Rotation curves of spiral galaxies and Tully Fisher Relationship

Kinematics of Spiral Galaxies

- Rotational curves can be obtained only for edge on systems for spiral galaxies.

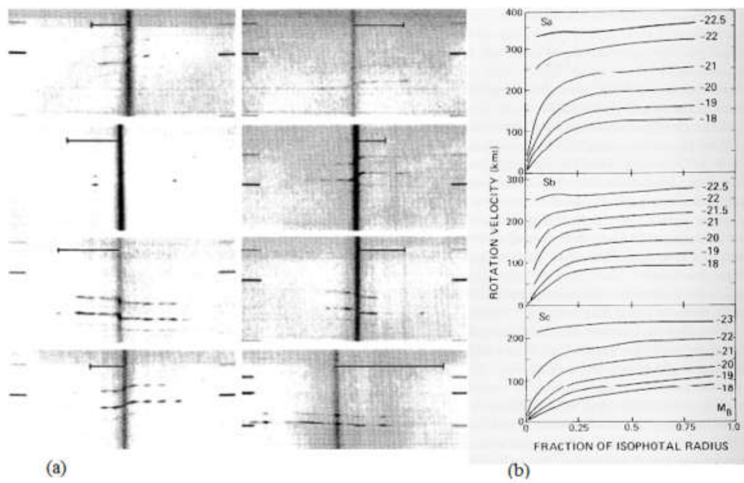

FIG 1a —Hα region major axis spectra for galaxies of different Hubble types, taken with the 4 m RC spectrograph plus Carnegie image tube plus preflashed IIIa-J plate. Plates are (*) H_2 treated, 26 Å mm^{-1}, KPNO; or (†) N_2 baked, 52 Å mm^{-1}, CTIO. For all spectra, scale perpendicular to the dispersion is 24″ mm^{-1}, and transfer optics are f/2. (*a*)*NGC 2590, Sb, exposure 120 minutes. (*b*)*NGC 1620, Sbc, exposure 129 minutes. (*c*)†NGC 3145, Sbc I, exposure 90 minutes. (*d*)*NGC 801, Sbc–Sc, exposure 150 minutes. (*e*)*NGC 7541, Sbc–Sc, exposure 114 minutes. (*f*)*NGC 7664, Sbc–Sc, exposure 119 minutes. (*g*)*NGC 2998, Sc I, exposure 200 minutes. (*h*)†NGC 3672, Sc I–II, exposure 120 minutes. On each spectrum, Hα is strongest emission line; [N II] λ6583 is at longer λ (*up* on print). Vertical stripe is continuum from stars in nucleus. Solid horizontal line on each spectrum indicates 20 kpc in plane of galaxy. Linear extent of spectra varies from a radius of r = 17.4 kpc (NGC 2590) to r = 49 kpc (NGC 801). Note that velocity is often not constant across emission regions (spiral features) but is lower at inner edge and higher at outer edge, especially apparent in NGC 2998. The letters (*a*) and (*b*) refer to the upper left and upper right, respectively.

FIG 1b: Rotational curves of Spiral Galaxies

- Spiral galaxies typically show flat rotation curves.
- The rotation of spiral galaxies gives the most solid proof for the existence of Dark Matter in the Universe.

Tully Fisher Relationship

- Cepheid variable stars are the primary means by which astronomical distances are measured.
- Beyond 20 Mpc, Cepheids become too faint, and hence we are in need of alternative means to measure these distances.
- One of the most popular secondary method is to makes use of the strong correlation between the luminosity of SPIRAL GALAXIES and their rotational velocities. This is known as the TullyFisher relation. This is an empirical relationship given as:

$$L \propto v_{max}^{\alpha} \tag{1}$$

where L is the luminosity of the galaxy, v_{max} is the peak circular velocity and α is a constant which takes the value 4 in most wave bands.

- This is used to measure the distances to spiral galaxies.But we don't know whether it is universally valid.

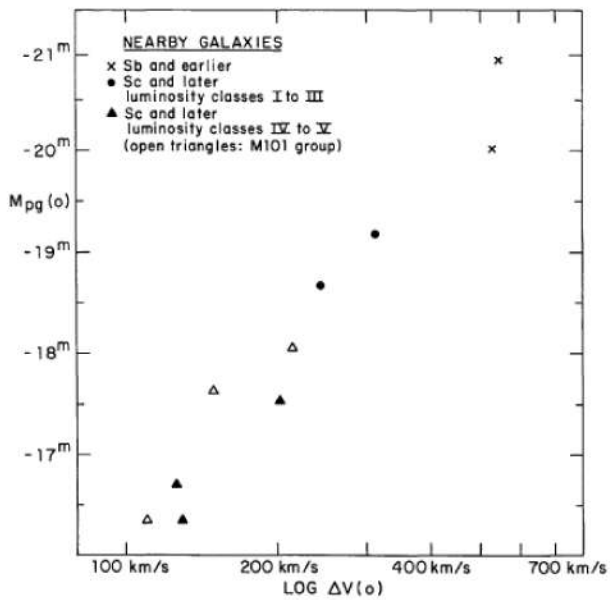

fig 2: Tully Fisher Relationship

Rotational Velocity, Mass distribution correlated with light

- Rotational velocity V at any radius r is given as:

$$V^2(r) = \frac{GM(r)}{r} \Rightarrow M = \frac{rv^2}{G} \tag{2}$$

$$M = \left(\frac{M}{L}\right) L \tag{3}$$

$$\left(\frac{M}{L}\right) L = \frac{rv^2}{G} \tag{4}$$

where M is the dynamical mass and $\frac{M}{L}$ is the mass to light ratio, G is the Gravitational constant.

- Usually, $\left(\frac{M}{L}\right)_{galaxy} >> \left(\frac{M}{L}\right)_{\odot}$ for all galaxies.

- When, $\left(\frac{M}{L}\right)_{galaxy} = \left(\frac{M}{L}\right)_{\odot}$, it implies that the light fully accounts for the mass.
- Surface brightness μ at some distance r,

$$\mu = \frac{L}{\pi r^2} \Rightarrow r^2 = \frac{L}{\pi\mu} \tag{5}$$

from (4) and (5) we can write(discarding π),

$$\sqrt{\frac{L}{\mu}}\left(\frac{v^2}{G}\right) = \left(\frac{M}{L}\right)L \tag{6}$$

$$L = \frac{v^4}{\mu G^2 \left(\frac{M}{L}\right)^2} \tag{7}$$

- If L$\propto$ v^4, then the denominator in (7) has to be a constant (i.e. $\mu\uparrow \rightarrow \left(\frac{M}{L}\right)^2 \downarrow$ and vise versa.)
- So Tully-Fisher works if surface brightness times total (not stellar) mass-to-light-ratio squared is constant. In other words, the stars and the dark matter are somehow linked.

Rotational Curves in Radio Wavelength

- In radio,the beam covers the whole galaxy and hence the rotational curve can't be obtained as in case of optical wavelength. But we can determine V$_{max}$.

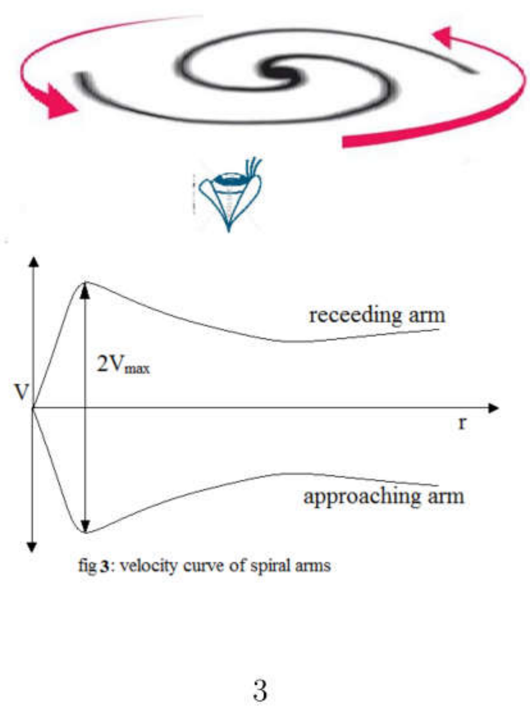

fig 3: velocity curve of spiral arms

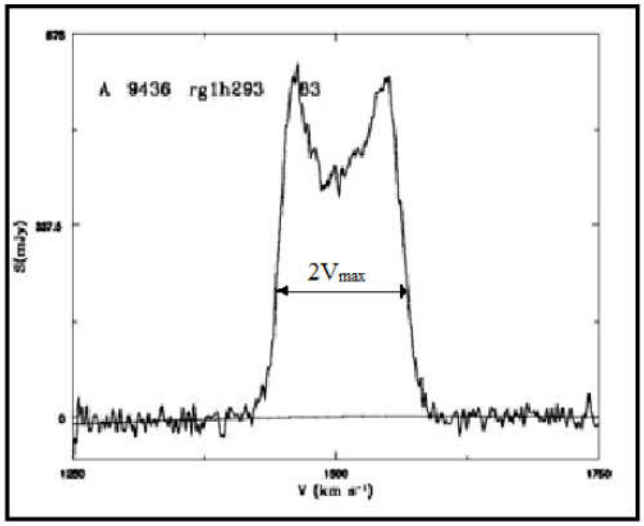

fig 4. 21cm Profile of a spiral galaxy

- Width of the double peak in the 21 cm profile(fig 4) gives us an estimate of V_{max}. In most cases,the width at 30% or 50% of the flux. Its denoted as w_{30} and w_{50} respectively.
- The difference in the peaks may be due to the difference in the HI emissions from the two arms. The dip in center accounts for the less concentration of neutral hydrogen in the galactic center/bulge.

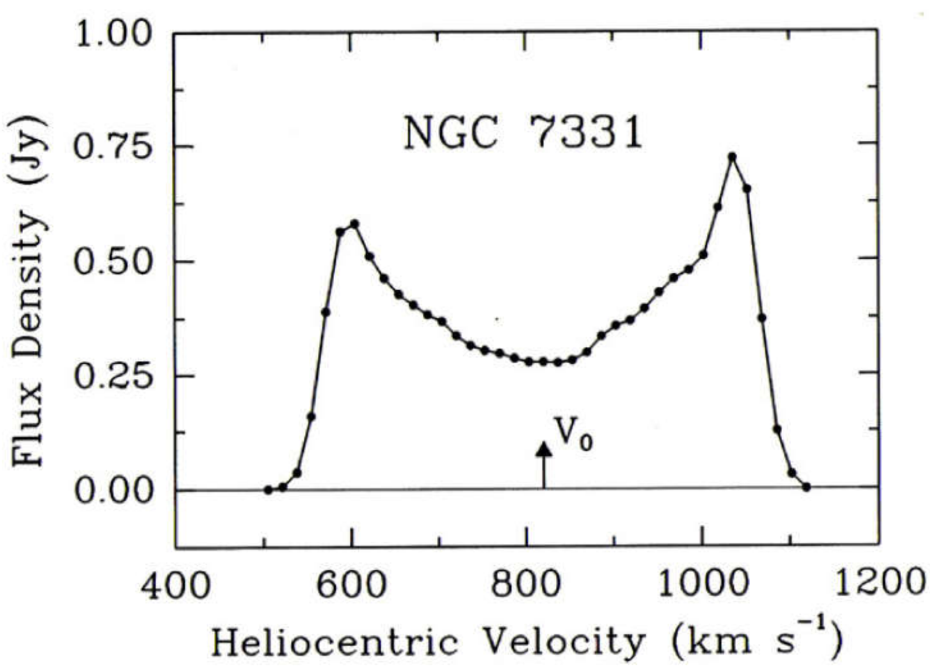

fig 5: 21 cm profile for NGC 7331

- The center is not rotating with respect to the observer, hence it gives estimate to the velocity of the galaxy. From the above plot, we can say that the galaxy is moving away from us at a velocity of 800 km/s.

- The observed velocity is a superposition of :

  a. Rotational velocity of HI gas in the galaxy.

  b. Velocity of the galaxy.

  c. Heliocentric velocity(velocity corrected for rotation of earth around the sun) of sun around the center of milky way.

Baryonic Tully fisher Relationship

- Disk galaxies obey a relation between disk mass and rotation velocity (V_{flat}). The plot below shows blue luminosity versus circular speed for a sample of spiral galaxies. We see the linear relationship, with a decent bit of scatter.

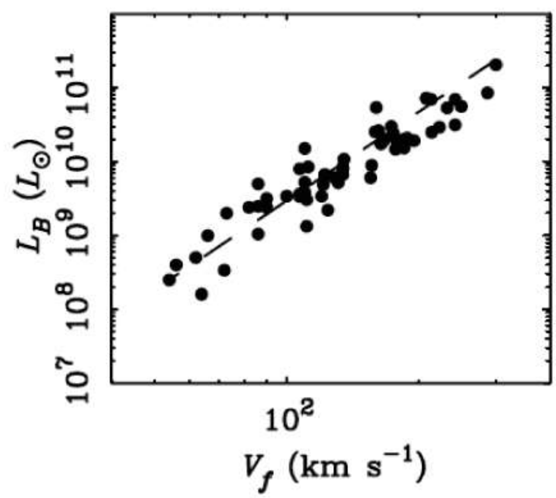

fig 6: Blue luminosity versus circular speed for a sample of spiral galaxies

- If we plot M_* v/s V_{flat}, its observed that the scatter is much less for massive galaxies, but the low mass galaxies don't fit.

- This is due to the fact that the gas mass is not taken into account. Low mass spirals are preferentially more gas-rich, so it ought to affect the plot .

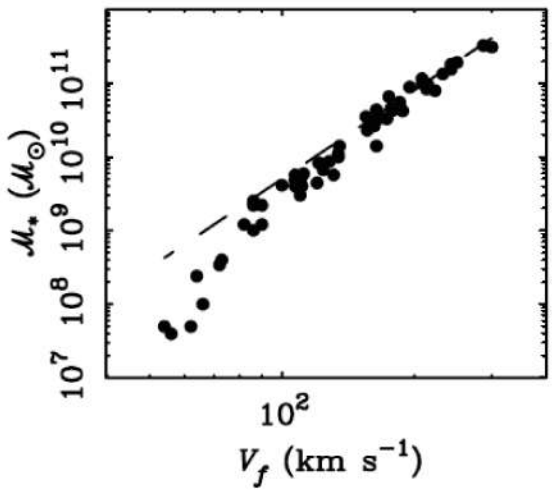

fig 7: Stellar disk mass (M*) versus circular speed (Vf)

- Ploting the total baryonic mass of the galaxy(M_* + M_{ISM}) gives an extremely tight relationship over orders of magnitude in mass.
- This is a huge constraint on models of dark matter and galaxy formation.

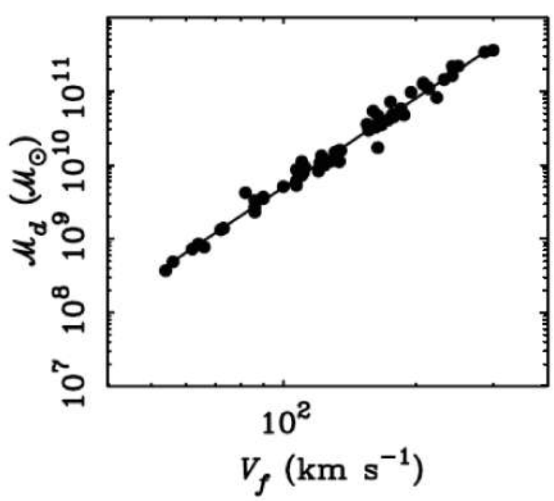

fig 8: Baryonic disk mass (Md) versus circular speed (Vf)