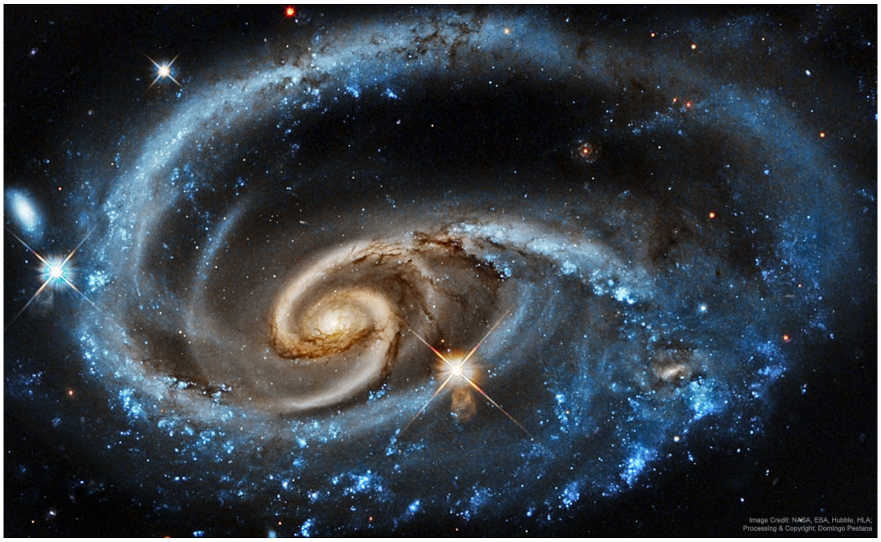
UT Austin Regional Tournament, Spring 2019

Astronomy C



Competitors: ______________________

School Name: ______________________

Team Number: ______________________

REMEMBER:

- Copy all your answers to the answer sheet before time is called
- Be sure to put your team number at the top of every page
- Tiebreaker: first question missed

TIPS:

This test is really long. (This is a result of my attempt to include questions from a wide distribution of difficulty.) I recommend answering questions that suit your strengths first; don't waste too much time on one question. Don't worry if you don't get to the end! Those questions are supposed to be hard anyways.

There are 3 sections, totalling 150 possible points. As always, you'll have 50 minutes to complete the test. Don't feel obligated to write in complete sentences; your priority is to get all your ideas on paper quickly. No wifi allowed, don't cheat, etc. Good Luck, Have Fun! And always remember: The Eyes of Texas Are Upon You!

Written by: Dhruva Karkada, *dkarkada@gmail.com*

Part I: True/False (30 points)

1 point each.

1. ________ The HR Diagram plots stars by their intrinsic properties.
2. ________ Cooler objects glow bluer than hotter objects.
3. ________ Older stars are typically bluer than younger stars.
4. ________ The color of a star gives us information about how hot it is.
5. ________ The size of a main-sequence star is correlated to its distance.
6. ________ Both the absolute and apparent brightness of Cepheids fluctuates over time.
7. ________ The majority of stars will end up as white dwarfs.
8. ________ The color of a main-sequence star is correlated to its mass.
9. ________ The sun emits most of its radiation in the radio-wave band.
10. ________ X-rays tend to originate from highly energetic sources.
11. ________ Faraway galaxies tend to seem redder than nearby galaxies.
12. ________ The core of a spiral galaxy contains young stars, compared to the spiral arms.
13. ________ Currently, in the Milky Way, helium is the most common element (by mass).
14. ________ Currently, in the Milky Way, helium is the most common element (by number).
15. ________ The apparent magnitude of a star is correlated with its temperature.
16. ________ Neutron stars are most often formed in a Type II supernova.
17. ________ The Andromeda galaxy is larger than the Milky Way.
18. ________ The spectral features of a star can tell us its mass.
19. ________ The pulsar mechanism is driven by a rapid magnetic flux.
20. ________ Accretion disks form almost exclusively around dense objects like neutron stars and black holes.
21. ________ Large-scale electric fields play an important role in star formation.
22. ________ Large-scale magnetic fields play an important role in star formation.
23. ________ Absorption lines reveal the chemical composition of a cool, intervening gas.
24. ________ The Hubble galaxy classification scheme also represents the evolutionary sequence of galaxies.
25. ________ Dwarf galaxies are the most common type of galaxy.
26. ________ A supermassive black hole has a larger gravitational well than a stellar-mass black hole.
27. ________ A supermassive black hole has a steeper gravitational well (at its event horizon) than a stellar-mass black hole (at its event horizon).
28. ________ Elliptical galaxies are more likely to be found in dense galaxy clusters than spirals.
29. ________ Starburst occurs more frequently in spiral galaxies than in elliptical galaxies.
30. ________ Turbulence was recently solved via explicit solution to the Navier-Stokes equation.

Part II: Multiple Choice (60 points)

2 points each.

31. Which of the following classes of main-sequence stars is the hottest?
    A. Type A
    B. Type B
    C. Type F
    D. Type G

32. Which of the following classes of main-sequence stars has the strongest Balmer lines?
    A. Type A
    B. Type B
    C. Type M
    D. Type O

33. The U-V index of a star is a measure of
    A. How blue the star is
    B. How far the star is
    C. How bright the star is
    D. How large the star is

34. Star formation regions enshrouded by dust tend to appear bright in
    A. Gamma rays
    B. Ultraviolet light
    C. Visible light
    D. Infrared light

35. Stellar luminosity is a measure of
    A. The inner temperature of a star
    B. The total energy output of a star
    C. The gravitational force of a star
    D. The apparent brightness of a star

36. White dwarfs are supported by
    A. Hydrostatic (thermal) pressure
    B. Electron degeneracy pressure
    C. Radiation pressure
    D. Proton degeneracy pressure

37. Why are neutron stars made mostly of neutrons?
    A. The protons and electrons were crushed together to create neutrons
    B. The protons and electrons were flung out in the planetary nebula
    C. The protons and electrons were burned in the core of the star during the star's life
    D. Neutron star is a misnomer – they are not made mostly of neutrons.

38. What relation/technique allows us to use period-luminosity relations of variables stars to determine distances?
    A. Mass-radius relation
    B. Parallax
    C. Tully-Fisher relation
    D. Distance modulus

39. As an accreting white dwarf approaches the Chandrasekhar mass, what happens to the electrons inside?
    A. They become relativistic
    B. They emit neutrinos via beta decay
    C. They become degenerate
    D. They emit light via bremsstrahlung

40. Which of the following detracts from the credibility of using Type Ia supernovae as a standard candle?
    A. Dark matter
    B. Uncertainty in the Hubble constant
    C. Turbulence in the accretion disk
    D. The double degenerate model

41. Spiral galaxies with ≈ 2 very prominent arms are called
    A. Lenticular galaxies
    B. Flocculent galaxies
    C. Grand design galaxies
    D. Early type galaxies

42. Elliptical galaxies are
    A. Rotationally supported
    B. Gravitationally supported
    C. Pressure supported
    D. Quasar supported

43. Galaxies that have some properties of spirals and some properties of ellipticals are called
    A. Lenticular galaxies
    B. Grand design galaxies
    C. Flocculent galaxies
    D. Early type galaxies

44. The orbital speed of outer-disk stars in a spiral galaxy
    A. Is approximately constant with distance from galactic center
    B. Decreases linearly with distance from galactic center
    C. Decreases logarithmically with distance from galactic center
    D. Decreases as a power law with distance from galactic center

45. Most large galaxies are thought to be surrounded by
    A. A dark matter halo
    B. A dense intergalactic medium
    C. Thousands of open clusters
    D. A "sea" of fermi particles

46. What is the distance to a type Ia supernova with an apparent magnitude of 3.2?
    A. 35,000 pc
    B. 350,000 pc
    C. 3.5 Mpc
    D. 35 Mpc

47. What is the absolute bolometric magnitude of a star with radius R = 8 solar radii, and temperature T = 30,000 K?
    A. -6.92
    B. -5.41
    C. -4.93
    D. -4.22

48. If the eccentricity of a planet's orbit is 0.5, what is the ratio between its linear velocity at the aphelion and its linear velocity at the perihelion?
    A. 3/4
    B. 1/2
    C. 1/3
    D. 1/6

49. What is the approximate distance to a galaxy with its first Balmer line measured at 667.00 nm?
    A. 80 pc
    B. 2 Mpc
    C. 10 Mpc
    D. 70 Mpc

50. A star with mass 5 solar masses is orbiting Sag A* such that its periapsis is 200 AU and its apoapsis is 400 AU. What is its velocity at the apoapsis?
    A. 23 km/s
    B. 423 km/s
    C. 754 km/s
    D. 2400 km/s

51. What DSO is shown in image 1?
    A. Abell 400
    B. ESO 137-001
    C. Phoenix Cluster
    D. SPT 0346-52

52. What DSO is shown in image 2?
    A. ESO 137-001
    B. Abell 400
    C. SPT 0346-52
    D. Phoenix Cluster

53. The mechanism that causes the tail seen in image 3 is called
    A. Polar excretion
    B. Ram pressure stripping
    C. Polar accretion
    D. Relativistic nucleatic shocks

54. Gamma rays detected from the DSO shown in image 4 were produced by
    A. Relativistic accretion
    B. The decay chain Ni-Co-Fe
    C. Beta decay processes
    D. The triple alpha process

55. Simulations suggest that the DSO shown in image 5
    A. Does not contain any strong infrared sources
    B. Is a strong source of gravitational waves
    C. Was the result of a large merger event
    D. Consists mainly of population I stars

56. The prominent spiral structure seen in image 6 has been enhanced by
    A. Increased rotation speeds
    B. Tidal interactions with a companion
    C. Starburst within a companion
    D. Relativistic pressure waves

57. What is one distinguishing characteristic of the galaxy seen in image 7?
    A. Does not contain a black hole
    B. Thought to contain youngest known black hole in cosmic neighborhood
    C. One of the oldest galaxies ever observed
    D. Emits almost all its light in infrared

58. Galaxy merger simulations that accurately reproduced the “tails” seen in image 8 were first done
    A. In 1954 by Eddington and Chandrasekhar
    B. In 1965 by Rubin, Thorne, et al.
    C. In 1972 by Toomre and Toomre
    D. In 2001 by Wolzjak, Fitzpatrick, et al.

59. The number of x-ray binaries in the galaxy shown in image 9 is
    A. 0
    B. Less than 10 (but more than zero)
    C. About 50
    D. More than 100

60. Careful observations of the orbits shown in image 10 were used to
    A. Determine the distance to the Whirlpool galaxy
    B. Provide evidence that all black holes must rotate
    C. Calibrate Hubble’s constant
    D. Confirm general relativity

Part III: Free Response (60 points)

Each question is worth 15 points, with subparts weighted equally (unless otherwise specified).

61. Image 11 shows the HR diagram for a globular cluster. The location of where a sun-like star would be is superimposed on the HR diagram.
    (a) The x and y axes are numbered, but not labelled! What are the appropriate labels and units for each axis? (Hint: HR diagrams for clusters are often called "CM diagrams.")
    (b) Stars in the lower part of the diagram appear to be on the main sequence, while stars in the upper part are scattered elsewhere (mostly in the top-right region). Why is there this difference? Why does this depend on the assumption that the stars are in the same globular cluster?
    (c) Estimate the age of this cluster, and explain how it supports the idea that globular clusters have low metallicity.
    (d) Estimate the distance to this cluster, in parsecs.
    (e) Explain why globular clusters are typically found in the galactic halo.

62. An active area of research is understanding how galaxy morphology relates to galactic evolution. Edwin Hubble was the first to provide a widely-used classification scheme for galaxies.
    (a) What is the Hubble type of the Milky Way? The Whirlpool galaxy? The Andromeda galaxy?
    (b) What is the main reason that early type galaxies tend to be redder than late type galaxies? (Bonus: name another reason.)
    (c) Hubble originally thought that his "tuning-fork" diagram was a model for galactic evolution; ellipticals would evolve into spirals and not vice versa. Modern astronomers no longer think that's the case. How do galaxy simulations (such as simulations of the Antennae Galaxies) provide evidence to contradict Hubble's hypothesis?
    (d) Why are elliptical galaxies preferentially found in dense galaxy clusters?
    (e) Consider two elliptical galaxies with similar mass: one with lots of gas, and one with very little gas. A friend claims that, if left alone, one of them will eventually evolve into a spiral while the other will not. Is she right? If so, which one evolves into a spiral, and why? If not, why not?

63. **(CHALLENGE)** Consider an astrophysical disk (such as an accretion disk). There are multiple forces acting on it: the self-gravity within the disk (causing the disk to clump up), the shearing force of the rotation (causing the disk to smear), and the pressure of the hot gas in the disk (which generally opposes self-gravity). Each of these forces have an accompanying *timescale*: a measure of the amount of time necessary for the force to "act".
    (a) Which will dominate: the force with the shortest timescale, or the force with longest timescale?
    (b) (9 points) The three timescales in the disk, at radius R, are roughly approximated using the following relations:

$$t_{grav} \sim \sqrt{\frac{R}{G\Sigma}} \qquad t_{shear} \sim \frac{1}{\Omega} \qquad t_{pr} \sim \frac{R}{c}$$

    where G is the gravitational constant, Σ is the surface mass density of the disk, c is the speed of sound in the disk, and Ω is the angular velocity of the disk at R. Let's assume that the timescales are related as follows:

$$t_{grav} \ll t_{shear} \qquad \text{and} \qquad t_{grav} \ll t_{pr}.$$

    Using these initial constraints, derive the so-called Toomre instability criterion:

$$\frac{c\Omega}{G\Sigma} \ll 1.$$

    (c) If the instability criterion is satisfied in a disk, what happens? Give an example of a type of astrophysical disk that satisfies the Toomre instability criterion.

The following excerpt is from the abstract of a June 2018 research paper published in the prestigious research journal *Nature*.

Stellar populations dominated by massive stars in dusty starburst galaxies across cosmic time

All measurements of cosmic star formation must assume an initial distribution of stellar masses – the stellar initial mass function – in order to extrapolate from the star-formation rate measured for typically rare, massive stars ($M \geq 8M_{\odot}$) to the total star-formation rate across the full stellar mass spectrum. The shape of the stellar initial mass function in various galaxy populations underpins our understanding of the formation and evolution of galaxies across cosmic time. Classical determinations of the stellar initial mass function in local galaxies are traditionally made at ultraviolet, optical and near-infrared wavelengths, which cannot be probed in dust-obscured galaxies, especially in distant starbursts, whose apparent star-formation rates are hundreds to thousands of times higher than in our Milky Way, selected at submillimetre (rest-frame far-infrared) wavelengths. The $^{13}C/^{18}O$ abundance ratio in the cold molecular gas – which can be probed via the rotational transitions of the ^{13}CO and $C^{18}O$ isotopologues – is a very sensitive index of the stellar initial mass function, with its determination immune to the pernicious effects of dust. Here we report observations of ^{13}CO and $C^{18}O$ emission for a sample of four dust-enshrouded starbursts at redshifts of approximately two to three, and find unambiguous evidence for a top-heavy stellar initial mass function in all of them. A low $^{13}CO/C^{18}O$ ratio for all our targets – alongside a well-tested, detailed chemical evolution model benchmarked on the Milky Way – implies that there are considerably more massive stars in starburst events than in ordinary star-forming spiral galaxies.

64. (a) The researchers find "unambiguous evidence for a top-heavy stellar initial mass function" in all of the starburst galaxies studied. What does this mean, in simple terms?

(b) According to the abstract, researchers have depended on multiband observations to estimate the (initial) relative abundances of different-mass stars. With some detail regarding the relevant physics, explain why this technique doesn't work for dusty galaxies.

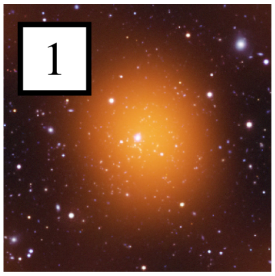
(c) The abstract implies an abundance of dust in starburst galaxies. Why is there a correlation between starbursts and high dust content?

(d) To probe relative stellar abundances, the researchers use the "$^{13}C/^{18}O$ abundance ratio in the cold molecular gas." What do ^{13}C and ^{18}O refer to?

(e) Their conclusion is supported by their observation of a "low $^{13}CO/C^{18}O$ ratio." What does this tell you about the origins of ^{13}C and ^{18}O? Note that measuring the $^{13}CO/C^{18}O$ ratio is equivalent to measuring the $^{13}C/^{18}O$ ratio.

Scratch Paper

Image Sheet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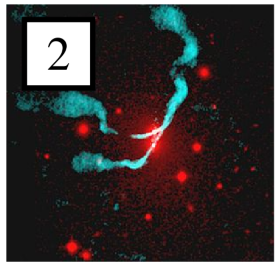
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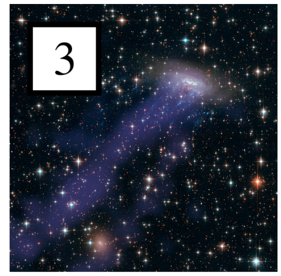
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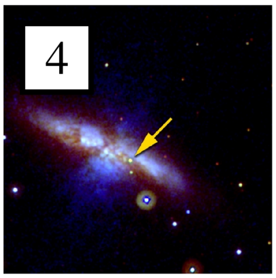
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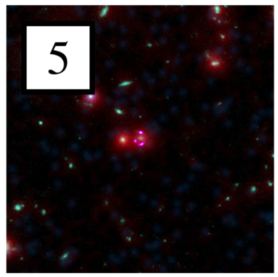
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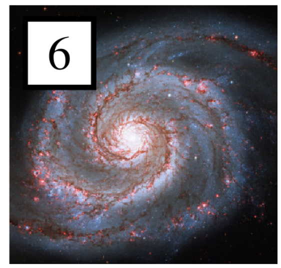
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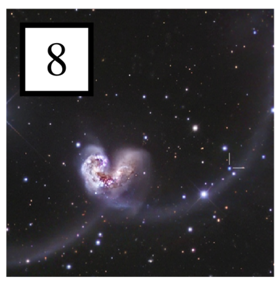
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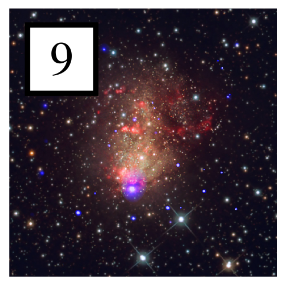
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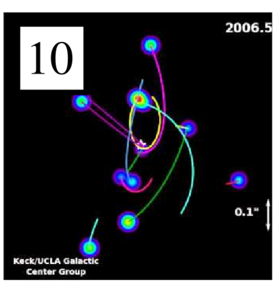
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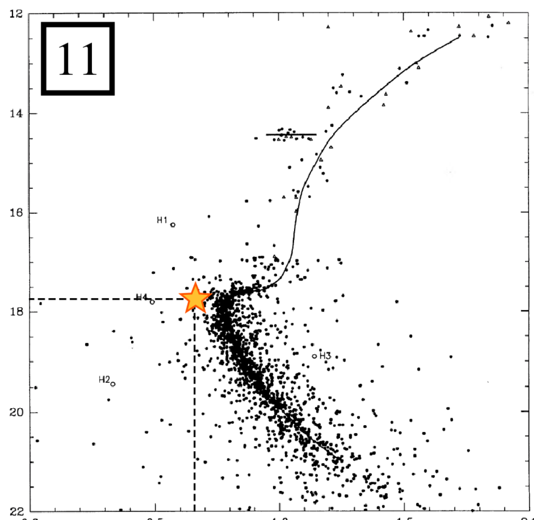
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18
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H1
H2
H3

Answer Sheet

1. ______	7. ______	13. ______	19. ______	25. ______
2. ______	8. ______	14. ______	20. ______	26. ______
3. ______	9. ______	15. ______	21. ______	27. ______
4. ______	10. ______	16. ______	22. ______	28. ______
5. ______	11. ______	17. ______	23. ______	29. ______
6. ______	12. ______	18. ______	24. ______	30. ______
31. ______	37. ______	43. ______	49. ______	55. ______
32. ______	38. ______	44. ______	50. ______	56. ______
33. ______	39. ______	45. ______	51. ______	57. ______
34. ______	40. ______	46. ______	52. ______	58. ______
35. ______	41. ______	47. ______	53. ______	59. ______
36. ______	42. ______	48. ______	54. ______	60. ______

61. (a)

(b)

(c)

(d)

(e)

62. (a)

(b)

(c)

(d)

(e)

63. (a)

(b)

(c)

64. (a)

(b)

(c)

(d)

(e)