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Multifrequency studies of the blazars detected by AGILE

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on behalf of the AGILE AGN WG

We report on the main results about γ-ray blazars achieved by AGILE during the first 3 years spent in orbit. AGILE detected several flaring blazars, covering the entire sequence from FSRQ to HBL objects and, thanks to the rapid dissemination of our alerts, we have been able to collect multiwavelength data from radio to TeV energy bands thanks to the sinergy with other observatories such as GASP-WEBT, REM, *Spitzer*, *Swift*, *RXTE*, *XMM-Newton*, *Suzaku*, *INTEGRAL*, MAGIC, VERITAS. This set of simultaneous data allowed us to study the multi-λ variability and to build up the spectral energy distribution of these blazars from radio to γ-ray energy bands. The most relevant properties of our sample of blazars will be presented with a particular emphasis on the spectral thermal components, time lags, spectral trends (in X-rays and γ-rays), jet geometry and acceleration mechanism at the inner portion of the jet itself.

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†A footnote may follow.

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1. The multi-frequency campaigns

Since its launch in 2007, AGILE (Tavani et al. 2009) has been involved in several multi-frequency campaigns to study the emission mechanisms of the brightest blazars in the γ-ray sky. This has been possible thanks to coordinated (quasi-)simultaneous observations basically obtained through the acceptance of several of monitoring proposals and/or Target of Opportunity (hereafter ToO) with X-ray observatories (*Swift*, *Suzaku*, *INTEGRAL*) and via an agreement with the radio-optical monitoring provided by the GASP-WEBT (Villata et al. 2008). Moreover, a good cooperation and data sharing has been obtained with the Cherenkov observatories MAGIC and VERITAS, allowing for the exploration of GeV-TeV connection. We recall that the first catalog of high-confidence γ-ray sources detected by AGILE during the first year of pointed observations includes 13 Blazars (7 FSRQ, 4BL Lacs, 2 unknown type) (Pittori et al. 2009). Source detections during flaring state were not included in the first catalog. The AGILE AGN working group handled a large set of multi-frequency data on a discrete number of sources ($\sim$ 20), which led us to analyze possible multi-λ flux correlations and probe the synchrotron and inverse Compton (IC) emissions. The wide coverage of the Spectral Energy Distribution (SED) of these blazars obtained in different states provided important constraints on the efficiency of their acceleration mechanisms, on the electron population, on the thermal emission variability, on possible time lag between optical and γ-ray emission and finally on the dissipation region of the γ-ray emission, which is actually still debated (Marscher et al. 2010, Tavecchio et al. 2010).

Since October 2009, AGILE changed its observing mode ("spinning mode") due to a failure of the reaction wheel. This failure prevented AGILE to continue with pointed observations and then it now surveys a large fraction of the sky ($\sim$ 80%) rotating at 0.8 degrees/s. In this paper, we will summarize the main results obtained by these multifrequency campaigns in pointing as well as in spinning mode.

2. Global properties of a sample of blazars

2.1 Thermal features

Simultaneous optical-UV and γ-ray observations in quiescent states are the key ingredient to estimate the contribution of the thermal component (if any) to the overall Spectral Energy Distribution. This is crucial to disentangle among the candidate seed photons (dusty torus, accretion disk, Broad Line Region (BLR), hot corona) in the external Compton (EC) model, posing constraints on the γ-ray dissipation region. The long term optical and γ-ray monitoring available for a subset of blazars detected by AGILE allowed us to unveil the thermal component often hidden in the synchrotron emission during the high γ-ray states. This has been the case for 3C 454.3 (Vercellone et al. 2010) and PKS 1510-089 (D'Ammando et al. 2011). In particular, in 3C 454.3 the disk component was observed only during the low γ-ray states of the source allowing for a disk luminosity estimate of 5×10^{46} erg cm^{-2} s^{-1}. This value was then injected in the model fitting of the SEDs in the higher γ-ray states, allowing to establish that the accretion disk emission as direct as reprocessed by the BLR was the dominant seed photon source in the IC emission. The case of PKS 1510-089 is even more intriguing. In this object the thermal component was detected also during the high γ-ray activity registered by AGILE in March 2008 (D'Ammando et al. 2009), with the synchrotron emission peaked in the infrared energy band. A multi-frequency campaign performed during new high γ-ray activity detected by AGILE in March 2009 revealed that the disk component in PKS 1510-089 was still observed, showing only a mild variation with respect to the past year. On the contrary strong variation at optical-UV energies was observed in the source during the brightest γ-ray state. Given the short time scale of this variation, this was interpreted as due to an acceleration process responsible for the shift of the synchrotron energy peak towards higher energies (see D'Ammando et al. 2011 for details).

2.2 Time Lags

Time lags between optical and γ-ray emission have been investigated when a continuous monitoring in both energy bands - lasting at least one month - was available (a small sample of four blazars). We deeply studied the optical-γ-ray correlation by means of a Discrete Correlation Function (DCF; Edelson & Krolik 1988; Hufnagel & Bregman 1992) which allowed us to infer possible time lag below the time binning of the γ-ray light curves (1-day binning) thanks to the centroid calculation (Peterson et al. 1998; Raiteri et al. 2003). The DCF method applied to our sample revealed **hints** of delay between optical and γ-ray variabilities only in the case of S5 0716+714 (Chen et al. 2008) and of 3C 454.3 (Donnarumma et al. 2009a, Vercellone et al. 2010). In detail, S5 0716+714 was observed simultaneously in optical (R) and in γ-ray energy bands between September and October 2007. The DCF showed a significant peak in correspondence with a time-lag of -1 day, suggesting a possible delay in the γ-ray flux variations with respect to the optical ones of the order of 1 day (see left panel in Fig.1). Moreover, the gamma variability showed a quadratic dependence on the changes in the optical flux, favoring a SSC interpretation, in which the emission at the synchrotron and IC peaks is produced by the same electron population, which self-scatters the synchrotron photons. The 1-day time-lag in the high-frequency peak emission found from the DCF could be seen as a further clue of the SSC interpretation, being likely associated with the light travel time of the synchrotron seed photons that scatter the energetic electrons.

3C 454.3 was the source best studied by AGILE because it is the blazar that dominates the γ-ray sky in the last years. A 18-month long monitoring from radio to γ-ray energy bands was available and the overall data were used in order to corroborate or falsify the evidence of 12-hour gamma-optical delay found during the December 2007 campaign (Donnarumma et al. 2009a). The resulting DCF showed a peak at $\tau = 0$, which implies no lag between optical and γ-ray emissions (see right panel in Fig.1). Neverthless, the asymmetric shape of DCF as probed also by the centroid distribution (see subpanel in Fig.1), suggested a possible lag occurred at $\tau = 0.4^{+0.6}_{-0.8}$ (Vercellone et al. 2010 for details). This result, consistent with the ones reported in Donnarumma et al. (2009a) and in Bonning et al. (2009), showed that γ-ray variations could be delayed by few hours with respect to the optical ones, in agreement with the dominance of the EC model provided by the SED modeling: such a delay is compatible with the typical blob dimensions and the corresponding crossing time of the external seed photons (Sokolov et al. 2004).

2.3 Spectral Trends: soft X and γ-rays

During the long term multi-λ campaign on 3C 454.3, several ToO observations were performed by *Swift*/XRT to monitor the soft X-ray behavior of the source, i.e. the raising tail of the IC emission. These observations showed that the X-ray data follow a "harder-when-brighter" trend,

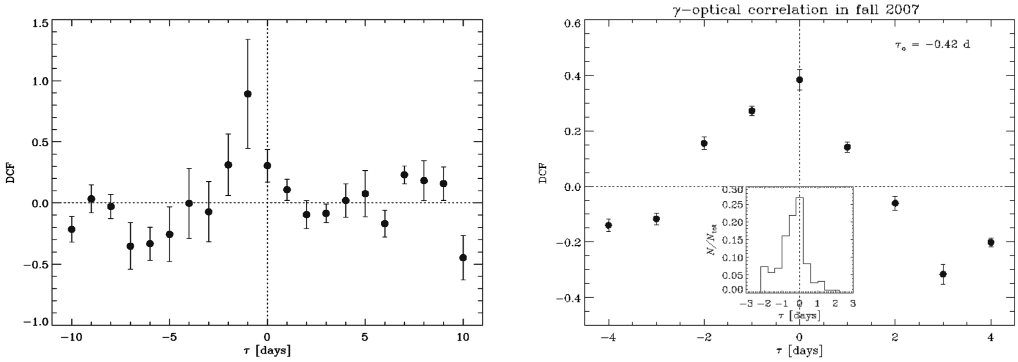

Figure 1: DCFs between optical and γ-ray light curves as performed for S5 0716+714 (left panel) and 3C 454.3 (right panel). These figures have been adapted from Chen et al. (2008) and Vercellone et al. (2010).

although a small deviation from this trend occurs at F$(2-10$ keV$)< 2\times10^{-11}$ erg cm^{-2} s^{-1} (Vercellone et al. 2010). Moreover, a "harder-when-brighter" trend appears also in the γ-ray data, although it is less pronounced than the X-ray ones due to the larger errors in the spectral slopes. The spectral trend observed in X-rays seems to be confirmed by the extension of this relation to higher fluxes provided the *Swift*/XRT observations performed during the γ-ray "giant flare" of 3C 454.3 detected by AGILE in December 2009 (Pacciani et al. 2010). Very interesting is a possible saturation of the photon index with increasing flux (see Fig. 2). We argued that the "harder-when-brighter" trend could be interpreted by invoking an higher accretion rate or a larger value of the bulk Lorentz factor coupled with a slightly lower value of the magnetic field. The variation of the X-ray slope appears moderate with respect to the other bands. If e- injection-acceleration was the only dominant mechanism then we would obtain a remarkable softer-when-brighter trend. A detailed interpretation of this trend will be given in Vercellone et al. 2011. We underline that this trend seems common in FSRQs as reported in Abdo et al. 2010a.

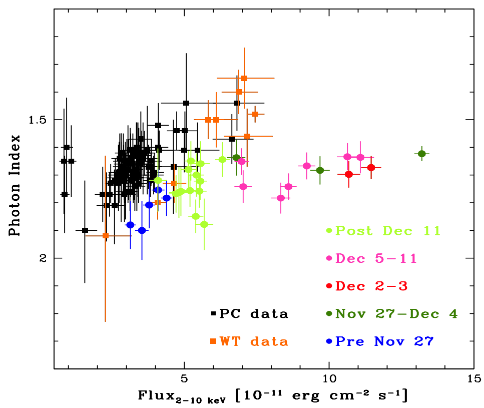

Figure 2: The photon index vs $F_{2-10\mathrm{keV}}$ relation as inferred by several *Swift*/XRT observations of 3C 454.3.

2.4 Jet geometry

Simultaneous radio, optical and γ-ray observations are sheding light on the study of the jet geometry. In particular strong correlation between radio (43 GHz) and γ-ray emissions have been observed during the strong enhancements detected in the γ-ray light curves of some blazars, as in the case of PKS 1510-089 (Marscher et al. 2010). Moreover, continuous polarimetric measurements in the optical energy bands revealed that significant variations of the polarization angle occurred slightly before or in coincidence with a bright γ-ray flare (see the case of 3C 279 reported in Abdo et al 2010b). These correlated multi-λ variabilities gave rise to several hypotheses on the jet structure and dynamics. Among them, there are the requirement of a non axis-symmetric magnetic field or a jet wobbling across the line of sight or a curved jet.

In this respect, it is worth noticing that we found a possible evidence of a curved jet also in the case of 3C 454.3 as inferred by the radio (220 GHz), optical (R) and γ-ray light curves of our 18-month long multi-wavelength campaign (see Fig. 3). During 2007, the more pronounced fluxes and variability of the optical and γ -ray bands seem to favor the inner portion of the jet as the more beamed one. On the other hand, the higher mm flux emission and its enhanced variability during 2008, together with the dimming trend in the optical and in the γ -ray bands, could indicate that the more extended region of the jet becomes more aligned with respect to the observer line of sight. This behavior resembles that of BL Lacertae (Villata et al. 2009), which could be interpreted in the framework of a change in orientation of a curved jet, yielding different alignment configurations within the jet itself.

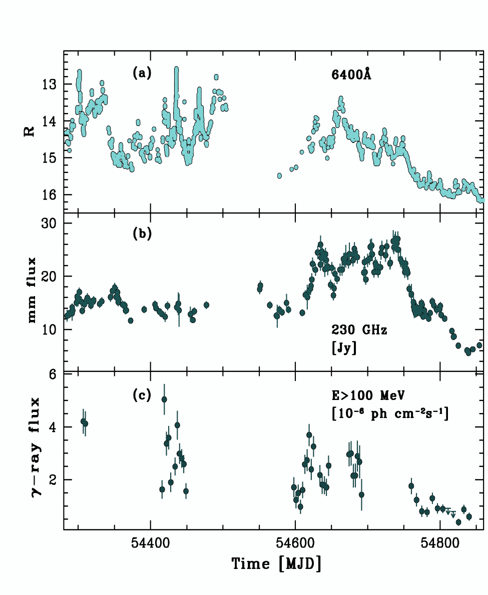

Figure 3: From top to bottom: Optical (R-band), millemetric (220 GHz) and γ-ray light curves of 3C 454.3. Adapted from Vercellone et al. 2010.

2.5 The Gev-TeV connection: Mrk 421 and W Comae

Mrk 421 Between 2008 June 9 and 15 AGILE pointed towards W Comae to follow a Very

High Energy (VHE) γ-ray flare from this blazar announced by VERITAS. During this observation a hard X-ray flare from the nearby blazar Mrk 421 was detected by AGILE with its hard X-ray monitor, SuperAGILE (Feroci et al. 2007). The source showed an increasing hard X-ray activity, culminating in a flux level of $\sim$ 55 mCrab. No significant γ-ray emission above 100 MeV was observed by AGILE-GRID integrating on daily-time scale. By integrating over all the data collected during the 1-week observation, Mrk 421 was detected by AGILE at $E > 100$ MeV with a flux of $(42 \pm 13) \times 10^{-8}$ photons cm^{-2} s^{-1}, consistent with the highest flux observed by EGRET. The soft X-ray emission as probed by the *RXTE/*ASM data together with a ToO observation performed by *Swift/*XRT showed that the source reached its historical maximum, i.e. $\sim 2.6 \times 10^{-9}$ erg cm^{-2} s^{-1}. TeV data were not acquired during the brightest X-ray flare and then also in correspondence with the γ-ray detection. Moreover, we found evidence of X-ray hardening during the brightest X-ray flare. On the basis of these evidences and on the relative variations observed in soft X-rays and in VHE γ-ray light curves, we interpreted the variability of the Spectral Energy Distribution of Mrk 421 in June 2008 as due to an acceleration process in a standard synchrotron self Compton (SSC) leptonic model rather than to a new injection of relativistic electrons (see Donnarumma et al. 2009b for further details).

W Comae A significant flux in VHE γ-rays from W Comae was detected by VERITAS between 2008 June 7 and 9, with a flux 2.5-3 times higher than during the γ-ray flare from W Com in 2008 March (Acciari et al. 2008). As described above, AGILE performed a ToO on W Comae field to follow this VHE γ-ray flare. A significant γ-ray emission above 100 MeV was detected only between June 12 and 13, at a flux level of $(90 \pm 32) \times 10^{-8}$ ph s^{-1} cm^{-2}. This flux is roughly a factor of 1.5 higher than the highest flux detected by EGRET (Hartmann et al. 1999). In the rest of the observing period, the source was not detected and 3-σ upper limits were obtained ($< 60 \times 10^{-8}$ ph s^{-1} cm^{-2} for a 2-3 day time scale, see Acciari et al. 2009). SuperAGILE did not detect W Comae and a 3-σ upper limit of $\sim$ 6 mCrab was derived by integrating over the whole duration of the AGILE observation. At the time of AGILE ToO, the source was observed in soft X-rays by both *Swift/*XRT and *XMM*-Newton. Radio, Optical and near-IR observations were also available during this campaign as provided by Noto, UMRAO Metsähovi radio telescopes and the GASP-WEBT consortium. Particularly interesting was the X-ray flux variability (a factor of 2) observed on hour time scale. On the same time scale, a slightly lower variability ($\sim$ 1.5) was observed also in the UV data. No significant variability was observed in optical *R*-band and radio (14.5, 37 GHz) data.

The simple SSC model did not allow equipartition in the emitting region: an EC component was required to bring the system within a factor of $\sim$ 3 close to equipartition. In particular, an EC component peaking at 1.5×10^{14} Hz, i.e. an infrared emission from e.g. a near-nuclear dust torus seems to provide an efficient source for EC emission. The simultaneous γ-ray and VHE γ-rays led to disentangle between the two models. Further details on the multi-frequency campaign are provided in Acciari et al. 2009.

3. Conclusions

AGILE accumulated almost four years of data, covering the whole sky. The forthcoming AGILE 2nd source catalog (Bulgarelli et al. in preparation) will contain a high number of extra-galactic sources both associated with low energy counterparts and still unidentified. We plan to

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cross-correlate the γ-ray data accumulated so far with data of other observatories operating in different energy bands, thus investigating the properties of the SEDs on a broader sample of objects.

4. Acknowledgements

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References

[1] Abdo, A. A., et al. 2010a, ApJ, 716, 835

[2] Abdo, A. A., et al. 2010b, Natur, 463, 919

[3] Acciari, V. A., et al. 2008, ApJ, 684, 73L

[4] Acciari, V. A., et al. 2009, ApJ 707, 612

[5] Bonning, E. W., et al. 2009, ApJ, 697, 81L

[6] Bulgarelli, A. et al. in preparation

[7] Chen, A. W., et al. 2008, A&A, 489, 37L

[8] D'Ammando, F., et al. 2009,A&A, 508, 18

[9] D'Ammando, F., et al. 2011, submitted to A&A

[10] Donnarumma, I., et al. 2009a, ApJ, 707, 1115

[11] Donnarumma, I., et al. 2009b, ApJ, 691, 13L

[12] Edelson, R. A. & Krolik, J. H. 1988, ApJ, 333, 646

[13] Feroci, M., et al. 2007, Nucl. Instrum. Meth. A, 581, 728

[14] Hartmann, R.C., et al. 1999, ApJS, 123, 79

[15] Hufnagel, B. R. & Bregman, J. N. 1992, ApJ, 386, 473

[16] Marscher, A.P., et al. 2010, ApJ, 710, 126L

[17] Pacciani, L., et al. 2010, ApJ, 716, L170

[18] Peterson, B. M., et al. 1998, PASP, 110, 660

[19] Pittori, C., et al. 2009, A&A, 506, 1563

[20] Raiteri, C. M. et al. 2003, A&A, 402, 151

[21] Sokolov, A., et al., 2004, ApJ, 613, 725

[22] Tavani, M. et al. 2009, A&A, 502 995

[23] Tavecchio, F., et al. 2010, MNRAS, 405, 94L

[24] Vercellone, S. et al. 2010, ApJ, 712, 405

[25] Vercellone, S. et al. 2011, submitted to ApJ

[26] Villata, M.,et al. 2008, A&A , 481, 79L

[27] Villata, M., et al. 2009, A&A, 501, 455