

## Multiwavelength Observations of the Gamma-ray Blazars Detected by AGILE

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Since its launch in April 2007, the AGILE satellite detected with the Gamma-Ray Imaging Detector several blazars in high  $\gamma$ -ray activity: 3C 279, 3C 454.3, PKS 1510–089, S5 0716+714, 3C 273, W Comae and Mrk 421. Thanks to the rapid dissemination of our alerts, we were able to obtain multiwavelength ToO data from other observatories such as *Spitzer*, *Swift*, RXTE, *Suzaku*, INTEGRAL, MAGIC, VERITAS, 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 truly simultaneous spectral energy distributions of these sources from radio to  $\gamma$ -ray energy bands and to investigate the different mechanisms responsible for their emission. We present an overview of the AGILE results on these  $\gamma$ -ray blazars and the relative multifrequency data.

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### I. INTRODUCTION

Among Active Galactic Nuclei (AGNs), blazars are a subclass characterized by the emission of strong non-thermal radiation across the entire electromagnetic spectrum and in particular intense and variable  $\gamma$ -ray emission above 100 MeV [1]. The typical observational properties of blazars include irregular, rapid and often very large variability, apparent super-luminal motion, 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 [2], [3].

Blazars emit across several decades of energy, from radio to TeV energy bands, and thus they are the perfect candidates for simultaneous observations at different wavelengths. Mul-

tiwavelength studies of variable  $\gamma$ -ray blazars have been carried out since the beginning of the 1990s, thanks to the EGRET instrument onboard *Compton Gamma-Ray Observatory (CGRO)*, providing the first evidence that the Spectral Energy Distributions (SEDs) of the blazars are typically double humped 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 at 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 scattering of seed photons by highly relativistic electrons [4], al-

though other models involving hadronic processes have been proposed (see e.g. [5] for a recent review).

3C 279 is the best example of multi-epoch studies at different frequencies performed by EGRET during the period 1991–2000 [6]. Nevertheless, only a few objects were detected on a time scale of two weeks or more in the  $\gamma$ -ray band and simultaneously monitored at different energies in order to obtain a wide multifrequency coverage.

With the advent of the AGILE and *Fermi*  $\gamma$ -ray satellites, together with the ground based Imaging Atmospheric Cherenkov Telescopes H.E.S.S., MAGIC and VERITAS, a new exciting era for the  $\gamma$ -ray extragalactic astronomy and in particular for the study of blazars is now open. Observations in the high-energy part of the electromagnetic spectrum in conjunction with a complete multiwavelength coverage will allow us to shed light on the structure of the inner jet and the emission mechanisms working in this class of objects.

## II. BLAZARS AND AGILE

AGILE (*Astrorivelatore Gamma ad Immagini LEggero*) is an Italian Space Agency (ASI) mission launched on April 2007 and devoted to high energy astrophysics [7]. The AGILE satellite is capable of observing cosmic sources simultaneously in X-ray (18–60 keV) and  $\gamma$ -ray (30 MeV–30 GeV) energy bands with the coded-mask hard X-ray imager (SuperAGILE) and the Gamma-Ray Imaging Detector (GRID), respectively. The GRID consists of a Silicon Tracker, a non-imaging CsI Mini-Calorimeter and a segmented anticoincidence system.

Gamma-ray observations of blazars are a key scientific project of the AGILE satellite. In the last two years, AGILE detected several blazars during high  $\gamma$ -ray activity and extensive multiwavelength campaigns were organized for many of them. Table 1 shows the list of AGILE flaring blazars observed up to April 2009. The  $\gamma$ -ray activity time scale goes from a few days (e.g. S5 0716+714 and 3C 273) to several weeks (e.g. 3C 454.3 and PKS 1510–089) and the flux  $\gamma$ -ray variability observed has been negligible (e.g. 3C 279), very rapid (e.g. PKS 1510–089) or extremely high (e.g. 3C 454.3 and PKS 1510–089). Even if at least one object for each blazar category (LBL, IBL, HBL and FSRQ) was detected, we note that only a few objects

were detected more than once in flaring state by AGILE and only already known  $\gamma$ -ray emitting source showed flaring activity. This evidence together with the early results from the first three months of *Fermi*-LAT  $\gamma$ -ray all-sky survey ([8]) suggests possible constraints on the properties of the most intense  $\gamma$ -ray emitters. In the following section we will present the most interesting results on multiwavelength observations of the individual sources detected by AGILE.

## III. INDIVIDUAL SOURCES

### A. 3C 454.3

3C 454.3 is the blazar which exhibited the most variable activity in the  $\gamma$ -ray sky during the last two years. In the period July 2007–January 2009 the AGILE satellite monitored intensively 3C 454.3 together with *Spitzer*, WEBT, REM, MITSuME, *Swift*, RXTE, *Suzaku* and INTEGRAL observatories, yielding the longest multiwavelength coverage of this  $\gamma$ -ray quasar so far (see [9]).

AGILE detected 3C 454.3 for the first time during a dedicated Target of Opportunity (ToO) activated immediately after an extremely bright optical flare in mid July 2007 [10]. The average  $\gamma$ -ray flux over 6 days of observation was  $F_{E>100\text{ MeV}} = (280 \pm 40) \times 10^{-8} \text{ photons cm}^{-2} \text{ s}^{-1}$ , more than a factor of two higher than the maximum value reported by EGRET. Moreover, the peak flux on daily time scale was of the order of  $400 \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$ . Since this detection, 3C 454.3 become the most luminous object of the  $\gamma$ -ray sky.

Subsequently, two multiwavelength campaigns on 3C 454.3 were organized during November 2007 and December 2007, as reported in [11] and [12]. The source underwent an unprecedented long period of very high  $\gamma$ -ray activity, showing flux levels variable on short timescales of 24–48 hours and reaching on daily timescale a  $\gamma$ -ray flux of the order of  $600 \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$  (see Fig. 1). Also the optical flux appears extremely variable with a brightening of several tenths of magnitude in a few hours. A correlation analysis between the optical and  $\gamma$ -ray flux variations is consistent with a time lag less than one day, as confirmed also by the analysis of the early *Fermi*-LAT data in [13]. As shown in Figure 2, the dominant emission mechanism in this source above 100 MeV seems

TABLE I: List of the AGILE flaring blazars. References: 1. Chen et al., 2008, A&A, 489, L37; 2. Giommi et al., 2008, A&A, 487, L49; 3. Donnarumma et al., 2009, ApJ, 691, L13; 4. Acciari et al., 2009, ApJ, 707, 612; 5. Pucella et al., 2008, A&A, 491, L21; 6. D’Ammando et al., 2009, A&A, 508, 181; 7. D’Ammando et al., 2010, submitted to A&A; 8. Pacciani et al., 2009, A&A, 494, 49; 9. Giuliani et al., 2009, A&A, 494, 509; 10. Vercellone et al., 2008, ApJ, 676, L13; 11. Wehrle et al., 2010, in preparation; 12. Vercellone et al., 2009, ApJ, 690, 1018; 13. Donnarumma et al., 2009, ApJ, 707, 111; 14. Vercellone et al., 2010, ApJ, 712, 405.

Name	Period <i>start : stop</i>	Sigma	ATel #	Ref.
S5 0716+714	2007-09-04 : 2007-09-23	9.6	1221	1
	2007-10-24 : 2007-11-01	6.0	-	2
Mrk 421	2008-06-09 : 2008-06-15	4.5	1574, 1583	3
W Comae	2008-06-09 : 2008-06-15	4.0	1582	4
PKS 1510–089	2007-08-23 : 2007-09-01	5.6	1199	5
	2008-03-18 : 2008-03-20	7.0	1436	6
	2009-03-01 : 2009-03-31	19.9	1957, 1968, 1976	7
3C 273	2007-12-16 : 2008-01-08	4.6	-	8
3C 279	2007-07-09 : 2007-07-13	11.1	-	9
3C 454.3	2007-07-24 : 2007-07-30	13.8	1160, 1167	10, 11
	2007-11-10 : 2007-12-01	19.0	1278, 1300	12
	2007-12-01 : 2007-12-16	21.3	-	13
	2008-05-10 : 2008-06-30	30.3	1545, 1581, 1592	14
	2008-07-25 : 2008-08-14	17.5	1634	14
	2008-10-17 : 2009-01-12	17.9	-	14

to be the inverse Compton scattering of relativistic electrons in the jet on the external photons from the Broad Line Region (BLR), even if the hard  $\gamma$ -ray spectrum and the high Compton dominance observed by AGILE in December 2007 seems to suggest that in some cases also the contribution of external Compton of seed photons from a hot corona could be not negligible [12]. Finally, the results of a extremely long  $\gamma$ -ray activity period between 10th May 2008 and 12th January 2009 are presented in [9].

## B. PKS 1510–089

PKS 1510–089 showed in the last two years high variability over all the electromagnetic spectrum, in particular a high  $\gamma$ -ray activity was observed by AGILE and *Fermi*. AGILE detected two intense flaring episodes in August 2007 ([14]) and March 2008 ([15]) and an extraordinary activity during March 2009, with several flaring episodes and a flux reaching  $500 \times 10^{-8}$  ph cm $^{-2}$  s $^{-1}$  [16]. Fig. 3 shows the SED of PKS 1510–089 relative to the rapid  $\gamma$ -ray flaring of mid March 2008 [15].

The multiwavelength data collected in optical and UV bands by GASP-WEBT and

*Swift*/UVOT not only in March 2008 but during the entire period 2008–2009 seem to indicate the presence of thermal features quasar-like such as the little blue bump and the big blue bump in the optical/UV spectrum of this source. Moreover, the *Swift*/XRT observations of mid March 2008 showed in X-ray band a harder-

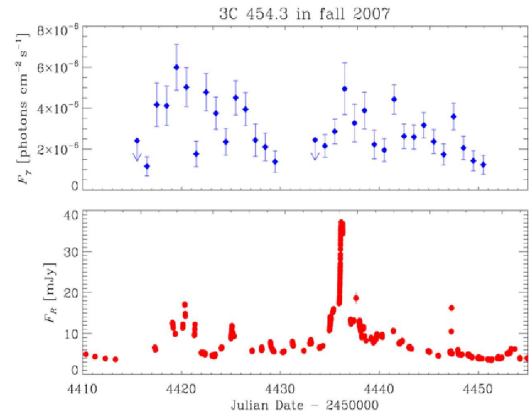


FIG. 1: Light curves of 3C 454.3 in  $\gamma$ -ray (upper panel) and optical band (lower panel) acquired during November–December 2007 by AGILE and GASP-WEBT, respectively.

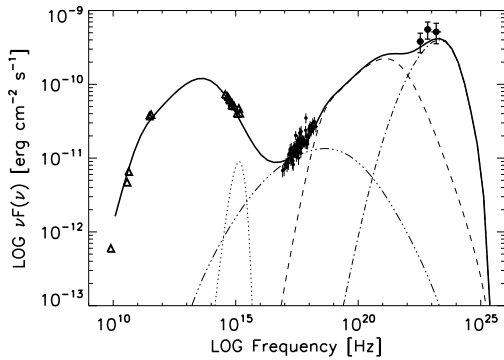


FIG. 2: Spectral Energy Distribution of 3C 454.3 for the period 13th–16th November 2007 with AGILE, *Swift* and GASP-WEBT data. The dotted, dashed, dot-dashed, and triple dot-dashed lines represent the accretion disk black body, the external Compton on the disk radiation, the external Compton on the BLR radiation and the SSC, respectively.

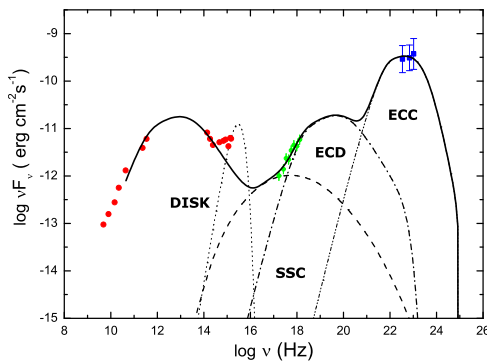


FIG. 3: Spectral Energy Distribution of PKS 1510-089 on mid March 2008 with AGILE, *Swift* and GASP-WEBT data. The dotted, dashed, dot-dashed, and double dot-dashed lines represent the accretion disk black body, the SSC, the external Compton on the disk radiation (ECD) and the external Compton on the BLR radiation (ECC), respectively.

when-brighter behaviour, already observed in this source by [17], but not usual in FSRQs.

### C. 3C 279

This is the first extragalactic source detected by AGILE, in mid July 2007, as reported in [18]. The average  $\gamma$ -ray flux over 4 days of ob-

servation 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 observed by EGRET and *Fermi*. The spectrum of this source during the flaring episode observed by AGILE is soft and this could be an indication of a low accretion state of the disk occurred some months before the  $\gamma$ -ray observations, suggesting a dominant contribution of the external Compton scattering of direct disk (ECD) radiation compared to the external Compton scattering of the broad line region 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 and the reduction of the activity of the disk should cause the decrease of the photon seed population produced by the disk and then 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.

### D. 3C 273

3C 273 was detected simultaneously by the GRID and SuperAGILE detectors onboard AGILE during a pre-planned multiwavelength campaign over three weeks between mid December 2007 and January 2008, involving also simultaneous REM, *Swift*, RXTE and INTEGRAL observations. During this campaign, whose results are reported in [19], the average flux in the 20–60 energy band is  $(23.9 \pm 1.2) \text{ mCrab}$ , whereas the source was detected by the GRID only in the second week, with an average flux of  $F_{E>100\text{ MeV}} = (33 \pm 11) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$ . The analysis of the light curves seems to indicate no optical variability during the whole campaign and a possible anti-correlation between the  $\gamma$ -ray and the soft and hard X-ray emission. The SED is consistent with a leptonic model where the soft X-ray emission is produced by the combination of Synchrotron Self Compton (SSC) and External Compton (EC) models, while the hard X-ray and  $\gamma$ -ray emission is due to ECD. 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.

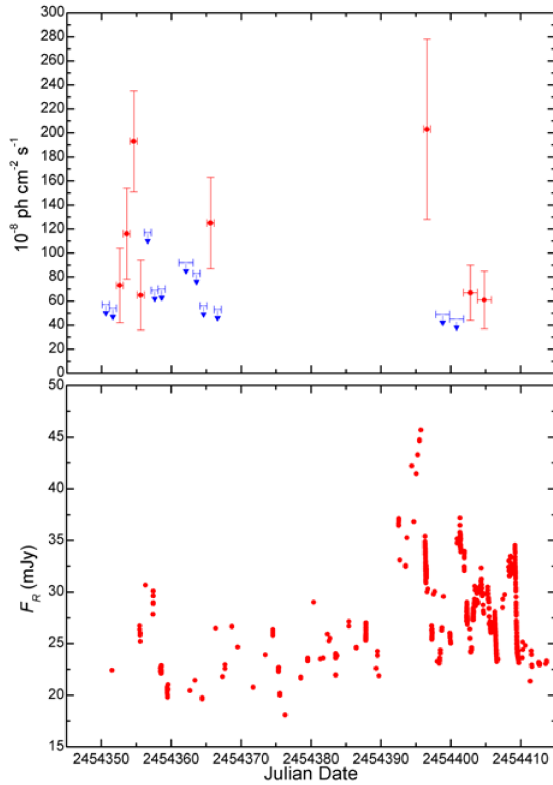


FIG. 4: Light curves of S5 0716+714 during September-October 2007 in  $\gamma$ -ray (upper panel) and optical band (lower panel) with AGILE and GASP-WEBT data, respectively.

### E. S5 0716+714

The intermediate BL Lac (IBL) object S5 0716+714 was observed by AGILE during two different periods: 4th–23rd September and 23rd October – 1st November 2007, as discussed in [20]. Between 7th and 12th September 2007 the source showed a high  $\gamma$ -ray activity with an average flux of  $F_{E>100\text{ MeV}} = (97 \pm 15) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$  and a peak level of  $F_{E>100\text{ MeV}} = (193 \pm 42) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$ , with an increase of flux by a factor of four in three days (see Fig. 4, upper panel). Another  $\gamma$ -ray flare of similar intensity was detected by AGILE on 22–23 September 2007. This source was detected by EGRET in low/intermediate  $\gamma$ -ray levels,  $F_{E>100\text{ MeV}} \simeq (20\text{--}40) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$ . The flux detected by AGILE is the highest ever detected from this object and one of the highest flux observed from a BL Lac object. A simultaneous GASP-WEBT optical campaign started after the AGILE detection (see Fig. 4,

lower panel) and the resulting SED is consistent with a two-component SSC model (see Fig. 5). Recently [21] estimated the redshift of the source ( $z = 0.31 \pm 0.08$ ) and this allowed us to calculate the total power transported in the jet during these two intense  $\gamma$ -ray flares, which results extremely high approaching or slightly exceeding the maximum power generated by a spinning black hole of  $10^9 M_{\odot}$  through the pure Blandford-Znajek mechanism [22] in most widely known models (see [23] for a detailed discussion).

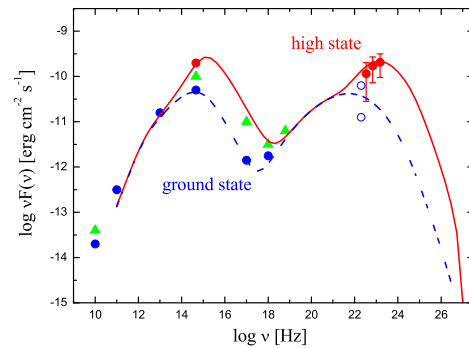


FIG. 5: SED of S5 0716+714 during mid September 2007 including optical GASP-WEBT and  $\gamma$ -ray AGILE data (red dots). Historical data relative to a ground state and EGRET data are represented, respectively, with filled and empty blue dots. Green triangles represent historical data during a high X-ray state.

During October 2007, AGILE detected the source at a flux about a factor of 2 lower than the September one with no significant variability; simultaneously, *Swift* observed strong variability in soft X-rays, moderate variability at optical/UV and approximately constant hard X-ray flux. Also this behaviour is compatible with the presence of 2 different SSC components in the SED [24].

### F. W Comae and Mrk 421

On 8th June 2008, VERITAS announced the detection of a TeV flare from the IBL object W Comae [25]. About 24 hours later, AGILE repointed towards the source and detected it [26]. The SED of W Comae during the VHE  $\gamma$ -ray flare can be modelled by a simple lep-

tonic SSC model, but the wide separation of the two peaks in the SED requires low ratio of the magnetic field to electron energy density far from the equipartition. Adding the contribution of the external Compton scattering of the IR photons from the torus, the model returns a magnetic field parameter closer to the equipartition, providing a satisfactory description of the broadband SED. The results of a multiwavelength campaign involving VERITAS, *Swift*, XMM-Newton and AGILE is described in detail in [27].

During the ToO towards W Comae, AGILE detected also the HBL object Mrk 421. Super-AGILE 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. The  $\gamma$ -ray flux detected by GRID,  $F_{E>100\text{ MeV}} = (42 \pm 13) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$ , is about a factor of 3 higher than the average EGRET value, even if consistent with its maximum. An extensive multiwavelength campaign from optical to TeV energy bands was organized with the participation of WEBT, *Swift*, RXTE, AGILE, MAGIC and VERITAS. The comparison of the light curves show a possible correlated variability between optical, X-rays and the high-energy part of the spectrum. The SED can be interpreted within the framework of the SSC model in terms of a rapid acceleration of leptons in the jet. An alternative more complex scenario is that optical and X-ray emissions come from different regions of the jet, with the inner jet region that produces X-rays and is partially transparent to the optical radiation, whereas the outer region produces only the lower-frequency emission.

#### IV. CONCLUSIONS

We presented the results on multiwavelength studies of the brightest blazars detected in  $\gamma$  rays by AGILE in the first two years of oper-

ation. The synergy between the AGILE wide field of view, its fast response to external triggers, and the availability of a network of ground-based telescopes together with several X-ray satellites, allowed us to obtain a coverage over the entire electromagnetic spectrum for almost all the detected sources, and to investigate the physics of different classes of blazars. From the modeling of the SED of BL Lacs and FSRQs observed by AGILE and the study of correlated variability among the emission at different frequencies seems to emerge that the SSC and EC frameworks, respectively, are good approximation for describing the high activity states of the two flavours of blazars, but going into details of the single observations more complex scenarios beyond the standard emission models are required.

Actually the interest in blazars is strongly 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 the jet structure and the emission mechanisms at work in blazars.

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