

Norwegian Olympiad on Astronomy and Astrophysics

Problem set (and solutions) for Round 2

2025/2026 school year

Date: Any date during week 4 (19 – 23 January 2026)

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.

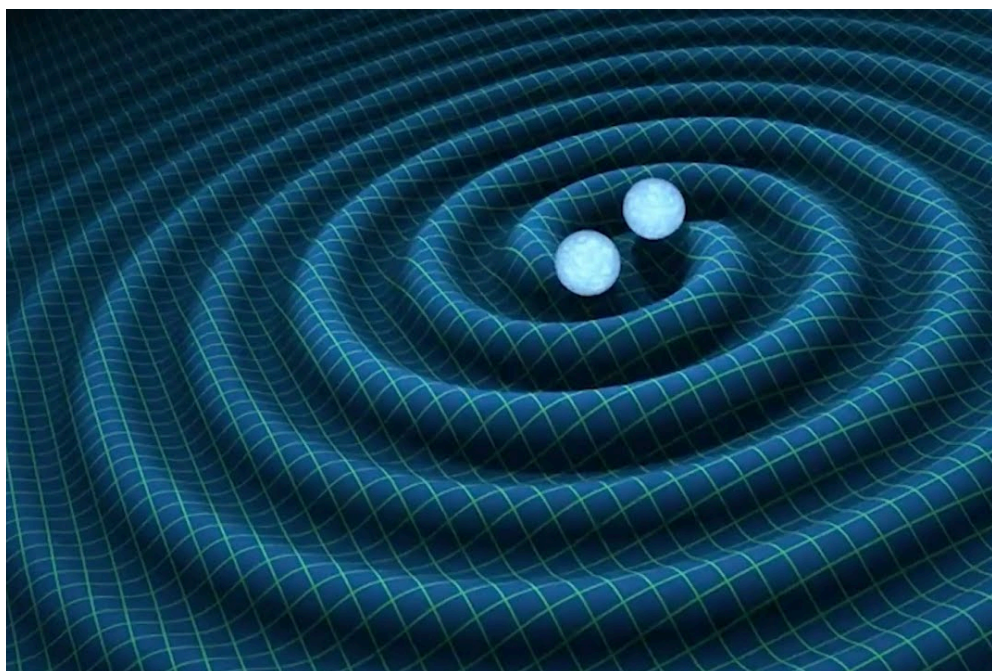
The problem set has 11 pages, and there are 20 problems.

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 $= 3 \cdot 10^8 \text{ m/s}$
- 1 parsec (pc) $\approx 3.26 \text{ light years}$
- 1 Astronomical Unit (AU) $\approx 1.5 \cdot 10^{11} \text{ m}$ (the distance between the Sun and the Earth)
- 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) Gravitational waves are often described as ripples in spacetime and are generated by the relative motion of gravitational masses, requiring presence of mass asymmetry in the system. (Image credit: LIGO)



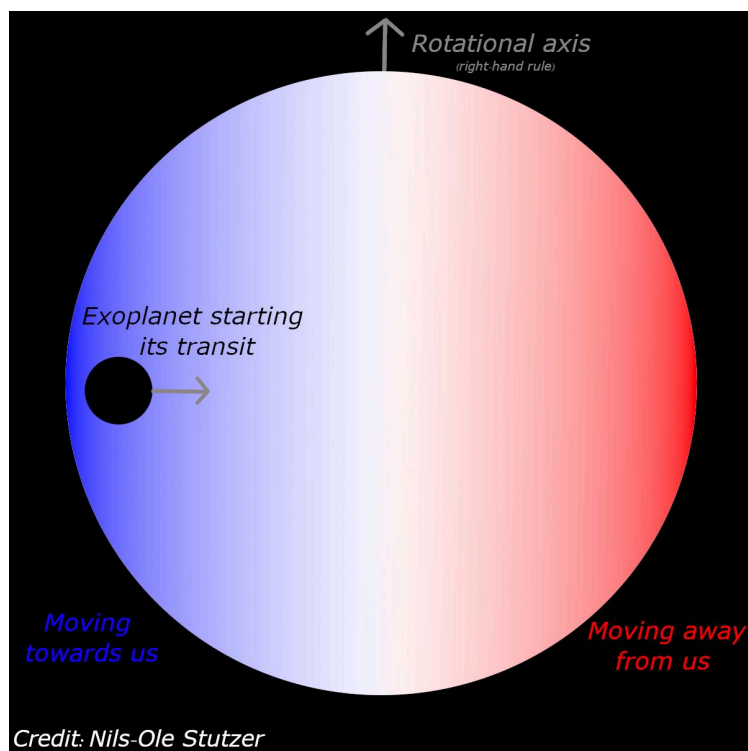
Which of the following celestial bodies/systems does **not** produce detectable gravitational waves?

- a) A binary system of black holes
- b) An asymmetric pulsar, which is a highly-magnetised spinning neutron star
- c) **A white dwarf**
- d) A supernova, exhibiting a non-uniform distribution of matter during an explosion

Solution: c) the non-static system needs to have a sufficient mass asymmetry (specifically at least a quadrupole moment) in order to produce oscillations in the gravitational field.

2) Assume you are looking at a distant star with an exoplanet in orbit around it. The star and exoplanet orbit are observed edge-on, and the rotational axis of the star and exoplanet orbit are perpendicular to our line-of-sight. Because the star is rotating, the side of the star that is moving towards us will appear doppler shifted into the blue, while the other half of the star moving away from us will experience a redshift. Assume we observe the distant star using the $H\alpha$ emission line. The exoplanet starts

a transit in front of the star's disk on the blueshifted side of the star (see illustration). What statement is true about the observed $H\alpha$ emission line of the rotating star when the planet starts its transit:



- a) The line will be infinitely narrow
- b) The line will appear significantly narrower than in a lab measurement
- c) The line appears at a slightly different wavelength redwards of a lab measurement**
- d) The line appears at a slightly different wavelength bluewards of a lab measurement

Solution c): Rossiter-McLaughlin effect: the line experiences rotational doppler broadening causing a widened line profile, but due to the transiting exoplanet, some of the blue light is blocked, causing a slight net red excess from the non-transited side of the star. Thus the line is shifted slightly to the red side of the spectrum.

3) Your friend, who was born at the exact same time as you, was recently in Ecuador for a month and argues that due to the higher rotational velocity at the equator, they are now the younger person. Are they right?

- a) No, time dilation only occurs when objects move close to the speed of light. Earth's rotational velocity is far too slow for any relativistic effects to occur.
- b) Yes, they are correct. Time dilation from the higher velocity at the equator means they aged slightly less, though the difference would be only a few nanoseconds over a month.**
- c) No, they would actually be older because moving faster causes time to speed up for the moving observer, not slow down.
- d) Yes, and the effect would be significant. The equator's rotational velocity of 465 m/s would cause a noticeable age difference of several seconds over a month.

Solution: b)

4) In an infinite static universe, you should see a star in every direction. But when we look up at night, we see mostly darkness. This is known as Olbers' Paradox. Your friend Isak Nyttun suggests: "The dark sky proves the universe must be finite and static - there simply aren't enough stars to fill every direction." Which of the following observations proves that your friend is wrong and definitively shows the universe is actually not static, but expanding?

- a) Telescopes reveal billions of galaxies beyond our own, proving there are far more stars than visible to the naked eye
- b) The matter in the universe is mostly dark matter
- c) We observe that galaxies are distributed uniformly in all directions on large scales, showing the universe has no edge or center
- d) Light from distant galaxies is redshifted, with more distant galaxies showing greater redshift**

Solution: d)

5) In the 1600s, Isaac Newton discovered the law of universal gravitation. In 1916, Albert Einstein's theory of general relativity (GR) was proposed, which accounts for observations that Newton's theory could not explain. While GR reduces to Newtonian gravity in systems with low potential and velocity, the formula for GR is fundamentally not similar to Newton's. Which statement about this is true?

(Question proposed by F. Neumann, winner of Astro-OL 2023 and 2024)

- a) GR includes all particles in the system simultaneously, and can therefore simulate n-body simulations much faster than Newton's theory. This is because Newton's theory calculates forces on each 2-body pair separately.
- b) In GR, gravity is not a force, but rather the result of mass bending spacetime. Objects in free fall follow the shortest path (geodesic) in curved spacetime, and from our perspective, this curved motion appears as gravitational attraction.**
- c) Newton's theory is a classical deterministic theory and is incompatible with modern quantum mechanics. GR, on the other hand, has Heisenberg's uncertainty principle baked into its theory, and is compatible with quantum mechanics.
- d) In GR, gravity is actually a complex wave that needs to be described using a combination of sines and cosines, while Newton's theory regards it as a simple force.

Solution: a) is wrong because GR is more mathematically complex. It requires solving nonlinear equations at every point in space and time, which slows simulations. c) is wrong because both theories are classical and neither includes quantum mechanics. In fact, GR is incompatible with quantum mechanics. d) is wrong.

6) The Sun has an effective temperature of about $T_{eff} = 5777K$ and a radius of

$R_{\odot} = 6.96 \cdot 10^8 \text{ m}$. If we happened to be building a telescope located 10.0 pc away from the Sun, what would the minimal diameter of the aperture (approximately) need to be so we can resolve the Sun? Assume the conditions are completely ideal. Furthermore, base this on the blackbody simplification; using only the wavelength λ_{max} where blackbody radiation per unit wavelength peaks.

(Question proposed by T. Strbkova, winner of Astro-OL 2024)

- a) 1.36 m
- b) $1.36 \cdot 10^2 \text{ m}$**
- c) $1.36 \cdot 10^5 \text{ m}$
- d) $1.36 \cdot 10^7 \text{ m}$

Solution: b) Wien's law gives us: $\lambda_{max} = \frac{b}{T} = \frac{2.90 \cdot 10^6 \text{ nm} \cdot \text{K}}{5777 \text{ K}} \approx 502 \text{ nm}$.

To find the approximate angular diameter of the Sun, we use the small-angle approximation:

$$\theta \approx \frac{2R_{\odot}}{d} = \frac{2 \cdot 6.96 \cdot 10^8 \text{ m}}{(10.0 \cdot 3.26) \text{ ly} \cdot (3600 \cdot 24 \cdot 365.24) \text{ s/y} \cdot (3.00 \cdot 10^8) \text{ m/s}} \approx 4.51 \cdot 10^{-9} \text{ rad}.$$

Finally, using the Rayleigh criterion, we obtain the answer:

$$D = 1.22 \cdot \frac{\lambda_{max}}{\theta} = 1.22 \cdot \frac{502 \cdot 10^{-9} \text{ m}}{4.51 \cdot 10^{-9} \text{ rad}} \approx 136 \text{ m}.$$

7) The image below shows an asterism we refer to as the “Summer Triangle”, containing the stars Vega, Deneb and Altair. It is most prominent on the night sky in summer, but can be seen almost throughout the year in the Northern Hemisphere. Which of these constellations does ***not*** contain a star that makes up the Summer Triangle?



- a) Lyra
- b) Andromeda**
- c) Cygnus
- d) Aquila

8) Altitude and azimuth are coordinates in the following coordinate system:

- a) Horizontal**
- b) Equatorial
- c) Galactic
- d) Cartesian

9) We observe a star rise on January 12th at 03:32 mean solar time. Which of these times is closest to when the star will rise on February 12th? Hint: a sidereal day is approximately 4 min shorter than a solar day.

- a) 22:00
- b) 01:00**
- c) 06:00
- d) 13:00

Solution: A sidereal day is approximately 4min shorter than 24hrs, so for each day, the star in question will rise 4min earlier. Between the given dates, there are 31 days, i.e. $31 \cdot 4 = 124\text{min}$, or 2hrs4min earlier, which turns out to be 01:28, so b) is the closest alternative

10) Which of these takes the longest time to happen?

- a) A photon from the Sun's core propagates to the Sun's surface through absorption and reemission
- b) A photon from the Sun's surface reaches Earth
- c) This exam runs its full duration
- d) The International Space Station makes an orbit around Earth

Solution: a). Although technically a single photon by itself never makes it to the surface, the random walk generated by repeated collisions leading to absorptions and reemissions with the myriad of other photons in the core leads to a time of tens of thousands of years, while the other alternatives are much smaller (c) and d) are actually almost the same :)).

11) A very ambitious railway engineer has managed to make train tracks that run exactly along the 30th parallel (i.e. 30 degrees north). You are sitting on a train moving eastwards along this track with a velocity of 120km/h. Approximately how long will daylight last for you on the 21st of March? Take Earth's radius to be 6400km.

- a) 3h
- b) 11.0h
- c) 13h
- d) 15.5h

Solution: b). The Earth rotates west-to-east, and the train in question also moves in the same direction. An otherwise stationary point on the Earth's surface will have the following velocity relative to the centre of the Earth

$v_0 = \frac{2\pi R_{\oplus}}{T} \cos \varphi \approx 1450 \frac{\text{km}}{\text{h}}$, with φ being the degree of latitude, in this case 30° . Since the train is moving in the same direction as Earth, its velocity relative to the centre of the planet will be $v = v_0 + 120 \frac{\text{km}}{\text{h}} = 1570 \frac{\text{km}}{\text{h}}$. The whole

day will therefore not be experienced as 24hr, but rather $T' = \frac{2\pi R_{\oplus}}{v} \cos \varphi \approx 22.06h$. On the 21st of March, we have equinox, i.e. day and night last the same, and $T_{day} \approx 11.0h$.

12) There are several empirical relationships widely used in astronomy, one of them being the famous Tully-Fisher relation that connects a spiral galaxy's rotational velocity in $\frac{km}{s}$ to its luminosity in solar luminosities with the expression $L \propto v^4$. One such galaxy is M101, or the Pinwheel Galaxy, whose hydrogen-alpha line ($\lambda_0 = 656 \text{ nm}$) you observe to have width $\Delta\lambda = 0.45 \text{ nm}$. Which of the following values is closest to the luminosity of the Pinwheel Galaxy given these data, and assuming that the proportionality constant is $25 L_{\odot} (\frac{km}{s})^{-4}$?

Hint: From the previous round, you might recall that we see spectral line broadening due to the Doppler effect when the object we are observing is rotating about its own axis.

- a) $1 \cdot L_{\odot}$
- b) $3.14 \cdot 10^6 L_{\odot}$
- c) $4.5 \cdot 10^{10} L_{\odot}$
- d) $7 \cdot 10^{13} L_{\odot}$

Solution: c). First, we get the rotational velocity from the Doppler effect as $v = \frac{\Delta\lambda}{\lambda} c$, which with the provided data gives $v \approx 206 \frac{km}{s}$. Raising this to the power of 4 and multiplying by 25 gives approximately $4.5 \cdot 10^{10} L_{\odot}$.



Image caption: M101, inclined at 30 degrees to us, imaged by Erik Sundheim, using the 35cm Deberitz telescope at Harestua Solar Observatory.

13) In reality, we are not observing M101 head on. It has an inclination of approximately 30 degrees, where 0 degrees means we are observing the galaxy head on, and 90 degrees means we are observing the galaxy directly from the side. Does this change the above result, and if so, how and why?

- a) No, because Doppler broadening is completely independent of the direction from which we observe the galaxy in question.
- b) Yes, because the velocity we observe via the broadening is not the actual velocity of rotation, merely one of its components, so the actual rotational velocity is the observed one multiplied by a factor of $\sin(30^\circ)$, making the actual luminosity 1/16 times as small.
- c) No, because although the observed velocity and actual rotational velocity are different due to the inclination, this factor is $2 \cdot \sin(i)$ due to geometric considerations, with i being the inclination, which turns out to be 1 in our scenario, i.e. no actual practical difference.
- d) Yes, because the velocity we observe via the broadening is not the actual velocity of rotation, merely one of its components, so the actual rotational velocity is the observed one divided by a factor of $\sin(30^\circ)$, making the actual luminosity 16 times as big.**

14) You observe a planet in an elliptical orbit around its host star, marked as the yellow dot in one of the ellipse's foci. You find that the planet takes the same amount of time to span the areas 1, 2 and 3. Using this knowledge, which of the areas is largest?

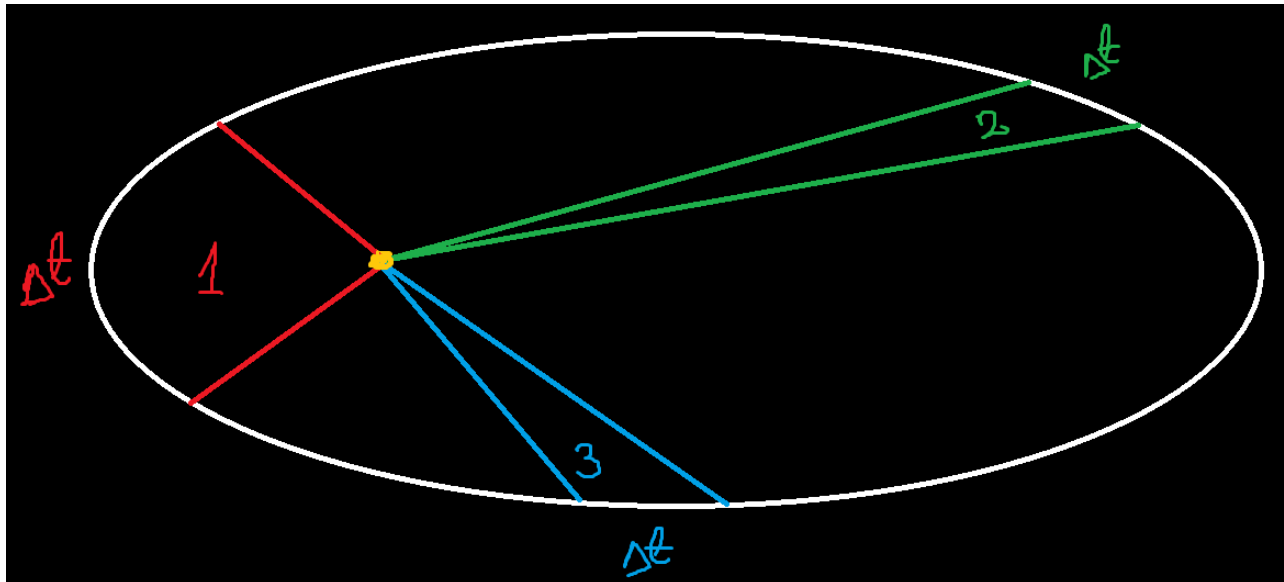


Figure description: An ellipse with one of its focus points clearly marked. From the focus points, six lines originate, with each pair of the lines defining an area of the ellipse. The area where the ellipse line is closest to the focus point is marked “1”. The area where the ellipse line is furthest from the focus point is marked “2”. The area that is some distance from the focus point (not closest, not furthest) is marked “3”. All areas are marked with “delta t”, denoting the fact that the planet takes the same amount of time to cover the areas.

- a) 1, as it is the closest to the host star
- b) 2, as it is the furthest from the host star
- c) 3, as it is located where the derivative of the ellipse area function is zero
- d) All of them are the same**

Solution: See Kepler's Second Law.

15) In star clusters, we assume that all stars are “born” approximately at the same time, so when we find stars that start straying away from the main sequence (meaning that they have burnt up the hydrogen in their core), those stars must be as old as the cluster itself.

The age of a star on the main sequence can be approximately determined from just its luminosity by the empirical proportionality $t \propto L^{\frac{1}{\alpha} - 1}$, where we take $\alpha = 3.5$ for upper main sequence stars. Knowing this and the fact that the Sun's age is $t_{\odot} = 10$ Gyr (giga-years), which of these is a good estimate of the age of the open cluster M45, otherwise known as the Pleiades, from the HR diagram of the cluster, given below?

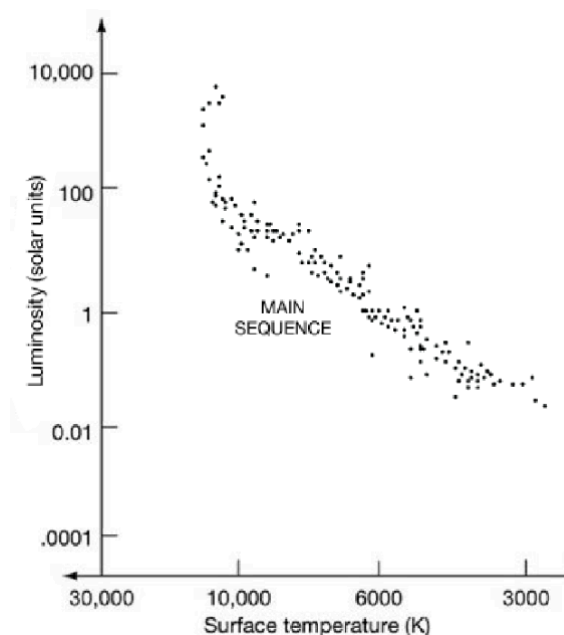


Figure description: A scatterplot representing stars in the M45 cluster. The y-axis is logarithmic, going from 0.0001 at the bottom to 10 000 at the top, with the unit being solar luminosities. The x-axis goes from 30 000 to 3000 (decreasing) and represents the surface temperature in Kelvin. The points are mostly scattered across a line going from approximately (10 000 K, 100 solar luminosities) to approximately (3000 K, 0.01 solar luminosities). At the former point, instead of continuing on the line, the points become scattered upwards, almost directly vertically.

- a) 0.4 Gyr
- b) 2 Gyr
- c) 10 Gyr
- d) 20 Gyr

Solution: The turn-off point is at approximately $L = 100L_{\odot}$, so the proportionality becomes $\frac{t}{t_{\odot}} = \left(\frac{100L_{\odot}}{L_{\odot}}\right)^{\frac{1}{3.5}-1} \Rightarrow t = t_{\odot} \cdot 100^{-0.714} \approx 0.4 \text{ Gyr}$.

16) A satellite in elliptical orbit around Earth has its closest approach at $8.37 \cdot 10^6$ m from Earth's center and its greatest distance at $25.1 \cdot 10^6$ m from Earth's center. The speed of the satellite at perigee is $8450 \frac{m}{s}$. Which of these is closest to the speed at apogee? Take Earth's mass to be $5.97 \cdot 10^{24}$ kg.

a) $2820 \frac{m}{s}$

b) $8450 \frac{m}{s}$

c) $25,350 \frac{m}{s}$

d) $4635 \frac{m}{s}$

Solution: a). Using conservation of energy, we can write:

$$\frac{1}{2}mv_p^2 - G\frac{Mm}{R_p^2} = \frac{1}{2}mv_a^2 - G\frac{Mm}{R_a^2}, \text{ and}$$

$$v_a = \sqrt{2GM\left(-\frac{1}{R_p} + \frac{1}{R_a}\right) + v_p^2} \approx 2825 \frac{m}{s}, \text{ so } 2820 \text{ m/s is the closest to this.}$$

17) Interstellar extinction is when electromagnetic radiation gets absorbed and scattered, causing an attenuation of background light. Extinction is more pronounced at shorter wavelengths, thereby also causing a reddening of light (infrared radiation would get attenuated less than ultraviolet). A patch of the sky may seem dark because of this phenomenon. What is the main cause of interstellar extinction? (Question proposed by T. Strbkova, winner of Astro-OL 2024).

a) **Interstellar dust**

b) Dark matter

c) Black holes

d) Meteoroids

Solution: a). Interstellar dust is one of the components of the interstellar medium. It consists of elements such as Fe, Si, C, etc. and is for example expelled by supernova explosions.

18) The star Alpha Canis Majoris (α CMa), also known as Sirius, has an apparent magnitude of $m_s = -1.46$ with a parallax of $p_s = 0.380$ arcsec. The binary star system Epsilon Boötis (ϵ Boo), better known as Izar, has an apparent magnitude of $m_I = 2.7$ with a parallax of $p_I = 0.014$ arcsec. Which of the celestial objects has more total luminosity (power) and by how many times more? Take Pogson's formula to be $m_1 - m_2 = -2.5 \log_{10}(\frac{F_2}{F_1})$.

- a) Izar, 16 times more
- b) Sirius, 16 times more
- c) Izar, 256 times more
- d) Sirius, 256 times more

Solution: a). From Pogson's formula, we get that the flux ratio is $\frac{F_I}{F_s} = 10^{0.4 \cdot (m_s - m_I)}$. We know that the flux is given as $F = \frac{L}{4\pi R^2}$, with R being the distance at which we observe the flux, or in this case the reciprocal of the parallax values. The ratio then becomes: $\frac{L_I}{L_s} = 10^{0.4 \cdot (m_s - m_I)} \cdot \frac{p_s^2}{p_I^2} \approx 16$, meaning that Izar is 16 times more luminous than Sirius, and the reason for us observing Sirius as much brighter in the night sky is its proximity to us.

19) Which of the following constellations will a planet not go through as seen from Earth (at least in the foreseeable future)?

- a) Gemini (Gem)
- b) Aquarius (Aqr)
- c) Ophiuchus (Oph)
- d) Ursa Major (UMa)

Solution: d). Ursa Major is the only one of these constellations to not lie on the Ecliptic. The Ecliptic is a line going through all the zodiacal constellations and represents the apparent path the Sun and the planets take across the sky. In

astrology, there are only 12 constellations in the zodiac, but the astronomical zodiac has 13 constellations, with the extra one being Ophiuchus (the snake bearer).

20) Saturn has approximately the same gravitational force on its “surface” as on Earth's surface. What's the ratio of the escape velocity (v_e) between the surfaces? The mass and radius of Saturn is $5.6 \cdot 10^{26}$ kg, and $5.8 \cdot 10^4$ km, while Earth's mass and radius are $6.0 \cdot 10^{24}$ kg, and $6.4 \cdot 10^3$ km.

(Question proposed by Nataniel Skjøndal-Bar, competitor at IOAA 2023)

- a) 1.0
- b) 2.9**
- c) 9.6
- d) 25

Solution: using the formula for the escape velocity, $v_e = \sqrt{\frac{2*GM}{r}}$, we can use the

ratios between the two: $\frac{v_{jupiter}}{v_{earth}} = \sqrt{\frac{\frac{2*GM_{jupiter}}{r_{jupiter}}}{\frac{2*GM_{earth}}{r_{earth}}}} = 2.9$