Shouldn’t Doppler 'De-boosting' be accounted for in calculations of the intrinsic luminosity of Standard candles?

M. Zilberman[1]

Shiny World Corporation, Ontario, Canada

Abstract

“Doppler boosting / de-boosting” is a well-known relativistic effect that alters the apparent luminosity of approaching/receding radiation sources. “Doppler boosting” alters the apparent luminosity of approaching light sources to appear brighter, while “Doppler *de*-boosting” alters the apparent luminosity of receding light sources to appear fainter. While “Doppler boosting / de-boosting” has been successfully accounted for and observed in relativistic jets of AGN, double white dwarfs, pulsars, in search of exoplanets and stars in binary systems it was ignored in the establishment of Standard candles for cosmological distances. A Standard candle adjustment appears necessary for “Doppler de-boosting” for high z, otherwise we would incorrectly assume that Standard candles appear dimmer, not because of “Doppler de-boosting” but because of the excessive distance, which would affect the entire Standard candles ladder at cosmological distances. The ratio between apparent (L) and intrinsic (Lo) luminosities as a function of redshift z and spectral index α is given by the formula $\mathcal{M}(z) = L/Lo=(z+1)^{\alpha-3}$ and for Type Ia supernova as $\mathcal{M}(z) = L/Lo=(z+1)^{-2}$. These formulas are obtained within the framework of Special Relativity and may require adjustments within the General Relativity framework. If confirmed in General Relativity the "Doppler de-boosting" effect may possibly explain the anomalously low luminosity of objects with a high z without the introduction of an accelerated expansion of the Universe.

Key words: galaxies: distances and redshifts - distance scale

1 INTRODUCTION

“Doppler boosting” is a well-known relativistic effect that increases the apparent luminosity of approaching light sources. Specifically, it allows to obtain the intrinsic value of the luminosities (L_o) of relativistic objects by their apparent luminosity (L), velocity and spectral index. “Doppler boosting” is combination of 3 individual relativistic effects, namely relativistic aberration, time dilation and Doppler shifts. “Doppler *de*-boosting” (Zhou & Su 2006; Yang 2010) is the term used for the same relativistic effect calculated and observed for receding sources of radiation.

The conservation of photon number and energy keeps the total of boosts and de-boosts unchanged. However, relativistic aberration changes the *distribution* of photons and energy in the observer’s rest frame compared to a comoving rest frame. In accordance to (Granot & Ramirez-Ruiz, 2012) “for a relativistic source moving with a Lorentz factor $\Gamma = (1-\beta^2)^{-1/2} \gg 1$ (in the lab frame), half of the photons and most (3/4) of the emitted energy are within an angle of $1/\Gamma$ around its direction of motion”.

The illustration fig.1 (re-drawn from the figure 11.2 of Granot & Ramirez-Ruiz, 2012) illustrates the distribution of energy in “boosting” and “de-boosting” zones of relativistic radiation sources. The arrows show the directions of photons in the observer’s frame for a source that emits isotropically in its own rest frame and moves to the right at different velocities. For supernovae located on cosmological distances we are always located in the “de-boosting” zone.

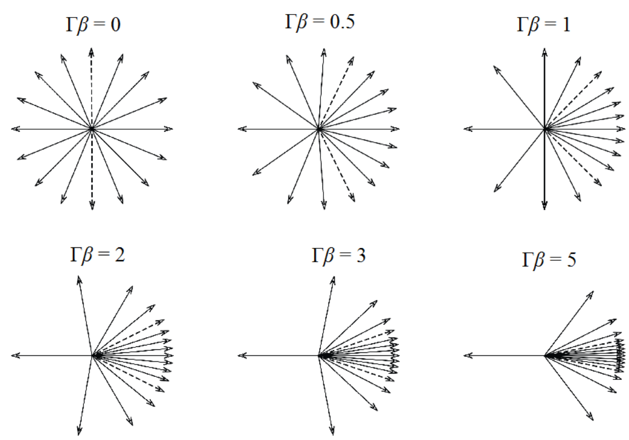

Figure 1. Relativistic boosting and de-boosting. Half of the photons (and 3/4 of the radiated energy) are within an angle of $1/\Gamma$ around the direction of motion (between the dashed arrows, which correspond to θ=90° in rest frame.) Per Granot & Ramirez-Ruiz, 2012.

“Doppler boosting” and “de-boosting” were successfully taken into account in the analysis of relativistic jets of active galactic nuclei (AGN), in observation of double white dwarfs, in research of pulsars, in search of exoplanets and stars in binary systems, and in the analysis of gamma-ray bursts (GRBs) (Kellermann, Kovalev & Lister 2007; Lister 2003; Shporer et al., 2010; Li K. L. et al, 2018; Placek 2019; Massi & Torricelli-Ciamponi 2014).

In cosmology however, the “Doppler de-boosting” effect was not accounted for in the establishment of Standard candles for cosmological distances. For distant galaxies we obviously cannot observe the “Doppler boosting” because each distant galaxy is moving away from the other due to the expansion of

[1] *Editor@IntellectualArchive.com*

space (Fig. 2) and we are always in the "de-boosting" zone. However, we have no reason to ignore the "Doppler de-boosting" effect, which is produced by that distancing or to assume that the Type Ia supernovae are exceptions to this effect.

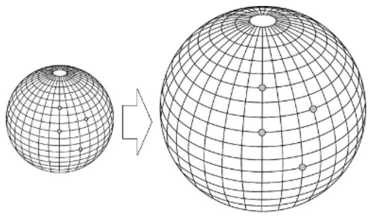

Figure 2. Every distant galaxy is moving away from each other.

2 ANALYSIS

Although disregarding "Doppler de-boosting" for low-speed Standard candles simplifies calculations, for Standard candles with z>0.1 the correction of "Doppler de-boosting" appears to be necessary. Otherwise, we would incorrectly assume that Standard candles appear dimmer, not because of "Doppler de-boosting," but because they are located further away than they truly are. This would affect the entirety of the Standard candles ladder at cosmological distances and the following cosmological models.

Per (Lister 2003), the relationship between the apparent luminosities (L), intrinsic luminosities (L_o) and spectral index is described by the following formulas:

$$L = L_o\,\delta^{p} \qquad (1),$$

where the Doppler factor δ is

$$\delta=\gamma^{-1}(1-\beta\cos\theta)^{-1} \qquad (2),$$

the Lorentz factor γ is

$$\gamma=(1-\beta^2)^{-1/2} \qquad (3),$$

the velocity β is the speed v of a relativistic light source normalized to the speed of light c

$$\beta=v/c \qquad (4),$$

θ is the angle between line of sight and the velocity direction, α is the spectral index ($S_\nu \propto \nu^{\alpha}$), and p=3-α for a discrete emitting region.

"Doppler de-boosting" (Zhou & Su 2006; Yang 2010) is the term of the same relativistic effect calculated and observed for receding sources of radiation. While "Doppler boosting" alters the apparent luminosity of approaching ($0<=\theta<=90^0$) sources to be greater, "Doppler de-boosting" alters the apparent luminosity of the receding ($90^0<\theta<=180^0$) sources to be fainter.

The following presents "Doppler de-boosting" using the redshift parameter z used in cosmology. As for cosmological objects the angle $\theta=180^0$, the Doppler factor δ is shown as

$$\delta=\gamma^{-1}(1+\beta)^{-1} \equiv (1-v^2/c^2)^{1/2}\,(1+v/c)^{-1} \qquad (5).$$

and since the redshift parameter z and velocity v are linked as

$$Z+1 = (1+v/c)\,(1-v^2/c^2)^{-1/2} \qquad (6),$$

the δ and z are linked as

$$\delta=1/(z+1) \qquad (7).$$

As such, for the discrete emitting object parameter p=3-α (Lister 2003), the apparent luminosities (L), redshift parameter z, and the intrinsic luminosities (L_o) relation is shown as

$$L = L_o / (z+1)^{3-\alpha} \equiv L_o\,(z+1)^{\alpha-3} \qquad (8),$$

$$\text{or } \mathcal{M}(z) \equiv L/L_o=(z+1)^{\alpha-3} \qquad (9),$$

where $\mathcal{M}(z)$ is the ratio between the apparent and intrinsic luminosities as a function of redshift z and spectral index α.

Regarding the spectral index α in formula (9). For Type Ia supernova (SNIa), which are considered as Standard candles on cosmological distances, per (Deng Wang & Xin-He Meng, 2018) the spectral index α is about 1 (per the "Joint Light-curve Analysis" sample containing 740 SNIa data points) and for the supernova remnant RCW 86 the spectral index is between 1.5 and 2 (Abramowski at al., 2018). In other words, for SNIa we can expect a relationship between L and L_o as

$$\mathcal{M}(z) \equiv L/L_o=(z+1)^{-2} \qquad (10)$$

Chart fig.3 presents the influence of Doppler de-boosting to the apparent luminosities of SNIa for spectral indices α=1 and α=2, i.e. $\mathcal{M}(z)=(z+1)^{-2}$ and $\mathcal{M}(z)=(z+1)^{-1}$.

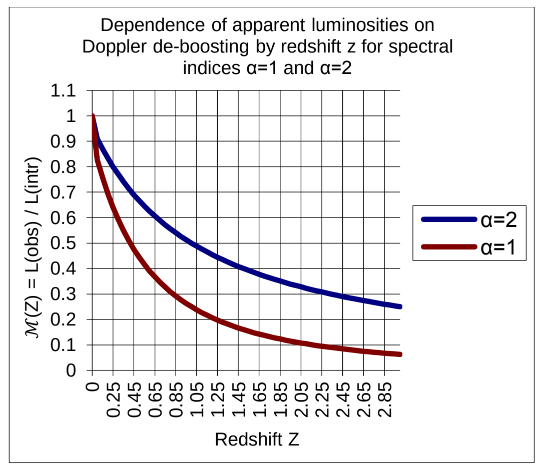

Figure 3. Influence of Doppler de-boosting to the apparent luminosities of SNIa for spectral indexes α=1 (red line) and α=2 (blue line).

As such, the luminosity of objects receding from the observer with a redshift of z=3 appears 4 times fainter for spectral index α=2 and 16 times fainter for spectral index α=1. If we do not consider the "Doppler de-boosting" effect, we can incorrectly assume that these objects are located many times further away than they truly are.

3 DISCUSSION

The base formula (1) was obtained within the framework of Special Relativity. The relativistic aberration, time dilation and Doppler shifts, which form the Doppler's "boosting" and "de-boosting" effects, exist in General Relativity as well.

Gravitational aberration has been known since the famous experiment that detected gravitational deflection in 1919 (Dyson, Eddington & Davidson, 1919) to the modern observation of gravitational lensing and black hole shadows (Chang & Zhu, 2020, also Arakida, 2021).

Gravitational time dilation was confirmed since the (Pound & Rebka, 1959) experiment and up to the recent research of gravitational redshift tracked by Radioastron (Nunes et al., 2020).

Doppler shifts are the basis of cosmology.

However strictly speaking we should derive the base formula (1) using *only* General Relativity equations. Even if the relativistic aberration, time dilation and Doppler shifts exist in General Relativity, the actual formulas that describe the Doppler's "de-boosting" effect can differ in General Relativity from the formula (1) obtained within the framework of Special Relativity.

Therefore, this article is merely asking the question and encouraging subsequent research of whether Doppler 'de-boosting' must be accounted for in calculations of the intrinsic luminosity of Standard candles and the distances to them.

This question is especially important because the "Doppler de-boosting" effect may possibly explain the anomalously low luminosity of objects with a high z without the introduction of an accelerated expansion of the Universe. Instead, it can reveal and support certain new models.

4 CONCLUSIONS

A Standard candle adjustment for cosmological objects with z>0.1 appears necessary for "Doppler de-boosting", otherwise we would incorrectly assume that Standard candles appear dimmer, not because of "Doppler de-boosting" but because of the excessive distance, which would affect the entire Standard candles ladder at cosmological distances. The obtained formulas may require adjustments within the framework of General Relativity.

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