

Question			Marking details	Marks available				Maths	Prac
				AO1	AO2	AO3	Total		
7	(a)		Microwave laser or amplifier or equivalent (1) from water [molecules] or water clouds or steam (1) in gas disk around (supermassive) black hole (or quasar) (1) pumping or excitation provided by collisions (accept light) (1) (em radiation) propagates outwards (away from black hole) or reference to population inversion (1) Treat as neutral reference to watermaser. (Don't award the individual marks if later contradicted)	1 1 1	1 1		5		
	(b)		Appropriate wavelength or energy or frequency chosen e.g. 400 nm-700 nm or 2-3 eV or $4-8 \times 10^{14}$ Hz (1) Valid method for obtaining ratio of frequencies, wavelength or energy (1) Answer 35 m[s] – 80 m[s] (1)	1	1 1		3	2	
	(c)		$\frac{3\,300}{68.9}$ (1) 48 [Mpc] (1)		2		2	2	
	(d)		Measure the velocity using Doppler shift or use of Doppler equation (1) at different times (1) acceleration = rate of change of velocity (1) Alternative: Measure the velocity using Doppler shift (1) Obtain v_{\max} (1) $a = \frac{v_{\max}^2}{r}$ or equivalent e.g. use v and r to calculate a (1)			3	3		

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	(e)	(i)	Use of $r = \frac{v^2}{a}$ (1) Acceleration conversion i.e. /365/24/3600 (1) Answer = 8.8×10^{14} [m] or 8.8×10^{11} k[m] (1)			3	3	3	
		(ii)	Approximation used i.e. $D = \frac{r}{\theta}$ (1) Answer = 7.8×10^{14} [m] (1) Hence consistent (since overlap) i.e. valid conclusion based on calculations (1) Comparing e.g. 1.53 ± 0.15 and 1.73 ± 0.17 but also accept combined error = 20% or 8.8×10^{14} is less than 20% bigger than 7.8×10^{14} (1)			4	4	2	
			Question 7 total	4	6	10	20	9	0