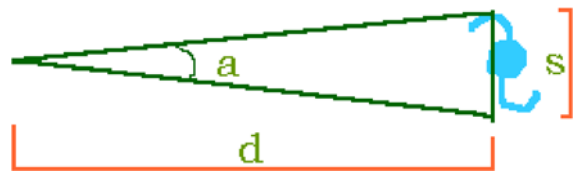
Step 4: Finding the distance to each galaxy

A trickier task is to determine the distances to galaxies. For nearby galaxies, we can use standard candles such as Cepheid variables or Type I supernovae. But, for very distant galaxies, we must rely on more indirect methods. **The key assumption for this lab is that we are measuring galaxies of similar Hubble type**. We then assume that they are all the same physical size, no matter where they are. This is known as "the standard ruler" assumption. We must first calibrate the actual size by using a galaxy to which we know the true distance. We are looking for galaxies in the sample that are Sb galaxies, as we would use the nearby Sb galaxy, M31 the Andromeda galaxy, to calibrate the distances. We **know** the distance to the Andromeda galaxy through observations of the Cepheid variables in it. Then, to determine the distance to more distant, similar galaxies, one would only need to measure their **apparent** (angular) sizes, and use the small angle formula.



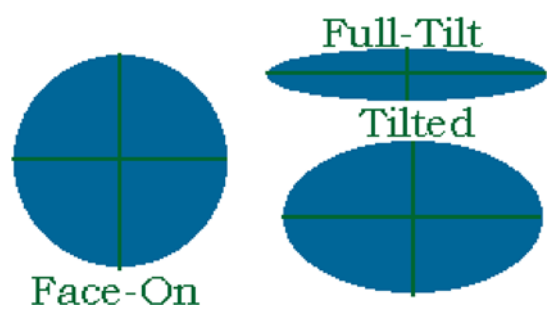
$$\mathbf{a} = \mathbf{s} / \mathbf{d} \text{ or: } \mathbf{d} = \mathbf{s} / \mathbf{a}$$

where **a** is the measured angular size (in radians), **s** is the galaxy's true size (diameter), and **d** is the distance to the galaxy.

Measuring the Galaxies

- **It is up to you to decide the criteria you will use in measuring these galaxies. <u>It is suggested that you try to measure as far out as you can see any fuzzy disk.</u>**
- The **angular size** of the galaxy is measured by using its **image**. Note that the images used in this lab are **negatives**, so that bright objects -- such as stars and galaxies -- appear dark. Note also that there may be more than one galaxy in the image; the galaxy of interest is always the one closest to the center.
- To measure the size, simply move the mouse and click on opposite ends of the galaxy, along its **longest** part. (You will need to make a total of **two** clicks.)

*Take a look at this schematic of a galaxy viewed from three different angles. Thought question: We assume that the spirals are all round, and that their different shapes are simply because we are viewing them from different angles. When measuring the angular sizes of the galaxies, why should you measure along the **longest** axis only?*



The angular size of the galaxy (in *milliradians*; 1 mrad = 0.057 degrees = 206 arcseconds) will be displayed; write this number down on your table, under "Galaxy Size."

If, at any point, you make an error while you're measuring (e.g. a miss-click), simply click on the "back" button of your web browser and take the measurement again.

Here is the "intercept" page (found on-line) that will link you to the <u>real data for the 27 galaxies</u>.

Checking Your Data

It would be a good idea to have your instructor look at your data now, before you do a ton of calculations. You wouldn't want to spend hours of your time only to discover that you made mistakes in steps 3 and 4.

Initial Calculations

If you feel confident of your data, then you are ready for the preliminary calculations:

Velocity Determination

For **each measured line** calculate the (redshift **z**), and enter this value in the box under the measured wavelength. Then take the average redshift of the measured lines for each galaxy, and enter it on the appropriate column. Finally, use this average redshift to calculate the velocity of the galaxy using the modified Doppler-shift formula:

$$v = c\,z$$

Distance Determination

Determine the distance (in Mpc) to each galaxy using the following, revised version of the small angle formula. Recall, we have had to make an important assumption: all of these galaxies are about the same actual size. Once you have the angular diameter in *mrad* (and with some adjusting of units), just take the **actual size** of each galaxy -- 22 kpc -- and divide it by the measured angular diameter. For example, if one of the galaxies had a measured angular diameter of 0.50 *mrad*, 22 / 0.50 = 44 Mpc.

Details for the manipulation of the units to come out with the correct distances
From calibrations, we know that galaxies of the type used in this lab are about **22 kpc** (1 kiloparsec = 1000 pc) across. We may then find the distance to the galaxies: **distance (kpc) = size (kpc) / a (rad)** or equivalently, upon multiplying the left side by 1000 and dividing the right side by 0.001 (which is exactly the same thing): **distance (Mpc) = size (kpc) / a (mrad)**
Note that we now have the equation in a form where we can simply substitute the size in kpc (22) and divide it by the angle returned by our measurements (already in *mrad*).