1 a) If forbidden transitions are seen, the gas must have extremely low density, so that collisional de-excitation of the upper level of the transition will not happen before the photon-emission de-excitation can occur.

b) $\lambda_{rest} = 500.7\,nm$

$\lambda_{obs} = 600.9 \pm 0.2\,nm$

For the small recession velocity form of the redshift equation

$$v/c = \frac{\Delta\lambda}{\lambda} = 0.200 \quad \frac{100.2 \pm 0.2\,nm}{500.7\,nm}$$

$$v = 4.004 \times 10^{4}\ km/s \quad \pm 1.2 \times 10^{2}\ km/s$$

$$= 60{,}040 \pm 120\ km/s$$

OR $\quad z = 0.2001 \pm 0.0004$

Assume a Hubble constant of $H_0 = 70\ km/s/Mpc$

$$\Rightarrow \quad d = 857.7 \pm 1.7\ Mpc$$

Both the distance implied & the velocity in question mean that peculiar velocities will have negligible impact. The redshift ($z = 0.2$) is small enough that evolution in H_0 is also not significant

Then given the distance we simply apply the distance modulus to get absolute magnitude

$$m - M = 5\log\left(\frac{d}{pc}\right) - 5$$

$$23.5 - M = 5\log\left[(857.7 \pm 1.7) \times 10^{6}\right] - 5$$

$$= 39.667$$

$$M = -16.167$$

· To get uncertainty in DM, tweak distance by the uncertainty

$$DM' = 5\log\left[\frac{(857.7+1.7)\,\text{mpc}}{\text{pc}}\right] - 5$$

$$= 39.671$$

$$\Rightarrow \Delta DM = 0.004$$

$$M = -16.167 \pm 0.004$$

[FYI: not part of marking
NB: In practice as the apparent magnitude is only good to ±0.1 mag, and H_0 is only good to ~ ±2 km/s/mpc, this uncertainty estimate is only formally true and is actually wildly optimistic

If we use $H_0 = 70 \pm 2$ km/s/mpc & $m = 23.5 \pm 0.1$

we get $d = 858 \pm 24$ mpc

$DM = 39.7 \pm 0.4$

$\Rightarrow M = -16.2 \pm 0.4$]

$m = 30.0 \pm 0.1$

2) We have a Cepheid with $P = 0.5 \pm 0.02$d

& $M = 3.0(\log \frac{P}{1d} - 1.0) - 5.0$

Period-Luminosity relation gives

$$M = 3.0\left[\log(0.5 \pm 0.02) - 1.0\right] - 5.0$$

$$= -8.90$$

Estimate unc by tweaking P

$$\Delta M = -8.90 - \left[-8.85\right]$$

$$= 0.05$$

So $M_{ceph} = -8.90 \pm 0.05$

Given we know $m_{ceph} = 30.0 \pm 0.1$

$$m - M = DM = 38.9 \pm 0.11$$

Est uncertainty here [which is just subtraction of two magnitudes] by adding in quadrature.

Which gives a distance $DM = 5\log\left(\frac{d}{pc}\right) - 5$

$$= 6.03 \times 10^8 \text{ pc}$$

$$= 603 \text{ Mpc} \pm 31 \text{ Mpc}$$

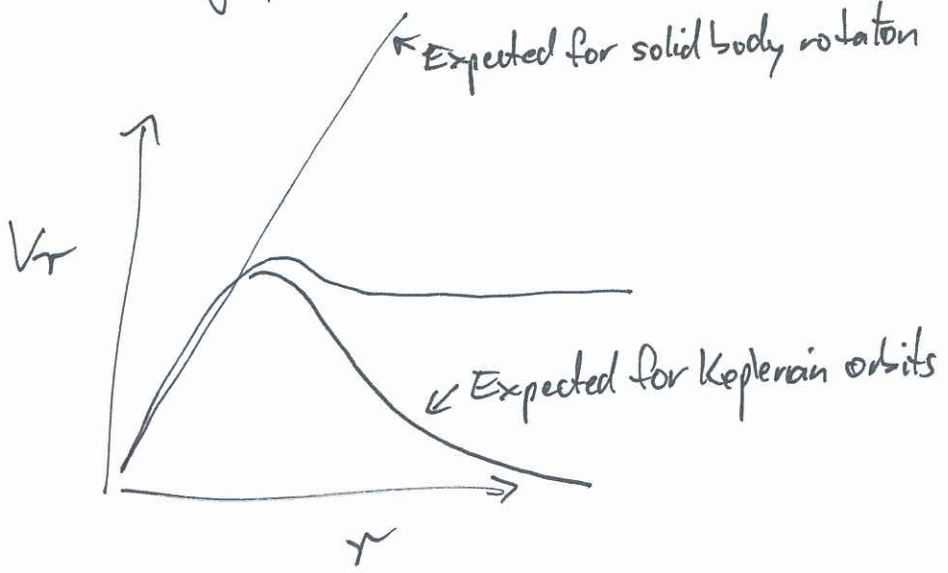
(est. uncertainty by tweaking DM+ unc)

Recall distance to Seyfert was 857.7 ± 1.7 Mpc

So these two are <u>not</u> consistent & the Cepheid is <u>not</u> in the Galaxy

3 b)

The "flat" rotation curve means that a plot of the rotation velocity (V_r) of a galaxy's disk, as a function of galactocentric radius, (r) flatten to a roughly constant value.



This is neither what is expected for solid body rotation (linearly increasing V_r as a function of r ($V_r \propto r$) nor for Keplerian orbits around an enclosed mass

$$V_r \propto \frac{1}{\sqrt{r}}$$

c) This flattening of the rotation curve happens at ~~dista~~ galactocentric radii that enclose essentially all of the luminous matter in other galaxies

To produce this flattened rotation curve there must be a mass distribution that drops as $1/r^2$, and it must be "dark" since we don't see evidence for such an extended luminous population of stars.

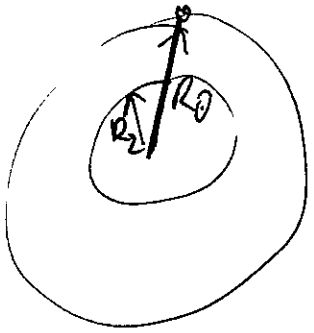
For more detail see pages 14 & 15 of Lecture 5.

3 a)

Galaxies have differential rotation, and (for the MW) we know the rotation period at the solar circle is ~200 kyr.

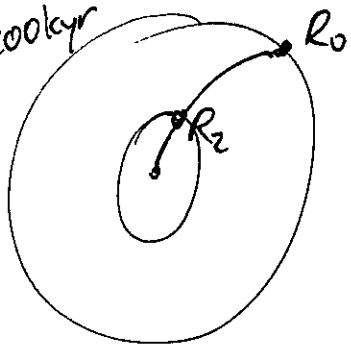
If we imagine a pattern fixed at time 0 (say a "straight line" in the galaxy, then differential rotation will mean that at smaller radii the pattern will rotate faster & advance.

t_0



Over multiple solar galactic rotations the straight pattern originally imagined will "wind up"

t_0 +200kyr



As the lifetime of the MW Galaxy is ~ 14Gyr, this is time for ~70,000 rotations, so any fixed pattern would be completely smeared out.

⋮

t_{0} + 200kyr x n