SEMESTER 1 EXAMINATION 2013-2014

INTRODUCTION TO ASTRONOMY AND SPACE SCIENCE

Duration: 120 MINS (2 hours)

This paper contains 8 questions.

Answer **five** 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. What are the apparent geometric patterns of a star on the sky induced by the annual motion of the Earth, if the star is located:

a) at the pole of the ecliptic (reminder: perpendicular to the plane of the Earth-Sun orbit); [1]

b) extremely close to the ecliptic; [1]

c) in any other position. [1]

A2. Derive the observed relationship $T \propto L^{\alpha}$, with $\alpha \sim 0.10 - 0.15$, between temperature and luminosity of main sequence stars in the Hertzprung-Russell diagram. Assume virial equilibrium ($kT = GMm_p/R$), and adopt the empirical correlation $L \propto M^{3.5}$. [4]

A3. What is the velocity of a star on the plane of the sky at a distance $D = 100$ pc with respect to Earth, if it moves with an apparent motion of 0.1 arcsec/yr? [4]

What is the radial velocity of the same star if its spectrum shows absorption lines displaced by 0.1% from their rest wavelengths? [3]

A4. If a star has a radius 10 times larger than the Sun's, what is its temperature assuming that its luminosity is that of the Sun. (You may assume the blackbody relation with $T_{\odot} = 5800$ K). [3]

A5. Compare the collecting areas and resolving powers of the main mirror (8.2m diameter) and one of the four movable mirrors (1.8m diameter) in the auxiliary telescopes at the Very Large Telescope. What is the true advantage of having large mirrors? [3]

Section B

B1. Suppose you are observing a galaxy for which the stellar mass estimate amounts to about $M_{\rm star} = 10^{11}\,{\rm M}_\odot$.

(a) If the galaxy has a total radius of ${\rm R}_{\rm star} = 10$ kpc, what would its expected circular velocity at ${\rm R}_{\rm star}/2$ be, assuming the virial theorem holds at this scale? (Note: Use the gravitational constant expressed in units of $G \approx 4.3 \times 10^{-6}\,{\rm kpc\,M}_\odot^{-1}\,({\rm km/s})^2$) [3]

Suppose now there is also dark matter. What would the new circular velocity be if the dark matter contained within ${\rm R}_{\rm star}/2$ amounts to 50% of the total stellar mass? [2]

(b) What is the expected angle (in arcsec) on the sky subtended by the same galaxy assuming the galaxy is $D = 20\,{\rm Mpc}$ away from Earth? Adopt the classical small angle approximation trigonometric formula. [3]

(c) What is the flux (in Watts per square metre) which would be detected by HST for the same galaxy? (Hint: Simply assume a mass-to-light ratio $M_{\rm star}/L_{\rm star} = 1\,M_\odot/L_\odot$ and that the luminosity of the Sun is $L_\odot = 4 \times 10^{26}$ Watt.) [4]

What is the surface brightness (in Watts per square metre per arcsec square) of the galaxy? [3]

(d) Briefly discuss the Hubble galaxy classification sequence and how morphology, number density, and star formation rate change along the sequence. [3]

What are the main differences between lenticulars and spirals? [2]

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B2. There is a growing super-massive Black Hole (SMBH) with a seed mass of $M_{\rm BH} = 10^3\,{\rm M}_\odot$ at $z = 10$. It is accreting at its Eddington limit, with a radiative efficiency of $\epsilon = 0.1$.

(a) What would its expected mass be at $z \sim 7$ assuming all the accretion parameters (radiative efficiency and Eddington ratio) are kept fixed? (Hint: Use the exponential growth curve of a SMBH, and consider a time lag of $T = 0.285$ Gigayears between $z = 10$ and $z = 7$, and recall that the Eddington timescale is $t_{\rm Edd} = 4 \times 10^8$ yr.) [4]

Would the resulting SMBH resemble the one recently observed at $z \sim 7$? [2]

(b) How massive should the SMBH seed mass be to equal a SMBH of mass $M_{\rm BH} = 10^9\,{\rm M}_\odot$, assuming the same accretion parameters as above? [3]

(c) Compute the bolometric luminosity associated to a SMBH of $M_{\rm BH} = 10^6\,{\rm M}_\odot$ accreting at the Eddington limit. [3]

What would its luminosity be if the SMBH is obscured by a gas column density along the line of sight of $N_H = 10^{23}\,{\rm cm}^{-2}$ (assume the optical depth approximately scales as $\tau = 2 \times [N_H/10^{22}\,{\rm cm}^{-2}]^{0.3}$)? [3]

(d) Compute the mass density $\rho_{\rm BH}$ in ${\rm M}_\odot\,{\rm Mpc}^{-3}$ of all SMBHs of mass between $\log M_{\rm BH}/{\rm M}_\odot = 9$ and $\log M_{\rm BH}/{\rm M}_\odot = 9.1$, assuming that their corresponding number density is constant in this mass interval and equal to $\phi(M_{\rm BH}) = 10^{-5}\,{\rm Mpc}^{-3}$ per unit interval of logarithmic mass. [5]

B3. Let's talk about the Sun.

(a) Approximating the Sun as a blackbody with temperature $T = 5778$ K and radius of $R = 695500$ km, what is its flux on Earth (in $\mathrm{W\,m^{-2}}$)? [3]

(b) Assume that the extinction suffered by the flux from the Sun on the surface of the Earth is 2 magnitudes. If you were unaware of such an absorption, how much would be your error in the estimate of the distance to the Sun? [6]

(c) Saturn orbits the Sun at a distance of 10AU. What would the angular separation in arcsec between Saturn and the Sun be if viewed from Proxima Centauri (~ 1.3 pc)? [3]

Saturn has an average radius of about 57000 km. Calculate the fraction of the Sun's light intercepted by Saturn. [3]

(d) Briefly discuss the main evolutionary steps of a 1 $M_\odot$ star like the Sun, from the main sequence to its final state. [5]

END OF PAPER

