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Beaming Effect and Polarization of Blazars

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Abstract. Based on the beaming model, a relation between the observed polarization and Doppler factor was obtained for BL Lacertae objects–BLs by Fan et al. (1997). If flat spectral radio quasars—FSRQs fit a similar polarization-Doppler factor relation as BLs, then we can find that the ratio, f, of the de-beamed jet luminosity to the unbeamed luminosity in the source frame in BLs is greater than that in FSRQs. That difference in f is consistent with the result by Fan (2002a), which perhaps accounts for the emission line difference between BLs and FSRQs.

1. Introduction

Observations indicate that there is a class of objects, which are called blazars, showing some special properties, namely, rapid variability, variable and high polarization, high luminosities, and superluminal motion etc (Blandford 2002). Blazars have two subclasses, namely BL Lacertae objects (BLs) and flat spectral radio sources (FSRQs). Those two subclasses show quite similar observational properties except for emission line property. There are strong emission lines in FSRQs but there are no emission lines in BLs, or the emission lines in BLs are weak. In addition, one can find that polarization in FSRQs is lower than that in BLs on average. From the multiwavelength continuum properties, we obtained that BL Lac objects and FSRQs are a single class (Fan 1997). However, their difference in emission lines can not be ignored. In this work, we propose the f difference to be responsible for the emission line difference. This work is arranged as follows, in section 2, we present results, in section 3, we give some discussions and in section 4 we give a brief conclusion.

2. Results

2.1. Result from Polarization

In a two-component beaming model of Padovani and Urry (1990) (see also Urry, Padovani. 1995), the emissions of an AGN are not from the jet alone, but from two components, namely beamed and unbeamed ones. Thus, the observed total flux, S^{ob}, is the sum of the unbeamed, S_{unb} and beamed, S_j^{ob} emissions. Assuming the intrinsic flux of the jet, S_j^{in}, to be a fraction f of the unbeamed flux, $S_{\rm unb}$, i.e., $S_j^{\rm in} = fS_{\rm unb}$, one can obtain $S^{\rm ob} = S_{\rm unb} + S_j^{\rm ob} = (1 + f\delta^p)S_{\rm unb}$. If we assume that the emissions in the co-moving jet are also composed of two components, namely polarized and unpolarized, with the two components being proportional to each other, $S_j^{\rm in} = S_j^{\rm p} + S_j^{\rm up}$, $S_j^{\rm p} = \eta S_j^{\rm up}$. We can then derive a relation between observed polarization and Doppler factor (Fan et al. 1997; see also Fan et al. 2001),

$$P^{\rm ob} = \frac{(1+f)\delta_{\rm o}^p}{1+f\delta_{\rm o}^p} P^{\rm in}, \tag{1}$$

where $P^{\rm in}$ is the intrinsic polarization, expressed in the form

$$P^{\rm in} = \frac{f}{1+f}\frac{\eta}{1+\eta}, \tag{2}$$

$\delta_{\rm o}$ is the optical Doppler factor, f and η are, respectively, the ratio of the beamed luminosity to the unbeamed luminosity and the ratio of the polarized to the unpolarized luminosity in the jets. The value of p depends on the shape of the emitted spectrum and the detailed physics of the jet, $p = 3 + \alpha$ is for a moving sphere and $p = 2 + \alpha$ is for a continuous jet case, and α is the spectral index.

Polarimetry observations have recently been done by many authors (see Wills et al. 1992; Tommasi et al. 2001, Efimov et al. 2002, and reference therein). In our discussion, we used the observed highest polarization vs the radio Doppler factors (See Fan 2002b).

For BLs and FSRQs, we can estimate their ratios as follows. f and η for BL Lacertae objects can be obtained by minimizing

$$\sum[P^{\rm ob} - \frac{(1+f)\delta_{\rm o}^p}{1+f\delta_{\rm o}^p} P^{\rm in}]^2.$$

Similarly, if FSRQs satisfy the polarization–Doppler factor relation

$$P^{\rm ob} = \frac{(1+f)\delta_{\rm o}^p}{1+f\delta_{\rm o}^p} P^{\rm in}$$

their parameters, f and η, can also be obtained by the same method. The results are $f = 1.501$ and $\eta = 0.431$ for BL Lacertae objects; and $f = 0.102$ and $\eta = 0.164$ for FSRQs. Therefore, we can obtain the intrinsic polarization, $P^{\rm in} = \frac{f}{1+f}\frac{\eta}{1+\eta} = 1.3\%$, for FSRQs and $P^{\rm in} = 18.1\%$ for BL Lac objects. In this sense, BL Lacertae objects have both higher f values and higher intrinsic polarization than FSRQs, namely, $f_{\rm BL} \sim 15 f_{\rm FSRQs}$, and $P^{\rm in}_{\rm BL} \sim 14 P^{\rm in}_{\rm FSRQs}$.

2.2. Result from Superluminal Sources

Orr & Browne (1982) defined a core-dominance parameter $R(\theta)$

$$R(\theta) = \frac{\text{flux density of beamed CC}}{\text{flux density of unbeamed components}}$$

$$R_T = R(90^\circ)$$

where θ is the viewing angle, CC, compact core, is assumed to be produced by emission from the unresolved bases of two oppositely directed jets, which moves with speed βc. If the jet spectra is flat, one can get the following relation

$$R = 1/2R_T[(1-\beta cos\theta)^{-3} + (1+\beta cos\theta)^{-3}] \tag{3}$$

for a moving sphere case.

¿From a paper by Urry & Padovani (1995), one can express a corresponding relation for a moving sphere case

$$R = f\{[\Gamma(1-\beta cos\theta)]^{-3} + [\Gamma(1+\beta cos\theta)]^{-3}\} \tag{4}$$

So, $f = \frac{1}{2}R_T\Gamma^3$ for the moving sphere case, then given Γ and R_T of a source, f can be obtained easily. Equation (4) means that if viewing angle (θ), Lorentz factor (Γ), and core-dominance parameter (R) are known for a source, then f can also be obtained. But Γ and θ are unobservable. Fortunately, from the beaming model, the Doppler factor and the superluminal velocity can be expressed as

$$\delta \ = \ [\Gamma(1-\beta cos\theta)]^{-1}, \beta_{app} = \frac{\beta sin\theta}{1-\beta cos\theta}$$

which suggest that the Lorentz factor (Γ) and the viewing angle (θ) can be expressed in the forms

$$\Gamma = \frac{\beta_{app}^2 + \delta^2 + 1}{2\delta}, \quad tan\theta = \frac{2\beta_{app}}{\beta_{app}^2 + \delta^2 - 1}$$

So, the ratio f can be obtained as long as the Doppler factor (δ), superluminal velocity (β_{app}), and the core-dominance (R) are known for a source. From a paper by Lahteenmaki & Valtaoja (1999), we have Lorentz factor and viewing angle while for core dominance parameters, they can be found from literature (See Fan 2002a). The results indicate that $\log f = 0.11 \pm 0.49$ for BLs and $\log f = -1.59 \pm 0.19$ for FSRQs. The averaged value difference in $\log f$ between BLs and FSRQs is $\Delta(\log f) = 1.68 \pm 0.52$. The difference given in a paper of Fan (2002b) is in this range.

3. Discussion

There are many similarities between BL Lac objects and FSRQs: large and rapid variability, high and variable polarization, superluminal motions, and strong gamma–ray emissions. They both share the same relations in the effective spectral index and the optical color–color index plots (Fan 1997). Comastri et al. (1997) found that X-ray and γ-ray indices of BL Lac objects and FSRQs show an anti-correlation. Both kinds of objects can not be distinguished from those observational properties. Nevertheless, the differences in their emission-line strength prevent one from classifying them as a single class. Do they belong to a single class or two different classes? If they are a single class, then how to explain their difference in emission lines? In the present work, we propose that they are the same class with (1) the ratio of beamed to unbeamed luminosities in BL Lac objects being higher than that in FSRQs, in this case, the beamed emissions dominate the line emissions in BL Lacertae objects, and (2) the intrinsic polarization in FSRQs is lower than that in BL Lacertae objects. Our results (Fan 2002a,b) support this propose.

From a paper of Padovani and Urry (1990), the observed emissions of an AGN are $S^{\mathrm{ob}} = S_{\mathrm{unb}} + S_j^{\mathrm{ob}} = (1 + f\delta^p)S_{\mathrm{unb}}$. If we assume that the line strengths are proportional to the unbeamed component, then for BL Lacertae objects the $f\delta^{3+\alpha}S_{\mathrm{unb}}$ term is much larger than the unbeamed term, S_{unb}; therefore, the emissions from the jet dominate those from the unbeamed, namely dominate the line emissions. However, for FSRQs, the two terms are comparable. Therefore, FSRQs show strong line emissions and high boosting effect as well.

4. Conclusions

From the analysis mentioned above, we have the following results:

(1) The polarization mechanism in FSRQs is similar to that in BL Lac objects and polarization is associated with beaming effect.

(2) That BL Lac objects show weaker emission lines than FSRQs can be accounted for by the fact that f in BL Lac objects is greater than that in FSRQs.

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