Back to H I and single telescopes….

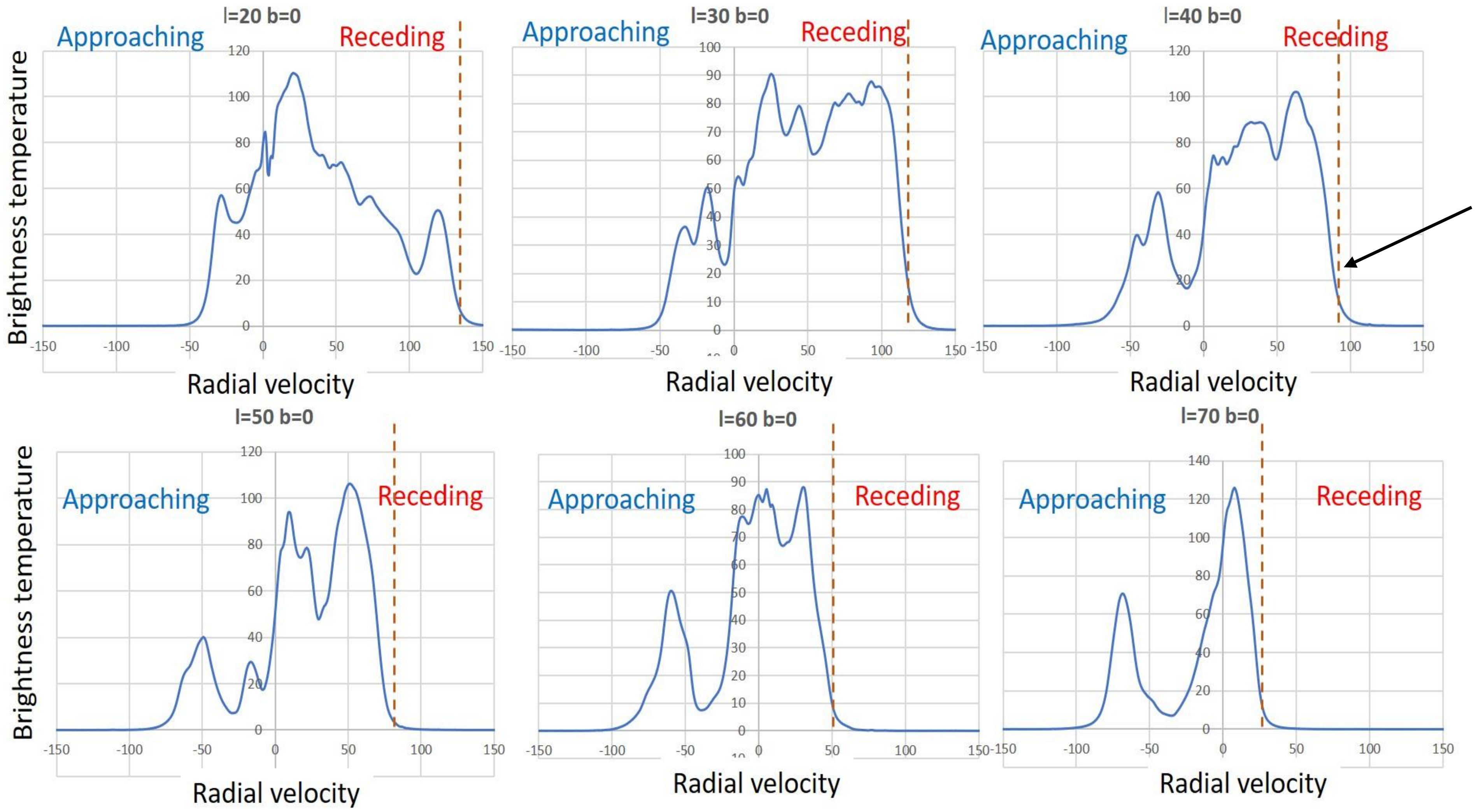
- The TTRT has too low an angular resolution to separate the radial velocity components clearly and hence pick out spiral arms – this requires a beam width of <5^{o} hence a ~3m or larger dish (as just shown in the video).

- The TTRT can, however, show the overall rotation of the Milky Way and explore the distribution of hydrogen as a function of galactic latitude – we will see this in e-seminar #2……

- To complement the TTRT spectra the instruction script contains a set of high resolution spectra taken with large (>30 metre diameter) radio telescopes around the world. With these *you can determine the rotation curve of the inner galaxy using the tangent point method*

- Let’s take a look at these spectra - noting that the radial velocity scale is in km/s

PROFILES IN QUADRANT 1

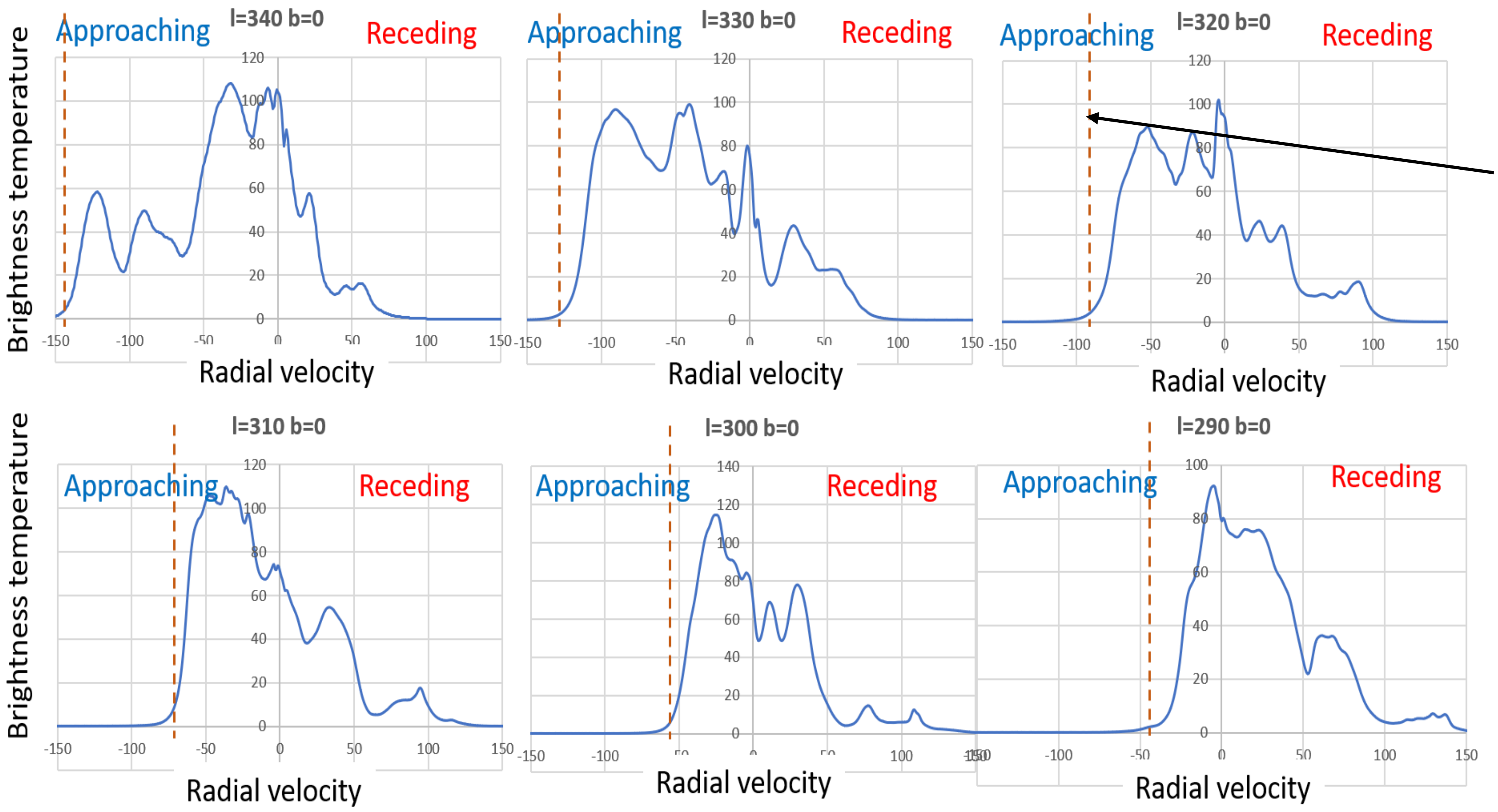


Maximum radial velocity $V_{rad,max}$ at longitude l=40°

In Quadrant 1 this corresponds to receding gas.

These H I "profiles" were downloaded from the web site hosted by the Argelander-Institut fur Astronomie (University of Bonn) https://www.astro.uni-bonn.de/hisurvey/AllSky_profiles/. See the References section in the script for full acknowledgements.

PROFILES IN QUADRANT 4



In Quadrant 4 the maximum radial velocities are seen in approaching gas.

These H I "profiles" were downloaded from the web site hosted by the Argelander-Institut fur Astronomie (University of Bonn) https://www.astro.uni-bonn.de/hisurvey/AllSky_profiles/. See the References section in the script for full acknowledgements.

Exercise 1: Determining the rotation curve for the inner galaxy

- On each of the H I profiles the dotted lines mark an estimate of the maximum radial velocity $V_{rad,max}$ seen at different longitudes l (allowing for smearing due to the random motions of the atoms.)

- Earlier on we showed that at a tangent point:

$$R = R_0 \sin l \quad \text{and} \quad V = V_{rad,max} + V_0 \sin l$$

- Hence, given the Sun's orbital parameters (R_0 = 8.15 kpc; V_0 = 236 km/s) and the measurements of $V_{rad,max}$ as a function of l (previous two slides) you can determine the Inner Galaxy rotation curve V vs R.

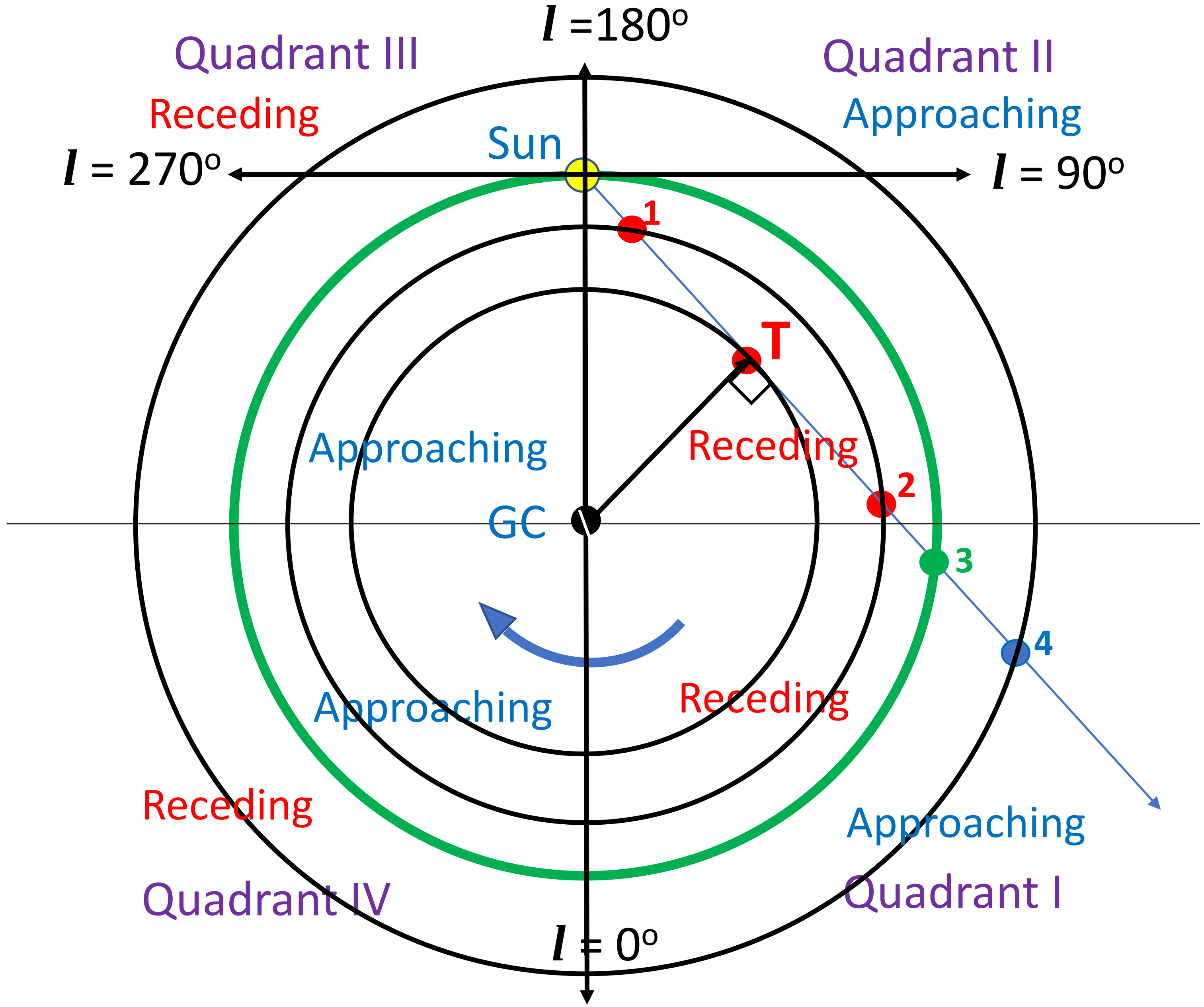
Exercise 1: Determining the rotation curve for the inner galaxy

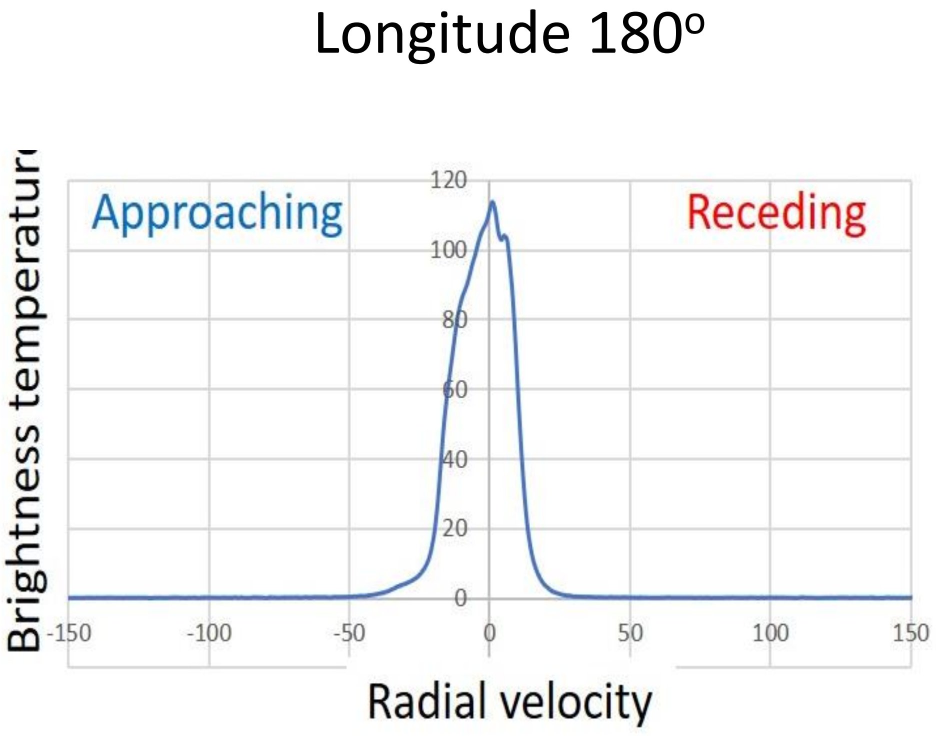
l	sin *l*	$R=R_o \sin l$ (kpc)	$V_{rad,max}$ (km/sec)	$V_o \sin l$ (km/sec)	*V* (km/sec)
20	0.342	2.79	+135	80.7	+215.7
30					
40					
50					
60					
70					
------	------	------------	----------------	-----------------	------------------
340	-0.342	-2.79	-145	-80.7	-225.7
330					
320					
310					
300					
290					

Now: plot the rotation curve keeping the signs

Note: the signs represent recession and approach in the two quadrants – reminder diagram in next slide

Exercise 1b: explain this spectrum…





This H I "profile" was downloaded from the web site hosted by the Argelander-Institut fur Astronomie (University of Bonn) https://www.astro.uni-bonn.de/hisurvey/AllSky_profiles/.

See the References section in the script for full acknowledgements.

Exercise 2: The mass of the inner Galaxy

Using Newtonian gravitation we can use the rotation curve you have determined to calculate the mass M_R which lies *within* the greatest distance R in your table i.e. for the "inner Galaxy"

$$F = \frac{GM_R m}{R^2} = ma = \frac{mV^2}{R}$$

thus

$$M_R = \frac{RV^2}{G}$$

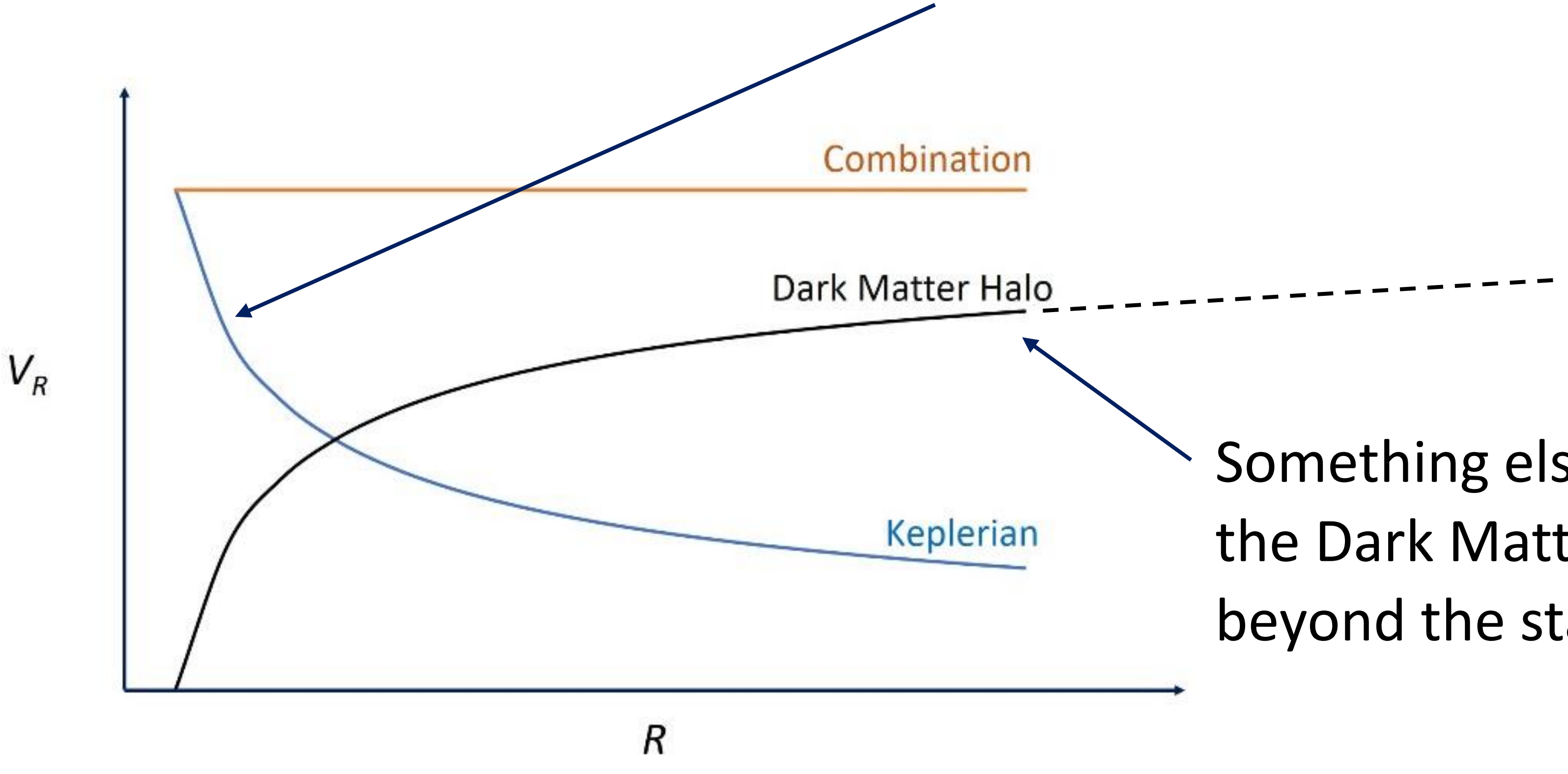
(Calculate M_R - *giving the answer in solar masses*)

Exercise 3: The Dark Matter Halo and its density distribution -1

In exercise 1 you should have found that the rotation curve is flat or even slightly rising with *R*.

V = constant → M_R α R

BUT the distribution of stars is strongly concentrated towards the centre of the Milky Way which should give a Keplerian-like rotation curve



Something else must be compensating….. the Dark Matter "halo" which extends much beyond the stars.

Exercise 3: The Dark Matter Halo and its density distribution -2

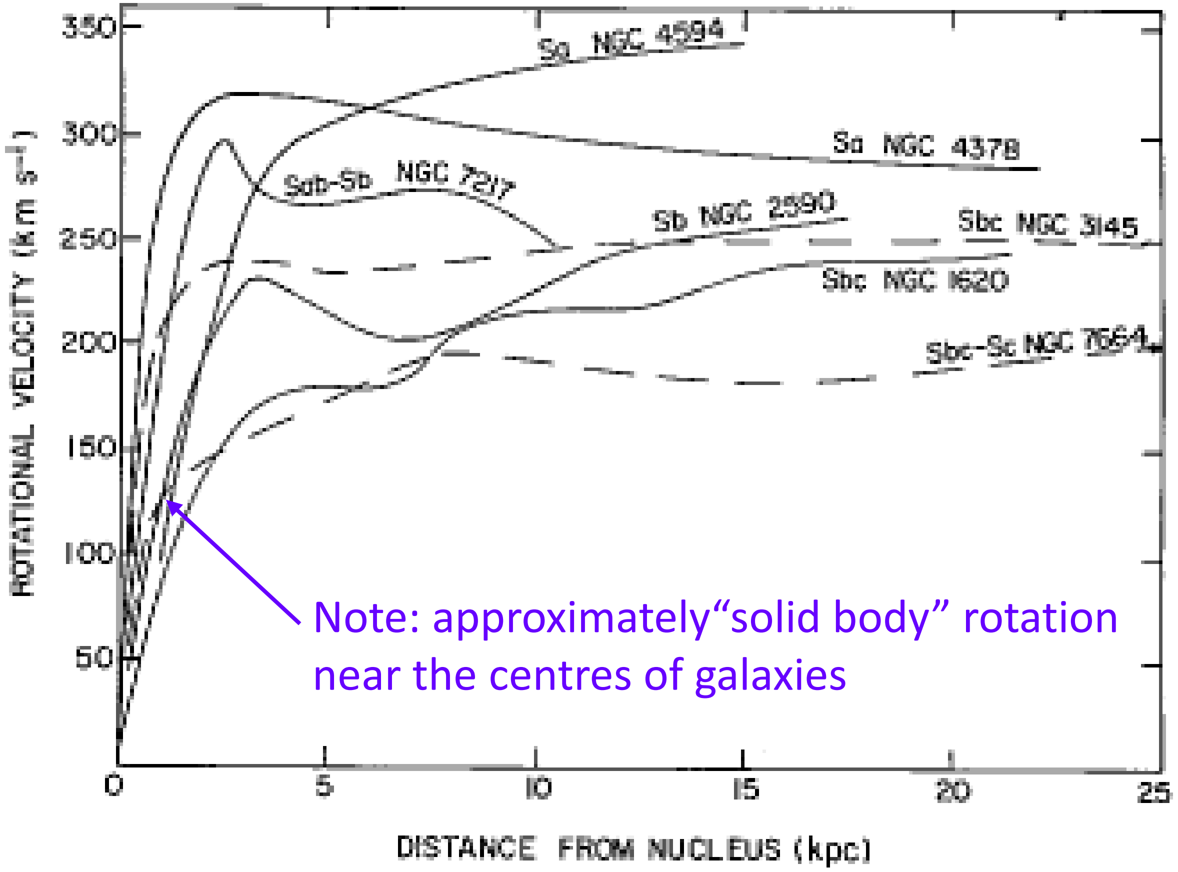


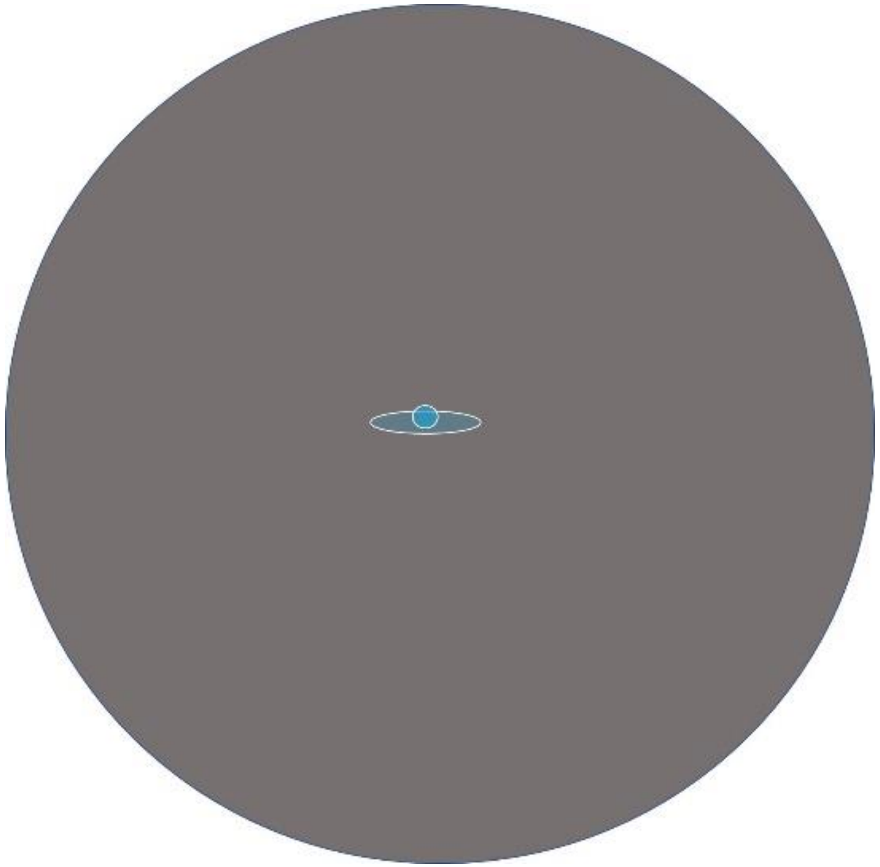
Figure from Rubin, Ford, and Thonnard (1978), Ap. J. Lett., 225, L107.

It was the observation of flat rotation curves, most easily seen in nearby external galaxies (using *optical* spectra), which led to the hypothesis that spiral galaxies are surrounded by a quasi-spherical “halo” of *Dark Matter* which beyond the distribution of stars.

The current estimate of the Milky Way’s total mass is at least ~10^{12} solar masses which is many times more than the value of M_R you will derived for the inner Galaxy.

The Dark Matter halo extends far beyond the Sun’s orbit around the Galactic centre.

Exercise 3: The Dark Matter Halo and its density distribution - 3



Schematic of the Milky Way galaxy surrounded by a much larger Dark Matter Halo which dominates the matter content.

The Milky Way's rotation curve has now been traced out to R~25 kpc but the outer extent of the halo remains uncertain.

Question: in a spherically symmetric DM halo how must the *average mass density* ρ_R vary as a function of R to account for the fact that the rotation curve is flat well beyond the stars?