UNIVERSITY OF SOUTHAMPTON PHYS2013W1

SEMESTER 1 EXAMINATION 2013-2014

GALAXIES

Duration: 120 MINS (2 hours)

This paper contains 9 questions.

Answer **all** questions in **Section A** 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.

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

A Sheet of Physical Constants is provided with this examination paper.

Only university approved calculators may be used.

A foreign language translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

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Section A

A1. Classify the following galaxies according to their Hubble types:
a) An elliptical galaxy with an ellipticity of $\epsilon = 0.5$.
b) A galaxy with no bulge and only very loosely wound arms.
c) A giant galaxy with massive star formation and no regular structure. [3]

A2. The V-band apparent magnitude of a star is measured to be 14.7 mag. From spectroscopic measurements, the star is identified to be an F-type star with an absolute magnitude of 3.2 mag. A dust layer is located along the line of sight, causing an extinction of $A_V = 1.5$ mag. Calculate the distance to the star in pc and its parallax. [3]

A3. Briefly explain in no more than four sentences each, two techniques that can be used to estimate the mass of a galaxy cluster. [5]

A4. A spiral galaxy appears slightly elliptical on the sky. How can the elliptical shape of the galaxy be explained? [1]

A5. A Cepheid star in the Andromeda galaxy has been observed with an average magntidue of $m_V = 22.48$ mag and a period of 1.53 days. The luminosity-period relation of the Cepheid is of the form

$$< M_V >= -2.78 \log(P[\text{days}]) - 1.37$$

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

If the Cepheids luminosity is $L_{Ceph} = 1.4 \times 10^5 L_\odot$, what flux F has been measured? You may assume a solar luminosity of $L_\odot = 3.85 \times 10^{26}$ W. [2]

A6. Two giant elliptical galaxies are measured to have the same redshift and similar luminosities. Both galaxies have stellar populations of similar ages but differ in their metallicity, one galaxy is more metal-rich than the other. Which galaxy is the redder one? Which galaxy is more massive? Explain in one to two

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sentences the physical mechanism that leads to this difference in metallicity and hence colour. [4]

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Section B

B1. (a) Draw and label the basic structure and the main components of our Galaxy, and give a brief description of the properties of the various components with respect to their stellar and gas content. [8]

(b) In order to measure the extinction along the line of sight to a young star cluster that is located behind an HII region, a spectrum of the HII region was obtained that shows the Balmer emission lines. The following line fluxes are measured for the H_α and H_β lines:
$F'_{H_\alpha} = 1.3 \times 10^{-12}$ W m^{-2}
$F'_{H_\beta} = 5.2 \times 10^{-13}$ W m^{-2},
where F' denotes the observed flux. The expected Balmer decrement for these two lines is $\frac{F_{H\alpha}}{F_{H_\beta}} = 2.86$, where F denotes the intrinsic flux of the line. The line extinctions are related by $\mathrm{A}_{\mathrm{H}_\beta} = 0.75\mathrm{A}_{\mathrm{H}_\alpha}$. State the relation between extinction and the observed and expected line fluxes, and work out the extinctions $\mathrm{A}_{\mathrm{H}_\alpha}$ and $\mathrm{A}_{\mathrm{H}_\beta}$ in magnitudes. [6]

(c) Spectra for two stars A and B have been obtained, and their Doppler shifted H_α lines have been measured at $\lambda_A = 656.295$ nm and $\lambda_B = 656.258$ nm. The rest wavelength for the H_α line is at $\lambda_0 = 656.281$ nm. What are the stars' radial velocities, and in which direction are they moving with respect to our Sun? [4]

(d) The halo of our Galaxy is thought to contain large amounts of dark matter. Explain the main evidence that supports this idea. [2]

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B2. (a) For the following four astronomical objects, which is the appropriate method to determine the distance to the object? In each case give a brief description (no more than one to two sentences) of the method.
(i) A nearby star, less than 100 pc away.
(ii) A galaxy, less than 100 kpc away.
(iii) A galaxy so distant that individual stars cannot be resolved, but less than 100 Mpc away. [6]

(b) An elliptical galaxy shows a surface brightness profile $\mu(R)$ (where R is the radius) that can be fit with a Sersic law with a Sersic index n = 4:

$$\mu(R) = \mu_0 + 7.4\,(\frac{R}{R_e})^{\frac{1}{4}}$$

R_e is the effective radius (which contains half the light of the galaxy), and $\mu_0 = 11.7$ mag arcsec^{-2} is a normalising factor. At a radius of 1 kpc, the surface brightness was measured to be 18.7 mag arcsec^{-2}. Work out the effective radius R_e and the surface brightness at a radius of 3 kpc. [4]

(c) The surface brightness profile $I(R)$ of the disc of a spiral galaxy is of the form

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

where *R* is the radius and *a* the scale length. Show that the total luminosity of the disc is given by $L = 2\pi I_0 a^2$ L$_\odot$ pc^2.
You may find the following standard integral useful: $\int x\ exp(-x)dx = -(x+1)exp(-x)$ [4]

(d) The total flux observed from an elliptical galaxy is $F = 3.7 \times 10^{-15}\mathrm{Wm}^{-2}$, and the galaxy's redshift is measured to be $z = 0.005$. Calculate the galaxy's distance and its luminosity in solar luminosities. State whether the galaxy is a giant or a dwarf. You may assume that 1 pc = 3.086×10^{16} m, $H_0 = 74.3$ km s^{-1} Mpc^{-1} and the speed of light $c = 3 \times 10^8 \mathrm{ms}^{-1}$ [6]

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B3. (a) List the ideas that have been put forward to explain what dark matter might consist of, including evidence for or against these ideas. [6]

(b) Observations of an AGN showed a brightening of the blue optical continuum. Two weeks later, a brightening of the broad emission lines was observed. The emission lines suggest a velocity of 770 km sec^{-1} of the line emitting region with respect to the nucleus. Work out the mass of the central supermassive black hole in solar masses. [5]

(c) A spherical galaxy cluster has a density profile that can be described by $\rho(R) = \rho_0 \, R^{-1/2}$ out to a truncation radius of R_{out}. Show that the kinetic energy of the galaxy cluster can be described as $K = \frac{12}{5}\pi\rho_0{\sigma_r}^2{R_{out}}^{5/2}$. [4]

(d) For the galaxy cluster given in question (c), show that its potential energy can be described as $U = -\frac{8}{5}G\pi^2{\rho_0}^2{R_{out}}^4$. Find an expression for the total mass of the galaxy cluster. [5]

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