Singapore Astronomy Olympiad 2021

Instructions

1. The entire Olympiad lasts for **3.5 hours** and is worth **a total of 200 marks**.
2. Fill in these details on the cover page (after the Contents page), the Summary Answer Sheet and each side of an SAO answer sheet:
   - Year of competition
   - Your participant code
   - The page number – which should be continuous from 1 to N
   - The part of the paper, and the question number
3. Cross out all workings or answers you do not wish to be evaluated.
4. You are allowed to leave the venue early upon submission of your answer script (**see Instructions on Cover Page**), but only **after one hour after the start** of the paper and **not within 30 minutes to completion** of the paper.
5. Please raise your hand to seek assistance from the invigilators (e.g. to visit the restroom, request for more answer sheets, enquire about an ambiguity, etc.)

Competition Rules and Regulation

1. Only the use of scientific calculators is permitted. No graphing or programmable calculators are allowed.
2. Disruptive behaviour, cheating, collusion to cheat or any integrity-related offences are grounds for immediate disqualification.
3. You may opt to retain the question paper and constants sheet for personal use. Return all unused answer sheets to the Organising Team.

References for Data Analysis Question

1. MS Star Details are derived from: Zombeck, Martin V. (1990). Handbook of Space Astronomy and Astrophysics (2nd ed.). Cambridge University Press
2. Additional MS Star Details are derived from: Vardavas, Ilias M.; et al. (2011), "Chapter 5. Incoming Solar Radiation" Radiation and Climate: Atmospheric Energy Budget from Satellite Remote Sensing.

Astronomy.SG would like to thank the organizing committee and the question setters. This document is typeset in LaTeX.

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1. Fill in all required details below, before time is up.

2. Ensure that all materials (answer sheets, graphing paper, practical question paper) you intend to submit for grading have been attached. Amendments to any answer script after it has been collected will not be entertained.

3. Details on each side of answer sheet:
   - Your participant code.
   - Question number.
   - Page number – continuous from 1 to *N* throughout your answer script.
   - **DO NOT WRITE YOUR NAME ON YOUR ANSWER SCRIPT.**

4. Order of answer script:
   - Stack 1:
     i. This cover page.
     ii. Summary Answer Sheet
     iii. Answer sheets from Part 1 to 3, in continuous order from page 1 to *M*.
   - Stack 2:
     i. Answer sheets for Part 4, in continuous order from *M* to *N*.
     ii. Graph(s) from Part 4.
   - Stack 3:
     i. Practical cover page.
     ii. Practical Component from Part 5.

Question	Marks	Question	Marks
1.1		4	
1.2		**Total**	
1.3		5.1	
1.4		5.2	
1.5		5.3	
1.6		5.4	
Total		5.5	
2.1		5.6	
2.2		**Total**	
2.3		6.1	
2.4		6.2	
2.5		6.3	
2.6		**Total**	
2.7			
Total		Theory	
3		DA	
Total		Practical	
	GRAND TOTAL		

Participant Code	
Total Number of Pages of SAO Answer Sheets	

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Marker's Initials	**Signature**

Singapore Astronomy Olympiad 2021

Summary Answer Sheet

Section A:

Question	Response
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	

Section B:

Question	Response
2.1	
2.2	
2.3	
2.4	
2.5	
2.6	
2.7	

Section C:

Question	Response	
3a	θ_m:	$\theta_\odot$:
	Annular / Total	
3b	$R_{umbra} =$	
3c	$\omega_m =$	$\omega_\odot$:
3d	$T_{Totality} =$	
3e	$T_{E-Year} =$	
3f		

Section D:

Question	Response
4a	$\pm$ nm
4b	$\mu =$
4c	$d =$ pc
4d	$\frac{R_P}{R_S} =$
4e	*Write your responses for these 3 parts on the answer sheets provided.*
4f	
4g	
4h	$M_S =$ $M_\odot$
4i	$R_P =$ R_{Earth}
	$R_S =$ $R_\odot$

Participant Code:	

1 Section A [12]

Write all your responses in the summary answer sheet provided.

1.1 True or False [2]

Which of the following statements are **true**?

i. Pluto is not considered a planet as it has not cleared the neighbourhood around its orbit.

ii. Orion is considered as a Winter Constellation.

iii. Due to the Moon being tidally locked to Earth, there are parts of the Moon there are never see Sunlight. This portion is known as the Dark Side of the Moon.

iv. Like a terrestrial observer, an observer on the Moon will see Earth go through phases as the Moon orbits around the Earth.

(A) (i) and (ii)

(B) (iii) and (iv)

(C) (i), (ii) and (iii)

(D) (i), (ii) and (iv)

1.2 Retrograde [2]

The size of Saturn's retrograde loops are smaller than Jupiter's because:

(A) Saturn moves slower in orbit.

(B) Saturn has more pronounced ring systems.

(C) Saturn is further from Earth than Jupiter.

(D) Saturn is at opposition more frequently.

1.3 Unseen [2]

Which planet cannot be seen on the local meridian at local midnight?

(A) Venus

(B) Mars

(C) Jupiter

(D) Saturn

1.4 Invisible [2]

Why are we not able to find any evidence of black dwarves?

(A) As their name suggests, they are too dim and are hence invisible to all our telescopes.

(B) Physically, they are too small for us to see them.

(C) Not enough time has passed in the universe for any to form yet.

(D) This category is a mistake, they are actually black holes.

1.5 Shift [2]

The Hydrogen-Alpha line has a wavelength of 656.28nm as measured in the lab. If the H-alpha line of a star is measured to occur at 660.28nm. The star must be:

(A) Moving towards the source, at 1800km/s

(B) Moving away the source, at 1800km/s

(C) Moving towards the source, at 400km/s

(D) Moving away the source, at 400km/s

1.6 Genesis [2]

Which concept encompasses the idea that life started when the elements on Earth, accompanied by the varying conditions of heat and pressure of the environment lead to the formation of many essential molecules of life?

(A) Panspermia

(B) Abiogenesis

(C) Spontaneous Generation

(D) Primordial Soup

2 Section B [54]

Section B(1): Short Questions [36]

This section contains a total of 5 short-length questions worth 9 marks each.
You are to **choose 4** to do.

2.1 Liquid Mirror Telescope [9]

A relatively inexpensive way to make a parabolic mirror involves rotating a liquid around in a circle. Such a construction is called a liquid mirror telescope. In this problem, we explore the physics of the liquid mirror telescope.

Consider a liquid rotating around in a cylinder with radius r at an angular velocity ω around the cylinder's axis. For the following parts, you are to ignore effects of surface tension.

(a) Let *y(r)* represent the height of the liquid surface at a radial distance r from the axis of rotation. By considering the forces acting on a small element on the surface of the container, determine the gradient $\frac{dy}{dr}$ as a function of r. **[3]**

(b) Determine an equation for the height of the mirror surface with radial distance r from the cylinder's axis. Should you need, $\int ax^n \, dx = \frac{ax^{n+1}}{n+1} + C$ **[2]**

(c) The *Large Zenith Telescope* had (it is no longer in use) a diameter of 6.0m and a rotation period of 8.51s. Determine the focal ratio and plate scale of this telescope.
Should you not have obtained an answer to the previous parts, you may use 12.0m as the focal length of the *Large Zenith Telescope*. **[4]**
Hint: The Cartesian equation of a parabola is given by $y = 4fx^2$.

2.2 Distance Parameters [9]

The *luminosity* distance d_L is defined in terms of the relationship between the absolute magnitude M and the apparent magnitude m of an astronomical object $M = m - 5(\log(d_L - 1))$, and the *angular diameter distance* d_A is defined in terms of an object's physical size x and the angular size θ of the object as viewed from the Earth: $d_A = \frac{x}{\theta}$. The comoving distance d_C is similar to the proper distance, but factors out the expansion of the universe, giving a distance that does not change in time – it is equal to proper distance d_P at present time.

(a) Show that the luminosity distance $d_L = d_C(1 + z)$ and the angular diameter distance $d_A = \frac{d_C}{1+z}$. **[3]**

(b) The intensity, or radiance, (the radiant flux per unit solid angle per unit projected area) of a distance light source changes with redshift $I_z \propto (1 + z)^m$. Determine the exponent m. **[4]**

(c) In an Einstein-de Sitter Universe, the comoving distance is $d_C = \frac{2c}{H_0}(1 - \frac{1}{\sqrt{1+z}})$. An object is measured to have redshift $z = 1$ and spans 102 kly across. Determine its angular diameter θ as viewed from the Earth. **[2]**

2.3 Galaxies [9]

Galaxies in rich clusters have a higher tendency to merge with other galaxies, and thus tend to be poor standard candles. The *Coma* cluster contains 1000 galaxies within its half-mass radius $r_h = 1.5Mpc$.

(a) Determine the mean number density of galaxies within r_h. **[2]**

(b) Given that the typical cross-sectional area of a galaxy is $A = 10^{-3}\text{MPc}^2$ and that the velocity dispersion of the Coma cluster is $v = 880\text{km/s}$, on average how far will a galaxy in the Coma cluster travel before colliding with another galaxy? Determine the average merger rate (per year). **[4]**

(c) *NGC 4874* in the Coma cluster, has an apparent magnitude of 12.7. Considering it to be approximately circular with angular diameter 1.26', determine its average surface brightness, in $mag/arcsec^2$. **[3]**

2.4 Stellar Observation [9]

The spectral radiance of a body for a wavelength λ at temperature T is given by

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

(a) For wavelengths such that $\frac{hc}{\lambda k_B T} << 1$, obtain an approximation for this formula. **[2]**
Hint: You are given that $e^x \approx 1 + x$ for small x

(b) Rigel is a blue supergiant with a surface temperature of 12100K, and $B - V$ colour index of -0.03. Determine its peak emission wavelength. **[2]**

(c) Given that the colour filter B corresponds to the wavelength 440nm and the colour filter V corresponds to 550nm, obtain a theoretical estimate for the $B - V$ index. How does it compare with the true $B - V$ index? **[5]**

2.5 Stellar Dance [9]

Two stars, separated by a distance d, orbit each other in an extremely close circular orbit around their center of mass. Due to their proximity, one of the stars is feeding the other stars, matter from one of the stars is transferred to the other star. Due to this, the orbital period and the semi-major axis of the binary system changes with time.

(a) Given that both stars of mass M_1 and M_2 are in a binary system with a semi-major axis of a. By considering the angular momentum of the binary system, derive an expression to describe $\frac{da}{dt}$ in terms of a, $\frac{dM_1}{dt}$, M_1 and M_2. **[7]**
Should you need, $\frac{d}{dx}x^n = nx^{n-1}$

(b) Over a period of 50 years, we observe that the semi-major axis of the binary system shrunk by 0.0000154 AU from a distance of 0.08 AU. Given that M_1 and M_2 initially had masses 5.42 and 2.51 solar masses respectively.Estimate the change in the masses of the stars δM_1 and δM_2 after 50 years. **[2]**

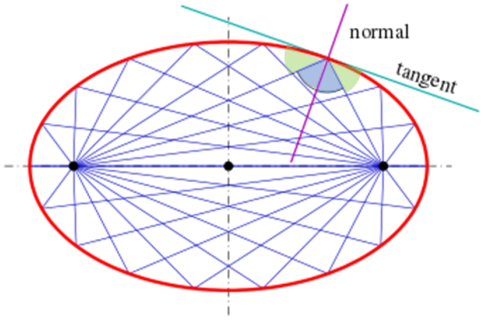
Section B(2): Medium Questions [18]

This section contains a total of 2 medium-length questions worth 18 marks each.
You are to **choose 1** to do.

2.6 Celestial Launch [18]

A rocket is launched from the North Pole such that it lands on the Equator.

(a) At what angle should the rocket be launched such that the required launch velocity is a minimum? *You may use the following ellipse property: The normal bisects the angle between the lines to the foci. Similarly, the smaller angles between the tangent and each line to the foci are equal. You are also encouraged to use any other relevant properties of an ellipse.* **[12]**



(b) What is this minimal launch velocity (in m/s)? Determine the maximum height (in meters) of the rocket as well. **[6]**

2.7 Sunset on a Plane [18]

Brendan is watching the sunset on board an airplane on Sept 23, 2021; from 11km above sea level.

We define the start of the sunset to be when the bottom of the disk of the Sun first touches the horizon and the end of the sunset to be when the top of the disk of the Sun detaches from the horizon.
The moment sunset starts, Brendan is at $\phi = 46.7655°N$ and $\theta_L = 17.2480°E$, travelling at 250m/s due directly **westwards**.

How long will Sunset last from Brendan's point of view? **[18]**

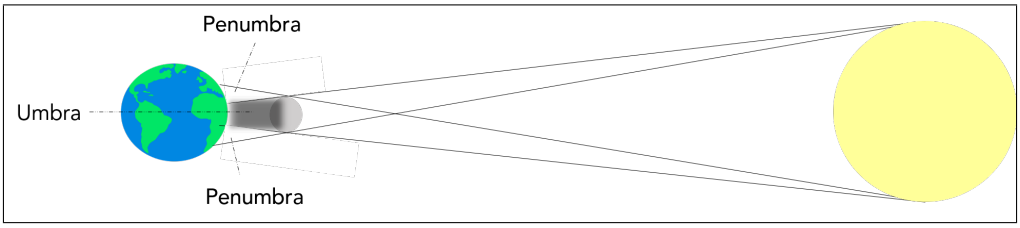
You are to account for atmospheric refraction with a value of $32'$.

3 Section C: Long Question [39]

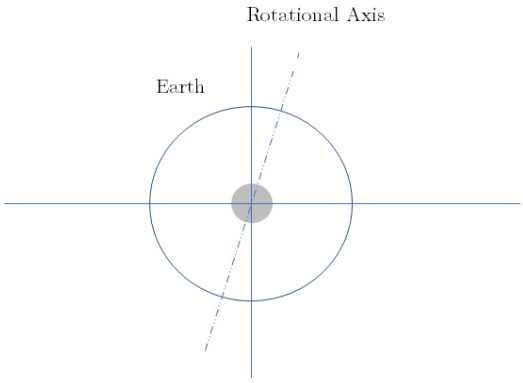
Write all responses on the answer sheets provided. The marks are stated in the brackets [] at the end of each sub-part.

Eclipses

On 26 December 2019, we observed an *annular eclipse* in Singapore. In this question, we concern ourselves with the dynamics of a solar eclipse occurring on the **vernal equinox**. The Earth-Sun distance on this day is $1.4897 \times 10^{11} m$ and the Earth-Moon distance is $3.5792 \times 10^{8} m$.



View along Earth-Sun line



3.1 Part 1: Eclipse Geometry [10]

(a) Determine the angular diameter of the moon and sun on the day of the eclipse. What type of solar eclipse is it? **[4]**

(b) Calculate the radius of the umbra to 3 significant figures, considering a geometry like above. State any assumptions made. **[6]**

3.2 Part 2: Eclipse Dynamics [15]

(c) Determine the angular velocity of the moon and Sun during the eclipse, as viewed from the Earth. **[6]**

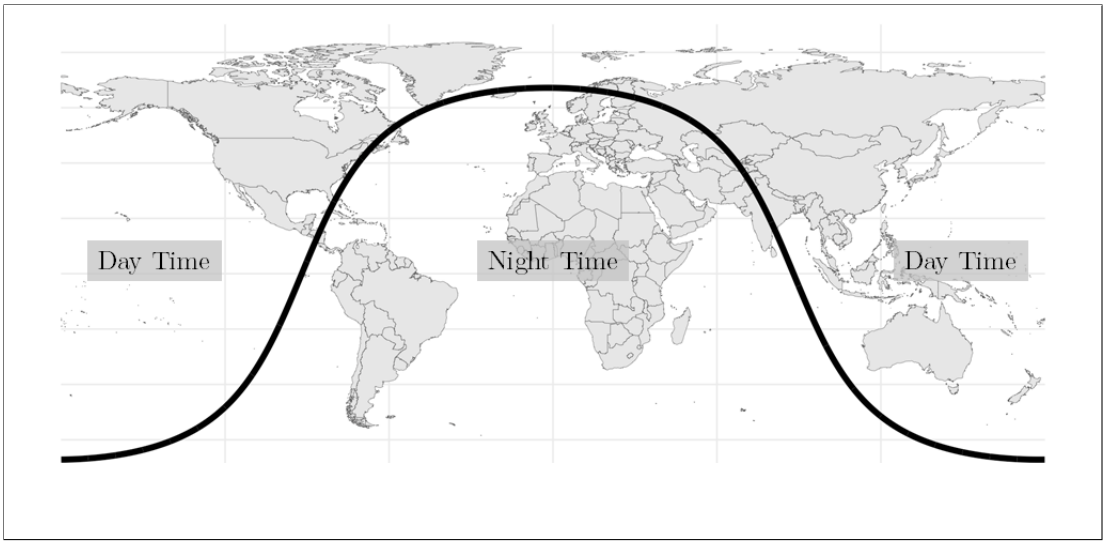
(d) Calculate the longest duration of totality for an observer on the equator, given an eclipse geometry (at peak eclipse) as shown above. *For simplicity, suppose that the moon moves along the ecliptic plane.* **[9]**

3.3 Part 3: Eclipse Year [4]

(e) The eclipse year describes the approximate periodicity of conditions giving rise to an eclipse, taking into account the precession of the lunar nodes and the orbit of the moon. The draconic month (27.2122 days) is the period of time between two consecutive passages of the moon through the same orbital node, and the synodic month is 29.5306 days. Evaluate the length of the eclipse year, to 4 significant digits. *You may neglect the eccentricity of the moon's orbit.* **[4]**

3.4 Part 4: The Terminator [10]

(f) On a Cartesian grid, with the Equator set as the x-axis and the Prime Meridian set as the y-axis, find the equation of the terminator line [1] on 21 December 2021, when it is local noon in Singapore. Singapore has a longitude of 103.82°E. In this question, you can treat the Sun as a point source. **[10]**



Terminator Line on a Mercator Projection

[1] The terminator is a line that divides the daylit side and the dark night side of a planetary body.

4 Section D: Data Analysis [45]

In this question, you will be taking on the role as an astronomer looking for extra-terrestrial lifeform.

4.1 Part 1: Eureka! [12]

In the distant future, scientists notice a burst of radio waves lasting for roughly 9 minutes. Given the long nature of the message, astronomers were able to pinpoint its origin.

Astronomers managed to find the most likely star candidate within a globular cluster, **SAO-2021**, from which the signal orginated. The stellar detail is given below.

Spectral Type	G6 V
App Magnitude	18.61
Peak Emission Wavelength	$(520 \pm 10)nm$

(a) Given the data, find out the surface temperature of the star, SAO-2021. Do also find the corresponding error in your value. **[4]**

On a separate piece of paper, you are given an HR diagram. The line represents the Main Sequence (MS) line, as plotted according to the corresponding *absolute magnitude* stars on the MS line is supposed to have.

The stars in the cluster are also plotted as points according to their *apparent magnitude*, with SAO-2021 marked with a $\times$. Specifically, there are two types of stars that have been plotted in the diagram, Main Sequence and Giant Stars.

The "distance factor", μ, is measured as the difference in magnitude between the MS line and the MS stars of the cluster that have the same temperature, $\mu = m_{stars} - m_{line}$.

(b) Measure the average distance factor of the cluster. **[5]**

(c) Hence, calculate the distance to this cluster. **[3]**

4.2 Part 2: Digging Deeper [11]

Our extra-terrestrial friends have sent us a message giving us extra data about their home world, **SAO-2021c**, but it is incomplete. Local astronomers have managed to get the light curves and isolated it for SAO-2021c.

On a separate piece of paper, Figure 2 shows the transit curve by SAO-2021c.

(d) Using the light curve, estimate the value of $\frac{R_P}{R_S}$, the ratio of the radius of SAO-2021c to the radius of SAO-2021. **[3]**

The light curve in Figure 2 has been labelled with the different events taking place during one transit, from events (A) to event (D).

(e) Explain the causes of events (A) **and** (C). **[3]**

(f) During event (B), the brightness is not constant, but rather dips slightly before rising slightly back to levels at the start. Give a plausible explanation for this. **[3]**

Please proceed on to the next page for the remaining portion of the Data Analysis question.

The overall stellar metallicity is usually conveniently defined as the ratio of the total iron content of the star to its hydrogen content. We define the ratio of Iron to Hydrogen as such, making a convenient comparison to the Sun's:

$$[FE/H] = \log_{10}\left(\frac{N_{FE}}{N_H}\right)_{star} - \log_{10}\left(\frac{N_{FE}}{N_H}\right)_{\odot}$$

Where N_{FE} and N_H are the number of iron and hydrogen atoms per unit volume respectively.

(g) Researchers have noted that the $[FE/H]$ value of SAO-2021 is $+\mathbf{0.08}$. Using this additional data, draw some conclusions about when SAO-2021 formed, relative to the Sun. **[2]**

4.3 Part 3: Earth-like? [22]

Now it is time to combine all our data together and try to reason out as to what kind of planetary system SAO-2021 hosts as compared to ours. Below is a table listing 15 different stars with their masses and luminosity.

Star	**Spectral Type**	**Mass**/$M_\odot$	**Luminosity**/$L_\odot$
Sirius	A1 V	2.06	25.4
Altair	A7 V	1.76	10.6
Alberio B	B8 V	3.70	2500
Achernar	B6 V	6.70	3150
11 Com	K0 III	1.66	110
δ Cyg	A0 IV	2.93	155
Girtab	B1.5 III	17.0	6910
Spica	B1 V	11.4	20500
Procyon	F5 IV	1.50	6.93
75 Cet	K1 III	1.85	56.1
Alkaid	B3 V	6.10	594
Alphecca	A0 V	2.58	74
ω Ser	G8 III	1.20	69
σ Oct	F0 III	1.59	38
Segin	B3 V	9.20	2500

(h) Hence, by taking into consideration the data given in the table and plotting a suitable graph, calculate M_S the mass of SAO-2021. You do not need to find the error for M_S. **[19]**

Hint: There is a rather peculiar relation between the mass and the luminosity of Main Sequence stars with $0.1M_\odot < M < 50M_\odot$, where:

$$L \propto M^\alpha$$

Where $1 \leq \alpha < 6$.

(i) Find the values of R_P and R_S. **[3]**

INSTRUCTIONS TO PARTICIPANTS:

1. Fill in all required details below, before time is up.

2. You are to detach this page and all subsequent pages as part of your response.

3. All detached pages are to be re-stapled and be part of your 3rd stack of your answer script.

4. All responses to this section of the paper are to be written on the question paper itself, in the spaces provided.

5. There will be a star chart provided as part of the question. Responses to the corresponding questions in that section are to be answered on the star chart itself.

6. All final responses shall be written legibly and unambiguously.

7. Details on each page:
   - Your participant code.
   - **DO NOT WRITE YOUR NAME ON YOUR ANSWER SCRIPT.**

Participant Code	

P(A) Multiple Choice Questions [20]

Attempt **ALL** questions in this section. Indicate the selected options clearly on the bottom of the page.

1. The Winter Hexagon is a large asterism consisting of 6 stars spanning 6 different constellations. The hexagon is large enough to encircle half of another constellation within it. Which constellation has been encircled in the hexagon? **[2]**

   A. Gemini
   B. Cancer
   C. Monoceros
   D. Hydra

2. Which of the following is **not** an asterism? **[2]**

   A. Little Dipper
   B. Big Dipper
   C. Spring Triangle
   D. The Sickle

3. How many of the 88 IAU Constellations have its IAU abbreviation the same as its name? **[2]**

   A. 1
   B. 2
   C. 3
   D. 4

4. You want to start a tradition of stargazing during the nights of one of the holidays. Which festive occasion do you pick to avoid a full moon? **[2]**

   A. Mid-Autumn Festival
   B. Vesak Day
   C. Christmas
   D. Hari Raya Aidilfitri (Eid al-Fitr)

5. Based on observations, the Sun is now in the constellation of Taurus. 2 months ago, on March 29, which constellation would the Sun be in? **[2]**

   A. Pisces
   B. Aries
   C. Taurus
   D. Aquarius

6. Jun Rui has pointed his refractor towards the Moon. However, he notices that at the rim of the Moon there is some splitting of colour resulting in a mini rainbow effect. What can he do to alleviate this problem? **[2]**

   A. Add a wide-field Barlow lens.
   B. Check the alignment of the secondary mirror.
   C. Use an apochromat lens with a low-dispersion glass.
   D. Use a Coma corrector.

7. How many of the following statements are **TRUE**? **[2]**

I Stars with the same RA rises/set at the same time.

II Observers with latitude that is north of 23.5°N will never see the Sun at the Zenith.

III The ecliptic intersects the celestial equator at the cardinal East and West points on the horizon.

IV There are places on Earth which only experience one high tide and one low tide in a day instead of the usual 2 high and 2 low tides.

A. 1
B. 2
C. 3
D. 4

8. Read the following excerpt to identify the constellation it has made reference to. **[2]**

"This constellation represented the hair of an Egyptian Queen, who vowed to sacrifice her beautiful hair should her husband returned safely from the 3rd Syrian War. Till today, this modern constellation remains as the only one named after an actual historical person."

A. Cassiopeia
B. Coma Berenices
C. Carina
D. Andromeda

1.	2.	3.	4.

5.	6.	7.	8.

9. Put a tick in the box beside the statements which are **TRUE** [**2**]

You can see Ursa Minor from Antarctica.	
To deem if an object can be more easily spotted as compared to another, one should only compare the objects' apparent magnitude and declination.	
To improve the Signal-to-Noise Ratio (SNR) of any photo, you should choose increasing the number of shots taken over increasing the exposure time, assuming the total exposure time is kept constant.	
For the best tracking of celestial objects, one should perform a Drift Alignment over visual alignment to Polaris.	

10. Sid wants to set up his German Equatorial Mount. After going through NS, he has forgotten the correct steps. He lists down the steps he needs to take but has forgotten the order. Write the correct order, numbering each step from (1) to (8) in the boxes beside the steps. [**2**]

Fix on the counterweight bar and counterweights.	
Set up the tripod, remembering to level it.	
Fix the mount onto the tripod. Aligning the tripod and the mount to the North Celestial Pole.	
Find a place with flat ground and with no blockages overhead.	
Fix on the main body of the telescope.	
Balance the RA axis.	
Balance the Dec axis.	
Attach the required accessories like the eyepieces and finder scope.	

P(B) Star Charts [8]

Answer **ALL** questions in this section.

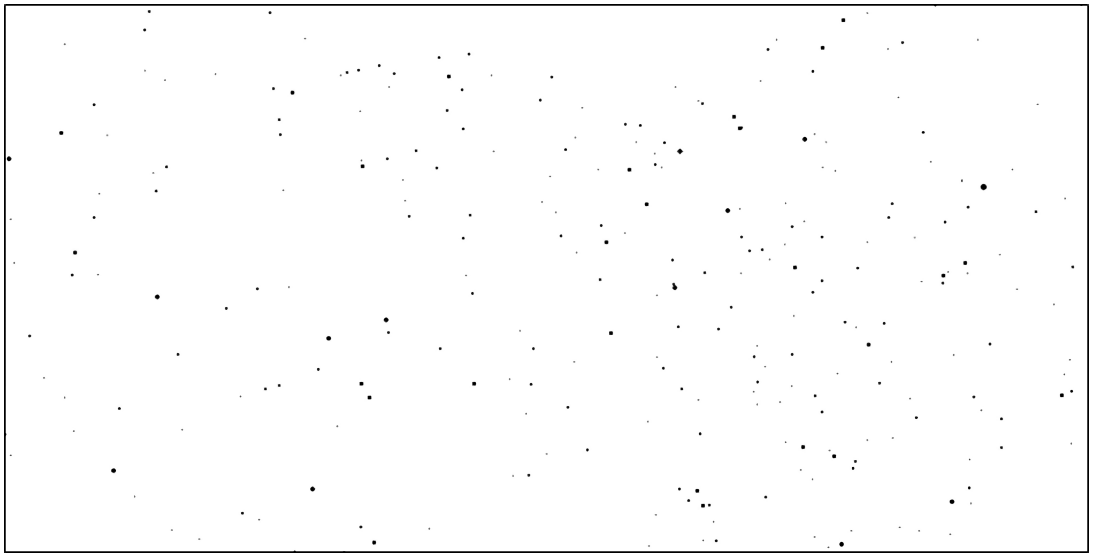
In the following two images,

a Trace **ONE** fully visible constellation (bright stars visible and most of its constellation boundaries within the frame) and name it. **[1]**

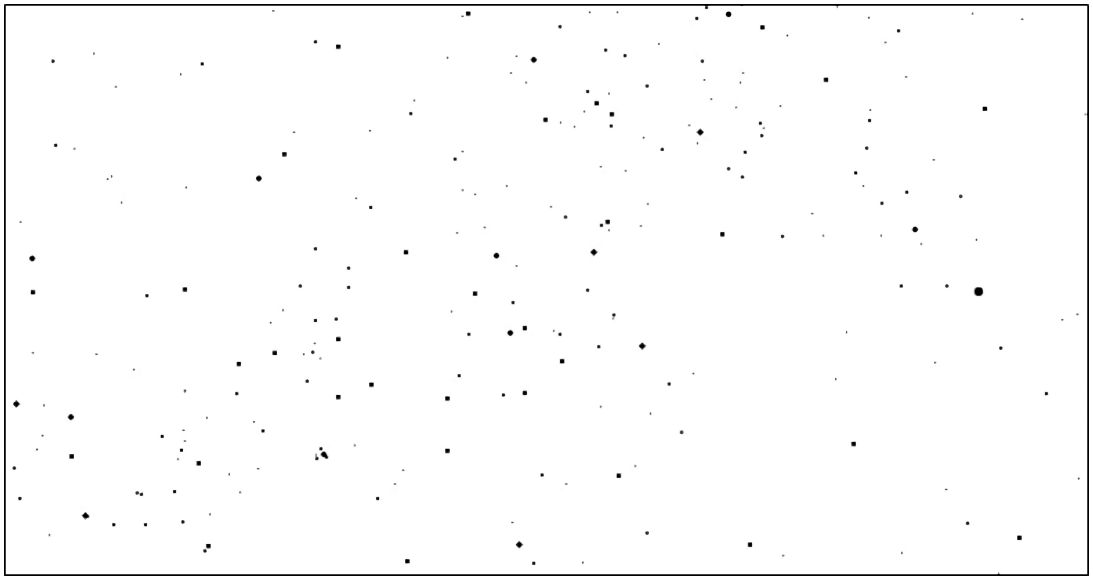
b Cross out **TWO** stars with an 'X' and state their common names or Bayer designations. **[1]**

c Cirle and identify **TWO** bright Deep Sky Object. **[2]**

1. Image 1: **[4]**



2. Image 2: **[4]**



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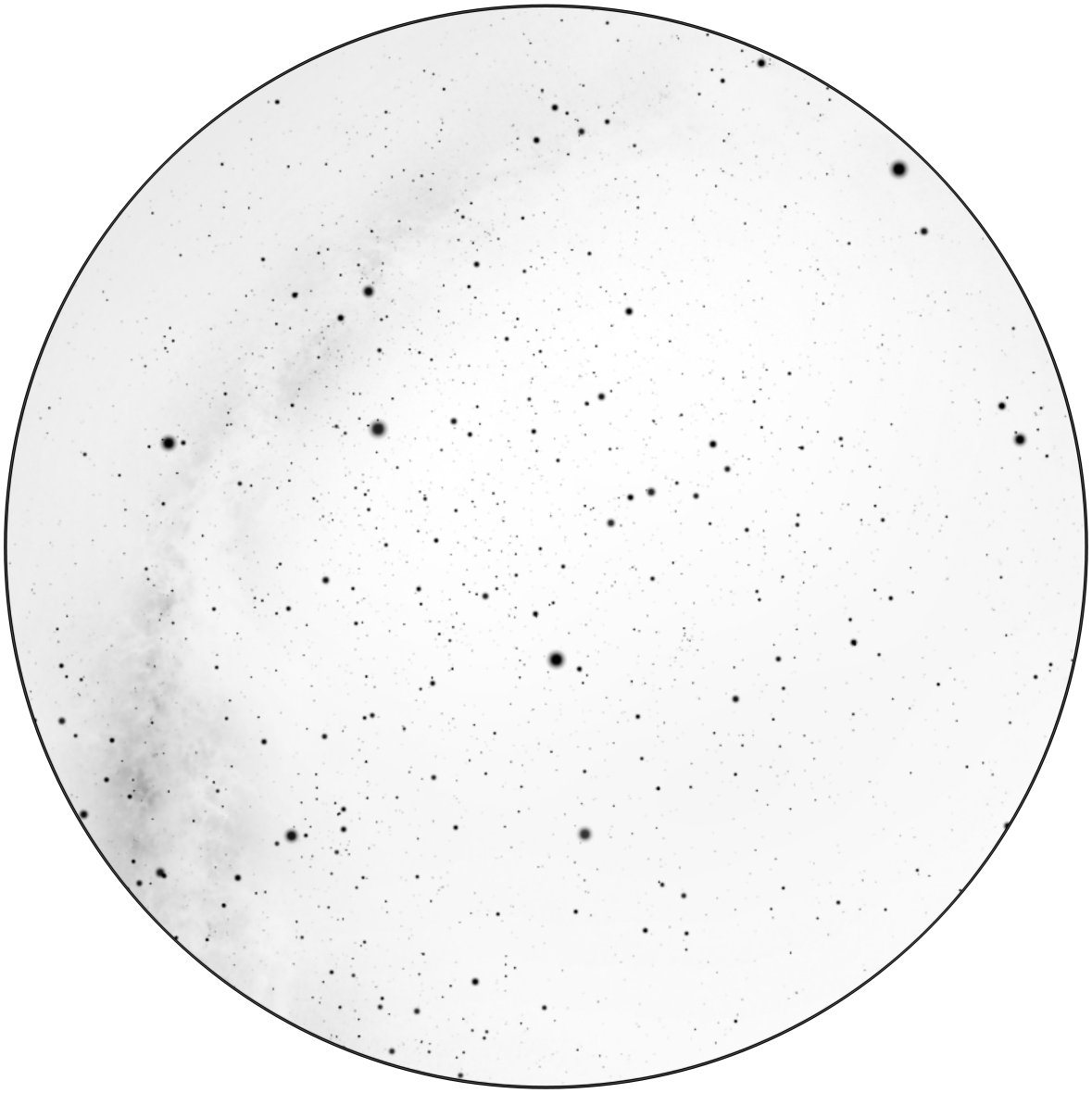
P(C) All Sky [22]

Answer **ALL** questions in this section.

You're suddenly teleported to the antipode of Point Nemo (41.123° N, 56.607° E). Even though you're at the opposite end of the "loneliest place on Earth", you're still stuck in the middle of a desolate desert in Kazakhstan-Uzbekistan border, and you've resigned to your fate. To kill time, you've decided to do some night sky observation.



Luckily for you, you have 2 watches! But you remember that's because one of them is faulty... You read the watches and they read as follows:

Watch 1: **20th March 2021 07:20 a.m. (GMT+8)**

Watch 2: **9h 28m 25.68s**

Where both watches read the local time and local sidereal time respectively.

Thankfully, your obsession with the constellation Boötes resulted in you being able to precisely remember the equatorial coordinates of Arcturus (14h 15m 38.22s, +19° 10' 10.0").

1. For starters, let's get your bearings straight. Mark on the star chart the cardinal directions (North, South, East and West) right outside the boundaries of the star chart with 'N' and 'S' respectively. The size of the letters should be similar to this font size. **[1]**

2. Trace and label **BOTH** the ecliptic and meridian. **[2]**

3. You remember a village elder from a nearby village said that today is the Vernal Equinox. Knowing this,
   (a) Mark with an 'X' on the boundary of the star chart where the Sun would rise. **[1]**
   (b) You suddenly remember that watch 2 is the faulty watch. Provide an estimate to what a correct reading should be. **[2]**

4. Now, for observation,
   (a) Is the Summer Triangle visible? What are its 3 constituent stars? Clearly mark it on the star chart by connecting the 3 stars and label it. **[2]**
   (b) Is the Keystone in Hercules visible? Clearly mark it on the star chart by connecting the stars that comprise this asterism and label it. **[1]**
   (c) Clearly mark and label **ANY 2** of the following constellations (They must be fully visible): **[4]**

      1. Aquila
      2. Scorpius
      3. Sagittarius
      4. Ophiuchus
      5. Perseus
      6. Lupus
      7. Cepheus
      8. Orion

      Note: As long as all of the lines fall within the constellation boundaries, the answer will be accepted

   (d) Circle clearly and label **ANY 3** of the following Deep Sky Objects (They must be visible): **[6]**

      1. M4 Crab Globular Cluster
      2. M16 Eagle Nebula
      3. M41
      4. M29 Cooling Tower
      5. C94 Jewel Box
      6. M44 Praesepe
      7. C80 Omega Centauri Cluster
      8. M45 Pleiades
      9. C102 Southern Pleiades
      10. Small Magellanic Cloud

   (e) A prominent star has been omitted from the star chart this whole time.
      i. Circle the approximate location of the star and identify the star. **[2]**
      ii. Name **ONE** Deep Sky Object that lies within the constellation boundaries this star is in. **[1]**

End of Paper

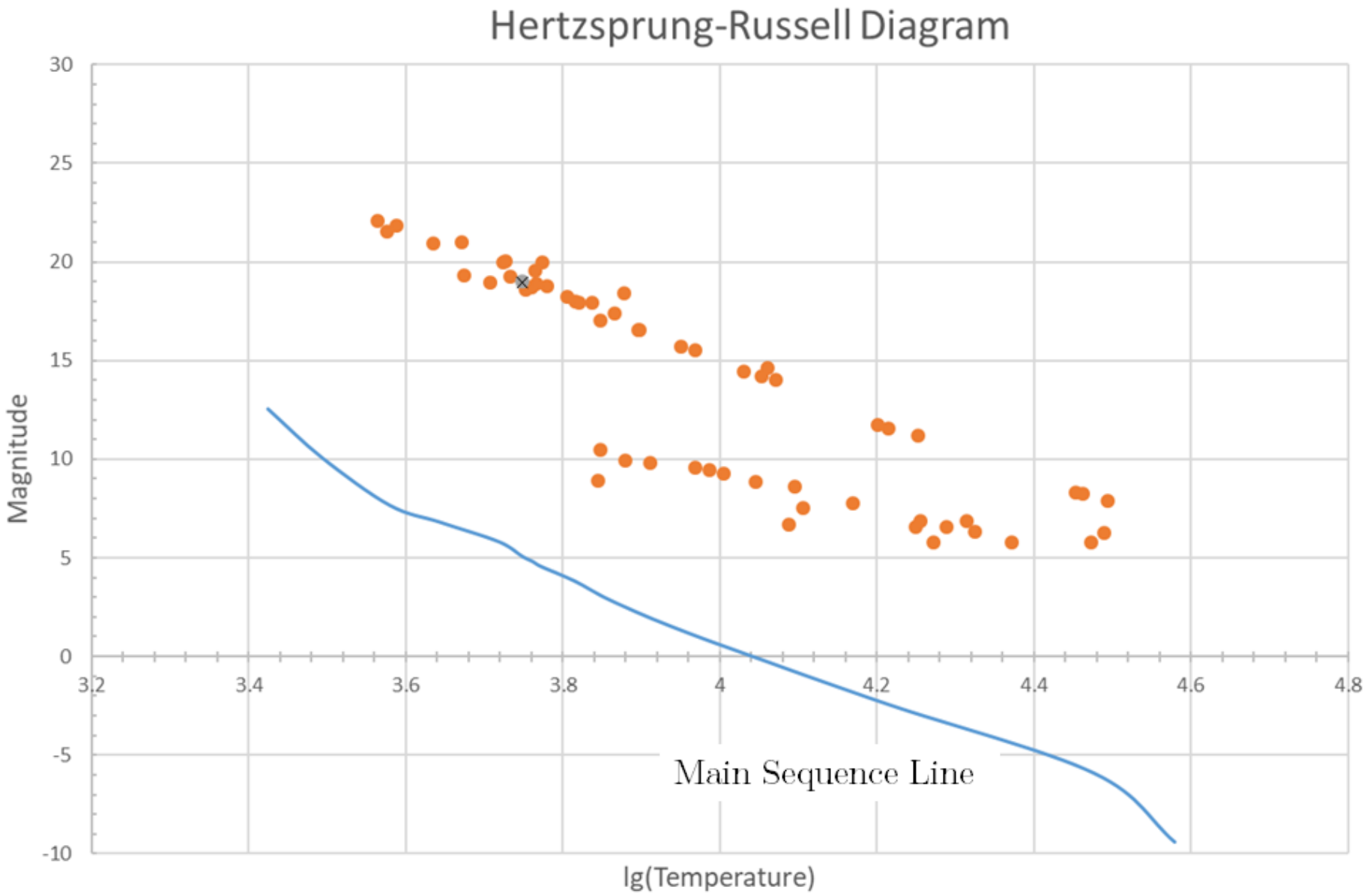


Figure 1: HR Diagram for SAO-2021 Cluster

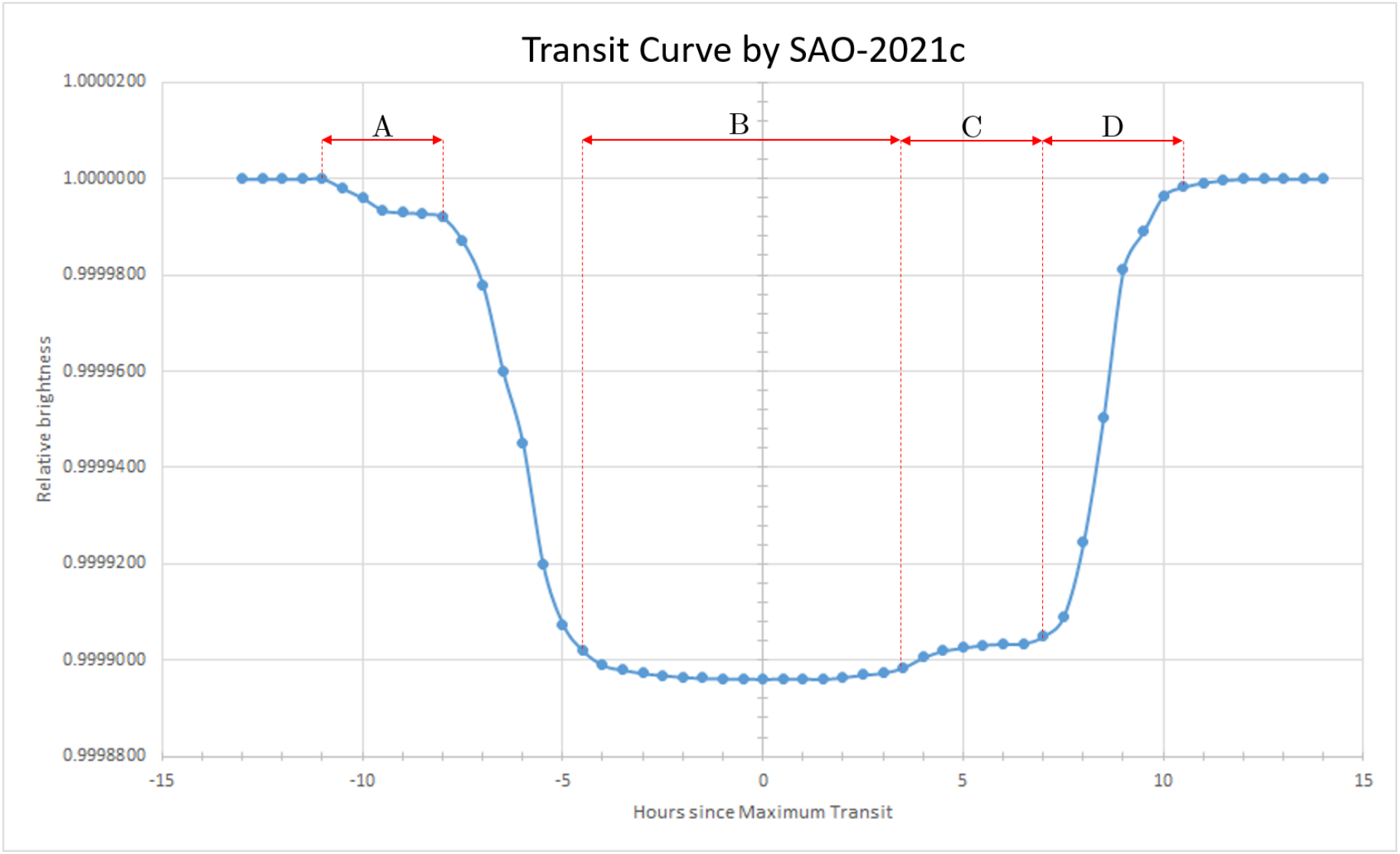


Figure 2: Transit Curve by SAO-2021c