On the structure of molecular clouds

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Accepted 2012 September 13. Received 2012 September 13; in original form 2012 May 17

ABSTRACT
We show that the inter-cloud Larson scaling relation between mean volume density and size $\rho \propto R^{-1}$, which in turn implies that mass $M \propto R^{2}$, or that the column density $N$ is constant, is an artefact of the observational methods used. Specifically, setting the column density threshold near or above the peak of the column density probability distribution function $N$-PDF ($N \sim 10^{21}$ cm$^{-2}$) produces the Larson scaling as long as the $N$-PDF decreases rapidly at higher column densities. We argue that the physical reasons behind local clouds to have this behaviour are that (1) this peak column density is near the value required to shield CO from photodissociation in the solar neighbourhood, and (2) gas at higher column densities is rare because it is susceptible to gravitational collapse into much smaller structures in specific small regions of the cloud. Similarly, we also use previous results to show that if instead a threshold is set for the volume density, the density will appear to be constant, implying thus that $M \propto R^{3}$. Thus, the Larson scaling relation does not provide much information on the structure of molecular clouds, and does not imply either that clouds are in Virial equilibrium, or have a universal structure. We also show that the slope of the $M-R$ curve for a single cloud, which transitions from near-to-flat values for large radii to $\alpha = 2$ as a limiting case for small radii, depends on the properties of the $N$-PDF.

Key words: stars: formation – ISM: clouds – ISM: general – ISM: kinematics and dynamics – galaxies: kinematics and dynamics.

1 INTRODUCTION
More than 30 years ago, Larson (1981) published his scaling relations for molecular clouds (MCs): the column density–size relation (or ‘Larson’s third relation’)

$$\rho \propto R^{\gamma_{1}}$$

and the velocity dispersion–size relation

$$\sigma \propto R^{\gamma_{2}}.$$  

The exponents reported in that work were $\gamma_{1} = -1.1$ and $\gamma_{2} = 0.39$, respectively. However, the more widely accepted values are $\gamma_{1} = -1$ and $\gamma_{2} = 0.5$; and these have been usually thought to be observational evidence that clouds are in Virial equilibrium, although it is important to recall that any pair $(\gamma_{1}, \gamma_{2})$ satisfying $\gamma_{1} = 2\gamma_{2} - 2$ will be consistent with Virial equilibrium (see e.g. Vázquez-Semadeni & Gazol 1995).

Larson’s relations have been used in many papers to describe the internal structure of clouds (e.g. Goldbaum et al. 2011, to cite just one of the more recent examples). However, their validity has been called into question for observational reasons (Kegel 1989; Scalo 1990; Vázquez-Semadeni, Ballesteros-Paredes & Rodriguez 1997; Ballesteros-Paredes & Mac Low 2002; Ballesteros-Paredes 2006; Ballesteros-Paredes et al. 2011a). Specifically, clouds should have a minimum column density to be detected; and if the column density were too large, clouds will become optically thick (in $^{12}$CO), and then such dense regions would not be easily detected. The net result of these effects would be that observed CO clouds should exhibit a small dynamic range in column density, independent of their intrinsic structure.

In a recent study, Lombardi, Alves & Lada (2010) used near-infrared extinction measurements to increase the dynamic range of inferred mass column densities. They studied a sample of local MCs with substantially different physical properties, from giant MCs hosting massive star formation, and masses of the order of $2 \times 10^{5}$ $M_{\odot}$ (e.g. Orion), down to clouds with less star formation activity, and masses of the order of several thousand $M_{\odot}$ (the Pipe Nebula). Their main results are as follows.

(i) For an ensemble of MCs observed at a given extinction threshold $A_0$, the mass varies with size as $M \propto R^{3}$, implying that the column density $\Sigma = N/\mu m_{H}$ is constant and depends on that threshold.

(ii) The numerical value of the column density changes with the value of the threshold $A_0$.  

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