Resonant stratification of young debris disks with planets

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1 Introduction

A massive planet, if present in a planetesimal disk of a single or a binary star, causes formation of various resonant large-scale patterns in the disk [1, 2, 3, 5, 6]. In young debris disks, the presence of gas affects the formation process of the patterns. We study the influence of the disk’s gas constituent on this process, as well as on the long-term stability of the emerging patterns. For this purpose, we perform massive numerical experiments using the SPH-method (described, e.g., in [7]). As objects for our study, we adopt models with the parameters of Kepler-16 (binary star) and HL Tau (single star) systems.

2 Simulations

In the case of Kepler-16, our previous study [8] showed that a ring-like pattern coorbital with the planet may form (Fig. 1).

Here we model the dynamics of planetesimals in the HL Tau system (Fig. 3). The mass of the planet is set to $3M_J$ (Jovian masses). It moves in a circular orbit with radius $23\, \text{AU}$ (as follows from the data in [10]).

The properties of the planetesimals are the same as adopted above in a case of Kepler-16. Initially they are spread homogeneously from 14 to 70 AU. Then the gas component is added in the model disk. As described above, the gas dynamics are simulated using the SPH-method. We use the isothermal approximation with the gas temperature set to $30\, \text{K}$, corresponding to the temperature near the planet’s orbit. The total mass of gas is $0.1\, M_J$, and it is spread from 14 to 130 AU. The time length of each simulation is 100 orbital periods of the planet.

Our simulation shows that even a massive gas constituent does not preclude formation of the resonant planetesimal ring-like pattern coorbital with the planet, at least on the timescale of the simulation. Figure 2 demonstrates that the radial density profiles of the ring, as well as the rates of decay of the number of planetesimals as functions of time, are almost the same in the models with and without gas. Therefore, our result favours the possible existence of the coorbital-with-planet pattern in the Kepler-16 system.

A planet-like “clump” and its coorbital and neighbouring resonant ring-like patterns are directly observed in the circumstellar disk of HL Tau [10]. These patterns definitely have resonant nature [5].

3 Results

For Kepler-16, our result favours the possibility of existence of the coorbital-with-planet pattern in the system. For HL Tau, the presence of gas in the disk affects to decrease somewhat the surface density of the coorbital ring-like pattern and the depths of other resonant gaps. However, the major resonant features of the matter distribution sustain unaffected. The presented results extend our theoretical and numerical inferences on the formation of multi-lane signatures of planets in planetesimal disks [5], and, generally, on the formation of structures in planetary disk systems [4]. It should be noted the gas component influences the motion and redistribution of planetesimals only weakly, but it strongly affects the motion and redistribution of small dust particles.

References