Abstract

During the first 3 years of operation the Gamma-Ray Imaging Detector onboard the AGILE satellite detected several blazars in a high $\gamma$-ray activity: 3C 279, 3C 454.3, PKS 1510–089, S5 0716+714, 3C 273, W Comae, Mrk 421, PKS 0537−441 and 4C +21.35. Thanks to the rapid dissemination of our alerts, we were able to obtain multiwavelength data from other observatories such as Spitzer, Swift, RXTE, Suzaku, INTEGRAL, MAGIC, VERITAS, and ARGO as well as radio-to-optical coverage by means of the GASP Project of the WEBT and the REM Telescope. This large multifrequency coverage gave us the opportunity to study the variability correlations between the emission at different frequencies and to obtain simultaneous spectral energy distributions of these sources from radio to $\gamma$-ray energy bands, investigating the different mechanisms responsible for their emission and uncovering in some cases a more complex behaviour with respect to the standard models. We present a review of the most interesting AGILE results on these $\gamma$-ray blazars and their multifrequency data.

Key words: Gamma-ray sources, quasars:active galactic nuclei, BL Lac objects,
1 Introduction

Gamma-ray astrophysics is an exciting field of astronomical sciences that received a strong impulse in recent years. Detecting γ-ray emission in the energy range from a few tens of MeV to a few tens of GeV is possible only from space instrumentation, and in the past 20 years several space missions had to face with the challenge of exploring the γ-ray domain. After the first observations with the second NASA Small Astronomy Satellite (SAS-2; Fichtel et al. 1975) and the European Cosmic ray Satellite (COS-B; Bennett 1990), the Compton Gamma-Ray Observatory (CGRO) in the 1990s substantially increased our knowledge of the γ-ray Universe and provided a wealth of data on a large variety of sources as well as unsolved puzzles. In particular, the Energetic Gamma-Ray Experiment Telescope (EGRET) onboard CGRO operating in the energy range 30 MeV–30 GeV carried out a complete sky survey detecting hundreds of γ-ray sources (Fichtel et al. 1997; Hartman et al. 1999). This scientific inheritance is the starting point for any high-energy astrophysics mission.

In particular, the detection of γ-ray loud Active Galactic Nuclei (AGNs) dates back to the dawn of γ-ray astronomy, when COS-B detected photons in the 50–500 MeV range from 3C 273 (Swanenburg et al. 1978). However, 3C 273 remained the only AGN detected by COS-B. The discovery of emission in the γ-ray domain from many AGNs by EGRET and by on-ground Cherenkov Telescopes was one of the most relevant breakthroughs of high energy astrophysics in the last 20 years, leading to the identification of the first class of γ-ray AGNs: the blazars (Punch et al. 1992; Hartman et al. 1999).

Blazars constitute the most extreme subclass of AGNs, characterized by the emission of strong non-thermal radiation across the entire electromagnetic spectrum and in particular intense γ-ray emission above 100 MeV, dominating the extragalactic high-energy sky. The typical observational properties of blazars include irregular, rapid and often very large variability, apparent superluminal motion, flat radio spectrum, high and variable polarization at radio and optical frequencies. These features are interpreted as resulting from the emission of high-energy particles accelerated within a relativistic jet closely aligned with the line of sight and launched in the vicinity of the supermassive

* Corresponding author

Email address: dammando@ifc.inaf.it (F. D’Ammando).
black hole (SMBH) harbored by the active galaxy (Blandford & Rees 1978; Urry and Padovani 1995).

Blazars emit radiation across several decades of energy, from radio to TeV energy bands, and thus they are the perfect candidates for simultaneous observations at different wavelengths. EGRET observations together with ground-based Cherenkov Telescopes and coordinated multiwavelength observations provided the first evidence that the Spectral Energy Distributions (SEDs) of blazars are typically double humped (see e.g. Mrk 421, Macomb et al. 1995), with the first peak occurring in the IR/optical band in the so-called red blazars (including Flat Spectrum Radio Quasars, FSRQs, and Low-energy peaked BL Lacs, LBLs) and in UV/X-rays in the so-called blue blazars (including High-energy peaked BL Lacs, HBLs). The first peak is 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 highly relativistic electrons (Ulrich et al. 1997), although other models involving hadronic processes have been proposed (see e.g. Böttcher 2007 for a recent review).

Despite the large efforts devoted to the investigation of the radiation mechanisms responsible for the high energy $\gamma$-ray emission in blazars the definitive answer is still missing. The interest in blazars is now renewed thanks to the simultaneous presence of two $\gamma$-ray satellites, AGILE and Fermi, and the possibility to obtain $\gamma$-ray observations over long timescales simultaneously with data collected from radio to TeV energies, allowing us to reach a deeper insight on the jet structure and the emission mechanisms at work in blazars. In this paper we present a review of the AGILE results on the studies of $\gamma$-ray blazars.

2 Blazars and AGILE

The $\gamma$-ray observations of blazars are a key scientific project of the Astrorivelatore Gamma ad Immagini LEggero (AGILE) satellite (Tavani et al. 2009). Thanks to the wide field of view of its $\gamma$-ray imager ($\sim 2.5$ sr), AGILE monitored tens of potentially $\gamma$-ray emitting AGNs during each pointing. After November 2009 AGILE, due to a reaction wheel failure, changed its scientific operation mode into a “spinning mode”, with the instrument boresight axis sweeping the sky with the angular speed of 1$\deg$ s$^{-1}$. This allows the satellite to observe about 80% of the sky ever day, thus the number of $\gamma$-ray sources simultaneously monitored by the satellite is still increased. In the first 3 years of operation, AGILE detected several blazars during high $\gamma$-ray activity and extensive multiwavelength campaigns were organized for many of
them, providing the possibility to have long-term observations of the brightest objects. The $\gamma$-ray activity timescales of these blazars goes from a few days (e.g. W Comae and 3C 273) to several weeks (e.g. 3C 454.3 and PKS 1510–089) and the flux variability observed has been negligible (e.g. 3C 279 and Mrk 421), very rapid (e.g. PKS 1510–089 and 3C 454.3), or extremely high (e.g. 3C 454.3 and 4C +21.35). We note that at least one object for each blazar flavour (LBL, IBL, HBL and FSRQ) was detected by AGILE, but only a few objects were detected more than once in high activity and mainly already known strong $\gamma$-ray emitting sources. This evidence, together with the results obtained by Fermi-LAT during the first 11 months of operation (Abdo et al. 2010b), suggests possible constraints on the properties of the most intense $\gamma$-ray emitters. Recent studies in radio of a subsample of the blazars detected by Fermi-LAT in the first three months showed that the $\gamma$-ray emitters blazars have faster apparent jet speeds (Lister et al. 2009), wider apparent opening angles (Pushkarev et al. 2009), and higher VLBI brightness temperatures (Kovalev et al. 2009) with respect to the objects not detected in $\gamma$ rays. Future investigations of a larger sample detected in $\gamma$ rays by Fermi and AGILE could give firm conclusion on the peculiar characteristics of the $\gamma$-ray blazars.

In the following we will present the most interesting results from the studies of the individual $\gamma$-ray blazars detected by AGILE.

3 Individual Sources

3.1 3C 454.3

Among the FSRQ class of blazars, 3C 454.3 is one of the brightest objects and also the source that exhibited the most variable activity in the last years. In particular, during May 2005 the source was reported to undergo a very strong optical flare (Villata et al. 2006). This exceptionally high state triggered observations by high-energy satellites (RXTE: Remillard 2005; Chandra: Villata et al. 2006; INTEGRAL: Pian et al. 2006; Swift: Giommi et al. 2006), which confirmed an exceptionally high flux also in X-ray band. Unfortunately, no $\gamma$-ray satellite was operative at that time.

In mid-July 2007, 3C 454.3 underwent a new optical brightening that triggered observations at all frequencies, including a Target of Opportunity (ToO) by the AGILE $\gamma$-ray satellite (Vercellone et al. 2008). That was the beginning of an extraordinary long-term $\gamma$-ray activity of the source until the huge $\gamma$-ray flares observed in early December 2009 (Striani et al. 2010a) and April 2010 (Ackermann et al. 2010). In the period July 2007–January 2009 the
AGILE satellite monitored intensively 3C 454.3 together with the Spitzer, GASP-WEBT, REM, MITSuME, Swift, RXTE, Suzaku and INTEGRAL observatories, with two dedicated campaigns organized during November 2007 and December 2007, as reported in Vercellone et al. (2009) and Donnarumma et al. (2009b), respectively, and yielding the longest multiwavelength coverage of this $\gamma$-ray quasar so far (Vercellone et al. 2010).

From the beginning of the AGILE operation the source underwent an unprecedented long period of high $\gamma$-ray activity, playing the same role for AGILE as 3C 279 did for EGRET (Hartman et al. 2001). The source showed flux levels variable on short timescales of 24–48 hours, reaching a $\gamma$-ray flux higher than $500 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ on daily timescales (see Fig. 1 and Fig. 2 bottom panel). A diminishing trend of the $\gamma$-ray flux from July 2007 to January 2009 was observed with a hint of a “harder-when-brighter” behaviour (see Vercellone et al. 2010, in particular their Fig. 4), previously observed in $\gamma$ rays only for 3C 279 (Hartman et al. 2001) and marginally in PKS 0528+134 (Mukherjee et al. 1999) in the EGRET era. The optical flux also appears extremely variable with a brightening of several tenths of magnitude in a few hours (see Raiteri et al. 2008). Emission in the optical range seems to be correlated with that at $\gamma$ rays, with a lag of the $\gamma$-ray flux with respect to the optical one less than 1 day during bright states. The correlation between the $\gamma$-ray flux and the optical flux density during November–December 2007 was investigated (Vercellone et al. 2010) by means of the discrete correlation function (DCF; Edelson & Krolik 1988). The corresponding DCF show a maximum DCF $\sim 0.38$ for a null time lag. By calculating the centroid and estimating the uncertainty by means of the the “flux randomization/random subset selection” method (Peterson 2001) Vercellone et al. found that the time lag between $\gamma$-ray and optical emission is $-0.4^{+0.6}_{-0.8}$ days, i.e. about 10 hours. They obtained
Fig. 2. 3C 454.3 light curves between July 2007 and January 2009 at increasing energies from top to bottom. Data were collected by AGILE, Swift (BAT, XRT, and UVOT), GASP-WEBT, UMRAO, and VLBA [Adapted from Vercellone et al. 2010].

a similar time lag considering the period October 2008 – January 2009, in agreement also with that obtained by Bonning et al. (2009) by analyzing the public γ-ray data from Fermi-LAT and the optical SMARTS data. However, superimposed to the overall trend some sub-structures on shorter timescales with different variability could be present in the optical and γ-ray bands (see e.g. Tavecchio et al. 2010).

From the comparison of the light curves from radio to γ rays shown in Fig. 2 it is noticeable that, while at almost all the frequencies the flux shows a diminishing trend with time during the period July 2007–January 2009, the 15 GHz radio core flux increases, although no new jet component seems to be detected in the high resolution VLBA images. The different behaviour observed in radio, optical and γ rays from the end of 2007 could be interpreted in the framework of a helical jet model (see Villata et al. 2009) as the change in the jet geometry between 2007 and 2008. The change of orientation yields different alignment configurations within the curved jet, therefore a different
angle of view with respect to the observer and consequently a different Doppler boosting of the emission, as discussed in Vercellone et al. (2010).

Fig. 3. Spectral Energy Distribution of 3C 454.3 including AGILE/GRID, INTEGRAL/IBIS, Swift/XRT, Swift/UVOT, and GASP-WEBT data collected in the period 19–22 November 2007. The dotted, dashed, dot-dashed, and triple-dot-dashed lines represent the accretion disk black body, the external Compton on the disk, the external Compton on the BLR and the SSC radiation, respectively [Adapted from Vercellone et al. 2009].

Considering the wide coverage obtained over the entire electromagnetic spectrum, we had the opportunity to build time-resolved SED of 3C 454.3 at different epochs and study in detail the emission mechanisms at work in this source. As shown in Fig. 3 the dominant emission mechanism above 100 MeV in 3C 454.3 seems to be the IC scattering of relativistic electrons in the jet on the external photons from the Broad Line Region (BLR; see also Vercellone et al. 2009, 2010), even if in some cases the contribution of external Compton (EC) of seed photons from a hot corona (Donnarumma et al. 2009b) or an infrared dusty torus (Sikora et al. 2008) could also be important. Moreover, the long-term monitoring confirmed the presence of an important contribution of the accretion disk emission during the low activity states of 3C 454.3 (Vercellone et al. 2010), as already detected by Raiteri et al. (2007) with simultaneous GASP and XMM-Newton observations.

On 2–3 December 2009, 3C 454.3 became the brightest $\gamma$-ray source in the sky, reaching a peak flux of about $2000 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ (Fig. 4). Intensive multifrequency observations showed an overall correlation at all wavelengths for both long and short timescales. However, the unusual $\gamma$-ray super-flaring activity was not accompanied by strong emission of similar intensity in the optical or even in the soft X-ray bands (see Pacciani et al. 2010). The pre- and post-flare broad band spectrum can be adequately represented by a simple one-zone synchrotron self Compton (SSC) model plus EC emission in which the accretion disk and the BLR provide the necessary soft radiation field for
the IC components. Instead, the spectrum of the 2–3 December 2009 super-flare would require with respect to the pre-flare an increase of the electron energy and density, and a slight reduction of the comoving magnetic field for the whole electron population of the blob (see Bonnoli et al. 2011). Pacciani et al. (2010) use a different approach, assuming a long-term rise and fall of the accretion rate onto the central black hole that causes an overall increase of the synchrotron emission and of the seed photons scattered by the primary component of accelerated electrons. An additional population of electrons, due to a further particle acceleration and/or plasmoid ejection near the jet basis, could be present during the super-flare. It is worth mentioning that, although rare, flaring episodes with similar extreme energetics are not unique, neither in this object (see e.g. Striani et al. 2010c, Sanchez and Escande 2010) nor in other FSRQ (see the $\gamma$-ray flare of 4C +21.35 in June 2010; Striani et al. 2010b, Iafrate et al. 2010).

3.2 PKS 1510–089

PKS 1510–089 is another blazar that in the last three years showed high variability over the whole electromagnetic spectrum. In particular, high $\gamma$-ray activity was observed by AGILE and Fermi-LAT. AGILE detected intense flaring episodes in August 2007 (Pucella et al. 2008) and March 2008
(D’Ammando et al. 2009) and an extraordinary activity during March 2009 (D’Ammando et al. 2010).

During the period 1–16 March 2008, AGILE detected an average $\gamma$-ray flux from PKS 1510–089 of $(84 \pm 17) \times 10^{-8}$ ph 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 value of $(281 \pm 68) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ on 19 March 2008. Moreover, between January and April 2008 the source showed an intense optical activity, with several flaring episodes of fast variability. A significant increase of the flux was observed also at submillimetric frequencies in mid-April, suggesting that the mechanisms producing the flaring events in the optical and $\gamma$-ray bands could also be responsible for the high activity observed in the sub-mm band, with a delay likely due to an opacity effect.

The $\gamma$-ray flare triggered 3 Swift ToO observations 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. The Swift/XRT observations showed 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), a trend usually observed in HBLs but quite rare in FSRQs such as PKS 1510–089.

![Fig. 5. SED of PKS 1510–089 in mid-March 2008 with AGILE, Swift and GASP-WEBT data. The dotted, dashed, dot-dashed, and double dot-dashed lines represent the accretion disk emission, the SSC, the external Compton on the disk radiation (ECD) and on the BLR radiation (ECC), respectively [Adapted from D’Ammando et al. 2009].](image)

This harder-when-brighter behaviour could be due to the contamination at low energies of a second component with respect to the EC emission that usually dominates the X-ray spectrum of the FSRQs. In PKS 1510–089 the X-ray spectral shape of the EC component should remain almost constant. On
the contrary, the contribution of the second component should vary according to the change of the source activity level, being more important when the source is fainter and almost hidden by the EC emission when the source is brighter. Different origins were proposed for this second component: the soft X-ray excess (Arnaud et al. 1985, Gierlinski & Done 2004), an important contribution of the SSC component in any activity states or a feature of the bulk Comptonization (Celotti et al. 2007). No conclusive evidence about its nature has been obtained so far. The SED of the AGILE observation of 17–21 March 2008 and the simultaneous data collected from radio-to-X-rays by GASP-WEBT and Swift is modeled with thermal emission of the disk, SSC model plus the contribution by EC scattering of direct disk radiation and of photons reprocessed by the BLR (see Fig. 5). Some features in the optical/UV spectrum clearly indicate the presence of Seyfert-like components, such as the little and big blue bumps.

Moreover, PKS 1510−089 showed an extraordinary γ-ray activity during March 2009, with several flaring episodes and a flux that reached $700 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ (Fig. 6). During February–March 2009 the source also showed an increasing activity from near-IR to UV, as monitored by GASP-WEBT, REM and Swift/UVOT, with a flaring episode on 26–27 March 2009, suggesting that a single mechanism is responsible for the flux enhancement observed in the low-energy part of the spectrum at the end of March. On the contrary, the Swift/XRT observations show no clear correlation of the X-ray emission with the optical and γ-ray ones. These X-ray observations, as well as the March 2008 observations, show a hard photon index ($\Gamma_x = 1.3–1.6$) with respect to most FSRQs and a hint of harder-when-brighter behaviour due to the possible presence of a second emission component in the soft X-ray part of the spectrum. This second component could be associated to the soft X-ray excess rather than with a SSC contribution. During March 2009 two short flaring episodes were detected in the 15–50 keV energy band by Swift/BAT: the first covered approximately 2 days, beginning on 8 March with a flux of 28 mCrab and peaking on 9 March at 40 mCrab; the second on 29 March with a flux of 15 mCrab. It is noteworthy that the first hard X-ray outburst detected by

Fig. 6. AGILE γ-ray light curve of PKS 1510−089 between 1 and 30 March 2009 for $E > 100$ MeV. The downward arrows represent 2-σ upper limits [Adapted from D’Ammando et al. 2010].
BAT occurred just at the beginning of the $\gamma$-ray activity observed by AGILE.

In Fig. 7 we compare the SED from radio-to-UV for 25–26 March 2009 with those collected on 20–22 March 2008 and 18 March 2009. The SED collected on 18 March 2009 confirmed the evidence of thermal signatures in the optical/UV spectrum of PKS 1510–089 also during high $\gamma$-ray states. On the other hand, the broad band spectrum from radio-to-UV during 25–26 March 2009 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 brighter $\gamma$-ray flare and therefore a significant shift of the synchrotron peak, usually observed in this source in the infrared band. This is in agreement with the drastic change of polarization angle observed in VLBA data simultaneously with the optical flare (see Marscher et al. 2010). The increase of the synchrotron emission leads to the decrease of the evidence of the thermal features observed in the other SEDs. This indicates that the main contributor to the optical/UV emission in this object could be alternatively a thermal or non-thermal mechanism during the different activity periods (D’Ammando et al. 2010).

![Fig. 7. SED of the low-energy part of the spectrum of PKS 1510–089 constructed with data collected by GASP-WEBT, REM and Swift/UVOT during March 2008 and March 2009 [Adapted from D’Ammando et al. 2010].](image)

3.3 S5 0716+714

The intermediate BL Lac (IBL) object S5 0716+714 was observed by AGILE during two different periods: 4–23 September and 22 October–1 November 2007, as discussed in detail in Chen et al. (2008). In particular, between 7 and 12 September 2007 the source showed a high $\gamma$-ray activity with an average flux of $F_{E>100\text{MeV}} = (97 \pm 15) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ and a daily peak of $F_{E>100\text{MeV}} = (193 \pm 42) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$, with an increase of flux by a
factor of four in three days. The γ-ray flux detected by AGILE is the highest ever detected from this object and one of the highest fluxes observed from a BL Lac object. The intense γ-ray flare detected by AGILE in mid-September 2007 triggered optical observations by GASP-WEBT. S5 0716+714 brightened from $R = (12.92 \pm 0.01)$ mag on 8 September to $R = (12.58 \pm 0.04)$ mag on 12 September, and faded to $R \sim 13.01–13.03$ mag on 15 September (Carosati et al. 2007).

About one month later, the GASP-WEBT observed a new bright phase of the source, triggering AGILE and Swift ToO observations. In particular, after a rather variable phase, the optical flux in mid-October started to rise, reaching a peak of $R = (12.15 \pm 0.01)$ mag on 22 October. This is the highest optical brightness level ever observed from this source. Moreover, a rare roughly contemporaneous radio-optical outburst seems to be detected by GASP-WEBT. However, when seen in detail, the event in the two bands showed different behaviours: the optical flux presents stronger and faster variations, whereas the radio flux rises and falls in a much smoother way (Villata et al. 2008). Another very intense γ-ray flare, at a flux level of the order of $200 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$, was detected by AGILE on 22–23 October 2007, simultaneously to the optical flare.

The SED built with the simultaneous data collected by AGILE and GASP-WEBT in mid-September 2007 is consistent with a SSC model, but only when including two SSC components of different variability. Together with the first SSC component, that is slowly variable and reproduces the ground state, Chen et al. (2008) and Vittorini et al. (2009) add a faster second SSC component dominating in the optical and γ-ray bands (see Fig. 8).

Nilsson et al. (2008) estimated the redshift of the source ($z = 0.31 \pm 0.08$) from optical imaging of the underlying galaxy. This allowed us to calculate the total power transported in the jet, which is extremely high for the two flaring
episodes, approaching or slightly exceeding the maximum power generated by a spinning BH of $10^9 M_\odot$ through the pure Blandford-Znajek (BZ) mechanism with conservative values of the magnetic field $B$ (Vittorini et al. 2009). S5 0716+714 is the first BL Lac object that approached the limit of the BZ mechanism and eventually exceeded it. If confirmed, this violation could be explained in terms of the alternative Blandford-Payne mechanism (Blandford & Payne 1982) that, however, requires an ongoing accretion not supported by the observations of S5 0716+714. Alternatively, such a high power could be due to a less conservative value of the magnetic field, up to $B^2/4\pi \leq \rho c^2$, related to particle orbits plunging from the disk toward the BH horizon into a region influenced by strong gravity effects (Meier 2002).

After the $\gamma$-ray flaring episode of 22–23 October, AGILE observed the source with a dedicated re-pointing between October 24 and November 1. The source was detected at a $\gamma$-ray flux about a factor of 2 lower than the September one with no significant variability. Simultaneously, Swift observed strong variability (up to a factor of $\sim 4$) in soft X-rays, moderate variability at optical/UV (less than a factor of 2), and approximately constant hard X-ray flux. The different variability observed in optical/UV, soft and hard X-rays is indicative of the injection of a second component (Giommi et al. 2008), in agreement with the two SSC components used for modelling the SED of the two $\gamma$-ray flares in September and October 2007.

3.4 The Virgo Region: 3C 279 and 3C 273

The Virgo region is one of the best studied regions of the sky by the CGRO, especially with EGRET, but also with OSSE and Comptel. During the CGRO observations the presence of two bright and variable $\gamma$-ray blazars was revealed: 3C 279 and 3C 273. Thus, the AGILE satellite performed dedicated pointings of this region for investigating in detail the properties of these two blazars.

3C 279 is the first extragalactic source detected by AGILE in mid-July 2007, at the beginning of the Science Performance Verification Phase of the satellite, as reported in Giuliani et al. (2009). The average $\gamma$-ray flux between 9 and 13 July 2007 is $F_{E>100\text{MeV}} = (210 \pm 38) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$, a flux level similar to the highest one observed by EGRET and Fermi-LAT. The simultaneous Swift/XRT observations performed between 10 and 13 July 2007 detected the source with an unabsorbed 2–10 keV flux nearly constant at about $10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ and a photon index of 1.4–1.5. No significant daily variability was detected in the $\gamma$-ray flux of 3C 279 during the short AGILE observation. Instead, the spectrum observed during the flaring episode by AGILE is softer with respect to the previous EGRET observations.
This could be an indication of a low accretion state of the disk occurred some months before the γ-ray observations, suggesting a dominant contribution of the external Compton scattering of direct disk radiation (ECD) compared to the external Compton scattering of the BLR clouds (ECC). As a matter of fact, a strong minimum in the optical band was detected by the REM telescope two months before the AGILE observations. The reduction of the activity of the disk should cause the decrease of the photon seed population produced by the disk and subsequently a deficit of the ECC component with respect to the ECD, an effect delayed by the light travel time required to the photons to go from the inner disk to the BLR. EGRET observations of 3C 279 hinted at a gradual hardening of the spectrum during the flaring states that can be interpreted as the ECC component dominating during the flaring states (Hartman et al. 2001). Only one flare, during EGRET observation P9, showed a soft ECD dominated spectrum. The AGILE observation seems to be similar to the P9 flare, supporting the idea that a soft spectrum during flaring episodes is not a extremely rare event. Only the long-term monitoring of this source in γ rays with the AGILE and Fermi satellites, together with the radio to optical data, would clarify the exact nature of the seed photons for the IC scattering and more generally provide us a new level of insight on the jet structure and the emission mechanisms in this blazar. Recently, the coincidence of a γ-ray flare of 3C 279 observed by Fermi-LAT with the dramatic change of optical polarization angle measured by the KANATA telescope suggested co-spatiality of the optical and γ-ray emission and provided evidence for the presence of highly ordered magnetic fields and a non-axisymmetric structure of the emission zone. This could imply a curved structure of the jet and a dissipation region far from the central BH (Abdo et al. 2010c).

On the other hand, 3C 273 is a peculiar AGN that shows both properties characteristic of a blazar, such as strong radio emission, apparent superluminal jet motion, large flux variations and a two-humped SED (see Courvoisier et al. 1998 for a review), and other features typical of Seyfert galaxies, such as a broad Fe emission line, the soft X-ray excess and the big blue bump. Surprisingly, 3C 273 was discovered to emit in γ rays by COS-B in 1976 (Swannenburg et al. 1978). EGRET pointed this FSRQ several times, not always detecting it, with an average flux over all the EGRET observations of \((15.4 \pm 1.8) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1} \ (E > 100 \text{ MeV})\). Recently Fermi-LAT detected two exceptional γ-ray outbursts by 3C 273, with a peak flux of \(\sim 1000 \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}\) (Abdo et al. 2010a).

We organized a 3-week multifrequency campaign between mid-December 2007 and January 2008 on 3C 273 involving REM, RXTE, INTEGRAL, Swift, and AGILE, with the aim of studying the correlated variability in the different energy ranges and of building a time-resolved SED for each of the 3 weeks from near-IR to γ rays. During this campaign, whose results are reported in Pacciani et al. (2009), the source was detected in a high state in X-rays, with
a 5–100 keV flux a factor of $\sim 3$ higher than the typical value in historical observations (Courvoisier et al. 2003), whereas it was detected in $\gamma$ rays only in the second week, with an average flux of $F_{E>100\text{MeV}} = (33 \pm 11) \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$. The simultaneous light curves from near-IR to $\gamma$ rays do not show any strong correlation, except for an indication of anti-correlated variability between X-rays and $\gamma$ rays: all the soft and hard X-ray measurements show a decreasing trend at the time of the AGILE detection in $\gamma$ rays in the second week. The SED is well represented by a leptonic model where the soft X-ray emission is produced by the combination of SSC and EC models, while the hard X-ray and $\gamma$-ray emission is due to ECD (Fig. 9). The spectral variability between the first and the second week is consistent with the acceleration episode of the electron population responsible for the synchrotron emission, leading to a shift of the IC peak towards higher energies. A possible shift of the IC peak was proposed when comparing the June 1991 campaign with the OSSE observation in September 1994 (McNaron-Brown et al. 1997). Our multifrequency observation and modeling (see Pacciani et al. 2009) suggests that this behaviour could be a more general feature of this source, happening on shorter timescales. Finally, considering the weak X-ray flux in the second week of the campaign we investigated the presence of a Seyfert-like disk reflection hump at $\sim 20–60$ keV. The wide band spectral data from all the instruments onboard INTEGRAL shows that the jet emission alone does not describe perfectly the energy spectrum and a reflection hump improves slightly the X-ray spectral modeling.
3.5 TeV blazars: Mrk 421 and W Comae

With the advent of the latest generation of Imaging Atmospheric Cherenkov Telescopes (IACTs) the number of sources detected in the TeV energy regime has significantly increased. While the majority of TeV sources are Galactic, so far 31 AGNs have been detected; only 8 of them were detected by EGRET. Most of these sources were discovered at TeV energies only by the new generation of IACTs, therefore the number of TeV blazars detected contemporaneously at MeV–GeV and TeV energy bands is still very low. Thus, until now multiwavelength campaign have been largely unable to probe information on this part of the electromagnetic spectrum.

With the launch of two new \(\gamma\)-ray satellites, AGILE and Fermi, the gap in the MeV–GeV domain has been closed giving the possibility to remove the degeneracies in the modeling of the SEDs of these objects. In fact, simultaneous observations from MeV to TeV, where most of the energy of blazars is emitted, could provide important information on the physics underlying the emission from these objects. As first examples of the synergy between \(\gamma\)-ray satellites and IACTs, multiwavelength campaigns including simultaneous AGILE, MAGIC, and VERITAS observations of Mrk 421 and W Comae were performed in June 2008.

W Comae was the first IBL object to be detected at very high energy (VHE; Acciari et al. 2008). It was discovered at TeV energies by VERITAS during observations carried out over January–April 2008, with an integrated flux of 9% of the Crab flux during a 4 days flare in mid-March. On 8 June 2008, VERITAS announced the detection of a second TeV flare from W Comae (Swordy 2008), with a three times higher flux with respect to the previous one. About 24 hours later, AGILE re-pointed towards the source and detected it with a flux of \((90 \pm 32) \times 10^{-8}\) ph cm\(^{-2}\) s\(^{-1}\) for \(E > 100\) MeV, roughly a factor of 1.5 larger than the highest flux observed by EGRET (see Verrecchia et al. 2008). A multiwavelength campaign that included Swift, XMM-Newton, and GASP observations was triggered, covering the entire electromagnetic spectrum from radio to TeV. Acciari et al. (2009) modeled the resulting SED during the VHE \(\gamma\)-ray flare by means of a simple leptonic SSC model, but the wide separation of the two peaks in the SED requires a low ratio of the magnetic field to the electron energy density \((\epsilon_B = 2.3 \times 10^{-3})\), far from the equipartition. On the contrary, the SSC+EC model returns magnetic field parameters closer to equipartition, providing a satisfactory description of the broadband SED. The external radiation field could be produced by a torus, whose emission peaks at \(1.5 \times 10^{14}\) Hz, that also explains the slight near-IR bump observed in the SED of W Comae. This bump could also be due to the host galaxy and future observations of variability of the IR component or very high-resolution imaging are required to break this degeneracy.
Fig. 10. a) R-band optical light curve from GASP-WEBT (24 May–23 June 2008); b) ASM (2–12 keV) light curve and XRT (2–10 keV) flux (grey triangle); c) Super-AGILE (20–60 keV, grey triangles; 1 Crab = 0.20 ph cm$^{-2}$ s$^{-1}$) and BAT (15–50 keV, empty black squares; 1 Crab = 0.29 ph cm$^{-2}$ s$^{-1}$); d) MAGIC and VERITAS ($E > 400$ GeV, empty black squares and black circles, respectively), the Crab flux at $E > 400$ GeV (horizontal dashed line), AGILE ($E > 100$ MeV, grey triangle); e) the hardness ratio computed by using the SuperAGILE and ASM data for each day. The dashed vertical lines mark the period of the TeV flare and the GeV flare, respectively [Adapted from Donnarumma et al. 2009a]
During the ToO towards W Comae, AGILE also detected the HBL object Mrk 421, in both hard X-rays and γ rays. SuperAGILE detected a fast increase of flux from Mrk 421 up to 40 mCrab in the 15–50 energy band, about a factor of 10 higher than its typical flux in quiescence (Costa et al. 2008), reaching about 55 mCrab on 13 June 2008. This observation was followed by the detection in γ rays by GRID with a flux, $F_{\gamma > 100\text{MeV}} = (42 \pm 13) \times 10^{-8} \text{ph cm}^{-2} \text{s}^{-1}$, about a factor of 3 higher than the average EGRET value, and $\sim 1.5$ higher, but still consistent, with its maximum. Two strong flares at TeV energies were detected also by the ARGO-YBJ detector between June 3 and 15 (Aielli et al. 2010). An extensive multiwavelength campaign from optical to TeV energy bands was organized with the participation of WEBT, Swift, RXTE, AGILE, MAGIC, and VERITAS, as reported in detail in Donnarumma et al. (2009a). SuperAGILE, RXTE/ASM and Swift/BAT show a clear correlated flaring structure between soft and hard X-rays with a high flux/amplitude variability in hard X-rays (Fig. 10). Hints of the same flaring activity is also detected in optical band by GASP-WEBT, with an overall decreasing trend with superimposed spikes of emission that show variations of the order of 10%–20% on timescales of few days. Moreover, Swift/XRT observed the source at the highest 2–10 keV flux ever observed ($\sim 2.6 \times 10^{-9} \text{erg cm}^{-2} \text{s}^{-1}$), with the synchrotron peak at $\sim 3$ keV, showing a shift with respect to the typical values of 0.5–1.0 keV. VERITAS and MAGIC observed the source on 6–8 June 2008 in a bright state at TeV energies, well correlated with the simultaneous peak in X-rays. The SED of Mrk 421 can be interpreted within the framework of the SSC model in terms of a rapid acceleration of leptons in the jet, in accordance also with the X-ray and VHE correlation. However, the different behaviour at optical and X-rays could suggest an alternative more complex scenario, in which the optical and X-ray radiation could be produced in different regions of a helical jet, with the inner jet region that produces the X-rays and is partially transparent to the optical radiation, whereas the outer region produces only the lower-frequency emission. This behaviour could be explained by a geometrical model, in which the emitting plasma flows along a rotating helical path (see e.g. Villata & Raiteri 1999).

3.6 PKS 0537–441

PKS 0537–441 is a bright and variable emitter at all frequencies from radio to γ rays, showing a SED typical of the LBLs. While BL Lacs usually exhibit optical featureless spectra, in the optical/UV spectrum of this source strong broad emission lines of Mg II, Lyα and C IV were observed (Peterson et al. 1976, Pian et al. 2002). Its relatively high redshift ($z = 0.896$) and the presence of broad emission lines in its spectrum, similarly to FSRQs, make this source peculiar, and possibly bridging the gap between BL Lacs and FSRQs.
Between 15 September and 3 October 2008 Fermi-LAT detected an increase of the $\gamma$-ray activity from the source (Tosti 2008), and this alert triggered multiwavelength observations by REM, Swift, and AGILE. During the period 10–17 October 2008, PKS 0537–441 was detected by AGILE with an average $\gamma$-ray flux of $F_{E>100\text{MeV}} = (42 \pm 11) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$ and a significant rise of the activity of the source in the second half of the observing period, as reported in Pucella et al. (2010). REM and Swift/XRT detected the source in near-infrared/optical and X-rays during a relatively low and intermediate activity states, respectively, with no signs of evident variability in the different observations. Instead, Swift/UVOT detected an increase between the first and the second part of the observing period, smaller than in $\gamma$ rays. The SED of PKS 0537–441 in mid-October 2008 seems to require two SSC components to be modeled, to account for the near-infrared/optical bump, the X-ray data, and the $\gamma$-ray flux level observed by AGILE. An alternative model where the optical bump is produced mainly by the accretion disk emission with a relatively high luminosity is also proposed; in this case a subsequent significant contribution of the EC scattering of both direct disk radiation and photons reprocessed by the BLR dominates the $\gamma$-ray band. In fact, even if BL Lacs are usually associated with low photon density ambient and therefore the EC contribution is negligible for this objects, past observations of broad emission lines in the optical/UV spectrum of PKS 0537–441 (Pian et al. 2002) suggests that the contribution of the EC could be important for the high-energy emission of this object, at least during high activity states.

4 Concluding remarks

We presented a review of the results on multiwavelength studies of the brightest blazars detected in $\gamma$ rays by AGILE in the first three years of operation, together with the simultaneous observations collected from radio to TeV energy bands of these objects. Based on the modeling of the SED of BL Lacs and FSRQs and the study of correlated variability at different frequencies, we found that the SSC and EC models are good approximation for describing the high activity states of the two populations of blazars, respectively. By contrast, when detailed observations are available, the fit of SEDs and the correlation studies require more complex scenarios beyond the standard emission models. Some examples are: i) the presence of two SSC components or the additional contribution of EC emission in BL Lacs; ii) some evidence in favour of an helical structure of the jet in blazars; iii) in a few FSRQs a possible contribution in the $\gamma$-ray band from the inverse Compton scattering of seed photons from the accretion disk, the dusty torus or the hot corona. Moreover, in some cases, Seyfert-like features such as the little and big blue bumps, the soft X-ray excess, and the Compton reflection component are de-
ected in the broad band spectrum of FSRQs, not only during low activity states. Finally, the long-term monitoring of these blazars allowed us to observe complex correlations between the emission at different frequencies and flaring episodes with extreme energetics in both BL Lacs and FSRQs.

To conclude, blazars constitute a very intriguing class of objects that show a variety of peculiar behaviours that for over thirty years draw the attention of astrophysicists around the world. However, early on the investigation of blazars were made difficult by the impossibility to obtain detailed observation of these objects over the entire electromagnetic spectrum. In particular, the $\gamma$-ray domain remained inaccessible for over 10 years after the end of the EGRET experiment, depriving us of important information essential to understand the emission mechanisms at work. At last, with the two $\gamma$-ray satellites AGILE and Fermi in orbit, a new window is now opened, not only for the observations in $\gamma$ rays but also for further coordinated investigations over the whole electromagnetic spectrum. It will allow us to expand the number of sources studied and the amount of information on them, shedding light on most of the mysteries of this exciting class of objects.

acknowledgements

F. D’Ammando would like to thank the organizers of the E-11 Event, L. Foschini and G. Tosti, for having organized such an excellent and fruitful meeting. The AGILE Mission is funded by the ASI with scientific and programmatic participation by the Italian Institute of Astrophysics (INAF) and the Italian Institute of Nuclear Physics (INFN). We thank the GASP-WEBT Collaboration for providing the data presented here. This investigation was carried out with partial support under ASI Contract No. I/089/06/1.

References

[1] Abdo, A. A., Ackermann, M., Ajello, M., et al. Fermi-Large Area Telescope observations of the exceptional gamma-ray outburst of 3C 273 in 2009 September, ApJ 714, L73-L78, 2010a

[2] Abdo, A. A., Ackermann, M., Ajello, M., et al. The first catalog of Active Galactic Nuclei detected by the Fermi Large Area Telescope, ApJ 715, 429-457, 2010b

[3] Abdo, A. A., Ackermann, M., Ajello, M., et al. A change in the optical polarization associated with a $\gamma$-ray flare in the blazar 3C 379, Nature 7283, 919–923, 2010c
[4] Acciari, V. A., Aliu, E., Beilicke, M., et al. *VERITAS discovery of > 200 GeV gamma-ray emission from the intermediate-frequency-peaked BL Lacertae object W Comae*, ApJ 684, L73-L77, 2008

[5] Acciari, V. A., Aliu, E., Aune, T., et al. *Multiwavelength observations of a TeV-flare from W Comae*, ApJ 707, 612, 2009

[6] Ackermann, M., Ajello, M., Baldini, M., et al. *Fermi Gamma-ray Space Telescope Observations of Gamma-ray Outbursts from 3C 454.3 in 2009 December and 2010 April*, ApJ 721 (2), 1383-1396, 2010

[7] Aielli, G., Bacci, C., Bartoli, B., et al. *Gamma-ray Flares from Mrk421 in 2008 Observed with the ARGO-YBJ Detector*, ApJ, 714 (2), L208-L212, 2010

[8] Arnaud, K. A., Branduardi-Raymont, G., Culhane, J. L., et al. *EXOSAT observations of a strong soft X-ray excess in MKN 841*, MNRAS 217, 105-113, 1985

[9] Bennett, K. *COS-B: The highlights*, Nuclear Physics B (Proc. Suppl.) 14B, 23-34, 1990

[10] Blandford, R. D., & Rees, M. *Some comments on radiation mechanisms in Lacertide*, in Pittsburg Conference on BL Lac Objects, Proceedings ed. A. M. Wolfe, Pittsburgh Press, 328-347, 1978

[11] Blandford, R. D., & Payne, D. G. *Hydromagnetic flows from accretion discs and the production of radio jets*, MNRAS 199, 883-903, 1982

[12] Bonning, E. W., Bailyn, C., Urry, C. M., et al. *Correlated Variability in the Blazar 3C 454.3*, ApJ 697 (2), L81-L85, 2009

[13] Bonnoli, G., Ghisellini, G., Foschini, L., et al. *The gamma-ray brightest days of the blazar 3C 454.3*, MNRAS, 410 (1), 368, 2011

[14] Böttcher, M. *Modeling the emission processes in blazars*, Astrophysics and Space Science 309 (1-4), 95-104, 2007

[15] Carosati, D., Larionov, V. M., Larionova, L., et al. *GASP detection of an optical flare of the blazar S5 0716+71*, The Astronomer’s Telegram 1223, 2007

[16] Celotti, A., Ghisellini, G., Fabian, A. C. *Bulk Comptonization spectra in blazars*, MNRAS 375 (2), 417-424, 2007

[17] Chen, A. W., D’Ammando, F., Villata, M. *AGILE detection of variable $\gamma$-ray activity from the blazar S5 0716+714 in September-October 2007*, A&A 489, L37-L40, 2008

[18] Costa, E., Del Monte, E., Donnarumma, I., et al. *SuperAGILE detects enhanced hard X-ray emission from Mrk 421*, The Astronomer’s Telegram 1574, 2008

[19] Courvoisier, T. J. L. *The bright quasar 3C 273*, A&AR 9 (1-2), 1-32, 1998

[20] Courvoisier, T. J. L., Beckmann, V., Bourban, G., et al. *Simultaneous observations of the quasar 3C 273 with INTEGRAL and RXTE*, A&A 411, L343-L348, 2003
[21] D’Ammando, F., Pucella, G., Raiteri, C. M., et al. AGILE detection of a rapid γ-ray flare from the blazar PKS 1510-089 during the GASP-WEBT monitoring, A&A 508, 181-189, 2009

[22] D’Ammando, F., Raiteri, C. M., Villata, M., et al. AGILE detection of amazing γ-ray activity from the blazar PKS 1510-089 during March 2009. Multifrequency Analysis, submitted to A&A, 2010

[23] Donnarumma, I., Vittorini, V., Vercellone, S., et al. The June 2008 Flare of Markarian 421 from Optical to TeV Energies, ApJ 691 (1), L13-L16, 2009a

[24] Donnarumma, I., Pucella, G., Vittorini, V., et al. Multiwavelength Observations of 3C 454.3 II. The AGILE 2007 December Campaign, ApJ 707 (2), 1115-1123, 2009b

[25] Edelson, R. A., & Krolik, J. H. The discrete correlation function - A new method for analyzing unevenly sampled variability data, ApJ, 333, 646-659, 1988

[26] Fichtel, C. E., Hartman, R. C., Kniffen, D. A., et al. High-energy gamma-ray results from the second small astronomy satellite, ApJ 198, 163-182, 1975

[27] Fichtel, C. E., Trombka, J. L. Gamma-Ray Astrophysics: New Insight Into the Universe, NASA Reference Publication 1386, 1997

[28] Gierlinski, M., & Done, C. Is the soft excess in active galactic nuclei real?, MNRAS 349, L7-L11, 2004

[29] Giommi, P., Blustin, A. J., Capalbi, M., et al. Swift and infra-red observations of the blazar 3C 454.3 during the giant X-ray flare of May 2005, A&A 456 (3), 911-916, 2006

[30] Giommi, P., Colafrancesco, S., Cutini, S., et al. AGILE and Swift simultaneous observations of the blazar S50716+714 during the bright flare of October 2007, A&A 487 (3), L49-L52, 2008

[31] Giuliani, A., D’Ammando, F., Vercellone, S., et al. AGILE observation of a gamma-ray flare from the blazar 3C 279, A&A 494 (2), 509-513, 2009

[32] Hartman, R. C., Bertsch, D. L., Bloom, S. D., et al. The Third EGRET Catalog of High-Energy Gamma-Ray Sources, ApJS 123 (1), 79-202, 1999

[33] Hartman, R. C., Böttcher, M., Aldering, G., et al. Multiepoch Multiwavelength Spectra and Models for Blazar 3C 279, ApJ 553 (2), 683-694, 2001

[34] Kataoka, J., Madejski, G. Sikora, M., et al. Multiwavelength Observations of the Powerful Gamma-Ray Quasar PKS 1510-089: Clues on the Jet Composition, ApJ 672 (2), 787-799, 2008

[35] Kovalev, Y. Y., Aller, M., Aller, H., et al. The Relation between AGN Gamma-Ray Emission and Parsec-Scale Radio Jets, ApJ 696 (1), L17-L21, 2009

[36] Iafrate, G., Longo, F., D’Ammando, F. Fermi LAT detection of a very intense GeV flare from 4C +21.35 (PKS 1222+21), The Astronomer’s Telegram 2687, 2010
[37] Lister, M. L., Homan, D. C., Kadler, M., et al. A Connection Between Apparent VLBA Jet Speeds and Initial Active Galactic Nucleus Detections Made by the Fermi Gamma-Ray Observatory, ApJ 696 (1), L22-L25, 2009

[38] Macomb, D. J., Akerlof, C. W., Aller, H. D., et al Multiwavelength Observations of Markarian 421 during a TeV/X-ray Flare, ApJ 449, L99-L103, 1995

[39] Marscher, A. P., Jorstad, S. G., Larionov, V. M., et al. Probing the Inner Jet of the Quasar PKS 1510−089 with Multi-Waveband Monitoring During Strong Gamma-Ray Activity, ApJ 710 (2), L126-131, 2010

[40] McNaron-Brown, K., Johnson, W. N., Dermer, C. D., et al. Time Variability Detected in the Gamma-Ray Emission of 3C 273 by OSSE, ApJ 474, L85-L89, 1997

[41] Meier, D. L. Grand unification of AGN and the accretion and spin paradigms, New Astron. Rev. 46 (2-7), 247-255, 2002

[42] Mukherjee, R., Böttcher, M., Hartman, R. C., et al. Broadband Spectral Analysis of PKS 0528+134: a report on six years of EGRET observations, ApJ 527, 132-142, 1999

[43] Nilsson, K., Pursimo, T., Sillanpää, A., et al. Detection of the host galaxy of S5 0716+714, A&A 487 (2), L29-L32, 2008

[44] Pacciani, L., Donnarumma, I., Vittorini, V., et al. High energy variability of 3C 273 during the AGILE multiwavelength campaign of December 2007-January 2008, A&A 494 (1), 49-61, 2009

[45] Pacciani, L., Vittorini, V., Tavani, M., et al. The 2009 December Gamma-ray Flare of 3C 454.3: The Multifrequency Campaign, ApJ 716 (2), L170-L175, 2010

[46] Peterson, B. A., Jauncey, D. L., Wright, A. E., et al. Redshift of southern radio sources, ApJ 207 (2), L5-L8, 1976

[47] Peterson, B. A. Variability in Active Galactic Nuclei, Advanced Lectures on the Starburst-AGN Connection, ed. I. Aretxaga, D. Kunth, & R. Mujica (Singapore: Word Scientific), 3, 2001

[48] Pian, E., Falomo, R., Hartman, R. C., et al. Broad-band continuum and line emission of the gamma-ray blazar PKS 0537-441, A&A 392, 407-415, 2002

[49] Pian, E., Foschini, L., Beckmann, V., et al. INTEGRAL observations of the blazar 3C 454.3 in outburst, A&A 449 (2), L21-L25, 2006

[50] Pucella, G., Vittorini, V., D’Ammando, F., et al. AGILE detection of intense gamma-ray emission from the blazar PKS 1510-089, A&A 491 (2), L21-L24, 2008

[51] Pucella, G., D’Ammando, F., Romano, P., et al. AGILE detection of intense γ-ray activity from the blazar PKS 0537-441 in October 2008, A&A 522, 109, 2010
Punch, M., Akerlof, C. W., Cawley, M. F., et al. Detection of TeV photons from the active galaxy Markarian 421, Nature 358, 477-478, 1992

Pushkarev, A. B., Kovalev, Y. Y., Lister, M. L., Savolainen, T. Jet opening angles and gamma-ray brightness of AGN, A&A 507 (2), L33-L36, 2009

Raiteri, C. M., Villata, M., Larionov, V. M., et al. WEBT and XMM-Newton observations of 3C 454.3 during the post-outburst phase. Detection of the little and big blue bumps, A&A 473 (3), 819-827, 2007

Raiteri, C. M., Villata, M., Chen, W. P., et al. The high activity of 3C 454.3 in autumn 2007. Monitoring by the WEBT during the AGILE detection., A&A 485 (2), L17-L20, 2008

Remillard, R. X-ray Outburst of the blazar 3C454.3, The Astronomer’s Telegram 484, 2005

Sanchez, D., Escande, L. Fermi LAT detection of a rapid and extraordinary GeV outburst from 3C 454.3, The Astronomer’s Telegram 3041, 2010

Sikora, M., Moderski, R., Madejski, G. 3C 454.3 Reveals the structure and Physics of its “Blazar Zone”, ApJ 675 (1), 71-78, 2008

Striani, E., Vercellone, S., Tavani, M., et al. The Extraordinary Gamma-ray Flare of the Blazar 3C 454.3, ApJ 718 (1), 455-459, 2010a

Striani, E., Verrecchia, F., Donnarumma, I., et al. AGILE detection of a gamma-ray flare from the blazar 4C +21.35 (PKS 1222+21), The Astronomer’s Telegram 2686, 2010b

Striani, E., Vercellone, S., Lucarelli, F., et al. AGILE detection of the extraordinary and prolonged gamma-ray activity from 3C 454.3, The Astronomer’s Telegram 3043, 2010c

Swanenburg, B. N., Hermsen, W., Bennett, K., et al. COS B observation of high-energy gamma radiation from 3C273, Nature 275, L298-L301, 1978

Swordy, S. TeV Outburst from W Comae, The Astronomer’s Telegram 1565, 2008

Tavani, M., Barbiellini, G., Argan, A., et al. The AGILE Mission, A&A 502 (3), 995-1013, 2009

Tavecchio, F., Ghisellini, G., Bonnoli, G., Ghirlanda, G. Constraining the location of the emitting region in Fermi blazars through rapid γ-ray variability, MNRAS 405, L94-L98, 2010

Tosti, G. Fermi LAT detections of gamma ray activity in three blazars: 3C 66A, PKS 0208-512, PKS 0537-441, The Astronomer’s Telegram 1759, 2008

Ulrich, M., Maraschi, L., Urry, C. M. Variability of Active Galactic Nuclei, ARA&A 35, 445-502, 1997
[68] Urry, C. M., & Padovani, P. Unified Schemes for Radio-Loud Active Galactic Nuclei, PASP 107, 803-845, 1995

[69] Vercellone, S., Chen, A. W., Giuliani, A., et al. AGILE Detection of a Strong Gamma-Ray Flare from the Blazar 3C 454.3, ApJ 676 (1), L13-L16, 2008

[70] Vercellone, S., Chen, A. W., Vittorini, V., et al. Multiwavelength Observations of 3C 454.3. I. The AGILE 2007 November campaign on the "Crazy Diamond", ApJ 690 (1), 1018-1030, 2009

[71] Vercellone, S., D’Ammando, F., Vittorini, V., et al. Multiwavelength Observations of 3C 454.3. III. Eighteen Months of Agile Monitoring of the "Crazy Diamond", ApJ 712 (1), 405-420, 2010

[72] Verrecchia, F., Gasparrini, D., Cutini, S., et al. AGILE detection of the blazar W Comae in the gamma-ray energy band, The Astronomer’s Telegram 1582, 2008

[73] Villata, M., & Raiteri, C. M. Helical jets in blazars. I. The case of MKN 501, A&A 347, 30-36, 1999

[74] Villata, M., Raiteri, C. M., Balonek, T. J., et al. The unprecedented optical outburst of the quasar 3C 454.3. The WEBT campaign of 2004-2005, A&A 453 (3), 817-822, 2006

[75] Villata, M., Raiteri, C. M., Larionov, V. M., et al Multifrequency monitoring of the blazar 0716+714 during the GASP-WEBT-AGILE campaign of 2007, A&A 481 (2), L79-L82, 2008

[76] Villata, M., Raiteri, C. M., Gurwell, A. M., et al The GASP-WEBT monitoring of 3C 454.3 during the 2008 optical-to-radio and γ-ray outburst, A&A 504 (3), L9-L12, 2009

[77] Vittorini, V., Tavani, M., Paggi, A., et al. Powerful High-energy Emission of the Remarkable BL Lac Object S5 0716+714, ApJ 706 (2), L1433-L1437, 2009