AstroChallenge 2018
Multiple Choice Questions
(Junior)

PLEASE READ THESE INSTRUCTIONS CAREFULLY

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

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. A periodic comet in the Solar System with an eccentricity of 0.6216 takes 76.69 years to complete an orbit around the Sun. What is its aphelion distance?

   (A) 18 AU.

   (B) 29 AU.

   (C) 36 AU.

   (D) 47 AU.

   (E) 59 AU.

   Solution. Answer: B.

   By Kepler's Third Law, since the comet orbits the Sun, if we measure distance from the Sun and the orbital period in terms of AU and years respectively, we get $T^2 = a^3$. Since

   $$\varepsilon = \frac{r_a - a}{a},$$

   therefore

   $$r_a = (1+\varepsilon)T^{\frac{2}{3}} = (1+0.6216)(76.69)^{\frac{2}{3}} = 29.271\,\text{AU}\,.$$

5. On the night of 11 November 2018 in Singapore, which star will rise the earliest? You may assume that none of these stars have risen before sunset.

   (A) Betelguese (RA: 5h 55min, Dec: $+7^\circ\,24'$).

   (B) Canopus (RA: 6h 23min, Dec: $-52^\circ\,41'$).

   (C) Procyon (RA: 7h 39min, Dec: $+5^\circ\,13'$).

   (D) Rigel (RA: 5h 14min, Dec: $-8^\circ\,12'$).

   (E) Sirius (RA: 6h 45min, Dec: $-16^\circ\,44'$).

   Solution. Answer: D.

   The star with the smallest right ascension will rise before the other stars.

6. Which of the following statements about moons in the Solar System is **false**?

   (A) The Earth experiences tides twice a day due to the Moon.

   (B) The four Galilean moons are in orbital resonance with each other.

   (C) Mercury and Venus do not have moons because they are too close to the Sun.

   (D) Saturn's shepherd moons are responsible for maintaining the shape of the rings of Saturn.

   (E) Due to Phobos' low orbit, it is likely that it will eventually enter its Roche limit and disintegrate.

Solution. Answer: B.

(A) is true.

(B) is false. Only Io, Europa and Ganymede are in orbital resonance with each other. Callisto is not.

(C) is true. See this link.

(D) is true.

(E) is true. Phobos orbits around Mars faster than Mars rotates about its axis, which results in tidal deceleration of Phobos. Thus its orbital radius is gradually decreasing.

7. The opposition of Mars in the Gregorian calendar can occur _____.

   (A) only in January, March, and August

   (B) in all months except February and April

   (C) in all months except April and October

   (D) in all months except March and September

   (E) in all months

   Solution. Answer: E.

   The Gregorian calendar is a solar calendar and does not rely on the position of Mars. The synodic period of Mars cannot be expressed as a rational number of Gregorian years. Thus, the opposition of Mars will gradually drift across all months in the Gregorian calendar.

8. From Singapore, which of the following constellations **cannot** be seen on October evenings?

   (A) Cetus.

   (B) Cassiopeia.

   (C) Cancer.

   (D) Corona Australis.

   (E) Cygnus.

   Solution. Answer: C.

   Since October lies in early fall, we should expect to see late summer/autumn constellations on October evenings. Cancer does not make the cut here: it is seen in spring.

9. The data of three G class stars are given in the following table.

Star	Tau Ceti	51 Pegasi	Alpha Centauri A
Spectral type	G8.5V	G5V	G2V
Declination	$-15^\circ\,56'\,15''$	$+20^\circ\,46'\,08''$	$-60^\circ\,50'\,02''$
Apparent magnitude	+3.50	+5.49	+0.01
Distance from Earth	11.9 ly	50.9 ly	4.4 ly
Colour index (B–V)	+0.71	+0.67	+0.71

Note that atmospheric refraction has an effect of less than $30'$. Which of the following statements is **wrong**?

(A) Tau Ceti has the lowest luminosity of the three stars.

(B) Only 51 Pegasi lies north of the celestial equator.

(C) All three are main sequence stars.

(D) Alpha Centauri is the hottest star out of the three stars.

(E) All three stars can be observed at latitude $+30^\circ$ on Earth.

Solution. Answer: E.

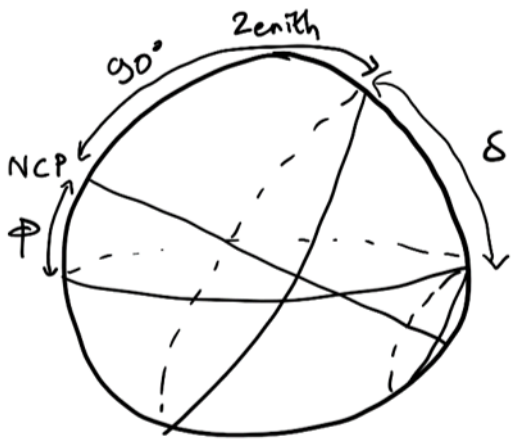
(A) Can be proven using the distance modulus.

(B) The declination is positive, implying this.

(C) V in the spectrum type refers to their main sequence type.

(D) Alpha Centauri has the lowest number after the letter G, implying that it has the hottest temperature.

(E) See the following picture.



If the star is circumpolar (under horizon)

$\varphi + 90^\circ + |\delta| > 180^\circ$

$\varphi + |\delta| > 90^\circ$

$|\delta| > 90^\circ - \varphi$

$|\delta| > 60^\circ$

Alpha Centauri lies below the horizon!

10. The following is an image of an active galactic nucleus.

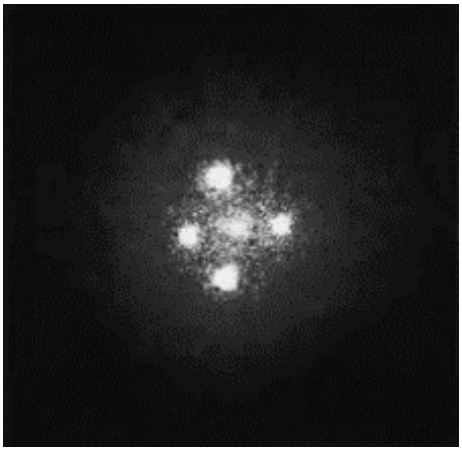


Figure 1: A solitary active galactic nucleus.

The distortion of the image is **most likely** due to _____.

(A) photon noise

(B) image binning

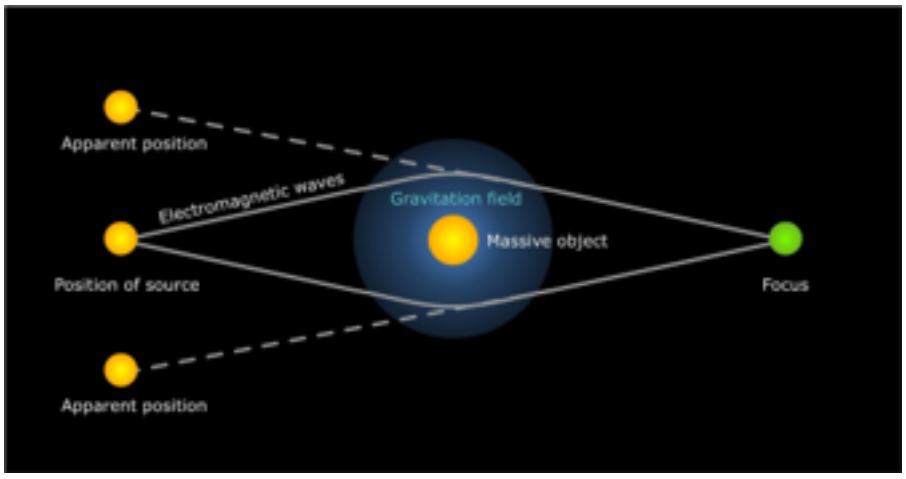
(C) gravitational lensing

(D) chromatic aberration

(E) dark current

Solution. Answer: C.

This is the image of the Einstein Cross. The Einstein Cross is produced by four images of a quasar behind a 'lensing galaxy' known as Hurcha's Lens. This effect is due to gravitational lensing, where gravity of massive objects causes light to bend.



11. Brian is new to astronomy and wants to purchase a pair of binoculars for stargazing. He came across the following three binoculars online.

- Oberwerk Mariner: 8×40 binoculars.
- Bushnell 8: 16×40 binoculars.
- Celectron Skymaster: 8×56 binoculars.

He then makes the following comparisons.

I. The Celestron Skymaster produces a brighter image as compared to the Oberwerk Mariner.

II. The Bushnell 8 has a better resolution than the Celestron Skymaster.

III. The Bushnell 8 has a higher magnification than the Celestron Skymaster.

Which of the above is/are **correct**?

(A) II only.

(B) III only.

(C) I and III only.

(D) II and III only.

(E) I, II, and III.

Solution. Answer: C.

III. is correct. Binoculars are characterised by two numbers, in the format

$$\text{magnification} \times \text{objective diameter}.$$

Hence, statement III. is true just by comparing the magnification.

II. is wrong. The larger the objective diameter, the smaller the resolution angle (as described by the equation for Rayleigh's criterion), and hence the better the resolution.

I. is correct. A larger objective diameter collects more light, causing the image to appear brighter.

12. Suppose that you have obtained spectra for three galaxies A, B, and C, and have measured the observed wavelength of a hydrogen emission line that has a rest wavelength of 656.3 nm for each of these galaxies. Your results are given in the following table.

Galaxy	A	B	C
Observed wavelength	$1.313\,\mu$m	$984\,\mu$m	$655.6\,\mu$m

Which of the following statements is **most likely correct** with respect to the blueshift data observed for galaxy C?

(A) The galaxy is moving towards Earth faster than the expansion of the universe at its distance from the Earth.

(B) This value is derived from the hydrogen emission spectrum of the cosmic microwave background radiation.

(C) The galaxy must be close to us. However, since galaxy redshift values are always positive, the negative redshift value obtained implies that the data obtained fell within the uncertainty range of the instrument used.

(D) As this value cannot be obtained through physical means, there must be a measurement error.

(E) There is a supermassive black hole in the center of galaxy C, which has gravitationally blueshifted the galaxy's emission lines.

Solution. Answer: A.

(A) is possible, and this wavelength value is exactly what you would measure the hydrogen emission spectrum from the Andromeda Galaxy that is currently moving towards us.

(B) is wrong as the CMBR redshift value is +1100, indicating both a redshift and that the value obtained would not have been a mere 1 nm away from the rest wavelength.

(C) is wrong as it assumes that galaxy redshift values are always positive, which is not true.

(D) is untrue, see (A).

(E) is wrong. Even if we accept this premise, the resultant emission would be *redshifted* as photons lose energy when they climb out of the gravitational well.

13. Consider the following statements about comets and asteroids.

    I. A meteor shower is caused by asteroids only.

    II. Asteroids can cause meteor showers.

    III. Asteroids are common in the Kuiper Belt.

    IV. Asteroids and comets are both formed approximately during the same period in the history of the Solar System.

    Which of the above statements is/are **correct**?

    (A) I only.

    (B) II and III only.

    (C) II and IV only.

    (D) III and IV only.

    (E) II, III, and IV only.

    Solution. Answer: C.

    I. is false. Meteor showers in general are caused by comets.

    II. is true. They can also be caused by asteroids, such as the Geminids meteor shower (caused by 3200 Phaethon, an asteroid).

    III. is false. In the Kuiper Belt, comets are more common than asteroids. This due to the higher percentage of hydrogen compounds present in the solar nebula, as it is so far away from the Sun that hydrogen compounds condense.

    IV. is true. Asteroids and comets are both formed at about the same time from planetesimals (rocky and icy ones respectively) that failed to coalesce into planets, and thus became asteroids and comets.

14. The Winter Hexagon (below) is a prominent asterism in the Northern Hemisphere, observable between December and March.

Figure 2: The Winter Hexagon.

Starting from the bottom star and proceeding in a **clockwise** direction, name the stars that make up the asterism.

(A) Capella, Procyon, Pollux, Canopus, Aldebaran, Rigel.

(B) Sirius, Procyon, Pollux, Capella, Aldebaran, Saiph.

(C) Canopus, Procyon, Pollux, Capella, Aldebaran, Rigel.

(D) Sirius, Procyon, Pollux, Capella, Aldebaran, Rigel.

(E) Canopus, Procyon, Pollux, Capella, Aldebaran, Saiph.

Solution. Answer: D.

Let us first identify the lowest star: it is the brightest star, and Orion's belt (the line of 3 identically bright stars) points to it. This means it is unmistakeably Sirius. The last star in the Hexagon is Rigel (Saiph is far dimmer than Rigel).

15. During full moon, the difference between the right ascension of the moon and the sun is approximately _____.

(A) 0h

(B) 9h

(C) 12h

(D) 15h

(E) 24h

Solution. Answer: C.

They are opposite each other with respect to Earth.

16. NASA scientists found an extrasolar planetary system around a M8V star named TRAPPIST-1 in early 2016. The system has seven terrestrial planets orbiting it, three of which lie in the habitable zone. Consider the following statements.

I. In the habitable zone, water exists in a liquid state on the surface.

II. The main component of the planets are rocks.

III. TRAPPIST-1 lies in the bottom right part of the Hertzsprung-Russell diagram.

IV. The peak emission of the TRAPPIST-1 spectrum lies in the blue region of the visible light spectrum.

Which of the above statements are **correct**?

(A) I and III only.

(B) II and III only.

(C) II and IV only.

(D) I, II, and III only.

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

Solution. Answer: B.

I. is wrong. This is a subtlety of the habitable zone – water can exist in liquid form, but might not actually exist in such a form.

II. is correct. By definition, terrestrial planets are composed of rocks.

III. is correct. TRAPPIST-1 is a red dwarf from its spectral type, which corresponds with the bottom right part of the HR diagram.

IV. is wrong. The peak emission of an M8V star is in the infrared region.

17. Consider the following statement.

The major meteor showers peak at the same few days every year.

Is this statement true? If it is true, why?

(A) The statement is true. They only occur when Earth is at the right place in its orbit to intersect a meteor trail.

(B) The statement is true. Poor weather prevents them from being observed at other times of year.

(C) The statement is true. The meteor trail is depleted and requires time to recharge.

(D) The statement is true. The constellations that they appear to originate from lie too close to the Sun to be observed.

(E) The statement is false. The peak date of a meteor shower cannot be predicted with any accuracy.

Solution. Answer: A.

A basic test of familiarity with meteor showers. (B), (C), and (E) are nonsense answers, while (D) isn't true: there are actually daytime meteor showers! These meteors are detectable through radio observations.

18. From Singapore, stars appear to rise four minutes later each night. This is largely because _____.

    (A) changes in Earth's axial tilt change the orientation of Earth relative to the stars

    (B) the motion of stars through interstellar space causes them to shift in position over time

    (C) the motion of the Sun through interstellar space causes stars to rise later over time

    (D) Earth's rotation is gradually slowing down due to the tidal effects of the Moon

    (E) Earth's orbital motion means that the Sun drifts relative to the stars

    Solution. Answer: E.

    While all other options could conceivably affect the rise time of a star, they require much greater timescales than the course of a day before these effects are detectable.

19. Which of the following statements is **false**?

    (A) From our perspective, Perseus lies within the plane of the Milky Way.

    (B) Traditionally, Algol (Beta Persei) has been regarded as one of the unluckiest stars in the sky, causing it to be known colloquially as the "Demon Star".

    (C) Algol dims sharply at regular intervals because it is a multiple star system in which two stars periodically eclipse each other from our perspective.

    (D) The heart of the Algol paradox is that the more massive star in this binary star system has turned into a red giant, while the less massive star is still on the main sequence.

    (E) Mass transfer between both stars is the cause of the Algol paradox.

    Solution. Answer: D.

    All statements are true except statement (D): the *less* massive star in the Algol binary is a red giant, while the *more* massive star is still on the main sequence.

20. From Singapore, which of these objects are **impossible** to see at 5.30 AM in December? Assume clear skies and a wholly unobstructed horizon.

    (A) The Great Square of Pegasus.

    (B) The Big Dipper.

    (C) Sirius.

    (D) The Orion Nebula.

    (E) The Southern Cross.

    Solution. Answer: A.

    Given that December lies in mid-winter, we should expect to see winter and spring constellations on December mornings. This excludes (A), which is a fall constellation/asterism.

21. Consider the following statement.

We do not see a lunar eclipse every full moon, or a solar eclipse every new moon.

Is this statement true? If it is true, why?

(A) The statement is true. Poor weather prevents us from observing them all the time.

(B) The statement is true. The fast motion of the Moon means these eclipses are extremely brief.

(C) The statement is true. The orbit of the Moon is inclined relative to the Earth's orbit around the Sun.

(D) The statement is true. Solar and lunar eclipses are only visible from a small fraction of Earth's surface area, making them rare when observing from a fixed location.

(E) The statement is false. We do indeed observe a lunar eclipse every full moon and a solar eclipse every new moon.

Solution. Answer: C.

(A), (B), and (E) are obviously wrong, while (D) is only true for solar eclipses.

22. Below are some statements about the life-cycle of stars.

I. Hydrogen fusion commences, and the protostar moves onto the main sequence.

II. The star forms an iron core, and subsequently goes supernova.

III. The star ejects its outer layers and becomes a white dwarf surrounded by a planetary nebula.

IV. Hydrogen runs out in the centre of a main sequence star, and the star turns into a red giant.

V. A gas cloud collapses on itself and forms a protostar surrounded by a protoplanetary disk.

VI. Helium runs out in the centre of the red giant, and the star becomes unstable and highly variable.

Five of these describe the life-cycle of a sun-like star. For such a star, arrange the relevant statements in chronological order, **starting with the earliest**.

(A) I, IV, VI, III, II.

(B) V, I, VI, III, II.

(C) V, I, IV, VI, III.

(D) I, V, IV, VI, II.

(E) V, IV, VI, II, III.

Solution. Answer: C.

Straightforward. It must start with statement V. and end with statement III., which eliminates all but two options.

23. Consider the following objects.

I. M7, Ptolemy Cluster.

II. Betelgeuse (a star of spectral classification M).

III. Ring Nebula.

IV. Eta Carinae.

Rank these objects in order of **descending** mass.

(A) I, III, IV, II.

(B) IV, I, II, III.

(C) I, IV, II, III.

(D) IV, III, I, II.

(E) III, I, IV, II.

Solution. Answer: C.

First, note that the options are in order: a star cluster, a red supergiant, a planetary nebula (remnant of a sun-like star), and a luminous blue variable (highly evolved massive

star). Once framed in this manner, it should be clear that the most massive option is I. (the star cluster), while the least massive option is III. (the planetary nebula). This leaves (C) as the correct answer.

24. Which of the following objects **cannot** be found within constellations along the ecliptic?

    (A) M8, the Lagoon Nebula.

    (B) Jupiter.

    (C) M44, the Beehive Cluster.

    (D) M45, the Pleiades Cluster.

    (E) C49, the Rosette Nebula.

    Solution. Answer: E.

    (A): M8 is in Sagittarius.

    (B): Jupiter is a planet and lies close to the ecliptic. It is regularly found in the zodiacal constellations.

    (C): M44, the Beehive Cluster, lies in Cancer.

    (D): M45 in Taurus.

    (E): C49, the Rosette in Monoceros.

25. Consider the following astronomical events.

I. Lunar eclipse.

II. Blue moon.

III. Solar eclipse.

IV. Full moon.

Rank these events according to how often they occur globally, **from the most frequent to the rarest**.

(A) IV, III, I, II.

(B) IV, III, II, I.

(C) IV, II, III, I.

(D) IV, II, I, III.

(E) IV, I, III, II.

Solution. Answer: A.

A blue moon occurs every 2.7 years, rarer than the other events. Solar eclipses are more common than lunar eclipses.

26. It is known that the moon has a synodic month of approximately 29.5 days, and a sidereal month of 27.3 days. This, in combination with the rotation of Earth about its axis, as well as the moon's orbit, causes the moon to rise approximately _____ later every day.

On a winter evening in Singapore, the local sidereal time is found to be 1h 30min. The star Aldebaran has an hour angle (HA) of 20h 54min. That evening, the moon rose 4h 57min before Aldebaran.

To the nearest minute, the right ascension (RA) of the moon 24h from this moment is _____.

(A) 49min; 22h 50min

(B) 49min; 00h 28min

(C) 50min; 00h 29min

(D) 53min; 22h 46min

(E) 53min; 00h 32min

Solution. Answer: B.

Using the synodic period, we get 48.8min.

Given that Aldebaran has an hour angle of 20h 54min and that the moon rose 4h 57min before Aldebaran, this suggests that the moon has an HA of 1h 51min. That the LST is 1h 30min hence suggests that the moon has a RA of 23h 39min. It would then have a later RA of 23h 39min + 49min = 00h 28min.

27. Which of the following statements about the cosmos is the **most accurate**?

(A) There is a point in the universe where the Big Bang originated from, albeit not necessarily from the centre of our galaxy.

(B) The number of young stars in any direction is approximately equal.

(C) There is certainty that our universe will collapse into a black hole in the future.

(D) Under the standard λCDM Cosmological Model, the universe is expanding with a decelerating rate due to dark energy.

(E) The standard λCDM Cosmological Model suggests that matter can be created out of nothingness.

Solution. Answer: B.

(A) goes against the Cosmological Principle. (C) is ridiculous. For (D), the universe is expanding with an accelerating rate. (E) is also nonsense. Only (B) is correct, as it follows from the cosmological principle.

28. Before the recombination epoch, nuclei, free protons, and free electrons interacted strongly with the ambient radiation and kept the constituents in the cosmological brew thermalised at constant temperature. The universe was therefore quite opaque to light in the beginning. Which of the following statements is **incorrect**?

(A) Gravitational wave astronomy is a technique that could possibly allow us to probe beyond the recombination epoch, as gravitational waves interact very weakly with the constituents.

(B) Observation of neutrinos from this time and beyond is a technique that could possibly allow us to look further into the past as neutrinos interact very weakly with the other constituents.

(C) The cosmic microwave background radiation originates from the radiation that leaked out from before the recombination epoch due to the early thermal fluctuations.

(D) The expansion of the universe resulted in a lower rate of reaction between matter and radiation, which led to their decoupling at the beginning of the recombination epoch.

(E) The weak nuclear interaction between electrons and protons allowed for the formation of bound states of hydrogen.

Solution. Answer: C.

(A) and (B) are equivalent to the definitions of neutrinos and gravitational waves. Observations of neutrino and gravitational waves allow us to study structures that exists before the recombination epoch emitting these radiations which would have otherwise not been possible.

(D) As the rate of expansion increased, the density and temperature decreased. Thus the constituents decouple from one another; the rate of reaction between matter and radiation therefore decreased.

For (E), with regards to the recombination epoch, the formation of the bound states of hydrogen, in light of the high expansion rate, allowed for the decoupling of hydrogen from the photon during the recombination epoch.

29. The figure below shows a record of 400 years of sunspot observation.

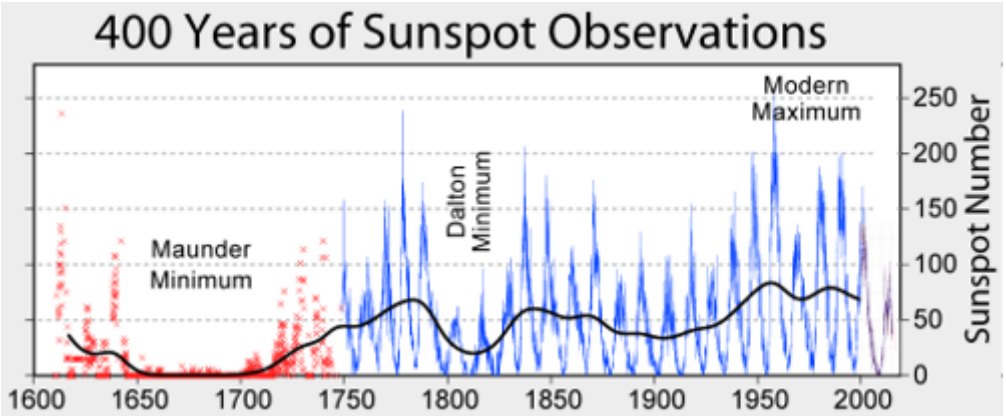


Figure 3: 400 years of sunspots.

Which of the following statements about the Sun is **incorrect**?

(A) The sun has an absolute bolometric magnitude of 4.7554.

(B) The next maximum in the solar cycle should occur approximately in early 2020.

(C) The frequency of auroras is unaffected by the solar cycle.

(D) Sunspots are cooler regions on the photosphere of the Sun.

(E) The corona lies above the photosphere of the Sun.

Solution. Answer: C.

(A): The absolute bolometric magnitude of the sun may be found by letting the ratio of the luminosities in the equation to be 1.

(B): We observe from the graph that there is a peak just after the year 2000, subsequently, the trend suggests that it the solar cycle has a period of about 10 (11) years. Hence, we expect the next peak to occur in early 2020.

(C): Frequency of auroras are determined by the activity of the sun which is also correlated to the number of sunspots. Hence, we expect the frequency of auroras to be affected by the solar cycle.

(D): Sunspots appear darker in contrast to the surround regions due to the difference in temperature and given that the luminance (or brightness essentially) of a blackbody (the Sun) is proportional to the temperature to the fourth power.

(E): The corona is an atmosphere made up of plasma that surrounds stars and extends far into the space.

30. Which of the following statements about the equinoxes and solstices is **correct**?

(A) The autumnal equinox occurs at the same time all over the world.

(B) Equinoxes and solstices are unaffected by the gyroscopic precession of the earth.

(C) Equinoxes are spaced approximately three months apart.

(D) In the southern hemisphere, the summer solstice occurs in December.

(E) The Sun crosses the celestial equator during the solstices.

Solution. Answer: D.

(A) and (D): The equinoxes and solstices occur in direct opposites for the different hemispheres.

(B): Equinoxes and solstices are affected by gyroscopic precession.

(C): Equinoxes are spaced 6 months apart.

(E): The Sun crosses the celestial equator during the equinoxes.

31. Consider the following five objects.

a. Elliptical galaxies.

b. Irregular galaxies.

c. Spiral galaxies.

d. Active galactic nuclei.

e. Dwarf elliptical galaxies.

Below are descriptions of the five objects above, in no particular order.

I. Often have radio jets aligned with their minor axes extending from their cores.

II. Disks with central bulges surrounded by spherical halos of old stars.

III. Giant spheroidal galaxies typically having no apparent structure.

IV. Thought to be remnants of the original building blocks of all galaxies.

V. Have very chaotic structure with no apparent symmetry.

Match the five descriptions to their respective objects.

(A) I–c; II–d; III–b; IV–e; V–a.

(B) I–c; II–a; III–d; IV–e; V–b.

(C) I–d; II–b; III–c; IV–e; V–a.

(D) I–b; II–c; III–a; IV–e; V–d.

(E) I–d; II–c; III–a; IV–e; V–b.

Solution. Answer: E.

By factual recall.

32. Which of the following statements about neutron stars is **false**?

(A) Newly formed neutron stars are thought to have an active phase making them "blink" as pulsars.

(B) Neutron stars spin very fast.

(C) If a person could survive this experiment, a scientist would weigh more standing on a white dwarf than standing on a neutron star.

(D) Neutron stars are supported by neutron degeneracy pressure.

(E) Neutron stars are as massive as the Sun, but only about 10 km across.

Solution. Answer: C.

A neutron star has a stronger gravitational field – about 400000 times stronger.

33. Three different star clusters A, B, and C with different ages are plotted separate diagrams shown below.

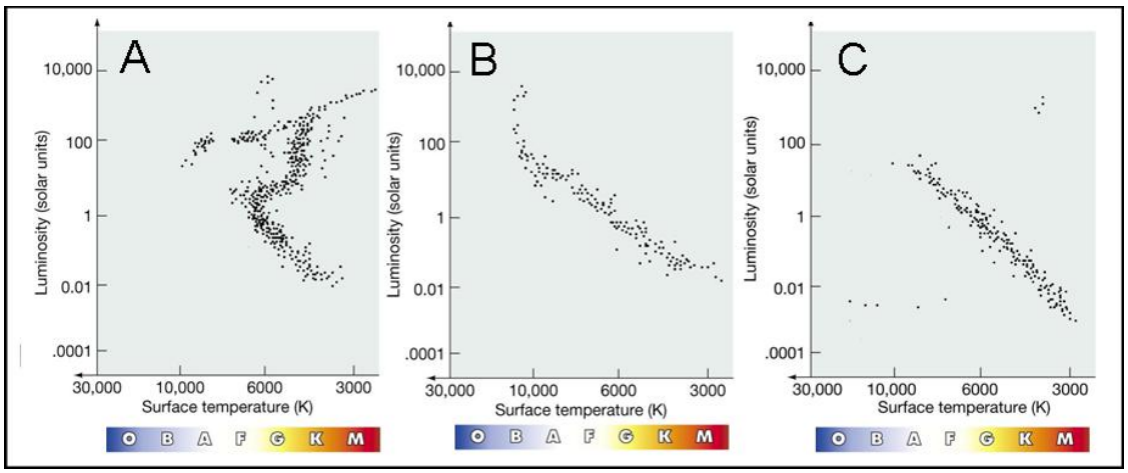


Figure 4: Profiles of three different star clusters.

Arrange the clusters **from youngest to oldest**.

(A) B, A, C.

(B) C, A, B.

(C) B, C, A.

(D) C, B, A.

(E) A, B, C.

Solution. Answer: C.

The turnoff point of the youngest cluster will lie on the leftmost side of the HR diagram.

34. In this question, you may assume the following facts.

- Mars has a diameter of 6794 km. It has an angular size of 5.5×10^{-3} degrees when viewed from Earth this week.
- The planet Uranus has a period of 84 years.

Consider the following statements.

I. It takes radio signals from the Opportunity rovers on the surface of Mars 236 s to reach the scientists on Earth.

II. Kepler's second law notes that a planet should move fastest at perihelion.

III. The semi-major axis of Uranus's orbit is 19.1 AU. Assuming that Uranus's orbit has zero eccentricity, the centripetal acceleration of Uranus in its orbit is 0.107 AU year^{-2}.

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: E.

For I.,

$$t = \frac{d}{v} = \frac{\frac{6794\times1000\times57.3}{5.5\times10^{-3}}}{3.0 * 10^8} = 236\,\mathrm{s}\,.$$

For III., from $T^2 = a^3$ we have

$$a = (84^2)^{\frac{1}{3}} = 19.1\,\mathrm{AU}\,.$$

Since

$$s = \frac{d}{t} = 2\pi\frac{19.1}{84} = 1.43\,\mathrm{AU\,year}^{-1},$$

thus

$$a_c = \frac{s^2}{r} = \frac{1.43^2}{19.1} = 0.107\,\mathrm{AU\,year}^{-2}\,.$$

35. The lithium test for brown dwarfs is sometimes used to determine if an object is a star or a brown dwarf. The test involves measuring the spectrum of the object in question, searching for lithium. While the test admits some ambiguity, it nevertheless provides a degree of surety past certain thresholds. Why does this test work?

    (A) Stars and brown dwarfs naturally contain lithium from formation, but cooler brown dwarfs are too cool for lithium to undergo fusion.

    (B) Brown dwarfs do not contain lithium since they are not sufficiently hot for hydrogen fusion. Conversely, young stars contain lithium due to hydrogen fusion.

    (C) Both stars and brown dwarfs contain lithium from formation. However, the intensity of lithium spectral lines for stars is higher due to lithium produced via fusion.

    (D) Both young stars and brown dwarfs contain lithium lines in their spectra. However, temperature warping changes the position of these lines for stars.

    (E) Both young stars and brown dwarfs contain lithium lines in their spectra. However, gravitational redshifting changes the position of these lines more significantly for stars.

    Solution. Answer: A.

    Lithium-proton fusion technically needs a slightly lower temperature than hydrogen fusion. This process is also known as lithium burning.

    The other half of the knowledge required is the presence of lithium in interstellar gas clouds, which originates from Big Bang nucleosynthesis.

36. How was Edwin Hubble able to use his discovery of a Cepheid in Andromeda to prove that "spiral nebulae" (like Andromeda) were actually located outside the Milky Way?

    (A) From the period-luminosity relation for Cepheids, he was able to determine the distance to Andromeda and show that it was far outside the Milky Way Galaxy.

    (B) Since a Cepheid is a type of luminous galaxy, when he found it in Andromeda he was able to prove that Andromeda was a separate galaxy from the Milky Way.

    (C) He used main-sequence fitting to determine the distance to Andromeda and show that it was far outside the Milky Way Galaxy.

    (D) There are no Cepheids in the Milky Way, so his discovery proved that it has to be in another galaxy.

    (E) He measured the stellar parallax of the Cepheid in Andromeda, was able to determine the distance to it and showed that it was far outside the Milky Way.

    Solution. Answer: A.

    (B): Cepheids are evolved stars, not galaxies.

    (D): There are Cepheids in the Milky Way.

    (C) and (E): Andromeda is sufficiently far away that both are wrong. Parallax would not be detectable at such distances, while main sequence stars are too dim to be easily observed with Hubble's telescope.

37. Orion is visible on winter evenings for most observers in the northern hemisphere, but not during summer evenings because of _____.

(A) the precession of the Earth's axis

(B) the tilt of the Earth's axis

(C) interference from the full moon

(D) the rotation of Earth around its own axis

(E) the location of the Earth in its orbit

Solution. Answer: E.

(A) is not significant over the course of a single year, while (B) explains why seasons occur (and has no bearing on the visibility of Orion).

Even if (C) was true (it's not), it is only a factor for the few days around the full moon. Lastly, (D) determines the length of a day and has no bearing on the question.

38. Assuming circular and coplanar orbits, what is the angle of maximum elongation for Venus from Mars?

(A) 19°.

(B) 22°.

(C) 25°.

(D) 28°.

(E) 31°.

Solution. Answer: D.

$$\theta = \sin^{-1} \frac{r_{\text{Venus}}}{r_{\text{Mars}}} = \sin^{-1} \frac{1.082 \times 10^{11}}{2.279 \times 10^{11}} = 28.34°.$$

39. What is the apparent magnitude of a binary star which has two stars of apparent magnitude 4.11 and 5.01 respectively?

(A) 0.90

(B) 3.21

(C) 3.72

(D) 4.56

(E) 9.12

Solution. Answer: C.

Let the dimmer star of magnitude 5.01 have a brightness of 1 arbitrary unit. That is,

$$m_x = 5.01, \qquad b_x = 1, \qquad m_y = 4.11.$$

The other star is brighter by a factor of

$$\frac{b_y}{b_x} = \frac{b_y}{1} = 100^{\frac{m_x - m_y}{5}}.$$

The brightness of the binary star is simply the sum of brightness of both stars, i.e.

$$b_B = b_x + b_y = 100^{\frac{m_x - m_y}{5}} + 1.$$

Comparing the brightness of the binary star and the dimmer star,

$$\frac{b_B}{b_x} = \frac{100^{\frac{m_x - m_y}{5}} + 1}{1} = 100^{\frac{m_x - m_B}{5}}.$$

Hence, taking logarithms (base 10), we have

$$\begin{aligned} m_B &= m_x - \frac{5}{2}\lg\left(100^{\frac{m_x-m_y}{5}}+1\right) \\ &= 5.01 - \frac{5}{2}\lg\left(100^{\frac{5.01-4.11}{5}}+1\right) \\ &= 3.717. \end{aligned}$$

(Note: The binary star is Beta Delphini.)

40. Which Messier object is **most easily observed** with the naked eye on a clear night in Singapore?

(A) Crab Nebula (M1).
(B) Butterfly Cluster (M6).
(C) Andromeda Galaxy (M31).
(D) Beehive Cluster (M44).
(E) Pleiades (M45).

Solution. Answer: E.

Do some observation at night. Alternatively, note the magnitude of the brightest star in the open clusters listed (stars are less affected by light pollution than extended objects).

41. The Celestron C8 is a Schmidt-Cassegrain reflective telescope with a focal ratio of 10 and a diameter of 203.2 mm. Using an objective lens (eyepiece) with a focus of 25 mm, a circular squirrel with a diameter of 25 cm fills the field of view completely. Assuming an apparent field of view of 50°, which of the following statements are **correct**?

I. The focal length of the telescope is 203.2 cm.
II. The true field of view of the telescope assembly is approximately 37'.
III. The distance from the squirrel to the observer is 2328 cm.
IV. The resolving power of the telescope is 0.68'.

(A) I and II only.
(B) II and IV only.
(C) I, II, and III only.
(D) II, III, and IV only.
(E) None of the above.

Solution. Answer: C.

I. is correct. Using the focal ratio, we can infer that the focus is ten times longer, i.e. 2032 mm.

II. is correct. Using $\text{FoV} = \frac{50}{M} = 50 \times \frac{f_{\text{oc}}}{f_{\text{ob}}} = 37'$.

III. is correct. The distance can be obtaind using trigonometry. Specifically, $d = \frac{h}{\tan\alpha}$, where $\alpha = 50°$.

IV. is wrong. The resolving power is $0.68''$ from $\theta = 1.22\frac{\lambda}{D}$.

42. A star has an average density of $1.08\,\mathrm{g\,cm^3}$. Find the approximate period of a planet orbiting at six times the radius of the star.

(A) 47 hours.

(B) 58 hours.

(C) 69 hours.

(D) 70 hours.

(E) 81 hours.

Solution. Answer: A.

We have

$$\rho = \frac{M}{V} = \frac{M}{\frac{4}{3}\pi r^3}.$$

By Kepler's third law,

$$T^2 = \frac{4\pi^2 a^3}{GM} = \frac{4\pi^2 a^3}{\frac{4}{3}\pi G\rho r^3} = \left(\frac{a}{r}\right)^3 \frac{3\pi}{\rho G} = 6^3 \frac{3\pi}{\rho G} = 46.7\,\text{hours}\,.$$

43. In 7.4×10^{11} years, the mass of the Sun will have dropped by 5%. This is caused by the Sun's fusion reaction that changes mass into energy. Assuming that Earth has a circular orbit, that the orbital speed of Earth remains constant, and that the Earth moves closer to the Sun to compensate, what is the length of a year in this future Earth?

(A) 0.91 years.

(B) 0.92 years.

(C) 0.93 years.

(D) 0.94 years.

(E) 0.95 years.

Solution. Answer: D.

Let v', M', d' be the new orbital speed, mass of the Sun, and distance of Earth from the Sun respectively. We have $v' = v$.

The formula for speed of an orbiting object yields

$$\sqrt{\frac{GM'}{d}} = v' = v = \sqrt{\frac{GM}{d}}.$$

By rearranging,

$$d' - \frac{dM'}{M} = 0.95d.$$

By Kepler's third law, the period of a revolution is thus

$$T = \sqrt{\frac{4\pi^2 d^3}{GM}} = 0.936\,\text{years}\,.$$

44. A binary system with two stars has a head-on inclination of 90°. The first star has an effective temperature of T_1 and radius R_1. The second star has an effective temperature of $T_2 = 2.5T_1$ and radius of $R_2 = 0.75R_1$. When the larger star eclipses the smaller one, what is the **change** in bolometric magnitude?

(A) 0.7

(B) 1.4

(C) 2.8

(D) 3.4

(E) 4.1

Solution. Answer: D.

The combined luminosity is

$$L = 4\pi R_1^2 \sigma T_1^4 + 4\pi R_2^2 \sigma T_2^4 = \left(1 + \frac{5625}{256}\right) \pi\sigma R_1^2 T_1^4.$$

At distance d, the combined received energy is

$$E_1 = \frac{L}{4\pi d^2} = \frac{\left(1 + \frac{5625}{256}\right) \sigma R_1^2 T_1^4}{4d^2}.$$

However, when the smaller star is eclipsed, the combined energy reduces to

$$E_2 = \frac{\sigma R_1^2 T_1^4}{4d^2}.$$

Comparing the magnitudes,

$$M_1 = -2.5 \lg E_1 + C,$$
$$M_2 = -2.5 \lg E_2 + C.$$

Subtracting yields

$$M_2 - M_1 = -2.5 \lg \frac{E_1}{E_2} = 2.5 \lg \left(1 + \frac{5625}{256}\right) = 3.4.$$

45. The Celestron Advanced VX Y Go-To Reflector Telescope has an Y'' optical tube assembly with specification $f/5$, where Y is an unknown value. The focal length of the optical tube is 1016 mm. Two eyepieces, one with diameter 8 mm and another with diameter 25 mm were provided. Determine the **minimum** size of a crater on the Moon that can be resolved by this telescope. Assume light of wavelength 550 nm.

(A) 1.27 km.

(B) 2.54 km.

(C) 10.2 km.

(D) 31.7 km.

(E) 72.7 km.

Solution. Answer: A.

The aperture diameter is determined by

$$D = \frac{f}{N} = \frac{1016}{5} = 203.2\,\text{mm}\,.$$

Using the formula for the Rayleigh criterion with $\lambda = 550\,\text{nm}$, $D = 203.2\,\text{mm}$, we get that the minimum angle that can be resolved is $0.0001892°$.

Using $s = r\theta$ and the Earth-Moon distance of $3.843 \times 10^8\,\text{m}$ (from the Data Booklet), we see that the minimum distance on the Moon that can be resolved is

$$s = 5.843 \times 10^8 \times \frac{0.0001892}{360} \times 2\pi = 1.27\,\text{km}\,.$$

(Note: Using eyepieces will not improve the resolution of an image.)

46. The Islamic calendar is an example of a lunar calendar consisting of 12 lunar (synodic) months. Each month has approximately 29.6 days.

    Eid al-Fitr, also known as Hari Raya Puasa, refers to the start of the next Islamic month, after the month of Ramadan (commonly known as the fasting month). In 2018, Hari Raya Puasa will fall on 15 June 2018 on the Gregorian calendar. Which day on the Gregorian calendar will the start of the month of Ramadan most probably be in 2019?

    (A) 10 April 2019.

    (B) 15 April 2019.

    (C) 5 May 2019.

    (D) 10 May 2019.

    (E) 25 June 2019.

    Solution. Answer: C.

    We know that one year on the lunar calendar is 12 lunar (synodic) months. This means that one lunar year is 355 days.

    Now, Hari Raya Puasa in 2018 falls on 15 June 2018. Hence, Hari Raya Puasa in 2019 falls on 5 June 2018. Since Hari Raya Puasa is the start of the next Islamic month after the month of Ramadan, the start of the month of Ramadan is 1 synodic month before this day.

    Hence, the start of the month of Ramadan is on 5 May 2019.

Use the diagram below to answer questions 47 *and* 48.

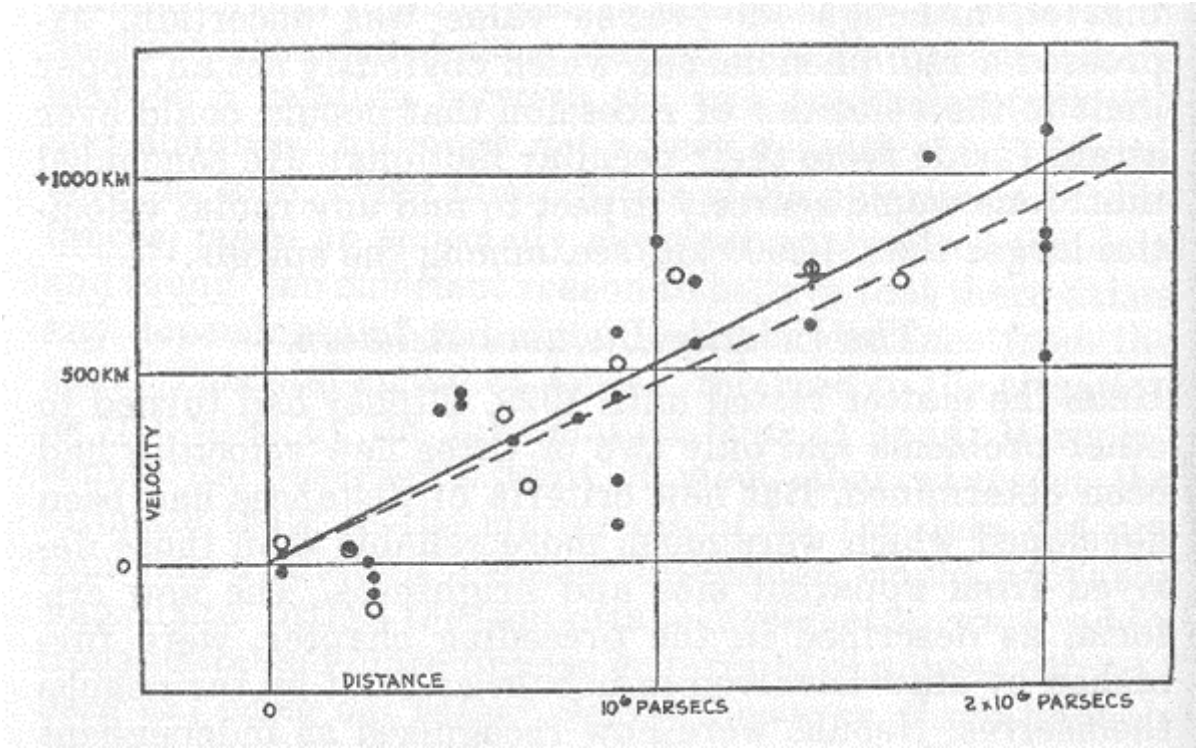


Figure 5: Hubble's plot to determine the Hubble constant. Note that the vertical axis has units $\mathrm{km\,s^{-1}}$.

47. The value of the Hubble Constant published in 1936 is **most probably** _____.

(A) $20.8\,\mathrm{km\,s^{-1}\,Mly^{-1}}$

(B) $76.7\,\mathrm{km\,s^{-1}\,Mly^{-1}}$

(C) $153\,\mathrm{km\,s^{-1}\,Mly^{-1}}$

(D) $815\,\mathrm{km\,s^{-1}\,Mly^{-1}}$

(E) $1630\,\mathrm{km\,s^{-1}\,Mly^{-1}}$

Solution. Answer: C.

Take the slope of the graph. The vertical axis is $\mathrm{km\,s^{-1}}$ but was not indicated by Hubble. Hence, the slope of the gradient is equal to the Hubble constant H_0 when he published his famous Hubble's Law

$$v = H_0 d.$$

Note that $1\,\mathrm{pc} = 3.26\,\mathrm{ly}$. Hence, $1\,\mathrm{Mpc} = 3.26\,\mathrm{Mly}$. The value of the gradient should be divided by 3.26.

48. The following are statements that attempt to account for this difference between Hubble's estimate of the Hubble constant versus its modern value today.

I. When Hubble first published this paper in 1929, he did not account for interstellar extinction in his calculations.

II. The Hubble Constant is not actually a constant. Its value changes with time. Hence, the value today is different from the value in 1929.

III. The distinction between Type I and Type II Cepheid variables was only discovered after Hubble's observations, which would have affected the distance measurement between Earth and the Cepheid variable stars.

Which of the above statements could possibly account for this difference?

(A) I only.

(B) II only.

(C) I and III only.

(D) II and III only.

(E) I, II, and III.

Solution. Answer: C.

Interstellar extinction causes blue light to be more attenuated than red light, causing objects to appear redder via a phenomenon known as interstellar reddening. Hence, the objects that Hubble used appears to be further away than it is. This causes an overestimation of distances, thus a lower H_0 value.

Indeed, Hubble constant is not a constant with time. However, this change in its value is insignificant relative to its large percentage uncertainty. Hence, this is not a good reason to account for this deviation.

Upon the discovery of Type II Cepheid variables, they realise that Type II Cepheid are actually less luminous at a given distance. This thus causes Hubble to overestimate the distance between Type II Cepheid and thus a lower value of Ho obtained.

49. Refer to the following table for this question.

Star	Right Ascension	Declination
Aldebaran	4h 36min	$16^\circ\,31'$
Antares	16h 29min	$-26^\circ\,26'$
Deneb	20h 41min	$45^\circ\,20'$
Miaplacidus	9h 13min	$-69^\circ\,42'$
Spica	13h 25min	$-11^\circ\,09'$

An observer at St. Petersburg ($59^\circ\,56'$ N, $30^\circ\,16'$ E) attempts to observe all five stars listed in the table above, and notes their proximity to the zenith when then culminate (i.e. reaches the meridian). Let the star closest to the zenith during its culmination be A. When A culminates above St. Petersburg, around which city will Arcturus (14h 16min, $19^\circ\,11'$) be undergoing its culmination?

(A) San Juan, Puerto Rico ($18^\circ\,24'$ N, $66^\circ\,04'$ W).

(B) Chiang Mai, Thailand ($18^\circ\,48'$ N, $99^\circ\,00'$ E).

(C) Belo Horizonte, Brazil ($19^\circ\,55'$ S, $43^\circ\,56'$ W).

(D) Antananarivo, Madagascar ($18^\circ\,56'$ S, $47^\circ\,31'$ E).

(E) Mexico City, Mexico ($19^\circ\,26'$ N, $99^\circ\,08'$ W).

Solution. Answer: A.

The star closest to zenith when it is highest in the sky observed from St. Petersburg is the one with declination closest to the latitude of St. Petersburg, which is Deneb.

If Deneb is crossing local meridian at midnight, at that instant the terrestrial meridian containing St. Petersburg ($30^\circ\,16'$) is aligned with the celestial meridian containing Deneb (20h 41min). For an observer to see Arcturus at her zenith, he/she must be located on the terrestrial meridian that is aligned with the celestial meridian containing Arcturus (14h 16min). This lies to the West of St. Petersburg by 6h 25min, or 96.25°.

Hence, Arcturus is crossing the meridian of observers at longitude $30^\circ\,16' - 96^\circ\,15' = 65^\circ\,59'$ W. The closest city to this coordinate is option A (San Juan, Puerto Rico).

50. The coordinates of the stars making up Northern Cross is given below.

Star	Right Ascension	Declination
Deneb	20h 41min	$45^\circ\,20'$
Gienah	20h 46min	$33^\circ\,58'$
Delta Cygni	19h 45min	$45^\circ\,08'$
Sadr	20h 22min	$40^\circ\,15'$
Albireo	19h 31min	$27^\circ\,58'$

According to an observer, all stars in the Northern Cross are always above the horizon. Assuming that atmospheric refraction can change the coordinate of a star up to $35'$, what is the **southernmost (lowest) possible latitude** of that observer?

(A) $28^\circ\,33'$.

(B) $44^\circ\,05'$.

(C) $45^\circ\,15'$.

(D) $61^\circ\,27'$.

(E) $62^\circ\,37'$.

Solution. Answer: E.

If Albiero is circumpolar, the other stars are also circumpolar. The atmospheric refraction causes the apparent position of the star to be shifted upwards.