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WORKSHEETS
ATTEMPT | CHECK | CORRECT | IMPROVE

OCR A A Level Astrophysics 3 cosmology and the expanding Universe worksheet

35-40 minutes independent practice + 15-20 minutes review | 48 marks

Specification points covered

- 5.5.3(a) Define the astronomical unit, light-year and parsec.
- 5.5.3(b) Describe stellar parallax and use d = 1 / p, where p is in arcseconds and d is in parsecs.
- 5.5.3(c) State the Cosmological Principle: on a large scale the Universe is homogeneous and isotropic, and the laws of physics are universal.
- 5.5.3(d) Describe the Doppler effect and the shift of electromagnetic radiation from moving astronomical sources.
- 5.5.3(e) Use $\Delta\lambda / \lambda = v / c$ for sources moving at speeds much less than the speed of light.
- 5.5.3(f) State and use Hubble's law $v = H_{0d}$.
- 5.5.3(g) Explain how cosmological redshift provides evidence for an expanding Universe.
- 5.5.3(h) Use the units km s^{-1} Mpc^{-1} and s^{-1} for the Hubble constant.
- 5.5.3(i) Describe the Big Bang model and supporting observations, including cosmic microwave background radiation at about 2.7 K.
- 5.5.3(j) Describe the expansion of the Universe as expansion of spacetime itself.
- 5.5.3(k) Estimate the age of the Universe using $t \approx 1 / H_0$.
- 5.5.3(l) Describe the evolution of the Universe from the Big Bang to the present.

Lumen Deep-Field Survey

The Lumen team builds a cosmic distance ladder. It begins with a nearby parallax calibration star, uses hydrogen lines to analyse the fictional galaxy Atria-19, and then tests a model for the whole Universe.
Keep units visible throughout. For spectral shifts, compare fractional changes rather than assuming that every line moves by the same number of nanometres.

1. Cosmic distance and stellar parallax

1. The survey uses the astronomical unit (AU), light-year (ly) and parsec (pc). State what each unit represents. [3 marks]

2. A nearby calibration star is photographed six months apart. Its total angular displacement against distant stars is 0.000120°. Explain why the parallax angle p is half this displacement. Convert p to arcseconds, then calculate the distance to the star in parsecs and light-years. Use 1° = 3600 arcseconds and 1 pc = 3.26 ly. [4 marks]

3. Explain why stellar parallax becomes unsuitable for very distant stars. State one practical improvement that allows a smaller parallax angle to be measured more reliably. [2 marks]

2. Reading a cosmological redshift

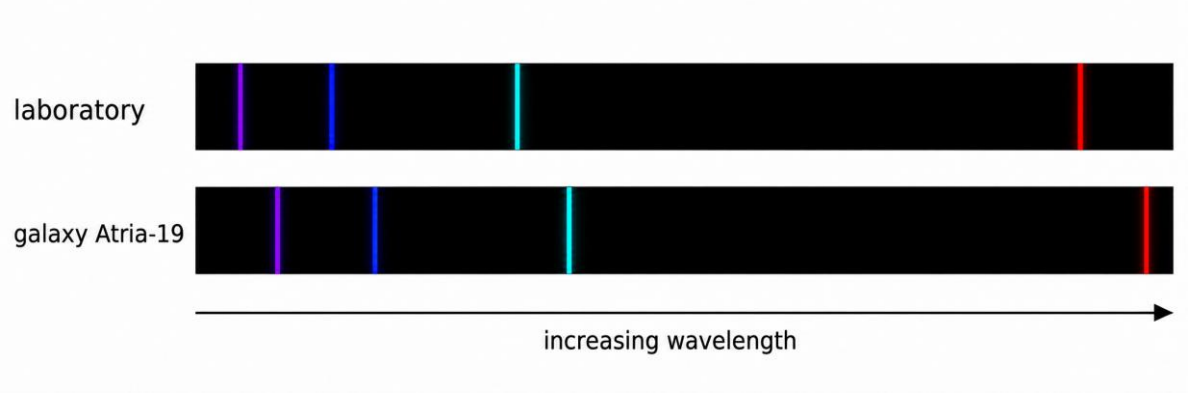

Figure 1: laboratory hydrogen lines and the spectrum of Atria-19

4. Figure 1 compares laboratory hydrogen lines with light from galaxy Atria-19. State whether the galaxy spectrum is redshifted or blueshifted and hence state whether Atria-19 is approaching or receding from Earth. Use the Doppler effect to explain the change in observed wavelength. [3 marks]

5. The laboratory Hα line has wavelength 656.3 nm. In Atria-19 it is observed at 679.9 nm. Calculate the wavelength change Δλ and the fractional change $z = \Delta\lambda / \lambda_{rest}$. [2 marks]

6. For the same galaxy, the laboratory Hδ line at 410.2 nm is observed at 425.0 nm. Show that its fractional change is consistent with your answer to Question 5. Explain why the two lines do not have the same change in wavelength measured in nanometres. [2 marks]

3. From redshift to distance

Survey model

For the speeds used here, $\Delta\lambda / \lambda_{rest} = v / c$.
The recession-speed–distance graph is a straight best-fit line through the origin, so its gradient is H_0.

7. Use the Hα data and $\Delta\lambda / \lambda_{rest} = v / c$ to calculate the recession speed of Atria-19 in km s^{-1}. Use $c = 3.00 \times 10^5$ km s^{-1}. [2 marks]

8. The best-fit line on the survey's recession-speed–distance graph passes through the origin and the point d = 240 Mpc, v = 16 800 km s^{-1}. Calculate the Hubble constant H_0 and give its usual astronomical unit. [2 marks]

9. Use your answers to Questions 7 and 8 to estimate the distance to Atria-19 in megaparsecs. [2 marks]

4. The Hubble constant, age and uncertainty

10. Convert H_0 = 70.0 km s^{-1} Mpc^{-1} to s^{-1}. Hence estimate the age of the Universe in seconds and in years using $t \approx 1 / H_0$. Use 1 Mpc = 3.09×10^{22} m and 1 year = 3.16×10^{7} s. [4 marks]

11. The value $1 / H_0$ is an estimate rather than an exact age. State the main assumption made about the expansion and explain why the assumption may not be valid throughout the history of the Universe. [2 marks]

12. The observed Hα wavelength is 679.9 ± 0.8 nm; uncertainty in the laboratory wavelength is negligible. Calculate the percentage uncertainty in the recession speed and hence the absolute uncertainty in the distance found in Question 9. [3 marks]

5. Interpreting the expanding Universe

13. A nearby galaxy in the Lumen Group has a small blueshift even though most distant galaxies are redshifted. Explain why this observation does not contradict Hubble's law. [2 marks]

14. On scales greater than about 500 Mpc, the survey finds approximately the same mean galaxy density in different regions and approximately the same appearance in every direction. Define homogeneous and isotropic. Explain why the existence of local clusters and voids does not disprove the Cosmological Principle. [3 marks]

15. A student says: 'Every distant galaxy is moving through space away from Earth, so Earth must be at the centre of the Big Bang.' Correct this description using the expansion of spacetime. [3 marks]

6. Evidence and the early Universe

16. Explain how cosmological redshift and cosmic microwave background radiation support the Big Bang model. Include the significance of the present CMB temperature of about 2.7 K. [3 marks]

17. Write a coherent account of the evolution of the Universe from the Big Bang to the present. Your answer should link expansion to falling temperature and should place these stages in a physically sensible order: quarks and leptons; hadrons; nuclei; atoms and released background radiation; stars and galaxies. [6 marks]