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Orbit Evolution of Satellite Galaxies in Dark Matter Haloes

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Abstract. We investigate the effect of the inhomogeneity of the background distribution on dynamical friction. We find a generalised Coulomb logarithm with position dependent maximum impact parameter scaling with the local scale length, which is usually much smaller than the distance to the centre of the background system. We apply the new formula to N-body calculations of satellite galaxies in Dark Matter haloes and find a systematic improvement of the orbit fits. Additionally a first order force not parallel to the motion of the massive object appears, which can be neglected at least in spherical systems due to the lack of a secular effect.

1. The Coulomb logarithm

Chandrasekhar's formula for dynamical friction was very successful in the past, but with increasing numerical power an improvement on the parameter dependence became necessary. Here we investigate the effect of the local density gradient on the Coulomb logarithm $\ln\Lambda$. We retain the velocity dependence of Λ and determine the maximum impact parameter by the local scale length $l = \rho/\nabla\rho$ and by excluding slow encounters with encounter timescale longer than the local dynamical time (Just & Peñarrubia 2002). This leads to the Coulomb factor

$$\Lambda_2 = \sqrt{\frac{1+\frac{W^4}{4}q_s^2\left(1+Q_2^2q_d^2\frac{W^2}{W^2+4X^2}\right)}{1+\frac{W^4}{4}q_s^2}} \approx \Lambda_0 = Q_0 q_d \qquad \text{with} \qquad (1)$$

$$X = \frac{v}{\sqrt{2}\sigma} \qquad W = \frac{V_0}{\sqrt{2}\sigma} \qquad q_d = \frac{l}{r_h} \qquad q_s = \frac{\sigma^2}{\sigma_0^2} \qquad (2)$$

and with satellite and encounter velocities v and V_0, respectively. As minimum impact parameter we use the half mass radius r_h approximated by $r_h = GM/(4\sigma_0^2)$ with central velocity dispersion σ_0 of the satellite. Q_0 and Q_2 are fitting parameters for the numerical orbit comparisons.

2. First order force

The usual dynamical friction is the 0. order term antiparallel to v for isotropic distribution functions. The 1. order dynamical friction due to the local density

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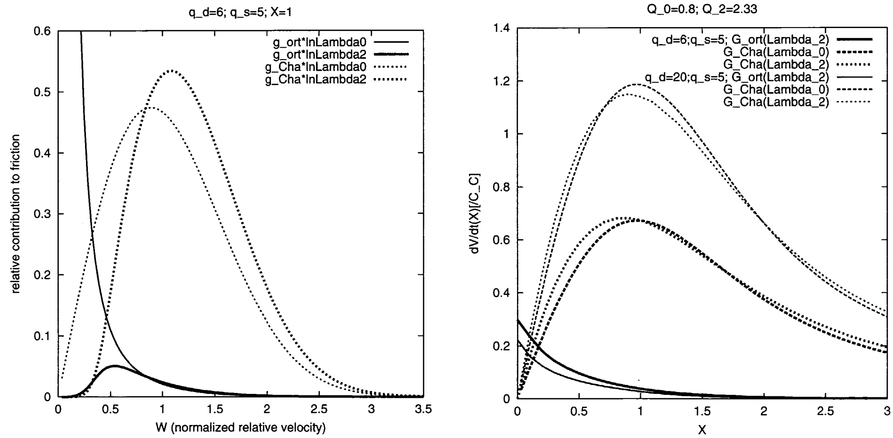

Figure 1. **left:** The effect of the varying Coulomb logarithm $\ln \Lambda_2$ on the contribution to the friction force for the 1. order part $g_{ort}(X, W)$ and standard Chandrasekhar $g_{Cha}(X, W)$. **right:** Normalised dynamical friction for parameters typical for a satellite with mass $M = 5.6 \times 10^9 M_\odot$ at distances of 17 and 55 kpc (thick and thin lines, respectively). We use the normalised force $G_{Cha}(X) = \int \ln \Lambda g_{Cha}(X, W) \mathrm{d}W$ (analogous for G_{par} and G_{ort}).

gradient (first estimated by Binney 1977) is in the v-$\nabla\rho$ -plane and has a parallel and orthogonal component $(\cos(\Psi)G_{par}(X), \sin(\Psi)G_{ort}(X))$ with respect to v instead of $G_{Cha}(X)$ for the 0. order force. Ψ is the angle between v and $\nabla\rho$. The magnitude of the 1. order force can be as large as 30% of the 0. order dynamical friction. But in a spherical halo both components of the 1. order force change sign at apo- and peri-centre. Therefore due to the symmetry of the unperturbed orbits, the dominating contribution has no secular effect on the orbit.

3. Numerical results

With the particle-mesh code SUPERBOX (using $N = 1.4 \times 10^6$ dark matter particles) we calculated a set of orbits with different eccentricities (with live and point-like satellites) and made a best fit analysis of the first few orbits with semi-analytic calculations. We find best fit values $Q_0 = 0.8$ and $Q_2 = 2.33$ and a systematic improvement using the position dependent $\ln \Lambda_0$ and even more with $\ln \Lambda_2$.

References

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