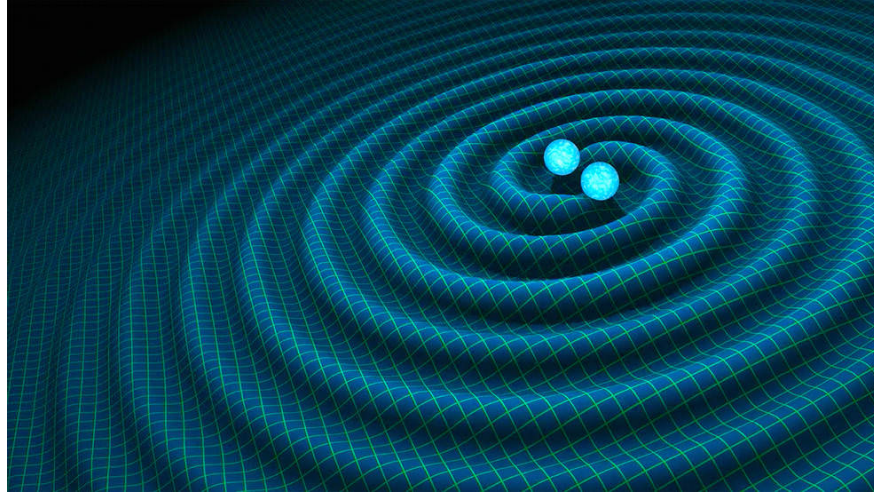


Science Olympiad Reach for the Stars UT Regional 2025

March 1, 2025
Austin, TX



Directions:

- You are allowed to bring in **two** 8.5" × 11" sheets of paper with information on both sides.
- This exam and image sheet are class sets. Please write all answers on your answer sheet.
- You can take apart the test as long as you restaple the pages in the correct order at the end.
- This exam consists of **three sections** containing questions worth **155 points**.
- There is no penalty for wrong answers.
- The exam will be available online at atxscioly.org and adi1008.github.io after the tournament.
- Above all else, just believe!

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Section A [20 points]

Each multiple choice question has only one answer and is worth 1 point for a total of 20 points.

- Which of the following best describes the Sun?
 - A moon
 - A planet
 - A star
 - A galaxy
 - A constellation
- What force keeps planets in orbit around the Sun?
 - Gravitational force
 - Electromagnetic force
 - Nuclear force
 - Centrifugal force
- If you double a star's radius while keeping its temperature constant, its luminosity will:
 - Double
 - Increase by a factor of 4
 - Increase by a factor of 8
 - Increase by a factor of 16
- If you double the distance between two objects, the gravitational force between those objects will:
 - Become $1/4$ of what it used to be
 - Become $1/2$ of what it used to be
 - Stay the same
 - Double
 - Increase by a factor of 4
- What is the primary factor that determines the path of a star's evolution?
 - Its location
 - Its temperature
 - Its composition
 - Its initial mass
- True or false: Cepheid variable stars are main sequence stars
 - True
 - False
- Through which process does the Sun primarily produce energy?
 - Proton-proton chain
 - CNO Cycle
 - Triple alpha process
 - None of the above
- In a contact binary system, mass transfer occurs primarily through:
 - Stellar winds
 - Magnetic fields
 - Roche lobe overflow
 - Radiation pressure
 - Tidal forces
- True or false: a cool star's blackbody spectrum will peak at a longer wavelength than that of a hot star.
 - True
 - False
- What is (are) the heaviest element(s) produced in the core of a massive star before it explodes in a Type II supernova?
 - Carbon
 - Silicon
 - Iron/Nickel
 - Oxygen
- Which of the following lists the order of the main spectral types from hottest to coolest?
 - OBAFGKM
 - BOGAFMK
 - ABFGKMO
 - ABCDEFGF
- Which of the following portions of the electromagnetic spectrum has the highest frequency?
 - Infrared
 - Visible
 - X-rays
 - Radio

13. Two stars are separated by 4 AU orbit each other with a period of 2 years. What is the combined mass of the two stars?
- A. $0.5 M_{\odot}$
 - B. $1 M_{\odot}$
 - C. $2 M_{\odot}$
 - D. $4 M_{\odot}$
 - E. $8 M_{\odot}$
 - F. $16 M_{\odot}$
 - G. None of these
14. Type Ia supernovae occur when:
- A. A single massive star explodes
 - B. Two neutron stars merge
 - C. A red giant sheds its outer layers
 - D. A white dwarf exceeds the Chandrasekhar limit through accretion
 - E. A black hole forms
15. A planetary nebula represents:
- A. A collection of newly forming planet
 - B. A collection of newly forming stars
 - C. The ejected outer layers of a dying low-mass star
 - D. A supernova remnant
 - E. An accretion disk around a white dwarf
16. JWST's sunshield is necessary because:
- A. It provides power
 - B. It enables communication
 - C. It shields from neutrinos
 - D. It keeps the telescope from becoming too hot
 - E. It provides structural support
17. Which of the following statements about white dwarfs is correct?
- A. All stars become $0.6 M_{\odot}$ white dwarfs
 - B. More massive progenitors produce more massive white dwarfs
 - C. White dwarf mass is independent of progenitor mass
 - D. All white dwarfs start at the Chandrasekhar limit
 - E. All of these are correct.
18. The Urca process in neutron stars primarily:
- A. Generates energy through fusion
 - B. Creates new elements
 - C. Maintains hydrostatic equilibrium
 - D. Cools the star through neutrino emission
 - E. Prevents gravitational collapse
19. What is the typical end product of a star that undergoes a Type II supernova?
- A. White dwarf
 - B. Neutron star or black hole
 - C. Red giant
 - D. Brown dwarf
20. Two telescopes in space (i.e. they don't have to worry about interference from the Earth's atmosphere) are observing the night sky at the same wavelength. However, one is bigger than the other. Generally, which one will have the better angular resolution?
- A. The smaller one
 - B. The bigger one
 - C. Both of them will be the same

Section B [80 points]

When applicable, use the Image Set to answer the following questions. Unless otherwise specified, each part of each question is worth 2 points for a total of 80 points.

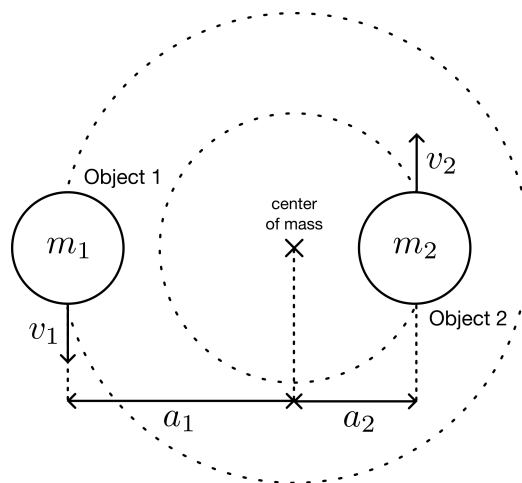
21. (4 points) Order the following images by how far the DSOs they depict are from Earth, from closest to farthest: 2, 3, 4, and 9.
22. (a) What image shows SN 1604?
(b) What type of supernova (type Ia, type Ib, etc.) was SN 1604?
(c) Will the Sun ever undergo a supernova like SN 1604? Explain why or why not.
23. (a) What image shows Mira?
(b) What spacecraft(s) or telescope(s) collected the data to create this image?
(c) What branch of the HR diagram is Mira currently on?
(d) What do scientists think Mira will become at the end of its evolution?
24. (a) Image 1 shows a typical light curve for RR Lyrae. What constellation is RR Lyrae in?
(b) What branch of the HR diagram are RR Lyrae stars on?
(c) The variability of RR Lyrae is thought to be due to the κ -mechanism, which describes how the opacity of a specific ionized element varies with temperature in the star. Which element?
25. (a) Which DSO is shown in Image 2?
(b) What spacecraft(s) or telescope(s) collected the data to create this image?
(c) In what portion(s) of the electromagnetic spectrum (e.g., visible, infrared, etc.) was/were the data in this image collected?
(d) Image 2 consists of a large-looking star in the middle with a small-looking star to its upper right. Which stages of stellar evolution are each of these stars in?
(e) What causes these two stars to appear to be different sizes in this photo?
26. (a) Image 3 shows a light echo of SN 1987A. In your own words, explain what a light echo is.
(b) There is one more image that shows SN 1987A. Which one is it?
(c) What type of supernova (type Ia, type Ib, etc.) was SN 1987A?
(d) What sort of stellar remnant is thought to be at the center of this DSO?
27. (a) What DSO is shown in Image 4?
(b) What spacecraft(s) or telescope(s) collected the data to create this image?
(c) In the top and left portions of the image, we see broad orange and red arcs. What causes this color?
28. (a) Image 5 shows the stellar disk and surrounding gas of a star on this year's rules. What is the name of the star?
(b) The image was produced with the help of a technique called adaptive optics. In your own words, explain what adaptive optics is.
29. (a) What spacecraft(s) or telescope(s) collected the data to create Image 7?
(b) In what portion(s) of the electromagnetic spectrum (e.g., visible, infrared, etc.) was/were the data in Image 7 collected?
(c) In a vacuum, do photons in this portion of the electromagnetic spectrum travel faster or slower than visible light?

30.
 - (a) What DSO is shown in Image 9?
 - (b) What spacecraft(s) or telescope(s) collected the data to create this image?
 - (c) This image shows material in a few different colors. Are the purple areas hotter or cooler than the red areas?
31.
 - (a) Image 10 is a composite image. In your own words, explain what that means.
 - (b) True or false: data collected from JWST is in this image.
32.
 - (a) What DSO is shown in Image 11?
 - (b) What type of object do scientists think this DSO is?
 - (c) This DSO is part of a binary system with another object. What are the name and type of that object?
 - (d) There is one more image that shows this DSO. Which one is it?
33.
 - (a) Image 12 shows an artist illustration of a DSO on this year's rules. Which one?
 - (b) This DSO is a prototypical dwarf nova. In your own words, explain what a dwarf nova is.

Section C [55 points]

For the following questions, please explain your answers (i.e., do not just write “yes” or “no”).

34. (8 points) As white dwarfs radiate their internal energy into space, they become dimmer and cooler. Suppose that after many years, a white dwarf has reached an absolute magnitude of 12.5.
- (2 points) In your own words, explain the difference between absolute magnitude and apparent magnitude.
 - (3 points) To the nearest power of 10, how many times dimmer than the Sun is this white dwarf? To make the math easy to do by hand, let the absolute magnitude of the Sun be 5. Please show your work.
 - (3 points) Without nuclear reactions to provide internal heat and pressure, you might think that white dwarfs shrink significantly as they cool. However, they typically stay the same size. Why?
35. (12 points) During the final stages of a star’s life, its convective zone may extend much deeper than usual. At these times, convection can “dredge up” heavy elements produced by later stages of fusion, transporting them all the way to the star’s surface.
- (4 points) In your own words, explain what convection is. What portions of the Sun are thought to be convective?
 - (6 points) An intermediate-mass star (say, $4 M_{\odot} \lesssim M \lesssim 8 M_{\odot}$) is thought to experience three dredge-up events. Briefly describe when each of these dredge-up events occur.
 - (2 points) The third dredge-up transports carbon to the surface of the star. What is the name of the process through which this carbon is produced in stars?
36. (30 points) Many of the DSOs on this year’s rules are binary systems, like SS Cygni or the Hulse-Taylor pulsar. Imagine that you’ve discovered a binary system containing two objects in perfectly circular orbits around their center of mass, as shown in the figure below.



- (2 points) Write an expression for the gravitational force between the two objects. Give your answer in terms of G , m_1 , m_2 , and a , where G is the gravitational constant, m_1 and m_2 are the masses of Objects 1 and 2, and $a = a_1 + a_2$ is the total distance between the objects.
- (4 points) Write an expression for a_2 in terms of m_1 , m_2 , and a . What is the value of a_2 if both of the objects are the exact same mass?
- (6 points) Gravity provides the centripetal force needed to make the objects move in a circular orbit. In the case of Object 2, the centripetal force is given by $F = m_2 v_2^2 / a_2$, where v_2 is the speed

at which Object 2 is moving. Show that

$$a_2 = \frac{Gm_1}{v_2^2} \left(\frac{m_1}{m_1 + m_2} \right)^2$$

- (d) (2 points) Write an expression for the period of this system in terms of a_2 and v_2 .

Further observation of the system shows that it consists of a neutron star and a black hole in an orbit that has decayed significantly. The black hole is twice the mass of the neutron star and is moving at a speed of $0.2c$, where c is the speed of light.

- (e) (4 points) What physical phenomenon caused the orbit in our system to decay? Is the orbit of the Earth around the Sun decaying in the same way? Explain.
- (f) (10 points) To the nearest order of magnitude, estimate (i) the separation between the neutron star and black hole in meters and (ii) the period of the system in seconds.
- You will need to use your knowledge of stellar evolution to assume a mass for the neutron star. This also determines the mass of the black hole, since $m_{\text{BH}} = 2m_{\text{NS}}$.
 - Some helpful values: $c = 3 \times 10^8$ m/s, $G = 7 \times 10^{-11}$ N m² kg⁻², and $1 M_{\odot} = 2 \times 10^{30}$ kg. Note that all of these are in base SI units, so you shouldn't need to convert anything.
 - Your answer is an estimate – do not waste time doing complicated arithmetic. Round numbers frequently and focus on the powers of ten.
- (g) (2 points) The assumption that we can use Newtonian mechanics in this question is not very accurate. Why is that the case?
37. (5 points) When preparing for this event, you probably studied some concepts that weren't covered explicitly on this exam, simply because this exam can't be infinitely long. Choose one of them and write about it in as much detail as you can. *Note: this question is also the first tiebreaker.*