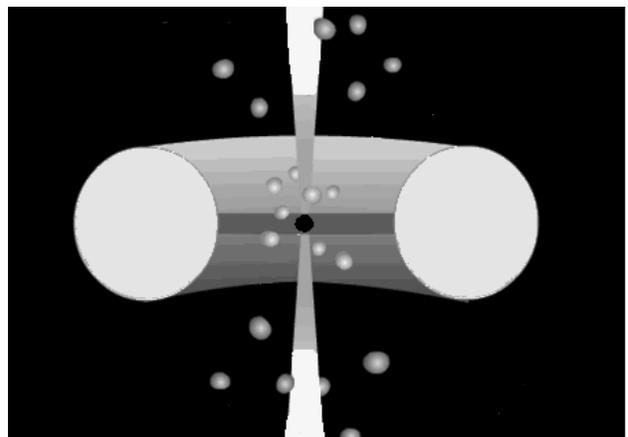


PENNSYLVANIA SCIENCE OLYMPIAD

STATE FINALS 2011

ASTRONOMY C DIVISION EXAM

APRIL 29, 2011



TEAM NUMBER _____ SCHOOL NAME _____

INSTRUCTIONS:

1. Turn in all exam materials at the end of this event. *Missing exam materials will result in immediate disqualification of the team in question.* There is an exam packet as well as a blank answer sheet.
2. You may separate the exam pages. Submit the answer sheet separately.
3. *Only* the answers provided on the answer page will be considered. Do not write outside the designated spaces for each answer. You may write in the exam booklet.
4. Include school name and school team number at the bottom of the answer sheet as well as on the title page. Indicate the names of the participants *legibly* at the bottom of the answer sheet. Be prepared to display your wristband to the supervisor when asked. *If you do not have a wristband, you may not participate.*
5. Point values for each question are in parentheses. Tiebreaker questions are indicated with a (T#) in which the number indicates the *order of consultation* in the event of a tie. Tiebreaker questions count toward the overall raw score, and are only used as tiebreakers when there is a tie. In such cases, (T1) will be examined first, then (T2), and so on until the tie is broken. There are 15 tiebreakers.
6. Pay close attention to the units given in the problem and the units asked for in the answer.
7. When the time is up, *the time is up*. Continuing to write after the time is up risks immediate disqualification.
8. Nonsensical, mocking, or inappropriate answers WILL RESULT IN DISQUALIFICATION.
9. In the bonus box on your answer sheet, indicate the name of the gentleman shown in the image on the cover sheet.
9. Use the following constants and relationships where applicable.

$$M_{\text{SUN}} = 2.00\text{E}30 \text{ kg}$$

$$H_0 = 70 \text{ km/s/Mpc}$$

$$1 \text{ AU} = 1.50\text{E}11 \text{ m}$$

$$L_{\text{EDD}} = (3.3 \times 10^4) \left(\frac{M}{M_{\odot}} \right) L_{\odot}$$

Questions numbered 1-40 refer to image page 1, image page 2, and the DSO list as published in the 2011 Science Olympiad Student Manual.

Consider Image 11 on image page 2.

1. The first four letters in this object's designation are an acronym. What do they stand for?
2. This image is a composite. What instrument produced the false color blue and purple clouds?
3. What do the blue and purple clouds indicate?

One of the images shows a quasar from a distance of about 2 billion light years.

4. Which image shows this object?
5. What is this quasar's designation?
6. The presence of what is indicated by the X-ray absorption of the light from this quasar?
7. What large-scale structure is apparently made up of the matter referenced in #6?
8. What technique was used to create the image referenced in #4?

One of the images shows the closest active galaxy to the Earth.

9. Which image shows this object?
10. What is its New General Catalogue number?
11. What phenomenon is indicated by infrared images of this object?
12. What wavelength is image 15 imaged in?

Consider image 7 on image page 1.

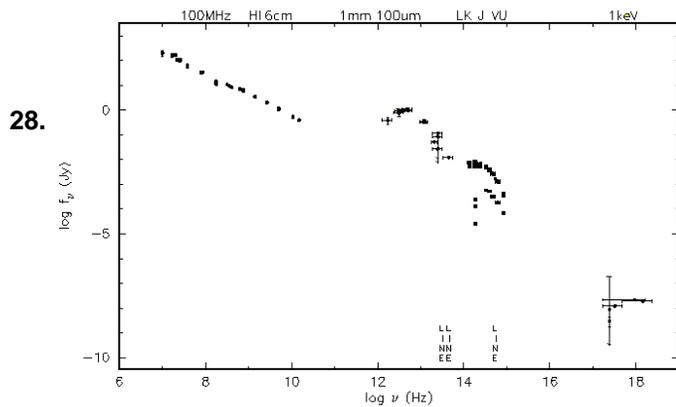
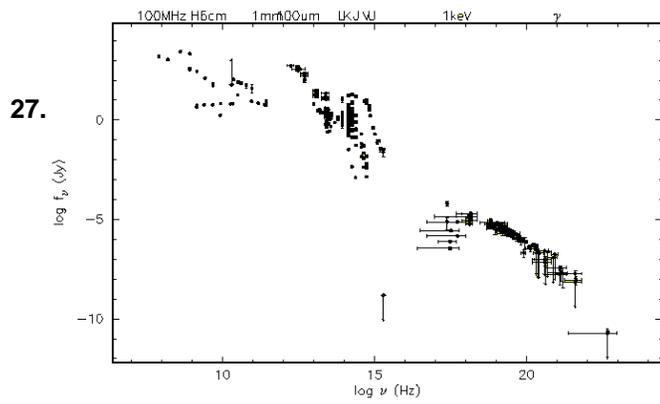
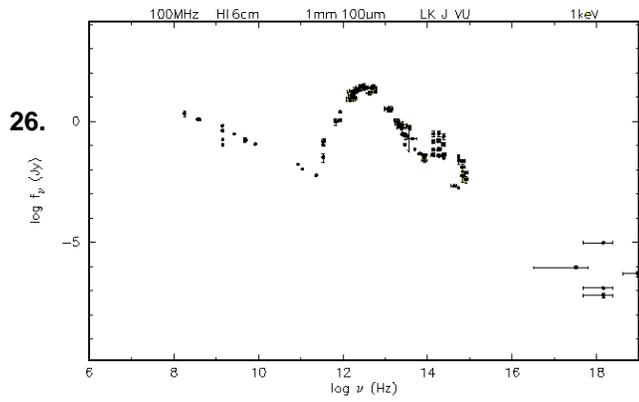
13. One of the galaxies in this image has a quasar behind it (or in it). Which galaxy is it, by NGC number?
14. (T6) What is the designation for the quasar that is behind or in the galaxy mentioned in #13?
15. What controversial astronomer has disputed cosmological redshift, due in part to these two objects?

Several of the 2011 DSOs are merging or interacting galaxies or clusters of galaxies. Questions numbered 16 – 25 deal with such interactions.

16. Which image shows a very late stage merger between two galaxies, such that there is a single central mass?
17. What is this object's number in Arp's Catalog of Peculiar Galaxies?
18. What is indicated by the contour lines on the image referred to in #16?
19. Which image shows two colliding galaxy clusters?
20. What is indicated by the contour lines on the image referred to in #19?
21. (T10) Compelling evidence for what is provided by X-ray images of the clusters in #19?
22. Which image shows four colliding galaxy clusters?
23. Which image shows a galaxy merger with two active galactic nuclei?
24. How is the composite object referred to in #23 classified?

25. The composite object referred to in #23 is also known as VV617. What does VV mean?

For questions numbered 26 – 28, select the image from image pages 1 or 2 that shows the object that produced the SED shown. SEDs courtesy of NASA/IPAC Extragalactic Database.

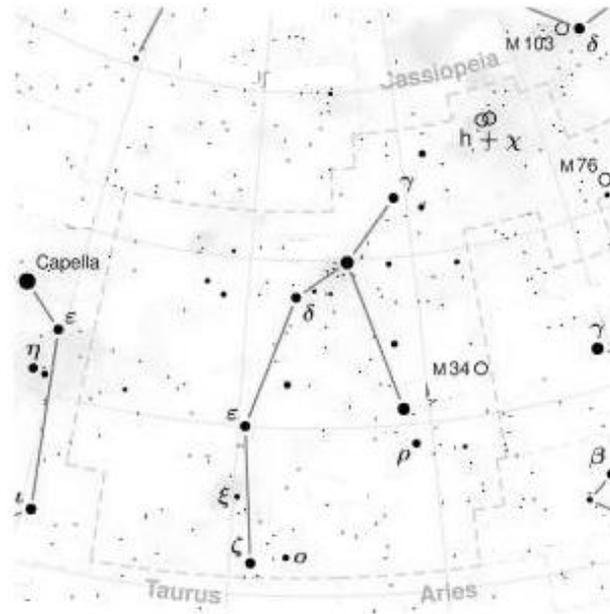


29. (T7) Which image shows the most distant galaxy cluster yet found?

30. Which image shows a small group of interacting galaxies in the constellation Pegasus?

31. What is the designation for the *fainter* of the two objects shown in image 14?

Two of the objects on the 2011 DSO list appear in the constellation shown below.



32. Which constellation is this?

33. (T15) Select *one* image from image pages 1 or 2 that shows an object that appears in this constellation.

34. One of the objects in #33 is really an “event.” What *may* have been left behind by this event?

Consider image 5 on image page 1.

35. What is the Principal Galaxies Catalogue number for the DSO shown in image 5?

36. (T2) What significant objects are indicated by the small white squares in image 5?

37. What is the galaxy cluster to which this DSO belongs?

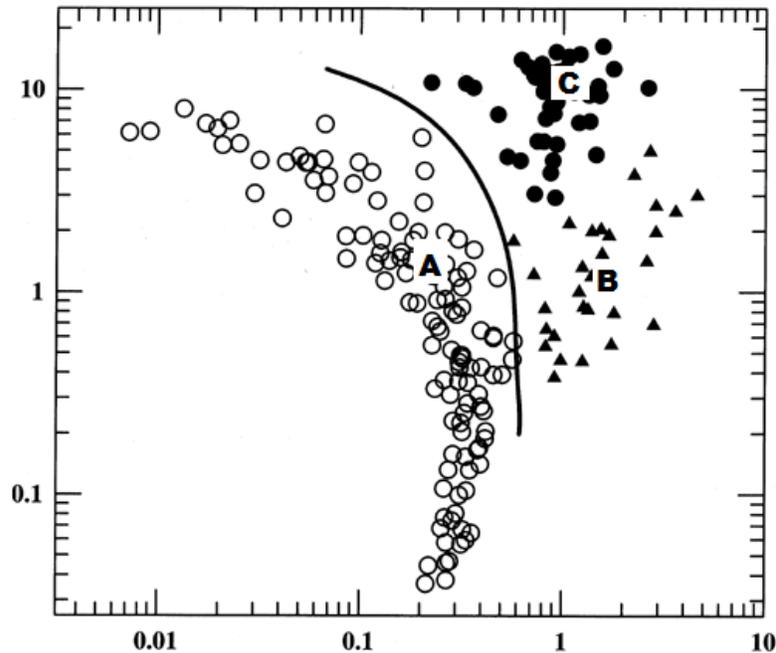
Consider image 12 on image page 2.

38. What is the Messier Catalog number for this object?

39. What unexpectedly appears in the linearly polarized flux spectrum of the object in image 12?

40. What conclusion is indicated by the answer to #39?

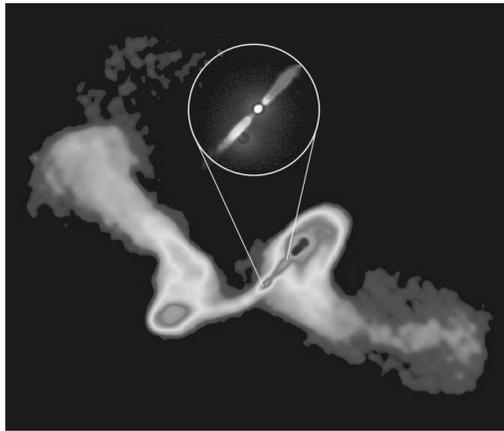
For questions numbered 41 – 45, consider the image below.



41. What quantity is displayed on the horizontal axis on image B?
42. (T3) What is this graph called?
43. What type of object would be found in the region lettered A in the graph?
44. What type of object would be found in the region lettered B in the graph?
45. What type of object would be found in the region lettered C in the graph?

46. What is the customary absolute visual magnitude that separates Seyfert galaxies from QSOs and quasars?
47. (T11) A quasar has a luminosity of $4.66E40$ W and an available fuel supply of $1.33E8$ solar masses of material. Assuming constant luminosity and 18.5% efficiency, estimate the quasar's lifetime in years.
48. What is the absolute magnitude of a quasar with $z = 2.83$ and apparent magnitude 18.6?
49. What mechanism is thought to power the acceleration of jets to nearly the speed of light?
50. An AGN has a central black hole of 400 million M_{\odot} . What is the Eddington Limit, in Watts?
51. How would you classify a beamed FR 1 galaxy?

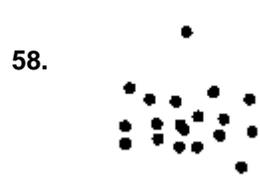
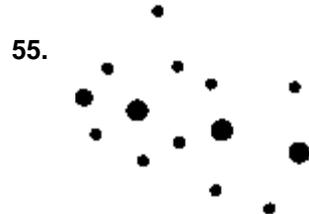
Consider the radio image of NGC 326 below for questions numbered 52 and 53.



52. What is this type of object called?

53. (T1) What most likely caused the radio morphology of NGC 326?

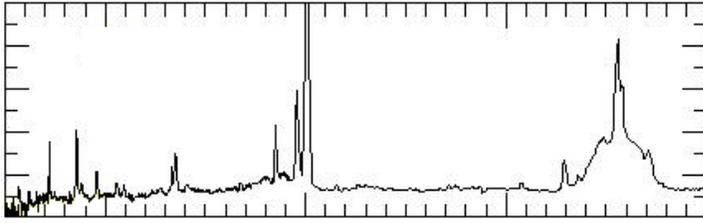
For questions numbered 54-59, classify the galaxy clusters according to the symbols in the Rood and Sastry classification scheme.



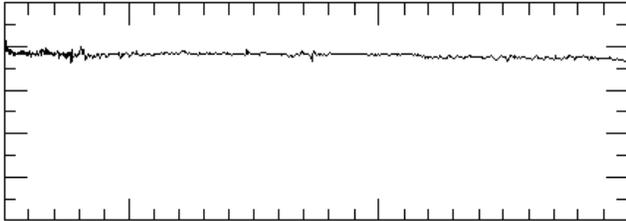
60. This astronomer is most well known for creating a catalog of galaxy clusters, originally with over 2700 clusters, published in the 1950s.

For questions numbered 61 – 66, list the type of galaxy for each of the *optical* spectra shown. In each case, the vertical axis displays intensity and the horizontal axis spans the visible spectrum.

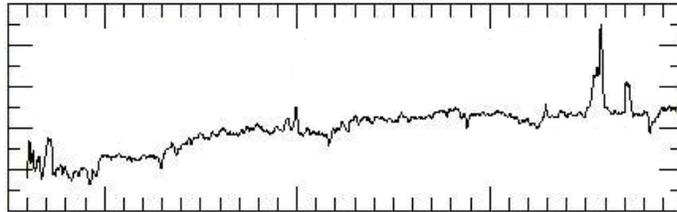
61.



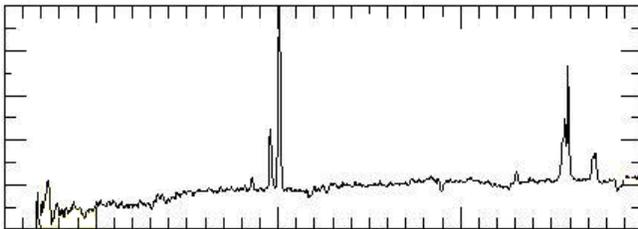
62.



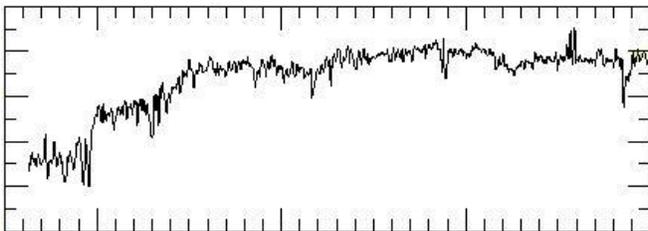
63.



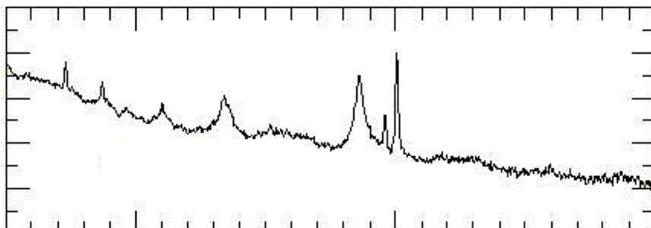
64.



65.



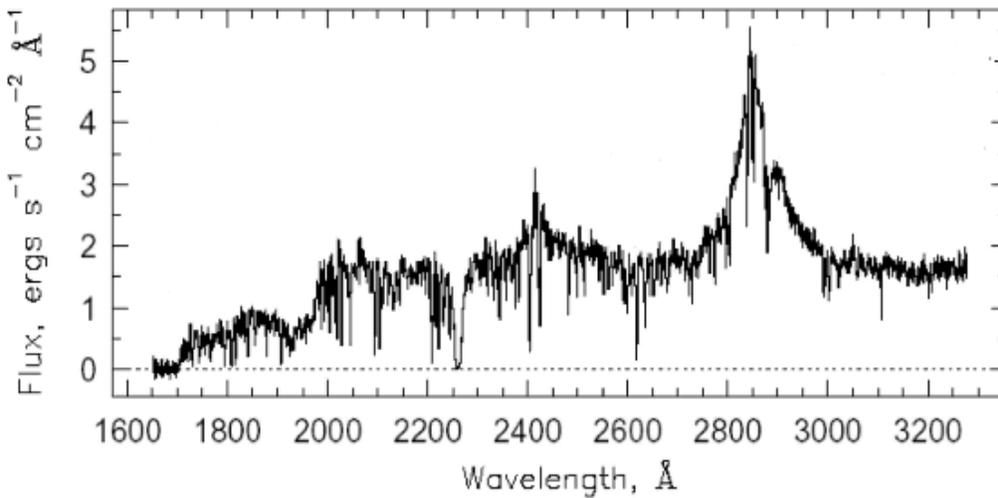
66.



Galaxies in a particular distant galaxy cluster are seen to have z -values ranging from 0.0422 to 0.0475. The cluster is roughly spherical and its angular diameter is $42'$. Consider this information for questions numbered 67 – 71.

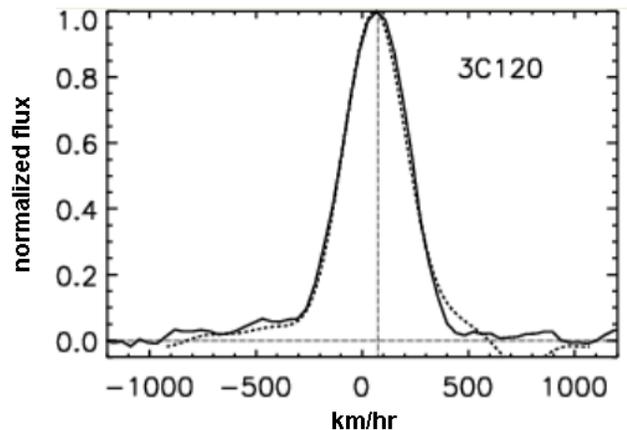
- 67. (T8) What is the recessional velocity of this cluster, in km/s?
- 68. What is the velocity dispersion of the galaxies in this cluster, in km/s?
- 69. According to the Hubble law, how far away is this cluster, in Mpc?
- 70. What is the diameter of this cluster, in Mpc?
- 71. What is the mass of this galaxy cluster, in solar masses?

Consider the quasar spectrum shown below. The prominent emission line is that of Lyman- α .



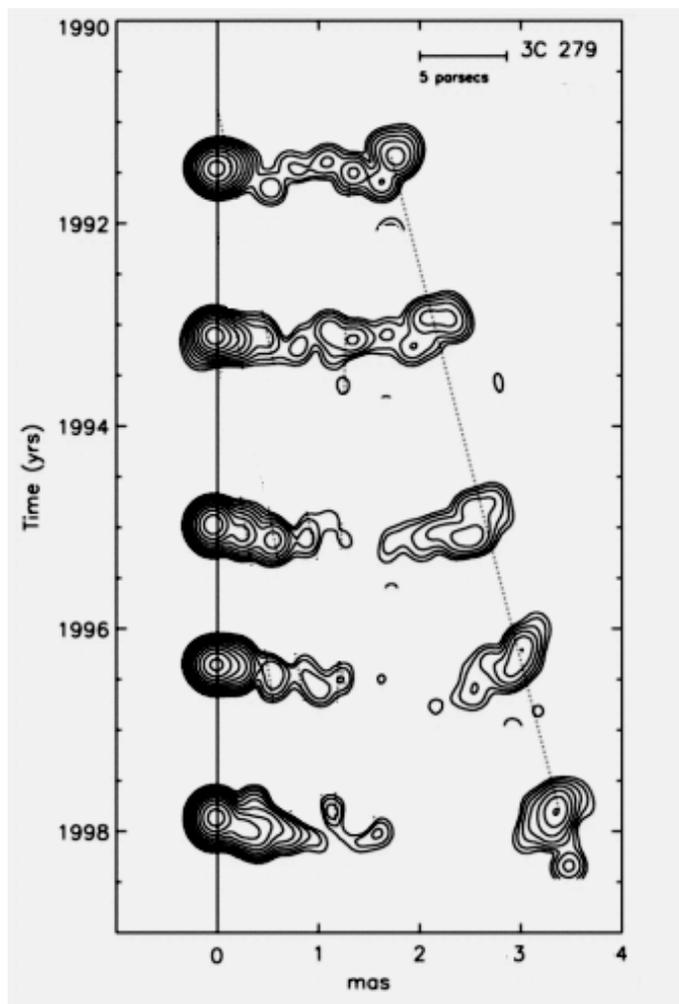
- 72. In what region of the spectrum does the Lyman- α line appear in this spectrum?
- 73. (T12) What is the z value for this quasar?
- 74. What is the region of this spectrum shortward of the Lyman- α emission line called?

Consider the emission lines shown below for the galaxy 3C120. The dotted line is the [O III] λ 5007 optical line, while the solid line shows the [O IV] $26\mu\text{m}$ line in the infrared. The lines are shown *relative* to the systemic velocity. Use this diagram for numbers 75-77.



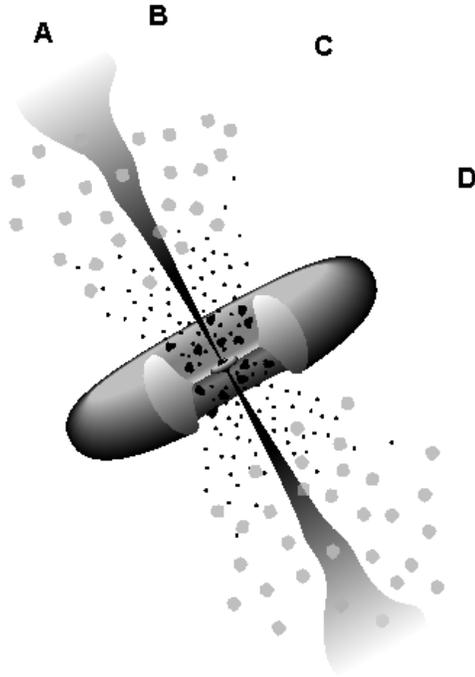
- 75. (T5) What is the v_{FWHM} of this line?
- 76. Is this a narrow emission line or a broad emission line?
- 77. Why is the center of the emission line not at 0?

Consider the radio maps of 3C 279 shown below. The fixed prominence on the left indicates the AGN. Note the scale bar in the upper right corner of the image indicates 5 parsecs. The images were obtained over a 6.5 year period.



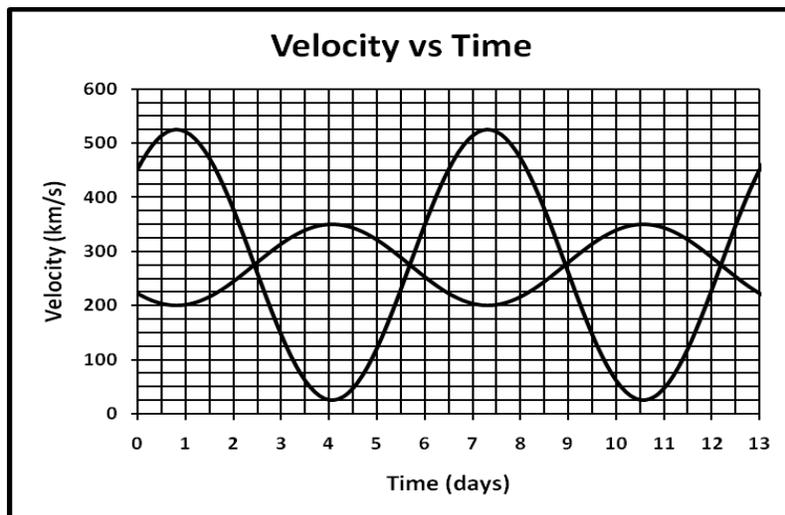
78. What is the *apparent* transverse speed, in terms of c , of the “knot” of material indicated by the dotted line?
79. (T9) What is the term for this apparent motion?
80. What are the two conditions necessary for this phenomenon to occur?
81. What is the “knot” most likely composed of?

Consider the unified AGN model shown below. Lettered locations on the diagram refer to line-of-sight of the observer. Use this diagram for questions numbered 82-84.



82. Assume the AGN shown is radio-loud. How would an observer at position D classify the object?
83. What physical feature is visible in the spectrum from positions B and C but not D?
84. The model has two jets. Why can the observer at B only see one of them?

Consider the following velocity graph for a binary system in the Large Magellanic Cloud for questions numbered 85 – 87.



85. What is the orbital velocity of the *more massive* of the two stars?
86. What is the mass ratio of the two stars?
87. What is the mass of the more massive star, in solar masses?

88. What is “quasar fuzz”?

89. (T13) Spectral flux density is measured in a unit called the Jansky. What is a Jansky in SI units?

Numbers 90 -100: Write the word or phrase that best matches the description.

90. The region between the static limit and the event horizon of a Kerr black hole

91. The progression of events in galaxy merger interactions, named for its originator

92. A feature of the AGN SED, thermal in origin, extending from roughly 4000 Å to 1000 Å

93. Detailed observation of the timing of BLR response to continuum changes

94. (T14) Alternate term for radio-loud x-ray binary

95. The relationship between source luminosity and the depth to which it ionizes surrounding hydrogen clouds

96. A spectral feature that is used to easily select for high redshift galaxies ($z \sim 3$)

97. A sensitive test for the presence of neutral hydrogen indicated by depression of the QSO continuum at wavelengths shortward of the Lyman α emission line

98. The minimum mass for a source of a given luminosity powered by accretion

99. (T4) In a galaxy collision, the act of a massive object creating a dense wake and slowing down as a result

100. The mechanism for extraction of energy from a rotating black hole, requiring an accretion disk and a strong polar magnetic field