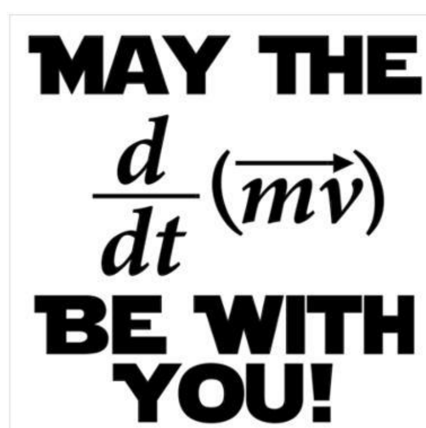
SCHOOL NAME: ________________Key____________________________ TEAM NUMBER: _____________

New York State Science Olympiad
2014 Astronomy Examination
200 Total Points

Directions:

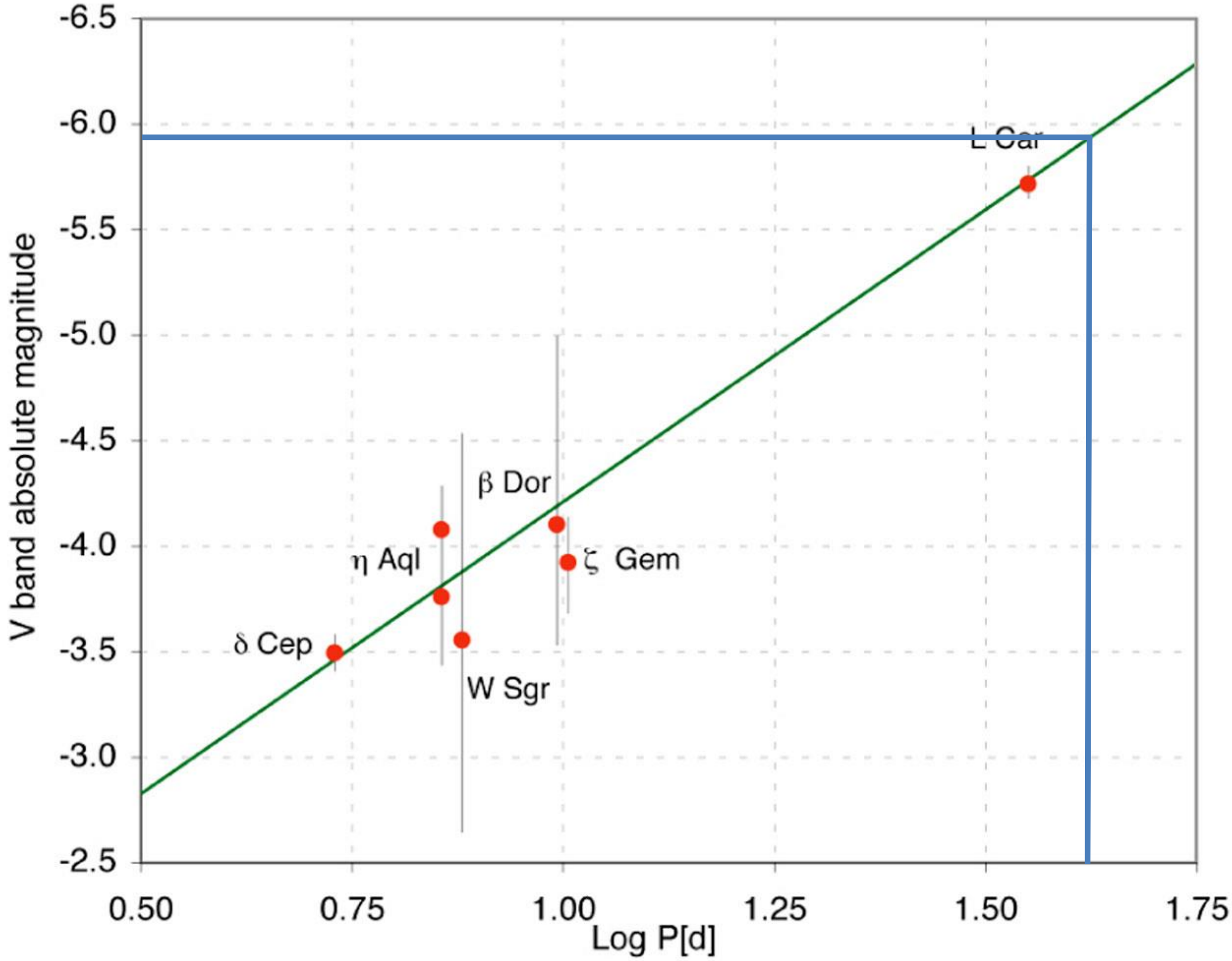
1. Place all answers in the space provided directly after each question.
2. All work must be shown for questions that require calculations. Zero points will be given for calculations without the required steps and units.
3. Please write your team number and school name at the top of each page.
4. A color 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: ________________________________

Potentially Useful Information



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)

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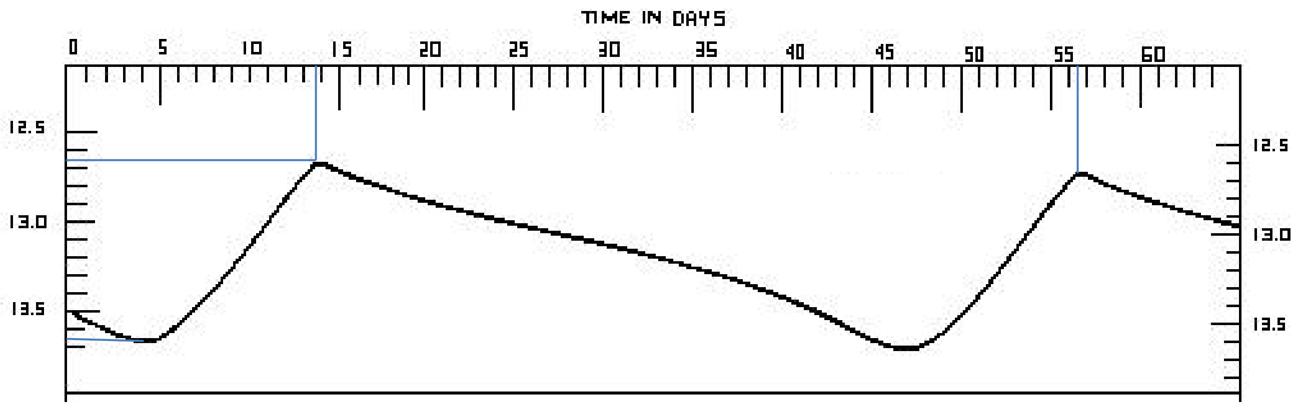
Part I: Unknown Star W (40 total points)

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)**

   Rapid rise in luminosity followed by a slow decline.
   Regular periodicity between 1 and 135 days.
   Change of magnitude of less than 2.

2. Identify the pulsation period of the star shown above. **(1 point)** **42-43 days**

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

   Absolute magnitude from period-luminosity relationship = -5.9
   Mean apparent magnitude = 13.0

   $d = 10^{0.2(13.0 - (-5.9) + 1)} = 60.3$ kpc
   Answers within 2 kpc are accepted. No partial credit awarded. No credit awarded without units or shown work.

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)**

   $\lambda_{max}T = 2.898 \times 10^{-3}$ mK
   $\lambda_{max} = 2.898 \times 10^{-3}$mK / 5355 K $= 5.41 \times 10^{-7}$ m
   $\lambda_{max} = 541$ nm
   No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in nanometers.

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)**

Due to the period-luminosity relationship, the star with the longer period will be more luminous; therefore, HV 1877 will be the more luminous star due to its longer period.

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)**

He^{2+} is more opaque than He^{+} to photons, which means that a shell of doubly ionized He will trap more photons than the singly ionized He. The opaqueness of the doubly ionized He will accelerate the rate of fusion in the core causing the pressure in the core to increase. This will cause the doubly ionized helium to be pushed outwards. As the doubly ionized helium expands, it loses kinetic energy to gravitational potential energy. The fraction of ions eventually switches to mostly singly ionized helium as the electrons are gained, which allows the photons to escape. The core temperature goes down due to a slower rate of nuclear fusion and the star's radius decreases. The compression of the singly ionized helium causes a rise in the core temperature and the re-ionization of He^{2+}, causing the cycle to repeat.

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)**

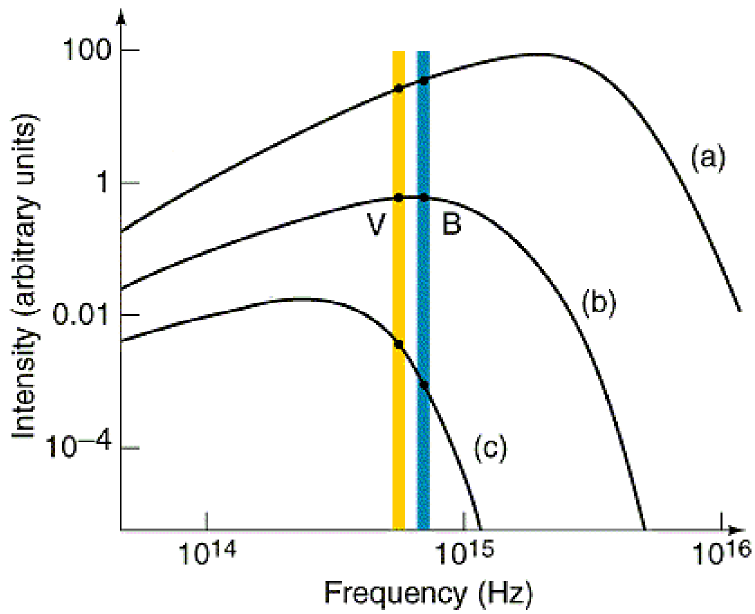
δ Cep has a greater metallicity since the ratio of iron to hydrogen is much higher compared to variable star W.

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

Stars with a larger amount of heavy elements are more likely to harbor a Jovian-sized planet; since unknown star W has a low metallicity, this indicates that the environment in which it formed is devoid of heaver elements and unlikely to support a Jovian-sized planet. Research has indicated that protoplanetary disks of lower metallicity have a shorter lifetime than those of higher metallicity; thus, the hydrogen and helium is dispersed at a much quicker rate in a lower metallicity environment.

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)**

Curve C. The positive difference in the color index indicates that the B filter has a larger magnitude. If the B has a larger magnitude, then the intensity in that filter is lower than the intensity in the V filter.

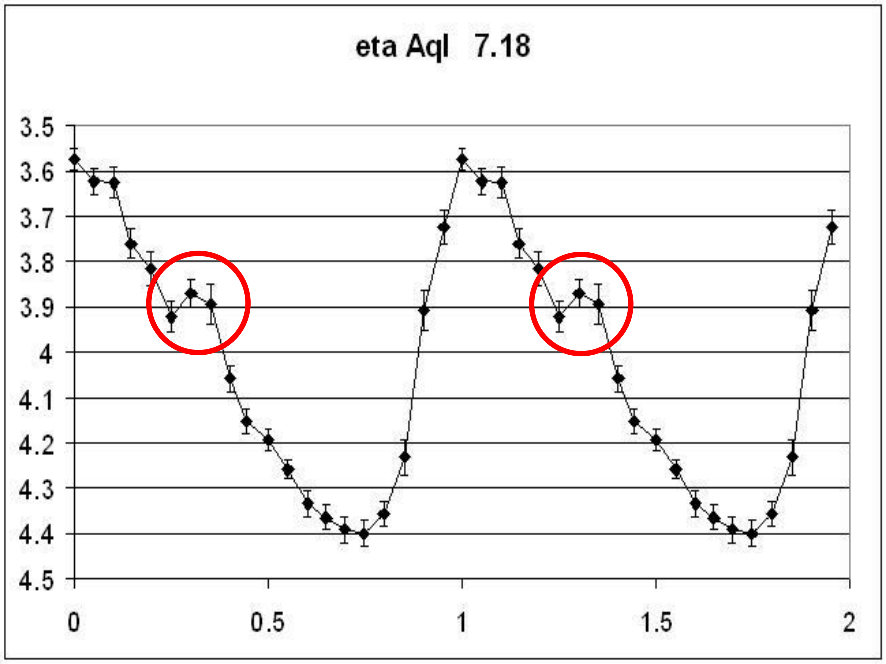


10. Variable star W is a Delta Cephei variable. Name one similarity and one difference between a Delta Cepheid and a Type II Cepheid. (**1 point each)**

Similarity: **both used for distance measurements; inhabit the same instability strip on the H-R diagram; pulsate for the same reason (κ-mechanism); similar period lengths**

Difference: **Delta Cephei variables are Population I stars, which are have a larger metallicity, are younger, and more massive than Type II Population stars. They have differences in their light curves. Different period-luminosity plots. Different location in the galaxies (Delta Cephei = along plane; Type II = globular clusters)**

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)**
Echo Model: During each cycle close to the phases of minimum radius and before the phase of maximum expansion velocity, a pressure excess is generated in the first He ionization region. This pressure excess causes the rapid expansion which in turn generates two pressure waves moving inward and outward. The inward reaches the stellar core close to the phase of maximum radius, then reflects and reaches the surface one cycle later causing the appearance of the bump.

Resonance Model: The bump is caused by a resonance between the second overtone and the fundamental mode and it takes place when the period ratio between these two modes is close to 0.5. The instability of the fundamental mode drives, due to resonance, the instability of the second overtone.

c. Does the variable W contain the Hertzsprung progression? Explain your answer. **(3 points)**
Unknown variable W does not contain the Hertzsprung progression, as bump variables are typically seen only with Cepheid variables with periods between 6 and 20 days.

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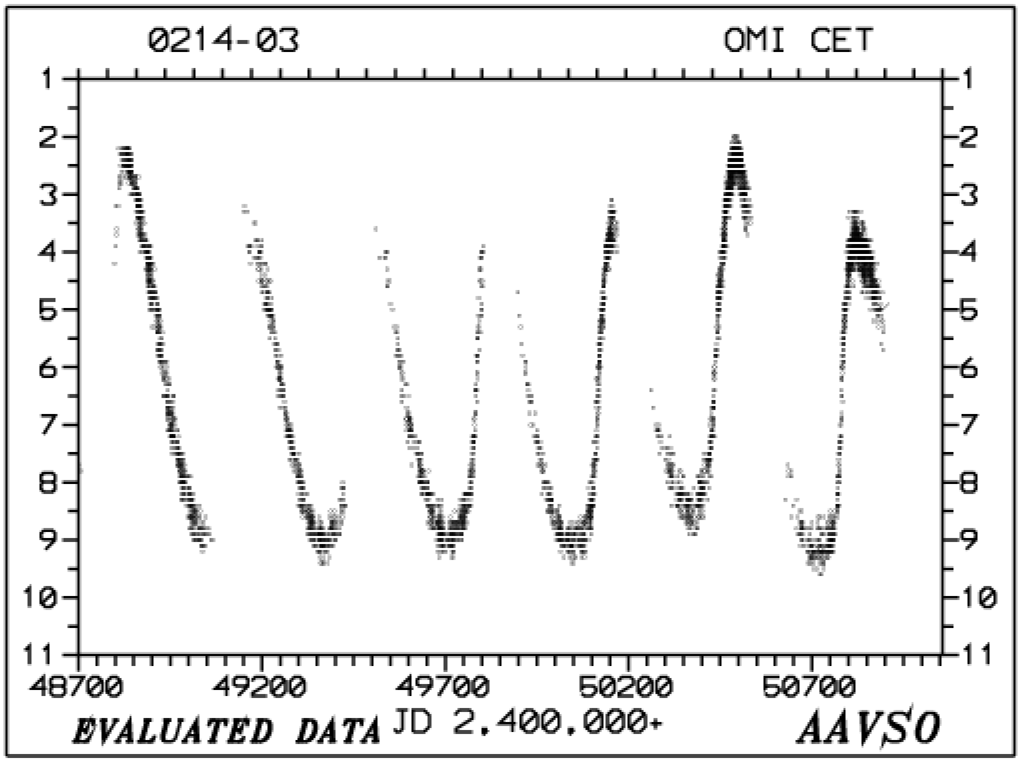
Part II: o Ceti (32 total points)

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)**
    Mira Variable/Pulsating Red Variable

13. Convert the separation to kilometers. **(1 point)**
    70 AU (1.496×10^8 km/AU) = 1.047×10^{10} km

    No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in kilometers.

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

15. Determine the mass of the companion star, VZ Ceti, in terms of solar masses. **(5 points)**
    $(m_1 + m_2)P^2 = R^3$
    $(1.18M_{\odot} + x)\,(400 \text{ years})^2 = (70 \text{ AU})^3$
    $1.18M_{\odot} + x = 2.14$
    $x = 0.96M_{\odot}$

    No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in solar masses.

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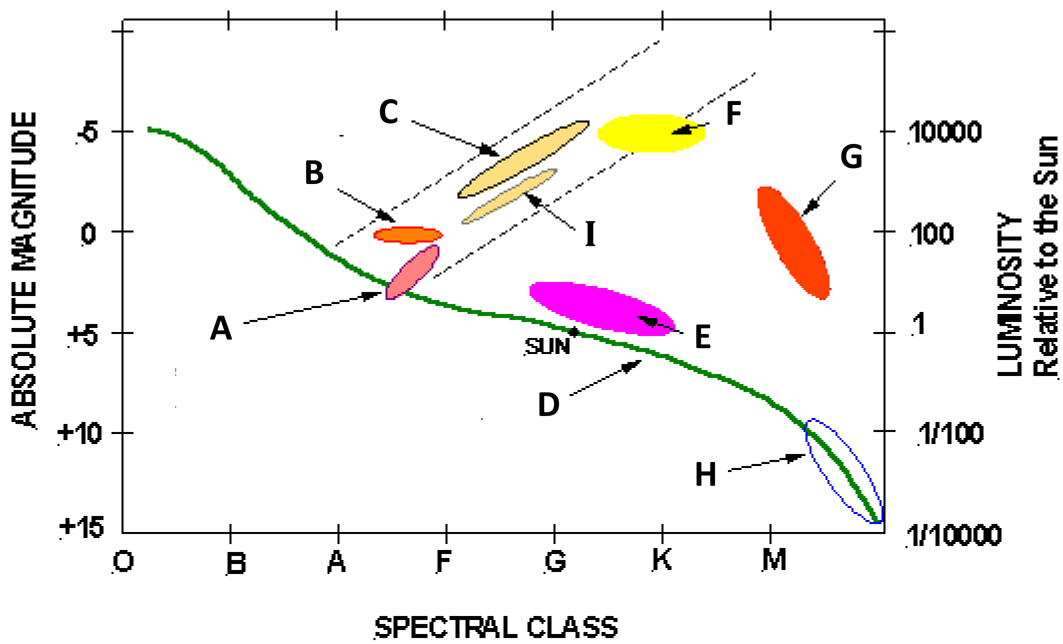
16. There is huge variability in the visible magnitude as opposed to the near-IR magnitude (around 1-3 μm). Provide two explanations as to why there are huge large variations in the visible magnitudes of o Ceti, as shown in the light curve on the previous page. **(3 point each)**
Explanation #1: As the star becomes fainter, it also becomes cooler, and a smaller fraction of the total energy is emitted in the visual portion of the spectrum.

Explanation #2: As the star becomes cooler, TiO molecules form and they absorb light preferentially in the visual part of the spectrum.

The following four questions refer to the following HR diagram.



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

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

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

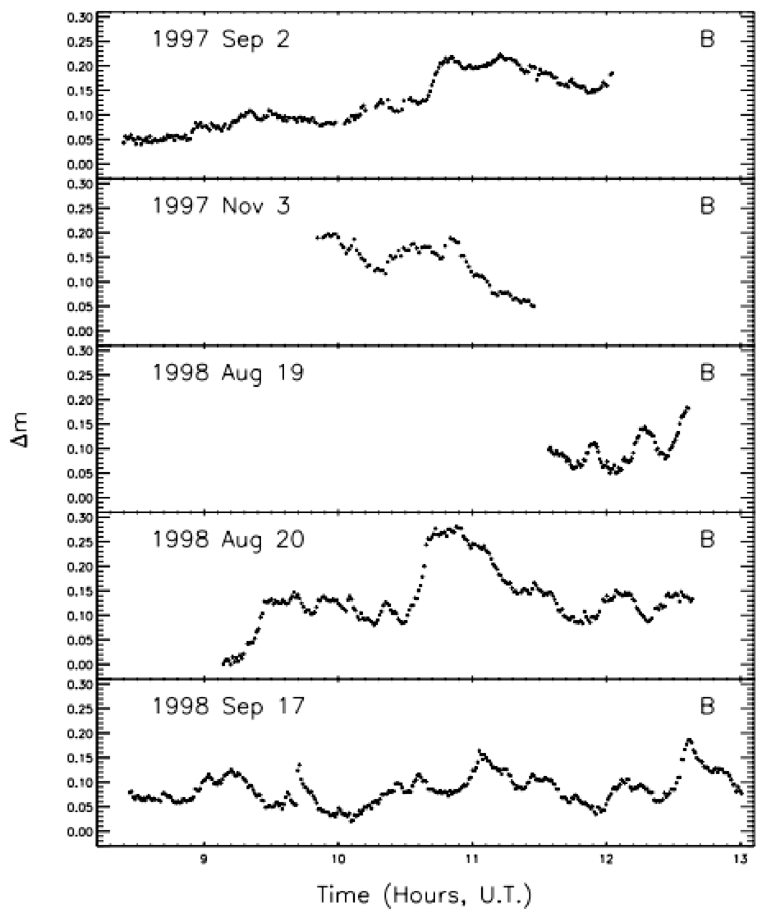
20. Provide the letter indicating where RR Lyrae would be located. **(1 point)** **B**

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)**

The star will eventually result in a planetary nebula and the formation of a white dwarf.

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)**

The rapid optical variability indicates that VZ Ceti is a white dwarf. The amplitude of the optical brightness fluctuations from VZ Ceti on the time scale of minutes is similar to those seen with white dwarves in cataclysmic variables and much larger compared to the predictions of an accreting main sequence star.

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)**

    The tail is showing the large amount of gas and dust that has been ejected from Mira over a long period of time. If this ejected material is able to accrete to form a protostar, a new star system can evolve.

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)**

    The bowshock forming ahead of the star heats the gas. The heated gas mixes with the cool hydrogen gas in the wind blowing off Mira. This heated hydrogen gas then flows behind the star, forming a wake. When the hydrogen gas is heated, it transitions to a higher electronic state, when then loses energy by emitting ultraviolet light.

Part III: Stellar Evolution (34 total points)

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

The Trapezium/
Orion Trapezium Cluster

47 Tucanae/NSC 104

Eight Burst Nebula/NGC 3132/
Southern Ring Nebula/Caldwell 74

26. Identify the protostar shown below. **(1 point)** **V1647 Ori**

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

McNeil's Nebula

28. Explain how this protostar formed and how it will eventually enter the main sequence. **(3 points)**
The formation of a protostar begins with a gravitational instability inside a molecular cloud, often triggered by shockwaves from supernovae. Once a region reaches a sufficient density of matter to satisfy the criteria for Jeans Instability, it begins to collapse under its own gravitational force. As the cloud collapse, individual conglomerations of dense dust and gas form called Bok globules. As a globule collapses and the density increases, the gravitational energy is converted into thermal energy, resulting in a temperature increase. When the protostellar cloud has approximately reached the stable condition of hydrostatic equilibrium, a protostar forms at the core. As it collapses, due to the conservation of angular momentum, the cloud will also begin to spin faster. When the core of a protostar becomes hot enough to initiate nuclear fusion of hydrogen, a main sequence star will form if sufficient mass is present (greater than 0.08 solar masses). The amount of time that it takes to enter the main sequence depends on its mass (higher mass, less time needed). For a star to form, gravitational equilibrium must be achieve (pressure generated by nuclear fusion is balanced by gravity).

29. Explain the source of energy for the protostar to shine, as shown above. **(3 points)**
Gravitational energy is released by the contraction of a forming protostar. This is the energy source that heats up the star to a temperature sufficient to enable it to shine visibly.

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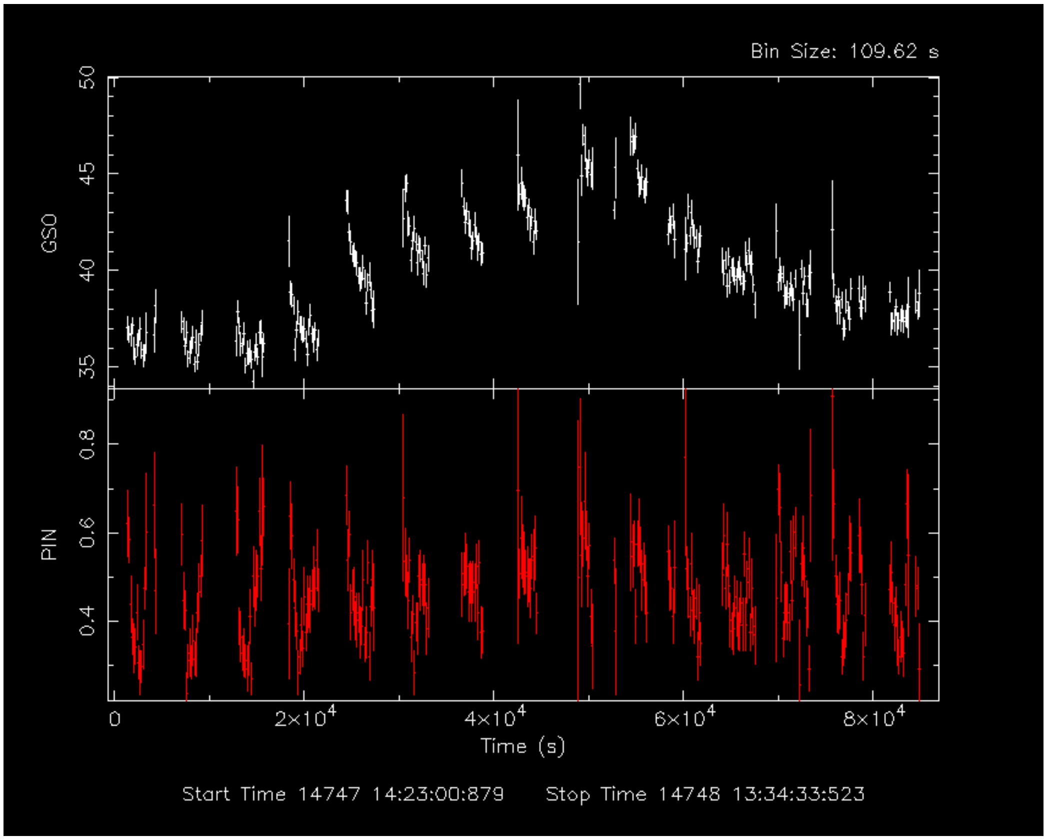
The following changes in x-ray emissions were observed from the protostar on the previous page.



30. Explain the origination of the changes in x-ray emissions. **(5 points)**
The matter in this protostar is accreting on the surface at two hotspot regions on opposite sides of the star. Due to the rotation of the star, these hot spots are moving in and out of the line of sight from Earth. When the hot spots are in line with the Earth, an "outburst" of x-ray radiation is observed, as shown in the top diagram above. The source of energy for these outbursts is linked to the accretion of matter from the accretion disk. The bursts of x-rays are thought to be linked to star-disk magnetic reconnection events (the heating of the plasma is sustained by the magnetic reconnection) associated with increased rates of accretion.

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

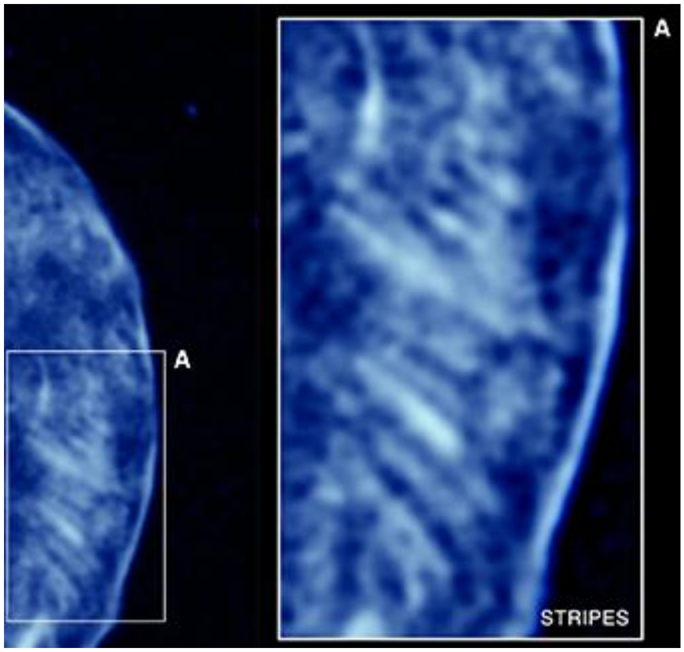
31. Identify the object shown in the image above. **(1 point)** **Tycho's Supernova Remnant**

32. Provide the right ascension of this object, in minutes. **(1 point)** **0 hr 25.3 min**

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

Tycho's Supernova Remnant was formed as a result of a Type 1a supernova. One of the stars present in a binary pair becomes a giant causing the gas to spill onto the secondary star. The secondary star expands and forms a common envelope with the larger mass star. The common envelope is ejected, leaving a core which contracts to a white dwarf. The secondary star starts to swell, spilling gas onto the white dwarf. If the white dwarf accretes enough mass to reach the Chandrasekhar limit, it becomes unstable and explodes in a supernova event.

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)** **x-rays**

35. Discuss the current theory as to how the stripes are formed. **(5 points)**
When a star explodes, it creates a fast-moving shock wave that spreads through space. High-energy particles, such as protons and electrons, can bounce back and forth across this shock wave repeatedly, gaining energy with each crossing. Near the expanding shock wave, magnetic fields become highly tangled and the motions of the protons and electrons become increasingly chaotic. This creates a network of x-rays, with regions of little emission to regions of large emissions. The stripes are regions where the magnetic fields are more tangled than the surrounding areas and the proton and electron movement is more turbulent. The protons and electrons become trapped and spiral around the magnetic field lines and the electrons emit a tremendous amount of x-rays in the process.

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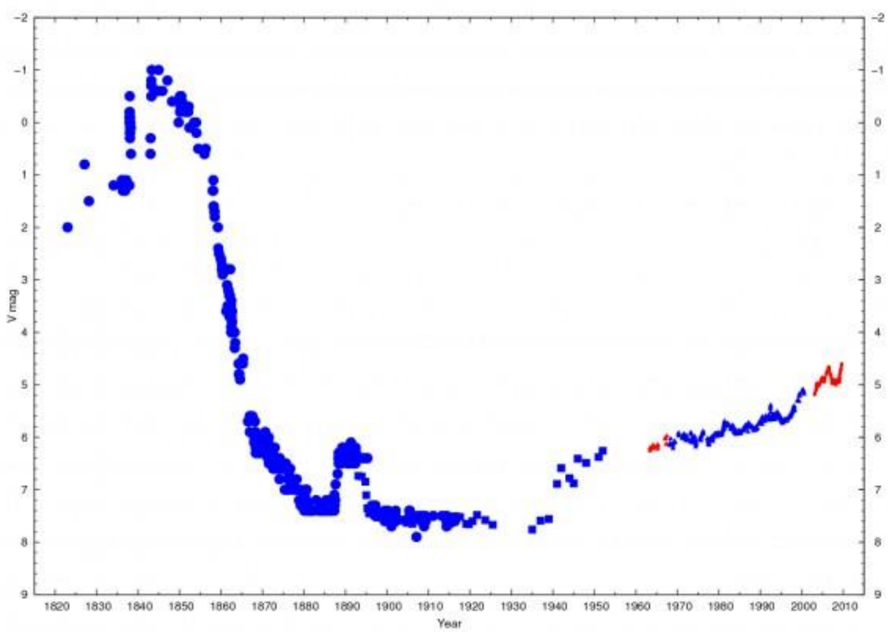
The image and associated light curve of an unstable star is shown below.



36. Identify the unstable star. **(1 point)** **Eta Carinae (η Car)**

37. Identify the class of variable star to which this star belongs. **(1 point)** **S Doradus or LBV**

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)**
The increase in radio emission has occurred because the cool gas in the outflow close to the star is excited by a blast of radiation. The system is a binary system, in which the hotter star supplies UV radiation which ionizes the gas close to the star. When the gas is ionized, it produces radio emissions. However, every 5.5 years, when the more evolved star in the binary system comes in between Earth and the hotter star, its wind absorbs all of UV light; therefore, the gas is no longer ionized and the radio emissions cease to be produced. As the evolved star moves back into orbit, the gas can become re-ionized and the radio emissions start back up.

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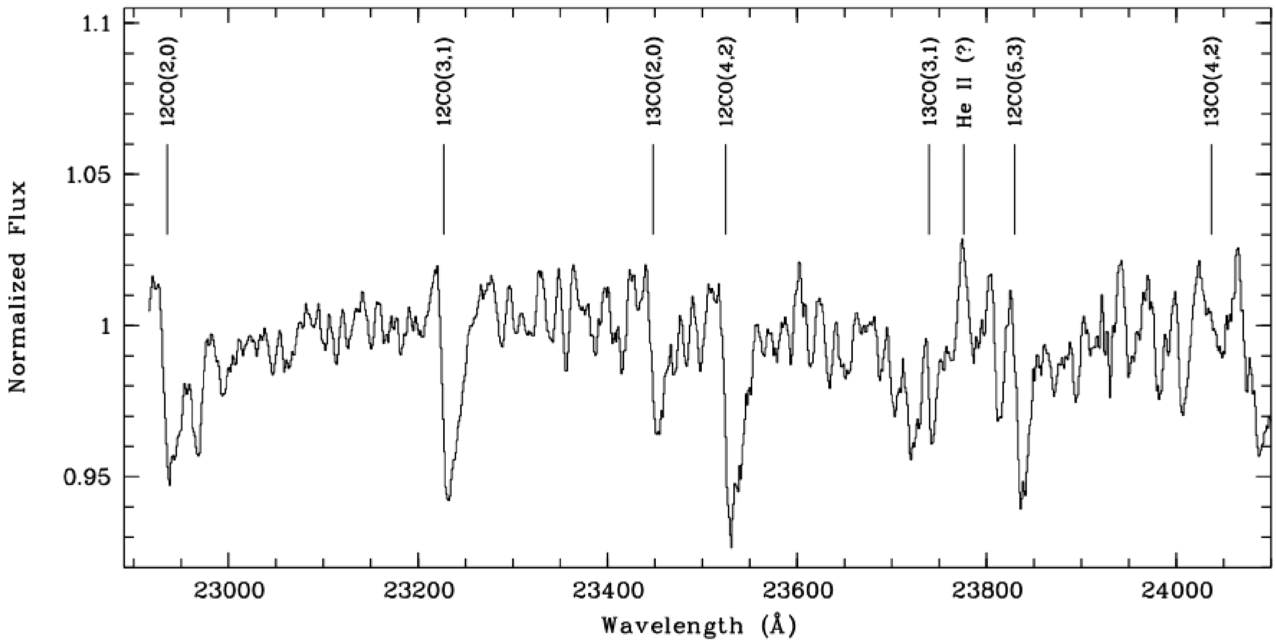
Part IV: Binary Systems (35 points)

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)** **Aquila**

40. Provide the declination, in degrees, of the binary system. **(1 point)** **+10°15'44"**

41. Provide the distance, in parsecs, of the binary system. **(1 point)** **11 kiloparsecs**

42. Identify the spectral class of the regular star found in the binary system and provide an appropriate rationale for your assignment. **(3 points)**
The star is either a K or M spectral class star due to the presence of the ^{12}CO and ^{13}CO bands in the spectrum above.

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)**
In both quasars and microquasars, the system contained a spinning black hole, an accretion disk heated by dissipation, and jets of relativistic particles. In microquasars, however, the black hole is only a few solar masses and the accretion disk is found at lower temperatures. In a microquasar, the material is drawn from a companion star in a binary system. In a quasar, the supermassive black hole is able to accrete matter from its surroundings. The quasar has a much larger accretion disk and emits UV and optical emissions. The microquasar has a smaller accretion disk and emits x-rays.

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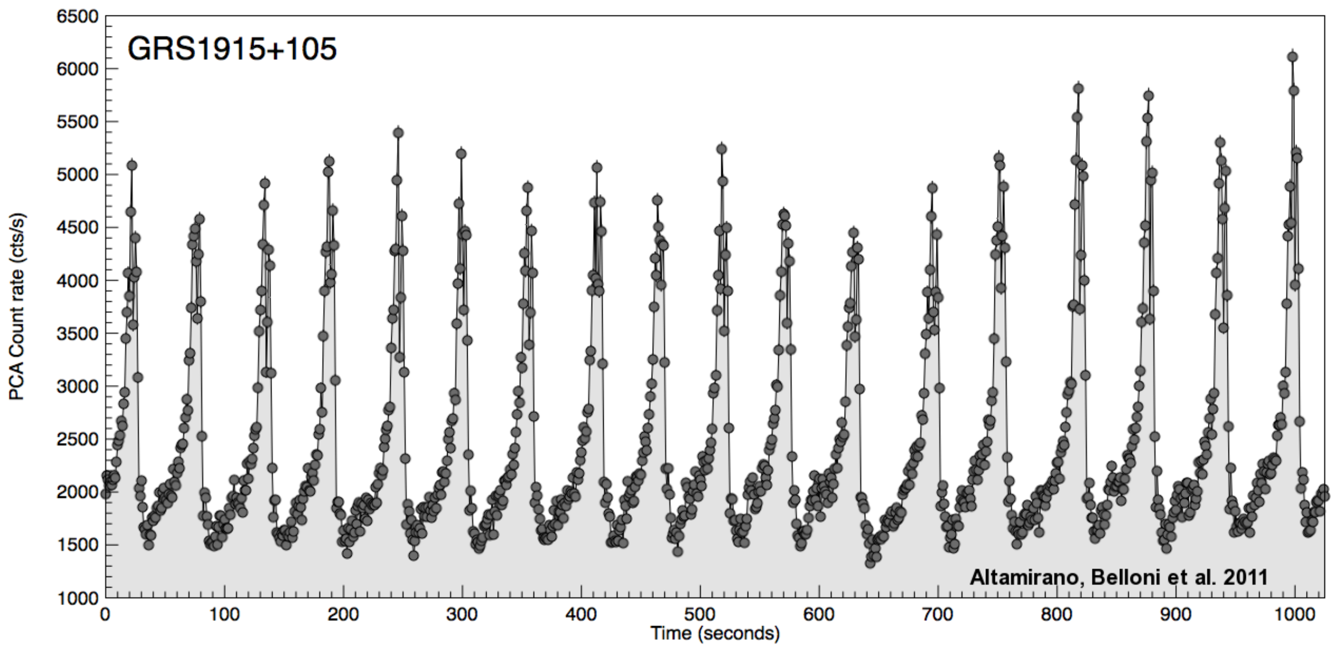
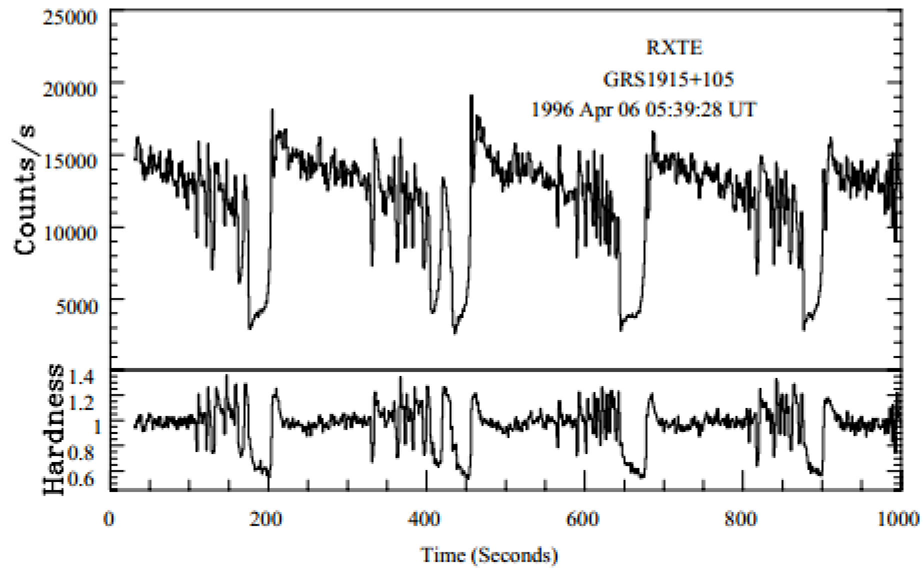
The following data were collected through a Proportional Counter Array instrument on the GRS 1915+105 binary system.

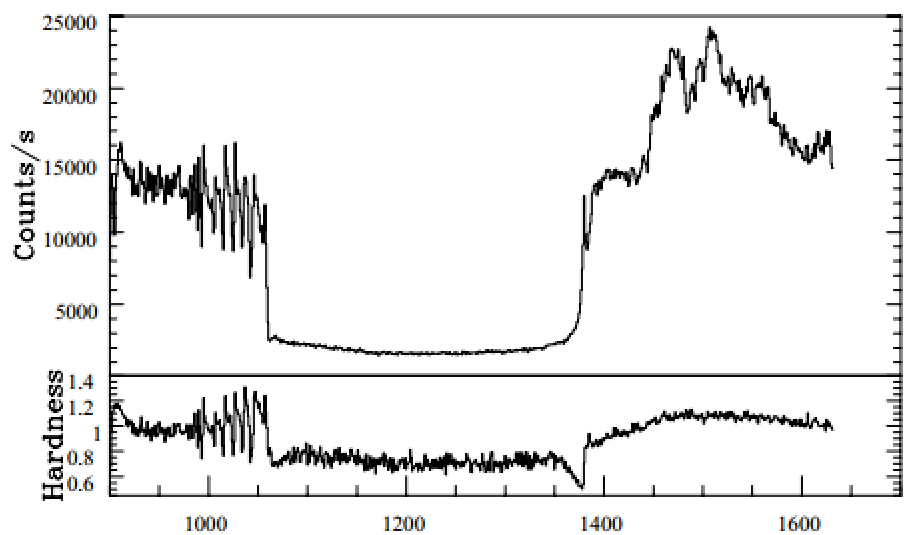


44. Provide an explanation for the cyclic nature of the emissions from the binary system. **(5 points)**

The intermittent bursts of x-ray emissions are caused when gas is accreted from its companion star to form a disk around the black hole, where it is heated by friction to very high temperatures. The temperatures are sufficiently hot to emit x-rays. The patterns represent cycles of accumulation and ejection in an unstable disk. The inner disk of the black hole emits enough radiation to push the material away from the black hole. This eventually causes the disk to become too hot that it disintegrates and the material plunges back toward the interior, thus causing the cycle to repeat again.

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)**
The inner portion of the accretion disk disappears every half hour or so. The disk reforms itself from pulling more matter from its companion star, thus restarting the cycle.

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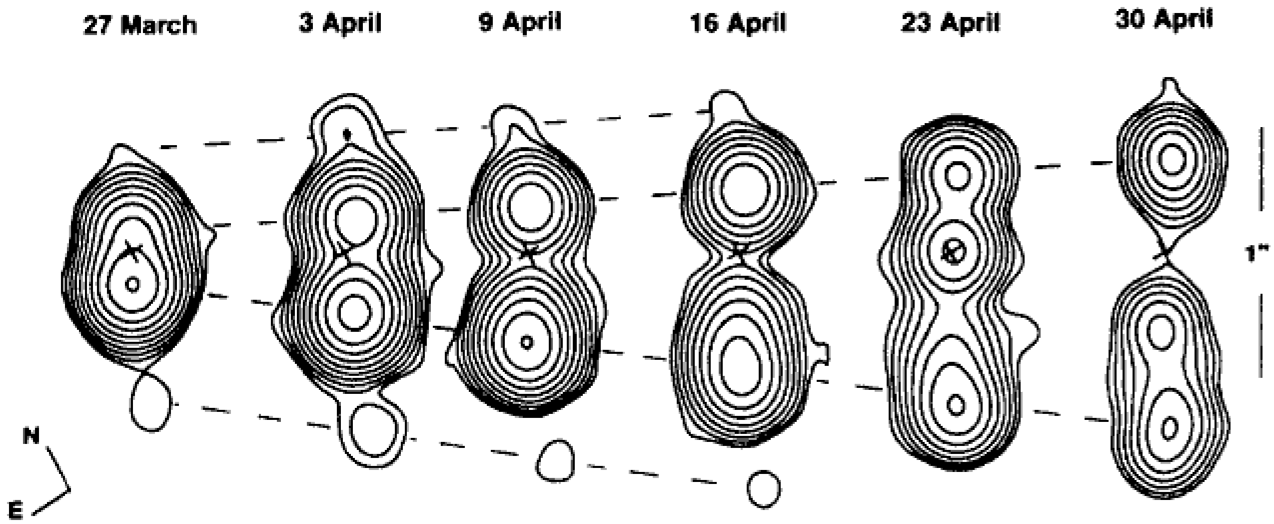
The image below contains time sequences of radio images of the binary system GRS 1915+105 which were captured over a course of approximately one month in 1994.



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)**
The two radio-emitting plasma circles are apparently moving at a speed greater than the speed of light, which would not be a possibility for radio waves according to the theory of relativity. However, the apparent motion can also be understood as the result of an illusion by the combination of the high velocity of the radio emissions and the angle of the jets along the direction close to the line of sight.

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)** **Cancer**

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

$$\frac{v}{c} = \frac{\lambda_{obs}}{\lambda_{emit}} - 1$$

$$\frac{650000\ m/s}{3.00\ x\ 10^{8}\ m/s} = \frac{\lambda_{obs}}{4686\ \text{Å}} - 1$$

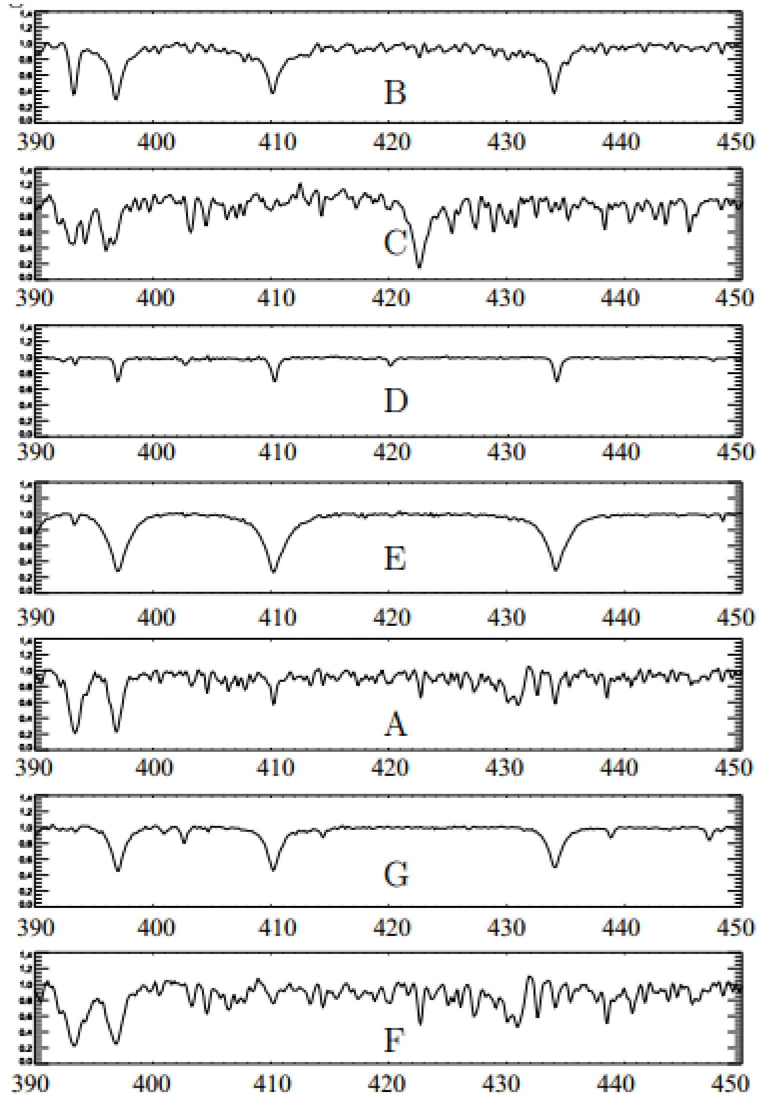
λ_{obs} = 4696 Å

No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in Angstroms.

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)**
The stars are moving closer to one another, indicating that the system is losing energy. According to relativity theory, the binary system will produce gravitational waves which are ripples in space time. Any passing gravitational wave would cause any planets or other objects to bob in space time, slightly altering the distance between the objects. Eventually, the two stars will merge to one.

Part V: Basic Astronomical Principles (59 points)

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



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

    DGEBAFC

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)**

    D 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.

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

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

    E Hydrogen lines very strong and dominate the spectrum.

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

    B Spectrum G

    A Spectrum E

    M Spectrum C

    O Spectrum D

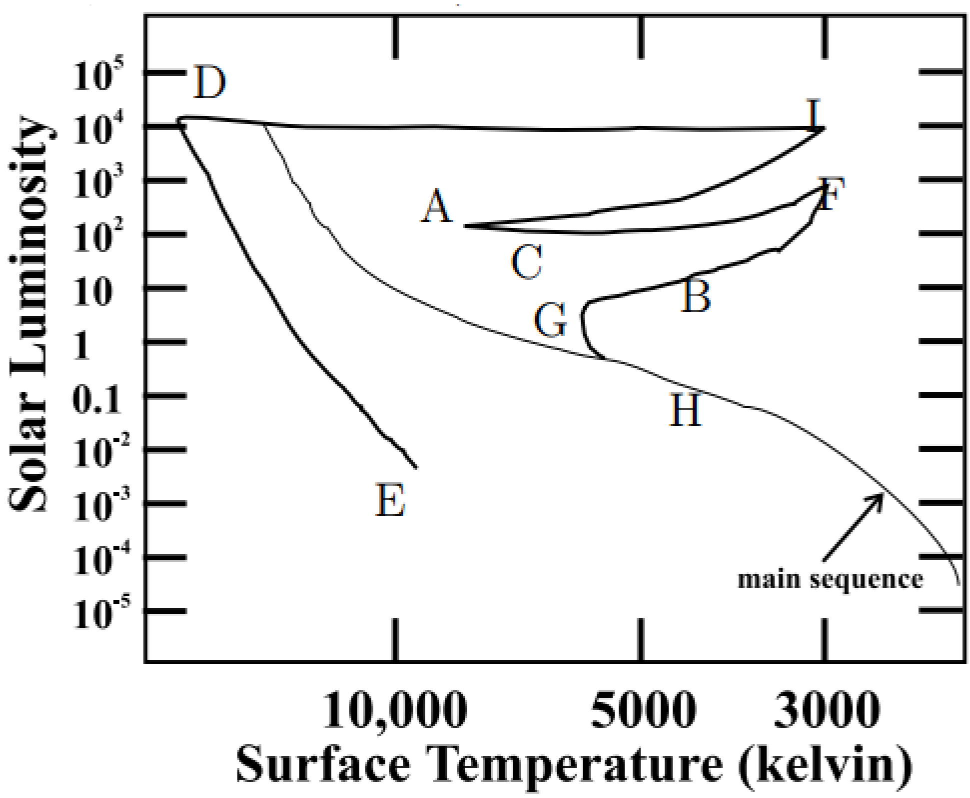
53. Complete the following equations representing nucleosynthesis in an unknown star. **(1 point each)**

    $^{20}_{10}Ne + {}^{0}_{0}\gamma \rightarrow {}^{4}_{2}He + {}^{16}_{8}O$

    $^{16}_{8}O + {}^{16}_{8}O \rightarrow {}^{1}_{1}H + {}^{31}_{15}P$

    $^{16}_{8}O + {}^{16}_{8}O \rightarrow 2\,{}^{4}_{2}He + {}^{24}_{12}Mg$

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)**



G Hydrogen used up, core collapses

B Hydrogen fusion in shell around core

A Helium used up, core collapses

D Envelope ejected

F 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 parsecs? **(3 points)**

$$d = \frac{1}{p} = \frac{1}{0.00378\ arcseconds} = 265\ pc$$

No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in parsecs.

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)**

$$\theta = \frac{l}{d} = \frac{74 \text{ x } 6.96 \text{ x } 10^{8}}{265 \text{ x } 3.086 \text{ x } 10^{16} \text{ m}} = 6.30 \text{ x } 10^{-9} \text{ radians} = 1.30 \text{ milliarcseconds}$$

Telescopes on Earth are limited to a resolution of 1 arcsecond, so the star would not be resolvable on Earth.

No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in milliarcseconds. No credit awarded without explanation of possible resolution on Earth telescope.

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

$$\frac{L}{L_{\odot}} = \frac{R^2T^4}{R_{\odot}^2T_{\odot}^4}$$

$$L = (74)^2 \text{ x } \left(\frac{12075K}{5778K}\right)^4 = 1.04 \text{ x } 10^5 \text{ solar luminosities}$$

Or

$$L = 4\pi R^2\sigma T^4$$
$$L = 4\pi(74 \text{ x } 6.96 \text{ x } 10^8 \text{ m})^2(5.670 \text{ x } 10^{-8} \text{ W/m}^2/\text{K}^4)(12075 \text{ K})^4$$
$$L = 4.016 \text{ x } 10^{31} \text{ W} * (1 \text{ solar luminosity}/3.839 \text{ x } 10^{26} \text{ W})$$
$$L = 1.05 \text{ x } 10^5 \text{ solar luminosities}$$

No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in solar luminosities.

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

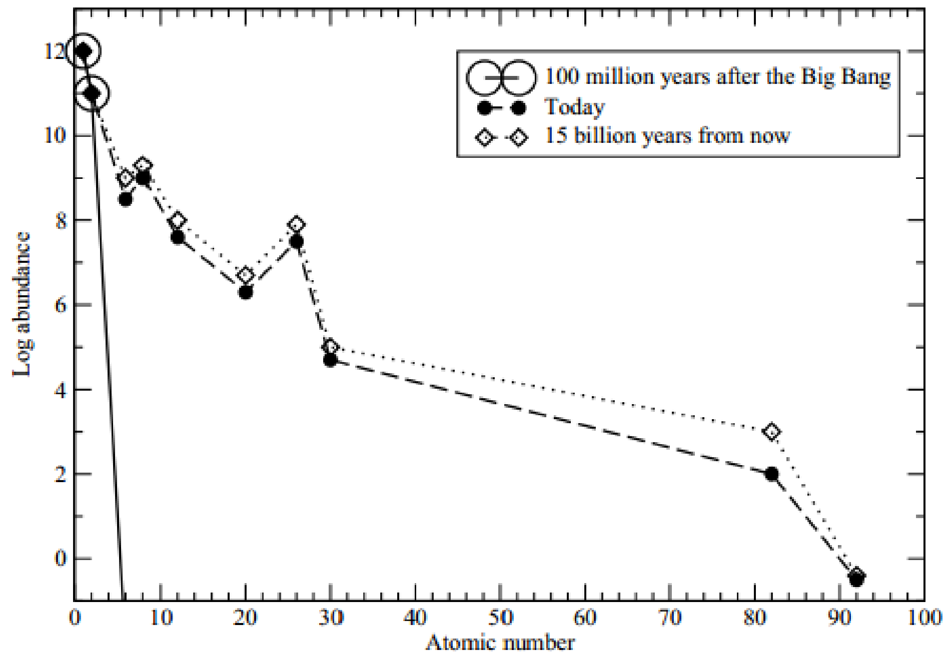
$$m - M = 5 \log d - 5$$
$$5 \log d - 5 = 5 \log(265) - 5 = 7.11$$
$$0.12 - M = 7.11$$
$$M = -6.99$$

No partial credit awarded. No credit awarded without units or shown work.

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

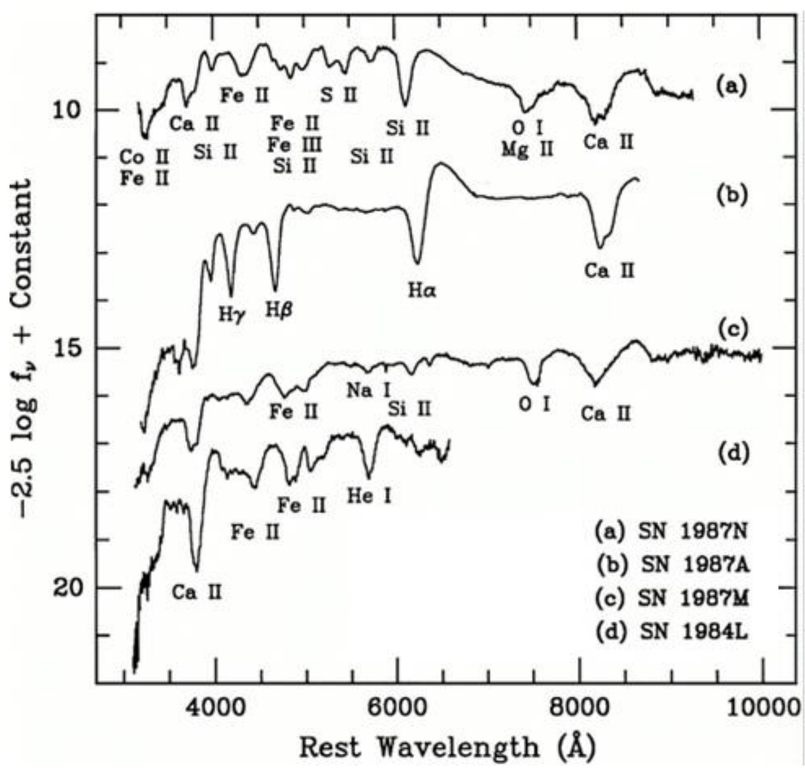
With a surface temperature of 12075 K and an absolute magnitude of -6.99, Rigel is a B spectral class star.
With a luminosity of 1.05 x 10^5 $L_{\odot}$, Rigel is a supergiant star, luminosity class 1a.

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.

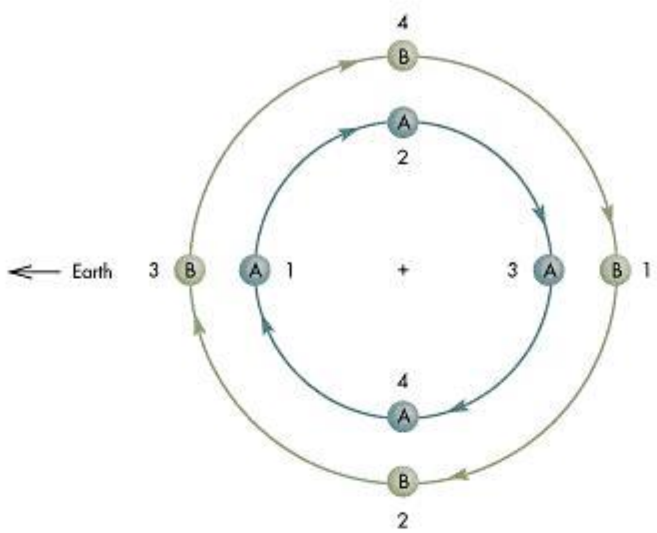


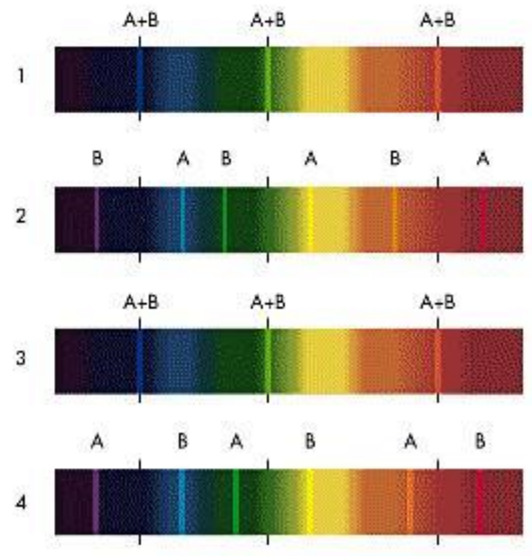
61. The diagram to the right shows the spectra of four different supernovae remnants. Identify which of the supernovae remnants formed as a result of a Type II supernova. Explain your answer. **(3 points)**

    SN 1987A (spectra B)
    Type II supernova have visible hydrogen spectra lines due to the hydrogen present in the outer shell of the very massive star. Type Ia spectra will lack the hydrogen lines as white dwarves will have previously exhausted its hydrogen fuel earlier in its life cycle.



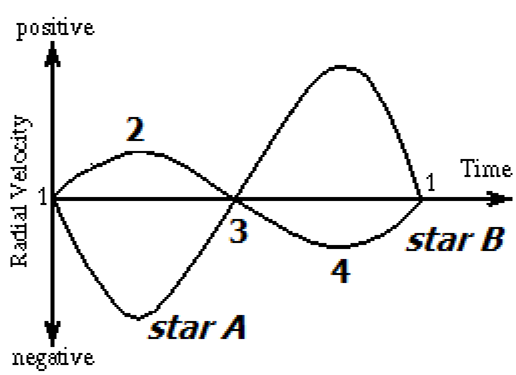
1The following partial diagram represents a spectroscopic binary system. The orbit of star A has been shown, and the orbit of star B has been omitted. The spectra provided are based upon the positioning of the two stars (positions 1 through 4), as shown by the numbers in the orbit of star A.





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) **The radial velocity amplitudes are reversed in image.**



64. Explain any similarities and differences between magnetars and pulsars. **(3 points)**
Both are types of neutron stars. Magnetars are highly magnetized neutron stars and pulsars are rapidly rotating neutron stars with a jet of radio waves that sweeps across the sky as the star spins. Magnetars rotate much slower compared to pulsars and other neutron stars. Magnetars provide bursts of high energy EM radiation (x-ray and gamma rays).

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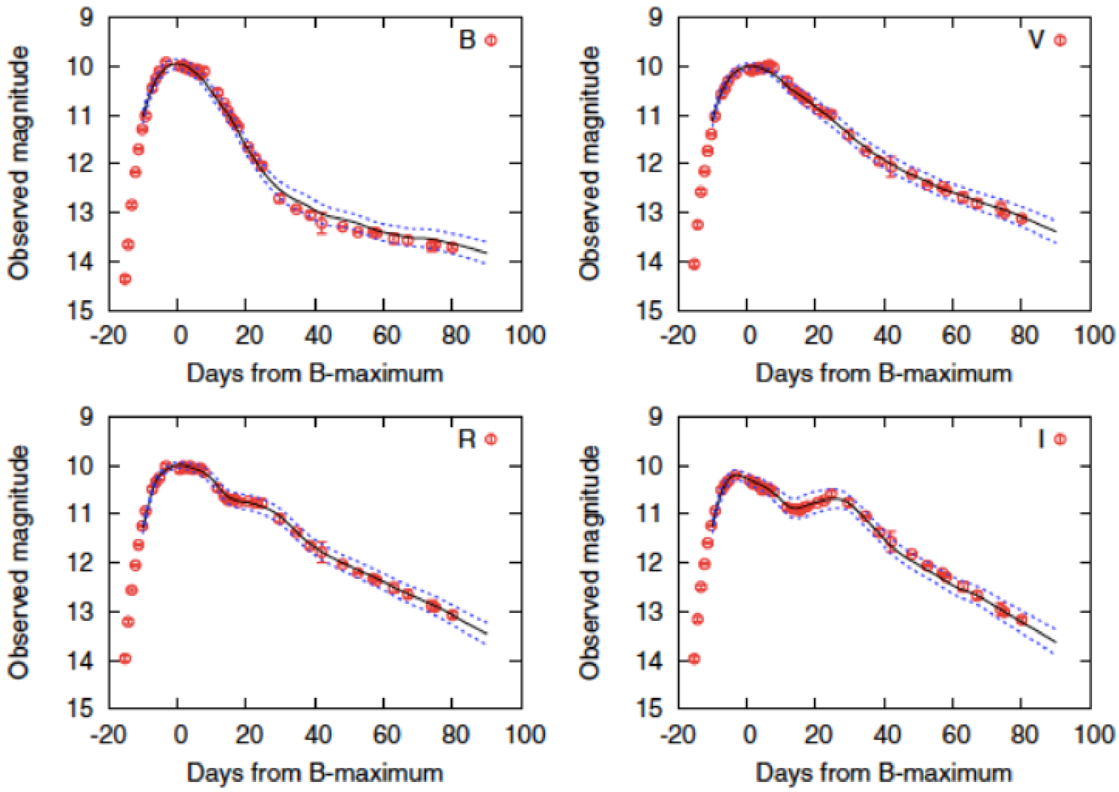
A Type Ia supernova was observed in 2011. The changes in the apparent magnitude during the supernova are shown below. The letters in the upper right-hand corner of each plot indicates the filter used to collect the apparent magnitudes (i.e. B= blue, V = visual; R = red; I = infrared).



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

m – M = 5logd – 5

10 – (-19.3) + 5 = 5log d

d = $10^{6.86}$ = 7.24 Mpc

Answers between 6.5 and 8.0 Mpc are acceptable. No partial credit awarded. No credit awarded without units or shown work. Answer must be reported in nanometers.

66. Explain how Type 1a supernovas have been able to provide evidence for dark energy. **(3 points)**
Evidence from Type 1a supernovas and associated red shift data demonstrated that the Universe is accelerating. A force must be responsible for the acceleration as gravity merely would cause the contraction of the universe (it is an attractive force). The force causing the Universe to expand has been equated to dark energy by many scientists.