2020-2021 SSSS
AstroClarinet's Astronomy C Test

*Names:*________________________________

*Team Name:*___________________________

Score: _____*/110*

All questions are worth 1 pt unless marked otherwise.
All numerical answers should be to three significant figures.

<u>Given constants:</u>

H_0=67.7 (km/s)/Mpc
G=6.67 × 10^{-11} $m^3/(kg \cdot s^2)$
c=3.00 × 10^8 m/s
h=6.63 × 10^{-34} $J \cdot s$
b=2.90 × 10^{-3} $m \cdot K$
σ =5.67 × 10^{-8} $J/(s \cdot m^2 \cdot K^4)$
$M_\odot$=1.99 × 10^{30} kg
$L_\odot$=3.85 × 10^{26} W
$R_\odot$=6.96 × 10^8 m

Image Sheet

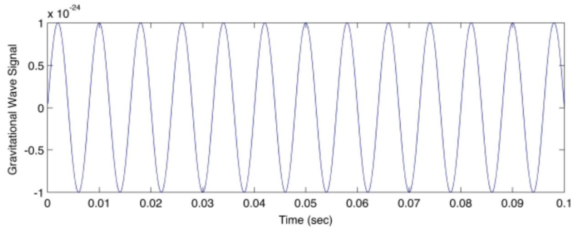

Image A

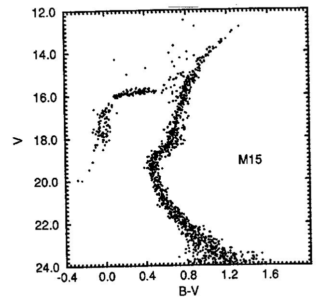

Image B

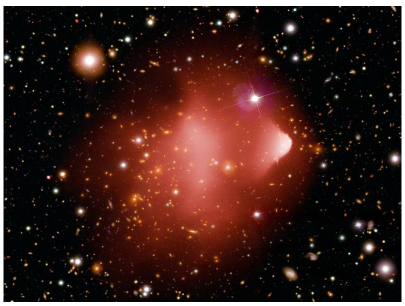

Image C

Image D

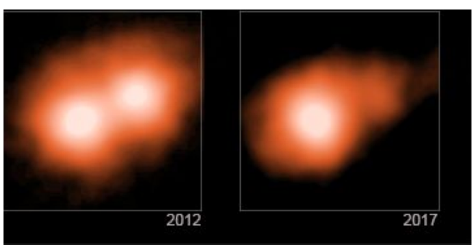

Image E

Image F

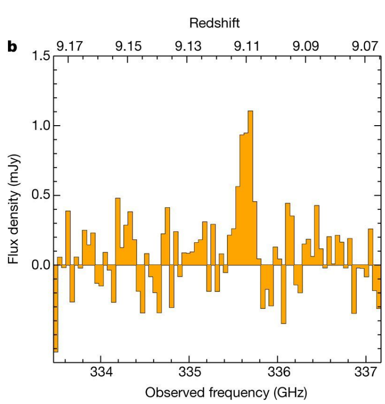

Image G

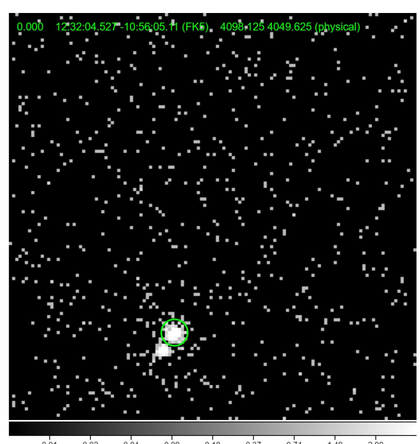

Image H

Section A (33 pts): Galaxy Formation & Evolution (+other topics)

A1: Which of the following types of radio galaxies is characterized by a decrease in luminosity as the distance from the center of the galaxy increases? **(2 pts)**
a. FR-I
b. FR-II
c. BLRG
d. NLRG

A2: Look at Image A. What type of object could produce a gravitational wave signal which would look like Image A?
a. Supernova
b. Binary neutron star merger (at the moment of collision)
c. A spinning neutron star with a mountain
d. Gravitational wave background

A3: The morphology-density relation suggests what about the evolution of galaxies? **(2 pts)**
a. The morphology of a galaxy depends on the density of stars inside of it.
b. The location of a galaxy affects how it evolves.
c. Dark matter haloes contributed to the formation of galaxies.
d. Galactic interactions do not play a significant role in the evolution of galaxies.

A4: Recently, an object in the "mass gap" between neutron stars and black holes was observed merging with a black hole. Astronomers are not sure of whether it was a neutron star or black hole due to the uncertainty in which limit?
a. Chandrasekhar limit
b. Tolman-Oppenheimer-Volkoff limit
c. Roche limit
d. Schönberg–Chandrasekhar limit

A5: Which of the following cannot be formed by galactic interactions?
a. Shells
b. Areas of starburst
c. Bars
d. None of the above

A6: Elliptical galaxies are thought to be formed from **(2 pts)**
a. Collapse of large gas clouds with low angular momentum in the early universe
b. Mergers of smaller galaxies
c. Quenched spiral galaxies
d. All of the above

A7: Which process causes blazars to appear brighter than expected?
a. Blandford-Znajek process
b. Relativistic beaming
c. Cyclotron radiation
d. Sunyaev-Zeldovich effect

A8: Which of these events can't be caused by the collision of astronomical objects? **(2 pts)**
a. Type Ia supernovae
b. Kilonovae
c. Planetary nebula formation
d. Gravitational wave emission

A9: cD galaxies are usually found where?
a. At the centers of clusters
b. At the edges of clusters
c. In galaxy groups
d. Outside of clusters and groups

A10: Strain is a measure of which characteristic of a gravitational wave?
a. Wavelength
b. Frequency
c. Period
d. Amplitude

A11: Quenched galaxies are most commonly found on which part of the galaxy color-magnitude diagram?
a. Red sequence
b. Blue cloud
c. Green valley
d. Yellow branch

A12: Which of these is not an intrinsic property of active galactic nuclei?
a. Black hole mass
b. Orientation of disk
c. Radio-loudness
d. Presence of jets

A13: Which of these is an example of internal secular evolution of a galaxy? **(3 pts)**
a. A cD galaxy cannibalizes a dwarf galaxy.
b. A protogalaxy forms.
c. A bar in a spiral galaxy causes its bulge to grow.
d. A galaxy in a cluster undergoes ram-pressure stripping.

A14: Explain how the major merger between the Milky Way and the Andromeda Galaxy will affect the evolution of both galaxies, and how this relates to NGC 2623. **(5 pts)**

A15: Image B shows the H-R diagram for the star cluster M15. Determine the relative age of the cluster (forming, young, old, etc.). Explain how you reached your answer, and why it may be different from the actual age of the cluster. **(5 pts)**

A16: Describe the geometry and most likely future of the universe if it currently had these density parameters: Ω_B=0.100, Ω_D=0.400, Ω_Λ=0.730, and Ω_{rel}=7.00 × 10^{-4}. **(4 pts)**

Section B (26 pts): DSO's

For questions B1 to B5, match the DSO to its significance. Some answers may be used multiple times, while other answers may not be used.

B1: _____ Demonstrated the first seen collision between four galaxy subclusters

B2: _____ Used to be the most redshifted galaxy cluster known

B3: _____ Largest known gravitational lens

B4: _____ Demonstrated the first clear separation between baryonic and dark matter

B5: _____ Lensed the most distant observed main sequence star.

a. H1821+643

b. JKCS 041

c. Bullet Cluster (1E 0657-56)

d. MACS J1149.5+2223

e. MACS J0717.5+3745

Questions B6-B9 relate to the DSO shown in Image C.

B6: Identify the wavelength band(s) that Image C was taken in (radio, infrared, visible, ultraviolet, X-ray, or gamma rays). ____

B7: Which component of this DSO makes up the majority of the baryonic mass?
a: Galaxies & stars
b: Intracluster medium
c: Dark matter
d: Dark energy

B8: How were the components of this DSO separated?
a. A galactic collision where stars passed by each other, dark matter passed through itself, and gas collided
b. A galaxy cluster collision where galaxies passed by each other, while dark matter and gas collided
c. A galaxy cluster collision where galaxies passed by each other, dark matter passed through itself, and gas collided
d. A supercluster collision where galaxies collided, while dark matter and gas passed through themselves

B9: Why do most astronomers consider this DSO to be evidence for dark matter? **(3 pts)**

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Questions B9-B15 relate to the DSO shown in Image D and Image E.
B10: Identify the wavelength band(s) that Image D was taken in (radio, infrared, visible, ultraviolet, X-ray, or gamma rays). ________________________________ **(2 pts)**

B11: What kind of active galaxy is this DSO?
a. Seyfert 2
b. Radio galaxy
c. Radio-quiet quasar
d. Optically violent variable quasar

B12: Image E shows a knot in the jet of this DSO which looked like it was moving at 6.3 times the speed of light. What is the name of this process?
a. Violation of locality
b. Dark energy-assisted motion
c. Bremsstrahlung
d. Apparent superluminal motion

B13: In 2019, an image of the supermassive black hole at the center of this DSO was published. What technique did the EHT use to take the picture?
a. Gravitational lensing
b. Very long baseline interferometry
c. Outfitting telescopes with Fabry Perot cavities
d. Orbital space telescope interferometry

B14: Name 2 reasons why taking an image of the black hole at the center of this DSO is considered easier than taking an image of the closer Sagittarius A*. **(4 pts)**

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B15: This DSO is classified as an E0p galaxy in the de Vaucouleurs system. Which feature of this DSO does the "p" reference? **(2 pts)**
a. Its extended halo
b. Its jet
c. Its light's polarization
d. Its large X-ray plumes

Questions B16-B19 relate to the DSO shown in Image F.

B16: Identify the wavelength band(s) that Image F was taken in (radio, infrared, visible, ultraviolet, X-ray, or gamma rays). ____

B17: This DSO gravitationally lensed a supernova called SN Refsdal, causing it to appear multiple times. How many total images do astronomers think there were of SN Refsdal?

a. 2
b. 3
c. 4
d. 6

B18: Image G shows the [O III] emission line found in MACS1149-JD1, a galaxy lensed by the DSO shown in Image E. Why is this emission line important to astronomy? **(2 pts)**

a. It suggests that spectral lines are unreliable at high redshifts.
b. It suggests that MACS1149-JD1 is the most distant object ever found.
c. It suggests that the first stars were formed earlier than previously thought.
d. It came from the most distant O_2 molecules ever detected.

Section C (34 pts): Math

C1a: Calculate the B-V color index of a star with an absolute B magnitude of 0.5 and an absolute V magnitude of -1.

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C1b: If the star from C1a has an apparent V magnitude of 10 (when viewed from Earth), how far (in light-years) is it from Earth? **(2 pts)**

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C2: Assuming that the star Icarus is a perfect blackbody, calculate its wavelength of peak emission (in nanometers) based on a temperature of 12,000 K. Which band of the electromagnetic spectrum (radio, infrared, visible, ultraviolet, X-rays, or gamma rays) is this wavelength a part of? **(4 pts)**

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C3a: Assuming that stars in our galaxy follow Kepler's 3rd law and have perfectly circular orbits, how many times faster would a star orbiting at a distance of 4 kiloparsecs from the galactic center be moving than a star orbiting at a distance of 10 kiloparsecs from the galactic center? **(5 pts)**

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C3b: Observational evidence shows that the stars in the galaxy do not actually follow a Keplerian rotation curve. Briefly explain why astronomers think this is. **(2 pts)**

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C4: Use the relativistic redshift formulas & Hubble's Law to approximate the distance in gigaparsecs of JKCS 041, which has a redshift of z=1.9. **(5 pts)**

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C5: Estimate the rest *wavelength* (in micrometers) of the [O III] emission line shown in Image G. **(4 pts)**

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C6: The Andromeda Galaxy has a z parameter of -0.001001. Estimate its radial velocity in kilometers per second (you should assume it isn't travelling relativistically). **(2 pts)**

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C7a: Use the Phillips relationship to find the absolute B magnitude of a type Ia supernova if it had a peak apparent B magnitude of 10.3 and an apparent B magnitude 15 days after the peak of 11.0. **(5 pts)**

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C7b: Calculate the distance (in parsecs) of the type Ia supernova from the previous question, using your rounded answer from C7a. (Alternatively, you may use an absolute B magnitude of -19.3 for half credit (2 pts).) **(4 pts)**

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Section D (17 pts): JS9

Step 1: Go to https://js9.si.edu/nso/nso.html.
Step 2: Click "Help", then "General Help", then "Accessing Data Archives".
Step 3: Click "The Unofficial Chandra Archive".
Step 4: Type in "17586" where it says "ObsID" and click "Search".
Step 5: Click on "17586" when the search results show up.
Step 6: Right click on the file which ends in ".evt2.fits.gz," and copy its link address.
Step 7: Go back to the JS9 tab, click "File", then "open remote".
Step 8: Paste the link into the box and click "Open".
Step 9: An image should appear. Answer question D1.
Step 10: Click "Zoom" and then "zoom 4".
Step 11: Click the circle icon in the toolbar. Drag it and resize it so that it looks like Image H.
Step 12: Click on "Regions" and then "list". The last data value is the width of the circle in arcsec ("). Answer questions D2 and D3.
Step 13: Click "Analysis" (in the toolbar) and then "Energy Spectrum". You can click and drag to zoom the spectrum.
Step 14: Answer questions D4, D5, and D6.

D1: Which DSO does this image show? **(2 pts)**

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D2: What object is the circle around? **(3 pts)**

a. DSO
b. DSO's host galaxy
c. Unrelated galaxy
d. Unrelated star

D3: If the object is 1.7 gigalight-years away, calculate the linear diameter of the circle in light-years. **(4 pts)**

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D4: At which frequency (in Hertz) were the most X-ray counts detected coming from inside the circle? If there are multiple peaks with the same number of counts, list both. **(4 pts)**

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D5: Although this image is in X-rays, this DSO was first observed in which wavelength band? **(2 pts)**
a. Infrared
b. Visible
c. Ultraviolet
d. Gamma rays

D6: This DSO was found to share similarities with another object. Why was this other object significant? **(2 pts)**
a. It was the first object observed in both gravitational waves and electromagnetic waves.
b. It was the most energetic transient observed.
c. It contributed to the discovery that the universe was undergoing accelerated expansion.
d. It was the first observation of a previously theoretical type of star.