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On the Superluminal Motion of Radio-Loud AGNs

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Abstract. Apparent superluminal motion of different radio-loud AGNs are similarly related with beaming effect. The cosmological expanding effect would play no part in the superluminal motion of radio galaxies, BL Lacertae objects as well as quasars. Meanwhile, we confirm that estimates for apparent velocity $\beta_{\rm app}$ and Doppler boosting factor δ based on multi-wavelength combination and variability are comparable.

Key words. Galaxies: active—galaxies: jets—radio continuum: galaxies—radiation mechanisms: non-thermal—quasars: general.

1. Introduction

Rees (1966) predicted that the transverse velocity of an object moving relativistically in some special directions may appear to exceed the speed of light. The apparent superluminal motion (SM) is essentially a geometric effect or a light travel-time effect in the frame of standard model (Chodorowski 2005).

The SM is not unique to quasars and radio galaxies (Cohen *et al.* 1971; Whitney *et al.* 1971), but also to other sources including micro-quasars and BL Lac objects (e.g., Mirabel & Rodríguez 1994; Fan *et al.* 1996; Jorstad *et al.* 2001; Kellermann *et al.* 2004). This may be because jet-like outflows are common among various kinds of astrophysical phenomena with different scales (Zhang 2007). Measurement of the apparent velocity can help us understand the geometry and underlying physics on the formation, ejection and acceleration of jets (Ghisellini & Celotti 2002).

The radio-loud AGNs, including BL Lacertae objects, radio galaxies and part of quasars, typically exhibit strong synchrotron radio radiation, variable, jetted outflows, X-ray emission and UV excess. Here, we compare some superluminal properties of these kinds of AGNs whose basic parameters, e.g., δ and $\beta_{\rm app}$, are determined by different methods.

2. Samples and data preparation

According to the relative geometry of ejecta to observer, the basic SM relations are $\beta_{\rm app} = \beta \sin\theta/(1-\beta\cos\theta)$ and $\delta = 1/[\gamma(1-\beta\cos\theta)]$, where θ is the viewing angle and $\gamma(= 1/\sqrt{1-\beta^2})$ is the Lorentz factor of the ejecta. Here, δ and $\beta_{\rm app}$ are two independent variables needed to be decided from observations. The $\beta_{\rm app}$ is usually

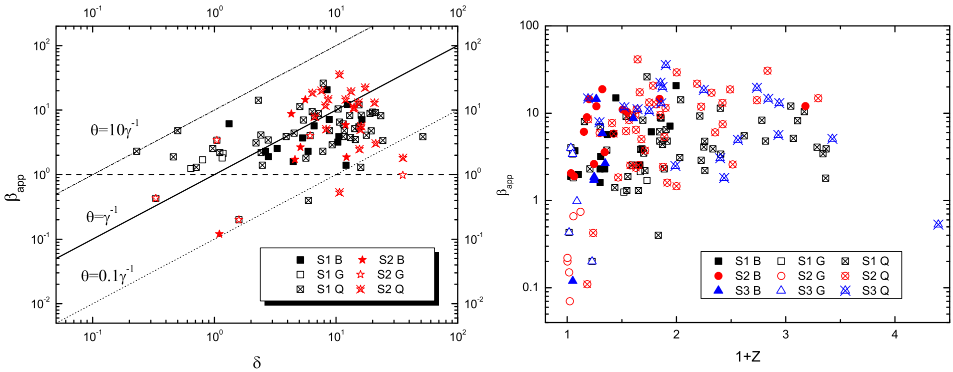

Figure 1. $\beta_{\rm app}$ *versus* δ in the left panel and $\beta_{\rm app}$ *versus* $1 + Z$ in the right panel, where Z is the cosmological red-shift. Symbols S1, S2 and S3 are described in the text.

measured with proper motion, i.e., $\beta_{\rm app} = \mu D_A/c$. Various ways had been proposed to calculate δ and were compared in Lähteenmäki & Valtaoja (1999). Here, we have compared SM from δ derived with multi-wavelength combination (Ghisellini 1993) and variability (Hovatta *et al.* 2009), respectively.

We have selected 8 radio galaxies, 15 BL Lac objects and 46 quasars with SM from literatures (Hong *et al.* 1995; Jorstad *et al.* 2001; Kellermann *et al.* 2004) to constitute sample 1 (S1). Also 6 radio galaxies, 13 BL Lac objects, and 44 quasars from Zhang & Fan (2008) were chosen to constitute sample 2 (S2). Another way to obtain δ has been utilized by Lähteenmäki & Valtaoja (1999) and then by Hovatta *et al.* (2009) in which we have taken 5 radio galaxies, 7 BL Lac objects, and 20 quasars to be our sample 3 (S3).

3. Results

In this section, we display the correlations of $\beta_{\rm app}$ with δ and $1 + Z$ in Fig. 1, from which we find that more than 90% of radio-loud AGNs in both S1 and S3 have a viewing angle θ from $0.1/\gamma$ to $10/\gamma$, clustering around $\theta \sim 1/\gamma$. In addition, $\beta_{\rm app}$ and δ are obviously positively correlated for diverse groups of radio-loud AGNs, which indicates that Doppler boosting effect plays an important role in SM. In the right panel we see an interesting phenomenon that SM of any kind of radio-loud AGNs shows no obviously cosmological evolution effect although quasars and BL Lac objects reside at a region with higher red-shift and larger $\beta_{\rm app}$, while radio-galaxies are located at a regime with lower red-shift and smaller $\beta_{\rm app}$.

Besides, we notice that radio galaxies with smaller values of δ and Z always reside at the low end of $\beta_{\rm app}$. According to the general statistical test, we conclude that estimations of δ and $\beta_{\rm app}$ derived from multi-wavelength analysis (e.g., Ghisellini 1993) and variability timescale (Lähteenmäki & Valtaoja 1999) are excellently consistent.

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