Self-Gravitating N-Body Systems out of Equilibrium

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Abstract. Real physical systems are often maintained off equilibrium by energy or matter flows. If these systems are far from equilibrium then the thermodynamical branch become unstable and fluctuations can lead them to other more stable states. These new states are often endowed with higher degrees of organization. In order to explore whether an energy-flow in combination with self-gravity can lead to complex, inhomogeneous structures, like observed in the interstellar medium (ISM), we perform N-body simulations of self-gravitating systems subjected to an energy-flow.

Moreover we perform some simple “gravo-thermal” N-body experiments and compare them with theoretical results. We find negative specific heat in an energy range as predicted by Follana & Laliena (1999).

1. Introduction

An energy-flow through a system is related to an entropy-flow. If the entropy-flow leaving the system is larger than the entering one, the system evacuates its internal, by irreversible processes produced entropy to the outer world. Consequently order is created inside the system, diverging from the classical thermodynamical equilibrium of a closed system. Far from equilibrium the system is no longer characterized by an extremum principle, thus losing its stability. Therefore perturbations can lead to long range order, through which the system acts as a whole. Such a behavior is well known in laboratory hydrodynamics and chemistry. The underlying concepts such as “dissipative structures” and “self-organization” were extensively studied (see e.g. Nicolis & Prigogine 1977). But in spite of their popularity they are until now only little studied in the context of non-equilibrium structures in self-gravitating astrophysical systems. Therefore we take up some ideas of these concepts and build a simple model of an open self-gravitating system. With this model we want to check if an energy-flow can maintain a self-gravitating system in an statistically stable state, out of thermodynamical equilibrium and if gravitation in combination with an energy flow can create structures with a higher degree of order.

2. Dissipative N-body Systems

Taking into account the highly clumpy nature of the interstellar medium, we use in our model dissipative particles, representing dense cloud fragments, to
simulate cosmic gas (Pfenniger 1998). Moreover, with such a realization we can check some thermodynamic results of self-gravitating systems.

3. Model

In order to prevent gravitationally unbound particles from dissolution, we confine the particles in a spherical potential well. This prevents matter flow. But the system is subjected to an energy flow, maintaining the system out of equilibrium. This flow is sustained by energy injection (heating) on large scales and local dissipation. The energy injection is due to time and position dependent potential perturbations. If the system represents a molecular cloud, then these potential perturbations can stem from star clusters, clouds or other high mass objects passing in the vicinity. Indeed such stochastic encounters must be quite frequent in galactic discs and we assume, \( 1/f_{\text{enc}} \geq t_{\text{dyn}} \), where \( f_{\text{enc}} \) is the mean frequency of the encounters. Thus these encounters can provide a continuing low frequency energy injection on large scales. The dissipation is due to “inelastic particle encounters”. Therefore we add friction forces to the equation of motion, depending on the relative particle velocities and positions.

If we switch off the heating process and use instead the local dissipation scheme (“inelastic particle encounters”) a scheme that dissipates the energy globally, then we can maintain the system during its evolution nearly in thermodynamic equilibrium. Thus we can perform some simple “thermodynamic experiments” of self-gravitating systems with softened potentials.

4. Results

Potential perturbations caused by astrophysical objects passing in the vicinity of a system can compensate the energy loss due to dissipation, thus prevent the system from collapsing and maintain a statistical equilibrium. This statistically steady state consists of a cold core moving in a hotter halo. The energy-flow leads however not to a phase transition to higher ordered structures.

The gravo-thermal experiments lead to the following results: A Plummer softened potential yields the same range of negative specific heat as found by Follana & Laliena. The negative specific heat range is related to a phase transition, separating a high energy homogeneous phase from a collapsed phase. As long as cooling processes are at work the collapsed phase shows no core-halo structure. After the cooling has stopped such a structure is formed on the relaxation time scale.

References

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