Science Olympiad
Astronomy C Division Event
University of Chicago Invitational

The University of Chicago
Chicago, IL

January 12, 2019

Team Number: _____

Team Name: _____

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) Please do not access the internet during the event. If you do so, your team will be disqualified.
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: Refer to the Image/Illustration Set to answer the following questions. Each sub-question in this section is worth one point.

1. (a) Which two images show the galaxy M82?
   (b) What type of galaxy is M82?
   (c) Which supernova occurred in M82 in 2014?
   (d) What type of supernova was this?
   (e) What is special about this supernova? Hint: a specific type of electromagnetic radiation was not seen.
   (f) The brightest pulsar ever discovered lies within M82. What is the name of this pulsar?

2. (a) Which image shows the starburst galaxy IC 10?
   (b) IC 10 has many binary systems composed of compact objects. These binary systems emit radiation at short wavelengths. Emission in which wavelength of radiation gives these binaries their common name?
   (c) What process causes this short-wavelength radiation in compact object binaries?
   (d) What step in the stage of stellar evolution leads a star to collapse into a compact object?
   (e) How massive, in Solar masses, must a star be for it to become a compact object?

3. (a) Which image shows the "runaway galaxy" ESO 137-001?
   (b) ESO 137 is called a runaway galaxy because it is moving very fast through space. Approximately how fast is ESO 137 moving in miles per hour? Give your answer to the closest order of magnitude.
   (c) The intergalactic gas ESO 137 is moving through has been measured using the Chandra X-ray telescopes to be extremely hot. Approximately how hot is this gas, in degrees Fahrenheit? Give your answer to the closest order of magnitude.
   (d) Because ESO 137 is moving so fast through space, it has a long tail of gas following the galaxy. What is happening in this tail of gas, causing strong short-wave electromagnetic radiation?

4. (a) Which image shows the Phoenix Cluster?
   (b) What type of objects is the Phoenix Cluster a cluster of?
   (c) Fill in the blank: the Phoenix Cluster holds a record for having the highest rate of __ formation of any cluster.
   (d) The Phoenix Cluster has large cavities inside of it, however, unlike those in my teeth these cavities weren't carved by sugar but by a different process. What process caused these gaps in the Cluster?
   (e) For fun: what is the full scientific identification of this cluster? Hint: It starts with "SPT-."

5. (a) Which image shows SPT0346-52?
   (b) What wavelength was this image taken in?
   (c) What type of object is SPT0346-52?
   (d) Approximately how far away, in light years, is SPT0346-52? Give your answer to the closest order of magnitude.
   (e) SPT 0346-52 emits copious amounts of infrared radiation. What process likely takes place in this object causing the infrared radiation?

6. Image 1 shows a famous cluster in our own Milky Way Galaxy.
   (a) What is the name of this cluster?
   (b) What type of cluster is this?
   (c) Is this cluster filled with young or old stars? Does this cluster lie near the center or edge of the galaxy?
   (d) What type of variable star is common in this type of cluster?
   (e) This cluster has a compact object with the closest orbit between a star and a black hole ever discovered. What is the name of this object?
   (f) The period of the binary system's orbit is very short. What unit (seconds, minutes, hours, days, years) is best to measure the period of this binary system?

7. (a) What image shows 3C 75?
   (b) What wavelength was this image taken in?
   (c) Which galaxy does 3C 75 reside in? Which galaxy cluster does 3C 75 reside in?
   (d) 3C 75 has an odd dumbbell structure. What process is thought to cause this structure?
   (e) There are two separate bright points in this dumbbell structure. What type of objects are these bright points?

8. Chandra recently took the deepest X-ray image ever, called the "Chandra Deep Field South."
   (a) Which image shows this?
   (b) The image shows the highest concentration of what type of object ever seen?
   (c) This image is approximately 16 arcminutes wide. How many degrees wide is this image?

9. (a) Which image shows NGC 4993/4994?
   (b) What type of galaxy is this?
   (c) A famous detection was made due to two neutron stars in this galaxy merging. What type of "radiation," predicted by the theory of relativity, was detected?
   (d) What was special about this detection? Hint: this merger was seen using multiple types of observations.

10. (a) Which image shows the Antennae galaxies?
    (b) What process is occurring to these galaxies?
    (c) The Antennae in the galaxies are long "arms" extending outwards. What causes these antennae?

11. (a) Which image shows a gas cloud orbiting the galactic center?
    (b) This gas cloud likely will be accreted by the object at the galactic center. What type of object lies at the center of our galaxy?
    (c) What is the name of this object at the center of our galaxy?

12. (a) Which image shows Centaurus A?
    (b) What wavelength was this image taken in?
    (c) A jet of outflowing material emanates from the center of the galaxy. What object lies at the center of the galaxy and causes this jet?
    (d) This galaxy has a large amount of star formation occurring within it. What is likely responsible for this starburst activity?

13. (a) What image shows the galaxy M100?
    (b) What type of galaxy is this?
    (c) M100 is undergoing strong star formation. As a result, what part of the electromagnetic spectrum is it unusually bright in?
    (d) Where does the star formation within M100 occur?

Section B: Each sub-question in this section is worth two points.

14. Star A is a nearby star with a parallax of 0.02".

    (a) How far away is Star A, in parsecs?

    (b) Star A is a main-sequence star with the same effective temperature as the Sun. What is the apparent magnitude of Star A?

    (c) Star A is in a binary system with Star B. Star B has a mass of twice that of Star A. How many times faster is the orbital velocity of Star A than that of Star B?

    (d) Star A and Star B are separated by 10 Astronomical Units. What is the period of their mutual orbit, in years?

    (e) What is the maximum projected angular separation of Star A and Star B, in milli-arcseconds?

15. Star C is a Cepheid variable star with a period of 20 days.

    (a) Using the Cepheid period-luminosity relationship of $M = -\left[2.76\left(\log_{10}P - 1\right)\right] - 4.16$, where M is absolute magnitude and P is period in days, calculate the absolute magnitude of Star C.

    (b) Star C resides in a galaxy that is known to be 1 mega-parsec from Earth. What is the apparent magnitude of Star C?

    (c) Hydrogen-α emission lines from galaxy that Star C resides in are observed to have a wavelength of 656.44 nanometers. This is larger than that expected from laboratory measurements, which is 656.28 nanometers, so the galaxy must be receding from Earth. What is the recessional velocity of Star C, in kilometers per second?

    (d) Using just the data from this galaxy, what is Hubble's constant in kilometers per second per Megaparsec?

16. Answer each of the following questions to order-of-magnitude. Write your answers as powers of ten (that is, write 10^9 as 9, or 10^{-2} as -2).

    (a) There are 100 billion stars in the Milky Way Galaxy. Assuming each star in the Milky Way Galaxy has a mass equal to that of the Sun, what is the total mass of stars in the Milky Way in kilograms?

    (b) The Sun is 8 kilo-parsecs from the center of the Milky Way Galaxy. Assuming that stars in the Milky Way are distributed in a sphere with a radius of 8 kilo-parsecs, what is the density of stars in the Milky Way Galaxy in stars per parsec?

    (c) The Sun's orbital velocity around the center of the Milky Way Galaxy is 230 kilometers per second. How long does it take the Sun to orbit around the center of the Milky Way, in years?

    (d) Assuming Hubble's constant is 65 kilometers per second per Megaparsec, what is the age of the universe in years?

    (e) Using the value of Hubble's constant above, how far is it to the edge of the observable universe, in parsecs?