Science Olympiad UT Invitational

October 29, 2022

Astronomy C

Directions:

- Each team will be given **50 minutes** to complete the test.
- There are four sections: **§A** (General Knowledge), **§B** (Deep-Sky Objects), **§C** (JS9 Investigation), and **§D** (Calculations).
- All answers must be indicated on your answer document. **Do not write on this exam!**
- For significant figures, **use 3 or more in your answers** unless otherwise specified.
- You may take apart the test, but make sure to staple it back together at the end of the event.
- Tiebreakers, in order: §D, §D1, §A, §B1, . . . , §B7.
- Best of luck! And may the odds be ever in your favor.

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Feedback? **Test Code**: *2023UT-AstronomyC-Bright*

Section A: General Knowledge

Use the images in Image Set A to answer the following questions. Unless otherwise specified, each question is worth two points, for a total of 75 points.

Use the stellar evolution graphic in image A1 to answer the following three questions.

1. What happens in the star that causes it to change from Stage 1 to Stage 2?
   A. The center of the object collapses, sending out a shockwave that expels all surrounding material away.
   B. The center of the star gets hot enough that it starts fusing hydrogen.
   C. The object begins to collapse down, giving off light from gravitational potential energy.
   D. Pulsations in the center object expel the surrounding material away, leaving only the center object.
2. Roughly what fraction of this star's lifetime will it spend in Stage 2?
   A. 10%
   B. 25%
   C. 50%
   D. 90%
3. Throughout Stage 3, we start seeing evidence of elements heavier than helium increasing in composition in the outer layers of the star. Where do these heavier elements come from?
   A. Planets that have been engulfed by the star.
   B. Elements heavier than helium fused in the core.
   C. Material carried through the universe by gravitational waves.
   D. Nearby supernovae.
4. What is the most massive element that can be sustainably fused in the core of a star?
   A. Helium
   B. Oxygen
   C. Iron
   D. Oganesson

Use the graph in image A2 to answer the following two questions.

5. The object in image A3 is located closest to which roman numeral on the graph?
   A. I
   B. II
   C. III
   D. IV
6. What stage of stellar evolution will come next for a star currently at IV on the graph?
   A. Red Dwarf
   B. Main-Sequence Star
   C. Red Supergiant
   D. Neutron Star
7. Which property is the main thing that determines how fast a star evolves?
   A. Initial Temperature
   B. Protostar Matter Accretion Rate
   C. Initial Mass
   D. Density of Surrounding Material

Use the following information to answer the next two questions. A research team observed the optical spectrum of a supernova and found that it contained helium lines (but notably, no hydrogen lines).

8. What type of supernova is this?
   A. Type Ia
   B. Type Ib
   C. Type Ic
   D. Type II

9. How might this type of supernova be formed?
   A. Two white dwarf stars merge.
   B. A compact neutron star exceeds the Tolman-Oppenheimer-Volkoff limit.
   C. The core of a hydrogen-poor star collapses.
   D. A hydrogen-rich protostar outbursts too strongly, tearing the protostar apart.

10. What stage of stellar evolution is a Mira Variable in?
    A. Protostar
    B. Main-Sequence
    C. Asymptotic Giant Branch
    D. White Dwarf

11. What is another type of Long-Period Variable that is similar to a Mira Variable?
    A. Luminous Blue Variable
    B. Semiregular Variable
    C. RR Lyrae Variable
    D. Cepheid Variable

12. What causes a material in a planetary nebula to emit light?
    A. UV Radiation from the central star ionizes the surrounding gas.
    B. High temperatures from the previous stage of stellar evolution that haven't cooled.
    C. Light from background stars illuminates the nebula.
    D. Light scattered from internal planets illuminates the nebula.

Light curves, like those in image A4 are incredibly useful for learning about objects in space. Use this image to answer the following three questions.

13. What quantities are on the x- and y-axes of a typical light curve?
    A. Time and Brightness
    B. Wavelength and Luminosity
    C. Radius and Luminosity
    D. Temperature and Brightness

14. If a certain pattern happens at regular intervals on a light curve, what is the time between these patterns known as?
    A. Luminous Intensity
    B. Spectral Type
    C. Magnitude
    D. Period

15. What type of object likely created the light curve?
    A. Pulsar
    B. Dwarf Nova
    C. Cataclysmic Variable
    D. Eclipsing Binary

16. What are the spectral classes of stars, listed from hottest to coolest?

    A. O, B, A, F, G, K, M

    B. A, B, F, G, K, M, O

    C. O, M, K, G, F, B, A

    D. F, G, B, O, K, M, A

17. If we notice peaks in a spectrum, where one narrow, specific color appears to get super bright, like the highlighted features shown in image A5, what do we call this?

    A. Absorption Peak

    B. Color Beam

    C. Spectral Energy Distribution

    D. Emission Line

For the following two questions, consider the chemical composition of Population I and II stars.

18. Which of the following is a spectral difference between all Population I and Population II stars?

    A. Population I stars show more metal-rich spectra.

    B. Population II stars have a bluer spectral energy distribution.

    C. Population I stars have a redder peak wavelength in their blackbody spectrum.

    D. Population II stars show a greater variety of helium absorption lines.

19. What main factor causes this spectral difference?

    A. Higher metallicity of the universe when the star formed.

    B. Temperature differences of Population I & II stars.

    C. Spectral effects of surrounding dust.

    D. Evolutionary stage of the star.

Use the following data about two Cepheid variables to answer the next two questions.

Star	**Period**	**Absolute Magnitude**
A	9.09 days	-1.99
B	9.84 days	-3.91

20. One of these is a Type I Cepheid, and the other a Type II. Which is the Type I Cepheid, and why?

    A. A is the Type I Cepheid because both stars have similar periods, and A is brighter.

    B. B is the Type I Cepheid because both stars have similar periods, and B is brighter.

    C. A is the Type I Cepheid because it has a shorter period.

    D. B is the Type I Cepheid because it has a longer period.

21. Which of these Cepheids is younger, and why?

    A. A is younger because it is dimmer.

    B. B is younger because it is brighter.

    C. A is younger because of the type of Cepheid it is.

    D. B is younger because of the type of Cepheid it is.

22. Cepheids are commonly used as standard candles. What property of standard candles makes them useful for measuring distances?

    A. Known flux

    B. Known temperature

    C. Known radius

    D. Known absolute magnitude

Use the following information to answer the next two questions. Over a period of a few years, a star is seen transitioning from a class O star to a class A star, and increasing in brightness by ∼1 magnitude.

23. A change in what property of this star could describe these observations?
    A. Radius
    B. Mass
    C. Rotational Speed
    D. Metallicity

24. [3 pts] What type of variable star exhibits the behavior described above?
    A. Mira Variable
    B. Luminous Blue Variable
    C. X-Ray Binary
    D. Cepheid Variable

Take a look at the image of a Wolf-Rayet Star in image A6 to answer the next five questions.

25. [3 pts] Which of the following accurately describes the difference between where nuclear fusion occurs in a Wolf-Rayet star and a solar-mass main sequence star?
    A. It occurs in a much smaller region in the center of the star
    B. It occurs in a region around an inert core
    C. It occurs in the envelope instead of the core
    D. It occurs in shells in the stellar core.

26. [3 pts] How is the amount of energy produced by nuclear fusion in a Wolf-Rayet star connected to the nebulous area around the star in the image?
    A. The higher energy causes high stellar winds that blow off material
    B. The higher energy causes periodic outbursts that throw material off the star
    C. The higher energy causes the star to go nova periodically that ejects material off the star
    D. The higher energy creates a field around the star that attracts surrounding dust

27. What event happens between the Wolf-Rayet stage of this star's evolution and the neutron star stage?
    A. Dwarf Nova
    C. Supernova
    B. Nova
    D. Kilonova

28. The resulting neutron star will be spinning quite fast. What causes the high rotational speed?
    A. High energy from the supernova spins the star up.
    B. The angular momentum from the original star is conserved, but at a much smaller radius.
    C. When the core collapses, interacting particles speed up the star's rotation.
    D. High magnetic fields from planets surrounding the star cause it to spin incredibly fast.

29. What type of variable star gets its variability from being a spinning neutron star?
    A. Symbiotic Variable
    B. RR Lyrae Variable
    C. Dwarf Nova
    D. Pulsar

30. Which of the following differences between a globular cluster and an open cluster is correct?
    A. Globular clusters contain population II stars, while open clusters contain population I stars
    B. Globular clusters are younger than open clusters
    C. Globular clusters are not strongly gravitationally bound, while open clusters are
    D. Globular clusters are more irregular-shaped than open clusters

31. Which of the following would be useful for finding the distance to a globular cluster?
    A. RR Lyrae Variables
    B. Type II Supernovae
    C. Kepler's Laws
    D. Hubble's Law

32. Which of the following observations would be most useful to a research group determining the age of a globular cluster that they know the distance to?
    A. Radial and tangential velocity of each component star.
    B. Location of the cluster in the galaxy.
    C. Apparent magnitude and temperature of each component star.
    D. Angular size measurements of the cluster.

The following four questions discuss white dwarfs.

33. What is the maximum mass of a white dwarf?
    A. 0.50 solar masses
    B. 1.44 solar masses
    C. 10.0 solar masses
    D. 36.6 solar masses

34. What happens if a white dwarf exceeds that mass?
    A. It collapses into a neutron star
    B. It spins up into a pulsar
    C. It evolves into a symbiotic variable
    D. It explodes in a Type Ia supernova

35. What is the most likely way a white dwarf would exceed that mass?
    A. Being blasted by jets of material from protostars
    B. Accretion from a binary companion
    C. Merging with a neutron star
    D. Steady buildup of interstellar material onto the surface of the white dwarf

36. Which of the following variables is a system that could lead to a white dwarf exceeding that mass?
    A. X-Ray Binary
    B. Symbiotic Variable
    C. Mira Variable
    D. Pulsar

Section B: Deep-Sky Objects

Use the images in Image Set B to answer the following questions. Points are shown for each sub-question, for a total of 55 points.

1. (a) [1 pt] The light curve of what object is shown in image B9?
   (b) [2 pts] Using the light curve, estimate the average period, in days, of the object from 1935 to 1940.
   (c) [2 pts] From the period and magnitude range, what type of variable star is this object?
2. (a) [2 pts] Identify the image(s) PSR J2030+4415 is displayed in.
   (b) [2 pts] What type of object is PSR J2030+4415?
   (c) [3 pts] A particle was surprisingly detected from this object. What is it and what is its "normal" counterpart?
3. (a) [1 pt] Which object does image B4 depict?
   (b) [3 pts] What is the nebula surrounding the star comprised of and where did it originate?
   (c) [2 pts] What is the diameter of the nebula, in ly?
   (d) [4 pts] Image B4 shows a white cross through the central star. Describe this phenomenon. Is it physical or just an artifact?
4. (a) [3 pts] What are the components that make up the object in image B5?
   (b) [2 pts] What wavelength is the ring imaged in? The blue blobs?
   (c) [4 pts] Describe the physical process that formed the ring.
   (d) [2 pts] How often does this occur, in years? An order of magnitude answer is sufficient.
5. (a) [1 pt] Image B6 shows what object?
   (b) [2 pts] How far is this object, in pc?
   (c) [3 pts] What geometric properties support the theory that the object had a binary progenitor?
6. (a) [2 pts] Image B7 shows various spectra. What type of spectrum is shown in red?
   (b) [3 pts] The NaID and the Earth symbols indicate features not from the target object. Which gas in Earth's atmosphere most likely caused the emergence of the two features? *(Hint: Take a look at image B8.)*
   (c) [3 pts] Can the remaining parts of the green and blue spectra be used? (Are they affected by atmospheric absorption?) Explain why.
7. (a) [1 pt] Image B10 is a graph of what event?
   (b) [3 pts] What type of graph is image B10? Explain the information being displayed.
   (c) [4 pts] A distinct signal can be seen in the first two plots, but not the last one. Why?

Section C: JS9 Exploration

Points are shown for each question, for a total of 20 points.

Navigate to js9.si.edu. In the JS9 analysis window, select [File > Open Remote]. In the URL field, enter bit.ly/js9ut23. Make sure "Proxy Server" is selected, then click [Open]. Wait for the file to load in.

1. [3 pts] If a scientist were to attempt to observe this object with a telescope of another wavelength, what right ascension and declination in the sky would they need to look at?

2. [2 pts] Generate a light curve of this object using [Analysis > Light Curve] (the first light curve, under server-side analysis). Notice a significant period of brightening. At the peak of this period, how many times brighter is this object than it was normally?

3. [3 pts] By how many X-Ray magnitudes would this object have brightened?

4. [2 pts] Now, record the start and end times of this period of brightening.

Open [Analysis > Event Filter]. In the "Event Filter" box, enter [time=START:END], replacing [START] and [END] with your recorded start and end times. This will generate a new image between just those two time frames.

Use the [File] menu to navigate back to the original image of this object.

Now, run another event filter, this time using the command [time=END:] (be careful about the colon!), replacing END with your recorded end time. This will generate another image of this object after the period of brightening.

Switch back to the image of the brightening period (the resulting image from the first event filter). Use [Analysis > Energy Spectrum] to generate an energy spectrum of this object. Now, switch to the second image we generated using the event filter. Generate an energy spectrum for this image as well.

5. [3 pts] Compare the spectra between these two images. What difference do you notice?

6. [3 pts] What might cause these spectra to differ?

7. [4 pts] Did the period of brightening appear to permanently alter this object in some way? How could you tell?

Section D: Calculations

Use the images in Image Set D to answer the following questions. Points are shown for each sub-question, for a total of 60 points.

1. **A Common Variable**

After a long day of graduate school classes, you sort through your papers and find this unlabeled light curve, scanned and shown in image D1. You flip it around to see a hastily scribbled annotation indicating a period of 18.18 days.

(a) [3 pts] Identify the type of star shown in the light curve. Explain what features led you to this conclusion.

(b) [2 pts] This light curve is "folded". What does this mean and how does the chosen period to fold at affect the final light curve?

(c) [2 pts] What is the time between visual maximum and minimum, in days?

(d) [3 pts] Calculate the ratio between the maximum and minimum luminosity.

(e) [2 pts] This star varies from F5 to G3. Estimate the minimum and maximum temperatures, in K.

(f) [3 pts] What is the percent increase of the star's radius from its minimum to its maximum?

(g) [3 pts] Suppose this object has an average absolute magnitude of -4.7. Find the star's distance, in pc.

(h) [3 pts] If there was another object located spatially near the star, discuss the accuracy of the methods used to calculate its distance:

i. Its parallax is observed over the course of six months.

ii. The object undergoes a Type Ia supernova event.

iii. Its radial velocity is determined and Hubble's law is used.

2. **Swirling Stars**

Your advisor JB collected the velocity curves shown in image D2. The binary system has a period of 1.31 days. He tells you to assume that the orbital plane lies in the ecliptic and that all orbits are circular. At his behest, complete the following tasks.

(a) [3 pts] Draw a top down view of the binary system (looking from above the orbital plane) such that the stars orbit clockwise at an orbital phase of 0.4. The direction down the page is towards Earth.

(b) [4 pts] Using two arrows, indicate the systemic radial velocity of the system and the velocity of the star with lower mass. Indicate the magnitude of each velocity vector in km/s.

(c) [5 pts] Find the total mass of the system, in kg.

(d) [2 pts] Calculate the mass ratio q.

(e) [3 pts] If the orbit was inclined at 30 degrees, determine whether or not the velocity curve would still be a simple sinusoid. Explain.

3. **Leavitt Up To You**

Your colleague Josie has collected the following data on a set of periodic variable stars she observes at a particular galaxy in the sky. She is able to discern that they are all the same type of variable star and predicts that they will have a similar period-luminosity relationship as other pulsating variables do. Unfortunately (or maybe fortunately) for her, she takes PTO soon after this data comes in and tasks you to complete the analysis before she returns.

Star	**Period (days)**	**Apparent Magnitude**
A	10.8	15.0
B	14.5	16.1
C	3.99	17.0
D	16.0	14.5
E	6.07	15.3
F	82.4	15.9
G	38.9	15.1
H	10.1	16.2

(a) [5 pts] Plot the data. Make sure to mark and label your axes. *(Hint: What type of scale should you use on the x-axis?)*

(b) [2 pts] What general trend can you see from the data?

(c) [6 pts] You recall Josie complaining about the galaxy she chose to observe. That it was “complex”, looked like “two overlapping galaxies”, and she wished she “was on vacation”. Maybe her complaints weren’t just about the galaxy.

Using this assumption, determine the trends in the plotted data by drawing two trend lines on the graph you made in part (a) and calculating the two empirical relationships.

(d) [3 pts] Were there any outlier(s) in the data you decided to exclude? If so, which star(s) were they and what object could the outlier(s) be?

(e) [3 pts] Calculate the ratio of the distance to the further galaxy and the closer galaxy.

(f) [3 pts] You remember that Josie always says that good astronomers (and all scientists!) consider multiple explanations for any phenomena. Give one possible physical explanation (not instrumentation nor statistical error) for the discrepancy between the two relationships, if all of the observed variable stars were contained in one galaxy.