4th Japan Astronomy Olympiad National Finals

Practical Problems

February 16, 2025 16:15–17:45

Instructions

1. Do not open this problem booklet until the signal to begin is given.
2. This problem booklet contains 12 pages in total. If you find any missing, disordered, or unclearly printed pages, raise your hand and notify the proctor.
3. Always use a black pencil or black mechanical pencil for your answers.
4. Write your examinee number in the designated field on the answer sheet and answer graph paper. Do not write your examinee number anywhere other than the designated field.
5. Write all answers in the designated spaces on the answer sheet and answer graph paper.
6. Do not write any characters, symbols, or marks unrelated to the answer in the answer fields.
7. The margins of this problem booklet may be used for rough work, but do not tear out pages.
8. The answer sheet and answer graph paper must not be taken home.
9. After the exam, take home the problem booklet, calculation paper, and draft paper.
10. Questions about the problems will not be accepted. If you believe there is an error in a problem, write it on the answer sheet or answer graph paper. It will be considered during grading.

Problem 1

Answer the following questions (Questions 1 and 2) regarding various aspects of astronomical observation. For problems specified on the answer sheet, write the equations and reasoning that lead to your answer.

Question 1. Figure 1–1 shows the night sky as observed from a location at longitude 135°E at 21:00 JST on August 11, 2025. Brighter objects are plotted as larger dots. Answer the following questions about this figure. The local sidereal time at the observation site is 18h 21m, and the Moon is omitted. In this question (Question 1), the azimuth is measured from south, increasing westward.

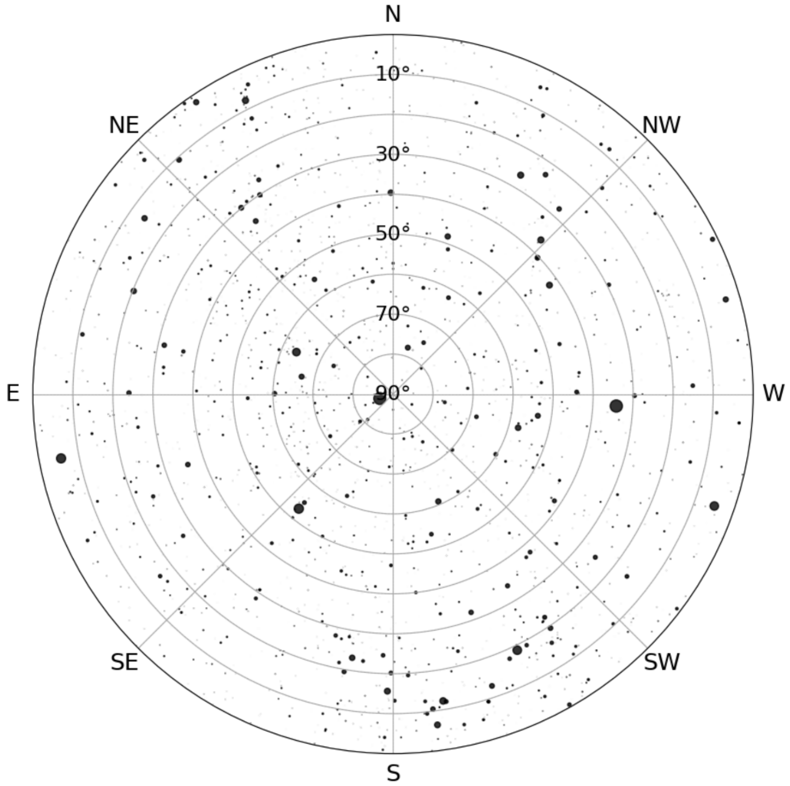

Figure 1–1: The night sky as observed from longitude 135°E at 21:00 JST on August 11, 2025. Lines indicating altitude and azimuth are drawn.

(1) State the latitude of the observation site as an integer.

(2) In Figure 1–1, which constellation contains the point at altitude 90°? Answer using the standard 3-letter abbreviation. Pay attention to the distinction between uppercase and lowercase letters.

(3) Are the following Messier objects included in this star chart? Write ◯ if included, or × if not included, in the designated spaces on the answer sheet.

[M 4, M 31, M 37, M 57, M 81]

(4) The same figure as Figure 1–1 is printed on the answer sheet. Answer all parts (4)(a) and (4)(b) by marking on the figure in the answer sheet.

(a) Circle all first-magnitude stars shown in the figure on the answer sheet. Note that answers where it is impossible to determine which star is being circled (due to the circle being too large, too faint, etc.) will be marked incorrect.

(b) Draw the ecliptic on the figure in the answer sheet.

Figure 1–2 is an enlarged view of the southern sky in Figure 1–1. Refer to this figure and answer the following questions.

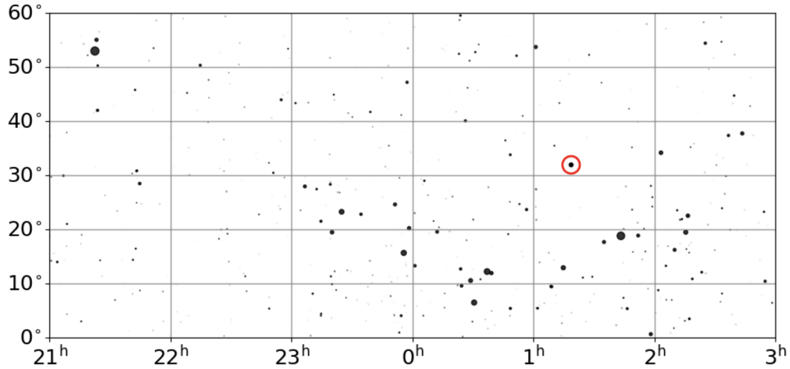

Figure 1–2: Enlarged view of the southern sky.

(5) In Figure 1–2, state the altitude and azimuth of the object circled in red, both as integers in degrees.

(6) State the right ascension and declination of the object circled in red. Express the right ascension in hours and minutes (integer minutes), and the declination as an integer in degrees.

(7) At the same location, state the time (JST) at which the object circled in red next sets below the horizon.

Question 2. Consider the situation of performing astronomical observation using a telescope with an aperture of 200 mm and a focal length of 1000 mm. Answer the following questions about this telescope. If necessary, you may use 1 au $= 1.5 \times 10^8$ km and an Earth radius of 6.4×10^3 km.

(1) Observations were made using an eyepiece with a focal length of 5 mm and an apparent field of view of 50°. State the magnification and the true field of view during the observation. Give the magnification to 1 significant figure, and the true field of view to 2 significant figures in arcminutes.

(2) Using this telescope and the eyepiece from (1), Jupiter was observed as shown in Figure 1–3. Taking the distance between Earth and Jupiter at the time of observation to be 5.0 au, state the radius of Jupiter in units of Earth radii, to 1 significant figure.

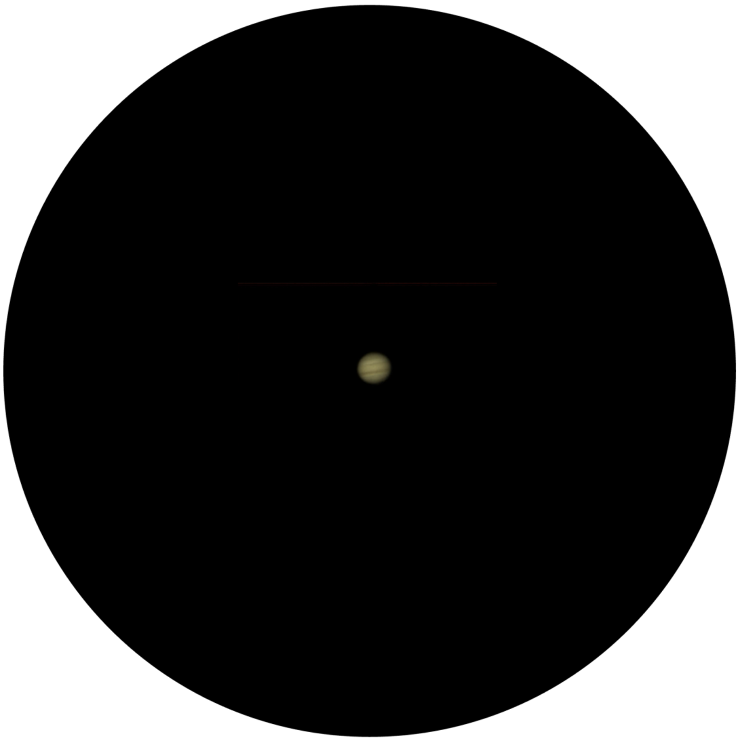

Figure 1–3: Jupiter as observed.

(3) If a person who can detect stars up to magnitude 6 with the naked eye uses this telescope, up to what magnitude can they detect? Assume the diameter of the human pupil to be 7 mm. Assume no light attenuation in the optical path.

This telescope is used mounted on an equatorial mount as shown in Figure 1–4.

Figure 1–4: Equatorial mount for the telescope (Courtesy: Vixen).

(4) Figure 1–5 shows the celestial sphere with lines of equal right ascension (hour circles) and equal declination. The telescope is currently pointed at the position marked with a cross (×), and we wish to slew to the object at the position marked with a filled circle (•). This requires rotating both the right ascension (RA) axis and the declination (Dec) axis of the equatorial mount. Illustrate the method of rotating these two axes as described below, referring to the example answer (Figure 1–6). Write your answer on the figure in the answer sheet (identical to Figure 1–5).

- Express the rotation method by showing the change in position on the celestial sphere that the telescope points to, using arrows.
- Motion when rotating the RA axis should be shown with a *solid* arrow; motion when rotating the Dec axis should be shown with a *dashed* arrow.
- When rotating, ensure that the counterweight does not go above the optical tube. Also ensure that the telescope does not point below the horizon.
- Do not point the telescope toward the celestial north pole during rotation.
- Assume that polar alignment of the equatorial mount has already been completed.

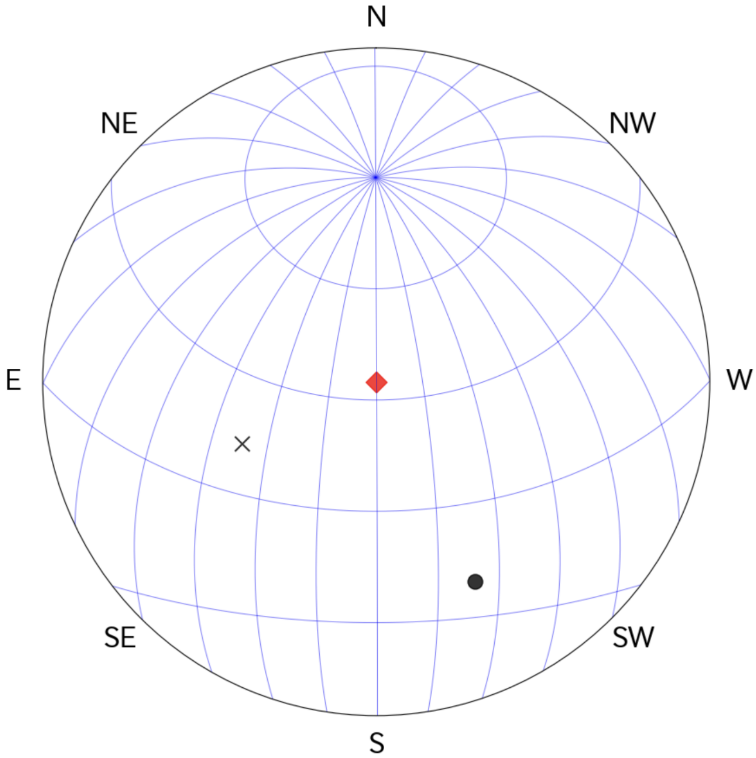

Figure 1–5: Target object. The red diamond in the figure represents the zenith.

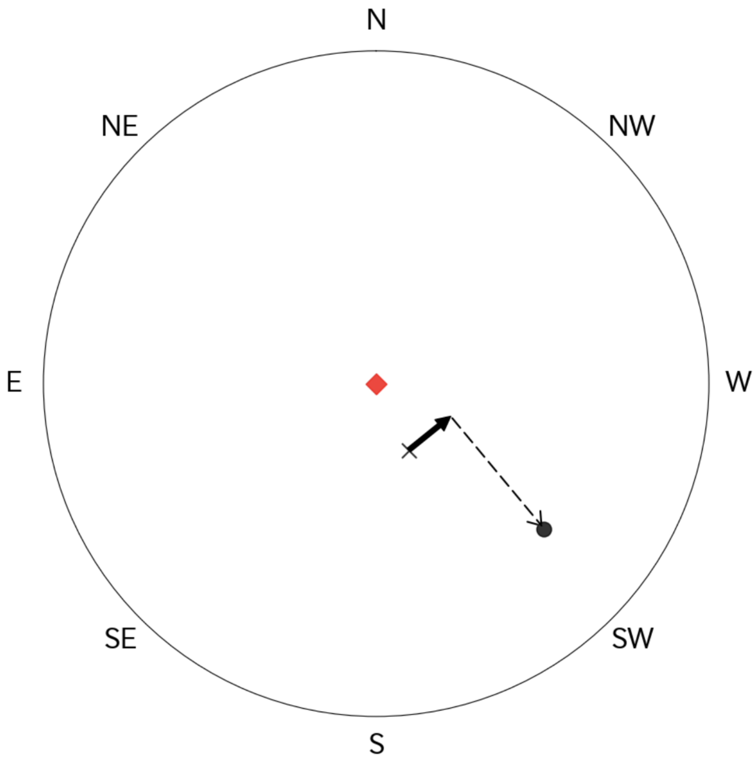

Figure 1–6: Example answer (positions of × and • differ from the actual problem).

Problem 2

By utilizing the line-of-sight (radial) velocity associated with the rotational motion of the Milky Way galaxy, it is possible to determine the distances to objects within the galaxy. As shown in Figure 2–1, the rotational speed of the Milky Way depends only on the distance R from the galactic center, and can be expressed as a function $V(R)$.

Table 2–1 shows, for 8 Giant Molecular Clouds (GMCs) located in the Milky Way, the galactic longitude l, the radial velocity V_r, the velocity dispersion along the line of sight σ, and the angular diameter r of each object.

Since the galactic latitudes of the objects listed in Table 2–1 are sufficiently small, throughout this problem we assume that these objects are all in the same plane as the Solar System, and that the Solar System and these objects all undergo uniform circular motion around the galactic center in the same direction. If necessary, use the distance from the galactic center to the Solar System: $R_0 = 8.0\,\mathrm{kpc}$.

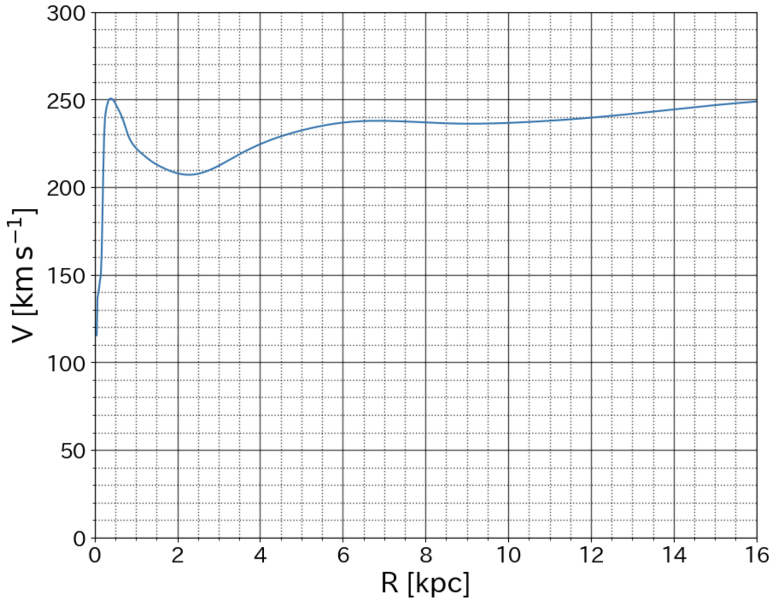

Figure 2–1: Rotation curve of the Milky Way galaxy.

Table 1: Observational data for Giant Molecular Clouds in the Milky Way

No.	l [deg]	V_r [km s^{-1}]	σ [km s^{-1}]	r [deg]
1	8.3	48	1.5	0.05
2	45.4	60	2.7	0.25
3	267.3	18	1.6	0.23
4	283.8	-5	2.9	0.93
5	290.6	15	3.1	0.53
6	302.3	32	4.0	0.41
7	314.0	28	3.3	0.21
8	335.5	27	1.9	0.06

(1) In Figure 2–2, consider an object P undergoing circular motion at speed $V(R)$

along galactic longitude l. Express $V(R)$ in terms of l, R, R_0, V_r, and V_0, where $V_0 = V(R_0)$ is the rotational speed of the Solar System.

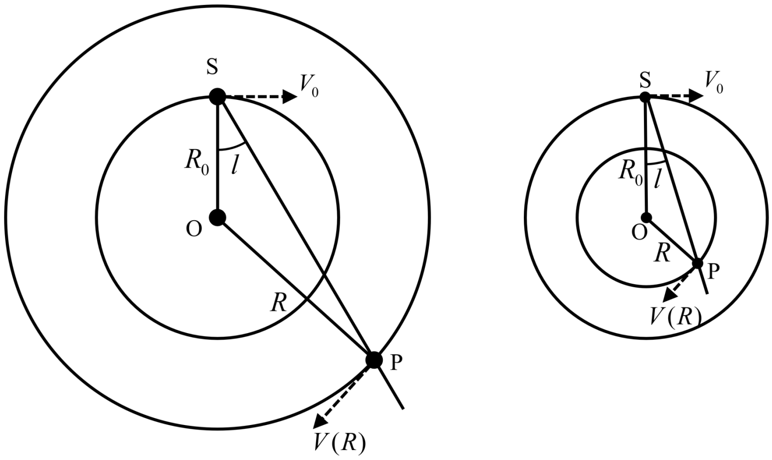

Figure 2–2: Positional relationship between object P and the Solar System. O denotes the position of the galactic center, S denotes the position of the Solar System.

(2) For each object listed in Table 2–1, determine the distance R of each object from the galactic center by drawing in Figure 2–1 the line satisfying the $V(R)$–R relation obtained in (1), and record the values in the table on the answer sheet.

(3) Using galactic longitude l and the value of R determined in (2), list all possible values of the distance d from the Solar System to each object, and record them in the table on the answer sheet. Note that for objects lying inside the Solar orbit (i.e., $R < R_0$), the distance d cannot be uniquely determined from the radial velocity alone.

(4) Even for objects inside the Solar orbit, it may be possible to uniquely determine d using a different observable quantity. Here we consider using the angular diameter of the GMC.

(a) It is known that the actual radius R_{GMC} of a GMC and the velocity dispersion along the line of sight σ are related by:

$$\frac{\sigma}{1\,\text{km/s}} = C\left(\frac{R_{\text{GMC}}}{1\,\text{kpc}}\right)^{\alpha}$$

where C and α are constants independent of the particular molecular cloud. For GMCs located *outside* the Solar orbit, estimate the values of the constants C and α including their uncertainties, by plotting appropriate quantities on answer graph paper ①.

(b) Using the R_{GMC}–σ relation obtained in (a), uniquely determine the distance d from the Solar System to the GMC(s) located *inside* the Solar orbit by selecting from the candidate values, and record them in the table on the answer sheet.

(5) Based on the above results, plot the positions of all GMCs within the Milky Way as seen from the galactic north pole, together with the positions of the Solar System and the galactic center, on answer graph paper ②.