SEMESTER 1 EXAMINATION 2014-2015

GALAXIES

Duration: 120 MINS (2 hours)

This paper contains 8 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.

Section A

A1. Classify the following galaxies according to their Hubble types:

a) An elliptical galaxy with an ellipticity of $\epsilon = 0.3$.

b) A galaxy with a large bulge and tightly-wound, ordered and well-defined spiral arms.

c) A giant galaxy with massive star formation and no regular structure. [3]

A2. A galaxy has a spherical shape and a density profile that can be described as $\rho(R) = \rho_0 R^{-2}$ out to a truncation radius R_{out}, beyond which the density drops to zero. Show that the kinetic energy of the galaxy can be expressed as $K = 6\pi\rho_0\sigma_r^2 R_{out}$, with σ_r the radial velocity dispersion. [5]

A3. A star cluster is located behind a layer of dust which contributes a B band extinction of $A_B = 3.7$ mag. The apparent B-band magnitude of the star cluster is 16.7 mag. Assuming that the star cluster is at a distance of 580 pc and contains ten equally bright stars, and further assuming that the cluster's luminosity is dominated by these ten bright stars, calculate the absolute B-band magnitude of these ten stars. [4]

A4. The brightest star in the star cluster is a main sequence star with a mass of 7 $M_\odot$. The initial mass function (IMF) of main sequence stars follows the Salpeter IMF

$$n(M) = kM^{-2.35}$$

where $k = 213$ is a constant of normalization, and M is the stellar mass in solar masses. Assuming that the lowest-mass stars have masses of 0.5 $M_\odot$, what is the total mass of the star cluster? Assuming a mass-to-light ratio of $M/L = 1.6$ in B-band, what is the total B-band luminosity of the star cluster? [4]

A5. Describe how the interstellar medium, and thus a galaxy, can become enriched in metals. [4]

Section B

B1. (a) Classify the following different types of active galaxies (AGN) based on their characteristics: (i) A luminous nucleus ($L_{bol} > 10^{38}$ W, with L_{bol} the bolometric luminosity) with powerful optical, IR, UV and X-ray emission, and both broad and narrow emission lines. (ii) A bright radio point-source with a highly polarised optical continuum and no spectral lines. (iii) A radio galaxy with a bright optical nucleus and broad emission lines. [3]

(b) Describe the basic structure of an AGN [6]

(c) An AGN has an X-ray luminosity of $L_X = 4.26 \times 10^{35}$ W. Assuming the X-ray radiation is about 30% of the bolometric radiation, at which fraction of the Eddington luminosity $L_{Edd} = 1.3 \times 10^{31} \frac{M_{BH}}{M_{\odot}}$ W does the black hole radiate? [3]

(d) There is a growing super-massive Black Hole (SMBH) with an initial mass of $M_{\rm BH} = 10^4\,{\rm M}_{\odot}$. It is accreting at its Eddington limit, with a radiative efficiency of $\epsilon = 0.1$. What would its expected mass be after $T = 0.4$ Gigayears assuming all the accretion parameters (radiative efficiency and Eddington ratio) are kept fixed? (Hint: a SMBH grows exponentially as $M_{\rm BH} \propto \exp(T/t_{ef})$, with $t_{ef} = \epsilon \times t_E$ the e-folding timescale, and $t_E = 4 \times 10^8$ yr) [4]

(e) The highest redshift SMBH, observed as a quasar, has been detected at a redshift $z \sim 7$. It has a mass of $M_{\rm BH} \sim 2 \times 10^9\,{\rm M}_{\odot}$. What do you think its seed mass was if it had accreted for the whole time since the Big Bang at its Eddington limit? (Simply approximate the cosmic time since the Big Bang as $t(z) = 13.5 \times (1+z)^{-1.5}$,where z is the cosmological redshift.) [4]

TURN OVER

B2. (a) Assume that we live in a universe populated by galaxies with a luminosity function

$$\frac{\partial n}{\partial L} = \begin{cases} \frac{\Phi_*}{L_*}\left(\frac{L}{L_*}\right)^{\alpha-1} & \text{for } L_{\rm min} \le L \le L_*, \\ 0 & \text{otherwise,} \end{cases}$$

with n is the number density of galaxies with luminosity in the range L and $L + dL$. Here Φ_*, α, $L_{\rm min}$ and L_* are constants. Show that the total density of galaxies in this universe is given by

$$n_{\rm tot} = \frac{\Phi_*}{-\alpha}\left[\left(\frac{L_{\rm min}}{L_*}\right)^{\alpha} - 1\right].$$

[2]

(b) The characterization of the spatial distribution of galaxies is usually quantified via the two-point correlation function $\xi(r)$, defined as the excess number of galaxy pairs of a given separation r relative to that expected from a random distribution. The two-point correlation function of a sample of field galaxies is a power-law of the form

$$\xi(r) \simeq (r/r_0)^{-\gamma}$$

with $\gamma \sim 1.8$ and $r_0 \sim 7$ Mpc. The correlation of a similar sample of galaxies in cluster environments can be represented by the same function but with $\gamma \sim 1.8$ and $r_0 \sim 30$ Mpc. Which are more clustered at a scale of 5 Mpc? What do you conclude? What about scales of 1000 Mpc? What do you conclude from both functions being so small at the latter scale? [4]

(c) The cluster has a redshift $z = 0.5$ and acts as a gravitational lens for a background galaxy at redshift $z = 1.5$. The image of the lensed galaxy is distorted into an Einstein ring with measured angular diameter $\theta = 53$ arcseconds. The lensing equation gives the physical radius of the Einstein ring as

$$R_{\rm E} = \sqrt{\frac{D_{\rm ls}D_{\rm l}}{D_{\rm ls} + D_{\rm l}}}\sqrt{\frac{2GM}{c^2}},$$

where M is the total mass of the gravitational lens, $G \approx 4.3\times10^{-6}\,\mathrm{kpc}\,\mathrm{M}_\odot^{-1}\,(\mathrm{km/s})^2$ is the gravitational constant, and c is the speed of light. D_l is the distance of the gravitational lens from us and D_ls is the distance between the lens and the lensed object. What is the total mass of the cluster in solar masses? (*Hint: Assume we live in an Einstein-de Sitter universe where the distance from us to an object at redshift z is given by $D = 2\left(1 - 1/\sqrt{1+z}\right) c/H_0$, with $H_0 = 70\,km\,s^{-1}\,Mpc^{-1}$.*) [5]

(d) More than half of the galaxies in the Universe can be found in larger scale structures called groups and clusters. List the different properties of galaxy groups and galaxy clusters in terms of their sizes, galaxy numbers, velocities and types. Describe the distribution of galaxies within a group or cluster, including a probable explanation of the distribution of galaxy types. [6]

(e) List three pieces of evidence for the existence of dark matter. [3]

TURN OVER

B3. (a) The total flux observed from an elliptical galaxy is $F = 5.5 \times 10^{-15}\,\mathrm{Wm^{-2}}$, and the galaxy's radial velocity is measured to be 1370 km s^{-1}. Calculate the luminosity in solar luminosities and state whether the galaxy is a giant or a dwarf. You may assume that 1 pc = 3.086×10^{16} m, and $H_0 = 73$ km s^{-1} Mpc^{-1}. [4]

(b) Explain what is meant with "cosmic downsizing". [5]

(c) Explain why the distances to the most distant galaxies cannot be measured from shifted spectral lines, and describe the method that can be used instead. [4]

(d) For each of the following three astronomical objects, detail one possible method to determine the distance to the object.

(i) A nearby star, less than 100 pc away.

(ii) A galaxy, less than 1 Mpc away.

(iii) A galaxy at a redshift larger than $z > 4$. [7]

END OF PAPER