Names:_____

_____

Score:_____/140

Aimer's Astronomy Test

Division C

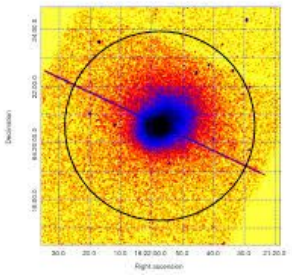
SSSS 2020

Notes:

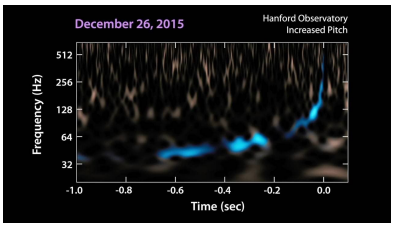
- This test is based on the Division C 2020 rules for Astronomy.
- You may use the resources detailed in section 2 of the Division C 2020 rules.
- There is no JS9 on this test, so please do not access the internet during this test.
- Use at least 3 significant figures for answers in the Calculations section.
- Please do not use this test for tournaments or tryouts.
- If you have feedback or questions, please contact me on Discord (Aimer#8317) or on the forums (Aimer).

Image Sheet:

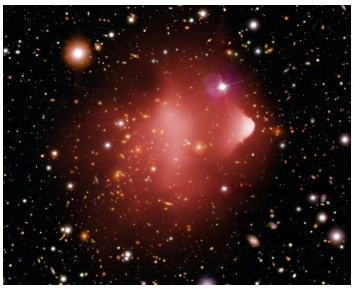
A:



B:

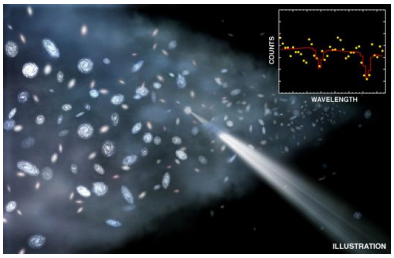


C:



D:

E:



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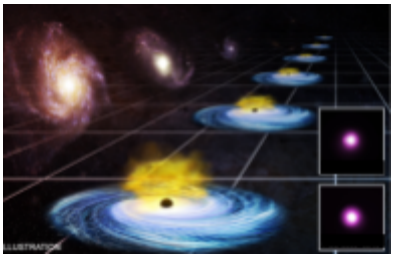
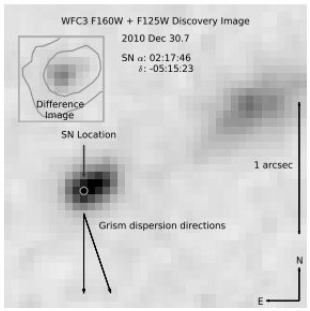
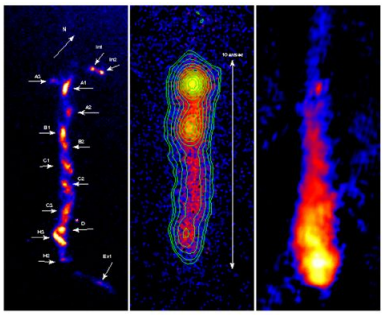


G:

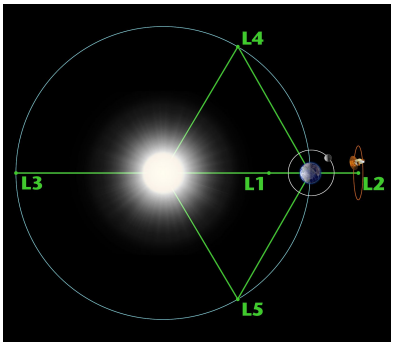
H:



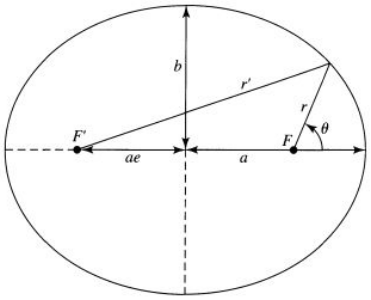
I:



J:



K:



Section 1: DSOs (42 pts)

1.
   a. Identify the DSO in image A and the wavelength the image is in. (2 pts)

   b. What is the mass of this DSO, in solar masses? (1 pt)

   c. True / False (circle one): This DSO is currently the most massive black hole with a precisely measured mass. (1 pt)

   d. How is this DSO used to detect the Warm-Hot Intergalactic Medium? (2 pts)

2.
   a. Identify the DSO in image B. (1 pt)

   b. What does this DSO suggest about binary black holes throughout the universe? (1 pt)

   c. What percentage of the final mass was radiated away as energy? Is this consistent with the percentage of mass radiated away from the first detected black hole merger (GW150914)? (2 pts)

3.
   a. Identify the DSO in image C and the wavelengths the image is in. (2 pts)

   b. Briefly explain why this DSO provides the best evidence for dark matter. (2 pts)

4.
   a. Identify the DSO in image D and the wavelengths the image is in. (2 pts)

   b. Which subcluster is moving quickly compared to the others? (1 pt)

   c. The subcluster from question 4b exhibits an effect that distorts the Cosmic Microwave Background radiation. What is the name of this effect? (1 pt)

   d. This DSO is the largest known _____. (1 pt)

5.
   a. Identify the DSO in image E. (1 pt)

b. What is the distance to this DSO, in light years? (1 pt)

c. Astronomers are using this DSO to detect the Warm-Hot Intergalactic Medium by looking for dips in the DSO's spectrum caused by the WHIM absorbing certain wavelengths. Which element inside the WHIM is responsible for these dips? (1 pt)

6.

a. Identify the DSOs in image F, and identify the wavelength of the smaller insets on the right. (2 pts)

b. What do these DSOs suggest about dark energy over time? (1 pt)

a. A new method involving both UV and X-ray light was used to measure the distance to these DSOs. In order for this method to work, what must happen to some of the UV light? (2 pts)

7.

a. Identify the DSO in image G and the wavelengths the image is in. (2 pts)

b. What does this DSO's relativistic jet suggest about active galaxies? (1 pt)

a. This DSO is notable for its large number of globular clusters. How might this DSO have accumulated some of these clusters? (1 pt)

c. What is the name of the technique used to image the supermassive black hole at the center of this DSO? (1 pt)

8.

a. Identify the DSO in image H. (1 pt)

b. What is the distance to this DSO? What was the approximate scale factor of the universe (a) when this DSO's light was emitted? (2 pts)

c. What does this DSO suggest about the two different models of Type Ia Supernovae? (1 pt)

9.

a. Identify the DSO in image I and list the wavelengths of each section of the image, from left to right (hint: the image shows a specific part of the DSO, not the entire object). (3 pts)

b. Why is this DSO significant compared to other objects of its type? (1 pt)

c. Why does this object have broad H α lines? (1 pt)

d. At visible wavelengths, how many times more luminous is this DSO than the Sun, assuming that both the Sun and this DSO are at a distance of 10 parsecs? (1 pt)

Section 2: Multiple Choice/Matching (19 pts)

1. Match each characteristic with its corresponding spectral type (OBAFGKM). Spectral types may be used more than once. (5 pts)

a. Comprises about 3% of main sequence stars in the solar neighborhood. _____
b. Particularly of interest in the search for extraterrestrial life. _____
c. Rare type of star but comprises 4 of the 90 brightest stars as seen from Earth. _____
d. Luminous and blue, and its spectra has neutral helium lines and moderate hydrogen lines. _____
e. Hydrogen lines are usually absent, but it has titanium oxide bands. _____
f. Surface temperatures of between 10,000 K and 30,000 K. _____
g. Strong hydrogen lines and lines of ionized metals are present. _____
h. Includes our Sun. _____
i. Comprises about 1/13 main sequence stars in the solar neighborhood. _____
j. Between 1.4 and 2.1 solar masses. _____

2. What percentage of the mass-energy of the universe is made up of dark energy? (1 pt)

a. 23%
b. 68%
c. 96%
d. 42%

3. Quantum field theory predicts the value of the cosmological constant (Λ) to be _____ orders of magnitude larger than we observe. (1 pt)

a. 5
b. 20

c. 60
d. Over 100

4. Which of the following is NOT a way that galaxies are organized? (1 pt)
   a. Clusters
   b. Groups
   c. Filaments
   d. All of these are ways galaxies are organized

5. What is the name of the upper limit to a neutron star's mass? (1 pt)
   a. Tolman-Oppenheimer-Volkoff limit
   b. Chandrasekhar limit
   c. Schwarzschild limit
   d. Einstein-Rosen limit

6. What is the most widely accepted explanation for the rapid rotation rate of millisecond pulsars? (1 pt)
   a. The stars they formed from rotated, and due to the conservation of angular momentum, its spin rate increased as the mass came closer to the center
   b. Pulsars with an especially strong magnetic field use the vacuum energy of the space around it to increase its rotation speed
   c. They siphon energy from a companion
   d. There is no widely accepted explanation and it is a topic of ongoing research

7. Put the following steps of the cosmological distance ladder in order, from shortest distances to longest. (1 pt)

Cepheid variables	Type Ia Supernovae	Gravitationally Lensed Quasars
Parallax		

   a. _____ (shortest)
   b. _____
   c. _____
   d. _____ (longest)

8. What would an outside observer see as an object approaches and crosses the event horizon of a black hole? (1 pt)
   a. The object would suddenly disappear as it crosses the event horizon

b. The object would speed up as it approaches the event horizon, before disappearing from view as it crosses
c. The object would seem to move backwards in time, moving away from the event horizon
d. The object would appear to move slower and slower as it approaches the event horizon, eventually appearing to freeze right before it crosses

9. Which relationship relates the luminosity of a galaxy to its rotational speed? (1 pt)
a. Tully-Fisher relationship
b. Kormendy relationship
c. Faber-Jackson relationship
d. CM relationship

10. What is the average temperature of the Cosmic Microwave Background? (1 pt)
a. 27.25 K
b. 2.725 K
c. 13.55 K
d. 1.355 K

11. About what percent of the universe's baryons are believed to exist in the Warm-Hot Intergalactic Medium? (1 pt)
a. 20%
b. 5%
c. 70%
d. 40%

12. Population I stars are _____ and _____, while Population II stars are _____ and _____. (1pt)
a. Older, less luminous; younger, more luminous
b. Older, more luminous; younger, less luminous
c. Younger, more luminous; older, less luminous
d. Younger, less luminous; older, more luminous

13. Which stellar population is more common in globular clusters? (1 pt)
a. Population I
b. Population II
c. Population III
d. They are all about equally common in globular clusters

14. The motion of the Andromeda galaxy towards the Milky Way galaxy despite the overall expansion of space is an example of which of the following? (1 pt)

a. Proper motion
b. Peculiar motion
c. Tangential motion
d. Angular motion

15. Which of the following characterizes a starburst galaxy? (1 pt)

a. Frequent supernova explosions
b. Relativistic jet originating at the core of the galaxy
c. An extremely high rate of star formation
d. A low number of protostars

Section 3: Short/Long Answer (38 pts)

1.

a. The Rayleigh-Jeans Law is an approximation of the spectral radiance of electromagnetic radiation based on the wavelength received from a blackbody at a given temperature. This law works well at large wavelengths, however it fails at shorter wavelengths. What is the name of this discrepancy between the observations of shorter wavelengths and the predictions of classical physics? (1 pt)

b. The resolution of this issue came in 1900 with the derivation of a new law that gave the correct radiation at all frequencies. What is the name of this law? (1 pt)

2. What is the fusion process that occurs in lower-mass stars that fuses hydrogen into helium? What is the fusion process that occurs in higher-mass stars that fuses heavier elements? (2 pts)

3. The upper limit of a neutron star's mass is about 2.16 solar masses. Above this limit, it is thought that neutron degeneracy pressure will fail and the neutron star will collapse into a black hole, however the smallest observed mass of a black hole is around 5 solar masses. What kinds of stellar remnants are theorized to exist with masses between 2.16 and 5 solar masses? (2 pts)

4.

a. The No Hair theorem states that a black hole can be completely characterized by three externally observable characteristics. What are these three characteristics? (1 pt)

b. In general relativity, the Schwarzschild solution to Einstein's field equations assumes two of the three external characteristics of a black hole are 0. Which two characteristics are they? (1 pt)

c. In the physical world, the Schwarzschild solution itself as a Schwarzschild black hole. Why is it unlikely that a Schwarzchild black hole actually exists in the universe? (2 pts)

5. The theory of inflation was driven by three major mysteries in cosmology, and inflation solves these mysteries very nicely. These three mysteries are described below:

- Opposite ends of the observable universe have nearly the same temperature and density, implying that they were once close together and were able to freely mix, however, the universe appears too young to have allowed that to happen.
- The curvature of spacetime is almost perfectly flat, which is extremely unlikely to occur by random chance.
- Astronomers believe the early universe was almost perfectly isotropic and homogeneous, however, lumps of matter must have existed to form today's stars and galaxies.

Inflation solves these mysteries by introducing a brief period of rapid, exponential expansion in the early universe.

a. Explain the mechanism that is believed to have caused inflation. (5 pts)

b. Explain how inflation solves each of the three mysteries. (6 pts)

6. Explain both models of how Type Ia supernovae occur. (2 pts)

7. Name the mechanism that prevents a white dwarf from collapsing, and name the principle in quantum mechanics that causes this. (2 pts)

8. Explain how gravitationally lensed quasars can be used to calculate Hubble's Constant. (2 pts)

9. Refer to Image J.
   a. What is the name of the points labelled on the image? (1 pt)

   b. Which of those points are stable? (1 pt)

10. From what event in the early universe did the CMB photons originate from? (1 pt)

11. What is the heaviest element that can be formed inside of a star? (1 pt)

12. Explain what Hawking radiation is and the mechanism that causes it. (3 pts)

13. Explain what the information paradox is and why it is such an issue. (4 pts)

Section 4: Calculations (41 points)

1. Refer to image K. A planet orbiting around its star, Star A, has an orbital eccentricity of e = 0.67 and a semimajor axis of a = 2.3 AU, and is in a position so that θ = 49.2°.

a. What is the distance between Star A and the planet? (3 pts)

b. What is the orbital period of the planet, in years? (2 pt)

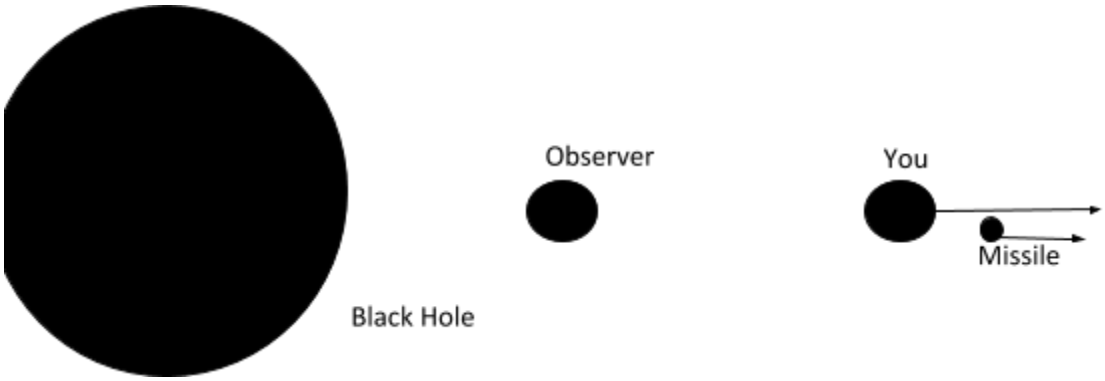
c. An observer on this planet measures a parallax angle for a distant star, Star B, to be 0.87". What is the distance between Star A and Star B? (2 pts)

2. Due to a series of mishaps, you find yourself a mere 140 km away from the center of a 20 solar mass black hole.

a. What is the escape velocity, in km/s? (2 pts)

b. If you only had the space technology of today, all hope would be lost as there is no way you could reach that escape velocity. Luckily, you happen to be from the future and you're in a spaceship capable of near-lightspeed travel. You set off away from the black

hole at the exact velocity calculated in question 2a. You notice some space debris in your path, so you fire a missile at it to clear it. You measure the speed of the missile to be 100,000 km/s in the positive *x* direction. An observer located directly behind you sees you and the missile travelling in the positive *x* direction. This situation can be seen below:



What is the velocity of the missile according to the observer? (6 pts)

3. You wake up in a different universe where most of the laws of physics are the same, however it hasn't followed the exact same evolution that our universe has. The distance to a galaxy is 32.4 Mpc, and the galaxy is found to have a recessional velocity of 1586.7 km/s.

a. What is the redshift of this galaxy? Either redshift equation (relativistic or approximate) is acceptable. (2 pts)

b. If we found a galaxy with the same recessional velocity in our universe, how far away would it be, in Mpc? (2 pts)

c. What is the value of the Hubble Constant in this universe? (2 pts)

d. How old is this universe? (2 pts)

4. A star located 17.6 pc away is observed to have an apparent magnitude of 6.1.
   a. What is the absolute magnitude of this star? (2 pts)

   b. If this star is on the main sequence, which two spectral classes might it belong to? (1 pt)

   c. Using an HR diagram, estimate the surface temperature of the star. What is the peak wavelength of this star? A range of answers will be accepted. (2 pts)

   d. Calculate the radiant heat energy in watts emitted per meter^2 for this star. (2 pts)

5. Consider a white dwarf with a mass of 1.1 solar masses and a companion star with a mass of 0.9 solar masses. They are part of a binary system and have a period of 9 hours and 24 minutes.
   a. What is the semimajor axis of their orbit? (2 pts)

   b. The white dwarf is accreting matter from its companion at a rate of $4.25*10^{22}$ kg per year. How many years will it take before the white dwarf goes supernova? Assume a constant accretion rate. (3 pts)

6. A Schwarzschild black hole has a mass of 7.2 solar masses.
   a. Calculate the Schwarzchild radius of the black hole. (2 pts)

b. Calculate the radius of the innermost stable circular orbit of the black hole. (2 pts)

c. Calculate the radius of the photon sphere of the black hole. (2 pts)