January 18th, 2020

Astronomy Division C Exam

Duke Science Olympiad

Time: 50 minutes **Resources:** Two laptops or binders, two stand-alone calculators of any type

- Write your team number on every page.
- You may rip apart the test, so long as the pages are returned in order.
- You are strongly encouraged to attempt every part.
- Please try to write within the answer boxes, however, no credit will be deducted if you your answers outside them so long as they're clearly marked.
- **No Internet access is allowed.**

Team Name: ______ **KEY** ______ **Team Number:** ______

Competitor Names: ______

As always, do your best and forget the rest. Good luck!

For official use only:

Page:	1	2	3	4	5	6	7	8	Total
Points:	15	15	15	15	18	16	12	14	120
Score:	**15**	**15**	**15**	**15**	**18**	**16**	**12**	**14**	**120**

This page was once a tree, and once it was blank. Now it is neither. You can make it less blank if you like. Turning it back into a tree is more effort, but also more worthwhile.

1. Answer the following questions related to stellar evolution.
   (a) (1 point) What is the mass of the Sun, in solar masses?

   1

   (b) (1 point) What fusion process dominates in an 8 $M_\odot$ star?

   CNO Cycle

   (c) (1 point) Stars A,B,C,D, and E have color indices -0.33, 1.40, 0.20, -0.50, and 1.10 respectively. Which would you expect to radiate most of its energy in the infrared?

   B

   (d) (1 point) What stellar population would you expect to find in a globular cluster?

   Population II

   (e) (1 point) A star spends most of its life in what stage of stellar evolution?

   Main Sequence

2. Answer the following questions related to supernova and stellar remnants.
   (a) (1 point) What type of supernova presents with both hydrogen and silicon spectral lines?

   Type Ia

   (b) (1 point) The Schwarzchild radius represents the radius of what astronomical object?

   Black hole

   (c) (1 point) What force counterbalances gravity in a white dwarf?

   Electron degeneracy

   (d) (1 point) What equation relates the decline in luminosity of a Type Ia supernova with its absolute magnitude?

   Phillips Relation

   (e) (1 point) What effect causes the apparent pulsation of pulsars?

   Lighthouse effect

3. Answer the following questions related to galaxies and galactic processes.
   (a) (1 point) In a few billion years, the Milky Way is expected to collide with what nearby spiral galaxy?

   Andromeda

   (b) (1 point) What type of galaxy would you expect to have little star formation relative to its mass?

   Elliptical

   (c) (1 point) What characterizes the spectral line width of a Seyfert II galaxy?

   Narrow emission lines

   (d) (1 point) What central dusty feature forms around the central black hole of an active galactic nucleus?

   Torus

   (e) (1 point) What forces trigger star formation in merging galaxies?

   Gravitational/tidal

Points earned: **15** / 15

4. Answer the following questions related to cosmology.
   (a) (1 point) What observational technique involves using an intervening mass to magnify a distant object?

   Gravitational lensing

   (b) (1 point) The Warm-Hot Intergalactic Medium (WHIM) was discovered using observations in what wavelength?

   X-ray

   (c) (1 point) The Cosmic Microwave Background was discovered using observations in what region of the electromagnetic spectrum?

   Radio

   (d) (1 point) What percent of the total mass-energy of the universe is in the form of dark matter?

   26-28 percent

   (e) (1 point) How quickly do gravitational waves travel?

   Speed of the light

5. Answer the following questions relating to Image 1.
   (a) (1 point) What object is depicted in this image?

   3C 273

   (b) (1 point) What about this object's distance makes it special?

   Closest known quasar

   (c) (1 point) What type of structure is depicted in the center of the image?

   Relativistic jet

6. Answer the following questions related to 152156.48+520238.5, 153714.26+271611.6, 222256.11-094636.2.
   (a) (1 point) What image shows depicts these objects?

   Image 2

   (b) (1 point) When viewed optically, these objects appear very similar to what type of object?

   Stars

   (c) (2 points) These objects are known to be unusually faint in X-rays. What about their central geometry causes this, and what does this imply about the black holes' accretion rates? Explain.

   - **(1 pt) X-rays blocked by the central torus of the black hole implies large torus.**
   - **(1 pt) Large torus implies lots of matter being accreted by the black hole.**

7. Answer the following questions relating to Image 5.
   (a) (1 point) What object is depicted here?

   H1821+643

   (b) (1 point) This object helped identify what cosmological structure?

   The WHIM

   (c) (1 point) What observational artifact does the prominent linear feature represent?

   Readout streak

Points earned: **15** / 15

8. Answer the following questions related to the Bullet Cluster.
   (a) (1 point) Which image depicts this object?

   Image 15

   (b) (1 point) What do the green contour lines represent?

   Mass distribution

   (c) (1 point) What type of matter is represented by the blue and orange colors?

   Baryonic matter (plasma)

   (d) (1 point) What can be inferred as a result of your answers to (b) and (c)?

   Existence of dark matter

   (e) (1 point) Through what technique were the green contour lines found?

   Gravitational lensing

9. Answer the following questions related to Image 13.
   (a) (1 point) What object is depicted in the image?

   JKCS 041

   (b) (1 point) What telescope provided the optical data for this image?

   Very Large Telescope

   (c) (1 point) The blue part of the image represents X-ray emissions. What is the source of this radiation?

   Hot gas

   (d) (1 point) The matter from (c) is often produced by the gravity of the cluster. What is the name for this mechanism?

   Thermal bremsstrahlung

10. Answer the following questions related to Image 14.
    (a) (1 point) Which object is associated with this image?

    GW151226

    (b) (1 point) What instrument produced this graph?

    LIGO

    (c) (1 point) What type of event was this?

    Gravitational wave

    (d) (1 point) What were the progenitors of this event?

    Binary black hole merger

    (e) (2 points) As time increases in the graph, the frequency of the waves changes. What is this change? What about the progenitor system causes this to occur?

    - **(1 pt) Frequency increases.**
    - **(1 pt) As the black holes get closer, they spin around each other more quickly. This increases the frequency of the gravitational waves.**

Points earned: **15** / 15

11. Answer the following questions related to M87.
   (a) (1 point) What image is best associated with this object?

   Image 10

   (b) (1 point) What, specifically, is depicted in the image?

   SMBH (M87*)

   (c) (1 point) What telescope took this image?

   Event Horizon Telescope

   (d) (1 point) Why was this image so important when it was taken in April 2019?

   First directly imaged black hole.

   (e) (3 points) The telescope from (c) views in radio waves, and is actually a global telescope array. Why is this wavelength best for viewing black holes in galactic centers, and what about this wavelength makes an array necessary?

   - **(1 pt) Galactic centers often have a lot of obscuring material, so radio waves can penetrate the gas and dust better.**
   - **(1 pt) Galactic centers are generally very bright in radio waves.**
   - **(1 pt) Radio waves require a much longer baseline for a given angular resolution, so an array is needed to simulate a single large disk.**

12. Answer the following questions related to SN UDS10Wil.
   (a) (1 point) Which image depicts this supernova event?

   Image 8

   (b) (1 point) What type of supernova was this?

   Type Ia

   (c) (2 points) If many supernovae of this type were found at such extreme redshifts, what progenitor model would it support? Explain.

   - **(1 pt) Mass-transfer model**
   - **(1 pt) Lots of stars forming at this epoch, so much easier for accretion-based systems to form.**

   (d) (2 points) If few supernovae of this type were found at such extreme redshifts, what progenitor model would it support? Explain.

   - **(1 pt) Double-degenerate model**
   - **(1 pt) Would need longer timescales for binary white dwarf systems to form.**

   (e) (2 points) Which of the models would put the accuracy of the Hubble constant in jeopardy? Explain.

   - **(1 pt) Double-degenerate.**
   - **(1 pt) Would imply differing starting masses for Type Ia supernovae, so they can't be used as standard candles when calculating the Hubble constant.**

13. Consider two neutron stars, A and B, in a binary system. They orbit each other once every 450 days.
    (a) (2 points) The system has parallax 1.5 milliarcseconds. How far away is it, in parsecs?

    620-700 pc

    (b) (2 points) The two objects have a mean separation of 2.2 AU. What is the mean angular diameter of the system as measured from Earth, in milliarcseconds?

    2.8-3.6 mas

    (c) (2 points) What is the total mass of the system, in solar masses?

    6.7-7.3 $M_\odot$

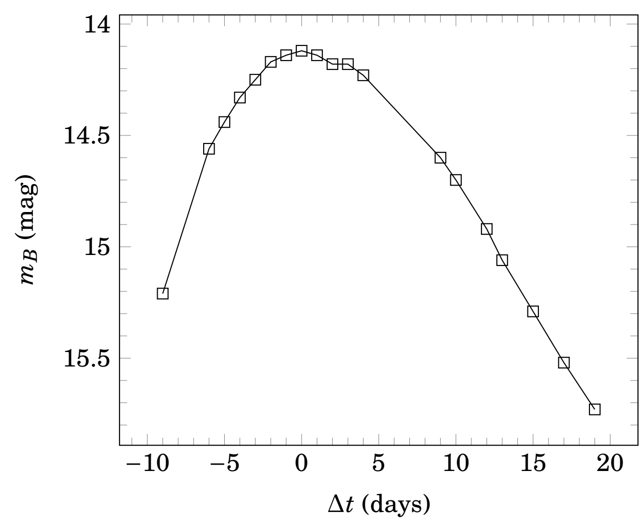
    (d) (2 points) Neutron star A is observed to have a radial velocity amplitude of $35.5\,\mathrm{km\,s^{-1}}$ while neutron star B has amplitude $17.2\,\mathrm{km\,s^{-1}}$. What is the mass of the larger neutron star, in solar masses?

    4.5-4.9 $M_\odot$

    (e) (2 points) What is the total angular momentum of the system, in $\mathrm{kg\,m^2\,s^{-1}}$? Assume that the axial rotation of the neutron stars is negligible. (This is highly inaccurate, but it simplifies the problem greatly.)

    $4 \cdot 10^{46} - 7 \cdot 10^{46}$ kgm²/s

14. Consider the following light curve of a Type Ia supernova.



    (a) (2 points) Assuming that this supernova has a maximum absolute magnitude of −19.5, what is its distance in megaparsecs?

    47-56 Mpc

    (b) (2 points) However, not all Type Ia supernova have this same absolute magnitude. A more accurate method is given by the Phillips relationship, which relates the supernova's absolute magnitude to the magnitude difference after 15 days. Formally, the relation is

$$M_{B_{max}} = -21.726 + 2.698\Delta m_{15(B)}.$$

    Knowing this, what is the distance to the supernova, in megaparsecs?

    30-38 Mpc

    (c) (2 points) Assuming the Hubble Constant has value $68\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, calculate the observed wavelength of the [Fe III] emission feature with rest wavelength 5900 Å in angstroms. Hint: use your answer from (b).

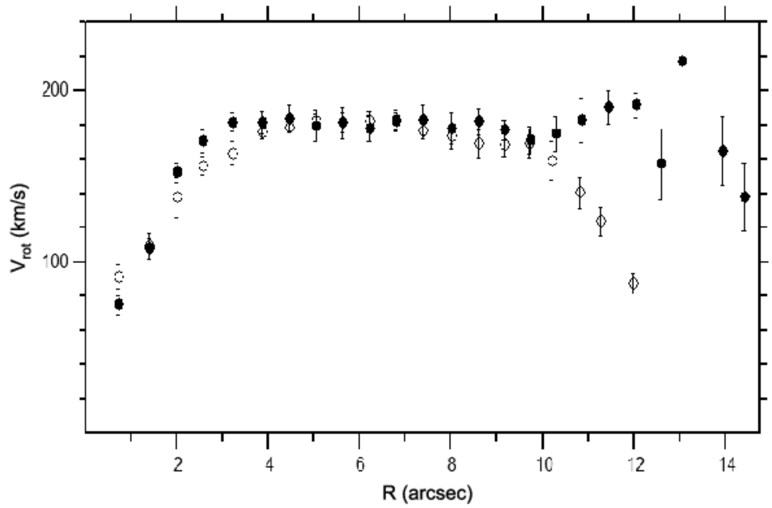
    5900-6000 angstroms

    (d) (2 points) The Phillips relation results from the radioactive decay of what isotope?

    Ni-56

Points earned: **18** / 18

15. Consider the following figure from Petrosa et al. (2008) depicting the rotation curve of a galaxy with a companion.



The approaching side of the galaxy is depicted using the black circle, while the receding one is depicted using empty circles.

(a) (3 points) What type of galaxy is depicted here? Why? Why might other galaxy types not work?

- **(1pt) Spiral (Lenticular acceptable)**
- **(1pt) One side approaching and the other side receding implies moving as a whole as a disk.**
- **(1pt) Cannot be an elliptical because ellipticals don't rotate in a uniform way.**

(b) (2 points) What galactic region is represented by the steep incline on the left of the graph?

Bulge

(c) (3 points) What does the bifurcation feature on the right potentially tell us about the geometry of this interaction?

- **(1pt) Companion galaxy likely interacted with the receding side/arm.**
- **(1pt) Receding arm has a steep drop, while the approaching one still remains relatively straight.**
- **(1pt) Rotation curves are flat due to dark matter, receding one disrupted.**

16. A black hole has mass $1.00 M_\odot$.

(a) (2 points) Calculate the Schwarzchild radius, in kilometers.

2.9-3.0 km

(b) (2 points) Suppose the center of a 2 meter bar is six kilometers away from the center of the same black hole. How much faster is one end of the bar accelerating towards the black hole than the other?

$\mathbf{1 \cdot 10^9 - 4 \cdot 10^9\ m/s^2}$

(c) (2 points) What is the effect in (b) known as?

Spaghettification

(d) (2 points) Suppose you fell into two black holes, A and B. Black hole A is one thousand times more massive than black hole B. Which black hole, if any, would you be more likely to cross the event horizon intact? Explain.

- **(1pt) Larger black hole**
- **(1pt) Smaller black holes have steeper gravitational gradient beyond the event horizon, so you'd like get ripped apart**

17. Answer the following questions relating to the evolution of the universe.

(a) (2 points) Before recombination, the universe was mostly composed of free electrons and protons. Would the universe have been opaque or transparent? Explain.

- **(1pt) Opaque.**
- **(1pt) Thompson scatting by electrons prevented photons from traveling very far (anything involving scattering is sufficient).**

(b) (1 point) What atom or molecule resulted from recombination? Be specific.

Neutral Hydrogen

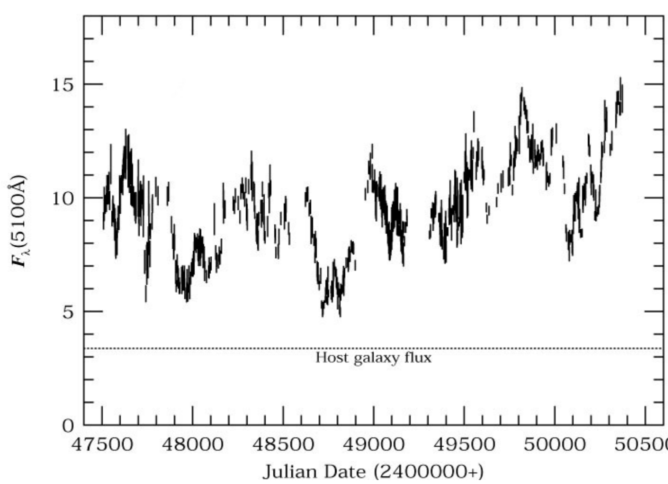
(c) (2 points) Eventually, stars and galaxies began to form. How did this affect the opacity of the universe?

- **(1pt) Became transparent across all wavelengths.**
- **(1pt) Stars and galaxies ionized the hydrogen, allowing for greater transparency.**

(d) (1 point) What is the name for the epoch described in (c)?

Reionization

18. Consider the following light curve with respect to time of a Seyfert galaxy from Peterson et al. (1999). The horizontal line indicates the contribution from the host galaxy with a standard aperture.



(a) (1 point) What region of the galaxy is likely observed here?

Nucleus

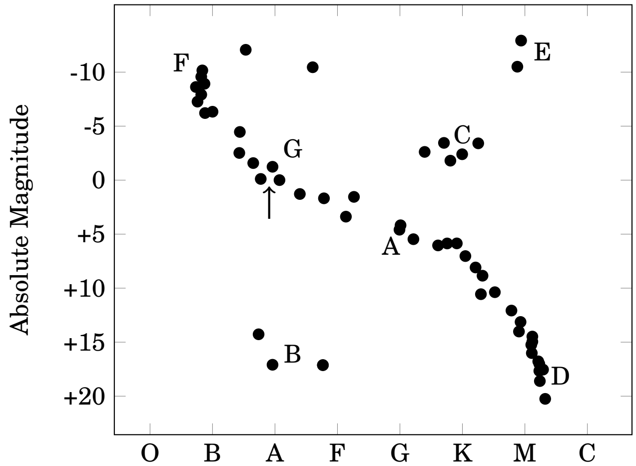
(b) (2 points) What Seyfert class would you expect this to be? Explain.

- **(1pt) Seyfert 1**
- **(1pt) Nucleus is substantially brighter than the host flux, as well as with large variations. A Seyfert 2 wouldn't be as bright compared to the rest of the galaxy due to intervening dust.**
- **Basically, direct line of sight.**

(c) (3 points) Would we expect this variability to be more or less pronounced in X-rays? Explain.

- **(1pt) More pronounced.**
- **(1pt) Friction/loss of gravitational potential heat up gas in the torus.**
- **(1pt) Gas heated to high temperatures, emits X-rays.**

19. Consider the following HR-diagram.



(a) (1 point) What is plotted on the x-axis of this diagram?

Spectral class

(b) (1 point) According to the diagram, the stars corresponding to which label are the hottest?

F

(c) (1 point) Which label(s) corresponds to stars that are considered "degenerate"?

B

(d) (1 point) Suppose the arrow points to Star M. If Star M is 125 parsecs distant, calculate its apparent magnitude assuming negligible extinction.

+5.3-5.7

(e) (2 points) Calculate the flux on Earth due to Star M, in Watts per meter squared.

$\mathbf{1.78 \cdot 10^{-10}\ W/m^2}$

(f) (2 points) Assuming a typical temperature for stars of this type of 8500K, determine the radius of Star M, in solar radii.

4.2-4.5 $\mathbf{R_\odot}$

(g) (2 points) How long will this star remain on the main sequence? You may assume that $L \propto M^{3.5}$ for a main sequence star.

$\mathbf{1 \cdot 10^8 - 5 \cdot 10^8}$ **years**

(h) (2 points) Order the following objects in order of decreasing radius: B, A, E, D.

E, A, D, B

(i) (2 points) Why are there no stars in the rightmost part of the diagram? Are stars ever in this region? Explain.

- **(1pt) No stars on the right side because not in hydrostatic equilibrium.**
- **(1pt) Protostars emerge in this region, but collapse and descend onto the main sequence.**

Points earned: **14** / 14