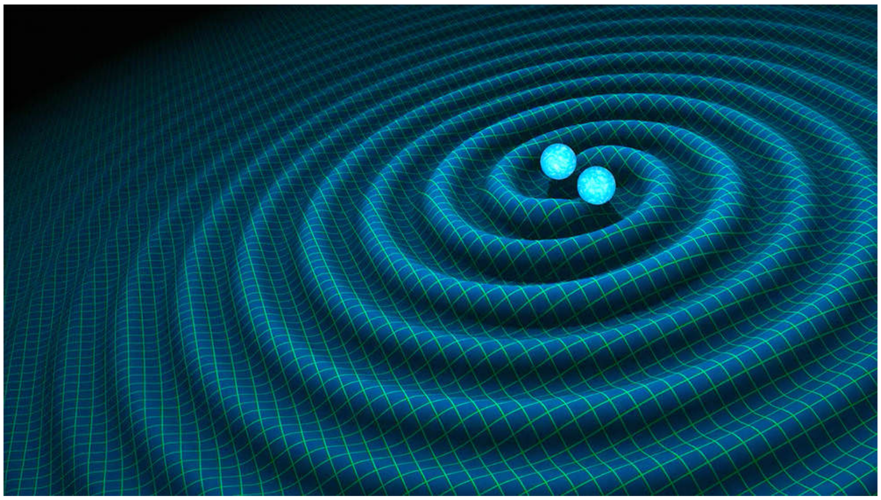
Science Olympiad
Reach for the Stars
UT Regional 2025

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!

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. What force keeps planets in orbit around the Sun?
   A. Gravitational force
   B. Electromagnetic force
   C. Nuclear force
   D. Centrifugal force

3. If you double a star's radius while keeping its temperature constant, its luminosity will:
   A. Double
   B. Increase by a factor of 4
   C. Increase by a factor of 8
   D. Increase by a factor of 16

4. If you double the distance between two objects, the gravitational force between those objects will:
   A. Become 1/4 of what it used to be
   B. Become 1/2 of what it used to be
   C. Stay the same
   D. Double
   E. Increase by a factor of 4

5. 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

6. True or false: Cepheid variable stars are main sequence stars
   A. True
   B. False

7. 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

8. In a contact binary system, mass transfer occurs primarily through:
   A. Stellar winds
   B. Magnetic fields
   C. Roche lobe overflow
   D. Radiation pressure
   E. Tidal forces

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

10. 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

11. Which of the following lists the order of the main spectral types from hottest to coolest?
    A. OBAFGKM
    B. BOGAFMK
    C. ABFGKMO
    D. ABCDEFG

12. Which of the following portions of the electromagnetic spectrum has the highest frequency?
    A. Infrared
    B. Visible
    C. X-rays
    D. 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.

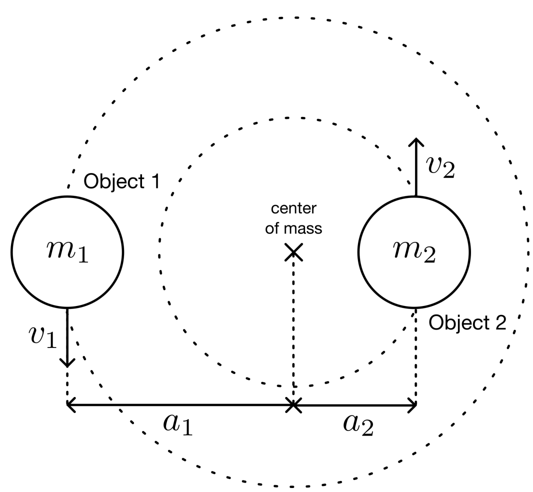
Section C [55 points]

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.
    (a) (2 points) In your own words, explain the difference between absolute magnitude and apparent magnitude.
    (b) (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.
    (c) (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.
    (a) (4 points) In your own words, explain what convection is. What portions of the Sun are thought to be convective?
    (b) (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.
    (c) (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.



    (a) (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.
    (b) (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?
    (c) (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.

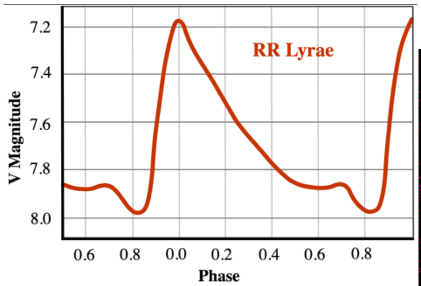
(f) (10 points) To the nearest order of magnitude, estimate (i) the separation between the neutron star and black hole in meters and (ii) the period of the system in seconds.

- 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 m^2 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.*

Image Set



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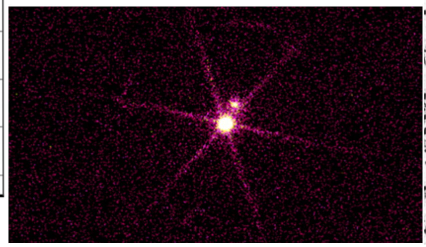

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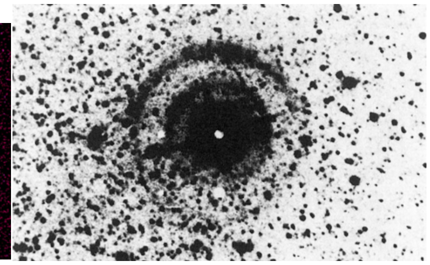

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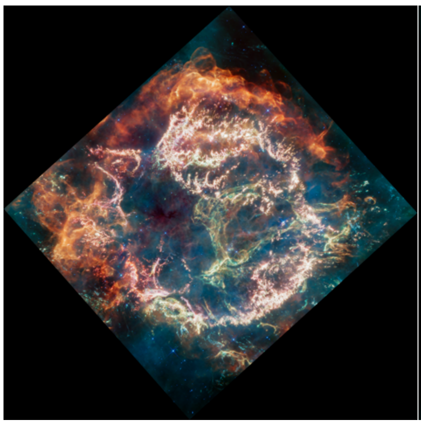

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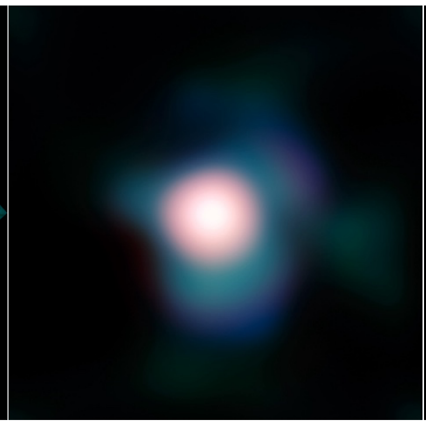

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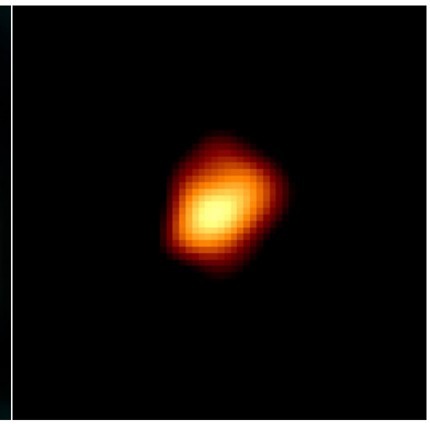

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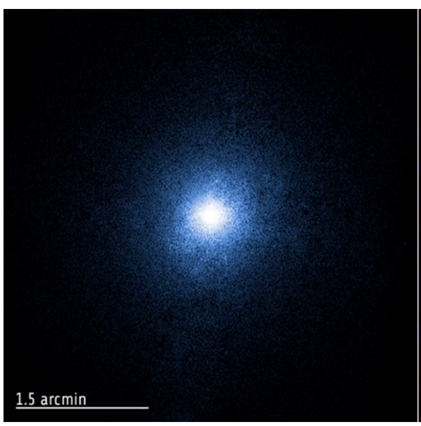

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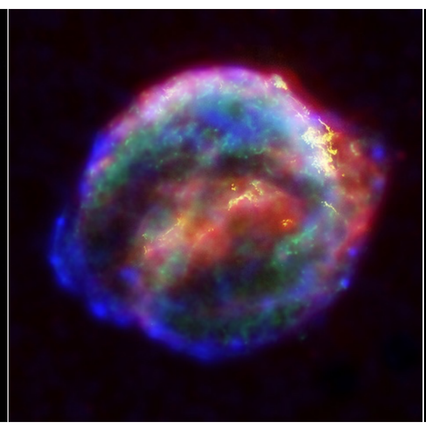

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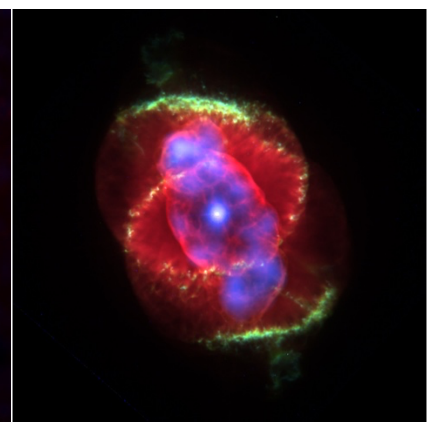

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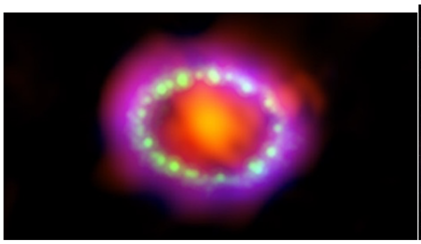

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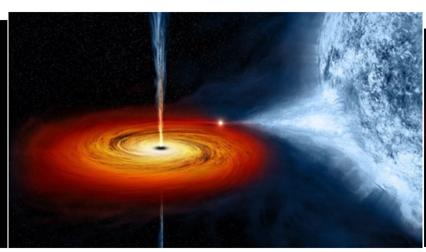

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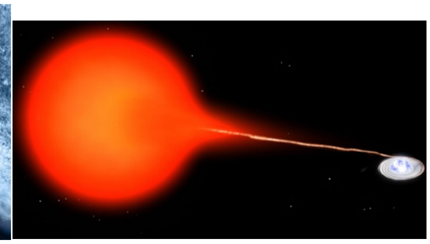

12

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 (80 points)

21. ______________________

22. (a) ______________________

(b) ______________________

(c) ______________________

23. (a) ______________________

(b) ______________________

(c) ______________________

(d) ______________________

24. (a) ______________________

(b) ______________________

(c) ______________________

25. (a) ______________________

(b) ______________________

(c) ______________________

(d) ______________________

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(e) ______________________

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26. (a) ______________________

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(b) ____________________

(c) ____________________

(d) ____________________

27. (a) ____________________

(b) ____________________

(c) ____________________

28. (a) ____________________

(b) ____________________

29. (a) ____________________

(b) ____________________

(c) ____________________

30. (a) ____________________

(b) ____________________

(c) ____________________

31. (a) ____________________

(b) ____________________

32. (a) ____________________

(b) ____________________

(c) ____________________

(d) ____________________

33. (a) ____________________

(b) ____________________

Section C (55 points)

34. (a)

(b)

(c)

35. (a)

(b)

(c)

36. (a)

(b)

(c)

(d)

(e) ____

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(f)

(g)

37.

Section A (20 points)

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

Section B (80 points)

21. 2, 9, 4, 3

22. (a) Image 8

    (b) Type Ia

    (c) No

23. (a) Image 6

    (b) Hubble

    (c) Asymptotic giant branch

    (d) White dwarf/planetary nebula

24. (a) Cygnus

    (b) Horizontal branch

    (c) Helium

25. (a) Sirius

    (b) Chandra

    (c) X-ray

    (d) Large: white dwarf (Sirius B).

    Small: main sequence star (Sirius A).

    (e) The Sirius B is much smaller physically, but emits more x-ray radiation than Sirius A since it is much hotter. In fact, the small dot we see for Sirius A may be due to ultraviolet radiation from Sirius A leaking through the filter on the detector.

26. (a) A light echo occurs when light from a bright event reflects off dust clouds at different distances from Earth, creating a visible echo effect as the reflected light reaches us at different times.

(b) Image 11

(c) Type II (peculiar)

(d) Neutron star

27. (a) Cassiopeia A

(b) JWST

(c) Emission from hot dust

28. (a) Betelgeuse

(b) Adaptive optics is a technology that corrects for atmospheric distortion in real-time by using a deformable mirror that changes shape to counteract the wavefront distortions caused by turbulence in Earth's atmosphere. The system measures these distortions using either a natural or laser guide star, then rapidly adjusts the mirror's shape to restore the original wavefront, resulting in much sharper astronomical images.

29. (a) Chandra

(b) X-ray

(c) Neither - all electromagnetic radiation travels at exactly the same speed in a vacuum, $c = 299,792,458$ m/s

30. (a) NGC 6543

(b) Chandra and Hubble

(c) Hotter

31. (a) A composite image combines data from multiple observations - either from different wavelengths, different times, or different instruments - into a single image. For example, an image might merge X-ray data from Chandra with infrared data from JWST to show different physical processes happening in the same object.

(b) False

32. (a) Cygnus X-1

(b) Black hole

(c) HDE 226868, blue supergiant

(d) Image 7

33. (a) SS Cygni

(b) A dwarf nova is a binary star system where a white dwarf accretes matter from a companion star through an accretion disk. Periodically, the disk becomes unstable and rapidly transfers matter onto the white dwarf, causing a sudden, temporary brightening (outburst) of the system.

Section C (55 points)

34. (a) (2 points) 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) (3 points) The white dwarf is $12.5 - 5 = 7.5$ magnitudes dimmer than the Sun. The magnitude scale is defined such that a factor of 100 in brightness corresponds to 5 magnitudes. (This is Pogson's ratio.) So, the white dwarf is $100^{7.5/5} = 10^{2\times1.5} = \boxed{10^3}$ times dimmer than the Sun.

    (c) (3 points) White dwarfs maintain their size due to electron degeneracy pressure. This quantum mechanical effect prevents electrons from occupying the same energy states (Pauli exclusion principle), creating an outward pressure that balances gravitational collapse regardless of temperature.

35. (a) (4 points) Convection is the bulk transport of material due to temperature differences, where hot material rises and cool material sinks. In the Sun, convection occurs in the outer 30% of its radius, known as the convection zone. (The deep interior is radiative.)

    (b) (6 points) Each dredge-up is worth 2 points:

    1. First dredge-up: After core hydrogen fusion stops (i.e., start of RGB).
    2. Second dredge-up: After core helium fusion ceases (i.e., at the end of the RGB)
    3. Third dredge-up: During a helium flash while on the AGB.

    (c) (2 points) The triple-alpha process, where three helium nuclei fuse to form carbon-12.

36. (a) (2 points) The gravitational force is:

$$\boxed{F = \frac{Gm_1m_2}{a^2}}$$

(b) (4 points) From the definition of center of mass, we know $m_1 a_1 = m_2 a_2$. By definition, $a = a_1 + a_2$. Solving:

$$a_1 = \frac{m_2}{m_1} a_2$$
$$a = a_2 \left(1 + \frac{m_2}{m_1}\right) = a_2 \left(\frac{m_1 + m_2}{m_1}\right)$$

Therefore,

$$\boxed{a_2 = \frac{m_1}{m_1 + m_2} a}$$

When $m_1 = m_2$, the quantity $m_1/(m_1 + m_2) = 1/2$. So, the objects will be the same distance from the center of mass and $\boxed{a_2 = \frac{a}{2}}$.

(c) (6 points) Start by equating the gravtational force and the centripetal force:

$$\frac{G m_1 m_2}{a^2} = \frac{m_2 v_2^2}{a_2}$$

Then, plug in $a = a_2(m_1 + m_2)/m_1$:

$$G m_1 m_2 \times \frac{m_1^2}{a_2^2 (m_1 + m_2)^2} = \frac{m_2 v_2^2}{a_2}$$

Solving for a_2 gives:

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

(d) (2 points) The period is the same for both objects. So, it will be the distance that an object travels divided by that object's speed. For a circular orbit, the distance the object travels is the circumference of the orbit. In the case of Object 2, it will be:

$$\boxed{P = \frac{2\pi a_2}{v_2}}$$

(e) (4 points) Gravitational waves, which are propagating gravitational fields produced by the motion of massive objects. They are often called ripples of space-time curvature. The orbit of the Earth around the Sun is decaying in the same way, but the effect is much weaker since the Earth is not that massive and they are separated by such a large distance.

(f) (10 points) From our knowledge of stellar evolution, we know that the mass of a neutron star should be between the Chandrasekhar limit and the Tolman-Oppenheimer-Volkoff limit. So, 1.4 $M_\odot \lesssim m_{NS} \lesssim 3\ M_\odot$. (People think the Tolman-Oppenheimer-Volkoff limit is between 1.5 $M_\odot$ and 3 $M_\odot$, probably around 2.1 $M_\odot$.) To make the math easier, we can let $m_{NS} \approx 2\ M_\odot = 4 \times 10^{30}$ kg. (Any value between 1.4 and 3 $M_\odot$ would be accepted.) This means $m_{BH} \approx 4\ M_\odot = 8 \times 10^{30}$ kg. After this, there are several ways to estimate a and P. Plugging in numbers to estimate a_2:

$$\begin{aligned}
a_2 &= \frac{Gm_1}{v_2^2}\left(\frac{m_1}{m_1+m_2}\right)^2 \\
a_2 &\approx \frac{7\times10^{-11}\times4\times10^{30}}{(0.2\times3\times10^8)^2}\left(\frac{4\times10^{30}}{4\times10^{30}+8\times10^{30}}\right)^2 \\
a_2 &\approx \frac{7\times10^{-11}\times4\times10^{30}}{(0.2\times3\times10^8)^2}\left(\frac{1}{3}\right)^2 \\
a_2 &\approx \frac{28\times10^{19}}{0.36\times10^{16}}\left(\frac{1}{3}\right)^2 \\
a_2 &\approx \frac{30\times10^{19}}{0.3\times10^{16}}\left(\frac{1}{3}\right)^2 \\
a_2 &\approx \frac{100\times10^{19}}{10^{16}}\times10^{-1} \\
a_2 &\approx 10^4 \text{ m}
\end{aligned}$$

However, this was for a_2. To find a:

$$a = \frac{m_1+m_2}{m_1}a_2 = 3a_2 \approx 3\times10^4 \approx 10^4 \text{ m}$$

The masses of the objects in our system were pretty similar, so it makes sense that a is the same order of magnitude as a_2. Even if you assume a different value for the mass of the neutron star, you should still get the same order of magnitude. Now, to estimate the period:

$$
\begin{aligned}
P &= \frac{2\pi a_2}{v_2} \\
P &\approx \frac{2\pi \times 10^4}{0.2 \times 3 \times 10^8} \\
P &\approx \frac{6 \times 10^4}{0.6 \times 10^8} \\
P &\approx \frac{10 \times 10^4}{10^8} \\
P &\approx 10^{-3}\ \mathrm{s}
\end{aligned}
$$

(g) (2 points) Newtonian mechanics assumes weak gravitational fields and low velocities ($v \ll c$) Here, we have strong fields and velocities of $0.2c$, requiring relativity for accurate results. Generally people say relativity becomes important when you are at speeds of $\gtrsim 0.1c$.

37. (5 points) Tiebreaker — answers will vary.