

7. Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

- (a) In your own words explain what a megamaser is and how it works. (See paragraphs 1, 4, 7 and 8.) [5]

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- (b) If the lifetime of a metastable level leading to visible light is  $2\mu\text{s}$ , estimate the lifetime of a 22.235 GHz maser transition. (See paragraph 2.) [3]

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- (c) The recessional velocity of the galaxy used in paragraph 10 is  $3\,300\text{ km s}^{-1}$ . Use Hubble's law to calculate the distance of the galaxy in Mpc. (N.B. use the value of  $H_0$  in paragraph 10. There is no need to change the units.) [2]

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- (d) What does the author mean by "We can also measure the centripetal acceleration,  $a$ , of maser clouds by observing how the Doppler shift velocity changes over time"? (See paragraph 9.) [3]

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- (e) (i) Doppler shift measurements are obtained for a gas disk orbiting a black hole. The orbital velocity of gas around the black hole is measured as  $410\text{ km s}^{-1}$  and the acceleration of the gas disk is measured as  $6\text{ km s}^{-1}$  **per year**. Calculate the distance of this region of the gas disk from the black hole. (See paragraph 9.) [3]

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- (ii) The angular size ( $\theta$ ) in radians of the gas disk is measured as  $5.1 \times 10^{-9}$  rad  $\pm 10\%$  and its distance from Earth is measured as  $1.53 \times 10^{23}$  m  $\pm 10\%$ . Evaluate whether or not these values are consistent with your calculation in part (e)(i). (See Diagram 2.) [4]

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**END OF PAPER**