S26 Stars Galaxies - Example Problems

Section I

1. A G0V star [$M_{\rm V} = 5.0$ and (B-V)$_0 = 0.6$] has $m_{\rm B} = 12.0$, $m_{\rm V} = 10.0$. Determine the extinction to the star. Determine the distance of the star. You may assume $A_{\rm V} = 3.2E(B-V)$.

2. Given that the stellar surface density near the Sun is 30 M$_\odot$ pc^{-2}, estimate the stellar mass of our Galaxy, stating any assumptions you make. What factors may increase this estimate? Estimate the mean star formation rate of our Galaxy in stars per year, stating any assumptions you make. Given that the Sun orbits the galactic centre at 220 km s^{-1}, estimate the fraction of the dynamical mass which is composed of stars.

3. Consider the HI gas in the Galactic disc. Sketch the radial velocity of the gas as a function of galactic longitude for three rings of gas orbiting the Galactic centre, one ring outside the orbit of the Sun, and two rings of different radii inside the orbit of the Sun. Explain how observations of HI gas inside the orbit of the Sun can be used to map out the Galactic rotation curve. How can we determine the orbital velocity of the Sun from the emission of HI gas? Given that the maximum radial velocity of HI gas at galactic longitude $l = -90^o$ is measured to be $V_{\rm r} = 150$ km s^{-1}, estimate the radius of the Galactic HI disc.

4. Explain how observations of molecular gas and young stars in our Galaxy have lead to the identification of several spiral arms.

5. Describe a typical rotation curve of a spiral galaxy. Show that outside of the galactic centre, the rotation curve implies that the mass of a spiral galaxy increases linearly with radius.

6. What special characteristics do RR Lyrae stars have? Describe the distribution of RR Lyrae stars in the Galactic halo. How can these stars be used to determine the distance to the galactic centre? Estimate the distance from the Sun to the Galactic centre given that the maximum number of RR Lyrae stars occurs at $m_{\rm V} = 15.3$, stating any assumptions you make. Hint: RR Lyrae stars typically have $M_{\rm V} = 0.6$.

7. What characteristics distinguish Population II stars from Population I stars?

8. Describe how the mass of the black hole at the Galactic centre has been measured. Given that the typical velocities of stars 0.01 pc from the black hole have velocities of 1000 km s^{-1}, estimate the mass of the black hole. What are the arguments against the massive object being a cluster of neutron stars?

9. Sketch and describe how the Galactic rotation curve can be reproduced by three main dynamical components.

S26 Stars and Galaxies – Problems 2

10. An elliptical galaxy has a major axis of 20 kpc and a minor axis of 10 kpc. What is its morphological type?

11. Discuss the variation in bulges, discs, gas content, stellar populations, spiral structure, when going from late to early type galaxies.

12. How do the light intensity profiles of typical elliptical and spiral galaxies vary with radius?

13. An elliptical galaxy has a half-luminosity radius of 20 kpc and a stellar velocity dispersion of 100 km s^{-1}. Estimate its mass, stating any assumptions you make.

14. Show how the assumption of virial equilibrium and a universal density law can explain a) the Tully-Fisher relation and b) the Faber-Jackson relation.

15. How can we tell that rotation is not the reason that elliptical galaxies are elliptical in shape? What is the reason that elliptical galaxies are elliptical in shape?

16. The collisionless Boltzmann equation describes the evolution of a positive distribution function $f(\mathbf{r}, \mathbf{v}, t)$. Describe the form of f that gives King's model for a spherical galaxy.

17. Describe the 'winding problem' for spiral galaxies. How can this lead to 'stochastic' spirals? Describe the mechanism for generating 'grand design' spirals.

18. What roles do spiral arms play in galactic evolution?

S26 Problem Set 2 – Our Galaxy and External Galaxies

1. (i) In 1920 Kapteyn used star counts to infer that our Galaxy is a disc of dimensions 2 kpc × 10 kpc. Why was this technique inaccurate, and did it under-estimate or over-estimate the size of our Galaxy, and why? **[1,2]**

Sketch and label the main components (Galactic structure regions) of the Milky Way, giving an indication of the characteristic scale-lengths of each. Indicate in each region whether Population I or Population II stars dominate. Describe the main differences between Population I and Population II stars. **[5,3]**

(ii) Sketch the rotation curve of the Galaxy (the orbital speed, V, as a function of radius, R). Mark the Sun's orbit at a radius of 8.5 kpc. **[2]**

If the Sun's orbital speed is 220 km s^{-1}, calculate the dynamical mass enclosed within the Sun's orbit. **[4]**

The local surface density of main sequence stars in the disc around the Sun is 100 pc^{-2}. If the average (mean) mass of a star on the main sequence is 0.3 solar masses, estimate the mass in stars of the Milky Way, stating any further assumptions you make. How could such an estimate be improved? **[4]**

Compare your estimates of the stellar mass and dynamical mass for the Milky Way. How could any difference be reconciled? **[2]**

(iii) Consider a galaxy with a flat rotation curve (i.e. the orbital speed, V, is constant and does not change with radius, R) and a spherically-symmetric mass distribution. Derive an expression for the variation of the local matter density $\rho(R)$ with R. For a radius of R_0 = 8.5 kpc and an orbital speed of 220 km s^{-1}, calculate the mass density $\rho(R_0)$ at $R = R_0$. **[5,2]**

2. What is the effect of astrophysical dust on astronomical observations? **[2]**

Draw a sketch of the effect of dust with wavelength, from the ultraviolet to the near-infrared (0.1 μm to 1 μm), **[3]**

By what mechanism(s) is this dust made and distributed around a galaxy? **[2]**

Explain how it is possible to observe dust directly in emission. **[2]**

3. **(**i) The unit of distance in astronomy is the parsec (pc). How is this defined? **[2]**

Define in words the terms **apparent magnitude**, m, and **absolute magnitude**, M. Write down a relation between m, M and the distance in parsecs, d. How is this equation modified if there are A_V magnitudes of extinction? [Assume the observations are taken in the V-band of the spectrum]. **[2,2,1]**

What are RR Lyrae stars, and why are they useful in determining astronomical distances? **[3]**

What is Baade's window? Towards this window, the number of RR Lyrae stars as a function of apparent magnitude peaks at m_V = 15.6 mag. Explain why this observation might give the distance to the Galactic centre. If the absolute magnitude of an RR Lyrae star in the visible waveband (V-band) is M_V = +0.6 mag, estimate the distance to the Galactic centre, explaining any assumptions you make. **[1,4]**

The intrinsic colour of an RR Lyrae star is $(B\text{-}V)_0$ = 0.30 mag. The apparent magnitudes of RR Lyrae stars in Baade's Window peak at m_B = 16.0 mag (in B-band). What is the colour excess $E(B\text{-}V)$? What is the average extinction in magnitudes of these stars in the V-band? Re-determine the distance to the Galactic centre taking into account this extinction. **[1,1,2]**

[*Hint:* you may take extinction $A_V = 3.2\ E(B\text{-}V)$]

(ii) RR Lyrae stars are too faint to see individually in other galaxies. Describe how distances to external galaxies are determined. **[3]**

4. (i) Outline the evidence for a massive black hole in the centre of our Galaxy. **[3]**

At a distance of 0.01 parcsec from the Galactic centre, stars are observed with orbital velocities of 1000 km s^{-1}. Estimate the mass within this radius. **[3]**

(ii) Draw a diagram which illustrates **Hubble's morphological classification of galaxies**. Label the four main regular types which are covered by this Hubble classification and indicate the sub-classifications. **[5]**

For each of the main galaxy Hubble types, compare the gas and dust content and relative stellar ages. Which of these galaxies are likely to have ongoing star formation? **[5]**