Section A (68 points)

1. (a) Gravitational wave event
   (b) Black hole
   (c) Hanford and Livingston
   (d) 10^{47} J
   (e) 10^{10} J

2. (a) SN UDS10Wil
   (b) Type 1a supernova
   (c) Neighboring galaxy
   (d) Gravitational lensing effect of the galaxy could have made the light brighter, which would make distance estimates closer.

3. (a) Image 3
   (b) Radio
   (c) 3000 $\mathrm{km\,s^{-1}}$

4. (a) GOODS-S 29323
   (b) Infrared, X-ray
   (c) DCBH candidate
   (d) The black hole seeds may have been more massive and the Eddington value may not cap black hole growth rates.

5. (a) Bullet Cluster
   (b) Mass distribution
   (c) Weak gravitational lensing

6. (a) 3C 273
   (b) 8.86×10^8 $M_\odot$
   (c) OVV quasar/FSRQ [1 pt for Blazar]
   (d) Infalling matter undergo accretion, heating the gas and emitting thermal radiation. This energy comes from gravitational potential energy.

7. (a) Image 12
   (b) Infrared
   (c) It is undergoing a lot of star formation.
   (d) LINER

8. (a) M87
   (b) Blue: X-ray, orange: radio
   (c) Synchrotron/magnetobremsstrahlung radiation

9. (a) Image 10
   (b) 4.34
   (c) Determined relationship between UV and X-ray radiation to luminosity, which was then used to calculate distance.

10. (a) H2356-309
    (b) They took multiple observations and simultaneously fit the spectra.
    (c) O VII
    (d) The Sculptor Wall

11. (a) DLA0817g
    (b) QSO, J081740.52+135134.5
    (c) The QSO is directly behind DLA0817g, which allowed astronomers to detect it through its absorption lines.
    (d) DLA0817g's observation was unbiased which means objects like it should be common among other galaxies at its redshift.

12. (a) Image 14
    (b) Infrared
    (c) A quiescent galaxy is one with no significant ongoing star formation, 15
    (d) Disk galaxies are younger, bluer galaxies with greater star formation, whereas elliptical galaxies are generally older and redder galaxies with less star formation, so the latter should make up a larger fraction of quiesced galaxies.

Section B (48 points)

1. (a) Iron (Fe)
   (b) Both increase
   (c) More nickel leads to more ionization which causes a longer peak

2. (a) C
   (b) D
   (c) F
   (d) Black hole

3. (a) 40-60
   (b) 0.01-0.02 $\mathrm{Mpc\,km^{-1}\,s^{-1}}$
   (c) Inverse of the slope is H_0
   (d) Accelerating expansion of the universe

4. (a) Neutron star
   (b) WHIM
   (c) Type Ia supernova
   (d) Seyfert galaxy
   (e) Blazar

5. (a) WFC3 (Wide Field Camera 3)
   (b) ACS (Advanced Camera for Surveys)
   (c) 1.3-1.7
   (d) 7.7 (7.5 - 8)

Section C (84 points)

1. (a) 3.28×10^4

   (b) 3.28×10^4 $L_\odot$ Larger

   (c) i. 5.48×10^8 $L_\odot$

   ii. 4.92×10^6 $L_\odot$

   iii. When a star's luminosity approaches or exceeds its Eddington limit, the forces of radiation pressure are stronger than the forces of gravity on its surface layers which results in significant mass loss. The Homunculus Nebula was formed as Carinae's ejecta in its massive outburst.

   (d) i. 4.14×10^{14} $L_\odot$

   ii. 2.07×10^{14} $L_\odot$

   iii. 2.00, yes

   iv. It can sustain a super-Eddington luminosity because it can sustain constant mass loss. It constantly **loses mass** via its AGN jets but this mass is **constantly supplied via infalling matter / accretion.**

2. (a) 12.9 Mpc

   (b) 18700 pc

   (c) 9350 pc

   (d) 976 $\mathrm{km\,s^{-1}}$

   (e) 75.9 $\mathrm{km\,s^{-1}}$

   (f) 1.25×10^{10} $M_\odot$

   (g) 1×10^{11} $M_\odot$

   (h) 1.4 $M_\odot\, {L_\odot}^{-1}$

   (i) Less

3. (a) 1.75 ″

   (b) 0.0163 ″

4. (a) $\rho_c = \frac{3H^2}{8\pi G}$

   (b) 9.21×10^{-27} $\mathrm{kg\,m^{-3}}$

   (c) 0.25 hydrogen atoms $\mathrm{m^{-3}}$

   (d) Inflationary theory