Option F — Astrophysics

F1. (a) (i) the apparent brightness is the power/rate of energy received per unit area at Earth; ***[1]***

(ii) a measure of the brightness of a star as it appears from Earth;
in a relative classification / on a 1-6 scale/logarithmic scale; ***[2]***

(iii) the apparent magnitude a star would have if viewed from a distance of 10 pc; ***[1]***

(b) luminosity; ***[1]***

(c) since apparent magnitude less than the absolute magnitude;
the star is close / closer than 10 pc;
answers must make the link between these two points to get the ***[2]*** *marks. No link then award* ***[1]***
stellar parallax can be used for distance up to 100/300 pc / less than 10 pc is close enough for parallax to be used; ***[3]***

(d) observation of spectrum allows determination of type of star (Main sequence, red giant, supergiant, *etc*.);
peak wavelength determines surface temperature;
hence position on HR is determined and hence luminosity;
if the luminosity is known then the absolute magnitude can be found / absolute magnitude is a measure of/related to luminosity; ***[4]***

(e) $d^2 = \frac{L}{4\pi b}$;
$d = 1.1\times10^{17}$ m;
$= 3.4$ pc; ***[3]***

F2. (a) universe is expanding / the galaxies are receding (from Earth); ***[1]***

(b) as the universe expands, it cools;
the microwave radiation corresponds to the radiation emitted by a hot early universe that has subsequently cooled / the microwave radiation is the red-shifted radiation from the big bang / *OWTTE*; ***[2]***

(c) the Doppler shift will get larger;
any sensible comment *e.g.* because the recessional speed is getting greater it is observable only over a very long-time period / not (a directly) observable effect; ***[2]***

(d) $\Delta\lambda = 33.50\,(\text{nm})$;
$\frac{\Delta\lambda}{\lambda} = 7.150 \times 10^{-2}\left(= \frac{v}{c}\right)$;
$v = 2.145 \times 10^{7}\ \text{m s}^{-1}$; ***[3]***

(e) (i) $H_0 = \frac{v}{d}$;
$H_0 = 74\,\text{km s}^{-1}\,\text{Mpc}^{-1}$ ***or*** $2.4 \times 10^{-18}\ \text{s}^{-1}$; ***[2]***

(ii) substitution into $T = \frac{1}{H_0} = 0.013\,\text{km}^{-1}\,\text{s Mpc}$;
$T(= 0.013 \times 10^{-3} \times 3.26 \times 10^{6} \times 9.46 \times 10^{15}) = 4.2 \times 10^{17}\ \text{s}$; ***[2]***

F3. (a) star A;
it has the smallest mass/mass closest to the Chandrasekhar limit/1.4 solar mass; ***[2]***

(b) any path shown from A to red giant region and then down to white dwarf region; ***[1]***
Allow ECF from part (a).

Option G — Relativity

G1. (a) a frame that is not accelerating / a frame in which Newton's first law is valid; ***[1]***

(b) (i) *Alice*:
the signal has equal distances to travel at constant speed / the signal takes the same time to reach the lamps;
they turn on simultaneously/together; ***[2]***

(ii) *Bob*:
the signals move away from Alice at the same speed, but lamp X moves towards the signal and lamp Y away from it;
lamp X receives the signal first (and turns on first); ***[2]***

(c) the electromagnetic path from switch to lamp X to Bob;
is longer than from switch to lamp Y to Bob; ***[2]***

(d) (i) the time measured by Alice, t_A, is proper time;
because the events happen at the same location;
therefore, Bob will measure a longer/dilated time; ***[3]***

(ii) the time dilation formula is independent of direction of motion;
there is no difference; ***[2]***

(e) (i) 30.0 m
the lamps are at rest in Alice's frame so she measures the proper length; ***[1]***
*Award **[0]** for a bald answer and/or incorrect explanation.*

(ii) $\gamma = 2.3$;
13.0 m; ***[2]***

G2. (a) $u' = \dfrac{0.900c + 0.950c}{1 + (0.900) \times (0.950)}$;

$u' = 0.997c$; ***[2]***

or

$0.900c = \dfrac{u - 0.950c}{1 - \dfrac{0.95u}{c}}$;

$u' = 0.997c$;

(b) $\gamma_P = \left(\dfrac{1}{\sqrt{1 - 0.900^2}} \right) = 2.29$;

$\gamma_L = \left(\dfrac{1}{\sqrt{1 - 0.997^2}} \right) = 12.9$;

$\Delta m = (10.6 \times 940) = 999\,\text{MeV}\,c^{-2}$; ***[3]***

*Award **[2 max]** for use of* $\Delta_m = \gamma m_0 - m_0$, *answer* $= \Delta_m = 1120\,\text{MeV}\,c^{-2}$.

G3. (a) energy of each pion $\left(=\frac{498}{2}\right)=249\,\text{MeV c}^{-2}$;

$$p=\sqrt{\frac{E^2-m_0{}^2c^4}{c^2}};$$

$$=\sqrt{249^2-135^2};$$

$$\simeq 209\,\text{MeV c}^{-1}$$ ***[3]***

(b) $\gamma m_0=249\left(\text{MeV c}^{-2}\right)$;

$p=209=249\text{u}$;

$u=0.84\text{c}$; ***[3]***

or

$$\gamma=\left(\frac{E}{m_0c^2}\right)=\left(\frac{249}{135}\right)=1.84;$$

$$v=\frac{p}{\gamma m_0} \quad \textbf{\textit{or}} \quad \gamma=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}};$$

$$v=\left(\frac{209}{1.84\times135}\right) \quad \textbf{\textit{or}} \quad \sqrt{\frac{1.84^2-1}{1.84^2}}=0.84\text{c};$$

or

$$v=\frac{p}{\gamma m_0};$$

$$v^2=\left[\frac{209}{135}\right]^2\times\left[1-v^2\right];$$

$$v=\left(\sqrt{\frac{2.41}{3.41}}\right)=0.84\text{c};$$

G4. (a) (i) spacetime is four dimensional quantity / three dimensions of space and one of time; ***[1]***

(ii) the path of an object in spacetime will be a line representing the geodesic/shortest spacetime displacement/distance; ***[1]***

(b) mass causes <u>spacetime</u> to curve / the mass of the black hole causes the curvature of <u>spacetime</u>;
such that shortest distance in spacetime is a path confined to region of black hole; ***[2]***

or

the black hole causes extreme curvature of <u>spacetime</u>;
such that no light/object/anything can escape from the surface;