UNIVERSITY OF SOUTHAMPTON PHYS2013W1

SEMESTER 1 EXAMINATION 2012/13

GALAXIES

Duration: 120 MINS

*Answer **all** questions in **Section A** and two **and only two** questions in **Section B**.*

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on it. Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins on it.

A Sheet of Physical Constants will be provided with this examination paper.

An outline marking scheme is shown in brackets to the right of each question.

Only university approved calculators may be used.

Section A

A1. A young star cluster is hidden behind a layer of dust which leads to an extinction in the V-band of $A_V = 0.87$ mag. The cluster's apparent magnitude is 3.2 mag and it is located at a distance of 500 pc to us. The star cluster contains 12 bright stars. Assume that the luminosity of the star cluster is dominated by these bright stars, and also that these 12 stars are all main sequence stars with the same mass. Calculate the absolute magnitude of the star cluster, and the apparent magnitude and absolute magnitude of the 12 bright stars. [4]

A2. Spectroscopic observations of two star clusters A and B determine their metallicities as $[\frac{Fe}{H}]_A = 0.5$ dex and $Z_B = 0.016$. Express the metallicity in terms of metal fraction Z for star clusters A, and in terms of $[\frac{Fe}{H}]$ for star cluster B. Assuming both star clusters have the same age and are located at the same distance to us, which star cluster should be the redder one? Briefly explain your reasoning. You may assume that the solar metallicity is Z=0.02. [4]

A3. The colour of the two star cluster with the same age and same distance to us has been observed to be the same, against expectations based on their metallicity which showed that cluster X has a higher metallicity than cluster Y. Explain which physical effect can cause both star clusters to have the same colour. [2]

A4. Classify the following galaxies according to their Hubble types:

a) A galaxy with no bulge and a flocculent, very loosely wound spiral arms.

b) A spiral galaxy with a bar-shaped bulge and well defined arm-structure that spirals from an outer ring into an inner ring around the bar.

c) An elliptical galaxy with a major axis that is twice as long as its minor axis. [4]

A5. A Cepheid star in the Large Magellanic Cloud, our closest neighbouring galaxy, has been observed with an average magnitude of $m_V = 17.46$ mag and a period of 1.34 days. The luminosity-period relation of the Cepheid is of the form

$$\langle M_V \rangle = -2.8 \log(P\,[\mathrm{days}]) - 1.4$$

Work out the distance and the absolute magnitude of the Cepheid. [2]

A6. A spiral galaxy is observed at a redshift of $z = 0.003$. What is the galaxy's recession velocity and distance to us? You may assume the Hubble constant $H_0 = 74.3$ km s^{-1} Mpc^{-1} and the speed of light $c = 3 \times 10^8$ m s^{-1}. [4]

Section B

B1. a) List and briefly explain three methods that can be used to determine distances to objects within our Milky Way. Briefly describe their limitations. [6]

b) From an observatory in La Palma, a star is observed with an uncalibrated V-band magnitude of $m'_1 = 4.2$ mag. At the same time, another star is observed from an observatory in Tenerife with an uncalibrated V-band magnitude of $m'_2 = 5.8$ mag. To put the observed, uncalibrated magnitudes on the same scale, that is to calibrate them, the standard star Vega was observed from both observatories, giving them uncalibrated magnitudes of $m'_{1,Vega} = 0.8$ mag at La Palma, and $m'_{2,Vega} = 1.1$ mag at Tenerife. Vega has an apparent V-band magnitude of $m_{Vega} = 0$ mag. What is the difference in apparent magnitude between the two stars? [4]

c) A young star cluster is embedded in an HII region. A spectrum is obtained from the HII region and the following line fluxes are measured: $F'_{H_\beta} = 1.3 \times 10^{-13}$ W m^{-2} and $F'_{H_\gamma} = 5.8 \times 10^{-14}$ W m^{-2}, where F' denotes the observed flux. The expected Balmer decrement for these two lines is $\frac{F_{H_\gamma}}{F_{H_\beta}} = 0.47$, where F denotes the intrinsic flux of the line. The line extinctions are related by $A_{H_\gamma} = 1.32 A_{H_\beta}$. What are the extinctions A_{H_β} and A_{H_γ} in magnitudes? [6]

d) Draw a sketch of the effect of the rotation of the Milky Way disc on the apparent motion of the stars within the Milky Way as seen from the Sun and give a brief explanation and description of the effect. [4]

B2. a) The surface brightness profiles of galaxies can be fitted with a Sersic profile

$$I(R) = I_0 \exp(-(\tfrac{R}{a})^{\frac{1}{n}})$$

Describe how galaxy properties, including galaxy type and the galaxy's internal dynamics, vary with Sersic index n. [5]

b) The surface brightness profile of a particular disk galaxy is best fit with an exponential function of the form:

$$I(R) = I_0 \exp(-\tfrac{R}{a})$$

where a is the scale radius. In this particular galaxy, a scale length of $a = 8.5$ kpc was measured, and the surface brightness at the scale length was measured to be $\mu(a) = 17.3$ mag arcsec^{-2}. Calculate the surface brightness at a radius of 5 kpc from the centre. [4]

c) For the galaxy described above, calculate the luminosity within a radius of $R_{out} = 5$ kpc, assuming that the central surface brightness is $I_0 = 10^6 L_\odot$ pc^{-2}. You might find the following integral helpful:
$\int x \exp(-\frac{x}{c}) dx = -c(c + x) \exp(-\frac{x}{c})$ [3]

d) For the galaxy described above, a rotation velocity of $v_{rot} = 220$ km s^{-1} has been measured. The galaxy has a density profile that can be described as $\rho(R) = \rho_0 R^{-1}$. Assuming that the disk has the same height h at all radii, find an expression for the mass contained within the scale radius $a = 8.5$ kpc. Show that the kinetic energy can be expressed as $K = v_{rot}^2 \pi h \rho_0 a$ and the potential energy as $U = -G 4\pi^2 h^2 \rho^2 a$. Calculate the mass of the galaxy in solar masses. You may assume $M_\odot = 1.99 \times 10^{30}$ kg, 1 pc = 3.086×10^{16} m and $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}. [8]

B3. a) List four pieces of observational evidence for dark matter in the universe. [4]

b) A survey of galaxies has a B-band apparent magnitude limit of $m_{lim} = 21.5$ mag and covers 0.8% of the sky. To what distance can you observe galaxies with an absolute magnitude of $M_B = -17$ mag? How many of these galaxies with $M_B = -17$ mag do you expect in your survey if the number density is 1.8×10^{-5} Mpc^{-3}? [4]

c) Explain the terms open, flat and closed Universe. [3]

d) Assuming a uniform density of matter across the Universe, find an expression for the critical density at which the Universe is stable and will not collapse under its own gravity. [6]

e) The luminosity function of a galaxy cluster follows the simple form of the Schechter function:

$$\Phi(L) = \frac{\Phi_\star}{L_\star} e^{-\frac{L}{L_\star}} (\frac{L}{L_\star})^{-1}$$

Assuming a normalising number density $\Phi_\star = 0.0055$ Mpc^{-3} and a normalising luminosity of $L_\star = 2 \times 10^{10} L_\odot$, calculate the total luminosity density of this galaxy cluster. You might find the following integral helpful: $\int exp(-x/a)dx = -a\exp(-x/a)$. [3]

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