1

any two differences + explanation eg
MS lifetime
Planetary nebula/Supernova
White dwarf/neutron star or black hole — **4**

2

(a)	$v = H_o r$, *with terms identified*		*1*
(b)(i)	use of Doppler		1
	equation		1
(ii)	correctly plotted: (-1 each error or omission, max 2)		2
	line of best fit through the origin		1
(iii)	H_o = gradient of graph		1
	= 48 – 54 km s^{-1} Mpc^{-1}		1

8

3

(a)	collapse under gravity GPE → KE: temperature rises Temperature rises fusion reactions start	3
(b)(i)	primordial He – formed in big bang	1
(ii)	first stars would have contained virtually no elements heavier than He OR solar He abundance > primordial	1

5

4

(a)	Any **two** from: Newtonian gravity spherical universe, uniform density	2
(b)	$\rho_o = 3 \times (1.6 \times 10^{-18})^2 / 8\pi \times 6.67 \times 10^{-11}$	1
	= 4.58×10^{-27} (kg m^{-3})	1
	$\rho_o = 4.58 \times 10^{-27} / 1.7 \times 10^{-27}$	1
	= 2.7 H atoms m^{-3}	1
(c)	open: $\rho < \rho_o$, will continue to expand forever, graph	2
	flat: $\rho = \rho_o$, will just continue to expand forever, graph	2
	closed: $\rho > \rho_o$, will expand and then contract back to a big crunch, graph	2

12

5

a		$\Delta m = 1.000 - 0.993 = 0.007$ kg	-1 for incorrect Δm		1
		$\Delta E = mc^2$			1
		$= 0.007 \times (3 \times 10^8)^2$	ecf		1
		$= 6.3 \times 10^{14}$ kg s^{-1}	full marks for correct answer		1
b		Rate of consumption = 3.9×10^{26} J s^{-1} / 6.3×10^{14} J kg^{-1} (ecf)			1
		$= 6.2 \times 10^{11}$ kg s^{-1}	full marks for correct answer		1
c	i	10% of 2×10^{30} kg = 2×10^{29} kg			1
		MS lifetime = 2×10^{29} kg / 6.2×10^{11} kg s^{-1}	ecf		1
		$= 3.2 \times 10^{17}$ s (= 1×10^{10} y) (unit penalty -1)	no marks for answer only		1
	ii	sun is 100% H at start of MS life/constant power output/temperature/other valid point			1
		Total			**[10]**

Question			Expected Answers	Further Guidance	Mk
6	a		Corresponds to T ≈ 3 K	allow 2.7-3 K	1
			Blackbody spectrum		1
			Uniform/isotropic		1
			shows ripples	COBE result	
	b		Early universe very hot		
			radiation has origin in BB		
			matter and radiation in equilibrium	5 max	
			universe expands/cools	NB. Correct sequence	
			atoms form/matter and radiation decoupled/universe becomes transparent	1 of 3	5
			radiation has stretched with the universe	allow doppler shifted/red shifted	
	c	i	Homogeneous - the same everywhere, uniform	1 only if wrong way round	1
			Isotropic - looks the same in every direction		1
		ii	CMB is highly uniform (so the universe must be uniform too)		1
			Total		**[11]**

7	(a)		Infinite universe		1
			Each line of sight ends on a star		1
			(Or shells argument)	2 for shells argument	
			so sky bright at night		1
			big bang model - finite universe	4 max for Olbers	1
			and expanding	or other valid point	1
			radiation from distant stars redshifted	2 max for Big Bang	1
	(b)	(i)	H_o = v/r = 21000/300 = 70 km s^{-1} Mpc^{-1}		1
		(ii)	70 km s^{-1} Mpc^{-1} = 70000/(3 x 10^{22}) s^{-1}	Allow ecf from (i)	1
			T ≈ 1/H_o		1
			= 1/(2.3 x 10^{-18}) = 4.2 x10^{17} s		1
		(iii)	Rate of expansion is non-uniform		1
			Because of gravity	Or other valid point	1

8	(a)		No experimental evidence Or unknown physics	Allow unattainable energies	1
	(b)		Matter/antimatter annihilation		1
			With slight asymmetry	Or wtte	1
	(c)		Thermal equilibrium		1
			Highly uniform/homogeneous		1

9	(b)	(i)	Change in position/apparent motion		1
			when viewpoint is changed		1
		(ii)	Distance at which the radius of the Earth's orbit		1
			subtends an angle of 1 arcsec		1

10	(a)		description of CMB (~3 K, blackbody, uniform, isotropic) universe much hotter in the past/has cooled Hubble law/expanding universe/galaxy redshift beginning in finite past/implies cooling **OR** Helium abundance He formed in hot BB	 Or valid alternative	1 1 1 1
	(b)	(i)	Collapse → explosion	Or other detail eg neutron star or Black hole formation	1 1
		(ii)	Universe contains insufficient mass to halt expansion, Expansion continues forever	Density < critical density	1 1
		(iii)	Increase		1

11	(a)	In an infinite And static universe sky would be bright at night because every line of sight ends on a star (constant rate of) expansion of universe Hubble law stated implies zero size in the finite past	 Or other argument To 6 max Or not static	 6
	(b)(i)	1 pc = 3 x 10^{16} m or 1 Mpc = 3 x 10^{22} m 70 km $s^{-1}Mpc^{-1}$ = 70 x1000/(10^6 x 3 x 10^{16}) = 2.33 x10^{-18} s^{-1}		1 1 1
	(ii)	$T \approx 1/H_o$ = 1/2.33 x 10^{-18} = 4.3 x10^{17} s		1
	(iii)	s = vt = cT = 3 x 10^8 x 4.3 x 10^{17} = 1.3 x 10^{26} m		1 1
	(c)	uniform rate expansion	Or other valid assumption	1 [13]

12	a	Any three from: final stage of stellar evolution low mass stars / correct reference to Chandrasekhar limit High density Small/hot /faint Fermi pressure prevents further collapse 3 max

13 a. any 6 points from:

1. initial singularity
2. high temperature
3. emergence of weak/strong/electrostatic force
4. matter-antimatter imbalance
4. pair-production from radiation/matter-radiation interchange
5. formation of protons/hydrogen nuclei/quarks/leptons/electrons/neutrinos
6. early stage helium nuclei formed
7. universe cools
8. recombination of electrons and protons

6 max: 6

b. open when $\Omega < 1$ / $\rho < \rho_0$ 1
universe expands for all time 1

flat when $\Omega = 1$ / $\rho = \rho_0$ 1
universe just expands for all time (owtte) 1
special case if M1 mark not scored:

closed when $\Omega > 1$ / $\rho > \rho_0$ 1
expansion eventually halts/ universe collapses/big crunch 1

14 (a) uniform intensity detected in all directions/ isotropic 1

15 (a) Any 5 from
red shift data for galaxies (accept stars) 1
calculate velocity from red shift 1
galaxies/ stars receding from Earth 1
distance data for galaxies/ stars 1
velocity α distance / v/r = constant / v-r graph straight line 1
universe began at a single point 1

(b) Any two
stars rotate around galactic centre 1
star with velocity component towards Earth 1
reference to motion/shape of galaxy 1
or other valid points eg blue shift

(c) $H_o = 75/ 3 \times 10^{19}\ s^{-1}$ 1
$t \approx 1/ 2.5 \times 10^{-18}$ 1
$t \approx 4 \times 10^{17}$ s 1

(d) critical density is that for flat universe 1
density > p_0 universe closed/contracts/big crunch 1
density < p_0 universe open/ expands forever 1
any 2 from
fate unknown because size/mass/density universe uncertain 1
fate unknown because p_0 / H_0 not known 1

Total 15

16

a. correct reference to 1 AU — 1

parallax of 1 arcsecond
(marks can be gained on labelled diagram) — 1

17

a. **Any 6 from**

Nuclear/hydrogen burning ends	1	
Mass > Chandrasekhar limit	1	
Expanding gas/planetary nebular/red giant	1	
Gravitational collapse /ref. to burning He or higher metals	1	
Correct ref. to (Fermi) pressure/ radiation pressure (must have ref. to pressure or force from radiation.)	1	
Neutron star (neutron by itself, not enough)	1	
Correct reference to Schwarzschild radius/ allow mass> 3M/ allow ref. critical radius	1	
Black Hole	1	6

b.i. Mass = $3.8 \times 10^{26} / (3 \times 10^{8})^2$ — 1

Mass = $4.2(2) \times 10^{9}$ kg s^{-1} — 1

b.ii. $3.8 \times 10^{26} = 10^{44}$ / time — 1

time = $8.2(2) \times 10^{9}$ y — 1

Total 10

18

a. Universe is isotropic/ same in all directions 1

homogenous/ evenly distributed 1

b. **Any 5 from**

Uniform intensity in all directions/ everywhere	1	
Structure in background intensity/ripples	1	
Produced when matter and radiation decoupled	1	
Originally gamma radiation	1	
(gamma) red-shifted to microwave/originally higher energy	1	
Evidence that universe began with big bang.	1	
Temperature corresponds to 2.7K / 3K / that predicted by big bang model	1	5

c. **Any 2 from**

No experimental evidence/ no physical evidence	1	
State of matter unknown/ laws of physics unknown	1	
Energies unreproducible/ ref. to very high temperature	1	2

Total 9

19

a. Open: Universe expands for all time 1

Flat: expands to a limit (but never reaches it) 1

Closed: Universe contracts/ collapses back 1

reference to role of gravity/ critical density 1

Marks for a. can be gained on <u>labelled</u> diagram.

b. $H_o^2 = 1 \times 10^{-26} \times 8 \times \pi \times 6.67 \times 10^{-11} / 3$ 1

$H_o = 2.36 \times 10^{-18}\ s^{-1}$ 1

Total 6

20 (a) (i) energies/temperatures irreproducible on Earth / laws of Physics break down [1]
(ii)temperature decreases [1]
universe expanding/work done against attractive forces/ energy converted to mass [1]

(iii)**any 3** from
protons and electrons separate initially [1]
matter-radiation equilibrium/charge prevents passage of em waves [1]
proton-electron recombination /formation of atoms [1]
gamma/ em waves no longer absorbed [1]
[3]

(b) **any 5** from:
star-light shows red shift [1]
galaxies (stars) receding from Earth [1]
recessional velocity proportional to distance [1]
cosmological microwave background radiation (CMBR) [1]
uniform intensity in all directions [1]
small ripple [1]
(black body temperature) 2.7 K (3K) [1]
High ratio of helium to hydrogen [1]
Indicates very high temperatures existed [1]
ratio too high to originate from stellar fusion [1] [5]

[total 11]

21 **any 4 from**:
end of H burning/red giant/supergiant [1]
onset of He fusion/fusion of heavier nuclei [1]
gravitational collapse of core [1]
supernova explosion/ star explodes [1]
suitable mass limit (chanderasekha limit 1.4M) [1]
supported against gavity by neutron gas pressure/ ref to Fermi pressure [1]
internal structure protons and electrons combined/ very thin atmosphere/ metallic crust [1] [4]

22 (a) isotropic [1]
homogenous [1]

(b) (i) $H_0 = 75 / 3.1 \times 10^{19}$ [1]
$t_0 = 1 / H_0 = 4.13 \times 10^{17}$ s [1]
$t_0 = 4.13 \times 10^{17}$ s / 365 x 24 x 3600 $= 1.3 \times 10^{10}$y [1]

(ii) any two from
universe expands to a limit/ flat universe [1]
but never reaches that limit [1]
density of universe = critical density [1] [2]

(iii) curve: passes through P [1]
curves over and back to time axis [1]
iv) Universe not so old (no ecf from (iii)/ Universe will end
in big crunch(no ecf from iii) / universe has finite lifetime [1]
[total 10]

23 **a)** change in frequency or wavelength **1**
from relative motion of source and/or observer **1**

24 **a)** any 6 from
very high temperature **1**
quarks/electrons/ positrons/ neutrinos formed **1**
temperature decreases/ inflation **1**
strong nuclear force takes effect **1**
protons/ neutrons/ pions formed **1**
annihilation/ excess matter to anti-matter **1**
synthesis of helium nuclei **1**
hydrogen atoms form **1**
25% of mass is helium **1**
6

b) EITHER

uniform intensity/isotropic **1**

from era when matter and radiation strongly coupled 1

OR

temperature of 3K **1**

agrees with expected cooling **1** **2**

c) **i)** $E = hf$ / $E = hc/\lambda$ **1**

$E = 6.63 \times 10^{-34} \times 3 \times 10^{8} / 1.1 \times 10^{-3}$ **1**

c) **ii)** $E = mc^2$ **1**

$E = 1.7 \times 10^{-27} \times (3 \times 10^{8})^2$ **1**

c) **iii)** $(1.53 \times 10^{-10} / 10^{9} \times 1.8 \times 10^{-22})$ **0**

8.5×10^{2}(ecf from c)i) and c)ii)) **1**

c) iv) Any 2 from

<u>shorter</u> photon wavelength / universe smaller **1**

photon energy greater **1**

ratio becomes <u>smaller</u>. **1** **2**

25

a. (apparent) change in position of a star 1

due to change in position of Earth 1

b.i distance = 1/ parallax angle 1

distance = 1/ 0.314 = 3.2 pc 1

b.ii $3.2 \times 3.1 \times 10^{16} = 9.9 \times 10^{16}$ m 1

c.i. all points plotted correctly 1

c.ii. best straight line drawn 1

c.iii. 1. gradient = 2.1×10^{-18} 1

unit: sec^{-1} 1

2. 1/ gradient = 4.8×10^{17} (s) ECF 1

c.iv. gradient is Hubble's constant 1

1/ gradient is approximate age of Universe 1

d. galaxies (stars) are more distant than that in part a. 1

parallax too small for accurate measurement 1

total 14

26

a. isotropic: appears the same in every direction 1
homogenous: (on a large scale) the same number of galaxies in any given volume / owtte 1

b.i. volume = mass / density = $2 \times 10^{30} / 3.3 \times 10^{23}$ 1
volume = 6.1×10^{6} pc^{3} 1

b.ii. any 3 from
density less than critical density 1
open universe 1
universe will expand forever 1
critical density; universe expands to limit 1

allow energy argument: any 3 from
required pe is now lessened/ ke of galaxies > Δpe 1
open universe 1
universe will expand forever 1
idea of escape velocity 1 3

total 7

27

(a) **Any 6 from**
light from galaxies is red shifted 1
speed of recession proportional to distance 1
universe is expanding 1

cosmic microwave background radiation(CMBR) 1
peak at 2.7K 1
uniform intensity in all directions/ very small ripple 1

ratio of helium to hydrogen 1
higher than can be accounted for by stellar fusion alone 1
created during initial high temperatures 1 6

(b)(i) H = 1/ t 1
Conversion process (alternative conversions allowed) 1
Correct answer (215 km s^{-1} Mpc^{-1}) 1 3
(H = 7×10^{-18} s^{-1} scores 2 max.)

(ii) <u>minimum time</u> so H is a maximum 1

(iii). v = H x r 1
velocity from red shift data/ distance from Cepheid variable 1
ref. to change of acceleration with increasing size of Universe 1 3

Total 13

28 **(a)** occurs at end of main sequence/ when hydrogen burning ceases 1
core compresses/ increase in outward pressure/ star expands/ planetary nebular/ density decreases 1
lower surface temperature/ increased luminosity 1 **3**

29 **(a)** any 5 from
very high temperature 1
expansion/ inflation 1
electrons formed 1
leptons/ positrons/ neutrinos/ quarks formed 1
reference to forces separating 1
protons/ neutrons/ hadrons formed 1
helium nuclei formed 1
extra detail 1 **5**

(b) **(i)** all points correct **1**

(ii) smooth curve each side **1**
continuous curve at peak **1**
correct frequency read from graph for max intensity **1**

(iii) $3 \times 10^8 = \lambda_p \times$ (frequency from b.ii) **1**
calculation of λ_p **1**

(iv) correct calculation of T (ecf from b.ii) **1**

(c) any 2 from
gamma radiation from Big Bang red shifted to microwave 1
T = 2.7K (3K) predicted by big bang theory/ measurements provide evidence for big bang theory 1
measurements contradicted steady state theory 1 **2**

total 14

30 **(a)** any 3 from
light from galaxies (accept stars) shows red-shift 1
galaxies (stars) moving away/ Universe expanding 1
red-shift proportional to distance (from Earth)/ v=H x d 1
distances to (Cepeid variable) stars measured 1 **3**

(b) expansion may continue forever (open universe)
universe may collapse back (closed universe)
expansion may continue to a limit (flat universe)
Any 2 of these alternatives 1
Third alternative 1
Consistently correct reference to critical density compared to density of open, closed or flat Universe 1 **3**

total 6

31 a. (1 parsec) = 3×10^{16} m 1
(mass of Sun) = 2×10^{30} kg 1

32

a.i mass loss = $0.02759 \times 1.66 \times 10^{-27} = 0.0458 \times 10^{-27}$kg — 1
$E = \Delta mc^2$ — 1
$E = 0.0458 \times 10^{-27} \times (3 \times 10^{8})^2 = 4.12 \times 10^{-12}$ J — 1

a.ii. 4: number of protons and neutrons/ mass number/ nucleon number. 2: number of protons/ proton number — 1

b. greater coulomb repulsion between He nuclei/ He nuclei have greater charge — 1

c. **Any 3 from**

Hydrogen fuel exhausted	1	
Core contracts/ onset of He burning/ shell H burning	1	
Outer layers expand and cool	1	
absolute magnitude decreases/ more negative, or (larger surface area) increases luminosity	1	3

d. **any 3 from**

very high temperature	1	
very high density	1	
much smaller than a star	1	
gravity balanced by electron degeneracy pressure	1	3
	total	11

33

a. change in frequency/wavelength of radiation/ sound — 1
due to velocity of source/observer/both — 1

b.iii galaxies are receding — 1

b.iv $\Delta\lambda = 86.1$ nm — 1

b.v $\Delta\lambda/\lambda = v/c$ or $86.1 / 410 = v / 3 \times 10^{8}$ — 1
$v = 6.3 \times 10^{7}$ ms^{-1} — 1

c. all points plotted correctly — 1
best straight line drawn — 1

d. gradient = 2.6×10^{-18} or 1/ gradient = 3.9×10^{17} — 1
age of Universe = 1/ gradient = 3.9×10^{17} — 1
unit : seconds — 1
total 14

34

a. homogeneous 1
isotropic 1

c. suppose the universe is infinite 1
all lines of sight end on a star 1
night sky should be bright/ not dark 1
either
age of universe is finite 1
all light not yet had time to reach earth 1
or
expansion of space causes cosmological redshift 1
energy of radiation is decreased 1
or
movement of galaxies causes redshift 1
energy of radiation is decreased 1 2

total 12

35

a. **any 5 from**
singularity/ very high temperature 1
matter and antimatter produced 1
excess matter over antimatter 1
forces freeze out 1
electrons/positrons/neutrinos formed 1
protons and neutrons formed 1
helium nuclei formed 1
approx 25% nuclei are helium 1
hydrogen and helium atoms formed 1 5

b **any 2 from**
reference to mass increase with velocity 1
cannot reproduce energies 1
high temperatures result in high KE/ high velocity 1 2

c.i. **any 2 from**
uniform intensity 1
black body temperature 2.7 (accept 3) K 1
left over from gamma radiation which passed through universe after recombination 1
expansion of Universe/space increased gamma wavelength to microwave 1 2

c.ii. different densities/ show places where galaxies forming 1

d. $v = H_0 r$ 1
$KE = \frac{1}{2} Mv^2 = \frac{1}{2} M H_0^2 r^2$ 1

e. critical density: expansion stops after infinite time 1
open universe/ universe will expand forever, if density $< \rho_0$ 1
closed universe/ universe contracts, if density $> \rho_0$ 1

total 15

36

(a) fusion of hydrogen nuclei/ protons — 1
helium nuclei formed — 1
mass loss produces energy / $E = mc^2$ — 1
(pp equations give first 2 marks)

(c) luminosity increases because surface area increases — 1
surface temperature decreases because work done expanding owtte — 1

(d) AU is average distance of Earth from Sun — 1
$1.49\ (1.5) \times 10^{11}$ metres — 1

(f) **any 6 from the following**

- Hydrogen burning in core has ceased/ Hydrogen is used up. — 1
- Planetary nebula formed/core collapses — 1
- Helium burning takes place/shell burning — 1
- reference to further expansion or contraction — 1
- (Core) mass greater than 2.5 – 3.0 M_0 — 1
- Supernova explosion occurs — 1
- Formation of black hole — 1
- Other relevant point eg formation of heavier Elements/reference to Schwartzchild radius — 1 — 6

37

(a) **(i)** $\Delta\lambda / \lambda = v / c$ — 1
$(656.3 - 651.0) / 656.3 = v / 3.0 \times 10^8$ — 1
$v = 2.42 \times 10^6\ m\ s^{-1}$ — 1

(ii) the star is approaching Earth (ora) — 1

(iii) any **5** from
measurements made of $\Delta\lambda$ for many galaxies (stars) — 1
measured distance to many galaxies (stars) — 1
light from galaxies was red-shifted — 1
calculated velocity of galaxies (stars) — 1
showed that $v = H_0 r$ ($v \alpha r$) — 1
H_0 is Hubble's constant — 1
Universe is expanding — 1
Age of Universe is $1 / H_0$ — 1
Other detail — 1 — 5

(b) **Either**

any **2** from

uniform intensity in all directions		1
very small ripples in intensity		1
equivalent black body temperature of 2.7K (3K)	1	2

Or

any **2** from

Accept argument based upon expansion of space

Gamma waves move through Universe after recombination		1
Wavelength increases as Universe/space expands		1
equivalent black body temperature of 2.7K (3K)	1	2

conclude that Universe began with big bang		1

Total 12

38

a.i. parallax angle subtended is 1 arcsecond — 1
when arc length is 1 AU (owtte) — 1

39

a. Change in wavelength/frequency — 1
due to motion of source/observer/both — 1

b.i. $\Delta\lambda = \lambda \times (v/c)$ — 1
galaxy E is moving faster and so light undergoes greater change in wavelength. — 1

b.ii. points plotted correctly — 1
best straight line drawn — 1

b.iii. equate H with gradient — 1
calculate H = 50 (ecf from graph) — 1
unit = km s^{-1} Mpc^{-1} — 1

c. Any **two** from

gravity causes galaxies to decelerate (owtte)	1	
ratio of v/r is becoming smaller	1	
recent evidence shows distant galaxies accelerating away	1	2

d. Cosmic Background Microwave Radiation — 1
Uniform intensity — 1
temperature approximately 3K — 1
or
Unexpectedly high abundance of helium — 1
Could not have come from stellar helium burning alone — 1
Helium created in the earliest moments of big bang — 1

total 14

40

a. uniform intensity detected in all directions/ isotropic/ black body spectrum at 2.7K (3K) 1

b. Hydrogen and helium in early stars and Sun 1
Sun has greater proportion of helium than early stars/ H changed to He by fusion in Sun 1
Virtually no higher elements in first stars ora (accept specific examples up to iron) 1

41

a. $v \propto r$ / $v = H_o \times r$ 1

Any 4 from

b.i infinite universe 1
static universe 1
uniformly populated with stars/ cosmological principle 1
all lines of sight end on a star 1
night sky should be bright / not dark 1
4

b.ii **either**
Hubble's law implies universe is expanding 1
Wavelength of light stretched by expansion/ red shift 1
light from distant galaxies red-shifted from visible to IR 1

or
Hubble implies universe started at particular time 1

finite age of universe/ age $= 1/ H_0$ 1
light from distant stars not had time to reach Earth/ finite number of stars 1
3

Total: 8

42	a.	Any 5 from	
		very high temperature	1
		leptons/quarks/electrons/positrons/neutrinos formed	1
		temperature decreases/ inflation	1
		strong nuclear force takes effect/ forces freeze out	1
		protons/neutrons/pions formed	1
		matter and antimatter formed/annihilation/ excess matter over antimatter	1
		synthesis of helium nuclei	1
		hydrogen atoms form	1
		25% mass is helium	1
		gamma radiation/ recombination/ universe becomes transparent	1
			5
	b.	isotropic: appears the same in every direction	1
		homogeneous: (on a large scale) the same number of galaxies in any given volume	1
	c.i	volume = mass/ density = $2 \times 10^{30} / 3.8 \times 10^{23}$	1
		volume = 5.3×10^{6} pc^{3}	1
	c.ii	density less than critical density	1
		open universe/ universe expands forever	1
		density greater than critical density	1
		universe collapses back/ closed universe	1
		universe expands to limit/ flat universe if density = critical density	1
			Total: 14