Science Olympiad
Astronomy C Division Event
2020 Astronomy Test

NASA Universe of Learning

May 15, 2020

Instructions:
1) Please turn in all materials at the end of the event.
2) Do not forget to put your team name and team number at the top of all answer pages.
3) Write all answers on the lines on the answer pages. Any marks elsewhere will not be scored.
4) Do not worry about significant figures. Use 3 or more in your answers, regardless of how many are in the question.
5) Usually, we would say please do not access the internet during the event. However, you will need to in order to answer Question #21.
6) Feel free to take apart the test and staple it back together at the end!
7) Good luck! And may the stars be with you!
Section A: Use the Image/Illustration Set to answer the following questions. Each question or sub-question in this section is worth one point.

1. (a) What NASA mission resulted in the map shown in image 32?
   (b) What type of radiation is being shown?
   (c) What theory did the results of this mission and radiation map confirm?

2. (a) What is the name and the numbers of the 2 Hubble images that show the furthest Type Ia supernova observed to date?
   (b) What is the number and letter of the image that shows the energy emitted from this type of event?

3. (a) What is the name and specific type of the object in image 3?
   (b) The concurrent observational data from two missions were combined to produce this image. Name the missions and the radiation energy they are observing.
   (c) Which image number displays a structure from one of the missions which had never been observed before, and what is the name of the structure?
   (d) Which two images show the x-ray and optical jets in image 3?

4. (a) What is the image number and the name that contains two merging galaxies?
   (b) What process is producing the blue parts in the image?
   (c) What is the number of the chart that shows the typical galactic spectra of these galaxies?

5. (a) The Chandra illustration in image 10 shows what type of event?
   (b) What is the image number and name of the Chandra observation of this event?
   (c) What type of energy besides high energy radiation does this type of event produce and what is the number of the image that shows this type of energy for a similar event?
   (d) Why was this second type of energy not detected for this object?

6. (a) What is the name and type of object in the Hubble observation shown in image 1?
   (b) What image shows the jet in x-rays?
   (c) What image shows a scaled comparison of energies from the jet? list the energies in order.

7. (a) What is the name of the object in image 13?
   (b) What process formed the structure in the image?
   (c) What type of matter does the image show?
   (d) What is the number of the image that contains this same object and what type of matter does it show?
   (e) What evidence does the different shape of the two types of matter provide?
8.  (a) What phenomenon is being illustrated in image 23?
     (b) What advantage does this phenomenon provide?
     (c) What is the name and image number that contains observational data that involves this
         phenomenon?
     (d) What object was found within this observation that is now being studied?

9.  (a) What is the name of the structure illustrated in image 20 and what type of material is
     surrounding the galaxies?
     (b) What is the image number that illustrates a similar structure?
     (c) What type of object is being observed that lies behind these two structures?
     (d) What are the absorption spectra from these objects being used to determine?
     (e) What image(s) show these spectra?

10. (a) What is the name of the object in image 18 and why is it of special interest?
     (b) What number of the Hubble image showing a population of objects within this object
         and what types of objects are they?
     (c) What image shows a plot of this population?
     (d) What image(s) contain spectra consistent with the majority of the population of objects?

11. (a) The Chandra illustration in image 8 resulted from a study of what types of objects?
     (b) These objects developed in the early universe. They were selected for observation due
         to what unusual emission characteristics?
     (c) What feature of this object is causing the unusual emissions?
     (d) How is this affecting the central black holes?

12. (a) What is the name of the object in image 14 and what type of object is it?
     (b) What process is taking place in this image?
     (c) What is the image number of a more recent study of this object that shows strong radio
         emissions due to shockwaves?
     (d) What is one method of determining if the process in image 14 has finished or is just
         beginning?

13. (a) What image number illustrates the observational data for the GOODS-S 29323 study?
     (b) What question about black holes in the early universe was this study designed to answer?
     (c) The evidence from the study provided what answer to the question?

14. (a) Image 34 classifies galaxies by what characteristic?
     (b) How do galaxies change over time?
     (c) What types of galaxies are in group B? A/D? in C?
     (d) What image number(s) show typical spectra for groups A/D?
     (e) What image number(s) show typical spectra for group B?
     (f) What image number(s) show typical spectra for group C?
Section B: Each question or sub-question in this section is worth one point.

15. Figure 1 depicts the absorption spectra of various types of supernovae.
   
   (a) Which of these spectra (A-D) corresponds to a supernova of Type Ia?
   
   (b) List at least two prominent characteristics of this line which indicate its identity as Type Ia.
   
   (c) Why are these characteristics seen in this type of supernova?

16. Consider an Active Galactic Nucleus (AGN) which has been seen to exhibit increased luminosity, as well as extremely powerful x-ray and gamma ray production, as compared to other known AGNs.

   (a) This is an example of what subclass of AGN?
   
   (b) Astronomers believe that the increased luminosity may be due to the process of Doppler boosting. Briefly (1-2 sentences) describe what physical processes cause Doppler boosting.
   
   (c) Doppler boosting in AGNs is often accompanied by an apparent relativistic paradox known as what?
17. Figure 2 shows the rough spectrum of H2356-309, an AGN in the Sculptor Wall supercluster similar to the theoretical one described in the question above.

(a) The spectrum shows two wide, distinct dips on the left and right edges, corresponding to decreased light detection. Why has this occurred?

(b) The dips are due in part to the presence of widely distributed oxygen atoms, representing convincing evidence for the existence of what large-scale cosmological structure?

(c) What is the Missing Baryon Problem, and how would this structure serve as a possible solution to it?

18. Figure 3 depicts a typical spiral galaxy viewed edge-on.

(a) Which letter corresponds to the bulge region of the galaxy?

(b) MACHOs are a class of compact object commonly found in which region of a galaxy such as the one pictured above (be as specific as possible)?

(c) What percentage of the dark matter in the region you specified in part (b) could be accounted for by MACHOs? How does this compare with current observations?

(d) What is the method by which MACHOs are often detected? How is this method applied to detect MACHOs?
19. Figure 4 shows a labeled schematic of a quasar.

   (a) What letter (A-F) corresponds to the torus of the quasar?
   (b) What letter (A-F) corresponds to the “broad-line region” of the quasar?
   (c) What type of “compact” object comprises the center of this quasar?
   (d) Points B-D correspond to potential viewing angles of the quasar. At which of these viewing angles (B, C, or D) would the quasar appear brightest?
   (e) At which viewing angle (B, C, or D) would the quasar appear dimmest?
   (f) A proposed theory for the varying appearance of quasars is that each quasar is intrinsically similar, but we observe them with different geometry. What is this theory called?

20. In 3-4 sentences, compare observations of Type Ia supernovae with those of the Cosmic Microwave Background radiation in providing evidence for the accelerating expansion of the Universe. How do CMB observations relate back to the theorized existence of dark energy?
Section C: Each question or sub-question in this section is worth one point.

21. Use JS9 to open Chandra observation ID 13515, “A high resolution image of the M87 Jet,” by P.I. Stephen Murray. To find this image, use the search function at https://www.cfa.harvard.edu/archive/chandra/search (the file name of the .fits image is "M87_Murray_Chandra_HRC.fits"). This image was taken with the HRC instrument onboard the Chandra X-ray observatory, which has an energy range of 0.06-10 keV. The exposure time was 74.3 kilo-seconds. Analyze this image with JS9 to answer the following questions. Note that each pixel of the image is 4.2176 arcseconds.

(a) Use the FITS header to determine the month and year that this observation was taken in.

(b) What is the Right Ascension and Declination at the center of the image, in sexagesimal units?

(c) Choose a log scale, and zoom in toward the center of M87. You will see that M87 is not axially symmetric – there is a line of high emitted flux going toward the bottom right of the image. What part of M87 does this region of high emitted flux that stretches from the center outward correspond to?

(d) Use the image to estimate the angular size, in degrees, of this region that stretches from the center of M87 to the bottom right.

(e) M87 lies at a distance of 16.4 Mpc from Earth. What is the physical size of the region above, in kpc?

(f) Use the regions tool to make a circle around the brightest point of M87. What is the peak number of counts per pixel in this image?

(g) Using the peak number of counts per pixel, estimate the total X-ray power in watts emitted from the brightest pixel. Assume that the photons have an energy of 1 keV, which is in the middle of the energy range of the HRC instrument.

22. A Type Ia supernova with an apparent magnitude of 14.63 occurs in a faraway galaxy.

(a) What is the distance to this galaxy, in Mpc?

(b) Assuming $H_0 = 70$ km/s/Mpc, what would the recessional velocity of this galaxy be if it followed Hubble’s law, in km/s?

(c) What redshift does the recessional velocity above correspond to?

(d) Typical uncertainties in $H_0$ are $\approx 2$ km/s/Mpc. What is the approximate percent uncertainty in recessional velocities, and what is the approximate percent uncertainty in distances to galaxies? Is the uncertainty in $H_0$ largely due to uncertainty in recessional velocity, or the uncertainty in distance to galaxies?

(e) The advent of what type of object as a standard candle significantly reduced distance uncertainties in the 1990s, enabling more precise determination of cosmological parameters?
23. Figure 5 above shows the cosmic microwave background (CMB) power spectrum as observed by the Planck spacecraft.

(a) What is the peak angular wavelength of CMB fluctuations, in degrees? Approximately what angular frequency (or “multipole moment”) does this correspond to?

(b) The units on the y-axis tell us about the amplitude of fluctuations in the temperature of the CMB. What is the maximum fluctuation of the CMB, in micro-Kelvin?

(c) The maximum fluctuation of the CMB corresponds to the first peak of the power spectrum, which was measured by the Boomerang and Maxima experiments. What process causes the shape of this first peak in the power spectrum?

(d) The amplitude of the second peak provides fundamental information about the universe. What property of the universe does the amplitude of the second peak constrain?

(e) There are a wide variety of peaks at higher multipole moments. What are these peaks called?

24. The Small Magellanic Cloud (SMC) is a dwarf galaxy that orbits the Milky Way. The SMC has a mass of approximately $7 \times 10^9 M_\odot$, and lies at a distance of 200 kly from the Milky Way.

(a) What is the mass ratio of the SMC to the Milky Way Galaxy?

(b) What is the orbital period of the SMC around the Milky Way Galaxy, in billions of years?

(c) The diameter of the SMC is 7 kly. What is the number density of stars per cubic light year in the SMC? Assume that the SMC is spherical and that every star in the SMC is identical to the Sun.

(d) What is the angular size of the SMC on the sky, in sexagesimal units? Round to the nearest arcminute.

(e) The SMC is tidally interacting with the Large Magellanic Cloud, another satellite galaxy of the Milky Way. Describe one way this interaction might affect your answers to parts (b) or (c) above.
Answer Page: Section A (1 point each)

1. (a) ______________________ (b) ______________________
   (b) ______________________ (c) ______________________
   (c) ______________________ (d) ______________________

2. (a) ______________________ (e) ______________________
   (b) ______________________ (a) ______________________

3. (a) ______________________ (b) ______________________
   (b) ______________________ (c) ______________________
   (c) ______________________ (d) ______________________
   (d) ______________________ (e) ______________________

4. (a) ______________________ (b) ______________________
   (b) ______________________ (c) ______________________
   (c) ______________________ (d) ______________________

5. (a) ______________________ (b) ______________________
   (b) ______________________ (c) ______________________
   (c) ______________________ (d) ______________________
   (d) ______________________

6. (a) ______________________ (b) ______________________
   (b) ______________________ (c) ______________________
   (c) ______________________

7. (a) ______________________ (b) ______________________
   (b) ______________________ (c) ______________________
   (c) ______________________
   (d) ______________________
   (e) ______________________
   (f) ______________________

8. (a) ______________________
   (b) ______________________
   (c) ______________________
   (d) ______________________

9. (a) ______________________
15. (a) 
(b) 
(c) 

16. (a) 
(b) 
(c) 

17. (a) 
(b) 
(c) 

18. (a) 
(b) 
(c) 
(d) 

19. (a) 
(b) 
(c) 
(d) 
(e) 
(f) 

20. 

Answer Page: Section B (1 point each)
21. (a) ______________________________
    (b) ______________________________
    (c) ______________________________
    (d) ______________________________°
    (e) ______________________________ kpc
    (f) ______________________________ counts/pixel
    (g) ______________________________ W

22. (a) ______________________________ Mpc
    (b) ______________________________ km/s
    (c) ______________________________
    (d) ______________________________
    (e) ______________________________

23. (a) __________________ degrees, \( l = \) __________________
    (b) ______________________________ micro-Kelvin
    (c) ______________________________
    (d) ______________________________
    (e) ______________________________

24. (a) ______________________________
    (b) ______________________________ Gyr
    (c) ______________________________ ly^{-3}
    (d) __________________ degrees, __________________ arcminutes (exact)
    (e) ______________________________