3D Modelling of HCO⁺ in The Low-mass Proto-star IRAS16293-2422

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Overview of the source

Goal: study the formation mechanism in a low-mass proto-star such as IRAS16293

- Better understanding of the different formation stages of future Sun-like stars.

- Located at 120 pc from the Sun (\(\rho\) Ophiuchus complex)
- Mass similar to the Sun (\(\sim 1\ M_\odot\))
- Luminous (22 \(L_\odot\))
- Binary system: 2 sources (Wootten et al. 1989; Pech et al. 2010)
  - A (1 \(M_\odot\)) and B (< 0.1 \(M_\odot\))
  - distant by 5’’
Why studying HCO$^+$ ?

- Tracers of the ionisation rate in the proto-stellar environment.

- Gravitational collapse slowed down by collisions between neutral species and ions + electrons linked to the magnetic field.

- Ionisation allows to create and destroy more complex molecules (up to COMs).
How studying HCO$^+$?

- Spectral surveys CHESS (Herschel/HIFI) and TIMASSS (IRAM 30m and JCMT + APEX) towards IRAS16293: 80-1000 GHz ($E_{up} \leq 850$ K)

- HCO$^+$: 11 transitions
- H$^{13}$CO$^+$: 7 transitions
- HC$^{18}$O$^+$: 5 transitions
- DCO$^+$: 5 transitions
- D$^{13}$CO$^+$: 3 transitions

31 transitions
3D modelling of the source

- 2 steps: generation of the 3D physical model + radiative transfer solution
- **GASS code**: Generator of Astrophysical Sources Structures (Quénard et al., in prep.)
- Radiative transfer code LIME (Brinch et al. 2010): 3D, non-LTE, Monte-Carlo/ALI method

⇒ GASS is coupled to LIME thanks to its interface (GUI)
GASS code
Generator of Astrophysical Sources Structures
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Generator of Astrophysical Sources Structures
Physical structure (H$_2$ density, temperature) determined by Crimier et al. (2010).

To fit line profiles, the infall radius ($r_{\text{inf}}$) is taken to be 2400 AU instead of 1280 AU.

No need to consider the multiplicity of the source to study the emission of HCO$^+$. 

Source A dominating → we suppose that only one envelope is centred on it.
Formation and destruction

Good recipe to form and/or destroy HCO⁺:

- CO abundance
- Ionisation by cosmic rays (ζ)
- H₂ density

Other important reactions: fractionation and deuteration!

Estimation of isotopologues abundances (H₁³CO⁺, DCO⁺, D¹³CO⁺,...)

New theoretical study made by Mladenović et al. (2014)
Chemical code Nautilus (gas + grain) (Using the physical structure shown previously)

Abundance profile for the envelope only

Different parameters are varied:

- Cosmic rays ionisation rate $\zeta$
- Evolution of the initial parental cloud (age, density, temperature)
- Age of the proto-star

$\rightarrow$ Trend of the parameters on the abundance profile
Rao et al. (2009) & Girart et al. (2013):
Young outflow detected (~ 400 yrs) in IRAS16293, seen with H$^{13}$CO$^+$!

Rollins et al. (2014) and Rawlings et al. (2000, 2004):
HCO$^+$ abundant in young outflows ➔ Chemistry destroys HCO$^+$ in older outflows
Different parameters (supposed to be \textit{constant} through the outflow) are varied:

- Kinetic temperature
- \( \text{H}_2 \) density
- \( \text{HCO}^+ \) abundance
HCO$^+$
713.3 GHz

$T_{MB}$ in K

$V_{LSR}$ in km s$^{-1}$

Envelope + Outflow

Outflow

Envelope
Line profiles

- Line fitting with both envelope + outflow (for HCO$^+$ and its isotopologues)
- Foreground cloud in front of the source (Coutens et al. 2012)
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Conclusions

- **HCO⁺ emission** coming from both the envelope **AND** the outflow.
- Modellings done with the combination of **GASS and LIME**.
- **31 transitions** of HCO⁺ and its isotopologues used **simultaneously**.
- Envelope abundance consistent with astrochemical modellings.