Hydrodynamic Simulations of Expanding Shells

The Gravitational Instability

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Abstract.
We are working on the 3D numerical model of an expanding self-gravitating shell using the ZEUS hydrocode. The goal is to resolve instabilities in the wall of the shell. Simulations should verify previous studies of gravitational instabilities of an expanding shell using the thin layer approximation. Linearized equations were solved by Elmegreen (1994) who obtained criteria for the shell instability. In the initial period of the evolution the shell is gravitationally stable due to stretching connected to the fast expansion. Later, when it decelerates, the gravity starts to be important. During its subsequent supersonic expansion the accumulation of the ambient medium may trigger gravitational instability and fragmentation. We are interested in the mass spectrum of fragments which may be compared with the observed mass spectrum of the giant molecular clouds and with the stellar initial mass function.

1. The gravitational instability of the expanding shell

The dynamics of the expanding bubble was described by Weaver et al. (1977) and many other authors. We are interested in the later period of the expansion, when gravitational instabilities may occur.

The Elmegreen's formula for the perturbation growth rate can be used to derive the mass spectrum of expanding shell fragments, Palouš et al. (2002). It can be approximated with the power law $dN/dm \sim m^{-\alpha}$, where $\alpha \doteq 2.35$ at the high mass end, which is very close to the mass spectrum index of the stellar IMF. Fig. 1 (left) shows the mass spectrum of the expanding shell compared to the spectra obtained in different models discussed in Palouš et al. (2003).

2. Hydrodynamic simulations

We develop the 3D numerical model of an expanding self-gravitating shell using the ZEUS hydrocode (Stone & Norman, 1992). It is the 3D second-order accurate Eulerian code based on the method of finite differences and it works in both Cartesian and spherical coordinates. We have implemented the new cooling routine, which uses more secure Brent's algorithm (e. g. Press et al., 1992) for the root finding. The

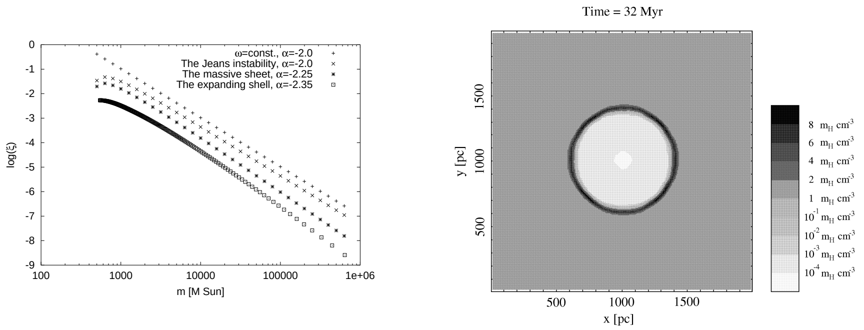

Figure 1. **Left panel:** The mass spectra. The scale-free instability (growth rate of the fragments does not depend on their mass) and the Jeans collapse yield the spectrum index $\alpha = 2.0$, while spectra obtained from the accreting massive sheet and the expanding shell are harder ($\alpha = 2.25$ and $\alpha = 2.35$). **Right panel:** 3D hydrodynamic simulation of expanding shell in Cartesian coordinates.

Poisson solver is based on the Dynamic Alternating Direction Implicit (DADI) method, which is the method originally used in the ZEUS, but its implementation is new (it will be described elsewhere).

The model has successfully passed tests based on the analytical solution and previous simulations. Currently we run first computations, where fragments should occur. The aim is to obtain their mass and compare it to the analytical solution and to observations.

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