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The Drag of Protostars on a Gaseous Medium

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Abstract. We present a numerical study of the drag on protostars in a gaseous medium. Our work investigates the evolution of a binary (equal mass) protostar in an isothermal gas for different M_{binary}/M_{gas} ratios. In this work we used the public Smooth Particle Hydrodynamics (SPH) code called GADGET (Springel, Yoshida, & White 2001). We find that the gravitational drag timescales are comparable with those of the star formation process. Hence, the drag can play an important role in the formation of stars and to determine the final separation of binaries.

1. Introduction

Our goal is to investigate the role of gravitational drag on binary/multiple star formation. Several other projects have been done studying other processes, for example accretion in the context of binary (Bate 2000) and multiple (Bonnell et al. 2001) star formation finding that it plays a relevant role in determining the final masses of the protostars.

On the other hand, little work has focused on the effects of gravitational drag (dynamical friction, Chandrasekhar 1943). Both analytical (Ostriker 1999) and numerical (Sanchez-Salcedo & Brandenburg 2001) approaches have been tried to solve the general physical problem, finding that the drag becomes important in a few orbital times. Other authors (e.g. Shima, Matsuda, & Inaguchi 1986, Ruffert 1996) calculate the drag of a test particle in linear motion in the context of the Bondi-Hoyle accretion problem, they find slightly less drag (~10%) due to the effect of including accretion.

We will study the effects of the gravitational drag in the context of star formation.

2. Drag Effects on Binary Protostars

2.1. Numerical Aspects & Setup of the Problem

In this work we use the technique called Smooth Particle Hydrodynamics (Lucy 1977). In SPH the gas is sampled and represented by particles, this is by construction free of geometrical restrictions.

We used the GADGET code that has been successfully used in a broad range of problems such as galaxy formation, star formation, and large scale structure of the universe (Springel, Yoshida, & White 2001). In addition, we performed several tests of the code such as Evrard collapse, collapse of a rotating cloud, and politropic oscillations.

The model consists of a gas sphere with an isothermal equation of state. The gas is initially in hydrostatic equilibrium and the density profile is the non-singular isothermal sphere (Bonnor-Ebert stable). We introduce a binary protostar (collisionless particle) in a supersonic circular orbit and follow its evolution on several orbits. The protostars have the same mass and we run simulations for a range of M_{binary}/M_{gas} ratios. We also check that the results converge as we increase the resolution (number of gas particles).

2.2. Results

We find that each protostar produces a spiral shock that propagates outwards with a barely supersonic speed ($1.1c_S$) produced by the supersonic motion of the protostars ($v \sim 1.4c_S$). The grey scale in the Figure 1 represents the density enhancement in the plane of the orbit ($z = 0$) for $t = 1$. The arrows are the two dimensional velocity field of the gas. The white curves are the individual orbits of the protostars between $t = 0$ and $t = 1$. In this figure the mass of the binary is 2% of the mass of the gas. The spiral feature is similar to that found by Sanchez-Salcedo & Brandenburg (2001).

We now are interested in quantifying how important is the drag effect on the evolution of a binary protostar and determine the timescales. Figure 2 shows the evolution of the binary separation, the different curves represents the distance between the protostars for different mass ratios: M_{binary}=$0.02M_{gas}$ (solid), $M_{binary} = 0.06M_{gas}$, $M_{binary} = 0.1\ M_{gas}$.

The results are given in internal code units, making it necessary to rescale it to typical star formation units.

$$t = 1.8 \times 10^4 \, (\frac{M_{gas}}{10M_\odot})^{-1/2} \, (\frac{D}{0.02pc})^{3/2} \, yr, \tag{1}$$

where M_{gas} is the total mass of the gas and D is the initial distance between the protostars. Our results can be applied for both low mass and high mass star formation.

In the case of low mass star formation, the total mass of the gas is 10 $M_\odot$ and the initial distance between the protostars is 0.02 pc. This gives a time unit of 1.8×10^4 yr. Thus, for a binary of 0.1 $M_\odot$ protostars the separation will decrease by a factor of 2 in approximately in 3.6×10^4 yr. For high mass star formation we scale the total gaseous mass to 100 $M_\odot$ and keep 0.02 pc as initial separation giving a time unit of 5.7×10^3 yr. For 5 $M_\odot$ protostars the separation of the binary will decrease by a factor of 2 in 5.7×10^3 yr.

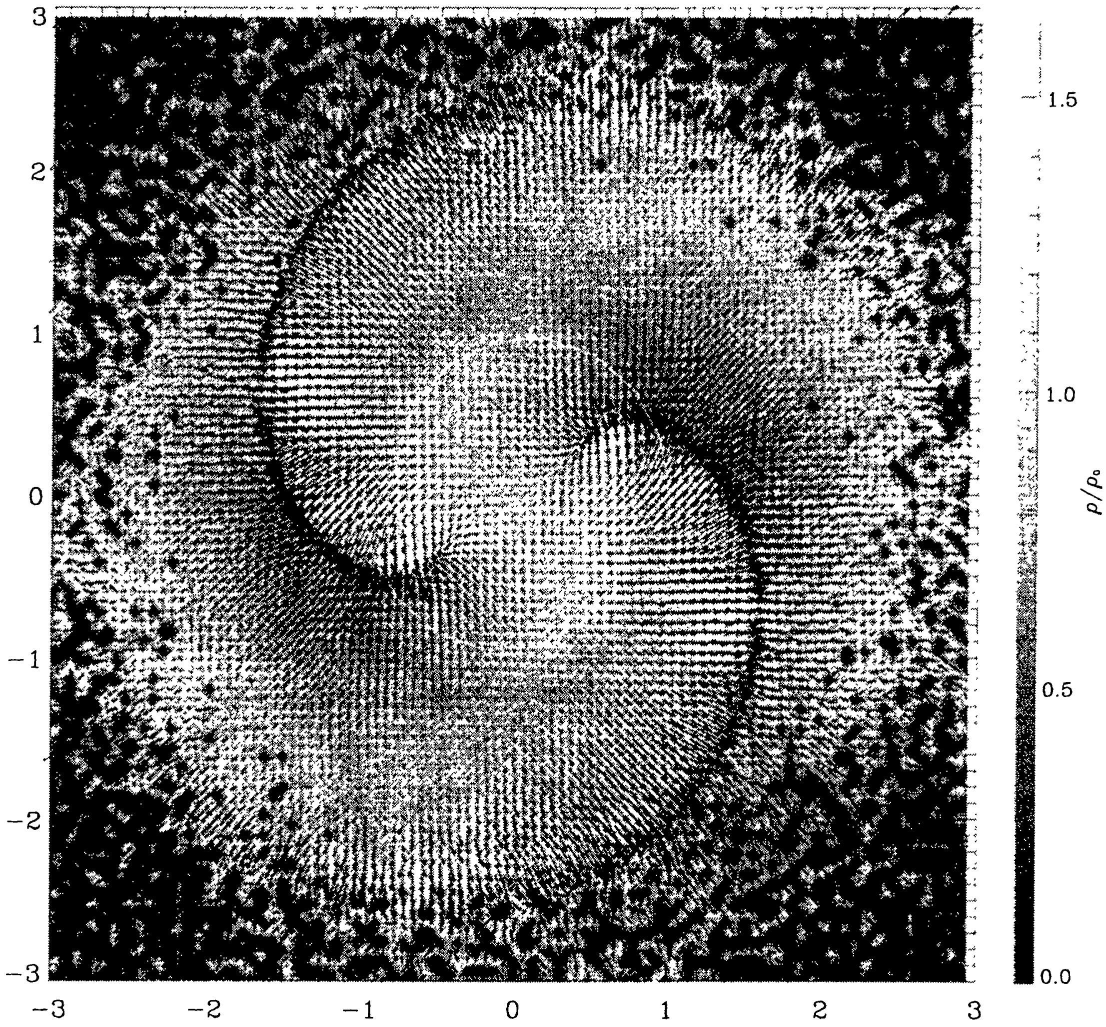

Figure 1. Grey scale plot the density enhancement $(\rho(r,t)/\rho(r,0))$ at the plane of the orbit and $t = 1$, together with the velocity vectors. The white curves are the individual orbits of the protostars.

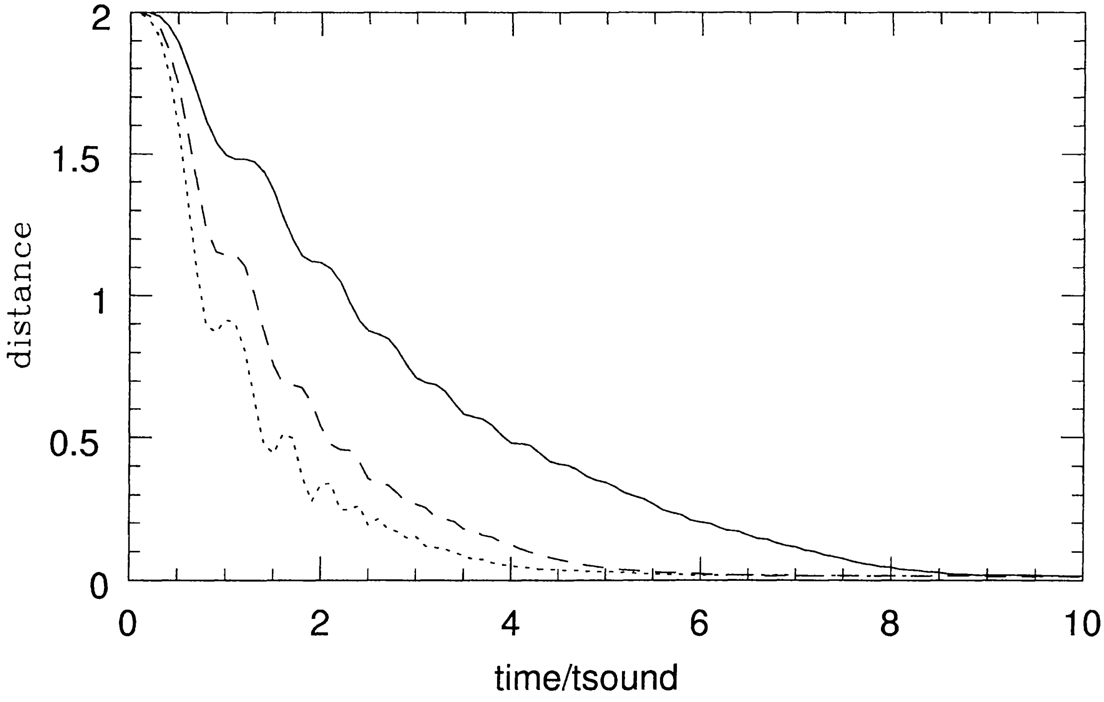

Figure 2. Evolution of the binary separation for mass ratios (M_{binary}/M_{gas}) of 0.02 (solid), 0.06 (dashed), 0.1 (dotted). The initial orbital period is 2.

3. Discussion

We have calculated the effect of drag on protostars in a range of cloud masses. We found that this effect has characteristic timescales of 5.7×10^3 yr in the high mass star formation and timescales of 1.8×10^4 yr for the low mass case.

The gravitational drag timescales are comparable with those of the star formation process. Hence, the drag can play an important role in the formation of stars and to determine the final separation of binaries.

This process helps to explain the distribution of binary separations, where all the proposed mechanisms (fission, fragmentation, capture, disintegration of a larger stellar system) predict an insufficient number of close binary systems (Bonnell 2001). The orbital migration of binary systems due to the gravitational drag is a promising mechanism for the formation of close binary stars.

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