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# The new gamma-ray and flaring blazar PKS 1502+106 discovered by Fermi LAT

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**Abstract.** The Large Area Telescope (LAT) on board the *Fermi* Gamma-ray Space Telescope discovered a high-energy gamma-ray outburst (characterized by a rapid rise and about five days duration) from a source identified with the blazar PKS 1502+106 (OR 103, S3 1502+10, z=1.839) starting on August 05, 2008 (MJD 54683.9). The outburst was followed by bright and variable gamma-ray flux over the next few months. A few selected highlights on the *Fermi* LAT multi-frequency campaign on PKS 1502+106 are introduced as an example of the optimal capabilities of *Fermi* LAT in monitoring cosmic high-energy flares, variability and being an essential companion of multi-waveband studies.

**Key words.** gamma-rays: observations – quasars: individual: PKS 1502+106 – quasars: general – galaxies: active – galaxies: jets – X-rays: galaxies

## 1. Introduction

The *Fermi* Gamma-Ray Space Telescope[1][2] (Ritz 2007) (successfully launched in June 11, 2008) is an international effort bringing together the astrophysics and high-energy particle physics communities. The Large Area Telescope instrument (LAT)[3][4] on board of *Fermi* is a pair tracker-converter telescope comprising a modular array of 16 towers, each with a tracker based on silicon micro-strip detector technology, and a calorimeter based on a hodoscopic array of 96 CsI(Tl) crystals, sur-

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[1] http://fermi.gsfc.nasa.gov
[2] http://www.nasa.gov/fermi
[3] http://www-fermi.stanford.edu
[4] http://fgst.slac.stanford.edu

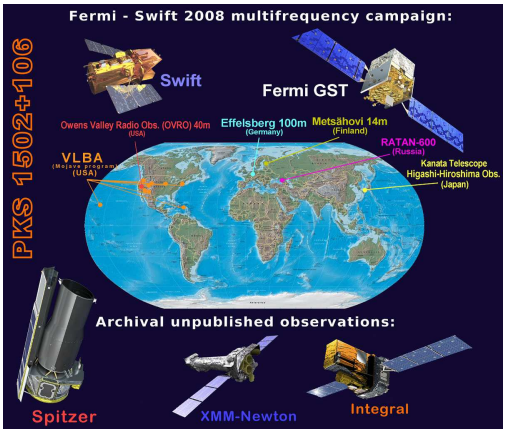


**Fig. 1.** A pictorial view of the participant facilities to the multi-frequency *Fermi-Swift* campaign on PKS 1502+106, involving the ground-based Owens Valley Radio Observatory, USA, the Effelsberg 100m dish radio telescope, Bonn, Germany, the ring radio telescope RATAN-600, Russia, the 13.7m Metsähovi radio telescope of the Helsinki University of Technology, the VLBA within the MOJAVE program, and the Kanata telescope of the Higashi-Hiroshima Observatory.

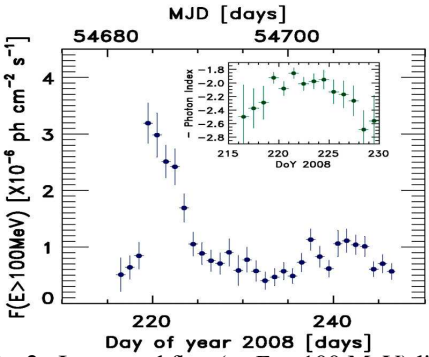


**Fig. 2.** Integrated flux (at $E > 100$ MeV) light curve obtained with a unbinned maximum-likelihood estimator of the spectral model parameters (`gtlike` tool) of PKS 1502+106 observed by *Fermi* LAT and calculated in daily time bins during August 2008. The outburst state and the subsequent post-flare activity is visible in this plot. In the inset panel the corresponding photon energy index light curve around the outburst period is reported.

rounded by an Anti-Coincidence Detector capable of measuring the directions and energies of cosmic $\gamma$-ray photons with energies between about 20 MeV and > 300 GeV (for details, see, e.g. Atwood et al. 2007, 2009).

As example of the optimal capabilities of *Fermi* LAT as an all-sky monitor for cosmic high-energy flares and variability, and essential companion of multi-waveband studies, here a few highlights from a multi-frequency campaign dedicated to PKS 1502+106 (also known as OR 103, S3 1502+10, z=1.839) are briefly introduced. PKS 1502+106 is a new and prominent gamma-ray blazar detected in the early phases of the *Fermi* mission and results are described in Abdo et al. (2009).

## 2. The gamma-ray outburst of PKS 1502+106

PKS 1502+106 is a luminous and distant, quasar-like (optically broad-line and flat radio spectrum) AGN, previously unknown at $\gamma$-ray energies. A cumulated $2\sigma$ upper limit by EGRET of $7 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ was reported (Phase/Cycle I, combined Viewing Periods: 24.0 to 25.0, i.e. April 02-23, 1992; Fichtel et al. 1994), and the source was likewise undetected in the following EGRET cycles. This is a well studied blazar at radio bands, but only one multi-frequency (radio to X-ray) work was dedicated to this object in the past (George et al. 1994).

At the beginning of August 2008, PKS 1502+106 was the second apparent brightest extragalactic source in the $\gamma$-ray sky, showing a fast, asymmetric, outburst, characterized by a rapid rise (started at the end of Aug. 05, 2008, MJD 54683.9) and a $\sim$ 5 days duration, and announced in ATel #1650. A renewed $\gamma$-ray activity observed by the LAT was announced again in Jan. 2009 through ATel #1905.

The outburst triggered the first Fermi multi-frequency campaign not planned in advance (Fig. 1). PKS 1502+106 displayed a bright gamma-ray flux and enduring activity after the outburst easily detected by the LAT on a daily basis, during the first months of mission. Over the five days of the outbursts (Fig. 2), the detected averaged flux above 100

MeV was (2.91 ± 1.4) × $10^{-6}$ ph $cm^{-2}$ $s^{-1}$, and the averaged spectrum was consistent with a single power law model with photon index 2.06 ± 0.02.

## 3. The multi-frequency campaign

The Fermi multi-frequency campaign on this blazar, started at the beginning of August 2008, soon after the first day of outburst. This observing campaign saw the participation of Swift (through a triggered target of opportunity, and with a 16-day follow up of this blazar) and, from the ground, VLBA (through the MOJAVE program), Owens Valley Radio Observatory 40m, Effelsberg-100m, Metshovi-14m, RATAN-600 and Kanata Higashi-Hiroshima observatories (Fig. 1).

*Swift* performed a Target of Opportunity (ToO) monitoring campaign of PKS 1502+106 from Aug. 07 to Aug. 22, 2008 (∼ 16 days of daily snapshots monitoring). The 0.3-10 keV *Swift*-XRT light curve showed an initial count rate of 0.05 counts/sec during the 5 days of the LAT outburst, and a gradual decay down to the level of about 0.02 counts/sec in the following decay phase. No significant spectral index variation was observed between the high and the low state, while the count rate and flux did vary (Fig. 3). The *Swift*-UVOT telescope observed a slight rise in flux during 3 days in the six UVOT bands (Fig. 4), followed by a fading similar to the flux decrease seen in $\gamma$-rays and X-ray bands. If the time of the observed UV and optical maximum is related to the flare activity at higher energies, this suggests a 4-day time lag.

Detailed sub-milliarcsecond scale radio images at 15 GHz of the superluminal jet in PKS 1502+106 have been obtained three times in 2008 when *Fermi* was already in orbit: on June 25, August 06 (during the maximum peak of the $\gamma$-ray outburst, Fig. 5), and November 19, pointing out a rotation of the electric vector position angle (EVPA) direction between 2007 and 2008, as possible precursor signature of an outburst that occurred in the VLBI core. More details on MOJAVE program and database are in Lister et al. (2009).

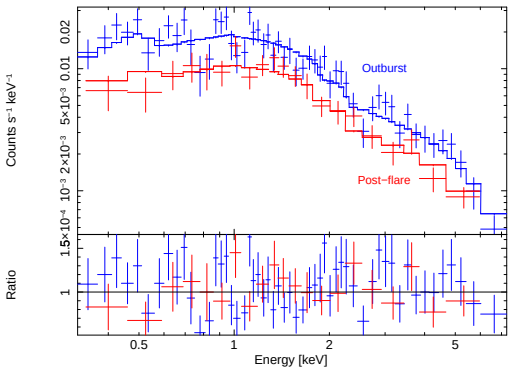


**Fig. 3.** Swift-XRT combined 0.3-10 KeV spectra of PKS 1502+106 extracted for the high state (MJD: 54685-54689) and the subsequent low state (MJD 54690-54701), mapping the X-ray behavior simultaneous to the LAT flare and to the days of the post-flare phase.

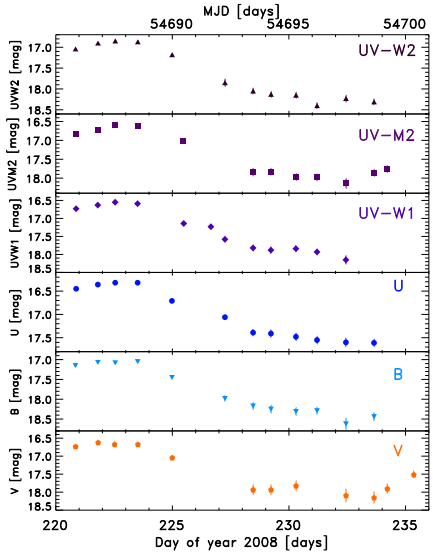


**Fig. 4.** Six bands UV-optical magnitude light curves of PKS 1502+106 obtained through the 16-days monitor of *Swift*-UVOT simultaneous to the *Fermi* LAT observations.

In addiction, archival unpublished observations of PKS 1502+106 by the XMM-*Newton* and *Spitzer* space telescopes were also analyzed for a a more complete multiwaveband picture. The unique (and unpublished) observation performed by *Spitzer* IRS (on August 13, 2005), showed a mid-infrared continuum rising to the near-IR band, and appeared fea-

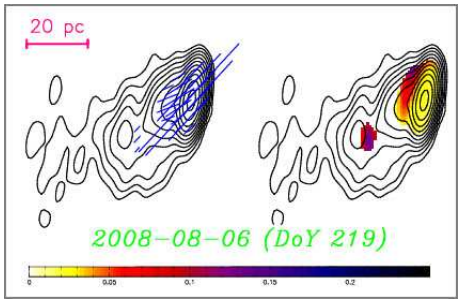


**Fig. 5.** Total intensity and linear polarization image obtained on Aug.06, 2008 (simultaneously to the day of the peak of the LAT outburst) by VLBA at 15 GHz as part of the large Fermi supporting MOJAVE program.

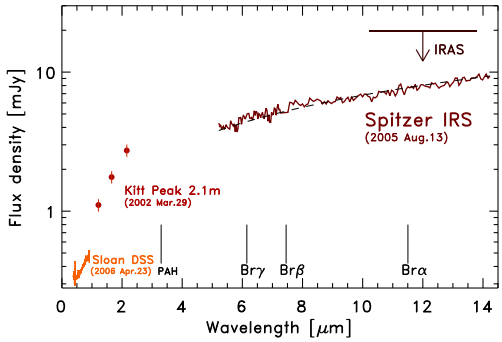


**Fig. 6.** The unique mid-IR spectrum of PKS 1502+106 in the range 5-14 $\mu$m obtained by the *Spitzer* Infrared Spectrograph (IRS) low resolution ($R = 60 - 130$) module, in August 13, 2005. In addition the optical spectrum by the SDSS on April 23, 2006, and JHK photometric flux measurements (Kitt Peak 2.1m telescope) of March 29, 2002 are also reported.

tureless, and consistent with pure synchrotron emission (power law form $F_\nu \propto \nu^{-0.9}$, Fig. 6).

## 4. Conclusions

*Fermi* LAT and multi-frequency observations of PKS 1502+106 allowed a firm source identification, a detailed analysis of the gamma-ray energy spectrum and temporal variability, a cross correlation investigation with respect to radio-optical-X-ray data, and the reconstruction of a simultaneous radio to gamma-ray spectral energy distribution. PKS 1502+106 was found to be a sub-GeV peaked, powerful flat spectrum radio quasar ($L_{E>100\mathrm{MeV}} \sim 1.1 \times 10^{49}$ erg s$^{-1}$, black hole mass likely close to $10^9$ M$_\odot$), and exhibiting marked gamma-ray bolometric dominance over the outburst. Basically this blazar can have a promising diagnostic and discovery potential in emission modeling, in spectral and temporal variability studies, and in understanding the radio-gamma-ray connection. More results are reported in Abdo et al. (2009).

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