Introduction

Please consult the attached images to answer the questions in Sections A and B.

When asked to give the name of an object which may have multiple designations, use the primary name (i.e. not the one given in parentheses) provided in the 2020 Event Description.

Please spell out acronyms in short-answer questions (e.g. use "Infrared" instead of "IR", "Hubble Space Telescope" instead of "HST", etc.).

Report all answers to 3 significant figures, regardless of how many are given in the problem.

In the event of a tie, total score on the following question ranges will be used as tiebreakers, in order: 48-54, 37-42, 32-34, 64-68, 9-13, 43-47, 18-21, 55-58, 59-63, 25-28, 35-36, 5-8, 22-24, 29-31, 14-17, 1-4

You will have 50 minutes to complete the test during the hour. At the end of your time, or the top of the next hour, the test will be shut down. Partners can work on different parts of the test at the same time. Please stay on the UMSO website, if you leave your time will be tracked and available to the event supervisor.

Good luck, and may the stars be with you!

Conclusion

Thank you for your participation today! We wish you GOOD LUCK in all your events!

Section A: For each set of questions below, please refer to the given image which precedes it

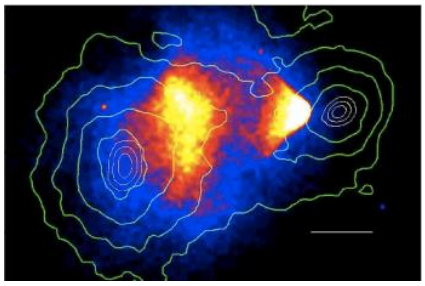

Image 1.

1. What is the name of the object depicted in Image 1? [1]

Bullet Cluster

2. The contour lines in this image represent a spatial distribution of mass in the object. How was the location of this mass determined? [1]

Gravitational lensing of the light from further galaxies

3. What is notable about these contours with respect to the underlying x-ray activity? [1]

They are disjointed (mass is not found in regions of high x-ray activity)

4. How does the above observation support theories of dark matter distribution in galaxies? [2]

Gravitational lensing suggests matter along contours, baryonic matter (plasma) is not; almost certainly dark matter

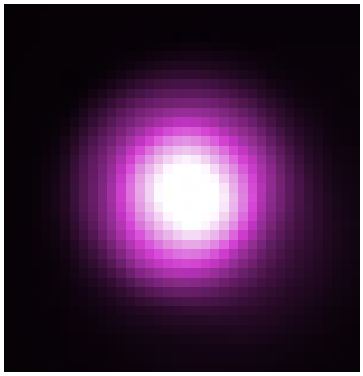

Image 2. PSS 0955+5940 (x-ray, Chandra)

5. Which observatory is responsible for conducting the survey which captured Image 2? [1]

Chandra X-ray Observatory

6. Briefly describe the purpose of this survey. What were astronomers hoping to better understand? [2]

Determine the effects of dark energy on early Universe through present day by observing quasar distances

7. The object in this image is one of almost 1600 of its type to be imaged in this survey. What is significant about this object compared to the others in this survey? [1]

It was one of the most distant observed

8. Based on this, why was this object of particular importance to the survey? [2]

The object's distance means that it can acts as an initial point in the early Universe to track its expansion rate over the greatest possible time

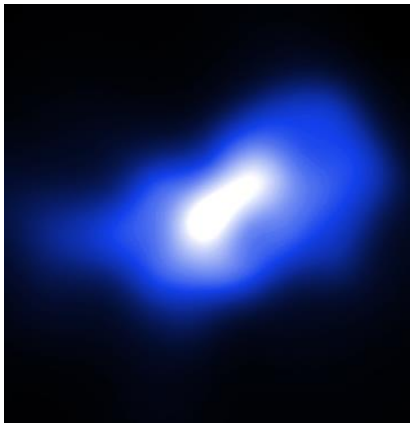

Image 3. MACS J1149.5+2223 (x-ray, Chandra)

9. What is the name of the object depicted in Image 3? [1]

MACS J1149.5+2223

10. What structure in this object is revealed by observations in the wavelength of Image 3? [1]

Diffuse gas associated with merging clusters

11. This object is notable for allowing observation, through gravitational lensing, of what smaller major object? [1]

MACS J1149 Lensed Star 1 (most distant star ever observed)

12. What aspect of this object enables it create such a lensing effect? [1]

High concentration of mass in a distributed arc

13. Compare the lensing effect of this object to that of a stellar-mass black hole. [2]

Black hole would create a singular point-like lens, while this object's arced distribution of sub-clusters results in an uneven lens that is stronger in some locations than others

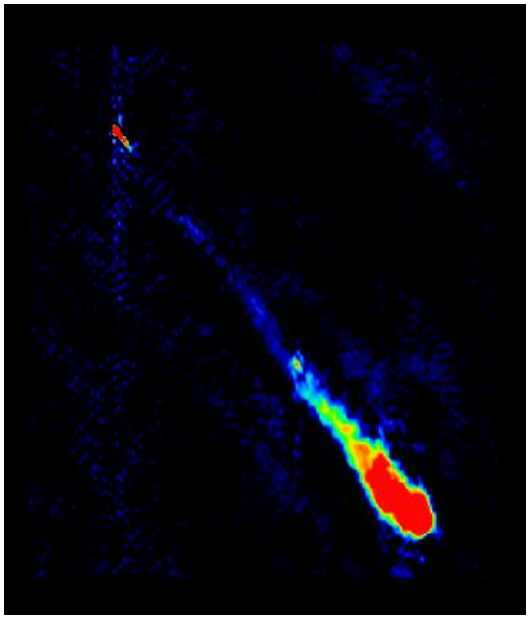

Image 4. 3C 273 (radio, MERLIN)

14. What is the name of the object depicted in Image 4? [1]

3C 273

15. What particular feature is seen in this radio image of the object? [1]

Multi-spectral jet

16. In what other wavelength(s) could this feature potentially be seen in? [2]

Optical, x-ray

17. Why is this object notable in the field of amateur astronomy? [1]

Due to the quasar's brightness, it is one of the furthest consistently-observable objects in the night sky

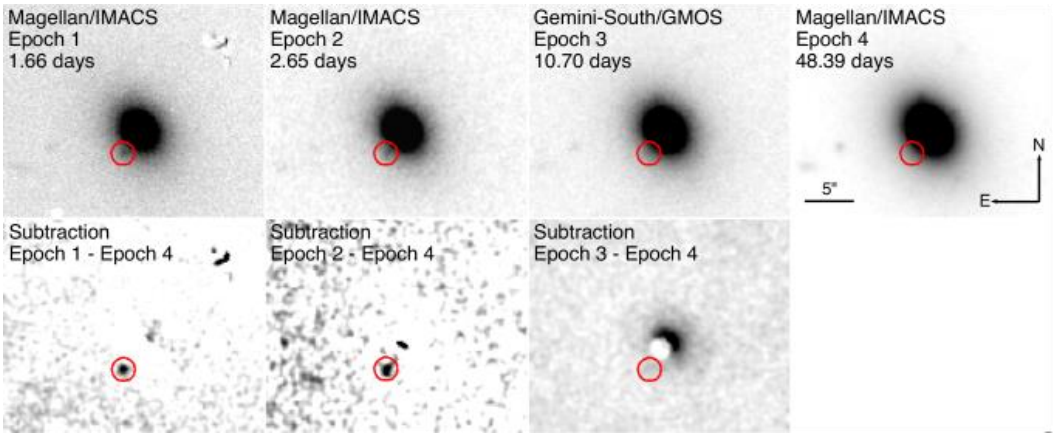

Image 5. GRB150101B (optical, Magellan)

18. Image 5 depicts the evolutionary progression of what type of astrophysical event? [1]

Gamma-ray burst

19. What type of object is represented by the large black ellipse in the center of Image 5? [1]

Active Galactic Nucleus

20. What phenomenon is depicted in the "Subtraction" images in this set? [1]

Gamma-ray burst afterglow

21. How would the feature in the red circle appear if imaged by a gamma-ray telescope? [2]

Would be much more visible in the top row, nearly invisible in the bottom row

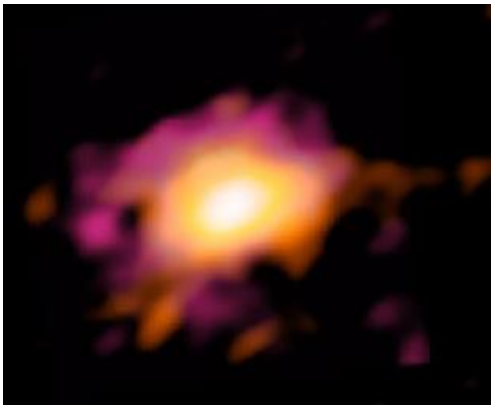

Image 6. DLA0817g (radio, ALMA)

22. What is the name of the galaxy depicted in Image 6? [1]

DLA0817g

23. Describe the morphology of this object. [1]

Cold, massive, rotating disk

24. How does this object contradict current models for galactic evolution? [2]

It appears to have formed extremely soon after the Big Bang by accretion of cold material, rather than hierarchical build-up by the funneling of gas into a condensing halo

Image 7. MACS J0717.5+3745

25. What is the name of the object depicted in Image 7? [1]

MACS J0717.5+3745

26. What structure is represented by the blue colors in Image 7? [1]

Constituent dark matter of the galaxy

27. These blue colors were not present in the original version of this image. Why were they originally missing, and how was their location determined? [2]

Needed to be added because image is optical (Hubble) and dark matter is invisible; location determined by observed gravitational lensing effect on light of background objects

28. How has the presence of this same structure impacted radio observations of the region around this object? [1]

Revealed distant radio sources behind the cluster which would have otherwise been invisible

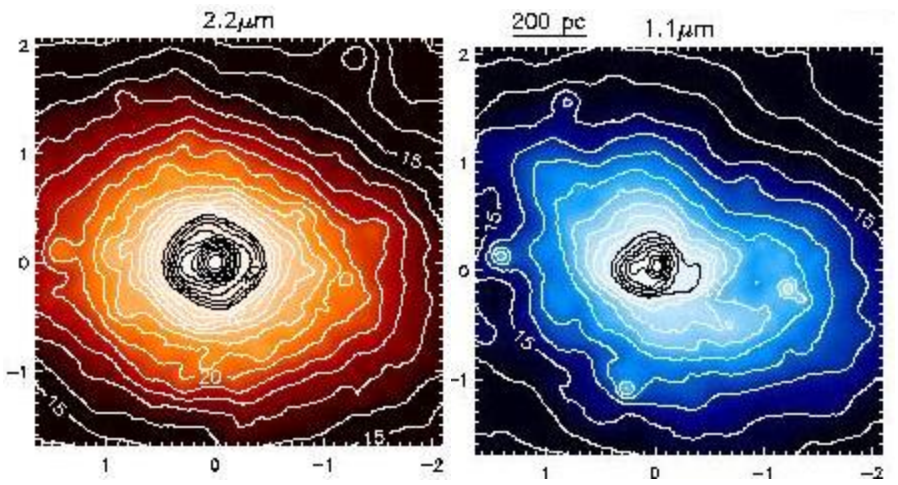

Image 8. NGC 2623 (IR, NICMOS)

29. In what wavelength were the two parts of Image 8 taken? [1]

Infrared

30. What do the lines on these images represent? [1]

Contoured areas of equivalent infrared light intensity

31. There are some discrepancies between these two images, particularly in the line structure around (-1.0”, -0.2”). What does this discrepancy physically represent, and why is it present? [2]

Represents a residual tail structure from a prior merging event; only present in 1.1-micron it is closer to optical light, where the feature is most prominent

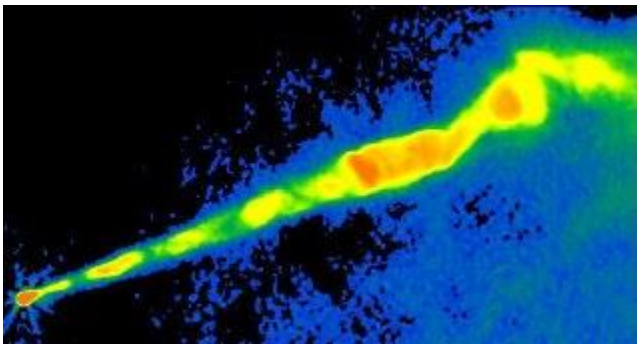

Image 9. M87 (radio, VLA)

32. What is the name of the object which produced the structure seen in Image 9? [1]

M87

33. This structure has been called “superluminal” due to what observed characteristic? Describe the process by which this characteristic is manifested. [2]

Material in jet appears to move faster than speed of light; results from jet falling nearly along line of sight, thus the material approaches the observer almost as fast as its own light, causing it to appear superluminal

34. Is this structure symmetrical with respect to its source (i.e. present on both sides)? If so, why does it not appear so in Image 9? If not, why not? Use as much detail as necessary. [3]

Yes, but doesn't appear so because of relativistic beaming, causing other jet to appear dimmer as it moves near-light speed in opposite direction (1 pt for correct yes/no, 2 pts for process identification and description)

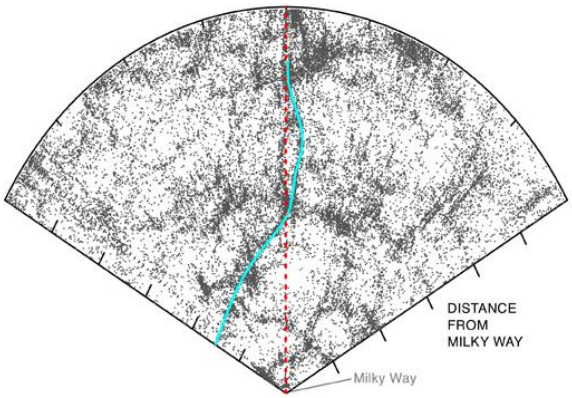

Image 10. H2356 (in Sculptor Wall)

35. What is represented by the red and blue lines of Image 10? [2]

Blue line is Sculptor Wall, red line is line-of-sight to H2356-309

36. How could Image be used to give evidence for the existence of WHIM? [2]

By depicting intersections between the light emitted by H2356-309 and the Sculptor Wall, extinctions in the former can be explained by the latter, which is thought to be where the WHIM would reside in the greatest concentration

Section B: For each set of questions below, please refer to the given image and/or text prompt which precedes it.

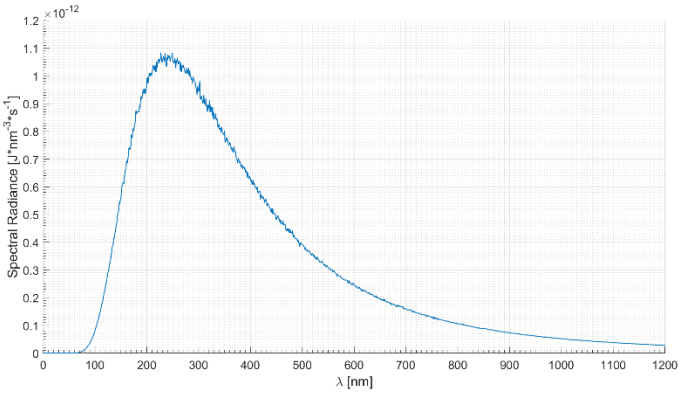

Image 11.

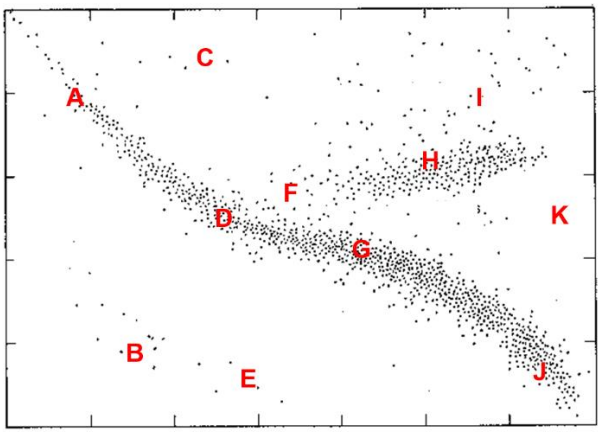

Image 12.

In your Introduction to Observational Astronomy lab class, you are asked to choose a star in the night sky and produce its blackbody spectrum, as well as measure its position and size. You produce the spectrum in Image 11 and find it to have a radius of approximately **79 $R_\odot$**. Six months later, you check the star's new position in the sky to find that it has moved through an angular distance of **7.692 milliarcseconds** in the sky.

37. What is the distance to this star from Earth in parsecs? [1]

255 – 265 pc

38. What is the star's effective temperature, in Kelvin? [2]

11,000 – 13,200 K

39. What is the star's luminosity, in Solar luminosities? [2]

0.82 – 1.71 x 10^5 $L_\odot$

40. What is the star's absolute bolometric magnitude? [2]

-7.5 – -8.3

41. What is the star's apparent visible magnitude? [4]

-0.83 – 0.97

42. What letter shows this star's approximate location on the HR diagram (Image 12)? [2]

C

Using the same H-R Diagram as given in Image 12, answer the following:

43. What is measured along the x-axis (multiple answers possible, give only one)? [1]

Spectral class, color index, temperature

44. What is measured along the y-axis (multiple answers possible, give only one)? [1]

Luminosity, absolute magnitude

45. By approximately what factor (that is, as a power of 10) does a star's luminosity increase from G to A? [2]

10000, or 10^4

46. Which letters show stars of luminosity class V? [1]

A, D, F, G

47. Which letters show the potential star types to have produced SN UDSWil10? [2]

B, E (almost definitely a white dwarf merge event rather than an accretionary event)

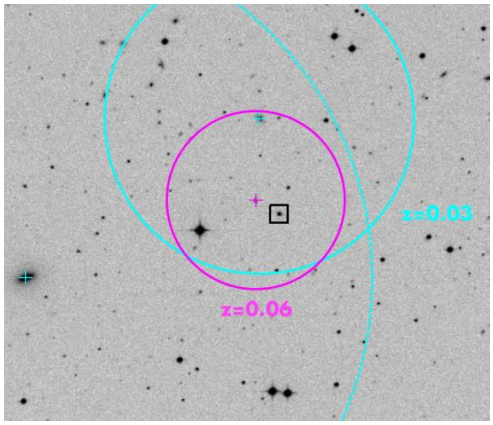

Image 13

Image 13 depicts the region of the sky around the quasar H2356+309, with the magenta and cyan circles indicating the virial radii at the denoted z-parameter of the nearest galaxies to H2356+309, all of which lie in front of the quasar along the line of sight. For these questions, consider only the galaxy denoted by the magenta circle (henceforth named "Magenta") in the current ΛCDM cosmological model.

48. Define the approximate (to no more than 2 significant figures) values of the following parameters of a ΛCDM universe: baryonic matter density, dark matter density, dark energy density, curvature, overdensity at zero redshift, and Hubble constant in (km/s)/Mpc [3]

$\Omega_b = 0.049$; $\Omega_c = 0.26$; $\Omega_\Lambda = 0.69$; $\Omega_k = 0.00$; $\Delta_c = 100$; $H_0 = 66\text{-}68$ (km/s)/Mpc

49. Determine the Hubble parameter in (km/s)/Mpc for this model at Magenta using the values you defined above. [3]

H(z) = 67.9 – 70.0 (km/s)/Mpc

50. Determine the critical density of the Universe at the age of Magenta, in kg/m^3. [3]

8.6E-27 – 9.2E-27 kg/m^3

51. What is the mean density within the virial radius of Magenta as defined in the current model? [1]

8.6E-25 – 9.2E-25 kg/m^3

52. In actuality, at z > 0, overdensity is typically normalized to 200. In this case, presume that the virial radius is 80 kpc, and determine the virial mass, in Solar masses, of Magenta (assume no change in critical density). [2]

$5.4 – 5.8 \times 10^{10} M_{\odot}$

53. Determine the recessional velocity of Magenta, expressed as a decimal fraction of the speed of light. [3]

0.058 – 0.060

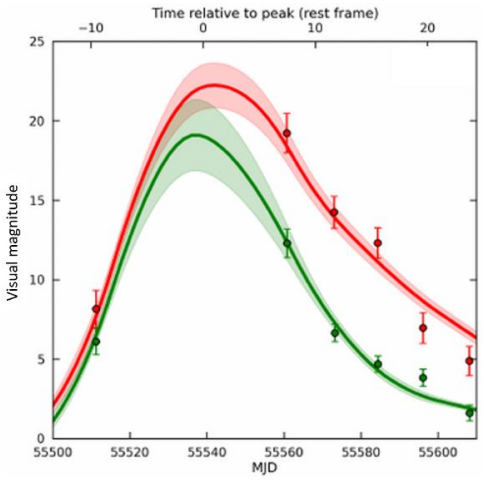

Image 14.

54. At the beginning of this problem, it was stated that the object H2356+309 is a quasar. Assume now that H2356+309 was determined instead to be a Type Ia supernova (with all other factors of distance and space environment unchanged), whose light curve was measured by two separate instruments and is given in Image 14 above. Citing the values you have calculated thus far, as well as your knowledge of H2356+309 in reality, determine whether or not an approximate average of the two data sets in Image 14 represents a reliable measurement of this object. [5]

Using Hubble's Law, distance is, at minimum, 256.6 – 272.5 Mpc. Type Ia SNs have consistent peak visual absolute magnitudes of M_v = -19.3, meaning H2356+309 would have a visual peak absolute magnitude (assuming no obstruction, redshift, etc.) of m_v = 17.7 – 17.9 Image 14 gives the light curve of a Type Ia SN which has an approximate m_v of ~20 when averaging the data sets. Though this is significantly dimmer than the 17.7 – 17.9 determined previously, we would expect some degree of dimming given the effects of WHIM extinction already theorized in H2356. Therefore, this data set is likely a reliable measurement of H2356.

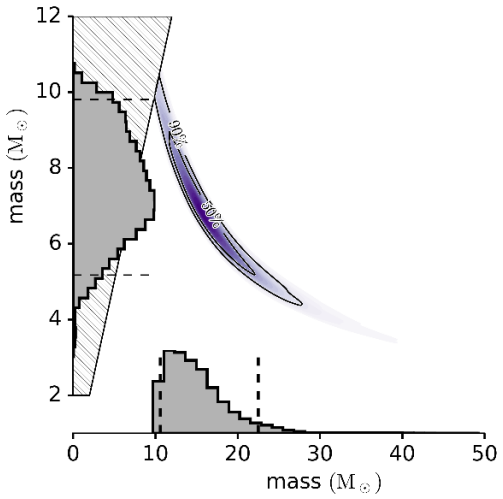

Image 15.

Image 15 shows the mass probability distribution of a black hole binary system responsible for one of the most groundbreaking recent signal observations in cosmology

55. What is the name of the signal produced by this system? [1]

GW151226

56. What are the individual component masses of the system when the mass of the secondary component is minimized at no worse than 50% confidence? 90%? [3]

50%: M=21–23 $M_\odot$, m=5–5.2 $M_\odot$ (2pt); 90%: M=26–29 $M_\odot$, m=4–4.5 $M_\odot$ (1pt)

57. The signal produced by this system resulted from the merging of the two components as their orbital separation diminished. Using the lower total system mass estimate of 17b, what was the orbital separation (in km) and gravitational potential energy (in J) of the system at an orbital period of 1 second? [3]

a = 4440 – 4560 km; E = 3.04E45 – 3.57E45 J (1.5pt each)

58. The point at which two black holes in a binary are considered “merged” is the subject of some debate in the astrophysics community. Assume for the purposes of this problem that “merging” occurs when the orbital separation between the black holes is less than the sum of their Schwarzschild radii. What were these same values (orbital separation and gravitational potential energy) at time of merging under this definition? [3]

a = 76.7 – 83.1 km (2pt); E = 1.67E47 – 2.06E47 J (1pt)

Section C: For each question below, a definition is given. Please give the general astrophysical term which best matches each definition.

59. Propagation of energy as curvatures of spacetime, often from massive-object interactions. [2]

Gravitational Waves

60. A uniform blackbody emission representing detectable traces of photon-matter decoupling in the early universe. [2]

Cosmic Microwave Background

61. Active galaxy type that displays strongly-ionized emission lines and a discernible host galaxy. [2]

Seyfert Galaxy

62. Limit which, if exceeded, would result in the collapse of a neutron star into a black hole. [2]

Tolman-Oppenheimer-Volkoff Limit

63. Variability about the mean radial velocity in a galactic cluster used to determine virial mass of the group. [2]

Velocity Dispersion

64. Pre-Main Sequence stars of early spectral type showing IR excess due to a circumstellar disk, coupled with strong Balmer emission lines. [2]

Herbig Ae/Be Star

65. Set of equations which describe the geometric distribution of matter in spacetime. [2]

Einstein Field Equations

66. Explanation for galactic spiral arm structure which differentiates between rotational speed of spiral arms and the stars which constitute them at any instant. [2]

Density Wave Theory

67. Process of black hole energy extraction which creates astrophysical jets and quasars. [2]

Blandford-Znajek Process

68. Criterion which relates the parameters of a rotating gaseous disks to predict its stability against collapse. [2]

Safronov-Toomre Criterion

Section A Total: 50 pts

Section B Total: 50 pts

Section C Total: 20 pts

Exam Total: 120 pts