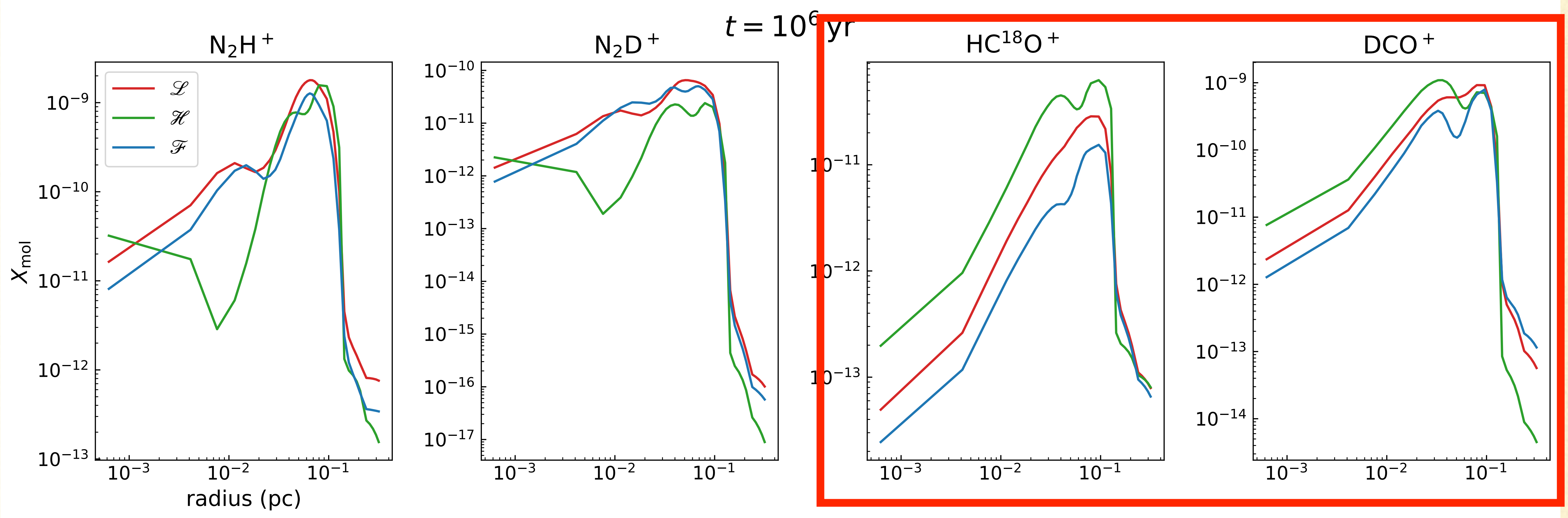
- Performed with MOLLIE (Keto 1990)
- No full sampling of parameter space
- The whole abundance profile can be multiplied by a factor f_{corr}

ABUNDANCE PROFILES

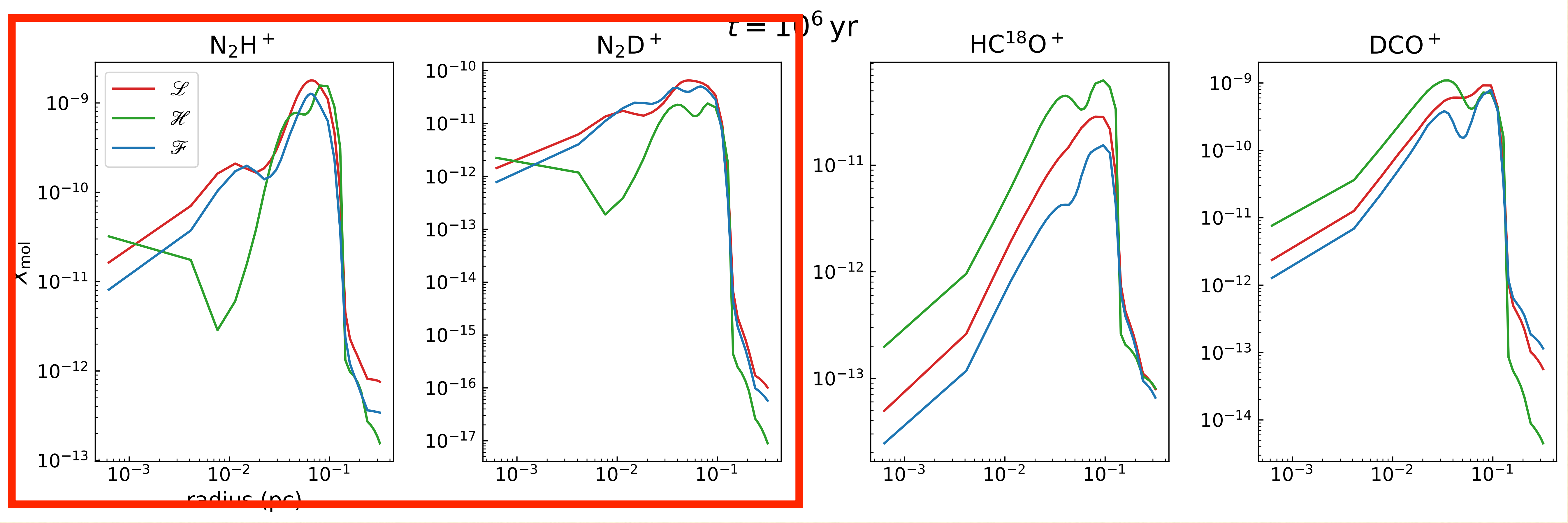


ABUNDANCE PROFILES

HCO+ and DCO+ are more sensitive to the CRIR

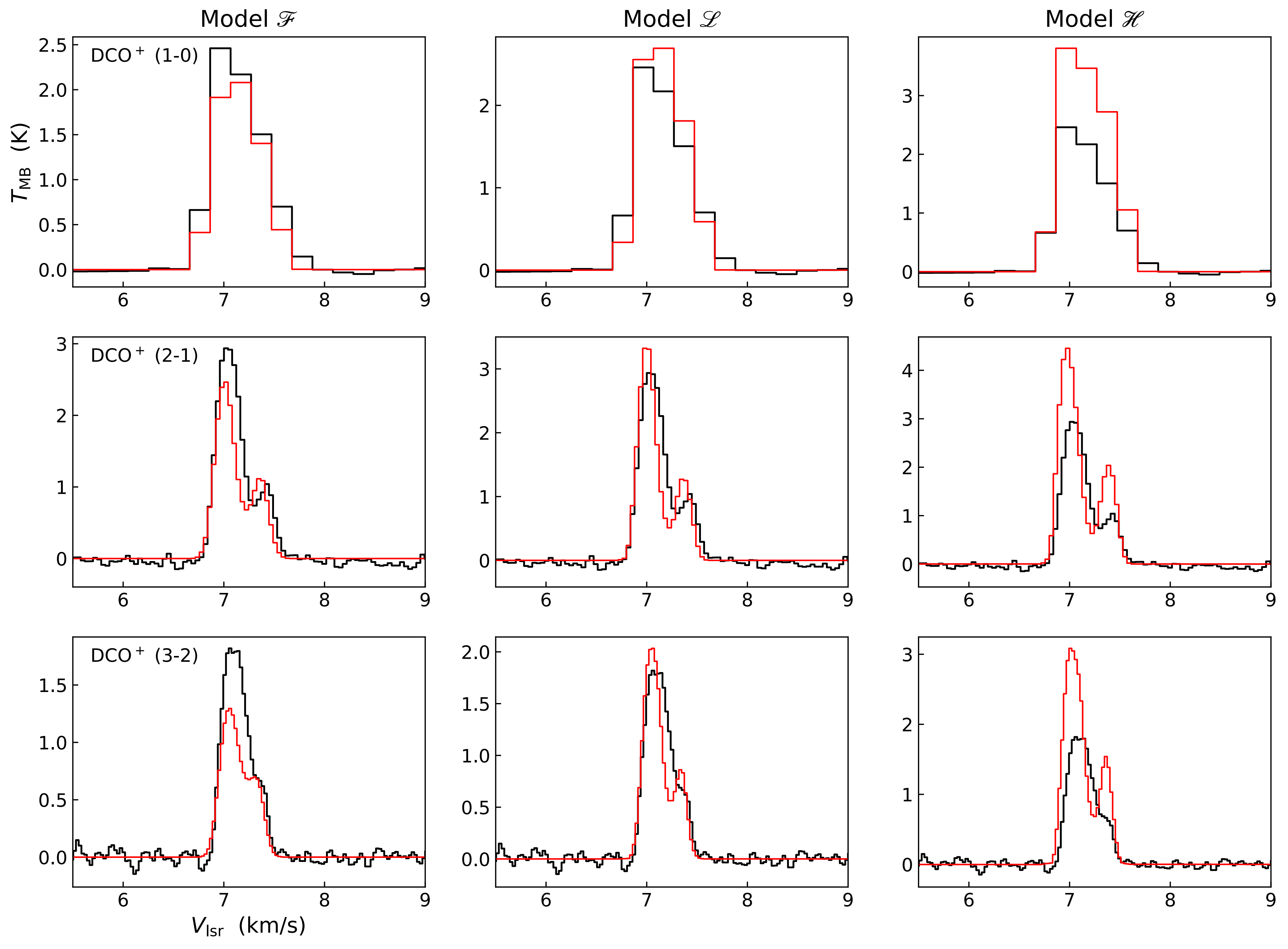


ABUNDANCE PROFILES



N_2H^+ and N_2D^+ have a more complex dependency

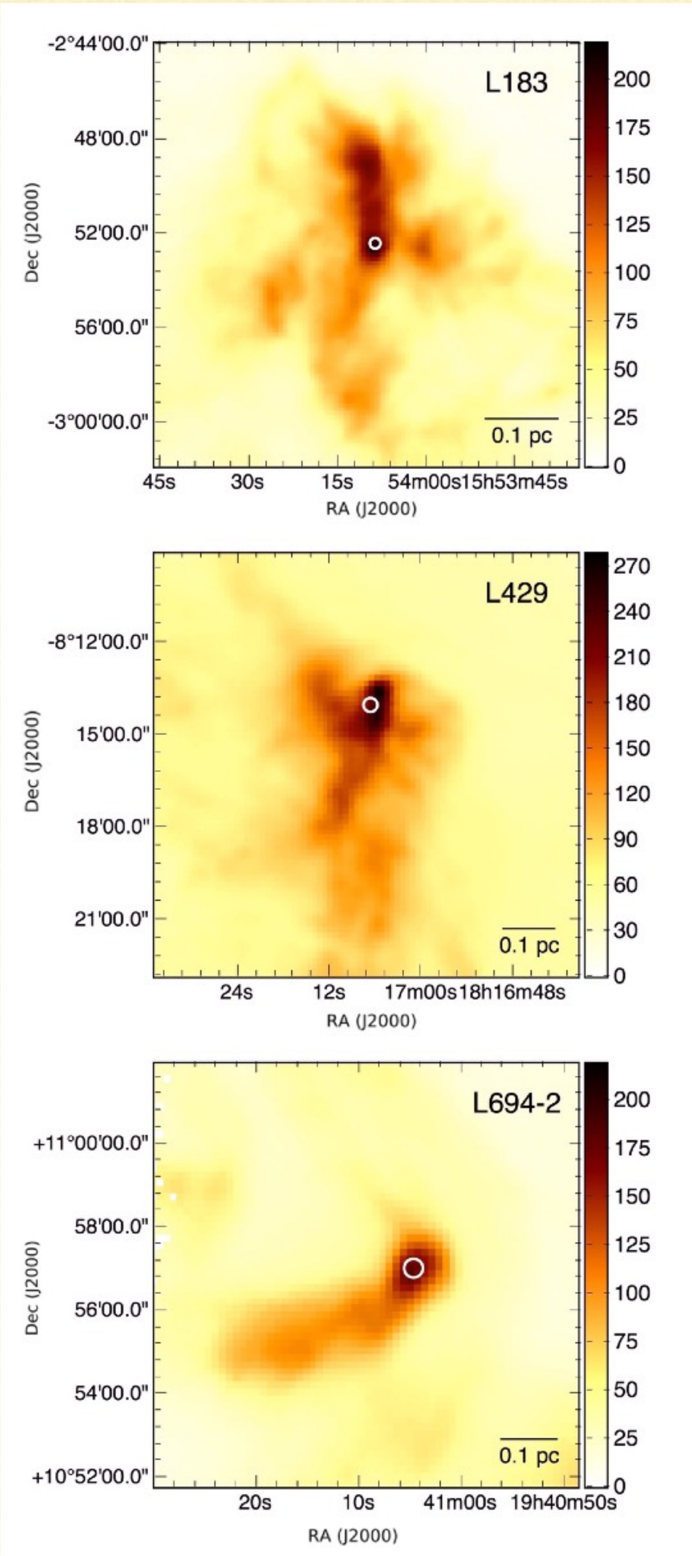
RESULTING FITS: DCO^+



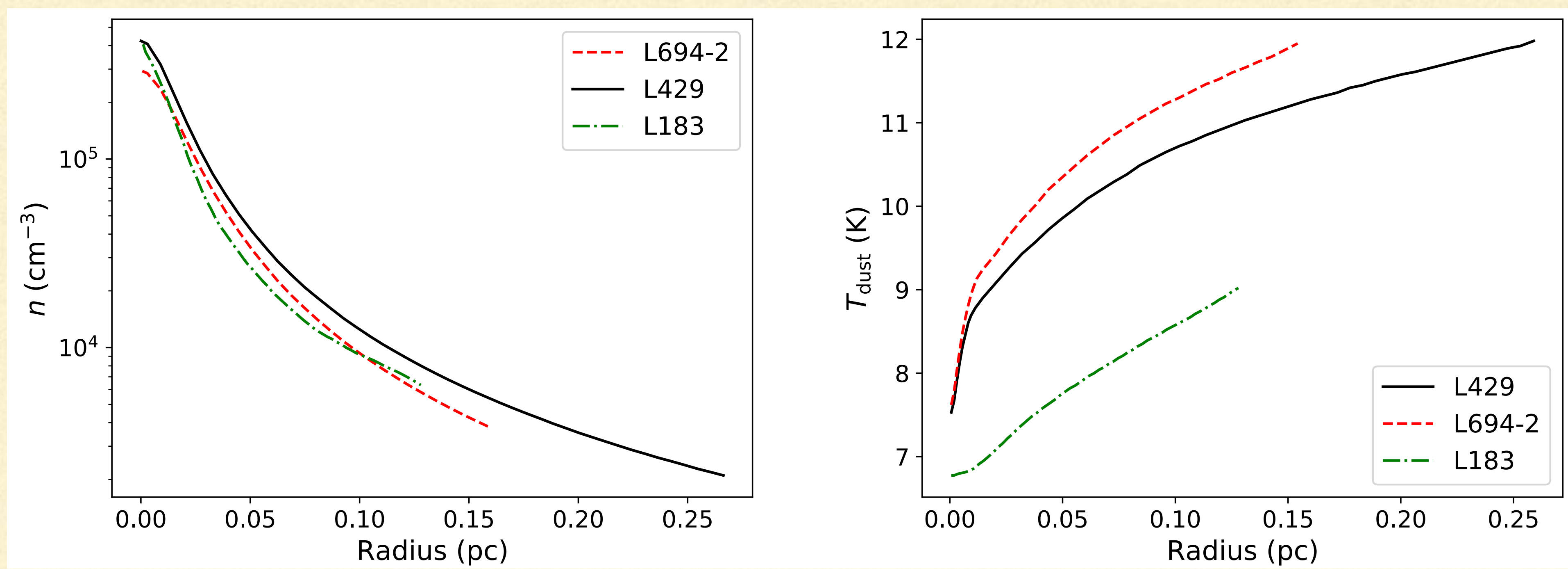
CONCLUSIONS

- L1544 is consistent with the “low” model of PI18
- Model “high” (which reproduces data in diffuse clouds) is excluded
- Higher resolution is needed to “catch” the attenuation
- What about other sources?

FUTURE PERSPECTIVES



Source	Coordinates[a]	Distance (pc)[b]	Location
L183	$15^h54^m8.32^s$, $-2^\circ 52'23.0''$	110	High lat. cloud
L429	$18^h17^m6.40^s$, $-8^\circ 14'0.0''$	200	Aquila Rift
L694-2	$19^h41^m4.50^s$, $10^\circ 57'2.0''$	250	Isolated core



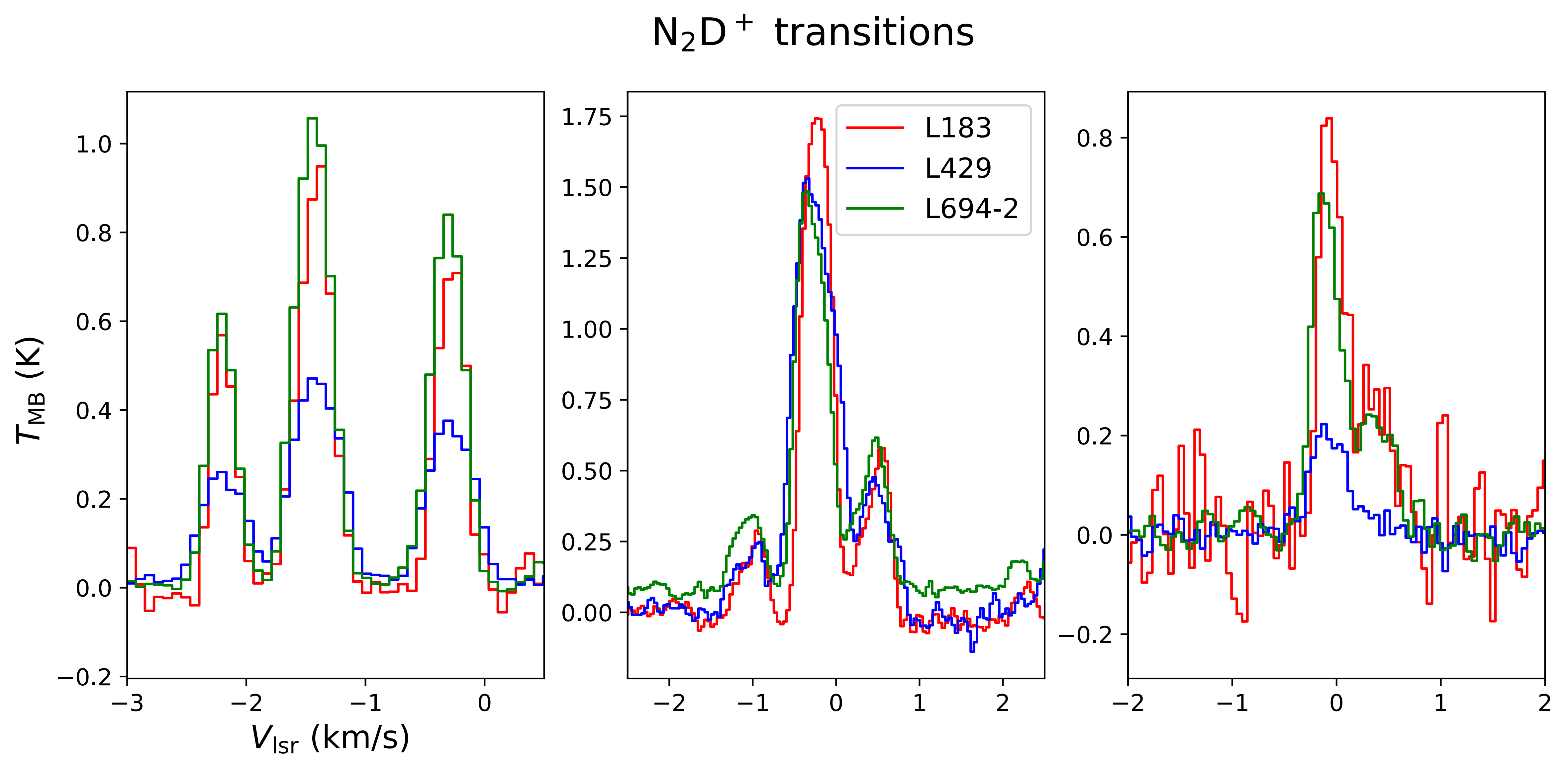
Redaelli+2018

IRAM 30M DATA

Line	Dv (km/s)	Rms (mK)		
		L183	L429	L694-2
DCO^+ (1-0)	0.2	20	40	30
DCO^+ (2-1)	0.08	15	10	15
DCO^+ (3-2)	0.05	40	30	20
N_2D^+ (1-0)	0.08	40	10	10
N_2D^+ (2-1)	0.04	30	30	15
N_2D^+ (3-2)	0.05	90	20	30
N_2H^+ (1-0)	0.06	20	20	10
N_2H^+ (1-0)	0.05	30	40	40
$HC^{18}O^+$ (1-0)	0.07	20	15	15

All detected with S/N>10!

FIRST LOOK AT THE DATA



THANKS FOR THE ATTENTION!

…Questions??