

## 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*

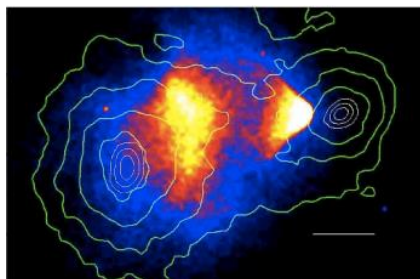
*You will have 50 minutes to complete the test during the hour. At the end of your time, or the top of the next hour, the test will be shut down. Partners can work on different parts of the test at the same time. Please stay on the UMSO website, if you leave your time will be tracked and available to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

***Good luck, and may the stars be with you!***

## Conclusion

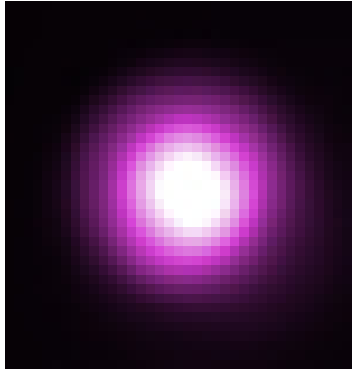
*Thank you for your participation today! We wish you GOOD LUCK in all your events!*

**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]
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]
3. What is notable about these contours with respect to the underlying x-ray activity? [1]
4. How does the above observation support theories of dark matter distribution in galaxies? [2]



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

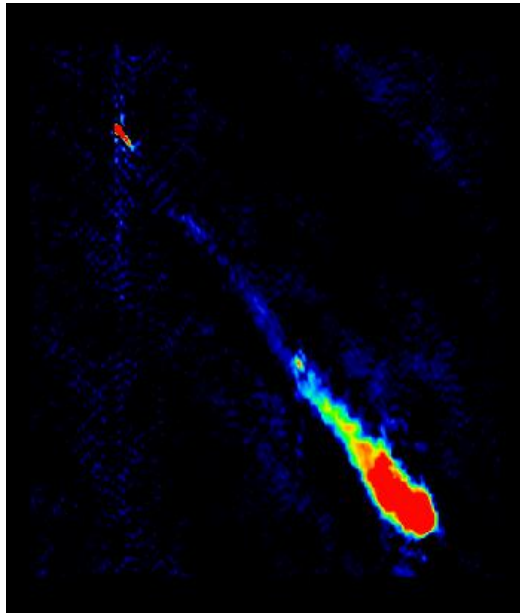
5. Which observatory is responsible for conducting the survey which captured Image 2? [1]
6. Briefly describe the purpose of this survey. What were astronomers hoping to better understand? [2]
7. The object in this image is one of almost 1600 of its type to be imaged in this survey. What is significant about this object compared to the others in this survey? [1]
8. Based on this, why was this object of particular importance to the survey? [2]



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

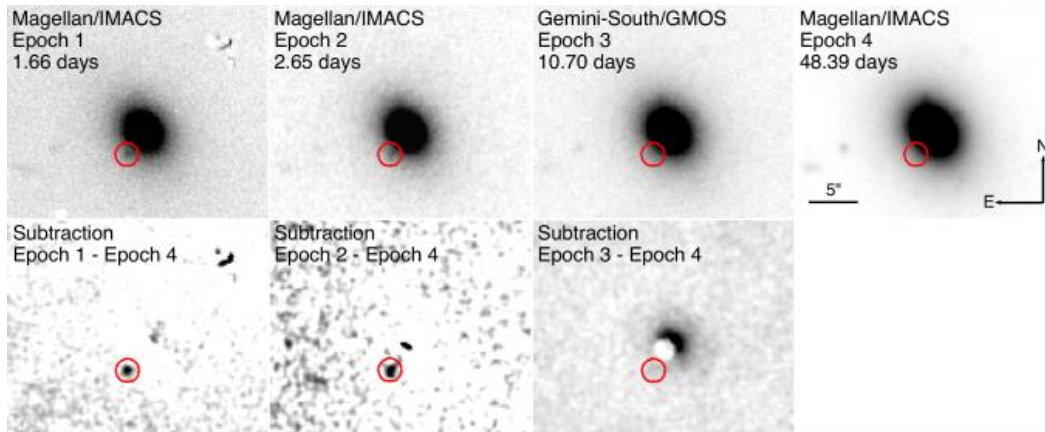
9. What is the name of the object depicted in Image 3? [1]

10. What structure in this object is revealed by observations in the wavelength of Image 3? [1]
11. This object is notable for allowing observation, through gravitational lensing, of what smaller major object? [1]
12. What aspect of this object enables it create such a lensing effect? [1]
13. Compare the lensing effect of this object to that of a stellar-mass black hole. [2]



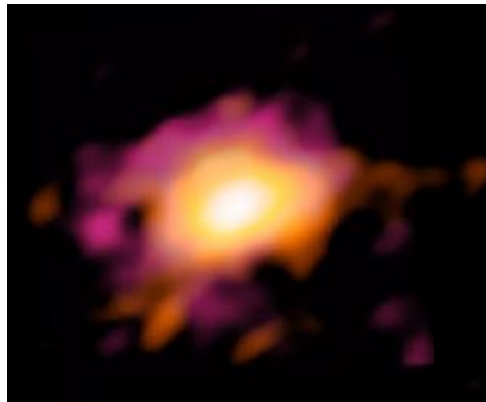
**Image 4.** 3C 273 (radio, MERLIN)

14. What is the name of the object depicted in Image 4? [1]
15. What particular feature is seen in this radio image of the object? [1]
16. In what other wavelength(s) could this feature potentially be seen in? [2]
17. Why is this object notable in the field of amateur astronomy? [1]



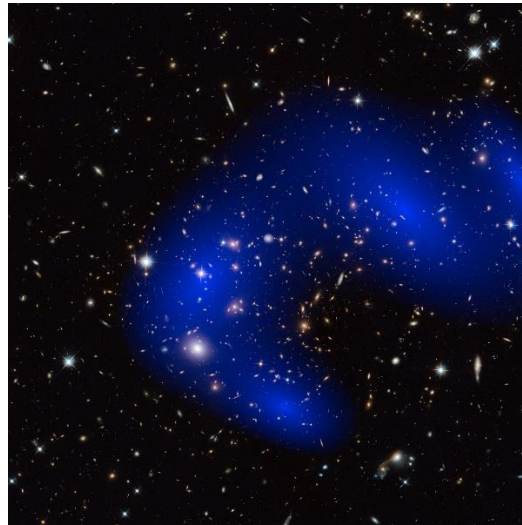
**Image 5.** GRB150101B (optical, Magellan)

18. Image 5 depicts the evolutionary progression of what type of astrophysical event? [1]
19. What type of object is represented by the large black ellipse in the center of Image 5? [1]
20. What phenomenon is depicted in the “Subtraction” images in this set? [1]
21. How would the feature in the red circle appear if imaged by a gamma-ray telescope? [2]



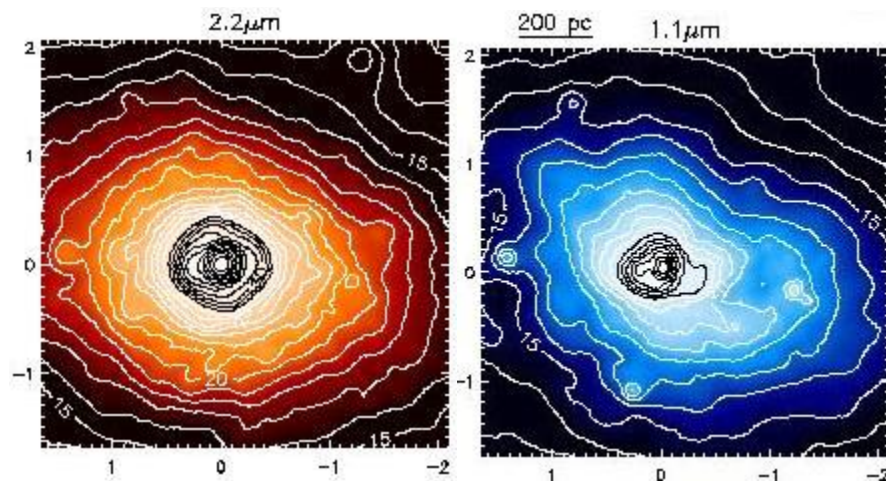
**Image 6.** DLA0817g (radio, ALMA)

22. What is the name of the galaxy depicted in Image 6? [1]
23. Describe the morphology of this object. [1]
24. How does this object contradict current models for galactic evolution? [2]



**Image 7.** MACS J0717.5+3745

25. What is the name of the object depicted in Image 7? [1]
26. What structure is represented by the blue colors in Image 7? [1]
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]
28. How has the presence of this same structure impacted radio observations of the region around this object? [1]

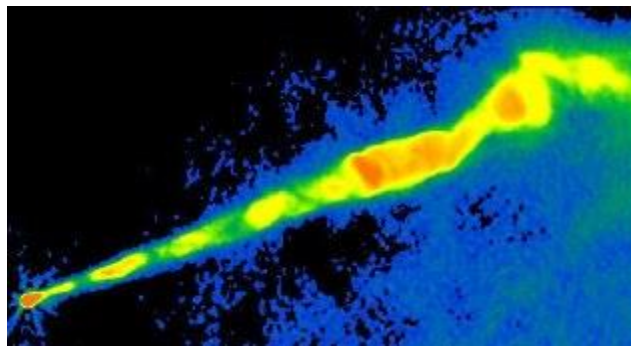


**Image 8.** NGC 2623 (IR, NICMOS)

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

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

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]

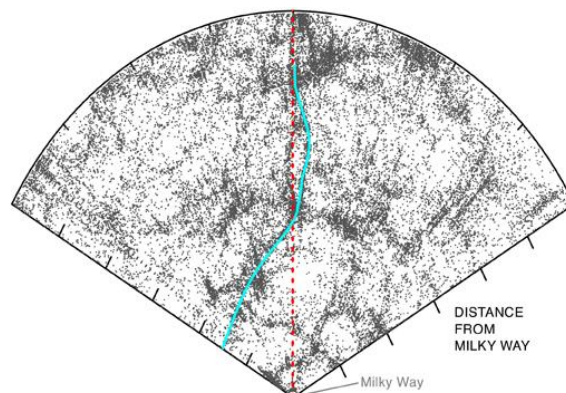


**Image 9.** M87 (radio, VLA)

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

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

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]

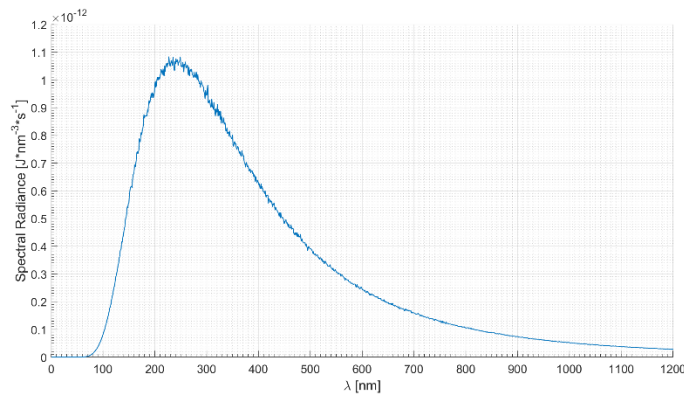


**Image 10.** H2356 (in Sculptor Wall)

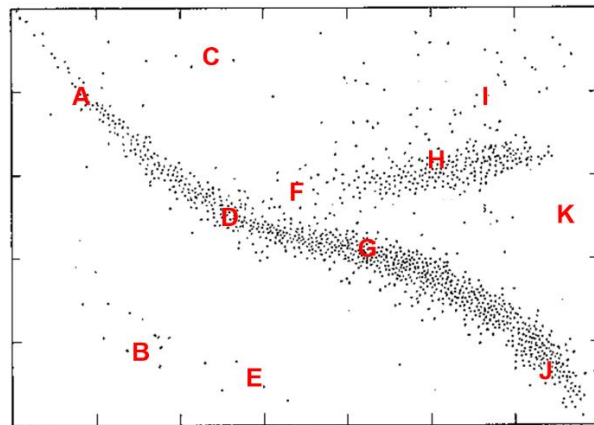
35. What is represented by the red and blue lines of Image 10? [2]

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

**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.

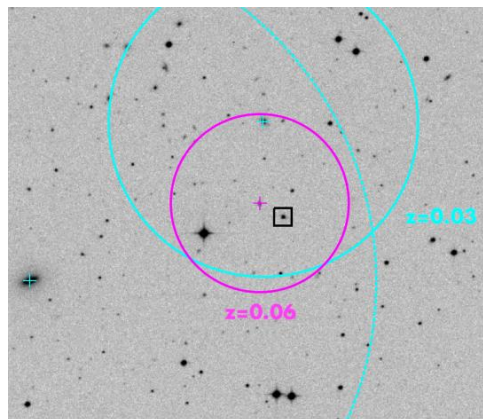
37. What is the distance to this star from Earth in parsecs? [1]



38. What is the star's effective temperature, in Kelvin? [2]
39. What is the star's luminosity, in Solar luminosities? [2]
40. What is the star's absolute bolometric magnitude? [2]
41. What is the star's apparent visible magnitude? [4]
42. What letter shows this star's approximate location on the HR diagram (Image 12)? [2]

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]
44. What is measured along the y-axis (multiple answers possible, give only one)? [1]
45. By approximately what factor (that is, as a power of 10) does a star's luminosity increase from G to A? [2]
46. Which letters show stars of luminosity class V? [1]
47. Which letters show the potential star types to have produced SN UDSWil10? [2]





### 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  $\Lambda$ CDM cosmological model.

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

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

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

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

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]

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

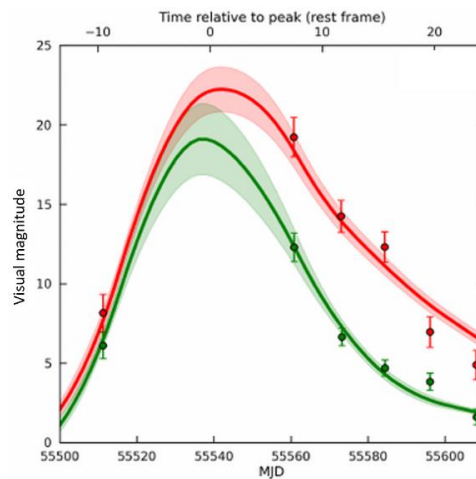
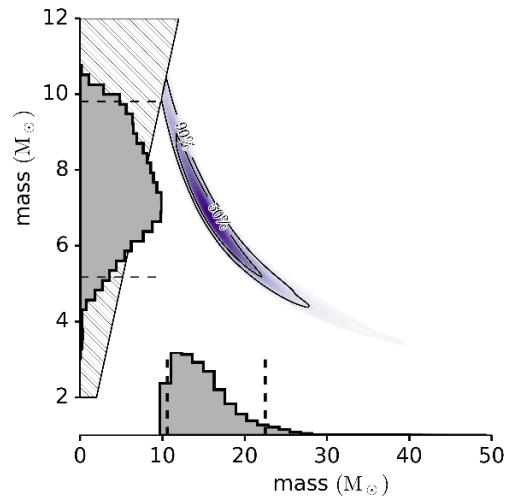


Image 14.

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]



**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]

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]

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]

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]

**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]

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

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

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

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

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

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

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]

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

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

Section A Total: 50 pts

Section B Total: 50 pts

Section C Total: 20 pts

Exam Total: 120 pts