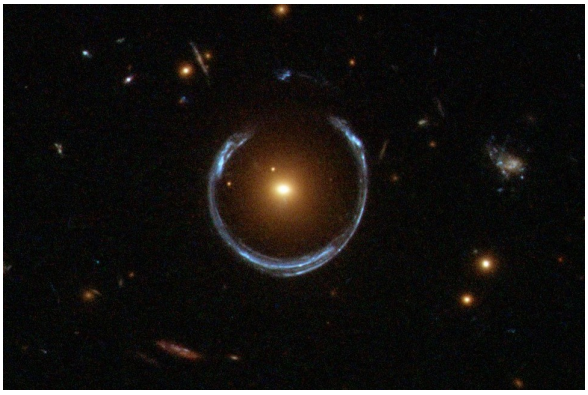
Science Olympiad
Astronomy
Solon Invitational 2020

February 1, 2020
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 what you consider a reasonable amount, regardless of how many are in the question.
- There is no live js9 for this event. Please do not access the internet during the event; if you do so, your team will be disqualified.
- Order of tiebreakers: Section A score, Section B Score, Section C score, first MC question missed, #51(e), #63(a), and lastly, #48(c)
- Above all else, just believe!

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Section:	A	B	C	Total
Points:	90	135	100	325
Score:				

Section A

Choose the correct answer to the following multiple choice questions to the best of your ability. Each question is worth 2 points for a total of 90 points.

1. Which of the following best describes the Sun?
    A. A moon
    B. A planet
    C. A star
    D. A galaxy
    E. A constellation

2. Which of the following best describes the Local Group?
    A. A globular cluster
    B. An open cluster
    C. A galaxy cluster
    D. A galaxy supercluster

3. Megaparsecs are a measure of _____.
    A. Distance
    B. Energy
    C. Time
    D. Speed

4. Luminosity is a measure of_____.
    A. Power
    B. Energy
    C. Distance
    D. Temperature

5. Redshift is a measure of _____.
    A. Volume
    B. Angular momentum
    C. Distance
    D. Energy

6. Which of the following elements is most common throughout the universe?
    A. Hydrogen
    B. Helium
    C. Carbon
    D. Iron
    E. Uranium

7. In the context of astronomy, which of the following elements is not considered a metal? Select all that apply.
    A. Hydrogen
    B. Carbon
    C. Oxygen
    D. Iron
    E. Gold

8. The spectral class of the Sun is:
    A. A
    B. G
    C. M
    D. O

9. Order the following from most abundant to least abundant in the universe: dark energy, dark matter, and regular matter.
    A. Regular matter, dark energy, dark matter
    B. Dark matter, regular matter, dark energy
    C. Dark energy, regular matter, dark matter
    D. Dark energy, dark matter, regular matter
    E. Regular matter, dark matter, dark energy

10. Which of the following lists the order of the main spectral types from hottest to coolest?
    A. OBAFGKM
    B. BOGAFMK
    C. ABFGKMO
    D. ABCDEFG

11. How do stars produce energy?
    A. Chemical reactions
    B. Nuclear reactions
    C. Electron degeneracy pressure
    D. Neutron degeneracy pressure
    E. None of the above

12. Balmer lines refer to spectral line emissions from which element?
    A. Hydrogen

B. Helium
C. Carbon
D. Oxygen
E. Xenon

13. Balmer lines are strongest in which spectral class?
    A. A
    B. B
    C. C
    D. G
    E. O

14. When the Sun "dies", it will become a:
    A. Black hole
    B. White dwarf
    C. Supernova
    D. Red dwarf

15. AGNs are best described as
    A. Explosive and remarkably bright variable stars with unusual spectra
    B. Old galaxies containing mostly neutral hydrogen
    C. Binary systems containing a black hole and white dwarf
    D. Cores of galaxies that are extremely luminous

16. True or false: we expect the Sun to undergo a supernova explosion at the end of its life.
    A. True
    B. False

17. On a typical H-R Diagram, _____ is on the x-axis, while _____ is on the y-axis.
    A. Temperature, pressure
    B. Temperature, luminosity
    C. Temperature, apparent magnitude
    D. Luminosity, apparent magnitude
    E. Radius, temperature

18. The Milky Way is a _____ galaxy.
    A. Spiral
    B. Barred-spiral
    C. Elliptical
    D. Irregular

19. A very hot star will most likely appear _____ in color to an observer on Earth.
    A. Red
    B. Black
    C. White
    D. Blue

20. The least luminous stars are _____ and _____.
    A. Big, hot
    B. Big, cool
    C. Small, hot
    D. Small, cool

21. Which of the following portions of the electromagnetic spectrum have the longest wavelength?
    A. Infrared
    B. Visible
    C. Ultraviolet
    D. Radio

22. Variable stars are located in an area called the _____ on an H-R Diagram.
    A. Uncanny valley
    B. Instability zone
    C. Metastable zone
    D. Instability strip

23. CMB refers to
    A. A period of rapid recombination during the universe's infancy
    B. The oldest electromagnetic radiation in the universe, thought to be a relic of the Big Bang
    C. "Combing", the process by which star formation rates in young galaxies are gradually reduced over time due to feedback
    D. Cosmic Millimeter Bursts, which result from particularly energetic supernovae

24. Supermassive black holes are typically found
    A. At the centers of stars
    B. At the centers of galaxies
    C. In distant galaxies

D. In interstellar space

25. White dwarfs are held up by
    A. Chemical reactions
    B. Nuclear reactions
    C. Electron degeneracy pressure
    D. Neutron degeneracy pressure
    E. None of the above

26. In an astronomy context, the word "relativistic" means:
    A. Slow
    B. Relative to an inertial reference frame
    C. Relative to a noninertial reference frame
    D. Traveling close to the speed of light

27. 21-cm radiation is associated with which of the following elements?
    A. Hydrogen
    B. Helium
    C. Oxygen
    D. Neon

28. LIGO is famous for
    A. Finding alien life
    B. Solving the solar neutrino problem
    C. Discovering gravitational waves
    D. Detecting dark matter around the Milky Way Galaxy.

29. Which of the following sequences below correctly describes the evolution of the Sun from young to old?
    A. Protostar, main-sequence, red giant, white dwarf
    B. Red giant, main-sequence, white dwarf, protostar
    C. Protostar, red giant, main-sequence, white dwarf
    D. White dwarf, red giant, main-sequence, protostar
    E. Red giant, main-sequence, red supergiant, protostar

30. Roughly how long does it take a stellar iron core to collapse during a supernova?
    A. About 1 second
    B. About 1 day
    C. About 1 year
    D. About 1 millennium

31. No matter what its mass, a star spends most of its time on the _____.
    A. Asymptotic giant branch
    B. Red giant branch
    C. Hayashi track
    D. Henyey track
    E. Main sequence

32. The sun will evolve off the main sequence when:
    A. It runs out of helium in its core
    B. It completely runs out of hydrogen
    C. It builds up an inert helium core
    D. It builds up an inert carbon core

33. Stars much more massive than the Sun primarily generate energy through which of the following processes?
    A. Combustion
    B. Antimatter fusion
    C. Proton-proton chain
    D. CNO cycle

34. Mass transfer in binary star systems occurs when at least one star overflows its _____
    A. Chandrasekhar Limit
    B. Eddington Limit
    C. Roche Lobe
    D. Toomre Limit

35. Stars in the same constellation are _____.
    A. The same size
    B. The same distance from Earth
    C. In the same direction when viewed from Earth
    D. The same brightness

36. In a galaxy, where do stars form the most?
    A. In its halo
    B. In its spiral arms
    C. In its nucleus
    D. In the dark matter orbiting it

37. What does "WHIM" stand for?
    A. white-hot interstellar medium
    B. warm–hot intergalactic medium
    C. white-hot imaging medium
    D. white-hot intergalactic mediation
    E. WHIMsical answer choices

38. To the nearest order of magnitude, what fraction of the universe's mass-energy content is thought to be WHIM?
    A. 10^{-4}
    B. 10^{-3}
    C. 10^{-2}
    D. 10^{-1}
    E. 10^{0}

39. To the nearest order of magnitude, what fraction of the galaxies in the universe are thought to be Seyfert galaxies?
    A. 10^{-4}
    B. 10^{-3}
    C. 10^{-2}
    D. 10^{-1}
    E. 10^{0}

40. Iron and nickel have higher binding energies per nucleon than hydrogen and helium, making their fusion at the center of stars being more efficient and energetically productive than hydrogen fusion.
    A. True
    B. False

41. Quasars are thought to be _____ common earlier in the universe's history, which is they are generally _____ us.
    A. more, near
    B. more, far from
    C. less, far from
    D. less, near

42. How do LINERs and Seyfert 2 galaxies differ?
    A. LINERs only emit synchrotron radiation while Seyfert 2 galaxies emit electromagnetic radiation as well
    B. Seyfert 2 galaxies have stronger hydrogen lines, implying a more moderate average temperature
    C. LINERs have stronger low-ionization lines, like [O I] and [N II]
    D. This is a trick question; they are the same thing

43. Order the following events from most recent to oldest: recombination, Big Bang, photon decoupling, reionization.
    A. Big Bang, photon decoupling, reionization, recombination
    B. Reionization, photon decoupling, recombination, Big Bang
    C. Big Bang, recombination, reionization, photon decoupling
    D. Recombination, reionization, photon decoupling, Big Bang

44. Which phenomenon/property is shown in the cover image of this test?
    A. Quantum entanglement
    B. Sunyaev–Zel'dovich effect
    C. Gravitational lensing
    D. None of the above

45. Comoving distance is affected by the expansion of the universe.
    A. True
    B. False

Section B

Use the attached Image Set for the questions in this section. Each part/subpart is worth 3 points for a total of 135 points.

46. (a) Which DSO is shown in Image 1?
    (b) Which telescope took this image?
    (c) In which portion of the electromagnetic spectrum is this image?

47. (a) Image 2 is a composite of x-ray, optical, and infrared data. X-ray data is represented by which color in this image?
    (b) Which DSO is shown in this image?
    (c) Image 9 also shows this DSO. What are the closed yellow curves drawn on the image?

48. (a) Which image shows the first quasar to be discovered?
    (b) Which telescope took this image?
    (c) This quasar lies at the center of what type of galaxy? Choose from elliptical, irregular, spiral, or barred-spiral.
    (d) Which image shows the constellation in which this quasar is located?

49. (a) What type of supernova is shown in Image 4?
    (b) What is notable about this supernova's distance from us?
    (c) In the bottom part of Image 4, there are three panels, labeled "Host galaxy", "Galaxy + Supernova", and "Galaxy subtracted" from left to right. An astronomy student remarks that in the middle panel, they can't make out the supernova. Why is that the case?

50. (a) Image 6 shows GRB 150101B. What does "GRB" stand for?
    (b) Which two telescopes collected the data used to make Image 6?
    (c) Astronomers believe that the event that caused GRB 150101B is similar to the event that caused GW170817. What types of objects have to merge to cause these events?
    (d) Suppose that GRB 150101B was caused by the same type of event as GW170817. Why would LIGO not be able to detect gravitational waves from GRB 150101B?

51. (a) Which image shows the first direct image of a black hole?
    (b) Which DSO is shown in this image?
    (c) This image was taken by the Event Horizon Telescope, a large array of radio telescopes across the world. What interferometric technique do astronomers use to combine the data from all these telescopes to produce an image?
    (d) One of the techniques used in analyzing the data for this image is the CHIRP algorithm. What does CHIRP stand for, and which scientist led its development?
    (e) Just for fun: the story of the Event Horizon Telescope is the subject of a book titled *Einstein's Shadow*, which was published in late 2018 (which I highly recommend reading if you love astronomy!). Who is the author of this book?

52. (a) Which of the following is shown in Image 8? Choose from supernova remnant, galaxy cluster, molecular cloud, and globular cluster.
    (b) The pink/magenta area is (dark/normal) matter, while the blue area is (dark/normal) matter.
    (c) As hinted by the previous part, the dark matter and normal matter in this DSO are relatively separated. Why is this so?

(d) Which other image shows this object? In what wavelength is this other image?

53. (a) Which gravitational wave event is shown in image 10?

(b) This event was the result of the merger of which types of objects?

(c) The mass of the resulting object after the merger is less than the sum of the masses of the two objects that combined before the merger. What happened to the "missing mass"?

54. (a) Image 18 shows three quasars. "Quasar" is a contraction of which phrase?

(b) These quasars are unusually faint in the x-ray portion of the electromagnetic spectrum. What physical property/feature of these quasars is thought to be causing this?

(c) Suppose astronomers discover another quasar with an unusually thick disk, as illustrated in image 18. What does this imply about the mass inflow rate of its supermassive black hole?

55. (a) Which DSO is shown in Image 15?

(b) Which telescope collected the data used to create this image?

(c) In which constellation is this DSO? *Hint: the constellation shares a name with a Harry Potter character!*

(d) Which image shows this constellation?

(e) The paper where I found this image notes that it is "dominated by ICM emission". What is "ICM emission"?

56. (a) Which image shows GOODS-S 29323?

(b) Evidence from observations of this DSO suggest what about the formation of black holes?

(c) Based on research regarding this DSO, which of the following scenarios is more likely? (1) supermassive black holes start large and grow at a normal rate or (2) supermassive black holes start small and grow rapidly.

57. (a) Which DSO is shown in image 17?

(b) This DSO is a blazar. What is a blasar?

58. (a) Which DSO is shown in image 19?

(b) In a paper published in early 2019, astronomers Guido Risaliti and Elisabeta Lusso showed how this type of object could be turned into a standard candle. What is a standard candle?

(c) By using this type of object as a standard candle, what did Risaliti and Lusso discover regarding dark energy?

Section C

Each part/subpart is worth 5 points for a total of 100 points.

59. You are studying a star whose blackbody spectrum peaks at 800 nanometers.
    (a) What is its effective (surface) temperature, in Kelvin?
    (b) Based on your answer to the previous part, what is the spectral class of this star?
    (c) After looking up this star in a catalogue, you realize this is one of the brightest stars in the sky. Based on this information, what area type of star do you expect this to be?

60. The brightest quasar in the night sky is 3C 273. It has an average apparent magnitude of 12.8 and an absolute magnitude of -26.7.
    (a) Based on this information, how far away is 3C 273, in parsecs? *Hint: use the Distance modulus.*
    (b) The accepted distance for 3C 273 is about 7.5×10^8 parsecs. Is this closer or farther than the distance you calculated in the previous part? What could explain this discrepancy?

61. Sun-like stars experience a helium flash, in which the fusion of helium into other elements begins abruptly. The entire helium flash is thought to take only seconds.
    (a) The process through which helium fuses into carbon has a special name. What is it?
    (b) During the brief moment that the helium flash occurs, astronomers estimate that the helium-fusing core has a luminositiy of roughly 10^{11} solar luminosities. Why don't we see a giant flash of light from the surface of the star when this happens?
    (c) Unintuitively, even though the star is adding a source of energy (helium), its luminosity goes down after the initial burst of energy from the helium flash. Explain why.
    (d) Once the helium flash is complete, in what stage of stellar evolution is the star? In other words, what part of the HR Diagram is it now on?

62. Image 1 shows the spectra of three quasars, labelled A, B, and C. The most prominent line in each spectra (i.e. the biggest spike) is due to Hα, which has a rest wavelength of 656.28 nanometers. Throughout this problem, assume that the Hubble constant, H_0, does not change with time and is 70 km/s/Mpc.
    (a) Order the quasars from least distant to most distant.
    (b) What is the redshift of the most distant quasar? *Hint:* $z = (\lambda - \lambda_0)/\lambda_0$
    (c) Estimate the distance to the most distant quasar, in Mpc.
    (d) Further observations determine that the energy flux from the most distant quasar is 2.5×10^{-13} erg cm^{-2} s^{-1}. Estimate the luminosity of this quasar, in solar luminosities, assuming that it emits light equally in all directions.
    (e) Suppose that the Eddington luminosity, in erg/s, can be approximated by the following expression:

$$L_{edd} \approx 10^{38}\left(\frac{M}{M_{sun}}\right)$$

    Astronomers estimate that the supermassive black hole associated with the most distant quasar has a mass of roughly 2×10^7 solar masses. Does your answer to the previous part violate the Eddington luminosity?

63. Image 2 shows a plot of recessional velocity of galaxies as a function of their distance.
    (a) Estimate the Hubble constant, H_0, in km/s/Mpc.
    (b) Use your answer to the previous part to calculate the Hubble time, in Gyr. *Hint: the Hubble time is the reciprocal of the Hubble constant.*

(c) Suppose that the universe is "flat" ($\Omega_0 = \Omega_m = 1$) and Newtonian cosmology holds. Based on this new information, what is the current age of the universe, in Gyr?

64. In roughly 4.5 billion years, astronomers predict that the Andromeda and Milky Way Galaxies will collide. For the purposes of this question, assume that the Andromeda Galaxy contains 10^{12} stars and the Milky Way contains 2.5×10^{11} stars. The radius of the Andromeda Galaxy is on the order of 10^{21} meters.

(a) Estimate the probability that the the Sun will hit a star in the Andromeda Galaxy, assuming that every star is modelled as a hard sphere with a radius of 1 solar radius, no stars are "hidden" behind each other, and that the Sun can hit any part of the Andromeda Galaxy with equal probability. Do not worry about planets or solar systems; only consider the stars themselves.

(b) Estimate the probability that *every* star from the Milky Way Galaxy will not hit a star in the Andromeda Galaxy. Assume the same constraints as the previous part.

(c) A student points out that stars are not evenly distributed within a galaxy; instead, their number density is higher towards the center of the galaxy than the outskirts. Still assuming that no star is "hidden" behind another and that gravitational interactions do not matter, does this impact your calculation from the previous two parts?