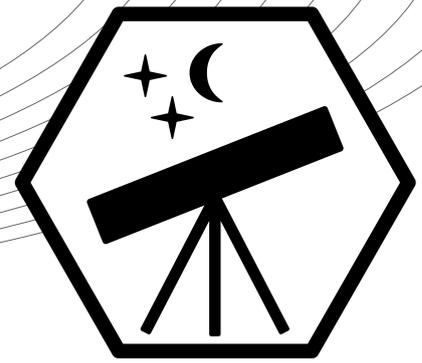# International Astronomy and Astrophysics Competition
Pre-Final Round 2024

Important: Read all the information on this page carefully!

General Information

- We <u>recommend</u> 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 <u>not</u> 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 <u>not</u> 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, <u>no</u> Word and Zip files).

- The deadline for uploading your solution is **Sunday 2. June 2024, 23:59 UTC+0**.

- The results of the pre-final round will be announced on Monday 10. June 2024.

**Good luck!**

Problem A.1: Rotation of the Earth (4 Points)

Rockets allow us to launch spacecraft and satellites into space, which are an essential part of our modern world. However, rocket launches need careful planning, and some places on Earth provide better launch conditions than others.

(a) Explain why most rocket launches take place close to the equator.

(b) Find an equation $v(\varphi)$ that calculates the rotational speed v of the Earth at latitude φ.

(c) Calculate the rotational speed at 5°S (near the equator) and 80°N (near the pole).

Note: The Earth's radius is 6371 km.

Problem A.2: Altitude of the ISS – Part 1 (4 Points)

The International Space Station (ISS) does not orbit the Earth at a perfectly constant altitude. Instead, the ISS changes its altitude over time due to collisions with atmospheric particles (downwards) and boosters that are used to adjust the orbit (upwards). The diagram below displays the ISS's altitude above the ground for the last months (December 2023 to April 2024).[1]
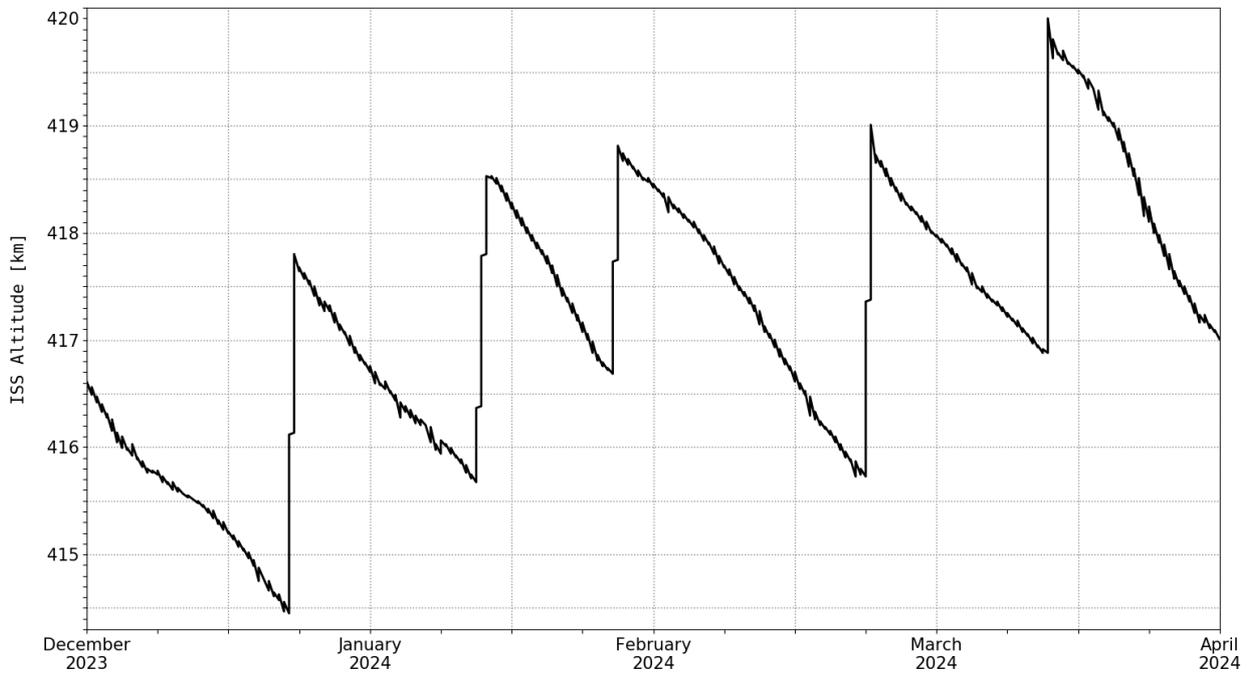
(a) How much did the ISS descend and ascend between December 2023 and April 2024?

(b) Determine the average *rate of descent* of the ISS.

Space is often considered to start at an altitude of 100 km above ground (the *edge of space*).

(c) How long would it take for the ISS to naturally descend to the *edge of space*?

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[1]A high-resolution version of the diagram is available online: https://iaac.space/A2-AltitudeISS.png

Problem B.1: Altitude of the ISS – Part 2 (6 Points)

As mentioned in Problem A.2, the ISS loses altitude due to the collision with atmospheric particles. This causes the ISS to experience a drag force F_d according to the drag equation

$$F_d = \frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot v^2$$

with the atmospheric density ρ, the dimensionless drag coefficient C_d, the ISS's cross-sectional area A, and the ISS's speed relative to the particles v.

Use the rate of descent from Problem A.2 to estimate
  (a) the atmospheric density ρ at the current position of the ISS and
 (b) the total amount of matter (in kg) which collides with the ISS every day.

Note: The following constants may be helpful: the gravitational constant: 6.67 x 10^{-11} m^{3}kg^{-1}s^{-2}, the mass of Earth: 5.97 x 10^{24} kg, the drag coefficient of the ISS: 1.3, the cross-sectional area of the ISS: 4800 m^2, the total mass of the ISS: 450 tons.

(extra page for problem B.1: Altitude of the ISS – Part 2)

Problem B.2: Stars in the Milky Way (6 Points)

In Problem B of the Qualification Round, you estimated the number of stars in the Milky Way by assuming a constant density of stars throughout the galaxy. However, the density of stars is not constant and varies significantly across different regions.

(a) Name the three regions A, B, C marked in the horizontal Milky Way drawing below.
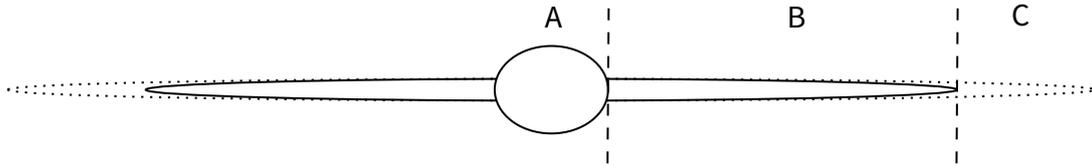
Scientists have developed a basic model for the Milky Way to describe the density distribution of stars $\rho(r)$ at distance r from the center by evaluating the three regions A, B, C:

$$\rho(r) = \Psi \cdot \left[\exp\left(\Omega_A - \frac{r}{R_A} \right) + \exp\left(\Omega_B - \frac{r}{R_B} \right) + \exp\left(\Omega_C - \frac{r}{R_C} \right) \right]$$

The model parameters have the values below:

$\Psi = 10^{-4}$ *stars/(light-year)³*
$R_A = 20$ *light-years*
$R_B = 12 \cdot 10^3$ *light-years*
$R_C = 5 \cdot 10^4$ *light-years*
$\Omega_A = 21, \ \Omega_B = -3, \ \Omega_C = -8$

(b) Create a *double logarithmic* plot of the density distribution $\rho(r)$ with respect to r.

(c) Using this model, calculate the number of stars in the Milky Way ($r \leq 130{,}000$ light-years).

Note: Assume that the Milky Way has a constant thickness of 1,000 light-years.

(extra page for problem B.2: Stars in the Milky Way)

Problem C.1 : Einstein Ring around Galaxy (8 Points)

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

A massive compact quiescent galaxy at z = 2 with a complete Einstein ring in JWST imaging.
van Dokkum, P., Brammer, G., Wang, B. et al. Nat Astron 8, 119-125 (2024).
Link: https://www.nature.com/articles/s41550-023-02103-9.pdf

Answer the following questions related to this article:

(a) What kind of object is the article about, and how was it discovered?

(b) Describe all elements visible in Figure 1a, including the names JWST-ER1g and JWST-ER1r.

(c) Find the galaxy's age, mass, and radius and compare them to our Milky Way.

(d) According to the study, what is and what is not likely to cause the lensing mass?

(e) Explain what the IMF is by using Figure 3a.

(f) Why is the ring in Figure 1a a gravitational lens and not a ring galaxy?

Problem C.2 : Volcanic Activity on Io (8 Points)

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

Io's polar volcanic thermal emission indicative of magma ocean and shallow tidal heating.
Davies, A.G., Perry, J.E., Williams, D.A. et al. Nat Astron 8, 94-100 (2024).
Link: https://www.nature.com/articles/s41550-023-02123-5.pdf

Answer the following questions related to this article:

(a) What is different about the presented observations compared to previous studies?

(b) Explain how the north pole, south pole and the lower latitudes differ in volcanic activity.

(c) What is Loki Patera and Tvashtar Paterae?

(d) How many hot spots did the researchers find in the north and south polar caps?

(e) According to the study's findings, which mechanism likely causes Io's volcanic activity?

(f) Describe how the scientists identified hot spots from the observation pixel data.