AstroChallenge 2025
Senior MCQ Round

Wednesday 4th June 2025

PLEASE READ THESE INSTRUCTIONS CAREFULLY.

1. This paper consists of a total of **25** printed pages, including this cover page.
2. Any materials other than the Question Paper and Formula Booklet are strictly prohibited.
3. Do **NOT** turn over this page until instructed to do so.
4. You have **2 hours** to attempt **ALL** questions in this paper. If you think there is more than one correct answer, choose the *most* correct answer.
5. At the end of the paper, submit the Optical Answer Sheet. You do not need to submit this booklet.
6. Please ensure that you have shaded the correct course code and matriculation number, and have written your name, school, and team number clearly on the Optical Answer Sheet.
7. It is *your* responsibility to ensure that your Optical Answer Sheet has been submitted.

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

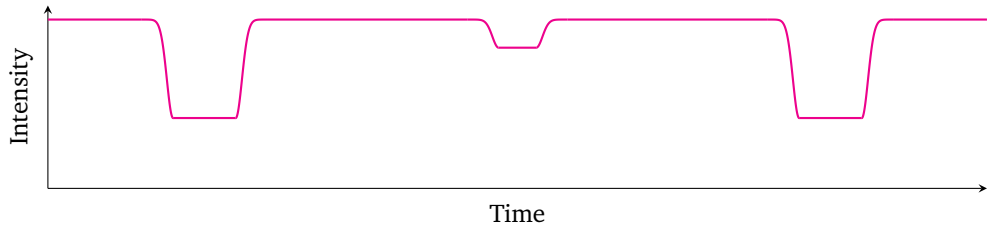

Figure 1: Question 1.

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

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.

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.

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

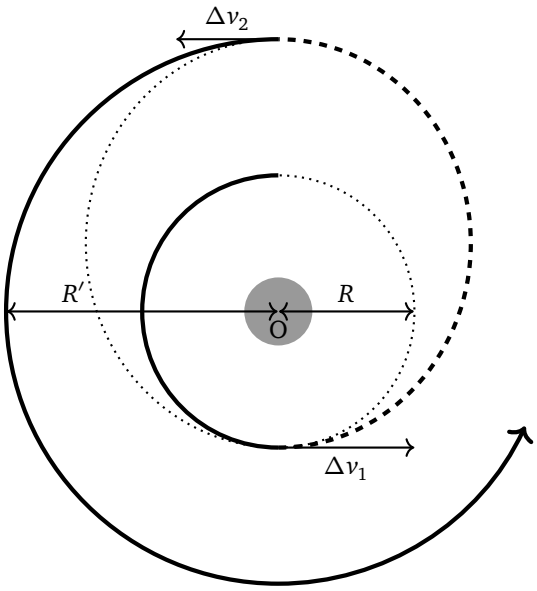

Figure 2: Question 4.

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

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.

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.

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

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.

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

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

(C) $M_A = M_B + 2.5\log(2)$

(D) $M_A = M_B + 2.5\log(3.5)$

(E) $M_A = M_B + 2.5^{3.5}\log(2)$

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

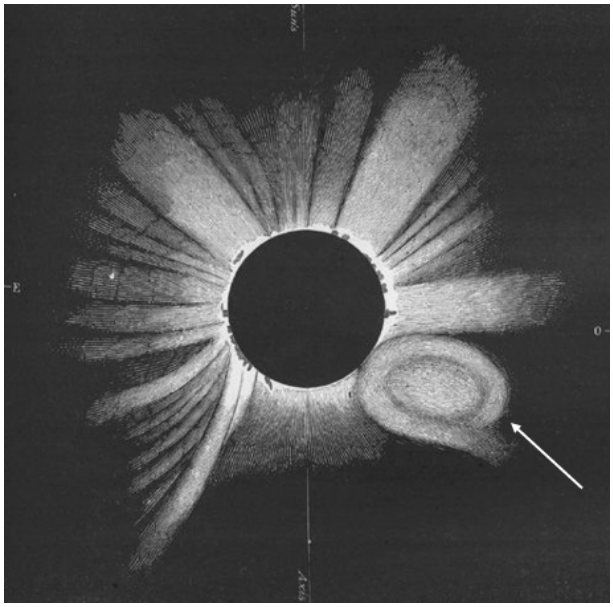

Figure 4: Question 20. [2]

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.

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

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

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

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

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

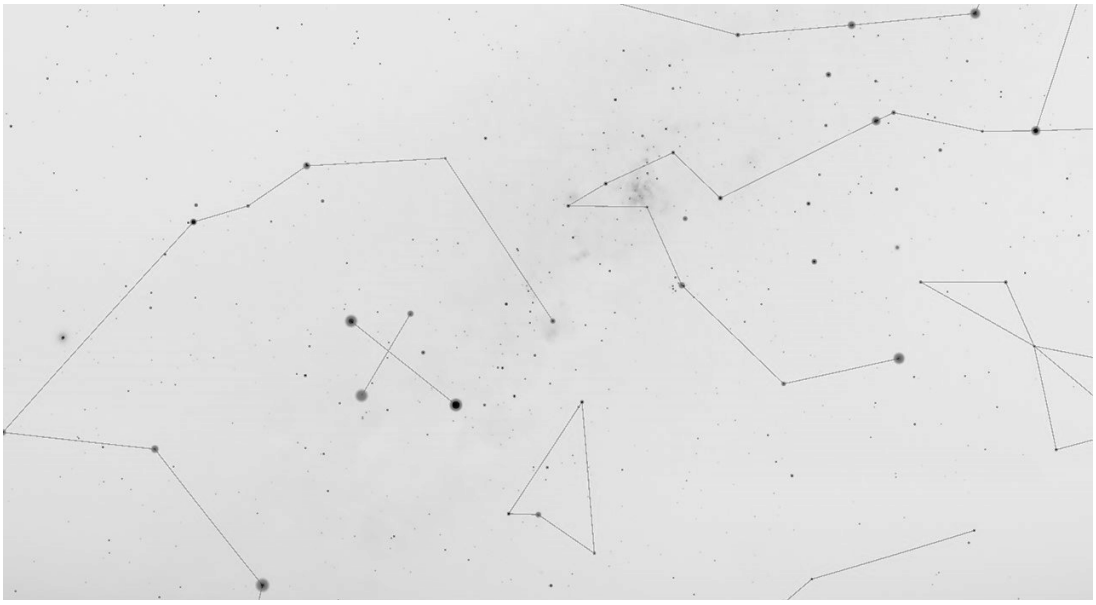

Figure 5: Question 25.

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.

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.

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

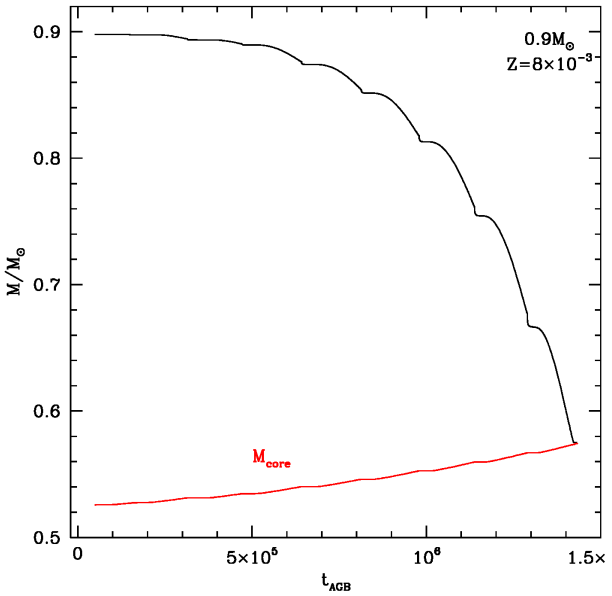

Figure 6: Question 27. [6]

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.

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

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

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

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

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

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 ($kg\,m^2\,s^{-1}$)**
Planet 1	3.0×10^{24}	1.0×10^{11}	3.0×10^{40}
Planet 2	3.0×10^{24}	3.0×10^{11}	4.4×10^{40}

Table 4: Parameters for the IPEZ system

(A) 2.7×10^7 seconds

(B) 3.8×10^7 seconds

(C) 4.2×10^7 seconds

(D) 5.3×10^7 seconds

(E) 6.6×10^7 seconds

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)?

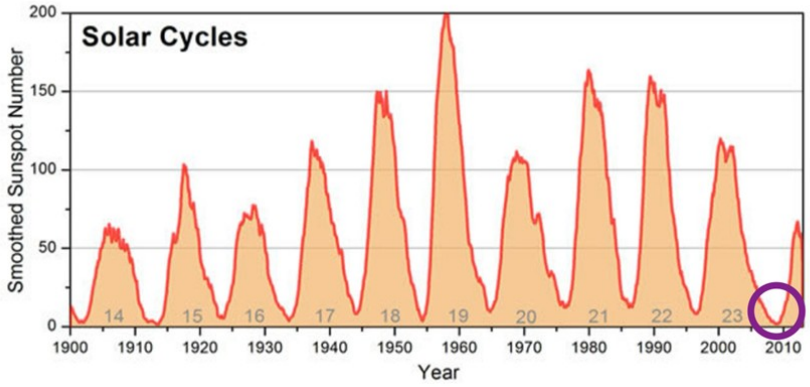

Figure 7: Question 32. [1]

(A) Galactic Cosmic Ray Flux

(B) Solar irradiance

(C) Coronal Mass Ejections

(D) Solar eclipses

(E) Solar radio flux

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.

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

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

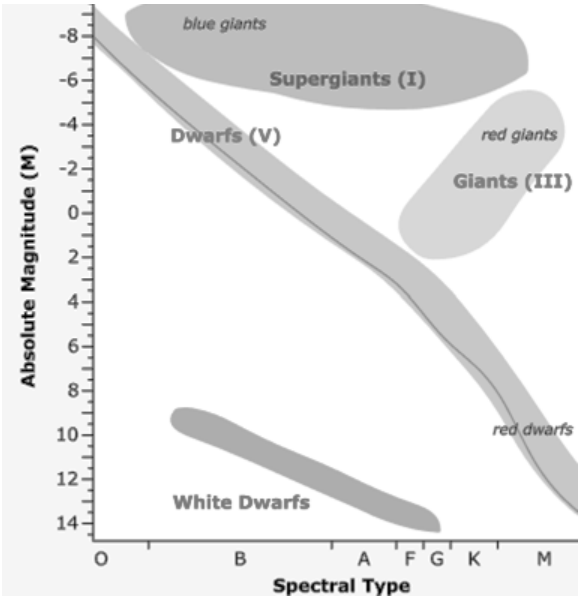

Figure 8: Question 35. [4]

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.

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.

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.

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.

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.

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

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

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

Use the following information to answer Questions 43 to 45.

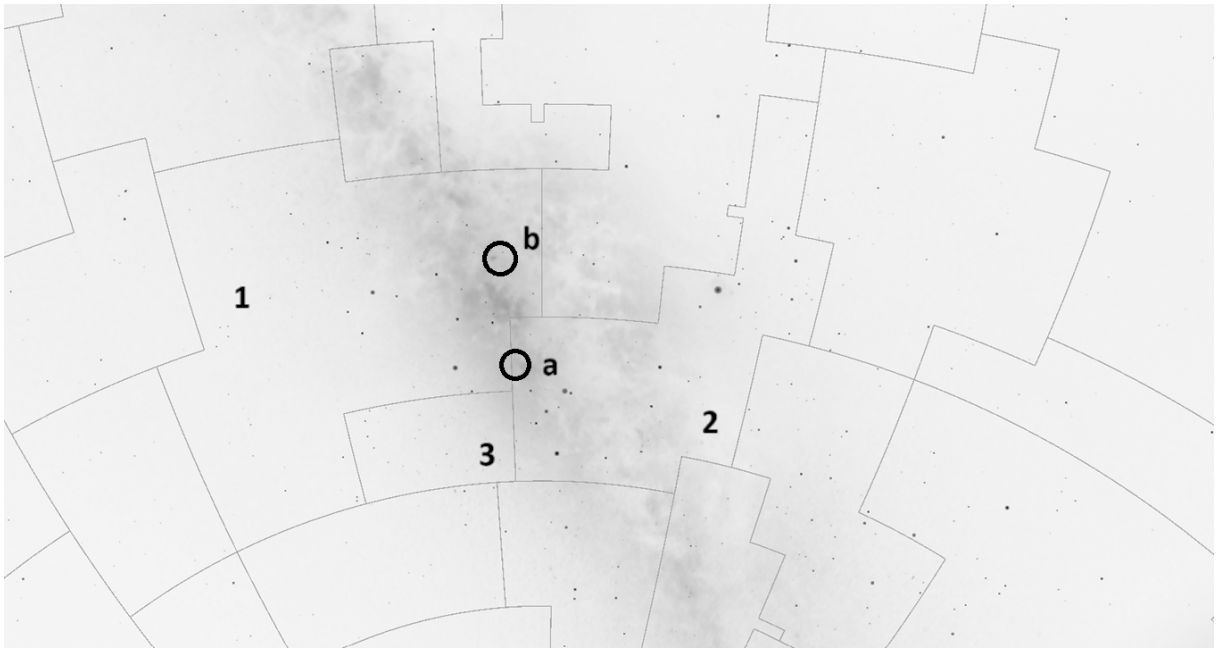

Figure 9: Questions 43 to 45.

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

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

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

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

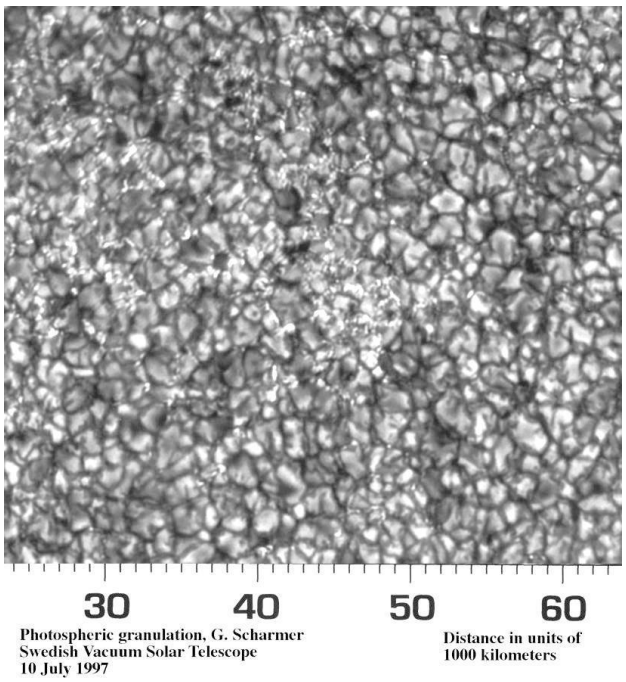

Figure 10: Question 46.

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.

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.

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.

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

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

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

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

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

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.

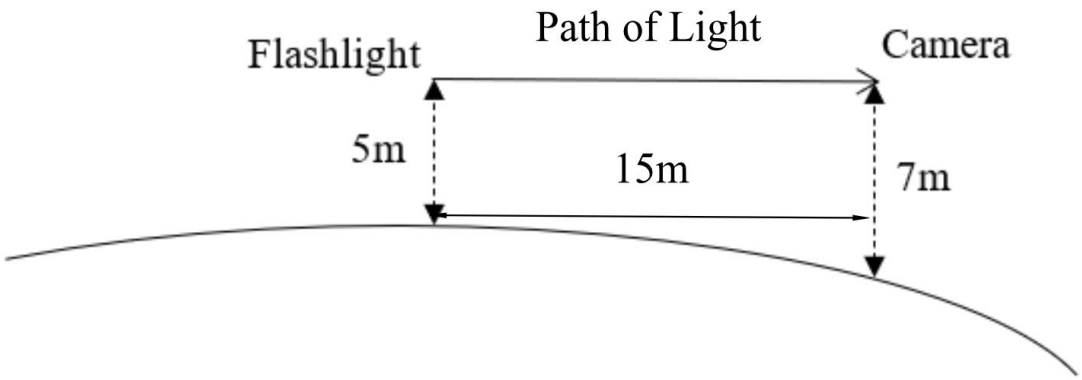

Figure 11: A greatly exaggerated display of the results of the experiment

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) $2.84 \times 10^{34}\,\text{kg}$

(B) $5.97 \times 10^{24}\,\text{kg}$

(C) $5.97 \times 10^{25}\,\text{kg}$

(D) $1.99 \times 10^{30}\,\text{kg}$

(E) $2.84 \times 10^{32}\,\text{kg}$

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