Galaxies: Structure, formation and evolution

Lecture 10

Yogesh Wadadekar

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3 major modes of optical spectrocopy

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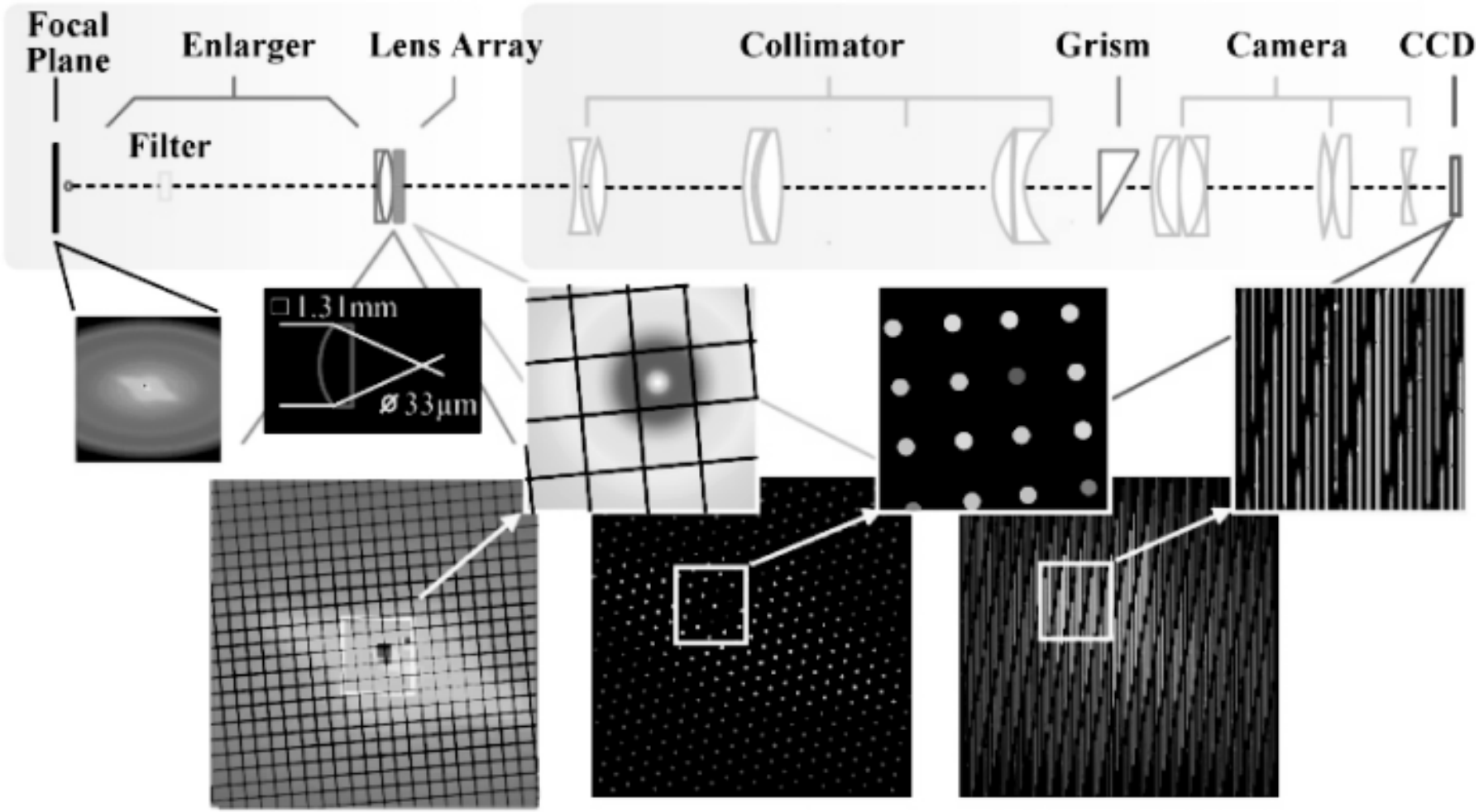
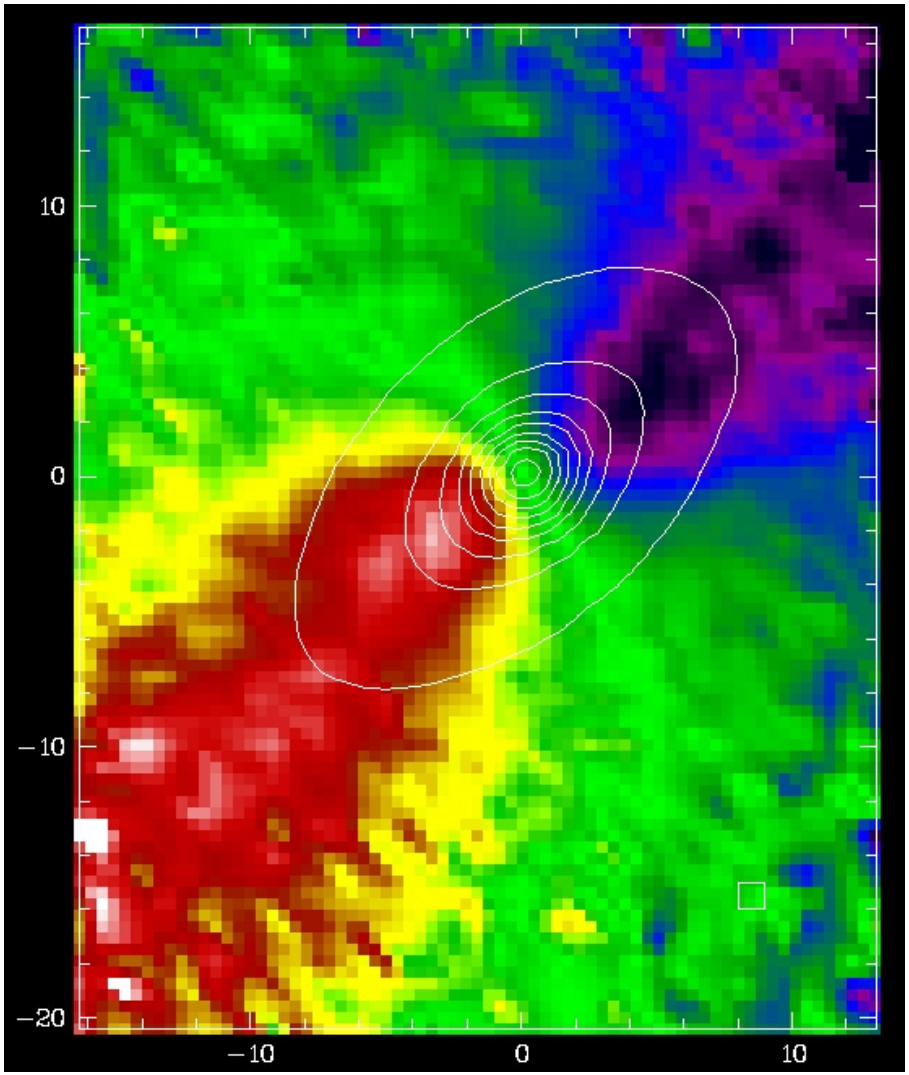
- 2D spectroscopy - “1D” slit input is dispersed producing a 2D spectrum.
- 3D spectroscopy - “2D” lenslets input is dispersed producing a 3D spectrum (data cube)

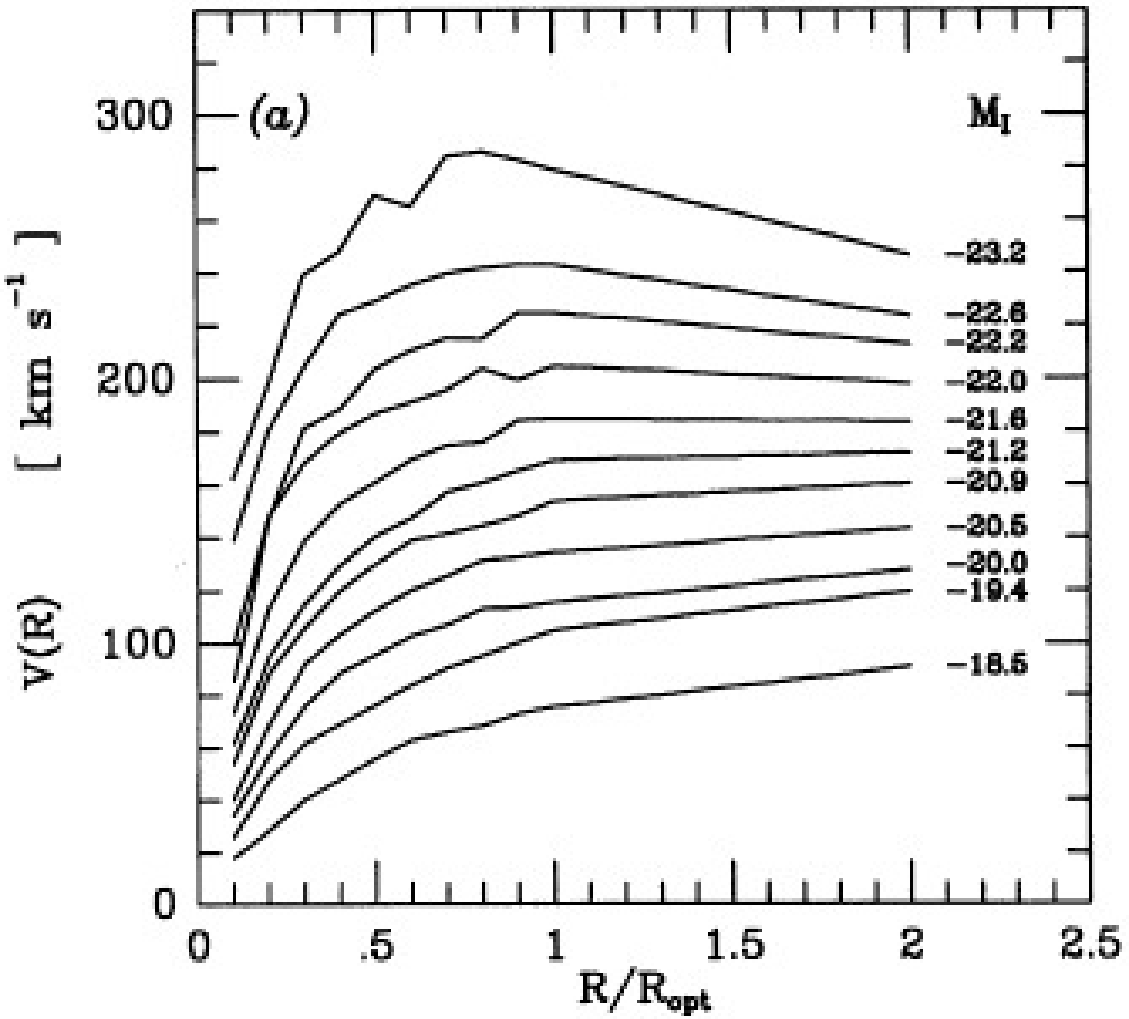
Sauron 3D spectroscopy



IFU spectrum



Rotation curves at different luminosities



As luminosity increases, the rotation amplitude increases; the initial rise steepens; the outer slope drops.

In the inner region

For luminous early type spirals, $V(r)$ rises very rapidly. $\rightarrow$ bulge more important.
For low luminosity later type spirals, $V(r)$ rises more slowly often $V(r) \propto r$ "solid body".
In the "hypothetical situation" where the supermassive black hole at the center contained most of the mass of the galaxy and there was no dark matter, how would $V(r)$ look?

Question

How to use circular velocities to measure mass within a certain radius?

Measuring the mass of galaxies for spherical symmetry case

Motions of stars and gas in the disc of a spiral galaxy are more or less circular (V_R and $V_Z << V_R$)
Acceleration of the star moving in a circular orbit must be balanced by the gravitational force. Hence force on a unit mass is:

$$\frac{V^2(r)}{r} = -F_r(r) \tag{1}$$

To calculate $F_r(r)$, we need to sum up all gravitational force from bulge, disk and halo. If the mass within radius r is $M(r)$, gravitational force on a unit mass is:

$$F_r = -\frac{GM(r)}{r^2} \tag{2}$$

From observed $V(r)$, we can infer $M(r)$.

Mass of a pure thin exponential disk

$V_c^2(R) = R\frac{\partial \phi}{\partial R}$ Solving this diff. equation results in a solution that includes modified Bessel functions of the first and second kind which simplify to:

$$V_c^2(R) = 0.767\frac{GM_d}{R_d}\frac{0.44(R/R_d)^{1.3}}{1+0.235(R/R_d)^{2.3}}, R < 4R_d$$

This rotation curve has peak at $R\mathrm{max} \sim 2.2R_d$, for $R > 3R_{\mathrm{max}}$ curve is Keplerian
See section 2.6 of B&T for the full details.

Milky way rotation curve

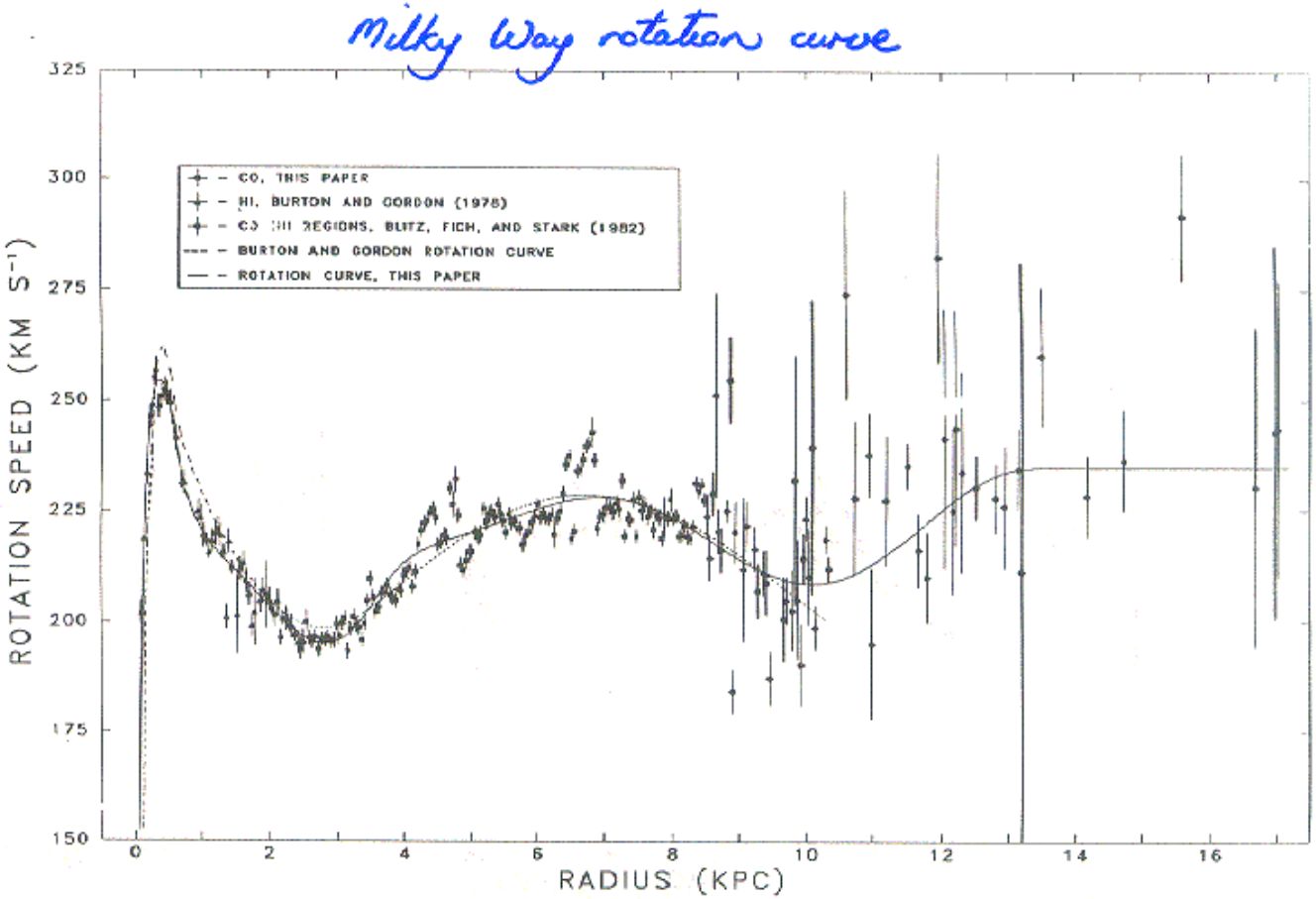
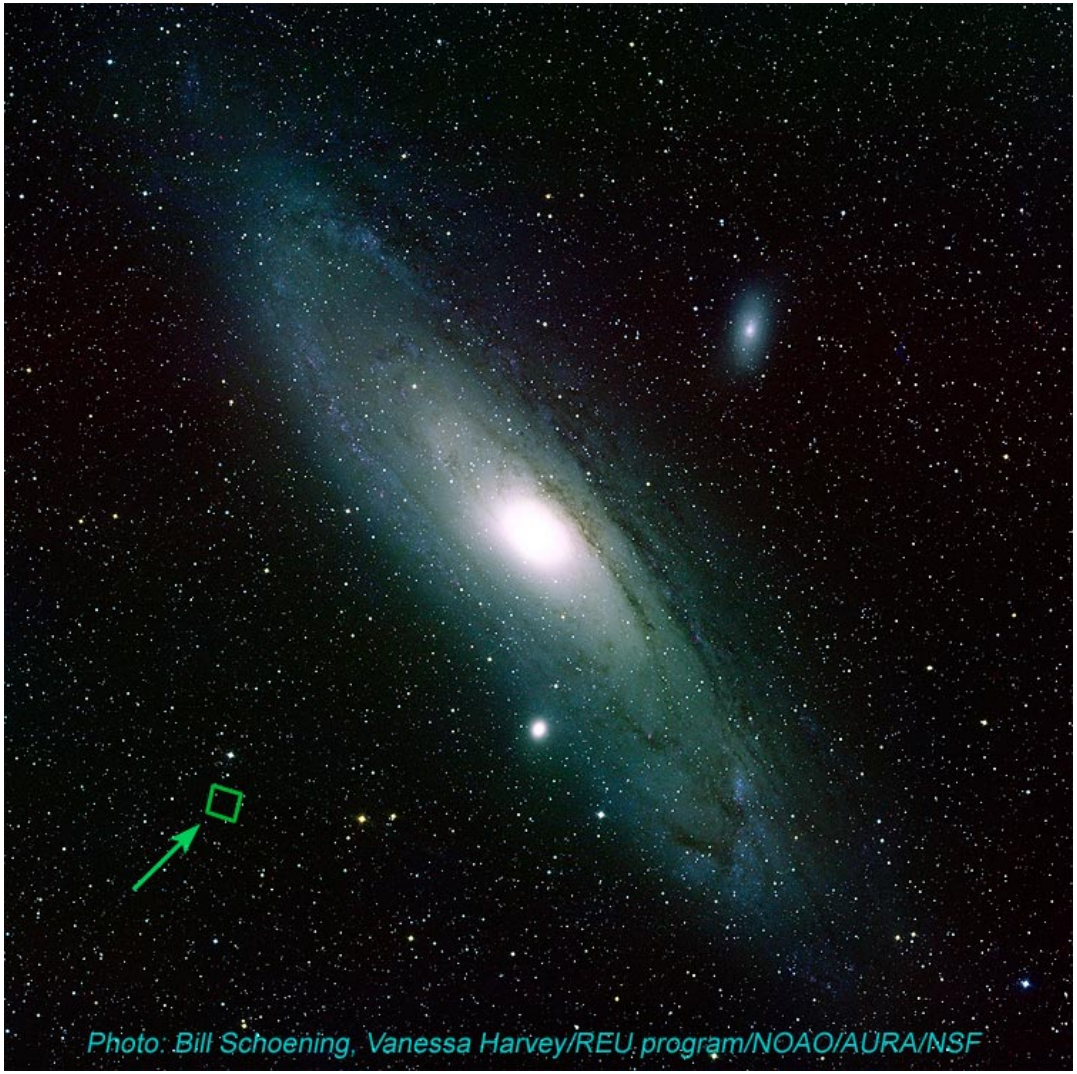


FIG. 3.—Plots of the rotation speed versus galactocentric radius. The solid lines correspond to the polynomials, and the dashed lines are the BG rotation curve. (*upper panel*) (R_0, θ_0) = (10 kpc, 220 km s^{-1}); (*lower panel*) (8.5 kpc, 220 km s^{-1}).

The stellar halo

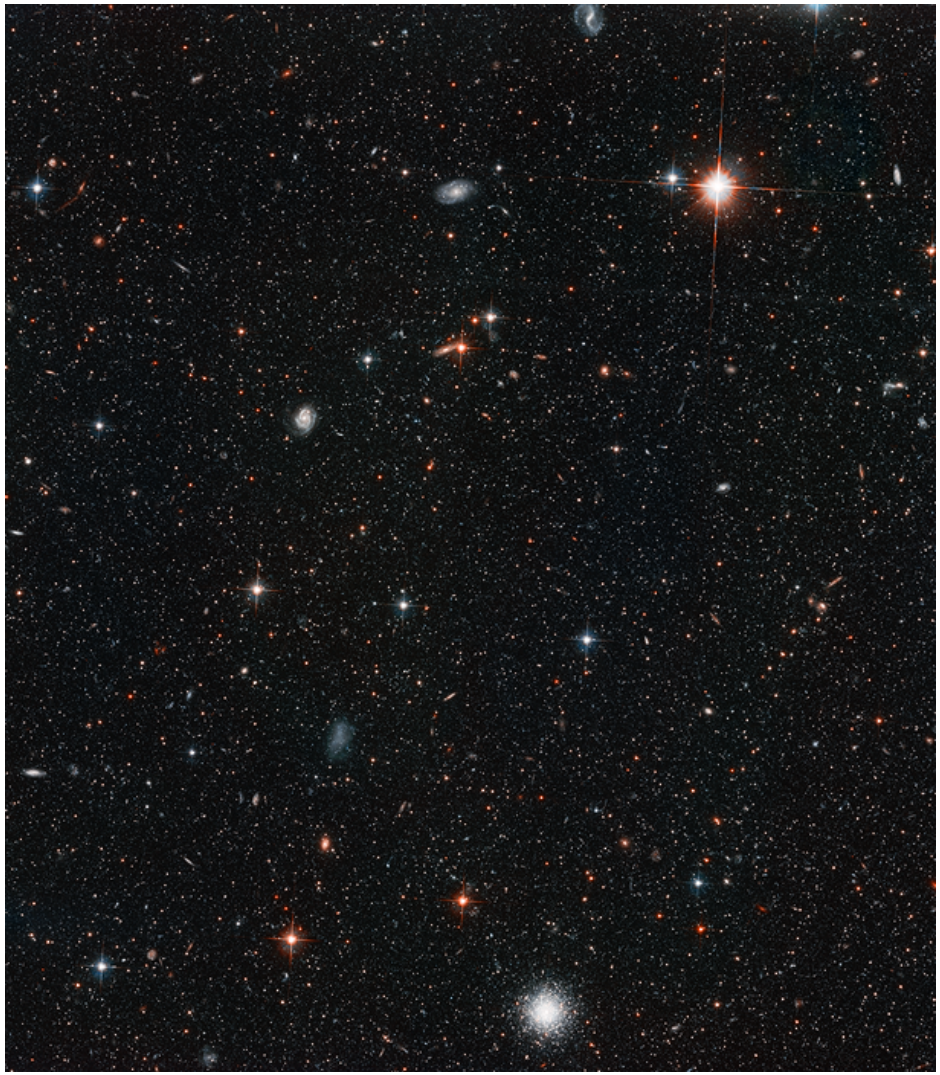
MW and M31 have resolved halos with metal poor stars, and globular clusters. Both of these systems contain significant substructure tidally stripped dwarf galaxies and globular clusters. However, M33 does not have a significant stellar halo.

The stellar halo of M31



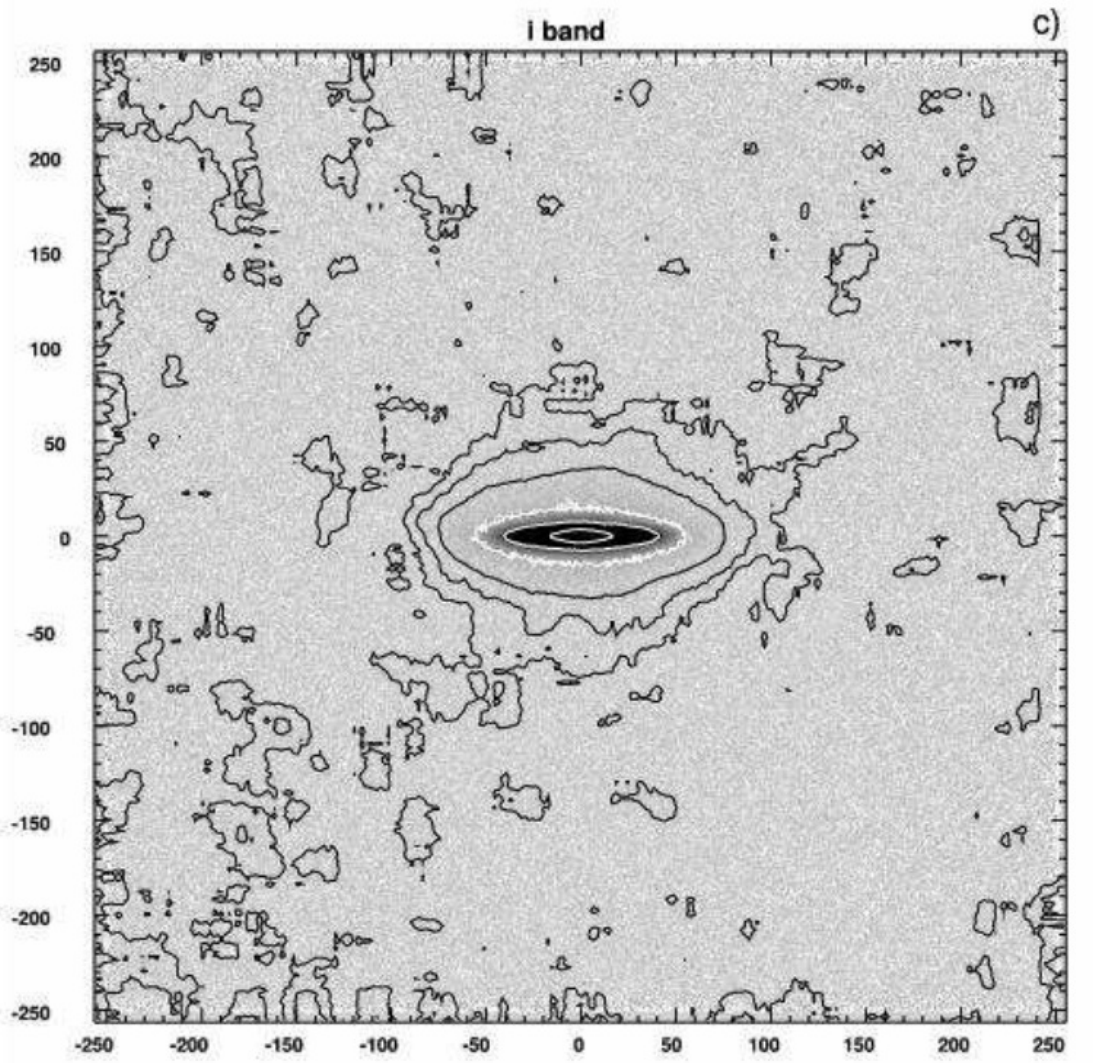
Brown et al. (2003)

The stellar halo of M31



Open questions: How much of stellar halo is in form of tidal streams
How many galaxies have stellar halos?

Stacking of 1000 SDSS edge-on spiral galaxies



Zibetti et al. (2003)

Stellar Velocities in the disk

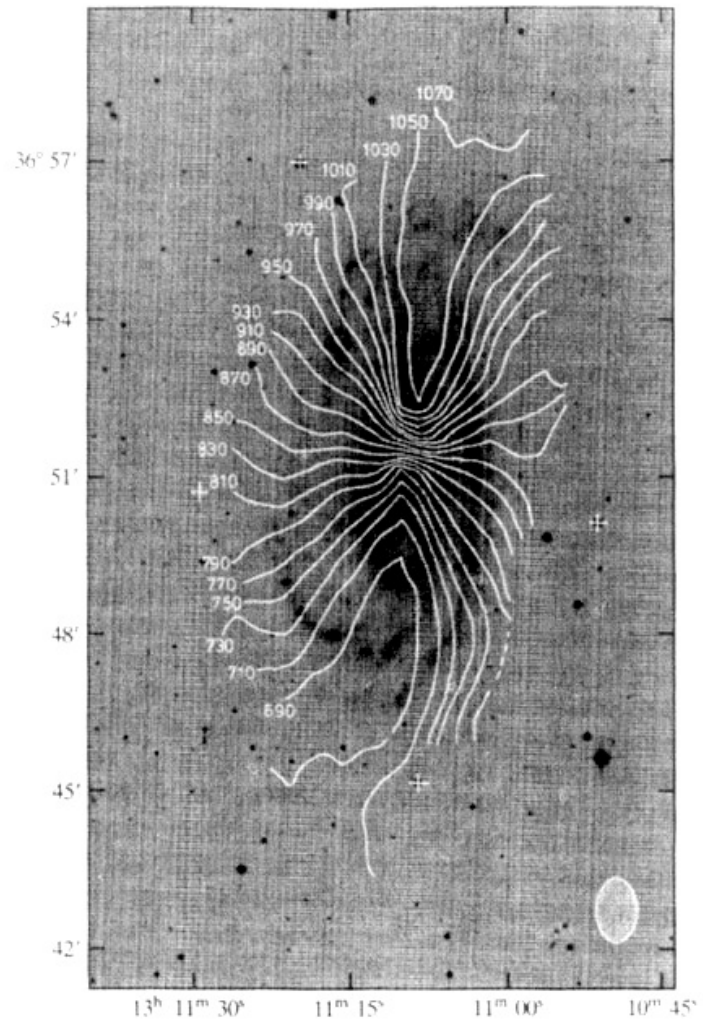
For disk stars, $V_{\rm los} >> \sigma_{\rm los}$ so stars are cold and have approximately circular orbits. Usually, $V_{stars} \sim V_{gas}$.
Sometimes, star orbital rotation velocity can be slower than the gas this is called **asymmetric drift** and indicates a higher stellar dispersion.
In S0s, $\sim$30% have counter-rotating gas disks. How do you think this is possible?

Galaxy rotation

stars | stars + hydrogen | hydrogen velocity

Contours of the last image are **spider diagrams**

Spider diagram



Spider diagram diagnostics

- **Kinematic Major Axis (KMA)**: line through nucleus perpendicular to velocity contours
- **Kinematic Minor Axis (KMI)**: $V_{\rm los}$ contour at $V_{\rm sys}$ through the nucleus
- KMA aligned with photometric major axis (PMA) and KMI aligned with photometric minor axis (PMI) $\rightarrow$ Circular velocity in an inclined circular disk
- equally spaced contours across nuclear KMA

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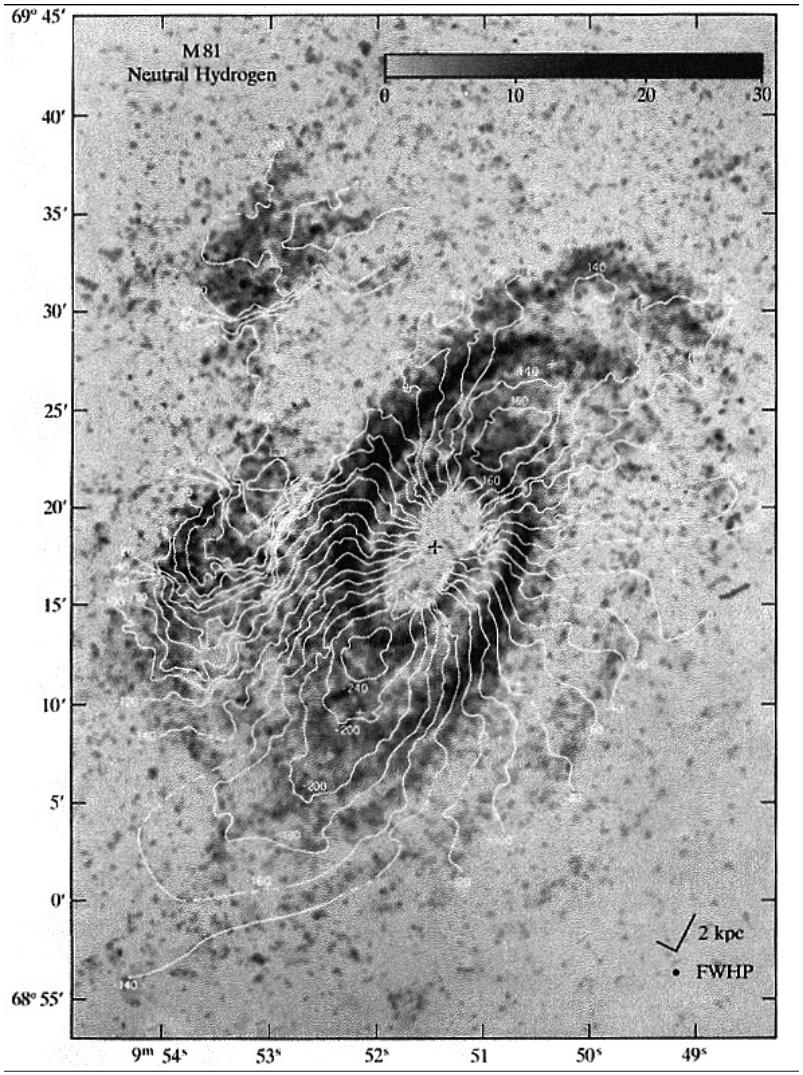
- equally spaced contours across nuclear KMA $\rightarrow$ Solid body rotation.
- Bars often show: evidence of radial motion over bar region. Warped disks have twisted contours in outer parts.

Spiral arm kinematics



Spiral arms yield small perturbations to $V_{\rm los}$ contours near arm positions, although photometrically they are large perturbations.

Kinematics modeling of spider diagrams

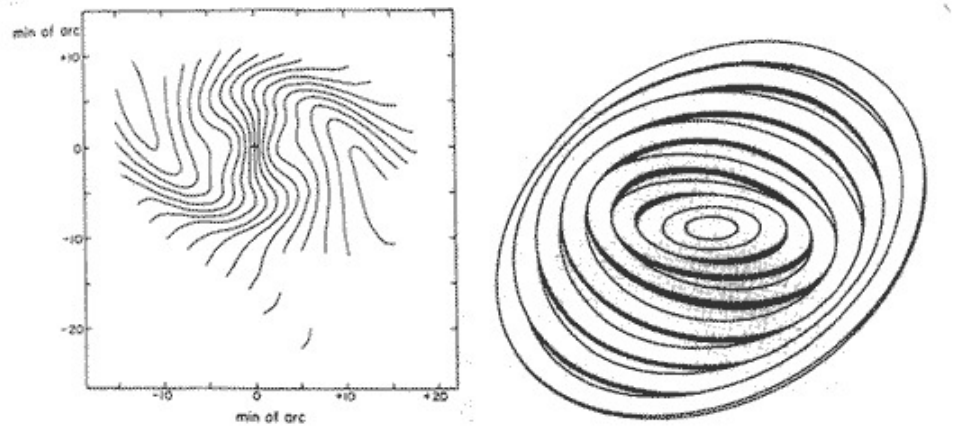


Figure 8.36 A tilted ring model of M83 (right) and the spider diagram predicted by this model (left). [After Rogstad, Lockhart & Wright (1974)]

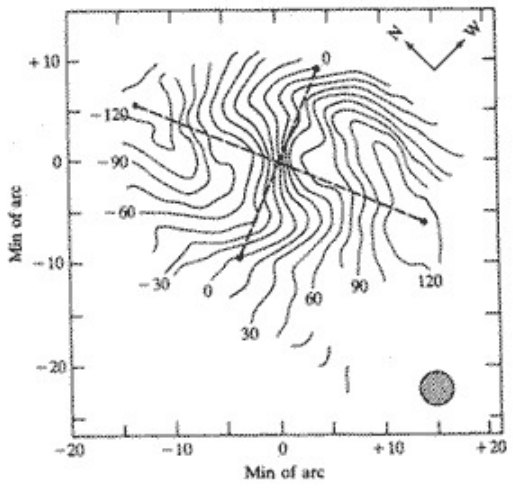


Figure 8.37 The observed spider diagram of M83. [After Rogstad, Lockhart & Wright (1974)]

Scaling relations

There are a number of correlations between the global parameters of galaxies: **Luminosity; Size; Surface Brightness; Rotation Velocity**. Such relations are called **Scaling Relations**.
They are important for several reasons:

- They reveal the internal properties of galaxies
- They must arise naturally in theories of galaxy formation.

In the case of disk galaxies, the most important is between $V_{\rm rot}$ and Luminosity

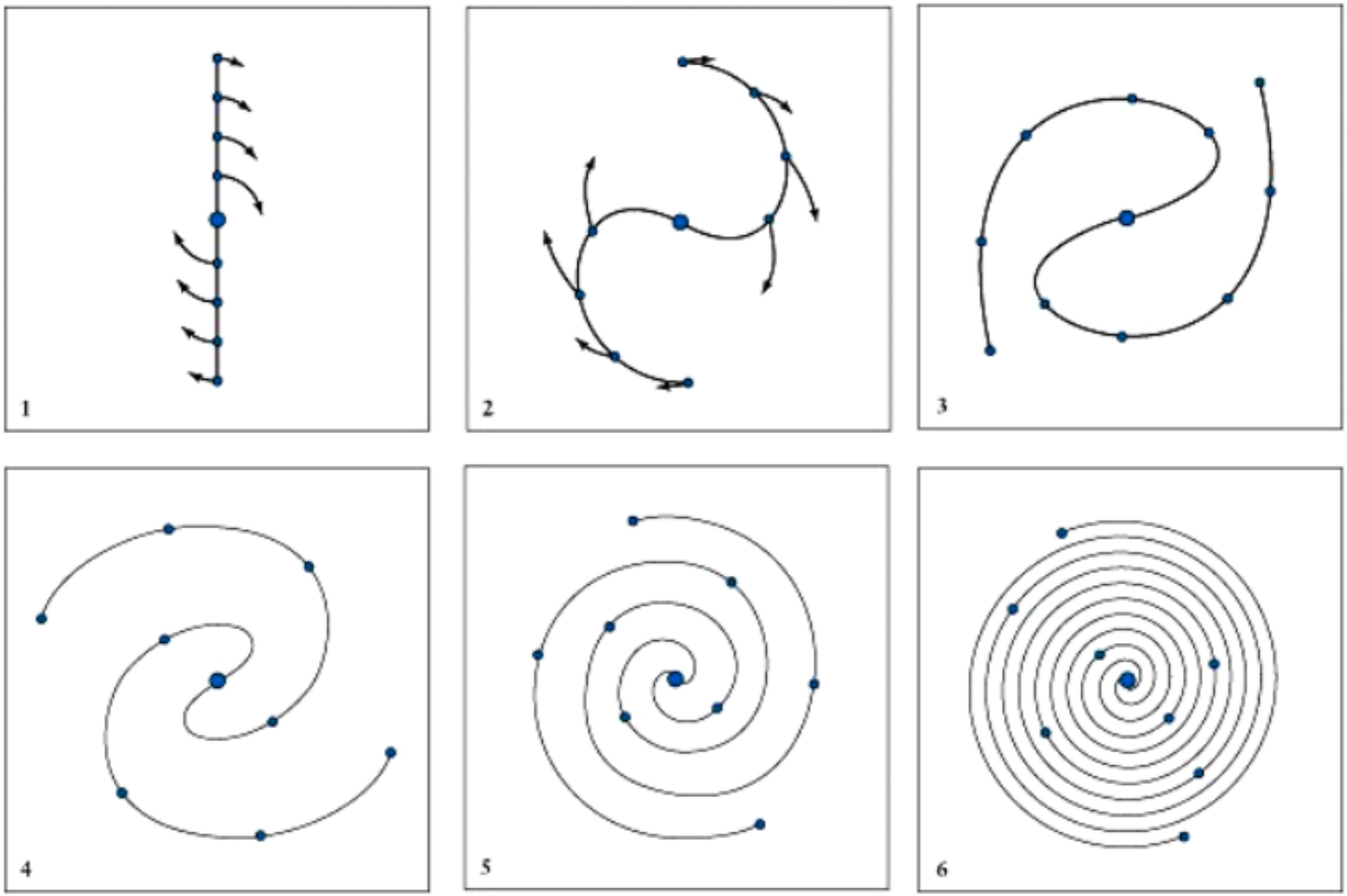
Tully Fisher relation

Tully & Fisher (1977) recognised that $V_{\rm max}$ correlates with galaxy luminosity $L \propto V_{\rm max}^{\alpha}$ where $\alpha \sim 3-4$
Scatter in T-F relation smaller at longer wavelengths.
Tully Fisher relation is an important distance indicator. How to measure distance with TF relation?

The winding problem

Why do flat rotation curves lead to winding of spiral arms?

Winding of spiral arms



Show winding video and Star Orbit Video

Another issue

Spiral arms are defined mainly by blue light from hot massive stars, thus lifetime is $<<$ galactic rotation period.
Should'nt spiral arms just fade away?

A cryptic observation

For galaxies where the galactic rotation has been measured, the spiral arms almost always **trail the rotation of the underlying disc**. Relative to the disk they seem to be rotating in a direction opposite to the disk.