## Observation Round: Procedure

You have 30 minutes to read the questions and plan your observations. Do not talk to other participants. When you are shown the sign to ‘GO NOW’ by the supervisor, follow the directions to the telescope location taking with you the questions, clipboard and pen/pencil (a red light will be provided at the telescope). Keep your distance from other participants and do not talk to them. Show your badge and code to the assistant at your telescope.

You will have a total of 30 minutes to complete the observing tasks, starting when all participants are ready. At the end of 30 minutes take your papers and clipboard (leave the light) and wait until called to leave the observing location.

Follow the directions back to the preparation hall. Keep your distance from other participants and do not talk to them.

You will have another 30 minutes to process your observations and complete the answer sheet (there will be a calculator, geometrical instruments etc.). If you had any technical problems you can write a report for your team leader on the form in the answer sheets. At the end of 30 minutes place your answer sheets and the report in the envelope and wait at your desk until directed to leave the hall.

## Observation Round: General Instructions

Scientists have discovered a crashed alien flying saucer. High up inside the hold, they found several screens transmitting views of the sky and telescopes have been set up to let you see them clearly from the level of the deck. Use your telescope to observe the (simulated) targets on the screens and record your results.

There are 5 screens on the opposite side: the central one will display video for tasks 1 and 2, the other four will display static images for tasks 3 and 4. The two screens closer to the centre will display the (same) image for task 3, and the two outer screens will display the (same) image for task 4. Point your telescope at the screens furthest away from you.

| | | | | |
|---|---|---|---|---|
| 4 | 3 | 1, 2 | 3 | 4 |

You will have a total of 30 minutes to complete the observing tasks, however tasks 1 and 2 will only be displayed once: just as with real observations you will only have one opportunity to collect the data. There will be two clocks visible showing the time remaining in the round.

At the start of the round a clock on the central screen will show the simulated time at the observer's location. The clock will have the correct orientation when seen through the telescope. The time will be shown for 3 minutes after which it will disappear; use this to set a start time for your observations.

Caution: the scale of the field of view is different between the video and still images.

## Observation 1: ‘Asteroid occultation’

Calculations based on the orbital elements predict that an asteroid will occult the star HD 163390 for 21 s, with the maximum occultation (mid-time) occurring at 23:03:32 UT. However, the ephemeris is not perfect and the prediction may be wrong by up to 20 s for the time and by 10s for the duration.

Based on your observations, find the true mid-time and duration of the occultation. To identify the star use Map 1 and the following coordinates:

HD 163390 RA: $17^{\mathrm{h}}\ 58^{\mathrm{m}}\ 05^{\mathrm{s}}$ DEC: $-18^\circ\ 50'\ 46.14''$

The map and the sky are in the same epoch.

(15 points)

### Answer Sheet

| Mid-time of occultation | ± error | Duration of occultation | ± error |
|---|---|---|---|
| | | | |

## Solution

Beginning of occultation: 23:03:31
End of occultation: 23:03:48

| Mid-time of occultation | ± error | Duration of occultation | ± error |
|---|---|---|---|
| 23:03:39.5 | 0.4 s | 17 s | 0.2 s |

## Marking

1. Mid-time $t$ of occultation:
    - 23:03:39.3 $\leq t <$ 23:03:39.7 $\implies$ 4 points
    - 23:03:39.0 $\leq t <$ 23:03:39.3 or 23:03:39.7 $< t \leq$ 23:03:40.0 $\implies$ 3 points
    - 23:03:38.0 $\leq t <$ 23:03:39.0 or 23:03:40.0 $< t \leq$ 23:03:41.0 $\implies$ 1 points
    - outside this range $\implies$ 0 points
2. Error in mid-time $\Delta t$:
    - $0.1 < \Delta x \leq 0.5 \implies$ 3 points
    - $0.5 < \Delta x \leq 0.7 \implies$ 2 points
    - $0.7 < \Delta x \leq 1.0 \implies$ 1 point
    - outside this range or missing $\implies$ 0 points
3. Duration $x$ of occultation (should be to 1 s.f.):
    - 16.8 s $\leq x \leq$ 17.2 s $\implies$ 4 points
    - 16 s $\leq x <$ 16.8 s or 17.2 s $< x \leq$ 18 s $\implies$ 3 points
    - 15 s $\leq x <$ 16 s or 18 s $< x \leq$ 19 s $\implies$ 1 points
    - outside this range $\implies$ 0 points
4. Error in duration $\Delta x$:
    - $0.05 < \Delta x \leq 0.2 \implies$ 3 points
    - $0.2 < \Delta x \leq 0.4 \implies$ 2 points
    - $0.4 < \Delta x \leq 1.0 \implies$ 1 point
    - outside this range or missing $\implies$ 0 points
5. Error of duration lower than and different from error in mid time ($\Delta x < \Delta t$) $\implies$ 1 point

## Observation 2: ‘Starlink’

In the same star field as for Question 1, a ‘train’ of Starlink satellites will appear near the meridian of $17^h\ 59^m$ at around 23:05 UT. Their passage will last for around three minutes.

You may assume that the centre of the star field is at an altitude of 20° and that the satellites are 400 km above the Earth’s surface moving on circular orbits with equal distances between them. You may also assume that satellites will move vertically (perpendicular to the horizon).

(a) Measure the angular velocity of the satellites as seen by an observer on the simulated sky.

(b) Measure the time interval between the passes of successive satellites and mark their path on the sky chart (Map 1).

(c) Calculate the theoretical angular velocity of the satellites as seen by the observer, using the information given in the question.

(d) Estimate the distance in km between two consecutive satellites.

Constants: $G = 6.674 \times 10^{-11}\text{Nm}^2\text{kg}^{-2}$; $M_{\text{Earth}} = 5.972 \times 10^{24}\text{kg}$ ; $R_{\text{Earth}} = 6378\text{km}$.

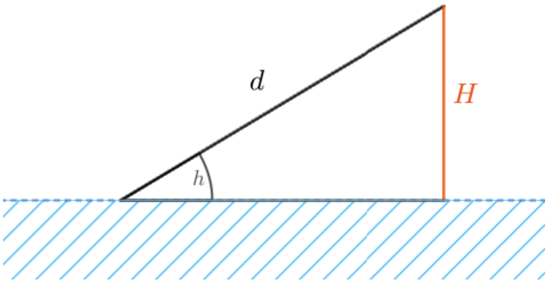
(15 points)

### Solution

The satellites are at an altitude $h = 20°$ and their height above the surface of the Earth is $H = 400$ km.

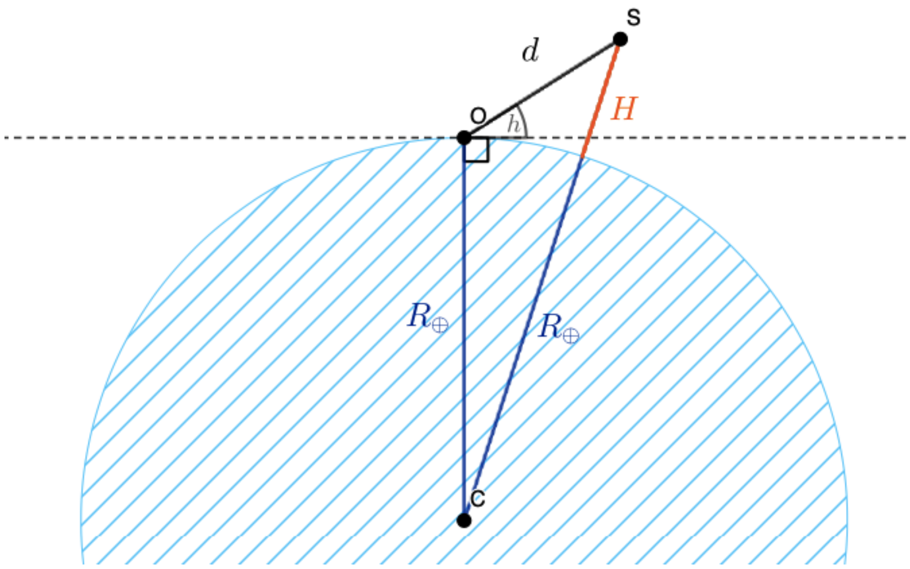
1) In the (simplified) solution neglecting the Earth’s curvature, the student will assume the distance to the satellites is equal to:

$$d_{flat} = \frac{H}{\sin h} = 1170 \text{ km}$$



2) In the solution taking into account the Earth’s curvature, let us draw the $OSC$ (observer–satellite–center of the Earth) triangle. The angles are: $\measuredangle COS = 90° + h$, $\measuredangle OSC$ that we shall denote as $\eta$, and $\measuredangle SCO = 180° - (90° + h) - \eta = 70° - \eta$.

The law of sines can be applied:



$$\frac{\sin(90^\circ + h)}{R_\oplus + H} = \frac{\sin\eta}{R_\oplus} = \frac{\sin(70^\circ - \eta)}{d_{curve}}$$

We calculate the distance to the satellites:

$$\eta = \arcsin\left(\frac{R_\oplus}{R_\oplus + H}\sin(90^\circ + h)\right) = 62^\circ, 2$$

$$d_{curve} = R_\oplus \frac{\sin(70^\circ - \eta)}{\sin\eta} = 980 \text{ km}$$

Knowing the radius of the orbit is $R_\oplus + H$, we calculate $v_{orbit} = \sqrt{GM_\oplus/(R_\oplus + H)} = 7.6$ km/s. The observer can only measure the tangential component of motion $v_t$.

The student will estimate the angular velocity to be $v_t/d = v_{orbit}\sin h/d = 2.2 \cdot 10^{-3}[1/s] = 7.6[{}'/s]$ (for the solution neglecting the Earth's curvature) or $2.6 \cdot 10^{-3}[1/s] = 9.0[{}'/s]$ (for the solution taking into account the Earth's curvature).

**5 points for predicting the angular velocity:**
5 points if within $8.55 - 9.45[{}'/s]$;
4 points if within $8.1 - 9.9[{}'/s]$);
3 point if within $7.5 - 10.5[{}'/s]$;
0 points otherwise

The simulated angular velocity is $8.5[{}'/s]$; the student should conclude this value is similar to their prediction[2].

**4 points for measuring the angular velocity:**

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[2] or optionally comment it is slightly lower and might imply e.g. the real orbit radius is minimally larger than predicted, but it is not necessary

4 points if agrees within 5% (8.1 - 8.9 $[' / s]$);
2 points if agrees within 10% (7.65 - 9.35 $[' / s]$);
0 points otherwise

**1 point for correct comparison**

The student should then measure the time interval between the passes to be $t = 2$ s.

**2 points for measuring the time interval:**
2 points if agrees within 5% (1.9 - 2.1 s); 0 points otherwise

In such a short time, the path along the orbit can be approximated with a straight line; the distance passed is $S = v_{orbit}t = 15$ km, which is the distance between the satellites. (Alternatively, if the student chooses to use their own $v_t$ measurement, $S = v_t t / \sin h = 14$ km).

**2 points for calculating the distance**
2 points if within 13.8-15.2 km
1 point if within 12.5-16.5 km
0 points otherwise

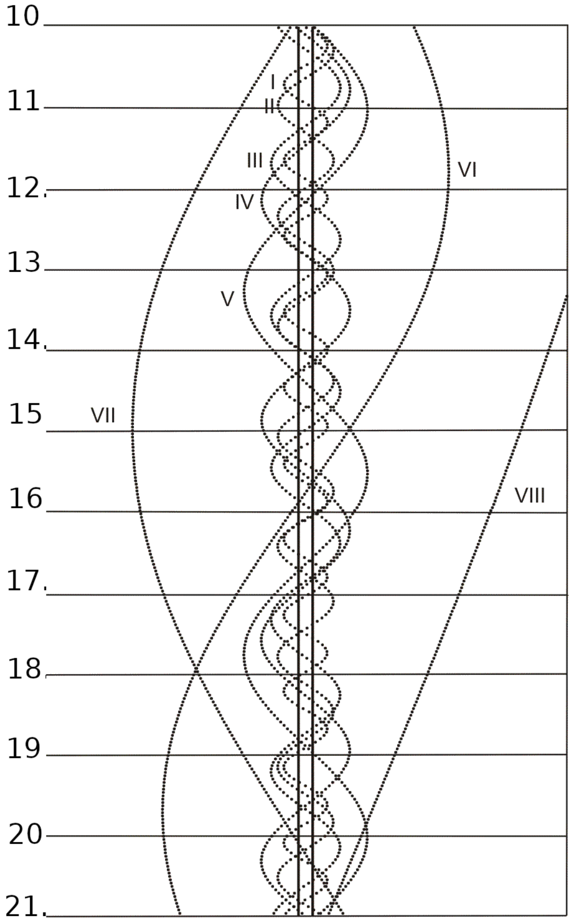
Finally, the student should mark the observed satellite path on the sky map.

**1 point for correctly marking the satellite trail**

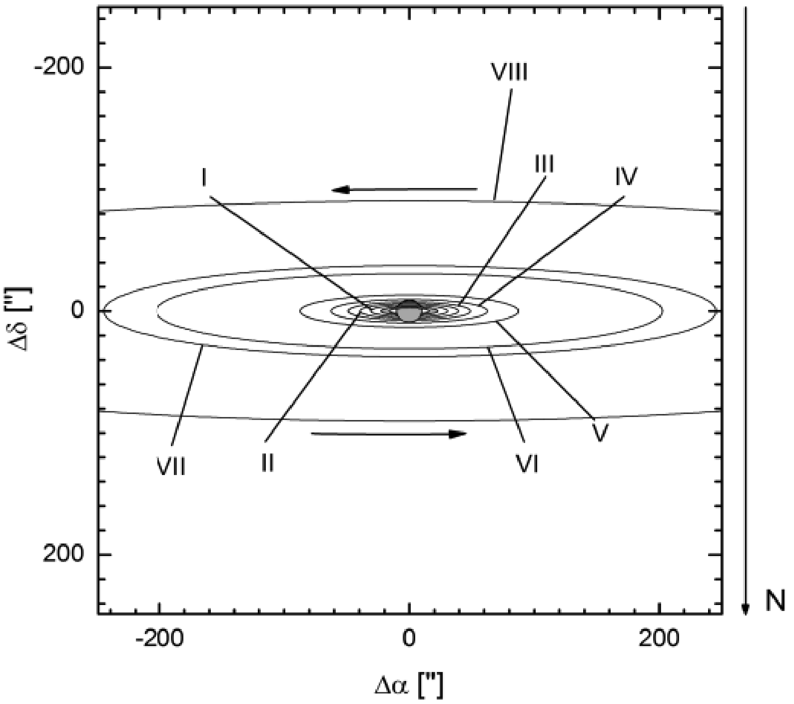
## Observation 3: ‘Planetary Moons’

The screen will display an image of one of the planets of the Solar System as seen on August 15, 2023, at 00:00 UT. Identify any five moons and mark them on the answer sheet (you may use the moon position chart attached below and the table showing their brightness).

(10 points)



The moon position chart. The numbers on the left indicate the days of August 2023 (at midnight UT).



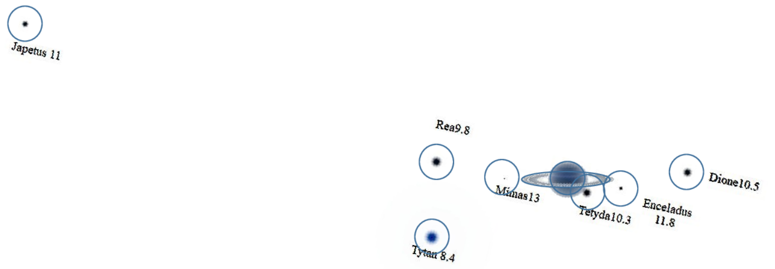
The moon position chart – moon numbers (I, II, . . . ) as above.

| Number | Name | Magnitude |
|---|---|---:|
| I | Mimas | 13.0 |
| II | Enceladus | 11.8 |
| III | Tethys | 10.4 |
| IV | Dione | 10.6 |
| V | Rhea | 9.9 |
| VI | Titan | 8.5 |
| VII | Hyperion | 14.4 |
| VIII | Japetus | 11.0 |

## Answer sheet

Mark the positions of any 5 moons with a dot on the following image and label them with their numbers (I, II, . . . ).

## Solution

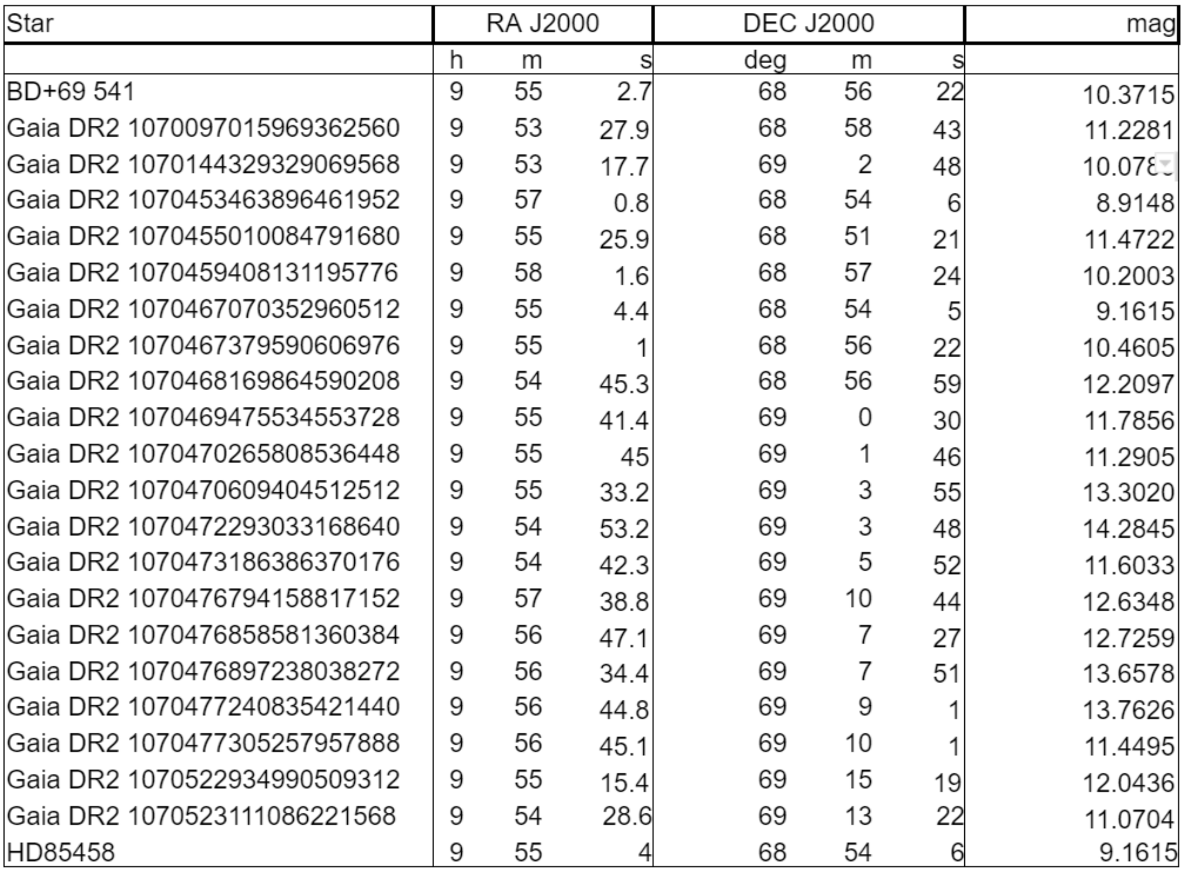


2 points for each moon: position (1 pt) and name (1 pt).

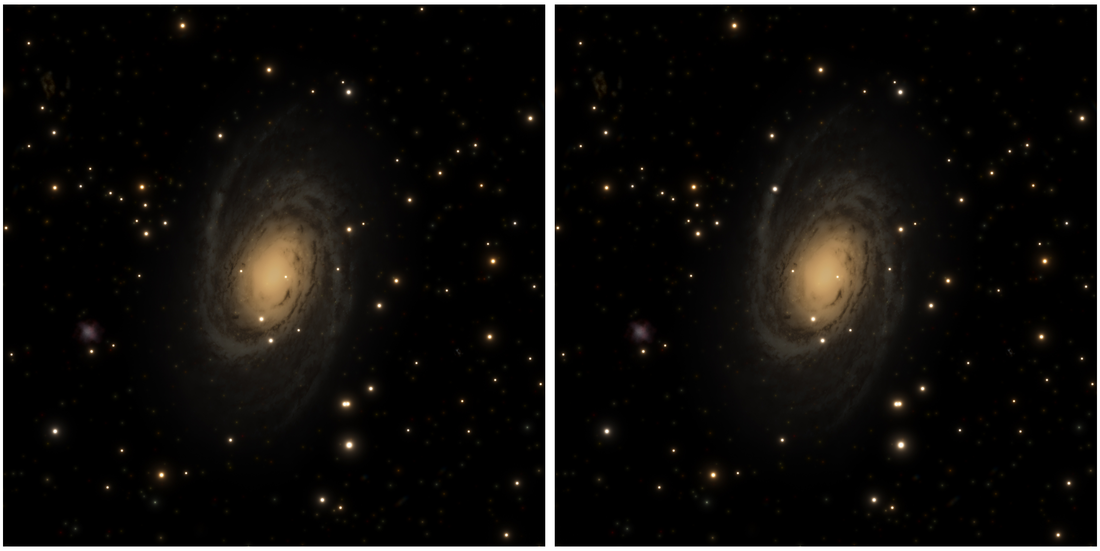
## Observation 4: ‘Supernova’

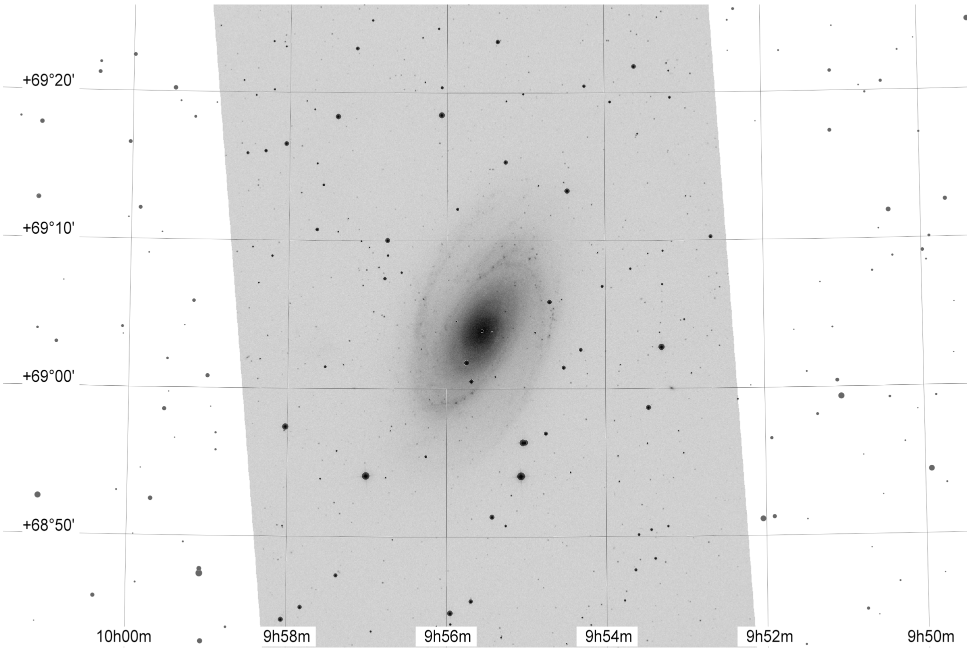
The other screen presents the view of a galaxy and a bright (mag < 11) object which was not visible previously. Estimate the right ascension (RA) and declination (DEC) coordinates of this star and estimate its magnitude. You may use Map 2, with stellar coordinates and a list of magnitudes.

(10 points)



| Star | RA J2000 | | | DEC J2000 | | | mag |
|---|---|---|---|---|---|---|---|
| | h | m | s | deg | m | s | |
| BD+69 541 | 9 | 55 | 2.7 | 68 | 56 | 22 | 10.3715 |
| Gaia DR2 1070097015969362560 | 9 | 53 | 27.9 | 68 | 58 | 43 | 11.2281 |
| Gaia DR2 1070144329329069568 | 9 | 53 | 17.7 | 69 | 2 | 48 | 10.078 |
| Gaia DR2 1070453463896461952 | 9 | 57 | 0.8 | 68 | 54 | 6 | 8.9148 |
| Gaia DR2 1070455010084791680 | 9 | 55 | 25.9 | 68 | 51 | 21 | 11.4722 |
| Gaia DR2 1070459408131195776 | 9 | 58 | 1.6 | 68 | 57 | 24 | 10.2003 |
| Gaia DR2 1070467070352960512 | 9 | 55 | 4.4 | 68 | 54 | 5 | 9.1615 |
| Gaia DR2 1070467379590606976 | 9 | 55 | 1 | 68 | 56 | 22 | 10.4605 |
| Gaia DR2 1070468169864590208 | 9 | 54 | 45.3 | 68 | 56 | 59 | 12.2097 |
| Gaia DR2 1070469475534553728 | 9 | 55 | 41.4 | 69 | 0 | 30 | 11.7856 |
| Gaia DR2 1070470265808536448 | 9 | 55 | 45 | 69 | 1 | 46 | 11.2905 |
| Gaia DR2 1070470609404512512 | 9 | 55 | 33.2 | 69 | 3 | 55 | 13.3020 |
| Gaia DR2 1070472293033168640 | 9 | 54 | 53.2 | 69 | 3 | 48 | 14.2845 |
| Gaia DR2 1070473186386370176 | 9 | 54 | 42.3 | 69 | 5 | 52 | 11.6033 |
| Gaia DR2 1070476794158817152 | 9 | 57 | 38.8 | 69 | 10 | 44 | 12.6348 |
| Gaia DR2 1070476858581360384 | 9 | 56 | 47.1 | 69 | 7 | 27 | 12.7259 |
| Gaia DR2 1070476897238038272 | 9 | 56 | 34.4 | 69 | 7 | 51 | 13.6578 |
| Gaia DR2 1070477240835421440 | 9 | 56 | 44.8 | 69 | 9 | 1 | 13.7626 |
| Gaia DR2 1070477305257957888 | 9 | 56 | 45.1 | 69 | 10 | 1 | 11.4495 |
| Gaia DR2 1070522934990509312 | 9 | 55 | 15.4 | 69 | 15 | 19 | 12.0436 |
| Gaia DR2 1070523111086221568 | 9 | 54 | 28.6 | 69 | 13 | 22 | 11.0704 |
| HD85458 | 9 | 55 | 4 | 68 | 54 | 6 | 9.1615 |




+69°20'
+69°10'
+69°00'
+68°50'
10h00m
9h58m
9h56m
9h54m
9h52m
9h50m

## Answer Sheet

| Right ascension | Declination | est. magnitude |
|---|---|---|
| | | |

## Solution

| Right ascension | Declination | est. magnitude |
|---|---|---|
| $9^{\mathrm{h}}\ 55^{\mathrm{m}}\ 54^{\mathrm{s}}$ | $+69^\circ\ 09'\ 11''$ | 10.2 mag |

1. Declination:
   (a) $< \pm 1.5' \implies$ 4 points
   (b) $\leq \pm 3' \implies$ 2 points
   (c) $> \pm 3' \implies$ 0 points
2. Right ascension:
   (a) $< \pm$ 22.5 s $\implies$ 4 points
   (b) $\leq \pm$ 45 s $\implies$ 2 points
   (c) $> \pm$ 45 s $\implies$ 0 points
3. Magnitude:
   (a) $< \pm$ 0.4 mag $\implies$ 2 points
   (b) $\leq \pm$ 0.8 mag $\implies$ 1 points
   (c) $> \pm$ 0.8 mag $\implies$ 0 points