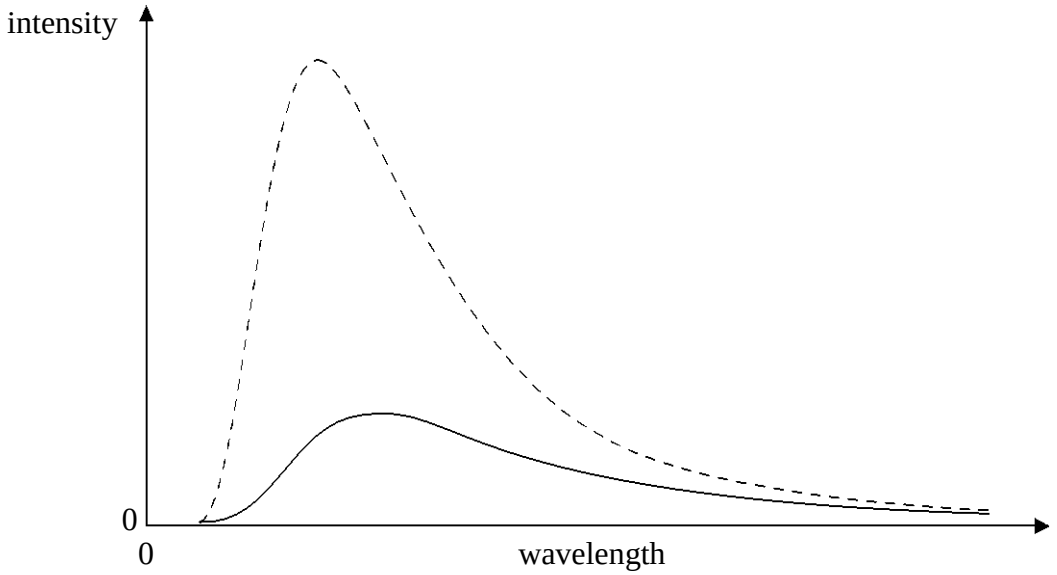
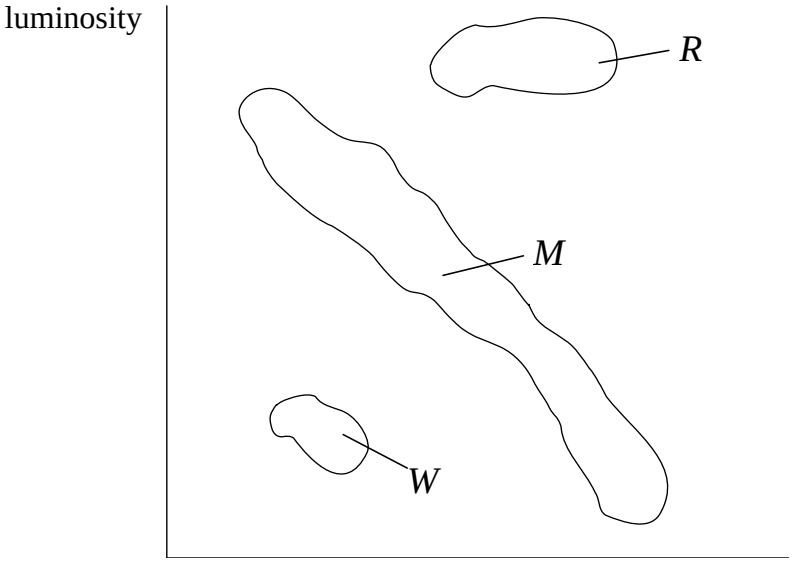
Option F — Astrophysics

F1. (a) (total) power radiated / energy radiated per unit time; ***[1]***

(b) the curve should be above the existing curve at all locations with sharper peak;
the peak should be shifted to shorter wavelengths; ***[2]***



(c) *Award **[1]** for one correct label, award **[2]** for all three correct.*



[2]

(d) luminosity depends on temperature;
luminosity depends on area/radius;
so different temperatures can have different luminosities / graph does not include area; ***[3]***

F2. (a) apparent magnitude is a measure of how bright an object appears (from Earth);
absolute magnitude is a measure of, how bright an object appears / the apparent magnitude, when observed from a distance of $10\,\text{pc}$; ***[2]***

(b) (i) $b = \frac{L}{4\pi d^2} \Rightarrow \frac{b_A}{b_B} = \frac{L_A d_B^{\ 2}}{L_B d_A^{\ 2}}$;

rearrange to give $d_B = \sqrt{\frac{b_A L_B}{b_B L_A}} d_A$;

substitution to give $d_B = \sqrt{25} d_A$; (hence $500\,\text{pc}$) ***[3]***

(ii) if star A was at 10 pc, it would be 100 times brighter (because brightness scales with d^{-2});
so absolute magnitude is five below the apparent magnitude; (hence 0.0) ***[2]***
N.B. *Award maximum credit for detailed calculation leading to correct answer.*

F3. (a) light from distant galaxies/stars is red-shifted / existence of CMB / interstellar gas temperature in distant galaxies is $> 3\,K$; ***[1]***

(b) (i) the critical density is the density of the Universe that would be necessary to stop the expansion after an infinite amount of time; ***[1]***
Do not accept answers based on "the density at which the universe is flat".

(ii) whether the universe will expand forever or close back in on itself is determined by the comparison of these values;
at low density, the universe will continue to expand forever;
at high densities, the universe will stop expanding and then contract / eventually contract; ***[3]***
Award of second and third marks means, by implication, that the first has been scored.

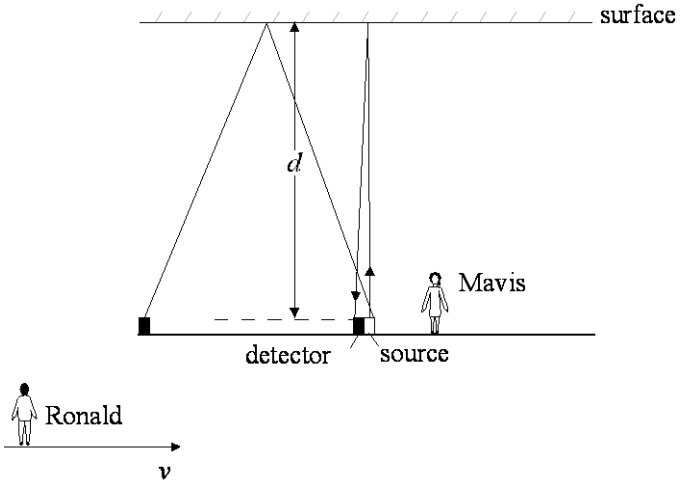
F4. (a) fusion/burning of elements higher than helium;
(in final stages) matter ejected as a supernova explosion;
core collapses to a neutron star; ***[3]***

(b) neutron star rotates rapidly (and has large magnetic field);
charged particles accelerated due to large magnetic field;
produce directed beams of radiation; ***[3]***

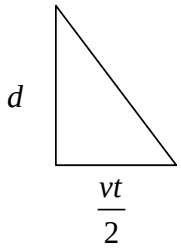
F5. use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$;
to give $v = 6.48\times10^{6}\ \text{m s}^{-1}$;
use of $v = H_0 d$;
to give $d = 93\,\text{Mpc}$; ***[4]***
*Award **[3 max]** if candidate divides by 401.8nm, v = 6.35 x 10^6m s^{-1}which gives 91 Mpc.*

Option G — Relativity

G1. (a) the detector drawn some distance away from the original pair and off to the left;
Accept indication with arrow(s).
a light beam symmetric about a vertical line passing through the point where the beam hits the mirror joining the emitter and detector; ***[2]***



(b)
(b) identifies triangle with a base equal to $\frac{vt}{2}$ and height $= d$;



application of Pythagoras' theorem;
total path twice hypoteneuse; ***[3]***

(c) (i) $t_0 = \frac{2d}{c}$; ***[1]***

(ii) observed time,

$t = \frac{L}{c} = \frac{2\sqrt{d^2 + \left(\frac{vt}{2}\right)^2}}{c}$;

rearrange to give

$t^2(c^2 - v^2) = 4d^2$;

thus

$t = \frac{2d}{c}\left(\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}\right)$; ***[3]***

$\left(\text{and hence } t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}\right)$

G2. light from clock A travels further to Frank than light from clock B;
at the same constant speed *c* / speed of light is same for both observers;
light from clock A takes longer to reach Frank / if Frank observes clock A change to 1, clock B will already have changed;
therefore, clocks do not read the same time;

or

events are simultaneous to Albert;
so cannot be simultaneous in a different/Frank's frame of reference;
light from B travels shorter distance at speed *c*;
so B changes first/runs faster; ***[4]***

G3. (a) if the muon measures 4500 m in its reference frame; *recognizes the idea of two frames of reference*
the muon/Earth would have to travel at $2.0 \times 10^9\ \text{m s}^{-1}$ / faster than the speed of light;
which is not possible;
distance travelled, <u>as measured in muon's reference frame</u> must be less/contracted; ***[4]***

(b) $mc^2 = Ve + m_0c^2$;
$= 210\,\text{MeV} + 105\,\text{MeV}$
$= 315\,\text{MeV}$;
$m = 315\,\text{MeV}c^{-2}$ ***or*** $3m_0$; ***[3]***

G4. (a) each proton must have two rest-mass energies $(=1860\text{ MeV})$ / rest mass energy of products is $4\times930\ (=1860\,\text{MeV})$;
particles after collision have no kinetic energy; ***[2]***

(b) use of $E^2 = p^2c^2 + m_0{}^2c^4$; ***or*** $mc^2 = \gamma m_0 c^2$;

$1860^2 = p^2c^2 + 930^2$; $\gamma = \dfrac{m}{m_0} = \dfrac{1860}{930} = 2$;

$p = \sqrt{\dfrac{(1860^2 - 930^2)}{c^2}}$; use of $\left(1-\dfrac{v^2}{c^2}\right)^{-\frac{1}{2}}$ to give $v = 0.866c$;

$p = 1610\,\text{MeV c}^{-1}$; $p = 1860\times0.866 = 1610\,\text{MeV c}^{-1}$; ***[4]***

G5. (a) Earth causes warping of spacetime;
satellite follows shortest path in spacetime $\rightarrow$ curve; ***[2]***

(b) black hole causes <u>extreme</u> warping of space in its vicinity;
extreme warping causes photons/light to curve back into the black hole; ***[2]***