



ASTROCHALLENGE 2023

SENIOR MCQ ROUND

Monday 29th May 2023

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.

© National University of Singapore Astronomical Society
© Nanyang Technological University Astronomical Society

1. Which of the following are **not** one of the ways astronomers measure the Hubble's constant?
 - (A) Using the merger of two black holes or neutron stars and measuring the subsequent gravitational waves to get their relative speeds to Earth
 - (B) Using the flat rotational curve model and absolute magnitude of Active Galactic Nuclei (AGN) to get their relative speeds to Earth
 - (C) Using spectroscopic analysis of a distant object of known distance to determine its relative redshift to Earth
 - (D) Use bubbles in the CMBR and the flat universe model to determine the distance of certain Supernovae to determine its relative speed to Earth
 - (E) All of the above methods are valid methods of measuring Hubble's constant

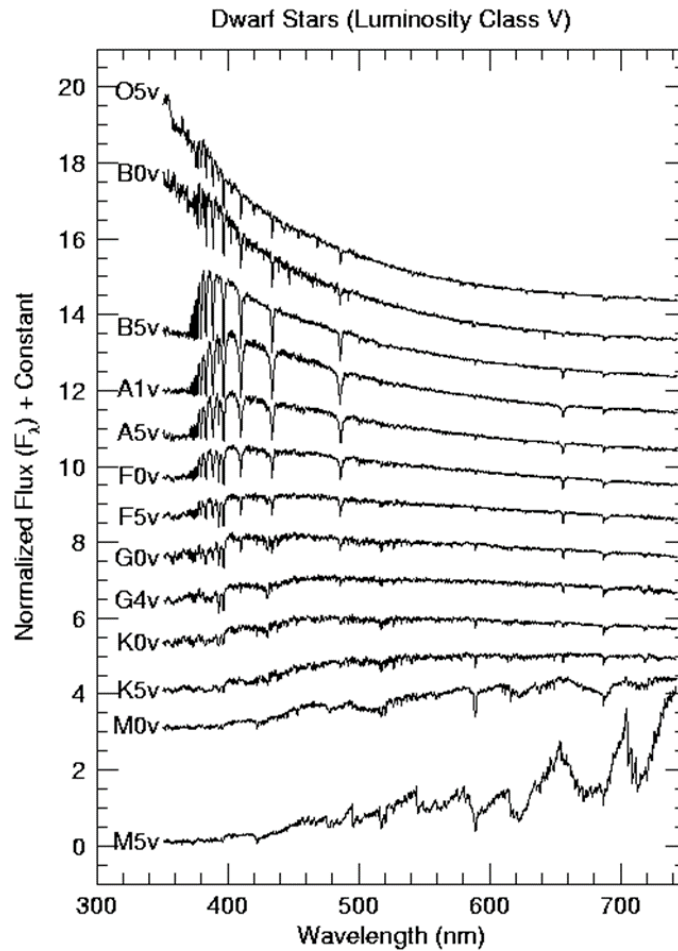
2. In both stars and stellar remnants (such as neutron stars), there is an outward force supporting them such that hydrostatic equilibrium is achieved. Which of these is not one of the main supporting forces in stars or stellar remnants?
 - (A) Proton degeneracy pressure
 - (B) Electron degeneracy pressure
 - (C) Neutron degeneracy pressure
 - (D) Thermal pressure
 - (E) Radiation pressure

3. Which of the following will likely happen in the event of a collision between two spiral galaxies?
 - (A) Many stars will collide and collapse into black holes
 - (B) The two galaxies' mass will be condensed into a supermassive black hole
 - (C) A dramatic increase in stellar formation will be visible
 - (D) The galaxies will together form a lenticular galaxy
 - (E) None of the above, since intergalactic collisions are improbable given intergalactic distances

4. Carbon is a highly versatile element for life due to its high valency of 4, allowing it to form a wide range of organic molecules. A carbon atom can bond to 4 different atoms or groups of atoms in a tetrahedral structure, which can lead to chirality. What is the relevance of this in Astrobiology?
- (A) There is a preference for a certain chirality of biomolecules, so organisms placed in exotic environments with molecules of the opposite chirality may not survive.
 - (B) This opens new possibilities of finding extraterrestrial life using molecules of different chirality.
 - (C) Due to the unique configurations of certain molecules, the mismatch in the conformations of biomolecules and the active sites of enzymes may lead to dire consequences.
 - (D) Only A and B are correct.
 - (E) A, B, and C are all correct.
5. Scientists have discovered a new star. It has an apparent magnitude of 0.16, a stellar parallax of $0.42''$ /year, and a temperature of 4758 K. Calculate the luminosity of the star in terms of solar luminosities.
- (A) 0.07
 - (B) 0.58
 - (C) 3.92
 - (D) 5.33
 - (E) 11.39
6. Black holes are regions of space where matter collapsed in on itself, creating a singularity. This collapse is so strong that not even light can escape the black hole's gravity. As a result, black holes are often described as being "invisible" because they do not emit any light or other radiation that we can detect.
- What methods do scientists use to measure the mass of "invisible" black holes?
- i Direct modeling of the motions of resolved stars that are in orbit near the black hole
 - ii Finding them in binary systems and measuring the motion of the companion object
 - iii Measurement of emitted gravitational waves in black hole mergers
 - iv Measuring the temperature difference between the black hole's core and event horizon
- (A) i and ii
 - (B) ii and iii
 - (C) i and iv
 - (D) i, ii, and iii
 - (E) All of the above

7. Let the apparent surface area of an exoplanet be 1.0% of that of its host star. When the exoplanet transits in front of the star, determine the maximum change in apparent magnitude of the star.
- (A) 0.011
 - (B) 0.015
 - (C) 0.018
 - (D) 0.021
 - (E) 0.025
8. Scientists use a variety of methods to identify planets outside of the solar systems, with some orbiting other stars and others wandering in interstellar space as rogue planets. Depending on their size, orbit, and circumstances, methods used may also change accordingly. Which of the following are methods used to detect exoplanets (including rogue planets)?
- i Radial Velocity Method
 - ii Transit Method
 - iii Gravitational Microlensing Method
 - iv Direct Imaging Method
- (A) i and iii
 - (B) ii, iii, and iv
 - (C) ii only
 - (D) i and iv
 - (E) All of the above
9. The central region of a planetary nebula has an apparent magnitude of 13.8 and a surface area of 3.16 square arcseconds. Therefore, its average surface brightness in magnitude per square arcseconds is
- (A) 4.4
 - (B) 6.87
 - (C) 10.4
 - (D) 15.1
 - (E) Insufficient information to answer this question

10. In the spectra of B to F type stars, one can typically observe a sudden increase in the emission continuum around the 364.5 nm wavelength as one goes from shorter to longer wavelengths. This sudden increase is often known as the ‘Balmer Jump’.



Which is the best explanation for this phenomenon?

- (A) The Balmer Jump reflects the onset of fusion dominated by the CNO-cycle in stars hotter than G-type stars.
- (B) At sufficiently high temperatures, singly ionized Hydrogen produces strong emission at the 364.5 nm wavelength, which is partially absorbed and re-emitted at lower wavelengths by metals in the stellar atmosphere.
- (C) Light with wavelengths shorter than 364.5 nm have sufficient energy to ionize electrons from the first excited state of Hydrogen and is thus absorbed, thus producing a continuum absorption feature left of the jump.
- (D) At sufficiently high temperatures, ionized metals such as Calcium and Titanium Oxide causes light with wavelengths shorter than 364.5 nm to be absorbed through Compton scattering.
- (E) None of the above.

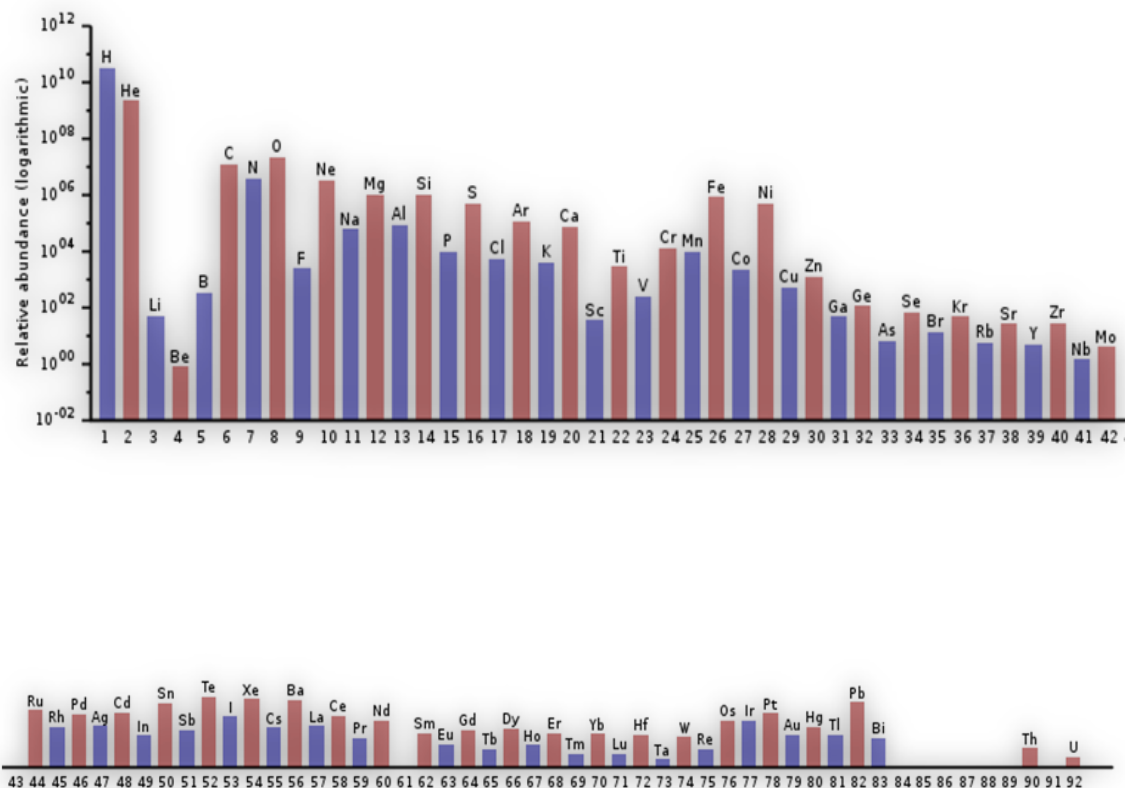
11. Read the following passage and identify objects A and B.

With an integrated apparent magnitude of 1.9, **Object A** is one of the brightest star clusters in the night sky. As such, it can be seen with the naked eye in Singapore and at least most of the Southern Hemisphere on a good night. It forms one of the vertices of a famous asterism.

Object A's visibility makes it a convenient starting point for starhopping to Object B, which is less than 5 degrees north of Object A. **Object B** is a vast region of star formation and contains several star clusters within its boundaries. However, its most notable feature is that it contains a highly luminous and variable star at its center. This star experienced a significant outburst in the 19th century, briefly becoming the second-brightest star in the night sky

- (A) Pleiades (M45) and Crab Nebula (M1)
 - (B) Pleiades (M45) and Flaming Star Nebula (C31)
 - (C) Southern Pleiades (C102) and Carina Nebula (C92)
 - (D) Southern Pleiades (C102) and Sagittarius Star Cloud (M24)
 - (E) 47 Tucanae (C106) and Tarantula Nebula (C103)
12. Capella is 46 light years away from Earth. Boss Rightyear is travelling on a spaceship to Capella at a speed such that the journey will take 20 years as measured by the clock on his spaceship. How long will his trip to Capella approximately take, as measured by clocks on Earth?
- (A) 20 years
 - (B) 46 years
 - (C) 50 years
 - (D) 64 years
 - (E) 82 years
13. Distant stars observed around the galactic center often appear redder than what might be expected from their spectral classes. Which of the following best explains the cause of this reddening?
- (A) Starlight is redshifted due to the expansion of the universe
 - (B) Starlight is scattered by interstellar gas and dust in the galactic plane, with blue light being preferentially scattered
 - (C) Starlight ionizes interstellar hydrogen gas, stimulating emission in the H-alpha wavelength
 - (D) Stars near the galactic center orbit in smaller and faster orbits, thus their light is Doppler shifted
 - (E) Stars near the galactic bulge tend to be older and thus redder

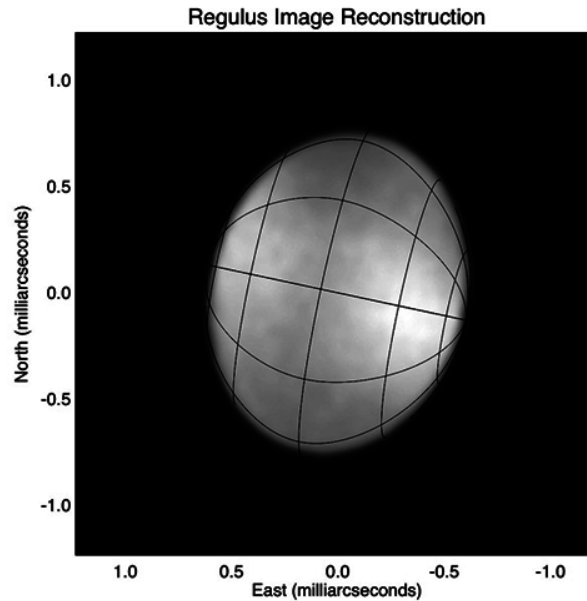
14. Figures below show the relative abundance of different elements in the universe according to our best estimates from the composition of the Solar System. Lighter and heavier elements have been separated for visibility.



Patterns in this abundance graph can be useful for astronomers in studying nucleosynthesis in stars and in the early universe. Which of the following is **not** true?

- (A) The relative abundance of even-numbered proton nuclei in the graph is due to the mechanism involved in forming them mainly involving helium nuclei.
- (B) The relative absence in the amount of Beryllium observed in the universe is an indication of the abundance of Beryllium burning stars that might be too dim to be observed by current technology.
- (C) The relative abundance of Iron and Nickel in the universe is due to them being the end point for massive star's stellar nucleosynthesis.
- (D) The gap between Bismuth and heavy radioactive elements (e.g., Th and U) is mainly due to the radioactive decay since their formation in supernovae as most of these elements have a short half-life time.
- (E) None of the above.

15. Regulus is a bright star in the constellation of Leo. It is notable for spinning so fast that it almost spins itself apart. Shown below is an image of Regulus taken with the help of interferometry, where the whiter parts of the image indicate higher temperatures.



Which of the following reason best accounts for the difference in brightness observed?

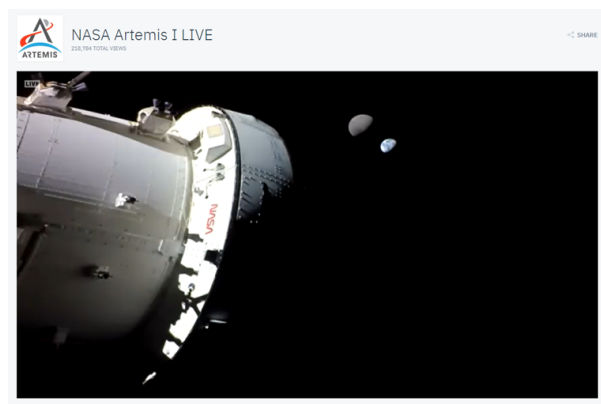
- (A) Doppler shift results in less photons received around the equator
- (B) Convection near the equator is disrupted and energy cannot be transported to the surface from the core to heat up the gas at the star surface efficiently
- (C) The surface gravity at the poles is higher and hence requires higher hydrodynamic pressure to balance it out, causing the poles to be hotter and brighter
- (D) The gas at the equator emits photons more directly aimed at us
- (E) The larger radius at the equator reduces the rate of heat transfer to the surface and hence makes the equator of the star cooler and dimmer
16. If the Crab Pulsar has a periodicity of 33ms, what is its minimum density (in kg/m^3) such that it will not rip itself apart from centrifugal force? You may assume the density within the pulsar is uniform.
- (A) 1.3×10^{14}
- (B) 1.3×10^8
- (C) 3.9×10^6
- (D) 3.6×10^3
- (E) None of the above

17. Astronomers often observe the 21 cm emission line produced by the spin-flip transition of neutral hydrogen in order to map out the large scale distribution of cosmic gas and dust. Which of the following are reasons for why the 21 cm emission wavelength is used?
- i The universe is predominantly filled with cold neutral hydrogen that produces 21 cm emission
 - ii Radiation with a 21 cm wavelength is easily scattered by cosmic dust, therefore allowing for the structure and distribution to be clearly mapped
 - iii 21 cm emission has a narrow spectral width which allows us to accurately determine velocities through Doppler shift
 - iv 21 cm emission is not absorbed by the atmosphere and thus can be observed by ground-based radio telescopes
- (A) i, iii and iv
- (B) i, ii, and iii
- (C) ii and iv
- (D) ii, iii, and iv
- (E) All of the above
18. Detecting a binary star with an elliptical orbit can be much tougher than circular ones as it involved many more parameters to be solved and could only be done by a computer. Which of the following parameters is not one of these new parameters that is required for determining the semi-major axis and masses ratio of the orbit?
- (A) Position of Perigee
- (B) Eccentricity
- (C) Angle position of Vernal Equinox
- (D) Argument of Perigee
- (E) Radial velocity
19. Suppose our Sun is replaced by a red dwarf of 0.4 solar masses. Estimate the apparent magnitude of the “new Sun” as seen from Earth. You may assume Earth does not change its orbit. Take the solar apparent magnitude as -26.74.
- (A) -30.27
- (B) -23.26
- (C) -18.63
- (D) -13.22
- (E) -4.76

20. A star has a special classification of B8Ia. We can thus conclude that

- (A) The radius of this star is much larger than our Sun
- (B) The star would appear very red to the naked eye
- (C) This star has 8 times the luminosity of our Sun
- (D) This star has 8 times the mass of the Sun
- (E) This star contains an unusually high abundance of A-group elements such as aluminum, argon, and arsenic

21. At one point during its journey, NASA's Artemis I live camera captured a moment in which the Moon's radius appeared 25% larger than the Earth's radius as seen below.



Assuming that the Earth and Moon are perfectly spherical and sufficiently far away from Artemis I such that the small angle approximation is valid, how much further was the Earth-Artemis I distance compared to the Moon-Artemis I distance? In other words, calculate the ratio of distances between Earth-Artemis and Moon-Artemis.

- (A) 5.74
- (B) 4.58
- (C) 3.67
- (D) 3.42
- (E) 2.93

22. A star cluster consists of 5 1-mag stars and 10 2-mag stars. What is the integrated magnitude of the star cluster?
- (A) -1.38
 - (B) +1.38
 - (C) -5.38
 - (D) +5.38
 - (E) None of the above

23. One of the implications of a flat galaxy rotation curve is the winding problem. If stars in a spiral galaxy all mostly move at around the same velocity, stars near the galactic core will make many more orbits than stars in the outer regions of the galaxy, as their orbital radii are smaller. Over time, this would cause the spiral arms of the galaxy to wind up, destroying the spiral structure.

What is currently believed to be the resolution for this winding problem?

- (A) Dark matter holds the star in place relative to the spiral arms.
 - (B) Dark energy causes the space between spiral arms to expand. However, the extra mass within the spiral arms counteracts the expansion, thus keeping the stars within the spiral arms.
 - (C) The spiral arms are actually maintained by density waves. Gas clouds enter the density wave and are compressed by them, triggering star formation which creates numerous luminous young stars - creating the spiral arms.
 - (D) Supernovae shockwaves propagating throughout the galaxy undergo constructive interference at the spiral arms, leading to more star formation within these arms.
 - (E) The winding problem does not exist.
24. A group of astronomers was chilling under the night sky when one noticed a peculiar supernova. Its brightness, B declined exponentially. In other words,

$$B \propto e^{-t/\tau}$$

where τ is a constant with a value of 30 minutes.

At its brightest, the supernova has an apparent magnitude of +4. Assuming the maximum magnitude that human eyes can see is +6, how long can they observe the Type 2L Supernova until it became invisible to them?

- (A) 40 mins
- (B) 45 mins
- (C) 50 mins
- (D) 55 mins
- (E) None of the above

You are provided with 3 telescopes with the following specifications. Answer question 25 and 26 based on the information given.

Name:	Telescope A	Telescope B	Telescope C
Type:	Newtonian Reflector	Schmidt Cassegrain	APO Triplet Refractor
Aperture:	203mm	127mm	107mm
Focal Ratio:	F3.9	F10	F7
Weight:	7.94kg	2.72kg	6.9kg

25. Which of the following statements is/are true given no accessories are used?

- i Telescope A contains 2 mirrors
- ii Telescope B is best for observing large Deep Sky Objects (DSO) as it has a long focal length
- iii Telescope C contains a mirror and a few lenses
- iv Telescope A has the shortest focal length

- (A) i only
- (B) i and ii
- (C) i, ii, and iv
- (D) ii and iv
- (E) All of the above

26. Given that an eyepiece of 15mm focal length and Apparent Field-of-View (AFOV) of 70° is used on Telescope B. Calculate the True Field-of-View (TFOV) of the setup.

- (A) 0.432°
- (B) 0.827°
- (C) 1.43°
- (D) 2.04°
- (E) 2.89°

27. A comet of mass m with a parabolic orbit passes its perihelion at distance p . If the mass of the Sun is M , what is the angular momentum of the comet?

- (A) \sqrt{GMmp}
- (B) $\sqrt{2GMmp}$
- (C) $\sqrt{GMm^2p}$
- (D) $\sqrt{2GMm^2p}$
- (E) $2\sqrt{GMm^2p}$

28. The no-hair theorem states that a stationary black hole can be completely described by three quantities. What are the three properties?
- (A) Mass, momentum, Schwarzschild radius
 - (B) Momentum, angular momentum, entropy
 - (C) Surface area, energy, entropy
 - (D) Surface area, energy, electric charge
 - (E) Mass, angular momentum, electric charge
29. Low mass stars of spectral types K and M tend to show more prominent metal absorption lines as compared to O, B and A spectral type stars. Which of the following statements is the best explanation?
- (A) O, B, and A spectral type stars have higher temperatures in their outer atmospheres which causes metals to be ionized. Ionized metals produce weaker absorption lines.
 - (B) K and M-type stars tend to be metal-rich as the presence of metals lowers the equilibrium temperature of stellar atmospheres, which is reflected in its spectral classification.
 - (C) The initial mass function of molecular clouds with high metallicities is skewed towards the lower-mass range, therefore metal-rich stars tend to be low-mass stars.
 - (D) Lower mass stars tend to be older, and therefore are usually population II stars which are defined by having excess metals in their atmosphere.
 - (E) In the Harvard spectral classification system, K and M types stand for Potassium and Magnesium, which are metals. On the other hand, O, B, and A stand for Oxygen, Boron and Argon which are not metals.
30. A hypothetical three-star system consists of three component stars with identical apparent magnitudes but different sizes and their orbits are coplanar with our line of sight to the system. Star A and B are 4 and 2 times larger in radius than Star C. Assuming they are visible but not resolvable with the naked eye, in which case will the system appears the dimmest?
- (A) All stars do not occult each other
 - (B) Star A occults Star B and C
 - (C) Star B occults Star A and C
 - (D) Star C occults Star A and B
 - (E) Star A occults Star C, but not Star B

31. It is November 2022 at 3 am and Mars just crossed the meridian a few minutes ago. At the same time and date in 2023, will Mars still be visible in the night sky?
- (A) Yes, Mars is around inferior conjunction
 - (B) Yes, Mars is around superior conjunction
 - (C) No, Mars is around inferior conjunction
 - (D) No, Mars is around superior conjunction
 - (E) Not enough information to tell

The following table contains information regarding a Cube-Satellite in Low Earth Orbit. Answer questions 32-34 with the information provided in the table.

Name	Eclipse-SAT
Mass	22.15 kg
Orbital Height	800 km
Orbital Type	Circular Sun-synchronous
Orbital Inclination	98.67°

32. Calculate the orbital period of the Eclipse-SAT satellite.

- (A) 89 minutes
- (B) 95 minutes
- (C) 101 minutes
- (D) 109 minutes
- (E) 120 minutes

33. Calculate the orbital speed of the Eclipse-SAT satellite.

- (A) 6.34 km/s
- (B) 7.46 km/s
- (C) 8.98 km/s
- (D) 9.49 km/s
- (E) 11.2 km/s

34. A communication center on ground last communicated with the Eclipse-SAT satellite directly overhead at midnight (0000 hrs) of 21 June 2023. If the satellite orbits in the equatorial plane on a prograde motion (i.e., same as Earth rotation's direction), when would the satellite be directly overhead the center again? Take the length of one sidereal day to be 86164 seconds.

- (A) 0014 hrs
- (B) 0029 hrs
- (C) 0142 hrs
- (D) 0145 hrs
- (E) 0149 hrs

35. Which of the below coordinate systems are **not** used for finding Deep Sky Objects regardless of location and time on Earth?

- (A) Equatorial coordinate system
- (B) Ecliptic coordinate system
- (C) Galactic coordinate system
- (D) Alt-azimuth coordinate system
- (E) None of the above

36. An alien civilization is more technologically advanced than the human civilization. An alien astrologer (*yes, astrology is a science for them*) observed the time evolution of the solar system and tabulated the distance between the aphelion and perihelion of each planet and the time each planet takes to orbit the Sun.

What can the alien astrologer know about the Sun from the gradient of the straight line with the highest accuracy? Assume their line of sight aligns with our ecliptic.

- (A) Sun's radius
- (B) Sun's luminosity
- (C) Sun's mass
- (D) Earth's radius
- (E) Earth's mass

37. Recently, astronomers discovered that the dwarf planet Quaoar possesses a ring system outside of its Roche limit. Why is this unusual?
- (A) Dwarf planets are too small to support a ring system
 - (B) Given enough time, this ring should coalesce into moons
 - (C) A ring system requires multiple moons in order to be stable, which Quaoar does not possess.
 - (D) Due to the presence of numerous other bodies in the Kuiper belt, these rings would be easily destabilized by the gravitational influence of other bodies
 - (E) This situation is not unusual at all
38. The James Webb Space Telescope is one of the most anticipated space telescopes with an immense budget. Because it is primarily designed for near-infrared astronomy, it must be positioned at the L2 Lagrange point of the Earth-Sun system. Which of the following statement(s) is/are true?
- i At L_2 , its instruments can be kept cold and thermally stable
 - ii It can only observe objects in certain angles at any instance of time due to its sunshield
 - iii It orbits around the Earth with the same period as the Moon
- (A) i only
 - (B) i and ii
 - (C) ii and iii
 - (D) All of the above
 - (E) None of the above
39. The Arecibo Telescope was a large radio telescope built in the mountains of Puerto Rico, US. Unlike conventional radio telescopes which have parabolic reflectors, the Arecibo Telescope had a spherical primary reflector. Which of the following reasons best explains why?
- (A) A spherical shape matched best the natural sinkhole it was built on
 - (B) A spherical reflector allowed the telescope to collect more light given the same area
 - (C) A spherical reflector allowed the telescope to only focus on very specific radio wavelengths
 - (D) A spherical shape allowed the detector to re-orientate and focus on any part of the primary reflector to look at different parts of the sky
 - (E) A spherical reflector does not suffer from chromatic aberration

40. Unlike planets like Earth and Uranus, Jupiter does not experience significant seasonal changes. This is primarily because:
- (A) Jupiter is tidally locked to the Sun
 - (B) Jupiter moves too slowly along its orbit
 - (C) The axial tilt of Jupiter is negligible
 - (D) The weather on Jupiter is driven by tidal forces exerted by the Galilean moons
 - (E) The weather on Jupiter is driven by deuterium fusion within its core
41. In the equatorial coordinate system, the 00hrs RA meridian is defined to be at the First Point of Aries, with RA increasing in the west-to-east direction. Which of the following statement(s) is/are true about RA-Dec coordinates? Note that we take the first point of Aries as the start of the tropical year.
- i The RA of the Sun increases throughout a tropical year
 - ii The RA of stars increase throughout a sidereal year
 - iii Celestial objects with a later RA rise later in the night
 - iv Stars with the same RA always rise and set at the same sidereal time
- (A) i only
 - (B) i and ii
 - (C) i and iii
 - (D) i, iii, and iv
 - (E) All of the above
42. Which of the following about Saturn's moons are **false**?
- (A) Saturn has many shepherd moons which help to confine particles within the rings and prevent them from spreading out into space
 - (B) Enceladus is thought to have a sub-surface ocean as it can get energy from tidal heating
 - (C) Orbital resonance between the moons keeps their orbits stable
 - (D) Titan is located in between the B Ring and C Ring, thus making it a shepherd moon as well
 - (E) None of the above

43. Which of the following statements are **incorrect**?

- I Due to libration and other orbital effects, we see a bit more than half of the Moon's surface from Earth despite the Moon being tidally locked to Earth
- II Ancient Greek philosophers cannot see some stars modern Greek astronomers can
- III Protostars, despite their lack of fusion, are always more luminous than when they reach the Main sequence.
- IV A future inhabitant of Mars will observe Earth go through different phases

- (A) None of them
- (B) I
- (C) II
- (D) III
- (E) IV

44. The Cosmic Microwave Background Radiation (CMBR) is an important tool in understanding the early universe. Which of the following description of CMBR is **incorrect**?

- (A) The CMBR is the light coming from the surface of last scattering, which is the earliest time light can freely travel in the universe
- (B) The CMBR is dated to about 380,000 years after the Big Bang
- (C) The effective blackbody temperature of CMBR is redshifted to about 2.7 K due to the expansion of the universe
- (D) The CMBR is emitted from the edge of the observable universe 46.5 billion light years away and only reaches us due to the expansion of the universe
- (E) The main variation of effective blackbody temperature of CMBR is due to Earth's relative velocity with respect to CMBR

45. The Milankovitch cycle attempts to account for long-term cyclical patterns in the Earth's climate by considering the effects of astronomical cycles and how Earth's rotation changes over time. Which of the following astronomical cycles are included in the Milankovitch cycles?
- i The Precession of the Equinoxes
 - ii The Solar Cycle (sunspot cycle)
 - iii Apical Precession of Earth's orbit
 - iv Nutation of Earth's orbital axis
 - v The Saros Cycle
- (A) i and iii
- (B) ii and iv
- (C) i, iii, and iv
- (D) ii, iv, and v
- (E) All of the options are correct
46. Suppose it is the March Equinox and you heard that there will be a meteor shower tonight. The meteor radiant lies close to the First Point of Aries. What can you do to maximize the number of shooting stars that you can visually observe from this meteor shower at night?
- (A) You should move north of the Arctic Circle to ensure that you enjoy 24 hours of night
- (B) You need to be on a spacecraft to observe these meteors burn up
- (C) You should only start observing after local midnight, to ensure that you are on the side of the Earth directly facing the meteor shower
- (D) There is nothing you can do as the radiant is only above the horizon in the daytime
- (E) You can simply wait a few months, and observe at the night in which the radiant rises at local sunset
47. Scientists can approximate densities of matter (including dark matter) of a dust cloud variable to its radius $\rho(r)$. Assuming that the matter moves in circular orbits with radius r from the center of the cloud, determine the relationship between $\rho(r)$ and r so that the orbital velocity still be the same for all values of orbital radius r
- (A) $\rho(r) \propto r^{-4}$
- (B) $\rho(r) \propto r^{-3}$
- (C) $\rho(r) \propto r^{-2}$
- (D) $\rho(r) \propto r^{-1}$
- (E) $\rho(r) \propto r$

48. You observe a galaxy emitting a H-alpha line at a wavelength of 785 nm. The rest-frame H-alpha emission wavelength is 656 nm. What is the radial velocity of the galaxy?
- (A) 0.549c, receding
 - (B) 0.549c, approaching
 - (C) 0.178c, receding
 - (D) 0.178c, approaching
 - (E) 0.243c, approaching
49. Which of the following is/are true about eclipses from an observer on the Moon?
- (A) At any given location, a solar eclipse on the Moon is rarer than on Earth
 - (B) During a purely penumbral lunar eclipse on Earth, every part of the nearside of the Moon sees a partial solar eclipse
 - (C) A solar eclipse (total or partial) can occur anywhere on the Moon
 - (D) During a total solar eclipse on Earth, Earth would appear reddish from an observer on the Moon
 - (E) None of the above
50. In the northern hemisphere during winter, in which directions do we expect the Sun to rise and set respectively?
- (A) NE, NW
 - (B) NE, SW
 - (C) SE, SW
 - (D) SE, NW
 - (E) Trick question. The Sun will always be below the horizon during winter.