PENNSYLVANIA SCIENCE OLYMPIAD

DIVISION C

ASTRONOMY EXAM

Team Number _______

Team Name ____

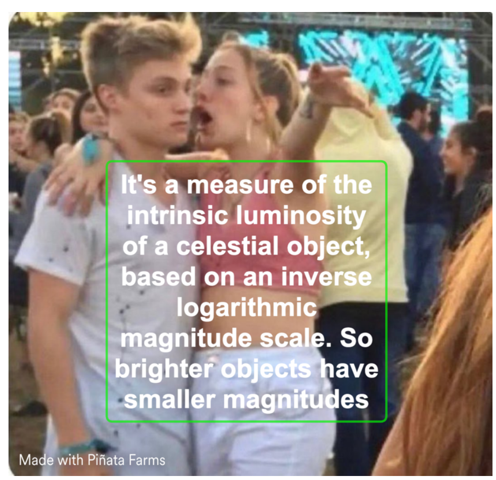
DO NOT OPEN THE EXAM UNTIL YOU ARE TOLD TO DO SO.
WRITE YOUR TEAM NAME AND NUMBER ON THE TEST AND ANSWER SHEETS.

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.**

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?

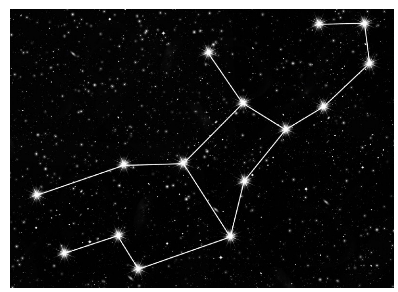
35. Which image shows this object?

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

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

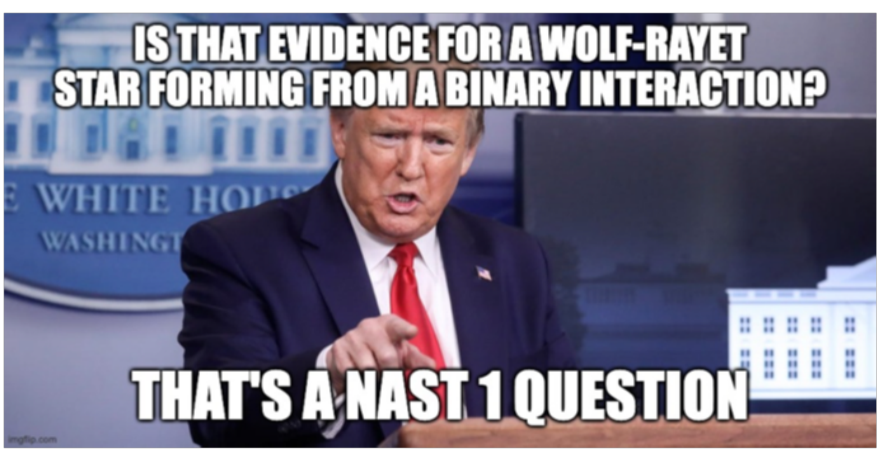
38. (T20) Which image shows an unusual Wolf-Rayet star that seems to have formed from a binary interaction?

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



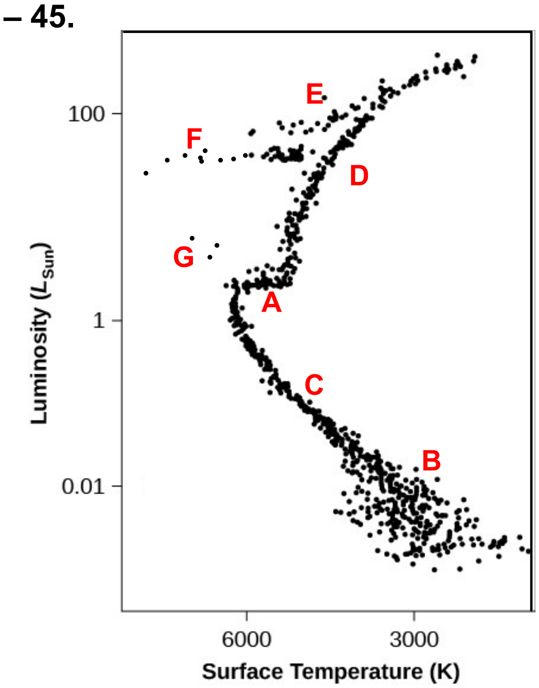
40. Which image shows this object's light curve?

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?

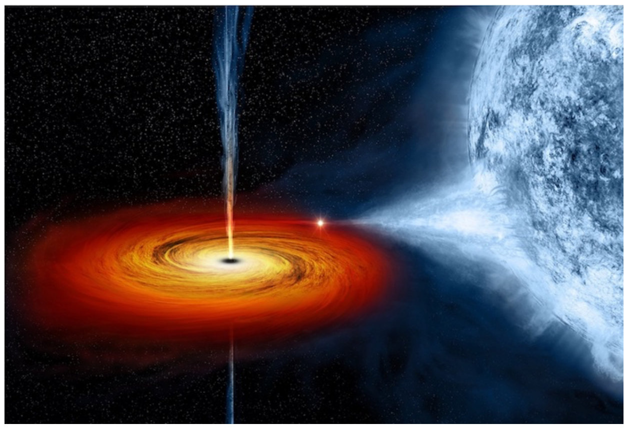
55. (T19) Why would a white dwarf display metal lines in its spectrum?

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?

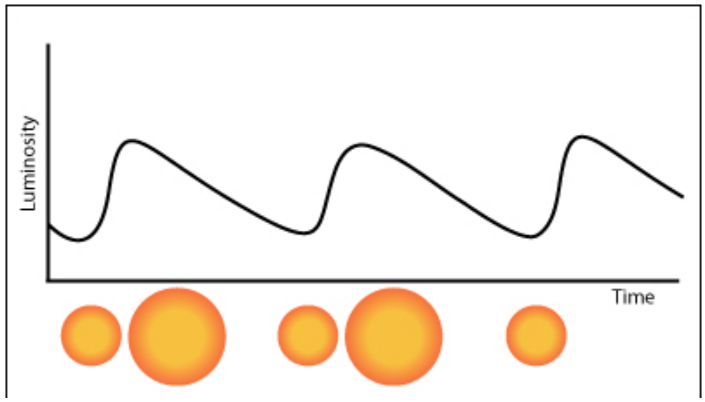
64. What must be exceeded in order for this object to collapse into a black hole?

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?

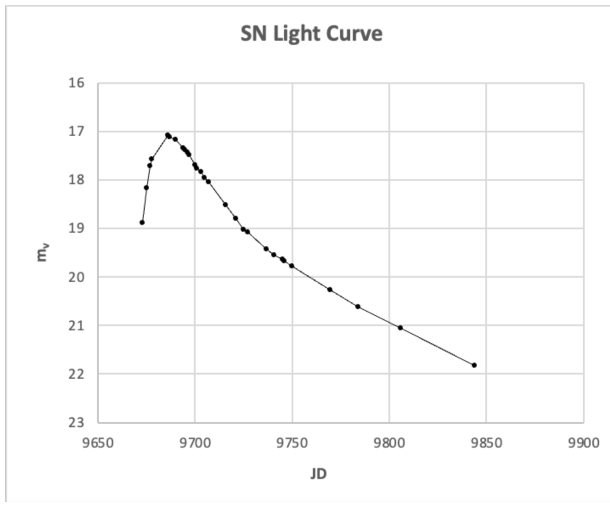
69. To what subclass would you categorize a type II Cepheid with a period of 4 days?

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

END OF SECTION 2

SECTION 3: Questions 71 - 90 deal primarily with the concepts and mathematical relationships listed in section 3b, page C6, of the 2023 Science Olympiad Division C Rules Manual.

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.

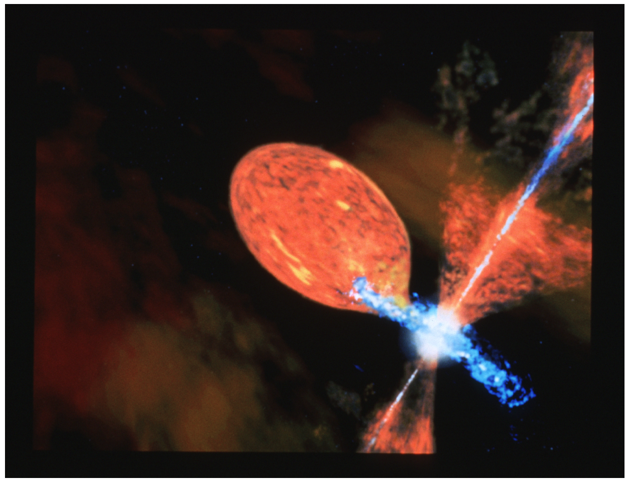
73. (T8) Determine the distance modulus for this event, assuming no extinction.

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 2.1$M_\odot$ and a secondary star of mass 0.74$M_\odot$ (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.

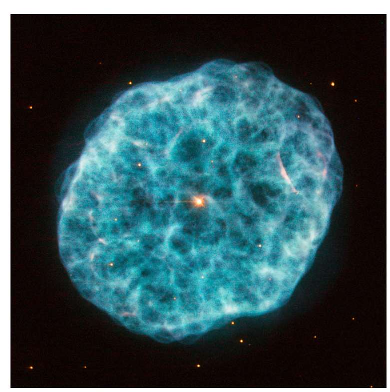
80. Calculate the orbital velocity of the primary star in km/s.

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.

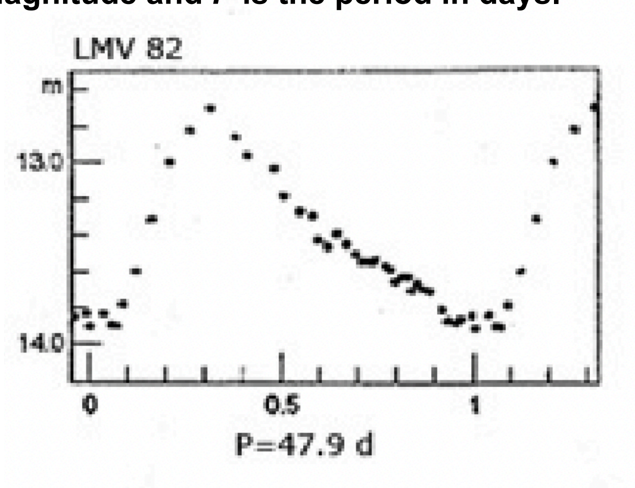
86. (T11) Calculate the nebula's parallax angle in mas.

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.



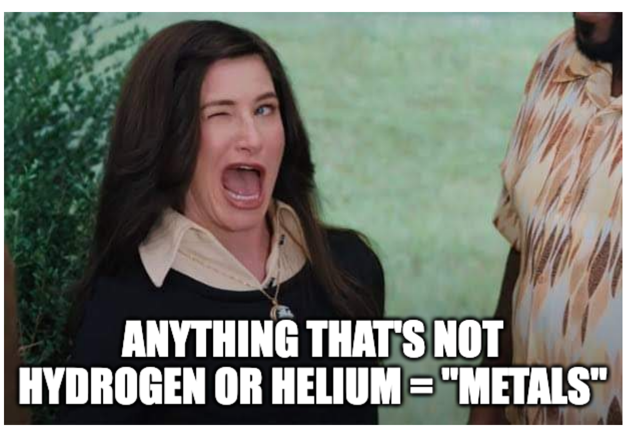
87. Based on the shape of the light curve, what type of star is this?

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.

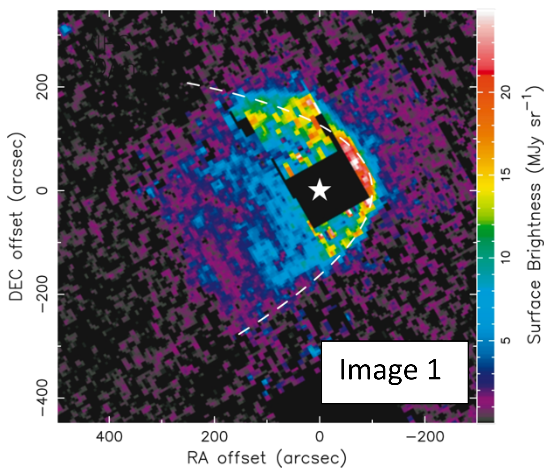
97. A rapidly spinning compact object such as a neutron star that is not a perfect sphere (its surface has a "bump" or imperfection) will generate this type of gravitational wave.

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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DEC offset (arcsec)
RA offset (arcsec)
Surface Brightness (MJy sr^{-1})
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0
−200
−400
400
200
0
−200
5
10
15
20

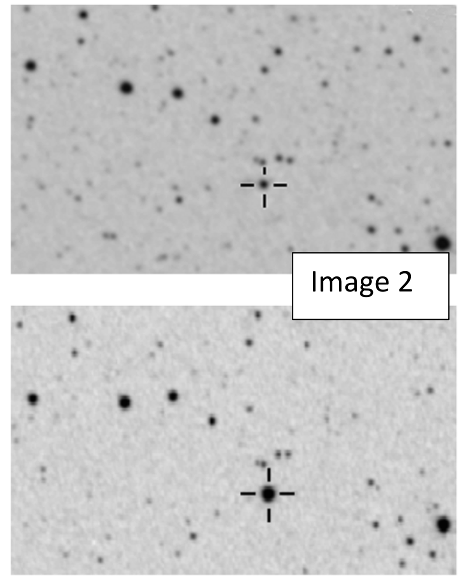
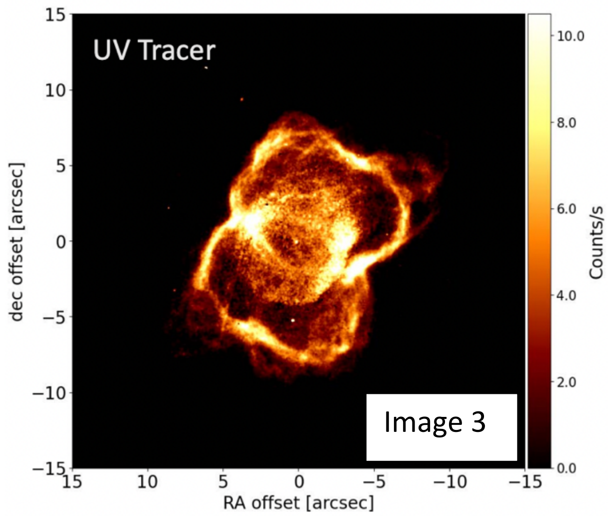


Image 2


UV Tracer
Image 3
dec offset [arcsec]
RA offset [arcsec]
Counts/s
15
10
5
0
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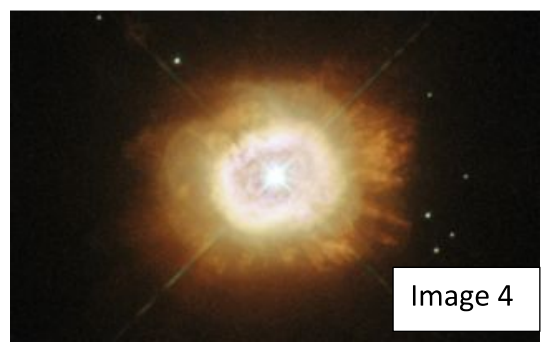
10.0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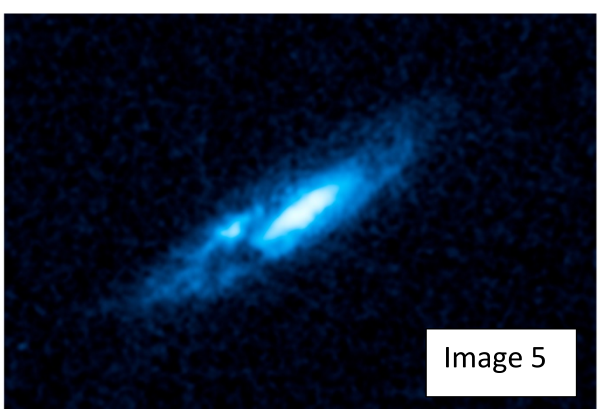
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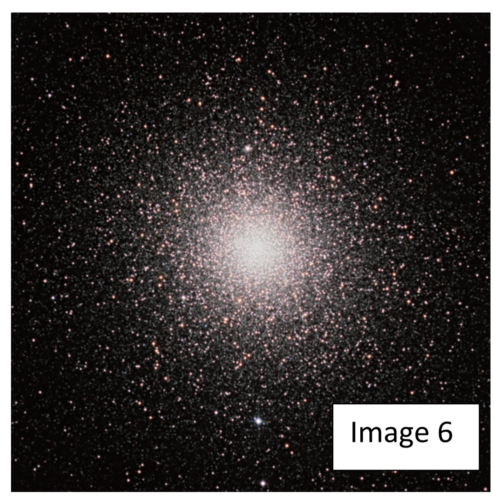
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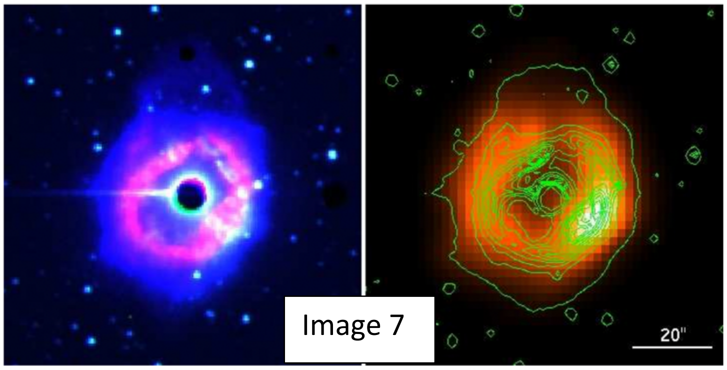
Image 7
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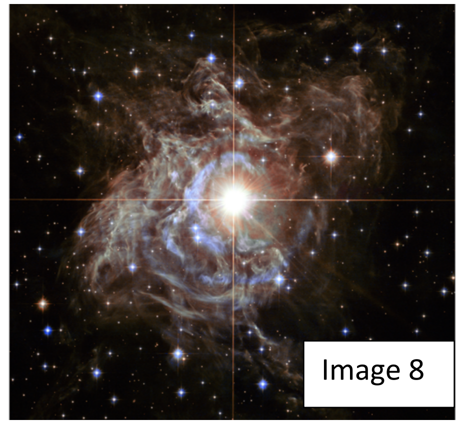
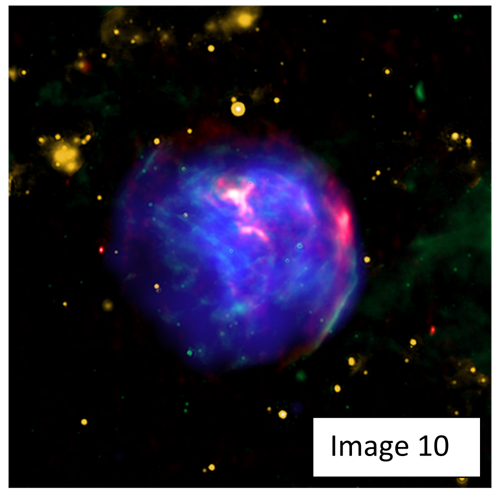


Image 8


Image 9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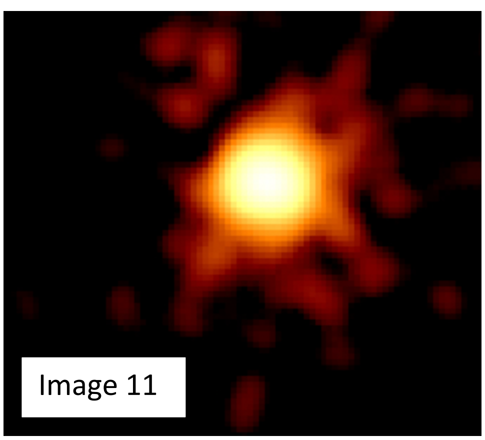
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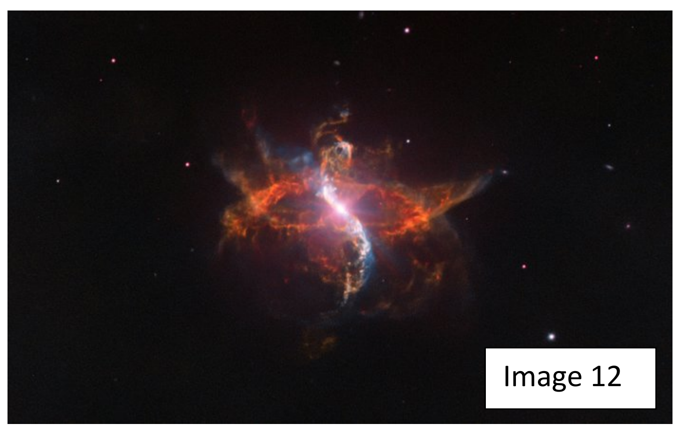
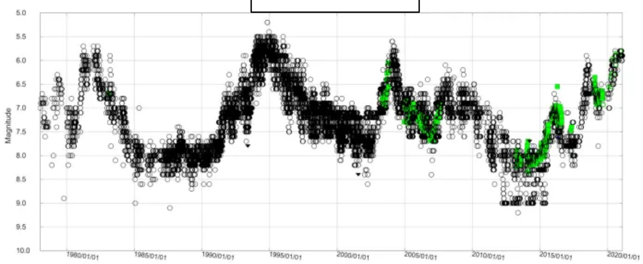


Image 12

Image 13



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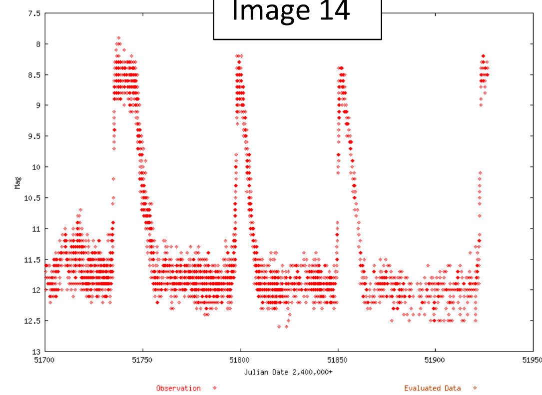

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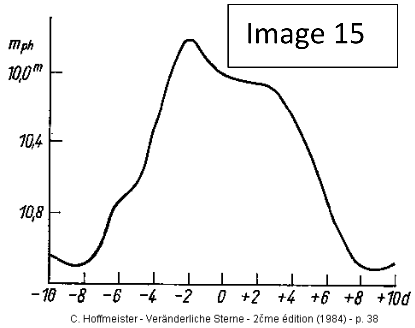

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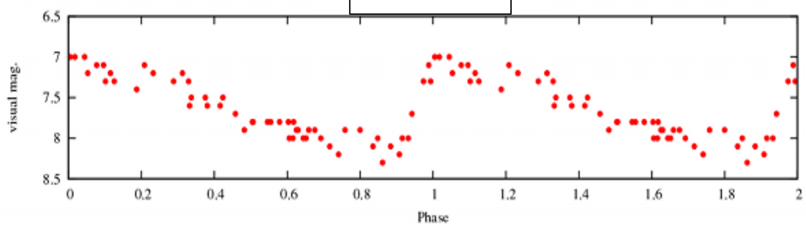

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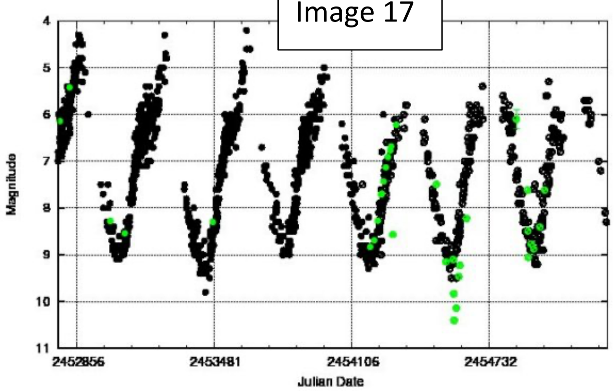

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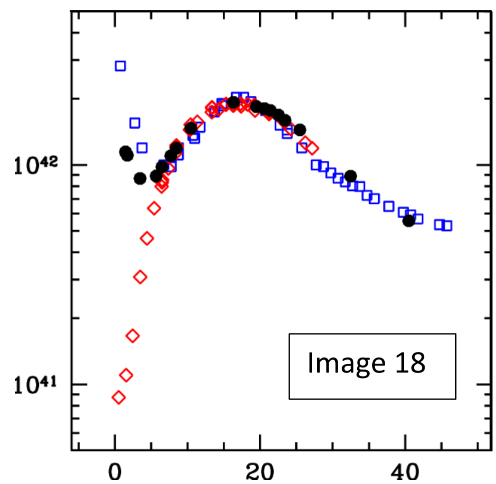

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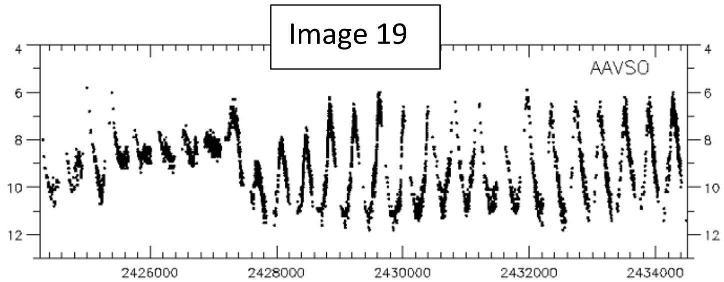

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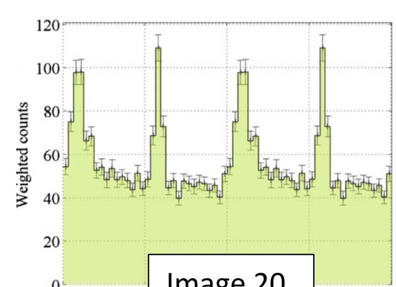

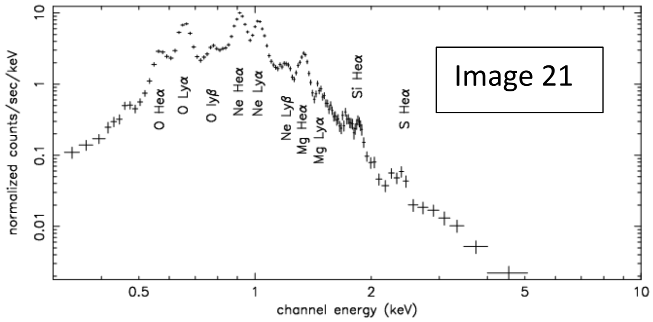

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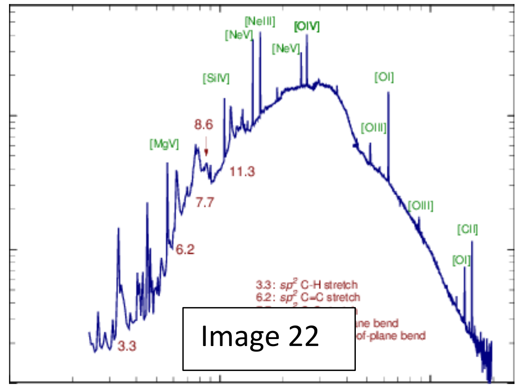

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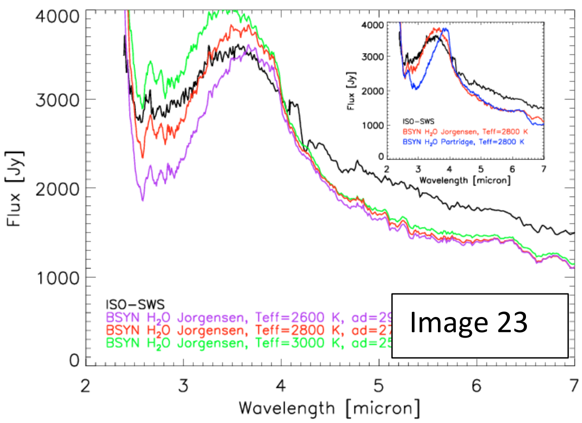

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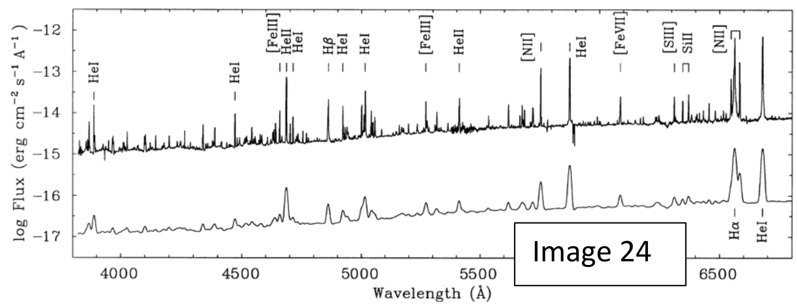

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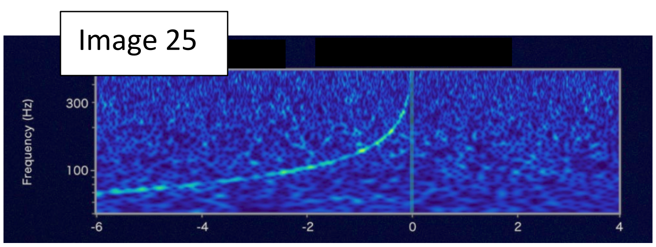

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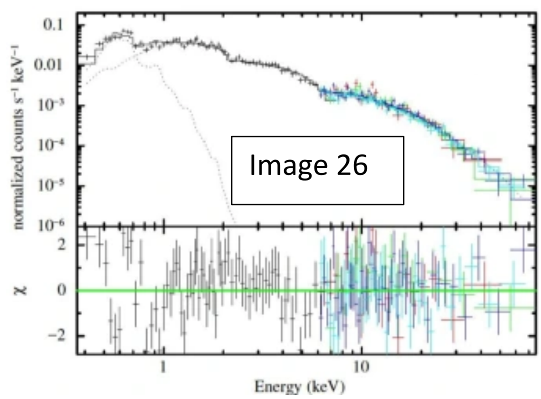

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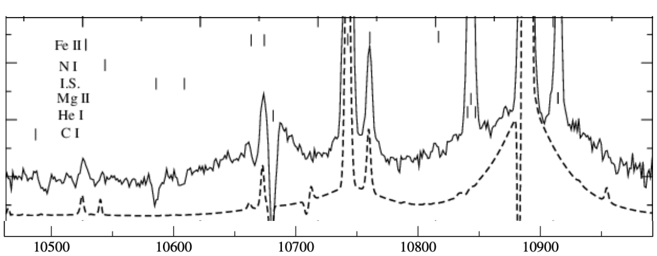

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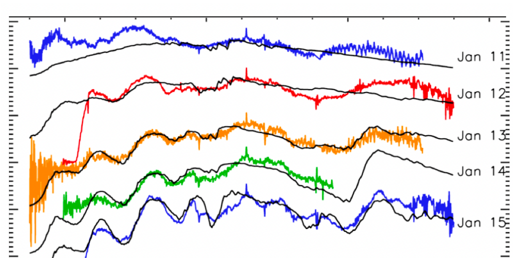

Image 28

Division C ASTRONOMY Answer Sheet
Team Name ____ Team # _______

SECTION 1

T18 1.________________

2.________________________

3.____

4.________________

T5 5.________________

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T12 14.________________

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T9 19.________________

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T1 24.________________

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T16 27.________________

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33.___________________________

T13 34.________________

35.________________

36.________________

37.________________

T20 38. ________________

39.________________

40.________________

BONUS__________________________

Page Score ______ out of _____ page points Total Score____________ Rank _____________

Division C ASTRONOMY Answer Sheet
Team Name ____ Team # _______

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. ____

61. ____

62. ____

63. ____

64. ____

65. ____

T14 66. ____

67. ____

68. ____

69.____

T10 70. ____

Page Score ______ out of _____ page points Total Score____________ Rank _____________

Division C ASTRONOMY Answer Sheet

Team Name ____ Team # _______

SECTIONS 3 & 4

71.________________________________

72.________________________________

T8 73.________________________________

74.________________________________

T3 75.________________________________

76.________________________________

T7 77.________________________________

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81.________________________________

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84.________________________________

85.________________________________

T11 86.________________________________

87.________________________________

T15 88.________________________________

89.________________________________

90. ________________________________

91. ________________________________

92. ________________________________

93. ________________________________

94. ________________________________

95. ________________________________

T4 96. ________________________________

97. ________________________________

98. ________________________________

99. ________________________________

100. ________________________________

Page Score ______ out of _____ page points Total Score____________ Rank _____________

Division C ASTRONOMY Answer KEY
Team Name ____ Team # _______

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

8. Image 28

9. NGC 2770

10. AG Carinae

11. Image 13

12. Image 27

13. SDOR (S Doradus)

T12 14. NGC 7027

15. Image 3

16. Image 22

17. Helium Hydride HeH^+

18. Undetected binary

T9 19. R Hydrae

20. Image 23

21. Image 1

22. Completion of a thermal pulse

23. Image 8

T1 24. Image 16

25. Light echoes

26. "poop deck"

T16 27. Image 25

28. AT2017gfo

29. Kilonova (GRB)

30. R Aquarii

31. Image 19

32. Cederblad 211

33. Mira + white dwarf, symbiotic binary

T13 34. SS Cygni

35. Image 2

36. Image 14

37. UGSS

T20 38. Image 5

39. W Virginis

40. Image 15

BONUS. Alicia Soderberg

Page Score ______ out of _____ page points Total Score____________ Rank ______________

Division C   ASTRONOMY Answer KEY

Team Name ____   Team # _______

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. κ mechanism, helium opacity, Eddington valve

Page Score ______ out of _____ page points   Total Score____________   Rank _____________

Division C ASTRONOMY Answer KEY

Team Name ____ Team # _______

SECTIONS 3 & 4

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 m^2/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
T4 96. Stefan-Boltzmann
97. continuous
98. Baade-Wesselink method
99. Planetary nebula
100. Color index

Page Score ______ out of _____ page points Total Score____________ Rank _____________