Answer Key

Section A

1. C
2. C
3. A
4. A
5. C
6. A
7. A
8. B
9. D
10. A
11. B
12. A
13. A
14. B
15. D
16. B
17. B
18. B
19. D
20. D
21. D
22. D
23. B
24. B
25. C
26. D
27. A
28. C
29. A
30. A
31. E
32. C
33. D
34. C
35. C
36. B
37. B
38. C
39. D
40. B
41. B
42. C
43. B
44. C
45. B

For official use only:

Section:	A	B	C	Total
Points:	90	135	100	325
Score:				

Section B

46. (a) NGC 2623
    (b) Hubble
    (c) Optical
47. (a) Blue
    (b) JKCS041
    (c) Contours of equal number density of galaxies
48. (a) Image 3
    (b) Hubble
    (c) Elliptical
    (d) Image 11
49. (a) Type Ia
    (b) It is the farthest type Ia supernova we've discovered
    (c) The supernova cannot be seen because it is too close to the centre of its host galaxy. That is why they mathematically "subtract" the light from the galaxy to create the third panel.
50. (a) Gamma-ray burst
    (b) Chandra and Hubble
    (c) Two neutron stars
    (d) GRB 150101B is too far away; the gravitational waves reaching Earth would be too weak.
51. (a) Image 14
    (b) M87 (also accept M87*, which is the name of the supermassive black hole itself)
    (c) Very-long-baseline interferometry (VLBI)
    (d) Continuous High-resolution Image Reconstruction using Patch priors, Katie Bouman
    (e) Seth Fletcher
52. (a) Galaxy cluster
    (b) normal, dark
    (c) The normal matter in each cluster was slowed by a drag force, similar to air resistance, during the collision of the two galaxy clusters. In contrast, the dark matter was not slowed by the impact because it does not interact directly with itself or the normal matter through gravity. Therefore, during the collision the dark matter clumps from the two clusters moved ahead of the normal matter, producing the separation of the dark and normal matter seen in the image.
    (d) Image 16, x-ray
53. (a) GW151226
    (b) Two black holes
    (c) It was radiated away as energy.
54. (a) Quasi-stellar radio source
    (b) Instead of having a thin disk around the black hole, the quasars have a thick torus which blocks x-rays produced near the black hole.
    (c) It is very high
55. (a) H1821+643
    (b) Chandra
    (c) Draco
    (d) Image 7
    (e) Emission (typically in the x-ray region) by superheated plasma between galaxies in a galaxy cluster.
56. (a) Image 13
    (b) They can form directly from the collapse of a massive gas cloud, skipping any intermediate steps.
    (c) Scenario (2)
57. (a) H2356-309
    (b) A blazar is an AGN with a relativistic jet directed towards Earth
58. (a) PSS 0133+0400
    (b) A standard candle is an astronomical object that has a known (or consistently calculable) luminosity.
    (c) Dark energy may vary over time, particularly towards the beginning of the universe.

Section C

59. (a) Accept answers between 3600-3650 Kelvin
    (b) M
    (c) Accept giant or supergiant
60. (a) Accept answers between $7.9 \times 10^8 - 8.0 \times 10^8$ parsecs
    (b) In the previous part, we calculate the distance using the distance modulus assuming no extinction to get about 7.95×10^8 parsecs. However, in reality, our view of 3C 273 is slightly obscured by gas and dust along the line of sight, making it appear dimmer than it actually is. As a result, we find that 3C 273 is closer to us than our distance modulus calculation would imply.
61. (a) Triple-alpha process
    (b) Much of the energy released during the helium flash goes into heating the core and terminating the degenerate state of the electrons. Second, the energy that does escape the core is largely absorbed by the star's outer layers, which are quite opaque.
    (c) After the onset of core helium fusion, a star's superheated core expands like an ideal gas. Temperatures drop around the expanding core, so the hydrogen-fusing shell reduces its energy output and the star's luminosity decreases. This allows the star's outer layers to contract and heat up. Consequently, a post-helium-flash star is less luminous, hotter at the surface, and smaller.
    (d) The horizontal branch
62. (a) B, C, A
    (b) Accept answers between 0.2000-0.2050
    (c) Accept answers between 775-875 Mpc
    (d) Accept answers between $4.5 \times 10^9 - 5.5 \times 10^9$ solar luminosities
    (e) No. The Eddington luminosity for this situation is roughly 2×10^{45} erg, while our answer to the previous question was approximately 2×10^{43} erg, which is two orders of magnitude less.
63. (a) Accept answers between 70-80 km/s/Mpc
    (b) Accept answers between 12.5-13 Gyr
    (c) Accept answers between 775-875 Mpc
    (d) Accept answers between 8.25-8.75 Gyr.
64. (a) Accept answers between $1 \times 10^{-13} - 2.5 \times 10^{-13}$
    (b) This is roughly $(1 - 1.75 \times 10^{-13})^{2.5 \times 10^{11}}$, so accept answers between 0.93-0.98
    (c) No. Because no stars are "hidden" behind another, having an area that's more dense with stars will be offset with other areas that are less dense with stars. Since the Sun could hit any part of the Andromeda Galaxy with equal probability, this effectively "cancels out".