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Evolution of an early Sun's Protoplanetary disk in an Open Cluster.

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Abstract

The recent observations of protoplanetary disks around stars in Open Clusters opened new perspectives on the investigation about the planet formation in a non-isolated context (see for example [3]). We present here our first approach to this problem, consisting in modelling a gaseous disk around one solar-like star and perturbing the gas by close encounter with a second star. Following some recent models according to which the Sun is supposed to be formed in an Open Cluster, we aim to focus in particular on possible macroscopical outward transport of matter triggered by the close star fly-by, as an explanation of the presence, detected on comets, of matter supposed to be originated in the regions close to the Sun. We use a Lagrangian Smoothed Particle Hydrodynamics (SPH, [4, 7]) approach and implemented a computational algorithm ([6]) able to treat self-gravitating gaseous systems interacting witha a series of stars.

1. Introduction

Recent observations stated that protoplanetary disks exist in complex stars systems and and can give rise to the formation of planets. It is thus extremely important investigate the disks evolution in Open Clusters and to work out the optimal conditions which lead to the gas gravitational collapse and to the further planet generation, taking into account the perturbations coming from the other stars, too. Such models acquire a peculiar relevance also in the field of the planetology concerning our Solar System, since some recent models postulated that the SS may have been formed in an open cluster ([5]).

Key roles in the evolution of a disk in a non isolated system may be played by the secular perturbations due to the field stars, and the strong perturbations induced, on a shorter time-scale, by the close fly-bys. The idea that the pre-Solar System disk could have been perturbed by other object represents a fascinating hypothesis that may support the investigation on the non-solved problems concerning its present configuration. One issue is represented by the unexpected observation of crystalline sylicates in comets. Despite they are expected to be amorphous, they present a crystalline structure which need to be generated in the inner regions. Some mechanisms have been hypotized to explain such outward transport [2]. We aim to investigate, through a numerical method, an alternative scenario in which the primordial Solar System, during its protoplanetary gaseous disk phase, lies in an Open Cluster. The disk thus is influenced by the gravitational perturbation of the other field Stars, possibly giving rise to a macroscopical transport of matter from the inner to the outer layers. In the following sections we describe the physical model and the numerical method adopted.

2. SPH tree-based code modelling Gas-stars systems.

SPH is a Lagrangian method developed for the resolution of the equations of the evolution of a gas distribution.

Its main task consists in representing a gaseous medium as a discrete ensemble of interpolating points, each one containing the informations of the density, pressure, velocity and other key hydrodynamical quantities characterizing the fluid in a certain region, and estimated through a suitable interpolation over an ensamble of neighbours particles. So, for example, for each peculiar point i, provided with a mass m_i and located in a position r_i, the volume-density can be calculated as follows:

$$\rho_i = \sum_j m_j W(h_i, r_{ij}) \quad (1)$$

where the sum is extended over a set of neighbour points j within a spherical region of radius h_i, with W a suitable weight function (kernel) which depends on the distance r_{ij} from the surrounding points. The Interpolation technique allows to write an expression for the Euler Equations of a perfect gas which are integrated with a 2nd-order Velocity Verlet Method.

The gas self-gravity is calculated by using a tree-code formalism (developed for the first time by [1]). The particles are subdivided according to a grid of nested boxes, progressively divided according to an octal progression. The grid allows the code to perform easily and efficiently the estimation of the gravitational field with a CPU computational time scaling as $N \log N$ rather than N^2 like classical N-body methods, and supports the neighbour particle searching routines to perform efficiently with a time scaling as N.

3. The Disk and stars Model

We model the disk following the classical and well-known flared disk model, in which the gas is present in a thin structure and its vertical scale height increases steeper than linearly with the distance from the central star. The gas distribution revolves around a central solar-like star with a roughly keplerian velocity. The surface density, projected along the midplane of rotation, follows a radial power law $\Sigma(R) \propto R^{-3/2}$. The thermodynamics of the gas is approximated with a vertical isothermal model, so that the temperature is considered vertically uniform and depends only on the distance through $T \propto R^{-3/7}$.

Despite the Sun, hosting the disk, is supposed to feel the gravity field of an ensemble of stars, these introduce secular perturbations. On a short time-scale we can simulate a sequence of flyby events taking into account only the gravitational field of a single star. The star and the sun+disk system are placed with initial conditions such that their total energy is positive. The goal of this first study is to investigate the perturbation effects infduced on the disk including ejection and outward transport of matter from the inner regions of the disk. Each event is simulated by choosing different initial conditions like disk midplane inclination with respect to the bullet-star trajectory, or the impact parameter.

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