Study of the transition between the atomic gas and the molecular gas in two cirrus clouds of the North Celestial Loop.

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Introduction

Following the discovery of the infrared (IR) cirrus clouds at high Galactic latitude (Low et al. 1984), the existence of a linear correlation between the infrared intensity and the HI column was shown (Boulanger & Perault 1988). Some potential sites of molecule formation were later found by examining the Far Infrared-HI ratio and looking for an excess over that expected from an atomic medium (Joncas et al. 1992; Reach et al. 1994, 1998). These cirrus clouds with high molecule abundance are excellent candidates to study the processes that influence the interstellar medium before star formation and can provide a better understanding of molecule formation.

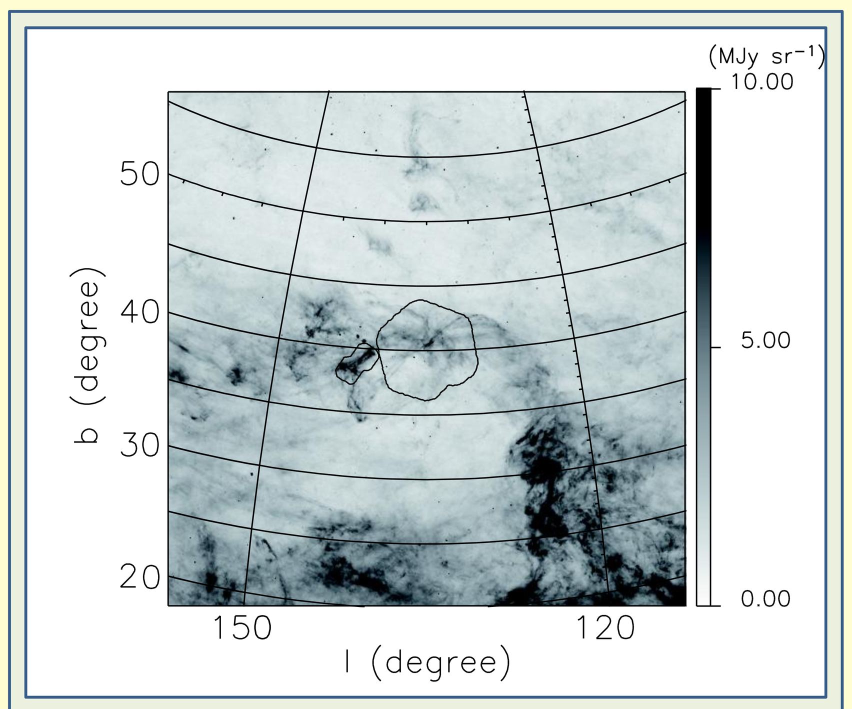


Figure 1– *Global view of the North Celestial Loop in IRAS 100 μm emission. The HI Spider field is located in the large polygon. The HI Ursa Major field is located in the small polygon.*

As the H_2 molecule is usually observed in absorption (Gillmon & Shull 2006), a surrogate molecule like CO is often used to trace H_2 (Heithausen et al. 1993). Whereas the ^{12}CO peak is coincident with the infrared excess peak for some regions (Reach et al. 1994), both peaks do not coincide in other regions and the reason why is not well understood.

To better understand the transition between the atomic gas and the molecular gas, HI line, ^{12}CO(*J=1–0*), and ^{13}CO (*J=1–0*) observations were obtained for diffuse gas located in a prominent HI loop toward the north celestial pole called the North Celestial Loop (see Figure 1).

Observations

Two cirrus clouds were observed (Barriault et al. 2010a): **the Spider** (large polygon in Figure 1) and **Ursa Major** (small polygon). The HI data were obtained at the Dominion Radio Astrophysical Observatory (DRAO) and the parameters of the observations are shown in Table 1. The Spider HI data come from the DRAO Planck Deep Fields observations. The ^{12}CO and ^{13}CO data were obtained at the Five College Radio Astronomical Observatory (FCRAO) and the parameters of the observations are shown in Table 2.

Table 1– *Parameters of the HI DRAO data cubes*

	Spider	Ursa Major
Channel separation (km s^{-1})	0.824	0.412
Number of channels	256	64
Angular resolution (arcmin)	1.0 × 1.06	1.0 × 1.06
Arcmin pixel^{-1}	0.3	0.5
rms noise	1	3
Observation date	2007	1989,1994

Table 2– *Parameters of the FCRAO data cubes*

	Spider	Ursa Major
Arcsec/pixel	22.5	20
^{12}CO binned resolution (km s^{-1})	0.254	0.254
^{12}CO rms noise (T_A*) (K)	0.05	0.05
^{12}CO angular resolution (arcsec)	45	45
^{13}CO binned resolution (km s^{-1})	0.265	0.265
^{13}CO rms noise (T_A*) (K)	0.02	0.02
^{13}CO angular resolution (arcsec)	46	46

Comparison between ^{12}CO integrated intensity and infrared intensity

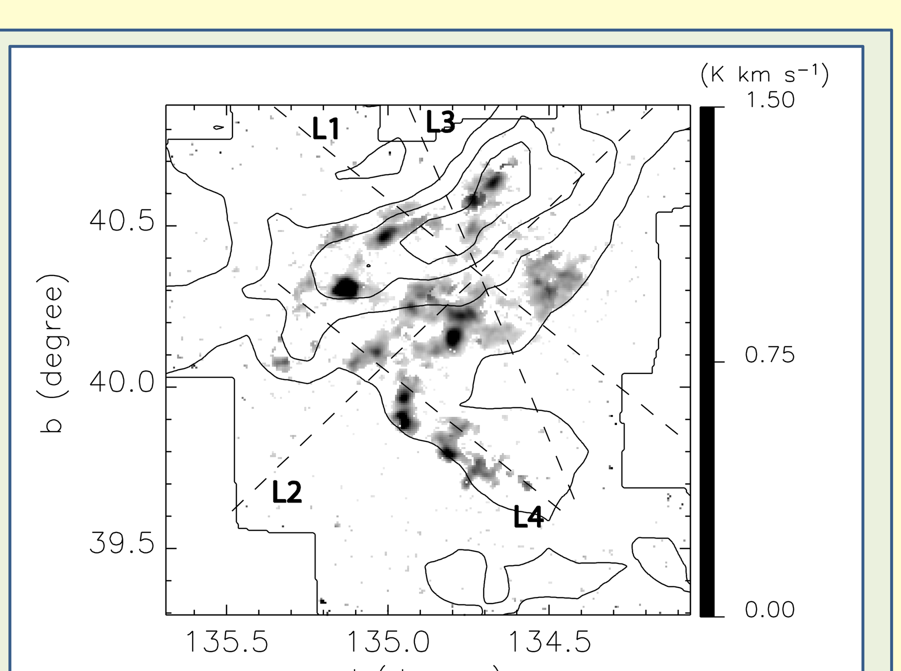
Using our HI observations and IRAS 100 μm data, we computed the infrared excess with respect to the IR-N(HI) correlation in both the Spider and Ursa Major. The infrared excess was also compared with the ^{12}CO integrated intensity. No coincidence was found between the ^{12}CO peak and the infrared excess peak in the Spider (see Figure 2) and in Ursa Major, indicating that CO might not be the best tracer of H_2 in these low-density regions. New observations from the Green Bank Telescope show that OH could be a better tracer of H_2 in these regions since one OH component actually coincides with the infrared excess peak (Barriault et al. 2010b).

Three reasons can explain the discrepancy between the ^{12}CO peak and the infrared excess peak:

1. **A density too small to allow CO excitation**
2. **An insufficient CO self-shielding**
3. **Variations of the dust properties**

While new Planck and Herschel data will be needed to determine the dust properties and look at the third hypothesis, an investigation was done on the first and second hypotheses. New ^{12}CO and ^{13}CO (*J=1-0*) data from IRAM and new ^{12}CO (*J=2-1*) data from JCMT were obtained for a small number of fields in the Spider and in Ursa Major. Using a large velocity gradient model on those data, Barriault et al. (2010, in preparation) show that the densities are smaller at the location of the infrared excess peak (~100 cm^{-3}) than at the location of the ^{12}CO peak (> 1000 cm^{-3}). On the other hand, the ^{12}CO column densities are larger than 10^{15} cm^{-2} everywhere, indicating that self-shielding should be efficient.

Figure 2– *^{12}CO integrated intensity maps for the Spider in greyscale. The contours show the infrared excess in the Spider map (with specific contours at 0.52, 1.52, 2,52, 3,52 MJy sr^{-1}). The four dashed lines (L1, L2, L3 and L4) show the directions along which position-velocity cuts will be drawn in Figures 3 and 4.*



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Comparison between ^{12}CO integrated intensity and HI

The Spider : a younger region than Ursa Major?
The ^{12}CO and HI profiles were fitted with Gaussian components to determine the kinematical behaviour of the molecular and atomic gas. The ^{12}CO and HI velocities coincide in the Spider for one component, while the velocity difference between both species is 1.7 km s^{-1} in Ursa Major. As the geometry is unknown, we cannot reject a scenario involving the North Celestial Loop, but small scale motions are probably the main effect that influence the gas kinematics. The velocity difference in Ursa Major could be the result of colliding HI features, while the velocity coincidence in the Spider might indicate that both species are well mixed. The Spider could therefore be younger than Ursa Major.

The contribution of endothermic reactions to molecule formation
Figures 3 and 4 show HI and ^{12}CO position-velocity cuts and the infrared excess profiles along lines L1 and L3 respectively of Figure 2. In Figure 3, the CO emission appears where one of the two HI components becomes weaker. A HI velocity shear is observed (≈ 44 km s^{-1} pc^{-1} between L1-a and L1-b) in the region where there is a large amount of CO. In Figure 4, the amount of CO is low at the location of the infrared excess peak, but a HI velocity shear is observed (≈29 km s^{-1} pc^{-1}). This can be the signature of a future CO clump at this location. Looking at the line widths, the low intensity ^{12}CO regions have HI dispersions extending to higher values than for the bulk of the ^{12}CO. This decrease of HI dispersion might indicate turbulence dissipation (Miville-Deschênes et al. 2002).

These observations show that CO formation is related to dynamical processes. The model of Godard et al. (2009) predicts that CO formation will occur in HI and H_2 gas where HI velocity shears are present. In this model, the dissipation of turbulence allows molecule formation eventhough UV shielding is not as efficient as in giant molecule formation. While CO formation in diffuse clouds usually results at low temperature from the reaction of C^+ with OH, the high temperatures due to turbulence dissipation allow nonequilibrium CH^+ formation which can increase CO formation.

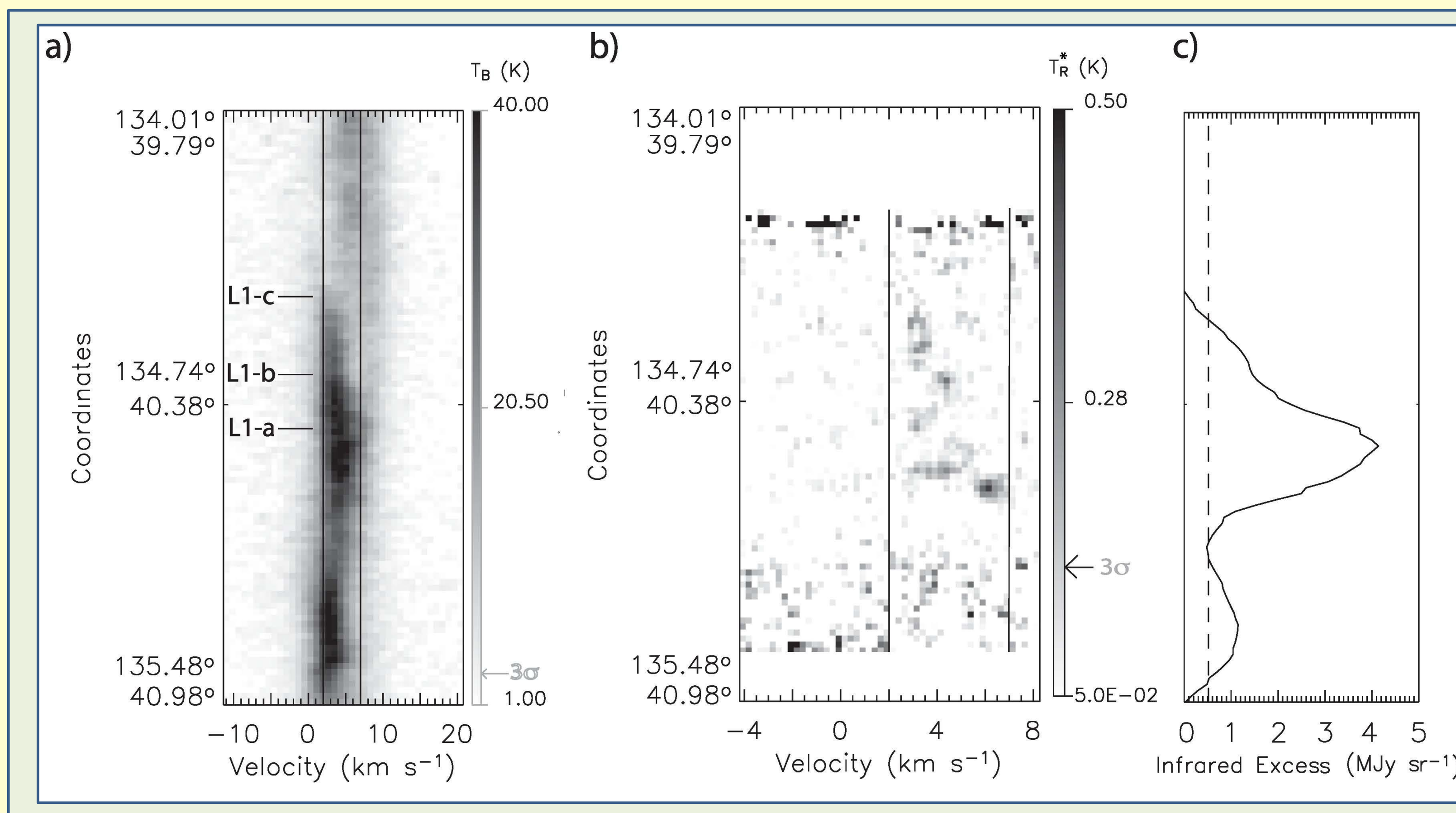

Figure 3 – *HI position-velocity plot (a), ^{12}CO position-velocity plot (b), and infrared excess profile (c) in the Spider along line L1 of Figure 2.*

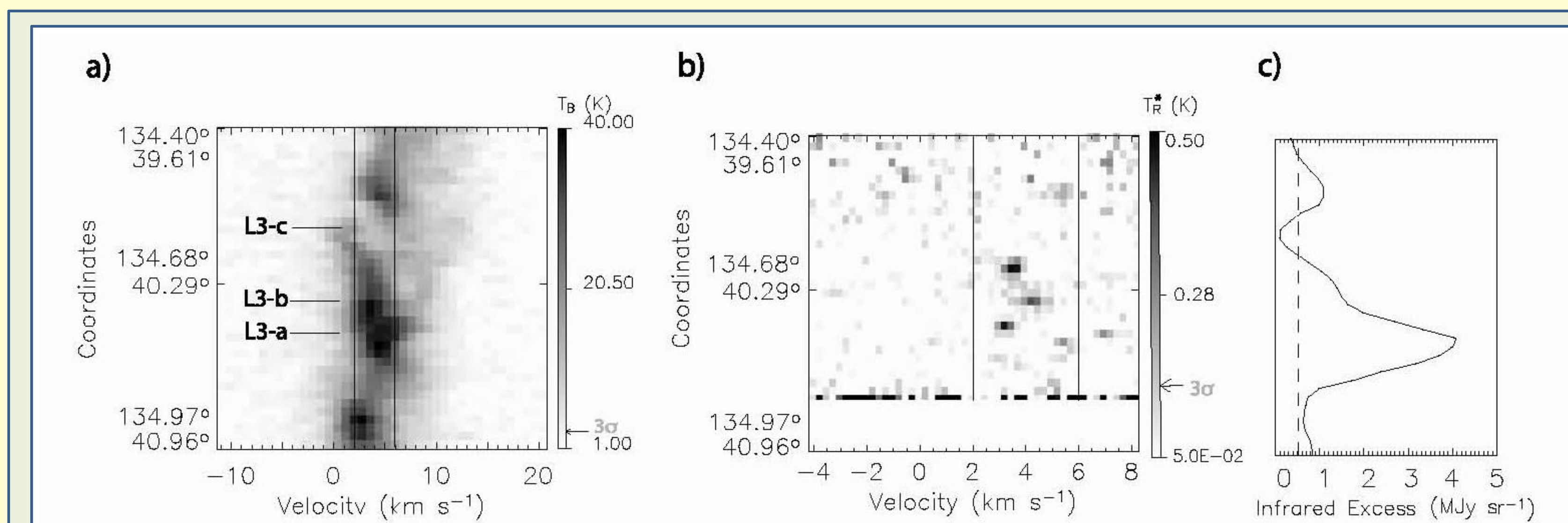

Figure 4 – *HI position-velocity plot (a), ^{12}CO position-velocity plot (b), and infrared excess profile (c) in the Spider along line L3 of Figure 2.*

H_2 formation is also affected by dynamical processes
As the turbulence timescale (10^6 years) is smaller than the H_2 formation and photodissociation timescales (10^7years), H_2 abundance is expected to be out of equilibrium. Interestingly, this can explain the absence of coincidence between the infrared excess peak and the ^{12}CO peak

Conclusions

Two potential sites of molecule formation have been observed and the following conclusions have been drawn:

1. The ^{12}CO peak does not coincide with the infrared excess peak indicating that ^{12}CO might not be the best tracer of H_2 in diffuse regions. This absence of coincidence is probably the result of densities too low to allow CO excitation at the infrared excess peak.
2. CO is found where HI velocity shears are observed indicating that dynamical processes influence molecule formation.

References

Barriault, L., Joncas, G., Falgarone, E., Marshall, D., Heyer, M., Boulanger, F. et al. 2010a, *MNRAS*, 406, 2713
Barriault, L., Joncas, G., Lockman, F., & Martin, P. 2010b, *MNRAS*, 407, 2645
Boulanger, F., & Perault, M. 1988, *ApJ* , 330, 964
Gillmon, K., & Shull, J.M. 2006, *ApJ*, 636, 908
Godard, B., Falgarone, E., & Pineau Des Forêts, G. 2009, *A&A*, 495, 847
Heithausen, A., Stacy, J.G., de Vries, H.W., Mebold, U., & Thaddeus, P. 1993, *A&A*, 268, 265
Joncas, G., Boulanger, F., & Dewdney, P.E. 1992, *ApJ*, 397, 165
Low, F.J., Young, E., Beintema, D.A., Gautier, T.N., Beichman, C.A., Aumann, H.H. et al. 1984, *ApJ*, 278, L19
Miville-Deschênes , M.-A., Boulanger, F., Joncas, G., & Falgarone, E. 2002, *A&A*, 381, 209
Reach, W.T., Koo, B.-C., & Heiles, C. 1994, *ApJ*, 429, 672
Reach, W.T., Wall, W.F., & Odegard, N. 1998, *ApJ*, 507, 507