Science Olympiad
Astronomy C
BirdSO Mini Invitational

December 11-18, 2021

Directions:

- Each team will be given **50 minutes** to complete the test.
- There are three sections: **§A** (General Knowledge), **§B** (Deep-Sky Objects), and **§C** (Calculations).
- For significant figures, **use 3 or more in your answers** unless otherwise specified.
- Tiebreakers, in order: §C, §C1, §A, §B1, . . . , §B10.
- Best of luck! And may the odds be ever in your favor.

Written by:
Jeff Xie, *jeffxie4@gmail.com*
Robert Lee, *robertyl@ucla.edu*
Lei Jiang, *leijianghome@gmail.com*

Feedback? **Test Code**: *2022BirdSOMini-AstronomyC-Oxygen*

Section A: General Knowledge

Use the images in Image Set A to answer the following questions. Each question or subquestion is worth two points unless otherwise specified, for a total of 65 points.

1. What element is in the core of a high-mass post-main sequence star?
2. What is the name for the maximum mass of a white dwarf?
3. What aspect of a Type Ia supernova makes it useful for distance calculations?
4. What are the 2 models put forth to explain the mechanism behind dwarf novas?
5. What process governs the creation of carbon in the core of a red giant?
6. [1 pt] What type of astronomical object are RR Lyrae stars commonly found in?
7. The RR Lyrae gap in the H-R diagram is located at what stage of stellar evolution?
8. What value is added to the distance modulus equation to take into account the effects of dust clouds?
9. Image A1 depicts an H-R Diagram with mass-dependent evolutionary paths of protostars.
   (a) What is the name of the track that gives a path that protostars take as they evolve towards being a main-sequence star?
   (b) What condition must protostars be in to be on the path on the H-R Diagram?
   (c) What process puts constraints of the evolution of a protostar as shown by the scientist that discovered the path on the H-R Diagram?
   (d) As the temperature increases, what particle dominates the opacity of the outer layers of the protostar?
10. [1 pt] As the initial mass of a protostar increases, does the contraction time increase or decrease?
11. What two quantities must be equal to have H II regions be in equilibrium?
12. What process allows radiation to be emitted from T Tauri stars?
13. [1 pt] What kind of object does a Herbig-Haro object shoot out from?
14. The forbidden lines in the spectra of T Tauri stars suggest what property about the gas density of T Tauri stars?
15. A P Cygni profile is characterized by what two main characteristics regarding a spectral line in a T Tauri star?
16. The shape of a P Cygni profile suggests what behavior about the mass of a T Tauri star?
17. Image A2 shows the light curve of a class of variable stars.
   (a) Name the specific class of variable star that the light curve exhibits behavior of.
   (b) What stage of stellar evolution is the class of variable star located in?
   (c) What is the main difference between the specific class of variable star that the light curve shows and semiregular variable stars?

18. Image A3 shows the light curve of a class of variable stars.
    (a) Name the specific class of variable star that the light curve exhibits behavior of.
    (b) What aspect of this specific class of variable star makes it useful for distance calculations?
    (c) What stage of stellar evolution is the class of variable star located in?
19. What can be detected around a recurrent novae that cannot be detected around a dwarf novae?
20. The conservation of what quantity explains the rapid rotation of neutron stars?
21. The conservation of what quantity explains the strong magnetic fields of neutron stars?
22. [1 pt] What law governs the relation between the maximum wavelength of an energy curve and the blackbody's temperature?
23. What law does the Planck radiation curve approach at low temperatures?
24. Explain the issue behind the "ultraviolet catastrophe".
25. Carbon stars are located in what stage of stellar evolution?
26. [1 pt] True or False: The carbon/oxygen ratio must be greater than 1 for carbon to form in the photosphere of the carbon star.
27. What kind of object is located in the center of planetary nebulae?
28. Does accretion follow the same direction as the magnetic field lines in magnetic cataclysmic variables?

Section B: Deep-Sky Objects

Use the images in Image Set B to answer the following questions. Each sub-question is worth two points unless otherwise specified, for a total of 65 points.

1. (a) [1 pt] Image B12 is what type of graph?
   (b) Identify the object graphed.
   (c) How far away is the object, in pc?
2. (a) Which image(s) show Tycho's SNR?
   (b) The expansion velocity of Tycho's SNR is non-uniform. Which cardinal (N/E/S/W) and/or ordinal (NE/SE/SW/NW) direction(s) are expanding the fastest? (There may be multiple answers)
   (c) Name one observational consequence of this non-uniformity.
3. (a) Image B5 depicts the spectra of what object?
   (b) What spectral line is around 4700 Å?
   (c) What is the mass of the degenerate star associated with the object, in $M_\odot$?
4. (a) How far is HBC 672, in pc?
   (b) What direction did the eastern lobe rotate? The western rotate?
   (c) [3 pts] Name two possible explanations for this phenomenon.
   (d) Why can't astronomers definitively say this phenomenon is periodic?
5. (a) Image B7 is the light curve for what object?
   (b) What is the mass of this object, in $M_\odot$?
   (c) What is its rotation rate, in hr?
   (d) What does this imply about its origin?
6. (a) Which image(s) show IC 4593 in x-ray?
   (b) What temperature do astronomers estimate the x-ray source to be at, in K?
   (c) [3 pts] List two possible types of objects that could reside at the center of IC 4593.
7. (a) Image B1 depicts what object?
   (b) [1 pt] What band is the image taken in?
   (c) The image also includes a line with the text 10″ above it. Explain what it means.
   (d) What is the period of this object, in days?
8. (a) [3 pts] Image B11 depicts the SEDs of HH 24-26. Name the unit on the y-axis and its equivalent in base SI units.
   (b) There seems to be a decrease in intensity for wavelengths >100 µm. What is its cause?
   (c) [3 pts] Identify the peak wavelength of the SEDs, in µm. What specific part of the EM spectrum is it?
9. (a) Which object is pictured in image B3?
   (b) What do the red circles and yellow stars each indicate?
10. (a) Which image(s) show the light curve of AR Scorpii?
    (b) What is the spectral type of the companion star, including its luminosity class?
    (c) [1 pt] What unique physical property does the other star have?

Section C: Calculations

Use the images in Image Set C to answer the following questions. Points are shown for each sub-question, for a total of 70 points.

1. **Big Beak Energy**

Spitzer Space Telescope provides an infrared view of our Galaxy that is full of surprise, and with some imagination, you can spot a bird in the direction of Sagittarius, with a big beak (depicted in image C1). Our estimated distance to this region is 8 kpc.

(a) [2 pts] Assume the beak size is 15 arcmin by 2 arcmin, what is the approximate area of the big beak in steradian?

(b) [2 pts] The red bright features in the eye and above the beak are collected in the 24 micron filter, a MIR wavelength. What is the frequency of 24-micron infrared in Hz?

(c) [2 pts] Calculate the MIR flux reaching us from the eye region, in $\mathrm{W\,m^{-2}}$, if the spectral flux density of this region is 1080 mJy in the MIR.

(d) [3 pts] If the zero point magnitude of 24-micron MIR is 6 Jy, what is the magnitude of the eye region?

(e) [3 pts] What is the region's power in equivalent solar luminosity?

(f) [3 pts] Strong 3-24 µm MIR emission is a hallmark of star formation. What are the emission sources at these wavelengths, and how do they get their energy?

2. **RR Lyrae**

KIC 5559631 is an RR Lyrae star with a pulsing period of 0.621 days. Its light curve is plotted in image C2 folded with the main period to show its variation over the full phase of a cycle. Answer the following questions using this graph.

(a) [3 pts] RR Lyrae itself – the star in Lyra, not the variable star category – has a maximum magnitude (minimum brightness) of 7.13, and a parallax of 0.0044 arcsec. If the KIC 5559631 is just like RR Lyrae, what is the distance to KIC 5559631 in parsec?

(b) [2 pts] Suppose that at maximum magnitude of 15.0 the effective surface temperature is 7400 K, what is the maximum radius of the KIC 5559631 in terms of solar radius?

(c) [2 pts] The pulsation period Φ is governed by the principle of hydrostatic equilibrium, and assume the period is related to the average density (ρ) ratio to solar density ($\rho_\odot$) as below:

$$\Phi = 0.04\sqrt{\frac{\rho_\odot}{\rho}}\ \text{days}$$

What is the mass of KIC 5559631 in terms of solar mass?

(d) [4 pts] Stellar pulsations like that of RR Lyrae occur in a specific regime on the HR diagram, referred to as the instability strip. What physical mechanism determines the blue (hot) and red (cold) boundaries of the strip in the HR diagram?

(e) [2 pts] What appears as noise or scatter in the data actually represents phase and amplitude modulation that occurs over multiple days on a slower time scale. What is the name for this effect?

3. **Magnetic Cataclysmic Variables**

A rare CV binary system was found with strong eclipsing of the secondary star accompanied by the flaring activities. A series of light curves are shown in image C3A around the phase of inferior conjunction at different epochs, three showing strong flaring, and the two during weak flaring. The period of eclipsing is found to be 0.3 days. A model light curve for the binary with a white dwarf and a secondary star is shown as an overlay to represent the ideal eclipsing binary behavior. Here the mass ratio is assumed as 0.5, and the inclination angle indicates an almost edge-on orbit ($i = 81°$).

(a) [3 pts] The variation in magnitude of the model curve is quite significant. What is the equivalent ratio of radius for the eclipsing WD versus that of the secondary star, based on this variation? Assuming WD has much lower surface brightness.

(b) [5 pts] Does your answer match the characteristics of a WD size and typical CV companion star? Explain briefly the eclipsing magnitude. (Note the strong contrast in eclipsing magnitude of the strong vs. weak flaring case.)

(c) [3 pts] Assuming during the eclipse, the obtained spectrum (Depicted as the red spectra in image C3B) is representative of the secondary star. What category of star is this?

(d) [2 pts] Extracted velocity dispersion based on Hα emission varies on order of minutes (Shown in the insert at lower right of image C3B). During the peak flaring, the range of velocity is $\pm 1000\,\mathrm{km\,s^{-1}}$. What would be the original width of the Hα emission line at the peak flaring stage in nm?

(e) [3 pts] Radial velocity measured from absorption lines is $240\,\mathrm{km\,s^{-1}}$ for the secondary star. Based on the inclination ($i = 81°$) and period (0.3 days), what is the distance in km between the secondary star and the center of mass for the binary system? Assume circular motion.

(f) [3 pts] What would be the total orbital radius in AU, assuming a mass ratio of 2:1 between WD and the secondary star?

(g) [3 pts] The mass function of a binary is defined as

$$\frac{m_1^3 \sin^3 i}{(m_1 + m_2)^2}$$

where m_1 represents the mass of the WD, and m_2 represents the mass of the companion. $i = 81°$ is the inclination of the orbit. Calculate the binary mass function in solar mass.

(h) [2 pts] Based on the mass ratio assumption of 2:1, what is the white dwarf mass in solar mass?

4. **Pulsating Stars**

For variable stars and pulsars, O-C diagrams (observed-minus-calculated) are extremely powerful to detect subtle changes in the time series and its periods. Images C4A through C4C shows the O-C diagram for the three following objects. A is the amplitude of the light curve in the V band and p is the period in days. The general fit for the O-C curve is the function $f(E) = a + bE + cE^2$ where E is the epoch (number of cycles).

Object	A	p	a	b	c
A	0.06	3.969	-0.146	1.125×10^{-4}	2.787×10^{-7}
B	0.6	10.152	$-0.016\,57$	-2.592×10^{-2}	-4.987×10^{-7}
C	~ 2	75.41	-7.639	6.023×10^{-2}	-9.658×10^{-5}

(a) [4 pts] Object A has a $T_{\text{eff}} \sim 7000\,\text{K}$. What is the period change in (second/year)? Based on this, describe the most likely evolution path object A is going through in the H-R diagram and the reason.

(b) [4 pts] For object B, what is the change of the period and its magnitude in (second/year)? Describe the type of the object. What is the most likely evolution path object B is going through on the H-R diagram?

(c) [5 pts] Image C4C shows a clear wave with a period of 9323.3 days. After filtering out the sinusoidal component, a parabolic fit of the longer-term variation is listed in the table for Object C. What is the type of the star and what direction it is evolving to in the H-R diagram?

(d) [5 pts] Rather than removing the sinusoidal wave, it can also be assumed that the variation from one cycle to the next is random with magnitude e, and that the variable $u(x)$ represents the variation in O-C value accumulated over x period, compared to the ephemeris. The average of cycle-to-cycle variation $< u(x) >$ is proportional to the number of cycles x if the period fluctuation e is significant. Image C4D shows such post-processing of variability in the O-C diagram.

What is the period fluctuation e in (days) based on Image C4D? How does it compare with the long-term period changes based on O-C parabola fit?