Exploring the World of Science

University of Michigan Science Olympiad
2023 Invitational Tournament

Solar System B

Test length: 50 Minutes

Team name: ________________________________

Team number: _____

Student names:

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Test Instructions: Please follow the instructions given in each section of the test. Higher scores will win, with the number of points for each question given in the question. No partial credit will be given except where indicated. In the event of a tie, the score on the following questions will be used as tiebreakers, in order: C1, B6, B7, B4, B2, A6, A2, A15. If a tie still exists after this, then the score of every individual remaining question, in the order assigned, will serve as a set of successive tiebreakers. (i.e. A1, A3, A4, etc)

Section A: Please answer the following multiple choice questions by circling the best answer below.

1. Which of the following is *not* present in large quantities in Mars' atmosphere? (1 point)
    a. N_2
    b. Ar
    c. H_2O
    d. CO_2
    e. None of the above

2. TOI-700 is a red dwarf of spectral class M. Which of the following is *not* a true statement about M-type red dwarfs that has significant implications for the formation of life around such stars? (1 point)
    a. M dwarfs give off relatively high amounts of ionizing radiation.
    b. M dwarfs live much longer than other stars.
    c. The long time it takes M dwarfs to accrete and reach the main sequence can cause planets to form before the star is fully formed and stabilized.
    d. Planets within M dwarfs' habitable zones are much more likely to be tidally locked than planets around other stars.
    e. M dwarfs are much more likely to have rocky planets around them than other stars.

3. 101955 Bennu is interesting in part because of the plumes of particles it releases. Circle all of the following hypothesized causes of these plumes. More than one answer may be circled, and partial credit may be given. (2 points)
    a. Thermal fracturing
    b. Meteoroid impacts
    c. Small-scale tectonic activity
    d. Underground air currents
    e. Tidal heating

4. Which of the following is a true statement about Enceladus? (1 point)
    a. Enceladus is particularly notable for having *chaos features* (also called *lenticulae*), smooth dark spots caused by meltwater released when water ice breaks through its surface.
    b. Enceladus has an extremely dense atmosphere -- even denser than Earth's -- primarily composed of water vapor thanks to collisions with Saturn's water-ice rings.
    c. Enceladus is tidally heated by its eccentric orbit stemming from its orbital resonance with Dione, driving geological activity.
    d. Aside from our own moon, Enceladus is the only moon that humans have ever landed a probe on.
    e. Alongside Io, Enceladus is the only moon known to be geologically active.

5. Which of the following is *not* a true statement about Venus' high surface temperatures? (1 point)
    a. Venus' tidal locking heats up one side to very high temperatures.
    b. High rates of volcanism heat up the surface and atmosphere.
    c. Venus' atmosphere is incredibly dense, allowing for fewer light to escape its surface.
    d. Venus' atmosphere is primarily composed of CO_2, which is exceptionally good at trapping heat in its atmosphere.
    e. High winds in the lower atmosphere mean that Venus' surface is nearly isothermal.

6. Which of the following is a true statement about factors influencing TRAPPIST-1's prospects of originating and/or sustaining extraterrestrial life? Circle all correct answers. More than one answer may be circled, and partial credit may be given. (2 points)
    a. Five of TRAPPIST-1's planets are known to have geological activity, which is a sign that their atmospheres could be warm enough to harbor life.
    b. High stellar winds from TRAPPIST-1 have the potential to destabilize the atmospheres of many of TRAPPIST-1's planets.
    c. While all of its planets are too far from TRAPPIST-1 to be in its habitable zone, tidal heating keeps the planets warm enough to harbor liquid water.
    d. The orbital resonances of TRAPPIST-1's planets have the ability to keep their orbits stable for billions of years.
    e. The orbital resonances of TRAPPIST-1's planets keep their orbits near-perfectly circular, keeping the flux received from their star stable and preventing tidal heating.

7. Which of the following is an accurate descriptor of 67P/Churyumov–Gerasimenko? (1 point)
    a. C-type asteroid
    b. S-type asteroid
    c. Tidally locked
    d. Ejection-trajectory comet
    e. Contact binary

8. Which of the following is *not* thought to currently have liquid oceans on or below its surface? (1 point)
    a. Europa
    b. Titan
    c. Mars
    d. Enceladus
    e. None of the above

9. Which of the following are confirmed to be present on Titan's surface? (1 point)
    a. Ethane and methane seas
    b. 4,000-km long canyon systems
    c. Continuously erupting argon volcanoes
    d. a and b
    e. b and c

10. Which planetary system was the <u>first</u> roughly Earth-sized world in its habitable zone detected around? (1 point)
    a. Proxima Centauri
    b. TRAPPIST-1
    c. TOI-700
    d. Kepler-186
    e. None of the above

11. Which of the following are features thought to be present on Europa? Circle all correct answers. More than one answer may be circled, and partial credit may be given. (2 points)
    a. *Lenticulae*, smooth dark spots and pits on the surface
    b. *Lineae*, dark streaks crisscrossing the surface
    c. *Pulvae*, thick water-ice dust storms roaming the surface
    d. *Foramen*, incredibly deep and wide craters over 500 million years old
    e. *Penitentes*, icy spikes up to 15 meters high on the equator

12. How far away is Proxima Centauri from the Earth? (1 point)
    a. 4.2 ly
    b. 42 ly
    c. 420 ly
    d. 4200 ly
    e. 42,000 ly

13. Which of the following is *not* a true statement about Europa's orbital or terrestrial features that could affect its prospects of originating and/or sustaining extraterrestrial life? (1 point)
    a. The slight eccentricity of Europa's orbit causes tidal heating, driving geological processes and keeping its subsurface ocean liquid.
    b. Earth-like levels of gaseous, dissolved hydrogen and oxygen are thought to exist below Europa's icy surface in part due to irradiation of ice on its surface.
    c. Earth-like levels of gaseous, dissolved hydrogen and oxygen are thought to exist below Europa's icy surface in part due to volcanism and/or interactions with minerals below its surface.
    d. Radioactive heating plays a dominant role in heating Europa's interior, driving geological processes and keeping its subsurface ocean liquid.
    e. Europa has a deep subsurface ocean, which has the theoretical potential to harbor life.

14. Why does Titan's atmosphere appear orange? (1 point)
    a. The atmosphere is clear, but the surface of Titan is orange, and so we see it as orange.
    b. Rayleigh scattering diffuses all the blue and purple light, causing it to appear orange.
    c. Hydrocarbons in Titan's atmosphere produce a thick orange smog.
    d. a and b
    e. a and c

15. While no evidence points to Mars currently harboring life, it is known to contain some common *biosignatures* -- molecules that cannot exist for long periods of time in their present locations, and so must be refreshed by some active source, such as life. Which of the following are potential biosignatures known to exist in Mars' atmosphere? (1 point)
    a. Methane (CH_4)
    b. Sulfur dioxide (SO_2)
    c. Nitrogen (N_2)
    d. Dimethyl sulfide ($(CH_3)_2S$)
    e. Argon (Ar)

16. Which of the following is *not* an indicator of active tectonic activity on a planet? (1 point)
    a. Volcanism
    b. Crater impacts
    c. Earthquakes
    d. a and b
    e. a and c

17. Scientists have proposed missions such as *Dragonfly*, a rotary-wing aircraft that would fly on other planets or moons (with rotors, in a similar manner to a helicopter.) On which of the following bodies would this concept be feasible? Circle all correct answers. More than one answer may be circled, and partial credit may be given. (2 points)
    a. Titan
    b. Enceladus
    c. Mars
    d. Europa
    e. 101955 Bennu

18. Unlike most other common elements in exoplanet atmospheres, Argon is an unreactive noble gas, yet it is very common in planetary atmospheres -- like those of Earth, Mars, and Titan, to name a few. Where does the majority of the most common isotope of argon in planetary atmospheres, argon-36, come from? (1 point)
    a. Radioactive decay from potassium in planetary crusts
    b. Reactions between CO_2 and O_3 with UV ways in upper atmospheres
    c. Nuclear reactions between carbon and oxygen in supernovas
    d. Decomposition of Ar_2 in circumstellar disks
    e. It's just always been there

19. As mentioned in the last question, argon is very common in planetary atmospheres. However, unlike the atmospheres of the Solar System's four gas giants, the atmospheres of Earth and Mars contain argon-40, as opposed to the generally more common argon-36. Where does the majority of this argon-40 come from? (1 point)
    a. Radioactive decay from potassium in planetary crusts
    b. Reactions between CO_2 and O_3 with UV rays in upper atmospheres
    c. Nuclear reactions between carbon and oxygen in supernovas
    d. Decomposition of Ar_2 in circumstellar disks
    e. It's just always been there

20. Which of the following are true statements about Mars' geological features? Circle all correct answers. More than one answer may be circled, and partial credit may be given. (2 points)
    a. Mars' surface soils are partially composed of perchlorate salts, in concentrations that are toxic to humans.
    b. Mars' volcano Olympus Mons is the largest mountain of any planet in the Solar System.
    c. Mars has over 40,000 craters with a diameter of 5 kilometers or more, as a result of the thin atmosphere failing to erode them.
    d. Mars' poles are so big that during a pole's winter, it freezes nearly a quarter of Mars' atmosphere into CO_2 ice (dry ice).
    e. Mars' soil has many elements, including magnesium, potassium, sodium, and iodine, that are found in soils on Earth and are thought to be necessary for plant growth.

Section B: Please answer the following short-answer choice questions in the space below, or answer the following multiple choice questions by circling the best answer below, if applicable.

1. In 2005, the *Spitzer* Space Telescope was the first telescope to directly capture light from exoplanets. What wavelengths of light does it detect? (1 point)
    a. Ultraviolet
    b. Visible
    c. Infrared
    d. b and c
    e. a, b, and c

2. You observe two transit detections corresponding to two planets transiting a given star. (Assume both planets transit across the center of the star, and that both planets are the same distance from the star, however unrealistic that may be.) The second transit has a dip in flux equal to four times the dip in flux from the first transit. What is the ratio of the radius of the first planet R_1 to that of the second planet R_2? (1 point)
    a. $16R_1 = R_2$
    b. $4R_1 = R_2$
    c. $2R_1 = R_2$
    d. $R_1 = R_2$
    e. $R_1 = 2R_2$

3. What is the primary reason 101955 Bennu was chosen for the OSIRIS-REx mission? (1 point)
    a. There is no reason to prefer any particular asteroid, and Bennu was simply the closest to Earth to study.
    b. Bennu is very notable for having an atmosphere, albeit thin, and OSIRIS-REx is designed to capture the gaseous atmosphere for study.
    c. Bennu has a very high risk of crashing into Earth in 2260, and OSIRIS-REx is designed to redirect it.
    d. Bennu is a very primitive asteroid, allowing us to see what early planetary makeup might have looked like.
    e. None of the above

4. Planet X orbits its host star at an equilibrium temperature T_{eq}. (Assume Planet X's only heat source is light from its host star.) If Planet X suddenly teleported to a location twice as far away from its host star as it was before, what will its new equilibrium temperature be? (1 point)
    a. $(2)T_{eq}$
    b. $(\sqrt{2})T_{eq}$
    c. T_{eq}
    d. $(1/\sqrt{2})T_{eq}$
    e. $(1/2)T_{eq}$

5. Which of the following is *not* the name of a group of asteroids or minor planets in the Solar System? (1 point)
    a. Trojans
    b. Earth-crossers
    c. Centaurs
    d. Plutinos
    e. Tauroids

6. Suppose we are attempting to identify the orbital features of a planet. Given each of the possible sources of data about the planet, fill in the boxes corresponding to which planetary or orbital features we can identify. (Assume we know all necessary properties of the host star, such as mass, luminosity, and radius. Assume light emitted from the star is isotropic. Assume all transits pass through the center of the host star, and this planet is known to not have an atmosphere.) Partial credit may be given in this problem. (5 points)

	Transit data only	Radial velocity data only	Transit + RV data
Planetary mass			
Minimum planetary mass			
Planetary radius			
Orbital inclination			
Orbital period			

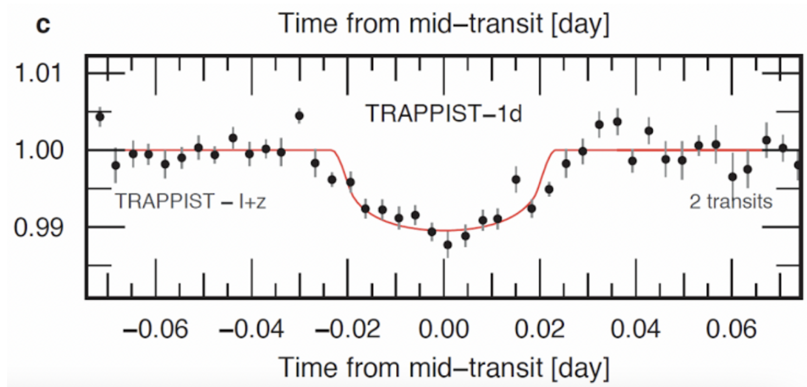
7. Which of the following statements about observational biases in exoplanet detection are true? More than one answer may be circled, and partial credit may be given. (2 points)
    a. Transit detection methods are better at detecting larger planets.
    b. Transit detection methods are better at detecting planets further from their stars.
    c. Radial velocity methods are better at detecting more massive planets.
    d. Radial velocity methods are better at detecting planets further from their stars.
    e. Direct imaging methods are better at detecting planets further from their stars.

8. Which of the following are correct differences between the JWST and TESS satellites? More than one answer may be circled, and partial credit may be given. (2 points)
    a. JWST primarily views in the near-infrared, while TESS views exclusively in the visible range.
    b. JWST has 29 different passbands (wavelength ranges) it can observe through in the infrared, while TESS only has 1.
    c. JWST orbits the Sun at the L2 Lagrange point, while TESS orbits the Sun at the L4 Lagrange point.
    d. JWST is a ground-based telescope, while TESS is a space-based telescope.
    e. JWST has a small field of view of roughly 3' x 3', while TESS can observe a substantial portion of the sky at any given time.

9. Which of the following are valid methods of determining the composition or structure of a planet's atmosphere? (1 point)
    a. *Transit spectroscopy*, where the atmosphere of a planet is observed while a planet is only partially transiting its star
    b. *Eclipse spectroscopy*, where the light reflected from a planet is directly observed
    c. *High-resolution spectroscopy*, where fainter spectra of the planet are observed when its orbital elements are detected by the radial velocity method
    d. a and b
    e. a, b, and c

Section C: Please answer the following questions using the associated images in the blank spaces provided below. Show all necessary work for full credit.

1. The image to the right shows a transit by TRAPPIST-1d of its host star. The image shows the flux, normalized to the average star flux, plotted as a function of time.



   a. Estimate the amount of time between the start of ingress and the end of egress, in days. Don't worry about the exact value, so long as you show your work. Partial credit may be given in this problem. (1 point)

   b. The bottom of the light curve shown has a slight upwards curve, which is due to a phenomenon called limb darkening. In your own words, explain what limb darkening is and why it would cause the curved shape we observe in the image. Partial credit may be given in this problem. (2 points)

   c. On the graph provided on the answer sheet, sketch the shape the transit light curve would have if limb darkening did not exist. Don't worry about the impact parameter of the transit, b (i.e., assume $b = 0$). (2 points)

   d. Estimate the radius of TRAPPIST 1-d, in units of host star radii. Partial credit may be given in this problem. (Once again, assume $b = 0$). (2 points)

   e. Now imagine we wanted to figure out more than just the radius of TRAPPIST 1-d, using *just* transit data of this planet. Name two other planetary or orbital properties we could figure out with just this data (assuming we know all necessary information about its host star), and how we might find these properties. Partial credit may be given in this problem. (3 points)