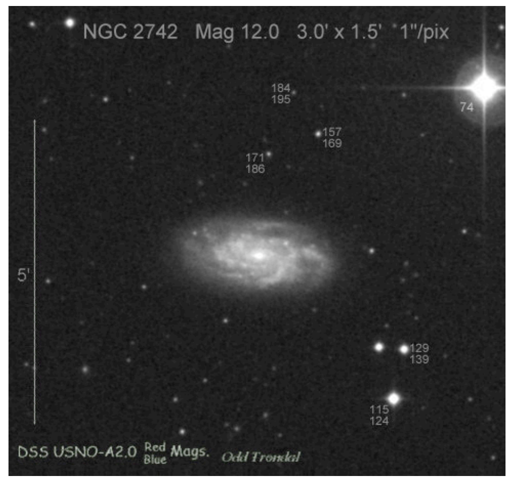
Measuring the Mass of the Galaxy NGC 2742

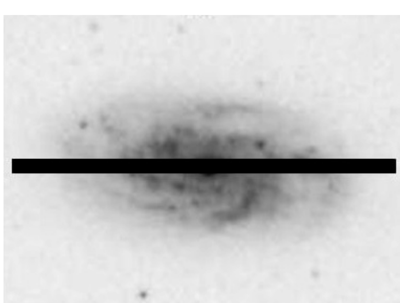
Summary Determine the mass of the galaxy NGC 2742 in two ways - from the revolution of its stars around the center of mass and from its total luminosity. Compare these methods to see if they agree.

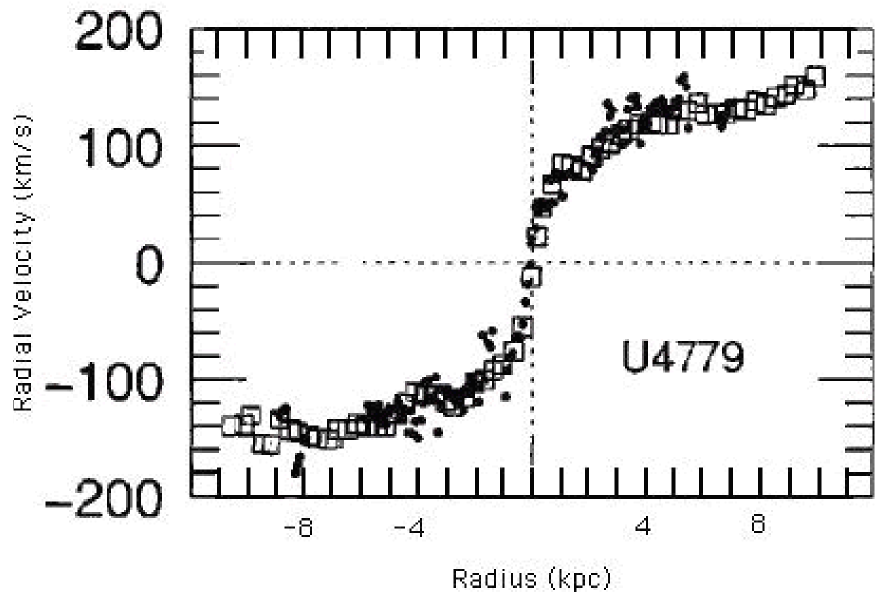
Background and Theory - How do you weigh a galaxy? Astronomers use two methods. The first measures the gravitational mass from the speed of rotation of a galaxy as a function of distance from the center, taking advantage of Newton's Laws to determine the mass around which the stars orbit. The second measures the total light produced by a galaxy; since we know how much light individual stars produce, we can determine how many stars are in the galaxy, and, hence, its luminous mass. The discrepancy between measurements of a galaxy's luminous mass and its gravitational mass provided the first evidence for the presence of dark matter.



Our experiment will examine the luminous mass and gravitational mass of the galaxy NGC 2742. NGC 2742 is a spiral galaxy similar to the Milky Way, but at a distance of about 65 million light years. NGC 2742 is oriented neither face-on nor edge-on, but has an intermediate inclination. Its intermediate inclination allows us to apply both methods to measure its mass, and compare them. We can determine the inclination of the galaxy by comparing its largest and smallest diameters and assuming the galaxy would be circular if we could see it face-on.

Gravitational mass. Below is a graph of NGC 2742 (also known as UGC 4779) that astronomers call a "rotation curve." The graph plots the radial velocity of the galaxy as a function of distance from the center of the galaxy. Radial velocity is the relative speed of the galaxy's stars directly toward or away from the observer. We can measure the radial velocity by taking a spectrum at points across the galaxy from the center to the edge along the longest diameter. The galaxy is placed on a slit (the dark line in the image at left) that allows light from the region of the galaxy we want to study to enter the spectrograph. The spectral lines from the portion of the galaxy rotating toward us will be shifted slightly to shorter wavelength, while spectral lines from the portion of the galaxy rotating away from us will be shifted slightly to longer wavelength. This shift is known as the Doppler Effect and it allows us to measure motions toward or away from us.





The radial velocity of NGC 2742 rises quickly from the center as we move out in radius, and reaches a maximum some distance out from the galactic center. The velocity rises outward because the amount of mass contained is increasing as we move outward. The speed of rotation is proportional to the square root of the mass inside and to the reciprocal of the distance from the center.

- Select 6 radii evenly spaced from the center to the edge of the galaxy, on either side. Record those radii in the table below.

- Determine the radial velocity at each of your radii. Record those values in the table.

- Use your values for radius and velocity to determine the mass of the galaxy inside each radius. According to Newton's law of gravity

$$M = \frac{v^2 R}{G}$$

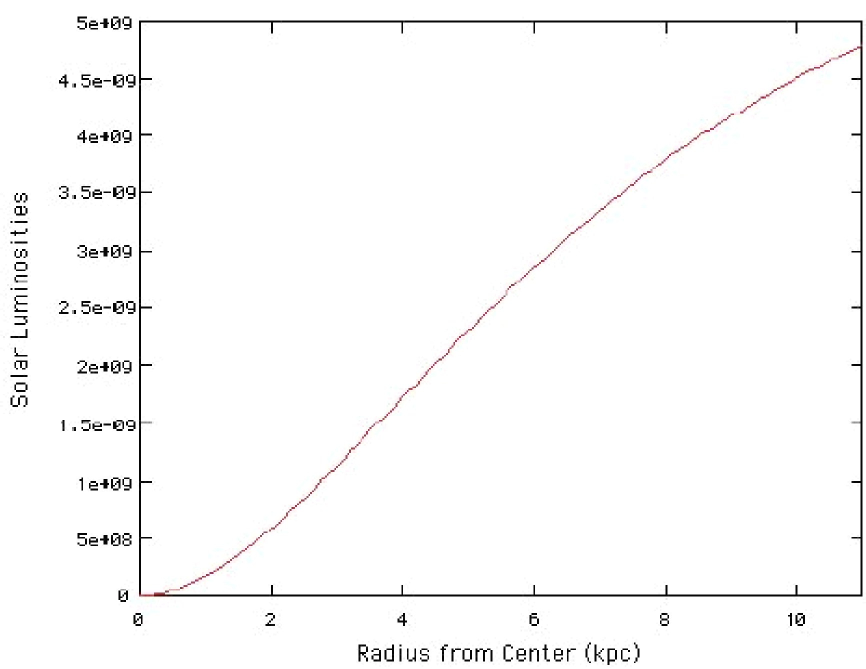
where G is the gravitational constant = 4.31 x 10^{-6}, and "M" is the mass contained inside of radius "R". Here, we are using astronomical units. Mass is measured in solar masses, length is measured in kiloparsecs (Kpc), and velocity is measured in km s^{-1}. Using these units, the gravitational constant has a value of 4.31 x 10^{-6} Kpc km^2 $M_{\odot}^{-1}$ s^{-2} .

Record your results in the "Gravitational Mass" column in the table. Your numbers should be big. This is a galaxy you're dealing with. It contains a lot of stars.

Radius (Kpc)	Rot. Vel. (km s^{-1})	Grav. Mass (solar masses)	Luminosity (solar lum.)	Luminous Mass (solar masses)	Ratio Lum/Grav Mass

The Luminous Mass - Now that you have found the total mass of the galaxy, we will investigate how much of that mass comes from matter we can see - the stars! The next figure is a graph of how many solar luminosities of light NGC 2742 produces inside of the area encompassed by some radius (where radius is the distance from the center of the galaxy measured in Kpc).

We add together all the luminosity from inside of a given radius to be consistent with the gravitational mass that we found before. The gravitational mass we calculated included all the mass inside of a spherical shell at some radius. At each of the radii that you have chosen, find a value for the luminosity within that radius of the galaxy and record it in the table.



Now that you have measured how much light is coming from NGC 2742, you can estimate the mass of the stars that produced that light. It would be easy if, for every solar luminosity of light we measure, we can assume that one solar mass of stars is producing it. Unfortunately, some light is blocked by dust in the galaxy we're observing, and the galaxy is comprised of mix of heavy and light stars. The luminosity of a star depends on its mass; massive stars produce more light per solar mass, while light stars produce less light per solar mass. Much of the light from NGC 2742 may be coming from a few young, hot bright stars, and many cooler, low mass stars may be hidden from view by the glare of the bright stars. Thus, we need to find a compromise between the high and low mass stars. A good way of estimating the true mass of material producing the light we see is to assume that there are two solar masses of stars producing each solar luminosity of light.

Using this assumption, compute the luminous mass contained within each of the radii you originally selected.

Finally, what fraction of the total mass of NGC 2742 is produced by the luminous matter? Divide the luminous mass by the total, gravitational mass. Is most of the mass luminous or dark?
