APhO 2024 – Theory Question No.3:

A1.

We can easily see that 27,3 days is equivalent to 655,2 hours or 39312 minutes or 2358720 seconds

The angle that the Moon moving across the background:

	Hours	Minutes	Seconds
Degrees	0,55	$9{,}17.10^{-3}$	$1{,}52.10^{-4}$
Arcminutes	33	0,55	$9{,}17.10^{-3}$
Arcseconds	1980	33	0,55

A2.

The angular velocity of the Moon:

$$\omega = \frac{2\pi}{T} = 2{,}66.10^{-6}\ (s^{-1})$$

With T is the sidereal month.

The time needed:

$$t = \frac{\phi}{\omega} = \frac{\frac{30}{60}\cdot\frac{\pi}{180}}{2{,}66.10^{-6}} = 3280\ (s) = 54{,}67\ (minutes)$$

B1. A

Reason: The answer cannot be B because if there is any instability in the mounting of the telescope, the researcher would fix it immidiately. The answer cannot be C and D because while the Moon covers the A and B spots, there is virtually no turbulence in the graphs provided. This means through process of elimination, the answer is A.

B2. C

Reason: The disapperance of the spots indicated that one disappears before the other, while the apperance of the spots looks smooth enough to show that both of them appears together. The answer is C.

B3.

The time from when A and B is detected in the sky to only B is detected:

$$t_1 = 0{,}6(minutes)$$

The angle distance from B to the point perpendicular with the Moon's surface at that point:

$$\gamma = \omega t_1 = 9{,}576.10^{-5}$$

The angle distance from A to B:

$$\sigma = \frac{\gamma}{\phi} = 0{,}011 = 0{,}63(degrees)$$

C1.

From Figure 2, we have:

We see that the H_δ line for the 3C 273 is at 477,27nm, and in the comparison spectrum, the H_δ line is at 413,63nm. The redshift is:

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{477{,}27 - 413{,}63}{413{,}63} = 0{,}154$$

C2.

Subsituting z into the equation $z = \frac{1}{\sqrt{1-\frac{2GM}{rc^2}}} - 1$, we have:

$M = \left(1 - \frac{1}{(1+z)^2}\right)\frac{rc^2}{2G} = 5{,}04.10^{47}(kg)$ for 3C 273 at the edge of the Milky Way

$M = \left(1 - \frac{1}{(1+z)^2}\right)\frac{rc^2}{2G} = 2{,}52.10^{39}(kg)$ for 3C 273 at the edge of the Solar System

To put into perspective, the mass of the Milky Way and the Solar System is $3{,}78.10^{42}(kg)$ and $2.10^{30}(kg)$ respectively.

This means that the newly discovered object would totally disrupt the system we are living in.

C3.

According to Hubble's Law, we have:

$$v = Hd$$

Combined with $z = \frac{v}{c}$, we have:

$$d = \frac{zc}{H} = 1{,}9.10^{25}(m) = 2.10^9(light\ years)$$

This is two thousand times larger than the Milky Way's diameter, which is about 100000 light years.

D1.

We have:

$$F_\upsilon = 25000\upsilon^{-0{,}3}(Jy) = 25.10^{-23}\upsilon^{-0{,}3}(Wm^{-2}Hz^{-1})$$

The luminosity of the source per unit frequency:

$$L_\upsilon = 4\pi d^2 F_\upsilon = 1{,}134.10^{30}\upsilon^{-0{,}3}(\frac{W}{Hz})$$

D2.

The total luminosity in the radio band of 3C 273:

$$L_{Total} = \int_{10^7}^{10^{11}} L_\upsilon d\upsilon = \int_{10^7}^{10^{11}} 1{,}134.10^{30}\upsilon^{-0{,}3} d\upsilon = 8{,}106.10^{37}(W)$$

D3.

As shown, the total luminosity of 3C 273 is $2{,}12.10^{11}$ times brighter than the Sun and brighter than the Milky Way.

E1.

Conservation of energy (Assuming that the matter and anti matter particles collide straight into each other)

$$2m_e c^2 = 2\frac{hc}{\lambda}$$

$$\lambda = \frac{h}{m_e c} = 1{,}38.10^{-23}(m) = 1{,}38.10^{-11}(nm)$$

This is X-ray emission wavelength and is not optical or radio emission.

E2.

The gravitational potential energy of a mass m:

$$U = -\frac{GMm}{R}$$

For 3C 273, we have:

$$U = -\frac{mc^2}{2}$$

With R as its Schwarzschild radius.

The power attained for the accretion per year:

$$\Delta U = \frac{mc^2}{2} = 8{,}98.10^{46}\left(\frac{J}{year}\right) = 2{,}8.10^{39}(Js^{-1})$$

This is more than sufficient to supply energy for 3C 273.

F1.

Magnetic energy density:

$$U_B = \alpha B^2$$

Particle energy density:

$$U_e = \beta B^{-\frac{3}{2}}$$

With α and β as abitrary constants.

The minimal energy density satisfies the condition that the first deverative of $U_B + U_e$ equals zero

We have:

$$0 = 2\alpha B\dot{B} + -\frac{3}{2}\beta B^{-\frac{5}{2}}\dot{B}$$

$$\frac{4}{3}\alpha B^{\frac{7}{2}} = \beta$$

From here, we have:

$$\frac{U_e}{U_B} = \frac{\frac{4}{3}\alpha B^2}{\alpha B^2} = \frac{4}{3}$$

F2.

The total power of 3C 273 jet:

$$W_{3C\ 273\ jet} = \frac{L_{Total}}{2} = 4{,}053.10^{37}(W)$$

Energy density of the field:

$$U_{field} = \frac{W_{3C\ 273\ jet}}{V} = 4{,}053.10^{-8}(Wm^{-3})$$

Magnetic energy density of the field:

$$U_B = \frac{3}{7}U_{field} = 1{,}737.10^{-8}(Wm^{-3})$$

The B field of the jet:

$$B = \sqrt{2U_B\mu_0} = 2{,}09.10^{-7}(T)$$