Question	Expected Answers	Further Guidance	Marks
1(a)(i)	Elliptical orbits (Sun at one focus)		1
	(Radius vector sweeps out) equal areas in equal times.		1
	$T^2 \propto R^3$ or equivalent		1
(ii)	Similarity- heliocentric		1
	Difference - Copernicus- circular orbits		1
(b)	$5.88^2/(3.55\text{x}10^5)^3 = 1.12^2/R^3$	Candidates <u>must</u> show their working	1
	$R^3 = 1.623\ \text{x}10^{15}$		1
	$R = 1.18\ \text{x}10^5$ km		1
(c)	Perturbations (of gravitational field)		1
	Due to proximity of other moons		1 [10]
2.(a)(i)	(Measure of) brightness of star	Allow equations if terms explained.	1
	as seen from <u>Earth</u>.		1
	(Measure of) brightness of star		1
	as seen from (standard distance of) 10 pc.		1
(ii)	$m-M = 5\ \lg\ (r/10)$		1
	r = distance in <u>parsecs</u>		1
(b) (i)	positions plotted correctly		1
(ii) 1	C		1
2	A		1
3	D		1
4	E		1 [11]
3.(a)	In an infinite		
	And static universe		
	sky would be bright at night	Or other argument	
	because every line of sight ends on a star	To 6 max	
	(constant rate of) expansion of universe		
	Hubble law stated		
	implies zero size		
	in the finite past	Or not static	6
(b)(i)	1 pc = 3×10^{16} m or 1 Mpc = 3×10^{22} m		1
	70 km $s^{-1}Mpc^{-1}$ = $70\ \text{x}1000/(10^6 \times 3 \times 10^{16})$		1
	$= 2.33\ \text{x}10^{-18}\ s^{-1}$		1
(ii)	$T \approx 1/H_o = 1/2.33 \times 10^{-18} = 4.3\ \text{x}10^{17}$ s		1
(iii)	s = vt = cT		1
	$= 3 \times 10^8 \times 4.3 \times 10^{17} = 1.3 \times 10^{26}$ m		1
(c)	uniform rate expansion	Or other valid assumption	1 [13]

	Marking Points	Additional guidance	Marks
4(a)	Speed of light constant (for all inertial observers)	Or other valid point	
	Laws of physics invariant for all inertial observers.		
	In absolute space, c should vary		
	with absolute velocity of observer, (but this is not the case - MM expt)	Accept other valid arguments to 6 max	
	mass increases with velocity		
	as v→c, m→∞,	Or $m = \gamma m_o$	
	so infinite energy/force needed to reach c		6
(b) (i)	$t = s/v = 2000/(3 \times 10^8) = 6.6\ \mu s$		1
	comparison with $3 \times t_{1/2}$		1
(ii)	$1/2^3 = 1/8$ left		1
	= 574/8 = 71.8 in one hour	Allow 70 - 72	1
(iii)	muons travel close to speed of light	Not just 'very fast'	1
	so for an observer on the ground, the muons 'clock' will run much more slowly		1
	so its half life will be much greater.		1
(iv)	Observed fraction = 439/574 (= 0.765)		1
(v)	correct substitution		
	$\gamma = 7.92$		1
(vi)	$\ln f = 2000 \times \ln 2/(0.992 \times 3 \times 10^8 \times 7.92)$		1
	$= -0.268$		
	$\rightarrow f = 0.765$, *(which agrees with expt)*		1
			1 [18]
5(a)	acceleration free		
	obeying Newton's 1st law		
	accelerating spaceship	Allow valid alternatives.	
	light moving perpendicular to acceleration		
	follows curved path to accelerated observer on ship		
	but straight path to inertial observer		
	so by EP, light bends in gravity fields.		6 max
(b)(i)	sky/Sun is very bright		1
	Only during an eclipse are stars near the sun visible.		1
(ii)	Gravity/curvature of spacetime strongest nearest Sun		
	Diagram showing Light bent by Sun		
	More bending for stars nearer Sun	3 max	3
	Apparent positions of stars shown		
(c) (i)	Complete table correctly		1
(ii)	Plot points correctly		1
	Straight line <u>through origin</u>		1
(iii)	Straight line (through origin)		1
	indicates that α is proportional to 1/r, QED		1
(iv)	k = gradient $= 1.8 \pm 0.15\ R_o$	correct calculation	1
(v)	$M_o = 1.8/8.79 \times 10^{-31} = (2 \pm 0.1) \times 10^{30}$ kg	based on data only:2	1 [18]

			Marking Points	**Additional guidance**	**Marks**
6	**(a)**	**(i)**	Idea of zig-zag path 3-5 reflections, i = r, reflection at boundary Refractive index of light guide > air (allow denser) Provided $i \geq C$, TIR occurs.	Any 3	1 1 1
		(ii)	$\sin C = 1/n$ $C = \sin^{-1}(1/1.58) = 39.3°$.		1 1
	(b)	**(i)**	$E = hc/\lambda = 6.63 \times 10^{-34} \times 3 \times 10^{8}/413 \times 10^{-9}$ $= 4.82 \times 10^{-19}/1.6 \times 10^{-19} = 3.01$ eV	Photon energy eV conversion	1 1
		(ii)	10^4 photons = 3.01×10^4 eV % conversion $=3.02 \times 10^4 \times 100\%/1.5 \times 10^6 = 2\%$		1 1
	(c)	**(i)**	$hc/\lambda = 2.2 \times 1.6 \times 10^{-19}$ $\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8/(2.2 \times 1.6 \times 10^{-19})$ = 566 nm	 560- 570 nm	1 1
		(ii)	the work function is greater than the photon energy / no photoelectron emission	Or equivalent	1
		(iii)	$hf = \phi + \frac{1}{2} m_e v_{max}^2$ $hf - \phi = (3.02 - 2.2) \times 1.6 \times 10^{-19} = 1.31 \times 10^{-19}$ J $v_{max} = \sqrt{(2 \times 1.31 \times 10^{-19}/9.1 \times 10^{-31})} = (5.0-5.4) \times 10^5$ ms^{-1}	Or $hf = \phi + KE$ Omit eV conversion: 2/3 KE = 3eV or 2.2eV: 1/3	1 1 1
	(d)	**(i)**	3^{12} = 531000	Allow 3^{13} = 1590000	1 1
		(ii)	$Q = ne = 531000 \times 1.6 \times 10^{-19} = 8.5 \times 10^{-14}$ C $I = Q/t = 8.5 \times 10^{-14} / 3 \times 10^{-9}$ $= 2.8 \times 10^{-5}$ A	 Q=e: 1/3	1 1 1