(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]

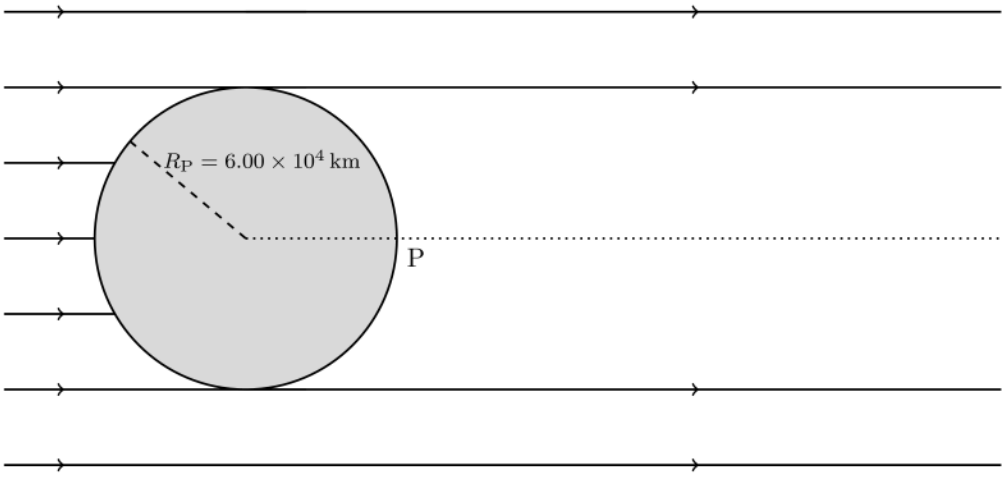
For this question use sky map Map-OP02.
The sky projected on the planetarium dome is as seen by an observer on some hypothetical ringed planet. The observer is located very near to the equator of the planet.

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 6.00×10^4 km. **5**