OPTION E TEST REVIEW
MARKSCHEME

1. (a) (i) spectral class; 1

Accept colour sequence.

(ii) absolute magnitude; 1

(b) 4

Star	*Type of star*
A	Main sequence;
B	Super Red Giant;
C	White Dwarf;
D	Main sequence;

*Award **[1]** for each correct name.*

(c) B more luminous than A;
and has lower temperature than A;
so from the Stefan-Boltzmann law;
B has greater area (radius); 3 max

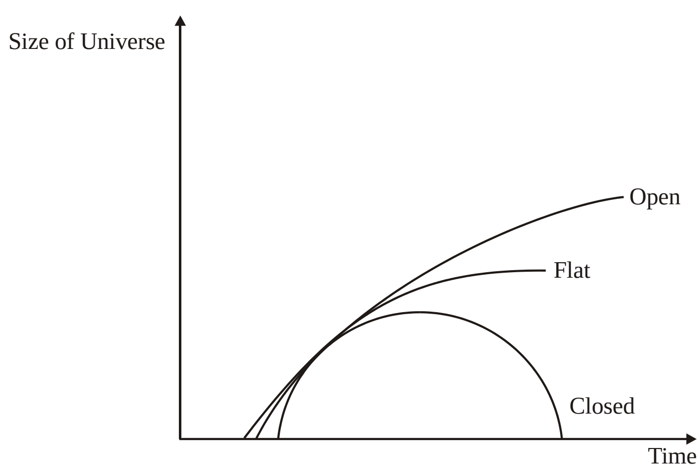
(d) use of $L = 4\pi bd^2$;
from the H-R diagram $L_B = 10^6 L_{Sun}$;
therefore $\frac{L_B}{L_{sun}} = 10^6 = \frac{7.0 \times 10^{-8} \times d_B^2}{1.4 \times 10^3}$;
to give $d_B = 1.4 \times 10^8$ *AU* (≈ 700 pc); 4

No mark is awarded for the conversion from AU to pc.

(e) at this distance the parallax angle is too small to be measured accurately;
OWTTE; 1 max

Do not accept "it's too far away"

2. (a)



3 max

*Award **[1]** for each correct label.*

(b) 3 max

Type of Universe	*Relation between ρ and ρ_0*
Open	$\rho < \rho_0$
Flat	$\rho = \rho_0$
Closed	$\rho > \rho_0$

*Award **[1]** for each correct entry.*

3. (a) mass; 1

(b) Chandrasekhar limit defines the maximum mass that a white dwarf can have;
at a mass equal to the limit the core of the star is prevented from contracting further by electrons;
above this mass the electrons cannot support the core and it further contracts causing the electrons to combine with protons to form neutrons;
OWTTE; 3 max

(c) pulsar; 1

4. (a) the universe is expanding; 1

(b) any sensible straight line; 1

(c) Slope of the graph; 1

(d) $T = H^{-1}$;
correct conversion of units to get $T \approx 10^{10}$ years; 2

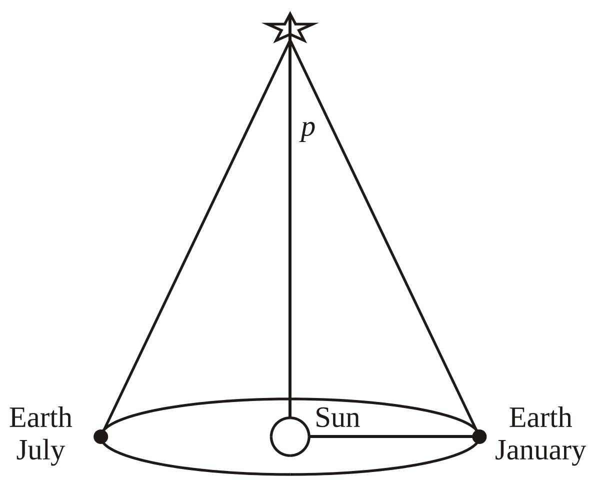
5. (a) Earth → Mars → Jupiter → Pluto; 2 max

*All correct **[2]**, two in the wrong place **[1]**.*

(b) Pluto → Mars → Earth → Jupiter; 2 max

*All correct **[2]**, two in the wrong place **[1]**.*

6. (a)



Mark the definition of p and description of its measurement along with the diagram.

Essentially diagram should:
show *p*;
position of Sun;
position of Earth;
then definition of $p = \frac{\text{(distance of Earth from Sun)}}{\text{(distance of star from Sun)}}$;
diagram should show Earth positions separated by about six months;

then description should mention that angle of sight is measured at these two positions such that the difference between these two angles is equal to $2p$; 6 max

*Award **[6 max]** for a clear description and diagram, **[3]** for an average and **[1]** for some rudimentary idea. Mark diagram and description together.*

(b) $d = \frac{1}{p} = \frac{1}{0.549} = 1.82$ pc;

$= 1.82 \times 3.26 = 5.94$ ly; 2 max

(c) (i) the radiant power from a star;

that is incident per m^2 of the Earth's surface;

Alternatively, define from $b = \frac{L}{4\pi d^2}$ *but terms must be defined to obtain the mark.*

definition of L;

definition of d; 2 max

(ii) $L = 4\pi d^2 b$;

therefore, $\frac{L_B}{L_S} = \frac{d_B{}^2 b_B}{d_S{}^2 b_S}$;

$d_S = 1\text{AU}$, $d_B = 3.8 \times 10^5$ AU;

therefore, $\frac{L_B}{L_S} = (3.8)^2 \times 10^{10} \times 2.6 \times 10^{-14} = 3.8 \times 10^{-3}$; 4 max

Allow any answer between (3.0 and 4.0) $\times 10^{-3}$.

(d) (i) temperature too low for it to be a white dwarf; 1 max

(ii) luminosity too low for it to be a red giant; 1 max

7. (a) fusion;

of hydrogen to form helium; 2 max

*Responses must have all three aspects correct eg "nuclear fusion" would receive **[0]**, "hydrogen forms helium", would receive **[1]**.*

(b) the temperature must be "high enough" is adequate; 1 max

(c) the stars "run out of" hydrogen (in their cores); 1 max

(d) *Award **[1]** each for any salient points for the two evolutionary paths post red giant stage. Award **[3]** "per path" up to **[6 max]**.*
*The **Chandrasekhar limit** must be correctly noted in **either** (i) **and/or** (ii) and scores **[1 max]**. Mention must be made of the Chandrasekhar limit to achieve full marks; else award **[1 max]**.*

Note that the information could be presented "pictorially" as stages in the evolutionary progress.

(i) *low mass stars*:

helium fusion in the core pushes out the outer layers of the star to form a planetary nebula;

with a small (collapsed) hot star at its centre – a white dwarf;

mass of the remaining core $\approx<$ Chandrasekhar limit / $\approx>$ $1.4M_{sun}$;

carbon fusion cannot take place;

when helium runs out the star cools;

core cannot collapse further due to "electron degeneracy pressure"; 3 max

(ii) *high mass stars*:

carbon fusion and fusion of heavier nuclei can take place;

mass of the remaining core > Chandrasekhar limit / > $1.4M_{sun}$;

the greater mass allows the gravitational attraction to overcome the electron

degeneracy pressure;
finally the core collapses giving a supernova and leaving behind;
either a neutron star (when the contraction / collapse is stopped
by neutron degeneracy pressure, core mass ~≤ $3M_{sun}$) or a black hole; 3 max

8. (a) (i) luminosity is the total power radiated by a star / source; 1

Do not accept $L = \sigma AT^4$.

(ii) apparent brightness is the power from a star received by an observer on Earth per unit area of the observer's instrument of observation; 1

Accept $b = \frac{L}{4\pi d^2}$ *if L and d are defined.*

(b) the surface area / size of the star changes periodically (due to interactions of matter and radiation in the stellar atmosphere); 1

(c) (i) at two days the radius is larger / point A;
because then the luminosity is higher and so the area is larger; 2

*Award **[0]** if no explanation is provided.*

(ii) *Award **[1]** for each relevant and appropriate comment to the process of using Cepheid variables up to **[3 max]** eg*

Cepheid variables show a relationship between period and luminosity;
hence measuring the period gives the luminosity and hence the distance (through $b = \frac{L}{4\pi d^2}$);
distances to galaxies are then measured if the Cepheid can be ascertained to be within a specific galaxy; 3

Marks can be back credited from answer (d) (ii).

(d) (i) $b = \frac{L}{4\pi d^2} \Rightarrow 1.25 \times 10^{-10} = \frac{7.2 \times 10^{29}}{4\pi d^2}$;

$d = \sqrt{\frac{7.2 \times 10^{29}}{4\pi \times 1.25 \times 10^{-10}}}$;

$d = 2.14(\pm 0.2) \times 10^{19}$ m; 3

(ii) *Award **[1]** for each relevant and appropriate comment to the phrase "standard candles" up to **[2 max]** eg*

the phrase *standard candle* means having a source (of light) with known luminosity;

measuring the period of a Cepheid allows its luminosity to be estimated / other stars in the same galaxy can be compared to this known luminosity; 2

9. (a) cosmic background radiation is microwave radiation;
"filling" the universe / from all directions; 2

Award other relevant and appropriate comments eg "at a temperature of about 3K or left over from the Big Bang".

(b) the Big Bang predicts an expanding universe that had a very high temperature at the beginning; during the expansion the universe is cooling down and the temperature of the radiation should fall to its present low value, (which is precisely what the cosmic background radiation measures); 2

or

Big Bang producing initially very short wavelength photons / em

radiation;
as the universe expands, the wavelengths become redshifted / longer (to reach current value); 2

(c) the redshift in the light observed from distant galaxies (indicating that they are moving away from each other) / the helium abundance in the universe which is about 25% and is consistent with a hot beginning of the universe; 1

__Note__: question asks for evidence so do not accept "universe is expanding" unless the answer mentions redshift etc.

(d) the student is wrong; space is created as the universe expands / there is no outside to the universe; 2

Award __[0]__ if no explanation or incorrect explanation.

10. (a) *Diagram should show*
spiral arms;
central disc;
the solar system on one of the arms about a third of the way from the centre; 3

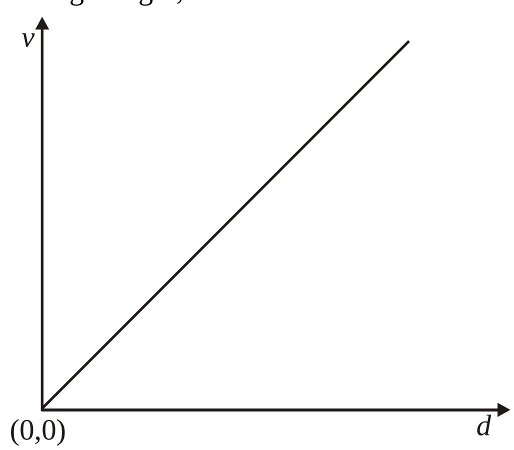
Be generous in the position – accept between $\frac{1}{4}$ and $\frac{3}{4}$.

(b) $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c} \Rightarrow \frac{670-658}{658} = \frac{v}{c}$;

hence $v = \frac{670-658}{658}c = 0.018c = 5.47 \times 10^3 \text{ km s}^{-1}$; 2

Award __[1 max]__ for $\frac{670-658}{670} = 0.0179$.

(c) (i) straight-line;
through origin; 2



(ii) relative speed of two points in the universe separated by distance d is $v = \frac{d}{T}$

where T is the age of the universe / argument to show $v = \frac{d}{T}$;

$v = \frac{d}{T} = H_0 d$ therefore $T = \frac{1}{H_0}$; 2

Award __[0]__ for answers that just show that $T = \frac{1}{H_0}$ has the right units.

(iii) the Hubble constant is obtained from the slope of the graph; 1

11. (a) massive body of gas / gas / plasma;
giving off light / radiant energy / electromagnetic radiation *etc*; 2

Allow alternative acceptable comments.

(b) *constellation*:
pattern of stars as seen from Earth;
not close to one another in space;

galaxy:
large group of stars;

other detail *eg* $\approx 10^{10}$ stars, diameter $\approx 10^{5}$ ly *etc*; 4

*Award other detail **[1]** for constellation or galaxy.*

16. (a) apparent magnitude is a measure of (comparative) brightness as seen from Earth (with 1 being brightest and 6 being dimmest);
absolute magnitude is the apparent magnitude that the star would have if it were a fixed distance from the Earth of 10 parsecs; 2

(b) yes plus reason; 1

***Note**: an explanation must be provided. Award **[0]** for bald "yes" without an attempt at a reason. eg since apparent magnitude low (less than one) therefore one of the brightest stars.*

(c) (i) distance away = $\dfrac{3.39\times10^{17}}{9.46\times10^{15}}$ = 35.8 ly = 11.0 pc; 1

(ii) since this is less than 100 pc;
the star is close enough for stellar parallax; 2

*Award **[1]** for a bald answer. Also allow ecf if conversion of units is muddled.*

(iii) *Award **[1]** each relevant piece of experimental description up to **[4 max]**.*
eg position of star compared with other star positions;
at different times of the year;
the maximum angular variation from the mean p is recorded;

the distance (in parsecs) can be calculated using geometry $d = \dfrac{1}{p}$ if p is in arcseconds;

***Note**: watch for ecf. If the response has suggested one of the other techniques in (ii) then award full marks for appropriate descriptions.*

example:
spectroscopic parallax: light from star analysed (relative amplitudes of the absorption spectrum lines);
to give indication of stellar class;
HR diagram used to estimate the luminosity;
distance away calculated from apparent brightness;

Cepheid variables: these stars' brightness vary over time;
the time period of the variation is related to their luminosity;
thus measurements of the time period of one star can be used to calculate its luminosity;
its distance away is calculated from maximum apparent brightness; 4 max

(d) spectral type / K / *OWTTE*;
thus at low end of temperature scale: OBAFGKM / Sun is G / *OWTTE*; 2

(e) (i) correct substitution into $L = \sigma AT^4$;

to get A = $\dfrac{3.8\times10^{28}}{(5.67\times10^{-8}\times4000^4)}$ $=2.62\times10^{21}$ m^2; 2

(ii) use of $4\pi r^2 = 2.62\times10^{21}$ m^2;
to get $r = 1.44\times10^{10}$ m (= 0.10 AU); 2

(iii) use of $\lambda_{max} = \dfrac{2.90\times10^{-3}}{4000}$;
= 725 nm ≈ 730 nm; 2

(f) red giant;
since it's big and it's red / *OWTTE*; 2

17. (a) Milky Way is a spiral galaxy with "concentration" of stars in the centre;
NGC5128 is an elliptical galaxy – form is different; 2

Ignore guessed references to band of dark dust outside our galaxy.

(b) (i) recession velocity is proportional to the distance away / *OWTTE*; 1

*Award **[0]** for formula taken from data book unless symbols are defined.*

(ii) a measurement to get recession velocity;
eg red shift measurement
a measurement to get distance away;
eg Cepheids
repeat procedure for many galaxies to get relationship from graph; 3

(c) (i) correct substitution into $v = Hd$;
and correct conversion of units to get
$v = 60\times\left(\dfrac{15\times10^6}{3.26\times10^6}\right)$ = 276.1 km s^{-1} ≈ 300 km s^{-1}; 2

(ii) correct substitution in $T = \dfrac{1}{H}$;
and correct conversion of units to get
T = 0.0167 km^{-1} s Mpc
$= 0.0167\times\dfrac{(10^6\times3.26\times9.46\times10^{15})}{10^3}$
$\approx 5\times10^{17}$ s; 2

Assumption that the rate of expansion has remained the same should be given credit and can replace the marking point above if a mathematical slip has been made.

18. (a) (i) the distance of both stars from the Earth are approximately the same (since they are part of the binary system);
and so apparent brightness is proportional to just luminosity; 2

*Award **[1]** for use of* $b = \dfrac{L}{4\pi d^2}$ *and **[1]** for a statement that distance is the same.*

(ii) $b = \dfrac{L}{4\pi d^2}$, $L = \sigma AT^4$

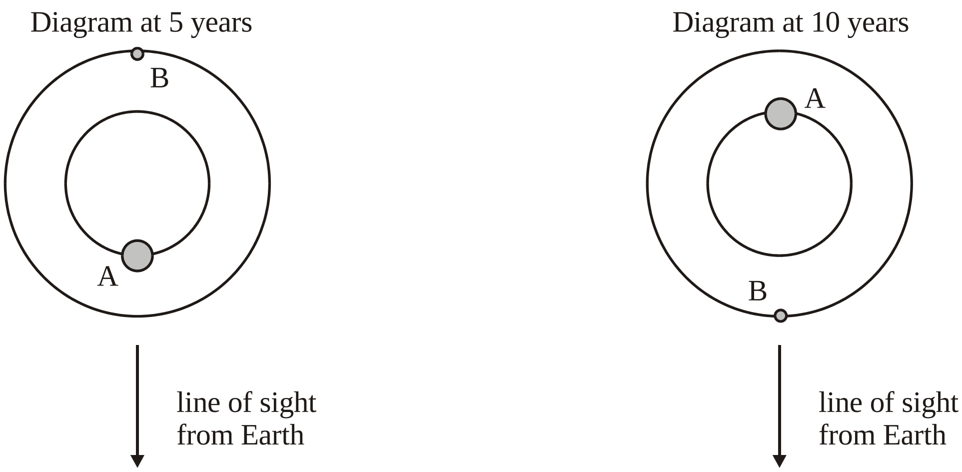
$$\frac{b_B}{b_A} = \frac{\dfrac{L_B}{4\pi d^2}}{\dfrac{L_A}{4\pi d^2}} = \frac{A_B T_B^4}{A_A T_A^4};$$

$$\frac{2.0\times10^{-14}}{8.0\times10^{-13}}=\frac{T_B^4}{10^4T_A^4}$$

$$\frac{T_B^4}{T_A^4}=250;$$

$$\frac{T_B}{T_A}=\sqrt[4]{250}=3.97\approx4;$$ 4

(b) (i)



stars shown eclipsing each other;
stars in correct positions; 2 max

(ii) 10 years; 1

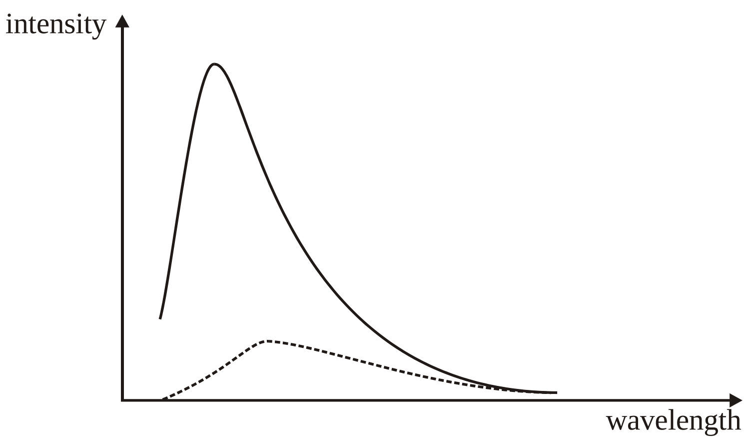
(iii) the <u>total</u> mass of the binary; 1

To receive the mark, it must be clear that the total mass is referred to.

23. (a) the radiation emitted by a perfect emitter / perfect absorber / cavity / emits radiation in accordance with the Planck law; 1

(b) wavelength / λ; 1

(c)



lower intensities;
maximum shifted to the longer wavelength; 2

(d) $T=\frac{2.90\times10^{-3}}{\lambda}=\frac{2.90\times10^{-3}}{9.70\times10^{-7}}=3000\ K;$ 1

24. (a) the universe is infinite in extent;
the stars are uniformly distributed; 2

(b) *Look for these points.*

if the stars are uniformly distributed the number of stars shining their light on the Earth increases with the square of the distance from the Earth / *OWTTE*;
so number of stars is proportional to R^2;

but the intensity of illumination varies as $\frac{1}{R^2}$;

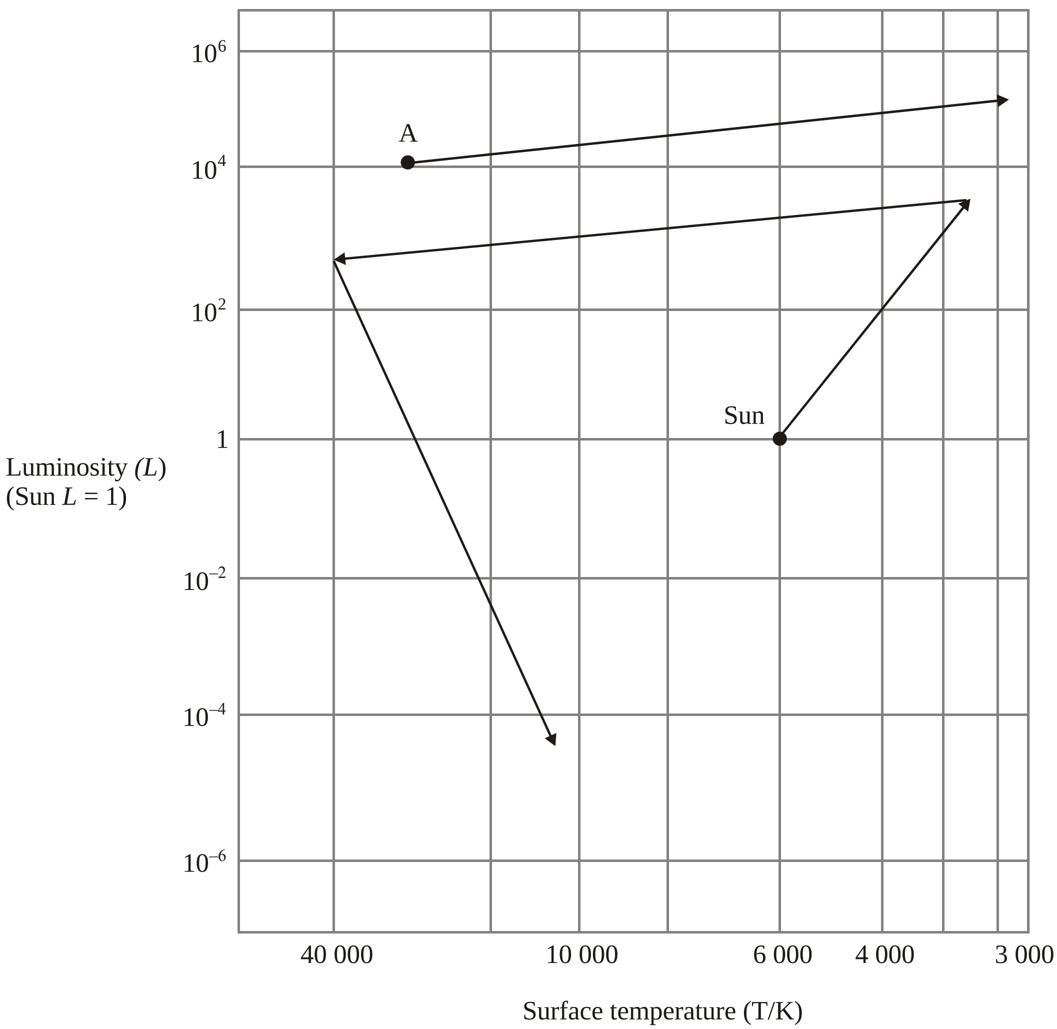
therefore, everywhere in the universe would be equally bright;

*Allow **[2]** for the following argument.*

if universe is infinite and static;
every line of sight will end on a star so night sky is bright; 4

(c) light from distant galaxies is red-shifted;
(from the Doppler effect) this suggests the universe is expanding / galaxies are moving away from each other; 2

25. (a)



Sun: to region of red giants approx luminosity $10 \rightarrow 10^3$,
temperature $3000 \rightarrow 4000$;
luminosity stays reasonably constant as temperature increases;

Accept horizontal straight-line.

then to region of white dwarfs approx luminosity $10^{-2} \rightarrow 10^{-5}$,
temperature $10\,000 \rightarrow 30\,000$;

Star A: to super red giant region approx luminosity $10^3 \rightarrow 10^5$, temperature 3000 → 4000; 4

***Note**: None of the lines needs to be straight.*

(b) *Look for these main points.*
the Sun ends up as a white dwarf;
the Chandrasekhar limit fixes the maximum mass of a white dwarf as 1.4 M_{sun};
during the red giant and planetary nebula phases of evolution;
the star can eject up to 80–90% of its original mass; 4

(c) hydrogen fusion is replaced / followed by helium fusion;
helium fusion is replaced / followed by carbon / oxygen / neon / sodium / silicon / sulphur fusion; 2

26. (a) (i) Jupiter; 1

(ii) Uranus; 1

(b) between orbits of Mars and Jupiter / 2 AU → $3\frac{1}{2}$ AU from Sun; 1

(c) highly elliptical;

most of orbit outside orbits of furthest planets / large orbits;

orbits are in many different planes; 2

27. (a) (i) blue (– white); 1

(ii) G(3); 1

(b) line absorption spectra;

give information on composition (of outer layers);

or:

Doppler Shift / red shift / blue shift;

gives information of speed relative to Earth / gives information as to rotational speed;

or:

intensity - wavelength distribution;

gives information on (surface) temperature;

stellar magnetic fields;

through splitting of emission spectrum lines; 4

*Award **[1]** each for any two sensible comments, plus **[1]** for some detail on each.*

29. (a) low mass stars will finish burning helium (into carbon and oxygen);

and collapse to a white dwarf; 2

(b) high mass stars will finish burning (silicon) to iron;

and collapse into a neutron star / black hole; 2

35. (a) there is an equilibrium;

between radiation pressure and gravitational pressure / *OWTTE*; 2

(b) *visual binary:*

stars (of system) can be separated through a telescope / binoculars / *OWTTE*;

spectroscopic binary:

(analysis of) light spectrum (from system) reveals two different (classes of) stars; 2

36. (a) (class M ⇒ low surface temperature ⇒) red; 1

(b) $d\,(pc) = \frac{1}{p} = \frac{1}{5.0\times10^{-3}} = 200\,\text{pc}$;

200 pc × 3.26 × 9.46 × 10^{15} = 6.2 × 10^{18} m; 2

(c) (i) use of $L = b\,(4\pi d^2)$;

$L = (1.6 \times 10^{-8}) \times (4\pi) \times (6.2 \times 10^{18})^2$;

$L = 7.6 \times 10^{30}$ W; 3

(ii) $T = \frac{2.9\times10^{-3}}{\lambda_{max}} = \frac{2.9\times10^{-3}}{935\times10^{-9}}$;

T = 3100K; 2

(d) $L = \sigma T^4 \left(4\pi R^2\right) \Rightarrow R = \frac{(L)^{\frac{1}{2}}}{\left(\sigma T^4\, 4\pi\right)^{\frac{1}{2}}}$;

$$R = \frac{\left(7.6\times10^{30}\right)^{\frac{1}{2}}}{\left(5.67\times10^{-8}\times(3100)^4\,(4\pi)\right)^{\frac{1}{2}}};$$

$\frac{R}{R_s} = \frac{R}{7.0\times10^{8}} = 500$; 3

37. (a) the intensity of illumination falls off as $1 / r^2$;

(since stars uniformly distributed) the number of stars seen from Earth increases as r^2;

therefore, the sky should be equally bright in any direction / *OWTTE*; 3

Award ***[1]*** *for "in any direction, the line of sight will encounter the surface of a star ⇒ sky as bright as sun".*

(b) the BB model leads to the idea of the expansion of the universe;

the BB model leads to the idea that the observable universe is not infinite; 2

Award ***[1]*** *for "because the universe (stars) is not infinitely old" (universe far younger than necessary for us to see a star in every direction. Finite speed of light means that we are not receiving light from all sources) / OWTTE.*