Science Olympiad
Reach for the Stars
UT Invitational 2023

December 2, 2023
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 [55 points]

When applicable, use the Image Set to answer the following questions. Each part is worth 1 point unless stated otherwise.

1. (2 points) Order the following objects by the stage of stellar evolution they represent (i.e., their age), from youngest to oldest: T Tauri, HOPS 383, Barnard 68, and HD 95086.

2. (2 points) Order the following objects (or groups of objects) by their physical size, from smallest to largest: Stephan's Quintet, Messier 42, HL Tauri, and Baby Boom Galaxy.

3. (a) HR Diagrams contain a band of stars going from the top left corner to the bottom right corner. What type of stars (e.g., white dwarf, red giant, main sequence star, etc.) does this correspond to?
   (b) The Sun is part of this group of stars. What letter on the HR Diagram at the end of the Image Set best corresponds to the Sun?
   (c) What element are these stars fusing in their cores?

4. (a) What is the name of the DSO shown on the cover of this test? *Hint: it is in the constellation Orion.*
   (b) This DSO is called a nebula. In your own words, explain what a nebula is.
   (c) Which image shows the first photograph of this DSO ever taken?

5. (a) Which image shows Stephan's Quintet? *Hint: look for the image that has multiple galaxies clearly visible in it.*
   (b) What constellation is Stephan's Quintet in?

6. (a) Image 1 shows one of the (if not the most) active star-making galaxies in the universe. What is its name?
   (b) Data from three telescopes were used to create this image. Name at least one if them.
   (c) What does the data in green (at the center of the image) represent?
   (d) What does the data in red/orange around the green splotch represent?

7. (a) What DSO is shown in Image 3?
   (b) Why does this DSO appear as a dark blob? In other words, why is it difficult to see through this DSO in visible light?
   (c) Astronomers think that this DSO may form a star in the future. In general, is it easier for gas clouds to collapse when they are hot or cold? Explain your answer.
   (d) What is the name of the mass above which internal gas pressure is not strong enough to prevent gravitational collapse of a region filled with matter?

8. (a) Which image shows NGC 1555?
   (b) In what portion of the electromagnetic spectrum (ultraviolet, visible, infrared, etc.) was this image taken?
   (c) This image also shows another DSO listed in the rules. What is its name?

9. (a) What DSO is shown in Image 4?
   (b) In what portion of the electromagnetic spectrum (ultraviolet, visible, infrared, etc.) was this image taken?
   (c) What spacecraft or telescope took the data used to make this image?
   (d) What do the knotty yellow-green features located in the lower portion of the image represent?

10. (a) Which image shows 30 Doradus?

(b) What galaxy is 30 Doradus in?

11. (a) Which DSO is shown in Image 5?
    (b) What spacecraft or telescope took the data used to make this image?
    (c) What causes the "bubble-like" shapes in the upper central region of this image?

12. (a) Image 8 shows ripples in one of the DSOs listed on this year's rules. Which DSO is it?
    (b) What forms these ripples?

13. (a) What DSO is shown in Image 9?
    (b) What spacecraft or telescope took the data used to make this image?
    (c) This spacecraft or telescope has been described as the successor to the Hubble Space Telescope. What is one advantage it offers over Hubble in terms of its observational capabilities?

14. (a) Which image shows HD 141569?
    (b) What spacecraft or telescope took the data used to make this image?
    (c) What constellation is HD 141569 in?

15. (a) What DSO is shown in Image 10?
    (b) What are the gaps in the disk thought to represent?
    (c) In what portion of the electromagnetic spectrum (ultraviolet, visible, infrared, etc.) was this image taken?
    (d) This image was taken by Atacama Large Millimeter Array (ALMA) in Chile, which is at an elevation of 5,000 meters above sea level. (For reference, this is about three times higher than Denver, Colorado.) Why would being at a high elevation help with taking better images?
    (e) ALMA consists of 66 telescopes spread out over a large area, which work together to create the images through a process called interferometry. In your own words, explain what this is.

16. (a) Which image shows the HD 100546 system?
    (b) What spacecraft or telescope took the data used to make this image?
    (c) What type of pre-main sequence star is HD 100546? *Hint: HD 100546 has a mass of 2 solar masses.*
    (d) Which letter on the HR Diagram at the end of the Image Set corresponds with this type of pre-main sequence star? (If there are multiple, you only need to provide one.)

17. (a) What DSO is shown in Image 14?
    (b) What spacecraft or telescope took the data used to make this image?
    (c) Circle one word from each pair: This DSO is thought to contain a large amount of O-type stars. Compared to the Sun, O-type stars are (more/less) massive and have (shorter/longer) main-sequence lifetimes.

18. (a) What DSO is shown in Image 15?
    (b) Which letter on the HR Diagram at the end of the Image Set corresponds with this type of pre-main sequence star? (If there are multiple, you only need to provide one.)
    (c) There is another DSO on this year's rules that does not appear on the Image Set and is the same type of pre-main sequence as this DSO. What is it?

Section B [50 points]

19. **Hydrogen.** The most common element in the Universe is hydrogen, which accounts for about 75% of all normal matter. It exists in several forms, which we see represented in the dust and gas clouds that eventually form stars.

    (a) (2 points) Astronomers use the notation "H I" to refer to neutral, un-ionized hydrogen atoms. How many protons and electrons are in one of these atoms?

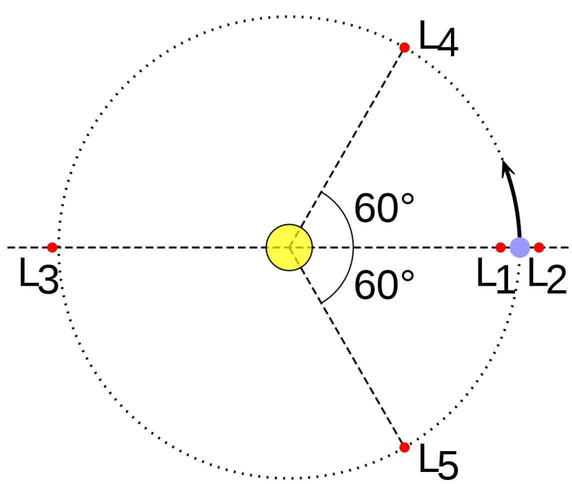
    (b) (2 points) When the hydrogen atom becomes ionized, astronomers call it "H II". In your own words, explain what it means to ionize an atom.

    (c) (3 points) H II regions are typically found near O or B type stars, which are very hot. Why would these types of stars be more conducive to creating H II regions as opposed to cooler stars?

    (d) (3 points) Hydrogen can also exist as a molecule, H_2, which is more stable (i.e., lower energy) than two separate neutral hydrogen atoms. Why might that be the case?

    (e) (5 points) Although H_2 is more stable than atomic hydrogen, the process through which H_2 forms in space is quite slow. Astronomers think it involves atomic hydrogen sticking to the surfaces of dust grains, where hydrogen atoms move around and eventually react with each other to form H_2. Bok globules (which are extremely cold and dense compared to other gas clouds) contain lots of H_2. Why do you think that it is easier to have H_2 in areas that are cold and dense?

20. **JWST.** Unlike the Hubble Space Telescope, which is in low Earth orbit, engineers made the conscious decision to put JWST at the "L2" Lagrange point in the Sun-Earth system.



    (a) (3 points) The Sun-Earth system has five Lagrange points, as shown in the diagram above. In your own words, explain what a Lagrange point is.

    (b) (3 points) Why did it not make sense for JWST to be in low Earth orbit?

    (c) (3 points) In principle, L3 could satisfy a lot of the same requirements as L2. Why is it better for JWST to be at L2 instead of L3?

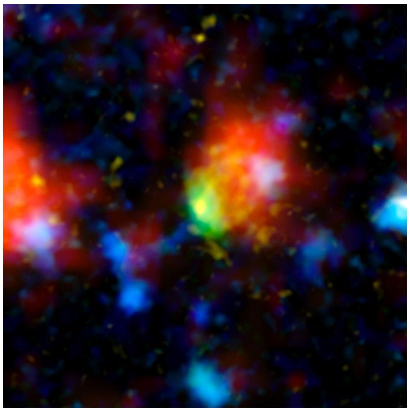
    (d) (3 points) JWST is powered using solar panels. However, the Earth and the Moon are between the Sun and L2, and a reasonable person might think that the light from the Sun would be blocked by the Earth and Moon. Why is the light from the Sun not completely blocked?

    (e) (3 points) Many spacecraft are powered by radioisotope thermoelectric generators (RTGs), especially in the outer Solar System. Why is JWST powered by solar panels instead of RTGs?

21. **The Forbidden Zone.** Pre-main sequence stars follow the Hayashi track downwards until they form a radiative zone. The Hayashi track also represents a boundary between “allowed” and “forbidden” regions of the HR diagram for objects in hydrostatic equilibrium. In this question, we’ll examine some of the physical intuition for why the forbidden zone exists.
    (a) (3 points) In your own words, explain what it means for an object to be in hydrostatic equilibrium.
    (b) (3 points) Unlike stars on the main sequence, protostars are not powered by nuclear fusion. What powers them instead?
    (c) (2 points) The core idea behind the forbidden zone comes down to the relative temperatures and densities of a gas, which depends on the temperature gradient within the star. The simplest way of relating these quantities is through the Ideal Gas Law, which can be written as $P \propto \rho T$, where P is pressure, ρ is density, and T is temperature. At a given pressure, does a lower temperature imply a higher or lower density?
    (d) (4 points) Consider a protostar that has a “superadiabatic” temperature gradient such that when a sample of gas moves radially inwards towards the center of the star, it ends up cooler than its surroundings. Based on the relative densities of the sample of gas and its surroundings, will the sample of gas continue moving towards the center or move back outwards? Explain your answer.
    (e) (3 points) Do you think the scenario in the previous part describes a stable object in hydrostatic equilibrium? Why or why not?

22. (5 points) 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. *Note: in addition to counting for 5 points, this question is the first tiebreaker.*

Image Set



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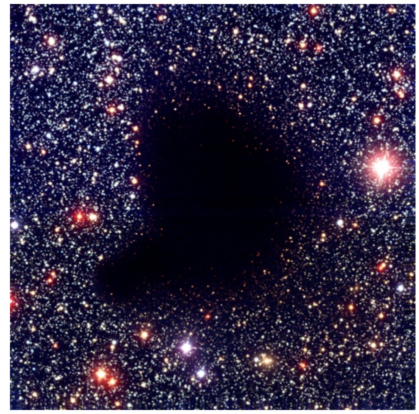

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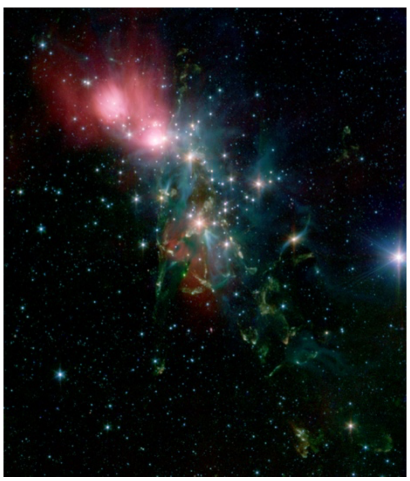

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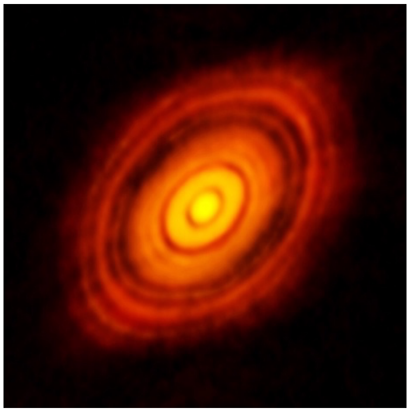
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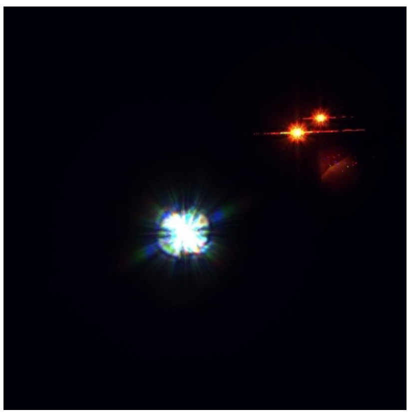
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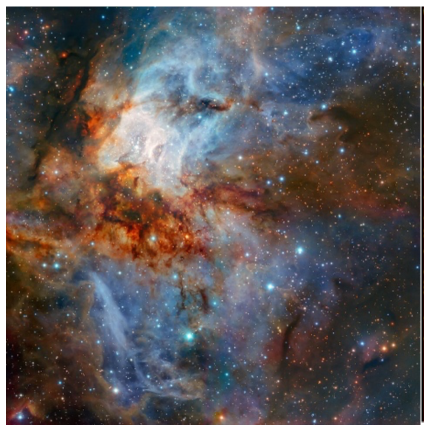
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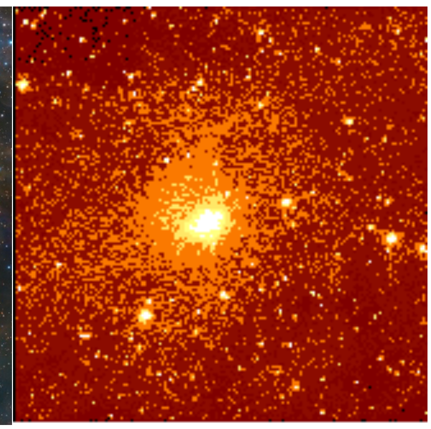
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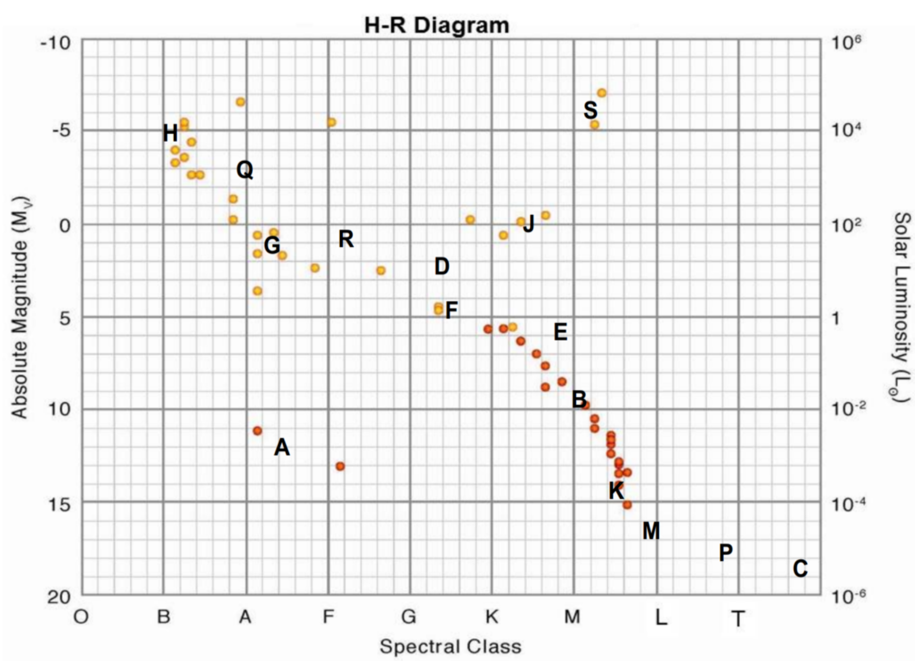

Answer Sheet

Section A [55 points]

1.

2.

3. (a)
   (b)
   (c)
4. (a)
   (b)
   (c)
5. (a)
   (b)
6. (a)
   (b)
   (c)
   (d)
7. (a)
   (b)
   (c)
   (d)
8. (a)
   (b)
   (c)
9. (a)
   (b)
   (c)
   (d)
10. (a)
    (b)
11. (a)
    (b)
    (c)
12. (a)
    (b)
13. (a)
    (b)
    (c)
14. (a)
    (b)
    (c)
15. (a)
    (b)
    (c)
    (d)
    (e)
16. (a)
    (b)
    (c)
    (d)
17. (a)
    (b)
    (c)
18. (a)
    (b)
    (c)

Section B [50 points]

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

20. (a)
    (b)
    (c)
    (d)
    (e)

21. (a)
    (b)
    (c)
    (d)
    (e)

22.

Answer Key

Section A [55 points]

1. (2 points) Barnard 68, HOPS 383, T Tauri, HD 95086
2. (2 points) HL Tauri, Messier 42, Baby Boom Galaxy, Stephan's Quintet
3. (a) Main sequence stars
   (b) F
   (c) Hydrogen
4. (a) Messier 42
   (b) A cloud of gas and dust in outer space; often (but not always) associated with star formation
   (c) Image 12
5. (a) Image 6
   (b) Pegasus
6. (a) Baby Boom Galaxy
   (b) Students should put (at least) one of the following: Hubble Space Telescope, Spitzer and Japan's Subaru Telescope in Hawaii
   (c) Gas
   (d) Star formation
7. (a) Barnard 68
   (b) It is close to Earth and very dense
   (c) It is easier when the gas cloud is cold, since the pressure is lower.
   (d) Jeans mass
8. (a) Image 11
   (b) Infrared
   (c) T Tauri
9. (a) NGC 1333
   (b) Infrared
   (c) Spitzer
   (d) Shock fronts
10. (a) Image 7
    (b) LMC
11. (a) L1527
    (b) JWST
    (c) Sporadic ejections from the protostar
12. (a) M42
    (b) Stellar wind "blowing" against the gas and dust clouds
13. (a) NGC 3324
    (b) JWST
    (c) Answers will vary (e.g., JWST is larger than HST)
14. (a) 13
    (b) Hubble
    (c) Libra
15. (a) Image 10
    (b) Forming planets
    (c) Radio
    (d) Reduced atmospheric interference; the light from space that hits the telescope has to pass through less of the atmosphere.
    (e) Signals from multiple telescopes are combined to make a higher resolution image. Theoretically, this process can produce images with the resolution of a huge telescope with an aperture equivalent to the distance across the array of telescopes.
16. (a) Image 2
    (b) Hubble
    (c) Herbig Ae/Be star
    (d) Q
17. (a) RCW 38
    (b) Very Large Telescope
    (c) more, shorter
18. (a) FU Orionis
    (b) D, E
    (c) V1057 Cygni

Section B [50 points]

19. (a) (2 points) 1 proton, 1 electron
    (b) (2 points) Add or remove an electron from the atom
    (c) (3 points) It takes 13.6 eV to remove an electron from its ground state in a hydrogen atom. Cool stars emit very few photons with energies that high. However, hotter stars emit more photons with that energy, so more hydrogen atoms can get ionized.
    (d) (3 points) Atoms typically "want" to have a "full" outermost electron shell, for lack of better words. Hydrogen atoms, for example, "want" to have two electrons in their outermost electron shell. When a hydrogen atom is on its own, it only has one electron. But, when it exists as H_2, the two hydrogen atoms in the molecule share their electrons in the form of a covalent bond, so both of the atoms feel like they have two electrons. (Quantum mechanics can explain this better, but is far beyond the scope of this event.)
    (e) (5 points) The rate at which H_2 forms in this situation depends on a number of factors. The frequency at which hydrogen atoms collide dust particles in the cloud increases when the cloud is denser, since the hydrogen and dust are closer together. Once the hydrogen atom and dust particle collide, we also need the hydrogen atom to stick to the dust particle, which is easier at lower temperatures. From the Ideal Gas Law, we can also intuit that lower temperatures will increase the density of the gas cloud. (Of course, the relationship between temperature, density, and reaction rate in this situation is more complicated than here, but the general ideas and trends are, in my opinion, close enough.)

20. (a) (3 points) A point in space where the gravitational pull of two large objects (for example, the Sun and the Earth) equals the centripetal force required for a small object to move with those objects. In essence, the objects can stay "still" relative to those two objects.
    (b) (3 points) JWST is an infrared telescope. Objects like the Sun, Moon, and Earth emit a lot of infrared light, so if JWST is facing them, it will add a lot of noise to the images it is taking. On top of that, the detectors on JWST need to be cold to function properly. If JWST is at L2, then it can face away from the Sun, Moon, and Earth with a insulating heat shield in between and look at the rest of the Universe.
    (c) (3 points) L2 is closer. As a result, it is easier and faster to transport JWST there and communicate with it afterwards.
    (d) (3 points) JWST orbits in a large halo orbit around L2 (larger than the distance between Earth and the Moon) such that it typically is not in the Sun-Earth line. JWST was specifically planned to avoid even partial moon or earth eclipse for 10.5 years in any possible JWST orbit due to power and thermal requirements.
    (e) (3 points) In the outer Solar System, missions opt for RTGs since solar panels are not able to produce enough energy (flux from the Sun falls off with r^{-2}). However, JWST is close enough for the solar panels to provide enough power. Beyond that, solar panels are generally relatively cheap lightweight compared to RTGs.

21. (a) (3 points) It has has balanced internal and external forces, preventing further collapse or expansion.
    (b) (3 points) Gravitational potential energy being released
    (c) (2 points) Higher density
    (d) (4 points) It will continue moving towards the center of the star, since it is denser than the surrounding gas.
    (e) (5 points) No. An object exhibiting this behavior would collapse very quickly until it reached hydrostatic equilibrium.

22. Answers will vary. Graded entirely based on effort, level of detail, and accuracy.