2020

Las Vegas Invitational

Astronomy C

Written by: Asher Noel

Team Number: _____

Team Name: _____

Team Members: _____

Directions:

Each sub-question is worth two points. Partial, integral credit will be given for sub-questions with multiple parts. Only the answer sheet will be scored. Computational problems will accept a range of numbers. Questions? Email me at ashernoel@college.harvard.edu!

Good Luck!

Contents

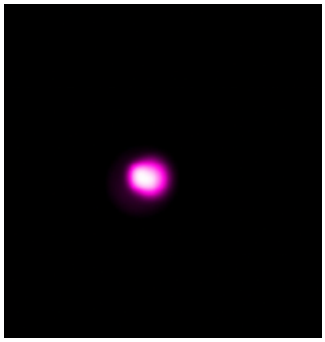
Question 1: DSOs 1

1. For the following ten images, identify the:

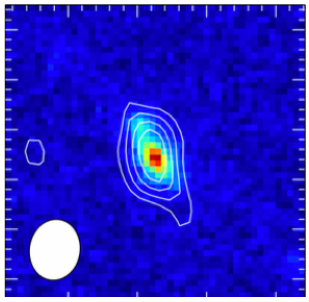
(a) DSO & the cause of the radiation in this wavelength.

(b) DSO & cause of the radiation in this wavelength.

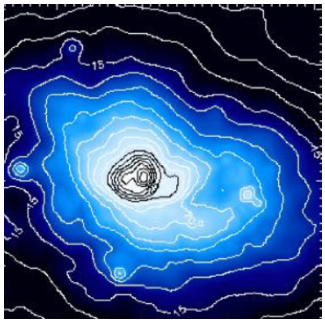
(c) DSO & redshift.



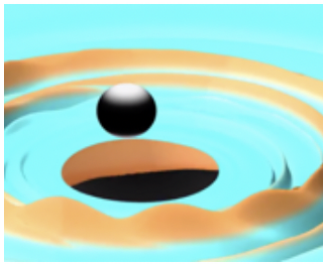
(d) DSO & redshift



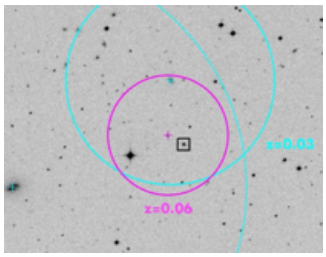
(e) DSO & telescope.



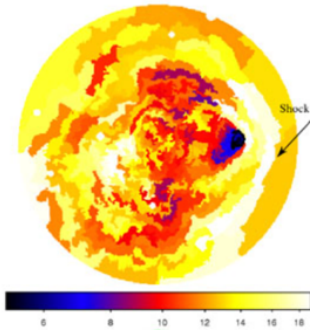
(f) DSO & the chirp mass, in solar masses.



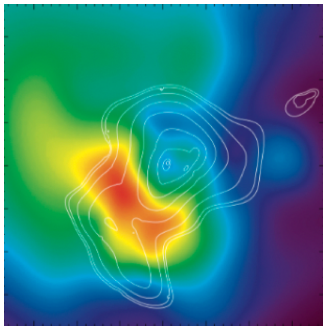
(g) DSO & type of AGN shown in the box.



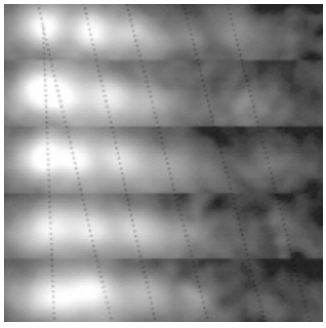
(h) DSO & cause of the shock front.



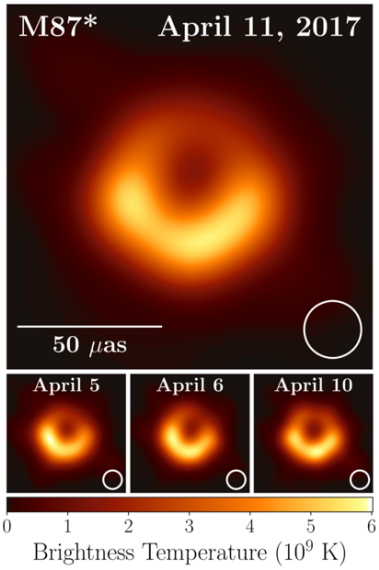
(i) Galaxy shown & DSO used as a lens.



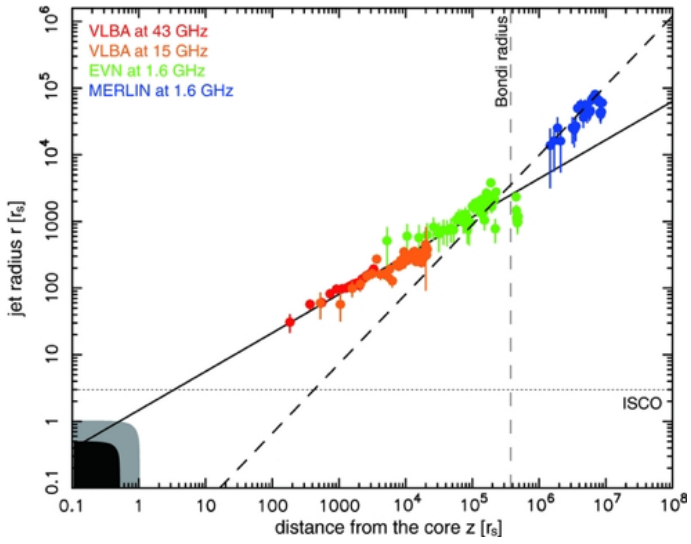
(j) DSO & what this suggests about the dynamics of of the DSO.



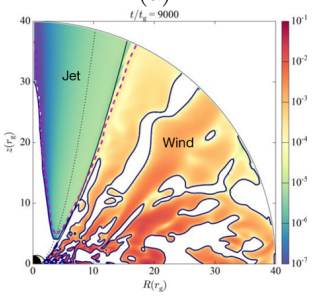
Question 2: M87 In Depth



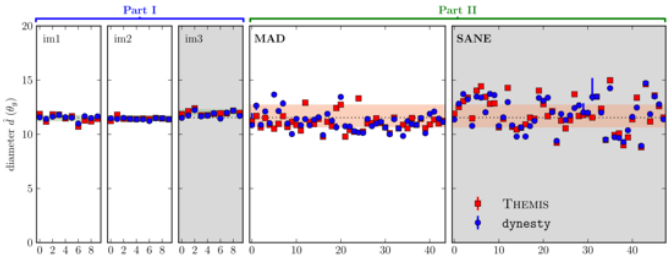
(a)



(b)



(c)



(d)

1. Image A shows an Event Horizon Telescope (EHT) image of M87* from observations on 2017 April 11. Image B shows how the jet evolves from parabolic to conical in nature. Image C shows a simulation of the environment in the vicinity of the black hole. Assume a distance of 16.8 megaparsecs. The following equation relates the gravitational ring diameter to the mass of and distance to a black hole:

$$\theta_g = \frac{GM}{c^2 D}.$$

   (a) Compare 1) the size of the gravitational radius and 2) the size of the photon ring to the more traditional Schwarzschild radius.

   (b) Using images A and D, calculate the size of the gravitational radius in microarcseconds.

   (c) Calculate the mass of M87's central black hole, in solar masses.

   (d) Calculate M87's Schwarzschild radius, in km.

   (e) Calculate the light crossing time of M87's central black hole, in seconds.

   (f) What does the horizontal dotted line in image A represent?

   (g) Based off the dynamics in image B, why might the jet be over collimated and parabolic in magnetically arrested areas closer than the Bondi radius?

   (h) Estimate how long will it be until the EHT publishes images of Sagittarius A*.

Question 3: Cosmological Equations

3. If you are a cosmologist, there are three equations worth tattooing to your forehead:

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{\kappa c^2}{a^2} + \frac{\Lambda c^2}{3}$$

$$\dot{\epsilon} + 3\frac{\dot{a}}{a}(\epsilon + P) = 0$$

$$\frac{\ddot{a}}{a} = \frac{-4\pi G}{3c^2}(\epsilon + 3P) + \frac{\Lambda}{3}$$

For the following eight questions, assume a=1.

(a) Identify the name of the first equation.

(b) Identify the name of the second equation.

(c) Identify the name of the third equation.

(d) Estimate the value of $\dot{a}$, in s-1.

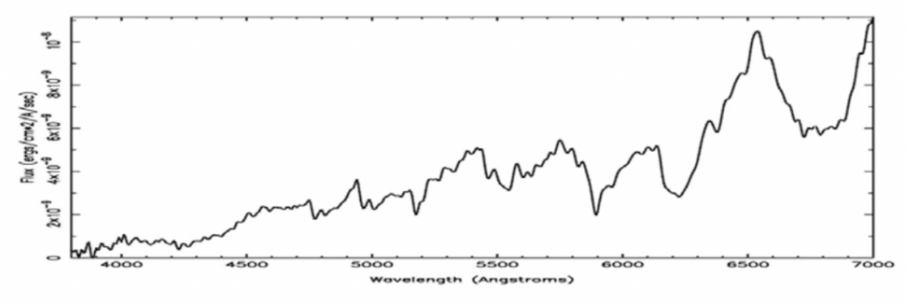
(e) Assuming a flat universe without dark energy, use the first equation to estimate the present critical density, in kg/m3.

(f) Interpret the physical meaning of a positive $\dot{a}$.

(g) Which term in the third equation dominates?

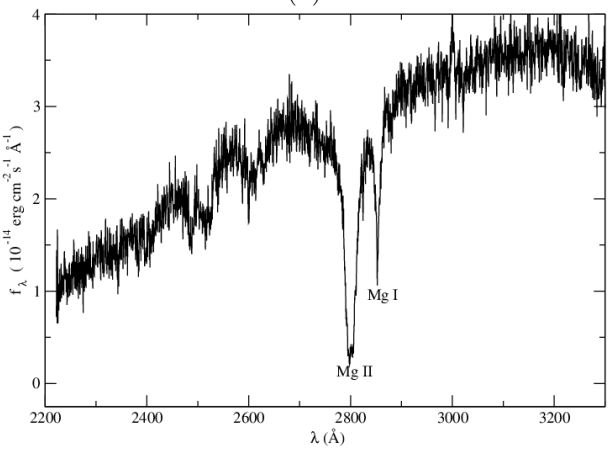
(h) Identify the sign of $\ddot{a}$.

Question 4: Spectral ID



(a)

(b)



(c)

4. (a) Identify the spectral type of the star shown in A
   (b) Estimate the effective surface temperature of the star.
   (c) Estimate the absolute bolometric magnitude of this star.
   (d) Identify the spectral type of the star shown in B.
   (e) Estimate the mass of this star.
   (f) How would the spectral lines be different if this star evolved into a supergiant?
   (g) Identify the spectral type of the star shown in C.
   (h) Which star is closest in mass to the sun? Why?
   (i) (4 points) Compare the nuclear fusion in stars A, B, and C to that of the sun.
   (j) Which stars would you expect to find in a cluster near the Milky Way's bulge? Why?
   (k) Which star would you expect to find in a cluster near the Sun? Why?
   (l) Which star would you expect to find in the Milky Way's halo? Why?
   (m) What causes the dark regions shown in B?
   (n) What causes the troughs shown in A and C?

Question 5: Reference Warm-Up

5. This question should serve as a good warm-up for the partner who does not start with DSOs. An essential component of any binder, whether physical or on a laptop, is quickly accessible reference information. For each of the following, write the correct number or equation on the corresponding part of the answer sheet. A range of answers will be accepted for the ambiguous values.

   (a) Meters in an AU.

   (b) AU in a parsec.

   (c) Arcseconds in a radian.

   (d) Solar mass in kg.

   (e) Solar effective temperature in Kelvin.

   (f) Solar absolute visual magnitude.

   (g) Solar apparent bolometric magnitude.

   (h) Julian year in seconds.

   (i) Absolute magnitude of RR Lyrae.

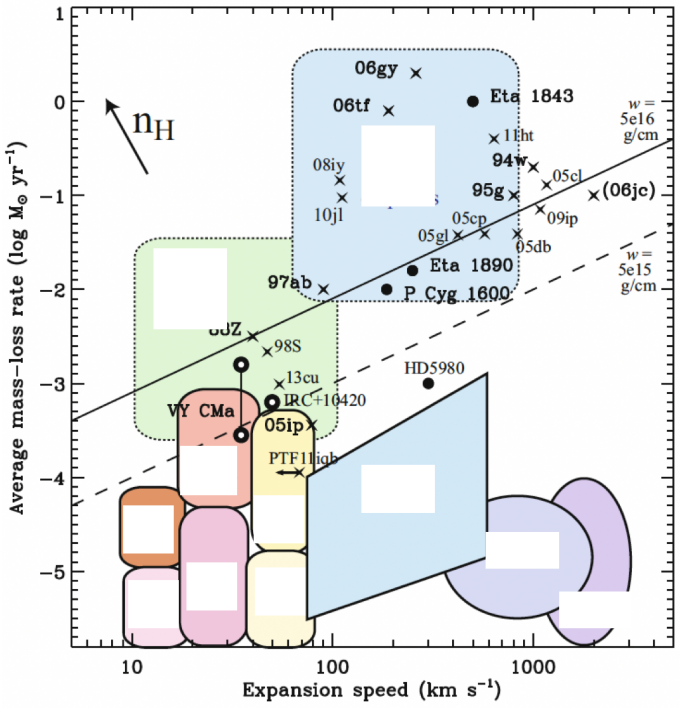
   (j) Effective temperature of an A0III star.

   (k) Radius of a A2Iab star in solar radii.

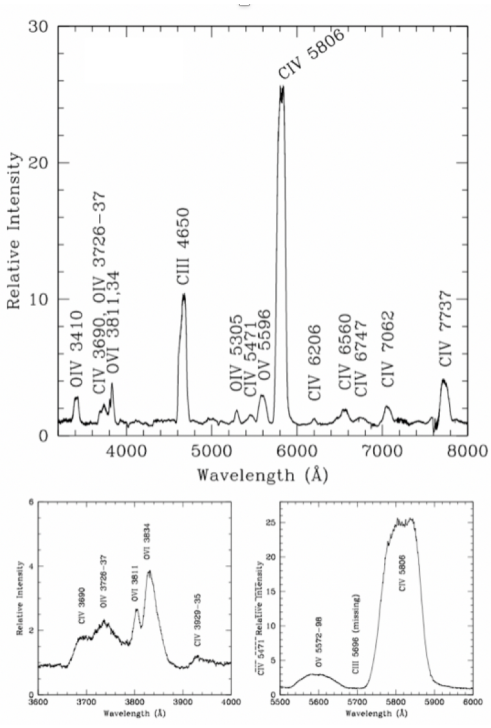
   (l) Equation for distance modulus (mu) as a function of distance in parsecs.

   (m) Equation for luminosity in watts as a function of radius in meters and temperature in kelvin.

Question 6: Wolf Rayet



(a)



(b)

5. (a) Identify the type of Wolf Rayet star shown in B:

(b) Explain why the emission lines are broad.

(c) What spectral feature occurs near the CIV 7737 line?

(d) Identify the color the region where you would expect to find Wolf Rayet stars in A.

(e) This Wolf Rayet star is a progenitor for what type of core collapse supernova? Why?

(f) Would you expect this star to be found in a high or low redshift galaxy? Why?

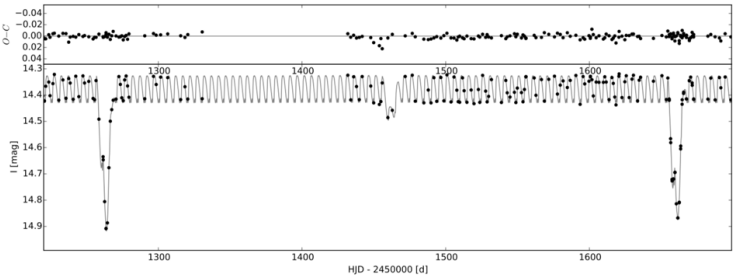
(g) Give one reason why this star might be found in younger populations, another reason why this star might be found in older populations, and then determine which dominates.

(h) Why might gravitational wave astronomers be interested in this object?

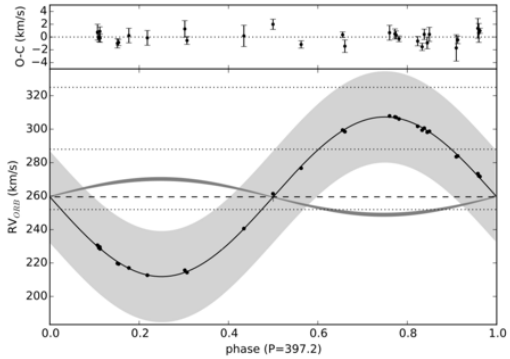
(i) Would you expect to find this star in NGC 2623?

(j) How might Wolf Rayet stars contribute to the Intergalactic Medium?

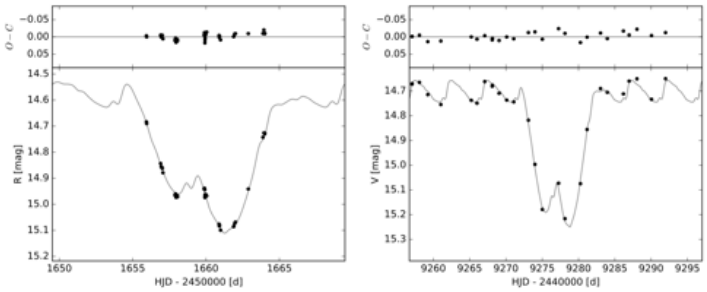
Question 7: A Cepheid Eclipsing Binary



(a)



(b)



(c)

6. OGLE LMC-T2CEP-098 is an eclipsing binary with a type II Cepheid. Given the light curve below an average apparent visual magnitude of 11 for the Cepheid, calculate:
   (a) The period of the Cepheid, in days.
   (b) The period of the binary orbit, in days.
   (c) The average absolute visual magnitude of the Cepheid.
   (d) The distance to the binary, in parsecs.
   (e) The maximum peculiar velocity of the Cepheid, in km/s.
   (f) The semi-major axis of the system, in solar radii.
   (g) The mass of the companion, in solar masses.
   (h) The radius of the companion, in solar radii.
   (i) The density of the companion, in kg/m3.
   (j) Identify the current stage of stellar evolution of the companion (main sequence, neutron star, LBV, etc.)

Question 8: Hubble Fun

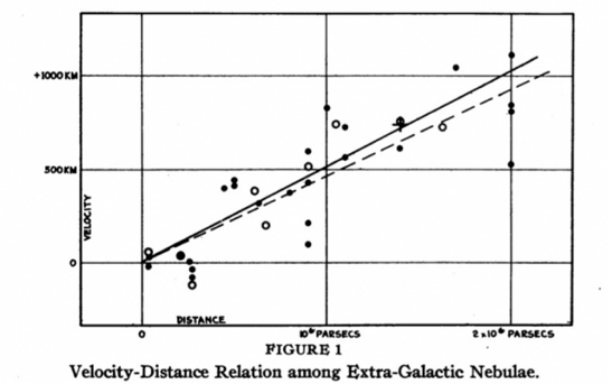
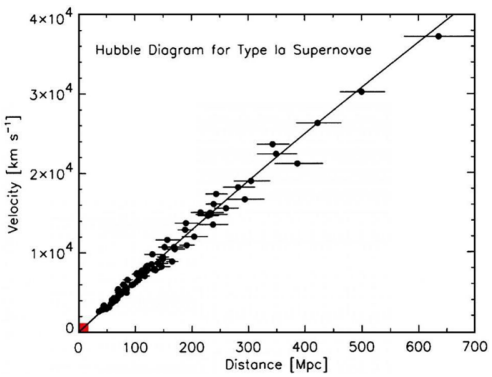
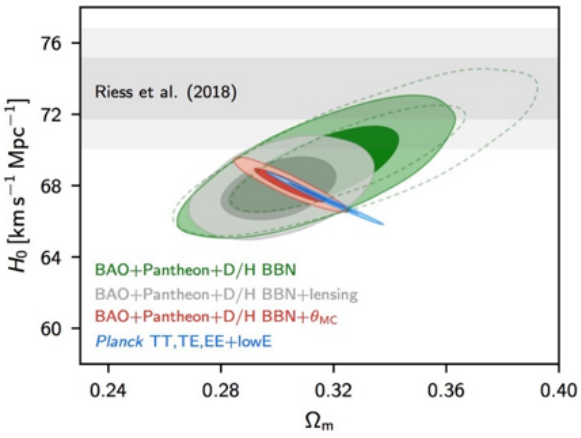


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.





7. Based off of the image in the image in the top left, calculate the Hubble constant, in km/s/Mpc.
8. Based off of the image in the image in the top right, calculate the Hubble constant, in km/s/Mpc.
9. Based off of the bottom image, calculate the Hubble constant, in km/s/Mpc.
10. Based off of the bottom image, what would the density parameter for matter Ω_m be if the Hubble constant was 72 km/s/Mpc?
11. In a universe with a $H_0 = 50 km/s/Mpc$,
    (a) (6 points) Calculate the present:
        i. Hubble time.
        ii. Hubble distance.
        iii. Cosmological constant.
    (b) (4 points) Describe the physical interpretation of the:
        i. Hubble flow.
        ii. Hubble friction.

Answer Sheet A: Questions 1-4

1. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   (f) _____
   (g) _____
   (h) _____
   (i) _____
   (j) _____
2. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   (f) _____
   (g) _____
   (h) _____
3. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   (f) _____
   (g) _____
   (h) _____
4. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   (f) _____
   (g) _____
   (h) _____
   (i) _____

(j) _____

_____

(k) _____

_____

(l) _____

_____

(m) _____

_____

(n) _____

_____

Answer Sheet B: Questions 5-8

5. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   _____
   (f) _____
   _____
   (g) _____
   _____
   _____
   (h) _____
   (i) _____
   (j) _____
   _____

6. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   (f) _____
   (g) _____
   (h) _____
   (i) _____
   (j) _____

7. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) i. A. _____
   B. _____
   C. _____
   (f) i. A. _____
   B. _____

8. (a) _____
   (b) _____
   (c) _____
   (d) _____
   (e) _____
   (f) _____
   (g) _____
   (h) _____
   (i) _____
   (j) _____