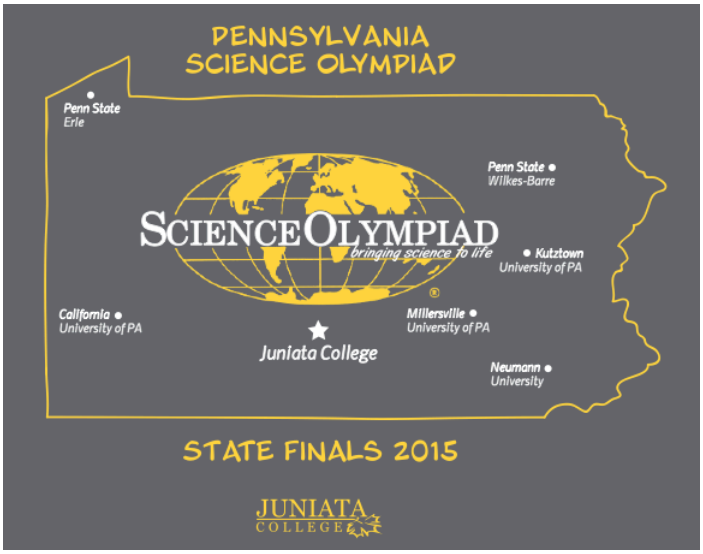


PENNSYLVANIA SCIENCE OLYMPIAD

STATE FINALS 2015

ASTRONOMY C DIVISION EXAM

APRIL 25, 2015

TEAM NUMBER _____ **SCHOOL NAME**_____

PARTICIPANTS_____

_____

INSTRUCTIONS:

1. **Turn in all exam materials at the end of this event. *Missing exam materials will result in immediate disqualification of the team in question*. There is an exam packet, an image packet, and two blank answer sheets.**

2. **You may separate the exam pages.**

3. ***Only* the answers provided on the answer page will be considered. Do not write outside the designated spaces for each answer. You may write in the exam booklet.**

4. **Write your team number, school name, and participants' names on the title page of the test booklet. By writing your participants' names, you agree to the General Rules, Code of Ethics, and Spirit of the Problem as defined in the 2015 Division C Rules Manual.**

5. **Write your team number, school name, and participants' names in the appropriate spaces on the answer sheets.**

6. **Each question is worth one point. Tiebreaker questions are indicated with a (T#) in which the number indicates the *order of consultation* in the event of a tie. Tiebreaker questions count toward the overall raw score, and are only used as tiebreakers when there is a tie. In such cases, (T1) will be examined first, then (T2), and so on until the tie is broken. There are 15 tiebreakers.**

7. **Pay close attention to the units given in the problem and the units asked for in the answer.**

8. **When the time is up, *the time is up*. Continuing to write after the time is up risks immediate disqualification.**

9. **Nonsensical, mocking, or inappropriate answers WILL RESULT IN DISQUALIFICATION.**

10. **In the bonus spot on your answer sheet, indicate the name of the gentleman shown in the image on the *lower left side* of the cover sheet.**

SECTION 1: Questions numbered 1-35 refer to image pages 1, 2 and 3, and the Object list as published in section 3c of the Astronomy rules in the 2015 Science Olympiad Division C Rules Manual. "Object" means one of the objects from the list.

1. Consider image 6 on image page 1. Which object is indicated in this image?
2. What characteristic of the object is indicated by image 6?
3. (T6) Which of the images on image page 1 shows HD 189733b?
4. What does the image of HD 189733b actually indicate?
5. Which image on image pages 2 and 3 shows the transit of HD 189733b?
6. Consider image 2 on image page 1. Which object is shown?
7. The presence of what types of molecules is implied by image 2?
8. Which image on image pages 2 and 3 shows the SED for the object shown in image 2?
9. One of the images on image page 1 shows a star-forming region in the constellation Sagittarius. What is this object's designation in the Sharpless catalog?
10. One of the images on image page 1 shows the "Mouth of the Fish." Which image is it?
11. Which of the images on image pages 2 and 3 shows the spectrum for the "Mouth of the Fish?"
12. (T10) What recent (2013) discovery expanded the extent of the "Mouth of the Fish"?
13. Which object possesses a circumstellar disk that is edge-on as seen from Earth?
14. Which image on image page 1 shows the object referred to in #13?
15. Which image on image pages 2 and 3 shows the SED for the object referred to in #13?
16. What is the term for the variability class of the object referred to in #13?
17. Which image on image page 1 shows the object that was among the first definitive detections of a brown dwarf?
18. The object referred to in #17 is the prototype for what spectral class?
19. Which image on image page 1 shows the nearest brown dwarf to our solar system?
20. The object referred to in #19 appears on which of the graphs on image pages 2 and 3?
21. What quantities are plotted on the graph referred to in #20?
22. Which of the images on image page 1 shows the first exoplanet to be directly photographed?
23. Which of the images on image pages 2 and 3 shows the spectrum of the exoplanet referred to in #22 (and its host)?
24. (T14) Consider image 10. Which object is shown in this image?
25. Which image on image pages 2 and 3 shows the SED for the object referred to in #24?
26. The SED referred to in #25 indicates what components of the object?
27. Which image on image page 1 shows a face-on circumstellar disk around a T-Tauri protostar?
28. (T4) What discovery in 2013 (regarding the object in #27) challenges planet-formation theories?

29. Which image on image pages 2 and 3 is the light curve for FU Orionis?

30. When did FU Orionis erupt?

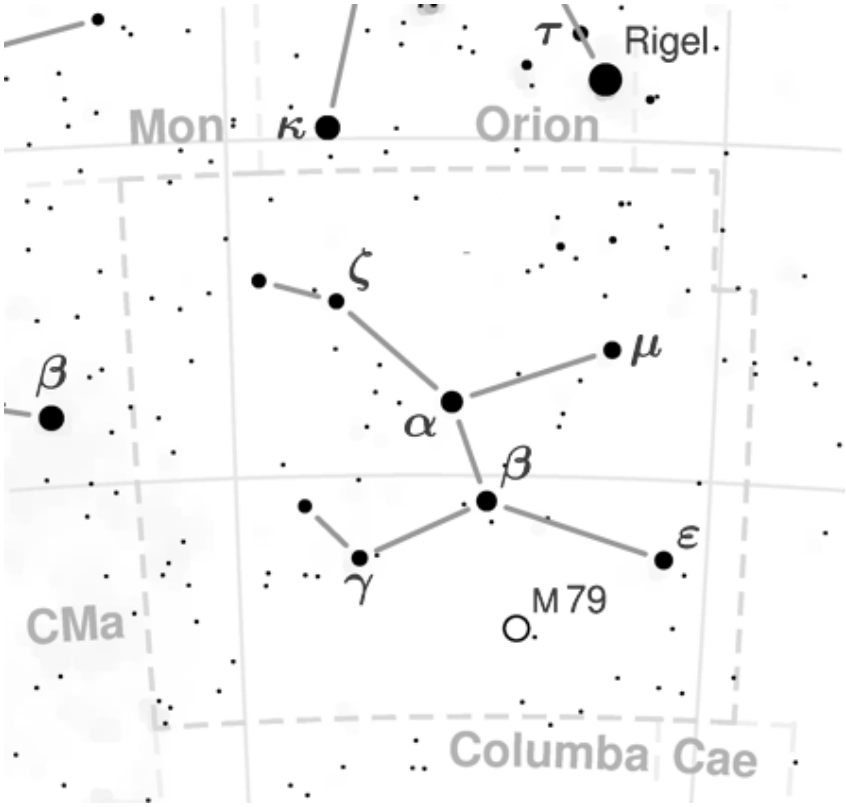
31. How long did it take for FU Orionis to fade from its initial eruption?

32. What is the significance of the letters FU in the designation FU Orionis?

33. What is the significance of the letters LP in the designation LP 944-20?

34. What is the inclination of the orbit of CoRoT-2b?

35. Which object appears in the constellation shown below?



SECTION 2: Questions numbered 36 - 56 deal primarily with the concepts, processes, and astronomical objects associated with section 3a of the Astronomy rules in the 2015 Science Olympiad Division C Rules Manual.

36. What is the maximum mass of a Herbig Ae/Be star in solar masses?

37. Why are there no Herbig Ae/Be stars with more than this mass?

38. What is the astronomical quantity that indicates the ratio of reflected radiation from a surface to the incident radiation on that surface?

39. This physical principle is the cause for the increase in the angular velocity of a collapsing molecular cloud

40. (T1) What is the range, in Jupiter masses, of brown dwarfs?

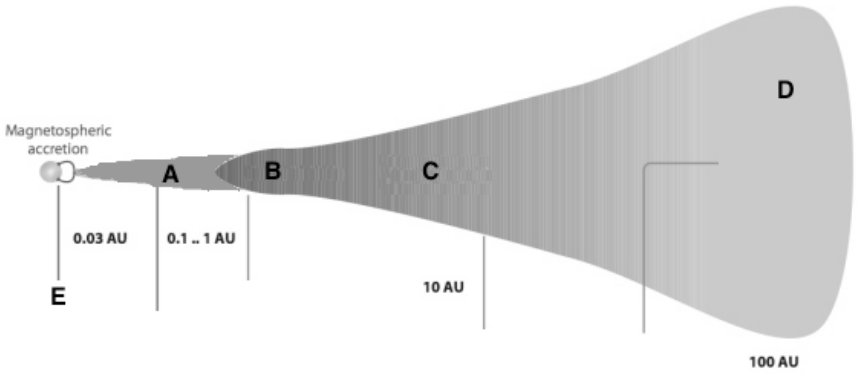
41. If one could see a brown dwarf with one's eyes, what color would it be?

42. What method can be used to determine the presence of *additional* planets in the event that a planet transits its host star from our vantage point?

43. What method can be used to determine the composition of an exoplanet's atmosphere by analysis of the starlight that is scattered by it?

44. What might you call an Earth-like terrestrial planet that orbits in a star's habitable zone?

Consider the image shown below for questions numbered 45 – 47. The image shows a young stellar object and a cross section of the circumstellar disk.

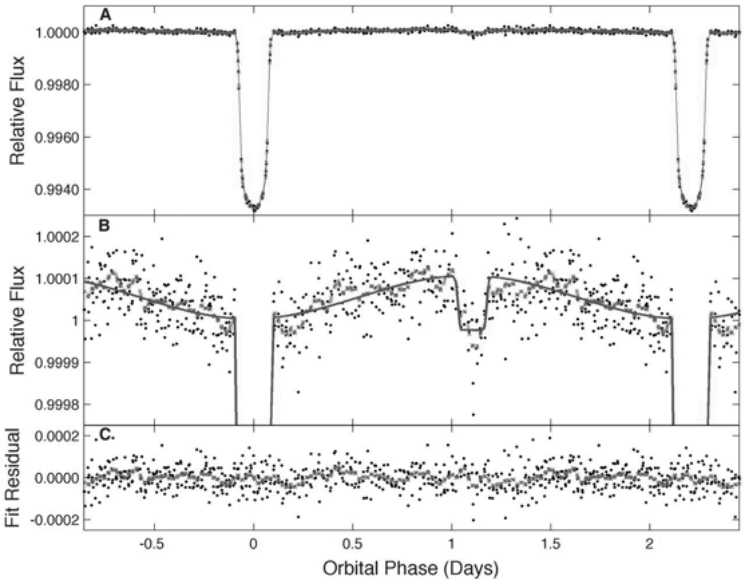


45. Which lettered component indicates the planet-forming region?

46. Which lettered component indicates the warm gas disk?

47. Which region would be best imaged in the sub-millimeter band?

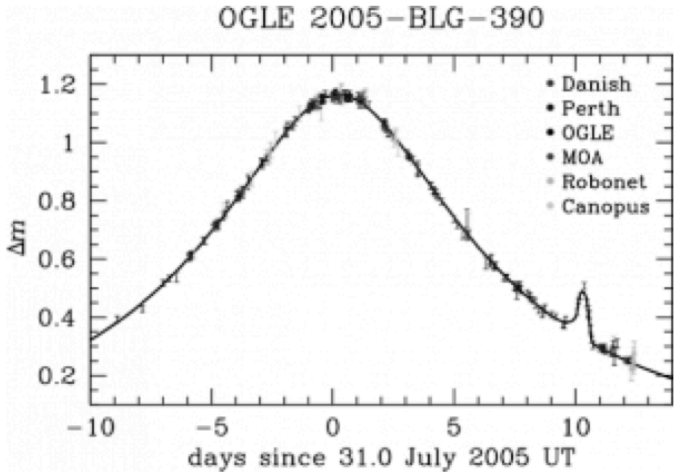
Consider the following Kepler observations of the planet HAT-P-7b, a hot Jupiter orbiting an F8V star in Cygnus, for questions 48 and 49.



48. What explains the increase in the flux from the system between orbital phase 0 and 1 in graph B?

49. Why would the fractional depth of the secondary eclipse tend to increase with wavelength?

Consider the following light curve, generated by the OGLE project, for questions 50 and 51.



50. (T5) What type of event is indicated by this lightcurve as a whole?

51. What is indicated by the "blip" (the jump in the lightcurve) on August 10th?

52. This method has one major inherent flaw as far as research purposes go. What is this major flaw?

53. How might one classify a circumstellar disk as protoplanetary or debris based on the age of the star?

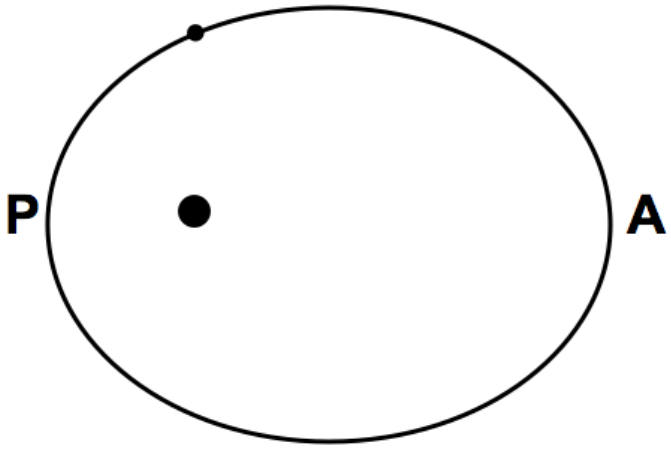
54. What is the primary *physical* difference between protoplanetary disks and debris disks?

55. (T11) Why would a hot Jupiter be unlikely to have any moons?

56. One proposed method to differentiate low-mass brown dwarfs from high-mass gas planets deals with the process of formation. What is the basis for differentiation according to this method?

SECTION 3: Questions numbered 57 – 89 deal with astrophysical measurements and calculations dealing primarily with exoplanets and their host stars; see section 3b of the Astronomy rules in the 2015 Science Olympiad Division C Rules Manual.

In 2000 a planet was discovered orbiting star HD 1237, a sun-like star in the constellation Hydrus. The star is G6V with a mass of 0.9 solar masses. Its planet, HD 1237b, has a mass of 3.49 Jupiter masses. its periastron distance is 0.35 AU and its apastron distance is 1.08 AU. Assume the albedo of the planet is zero. Image is not necessarily to scale. Use this information for questions 57 – 70.



57. (T9) What is the semimajor axis of the orbit in AU?

58. What is the eccentricity of the orbit?

59. What is the total mechanical energy of the orbit in Joules?

60. What is the gravitational potential energy in Joules of the system when the planet is at periastron?

61. What is the kinetic energy in Joules of the planet when it is at periastron?

62. What is the velocity in m/s of the planet when it is at periastron?

63. What is the angular momentum of the planet when it is at periastron?

64. What is the equilibrium temperature of the planet at periastron in K?

65. What is the gravitational potential energy in Joules of the system when the planet is at apastron?

66. What is the kinetic energy in Joules of the planet when it is at apastron?

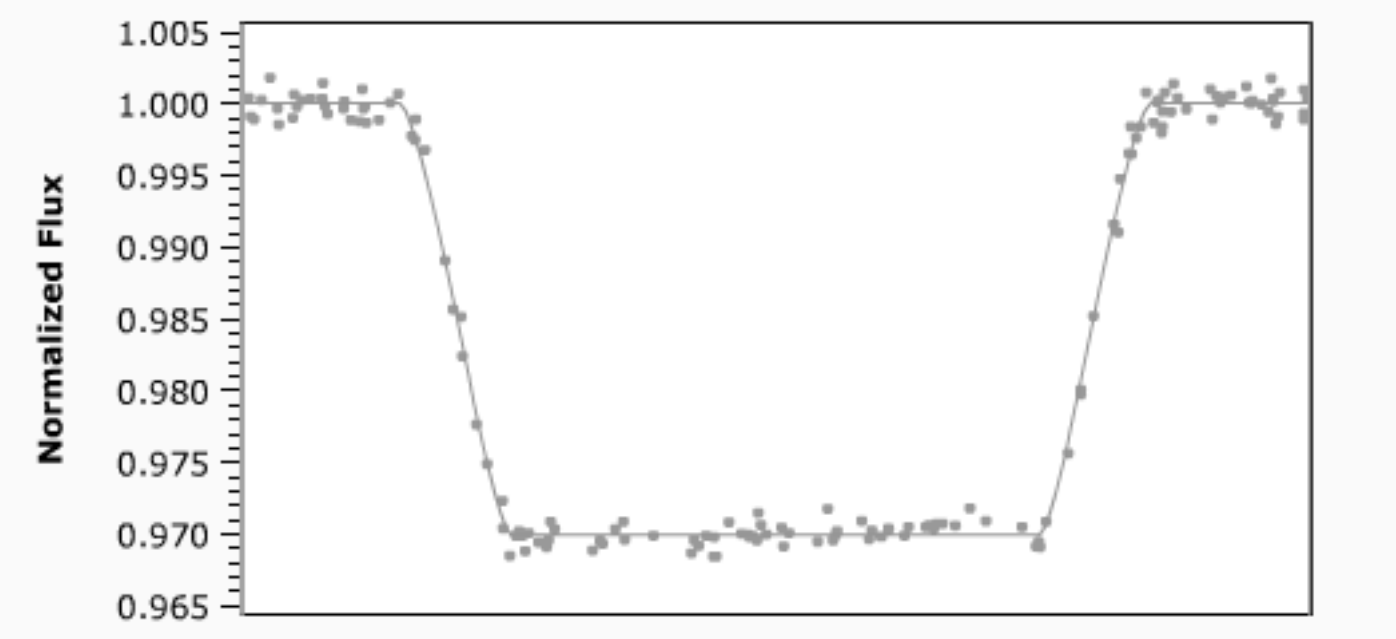
67. What is the velocity in m/s of the planet when it is at apastron?

68. What is the angular momentum of the planet when it is at apastron?

69. What is the equilibrium temperature of the planet at apastron?

70. (T8) What are the inner and outer extents of the star's habitable zone, in AU?

Consider the following simulated transit curve for questions numbered 71 - 81. The star is a main-sequence K0 with a mass of 0.81 solar and a radius of 0.80 solar. The eclipse takes 4.61 hours from the start of ingress to the end of egress and the total orbital period is 16.0 days. The apparent magnitude of the star (off-transit) is 11.800. The orbit is circular and the observer is in the plane of the orbit. The impact parameter is zero.



71. What is the depth of the transit?

72. (T2) What is the absolute magnitude of the star?

73. What is the distance to the star in parsecs?

74. What is the apparent magnitude of the star at mid-transit (to 5 significant figures)?

75. What is the radius of the planet's orbit in AU?

76. What is the velocity of the planet in km/s?

77. What is the reflex velocity of the star in m/s?

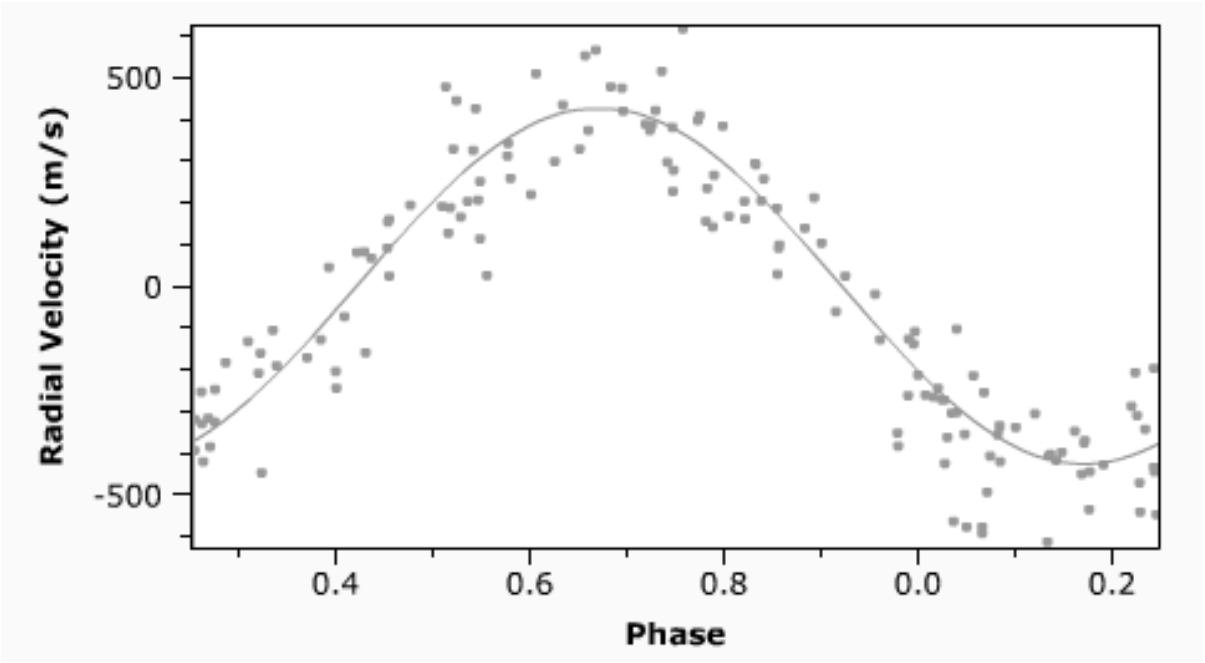
78. What is the mass of the planet in Jupiter masses?

79. What is the radius of the planet in Jupiter radii?

80. (T12) Describe what is meant by an impact parameter of zero.

81. What realistic effect is ignored by the flat-bottomed transit best fit?

Consider the following reflex velocity curve for a star with a planet in a circular orbit for questions numbered 82 – 89. Positive velocities are radially away from the observer. The orbital period is 2.68 days and the observer is in the plane of the orbit. The star is an A9V with a mass of 1.41 solar masses.



82. What is the radius of the planet's orbit in AU assuming its mass is much less than that of the star?

83. (T3) What is the orbital velocity of the star in m/s?

84. What is the orbital velocity of the planet in km/s?

85. What is the mass of the planet in Jupiter masses?

86. What is the orbital phase when the star is moving the fastest away from the observer?

87. What is the orbital phase when the star is the farthest away from the observer?

88. What is the orbital phase when the planet is farthest away from the observer?

89. What is the orbital phase of the center of the primary transit?

SECTION 4: For questions numbered 90-100, provide the term, acronym, or phrase that best fits the description provided.

90. Many hot Jupiters have identical rotation and orbital periods due to this phenomenon.

91. An anomalous Doppler shift that takes place during a planetary transit due to the blocking of portions of the star's spectrum

92. (T7) Classification scheme for gas giant exoplanets based on composition

93. The reduction in eccentricity of an orbit, typically due to tidal interactions

94. Stars that accrete from a metal-poor circumstellar disk are depleted in heavy elements. These stars are classified as:

95. (T13) Hypothetical class of celestial objects resulting from the stripping away of the hydrogen and helium atmosphere of a planet due to proximity to a star, leaving a rocky or metallic core

96. This effect causes perturbations in the orbit of an inner satellite due to the orbit of another body further out; it causes libration and oscillation in the orbital eccentricity and inclination angle.

97. The region around a planet inside which the gravity of the planet dominates the gravity of the host star

98. The process by which stellar radiation causes a dust grain to lose angular momentum relative to its orbit around the star

99. The stage of planetesimal increase in size between 100 km and 1000 km

100. (T15) The pioneering Russian astronomer who developed the Solar Nebular Disk Model in the 1970s