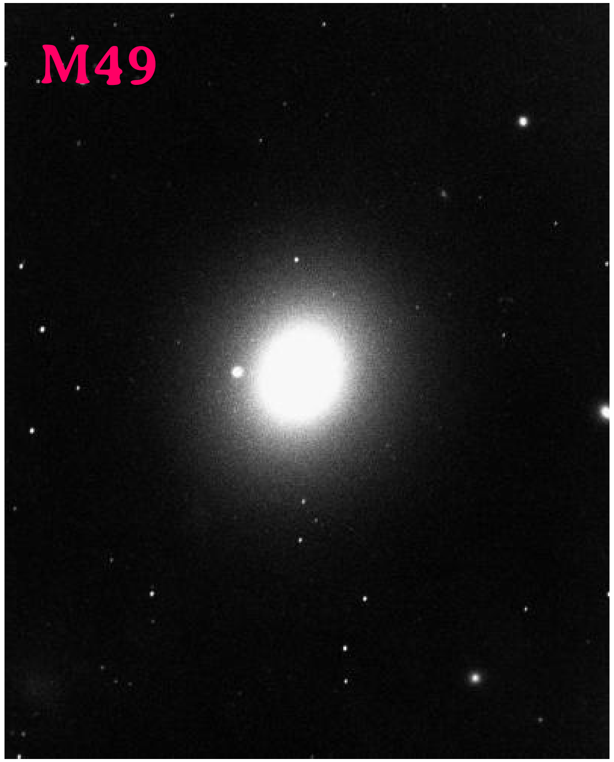
The Kinematics of Galaxies

- How stars and gas move within galaxies is a direct measure of the underlying dynamical mass of galaxies.

- The kinematics also gives insight into how galaxies acquire their shape

Kinematics of Elliptical Galaxies

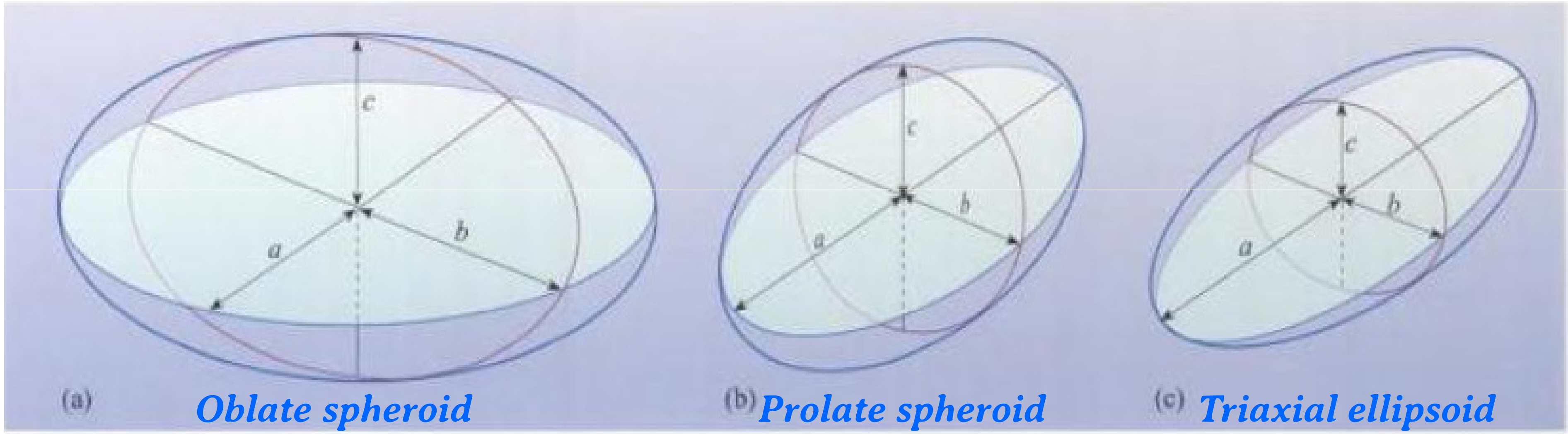


What is the true shape of elliptical galaxies? What we see is the projected two-dimensional shape of these galaxies. It was not clear in the early days whether the apparent differences between the Hubble sequence from E0 - E7 was a result of viewing a single common shape of ellipticals from different viewing directions?

Any 3D shape that appears to be elliptical 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***.

Kinematics of Elliptical Galaxies

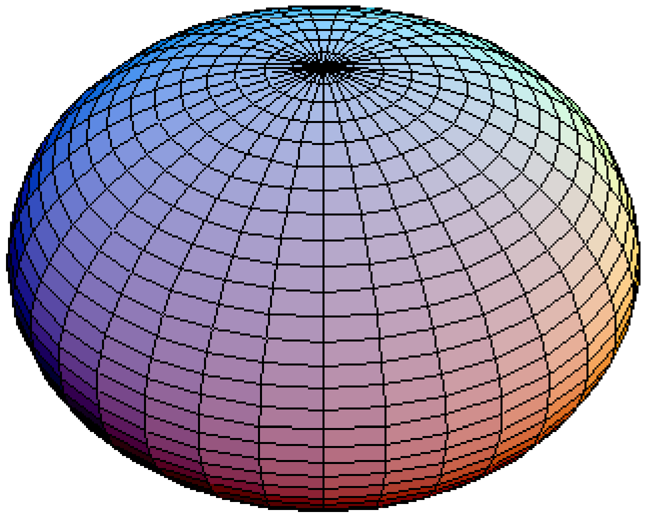
The spheroid is classified as *oblate spheroid* (a = b > c) or a *prolate spheroid* (a > b = c) depending on whether the third axis is shorter or longer than the other two. Ellipsoids with three unequal axes do not appear circular from any direction, and are called *triaxial ellipsoids (a > b > c)*.



Before the 3D shape of elliptical galaxies were properly studied, it was assumed based on the variety of observed morphology that every elliptical galaxy was an oblate spheroid. It was also widely assumed that elliptical galaxies rotated about the shortest axis and the flattening was mainly due to this rotation, similar to the polar flatenning of Earth.

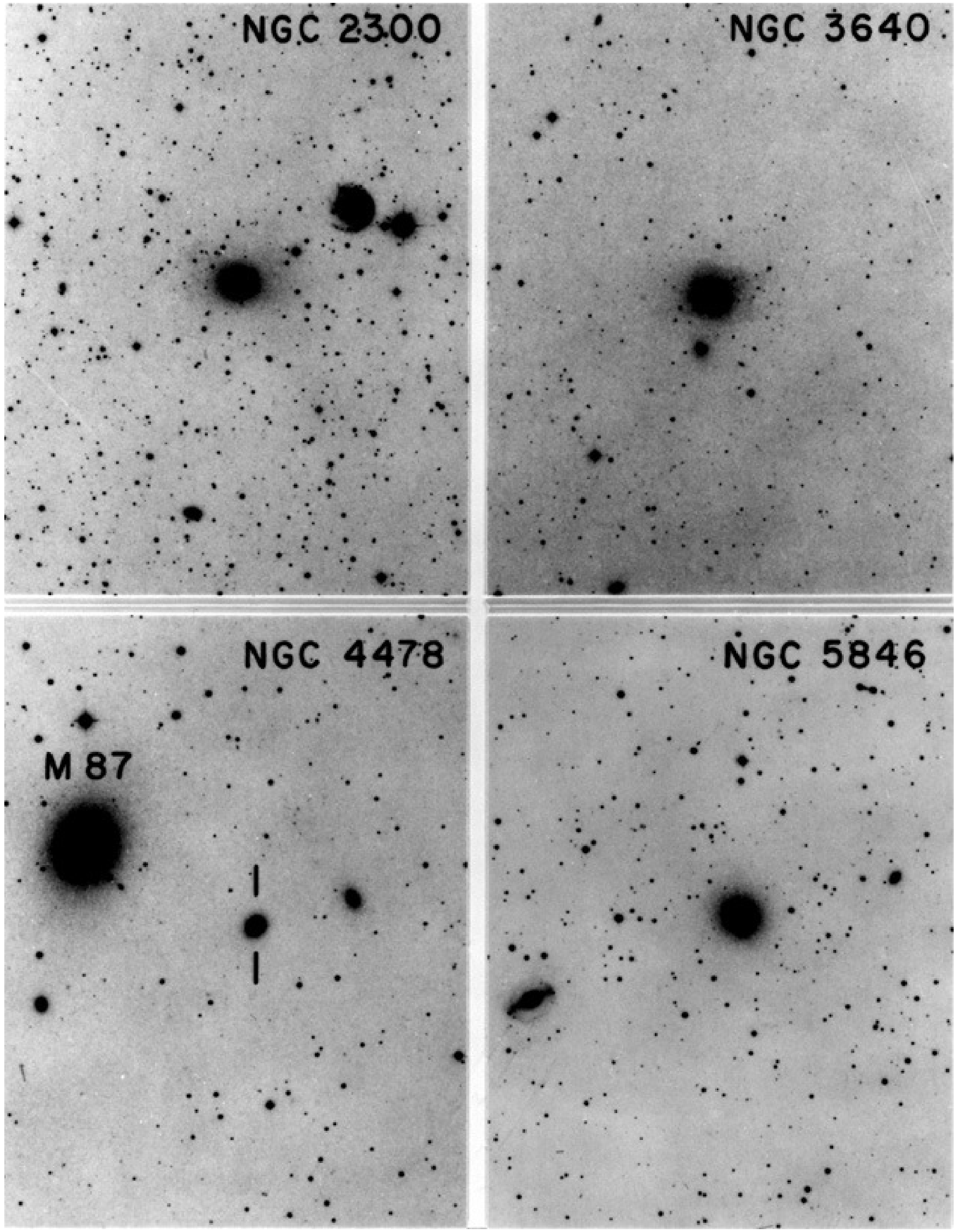
Kinematics of Elliptical Galaxies

For a long time it was proposed (*without observational backing*) that elliptical galaxies were oblate spheroids and that their flattening was due to rotation



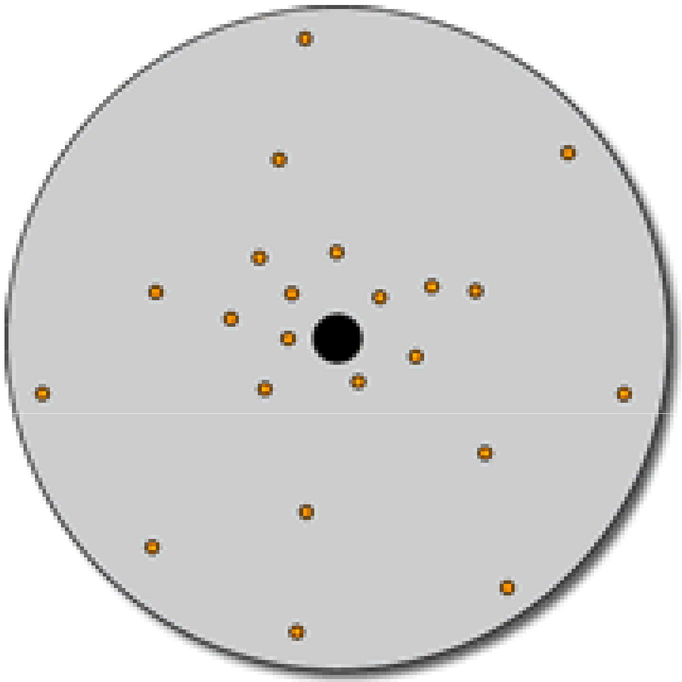
Oblate spheroid

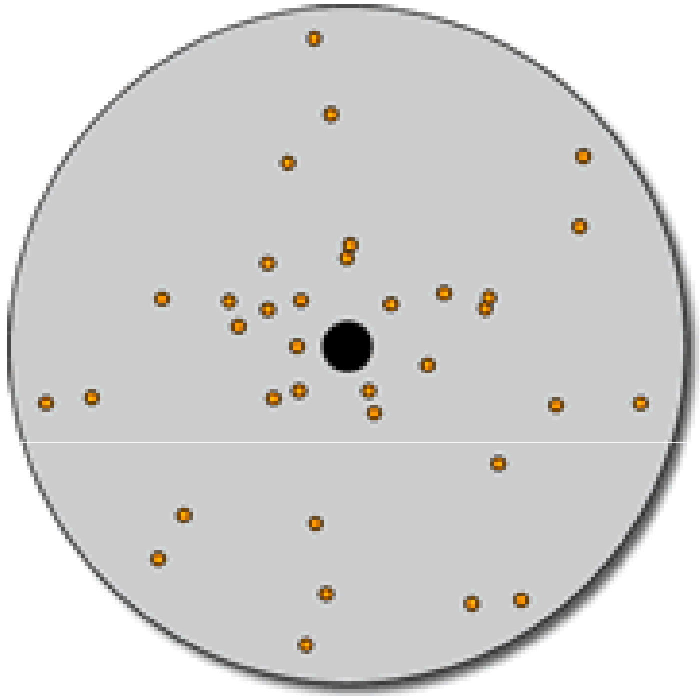
a = b > c



The observational clues for understanding how elliptical galaxies acquire their shape comes from studying the kinematics of stars in them.

The Two Kinds of Overall Motion



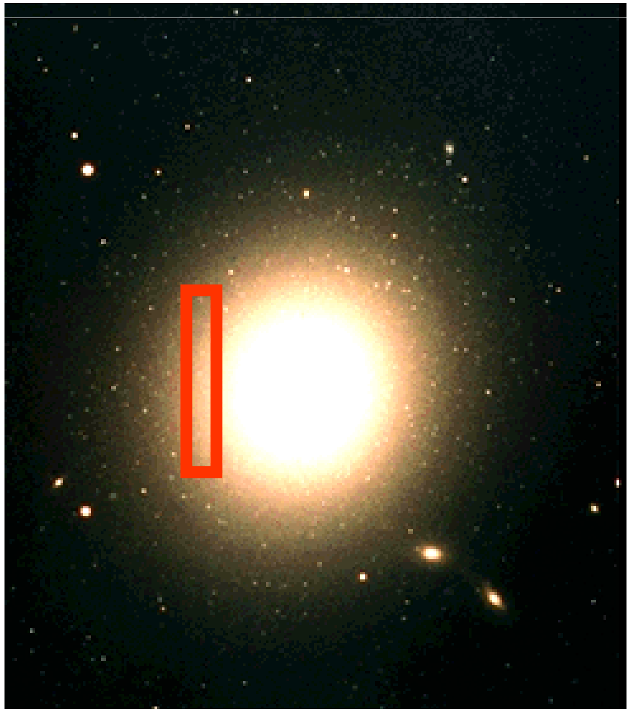


Systematic rotation : majority of the material orbiting in the same direction

Random Motion : on an average, equal number of material orbiting in all direction.

Kinematics of Elliptical Galaxies

- The overall kinematics of stars in a galaxy can be measured through spectroscopy
- Spectrum of a galaxy = superposition of the spectrum of individual stars in that galaxy

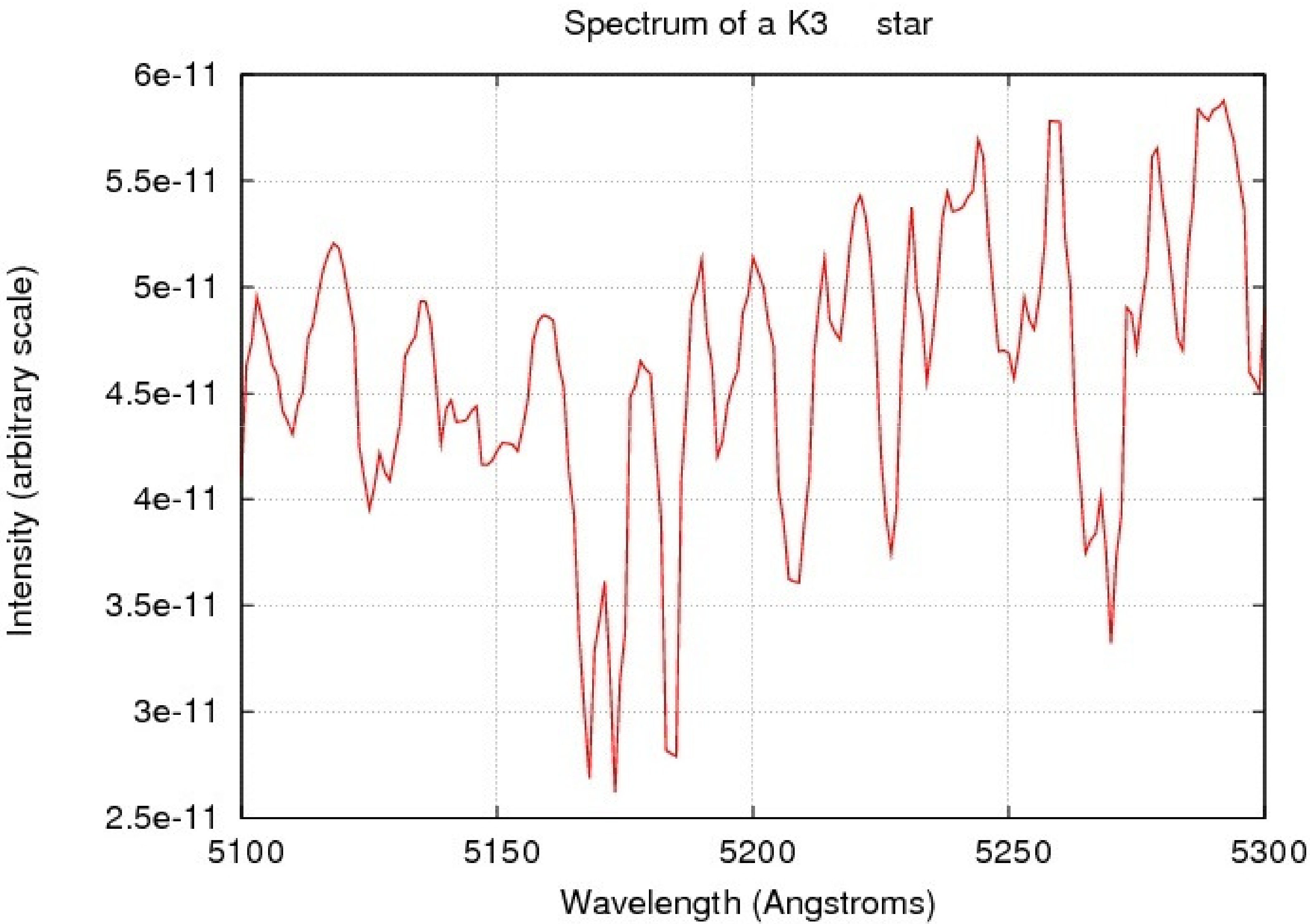


- Bulk radial velocity of stars within the slit (*tracing rotational motion*)
- Radial velocity dispersion of stars within the slit (*tracing random motion*)

Kinematics of Galaxies

Consider an elliptical galaxy in which all the stars are main sequence stars of spectral type K. The spectrum of an individual K star is shown in the next slide.

Kinematics of Elliptical Galaxies

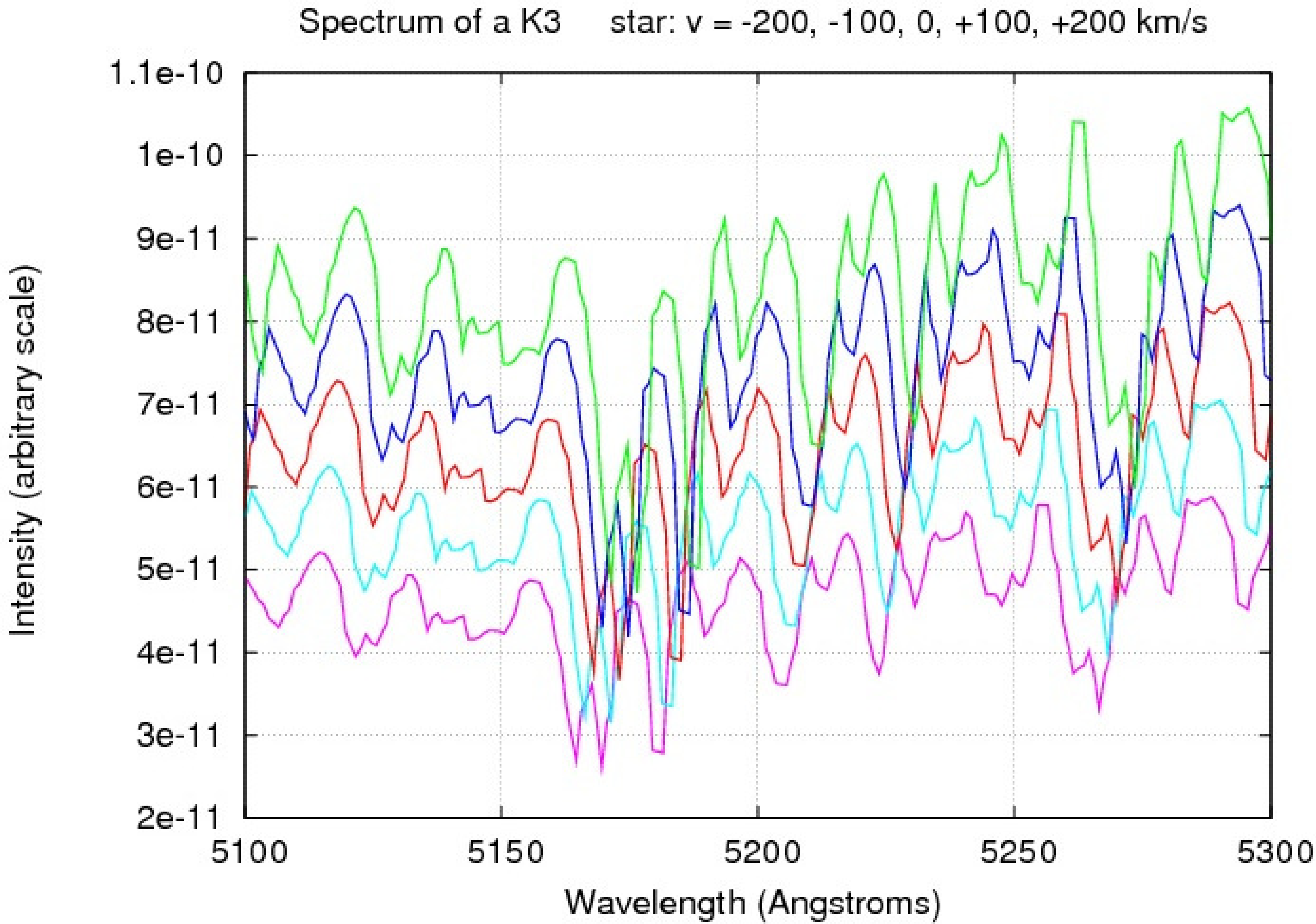


Kinematics of Elliptical Galaxies

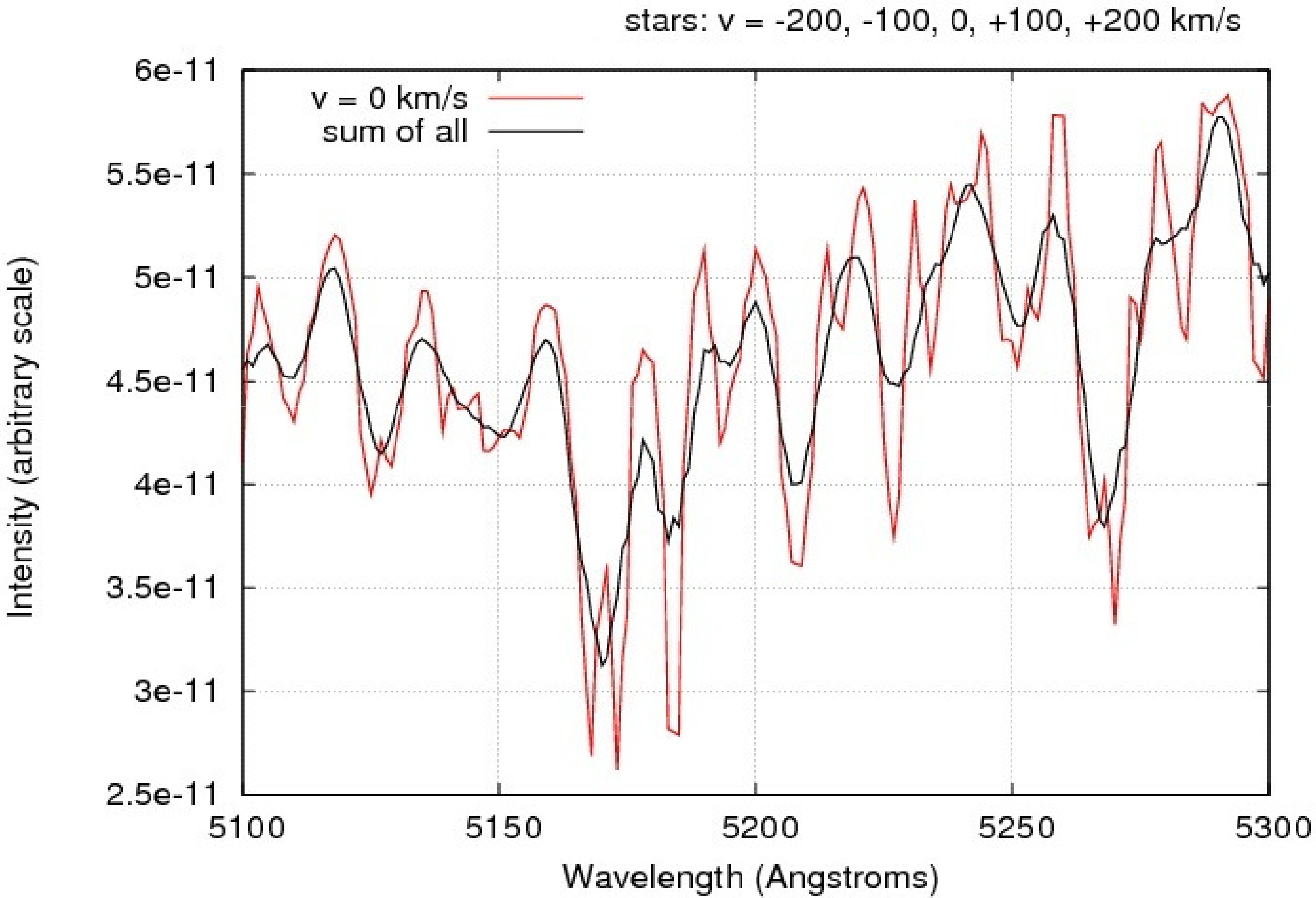
The spectrum of any galaxy will be a superposition (or coaddition) of the spectra all the stars and ISM in that galaxy. Consider the first scenario where the kinematics of stars in the galaxy is organized and systematic (and not random). The extent of Doppler shift in the spectrum of individual stars in that galaxy will be roughly the same. There will be a Doppler shift in the final coadded spectrum.

If the stars are all moving at random unequal velocities, then the spectrum of each individual star will be slightly redshifted or blueshifted by different extent with respect to every other star. A coaddition of such differently Doppler shifted spectra would result in a spectrum in which the absorption and emission features are diluted. This scenario is illustrated in the next two slides.

Kinematics of Elliptical Galaxies



Kinematics of Elliptical Galaxies

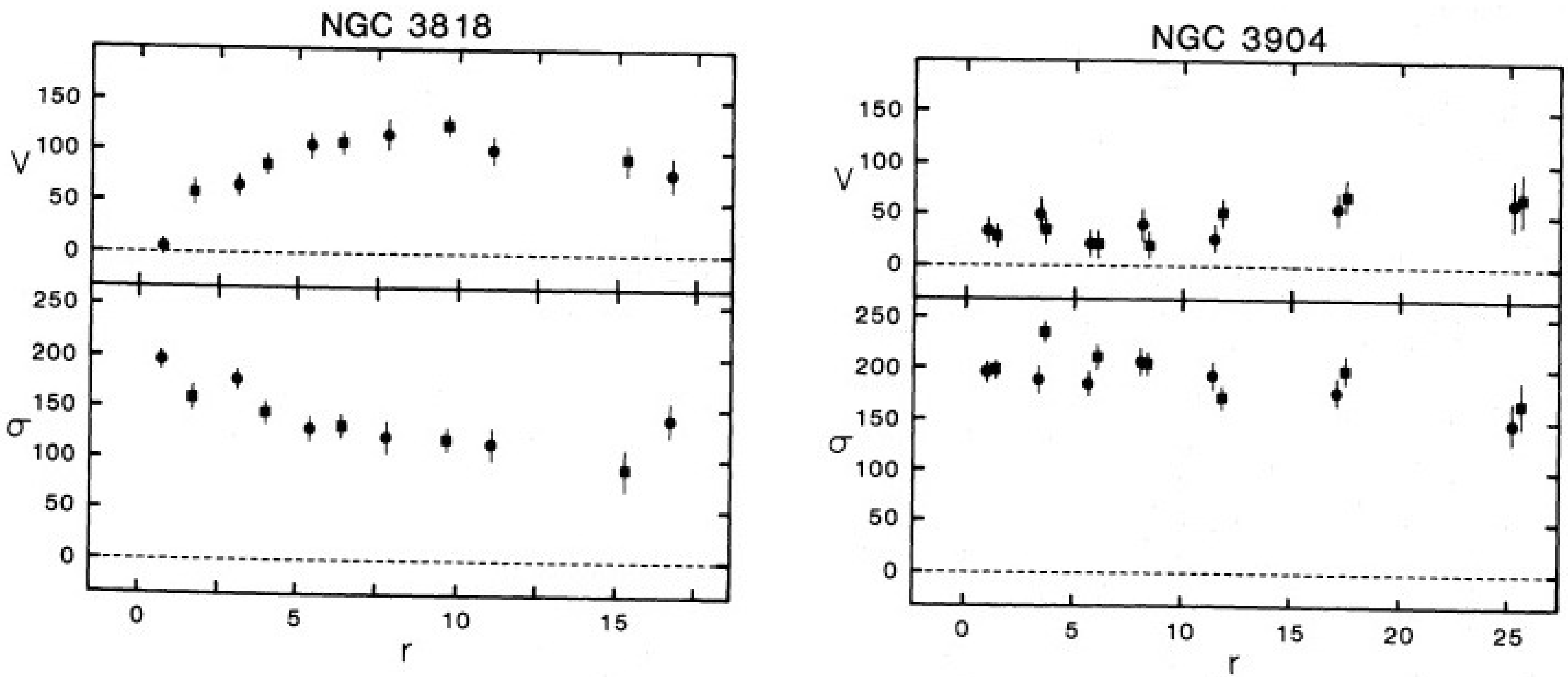


Kinematics of Elliptical Galaxies

If an elliptical galaxy is sufficiently close then we can spatially resolve the galaxy. This would allow us to obtain spectrum at different radii from the centre of the galaxy. At each radii we will be able to calculate the systematic rotational velocity and the velocity dispersion (a measurement of the randomness of velocities).

A comparison of these two values would allow us to determine whether the kinematics of stars (and gas) in the galaxy is predominantly systematic rotation ($\boldsymbol{v}_{rot}$) or random motion (σ) . Such observations have been done for a large sample of elliptical galaxies. Two examples are shown in the slide next.

Kinematics of Elliptical Galaxies

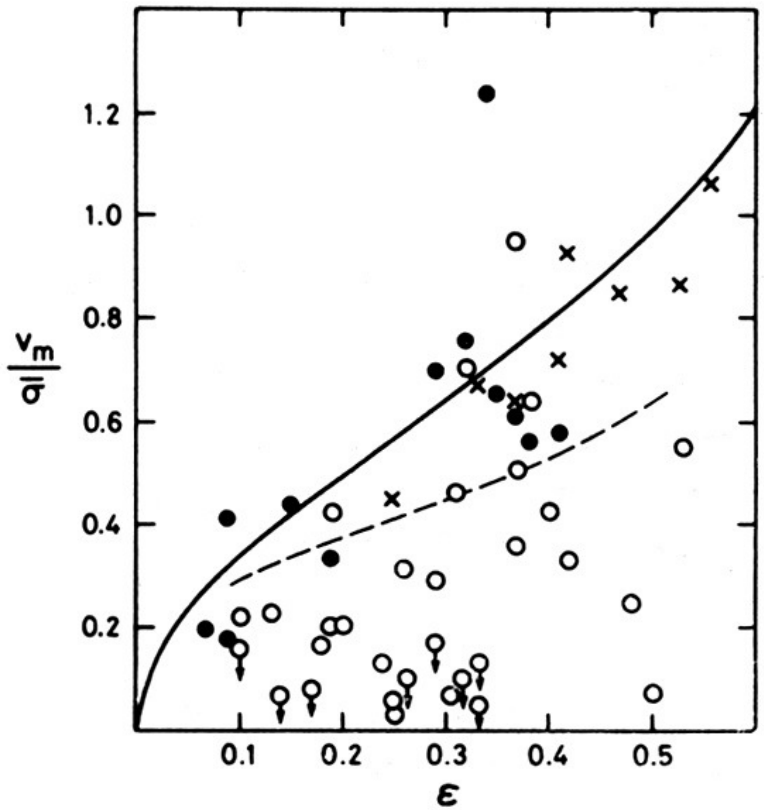


NGC 3818 and NGC 3904 are two elliptical galaxies in the nearby universe. The figure in the left and right panels show the rotational velocity (V) and the velocity dispersion as a function of the distance (*r*) from the center of each galaxy. In either case, at any given radius *r*, the velocity dispersion 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

Elliptical Shape of Elliptical Galaxies

- v_{rot}/σ is small, implying there is not enough net rotation (to overpower random motion) to explain its observed flattening.

- No *well established* correlation between rotational velocity v_{rot} and observed ellipticity for brighter galaxies. A weak correlation for fainter galaxies. Brighter galaxies



The ratio of the maximum rotational velocity to the mean velocity dispersion in the central regions plotted against ellipticity. Open circles are for elliptical galaxies with $M_B < -19.0$ and filled circles show results for faint ellipticals with $M_B > -19.0$. Crosses show results for the bulges of disc galaxies.

From Davies et al. (1983)

Elliptical Shape of Elliptical Galaxies

- The observed line-of-sight velocities of stars in elliptical galaxies are not consistent with a spheroidal distribution.

- The measured rotation velocities (*circular velocity*, *systematic velocity*) are too slow to produce the observed flattening.

- Some elliptical galaxies appear to be rotating about an axis other than the shortest axis, so their flattening cannot be due to systematic rotation.

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