Option F — Astrophysics

F1. (a) between Mars and Jupiter; ***[1]***

(b) as the Earth orbits the Sun, the Sun moves against the background of stars;
constellations cannot be seen when they are behind the Sun / *OWTTE*; ***[2]***
*Award **[1]** for realization that the Earth-Sun-star line falls on different stars through the year and **[1]** for realization that we cannot see those stars at that time.*

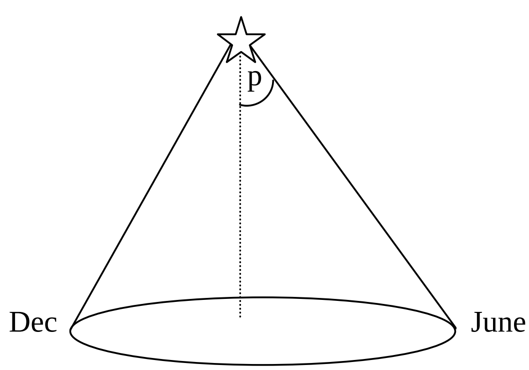
F2. (a) (i) the total power emitted (by the star); ***[1]***

(ii) the (incident) power per unit area on/received at the (surface of) Earth; ***[1]***

(b) (i) spectroscopic parallax; ***[1]***

(ii) use of $b = \frac{L}{4\pi d^2}$ to give $d = \sqrt{\frac{L}{4\pi b}}$;
$d = 5.3 \times 10^{19}$ m;
unit conversion gives 1700 pc; ***[3]***

(c) (i) measure angular position of star (against background of fixed stars);
at six month intervals;
$d = \frac{1}{p}$;
p identified; ***[4]***



(ii) $d = \frac{1}{5 \times 10^{-3}} = 200\,\text{pc}$; ***[1]***

F3. (a) spectral lines/frequency/wavelength of light from galaxies/distant objects are Doppler shifted to the red;
suggesting that galaxies/distant objects are moving away from each other;

or

Accept argument of Cosmic Microwave Background radiation.
everywhere in space there is a (uniform) radiation corresponding to a (black-body) temperature of $3\,\mathrm{K}$ / *OWTTE*;
(suggesting) an initially hot universe that has cooled has it has expanded / *OWTTE*; ***[2]***

(b) (the critical density) is the density of the universe for which the expansion rate (of the universe) will slow to zero but never reverse / produces a flat universe; ***[1]***

(c) a knowledge of the density gives knowledge of the future/past of the universe / *OWTTE*;
if $\rho < \rho_C$ then universe will expand forever;
if $\rho > \rho_C$ then universe will eventually reverse its expansion/contraction; ***[3]***

F4. (a) (i) $v = H_0 d$
the further galaxies are away (from Earth) the more difficult it is to accurately determine their distance away / *OWTTE*;
because of the difficulty of locating a standard candle/Cepheid variable (in the galaxy) / difficulty of accurately measuring luminosities (of the galaxy / of the standard candle); ***[2]***

(ii) to determine an accurate value of the age of the universe / to determine an accurate value of the rate of expansion of the universe / to determine an accurate value to very distant galaxies; ***[1]***

(b) $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

$\Delta\lambda = 90 \times 10^{-9}\,\mathrm{m}$;

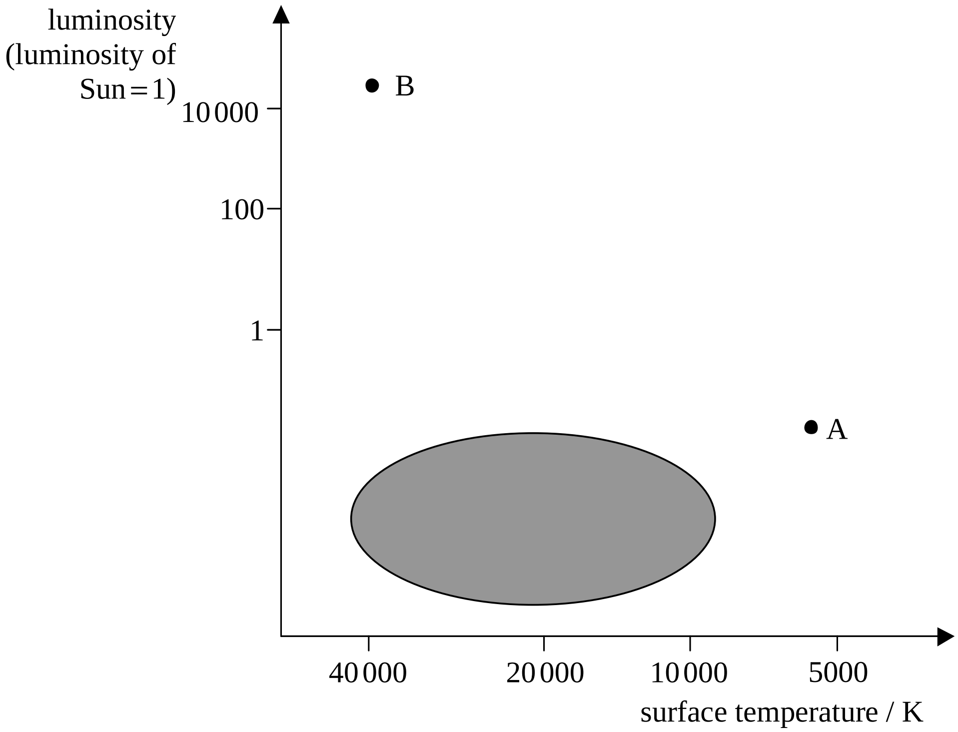
$v = 3 \times 10^{8} \times \frac{90 \times 10^{-9}}{660 \times 10^{-9}} = 4.1 \times 10^{7}\,\mathrm{m\,s^{-1}}$;

$d = \frac{v}{H} = \frac{4.1 \times 10^{4}}{75} = 550\,\mathrm{Mpc}$; ***[3]***

F5. (a) star B since much brighter and hotter (than star A);
indicating much greater amount of nuclear fusion taking place / is therefore radiating more energy / *OWTTE*; ***[2]***

(b) star B is able to fuse elements with higher atomic number than helium / is able to fuse silicon/carbon/neon/oxygen; ***[1]***

(c)



roughly in the shaded area; ***[1]***
Be generous – essentially "bottom left hand corner".

Option G — Relativity

G1. (a) a coordinate system (in which measurements can be made);
that is not accelerating / Newton's first law holds; ***[2]***

(b) there is no preferred inertial reference frame / the laws of physics are the same for all inertial observers;
the speed of light in a vacuum is constant;
in all inertial reference frames/for all inertial observers; ***[3]***

(c) (i) calculation of $\gamma = \frac{1}{\sqrt{1-0.80^2}} = 1.7$;
substitution into $L = \frac{L_0}{\gamma} = 140\text{ m}$; ***[2]***

(ii) substitution into $u_x{}' = \frac{u_x - v}{1 - \frac{u_x v}{c^2}}$
$u_x{}' = +0.60\text{c}$ and $v = -0.80\text{c}$;
calculation to give $u_x = -0.38\text{c}$;

or

$u_x{}' = -0.60\text{c}$ and $v = +0.80\text{c}$;
(signs are irrelevant, as long as they are opposite)
calculation to give speed $= 0.38\text{c}$ ***or*** $u_x = -0.38\text{c}$; ***[2]***
*Award **[0]** if non-relativistic kinematics is used.*

(iii) towards the star / to the left; ***[1]***

(d) $E = \gamma m_0 c^2 = \left(5.1\times10^3\text{ kg}\right)\times\left(9.0\times10^{16}\text{ m}^2\text{ s}^{-2}\right)$;
$E = 4.6\times10^{20}\text{ J}$; ***[2]***
Allow calculation from $E^2 = p^2c^2 + m_0{}^2c^4$.
Do not deduct unit mark.

G2. (a) the time between any two events that occur at the same place in an inertial reference frame / the proper time in particular reference frame will be measured to be longer;
by observers in any other inertial reference frame; ***[2]***

(b) muons (are produced in the upper atmosphere and) can be detected on the ground;
the half-life/life/average life of a muon in its own frame of reference is not long enough according to an observer on the ground for many of the muons to survive long enough to reach the ground / *OWTTE*;
the observed (ratio of) number detected on the ground (to number detected in the upper atmosphere) is higher than expected;
because the half-life/life/average life of a muon as measured by the an observer on the ground is long enough to for the muons to reach the ground / *OWTTE*;

or

muons (are produced in the upper atmosphere) and can be detected on the ground;
the half-life/life/average life of a muon in its own frame of reference is less than the time it takes to travel through the atmosphere as measured by an observer on the ground / *OWTTE*;
the measured lifetime of such a muon by an observer on the ground is longer than would be measured if the observer were moving with the muon / *OWTTE*;
the difference indicates that time has been dilated (from the short lifetime to the long transit time); ***[4]***

(c) lifetime as measured by Earth observer $\gamma \times 2.20\,\mu\text{s} = 2.20 \times 10^{-5}$ s ;
distance $= 0.995 \times 3 \times 10^{8} \times 2.20 \times 10^{-5} = 6.57 \times 10^{3}$ m ; ***[2]***

G3. (a) $mc^2 = m_0c^2 + E_K$;
$mc^2 - m_0c^2 = E_K$ and $mc^2 = \gamma m_0 c^2$;
so $m_0c^2(\gamma - 1) = E_K$ ***[2]***

(b) $E_K = 1.450 - 0.510 = 0.940$;
therefore $\gamma = \dfrac{0.940}{m_0c^2} + 1 = 2.84$;
$2.84 = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ to give $v = 0.936c$; ***[3]***

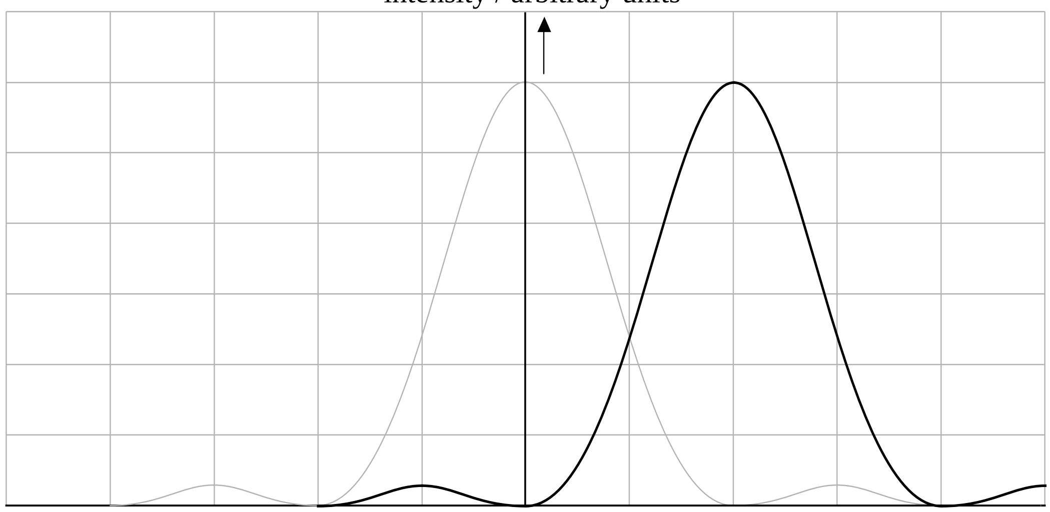
G4. (a) (the frequency is) lower; ***[1]***

(b) the principle says that it is impossible to distinguish between an accelerating reference frame and a gravitational field;
therefore light emitted from Y will have a lower frequency when compared to light from X / *OWTTE*; ***[2]***

(c) $f = \frac{c}{\lambda} = \frac{3\times10^{8}}{6.6\times10^{-7}} = 4.5\times10^{14}\text{ Hz}$;

$\Delta f = f\,\frac{g\Delta h}{c^{2}} = \frac{9.81\times4.5\times10^{14}\times1.4\times10^{4}}{9\times10^{16}} = 690\text{ Hz}$; ***[2]***

H3. (a)



maxima to coincide with minima and minimum at maximum of first source;
minima to touch x-axis and intensity of maxima to equal intensity of maximum of first source; ***[2]***
Only one maximum and minimum need be shown.

(b) angle subtended at eye $= \dfrac{2.3\times10^{6}}{4.5\times10^{12}} = 5.1\times10^{-7}$ rad;

$= 1.22\dfrac{\lambda}{b}$ to give $b = \dfrac{1.22\times5\times10^{-7}}{5.1\times10^{-7}} = 1.2\text{ m}$;

Do not penalize if 1.22 not used (1.0 m).
some comment to the effect that this much larger than the diameter of the pupil so that Pluto <u>cannot</u> be resolved as a disk / is a point source; ***[3]***
Accept an answer based on a reasonable estimate for pupil diameter and therefore, shows that Pluto would have to be much nearer to be resolved.

H4. (a) light reflected from the top surface of the wedge interferes with light reflected from the bottom surface;
some statement about the condition for <u>either</u> maximum <u>or</u> minimum in relation to the thickness of the film; ***[2]***
e.g. path difference depends on wedge thickness so goes through maximum and minimum / OWTTE (no need to mention phase change on reflection).

(b) number of fringes in 5.0×10^{-2} m $= 4.2\times10^{2}$;
path difference at edge of tape $= m\lambda = 4.2\times10^{2}\times4.8\times10^{-7}$;
$= 2d$ to give $d = 1.0\times10^{-4}$ m; ***[3]***