Exploring the World of Science

Inaugural University of Michigan Science Olympiad Invitational Tournament

Astronomy
(EXAM)

Test length: 50 Minutes

Team number: ___________________________________

School name: ___________________________________

Student names: ___________________________________

Directions:

~Answer all questions on the answer sheet provided. Please do NOT access the internet during the event.

~In order, the tiebreakers for this test are: 24f, 16c, 12b, 23f, 7c, 24b, 3c, 22b, 8c, 21d, and 11a.

~Questions worth 2 points include: 1, 21b, 21d, 22c, 23b, 23c, 23d, 23e, 23f, 24a, 24b, 24e.

~Have fun! If you have any questions about the exam, please email me at arubinstein96@gmail.com.

Section A: DSOs and Concepts. Refer to Image Sheet for Images.

1. Order Images 5, 11, 13, 16 from closest to furthest.

2. Which DSOs, if any, may be seen in the constellation in Image 21?

3. (a) What is the name of the DSO shown in Image 5?
   (b) This DSO contains an HII region. HII refers to Hydrogen in what state? (Excited, ionized, molecular, etc.)
   (c) Young, hot stars often lead to the formation of HII. These stars were observed at what wavelength of light in Image 5?

4. (a) Which Image shows a star-forming complex in the constellation Cepheus?
   (b) One of the hottest stars in this DSO is BD+66 1673, an Algol-type eclipsing binary star. Which Image shows its light curve?
   (c) A group of extremely hot stars, like in this DSO, are collectively known as what type of association?

5. (a) Which DSO is the brightest star in the constellation in Image 17?
   (b) This DSO was the first star (other than the Sun) to have what quantity measured for its photosphere?
   (c) One difficulty when making this measurement was the fact that stars appear dimmer at their edges. What is the name for this phenomenon?

6. (a) What is the Image number for AG Car's light curve?
   (b) AG Car is an LBV, which is demonstrated by what feature of the light curve?
   (c) As a massive LBV, AG Car will likely undergo what type of supernova?

7. (a) Which spectrum (a – d) in Image 22 is most like the spectrum of S Doradus?
   (b) Image 22 contains what type of spectral lines? (Absorption, emission, both, neither, etc.)
   (c) Which letter on the HR diagram (Image 26) best represents S Doradus?
   (d) What region of variability on the HR diagram does this DSO occupy?

8. (a) Image 20 shows which DSO?
   (b) What is the Image number for the light curve that best shows the behavior of this object?
   (c) Based on the light curve for this DSO, what is the inclination of this system?

9. (a) Which Image shows one of the youngest known X-ray binary systems?
   (b) This Image shows observations taken in what wavelength of light?
   (c) This DSO is thought to be bright in this wavelength of light because it may also be a microquasar. This means it produces radiation through what compact, relativistic phenomenon?

10. (a) The light curve in Image 6 shows which DSO?
    (b) One possible explanation for this DSO's incredibly large luminosity is that it is what type of object, a highly-magnetic neutron star?
    (c) An alternative explanation is that a supermassive black hole along the line-of-sight of the supernova asymmetrically ripped apart a star. What is the name for this process (Hint: Its acronym is TDE)?

11. (a) SN 1987a is considered a Type II supernova because of the presence of which element in its spectrum?
    (b) In Image 24, which spectrum (a – d) matches the spectrum of SN 1987a?
    (c) What is the cause of supernovae like SN 1987a?

12. (a) What type of object is at the center of RCW 103?
    (b) RCW 103 would be in what region of Image 26, the HR diagram? (Upper left, upper center, upper right, etc.)
    (c) What is the Image number that shows an artist's depiction of the central object of RCW 103?

13. (a) Which Image shows the Jellyfish Nebula?
    (b) In the X-ray part of this Image, a ring-like structure appears to surround the central object. This may be due to what phenomenon where a sharp change in pressure occurs, like a sonic boom?
    (c) What is the type of morphology for the SNR in the Jellyfish Nebula?

14. (a) Image 13 shows which DSO?
    (b) Based on this Image, what is significant and uncommon about the shape of the DSO?
    (c) What specific type of supernova caused this DSO?

15. (a) What is the Image number for the light curve of Geminga?
    (b) What wavelength of light was used to make this light curve?
    (c) What is the name of the effect where we see "pulses" of radiation from pulsars like Geminga?

16. (a) Which Image shows an artist's depiction of M82 X-2?
    (b) This DSO is known to be ultra-luminous in X-rays, meaning it is brighter than the Eddington Limit. What two forces are assumed to be in balance in this limit?
    (c) Often black holes are the source of ultra-luminous X-rays. The central object of this DSO is a pulsar, therefore will its Eddington limit be higher or lower than that of black holes? Why?

17. (a) Image 16 shows which DSO?
    (b) What is the name for the bright material surrounding the central object of this DSO?
    (c) Often this material piles up when moving at supersonic speeds, forming arcs. What are these features called?

18. (a) DEM L241 is shown in which Image?
    (b) DEM L241 is located in which galaxy?
    (c) The progenitor of the compact object within this DSO may be approximately 20 to 45 solar masses. On the HR diagram (Image 26), what letter(s) best show(s) the approximate position of such a star?

Section B: Math and Concepts. Refer to Image sheet for Images.

19. What is the distance to a star with a parallax of 0.5 mas in kpc?

20. What is the temperature, in K, of a star that peaks in its blackbody emission at 550 nm?

21. Black holes are pretty extreme. Let's calculate some properties for one.

    (a) If a black hole has a mass of 7.52 Msun, what is its Schwarzschild radius in km?

    (b) What is the average density of this black hole in kg/m^3? (Note that "average density" means treating the black hole as a sphere with a radius equal to the Schwarzschild radius.)

    (c) If a student with a mass of 70 kg is 1000 km away from this black hole, what is the force on the student due to the black hole, in N?

    (d) One model for the temperature (in K) of gas around a black hole is $T = (2 * 10^9) * R^{-0.75}$, where R is in m. What is the temperature of gas, in K, where the student is standing (1000 km away)?

22. You observe a Type I Cepheid in a star cluster for multiple days. From its light curve, it has a period of 15 days. From past research papers, the period-luminosity relationship for these stars is:

    $M_v = -2.43 * (\log_{10}(P) - 1) - 4.05$, where P is in days

    (a) Who (first *and* last name) originally discovered this relationship?

    (b) What is the absolute magnitude of this star?

    (c) This Cepheid has an apparent magnitude of 10.0. What is the distance to this star in kpc?

    (d) Using the relation for Cepheids in star clusters, the relation may be recalibrated for Cepheids in what nearby satellite galaxy (there are two options, only one is necessary)?

23. For this question, refer to the light curve of the eclipsing binary star in Image 25. This eclipsing binary contains two stars, Stars C and D. The *smaller dips* in the light curve correspond to Star C passing in front of Star D. This system also happens to be a spectroscopic binary. Past data indicates that Star C is moving at a maximal radial velocity of 128 km/s, while Star D is moving at 277 km/s. The period for this system is 38.5 days.
    Assume: These stars have circular orbits and that Star C is larger and cooler than Star D.

    (a) What is the semi-major axis of this system in au?

    (b) What is the mass of Star C in Msun?

    (c) What is the radius of Star C in Rsun?

    (d) What is the ratio of the temperature of the smaller star to the temperature of the larger star?

    (e) Assume the temperature of the larger star is 15,000 K. What is the luminosity of this star in Lsun?

    (f) What is the Eddington luminosity of this larger star in Lsun? Use the relation assuming a star completely made out of Hydrogen, $L_{Edd} = (3.2 * 10^4) * M$, which uses M in Msun to output a luminosity in Lsun). If this star was made completely of Hydrogen, would the star be undergoing an outflow? Why or why not?

24. A certain supernova remnant (SNR) has an angular size of 1.7”. [Note: Originally, students were meant to measure the angular size of the SNR in Image 27, but the scale never got changed]

(a) Given that the distance to this SNR is 5.193 million ly, what is the diameter of this SNR (measured from left to right in the Image) in ly?

(b) Assuming this SNR has approximately the same density as the surrounding dust and gas throughout the Milky Way (known as the interstellar medium, or ISM), then the SNR has a density of 10^{-21} kg/m^3. Also assuming the SNR is spherical, what is the mass of this SNR in Msun?

(c) Assume that most of the mass from a supernova went into making this SNR. With this assumption, what type(s) of supernova(e) could have produced this SNR?

(d) It is difficult to find the distance of an object that is more than several Mpc away. Hubble’s Law sometimes is used to find distances to faraway objects. Using the distance of 5.193 million ly, and H_0 = 70 km/s/Mpc, what is the recessional velocity of this SNR in km/s?

(e) We can check whether this object could be observed! Hubble’s Law comes from finding recessional velocity based on the redshift of a spectral line. Using the Lyman-α Hydrogen line (λ_0 = 121.6 nm), what is the change in wavelength needed to measure the recessional velocity in part (d)? Hint: It should be small.

(f). How would you change the line used, or the SNR you looked for, so that you *could* apply Hubble’s Law?