Flaring $\gamma$-ray emission from high redshift blazars

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High redshift blazars are among the most powerful objects in the Universe. Although they represent a significant fraction of the extragalactic hard X-ray sky, they are not commonly detected in $\gamma$-rays. High redshift ($z>2$) objects represent <10% of the AGN population observed by Fermi so far, and $\gamma$-ray flaring activity from these sources is even more uncommon. The characterization of the radio-to-$\gamma$-ray properties of high redshift blazars represent a powerful tool for the study of both the energetics of such extreme objects and the Extragalactic Background Light. We present results of a multi-band campaign on TXS 0536+145, which is the highest redshift flaring $\gamma$-ray blazar detected so far. At the peak of the flare the source reached an apparent isotropic $\gamma$-ray luminosity of $6.6\times10^{49}$ erg/s, which is comparable with the luminosity observed from the most powerful blazars. The physical properties derived from the multi-wavelength observations are then compared with those shown by the high redshift population. In addition preliminary results from the high redshift flaring blazar PKS 2149-306 will be discussed.

1. Introduction

The population of high redshift ($z>2$) blazars represents a small fraction (<10%) of the extragalactic $\gamma$-ray sky. They are mainly associated with flat spectrum radio quasars (FSRQ), although a few BL Lacs with $z>2$ are present in the third catalog of active galactic nuclei detected by the Large Area Telescope (LAT) on board the Fermi satellite after the first four years of scientific observations [6]. The number counts drop when higher energies are considered. In the first LAT catalog of $\gamma$-ray sources above 10 GeV (1FHL) only seven objects with $z>2$ are detected [5]. Although the detection of high redshift blazars during a $\gamma$-ray flare is even more uncommon, the characterization of the radio-to-$\gamma$-ray properties of high redshift blazars represent a powerful tool for the study of both the energetics of such extreme objects and the Extragalactic Background Light (EBL). During $\gamma$-ray flaring episodes the spectra of FSRQ sometimes show the intrinsic source spectrum.

So far, 10 blazars at $z>2$ have been detected during $\gamma$-ray flaring activity. Among these objects there are TXS 0536+145 at $z=2.69$, and PKS 2149-306 at $z=2.34$. TXS 0536+145 was not part of the Fermi-LAT first (1FGL) and second source (2FGL) catalogs [1, 14], indicating its low activity state during the first two years of Fermi-LAT observations. On 2012 March 22 it underwent a $\gamma$-ray flare, becoming the $\gamma$-ray flaring object at the highest redshift observed so far [16]. PKS 2149-306 was detected by Fermi-LAT in a flaring state on 2013 January 4 [9], with a daily $\gamma$-ray flux about 25 times higher than the average source flux reported in the 2FGL catalog [14].

The high activity states observed in both sources triggered multiwavelength monitoring observations aimed at characterizing the variability in the various bands of the electromagnetic spectrum and at determining the spectral energy distribution of these extreme objects.

2. TXS 0536+145

2.1. Fermi-LAT data

We analyzed Fermi-LAT data collected during the first five years of scientific observations, from 2008 August 4 (MJD 54682) to 2013 August 4 (MJD 56508). We considered an energy range between 0.1 and 100 GeV, and we followed the standard LAT analysis procedures (for more details see [16]).

TXS 0536+145 was not detected during the first two years of observations. The $2\sigma$ upper limit estimated over this period is $10^{-8}$ ph cm$^{-2}$ s$^{-1}$. During the third and fourth years of observations, the source was detected with a flux of $(4.2 \pm 0.6) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ and a photon index $\Gamma = 2.37 \pm 0.09$. On 2012 March 22 the source was observed during a $\gamma$-ray flare, when it reached a flux of $(1.0 \pm 0.3) \times 10^{-6}$ ph cm$^{-2}$ s$^{-1}$ and a photon index $\Gamma = 2.05 \pm 0.08$, indicating a hardening of the spectrum. This flux corresponds to an apparent isotropic luminosity of $6.6\times10^{49}$ erg/s. Before this flare, the source was first detected in $\gamma$-rays on 2012 January showing an enhancement of its high-energy activity, but without reaching a similar peak flux (Fig. 1).
2.2. Radio properties

Monitoring campaigns of TXS 0536+145 with the Very Long Baseline Array (VLBA) at 8.4, 15, and 24 GHz, and with the European VLBI Network (EVN) at 22 GHz were triggered by the $\gamma$-ray flare with the aim of studying changes in the parsec-scale structure and the flux density variability related to the central region of the source. The observations were performed between 2012 April and 2013 October. The source has a core-jet structure (Fig. 2). The radio emission is dominated by the compact bright core component, which accounts for about 90 per cent of the total flux density at 8.4 GHz, and about 95 per cent at 15 and 24 GHz. The jet emerges from the main component with a position angle of about 180°, then at $\sim$ 1.5 mas (i.e. $\sim$ 12 pc) it slightly changes orientation to about 160° and extends to $\sim$ 6 mas (i.e. $\sim$ 48 pc).

The flux density variability is ascribed to the core region, while the jet is not variable. The radio light curves show a flux density increase about 2-3 months after the $\gamma$-ray flare, with longer delay occurring at lower frequencies. The spectral index of the core computed between 8.4 and 15 GHz shows a softening of the spectrum from $\alpha \sim -1.0$ just after the flare, to $\alpha \sim 0.1^1$ a few months later (upper panel of Fig. 3). The light curve at 15 GHz shows a possible double hump similar to that observed in $\gamma$-ray light curve (bottom panel of Fig. 3).

No new superluminal component was observed after the flare. This may be related to the high redshift of the target. In fact, only superluminal components with a speed higher than $35c$ would have been picked up during the 16-month monitoring campaign.

2.3. Swift data and SED

Triggered by the flaring activity, Swift observed TXS 0536+145 a few days after the 2012 March $\gamma$-ray flare, and the source was found in a high state in X-rays. The X-ray flux decreases of a factor of two a couple of weeks after the peak. An additional observation was carried out a few months later, when the source was in a similar low activity state. In the past, the source was not detected by the ROSAT all-sky survey. Therefore, this is the first detection of TXS 0535+145 in X-rays.

Due to severe Galactic absorption and the short exposures, the source was not detected by UVOT in

\[ S_\nu \propto \nu^{-\alpha} \]

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\(^1\)The radio spectral index is defined as $S_\nu \propto \nu^{-\alpha}$
The hard X-ray flux of this source turned out to be below the sensitivity of the BAT instrument for such short exposures, and therefore the source was not detected. The source was not present in the Swift BAT 70-month hard X-ray catalogue [8].

The spectral energy distribution (SED) of TXS 0536+145 in flaring activity is well fitted by a synchrotron/external Compton model where the seed photons upscattered to high energies may be those from the dusty torus (see e.g., [16]). Due to the rather poor optical coverage, the model parameter are not well constrained.

4. Discussion and conclusions

High redshift flaring blazars are among the most luminous objects in the Universe. The high redshift FSRQ TXS 0536+145 and PKS 2149-306 underwent a huge γ-ray flare, reaching an apparent isotropic luminosity (0.1-100 GeV) of $6.6 \times 10^{49}$ erg/s and $1.5 \times 10^{50}$ erg/s, respectively. Such values are comparable to the luminosity observed in the high-redshift gravitationally lensed blazar PKS 1830-211 detected during a flare ($L_\gamma \sim 3 \times 10^{49}$ erg/s; [3]), as well as in the brightest flaring blazars, like 3C 454.3 ($L_\gamma \sim 2 \times 10^{50}$ erg/s; [2]), PKS 1510-089 ($L_\gamma \sim 4 \times 10^{48}$ erg/s; [15]), and PKS 1622-297 ($L_\gamma \sim 4 \times 10^{48}$ erg/s; [13]).

We compared the γ-ray properties of TXS 0536+145 and PKS 2149-306 with those shown by the population of high redshift ($z > 2$) γ-ray sources from the 2LAC [4]. The photon index and the luminosity in the low activity state of the targets are in agreement with those of the other high-z objects. During the flaring state both sources showed a hardening of the spectrum. A similar behaviour was observed in the high-z flaring blazar 4C+71.07 [7]. Despite the harder spectrum, no significant emission...
above 10 GeV is observed for TXS 0536+145. Although this value is consistent with current EBL models (e.g. [12]), the low statistics do not allow us to attribute the spectral curvature to this effect [16]. The improved sensitivity of the LAT at a few GeV with Pass 8 data will be important for characterizing in more detail the $\gamma$-ray spectrum of the high-redshift blazar population.

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