# Science Olympiad CSE 2024
# Astronomy C
# Novi High School

**Written by:** Ethan Chen, Rushil Yeole

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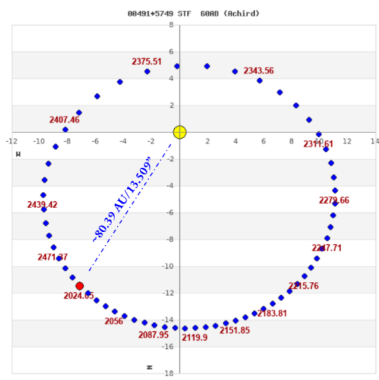
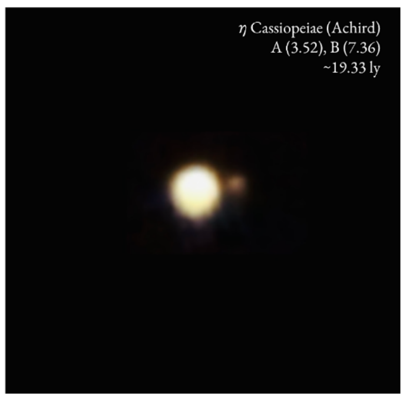
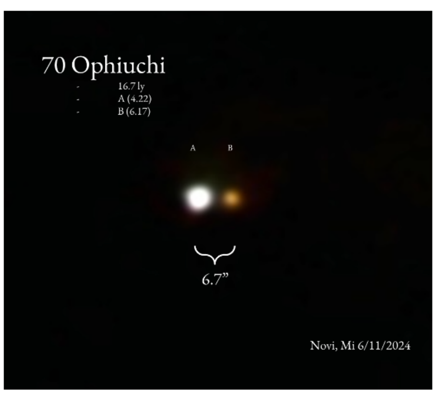
Questions? Email ethankchen6@gmail.com or rushilyeole09@gmail.com

Score: /315








# 1 Multiple Choice

**2 points per question**

1. Which of these is **NOT** a measure of **astronomical** distance?
   (a) Parsecs
   (b) Lightyears
   (c) Astronomical units
   (d) Wavelength

2. Nuclear fusion in the Sun works by fusing which 2 atoms of which element?
   (a) Hydrogen
   (b) Helium
   (c) Carbon
   (d) Calcium

3. Which of these can be used to determine the atmospheric composition of an exoplanet?
   (a) Transit spectroscopy
   (b) JS9
   (c) Albedo
   (d) None of the above

4. Which of these is **NOT** normally determined directly from an H-R Diagram ?
   (a) Age
   (b) Luminosity
   (c) Temperature
   (d) Trace elements

5. What are the limiting constraints of the Jeans Mass?
   (a) It assumes a constant density
   (b) It assumes the cloud is half hydrogen and half dust
   (c) It assumes that it follows the laws of thermodynamics
   (d) It assumes that all matter is ionized in hot star formation

6. An excess of infrared radiation around a star usually indicates:
   (a) Low Mass Companion/Brown Dwarf
   (b) Cloud of cold molecular hydrogen
   (c) Dust/Debris Disk
   (d) Accretion of Gas

7. Hydrostatic Equilibrium can be achieved through the following means except:
   (a) Electron Degeneracy Pressure
   (b) Radiation Pressure
   (c) Thermal Pressure
   (d) Convecting Pressure

8. What exoplanet detection method can work in tandem with the transit method?
   (a) Speckle Photometry
   (b) Timing Variations
   (c) Astrometry
   (d) Microlensing

9. A key difference between albedo and emissivity is
   (a) Albedo deals with mostly with reflection in the optical spectrum of light while emissivity deals with thermal radiation.
   (b) Albedo is a measure of reflection while emissivity is a measure of absorbance
   (c) Albedo measures reflection of thermal radiation while emissivity measures absorbance of optical wavelengths.
   (d) There is no difference.

10. Launched in 2009, the Kepler Space Telescope found exoplanets in a “field” of stars around what constellations?
    (a) Cygnus, Sagitta, Draco
    (b) Cygnus, Delphinus, Aquila
    (c) Cygnus, Lyra, Cassopeia
    (d) Cygnus, Lyra, Draco

# 2 Short Answer

## 2.1 Stellar Evolution

### 2.1.1 Pre-Main Sequence

1. What track can PMS stars follow if they have mass less than 3 solar masses? [2 points]

2. A certain type of PMS star contracting around the Hayashi track is commonly found near molecular clouds. State the type of star it is, then tell which metal is burned by the proton-proton chain. [3 points]

3. Name the other path PMS stars can take if they have a mass above 0.5 solar masses. How does luminosity change as a star following this sequence approaches the main sequence? [3 points]

### 2.1.2 Apple Grape Banana (AGB)

1. What does the acronym AGB stand for in stellar evolution? [2 point]

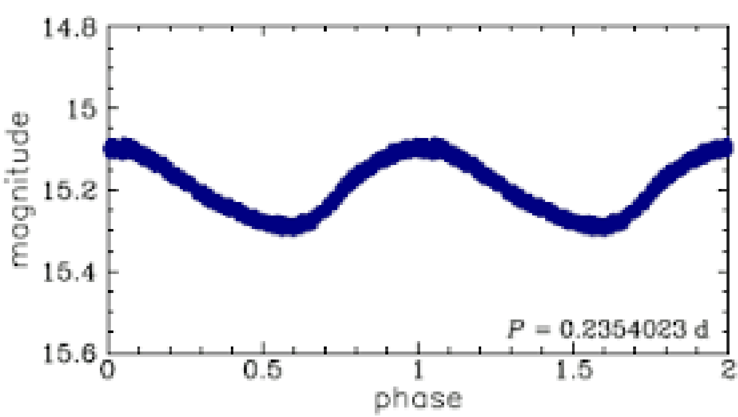
2. How does energy generation during the AGB phase compare to that of red giant evolution? [2 points]

3. What becomes of the central star post-AGB? [2 points]

## 2.2 Variables

### 2.2.1 RR Lyrae

1. An RR Lyrae light curve is shown below. Which type of RR Lyrae Variable is it? [2 points]




2. For the above type of RR Lyrae variable, write approximately what percent of RR Lyrae variables fall under this classification. Is the period shorter or longer than other types of RR Lyrae variables? [4 points]

3. Describe the light curve of the other type(s) of RR Lyrae variables. Are they more or less common than the RR Lyrae variable type shown above? [5 points]

4. RR Lyrae variables are classified as standard candles. Explain what a standard candle is, and tell the name of another type of star that can be used as a standard candle. [5 points]

### 2.2.2 Mira Variables

1. In the box below, draw a light curve that would be typical of a Mira variable. Be sure to include an appropriate pulsation period. [3 points]

2. A process in Mira variables produces dredge-ups. What are dredge-ups, and what causes them? [4 points]

3. In solar masses, what is the approximate maximum mass of a Mira variable? [1 point]

4. Interestingly, some Mira variables appear to change their period over time. What causes this phenomenon? [3 points]

## 2.3 Hertzsprung-Russell Diagrams

1. Fill out the table below based on the types of stars found in regions of an HR diagram: [5 points]

| | |
|---|---|
| I | |
| II | |
| III | |
| IV | |
| V | |

2. If a star were following the Hayashi track, which direction would it be traveling on an HR diagram? [3 point]

3. If a star were following the Henyey track, which direction would it be traveling on an HR diagram? [3 point]

4. What does a white dwarf star's position on the HR diagram say about its temperature and luminosity? [3 point]

# 3 Astrophysics

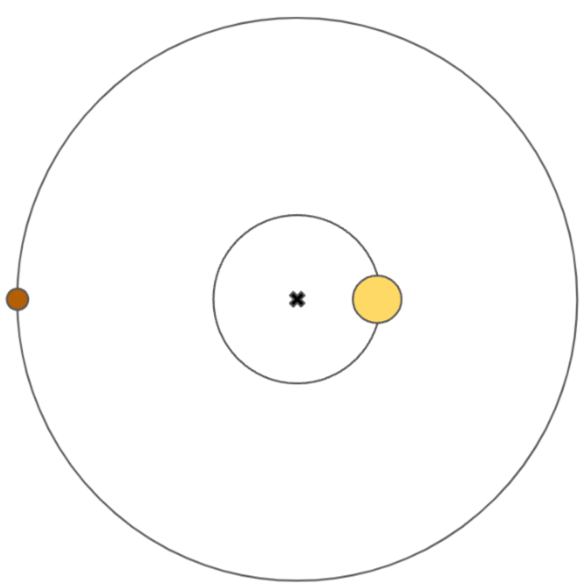
## 3.1 Low Mass Stellar Companion (80 Points)

Large gas exoplanets may be erroneously categorized as brown dwarfs as it is difficult to distinguish between them in forming star systems. A supposed exoplanet in a binary system named **Novi C12** is observed in a circular orbit 16.3 light years away. The parent star has a mass of 0.579 $M_\odot$ with a radial velocity amplitude of 1300 m/s.

1. The orbital period of the system is recorded as 2.315 years and the orbit is inclined at 60 degrees. What is the mass of the secondary object (Novi C12 B) in $M_J$? [10 Points]

2. At maximum angular separation, the two bodies are observed to be $\theta = 300\ mas$, what is the the physical separation between each star and the barycenter in AU? [10 Points]

3. Because this system involves only two bodies, we can solve the parameters of the system. Label $\theta$, $a, a_1, a_2$, and the true velocities $v_1$ and $v_2$ adjusted for orbital inclination. [15 Points]



4. Brown Dwarfs, for a brief period, gravitationally contract over time before the onset of deuterium fusion. Using the Virial Theorem and the equation for the gravitational potential energy of a sphere with uniform density, an expression for the rate of energy released for a brown dwarf through gravitational contraction. [15 Points]

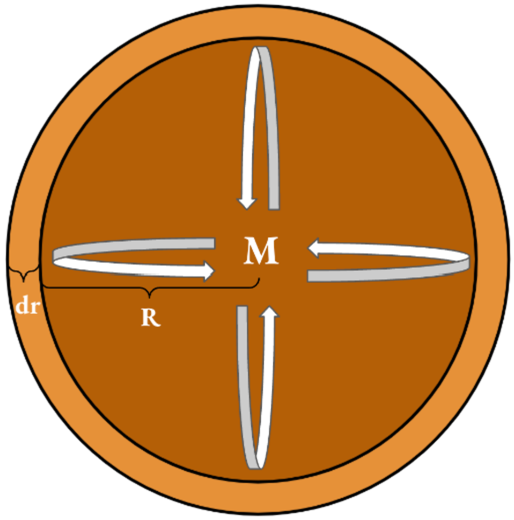
$$U = -\frac{3GM^2}{5R}, 2K + U = 0$$

5. Jupiter undergoes a similar process in our solar system, shrinking at a rate of around 2cm/yr. Because Brown Dwarfs have similar properties and compositions to Jupiter, assume that Novi C12 B goes through the same rate of contraction, what is the radius of Novi C12 B, knowing that its luminosity is $4.5 \cdot 10^{-5}\ L_\odot$? [10 Points]

6. How does the effective temperature of Novi C12 B compare to its equilibrium temperature? What does this mean about the energy generation? (Assume Novi C12 B has similar emissivity and albedo to Jupiter, 0.27 and 0.5 respectively) [20 Points]

## 3.2 Brown Dwarfs (80 Points)

As mentioned earlier, Brown Dwarfs are very difficult to distinguish from very low-mass stars and even more difficult high-mass planets. The interior of Brown Dwarfs are fully convective. Assume, for simplicity, that there is constant density.




1. From the equation for Hydrostatic Equilibrium, derive an expression for core pressure $P_c$ of a celestial object, in terms of M and R, using the given equations below. [20 Points]

$$\frac{dP}{dr} = -G\frac{m(r)\rho(r)}{r^2}, \qquad \int_0^R r\,dr = -\frac{1}{2}R^2$$

2. What unit is $P_c$ in? Find $P_c$ in terms of Solar Mass $(M/M_\odot)$ and Solar Radii $(R/R_\odot)$. If you could not answer the previous question, use $P_c = \frac{GM^2}{16R^4}$ for half points. [15 Points]

3. Using the equation of state below for stars, estimate the core temperature of the lowest mass stars with a mass of 0.08 $M_\odot$ and radius of 0.1 $R_\odot$. Assume the star is fully atomic hydrogen and has uniform density. [15 Points]

$$P\mu m_H = \rho kT, \quad m_H = 1.674 \cdot 10^{-27} kg, \quad \mu = 1$$

4. For the equation of state on the star above, it is assumed that the mean molecular weight $\mu$ (in terms of $m_H$) is 1. Based on the star's mass (and therefore, other properties), why are we sure that $\mu = 1$ is a reasonable approximation? [10 Points]

5. Why is it a reasonable approximation that the star in Question 2c is fully hydrogen? [10 Points]

6. Where does our core pressure model fail? [10 Points]

### 3.3 70 Ophiuchi (80 Points)

Seven score and a decade before the first exoplanet was discovered in the 90s, astronomers already postulated methods of detecting exoplanets. In 1855, William Stephen Jacob of Madras Observatory asserted that perturbations in binary star system 70 Ophiuchi represented claims of an unseen exoplanet. It is now known that these observations were erroneous. Using the information below, answer the following.


Combined semi-major axis: 23.328 AU, e = 0.5

1. What method of detection was Jacob attempting to utilize? [5 Points]

2. Famed German astronomer Friedrich Bessel had previously used the method in 1844 to detect what formerly unseen companion around which famous bright star? [10 Points]

3. How far apart are 70 Oph A and 70 Oph B? [10 Points]

4. Using the masses of 0.90 M and 0.70 M for 70 Oph A and 70 Oph B respectively, determine at what distance from 70 Oph A the gravitational forces from 70 Oph A and B would balance. What is this point called? Is it stable for an exoplanet? [15 Points]

5. 70 Ophiuchi is currently near apoapsis for the previous question. What is the distance from 70 Oph A where gravitational forces balance at periapsis? What does this distance mean for an exoplanet? [20 Points]

6. In 1943, astronomers Dirk Reuyl and Erik Holberg claimed to have indirectly observed a planet of theoretical mass between 8.38 MJ , 12.58 MJ with a 17 year period around 70 Oph A. Assuming the planet's mass to be negligible (it probably isn't) and that it is in a circular orbit, determine if the planet is in a stable orbit. Note that the gravitational force from 70 Oph B should not be negligible. Use the periapsis of both stars for this calculation. [20 Points]