MOLECULAR CLOUDS AND THE INTERSTELLAR MEDIUM IN M33

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ABSTRACT. A total of 38 molecular clouds have been mapped in the inner kiloparsec of the nearby galaxy M33. The properties of these clouds (diameters, velocity widths, brightness temperatures, and masses) are very similar to the properties of Galactic giant molecular clouds. The cloud mass spectrum is also similar in the two galaxies, except that the M33 mass spectrum is deficient in the highest mass clouds. A comparison of the interferometer and single dish fluxes shows that only 40% of the CO flux is contained in clouds more massive than 10^5 $M_\odot$, while 60% of the flux is due to diffuse gas or a fairly smooth distribution of small clouds that cannot be detected with the interferometer. Comparing the CO maps with a high-resolution HI map and optical Hα photometry reveals that peaks in these three components are always found close together. The atomic gas peaks near the molecular clouds are probably produced via photo-dissociation of the molecular gas.

1. Introduction

The properties of giant molecular clouds in our own Galaxy are now fairly well understood (see, e.g., Sanders, Scoville, and Solomon 1985), but until quite recently there has been little detailed information on the properties of molecular clouds in other galaxies. This is because very large single dish telescopes or interferometers are required to resolve individual molecular clouds in galaxies more distant than the Magellanic Clouds. In the last few years individual molecular clouds have been mapped in M31 with Nobeyama (Lada *et al.* 1988), OVRO (Vogel, Boulanger, and Ball 1987), and IRAM (Casoli, Combes, and Stark 1987; Casoli and Combes 1988). Molecular clouds have also been mapped with OVRO in the nucleus of M33 (Wilson *et al.* 1988) and in its giant HII region NGC 604 (Boulanger *et al.* 1988). However, in order to make a detailed comparison of the properties of molecular clouds in another galaxy with clouds in the Milky Way, a large sample of clouds is required, preferably all mapped with the same instrument for uniform sensitivity and resolution. The results of such a survey of the inner region of M33 are summarized here; details are given in Wilson and Scoville (1990, 1991).

2. Molecular Clouds in M33

Nineteen fields within one kiloparsec of the nucleus of M33 have been mapped with the Owens Valley Millimeter-Wave Interferometer and a total of 38 individual molecular clouds have been found. The physical properties of the clouds in M33 are very similar to those

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of Galactic giant molecular clouds. The clouds have deconvolved diameters of 20 to 60 pc, velocity widths (full-width half-maximum) of 4 to 11 km s^{-1}, peak brightness temperatures of 1 to 5 K, and masses of 2×10^4 to 5×10^5 $M_\odot$. Nine of the clouds are sufficiently well resolved that their diameters can be deconvolved from the synthesized beam. These clouds obey the size-line width relation derived for Galactic giant molecular clouds (Solomon *et al.* 1987). In addition, masses calculated using the virial theorem and masses calculated from the CO fluxes (adopting $\alpha = 3\times10^{20}$ cm^{-2} (K km $s^{-1})^{-1}$) agree to within 10% (Figure 1). Thus the value of α, the conversion factor from CO flux to H_2 column density, is the same in the inner kiloparsec of M33 as it is in our own Galaxy.

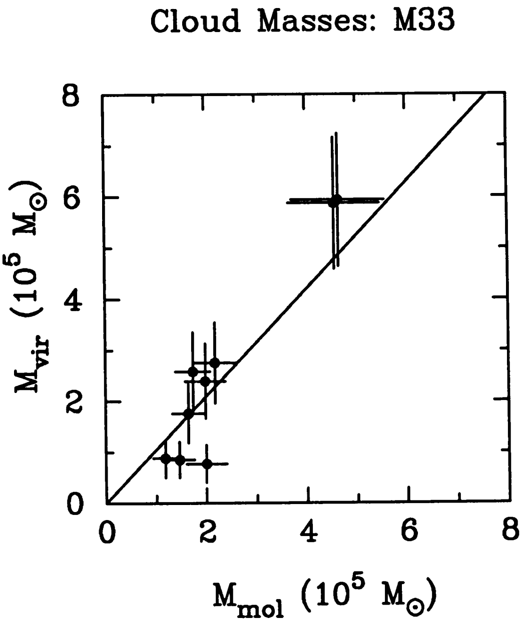

Figure 1. Virial mass versus molecular mass for molecular clouds in M33. The line is a fit to the data, which gives $M_{vir} = (1.05\pm0.10)\ M_{mol}$.

The mass spectrum of the clouds in M33 agrees well with the Galactic cloud mass spectrum, but it is deficient in the lowest and highest mass clouds. The lack of low mass clouds is probably due to our selection criteria, but the lack of high mass clouds is both real and significant. In the Galaxy, 25% of the clouds are more massive than 5×10^5 $M_\odot$, while no clouds above this mass limit are found in M33. This suggests that the upper mass cutoff to the cloud mass spectrum is different in the two galaxies. A model has been proposed in which the upper mass cutoff is produced by a balance between the processes of cloud growth by accretion of material and cloud destruction via star formation and ionization (Wilson and Scoville 1990).

Since the interferometer is not sensitive to structures larger than $\sim 30''$, it is important to compare the flux detected by the interferometer with the flux detected by single dish telescopes. Comparing the interferometer data with the single dish map of M33 at $55''$ resolution (Wilson and Scoville 1989) reveals that the interferometer is only detecting 40% of the single dish flux. Thus a large fraction of the CO flux and presumably of the H_2 mass is contained in either a diffuse component or in many small clouds distributed fairly uniformly across the beam. This is in contrast to our own Galaxy, where it is claimed that 85% of the flux is contained in structures larger than 10^5 $M_\odot$ (Sanders, Scoville, and Solomon 1985).

3. Comparison of the Molecular, Atomic, and Ionized Gas Distributions

The interferometer maps have been compared with a high-resolution HI map (Deul and van der Hulst 1987) and Hα CCD data (Wilson and Scoville 1991). All the molecular clouds lie near a peak in the HI distribution and no atomic gas peaks are found in the interferometer fields that do not have a molecular cloud. In addition, many of the clouds contain Hα emission and, again, all of the Hα emission in the interferometer fields is associated with a molecular cloud. The close proximity of these three phases of the interstellar medium suggests that they are physically related.

In the region of the southern spiral arm, which may be generated by a spiral density wave (Humphreys and Sandage 1980), the atomic peaks are systematically offset downstream from the molecular clouds. The relative offset implies that the atomic gas has recently formed from the molecular gas. Calculations show that the observed atomic gas peaks could be produced via photo-dissociation of molecular hydrogen by the stars in the HII regions near the individual clouds. However, the typical density that the photo-dissociating radiation encounters in the cloud must be ~ 4 times smaller than the mean density of the cloud, i.e., the cloud must have a clumped structure.

4. References

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Ship's boys help astronomers to settle down for the party.