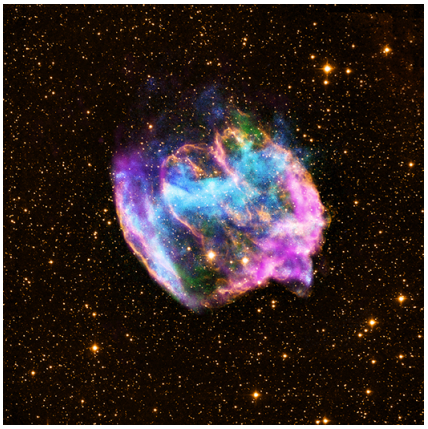
Science Olympiad
Astronomy
Katy Regional Tournament 2017

Beckendorff Junior High
Katy, TX
March 24, 2018



School: _____

Team Number: _____

Name(s): _____

Directions:

- Please turn in all materials at the end of the event.
- Write all answers on the answer pages. 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.
- If you have any questions about the test, please contact me at `adityashah108@gmail.com`
- Above all else, just believe!

For official use only:

Section:	1	2	Total
Points:	90	120	210
Score:			

Section 1: Deep Sky Objects

1. Which DSO is shown on the cover page?
    A. NGC 7822
    B. DEM L241
    C. NGC 6357
    D. SN W49B
    E. PSR B0355+54

2. Which of the following correctly orders the DSOs shown in Images 10, 11, 17, and 18 by distance from Earth, going from closest to furthest?
    A. 10, 11, 17, 18
    B. 11, 18, 17, 10
    C. 11, 10, 18, 17
    D. 18, 17, 10, 11

3. Which object is shown in Image 1?
    A. NGC 7822
    B. NGC 6357
    C. AG Carinae
    D. SN 1987 A

4. What other images also show this object?
    A. Image 2
    B. Images 2 and 3
    C. Image 8
    D. Images 2 and 19

5. In what wavelength is Image 1 taken?
    A. Infrared
    B. Visible
    C. Ultraviolet
    D. X-ray

6. What telescope most likely took Image 1?
    A. Chandra
    B. Spitzer
    C. SuperCosmos Sky Survey
    D. ALMA
    E. Hubble Space Telescope

7. In what wavelength is Image 2 taken?
    A. Infrared
    B. Visible
    C. Ultraviolet
    D. X-ray

8. In what wavelength is Image 3 taken?
    A. Infrared
    B. Visible
    C. Ultraviolet
    D. X-ray

9. Which term best describes the DSO found in Image 3?
    A. Nebula
    B. Galaxy
    C. Star
    D. Supernova Remnant
    E. Hypernova

10. Which letter on the HR Diagram best represents the location of the DSO pictured in Image 4?
    A. W
    B. G
    C. E
    D. A

11. Between which two stages of stellar evolution is the object shown in Image 4?
    A. LBV and WR
    B. Main sequence and subgiant
    C. Cepheid and Red supergiant
    D. Red supergiant and neutron star

12. Which image shows IC 443?
    A. Image 2
    B. Image 9
    C. Image 10
    D. Image 16
    E. Image 21

13. Which of the following is another name for IC 443?
    A. Jellyfish Nebula
    B. Sharpless 3674
    C. 396 Aria
    D. SN 2018fg
    E. Gamma Doradus

14. What constellation is the DSO pictured in Image 5 in?

A. Orion
B. Andromeda
C. Cygnus
D. Ursa Major
E. Ursa Minor

15. What term best describes the DSO found in Image 6?
    A. Star cluster
    B. Star
    C. Planet
    D. Elliptical galaxy
    E. Supernova

16. What type of supernova is this DSO expected to explode as?
    A. II-P
    B. II-L
    C. IIn
    D. IIb
    E. Ia
    F. Ib
    G. Ic

17. What other image shows this same DSO?
    A. Image 4
    B. Image 5
    C. Image 7
    D. Image 10
    E. Image 14

18. In what wavelength was Image 9 taken?
    A. Infrared
    B. Visible
    C. Ultraviolet
    D. X-ray

19. What do the four circular rings present in Image 9 represent?
    A. Neutrino chains
    B. Gamma-ray bursts
    C. Light echoes
    D. Stellar opacity

20. Which image shows a radio-quiet pulsar in the constellation Gemini?
    A. Image 4
    B. Image 11
    C. Image 12
    D. Image 14

21. In what wavelength was the DSO referenced in the previous question discovered?
    A. Gamma rays
    B. X-rays
    C. Microwaves
    D. Infrared

22. In what year did this pulsar undergo a glitch?
    A. 1054
    B. 1572
    C. 1996
    D. 2007

23. When a pulsar undergoes a glitch, what happens to its period?
    A. It becomes shorter
    B. It becomes longer
    C. It stays the same
    D. It becomes impossible to predict

24. Image 15 shows the light curve of a DSO from this year's list. Which image shows this DSO?
    A. Image 1
    B. Image 6
    C. Image 10
    D. Image 14

25. In what galaxy is the DSO whose behavior (light curve) is shown in Image 15?
    A. Milky Way Galaxy
    B. Andromeda Galaxy
    C. Large Magellanic Cloud
    D. Small Magellanic Cloud

26. What is an alternate designation of the DSO shown in Image 10?
    A. Omega Centauri
    B. V766 Centauri
    C. Alpha Centauri
    D. HR 5271 B

27. Which of the following is closest to the surface temperature of the primary star?
    A. 500 Kelvin

B. 5000 Kelvin

C. 50000 Kelvin

D. 500000 Kelvin

28. Image 10 is best described as an

A. Artist impression

B. Image taken by Chandra

C. Image taken by VLT

D. Image taken by Spitzer

E. Image taken by Hubble

29. What DSO is shown in Image 12?

A. RCW 103

B. HR 5171A

C. Geminga

D. PSR B0355+54

30. Which of the following is true about the DSO shown in Image 12?

A. It has strong radio emission and no gamma radiation

B. It has strong radio emission and strong gamma radiation

C. It has no radio emission and no gamma radiation

D. It has no radio emission and strong gamma radiation

31. Image 17 is best described as an

A. Artist impression

B. Image taken by Chandra

C. Image taken by VLT

D. Image taken by Spitzer

E. Image taken by Hubble

32. Which DSO is shown in Image 17?

A. ASASSn-15lh

B. DEM L241

C. AG Carinae

D. SN W49B

E. PSR B0355+54

33. Which of the following is not a possible explanation for the unusually high luminosity of this DSO?

A. Kerr Black Hole

B. Superluminous supernova (SLSN)

C. Gamma ray burst

D. Quark Nova

E. Magnetar

F. Tidal Disruption Event (TDE)

34. Which image shows a luminous blue variable in submillimeter wavelengths?

A. Image 1

B. Image 4

C. Image 6

D. Image 19

E. Image 21

35. To which stage of stellar evolution is the star from the previous question transitioning?

A. Wolf-Rayet

B. Cepheid

C. Red giant

D. Neutron Star

E. RR Lyrae

36. Image 18 shows the DSO DEM L241. A bit of trivia: what do the letters "DEM" represent in its name?

A. The telescope/observatory that discovered it

B. The last initials of the people that first mapped the object

C. The catalog that the object is in

D. The location of the constellation Dorado in which the DSO resides

E. A designation for the type of DSO it is (e.g. black hole, supernova remnant, etc)

37. Which terms best describes the DEM L241?

A. Supernova remnant

B. HII region containing a high-mass x-ray binary

C. High-mass x-ray binary

D. Globular cluster

E. Open cluster

38. Image 20 shows the DSO SN 1987A, one of the most famous supernovae ever. Which of the following is true about the actual supernova?

A. Its progenitor was a blue supergiant as opposed to the typical red supergiant

B. The supernova was unusually luminous

C. Two neutron stars collided to create this supernova

D. The explosion was not visible to the naked eye

E. The supernova occurred in the Milky Way Galaxy

39. Image 20 is best described as an

A. Artist impression

B. Image taken by Chandra

C. Image taken by VLT

D. Image taken by Spitzer

E. Image taken by Hubble

40. What is most likely at the center of SN 1987A?

A. Planet

B. Star

C. Neutron star or black hole

D. White dwarf

E. Comet

41. Which letters on the HR diagram best represents the location of the progenitor of SN 1987A?

A. G and T

B. P and X

C. P, X, and B

D. J and G

E. J, G, and R

42. Which letters (be sure to list all) on the HR diagram's main sequence represent stars that would not end their lives as the type of supernova that SN 1987A is?

A. K and E

B. L, K, and E

C. D, L, K , and E

D. N, D, L, K, and E

E. Q, N, D, L, K, and E

43. How many images directly related to S Doradus are on the image sheet?

A. 1

B. 2

C. 3

D. 4

44. Which DSO has the supernova remnant with the slowest-spinning (that is, longest period) pulsar?

A. RCW 103

B. SN 1987A

C. SNR W49B

D. PSR B0355+54

45. Which image shows the DSO mentioned in the previous question?

A. Image 13

B. Image 17

C. Image 19

D. Image 20

Section 2: Calculations and Applications

Tip: Math in the Astronomy event is often seen as something impossibly hard; as a result, many people simply leave math-related questions completely blank on tests. For this test, it is recommended that you attempt every single question; often, questions seem intimidating, but when you read them, you realize that they're actually quite simple. Most math problems are little more than a few unit conversions and plugging numbers in the right equations. In order to create some separation between the top teams, the problems will get generally progressively harder as the section goes on (but difficulty depends greatly on the person).

The following tables may provide useful information throughout this section:

Astronomical unit	SI unit conversion
Solar mass	1.988×10^{30} kg
Solar radius	6.955×10^{8} m
Solar luminosity	3.846×10^{26} W

Name	Formula
Stefan-Boltzmann Law	$L = 4\pi r^2 \sigma T^4$
Wien's Displacement Law	$\lambda_{peak} = b/T$
Kepler's Third Law	$P^2 \propto a^3/(M+m)$
Distance (parallax)	$d = 1/p$
Distance modulus	$m - M = 5\log(d/10)$

46. Convert each of the following to the specified units. Hint: some conversion factors are given in the table above!
    (a) 4 Astronomical Units (AU) to kilometers
    (b) 10 solar masses to kilograms
    (c) 15 milliarcseconds to arcseconds
    (d) 1.7 arcminutes to radians
    (e) 1.2×10^5 solar luminosities to Watts
    (f) 3.6 parsecs to light years
    (g) 10^{12} Joules to erg
    (h) 700 nanometers to micrometers
    (i) 6.022×10^4 light years to kiloparsecs
    (j) 1000 solar radii to meters
    (k) 2 steradians to square degrees
    (l) The speed of light to centimeters per year
    (m) Hubble's constant to s^{-1}

47. Two stars, of 20 and 50 solar masses, orbit each other with a mean separation of 100 AU. How long does each orbit take, in years? Hint: use Kepler's third law and don't convert any of the units.

48. A certain supernova remnant has an angular radius of 2.9 arcminutes. Radial velocity measurements show that the remnant is expanding at 1,500 km/s.
    (a) Over the course of one year, the remnant's angular radius increases by 0.15 arcseconds. How many kilometers did the radius of the remnant expand by?
    (b) How far away is the remnant?
    (c) What is the physical diameter of the remnant, in kilometers?

49. A black hole has a mass of 10.4 solar masses.

(a) What is its Schwarzschild radius, in km?

(b) If a star with a mass of 5 solar masses is 10 pc away from the black hole, what is the gravitational force between the black hole and the star, in Newtons?

(c) What is the acceleration of the star, in m/s^2, due to the black hole? Assume there are no other forces acting on the star other than the gravitational force.

(d) Spaghettification refers to the vertical stretching and horizontal compression of objects into long thin shapes (rather like spaghetti) as they approach a black hole. Briefly explain why it's more extreme for smaller, stellar-mass black holes than the supermassive black holes at the center of galaxies like the Milky Way.

50. Star A is said to have a luminosity of 6×10^{31} Watts

(a) How much energy does Star A output in one hour, in Watts? Think about the physical definition of luminosity and the unit Watt.

(b) What is the luminosity of Star A, in solar luminosities?

(c) Estimate the mass of this star by using the approximation $L \propto M^{3.5}$.

(d) Analysis of the star's spectrum shows weak Balmer lines and very strong Na I and TiO lines. What is the spectral class (OBAFGKM) of this star?

(e) Further observations determines the temperature of the star is 3500 Kelvin. What is the radius of this star, in solar radii?

(f) Based on the temperature (spectral class) and luminosity of this star, what letter on the HR Diagram best describes its location? Two answers will be accepted, but you only have to put one.

(g) Give two reasons why the approximation we used (c) shouldn't have been used.

51. The main source of energy for core collapse supernovae comes from the release of gravitational potential energy as the core collapses

(a) Given that the core has a mass of 1.5 solar masses, an initial radius of about 10,000 km, and a final radius of 20 km, estimate the amount of gravitational potential energy released to the nearest power of 10

(b) Observations of a supernova remnant determine that it contains 5×10^{31} kg of mass and has an average velocity of roughly 2×10^6 m/s. What is the kinetic energy carried by the supernova remnant?

52. Suppose that a star has a parallax of 40 milliarcseconds when viewed from Earth.

(a) How far away is the star, in light years?

(b) In a future where space exploration is supported by the US government, scientists on Mars also observe this star. Would they see a bigger, smaller, or same parallax angle as on Earth?

(c) Briefly justify your answer to (b)

(d) Although parallax is very useful to find distances to nearby stars, for farther objects, astronomers have to use different methods. What is the main reason this limitation for using parallax exists?

(e) In general, space-based telescopes (like Hipparcos) are able to yield better parallax measurements than ground-based ones. Why is that so?

53. Suppose that a star's spectrum peaks at 450 nanometers.

(a) What is its effective (surface) temperature, in Kelvin? Hint: use Wien's Displacement Law

(b) The Planck function can be thought of plotting wavelength on the x-axis and how much energy is emitted at that specific wavelength on the y-axis. Using this information, would you derive Wien's Displacement Law by taking the derivative of the Planck function or integrating it?

(c) Does the star emit more energy at 400 nanometers or 500 nanometers? You can calculate this using the Planck function, but it isn't necessary to solve the problem if you think qualitatively!

(d) During another observation, the spectrum of the star peaks at 450 nm but the luminosity stayed the same. Did the star get bigger or smaller, and by what factor?

54. If Hubble's constant is 67 km s^{-1} Mpc^{-1}, answer the following questions. Hint: think about the dimensions of the Hubble constant and the dimensions of what you want to find.

(a) What is the age of the universe, in Gyr?

(b) What is the Hubble length, in meters?

(c) What is the Hubble volume, in cubic meters? The Hubble volume is the volume of a sphere with a radius of the Hubble length.

(d) A galaxy is observed with a recession velocity of 10750 km $\cdot$ s^{-1}. How far away is it?

(e) The apparent magnitude of the galaxy in the previous part is 14.7. What is the absolute magnitude? Hint: use the Distance Modulus.

(f) What is the distance modulus, μ, of this galaxy? μ is defined as $m - M$.

55. Image 23 shows a diagram with with magnetic field strength plotted on the y-axis and spin period plotted on the x-axis for pulsars

(a) Are the x and y-axes plotted on a linear or logarithmic scale?

(b) What unit is the y-axis measured in?

(c) What is the period, in seconds, of a pulsar at letter A on the diagram?

(d) In general, would older pulsars be found to the right or left of the diagram?

(e) Which letter on the diagram best represents the location of a pulsar when it is first formed?

(f) What explains the lack of (observable) pulsars in the area near letter F?

(g) What is the name of the dashed line?

(h) What is the name of the blue line?

(i) What type of pulsar is represented by the blue stars in the region denoted with a B?

(j) What type of pulsar is represented by the green crosses?

(k) The evolutionary process denoted by the letter C is best described as (field decay/spin up)

(l) During the evolutionary process denoted by the letter D, is the period of the pulsar becoming longer or shorter?

(m) For the same process as the part above, is the pulsar losing energy faster or slower than it was before?

(n) Out of all the letters on the diagram (A-H), which represents the pulsar with the highest rate of kinetic energy loss? Disregard whether that pulsar actually exists and simply go by the letter's location on the diagram.

(o) Briefly justify your answer to (n)

56. **Tiebreaker:** Suppose you are an observer standing at $x = 0$. An infinite number of stars of luminosity L are at $x = 1$, $x = 2$, and so on. In terms of L, what is the apparent brightness of all the stars combined to you? Don't worry about units/dimensions.

Note: this question was inspired (or rather, stolen) from a video made by 3blue1brown on the Basel problem. It requires a bit of astronomy knowledge in the beginning, but after that, it just becomes a math problem/bit of trivia involving an infinite series. Unless you can immediately tell where this question is going or have finished everything else, it may be better to spend your time on other problems.

The order of tiebreakers is #56, then the total score on Section 2, and then the total score on Section 1. If needed, the last tiebreaker will be comparing the question numbers (e.g. #26 vs. #47) of the last question that the tied teams got right. The higher question number wins the tiebreaker.