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Effects of neutral ISM gas flow on debris disks: the role of the optical depth

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Abstract

The motion of dust particles in debris disks can be strongly perturbed by the interactions with the local flux of ISM neutral atoms surrounding the host We focus on grains $1-10$ μm in radius, larger than blow-out threshold. With a numerical approach we show that for large values of the optical depth the influence of ISM flow on the disk shape is almost negligible: the grains are collisionally destroyed before they can accumulate enough orbital changes due to the ISM flow. However, when the optical depth is small (faint disk) the Keplerian orbits are strongly perturbed, the disk becomes eccentric and peculiar patterns develop in the density distribution. In most cases, due to the large eccentricity excited by the ISM perturbations, a fast inward migration is observed leading to a fast sink mechanism for the disk.

1. Introduction

We focus on the effects of the ISM neutral flow on $1-10$ μm dust particles in debris disks around solar type stars, because these are the smallest grains on bound orbits and should as such dominate the disk's luminosity at wavelengths up to the mid IR (e.g., [6]). The timescale for large orbital changes is the Stark period equal to $T_{stark} = \frac{4\pi m_g}{3S}\sqrt{\frac{GM_\odot}{a}}$ where a is the orbital semimajor axis, G the gravitational constant, $M_\odot$ the star mass and S is the force due to the ISM flux ([2]). We focus on a disk produced by a ring of parent bodies evenly distributed in between 50-70 AU on circular orbits. In this scenario the T_{stark} is approximately equal to 2.3 Myr for 1 μm particles. This timespan is much longer than that considered by [3] and [4] who concentrated on blow–out particles.

We find that the efficiency of the ISM flow in shaping debris disks is strongly dependent on the optical thickness of the disk. One of the dominant mechanisms of dust evolution is in fact cratering and fragmentation by mutual collisions. The collisional avalanche process reduces the lifetime of dust grains limiting the amount of time their trajectories can be perturbed by non–gravitational forces like radiation pressure, PR drag and interaction with ISM ([5]). In particular, for 1 μm particles the collisional lifetime is of the order of 10^5 yrs, much shorter than T_{stark}.

2 Numerical results

We compute the trajectories of a large number (10^4) of test particles under the action of ISM neutral gas, radiation pressure and PR drag. A low inclination (lower than 10^o) is assumed between the orbital plane of the parent body and that of the ISM flow. In Fig.1 we show the normalized density distribution of dust particles in a debris disk with $\tau = 1 \times 10^{-3}$. The presence of the inner and outer overdense rings are due to the large value of β, the ratio of radiation pressure to stellar gravity. β determines the large eccentricities of the grains released by the parent bodies. The outer ring is related to the location of the particle aphelia while the inner ring is related to the perihelia.

The trajectories of the grains in our sample are integrated until a steady state is reached (1 Myr). This steady state depends in this case on the collisional lifetime. Whenever the time spent by a test particle within the disk is comparable to the collisional lifetime ($t_c \sim \frac{T}{12\tau}$ where T is the orbital period), it is removed from the ensamble and replaced by a new one. The ISM flow can perturb the particle orbits only for a timescale equal to t_c. The effects of the ISM flux appear as a slight asymmetry along the y–axis in the density distribution plot.

Significantly more asymmetric is the debris disk when the optical depth is set to $\tau = 1 \times 10^{-6}$ (Fig.2). Particles evolve towards high eccentricity values (~ 1) while, at the same time, the pericenter values tend to $270°$. When large values of eccentricity are achieved, the particles drift quickly inside because of the drag

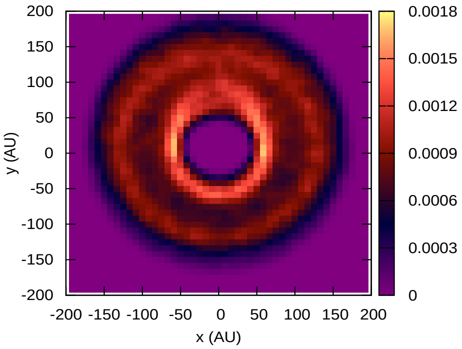

Figure 1: 2–D density distribution of 1 μm size dust particles in debris disks generated by a ring of parent bodies moving on circular orbits in between 50–70 AU. The density is computed as number of particles populating a squared region at a given timestep divided by the total number of particles in the model. The optical depth is $\tau = 1 \times 10^{-3}$. Negligible effects due to the ISM flow are observed.

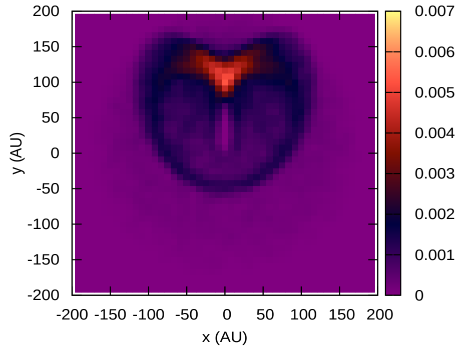

Figure 2: As in Fig.1 but the optical depth is now $\tau = 1 \times 10^{-6}$.

component of the forces. The disk appears as a superposition of two ellipses because most particles cluster either from below or from above around the fixed pericenter value of 270^o.

When we consider larger particles (10 μm), a different balance between perturbative changes due to ISM and lifetime is reached. The initial disk is expected to be less radially spread since the value of β is smaller and the initial orbital elements of the grains are closer to those of the parent bodies. Again, if the optical depth is set to $\tau = 10^{-3}$ the disk does not show any significant difference from the case where ISM is neglected. When $\tau = 10^{-6}$, the orbits of the grains reach a maximum eccentricity of $\sim$ 0.8 and a significant clump develops close to the apocenter of the orbits. The two–ellipse pattern, observed for 1 μm in Fig.1 collapses into a single elliptical structure due to the different dynamical behaviour of 10 μm dust grains.

3. Summary and Conclusions

We have shown by numerical modeling the evolution of debris disks under the effects of solar radiation pressure, PR drag and ISM flux, that for typical values of optical depth $\tau \sim 10^{-3}$ the signatures of the ISM wind on $1 - 10$ μm grains, just above the cut-off size imposed by radiation pressure, are almost negligible.

Our study suggests that observational data of debris disks need care to be interpreted. Potential asymmetries identified in the density distribution may be ascribed to interactions with the local flux of ISM neutral atoms surrounding its parent star only if the disk has a very low optical depth. Otherwise, alternative explanations, like the presence of planets, must be investigated.

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