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SPECTRAL VARIABILITY AND TRANSIENT INJECTION OF RELATIVISTIC ELECTRONS FOR BL LAC OBJECTS*

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The spectral hardening with increasing intensity in optical range for four BL Lac objects have been found by analyzing our observed data. Making use of the synchrotron loss of transient injection of relativistic electrons, we succeeded in explaining the phenomenon of the spectral hardening in the outburst phase. The value of magnetic intensity and the limit condition of the transient injection of relativistic electrons seem to be reasonable.

Keywords: BL Lac objects, spectrum, radiation mechanism
PACC: 9850, 9870

I. INTRODUCTION

The relation between the change in spectral shape and that in intensity has been noticed in many frequency ranges for several BL Lac objects. The spectral hardening with increasing intensity in IR-optical range for OJ287 has been reported by Hanson and Coe[1] and Gear *et al.*[2] A similar tendency has been reported for the IR-optical continuum of PKS0048-09 by Falomo *et al.*[3] and for the IR-optical continuum of PKS0422+00 and 0537-44 by Tanzi *et al.*[4] For OI090.4, spectral hardening with increasing intensity has been reported by Worrall *et al.*[5] in UV range. A strong correlation ($> 90\%$ confidence level) between intensity and spectral slop was present in near-infrared spectrum of 0235+164, 0735+178 and 1308+326.[6] A weak correlation between the change in spectral shape and the change in intensity might be present in UV range for Mark421.[7] Have all radio-selected BL Lac objects the same behavior mentioned above? In this paper, we report the systematic analysis of the quasi-simultaneously observed data in our monitoring program and discuss the emission mechanism of BL Lac objects.

II. OBSERVED DATA AND THE ANALYSIS OF THEM

The BL Lac objects are violent variables, their color indices should ideally be derived from simultaneous observations in the various colors. However, if the interval between the B and V observations is sufficiently small, these observations could be regarded as quasi-simultaneous. In our monitoring program, the time interval for completing one set of observations were generally 5–8min. We selected those observations in our monitoring program when the B and V photometry is obtained within less than this time, which is one order of magnitude smaller than the variability time scale. Using our monitoring data, we obtained the following results:

When the linear regression analysis is performed on data of PKS0735+178 observed on Jan. 26–29, 1990 by Xie *et al.*,[8] the result is

$$B - V = (0.587 \pm 0.079)B + (-8.664 \pm 1.255), \quad (1)$$

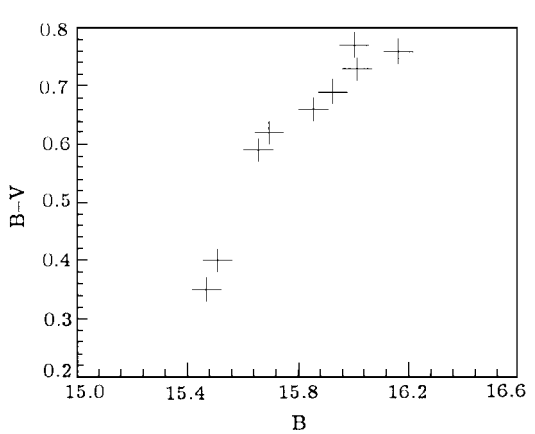


Fig.1. The results of B and B-V based on data of PKS0735+178 observed on Jan. 26–29, 1990 by Xie *et al.*[8]

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with a correlation coefficient of γ=0.942. For n–2=7, we have $\gamma_{0.01} = 0.798$, hence the correlation is obvious (see Fig.1).

When the linear regression analysis is performed on data of OI090.4 (0745+100) observed on Dec. 11, 1989 by Xie *et al.*,[9] the result is

$$B - V = (0.798 \pm 0.105)B + (-13.128 \pm 1.792), \quad (2)$$

with a correlation coefficient of γ=0.937. For n–2=8, we have $\gamma_{0.01} = 0.765$, hence the correlation is also very obvious (see Fig.2).

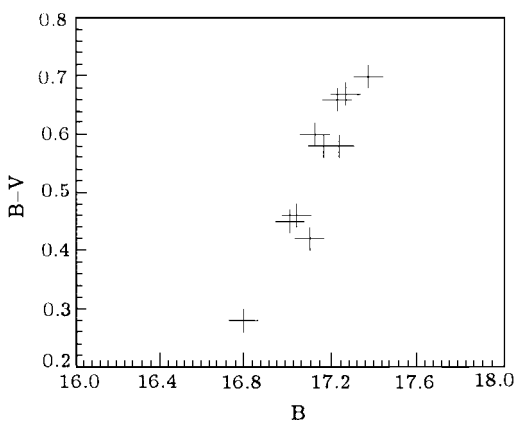


Fig.2. The results of B and B-V based on data of OI090.4 observed on Dec. 11, 1989 by Xie *et al.*[9]

When the linear regression analysis is performed on data of OJ-131 (0818-128) observed on Dec. 12, 1988 by Xie *et al.*,[9] the result is

$$B - V = (0.755 \pm 0.086)B + (-12.888 \pm 1.501), \quad (3)$$

with a correlation coefficient of γ=0.965. For n–2=4, we have $\gamma_{0.01} = 0.834$, hence the correlation is very strong (see Fig.3).

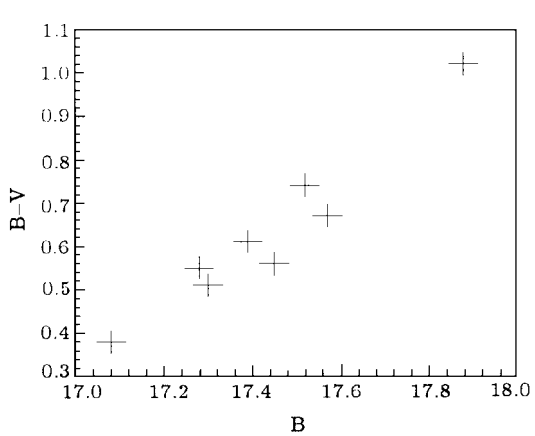


Fig.3. The results of B and B-V based on data of OJ-131 observed on Dec. 12, 1988 by Xie *et al.*[9]

When the linear regression analysis is performed on data of ON+231 (1219+285) observed on Feb. 14, 1989 by Xie *et al.*,[10] the result is

$$B - V = (1.107 \pm 0.093)B + (-16.044 \pm 1.510), \quad (4)$$

with a correlation coefficient of γ=0.988. For n–2=3, we have $\gamma_{0.01} = 0.959$, hence the correlation is also very strong (see Fig.4).

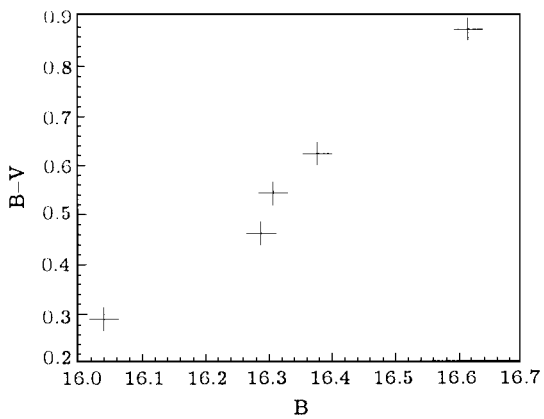


Fig.4. The results of B and B-V based on data of ON+231 observed on Feb. 14, 1989 by Xie *et al.*[10]

In summary, our observation data show that the spectra appear hardening when the source is in outburst for PKS0735+178, OI090.4, OJ-131 and ON+231.

Ⅲ. EMISSION MECHANISM

In this section, we discuss the emission mechanisms about the phenomena of the spectrum hardening when the source is outburst as obtained above. It is well known that the phenomena of the spectrum weakening with outburst of the source can be explained using the continuous injection model and transient injection model. As we can see in the following section, a magnetic field estimated by the spectrum variability is very large, then the inverse Compton loss is less than the synchrotron loss for relativistic electrons. Hence we neglect the inverse Compton loss.

A. The continuous injection model

In the continuous injection model, electrons are continuously injected into the emitting region with a high-energy and nonthermal distribution. In the energy space, let $N(\gamma, t)$ denote the number of relativistic electrons in the unit volume of the source at time

t with the energy lying in the range of γ and $\gamma + \mathrm{d}\gamma$. The equation for the evolution of $N(\gamma, t)$ is given by

$$\frac{\partial}{\partial t}N(\gamma,t) = -\frac{\partial}{\partial \gamma}[\dot{\gamma}N(\gamma,t)] + S_0(\gamma,t), \qquad (5)$$

where $\frac{\mathrm{d}\gamma}{\mathrm{d}t} = -a(1+\varepsilon)\gamma^2$, $\varepsilon = \frac{U_S}{U_B}$, U_S and U_B are the energy density of radiation and that of magnetic field for the source, respectively. Neglecting the inverse Compton loss, we have

$$\frac{\partial}{\partial t}N(\gamma,t) = b\frac{\partial}{\partial \gamma}[\gamma^2 N(\gamma,t)] + S_0(\gamma,t), \qquad (6)$$

where $b = a$ is the rate of synchrotron loss, $S_0(\gamma)$ is the continuous injection function which we assume to have no relation with time and have a power law distribution

$$S_0(\gamma,t) = S_0(\gamma) = Q_0\gamma^{-n}. \qquad (7)$$

In the steady state, $\frac{\partial}{\partial t}N(\gamma,t) = 0$ and the solution of Eq.(6) is given by

$$N(\gamma,t) = \frac{Q_0}{b(n-1)}\gamma^{-(n+1)} = N_0\gamma^{-(n+1)}. \qquad (8)$$

B. The transient injection model

The equation for the evolution of $N(\gamma, t)$ is given by

$$\frac{\partial}{\partial t}N(\gamma,t) = b\frac{\partial}{\partial \gamma}[\gamma^2 N(\gamma,t)] + S_1(\gamma,t). \qquad (9)$$

We assume that there is a transient injection as the pulse injection at the start of the outburst (t=0), it has also a similar power law distribution to the continuous injection and the same power law index, as follows:

$$S_1(\gamma,t) = Q_1\gamma_0^{-n} \qquad (\gamma_1 < \gamma_0 < \gamma_2), \qquad (10)$$

and after the start of the outburst, one has the transient injection $S_1 = 0$. Here γ_0 is the energy of the transient injection electrons at the time when the pulse transient injection just stops. At this time, the distribution of the electrons is

$$N(\gamma_0) = N_1\gamma_0^{-n}\mathrm{d}\gamma_0, \qquad (11)$$

that is, $N(\gamma_0)$ and S_1 have the same spectral shape and the same index. After that, the distribution of electrons will evolve and change its spectral index due to the synchrotron radiation loss.

The radiation loss can be given simply as, $\frac{\mathrm{d}\gamma}{\mathrm{d}t} = -a\gamma^2$, then we have $\gamma = \frac{\gamma_0}{(1+a\gamma_0 t)}$ and $\gamma_0 = \frac{\gamma}{(1-a\gamma t)}$. Therefore, one has

$$\mathrm{d}\gamma_0 = \frac{\gamma}{(1-a\gamma t)^2}. \qquad (12)$$

Due to the radiation loss, the electrons, which are in the energy range between γ_0 and $\gamma_0 + \mathrm{d}\gamma_0$ at $t = 0$, will enter into the energy range between γ and $\gamma + \mathrm{d}\gamma$ at t, so we have

$$N(\gamma_0)\mathrm{d}\gamma_0 = N(\gamma,t)\mathrm{d}\gamma, \qquad (13)$$

then, for the pulse injection, the solutions are

$$N(\gamma,t) = N_1\gamma^{-n}(1-a\gamma t)^{n-2} \quad (\gamma_1 < \gamma < \gamma_2) \qquad (14)$$

and

$$N(\gamma,t) = 0 \qquad \text{(otherwise)},$$

where $\gamma_1 = \gamma_{\min}$ and $\gamma_2 = \gamma_{\max}$.

C. A new model

We assume that the equation for the evolution of $N(\gamma, t)$ is given by

$$\frac{\partial}{\partial t}N(\gamma,t) = a\frac{\partial}{\partial \gamma}[\gamma^2 N(\gamma,t)] + S(\gamma,t). \qquad (15)$$

The injection function $S(\gamma, t)$ now have two components, the continuous injection $S_0(\gamma, t)$, and the pulse injection $S_1(\gamma, t)$. That is

$$S(\gamma,t) = S_0(\gamma) + S_1(\gamma,t). \qquad (16)$$

The continuous injection results in a stable radiation of the source. The transient injection of the electrons is produced by the instability of the central nuclei of the source, which results in outburst itself. Now we can obtain the general solution of Eq.(15) as

$$N(\gamma,t) = N_0\gamma^{-(n+1)} + N_1\gamma^{-n}(1-a\gamma t)^{n-2}. \qquad (17)$$

If $a\gamma t \ll 1$, Eq.(17) becomes

$$N(\gamma,t) = N_0\gamma^{-(n+1)} + N_1\gamma^{-n} = N_1\gamma^{-n}(\frac{N_0}{N_1}\gamma^{-1} + 1). \qquad (18)$$

If $\frac{N_0}{N_1\gamma} \ll 1$, we can obtain

$$N(\gamma,t) = N_1\gamma^{-n}. \qquad (19)$$

Comparing Eq.(19) with Eq.(8), we can see that the radiation spectrum of the outburst hardens for the stable radiation, just as expected. From the limit condition of $a\gamma t \ll 1$ and the time scale of spectrum

variability $t \approx$ hour, we can estimate the low limit of the magnetic intensity for this model in X-ray range of 0.2–5 keV, it is $B \approx 10^{-3}$T. According to the estimate of Henri *et al.*,[11] the maximum magnetic field strength is 10^{-2}T. Therefore, our result is reasonable. Let us go back to the condition of $\frac{N_0}{N_1\gamma} \ll 1$. Because $\gamma \gg 1$, the above condition is equivalent to the limit

$$N_1 > N_0. \tag{20}$$

This result is also reasonable.

IV. DISCUSSION AND CONCLUSION

The model of the synchrotron loss of transient injection of relativistic electrons we proposed is successful in explaining the phenomenon of spectral hardening in the outburst phase in the optical range for BL Lac objects. The value obtained for magnetic intensity and the limit condition of the transient injection of relativistic electrons is reasonable. Recently, the observation of BL Lac objects has developed very rapidly. The observed phenomena are very copious. In X-ray range, the only objects which we were able to study in this way are X-ray-selected. It has been noticed that the radiation spectrum of X-ray selected BL Lac objects(XBLs) appears flat when its central source is outburst;[11] the systematic analysis clearly shows that this phenomenon is very common in XBLs.[12] Therefore, it is not known whether XBLs show similar spectral change. But the opposite phenomenon, i.e., spectral steeping with increasing brightness, seems to be rather common in other types of AGN. In the optical and UV wavebands, the spectral variability of radio-selected BL Lac objects (RBLs) are very complicated. Some of RBLs have spectral flatting with increasing brightness, such as the objects observed by us.

It is not known whether XBLs also show similar spectral changes in the optical and UV bands like RBLs. Because a large majority of XBLs have only recently been discovered and have not been monitored as extensively as most of the famous and long-known RBLs. Therefore continuous high frequent monitoring, such as the infrared, the optical and X-ray monitoring, is essential to test the emission process for extremely variable BL Lac objects.

REFERENCES

[1] C. G. Hanson, M. J. Cor, *Astron. J.*, **217**(1985),831.

[2] W. K. Gear, E. I. Balonek, L. M. J. Brown, *Nature*, **324**(1986),546.

[3] R. Falomo, P. Bouchet, L. Maraschi, E. G. Tanzi, A. Treves, *Astrophys. J.*, **335**(1988),122.

[4] E. G. Tanzi, R. Falomo, P. Bouchet, M. Bersaneli, L. maraschi, A. Treves, In Lecture Notes in Physics, BL Lac Objects (Maraschi, Springer-Verlag, Berlin, 1989),p.171.

[5] D. M. Worrall *et al.*, *Astrophys. J.*, **286**(1984),711.

[6] R. M. J. Brown, E. I. Robson, W. K. Geer, M. G. Smith, *Astrophys. J.*, **286**(1989),711.

[7] M. -H. Ulrich, K. R. H. Hackney, R. L. Hackney, Y. Kondo, *Astrophys. J.*, **276**(1984),466.

[8] G. Z. Xie *et al.*, *Asrophys. J. Suppl.*, **80**(1992),683.

[9] G. Z. Xie *et al.*, *Astron. Asrophys. Suppl.*, **87**(1991),461.

[10] G. Z. Xie *et al.*, *Astron. Asrophys.*, **229**(1990),329.

[11] G. Henri, G. Pelletier, J. Roland, *Asrophys. J.*, **404**(1993),41.

[12] P. Giommi, P. Barr, B. Garilli, D. Maccagni, M. T. Pollock, *Astrophys. J.*, **256**(1990),432.