JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
38: 245 ∼ 248, 2005

HCN AND HCO^+ EMISSION IN M31 : TRACING THE DENSE MOLECULAR GAS IN A GALACTIC DISK

SÉBASTIEN MULLER[1], NATHALIE BROUILLET[2], FABRICE HERPIN[2], JONATHAN BRAINE[2], AND THIERRY JACQ[2]
[1]Academia Sinica Institute of Astronomy and Astrophysics P.O. Box 23-141 Taipei 106, Taiwan
E-mail: muller@asiaa.sinica.edu.tw
[2]Observatoire de Bordeaux, Université Bordeaux 1- CNRS, B.P. 89, F-33270 Floirac, France
(Received February 1, 2005; Accepted March 15, 2005)

ABSTRACT

We present mm observations with the IRAM 30m radiotelescope of the HCN (J=1-0) and HCO^+ (J=1-0) emission lines from Giant Moleculat Clouds (GMC) in the disk of the Andromeda Galaxy. The selected GMC targets have various morphology and environments, including locations within spiral arms or in interarm regions and with galactocentric radii ranging from 2.4 to 15.5 kpc over the disk. The radial distributions of the ratios HCN/CO and HCO^+/CO are discussed and their values are compared to other galaxies.

Key words : Galaxies: ISM - Galaxies: M31 - ISM: molecules

I. INTRODUCTION

Most of our knowledge about the molecular gas in the disks of external galaxies comes from CO observations. However, complementary information on the physical and chemical state of the interstellar medium can be derived using other molecules. The excitation of the J=1-0 lines of HCN and HCO^+ corresponds to much higher critical densities (n > 10^5 cm^{-3}) than required for the CO(J=1-0) transition (n∼10^3 cm^{-3}). Because of their high electric dipole moment (μ=2.98 and 3.30 debyes respectively for HCN and HCO^+), large gas densities are required for collisional excitation by molecular hydrogen. Both molecules are therefore referred to as dense molecular gas tracers, and HCN and HCO^+ may actually provide the best link with star formation. The gas density in active star forming regions is indeed more than one order of magnitude higher than in average. Adding to this, HCN and HCO^+ are relatively abundant interstellar molecules and their emission is rather easily detectable with the current generation of mm radiotelescopes and receivers, making them good candidates to study the dense molecular gas.

So far, observations of HCN have been reported towards the nuclei of numerous normal, starburst, Seyfert and ultra-luminous infrared galaxies (see for example Gao & Solomon 2004 and references therein or Sorai *et al.* 2002 for nearby bright CO galaxies). However, these studies only focus in the inner 1 kpc or so and do not extend to larger radii. On the other hand, only few studies focus on galactic disks and they are mostly limited to the inner part of the disk (R < 3 kpc) except for the Milky Way (Helfer & Blitz 1997a). One remarkable issue is that the ratio of HCN over CO emission is usually 5 to 10 times lower in the disks than towards nuclei (see *Tab.1*), which indicates that the physical conditions of the molecular gas differ drastically between nuclei and disks.

The HCN and CO J=1 levels stating at 4.3 K and 5.5 K respectively above ground level, the corresponding J=1-0 transitions reflect density rather than temperature. As a matter of fact, Paglione *et al.* 1998 showed that the ratio HCN/CO could be a reliable measure of the gas pressure. While the difference is large between nucleus and disk, the ratios HCN/CO and HCO^+/CO remain almost constant over the disk.

Here (see also Brouillet *et al.* 2005), we present HCN and HCO^+ (J=1-0) observations in the disk of M31 towards a sample of molecular complexes with galactocentric radii ranging from 2.4 to 15.5 kpc, *i.e.*, extending to much higher galactic radii as compared to previous nearby galaxies studies.

II. OBSERVATIONS

We have used the IRAM 30M telescope to observe the HCN(J=1-0) (ν=88.6 GHz) and HCO^+(J=1-0) (ν=89.2 GHz) lines emission in the disk of M31. The observed positions were Giant Molecular Clouds (GMC) previously identified in the 30M IRAM CO(J=1-0) survey of the whole galaxy (Guélin *et al.* 2000, Nieten *et al.* 2005). At these frequencies, the beam angular resolution of the 30M is 27.5", corresponding to a spatial scale of ∼100 pc (assuming a distance of 0.78 Mpc), which is about the typical size of giant molecular complexes.

We detected the HCN emission on 9 positions over 11 observed, and 11 over 14 for HCO^+. As an illustration, we present some spectra and indicate their positions in *Fig.*1.

Proceedings of *the 6th East Asian Meeting of Astronomy*, held at Seoul National University, Korea, from October 18-22, 2004.

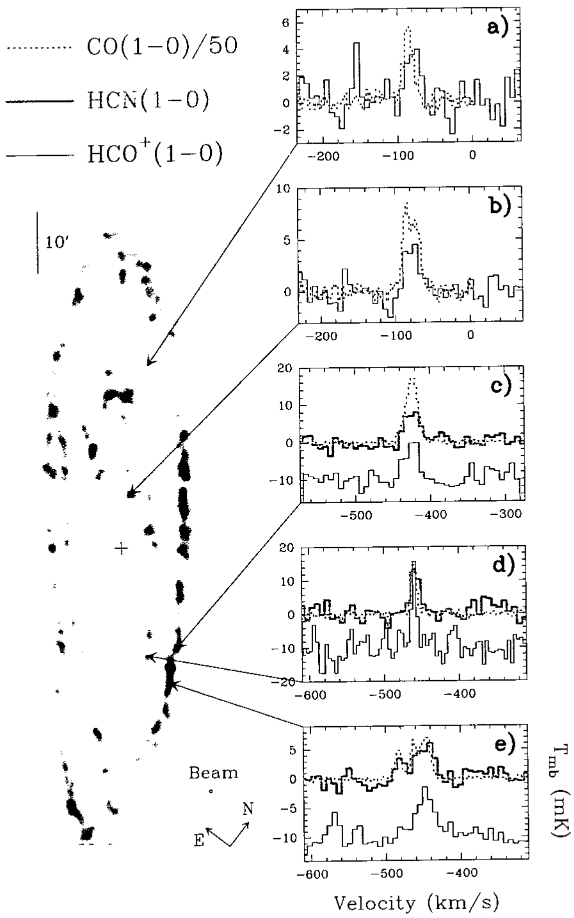

Fig. 1.— HCN, HCO^+ and CO(1-0) spectra of few selected positions in our survey. The map corresponds to the CO(J=1-0) integrated intensity observed with the IRAM 30M telescope and smoothed to a resolution of 45" (Guélin *et al.* 2000 and Nieten *et al.* 2005). The CO(1-0) spectra are convolved to the same spatial resolution as the HCN and HCO^+ and divided by 50. The HCO^+ spectra are shifted in intensity for a better reading when the HCN spectra are presented.

III. DISCUSSION

As can be seen in *Fig.*1, the HCN and HCO^+ emission is well detected at the same velocities and with a typical intensity about 50 times weaker than the CO.

We selected few observed spectra among our survey to illustrate positions such as a) an interarm complex; b) a complex close to the center (D_{gal}=2.4 kpc); and c,d,e) complexes in the spiral arms. The position d) corresponds to a well isolated molecular complex located in the inner arm. The CO line width is relatively narrow (~8 km/s). On the other hand, the CO spectrum at the position e) shows a broader profile (~60 km/s at the baseline) with multi peaks, also seen in HCN.

Within the noise, the line widths and line profiles of HCN(J=1-0), HCO^+(J=1-0) and CO(J=1-0) are very similar, implying that these molecules trace gas from the same physical regions.

In the following, we defined the dense gas fration χ, as the emission of HCN or HCO^+ normalized to CO(1-0) :

$\chi(HCN) = 100\ I_{HCN}\ /\ I_{CO(1-0)}$

$\chi(HCO^+) = 100\ I_{HCO+}\ /\ I_{CO(1-0)}$

(a) Correlation χ(HCN) - $\chi(HCO^+)$

There is a relatively good correlation between χ(HCN) and $\chi(HCO^+)$ (*Fig.*2). The HCO^+ emission is slightly stronger than HCN: $\chi(HCO^+) \sim 1.1\chi(HCN)$. Nguyen-Q-Rieu *et al.* 1992 noticed some differences in the ratio HCO^+ over HCN from galaxy to galaxy. They interpreted this as variations in the excitation or abundance ratio due to different ambient radiation field and ionization by cosmic rays.

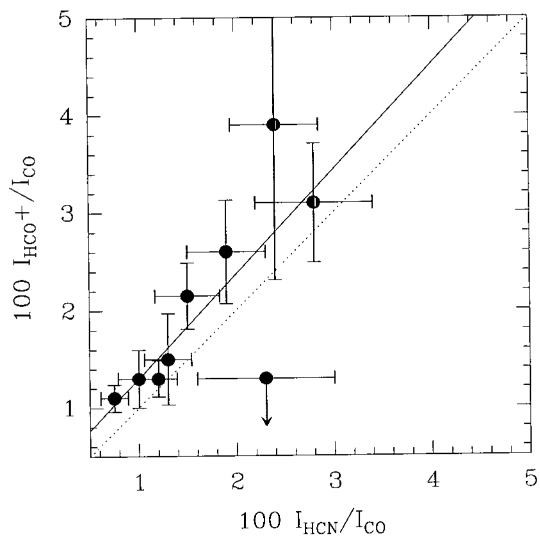

Fig. 2.— Correlation of the HCO^+ and HCN emissions normalized by the CO luminosity. The solid line represents a least-square linear fit to the data $\chi(HCO^+) = 1.07\ \chi(HCN)+0.23$ without taking into account the point indicated as an upper limit.

(b) Radial Distribution of the Dense Gas

The number of GMC we observed and their locations ranging all over the disk allow us to study the radial distribution of the dense gas. Both χ(HCN) and $\chi(HCO^+)$ show a little trend to decrease with galactic radii (*Fig.*3). However, since the HCN, HCO^+ and CO are basically composed from the same elements, this trend should be due to excitation effects rather than abundance gradient.

Concerning $\chi(HCO^+)$, the typical Galactic disk values are 1–2.5 (Liszt 1995). The ratio peaks at the location of the Galactic molecular ring (R=4–5 kpc) but

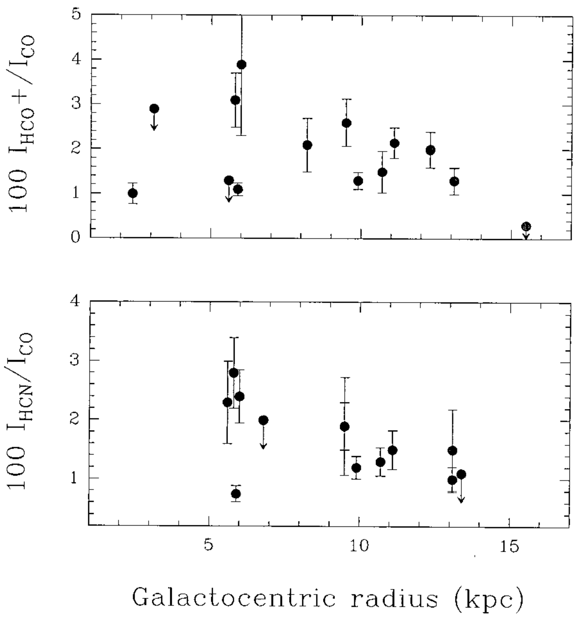

Fig. 3.— Evolution of the ratio $\chi(HCO^+)$ (up) and $\chi(HCN)$ (down) with the galactocentric radius.

remains almost constant over 3–9 kpc. LVG calculations show that HCO^+ is excited at lower density ($\sim 10^5$ cm^{-3}) than HCN and that its abundance varies with the cosmic ray flux. Nevertheless, the ratio of HCO^+ over HCN remains remarkably constant ($\sim$ 1.1) over the disk of M31.

(c) Comparison with other Galaxies

The comparison of the fraction of dense gas from galaxy to galaxy should allow to better understand the link between dense gas, star formation and star formation efficiency. However, the fraction of dense gas may strongly be biaised depending on the spatial resolution of the observations. While the CO emission is expected to closely trace the whole molecular gas, dense molecular gas tracers such as HCN, HCO^+ or CS, do trace only the densest parts. For this reason also, the fraction of dense gas derived from interferometric data has to be interpreted carefully because of the missing flux due to the filtering of extended structures.

Nevertheless, there is a strong trend between galactic nuclei and disks, as can be seen from *Tab.*1. This implies that the physical conditions of the molecular gas and/or the excitation are very different from nucleus to disk regions: higher densities and kinetic temperatures are indeed expected towards galactic nuclei, especially for starburst and Seyfert galaxies.

While the CO emission from the central regions of M31 is weak compared to the disk, the values of $\chi(HCN)$ over the disk itself are similar to the values in the other galactic disks.

*Fig.*4 shows the correlation between the integrated intensity of HCN and the integrated intensity of CO(1-0) for the observed GMC in M31 and for the sample of galactic nuclei observed by Gao & Solomon 2004. The fit results in $\log(I_{HCN}) = 1.07\log(I_{CO})$-1.50 (not taking into account HCO^+ data points).

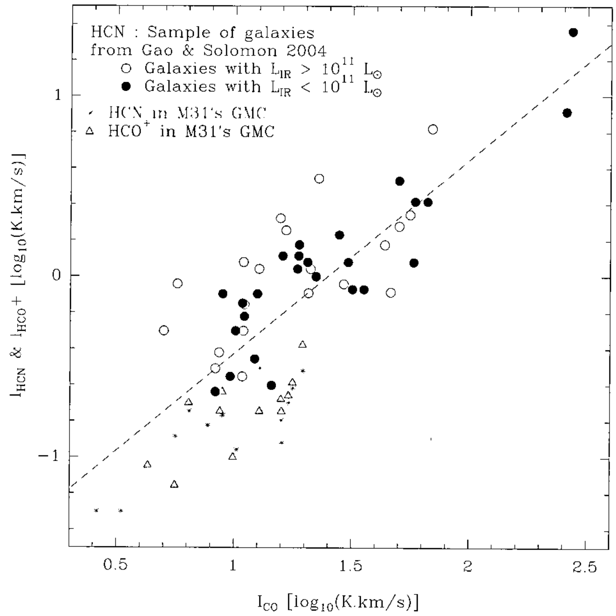

Fig. 4.— Correlation between the integrated intensities of HCN and CO(1-0) for the observed Giant Molecular Clouds in M31 and a sample of galactic nuclei observed by Gao & Solomon 2004. Points concerning HCO^+ in M31's GMC are also indicated but they are not taken into account in the fit.

IV. CONCLUSION

Our observations present for the first time HCN and HCO^+ detections so far out in a galactic disk, except the Milky Way. They allow to investigate the distribution of the dense gas on a scale even larger than for our Galaxy. The sample contains GMCs with different environments and star formation activity, ranging in galactocentric distances from 2.4 to 15.5 kpc. Both emission lines are well correlated. They have nearly similar intensity and the fraction of dense gas, quoted as the intensity of HCN or HCO^+ normalized to the intensity of CO, is comparable to the values in the Galactic disk. On the other hand, the nuclear regions of starburst, Seyfert and luminous infrared galaxies show a much higher ratio.

There is trend for the fraction of dense gas to decrease with galactocentric radii. This is interpreted as excitation effects rather than abundance gradient. However, higher J transitions study will be required to check in more details the excitation conditions of the dense gas across the disk.

REFERENCES

Brouillet N., Muller S., Herpin F., Braine J., & Jacq T.,

TABLE 1.
COMPARISON OF THE RATIO $\chi(\mathrm{HCN}) = 100.\mathrm{I}_{HCN(1-0)}/\mathrm{I}_{CO(1-0)}$ BETWEEN NUCLEI AND DISKS FOR DIFFERENT GALAXIES

Source	Regions	χ(HCN)	References
M31	Disk: 2.4 < R < 15.5 kpc (beam scale 100 pc)	1.7 ± 0.5	Brouillet *et al.* 2005
Milky Way	Center R < 300 pc	8 (averaged)	Jackson *et al.* 1996
	Disk: 3.5 < R < 7 kpc (on size scales of 200 pc)	2.6 ± 0.8	Helfer & Blitz 1997a
	Nearby GMC (scale 40 pc)	1.4 ± 2.0	Helfer & Blitz 1997a
M51	Center	8.6 ± 0.7	Sorai *et al.* 2002
	3 positions in the arms	1.1 – 1.9	Kuno *et al.* 1995
IC342	Inner regions	14	Downes *et al.* 1992
	Beginning of spiral arms	< 7	Downes *et al.* 1992
NGC6946	Center R < 150 pc	11 ± 1 (averaged)	Helfer & Blitz 1997b
	Disk 150 pc <R < 800 pc	< 1	Helfer & Blitz 1997b

2005 A&A 429, 153

Downes D., Radford S. J. E., Guilloteau S., Guélin M., Greve A., & Morris D., 1992 A&A 262, 424

Gao Y. & Solomon P. M., 2004, ApJ 152, 63

Guélin M., Nieten C., Neininger N., Muller S., Lucas R., Ungerechts H., & Wielebinski R., 2000, The interstellar medium in M31 and M33, Proceedings, 232 Eds

Berkhuijsen E., Beck R., & Walterbos R. A. M., Shaker, Aachen, 15

Helfer T. T. & Blitz L., 1997, ApJ, 478, 233 (a)

Helfer T. T. & Blitz L., 1997, ApJ, 478, 162 (b)

Jackson J. M., Heyer M. H., Paglione T. A. D., & Bolatto A. D., 1996 ApJ 456, L91

Kuno N., Nakai N., Handa T., & Sofue Y., 1995 PASJ 47, 745

Liszt H. S., 1995, ApJ, 442, 163

Nguyen-Q-Rieu, Jackson J. M., Henkel C., Truong-Bach, & Mauersberger R., 1992, ApJ, 399, 521

Nieten C., Neininger N., Guélin M., Ungerechts H., Lucas R., Wielebinski R., Beck R., & Berkhuijsen E. M., 2005, submitted to A&A

Paglione T. A. D., Jackson J. M., Bolatto A. D., & Heyer M. H., 1998, ApJ 493, 680

Solomon P. M., Downes D., & Radford S. J. E., 1992, ApJ ,387, L55

Sorai K., Nakai N., Kuno N., & Nishiyama K., 2002, PASJ, 54, 179