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Galactic & Extragalactic Astronomy Exercise # 1

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1. Hubble law: $v = H_0 \cdot d$ Redshift $z = \frac{\Delta\lambda}{\lambda_0} = \frac{\lambda_{obs} - \lambda_0}{\lambda_0}$

Lyman-α: $\lambda_\alpha = 121{,}5\ nm = 1215\ Å$

a) from spectrum $\lambda_{obs} = 1214\ Å$ $\Rightarrow$ $\Delta\lambda = -1\ Å$

$\Rightarrow$ redshift of andromeda: $z = -\frac{1}{1215} = -0{,}0008 = -8 \cdot 10^{-4}$

$\Rightarrow$ radial velocity: $v = c \cdot z = 3 \cdot 10^8 \frac{m}{s} \cdot (-8 \cdot 10^{-4})$

$= -2{,}5 \cdot 10^5 \frac{m}{s}$

$= -247 \frac{km}{s}$

b) $d = 780\,kpc = 0{,}78\,Mpc$

$v = 71 \cdot 0{,}78 \cdot \frac{km}{s} \cdot \frac{Mpc}{1} \cdot \frac{1}{Mpc} = 55{,}4 \frac{km}{s}$

radial velocity from Hubble law: ~~$71 \cdot 0{,}78 \frac{km}{s} \ldots \frac{km}{s}$~~

Large discrepancy! This is because galaxies also possess a certain peculiar motion. Andromeda actually moves towards the Milky Way (as shown in a)). ~~[illegible]~~

The Hubble law produces exacter radial velocities the farther away a galaxy is. For these galaxies the peculiar motion of a galaxy becomes smaller compared to the Hubble flow velocity and is negligible. For close-by galaxies like Andromeda, however, the peculiar velocity is dominant.

c) $z = 0{,}05$ radial velocity: $v = c \cdot z = 15 \cdot 10^6 \frac{m}{s} = 15 \cdot 10^3 \frac{km}{s}$

distance: $d = \frac{v}{H_0}$

$= \frac{15 \cdot 10^3}{71} \frac{km}{s} \cdot \frac{s \cdot Mpc}{km}$

$= 211{,}3\ Mpc$

2. $E \approx k_B T$ $\left(\frac{T}{K}\right) \approx 1{,}5 \cdot 10^{10} \left(\frac{t}{s}\right)^{-1/2}$

a) electron-positron pair production: $\gamma + \gamma \rightarrow e^- + e^+$

Electrons / Positrons have a restmass of 0,511 MeV. Therefore, pair production requires a minimum photon energy of 1,02 MeV.

$$\Rightarrow \text{minimum temperature:} \quad T = \frac{E}{k_B} = 1,02 \cdot 10^6\, eV \cdot \frac{1}{8,62 \cdot 10^{-5}} \frac{K}{eV}$$
$$= 12 \cdot 10^9\, K$$

Below this temperature the photons will not carry sufficient energy to enable pair production

b)

At this stage the photon - baryon ratio was 10^9 to 1.

$$T = 1,5 \cdot 10^{10} \left(\frac{t}{s}\right)^{-\frac{1}{2}} K$$
$$= 1,5 \cdot 10^{10}\, K$$

where we have inserted $t = 1s$

$$E = k_B T = 1,3 \cdot 10^6\, eV = 1,3\, MeV$$

c)

$$p + n \rightleftharpoons D + \gamma$$

The deuteron has a binding energy of 2,2 MeV. A photon must carry this energy to be able to break apart a deuteron. Thus the photon frequency is

$$\nu = \frac{E}{h} = \frac{2,2 \cdot 10^6\, eV}{4,14 \cdot 10^{-15}\, eV \cdot s}$$
$$= 5,31 \cdot 10^{20}\, \frac{1}{s}$$

As the deuteron's binding energy is relatively small, the photons in the early universe were well able to break them apart, i.e. frequent disintegration occured. At some point ($t \approx 3s$) the deuterons start surviving but are then immediately used for further nucleosynthesis. Thus, deuterons never got the chance to accumulate until much later ($t \approx 200s$)