1994A&A...287..581M

Astron. Astrophys. 287, 581–584 (1994)

ASTRONOMY
AND
ASTROPHYSICS

Critical density for magnetic decoupling: preliminary observations

M. Massi[1] **and S. Lizano**[2]

[1] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[2] Instituto de Astronomia, UNAM, Apdo. 70-264, 04510 Mexico D.F., Mexico

Received 29 April 1993 / Accepted 13 February 1994

Abstract. In this paper we report on NH_3 observations towards regions where cores with densities $\geq 10^4$ cm^{-3} were expected to exist, in order to verify the conjectured non-correlation between their morphology and their axis of rotation with the magnetic field (Heyer 1998). Among five predicted cores we have detected only one, and this one has different parameters from those predicted.

We also mapped in NH_3 (1,1), three sources from the sample by Myers & Benson (1983) with higher spatial resolution. In the four cores we detected, of density n$\geq 10^5$ cm^{-3}, there is no obvious relationship between the orientation of the rotation axis, the flattening, and the magnetic field. This non-correlation might indicate that at this density the magnetic field stresses are already dynamically unimportant. However, a statistically significant sample of dense cores has to be studied to establish this conclusion.

Key words: ISM: clouds – ISM: magnetic fields – ISM: molecules – radio lines: ISM

1. Introduction

The dynamical role of magnetic fields in the support and evolution of molecular clouds has been a subject of great study both observationally and theoretically (see e.g., review of McKee et al. 1993; hereafter MZGH93). Magnetic fields strengths in molecular clouds have been measured by Zeeman splitting of HI in self-absortion and thermal OH. The magnitudes of these fields range between 20 to 120 μG (see Heiles et al. 1993 and references therein). These field strengths are enough to support the clouds against gravitational collapse and are not easily dissipated for the average physical conditions in these clouds. The direction of the field is indicated by linear polarization of the light of background or embedded stars produced by dust in the cloud (e.g. Vrba et al. 1976; Moneti et al. 1984; Tamura el al. 1987; Heyer et al. 1987; Sato el al. 1988; Tamura et al. 1988; Goodman et al. 1990; Goodman et al. 1992). In particular, even though NIR polarization measurements give information of the magnetic field direction in regions with extinction higher than in those in which optical measurements are possible, up to now, the patterns of polarization found with both type of measurements seem to coincide (see discussion in Goodman et al. 1992).

Beside of its importance in the support against collapse, the magnetic field plays an important role in the cloud kinematics. In fact, angular momentum can be redistributed by magnetic braking which couples the rotational motion of a cloud core to the less dense outer envelope (see MZGH93 and references therein).

Observationally, these two aspects of the dynamic importance of the magnetic field are signed by i) a flattening of the gas along the field lines since lateral collapse is inhibited by magnetic forces, and ii) by an alignement of the rotational axis with the magnetic field direction, since magnetic braking is more efficient in the direction perpendicular to the direction of the magnetic field $\boldsymbol{B}$.

By mapping five dark clouds in Taurus in the ^{13}CO line, Heyer et al. (1987) tested the predicted correlation among properties molecular cloud and magnetic field direction for scales ≥ 2 pc and densities $\leq 10^3 cm^{-3}$, finding minor axes and rotational axes parallel to $\boldsymbol{B}$.

The next important question is: at which scale will the magnetic field decouple from the neutral matter? This process has to occur in order for the collapsing piece of the cloud to be able to get rid of enough magnetic flux to form a star. Otherwise, flux conservation will amplify the magnetic field to a degree never observed in stars (Nakano 1983).

Some theoretical work suggests that the decoupling will occur at densities much larger than 10^4 cm^{-3} (Nakano & Umebayashi 1986a,b; Shu et al. 1987; Nishi et al. 1991) while other one predicts decoupling will occur at densities lower than $10^6 cm^{-3}$ (Mouschovias et al. 1985; but see discussion in MZGH93).

Lacking observations of high density tracers, Heyer (1988; hereafter H88) has attempted to extract information about high density cores in the clouds from the above mentioned ^{13}CO maps, in which several peaks were present. The ^{13}CO emission is typically more extended than that of NH_3 and CS since lower densities ($\sim 10^3$cm^{-3}) are required to excite the ^{13}CO J=1-0 transition. In order to distinguish cores from each cloud mapped

---

Send offprint requests to: M. Massi

1994A&A...287..581M

in ^{13}CO, he used an empirical criterion for defining cores as those regions with emission above a mean value derived from extended emission in the maps.

From his ^{13}CO maps Heyer extracted 31 cores with estimated density around 10^4cm^{-3} and with orientations and rotational axes not systematically aligned with the magnetic field direction. As a consequence, he concluded that the magnetic field is unable to exert a significant stress upon the material already at such low density as 10^4cm^{-3}, in agreement with the predictions of Mouschovias et al. (1985).

In order to observationally test the predicted non correlation between the morphology of the cores and their axis of rotation with the magnetic field, we have performed NH_3 observations with the 100 m Effelsberg telescope, since this molecule is a direct tracer of high density gas, n> $10^{3.7}$cm^{-3} (Myers & Benson 1983). We selected, among the Heyer's cores, those with the smallest sizes (0.1 pc) and highest predicted density, in the range ($10^{3.9}$ – $10^{4.4}$)cm^{-3}. The observations are described in Section 2 and results discussed in Section 3. In Section 4 we present new observations of three cores also in Taurus, previously detected at lower spatial resolution by Myers & Benson (1983).

The cloud cores studied in this work with high spatial and spectral resolution are intended to be part of a representative sample for a statistical study aimed to determine the critical density for which the magnetic decoupling occurs.

2. Observations

The observations of the NH_3 (J,K)=(1,1) and (2,2) lines, at 1.3 cm, were made in October 1990 at the 100 m telescope, at Effelsberg, of the MPIfR (Bonn). The (1,1) and (2,2) transitions were simultaneously observed by using 512 channels and a bandwidth of 3MHz for each trasition. The resulting velocity resolution was therefore 0.08km sec^{-1}. The half-power beamwidth is about 40". A maser receiver was used with a system temperature of $T_{\rm sys}$ = $75K$. Maps of at least 5x5 points, spaced 30", were made around each position given in Table 1. The theoretical rms antenna temperature, in one channel, for the adopted integration time (ranging from 5 to 10 minutes) was typically of 0.05 K. In bad weather conditions the observed rms reached values as high as 0.2 K. For the data reduction we used the spectral line software CLASS.

3. Results

In the sources B18-C, HCL2-D, B18-F and B217-D taken from Heyer (1988), no NH_3 line emission, above 0.2 K, was observed in the mapped area of 150"x150", centered at the positions given in Table 1. We remind that, at a distance of 140 pc for Taurus, the predicted sizes of 0.1 pc correspond to 150".

Table 1. Core coordinates

name	α(1950)	β(1950)
Heyer's sources		
HCL2-D	04 36 53	25 34 09
B217-D	04 24 37	26 13 30
B18-C	04 29 14	24 39 42
B18-F	04 28 28	24 04 24
B18-I	04 32 377	24 03 00
Myers and Bensons sources		
B217	04 24 42.5	26 11 13
TMC-2A	04 28 54.0	24 26 27
L1517B	04 52 07.2	30 33 18

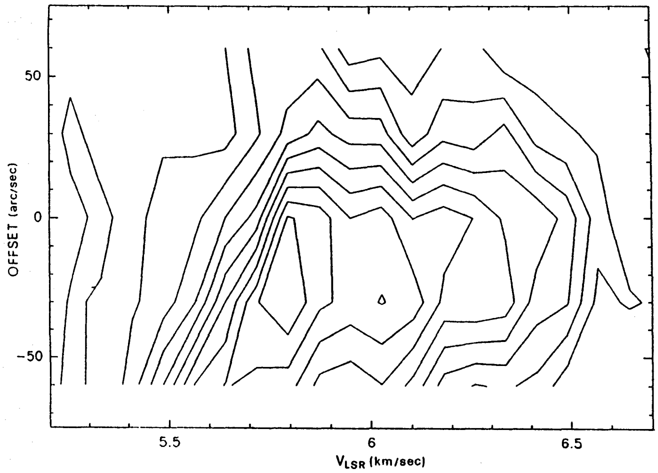

Fig. 1. A spatial velocity diagram along a strip centered on the position $\alpha(1950) = 04^h32^m37^s$, $\delta(1950) = 24^h03^m00^s$ cut along a position angle of 90°. The cut along the cloud is shown with positive and negative offset marks in arcseconds

An NH_3 (1,1) new detection was found instead at the position of B18-I. The strongest peak is offset of -30" in right ascension with respect to the position in H88. The velocity gradient $\frac{dv}{dy}$[1] is almost 4 km sec^{-1}pc^{-1}, one order of magnitude larger than that predicted by H88. This gradient can be seen in Fig. 1 which shows a strip centered at the position of Table 1 and cut along a position angle of 90°. The two features present in Fig. 1 represent the two hyperfine components of the main line which are resolved at our spectral resolution.

The NH_3(1,1) spectra have been fitted, following the procedure described in Ungerechts et al. (1986), and the column density in the (1,1) level determined. The total ammonia column density, derived assuming the molecular levels populated according to LTE at a single kinetic temperature of 10 K, has been integrated spatially over the core to give an estimate of the total number of ammonia molecules. This has been converted into total number of H_2 using the value of 10^{-7} for the abundance of the NH_3 relative to molecular hydrogen. The H_2

---

[1] The direction of the rotational axis of a core is determined by rotating the coordinate axes such that the difference between velocity gradients $\frac{dv}{dy} - \frac{dv}{dx}$ is a maximum.

Table 2. Core parameters

name	FWHP pc	FWHP pc	PA (minor ax.)	$\frac{dv}{dr}$ km s^{-1} pc^{-1}	PA (rot. ax.)	PA (B)	log(n_{H2}) cm^{-3}
HCL2-D							
B217-D							
B18-C							
B18-F							
B18-I	0.08	0.08		4	0	52	4.7
B217	0.09	0.05	-45	$\simeq$ 3	-45	30±10	4.8
TMC-2A	0.08	0.05	90	$\leq$ 1	180	57±5	5.0
L1517B	0.05	0.05		1	180	55	5.1

volume density has been finally determined assuming a spherical geometry for the core.

The core parameters: major and minor axis (for an assumed distance of 140 pc), morphological position angle, velocity gradient, position angle of the rotation axis, position angle of the magnetic field (taken from H88), and volume density are shown in Table 2. The FWHP of the line at the peak of the map is $\Delta v = 0.33$km s^{-1}.

In summary, among five cores predicted in H88, only one among them has been found (B18-I). However, this only one shows different parameters from those predicted for it in H88.

4. Myers and Benson sources

Three sources detected by Benson & Myers (1983) have been reobserved at higher spatial resolution. The three sources have been selected because of their proximity with some of H88 sources. In particular, B217 is displaced by only 4 beams from B217-D; L1517B $\sim$ 12 beams from L1517-D; and TMC2A is located between B18-C and B18-F. Because of the proximity to some of the cores in H88, it is possible to use the information about the magnetic field direction as reported by H88, estimating an error from surrounding field directions. The major and minor axis, morphological position angle, velocity gradient, position angle of the rotation axis, position angle of the magnetic field (taken from their neighbors as reported by H88), and volume densities are shown in Table 2. The FWHP of the line at the peaks of the maps are in agreement with those reported by Myers & Benson (1983). We were able to detect the NH_3 (2,2) line, which was still undetected in B217, with an integration time of 2 hours.

In conclusion, at the positions given in Table 1 four cores were detected in NH_3, the characteristics of which are given in Table 2. Two cores are circular and two are flattened. All of them have density around 10^5 cm^{-3}. The two circular sources are not affected by either rotation or the magnetic field in any obvious way. The flattened ones are not aligned with the field.

5. Conclusions

Of the five cores predicted in H88, we have detected only one of them (B18-I). For this one we found different parameters from those predicted by H88. The volume density in the four regions where NH_3 emission was undetected must be lower than expected. Based on these results, it seems that the physical parameters of dense cores estimated with the method of H88 are rather unlikely. Therefore, this first part of our observations do not support the limit estimated by H88 of 10^4 cm^{-3} for the critical density for which the magnetic field stresses become ineffective to determine the morphology and kinematics of dense cores.

From the second part, that is, from the mapping in the NH_3 (1,1) line of three sources of Myers & Benson (1983) sample and from the map of B18-I, we found no correlation between the morphology and the axis of rotation with the magnetic field. The density of the mapped clouds is in the range $10^{4.7} - 10^{5.1}$ cm^{-3} implying a critical density value for the magnetic decoupling $\leq 10^{4.7}$ cm^{-3}. However, this result is based on quite a small sample and must be confirmed by a statistical study of a representative sample of dense cores. As the main conclusion of this work, it shows the necessity of using for such a statistical study a high density tracer owing to the risk, here shown, of using a low density tracer as ^{13}CO to define dense cores. Moreover such a study must rely on an accurate value for the abundance of the tracer relative to molecular hydrogen. We note, in fact, that we have determined the volume densities assuming a value of 10^{-7} for the abundance of the NH_3 relative to molecular hydrogen. Because the observed range is $10^{-8} - 2 \times 10^{-7}$ (Irvine et al. 1987), and in particular in TMC1 a value of 10^{-8} has been given, our values might be underestimated by an order of magnitude.

Acknowledgements. We wish to thank C. Heiles for the helpful suggestions and Riccardo Cesaroni for its valuable assistance during the observations and data reduction.

References

Goodman, A. A., Bastien, P., Myers, P. C., and Ménard, F. 1990, *Ap. J.*, **359**, 363.

Goodman, A. A., Jones, T. J., Lada, E. A., and Myers, P. C. 1992, *Ap. J*, **399**, 108.

Heiles, C., Goodman, A. A., McKee, C. F., and Zweibel, E. G. 1993, *Protostars and Planets III*, eds. M. Mathews and E. Levy, (Tucson: University Press), in press.

Heyer, M. H., Vrba, F. J., Snell, R. L., Schloerb, F. P., Strom, S. E., Goldsmith, P. F., and Strom, K. M. 1987, *Ap. J.*, **321**, 855.

Heyer, M. H. 1988, *Ap. J.*, **324**, 311.

Irvine, W. M., Goldsmith, P. F., Hjalmarson, A. 1987, in Interstellar Processes, eds. D. J. Hollenbach and H. A. Thronson, Jr., (Dordrecth: Reidel), 561.

McKee, C. F., Zweibel, E. G., Goodman, A. A., and Heiles, C. 1993, *Protostars and Planets III*, eds. M. Mathews and E. Levy, (Tucson: University Press), in press.

Moneti, A., Pipher, J. L., Helfer, H. L., McMillan, R. S., and Perry, M. L. 1984,

Myers, P. C., and Benson, P. J. 1983, *Ap. J.*, **266**, 309.

Mouschovias, T. Ch., Paleologou, E. V., and Fieldler, R. A. 1985, *Ap. J.*, **291**, 772.

Nakano T. 1983, *Publ. Astron. Soc. Jpn.*, **35**, 87.

Nakano T., and Umebayashi T. 1986a, *M.N.R.A.S.*, **218**, 663.

Nakano T., and Umebayashi T. 1986b, *M.N.R.A.S.*, **221**, 319.

Nishi, R., Nakano, T., and Umebayashi, T. 1991, *Ap. J.*, **368**, 181.

Sato, S., Tamura, M., Nagata, T., Kaifu, N., Hough, J., Mclean, I. S., Garden, R. P., Gatley, I. 1988, *M.N.R.A.S.*,**230**, 321.

Shu, F. H., Adams, F. C., and Lizano, S. 1987, *Ann. Rev. Astr. Ap.*, **25**, 23.

Tamura, M., Nagata, T., Sato, S. and Tanaka, M. 1987, *M.N.R.A.S.*, **224**, 413.

Tamura, M., Yamashita, T., Sato, S., Nagata, T., Gatley, I. 1988, *M.N.R.A.S.*, **231**, 445.

Vrba, F. J., Strom, K. M., and Strom, S. E. 1976, *A. J.*, **81**, 958.

This article was processed by the author using Springer-Verlag TEX A&A macro package 1992.