Solutions for Option D – Astrophysics

1. a) (i) take image of star in January and July and measure the distance star appears to have moved
(ii) \[ d = \frac{1}{P} = \frac{1}{0.419} = 2.39 \text{ pc} = 7.78 \text{ ly} \]
(iii) it is difficult to measure parallax of stars at great distances due to absorption and scattering of light in the atmosphere
b) \[ b \propto \frac{L}{d^2} \text{ so } \frac{\text{luminosity of Wolf 359}}{\text{luminosity of Sun}} = \frac{3.7 \times 10^{-15}}{1.58 \times 10^{-6}} = 8.9 \times 10^{-4} \]

2. a) \[ L = 4\pi \times (1.50 \times 10^{11})^2 \times 1.37 \times 10^3 = 3.9 \times 10^{26} \text{ W} \]
b) \[ L = \sigma T^4 \text{ so } T = \left( \frac{3.9 \times 10^{26}}{5.67 \times 10^{-8} \times 4\pi \times (6.96 \times 10^8)^2} \right)^{\frac{1}{4}} = 5.8 \times 10^3 \text{ K} \]

3. a) red super-giant → supernova → black hole
   b) (i) above this mass, gravity is too strong to be opposed by electron degeneracy pressure
   (ii) star can throw off mass to form planetary nebula

4. a) total power radiated by a star
   b) ![Graph of intensity vs. wavelength]
   c) ![Graph of luminosity vs. temperature]
   d) luminosity also depends on size of star

5. a) A & D are main sequence stars; B is red giant; W is white dwarf
   b) A and B have similar luminosities but A is far hotter. Luminosity is proportional to the area of the star and the temperature so if A is hotter than B must be larger.
   c) luminosity of sun = 4\pi d^2b
      from HR diagram, luminosity of B = 10^6 \times L_{\text{Sun}} = 3.6 \times 10^{31} \text{ W}
      \[ d_{B} = \sqrt{\frac{L_{B}}{4\pi b}} = 6.4 \times 10^{19} \text{ m} = 700 \text{ pc} \]

6. a) thermal radiation left over from the Big Bang – universe shows spectrum of blackbody emitter at around 3 K
   b) CMB is isotropic (looks the same in all directions), provides evidence of the high temperature early universe that cooled as it expanded
7. a) Lines from distant galaxy are red-shifted as galaxy is receding away from us
   b) Hubble’s law: \( v = H_0 d \); can estimate \( v \) by determining redshift and so estimate distance \( d \).
   c) More accurate techniques exist, such as using Cepheid variables

8. a) Milky Way is a spiral galaxy and contains more gas and dust than elliptical galaxies
   b) i) \( v = H_0 d \)
      ii) To measure Hubble constant, plot graph of \( v \) against \( d \). \( v \) can be obtained by measuring redshift of galaxies; \( d \) can be determined using Cepheid variables
   c) i) \( v = 68000 \times 4.6 = 313 \text{ km s}^{-1} \)
      ii) Age of universe = \( H_0^{-1} = 4.5 \times 10^{17} \text{ s} \)

9. a) An intergalactic cloud of gas and dust where all stars begin to form
   b) Jeans criterion is met when gravitational attraction within a gas is strong enough to overcome radiation pressure and begin forming a star

10. a) Proton-proton chain: three stage chain, using four hydrogen nuclei and producing He-4 as a product
   b) CNO cycle: six-stage process, also uses four hydrogen nuclei, uses carbon-12 as a fuel. C-12 and He-4 produced.

11. a) i) Neutrons are captured by the nucleus of other atoms through the strong force, producing a heavier isotope of the same element.
    ii) \( ^{4}A + ^{1}n \rightarrow ^{4}B \)
   b) s-process: slow neutron capture; stars provide small neutron flux as a by-product of carbon, oxygen and silicon burning; nuclides have time to undergo beta decay before further neutron captures so produce heavier and heavier isotopes of element
   r-process: not enough time for beta decay to occur so successively heavier isotopes are built up very quickly; high neutron flux

12. Massive stars need higher core temperatures and pressures to prevent gravitational collapse, and so fusion reactions occur at a greater rate than smaller stars.

13. After a star goes supernova, left with a white dwarf: gravity is opposed by electron degeneracy pressure. However, if the star is greater than the Chandrasekhar limit, electron degeneracy pressure is not strong enough to oppose gravity, and star collapses to form a neutron star, where gravity is instead opposed by neutron degeneracy pressure.

14. a) Critical density is the necessary density of matter in the universe for it to expand to a maximum limit
   b) i) \( 1.3 \times 10^{-26} \text{ kg m}^{-3} \)
      ii) Number of nucleons per unit volume = \( \frac{\rho_s}{m_p} = 7.8 \text{ m}^{-3} \)

15. a) Redshift of distant galaxies; CMB
   b) Necessary density of matter in the universe for it to expand to a maximum limit
   c) Fate of universe; big bang vs. big crunch

16. a) Implies universe is open and will keep expanding forever
   b) i) Evidence points to additional mass in universe; suggested that there is a dark matter halo surrounding the luminous matter in the universe which gives it extra mass
      ii) MACHOS: high density stars, hidden as they are far away from any luminous object
         WIMPs: non-baryonic subatomic particles, weakly interacting with baryonic matter; need huge quantities to make up dark matter