Daniel Rodener

Galactic & Extragalactic Astronomy – Exercise Sheet #1

Exercise 1.

a) From figure 1 we can obtain the wavelength of Andromeda's $Ly\,\alpha$ line to be at $\lambda_{obs} =$ 1213.6 Å. The rest wavelength obtained from literature however is $\lambda_{rest} = 1215.7$ Å, allowing us to calculate the "redshift" as $\boldsymbol{z} = \frac{\Delta\lambda}{\lambda_{rest}} = \mathbf{-0.001727}$
(negative, as Andromeda is moving toward the milky way)
Using this, the radial velocity can be calculated as $\boldsymbol{v_r} \approx \boldsymbol{cz} = \mathbf{517.7}\,\frac{\boldsymbol{km}}{\boldsymbol{s}}$ (which differs from the literature value of only 110 km/s due to v=cz being a non-relativistic approximation)

b) Using the Hubble law $v_r = H_0 d$ with a given Hubble constant of $H_0 = 71\,\frac{km}{s\,Mpc}$ and a distance $d_{Andro} = 780\,kpc = 0.78\,Mpc$ the expected radial velocity would be $\boldsymbol{v_r} = \mathbf{55.38}\,\frac{\boldsymbol{km}}{\boldsymbol{s}}$
Which is highly inconsistent with measurements, as the Hubble law does not factor in the dynamics of gravitationally bound systems (such as the gravitational attraction between the two largest galaxies of the local group).

c) This galaxy would show an approximate radial velocity of $\boldsymbol{v_r} \approx \mathbf{14,990}\,\frac{\boldsymbol{km}}{\boldsymbol{s}}$ and thusly, assuming the same H_0 as in b), a distance of about $\boldsymbol{d} = \frac{v_r}{H_0} = \mathbf{211.1}\,\boldsymbol{Mpc}$

Exercise 2.

a) The minimum energy needed for pair production equals twice the electron/position rest-mass (equivalent to energy using the relativistic energy-momentum-relation) of $m_e = 511$ keV, so about 1.02 MeV. As two photons are involved, on average, both photons would each need to carry a minimum of 511 keV of energy. Using $E \sim k_b T \;\; \rightarrow \boldsymbol{T} \sim \frac{m_e}{k_b} = \mathbf{5.93 * 10^9}\,\boldsymbol{K}$

b) At $t \sim 1s$ the temperature would be $\boldsymbol{T} \sim \mathbf{1.5 * 10^{10}} * \frac{\mathbf{1}}{\sqrt{\mathbf{1}\,\boldsymbol{s}}} = \mathbf{1.5 * 10^{10}}\,\boldsymbol{K}$, the Energy involved $\boldsymbol{E} \sim \boldsymbol{k_b T} = \mathbf{1.3}\,\boldsymbol{MeV}$. The ratio between photons:baryons was about $\mathbf{10^9 : 1}$

c) Energy needed for photo-disintegration of deuterons is $\boldsymbol{E} = \mathbf{2.23}\,\boldsymbol{MeV}$, which equals a photon frequence of $E = h\nu \rightarrow \quad \boldsymbol{\nu} = \frac{\boldsymbol{E}}{\boldsymbol{h}} = \mathbf{5.39 * 10^{11}}\,\boldsymbol{Hertz}$, placed at the lower end of Infrared
The reason deuteron/deuterium abundances have dropped significantly since the early universe due to primordial deuteron fusion stopping at a certain point in the timeline (as its binding energy is higher than the combined rest mass of proton and neutron, the reaction requires energetic input), deuterium has then fused to helium in great quantities. Another (trace) effect was, for example, the progressive photo-disintegration of D due to its low binding energy by non-primordial IR-photon sources (radiation from warm gas and dust, stars, etc.)