# The 5th International Olympiad on Astronomy and Astrophysics 2011

## Silesia, Poland

# The 5th International Olympiad on Astronomy and Astrophysics

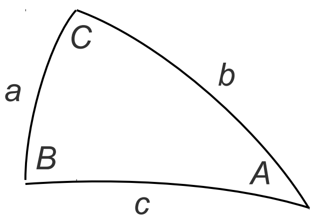
## Silesia, Poland

## Theoretical Round

## Astronomical and physical constants

| | |
|---|---|
| Astronomical unit (AU) | $1.4960 \times 10^{11}$ m |
| Light year (ly) | $9.4605 \times 10^{15}$ m = 63 240 AU |
| Parsec (pc) | $3.0860 \times 10^{16}$ m = 206 265 AU |
| 1 Sidereal year | 365.2564 solar days |
| 1 Tropical year | 365.2422 solar days |
| 1 Calendar year | 365.2425 solar days |
| 1 Sidereal day | $23^{h}\ 56^{m}\ 04^{s}.091$ |
| 1 Solar day | $24^{h}\ 03^{m}\ 56^{s}.555$ units of sidereal time |
| Mass of Earth | $5.9736 \times 10^{24}$ kg |
| Mean radius of Earth | $6.371 \times 10^{6}$ m |
| Equatorial radius of Earth | $6.378 \times 10^{6}$ m |
| Mean velocity of Earth on its orbit | 29.783 km $s^{-1}$ |
| Mass of Moon | $7.3490 \times 10^{22}$ kg |
| Radius of Moon | $1.737 \times 10^{6}$ m |
| Mean Earth – Moon distance | $3.844 \times 10^{8}$ m |
| Mass of Sun | $1.98892 \times 10^{30}$ kg |
| Radius of Sun | $6.96 \times 10^{8}$ m |
| Effective temperature of the Sun | 5 780 K |
| Luminosity of the Sun | $3.96 \times 10^{26}$ J $s^{-1}$ |
| Solar constant | 1366 W $m^{-2}$ |
| Brightness of the Sun in V-band | −26.8 mag. |
| Absolute brightness of the Sun in V-band | 4.75 mag. |
| Absolute bolometric brightness of Sun | 4.72 mag. |
| Angular diameter of the Sun | 30′ |
| Speed of light in vacuum (c) | $2.9979 \times 10^{8}$ m $s^{-1}$ |
| Gravitational constant (G) | $6.6738 \times 10^{-11}$ N $m^2$ $kg^{-2}$ |
| Boltzmann constant (k) | $1.381 \times 10^{-23}$ m kg $s^{-2}$ $K^{-1}$ |
| Stefan−Boltzmann constant (σ) | $5.6704 \times 10^{-8}$ kg $s^{-3}$ $K^{-4}$ |
| Planck constant (h) | $6.6261 \times 10^{-34}$ J s |
| Wien's constant (b) | $2.8978 \times 10^{-3}$ m K |
| Hubble constant ($H_0$) | 70 km $s^{-1}$ $Mpc^{-1}$ |
| electron charge (e) | $1.602 \times 10^{-19}$ C |
| Current inclination of the ecliptic ($\varepsilon$) | 23º 26.3′ |
| Coordinates of the northern ecliptic pole for epoch 2000.0 ($\alpha_E$ , $\delta_E$) | $18^{h}\ 00^{m}\ 00^{s}$, + 66º 33.6′ |
| Coordinates of the northern galactic pole for epoch 2000.0 ($\alpha_G$ , $\delta_G$) | $12^{h}\ 51^{m}$, + 27º 08′ |

You can try to solve an equation $x = f(x)$ using iteration: $x_{n+1} = f(x_n)$.




Basic equations of spherical trigonometry

$$\sin a \sin B = \sin b \sin A \ ,$$
$$\sin a \cos B = \cos b \sin c - \sin b \cos c \cos A \ ,$$
$$\cos a = \cos b \cos c + \sin b \sin c \cos A \ .$$

**Short theoretical questions**

**Each question max 10 points**

1. Most single-appearance comets enter the inner Solar System directly from the Oort Cloud. Estimate how long it takes a comet to make this journey. Assume that in the Oort Cloud, 35 000 AU from the Sun, the comet was at aphelion.

2. Estimate the number of stars in a globular cluster of diameter 40 pc, if the escape velocity at the edge of the cluster is 6 km $s^{-1}$ and most of the stars are similar to the Sun.

3. On 9 March 2011 the Voyager probe was 116. 406 AU from the Sun and moving at 17.062 km $s^{-1}$. Determine the type of orbit the probe is on: (a) elliptical, (b) parabolic, or (c) hyperbolic. What is the apparent magnitude of the Sun as seen from Voyager?

4. Assuming that Phobos moves around Mars on a perfectly circular orbit in the equatorial plane of the planet, give the length of time Phobos is above the horizon for a point on the Martian equator. Use the following data:
   Radius of Mars $R_{\mathrm{Mars}}$ = 3 393 km Rotational period of Mars $T_{\mathrm{Mars}}$ = 24.623 h. Mass of Mars $M_{\mathrm{Mars}} = 6.421 \times 10^{23}$kg Orbital radius of Phobos $R_{\mathrm{P}}$ = 9 380 km .

5. What would be the diameter of a radiotelescope working at a wavelngth of $\lambda$ = 1 cm with the same resolution as an optical telescope of diameter $D$ = 10 cm?

6. Tidal forces result in a torque on the Earth. Assuming that, during the last several hundred million years, both this torque and the length of the sidereal year were constant and had values of $6.0 \times 10^{16}$ N m and $3.15 \times 10^{7}$ s respectively, calculate how many days there were in a year $6.0 \times 10^{8}$ years ago. Moment of inertia of a homogeneous filled sphere of radius $R$ and mass $m$ is $I = \frac{2}{5} m R^2$

7. A satellite orbits the Earth on a circular orbit. The initial momentum of the satellite is given by the vector **p**. At a certain time, an explosive charge is set off which gives the satellite an additional impulse $\Delta\mathbf{p}$, equal in magnitude to $|\mathbf{p}|$. Let $\alpha$ be the angle between the vectors **p** and $\Delta\mathbf{p}$, and $\beta$ between the radius vector of the satellite and the vector $\Delta\mathbf{p}$. By thinking about the direction of the additional impulse $\Delta\mathbf{p}$, consider if it is possible to change the orbit to each of the cases given below. If it is possible mark YES on the answer sheet and give values of $\alpha$ and $\beta$ for which it is possible. If the orbit is not possible, mark NO.

   (a) a hyperbola with perigee at the location of the explosion.

(b) a parabola with perigee at the location of the explosion.

(c) an ellipse with perigee at the location of the explosion.

(d) a circle.

(e) an ellipse with apogee at the location of the explosion.

Note that for $\alpha = 180^{\circ}$ and $\beta = 90^{\circ}$ the new orbit will be a line along which the satellite will free fall vertically towards the centre of the Earth.

8. Assuming that dust grains are black bodies, determine the diameter of a spherical dust grain which can remain at 1 AU from the Sun in equilibrium between the radiation pressure and gravitational attraction of the Sun. Take the density of the dust grain to be $\varrho = 10^{3}$ kg m$^{-3}$.

9. Interstellar distances are large compared to the sizes of stars. Thus, stellar clusters and galaxies which do not contain diffuse matter essentially do not obscure objects behind them. Estimate what proportion of the sky is obscured by stars when we look in the direction of a galaxy of surface brightness $\mu = 18.0$ mag arcsec$^{-2}$. Assume that the galaxy consists of stars similar to the Sun.

10. Estimate the minimum energy a proton would need to penetrate the Earth's magnetosphere. Assume that the initial penetration is perpendicular to a belt of constant magnetic field 30 μT and thickness 1.0 x $10^{4}$ km. Prepare the sketch of the particle trajectory. (Note that at such high energies the momentum can be replaced by the expression $E/c$. Ignore any radiative effects).

11. Based on the spectrum of a galaxy with redshift $z = 6.03$ it was determined that the age of the stars in the galaxy is from 560 to 600 million years. At what $z$ did the epoch of star formation occur in this galaxy? Assume that the current age of the Universe is $t_0 = 13.7 \times 10^{9}$ years and that the rate of expansion of the Universe is given by a flat cosmological model with cosmological constant $\Lambda = 0$. (In such a model the scale factor $R \propto t^{2/3}$, where $t$ is the time since the Big Bang.)

12. Due to the precession of the Earth's axis, the region of sky visible from a location with fixed geographical coordinates changes with time. Is it possible that, at some point in time, Sirius will not rise as seen from Krakow, while Canopus will rise and set? Assume that the Earth's axis traces out a cone of angle $47^{\circ}$. Krakow is at latitude $50.1^{\circ}$ N; the current equatorial coordinates (right ascension and declination) of these stars are:
Sirius (α CMa) : $6^{h}\,45^{m}$, $-16^{\circ}\,43'$
Canopus (α Car) : $6^{h}\,24^{m}$, $-52^{\circ}\,42'$

13. The equation of the ecliptic in equatorial coordinates ($\alpha$, $\delta$) has the form:
$\delta = \arctan(\sin\alpha \tan\varepsilon)$,
where $\varepsilon$ is the angle of the celestial equator to the ecliptic plane. Find an analogous relation $h = f(A)$ for the galactic equator in horizontal coordinates ($A$, $h$) for an observer at latitude $\varphi = 49^{\circ}\,34'$ at local sidereal time $\theta = 0^{h}\,51^{m}$.

14. Estimate the number of solar neutrinos which should pass through a 1 $m^2$ area of the Earth's surface perpendicular to the Sun every second. Use the fact that each fusion reaction in the Sun produces 26.8 MeV of energy and 2 neutrinos.

15. Given that the cosmic background radiation has the spectrum of a black body throughout the evolution of the Universe, determine how its temperature changes with redshift $z$. In particular, give the temperature of the background radiation at the epoch $z \approx 10$ (that of the farthest currently observed objects). The current temperature of the cosmic background radiation is 2.73 K .

**Long theoretical questions**

**Instructions**

1. You will  receive in your envelope an English and native language version of the questions.

2. You have 5 hours to solve 15 short  (tasks 1-15) and 3 long tasks.

3. You can use only the pen given on the desk.

4. The solutions of each task should be written on the answer sheets, starting each question on a new page. Only the answer sheets will be assessed.

5. You may use the blank sheets for additional working. These work sheets will not be assessed

6. At the top of each  page you should put down your code and  task number.

7. If solution exceeds one page, please number the pages for each task.

8. Draw a box around your final answer.

9. Numerical results should be given with appropriate number of significant digits with units.

10. You should use SI or units commonly used in astronomy. Points will be deducted if there is a lack of units or inappropriate number of significant digits.

11. At the end of test, all sheets of papers should be put into the envelope and left on the desk.

12. In your solution please write down each step and partial result.

**Long theoretical questions** (max 30 points each)

1. A transit of duration 180 minutes was observed for a planet which orbits the star HD209458 with a period of 84 hours. The Doppler shift of absorption lines arising in the planet's atmosphere was also measured, corresponding to a difference in radial velocity of 30 km/s (with respect to observer) between the beginning and the end of the transit. Assuming a circular orbit exactly edge-on to the observer, find the approximate radius and mass of the star and the radius of the orbit of the planet.

2. Within the field of a galaxy cluster at a redshift of $z = 0.500$, a galaxy which looks like a normal elliptical is observed, with an apparent magnitude in the $B$ filter $m_B = 20.40$ mag.

   The luminosity distance corresponding to a redshift of $z = 0.500$ is $d_L = 2754$ Mpc.

   The spectral energy distribution (SED) of elliptical galaxies in the wavelength range 250 nm to 500 nm is adequately approximated by the formula:

$$L_\lambda(\lambda) \propto \lambda^4$$

   (i.e., the spectral density of the object's luminosity, known also as the monochromatic luminosity, is proportional to $\lambda^4$.)

   a) What is the absolute magnitude of this galaxy in the $B$ filter ?

   b) Can it be a member of this cluster? (write YES or NO alongside your final calculation)

   Hints: Try to establish a relation that describe the dependence of the spectral density of flux on distance for small wavelength interval. Normal elliptical galaxies have maximum absolute magnitude equal to -22 mag.

3. The planetarium program 'Guide' gives the following data for two solar mass stars:

| Star | 1 | 2 |
|---|---|---|
| Right Ascension | $14^h 29^m 44.95^s$ | $14^h 39^m 39.39^s$ |
| Declination | –62º 40′ 46.14″ | –60 50′ 22.10″ |
| Distance | 1.2953 pc | 1.3475 pc |
| Proper motion in R.A. | –3.776 arcsec / year | –3.600 arcsec / year |
| Proper motion in Dec. | 0.95 arcsec / year | 0.77 arcsec / year |

   Based on these data, determine whether these stars form a gravitationally bound system. Assume the stars are on the main sequence. Write YES of bound or NO if not bound alongside your final calculation.

   Note: the proper motion in R.A. has been corrected for the declination of the stars.

# The 5th International Olympiad on Astronomy and Astrophysics

## Silesia, Poland

## Observational Round

**Observing competition – night round**

**Instructions**

1. There are 2 questions, each worth 25 points. You have **80** minutes to solve them, of which :
   (a) **25** minutes for reading the question and preparing for the observations,
   (b) **30** minutes to perform all the observations at the telescope (for both questions),
   (c) **25** minutes for calculations and finishing your work.
2. Additional time is allowed to move to and from the observing site.
3. Along with the questions you will receive a map of the sky, for use with both questions.
4. At the observing site you will find ready :
   (a) a refracting telescope with a right-angle mirror and an eyepiece with an illuminated reticle, which can be rotated about the optical axis,
   (b) a red torch, stopwatch, pencil, eraser and clipboard,
   (c) a chair.

   Note: the telscope is already aligned – do not change the position of the tripod!

   The brightness of the reticle can be adjusted by turning the on-off switch.
5. You are allowed to take only the questions, answer sheet and blank paper for additional work with you to the telescope.
6. Only the answer sheet will be assessed. The additional worksheets will not be assessed.
7. Clearly mark every page of the answer sheet with your code number.
8. If you have difficulty with the equipment (not related to the question) or disturb the alignment of the telescope, call an assistant.

## Observing competition – night round

### 1. The Little Dolphin

An asterism known as the Little Dolphin lies near a line connecting the stars α Peg (Markab) and β Peg (Scheat). It is marked with a cicle on the large-scale map.

The map also shows the constellation of Delfinus, the Dolphin, with the brightest stars labelled with their Bayer designations (α, β, γ, δ and ε).

The coordinates of α and β Peg and the Little Dolphin (in right ascension order) are:

| | Right Ascension $\alpha$ | Declination $\delta$ |
|---|---|---|
| Little Dolphin | $23^{h}\,02^{m}$ | $+23.0^{o}$ |
| β Peg | $23^{h}\,04^{m}$ | $+28.1^{o}$ |
| α Peg | $23^{h}\,05^{m}$ | $+15.2^{o}$ |

Based on your observations, make two drawings on the answer sheet :

On Drawing 1 :

Draw the view of the constellation **Delphinus** (Del) as seen through the finder scope. Include as many stars as you can see in the field of view.

With an arrow, mark the apparent direction of motion of the stars across the field of view of the finder scope caused by the rotation of the Earth.

Label the stars with the Bayer designations given on the map (α, β, γ, δ and ε).

Also label the brightest of these 5 stars “$m_{max}$”.

Also label the faintest of these 5 stars “$m_{min}$”.

On Drawing 2 :

Draw the view of the **Little Dolphin** as seen through the larger telescope. Include as many stars as you can see in the field of view.

With an arrow, mark the apparent direction of motion of the stars across the field of view of the telescope caused by the rotation of the Earth.

Label the stars of the Little Dolphin α′, β′, γ′, δ′ and ε′ such that they match the labels of the stars in the constellation Delphinus as given on the map.

Label the brightest of these 5 stars “$m_{max}$”.

**2. Determining declination**

The two pictures on the next page show a small asterism, as seen directly on the sky and as a mirror image. Three stars are labelled: S1, S2 and S*x*. The position of the asterism is also marked with a rectangle on the larger-scale map of the sky.

Find this asterism and point your telescope to it.

Using the illuminated reticle as a fixed reference point, and the stopwatch, measure the time taken for the stars S1, S2 and *Sx* to move across the field. You may rotate the eyepiece so that the cross-hairs of the reticle are in the most convenient position for your measurement.

Use your measurements and the known declinations of stars S1 and S2 as given below to determine the declination of star *Sx.*

On the answer sheet, give your measurements and working, and estimate the random error in your result.

For each set of measurements you make, draw the view through the eyepiece on the answer sheet. (Use the blank circular field on the answer sheet.)

Mark the drawing with the compass directions N and E. Draw the reticle and the tracks of the stars to show the motion which you timed using the stopwatch.

Mark the ends of each timed track and show which time measurement refers to which track – for example, for measurement "T1" marking the ends "Start T1" and "End T1".

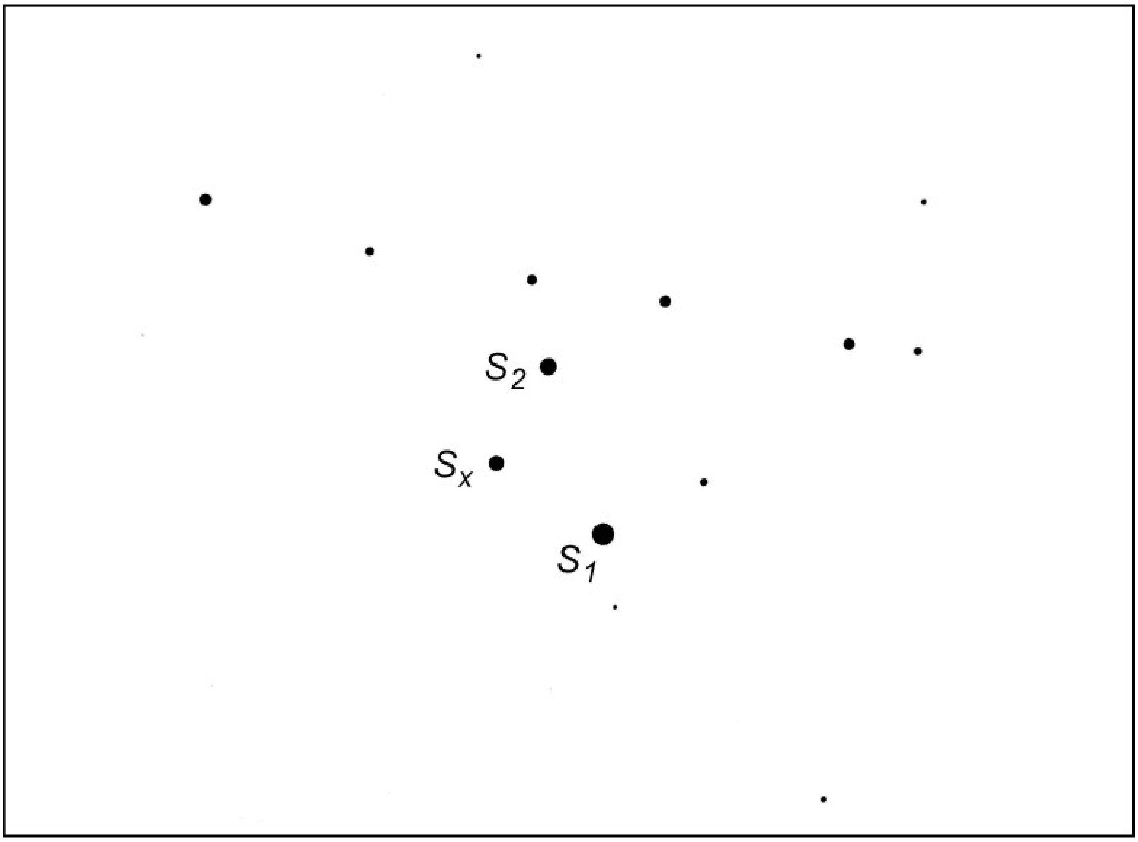
The angle of the reticle can be easily adjusted by rotating the eyepiece around its optical axis. If you change the angle of the reticle for a new measurement, draw a new diagram.

The declinations of the field stars S1 and S2 are :

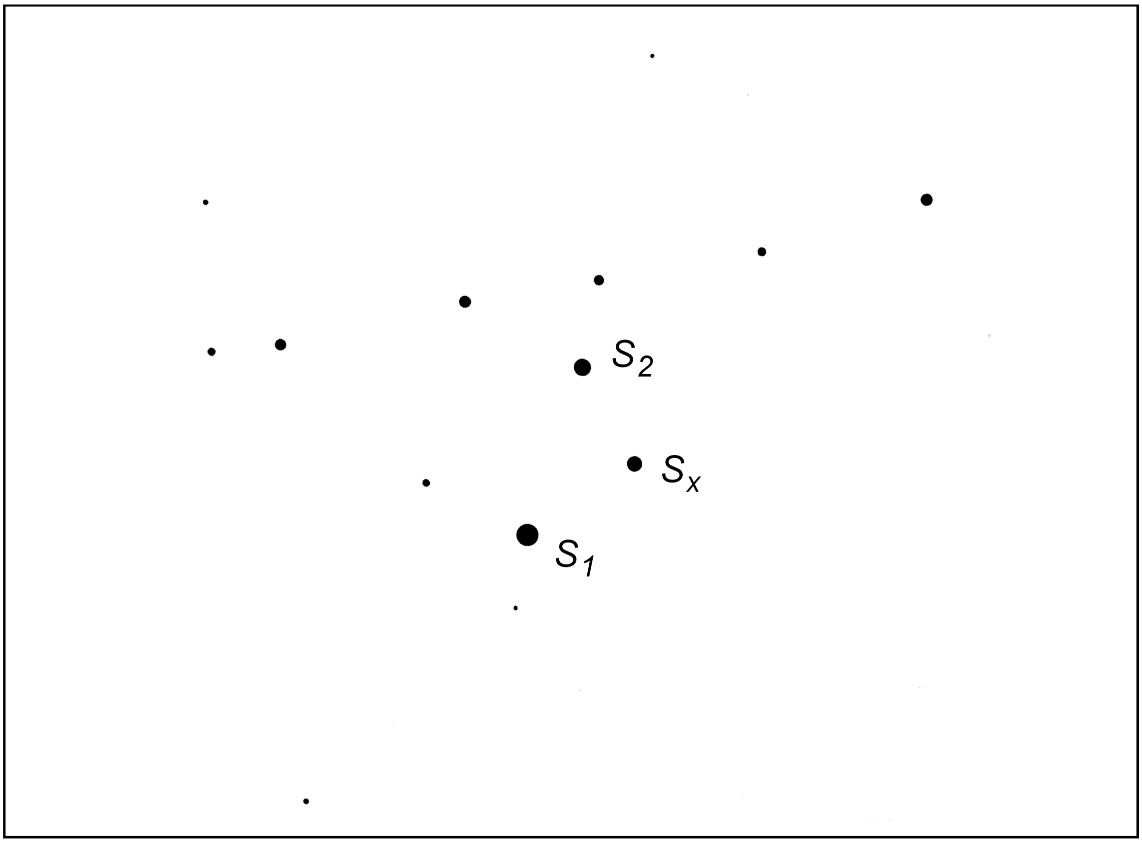
$S_1$ : $\delta = +19^\circ\, 48'\, 18''$ $S_2$ : $\delta = +20^\circ\, 06'\, 10''$

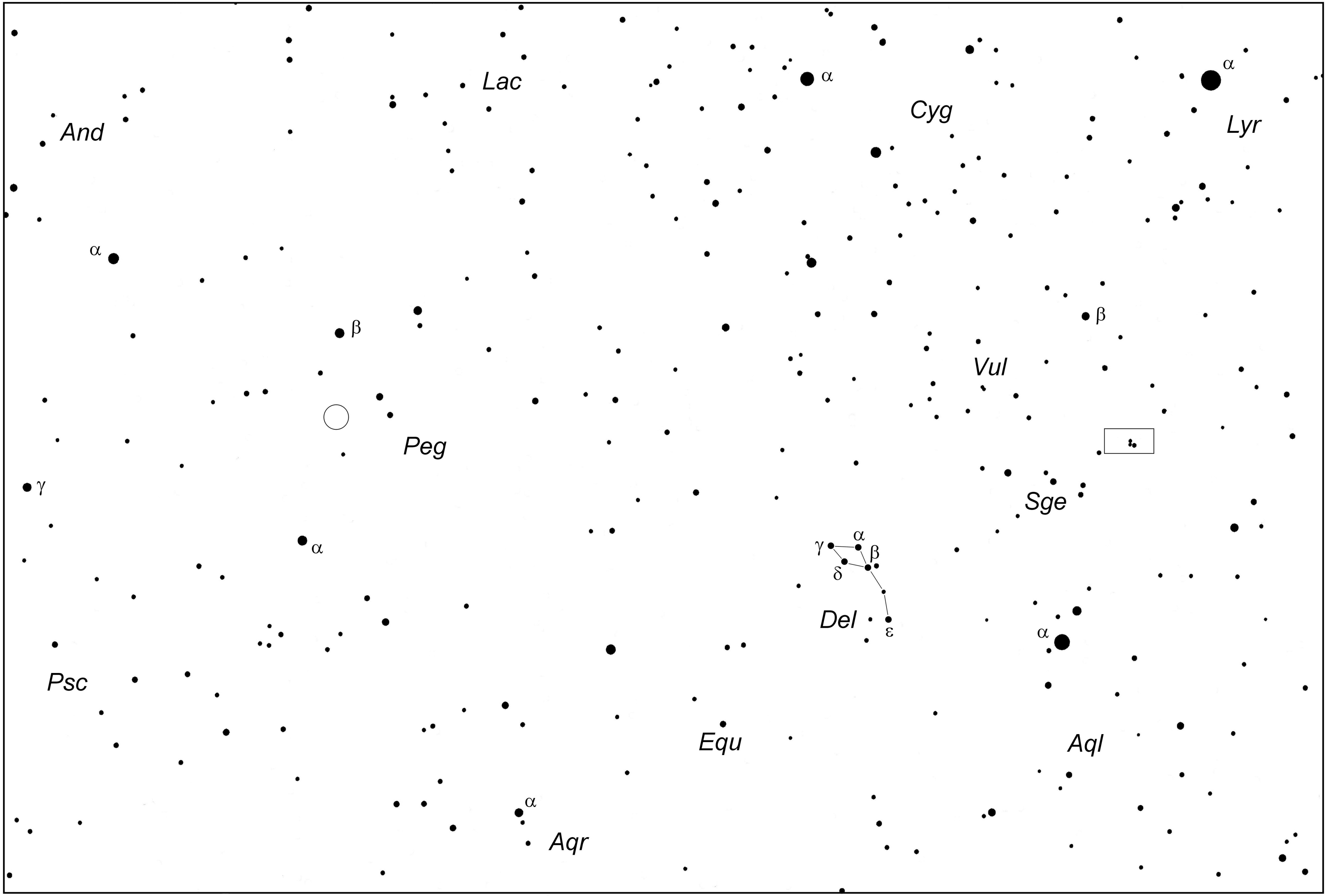
Assume that: $\delta(S_2) > \delta(Sx) > \delta(S_1)$.

Direct view:




Mirror image:




And
Lac
Cyg
Lyr
α
β
Peg
Vul
Sge
γ
δ
Del
ε
Psc
Equ
Aql
Aqr

## Observing competition – planetarium round

### General instructions

1. There are 2 questions, each worth 25 points. You have **80** minutes to solve them, of which :

   (a) **20** minutes for reading the question and preparing for the observations,

   (b) **40** minutes to perform all the observations in the planetarium
   (20 minutes for each questions),

   (c) **20** minutes for calculations and finishing your work.

2. Additional time is allowed to move to and from the planetarium.
3. Along with the questions you will be given a map of the sky, for use with both questions. The map is for epoch J 2000.0, using a polar projection with a linear scale in declination, and covers stars down to about 5$^{th}$ magnitude. You will also be given paper for working and notes, writing implements, a pencil sharpener and an eraser.

   Please take everything from the desk in the first room with you to the planetarium dome, as you will be going to a different room afterwards to finish your work.
4. At your place in the dome you will find a torch and clipboard. Please leave these two items behind for the next contestant.
5. Only answers given in the appropriate places on the question sheet and on the map of the sky will be assessed. The additional worksheets will not be assessed.
6. Clearly mark every page with your code number.

### About the questions

**In Question 1 :**

1. The sky is stationary, the observer is on the surface of the Earth.
2. Visible on the sky are: a comet, the Moon and a nova of about 2$^{nd}$ magnitude.
3. From the 11$^{th}$ minute, a grid representing horizontal coordinates will be projected on the sky, and will remain on until the end of the question.

**In Question 2 :**

1. Four consecutive days on the surface of Mars will be shown.
2. There is a Martian base visible on the horizon.
3. During the Martian daytime the sky will be slightly brightened.
4. The moons of Mars and the other planets will not be displayed.
5. The local meridian will be continuously visible on the sky.

**Note: Azimuth is counted from 0º to 360º starting at S through W, N, E.**

## Observing competition – planetarium round

### 1. Earth

A) On the map of the sky, mark (with a cross) and label the nova (mark it "N") and the Moon (mark it with a Moon symbol) and draw the shape and position of the comet.

B) In the table below, circle only those objects which are above the astronomical horizon. Note: you will lose 1 point for every incorrect answer.

| | | |
|---|---|---|
| M20 – Triffid Nebula | o Cet – Mira | δ CMa – Wezen |
| α Cyg – Deneb | M57 – Ring Nebula | β Per – Algol |
| δ Cep – Alrediph | α Boo – Arcturus | M44 – Praesepe (Beehive Cluster) |

C) When the coordinate grid is visible, mark on the map the northern part of the local meridian (from the zenith to the horizon) and the ecliptic north pole (with a cross and marked "P").

D) For the displayed sky, give the :

geographical latitude of the observer : $\varphi =$ . . . . . . . . . ,

Local Sidereal Time : $\theta =$ . . . . . . . . . ,

time of year, by circling the calendar month :

Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec.

E) Give the names of the objects, whose approximate horizontal coordinates are :

azimuth $A_1 = 45°$ and altitude $h_1 = 58°$ : . . . . . . . . . . . . . . . . . . . . . . . ,

azimuth $A_2 = 278°$ and altitude $h_2 = 20°$ : . . . . . . . . . . . . . . . . . . . . . . . .

(If you can, use Bayer designations, IAU abbreviations and Messier numbers or English or Latin names.)

F) Give the horizontal coordinates (azimuth, altitude) of :

Sirius ($\alpha$ CMa) : $A_3 =$ . . . . . . . . . . . ; $h_3 =$ . . . . . . . . . . . .

The Andromeda Galaxy (M 31) : $A_4 =$ . . . . . . . . . . . ; $h_4 =$ . . . . . . . . . . . .

G) Give the equatorial coordinates of the star marked on the sky with a red arrow :

$\alpha =$ . . . . . . . . . . . . . . . . ; $\delta =$ . . . . . . . . . . . . . . . .

**2. Mars**

H) Give the areographic (Martian) latitude of the observer : $\varphi$ = . . . . . . . . .

I) Give the altitudes of upper ($h_u$) and lower ($h_l$) culmination of :

Pollux (β Gem) : $h_u$ = . . . . . . . . . . ; $h_l$ = . . . . . . . . . . ,

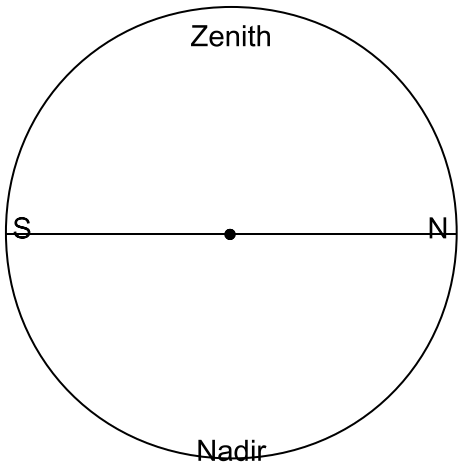
Deneb (α Cyg) $h_u$ = . . . . . . . . . . ; $h_l$ = . . . . . . . . . . ,

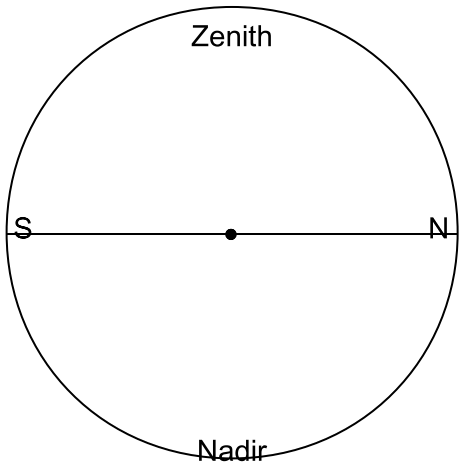
J) Give the areocentric (Martian) declination of :

Regulus (α Leo) $\delta$ = . . . . . . . . . . .

Toliman (α Cen) $\delta$ = . . . . . . . . . . .

K) Sketch diagrams to illustrate your working in questions (I) and (J) above :




L) on the map of the sky, mark (with a cross) and label (“M”) the Martian celestial North Pole.

M) Give the azimuth of the observer as seen from the Martian base :

$A$ = . . . . . . . . . .

N) Estimate the location of the base on Mars, and circle the appropriate description :

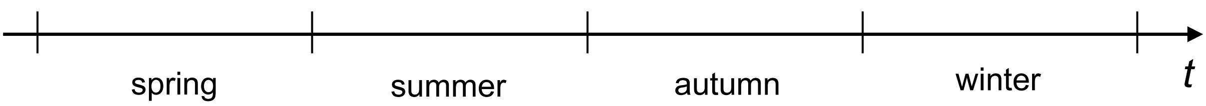
*a.* near the Equator

*b.* near the northern Tropic circle

*c.* near the northern Arctic circle

*d.* near the North Pole

O) The time axis below shows the Martian year and the seasons in the northern hemisphere. Mark the date represented by the planetarium display on the axis.



# The 5th International Olympiad on Astronomy and Astrophysics

## Silesia, Poland

## Data Analysis Round

**Data Analysis questions**

**Instructions**

1. In your envelope you will receive an English and native language versions of the questions.
2. You have 2.5 hours to solve 2 tasks.
3. You can get maximum 25 points for each task.
4. You can use only the pen and tools given on the desk.
5. The solutions of each task should be written on the answer sheets, starting each question on a new page. Only the answer sheets will be assessed.
6. You may use the blank sheets for additional working. These work sheets will not be assessed
7. At the top of each page you should put down your code and task number.
8. If solution exceeds one page, please number the pages for each task.
9. Draw a box around your final answer.
10. Numerical results should be given with appropriate number of significant digits with units.
11. You should use SI or units commonly used in astronomy. Points will be deducted if there is a lack of units or inappropriate number of significant digits.
12. At the end of the test, all sheets of paper should be put into the envelope and left on the desk.
13. In your solution please write down each step and partial results.
14. Graphs for tasks number 1 and 2 should be prepared on the plotting paper.

## Data Analysis questions

### 1. Analysis of times of minima

Figure 1 shows the light curve of the eclipsing binary V1107 Cas, classified as a W Ursae Majoris type.

Table 1 contains a list of observed minima of the light variation. The columns contain: the number of the minimum, the date on which the minimum was observed, the heliocentric time of minimum expressed in Julian days and an error (in fractions of a day).

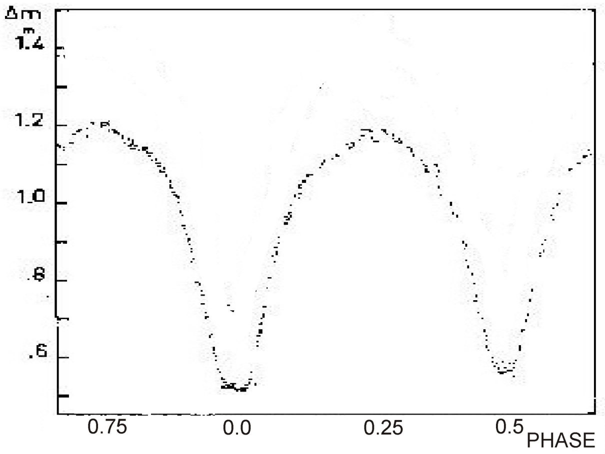



Fig. 1: Light curve of V1107 Cas.

Using these data:

(a) Determine an initial period of V1107 Cas, assuming that the period of the star is constant during the interval of observations. Assume that observations during one night are continuous. Duration of the transit is negligible.

(b) Make what is known as an (O−C) diagram (for "observed − calculated") of the times of minima, as follows: on the $x$-axis put the number of periods elapsed (the "epoch") since a chosen initial moment $M_o$; on the $y$-axis the difference between the observed moment of minimum $M_{obs}$ and the moment of minimum calculated using the formula ("ephemeris"):

$$M_{calc} = M_o + P \times E$$

where $E$, the epoch, is exactly an integer or half-integer, and $P$ is the period in days.

(c) Using this (O−C) diagram, improve the determination of the initial moment $M_o$ and the period $P$, and estimate the errors in their values.

(d) Calculate the predicted times of minima of V1107 Cas given in heliocentric JD occurring between 19h, 1 September 2011 UT and 02h, 2 September 2011 UT.

| No. | Date of minimum (UT) | Time of minimum (Heliocentric JD) | Error |
|---|---|---|---|
| 1 | 22 December 2006 | 2 454 092.4111 | 0.0004 |
| 2 | 23 December 2006 | 2 454 092.5478 | 0.0002 |
| 3 | 23 September 2007 | 2 454 367.3284 | 0.0005 |
| 4 | 23 September 2007 | 2 454 367.4656 | 0.0005 |
| 5 | 15 October 2007 | 2 454 388.5175 | 0.0009 |
| 6 | 15 October 2007 | 2 454 388.6539 | 0.0011 |
| 7 | 26 August 2008 | 2 454 704.8561 | 0.0002 |
| 8 | 5 November 2008 | 2 454 776.4901 | 0.0007 |
| 9 | 3 January 2009 | 2 454 835.2734 | 0.0007 |
| 10 | 15 January 2009 | 2 454 847.3039 | 0.0004 |
| 11 | 15 January 2009 | 2 454 847.4412 | 0.0001 |
| 12 | 16 January 2009 | 2 454 847.5771 | 0.0004 |

Table 1: Observed times of minima of V1107 Cassiopeae

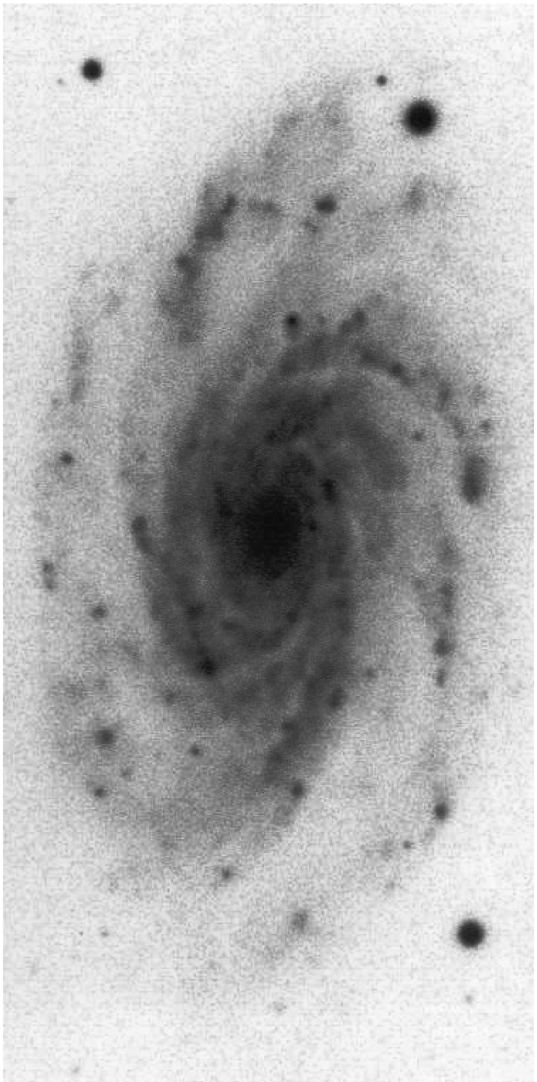
**2. Weighing a galaxy**

The attached images show a photograph of the spiral galaxy NGC 7083, which lies at a distance of 40 Mpc, and a fragment of its spectrum. The slit of the spectrograph was aligned with the major axis of the image of the galaxy. The $x$-axis of the spectrum represents wavelength, and the $y$-axis represents the angular distance of the emitting region from the core of the galaxy, where 1 pixel = 0.82 arcsec. Two bright emission lines are visible, with rest wavelengths of $\lambda_1 = 6564$ Å, $\lambda_2 = 6584$ Å.

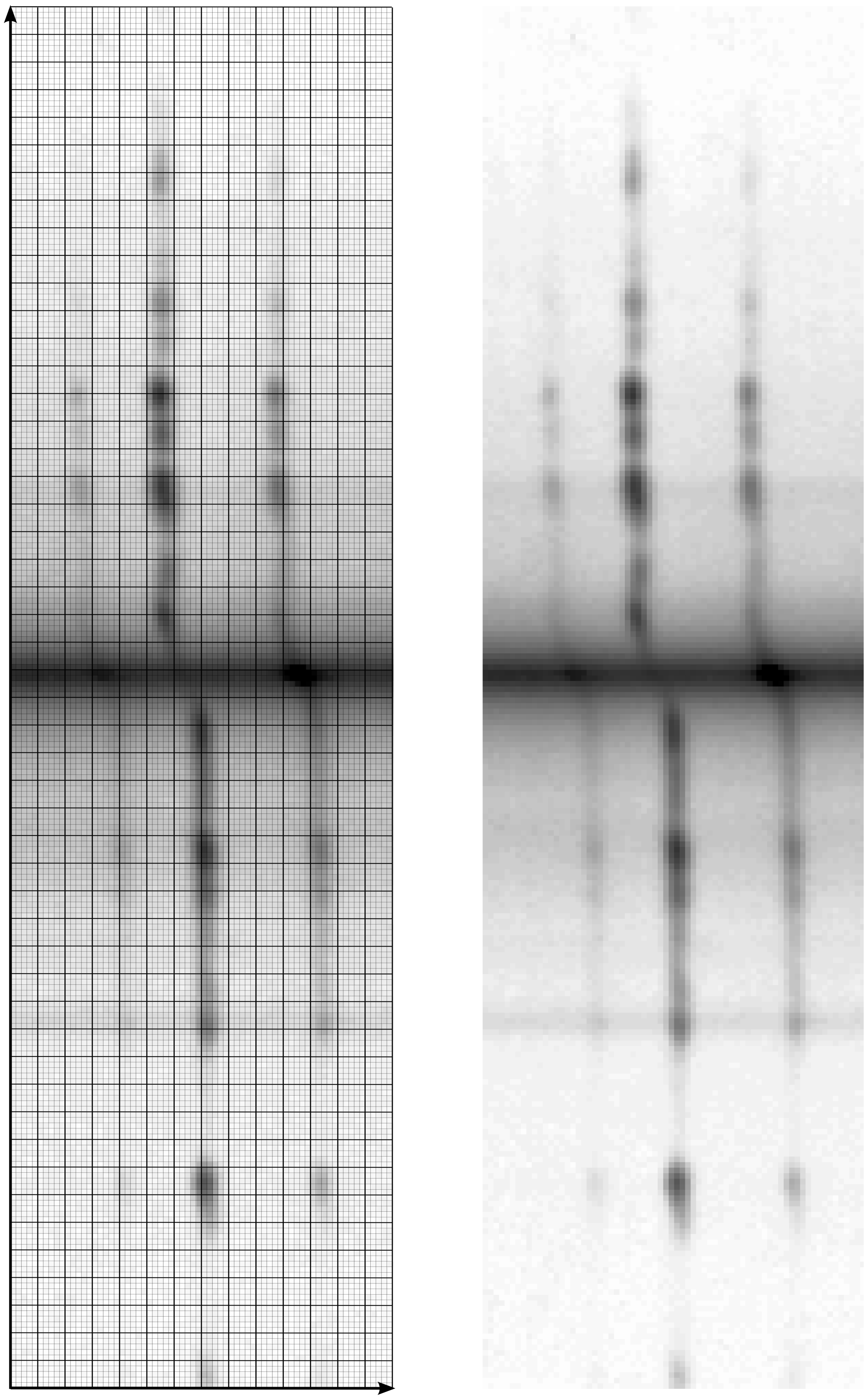
Use the spectrum to plot the rotation curve of the galaxy and estimate the mass of the central bulge.

Assumption: central bulge is spherical.

The photograph of the galaxy has the correct proportions.



*NGC 7083*



*Spectrum of NGC 7083. Grid marks pixels.*

# The 5th International Olympiad on Astronomy and Astrophysics

## Silesia, Poland

## Group Round

**Group competition rules**

1. Teams consisting of three or more students can participate in the group competition.
2. The team will be given a set of 5 problems to solve in 60 minutes.
3. The team's result is decided by the sum total of the points obtained for all 5 problems. Up to 20 points can be obtained for each problem. The team can gain extra points by handing in their solutions to all 5 problems before the end of the allotted 60 minutes, and will lose points for time taken beyond the 60 minutes, as follows:
4. If, at the moment the team's solutions are handed in, $n$ full minutes are left before the allotted time, then the sum total of the points obtained by the team for their solutions will be multiplied by a factor

$$k = 1 + n/100,$$

thus the team gets an extra 1% of their total result for every minute saved.

5. If the team hand in their solutions $n$ full minutes after the allotted 60 minutes have passed, the sum total of the points obtained by the team of the team will be multiplied by the factor

$$k = 1 - n/100,$$

thus the team will lose 1% of their result for every minute used beyond the allotted time.

6. The team with the most points after adjustment for time wins.
7. Every student of the winning team will be given a prize and gold medal of the group competition.

**Additional Instructions**

1. You may complete the questions in any order and using any combination of team members working individually or together.
2. Hand your answers in when you have finished working on <u>all</u> of the problems.
3. A team combined from two countries will receive all of the questions in both languages, but should complete and hand in no more than <u>one</u> version of each question.
4. For question 1, mark your answers on the maps provided. For question 3, mark your answers on the question sheet in the appropriate places. For questions 2 and 4 please use the attached answer sheets. For question 5 mark the card.

## Group competition

### 1. Constellations

Jan Hevelius (1611–1687) introduced 11 new constellations onto the sky. The International Astronomical Union confirmed 7 of those in 1928:

| Serial No. | IAU Abbreviation | Latin name | Translation | Equatorial coordinates of the centre of the constellation | |
|---|---|---|---|---|---|
| | | | | Right ascension $\alpha$ | Declination $\delta$ |
| 1 | CVn | Canes Venatici | Hunting dogs | $13^h\,00^m$ | $+40^o$ |
| 2 | Lac | Lacerta | Lizard | $22^h\,30^m$ | $+46^o$ |
| 3 | LMi | Leo Minor | Smaller Lion | $10^h\,10^m$ | $+32^o$ |
| 4 | Lyn | Lynx | Lynx | $8^h\,00^m$ | $+48^o$ |
| 5 | Sct | Scutum | Shield | $18^h\,40^m$ | $-10^o$ |
| 6 | Sex | Sextans | Sextant | $10^h\,15^m$ | $-3^o$ |
| 7 | Vul | Vulpecula | (Little) Fox | $20^h\,15^m$ | $+24^o$ |

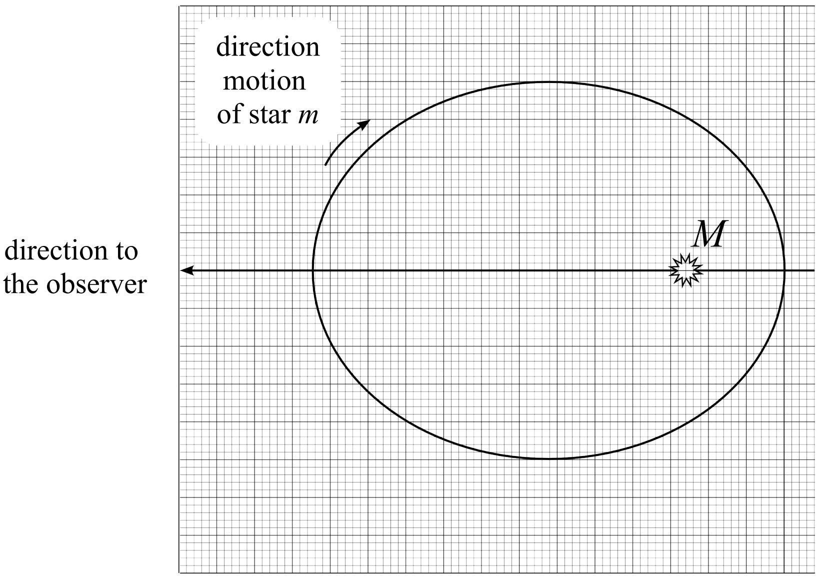
(a) For each of the above constellations, clearly mark on the attached map a point lying anywhere within the constellation, using the appropriate serial number or IAU name.

(b) On the same map, clearly mark (using a cross or arrow) the positions of any 13 objects from the Messier Catalogue (not necessarily from the constellations above), giving the Messier number (“M *xx*”) for each.

The map is prepared for epoch J 2000.0 and uses a polar projection with a linear scale in declination. It includes stars brighter than about 5th magnitude.

**2. Orbital motion**

The scale diagram below represents the relative orbit of a physically double star:




A star of mass $m$ moves around a star of mass $M$ in the indicated direction, where $m \ll M$. The major axis of the ellipse is aligned with the direction to the observer, and the motion of the star is in the plane of the diagram.

(a) Find the part of the ellipse where the angular velocity $\omega$ of star $m$ is less than its mean angular velocity $\langle\omega\rangle$, and indicate this as accurately as possible on the scale diagram on the answer sheet.

<u>Note</u>: The instantaneous angular velocity $\omega$ of star $m$ is equal to the mean angular velocity $\langle\omega\rangle$ when the distance between stars $r = \sqrt{(ab)}$ , where $a$ and $b$ are the semi-axes of the orbit.

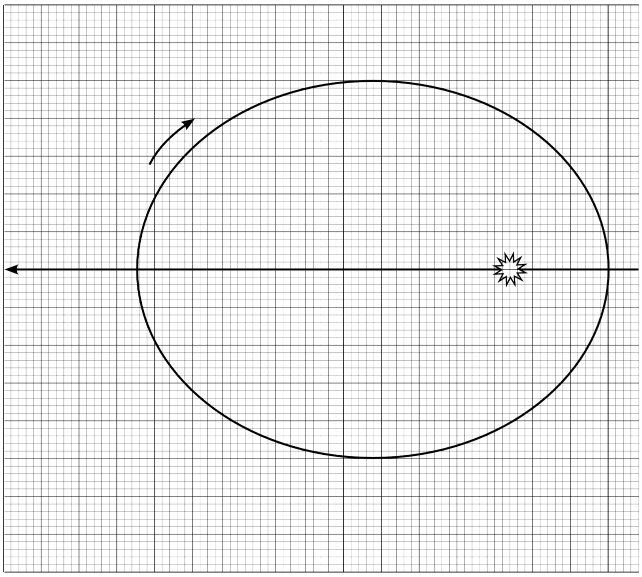
Also mark those places on the ellipse for which the observer will see:

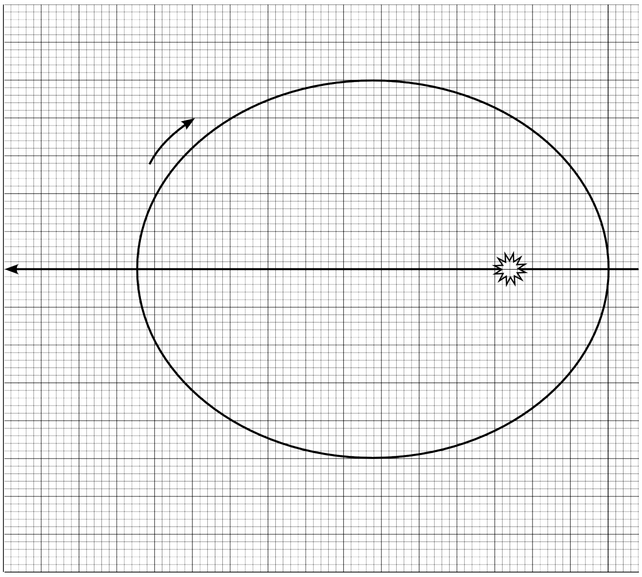
(b) extreme tangential (perpendicular to line of sight) velocity: $\boldsymbol{v}_{t\,\max}$ and $\boldsymbol{v}_{t\,\min}$ ,

(c) extreme radial (parallel to line of sight) velocity: $\boldsymbol{v}_{r\,\max}$ and $\boldsymbol{v}_{r\,\min}$ .

(You may use one or both of the diagrams on the answer sheet to show your answer.)

Answer sheet for Question 2





Answer sheet for Question 2

**3. Identifying telescope components**

(a) Look at the pictures of the telescope and match the names of the items with the corresponding letters. Write your answers in the table below:

| Item name | Letter | Points |
|---|---|---|
| *(example)* Tripod | **M** | 0 |
| 1. Counterweight | | |
| 2. Right Ascension Setting Circle (R.A. Scale) | | |
| 3. Declination Setting Circle (Declination Scale) | | |
| 4. Right Ascension locking knob | | |
| 5. Declination locking knob | | |
| 6. Geographical latitude scale | | |
| 7. Finder scope | | |
| 8. Focuser tube | | |
| 9. Focuser knob | | |
| 10. Eyepiece | | |
| 11. Declination Axis | | |
| 12. Right Ascension Axis (Polar Axis) | | |
| 13. Right Ascension slow motion adjustment | | |
| 14. Declination flexible slow motion adjustment | | |
| 15. 90$^{\circ}$ diagonal mirror | | |
| 16. Azimuth adjustment knobs | | |
| 17. Altitude adjustment screws | | |
| 18. Lock screw | | |
| 19. Spirit level bubble | | |
| 20. Eyepiece reticle light – on/off switch & brightness control | | |

(b) Select and circle the correct answer for each of the questions below:

21. Mount design :

*a*. Fork *b*. Transit *c*. Dobsonian Alt-Azimuth *d.* German Equatorial

22. Optical type :

*a*. Newtonian *b*. Cassegrain *c*. Keplerian *d.* Galilean

23. Objective aperture :

*a.* 60 mm *b.* 80 mm *c.* 90 mm *d.* 100 mm

and objective lens focal length :

*a.* 400 mm *b.* 500 mm *c.* 600 mm *d.* 800 mm

24. Eyepiece focal length :

*a.* 4 mm *b.* 6 mm *c.* 12.5 mm *d.* 25 mm

25. Used for visual observations of the sky, the finder scope gives a picture which is :

*a*. normal *b*. rotated by 180º *c*. reflected in one axis *d*. rotated by 90º

26. Used for visual observations **with** the diagonal mirror, the instrument gives a picture which is :

*a*. normal *b*. rotated by 180º *c*. reflected in one axis *d*. rotated by 90º

(c) Determine the following theoretical instrument parameters

27. Magnification : ______________________________

28. Focal ratio : ______________________________

29. Resolution : ______________________________
(in arcseconds)

30. Limiting magnitude: ______________________________

**4. Minimum of an eclipsing binary**

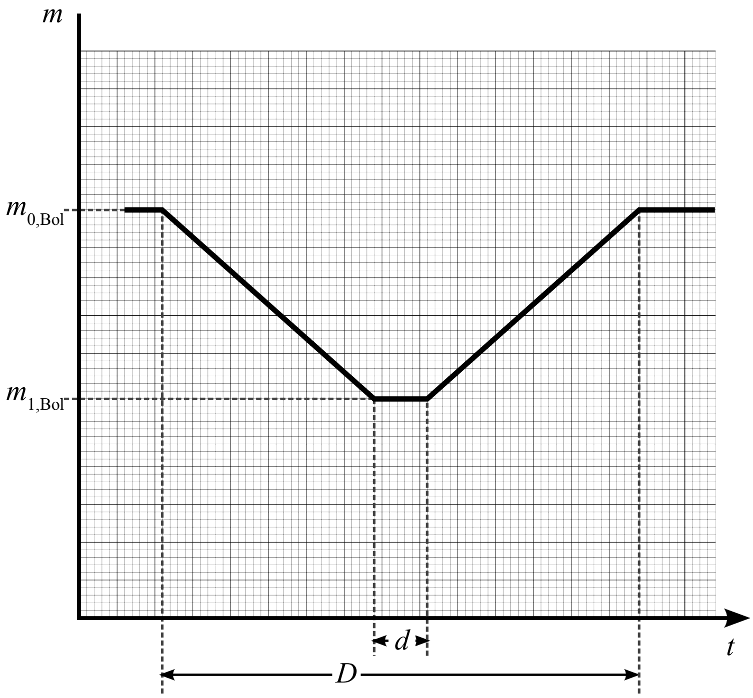
The figure shows the secondary (shallower) minimum of the bolometrically - corrected light curve of an eclipsing binary star. The difference between magnitudes $m_{1,Bol} - m_{0,Bol} = 0.33$ magnitude.

We also know from simultaneous spectroscopy that the star with the smaller radius was totally eclipsed by the larger star during the secondary minimum (since only one spectrum was observable during the minimum).

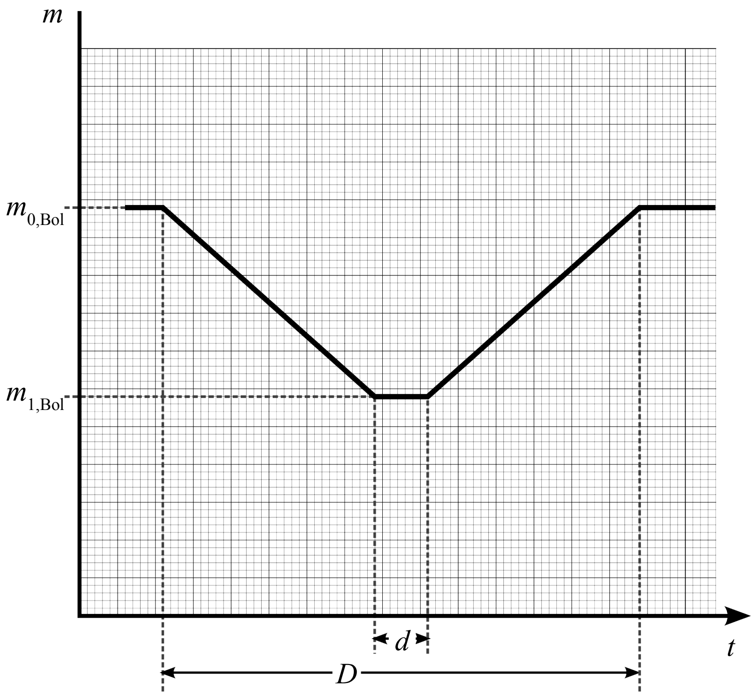
Determine the change of brightness of this binary during the primary minimum and draw the shape of the primary minimum using the same scale as the secondary minimum. Label the graph with all appropriate parameters.

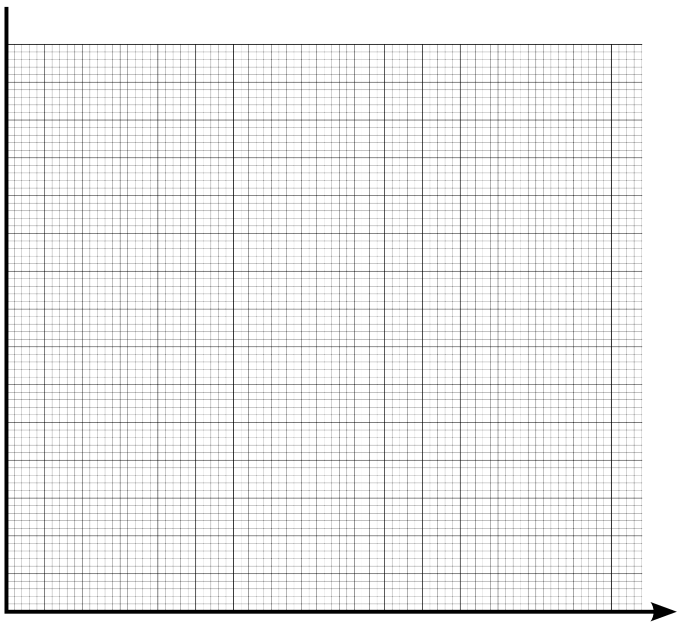
Use the answer sheets (one blank, one with the light curve plots) for your final answers.

You may assume that the eclipses are central, that the stars are spheres of constant surface brightness, and that the distance between the stars does not change.



Answer sheet for Question 4



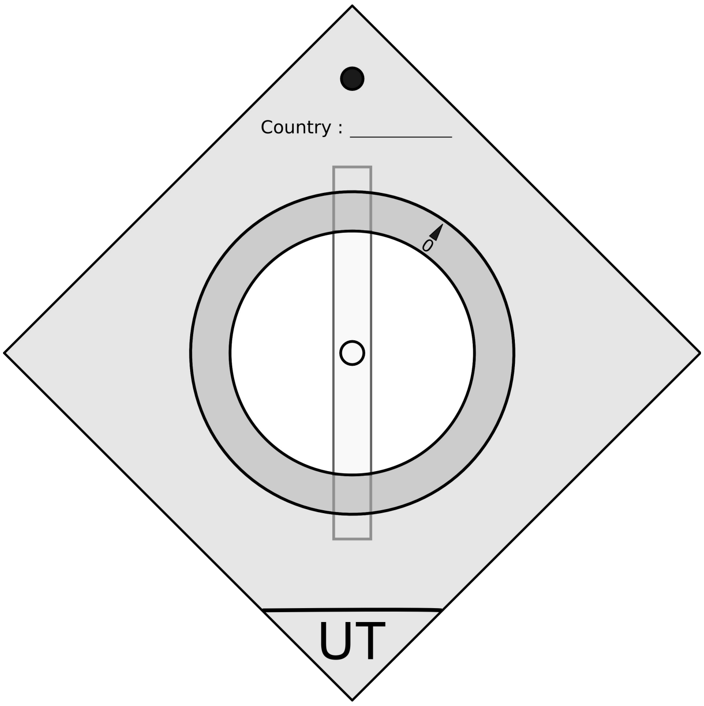



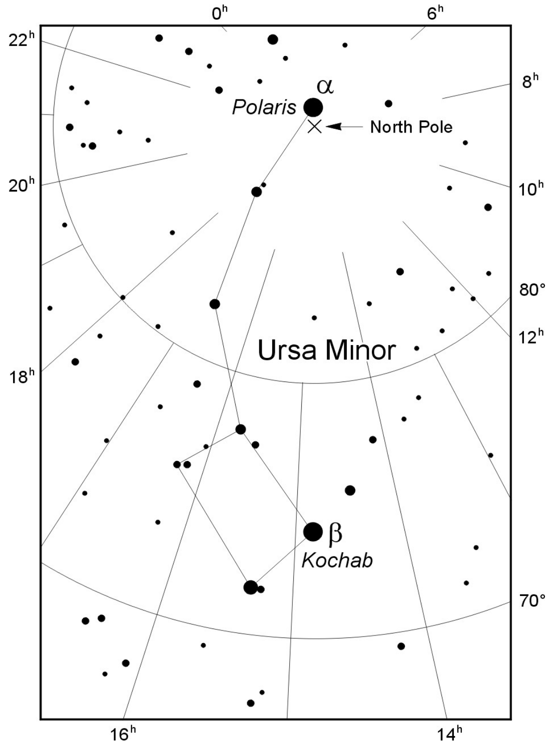
Answer sheet for Question 4

**5. Nocturnal**

Circumpolar stars describe a full circle around the Celestial Pole over 24 hours. This can be used to make a simple clock.

You are given a blank card with a movable ring, along with a clear strip with a centre circle. If the card has a suitable scale, the clear strip is attached as in the diagram below and the Pole Star is visible through the centre circle, then the position of the star Kochab (β UMi) on the inner edge of the ring will give the current time.




Design and mark on the card and ring suitable inner and outer scales (as required) such that, in Katowice for any night of the year, the side of the clock marked "UT" can be used to show current Universal Time, and the other side (marked "ST") can be used independently to show current Local Sidereal Time.

For 27 August in Katowice, the lower culmination of Kochab is at 05:15 Central European Summer Time (UT+2). The coordinates of Kochab (β UMi) are : $\alpha$: $14^h\ 51^m$, $\delta$: $+74.2^\circ$.

Notes: – The blank card is marked with a line which should be held horizontally when the device is used.

– The clear strip will be attached later, after you have finished and handed in the card. For now it is left off so that it does not get in your way when making the scale.