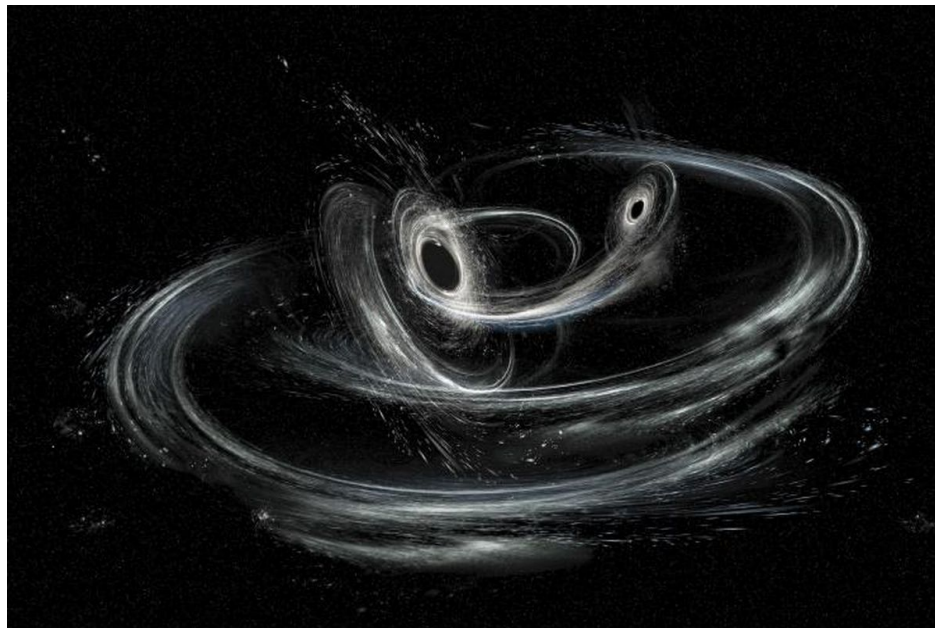# Astronomy C

Competitors: _____
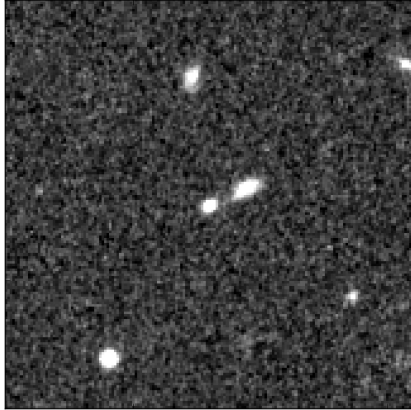
School name: _____

Team number: _____

Welcome to Astronomy! This exam has a multiple choice section followed by a free response section. As always, you'll have 50 minutes to complete the test. You may separate the pages. Don't feel obligated to write in complete sentences; your priority is to get all your ideas on paper quickly. Don't worry about significant digits; one or two sigfigs is fine. Tiebreaker: first question missed.

WiFi is allowed, but only to access the Js9 website. Any team caught using the internet for anything else will be immediately disqualified. Don't cheat. Good Luck, Have Fun! And always remember: The Eyes of Texas Are Upon You!

DSOs
Each subpart is worth 1 point. It's beneficial to guess if you don't know the answer.

The next four questions refer to the DSO depicted in the image below.

1. Which DSO is shown in the picture above?
    A. MACS J0717.5+3745
    B. PSS 0955+5940
    C. GRB 150101B
    D. SN UDS10Wil

2. What is our best estimate for the distance to this object?
    A. 1600 kpc
    B. 3200 kpc
    C. 1600 Mpc
    D. 3200 Mpc

3. If it is observed at a redshift of 1.9, and we don't account for relativistic corrections, what is its calculated distance?
    A. 3200 Mpc
    B. 6600 Mpc
    C. 8100 Mpc
    D. 10100 Mpc

4. The universe is thought to have been 1/3 of its current size at the time of photon emission. What was the scale factor a, given that the current scale factor $a_0 = 1$?
    A. 1/9
    B. 1/3
    C. 3
    D. 9

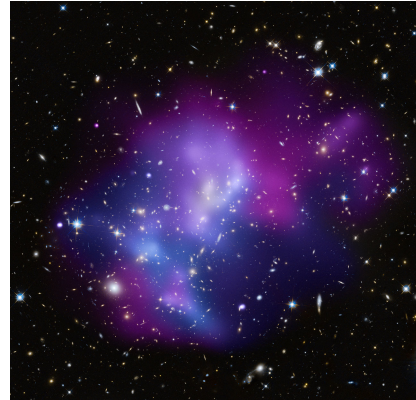The next four questions refer to the DSO depicted in the image below.

5. Which DSO is shown in the picture above?
    A. Bullet Cluster
    B. M87
    C. NGC 2623
    D. 152156.48+520238.5

6. What is another name for this DSO?
    A. Arp 243
    B. Warm Hot Intergalactic Medium
    C. 2305842+4329.2
    D. The CfA2 Great Wall (Coma Wall)

7. This object exhibits starburst. Why do its arms appear bluish?
    A. Molecular clouds can excite the forbidden [O III] transition, which is in the blue region of the spectrum.
    B. The light is blueshifted due to Hubble expansion.
    C. An increase in starburst gas increases the temperature of the interstellar medium, emitting blue light.
    D. Blue stars die fast, so they're typically concentrated in areas of high star formation.

8. Why is starburst occurring in the arms?
    A. The quasar in the AGN emits polar jets which excite gas in the arms to collapse.
    B. Since $\Lambda > 0$ in the Friedmann equation, dark energy causes matter to gravitationally collape.
    C. Tidal forces due to the merger compresses gas in the arms.
    D. Dark matter flung from the central black hole compresses gas in the arms.

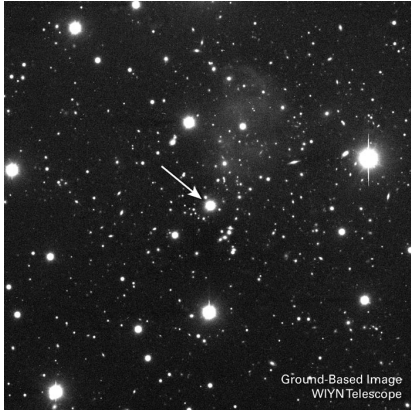The next four questions refer to the DSO depicted in the image below.

9. Which DSO is shown in the picture above?

     A. JKCS 041

     B. NGC 2623

     C. H2356-309

     D. PSS 0955+5940

10. Which one of the following is true about the DSO?

     A. It contains more matter than dark matter.

     B. It is one of the farthest galaxy groups to be observed.

     C. It is one of the first quasars to be observed.

     D. It contains one of the most newly formed SMBHs.

11. This picture was taken by the Chandra space telescope. What waveband does Chandra observe in?

     A. Visible

     B. X-ray

     C. Ultraviolet

     D. Infrared

12. This object is thought to be at a redshift of around 2. Should you use the relativistic form of Hubble's Law to determine distance?

     A. No, the redshift is too low for relativistic corrections to be significant.

     B. No, relativistic calculations are not relevant at high redshift.

     C. Yes, the object is moving relativistically due to Hubble expansion.

     D. Yes, the nonrelativistic form of Hubble's law is only valid within the Milky Way.

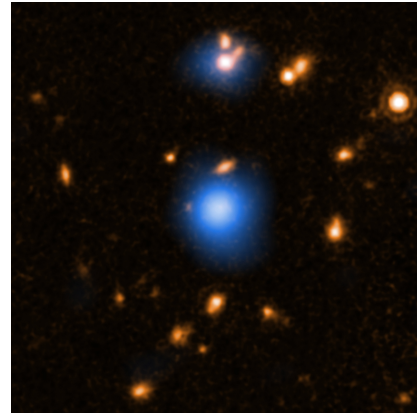The next four questions refer to the DSO depicted in the image below.

13. Which DSO is shown in the picture above?

     A. NGC 2623

     B. 222256.11-094636.2

     C. MACS J0717.5+3745

     D. GW151226

14. What is occurring in this DSO?

     A. Two galaxies have collided, prompting starburst

     B. A quasar has formed from a direct-collapse black hole

     C. Four galaxy clusters have collided and merged

     D. A neutron star merger has produced gravitational waves

15. How can we estimate the speed of the objects within the DSO?

     A. Examine the spectal composition of the gas

     B. Use the Sunyaev-Zel'dovich effect to estimate surface density

     C. Examine the offset between galaxies and gas

     D. Use Hubble's law to determine the peculiar motions

16. What is the Sunyaev-Zel'dovich effect?

     A. The distortion of spacetime due to gravitational interactions

     B. The distortion of spacetime due to the CMB

     C. The distortion of the CMB due to Compton scattering

     D. The distortion of the CMB due to gravitational lensing

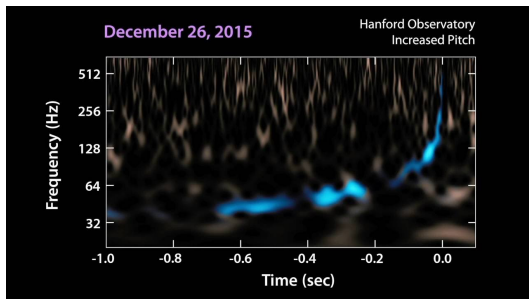The next four questions refer to the DSO depicted in the image below.

17. Which DSO is shown in the picture above?

    A. H1821+643

    B. PSS 0955+5940

    C. 222256.11-094636.2

    D. GW151226

18. What is a quasar?

    A. A stellar-mass black hole with a highly active accretion disk.

    B. A dormant galactic nucleus which emits radiation through the SZ effect.

    C. An active SMBH which emits high-energy radiation, often through polar jets.

    D. A source of dark energy, contributing to the Λ term in the ΛCDM model.

19. Why are quasars x-ray bright?

    A. The quasar emits Hawking radiation which is in equilibrium with the CMB.

    B. The dark energy interacts strongly with surrounding gas, producing synchrotron emisison.

    C. The accretion disk absorbs angular momentum from the CMB, prompting emission of x-ray photons.

    D. The accretion disk gets very hot and emits x-ray light along with highly-accelerated polar jets.

20. If the mass of the quasar is 20 billion solar masses, what is its Schwarzschild radius?

    A. 2.9×10^{13} meters

    B. 5.9×10^{13} meters

    C. 1.2×10^{14} meters

    D. 1.7×10^{14} meters

The next four questions refer to the DSO depicted in the image below.
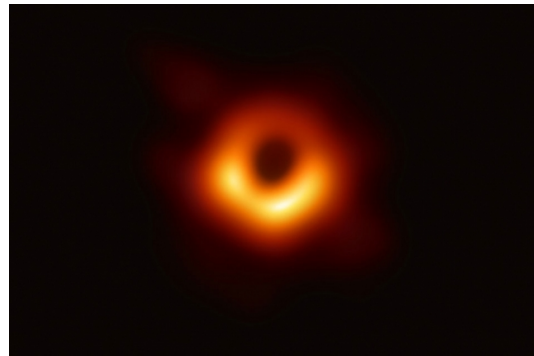

21. Which DSO is shown in the picture above?

    A. SN UDS10Wil

    B. Bullet Cluster

    C. GOODS-S 29323

    D. M87*

22. Which colors correspond to which wavebands?

    A. Blue: optical, Orange: x-ray

    B. Blue: gamma, Orange: ultraviolet

    C. Blue: ultraviolet, Orange: infrared

    D. Blue: x-ray, Orange: optical

23. Approximately how old are hypothetical direct-collapse black holes?

    A. 500 million years

    B. 2 billion years

    C. 5 billion years

    D. 13 billion years

24. Why do we think some supermassive black holes formed via direct collapse?

    A. We have directly observed quasars form via direct collapse

    B. They are too massive too early in the universe to have gained mass through slow accretion

    C. The Friedmann equation relies on the existence of direct collapse black holes

    D. There is no other proposed mechanism for supermassive black hole formation

The next four questions refer to the DSO depicted in the image below.

25. Which DSO is depicted in the picture above?

    A. GW151226

    B. H1821+643

    C. GRB 150101B

    D. M87

26. Which theory predicts the type of radiation observed by LIGO?

    A. General relativity

    B. Special relativity

    C. Quantum mechanics (path integral formulation)

    D. ΛCDM model + standard model

27. Where are the detectors which observed this signal located?

    A. Oregon and Italy

    B. Washington and Louisiana

    C. Italy and Washington

    D. Louisiana and Vermont

28. What does the image show?

    A. The observed time-domain signal

    B. The eigenvalues of the time-domain signal

    C. The Fourier transform of the time-domain signal

    D. The second moment of the time-domain signal

The next four questions refer to the DSO depicted in the image below.

29. Which DSO is shown in the picture above?

    A. JKCS 041

    B. M87*

    C. GW151226

    D. H1821+643

30. Why is there a ring of light around the dark region?

    A. The eclipsed star has a bright corona

    B. There is starburst in the galactic arms, producing yellow-orange light

    C. Gravitational lensing distorts light from the accretion disk

    D. The supernova is spherically symmetric

31. The photon sphere is the region within which photons must travel in orbits. How does the photon sphere radius r_p compare with the Schwarzschild radius R_s?

    A. $r_p = R_s$

    B. $r_p = 1.5R_s$

    C. $r_p = 3R_s$

    D. $r_p = 10R_s$

32. The shadow radius is the radius of the dark region (where photons are captured by the black hole). How does the shadow radius r_s compare with the Schwarzschild radius R_s?

    A. $r_s = R_s/2$

    B. $r_s = R_s$

    C. $r_s = \sqrt{27}R_s/2$

    D. $r_s = 9R_s/2$

Section B

Each subpart is worth 2 points. For calculations, show work for partial credit (be sure to answer in the units requested).

33. Open the file mystery.fits at js9.si.edu/ and ensure you can see the image. Upload the file to the server for server-side analysis (under the Analysis tab).

    (a) Which DSO is shown in the FITS file?

    (b) Create an annulus centered around the central brightest pixel. Resize the bounding box to a width of 24 (physical units). Use the "Counts in Regions" and "Radial Profile" analyses to answer the following questions.
        i. arcsec/pixel gives the width of a pixel in arcseconds. About how many pixels are in a square arcsecond?
        ii. Let's assume that the width of our bounding box is the same as the width of the object. What is the angular size of the object, in arcseconds?
        iii. If the object is 750 Mpc away, how wide is the object in kpc? There are 206265 arcseconds in a radian.
        iv. What general trend do you see in the radial profile? What class of mathematical functions might fit this data well?

34. Many people often confuse dark matter and dark energy. They are two very different things!

    (a) What is dark matter? What is dark energy? How are they different?

    (b) About what percentage of the mass-energy content of the universe is thought to comprise of dark matter? Dark energy?

    (c) How do galactic rotation curves support the existence of dark matter?

    (d) What is the relationship between dark energy and the cosmological constant?

35. A star has a parallax angle of 0.0111 arcseconds when viewed from Earth. Over the past 5 years, its position in the sky has changed by 0.10 arcseconds.

    (a) How far away is this star from Earth, in parsecs?

    (b) What is the proper motion of this star, in arcseconds per year?

    (c) What is the star's tangential velocity, in km/s? There are 206265 arcseconds in a radian.

    (d) Radial velocity measurements show that the Hα line is shifted from 656.28 nm to 656.30 nm. What is this star's radial velocity, in km/s?

    (e) 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.

    (f) 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.

    (g) Explain a cause of the discrepancy between the distances calculated in part (a) and part (f). Which distance is likely more accurate?

Answer Sheet

1. _____   8. _____   15. _____   22. _____   29. _____

2. _____   9. _____   16. _____   23. _____   30. _____

3. _____   10. _____   17. _____   24. _____   31. _____

4. _____   11. _____   18. _____   25. _____   32. _____

5. _____   12. _____   19. _____   26. _____

6. _____   13. _____   20. _____   27. _____

7. _____   14. _____   21. _____   28. _____

33. (a)

    (b)   i.

        ii.

        iii.

        iv.

34. (a)

    (b)

    (c)

    (d)

35. (a)

    (b)

    (c)

    (d)

    (e)

    (f)

    (g)