International Astronomy and Astrophysics Competition
Pre-Final Round 2025

Important: Read all the information on this page carefully!

General Information

- The six problems are separated into three categories: 2x basic problems (A; 4 points), 2x advanced problems (B; 6 points), 2x research problems (C; 8 points). The research problems require you to read a short scientific article to answer the questions. A link to the PDF article is provided.
- You can write your solution in the blank space under the problems or type your solution digitally on a computer. If you need more space for your solution, you can use extra sheets of paper.
- You receive points for the correct solution as well as for the performed steps. That means: You will not get full points for a correct value if the calculations and steps are missing.
- Make sure to **clearly** mark your final solution values (e.g., by underlining, red color, box).
- You can reach up to 36 points in total. You qualify for the Final Round if you reach at least 16 Points (Junior), 20 points (Youth), or 24 points (Senior).
- It is not allowed to work in groups. Assistance from teachers, friends, family, or the internet is prohibited. Textbooks and calculators are allowed. Cheating will result in immediate disqualification!

Uploading Your Solution

- Please upload a PDF document containing clear pictures of the problem sheet pages with your written solutions in the blank space, or upload a digitally typed document.
- You can upload your solution online via your account: https://iaac.space/login
- Only upload **one single PDF file!** If you have multiple pictures, please merge them into one file. Do not upload your solution in any different format. (Example: No Word or Zip files.)
- The submission deadline is **Sunday, 17 August 2025, 23:59 UTC+0**.
- The results of the Pre-Final Round will be announced on Monday, 1 September 2025.

Good luck!

Problem A.1: Scales of Gravitation (4 Points)

Every object around us exerts a gravitational force: from small items nearby to massive celestial bodies in our solar system and beyond. In this problem, you will compare the gravitational effects of various objects. For this comparison, assume your mass is 70 kg.

(a) Determine the gravitational force (in Newton [N]) between you and the following objects:

	Distance	**Mass**	**Force**
Another Person	1 m	70 kg	
Truck on the Street	3 m	30,000 kg	
Moon	385,000 km	7.3×10^{22} kg	
Jupiter	780×10^{6} km	1.9×10^{27} kg	
Alpha Centauri A	4.37 light-years	1.1 $M_\odot$	
Andromeda Galaxy	2.5×10^{6} light-years	1.5×10^{12} $M_\odot$	

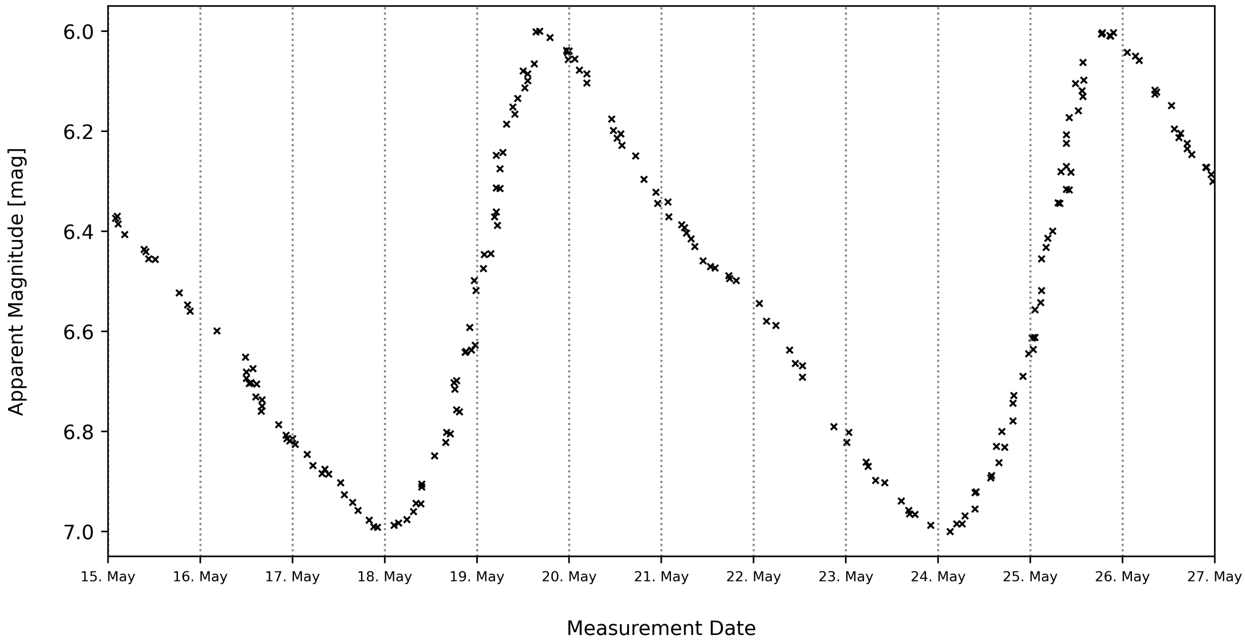
Notes: Express results in exponential format (e.g., 2×10^{-3} N). One solar mass $M_\odot = 2 \times 10^{30}$ kg.

(b) Rank the objects from strongest to weakest gravitational effect on you.

(c) Which objects have a very similar force despite being of much different scale?

Problem A.2: Variable Star (4 Points)

In May 2025, a research team observed a section of the night sky continuously for several days. One star appears to change its brightness. Here is a plot of its apparent magnitude:



Stars with such a behaviour are called *Cepheids* and their absolute magnitude M can be calculated by applying the *Leavitt Law (Period–Luminosity relation)*

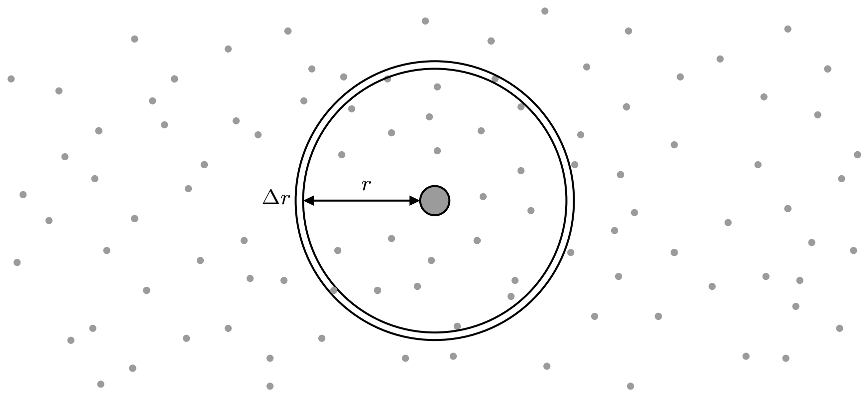
$$M = -2.43 \cdot (\log_{10}(T) - 1) - 4.05,$$

where T is the star's pulsation period in days. The research team finds that the star's average apparent magnitude is 6.5 mag. Determine the star's distance to the Earth in parsecs.

Problem B.1: Brightness of the Night Sky (6 Points)

The night sky is not entirely dark because of the thousands of stars that shine. Some stars are closer to us, while others are farther away, which, along with other factors, affects their brightness. For simplicity, we assume that stars are uniformly distributed with a density of 0.004 stars per cubic light-year, and that their luminosity is comparable to that of the Sun (3.8 x 10^{26} watts).

Consider a thin spherical shell of radius r and thickness Δr with the Earth at its center:



(a) Find an expression for the number of stars $\Delta N(r)$ in this shell and for the total radiation power $\Delta P(r)$ reaching the Earth from this shell.

(b) Find an expression for the total power $P(r)$ received from all stars up to a distance r.

(c) The universe is infinite. What is the total power received for $r \to \infty$?

(d) Explain, why modern cosmology is relevant for correctly interpreting this result.

(extra page for problem B.1: Brightness of the Night Sky)

Problem B.2: Non-relativistic Friedmann Equation (6 Points)

Besides other questions, cosmology studies how the universe will evolve in the future. To determine its fate, we can consider the non-relativistic form of Hubble's law,

$$v(t) = H(t) \cdot r(t),$$

which gives the recessional velocity v at a distance r from an observer at a given time t. It is possible to make predictions about the universe using non-relativistic mechanics. For this, we assume a constant matter density ρ throughout the universe and consider the behaviour of a sphere of radius r centered on an observer, containing all the matter within it.

(a) Find an expression for the kinetic energy E_{kin} and the potential energy E_{pot} of the sphere.

(b) Show that the total energy E is given by

$$E = \frac{4}{3}\pi G m r^2(\rho_c - \rho),$$

where G is the gravitational constant, and find the expression for the *critical density* ρ_c.

(c) Discuss the fate of the universe for the following three scenarios:

$$\rho < \rho_c \qquad \rho = \rho_c \qquad \rho > \rho_c$$

(d) Derive the first non-relativistic Friedmann equation (with some constant k):

$$H^2 = \frac{8\pi G\rho}{3} - \frac{k}{r^2}$$

(extra page for problem B.2: Non-relativistic Friedmann Equation)

Problem C.1 : Milky Way-Andromeda Collision (8 Points)

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

No certainty of a Milky Way-Andromeda collision.
Sawala, T., Delhomelle, J., Deason, A.J. et al. Nat Astron (2025).
Link: https://www.nature.com/articles/s41550-025-02563-1.pdf

Answer the following questions related to this article:

(a) Which objects in the Local Group and which physical processes are most relevant for determining collision probabilities?

(b) Explain the meaning of each column presented in Table 1.

(c) What is the difference between Figure 1 and Figure 2?

(d) How do M33 and the LMC each affect the probability of a MW–M31 collision?

(e) How likely is a merger occurring within 5 Gyr, assuming a 20 kpc distance threshold?

(f) What is gravit. softening, and why is a too small or too large softening length problematic?

Problem C.2 : New Solar System Objects (8 Points)

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

Discovery and dynamics of a Sedna-like object with a perihelion of 66 au.
Chen, YT., Lykawka, P.S., Huang, Y. et al. Nat Astron (2025).
Link: https://www.nature.com/articles/s41550-025-02595-7.pdf

Answer the following questions related to this article:

(a) What do the terms *trans-Neptunian object*, *perihelion distance*, and *semi-major axis* mean?

(b) What are Sedna-like objects, and why is Ammonite one of them?

(c) Explain the *perihelion gap*, and why Ammonite is important for it.

(d) How is Ammonite's orbit different from the other Senda-like TNOs?

(e) How does Ammonite provide evidence for an important event about 4.2 billion years ago?

(f) What challenges did the scientists face during their observations?