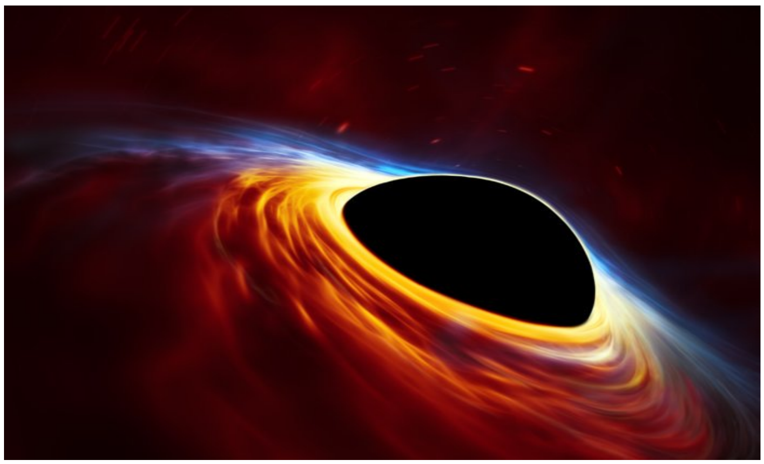
# Science Olympiad
# Astronomy
# Seven Lakes Invitational 2017

December 2, 2017



School: ____________________

Team Number: ____________________

Name(s): ____________________

**Directions:**

- Please turn in all materials at the end of the event.
- Do not forget to put your team name and team number at the top of all answer pages.
- Write all answers on the answer pages. Any marks elsewhere will not be scored.
- Do not worry about significant figures. Use 3 or more in your answers, regardless of how many are in the question.
- Please do not access the internet during the event. If you do so, your team will be disqualified.
- You are more than welcome to take apart the test as long as you restaple the pages in the correct order at the end. Page numbers have been added for your convenience.
- Good luck! And may the stars be with you!

For official use only:

| Page: | 2 | 3 | 4 | 5 | 6 | 7 | Total |
|---|---|---|---|---|---|---|---|
| Points: | 40 | 41 | 6 | 44 | 52 | 57 | 240 |
| Score: | | | | | | | |

**Use Image Set 1 to answer questions on pages 2-4 when applicable. An HR Diagram is given. The amount of points each question is worth is given next to it.**

1. (a) (1 point) What DSO is shown on the cover?
   (b) (1 point) What constellation is this DSO in?
   (c) (1 point) When was this DSO discovered?
   (d) (1 point) What other image shows this DSO?
   (e) (2 points) One theory for the nature of this DSO is that it is a superluminous supernova (SLSN). Usually, SLSNe have been found in active star-producing galaxies. In what type of galaxy was this DSO found?
   (f) (3 points) Why would it make sense for SLSN to be found in galaxies that are relatively young and still producing lots of stars?

2. **Image 1** is an x-ray image of a supernova remnant formed in the Milky Way Galaxy.
   (a) (1 point) What is the name of this DSO?
   (b) (1 point) What is unique about the way this supernova remnant was ejected?
   (c) (2 points) What element does the pink represent, and how does this provide evidence of your answer to (b)?
   (d) (1 point) What is believed to be at the center of this DSO?
   (e) (2 points) This SNR is thought to have produced a certain type of high-energy phenomenon. What is the name of this phenomenon?
   (f) (2 points) How does your answer to (e) provide evidence of (d)?
   (g) (2 points) If you were looking for a Type II supernova, would it be better to look in an open cluster or a globular cluster?
   (h) (3 points) Briefly justify your answer to (g).

3. **Image 2** shows an x-ray image of a supernova remnant with a pulsar at its center.
   (a) (1 point) What is the name of this DSO?
   (b) (1 point) What constellation is this DSO in?
   (c) (1 point) What image shows this constellation?
   (d) (1 point) This pulsar has an extremely powerful magnetic field, a phenomenon observed in some neutron stars. What is the name given to this specific type of pulsars?
   (e) (1 point) What is the most strikingly unusual thing about this pulsar compared to other pulsars?
   (f) (2 points) Describe one of the primary current proposals for the reason behind its unusual behavior.

4. **Image 3** depicts a composite image of a section of the night sky containing a very interesting star.
   (a) (1 point) What is the name of this DSO?
   (b) (1 point) What constellation is this DSO in?
   (c) (1 point) What image shows this constellation?
   (d) (3 points) This star is a special type of star that exhibits extreme luminosities and mass loss. What is the name of this type of star, and why do both of these two phenomena occur?
   (e) (2 points) This star is part of a unique type of binary system where they actually touch. What is the name of this type of binary?
   (f) (1 point) What is the name of the point between these two stars that matter had to cross to become this type of binary?
   (g) (1 point) What letter on the HR Diagram best represents this star?

5. **Image 4** shows the outer layers of another very interesting star.
   (a) (1 point) What DSO is this?
   (b) (1 point) Which telescope took this picture?
   (c) (2 points) What camera on this telescope, which has since been replaced, took this picture?
   (d) (2 points) What letter on the HR Diagram best represents this object?
   (e) (3 points) Astronomical seeing, the blurring and twinkling of astronomical objects like stars due to turbulent mixing in the Earth's atmosphere, is something that makes it harder to accurately view objects in space. What imaging technique, invented by Antoine Labeyrie in the 1970s, allowed astronomers to obtain more precise measurements of this object's photosphere?

6. **Image 6** shows an image of NGC 1910, an open cluster in the LMC.
   (a) (1 point) What is the name of the HII region in this cluster?
   (b) (1 point) Do open clusters typically contain young stars or old stars?.
   (c) (1 point) Which DSO on this year's list is shown in this image?
   (d) (1 point) Which image shows the behavior (light curve) of this object?

7. **Image 12** is an image of an extremely famous pulsar.
   (a) (1 point) What is the name of this DSO?
   (b) (1 point) What section of the electromagnetic spectrum was this image taken in?
   (c) (2 points) In images of this DSO we can see long narrow trails to its side. What are these thought to be?
   (d) (2 points) Why is this pulsar unusual, compared to most pulsars that we observe?
   (e) (2 points) What part of the electromagnetic spectrum does this DSO emit very strongly in?

8. **Image 14** is an image of the night sky containing a pulsar.
   (a) (1 point) What is the name of this DSO?
   (b) (1 point) What part of the electromagnetic spectrum was the pink area taken in?
   (c) (3 points) This image does not only showcase this pulsar-there is an unseen companion also displayed. What is its name, and what type of interstellar body is it thought to be?
   (d) (3 points) This pulsars luminosity appears to violate a basic physics guideline. What is the name of this guideline, and what is thought to be an explanation of this violation?
   (e) (2 points) The pulsar and its companion are designated as ULXs. What does ULX stand for?
   (f) (2 points) How did the discovery of this pulsar contradict what ULXs were previously thought to be?

9. Classify the objects below into one of these groups: star formation region, massive star, type II supernova, pulsar, or binary system.
   (a) (2 points) IC 443 (1 point bonus for correctly stating a second group)
   (b) (1 point) PSR BO 355+54
   (c) (1 point) Circinus X-1
   (d) (1 point) DEM L241
   (e) (1 point) NGC 7822
   (f) (1 point) AG Carinae
   (g) (1 point) NGC 6357

10. Reverse definitions: Write the word or phrase that best matches each description.

(a) (1 point) The upper bound to the mass of neutron stars

(b) (1 point) A rapidly rotating neutron star

(c) (1 point) Force supporting neutron stars against gravity

(d) (1 point) Process that initially cools neutron stars after they have formed

(e) (1 point) $H_\alpha$, $H_\beta$, and $H_\gamma$

(f) (1 point) The radius of the event horizon surrounding a non-rotating black hole

**Use Image Set 2 and the HR Diagram to answer questions on pages 5-7 when applicable. The amount of points each question is worth is given next to it.**

11. **Image A** shows something happening to the period of a pulsar.
    (a) (2 points) What is the general name of this event?
    (b) (1 point) Did the period of the pulsar increase or decrease?
    (c) (1 point) Did the rotational frequency of the pulsar increase or decrease?
    (d) (5 points) Previously, this event was thought to be formed by something called *starquakes*. However, today's astronomers no longer believe that to be the case. Briefly explain what the current consensus is for the cause of these events.

12. (5 points) Determine which of the supernovae shown in **Image B** is/are type II supernovae. Include a brief explanation of some spectral features that support your choice.

13. Consider a red supergiant, whose blackbody spectrum is shown in **Image C**. The star has a parallax of 5.1 milliarcseconds.
    (a) (2 points) What is the surface temperature of this star? Assume $b = 2.898 \times 10^{-3}\text{m} \cdot \text{K}$
    (b) (2 points) How far away is this star, in parsecs?
    (c) (2 points) Suppose that this star has a radius of $1000R_\odot$. What is its luminosity, in solar luminosities?
    (d) (2 points) What is this star's absolute magnitude?
    (e) (3 points) What is this star's apparent magnitude? Would it be visible in the night sky? Humans can generally see stars with apparent magnitude 6 or less.

14. (3 points) A type II supernova remnant is formed from a progenitor star of 19.5 solar masses and has an average expansion velocity of 3,000 kilometers per second. Estimate the kinetic energy released by the supernova that formed the remnant, in Joules.

15. A star has a proper motion of 3940 milliarcseconds/year. The star is 12.4 light years away and the H$\alpha$ spectral line ($\lambda_{\text{rest}} = 656.28$ nm) has been shifted to 656.56 nm.
    (a) (3 points) What is the tangential velocity of the star, in m/s?
    (b) (1 point) Is the star moving towards or away from the observer?
    (c) (3 points) How fast is the star moving towards/away from the observer, in m/s?
    (d) (2 points) What is the true space velocity of this star, in m/s?

16. The following shows the triple alpha process and a table with the masses of Helium-4, Beryllium-8, and Carbon-12.

$$^{4}\text{He} + {}^{4}\text{He} \rightarrow {}^{8}\text{Be} + \gamma$$

$$^{4}\text{He} + {}^{8}\text{Be} \rightarrow {}^{12}\text{C} + \gamma$$

| Isotope | Mass (amu) |
|---|---|
| Helium-4 | 4.0026 |
| Beryllium-8 | 8.0053 |
| Carbon-12 | 12.0000 |

    (a) (1 point) Why is the process called the triple alpha process?
    (b) (2 points) At what evolutionary stage in a star's life (assuming it is massive enough to undergo such a process) will the reactions above occur?
    (c) (2 points) Will a main sequence star at D on the HR Diagram ever fuse helium this way?
    (d) (2 points) Will a main sequence star at E on the HR Diagram ever fuse helium this way?

(e) (5 points) How much energy, in MeV, is (released/taken up) in the process $^4\text{He} +^4 \text{He} \rightarrow^8 \text{Be}$?

(f) (5 points) How much energy, in MeV, is (released/taken up) in the process $^4\text{He} +^8 \text{Be} \rightarrow^{12} \text{C}$?

17. An astronomer peers through his telescope and examines a section of the night sky. He discovers a brightly shining star. The astronomer is pretty sure he has never seen it before, and he decides to observe it.

    (a) (1 point) Over the course of the next year, the astronomer measures out a parallax angle of 0.015 arcseconds. What is the distance to this star, in lightyears?

    (b) (3 points) The astronomer measures a radiative flux of 2 W km$^{-2}$ from this star. What is the star's luminosity, in solar luminosities?

18. Upon careful reexamination of the stars spectrum at a later date, the astronomer is shocked to see that one of the lines he observed had split into two lines slightly shifted from their original position! The astronomer realizes that this must mean the star he has observed is really a system of two stars. Through careful observation, the astronomer measures an orbital period of 2 years and a separation distance of 4 AU, and creates a RV graph shown in **Image D**.

    (a) (3 points) What is the recessional velocity of this binary system, in kilometers per second?

    (b) (3 points) What are the individual masses of the two stars, in solar masses?

    (c) (3 points) What is the distance of star A from the center of mass of this system?

19. **Image E** shows the a plot of apparent magnitude in the V band on the y-axis and $\log P$ on the x-axis from the OGLE and ASAS catalogs for Type I Cepheids (also known as Classical Cepheids) in the Large Magellanic Clouds (LMC). The regression lines for each set of data are:

$$V_{OGLE} = -2.366 \log P + 16.784$$

$$V_{ASAS} = -2.762 \log P + 17.530$$

    (a) (1 point) What do OGLE and ASAS stand for, respectively?

    (b) (3 points) Why is it possible to make a period-luminosity relation based on these things when we only have the apparent magnitudes?

    (c) (1 point) Using the equation for OGLE data, what is the apparent V magnitude of the Type I Cepheid with a period of 80 days?

    (d) (3 points) Suppose that the star from the part above is 120,000 light years from Earth. What is its absolute magnitude?

    (e) (3 points) What is the percent difference in apparent magnitudes of a Type I Cepheid with a period of 120 days between the ASAS and OGLE period-luminosity relationships?

    (f) (2 points) As the period of the Type I Cepheid increases, does the percent difference between the two datasets increase or decrease?

20. The shockwave that traveled through the progenitor of SN 1987A, Sanduleak -69° 202, took 3 hours to reach the surface.

    (a) (4 points) Estimate the speed, in meters per second, of the shockwave travelled through the star, given that the radius of the progenitor was about 10 solar radii. Because the iron core is much smaller than the rest of the star, assume that the shockwave starts in the center.

    (b) (12 points) The part above mentions tells you to assume that the radius of the star (which is a blue supergiant!) is a mere 10 solar radii - a far cry from the 100 solar radii of the red supergiants once thought to be the sole progenitors of core collapse supernovae. Explain, from an energy budget perspective, why the smaller size of the progenitor would cause the resulting supernova to be much dimmer than other type II supernova.

(c) (8 points) What is an observational bias that explains the apparent rarity of type II supernovae from blue supergiant progenitors?

(d) (4 points) When Sanduleak -69° 202 exploded, it took $6.6 \times 10^{-1}$ years for the energy from the supernova to reach the primary ring. What is the radius, in parsecs, of the primary ring?

(e) (4 points) Observations show that the angular radius of the primary ring is $8.10 \times 10^{2}$ milliarcseconds. How far away is SN 1987A from Earth, in kiloparsecs?

(f) (3 points) What is the distance modulus of SN 1987A?

21. Pulsars are rapidly rotating neutron stars that exhibit "pulses" once a rotation. Their incredibly short period presented numerous challenges in understanding their nature after their discovery in 1967 by Jocelyn Bell. There were many theories for what neutron stars could be (e.g. pulsating white dwarfs, pulsating neutron stars, etc), but ultimately, the current model, a rapidly rotating neutron star, prevailed. Background info: The pulsar with the longest period (slowest) is PSR 1841-0456 (P = 11.8s); the pulsar with the shortest period (fastest) is Terzan 5ad (PSR J1748-2446ad, P = 0.00139s). The mean period of a pulsar is about 0.79 seconds.

(a) (6 points) One way of producing a rapid, regular pulse in astronomy is through a binary star system with a very short orbital period. Explain, using Kepler's Third Law, why a binary system of white dwarfs would not be able to produce pulses fast enough, but a binary system of two neutron stars theoretically could. Assume that the mass of each white dwarf or neutron star is exactly $1M_{\odot}$

(b) (6 points) Neutron stars are small enough such that a binary pair of them could orbit close enough to produce rapid pulses with a period in agreement with pulsars. However, this possibility is ruled out by Einstein's general theory of relativity. Explain why, in a short paragraph. Hint: this requires no math; just think about decaying orbits and gravitational waves!

(c) (5 points) Another way to produce these pulses is through oscillations in the star. White dwarfs oscillate with periods between 100s and 1000s. Explain why neutron stars, with a density $10^8$ times higher than white dwarfs, oscillate with a period too short for the slowest pulsars and cannot be a viable explanation for pulsars. Recall that the period of oscillation, $P$, is proportional to $\rho^{-\frac{1}{2}}$, where $\rho$ is the density of the star.

(d) The last way to produce such pulses is through rapid rotation. The period of a rotating star, $P$, is limited by how strong the gravitational acceleration is holding it together - if it's too weak, the star will fly apart.

i. (15 points) Derive an expression for the minimum density a rotating star can have in terms of its rotational period such that it will not fly apart. Hint: equate centripetal force and gravitational force!

ii. (3 points) Using the expression you derived above, explain why a white dwarf cannot physically spin fast enough to be a pulsar. Assume that $M = 0.978M_{\odot}$ and $R = 0.0084R_{\odot}$.

iii. (3 points) Likewise, use that expression to explain why a neutron star can rotate fast enough to accommodate the complete range of periods observed for pulsars. Assume that $M = 1.4M_{\odot}$ and $R = 10km$.