Diploma Programme
Programme du diplôme
Programa del Diploma

Astronomy
Standard level
Paper 2

Friday 29 April 2022 (afternoon)

Candidate session number

1 hour 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **astronomy data booklet** is required for this examination paper.
- The maximum mark for this examination paper is **[60 marks]**.

2222 – 9005

Section A

Answer **all** questions. Answers must be written within the answer boxes provided.

1. (a) The ExoMars Orbiter probe was set in a circular orbit at an altitude of 400 km above the surface of Mars. Energy for orbit insertion was obtained from on-board fuel. Friction in Mars' thin atmosphere can be ignored.

Mars data:
Radius $= 3400\,\text{km}$
Mass $= 6.4 \times 10^{23}\,\text{kg}$

(i) Calculate the probe's orbital period. [2]

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(ii) Analyse why no additional energy from fuel was needed to maintain the probe moving in this orbit. [2]

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(b) Two stars, Avior and Alkaid, have the same apparent brightness.

(i) Their distances from the Sun are 172 and 33 pc, respectively. Calculate the luminosity of Avior relative to the luminosity of Alkaid. [2]

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(Question 1 continued)

(ii) The spectral types of Avior and Alkaid are K and B, respectively. State the name of **one** element that shows strong lines in the spectrum of each star. [2]

Avior (K): . . . . . .

Alkaid (B): . . . . . .

(c) Discuss why it would be more challenging to discover galaxies in the constellation of Orion using visual observations. [2]

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2. (a) All terrestrial planets are small and rocky. Explain why these properties are related to their location within the Solar System. [3]

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(b) (i) Earth's average temperature is about 290 K. Assuming Earth behaves like a black body, estimate how much power per unit area it emits in the form of electromagnetic radiation. [1]

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(ii) Greenhouse gases are efficient absorbers of certain wavelengths of electromagnetic radiation. Write down the name of **one** such gas next to the name of the type of radiation it absorbs. [2]

Ultraviolet	
Visible	
Infrared	
Radio	

(iii) Global warming is an increase in the average temperature of Earth. State **one** change to Earth's climate caused by global warming. [1]

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(This question continues on the following page)

(Question 2 continued)

(c) The Oort Cloud is believed to surround the planets at a great distance beyond Neptune. Explain, with reference to the observations, why astronomers think the cloud is there. [2]

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3. (a) S66 is a star orbiting Sagittarius A*, a supermassive black hole located at the centre of the Milky Way galaxy. The star lies about 1.6×10^{15} m from Sagittarius A* and its average speed is $5.9 \times 10^{5}\,\text{m}\,\text{s}^{-1}$. Assume S66 moves in a circular orbit.

(i) Show that the mass of Sagittarius A* is about $4 \times 10^{6}\,M_{\odot}$. [2]

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(ii) Suggest why S66 and other stars in the region are detected in the infrared and not in visible light. [1]

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(iii) Describe another piece of evidence that would confirm Sagittarius A* as a black hole. [2]

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(Question 3 continued)

(b) The image shows the Small Magellanic Cloud, a small galaxy companion to our Milky Way.

Identify the galaxy's type according to the Hubble classification for naming galaxies. [1]

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(This question continues on the following page)

(Question 3 continued)

(c) The image shows the starburst galaxy NGC 2442. Unlike typical spiral galaxies, this galaxy shows asymmetric spiral arms.

(i) Explain the reason for the lack of symmetry. [3]

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(Question 3 continued)

(ii) Astronomers believe that the lack of symmetry in NGC 2442 also provoked a burst of star formation. Identify the features seen in the image in part (c) that provide evidence of the star formation process. [2]

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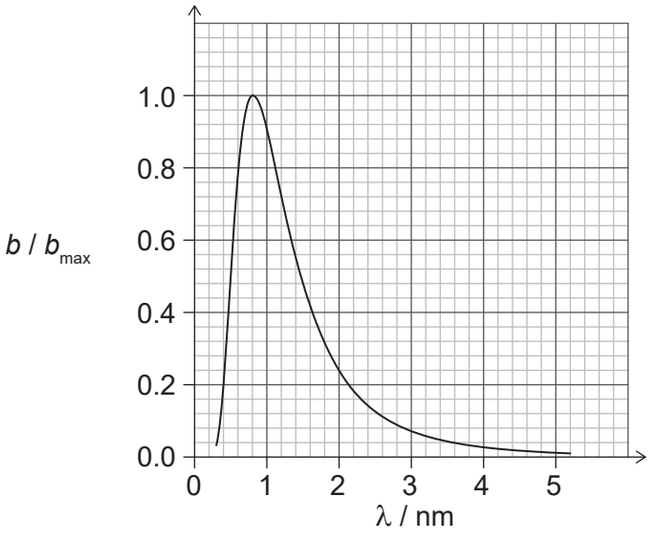
4. (a) The graph shows a plot of the cosmic microwave background (CMB). The vertical axis is the intensity relative to its maximum intensity.



(i) Show whether this curve represents the present-day CMB. [3]

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(ii) The intensity of the CMB is said to be isotropic. Define isotropic. [1]

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(Question 4 continued)

(b) The galaxy NGC 264 has a measured redshift of 0.017.

(i) Some of the redshift in NGC 264 is due to the expansion of the universe. Explain what other effect may cause the observed redshift of this galaxy. [2]

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(ii) Assuming that all the redshift is due to the expansion of the universe, calculate, in light-years, its distance from the Sun. [2]

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(c) Astronomers believe that the expansion of the universe is accelerating. Identify the cause of this apparent acceleration. [1]

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(d) Outline how the scientific community came to accept a theory, such as the Big Bang model. [1]

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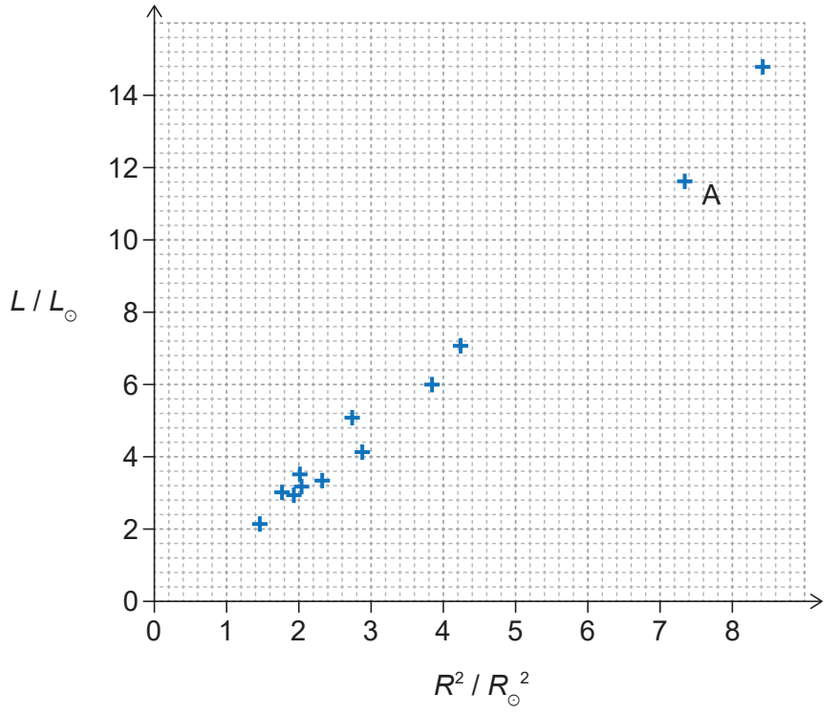
Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

5. (a) The graph shows the luminosity L as a function of the radius squared, R^2, for several stars. The stars have approximately the same temperatures. Errors are too small to be plotted.



(i) Estimate the radius of the star labelled A in the graph. [1]

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(Question 5 continued)

(ii) Assuming stars behave like black bodies, justify why the graph should show a linear relationship. [3]

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(iii) Draw a line of best fit through the data. [1]

(iv) Estimate, using your work in (a)(iii), the mean temperature, in K, of these stars. [3]

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(Question 5 continued)

(b) 84 Ceti is a main sequence star of spectral type F. The following data are also available.

Parallax (in seconds of arc)	4.5×10^{-2}
Angular diameter (in seconds of arc)	5.0×10^{-4}

(i) Show that the distance from 84 Ceti to the Sun is about 7×10^{17} m. [2]

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(ii) Calculate the radius of 84 Ceti in units of the solar radius. [3]

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(iii) Estimate the luminosity of 84 Ceti from the graph in part (a). [2]

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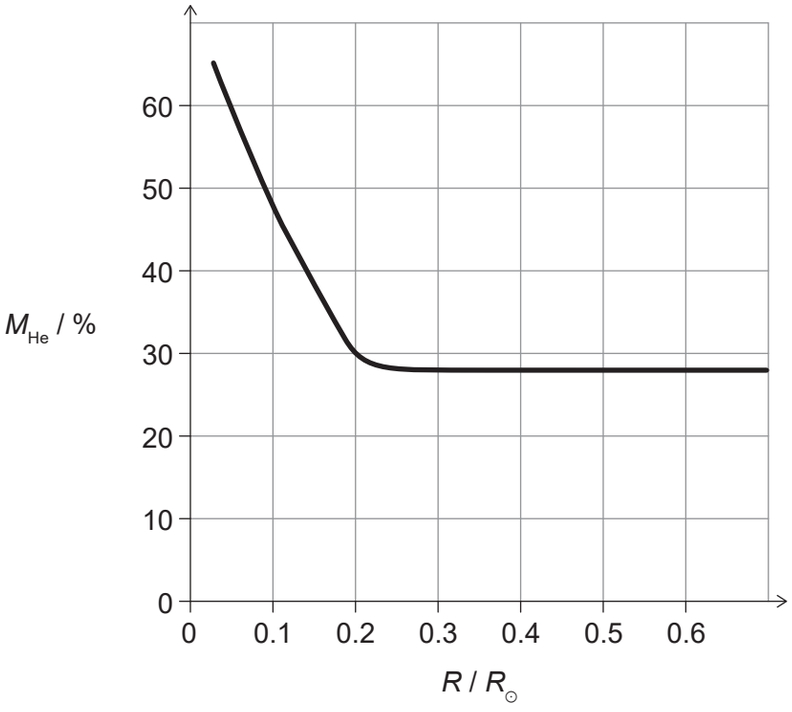
(Question 5 continued)

(c) The graph shows the mass of helium in the interior of the Sun as a function of the solar radius. The vertical axis represents the helium mass relative to the total mass at that radius.



(i) The solar core extends to about 0.25 of the solar radius. State where the helium outside the solar core comes from. [1]

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(ii) Explain the cause of the rise in the mass of helium within the solar core. [2]

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(Question 5 continued)

(iii) Explain at what point in the life of the Sun there will be an increase in the mass of helium outside the solar core. [1]

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(d) The graph in part (c) is a scientific model. Justify the use of such models in the study of the stars. [1]

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References:

3. (b) Image (b) Eso, 2017. *VISTA's view of the Small Magellanic Cloud*. [image online] Available at: <https://cdn.eso.org/images/publicationjpg/eso1714a.jpg> [Accessed 3 September 2020].

3. (c) Image (c) Eso, 2017. *Wide-field view of the Meathook galaxy*. [image online] Available at: <https://www.eso.org/public/images/eso1115a/> [Accessed 3 September 2020].

5. (a) Graph (a) Boyagian, T. S. et al., 2013. Stellar Diameters and Temperatures III. Main Sequence A, F, G, & K Stars: Additional high-precision measurements and empirical relations. *Astrophysical Journal*, 771, p.40.

5. (c) Graph (c) Ambastha, A.. 2010. *Solar Interior. 10.1007/978-3-642-11341-3_2*. Available at: <https://www.researchgate.net/publication/225250532_Solar_Interior> [Accessed 18 February 2021].

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