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The Distance from Nearby or Distant Galaxy to the Earth: A New Approach

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The cosmological redshift of nearby or distant galaxies, z_G, is defined in wavelength as

$$z_G = (\lambda - \lambda_G)/\lambda_G$$

where λ is the wavelength observed by an Earth's observer and λ_G is the emitted by the galaxy. There is an approximately linear relationship between the cosmological redshift of a nearby galaxy (or in the limit $0.001 \leq z_G \leq 0.1$)[1] and the current distance from the Earth to this galaxy, D_G. This relation is the well-known Hubble law which can be expressed in the following form

$$D_G = (cz_G/H_0) \quad \dots (1).$$

Here c ($\approx 3\times10^8$ m sec^{-1}) is the speed of light and H_0 is the Hubble constant at present. H_0 represents the constant rate of the Universe expansion caused by the stretching space (or better space-time) itself. This rate is about 72 km sec^{-1} Mpc^{-1} and it corresponds approximately to 2.21×10^{-18} sec^{-1}. $1/H_0$ is the Hubble time and is related to the age of the Universe, A_U, from the Big Bang to today. For the above value H_0, $A_U \approx 13.8$ Gy.

Applying the Principle of energy conservation, Premović [2] has shown the speed of light c_t emitted by nearby or distant galaxies at time t in the cosmological past is lower than the (current) speed of this light c reaching the Earth. The extent of this lowering depends on the factor $(1 + z_G)$ or

$$c_t = c/(1 + z_G) \quad \dots (2).$$

The average speed of light emitted from a nearby or distant galaxy is $c_{av} = (c_t + c)/2$. Combining this equation and eqn. (2), and after a bit of algebra, we get

$$c_{av} = c(2 + z_G)/2(1 + z_G) \quad \dots (3).$$

We propose the following form of the Hubble law equation for the distance from the Earth to a nearby or distant galaxy

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

$$D_G = (c_t z_G)/H_0.$$

Combining this equation and eqn. (2), and after some rearrangement, we get

$$D_G = [cz_G/(1 + z_G)](1/H_0) \quad \ldots (4).$$

For the limits of nearby galaxies, $0.001 \leq z_G \leq 0.1$, this equation has the classical Hubble law form [eqn. (1)].

Introducing into this equation the age of the Universe, A_U ($\approx$ 13.8 Gy) instead $1/H_0$ we have

$$D_G = A_u c[z_G/(1 + z_G)]$$

or

$$D_G = 13.8\mathbf{c}[z_G/(1 + z_G)] \text{ (in Gly)} \quad \ldots (5).$$

If $z_G \to 0$ then $D_G \to 0$ Gly. If $z_G >> 1$ then $D_G \to 13.8$ Gly.

The light travel time $T_L = D_G/c_{av}$. Combining eqns. (3) and (4) we find that.

$$T_L = 2A_U[z_G//(2 + z_G]$$

Or

$$T_L = 27.6[z_G/ (2 + z_G)] \text{ (in Gy)} \quad \ldots (6).$$

Examples:

1. The "megamaser" method has been used for the direct distance measurement of nearby galaxies. However, it appears this method is suitable for very few of these galaxies - "megamaser" galaxies. For the present case, we select the farthest of these galaxies (with a negligible peculiar speed): NGC 6264 with redshift $z_G = 0.03384$. Using eqn. (5) we find the distance between this galaxy and the Earth $D_G \approx 0.45$ Gly. The experimentally determined value of D_G is 0.447 Gly [3]. Employing eqn. (6), we calculate $T_L \approx 0.46$ Gy. For the observationally favored (H_0 = 72 km sec^{-1} Mpc^{-1}, (Ω_M, Ω_Λ = 0.3, 0.7) Universe (OFU) T_L = 0.45 Gy.

2. The most distant "ordinary" galaxy is GN–z11 with redshift $z_G = 11.1$. Using eqns. (5) and (6), we calculate $D_G \approx 12.7$ Gly and $T_L \approx 23.4$ Gy. The (OFU) T_L = 12.7 Gy.

3. According to current cosmology, galaxies moving with a redshift ≤ 1.5 are currently moving away from the Earth with a recessional speed $v \leq c$. Using eqns. (5) and (6), we find $D_G < 8$ Gly and $T_L < 11.4$ Gy. The (OFU) $T_L < 8.8$ Gy.

4. The minimum galaxy's cosmological redshift z_G = 136 [5]. Using eqns. (5) and (6), we calculate that $D_G \approx 13.7$ Gly and $T_L \approx 27.2$ Gy. The (OFU) $T_L \approx 13.1$ Gy.

References

[1] P. I. Premović, *Nearby and distant galaxies: a brief note*. The General Science Journal, August 2024.
[2] P. I. Premović, *The Speed of Light and the Principle of Energy Conservation*. The General Science Journal, April 2022.
[3] C. Y. Kuo, J. A. Braatz, M. J. Reid, et al., *The megamaser cosmology project. V. An angular-diameter distance to NGC 6264 at 140 Mpc.* Astrophys. J. 767, 155-168 (2013).