Science Olympiad
Hawk and Hornet 2026 Invitational

November 15th, 2025

Astronomy C Key

Directions:

- Each team will be given 50 minutes to complete this exam
- 3 sections: Section A (General), Section B (DSO). Section C (Astrophysics)
- Use 2-3 decimal places in final answers for Section C, partial credit will be given for work
- Tiebreakers: Astrophysics #2e, General #18, DSO #4c, DSO #4d, Astrophysics #1h
- Good luck!

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Questions? Email ethankchen6@gmail.com

Name(s): ____ Team #: C___

Section A: 26/26 Section B: 36/36 Section C: 26/26

Total: 88/88

Section A (General)

(1 pt unless otherwise specified)

1) What are standard candles?
   a) Objects with a varying apparent magnitude
   b) Objects with a varying absolute magnitude
   c) Objects with a known apparent magnitude
   d) Objects with a known absolute magnitude

2) Kepler's Third Law is derived by equating what two forces?
   a) Gravitational Force and Centrifugal Force
   b) Gravitational Force and Orbital Velocity
   c) Gravitational Force and Tidal Force
   d) Centrifugal Force and Tidal Force

3) Cepheids and RR Lyrae variable stars follow what relation?
   a) Mass-Radius Relationship
   b) Mass-Luminosity Relationship
   c) Period-Mass Relationship
   d) Period-Luminosity Relationship

4) Cepheid and RR Lyrae variable stars pulsate due to what element in their stellar atmospheres?
   a) Hydrogen
   b) Carbon
   c) Helium
   d) Oxygen

5) If the said element above is more ionized, it is then more opaque, allowing less radiation to escape and absorbing more.
   a) True
   b) False

6) A stellar classification of V denotes what classification?
   a) Giants
   b) Main Sequence
   c) Supergiants
   d) Cepheids

7) 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

8) What are Population I stars?
   a) Metal-Rich, Younger Stars,
   b) Metal-Rich, Older Stars
   c) High-Mass, Old Stars
   d) Metal-Poor, Younger Stars

9) What happens directly before the horizontal branch of an HR diagram?
   a) Helium Flash
   b) Ignition of Hydrogen Fusion
   c) Type Ia Supernova
   d) Roche-Lobe Overflow

10) Where are white dwarfs found on the Hertzsprung-Russell Diagram?
   a) Center
   b) Top right
   c) Lower Right
   d) Lower Left

11) Carbon Stars are a type of star with an abundance of carbon in the atmosphere. This is a result of what stage of stellar evolution?
   a) Main Sequence
   b) T-Tauri Stage
   c) Red Giant Branch
   d) Asymptotic Giant Branch

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

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

14) Why are standard candles so important?
   a) Can help determine average brightness of certain stars
   b) Can help determine distance to objects in space
   c) Not important in Astronomy
   d) Determines age of stars

15) What are the end states of stars after nuclear fusion from lowest mass to highest mass.
   a) Black Hole, Neutron Star, White Dwarf
   b) Red Giant, Neutron Star, Black Hole, White Dwarf
   c) Red Giant, White Dwarf, Neutron Star, Black Hole
   d) White Dwarf, Neutron Star, Black Hole

Short Answer

16) What is a classical novae? (2)

White dwarf star orbiting a companion that accretes a layer of hydrogen gas until it is ignited in a thermonuclear explosion

17) When a Helium Flash occurs, why does the overall radius of the star actually decrease? (2)

The Helium Flash energy is absorbed by the core, which expands and lowers the rate of fusion, thereby lowering the radius of the star

18) How was the Schwarzschild Radius derived? (2.5)

Setting the escape velocity equation equal to the speed of light

19) Why are protostars generally brighter than their main-sequence counterparts? (2.5)

They have a larger radii than protostars, but cannot sustain this luminosity for long, so they gravitationally collapse down

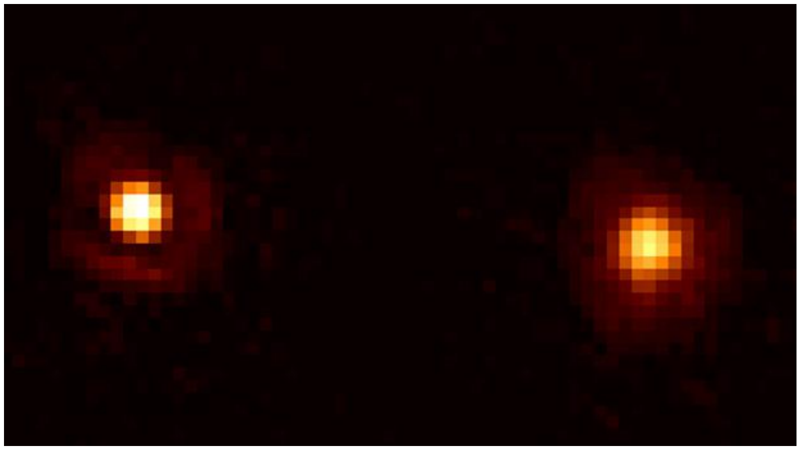
20) Why can no star fuse Iron? (2)

The combination of protons and neutrons make fusing Iron require more energy than is released from fusing it.

Section B (DSOs)

(1 pt each unless otherwise specified)

1)



a) What DSO is shown on the right?

Mira (Omicron Ceti)

b) Which objects are the primary and secondary stars respectively?

Mira A on right, Mira B on left

c) In 1995, the Hubble Space Telescope successfully resolved this system. What was the angular separation then?

~0.76 arcseconds

d) What was the physical separation then?

70 AU

e) In 2007, what was discovered around the secondary star?

Protoplanetary disk, made of material from the primary

f) What is the average radius of the primary in $R_{\odot}$?

367 $R_{\odot}$

2)

a) What is the Sharpless Catalog?

Catalog of 313 HII regions published in 1959 by Stewart Sharpless

b) What causes the red glow of Sharpless 29?

The Hydrogen-Alpha Line (656.6 nm) caused by ionizing radiation from stars "exciting" electrons in Hydrogen atoms

c) What is the approximate distance to Sharpless 29?

5000 light years

d) Sharpless 29 is located nearby two other bright HII regions. What are these regions?

Messier 8 (Lagoon Nebula), Messier 20 (Trifid Nebula)

e) Who discovered Sharpless 29 and when?

John Herschel, 1826

f) What is the more unique and more peculiar name to Sharpless 29

The Chinese Dragon Nebula

3)

a) How old is the Ophion Star Family?

20 Million Years Old

b) Knowing the age, what is the maximum possible mass for a main sequence star in this cluster in $M_{\odot}$.

$T_{MS}\,[yrs] = 10^{10}\left(\frac{M}{M_{\odot}}\right)^{-2.5}$, $20 \cdot 10^{6}\,yrs = 10^{10}\left(\frac{M}{M_{\odot}}\right)^{-2.5}$, $\frac{M}{M_{\odot}} \rightarrow 12M_{\odot}$

c) Roughly what distance and constellation is Ophion located in

~650 ly, Ophiuchius

d) What is a usual explanation for the cause of runaway stars?

Orbital interactions with a black hole

e) What did astronomers analyze compared to Gaia Data Release 3 to discover the Ophion Star Family?

Astronomers searched through Gaia's large spectroscopic data on stars and filtered out stars older than 20 mya in the database

f) What is the leading hypothesis for the large average velocity of this cluster relative to nearby stars?

Supernovae explosions and remnants that created cavities of low density interstellar gas. Gravitational feedback to "refill" this cavity would have accelerated stars.

4) The questions below relate to WDJ181058.67+311940.94

a) What is the total mass of this system?

$1.56\ M_{\odot}$

b) At their current orbital period, what is the combined orbital radius in Earth radii?

$\sim 372\ R\oplus$

c) Before collision, the stars will be simulating to orbit in just 30 seconds. What would be the orbital radius in Earth radii? (1.5)

$\sim 2.6\ R\oplus$

d) Does a higher mass white dwarf have a higher radius? Why or why not?

No, white dwarves are supported by electron degeneracy pressure. A higher mass compresses the star further, so the electrons move to higher energy states to resist further compression instead of increasing the star's radius.

e) When a Type Ia supernovae does occur in this system, it is estimated to be 200,000 times brighter than Jupiter. Knowing the apparent magnitude of Jupiter to be -2.94 (at min), what is the apparent magnitude of WDJ181058.67+311940.94 at supernovae?

$$(-2.94) - m = 2.5log(200,000), \quad m = -16.19$$

f) When will the Type Ia supernovae of WDJ181058.67+311940.94 occur?

23 Billion years

5)

a) What DSO is imaged on the right?

HP Tauri

b) What wavelength was the image captured in?

Visible

c) What is the energy source for this DSO?

Gravitational contraction

d) What is the name for this energy source?

Kelvin-Helmholtz Mechanism

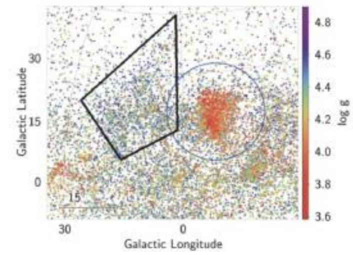
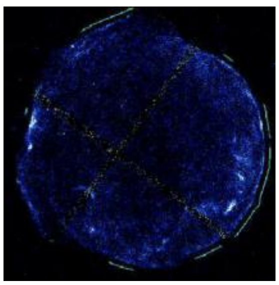
e) What type of nebulae surrounds this DSO?

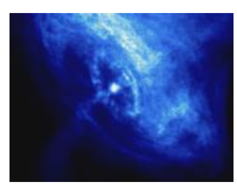
Reflection Nebulae

f) Name the three bright stars in the center of the nebulae

HP Tau, HP Tau G2, and HP Tau G3

Write the name of the DSO in the space provided above the images (0.5 each)

WDJ181058.67+311940.94	Ophion Star Family	Cassiopeia A
		
Tycho's SNR	Janus ZTF J203349.8+322901.1	Orion Molecular Cloud Complex
		
Mira (Omicron Ceti)	Orion Molecular Cloud Complex	Mira (Omicron Ceti)
		

M1 Crab Nebula	
Cassiopeia A	

Section C (Astrophysics)

1) In 1861, a comet passed near Earth and was visible to the naked eye for 3 months. The semi-major axis is 55.1 AU and orbital eccentricity is 0.985.

   a) To the nearest year, when is the next perihelion? (1)

$$(P\ [yrs])^2 = \frac{(a\ [AU])^3}{1\ M_\odot}$$

$$P\ [yrs] = \left((55.1\ AU)^3\right)^{1/2} = 409\ years$$

Year: 1861 + 409 = 2270 AD

   b) What is the orbital velocity in km/s at perihelion? (1)

$$55.1(1 - 0.985) = 0.8265\ AU$$

$$0.8265\ AU \cdot \left(1.5 \cdot 10^{11}\ m/AU\right) = 1.23975 \cdot 10^{11}\ m$$

$$v = \sqrt{G\left(1.989 \cdot 10^{30}\ kg\right)\left(\frac{2}{1.23975 \cdot 10^{11}} - \frac{1}{55.1\ AU\ \left(1.5 \cdot 10^{11}\ m/AU\right)}\right)} \rightarrow 46.100\ km/s$$

   c) What is the orbital velocity in km/s at aphelion? (1)

$$55.1(1 + 0.985) = 109.3735\ AU$$

$$109.3735\ AU \cdot \left(1.5 \cdot 10^{11}\ m/AU\right) = 1.64 \cdot 10^{13}\ m$$

$$v = \sqrt{G\left(1.989 \cdot 10^{30}\ kg\right)\left(\frac{2}{1.64 \cdot 10^{13}\ m} - \frac{1}{55.1\ AU\ \left(1.5 \cdot 10^{11}\ m/AU\right)}\right)} \rightarrow 0.348\ km/s$$

   d) What is the apparent magnitude of the Sun at aphelion? (2)

$$m_{Sun} - m = 2.5 log\left(\frac{F_{Aphelion}}{F_{1\ AU}}\right)$$

$$-26.74 - m = 2.5 log\left(\frac{\frac{L_\odot}{4\pi\left(109.3735\ AU \cdot 1.5 \cdot 10^{11}\ m/AU\right)}}{\frac{L_\odot}{4\pi\left(1.5 \cdot 10^{11}\ m\right)^2}}\right), \quad m = -16.5$$

   e) What is the escape velocity of the comet at perihelion in km/s? (1)

$$v_{esc} = \sqrt{\frac{2GM_\odot}{0.8265\ AU \cdot \left(1.5 \cdot 10^{11}\ m/AU\right)}} = 46.274\ km/s$$

f) Assume the comet has a mass of 10^{14} kg. What is the orbital energy (J) of the comet at any point in its orbit? (2)

For a one-body system:

$$E = -\frac{Gm_1m_2}{2a} = -\frac{G(1.989e30\ kg)(10^{14}\ kg)}{2(55.1\ AU\ (1.5\cdot10^{11}\ m/AU))} = -8.03\cdot10^{20}\ J$$

g) To achieve escape velocity, what would be the energy (J) that would have to be added to the comet? (2)

$$W = \frac{1}{2}m\left(v_f^{\ 2} - v_i^{\ 2}\right)$$

$$\frac{1}{2}(10^{14}\ kg)\left((46.274\cdot10^3\ m/s)^2 - (46.100\cdot10^3\ m/s)^2\right) = 8.03\cdot10^{20}\ J$$

h) The comet's position is at perihelion. Assume we wanted to fire a rocket engine for 30 minutes to achieve the comet's escape velocity. What would be the force of the rocket engine in kilonewtons, assuming it is constant? (3)

$$m\left(v_{esc} - v_{perihelion}\right) = F_{rocket}\Delta t$$

$$(10^{14}\ kg)\left((46.274\cdot10^3\ m/s) - (46.100\cdot10^3\ m/s)\right) = F_{rocket}\left(30\ min\left(60\frac{sec}{min}\right)\right)$$

$$F_{rocket} = 9.67\cdot10^9\ kN$$

2) There exists a well known general relation for Main Sequence Stellar Mass and Luminosity, $\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^{3.5}$. Since this relation is based on observational data of stars, it is then similarly possible to make a Mass-Radius Relation utilizing the same method.

a) Generally, at what distance [pc] does stellar parallax become unreliable? (1)

~100 pc

b) When stellar parallax becomes unreliable, what does this mean for our dataset? (1)

Our dataset of stars must be within this range to ensure accurate distance measurement

c) Interferometry data shows that Alpha Centauri B has an angular diameter of 6 mas. Knowing that the stellar parallax of the system is 0.75", what is the radius of Alpha Centauri B in $R_\odot$? (1)

$$\theta = 206265 \frac{diameter}{Distance}, \qquad Distance = \frac{1}{0.75"} = 1.333\ pc$$

$$6 \cdot 10^{-3}\ arcsec = 206265 \frac{diameter}{1.333\ pc \cdot 3.09e16\ m/pc}$$

$$diameter = 1.198 \cdot 10^{9}\ m, \text{ this is diameter, not radius}$$

$$\frac{1}{2} \cdot 1.198 \cdot 10^{9} m \left(\frac{1\ R_\odot}{6.96 \cdot 10^{8}\ m}\right) = 0.86\ R_\odot$$

It is also particularly convenient if stars are in a binary system, as their masses can be accurately determined.

d) α Centauri A and α Centauri B are observed to have a period of 79 years and an observed average angular separation of 17”. Calculate the combined mass of the system in $M_{\odot}$? (1)

$$17" = 206265 \frac{Orbital\ Distance}{1.333\ pc \cdot 3.09e16\ m/pc},\ d \rightarrow 22.63\ AU$$

$$M_{tot} = \frac{a^3\ [AU]}{P^2\ [years]} = 1.857\ M_{\odot}$$

e) α Centauri A is observed at an average distance of 7.2147” from the center of mass. Determine the mass of each star in $M_{\odot}$. Note: the COM equation might be useful. (2)

$$m_{total} x_{COM} = m_1 x_1 + m_2 x_1$$

X coordinate units are in arcseconds [“]

This solution sets the origin at the center of mass, but there are other methods.

$$x_{COM} = 0",\quad x_1 = 7.2147", x_2 = 17" - 7.2147" = 9.7853"$$

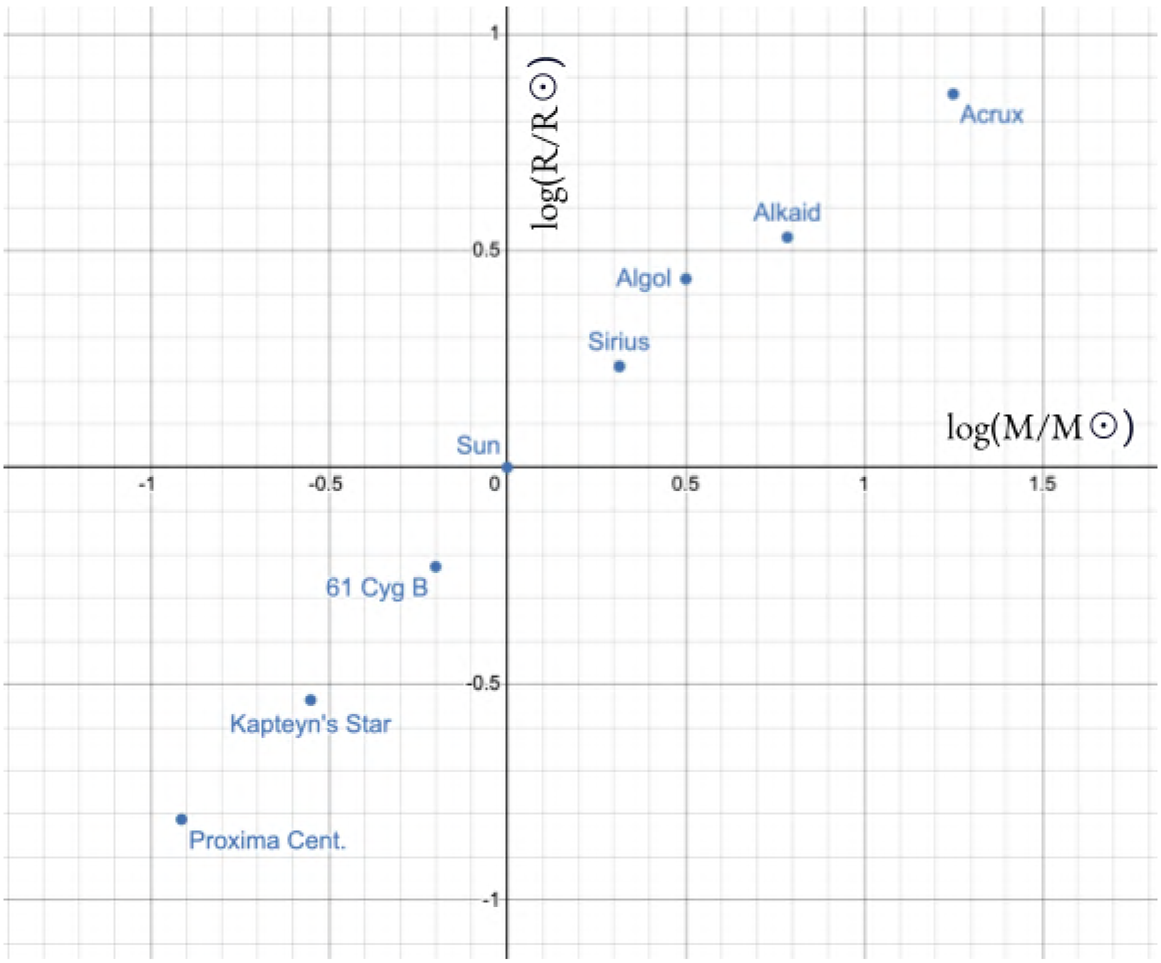
$$\left(1.857\ M_{\odot}\right)(0") = m_1(7.2147") + m_2(-\ 9.7853")$$

$$m_1 + m_2 = 1.857\ M_{\odot}$$

Solve the linear equations

$$m_1 = 1.069\ M_{\odot},\quad m_2 = 0.788\ M_{\odot}$$

Parts a - e can be repeated for multiple stars (preferably binary stars) to generate a catalog of stars with known mass and radii. A dataset has been prepared below with nearby stars.



f) Draw a line of best fit (ON THE ANSWER SHEET) and calculate the slope of the line. The line must pass through (0,0). A range of answers will be accepted. (1)

Using an actual regression calculator, the slope is 0.77, but values within [0.7, 0.9] will be accepted

g) Why is the scale a logarithmic plot? (1)

Stellar masses and radii are not a linear scale, so it is easier to visualize on a log plot

h) For $\frac{R}{R_\odot} = \left(\frac{M}{M_\odot}\right)^\alpha$, determine the value of α in the Mass-Radius Relationship. (2)

$$y = 0.77x$$

$$log\left(\frac{R}{R_\odot}\right) = 0.77log\left(\frac{M}{M_\odot}\right)$$

$$10^{log\left(\frac{R}{R_\odot}\right)} = 10^{0.77log\left(\frac{M}{M_\odot}\right)} = \left(10^{log\left(\frac{M}{M_\odot}\right)}\right)^{0.77}$$

$$\frac{R}{R_\odot} = \left(\frac{M}{M_\odot}\right)^{0.77}$$

i) What is the estimated radius of Vega (α $Lyrae$) according to our model if it has a mass of 2.15 $M_\odot$? A range of answers will be accepted. (1)

$$\frac{R}{R_\odot} = \left(\frac{M}{M_\odot}\right)^{0.77}$$

$$\frac{R}{R_\odot} = \left(2.15\frac{M}{M_\odot}\right)^{0.77} \rightarrow 1.80\ R_\odot$$

Because a range of [0.7, 0.9] was accepted for the slope, the answer to this question should lie between

$$\left[(2.15)^{0.7}\ R_\odot,\ (2.15)^{0.9}\ R_\odot\right]$$

$$\left[1.71\ R_\odot,\ 1.99\ R_\odot\right]$$

j) Establish a Luminosity-Radius relation for the main sequence in $R_\odot$ and $L_\odot$, with $\alpha = 0.7$ (1)

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^{3.5}, \qquad \frac{M}{M_\odot} = \left(\frac{L}{L_\odot}\right)^{2/7}$$

$$\frac{R}{R_\odot} = \left(\frac{M}{M_\odot}\right)^{\alpha} = \left(\frac{L}{L_\odot}\right)^{(2/7)\alpha} \Rightarrow \left(\frac{L}{L_\odot}\right)^{\frac{2}{7}\cdot\frac{7}{10}} \Rightarrow \frac{R}{R_\odot} = \left(\frac{L}{L_\odot}\right)^{1/5}$$

k) Proxima Centauri has a point of $(-\ 0.913,\ -\ 0.812)$. What is the percent error of our model's prediction of Proxima Centauri's radius, with $\alpha = 0.9$? (1)

$$10^{-0.913} = 0.122\ M_\odot, \qquad 10^{-0.812} = 0.154\ R_\odot$$

$$\left(0.122\ M/M_\odot\right)^{0.90} = 0.151\ R_\odot$$

$$\left|\frac{0.151\ R_\odot - 0.154\ R_\odot}{0.154\ R_\odot}\right| \cdot 100[\%] = 2.23\%$$