TD *[75 marks]*

1a. *[2 marks]*

Markscheme

luminosity=$30^{3.5}$×148 000 (times the luminosity of the Sun) ***or***

mass=$(1.5\times10^{5})^{3.5}$=30 (times the mass of the Sun);

(this is close to the quoted luminosity/mass and) so X must be on the main sequence;

Examiners report

[N/A]

1b. *[3 marks]*

Markscheme

(i) red (super)giant goes supernova with core remaining;

(ii) Oppenheimer–Volkoff/mass of remnant will determine final fate;

(to give) neutron star/black hole;

Examiners report

[N/A]

2a. *[3 marks]*

Markscheme

(fabric of the) universe is expanding;

so the wavelength of the light increases;

during the time it has traveled from emitter to detector;

Examiners report

[N/A]

2b. *[4 marks]*

Markscheme

(i) correct substitution into \({H_0} = \frac{v}{d}\);

2.7×10^{-18} (s^{-1});

(ii) \(\frac{1}{{2.7 \times {10}^{ - 18}}} = 3.8 \times {10^{17}}\) (s)/3.7×10^{17};

Allow ECF from (b)(i).

(iii) universe has always had a constant rate of expansion;

Examiners report

[N/A]

3a. *[4 marks]*

Markscheme

(i) $T = \frac{0.0029}{\lambda}$;
3080/3090 (K); *(more than 1 SD must be shown)*

(ii) temperature too low for white dwarf;
not luminous enough for red giant;

Examiners report

[N/A]

3b. *[8 marks]*

Markscheme

(i) $L = 4\pi d^2 b$;
$\frac{d_B}{d_S}\left(= \sqrt{\frac{L_B}{L_S}}\frac{b_S}{b_B} \right) = \sqrt{\frac{3.8 \times 10^{-3}}{2.5 \times 10^{-14}}}$;
3.9×10^5 AU;

(ii) conversion of AU to 1.89 pc;
0.53 (arc-seconds);

(iii) measure position of star;
with respect to fixed background;
with six months between readings;
parallax angle is half the total angle / *OWTTE*;
May be shown in a diagram.

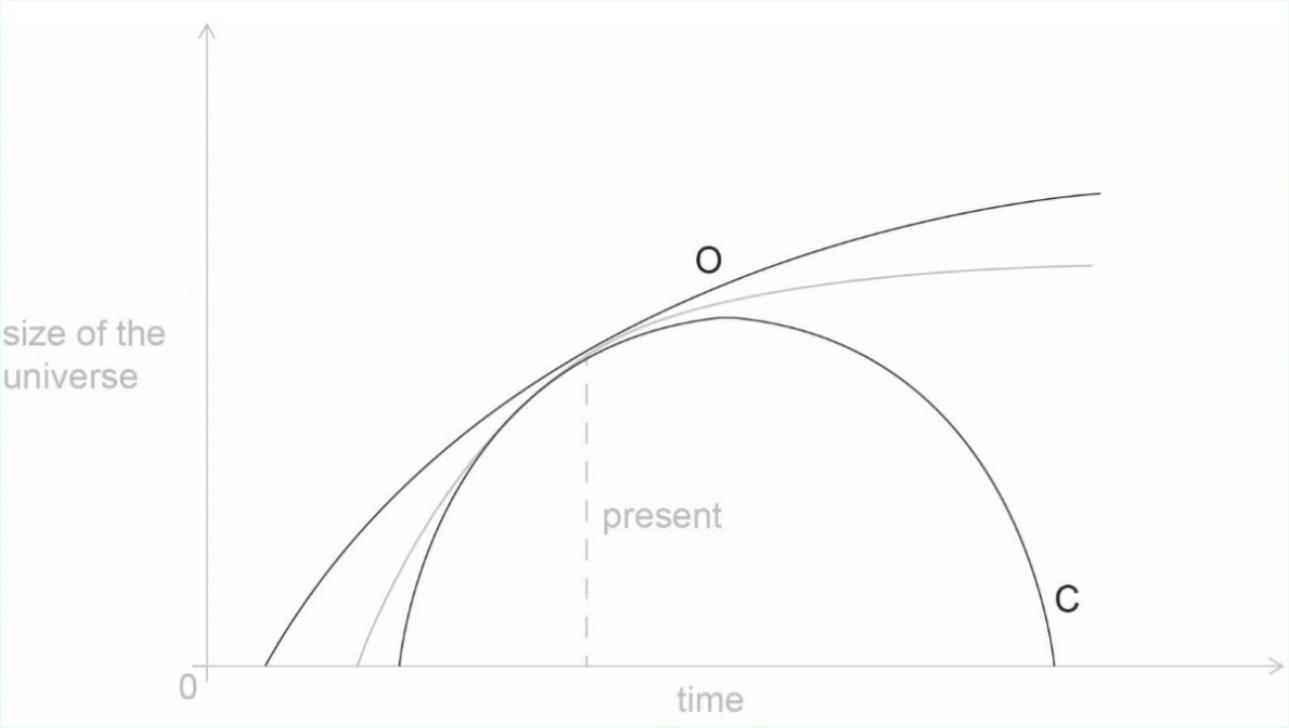
Examiners report

[N/A]

4a. *[2 marks]*

Markscheme

after present, open universe curve drawn above flat curve **and** closed universe curve drawn under flat curve; *(both needed for mark)*
all meet at “present time”;
Ignore curves before present time.



Examiners report

[N/A]

4b. *[3 marks]*

Markscheme

if density less than critical density/too low the universe will expand forever;
if greater than critical density the universe contracts;
after an initial expansion;
*If critical density not mentioned award **[1 max]**.*

Examiners report

[N/A]

4c. *[1 mark]*

Markscheme

presence of dark matter / WIMPS / MACHOS *etc*;

Examiners report

[N/A]

5a. *[3 marks]*

Markscheme

A: white dwarf;

B: main sequence / blue giant / blue supergiant;

C: red giant / red supergiant;

Examiners report

In part (a) nearly everyone could name the types of stars.

5b. *[4 marks]*

Markscheme

(i) *apparent brightness:* (total) power received per unit area/per m^2 } *(accept luminosity for power)*
luminosity: (total) power radiated;
Accept energy per second instead of power.

(ii) $d = \sqrt{\frac{L}{4\pi b}} \left({ = \sqrt {\frac{{{{10}^4} \times 3.9 \times {{10}^{26}}}}{{4\pi \times 3.8 \times {{10}^{ - 10}}}}} } \right)$; *(mark is for rearrangement)*

d=2.9 $\times$ 10^{19} (m);

*Award **[1]** for 2.9×10^{17} (misses factor of 10000).*
*Award **[2]** for a bald correct answer.*

Examiners report

The apparent brightness and power of a star in (c)(i) were usually correctly stated. Mistakes usually involved stating power per second or energy. Part (c)(ii) was done well also, although arithmetic errors were common. In (d) nearly all candidates found the star's peak wavelength and drew a suitable graph. Overall a very well answered question.

5c. *[2 marks]*

Markscheme

same shape as curve in graph and displaced to right;

peak at 10 ± 2 $\times$ 10^{-7} m with intensity ≤1;

Examiners report

In (d) nearly all candidates found the star's peak wavelength and drew a suitable graph. Overall a very well answered question.

6a. *[1 mark]*

Markscheme

(distant) galaxies are all moving away from each other/Earth;
the distance between galaxies is increasing;
the volume/diameter/radius/scale factor of the universe is increasing;
space itself is stretching with time;
Do not accept answers such as "everything is moving away from everything else" as this is clearly not true.

Examiners report

In (a) far too many candidates just repeated the question rather than stating that expansion refers to galaxies moving further apart.

6b. *[4 marks]*

Markscheme

(i) cosmic microwave background/CMB/CBR;
helium/hydrogen ratio/abundance;
darkness of night sky (Olbers' paradox);
Do not accept answers that refer to Hubble's law/red-shift of galaxies.

(ii) CMB was a prediction of the Big Bang model;
radiation present in the early universe was at a high temperature/short wavelength;
as the universe expanded it cooled/wavelength increased;
so the radiation present today is in the microwave region / has temperature of 2.7 K;

or

the early universe contained high energy neutrons/protons;
as the universe expanded and cooled (to 10^9 K) nucleosynthesis could start, producing helium;
as the temperature dropped further, nucleosynthesis stopped leaving an excess of protons/hydrogen;
the current abundance of hydrogen and helium is consistent with the predictions of the Big Bang/expansion;

or

Olbers' paradox asks "why is the night sky dark?";
this cannot be explained if universe is infinite and static / *OWTTE*;
in an expanding universe some light is red-shifted out of visible range;
in a Big Bang universe some light from distant galaxies has not reached us yet;

Examiners report

CMB radiation was usually mentioned in (b)(i). The fact that CMB was a specific prediction of the Big Bang model, long before its discovery, was sometimes mentioned in (b)(ii). Most were able to refer to cooling and wavelength increase of CMB as being consistent with the Big Bang model.

7a. *[2 marks]*

Markscheme

$\frac{L}{{L_\odot }} = {2^n}$ with *n* between 3 and 4;
so $8{L_\odot } < L < 16{L_\odot }$;
*Award **[2]** for a bald correct answer.*

Examiners report

In part (a) most candidates correctly referred to the mass–luminosity equation and used it to determine the luminosity range for the star.

7b. *[3 marks]*

Markscheme

(i) the core/remnant mass must be less than the Chandrasekhar limit/1.4 solar masses; } *(must see core or remnant or similar term)*

(ii) residual/thermal/internal energy of the star / *OWTTE;*
Do not allow fusion.

(iii) C/O/Ne/Mg; (*accept no others*)

Examiners report

Part (b)(i) was answered well by many, but there were also many who did not refer to the remnant or core mass being below the Chandrasekhar limit. In (b)(ii) there were far too many candidates who referred to fusion continuing in a white dwarf. In part (b)(iii) carbon or oxygen were almost always correctly stated.

7c. *[2 marks]*

Markscheme

gravitational attraction/pressure is balanced by;
electron (degeneracy) pressure/repulsion / pressure/force due to Pauli exclusion principle;
Award the first marking point independently of the second.

Examiners report

In (c) it was expected that electron degeneracy pressure would be mentioned, many did so but fusion radiation pressure was also incorrectly mentioned.

8a. *[1 mark]*

Markscheme

combining $\frac{{\Delta \lambda }}{\lambda } = \frac{v}{c}$ and $v=H_0 d$;
Answer given, check working.

Examiners report

In part (a) there were almost no incorrect answers.

8b. *[1 mark]*

Markscheme

$d = \frac{{c\Delta \lambda }}{{\lambda {H_0}}} = \left({\frac{{3 \times {{10}^5} \times 35}}{{620 \times 68}}} \right)$;
(mark is for rearrangement)
d=250(Mpc) ***or*** 7.7×10^{24} (m);
Allow only first marking point if incorrect value for λ is used.
*Award **[2]** for a bald correct answer.*

Examiners report

In part (b) far too many candidates lost 1 mark because they used the wrong power of ten for velocity in Hubble's constant.

9. *[2 marks]*

Markscheme

icy/dusty object;
moving around the Sun on a (highly) elliptical orbit;
when close to Sun likely to display atmosphere (coma)/tail;
when far from Sun (ice re-freezes and) atmosphere no longer present;

*Award **[2]** only if it is clearly stated that the object is a part of a Solar system.*

Examiners report

HL Candidates scored well. Some candidates did not refer to the Sun or other star. Only a few candidates outlined the nature of another body instead of comet, sometimes an asteroid. Some weaker answers mentioned a body just moving in space. At SL, many answers demonstrated a poor understanding of comets, ranging from parts of dead stars to asteroids to meteors and meteorites.

10. *[3 marks]*

Markscheme

balance of two forces/pressures;
(balance) between radiation/pressure and gravitational force/pressure;
(radiation pressure is when) photons/radiation exert outwards force on nuclei/ particles;
(gravitational pressure is when) gravitational force between particles/layers of the star acts inwards;

Examiners report

(a) There was evidence of superficial learning from the syllabus. Only a few of the best candidates wrote details of radiation and/or gravitational pressure, in response to the “outline” command term.

11a. *[3 marks]*

Markscheme

balance of two forces/pressures;
(balance) between radiation/pressure and gravitational force/pressure;
(radiation pressure is when) photons/radiation exert outwards force on nuclei/ particles;
(gravitational pressure is when) gravitational force between particles/layers of the star acts inwards;

Examiners report

(a) There was evidence of superficial learning from the syllabus. Only a few of the best candidates wrote details of radiation and/or gravitational pressure, in response to the “outline” command term.

11b. *[2 marks]*

Markscheme

whilst on the main sequence hydrogen fusion/burning to give helium;
after leaving the main sequence helium fusion/burning to give carbon;

Examiners report

There was evidence in (b) [HL only] that some candidates do not read the question carefully. Better candidates clearly outlined the processes before and after moving off the main sequence. Only a few demonstrated a good understanding of the term nucleosynthesis and answered this question clearly. These candidates referred to hydrogen to helium while in the main sequence and helium to carbon after leaving the main sequence.

11c. *[3 marks]*

Markscheme

star in (b) forms red giant, heavier star forms (red) supergiants; } *(do not allow “giant”)*
star in (b) forms planetary nebula, heavier star goes supernova;
star in (b) forms white dwarf, heavier star forms neutron star/black hole;

Examiners report

In (c) [HL], quite a high number of candidates outlined only the fate of a star with much greater mass and did not compare this with the fate of a star with mass equal to mass of the Sun. Candidates who understood that comparison is required, often omitted planetary nebulae. The main issue here was the superficial reading of the questions. Many responded with memorized tracts of stellar evolution and did not answer the question.

12a. *[2 marks]*

Markscheme

$L\left({ = 4\pi b{d^2}} \right) = 4 \times {\rm{\pi }} \times 1.2 \times {10^{ - 7}} \times {\left[{8.1 \times {{10}^{16}}} \right]^{^2}}$;
9.9×10^{27}(W);
Allow 1.3×10^{28}(W) if candidates use 3 (pc) from (a).

Examiners report

Some candidates had difficulty in manipulating a logarithmic equation. (b) discriminated well. Many candidates used the equation from the data booklet value in non-SI unit and forgot to convert pc to meters. This was not a surprise to the examining team. Quite a high number forgot to square the distance.

12b. *[2 marks]*

Markscheme

$\frac{{{{\rm{M}}_{{\rm{Sirius}}}}}}{{{{\rm{M}}_{{\rm{Sun}}}}}}\left({ = {{\left[{\frac{{{{\rm{L}}_{{\rm{Sirius}}}}}}{{{{\rm{L}}_{{\rm{Sun}}}}}}} \right]}^{\frac{1}{{3.5}}}} \right) = {\left[{\frac{{9.9 \times {{10}^{27}}}}{{3.8 \times {{10}^{26}}}}} \right]^{\frac{1}{{3.5}}}}$;
${{\rm{M}}_{{\rm{Sirius}}}} = 2.5{{\rm{M}}_{{\rm{Sun}}}}$;
Allow ECF from (b).

Examiners report

In (c), many candidates did not present their working in logical manner, especially those who did not understand mass-luminosity relations and incorrectly used the formula from data booklet.

13a. *[2 marks]*

Markscheme

(i) galaxies arranged in clusters (that are themselves arranged in superclusters);
(ii) galaxies/clusters/superclusters move further apart / distance between galaxies/ clusters/superclusters increases;

Examiners report

Candidates generally understood the distribution of galaxies in the universe and could clearly explain red-shift.

13b. *[3 marks]*

Markscheme

increase in wavelength / red-shift is observed in light from distant galaxies;
the red-shift increases with distance;
therefore (the metric of) space is expanding (with time) / the separation between galaxies is increasing;
following the Big Bang;
Galaxies are moving away from us or from Earth is not enough for the third mark.
Do not award mark for background radiation.

Examiners report

Candidates generally understood the distribution of galaxies in the universe and could clearly explain red-shift.