# Science Olympiad
# Reach for the Stars
# UT Regional 2024

February 24, 2024
Austin, Texas



**Directions:**

- You are allowed to bring in **two** 8.5" × 11" sheets of paper with information on both sides.
- This exam and image sheet are class sets. Please write all answers on your answer sheet.
- You can take apart the test as long as you restaple the pages in the correct order at the end.
- There is no penalty for wrong answers.
- Above all else, just believe!

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# Section A [53 points]

**When applicable, use the Image Set to answer the following questions. Each multiple choice question and each part are worth 1 point for a total of 53 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. How do stars produce energy?

    A. Chemical reactions

    B. Nuclear reactions

    C. Electron degeneracy pressure

    D. Neutron degeneracy pressure

3. Through which process does the Sun primarily produce energy?

    A. Proton-proton chain

    B. CNO Cycle

    C. Triple alpha process

    D. None of the above

4. Which of the following lists the order of the main spectral types from hottest to coolest?

    A. OBAFGKM

    B. BOGAFMK

    C. ABFGKMO

    D. ABCDEFG

5. Which of the following portions of the electromagnetic spectrum has the shortest wavelength?

    A. Infrared

    B. Visible

    C. Ultraviolet

    D. Radio

6. Molecular clouds primarily consist of which element?

    A. Hydrogen

    B. Helium

    C. Carbon

    D. Oxygen

7. A distant galaxy (say, the Baby Boom Galaxy) is moving away from Earth. As a result, the light from this galaxy as it is viewed on Earth will be blueshifted.

    A. True

    B. False

8. Which of the following is **not** one of the James Webb Space Telescope's primary areas of study?

    A. Early stages of galactic evolution

    B. Exoplanet formation

    C. Energetic supernova detection

    D. Exoplanet atmospheres

9. Hydrostatic equilibrium refers to the state in which a star is supported against the inward force of its _____ by the outward pressure of its _____.

    A. radiation; angular momentum

    B. gravity; radiation

    C. luminosity; gravity

    D. angular momentum; luminosity

10. What is the primary factor that determines the path of a star's evolution?

    A. Its age

    B. Its initial mass

    C. Its temperature

    D. Its composition

11. True or false: a cool star's blackbody spectrum will peak at a longer wavelength than that of a hot star.

    A. True

    B. False

12. Consider two stars, A and B. The temperature of Star A is twice that of Star B, but the radius of Star A is 1/2 that of Star B. What is the ratio of their luminosities, $L_A/L_B$?

    A. 1/2

    B. 1

    C. 2

    D. 4

13. Two telescopes in space (i.e. they don't have to worry about interference from the Earth's atmosphere) of equal size observe the night sky in different wavelengths. Generally, which one will have the better angular resolution?

    A. The one observing in long wavelengths

    B. The one observing in short wavelengths

14. True or false: the Sun is a main sequence star.

    A. True

    B. False

15. True or false: T Tauri stars are more massive than Herbig Ae/Be stars.

    A. True

    B. False

16. Which of the following best describe H II regions?

    A. A region containing $H_2$ molecules

    B. A region containing deuterium, an isotope of hydrogen with a mass number of 2

    C. A region containing singly ionized hydrogen

    D. A region containing both hydrogen and helium, but no other elements

17. As stars form, planets may form around them. Consider a planet orbiting a star with the mass of the Sun at a distance of 4 AU. How long does it take for the planet to go around the star; i.e., what is the period? Assume the mass of the planet is much less than that of the star. *Hint: use Kepler's third law.*

    A. 2 Earth years

    B. 4 Earth years

    C. $2\sqrt{2}$ Earth years

    D. 8 Earth years

    E. 16 Earth years

18. Which of the following is closest to the temperature of a Bok globule?

    A. 10 K

    B. 1000 K

    C. 100000 K

19. True or false: an electron in a hydrogen atom goes from the third energy level ($n = 3$) to the second energy level ($n = 2$). This results in a photon being emitted.

    A. True

    B. False

20. True or false: more massive protostars take longer to reach the main sequence.

    A. True

    B. False

21. Let the amount of time the Sun spends on the main sequence be $t_{\text{Sun}}$. Another star has 4 times the mass of the Sun and spends $t_*$ on the main sequence. What is $t_*/t_{\text{Sun}}$?

    A. 1/32

    B. 1/4

    C. 1

    D. 4

    E. 32

22. What element are main sequence stars primarily composed of?

    A. Hydrogen

    B. Helium

    C. Carbon

    D. Oxygen

23. The pulsations in T Tauri stars are driven by opacity in the stellar envelope due to what ion?

    A. $H^+$

    B. $Li^+$

    C. $O^+$

    D. $He^+$

24. True or false: on the main sequence, more massive stars are more luminous.

    A. True

    B. False

25. True or false: on the main sequence, more massive stars have smaller radii.

    A. True

    B. False

26. (a) What DSO is shown in Image 1?

    (b) The center of this DSO appears completely black, but towards the edges, we can start to make out some stars. Why is that the case?

27. (a) Which image shows the Baby Boom Galaxy?

    (b) This galaxy has its name due to the extremely high rate of star formation within it. To the nearest order of magnitude e.g., 0.1, 1, 10, 100, 1000, etc.), how many new stars are formed every day in this galaxy?

28. (a) What DSO is shown in Image 3?

    (b) This DSO is sometimes described as an "embedded" cluster. What does that mean?

29. (a) Which image shows HL Tauri?

    (b) What spacecraft or telescope collected the data to create this image?

30. (a) Which image shows M42, the Orion Nebula?

    (b) What spacecraft or telescope collected the data to create this image?

    (c) In what portion(s) of the electromagnetic spectrum (e.g., visible, infrared, etc.) was/were the data in this image collected?

    (d) In your own words, briefly describe what a nebula is.

31. (a) Which image shows Stephan's Quintet?

    (b) What is the blue arc across the top center of the image?

32. (a) Which image shows 30 Doradus, the Tarantula Nebula?

    (b) 30 Doradus is thought to be one of the largest H II regions in the Local Group. In your own words, explain what the Local Group is.

33. (a) Image 8 shows an artist's illustration of one of the DSOs on this year's rules. Which one?

    (b) Is this DSO older or younger than the Sun?

34. (a) What DSO is shown in Image 9?

    (b) Fill in the blank: this DSO was the youngest _____ to have had an outburst.

35. (a) Image 10 shows an exoplanet observed around one of the stars on this year's rules. What is the name of the star?

    (b) What spacecraft or telescope collected the data to create this image?

    (c) Through what exoplanet detection method was this exoplanet discovered? Choose from transit, radial velocity, and direct imaging.

36. (a) What DSO is shown in Image 11?

    (b) Which of the following types of pre-main sequence stars is this DSO? Choose from Herbig Ae/Be, T Tauri, and FU Orionis.

37. (a) What image shows NGC 1333?

    (b) In what portion(s) of the electromagnetic spectrum (e.g., visible, infrared, etc.) was/were the data in this image collected?

    (c) What constellation is NGC 1333 in?

# Section B [30 points]

38. **Binary systems.** Although the Sun is the only star in our Solar System, a large fraction of T Tauri stars are members of binary or multiple star systems. Consider the system depicted below, in which two stars of masses $m_1$ and $m_2$ are separated by a total distance $a$.
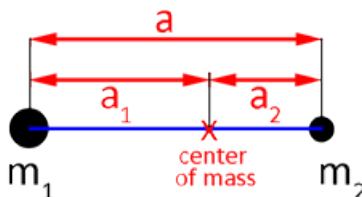


   (a) (2 points) Using Newton's Law of Gravity, write an equation for the force of gravity between these two stars.

   (b) (2 points) Imagine that we were to double $m_1$ while keeping $m_2$ the same. By what factor would the force of gravity increase?

   (c) (3 points) Determine $a_1$, the distance between the star of mass $m_1$ and the center of mass of the binary system. Express your answer only in terms of $m_1$, $m_2$, and $a_2$.

39. **Cloud collapse.** Stars are thought to be formed from the collapse of large clouds of gas and dust. But what conditions lead to cloud collapse? Let's take a look...

   (a) (2 points) Based on your intuition, do you think the cloud is more likely to collapse if it is very hot or very cold? Explain your answer.

   (b) (2 points) Based on your intuition, do you think the cloud is more likely to collapse if it has a very high density or very low density? Explain your answer.

   (c) (5 points) Let's put some math to this. Consider a spherical cloud that consists of $N$ uniformly distributed, spherically symmetric molecules of mass $\mu$ at a temperature $T$. The kinetic energy of the cloud is $K = \frac{3}{2} N k_B T$. Write an expression for $K$ in terms of its radius $R$ and density $\rho$.

   (d) (5 points) The gravitational potential energy of our cloud is approximately $U = -\frac{3}{5} \frac{GM^2}{R}$, where $M$ is the total mass of the cloud. Write an expression for $U$ in terms of its radius $R$ and density $\rho$.

   (e) (5 points) The virial theorem states that on average, $2K = -U$. Using this, solve for the *Jeans' length*, the radius at which the cloud is in equilibrium. Will the cloud collapse if its radius is larger or smaller than this value?

   (f) (4 points) Real clouds aren't uniformly dense, however. What area of the cloud is likely to be the densest? Would this non-uniformity in the density increase or decrease the Jeans' length?

40. *Tiebreaker:* When preparing for this event, you probably studied some concepts that weren't covered explicitly on this exam, simply because this exam can't be infinitely long. Choose one of them and talk about it in as much detail as you can.