

Observation Examination Planetarium Round Instructions

- At the entrance of the Planetarium Dome the following items were handed over to you:
 1. An envelope marked **[B]**.
 2. A pouch containing a stopwatch, a head torch and a green pen.
 3. A writing board
- Please verify the Contestant Code printed on envelope marked **[B]**.
- The Question Paper, two Sky Maps, and Summary Answersheets are kept inside the smaller envelope **[S]**. **You are allowed to open this envelope ([S]) only when the whistle is blown to mark the start of the examination.** The exam time (1 hour) starts from this point.
- There are two questions in this exam: OP01 and OP02. You will have **15 minutes** to read the question paper, and make any preliminary plans for your observation. During this time, lights in the planetarium dome will be on.
- Time for question OP01 is **15 minutes**:
 - Dark adaptation and familiarisation with the sky: 3 minutes
 - Main task: 12 minutes
- Time for question OP02 is **10 minutes**.
- A whistle will be blown at the start and at the end of each question.
- There will be a break of **2 minutes** between the questions.
- The time remaining for each question will be displayed on the dome at one minute intervals. Please pay attention.
- At the end of the projection, lights will be turned on again, and you will have **18 minutes** to finalise your answers.
- If you use a pencil to mark or trace something, please overwrite by the green pen (supplied in your pouch) before submission to improve clarity.
- At any time during the examination, you may stand up at your place and/or turn around. However, you are not allowed to move out of your place.
- You must maintain strict silence throughout the examination.
- The flow of the examination is as follows:

Lights ON	15 min	Question reading and observation planning
Lights OFF:	27 mins 20 sec	Projection on dome
Time (min:sec)	Duration	Projection
00:00 – 00:10	10 sec	Question OP01 text message on dome
00:10 – 15:10	15 min	Projection for Question OP01
15:10 – 17:10	2 min	Break
17:10 – 17:20	10 sec	Question OP02 text message on dome
17:20 – 27:20	10 min	Projection for Question OP02
Lights ON	18 min	Calculation and finalisation

• **At the end of the examination:**

- Check that you have correctly written your Contestant Code and page numbers on all used sheets.
- Arrange your sheets in the following order:
Summary Answersheet of (OP01), sky map Map-OP01, Working Sheet(s) used for (OP01), Summary Answersheet of (OP02), sky map Map-OP02, Working Sheet(s) used for (OP02).
- Place the bunch of the above sheets inside the smaller envelope **[S]**. Both Summary Answersheets must be placed inside the envelope **[S]** irrespective of whether you have used them or not.
- **Only the contents of the smaller envelope [S] will be evaluated. Any sheet that is not placed inside this envelope will not be evaluated.**
- Place the smaller envelope **[S]** inside the bigger envelope **[B]**.
- All other sheets, namely, Instruction Sheet(s), Question Paper(s), Data Sheet(s) and unused Working Sheet(s) should be placed directly inside the bigger envelope **[B]**.
- Tie the thread seal on the envelope **[B]**.
- Place the head torch, stopwatch, and the green pen inside the pouch.
- Carry the envelope **[B]**, the writing board, and the pouch to the exit and drop them in the designated boxes.

(OP01) Hypothesized Planet in the Solar System

[25 marks]

For this question use sky map Map-OP01. This is an angle preserving projection of the sky.

The sky projected on the planetarium dome is as seen from the solar system barycentre. The Earth's orbit as seen from this position has been marked in green both on the projected sky and in sky map Map-OP01. The first 3 minutes are for dark adaptation and familiarization of the sky.

After first 3 minutes, four Trans-Neptunian Objects (TNOs) labelled O1, O2, O3 and O4 will begin to appear on the dome. The brightness of the TNOs has been enhanced to make them visible. No other solar system object is visible in the projected sky. Time has been sped up to make their movements noticeable.

We will assume that the orbital plane of a hypothesized new planet has an inclination equal to the mean of the inclinations of the orbits of these 4 TNOs.

- (OP01.1) Arrange the 4 TNOs in ascending order of the lengths of their semi-major axes and write their names in the appropriate boxes in the Summary Answersheet. Show measurements in the working sheet to justify your answer. 8
- (OP01.2) Trace at least 50% of the visible trajectories for each of the 4 TNOs on the map Map-OP01. From these traces find the inclination angles, i_1, i_2, i_3, i_4 , of the 4 TNOs, respectively, with respect to the Ecliptic. Hence obtain the best estimate of the inclination, i_{hp} , of the plane of the orbit of the hypothesized planet. 17

(OP02) Observer on a Ringed Planet

[25 marks]

For this question use sky map Map-OP02.

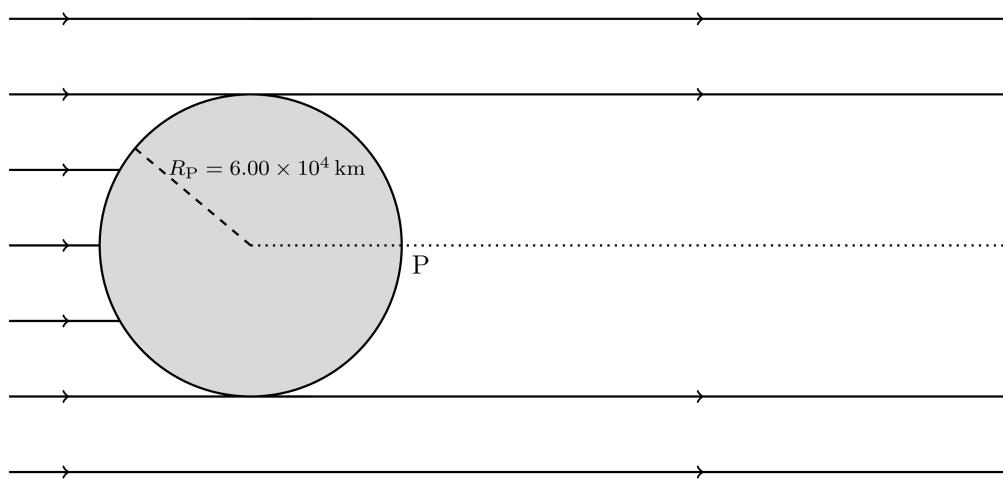
The sky projected on the planetarium dome is as seen by an observer on some hypothetical ringed planet. The observer is located very near to the equator of the planet.

Assume that the ring lies in the equatorial plane of the planet and the distance of the planet from its parent star is more than 15 au. Note that except for the 10 moons of this planet no other object from this planetary system (other planets, their satellites, asteroids and even the parent star) are visible on the projected sky.

At the start of the question the sky will make 3 full rotations at the rate of 1 rotation every minute. After that the sky will stop rotating at the observer's midnight. This sky view will remain on the dome for next 7 minutes.

Solve the following questions once the sky stops rotating.

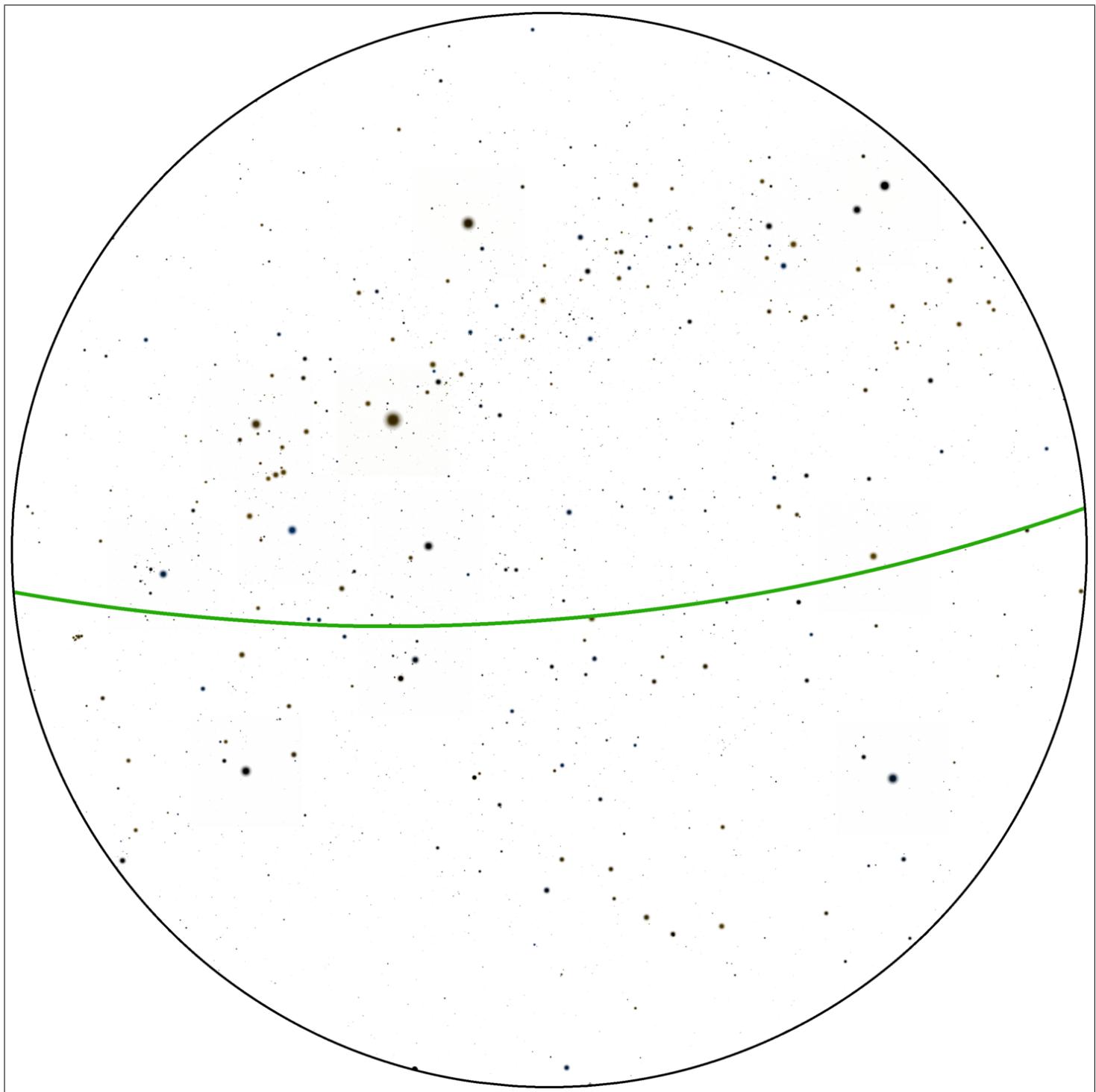
- (OP02.1) Mark the positions of any 4 (only 4) out of the 10 visible moons of the planet with a \otimes sign and label them as "M" in the sky map. 8
- (OP02.2) The figure shown below is as seen from the top of the north pole of the planet (grey circle) and the horizontal lines are parallel light rays from its parent star. 12

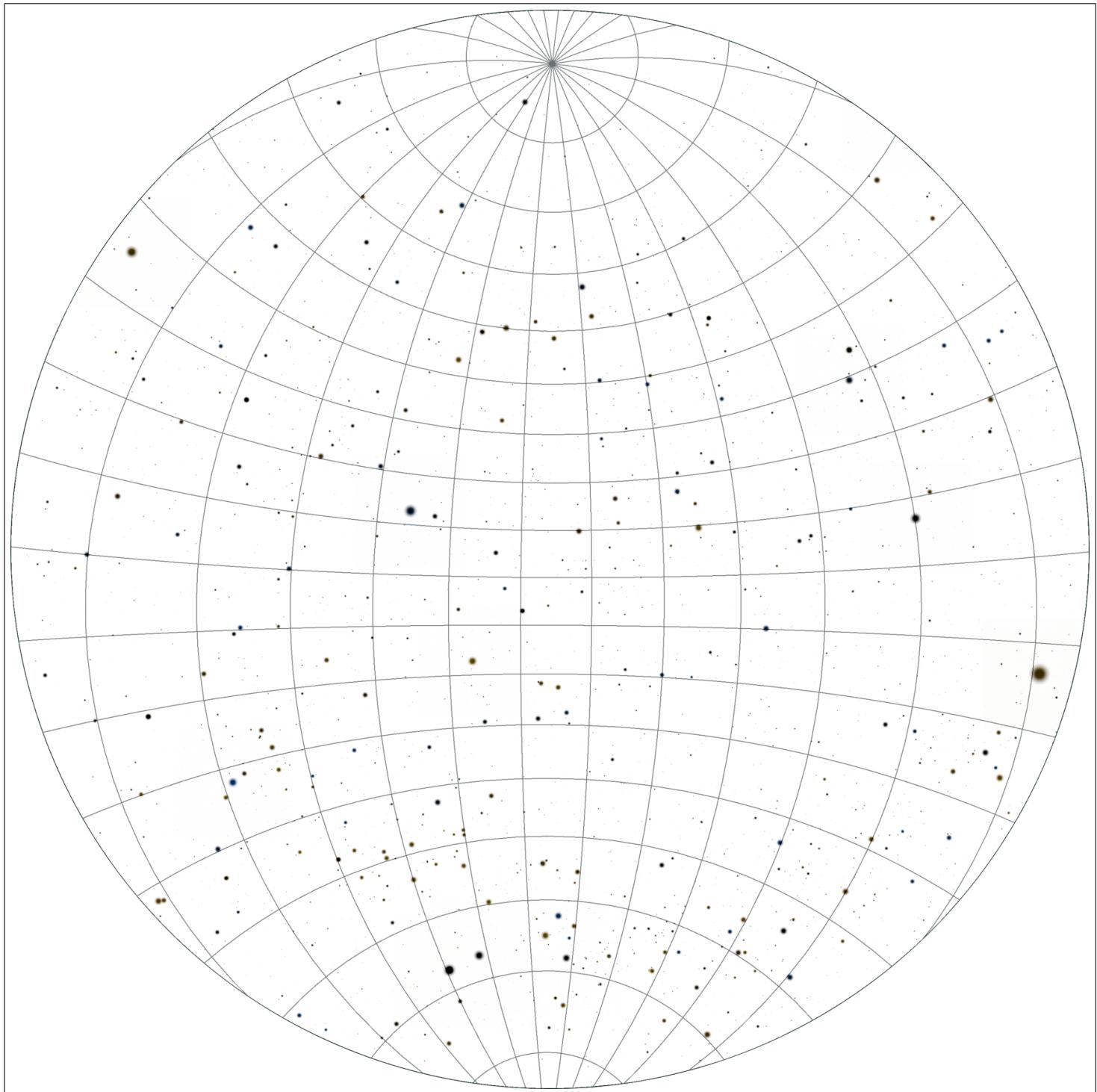


Using the view of the ring on the dome, draw the inner and outer boundaries of the ring on this diagram, reproduced in the Summary Answersheet. Your sketch must be to scale.

- (OP02.3) Use the diagram above to determine the width of the ring, w_{ring} (in km), given that the radius of the planet is $6.00 \times 10^4 \text{ km}$.

5







**Summary
Answersheet**
FRONT

Contestant Code -

Q. No. OP01 Page No. SA-1

Final answers

(OP01.1)	<input type="text"/>	<	<input type="text"/>	<	<input type="text"/>	<input type="text"/>	Marks (8.0)
----------	----------------------	---	----------------------	---	----------------------	----------------------	-------------

(OP01.2)	Use sky map Map-OP01.						Marks (17.0)
	$i_1 =$		$i_2 =$				
	$i_3 =$		$i_4 =$				
	$i_{hp} =$						

Total:

End of Summary Answersheet



Summary Answersheet

BACK

Contestant Code -

Q. No. **OP01** Page No. **SA-2**

DO NOT WRITE



Summary Answersheet

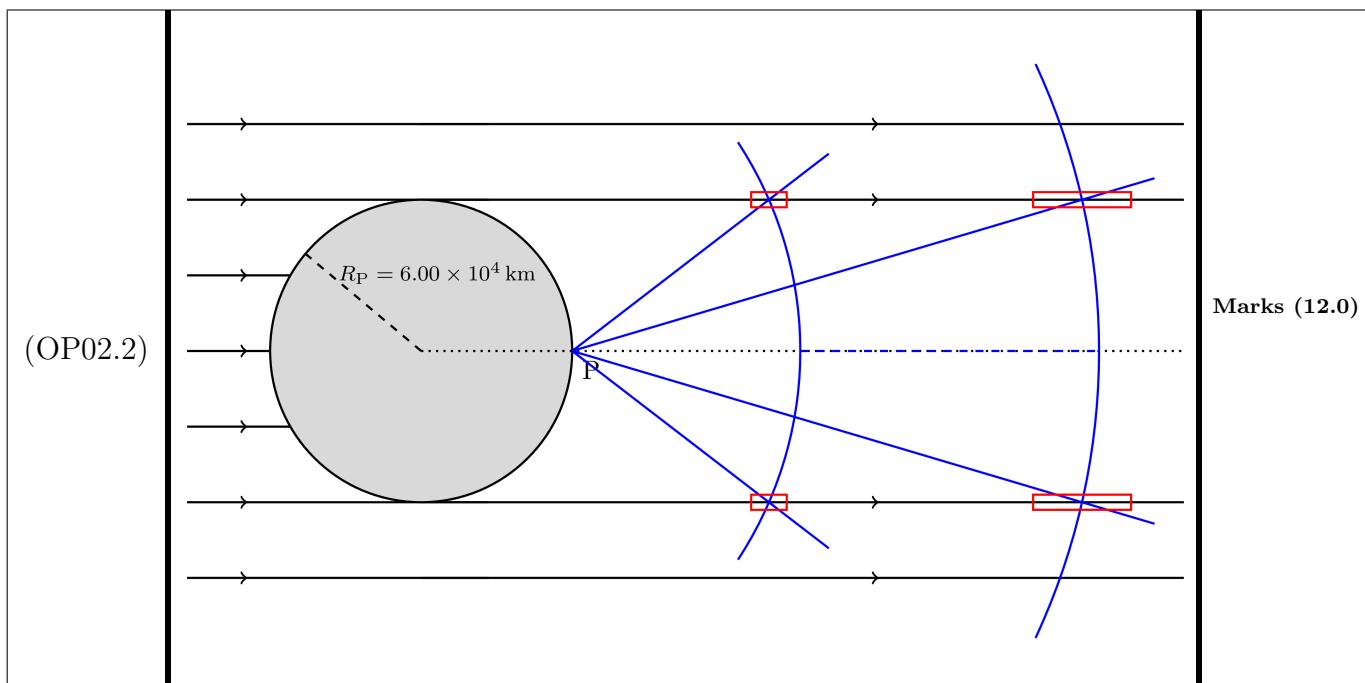
FRONT

Contestant Code _____ — _____

Q. No. OP02 **Page No.** SA-3

Final answers

(OP02.1)	Use Map-OP02.	Marks (8.0)
----------	---------------	-------------



(OP02.3)	$w_{\text{ring}} =$	km	Marks (5.0)
----------	---------------------	----	-------------

Total:

End of Summary Answersheet



Summary Answersheet

BACK

Contestant Code -

Q. No. **OP02** Page No. **SA-4**

DO NOT WRITE

(OP01) Hypothesized Planet in the Solar System
[25 marks]

For this question use sky map Map-OP01. This is an angle preserving projection of the sky.

The sky projected on the planetarium dome is as seen from the solar system barycentre. The Earth's orbit as seen from this position has been marked in green both on the projected sky and in sky map Map-OP01. The first 3 minutes are for dark adaptation and familiarization of the sky.

After first 3 minutes, four Trans-Neptunian Objects (TNOs) labelled O1, O2, O3 and O4 will begin to appear on the dome. The brightness of the TNOs has been enhanced to make them visible. No other solar system object is visible in the projected sky. Time has been sped up to make their movements noticeable.

We will assume that the orbital plane of a hypothesized new planet has an inclination equal to the mean of the inclinations of the orbits of these 4 TNOs.

- (OP01.1) Arrange the 4 TNOs in ascending order of the lengths of their semi-major axes and write their names in the appropriate boxes in the Summary Answersheet. Show measurements in the working sheet to justify your answer. **8**

Solution:

The orbits of the 4 TNOs are elliptical, which can be noticed from careful observations of their speed. Hence, to estimate lengths of their semi-major axes it is essential to measure the time period of one complete revolution of each TNO. The time periods of the planets are

O1: 40 sec, O2: 30 sec, O3: 48 sec, O4: 34 sec

Hence, the correct ascending order is: O2 < O4 < O1 < O3.

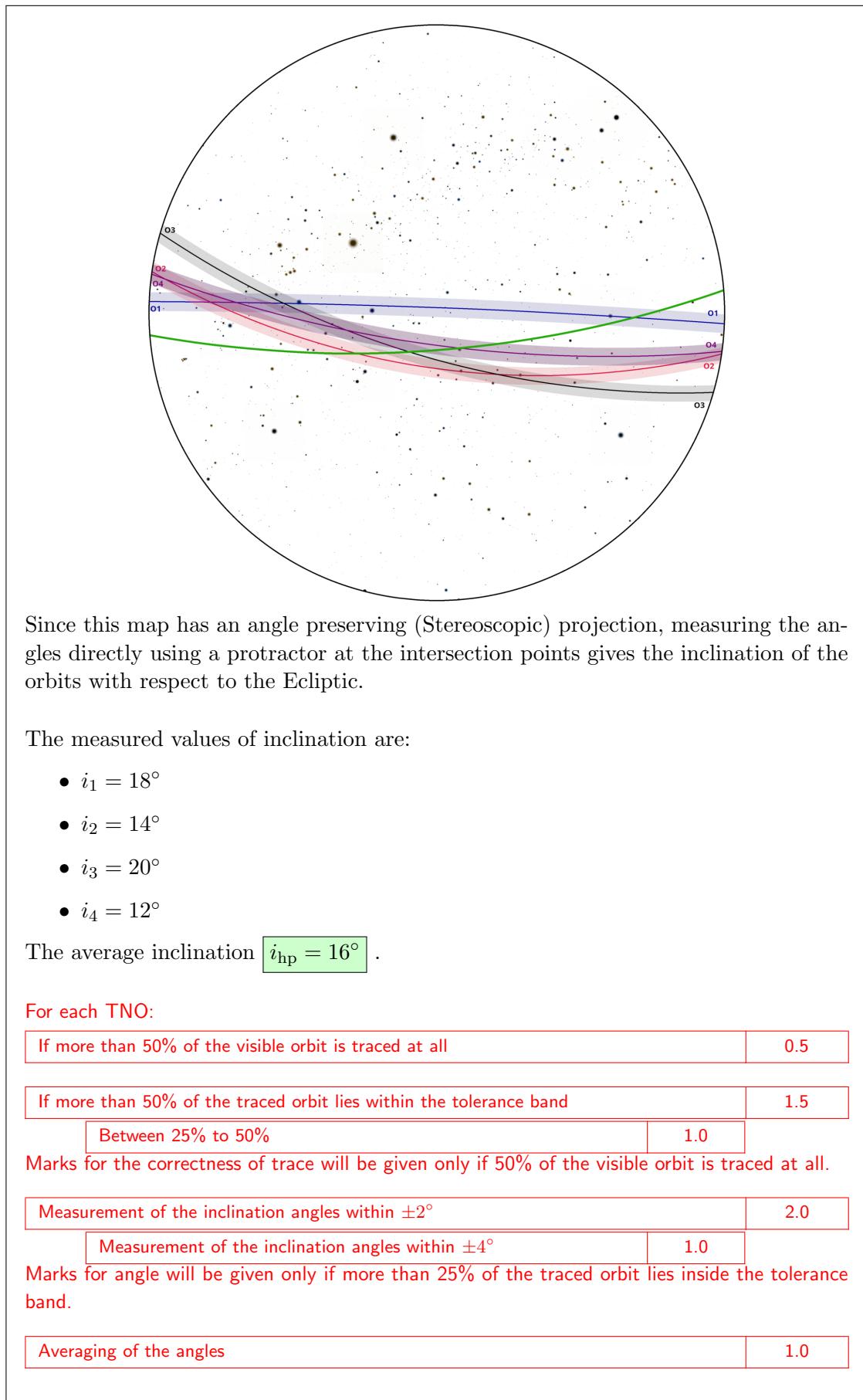
Credit of 1.0 for every pairwise correct order, and 2.0 extra for fully correct order.

O1 < O2 < O3 < O4	3.0	O2 < O1 < O3 < O4	4.0
O1 < O2 < O4 < O3	4.0	O2 < O1 < O4 < O3	5.0
O1 < O3 < O2 < O4	2.0	O2 < O3 < O1 < O4	3.0
O1 < O3 < O4 < O2	1.0	O2 < O3 < O4 < O1	4.0
O1 < O4 < O2 < O3	3.0	O2 < O4 < O1 < O3	8.0
O1 < O4 < O3 < O2	2.0	O2 < O4 < O3 < O1	5.0
O3 < O1 < O2 < O4	1.0	O4 < O1 < O2 < O3	4.0
O3 < O2 < O4 < O1	3.0	O4 < O3 < O1 < O2	2.0
O3 < O1 < O4 < O2	0.0	O4 < O1 < O3 < O2	3.0
O3 < O2 < O1 < O4	2.0	O4 < O2 < O1 < O3	5.0
O3 < O4 < O1 < O2	1.0	O4 < O2 < O3 < O1	4.0
O3 < O4 < O2 < O1	2.0	O4 < O3 < O2 < O1	3.0

- (OP01.2) Trace at least 50% of the visible trajectories for each of the 4 TNOs on the map Map-OP01. From these traces find the inclination angles, i_1, i_2, i_3, i_4 , of the 4 TNOs, respectively, with respect to the Ecliptic. Hence obtain the best estimate of the inclination, i_{hp} , of the plane of the orbit of the hypothesized planet. **17**

Solution:

The orbits of the TNOs can be drawn by marking a few important constellations and noticing the fact that some prominent or important stars lie along the TNOs' paths. Also the intersection points of each TNO trajectory with respect to the Earth's orbit (i.e. the Ecliptic) lie near prominent stars.



(OP02) Observer on a Ringed Planet

[25 marks]

For this question use sky map Map-OP02.

The sky projected on the planetarium dome is as seen by an observer on some hypothetical ringed planet. The observer is located very near to the equator of the planet.

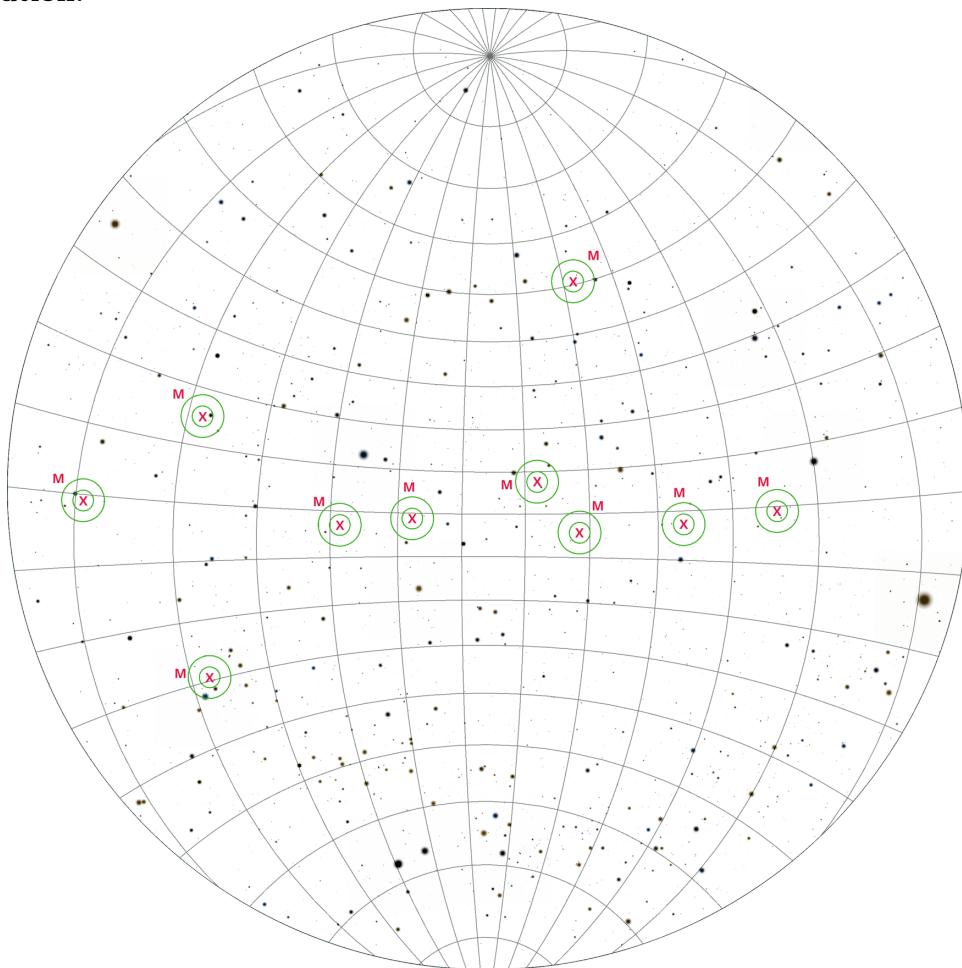
Assume that the ring lies in the equatorial plane of the planet and the distance of the planet from its parent star is more than 15 au. Note that except for the 10 moons of this planet no other object from this planetary system (other planets, their satellites, asteroids and even the parent star) are visible on the projected sky.

At the start of the question the sky will make 3 full rotations at the rate of 1 rotation every minute. After that the sky will stop rotating at the observer's midnight. This sky view will remain on the dome for next 7 minutes.

Solve the following questions once the sky stops rotating.

- (OP02.1) Mark the positions of any 4 (only 4) out of the 10 visible moons of the planet with a \otimes sign and label them as "M" in the sky map. 8

Solution:



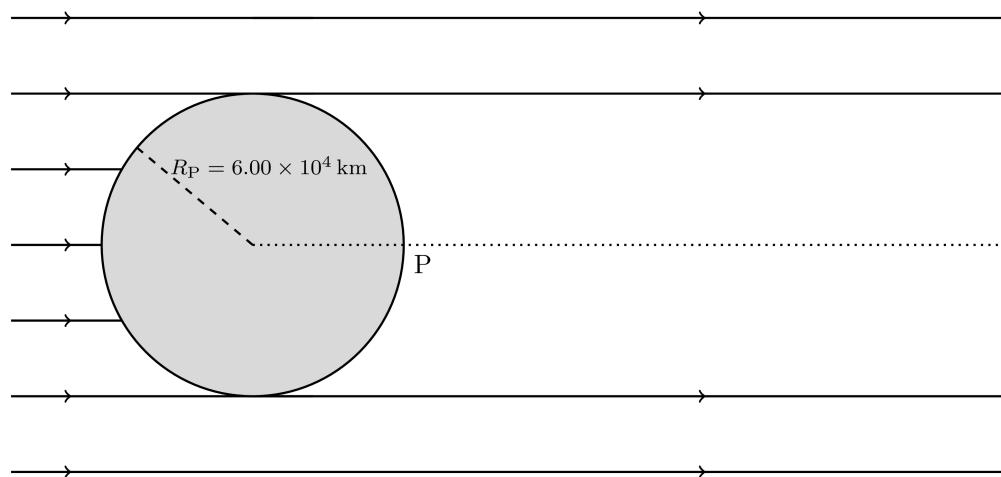
For each moon

Centre of the \otimes within the inner circle	2.0
---	-----

Centre of the \otimes between the inner and outer circles	1.0
---	-----

Use 4 correctly placed moons for marking. Every incorrectly placed moon beyond 4 gets -1.0 , upto a minimum of 0.

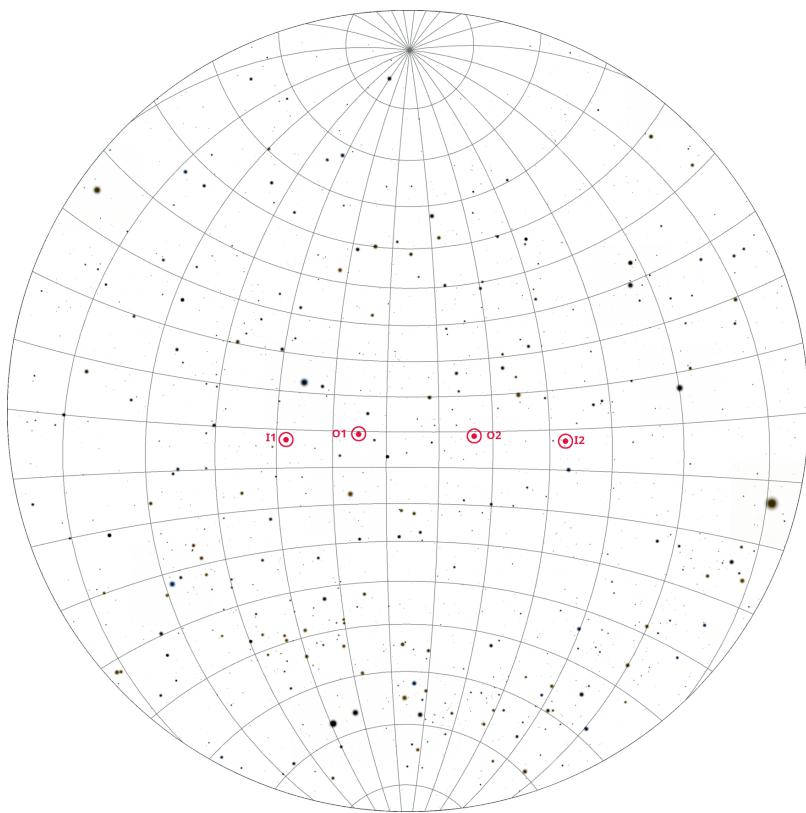
- (OP02.2) The figure shown below is as seen from the top of the north pole of the planet (grey circle) and the horizontal lines are parallel light rays from its parent star. **12**



Using the view of the ring on the dome, draw the inner and outer boundaries of the ring on this diagram, reproduced in the Summary Answersheet. Your sketch must be to scale.

Solution:

The different angular extents of the shadow on the inner and outer edges of the ring are visible on the dome. These edges may be marked on the sky map (using convenient positions of the stars nearby).



From the grid of the RA lines on the map the angular sizes are measured to be:

Inner edge: $\approx 75^\circ$

Outer edge: $\approx 33^\circ$

These angles need to be used in the schematic diagram to locate the rings.

Place a protractor with its baseline along the dotted line, and with its origin at P (the position of the observer).

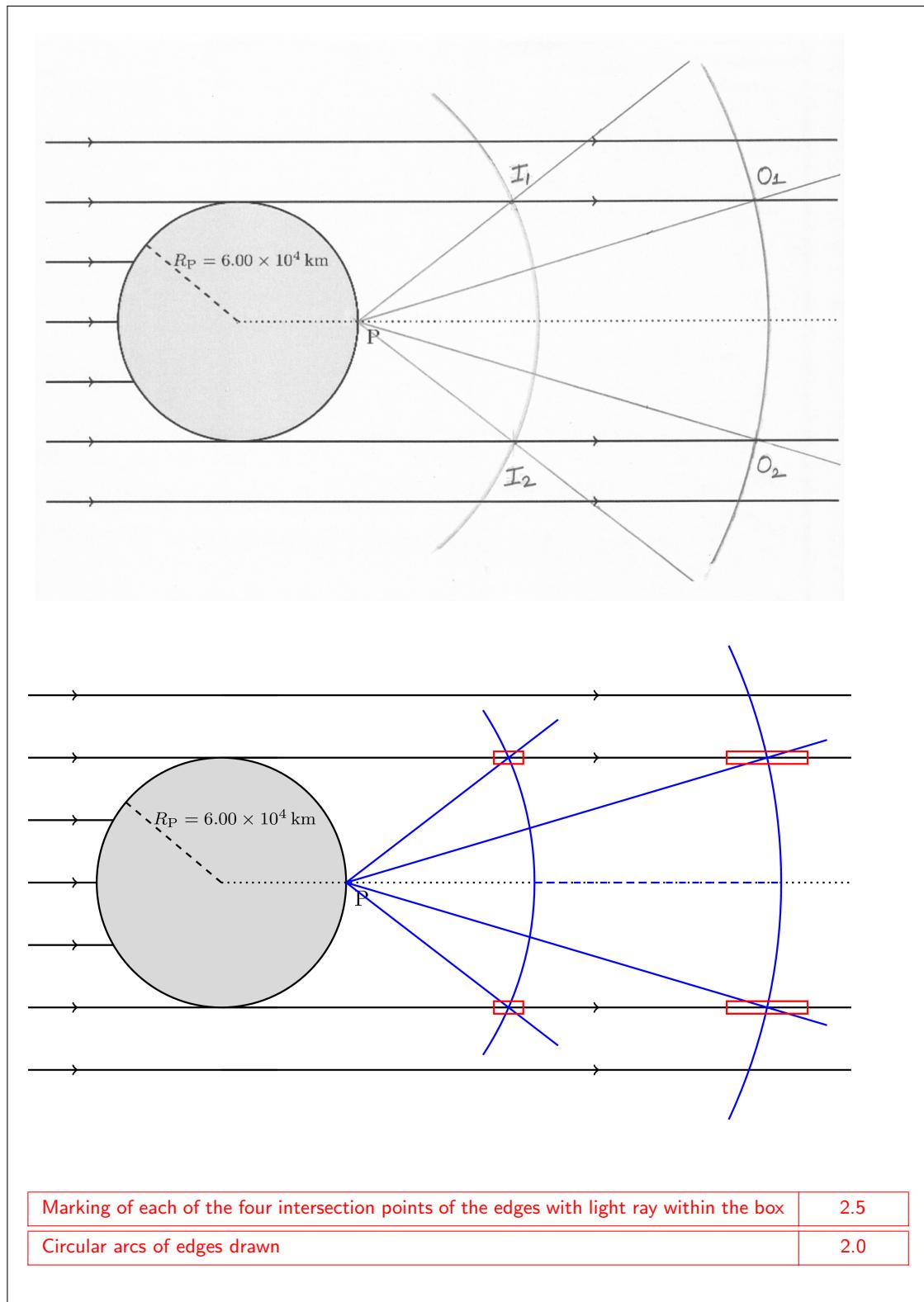
Find the line of sight to the inner edge that subtends an angle of $75^\circ/2 = 37.5^\circ$ at P. Extend this line to intersect the tangent ray.

This point marks one end of the shadow on the inner ring.

Similarly, find the other ends of the shadow on the inner edge.

Draw a circular arc (with centre at the centre of the planet) passing through these two points of intersection to show the inner edge of the ring.

Repeat for the outer edge.



- (OP02.3) Use the diagram above to determine the width of the ring, w_{ring} (in km), given that the radius of the planet is 6.00×10^4 km.

5

Solution:

Once the edges of the ring are drawn, the width can be calculated by measuring the

difference of their distances from the centre of the planet. Use a ruler to measure these distances. Also measure the radius of the planet on the diagram with the ruler to find the calibration.

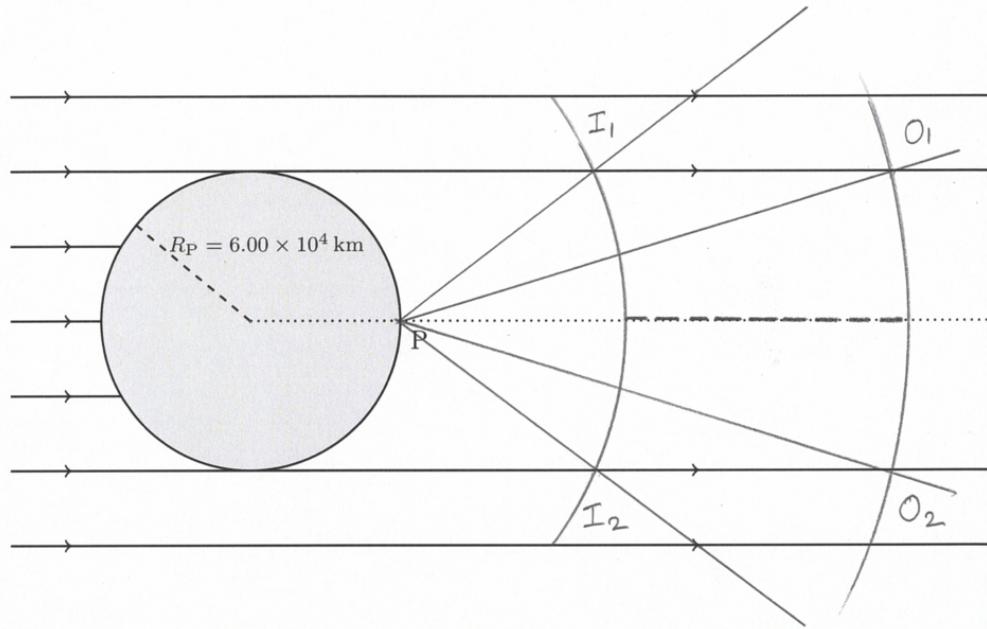
We find,

Distance between the two rings along the dotted line: 3.8 cm

Radius of the planet on the diagram: 2 cm equivalent to 6.00×10^4 km (given)

Therefore,

$$\text{Width of the ring in km: } = \frac{3.8 \text{ cm}}{2 \text{ cm}} \times 6.00 \times 10^4 \text{ km} = 11.4 \times 10^4 \text{ km}$$



Tolerance on values of radii of inner and outer edges

Half credit lower limit	Full credit range	Half credit upper limit
9.45×10^4 km	10.60×10^4 km to 13.40×10^4 km	14.55×10^4 km

