InkPhysics

ANSWER BOOK

Quasars and exoplanets

Astrophysics · Year 13

AQA 3.9.3.3, 3.9.3.4

10 questions · 30 marks

NAVY EDITION

SECTION A · Warm-up

A1 Quasi-stellar radio source: they were found in the 1950s as strong radio sources whose optical counterparts looked like faint star-like points, not galaxies. [2]

A2 Its star outshines it by a factor of order a billion, and at interstellar distances the angular separation between planet and star is below the diffraction-limited resolving power of telescopes. [2]

A3 The fractional dip equals $(r_p/r_s)^2$, the squared ratio of planet radius to star radius, so it measures the planet's relative size. The interval between dips is the planet's orbital period. [2]

SECTION B · Standard

B1 $v = zc = 0.40 \times 3.0 \times 10^8 = 1.2 \times 10^8$ m s^{-1}. $d = v/H = 120\,000/65 \approx 1846$ Mpc: among the most distant objects measurable, with the caveat that $z = v/c$ strains at such speeds. [4]

B2 An object cannot brighten as a whole faster than light crosses it: size $\leq ct = 3.0 \times 10^8 \times 3 \times 86\,400 \approx 7.8 \times 10^{13}$ m, a few times Pluto's orbit: solar-system sized, despite galaxy-scale power. [3]

B3 $r_p/r_s = \sqrt{(2.5 \times 10^{-3})} = 0.050$, so $r_p = 0.050 \times 6.96 \times 10^8 = 3.5 \times 10^7$ m: about half of Jupiter's radius. The square root is the essential step: the dip compares areas. [3]

B4 $\Delta\lambda = \lambda v/c = 656.3 \times 55/3.0 \times 10^8 = 1.2 \times 10^{-4}$ nm: a ten-thousandth of a nanometre, which is why the radial velocity method demands extraordinarily stable spectrographs. [3]

SECTION C · Stretch

C1 $M = m - 5\log(d/10\text{ pc}) = 16.1 - 5\log(1.846 \times 10^8) = -25.2$. That is 4.2 magnitudes brighter than the galaxy: a factor of $2.51^{4.2} \approx 49$, from a region the size of the solar system. [4]

C2 Matter spiralling toward the black hole heats by friction to millions of kelvin and radiates fiercely before crossing the event horizon, releasing energy far more efficiently than fusion, so a galaxy's worth of power is possible. The engine is only as big as the hole and its inner disc, a solar-system-scale region, consistent with the rapid brightness variation. [4]

C3 The transit dip gives the planet's size, through $(r_p/r_s)^2$, and its interval gives the orbital period. The radial velocity wobble confirms the period and its size reflects the planet's mass, since a heavier planet drags its star through a faster counter-orbit. [3]