Galactic Interactions

Dynamical friction Galaxy merging & Cluster transformation

October 24, 2024

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Consider the subject mass on a circular orbit in a spherical, singular isothermal host halo with the density distribution

$$\rho(r) = \frac{V_c^2}{4\pi G r^2}$$

(Remember: V_c is independent of radius.) Under the assumption that the velocity distribution of field particles is a Maxwell-Boltzmann distribution with velocity dispersion $\sigma = \frac{V_c}{\sqrt{2}}$, the dynamical friction force is

$$F_{df} = -0.428 \frac{GM_S^2}{r^2} \ln \Lambda \hat{v}_S$$

where $\ln \Lambda$ is the Coulomb logarithm, which can be approximated as $\ln \Lambda \approx \left(\frac{b_{\max}}{b_{90}}\right)$. $b_{\max} \sim R$ is the maximum impact parameter, approximately equal to the size of the system in which the mass is orbiting, and $b_{90} \sim \frac{GM_S}{\sqrt{\langle v_m^2 \rangle}}$ is the impact parameter for which a field particle is deflected by 90°.

Being on a circular orbit, the rate at which the subject mass loses its orbital angular momentum, $L_S = rv_S$, is therefore

$$rac{dL_S}{dt} = r rac{dv_S}{dt} = rac{r}{M_S} F_{df} = -0.428 rac{GM_S}{r} \ln \Lambda$$

Since V_c is independent of r, the subject mass continues to orbit with a speed $v_S = V_c$ as it spirals inwards, so that the orbital radius changes as

$$v_S rac{dr}{dt} = -0.428 rac{GM_S}{r} \ln \Lambda \quad
ightarrow \quad r rac{dr}{dt} = -0.428 rac{GM_S}{V_c} \ln \Lambda$$

With this, we can calculate how long it takes for the orbit to decay from some initial radius r_i to r = 0. The dynamical friction time is

$$t_{df} = \frac{1.17}{\ln\Lambda} \frac{r_i^2 V_c}{GM_S} = \frac{1.17}{\ln\Lambda} \left(\frac{r_i}{r_h}\right)^2 \left(\frac{M_h}{M_s}\right) \frac{r_h}{V_c}$$

with $V_c = \sqrt{GM_h/r_h}$. Only systems with $M_s/M_h > 0.03$ experience significant mass segregation.

When orbits are eccentric, dynamical friction may cause the orbit's eccentricity to evolve as a function of time. As shown by van den Bosch et al. (1999),

$$\frac{de}{dt} = \frac{\eta}{v} \frac{de}{d\eta} \left[1 - \left(\frac{v}{V_c}\right)^2 \right] \frac{dv}{dt}$$

where

e = b/a is the eccentricity $\eta = \frac{L}{L_c(E)}$ is the circularity, where L is the orbital angular momentum $L_c(E)$ is the orbital angular momentum of a circular orbit with the same energy

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Since $\frac{de}{d\eta} < 0$ and dynamical friction causes $\frac{dv}{dt} < 0$,

$$rac{de}{dt} < 0$$
 for $v > V_c \rightarrow$ orbit circularizes near pericenter
 $rac{de}{dt} > 0$ for $v < V_c \rightarrow$ orbit becomes more eccentric near apocenter

Numerical simulations show that these two effects cancel, so $\frac{de}{dt} \sim 0$ over an entire orbit. Therefore, dynamic friction does not circularize orbits.

Simulations also show that $t_{df} \propto \eta^{0.53}$: more eccentric orbits decay faster.

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Impact of mass loss with dynamical friction

Unless the system mass is compact, the tidal forces of the host system will cause mass loss, decreasing M_S with time.

Accounting for mass loss results in an increase of the average dynamical friction time by a factor of \sim 2.8.

Simulations show that the dependence of the dynamical friction time on the orbital circularity becomes

 $t_{df} \propto \eta^{0.3-0.4}$

when mass loss is taken into account. This effect is weaker than ignoring mass loss, reflecting the fact that tidal stripping is more effective in orbits with small pericenters.

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Dynamical friction assumptions

This expression for the dynamical friction force is based on the following three assumptions:

- ▶ The subject mass and field particles are point masses.
- ► The self-gravity of the field particles can be ignored.
- ► The distribution of field particles is infinite, homogeneous, and isotropic.

The last of these is the reason why the Coulomb logarithm has to be introduced; the maximum impact parameter is needed to prevent the divergence of the field particles.

This dynamical friction is considered as the sum of uncorrelated two-body interactions between a field particle and the subject mass. However, this ignores the collective effects due to self-gravity of the field particles.

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Criterion for galaxies to merge

In the simple case, we have two identical galaxies which are non-rotating and spherical. If each galaxy has a mass M and an average radius r_{med} , then their internal mean-square velocity is

$$\langle v^2 \rangle = \frac{aGM}{r_{\rm med}}$$

The results of the encounter can then be completely defined by the orbital energy per unit mass, E_{orb} and the orbital angular momentum per unit mass, L, via

$$\hat{E} \equiv rac{2E_{
m orb}}{\langle v^2
angle} \qquad \hat{L} \equiv rac{L}{\sqrt{\langle v^2
angle} r_{
m med}}$$

Galaxy merge criterion



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Merger demographics NGC 7252 (ESO. HST/NASA/ESA)



October 24, 2024 (UR)

Astronomy 465 | Fall 2024

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The resulting structure of the merger remnant mainly depends on four properties:

- Progenitor mass ratio, $q \equiv \frac{M_1}{M_2}$, where $M_1 \ge M_2$
- Progenitor morphologies
- Progenitor gas mass fraction
- Orbital properties

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Mergers can produce starbursts, AGN

Centaurus A (*ESO/WFI*, *MPIfR/ESO/APEX/A*. *Weiss et al.*, *NASA/CXC/CfA/R*. *Kraft et al.*) & M82 (NASA/ESA/Hubble Heritage Team)





October 24, 2024 (UR)

Disk heating from minor mergers

In the case of minor mergers (mass ratio $q \gg 1$), the more massive progenitor will only be mildly perturbed.

A satellite of mass M_s orbiting within a halo of mass $M_h \gg M_s$ that hosts a central disk galaxy of mass M_d will experience a drag force due to dynamical friction, losing orbital energy as it spirals towards the center of the halo. This energy is transferred to the halo and disk, heating both of them up.

Assuming that the initial disk has a density

$$ho_d(R,z)=
ho_0 e^{-R/R_d} \operatorname{sech}^2\left(rac{z}{2z_d}
ight)$$

we find that the disk will thicken by

$$\frac{\Delta z_d}{z_d}(R) = \frac{2}{9} \frac{\lambda}{\sqrt{2}} \ln\left(\frac{\sqrt{2}}{\lambda}\right) \frac{R_d}{z_d} \frac{M_s}{M_d} e^{R/R_d}$$

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Cluster galaxy transformations

The characteristics of cluster galaxies (redder, less gas-rich, lower sSFR) are so different from those in the field that it is thought that some process exists to transform galaxies when they enter or become a part of the denser environment.

The cluster environment is likely to affect cluster galaxies via

- ▶ Tidal interactions with other members and/or the cluster potential
- Dynamical friction
- ▶ Interactions with the hot intracluster medium (ICM)

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All galaxy interactions within a cluster can be considered high-speed encounters, since the galaxy velocity is approximately equal to the galaxy velocity dispersion in the cluster, which is much smaller than the internal galaxy velocity dispersion.

Colliding galaxies within a cluster are thus impulsively heated, resulting in it being less bound and more vulnerable to further disruptions form galactic encounters or tidal interactions with the cluster potential.

The cumulative effect of multiple high-speed impulsive encounters is known as galaxy harassment.

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