



ASTROCHALLENGE 2021 JUNIOR TEAM ROUND

Monday 7th June 2021

PLEASE READ THESE INSTRUCTIONS CAREFULLY.

1. This paper consists of **23** printed pages, including this cover page.
2. You are required to keep your microphone and camera on at all times throughout the round.
3. You are not allowed to use your keyboard at all times, but you may use your mouse to scroll through the question paper as well as switch to the formula booklet.
4. Any materials other than the Question Paper, Formula Booklet, and **ONE** A4-sized cheat sheet held by **ONE** team member only, are strictly prohibited.
5. You have **2 hours** to attempt all questions in this paper.
6. Write your answers on blank pieces of A4 paper or graph paper. Do **NOT** mix solutions for different questions on the same sheet of paper.
7. You will be given time after the paper to collate your answers. You should collate your answers into **separate PDF files** for each question.
8. It is *your* responsibility to ensure that your answer scripts have been submitted.
9. The marks for each question are given in brackets in the right margin, like such: **[2]**.
10. The **alphabetical** parts (i) and (l) have been intentionally skipped, to avoid confusion with the Roman numeral (i).

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

Question 1 Short Answer Questions

Part I HR Diagrams

For this part, you are given the following H-R diagram.

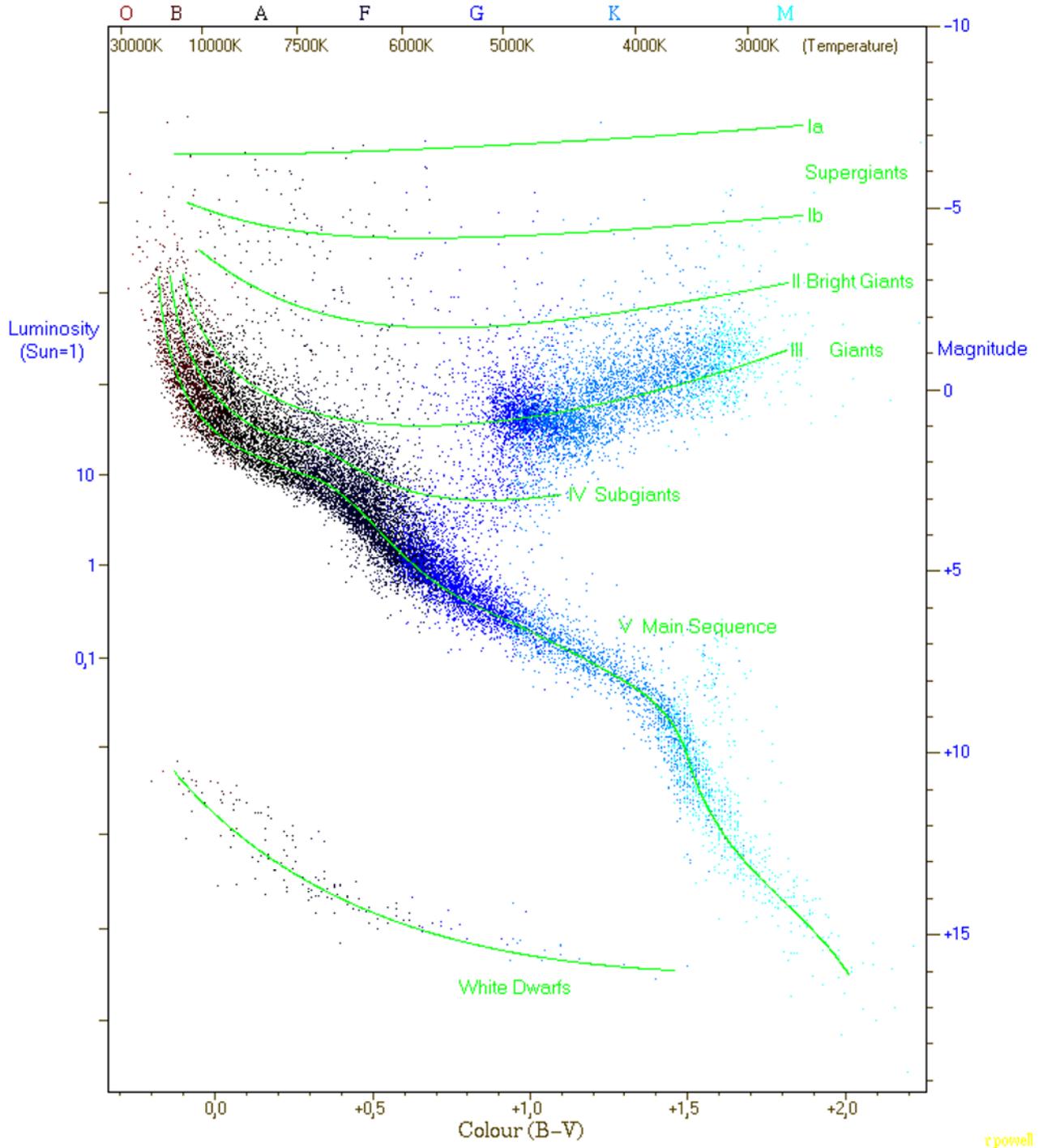


Figure 1: H-R diagram.

You are also given the following star.

Name	X Astrochallengae
Right Ascension	2h 30min 49s
Declination	67°28'43"
Distance	142ly
Apparent Magnitude	4.5
Absolute Magnitude	1.31
Magnitude Difference (B-V)	0.15

Table 1: Information regarding X Astrochallengae.

- (a) With the aid of the H-R diagram (Figure 1), deduce the spectral class as well as the luminosity of X Astrochallengae. [2]
- (b) Name the spectral class of the Sun. [1]
- (c) Using the information in Table 1 as well as your own knowledge, compare the Sun with X Astrochallengae in terms of radius as well as lifespan. [3]
- (d) How can one use a H-R diagram such as Figure 1 to determine the distance to a star cluster? [2]

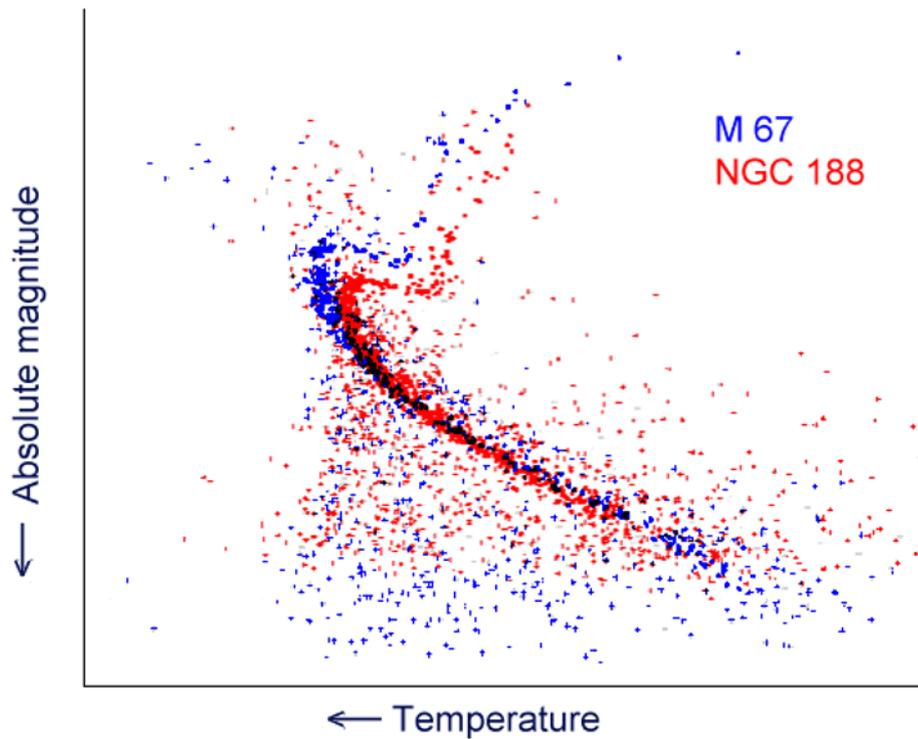


Figure 2: Main sequence turnoff points for two different star clusters

- (e) Figure 2 shows examples of a main sequence turnoff point for two different star clusters. How can one deduce the age of a star cluster using the turnoff point? [2]

Part II Dubious Statements

This part comprises 5 statements. For each statement, indicate clearly whether it is **TRUE** or **FALSE**.

Support your answer with no more than 3 sentences, including any assumptions where required. You may draw up to one additional diagram if they aid your explanation.

Mathematical working is not required, and there are no errors in any of the statements below.

Each statement is worth 2 marks, **attributed only to the quality of the justification.**

- (f) The most important factor to determine the visibility of an object is its absolute magnitude. [2]
- (g) Pluto is not a planet because it has a large moon orbiting around it. [2]
- (h) Hydrogen is the most abundant element everywhere in the Universe, including on Earth. [2]
- (j) Generally, because nuclear fusion produces more energy than nuclear fission, stars less massive than the Sun are powered by fission while stars more massive than the Sun are powered by fusion. [2]
- (k) Exoplanets orbiting a Sun-like star at the orbit of Mercury cannot have an atmosphere. [2]

Question 2 History of Astronomy

Humans have been looking up at the sky since antiquity and have always attempted to make sense of what rules the heavens. In this question, you will be taken through a brief journey of the history of astronomy and explore the discoveries and inventions made by historical figures, all of which eventually led to the domain of astronomy that we are familiar with today. While we will be focusing mostly on astronomical progress in Western civilisations, we must also appreciate that several other civilisations too have made outstanding contributions to modern astronomy.

Part I We're So Very Small, in the End

Astronomy has had a long history. In the West (European civilisations), astronomy emerged as the first branch of natural sciences to form a robust (but not necessarily correct) system of explanations for how the night sky behaved. The first to do so comprehensively were the ancient Greek philosophers, who had a keen eye in observing the heavens. They noticed some stars in the heavens always seemed to be moving against the other stars, hence naming them $\pi\lambda\alpha\nu\acute{\eta}\tau\eta\varsigma$ (planetes), meaning 'wanderer'. This eventually evolved to the word 'planets' which we are familiar with today. The ancient Greeks eventually came up with a system of explanation for the motion of the planets, now known as geocentrism. The below diagram is an exemplification of the Ptolemaic system of geocentrism, known to many as the height of geocentrist models.

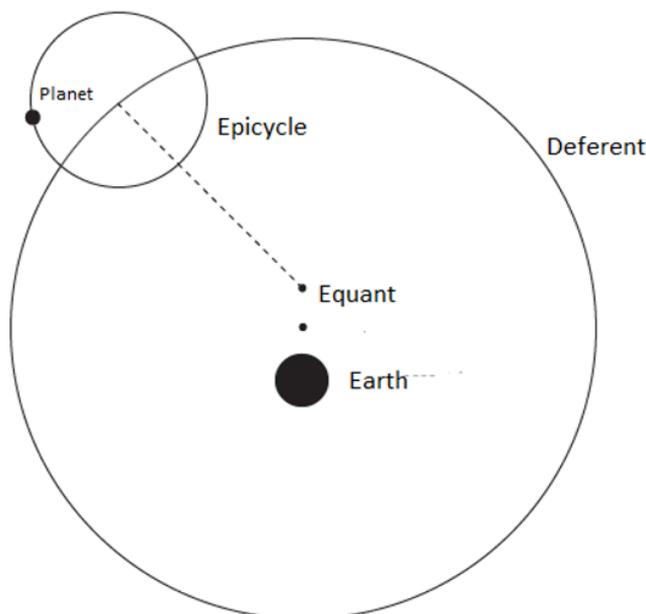


Figure 3: The Ptolemaic system.

As mentioned above, the ancient Greeks observed that planets curiously seem to move backwards at times, counter to their general direction of motion. This effect is now known as *retrogression*. In order to explain the observed phenomenon of retrogression, the ancient Greeks came up with the idea of *epicycles*. Epicycles are circles located along the larger orbits (formally called the *deferent*).

- (a) In Figure 3, we assume that we are viewing Earth from the North pole of the ecliptic. Copy Figure 3 and do the following:
- (i) Indicate with arrows the direction of the epicycle along the ecliptic and the motion of the planet around the ecliptic which results in retrogression.
 - (ii) Mark out the part of the epicycle which will see the planet in retrogression.

[2]

- (b) Using your current knowledge of astronomy, describe how the phenomenon of retrogression relative to Earth-bound observers actually occurs. You may use a diagram to aid your explanation. [2]

Due to the apparent simplicity and elegance of the geocentrist model, it was recognised as the mainstream model of the universe for over a millennium. It was not until the 16th century that the *De revolutionibus orbium coelestium*, written by Nicolaus Copernicus (1473–1543), was published, reintroducing the neglected idea of heliocentrism to the world.

Copernicus’ model of the universe, known as the *Copernican system*, was such that the Sun was at the centre of the Universe, with the planets, including Earth, revolving around the Sun. The diagram below is a representation of the Copernican system.

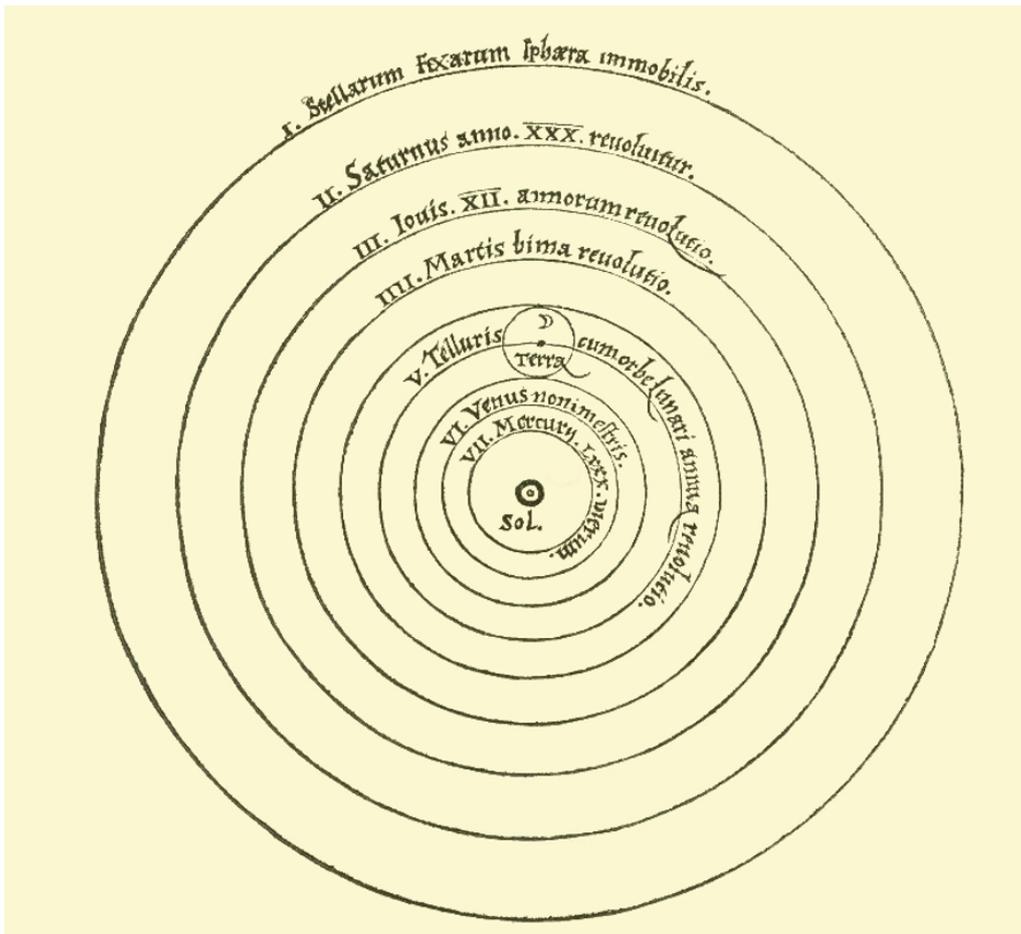


Figure 4: The Newtonian system.

During that early era, heliocentrism was met with heavy criticism. One notable opponent was Tycho Brahe (1546–1601). Tycho Brahe was one of the greatest observational astronomers of the pre-telescopic era, possessing sophisticated instruments to aid him in his observation of stellar positions. He argued that since he was unable to observe parallax in any of the stars, hence Copernicus’ theory must necessarily be wrong. It was not until 1838 that German astronomer Friedrich Bessel (1784–1846) performed the first observation of stellar parallax and estimated the distance to the star system 61 Cygni.

- (c) In 1838, over the course of a year, Friedrich Bessel observed 61 Cygni constantly, eventually detecting a maximum displacement of 0.314 arcseconds in its position in the night sky. You are given that the Earth orbits the Sun at approximately 150 million kilometres. Using this information, draw a diagram to exemplify the idea of parallax and use it to calculate the approximate distance to 61 Cygni as obtained by Friedrich Bessel. Leave your answer in light years. Note that one light year is approximately 9.461×10^{12} km. [3]
- (d) The true distance to 61 Cygni is now known to be closer to 11.4 light years. Give a reason why this discrepancy might have arisen. [1]

Part II The Good Ol' Days

Let us now return to the earlier days of astronomy. We turn our attention to another notable genius of that era, Johannes Kepler, best known for developing the three laws of planetary motion. Let us focus on his third law which eventually leads to the theorem that, for a circular orbit, $T^2 \propto r^3$, where T is the orbital period of a planet and r is the radius of said planet's orbit.

- (e) Assume for simplicity that the orbits of Earth, Jupiter, and Saturn are all perfectly circular. Based on Kepler's third law, given that Jupiter is 5.2044 AU from the Sun with an orbital period of 11.862 Earth years, and that Saturn's orbital period is 29.457 Earth years, what is the distance of Saturn from the Earth at opposition? Give your answer in AU. [1]

As time progressed, telescopes were invented and Galileo Galilei (1564–1642) became the first person to turn the invention towards astronomical observations in 1609. He was the first person to note craters on the Moon and note the satellites of Jupiter, uncovering concrete evidence that would ultimately overturn geocentrism. Telescope technology spread widely across Europe in the following decades, with many more adopting them to peer into the heavens.

- (f) Jupiter's satellite Io is known in modern astronomy to be the most volcanic world in the Solar System. Explain how its volcanism arises. [1]
- (g) Other major satellites of Jupiter are not known to be as volcanic in nature. Explain the difference. [1]
- (h) At that point in time, telescopes were mostly simple refractors which suffered from many issues. After telescopes became widespread, its technology and diversity also advanced rapidly, with Sir Isaac Newton inventing the Newtonian telescope in 1668. This design marked a significant improvement over its predecessors for a variety of reasons. Name two such reasons. [2]

The first renowned usage of the Newtonian telescope was by Sir William Herschel, a musician-turned-astronomer. He developed skills for mirror polishing, and eventually built telescopes for himself and his sister, Caroline Herschel, to pursue their astronomical work. From 1785 to 1789, Herschel built the world's largest telescope of the time, with an aperture of 48 inches (1.22m) and a focal length of 40 feet (12.2m), giving a focal ratio of f/10. The primary mirror was craft out of speculum, an alloy of copper and tin, polished in such a way to make it reflective. A speculum mirror can reflect up to 66% of light that hits it.

- (j) Modern mirrors, commonly made of fused quartz, regularly reflect up to 94% the amount of light that hits the primary in a reflecting telescope. Compared to the speculum mirror of the 40-foot telescope, what aperture of a fused quartz mirror would reflect the same amount of light? You may leave your answer in either inches or metres for this question only. [2]
- (k) However, the speculum mirror, with its aperture, will still have one advantage over the quartz mirror due to its larger aperture. What advantage is it? [1]

A notable legacy of William and Caroline Herschel, as well as William's son, John Herschel, is their records of celestial objects which would eventually be compiled to form the New General Catalogue (NGC). The NGC remains one of the most notable and comprehensive catalogue of deep-sky objects till this day.

Another renowned catalogue that is widely referenced in the astronomy community is the Messier Catalogue (M). It was compiled by French astronomer Charles Messier (1730–1817) and his assistant, Pierre Méchain (1744–1804). This catalogue started out as an endeavour by Messier to sieve out celestial objects that resembled comets, but were eventually found not to be comets.

- (l) State one reason why the observation of a comet could potentially be confused with that of a deep-sky celestial object. Then state how the comet can be distinguished from the deep-sky object. [1]

Part III The Rabbit Hole is Truly Deep

In 1924, Edwin Hubble (after whom the Hubble Space Telescope is named) discovered that the distance to the Andromeda Galaxy (M31) was far greater than ever had been thought, extending far beyond the Milky Way. This conclusion was made through repeated measurements of a special type of star in the Andromeda Galaxy, called a Cepheid variable. In particular, the star he observed was a classical Cepheid known as V1. Cepheid variables are a class of stars that are known to oscillate regularly in observable brightness, corresponding to its luminosity.

The diagram below shows the brightness data for the star V1, as measured by the American Association of Variable Star Observers (AAVSO) and the Hubble Space Telescope.

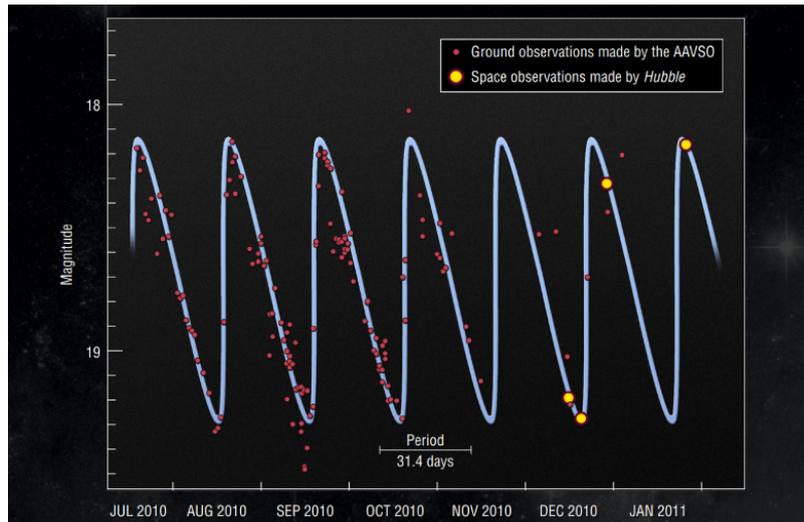


Figure 5: Brightness data for star V1.

The diagram below shows the average relationship between the period of a Cepheid’s magnitude oscillation and its magnitude.

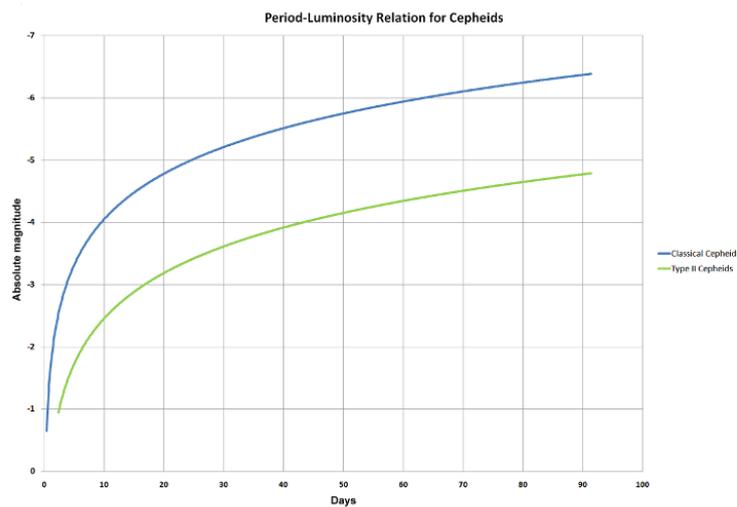


Figure 6: The average relationship between the period of a Cepheid and its magnitude.

- (m) Approximate the average apparent magnitude of V1, as well as its absolute magnitude. Hence by comparing these two values, estimate the distance to V1 and therefore to the Andromeda Galaxy. [3]

Question 3 Stephan's Quintet

Part I Cosmological Redshift

Stephan's Quintet is a visual grouping of five galaxies, four of which are physically interacting with one another. We will name the galaxies arbitrarily as A, B, C, D, and E for now. Their redshifts are given in Table 2 below.

Galaxy	Redshift z
A	2.20×10^{-2}
B	2.21×10^{-2}
C	1.92×10^{-2}
D	2.25×10^{-2}
E	2.63×10^{-3}

Table 2: Redshifts of the 5 galaxies

- (a) Which of the five galaxies is the odd one out? [1]
- (b) Suggest a reason for its difference from the others. [1]
- (c) Calculate the recessional velocity in kms^{-1} for the galaxy you have chosen in part a. [1]

We shall now assume that emitted light from galaxy you have chosen in part a is being redshifted solely due to the cosmological expansion of the Universe.

- (d) Based on this assumption, and the recessional velocity calculated in part c, calculate the proper distance between Earth and this galaxy. Give your answer in light years up to 3 significant figures. [2]
- (e) Explain why this assumption must be made to achieve a more accurate value of the proper distance of this galaxy from Earth. [1]
- (f) Assuming that this galaxy was formed immediately at the start of the Universe, and that it had maintained a constant recessional velocity throughout its lifetime, calculate the estimated age of the Universe using the proper distance calculated in part d. Give your answer in years up to 3 significant figures. [2]

From part f, we can glean some insights into the relation between the age of the Universe and the Hubble constant.

- (g) Show that the age of the Universe can be expressed by the following equation, where H_0 is the Hubble's constant:

$$\text{Age of Universe} = \frac{1}{H_0}$$

- [1]
- (h) Assuming our Universe's mean density is slightly lower than the critical density, state how Hubble's "constant" will change as the age of our Universe tends towards infinity. [2]

Part II Galaxy Wars

Assuming that your answer in part a is correct, the galaxy you have chosen is actually NGC 7320, thought to be a galaxy discordant from the main group of NGC 7317, NGC 7318a, NGC 7318b and NGC 7319. In particular, NGC 7318b is infalling into the other three galaxies at high velocities and currently colliding with them.

The quintet is also associated with the galaxy NGC 7320c, which lies 3 arcminutes east-northeast from NGC 7319. Twin tidal tails run from both NGC 7319 and NGC 7320 to NGC 7320c, suggesting past or ongoing gravitational influences. The former (the inner tail shown in the image below¹) is narrower, less diffuse and has a higher surface brightness than the latter (the outer tail shown in the image below).

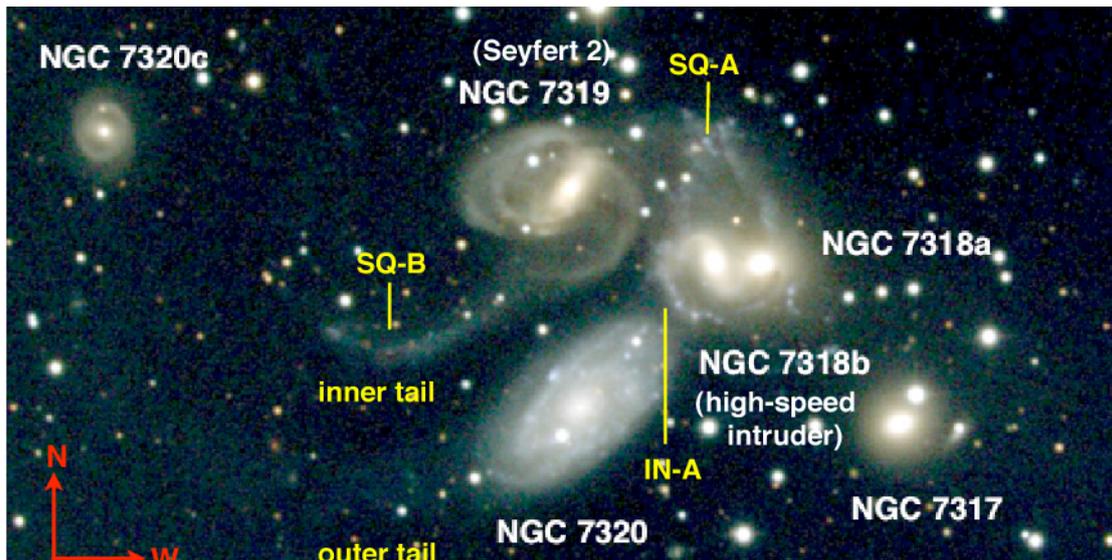


Figure 7: Image of Stephan’s Quintet constructed from telescopic data, showing the five members NGC 7317, NGC 7318a, NGC 7318b, NGC 7319, and NGC 7320, as well as a neighbouring galaxy NGC 7320c.

(j) Based on the aforementioned information, rank the following interactions between the galaxies in chronological order.

- I NGC 7320c becomes loosely bound to the group.
- II NGC 7320c interacts gravitationally with NGC 7320.
- III NGC 7317, NGC 7318a, and NGC 7319 become bound together, forming the group’s core.
- IV NGC 7318b collides with the trio of NGC 7317, NGC 7318a, and NGC 7319.
- V NGC 7320c interacts gravitationally with NGC 7319.

[3]

The group as a whole is massive enough to attract visitors like NGC 7318b episodically. Due to frequent gravitational interactions with their neighbours, the galaxies in the group have their gas stripped, shocked, and spewed into intergalactic space.

(k) Suggest how this will affect the rate of star formation in the group. Explain your answer briefly.

[2]

(m) Computer simulations predict that in the near future, despite gravitational attractions among the galaxies, the group is unlikely to merge into one galaxy. Briefly explain what might be keeping them apart.

[1]

(n) State the **least** likely shape or type of the final galaxy if the group of galaxies were to eventually merge into one galaxy.

[1]

¹©NAOA/AURA/NSF (Original Image). ©Jeong-Sun Hwang, “Models of galaxy collisions in Stephan’s quintet and other interacting systems”, 2010 (image edited with annotations).

NGC7319 is a Type II Seyfert galaxy. Seyfert galaxies are galaxies that have active galactic nuclei, which often contain a supermassive black hole in their centre.

- (o) Suggest an **observable** characteristic of NGC 7319 that might have given its status as a Seyfert galaxy away to astronomers. [1]

NGC 7320 is found to be significantly less red than the other galaxies in the quintet. Some reasons could be that NGC 7320 is moving towards us, or it is much closer to us than the other galaxies. Therefore, the light it emits is redshifted less.

- (p) Suggest **another** possible reason for this. [1]

Question 4 Aim for the Stars; If You Miss, You'll Drift in Interstellar Space

Episode IV A New Orbit

The first satellite placed in a geostationary orbit was Syncom 3, launched by a Delta D rocket in 1964. The 39kg satellite was able to transmit live coverage of the 1964 Summer Olympics from Japan to America, something which was impossible to do before Syncom 3 was launched.

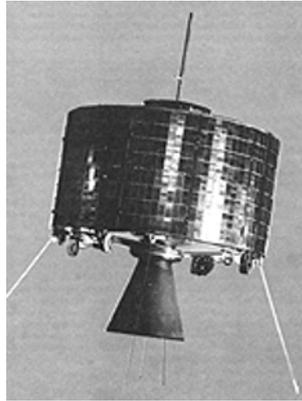


Figure 8: Syncom 3 satellite. (NASA)

Both geostationary and geosynchronous satellites have the same orbital period of 24 hours. Due to their orbital characteristics, geostationary satellites usually perform certain roles for certain countries.

- (a) State the difference between a geostationary orbit and a geosynchronous orbit. [1]
- (b) Briefly explain why high latitude countries such as Russia and Japan are unable to have geostationary satellites over their land. [1]
- (c) The Russians got around this problem by launching satellites in highly eccentric elliptical orbits called Molniya orbits (Figure 9). Suggest why satellites in Molniya orbits can perform roles for high latitude countries similar to those roles performed by satellites in geostationary orbits. [2]

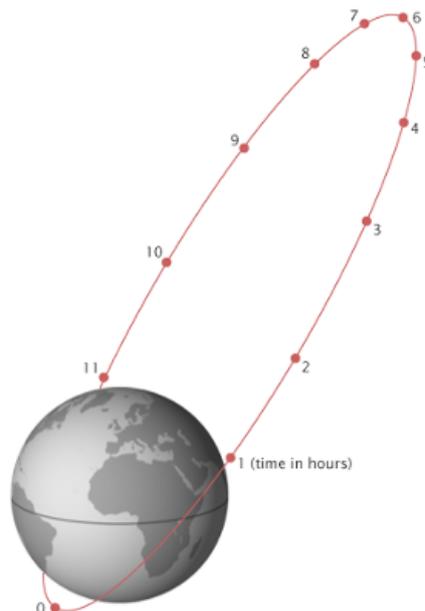


Figure 9: Molniya orbit around the Earth with time marks. (NASA)

Episode V The Jebediah Strikes Out

Jebediah Aerospace wants to put a 123kg satellite named Jeblink into geostationary orbit, but the company doesn't know what the required altitude is. Wernher von Kerman advises them that Kepler's 3rd law states that the square of the period of the orbit of a satellite about its parent body is proportional to the cube of the semi-major axis of the satellite's orbit. That is,

$$T^2 \propto a^3,$$

where T is the satellite's period and a is the semi-major axis (long side) of the orbit.

For the special case of semi-major axis being equal to the semi-minor axis, the orbit is perfectly circular and hence the semi-major axis can be taken as the orbit's radius r .

- (d) The Formula Booklet shows the general Kepler's 3rd law for any elliptical orbit and non-negligible relative masses. Derive Kepler's 3rd law in the case of a satellite in a circular orbit around a much more massive body. [2]
- (e) Using the relevant values in the Formula Booklet, show that if Jeblink is in geostationary orbit, its altitude (height above sea level) is 35870km. Assume a perfectly circular orbit (0 eccentricity) and a spherical Earth. [2]
- (f) Hence, using the relevant values in the Formula Booklet, show that if Jeblink is in geostationary orbit, its orbital speed will be 3071.8ms^{-1} . [3]
- (g) Using the altitude given above and the fact that low Earth orbit (LEO) ranges from 80km to 2000km in altitude,
- (i) state two different uses of a satellite in a geostationary orbit, and [1]
 - (ii) give a reason why satellite operators prefer geostationary orbits instead of LEOs, even though it is easier and cheaper to place satellites in LEO. [2]

Now that Jebediah Aerospace has figured out the required altitude to put their satellite Jeblink into geostationary orbit, the company decides to build a rocket to execute their plans.

- (h) The company puts their satellite Jeblink aboard the largest rocket booster they can find and launches it straight upwards from the ground to geostationary orbit altitude. Upon arrival, the speed of the satellite is precisely the orbital speed given in part f.

However, instead of orbiting Earth in geostationary orbit as expected, the rocket instead reaches a certain apoapsis point before crashing back to Earth. Based on this scenario, suggest and explain a reason why Jeblink failed to enter geostationary orbit. [1]

Episode VI Return of the Jeblink

Following this failure, Jebediah Aerospace quickly rebuilds a Jeblink 2 satellite and decides to outsource the launch to SpaceZ, a leading rocket launch provider. SpaceZ is able to provide an appropriately-sized rocket booster and the correct flight profile to put Jeblink 2 into equatorial LEO at 100km altitude, avoiding the catastrophe that was the original Jeblink.

However, SpaceZ refuses to design the upper stage to cover the remaining journey to geostationary orbit. It needs to be designed by Jebediah Aerospace. To perform this transfer, Jebediah Aerospace decides to use the Hohmann transfer orbit.

The Hohmann transfer orbit is an elliptical orbit used to transfer a spacecraft between two circular orbits of different radii around a central body in the same plane. The orbital manoeuvre to perform the Hohmann transfer uses two engine burns, one to move the spacecraft from the initial orbit onto the elliptical transfer orbit, and a second burn to circularise at the desired altitude.

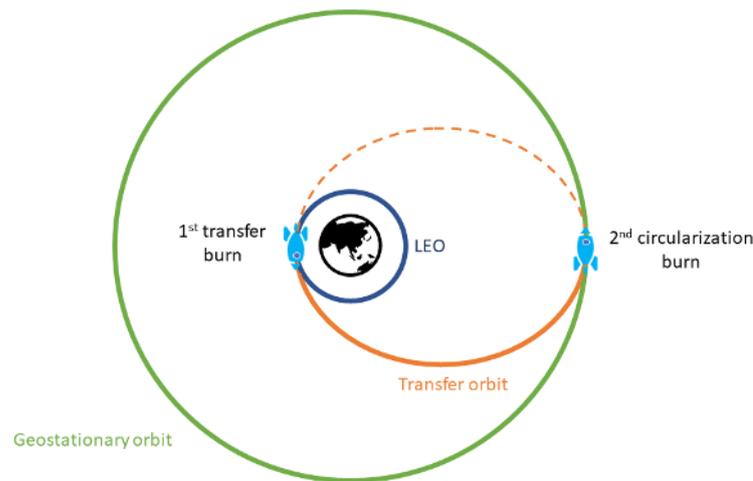


Figure 10: Hohmann transfer manoeuvre from geostationary LEO (dark blue) to geostationary orbit (green) via the Hohmann transfer orbit (orange)

For any satellite in an orbit about a planet, the vis viva equation

$$v^2 = GM \left(\frac{2}{r} - \frac{1}{a} \right)$$

allows one to compute the instantaneous orbital speed v of the satellite given the semi-major axis a of the orbit and the instantaneous distance r between the spacecraft and the planet's centre of mass.

- (j) It is given that the upper stage's orbital velocity in LEO at 100km altitude is 7848.7ms^{-1} . Calculate Δv , the total change in speed of the satellite needed to bring the satellite from 100km equatorial LEO to geostationary orbit. [3]

After a certain amount of research, Jebediah Aerospace engineers have found three different possible propulsion systems to use for the upper stage.

	Option 1	Option 2	Option 3
Name	BACC SRB	48-7S LFE	IX-6315 EPS
Type	Solid fuel booster	Liquid fuel engine	Electric ion engine
Mass of Engine System	1.5 tonne	0.13 tonne	0.3 tonne
Mass of Fuel	6.25 tonne	1 tonne	0.04 tonne
Thrust (vacuum)	300 kN	20 kN	2.0N
Specific Impulse (vacuum)	210s	320s	4200s
Burn Time	42s	157s	825000s

Table 3: Details about the three possible propulsion systems.

It is given that effective exhaust velocity v_e (units ms^{-1}) is given by

$$v_e = g_0 I_{sp},$$

where $g_0 = 9.80665\text{ms}^{-2}$ is standard gravity and I_{sp} is the specific impulse of the rocket engine.

- (k) Jeblink 2's mass is also identical to Jeblink, at 123kg. Choose and explain, with relevant calculations and explanations, which of the three propulsion systems is the only sensible choice to bring Jeblink 2 from 100km equatorial LEO to geostationary orbit from 100km LEO.

(**Hint:** Can the given propulsion systems reach the desired orbit reasonably? Consider Δv , the thrust-to-weight ratio, and any peculiarities of the engine systems.)

[2]

Epilogue

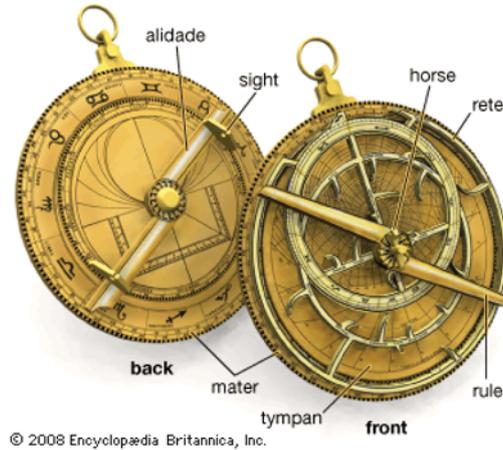
“From our calculations, we will go with Option [REDACTED]”, says Valentina Kerman, a rocket scientist.

The rocket was built and prepped for an early morning launch. SpaceZ's Eagle 9 rocket launched the upper stage into 100km LEO without any hiccup. The upper stage continued the journey to geostationary orbit and successfully circularised. The payload was released and Jeblink 2 was able to link up with Ground Control. Hooray!

Question 5 An Ancient Sky Atlas

Apollonius of Perga was said to have invented the astrolabe, an ancient astronomical device that had major significance in observational astronomy. It has many functions: from measuring the altitude of celestial bodies, to identifying visible stars in the celestial sphere.

Carefully read and understand how the astrolabe works before attempting the questions.



© 2008 Encyclopædia Britannica, Inc.

Figure 11: Components of an astrolabe.

The astrolabe has a front and back. Its main components consist of the following:

Mater The main panel to which all other components are attached to. It has markings on its outer circle to indicate the time (24-hour clock written in Roman numerals, with midnight starting clockwise from the bottom).

Tympan A plate inserted into the mater. It has line engravings that show the visible section of the night sky at a particular time (Anything within the grid lines will be visible to the observer). The concentric circles represent the altitude (the centre represents the zenith), while the intersecting lines represent the azimuth. Each line interval is 5°. The boundary grid line represents the horizon.

Rete A frame placed over the tympan that is free to rotate. The main circle (upper-most circle represented as an astronomical clock) indicates the ecliptic line that the Sun lies on. Its pointers (protrusions) indicate the position of bright stars. If rotated clockwise, it is similar to how the celestial sphere rotates with reference to the observer, with one complete rotation representing a single day.

Rule A rotatable pointer used to align the rete, tympan, and mater.

Horse A pin holding everything in place.

Alidade with Sight A rotatable pointer used to measure the altitude of celestial objects.

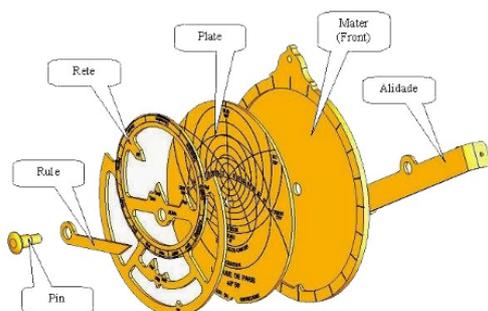


Figure 12: Anatomy of an astrolabe.

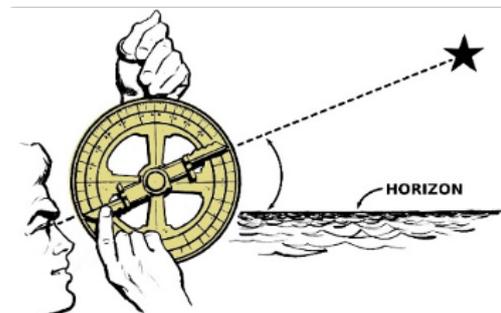


Figure 13: Measuring the altitude of a star using the alidade with sight.

- The rete is then rotated together with the rule (with the alignment obtained in Step 1) to the current time indicated on the outer circle of the mater.

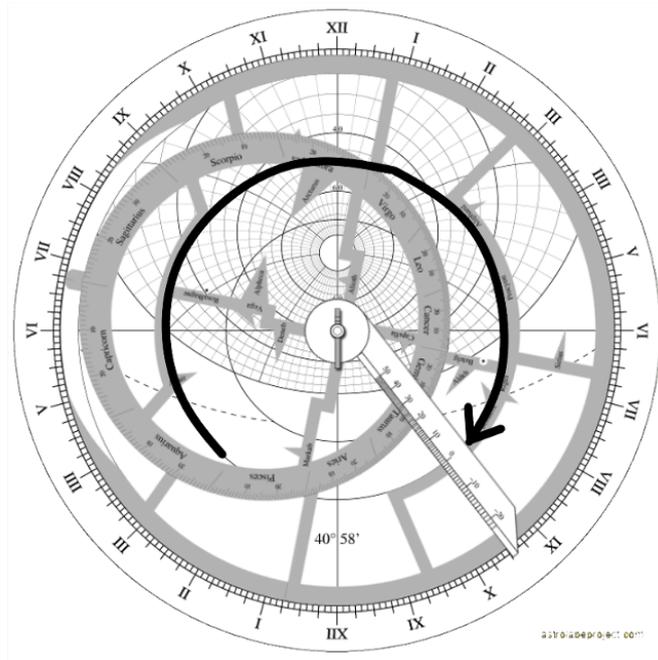


Figure 16: Astrolabe with rule and rete aligned to time 2130.

- The current celestial sphere visible to the observer is read off from the tympan.

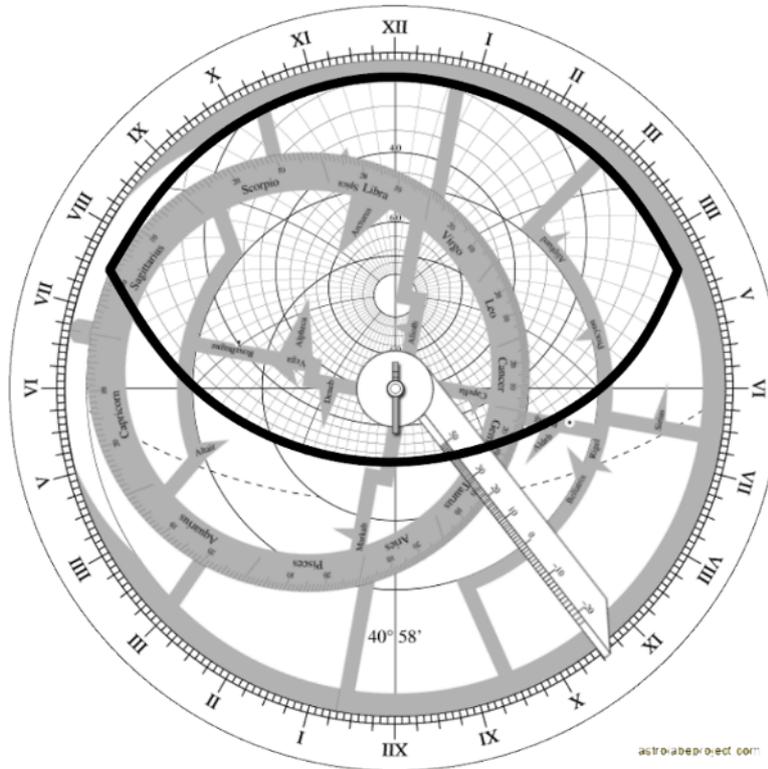


Figure 17: Celestial sphere visible to observer (marked out with black boundary).

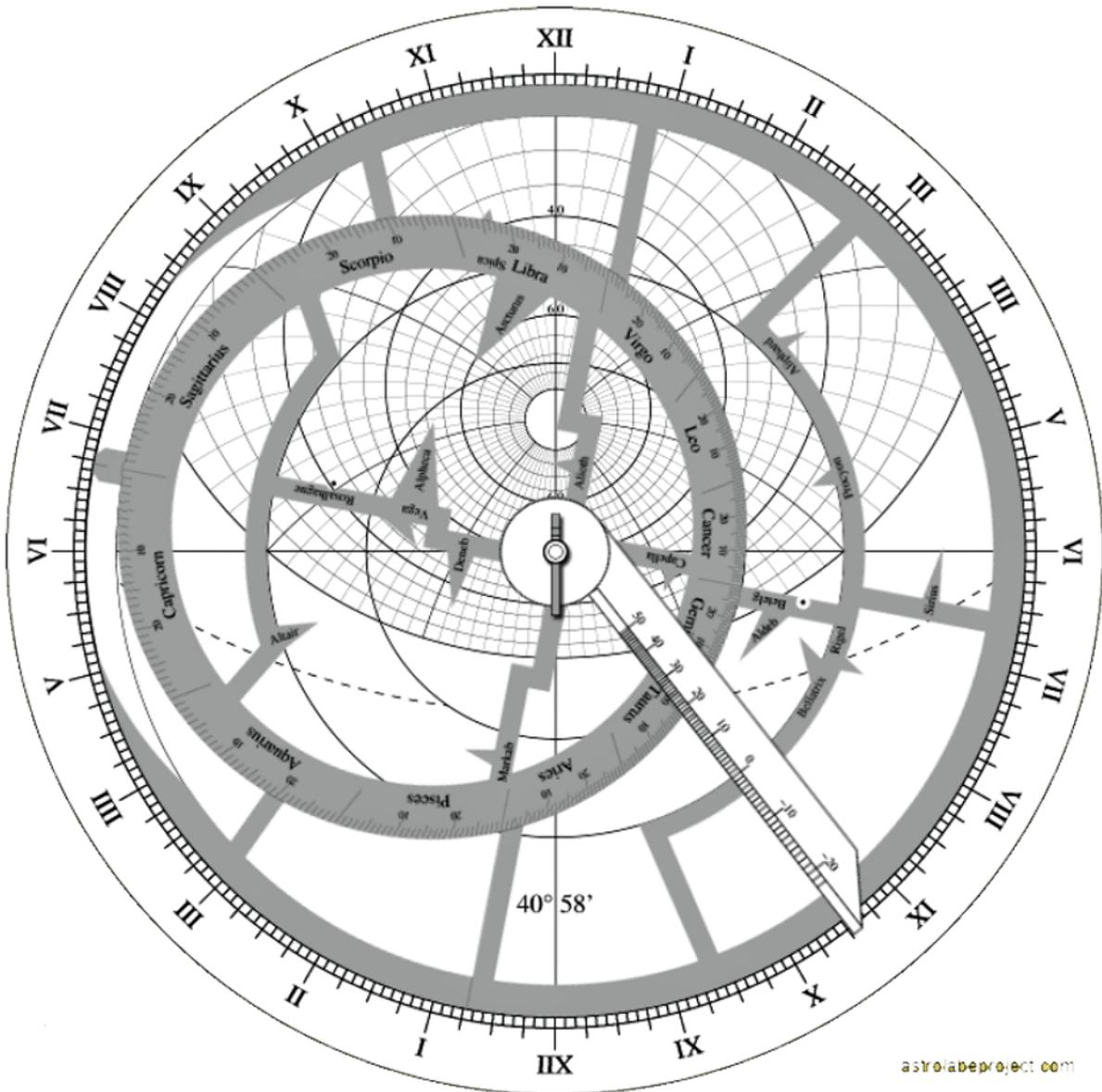


Figure 18: Front view of an astrolabe.

Figure 18 shows an astrolabe indicating that the Sun is currently within 20° of Taurus. The time is 2130. It is given that the tympan was made for a location at $40^\circ 58'$ latitude.

- (a) Gacrux has a declination of approximately -57° . State and explain if it is visible from this location. [1]

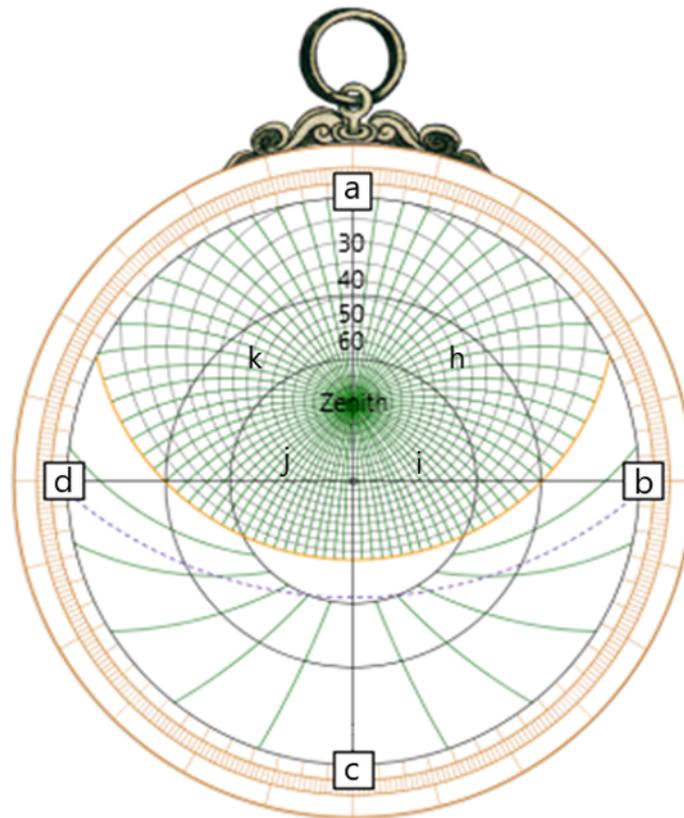


Figure 19: The same astrolabe, labelled for parts b to e.

- (b) Based on Figure 18 and the relevant information given, state the cardinal directions labelled as 'a', 'b', 'c', and 'd' respectively on the tympan shown in Figure 19. [1]
- (c) The summer triangle is a popular western asterism. State the name of its constituent stars and explain whether it is currently fully visible to the observer. [2]
- (d) Deduce the approximate time Procyon will set below the horizon. [1]
- (e) Currently, it is given that Regulus is approximately 235° in azimuth and 40° in altitude with reference to the observer. State which of the four positions 'h', 'i', 'j', and 'k' in Figure 19 is the correct position of Regulus. [1]

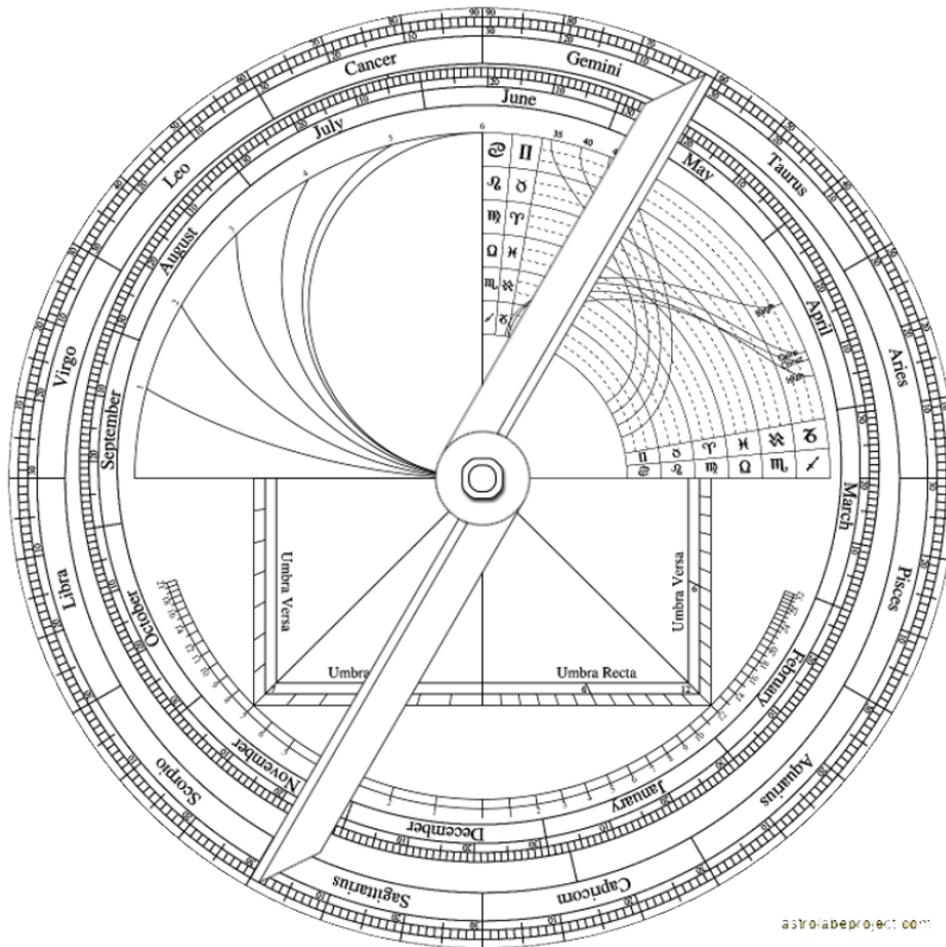


Figure 20: Back view of the same astrolabe.

Figure 20 shows the back view of the same astrolabe after measuring the altitude of a bright star. For simplicity, ignore the complex diagrams in the inner circle and focus only on the outer circles, starting from the circle with the months.

- (f) With reference to the front and back views of the astrolabe, state the measured altitude and deduce the name of the bright star. [1]

The astrolabe also allows users to easily find the current date given the Sun’s position amongst the constellations and vice versa. This done by aligning the alidade to the given value and reading off the corresponding date. You are given that the current date is 11 December.

- (g) Deduce the Sun’s current position amongst the constellations. [1]
- (h) Another useful feature of the astrolabe is the ability to deduce the time of sunrise or sunset. State the time of sunrise and explain how it can be obtained by using both the front (Figure 18) and back of the astrolabe (Figure 20).

(Hint: In order to find the timings using the front of the astrolabe, the “point at which the rule aligns to the Sun’s position on the rete” must lie at the position of the sunrise indicated on the mater. [2]

The names of most celestial bodies we know today were derived from Greek mythology. One famous folklore references Orion, the Hunter, and Scorpio, the Scorpion. Orion was so great that Gaia set Scorpio against him to put an end to his arrogance. The Scorpion succeeded and chases Orion through the night sky to this day.

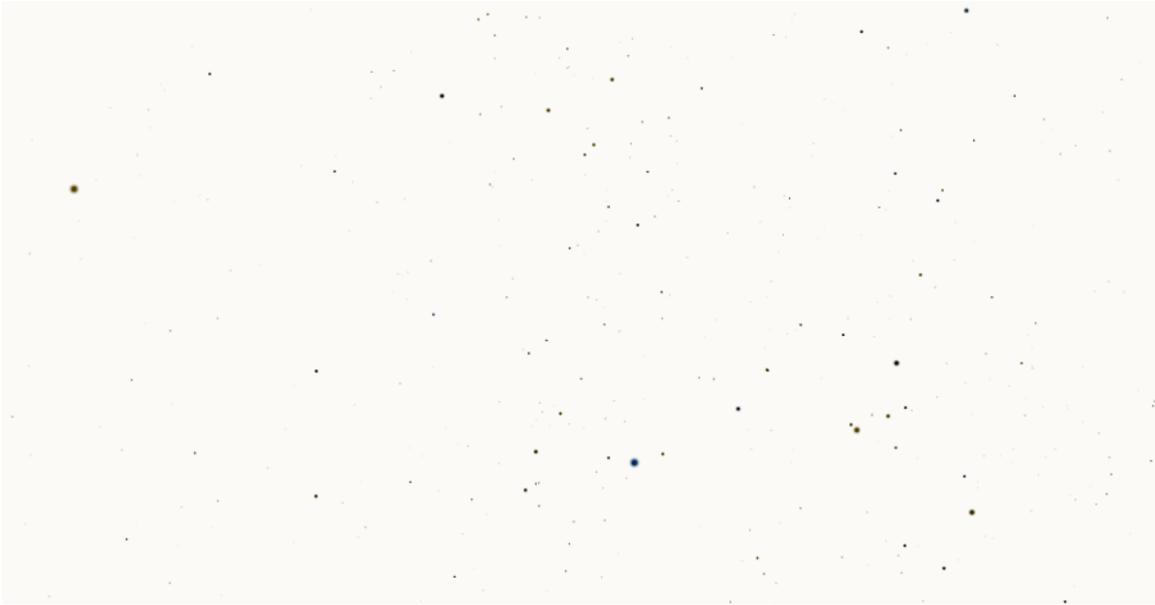


Figure 21: View of a section of the night sky.

- (j) State the proper name of α Scorpii and the month in which it culminates at exactly 0000 hrs. [2]
- (k) State the name of the star that represents the stinger of the scorpion's tail. [1]
- (m) Near Scorpius lies a open star cluster named after a famous astronomer. State the name of the star cluster and explain how it can be found with reference to Scorpius. [2]
- (n) State one other constellation that is fully visible in Figure 21. [1]

Although the hunter Orion is often depicted as facing the charge of Taurus, the bull, few myths directly relate the two. One myth, however, references Orion and how he fell in love with the Seven Sisters and pursues them across the night sky.



Figure 22: View of a section of the night sky

- (o) State the name or catalogue number of two deep-sky objects (DSOs) in Figure 22 that are not in the constellation Orion. [2]
- (p) The Mayans had a myth that described the creation of mankind. Within this myth, the Orion Nebula plays a central role as the flames of creation that burned in the centre of the heavenly hearth, marked by three stars in Orion: Alnitak, Saiph, and one other star. Deduce the name of that star. [1]
- (q) Given that Aldebaran crossed the meridian at 2351 on 18 Dec, deduce the approximate time at which it will cross the meridian on 21 Dec. [1]

~ FIN ~