

## STATIONARY ORBITS OF SATELLITES OF DISK GALAXIES

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ABSTRACT. The satellite of an S-galaxy will experience opposing dynamical-friction forces from the stars of the disk and the halo. If these forces are in balance, the satellite may travel in a stable, near-circular orbit whose radius, for a wide range of physical parameters, should be limited to a zone 1.2 to 1.4 times the disk radius, much as is observed.

The idea of the paper (1) is very simple. The dynamical friction acting on a small satellite, moving through a stellar galactic halo, makes this satellite slow down. On the other hand, a stellar disk, rotating faster than a satellite, makes it speed up. But the density distributions in radius for disk's and halo's stars in real flat galaxies are quite different (respectively, exponential and power-law). Moreover, the observational data show that the exponential profile for disk's surface density drops abruptly at some radius ( $r_d$ ). So it is natural to expect that a stationary orbit could place near the edge of a disk (where two effects are mutually compensated).

1. Dynamical friction for a satellite near a disk with a sharp edge. We begin with the well-known formula by Lynden-Bell and Kainajs (2) for the rate of change of the satellite's angular momentum due to interaction with the rotating stellar disk. It is a particular sum over resonances. If then we shall be interested in only the case when orbits of both a satellite and a disk are nearly circular, it will be sufficient to take into account only contributions from inner Lindblad resonances:

$$\dot{L}_d = \sum_m^{m_{\max}} \dot{L}_d(m), \quad m_{\max} = \sqrt{2R/(R-1)}, \quad (1)$$

where  $R = r_s/r_d$ ,  $r_s$  is the satellite's orbit radius,  $\dot{L}_d(m)$  can be calculated (these quantities correspond to contributions of separate resonances).

2. Dynamical friction of the satellite due to a halo.

Collision effects in spherical stellar systems were considered in our old paper (3). One of the effects--dynamical friction--was then studied in more detail by Tremaine and Weinberg (4). The rate of change of the satellite's angular momentum due to resonance interaction with stars of the isothermal halo may be written as (5)

$$\dot{L}_h = -\Lambda_g I(R), \quad (\Lambda_g = (2\pi)^{5/2} G M_s / e r_s v_o^2), \quad (2)$$

where  $M_s$  is the satellite's mass,  $V_0 = \Omega(r_d)r_d$  is the circular velocity (and we consider the rotation curve to be flat),

$$I(R) = 0.0759 \ln(R/P) - 0.0228 \quad (3)$$

$P/R = (r_b/r_d)/(r_s/r_d)$ ,  $r_b$  is the effective radius of the satellite nucleus (the parameter arising due to the necessity to consider a satellite with finite size), and the potential of the satellite is

$$\Phi_b(r) = -GM_s / \sqrt{r^2 + r_b^2}. \quad (4)$$

( $G$  is the gravitational constant.) Such an approximation allows us to remove some uncertainties of the point-mass approximation.

3. Location of the stationary orbit of a satellite. The condition for the satellite orbit to be stationary,  $L_d = L_h$ , reduces to the form, depending on three parameters: (1)  $D = r_d/r_e$ , where  $r_e$  is the scale of exponential decay of disk's surface density,  $\sigma_0(r) = \sigma_0(0)\exp(-r/r_e)$ , (2)  $P = Rr_b/r_s$  - the dimensionless parameter of the satellite's features,

(3)  $\gamma = eGM_d/4\pi r_e V_0^2$ , where  $M_d$  is the total disk's mass,  $r = 1$  for  $M_d = 10^{11} M_\odot$ ,  $V_0 = 200$  km/s,  $r_e = 4$  Kpc.

Left and right sides of the stationary condition are represented in Figure 1 as the functions of dimensionless radius  $R = r_s/r_d$ , for  $\gamma = 1$  and a few values of  $D$  and  $P$  parameters. These values cover the whole range of parameters for real galaxies as one could expect, the stair-like disk's curve is very sharp, while the halo's curve is rather smooth and its dependence on values of the parameter  $P$  is rather weak. It is evident from the figure that possible values for radii of the satellite orbit are strongly restricted to a rather narrow range:  $1.2 < R < 1.4$ , near the disk edge (where  $R = 1$ ).

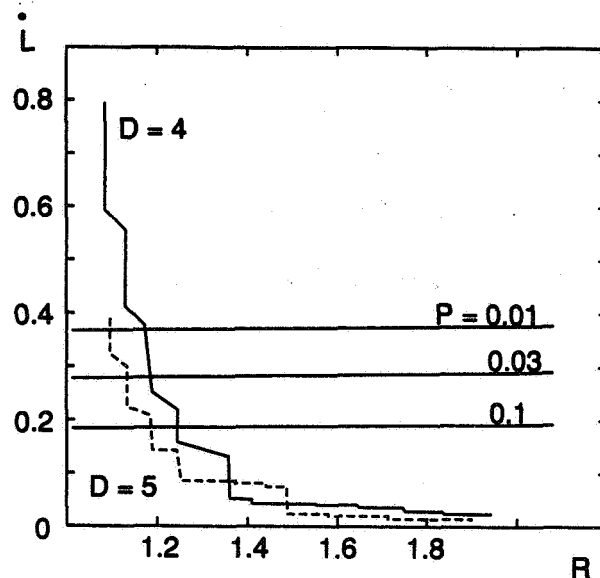


Figure 1. Radial dependence of the dynamical friction exerted on a satellite by (smooth lines) the halo stars and (stepped curves) the disk population. For a satellite at the disk edge,  $R = 1$ . Parameter  $P$  measures the effective size of the satellite's core;  $D$  measures the steepness of the exponential decline in the disk surface density. The two countervailing friction forces will be

in balance at the intersection points, which are limited to the zone  $R = 1.1$  to  $1.4$ .

The study of satellites' distribution over ratio  $R = r_s/r_d$  (fulfilled recently by I.I.Pasha on the basis of the well-known Arp's Atlas of interacting galaxies) shows that this distribution has a distinct maximum, just corresponding to the region near  $R = 1.3$ . As to inclinations of orbits (and percentage of plane orbits among them) this problem needs to be studied.

Of course, all above is valid only for satellites with sufficiently small masses: the gravitational potential of the satellite should not destroy strongly the effective potential well of particles at the disk edge (so that these particles cannot reach the satellite orbit). Otherwise, we shall have the direct tidal interaction between the satellite and the tail of particles pulled out from the disk edge by the satellite (such an interaction leads inevitably to slowing down).

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