Team name: ______________________________ Team Number: __________

Astronomy: Answer Key

Seven Lakes Invitational 2017
December 2, 2017

1. (a) (1 point) ASASSn-15lh
   (b) (1 point) Indus
   (c) (1 point) June 14, 2015
   (d) (1 point) Image 13
   (e) (2 points) In the central region of a large galaxy
   (f) (3 points) SLSN would be produced by very massive, and therefore, very young stars. These would be more common in younger galaxies with lots of star formation.

2. (a) (1 point) SN W49B
   (b) (1 point) Its matter was ejected asymmetrically from its center
   (c) (2 points) Iron; this iron only makes up half of the SNR, implying its asymmetric creation
   (d) (1 point) Black hole
   (e) (2 points) Gamma-ray burst (GRB)
   (f) (2 points) GRBs are largely produced from star collapse into black holes
   (g) (2 points) Open cluster
   (h) (3 points) Globular clusters typically contain lower mass, older stars that will not produce a supernova. However, an open cluster contains younger stars and it more likely to the higher mass stars that will produce a supernova.

3. (a) (1 point) RCW 103
   (b) (1 point) Norma
   (c) (1 point) Image 5
   (d) (1 point) Magnetar
   (e) (1 point) It has a much slower rotation period
   (f) (2 points) Either an orbiting binary system with another star or its magnetar nature causing debris falling on its magnetic lines to slow it.

4. (a) (1 point) HR 5171A
   (b) (1 point) Centaurus
   (c) (1 point) Image 16
   (d) (3 points) Hypergiants; high luminosity due to their extreme masses, and lose mass through stellar winds due to their very unstable nature, with luminosities around the Eddington limit.
   (e) (2 points) Contact binary
   (f) (1 point) Lagrange point
   (g) (1 point) Z

5. (a) (1 point) Alpha Orionis (Betelgeuse)
   (b) (1 point) Hubble Space Telescope
   (c) (2 points) Faint Object Camera
   (d) (2 points) A
   (e) (3 points) Speckle interferometry

6. (a) (1 point) N119
   (b) (1 point) Young
   (c) (1 point) S Doradus
   (d) (1 point) Image 11

7. (a) (1 point) Geminga
   (b) (1 point) X-ray
   (c) (2 points) Narrow jets from the pulsar's spin poles
   (d) (2 points) Does not emit radio waves
   (e) (2 points) Gamma rays

8. (a) (1 point) M82 X-2
   (b) (1 point) X-ray
   (c) (3 points) M82 X-1, black hole
   (d) (3 points) Eddington limit, possibly because of funneling of in-falling material along magnetic lines.
   (e) (2 points) Ultraluminous X-ray source
   (f) (2 points) It was previously thought that they were caused by matter falling onto black holes, but this was a neutron star.

9. (a) (2 points) Type II Supernova, pulsar
   (b) (1 point) Pulsar
   (c) (1 point) Binary
   (d) (1 point) Binary
   (e) (1 point) Star formation region
   (f) (1 point) Massive star
   (g) (1 point) Star formation region

10. (a) (1 point) Tolman-Oppenheimer-Volkoff limit
    (b) (1 point) Pulsar
    (c) (1 point) Neutron degeneracy pressure
    (d) (1 point) URCA Process
    (e) (1 point) Balmer Lines
    (f) (1 point) Schwarzchild Radius

11. (a) (2 points) Glitch
    (b) (1 point) Decrease
    (c) (1 point) Increase
    (d) (5 points) As a rotating neutron star radiates energy into space, the rotation of its crust slows down, but the neutron whirlpools in the star's interior continue to rotate with the same speed. Some of the whirlpools cling to the crust, and after some time, they deliver a sharp jolt to the crust that makes the crust speed up suddenly.

12. (5 points) B - the presence of H_α, H_β, and H_γ lines

13. (a) (2 points) 3,517 Kelvin
    (b) (2 points) 196 parsecs
    (c) (2 points) 137,108 solar luminosities
    (d) (2 points) -8.013
    (e) (3 points) -1.551, Yes

14. (3 points) 1.755×10^{44} Joules

15. (a) (3 points) 71,000 m/s
    (b) (1 point) Away
    (c) (3 points) 128,000 m/s
    (d) (2 points) 146,400 m/s

16. (a) (1 point) An alpha particle is a Helium-4 nucleus. Three of these helium nuclei (in other words, three alpha particles) are needed to reach the end product of Carbon-12 for the triple alpha process.
    (b) (2 points) Red Giant
    (c) (2 points) Yes
    (d) (2 points) No
    (e) (5 points) 0.0918 MeV is taken up
    (f) (5 points) 7.367 MeV is released

17. (a) (1 point) 217.33 light years
    (b) (3 points) 567 solar luminosities

18. (a) (3 points) 30 km/s
    (b) (3 points) Star A - 10.2 solar masses; Star B - 5.8 solar masses
    (c) (3 points) 1.45 AU

19. (a) (1 point) OGLE - Optical Gravitational Lensing Experiment; ASAS - All Sky Automated Survey
    (b) (3 points) All the Cepheids are about the same distance away from Earth since they are all in the LMC
    (c) (1 point) 12.281
    (d) (3 points) -5.549
    (e) (3 points) 0.65%
    (f) (2 points) Increase

20. (a) (4 points) 6.4×10^5 m/s
    (b) (12 points) The progenitor was relatively small when it collapsed (about 1/10 of the normal size of some red supergiants, which are the normal progenitors for type II supernovae). As a result, more of the supernova's energy had to go into pushing the layers of the star outwards (because gravitational force is stronger at closer distances). As a result, there was less energy left over to contribute to the brightness of the supernova. In fact, SN 1987A was only about 1/10 as bright as expected!
    (c) (8 points) Because blue supergiant type II supernovae are not as bright as those generated by red supergiants, it is harder to see as many of them. As a result, we could be missing blue supergiant type II supernovae while finding type II supernovae that came from red supergiants at the same distance away. The end result would be thinking that supernovae produced by blue supergiants are rarer, when in reality, they are just harder to see due to their lower luminosities.
    (d) (4 points) 0.20 parsecs

(e) (4 points) 51 kiloparsecs

(f) (3 points) 18.535

21. (a) (6 points) Using Kepler's Third Law, we see that if two $1M_\odot$ white dwarfs were to orbit each other with a period of 0.79 seconds (the average period of a pulsar), their mean separation would be about 1.6×10^6 m. Even the most massive white dwarfs typically have radii larger than this, so it would be physically impossible for them to orbit at that distance. This problem is even worse for pulsars with shorter periods (faster rotation), since the separation would have to be even less.

(b) (6 points) The periods of pulsars increase (as shown by observations of them). However, Einstein's theory of general relativity means that the orbit of the orbiting bodies should decay - that is, their period should decrease. This is because gravitational waves from the system cause it to lose energy. These results contradict each other, so orbiting bodies cannot explain pulsars.

(c) (5 points) Neutron stars are 10^8 times denser than white dwarfs, so the period of their pulsation is 10^4 times shorter. This would results in nonradial g-mode periods between 10^{-2} and 10^{-1} seconds. This is much too short to explain the periods of slower pulsars. This discrepancy is even worse if you consider radial fundamental modes, which would vibrate even faster.

(d) i. (15 points) Equating centripetal force and gravitational force yields

$$\frac{v^2}{R} \leq \frac{GM}{R^2}$$

Recalling that $v = 2\pi R/P$ gives

$$\frac{4\pi^2}{P^2} R \leq \frac{GM}{R^2}$$

Noting that

$$\rho^{-1} = \frac{4\pi R^3}{3M}$$

and substituting finally gives the intended answer:

$$\rho_{\min} \geq \frac{3\pi}{GP^2}$$

ii. (3 points) Plugging a value of $P = 0.79$ seconds into the equation above, we find that the minimum density must be about 2.26×10^{11} kilograms per cubic meter. This is considerably more than the usual density for a white dwarf, which is usually on the order of 10^9 kilograms per cubic meter. This can be verified by finding the density of the hypothetical white dwarf that values were given for in the question.

iii. (3 points) Finding the density of the hypothetical neutron star yields an answer on the order of 10^{17} kilograms per cubic meter. This is well above the minimum calculated in the subpart above. Repeating the procedure for the shortest and longest periods verifies that neutron stars can explain the entire range of periods of pulsars.