Science Olympiad
Astronomy
Solon Invitational 2019

February 2, 2019
Solon, Ohio

School: _____

Team Number: _____

Name(s): _____

Directions:

- Write all answers on the answer sheets. 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.
- Order of tiebreakers: Section B Score, Section A score, #20, #21, and lastly, #27
- Above all else, just believe!

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Section:	A	B	Total
Points:	81	90	171
Score:			

Section A

Use Image Set 1 to answer questions on pages 2-4 when applicable. All questions/parts are worth 1 point each for a total of 81 points. Section A is *not* necessarily easier than Section B; do not spend all of your time here.

1. Order Images 1, 4, 5, and 20 by size (i.e. physical diameter) from smallest to largest.
2. Order SN 2014J, NGC 4993, and 47 Tucanae/X9 from closest to furthest.
3. List all of the letters on the H-R Diagram that represent stars that will not evolve to produce core-collapse supernovae.
4. (a) What is the Messier designation of the DSO pictured in Images 1 and 2?
   (b) What parts of the electromagnetic spectrum were Image 1 and Image 2 taken in, respectively?
   (c) Image 1 has primarily purple and white areas. Which color represents hotter areas?
   (d) Earlier this year, astronomers detected a ULX in this DSO. Would it be easier to detect this type of object in Image 1 or Image 2? *Hint: think about what ULX stands for.*
5. (a) In one sentence or less, explain what makes a starburst galaxy different from a normal galaxy.
   (b) Red arrows are pointing to numerous objects in Image 3. What wavelength of electromagnetic radiation do they emit unusually high amounts of?
   (c) Why is IC 10, the DSO pictured in Image 3, difficult for astronomers to observe, despite its proximity to us?
6. (a) Which image contains the second brightest globular cluster when viewed from Earth?
   (b) Will there be a higher concentration of high-mass stars towards the center or edge of this DSO?
   (c) Which of the four fundamental forces would best explain your answer to the part above? Choose from gravity, electromagnetism, the weak force, and the strong force.
   (d) What are the diagrams shown in Images 34 through 36 called?
   (e) Which of the images mentioned in the previous part (34, 35, and 36) pertain to this DSO?
7. (a) Which image shows the constellation that contains SN 2014J? *Hint: it contains the Big Dipper.*
   (b) What class of supernova (e.g. Ia, IIp, etc) was SN 2014J?
   (c) Will our Sun ever explode as the type of supernova specified in part (b)? Why or why not?
   (d) Which letter on the H-R Diagram best corresponds to the location of the progenitor of SN 2014J?
   (e) Which image shows the galaxy in which SN 2014J took place?
8. (a) What DSO is shown in Image 9?
   (b) What wavelength is this image taken in?
   (c) This image shows inner cavities. How do scientists think these inner cavities were formed?
   (d) This object also has outer cavities, which, as their name implies, are further from the center. Based on the image, which are bigger?
   (e) What other image(s) shows this object?
   (f) What portions of the electromagnetic spectrum is this image taken in?
9. (a) Which image shows Sagittarius A*?
   (b) Which telescope took this image?
   (c) Why is it difficult, if not impossible, to image this DSO in optical light?
   (d) What name have scientists given the molecular-hydrogen-rich gas clouds shown in the image?

10. (a) What is the common name of the closest AGN to Earth?
    (b) Which image shows this object in visible wavelengths?
    (c) What telescope took the image referenced in (c)?
    (d) Which image shows this object in radio wavelengths?
    (e) What is the name of the structure shown in the image referenced in part (e)?

11. (a) What DSO is shown in Image 5?
    (b) What wavelength is this image taken in?
    (c) This image shows two swept-back jets coming from two central bright spots. What causes their swept-back appearance?
    (d) What are the two bright spots?
    (e) There are two more images of this object in Image Set 1. Which ones are they?
    (f) Which of the images in part (e) are taken using Chandra?

12. (a) Which image shows SPT 0346-52 in a composite of radio, visible, and infrared wavelengths?
    (b) Data from ALMA revealed that this galaxy emits an unusually high amount of infrared light. Previously, one explanation was that a supermassive black hole at the galaxy's center caused the surrounding dust and gas to heat up and emit infrared light. However, scientists have ruled out this possibility. Why is that so?
    (c) What do scientists currently believe is the most likely cause of this galaxy's unusually high infrared emission?
    (d) What image shows an image from a computer simulation of this galaxy?

13. (a) What are the NGC designations of the two galaxies shown in Image 12?
    (b) What constellation are they in?
    (c) Which image shows the constellation in part (b)?
    (d) What color represents the star-forming regions in Image 12?
    (e) What is the wavelength of the atomic transition that causes the color in your answer to part (d)?
    (f) When the galaxies finish merging, what type of galaxy (elliptical, spiral, barred-spiral, or irregular) will the merged galaxy most likely be?
    (g) Image 16 shows another image of this DSO. What wavelength is it in?
    (h) What produces the bright spots visible in Image 16?

14. (a) Which image shows Chandra Deep Field South?
    (b) To the nearest power of ten, how many seconds did Chandra observe this patch of the sky? Write your answer as a power of ten (e.g. 10^4).
    (c) Using data from Chandra Deep Field South, what did astronomers discover about the growth rate of black holes in the early Universe?

15. (a) What DSO is shown in Image 18?
    (b) In which direction (up, down, towards the bottom left, etc) is this object moving within the image?
    (c) This galaxy is moving at over 2×10^6 m/s through the surrounding gas, causing much of its gas to get stripped away. Why don't the stars get stripped as well?
    (d) As this DSO moves throughout space, how will its ability to produce new stars be impacted?
    (e) Briefly justify your answer to part (d).

16. (a) Which image shows Bode's Galaxy?

(b) What is the Messier designation for this DSO?

(c) Which image shows the constellation that this DSO is in?

(d) Only one supernova has been detected in this galaxy. What classification (e.g. IIp, IIn, Ia, etc) is this supernova given?

(e) Which letter on the H-R Diagram best represents the behavior of progenitor of the supernova before collapse?

17. (a) Which DSO is shown in Image 24?

(b) What type of galaxy is the DSO? Choose from spiral, barred spiral, lenticular, elliptical, or irregular.

(c) This DSO is famous for being the host of a neutron star merger detected as a gravitational wave. Unlike other gravitational wave events, scientists have been able to constrain the location of the source far more accurately. Why is this so?

(d) Which image shows data from the grvaitational wave detection that took place in this DSO?

18. (a) Which DSO is pictured in Images 31 and 32?

(b) Why is Image 31 so much blurrier than Image 32?

(c) Cepheid variable stars can be used to estimate the distance to this DSO. Which image shows the light curve of a Cepheid variable star?

(d) Which letter on the H-R Diagram best represents the behavior of Cepheid variable stars?

19. Consider the list of the following telescopes: Chandra, Fermi, GALEX, Hubble, Spitzer, and VLA.

(a) Which of these telescopes have been discontinued?

(b) Which of these telescopes are ground-based telescopes?

(c) What is the full name of the astronomer that the Chandra telescope is named after?

(d) What is the (planned) successor to the Hubble Space Telescope?

(e) What does "VLA" stand for?

(f) Order the list of telescopes by the wavelengths they primarily observe, from shortest wavelength to longest wavelength.

(g) Suppose that two telescopes (one big and one small) observe the sky at the same wavelength. Which one would you expect to have the better angular resolution?

Section B

Use Image Set 2 to answer questions on pages 5-6 when applicable. All questions/parts are worth 3 points each for a total of 90 points.

20. Image 1 shows a star's blackbody spectrum. What is its effective temperature, in Kelvin?

21. The Andromeda Galaxy has a diameter of 220,000 light years and is 2.54×10^6 light years from the Milky Way. What is its angular diameter when viewed from Earth, in degrees?

22. Two stars orbit their barycenter (center of mass) with a period of 25 years with a mean separation (semi-major axis) of 10 AU.
    (a) What is the combined mass of the two stars, in solar masses?
    (b) Radial velocity measurements show that one star is travelling three times as fast as the other. What is the mass of the more massive star, in solar masses?
    (c) How far is the more massive star from the barycenter, in AU?

23. Consider a star of radius R, temperature T, and luminosity L. Express your answers to the following parts in terms of one of these three variables (e.g. $10L$, $2R$, etc).
    (a) Star B has radius $2R$ and temperature T. What is its luminosity?
    (b) Star C has radius R and luminosity $2L$. What is its temperature?
    (c) Star D has radius $R/2$ and temperature $2T$. What is its luminosity?

24. Suppose you discover a Type Ia supernova in a distant galaxy. At its brightest, the supernova reaches and apparent magnitude of 12.
    (a) How far away is the galaxy, in Mpc?
    (b) How many times brighter is the Sun than this supernova, when viewed from Earth?

25. A star has a parallax of 0.04 arcseconds and a proper motion of 1008 milliarcseconds per year. Radial velocity measurements indicate that the Hα line has been redshifted 0.04 nanometers.
    (a) What is the distance to this star, in parsecs?
    (b) How long would it take light from this star to reach Earth, in years?
    (c) What is the tangential velocity of this star, in kilometers per second?
    (d) What is the radial velocity of this star, in kilometers per second?
    (e) What is the true space velocity of this star, in kilometers per second? *Hint: Consider using the Pythagorean Theorem and the values you found for parts (c) and (d).*
    (f) An astronomy student looks at the radial velocity and suggests using Hubble's Law to estimate the distance to this star. What distance, in parsecs, does she get when she uses this method? Assume that the Hubble constant, H_0, is 72 km s^{-1} Mpc^{-1} for this part.
    (g) Briefly explain the cause of the discrepancy between the distances found in part (a) and part (f). Which distance is more accurate?

26. Image 2 shows four graphs of different quantities plotted against time for a certain Cepheid variable star, labelled A through D in red.
    (a) Which of the graphs show surface temperature vs. time?
    (b) Which of the graphs show radius vs. time?
    (c) Intuitively, it makes sense that gases heat up when compressed, and these hotter gasses emit more energy. However, a Cepheid variable star's magnitude and surface temperature are at a maximum *after* the star has reached its smallest radius. Briefly explain why this discrepancy exists.

(d) When plotted on an H-R Diagram, Cepheid variable stars are in the Instability Strip. Why do stars in that temperature range pulsate, while hotter or cooler stars generally do not?

(e) Image 3 shows plots of magnitude vs. time of a typical Cepheid at different wavelengths. Notice how as the wavelength increases, the amplitude of the variations becomes smaller and the maximum happens later. Briefly explain why.

27. Image 4 shows possible relation between the stellar mass of a galaxy and its metallicity. In the plot, stellar mass is plotted on the x-axis, and its metallicity is plotted on the y-axis.

(a) When an astronomer refers to "non-metals", what elements are they referring to?

(b) For stellar studies, "metallicity" usually refers to the iron abundance, but in galaxies, astronomers often use oxygen instead. Give an advantage oxygen would have over iron as an indicator of metallicity for galaxies.

(c) Based on the figure, do more massive galaxies tend to have higher or lower metallicities than their less massive counterparts?

(d) Briefly justify your answer to part (c) using astronomy concepts.

28. Suppose we take the relation we explored in the previous question and delve slightly deeper. Image 5 shows the same relation as Image 4, but for at five different epochs (ages) of galaxies.

(a) Which curve (A, B, C, D, or E) represents the youngest galaxy?

(b) What is the recessional velocity, in kilometers per second, of the galaxy represented by curve D?

(c) Based on the figure (and assuming that the five galaxies plotted are representative of an average galaxy), how have the overall metallicities of galaxies changed over time? Essentially, state a trend.

(d) Qualitatively justify your answer to part (c) using astronomy concepts.