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Minimum Quantum Energy of the Observable Universe

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Light emitted by all nearby and distant galaxies[1] shows the cosmological redshift. This shift is defined as

$$z = (\lambda - \lambda_0)/\lambda_0$$

where λ_0 is the wavelength of the emitted light and λ is the wavelength measured by the Earth's observer. Modern cosmology, which is based on the General theory of relativity, explains the cosmological redshift by the expansion of the Universe.

Denote now with D the distance between the Earth and a nearby or distant galaxy (hereinafter galaxy). It is rational to propose that the photon's wavelength λ cannot be larger than this distance or $\lambda \leq D$. Thus, the maximum wavelength of a galaxy's photon can be about the distance D or $\lambda_{max} = D$.

We know that the photon's wavelength is inversely proportional to its frequency. The relation between D ($= \lambda_{max}$) and the corresponding frequency ν_{min} is given by the formula $D = c/\nu_{min}$ where c ($\approx 3\times10^8$ m sec^{-1}) is the speed of light. Multiplying both sides of this inequality with Planck's constant h ($= 6.63 \times 10^{-34}$ J sec) and after a bit of algebra we find

$$E_{min} = hc/D$$

where $E_{min} = h\nu_{min}$. Introducing into this equation the above-given values for c and h we have

$$E_{min} = 2 \times 10^{-25}/D.$$

In Hubble terminology, the Hubble distance is defined as

$$D_H = c/H_0$$

where H_0 is the Hubble constant. (Note the reciprocal of H_0 is known as the Hubble time $t_H \approx 14$ Gy). This distance represents, roughly speaking, the radius of the observable Universe. For $H_0 = 72$ km sec^{-1} (Mpc)$^{-1}$, we can take very roughly $D_H \approx 14$ Gly. This is the limit of the observable Universe or our observable cosmic horizon, the maximum wavelength of the galaxy's light, λ_{max},

[1] We define nearby galaxies as those whose redshift z is from 0.001 to 0.1 (or $0.001 \leq z \leq 0.1$) and distant galaxies with $z > 0.1$. Of course, there is no sharp line between nearby and distant galaxies [1].

coming from the horizon to the Earth would be about 14 Gly. Of course, a photon with a wavelength of 14 Gly cannot be detected. The oldest photon which that can be detected is that of the cosmic microwave background (CMB) radiation. Its wavelength of 1.9 mm is in the microwave regime.

We also know that the photon's wavelength is inversely proportional to its energy or in our case

$$E_{min} = hc/\lambda_{max} = hc/D_H.$$

Introducing the above data for h, c and λ_{max} or D_H in the appropriate part of this expression, we find that E_{min} (= $h\nu_{min}$) = 1.5×10^{-51} J. This energy is previously denoted as ε. {For further details see references [2 and 3]}. Very obviously, it represents the minimum quantum of energy of the observable Universe. This was the main aim of this piece of work.

Moreover, for $H_0 = 72$ km sec^{-1} $(Mpc)^{-1} = 2.3 \times 10^{-18}$ sec^{-1}, $\nu_{min} = H_0 = 2.3 \times 10^{-18}$ sec^{-1}, the minimum photon momentum $p_{min} = \varepsilon/c = hH_0/c$ (= 1.5×10^{-51} J/3×10^8 m) = 5×10^{-60} kg m sec^{-1} and its minimum rest mass $m_{min} = \varepsilon/c^2$ (= 1.5×10^{-51} J/9×10^{16} m^2 sec^{-2}) = 1.7×10^{-68} kg. These values are listed in Table 1 of Reference [2] but marked with the subscript ε instead m_{min}.

Heisenberg's Uncertainty Principle for energy and time is related to simultaneous measurements of energy and time. In expression form

$$\Delta E \Delta t \geq h$$

where ΔE is the uncertainty in energy and Δt is the uncertainty in time. The maximum uncertainty in time Δt_{max} is found using the equals sign in this equation. In our case, after a bit of algebra,

$$\Delta t_{max} = h/E_{min}.$$

Putting the above value of E_{min} (= 1.5×10^{-51} J) in this expression we get $\Delta t_{max} \approx 14$ Gy. It is not unreasonable in this case to estimate the maximum uncertainty of time here as simply the maximum time itself. (It will at least give the correct order of magnitude). In other words, the Hubble time t_H (= 14 Gy) represents the maximum time of the observable Universe.

There is a lower limit for the photon energy in the observable Universe, and it comes from the above Uncertainty principle expression. This minimal photon energy is of the order of $E_{min} = h/A_U$, where A_U (= $1/H_0$) is the age of the Universe. So, $E_{min} = hH_0 = \varepsilon$.

References

[1] P. I. Premović**,** *Nearby and distant galaxies: a brief note*. The General Science Journal, August 2024.
[2]. I. Premović, *The Hubble photon quantum of energy of the observable Universe*. The General Science Journal, September 2024.
[3] P. I. Premović, *The Big Bang Universe and the Principle of energy conservation.* The General Science Journal, January 2023.