Questions on Universe MS

1. Explanation:
Doppler shift:
change in frequency/wavelength **(1)**
due to motion of source/galaxy/observer **(1)**

Galaxies:
The shift of a spectral line **or** use formula to find v. **(1)**
'Red shift' $\Rightarrow$ receding **or** 'Blue shift' $\Rightarrow$ approaching **(1)**
Quality of written communication **(1)** 5

Graph:
Shape rough parabola; must hit time axis. **(1)** 1

Experimental difficulties:
$\upsilon = Hd$[No mark]
d difficult to measure for distant galaxies **(1)**
Hence H is inaccurate/uncertain. [consequent] **(1)**
υ fairly accurately measured or H is squared so error bigger **(1)** 3

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2. Frequency of spectral line for calcium

Use of $c = f\lambda$ 1

$f = 7.63 \times 10^{14}$ Hz 1

Ultra violet 1

Line spectrum

(A series of) lines on a dark /white background 1

Wavelength of calcium line

Use of $\Delta\lambda = \upsilon/c \times 393$ nm 1

$393 \pm 18 - 19$ (nm) 1

$\lambda = 411–2$ nm 1

Hubble constant

See $365 \times 24 \times 60 \times 60/3.2 \times 10^7$ 1

Use of 3×10^8 [$d = 9.5 \times 10^{24}$] 1

Use of $\upsilon = Hd$ 1

$H = 1.50 \times 10^{-18}$ [no ue as unit given] 1

Recessional velocity

$\upsilon = 5.72 \times 10^7$ (ms^{-1}) [No u.e.] 1

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3. Red shift

Change in wavelength/frequency of the light **(1)**

Wavelength increased/frequency decreased **(1)** 2

Explanation of how red shift is thought to occur

Galaxies moving away (from us) **(1)**

Shift is due to Doppler effect **(1)**

(Suggests) universe is expanding **(1)**

Evidence for Big Bang **(1)** Max 3

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4. Velocity of galaxy

Calculation of 7 or 11nm, **(1)**

Consistent values substituted in $\Delta\lambda/\lambda$ $\Delta\lambda$ must be 7 or 11 **(1)**

[Ignore 10^X errors]

5.0 or 5.12 $\times 10^6$ ms^{-1} (consequent mark) **(1)**

Moving away from the Earth/Milky Way/us/observer **(1)** 4

Estimation of distance of galaxy from Earth

Use of $\upsilon = Hd$ **(1)**

d = 2.8-2.9 $\times 10^{24}$ m [Allow e.c.f their υ above] **(1)** 2

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5. (a) Electromagnetic Doppler effect

Change in the frequency/wavelength (of the light/radiation from a source) **(1)**

because of relative motion between source and observer **(1)** 2

[If giving specific examples must cover both possibilities of change in frequency and relative motion eg describe red shift and blue shift]

(b) Hubble's conclusions

Any two from:

- (Recession) velocity $\propto$ galaxy distance [NOT stars]
- Red shift due to a galaxy moving away from Earth/observer
- Deduction of the expanding Universe [not the Big Bang] **(1) (1)** 2

[only penalise lack of galaxy **once**]

(c) Minimum velocity

$\Delta\lambda$= 660 (nm) − 390 (nm) = 270 (nm) **(1)**

Their $\Delta\lambda$/ their short $\lambda = v/c$ **(1)**

Correct substitution of $c = 3 \times 10^8$ (m s^{-1}) **(1)**

Maximum velocity = 2.1 $\times 10^8$ (m s^{-1}) **(1)** 4

(d) Critical mean density

Density is large enough to prevent Universe expanding for ever **(1)**

but not too big to cause a collapse/contraction of the Universe **(1)** 2

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6. (a) Units

s^{-1} / km s^{-1} kpc^{-1} /km s^{-1} Mpc^{-1} **(1)** 1

(b) Estimate

See $d = vt$ or rearrangement **(1)**

Substitution in $v = Hd$ for v to give $t = 1/H$ **(1)**

[Substitute value of H to obtain t]

Assumption

Since the Big Bang/start of time **(1)**

(All) galaxies/galaxy is/are travelling at constant speed /no **(1)**
gravitational attractive forces / Universe expands at a constant rate

[H is constant scores max 1 for Assumption. Allow credit for the 4 marking points anywhere within (b)] 4

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7. (a) (i) Hubble constant

Use of $v = Hd$ or gradient = H **(1)**
Converts y to s i.e. × (365 × 24 × 60 × 60) **(1)**
Correct × by 'c' **(1)**
[Seeing 9.46×10^{15} gets previous two marks]
1.7 to 1.8×10^{-18} (s^{-1}) **(1)** 4

[No marks for a bald answer]

e.g. $H = 60 \times 10^6$ m s^{-1} /
(3.6×10^7 1y × 365 × 24 × 3600 × 3×10^8 m $1y^{-1}$)
= 1.8×10^{-18} s^{-1}

(ii) Uncertainty

Distance / d **(1)** 1

(b) Age of Universe

States that $d = vt$ (any arrangement) **(1)**
Combines this with restated Hubble law (any arrangement) to give

$t = \frac{1}{H}$ **(1)** 2

(c) Recessional Speed

Red shift = 76 nm / 469 – 393 nm **(1)**

Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ **(1)**

5.8×10^7 m s^{-1} **(1)** 3

e.g. $v = 76 \times 10^{-9}$ m × 3×10^8 m s^{-1}/393×10^{-9} m
= 5.8×10^7 ms^{-1}

(d) Average mass-energy density

Closed : high density/above critical density **(1)**
Then gravitational pull (or force or attraction) sufficient to cause
Big Crunch/pull everything back/stop expansion **(1)**
[NOT to hold the galaxies together]
OR equivalent argument for Open
[Don't accept mass for density in mark 1 or just "gravity" in mark 2] 2

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8. (a) Hubble constant

Attempt to find gradient **(1)**
1.9×10^{-18} s^{-1} **(1)** 2

Distance of this galaxy from Earth

$\Delta\lambda = 37.3$ or see $(410 - 372.7)$ **(1)**

Use of $\Delta\lambda/\lambda = \upsilon/c$ **(1)**

Use of $\upsilon = Hd$ [$\upsilon = 3.0 \times 10^7$ m s^{-1}] **(1)**

1.6×10^{25} m **(1)** 4

[full ecf $H = 2 \times 10^{-18}$ s^{-1} $\rightarrow 1.5 \times 10^{25}$ m]

(b) Balloon – position of three dots

P, Q, R further apart on larger balloon **(1)**

Approximately similar triangles, i.e. approx. isosceles with base approximately ½ of long sides **(1)** 2

How balloon can be used to model expansion of Universe

Quality of written communication **(1)**

Dots represent galaxies **(1)**

Balloon inflation represents expanding universe **(1)**

Dots further apart move apart faster, (as with galaxies) **(1)** 4

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9. Discussion:

Credit to be given for all good, relevant Physics

Examples of mark scoring points:

Universe may continue to expand **(1)**

or may collapse back on itself **(1)**

Fate depends on mass of Universe **(1)**

Since mass determines force/deceleration on moving stars **(1)**

So far, not enough mass has been found to stop expansion **(1)**

There may be matter present which is currently undetectable **(1)**

Nature of this dark matter

e.g. neutrinos, very hard to detect **(1)**

black holes, no light escapes **(1)**

WIMPS explained **(1)**

neither expand nor collapse **(1)**

explained in terms of energy **(1)**

[Max 6]

10. What *I* represents

Surface temperature of star **(1)** 1

Sun on diagram

S correctly marked at $L / L_{sun} = 1$ **(1)** 1

Flux calculation

$L = 10^{-2} \times 3.9 \times 10^{26}$ W $= 3.9 \times 10^{24}$ W **(1)**
Use of $F = L/4\pi d^2$ **(1)**

$= 3.9 \times 10^{24}$ W$/4\pi \times (500 \times 3.09 \times 10^{16}$ m$)^2$
$= 1.3 \times 10^{-15}$ W m^{-2} **(1)** 3

Force which holds Sun together

Gravity **(1)** 1

How nuclear processes release energy

Any three from:

- Nuclear fusion
- When hydrogen nuclei combine to form helium
- There is a loss of mass [OR mass defect]
- This mass loss is converted to energy ($\Delta E = c^2 \Delta m$) **(1) (1) (1)** 3

Sun becoming red giant

(i) Recall of $F = Gm_1m_2/r^2$ [OR $g = GM/r^2$] **(1)**
Gravitational force does not change, since this depends on the mass of the Sun and distance to (centre of) Sun, which have not changed **(1)**

(ii) Arrow from S pointing right and upwards **(1)** 3

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