Part I: Matching

1. _G_   4. _F_   7. _C_   10. _B_   13. _M_

2. _O_   5. _I_   8. _K_   11. _E_   14. _H_

3. _D_   6. _N_   9. _A_   12. _L_   15. _J_

Part II: Multiple Choice

16. _B_   23. _A_   30. _A_   37. _D_   44. _C_

17. _A_   24. _C_   31. _B_   38. _A_   45. _B_

18. _C_   25. _B_   32. _D_   39. _A_   46. _A_

19. _C_   26. _A_   33. _C_   40. _B_   47. _A_

20. _B_   27. _A_   34. _B_   41. _D_   48. _C_

21. _C_   28. _B_   35. _D_   42. _A_   49. _D_

22. _D_   29. _D_   36. _B_   43. _B_   50. _D_

Part III: Free Response

51.a.

X-rays have very short wavelengths, while infrared radiation has long wavelengths. Shorter wavelength/higher frequency light means more energy.

51.b.

Binary systems with black holes tend to form accretion disks around the black hole. The accretion disk gets very hot due to internal friction and viscosity. As a result, it radiates X-rays as blackbody radiation.

51.c.

Light is only "trapped" once it is within the event horizon. Light which is emitted by the accretion disk is sufficiently far from the event horizon, and can escape.

52.

$$\frac{2.898 \times 10^{-3}}{2.7} = 1.07 \times 10^{-3} \text{ m} = 0.00107 \text{ m}$$

53.a.

$d \approx \frac{1}{\theta} = 75$ parsecs (small angle approximation)

53.b.

$0.05/5 = 0.01$ arcseconds/year

53.c.

$.01 * 75 * \dfrac{1 \text{ rad}}{206265 \text{ arcsec}} * \dfrac{3.08e13 \text{ km}}{\text{pc}} * \dfrac{1 \text{ yr}}{3.15e7 \text{ s}} = 3.6$ km/s (small angle approximation)

53.d.

$\dfrac{\Delta\lambda}{\lambda_0} * c = \dfrac{0.02}{656.28} * 2.99 \times 10^5 = 9.1$ km/s

---

53.e.

$\sqrt{3.6^2 + 9.1^2} = 9.8$ km/s

53.f.

$\dfrac{v}{H_0} = \dfrac{9.1}{70} = 0.13$ Mpc $= 130,600$ pc

53.g.

When calculating the distance using Hubble's Law, the astronomer is assuming that the object is quite far away and the majority of its recessional velocity is coming from the expansion of the universe. However, this star is undoubtedly within our own galaxy (it is very hard to measure the properties of distant stars accurately and parallax is very accurate for relatively short distances). Its motion through the galaxy and gravitational interactions with nearby objects will be much more significant than the recessional velocity caused by the expansion of the universe. As a result, the distance obtained using parallax measurements will be much more accurate than the one found by applying Hubble's Law.

54.a.

In these units, most of the constant factors drop out, leaving $P^2 = \dfrac{1}{M}a^3$ so $a = (22^2 * 2 \times 10^6)^{1/3} = 1250$ AU

54.b.

Using (a variant of) the vis-viva equation, $v = \sqrt{\dfrac{GM}{a}\left(\dfrac{2}{r/a} - 1\right)} = 3.0 \times 10^6$ m/s

---

54.c.

$$e = \frac{r_{max} - r_{min}}{r_{max} + r_{min}} = 0.5$$

55.a.

M82 (partial credit for saying galaxy).

55.b.

Dense clouds of cold gas and dust is blocking the light.

55.c.

Very hot gas being ejected from the galaxy is glowing bright in far UV and X-ray.

Part IV: Research Literacy
56.

Compare theoretical models of X-ray emission (for a neutron star) with the observed X-ray emission, and show that they don't match.

57.

Since the mass is above the TOV limit, if the neutron star weren't rotating then it would immediately collapse to a black hole. However, a massive neutron star which is rotating sufficiently fast can resist collapse via the centrifugal "force".

58.

As a neutron star spins, its strong magnetic field interacts with the surrounding plasma, accelerating the charged particles, which then emit light via synchrotron emission. This energy is taken from the rotational energy of the neutron star; consequently, the emission of synchrotron light actually slows down the neutron star.

59.

The X-ray emission from spin-down emission would deposit energy into the local interstellar medium, which would result in a brightening. (As an aside: the delay is caused by the time it takes for the energy to propagate through the shock to the shock front.)

60.

Full credit for mentioning either relativistic shocks or relativistic jets.

61.

"$U - B$" is the difference between the galaxies' U and B magnitudes and "$B - V$" is the difference between the galaxies' B and V magnitudes.

62.

For any color index (including the two in this problem), a lower number signifies being "bluer". The y-axis decreases going up, while the x-axis decreases going to the left. As a result, the "bluest" galaxy would be something in the top left corner, where letter A is.

63.

Type 1 Seyfert galaxies have two sets of emission lines, superposed on one another. One set of lines is characteristic of a low-velocity gas and are referred to as the "narrow lines". A second set of "broad lines" are seen, corresponding to higher velocities. Type 2 Seyfert galaxies differ from Seyfert 1 galaxies in that the broad lines are weaker/absent in type 2 spectra.

64.

The non-interacting galaxies have a comparable scatter to the "normal" galaxies of the Hubble Atlas, but the interacting galaxies have a lot more variation. As a result, the interacting galaxies must be the cause of the large amounts of variation in the "peculiar" galaxies' colors.

65.

Galaxy interactions can lead to high velocity collisions and shock fronts. Both should be effective in compressing gas to high densities and ultimately leading to star formation.