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Spectral Variation of NLS1 Galaxy PMN J0948 + 0022

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Abstract. Four well-sampled Spectral Energy Distributions (SEDs) of PMN J0948 + 0022 are fitted with the syn + SSC + EC model to derive the physical parameters of its jets and to investigate the spectral variations of its SEDs. A tentative correlation between the peak luminosity (L_c) and peak frequency (ν_c) of its inverse Compton (IC) bump is found in both the observer and co-moving frames, indicating that the variations of luminosity are accompanied by the spectral shift. A correlation between L_c and δ is found, and thus the magnification of external photon field by the bulk motion of the radiation regions is an essential reason for the spectral variation since, IC bump of PMN J0948 + 0022 is dominated by the EC process.

Key words. Galaxies: active—galaxies: individual: PMN J0948 + 0022—galaxies: Seyfert—galaxies: jets—γ-rays —theory.

1. Introduction

Narrow-line Seyfert 1 (NLS1) galaxies are a relatively peculiar subclass of Active Galactic Nuclei (AGNs), which are characterized by their optical spectra with narrow permitted lines (FWHM (H_β) < 2000 km s^{-1}), the ratio of [O III]$\lambda5007/H_\beta < 3$, and the bump of Fe II (e.g., Pogge 2000). NLS1s are also interesting for their low masses of central black holes and high accretion rate. NLS1s are generally radio-quiet; only a small percentage is radio-loud (<7%; Komossa *et al*. 2006). So far, four NLS1s are confirmed to be GeV emission sources by Fermi/LAT, which should have relativistic jets as predicted by Yuan *et al*. (2008).

PMN J0948 + 0022 ($z = 0.5846$) is the first NLS1 detected in GeV band by Fermi/LAT. The inverted spectrum in radio band indicates the presence of a relativistic jet viewed at small angles (Zhou *et al*. 2003), which is similar to the properties of blazars. The significant variabilities of PMN J0948 + 0022 are detected, especially in the GeV band (Abdo *et al*. 2009; Foschini *et al*. 2011). It is found that the observed luminosity variations are usually accompanied by the shift of peak frequencies of SEDs, similar to some GeV–TeV BL Lacs (Zhang *et al*. 2012). The abundant broadband observational data provide an opportunity to study the physical mechanism of the spectral variations of PMN J0948 + 0022.

2. SED selection and modelling

We compile the observed broadband SEDs of PMN J0948 + 0022 from literature. Four available SEDs shown in Fig. 1(a) are defined as SEDs 'a', 'b', 'c' and 'd' according to their peak luminosity of IC bump of SEDs. The data of SEDs 'a' and 'b' are from Foschini *et al*. (2011) and are obtained by the observations in 2010, July 8th and 2011, October 9th–12th, respectively. The SEDs 'c' and 'd' of this source are taken from the observations in 2009, June 14th and 2009, May 5th (Abdo *et al*. 2009).

The broadband SEDs of PMN J0948 + 0022 are similar to the typical FSRQs and thus γ-ray emission should be dominated by jet emission. We use the syn + SSC +

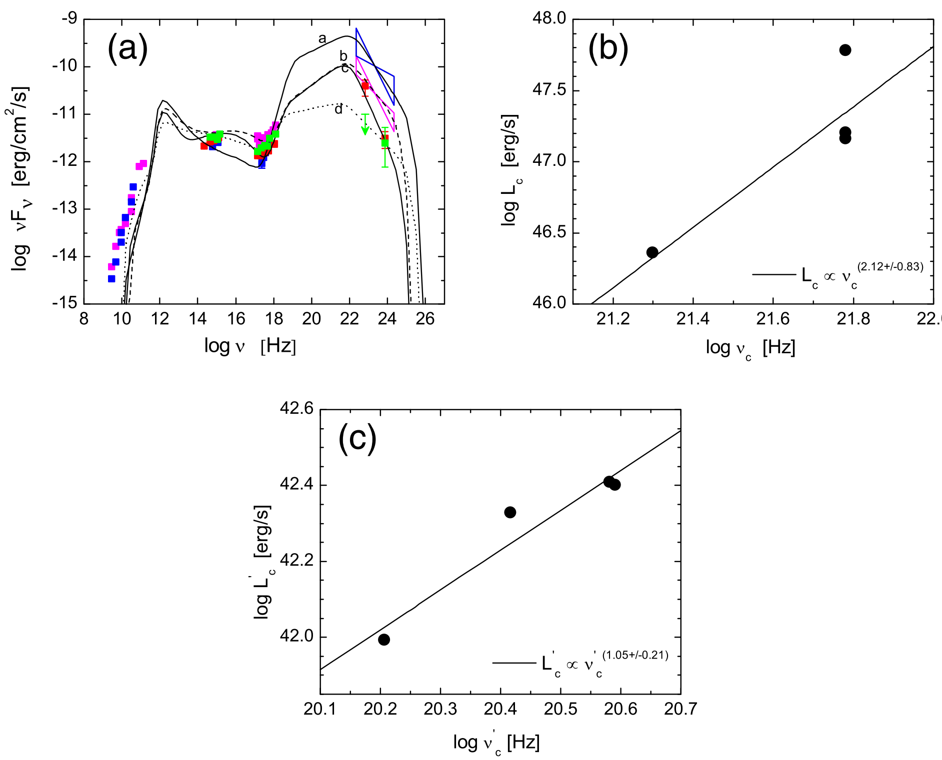

Figure 1. (**a**) Observed SEDs (scattered data points) with model fitting (lines) for PMN J0948 + 0022. The four SEDs are marked as states 'a' (blue points and thick solid line), 'b' (magenta points and dashed line), 'c' (red points and thin solid line) and 'd' (green points and dotted line), respectively. L_c as a function of ν_c in both the observer (**b**) and co-moving (**c**) frames.

EC model to fit its SEDs because the contributions of the external field photons from the Broad Line Region (BLR) need to be considered. The total luminosity of BLR is calculated using the luminosity of its emission lines (Zhou *et al*. 2003) with equation (1) given in Celotti *et al*. (1997). The size of BLR is calculated using BLR luminosity with equation (23) in Liu & Bai (2006). The energy density of BLR measured in the co-moving frame is $U'_{\rm BLR} = 6.76 \times 10^{-3}\Gamma^2$ erg cm^{-3}, where we take $\Gamma \sim \delta$. The minimum variability timescale is taken as $\Delta t = 12$ hr. The details of the model and the strategy for constraining its parameters can be found in Zhang *et al*. (2012).

SEDs of PMN J0948 + 0022 are well explained with the syn + SSC + EC model, as shown in Fig. 1(a). EC component of SEDs for PMN J0948 + 0022 presents a further constraint on δ, thus making a tighter constraint on δ and B than that for BL Lacs in Zhang *et al*. (2012). The fitting parameters of SEDs for PMN J0948 + 0022 are also more tightly clustered; the magnetic field strength B is from 2.24 ± 0.11 G to 3.34 ± 0.50 G, the Doppler factor is from 12.4 ± 0.8 to 23.0 ± 0.8, and the break Lorenz factor of electrons is from 91 ± 3 to 107 ± 9.

3. Spectral variation of IC bump

The broadband SEDs of PMN J0948 + 0022 are dominated by EC process, and there are significant variabilities in the GeV band. The peak luminosity ($L_{\rm c}$) as a function of peak frequency ($\nu_{\rm c}$) of the IC bump in both the observer and co-moving frames are given in Figures 1(b), (c). A tentative correlation between the peak luminosity and peak frequency in both the observer and co-moving frames is found, i.e., $L_{\rm c} \propto \nu_{\rm c}^{(2.12\pm0.83)}$ with $r = 0.87$ (Pearson correlation coefficient) and $p = 0.13$ (chance probability), and $L'_{\rm c} \propto \nu_{\rm c}^{(1.05\pm0.21)}$ with $r = 0.96$ and $p = 0.04$, respectively, indicating that the luminosity variations of the IC bump are accompanied with a spectral shift.

To investigate the possible physical reason of this phenomenon, we show IC peak luminosity as functions of B, δ and $\gamma_{\rm b}$ in both the observer and co-moving frames in Fig. 2. It can be found that: (1) Both $L_{\rm c}$ and $L'_{\rm c}$ are anticorrelated with B. Pearson correlation analysis and the best linear fits yield $L_{\rm c} \propto B^{(7.11\pm1.66)}$ with $r = -0.95$, $p = 0.05$ and $L'_{\rm c} \propto B^{(2.34\pm0.65)}$ with $r = -0.93$ and $p = 0.07$. (2) $L_{\rm c}$ seems to be correlated with δ with $r = 0.96$ and $p = 0.04$. (3) No correlation between $\gamma_{\rm b}$ with $L_{\rm c}$ and $L'_{\rm c}$ is found, which may be due to uncertainties of the synchrotron radiation peak for SEDs. These facts indicate that the spectral variations of the IC peak for PMN J0948 + 0022 may be attributed to the variations of δ and B, similar to the results of a typical FSRQ 3C 279 (Zhang *et al*. 2013).

The significant variations of the IC peak for PMN J0948 + 0022 in the GeV band are dominated by the EC process. The energy density of the external photon field would be magnified by Γ^2 and the energy of the seed photons would be magnified by Γ due to the motion of the emitting regions, hence a small variation of δ would result in significant variations of $\nu_{\rm c}$ and $L_{\rm c}$. As mentioned above, B is also anticorrelated with $L_{\rm c}$ in both the observer and as well as the co-moving frames, indicating the variations of B for this source between different states, which are also accompanied with the variations of δ, that might be linked to the variations of some intrinsic physical parameters of the central black hole, such as the disk accretion rate or the corona

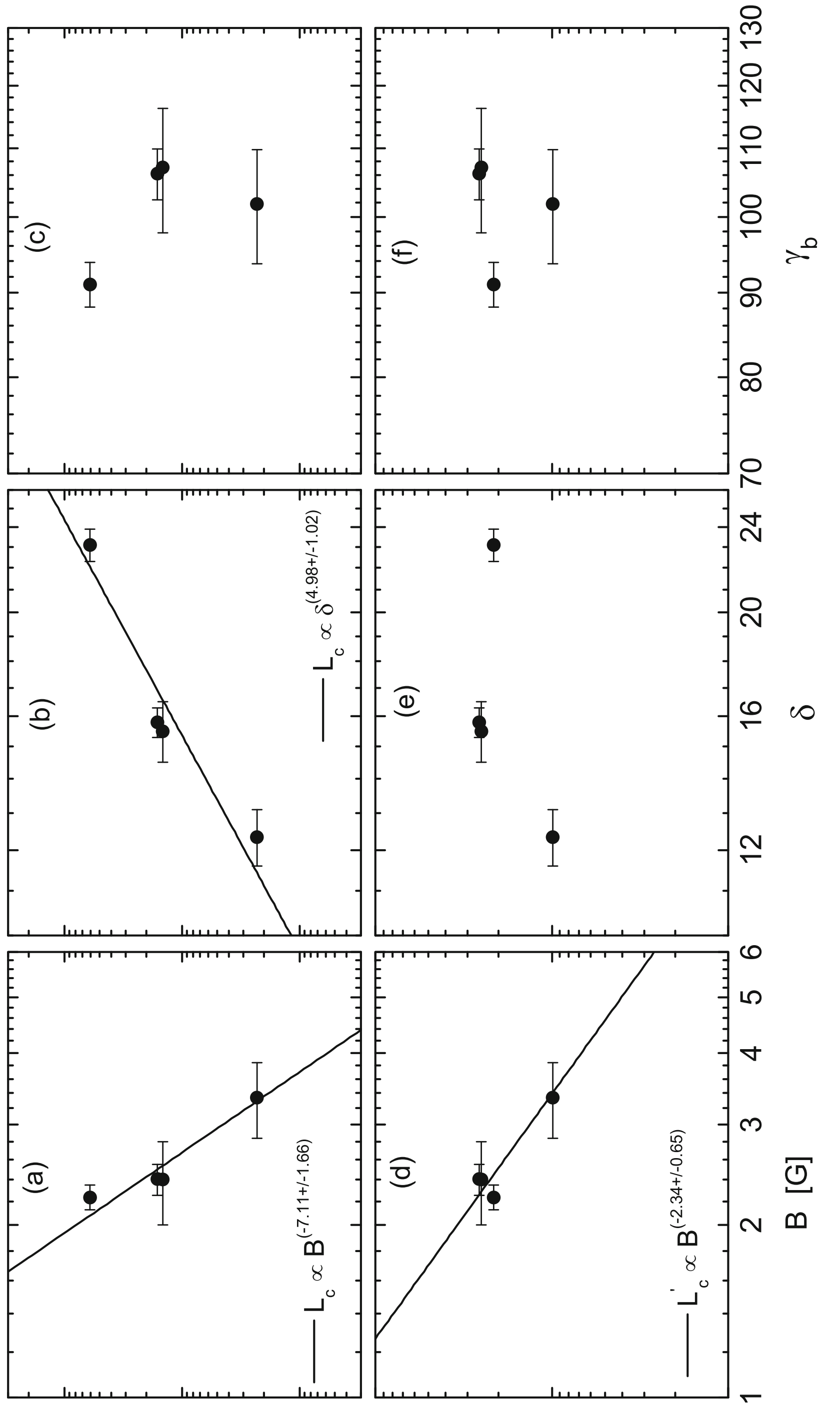

Figure 2. L_c as functions of B, δ and γ_b in both the observer (**a**, **b**, **c**) and co-moving (**d**, **e**, **f**) frames.

(Zhang *et al*. 2013). The instabilities of corona or disk accretion rate may result in the variations of the jet's physical condition and the variations of jet's emission.

4. Conclusion

SEDs observed at four epochs for PMN J0948 + 0022, which can be explained well with the syn + SSC + EC model, are compiled from literature to investigate its spectral variation. A tentative correlation between the peak luminosity and peak frequency of its IC bumps is found, indicating that a higher GeV luminosity corresponds to a harder spectrum for the emission in the GeV band, similar to the properties of some blazars. SEDs of PMN J0948 + 0022 are dominated by EC bumps and thus the magnification of the external photon field by the bulk motion of the radiation regions is an essential reason for the spectral variation. The variations of B and δ for PMN J0948 + 0022 between different states may be produced by the instabilities of the corona or the disk accretion rate.

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