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

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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, 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 (L_0) luminosities as a function of redshift Z and spectral index α is given by the formula $\mathcal{M}(Z) = L/L_0 = (Z+1)^{\alpha-3}$ and for Type Ia supernova as $\mathcal{M}(Z) = L/L_0 = (Z+1)^{-2}$. These formulas are obtained within the framework of Special Relativity and may require adjustments within the General Relativity framework.

Key words. Doppler boosting, Standard Candles, Doppler *de*-boosting, Cosmology, high-redshift

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_0) 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.

“Doppler boosting” and “*de*-boosting” were successfully taken in account in analysis of relativistic jets of the active galactic nuclei (AGN), in observation of double white dwarfs, 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; Placek 2019; Massi & Torricelli-Ciamponi 2014 for LS I +61°303).

In cosmology however, “Doppler *de*-boosting” was not accounted for in the establishment of Standard candles for cosmological distances. For distant galaxies we obviously cannot expect the existence of “Doppler boosting” because every distant galaxy is moving away from the other due to the expansion of space (Fig. 1). However, we have no reason to ignore “Doppler *de*-boosting”, which is produced by that distancing.

Figure 1. 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) relationship between the apparent luminosities (L), intrinsic luminosities (L_0) and spectral index is described by the following formulas:

$$L = L_0 \delta^p \quad (1),$$

where the Doppler factor δ is

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

the Lorentz factor γ is

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

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

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

θ is the angle between line of sight and the velocity direction, α is the spectral index ($S_\nu \propto \nu^\alpha$), and $p = 3 - \alpha$ 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 ($0 \leq \theta \leq 90^\circ$) sources to be greater, “Doppler *de*-boosting” alters the apparent luminosity of the receding ($90^\circ < \theta \leq 180^\circ$) sources to be fainter.

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

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

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

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

the δ and Z are linked as

$$\delta = 1/(Z+1) \quad (7).$$

As such, for the discrete emitting object parameter $p=3-\alpha$ (Lister 2003), the apparent luminosities (L), redshift parameter Z , and the intrinsic luminosities (L_0) relation is shown as

$$L = L_0 / (Z+1)^{3-\alpha} \equiv L_0 (Z+1)^{\alpha-3} \quad (8),$$

$$\text{or } \mathcal{M}(Z) \equiv L/L_0 = (Z+1)^{\alpha-3} \quad (9),$$

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 et al., 2018). In other words, for SNIa we can expect a relationship between L and L_0 as

$$\mathcal{M}(Z) \equiv L/L_0 = (Z+1)^{-2} \quad (10)$$

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

Figure 2. Influence of Doppler *de*-boosting to the apparent luminosities of SNIa for spectral indices $\alpha=1$ (red line) and $\alpha=2$ (blue line).

As we can see, the luminosity of objects receding from the observer with a redshift of $Z=3$ appears 4 times fainter for spectral index $\alpha=2$ and 16 times fainter for spectral index $\alpha=1$. 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.

Relativistic aberration is known since famous experiment that detected the gravitational deflection in 1919 (Dyson, Eddington & Davidson, 1919) and up to observation of gravitational lensing and black hole shadows (Chang & Zhu, 2020).

The gravitational time dilation was confirmed in the well-known (Pound & Rebka, 1959) experiment.

The Doppler shifts is 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 the question, whether Doppler ‘*de*-boosting’ must be accounted for in calculations of the intrinsic luminosity of Standard Candles and distances to them.

4. Conclusion

A Standard Candle adjustment for $Z>0.1$ appears necessary for “Doppler *de*-boosting”, otherwise we would incorrectly assume that Standard Candles look 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 General Relativity framework.

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