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Simulations of asteroid-type bodies within an accretion disc: effects on tilted orbits

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Abstract. At present, it is difficult to identify extrasolar planets whose masses are lower than that of Neptune. Current theories on planetary formation describe the formation process as: 1) grain coalescence in kilometre-sized planetesimals; 2) growing-up of planetesimals by accumulation through sweeping in about 100 Km planetesimals; 3) "oligarchic" growing-up of such protoplanets by collisions with other minor objects, up to 10 terrestrial masses beyond 3 AU, or the formation of martian planets within 3 AU. Martian planets could grow up by mutual collision and accumulation forming terrestrial planets. In this work, 3D SPH simulations are performed to study the kinematic evolution of a fragment (planetesimal or asteroid) in a tilted orbit with respect to the accretion disc.

Key words. Stars: planetary systems: formation, protoplanetary discs – Planets and satellites: formation

1. Introduction

Up to now, more than 200 extrasolar planets have been detected. Current theories on planet formation inside an accretion disc (Artymowicz 2004; D'Angelo et al. 2003; Goldreich & Tremaine 1980; Lin & Papaloizou 1986) need to account for a correct balance between the disc accretion and dissipation times and protoplanet migration times. Migration times of the order of $10^4 - 10^5$ years, starting from about 5 AU are currently predicted and the observational discovery of many Jupiter-like planets within 3 AU seems to support this scenario. Most models are 2D (see Cresswell et al. 2007, as a 3D example), so there is still the need to scrutinise the disc-planet interaction in 3D, particularly for tilted orbits of the forming protoplanets. Moreover current models often use laminar disc motion and Keplerian distribution of gas velocity as reasonable hypotheses, while the role of turbulence in planet migration times still needs to be studied (Nelson & Papaloizou 2004). In this work an exploratory study on these effects is proposed, adopting a Lagrangian SPH code. Indeed the

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evolution of the orbit of a "small" fragment with an initial tilted orbit is focused here.

2. The model and preliminary results

Simulations are performed through the SPH method (Monaghan 1992), with the spacial resolution parameter $h = 0.3$. Dimensionless quantities are used, and reference physical units are: 1) the initial stellar mass M_0; 2) the stellar radius R_0; 3) the Keplerian orbital period of an orbit of radius R_0 around a star of mass M_0. Gas particles are injected at a distance of 130 to the central star, with tangential velocities linked to the initial value of the angular momentum per unit mass λ. Particles are eliminated when they are close to the star or outside of the computational domain ($\sqrt{x^2 + y^2} < 140$ and $|z| < 140/3$). Adopted values for λ are: 18, 36, 54 (models A, B, C). The resulting velocity distribution of the accretion disc is sub-Keplerian, so that particles start decreasing their radial distance, until they "hit" the centrifugal barrier. The asteroid is inserted once the accretion disc reaches a nearly steady state population ($2 \times 10^5 - 10^6$ particles). The model includes the following gravitational interactions: gas particles - central star; asteroid - star; particles - asteroid. Gas pressure between neighbouring gas particles is included, but no physical viscosity, at least for the moment. The initial positions and velocities of the fragment are chosen in order to locate it near the centrifugal barrier for gas particles (the most populated zone of the accretion disc), with an initially circular orbit, tilted with respect to the disc by an angle of about $\alpha = 7°$. The mass of the particles is set to 10^{-11}. The planetesimal fragment has about the same mass as the gas particles, which, referring to solar values as an example, gives a fragment of about 10^{19} Kg, (with radius of $\sim$ 100 Km). The models have been evolved for about a pair of orbits and the following asteroid orbital parameters are tracked: e (eccentricity); a, b (semi-major and semi-minor axes); α (angle between the fragment angular momentum and the z axis). For model B, Fig.1 shows a periodic behaviour for both e and α, directly linked to the fragment passages through the bulk of the disc gas distribution, and probably due to the gravitational torque exerted by the accretion disc. A slow non periodic decrease of the semi-major axis seems to occur, as reported by Cresswell et al. (2007), which suggests a slow fragment migration towards the central star. However the simulations should go much further, for 50-100 orbits, to state a convincing trend in this direction. Similar results are obtained with models A and C. A more complete set of results will be presented in a future work.

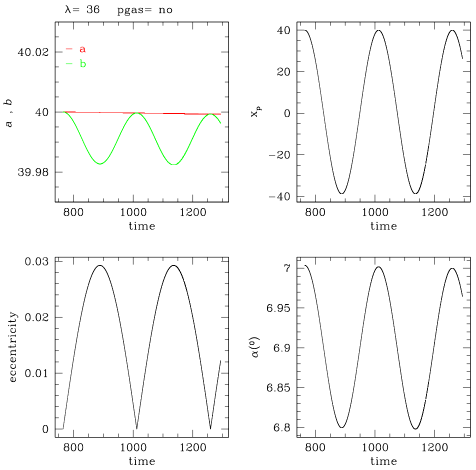

Fig. 1. Fragment orbital parameters evolution with the $\lambda = 36$ accretion disc (see text).

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