National Science Olympiad
Astronomy C Division Event
21 May 2011
University of Wisconsin
Madison, WI

TEAM NUMBER: _____

TEAM NAME: _____

INSTRUCTIONS:

1) Please turn in <u>ALL MATERIALS</u> at the end of this event.

2) Do not forget to put your <u>TEAM NAME</u> and <u>TEAM NUMBER</u> at the top of all Answer Pages.

3) This event and the answer key will be available on the following website:

4) Good Luck! And May the Stars be With You!

The X-Ray Spectrum of an AGN is shown in Image B.

1. The Chandra Observation of which Deep Sky Object produced this spectrum?
2. What causes the sharp peak shown at point A in this image?
3. Which image shows this object in the near-infrared band?

Centaurus A is the 5th brightest galaxy in the sky.

4. What is the New General Classification number of this object?
5. Which two images show this object?
6. Centaurus A is the largest member of a group of galaxies that is split into two subgroups, one of which is the Centaurus A subgroup. What is the other subgroup?
7. What is the name of the supercluster that harbors Centaurus A's group of galaxies?
8. This supercluster has a mass of 10^{15} Solar masses, and a total optical luminosity of 3×10^{12} Solar luminosities. The mass to light ratio of the Sun is approximately 5133 kg/W. What might explain the difference in mass to light ratio for Centaurus A's supercluster?

Hickson Compact Group 92 is shown in image D and image E. Use the letters on image E to identify each galaxy within the group

9. In image D, what type of feature is shown by the bright blue region in the center?
10. The collision of which galaxy (A,B,C,D,E,F) with HCG 92 created this feature?
11. Which galaxy (A,B,C,D,E,F) is simply a visual member of the group, as it is at a much lower redshift than HCG 92?
12. Galaxy D is observed to have a narrow-lined emission spectrum. What type of Seyfert galaxy is Galaxy D?

3C 321, colloquially termed the "Death Star Galaxy" is shown in composite image F.

13. Which image (H, I, or J) shows Radio emission from the AGN in 3c321?
14. If one were to look at a composite image of this object similar to image F, but with larger field of view, what difference(s), if any, would one expect to observe?

Observations of a distant spiral galaxy (with its axis of rotation pointing directly at earth) reveal records of two Cepheid variable stars that are located in the same arm of the galaxy and have the same period. One star, however, appears four times as luminous as the other. Two hypotheses are put forward to explain this difference:

> **I: One star is more distant than the other and only appears to be in the galaxy.**
> **II: Both stars are part of the same galaxy, but differences in extinction from intervening dust and gas causes one to appear dimmer than the other.**

15. Could parallax calculations from measurements with existing earth-based telescopes distinguish between these hypotheses? Why or why not?
16. Could measurements of these stars at different wavelengths be used to distinguish between these hypotheses? Why or why not?
17. Could theoretical consideration of the variations in dust and gas density required to cause the observed difference be used to distinguish between these hypotheses? Why or why not?

The NGC 7771 group is an interacting triplet of galaxies in the constellation Pegasus.
18. Which image shows this group?
19. Is NGC 7771 itself the more edge-on or face-on of the two brighter galaxies in the triplet?
20. NGC 7771 has a much greater rate of star formation than the prototype starburst galaxy, M82. Yet, it does not harbor an AGN. What, then, causes the starburst activity in this galaxy?
21. Which Image shows the Deep Sky Object that most closely resembles the state of the NGC 7771 group after the triple galaxy merger is complete?

JKCS041 is the most distant galaxy cluster yet observed, at 10.2 billion light years away.
22. Which image shows a number density image of JKCS041?
23. Even though JKCS041 is a cluster, which are not necessarily very bright in infrared, it was first observed by the United Kingdom Infrared Telescope. How is this possible?
24. It was proposed that JKCS041 may not be a galaxy cluster, but instead a filament that is viewed along our line of sight. What two properties of the gas in JKCS041 rule out the possibility of it being a filament?

MACS J0717.5 + 3745 is the first well-documented evidence of the collision of four separate galaxy clusters. An optical image of this object is shown in image N.
25. Using the name of this object, what is its declination (celestial latitude) in degrees and minutes?
26. The contours in image N display flux from which region of the electromagnetic spectrum?
27. Galaxy concentrations are displayed by the circles lettered A through D. Of these, only A and C are well aligned with peaks in X-ray surface brightness. The very good alignment of C makes this subsystem a candidate for being what?
28. Region A has a high X-ray temperature, yet lies on the edge of MACS J0717.5 +3745. What does that imply about this subcluster?

Image R displays X-ray emission from an Active Galactic Nucleus.
29. What is the New General Classification number of this object?
30. What type of AGN is this? Be specific.
31. The bands surrounding the AGN are high velocity spectral line emitting filaments. What keeps these relatively cold filaments together?
32. Image U shows this object in visible light. What evidence do you see in this image which implies that the formation of this object was from galactic collision?

Two thermodynamic maps of a cluster merger are shown in image S. The map on the left displays X-Ray surface brightness.
33. What quantity is displayed by the map on the right?
34. What is the colloquial name of the cluster that creates the blue concentration on the right side of both maps?
35. What property of its motion relative to the intra-cluster medium gives it its characteristic shape?
36. This blue concentration means that it is the coldest part of this system. Why is it so relatively cold?
37. What class of galaxy is most prevalent in regular (compact) clusters?

SN2006gy is the second-brightest supernova ever observed, a pair-instability hypernovae due to collapse of a 150 solar mass star. It is located in NGC 1260.

38. Which image shows this object's host galaxy?
39. Its peak visual magnitude was +14.6, and the distance to NGC 1260 is 72 Mpc. What was the maximum absolute magnitude of this star?
40. The peak absolute magnitude of SN 1987A was -15.5. How many times brighter than SN 1987A was SN 2006gy at maximum?
41. Pair instability in the core of a star is caused by high energy photons converting into particle and anti-particle pairs, leading to an increase in temperature in the star, which causes even more high energy photons, which hence leads to runaway pair production, causing core collapse. What is the anti-particle formed in this pair production event?

NGC 1068 is a spiral galaxy, and is the brightest X-ray source in the constellation Cetus. The inclination angle of this galaxy to our line of sight is 51 degrees.

42. Which image shows this object?
43. What type of active galaxy is NGC 1068? Be specific.
44. The fact that there are a variety of types of objects, all caused by the same mechanism, is titled which model of Active Galactic Nuclei?
45. There is also intense starburst activity in this object. In what part of this object does this star forming activity occur?
46. In what region of the electromagnetic spectrum is this star forming activity most visible?

A diagram of a general AGN is shown in image Z. Use this diagram to answer the following questions.

47. If the Earth were located at position B, which type of AGN would be observed?
48. What is the name of the area that position C is located in?
49. What is the name of the area that the molecular clouds are concentrated within?
50. If this image were of NGC 1068, which position is Earth located at (A, B, C, or D)?

NGC 4603 is a spiral galaxy located 108 x 10^6 light years away. It harbors more than 36 Cepheid variable stars, whose period-luminosity diagram -corrected for NGC 4603's distance modulus- is shown by image EE. The center line is the best fit to the data displayed.

51. Which image shows this object?
52. Which cluster is this object located in?
53. What is the period, in days, of a Cepheid lying in the disk of this galaxy that has absolute magnitude of -5.1?

Image FF is a collection of "Postage Stamps" created using ds9 software with BOLOCAM data, displaying the same field of sky in different regions of the electromagnetic spectrum. From the left to the right, the images are in: Radio, Sub-Millimeter, Infrared, Optical, UV, and X-Ray.

54. In which regions of the electromagnetic spectrum (besides radio) does the flux peak at the same position as in the radio image on the far left? The position may be read by the green contours overlaid on the postage stamps.
55. Utilizing this information, what general type of object causes the radio flux peak?

A 0.1 solar radius accretion disk surrounds Star α, a 0.01 solar radius white dwarf that is approximately at the Chandrasekhar limit. It is part of a binary system with Star β, a red giant. The distance between the stars is 10 A.U., and the period of their concentric orbit is 8.06 years. The accretion disk gains 10^{14} kg/s. Assume that the accretion disk has a negligible width compared to its radius.

56. What is the mass of Star α, in solar masses?
57. What is the mass of Star β, in solar masses?
58. At a time not far into the future, Star α explodes as a supernova, and it is observed to have an apparent magnitude of 12. What is the distance to this binary system, in Mpc?
59. What is the temperature of the accretion disk, in Kelvin? The Luminosity of an accretion disk, L = (GMk)/2R, where G is the universal constant of gravitation, M is the mass of the primary, k is the mass accretion rate, and R is the radius of the primary.

The Sculptor wall is shown by the red curve in image BB, where dots in the image are individual galaxies and the objects designated by A with a number following (Abell numbers) are superclusters.

60. Which supercluster is labeled by green Abell numbers?
61. What type of region is seen by the lack of galaxies between Earth and this supercluster?

Circinus Galaxy X-2 is a supernovae that occurred in 1996, but was not observed until over a decade later. A spectrum of this supernovae is displayed by image DD. Its light curve in (from top to bottom): Visible, Radio, and X-Ray is shown in image AA.

62. The H-alpha emission of this supernovae is especially bright and narrow. Knowing this, what type of supernova is Circinus Galaxy X-2? Be specific.
63. The X-ray data between 2000-2007 show a strong and significant rise. What does this imply about the blast wave of this object?
64. The radio data show a very sharp rise directly before this. What does this imply about the change in density and velocity of the blast wave of the supernovae?

The X-ray spectra for two separate Seyfert galaxies are shown in images Y and CC.

65. Which spectra is that of a type II Seyfert?
66. What feature of the spectra enabled the identification of this spectra as that of a type II Seyfert?

A Baldwin, Phillips, and Terlevich (BPT) diagram is shown in image W. It is used to demonstrate the difference between Low-Ionization Nuclear Emission line Regions (shown by the triangles), HII regions, and normal AGNs. The vertical axis shows the [O III] λ5007 / Hβ flux ratio and the horizontal axis is the [N II] λ6583 / Hα flux ratio.

67. Which type of object is designated by the open circles?
68. What does the black line in the diagram show?

Image V shows a spectral energy distribution (SED) measured by the VERITAS instrument, for quasar PKS 1424+240, a BL Lacertae object.

69. What is the mechanism most likely causes the gamma-ray emission from the AGN of PKS 1424+240?

70. What mechanism most likely causes the emission seen in the first peak on the SED, seen near 10^{16} Hz?

Though there are supermassive black holes in many galaxies, only 1% of them exhibit AGN-like behavior.

71. What process creates an AGN out of a supermassive black hole?

72. How does this explain why there are more AGN at higher redshifts?

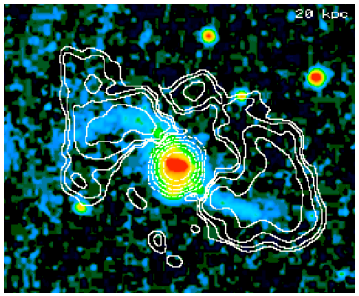
73. Using Image X, determine Hubble's constant, in traditional units. The broken black line is the best fit to the data.

The spectrum of a galaxy harboring an AGN is shown in image GG.

74. What mechanism causes its spectral lines to have a much greater width than that of a normal galaxy?

75. Galaxy δ and galaxy ε lie in the same cluster. Galaxy δ has a measured rotation rate of 125 km/s, and a luminosity of 3.67×10^8 solar luminosities. Galaxy ε's rotation rate is 200 km/s, and it is known to have an apparent magnitude of 14. What is the distance to this cluster, in Mpc?

A



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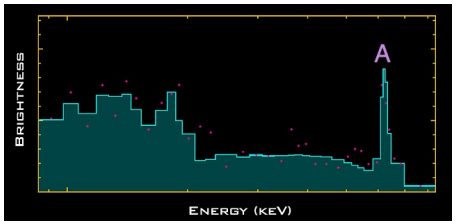

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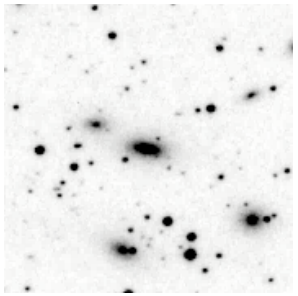

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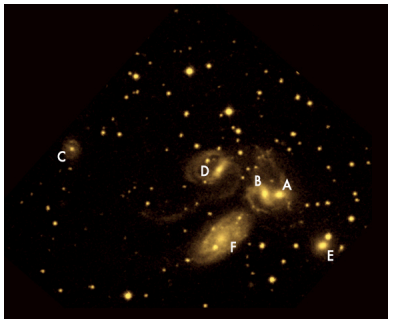

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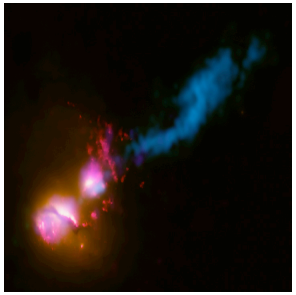

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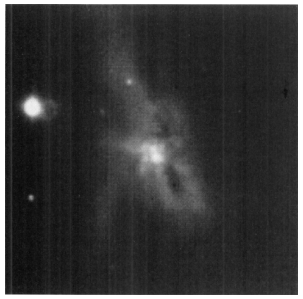

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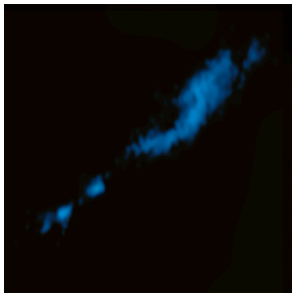

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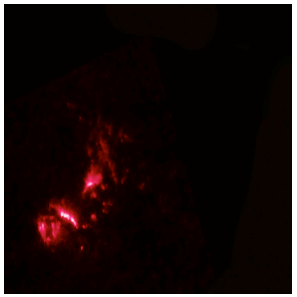

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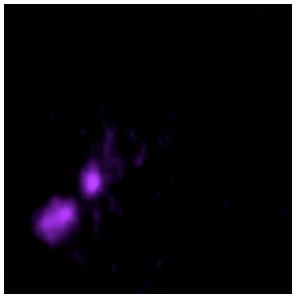

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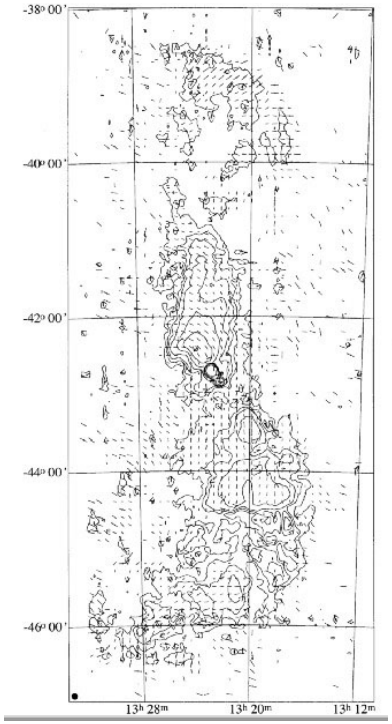

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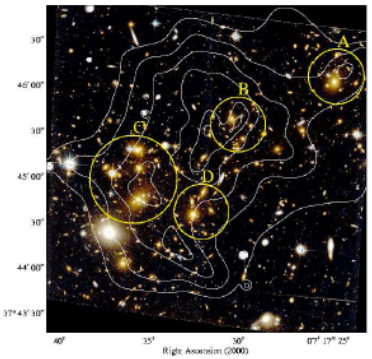

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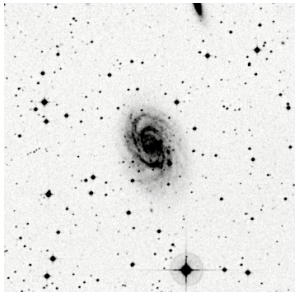

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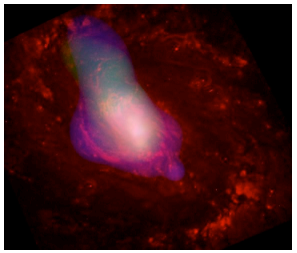

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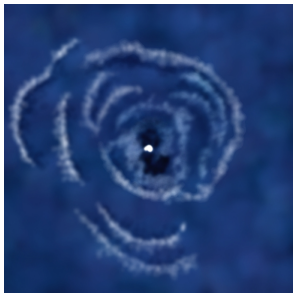

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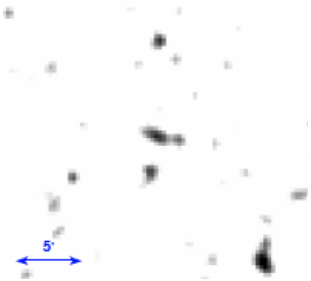

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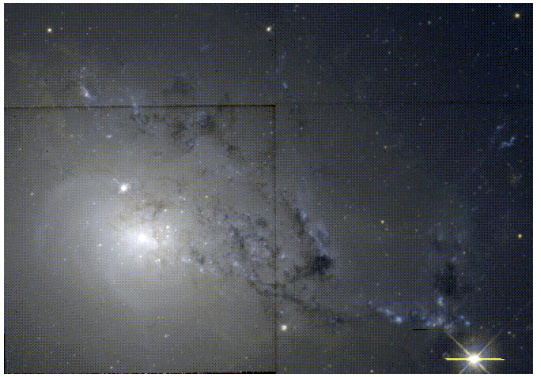

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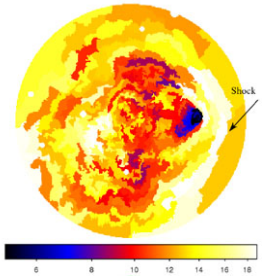

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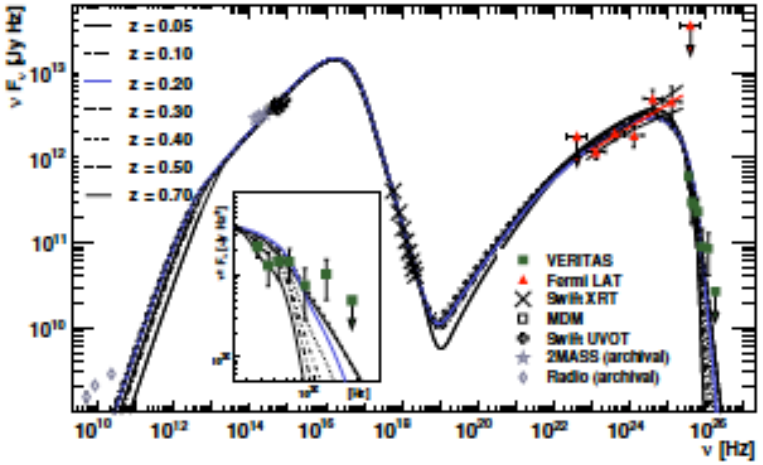

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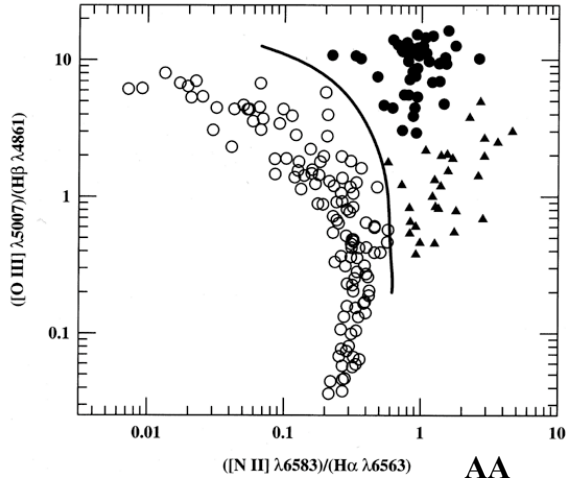

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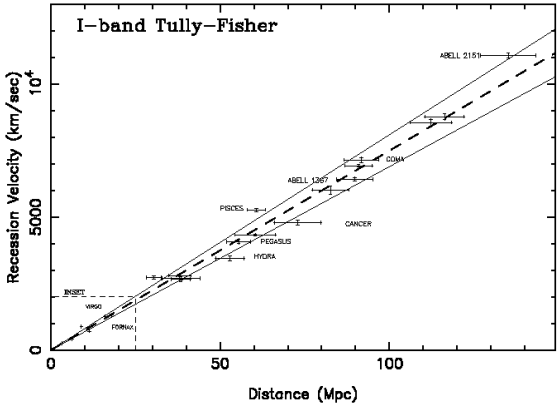

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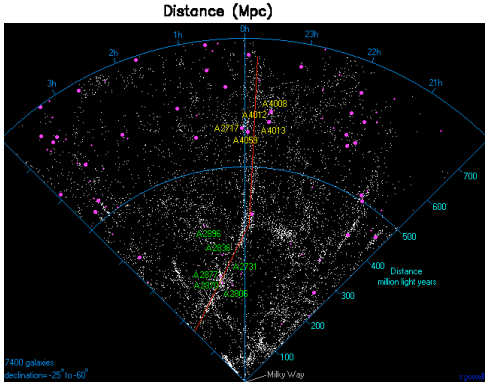

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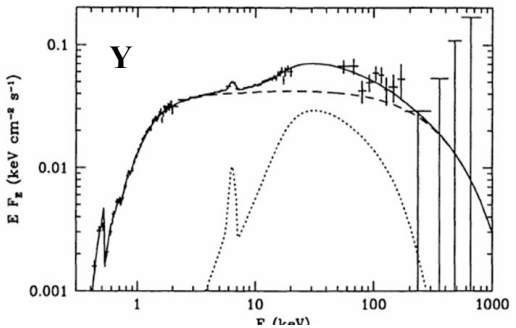

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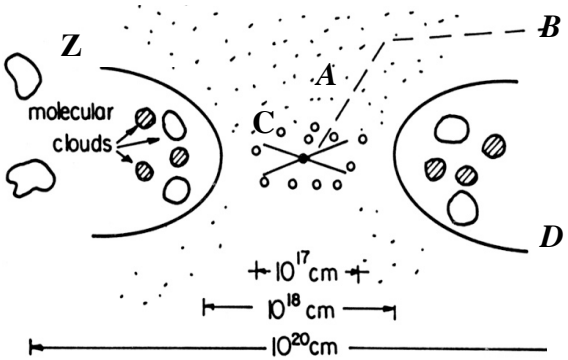

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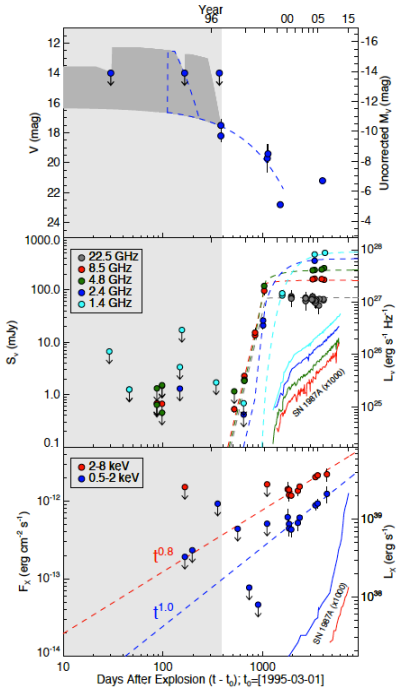

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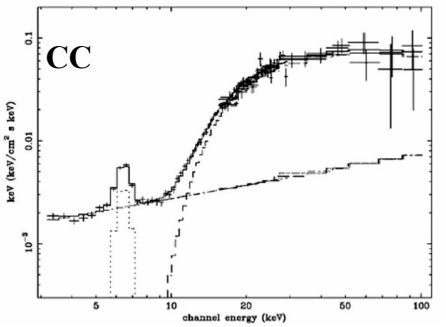

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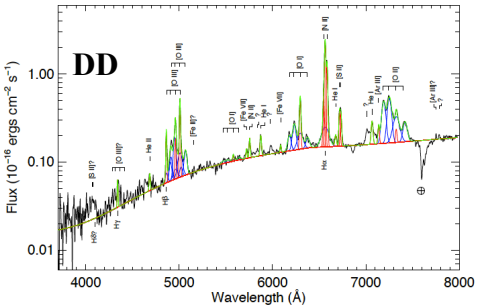

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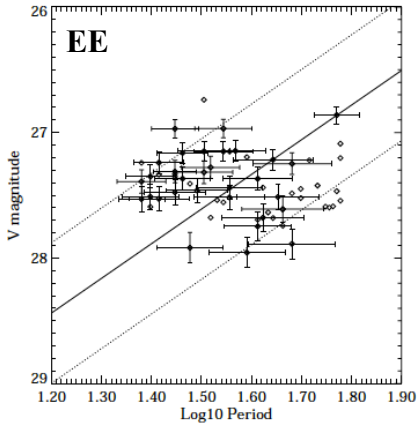

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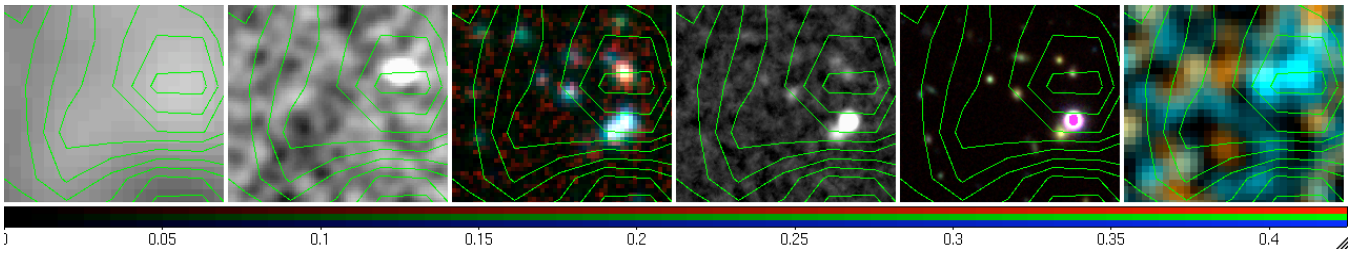

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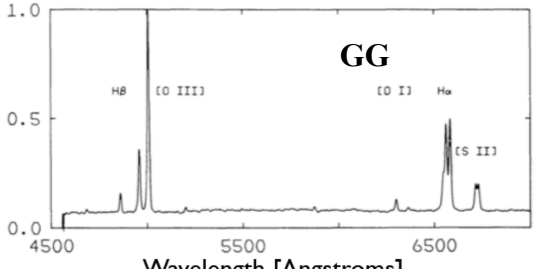

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