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Interactions in Barred Galaxies: Effects of a Companion on the Bar Pattern Speed

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Abstract. We study the effects of a companion in a parabolic co-planar orbit on the bar pattern speed. Unlike previous simulations, we use fully self-consistent 3D N-body simulations with live haloes, which are known to be important for bar evolution.

The simulations of Gerin *et al.* (1990), Sundin & Sundelius (1991), and Sundin *et al.* (1993) have shown an unexpected behaviour in the rotation of perturbed barred galaxies. In those previous studies, the force calculation was made via a 2D polar grid, and haloes and companions were treated as rigid Plummer spheres. Here, we have constructed multi-component models (disk+bulge+halo) with $N = 10^5$ particles (for the technique to assembly such models, see Athanassoula *et al.* 1997). The target galaxy is simulated using $M_H = 1.5$, $M_B = 0.1$ and $M_D = 0.4$. With this mass distribution, a long lasting bar formed. Adopting a galaxy with $M_G = 1.2 \times 10^{11}\ M_\odot$, and scaling to a $R = 15$ kpc disk, we evolved all models for a total time of 2.5 Gyr in 20000 steps using a Barnes-Hut based treecode. The energy conservation was better than 0.1% for all simulations. The companion is a live Plummer sphere. We calculated the bar position angle for each time step, as well as the change of the bar pattern speed compared to the isolated model. We also calculated the transfer of angular momentum. Fourier techniques are applied to get insights into the spiral modes triggered by the passage of the companion, as well as the existent bar mode.

We found a weak dependence of the bar pattern speed variation with α, the angle between the bar and the companion at the perigalacticon. In contrast, a strong dependence on the companion mass and direction of the orbit is evident. In our isolated model, the bar affects the disk outskirts triggering very low amplitude $m = 2$ modes. We calculated the angular momentum lost as function of time and radius. We show that the beating between the bar and the strong spiral arms is important in the process of transferring angular momentum. In direct orbits, a $m = 2$ trailing spiral is triggered and this perturbation travels inwards. It reaches a maximum amplitude that depends on the companion mass. We found that the decay of the amplitude of the spirals is not monotonic. The amplitude decays and oscillates with the beating of the bar and the spiral arms. The morphology of the bar is weakly affected by these parabolic orbits. We notice some changes in a number of bar particle orbits (particles falling in bar orbit families and others leaving it behind). We need mergers or large central mass concentrations to modify effectively a large number of bar particle orbit. In retrograde orbits, even the heaviest companion ($M_C = 0.5 M_G$) is unable to modify the disk structure. We found weak $m = 1$ leading modes being triggered in this kind of encounters, even in the presence of the bar.

References: Athanassoula *et al.* 1997, MNRAS 286, 284; Gerin *et al.* 1990, A&A 230, 37; Sundin & Sundelius 1991, A&A 245, L5; Sundin *et al.* 1993, A&A 280, 105.