Galactic mergers

Most dramatic examples: **major mergers** between galaxies of comparable mass. Large morphological changes as a consequence of the interaction.

Observationally and theoretically, find that major mergers are uncommon - perhaps ~1 such merger in the lifetime of the Universe for a large galaxy in the field.

Minor mergers between galaxies of very different masses are much more common.

Example: the Magellanic clouds

Bound satellites orbiting within the extended halo of the Milky Way (~50 kpc distance)

Eventually will spiral in and merge

Sagittarius dwarf galaxy is another satellite which is now in process of merging…

Dynamical Friction

Why does the orbit of a satellite galaxy moving within the halo of another galaxy decay?

Stars in one galaxy are **scattered** by gravitational perturbation of passing galaxy.

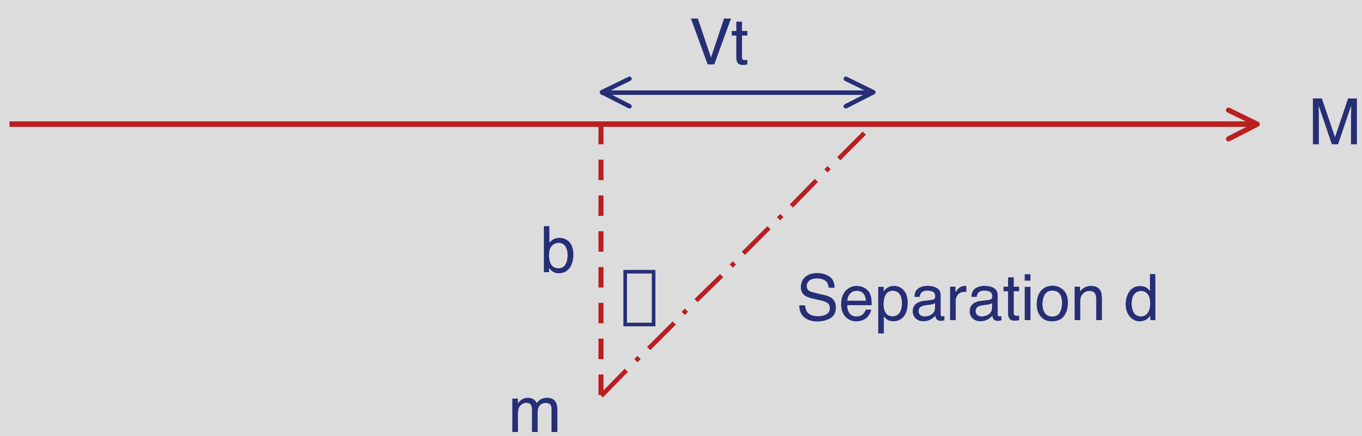
Stellar distribution around the intruder galaxy becomes asymmetric - higher stellar density downstream than upstream.

Gravitational force from stars produces a `frictional' force which slows the orbital motion.

Calculate energy exchange using the impulse approximation - assume that we can calculate force along *unperturbed* path.

Let galaxy have mass M

Move past star of mass m in other galaxy with closest approach distance b (the impact parameter), at velocity V



Force perpendicular to direction of motion is:

$$F_{\perp} = F\cos\theta = \frac{GMm}{d^2} \times \frac{b}{d} = \frac{GMmb}{\left(b^2 + V^2 t^2\right)^{3/2}} = M\frac{dV_{\perp}}{dt}$$

Total change in perpendicular velocity as a result of the flyby is obtained by integrating over time:

$$\Delta V_{\perp} = \frac{1}{M} \int_{-\infty}^{\infty} F_{\perp}(t) dt = \frac{2Gm}{bV}$$

Low relative velocities -> larger deflections

Star of mass m also receives a transverse impulse. By conservation of momentum, magnitude is:

$$\Delta v_{\perp} m = \Delta V_{\perp} M$$

Total kinetic energy in transverse motions is:

$$\Delta KE_{\perp} = \frac{M}{2}\left(\frac{2Gm}{bV}\right)^2 + \frac{m}{2}\left(\frac{2GM}{bV}\right)^2$$

This energy must come from the change in the `forward' velocity of the galaxy:

$$\Delta KE_{\perp} = \frac{M}{2}V^2 - \frac{M}{2}\left(V + \Delta V_{\parallel}\right)^2 - \frac{m}{2}\left(\frac{M}{m}\Delta V_{\parallel}\right)^2$$

Neglecting the very small $\Delta V_{\parallel}^2$ terms, find:

$$\Delta V_{\parallel} \approx -\frac{2G^2 m(M+m)}{b^2 V^3}$$

Final step is to integrate over all impact parameters. Suppose galaxy is passing through region where the stellar density is n stars per cubic pc. Then:

$$\frac{dV}{dt} = -\int_{b_{\min}}^{b_{\max}} 2\pi b n V \frac{2G^2 m(M+m)}{b^2 V^3} db = -\frac{4\pi G^2 (M+m)}{V^2} nm \ln \Lambda$$

…where $\Lambda = b_{max} / b_{min}$

How quickly will the LMC merge with the Milky Way?

Simple estimate - dynamical friction time:

$$t_{friction} \approx \frac{V}{|dV/dt|} \approx \frac{V^3}{4\pi G^2 M n m \ln \Lambda}$$

V: 200 km/s

M: 10^{10} Solar masses

nm: Galactic density at LMC - for flat rotation curve estimate 3×10^{-4} Solar masses / pc^3

$\ln \Lambda$: ~3

With these numbers, estimate orbit will decay in ~3 Gyr

Close satellite galaxies will merge!