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Dynamical Friction between Lopsided Disks and Spherical Halos

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1. Introduction

It has long been known that some spiral galaxies have a large-scale lopsided structure (e.g., Baldwin, Lynden-Bell, & Sancisi 1980). The frequency of the lopsidedness in disk galaxies reaches to half of H I disks (e.g., Richter & Sancisi 1994) and one third of stellar disks (e.g., Zaritsky & Rix 1997). The fraction of lopsided disks is large, nevertheless their origin is not understood well. Although some theoretical models are proposed to explain the lopsidedness, dynamical friction between lopsided disks and spherical halos has not been taken into account. Then, in this contribution, we have examined the effect of dynamical friction on lopsided disks. To avoid discreteness noise due to small number of particles on the estimate of dynamical friction, we have used the matrix method.

2. Numerical models and method

In this contribution, dynamical friction is treated as a drag force due to the gravitational interaction between density wake and the lopsidedness. The amplitude of the lopsidedness is assumed to be small so that the lopsidedness is treated as a perturbation. Then, the density response to a perturbation can be determined by using the matrix method (Kalnajs 1977; Weinberg 1989).

The halo is the King model with a normalized central potential $W_0 = 3$, a halo mass $M_{\mathrm{h}} = 10$, and a tidal radius $R_t = 56$ in the units described below. The disk is an exponential disk model,

$$\Sigma(R, \phi, t) = \frac{M_{\mathrm{d}}}{2\pi} \exp(-R) \left[1 + A_1(R) \cos(\phi - \Omega_p t)\right], \tag{1}$$

where M_{d} is a disk mass and Ω_p is a pattern speed of the lopsidedness. Here, the amplitude of the lopsidedness A_1 is assumed to be

$$A_1(R) = \frac{dR}{25 + R^2}. \tag{2}$$

Units are chosen such that the disk mass $M_{\mathrm{d}} = 1$ and the exponential scale length $R_{\mathrm{d}} = 1$. The gravitational constant is set to be 1.35 so that the circular velocity at the solar radius, i.e., 8.5 kpc, is equal to 220 km s^{-1}. If these units are scaled to physical values appropriate for the Milky Way, i.e., $R_{\mathrm{d}} = 3.5$ kpc and $M_{\mathrm{d}} = 6.0 \times 10^{10} M_{\odot}$, unit time and velocity are 1.09×10^7 yr and 321 km s^{-1}, respectively.

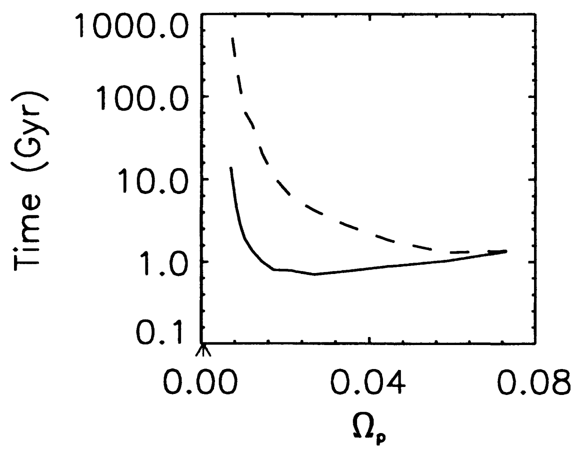

Figure 1. Damping time defined by the rate of angular momentum loss as a function of the pattern speed. The solid line shows results that include the self-gravity of density wake, and the dashed line shows the non-self-gravity case. The arrow at the left side shows the pattern speed of weakly damped modes.

3. Results

The damping time scale defined by the rate of angular momentum loss is represented in Figure 1 as a function of the pattern speed. The units are scaled to the values suitable for the Milky Way. The solid line shows the friction due to the self-gravitating response, and the dashed line shows the friction due to the non-self-gravitating response. Clearly, as the pattern speed becomes slow, the difference between self-gravitating and non-self-gravitating responses becomes large. In addition, the damping time scale is shorter than a Hubble time unless the pattern speed is quite slow.

The pattern speed of weakly damped modes (Weinberg 1994) is found to be 0.0005, which is indicated by an arrow in Figure 1. Then, such mode may survive for a long time against dynamical friction. Therefore, the weakly damped modes might play an important role in lopsided disks.

References

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