AstroChallenge 2018
Multiple Choice Questions
(Senior)

PLEASE READ THESE INSTRUCTIONS CAREFULLY

1. This paper consists of **20** printed pages, including this cover page.
2. Do **NOT** turn over this page until instructed to do so.
3. 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.
4. At the end of the paper, submit this booklet together with your answer script.
5. Your answer script should clearly indicate your name, school, and team.
6. It is your responsibility to ensure that your answer script has been submitted.

Solution. Summary of answers.

Qn	Ans	Qn	Ans	Qn	Ans	Qn	Ans	Qn	Ans
1	B	11	A	21	D	31	E	41	D
2	A	12	D	22	D	32	A	42	C
3	D	13	C	23	D	33	E	43	D
4	E	14	E	24	D	34	C	44	E
5	C	15	E	25	E	35	B	45	C
6	D	16	B	26	C	36	C	46	A
7	D	17	A	27	A	37	C	47	B
8	B	18	C	28	D	38	E	48	B
9	A	19	E	29	C	39	C	49	D
10	B	20	C	30	E	40	D	50	C

1. Consider the following planets and their orbital eccentricities.

Planet	Orbital Eccentricity
A	0.206
B	0.007
C	0.017
D	0.093
E	0.048

Which planet has the **most circular** orbit?

(A) Planet A.

(B) Planet B.

(C) Planet C.

(D) Planet D.

(E) Planet E.

Solution. Answer: B.

The planet with the lowest orbital eccentricity has the most circular orbit.

2. Which of the following **best** characterises the movement of a star onto the horizontal branch of a HR diagram?

(A) The onset of helium burning after a helium flash.

(B) The onset of neon burning in an extremely massive star.

(C) The expansion of a low-mass star into a red giant.

(D) The sudden collapse of an iron core into a compact ball of neutrons.

(E) The sudden outpouring of X-rays from a newly formed accretion disk.

Solution. Answer: A.

When a red giant reaches the tip of the red giant branch, it undergoes a helium flash. The ignition of helium burning then brings it down to the horizontal branch.

3. The following are some neolithic structures portraying the effects of astronomical alignment, as well as an archaeological relic that was thought to be previously used for astronomical purposes.

I. Khafre's pyramid in Egypt ($29^\circ\,59'$) was built about 4700 years ago with one of its sides aligned with the direction in which the star 3-Scorpii sets.

II. The neolithic burial chamber Maeshowe ($59^\circ\,00'$) was built about 5000 years ago so that the last rays of the setting sun on the winter solstice would travel down the long entrance tunnel to illuminate the interior of the tomb.

III. The Antikythera mechanism, thought to be built in 100–150 BC, predicted eclipses based on the Saros cycle.

Which of these will still work this year? Ignore any effects of erosion and rusting.

(A) II only.

(B) I and II only.

(C) I and III only.

(D) II and III only.

(E) I, II, and III.

Solution. Answer: D.

Paraphrasing the question, this question is asking if the same effect can still be observed today, accounting for axial precession of the Earth over a long period of time.

I. will not work due to precession. The RA and declination at which 3-Scorpii sets is no longer the same.

II. will work because the winter solstice is defined for a fixed declination of the Sun. Hence, the same effect will occur on the same day (winter solstice), just at a different time.

III. The Saros cycle accounts for the difference caused by precession. Hence, the length of a Saros cycle will not change.

4. Consider the following HR diagrams for different clusters of stars.

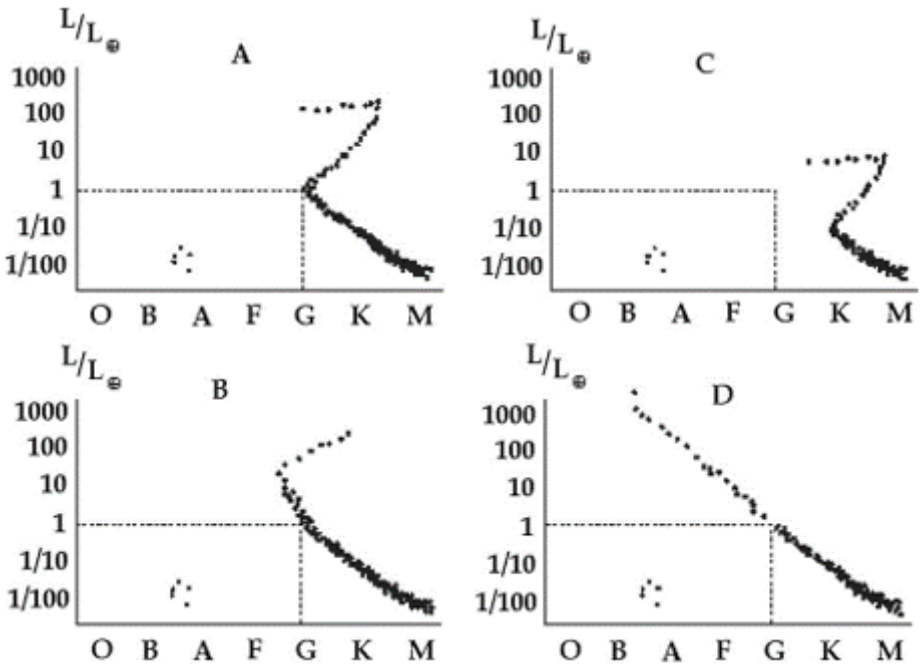


Figure 1: HR diagrams for several star clusters.

Consider the following statements.

I. Cluster D is the youngest.

II. Cluster A is probably about 10 billion years old.

III. The average temperature of the main sequence stars in cluster C is lower than the temperature of our Sun.

Which of the statements above is/are true?

(A) I only.

(B) I and II only.

(C) I and III only.

(D) II and III only.

(E) I, II, and III.

Solution. Answer: E.

I. is true. The main-sequence turnoff point for Cluster D is still at the O stars, hence indicating that the star cluster is relatively new.

II. is true. Cluster A has a main-sequence turnoff point at the G stars, hence stars in Cluster A have similar characteristics as our Sun. Since our sun has a lifespan of about 10 billion years, a main-sequence turnoff point at a G star implies that the star cluster is about 10 billion years old.

III. is true. For Cluster C, we can see that there are more K and M stars, which are generally of a lower temperature than a G star like the sun.

5. What is the theoretical maximum number of eclipses that can occur in a calendar year? Note that the length of a synodic month is 29.5 days, and that the length of an eclipse cycle is approximately 31 to 37 days.

   (A) 5

   (B) 6

   (C) 7

   (D) 8

   (E) 9

   Solution. Answer: C.

   The Sun only intersects the line of nodes of the Moon's orbit about the Earth every 6 synodic months. If the Sun is currently on the line of nodes, then 6 synodic months later, the moon will be at the same orientation, on the exact opposite side of this orientation. To understand this theoretical maximum, assume that the start of the ecliptic cycle is on Jan 1 and is of a particular type of eclipse. Since the period in which an eclipse typically occurs is 31 - 37 days, so we obtain a maximum of 3 eclipses in one eclipse season, and this season re-occurs after 6 synodic months.

   Assume that we have 6 eclipses occurring after 12 synodic months, i.e. after $29.5 \times 12 = 354$ days. Hence, the theoretical maximum number of eclipse in 355 days is 7, with an eclipse on the 355^{th} calendar day. The next possible eclipse can only occur 14 days later, so no further eclipses can occur in that year.

   Example: In 1985, there were a total of 7 eclipses. They occurred on the following dates.

   - Jan 9 – Lunar.
   - Jan 25 – Solar.
   - Jun 21 – Solar.
   - Jul 6 – Lunar.
   - Jul 20 – Solar.
   - Dec 15 – Solar.
   - Dec 30 – Lunar.

Refer to the information below to answer Questions 6 and 7.

In a hypothetical star system, an exoplanet was discovered by the Singapore Space Agency (SSA) in the year 2050. This exoplanet, named Singa, was discovered through the transit method, whereby the brightness of the only main-sequence star, named Marie, drops by 0.845% every 25.35 years. The luminosity of Marie is thrice the luminosity of the Sun in our solar system. Coincidentally, the mass of Singa was determined to be equal to the mass of the Earth. Assume that Singa revolves around Marie in a circular orbit. Furthermore, assume that both Marie and Singa are perfectly spherical.

6. Let V_M and V_S be the volumes of Marie and Singa respectively. What is the value of $\frac{V_M}{V_S}$?

   (A) 8.34

   (B) 24.1

   (C) 118

   (D) 1290

   (E) 46200

   Solution. Answer: D.

   Since the brightness of Marie drops by 0.845%, we then know that the fraction of Singa's area to Marie's area is $\frac{0.845}{100}$. Taking the reciprocal, we have

   $$\frac{A_M}{A_S} = \frac{100}{0.845}.$$

   Since area is proportional to the square of radius, we have

   $$\frac{r_M}{r_S} = \sqrt{\frac{100}{0.845}}.$$

   Finally, since volume is proportional to the cube of the radius, we have

   $$\frac{V_M}{V_S} = \left(\frac{100}{0.845}\right)^{\frac{3}{2}} = 1290.$$

7. What is the orbital angular momentum of Singa with respect to Marie?

   (A) 2.74×10^{40} kg m^2 s^{-1}.

   (B) 7.04×10^{40} kg m^2 s^{-1}.

   (C) 8.23×10^{40} kg m^2 s^{-1}.

   (D) 9.63×10^{40} kg m^2 s^{-1}.

   (E) 2.47×10^{41} kg m^2 s^{-1}.

   Solution. Answer: D.

Using the relation for the luminosity and mass of a main-sequence star, i.e. $L \propto M^{3.5}$, we see that

$$\frac{L_M}{L_\odot} = \left(\frac{M_M}{M_\odot}\right)^{3.5},$$

i.e. $M_M = 3^{\frac{2}{7}} M_\odot$.

Then, using the formula for angular momentum $L = mr^2\omega$, Kepler's third law $T^2 = \frac{4\pi^2}{GM}a^3$, and the definition of angular velocity $\omega = \frac{2\pi a}{T}$ given in the formula booklet, by substitution of values, the angular momentum that is obtained is 9.63×10^{40} kg m^2 s^{-1}.

8. Which of the following rotational/orbital/circular motions are anti-clockwise (rather than clockwise) when observed top-down with North of the ecliptic plane on top?

   I. Rotation of Venus about its own rotational axis.

   II. The circle traced by the North Celestial Pole due to precession of the Earth.

   III. The orbit of Uranus about the Sun.

   IV. The rotation of the Earth's Moon about its own rotational axis.

   Which of the above statements are correct?

   (Hint: Consider the direction of rotation of the protoplanetary disk.)

   (A) I and II only.

   (B) III and IV only.

   (C) I, II, and III only.

   (D) II, III, and IV only.

   (E) I, II, III, and IV.

   Solution. Answer: B.

   All circular motions in general tends to rotate or orbit in the anti-clockwise direction. However, statements I. and II. are surprising.

   Venus is the exception in the general trend of the direction of rotation of planets about their own rotational axis. This is actually an interesting phenomenon whose reason is still being debated today! Possible theories proposed today include chaotic system dynamics during the birth of our Solar System, and Venus's unusual rotational stability in this opposite direction.

   Statement II. might come off surprising for some. Even though the Earth rotates about its own axis in the anti-clockwise direction, the direction of precession is opposite. This is true for all forms of precession. The general idea is the application of the principles of conservation of angular momentum.

9. Consider the following statements about general relativity.

   I. Earth orbits the Sun because the Earth and Sun are connected by "rope-like" set of invisible, subatomic particles.

   II. Different reference frames will measure time differently because they are experiencing the same 4D spacetime, but from different perspectives.

   III. Time runs faster in stronger gravitational fields.

   IV. Wormholes violate general relativity.

   Which of the statements above is/are true?

   (A) II only.

   (B) I and III only.

   (C) II and III only.

   (D) II, III, and IV only.

   (E) I, III, and IV only.

   Solution. Answer: A.

   I. is false. Earth orbits the Sun because it is following the straightest possible path, but along a curved spacetime geometry.

   II. is true. As the famous quote goes:

   Space is relative. Time is relative. Spacetime is absolute for everyone.

   III. is false. Time runs slower in stronger gravitational fields. This is known as gravitational time dilation.

   IV. is false. Wormholes do not violate general relativity. They are theoretically possible, but no one knows much about its existence, neither can they disprove it.

10. The following graph shows the visual magnitude of a variable star. The average absolute magnitude of the star is 0.75.

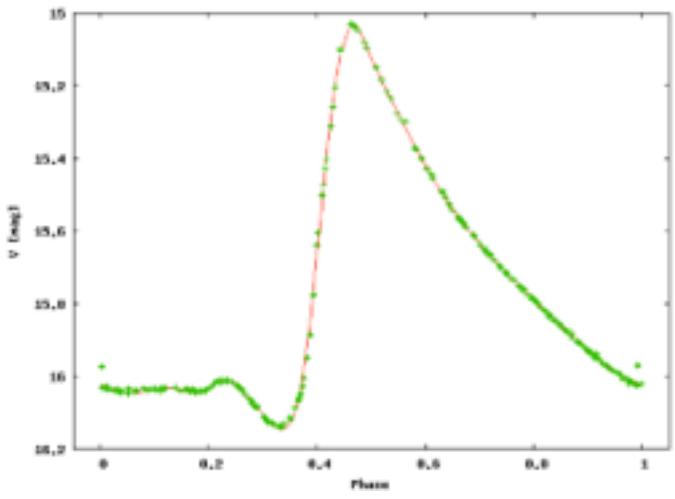


Figure 2: Visual magnitude of a variable star.

The variable star mentioned is a _____.

(A) T-Tauri variable with a distance of 2.5×10^3 pc.

(B) RR Lyrae variable with a distance of 9×10^3 pc.

(C) Algol variable with a distance of 1×10^4 pc.

(D) Mira variable with a distance of 2.3×10^4 pc.

(E) S Cepheid variable with a distance of 6.9×10^4 pc.

Solution. Answer: B.

From the light curve we can deduce that it is not an Algol or T-Tauri variable. Algol is an eclipsing binary variable, so its light curve should be constant with dips in a periodic manner. T-Tauri is a nebular variable, thus its light curve should have an irregular and small fluctuations. The rest are fluctuating variables and from the visual magnitude, we can deduce the approximate distance.

11. Consider the following statements regarding a Schwarzschild (non-rotating) black hole.

    I. If an object falls into a black hole, according to an observer infinitely far from the black hole, the object never crosses the event horizon.

    II. All black holes have a mass density greater than the density of the Earth. (Note: We define the density of a black hole as the event horizon density, i.e. the mass divided by the volume enclosed by its event horizon. Of course in reality, black holes do not have a well-defined density.)

    III. A black hole cannot emit any particle since everything that are trapped inside the event horizon can only move closer to the centre of the black hole and can never escape.

    Which of the above statements is/are correct?

    (A) I only.

    (B) II only.

    (C) I and II only.

    (D) I and III only.

    (E) II and III only.

    Solution. Answer: A.

    I. is true. Due to time dilation, the velocity of the object will approach zero just before touching event horizon according to an infinitely far observer.

    II. is clearly not true.

    III. is not true. We know that black holes can emit certain particles due to quantum effect near the event horizon and black holes do evaporate. This is known as Hawking radiation.

12. Barnard's star is one of the fastest moving stars as seen from the Earth. It has a tangential velocity of $89.7\,\mathrm{km\ s^{-1}}$ and a radial velocity of $-108\,\mathrm{km\ s^{-1}}$ as seen from the Earth. It has a distance of $1.83\,\mathrm{pc}$ from the Earth.

    If its motion remains approximately constant, how long will it take for Barnard's star to reach its closest approach to the Sun?

    (Hint: Drawing a diagram of the situation will help.)

    (A) 7060 years.

    (B) 7970 years.

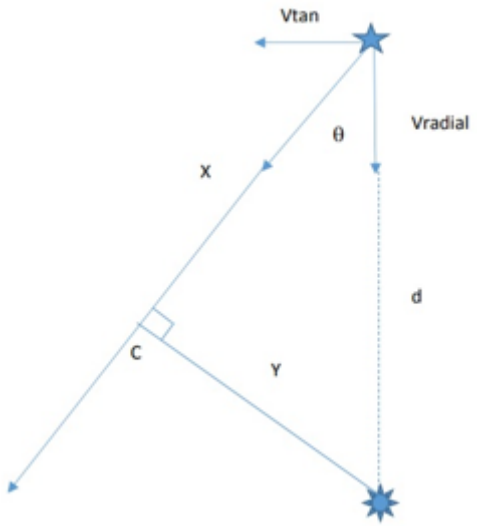
    (C) 8880 years.

    (D) 9790 years.

    (E) 10700 years.

    Solution. Answer: D.

    Consider the following diagram.



We have

$$\theta = \tan^{-1} \frac{v_{\text{tangential}}}{v_{\text{radial}}} \approx 39.5^\circ.$$

Hence,

$$X = 1.83 \cos\theta \approx 1.4\,\text{pc},$$

which is approximately 4.3×10^{13} km. Therefore,

$$t = \frac{X}{\sqrt{v_{\text{tangential}}^2 + v_{\text{radial}}^2}} \approx \frac{4.3 \times 10^{13}}{140} \approx 3.1 \times 10^{11}\,\text{s}\,.$$

This is equivalent to approximately 9790 years.

13. Complete the following statement if it is true; otherwise pick Option (E).

Emission nebulae are typically red because _____.

(A) they surround young stars that emit red light

(B) atmospheric extinction absorbs blue light from the nebula

(C) hydrogen in these nebulae are excited and preferentially emit red light

(D) dust in the nebula preferentially reflects red light, giving it a red appearance

(E) This is false. Emission nebulae tend to be blue.

Solution. Answer: C.

(A) is wrong. They are sites of star formation. Emission nebulae often contain massive young stars that preferentially emit blue light.

(B) and (E) are clearly wrong. If you go out and observe the night sky and/or astronomical images, note that there are blue naked eye stars and most emission nebulae are red.

(D) is wrong. It confuses reflection nebulae with emission nebulae. Dust is far more efficient in scattering/reflecting blue light than red.

14. Consider the following statement in an astronomy magazine on an upcoming conjunction of Mars and Venus.

Whenever Mars appears anywhere near Venus, it seems to get scared and fade.

Is this statement true? Why?

(A) It is true. A conjunction of Mars and Venus reminds us that love overcomes conflict.

(B) It is false. Mars can be at peak brightness while near Venus.

(C) It is true. Even though the brightness of Mars is constant, Venus is so bright that our eyes cannot adapt properly, causing Mars to "appear" dimmer during this period.

(D) It is false. The astronomy magazine is in error.

(E) It is true. Geometry dictates that Mars must be on the far side of its orbit in order to be at conjunction with Venus.

Solution. Answer: E.

Sketch out the orbits of Mars and Venus. You'll see that E is true as Venus is an inferior planet relative to Earth and Mars. Because of this, B and C are necessarily false: being on the far side of its orbit, Mars will dim appreciably compared to when it is at opposition. A is an obvious nonsense answer, and since E is correct, D is wrong.

15. I observe that Star A and Star B have the same brightness in the same field of view. Which of the following statements (considered individually) provide sufficient information for me to definitively conclude that Star A has a lower luminosity than Star B?

(A) Star B has a greater mass than Star A.

(B) Star B is closer to us than Star A.

(C) Star B has evolved onto the horizontal branch, while Star A is still on the main sequence.

(D) Star B is bluer than Star A.

(E) None of the statements above provide sufficient information individually.

Solution. Answer: E.

This question implicitly tests your knowledge of HR diagrams. The point of this question is that luminosity is far more difficult to determine than brightness.

(A) is wrong. It would be true if we knew that both A and B are on the main sequence (MS). However in this case, it is possible that the heavier Star B is still on the MS, while Star A is a red giant.

(B) is wrong. It gives us enough information to know that Star A is more luminous than Star B.

(C) is wrong. We could have an extremely young and massive MS star (e.g. 15 Monocerotis Aa, an O7V star, luminosity approximately 200,000 solar luminosities), compared to a typical horizontal branch star (approximately 100 solar luminosities).

(D) is wrong. Consider the stars in the red giant branch. Bluer red giants are actually less luminous than their redder counterparts!

16. The cosmic microwave background allows us to observe information about the early universe up to around 3.8×10^5 years after the Big Bang, after recombination (formation of electrically neutral hydrogen) has occurred. An astronomer proposes studying the following to obtain even earlier information of the universe.

I. Gravitational wave background (stochastic background).

II. Diffuse supernova neutrino background.

III. Cosmic neutrino background.

IV. The Hubble eXtreme deep field (i.e. even older galaxies in the Hubble ultra-deep field than have been previously studied).

Which of the above might work?

(A) I and II only.

(B) I and III only.

(C) III and IV only.

(D) I, II, III, and IV.

(E) None of the above methods would work.

Solution. Answer: B.

I. is plausible. Future gravitational waves observatories could observe primordial gravitational waves, relics of the early universe, up to less than a second after the Big Bang. See this link for more information.

II. is wrong. The Diffuse Supernova Neutrino Background (DSNB) is a theoretical population of neutrinos (and anti-neutrinos) originating from all of the supernovae events which have occurred throughout the Universe, and has nothing to do with the early universe.

III. is plausible. The cosmic neutrino background (CNB, CνB) is the universe's background particle radiation composed of neutrinos, sometimes known as relic neutrinos; while the CMB dates from when the universe was 379,000 years old, the CνB decoupled from matter when the universe was one second old. But as low-energy neutrinos interact only very weakly with matter, they are notoriously difficult to detect and observe directly with current technology. (Source: Steven Weinberg (2008). Cosmology. Oxford University Press. Cosmos: A Spacetime Odyssey.)

IV. is wrong. The Hubble eXtreme deep field galaxies formed 13.2 billion years ago, way after recombination.

17. Consider the following statements about Titan, Saturn's moon.

(I) Titan and Earth are the only celestial bodies in the solar system that experience precipitation (i.e. condensation of any atmospheric vapour that falls under gravity, such as rain).

(II) Titan and Earth are the only celestial bodies in the Solar System with an atmosphere of mostly nitrogen gas.

(III) If Titan had life, they would likely utilise liquid hydrocarbons as a solvent for biochemical processes, as compared to water for life on Earth.

(IV) Titan is likely to have volcanism in the form of cryo-volcanoes that spew water and ammonia, as compared to volcanoes that spew molten rock (lava) on Earth.

Which of the above statements is/are definitely false?

(A) I only.

(B) IV only.

(C) II and III only.

(D) II and IV only.

(E) None of the statements are definitely false.

Solution. Answer: A.

I. is false. Venus experiences precipitation in the form of sulfuric acid; however, they evaporate before reaching the surface due to high atmospheric temperature. There is good evidence that helium precipitates on Jupiter and Saturn as well.

The rest are not definitively false, though admittedly III. is speculative and IV. is disputed, with respect to the evidence and geological mechanisms responsible for cryo-volcanism. Thus the phrasing "definitely false" in the question.

18. Fermi's paradox is stated as follows.

There is a lack of evidence of extra-terrestial life, despite high probability estimates for the existence of extra-terrestrial life.

Which of the following is NOT a plausible reason that could account for Fermi's paradox?

(A) Nearby alien lifeforms are either too primitive or too advanced for humans to detect with our technology.

(B) The physical distances across galaxies and planets might be too great to warrant extensive interstellar travel as a feasible colonisation strategy for even advanced civilisations.

(C) There is no evidence that complex biomolecules can form naturally from simple, inorganic molecules.

(D) The biological factors allowing for the evolution of biologically complex and/or intelligent life involve occurrences with extremely low probabilities, which might only have been fulfilled on Earth thus far.

(E) Intelligent lifeforms tend to destroy themselves and/or other such lifeforms.

Solution. Answer: C.

There are many biomolecules that are shown to exist in space, meteorite samples and even on other celestial bodies, from amino acids to hydrocarbons. There is in fact sufficient evidence that complex biomolecules can form naturally, but the matter of how they result in the first living cell still remains under debate.

The rest are all otherwise plausible reasons, according to the Rare-Earth Hypothesis.

19. Rank the following nebulae in order of increasing size.

- Ring Nebula (M57): A famous and colourful planetary nebula.
- Tarantula Nebula (30 Do): Emission nebula, starburst region in Large Magellanic Cloud.
- Crab Nebula (M1, once SN 1054): Supernova remnant of a recent supernova.
- Stingray Nebula (Hen 3-1357): Youngest known Planetary Nebula.
- Lagoon Nebula (M8): Emission nebula, with NGC 6530 (an open cluster) in its foreground.

(A) Ring $<$ Tarantula $<$ Crab $<$ Stingray $<$ Lagoon

(B) Crab $<$ Ring $<$ Lagoon $<$ Stingray $<$ Tarantula

(C) Ring $<$ Stingray $<$ Crab $<$ Tarantula $<$ Lagoon

(D) Crab $<$ Ring $<$ Stingray $<$ Lagoon $<$ Tarantula

(E) Stingray $<$ Ring $<$ Crab $<$ Lagoon $<$ Tarantula

Solution. Answer: E.

Size in diameter, for option (E), in terms of light years:

$$0.16 < 2.6 < 11 < 55 \text{ by } 20 < 600.$$

Each nebula is roughly one order of magnitude bigger than the previous one!

(A) is a scam, arranged in order of the size of the objects they are named after.

(B) is random.

(C) has the right order of magnitude of size, but swapped the order of nebula in each size category.

(D) plays with the misconception that 'since the crab nebula occurred in recent history it is probably smaller', when in fact the force from the supernova explosion makes it expand really fast.

20. Which of the following statements on galactic astronomy is correct?

(A) Hubble's tuning fork provides an accurate description of the evolution of galaxy formation.

(B) The galactic coordinate system uses the centre of the Milky Way as its origin.

(C) Active galactic nuclei (AGN) refer to the centres of certain galaxies that radiate with higher-than-expected luminosity and whose emission is atypical of starlight.

(D) The star-forming regions of galaxies are typically found near the core of the galaxy.

(E) The old population of globular clusters are largely found along the spiral arms of galaxies.

Solution. Answer: C.

(A) is wrong. Hubble's Tuning Fork is not a representation of galaxy evolution, albeit that was the original interpretation.

(B) is wrong. The galactic coordinates system uses the centre of the sun as its origin.

(C) is correct. As it is, AGNs are commonly high gamma/x-ray emitters too.

(D) is wrong. Star-forming regions are found near the spirals arms of galaxies.

(E) is wrong. Globular clusters are generally found within the dark halo, above or below the galactic plane.

21. Which of the following statements is false?

(A) A spiral galaxy has both old and young stars.

(B) Globular clusters can contain millions of stars, but usually no gas or dust.

(C) The birth of stars is a battle between gravity and radiation pressure.

(D) You drop an indestructible probe with lights near a black hole and watch it fall in. The lights on the probe would appear to become bluer.

(E) You drop an indestructible probe with a clock near a black hole and watch it fall in. The clock would appear to stop when it reaches the event horizon.

Solution. Answer: D.

When astronomical bodies move away from the observer, they appear red in colour. This redshift happens because the speed at which they move away from the observer stretches the wavelength of visible light emitted by the object. This light is shifted toward the red end of the electromagnetic spectrum, which is characterised by longer wavelengths.

Gravity has the same effect, so as the probe as it approaches the event horizon of a black hole, the light it emits experiences a redshift whose value tends to infinity. Hence, the light appears redder in colour to an observer until at the moment that it actually crosses the event horizon.

Refer to Hong Kiat's observation plan below to answer Questions 22 to 25.

Object	**Constellation**	**RA**	**Declination**	**Apparent Brightness**	**Surface Brightness**	**Distance to object (kpc)**
M36 (Pinwheel Cluster)	Auriga	5h 36min	$+34^\circ\,08'$	6.00	10.74	1.30
M38 (Starfish Cluster)	Auriga	5h 28min	$+35^\circ\,51'$	6.40	12.02	1.30
M41	Canis Major	6h 46min	$-20^\circ\,46'$	4.50	12.19	0.71
M45 (Pleiades Cluster)	Taurus	3h 47min	$+24^\circ\,07'$	1.20	11.14	0.14
C92 (Eta Carinae Nebula)	Carinae	10h 44min	$-59^\circ\,53'$	1.00	11.13	2.00

22. Which of the following statements about these objects is the most accurate given the information provided above?

    (A) The Pinwheel Cluster has a greater maximum altitude in the night sky (i.e. approaches closer to the zenith) than M41.

    (B) M41 would never rise for astronomers at the South Pole.

    (C) The Pleiades Cluster would rise approximately two hours after M36.

    (D) All of the objects can be found within or along the Milky Way.

    (E) M36 is significantly brighter than the Pleiades Cluster.

    Solution. Answer: D.

    (A) is wrong. Refer to alt-azimuth coordinates. Note that from Singapore, the celestial equator (declination $0^\circ\,00'$) is approximately perpendicular to the local meridian.

    (B) is wrong. M41 has a DEC of -20° which can be observed from the South pole.

    (C) is wrong. M45 would rise two hours after M36.

    (D) is generally true from observations.

    (E) is wrong. M36 is dimmer; the magnitude system decreases in brightness with increasing number.

23. In which order should one observe the objects listed in the above observation plan (from earliest to latest).

    (A) M45, M38, C92, M36, M41.

    (B) M41, M36, M38, M45, C92.

    (C) M45, M41, C92, M36, M38.

(D) M45, M38, M36, M41, C92.

(E) C92, M45, M41, M36, M38.

Solution. Answer: D.

Observe in increasing right ascension. Note that we typically observed from the West to East so as to catch the objects that are about to set first.

24. The rising time of M36 is _____h, and the setting time of M45 is _____h.

(A) 1935; 2346

(B) 2125; 2246

(C) 0043; 0247

(D) 1935; 0535

(E) 0536; 0646

Solution. Answer: D.

Set time and rise time differ by 12h. M36 has a set time of 0735h, hence subtracting 12h from 0735h, it must then have a rise time (HA of 1800h) of 1935h. M45 has a RA that is about 1h 49min ahead of M36. It must then set 1h 49min before M36. Hence, from 0735h, the set time of M45 must be 0546h after subtraction.

Note that we could just add 12h to 1746h to get the same answer.

25. What was the local time on 9 December when the Local Sidereal Time was 0h 00min?

(A) 0245h.

(B) 0643h.

(C) 1359h.

(D) 1735h.

(E) 1959h.

Solution. Answer: E.

The Local Sidereal Time (LST) is the value of the right ascension at the meridian; the LST is equal to the right ascension of M45 when it is at the meridian (0347h).

The difference in HA between rise time and time at meridian is 6h. Furthermore, on 9 December, the rise time of M45 is 1746h. We find that the LST is 2147h when M45 has just risen after subtracting 6h from the RA of M45. It would be another 2h 13min before 0h 00min. Hence, 1746h + 2h 13min gives 1959h.

Using the following information, answer Questions 26 and 27.

It is known that a certain Seyfert galaxy, XHK1996, has an active galactic nucleus (AGN) so luminous that its core appears to be a star under telescope magnification. It was observed that the peak wavelength of the O III primary transition line of 5007 angstroms has been redshifted to 5089 angstroms.

26. How far does XHK1996 lie away from us?

(A) 56 Mpc.

(B) 68 Mpc.

(C) 72 Mpc.

(D) 86 Mpc.

(E) 100 Mpc.

Solution. Answer: C.

Let z be the redshift. We have

$$\lambda_{\text{observed}} = (z+1)\lambda_{\text{emitted}}.$$

Solving for z, we get

$$z = \frac{5089}{5007} - 1 = 0.01638.$$

Since z is small, we can assume $\frac{v}{c} \ll 1$, so that

$$z = \frac{v}{c} = H_0 d,$$

which gives $d = 72$ Mpc.

27. What is an appropriate upper bound to the diameter of the galactic nucleus, given that XHK1996 appears to be an unresolved star even when observed by the 3.0m Arcillas Brian Space Telescope?

    (Hint: You might find it helpful to recall that the visible spectrum lies between 390 nm to 700 nm.)

    (A) 11.30 pc.

    (B) 12.81 pc.

    (C) 16.45 pc.

    (D) 25.62 pc.

    (E) 32.74 pc.

    Solution. Answer: A.

    From Rayleigh's criterion,

    $$\theta = 1.22 \times \frac{\lambda}{D}.$$

    We use the lowest wavelength for maximum resolution. For $\lambda = 390 \times 10^{-9}\,\text{m}$ with $D = 3\,\text{m}$, we get

    $$\theta = 1.57 \times 10^{-7}\,\text{rad}\,.$$

    Since θ is small, by small angle approximations $\tan\theta \approx \theta \approx \sin\theta$, we have

    $$\theta = \frac{\text{diameter}}{\text{distance}} = 1.57 \times 10^{-7},$$

    which yields the diameter as 11.30 pc.

28. What is happening inside a star while it is expanding into a sub-giant?

    (A) It is fusing helium into carbon in a shell outside the core.

    (B) It is fusing helium into carbon in the core.

    (C) It is fusing hydrogen into helium in the core.

    (D) It is fusing hydrogen into helium in a shell outside the core.

    (E) It is not fusing any element, it is contracting and heating up.

    Solution. Answer: D.

    The subgiant stage occurs as the star begins to leave the main sequence. At this point in time, the core of the star is composed of helium, which does not fuse. As the centre of the star compresses under its own weight, hydrogen ignites in a shell around the core. Note that the stellar surface expands even though the core contracts. In general, the ongoings of the stellar core have little to no bearing on what occurs on the stellar surface.

29. The following graph shows the rotation curve of the Milky Way.

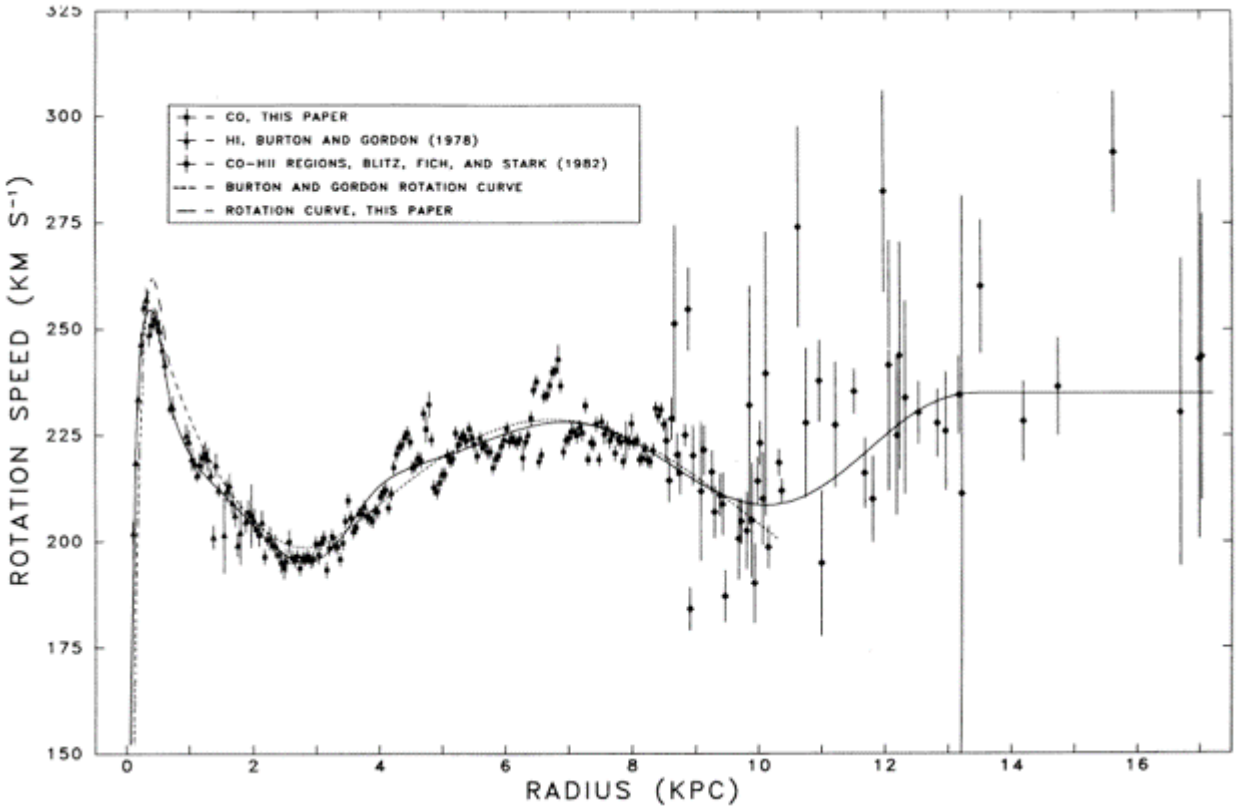


Figure 3: Rotation curve of the Milky Way.

Which of the following statements about the Milky Way is inaccurate?

(A) The rotation curve provides supporting evidence that there exists non-luminous matter, dark matter residing beyond 12 kpc.

(B) Our Solar System has an approximate rotation speed of 225 km s^{-1} about the galactic core.

(C) Our Solar System lies about 7 to 8 Mpc away from the centre of the galactic core.

(D) The curve is fitted using data from various sources.

(E) Before introducing dark matter, models derived from purely General Relativity and Newtonian gravity are unable to adequately account for the behaviour at distances beyond 10 kpc.

Solution. Answer: C.

(A) and (E) are correct. From Newtonian gravity and general relativity, if we consider only luminous matter, it is expected that the values should tail off beyond a certain range. The graph's constant value beyond 10 kpc contradicts this.

(B) is correct.

(C) is incorrect. The Solar System is known to be a third away from the centre of the galaxy, hence giving a rough estimate of 6 to 7 kpc, not in the Mpc range.

(D) is correct. This is simply graph reading.

Using the following information, answer questions 30 to 32.

It is the winter solstice, 22 December 2017. The sun is lowest in altitude at maximum during the winter solstice (at local noon), and the angle of tilt of the Earth is 23.5° from the ecliptic.

30. What is the local sidereal time?

    (A) 0000h.

    (B) 0600h.

    (C) 1200h.

    (D) 1800h.

    (E) There is insufficient information to determine the local sidereal time.

    Solution. Answer: E.

    No location and local time is provided in the question.

31. What is the sun's approximate declination and altitude in the sky when it is along the local meridian?

    (A) 23.5°; 23.5°.

    (B) 23.5°; 65.5°.

    (C) −23.5°; 23.5°.

    (D) −23.5°; 65.5°.

    (E) There is insufficient information to determine the approximate declination and altitude.

    Solution. Answer: E.

    No location and local time is provided in the question.

32. Consider the following objects.

Object	**Right ascension**	**Declination**
M8 (Lagoon Nebula)	18h 03min	$-24^\circ\,22'$
M57 (Ring Nebula)	18h 53min	$+33^\circ\,01'$
NGC 6334 (Cat's Paw Nebula, in Scorpius)	17h 20min	$-36^\circ\,06'$
C92 (Eta Carinae Nebula, in Carina)	10h 44min	$-59^\circ\,53'$

    During the said winter solstice, which of the above objects cannot be observed anywhere on earth?

    (A) M8, NGC 6334.

    (B) M8, M57, C92.

(C) M8, NGC 6334, C92.

(D) M57, NGC 6334, C92.

(E) There is insufficient information to determine.

Solution. Answer: A.

The Sun's right ascension during the Winter Solstice of the northern hemisphere (clue from 22 December 2017) is at approximately 18h 00min. We would hence be unable to see objects in the vicinity.

In particular, the sun is approximately in Sagittarius/Scorpius, hence we would not be able to see M8 (in Sagittarius) and NGC6334 (in Scorpius).

M57 is reasonably far enough to be observed possibly at the North Pole. We use the 18° standard from astronomical twilight as basis for keeping NGC 6334 too.

33. The four-arm model of the Milky Way is a popular candidate for the precise shape of the galaxy we live in, and is supported by several studies. One of these involve high-mass stars. What is a main reason for using such stars?

(A) High mass stars are easier to detect due to their brightness.

(B) High mass stars generally form in gas clouds of lower density tracing the edges of the arms.

(C) High mass stars form from gravity waves passing through the arms.

(D) High mass stars are bound closer together due to higher gravitational forces between such stars.

(E) High mass stars do not have the time to migrate.

Solution. Answer: E.

High mass stars burn out very quickly. They do not live for very long, and so there is insufficient time for such stars to migrate across arms of the Milky Way.

34. You have a telescope of focal specifications 6-inch f/20. You wish to point your telescope at Sirius (declination $16^\circ\,42'\,58''$) from Singapore and introduce your friend to this system. You need Sirius to stay in the FOV for at least half a minute. Assume the telescope is completely stationary.

Which of the following eyepieces provides the highest zoom satisfying the needed duration for Sirius to remain in the FOV?

(A) Eyepiece A: 20 mm focal length, 50° AFOV.

(B) Eyepiece B: 15 mm focal length, 50° AFOV.

(C) Eyepiece C: 10 mm focal length, 56° AFOV.

(D) Eyepiece D: 6 mm focal length, 56° AFOV.

(E) Eyepiece E: 4 mm focal length, 60° AFOV.

Solution. Answer: C.

Because we are in Singapore, and Sirius' declination is sufficiently small, and the TFOV is very small, we may reasonably utilise the following approximations.

The distance Sirius covers in the sky in 30 seconds is approximately

$$30v_S \approx \frac{360}{86400} \times 30 = 0.125^\circ.$$

Let M be the magnification, f_S be the focal length of the objective, and f be the focal length of the eyepiece. Then,

$$M = \frac{f_S}{f} \approx \frac{6 \times 25.4 \times 20}{f} = \frac{3048}{f},$$

and thus

$$\mathrm{TFOV} = \frac{\mathrm{AFOV}}{M} = \frac{f \times \mathrm{AFOV}}{3048}.$$

With this formula, we get TFOVs as

A: 0.328°,

B: 0.246°,

C: 0.183°,

D: 0.110°,

E: 0.079°.

So Eyepiece C has the highest zoom satisfying the needed condition.

Note: If we accounted for the difference in declination/latitude, a difference of at most about 0.007° in movement would be expected. This is not significant enough to affect the result.

35. The Big Bang model is commonly accepted today as the model describing the universe and its formation. The main difference between the Big Bang model and the Steady State model (another postulated model in the 20^{th} century) is that the Steady State model postulates that the density of the expanding universe remains constant due to continuous formation of matter. Under this hypothesis, the cosmic microwave background radiation is caused by the scattering by galactic dust. Which of the following statements is true?

(A) The Steady State model does not account for the observed homogeneity of the observable universe.

(B) The Steady State model does not account for the observation that radio sources are primarily found at great distances.

(C) The Steady State model can account for the observed uniform distribution of cosmic microwave background radiation.

(D) The Steady State model accounts for the presence of radio sources in the star clusters orbiting the Milky Way galaxy.

(E) Both the Big Bang model and the Steady State model account for the observed polarisation of the cosmic microwave background radiation.

Solution. Answer: B.

(A) is clearly false under assumption.

(B) is true. Under the assumption, radio sources would have to be found everywhere, up to and including close to us.

(C) is false under assumption.

(D) is false.

(E) is false, but not by assumption. The CMB does not have observed polarisation.

36. If the average mass density of the Universe exceeded the critical density, which of the following statements would be true?

(A) The curvature of space would be negative.

(B) The mass density will eventually decrease to be equal to the critical density.

(C) The Universe would eventually re-collapse.

(D) The sum of angles of a (very large) triangle would be less than 180°.

(E) The present Hubble expansion would slow down but never come to a stop.

Solution. Answer: C.

The critical density denotes the density for the geometry of the Universe to remain "flat" (or if you will, at balance between gravity and expansion). Beyond the critical density, gravity wins. The expansion of the Universe slows and eventually reverses.

37. Which of the following conditions are required for a solar eclipse to occur?

(A) The phase of the Moon can be new or full, and the nodes of the Moon's orbit must be nearly aligned with the Earth and the Sun.

(B) The phase of the moon must be full, and the Moon's orbital plane must lie in the ecliptic.

(C) The phase of the Moon must be new, and the nodes of the Moon's orbit must be nearly aligned with the Earth and the Sun.

(D) The phase of the moon must be new, and the Moon's orbital plane must lie in the ecliptic.

(E) The phase of the Moon must be full, and the nodes of the Moon's orbit must be nearly aligned with the Earth and the Sun.

Solution. Answer: C.

The nodes of the Moon's orbit refers to the points where the Moon's orbit intersects with the ecliptic plane. With this in mind, it is easy to see why the nodes of the Moon's orbit must be aligned with the Earth and Sun for an eclipse to occur. It should hopefully be obvious that a new moon is necessary for a solar eclipse to occur.

38. Consider the following properties of a planet with seasons.

I. Axial tilt.

II. Eccentricity.

III. Semi-major axis.

Which of the above determine(s) the length of the planet's seasons?

(A) I only.

(B) II only.

(C) I and II only.

(D) I and III only.

(E) II and III only.

Solution. Answer: E.

I is wrong. The axial tilt gives rise to the presence of seasons but does not affect the lengths of seasons.

II is correct. If a planet has an eccentric orbit, from Kepler's second law, its orbital speed varies throughout its orbit, resulting in some seasons being longer than others.

III is correct. The total length of the four seasons is equal to the planet's orbital period, which is related to the planet's semi-major axis by Kepler's third law.

39. Which of the following statements regarding detection methods for exoplanets is false?

(A) Gravitational microlensing events of exoplanets almost never repeats.

(B) The Doppler method can be used to determine an exoplanet's minimum mass.

(C) The transit method favours the detection of exoplanets with similar mass to Earth.

(D) Few exoplanets have been detected by ground-based astrometry due to atmospheric distortion.

(E) Unlike other methods, direct imaging is more effective for exoplanets with face-on orbits rather than those with edge-on orbits.

Solution. Answer: C.

A is true. Such exoplanets are very far away and the chance of such precise alignments happening again is very low.

B is true. It can only estimate the minimum mass and not the true mass because the inclination of the exoplanet's orbit needs to be considered.

C is false. The transit method is independent of an exoplanet's mass.

D is true. Changes in the positions of the parent star are very minute such that errors due to atmospheric distortion are very significant.

E is true. Other methods work better with edge-on orbits because they mainly look for the change in brightness of the parent star due to the exoplanet.

40. The stars that make up the Winter Hexagon come from the constellations Auriga, Taurus, Orion, Canis Major, Canis Minor, and Gemini. What other constellation can be found within the Winter Hexagon?

    (A) Lepus.

    (B) Cancer.

    (C) Lynx.

    (D) Monoceros.

    (E) Hydra.

    Solution. Answer: D.

    Go out for observation in late winter, or alternatively fire up Stellarium.

41. Which of the following statements about the Milky Way is false?

    (A) While we believe the Milky Way is a spiral galaxy, it is extremely difficult to determine the exact shape of the Milky Way as we are located within it.

    (B) All of the stars that we can see with the naked eye belong to the Milky Way.

    (C) A supermassive black hole is believed to exist at the centre of the Milky Way.

    (D) From our perspective, the Galactic Centre appears to lie within the constellation of Scorpius.

    (E) From the Northern Hemisphere, the core of the Milky Way is best seen in summer.

    Solution. Answer: D.

    (C) is true. Sagittarius A* is a supermassive black hole and defines the position of the Galactic Centre.

    (D) is therefore false, since the Galactic Centre lies in Sagittarius.

    (E) is true since Sagittarius is a summer constellation.

    (A) is true, since intervening gas and dust along the Milky Way's plane causes us to have great difficulty in mapping out the far reaches of the Milky Way (e.g. the debate over whether the Monoceros Ring is a stellar stream or part of the Milky Way's galactic disk).

    (B) is true due to the great distance between us and other galaxies.

42. It is local midnight, and these are the following constellations you can observe when you look at the night sky.

    - Caelum (southern constellation) near the zenith.
    - Regulus.
    - Auriga approximately due North.

    Given that the Sun lies in Leo from July to August, which season are you currently experiencing?

    (A) Winter.

(B) Spring.

(C) Summer.

(D) Fall.

(E) There is insufficient information to determine the season.

Solution. Answer: C.

The fact that Caelum lies near the zenith informs us that we are in the Southern Hemisphere. Auriga is a winter constellation from the Northern Hemisphere, while Regulus is also a late-winter/early spring constellation, and thus rises around midnight in midwinter (or what passes for midwinter) in the northern tropics. These two lines of evidence suggest that we are in winter in the Northern Hemisphere, aka summer in the Southern Hemisphere.

43. If the Earth suddenly lost all of its orbital velocity, how long would it take the Earth to fall into the Sun?

(A) 35 days.

(B) 45 days.

(C) 55 days.

(D) 65 days.

(E) 75 days.

Solution. Answer: D.

Using Kepler's laws and regarding a straight line as the limit of an extremely elongated ellipse, we have

$$t = \frac{1}{2} \times \left(\frac{1}{2}\right)^{\frac{3}{2}} \text{ years},$$

which is approximately 65 days.

Note that you can use integration (from conservation of energy) if you have any doubt. ~~The integral is trivial and left as an exercise to the reader.~~

44. For a reference planet A and another planet B in the same system, the synodic period S of B is related to its sidereal period P and the sidereal period $P_\oplus$ of A by the following formula.

$$\frac{1}{S} = \begin{cases} \frac{1}{P} - \frac{1}{P_\oplus}, & B \text{ is an inferior planet,} \\ \frac{1}{P_\oplus} - \frac{1}{P}, & B \text{ is a superior planet.} \end{cases}$$

Let the period of orbit of a reference planet around its star in a star system be S_p. Which of the following statements about the synodic period of an inferior planet S_i, and the synodic period of a superior planet S_s, is true for **all** star systems with inferior and superior planets?

(A) $S_i \neq S_s$.

(B) $S_i > S_s$.

(C) $S_s > S_i$.

(D) As the distance of an inferior planet from the star tends towards zero (i.e goes very close to the star), S_i tends towards S_p.

(E) As the distance of a superior planet from the star tends towards infinity (i.e goes very far away from the star), S_s tends towards S_p.

Solution. Answer: E.

(A) is false because there exists such a combination. For instance, if the inferior planet satisfies $P = \frac{1}{2}P_\oplus$, we see that $S_i = P_\oplus$. Similarly, if another superior planet is far such that $P = 2P_\oplus$, then, we see that $S_s = P_\oplus$. In this case $S_i = S_s$.

Similar arguments show (B) and (C) are false.

(D) is false because as distance tends towards zero, P tends towards zero. This causes S_i to tend towards zero.

(E) is true because as distance tends towards infinity, P tends towards infinity, thus $\frac{1}{P}$ tends towards zero. Hence, S_s tends towards $P_\oplus$.

45. Astronomers have reported that the centre of the Milky Way galaxy smells like raspberries and tastes like rum. This is due to the presence of certain organic molecules formed via abiogenesis. Consider the following statements regarding the "smell" of the centre of the Milky Way galaxy.

I. Abiogenesis suggests that these organic molecules are formed from inorganic molecules and matter.

II. The presence of these organic molecules indicates that the presence of extra-terrestrial intelligence near the centre of the Milky Way galaxy.

III. The fruity smell of raspberries can possibly be attributed to an ester (e.g. ethyl formate).

Which of the above statements is/are true?

(A) I only.

(B) I and II only.

(C) I and III only.

(D) II and III only.

(E) I, II, and III.

Solution. Answer: C.

I. is true. It is the definition of abiogenesis.

II. is false. The presence of organic molecules does not indicate the presence of extra-terrestrial intelligence. The right conditions for life must also be present. The converse could however be true, that the presence of extra-terrestrial intelligence indicates the presence of organic molecules.

III. is true. Esters are sweet smelling in general. Hence, it is possibly the cause of (and in fact is partially responsible for) the analogous sweet smell in raspberries.

46. Consider the following statements about the categorisation of some of the more prominent stars in the night sky according to their asterisms.

I. The lid of the teapot asterism is formed by the three stars in the constellation of Sagittarius λ Sgr (Kaus Borealis), δ Sgr (Kaus Media), and ϕ Sgr.

II. The Northern Cross is essentially a cross formed by two lines, one line joining α Crucis (Acrux) and γ Crucis (Gacrux), and another line joining β Crucis (Mimosa) and δ Crucis.

III. The Winter Triangle is a triangle formed by Sirius, Betelgeuse and Procyon.

IV. The Summer Triangle is a triangle formed by Arcturus, Regulus and Spica.

Which of the statements above are true?

(A) I and III only.

(B) II and III only.

(C) I, II, and IV only.

(D) I, III, and IV only.

(E) II, III, and IV only.

Solution. Answer: A.

The truth of I. and III. can be easily verified using Stellarium.

II. is essentially describing the Southern Cross (Crux). The contradiction here can either lie in knowing that the name of the stars forming the Northern Cross do not coincide with the names mentioned above, or that "Crucis" already refers to the constellation of Crux.

IV. is false. These three stars form the Spring Triangle, not the Summer Triangle.

47. The phantom time hypothesis is a historical conspiracy theory asserted by Heribert Illig. First published in 1991, the hypothesis proposes a conspiracy by the Holy Roman Emperor Otto III, Pope Sylvester II, and possibly the Byzantine Emperor Constantine VII, to fabricate the Anno Domini dating system retrospectively, so that fast-forwarding the date placed them at the special year of AD 1000, and to rewrite history to legitimise Otto's claim to the Holy Roman Empire.

Heribert argued that there is a phantom time of X years before AD 1000. This is because when the Gregorian calendar was introduced in AD 1582, relative the date of effect of the Julian calendar 45 BC, a certain number of days should be subtracted to be converted from the Julian calendar to the Gregorian calendar. However, the astronomers and mathematicians working for the pope then found that the adjustment only needs to be 10 days.

Note that the difference between a Julian year and a Gregorian year is 11 minutes. What is the approximate length of the period of "phantom time" (missing time) hypothesised by Heribert in this conspiracy theory?

(A) 150 years.

(B) 300 years.

(C) 450 years.

(D) 600 years.

(E) 750 years.

Solution. Answer: B.

What the question really wants is to understand the difference between a Julian year and a Gregorian year. The difference between the two years are also given.

Let us attempt to work backwards; determine the number of years of difference between the two types of years that is required to produce a difference of 10 days. For every year, the difference in a year is 11 minutes. Hence, we obtain $\frac{10\times24\times60}{11} = 1310$ years.

However, between 45 BC to AD 1582, there is a difference of 1627 years. Hence, a "gap" of approximately 300 years was hypothesised with this as the evidence.

48. The "full cold moon" happens on the eve of Christmas (night of 24 December). This phenomenon can be observed _____.

(A) from everywhere on Earth

(B) from the North pole

(C) from the South pole

(D) neither from the North nor South pole

(E) only from the North pole, and nowhere else

Solution. Answer: B.

During the eve of Christmas, the Sun is just three days after the winter solstice. So the full moon does not rise at the South pole. Note that while the moon's orbit is inclined relative to the ecliptic, the inclination is small enough (5°) for it to not matter in this instance.

49. Equinoxes happen twice a year, at spring (21 March) and autumn (22 September). Consider the following statements.

I. At the equinoxes, the sun rises exactly due east.

II. The sun passes through the zenith of all observers at equinox.

III. At the equinoxes, the geometric centre of the Sun is above the horizon for exactly half a day, ignoring atmospheric refraction and the change in the Sun's declination in a single day.

IV. The autumnal equinox happens when the right ascension of the Sun is 0h 00min.

From the Northern Hemisphere, which of the above statements are wrong?

(A) I and II only.

(B) I and III only.

(C) II and III only.

(D) II and IV only.

(E) I, II, and III only.

Solution. Answer: D.

I. is true, as the declination of the Sun is $0^\circ\,00'$ at equinoxes.

II. is wrong, as this is only true for observers on the equator.

III. is true, due to the geometry of the celestial sphere.

IV. is wrong. When the right ascension of the Sun is 0h 00min, it is the vernal equinox.

50. Which of the following shows an astronomically correct crescent moon in context of Singapore, i.e from an observer from Singapore viewing the moon as it is seen just above the west horizon?

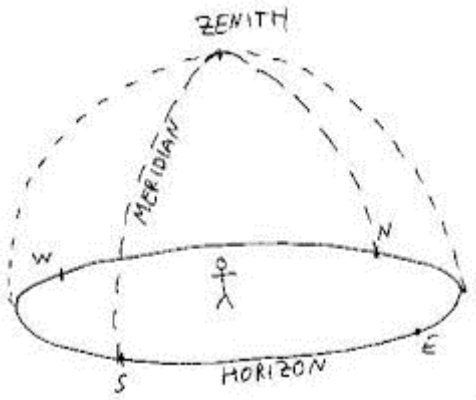


Figure 4: Visual representation of observer and horizon.

(A) Upright Singapore Flag:

(B) Laterally Inverted Singapore Flag:

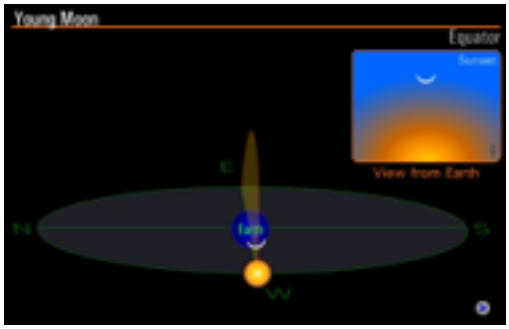
(C) Upright Singapore Coat of Arms:

(D) Inverted Singapore Coat of Arms:

(E) None of the above.

Solution. Answer: C.

Note that (D) is immediately eliminated as the crescent faces the Sun, and hence can never be a top crescent (at night). To visualise this, refer to the image below.



Since the moon's orbit is at a small angle (approx. 5°) with respect to the ecliptic, we shall consider the shape of the ecliptic. At equatorial latitudes, the ecliptic (path of the moon) is almost perpendicular to the horizon throughout the year. Hence, the moon will have its lighted face facing down towards the Sun throughout the year. This is true even for quarter moons, both the first and third quarter moon have their lighted side face downwards.