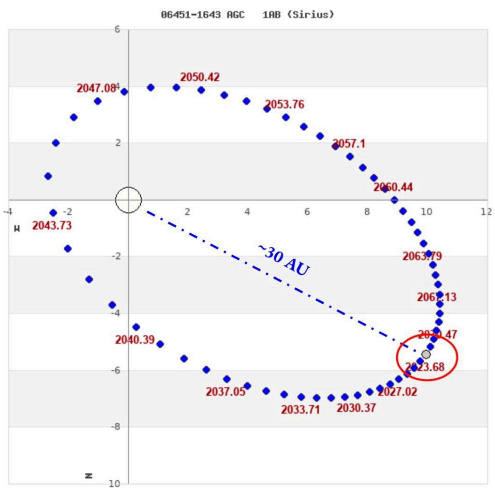
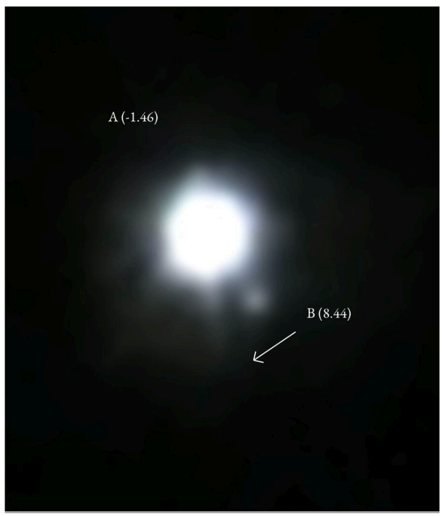
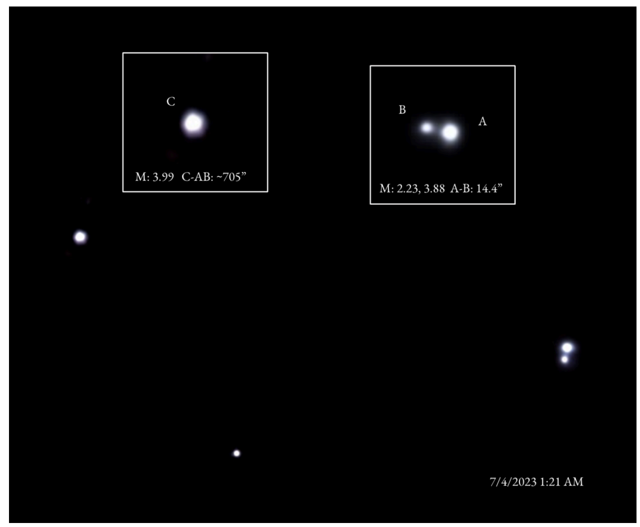
Science Olympiad CSE 2023

Novi High School

Astronomy C Test







Directions:

- **Do not open the test until told to start!**
- **Each team will be given 50 minutes to complete the test.**
- **2 sections: Section A (General Knowledge), Section BC (Calculations).**
- **Try to use 2-3 decimal places in final answers for Section BC**
- **Good luck!**

Test Written/Cover Images Credit by: Ethan Chen (Novi '25)

Questions? Email ethankchen6@gmail.com

Name(s): ______________________________________

Score: /910

Section A (Theory - 10 Points Each)

1. A stellar classification of V denotes a
    a. Giants
    b. Main Sequence
    c. Supergiants
    d. Cepheids

2. Kepler's 2nd Law is derived from which law?
    a. Law of Conservation of Momentum
    b. Kepler's 1st Law
    c. Law of Conservation of Momentum
    d. Newton's Third Law

3. What Main Sequence star has the strongest Balmer Lines?
    a. Type O
    b. Type A
    c. Type G
    d. Type M

4. If a planet had it's orbital period doubled, by what factor would its orbital radius increase?
    a. $\sqrt{2}$
    b. $\sqrt[3]{4}$
    c. 2
    d. $\sqrt{3}$

5. All are ways to measure distances in Astronomy except:
    a. Type Ia Supernovae
    b. Classical/Recurrent Novae
    c. RR Lyrae Variables
    d. Mira Variables

6. The Dynamical Timescale is a simplified mechanism to explain…
    a. The amount of time it takes for open star clusters to dissipate
    b. The amount of time stars can radiate away any nuclear energy
    c. The amount of time stars would contract under gravity without any outward force/pressure
    d. The amount of time it takes for a White Dwarf to exceed the Chandrasekhar Limit

7. The Thermal Timescale is a simplified mechanism to explain…
    a. The amount of time it takes for an open star cluster to lose half of it's mass
    b. The amount of time a star can radiate energy at it's Eddington Luminosity
    c. The amount of time it takes for a star to radiate away any gravitational potential energy.
    d. The amount of time it takes for a molecular cloud to collapse into a protostar

8. All of which are methods to detect exoplanets except…
    a. Transit Method
    b. Direct Imaging
    c. Doppler Curving
    d. Pulsar/Variable Star Timing

9. What can the radial velocity method for detecting exoplanets not tell us?
    a. Mass of the Planet
    b. Orbital Velocity and Radius and Planet
    c. Orbital Momentum of the Planet
    d. Radius of the Planet

10. In close binary star systems, mass may be transferred from one star to another or be lost completely from the system. What could be a resulting effect? Select all that apply.
    a. Type Ia Supernova
    b. Recurrent Nova
    c. Type II-P Supernova
    d. Orbital Period Decreasing

11. The blue loop in stellar evolution occurs after what stage of evolution?
    a. Main Sequence
    b. Planetary Nebula Phase
    c. Subgiant Branch
    d. Horizontal Branch

12. "Hot Jupiter" Exoplanets are thought to be formed by:
    a. Collision between two rocky or gas planets inside the frost line
    b. Jupiter sized planet losing its atmosphere from stellar wind
    c. Rocky planet accreting an atmosphere of mainly carbon/hydrogen based compounds
    d. Jupiter sized planets "migrating" towards the parent star

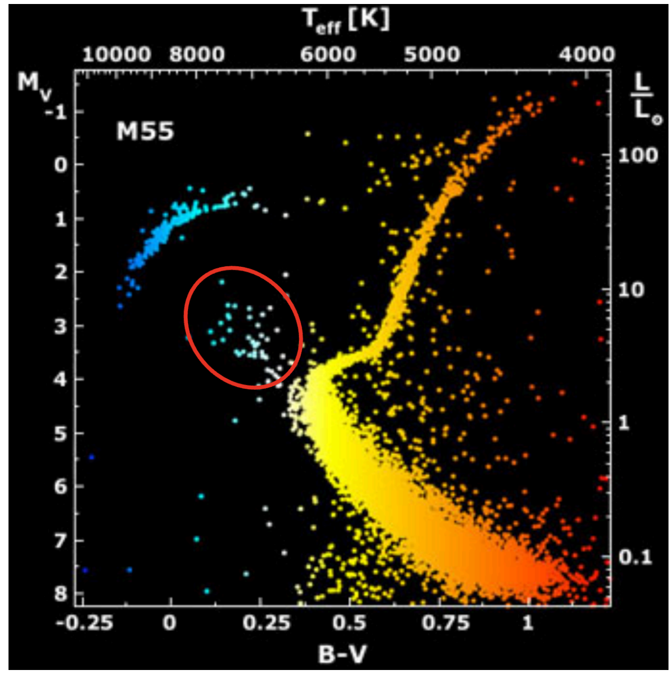
13. For an object that is gravitationally bound to another, the orbital energy is always: (select all that apply):
    a. Positive
    b. Negative
    c. Constant
    d. Varies at points in the orbit

14. Type Ib and Ic Supernova lack the emission line of what element?
    a. Carbon
    b. Neon
    c. Hydrogen
    d. Silicon

15. How can Type Ib or Ic Supernovae occur instead of a Type II Supernova?
    a. Binary Star Interaction with close companion
    b. Ignition of Helium Fusion in Core
    c. WR Stars expelling outer layers through stellar wind
    d. Ignition of Iron/Magnesium Core Fusion

16. The detection of metals (such as lithium) in Population I stars can be attributed to
    a. Classical/Recurrent Novae
    b. Type Ia/II Supernovae
    c. Asymptotic Giant Branch Stars
    d. Incorrect models of globular clusters

Questions 17-20 relate to the Hertzsprung-Russell Diagram of the globular cluster M55.



17. What B-V color index and absolute magnitude respectively would RR Lyrae variables be found?
    a. 0.20/3.50
    b. There are no RR Lyrae Variables in this cluster
    c. 0.3/0.00
    d. 1.00/-1.00

18. Why is the Main-Sequence Turnoff Point Important?
    a. Enables astronomers to determine metallicity of the cluster
    b. Enables astronomers to determine the age of the cluster
    c. Astronomers can use the turnoff point to determine the amount of stars in the cluster
    d. Main-Sequence Turnoff point can show astronomers the half-light radius of the cluster

19. At approximately what solar luminosity does the Main Sequence Turn-Off Point occur (Probably inaccurate due to interstellar extinction)?
    a. $0.5\ L_\odot$
    b. $5\ L_\odot$
    c. $2\ L_\odot$
    d. $8\ L_\odot$

20. The stars circled in red on the diagram are called blue stragglers. How are these stars formed?
    a. Stars that formed with a higher mass than the rest of the cluster
    b. Merger of two stars in a binary system
    c. Stars that have lost mass in stellar wind to continue on the main sequence longer
    d. White Dwarf accreting material from companion star

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21. All Transiting Exoplanets and Eclipsing Binary Star Systems have inclination angles of approximately
    a. 0°
    b. 90° (Answer)
    c. 45°
    d. 180°

22. During a helium flash in low-intermediate mass stars, why does the overall luminosity decrease?
    a. Helium Flash causes radius to decrease and temperature to increase
    b. The fusion of hydrogen in a shell is disrupted
    c. Helium Flash does not lower the overall luminosity
    d. The overall luminosity decreases because the onset of helium fusion transfers energy away from the outer layers of the star

23. The "plateau" seen in a Type II-P Supernova is caused by
    a. Recombination of Helium ejected from stellar wind
    b. Opaque Ionized Hydrogen
    c. Fusion of more heavier elements during the supernova
    d. Opaque Ionized Silicon decaying into Nickel

24. Why do low mass stars have radiative cores while high mass stars have convective cores?

a. Low mass stars do not have a core hot enough to be convective
b. Low mass stars have a low temperature gradient
c. High mass stars have a core too hot to be radiative
d. High mass stars have a low temperature gradient

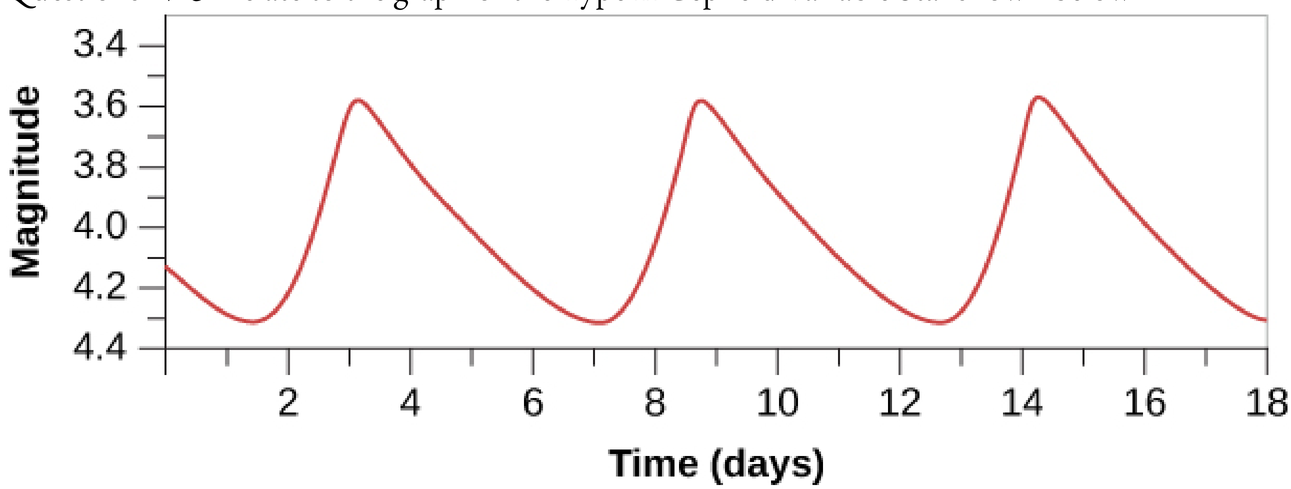
25. Stars move onto the Asymptotic Giant Branch track of the HR diagram when:

a. Hydrogen begins to run out in the core
b. The onset of helium fusion in the core
c. Fusion of hydrogen in a shell around the core stops
d. Helium begins to run out in the core

26. Why can't stars fuse iron?

a. The high binding energy of iron makes iron fusion endothermic
b. Iron is unstable inside the cores of stars
c. Fusion of heavier elements in other shells prevents stable fusion of iron
d. Iron decays immediately into Nickel

Questions 27-31 relate to the graph of the Type II Cepheid Variable Star shown below



27. By how many magnitudes are Type II Cepheids higher than Type I Cepheids?

a. 3.0
b. 1.5
c. 1.0
d. 0.5

28. If the light curve shown was of a Type I Cepheid, what would it's average absolute magnitude be?
    a. -2.5
    b. -3.0
    c. -3.5
    d. -4.0

29. Why are Type II Cepheids less luminous than Type I Cepheids?
    a. Type I Cepheids have more helium in their photosphere
    b. Type II Cepheids use a different pulsation method
    c. Type I Cepheids are older
    d. Type II Cepheids are older

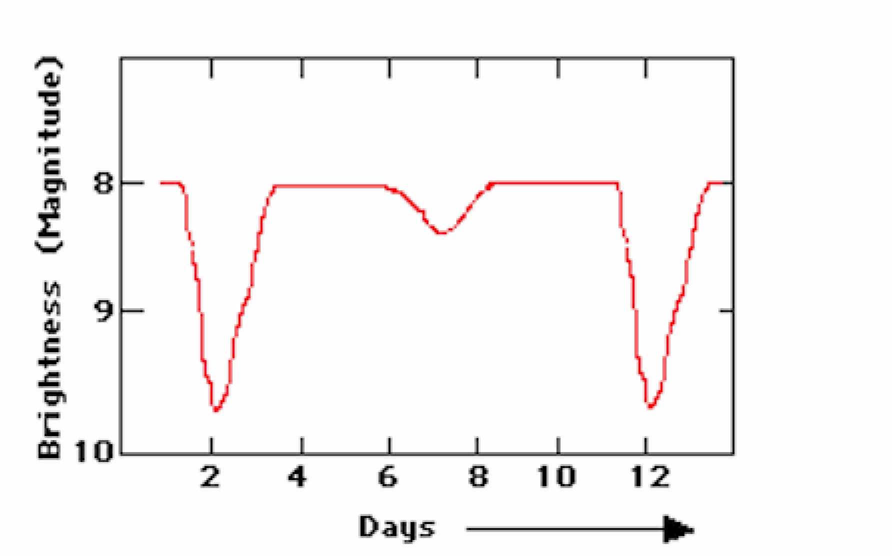
30. Cepheid variables are thought to be going through the
    a. Horizontal Branch
    b. Asymptotic Giant Branch
    c. Giant Branch
    d. Blue Loop

Section B: Short Answer (15 Points Each)

(135 Points Total)

31. What is the period of the Cepheid light curve shown?

32. How are Type Ia Supernovae different from Classical/Recurrent Novae



Questions 33-35 relate to the graph shown

33. What object is the graph depicting?

34. By what factor does the luminosity change from no eclipse to the primary eclipse?

35. By what factor does the luminosity change from no eclipse to the secondary eclipse?

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36. What causes stars to undergo a blue loop on the HR diagram in stellar evolution?

37. At what points (Lowest/Highest Luminosity) of a Cepheid Pulsating Variable is helium ionized?

38. Explain why the radial velocity method for detecting exoplanets will not always give an accurate value for the exoplanet's mass

39. What is the Eddington Luminosity and why is it important?

40. True or False, during outbursts the bolometric luminosity of Luminous Blue Variables remains constant.

Section BC (Calculations)

465 Points Total

1. Kepler's Laws and Virial Theorem are two very important laws in astrophysics that define countless other laws and theorems, but how are they derived?

    a. Write a derivation of Kepler's Third Law relating orbital period T and orbital radius A (Hint: Centripetal Force with angular velocity and Gravitational Force). Note: this is only the derivation for a **circular** orbit **(35 Points)**

b. Virial Theorem states that for any gravitationally bound system, the average kinetic energy is equal to the $-\frac{1}{2}$ the average gravitational potential energy. Show how centripetal force/gravitation are related to kinetic/gravitational energy **(15 Points)**

The equation for Gravitational PE is provided below

$$U = -\frac{GMm}{R}$$

c. Rewrite your answer above in terms of Kinetic Energy **T** and Gravitational Potential Energy **U** **(15 Points)**

d. From the first step in the derivation of Kepler's Third Law, derive the equation for pure circular orbital velocity in terms of v (Hint: What is another form to write centripetal force in?) **(20 Points)**

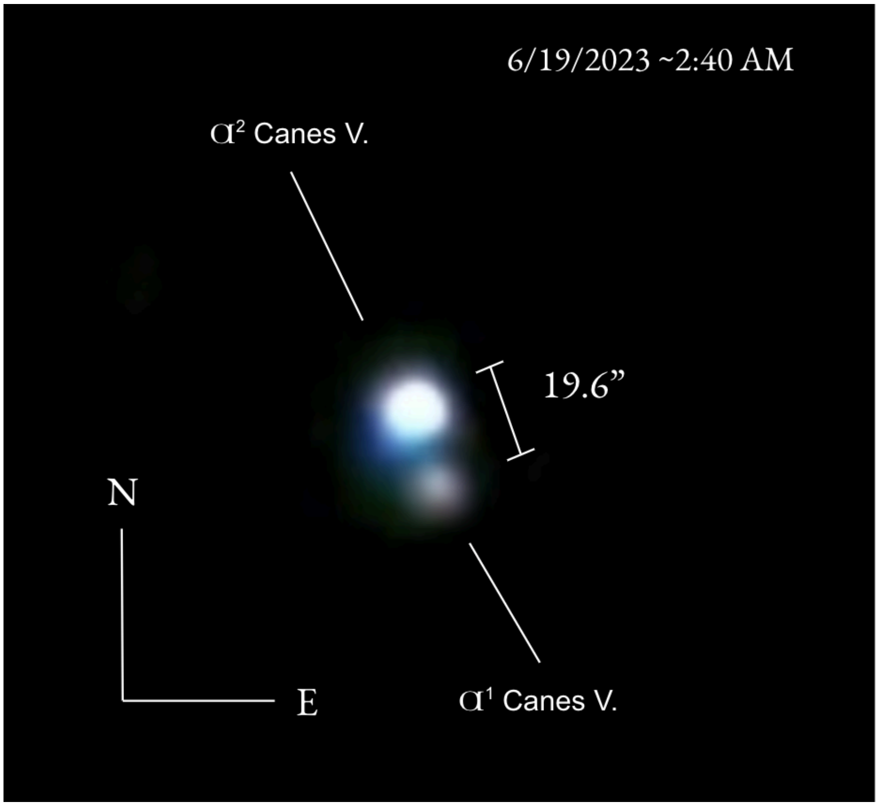
2. Double stars have fascinated early astronomers as they appeared as a single point of light without a telescope and they enabled astronomers to measure proper motions relative to another star. Some double stars are gravitationally related while others are optical "line of sight" binaries.

- Cor Caroli (α Canum Venaticorum) is a double star (image taken by test author shown) in the constellation of Canes Venatici Information about the two stars is given in the table below

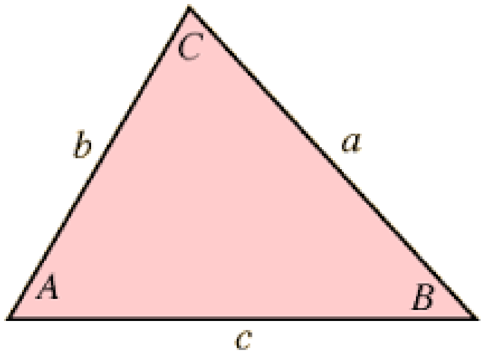
Star	Mass	Spec. Type	Proper Motion (Dec)	Proper Motion (RA)	Radial Velocity	Distance
α^2 C.V.	$2.97\ M_\odot$	A0V	$53.54 \frac{mas}{yr}$	$-235.08 \frac{mas}{yr}$	$-4.10 \frac{km}{s}$	100 ly
α^1 C.V.	$1.47\ M_\odot$	F2V	$55.69 \frac{mas}{yr}$	$-232.86 \frac{mas}{yr}$	$-0.60 \frac{km}{s}$	106.5 ly

Proper Motion Equation: $v_t = 4.7406 \mu d$

$[\mu]$ = "/yr
[d] = parsecs
$[v_t]$ = km/s



$$c^2 = a^2 + b^2 - 2ab\cos C$$

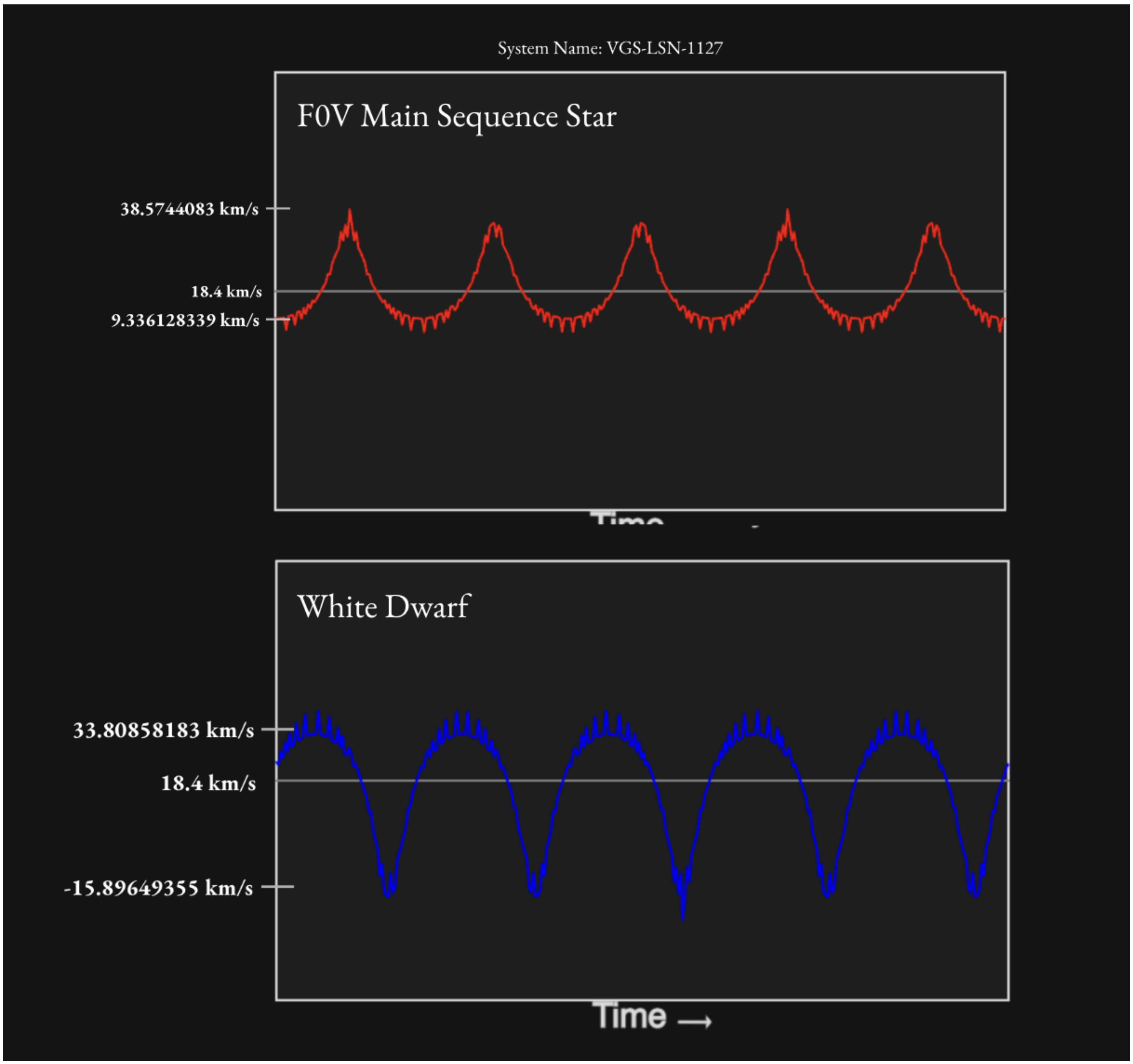


a. Hydrogen Alpha Lines (electrons falling from 3rd to 2nd energy level in H) have a wavelength of approximately 656.28 nm. What is the change in wavelength ($\Delta\lambda$) due to blue/redshift for both stars? Is it a red or blue shift? **(25 Points)**

b. The stellar components of Cor Caroli share a common proper motion (different from an orbit), but do they form a gravitationally bound orbit? Using the data and information given, determine if Cor Caroli is gravitationally bound in an orbit. **(70 Points)**

3a. A F-Class Main Sequence Star with a mass of $1.7\, M_{\odot}$ and a White Dwarf Star have their radial velocity curve shown below. Using radial-velocity curve and data given below, answer the following questions

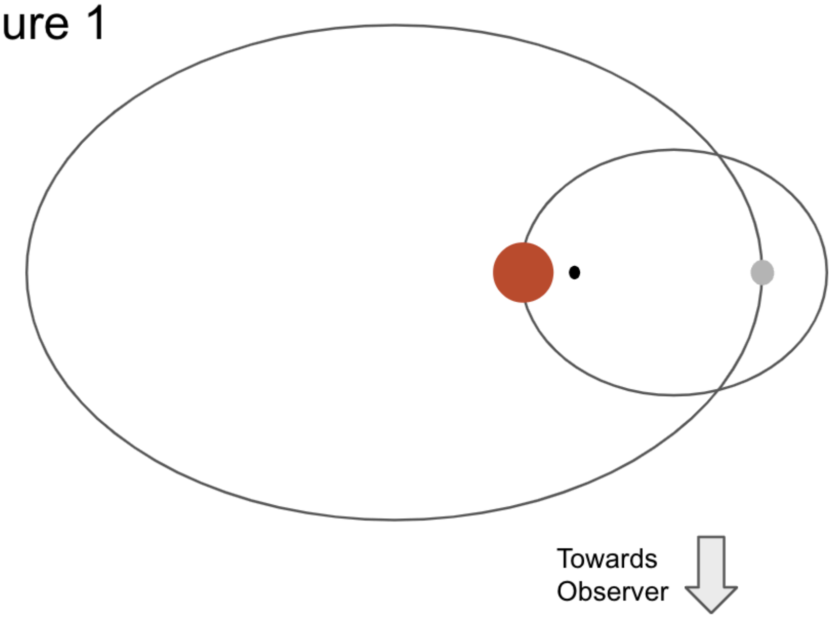
- Orbital Inclination: 66° **(Important for radial velocity)**
- Orbital Period: 1.18678792 yr
- A distance of 0.93 AU between the two stars at perihelion



a. Is this star system moving away or towards the observer? How can you tell? **(10 Points)**

b. On the orbital diagram below, label the following **(5 Points Each)**
  - Closest approach of 0.93 AU
  - Arrows denoting the direction of their velocities and movement of the barycenter
    - Value of the velocity that the barycenter is receding from the observer
    - **Not required to find the velocities of each star**

Figure 1



c. What is the velocity (in km/s) of the F-Main Sequence Star and White Dwarf in km/s at Aphelion and Perihelion **relative to the barycenter**? (Include correct negative signs) **(40 Points)**

d. What is the mass (in solar masses) of the White Dwarf Companion? **(15 Points)**

e. What is the combined semi major axis (in AU) of the system? **(15 Points)**

f. What is the farthest separation (in AU) between the two stars? **(45 Points)**

3b. The F0V Main Sequence Star evolves off the Main Sequence onto the Red Giant Branch. Due to the gravitational pull of the White Dwarf Companion, the primary star loses mass at a constant rate of $10^{-6} \frac{M_{\odot}}{yr}$. 20% of the stellar mass loss is accreted (constantly) onto the White Dwarf. **(145 Points Total)**

a. How long (in millions of years) will it take for the white dwarf to exceed the Chandrasekhar Limit? **(10 Points)**

b. What is the rate of loss of energy (in J/s) the star system is losing from the stellar mass loss? Assume the change in the orbital distances caused by the mass loss to be negligible (for now). **(30 Points)**

c. From an accreting mass m, formulate an expression for the energy generated for the accreting mass falling a distance **R** Assume the white dwarf's radius **r** is negligible. **(15 Points)**

d. What is the rate of energy generation produced by the accreting matter in solar luminosities? Assume an average accretion distance of 1.5 AU (the combined semi major axes). Assume the mass of the White Dwarf m_2 does not change significantly with a small mass accreted m. Answer in $L_\odot$ **(30 Points)**

e. What is the rate that the closest approach (in m/s) between the 2 stars of 0.93 AU increases/decreases? (Hint: Use the answer from question b and orbital energy conservation) **(60 Points)**