Science Olympiad
UT Invitational
October 25, 2025

Astronomy C

Directions:

- Each team will be given **50 minutes** to complete the exam.
- There are **four sections** with a total of **65 questions**.
- **Do not write on the exam or image sheet**. Only write on your answer sheet.
- For calculation questions, **work will be graded**. Please show all your work.
- Unless otherwise specified, report numerical answers to **three significant figures**.
- The use of AI tools (e.g. ChatGPT) are expressly forbidden.
- Tiebreakers, in order: §A, §B, §D.
- After the tournament, the exam will be available online at `robertyl.com/scioly`
- Good luck! And may the stars align for you.

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Reference Page

Deep-Sky Objects:

- The Orion Molecular Cloud Complex,
- Sharpless 29 (NGC 6559),
- Ophion Star Family,
- HP Tau,
- Mira (Omicron Ceti),
- Helix Nebula (NGC 7293),
- Janus (ZTF J203349.8+322901.1),
- WDJ181058.67+311940.94,
- The Crab (M1),
- The Bone (G359.13),
- Cas A,
- Tycho's SNR.

Conversions and Constants:

$$1\,\mathrm{au} = 1.496 \times 10^{11}\,\mathrm{m}$$
$$1\,\mathrm{ly} = 9.461 \times 10^{15}\,\mathrm{m}$$
$$1\,\mathrm{pc} = 3.086 \times 10^{16}\,\mathrm{m}$$
$$1\,\mathrm{yr} = 365.25\,\mathrm{d}$$
$$1\,\mathrm{d} = 86\,400\,\mathrm{s}$$

$$1\,\mathrm{R}_\odot = 6.957 \times 10^{8}\,\mathrm{m}$$
$$1\,\mathrm{M}_\odot = 1.989 \times 10^{30}\,\mathrm{kg}$$
$$M_{\mathrm{bol},\odot} = +4.75 \text{ (abs. mag.)}$$
$$1\,\mathrm{R_J} = 7.149 \times 10^{7}\,\mathrm{m}$$
$$1\,\mathrm{M_J} = 1.899 \times 10^{27}\,\mathrm{kg}$$
$$1\,\mathrm{R}_\oplus = 6.378 \times 10^{6}\,\mathrm{m}$$
$$1\,\mathrm{M}_\oplus = 5.972 \times 10^{24}\,\mathrm{kg}$$

$$G = 6.674 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$$
$$b = 2.898 \times 10^{-3}\,\mathrm{m\,K}$$
$$\sigma = 5.670 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$$
$$h = 4.136 \times 10^{-15}\,\mathrm{eV\,Hz^{-1}}$$
$$H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

Section A: Stars! [23 points]

1. [1 pt] The sun is classified as a G2V star under what widely-used stellar classification scheme?
   A. Harvard system
   B. Secchi classification
   C. Draper system
   D. Morgan–Keenan system

2. [2 pts] In this classification scheme, Roman numerals are used to denote different luminosity classes. Match each luminosity class (I, III, IV, V, VII) with its corresponding star type:
   - White dwarf
   - Giant
   - Main sequence
   - Subgiant
   - Supergiant

3. [1 pt] The Chandrasekhar limit is the upper bound mass to what astronomical object?

4. [1 pt] The Tolman–Oppenheimer–Volkoff limit is the upper bound mass to what astronomical objects?

5. [2 pts] Order these five wavelength regimes by <u>increasing frequency</u>:
   - Visible
   - Infrared
   - Gamma
   - Microwave
   - Far ultraviolet

The following five (5) questions refer to the Hertzsprung–Russell (HR) diagram in Image 1.

6. [1 pt] Which letter is closest to where our sun would be on this diagram? (A–I)

7. [1 pt] Which letter is closest to where our sun would be in about 5 billion years? (A–I)

8. [1 pt] Which letter is closest to where our sun would be in about 10 billion years? (A–I)

9. [1 pt] Which letter is closest to where a red dwarf would be on this diagram? (A–I)

10. [1 pt] What is the name of the red dashed line?

11. [2 pts] Can brown dwarfs be plotted on an HR diagram? If so, what general area would they be in Image 1?

12. [2 pts] HR diagrams don't necessarily require temperature or luminosity themselves on the x- and y-axes—a diagram with parameters that relate to temperature and luminosity will work just as well. Name a potential set of x- and y-axis parameters that could be used.

Spectra of two objects are depicted in Image 2. Use the spectra to answer the following three (3) questions.

13. [1 pt] What idealized object closely approximates the spectra?

14. [2 pts] Name the non-ideal features apparent in the spectra. Describe the process (at the atomic level) through which they are created.

15. [2 pts] Which object is warmer? Explain why.

16. [2 pts] Image 3 depicts the spectra of another two objects. Why can't you approximate them by the idealized object in question 13?

Section B: Star Birth [25 points]

The following six (6) questions refer to the object in the cover image.

17. [1 pt] Identify the object.

18. [1 pt] What is the name of the bright red circular structure on the right side of the image?

19. [1 pt] What is the name of the red arc-like structure on the left side of the image?

20. [1 pt] What is suspected to have caused the aforementioned structures to assume their circular shape?

21. [2 pts] This object is one of the largest areas of stellar formation in our vicinity. What wavelength of light would be best suited to study this area, and why?

22. [2 pts] How old is this object? What would the stars and gas in this object look like in a few million years' time?

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23. [1 pt] Name the cold, dense regions of gas and dust that lead to star formation.

24. [2 pts] As gas and dust collapses into protostars, gravitational potential energy is released. What is the energy first converted into?

25. [2 pts] This process eventually forms groups of stars like the Ophion star family. What unique property makes it different from other stellar families?

These regions are primarily (by mass) composed of H_2 which is difficult to detect directly due to their low temperatures.

26. [1 pt] What other abundant, simple molecule is often used as a tracer for H_2?

27. [1 pt] What wavelength is used to detect them?

For the following two (2) questions, use the following information. Two mass functions are evaluated for two star clusters formed from identical regions of gas and dust, and are plotted in Image 5. A mass function represents the distribution of masses for a population of stars; in these plots, each bar represents the relative number of stars (y-axis) at a particular mass (x-axis). For example, there are 100 times more $1\,M_\odot$ stars than there are $4\,M_\odot$ stars in cluster B.

28. [3 pts] What is the mass ratio of cluster A captured in low-mass stars (less than 2 M)?

29. [3 pts] Which cluster is older? Justify your answer.

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30. [1 pt] Which image depicts HP Tau?

31. [1 pt] What type of variable star is HP Tau?

32. [2 pts] Fill in the four blanks in the provided diagram of the type of star from the previous question.

Section C: Star Death [41 points]

Setup Instructions

- Go to `nso.js9.org`
- Select `[The Unofficial Chandra Archive Search Page]` button on the right of the screen. A pop-up should appear.
- Type "`4384`" in the upper left box (labeled `[Chandra Obs ID]`).
- Click `[Search]`.
- Then, scroll down and drag and drop the title link into the window, as shown in Image 7.
- Select `[Scale > log]` so you can see the image. You can also click and drag around on the image to change the contrast/bias.

Now, select `[Analysis > FITS Header(s)]`.

33. [1 pt] Look for the "`OBJECT`" field. What is the name of the object shown in this observation?

34. [1 pt] What type of object is this?

Click on the circle icon in the top bar to create a circular region. Don't change the size of this region. Place this region around the central object, shown in Image 8.

35. [2 pts] What are the coordinates of this central object?

36. [2 pts] Click `[Analysis > Energy spectrum]`. Estimate the energy corresponding to the peak of the continuous emission, in eV.

37. [2 pts] Select `[Analysis > Counts in Regions]`. Record the number from the "`net_counts`" column.

Now, move the region to the bright knot region around the top, shown in Image 9. Again, don't change the size of the region.

38. [2 pts] Select `[Analysis > Energy spectrum]`. What additional feature(s) do you observe in this spectrum from the central object spectrum?

39. [1 pt] Select `[Analysis > Counts in regions]`. Is this knot brighter or dimmer than the central object in x-rays?

40. [2 pts] Given the type of object this is, what is likely happening in this region that results in these x-ray bright knots?

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41. [1 pt] What object is shown in Image 10?

42. [1 pt] How far is this object, in parsecs?

43. [2 pts] This object is a planetary nebula, but this name is a misnomer as its extended envelope is not related to planets. How does this extended envelope form and why does it glow?

44. [2 pts] Identify the type of object at the center of Image 10 and list the two elements it is primarily composed of.

Section C continued...

45. [1 pt] Which of the following best explains why not all neutron stars are pulsars?
    A. Only neutron stars whose progenitors had a high angular momentum became pulsars.
    B. Many neutron stars used to pulsate, but have since lost rotational energy and no longer do.
    C. Pulsars require a lot of energy transfer from supernovae, and only the most massive progenitor stars end up as pulsars.
    D. Pulsars require mass transfer from a secondary object to generate rotational energy, and many neutron stars are not accompanied by another star.
46. [1 pt] What object is portrayed in Image 11?
47. [2 pts] This image is a composite image of infrared, visible, and x-ray light. Which three telescopes helped to create this image?
48. [1 pt] This object is an extremely young stellar remnant! What year did it form, and how old is it right now, in years?
49. [2 pts] How many revolutions per second does this object complete?
50. [3 pts] Despite being very young and energetic, many other pulsars spin even faster than this object. What are these pulsars called, and why do they spin faster despite being much older?

The next four (4) questions focus on Cas A.

51. [1 pt] Identify the image of it.
52. [1 pt] What type of supernova is it? Be specific.
53. [1 pt] Although this supernova formed over three centuries ago, its spectrum was recently reconstructed to confirm its classification. How was this done?
54. [1 pt] What is the main distinction between type I and II supernovae?

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55. [5 pts] Your friend Maddy has come up with a few models for the orbital motion of a double white dwarf binary system. Image 6 depicts three possible configurations of the system, with a white dwarf in blue and one in red. For each one, tell her if it is valid or not. If it is, estimate the ratio of the masses to the nearest integer (i.e., $M_{\text{blue}} : M_{\text{red}}$), and if it is not, explain to her why.
56. [1 pt] What law can be used to determine the total mass of the system?
57. [1 pt] Which object in this year's list is a double white dwarf binary?
58. [1 pt] That binary system is predicted to merge in 23 million years. What is the source/cause of the orbital decay of the system?

Section D: Star Math [16 points]

A Twinkling Star. Katrina runs an observatory and wants to determine some properties of a star.

59. [2 pts] Using the spectrum in Image 4, help her find the effective surface temperature of the star, in kelvin.

60. [3 pts] With her expertise, she determines the star has an absolute, bolometric magnitude of +4.75. She asks you to calculate the radius of the star, in km.

Climbing the Ladder. The cosmic distance ladder is an important arsenal of methods for measuring distances that covers the many magnitudes found in astronomy. In this problem, we'll climb up the most important rungs.

61. [2 pts] Tycho owns an observatory and discovers a bright star in the night sky. Over the course of a year, he observes an annual parallax of 200 milliarcseconds. How far away is this star, in parsecs?

Unfortunately, direct measurements—even from space—are currently limited to the order of kiloparsecs. Fortunately, Tycho discovers some variable stars in a globular cluster at a distance of 10 kpc. He notices these stars are not Cepheid nor RR Lyrae stars, so he observes them in detail and lists the apparent magnitude (m) and period (P) of four such stars in the table below.

Star	m	P [days]
Jeff	10.9	5
Britta	12.1	20
Abed	12.9	55
Troy	13.8	190

62. [3 pts] For each of the four stars, find their absolute magnitude and the base 10 logarithm of their period.

63. [2 pts] Plot these two parameters in the given space, with the base 10 logarithm of their period ($\log_{10} P$) on the x-axis and the absolute magnitude (M) on the y-axis. Make sure to include axes labels and appropriate tick marks.

64. [3 pts] Draw a line of best fit to the data computed above and determine a period-luminosity relationship for this class of variable stars (i.e., find the slope α and y-intercept β for the line $M = \alpha \log_{10} P + \beta$).

65. [1 pt] Variable stars are often used as standard candles. What type of supernova is also used as one?