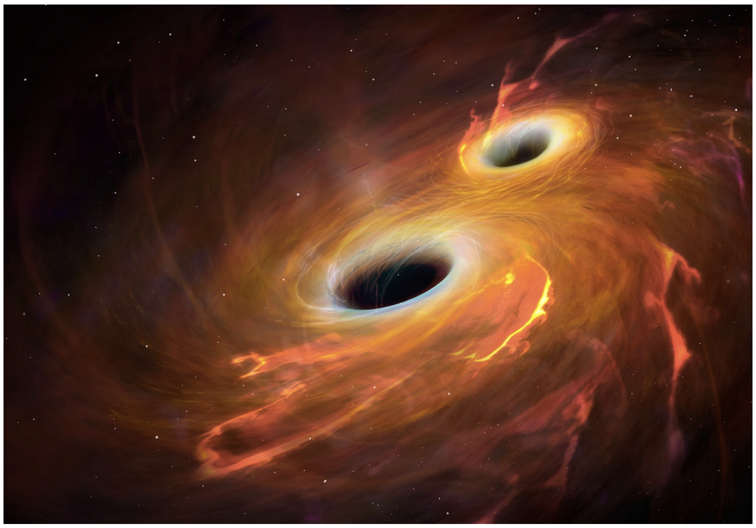
Science Olympiad
Reach for the Stars
UT Invitational 2024

October 26, 2024
Austin, Texas



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 **115 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!

Written by: Aditya Shah

Section A [20 points]

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

1. Which of the following best describes the Sun?
   - A. A moon
   - B. A planet
   - C. A star
   - D. A galaxy
   - E. A constellation
2. How do stars produce energy?
   - A. Chemical reactions
   - B. Nuclear reactions
   - C. Electron degeneracy pressure
   - D. Neutron degeneracy pressure
3. A star's temperature
   - A. Increases towards the center.
   - B. Decreases towards the center.
   - C. Is fairly constant throughout the star.
   - D. Increases towards the center, until the deep core which is relatively cool.
4. True or false: more massive white dwarfs have smaller radii
   - A. True
   - B. False
5. Through which process does the Sun primarily produce energy?
   - A. Proton-proton chain
   - B. CNO Cycle
   - C. Triple alpha process
   - D. None of the above
6. What is (are) the heaviest element(s) produced in the core of a massive star before it explodes in a Type II supernova?
   - A. Carbon
   - B. Silicon
   - C. Iron/Nickel
   - D. Oxygen
7. What force keeps planets in orbit around the Sun?
   - A. Electromagnetic force
   - B. Nuclear force
   - C. Centrifugal force
   - D. Gravitational force
8. Which of the following lists the order of the main spectral types from hottest to coolest?
   - A. OBAFGKM
   - B. BOGAFMK
   - C. ABFGKMO
   - D. ABCDEFG
9. Which of the following portions of the electromagnetic spectrum has the shortest wavelength?
   - A. Infrared
   - B. Visible
   - C. Ultraviolet
   - D. Radio
10. What is the maximum mass a white dwarf can have?
    - A. 5 solar masses
    - B. 1 solar mass
    - C. 1.4 solar masses
    - D. 3.0 solar masses
11. 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
12. Hydrostatic equilibrium refers to the state in which a star is supported against the inward force of its ______ by the outward pressure of its ______.
    - A. radiation; angular momentum
    - B. gravity; radiation
    - C. luminosity; gravity
    - D. angular momentum; luminosity
13. What is the primary factor that determines the path of a star's evolution?

A. Its location
B. Its temperature
C. Its composition
D. Its initial mass

14. What is the source of energy that drives a supernova explosion in a massive star?
    A. Hydrogen fusion
    B. Gravitational collapse of the core
    C. Helium fusion
    D. Electron degeneracy pressure

15. Consider two stars, A and B. The temperature of Star A is twice that of Star B, but the radius of Star A is 1/2 that of Star B. What is the ratio of their luminosities, L_A/L_B? *Hint: use the Stefan-Boltzmann Law.*
    A. 1/4
    B. 1/2
    C. 2
    D. 4

16. True or false: the Sun is a main sequence star.
    A. True
    B. False
    C. This is a trick question; the Sun is not a star

17. Two telescopes in space (i.e. they don't have to worry about interference from the Earth's atmosphere) of equal size observe the night sky in different wavelengths. Generally, which one will have the better angular resolution?
    A. The one observing in long wavelengths
    B. The one observing in short wavelengths

18. What happens to a neutron star with a mass greater than the Tolman-Oppenheimer-Volkoff limit?
    A. It will collapse into a black hole.
    B. It will become a pulsar.
    C. It will form a white dwarf.
    D. It will form a planetary nebula.

19. True or false: a cool star's blackbody spectrum will peak at a shorter wavelength than that of a hot star.
    A. True
    B. False

20. What force prevents a neutron star from collapsing into a black hole?
    A. Electron degeneracy pressure
    B. Neutron degeneracy pressure
    C. Nuclear fusion in the core
    D. Gravitational waves

Section B [60 points]

When applicable, use the Image Set to answer the following questions. Each part of each question is worth 2 points for a total of 60 points.

21. (a) What image shows SN 1604?
    (b) The "SN" in the name stands for "supernova". What type of supernova was SN 1604?

22. (a) What DSO is shown in Image 1?
    (b) What image shows the constellation that this DSO is in?
    (c) Complete the sentence: This DSO was the first object widely accepted to be a ______.

23. (a) One of the DSOs on this year's rules is the Hulse-Taylor pulsar. In your own words, explain what a pulsar is.
    (b) Image 7 shows evidence of orbital decay in the system. What types of objects are in the orbit, and why is the orbit decaying?

24. (a) Image 6 shows an artist's illustration of gravitational waves. Which DSO on this year's rules corresponds to the first direct detection of gravitational waves?
    (b) What was the name of the observatory/project that was used to first detect gravitational waves?
    (c) The gravitational waves from this DSO were produced by two objects orbiting each other. What type of objects (e.g., planets, white dwarfs, etc.) were they?

25. (a) Which image shows Betelgeuse?
    (b) What image shows the constellation that this DSO is in?
    (c) What spacecraft(s) or telescope(s) collected the data to create the image from part (a)?
    (d) In what portion(s) of the electromagnetic spectrum (e.g., visible, infrared, etc.) was/were the data in this image collected?
    (e) True or false: scientists think that Betelgeuse will eventually explode as a supernova.

26. (a) What DSO is shown in Image 9?
    (b) This DSO contains two objects: one big and one small. Which one started out as the more massive star?

27. (a) Which image shows Cassiopeia A?
    (b) What spacecraft(s) or telescope(s) collected the data to create this image?
    (c) Cassiopeia A is the strongest radio source beyond our solar system. Do radio waves have a shorter or longer wavelength than visible light?

28. (a) What DSO is shown in Image 10?
    (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) What process creates the "red" color in this image?

29. (a) Image 5 shows the light curve for a star from this year's rules. Which star?
    (b) What region/branch of the H-R diagram would this star be in?

30. (a) What image shows SN 1987A?
    (b) What sort of stellar remnant is thought to be at the center of this DSO?
    (c) In what galaxy did this supernova occur?
    (d) Neutrinos from this supernova arrived at Earth three hours before photons did. However, nothing can travel faster than light. How did the neutrinos get here earlier?

Section C [35 points]

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

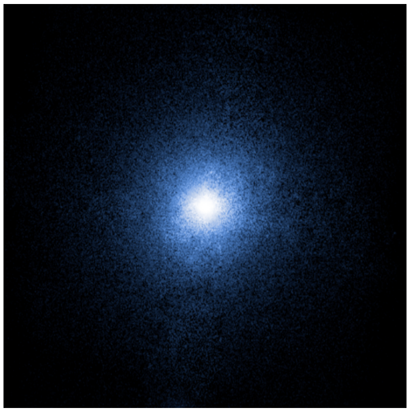
31. (7 points) The most massive stars will eventually form black holes, some of the most exotic objects in the universe.
    (a) (2 points) Explain what an *event horizon* is. Does the Sun have an event horizon?
    (b) (2 points) Suppose that someone replaced the Sun with a black hole of the same mass. Would the Solar System immediately be sucked into the black hole? Why or why not?
    (c) (3 points) *Spaghettification* refers to the vertical stretching and horizontal compression of objects into long thin shapes (rather like spaghetti) as they approach a black hole. Explain why it's more extreme for smaller, stellar-mass black holes than the supermassive black holes at the center of galaxies like the Milky Way.

32. (8 points) When the Sun is the on the main sequence, it is fusing hydrogen into helium in its core. However, after 4 to 5 billion more years, this process will stop, and the Sun will become a *red giant*.
    (a) (2 points) When the Sun runs out of hydrogen in the core, the temperature of the core initially *increases*. How could that be the case when there is no nuclear fusion occurring to generate energy?
    (b) (2 points) Although core hydrogen fusion stops, hydrogen starts being fused into helium in a shell around the core. Explain why this causes the outer layers of the star to expand.
    (c) (2 points) When the Sun is a red giant, it will undergo significant mass loss (i.e., material from its outer layers will escape from the star). Why is this the case?
    (d) (2 points) At the end of its life, the Sun will shed its outer layers, forming a planetary nebula. What will remain at the center, and what is the name of this object?

33. (15 points) Astronomers have many different ways of characterizing the brightness of objects. One way is through the *magnitude scale*, which was first introduced by the Greek astronomer Hipparchus.
    (a) (2 points) Explain what apparent magnitude (m) and absolute magnitude (M) are.
    (b) (2 points) Star A has an absolute magnitude of 2, while Star B has an absolute magnitude of -1. Which one has a higher luminosity?
    (c) (2 points) Star C and Star D both have the same apparent magnitude, but Star C has a much higher absolute magnitude than Star D (in other words, $M_C > M_D$). Which star is closer to Earth?
    (d) (2 points) Stars E and F have the same apparent and absolute magnitudes. However, our line of sight to Star E passes through a very dusty patch of space, while the line of sight to Star F is clear of any obstructions. Which star is closer to Earth?
    (e) (2 points) If you wanted to observe Star E with less interstellar extinction, should you view it using a longer or shorter wavelength? Explain.
    (f) (2 points) Astronomers often use "standard candles" to estimate distances. In your own words, explain what a standard candle is and how they can help us determine distances.
    (g) (3 points) Imagine two universes: Universe 1, where flux falls off with $1/r$, and Universe 2, where flux falls off with $1/r^2$. In each of these universes, we view a type Ia supernova from Earth, and both of them *appear* to be the same brightness. In which universe is the supernova farther away?

34. (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.*

Image Set



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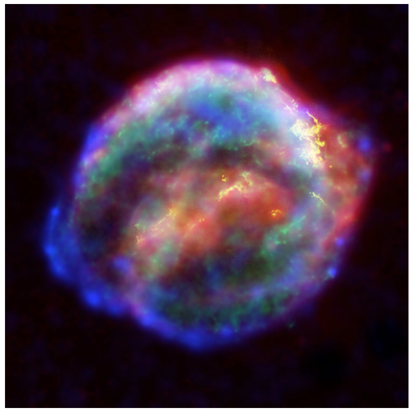

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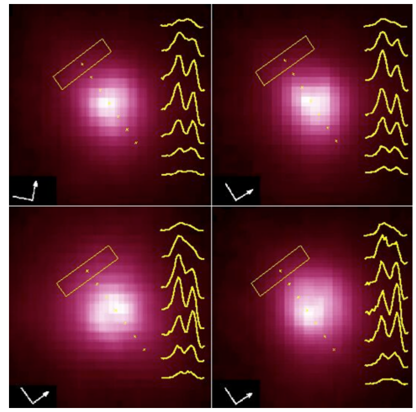

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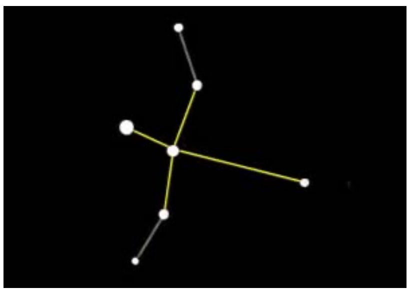

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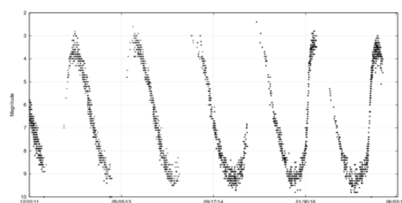

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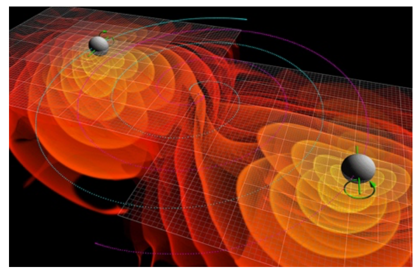

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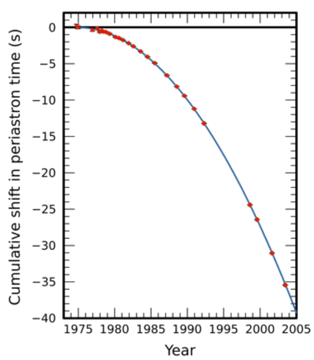

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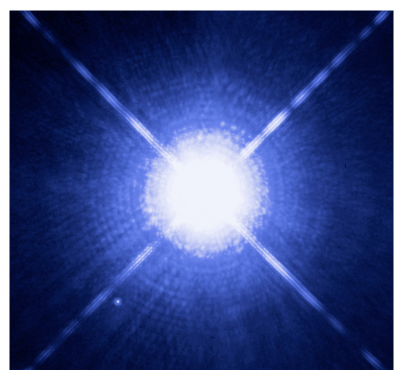

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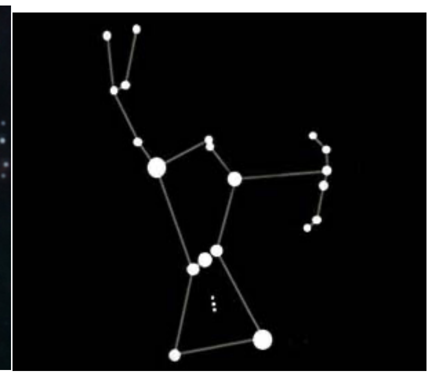

12

Section A (20 points)

1. ____	5. ____	9. ____	13. ____	17. ____
2. ____	6. ____	10. ____	14. ____	18. ____
3. ____	7. ____	11. ____	15. ____	19. ____
4. ____	8. ____	12. ____	16. ____	20. ____

Section B (60 points)

21. (a) ____
    (b) ____

22. (a) ____
    (b) ____
    (c) ____

23. (a) ____
    ____
    ____
    (b) ____
    ____
    ____

24. (a) ____
    (b) ____
    (c) ____

25. (a) ____
    (b) ____
    (c) ____
    (d) ____
    (e) ____

26. (a) ____
    (b) ____

27. (a) ____
    (b) ____
    (c) ____

28. (a) ____
    (b) ____
    (c) ____
    (d) ____
    ____
    ____

29. (a) ____
    (b) ____

30. (a) ____
    (b) ____
    (c) ____
    (d) ____
    ____
    ____

Section C (35 points)

31. (a)

(b)

(c)

32. (a)

(b)

(c)

(d)

33. (a)

(b)

(c)

(d)

(e)

(f)

(g)

34.

Section A (20 points)

1. C
2. B
3. A
4. A
5. A
6. C
7. D
8. A
9. C
10. C
11. B
12. B
13. D
14. B
15. D
16. A
17. B
18. A
19. B
20. B

Section B (60 points)

21. (a) Image 2
    (b) Type Ia
22. (a) Cygnus X-1
    (b) Image 4
    (c) Black hole
23. (a) A highly magnetized rotating neutron star that emits beams of electromagnetic radiation out of its poles
    (b) One neutron star and one pulsar. The orbit is decaying due to the loss of energy from gravitational waves
24. (a) GW150914
    (b) LIGO
    (c) Two black holes
25. (a) Image 3
    (b) Image 12
    (c) Hubble Space Telescope
    (d) Ultraviolet
    (e) True
26. (a) Sirius
    (b) The small object (the white dwarf)
27. (a) Image 8
    (b) JWST
    (c) Longer
28. (a) NGC 6543
    (b) Hubble and Chandra
    (c) Optical and x-ray
    (d) Electrons falling from $n = 3$ to $n = 2$ in a hydrogen atom, releasing a photon with $\lambda = 656.28$ nm.
29. (a) Mira
    (b) AGB
30. (a) Image 11
    (b) Neutron star
    (c) Large Magellanic Cloud,
    (d) Neutrinos interact very weakly with matter, allowing them to escape the collapsing star almost instantly, while photons are delayed by the time it takes for the shock wave to reach the star's surface.

Section C (35 points)

31. (a) An event horizon is a boundary beyond which events cannot affect an observer. Within the event horizon of a black hole, gravity is so strong that not even light can escape. The Sun doesn't have an event horizon in that sense, but if you tried to squeeze the entire mass of the Sun into a sphere with a radius of about 3 km, then it would turn into a black hole with an event horizon.

    (b) No. The gravitational force exerted by an object depends on its mass, not its size or density. A black hole with the same mass as the Sun would exert the same gravitational pull on the planets as the Sun does currently.

    (c) Spaghettification is caused by tidal forces, resulting from the difference in gravitational pull on different parts of an object. In smaller black holes, this difference is much greater, stretching objects. It's the gravitational differential, not the strength, that causes spaghettification.

32. (a) When nuclear reactions stop in the core, there is nothing there to produce heat. So, the core starts to cool and the pressure in the core decreases, causing it to compress under the weight of the outer layers. When it compresses, the outer layers its temperature increases.

    (b) Shell fusion increases the internal pressure within the star, pushing the outer layers of the star outwards.

    (c) Red giants are very big but don't have very high masses (for a star, at least). So, the strength of gravity at their surface is pretty weak. As a result, it is relatively easy for gas to escape from the surface.

    (d) A white dwarf

33. (a) Apparent magnitude: the magnitude of an object as it appears from Earth

    Absolute magnitude: the magnitude of an object if it were 10 parsecs away

  (b) Star B

  (c) Star C

  (d) Star E

  (e) You should view it at longer wavelengths. Shorter wavelengths are scattered more.

  (f) A "standard candle" in astronomy is an object or class of objects with a known/predictable brightness (or luminosity). If we know how intrinsically bright the object is and how bright it appears to be on Earth, we can calculate how far away the object must be.

  (g) The answer is that the supernova is farther away in Universe 1, where the flux falls off with $1/r$. Since flux in Universe 1 decreases more slowly with distance, the supernova in Universe 1 would have to be farther away to appear as bright as the one in Universe 2, where the flux decreases more quickly.

34. Tiebreaker — answers will vary.