Astronomy 401/Physics 903
Lecture 14
Galaxy Interactions

Here we briefly consider some of the important processes involved in galaxy interactions.

1 Tidal interactions

Even if galaxies don't physically collide, they can be disrupted by tidal forces. The same analysis that is used to describe the interactions of close binary stars is useful here. When two stars are in a close orbit they can be distorted by tidal forces (the differential force of gravity across the star), and mass can be transferred from one star to the other.

These effects can be analyzed in detail, but we we will just look at the **tidal radii** of the two interacting galaxies. If stars or gas clouds extend beyond the tidal radius they are likely to be stripped from the galaxy; this is probably the cause of the Magellanic Stream, the long ribbon of gas associated with the Magellanic Clouds. The process is called **tidal stripping**.

The tidal radii are the distances from each galaxy to the inner Lagrangian point L_1, the point at which the gravitational and centrifugal forces balance.

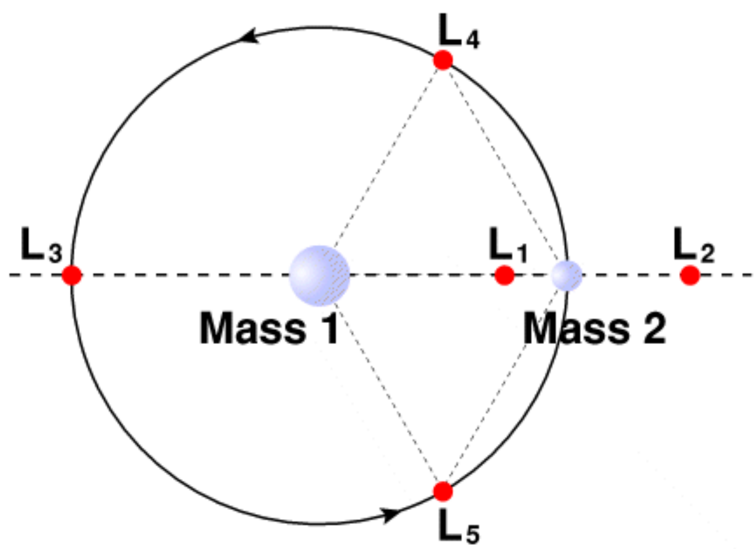

Figure 1: The Lagrangian points

Approximate expressions for the tidal radii, the distances from M_1 to L_1 (l_1) and from M_2 to L_1 (l_2) are:

$$l_1 = a\left[0.500 - 0.227\log\left(\frac{M_2}{M_1}\right)\right] \tag{1}$$

$$l_2 = a\left[0.500 + 0.227\log\left(\frac{M_2}{M_1}\right)\right], \tag{2}$$

where a is the distance between M_1 and M_2. The tidal radii will constantly change as the galaxies move with respect to each other.

Tidal interactions are very important in creating features seen in interacting galaxies. The most well-known are **tidal tails**, which are long, curved tails of gas and stars pulled out of interacting galaxies by tidal forces. See Figure 2, the Mice galaxies in the Coma cluster.

Figure 2: Tidal tails of the Mice, interacting galaxies in the Coma cluster

2 Ram-pressure stripping

Early interactions between galaxies in clusters probably caused the galaxies to lose most of their gas, from bursts of star formation triggered by the interactions and tidal stripping. Once the process is underway, it is enhanced by **ram pressure stripping**. Ram pressure is the pressure exerted on something moving through a fluid medium, and it creates a strong drag force. As you'd expect, it depends on the velocity at which the object is moving and the density of the medium:

$$P = \rho v^2. \tag{3}$$

In the case of galaxies moving through the intracluster medium, the ram pressure can be strong enough to strip most of the gas out of galaxies. So this is another reason why most galaxies in the centers of clusters are ellipticals with little gas.

3 Dynamical friction

Now we'll consider another gravitational effect, one that is important to satellite galaxies, globular clusters, and general interactions of small galaxies with large ones.

Consider a small galaxy or cluster of mass M moving through an infinite collection of stars, gas clouds and dark matter, with constant mass density ρ. There are no collisions, and the masses of the individual objects are too small to deflect M, so it continues forward. However, the gravitational force of the large object pulls the smaller objects toward it, causing a density enhancement behind it along its path (see Figure 3). There is then a net gravitational force that opposes its motion. This is called **dynamical friction**, and it results in a transfer of kinetic energy from M to the surrounding material.

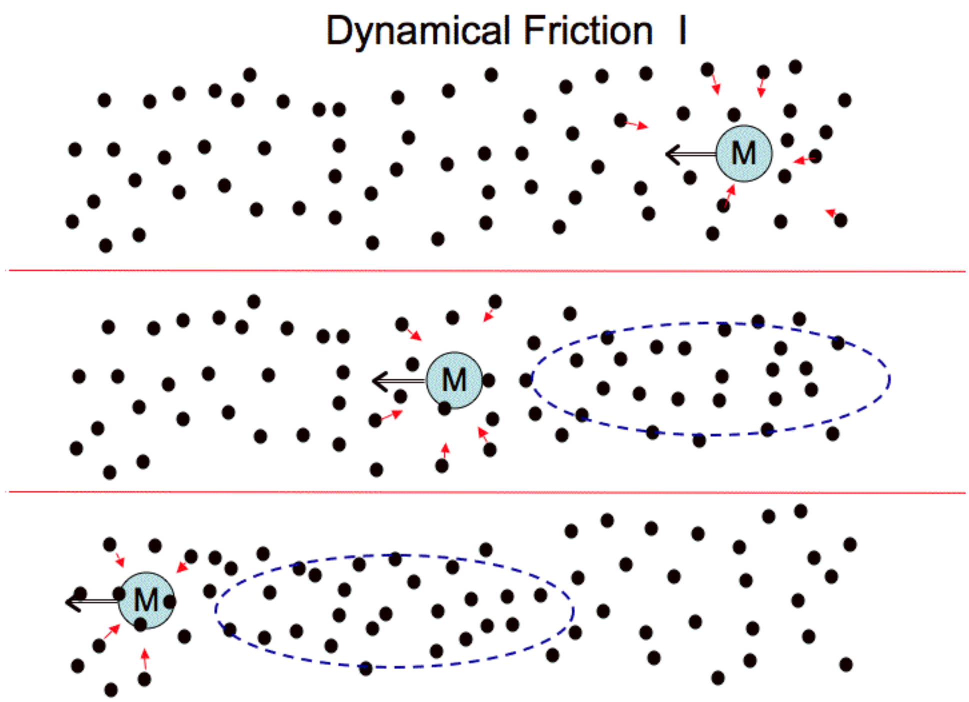

Figure 3: An illustration of dynamical friction. A massive object moving through a collection of smaller objects attracts the smaller objects, and leaves an overdensity in its wake.

We won't derive an expression for the force of dynamical friction here, but it's easy to see that the relevant physical quantities are the mass of the object M, its speed v_M, and the mass density ρ of the surrounding material. So the expression for the force of dynamical friction must depend on GM, v_M and ρ. There is only one combination of these variables with units of force, so the force of dynamical friction f_d must look like:

$$f_d = C\,\frac{G^2M^2\rho}{v_M^2} \tag{4}$$

C isn't a constant; it's a function that depends on how v_M compares with the velocity dispersion of the surrounding medium. As we'd expect, the force is stronger when the mass M is larger and when the density of surrounding material is higher. To understand the inverse squared dependence on velocity, think about the impulse of the encounter: the impulse is the integral of the force with respect to time, and is equal to the change in momentum.

$$I = \int F\, dt = \Delta p \tag{5}$$

The faster the object is moving, the shorter the time the force will be applied. If it's moving twice as fast, it will spend half as much time near a given object and the impulse will be half as large. Then the density enhancement will develop only half as fast, and M will be twice as far away by the time the enhancement arises.

This means that slow encounters are much more effective at decreasing the speed of an interacting object than fast ones.

Dynamical friction explains why the most massive galaxies in clusters are found near the center of the cluster. It also affects satellite galaxies of larger galaxies. The Milky Way has already swallowed some satellite galaxies via dynamical friction, and the Magellanic Clouds will probably merge with the Milky Way in another 14 billion year or so. Globular clusters in the halos of galaxies also lose energy due to dynamical friction, causing them to spiral in to the centers of galaxies. This may be why the Andromeda galaxy has no massive globular clusters.