Section A (20 points)

1. C	5. A	9. C	13. D	17. B
2. B	6. C	10. C	14. B	18. A
3. A	7. D	11. B	15. D	19. B
4. A	8. A	12. B	16. A	20. B

Section B (60 points)

21. (a) Image 2
    (b) Type Ia

22. (a) Cygnus X-1
    (b) Image 4
    (c) Black hole

23. (a) A highly magnetized rotating neutron star that emits beams of electromagnetic radiation out of its poles
    (b) One neutron star and one pulsar. The orbit is decaying due to the loss of energy from gravitational waves

24. (a) GW150914
    (b) LIGO
    (c) Two black holes

25. (a) Image 3
    (b) Image 12
    (c) Hubble Space Telescope
    (d) Ultraviolet
    (e) True

26. (a) Sirius
    (b) The small object (the white dwarf)

27. (a) Image 8
    (b) JWST
    (c) Longer

28. (a) NGC 6543
    (b) Hubble and Chandra
    (c) Optical and x-ray
    (d) Electrons falling from $n = 3$ to $n = 2$ in a hydrogen atom, releasing a photon with $\lambda = 656.28$ nm.

29. (a) Mira
    (b) AGB

30. (a) Image 11
    (b) Neutron star
    (c) Large Magellanic Cloud,
    (d) Neutrinos interact very weakly with matter, allowing them to escape the collapsing star almost instantly, while photons are delayed by the time it takes for the shock wave to reach the star's surface.

Section C (35 points)

31. (a) An event horizon is a boundary beyond which events cannot affect an observer. Within the event horizon of a black hole, gravity is so strong that not even light can escape. The Sun doesn't have an event horizon in that sense, but if you tried to squeeze the entire mass of the Sun into a sphere with a radius of about 3 km, then it would turn into a black hole with an event horizon.

    (b) No. The gravitational force exerted by an object depends on its mass, not its size or density. A black hole with the same mass as the Sun would exert the same gravitational pull on the planets as the Sun does currently.

    (c) Spaghettification is caused by tidal forces, resulting from the difference in gravitational pull on different parts of an object. In smaller black holes, this difference is much greater, stretching objects. It's the gravitational differential, not the strength, that causes spaghettification.

32. (a) When nuclear reactions stop in the core, there is nothing there to produce heat. So, the core starts to cool and the pressure in the core decreases, causing it to compress under the weight of the outer layers. When it compresses, the outer layers its temperature increases.

    (b) Shell fusion increases the internal pressure within the star, pushing the outer layers of the star outwards.

    (c) Red giants are very big but don't have very high masses (for a star, at least). So, the strength of gravity at their surface is pretty weak. As a result, it is relatively easy for gas to escape from the surface.

    (d) A white dwarf

33. (a) Apparent magnitude: the magnitude of an object as it appears from Earth

    Absolute magnitude: the magnitude of an object if it were 10 parsecs away

    (b) Star B

    (c) Star C

    (d) Star E

    (e) You should view it at longer wavelengths. Shorter wavelengths are scattered more.

    (f) A "standard candle" in astronomy is an object or class of objects with a known/predictable brightness (or luminosity). If we know how intrinsically bright the object is and how bright it appears to be on Earth, we can calculate how far away the object must be.

    (g) The answer is that the supernova is farther away in Universe 1, where the flux falls off with $1/r$. Since flux in Universe 1 decreases more slowly with distance, the supernova in Universe 1 would have to be farther away to appear as bright as the one in Universe 2, where the flux decreases more quickly.

34. Tiebreaker — answers will vary.