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Dynamical Interactions and the Eccentricities of Binary Millisecond Pulsars in Globular Clusters

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Abstract. Using a combination of analytical perturbation calculations and numerical scattering experiments, we have re-examined the question of orbital perturbations of binaries during close encounters with passing stars in a dense cluster. We have treated with particular care the difficult case of an initially circular orbit, and we have found some new results that disagree with those obtained in previous studies. We discuss here the implications of these new results for binary millisecond pulsars in globular clusters.

1. Introduction

Low-mass binary millisecond pulsars (LMBPs) are thought to be formed when an old neutron star in a binary system accretes material from a red-giant companion. This leads to the production of a spun-up (recycled) pulsar with a low-mass white-dwarf companion in a wide, circular orbit. This formation process is well understood theoretically (Bhattacharya & van den Heuvel 1991; Verbunt 1993; Phinney & Kulkarni 1994). In particular, the predicted relations between white-dwarf mass and orbital period (Rappaport et al. 1995) and between orbital eccentricity and period (Phinney & Kulkarni 1994) are in remarkable agreement with observations. The orbits tend to be very efficiently circularized by tidal torques and viscous dissipation in the red-giant envelope during the mass-transfer phase. Residual eccentricities $e_i \sim 10^{-6}$–10^{-3} for LMBPs at birth can be explained as arising from small fluctuations of the external gravitational field of the red giant caused by the convective motions in its envelope (Phinney 1992). In globular clusters, however, the wide orbits of LMBPs can be perturbed significantly by passing stars (Heggie 1975; Rappaport, Putney, & Verbunt 1989). Thus final eccentricities $e_f \gg e_i$ can be observed today, and the measured values contain important information about the dynamical history of the binaries and their environment.

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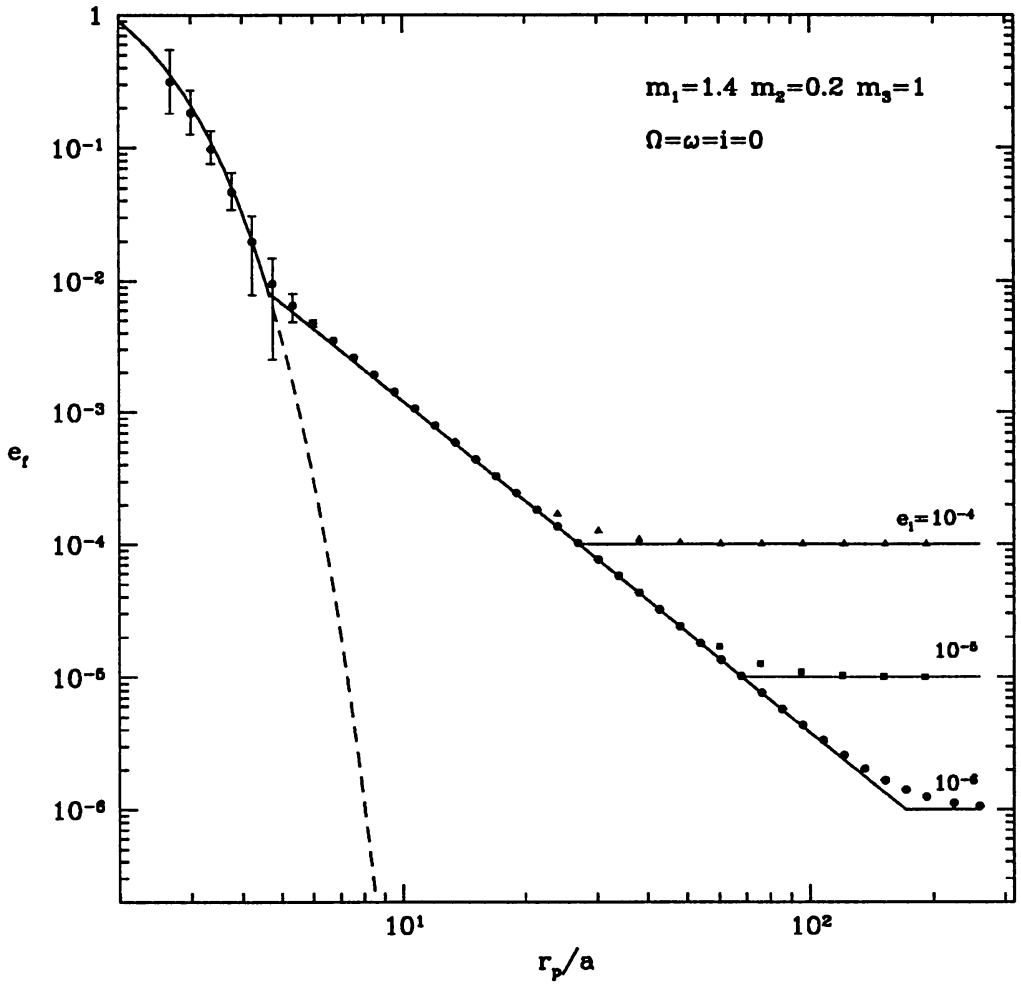

Figure 1. Final orbital eccentricity e_f following an interaction between the LMBP and another star on a coplanar prograde parabolic orbit with pericenter distance r_p (given in units of the binary semi-major axis a). The masses of the two binary components are $m_1 = 1.4\,M_\odot$ and $m_2 = 0.2\,M_\odot$; the mass of the passing star is $m_3 = 1\,M_\odot$. Solid lines show our analytical results (Heggie & Rasio 1996); dots show the results of numerical integrations. Round dots are for a system with initial eccentricity $e_i = 10^{-6}$, squares for $e_i = 10^{-5}$, and triangles for $e_i = 10^{-4}$. The "error bars" show the full extent of the dependence on the orbital phase. The dashed line shows the exponential decay predicted in all previous studies (Rappaport et al. 1989; Phinney 1992).

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2. Results

We have derived new analytical results for the induced eccentricity of initially circular binaries (Heggie & Rasio 1996). On the basis of detailed comparisons with numerical integrations, we believe these analytical results to be correct over the entire range of interest for LMBPs, $10^{-6} \lesssim e_f \lesssim 1$. Some previously published expressions in which e_f decreases exponentially with pericenter distance r_p can grossly underestimate the effect when $e_f \lesssim 0.01$. Indeed, we find that over the intermediate range where $e_i < e_f \lesssim 10^{-2}$, the induced eccentricity generally varies as a *power-law* $e_f \propto r_p^{-5/2}$ (Fig. 1), making the cross section much larger than would be estimated on the basis of previous work. The implications of our results for LMBPs in globular clusters are discussed in Rasio & Heggie (1995). We find that *all* currently known LMBPs in clusters were probably affected by interactions, with their current eccentricities typically an order of magnitude or more greater than at birth. Measured orbital eccentricities of cluster LMBPs can therefore help us constrain the ages of recycled pulsars.

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