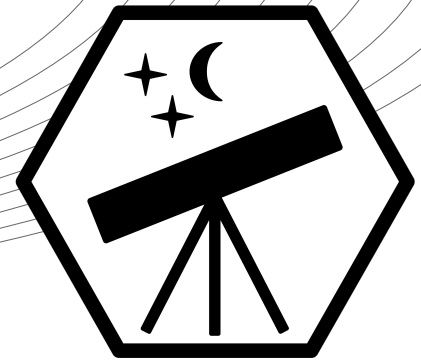


International Astronomy and Astrophysics Competition

Pre-Final Round 2023



Important: Read all the information on this page carefully!

General Information

- We recommend to print out this problem sheet. Use another paper to draft the solutions to the problems and write your final solution (with steps) on the provided space below the problems.
- You may use extra paper if necessary, however, the space under the problems is usually enough.
- Typing the solution on a computer is allowed but not recommended (no extra points).
- The six problems are separated into three categories: 2x basic problems (A; four points), 2x advanced problems (B; six points), 2x research problems (C; eight points). The research problems require you to read a short scientific article to answer the questions. There is a link to the PDF article.
- You receive points for the correct solution **and** for the performed steps. Example: You will not get all points for a correct value if the calculations are missing.
- Make sure to clearly mark your final solution values (e.g. underlining, red color, box).
- You can reach up to 36 points in total. You qualify for the final round if you reach at least 18 points (junior, under 18 years) or 24 points (youth, over 18 years).
- It is not allowed to work in groups on the problems. Help from teachers, friends, family, or the internet is prohibited. Cheating will result in disqualification! (Textbooks and calculators are allowed.)

Uploading Your Solution

- Please upload a file/pictures of (this sheet with) your written solutions: <https://iaac.space/login>
- Only upload **one single PDF file!** If you have multiple pictures, please compress them into one single file. Do not upload your pictures in a different format (e.g. no Word and Zip files).
- The deadline for uploading your solution is **Sunday 28. May 2023, 23:59 UTC+0.**
- The results of the pre-final round will be announced on Monday 5. June 2023.

Good luck!

Problem A.1: Parabolic Trajectory (4 Points)

As presented in the qualification round, the comet *P/2023 IAAC* circles the Sun in an elliptical orbit. There are other comets with a parabolic trajectory, for example the comet *C/2023 IAAC*.

(a) Explain the meaning of the letters *P* and *C* in the names of the two comets.

The *vis-viva-equation* can be extended for different types of trajectories as follows:

$$v(x) = \sqrt{\mu \left(\frac{2}{x} - \frac{1}{a} \right)} \quad \text{with} \quad \begin{array}{ll} a > 0 & \text{for ellipses} \\ a = \infty & \text{for parabolas} \\ a < 0 & \text{for hyperbolas} \end{array}$$

and $\mu = G(m_1 + m_2)$. Here, m_1 is the comet's mass, m_2 the Sun's mass (1.9×10^{30} kg), x the distance between the comet and the Sun, and G is the gravitational constant ($6.67 \times 10^{-11} \text{ m}^3\text{kg}^{-1}\text{s}^{-2}$).

(b) Determine the velocity (in km/s) of *C/2023 IAAC* for a distance of 0.8 AU to the Sun.

Problem A.2: Brightness of a Binary Star (4 Points)

A binary star system consists of two stars very close to one another. The two stars have apparent magnitudes of $m_1 = 2$ and $m_2 = 3$. The apparent magnitude m is defined with a stars' flux density F , compared to a reference star with m_0 and F_0 :

$$m - m_0 = -2.5 \log_{10} \left(\frac{F}{F_0} \right)$$

Calculate the total apparent magnitude of the binary star system.

Problem B.1: Temperature of the Sun (6 Points)

Assume a constant density $\bar{\rho}$ of $1.4 \times 10^3 \text{ kg}\cdot\text{m}^{-3}$ for the entire Sun. The ideal gas law states that

$$pV = NkT$$

with the pressure p , the volume V , the number of particles N , the Boltzmann constant k ($1.38 \times 10^{-23} \text{ m}^2\text{kg s}^{-2}\text{K}^{-1}$) and the temperature T .

(a) Show that the temperature T at a certain pressure p is given by

$$T(p) = \frac{p\bar{m}}{\rho k}$$

with the average particle mass \bar{m} within the Sun ($1.02 \times 10^{-27} \text{ kg}$).

(b) Explain why the Sun must be in a state of *hydrostatic equilibrium*:

$$\frac{dp}{dr} = -g(r)\bar{\rho}$$

(c) Find the gravitational acceleration $g(r)$ at a radius r from the Sun's center.

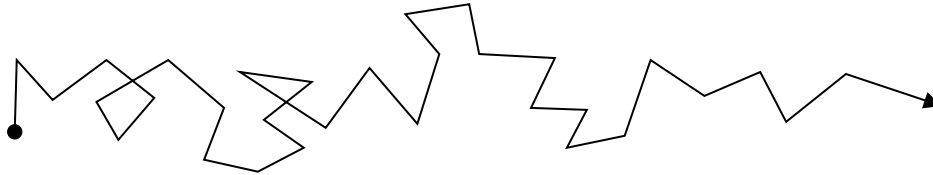
(d) Use the condition of hydrostatic equilibrium to show that the pressure p inside the Sun at a radius of $R/4$ from the centre is about $1.26 \times 10^{14} \text{ Pa}$, where R is the Sun's radius of $0.7 \times 10^9 \text{ m}$.

(e) Determine the Sun's temperature at a radius of $R/4$. Why is this result only a broad estimate?

(extra page for problem B.1: Temperature of the Sun)

Problem B.2: Escaping a Star (6 Points)

It takes many years for a photon produced in a star's centre to reach its surface and escape into space. This is due to its constant interaction with other particles. To estimate the time it takes for a photon to escape a star's interior, we assume that the photon is deflected in equal time intervals into a random direction in a two-dimensional space (i.e., a random walk):



At each step i , the photon moves a constant distance ε in an angle φ_i , thus changing its position:

$$\Delta \vec{x}_i = \varepsilon \begin{pmatrix} \cos(\varphi_i) \\ \sin(\varphi_i) \end{pmatrix}$$

(a) Determine the distance $R(n)$ from the centre $(0,0)$ after n steps.

Assume that the step-distance ε is about 1.0×10^{-4} m for a photon moving inside the Sun:

(b) How many steps does the photon need to reach the Sun's surface?

(c) Estimate the time it takes for the photon to escape into space (in years).

(extra page for problem B.2: Escaping a Star)

Problem C.1 : Zhurong Rover Mars Landing (8 Points)

This problem requires you to read the following recently published scientific article:

Geomorphic contexts and science focus of the Zhurong landing site on Mars.

Liu, J., Li, C., Zhang, R. et al. Nat Astron 6, 65–71 (2022).

Link: <https://www.nature.com/articles/s41550-021-01519-5.pdf>

Answer the following questions related to this article:

(a) What was done to find a suitable landing site and which factors were considered?

(b) Describe three geomorphic features present near the landing site.

(c) Which features described in (b) are likely related to volcanism?

(d) Name all instruments on board the Zhurong rover and explain the purpose of MarSCoDe.

(e) Which instrument measures the magnetic field and for which scientific reason?

(f) What is possible evidence for ancient oceans that the Zhurong rover may find?

Problem C.2 : Young Stars in the Galactic Centre (8 Points)

This problem requires you to read the following recently published scientific article:

Detection of an excess of young stars in the Galactic Centre Sagittarius B1 region.

Nogueras-Lara, F., Schödel, R. & Neumayer, N. Nat Astron 6, 1178–1184 (2022).

Link: <https://www.nature.com/articles/s41550-022-01755-3.pdf>

Answer the following questions related to this article:

(a) How high is the star formation rate in the Galactic Center and how was it estimated?

(b) What is the *missing clusters problem*?

(c) What is the K_s luminosity function?

(d) How do the regions in Figure 4 compare to each other?

(e) Why is it hard to determine the location of where the young stars formed?

(f) What do the findings tell us about the evolution of the young stars?