'PENNSYLVANIA SCIENCE OLYMPIAD
DIVISION C
ASTRONOMY EXAM

Team Number ______

Team Name ________________________________________________________________

DO NOT OPEN THE EXAM UNTIL YOU ARE TOLD TO DO SO.
WRITE YOUR TEAM NAME AND NUMBER ON THE TEST AND ANSWER SHEETS.
PENNSYLVANIA SCIENCE OLYMPIAD
STATE FINALS 2023
ASTRONOMY C DIVISION EXAM
APRIL 22, 2023
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 booklet, an image packet, and 3 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 and school name on the front page of the test booklet and each page of the answer sheets. By doing so, you agree to the General Rules, Code of Ethics, and Spirit of the Problem as defined on the Science Olympiad website: [https://www.soinc.org/code-ethics-general-rules](https://www.soinc.org/code-ethics-general-rules).

5. Failure to indicate school name and number on each page of the answer sheets will result in the answer sheet being unscored and discarded.

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 20 tiebreakers.

7. When the time is up, *the time is up.* Continuing to write after the time is up will result in a deduction of -10 applied to the raw score.

8. Nonsensical, mocking, or inappropriate answers WILL RESULT IN DISQUALIFICATION.

9. In the bonus line on the answer sheet, indicate the name of the woman shown in the image on the 2nd cover sheet. Not the shouting musical festival woman, the other one.

10. Staple the exam booklet back together when your materials are submitted. The pages do not need to be in order but the title page MUST be on top.

11. Illegible answers will be considered wrong. If I can’t read it, I can’t score it.

12. Leave the answer sheets separate.
SECTION 1: Questions 1-40 refer to the objects listed in section 3c, page C6, of the 2023 Science Olympiad Division C Rules Manual. “Identify and answer questions relating to the content areas outlined above for the following objects.” The term object used in this section of the exam refers to one of the listed objects.

47 Tucanae is the second brightest object of its type in terms of apparent magnitude.

1. (T18) Which image shows 47 Tucanae?

2. What type of object is 47 Tucanae?

47 Tucanae X9 is a notable object discovered in 47 Tucanae.

3. What is the nature of 47 Tucanae X9?

4. Which image shows the spectrum of this notable object?

In early 2008, a group of Princeton researchers had reserved observation time with the Swift satellite (since renamed the Neil Gehrels Swift Observatory) and had it pointed in just the right direction at just the right time.

5. (T5) What did these researchers get to see in real time?

6. Which image shows this event as seen by Swift’s X-ray telescope?

7. Which image shows the light curve for this event?

8. Which image shows the spectrum for this event?

9. In what galaxy did this event take place?

Consider Image 7 for questions 10 - 13.

10. Which object is shown in this image?

11. Which image shows the light curve for this object?

12. Which image shows the spectrum for this object?

13. How does the GCVS categorize objects of this type?
One of the objects is named (informally) for the insect shown.

14. (T12) Which object is this?

15. Which image shows this object?

16. Which image shows this object’s spectrum?

17. This ion was detected (in space) for the first time in this object.

18. What is suspected to have caused this object’s complex morphology?

Consider image 17 for questions 19 – 22.

19. (T9) Which object created this light curve?

20. Which image shows the spectrum from this object?

21. Which image shows the object as seen by the Spitzer Space Telescope?

22. Why did this object’s period decrease between 1700 and 1950?

One of the objects is a Classical Cepheid. Consider this object for questions 23 – 26.

23. Which image shows this object as seen by the HST?

24. (T1) Which image shows the light curve generated by this object?

25. How does the nebulosity around the object contribute to a distance measurement?

26. What is the translation of the Latin name for the constellation in which this object is found?

One of the images shows evidence for a neutron star merger. Consider for questions 27 – 29.

27. (T16) Which image indicates this event?

28. What is the designation for the electromagnetic counterpart to this event?

29. What is the generic name for this kind of merger event?
Consider image 12 for questions 30 – 33.

30. Which object is shown in image 12?

31. Which image shows the light curve for this object?

32. What is the formal designation for the nebulosity around the object in image 12?

33. What type of object(s) are present in image 12?

One of the objects is a dwarf nova. Consider this object for questions 34 – 37.

34. (T13) Which object is a dwarf nova?

35. Which image shows this object?

36. Which image shows this object’s light curve?

37. How is this type of object classified by the GCVS?

38. (T20) Which image shows an unusual Wolf-Rayet star that seems to have formed from a binary interaction?

39. Which object appears in the constellation shown at right?

40. Which image shows this object’s light curve?

END OF SECTION 1
SECTION 2: Questions 41 - 70 deal primarily with the concepts and types of astronomical objects listed in section 3a, page C6, of the 2023 Science Olympiad Division C Rules Manual.

Consider the H-R diagram shown at right for questions 41 – 45.

41. (T2) What type of astronomical object would produce this H-R diagram?
42. What is the term for region F in the diagram?
43. What is the term for region E in the diagram?
44. What is the term for region A in the diagram?
45. What would you find in region G in the diagram?

46. LBV stars (not exclusively) frequently display this spectroscopic feature whereby the same line appears both in emission and relatively blueshifted absorption.

47. (T6) What does the spectroscopic feature in #46 indicate?
48. What is the region of the H-R diagram in which you would find LBVs?
49. This serves as an upper limit on the luminosity of LBV stars.

50. How are WNE stars similar to WNL stars?
51. (T17) How are WNE stars dissimilar to WNL stars?
52. What is the final stage in the evolution of most Wolf-Rayet stars?

53. A particular white dwarf star is classified with a spectrum DQ. What is the implication of the symbol “D” in its description?
54. What is the implication of the symbol “Q” in the DQ white dwarf description?
55. (T19) Why would a white dwarf display metal lines in its spectrum?
56. Some white dwarf stars are variable. What mechanism drives this variability?

57. These stars are in transition from the central star in a planetary nebula to a white dwarf.

58. The stars referred to in question 57 are sometimes subdivided into these two classes.

Consider a high-mass X-ray binary in which the compact object is a remnant neutron star and the other object is a red giant. This applies to questions 59 – 65.

59. What process is creating the observed X-rays?

60. Mass accumulating on the neutron star can be subject to a rapid thermonuclear fusion event, resulting in a tenfold increase in luminosity that peaks in X-ray. What would this event be called observationally?

61. What type of cataclysmic variable does the event in question 60 resemble?

62. Why might the neutron star have a velocity relative to the original orbit of its progenitor?

63. What type of object results if this relative velocity intersects with the red giant?

64. What must be exceeded in order for this object to collapse into a black hole?

65. What would this object “look” like, assuming it did not collapse into a black hole?
66. (T14) How are Mira variables and semiregular variables classified together?

67. What is the major difference between Mira variables and semiregular variables?

Cepheid variable stars are divided into categories (type I and type II). Before this differentiation took place, both types were lumped together.

68. What consequence did this differentiation have for the size estimates of the universe?

69. To what subclass would you categorize a type II Cepheid with a period of 4 days?

70. (T10) What is the source of Cepheid variable stars’ pulsation?

END OF SECTION 2
SN 2010cz was observed in an anonymous spiral galaxy. This was an average Type Ia supernova. Below is the light curve for this event. Use this image for questions 71 – 74.

71. Determine the apparent magnitude of the supernova at maximum.

72. Determine the absolute magnitude of the supernova at maximum.

73. (T8) Determine the distance modulus for this event, assuming no extinction.

74. Determine the distance to the host galaxy in megaparsecs.

75. (T3) A particular white dwarf star has a surface temperature of 46000 K and a radius of 6500 km. Calculate its luminosity in solar luminosity units to three significant figures of precision.

76. A particular red supergiant star has a radius 287 times that of the sun and a luminosity of 26700 $L_{\odot}$. Calculate the effective surface temperature of this star in Kelvins.
The artist conception below shows a symbiotic variable star system. One such system, designated V1329 Cyg, consists of a primary star of mass $2.1M_\odot$ and a secondary star of mass $0.74M_\odot$ (where $M_\odot$ is the mass of the sun) orbiting each other with a period of 956 days in circular orbits. Use this information for questions 77 – 84. Provide 3 significant figures of precision.

77. (T7) Calculate the orbital separation of the stars in the system, in AU.

78. Calculate the orbital radius of the primary star in km.

79. Calculate the orbital radius of the secondary star in km.

80. Calculate the orbital velocity of the primary star in km/s.

81. Calculate the orbital velocity of the secondary star in km/s.

82. Calculate the gravitational potential energy of the system.

83. Calculate the total energy of the system.

84. Calculate the angular momentum of the system (exclude rotational component)

NGC 1501, shown at right, is a nearly circular planetary nebula, located in the constellation Camelopardalis. The nebula is estimated to be 4240 light years away, and subtends an angle of 0.863 arc minutes. Use this information for questions 85 and 86.

85. Calculate the radius of the nebula in light years.

86. (T11) Calculate the nebula’s parallax angle in mas.
The light curve shown below was created by combining observations of a variable star. The vertical axis indicates apparent magnitude and the horizontal axis indicates the phase of the variability. Use this diagram and the following information for questions 87 – 90.

One accepted period-luminosity relation (according to Lanoix, et al, 1999) for stars of this type is as follows:

\[ m_v = -2.77 \log(P - 1) - 4.07 \]

Where \( m_v \) is the absolute magnitude and \( P \) is the period in days.

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87. Based on the shape of the light curve, what type of star is this?

88. (T15) Determine the absolute magnitude of this star.

89. Determine the mean apparent magnitude of this star.

90. Determine the distance to this star in parsecs.

END OF SECTION 3
SECTION 4: For questions numbered 91-100, provide the term, acronym, name, or phrase that best fits the description provided.

91. This is the mechanism by which mass is accreted in most symbiotic stars.

92. A young star typically exhibits this feature in its SED owing to absorption and reemission of starlight at longer wavelengths by circumstellar dust.

93. This type of diagram shows how the interior of a star evolves over time, including the appearance of convective burning cores/shells.

94. This is the collective term used for both Type Ib and Type Ic supernovae (NOT Type Ibc).

95. These are the units of surface brightness, used typically for a spatially extended object such as a galaxy.

96. (T4) This radiation law describes the radiant energy output of an object as it relates to the object’s temperature.

97. A rapidly spinning compact object such as a neutron star that is not a perfect sphere (its surface has a “bump” or imperfection) will generate this type of gravitational wave.

98. This method of distance determination for Cepheids involves the measurement of color, surface brightness, apparent magnitude, angular diameter, and radial velocity of the surface at various points in the star’s pulsation.

99. The term for this phenomenon (or type of object) is a misnomer because when the term was originated, the limits of telescopic power at the time caused the phenomenon to be misinterpreted.

100. An astronomer observes an object through different filters, then records and compares the respective magnitudes of the object. What is the astronomer measuring?

END OF SECTION 4
SECTION 1

T18  1.________________
     2.________________
     3.________________
     4.________________

T24  21.________________
     22.________________
     23.________________

T5   5.________________
     6.________________
     7.________________

T16  25.________________
     26.________________
     27.________________

T1   24.________________

T12  28.________________
     29.________________
     30.________________

T13  31.________________
     32.________________
     33.________________

T17  34.________________
     35.________________
     36.________________

T20  37.________________
     38.________________

T9   39.________________
     40.________________

BONUS__________________________

Page Score _____ out of _____ page points   Total Score__________   Rank ____________
SECTION 2

T2 41. ____________________________________________
42. ____________________________________________
43. ____________________________________________
44. ____________________________________________
45. ____________________________________________
46. ____________________________________________

T6 47. ____________________________________________
48. ____________________________________________
49. ____________________________________________
50. ____________________________________________

T17 51. ____________________________________________
52. ____________________________________________
53. ____________________________________________
54. ____________________________________________

T19 55. ____________________________________________
56. ____________________________________________
57. ____________________________________________
58. ____________________________________________
59. ____________________________________________
60. ____________________________________________
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65. ____________________________________________

T14 66. ____________________________________________
67. ____________________________________________
68. ____________________________________________
69. ____________________________________________

T10 70. ____________________________________________

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SECTIONS 3 & 4

71. ____________________________ 90. ____________________________
72. ____________________________ 91. ____________________________
T8 73. ____________________________ 92. ____________________________
74. ____________________________ 93. ____________________________
T3 75. ____________________________ 94. ____________________________
76. ____________________________ 95. ____________________________
T7 77. ____________________________ T4 96. ____________________________
78. ____________________________ 97. ____________________________
79. ____________________________ 98. ____________________________
80. ____________________________ 99. ____________________________
81. ____________________________ 100. ____________________________
82. ____________________________
83. ____________________________
84. ____________________________
85. ____________________________
T11 86. ____________________________
87. ____________________________
T15 88. ____________________________
89. ____________________________

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SECTION 1

T18  1. Image 6
   2. Globular cluster
   3. Black hole pulling mass from white dwarf
   4. Image 26

T5   5. SN 2008D
   6. Image 11
   7. Image 18

T16  T24. Image 16

T1   T20. Image 13

T13  34. SS Cygni

T12  14. NGC 7027
   15. Image 3
   16. Image 22
   17. Helium Hydride HeH⁺
   18. Undetected binary

T9   19. R Hydrea
   20. Image 23

T10  30. R Aquarii
   31. Image 19
   32. Cederblad 211
   33. Mira + white dwarf, symbiotic binary

BONUS. Alicia Soderberg
SECTION 2

T2 41. Globular cluster
   42. Horizontal branch
   43. Asymptotic Giant branch
   44. Subgiant branch
   45. Blue stragglers
   46. P Cygni profile

T6 47. Mass loss, rapidly expanding gas
   48. S Doradus instability strip
   49. Humphreys-Davidson limit
   50. He and H abundances are similar, from the CNO cycle

T17 51. WNE has no hydrogen, WNL has hydrogen
   52. Type Ibc supernova
   53. Degenerate
   54. The presence of atomic or molecular carbon

T19 55. It accreted a rocky planet recently
   56. Gravitational wave pulsation
   57. PG 1159 or GW Vir
   58. DOV and PNNV
   59. Stellar wind from the red giant falling onto the neutron star
   60. X-Ray burster
   61. Recurrent nova
   62. It may receive a “kick” from an asymmetrical supernova explosion
   63. Thorne-Zytkow object
   64. Tolman-Oppenheimer-Volkoff limit
   65. A red supergiant with unusual isotopes or a Wolf-Rayet star

T14 66. Long period variables (LPV)
   67. Mira stars pulsate in the fundamental mode, semiregular stars pulsate in overtones
   68. Walter Baade doubled the size of the universe in 1952
   69. BL Herculis

T10 70. \( \kappa \) mechanism, helium opacity, Eddington valve
71. 17
72. -19.3

T8 73. 36.3
74. 182 Mpc

T3 75. 0.351
76. 4360 K

T7 77. 2.69 AU
78. 1.05E8 km
79. 2.98E8 km
80. 8.00 km/hr
81. 22.7 km/hr
82. -1.03E39 J
83. -5.14E38 J
84. 1.35E46 kg m²/s
85. 0.532 ly

T11 86. 0.769 mas
87. Classical Cepheid

T15 88. -5.95
89. 13.7
90. 85100 parsec
91. Wind accretion or Bondi-Hoyle accretion
92. Infrared excess
93. Kippenhahn diagram
94. Stripped core-collapse
95. Magnitudes per square arcsecond
96. Stefan-Boltzmann
97. continuous
98. Baade-Wesselink method
99. Planetary nebula
100. Color index