

Norwegian Olympiad on Astronomy and Astrophysics

Problem set (and solutions) for Round I

2024/2025 school year

Date: Any date during week 42 – 45 (14 October – 8 November 2024)

Allowed aids: Calculator, pencil/pen and physical constants and formulas given below. Time: 90 minutes

This is a multiple choice problem set. There are four possible answers for each problem - A, B, C og D. Use the answer sheet at the end of the problem set to mark the letter corresponding to your chosen answer. There is only a single correct answer for each problem and all problems yield the same number of points. Zero points are given for a problem if more than one answer is marked. Wrong answers do not yield negative points.

The problem set has 9 pages, and there are 20 problems.

Good luck!

Constants and formulas:

- Apparent magnitude: $m = -2.5 \log(F/F_0)$
- Hubble's law: $v = H_0 d$, $H_0 \approx 73 \text{ km/s/Mpc}$
- Doppler formula: $v/c = (\lambda - \lambda_0)/\lambda_0$
- The Rayleigh criterion: $= 1.22 \cdot \lambda/D \text{ rad}$
- Speed of light $= 299792458 \text{ m/s}$
- 1 parsec (pc) $\approx 3.26 \text{ light years}$
- 1 Astronomical Unit (AU) $\approx 1.5 \cdot 10^{11} \text{ m}$
- Newton's law of gravity: $F_G = GmM/r^2$, $G \approx 6.67 \cdot 10^{-11} \text{ m}^3/\text{kg/s}^2$
- Wien law: $\lambda_{\text{max}} = b/T$, $b \approx 2.9 \cdot 10^6 \text{ nm} \cdot \text{K}$
- Stefan-Boltzmann's law: $F = \sigma T^4$, $\sigma \approx 5.67 \cdot 10^{-8} \text{ W/m}^2/\text{K}^4$

- 1) What astronomical phenomenon can we see on the picture below, taken on Svalbard in March 2015? (made by D. Veljkovic, winner Astro-OL 2021)

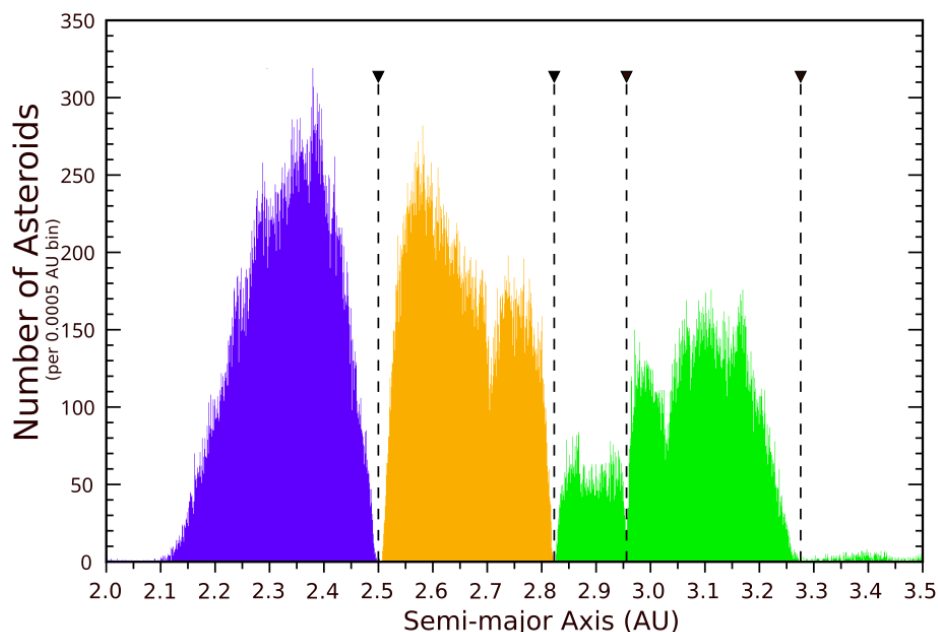


- a) **Total solar eclipse**
 - b) Total lunar eclipse
 - c) Peak of sun spot activity, where so many sun spots are active that they cover most of the sun, also called Black Hole Sun
 - d) Camera artifact from pointing straight at the sun
- 2) On average, the Moon and the Sun are 380.000 km and 150.000.000 km away from Earth. The radius of the Sun is around 700.000 km. What is the radius of the Moon?
- a) 800 km
 - b) 1700 km**
 - c) 2500 km
 - d) 3400 km

Solution: We can use that the Moon covers almost exactly 100% of the Sun during a total solar eclipse. Since the Moon is $150\,000/380 = 395$ times closer than the Sun, its radius must be equally smaller:
 $700\,000\text{ km}/395 = 1700\text{ km}.$

- 3) What is the name of the highest point in the sky directly above the observer? (made by D. Velikovich, winner Astro-OL 2021)
- a) Ecliptic

- b) Zenith**
 c) Nadir
 d) Horizon
- 4) Astronomers Giovanni Cassini and Jean Richer are credited with finding the distance between Earth and Mars in the late 1600s. They both observed Mars in opposition and recorded simultaneous data, one in France, and one in French Guiana (located in South America), after which they met up and compared their sky maps. Measuring the difference between the positions of Mars in the sky they plotted enabled them to approximate the distance between Mars and Earth. What is the name of the effect that makes it so that Mars's location in the sky is just a bit different in these two places on Earth? (made by D. Veljkovic, winner Astro-OL 2021)
- a) Precession
b) Parallax
 c) Analemma
 d) Apogee
- 5) The asteroid belt in our Solar System has several regions that contain much fewer asteroids than any other region, marked by the dashed lines. We call these the "Kirkwood gaps", and they are the regions from which the majority

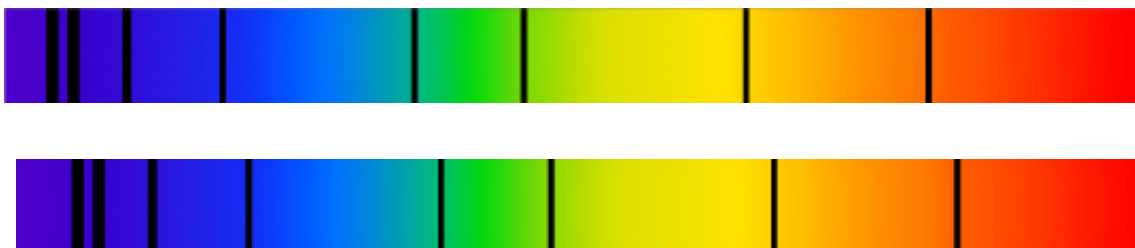


of near-Earth asteroids come. What celestial body is responsible for this gap?
(made by D. Veljkovic, winner Astro-OL 2021)

- a) Mars
- b) Jupiter**
- c) Sagittarius A*
- d) Sun

Solution: The gaps are at specific ratios we call orbital resonances and are due to perturbations from the gravitational effects of Jupiter, which is the first planet outside of the asteroid belt. For example, the leftmost gap is at 3:1 orbital resonance, meaning that for every revolution Jupiter makes around the Sun, an asteroid orbiting with that semi-major axis would make three revolutions.

- 6) In this problem, we will look at two different spectra. For purposes of this task, we have only presented the hydrogen lines. The spectrum above is from observing hydrogen in a laboratory setting here on Earth. The spectrum below is from observing a far-away star. What conclusion can we draw from these?
(made by D. Veljkovic, winner Astro-OL 2021).

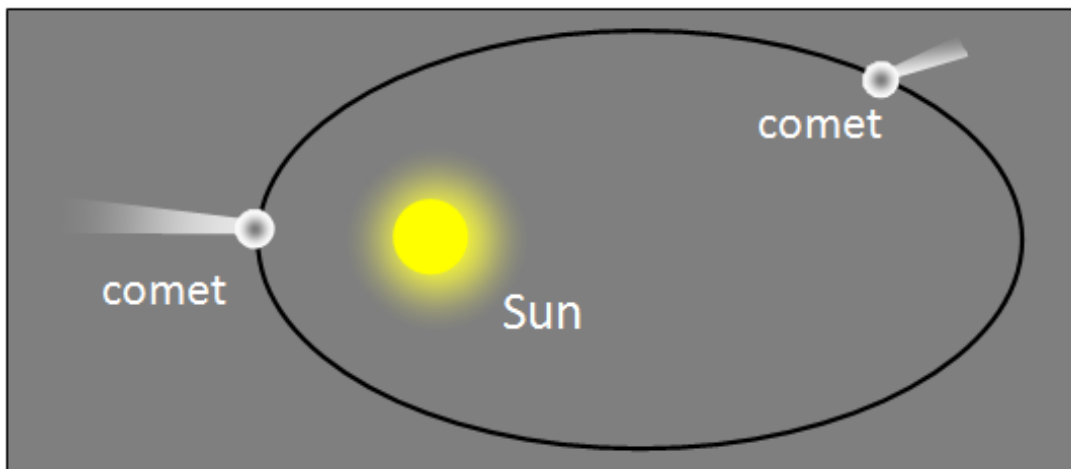


- a) This is an emission spectrum and the star is moving towards us.
- b) This is an absorption spectrum and the star is moving towards us.
- c) This is an emission spectrum and the star is moving away from us.
- d) This is an absorption spectrum and the star is moving away from us.**

Solution: The black lines seen are absorption lines of hydrogen, and between the two spectra, they are clearly shifted towards more red wavelengths. By the Doppler effect, we know that if the light is shifted in this manner, the star must be moving away from us.

- 7) So far in physics, you have mostly assumed that orbits of celestial bodies are perfectly circular. In reality, they are more elliptical and can be described by a

parameter we call “eccentricity”, i.e. how “stretched out” an ellipse is in comparison to a perfect circle (e.g. eccentricity 0 means we have a perfect circle). Mathematically, the eccentricity of an orbit is given by the ratio of the distance from the ellipse centre to the body that is being orbited around (i.e. the Sun) and the ellipse’s longer radius (the “semi-major axis”). The famous Halley’s comet orbits our Sun with an eccentricity of 0.967. Knowing this, approximately how many times further away is Halley’s comet when it is at its furthest from the Sun, compared to when it is at its closest? (made by D. Veljkovic, winner Astro-OL 2021).



- a) 20
- b) 40
- c) **60**
- d) 80

Solution: The eccentricity is given as $e = \frac{f}{a}$, with f being the distance from the centre of the ellipse to the Sun and a the semi-major axis of the orbit. At its closest, the comet is at a distance of $a - f$ from the Sun, and at its furthest, it is $a + f$ from the Sun. With $f = e \cdot a$ from the eccentricity formula, we can write the ratio of these distances as:

$$\frac{a + f}{a - f} = \frac{a + e \cdot a}{a - e \cdot a} = \frac{a(1 + e)}{a(1 - e)} = \frac{1 + e}{1 - e} = \frac{1 + 0.967}{1 - 0.967} = \frac{1.967}{0.033} \approx 59.6 \approx 60$$

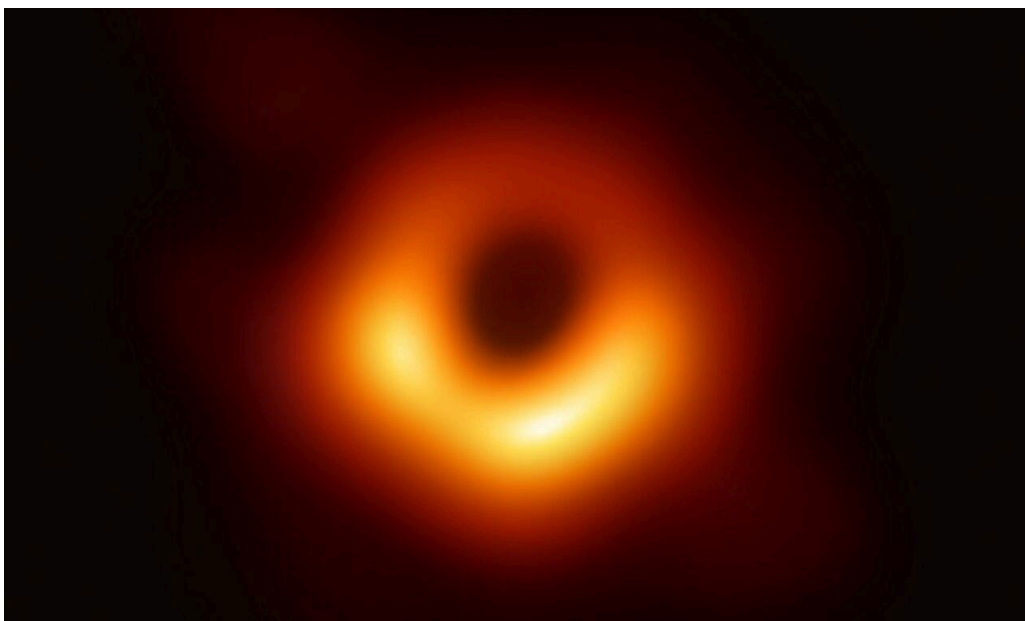
times further.

- 8) Most planets outside the Solar System (exoplanets) are discovered through ...
- a) reflections of gravitational waves emitted by black holes.
 - b) direct observations with modern high-resolution telescopes.

- c) eclipses when they transit between us and their host stars.
- d) focusing of light bent by their gravitational fields.

Solution: Most exoplanets have been discovered with the “transit method” (before it was the “radial velocity method”, which is not an alternative).

9) What is this?



- a) A donut-shaped exoplanet
 - b) A direct image of a black hole**
 - c) Radiation from the cosmic microwave background
 - d) A partial solar eclipse
- 10) Which of these definitions corresponds best to a *solar day* (24 hours; “a day” in everyday language)?
- a) Exactly 1/30 of a month.
 - b) Exactly 1/365 of a year.
 - c) The time it takes for Earth to rotate 360 degrees around its own axis.
 - d) The time it takes for the Sun to reappear in the same position on the sky.**

Solution: A solar day (24 hours) is the time between two consecutive noons. Since Earth spins *while* it orbits the Sun, it uses 4 minutes less to rotate 360 degrees around its own axis (this is called a “sidereal day”).

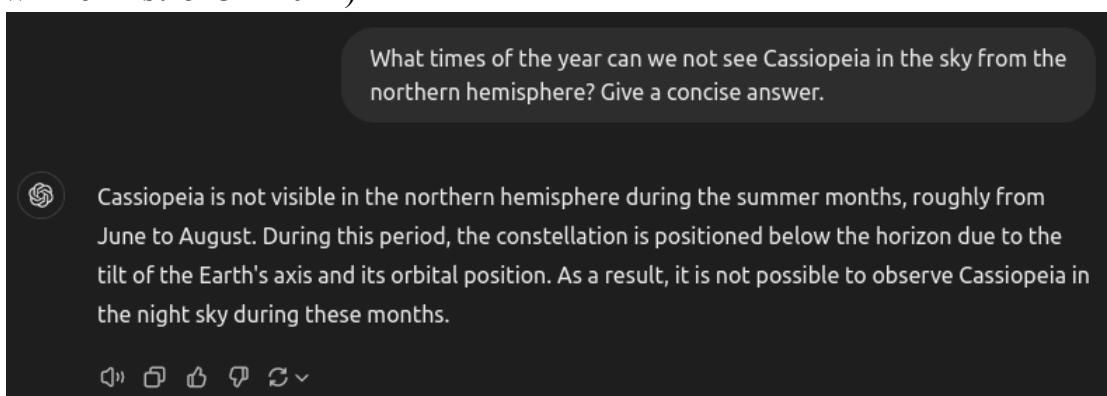
- 11) The Sun ejects charged particles called “solar wind” that interact with Earth’s magnetic field to produce aurorae. What determines the colors of the aurora?

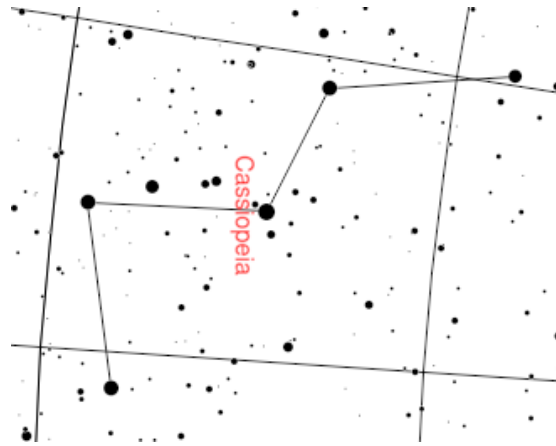


- a) The composition of the Sun’s atmosphere.
- b) The latitude at which solar wind hits Earth.
- c) The composition of Earth’s atmosphere.**
- d) The local orientation of Earth’s magnetic field.

Solution: The photons that make up the aurora are emitted from molecules in Earth’s atmosphere that relax to lower energy states after being excited by interactions with solar wind. For example, oxygen molecules contribute the green color, and both oxygen and nitrogen at varying altitudes contribute the purple color.

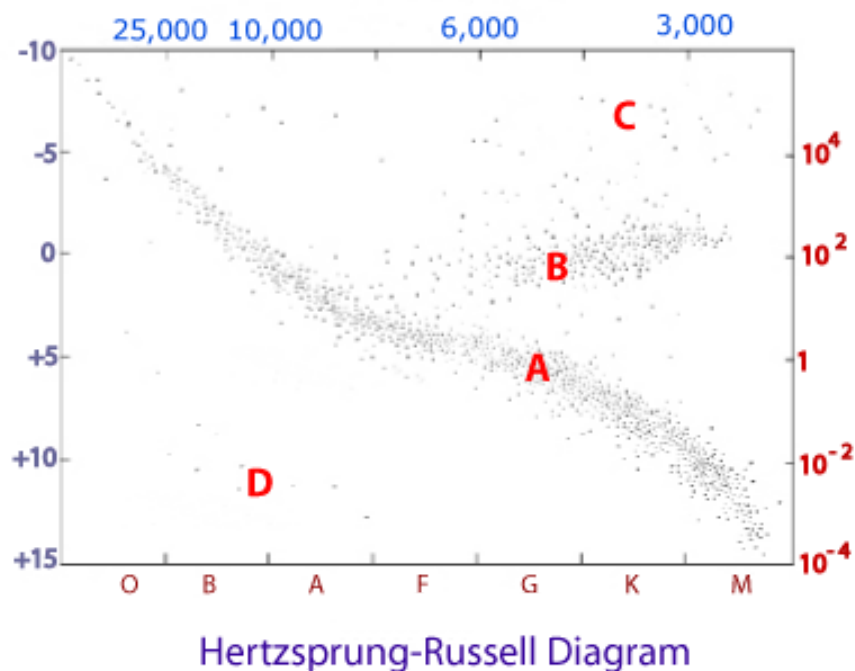
- 12) This is a conversation between the question author and ChatGPT. How would you evaluate the response provided by the AI model? (made by D. Veljkovic, winner Astro-OL 2021)





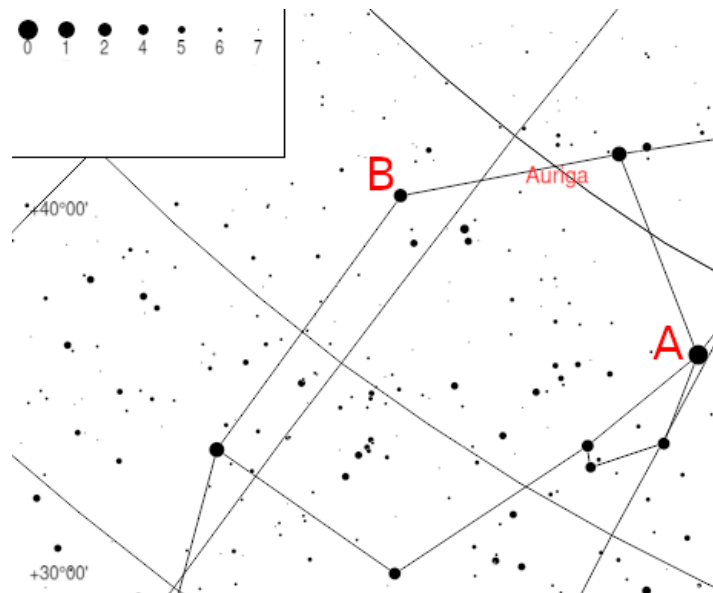
- a) The answer is correct.
- b) Wrong - Cassiopeia can be seen in the summer months, but not in the winter months, e.g. December.
- c) Wrong - Cassiopeia can never be seen in the northern hemisphere.
- d) **Wrong - Cassiopeia can be seen throughout the year in the northern hemisphere.**

13) What are the four axes present on an HR-diagram, a diagram where stars are placed based on some of their properties? (made by D. Veljkovic, winner Astro-OL 2021)



- a) Spectral Class, Distance from Sun (in AU), Effective Temperature (in K), Absolute Magnitude
- b) Spectral Class, Luminosity (in Sun luminosities), Effective Temperature (in K), Absolute Magnitude**
- c) Spectral Class, Luminosity (in Sun luminosities), Effective Temperature (in °C), Apparent Magnitude
- d) Spectral Class, Luminosity (in Sun luminosities), Effective Temperature (in K), Angular separation from Sun in night sky (in degrees)

14) Which of the following can be concluded about stars A and B from reading the star chart of the constellation Auriga provided below?



- a) The numerical value of the absolute magnitude of A is higher than the numerical value of the absolute magnitude of B
- b) The numerical value of the absolute magnitude of A is lower than the numerical value of the absolute magnitude of B
- c) The numerical value of the apparent magnitude of A is higher than the numerical value of the apparent magnitude of B
- d) The numerical value of the apparent magnitude of A is lower than the numerical value of the apparent magnitude of B.**

Solution: Sky charts show magnitudes of stars as seen from Earth, or their *apparent* magnitudes. Remember that higher apparent magnitude means that the object is *dimmer*. Since star A is bigger than star B on the chart, it means it's brighter, but the value of the apparent magnitude is therefore

lower.

- 15) Approximately what is the lowest temperature (in degrees Celsius) a black body can have so that its spectrum peaks at a wavelength we are able to see? Assume that the visible spectrum spans frequencies 400 THz - 800 THz.

- a) 3600°C
- b) 3870°C
- c) 7470°C
- d) 7740°C

Solution: The peak wavelength of black body radiation is given by Wien's law: $\lambda_{max} = \frac{b}{T}$, so the temperature at the corresponding peak is

$T = \frac{b}{\lambda_{max}}$. The lowest temperature is when the wavelength is highest.

The wavelength is given by $\lambda = \frac{c}{f}$, where c is the speed of light, so the highest wavelength is when the frequency is lowest. Finally, we get the

temperature to be $T \approx \frac{2.9 \cdot 10^{-3} \text{ m} \cdot \text{K}}{\frac{3 \cdot 10^8 \frac{\text{m}}{\text{s}}}{400 \cdot 10^{12} \text{ Hz}}} \approx 3870 \text{ K}$. Notice that the

temperature we get using the formula is in Kelvin, but the alternatives are in degrees Celsius. The final answer is therefore

$$(3870 - 273.15)^\circ \text{C} = 3596.85^\circ \text{C} \approx 3600^\circ \text{C}.$$

- 16) The two stars in the binary system Gamma Leonis are 3 arcsec apart from each other at a certain point in time. Can we use an amateur telescope with an aperture diameter of 50mm to see them as two distinct stars, and why? Assume that the wavelength of light is 550nm on average, and that observing conditions are otherwise ideal. (1 deg = 3600 arcsec)

- a) Yes - the Rayleigh criterion gives an angle smaller than the separation, which means we can resolve the two stars.
- b) No - the Rayleigh criterion gives an angle smaller than the separation, which means that we cannot resolve the two stars.
- c) Yes - the Rayleigh criterion gives an angle greater than the separation, which means we can resolve the two stars.
- d) No - the Rayleigh criterion gives an angle greater than the separation, which means we cannot resolve the two stars.

Solution: The Rayleigh criterion gives the minimum resolvable detail, meaning that if we want to resolve the stars, the angle given by the criterion needs to be *smaller* than the angular separation of the stars. The

criterion gives the angular resolution as

$$\theta = 1.22 \frac{\lambda}{D} = 1.22 \frac{550 \cdot 10^{-9}}{50 \cdot 10^{-3}} \approx 0.00001 \text{ rad} = 0.00001 \cdot \frac{180^\circ}{\pi}$$

$\approx 0.00057^\circ = 0.00057 \cdot 3600 \text{ arcsec} = 2.052 \text{ arcsec}$. This is taking into account rounding in the intermediate steps. With no rounding, this turns out to be 2.768 arcsec which is still smaller than the 3 arcsec separation given in the problem text.

17) You are looking at the night sky. In one direction you can see Ursa Major and Polaris. In the opposite direction you can see the Southern Cross. What is your approximate location on Earth?

- a) In the Arctic region
- b) In the Antarctic region
- c) In the tropical region and north of the equator**
- d) In the tropical region and south of the equator

Solution: Polaris is very close to the celestial North pole and therefore only visible from the northern hemisphere. The Southern Cross is not visible from the Arctic region and only visible south of approximately 25 degrees northern latitude.

18) In the 1920s both Georges Lemaître and Edwin Hubble found observational evidence that galaxies move away from each other proportional to their distance. At what distance will objects recede faster than the speed of light as observed from Earth? (made by F. Neumann, winner Astro-OL 2023 and 2024)

- a) 1 Mpc
- b) 20 Mpc
- c) 300 Mpc
- d) 4000 Mpc**

Solution: Using Hubble's law, we input $v = c$ and solve for d .

$$c = H_0 d \Rightarrow d = \frac{c}{H_0} = \frac{3 \cdot 10^5 \text{ kms}^{-1}}{73 \text{ kms}^{-1} \text{ Mpc}^{-1}} \approx 4000 \text{ Mpc}$$

19) Cosmology is the study of the universe as a whole. To understand our universe, it is necessary to define some attributes of it. Isotropy means that the universe looks the same in every direction. Homogeneity means that the universe looks the same in every point. Which statement is consistent with

observations regarding our universe? (made by F. Neumann, winner Astro-OL 2023 and 2024)

- a) **The universe is both isotropic and homogeneous at large scales**
- b) The universe is isotropic only at large scales, but always inhomogeneous
- c) The universe is anisotropic and inhomogeneous at every scale
- d) The universe is isotropic and homogeneous at every scale

Solution: Observations of the large-scale distribution of galaxies and of the cosmic microwave background show that the universe can be well described as isotropic and homogeneous on scales larger than approximately 250 million light years.

20) The Sun has a surface temperature of 5800K. Imagine that the Sun is replaced by a star with the same mass (such that the orbit of the Earth is unchanged); however the star has a surface temperature of 2900K and has a radius four times the radius of the Sun. How would the total amount of energy received by the Earth change in this scenario?

- a) **The Earth would still receive the same total amount of energy.**
- b) The Earth would receive four times as much energy
- c) The Earth would receive half as much energy
- d) The Earth would receive twice as much energy

Solution: Since the surface temperature of the star is half that of the Sun, the ratio of the luminosities would be

$$L_{\text{sun}}/L_{\text{star}} = (R_{\text{sun}}/R_{\text{star}})^2 (T_{\text{sun}}/T_{\text{star}})^4 = (1/4)^2 * 2^4 = 1$$
, so the Earth would receive the same amount of energy.