A simple note on the light redshift

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The gravitational redshift might explain any case of light redshift.

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1. Introduction

Generally, it is considered that the universe was originated in the Big Bang, and since then it is expanding. In that theory, the redshift of the light emitted from distant galaxies (the so-called cosmological redshift [1]) is interpreted as a Doppler effect and then considered as an indication of the expansion of the universe, following the law of Hubble. This empirical law is stated as

$$v_r = Hd \tag{1.1}$$

where v_r is the velocity of recession, namely the speed at which a light source moves away from the observer, due to the expansion of the space between them; H is the constant of Hubble, and d is the distance between the observer and the light source. The light redshift parameter is defined as

$$z = \frac{\nu_e - \nu_o}{\nu_o} \tag{1.2}$$

being ν_e and ν_o the light frequencies emitted and observed, respectively. For low values of z ($z << 1$) [1]

$$z = \frac{v_r}{c} = \frac{Hd}{c} \tag{1.3}$$

being c the velocity of the light in the vacuum, therefore the (low) redshift of the galaxies is proportional to their distances to the observer. As more distance, more redshift.

However, we are going to consider, using only very elemental arguments, that the redshift in the light coming from the galaxies might be produced by the gravitational potential.

2. The light redshift

The stars are the most numerous objects in the universe. They represent the 98% of its mass [2] (p. 385). The majority of the stars are in the so-called main sequence phase (MSP), which corresponds to the stage of the hydrogen nuclear fusion (HNF) and that occupies the 90% of the life of a star. Also, the majority of the stars in the MSP verify the following relations [2] (pp. 401-402):

$$L_{bol} = R^{5.2} \tag{2.1}$$

$$L_{bol} = M^{3.9} \tag{2.2}$$

being L_{bol}, R and M the bolometric luminosity, the radius and the mass of the star, respectively. From (2.1) and (2.2), $M^{3.9} = R^{5.2} = R^{3.9}R^{1.3}$, $\left(\frac{M}{R}\right)^{3.9} = R^{1.3}$, $\frac{M}{R} = R^{\frac{1.3}{3.9}}$ and [2] (p. 403)

$$\frac{M}{R} = R^{\frac{1}{3}} \tag{2.3}$$

For the gravitational redshift we have that [1]

$$\frac{z}{z+1} = -\frac{\nu_o - \nu_e}{\nu_e} = -\frac{\varphi_e - \varphi_o}{c^2 + \varphi_o} \tag{2.4}$$

being φ_e and φ_o the gravitational potentials at the points of emission and observation, respectively. For $|\varphi_o| << c^2$

$$\frac{z}{z+1} = -\frac{\nu_o - \nu_e}{\nu_e} = -\frac{\varphi_e - \varphi_o}{c^2} \tag{2.5}$$

Note that the equation

$$\frac{\nu_o - \nu_e}{\nu_e} = \frac{\varphi_e - \varphi_o}{c^2} \tag{2.6}$$

is derived for a weak gravitational field in the framework of the General Theory of the Relativity (GTR) in [3] (p. 349).

In a homogeneous and isotropic universe (cosmological principle), the gravitational potential does not change at large scale, then theoretically $\varphi_e = \varphi_o$, and, from (2.4),

$z = 0$. However, this might not be like that when we consider the age of the stars. The radii of the stars in the MSP decrease with the time. In a young star his radius would be greater because the force of contraction produced by the inner gravitational force is counteracted by the force of expansion produced by the energy of the HNF, but this last force decreases as decreases the hydrogen. The gravitational potential varies with the inverse of the distance and always is $\varphi < 0$, only $\varphi(\infty) = 0$. In the mechanics of Newton

$$\varphi = -\frac{GM}{R} \tag{2.7}$$

being G the gravitational constant of Newton, and M and R the mass and the radius of the star, respectively. For the stars in the MSP we can substitute (2.3) into (2.7). Note also that the distance from a star to us, for a light signal, is

$$d = ct \tag{2.8}$$

being t the time, and this time has to be computed to calculate ages. With these premises we can consider, without violating the cosmological principle, that φ_e and φ_o may be different, and, from (2.4), z may be different of zero. Thus, for $|\varphi_o| << c^2$, $|\varphi_o| << |\varphi_e|$ and $z << 1$, from (2.4), (2.7) and (2.3), we would have that

$$z = -\frac{\varphi_e}{c^2} = -\frac{-\frac{GM}{R}}{c^2} = \frac{GM}{Rc^2} = \frac{G}{c^2} R^{\frac{1}{3}} \tag{2.9}$$

and z increases with R as $R^{\frac{1}{3}}$, or in other words, as younger the star is, larger radius, so greater redshift.

Due to (2.8), as more distant a star is, younger was when emitted its light, and then, (1.3) and (2.9) seem to give similar values ([1] goes in this way). But, (1.3) cannot explain the observed case [4] of a quasar (with high redshift, $z = 2.114$) in front of a galaxy (NGC 7319, with much lesser redshift, $z = 0.0225$), because the quasar seems to be even closer to us than the galaxy. However, (2.9) can explain it assuming that the quasar is much younger than the galaxy. In the enlarged photograph of the event, it can be seen that exists a "V" shaped jet of matter between the quasar and the galaxy that might confirm that the quasar was ejected by the nucleus of the galaxy. Note also that (1.3) serves only for the redshift, whereas (2.4) serves for the redshift ($|\varphi_o| < |\varphi_e|$, $\nu_o < \nu_e$) or for the blueshift ($|\varphi_o| > |\varphi_e|$, $\nu_o > \nu_e$).

For last, the mass density of a star is

$$\rho = \frac{M}{\frac{4}{3}\pi R^3} \tag{2.10}$$

and for a star in the MSP, substituting (2.3), we have that

$$\rho = \frac{1}{\frac{4}{3}\pi R^{\frac{5}{3}}} \tag{2.11}$$

and ρ decreases with R as $\frac{1}{R^{\frac{5}{3}}}$, or in other words, as younger the star is, larger radius, so lesser density.

3. Conclusion

We conclude that the gravitational redshift might explain any case of light redshift.

References

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