To be or not to be a blazar. The case of the Narrow-Line Seyfert 1 SBS 0846+513

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Abstract. The presence of a relativistic jet in some radio-loud Narrow-Line Seyfert 1s (NLSy1) galaxies, first suggested by their variable radio emission and the flat radio spectra, is now confirmed by the Fermi-LAT detection of five NLSy1s in γ rays. In particular, a strong γ-ray flare from SBS 0846+513 was observed in 2011 June by Fermi-LAT reaching a γ-ray luminosity (0.1–300 GeV) of ∼10^{48} erg s^{-1}, comparable to that of bright flat spectrum radio quasars. Apparent superluminal velocity in the jet was inferred from 2011–2012 VLBA images, suggesting the presence of a highly relativistic jet. Both the power released by this object during the flaring activity and the apparent superluminal velocity are strong indicators of the presence of a relativistic jet as powerful as those in blazars. In addition, variability and spectral properties in radio and γ-ray bands indicate a blazar-like behaviour, suggesting that, except for some distinct optical characteristics, SBS 0846+513 could be considered as a young blazar at the low end of the blazar’s black hole mass distribution.

Keywords: Astronomical observations: γ-ray, Active galactic nuclei, Seyfert, γ-ray sources

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NARROW-LINE SEYFERT 1 GALAXIES AND FERMILAT

Relativistic jets are the most extreme expression of the power that can be generated by a super-massive black hole (SMBH) in the center of an AGN. These objects have a total bolometric luminosity of up to 10^{49–50} erg s^{-1} [e.g. 1, 2], with a large fraction of the power emitted at high energies. Before the launch of the Fermi satellite only two classes of AGN were known to generate relativistic jets and to emit in the γ-ray energy range: blazars and radio galaxies, both hosted in giant elliptical galaxies [3]. The first two years of observations by Fermi-LAT confirmed that these two populations represent the majority of the identified sources in the extragalactic γ-ray sky [4, 5]. However the discovery of variable γ-ray emission from four radio-loud NLSy1 galaxies revealed the presence of a possible third class of AGN with relativistic jets [6].

The NLSy1s are a class of AGN identified by [7] and characterized by the following optical properties: narrow permitted lines (FWHM (Hβ) < 2000 km s^{-1}), [OIII]/Hβ < 3, and a Fe II bump [for a review see 8]. They have smaller central black hole masses (i.e. 10^6–10^8 M_☉) than those in blazars and radio galaxies, and higher accretion rates close to or above the Eddington limit [9]. These sources are generally radio-quiet, with only a small fraction (<7%) classified as radio-loud [10], and objects with high values
of radio-loudness ($R > 100$) are even more sparse (~2.5%). The strong radio emission and the flat radio spectrum, together with variability studies, suggest the presence of a relativistic jet in some radio-loud NLSy1s. This has been confirmed by the Fermi-LAT detection of $\gamma$-ray emission from some of them. By considering that NLSy1s are usually hosted in spiral galaxies [e.g. 11] the presence of a relativistic jet is in contrast to the paradigm that the formation of relativistic jets could happen only in elliptical galaxies [see e.g. 12], giving an indication that relativistic jets can form and develop independently of their host galaxies.

**FERMI-LAT OBSERVATIONS**

SBS 0846+513 was not in the first and second Fermi-LAT (1FGL and 2FGL) catalogues, indicating that the source was not detected with Test Statistic (TS) > 25 in either one year or two years of Fermi observations [4, 5]. Integrating over the first two years of Fermi operation the likelihood fit yielded a $\text{TS} = 14$, with a 2-$\sigma$ upper limit of $8.5 \times 10^{-9}$ photons cm$^{-2}$ s$^{-1}$ in the 0.1–300 GeV energy range, assuming a photon index $\Gamma = 2.3$. On the contrary, the likelihood fit with a power-law model to the data integrated over the third year of Fermi operation (2010 August 4 – 2011 August 4; MJD 55412–55777) in the 0.1–300 GeV energy range results in a $\text{TS} = 653$, with an integrated average flux of $(6.7 \pm 0.5) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ and a photon index of $\Gamma = 2.23 \pm 0.05$.

Figure 1 (left panel) shows the $\gamma$-ray light curve of the third year of Fermi observations built using 1-month time bins. If $\text{TS} < 10$ the value of the flux was replaced by the 2-$\sigma$ upper limits. A clear increase of the flux was observed in the period 2011 June 4–July 4, for which 5-day time bins were used in Fig. 1. Considering the high activity of the source we extracted a spectrum over that period, obtaining a photon index of $\Gamma = 1.98 \pm 0.05$ and a flux of $(24.4 \pm 2.1) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$. The spectral evolution during the flaring activity in 2011 June observed in $\gamma$ rays from SBS 0846+513 is a common behaviour in bright FSRQs and low-synchrotron-peaked BL Lacs detected by Fermi [13], with a change in photon index $< 0.2–0.3$. The peak of the emission was observed on 2011 July 1, with a flux of $(98 \pm 19) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ in the 0.1–300 GeV energy range, corresponding to an isotropic $\gamma$-ray luminosity of $\sim 1.1 \times 10^{48}$ erg s$^{-1}$. Further details about the LAT data analysis and results are given in [14].

**THE RADIO MORPHOLOGY AND VARIABILITY**

When imaged with the high spatial resolution of the VLBA SBS 0846+513 is resolved in two components with a core-jet structure, as also pointed out in a previous work by [15]. At 15 GHz the jet structure (component E in Fig. 1, right panel) shows an extended low-surface brightness structure with a steep spectrum. On the other hand the core (component W) is resolved into two compact components (labelled W1 and W2 in Fig. 1, right panel). To investigate a possible proper motion of the jet, we compared the separation between W1, considered the core region, and W2, assumed to be a knot in the jet, at the four MOJAVE observing epochs available up to now. We model-fitted the visibility data using gaussian components of the four-epoch data by means of the
model-fitting option in DIFMAP. From this comparison we found that W1 and W2 are separating with an apparent velocity of (0.32 ± 0.04) mas/yr, which corresponds to (10.9 ± 1.4)c. This apparent superluminal velocity suggests the presence of boosting effect.

Before the γ-ray flaring episode, the simultaneous multifrequency observations performed by Effelsberg showed a flat radio spectrum up to 32 GHz. After the flare, the spectral shape observed changed, becoming convex. The spectral variability was also accompanied by variations in the radio flux density, as observed by OVRO and Medicina telescopes, indicating a blazar-like behaviour. Further details are given in [14].

**DISCUSSION**

After PMN J0948+0022 [16], SBS 0846+513 is the second NLSy1 observed to generate such a high power in γ rays. This could be an indication that all the radio-loud NLSy1s are able to host relativistic jets as powerful as those in blazars, despite the lower BH mass; alternatively some NLSy1s could have peculiar characteristics allowing the development of these relativistic jets. The mechanism at work for producing a relativistic jet is not clear, and the physical parameters that drive the jet formation is still under debate. One fundamental parameter could be the black hole mass, with only large masses allowing for the efficient formation of a relativistic jet. The large radio loudness of SBS 0846+513 could challenge this idea if the black hole mass (between $8.2 \times 10^6 M_\odot$ and $5.2 \times 10^7 M_\odot$) estimated by [17] is confirmed. According to the “modified spin paradigm” discussed in [18], another fundamental parameter for the efficiency of a relativistic jet production should be the BH spin, with SMBHs in elliptical galaxies.
having on average much larger spins than SMBHs in spiral galaxies.

In this context the discovery of relativistic jets in a class of AGN usually hosted by spiral galaxies, such as the NLSy1s, was a great surprise. We note that BH masses of radio-loud NLSy1s are generally larger with respect to the entire sample of NLSy1s [10, 9], even if still small when compared to radio-loud quasars. The larger BH masses of radio-loud NLSy1s with respect to radio-quiet NLSy1s could be related to prolonged accretion episodes that can spin-up the BHs. The small fraction of radio-loud NLSy1s with respect to radio-loud quasars could be an indication that in the former the high accretion usually does not last sufficiently long to significantly spin-up the BH [19]. To conclude, SBS 0846+513 shows all the characteristics of the blazar phenomenon and could be a low mass (and possible younger) version of blazar.

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