University of Michigan Science Olympiad
2023 Invitational Tournament

Exploring the World of Science

Solar System B

Test length: 50 Minutes

Team name: KEY
Student names: KEY

UMSO Division B Solar System Key

Section A (25 points):

1. (1 point) C -- H_2O
2. (1 point) E -- M dwarfs are much more likely to have rocky planets around them than other stars.
3. (2 points; 0.5 points off per incorrect answer) A -- Thermal fracturing; B -- Meteoroid impacts
4. (1 point) C -- Enceladus is tidally heated by its eccentric orbit stemming from its orbital resonance with Dione, driving geological activity.
5. (1 point) A -- Venus' tidal locking heats up one side to very high temperatures.
6. (2 points; 0.5 points off per incorrect answer) B -- High stellar winds from TRAPPIST-1 have the potential to destabilize the atmospheres of many of TRAPPIST-1's planets; D -- The orbital resonances of TRAPPIST-1's planets have the ability to keep their orbits stable for billions of years.
7. (1 point) E -- Contact binary
8. (1 point) C -- Mars
9. (1 point) A -- Ethane and methane seas
10. (1 point) D -- Kepler-186
11. (2 points; 0.5 points off per incorrect answer) A -- *Lenticulae*; B -- *Lineae*; E -- *Penitentes*
12. (1 point) A -- 4.2 ly
13. (1 point) D -- Radioactive heating plays a significant role in heating Europa's interior, driving geological processes and keeping its subsurface ocean liquid.
14. (1 point) C -- Hydrocarbons in Titan's atmosphere produce a thick orange smog.
15. (1 point) A -- Methane (CH_4)
16. (1 point) B -- Crater impacts
17. (2 points; 0.5 points off per incorrect answer) A -- Titan; C -- Mars
18. (1 point) C -- Nuclear reactions between carbon and oxygen in supernovas
19. (1 point) A -- Radioactive decay from potassium in planetary crusts

20. (2 points; 0.5 points off per incorrect answer) *All 5 answers are correct.*

Section B (15 points):

1. (1 point) C -- Infrared

2. (1 point) C -- $2R_1 = R_2$

3. (1 point) D -- Bennu is a very primitive asteroid, allowing us to see what early planetary makeup might have looked like.

4. (1 point) D -- $(1/\sqrt{2})T_{eq}$

5. (1 point) E -- Tauroids

6. (5 points; 0.5 points off per incorrect answer)

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

7. (2 points; 0.5 points off per incorrect answer) A -- Transit detection methods are better at detecting larger planets; C -- Radial velocity methods are better at detecting more massive planets; E -- Direct imaging methods are better at detecting planets further from their stars

8. (2 points; 0.5 points off per incorrect answer) A -- JWST primarily views in the near-infrared, while TESS views exclusively in the visible range; 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. (1 point) E -- a, b, and c

Section C (10 points):

1.

a. (1 point) Anywhere between 0.04 to 0.06 days is a valid answer. This answer may be found by measuring the length from one edge of the dip to the other; any work that shows this will count as valid reasoning.

If the correct answer is given but without reasoning, or with invalid reasoning, award 0.5 out of 1 points.

b. (2 points) 1 point will be awarded based on explaining *what* limb darkening is, while 1 point will be awarded based on *why* is occurs.An answer that would award full credit is as follows:

Limb darkening is an optical effect seen in stars (including the Sun), where the central part of the disk appears brighter than the edge, or limb. At far reaches of the star, the only bit of a star seen is the surface of the star, whereas looking dead-on you can see deeper into a star. The inner reaches of a star are brighter due to their increased temperature, making it appear brighter near the center of the star, meaning a bigger dip in flux when the center of the star is what is being blocked by a planet.

This amount of detail need not be given, however. To correctly explain *what* limb darkening is, the answer must include a mention of the fact that the center part of the Sun appears brighter than the edge. If this is correctly explained, award 1 out of 2 points.

To correctly explain *why* this effect occurs, the answer must either include

- a reference to seeing "deeper" into the star, as well as mentioning the temperature of the star being higher deeper in as an explanation to *why* this causes the center to be brighter, or
- a reference to optical depth (denoted τ), as well as mentioning the temperature of the star being higher deeper in as an explanation to *why* this causes the center to be brighter.

If only optical depth is referenced, or "seeing deeper" is referenced, *without* mentioning temperature of the star being higher deeper in, award 0.5 out of 1 points for the why. Similarly, if the answer mentions temperature of the star being higher deeper in *without* mentioning either optical depth or "seeing deeper", award 0.5 out of 1 points for the why.

c. (2 points) The correct answer would mark a rectangle, with the width of the rectangle equal to the width of the existing dip and a depth equal to the maximum depth of the existing dip. No partial credit is given in this problem; if either of these two qualifications are not met, award 0 out of 2 points.

d. (2 points) Because $\delta = \left(\frac{R_p}{R_*}\right)^2 = 0.01$, $R_p = 0.1\,R_*$. Any valid justification must include this equation, or equivalently explaining the equation in plain text. If the correct answer is given with no (or invalid) justification, award 1 out of 2 points. If valid justification is made but leads to the wrong answer, award 1 out of 2 points.

e. (3 points) There are too many valid answers to list here, given how many creative methods of estimating planetary and orbital parameters there are, but common ones would include:

- The orbital period, by measuring the time between transits
- The orbital inclination -- it has to be very close to 90° if it's transiting
- The atmospheric makeup of the planet, by observing its absorption/emission spectrum as it transits
- Its resonant state, by measuring the variations in transit time over a long period of orbits

(If an answer other than these ones are given, and the grader is unsure as to whether it might count, please ask the Event Supervisor.)

Each of the two given answers are worth 1.5 points, if valid and with valid justification. In the event of a valid planetary or orbital property, but with invalid or no reasoning, assign 0.5 out of 1.5 points for that half of the answer.