S2821406F1

S282/F

Module Examination 2014

ASTRONOMY

Thursday, 5 June 2014 **2:30 pm – 5:30 pm**

Time allowed: 3 hours

This examination consists of **THREE** parts (1, 2 and 3). **ALL** of which should be attempted. Carefully follow the instructions given in each part.

Part	Nature of question	Choice of question	Time allocation (minutes)	Proportion of marks (%)
1	computer marked	**NONE**: answer all questions	50	28
2	written answer	answer **THREE** out of four	60	36
3	written answer	answer **THREE** out of four	60	36

You are advised to spend about 10 minutes reading through the examination paper carefully before you begin answering the questions.

Your answers to Part 1 must be entered on the Computer Marked Examination form (CME form) provided. **YOU WILL NOT BE GIVEN EXTRA TIME TO DO THIS**.

Your answers to Parts 2 and 3 must be written in the answer book provided. You will be supplied with additional answer books on request.

At the end of the examination

Check that you have completed Part 1 of the CME form and written your personal identifier and examination number on each answer book used. **Failure to do so will mean that your work cannot be identified.**

Put all your used answer books together with your signed desk record on top. Fasten them in the top-left corner with the round paper fastener. Attach the CME form and this question paper to the back of the answer books with the flat paper clip.

Instructions for Part 1

1 General

1.1 You are advised to spend about **50 minutes** on this part, which carries 28% of the total marks for the examination. **TAKE CARE NOT TO SPEND TOO LONG ON THIS PART.**

1.2 You should attempt all eight questions, and enter your answers on the CME form provided.

2 Instructions for completing the CME form

2.1 You will find one CME form provided with this paper. The invigilator has a supply of spare forms if you should need any.

2.2 The general instructions are the same as for the computer-marked assignment that you did during the year. You should use an HB pencil to make entries on the CME form. If you make any smudges or other spurious marks on the form which you cannot cancel out clearly, you should *ask the invigilator for a new form*, and transfer your entries to it.

2.3 If you do not wish to answer a question, pencil across the ‘don’t know’ cell (‘?’).

2.4 If you think that a question is unsound in any way, pencil across the ‘unsound’ cell (‘U’), *in addition* to pencilling across either an answer cell or the ‘don’t know’ cell.

2.5 For each question, you **must** pencil across **either** the required number of answer cells **or** the ‘don’t know’ cell.

2.6 We suggest that, in the first instance, you answer by pencilling across the relevant cells in the facsimile CME rows reproduced opposite. Check your answers before transferring them to your actual CME form.

2.7 You should note that **NO ADDITIONAL TIME** will be allowed at the end of the three-hour examination period for transferring your marks to the actual CME form.

2.8 On Part 1 of the CME form, you must *write* in your personal identifier (NOT the examination number) and the ‘assignment number’ for this examination (**S282 81**). You should also *pencil across* the cells in the two blocks in Part 1 of the form corresponding to your personal identifier and the assignment number given above. We suggest you check that Part 1 on the CME form has been completed correctly before moving on to Parts 2 and 3 of the examination paper.

2.9 Failure to follow the above instructions may mean that we shall not be able to award you a mark for this part of the examination.

Note

You may use a page in your answer book for any rough work required in Part 1. Please note that this rough work will not be considered by the examiners.

Facsimile CME rows

1	A	B	C	D	E	F	G	H	?	U	21	A	B	C	D	E	F	G	H	?	U	41	A	B	C	D	E	F	G	H	?	U
2	A	B	C	D	E	F	G	H	?	U	22	A	B	C	D	E	F	G	H	?	U	42	A	B	C	D	E	F	G	H	?	U
3	A	B	C	D	E	F	G	H	?	U	23	A	B	C	D	E	F	G	H	?	U	43	A	B	C	D	E	F	G	H	?	U
4	A	B	C	D	E	F	G	H	?	U	24	A	B	C	D	E	F	G	H	?	U	44	A	B	C	D	E	F	G	H	?	U
5	A	B	C	D	E	F	G	H	?	U	25	A	B	C	D	E	F	G	H	?	U	45	A	B	C	D	E	F	G	H	?	U
6	A	B	C	D	E	F	G	H	?	U	26	A	B	C	D	E	F	G	H	?	U	46	A	B	C	D	E	F	G	H	?	U
7	A	B	C	D	E	F	G	H	?	U	27	A	B	C	D	E	F	G	H	?	U	47	A	B	C	D	E	F	G	H	?	U
8	A	B	C	D	E	F	G	H	?	U	28	A	B	C	D	E	F	G	H	?	U	48	A	B	C	D	E	F	G	H	?	U
9	A	B	C	D	E	F	G	H	?	U	29	A	B	C	D	E	F	G	H	?	U	49	A	B	C	D	E	F	G	H	?	U
10	A	B	C	D	E	F	G	H	?	U	30	A	B	C	D	E	F	G	H	?	U	50	A	B	C	D	E	F	G	H	?	U
11	A	B	C	D	E	F	G	H	?	U	31	A	B	C	D	E	F	G	H	?	U	51	A	B	C	D	E	F	G	H	?	U
12	A	B	C	D	E	F	G	H	?	U	32	A	B	C	D	E	F	G	H	?	U	52	A	B	C	D	E	F	G	H	?	U
13	A	B	C	D	E	F	G	H	?	U	33	A	B	C	D	E	F	G	H	?	U	53	A	B	C	D	E	F	G	H	?	U
14	A	B	C	D	E	F	G	H	?	U	34	A	B	C	D	E	F	G	H	?	U	54	A	B	C	D	E	F	G	H	?	U
15	A	B	C	D	E	F	G	H	?	U	35	A	B	C	D	E	F	G	H	?	U	55	A	B	C	D	E	F	G	H	?	U
16	A	B	C	D	E	F	G	H	?	U	36	A	B	C	D	E	F	G	H	?	U	56	A	B	C	D	E	F	G	H	?	U
17	A	B	C	D	E	F	G	H	?	U	37	A	B	C	D	E	F	G	H	?	U	57	A	B	C	D	E	F	G	H	?	U
18	A	B	C	D	E	F	G	H	?	U	38	A	B	C	D	E	F	G	H	?	U	58	A	B	C	D	E	F	G	H	?	U
19	A	B	C	D	E	F	G	H	?	U	39	A	B	C	D	E	F	G	H	?	U	59	A	B	C	D	E	F	G	H	?	U
20	A	B	C	D	E	F	G	H	?	U	40	A	B	C	D	E	F	G	H	?	U	60	A	B	C	D	E	F	G	H	?	U

If you use these facsimile CME rows while answering questions in Part 1 of the examination paper then remember to transfer your answers to your actual CME form. **NO ADDITIONAL TIME** will be allowed at the end of the three-hour examination period for transferring your marks to the actual CME form.

Useful data, equations and expressions

$c = 3.00 \times 10^{8}$ m s^{-1}

$h = 6.63 \times 10^{-34}$ J s

$k = 1.38 \times 10^{-23}$ J K^{-1}

$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

$m_{\mathrm{e}} = 9.11 \times 10^{-31}$ kg

1 AU $= 1.50 \times 10^{11}$ m

1 eV $= 1.60 \times 10^{-19}$ J

1 pc $= 3.09 \times 10^{16}$ m

$M_{\odot} = 1.99 \times 10^{30}$ kg

$R_{\odot} = 6.96 \times 10^{8}$ m

$T_{\odot} = 5770$ K

$L_{\odot} = 3.84 \times 10^{26}$ W

$H_0 \approx 72$ km s^{-1} Mpc^{-1}

$\varepsilon = hf$

$c = f\lambda$

$(\lambda_{\mathrm{peak}}/\mathrm{m}) = 2.90 \times 10^{-3}/(T/\mathrm{K})$

$\upsilon_{\mathrm{r}} = c(\lambda' - \lambda)/\lambda$

$\upsilon_{\mathrm{t}} = d \times (\mu/\mathrm{radians})$

$\Delta\lambda/\lambda \approx \Delta\upsilon/c$

$$\Delta\upsilon \approx \left(\frac{2kT}{m}\right)^{1/2}$$

$L = 4\pi R^{2}\sigma T^{4}$

$L = 4\pi d^{2}F$

$m_1 - m_2 = -2.5 \log(b_1/b_2)$

$$M + m = \frac{4\pi^{2}a^{3}}{GP^{2}}$$

$M = m - 5 \log d + 5$

$d = l/(\theta/\mathrm{radians})$

$d/\mathrm{AU} = 1/(p/\mathrm{radians})$

$(d/\mathrm{pc}) = 1/(p/\mathrm{arcsec})$

$\omega = 2\pi/T$

$L_E/W = (1.3 \times 10^{31})M/M_\odot$

$R_S = 2GM/c^2$

$R \sim c\Delta t$

$E = mc^2$

$M = rv^2/G$

$M \approx R_A(\Delta v)^2/G$

$$z = \frac{(\lambda_{\text{obs}} - \lambda_{\text{em}})}{\lambda_{\text{em}}}$$

$$z = \frac{H_0}{c}d$$

$$\theta_E = \sqrt{\frac{4GM}{c^2}\frac{D_{LS}}{D_L D_S}}$$

$$q(t) = \frac{\Omega_m(t)}{2} - \Omega_\Lambda(t)$$

$$\Omega_m + \Omega_\Lambda - 1 = \frac{kc^2}{R^2H^2}$$

$$z = \frac{R(t_{\text{obs}})}{R(t_{\text{em}})} - 1$$

$t = 1/H_0$

$$T \propto \frac{1}{R(t)}$$

PART 1 Computer-marked questions S282 81

Attempt **ALL** *questions in this part.*

This part carries 28% of the total marks.

You are advised to spend about **50 minutes** *on this part.*

Pencil your answers on the CME form provided. Detailed instructions for completing it are printed on page 2. Each question specifies the number of answers required. No marks will be given for questions where more than the required number of answers has been selected from the key.

There are no penalty marks for incorrect answers.

Question 1 Which *two* statements about the structure and interior of the Sun are *correct*? Pencil across *two* cells in row 1.

Key for Question 1

A Energy is transported from the nuclear reactions in the core to the photosphere by radiation.

B The Sun's energy is produced entirely from conversion of hydrogen to helium by the ppI chain.

C The 'solar neutrino problem' refers to the difficulty of detecting neutrinos produced from nuclear reactions in the Sun's core, because they pass through most matter without interacting.

D The solar cycle of approximately 11 years is the period between peaks in sunspot numbers and reversals of the solar magnetic field.

E The Sun's magnetic field resembles a dipole field at times of solar maximum.

F The Sun exhibits differential rotation. The observed rotation period derived from surface features depends on their solar latitude, with the period at the equator being longer than that at the pole.

G The helium mass fraction is approximately 25% everywhere in the Sun except in the core, where it is lower.

H Helioseismology is the study of global oscillations of the Sun. Oscillations of different frequencies travel different distances inside the Sun, allowing its internal structure to be studied.

Question 2 Table 1 below describes the properties of different regions of the interstellar medium. Which two regions best describe a supernova remnant and a dense cloud?

Table 1 Properties of different regions of the interstellar medium

Region	Mass ($M_\odot$)	Temperature (K)	Density (n/m^{-3})	Form of hydrogen	Abundance of molecules
1	<1	300	10^{15}	H or H_2	Diatomic and small molecules common
2	<1	10^4	10^9	H^+	Very low
3	3	10^6	10^7	H^+ or H	Very low
4	3	30	10^7	H or H_2	Diatomic molecules common
5	100	10	10^{11}	H_2	Large molecules common
6	100	10^4	10^7	H^+	Very low

Pencil across *one* cell in row 2

Key for Question 2

A Regions 1 and 2

B Regions 1 and 5

C Regions 2 and 3

D Regions 2 and 5

E Regions 3 and 5

F Regions 3 and 6

G Regions 4 and 5

H Regions 4 and 6

Question 3 The nuclear reaction ${}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{16}_{8}\mathrm{O} + \gamma$ occurs in red giants. The masses of ${}^{12}_{6}\mathrm{C}$, ${}^{4}_{2}\mathrm{He}$ and ${}^{16}_{8}\mathrm{O}$ are 1.9926×10^{-26} kg, 6.6447×10^{-27} kg and 2.6560×10^{-26} kg respectively. What is the approximate energy of the photon? Pencil across *one* cell in row 3.

Key for Question 3

A 9.6×10^{-13} eV

B 5.4×10^{-11} eV

C 0.02 eV

D 110 eV

E 2.7 keV

F 150 keV

G 6.0 MeV

H 340 MeV

Question 4 Which *one* of the options (A–H) in Table 2 correctly describes the structure (from the centre to the surface) of a 5 $M_{\odot}$ star at the appropriate stage of its evolution? Pencil across *one* cell in row 4.

Table 2 Key for Question 4

	Location on the Hertzsprung–Russell diagram	**Structure (from centre, outwards to the surface)**
A	horizontal branch	quiescent helium core hydrogen burning shell helium and hydrogen envelope
B	main sequence	quiescent helium core hydrogen burning shell helium and hydrogen envelope
C	asymptotic giant branch	carbon burning core quiescent carbon-oxygen shell helium burning shell quiescent helium shell hydrogen burning shell helium and hydrogen envelope
D	red giant branch	hydrogen burning core helium and hydrogen envelope
E	between main sequence and red giant branch (a sub giant)	hydrogen burning core helium and hydrogen envelope
F	asymptotic giant branch	quiescent carbon-oxygen core helium burning shell quiescent helium shell hydrogen burning shell helium and hydrogen envelope
G	horizontal branch	helium burning core hydrogen burning shell helium and hydrogen envelope
H	red giant branch	helium burning core quiescent helium shell hydrogen burning shell helium and hydrogen envelope

Question 5 Which *two* of the following statements about the Milky Way are *true*? Pencil across *two* cells in row 5.

Key for Question 5

A Current star formation occurs exclusively in the bulge.

B Current observations suggest that the disc is not warped.

C The globular clusters within the Galaxy contain its most youthful stellar population.

D The scale height of the interstellar medium in the disc is less than the scale height of stars of spectral types O and B.

E The 21 cm radio emission that is used to map the distribution of the interstellar medium is emitted by neutral hydrogen.

F The mass of gas in the disc is about 10% of the mass of stars in the disc.

G Globular clusters are preferentially located in the galactic disc.

H The central bulge of the Galaxy has a radius of 30 kpc.

Question 6 Observations of a galaxy reveal the Hα line at 691.0 nm. Assuming a rest wavelength of 656.3 nm and a Hubble constant of H_0 = 72 km s^{-1} Mpc^{-1}, what would be the distance to the galaxy? Pencil across *one* cell in row 6.

Key for Question 6

A 140 kpc

B 220 kpc

C 270 Mpc

D 280 Mpc

E 3.2 Gpc

F 5.7 Gpc

Question 7 Which of the following statements regarding active galaxies is true? Pencil across *one* cell in row 7.

Key for Question 7

A Active galaxies are powered by intense bursts of star formation.

B All of the emission lines in the spectra of active galaxies have the same width.

C Active galaxies emit so much energetic radiation that they are entirely dust free.

D All active galaxies are physically the same, and look identical no matter what orientation they are observed at.

E The emission from active galaxies shows no variability at any wavelength.

F The number of active galaxies present in a given volume of space shows a dependence on redshift.

Question 8 Which *two* of the following statements about the early Universe are *correct*? Pencil across *two* cells in row 8.

Key for Question 8

A The earliest time in the history of the Universe about which anything can be said is the so-called *Planck time* which occurred about 240 seconds after the big bang.

B At the earliest times in the history of the Universe, two or more of the four fundamental interactions were unified into a single interaction.

C The temperature required for electroweak unification in the early Universe is greater than the temperature required for grand unification.

D Pair creation and particle–antiparticle annihilation reactions may be seen as the opposite to each other.

E In the early Universe, when triplets of quarks became bound together inside hadrons, the initial result was that there were three neutrons produced for every one proton.

F In the process of primordial nucleosynthesis, all the elements of the Periodic Table from hydrogen (atomic number = 1) to iron (atomic number = 26) were created in their current proportions.

PART 2 *Attempt* **THREE** *of the four questions in this part.*

All questions in this part carry equal marks.

This part carries 36% of the total marks.

You are advised to spend about **60 minutes** *on this part.*

If the answer to a question is to be prose, free of sketches and calculations, then about 200 words per complete question should be sufficient to earn full marks, with appropriate proportions for parts of questions.

Some answers might require annotated sketches, in which case you will not need to write so much.

In any calculation, show full details of your working.

Question 9
part (a), 4%
part (b), 4%
part (c), 4%

The spectrum of the Sun's photosphere contains an absorption line from CaII at a frequency of 7.56×10^{14} Hz. The spectrum of the Sun's corona contains an emission line resulting from a transition between states of Ca^{14+} with an energy difference of 2.183 eV.

(a) Explain, with the aid of a diagram, why the CaII line is seen as an *absorption* line.

(b) (i) What do the 'II' and '14+' signify about the calcium atoms?

(ii) Calculate the wavelength in nanometres of the CaII line.

(iii) Calculate the wavelength in nanometres of the Ca^{14+} line.

(c) (i) The temperature of the corona is several million K. Why is the brightness of the corona in the visual part of the spectrum so low compared with the photosphere when its temperature is so much higher?

(ii) Briefly describe *one* technique that can be adopted in order to make observations of the corona in the visual part of the electromagnetic spectrum.

(iii) Explain why the temperature of the corona cannot be maintained by the transfer of heat from the photosphere.

(iv) Give the name of one proposed mechanism for the supply of energy to the corona.

Question 10
part (a), 6%
part (b), 6%

This question concerns Antares, the brightest star in the constellation of Scorpius. Antares is a binary star. Table 3 below lists some of the properties of the two component stars, A and B. The parallax for both Antares A and B is 0.0054 arcseconds.

Table 3 Some of the properties of stars, A and B

Property	**Antares A**	**Antares B**
Apparent visual magnitude	1.09	
Temperature (K)	3500	18 500
Angular diameter in arcseconds	0.041	

(a) (i) Calculate the distance in parsecs of Antares.

(ii) Calculate the absolute visual magnitude of Antares A.

(iii) Antares B appears 58 times fainter than Antares A in the visual waveband. Calculate its apparent visual magnitude.

(iv) What is the spectral class of each star?

(v) What are the dominant features in the spectra of each of Antares A and Antares B?

(b) (i) Show (by calculation) that the radius of Antares A is 820 $R_{\odot}$ (note 1 radian = 206 265 arcsec).

(ii) Use the answer to part b(i) and the fact that Antares A and B are at the same distance (and hence the ratio of luminosities $L_A/L_B = 58$) to calculate a radius for Antares B in units of solar radius.

(iii) State *two* assumptions you made to obtain your answer to part (b)(ii).

(iv) Which of Antares A or B is a main sequence star? Explain how you obtained your answer. In which region of the Hertzsprung–Russell diagram is the other star likely to lie?

Question 11
part (a), 5%
part (b), 7%

(a) (i) Explain what distinguishes the upper main sequence from the lower main sequence.

(ii) What nuclear reactions occur *shortly* after a star leaves the main sequence, and where in the star do they occur?

(iii) The next nuclear process to occur is the triple alpha process. What is the net effect of this process on the composition of a star?

(iv) What nuclear reactions follow in the *core* of a lower main sequence star?

(b) (i) Sketch a Hertzsprung–Russell (H–R) diagram. Label the axes with luminosity and temperature, including appropriate units and values.

(ii) Draw the positions of the following regions on your H–R diagram:

- the main sequence,
- red giants,
- white dwarfs,
- supergiants,
- instability strip.

(iii) Indicate the approximate positions of the following stars on your H–R diagram.

- S1: a 1 $M_\odot$ T Tauri star
- S2: a Mira variable star
- S3: an RR Lyrae star
- S4: a 1 $M_\odot$ stellar remnant

Question 12
part (a), 4%
part (b), 5%
part (c), 3%

This question concerns the properties of stars at the end of their evolution

(a) A star of initial mass less than about 11 $M_\odot$ becomes a white dwarf.

(i) What is the limiting mass of a white dwarf?

(ii) How is mass lost during formation of the white dwarf?

(iii) How do the following four properties of a white dwarf compare with those of the original star? (The answers you can select are: much greater, similar or much smaller.)

- radius
- density
- luminosity
- temperature

(iv) What force prevents the collapse under gravity of a white dwarf?

(b) A star of initial mass more than about 11 $M_\odot$ becomes a neutron star.

(i) How is mass lost during the formation of a neutron star?

(ii) How do the radius and density of a neutron star compare with those of a white dwarf?

(iii) What force prevents the collapse under gravity of a neutron star?

(iv) Briefly explain how a neutron star can be formed from a star with an initial mass less than 11 $M_\odot$.

(c) The most massive stars leave a remnant in the form of a black hole, from which no electromagnetic radiation can escape.

(i) State two ways in which a black hole could be detected.

(ii) A black hole has a Schwarzschild radius of 1.5 km. What is its mass in units of solar mass?

PART 3 *Attempt* **THREE** *of the four questions in this part.*

All questions in this part carry equal marks.

This part carries 36% of the total marks.

You are advised to spend about **60 minutes** *on this part.*

If the answer to a question is to be prose, free of sketches and calculations, then about 200 words per complete question should be sufficient to earn full marks, with appropriate proportions for parts of questions.

Some answers might require annotated sketches, in which case you will not need to write so much.

In any calculation, show full details of your working.

Question 13
part (a), 5%
part (b), 2%
part (c), 5%

The Galaxy may be broken down into four components: its disc, stellar halo, bulge and dark matter halo.

(a) How does the stellar component of the Galactic disc compare to that of the stellar halo in terms of:

(i) total masses of stars

(ii) their ages and chemical compositions.

(b) The stars in the bulge of our galaxy differ from those in both the disc and halo because they are old and metal rich. What does this observation imply for the history of star formation in the bulge?

(c) Briefly summarise the argument for the presence of the dark matter halo based on the properties of the Galactic rotation curve (shown in Figure 1) and the observed distribution of stars in the Galaxy.

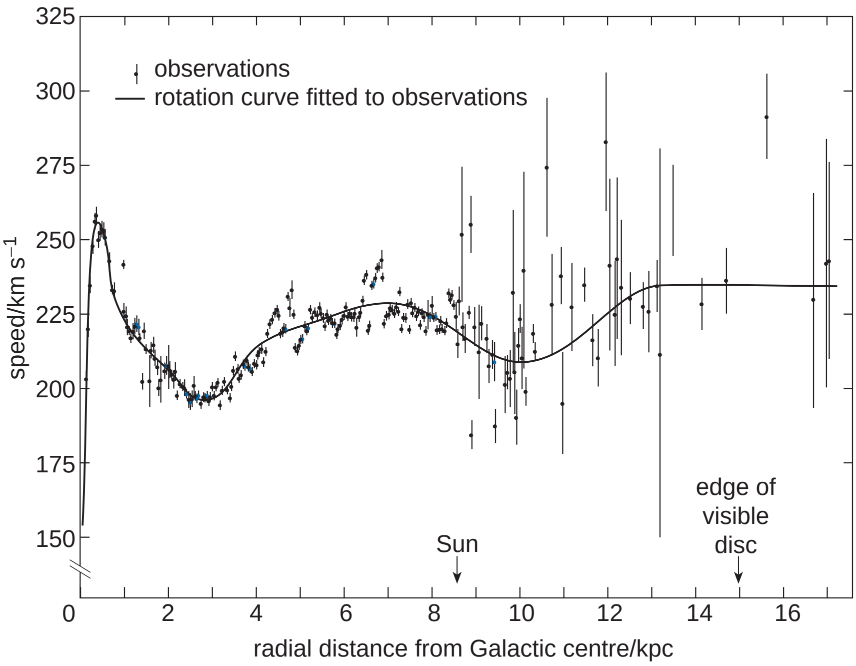

Figure 1 For use with Question 13.

Question 14
part (a), 4%
part (b), 8%

(a) An astronomer observes a star in a circular orbit of radius 0.3 pc around the centre of our Galaxy.

(i) How might the astronomer determine the orbital velocity of the star?

(ii) If the star is moving at 245 km s^{-1}, what is the mass of the object it is orbiting in solar masses?

(b) If the star is orbiting a supermassive black hole at the centre of our Galaxy we might also determine the mass of the black hole via the energy it radiates as matter falls into it.

(i) Explain the term *Eddington limit* in the context of an accreting black hole.

(ii) List two assumptions that are normally made in deriving the Eddington limit.

(iii) If the black hole at the Galactic centre has a luminosity of 2.2×10^{37} W, what is its minimum mass?

(iv) Why might the estimates for the mass of the black hole at the centre of the Galaxy derived from these two methods differ?

Question 15
part (a), 3%
part (b), 6%
part (c), 3%

(a) What are *standard candles*, and what is their importance in astronomy?

(b) For each of the astronomical objects below state whether or not they may be used as a standard candle, stating your reasoning.

(i) Cepheid variable

(ii) Pulsar

(iii) Type Ia supernova

(c) The earliest measurement of Hubble's constant was 600 km s^{-1} Mpc^{-1}. Quantitatively explain why this is incompatible with our current estimate of stellar ages.

Question 16
part (a), 6%
part (b), 6%

(a) (i) Sketch graphs of the scale factor (R) against time (t) for the four Friedmann–Robertson–Walker cosmological models that are usually described as 'closed', 'critical', 'open', and 'accelerating'. Take care to clearly label each graph.

(ii) State which of the four models listed in part (a)(i) is currently thought to provide the best description of our own Universe. Indicate the value of the curvature parameter (k) and the signs of the cosmological constant and deceleration parameter that currently describe that model.

(b) (i) In the context of cosmology, state, in a sentence or two, what is meant by inflation.

(ii) Briefly describe the horizon and flatness problems, and explain how inflation might solve each of these problems.

[END OF QUESTION PAPER]