ASTROCHALLENGE 2025
SENIOR MCQ ROUND

SOLUTIONS

Wednesday 4th June 2025

1. Figure 1 shown below is a light curve of a star.

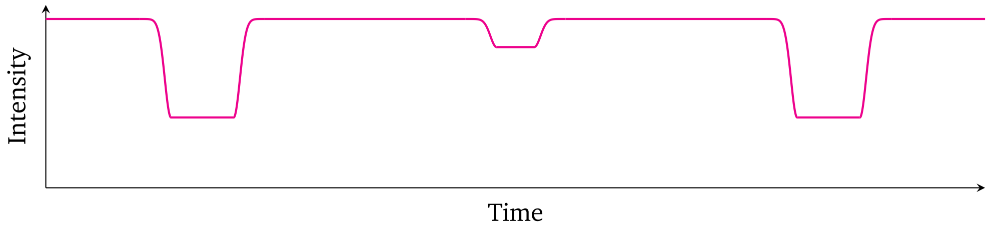


Figure 1: Question 1.

Which of the following statements are plausible explanations for the shape of the light curve?

I The star is a T-Tauri Star which are young and unstable stars which results in their periodic swelling and contraction causing this light curve.

II The curve is likely caused by two massive exoplanets eclipsing a dwarf star.

III The star is a Cepheid variable with its characteristic periodic dimming.

IV This curve is a result of eclipses of a binary star system.

(A) I and II only

(B) II only

(C) **II and IV only**

(D) III only

(E) I, II, III and IV

Solution:

The observed light curve in Figure 1 shows two distinct dips in brightness over time, with one dip being deeper than the other. This shape is characteristic of:

- An eclipsing binary star system, where two stars orbit each other and periodically pass in front of one another from our viewpoint. The deeper dip typically corresponds to the larger or brighter star being eclipsed.
- A system involving transiting exoplanets, such as two massive exoplanets eclipsing a star at different times.

However, the depth and regularity of the dip seems to suggest that it is more likely to be a binary star system rather than a system involving exoplanets due to the scale and intensity changes. However, we cannot rule out the possibility of the latter.

Now, evaluate each statement:

I. **T Tauri stars** are known for erratic and irregular light curves due to their unstable nature, not periodic dips like this one. ⇒ **Implausible**

II. Two exoplanets could theoretically cause this, but the sharpness and symmetry of the dips match stellar eclipses more closely. Still, **plausible**.

III. Cepheid variables show smooth, sinusoidal light curves—not flat-topped dips like here. ⇒ **Implausible**

IV. Binary star eclipses can produce exactly this type of light curve, especially if the stars are of different brightness. ⇒ **Plausible**

Therefore, only Statements II and IV are plausible explanations.

Correct answer: C

2. Where and how are stable beryllium isotopes synthesised?

(A) Inside the cores of low mass stars, due to the proton-proton chain.

(B) During a supernova, due to the s-process.

(C) Inside brown dwarves, as a product of Lithium Burning.

(D) During neutron star mergers, due to the rp-process.

(E) In interstellar medium, from break-up of heavier elements under cosmic ray bombardment.

Solution:

Stable Beryllium isotopes can only be synthesised in the interstellar medium via cosmic ray spallation, where cosmic ray particles, consisting of particles like a proton, neutron or alpha particles collide with matter in the interstellar medium, resulting in the formation of stable isotopes of lighter elements such as lithium, beryllium and boron. This is because in stellar environments, Beryllium is unstable and rapidly decays or fuses into other elements such as Boron, Helium, or Lithium. Hence, stable beryllium is theoretically only naturally formed at a high rate due to cosmic ray spallation where the temperatures are lower and there is lower density and pressure.

Correct answer: E

3. A sun-synchronous orbit ensures that a satellite in the orbit passes over the same point on Earth at the same local solar time each day. Which of the following is a characteristic of a sun-synchronous orbit?

(A) It has a low inclination.

(B) Satellites in sun-synchronous orbit stays stationary above a fixed point of Earth as its orbital period is 24 hours.

(C) It generally takes less Δv for a satellite to reach sun-synchronous orbit compared to the International Space Station on low Earth orbit, when launched from the equator.

(D) Sun-synchronous orbit has a nodal precession period of 1 solar year.

(E) It is a hoax, sun-synchronous orbit is impossible in real life.

Solution:

A sun-synchronous orbit ensures that the satellite passes over the same point on Earth at the same local solar time each day. It is a highly polar orbit with a nodal precession period of 1 solar year.

Due to its high inclination (A), it is not geostationary (B) and that it generally takes more Δv to reach compared to the International Space Station (C).

Sun-synchronous orbit is impossible if the Earth is a perfect sphere. However, it is not in real life.

Correct answer: D

4. Figure 2 shown below is a diagram of the Hohmann transfer orbit.

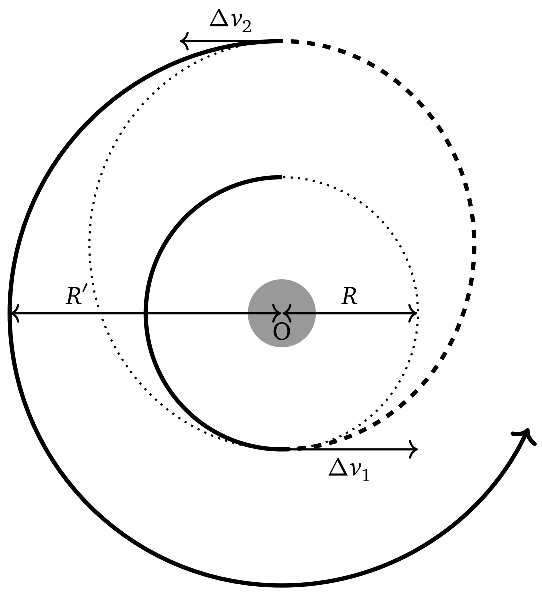


Figure 2: Question 4.

Which of the following is/are true about the Hohmann transfer orbit?

I It is often the most fuel-efficient way to accomplish the transfer because it requires the lowest impulse.

II It is usually the fastest way to transfer orbits.

III It is suitable for interplanetary travel without adjustments for relative motion of planets.

IV The time required for a Hohmann transfer orbit depends on the semi-major axis of the transfer ellipse.

(A) **I and IV only**

(B) II only

(C) II and III only

(D) IV only

(E) I, II, III and IV

Solution:

Let us evaluate each of the statements:

(i) **True.** The Hohmann Transfer is the most fuel-efficient method for transferring between two orbits, assuming they are circular and coplanar. It requires the lowest total impulse (Δv), which makes it ideal when minimizing fuel consumption.

(ii) **False.** Although it is efficient, it is not the fastest. In fact, it is slower compared to higher-energy transfers like bi-elliptic or impulsive maneuvers. The Hohmann transfer is optimal in fuel, not speed.

(iii) **False.** The Hohmann transfer assumes circular and coplanar orbits, but it does not account for planetary motion (orbital alignment or phasing). Therefore, interplanetary travel usually requires adjustments for relative motion of planets (e.g., launch windows).

(iv) **True.** According to Kepler's 3rd law, the period of an elliptical orbit depends on the semi-major axis:

$$T = 2\pi\sqrt{\frac{a^3}{GM}}$$

Hence, the time required for the transfer is directly related to the semi-major axis of the transfer ellipse.

Therefore, only statements (i) and (iv) are correct.

Correct answer: A.

5. Jupiter's Moons, Io, Europa and Ganymede exhibit Laplace resonance, a special type of orbital resonance between 3 bodies where the ratio of the orbital periods of the moons is 4:2:1. Which of the following explanations best describes why Laplace resonance occurs in the Jovian system?

(A) The gravitational influence of other Jovian Moons, especially Callisto, "shepherds" the 3 moons into the Laplace resonance ratio.

(B) **The 3 moons exert regular, periodic gravitational influences on each other, resulting in the Laplace resonance structure.**

(C) Resonances in the proto-satellite disk (akin to the Huygens gap in Saturn's rings), where the 3 moons formed, resulted in the 3 moons following similar periodic ratios as the debris which they were formed from, thus resulting in the Laplace resonance structure observed today.

(D) Jupiter's Trojan asteroids exert gravitational influences on the 3 moons, locking them into a Laplace resonance structure.

(E) None of the above.

Solution:

Laplace resonance arises due to the periodic and mutual gravitational interactions among Io, Europa, and Ganymede. These interactions cause them to maintain a 4:2:1 orbital period ratio.

Correct answer: B

6. While learning astronomy, Xixun encounters that white dwarfs will cool to form black dwarfs, however we have not found any so far because,

(A) They radiate in ultraviolet wavelengths, which are very hard to detect.

(B) The electron degeneracy pressure causes a black dwarf to immediately turn back into a white dwarf; black dwarf is an unstable state.

(C) **The universe is not old enough to host black dwarfs.**

(D) Black dwarfs cannot exist for a long time because low energy causes them to collapse and undergo supernova.

(E) Black dwarfs are repelled by interstellar gas, which keeps them from forming in any known galaxy.

Solution:

White dwarfs cool slowly over timescales exceeding the current age of the universe. Hence, black dwarfs have not yet formed. Option C is correct.

- A: UV is detectable
- B and E: Scientifically implausible
- D: Electron degeneracy pressure prevents collapse, regardless of temperature

Correct answer: C

7. Why is there a notable absence of ground-based observatories operating in the gamma, X-ray and ultraviolet bands of the electromagnetic (EM) spectrum?

(A) Due to light pollution, it is difficult to detect shorter wavelengths of EM radiation in ground-based observatories.

(B) **Earth's atmosphere absorbs most of these shorter wavelengths of EM radiation, making them difficult to observe from ground-based observatories.**

(C) Current technology to detect these wavelengths of EM radiation are simply too expensive to be feasible for astronomy research.

(D) Current observatories that operate in the visible spectrum, near-infrared and radio wavelengths are more than sufficient to conduct astronomy research.

(E) Actually, there are ground-based observatories that operate in the gamma, X-ray and ultraviolet bands of the EM spectrum.

Solution:

Gamma rays, X-rays, and ultraviolet (UV) radiation are forms of electromagnetic (EM) radiation with very short wavelengths and high energy. The primary reason ground-based observatories cannot operate effectively in these bands is:

Earth's atmosphere absorbs most of this high-energy radiation before it reaches the surface.

In particular:

- The ozone layer blocks most ultraviolet radiation.
- The atmosphere is opaque to X-rays and gamma rays due to absorption by various gases like oxygen and nitrogen.

This makes it nearly impossible for ground-based telescopes to detect these wavelengths, which is why observatories for these bands (e.g., Chandra for X-rays, Fermi for gamma rays) are placed in space.

Correct answer: B

8. KY is an eccentric astronomer. He only looks at funny DSOs. Table 1 shows information about some DSOs KY wishes to observe.

Name	Right Ascension	Declination	Apparent Magnitude
Heart Nebula	2h32m44.07s	+61°27′13.4″	6.50
Jolly Roger Cluster	4h07m52.71s	+62°20′02.2″	6.90

Table 1: Question 8.

If KY observes the Heart Nebula culminating in Singapore at 22:08:19 local time, when will KY observe the Jolly Roger Cluster culminating at the same location?

(A) Same time as Heart Nebula, because their declination is very close.

(B) 23:43:28 local time

(C) 20:33:10 local time

(D) 21:37:19 local time

(E) It will never culminate.

Solution:

To calculate the time difference between the culmination of the Jolly Roger Cluster and the Heart Nebula, we consider their Right Ascension (RA) values:

$$\mathrm{RA}_{\mathrm{Heart}} = 2^{\mathrm{h}}32^{\mathrm{m}}44.07^{\mathrm{s}}$$

$$\mathrm{RA}_{\mathrm{Jolly}} = 4^{\mathrm{h}}07^{\mathrm{m}}52.71^{\mathrm{s}}$$

$$\Delta\mathrm{RA} = \mathrm{RA}_{\mathrm{Jolly}} - \mathrm{RA}_{\mathrm{Heart}}$$

$$= 1^{\mathrm{h}}35^{\mathrm{m}}8.64^{\mathrm{s}}$$

Assuming the Heart Nebula culminates at:

$$t_{\text{culmination, Heart}} = 22^{\mathrm{h}}08^{\mathrm{m}}19^{\mathrm{s}}$$

Then the Jolly Roger Cluster, which has a higher RA, will culminate later by ΔRA:

$$t_{\text{culmination, Jolly}} = 22^{\mathrm{h}}08^{\mathrm{m}}19^{\mathrm{s}} + 1^{\mathrm{h}}35^{\mathrm{m}}8.64^{\mathrm{s}} \approx 23^{\mathrm{h}}43^{\mathrm{m}}28^{\mathrm{s}}$$

Correct answer: B

9. The wavelength of the Lyman-alpha line in the hydrogen spectrum is measured in the laboratory to be 122 nm. In the hydrogen spectrum of a galaxy, the Lyman-alpha line is measured to be 129 nm. Determine the distance of this galaxy from the Earth.

(A) 227 Mpc

(B) **240 Mpc**

(C) **254 Mpc**

(D) 262 Mpc

(E) 275 Mpc

Solution:

We first calculate the redshift:

$$z = \frac{\lambda_{\text{obs}} - \lambda_{\text{ref}}}{\lambda_{\text{ref}}} = \frac{129 - 122}{122} = 0.057377$$

Case 1: We assume $v \ll c$ In this case, the recessioinal velocity can be approximated by

$$v \approx zc \approx 0.057377 \times 3.00 \times 10^5 = 17{,}213.1\,\text{km}\,\text{s}^{-1}$$

Using Hubble's Law:

$$d = \frac{v}{H_0} = \frac{17213.1}{67.8} = 253.881\,\text{Mpc} \approx 254\,\text{Mpc}$$

Thus, option C is correct.

Case 2: We do not assume anything about the speed In this case, we cannot use the approximated redshift. Instead, we directly use,

$$1 + z = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}$$

$$\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} = (1 + z)^2$$

$$1 + \frac{v}{c} = (1 + z)^2 - \frac{v}{c}(1 + z)^2$$

$$v = \left(\frac{(1 + z)^2 - 1}{(1 + z)^2 + 1}\right)c$$

$$\approx \frac{1.057377^2 - 1}{1.0577377^2 + 1} \times 3 \times 10^5$$

$$\approx 16{,}720\,\text{km}\,\text{s}^{-1}$$

Using Hubble's Law:

$$d = \frac{v}{H_0} \approx \frac{16720}{67.8} \approx 246.608\,\text{Mpc} \approx 247\,\text{Mpc}$$

247 is 7 Mpc away from 240 (Option B) and 7 Mpc away from 257 (Option C).

Keeping in mind the two cases, both options B and C were accepted as answers.

Correct answer: Both B and C are accepted

10. The cosmic microwave background was produced during the epoch of recombination, when light decoupled from matter and could travel freely through the universe. This decoupling happened because:

(A) The density of matter in the universe has decreased sufficiently so that the mean free path of photons becomes much larger than the width of a proton.

(B) The electroweak interaction underwent symmetry breaking and separated into the electromagnetic and weak interactions.

(C) **The temperature has cooled enough for neutral hydrogens to form from an ionized plasma of electrons and protons.**

(D) The temperature has cooled enough for gas clouds to collapse and heat up, resulting in the reionization of hydrogen and production of h-alpha radiation.

(E) The temperature has cooled sufficiently so that matter in the universe is no longer emitting blackbody radiation at high intensities.

Solution:

The epoch of recombination is a sudden transition rather than a gradual one (a phase transition). Option A implies a gradual transition so it is not correct. Option B is wrong because this decoupling happened during the quark epoch at much higher temperatures. D refers to the period of reionization rather than recombination. E is wrong because the temperature of the universe is still very high at recombination (resulting in the CMB).

11. In 1588, Tycho Brahe published the Tychonic system, which is a geoheliocentric model in which the Sun, the Moon and stars revolve around the Earth, and other five planets (Uranus and Neptune were not yet discovered) revolve around the sun.

Back when it was proposed, it was a major competitor, along with the Copernican heliocentric model, as an alternative to the Ptolemy's geocentric model.

However, the scientific community eventually replaced the Tychonic model with the Copernican model. Which one of the following observations could have contributed to the support for Copernicus' heliocentric model **over the Tychonic model**?

(A) The observed seasonal change of the declination of the Sun on the celestial sphere.

(B) The observation of the retrograde motion of Mars.

(C) The observation of the phases of Venus in 1610.

(D) **The observation of stellar parallax of 61 Cygni in 1838.**

(E) All of the above.

Solution:

While all observations are true, only D demonstrated a clear reason why the Copernicus heliocentric model should be chosen in favour of the Tychonic geoheliocentric model.

The Tychonic model explains observations A, B and C perfectly well.

Observation A could be modelled by geocentric (and geoheliocentric) models as the Sun moving along the ecliptic on the celestial sphere. In fact, this view is some time still used for convenience today, especially in practical astronomy.

As the Tychonic model involves the planets orbiting the Sun, which in turn, orbits the Earth, it explains why there would be Venus phases (Observation B) and retrograde motion (Observation C) perfectly well.

Since the Tychonic model proposes that Earth is the centre of the universe, there should not be any stellar parallax. After stellar parallax was observed (D), it seems that Copernicus' heliocentric model, which could explain stellar parallax, seemed to be a better model.

Correct answer: D

12. It is common advice to look away from the radiant point while observing a meteor shower. Is this true and why?

(A) **True. Meteors will appear to have longer streaks away from the radiant point; an observer should be looking away.**

(B) True. In order to best protect oneself from meteorites that fall to the ground, an observer should be looking away.

(C) Not true. Since the meteor shower originates from the radiant point, most meteors can be easily seen at that point.

(D) Not true. Since meteors can penetrate through a thick layer of clouds, the meteor shower will be clearest at the radiation point - even on a cloudy night.

(E) It does not matter if one looks towards or away from the radiant point.

Solution:

Looking away from the radiant point allows one to see longer meteor trails, as meteors coming in at angles appear to streak farther across the sky.

Correct answer: A

13. Which of the following is true about the Hayashi Track?

(A) Stars along this track are continuously expanding, until the temperature cools down and gravity pulls it inwards, starting nuclear fusion and entering the Main Sequence.

(B) Stars along this track are continuously decreasing in temperature, but at a constant luminosity.

(C) **Stars along this track are continuously contracting, but at the same temperature, resulting in a decrease in luminosity.**

(D) Stars along this track are called the Main Sequence stars, and have started fusing hydrogen into helium (e.g., our Sun).

(E) Stars who ride along this track include Max Verstappen.

Solution:

- A is incorrect because it is not physically accurate.
- B is incorrect as it better describes the Henyey Track.
- C is correct: Stars on the Hayashi Track contract at roughly constant temperature, leading to a decrease in luminosity.
- D is incorrect because stars on the Hayashi Track are pre-main sequence stars and have not begun core hydrogen fusion.
- E is incorrect because it's a joke option.

Correct answer: C

Use the following information to answer Questions 14 to 15.

SKA - Low is a radio telescope being built in Western Australia and is set to be the biggest radio telescope in the world when it is completed in 2028. It uses 131,072 log-periodic antennas spread between 512 stations at a length around 75km. The antennas are arranged in an interesting shape as shown in Figure 3.

Figure 3: Questions 14 to 15. [5]

14. Which of the following best explains why the antennas are in a Christmas tree shape?

(A) Antennas are stacked vertically on top of each other to filter out unnecessary wavelengths of light for higher sensitivity.

(B) **Antennas of different lengths are able to capture different frequencies - longer antennas for lower frequencies and shorter antennas for higher frequencies. This allows scientists to study the universe in a range of frequencies.**

(C) Some antennae are used for communication between 'trees' while only some are used in observing the night sky.

(D) The Christmas tree shape provides the best structural stability against weather conditions such as sandstorms and rain.

(E) The engineers who designed SKA - Low proposed their plan on Christmas day.

Solution:

A. False. Stacking antennae does not filter out wavelengths.
B. Correct answer
C. False. The antennae are not used for communication
D. False.
E. False.

Correct answer: B

15. Population III stars are thought to be the first stars in the universe and have very low metallicity - mostly made of hydrogen and helium. Despite having observed the earliest galaxies with JWST, why haven't we detected Population III stars and how will SKA - Low help detect them?

(A) Population III stars formed much earlier than the earliest galaxies and impacted the epoch of reionisation. SKA - Low will provide high spectral resolution and high sensitivity data with its large size and density of telescopes; this helps to study spectral changes during this epoch, giving us a chance to detect Population III stars.

(B) Population III stars are large and energetic and can only be visible in high frequency gamma rays that our current telescopes cannot detect and SKA - Low will be able to detect high frequency gamma rays, helping us detect Population III stars.

(C) Individual Population III stars cannot be resolved with current telescopes and SKA - Low can provide a higher angular resolution such that individual Population III stars can be resolved.

(D) Population III stars are almost indiscernible from higher metallicity Population II stars and SKA - Low is able to provide a high spectral resolution to tell them apart.

(E) It is not true. We have already detected Population III stars.

Solution:

A. True.
B. False. Population III stars are not expected to be predominantly in gamma rays and we do have telescopes that can detect gamma rays.
C. False. SKA - Low is not expected to resolve single population III stars. They are too far away to be resolved even with the telescope's large aperture.
D. False. Population III stars should have significantly less metalicity as compared to population II stars.
E. False. We have not yet detected population III stars.

Correct answer: A

16. Sam sees a gibbous moon setting in the west at 12am today. What will he see at 12am 12 days later?

(A) A crescent moon in the east.

(B) A half moon in the east.

(C) A gibbous moon in the west.

(D) A full moon at local meridian.

(E) A new moon.

Solution:

In 12 days, the moon goes through about 3.25 of its 8 phases - 8/29.53*12. This places the next moon phase closest to a waning half moon.

Correct answer: B

Use the following information to answer Questions 17 to 18.

Figure I-1 is an absorption spectrum captured by the James Webb Space Telescope's Near Infrared Spectrograph (NIRspec). It shows the absorption spectra at the morning terminator (green data) and evening terminator (yellow data) of Wasp 39b.

Wasp 39b is an exoplanet orbiting the star Wasp 39. In Questions 17 and 18, we will study this system assuming there is no influence from other gravitational masses and the star-planet bodies are in circular orbits.

17. We know that hotter gas moves only from dayside to nightside (as a day progresses) in a powerful equatorial jet stream. Using this information and Figure I-1, what are the similarities and differences between the morning and evening atmosphere?

(A) Similarity: At both times the atmosphere is of the same temperature.
Difference: The atmosphere has significantly more water but less carbon dioxide in the evening.

(B) Similarity: At both times the atmosphere is of the same temperature.
Difference: In the evening, the atmosphere is much thicker while in the morning it is much thinner, with only an exosphere.

(C) Similarity: At both times, the atmosphere has no net pressure gradient.
Difference: The atmosphere has a higher temperature in the evening as compared to the morning.

(D) Similarity: At both times, the atmosphere has a similar composition.
Difference: The atmosphere has a higher temperature in the evening as compared to the morning.

(E) There are no differences in the atmosphere. Differences in the graph are simply due to sensor sensitivity.

Solution:

Since the peaks and troughs of the transmission spectra look similar at both times, the atmosphere has similar compounds creating the absorption spectra. Since hotter gas travels from dayside to nightside and the equatorial jet stream travels throughout the planet, the hot gas has to travel from the evening, to the night, then to the morning atmospheres and the gas gets reheated throughout the day again till the evening.

Correct answer: D

18. Wasp 39b is 0.28 times the mass of Jupiter while Wasp 39 has a mass of $0.91\,M_\odot$. Given that their centres are 0.0486AU apart, what is the distance of Wasp 39b from the barycentre (centre of mass of the two bodies)?

(A) 0.0150 AU

(B) 0.0114 AU

(C) 0.0243 AU

(D) 0.0486 AU

(E) 0.0372 AU

Solution:

We use the concept of the barycentre (center of mass):

$$m_1 a_1 = m_2 a_2$$

Let the total separation between the two bodies be:

$$a_{\text{total}} = a_1 + a_2 = 0.0486 \times 1.496 \times 10^{11}\ \text{m}$$

Let:

$$m_1 = 0.28 \times 1.899 \times 10^{27}\ \text{kg} \quad (\text{mass of Wasp 39b})$$

$$m_2 = 0.91 \times 1.989 \times 10^{30}\ \text{kg} \quad (\text{mass of Wasp 39})$$

Substitute $a_2 = a_{\text{total}} - a_1$ into the first equation:

$$m_1 a_1 = m_2(a_{\text{total}} - a_1) \Rightarrow a_1(m_1 + m_2) = m_2 a_{\text{total}}$$

Solve for a_1:

$$a_1 = \frac{m_2 a_{\text{total}}}{m_1 + m_2}$$

Substitute the values and convert to AU:

$$a_1 \approx \frac{(0.91 \times 1.989 \times 10^{30}) \times (0.0486 \times 1.496 \times 10^{11})}{(0.28 \times 1.899 \times 10^{27}) + (0.91 \times 1.989 \times 10^{30})}$$

$$a_1 \approx 0.0486\,\text{AU}$$

Correct answer: D

19. [VOIDED QUESTION] Given that star A is twice as massive as star B, find the absolute magnitude of star A in terms of the absolute magnitude of star B. (Assume both A and B are main sequence stars)

- (A) $M_A = 2M_B$
- (B) $M_A = M_B + 2.5\log(2^{3.5})$
- (C) $M_A = M_B + 2.5\log(2)$
- (D) $M_A = M_B + 2.5\log(3.5)$
- (E) $M_A = M_B + 2.5^{3.5}\log(2)$

Solution:

From the mass-luminosity relation for main-sequence stars:

$$\frac{L_A}{L_B} = \left(\frac{M_A}{M_B}\right)^{3.5} = 2^{3.5}$$

Using the relationship between luminosity and absolute magnitude:

$$\frac{L_A}{L_B} = 10^{(M_B - M_A)/2.5} \Rightarrow \log\left(2^{3.5}\right) = \frac{M_B - M_A}{2.5}$$

Solving for M_A:

$$M_A = M_B - 2.5\log\left(2^{3.5}\right)$$

Correct answer: None of the given options. Voided question.

20. While observing the sun during a solar eclipse, Ray captured this image.

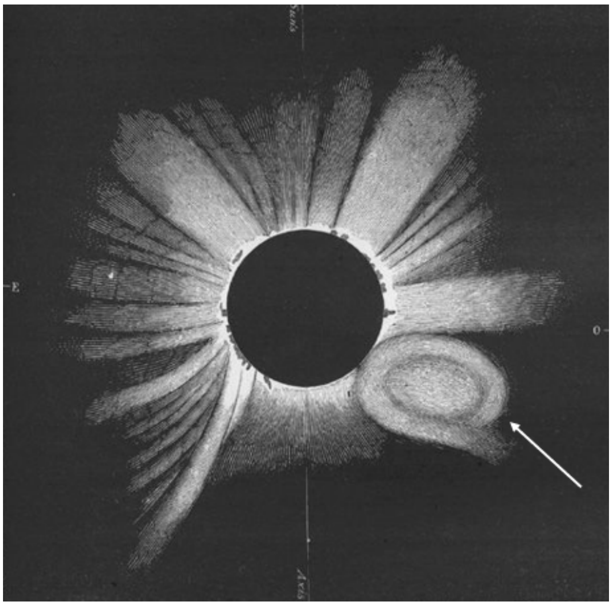


Figure 4: Question 20. [2]

There is a peculiar pattern on the bottom right of the image. Curious to know what she had just observed, she asked a few AI Chatbots "What do I see in this image of the Sun?"

BB-9: You observe a new moon. During a solar eclipse, the new moon blocks the sun.

RantGTP: Hi Ray, you are seeing the corona of the Sun. The corona is more visible during a solar eclipse, when it isn't outshone by the surface of the Sun.

Orion: Those are magnetic field lines of the Sun. Invisible magnetic field lines are only seen in the dark, such as during a solar eclipse.

J-3po: This is a coronal mass ejection - plasma is ejected from the solar corona.

Which chatbots gave her correct answers?

(A) None gave a correct answer.

(B) RantGTP and J-3po.

(C) BB-9 and J-3po and Orion.

(D) BB-9, RantGTP, J-3po.

(E) All gave correct answers.

Solution:

Image was taken during a solar eclipse, that the new moon blocks the Sun. Patterns of corona visible magnetic field lines are not directly observable in the image. Strange pattern on the right is due to a coronal mass ejection.

Correct answer: D

21. A supernova shines with a luminosity 10^{11} times that of our Sun and is observed to have half of the Sun's solar intensity as viewed from Earth. What is the distance between Earth and the supernova?

- (A) 15 pc
- (B) 0.9 pc
- (C) **2.2 pc**
- (D) 127 pc
- (E) 1.5 pc

Solution:

Using the inverse square law:

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2 = \frac{L_2}{L_1} \Rightarrow \left(\frac{d}{1\text{ AU}}\right)^2 = \frac{10^{11}}{0.5} \Rightarrow d \approx 2.2\text{ pc}$$

Correct answer: C

22. Table 2 is an observation list collated by Wu Xiao in Singapore. He is currently using a refractor telescope on a German equatorial mount. His telescope is pointed at Merope Nebula, and C28 is setting on the Western Horizon. Suddenly, a nosy kid asks Wu Xiao that he wants to look at another object from the table below. Wu Xiao gets irritated and says, "Wait a while, I do not want to perform a meridian flip yet". Which of the following objects could the nosy kid have asked for?

Number	Name	Right Ascension	Declination	Apparent Magnitude
1	Merope Nebula	3h46m01.36s	+23°54′04.8″	4.18
2	C28	1h57m42.08s	+37°47′17.1″	5.70
3	Wishing Well Cluster	11h05m39.42s	−58°44′52.6″	3.00
4	Shoe Buckle Cluster	6h08m55.50s	+24°19′58.4″	5.10
5	Great Orion Nebula	5h35m18.69s	−5°23′26.8″	4.00
6	Beehive Cluster	8h40m25.00s	+19°39′57.1″	3.10

Table 2: Observation list of Wu Xiao

(A) 2, 3, 4, 5, or 6

(B) 3 or 4

(C) 5 or 6

(D) 4, 5 or 6

(E) **3 or 6**

Solution:

If C 28 is on the western horizon, that implies the meridian is approximately 6 hours behind C 28 in Right Ascension, since we're observing from near the equator.

$$RA_{C28} = 1^h 57^m 42.08^s$$
$$RA_{meridian} = RA_{C28} + 6^h = 7^h 57^m 42.08^s$$

Any object with a Right Ascension greater than this value would lie east of the meridian and would require a meridian flip for a German equatorial mount telescope.

From the table:

- Object 3 (Wishing Well Cluster): RA = 11h 05m 39.42s ⇒ Requires meridian flip
- Object 6 (Beehive Cluster): RA = 8h 40m 25.00s ⇒ Requires meridian flip

Therefore, the nosy kid could have asked for object 3 or 6 — and only those would require a meridian flip.

Correct answer: E

23. Which of the below astronomical parameters constitute the Milankovitch cycles?

I The eccentricity of the Earth's orbit

II The magnetic fields of the Earth

III The obliquity of the Earth's orbit

IV The mass of the Earth

V The precession of axis about which Earth spins

(A) I only

(B) I and III only

(C) II and IV only

(D) **I, III and V only**

(E) I, III, IV and V only

Solution:

The Milankovitch cycles include:

- Eccentricity of Earth's orbit (I)
- Obliquity of the Earth's axis (III)
- Precession of Earth's axis (V)

Options II and IV (Earth's magnetic field and mass) are not part of the cycles.

Correct answer: D

24. Suppose that a classical Cepheid variable's radius changes such that $\frac{r_{max}}{r_{min}} = 1.25$. By how much would the apparent magnitude change ($|\Delta m|$)? Assume temperature and flux at the surface does not change.

(A) 1.23

(B) 1.54

(C) **0.48**

(D) 2.57

(E) 1.96

Solution:

We use the magnitude-luminosity-radius relation under constant temperature and flux:

$$L \propto R^2 \quad \Rightarrow \quad \Delta m = -2.5 \log\left(\frac{L_{\text{max}}}{L_{\text{min}}}\right) = -2.5 \log\left(\left(\frac{R_{\text{max}}}{R_{\text{min}}}\right)^2\right) = -5 \log(1.25)$$

$$\approx -5 \times 0.0969 \approx -0.4846 \quad \Rightarrow 0.48$$

Correct answer: C

25. Figure 5 shows a part of the night sky.

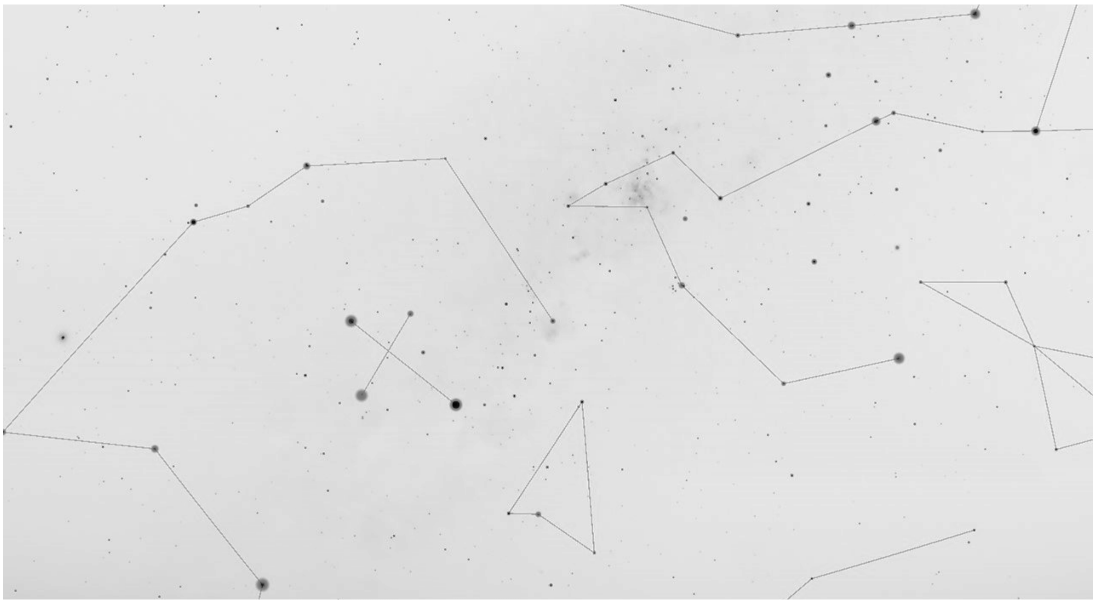


Figure 5: Question 25.

Kush asserts that he has seen Jupiter in this region of the sky. He is:

(A) Telling the truth.

(B) Telling the truth, but only if you are in the northern hemisphere.

(C) Telling the truth, but only if you are in the southern hemisphere.

(D) **Telling a lie.**

(E) Making a claim which cannot be verified due to insufficient information in the starchart.

Solution:

This region is very far from the ecliptic, where the planets are usually observed. Therefore, it is not possible to observe Jupiter there.

Correct answer: D

26. Up until the 1920s, it was widely believed that our galaxy, the Milky Way, was the only galaxy in the universe. How did Edwin Hubble prove that this was not the case?

(A) **Hubble observed Cepheid variable stars in the Andromeda galaxy, allowing him to determine their distance, which was calculated to be much larger than estimates of the diameter of the Milky Way, proving that it had to be outside the Milky Way.**

(B) Hubble plotted positions of globular clusters in the sky and determined their distances by observing Cepheid variables in the globular clusters, which was larger than estimates of the diameter of the Milky Way, proving they had to be outside of the Milky Way.

(C) Hubble measured the angular rate of rotation of spiral galaxies and concluded that their distance away must be greater than the estimated diameter of the Milky Way in order for their implied rotational velocities to be within an acceptable physical range.

(D) Hubble observed that novae in the Milky Way were similar to novae observed in spiral nebulae composed of stars, implying that the nebulae were not only distant, but were also galaxies instead of nebulae.

(E) Hubble measured the radial velocities of the spiral galaxies and determined their distances away based on how much they had redshifted, which were greater than the estimated diameter of the Milky Way.

Solution:

Hubble's critical discovery involved observing Cepheid variable stars in the Andromeda galaxy. Using their period-luminosity relation, he calculated their distance to be far greater than the Milky Way's size, confirming Andromeda is a separate galaxy.

Correct answer: A

27. Figure 6 shows the effective mass of an Asymptotic Giant Branch (AGB) star (higher line) and its core (lower line) over time.

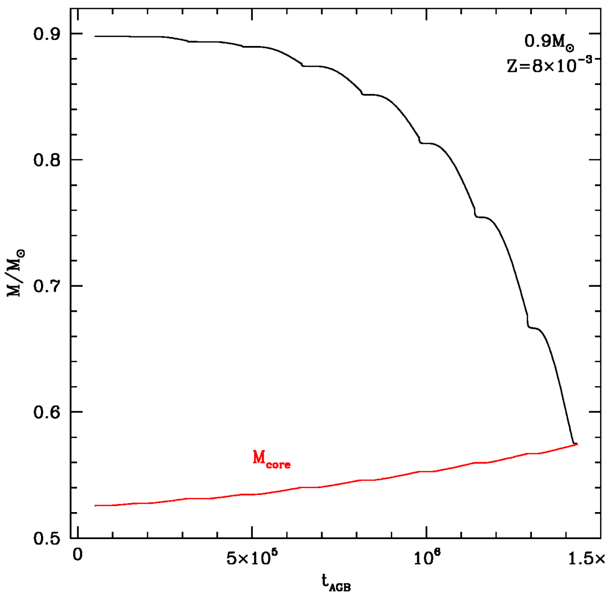


Figure 6: Question 27. [6]

Which of the following reasons explain the decreasing effective mass of the star?

(A) AGB stars always exist in a binary system. Thus, the mass of one star decreases as it is accreted by the other star.

(B) AGB stars undergo Type II supernova, which causes expulsion of the outer layers of the star and thus decrease in mass.

(C) AGB stars are superluminal, hence it appears that the mass is decreasing from our point of view.

(D) AGB stars are asymptotic to the red giant stars, and thus lose mass to them.

(E) **AGB stars have strong stellar wind and large radii, which causes the outer layers of the star to shed off resulting in a lower mass.**

Solution:

Options A through D describe implausible or incorrect physical mechanisms:

- **A.** Not all AGB stars are in binary systems, and mass transfer is not guaranteed.
- **B.** AGB stars do not end in Type II supernovae; that is reserved for more massive stars.
- **C.** Superluminal (faster-than-light) motion is unphysical and not observed.
- **D.** Red giants and AGB stars are distinct phases; there is no mass transfer between them.

E is the only physically valid explanation. AGB stars lose mass through intense stellar winds and pulsations, resulting in decreasing mass over time.

Additionally, it is interesting to observe that the black (total mass) and red (core mass) lines in the diagram converge. This indicates that the star has shed its outer envelope entirely, leaving behind only the core — a **white dwarf**.

Correct answer: E

28. A planet is in a circular orbit of radius r_1 about a star. The period of the planet in its orbit is T. A second planet orbits the same star in a circular orbit of radius r_2. Which of the following is a correct expression for the period of the second planet in its orbit about the star?

(A) $\left(\frac{r_2}{r_1}\right)^3 \times T^2$

(B) $\left(\frac{r_2}{r_1}\right)^{3/2} \times T^2$

(C) $\boldsymbol{\left(\frac{r_2}{r_1}\right)^{3/2} \times T}$

(D) $\left(\frac{r_2}{r_1}\right)^2 \times T$

(E) $\left(\frac{r_2}{r_1}\right) \times T$

Solution:

From Kepler's Third Law:

$$\left(\frac{T_2}{T}\right)^2 = \left(\frac{r_2}{r_1}\right)^3 \Rightarrow T_2 = T \cdot \left(\frac{r_2}{r_1}\right)^{3/2}$$

Correct answer: C

29. Cindy is playing a sandbox universe building game, and she's working on making a new planet. She has decided that she wants this planet to have rings. However, this game does not directly allow her to create a planet with rings, rather, she can only create a planet with a 'moon' orbiting it first and wait for it to (possibly) disintegrate due to tidal forces.

Here are some possible combinations of parameters for her to choose from. Which of the below systems will eventually produce a planet with rings?

System	Mass of planet (kg)	Mass of moon (kg)	Density of planet ($kg\,m^{-3}$)	Density of moon ($kg\,m^{-3}$)	Distance (km)
A	8.6×10^{24}	6.9×10^{22}	8760	2130	33200
B	2.8×10^{25}	1.2×10^{24}	9790	9500	28900
C	4.3×10^{23}	7.4×10^{21}	8540	2240	25400
D	7.1×10^{26}	9.3×10^{24}	13400	5630	41800
E	1.4×10^{27}	3.5×10^{24}	9520	6980	30400

Table 3: Parameters of planet-moon systems

(A) A

(B) B

(C) C

(D) D

(E) E

Solution:

To determine which system will form a ring, we apply the Roche limit formula:

$$d_{\text{Roche}} \approx 1.26 R \left(\frac{\rho_{\text{planet}}}{\rho_{\text{moon}}}\right)^{1/3}$$

We compare each system's actual distance with the Roche limit calculated using planet and moon densities. If the moon's distance is **less than** the Roche limit, it will disintegrate and potentially form a ring.

After computing for all options, only **System E** satisfies this condition — its moon lies within the Roche limit.

Correct answer: E

30. Rank the following exoplanet detection methods from the most to the least number of exoplanets detected by each method.

I Transit Photometry

II Astrometry

III Direct Imaging

IV Radial Velocity

V Gravitational Microlensing

(A) **I, IV, V, III, II**

(B) II, III, V, I, IV

(C) V, IV, II, I, III

(D) I, II, III, IV, V

(E) V, IV, III, II, I

Solution:

As of 20th May 2025, according to NASA:

- Transit Photometry: 4378 detections
- Radial Velocity: 1121 detections
- Gravitational Microlensing: 243 detections
- Direct Imaging: 83 detections
- Astrometry: 5 detections

We can eliminate answer options using logical reasoning:

- **Options C and E:** Lensing events are rare and unpredictable, making it unlikely for gravitational microlensing to rank higher than methods like transit or radial velocity.
- **Option D:** Astrometry is highly challenging due to the precision required to detect small stellar wobbles. It's not feasible as the 2nd most common method.
- **Option B:** Direct imaging is still relatively new and technologically demanding, requiring suppression of starlight. It is unlikely to be the 2nd most common detection method.

Only Option A remains plausible:

Transit > Radial Velocity > Microlensing > Direct Imaging > Astrometry

Correct answer: A

31. Huixin, the queen of an outer space empire, is planning on boosting the economic growth of her empire through the opening of the Inter Planetary Economic Zone (IPEZ). To achieve this, she plans to build a light, rigid bridge between two of her planets as shown below. Assume she does this without exerting any external torque on the system, and that she does this instantly when the two planets and the central star are all aligned in a straight line. The system can be seen as shown in Figure I-2.

To aid in her planning for the financial future of the empire, she needs to know how long a year would be in the IPEZ. To fulfil the queen's wishes, find the orbital period of the IPEZ around the central star using the parameters given below.

Planet	**Mass (kg)**	**Distance from central star (m)**	**Initial angular momentum ($\mathrm{kg\,m^2\,s^{-1}}$)**
Planet 1	3.0 x 10^{24}	1.0 x 10^{11}	3.0 x 10^{40}
Planet 2	3.0 x 10^{24}	3.0 x 10^{11}	4.4 x 10^{40}

Table 4: Parameters for the IPEZ system

(A) 2.7 x 10^7 seconds

(B) 3.8 x 10^7 seconds

(C) 4.2 x 10^7 seconds

(D) 5.3 x 10^7 seconds

(E) **6.6 x 10^7 seconds**

Solution:

Treat the IPEZ as a rigid body with center of mass determined by the weighted average of the two planets. Use conservation of angular momentum:

$$L = mr^2\omega \quad \Rightarrow \quad \omega = \frac{L}{mr^2}$$

Then, use:

$$T = \frac{2\pi}{\omega}$$

to find the orbital period.

$$m_{\text{IPEZ}} = m_1 + m_2 = 3 \times 10^{24} + 7 \times 10^{24} = 1 \times 10^{25}\,\text{kg}$$

$$\begin{aligned} r_{\text{IPEZ}} &= \frac{m_1 r_1 + m_2 r_2}{m_1 + m_2} \\ &= \frac{3 \times 10^{24} \times 1 \times 10^{11} + 7 \times 10^{24} \times 3 \times 10^{11}}{3 \times 10^{24} + 7 \times 10^{24}} \\ &= \frac{2.4 \times 10^{36}}{1 \times 10^{25}} \\ &= 2.4 \times 10^{11}\,\text{m} \end{aligned}$$

$$\begin{aligned} \text{Total initial momentum} &= 1.1 \times 10^{40} + 4.4 \times 10^{40} \\ &= 5.5 \times 10^{40}\,\text{kg}\,\text{m}^2\,\text{s}^{-1} \end{aligned}$$

By Conversation of angular momentum,

$$\begin{aligned}\text{Final angular momentum} &= 5.5 \times 10^{40}\,\text{kg}\,\text{m}^2\,\text{s}^{-1} \\ &= m_{\text{IPEZ}} r_{\text{IPEZ}}^2 \left(\frac{2\pi}{T}\right)\end{aligned}$$

$$\begin{aligned}T_{\text{IPEZ}} &= \frac{2\pi(1 \times 10^{25})(2.4 \times 10^{11})^2}{5.5 \times 10^{40}} \\ &= 6.6 \times 10^7\,\text{s}\end{aligned}$$

Correct answer: E

32. Figure 7 is a graph of the frequency of sunspots seen against time. which of the following observable quantities will reach a maximum during a sunspot minimum (e.g. in 2010, circled below)?

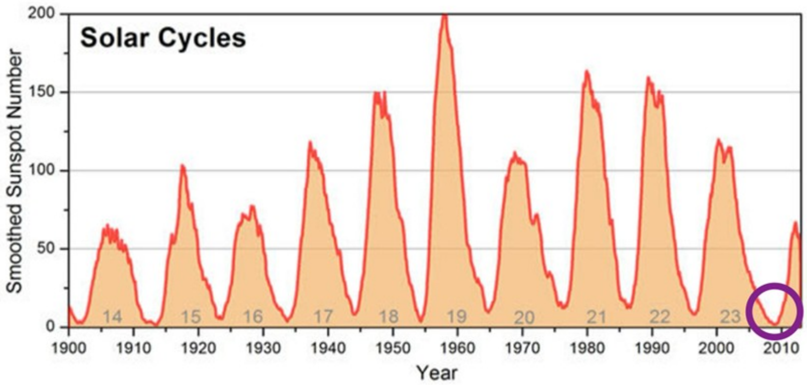


Figure 7: Question 32. [1]

(A) **Galactic Cosmic Ray Flux**

(B) Solar irradiance

(C) Coronal Mass Ejections

(D) Solar eclipses

(E) Solar radio flux

Solution:

The circled point corresponds to solar minimum. At this time, the Galactic Cosmic Ray Flux is highest due to reduced solar magnetic activity and shielding.

Correct answer: A

33. The Gravitational Wave Background is a random background of gravitational waves, akin to the Cosmic Microwave Background with respect to microwave radiation. With recent advancements in Gravitational wave detection, such Pulsar Timing Arrays, the GWB could become detectable in the near future.

Which of the following can be detected by current ground-based interferometers such as LIGO and VIRGO?

(A) Electroweak Phase transition during the Quark Epoch in the early universe.

(B) A Supernova.

(C) Unstable millisecond pulsars.

(D) **Stellar mass black hole mergers.**

(E) None of the above.

Solution:

Ground-based interferometers like LIGO and VIRGO are sensitive to high-frequency gravitational waves, such as those generated by stellar mass black hole or neutron star mergers. Events such as supernovae or early universe phase transitions produce gravitational waves at frequencies too low for these detectors.

Correct answer: D

34. A Quasar is observed to have a redshift, $z = 0.05$. What could be its approximate distance from Earth?

(A) 925 Mpc

(B) **221 Mpc**

(C) 494 Mpc

(D) 6.12 Mpc

(E) 21 Gpc

Solution:

Using the approximation $d \approx \frac{cz}{H_0}$ with $H_0 \approx 67.8$ km/s/Mpc:

$$d \approx \frac{(3 \times 10^5 \text{ km/s}) \times 0.05}{67.8} \approx 221.2 \text{ Mpc}$$

Correct answer: B

35. [VOIDED QUESTION] The spectral class of the star Wertz is A0V. The apparent magnitude of Wertz is measured at +2.102.

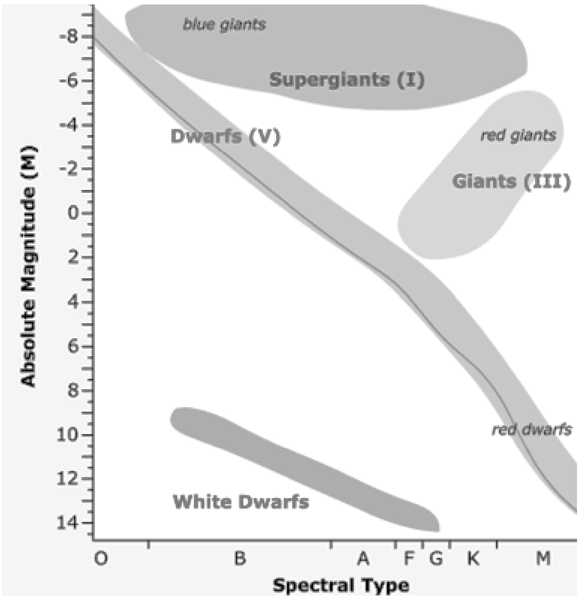


Figure 8: Question 35. [4]

Assume that the star Wertz lies on the Zero Age Main Sequence (ZAMS) curve (the curve in Figure 8), what is the distance to Wertz?

(A) 7.42 pc

(B) 10.5 pc

(C) **16.6 pc**

(D) **20.9 pc**

(E) Not enough information.

Solution:

An A0V star on the ZAMS curve has an absolute magnitude of +1. Using the distance modulus:

Considering the solid dark grey line for Dwarfs: $d = 10^{(m-M+5)/5} = 10^{(2.102-1+5)/5} \approx 16.6\,\text{pc}$

OR Taking the middle of the light grey band for Dwarfs: $d = 10^{(m-M+5)/5} = 10^{(2.102-0.5+5)/5} \approx 20.9\,\text{pc}$

Correct answer: C or D. Voided question.

36. According to the Nice model of the dynamical evolution of the Solar System, it is theorised that the 4 giant planets of the Solar System migrated outwards from their initial configuration, where they were closer together, to their current positions.

Which of the following options strongly support the Nice model?

(A) **The Jupiter Trojans have high inclinations and seem to be depleted when compared to predictions of the capture model. This is due to the mean motion resonances of Saturn and Jupiter during the migration of the planets.**

(B) The predominance of D-Type asteroids amongst Jupiter's trojans, which is commonly found in the outer regions of the asteroid belt, which was caused by secular resonances between the asteroid belt and Jupiter due to planetary migration.

(C) The formation of the Moon from a head-on collision of the Earth with a planetesimal approximately the size of Mars, which would not have been possible without outward migration of the giant planets causing instabilities in the orbits of large planetesimals which led one on a collision course with early Earth.

(D) Triton's retrograde orbit around Neptune, which is due to capture of Triton by Neptune during it's outward migration.

(E) None of the above.

Solution:

Option A is a direct prediction and strong piece of evidence for the Nice model. While B, C, and D may be consistent with the model, they are not strong confirmations since they could also arise from other planetary formation theories.

Correct answer: A

Use the following information to answer Questions 37 to 39.

The Chinese calendar is a lunisolar calendar. A lunisolar calendar is a calendar that combines monthly lunar cycles with the solar year. This means that, while the date of a lunisolar calendar reflects the Moon phase, the calendar is "reset" periodically into a rough agreement with the solar year and thus with the seasons. Note also that a lunisolar year always has a whole number of months. For the purpose of this paper, we are translating all dates into the more familiar format. For example: the Chinese New Year falls on the 1st day of the 1st month.

A lunar calendar, on the other hand, is a calendar based on the monthly cycles of the Moon's phases. We shall invent a hypothetical lunar calendar *Sigma*, in which the 1st day of each month always represent the day when the moon phase is new moon and the 15th day of each month usually represent the day when the moon phase is full moon. In fact, the Chinese calendar shows this exact pattern as well.

The difference between the hypothetical *Sigma* calendar and the Chinese calendar, however, is that each year in the *Sigma* calendar is 354 or 355 days long, being 12 lunar months of 29 or 30 days each, which does not line up with the Earth's orbital period, 365 or 366 days, that we are familiar with. On the contrary, the Chinese months, although not coinciding with the Gregorian months (Gregorian calendar is the one we are currently using in Singapore), do roughly reflect the seasonal pattern. For example, Chinese New Year (1st day of the 1st month) is always in the Gregorian January or February, which is winter in China.

To promote agriculture, ancient Chinese also introduced the 24 Solar Terms (Jie Qi) to perfectly reflect the seasonal change, that is, to perfect reflect the way the Earth revolve around the Sun (Hence solar terms). Both equinox and both solstices, in fact, coincide with four of the Solar Terms.

37. Which of the following changes, when applied to the calendar *Sigma*, will make it a lunisolar calendar instead (like the Chinese calendar)?

(A) Have an additional day in a month, every few months so that new moon is always on the 1st day of the month.

(B) **Have an additional month in a year, every few years so that winter solstice is always on the second last month of the year.**

(C) Have an additional year in a decade, every few decades so that the 1st year of each decade will have its vernal equinox in the 3rd month.

(D) Have additional or less seconds in an hour, every few hours so that the local solar noon is always at 1200hrs on the clock.

(E) None of the above.

Solution:

To adjust *Sigma* into a lunisolar calendar, we should not change the length of each month (since it is already aligned with the moon phases) or the length of each day (since it is already aligned with the solar day). Rather, we should adjust the number of months in a year (adding leap months) so that in the long term, the calendar is aligned with the solar year/seasons.

B. As explained above, we need a leap month every few years. In fact, this is exactly how the Chinese calendar add leap months.

A: This is, in fact, how both the Chinese calendar and *Sigma* ensure that the months follow the lunar phases. Since *Sigma* is already a lunar calendar, we should not change the number of days each month if we wish to get a lunisolar calendar.

C: There are no examples of calendar that uses this pattern. In fact, adding additional month is preferred to adding additional years to better reflect seasonal changes each year.

D: This only helps adjust the length of each day, so that our clock is keeping apparent solar time instead of the mean solar time we normally keep. It does not help adjust the lunar calendar into the solar year.

As an extension, the mean solar time and apparent solar time are indeed different due to the equation of time. However, we tend to stick to mean solar time for daily timekeeping purposes out of convenience, since, in our daily lives, it is not very important that 12pm should always be the moment when the Sun is directly above our head (we can live with a bit of deviation as long as the time is roughly aligned with a solar day), and that we rather prefer less frequent adjustment of our clock by adopting the mean solar time instead.

Correct answer: B

38. Which of the following methods is the best at helping the ancient Chinese to determine when Solar Terms should be? Assuming that any solar calendar date is not available and that each of the following options are possible to be carried out.

(A) Look for a particular day of each year on the Chinese Calendar (eg 20th day of the 3rd month).

(B) Observe the moon's phase and declare one Solar Term at new moon and one at full moon.

(C) **Divide up the ecliptic into 24 equal portions and determine (empirically or mathematically) the date, on the Chinese Calendar, that the sun will be at the start of each portion.**

(D) Observe the behaviour of other organisms on Earth.

(E) Count the number of days since Chinese New Year.

Solution:

C. This is roughly how the ancient Chinese actually does it. In the old days, people tend to simply divide a solar year up into 24 equal portions whereas in the modern-day, Solar Terms are defined by the right ascension of the sun, so it is actually not 24 exactly equal portions on the ecliptic.

A and E are essentially the same method. Since Chinese calendar is a lunisolar calendar, this method does give a rough idea of seasons (for eg 6 months after Chinese New Year should be summer in China) but does not help determine Solar Term accurately.

B does not help determine the solar term. In fact, borrowing knowledge from solar calendars, there should be about 365.25/24=15.22 days between each Solar Term while there are about 29.5/2=14.75 days between a new moon and a full moon. There will be systematic error in the long term.

D empirically help us determine seasonal change but is far from ideal from being a reliable calendar.

Correct answer: C

39. For a very long time, ancient Chinese Astronomy Constellations (Xing Gong) did not cover the entire celestial sphere. The Chinese only managed to rectify this in 1600s after learning new knowledge from the western star catalogue. What is the most plausible reason? Assume that the latitude of the southernmost part of the Chinese empire is no lower than 20 °N.

(A) The emperors before the 1600s all thought that some part of the sky is cursed and should not be catalogued.

(B) **Even if observed from the most southern part of the empire, there are still stars in the southern sky that never rise above the horizon.**

(C) The Chinese before the 1600s used to be firm believer of Charles Messier whose catalogue also mysteriously omit part of the sky.

(D) China is east of Europe, so western sky is not visible to them.

(E) The Chinese believed that the Earth was flat and thought that the sky was round.

Solution:

From a latitude of 20°N, stars with declination below -70° are never visible. Hence, they could not be observed or catalogued without access to the southern hemisphere.

Correct answer: B

40. [VOIDED QUESTION] As observed from the North Celestial Pole, what is the (linear) speed of the surface of the Earth at the equator due to the rotation of the Earth? You may assume that the Earth is a perfect sphere. It is given that one sidereal day is 86164 seconds and one mean solar day is 86400 seconds.

(A) $70.2\,\mathrm{m\,s^{-1}}$

(B) $73.7\,\mathrm{m\,s^{-1}}$

(C) $73.9\,\mathrm{m\,s^{-1}}$

(D) $140\,\mathrm{m\,s^{-1}}$

(E) $1.71 \times 10^{6}\,\mathrm{m\,s^{-1}}$

Solution:

When viewed from the north celestial pole, the Earth completes one full rotation in one sidereal day.

$$1 \text{ sidereal day} = 86164 \text{ s}$$

$$\omega = \frac{2\pi}{86164} \approx 7.29 \times 10^{-5}\,\mathrm{s^{-1}}$$

$$v = R_{\text{Earth}}\,\omega = 6.37 \times 10^{6} \times 7.29 \times 10^{-5} = 464.5\,\mathrm{m\,s^{-1}}$$

Correct answer: None of the given options. Voided question.

41. Estimate the pressure at the centre of the Sun (assume constant density). Neglect radiation pressure, accounting only for gravitational effects.

Hint: Consider the hydrostatic equilibrium, and the appropriate use of integration in solving an differential equation.

(A) **1.3 x 10^{14} Pa**

(B) 2.5 x 10^{16} Pa

(C) 8.8 x 10^{11} Pa

(D) 2.4 x 10^{8} Pa

(E) 7.4 x 10^{12} Pa

Solution:

We begin with the hydrostatic equilibrium equation:

$$\frac{dP}{dR} = -\rho\frac{GM_r}{R^2}$$

Assume constant density ρ, and use:

$$M_r = \frac{4}{3}\pi R^3 \rho$$

Substitute into the differential equation:

$$\frac{dP}{dR} = -\rho \cdot \frac{G \cdot \frac{4}{3}\pi R^3 \rho}{R^2} = -\frac{4}{3}\pi G \rho^2 R$$

Integrate from $R = 0$ to $R = R_\odot$, and from $P = P_c$ to $P = 0$:

$$\int_{P_c}^{0} dP = -\frac{4}{3}\pi G \rho^2 \int_0^{R_\odot} R\, dR$$

$$-P_c = -\frac{4}{3}\pi G \rho^2 \left[\frac{R^2}{2}\right]_0^{R_\odot} \Rightarrow P_c = \frac{2}{3}\pi G \rho^2 R_\odot^2$$

Now substitute $\rho = \frac{M_\odot}{\frac{4}{3}\pi R_\odot^3}$:

$$P_c = \frac{2}{3}\pi G \left(\frac{M_\odot}{\frac{4}{3}\pi R_\odot^3}\right)^2 R_\odot^2 = \frac{3GM_\odot^2}{8\pi R_\odot^4}$$

Now substitute values:

$$P_c = \frac{3 \cdot 6.674 \times 10^{-11} \cdot (1.989 \times 10^{30})^2}{8\pi \cdot (6.96 \times 10^8)^4} \approx 1.3 \times 10^{14}\,\text{Pa}$$

Correct answer: A

42. Suppose that Orion is at your local meridian at 11pm. After 45 days later, what time will Orion be at your local meridian?

(A) 2 am

(B) 9 pm

(C) 3 am

(D) **8 pm**

(E) 11 pm

Solution:

Each day, stars rise about 4 minutes earlier. After 45 days:

$$45 \times 4 = 180\,\text{minutes} = 3\,\text{hours} \Rightarrow \text{Orion will culminate at } 11\,\text{pm} - 3\,\text{h} = 8\,\text{pm}$$

Correct answer: D. 8 pm

Use the following information to answer Questions 43 to 45.

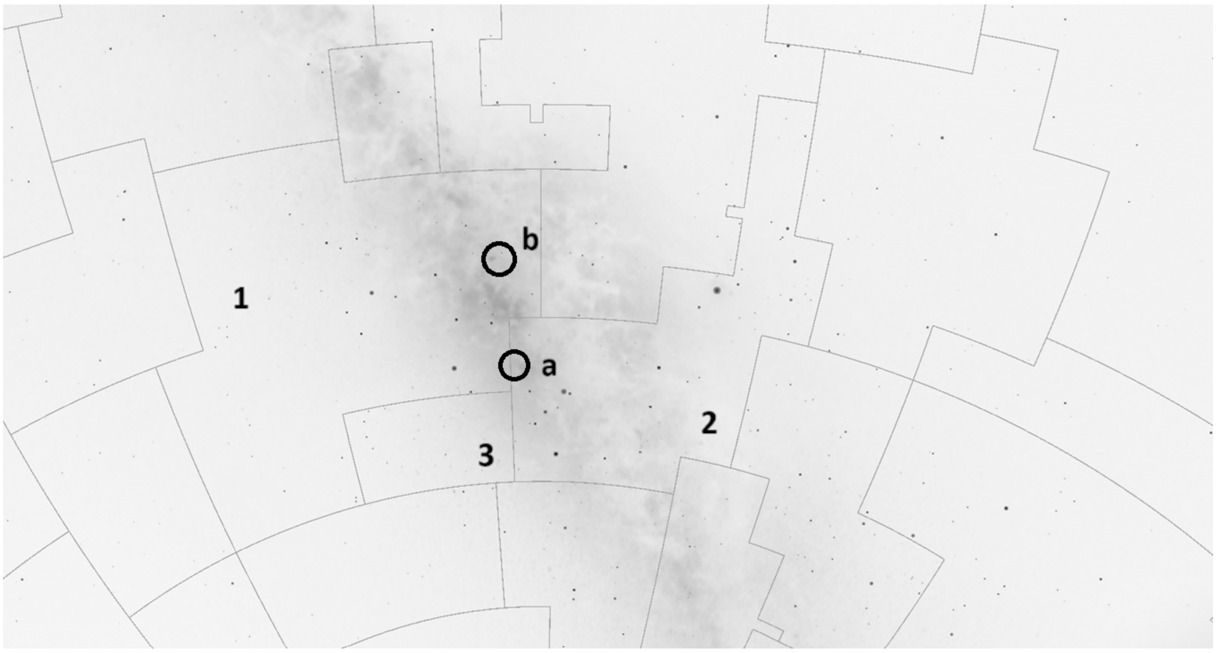


Figure 9: Questions 43 to 45.

43. Which celestial hemisphere does constellations 1, 2 and 3 lie in, and which month are you most likely to see them reach their upper culmination at around local midnight in Singapore?

(A) Northern hemisphere, December

(B) Northern hemisphere, July

(C) Northern hemisphere, October

(D) Southern hemisphere, December

(E) **Southern hemisphere, July**

Solution:

Constellation 1 is Sagittarius, 2 is Scorpius and 3 is Corona Australis. They are in the Southern sky and are typically called "summer constellations", hence option E should be chosen.

More formally, their right ascension is around 16–19h, implying culmination at midnight during June–July. As their declination is negative, they are in the southern celestial hemisphere.

Correct answer: E

44. What is the name of these three constellations?

(A) 1: Scorpius; 2: Sagittarius; 3: Corona Borealis

(B) 1: Sagittarius; 2: Scorpius; 3: Corona Borealis

(C) **1: Sagittarius; 2: Scorpius; 3: Corona Australis**

(D) 1: Virgo; 2: Bootes; 3: Corona Borealis

(E) 1: Virgo; 2: Bootes; 3: Corona Australis

Solution:

Based on shapes and placement: 1 = Sagittarius, 2 = Scorpius, 3 = Corona Australis.

Correct answer: C

45. Which of the following DSOs are correctly identified as being in (a) and (b)?

(A) (a) M6 (Butterfly Cluster) (b) M4 (Spider Globular Cluster)

(B) **(a) M7 (Ptolemy Cluster) (b) M8 (Lagoon Nebula)**

(C) (a) C76 (False Comet) (b) M8 (Lagoon Nebula)

(D) (a) M7 (Ptolemy Cluster) (b) M4 (Spider Globular Cluster)

(E) (a) M6 (Butterfly Cluster) (b) M5

Solution:

(a) is M7 (Ptolemy Cluster), and (b) is M8 (Lagoon Nebula), based on their known placement near Sagittarius and Scorpius.

Correct answer: B

46. Granules are small cell-like structures that can be seen covering the entire surface of the sun when imaged in white light.

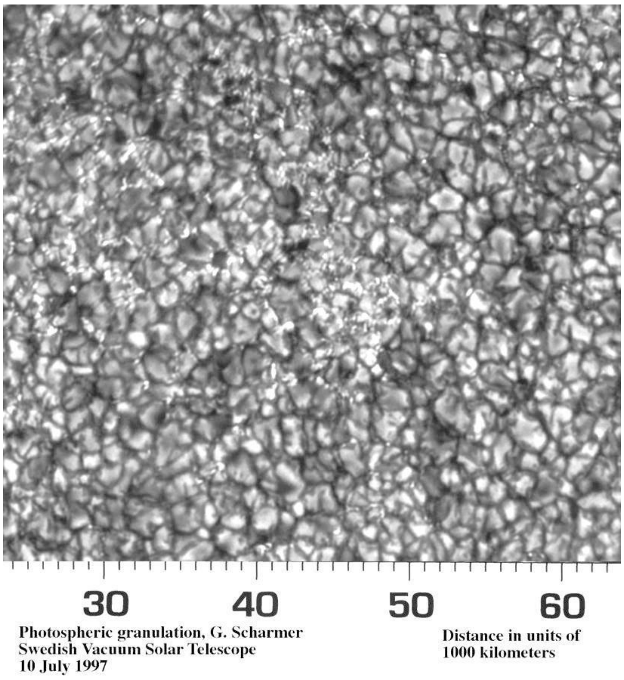


Figure 10: Question 46.

These granules are produced by:

(A) Magnetic field lines: bright cell centres are regions of strong magnetic field while dark boundaries are regions of weaker magnetic field.

(B) **Convection: bright cell centres are regions of convective upwelling, while dark boundaries are regions of convective downwelling.**

(C) Metals: bright cell centres have lower metal densities and less absorption, while dark boundaries have higher metal densities and more absorption.

(D) Density fluctuations: bright cell centres are region of over-densities in the plasma, while dark boundaries are due to underdensities in the plasma.

(E) None of the above. These granules are imaging artifacts and do not correspond to real physical features in the sun.

Solution:

Brighter areas correspond to higher surface temperatures; the only option that results in significantly higher surface temperatures is convective upwelling, which brings hotter material from the interior of the star to the cooler surface.

Correct answer: B

47. H II regions are large regions of singly-ionized hydrogen which typically surround newly-formed star clusters. These regions glow with a reddish hue, because:

(A) They are thermally heated by nearby stars and emit blackbody radiation.

(B) They reflect light off nearby stars, which tend to be M-type stars.

(C) Radiation is emitted by the excitation and de-excitation of hydrogen from its first excited state to the ground state.

(D) Radiation is emitted by the excitation and de-excitation of hydrogen from its second excited state to the first excited state.

(E) **Radiation is emitted by the recombination of free electrons with ionized hydrogen, and subsequent de-excitation back into the ground state.**

Solution:

Within the Strömgren sphere of a star, hydrogen is very nearly entirely ionized, therefore, H-α radiation can only be emitted by recombination rather than by bound-bound excitation

Correct answer: E

48. Messier 87 is a large elliptical galaxy located in Virgo and received recent attention due to a study by the Event Horizon Telescope which resulted in the first picture of a black hole successfully taken. The table below shows some key information about the galaxy:

Morphological Classification	E0p
Apparent Magnitude	8.6
Absolute Magnitude	−22
Apparent Size	$7.2' \times 6.8'$

Table 5: Question 48.

Using the information provided above, which one of the following methods is the most appropriate in verifying the distance between the Earth and M87?

(A) Using the Tully-Fisher Relation and using M87's cosmological redshift.

(B) Spectroscopic Parallax and using Cepheid Variables as Standard Candles.

(C) **Using Type 1a Supernovae as Standard Candles and Faber-Jackson Relation.**

(D) Determining the distance of M87 by measuring the shift in apparent position over half a year and Hubble's Law.

(E) Using Trigonometry to determine the distance using M87's apparent size, as well as using Hubble's Law.

Solution:

While uncommon, Type 1a Supernovae serves as good standard candles when determining the distance between a galaxy due to their predictable progression as well as high and consistent peak luminosity, which allows it to be easily observable from another galaxy.

The Faber-Jackson Relation connects the luminosity of elliptical galaxies to the velocity dispersion of their stars, which can then be used to determine the distance from the galaxy through its galaxy. Since M87 is an elliptical galaxy, it is appropriate to determine the distance using the relation.

The other options are not selected due to either one, or both methods being unsuitable to measure the distance between Earth and a galaxy. For example:

- The Tully-Fisher Relation is a relation that is primarily used for spiral galaxies, relating their luminosities to their rotation speeds. Since M87 is an elliptical galaxy, the relation is not ideal for such purposes.
- Spectroscopic Parallax is a technique used to primarily determine the distance to Main Sequence stars, and not galaxies.
- M87 is simply too far for a significant shift in apparent position for Trigonometric Parallax to work.
- Determining the distance using M87's apparent size requires knowledge of the radius of the galaxy, which is not available in this question. This method is hence not feasible.

Correct answer: C

49. Two objects of equal masses m, initially distance d apart, fall directly towards each other under their mutual gravitational attraction. How long does it take for them to collide? (Hint: consider Kepler's Third Law)

(A) $\frac{\pi d^{\frac{3}{2}}}{2\sqrt{Gm}}$

(B) $\frac{\pi d^{\frac{3}{2}}}{4\sqrt{Gm}}$

(C) $\frac{\pi d^{\frac{3}{2}}}{\sqrt{Gm}}$

(D) $\frac{\pi d^{\frac{3}{2}}}{2\sqrt{2Gm}}$

(E) $\frac{\pi d^{\frac{3}{2}}}{8\sqrt{Gm}}$

Solution:

We model the motion of two equal masses falling toward each other from rest, under mutual gravity, separated by distance d. This is equivalent to a degenerate elliptical orbit with semimajor axis $a = \frac{d}{2}$.

From Kepler's Third Law:

$$T^2 = \frac{4\pi^2 a^3}{G(m_1 + m_2)} = \frac{4\pi^2 \left(\frac{d}{2}\right)^3}{G(2m)} = \frac{\pi^2 d^3}{4Gm} \Rightarrow T = \frac{\pi d^{3/2}}{2\sqrt{Gm}}$$

However, the time to collision is only **half the orbital period**, so:

$$t_{\text{collision}} = \frac{T}{2} = \frac{\pi d^{3/2}}{4\sqrt{Gm}}$$

Correct answer: B

50. A Flat Earther tests for the curvature of the Earth by shining a flashlight through a small hole in a wall positioned approximately 5 meters above the ground, and using a camera propped up 5 meters above the ground to determine whether the Earth is flat. The horizontal distance between the flashlight and the camera is 15m.

The Flat Earther determined that the camera was able to capture the light only at a height of approximately 7 meters above the ground, as reflected in the schematic shown in Figure 11.

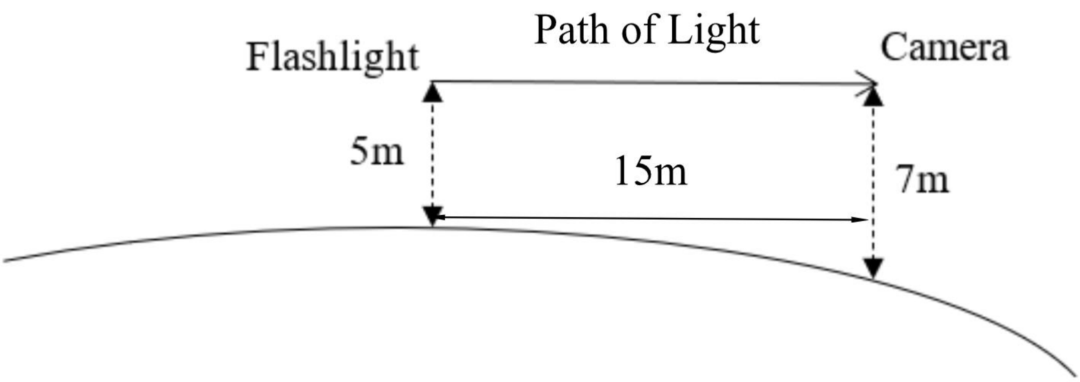


Figure 11: A greatly exaggerated display of the results of the experiment

If the Earth's mass is significant enough, gravitational lensing can occur such that the light deviates far enough for the light to enter the camera when it is at a height of 5m. The angle that light will be deflected from its original path due to gravitational lensing is given by:

$$\theta = \frac{4GM_{\text{Earth}}}{c^2 r}$$

towards the Earth such that the light originates at a distance r from the centre of Earth. Determine the required mass of Earth is required for this to occur. You may assume that the radius of the Earth does not change.

(A) 2.84×10^{34} kg

(B) 5.97×10^{24} kg

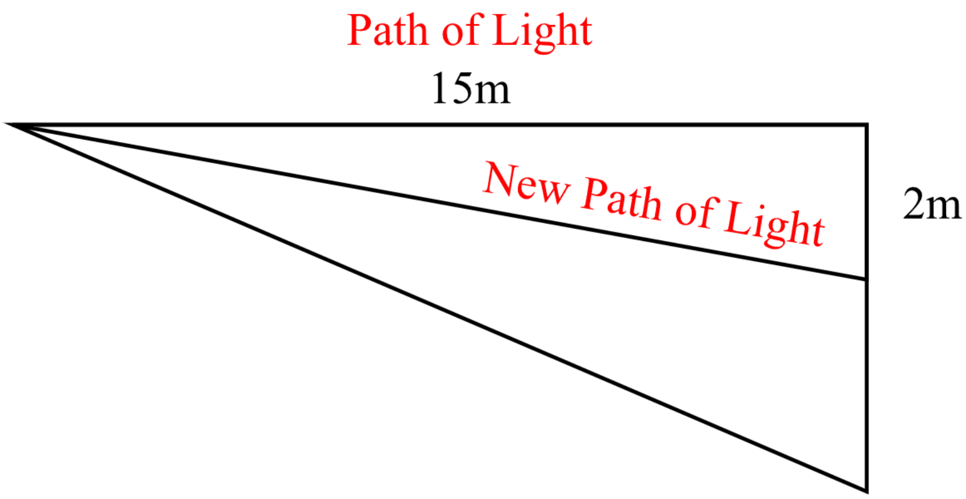
(C) 5.97×10^{25} kg

(D) 1.99×10^{30} kg

(E) 2.84×10^{32} kg

Solution:

We may determine the angular deviation of the light ray through a pair of similar triangles:



Through basic trigonometry, we therefore see that the angular deviation of the light ray is

$$\theta = \frac{4GM_{\text{Earth}}}{c^2 r} = \arctan\left(\frac{2}{15}\right)$$

Solving for M_{Earth}, we get approximately

$$M_{\text{Earth}} = 2.84 \times 10^{32}\,\text{kg}$$

Correct answer: E

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