

UT Invitational, Fall 2018

Astronomy C



Competitors: _____

School Name: _____

Team Number: _____

This test contains 4 sections; questions roughly increase in difficulty as the test progresses. If you're new to astronomy or Science Olympiad in general, welcome! The first parts of the test are hopefully accessible to you. For the dedicated veterans, I hope you'll find more challenging material near the end.

As a result of this attempt to include questions from a wide distribution of difficulty, this test is long. You're not expected to finish the exam. You can complete the questions in the order that best suits your team's strengths.

As always, you'll have 50 minutes to complete the test. You may separate the pages; be sure to put your team number at the top of every page. Don't feel obligated to write in complete sentences; your priority is to get all your ideas on paper quickly. Don't worry about keeping track of significant digits; one or two sigfigs is fine¹. No wifi allowed, don't cheat, etc. Tiebreaker: first question missed.

Good Luck, Have Fun! And always remember: The Eyes of Texas Are Upon You!

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¹As my professor puts it, "Don't worry about numbers. They're not important."

Part I: Matching

2 points each. Each choice will be used exactly once.

A	47 Tucanae/X9	B	Abell 400	C	Antennae Galaxies
D	Cen A	E	Chandra deep field-south	F	ESO 137-001
G	IC 10	H	M100	I	M51
J	M81	K	NGC 4993	L	Phoenix Cluster
M	SN2014J	N	SPT 0346-52	O	Sagittarius A*

- _____ The only starburst galaxy in the local group, containing about 110 observable X-ray sources.
- _____ The closest supermassive black hole to earth.
- _____ A bright radio galaxy, about 12 million lightyears away, with a strange “dust lane” feature.
- _____ A galaxy whose rapid velocity results in its gas being stripped off.
- _____ The Deep Sky Object (DSO) pictured in Image 1.
- _____ The farthest object in the DSO list.
- _____ The DSO pictured in Image 2.
- _____ The galaxy which hosted the first-detected gravitational wave event of neutron stars merging.
- _____ A white dwarf-black hole binary with orbital period 25 minutes.
- _____ A galaxy cluster containing two supermassive black holes doomed to merge in a few million years.
- _____ The deepest X-ray image ever taken.
- _____ A galaxy cluster containing a giant central galaxy with extreme starburst.
- _____ The DSO being pointed to in Image 3.
- _____ A grand design galaxy about 55 million lightyears away, with starburst concentrated in an inner ring.
- _____ A galaxy whose interactions with the Cigar galaxy is prompting starburst in the latter.

Part II: Multiple Choice

2 points each.

16. Which of the following lists the order of the main spectral types from hottest to coolest?
- A. BOGAFMK
 - B. OBAFGKM
 - C. OBAGFMK
 - D. BOAGFKM
17. Which of the following processes is responsible for preventing the sun from collapsing under its own weight?
- A. Nuclear fusion
 - B. Nuclear fission
 - C. Solar beta reduction
 - D. Neutrino emission
18. What are the three common stellar remnants?
- A. Nebula, interstellar gas, white dwarf
 - B. Red giant, planetary nebula, white dwarf
 - C. White dwarf, neutron star, black hole
 - D. White dwarf, brown dwarf, red dwarf
19. The spectral class of the sun is:
- A. A
 - B. F
 - C. G
 - D. M
20. Observe Image 4. Which letter denotes where the sun is located?
- A. A
 - B. B
 - C. C
 - D. D
21. Observe Image 4. Which letter denotes the location of Sag A*?
- A. A
 - B. B
 - C. C
 - D. D
22. Observe Image 4. Suppose a 1 solar mass star is located at point E. Which is the most likely fate for the star?
- A. Undergo supernova
 - B. Collide with another star
 - C. Fall into the supermassive black hole at the center of the galaxy
 - D. Planetary nebula and white dwarf
23. Our solar system
- A. Orbits the center of the milky way at approximately the same distance.
 - B. Is falling directly towards the center of our galaxy.
 - C. Is spiraling outwards from the center of our galaxy.
 - D. Is spiraling inwards towards the center of our galaxy.
24. Stars form when
- A. Planets gain enough mass to start glowing.
 - B. A planetary nebula collapses onto a white dwarf.
 - C. A cloud of cool gas collapses due to its own gravity.
 - D. Scientists have no idea how stars form.
25. ___ dwarfs are stellar remnants; ___ dwarfs are sub-stellar objects; ___ dwarfs are main sequence stars.
- A. Red; white; brown
 - B. White; brown; red
 - C. White; red; brown
 - D. Red; brown; white
26. A star's temperature
- A. Increases towards the center.
 - B. Decreases towards the center.
 - C. Is fairly constant throughout the star.
 - D. Increases towards the center, until the deep core which is relatively cool.
27. A very massive main-sequence star is likely to be
- A. Very hot.
 - B. Very cool.
 - C. Larger than a red giant.
 - D. Smaller than a red dwarf.

28. Imagine two stars orbiting each other. If the distance between them decreases, then the speed at which they orbit each other
- Decreases.
 - Increases.
 - Is unchanged.
 - Not enough information
29. About what percentage of main-sequence stars fuse hydrogen in their cores?
- 10%
 - 40%
 - 70%
 - 100%
30. Which of the following statements about black holes is FALSE?
- It's impossible to orbit a black hole for a long period of time.
 - Time flows differently near a black hole.
 - Their properties are described by Einstein's theory of general relativity.
 - Once something has fallen in, it can't leave.
31. Stars appear to twinkle because of
- Variations in their stellar atmospheres.
 - Turbulence in earth's atmosphere.
 - The brain's inability to perceive point-sources of light.
 - Interfering nebulae between the star and earth.
32. Evidence that the universe is expanding first came from
- Annie Jump Cannon.
 - Subrahmanyan Chandrasekhar.
 - Albert Einstein.
 - Edwin Hubble.
33. Light can be described² as
- Electromagnetic waves only.
 - Photons only.
 - Either a particle or a wave depending on context.
 - Neither a particle nor a wave.
34. Which of the following statements about the Big Bang model is FALSE?
- It asserts that the universe is 13.7 billion years old.
 - It was the prevailing view of the universe during Newton's time.
 - It replaced the idea that the universe is unchanging.
 - It suggests that the universe expanded from a singularity.
35. The chemical makeup (by mass) of the universe is closest to:
- 31% hydrogen, 25% helium, 44% other
 - 42% hydrogen, 42% helium, 16% other
 - 53% hydrogen, 43% helium, 4% other
 - 73% hydrogen, 25% helium, 2% other
36. Supermassive black holes are
- Concentrated at the center of the Milky Way.
 - Mostly found at the centers of galaxies.
 - Randomly distributed throughout the universe.
 - Mostly found in very distant galaxies.
37. A star whose radius pulsates regularly is known as
- A red giant.
 - A blue supergiant.
 - A pulsar.
 - A Cepheid.
38. A pulsar is a special type of
- Neutron star.
 - Planetary nebula.
 - White dwarf.
 - Brown dwarf.
39. Since the universe is expanding, we notice that
- Most galaxies seem to move away from us, with farther galaxies receding faster.
 - Most galaxies seem to move away from us, with equal recession rates.
 - Most galaxies are not moving relative to us, but the intergalactic dark energy is increasing.
 - Most galaxies are not moving relative to us, since universal expansion is a purely quantum phenomenon.

²In this question we're ignoring quantum field theoretic formulations. If you don't know what that means, don't worry.

40. Gravitational waves (which we can currently detect) can be produced by
- A. Any sufficiently dense object.
 - B. Black holes rapidly orbiting each other.
 - C. A supermassive black hole.
 - D. Rapidly rotating black holes.
41. The famous gravitational wave detection laboratory is called
- A. Chandra.
 - B. SETI.
 - C. APEX.
 - D. LIGO.
42. The brightness of blackbody radiation is limited by
- A. The Eddington limit.
 - B. The Planck limit.
 - C. The photoionization limit.
 - D. The Chandrasekhar limit.
43. If the Milky Way were the size of a frisbee, the nearest spiral galaxy would be
- A. A few inches away.
 - B. Several feet away.
 - C. Hundreds of yards away.
 - D. A few miles away.
44. Which of the following is NOT a galaxy in the local group?
- A. Large Magellanic Cloud
 - B. Triangulum Galaxy
 - C. Whirlpool Galaxy
 - D. Andromeda Galaxy
45. When two galaxies collide:
- A. The stars are totally unaffected.
 - B. Some stars may be flung out, but most will not encounter star-star collisions.
 - C. Stars will not be flung out, but there will be many star-star collisions.
 - D. We have no way of knowing whether or how galaxies collide.
46. Stars tend to form in galaxies because
- A. Gas in intergalactic space is too sparse.
 - B. The magnetic force of the galactic nucleus is critical in star formation.
 - C. Most stars don't form in galaxies, but the gravitational pull of galaxies results in stars eventually collecting in galaxies.
 - D. Most stars don't form in galaxies; the extragalactic stars are just exceedingly dim.
47. Which of the following is FALSE³?
- A. The orbit of a planet is an ellipse, and the star is always at the center of the ellipse.
 - B. Stars orbiting each other obey Kepler's 3rd law.
 - C. A small planet orbiting a star sweeps out equal areas in equal time intervals.
 - D. Planets orbiting a star obey Kepler's laws.
48. Wien's displacement law gives us information about
- A. The orbital velocities of stars in a galaxy
 - B. The hydrogen ionization temperature of a star
 - C. The peak blackbody radiation wavelength of a star
 - D. The intrinsic luminosities of Cepheid stars
49. A starburst can be caused by all of the following except
- A. Sudden morphological changes in the galaxy.
 - B. Interaction with another galaxy.
 - C. Interaction with hot intergalactic dust.
 - D. An active galactic nucleus.
50. The balance between a star's inward pull of gravity and its outwards pressure gradient is called
- A. Stellar equilibrium.
 - B. Quasistatic stellar continuum.
 - C. Stellar uniformity.
 - D. Hydrostatic equilibrium.

³Assume that Keplerian physics holds; we aren't concerned with the precision of general relativity.

Part III: Free Response

Each sub-part is worth 3 points.

51. The Chandra observatory specializes in looking for x-ray sources.
- X-rays are considered to be “energetic” compared to, for example, infrared radiation. Why is this?
 - Many bright X-ray sources are thought to be binary systems containing black holes. How are the X-rays produced? Briefly explain the relevant physics.
 - Why isn’t all the X-ray light sucked into the black hole?
52. Given that cosmic background radiation (CMB) has a temperature of 2.7 Kelvin, at what wavelength is it the brightest, in meters?
53. A star has a parallax angle of 0.0133 arcseconds when viewed from Earth. Over the past 5 years, its position in the sky has changed by 0.05 arcseconds.
- How far away is this star from Earth, in parsecs?
 - What is the proper motion of this star, in arcseconds per year?
 - What is the star’s tangential velocity, in km/s?
 - Radial velocity measurements show that the $H\alpha$ line is shifted from 656.28 nm to 656.30 nm. What is this star’s radial velocity, in km/s?
 - Given your answers to parts (c) and (d), what is the true space velocity of this star, in km/s? Hint: think about using the Pythagorean Theorem.
 - An astronomy student suggests using Hubble’s Law as means of checking the star’s distance (previously calculated in part (a)). What distance, in parsecs, does this student get when they carry out the calculation? Assume Hubble’s constant is 70 km/s/Mpc.
 - Explain a cause of the discrepancy between the distances calculated in part (a) and part (f). Which distance is likely more accurate?
54. The supermassive black hole at the center of a galaxy has a mass of 4×10^6 solar masses. A star is travelling around it in a very elliptical orbit. Because the supermassive black hole is far more massive than the star, assume the star’s mass is negligible.
- Long term observations of the star show that it has an orbital period of 22 years. What is its semimajor axis, in AU?
 - At its periapsis (closest point in the orbit), the star’s distance from the supermassive black hole is one-half of its semimajor axis. At this point, how fast is the star moving, in m/s?
 - The apoapsis (furthest point in the orbit) of this star’s path is three times its periapsis. What is the eccentricity of its orbit?
55. Examine Images 5, 6, and 7. These are observations of the same object, in 3 different bands: blue, red, and far ultraviolet respectively.
- What is pictured? Be as specific as possible.
 - All the images feature a dark band, which is highlighted in red. What is most likely causing the dark band?
 - Image 7 looks different than the other two. What is causing the far-UV glow in the upper and lower regions?

Part IV: Research Literacy

Each question is worth 3 points.

The following excerpt is from the abstract of a May 2018 research paper (co-authored by a researcher here at UT!) published in the research journal *The Astrophysical Journal*.

GW170817 Most Likely Made a Black Hole

There are two outstanding issues regarding the neutron-star merger event GW170817: the nature of the compact remnant and the interstellar shock. The mass of the remnant of GW170817, $\approx 2.7M_{\odot}$, implies the remnant could be either a massive, rotating, neutron star, or a black hole. We report Chandra [...] observations made in 2017 December and 2018 January, and we reanalyze earlier observations from 2017 August and 2017 September, in order to address these unresolved issues. We estimate the X-ray flux from a neutron star remnant and compare that to the measured X-ray flux. If we assume that the spin-down luminosity of any putative neutron star is converted to pulsar wind nebula X-ray emission in the 0.5 – 8 keV band with an efficiency of 10^{-3} , for a dipole magnetic field with $3 \times 10^{11} \text{ G} < B < 10^{14} \text{ G}$, a rising X-ray signal would result and would be brighter than that observed by day 107; we therefore conclude that the remnant of GW170817 is most likely a black hole. Independent of any assumptions of X-ray efficiency, however, if the remnant is a rapidly-rotating, magnetized, neutron star, the total energy in the external shock should rise by a factor $\approx 10^2$ [...] after a few years; therefore, Chandra observations over the next year or two that do not show substantial brightening will rule out such a remnant. The same observations can distinguish between two different models for the relativistic outflow, either an angular or radially varying structure.

56. Briefly summarize (1-2 sentences) the researchers' strategy to show that the remnant is probably not a neutron star.
57. The researchers claim that since the remnant's mass is $\approx 2.7M_{\odot}$, it "could be either a massive, rotating, neutron star, or a black hole." If the object were a neutron star, why do the scientists conclude it must be rotating?
58. What is the "spin-down luminosity"? Briefly explain the mechanism.
59. Why would a neutron star remnant display brightening over the next few years?
60. What might the "relativistic outflow" be referring to?

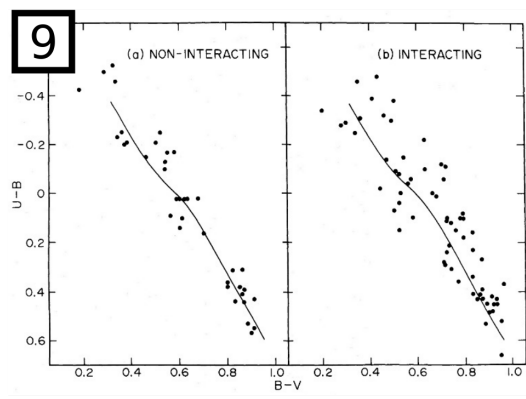
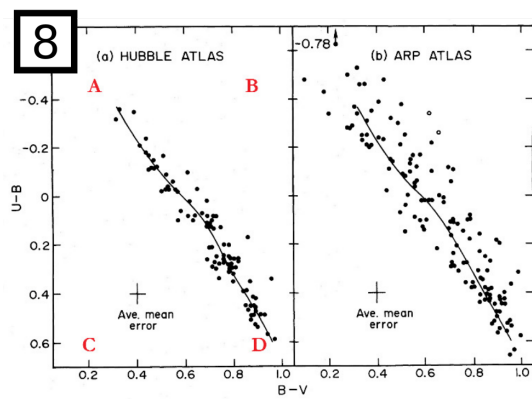
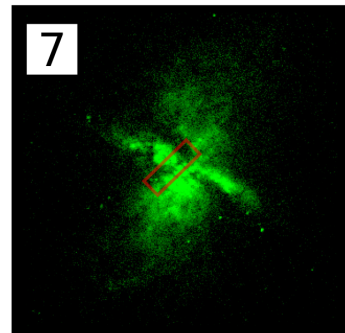
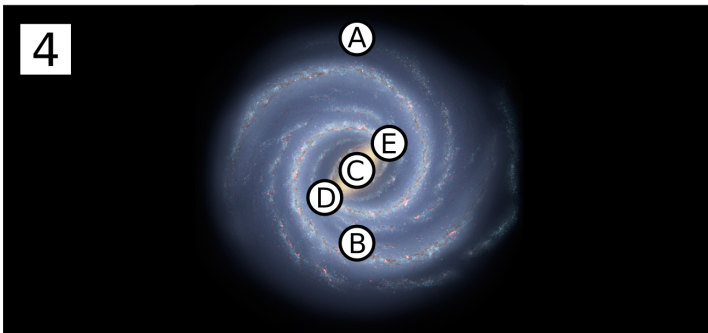
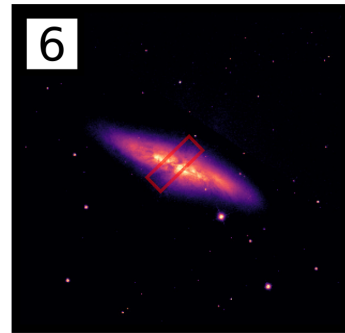
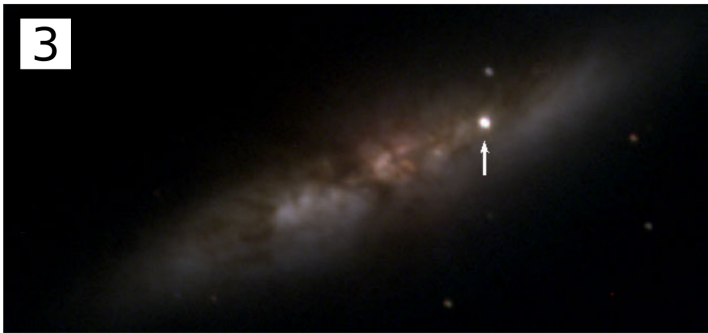
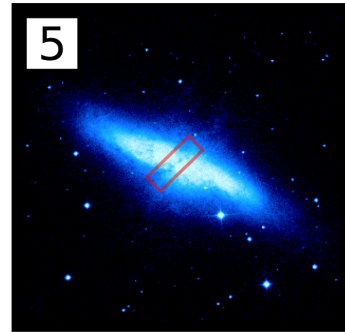
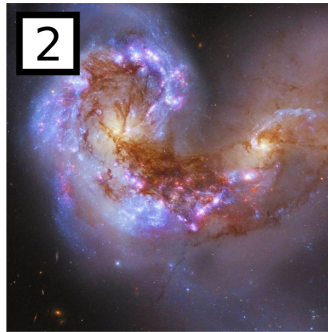
Image 8, from Larson and Tinsley (1978), shows $U - B$ vs. $B - V$ color for "normal morphology" galaxies from the Hubble Atlas (left) and for "peculiar" galaxies from the Arp Atlas (right). The red letters have been added in by the authors of this test to denote locations on the diagram. Notice how the "peculiar" galaxies have significantly more scatter in their color.

61. What do " $U - B$ " and " $B - V$ " mean?
62. Which location (A-D) represents the "bluest" galaxy? Disregard whether that galaxy exists and simply go by the letter's location on the diagram.
63. The two open circles in the diagram for "peculiar" galaxies from the Arp Atlas are Type 1 Seyfert galaxies. What is the difference between the spectra of Type 1 and Type 2 Seyfert Galaxies?

Image 9 shows $U - B$ vs. $B - V$ for galaxies from the Arp Atlas, separated into non-interacting (left) and interacting (right).

64. Based on this diagram, what seems to be the cause of the "peculiar" galaxies' greater variation in color?
65. "Peculiar" galaxies are often sites of short, yet intense bursts of star formation. Explain how galaxy interactions could lead to these bursts.

Images



Answer Sheet

Part I: Matching

- | | | | | |
|----------|----------|----------|-----------|-----------|
| 1. _____ | 4. _____ | 7. _____ | 10. _____ | 13. _____ |
| 2. _____ | 5. _____ | 8. _____ | 11. _____ | 14. _____ |
| 3. _____ | 6. _____ | 9. _____ | 12. _____ | 15. _____ |

Part II: Multiple Choice

- | | | | | |
|-----------|-----------|-----------|-----------|-----------|
| 16. _____ | 23. _____ | 30. _____ | 37. _____ | 44. _____ |
| 17. _____ | 24. _____ | 31. _____ | 38. _____ | 45. _____ |
| 18. _____ | 25. _____ | 32. _____ | 39. _____ | 46. _____ |
| 19. _____ | 26. _____ | 33. _____ | 40. _____ | 47. _____ |
| 20. _____ | 27. _____ | 34. _____ | 41. _____ | 48. _____ |
| 21. _____ | 28. _____ | 35. _____ | 42. _____ | 49. _____ |
| 22. _____ | 29. _____ | 36. _____ | 43. _____ | 50. _____ |

Part III: Free Response

51.a.

51.b.

51.c.

52.

53.a.

53.b.

53.c.

53.d.

53.e.

53.f.

53.g.

54.a.

54.b.

54.c.

55.a.

55.b.

55.c.

Part IV: Research Literacy

56.

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58.

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