Not only once: the amazing $\gamma$-ray activity of the blazar PKS 1510–089

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Abstract. PKS 1510–089 is a powerful Flat Spectrum Radio Quasar at $z=0.361$ with radiative output dominated by the $\gamma$-ray emission. In the last two years PKS 1510–089 showed high variability over all the electromagnetic spectrum and in particular very high $\gamma$-ray activity was detected by the Gamma-Ray Imaging Detector on board the AGILE satellite with flaring episodes in August 2007 and March 2008. An extraordinary activity was detected in March 2009 with several flaring episodes and a flux that reached $500 \times 10^{-8}$ photons cm$^{-2}$ s$^{-1}$. Multiwavelength observations of PKS 1510–089 seem to indicate the presence of Seyfert-like features such as little blue bump and big blue bump. Moreover, X-ray observations suggested the presence of a soft X-ray excess that could be a feature of the bulk Comptonization mechanism. We present the results of the analysis of the multiwavelength data collected by GASP-WEBT, REM, Swift and AGILE during these $\gamma$-ray flares and the theoretical implications for the emission mechanisms.

1. Introduction

Blazars are the most extreme class of Active Galactic Nuclei (AGNs) characterized by the emission of strong non-thermal radiation across the entire electromagnetic spectrum, from radio to very high $\gamma$-ray energies. The typical observational properties of blazars include irregular, rapid and often very large variability, apparent super-luminal motion of the jet at VLBI scales, flat radio spectrum, high and variable polarization at radio and optical frequencies. These features are interpreted as the result of the emission of electromagnetic radiation from a relativistic jet that is viewed closely aligned to the line of sight, thus causing strong relativistic amplification (Blandford & Rees 1978; Urry & Padovani 1995).

The EGRET instrument onboard Compton Gamma-Ray Observatory detected for the first time strong and variable $\gamma$-ray emission from blazars in the MeV-GeV region. In conjunction with ground-based Cherenkov telescopes and
coordinated multiwavelength observations, this provided evidence that the Spectral Energy Distributions (SEDs) of blazars are typically double-humped with the first peak occurring in the IR/optical band for the so-called red blazars (including Flat Spectrum Radio Quasars, FSRQs, and Low-energy peaked BL Lacs, LBLs) and at UV/X-rays for the so-called blue blazars (including High-energy peaked BL Lacs, HBLs). The first peak is commonly interpreted as synchrotron radiation from high-energy electrons in a relativistic jet. The SED second component, peaking at MeV-GeV energies in red blazars and at TeV energies in blue blazars, is commonly interpreted as inverse Compton (IC) scattering of seed photons, internal or external to the jet, by relativistic electrons (Ulrich et al., 1997), although other models have been proposed (see e.g., Böttcher 2007 for a recent review). Blazars with greater bolometric luminosity have smaller peak frequencies and “redder” SEDs, while blazars of lower bolometric luminosity have higher peak frequencies and then are “bluer” (Fossati et al., 1998). This spectral sequence was interpreted by Ghisellini et al. (1998) as consequence of the different radiative cooling suffered by the emitting electrons of blazars of different power.

With the detection of several blazars in the γ-rays by EGRET (Hartman et al., 1999) the study of this class of objects has made significant progress. In fact, considering that the large fraction of the total power of blazars is emitted in the γ-rays, information in this band is crucial to study the different radiation models. The interest in blazars is now even more renewed thanks to the simultaneous presence of two γ-ray satellites, AGILE and Fermi, and the possibility to obtain γ-ray observations simultaneously with multiwavelength data collected from radio to TeV energies will allow us to reach a deeper insight on the jet structure and the emission mechanisms at work in blazars.

2. PKS 1510−089

PKS 1510−089 is a highly polarized radio-loud quasar at redshift z = 0.361 belonging to the class of the FSRQs with radiative output dominated by the γ-ray emission, while the synchrotron emission peaks around IR frequencies below a pronounced UV bump, likely due to the thermal emission from the accretion disc (Malkan & Moore 1986; Pian & Treves 1993). Its radio emission exhibited very rapid, large amplitude variations in both total and polarized flux (Aller, Aller, & Hughes 1996). The radio jet shows superluminal motion up to 20c, with the parsec and kiloparsec scale jets misaligned of 177 degrees (Wardle et al., 2005).

PKS 1510−089 has been extensively observed in X-rays in the last three decades from the first observation by Einstein (Canizares and White 1989) up to a long-term monitoring performed by Swift in July–August 2009 in the context of an extensive multifrequency campaign on this source, whose results will be presented in a forthcoming paper (D’Ammando et al., in preparation).

The X-ray spectrum of the source observed by ASCA in the 2–10 keV band (Singh, Shrader, & George 1997) was very flat (with photon index Γ ≃ 1.3), but steepened in the ROSAT bandpass below 2 keV (Γ ≃ 1.9), suggesting the possible presence of a spectral break around 1–2 keV, associated with the existence of a soft X-ray excess. Observations by BeppoSAX (Tavecchio et al.,
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(2000) and Chandra (Gambill et al., 2003) confirms the presence of a soft X-ray excess below 1 keV. A similar soft excess has been detected in other blazars such as 3C 273, 3C 279 and 3C 454.3, even if the origin of the soft X-ray excess is still an open issue, not only for blazars but for all AGNs (see e.g. D’Ammando et al., 2008a for a discussion on the soft X-ray excess problem in the radio-quiet AGNs).

A monitoring campaign on this source was organized during August 2006 by Suzaku and Swift. The Suzaku observations confirm the presence of a soft X-ray excess, suggesting that it could be a feature of the bulk Comptonization, whereas the Swift/XRT observations reveal significant spectral evolution of the X-ray emission on timescales of a week: the X-ray spectrum becomes harder as the source gets brighter (Kataoka et al., 2008).

Gamma-ray emission from PKS 1510−089 has been detected in the past by EGRET during low/intermediate states with an integrated flux above 100 MeV varying between $(13 \pm 5)$ and $(49 \pm 18) \times 10^{-8}$ photons cm$^{-2}$ s$^{-1}$. Instead in the last two years this source showed an intense γ-ray activity with several flaring episodes detected by AGILE and Fermi.

In this paper we present the results of the analysis of the AGILE, Swift, GASP-WEBT and REM data obtained during the multiwavelength observations of PKS 1510−089 performed in August 2007, March 2008, and March 2009. Throughout the paper the quoted uncertainties are given at 1-σ level, unless otherwise stated.

3. August 2007

PKS 1510−089 was detected for the first time by AGILE in high γ-ray activity during the period 23 August – 1 September 2007, as reported in Pucella et al. (2008). AGILE detected the source in a very bright state, with an average flux of $F_{100MeV} = (195 \pm 30) \times 10^{-8}$ photons cm$^{-2}$ s$^{-1}$ between 28 August and 1 September 2007.

The simultaneous optical monitoring of the GLAST AGILE Support Program (GASP) of the Whole Earth Blazar Telescope (WEBT) showed that PKS 1510−089 was in optical decrease during the period of the AGILE observation, following a bright state in mid August with the source at $R = 15.0$ mag. The SED is modelled with a synchrotron self Compton (SSC) + external Compton (EC) emissions. The IC scattering of external photons from the BLR seems to explain the observed hard γ-ray spectrum observed by AGILE.

After this flaring episode many more γ-ray flares of PKS 1510−089 were detected by the AGILE and Fermi satellites between March 2008 (D’Ammando et al., 2008b) and April 2009 (Cutini et al., 2009).

4. March 2008

During a pointing toward the Galactic Center region, between 1 and 30 March 2008, AGILE detected a rapid γ-ray flare from PKS 1510−089, as discussed in detail in D’Ammando et al. (2009a). After two episodes of medium intensity the
source was not detected for some days in the $\gamma$-ray band and suddenly a rapid flare was observed by AGILE on 18–19 March (see Fig. 1, left panel).

During the period 1–16 March 2008, AGILE detected an average flux from PKS 1510−089 of $(84 \pm 17) \times 10^{-8}$ photons cm$^{-2}$ s$^{-1}$ for $E > 100$ MeV. The flux measured between 17 and 21 March was a factor of 2 higher, with a peak level of $(281 \pm 68) \times 10^{-8}$ photons cm$^{-2}$ s$^{-1}$ on 19 March 2008.

Moreover, between January and April 2008 the source showed an intense and variable optical activity with several flaring episodes of fast variability. Peaks were detected by GASP-WEBT in the optical band on 15 February, 29 March and 11 April 2008 (see Fig. 1, right panel). A significant increase of the flux was observed also at millimetric frequencies in mid April, suggesting that the mechanisms producing the flaring events in the optical and $\gamma$-ray bands also interested the millimetric zone, with a delay.

The $\gamma$-ray flare triggered 3 ToO observations with Swift in three consecutive days between 20 and 22 March 2008. The first XRT observation showed a very hard X-ray photon index ($\Gamma = 1.16 \pm 0.16$) with a flux in the 0.3–10 keV band of $(1.22 \pm 0.17) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ and a decrease of the flux of about 30% between 20 and 21 March. Moreover, the Swift/XRT observations seem to show a harder-when-brighter behaviour of the spectrum in the X-ray band, confirming a behaviour already observed in this source by Kataoka et al. (2008). This is a trend usually observed in HBL such as Mrk 421 (see e.g. Tramacere et al., 2007) but quite rare in FSRQs such as PKS 1510−089. This harder-when-brighter behaviour is likely due to the different variability of the SSC and EC components, therefore to the change of the relative contribution of each component. Thus, the X-ray photon index observed on 20 March could be due to the combination of SSC and EC emission and therefore to the mismatch of the spectral slopes of these two components.

The SED for the AGILE observation of 17–21 March 2008 together with the simultaneous data collected in radio, mm, near-IR, and optical bands by GASP-WEBT and UV and X-ray bands by Swift is modelled with thermal emission of the disc, SSC model plus the contribution by the external Compton scattering of direct disc radiation and of photons reprocessed by the Broad Line
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Region (BLR; see Fig. 2, left panel). Some features in the optical-UV spectrum seem to indicate the presence of Seyfert-like components, such as the little and big blue bumps (see also Fig. 2, right panel).

![Figure 2](image1)

**Figure 2. Left panel:** Broad-band SED of PKS 1510–089 for the AGILE observation of 17–21 March 2008 including quasi-simultaneous radio-to-optical GASP data, UV and X-ray *Swift* data. The dotted, dashed, dot-dashed and double-dot-dashed lines represent accretion disc black body, the SSC, the EC of the disc and of the BLR, respectively. **Right panel:** SED of the low-energy part of the spectrum constructed with data collected by GASP-WEBT and *Swift*/UVOT during March 2008 and March 2009.

5. March 2009

PKS 1510–089 showed an extraordinary $\gamma$-ray activity during March 2009, with several flaring episodes that could be an overlapping of different events (see Fig. 3, left panel). After a low intensity period in February 2009, the optical activity of the source is also greatly increased in March 2009 with an intense flare on 25–26 March (see Fig. 3 right panel). A similar behaviour was observed by the REM Telescope, with an achromatic variation in the near-infrared and optical bands. Taking into account that the dip at the UVW1 frequency it is also found for other blazars with different redshift and could be systematic, the data collected from radio-to-UV on 25-26 March 2009 (Fig. 3, right panel) seem to show a flat spectrum in the optical/UV energy band, suggesting an important contribution of the synchrotron emission in this part of the spectrum during the huge flaring episode and therefore a possible shift of the synchrotron peak, usually observed in this source in the infrared band.

During the 14 ToO observations performed in March 2009, *Swift*/XRT observed the source in an intermediate state with a 0.3–10 keV flux in the range \((7.5 \pm 10.8) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}\). The X-ray flux seems not to be correlated with the high optical and $\gamma$-ray activity. A hard X-ray outburst of this source was detected by *Swift*/BAT on 9 March 2009, with a rise from 15 mCrab to 40 mCrab in 24 hours. On 10 March the source faded below the BAT sensitivity (Krimm et al., 2009). It is interesting to note that this outburst in the 15–50 keV energy band occurred just at the beginning of the $\gamma$-ray activity observed by AGILE. The results of the multiwavelength campaign of March 2009 will be presented in D’Ammando et al. (2009b).
Figure 3.  **Left panel:** AGILE γ-ray light curve between 1 and 30 March 2009 at 1-day resolution for $E > 100$ MeV. The downward arrows represent 2-σ upper limits. **Right panel:** R-band light curve obtained by GASP-WEBT during the period February-March 2009. Different symbols refer to different observatories.

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