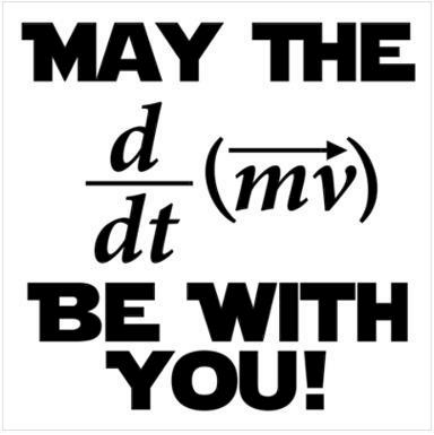
SCHOOL NAME: _____ TEAM NUMBER: _____

New York State Science Olympiad
2014 Astronomy Examination
200 Total Points

Directions:

1. Place all answers in the space provided directly after each question.
2. All work must be shown for questions that require calculations. Zero points will be given for calculations without the required steps and units.
3. Please write your team number and school name at the top of each page.
4. A color inlay has been provided for increased clarity for some of the questions with images.
5. The point values are notated after each question. **No partial credit will be given.** With that in mind, please answer each question as completely as possible.
6. You may choose to separate the test to work independently; however, the test must be placed in order before submitting them to the proctor. Failure to do so will result in a penalty. The pages have been numbered to make this easier for you.
7. No formulas have been provided. It is the expectation that you have assembled these resources ahead of time, so do not ask. If constants have been provided, you are required to use those values.
8. You are expected to stop working when time has expired. You will be given warnings when the following times are remaining: thirty minutes, fifteen minutes, five minutes, and one minute. As such, if students opt to continue working after time has been called, the team will be **disqualified**, at the discretion of the proctor and/or tournament director. Specifically:
    a. all writing instruments, calculators, and other resources must be put down immediately when instructed to do so.
    b. the only permissible action of each team is to re-order the test papers, if necessary.
9. Communication between groups while the test is in progress and being collected will result in immediate **disqualification** of all involved parties.
10. All cell phones must be **turned off**. Should any cell phone ring, vibrate, or light up during the exam, the team will be instantly **disqualified**.
11. All wireless connections, including but not limited to WiFi, Bluetooth, and IrDA, must be turned off. Any team found otherwise will be immediately **disqualified**.
12. In the event of a tie, the following tiebreakers will be instituted:
    a. Total number of 5 point questions correct
    b. Total number of 3 point questions correct
    c. Total combined score on Part Five
    d. Any additional tiebreakers will be based upon the next section of the exam with the highest total points (i.e. Part One, Part Four, Part Three, and Part Two).



Team Member 1: _____

Team Member 2: _____

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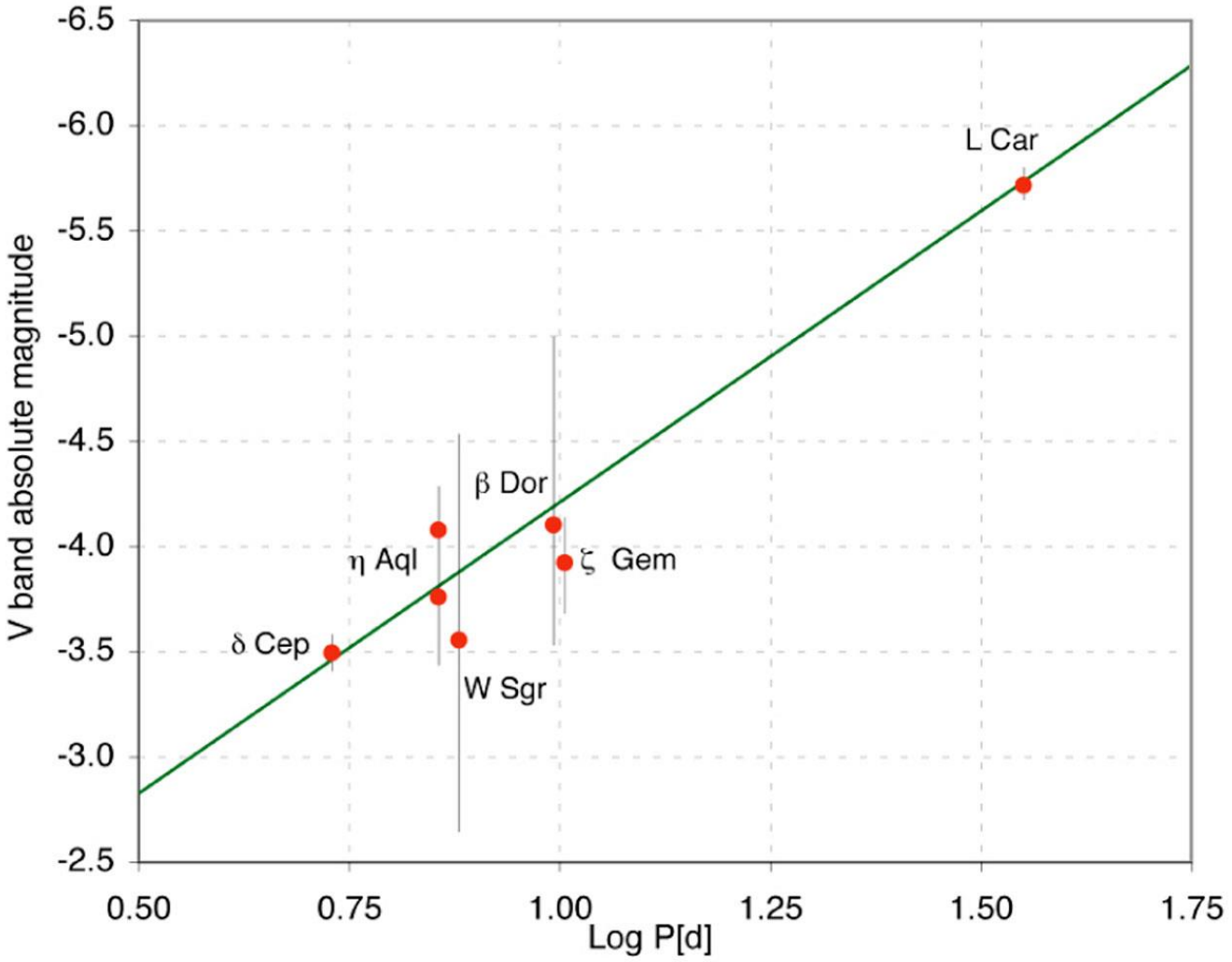
Potentially Useful Information



*If any of the following are needed, you **must** use these values:*

Wien's Constant: 2.898 x 10^{-3} m•K

Radius of the Sun: 6.96 x 10^{5} km

Surface Temperature of the Sun: 5778K

Stefan-Boltzmann Constant: 5.670 x 10^{-8} W m^{-2} K^{-4}

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PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.0079																	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.179
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.938	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **§** (269)	111 **§** (272)	112 **§** (277)						

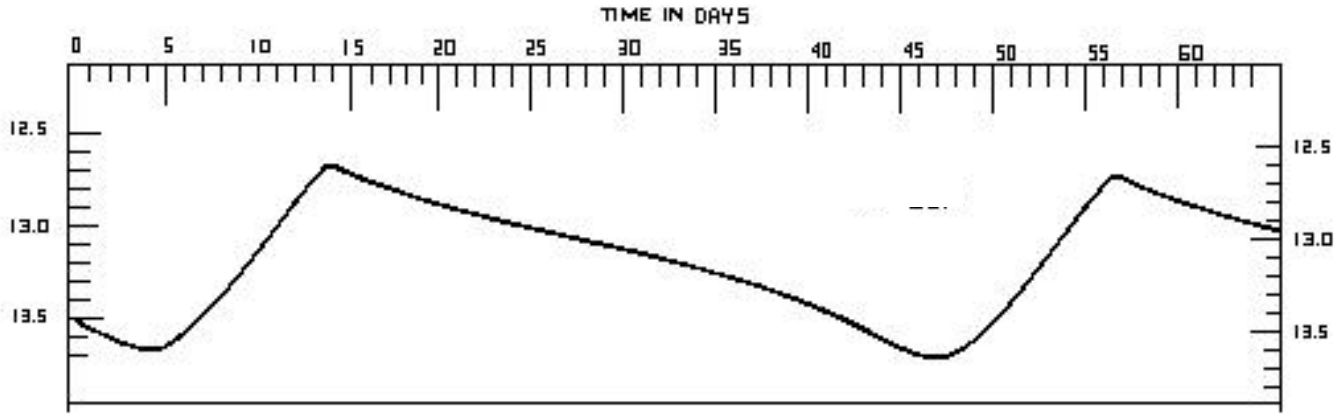
§Not yet named

*Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
†Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** 237.05	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

SCHOOL NAME: _____ TEAM NUMBER: _____

Part I: Unknown Star W (40 total points)

The light curve of the variable star W in the Small Magellanic Cloud is shown below.



1. Explain why the variable star W is considered a Cepheid variable. **(3 points)**

2. Identify the pulsation period of the star shown above. **(1 point)** _____

3. Determine the distance to the variable star W, in terms of parsecs. Assume no visual extinction along the line of sight. **(5 points)**

4. The effective temperature of the variable star W was determined to be 5355K. Give the wavelength of maximum absorption, in terms of nanometers, which allowed for this determination. **(3 points)**

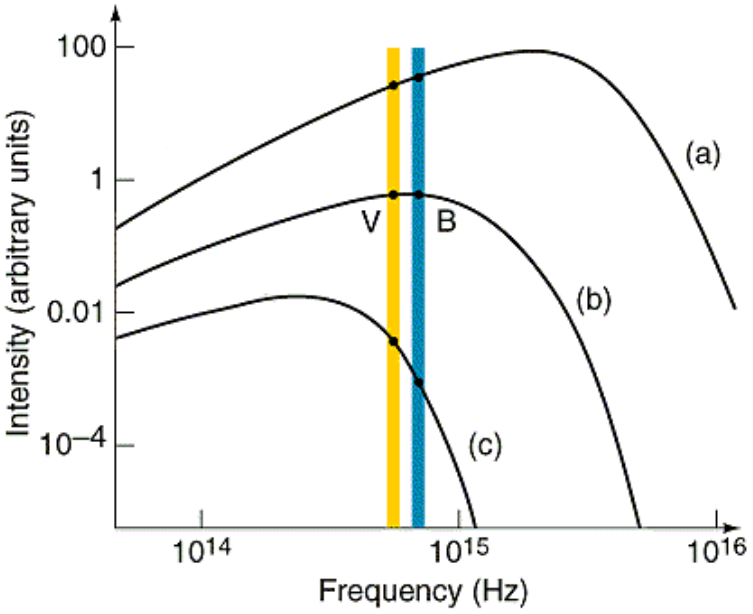
5. Another variable star in the Small Magellanic Cloud, HV 1877, has a pulsation period of 50.1 days. Which of the two stars, Star W or HV 1877, is more luminous? Explain your answer. **(3 points)**

6. Explain how Cepheid variable stars are capable of the changes in apparent magnitude as seen in these cyclic patterns. Your answer should illustrate any changes occurring within the star during these observed cyclic patterns. **(5 points)**

7. The [Fe/H] ratio for the variable star W is -0.83. The [Fe/H] ratio for δ Cep is +0.10. Which of the two stars has the greater metallicity? Explain your answer. **(3 points)**

8. Would unknown star W likely host Jovian-sized planets? Explain why or why not. **(3 points)**

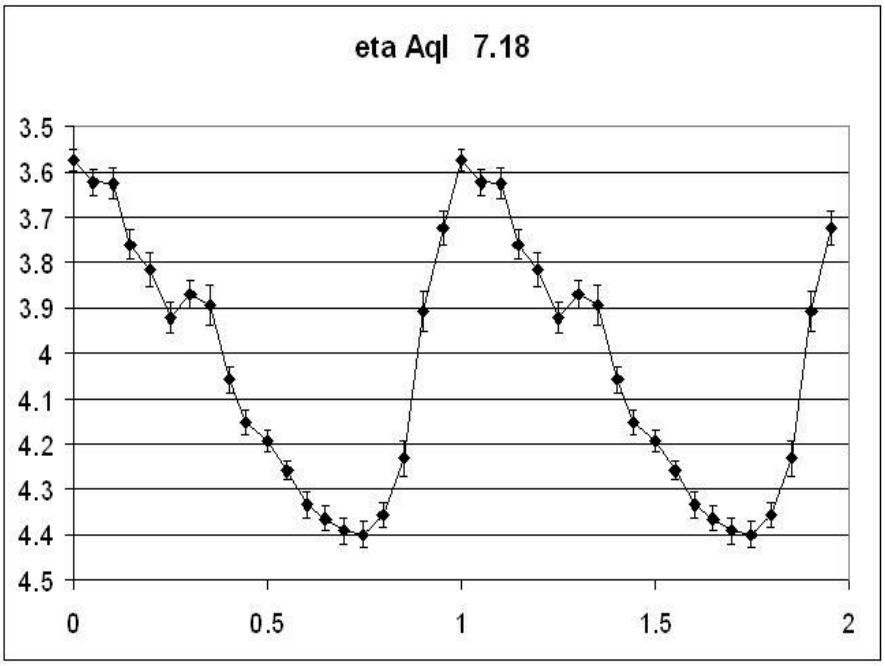
9. The BV color index for the variable star W was determined to be 0.86, in terms of magnitude. Based on the plot to the right, identify the letter which most closely represents unknown variable W and justify your response based on the information provided in the graph. **(3 points)**



10. Variable star W is a Delta Cephei variable. Name one similarity and one difference between a Delta Cepheid and a Type II Cepheid. (**1 point each)**
Similarity:

Difference:

11. Another Delta Cephei variable, η Agl, has a period of 7.18 days. The light curve of this variable star is shown below.



a. Circle on the light curve above how this diagram represents the Hertzsprung progression. **(1 point)**

b. Explain the mechanics behind the Hertzsprung progression, based on current scientific theory. **(5 points)**

c. Does the variable W contain the Hertzsprung progression? Explain your answer. **(3 points)**

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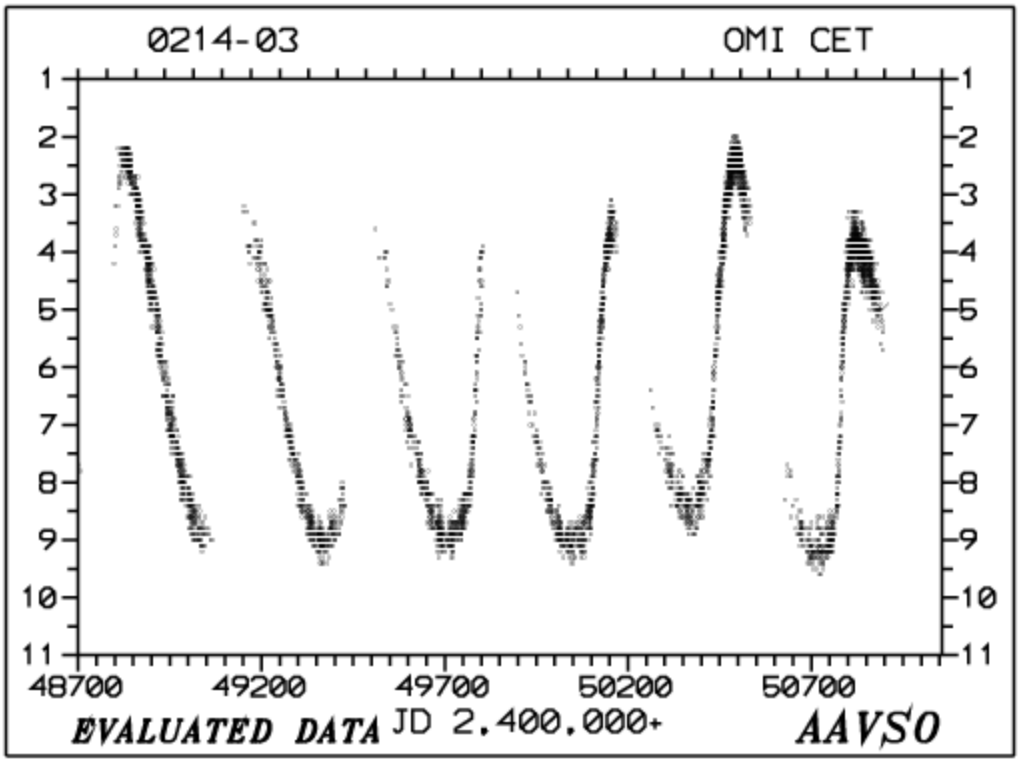
Part II: o Ceti (32 total points)

The light curve of the variable star o Ceti, of mass 1.18 $M_{\odot}$, is shown below. The variable star has a companion star, VZ Ceti. The separation between the two companion stars in this binary system has been approximated to be 70 astronomical units with an orbital period of approximately 400 years.



12. Identify the class of variable star to which o Ceti is classified. **(1 point)** _____

13. Convert the separation to kilometers. **(1 point)**

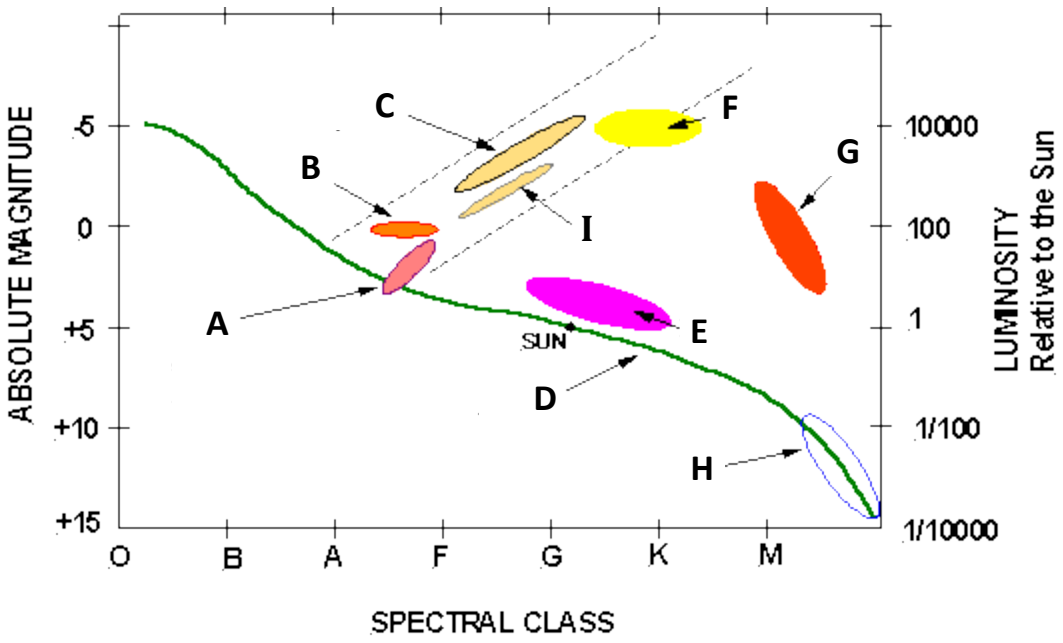
14. Provide the common name of the star o Ceti. **(1 point)** _____

15. Determine the mass of the companion star, VZ Ceti, in terms of solar masses. **(5 points)**

16. There is huge variability in the visible magnitude as opposed to the near-IR magnitude (around 1-3 μm). Provide two explanations as to why there are huge large variations in the visible magnitudes of o Ceti, as shown in the light curve on the previous page. **(3 point each)**
Explanation #1:

Explanation #2:

The following four questions refer to the following HR diagram.



17. Provide the letter indicating where o Ceti would be located. **(1 point)** _____

18. Provide the letter indicating where the star V1 would be located. **(1 point)** _____

19. Provide the letter indicating where T Tauri would be located. **(1 point)** _____

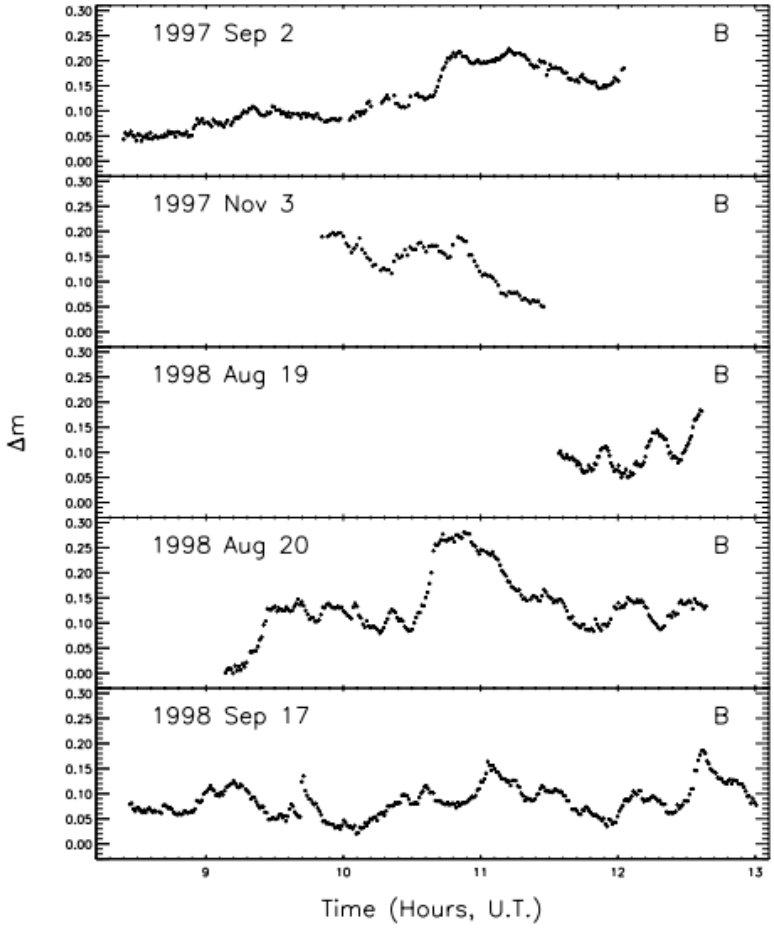
20. Provide the letter indicating where RR Lyrae would be located. **(1 point)** _____

o Ceti is losing mass through slow stellar winds to its companion star, VZ Ceti, at a rate of approximately 10^{-6} solar masses per year.

21. What is the eventual fate of o Ceti? Be specific. **(3 points)**

There is much debate as to how to classify the companion star VZ Ceti. The diagram to the right has been offered as evidence as the companion star as being either a main-sequence star or a white dwarf. The diagram shows changes in the B-band light curves on five different days when the binary system had an observable minimum in o Ceti.

22. Provide an argument, based on the changes in the B-band light curves, to support the companion star to o Ceti as a main-sequence star or dwarf star. **(5 points)**



o Ceti is also known for its atypical tail seen in the UV region of the electromagnetic spectrum, as shown in the image below.

23. Explain how the process shown above could lay the seed for a new star system to evolve. **(3 points)**

24. The tail had remained elusive to scientists due to its location in the UV region of electromagnetic radiation. Provide a rationale as to why the tail would fluoresce in the UV range. **(3 points)**

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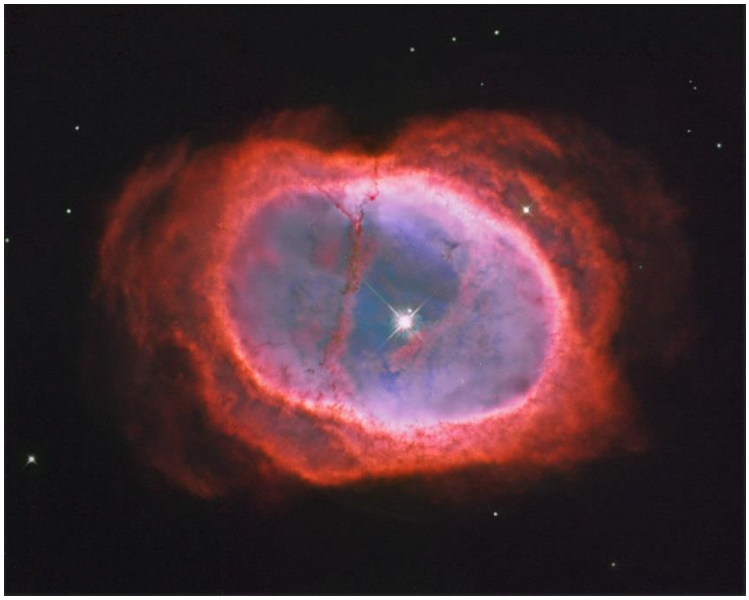
Part III: Stellar Evolution (34 total points)

25. Identify the following regions. Please refer to color inlay for increased clarity. **(1 point each)**



26. Identify the protostar shown below. **(1 point)** _____

27. Identify the nebula first cataloged due to the activity of this protostar. **(1 point)**

_____

28. Explain how this protostar formed and how it will eventually enter the main sequence. **(3 points)**

29. Explain the source of energy for the protostar to shine, as shown above. **(3 points)**

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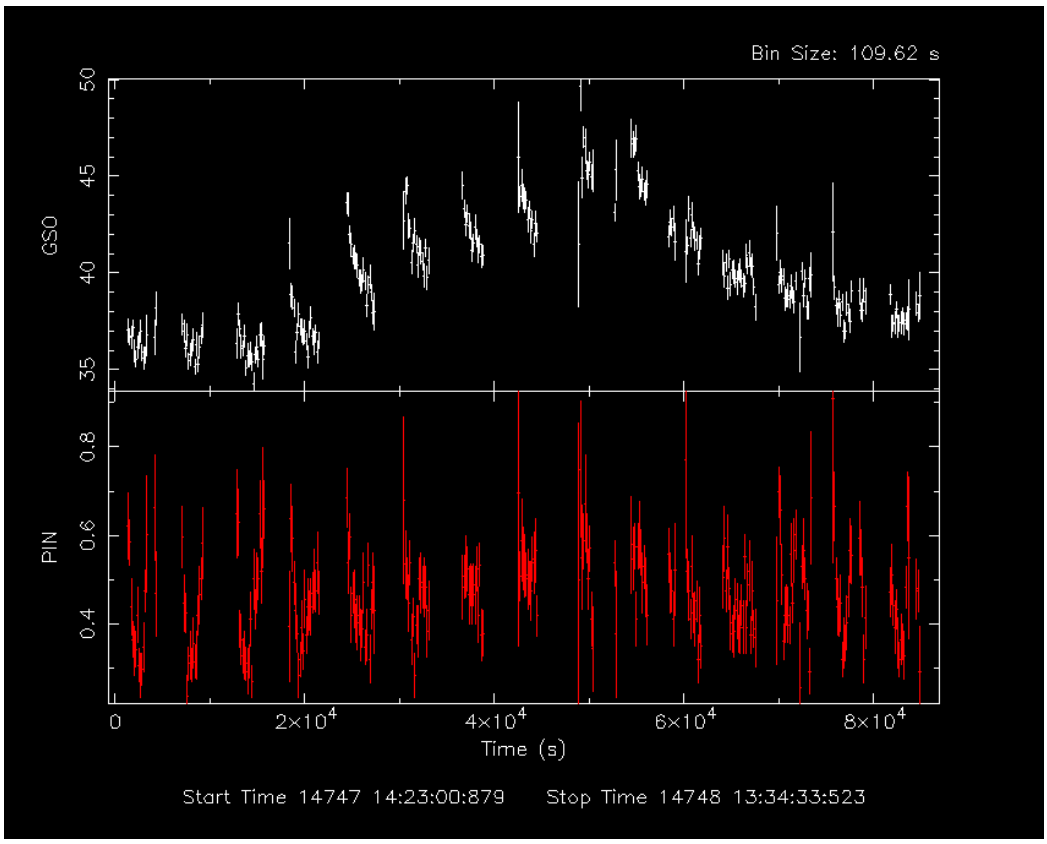
The following changes in x-ray emissions were observed from the protostar on the previous page.



30. Explain the origination of the changes in x-ray emissions. **(5 points)**

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The following image represents the remains of a star at the end of its lifetime.

31. Identify the object shown in the image above. **(1 point)** _____

32. Provide the right ascension of this object, in <u>minutes</u>. **(1 point)** _____

33. Explain the steps leading to the formation of the object shown in the image above. Be specific. **(5 points)**

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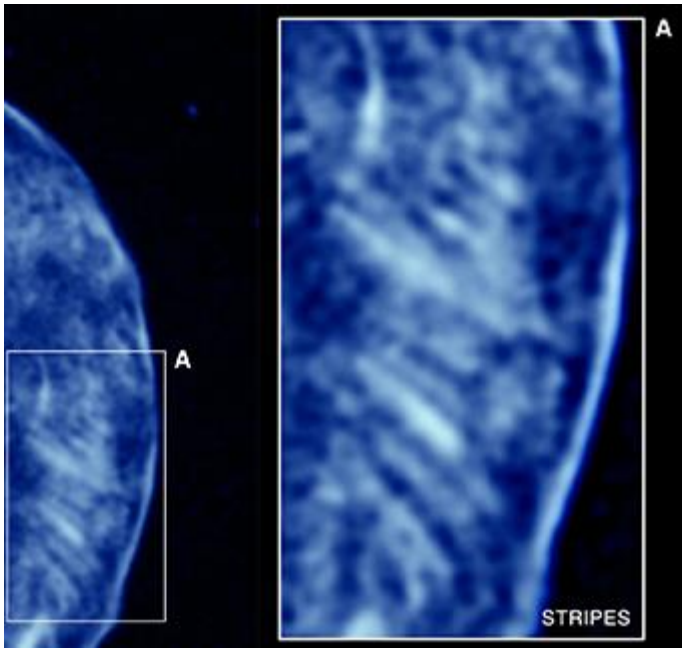
The remains from the previous page have characteristic stripes on one portion of the object, as shown on the image below.



34. Identify the matter/energy responsible for the imaging of these stripes. **(1 point)** _____

35. Discuss the current theory as to how the stripes are formed. **(5 points)**

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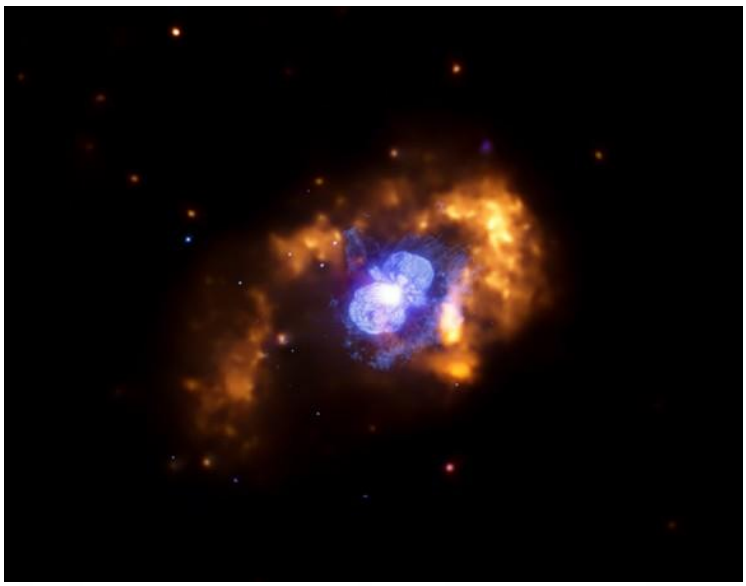
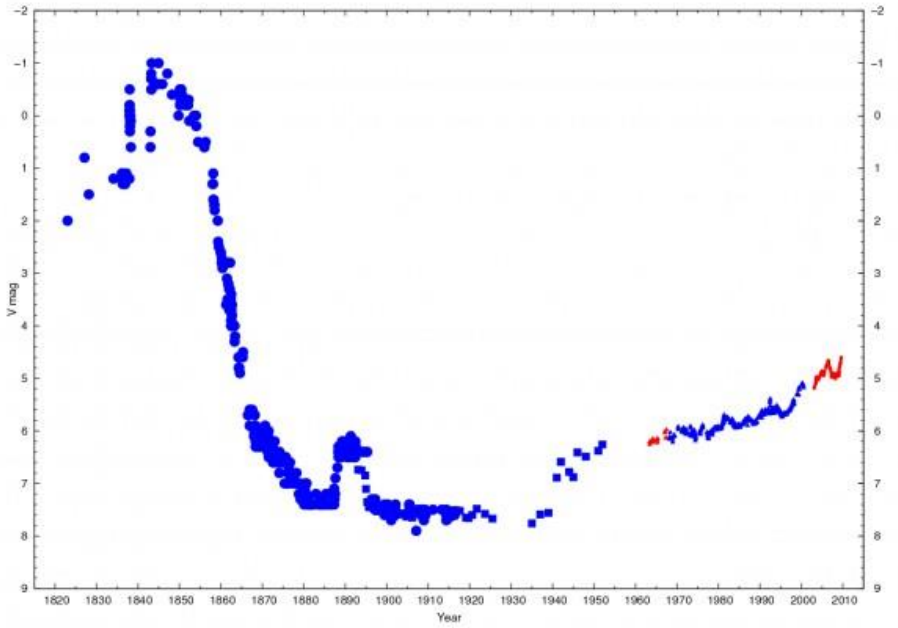
The image and associated light curve of an unstable star is shown below.





36. Identify the unstable star. **(1 point)** _____

37. Identify the class of variable star to which this star belongs. **(1 point)** _____

38. This star appears to have a 5.5-year cycle in radio-wave emissions. Explain the rationale as to why this star has a significant change in radio-wave emission during this apparent cycle. **(3 points)**

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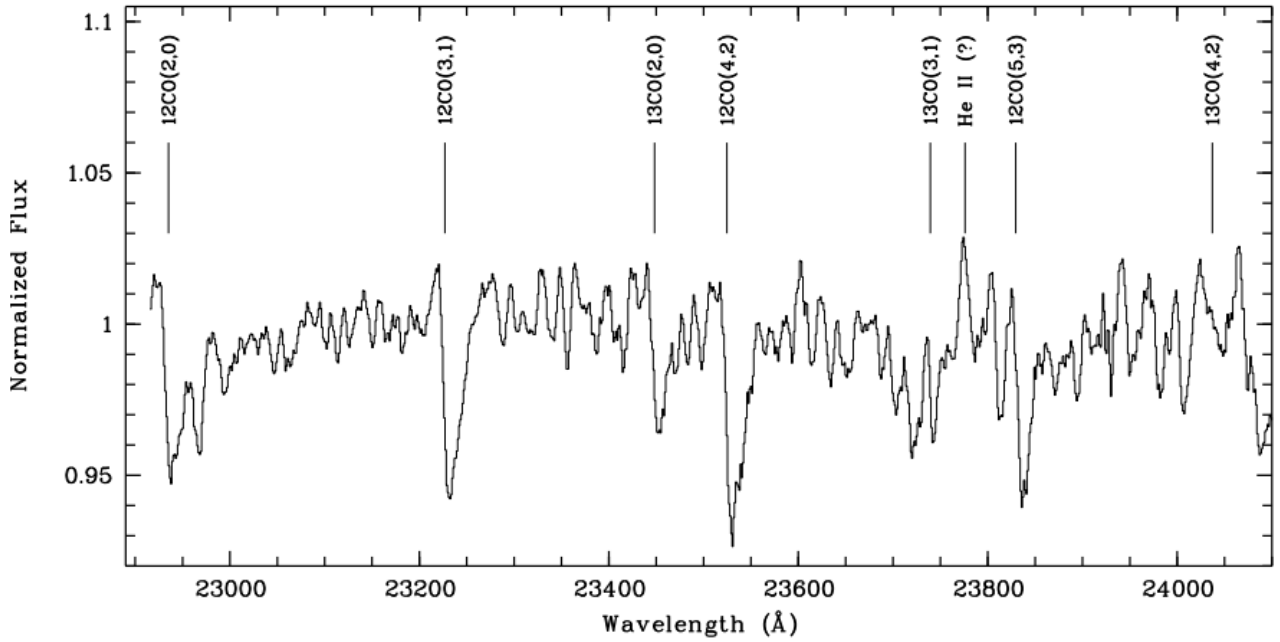
Part IV: Binary Systems (35 points)

The binary system GRS 1915+105 contains a regular star and a black hole. A portion of the spectrum of the regular star in this binary system is shown below.



39. Identify the constellation in which the binary resides. **(1 point)** _____

40. Provide the declination, in <u>degrees</u>, of the binary system. **(1 point)** _____

41. Provide the distance, in <u>parsecs</u>, of the binary system. **(1 point)** _____

42. Identify the spectral class of the regular star found in the binary system and provide an appropriate rationale for your assignment. **(3 points)**

43. The binary system is considered a microquasar. Explain the properties which make it a microquasar and then compare these properties to those expected of a quasar. **(5 points)**

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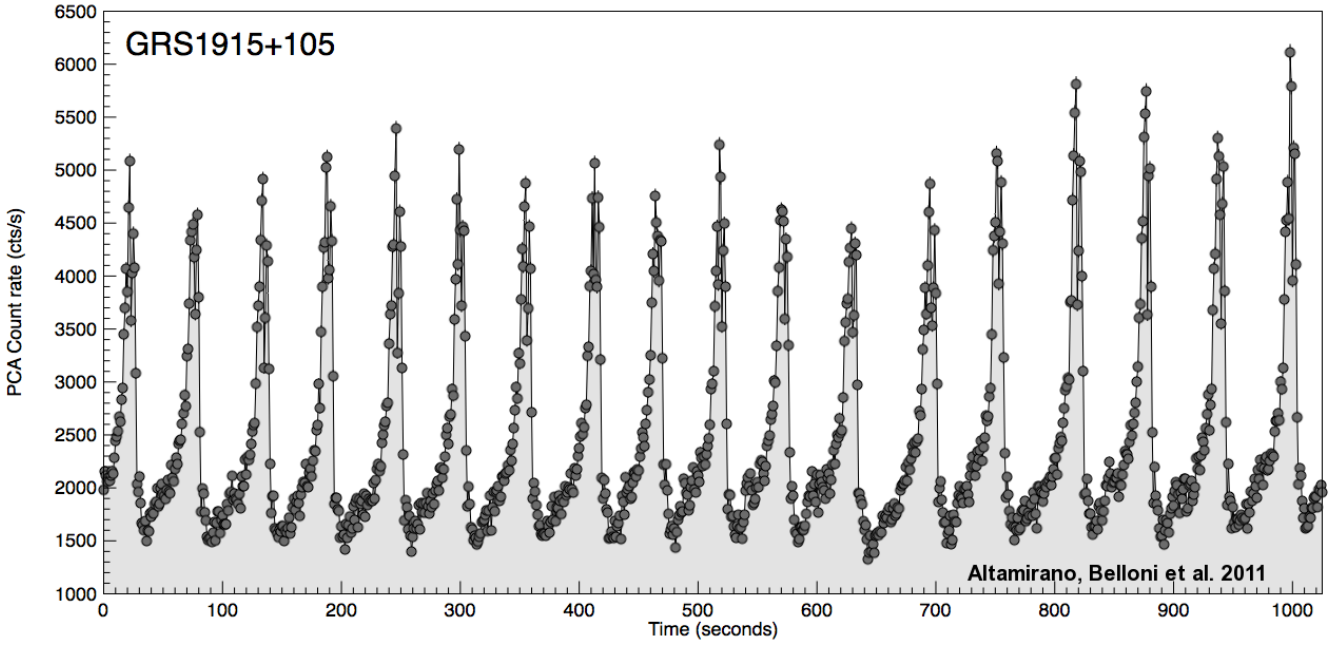
The following data were collected through a Proportional Counter Array instrument on the GRS 1915+105 binary system.



44. Provide an explanation for the cyclic nature of the emissions from the binary system. **(5 points)**

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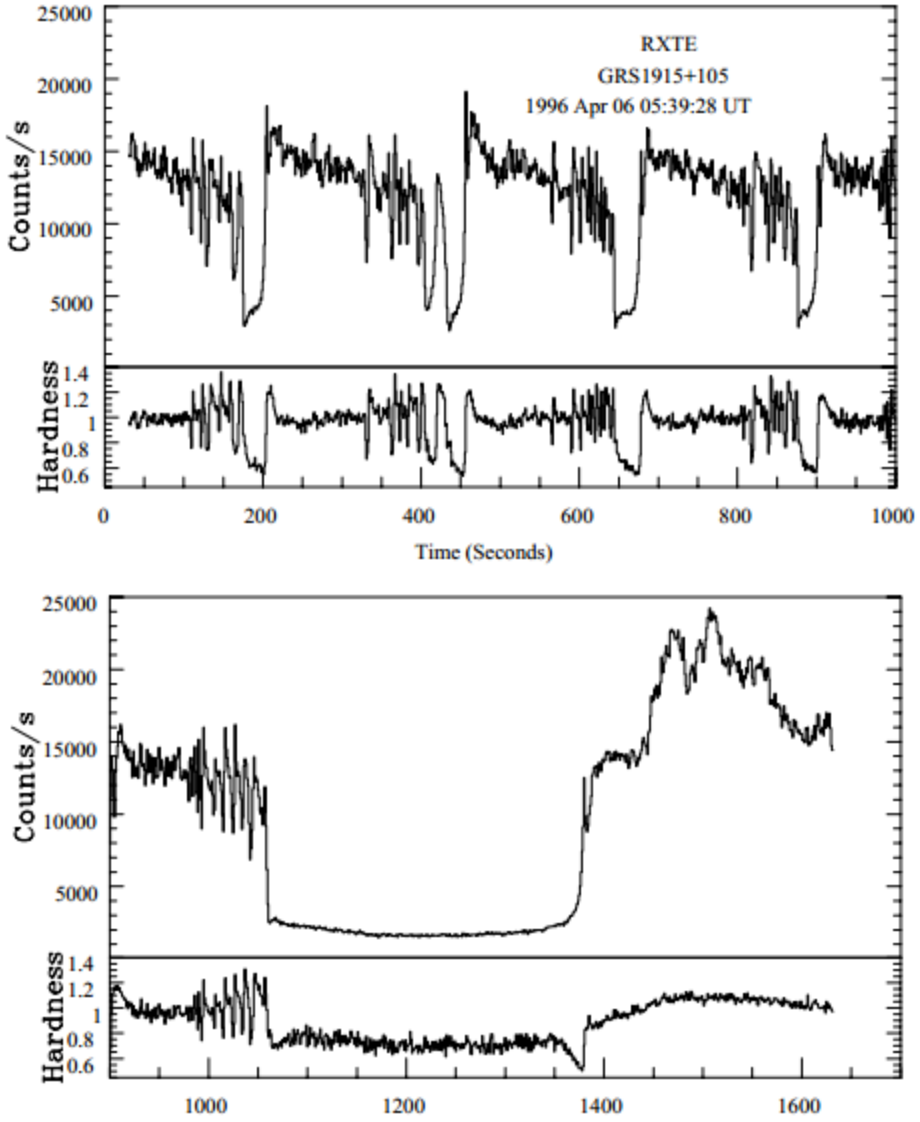
The following data were collected from the GRS 1915+105 binary system, showing a "sputtering" of emissions.



45. Provide a rationale for the sputtering observed in the binary system. **(5 points)**

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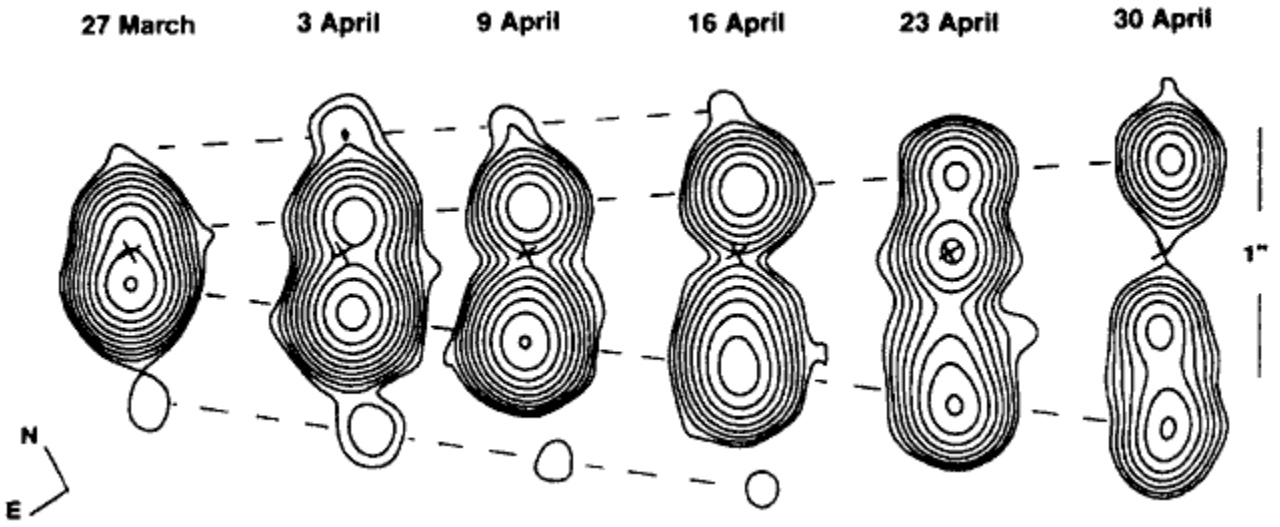
The image below contains time sequences of radio images of the binary system GRS 1915+105 which were captured over a course of approximately one month in 1994.



46. Explain how some scientists have used this data from GRS 1915+105 to demonstrate a violation of Einstein's theory of relativity. Discuss how other scientists have provided an explanation to refute these claims. **(5 points)**

Another binary system, HM Cnc, is an x-ray binary star system, containing two dense white dwarves orbiting one another every 5.4 minutes. The radial velocity was measured to be 650 km/s based on the data obtained from the He 4686Å spectral line. The two white dwarves are separated by a mere 80,000 kilometers.

47. Identify the constellation in which HM Cnc resides. **(1 point)** _____

48. Determine the wavelength of the He 4686Å spectral line observed for HM Cnc during red-shift, in terms of Angstroms. **(3 points)**

49. The orbital period of the binary system HM Cnc is slowly decreasing at a rate of 1.2 milliseconds per year. Based on relativity theory, explain the ramifications of the decrease in the orbital period on said binary system. **(5 points)**

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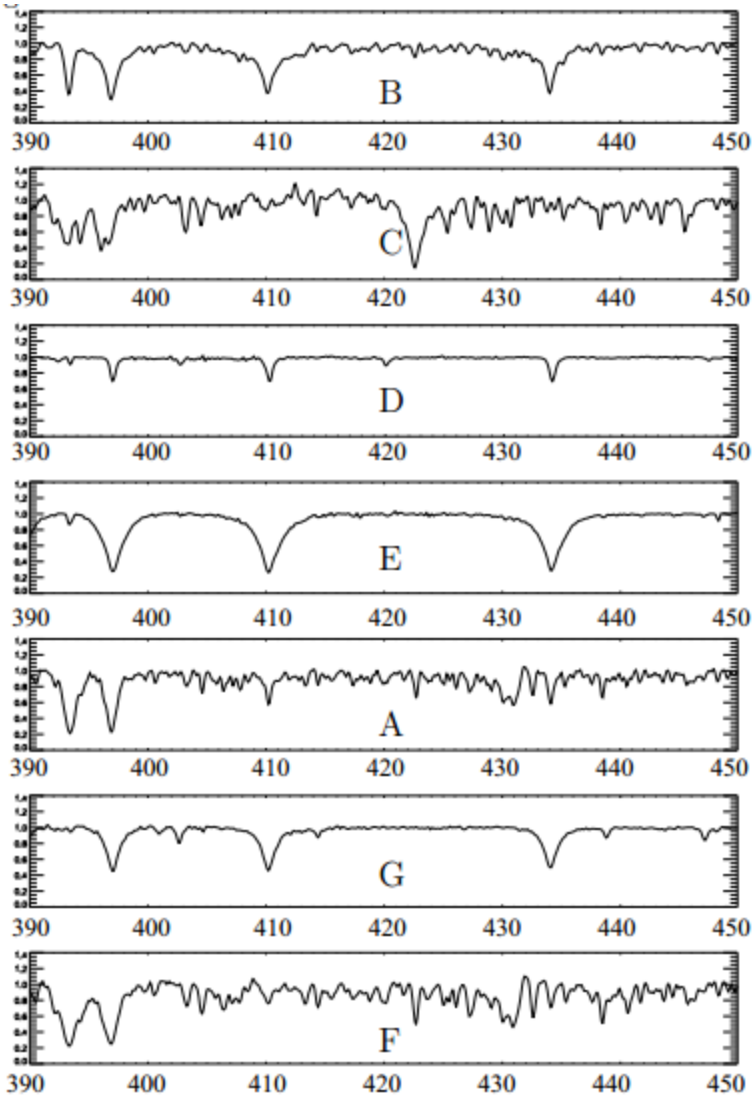
Part V: Basic Astronomical Principles (59 points)

Digital spectra of each spectral class are shown to the right. Recall that blue hydrogen lines are at 3970Å, 4101Å, and 4471Å and calcium II lines are at 3933Å and 3968Å.



50. Select the correct order of the digital spectra from hottest to coldest. **(3 points)**

    _____, _____, _____, _____, _____ ,_____, _____

51. Match the letter located in the digital spectra to the right with the correct statement about each spectrum. Place the appropriate letter which labels the matching spectrum on each line. **(1 point each)**

    _____ Lines of ionized helium; most lines are weak because the star is so hot most electrons are removed from atoms and there are few atoms making transitions.

    _____ Lines of neutral helium. Hydrogen lines are moderately strong.

    _____ Many lines of neutral elements and molecular states in the coolest of stars.

    _____ Hydrogen lines very strong and dominate the spectrum.

52. Identify the spectral type (OBAFGKM) of the given spectra shown above. **(1 point each)**

    _____ Spectrum G

    _____ Spectrum E

    _____ Spectrum C

    _____ Spectrum D

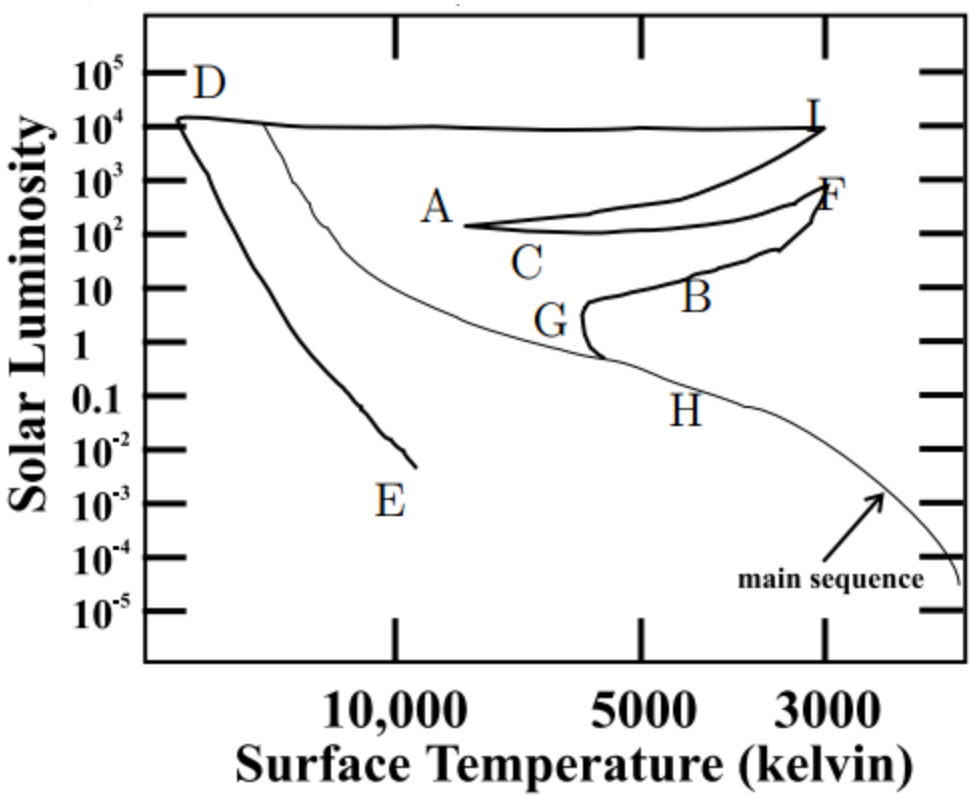
53. Complete the following equations representing nucleosynthesis in an unknown star. **(1 point each)**

    $^{20}_{10}Ne + \_\_\_\_\_ \rightarrow {}^{4}_{2}He + {}^{16}_{8}O$

    $^{16}_{8}O + {}^{16}_{8}O \rightarrow {}^{1}_{1}H + \_\_\_\_\_$

    $^{16}_{8}O + {}^{16}_{8}O \rightarrow 2{}^{4}_{2}He + \_\_\_\_\_$

54. Identify the location in the H-R diagram of the phases of stellar evolution. For each statement, select the proper letter, as shown in the diagram. **(1 point each)**



_____ Hydrogen used up, core collapses

_____ Hydrogen fusion in shell around core

_____ Helium used up, core collapses

_____ Envelope ejected

_____ Red giant, helium flash

Questions 55 through 59 refer to the following information.
The star Rigel is an Alpha Cygni variable star in the constellation Orion. It has a peak wavelength of 240 nm and a parallax of 3.78 milliarcseconds. It has an apparent v-band magnitude of 0.12.

55. How far away is Rigel, in <u>parsecs</u>? **(3 points)**

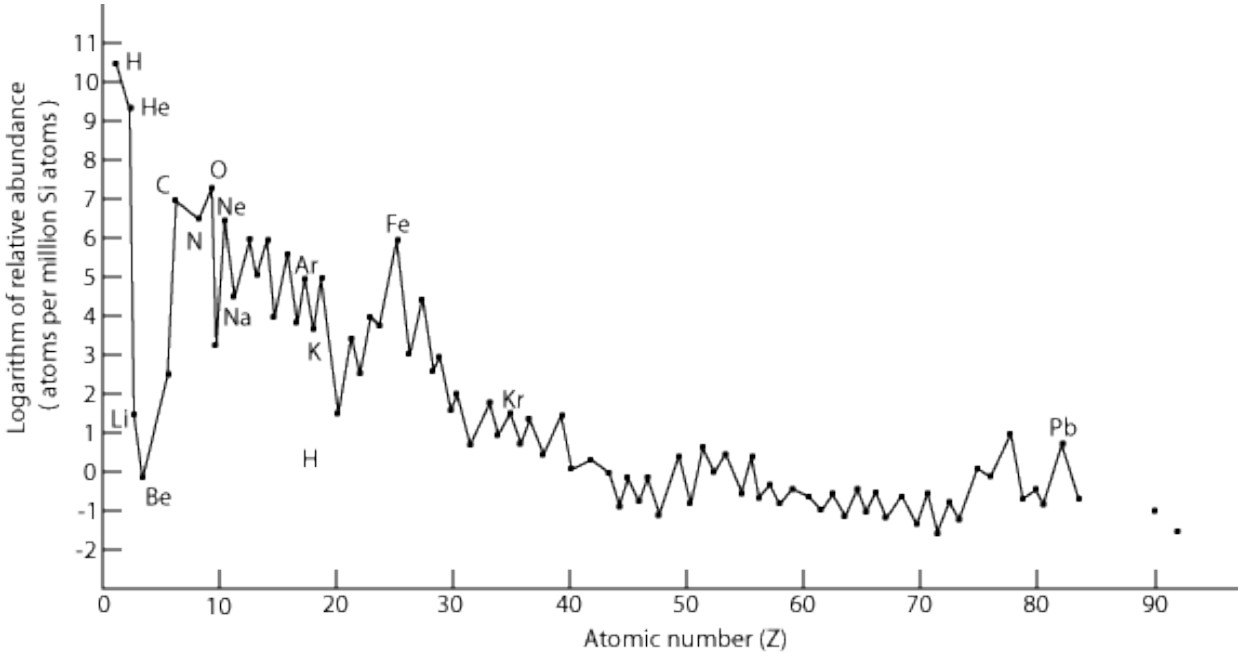
56. The radius of the star is $74R_{\odot}$. What is the angular size, in terms of milliarcseconds, and would this be resolvable in a telescope on Earth? **(3 points)**

57. What is the luminosity of Rigel in terms of solar luminosities? You may assume that Rigel is a blackbody. **(3 points)**

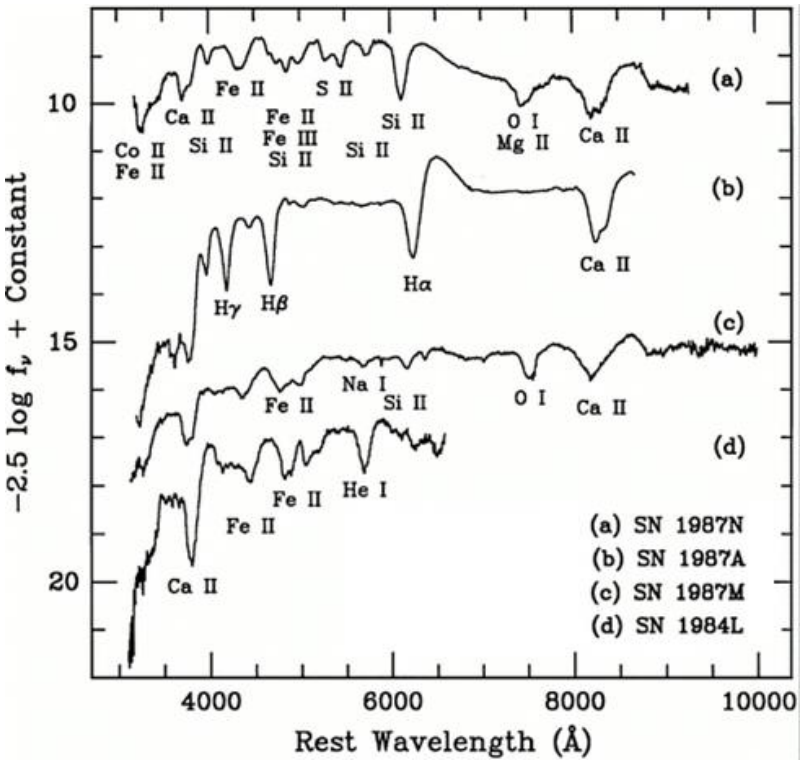
58. What is the absolute magnitude of Rigel? **(3 points)**

59. What is the spectral type and luminosity class of Rigel, based on the information solved above? Justify your response. **(3 points)**

60. The current relative abundances of the chemical elements in the Universe are shown below. (**1 point each**)
    a. Clearly sketch on the graph how the abundances of the elements appeared 100 million years after the Big Bang by drawing a solid line (—) connecting each abundance.
    b. Clearly sketch on the graph how the abundances of the elements will appear 15 billion years from now by drawing a dashed line (- - -) connecting each abundance.



61. The diagram to the right shows the spectra of four different supernovae remnants. Identify which of the supernovae remnants formed as a result of a Type II supernova. Explain your answer. **(3 points)**



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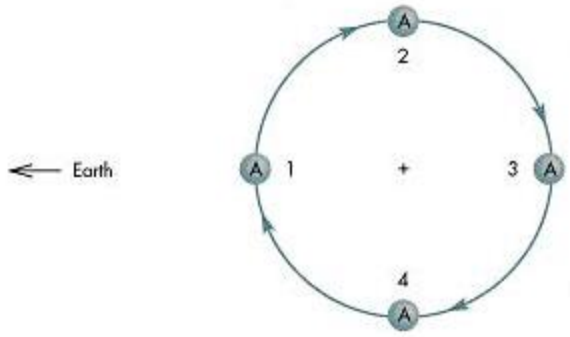
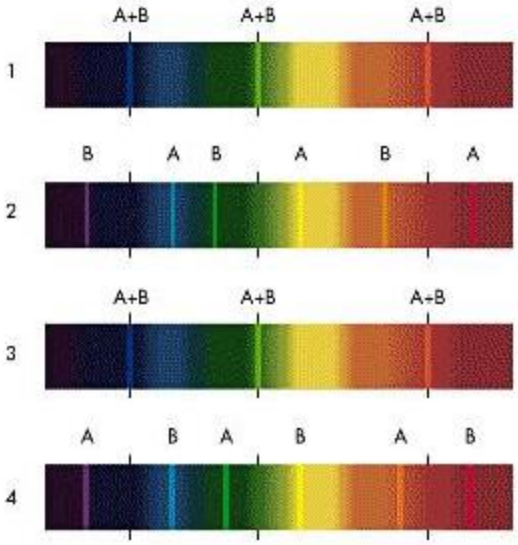
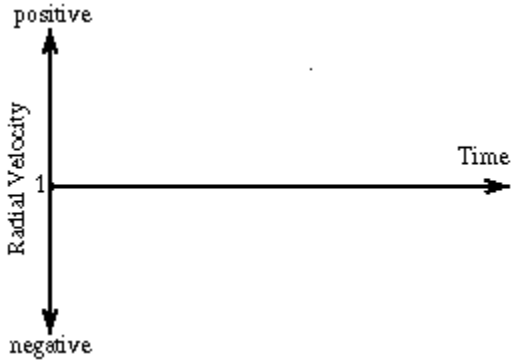
The following partial diagram represents a spectroscopic binary system. The orbit of star A has been shown, and the orbit of star B has been omitted. The spectra provided are based upon the positioning of the two stars (positions 1 through 4), as shown by the numbers in the orbit of star A.





62. On the diagram above, sketch a possible orbit of star B. Be sure to include the direction of its orbit and its position (1 – 4) in relation to star A. **(3 points)**

63. On the plot below, sketch how the radial velocities of star A and star B would appear over the course of its orbit. Be sure to clearly label the difference between the two stars.
(3 points for each star; 6 points total)



64. Explain any similarities and differences between magnetars and pulsars. **(3 points)**

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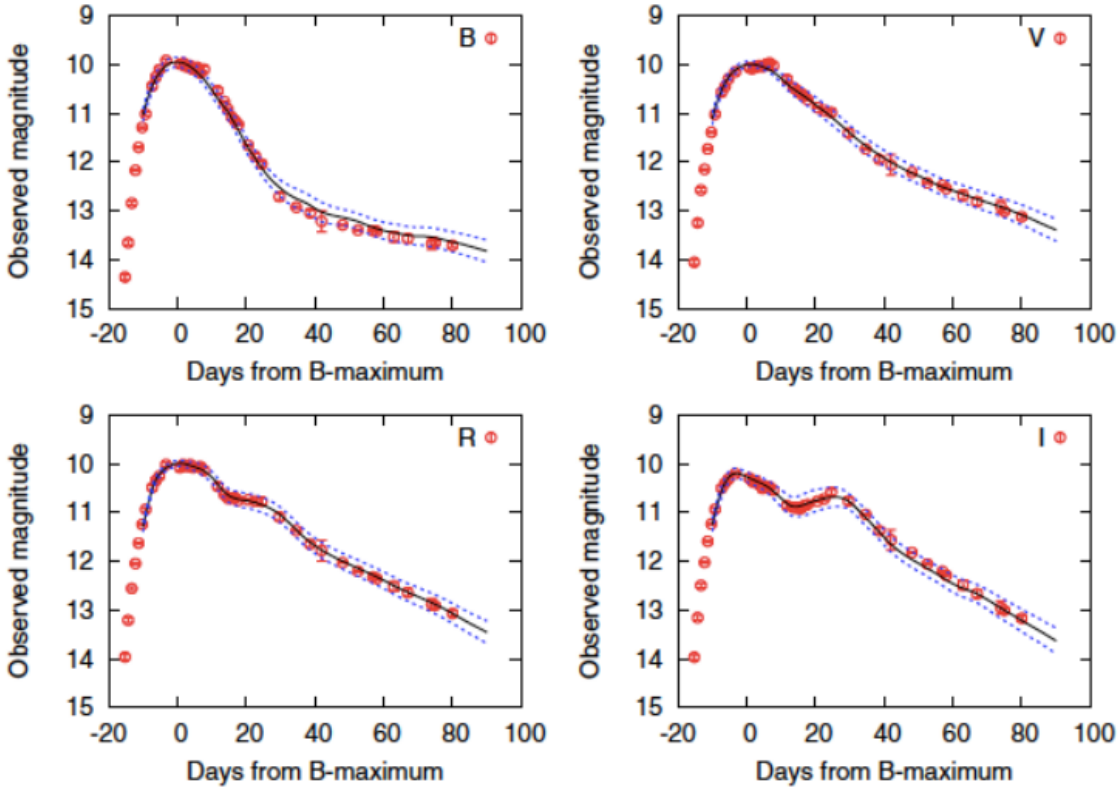
A Type Ia supernova was observed in 2011. The changes in the apparent magnitude during the supernova are shown below. The letters in the upper right-hand corner of each plot indicates the filter used to collect the apparent magnitudes (i.e. B= blue, V = visual; R = red; I = infrared).



65. Determine the distance, in terms of parsecs, to this supernova. **(5 points)**

66. Explain how Type Ia supernovas have been able to provide evidence for dark energy. **(3 points)**