MOLECULAR CLOUDS IN M51 AND IN THE GALAXY

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INTRODUCTION

Studies of molecular clouds in nearby galaxies require high angular resolution. Ten arcseconds corresponds to 0.5 kpc at the distance of M51. Typical gigant molecular clouds (GMC:s) have a size of 5-30 pc (Solomon et al. 1985). However complexes of GMC:s (Superclouds) can be several hundred parsecs (Elmegreen 1985; Rivolo et al. 1985). The higest angular resolution achived in CO(J=1-0) line observations of external galaxies is 7" (Lo et al 1984,1985). The resolution problem can be eased by observing M31 with a distance of only ≈ 690 kpc (10" corresponds to 34 pc), which has been done by Combes et al. 1977a,b; Boulanger et al. 1984; Ryden and Stark 1985; Stark 1985; Blitz 1985; Ichikawa et al. 1985. In M31 the CO emission is strongly concetrated to the spiral arms with a arm interarm ratio of ≥ 25 (Ryden and Stark 1985; Stark 1985). The emission is caused by many small clouds unresolved with present resolution together with some larger clouds. Streaming is observed to occur across the arms. Extragalatic studies have the advantage of being more easy to interpret in terms of arm interarm contrast, noncircular motion, and galatic structure. They also make possible studies of the mass fraction of gas as a function of radius in different morphological types of galxies. Answers to questions like "Do any relation exist between galaxy type and molecular abundance ?" are very important for our understanding of galatic evolution.

In order to resolve GMC:s are we forced to observe them in the Galaxy. Smaller dark clouds can only be observed with enough resolution in the solar vicinity. A number of surweys have been done to observe the general distribution. A few example are Scoville and Solomon 1975; Burton et al. 1975; Gordon and Burton 1976; Cohen and Thaddeus 1977; Stark 1979; Cohen et al. 1980; Dame 1984; Sanders et al. 1984.; Knapp et al. 1985. An number of papers deal with the structure of invidual molecular clouds. See for instance the procedings

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of IAU symposium No 115 on star forming regions, Tokyo Nov. 1985. The close association between molecular clouds and star formation is amply demonstrated. This connection between starformation and GMC:s implies that the evolution of galaxies is dependent on the distribution of molecular matter.

The molecular clouds themself shows a great deal of structure on many scales. Structure on the scale of .025 pc have been observed in the Orion molecular cloud (Harris et al. 1983). Clumps of similar size are observed in nearby dark clouds (Ungerechts et al. 1980; Snell et al. 1982; Friberg 1986). Small scale structure has been reviewed recently by Wilson 1985.

M51

M51 has been mapped in the CO(J=1-0) line with the Onsala 20 m telescope by Rydbeck et al. 1985 . The beamsize is 33" with corresponds to 1.5 kpc at 10 Mpc distance. Altogether 180 points have been observed with the NE quadrant completely sampled (See figure 1a for observed positions). M51 has a grand design spiral structure. The azimuthally averaged CO-luminosity has a slight depression in the center followed by a maximum appering about 1 kpc from the center. From its peak value at 1 kpc the emission decreases sharply out to 3 kpc where a more flat disk distribution takes over. With that background is it hard to make arms directly visible in a contour plot. Figure 1b shows a contour plot of the CO emission with an azimuthal average subtracted at each radius. A molecular cloud ridge along the outer arm is clearly apparant. The arm interarm contrast is on average 1.7 but varies from almost zero to about 2.5 (without correction for beam dilution). The mass of the central arm complex seen in figure 1b is about 10^{8} M_{o} using a conversion factor $N(H_2)/W(CO) \approx 3*10^{20}$ $cm^{-2}K^{-1}km^{-1}s$. The surface density is then 35 $M_{o}pc^{-2}$. The difference in CO emissivity between the arm and interarm regions might also in part be due to a temperature difference. The temperature of GMC:s in the spiral arms of the Galaxy is higher than the temperature for clouds between the arms (Solomon et al. 1985). The mass inside a radius of 1.5 kpc from the M51 center is 10^{9} M_{o} (using the same conversion factor). The thick dashed line in figure 1b marks ridges of maximum nonthermal continiuum emission, which indicating where the magnetic field is compressed. This compression occurs on the inside of the spiral arm, as expected from density wave theory. The thick solid line shows the border between positive and negative

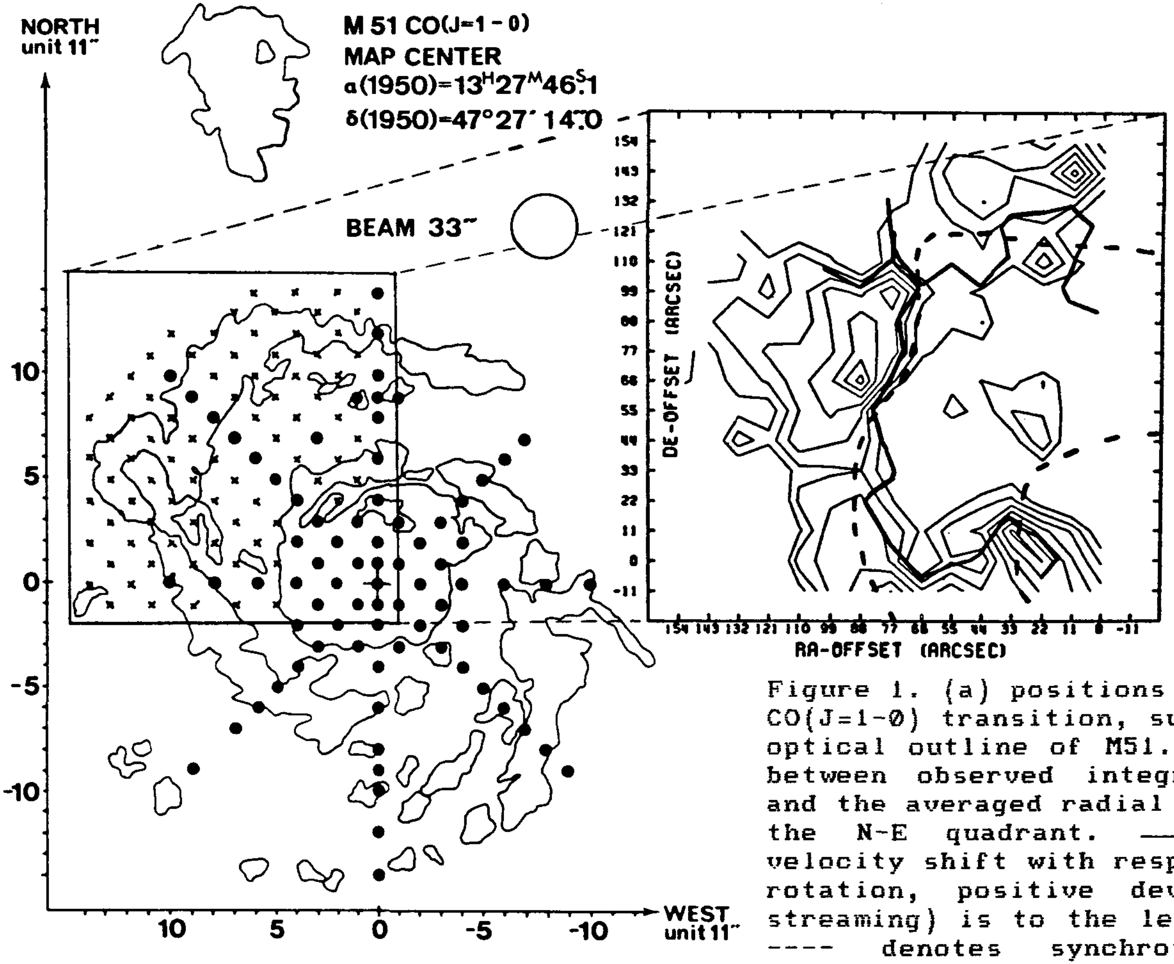

Figure 1. (a) positions observed in the CO(J=1-0) transition, superposed on the optical outline of M51. (b) difference between observed integrated intensity and the averaged radial distribution in the N-E quadrant. —— marks zero velocity shift with respect to circular rotation, positive deviation (inward streaming) is to the left of the line. ---- denotes synchrotron continuum ridges.

velocity offsets from circular rotation. The interarm region has negativ and the arm positive velocity deivation. This means that the gas is streaming outwards in the interarm area, becomes compressed when it hits the arm and then starts to stream inwards. Corrected for inclination the velocity shift is 70 kms^{-1}, a very large value.

The CO-rotation curve of M51 differs from the Hα-rotation curve (Goad et al. 1979) in that sense that the Hα rotates faster. This is also apparent in NGC5055 (Johansson and Booth 1986) and NGC253 (Scoville et al 1985). Scoville et al. suggests high optical extinction as the cause. If the velocity shifts are real they depict a very interesting streaming between young stars and the bulk gas motion (averaged over 33").

OVRO CO(J=1-0) aperture synthesis maps clearly demostrate spiral arms close to the center of M51 (Lo et al.1985). Similar results is also reached by Rydbeck et al.(1985), based on modeling of the central region.

MOLECULAR CLOUDS IN THE GALAXY

Star formation occurs in molecular clouds. Regions with massive star formation are well known e.g. W49, W51, W3, NGC7538, ... The general outlines of these regions and cloud complexes are best studied in CO. A number of such studies have been done with the Columbia university 1.2 m telescopes and at other institutions (May et al. 1985; Jacq et al. 1985; Murphy and Myers 1985). In order to study the more central parts several other molecular probes are used. By selecting a suitable molecule and transition regions with different physical properties can be studied. An example is formaldehyde which appears in absorbtion at densities below $\approx 1*10^6 cm^{-3}$ and emission at heigher densities (Evans et al. 1979, Wilson et al. 1980). Another example is methyl cyanide. It is a symmetric top molecule so several lines originateing from differnt energy levels appear very close together in frequency. The relative intensities are sensitive to the temperature. Due to the high dipol moment high densities are necessary to get strong emission. The region around Orion KL has been mapped in methyl cyanide (Andersson 1985). Faint emission is seen in the north. The faintness and the fact that only the two low energy lines are visible tells ous that the temperature is about 40K and that we have a density of rougly $10^{4.5} cm^{-3}$. At the center position the emission is very much stronger. The increase in emission is due to increase in temperature, density and probably abundance. The derived density and temperature is $10^6 cm^{-3}$ and $\gtrsim$ 160 K, respectively. The emission decays slowly from the KL position towards the south. The slow decay is due to another source just south of the KL region. This phenomen with several sources is common in star forming regions and probably depicts the formation of OB associations.

Smaller dark clouds in our vicinity do not show any signs of massive star formation but still have a lot of structure and turbulence (Ungerechts et al. 1980; Snell et al. 1982; Friberg 1986). The source of the turbulence and structure is not known. Norman and Silk (1980) have proposed that winds from the formation of low mass stars is the cuase. Recently Goldsmith et al. (1985) detected high velocity flows around four IRAS sources in the dark cloud B5. However dark clouds without any signs of high velocity flows or IRAS sources also have structure and turbulence. Usually T-Tauri stars are associated with these clouds.

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