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DYNAMICS OF MOLECULAR CLOUDS UNDER THE INFLUENCE OF IONIZING RADIATION FROM YOUNG MASSIVE STARS

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RESUMEN

Presentamos simulaciones numéricas sobre la implosión radiativa de inhomogeneidades en núcleos de nubes moleculares debido a la radiación ionizante de estrellas masivas. Hicimos cálculos SPH con una distribución Gaussiana de perturbaciones en la densidad. Encontramos que las pertubaciones a gran escala con un espectro de potencias de −3, no pueden prevenir el colapso gravitacional de núcleos comprimidos, mientras que las perturbaciones a pequeña escala (con un índice de −1) pueden al menos retrasarlo durante una fracción importante del tiempo de compresión.

ABSTRACT

We present numerical simulations treating the radiative driven implosion of density enhancements in molecular cloud cores under the influence of ionizing radiation from massive stars. We performed SPH calculations with initial density perturbations described by Gaussian random fields. We found that large scale perturbations with index −3 in their power spectrum cannot prevent gravitational collapse in the compressed cloud cores, whereas small scale perturbations (power index −1) can at least delay the onset of gravitational instability for a significant fraction of the compression time.

Key Words: **HII REGIONS — HYDRODYNAMICS — STARS: EARLY-TYPE**

1. INTRODUCTION

The heating of the parental molecular cloud by the ionizing radiation of young, massive stars leads to compression of the cold, neutral cloud material, a process referred to as radiative-driven implosion (RDI). High-density regions could subsequently collapse due to gravitational instability and thus form a new generation of stars. Sandford, Whitaker, & Klein (1982) performed numerical simulations concerning RDI in 2D. They pointed out that the mass distribution of stars formed in a perturbed cloud affected by RDI may sensitively depend on the spatial scale of the perturbations. Lefloch & Lazareff (1994) followed a similar approach to the problem. Bertoldi & McKee (1990) performed a semi-analytical treatment on RDI and constrained the ranges for mass and ionizing flux in which collapse of compressed globules in pressure equilibrium with their surroundings should occur.

Up to now, all models of RDI were either semi-analytical or restricted to two spatial dimensions, neglecting self-gravity. We performed numerical simulations of RDI in 3D with self-gravity by using the new, fast SPHI method which is described in detail in Kessel-Deynet & Burkert (2000).

2. INITIAL CONDITIONS

Our initial setup of the cloud is a critical Bonnor-Ebert (BE) sphere, containing 1 Jeans mass. The maximum density is set to 1000 cm^{-3}. The flux of ionizing photons irradiating the cloud was chosen to model a density enhancement, or clump, positioned close to the border of the initial Strömgren radius. We test whether the subsequent compression of the cloud can trigger gravitational instability.

We vary the temperature of the neutral gas (by definition of the BE sphere scaling the total mass), which was set to 100 K (7000 $M_\odot$) for model A and 10 K (200 $M_\odot$) for model B. The second investigated parameter is the exponent γ in the power spectrum $P(k) \propto k^\gamma$ of the initial Gaussian density perturbations, varying from no perturbations at all over $\gamma = -3$ (large scales) to $\gamma = -1$ (small scales).

3. RESULTS AND DISCUSSION

During the compression phase, a shock front in the tip of the evolving globule directed towards the source forms and converges towards the symmetry axis. The gas reaches maximum compression after 400 (130) kyr for model A (B). At this point, the evolution starts to differ. For model A, gravitational

TABLE 1

SUMMARY OF THE RESULTS DEPENDING ON INITIAL PERTURBATIONS

Model	T/K	$M/M_\odot$	no pert.[a]	large scale[a]	small scale[a]
A	100	7000	⊗	⊗	⊗
B	10	200	⊗	⊗	○

[a] The symbols denote: ⊗ collapse at maximum compression, ○ delay beyond this point.

instability sets in for all types of initial perturbations. In model B, similar behavior is observed except for $\gamma = -1$ (small scale perturbations). In the latter case gravitational collapse is delayed beyond the point of maximum compression. The delay time spreads between 80 and 200 kyrs, depending on the initial random seed and resolution. Table 1 summarizes these results.

In all models, the internal energy cannot keep the globules from collapsing. This is consistent with the semi-analytic treatment by Bertoldi & McKee (1990), since all our models lie far in the regime of gravitational instability in Fig. 14 of their paper. Nevertheless, the delay in model B, $\gamma = -1$, was never anticipated in theoretical work before. The possibility for observing it is a consequence of the simultaneous treatment of 3D gas dynamics and self-gravity. Leaving aside magnetic fields, only the kinetic energy can cause this delay. The velocity of the shocked layer relative to the neutral gas is about one half of the sound velocity in the ionized material, $a_{\rm i} \simeq 13$ km s^{-1}. Thus the total kinetic energy injected into the system scales roughly $\propto M$. In contrast, the depth of the gravitational well is roughly $\propto M^2$ (the size of the globules does not differ significantly). Consequently, $R = E_{\rm kin}/|E_{\rm pot}|$ increases with decreasing mass. The maximum value of $R \simeq 10$ for model A, whereas in model B it is $\simeq 100$. If only a small fraction of $E_{\rm kin}$ is transformed into undirected motion, this helps in case B to delay gravitational collapse. The study for different γ shows that large scale perturbations are not sufficient for this, but small scale perturbations can indeed cause this transformation.

4. PROSPECTS

In the calculations presented here, the time we can follow the evolution is restricted to the moment when the first gravitational collapse occurs. Due to the high densities which evolve in consequence, the computational timesteps become prohibitively small.

In order to perform the simulations further, we are planning to introduce "sink particles" as proposed by Bate, Bonnell, & Price (1995). In this method, the collapsing region is substituted by a point mass which accumulates the infalling mass.

We will explore whether the properties of the generated fragments are very different for the case of collapse at maximum compression and the case of delayed collapse. By studying the statistical behavior of the fragments, we hopefully can elaborate a recipe how to discriminate between the two different cases based on observations.

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