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Debris Discs in Binaries: Spatial Structures

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Abstract

Following the preliminary results of [6], we present new simulations of the evolution of debris discs in binaries using a new, specifically developed code that can handle both the dynamical and collisional evolution of the system. We show how the radial extension of the disc and its shape crucially depend on the companion star's orbit. The complex interplay between gravitational perturbations and collisional production of small grains leads to the development of periodic and short-lived (for very eccentric binaries) or long-lived-but-precessing (for circular orbits) spiral structures. We also find that the disc morphology strongly depends on the companion star's position on its orbit. We compare these results to known debris discs in order to assert to what extent binarity can be the source of observed spatial structures. Our new code has the potential to be applied to all perturbed debris discs cases.

1. Introduction

Debris discs in binaries have been investigated in several recent works, both observational ([7, 5, 3]) and theoretical ([6]). The main issue investigated in these studies is that of the extent of circumprimary discs, in particular if the companion star can induce a truncation that can be detectable when looking at infra-red excesses or at the radial profile of the resolved disc.

The numerical study of [6] showed that the coupling of collisional activity and radiation pressure plays a crucial role, steadily placing small dust grains in regions that are in principle dynamically unstable. Since these grains dominate the flux at all wavelengths up to mid-IR, debris discs can thus appear to extend far beyond the theoretical radial distance r_{crit} for orbital stability around the primary.

However, [6] used a collisional code with only 1-D spatial resolution (all azimutal information being lost in phase averaging), and were thus unable to study how binarity affects the *shape* of circumstellar discs. This issue is a crucial one, as the presence of a companion star has been invoked as a possible explanation for several systems' aspect, in particular HR4796 ([2]) or HD141569 ([1]). We investigate this issue with a specifically developed numerical code.

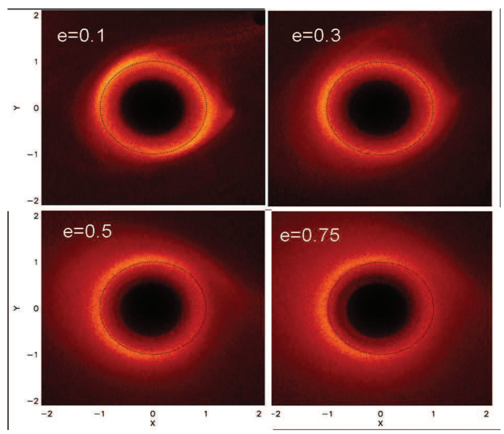

Figure 1: Normal optical depth, at steady state, for a circumprimary debris disc perturbed by a planetary companion with 4 different orbital eccentricities. The dotted line marks the theoretical limit r_{crit} for orbital stability according to [4]. All plots correspond to the passage of the companion star at periastron (a larger and animated version of this Figure can be found at http://lesia.obspm.fr/perso/philippe-thebault/bindeb.html)

2. Model

We assume that the system has reached a steady state, both dynamically and collisionally. We consider gravity and radiation pressure from the central star as well as the gravitational pull from a stellar companion. Collisions are assumed to produce bodies following a size distribution in $dN \propto s^q ds$. We divide particles into two categories: parent bodies (PB), large enough not to be affected by radiation pressure, and small fragments steadily produced by collisions from these PB and placed on eccentric or unbound orbits by radiation pressure.

We first perform 1) a *parent body run*, which is stopped when the system has reached a dynamical steady state. The steady-state profile of this PB disc is recorded at N_{sav} different, regularly spaced in time, phases of the binary orbit. Then, 2) A series of *collisional runs* is performed, each taking one of the N_{sav} PB profiles as a starting position from which a full distribution of small grains is released. The collisional runs are stopped when all released grains have been removed, either by collisions or by dynamical ejection. At the end of this step, to each initial phase i_ϕ of the perturber, is assigned a series of density maps $\tau'(i_\phi,0), \tau'(i_\phi,1), .., \tau'(i_\phi,j)$, recorded at regularly spaced intervals in time Δt_{sav}, following the fate of all particles released when the perturber was at the i_ϕ position. Finally, 3) we use all data collected in step 2 to reconstruct the dust distribution, *at steady state*, for each possible orbital phase of the perturber. The principle is that, at a given time t_{i_ϕ} corresponding to the perturber's position i_ϕ, the total dust population consists of grains that have just been produced, as well as surviving grains that have been produced earlier and that have not been collisionally destroyed or dynamically ejected. The procedure is then the following: we start with the most recent dust particles, procuded at t_{i_ϕ}, whose spatial distribution is given by the saved record $\tau'(i_\phi,0)$. We then add the previous generation, produced at $t_{i_\phi} - \Delta t_{sav}$ when the perturber was at angular position index $i_\phi - 1$, whose spatial distribution at time t_{i_ϕ} is given by the saved record $\tau'(i_\phi - 1, 1)$. This procedure is then iterated, working our way back in time and piling up all the surviving grains from the successive records $\tau'(i_\phi - j, j)$, to produce the total geometrical optical depth at time t_{i_ϕ}

$$\tau(i_\phi) = \sum_{j=0}^{j=j_{max}} \tau'(i_\phi - j, j) \tag{1}$$

3. Results

We consider a binary of varying separation a_b and eccentricity e_b. We make the assumption that the disc of *parent bodies* has been shaped and truncated by the companion star. To ensure this, we make the initial disc extend slighly beyond the empirical (1-D) outer limit r_{crit} for orbital stability derived by [4], and let the code naturally "shave off" the disc from all its unstable particles. All distances are normalized so that $r_{crit} = 1$.

Fig.1 shows the steady-state optical depth, when the companion star is at periastron, for 4 different orbital configurations of the binary. For all considered cases, the steady production of small grains populates the "forbidden" dynamically unstable regions. For moderatly eccentric binaries, long-lived and precessing spiral structures develop. For more eccentric orbits, transient spiral features appear only close to periastron passages, the rest of the time the disc has a smooth but strongly asymetric structure.

4. Conclusions and Perspectives

These results show the crucial, but sometimes counterintuitive role of stellar companions in shaping debris discs. Because of the steady collisional production of small, radiation-pressure affected fragments, binaries can never "truncate" a circumstellar disc, but can induce spiral structures that can be transient or long-lived. Moreover, the aspect of the circumprimary disc can strongly vary depending on the phase of the companion star on its orbit.

The code that has been spefically developed to address this issue, with its ability to handle $both$ the dynamics and collisions, will be applied, in a close future, to the more generic case of any perturbed debris disc (embedded or external planet, passing star, etc...).

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