International Astronomy and Astrophysics Competition
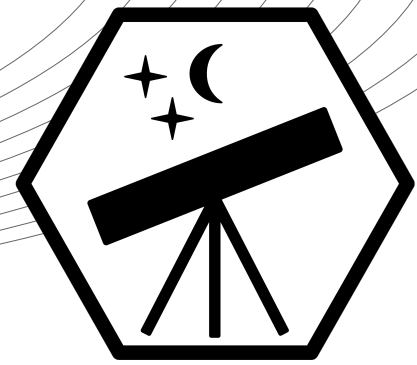## Pre-Final Round 2022

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 **<u>and</u>** 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 26. June 2022, 23:59 UTC+0**.

- The results of the pre-final round will be announced on Monday 4. July 2022.

Good luck!

Problem A.1: Looking back with the JWST (4 Points)

The James Webb Space Telescope (JWST) will allow us to look back in time and observe the early universe. You are a scientist trying to observe an object that emitted its light a long time ago.

(a) Explain why the light you receive from the object is *red-shifted*.

The object has a redshift of 7.6 and the JWST observes the object at a wavelength of 2 micrometres (mid-infrared light).

(b) What is the wavelength of the light emitted by the object?
(c) What type of radiation was originally emitted by the object?

Problem A.2: Counting Asteroids (4 Points)

An extraterrestrial civilisation lives on a planet with a very elliptical orbit. Additionally, thousands of large asteroids orbit their solar system. The civilisation uses the light from their home star to count the number of asteroids in the direct line between the star and their planet.
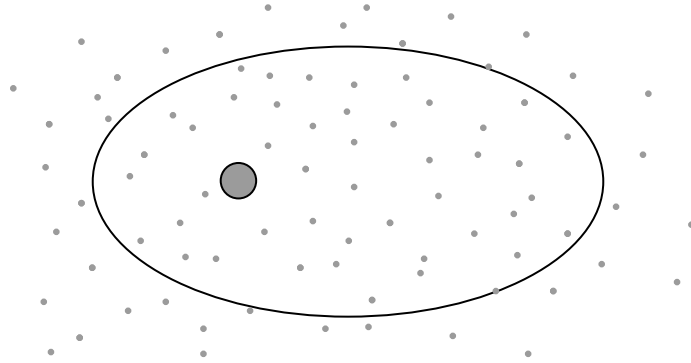

For a first measurement, they count the asteroids for 60 days and detect 1000 objects. Several months later, they start a second measurement: This time, they count for 80 days.

How many asteroids will they detect during the second measurement? Explain why.
(Note: *Assume that the asteroids are homogeneously distributed in their solar system.*)

Problem B.1: Rotating the JWST (6 Points)

The JWST has a propulsion system to adjust the orbit and orientation of the telescope.

For this problem, we assume that the JWST only consists of the 18 primary mirror segments (with a weight of 40 kg each, m_1) forming a cylinder with a radius of 3.3 m (R), the Aft optical subsystem with a weight of 120 kg (m_2) forming a cone with a radius of 65 cm (r), and the science instrument module with a weight of 1400 kg (m_3) forming a cuboid with a side length of 5.3 m (a):
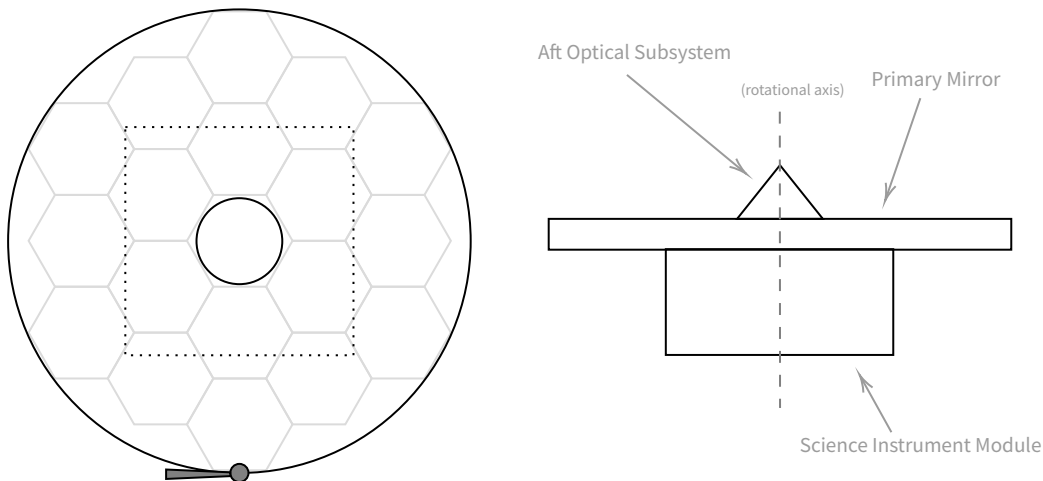
(a) Derive a general expression for the moment of inertia I of the telescope's shape with respect to the dimensions R, r, a and the masses m_1, m_2, m_3. (Hint: Derive the moment of inertia for the individual components first. The rotational axis is the axis of symmetry.)

(b) Calculate the numerical value of I for the JWST. (Use only the values from the text above.)

To perform calibration measurements, the researchers need to rotate the telescope by 90 degrees. For that, they fire the MRE-1 thrusters at the bottom edge of the primary mirror (see figure) for 0.5 seconds with a thrust of 2.5 newtons.

(c) How long does it take for the telescope to rotate by 90 degrees?

(extra page for problem B.1: Rotating the JWST)

Problem B.2: Changing Temperature (6 Points)

The energy of our Sun is responsible for life on Earth. We are very lucky that the Sun has the right conditions and that the Earth is at the exact right position to create habitable temperatures.

(a) Find an equation for the surface temperature of the Earth $T_E(R, T)$ with respect to the radius R and the surface temperature T of the Sun.
(Note: *Approach the Earth and the Sun as black bodies; then, account for the Earth's albedo of 30% and add an atmosphere correction factor of 1.13 to the surface temperature of the Earth.*)

The radius of the Sun is 696 x 10^3 km, and the surface temperature is 5772 K:

(b) Confirm with your equation that Earth's current surface temperature is 15 °C.

The two axes of the diagram below display a relative change in the surface temperature (x-axis) and radius (y-axis) of the Sun.

(c) Draw a black line in the diagram for all pairs (R, T) that still result in a temperature of 15 °C on the Earth. If the Sun's temperature increases by 10%, how much needs the radius to decrease to maintain 15 °C on Earth?

(d) Draw a grey area in the diagram for all (R, T) that result in a temperature $\pm$ 10° from 15 °C.
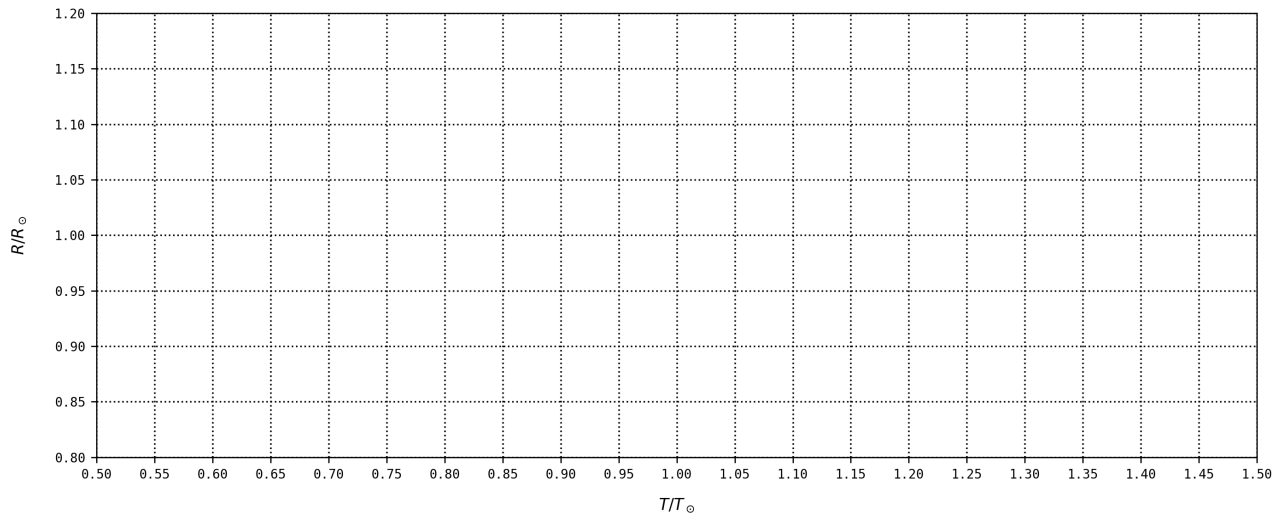
(extra page for problem B.2: Changing Temperature)

Problem C.1 : The Surface of Planets (8 Points)

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

Inferring Shallow Surfaces on Sub-Neptune Exoplanets with JWST.
Shang-Min Tsai et al 2021 ApJL 922 L27. Link: https://iopscience.iop.org/article/10.3847/2041-8213/ac399a/pdf

Answer the following questions related to this article:

(a) What is a _proxy_? What proxy is this study trying to find, and what are they doing differently compared to previous studies?

(b) Explain the meaning and use of the following acronyms: HELIOS, Exo-FMS, HAZMAT, NIRSpec.

(c) Make a sketch of the components used to model the planet (including the pressure-longitude grid and the equatorial regions):

(d) Explain the components of Figure 1. Why was it included in the paper?

(e) Why is CH_4 not a suitable proxy for the surface pressure?

(f) You detect CH_3OH but non NH_3 in the atmosphere of a sub-Neptune planet. What type of surface does this planet have?

Problem C.2 : Black Holes and the JWST (8 Points)

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

The Age of Discovery with the James Webb:
Excavating the Spectral Signatures of the First Massive Black Holes.
Inayoshi, K. et al. arXiv:2204.09692 [astro-ph.GA] (2022). Link: https://arxiv.org/pdf/2204.09692.pdf

Answer the following questions related to this article:

(a) What are massive black holes (BH)? Why is the observation of young massive BHs important?

(b) What is the *spectral energy distribution (SED)*?

(c) Figure 2 shows the total SED with three OI peaks: Where do they come from?

(d) What are broad-band filters, and what is their use in astronomy?

(e) Explain the increase of all lines for high z in Figure 3, top-left panel.

(f) Explain the meaning and use of the magenta rectangle in Figure 4.