

Norwegian Olympiad on Astronomy and Astrophysics

Problem set for Round II

2024/2025 school year

Date: Any day during week 4, 2025 (January 20 – 24, 2025)

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 10 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 in vacuum $= 3 \cdot 10^8 \text{ m/s}$
- 1 parsec (pc) $\approx 3.26 \text{ light years}$
- 1 Astronomical Unit (AU) $\approx 1.5 \cdot 10^{11} \text{ m}$
- 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: $\lambda_{\max} = b/T$, $b \approx 2.9 \cdot 10^6 \text{ nm}\cdot\text{K}$
- Stefan-Boltzmann's law: $F = \sigma T^4$, $\sigma \approx 5.67 \cdot 10^{-8} \text{ W/m}^2/\text{K}^4$

- 1) The Nobel Prize in physics in 1974 went to Sir Martin Ryle and Anthony Hewish for a very important astronomical discovery made in 1967. Not long after, it came out that the idea and first observations came from Dame Jocelyn Bell Burnell, who was a student of Hewish's at the time, but wasn't credited in the prize awarding. The observations in question were made using radio-telescopes pointed at the sky whose signals revealed extremely regular and periodic bursts. What had they discovered? (made by D. Veljkovic, winner Astro-OL 2021)
- a) **Pulsars**
 - b) Black Holes
 - c) Supernovae
 - d) Gravitational Lensing

Solution: a) Pulsars are rotating neutron stars with extremely regular periods, and are the only thing provided on the list that can give a periodic signal on a radio telescope. Fun fact: Dame Bell Burnell marked these strange signals at the time using "LGM", standing for "Little Green Men" as she didn't recognise the shape and occurrence of the pulsar signals and jokingly classified them as alien!

- 2) Declination and hour angle are coordinates in what system we use in astronomy? (made by D. Veljkovic, winner Astro-OL 2021)
- a) Horizontal
 - b) **Equatorial**
 - c) Ecliptic
 - d) Galactic
- 3) In cosmology, an extremely important aspect is measuring distances to far-away galaxies. A cornerstone of distance calculations are so-called "standard candles", and the foundation for these was laid by Henrietta Swan Leavitt back in 1912, enabling Edwin Hubble to use it in 1924. She observed a certain type of star and saw a direct correlation between the period of the variability of this type of star's luminosity with how bright these stars were. What stars had she observed? (made by D. Veljkovic, winner Astro-OL 2021)
- a) Main sequence stars
 - b) Pulsars
 - c) Eclipsing binaries
 - d) **Cepheids**

Solution: This property of cepheid variables was extremely important in enabling distance calculations, and is still a method used today, so much so that Henrietta Swan Leavitt was nominated for a Nobel prize, but that had to be withdrawn as she had died a couple of years prior to her nomination. Fun fact: Henrietta Swan Leavitt's job title was "computer" - before the dawn of actual computer processing, women were often employed with performing tedious calculations and signal analyses.

- 4) What is chromatic aberration, shown on the image below? (made by D. Veljkovic, winner Astro-OL 2021)

- a) An artefact due to atmospheric turbulence when observing on particularly humid nights.
- b) An artefact inherent to refracting telescopes, because different wavelengths of light will be refracted by the lenses at different angles.**
- c) An artefact inherent to reflecting telescopes, because different wavelengths of light will be reflected off the mirrors at different angles.
- d) An artefact due to not using a suitable blue-light filter in front of the telescope when observing from the Earth.

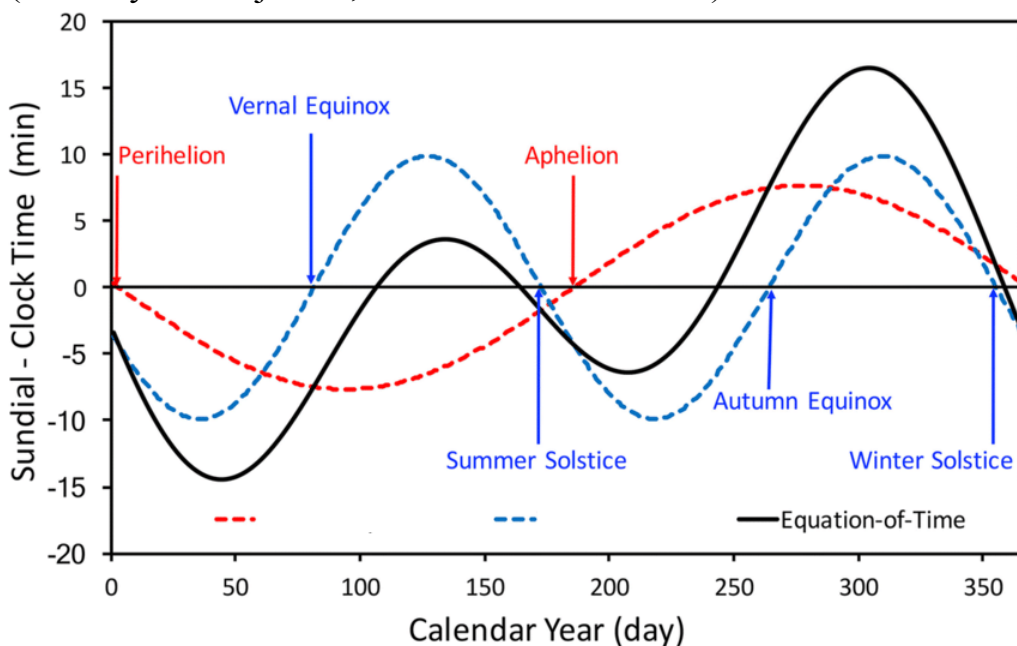


- 5) Why do we always see the same side of the Moon from Earth?
- a) The Moon's rotation and orbit are synchronized**
 - b) The Moon's rotation and Earth's rotation are synchronized
 - c) The Moon's orbit and Earth's orbit are synchronized
 - d) The Moon's orbit and Earth's rotation are synchronized

Solution: The moon is tidally locked because it rotates around its own axis in the same time that it takes to orbit Earth.

- 6) The black line on the image below shows a discrepancy in time that we call "equation of time". It represents the time difference between apparent solar time (following the actual Sun) and mean solar time (following an "average" Sun) which our timekeeping is based upon. The equation of time has two components, shown in red and blue. What are those components due to?

(made by D. Veljkovic, winner Astro-OL 2021).



- a) Solar storms and shifts in Earth's magnetic field
 - b) Rotation of the Moon and shift in Sun's galactic coordinates
 - c) **Earth's orbital obliquity and orbital eccentricity**
 - d) The non-perfect spherical shapes of the Earth and Sun
- 7) Much like stars gather into galaxies, galaxies gather into galaxy clusters on larger distance scales. How do some galaxy clusters suggest the existence of dark matter?
- a) **Their visible mass is not sufficient to keep the galaxies bound by gravity.**
 - b) The expanding universe makes their galaxies drift apart at an accelerating rate.
 - c) The material between their galaxies is darker than the intergalactic medium.
 - d) They eject dark matter particles through energetic jets that have recently been detected in gravitational wave observatories.
- 8) If we were to dig a tunnel halfway down to the centre of our planet, what would be the gravitational force we would feel exerted on us compared to on the surface? Assume that the Earth is a uniformly dense sphere. (made by D. Veljkovic, winner Astro-OL 2021)
- a) Double what we feel on the surface
 - b) **Half of what we feel on the surface**
 - c) An eighth of what we feel on the surface

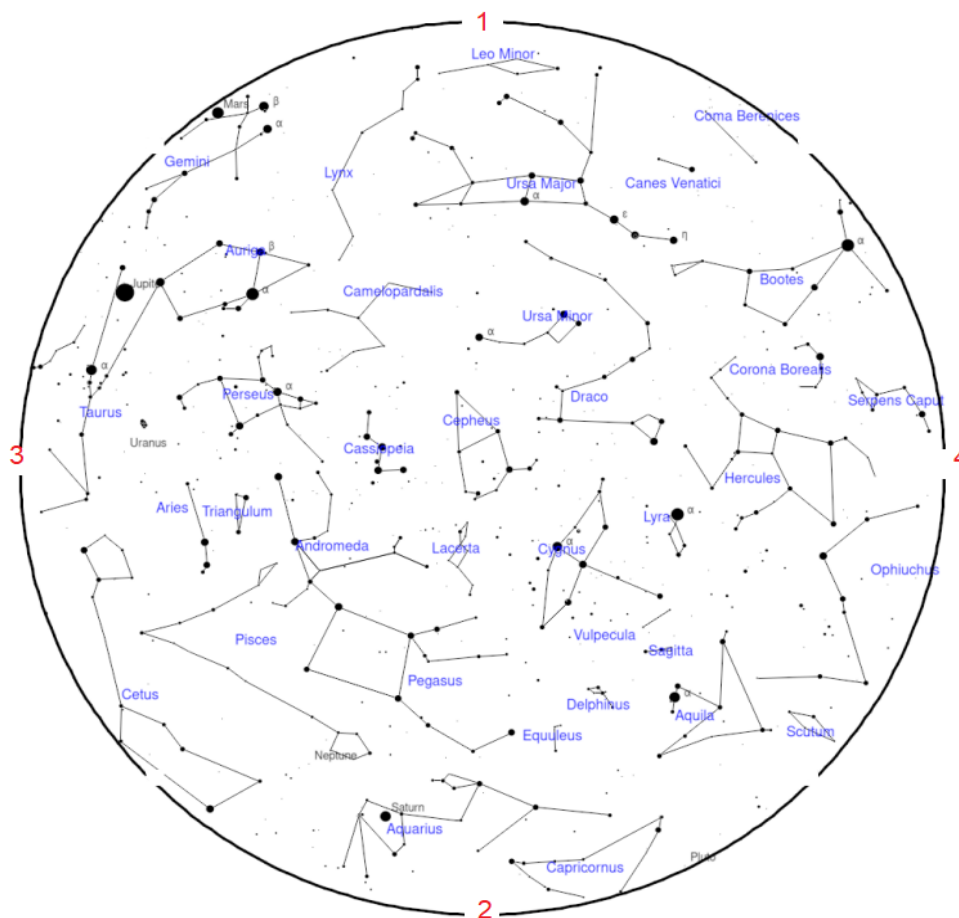
- d) Eight times as much as what we feel on the surface

Solution: According to the second shell theorem, only the part of the Earth from us to the centre will exert a force, and not the part we've already dug past. The mass of this new part is: $\frac{M_{part}}{M_{\oplus}} = \frac{\frac{4}{3}\pi r^3 \rho}{\frac{4}{3}\pi R_{\oplus}^3 \rho} = \frac{r^3}{R_{\oplus}^3} \Rightarrow$
 $M_{part} = \frac{r^3}{R_{\oplus}^3} M_{\oplus}$, and with $r = \frac{R_{\oplus}}{2}$, this turns out to be $M_{part} = \frac{1}{8} M_{\oplus}$.
 Inserting this into Newton's Law of Gravity gives $F = G \frac{M_{part}m}{r^2} =$
 $G \frac{\frac{M_{\oplus}m}{8}}{\frac{R_{\oplus}^2}{4}} = \frac{1}{2} G \frac{M_{\oplus}m}{R_{\oplus}^2}$ which is exactly half of what we would feel on the surface.

- 9) Why is it incorrect to say that Earth rotates 360 degrees around its own axis in exactly 24 hours?
- a) Trick question; Earth does rotate 360 degrees in exactly 24 hours.
 - b) 24 hours is the time it takes for a point on Earth to directly re-face the Sun, and Earth must rotate more than 360 degrees to compensate for movement in its orbit around the Sun in this time interval.**
 - c) Earth's rotation velocity fluctuates significantly, and the statement is only true when averaged over one year.
 - d) Earth's orbit is not a perfect circle, but an ellipse, and effects from Einstein's theory of relativity means that time passes differently when Earth is at different distances from the Sun.
- 10) Over one year, the position of a distant star on the sky changes by 0.00002 degrees relative to the background stars. Roughly how far away is the star?
- a) 500 000 AU
 - b) 6 000 000 AU**
 - c) 70 000 000 AU
 - d) 800 000 000 AU

Solution: Parallax half-angle 0.00001 degrees, and parallax distance $1 \text{ AU} / (10^{-5}/180 \cdot \pi) \approx 6 \cdot 10^6 \text{ AU}$.

11) Match the numbers to the cardinal directions on the sky chart (made by D. Veljkovic, winner Astro-OL 2021):



- a) 1-North, 2-South, 3-West, 4-East
- b) 1-North, 2-South, 3-East, 4-West**
- c) 1-South, 2-North, 3-West, 4-East
- d) 1-South, 2-North, 3-East, 4-West

Solution: [See handout on observational astronomy for explanation.](#) This exact chart is used throughout the handout as an example.

12) Using the same star chart above, we can determine that the latitude of the observer that sees this sky is approximately (made by D. Veljkovic, winner Astro-OL 2021):

- a) 0°
- b) 30° N
- c) 60° N**
- d) 90° N

Solution: The key to this question is to recognise that the altitude of Polaris above the horizon corresponds to the observer's degree of latitude. Polaris is marked with the Greek letter alpha in the Ursa Minor constellation. If the latitude were 0° , the star would be exactly on the horizon (the circumference of the circle), and if it were 90° , it would be exactly in the centre, representing the zenith. As it is more than halfway between the horizon and the zenith, the approximate solution is 60° . The sky chart generated is in Trondheim, 2024-10-11 22:00:00 (CEST), which is at about 63°N .

- 13) Which of the following is a list of bright stars which can be occulted by the moon, as seen from the surface of the Earth?
- a) Rigel (Alpha Orionis), Sirius (Alpha Canis Majoris), Toliman (Alpha Centauri) and Achernar (Alpha Eridani)
 - b) Antares (Alpha Scorpii), Aldebaran (Alpha Tauri), Regulus (Alpha Leonis) and Spica (Alpha Virginis)**
 - c) Fomalhaut (Alpha Piscis Austrinus), Procyon (Alpha Canis Minoris), Capella (Alpha Aurigae) and Vega (Alpha Lyrae)
 - d) Arcturus (Alpha Boötis), Adhara (Epsilon Canis Majoris), Deneb (Alpha Cygni) and Altair (Alpha Aquilae)

Solution: As indicated by their Bayer designations, all the stars listed in alternative b) are located within zodiacal constellations (Scorpius, Taurus, Leo, and Virgo, respectively). The ecliptic (= the Earth's orbital plane) intersects these constellations, implying that the sun, moon and planets will appear to move through these constellations as seen from the surface of the Earth. As a result, these stars will all be occulted by the moon occasionally. None of the stars listed as alternatives are in zodiacal constellations.

- 14) What are the best conditions for producing planets with thick atmospheres?
- a) Strong gravitational field and high temperature at the surface
 - b) Strong gravitational field and low temperature at the surface**
 - c) Weak gravitational field and high temperature at the surface
 - d) Weak gravitational field and low temperature at the surface

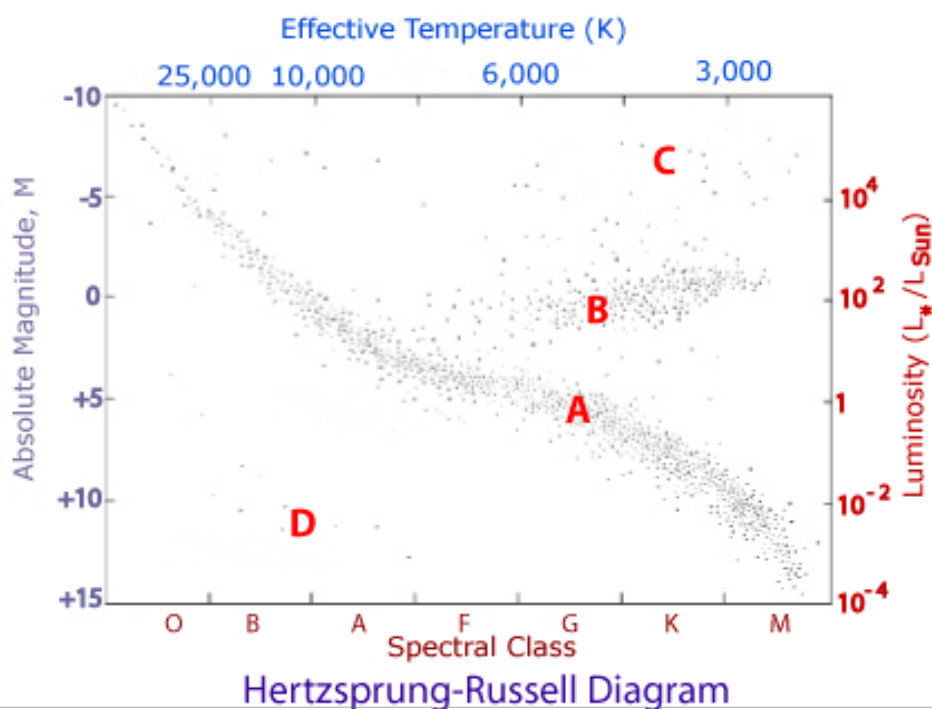
Solution: The atmosphere is a gas of particles. Stronger gravity pulls the particles towards the surface. Lower temperature means the particles have lower velocity, so they are less likely to run away.

15) A main sequence star which is more massive than the Sun ...

- a) is less luminous than the Sun.
- b) is smaller than the Sun.
- c) is cooler (lower temperature) than the Sun.
- d) lives a shorter life than the Sun.**

Solution: More massive main sequence stars burn up their “fuel” faster, despite having more “fuel” to start with.

16) Sirius B is a white dwarf. Which of the following numbers can approximately represent the ratio between its luminosity and that of our Sun? Use the HR-diagram provided below to help you (made by D. Veljkovic, winner Astro-OL 2021).



- a) 0.01**
- b) 1
- c) 100
- d) 100 000

Solution: White Dwarfs can be found in the region labelled with D in the diagram above. As such, the fraction which can be read off of the rightmost axis must be less than 1. Sirius B’s actual luminosity is about 0.026 that of the Sun, but we are only looking for an approximation here, showing that

the students know where the different star groups are in the HR diagram.

- 17) The two spectra below are sketches of observing two different stars of the same composition. What is different between the two stars that leads to the difference we see in the spectra? (made by D. Veljkovic, winner Astro-OL 2021)

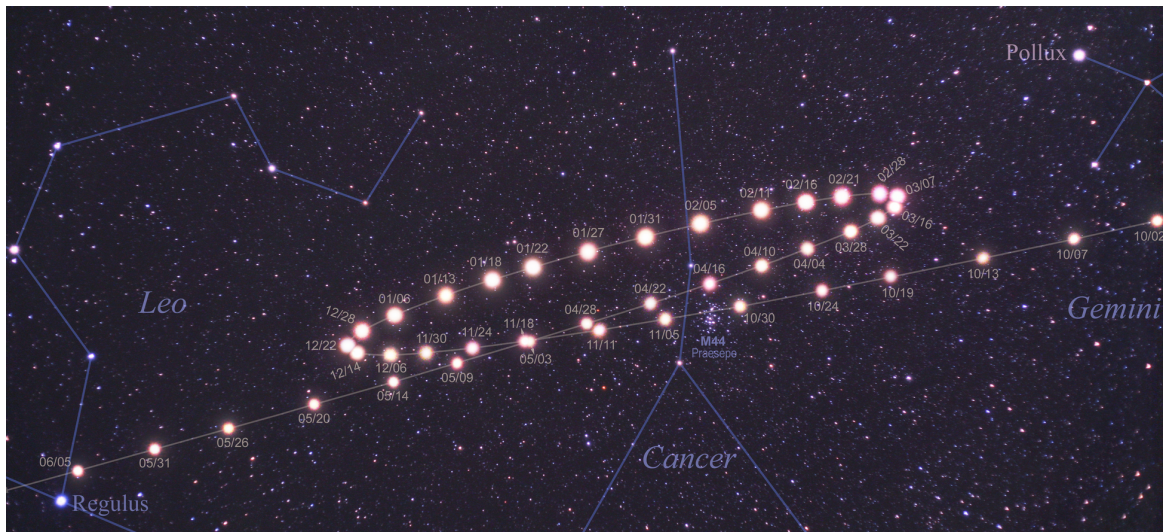


- a) **The star with the wider absorption lines is rotating about its own axis at a greater velocity than the one with the narrower absorption lines.**
- b) The star with the wider absorption lines is moving away from us at a greater velocity than the one with the narrower absorption lines.
- c) The star with the wider absorption lines is moving away from us at a lower velocity than the one with the narrower absorption lines.
- d) The spectral line broadening is due to the spectroscopic version of chromatic aberration, better illustrated in Problem 3.

Solution: We must keep in mind that stars are not just point sources of light. When they rotate, one side of the star is moving towards us, and one is moving away. Because of the light coming from different parts of the star with different velocities relative to us, we will observe broader spectral lines, even sometimes having the consequence of lines that are close together merging into one thick one, as is the case with the leftmost ones in the example given.

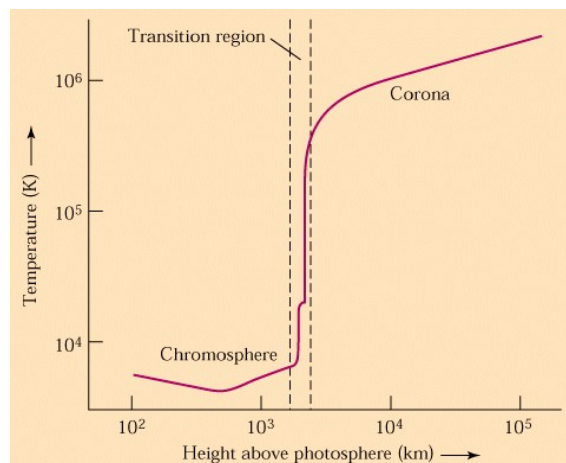
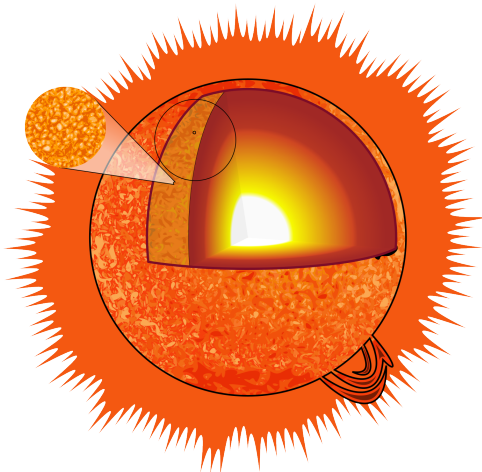
- 18) From Earth, Mars is sometimes seen moving in a backwards loop on the sky relative to the background stars. This is called retrograde motion. Why is this?

(made by D. Veljkovic, winner Astro-OL 2021)



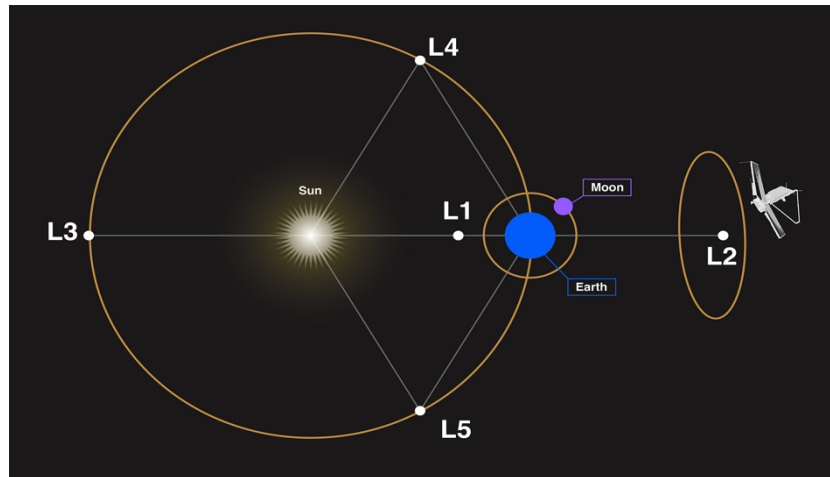
- Mars and Earth follow non-negligible elliptical orbits with varying velocities, and their relative velocity changes direction when one planet attains its maximum velocity while the other attains its minimum velocity.
- Mars' orbit is susceptible to very massive asteroids, and regularly slings around them due to gravity.
- It is a natural feature of two circular orbits around the same point that is seen when the inner planet overtakes the outer planet.**
- Mars does not orbit the Sun directly, but really orbits *a point* that orbits the Sun (deferent and epicycle), and retrograde motion occurs when these move in opposite directions.

19) The Sun's temperature is ...



- Hottest in the center and coldest in the outer atmosphere
- Hottest in the center and coldest near the surface**
- Coldest in the center and hottest in the outer atmosphere
- Coldest in the center and hottest near the surface

20) Lagrange Points are 5 positions in space where a small object could remain “stationary” in a two-body system (i.e. rotating with the same period as Earth in the Sun-Earth system). Which statement about the Lagrange Points is **incorrect**? (made by F. Neumann, winner Astro-OL 2023 and 2024).



- a) **The downside of having JWST at L2 is that there are parts of the sky which are inaccessible.**
- b) L1 provides a good spot for space based solar observatories.
- c) Only L4 and L5 are stable. The remaining points require fuel for orbital corrections.
- d) There are no spacecraft in L3, as it is always behind the Sun and therefore difficult to communicate with.

Solution: a) It is true that JWST has parts of the sky obscured by the Earth and the Sun, but that part changes throughout the year. c) L1, L2 and L3 are like balancing a marble on a saddle. Objects there have a tendency to become unstable as time passes. d) L3 is always behind the Sun, making it much more difficult to communicate with satellites there than the other Lagrange points.