Characterizing energetic processes of low-mass protostars with *Herschel*-HIFI

Spectrally resolved high-*J* CO lines

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Introduction

Most ground-based observations of CO and its isotopologues have been limited to low rotational lines (E_{up} = 35K). Characterizing the dynamics involved in low-mass star-formation is important as well as disentangling energy input of the passively heated envelope and shock- and UV-excitation. Because of its high abundance and strong lines, CO is the primary molecule to probe the various components of protostellar systems (envelope, outflow, outflow cavity).

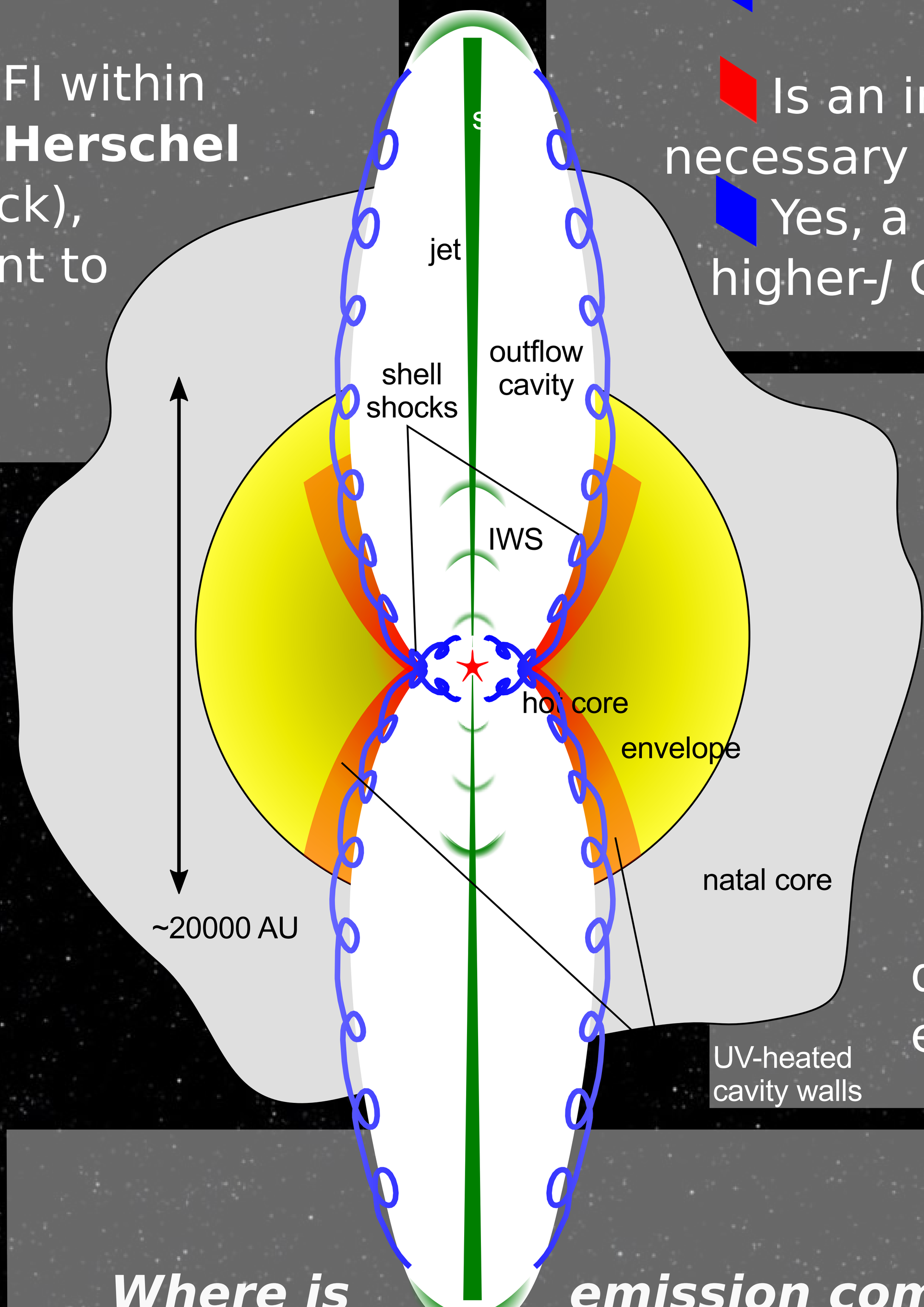
Data were obtained with Herschel-HIFI within the **Water in star-forming regions with Herschel (WISH)** key program (PI: Ewine van Dishoeck), where CO data are an important complement to H_2O data.

Q & A

Do CO and its isotopologues trace different material in the protostellar region?
Yes, ^{12}CO traces shocked gas on larger scales (>1000AU), ^{13}CO traces small-scale shocks (<1000AU) and $C^{18}O$ traces the envelope material.

Does the $C^{18}O$ 10-9 line (E_{up} = 290K) trace gas of the same temperature?
No, $C^{18}O$ 10-9 traces the gas at T~50K.

Is an increase in the CO abundance in the inner envelope necessary for reproducing observed intensities?
Yes, a drop profile is required to reproduce both lower and higher-*J* $C^{18}O$ lines.



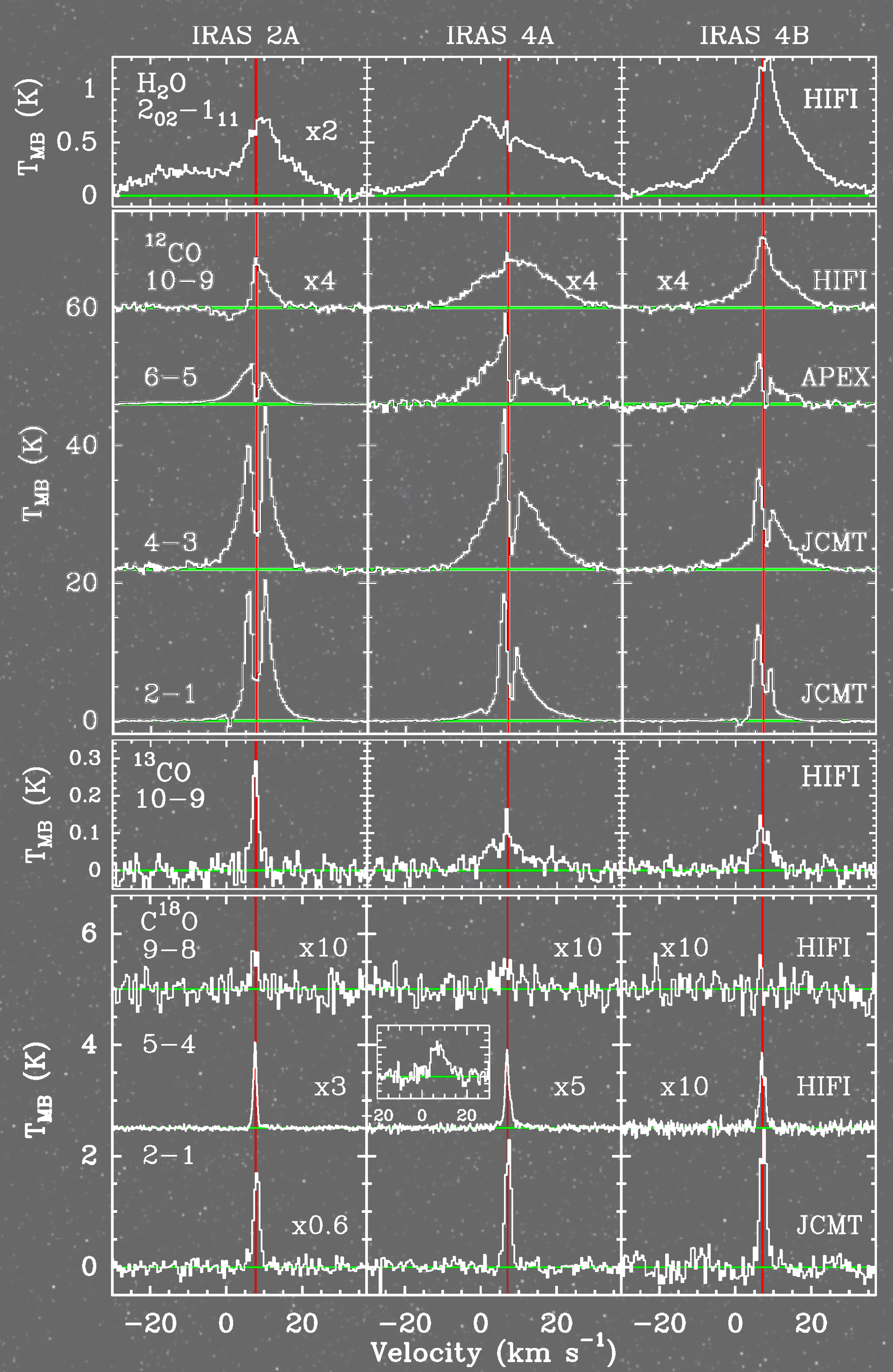
Results

We derive the temperature for the outflowing gas from the ratio of CO 6-5/10-9 as:
IRAS 2A: T_{kin}=70-130 K
IRAS 4A: T_{kin}= 90-120 K
IRAS 4B: T_{kin}= 140-180 K

In order to reproduce higher-*J* $C^{18}O$ lines within the context of the adopted physical model, a jump in the CO abundance due to evaporation is required in the inner envelope.

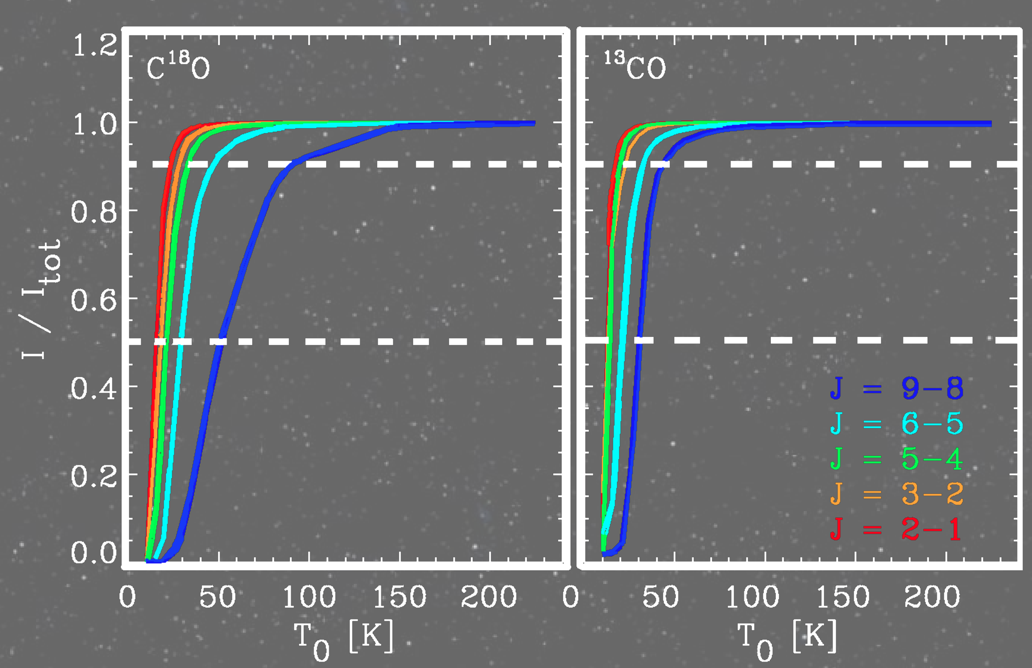
NGC 1333 Star-forming Region

Three Class 0 objects in the NGC 1333 region (d=235 pc) observed with HIFI.

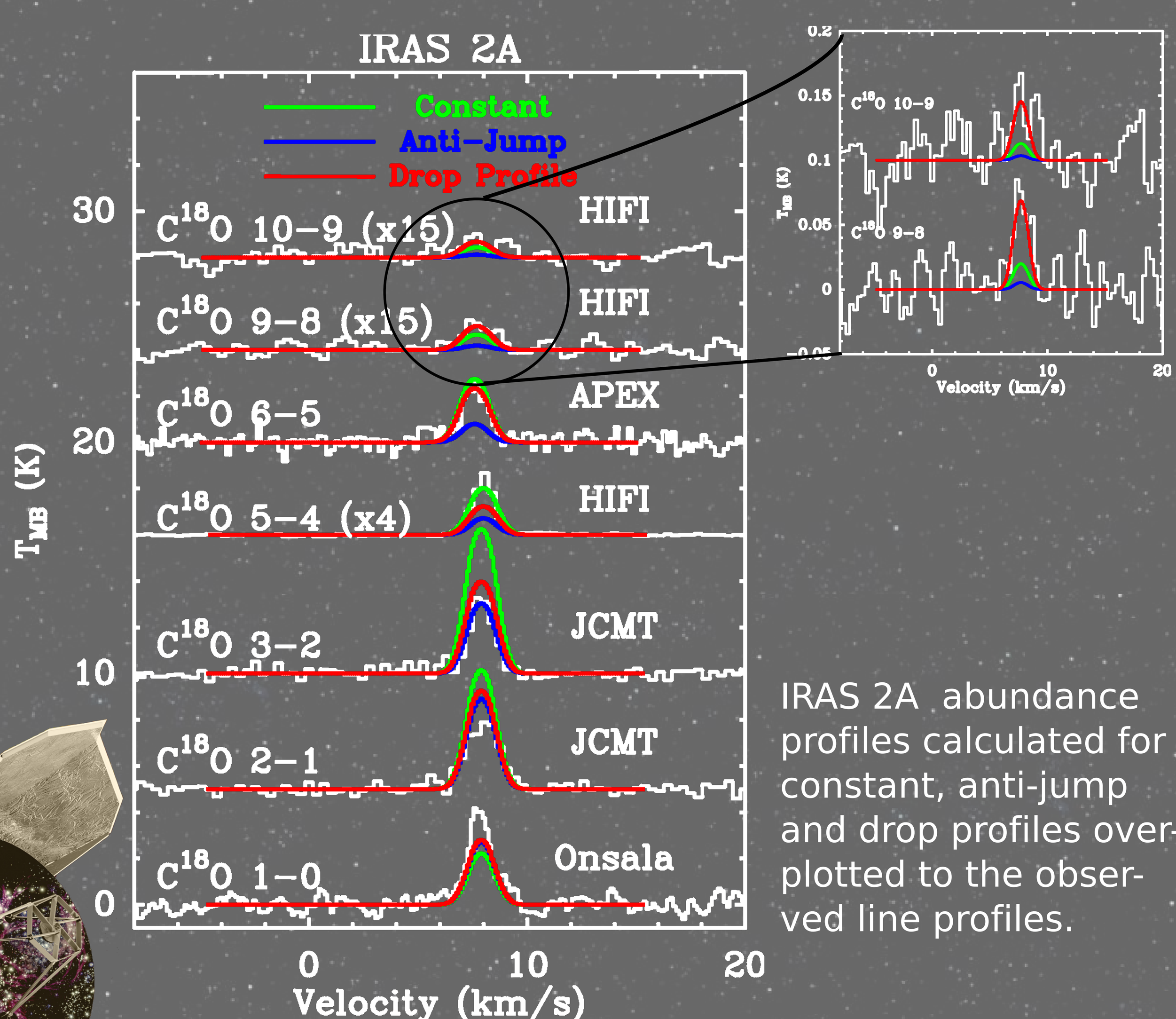


Spectra of the IRAS 2A, 4A and 4B protostars. Note the medium-broad component in the $C^{18}O$ 5-4 spectrum shown in the inset.

Where is emission coming from?



Most emission, even for the high-*J* lines, comes from colder, T<40 K part of the envelope.



IRAS 2A abundance profiles calculated for constant, anti-jump and drop profiles overplotted to the observed line profiles.

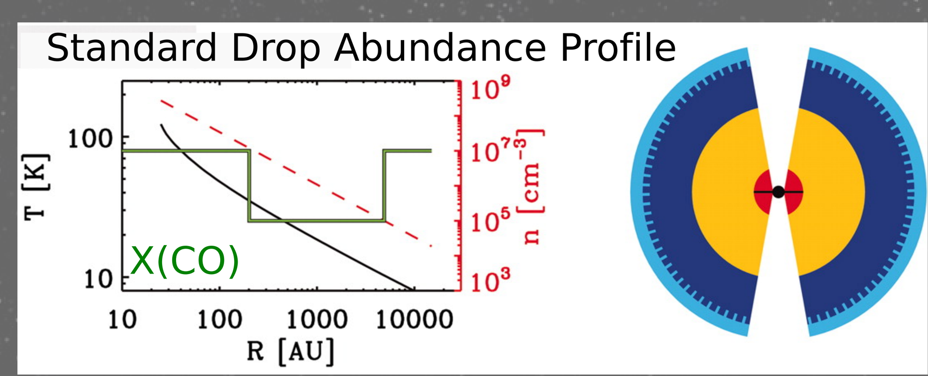
Abundance Studies

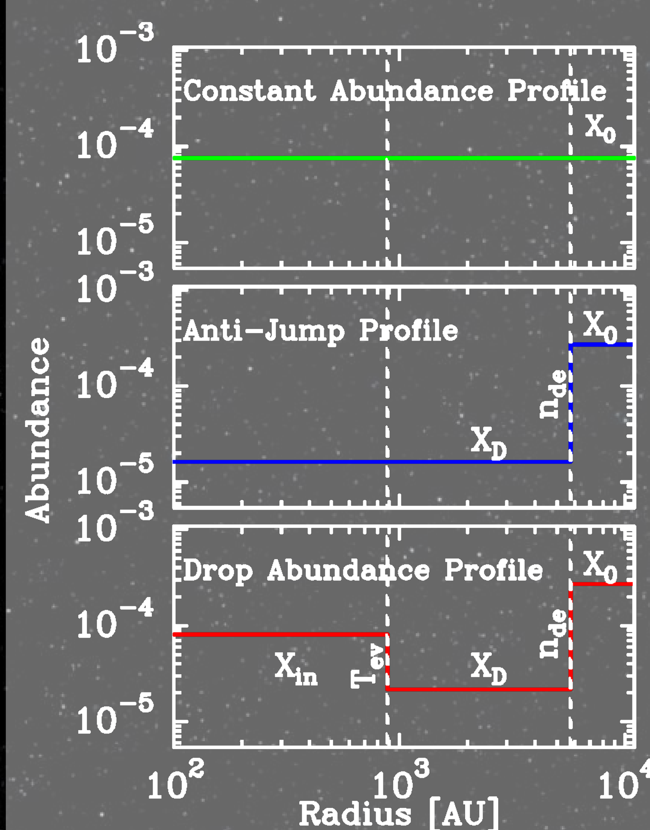
RATRAN models for several abundance profiles; intensities convolved with beam.

Constant: The simplest abundance profile cannot simultaneously reproduce all line intensities.

Anti-jump: Low-*J* $C^{18}O$ lines fitted well, but higher-*J* lines underproduced.

Drop-abundance: Best fit to data if inner abundance is increased to $1.5x10^{-7}$ ($CO=8x10^{-5}$) above T_{ev}=25K.



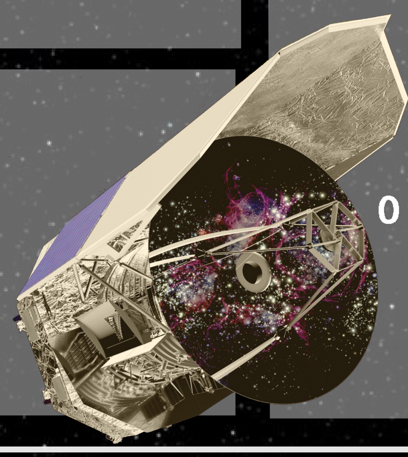


Abundance models that were examined.

References

(1) Yildiz et al., A&A, in press,astro-ph: 1008.0867
(2) Kristensen et al. A&A, in press, astro-ph: 1007.3031
(3) Jorgensen et al., 2002, A&A, 389, 908
(4) Jorgensen et al., 2005, A&A, 435, 177

Center Image: R. Visser



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