2018 CPS Regionals @ IIT
Astronomy Div. C

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Team Name: ______________________________

Team Number: ______________________________

Participant names: ______________________________

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Here are a few things to keep in mind:

- Read through every question even if you can. They may be easier than they look!
- For numerical questions, you can mostly ignore significant figures, but it should be clear you have the right answer. Three sig figs should be safe.
- Remember your units!
- Write all your answers in your Answer Sheet!

Good luck and have fun!

Problems

Question 1. (12 points) Figure 1 on the picture sheet is a Hertzsprung Russell Diagram.

a-e. Identify the different points on the diagram.

f. What's the name of the process by which Helium nuclei are able to fuse into a Carbon nucleus?

g. Why is there no (or very little) helium fusion early on in a star's life?

h. In post-main-sequence evolution of larger stars, what causes the Helium flash?

i. What branch does the Helium flash mark the end of?

j. What sorts of stars can be found in the instability strip?

k. What mass range of stars can turn into red giants?

l. Mass loss from red giants can form clouds of gas. What type of nebulae are these?

Question 2. (8 points) Wolf–Rayet stars.

a. What's the abbreviation for a Wolf–Rayet star whose spectrum shows hydrogen lines?

b. How do these Wolf–Rayet stars compare in size with others that have no hydrogen?

c. What process is responsible for producing Nitrogen seen in Wolf–Rayet spectra?

d. What other common element emission lines appear in Wolf–Rayet spectra?

e. How does increasing metallicity affect Wolf–Rayet mass loss rates?

f. What's the nebula formed by the ejections of a Wolf–Rayet star called?

g. What range of light is most of a Wolf–Rayet's radiation in?

h. Why would this not be in the visible range like the sun's radiation?

Question 3. (5 points) Cepheid variable stars.

a. Where does the name "Cepheid" come from?

b. When did Henrietta Swan Leavitt discover the Period-Luminosity relation?

c. How did she know the true luminosity to set up the relation to begin with? Or, at least, how did she adjust for differences in apparent and absolute magnitude?

d. What direction is a Cepheid's pulsation in? (radial/tangential/both)

e. A Cepheid's maximum brightness occurs (before/at/after) it reaches minimum radius. Whats this effect called?

Question 4. (11 points) SN 2005cs's light curve (black squares) is shown in Figure 2. Use the light curve and your knowledge to answer the following questions:

a. What type of supernova is this?
b. Is hydrogen present?
c. Nickel-56 deposits energy into the Hydrogen envelope through what radioactive process?
d. Decay of what isotope accounts for the light curve's shape at letter A?
e. Recombination of what element accounts for the light curve's shape at letter B?
f. Before the collapse of the core, the following occurs:

$$^{56}_{26}\text{Fe} + \gamma \rightarrow 13\ ^{4}_{2}\text{He} + 4n$$

$$^{4}_{2}\text{He} + \gamma \rightarrow 2p^{+} + 2n$$

What is the name of this process?

g. What types of photons are destroying Fe-56 (i.e., what range of light)? Is the process exothermic?

h. The following process results from the process described in part f. What is it called?

$$p^{+} + e^{-} \rightarrow n + \nu_e$$

i. As a result of the above process, what type of degeneracy pressure will be absent in the core?

j. Without this pressure, the core collapses. Based on the processes above, what particle deposits kinetic energy to create the shock wave?

k. Going back to part c. - energy from what radioactive decay process accounts for the photon energy released over the timeframe of the light curve?

Question 5. (11 points) On June 8, 2017, LIGO observed the merging of two neutron stars with masses 1.4 $M_{\odot}$ and 2.2 $M_{\odot}$. See figure 3.

a. What's the name of the upper bound on mass of neutron stars around 2 to 3 $M_{\odot}$?
b. What's a typical radius of a neutron star, in kilometers?
c. What pressure supports the neutron star from collapsing due to gravity?
d. Figure 2 shows a time-frequency diagram. What type of radiation drives this?
e. During coalescence, high-energy light is released in what energetic burst?
f. The result of merger is most likely a(n) __________.
g. Could the Sun become a black hole?
h. What's the speed of light around a black hole, in m/s?
i. What's the Schwarzschild radius of this black hole in km? (assume the total mass of the system is 3.6 $M_{\odot}$)

j. Einstein's theory of General Relativity predicts that light's frequency from the edge of the event horizon should __________ (decrease/stay the same/increase) as it escapes the potential well. What's this effect known as?

k. General Relativity also predicts that a clock near the event horizon should measure time __________ (slower than/at the same rate as/faster than) time on a distant clock (in a weak gravitational field).

Note that a "faster" clock near the black hole means that a second near the black hole appears shorter than a second measured far away. Think of GPS satellites or Interstellar.

Question 6. (6 points) Figure 5 shows a light curve representing an eclipsing binary system in circular motion. The first dip represents Star A passing in front of Star B. Note that since this dip is bigger than the second dip, Star B should be brighter and bigger. Let Star A have a radius r_a and Star B radius r_b.

a. What do the flat bottoms of the curve suggest about the orientation of the binary system?

b. The fact that stars appear brighter towards the middle (and darker on the outsides) could make the flat bottoms to be rounded instead. What is this effect called?

c. What is happening in the time interval between t_1 and t_2 represent (in terms of Star A in relation to Star B)?

d. Assume that Star B is significantly brighter than Star A. Then the (fractional) difference in brightness during the first dip becomes $\frac{\Delta\text{Brightness}}{\text{Brightness}} = \left(\frac{r_a}{r_b}\right)^2$. Using the graph, find the ratio $\frac{r_a}{r_b}$.

e. If two stars in a system are very close, parts of a star may exceed its __________ lobe, after which point gravitational attraction to the companion is stronger than to itself, and material will move to its companion. What is the name of this lobe?

f. It's possible to measure the radial velocity of the two stars based on the red/blueshift caused by the orbital motion. If the system were not viewed straight on (there's some inclination), our calculation of the mass of the system may be too __________ (high/low).

Question 7. (5 points) Look at Figure 4 on the pictures sheet.

a. What's this object called?
b. What type of object is it?
c. How far is it from us?
d. How massive is the nebula surrounding this object?
e. What is its rotational period?

Question 8. (4 points) Look at Figure 6 on the picture sheet.

a. What's this object called?
b. How far is it?
c. What constellation is it located in?
d. How wide is it across?

Question 9. (4 points) Consider ASASSN-15lh.

a. When was it first detected? (give a year)
b. What is its peak apparent magnitude.
c. Give one proposal of what ASASSN-15lh is.
d. How far is ASASSN-15lh from us?

Question 10. (6 points) Look at Figure 7 on the picture sheet.

a. What is the name of this object, as it appears in the rulebook?

b. What is its nickname?

c. What type of object is this?

d. What is thought to be the source of this object?

e. What else is though to have resulted from the same source?

f. How old is this object? (just pick one possible value from the range since we don't have a definite date)

Question 11. (4 points) Look at Figure 8 on the picture sheet.

a. What is the name of this object?

b. Where is it located?

c. How has the object changed since it was first observed?

d. What type of object is it?

Question 12. (4 points) The distance modulus is defined as $\mu \equiv m - M = 5\log_{10}(d) - 5$.

a. What is the distance modulus for Alpha Centauri A, which is about 1.34 pc away?

b. If its luminosity fell by a factor of 100 times, how much would the absolute magnitude drop? Or the apparent magnitude? Note that we're not changing the distance, so the distance modulus is constant and the apparent and absolute magnitudes should change by the same amount.

Question 13. (6 points) Two stars are orbiting each other in circular motion. Star A has mass $\frac{1}{3}M_{\odot}$, while Star B has mass $\frac{2}{3}M_{\odot}$. They are located 4 AU from each other.

a. What's the orbital period in (Earth) years? (hint: don't convert to SI)

b. How far is the barycenter (center of mass around which both stars are orbiting) from Star A?

c. If we preserved the semimajor axes of Stars A and B but changed the eccentricity to $e = 0.8$, how would the orbital period change? (hint: think of Kepler's 3$^{\text{rd}}$ law)

Question 14. (4 points) A star's H_{α} emission line is observed to be at 656.20 nm instead of 656.28 nm.

a. How fast is the star receding from us? (ignore relativistic effects)

b. If the star were located 100 pc away from us, how much of this motion would come from the expansion of the universe?

Question 15. (8 points) A main sequence star has luminosity 15 $L_\odot = 5.78 \times 10^{27}$ W and temperature 9200 K. You can assume that $\dfrac{L}{L_\odot} = \left(\dfrac{M}{M_\odot}\right)^{3.5}$ where M is mass rather than absolute magnitude.
For your convenience: $L_\odot = 3.85 \times 10^{26}$ W and $\sigma = 5.67 \times 10^{-8} \dfrac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{K}^4}$.

a. What is the mass of the star? (hint: it's easier to do in $M_\odot$)

b. What's the radius of the star?

c. What's its average density?

d. Compare to the sun's density. For your convenience: $R_\odot = 6.96 \times 10^8$ m, and $M_\odot = 1.99 \times 10^{30}$.

Question 16. (6 points) A star has luminosity 1 $L_\odot = 3.85 \times 10^{26}$ W and is 10 ly = 9.467 $\times 10^{16}$ m away from us.

a. What flux do we see from here? (answer in W m^{-2})

b. Sometimes astronomers like to use cgs rather than mks (SI). Ew. But you should still know the conversion. What is the flux from part a. in erg s^{-1} cm^{-2}? (1 W = 10^7 erg s^{-1})

c. The Hubble Space Telescope has an aperture with diameter 2.4 m. How much power from the star passes through the HST's aperture? (answer in W)
This is why exposure times tend to be pretty long, especially if you're using a comparatively small telescope and are within Earth's noisy atmosphere!