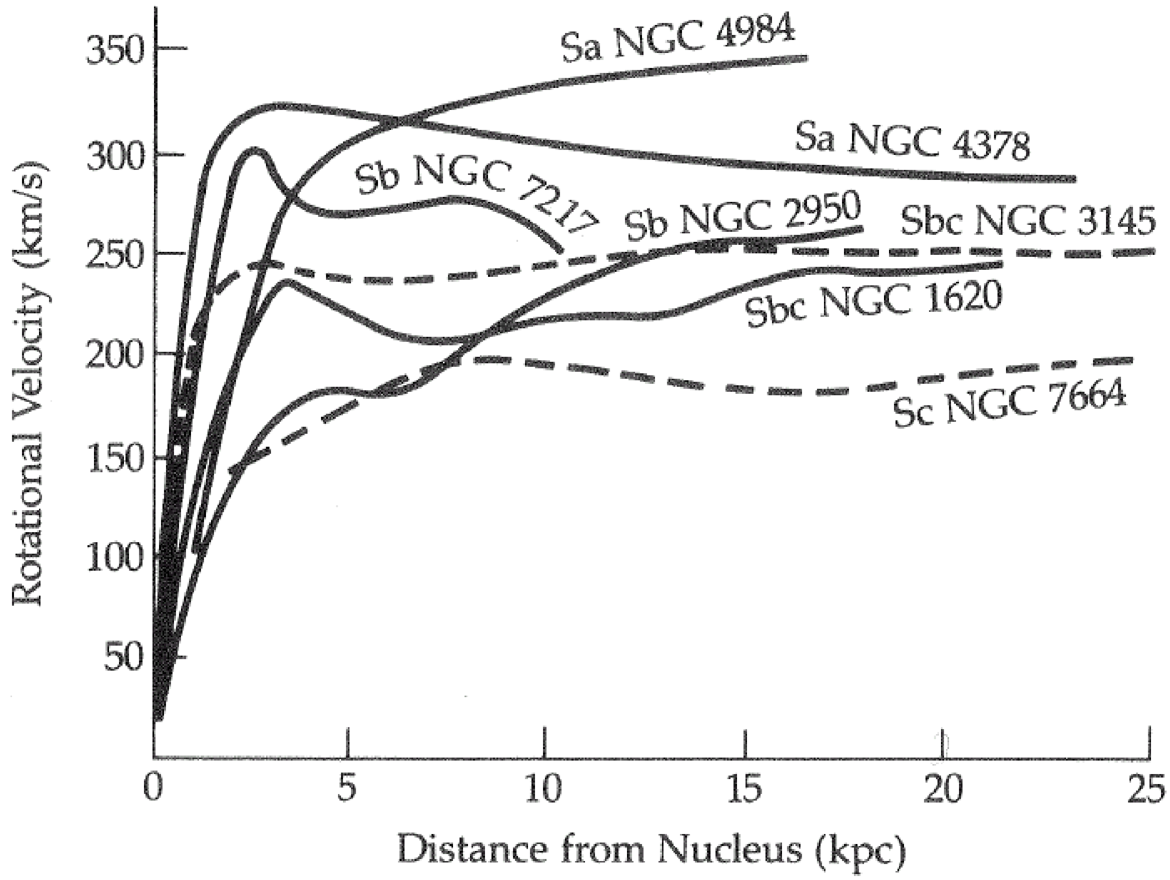
Workshop 9

1. The diagram below shows rotation curves for several spiral galaxies (see Fig 21-9 in Zeilik and Gregory).




If we assume that the material is in circular rotation around the galaxy then equating the outward centripetal acceleration to the inward gravitational acceleration gives

$$\frac{v^2}{r} = \frac{GM(r)}{r^2} \quad \text{or} \quad v = \sqrt{\frac{GM(r)}{r}}$$

$$\text{and} \qquad M(r) = \frac{rv^2}{G}$$

where M(r) is the mass interior to radius r and G is the gravitational constant ($G=6.7\times10^{-11}$ $Nm^2kg^{-2}$). Note this is Keplerian rotation. Choose a galaxy from those listed in the table below and evaluate M(r) at the outermost radius measured. State the masses in solar masses (1 solar mass = $2\times10^{30}$ kg and 1 pc = $3.1\times10^{16}$ m).

2. The table below gives the total apparent magnitudes for each galaxy. Calculate the absolute visual magnitude ($M_V$), ignoring extinction and then estimate the total visual luminosity of the galaxy in solar luminosities taking the absolute visual magnitude of the Sun to be +4.8. Then calculate the mass-to-light ratio (M/L) in solar units for the outermost radius of the galaxy.

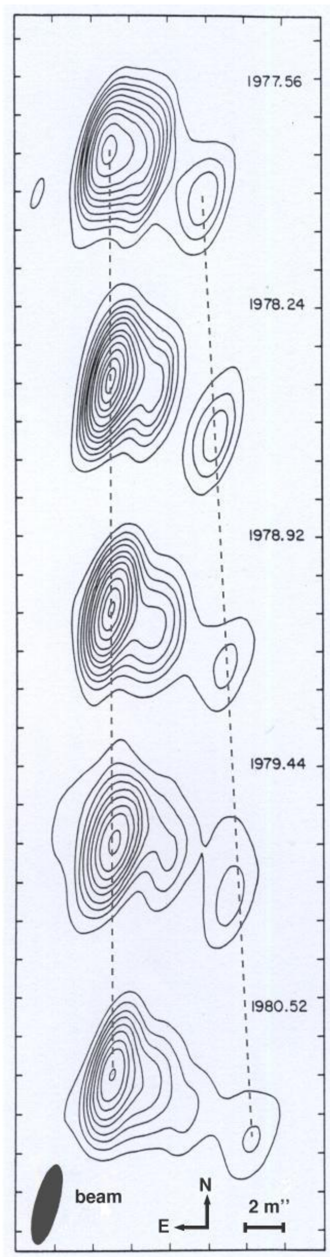
| Galaxy | Distance (Mpc) | B or $m_B$ | V or $m_V$ |
|---|---|---|---|
| | | | |
| NGC 4378 | 40.2 | 12.2 | 11.3 |
| NGC 3145 | 52.7 | 12.5 | 11.7 |
| NGC 1620 | 42.9 | 13.1 | 12.3 |
| NGC 7664 | 43.5 | 13.4 | 12.7 |
| NGC 2950 | 18.7 | 11.8 | 10.9 |

3. Given the colour of the galaxy choose appropriate types of star from the table below (from Zeilik & Gregory) and evaluate their M/L ratio. Note the type V corresponds to main sequence stars and type III to red giants. You can calculate the luminosity from $L = 4\pi R^2 \sigma T_{eff}^4$ where $\sigma = 5.7\times10^{-8}$ $Wm^{-2}K^{-4}$ the Stefan-Boltzmann constant, solar radius is $7\times10^8$ m, and solar luminosity is $4\times10^{26}$ W. Compare this with the value you found for the galaxy and comment. Can any type of star explain the M/L ratios for the galaxies?

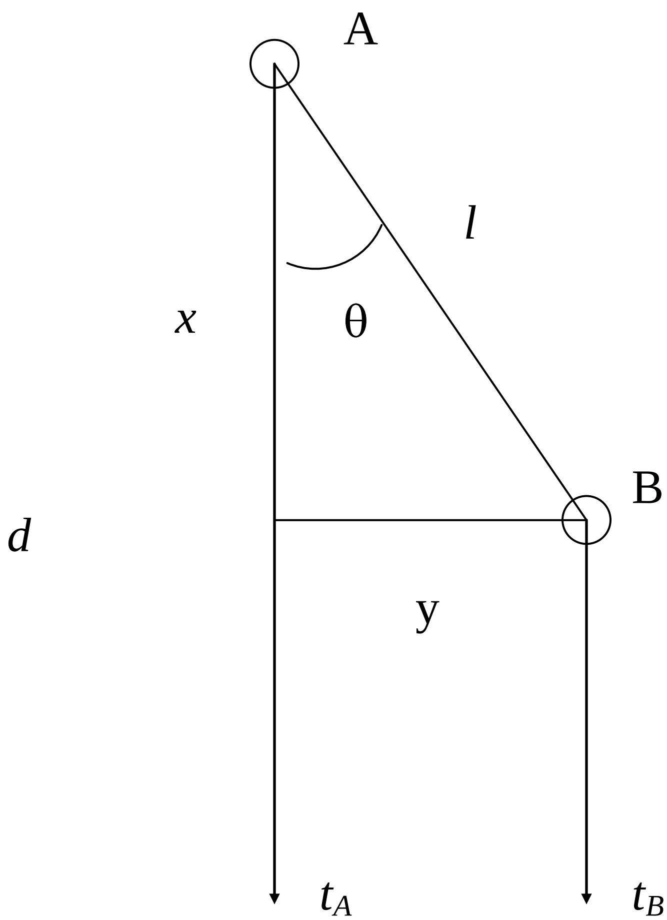
**TABLE A4–3** Stellar Characteristics by Spectral Type and Luminosity Class

| Spectral Type | $M_V$ | | | $B - V$ | | | $T_{eff}$ (K) | | | BC | $R/R_\odot$ | | | $M/M_\odot$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | III | Ib* | V | III | I | V | III | I | V | V | III | I | V | III | I |
| O5 | −6.0 | | | −0.32 | −0.32 | −0.32 | 50,000 | | | −4.30 | 18 | | | 40 | | 100 |
| B0 | −4.1 | −5.0 | −6.2 | −0.30 | −0.30 | −0.24 | 27,000 | | | −3.17 | 7.6 | 16 | 20 | 17 | | 50 |
| B5 | −1.1 | −2.2 | −5.7 | −0.16 | −0.16 | −0.09 | 16,000 | | | −1.39 | 4.0 | 10 | 32 | 7 | | 25 |
| A0 | +0.6 | −0.6 | −4.9 | 0.00 | 0.00 | +0.01 | 10,400 | | | −0.40 | 2.6 | 6.3 | 40 | 3.6 | | 16 |
| A5 | +2.1 | +0.3 | −4.5 | +0.15 | +0.15 | +0.07 | 8200 | | | −0.15 | 1.8 | | 50 | 2.2 | | 13 |
| F0 | +2.6 | +0.6 | −4.5 | +0.30 | +0.30 | +0.24 | 7200 | | | −0.08 | 1.3 | | 63 | 1.8 | | 13 |
| F5 | +3.4 | +0.7 | −4.5 | +0.45 | +0.45 | +0.45 | 6700 | 6500 | 6200 | −0.04 | 1.2 | 4.0 | 80 | 1.4 | | 10 |
| G0 | +4.4 | +0.6 | −4.5 | +0.60 | +0.65 | +0.76 | 6000 | 5500 | 5050 | −0.06 | 1.04 | 6.3 | 100 | 1.1 | 2.5 | 10 |
| G5 | +5.2 | +0.3 | −4.5 | +0.65 | +0.86 | +1.06 | 5500 | 4800 | 4500 | −0.10 | 0.93 | 10 | 126 | 0.9 | 3 | 13 |
| K0 | +5.9 | +0.2 | −4.5 | +0.81 | +1.01 | +1.42 | 5100 | 4400 | 4100 | −0.19 | 0.85 | 16 | 200 | 0.8 | 4 | 13 |
| K5 | +8.0 | −0.3 | −4.5 | +1.18 | +1.52 | +1.71 | 4300 | 3700 | 3500 | −0.71 | 0.74 | 25 | 400 | 0.7 | 5 | 16 |
| M0 | +9.2 | −0.4 | −4.5 | +1.39 | +1.65 | +1.94 | 3700 | 3500 | 3300 | −1.20 | 0.63 | | 500 | 0.5 | 6 | 16 |
| M5 | +12.3 | −0.5 | −4.5 | +1.69 | +1.85 | +2.15 | 3000 | 2700 | | −2.10 | 0.32 | | | 0.2 | | |

4. Use the diagram below to measure the apparent velocity of the blob in the jet (on the right) emanating from the core of the quasar 3C273 (on the left). A scale bar indicates 2 milli-arcsecond. The distance to 3C273 is 640 Mpc.



5.




In the above diagram A represents a blob of material that is observed to be emitted from the core of an AGN jet a distance $d$ away. This is observed from Earth to occur at time $t_A$. At a time interval $t_{int}$ later, as measured in the AGN frame of reference, the blob has moved to point B which is observed from Earth to occur at time $t_B$. The blob is moving at a speed $v=\beta c$ where $\beta<1$ at an angle θ to the line of sight. Point A is a total distance $d$ from Earth. By considering the arrival times of the observations of the two positions show that the apparent velocity of motion as seen from Earth is

$$v_{app} = \frac{\beta \sin\theta}{1-\beta\cos\theta} c$$

Evaluate $\beta$ for the superluminal velocity you measured for the jet in 3C273 assuming $\theta = 10^{\circ}$.