Possible origin of Larson’s lows

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It was found that approximately constant column densities of giant molecular clouds (Larson’s low) can be explained as cloud existence condition in external (galactic) gravitational field. This condition can be also applied to objects (clumps and cores) embedded into the cloud and its gravitational field. Derived existence condition do not rely on any internal dynamic of a cloud and embedded objects.

1. Introduction

Giant molecular clouds (GMCs) play a crucial role in the star formation process ([1],[2],[3],[4],[5]). GMCs are complex objects with masses $\sim 10^5-6 M_\odot$, diameters $\sim 50pc$ and average densities $n_{H_2} \sim 10^2cm^{-3}$ (e.g. [6]). GMCs are generally gravitationally bound and may contain several sites of star formations. Equilibrium of self-gravitating gas was theoretically investigated in many works (e.g. [4],[9] and references in these papers). Internal structure of GMS is usually very complicated. The inhomogeneous structure of cloud could be described as a set of descrete clumps ([7]). These clumps themselves contain dense cores with densities $n \sim 10^3-5cm^{-3}$. The one point of view at this time is that this cloud structure is due to supersonic turbulence. Remarkably enough, the properties of cloud complexes are rather simply interrelated. Total masses, mean densities and average velocity dispersions vary with sizes (effective radii) roughly as $M \propto R^2, \rho \propto R^{-1}, \sigma \propto R^{1/2}$ (Larson’s lows) ([8]).

In this paper I propose simple hypothesis to explain relation between masses and sizes of clumps and cores, embedded into clouds.

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2. Larson’s lows

Let us briefly consider some of the most salient characteristics of GMCs summarized by Larson ([8]). See also ([2]). The first relation is the line width-size relation: molecular clouds are supersonically turbulent with line widths $\Delta v$ that increase as a power of size, $\Delta v \propto R^p$. Larson himself estimated that $p \simeq 0.38$. Subsequent work has distinguished between the relation valid for a collection of GMCs and that valid within individual GMC. Within low-mass cores, Caselli & Myers ([10]) found that the nonthermal velocity dispersion is

$$\sigma_{nt} \simeq 0.55R_{pc}^{0.51} \text{ km s}^{-1},$$

which is near to relation

$$\sigma \propto R^{1/2}.$$  \hspace{1cm} (2.2)

Larson’s second result was that GMCs and clumps within them are gravitationally bound. It implies that

$$\sigma^2 \propto GM/R.$$ \hspace{1cm} (2.3)

This relation is result of virial equilibrium.

His third conclusion was that all GMCs have about the same column density

$$N \simeq \text{const}.$$ \hspace{1cm} (2.4)

Column density is defined as

$$N \propto M/R^2 \propto nR.$$ \hspace{1cm} (2.5)

As Larson pointed out, only two of these conclusions are independent: any one of them can be derived from other two. Opposite to the second conclusion the first and the second Larson’s lows have no evident explanation. I think this explanation may be as follows.

Embedded clumps and cores moves through the cloud in its gravitational field and are subject of turbulent motion and various accelerations. If their own gravitational field is not enough to hold on these objects they must rapidly decay. It is easy to derive necessary condition for confinement gaseous body with mass $M$ and radius $R$ in external gravitational field of cloud with mass $M_{cl}$ and radius $R_{cl}$. The variation of self gravitational potential $\Delta \phi$ must be greater then that of the cloud on size $R$. Bearing in mind that

$$\Delta \phi \simeq GM/R$$ \hspace{1cm} (2.6)
and
\[ \Delta \phi_{cl} \simeq R \frac{d}{dR_{cl}} GM/R_{cl} \simeq GMR/R_{cl}^2 \] (2.7)
we get
\[ GM/R \geq GM_{cl}R/R_{cl}^2 \] (2.8)
or equivalently
\[ M/R^2 \geq M_{cl}/R_{cl}^2. \] (2.9)
Inequality (2.9) is the main result of this work. It is important for understanding the third Larson’s low (2.4). Inequality (2.9) is strong only for very massive and compact objects within the cloud which are hard to generate in turbulent motion. So inequality can not be strong for almost all objects. Further, in expression (2.7) we did not take into account placement of object within the cloud. Summarizing all we can generalize third Larson’s low in the form
\[ \frac{M}{R^2} \approx C \frac{M_{cl}(r)}{r^2}, \] (2.10)
where \( r \) is the distance of object from the center of cloud, \( M_{cl}(r) \) is the mass of cloud within \( r \), \( C \) is the non-dimensional constant of order one. As far as clouds itself are concerned they move in galactic gravitational field through the interstellar gaseous media (ISM) and we can get for them analogous condition
\[ \frac{M_{cl}}{R_{cl}^2} \approx C \frac{M_{gal}(r)}{r^2}, \] (2.11)
where \( r \) is the distance of cloud from the center of galactic, \( M_{gal}(r) \) is the mass of galactic within \( r \).

3. Summary

We have seen that it is possible to understand the third Larson’s low and some properties of molecular clouds and objects within them in terms of their existence conditions in external gravitational field. In particular, we have seen possible reason why the clouds have approximately constant column densities. I have to stress now that conditions (2.10) and (2.11) do not rely on any internal dynamic of cloud. It will be also interesting to examine
relations (2.10) and (2.11) with astronomical data sets.

[1] McLaughlin Dean E., Pudritz Ralph E. *A model for the internal structure of molecular cloud cores*. arXiv:astro-ph/9605018

[2] McKee Christopher F. *The dynamical structure and evolution of giant molecular clouds*. arXiv:astro-ph/9901370

[3] Williams Jonathan P., Blitz Leo, McKee Christopher F. *The structure and evolution of molecular clouds: From clumps to cores to the IMF*. arXiv:astro-ph/9902246

[4] McKee Christopher F., Holliman John H., II *Multi-pressure polytropes as models for the structure and stability of molecular clouds. I. Theory*. arXiv:astro-ph/9903213

[5] Padoan Paolo, Nordlund Ake, Kritsuk Alexei G., Norman Michael L., Shing Pak Li *Two regimes of turbulent fragmentation and the stellar IMF from primordial to present day star formation*. arXiv:astro-ph/0701795

[6] Blitz L. 1993. Giant molecular clouds. In *Protostars and Planets III*, eds E.H. Levy and J.I. Lunine, (Tucson: Univ. of Arizona Press), pp 125-161.

[7] Blitz L., Stark A. A. 1986. *Detection of clump and interclump gas in the Rosette molecular cloud complex*. Astrophys. J. Lett. 300:L89-L93

[8] Larson R. B., 1981, MNRAS, 194, 809.

[9] Zaharow A. W. *Gravitational stability of finite massive bodies*. arXiv:astro-ph/0610450

[10] Caselli P., Myers P. C. 1995, ApJ, 446, 665.