Diploma Programme
Programme du diplôme
Programa del Diploma

Astronomy
Standard level
Paper 2

28 April 2023

Zone A morning | **Zone B** afternoon | **Zone C** 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]**.

2223 – 9005

12 pages

Section A

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

1. (a) Sunspots are sometimes observed across the solar photosphere with measured temperatures of 4.2×10^3 K.

(i) Show that the apparent brightness of a sunspot is about 30 % of the apparent brightness of the photosphere. [3]

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(ii) State what a *sunspot minimum* is. [1]

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(iii) Explain why sunspots are very often seen in pairs. [2]

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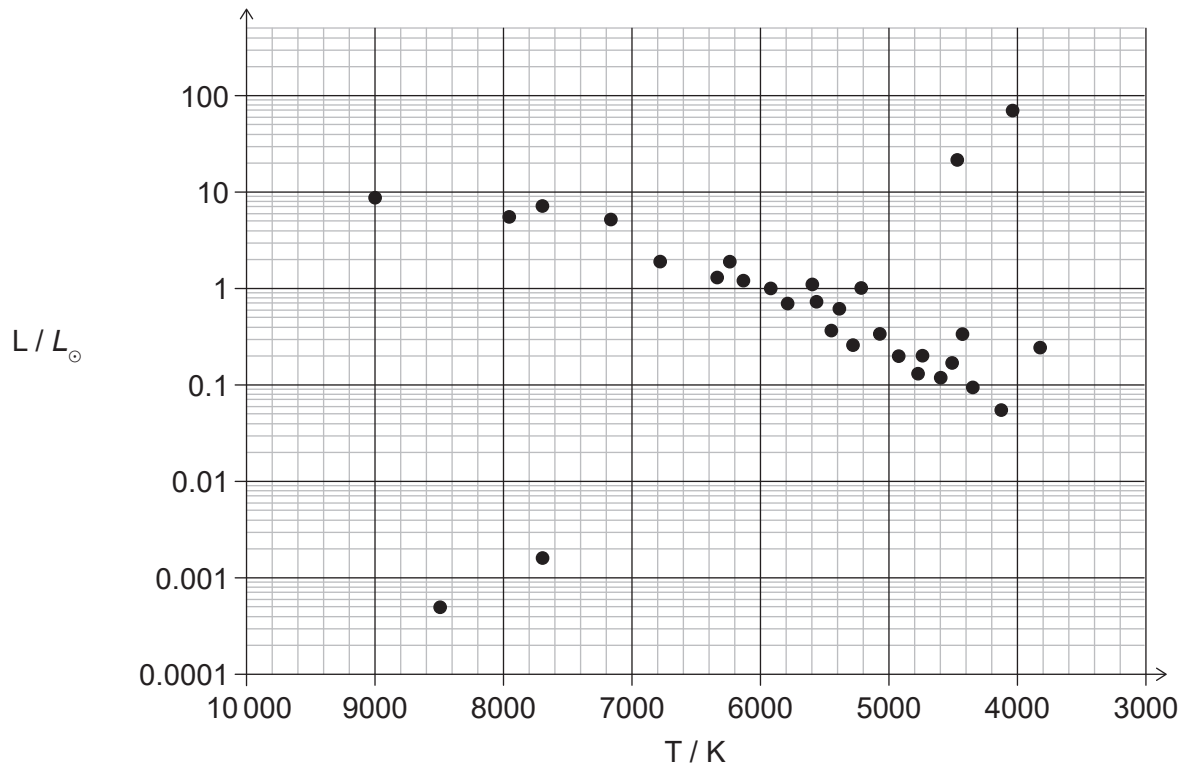
(Question 1 continued)

(b) The graph shows the Hertzsprung-Russell (HR) diagram of a group of stars.



(i) Estimate the temperature of a main sequence star with 10 % the luminosity of the Sun. [1]

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(ii) Sketch, with an arrow, the approximate path that a star of 1 solar mass will follow across the HR diagram from the main sequence until it becomes a red giant. [2]

(c) Explain how the Sun will generate energy when it becomes a red giant. [2]

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2. (a) The "nebular theory" for the formation of the solar system attempts to describe the observed motions of the planets.

(i) State **one** property of planetary motions satisfied by the nebular theory. [1]

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(ii) Outline the main stages that led to the formation of the solar system according to the nebular theory. [3]

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(b) (i) With reference to the internal structure of the planets, define *differentiation*. [2]

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(ii) Describe **one** mechanism that allows planets to become differentiated. [2]

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(Question 2 continued)

(iii) Explain why seismic waves allow scientists to study the internal structure of Earth and other planets. [2]

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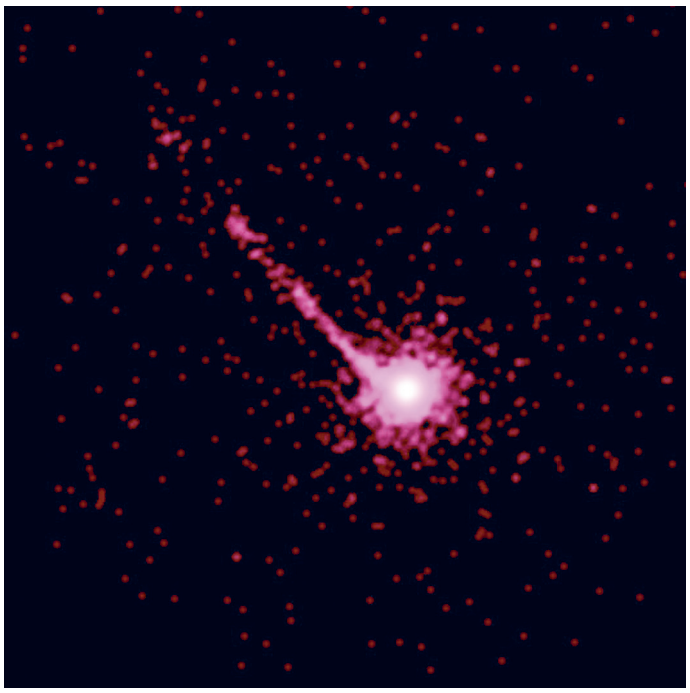
3. (a) The image shows a jet extending out of the nucleus of the quasar PKS 1127-145, which lies 3.2×10^3 Mpc from the Sun.



(i) State what is at the centre of the quasar. [1]

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(ii) The jet has a length of at least 1.1×10^{-4} radians. Estimate, in parsecs, the size of the jet. [2]

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(Question 3 continued)

(iii) Explain the source of the quasar's luminosity. [3]

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(iv) Sometimes, the features of the galaxy containing the quasar cannot be determined. Suggest why this is so. [2]

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(b) Many scientific papers about quasars have been published since their discovery in the 1960s. Suggest **one** reason why papers always include a bibliography section. [1]

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(c) Starburst galaxies are the result of galactic collisions. Identify the type of objects that are observed in starburst galaxies. [2]

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4. (a) Observations of the cosmic microwave background radiation (CMB) suggest that the universe has an average mass density almost equal to the critical density.

(i) State what is meant by *average mass density of the universe*. [2]

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(ii) Identify which type of geometry of the universe is implied by the CMB observations. [1]

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(iii) Explain how inflation solved the problem implied by the CMB observations. [3]

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(b) The local cluster of galaxies contains at least 70 known galaxies. Describe how astronomers found the location within the cluster for each galaxy. [2]

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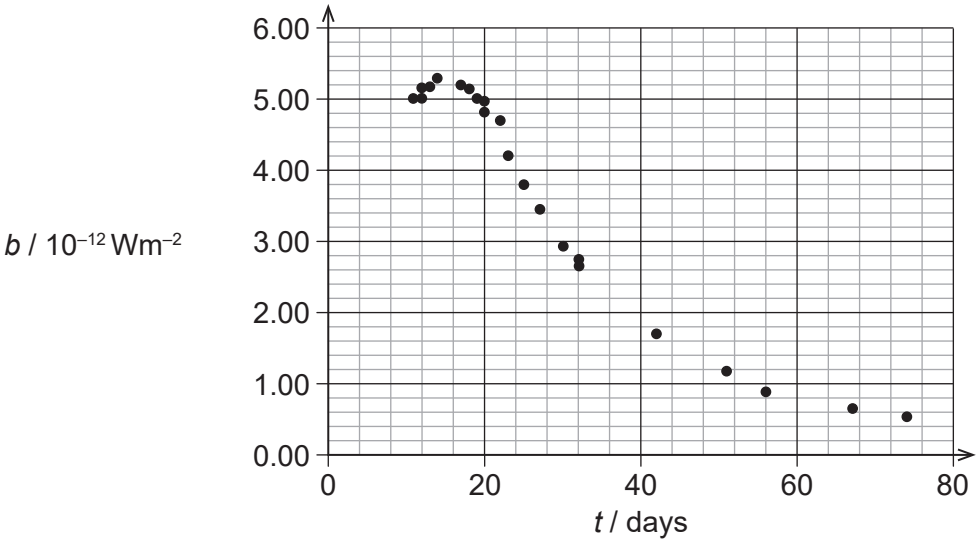
Section B

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

5. The graph shows the light curve of a type Ia supernova observed in the galaxy NGC 4527.



(a) At the peak of the explosion, the supernova generates a luminosity of about $5 \times 10^9 L_\odot$.

(i) Estimate, in light-years, the distance to NGC 4527 from the supernova light curve. [3]

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(ii) Discuss whether supernovae are better than cepheid variable stars as indicators of distance. [3]

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(Question 5 continued)

(b) Amateur astronomers regularly contribute data from supernova observations to professional astronomers. Suggest why amateur data may be useful for professional astronomers. [1]

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(c) The image shows the galaxy NGC 4527.

(i) Identify the type of this galaxy in the Hubble classification scheme. [2]

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(ii) Explain the presence of the dark regions across the disk of the galaxy. [2]

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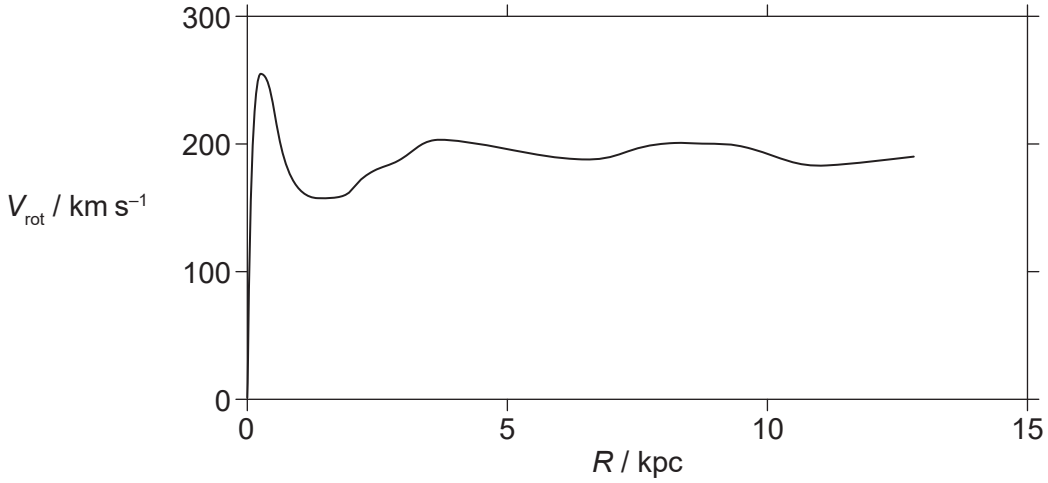
(Question 5 continued)

(d) The rotation curve of NGC 4527 is shown in the graph. Rotation curves suggest that galaxies contain large quantities of dark matter.



(i) Estimate, in solar masses, the total amount of matter within 5.0 kpc from the centre of NGC 4527. [3]

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(ii) Explain, without calculation, why the mass obtained in (d)(i) must be larger than the mass predicted by a rotation curve that follows Kepler's laws. [2]

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(Question 5 continued)

(e) The Sun has been a stable star since it formed 4.6×10^9 years ago. The formula shows part of the nuclear fusion process that takes place in the core of the Sun.

$$ {}_{1}^{1}H + \text{.....} \rightarrow {}_{2}^{3}He + \gamma $$

(i) Identify the missing term in the formula. [1]

(ii) Calculate the mass of hydrogen required to produce the energy the Sun emits in one second. [1]

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(iii) Using your answer for (e)(ii), show that about 0.03 % of the mass of the Sun was transformed into energy since the Sun formed. [2]

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References:

1. (b) Hoffleit, D. and Jaschek, C., eds., 1991. *Diagram based on selected numerical data*. [graph] The Bright Star Catalog, 5th ed. New Haven: Yale University Observatory. SOURCE ADAPTED.

3. (a) NASA; CXC; Siemiginowska, A; Bechtold, J., 2002. Quasar PKS 1127-145. [image online] Available at: https://chandra.harvard.edu/photo/2002/1127/. [Accessed 28 October 2021].

5. (a) Lira, P., *et al.* 1998. *Optical Light Curves of the Type Ia Supernovae 1990N and 1991T*. Astronomical Journal, vol. 115, p.234. SOURCE ADAPTED.

5. (c) Sloan Digital Sky Survey, 2019. *NGC 4527.* [image online] Available at: https://en.wikipedia.org/wiki/NGC_4527#/media/File:NGC4527_-_SDSS_DR14_(panorama).jpg [Accessed 28 October 2021].

5. (d) Sofue. Y., Tomita. A., Honma M. and Tutui Y., 1999. Central Kinematics and Rotation Curve of the Sb Galaxy NGC 4527 in CO, Hα, and [NII] Lines. *Publications of the Astronomical Society of Japan*. [e-journal] 51. Available at: https://articles.adsabs.harvard.edu//full/1999PASJ...51..737S/0000742.000.html. [Accessed 1 March 2022]. SOURCE ADAPTED.

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