Gravitational Doppler 'De-boosting' within the Vicinity of Black Holes

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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. 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 analysis of radiation near strong gravitational objects (e.g. black holes.) The de-boosting factor as a function of gravitational redshift z allows to build the de-boosting diagram, which matches with the observed images of black holes.

1 Introduction

"Doppler boosting / de-boosting" is a well-known relativistic effect that changes the apparent luminosity of approaching / receding 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" 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, Zhou & Su 2006; Yang 2010).

Even so, "Doppler de-boosting" was ignored in the analysis of radiation within the vicinity of strong gravitational objects (e.g. black holes.)

2 Analysis

Analysis of "Doppler de-boosting" within the general relativity framework produces the $(z+1)^{-2}$ coefficient for change in flux between the source's and observer's frames of reference, where z is gravitational redshift. This result was obtained under quite general assumptions, namely that photons travel along null geodesics of the spacetime metric and that the number of photon is conserved (Ellis et al., 2012, Boero & Moreschi, 2018).

One (1+z) de-boosting factor appears because the *energy* (E) of an individual photon is red-shifted in accordance to the gravitational Doppler effect and formula $E=hc/\lambda$, where λ is the photon's wavelength, *c* is the speed of light and *h* is Planck's constant. The second (1+z) de-boosting factor is related to the emitter's time dilation. This time dilation not only changes the frequency of individual photons but also decreases the *number* of photons arriving to observer per unit of time (Ellis et al., 2012).

Gravitational redshift z of photons emitted near gravitational objects can be calculated using the formula

$$z+1=(1-R_s/R_e)^{-1/2} \quad (1),$$

where R_s is the Schwarzschild radius and R_e is the radius at which the photon was emitted.

As such, the de-boosting factor $(z+1)^{-2}$ can be calculated as $[(1-R_s/R_e)^{-1/2}]^{-2}$ or

$$(z+1)^{-2} = 1-R_s/R_e \qquad (2).$$

Fig.1 presents the values of the de-boosting factor for radiation emitted at various distances near the gravitational source (normalized to the Schwarzschild radius.) As we can see by emitter approaching to the Schwarzschild radius, the de-boosting effect becomes more significant and the dimming of the emitted light becomes stronger and approaches “0” brightness at the Schwarzschild radius.

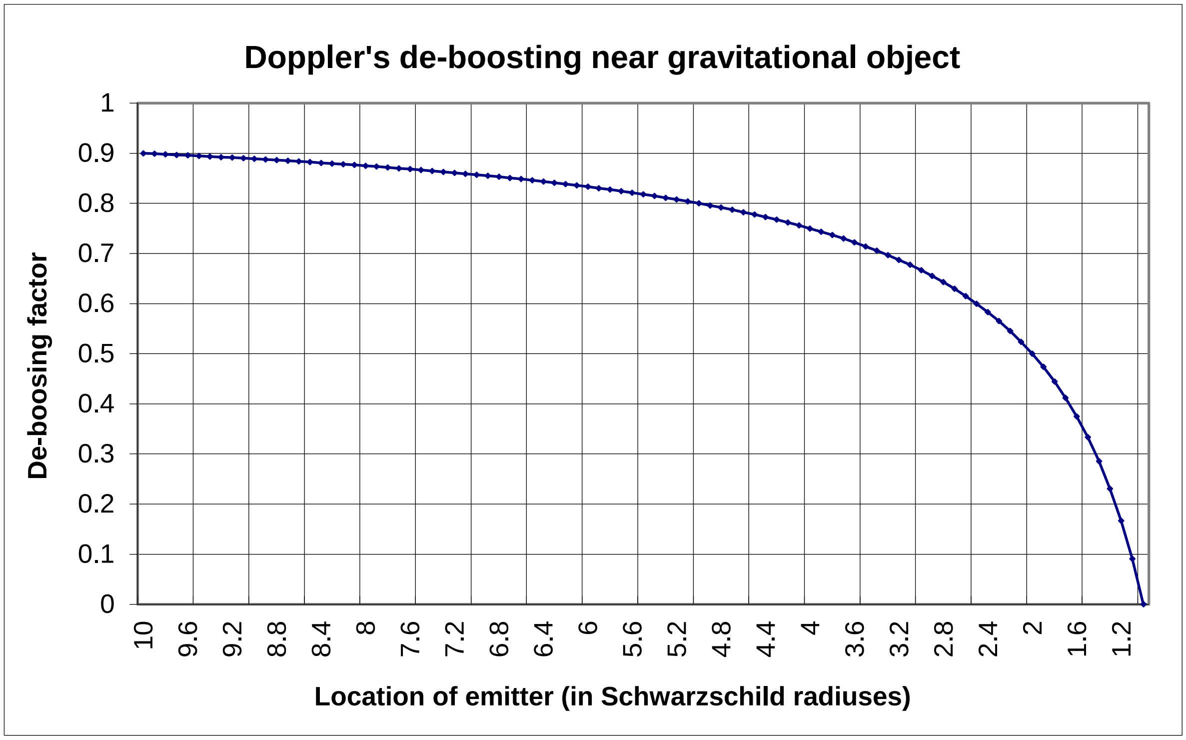

Figure 1. De-boosting factor for radiation emitted at various distances (normalized to the Schwarzschild radius.)

The graph fig. 1 duly matches the observed images of black holes where the intensity of radiation decreases *smoothly* while the emitting area approaches the Schwarzschild radius (fig. 2 below).

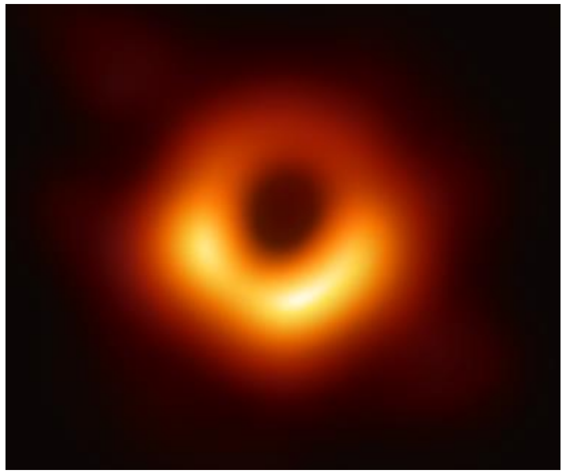

Figure 2. Black hole at the center of galaxy M87.
Credits: Event Horizon Telescope collaboration et al.

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