ASTRONOMY

Information

- Traditionally, you would have 50 minutes to complete this test. However, it is unreasonably long, with 104 questions and 137 points total, so you probably won't be able to finish in that much time.
- This test was written using the 2021 rules (Topic: Star and Galaxy Formation and Evolution). +Extra AGNs!
- I used a very unusual style for writing test questions, and this exam is more difficult than normal. If you find that you are having trouble with it, don't worry. It was meant to be a little too difficult.
- Record your answers legibly on this exam packet, and write your team number on each page.
- There is a JS9 question, so you may access the internet on your device *only* to complete it.
- Don't stress on significant figures, just use 3+. Units will be specified and a range of answers will be accepted.
- Written by RiverWalker88. Feel free to message me on the scioly.org forums, discord, or by email (riverwalker088@gmail.com) if you have any questions or feedback (please give me feedback, it helps a lot).

Good Luck! Reach for the Stars!

Section:	A	B	C	D	Total
Points:	0	48	64	25	137
Score:					

Team Name: _____ Team #: _____

Participants: _____ _____

Part A: Deep Sky Objects

This section contains 40 questions from mainly Part C in the rules for 0 points.

1. Identification

Identify the image on the image sheet depicting each of the following DSOs.

(a) 3C 273 (b) MACS J1149.5+2223 (c) GW151226 (d) 1E 0657-56

2. SN UDS10Wil

(a) In which image on Image Set A is this DSO depicted?

(b) What may have caused this supernova? *Hint: Think Generally*

(c) The field in which SN UDS10Wil can be found had been imaged by Hubble multiple times. How did astronomers use this to find this supernova?

(d) How were astronomers able to determine without measuring a spectrum that this was probably a supernova and not just an outburst of an Active Galactic Nucleus?

3. NGC 2623

(a) In which image on Image Set A is this DSO depicted?

(b) Consider the five stages of galactic merging, described below.

I. **First Approach**: This is the earliest stage of the interaction. The galaxies have not yet met, they have just begun to become intertwined in each other's gravitational force.

II. **First Contact**: At this point, the disks overlap, but there are no strong bars or tidal tails.

III. **Pre-Merger**: This stage shows well-developed tidal tails and bridges, and shows two distinct, identifiable nuclei.

IV. **Merger**: The nuclei have apparently coalesced (they now appear only as one nucleus), and the system shows tidal features.

V. **Old Merger**: These systems don't show clear, direct signs of tidal features, but do have knots of star formation.

Based on this information, what stage of galactic merging is NGC 2623 in? What physical characteristics of NGC 2623 gave you the answer?

(c) Based on our current ideas of galactic mergers, what type of galaxy is NGC 2623 most likely going to end up as? What challenges does the plot in Image i on Image Set B (Cortijo-Ferrero et al. 2017), which shows the stellar mass surface density as a function of distance from the center of the galaxy, provide for this?

(d) Look at Image ii on Image set B. This figure (Cortijo-Ferrero et al. 2017) is a plot of the percentage of stars that are of a stellar age range. The blue lines correspond to the youngest stars, of younger than 140 Myr. The red lines correspond to the oldest stars, older than 1.4 Gyr. The green line shows the intermediate-age stars, lying between 140 Myr and 1.4 Gyr of age. The dot lines represent the typical distribution in a type Sbc galaxy, and the connected lines with a colored blur around them represent NGC 2623. The y-axis shows the percentage of stars in that age range, and the x-axis shows the distance from the center of the galaxy.

Using this figure, determine in which galactic structure the rate of star formation is most abnormally high in NGC 2623.

4. MACS J0717.5+3745

(a) In which image on Image Set A is this DSO depicted?

(b) This galaxy cluster is one of the largest gravitational lenses known. How might being at the outflow of a filament contribute to this?

(c) Gravitationally lensed Active Galactic Nuclei (AGNs), which are bright in Radio and X-Ray, tend to be much rarer to find than lensed typical galaxies. One study chose to conduct a survey using the Jansky Very Large Array radio interferometer (in O Fair New Mexico) to look for gravitationally lensed AGNs around this cluster. Why might they have chosen this cluster, specifically?

(d) Observations of the distortion of background radiation observed in the microwave band of the electromagnetic spectrum allowed astronomers to determine a property of one of the subclusters of this cluster. What was this property, and how did it differ from the other subclusters?

5. PSS 0955+5940

I'll spare you staring at fuzzy purple dots to try to figure out which one is PSS 0955+5940. Instead, you get a fourth content-based question!!

(a) What is the redshift of this object?

(b) This object is a sub-DLA. Because I (frustratingly) could not easily figure out what this really implicated, I'll instead ask a much more unsatisfying question. What does sub-DLA stand for?

(c) When photons in a UV-bright accretion disk slams into a gas cloud, what happens to the energy in the photons? Emission in what wavelength is a result of this interaction?

(d) Given that there is a relationship between UV brightness and X-Ray brightness caused by the interaction described above, how would you go about determining the distance to a distant quasar (give the steps process from start to finish).

6. GOODS-S 29323

(a) In which image on Image Set A is this DSO depicted?

(b) This object is mainly visible in X-Rays. What causes this X-Ray emission?

(c) We are looking into the distant past at this object. If we were to travel into the future and see this object as it physically is today (not how we are observing its distant past self), what would we most likely find?

(d) Out of all of the objects in the GOODS-S survey, what was it about this object that was of particular interest to study as a potential Direct-Collapse Black Hole?

7. DLA0817g

(a) In which image on Image Set A is this DSO depicted?

(b) This galaxy is... actually pretty typical. Why was this unexpected?

(c) How did astronomers determine the rotational velocity of the disk?

(d) The figure in Image iii on Image Set B shows the velocity dispersion as a function of the distance from the center of the galaxy. Using this figure, determine a general relationship between the regularity of orbits and the distance from the center of the galaxy.

8. JKCS041

(a) In which image on Image Set A is this DSO depicted?

(b) When distant galaxy clusters (such as this one) are discovered, they often are discovered first in optical and infrared observations. What do they see at these wavelengths that suggests that there may be a distant galaxy cluster at that location?

(c) The temperature of this object confirmed it to be a deep potential well. Why might high temperature indicate that this is a potential well (*Hint: think about gravitational equilibrium.*)?

(d) We also wanted to make sure that JKCS041 wasn't just a filament pointing toward us that looks like a galaxy cluster. In addition to measuring temperature, astronomers measured density to determine that this was not, indeed, a filament, but rather, it was a galaxy cluster. If JKCS041 were a filament, would we have measured its density to be greater of less than that of it as a cluster? Why?

9. M87

The image of M87 in image iv on Image Sheet B will help answer the last three parts of this question.

(a) In which image on Image Set A is this DSO depicted?

(b) What is the Fanaroff-Riley classification of this galaxy?

(c) You can see a jet of M87 in multiple wavelengths extending to the right in the image. Why don't we detect another one?

(d) The same phenomenon that is causing the blob of radio emission at the left is also causing the curve of the jet on the right. What is the cause of these features?

10. H2356-309

(a) In which image on Image Set A is this DSO depicted?

(b) This object is a blazar, meaning that it is a quasar with its jet angled nearly directly at us. What effect makes the light from this jet significantly brighter pointed towards us than if it were pointed away from us?

(c) This object was used as a backlight source to attempt to detect absorption of oxygen lines to verify the presence intergalactic medium (IGM). Why search for Oxygen, specifically?

(d) Why might WHIM be organized into the filaments that we detect, rather than perfectly homogeneously distributed throughout the universe?

Part B: Star & Galaxy Formation & Evolution

This section contains 53 questions from mainly Part A in the rules for 48 points.

11. Stellar Evolution

(a) (2 pts) In what stage of stellar evolution is a star in if it is fusing hydrogen?

(b) (2 pts) Unlike humans, a star's evolution is predictable. What property of a star determines its evolutionary sequence?

(c) (2 pts) When stars begin to fuse helium, what is the effect on their intrinsic brightness?

(d) (2 pts) What specific process would mainly generate the energy radiated by an O-Type star?

12. Star-Forming Regions

(a) (2 pts) In a spiral galaxy, you find the greatest quantity of star-forming regions in the spiral arms. Why is this?

(b) (2 pts) Star-Forming regions consist of clumps of interstellar medium. What element makes up a large majority of the interstellar medium?

(c) (2 pts) An image of a Bok Globule (a small star-forming region) in optical light is shown in Image xii on Image Sheet B. What component of interstellar medium causes this object to appear dark?

(d) (4 pts) Star-forming regions can be drastically eroded and shaped into the forms we see today. Radiation in what part of the electromagnetic spectrum is mainly responsible for this (2 points)? What type of object does it come from (2 points)?

13. The Almighty Hertzsprung-Russell Diagram

The H-R Diagram shown in Image v on Image Sheet B will be used to answer these questions.

(a) (2 pts) What is the curvy diagonal line spanning from the top left to the bottom right known as?

(b) (2 pts) Give two points that show a star that will NOT be capable of producing a Type II Supernova. There is more than two correct answer, but you only need to give two.

(c) (2 pts) At what point does a progenitor to a Type Ia Supernova fall?

(d) (2 pts) Which point lands on a place where our sun would be prior to it reaching the main sequence?

14. Stellar Remnants Part I - The Strange

This question is about neutron stars.

(a) Where in a neutron star would you find a proton? Why?

(b) An isolated pulsar is spinning, giving us a consistent light curve. However, it hits a brief period of spinup, and the light curve changes (ever so slightly). What is this called, and what happened on the neutron star that caused this?

(c) Now, let's turn to another (also slightly freaky) type of neutron star. A magnetar is a neutron star with an insane magnetic field (if you haven't heard of them, I suggest you look them up after you finish, they're pretty cool). Sometimes this magnetic field will cause a spectacular outburst of light. Give the name of and describe the phenomenon that causes this spectacular outburst.

(d) Fun fact: when US Satellites first detected Gamma-ray bursts in the '60s, they were concerned that it was Soviet nuclear explosions that might be the cause (dang Soviets and their neutron stars smh). If we happened to see a Gamma-Ray burst in a spiral galaxy, what galactic structure would it most likely be located in? Why?

15. Stellar Remnants Part II - The Unseen

This question is about stellar mass black holes.

(a) We can't normally detect black holes. However, when with a companion star, we can detect where they are. Emission in what wavelength, caused by what structure formed by this system clues us to the presence of the black hole?

(b) Consider two stars with the same initial mass of 60 $M_{\odot}$. One has a very high metallicity and the other has a very low metallicity. Which one would be more likely to form a black hole at the end of its life? Why?

16. Galactic Anatomy, Physiology, & Spectroscopy

(a) (2 pts) What Hubble class of galaxy exhibits evident density waves in its disk?

(b) (2 pts) Observed from a normal galaxy is a significant amount of X-Ray bright material. What Hubble class of galaxy am I most likely looking at?

(c) (3 pts) Delta is a Radio Astronomer. While cleaning out an old server (things can get busy sometimes), she randomly finds a FITS file with an indistinct title (cool_galaxy_1.fits... we've all done it before). To try to figure out what it was, she loaded it up in an image analysis software and looked at the radio spectrum. In that spectrum she saw... no 21-cm line. What Hubble class of galaxy is she looking at? Why?

(d) (3 pts) Why does a blackbody spectrum approximate a normal galaxy's spectrum better than an active galaxy's spectrum?

17. What's Going On In That Galaxy??

(a) (3 pts) ***ROUND 1:*** Look at the elliptical galaxy in Image vi. Notice the dust lanes. What most likely happened to this galaxy such that it is an elliptical with dust lanes?

(b) (3 pts) ***ROUND 2:*** Look at image vii. This image shows the same field of a galaxy. You might notice a bright spot in the left image (pointed at by the arrow), that doesn't appear in the right image. What was this bright spot?

(c) (3 pts) ***ROUND 3:*** Take a quick look at the infrared and ultraviolet images of M101 shown in image viii on Image Set B. Why is the distribution of infrared radiation compared to the distribution of ultraviolet radiation unexpected?

(d) (3 pts) ***ROUND 4:*** In this final round, we will be looking out our home galaxy, the Milky Way. If we look in a particular area, we see a a spot of extremely bright Radio and X-Ray emission. What is the cause of this?

18. Radio Galaxies, Jets, and a Random AGN Question

(a) Radio Galaxies are typically what Hubble class of galaxy?

(b) Why is a thicc, dusty torus necessary for an Active Galactic Nucleus?

(c) In the radio lobe of a radio galaxy, at the end of the jet, you will find a "Hot Spot". What is the cause of these hot spots?

(d) Particles in the jet travelling at a significant fraction ($0.99c$) are mainly propelled by electromagnetic forces from the black hole. What type of radiation is emitted by these particles so that we can see the center AGN and jets in active galaxies?

19. Bizarre Blazars

Try saying that 10 times fast.

(a) Blazars vary on much shorter timescales than other types of AGN. Why is this?

(b) Look at the spectrum of a blazar in image ix. Why are there two bumps present in the spectrum?

(c) What is the cause of the broad-line region in a spectrum, and which bump in the blazar spectrum corresponds the the broad-line region?

20. Seyfert Galaxies

(a) According the unified model of AGN, what is the main cause of the difference between Seyfert 1 and Seyfert 2 AGN?

(b) Evidence was presented that there are two major differences between typical classes of Seyfert galaxies:

1. Seyfert Galaxies with a detectable Broad-Line Region (BLR) tended to have higher 10μm emission lines than Seyfert Galaxies without a detectable Broad-Line Region.
2. Seyfert 2 Galaxies have substantially higher star formation than Seyfert 1 galaxies.

Why does this challenge the unified model of AGN for Seyferts?

(c) The spectrum in image x shows the spectrum of a Seyfert Galaxy. The blue highlighted region shows the ”Big Blue Bump”. What feature of the active galactic nucleus cases this spectral bump that peaks in ultraviolet?

Part C: A Little Astrophysics

This section contains 20 questions from Parts A, B, *and* C in the rules for 64 points.

IMPORTANT ASSUMPTIONS

Unless specifically told otherwise, for questions 25-27 assume: no relativistic effects, Hubble's constant has a value of 70 km/s/Mpc, and the absolute magnitude of a Type Ia Supernova is -19.3.

21. If you don't hate me already, this question ought to do it. Have fun!!

A spiral galaxy, JENNY 867-5309, has an apparent magnitude of 15.34. The angle of the disk is directly parallel to our line of sight, similar to the object shown in image xi. Having some fun with a mass-luminosity relationship for galaxies, the mass of the luminous matter in the galaxy was deemed to be $1.58 \times 10^{11} M_{\odot}$.

(a) **Supernovae!!**

A Type Ia Supernova went off in this galaxy, with an apparent magnitude of 16.2.

i. (2 pts) If we were able to determine a spectrum of this supernova, what main spectral feature would be present for us to be able to determine that it was Type Ia?

ii. (2 pts) It's more likely that we observed it over a long period of time, monitoring how bright it appears. How would this information help us determine that it is Type Ia?

iii. (5 pts) How far away is this galaxy (in parsecs)?

Final Answer: _____ pc

(b) **Orbits & Other Random Galactic Measurements!!**

A star is orbiting in a circular, regular orbit at the very outskirts of this galaxy, 26100 parsecs from the center. It is measured to have a linear velocity of 254km/s.

i. (5 pts) What is the angular diameter of this galaxy (in arcseconds).

Final Answer: _____ "

ii. (5 pts) What is the range of wavelengths the 21-cm band will cover (in centimeters)? (Hint: at resting wavelength, the 21-cm line is at 21.1061 cm). Answer to an unruly amount of 5 significant figures.

Final Answer: _____ cm to _____ cm

iii. (5 pts) What is the orbital period of this star (in seconds, to make things easy)? Assume circular orbit.

Final Answer: _____ s

(c) **Dark Matter!!**

i. (5 pts) What is the mass of dark matter in this galaxy (in solar masses)?

Final Answer: _____ $M_\odot$

ii. (5 pts) If this galaxy is homogeneously distributed in a spherical halo around the galaxy, with a diameter of that of the disk, what is the density of dark matter in this galaxy (in kilograms per cubic meter)?

Final Answer: _____ kg/m^3

iii. (5 pts) Not quite dark matter, but ¯_(ツ)_/¯. What is the average luminosity ($L_\odot$) per solar mass of **baryonic** matter in this galaxy? There's really no point to this question, just have fun with it, I guess.

Final Answer: _____ $L_\odot/M_\odot$

22. What's this doing in Section C???

Let's talk about 3C273, but shed a different light on it than usual.

When we first saw 3C273, we thought it was a wack star. Let's pretend it actually was, for a moment. 3C273 has an apparent magnitude of 12.9 and a peak spectral wavelength of 5620 Å. Using an H-R diagram, we determined the luminosity to be 0.370 $L_\odot$. Let's also assume it was a main-sequence star, to make our lives easier.

(a) What would the temperature of this star be (in kelvin)?

Final Answer: _____ K

(b) What is 3C 273 (star)'s radius (in solar radii)?

Final Answer: _____ $R_\odot$

(c) What is its approximate mass (in solar masses)?

Final Answer: _____ $M_\odot$

(d) How far away would it be (in parsecs)?

Final Answer: _____ pc

(e) About how long would this star's lifetime be (in years)?

Final Answer: _____ yr

23. In case you aren't completely done with AGNs yet

A active galaxy is located 1050 Mpc away from us. The radio flux density of the active galaxy is 3.124×10^{-14} Jy, and the optical flux density of the active galaxy is 2.55×10^{-15} Jy (Hopefully these are reasonable... they're somewhat educated guesses). The supermassive black hole in the center has a mass of 1.86×10^9 $M_\odot$. This active galaxy has two relativistic jets, but we will only be examining one of them.

(a) **Miscellaneous Properties**

Here's where I put the cool stuff that didn't fit in the other two categories.

i. (5 pts) Is this galaxy radio-quiet or radio-loud? Why?

ii. (5 pts) If the supermassive black hole were to create an Einstein ring, what would the radius of the ring be (in arcseconds)?

Final Answer: _____ ″

(b) **Relativistic Jet**

Now, we'll take a look at one of the relativistic jets. This jet is 3.22pc long. Also, this probably isn't how particles work. Please don't judge (too much). Actually, just confirmed: this has some probable inaccuracies... let's just pretend, for the sake of the question, okay?

i. (5 pts) The material in the jet is accelerated to $0.994c$ by the black hole (where c is the speed of light). An electron barrels through space at this high speed, and then comes into contact with a "hot spot" at the end of the jet. Assume that, at this point, all of the object's kinetic energy it gained from the black hole is converted into electromagnetic energy all at once. In what wavelength would we see this emission (in nanometers)? Furthermore, in what portion of the electromagnetic spectrum would we see this emission?

Final Answer: _____ nm, Region of EM Spectrum: _____

ii. (5 pts) What is the temperature of the hotspot (in kelvin)? Assume thermal equilibrium.

Final Answer: _____ K

iii. (5 pts) The hotspot has an angular diameter of 0.285″. Calculate the hotspot's luminosity (in Watts).

Final Answer: _____ W

(c) **Accretion**

i. Theoretically, how close to the central black hole would a particle have to be to be orbiting the black hole with a linear velocity of the speed of light (in meters)? Remember to ignore relativistic effects (yes, this exam just keeps getting more cursed as it goes on).

Final Answer: _____ m

ii. Would this point fall within, outside of, on on the event horizon? Justify your answer with a calculation (this is the major calculation section after all).

AUTHOR'S NOTE

I chose not to include any calculative cosmology questions in this practice test. However, it has become a slightly larger part of this event. If you are looking for cosmology practice, I suggest you check out some of the other tests on the (slightly more formal) test exchange, or some of the tournament-released sets on the test exchange.

Part D: JS9 Investigation

This section contains 7 questions from all parts in the rules, using the JS9 software to analyze an image for 25 points.

INSTRUCTIONS

Go to js9.si.edu/nso/nso.html and open the Chandra image of the El Gordo Galaxy Cluster (Observation ID of 14022) using the Data Link below. To do this, click `File > Open Remote` and paste the link below into the box. Make sure `Proxy Server` is selected, and then click `open`.

I recommend using the blur feature (`Analysis > Blur`), with a sigma of 1.5, and a colormap with lots of colors (like sls, `Color > sls`). These just make it easier to see the object.

DATA LINK

`https://cxc.cfa.harvard.edu/cdaftp/science/ao13/cat8/14022/primary/acisf14022N001_evt2.fits.gz`

24. El Gordo

Navigate to the El Gordo galaxy cluster (you may have to go up and left a little bit—it's the big bright spot, I'm not trying to trick you).

(a) (2 pts) What this object's galactic coordinates in the sky? Check from approximately the center of the object.

(b) (2 pts) What is causing a majority of the X-Ray emission we are observing in this image?

(c) (3 pts) What is the energy that most of the particles in this cluster are emitting brightest in X-Ray at?

(d) (3 pts) There is some variability in the number of photons that we see over time in this object. During the time this image was taken, what is the *maximum* difference of observed photons?

(e) (6 pts) At this object's brightest during this observation, what was its flux, in photons·arcsec^{-2}?

Final Answer: _____ photons·arcsec^{-2}

(f) (4 pts) This galaxy cluster is actually undergoing a collision. Does this cluster appear to be early or late in the collision process? Again, what indicated this?

(g) (5 pts) Last one! Describe where you would expect the mass to be located in this cluster relative to the X-Ray bright blob we've been observing. How about the galaxies?