Planetesimal accumulation around Kepler-16 (AB)

F. Marzari[1], G. Picogna[1], S. Desidera[2], V. Vanzani[1], [1] Dep. of Physics, Univ. of Padova, Italy, [2] INAF-Observatory of Padova, Italy

Planetesimal accumulation in the exoplanetary system Kepler-16 (AB) appears to be a complex process due to the secular perturbations of the binary and the gas drag related to the protoplanetary nebula surrounding the two stars. We show that the formation of planetary embryos may be possible only beyond 3 AU while the observed planet has a semimajor axis of 0.7 AU. By modeling planet migration in a fully radiative disk we find that the planet, once formed, quickly migrates into the inner regions of the gaseous disk. This may explain the present orbit of the detected exoplanet.

Introduction

The planet detected around the tight binary system Kepler-16 (AB) [3] has a semimajor axis of about 0.7 AU, just outside the dynamical stability limit computed by [4] which is 0.645 AU. Within the core–accretion model, planetesimals in the protoplanetary disk surrounding the two stars should have accumulated to form the Saturn–like planet (its mass is estimated to be 0.333 M_J). The binary tidal force coupled to gas drag might lead to pericenter alignment which is an important mechanism for favoring an efficient planetesimal growth [9]. However, the presence of spiral waves in the disk excited by the binary gravitational force is a strong source of dynamical perturbations for the planetesimals. The irregular distribution of mass within the disk and the non–radial component in the motion of the gas may significantly affect the motion of planetesimals causing large relative impact velocities which can halt the accumulation process inhibiting the formation of a planet [6].

The model

We study the planetesimal accretion process by studying their orbital evolution within the disk perturbed by the tidal force of the binary system. The hydrodynamical code FARGO [7] have been used to computed both the disk evolution and the drag force on the planetesimals. Since the disk's radiative properties may play an important role in its evolution, we include all the relevant terms in the energy equation like viscous internal heating, radiative diffusion and cooling. The disk extends from 0.5 AU, the inner limit for tidal truncation due to the binary perturbations [1], to 10 AU with an initial density equal to that of the Minimum Mass Solar Nebula. The planetesimals size is set to $5km$ and a bulk density of $2g/cm^3$ is adopted. The drag force is computed as $\mathbf{F} = -\mathbf{k}\mathbf{v}\mathbf{v}$

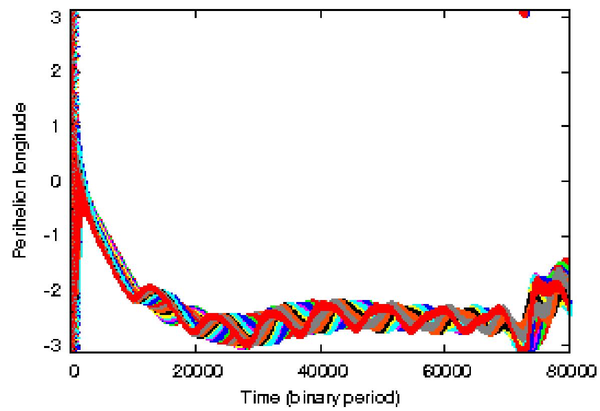

Figure 1: Pericenter longitudes of 20 planetesimals orbiting in between 3 and 5 AU from Kepler-16 (AB). Different colors mark different initial semimajor axis. Their size is 5 km.

where k is the drag constant given in [5].

Planetesimal accumulation

Within the model described above, similar to that used by [6], we compute the planetesimal trajectories in two separate semimajor axis regions around Kepler-16 (AB). The first region extends from 1 to 3 AU while the second ranges from 3 to 5 AU. In the inner region the pericenter longitudes of the planetesimals mostly circulate and the average eccentricity is around 0.08. The lack of pericenter alignment leads to high impact velocities favoring fragmentation rather than accretion. On the outer region, the pericenter longitudes appear instead aligned, as illustrated in Fig. 1. However, the eccentricity has a larger value up to 0.1 on average. This large value, not damped by the gas drag force, is due to the irregular non–axisymmetric gravity field of the disk and by non–radial component of the gas velocity.

Planet inward migration

If there is a chance of forming a planet within the core–accretion model, this must have occurred in the outer regions of the disk. As a consequence, the planet had to migrate inside to its present location by interaction with the gaseous disk. Its mass is not large enough to create a full gap in the disk, so its inward drift will be intermediate between type I and type II migration. We have

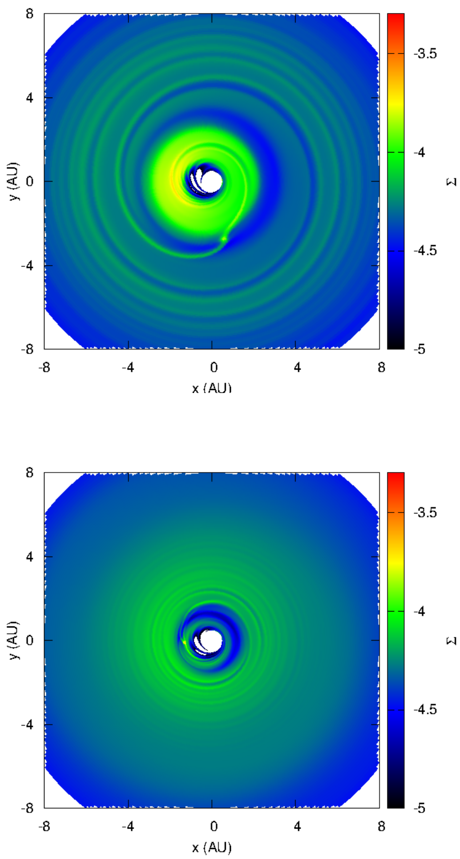

Figure 2: Logarithm of the disk density distribution (in normalized units) at two different evolutionary times. The planet is moving inwards by interacting with the gaseous disk whose density is half that of the MMSN.

used the hydrocode FARGO to compute the inward migration of the planet in a context similar to that of [8]. The density of the disk has been reduced by a factor 2 respect to the previous simulation and in the computation of the disk-planet interaction the material that is gravitationally bound to the planet has been disregarded [2]. In Fig. 2 we show the disk density distribution as the planet approaches the two stars. Density waves are excited by both the planet and the star couple. The planet, as expected, opens only a partial gap but it migrates inside in spite of the interferences by the binary gravity field.

Fig. 3 illustrates the semimajor axis evolution with time of the planet which approaches the inner regions of the disk.

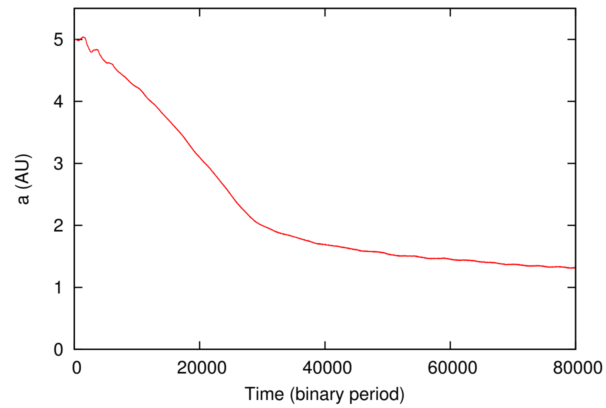

Figure 3: Semimajor axis of the planet embedded in the disk as a function of time expressed in binary revolutions. Density waves are excited by both the planet and the tidal gravity field of the binary.

Conclusions

Planetesimal accumulation around Kepler-16 (AB) was potentially successful in forming a planet only in the outer regions of the disk, far from the gravitational perturbations of the binary and of an asymmetric disk. A more detailed study is underway on the planetesimal dynamics farther away from the stars. The planet, once reached a large enough mass, migrated into the inner regions of the disk reaching its present position.

References

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