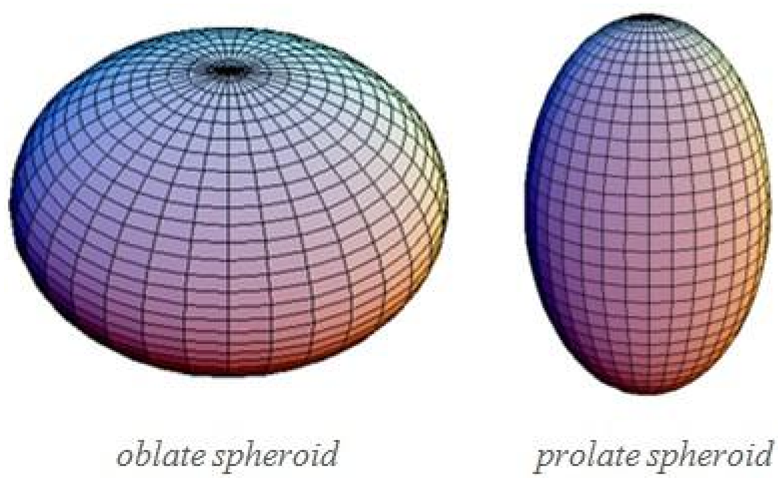
Kinematics of Elliptical Galaxies

- Information provided by Kinematics
  1. Dynamical mass of the galaxy
  2. Factors leading to the shape of the galaxy

- The Ellipsoid
  Any shape that appears to be ellptical from all directions is called an ellipsoid. The shape of an ellipsoid is determined by the relative lengths of its three axes. If two of the axes are of equal length, the ellipsoid will have a circular cross-section when seen along its third principal semi-axis. An ellipsoid of this kind is called a spheroid.

  The spheroid is further classified into two types:-

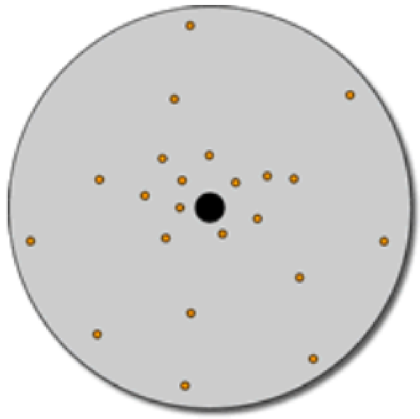


  1. Oblate spheroid: $a = b > c$
  2. Prolate spheroid: $a > b = c$

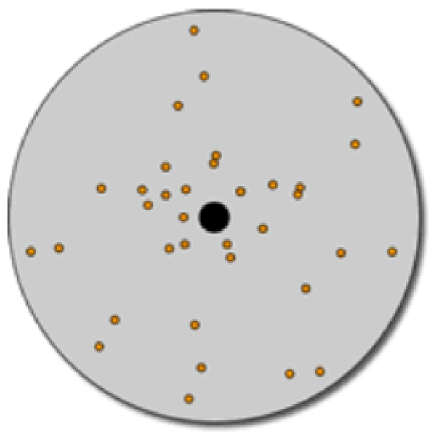
  Ellipsoids with three unequal axes do not appear circular from any direction and are called as triaxial ellipsoids.

  Note: For a long time it was thought that the ellptical galaxies were oblate spheroids and their flatenning was due to rotation. Kinematics of the galaxies can provide us with a definitive explanation for their shapes.

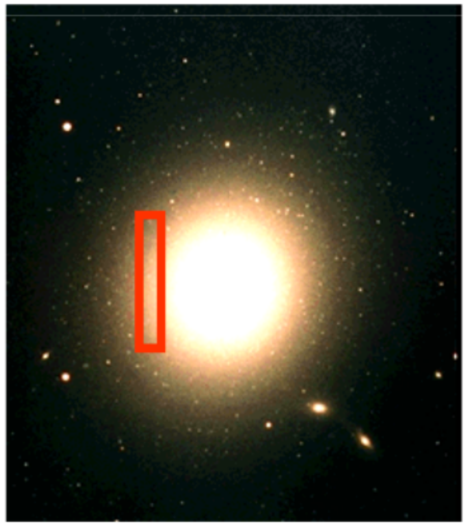
- Overall Motions
  There are two kinds of overall motion observed in galaxies:-
  1. Systematic rotation: Majority of the material orbits in the same direction. This motion is almost Keplarian.



2. Random motion: On an average, there is equal no. of material moving in all direction.



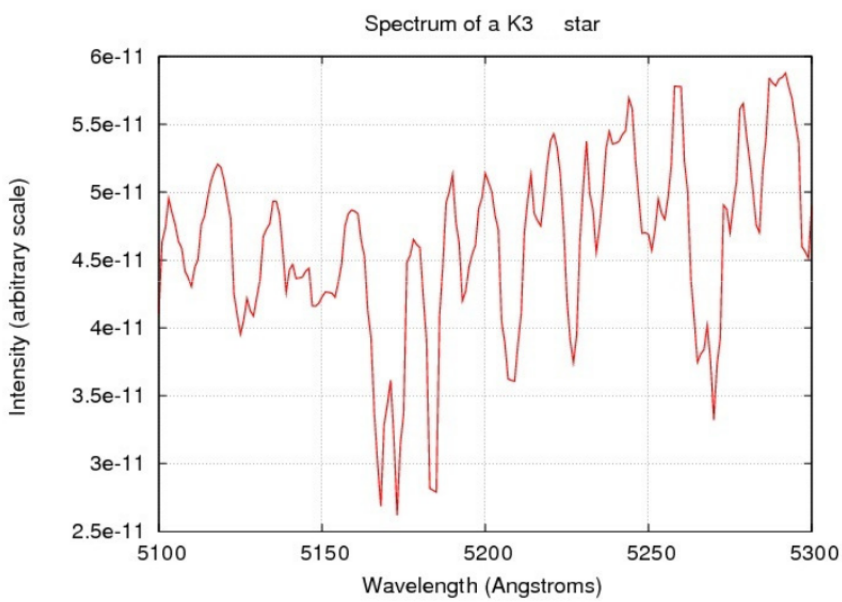
- Determining Kinematics of a Galaxy
  Overall kinematics of a gaalxy can be measured using spectroscopy. If a galaxy is nearby it will be spatially resolved. In order to determine spectra of regions of a galaxy at different distances from its center, we can begin by positioning the slit so that the flux from the periphery of the galaxy is observed. This is shown below.



We record the spectra and move the slit towards the center so that the next neighbouring region is covered. This process is repeated until we have obtained spectra for whole spatial extent of the galaxy.

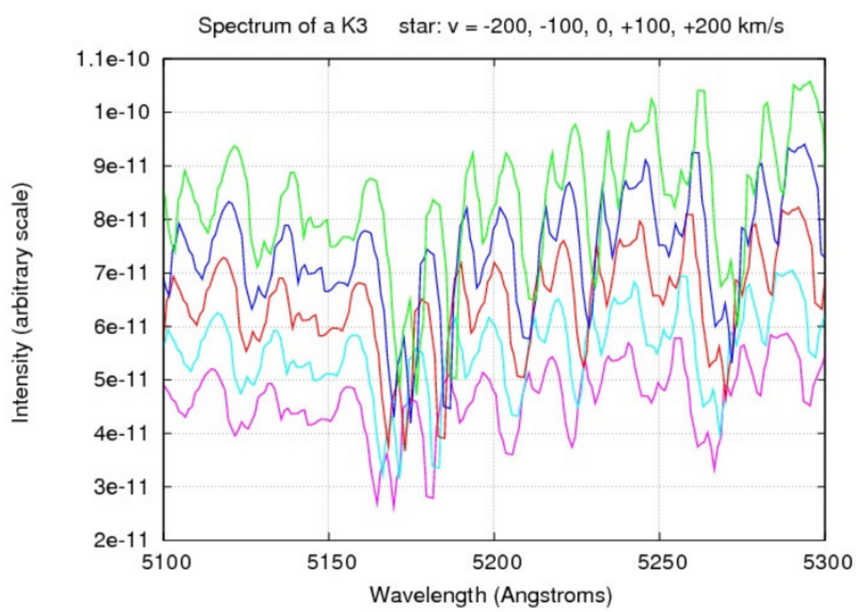
We can derive two types of velocities from this information:-
1. Bulk velocity of the stars (tracing the rotaional motion)
2. Velocity dispersion of the stars (tracing random motion)

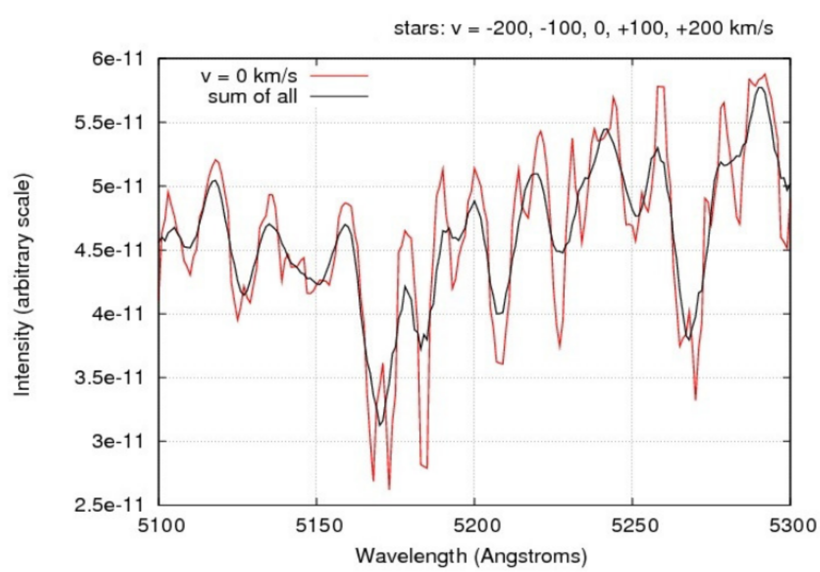
Let us consider a galaxy with only K type stars. Now, spectrum of an individual K type star is as follows:-



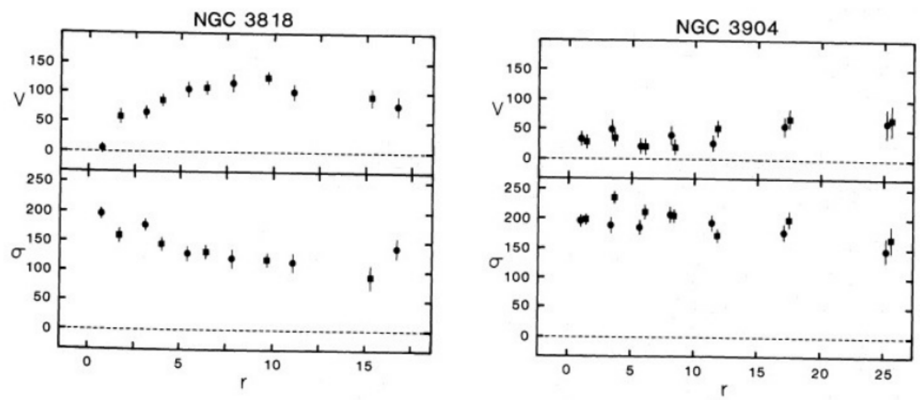
The spectrum of any galaxy will be superposition of the spectra of all the stars and ISM in that galaxy. Consider the first scenario where the kinematics of stars in the galaxy

is organized and systematic. The extent of doppler shift in the spectrum of individual stars in that galaxy will be roughly the same. There will be a Doppler shift in the final coadded spectrum.
If the stars are are moving at random unequal volicites, then the spectrum of each individual star will be slightly redshifted or blueshifted by different extent with respect to every other star. A superposition of such differently Doppler shifted spectra would result in a spectrum in which the absorption and emission featues are diluted. This scenario is illustrated in the following two images.



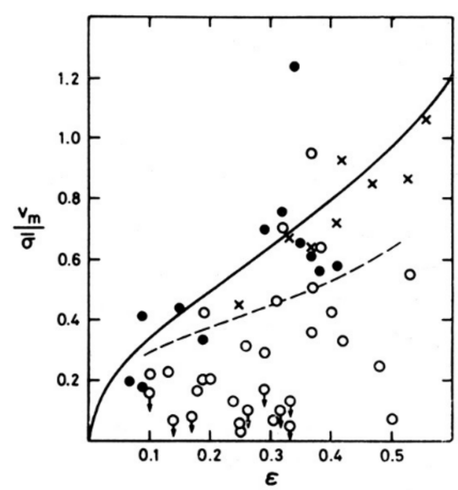


We can use spectrum at different radii from the galactic center and calculate the systematic rotational velocity and the velocity dispersion. A comparison of the two values would allow us to determine whether the kinematics of stars in the galaxy is predominantly systematic rotation or random motion. Such observations have been done for a large sample of elliptical galaxies. For example,



NGC 3818 and NGC 3904 are two elliptical galaxies in the nearby universe. The figure in the left and right panels show the rotational velocity (V) and the velocity dispersion as a function of the distance (r) from the center of each galaxy. In either case, at any given radius r, the velocity dispersion is larger than the rotational velocity. The ratio $V/\sigma < 1$ suggests that at all radii, velocity dispersion (or random motion) is more dominating than systematic rotation. Figure taken from Davies et al. 1983, ApJ

- Inferences drawn from observations
  Davies et.al published the following result of ratio of the maximum rotational velocity to the mean velocity dispersion in the central regions against ellipticities,



Here open circles are for magnitudes lesser than -19 and filled circles correspond to faint galaxies with magnitudes greater than -19.

From all the data that is available, we can derive following inferences about elliptical galaxies:-
1. Rotational velocity to sigma ratio is too small to explain the shape of elliptical galaxies i.e flatenning.
2. No well established correlation between rotational velocity and ellipticity of bright galaxies. Although, there is a weak correlation for fainter galaxies.

So, the status quo on elliptical galaxies is as follows:-
1. The observed line-of-sight velocites of stars in elliptical galaxies are not consistent with a spheroidal distribution.
2. The measured rotational veloctiies are too slow to produce the observed flatenning.
3. Some elliptical galaxies appear to be rotating about an axis other than the shortest axis, so their flatenning cannot be due to systematic rotation.

Note: How elliptical galaxies acquired their shapes is still an open question.