

2022 SCIENCE OLYMPIAD NATIONAL INVITATIONAL

JANUARY 8, 2022

Solar System B

Directions: Welcome to 2022 Science Olympiad National Invitational Tournament! This test is for Solar System in Division B. You will have 50 minutes to complete this exam.

You are allowed to use two 8.5" × 11" sheets of paper with information on both sides as notes.

You are not allowed to use any calculators on this exam. There is no penalty for wrong answers.

Above all else, just believe!

FROM THE HOSTS OF THE 2022 NATIONAL TOURNAMENT



Caltech



Section A The Sun is at the center of the Solar System.

1. (1 point) A. True
 B. False
2. (1 point) Pluto is a dwarf planet.
 A. True
 B. False
3. (1 point) Venus is the hottest planet in the Solar System.
 A. True
 B. False
4. (1 point) Saturn is the most massive gaseous planet in the Solar System.
 A. True
 B. False
5. (1 point) Io is in an orbital resonance with Iapetus.
 A. True
 B. False
6. (1 point) The Cassini spacecraft visited Arrokoth in 2020.
 A. True
 B. False
7. (1 point) Ralph and Alice are instruments on the Galileo spacecraft.
 A. True
 B. False
8. (1 point) Pluto's largest moon is Charon.
 A. True
 B. False
9. (1 point) The planets in the HR 8799 system were discovered using the radial velocity technique.
 A. True
 B. False
10. (1 point) The Great Red Spot is on Jupiter.
 A. True
 B. False
11. (1 point) ALMA is a ground-based telescope located in Chile.
 A. True
 B. False
12. (1 point) Iapetus is a moon around Uranus.
 A. True

- B. False
13. (1 point) Uranus and Neptune are "ice giants".
- A. True
- B. False
14. (1 point) The interior of Venus is thought to contain some amount of metallic hydrogen.
- A. True
- B. False
15. (1 point) The barycenter (center of mass) of the Pluto-Charon system lies outside of either object.
- A. True
- B. False
16. (1 point) Venus's atmosphere consists primarily of sulfur dioxide.
- A. True
- B. False
17. (1 point) Io is thought to have been captured from the Asteroid Belt.
- A. True
- B. False
18. (1 point) TOI-561 is an old, metal-poor star.
- A. True
- B. False
19. (1 point) Triton has a retrograde orbit.
- A. True
- B. False
20. (1 point) Kepler-138d is a rocky super-Earth.
- A. True
- B. False

Complete the following statements with the name of an object or mission explicitly listed on the rules. No object or mission will be used more than once. Use the exact spelling shown in the word bank below.

Word Bank:

Solar System Objects: Venus, Jupiter, Saturn, Uranus, Neptune, Io, Iapetus, Triton, Pluto, Arrokoth
Extrasolar Systems/Planets: HL Tauri, HR 8799, Kepler 138, K2-18b, K2-33b, TOI-561
Missions: Magellan, Galileo, Juno, Cassini, Voyager 2, New Horizons, ALMA, Kepler, TESS

21. (1 point) The innermost planet of the _____ system completes an orbit in less than one Earth day.
- _____
22. (1 point) The moon _____, despite its high orbital inclination, was almost definitely not captured by the planet it orbits
- _____
23. (1 point) The Galilean moons are the four largest moons of the planet _____.

- _____
24. (1 point) The pre-main-sequence star _____ has greatly changed our understanding of how early planets may form in a star system.
- _____
25. (1 point) The Solar System mission _____ included fly-by's of Jupiter, Pluto, and 486958 Arrokoth.
- _____
26. (1 point) The planet _____ was the first Earth-sized exoplanet in its star's habitable zone to have its atmosphere detected.
- _____
27. (1 point) _____ is unique among the ice giants in our Solar System for radiating almost no excess heat relative to what it receives from the Sun.
- _____
28. (1 point) The _____ mission succeeded Kepler in searching for exoplanets via the transit method.
- _____
29. (1 point) Though other missions have followed, _____ is the most recent American spacecraft to explore the planet Venus, not counting fly-by's.
- _____
30. (1 point) Due to its surface activity, the moon _____ has a thin atmosphere consisting almost exclusively of sulfur and sulfur compounds.
- _____

Section B

Use the attached Image Set for the questions in this section. Each part within each question is worth 1 point unless otherwise specified.

31. (2 points) Order the objects shown in the following images by their distance from the Sun, from closest to farthest: 1, 2, 5, 10, 12
32. (2 points) Order the objects shown in the following images by their average density, from least dense to most dense: 2, 6, 8, 17
33. (3 points) (a) What spacecraft provided the image of Saturn shown in Image 17? [1 pt]
(b) Where is this spacecraft currently located? [1 pt]
(c) What is the number of the image that shows the message carried by this spacecraft? [1 pt]
34. (2 points) (a) What is the name of the object illustrated in Image 20? [1 pt]
(b) What is notable about the composition of this object's atmosphere? [1 pt]
35. (4 points) (a) Which image shows Venus as taken by Mariner 10 as it left the planet? [1 pt]
(b) Which series of spacecraft was the first to land on the surface of Venus? [1 pt]
(c) Which image shows a spacecraft on the Venusian surface? [1 pt]
(d) Why is the photo from part (c) iconic? [1 pt]
36. (4 points) (a) What the name of the system shown in Image 7? [1 pt]
(b) The star in this system is categorized as belonging to a rare population of stars. What is it? [1 pt]

- (c) How is the chemical composition of this group different from other groups of stars? [1 pt]
- (d) What two telescopes combined observations to study this system in detail? [1 pt]
37. (7 points) (a) Which object is shown in Image 12? [1 pt]
- (b) Broadly speaking, what type of object is this? (There are multiple correct answers.) [1 pt]
- (c) In what area of the Solar System is this object located? [1 pt]
- (d) What causes the blue color shown in Image 12? [2 pt]
- (e) Which object(s) in the rules is/are farther from the Sun (but still within the Solar System) than this object? Which image(s) show(s) them? [2 pt]
38. (4 points) (a) Which image shows Jupiter's global circulation system? [1 pt]
- (b) What mission is currently exploring this planet? [1 pt]
- (c) Which image shows the processes taking place at the south pole of Jupiter? [1 pt]
- (d) Which image shows X-ray emissions at the north pole of Jupiter? [1 pt]
39. (2 points) (a) A special phenomena involving Jupiter's magnetosphere occurs at its poles. What is the name of this phenomena? [1 pt]
- (b) The Earth also displays these same phenomena. What is the major difference in these phenomena between Earth and Jupiter? [1 pt]
40. (6 points) (a) What is the name of the most volcanically active object in the Solar System? [1 pt]
- (b) True or false: the volcanism on this object is icy. [1 pt]
- (c) Which image shows this object? [1 pt]
- (d) In one sentence or less, explain the root cause of this volcanism. [1 pt]
- (e) What were the first spacecraft to image a volcanic eruption on this object? [1 pt]
- (f) The image shown in part (a) above was taken by what mission? [1 pt]
41. (6 points) (a) One of the objects on the rules is a young T-Tauri star with a protoplanetary disk. What is its name? [1 pt]
- (b) Which image shows this object? [1 pt]
- (c) What telescope or spacecraft took this image? [1 pt]
- (d) What is the image number that shows a distance density profile for the protoplanetary disk for this object? [1 pt]
- (e) Which image shows another planetary system being discovered using direct imaging? [1 pt]
- (f) What system is shown in the image from part (e)? [1 pt]
42. (7 points) (a) One of the objects on the rules is a moon around Saturn. What is its name? [1 pt]
- (b) Which image shows this object? [1 pt]
- (c) What is notable about this object's orbit around Saturn? [1 pt]
- (d) What is the most likely cause of the extreme difference in albedo between the leading and trailing hemispheres of this object? [2 pt]
- (e) This object is also known for its distinctive equatorial ridge. There are several theories for the formation of this ridge; explain one of them. [2 pt]
43. (6 points) (a) Image 22 shows the surface of what object? [1 pt]

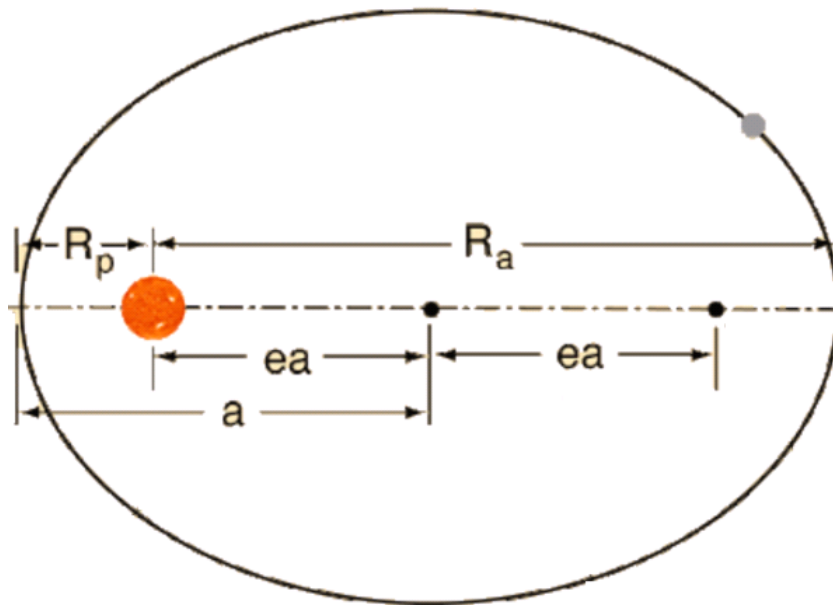
- (b) What is the name of the mission that took this image? [1 pt]
- (c) Which instrument(s) was/were used to collect the data used to create this image? [1 pt]
- (d) What is the name of the smooth area towards the right of the image? [1 pt]
- (e) What is the name of the mountains shown in the middle of the image? [1 pt]
- (f) Generally, what do scientists believe make up these mountains? [1 pt]
44. (7 points) (a) There are three methods of detecting exoplanets explicitly listed in the rules for this event. Of these, which method has detected the most exoplanets? [1 pt]
- (b) Which image depicts the exoplanet detection method from part (a)? [1 pt]
- (c) Which method has detected the second highest number of exoplanets? [1 pt]
- (d) Which image depicts the exoplanet detection method from part (c)? [1 pt]
- (e) What makes the third method so difficult for detecting exoplanets? [2 pt]
- (f) Image 30 shows a plot of planet mass vs. semi-major axis for exoplanets discovered using two methods. Which methods are represented by the colors red and blue, respectively? [1 pt]
45. (5 points) (a) There is one object on the rules that is a moon of Neptune. What is its name? [1 pt]
- (b) Which image shows this object? [1 pt]
- (c) What is unique about the orbital motions of this moon? [1 pt]
- (d) Which image shows a colored global map of this moon's surface? [1 pt]
- (e) Image 31 shows white domes on Earth similar to those seen on the Neptunian moon, suggesting that this moon may be a watery world. What type of feature is shown? [1 pt]
46. (2 points) (a) From where is the moon from the previous question thought to have originated? [1 pt]
- (b) The moon from the previous question is most similar in formation, structure, and origin to which of the other objects listed in the rules? [1 pt]
47. (2 points) (a) Which image shows Neptune? [1 pt]
- (b) Which spacecraft visited Neptune and its moons? [1 pt]
48. (4 points) (a) Which image shows Kepler-138? [1 pt]
- (b) Broadly speaking, what type of exoplanet is the "b" component in this system? [1 pt]
- (c) What exoplanet detection method was used to discover the planets in this system? [1 pt]
- (d) Which image shows the radial velocity of the parent star in the system? [1 pt]
49. (2 points) (a) Image 29 shows the spectra of some planet and exoplanet atmospheres, with Earth's atmosphere represented by the green line. Which line represents the Kepler-138b? [1 pt]
- (b) One of the spectra in Image 29 represents a planet in our Solar System. Which line is it, and which planet does it represent? [1 pt]
50. (3 points) (a) Which object is shown in Image 11? [1 pt]
- (b) Which spacecraft or telescope took this image? [1 pt]
- (c) In which portion of the electromagnetic spectrum was this image taken? [1 pt]
51. (7 points) (a) Which image shows a map of the surface of Venus? [1 pt]
- (b) Which spacecraft or telescope took the image from part (a)? [1 pt]

- (c) Which image shows a complex impact on the surface of Venus taken by the mission from part (b)? [1 pt]
- (d) Which image shows the southern polar region of Venus and was taken by the Venus Express spacecraft? [1 pt]
- (e) Saturn has a similar feature near its poles. Which image shows this feature? [1 pt]
- (f) Which spacecraft or telescope took the image from part (e)? [1 pt]
- (g) In no more than a couple of words, what are these features? [1 pt]

Section C

Kepler's Laws

The figure below depicts a geometrically-exaggerated diagram of a planet (grey) in orbit around a star (orange). Let the planet, which orbits with period P , have a mass m , and the star have a mass M .



In your answers to the following four questions, you may indicate subscripts using the “_” character (e.g., A_B would be A_B) and superscripts using the “^” character (e.g., X^2 would be X^2).

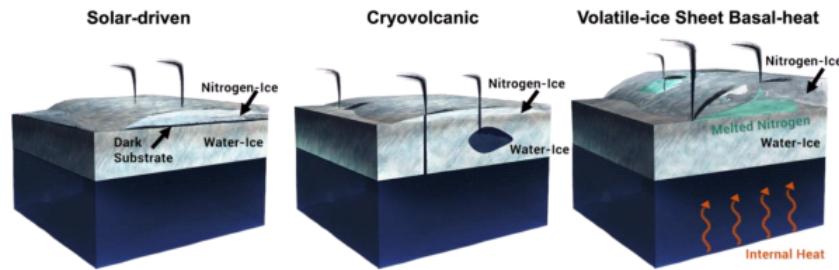
52. (6 points) In your own words, give a brief explanation of what a , R_a , and R_p represent in this diagram. Then, write a formula for a in terms of R_a , R_p , and any other necessary constants.
53. (4 points) Write a formula that would allow you to determine a if you knew the values of P , m , and M without knowing R_a or R_p . Assume that each value is given in base SI units, not AU, years, or solar masses. (i.e., be sure to include all necessary constants, like π).
54. (3 points) By what factor would the value of a change if the period of the planet's orbit, P , was doubled, with all other values held constant?
55. (7 points) By what factor would the value of P change if the mass of the planet were doubled with all else constant? What if the mass of the star were doubled with all else constant? Explain why these two values either differ or are the same, based on your answer.

Triton's Plumes

Currently, Io, Titan, Europa, Enceladus, and Triton are the only moons thought to be currently geologically active. Triton's plumes were discovered in 1989 when the Voyager 2 spacecraft visited it, but their origin is still an open question in the field. Currently, there are five theories for the source of these plumes, some with more plausibility than others:

Solar-driven Cryovolcanism Volatile-ice Sheet Basal-heat Buoyant Methane Dust Devils

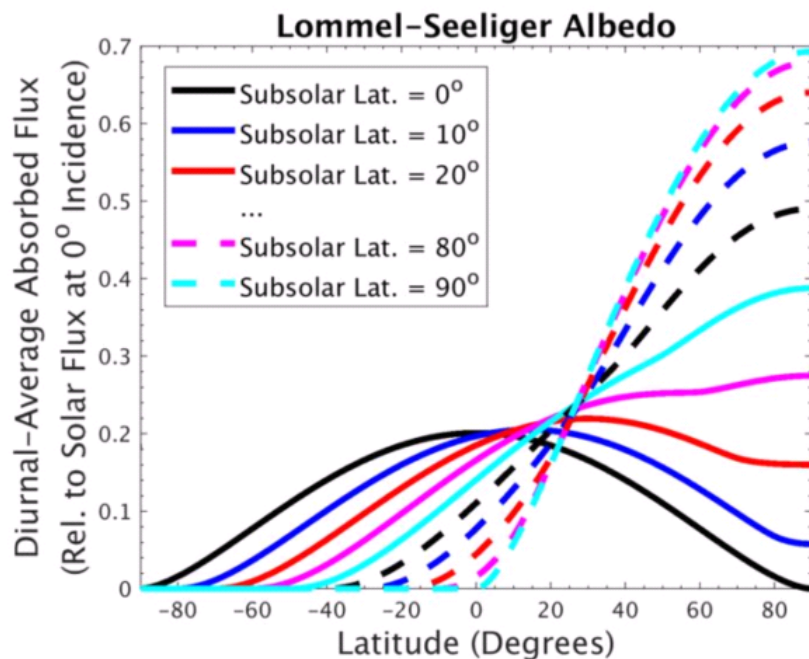
56. (2 points) The "Buoyant Methane" and "Dust Devil" hypotheses for Triton's plumes are no longer considered likely candidates. Why is this the case?



Artistic depiction of three remaining, eruption-based hypotheses for Triton's plumes, taken from Hofgartner et al. (2019). Features are not shown to scale. The dark blue portion towards the bottom of the figure represents a subsurface water ocean (which Triton may have), but this isn't necessary in any of the three hypotheses.

57. (6 points) Hansen et al. (1990) and Kirk et al. (1990) argued that the geographic distributions of plumes and fans on Triton was strong evidence of the plumes being solar-driven. For three decades, this was the leading hypothesis for the origin of Triton's plumes, as when Voyager 2 had observed Triton, the plumes were close to the subsolar latitude (i.e., the latitude where the sun appears directly overhead at that moment). Recently, however, Hofgartner et al. (2019) argue that this isn't necessarily the case.

The plot below shows how the daily-averaged solar flux varies with latitude for different subsolar latitudes. Using this plot and knowing that the two confirmed, active plumes on Triton were located at 49° S and 57° S, briefly explain why the plumes' locations aren't necessarily as supportive of the solar-driven hypothesis as previously thought.



58. (4 points) Hofgartner et al. suggest that it is possible to determine which of the three remaining theories is the origin of Triton's plumes through remote sensing.

Suppose that in the future, a spacecraft visits Triton. It finds the following:

The distribution of active plumes is independent of seasons and the distribution of nitrogen ice The fans and plumes are water-rich The temperatures associated with plumes are above the boiling point of nitrogen on

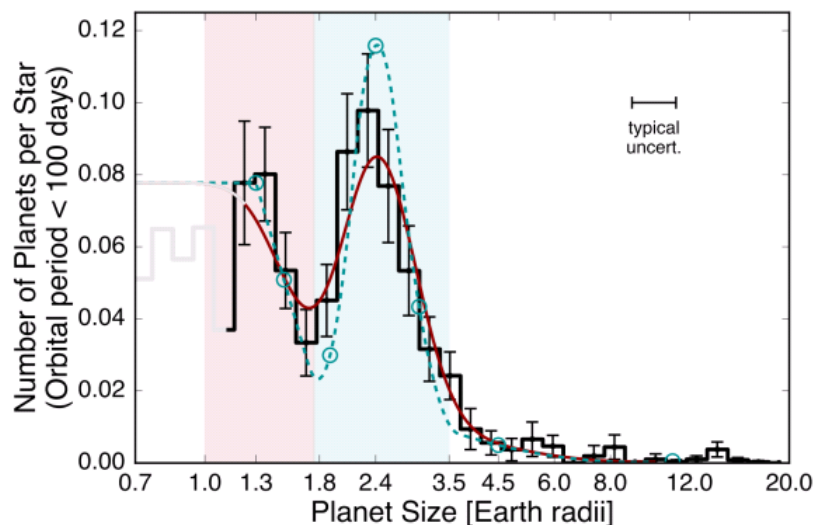
Triton

Based on this information, which of the three theories would you think is the origin of Triton's plumes?

The Radius Gap

Our Solar System has small, rocky planets (e.g., Earth and Mercury) and large planets with thick, gaseous envelopes (e.g., Jupiter and Neptune), but nothing in between. Outside of our Solar System, however, we know that planets between the size of Earth and Neptune exist. What are these planets like, and how common are they?

Using the California-Kepler survey, Fulton et al. (2017) find that the radii of these types of planets has a bimodal distribution, leading to a "radius gap" (sometimes called a "radius valley"). In other words, although it's very common to see planets with a radius of 1.2 or 2.4 Earth radii, a planet with a radius of 1.8 Earth radii is relatively uncommon, resulting in a distribution with two peaks as shown below:



59. (4 points) What is the difference between the atmospheres of the planets that comprise each of the peaks in the distribution?

In your answer, refer to the peaks as the "lower peak" (which has a red background) and "higher peak" (which has a light blue background) to prevent any misunderstandings while grading.

60. (4 points) One possible cause of this bimodal distribution is photoevaporation. Briefly explain what photoevaporation is and how it could result in the planet characteristics you mentioned in the previous question.
61. (6 points) Ginzburg et al. (2017) proposes an alternate mechanism for the radius gap based on the residual heat of the core of the young planet leading to atmospheric erosion (also known as "core-powered mass loss"). In order to determine which mechanism (photoevaporation or core-powered mass loss) contributes more, they suggested seeing how the radius gap varies with stellar type (i.e., seeing if having a hotter or cooler parent stars effects the radius gap). Theoretically, how would this help astronomers distinguish between the two?

Planetary Migration

Our Solar System's structure is also unique. All eight planets lie in roughly the same plane and move in the same direction as the spin of our Sun. Furthermore, the four rocky planets are close to the Sun, while the large, gaseous planets are all farther away. This "tidiness" led astronomers centuries ago to think that planets (and planetary systems) stayed roughly the same after the planets first formed.

Over the past few decades, astronomers have discovered systems that shatter these antiquated theories. Among these are systems that include large planets that orbit very, very close to their parent stars. K2-33b is such a planet.

62. (2 points) The radial velocity and transit detection methods are very effective for finding large planets that orbit close to their parent stars. Why is this the case?

63. (4 points) Observationally, there are many spectroscopic indicators that K2-33 is a very young system, such as the infrared excess in K2-33's spectral energy distribution (SED). What causes this "infrared excess", and how would it be an indicator that the system is young?

64. (6 points) Determining whether planets like K2-33b formed near their present position (in situ) or formed elsewhere and migrated to their present position is an open question. Conceptually speaking, planet migration mechanisms can be loosely classified into three categories:

interactions with the protoplanetary disk

interactions with a stellar companion and the planet

interactions between multiple planets in the system

Due to its size, location, and age, what can K2-33b tell us about what is possible in terms of planetary migration? Between forming in-situ and the three migration mechanisms outlined earlier, which one(s) seem(s) plausible for K2-33b?

65. (4 points) Studying exoplanets has yielded new insight into the formation and early evolution of our Solar System. The earliest investigators focused primarily on whether gravitational interactions within the Solar System could scatter or even eject objects, which would populate the Oort Cloud.

A planet ejecting an object results in the planet's orbit moving inwards slightly. From an energy conservation perspective, why is this the case? Of the eight planets in the Solar System, which would scatter or eject objects the most efficiently?

66. (4 points) Planetary scientists have had difficulty explaining the formation of Neptune via the core accretion process at its current location. In 2005, a series of papers by Rodney Gomes, Hal Levison, Alessandro Morbidelli, and Kleomenis Tsiganis established the first version of the Nice model (named after the French city, where some of the original work was done). In what way(s) does the Nice model potentially address this issue?

Conclusion: We hope you had a wonderful time taking this exam! Please consider filling out the official feedback form for the National Invitational and/or posting on the Scioly.org forums to help us make this event the best it can be.