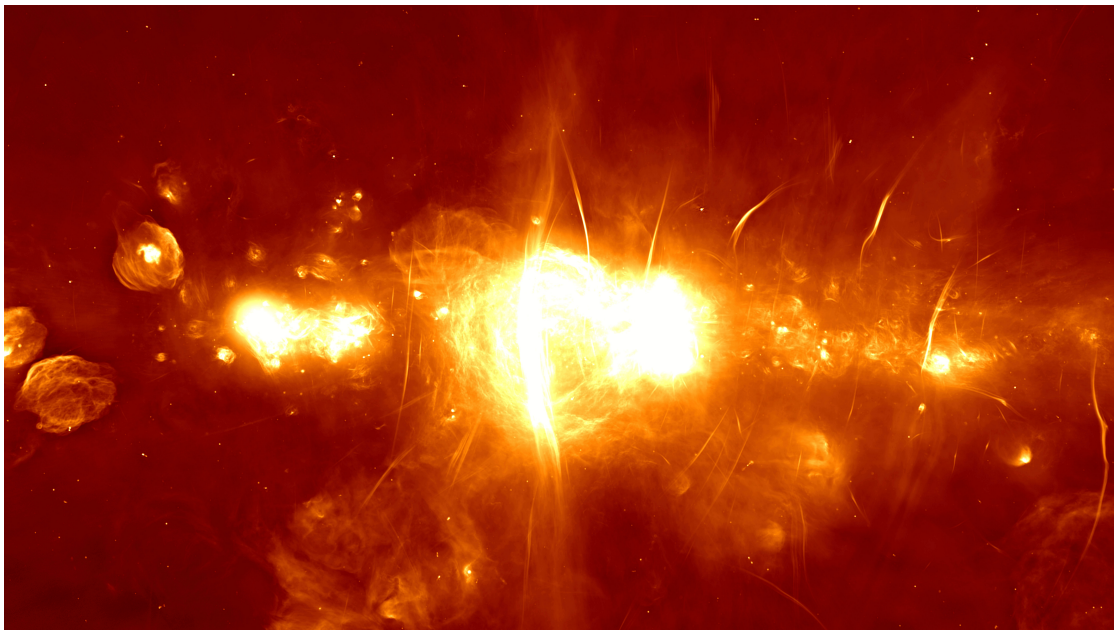
Science Olympiad
Northview Invitational
December 6, 2025

Astronomy C



Directions:

- Each team will be given **50 minutes** to complete the exam.
- There are **two 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: 31–37, 13–26, 58–61, 40–47.
- 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:

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

$$T_{\mathrm{eff},\odot} = 5778\,\mathrm{K}$$
$$1\,\mathrm{R}_\odot = 6.957 \times 10^{8}\,\mathrm{m}$$
$$1\,\mathrm{M}_\odot = 1.989 \times 10^{30}\,\mathrm{kg}$$
$$M_{\mathrm{bol},\odot} = +4.75\ \text{(abs. mag.)}$$
$$1\,\mathrm{R}_\mathrm{J} = 7.149 \times 10^{7}\,\mathrm{m}$$
$$1\,\mathrm{M}_\mathrm{J} = 1.899 \times 10^{27}\,\mathrm{kg}$$
$$1\,\mathrm{R}_\oplus = 6.378 \times 10^{6}\,\mathrm{m}$$
$$1\,\mathrm{M}_\oplus = 5.972 \times 10^{24}\,\mathrm{kg}$$

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

Section A: Multiple Choice

This section consists of 26 multiple choice and multiple select questions. Unless otherwise specified, each question is worth 2 points, for a total of 60 points.

1. Roughly what percentage of the stars in our galaxy are in the main sequence?
   A. 10 %
   B. 25 %
   C. 50 %
   D. 90 %

2. A-type stars were originally defined by what spectral feature?
   A. Ionized hydrogen (H II)
   B. Balmer lines (H I)
   C. Titanium oxide (TiO)
   D. Neutral helium (He I)

3. A main sequence star with a luminosity one-tenth that of the sun has a _____ core and a _____ envelope.
   A. radiative, radiative
   B. radiative, convective
   C. convective, radiative
   D. convective, convective

4. The Hayashi track, in addition to describing the evolution of low-mass pre-main-sequence stars, may also be used to
   A. approximate the chemical composition of protostars.
   B. determine the conditions under which a star is fully convective or radiative.
   C. estimate the size of the protostar's progenitor gas cloud.
   D. track the formation of low-mass main sequence stars into red giants.

5. [4 pts] During ascent of the red giant branch, a low-mass star primarily increases in luminosity because (Select all that apply)
   A. thin-shell hydrogen fusion becomes increasingly efficient.
   B. the core eventually contracts such that triple-alpha fusion briefly starts.
   C. emitted flux increases as a result of an increase in the star's surface temperature.
   D. the hydrogen envelope expands dramatically, increasing the star's radiating surface area.

6. Which condition triggers the helium flash in low-mass red giants?
   A. Sudden temperature increase causes explosive carbon ignition
   B. Helium degeneracy in the core inhibits expansion
   C. The cessation of hydrogen fusion in the core
   D. Temperature drops under the triple-alpha process threshold

7. A planet orbits a star in a highly eccentric orbit. Which of the following statements must be true?
   A. The planet's average orbital speed is faster than that of a circular orbit at the same semi-major axis.
   B. The planet will escape its orbit if its eccentricity decreases below 1.
   C. The specific orbital energy depends only on the semi-major axis.
   D. The orbital period is dominated by time spent near periapsis.

8. The mass estimates of spectroscopic binary stars are generally

    A. lower bounds because the inclination of the orbit is unknown.

    B. upper bounds because red/blueshift systematically overestimate radial velocities.

    C. lower bounds because distances to spectroscopic binaries are poorly constrained.

    D. upper bounds because the more massive star contributes overwhelmingly to the observed spectrum.

9. [4 pts] Which of the following statements about T Tauri variable stars are true?
(Select all that apply)

    A. They exhibit both periodic and aperiodic variation.

    B. Internal ram pressure inhibits their direct transition to the main sequence.

    C. Gravitational collapse fuels their energy production.

    D. They are typically bright in infrared due to their low surface temperatures.

10. [4 pts] Periodic variable stars on the instability strip pulsate due to the kappa mechanism. Which of the following related statements are true?
(Select all that apply)

    A. Mira variable stars are on the instability strip.

    B. The pulsation frequency is inversely correlated with mass.

    C. Convection regulates the distribution of singly and doubly ionized helium.

    D. A cool red giant star doesn't pulsate due to their helium ionization zone being too deep.

11. Type II supernovae show hydrogen lines because

    A. core collapse causes nearly instantaneous helium fusion.

    B. their shockwaves strip hydrogen from their associated interstellar gas clouds.

    C. the progenitor star retains its outer envelope.

    D. hydrogen in the interstellar medium is compacted by the explosion.

12. Which of the following correctly describes the behavior of a white dwarf's radius as its mass increases?

    A. The radius increases because electron degeneracy pressure pushes outward from the core.

    B. The radius decreases because stronger gravity overcomes the degenerate matter.

    C. The radius increases because neutron degeneracy pressure takes over at large masses.

    D. White dwarfs notably have no correlation between mass and radius.

The following three (3) questions refer to the cover image—the Milky Way Galactic Center imaged in radio by MeerKAT.

13. What are the bright streaks known as?
    A. Webbing
    B. Strings
    C. Filaments
    D. Hairs

14. The vertical streaks emit what type of radiation?
    A. Blackbody
    B. Synchrotron
    C. Thermal
    D. Bremsstrahlung

15. Where is the Bone (G359.13) located in the image?
    A. Left
    B. Top
    C. Top right
    D. Right

The next three (3) questions concern Tycho's SNR and refer to Image 1 that shows the high energy x-rays emitted by the SNR.

16. What type of supernova produced Tycho's SNR?
    A. Ia
    B. Ib
    C. Ic
    D. II

17. What telescope took this image?
    A. Hubble
    B. IXPE
    C. Chandra
    D. Swift

18. What is the purported explanation for the presence of the circled x-ray arc?
    A. The relativistic jet from the stellar remnant pierced a hole in the outer shell of the SNR.
    B. Collimated material ejected by the progenitor system inhibited expansion in the direction of the arc.
    C. It was formed by the shock wave of the supernova stripping the surface of a companion star.
    D. A shock front was produced as the supernova hit a nearby dense cold molecular cloud.

The following three (3) questions refer to Image 2.

19. Identify the object shown in the image.
    A. NGC 6559
    B. The Orion Molecular Cloud Complex
    C. NGC 7293
    D. M1

20. Which region of the object scatters the light from newly formed, energetic stars? (A–D)

21. [4 pts] Which of the following statements are true? (Select all that apply)
    A. This object is small, only a few-light years across—two orders of magnitude smaller than its neighboring object of the same type.
    B. Region D in the image is known as an H II region, composed of ionized atomic hydrogen created by short-lived blue stars.
    C. The unique interstellar medium of this object does not contain much dust, allowing formation of more high mass stars than usual.
    D. Located in the Milky Way and 1500 pc away, this object can be seen from the southern hemisphere.

The next five (5) questions refer to Omnicron Ceti, a binary system.

22. Which types of stars comprise the system? (Select two)
    A. Red dwarf
    B. Blue supergiant
    C. A-type main sequence
    D. Blue straggler
    E. White dwarf
    F. K-type main sequence
    G. Red giant

23. [1 pt] The optical variation of the primary star is on the order of _____.
    A. days
    B. months
    C. years
    D. decades

24. [1 pt] The optical variation of the secondary star is on the order of _____.
    A. minutes
    B. hours
    C. days
    D. weeks

25. The stellar interior of Mira A is best characterized by which description?
    A. Core hydrogen burning
    B. Inert helium core, shell hydrogen burning
    C. Core helium and shell hydrogen burning
    D. Inert carbon core, shell helium and hydrogen burning

26. [4 pts] Which image(s) depict the system? (Select all that apply)
    A. Image 3
    B. Image 4
    C. Image 5
    D. Image 6

Section B: Free Response

This section consists of 39 free response questions. Points are shown for each question, for a total of 100 points.

27. [2 pts] Why must molecular clouds be cold for star formation to begin?

28. [2 pts] Most stars have been observed to be in binary systems; our sun is an exception. Briefly explain what physical process causes lone star systems to be rare.

29. [2 pts] What is the primary reason we are unable to detect a vast majority of pulsars in our galaxy?

30. [2 pts] Type Ia supernovae are commonly used as standard candles. Briefly explain why they are effective in computing cosmological distances.

On the island of Hven, a famed astronomer observes two clusters, Aepdiles and Houcusphi, collecting B and V band apparent magnitude data of stars within them. The astronomer takes 100 of their best observations (50 from each cluster) and plots them—which you can find on your answer sheet. They ask you to analyze the plots.

31. [1 pt] What are these plots known as?

32. [3 pts] Draw the main sequence line and circle the turnoff point on both plots.

33. [3 pts] Which cluster is older? Justify your answer.

34. [3 pts] Trace and label the subgiant, red-giant, and horizontal branches on the plot of Houcusphi.

35. [1 pt] What type of variable star intersects the horizontal branch?

Observational data of the apparent magnitude from a variable star of that type is collected over a long time.

36. [1 pt] Name a method astronomers would use to determine the unknown period P of the star.

37. [3 pts] With this period P, explain how astronomers would process this data to reveal clear, repeating patterns. Identify this procedure.

In a distant galaxy, there are two stars: Nadir (G9V) and Barnes (K2I).

38. [5 pts] Compare and contrast these two stars <u>against our sun</u>:
    (a) [2 pts] Are they hotter or cooler?
    (b) [2 pts] Are they more or less massive?
    (c) [1 pt] Are they more or less luminous?

39. [3 pts] What is the name of the spectral feature in Image 7? Which star is more likely to exhibit this feature? Why?

In the following eight (8) questions, we will investigate some young stellar objects in a region of star formation in X-rays. To set up the image, follow the following instructions.

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.
- In the box labeled `[Chandra Obs ID]`, enter "`17739`"; then click `[Search]`.
- Then, scroll down and drag and drop the `Title` link into the JS9 window.
- Select `[Scale > log]` so you can see the image.
- Under `[Analysis > Blur, equivalent sigma]`, enter "`1`".
- Zoom in once.
- Your image should look similar to Image 8.

40. [1 pt] Look for the "`OBJECT`" field. What is the name of the object shown in this observation? *(Hint: Use `[Analysis > FITS Header(s)]`.)*

41. [3 pts] Click on the circle icon in the top bar to create a circle region. Resize and move this region over Object A, as shown in Image 8. Select `[Analysis > Light Curve]`.
Use the one under "`Server-side Analysis`", <u>NOT</u> the one under "`NSO Analysis`".

    Estimate the average brightness measured from this object, in counts. Estimate the range of the brightness measured from this object, in counts.

42. [3 pts] Now, move the circle over Object B, as shown in Image 8. Select `[Analysis > Light Curve]`.
Use the one under "`Server-side Analysis`", <u>NOT</u> the one under "`NSO Analysis`".

    What is different about this light curve from the one you observed previously?

43. [3 pts] What is likely causing the behavior you observe in the x-ray light curve of Object B?

44. [2 pts] Now, estimate the angular separation between any two adjacent stars. Which of the following is the best estimate of the angular separation between the objects in this star-forming region?

    A. $0.1''$

    B. $10''$

    C. $1000''$

    D. $10\,000''$

45. [3 pts] This object is at a distance of roughly 1030 ly. For the angular separation you selected above, what is roughly the distance between these objects, in ly?

46. [2 pts] The stars in this region remain gravitationally bound over the next 10 Gyr. As the cosmic dust clears and the stars evolve, what type of cluster will be formed?

47. [2 pts] By the time the cluster from the previous question is formed, what will likely have happened to the bright objects we observe here?

The Helix Nebula is a planetary nebula located 650 light-years away from Earth. Image 9 depicts the nebula in 3.6 µm (left) and 24 µm (right).

48. [2 pts] Identify the wavelength regime of the two images.

49. [4 pts] Describe the physical process producing the knots at the periphery of the nebula. Why do their tails all point away from the central star?

50. [2 pts] What is the dust mass of the central extended region in 24 µm, in $M_\oplus$?

Janus is a white dwarf of great interest. Image 10 shows phase-resolved and phase-binned spectra of Janus, normalized and shifted vertically for clarity. The numbers on the right indicate the centre of each phase bin. The blue vertical lines highlight the position of the hydrogen Balmer lines and the red vertical lines indicate neutral helium lines.

51. [2 pts] Janus was discovered by what survey? Provide the *full name*, **not** the acronym.

52. [3 pts] Describe what "phase-resolved spectra" means in this context.
(What does "phase" mean? How is it "resolved"?)

53. [3 pts] Are the lines absorption or emission lines? The lines correspond to the composition of what part of the white dwarf?

54. [2 pts] Based on the spectra, helium is dominant near which phase?

The helium flash is a rapid and extreme phase of nuclear burning for low-mass stars—namely those between $0.6\,M_\odot$ and $2.0\,M_\odot$.

55. [1 pt] Is the helium flash a positive or negative feedback loop?

56. [4 pts] Explain why a helium flash does not occur for stars with masses less than $0.6\,M_\odot$ or greater than $2.0\,M_\odot$.

57. [3 pts] It is said that the peak energy production during the helium flash rivals that of our Milky Way. The majority is efficiently transported to the edge of the core. From here, where does the energy go?

One December night, Fredenandus looks towards the north ecliptic pole and observes the star Jregory from Fairbanks, Alaska. Six months later, he returns to the same spot and measures a parallax angle of 150 milliarcseconds (mas) relative to the background galaxies.

58. [3 pts] Calculate the distance to Jregory in parsecs (pc).

59. [3 pts] Using photometry, Fredenandus measures Jregory's V-band apparent magnitude to be $m_V = 9.2$. Calculate the V-band absolute magnitude of Jregory.

60. [3 pts] Fredenandus obtains a spectrum of Jregory and notices that its emission peaks at a wavelength of $\lambda = 483\,\text{nm}$. Estimate the surface temperature T of Jregory, in kelvin.

61. [3 pts] To learn more about Jregory, Fredenandus later measures its total luminosity and finds that Jregory radiates about five times the luminosity of our sun (i.e., $5.0\,\text{L}_\odot$). Calculate the radius of Jregory, in meters.

A star named Altheon and a neutron star orbit each other around their common center of mass. Altheon has the same mass as our sun ($1\,\text{M}_\odot$), while the neutron star has a mass of $1.4\,\text{M}_\odot$. The binary's orbital motion can be described equivalently as a *reduced-mass* particle moving in a **circular** orbit of radius a, the separation between the two stars.

62. [3 pts] The orbital period of the Altheon-neutron star binary is measured to be $P = 10.0\,\text{days}$. Calculate the semi-major axis a of the relative orbit in meters.

63. [2 pts] Using your value of a from the previous question as the separation between Altheon and the neutron star, calculate the gravitational force between them in newtons.

64. [4 pts] The total mechanical energy of the system in the center of mass frame is calculated by adding the kinetic and gravitational potential energies:

$$\frac{1}{2}\mu v^2 - \frac{GMm}{a},$$

where $\mu = Mm/(M+m)$ is the reduced mass. Compute the speed v of the reduced-mass particle (the relative orbit) in km/s and the total mechanical energy in joules.

65. [3 pts] What is the sign of the total mechanical energy and what does it tell you about the dynamics of the binary system?
