The Evolution of Molecular Clouds

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Abstract

A comparative study of the structure of two molecular clouds of similar mass, but very different stellar content, is presented and the effect of massive stars on the molecular ISM assessed. A possible evolutionary scenatio for molecular clouds is proposed.

Since stars form in molecular clouds, their interaction with the ISM is initially and most directly with the ambient molecular material from which they formed. The effect may be to propagate star formation throughout the cloud [1], or to destroy the cloud, thereby limiting the rate and efficiency of star formation [2]. If we are to learn more about the interplay between massive star formation and the ISM on galactic scales, it is imperative that any feedback processes between newly formed stars and star forming material – molecular gas – be better understood on cloud size scales.

By observing nearby Galactic giant molecular clouds (GMCs), the interaction between massive stars and molecular gas can be measured in detail. I present here a comparative study of two clouds, one which is forming OB stars, and the other not, and make inferences about how molecular cloud evolution is driven by the star formation within them. Only the briefest possible account is possible here, but full details are available in [3]. The two objects are the Rosette [4] and Maddalena–Thaddeus [5] clouds. They have similar masses, $\sim 1-3\times 10^5 M_\odot$, but quite different stellar contents (Figure 1). The lack of star formation within the MTC may be due to either extreme youth or old age (see [6]), but is nevertheless due to the cloud being in a quite different evolutionary state to the RMC. These two clouds, therefore, are an excellent laboratory for studying the evolution of GMCs, and the effect of OB stars on the molecular ISM.

Even without any detailed analysis, clear differences in the molecular content of the two clouds are seen. Figure 2 shows that the non-star forming MTC may be described as a large, low

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surface brightness GMC. Its disjointed, "puffy" appearance is precisely what would be expected for a young cloud prior to star formation in the photo-ionization limited star formation model of McKee [7].

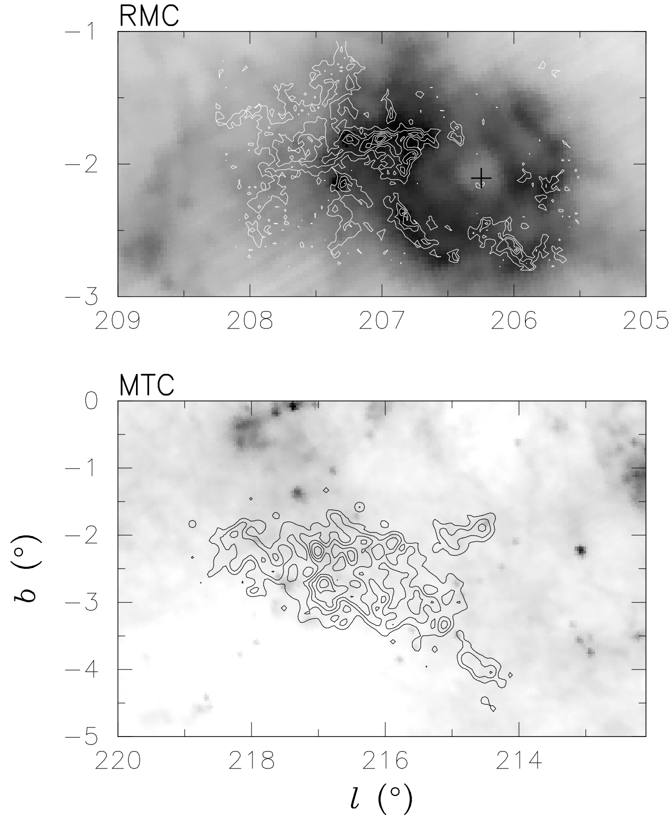

Figure 1: Infrared emission from stars in the Rosette and Maddalena–Thaddeus molecular clouds. The gray scale corresponds to *IRAS* 100μm flux and is on a logarithmic scale ranging from 20 to 500 MJy sr^{-1}, the same for both clouds. The contours are of velocity integrated CO emission and are at 18, 36, 54. . . K km s^{-1} for the RMC and 4, 8, 12. . . K km s^{-1} for the MTC. The Rosette nebula (containing 4 O and 13 B stars) is visible as a ring centered on the cross, and the cloud as a whole is more than an order of magnitude brighter than the MTC, demonstrating the differences in their stellar content.

How does the molecular gas in the two clouds compare at higher resolution? Figure 3 shows two position–velocity slices, but this time without any scales on the axes or in the contouring. The internal structure of the two clouds looks remarkably similar. A number of discrete, clump-like, objects can be seen, and also low level blending of peaks of emission, but, based on this infomation alone (*i.e.*, looking only at the *topology* of the gas), it is not at all clear which cloud is forming stars, and which is not.

This intuitive conclusion is quantified in Figure 4 which shows a number of clump properties plotted against each other for each cloud. The data cubes for each cloud have been analyzed in the same manner using an automated "clump-finding" algorithm [8] so as to make the comparison as uniform and objective as possible. Least squares fits are shown for each cloud; their slopes are very similar (*c.f.* the ubiquity of Larson's laws and clump mass spectrum $dN/dM \sim M^{-1.5}$ for many different clouds, e.g. [9]), but there are offsets between the two fits suggesting that the principal difference between the clouds is not in their structure, but in their scale – as for the large scale picture of the clouds in Figure 2. Note that although some of the offsets are sensitive to the assumed distance to the clouds, the dependence is different for each one and therefore not all can be simultaneously due to errors in the assumed distances to the RMC or MTC (1.6 kpc and 2.3 kpc respectively).

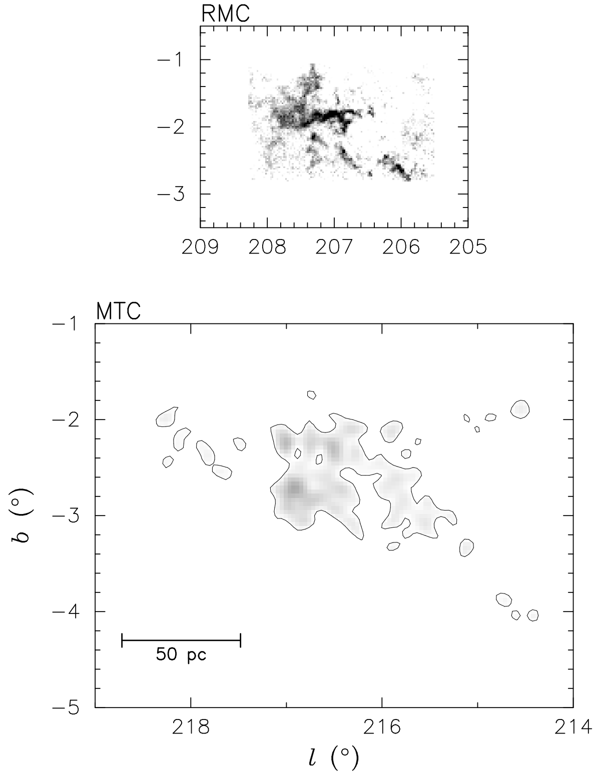

Figure 2: Molecular column density in the RMC and the MTC. For the comparison, the CO emission in each cloud has been integrated over the full velocity range for each cloud and is shown in grayscale ranging from 10 to 60 K km s^{-1}, the same for both clouds. The linear scale is also the same for both plots (indicated on the lower left of the bottom panel). It is apparent that the non-star forming MTC is larger, but has a lower average column density than the star forming RMC.

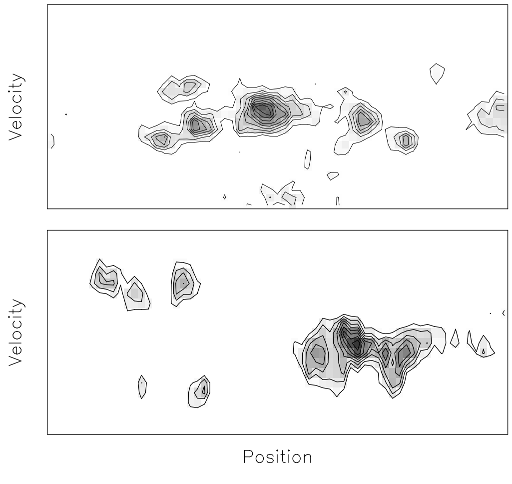

Figure 3: Position–velocity diagrams for the Rosette and Maddalena–Thaddeus clouds. Clumpy structure is readily apparent in both. The scales on the two axes have been deliberately omitted, and the contours arbitrarily chosen so as to demonstrate the structural similarities between the two clouds; without knowing the sizes, linewidths, or column densities of the clumps, it is difficult to tell the two clouds apart. This suggests that the principal difference between the two clouds is not one of structure, but of scale.

This is not to say that the internal structure of a cloud tells us nothing about its evolution (quite the opposite [10]), but rather that cloud evolution appears to proceed by, for example, clumps losing kinetic energy (Δv decreases) and consequently becoming more bound ($M_{\rm grav}/M$ decreases), becoming more centrally condensed ($N_{\rm peak}$ increases), etc. *in a structure-independent manner.* Note that this is not the same as statements on cloud structure being or not being self-similar.

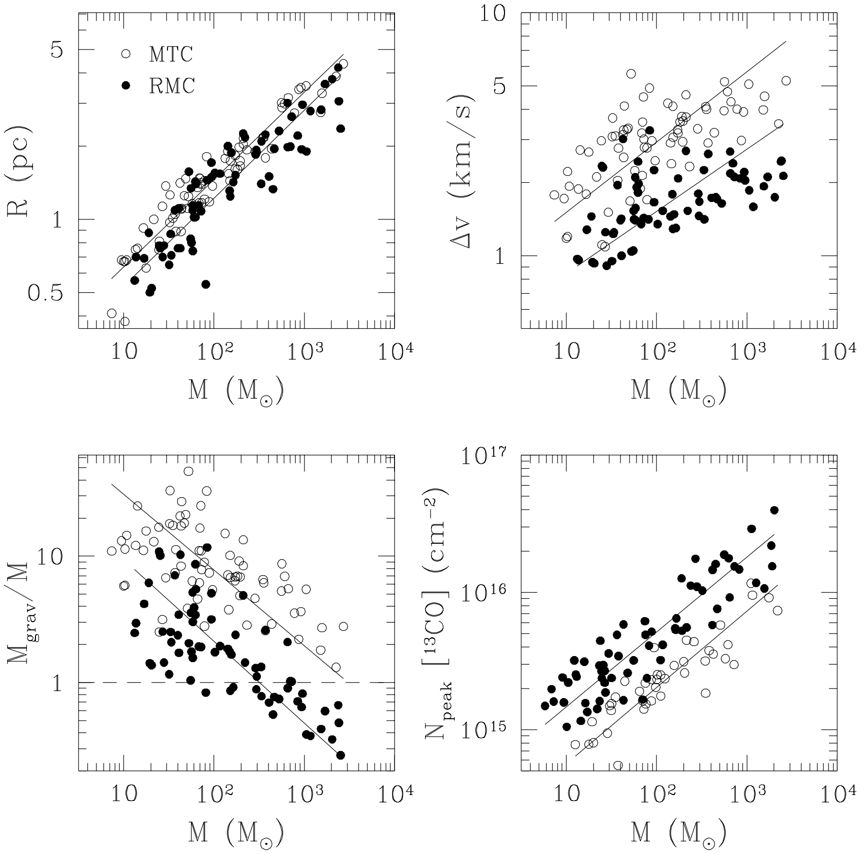

Figure 4: Power law relations between clump size, R, clump linewidth, Δv, gravitational parameter, $M_{\rm grav}/M$, and peak column density, $N_{\rm peak}$, with clump mass, M. A least squares power law fit is shown for each cloud. The differences between the fits is not in the slope, but in the offset: that is, not in the (clumpy) structure of the gas, but in the scale of the structure (clumps).

A heuristic scenario that is tentatively suggested by these observations is that, without stellar energy input to support them, molecular clouds contract gravitationally thereby becoming smaller (accompanied by a corresponding increase in the average column density). The collective structure of the gas remains essentially the same – in a topological sense – which may be of use in constraining solutions to the MHD equations governing the cloud physics, but the structures themselves (clumps) become more tightly bound and more centrally condensed until dense cores and eventually stars form. The stars support the cloud [7],[11] and may act to reverse the above process by stirring up the gas causing clumps to become less bound and less centrally condensed, and the cloud as a whole to become larger. Such wild speculation is going to need a lot of evidence to back it up, coming from many more cloud comparisons and more sophisticated analyses of structures. It would seem, however, that a cloud's evolution is, to a large extent, governed by the stars that form within it.

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