Study of the structure of molecular clouds by use of a statistical approach

Sava Donkov
Department of Applied Physics, Technical University,
8 Kliment Ohridski Blvd., 1000 Sofia, Bulgaria
e-mail: savadd@tu-sofia.bg
(Summary of the Ph.D. Dissertation; Thesis language: Bulgarian
PhD is awarded on October 3, 2013, at the Faculty of Physics, University of Sofia)

Abstract. We model molecular clouds (MCs) at an early stage of their evolution as supersonic compressible turbulence is assumed to be saturated and prevails over gravity at large scales, while gravity dominates at small scales. We consider isothermal, homogeneous and isotropic medium characterized by a lognormal probability density function of density. The latter corresponds to the density distribution of introduced abstract statistical objects labeled condensations (or, simply, 'clumps'). A basic assumption in the model is the existence of a power-law relationship between density and mass of the clumps with index called 'structure parameter'. This parameter is obtained by solving the equations of equipartition between main clump energies. By use of the structure parameter, we model the global MC structure (the 'mass-scale' diagram) and derive the clump mass function and 'mass-size' diagram. The results are compared with observational maps of Galactic MCs from molecular emission or dust continuum. The model predictions show good agreement with observations mostly at intermediate scales (between 1 and 10 parsec).
Key words: ISM: clouds - ISM: structure - turbulence - methods: statistical

The main objective of this Thesis is to model molecular clouds (MCs) at an early stage of their evolution. Our model is based on the well-known phenomenology of turbulent media and predicts: A) the global cloud structure in terms of mass-scale relationship (i.e. how the mass of a cloud region, delineated by a strictly defined density cut-off, depends on its effective size); B) the mass distribution of clumps generated in MCs; and C) the mass-size relationship of these clumps.

The model assumptions are as follows: i) turbulence dominates over gravity at large scales, while the latter takes over at small scales; ii) the fully developed supersonic turbulence produces an inertial range of scales within which a cascade of turbulent kinetic energy occurs and scaling laws of mass, density and turbulent velocity fluctuations are defined (i.e. fractal structure); iii) turbulence is isothermal and locally homogeneous and isotropic; iv) density is distributed lognormally at each scale under steady-state conditions which allows for applying the ergodic hypothesis; v) the density distribution is represented through abstract statistical objects ('clumps') whose statistics is identical to that of the pixels at the considered scale while the collective behavior is identical to that of the real objects; vi) a power-law mass-density relationship of the statistical clumps whose index ('structure parameter') is scale-dependent and can be expressed by the density scaling index and hence determines the global cloud structure, the clump mass distribution and the clump mass-size relationship (see points A, B and C above).

The 'structure parameter' is obtained by solving equations of equipartition between kinetic (turbulent), gravitational, internal and magnetic energies, in various virial-like combinations. The equations are written for the most probable clump at each scale. Though not derived directly from the Virial theorem, their use in relation to statistical objects is justified through the general ensemble-averaged virial equation. The obtained solutions are compared with observations of MCs, constraining the parametric space in each case and commenting on the physical meaning. A good agreement is found between the characteristics of observed objects and the model predictions.

The study realized in three main stages. The first stage was to construct the model and to compare the solutions for 'structure parameter' with mass-scale diagrams for several Galactic MCs (Donkov, Veltchev & Klessen, 2011; hereafter, DVK-2011) by use of the observational study of Lombardi, Alves & Lada (2010). The comparison with observations enabled us to probe which of the initially chosen equipartition equations yield reasonable solutions and to constrain the ranges of free parameters. The main conclusion is that kinetic (turbulent) and gravitational energy must be always present in the equipartition equations. The internal (thermal) and magnetic energies play rather supporting role. This is an important physical conclusion regarding the energy balance in real MC condensations.

The second stage, accomplished in the second paper (Donkov, Veltchev & Klessen, 2012) has been devoted to the construction of the mass distribution of statistical clumps and the resulting clump mass-size diagram. The investigation was restricted to study of equipartition equations found to yield reasonable solutions (DVK-2011). The main result is that the model mass functions reproduce very well the observational high mass range with typical fractal slope '-1'. Moreover, the intermediate mass range can be also reproduced using some of the equations (and definite free-parameter sets). This intermediate-mass range is characterized by a shallower slope and a characteristic mass which separates it from the high-mass one. The mass-size diagrams exhibit approximately the same slopes like in observations and simulations. Thus the model has been completed and the free parameter space has been additionally constrained.

The third stage was devoted to comparison of the model predictions with observations (Veltchev, Donkov & Klessen, 2013). That was accomplished through consecutive fitting of the mass-scale diagram, deriving the clump mass distribution and eventually the mass-size diagram for the considered Galactic clouds. At the first two steps, the free parameters of the model are fixed and then the third diagram is determined completely. We used maps of Galactic MCs from molecular emission and dust continuum. In the former case, the abovementioned three steps were made while in the latter (with one exception) no data on the global cloud structure were available and thus only the last two steps were made. The predicted global cloud structure is in a good agreement with the observations mostly at intermediate scales (between 1 and 10 pc), while diversions were found at small (below 1 pc) and at large scales (above 10 pc).

The latter result can be explained with different physical conditions in comparison with our model assumptions. The derived mass functions exhibit a good agreement at high and intermediate mass ranges. The largest disagreement between the observational data and the model was found in the mass-size diagrams. The slopes are satisfactory (within two times standard deviation) but there are large shifts in sizes and/or masses. That can be explained with the applied various clump-finding techniques which are not consistent with each other and with our statistical approach. This is one of the problems we aim to solve in the future.

Another important task is to investigate the MC structure and the mass function of cores at smaller scales (less than 1 pc). These dense objects are birth sites of stars.

References

Donkov S., Veltchev T., Klessen R.S., 2011, *MNRAS*, 418, 916 (DVK-2011)
Donkov S., Veltchev T., Klessen R.S., 2012, *MNRAS*, 423, 889
Lombardi M., Alves J., Lada C., 2010, A&A, 519, 7
Veltchev T., Donkov S., Klessen R.S., 2013, *MNRAS*, 432, 3495