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Letter to the Editor

AGILE detection of variable γ-ray activity from the blazar S5 0716+714 in September–October 2007[⋆,⋆⋆]

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ABSTRACT

Aims. We report the γ-ray activity from the intermediate BL Lac S5 0716+714 during observations acquired by the AGILE satellite in September and October 2007. These detections of activity were contemporaneous with a period of intense optical activity, which was monitored by GASP–WEBT. This simultaneous optical and γ-ray coverage allows us to study in detail the light curves, time lags, γ-ray photon spectrum, and Spectral Energy Distributions (SEDs) during different states of activity.

Methods. AGILE observed the source with its two co-aligned imagers, the Gamma-Ray Imaging Detector (GRID) and the hard X-ray imager (Super-AGILE), which are sensitive to the 30 MeV–50 GeV and 18–60 keV energy ranges, respectively. Observations were completed in two different periods, the first between 2007 September 4–23, and the second between 2007 October 24–November 1.

Results. Over the period 2007 September 7–12, AGILE detected γ-ray emission from the source at a significance level of 9.6-σ with an average flux ($E > 100$ MeV) of $(97 \pm 15) \times 10^{-8}$ photons cm^{-2} s^{-1}, which increased by a factor of at least four within three days. No emission was detected by Super-AGILE for the energy range 18–60 keV to a 3-σ upper limit of 10 mCrab in 335 ks. In October 2007, AGILE repointed toward S5 0716+714 following an intense optical flare, measuring an average flux of $(47 \pm 11) \times 10^{-8}$ photons cm^{-2} s^{-1} at a significance level of 6.0-σ.

Conclusions. The γ-ray flux of S5 0716+714 detected by AGILE is the highest ever detected for this blazar and one of the most intense γ-ray fluxes detected from a BL Lac object. The SED of mid-September appears to be consistent with the synchrotron self-Compton (SSC) emission model, but only by including two SSC components of different variabilities.

Key words. gamma rays: observations – galaxies: BL Lacertae objects: general – galaxies: BL Lacertae objects: individual: S5 0716+714

1. Introduction

The source S5 0716+714 was discovered in 1979 as the optical counterpart to an extragalactic radio source (Kühr et al. 1981). Two years later, it was classified as a BL Lac (Biermann et al. 1981) because of its featureless optical spectrum and high linear polarization. The optical continuum was so featureless that every attempt to determine its spectroscopic redshift has failed. However, by optical imaging of the underlying galaxy, Nilsson et al. (2008) derived a redshift of $z = 0.31 \pm 0.08$.

According to its spectral energy distribution the source belongs to the intermediate BL Lac class, observations by BeppoSAX (Tagliaferri et al. 2003; Giommi et al. 1999) and XMM-*Newton* (Foschini et al. 2006; Ferrero et al. 2007) provide evidence for a concave X-ray spectrum in the 0.1–10 keV band, which is a signature of the presence of both the steep tail of the synchrotron emission and the flat part of the Inverse Compton spectrum. The detection in the X-ray band of fast variability only in the soft X-ray component can be interpreted as a slowly variable Compton component and a fast, erratic variable tail of the synchrotron component.

In general, the variability of this blazar is strong in every band on both long and short (intraday) timescales. The optical and radio historical behaviour was analyzed by Raiteri et al. (2003), while the EGRET telescope on the Compton Gamma-Ray Observatory (Hartman et al. 1999) detected S5 0716+714 several times in the γ-rays (Lin et al. 1995; von Montigny et al. 1995). The integrated flux above 100 MeV varied between (13 ± 5) and $(53 \pm 13) \times 10^{-8}$ photons cm^{-2} s^{-1}.

In this Letter, we present the analysis of the AGILE data obtained during the S5 0716+714 observations in the period 2007 September–October, in particular two flaring episodes: the first in mid-September, the other on 2007 October 22, 23. Preliminary results were communicated in Giuliani et al. (2007).

The intense γ-ray flare detected by AGILE in mid-September triggered observations by the GLAST-AGILE Support Program

⋆ The optical data presented in this paper are stored in the GASP-WEBT archive; for questions regarding their availability, please contact the WEBT President Massimo Villata.

⋆⋆ Figure 5 is only available in electronic form via http://www.aanda.org

(GASP) of the WEBT[1] (see Carosati et al. 2007). About one month later, the GASP observed a bright phase of the source, triggering new AGILE and Swift observations. In the period from September to October 2007, S5 0716+714 showed intense activity with strong optical flaring episodes and a rare contemporaneous optical-radio outburst (Villata et al. 2008).

The results of a multiwavelength campaign on S5 0716+714 with simultaneous Swift and AGILE observations in October 2007 are discussed in Giommi et al. (2008). Throughout this paper, the quoted uncertainties are given at the 1-σ significance level, unless otherwise stated.

2. AGILE observation of S5 0716+714

The AGILE scientific Instrument (Tavani et al. 2008) is very compact and combines four active detectors that provide broadband coverage from hard X-rays to γ-rays: a Silicon Tracker optimized for γ-ray imaging in the 30 MeV–50 GeV energy band (Prest et al. 2003); a co-aligned coded-mask X-ray imager sensitive in the 18–60 keV energy band (Feroci et al. 2007); a non-imaging Cesium Iodide Mini-Calorimeter sensitive in the 0.3–100 MeV energy band (Labanti et al. 2006); and a segmented Anticoincidence System (Perotti et al. 2006).

In September, during its Science Performance Verification Phase, the AGILE satellite devoted three weeks to the observation of S5 0716+714 between 2007 September 4 14:58 UT and September 23 11:50 UT, for a total pointing duration of ~16.9 days[2]. In October, AGILE repointed toward the source and observed S5 0716+714 between 2007 October 24 9:47 UT and November 1 12:00 UT, for a total pointing duration of ~8.1 days.

3. Data analysis and results

Level-1 AGILE-GRID data were analyzed using the AGILE Standard Analysis Pipeline. After the alignment of all data times to Terrestrial Time (TT), an ad-hoc implementation of the Kalman Filter technique was used to achieve track identification and event direction reconstruction. Subsequently, a quality flag was assigned to each GRID event: G, P, S, or L, depending on whether it was recognized to be a γ-ray event, a charged particle, a single-track event, or if its nature was uncertain, respectively. We selected only events flagged as confirmed γ-ray events, while all events collected during the South Atlantic Anomaly were rejected. We also rejected all γ-ray events with reconstructed directions that formed angles with the satellite-Earth vector smaller than 80°; this reduced the γ-ray Earth Albedo contamination by excluding regions within ~10° of the Earth limb. Counts, exposure, and Galactic background γ-ray maps were created with a binsize of $0.^\circ3 \times 0.^\circ3$ for photons of energies higher than 100 MeV.

The average γ-ray flux as well as the daily values were derived by the maximum likelihood analysis of Mattox et al. (1993). First, the entire period was analyzed to determine the diffuse emission parameters, then, the source flux density was estimated independently for each of the 1-day periods with the diffuse parameters fixed at the values obtained in the first step.

[1] http://www.oato.inaf.it/blazars/webt/
see e.g. Villata et al. (2006, 2007); Raiteri et al. (2006, 2007).

[2] Between 2007 September 15 12:52 UT and September 16 12:42 UT AGILE performed a calibration test on the Crab pulsar and S5 0716+714 was out of the Field of View of the satellite for two days.

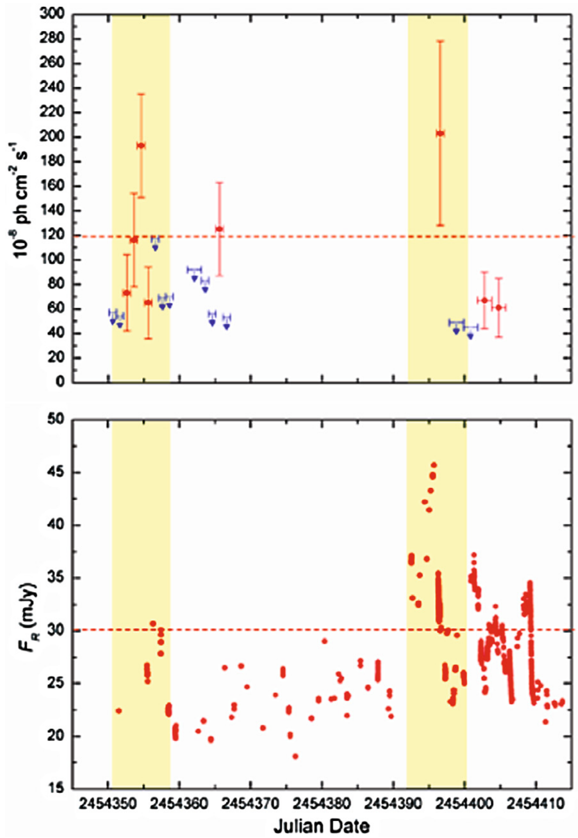

Fig. 1. *In the top panel*, the AGILE–GRID γ-ray light curve with 1-day or 2-day resolution for fluxes in units of 10^{-8} photons cm^{-2} s^{-1} for $E > 100$ MeV. The downward arrows represent 2-σ upper limits. In the bottom panel, the R-band optical light curve as observed by GASP-WEBT. In both panels, the mean flux level is highlighted with horizontal red dashed lines and the yellow shaded regions indicate the two high-activity periods in the γ-ray band.

The AGILE 95% maximum likelihood contour level barycenter of the source is $l = 143.^\circ87, b = 28.^\circ00$. The distance between this position and the S5 0716+714 radio position ($l = 143.^\circ98, b = 28.^\circ02$) is $0.^\circ16$. The AGILE 95% maximum likelihood contour level has a semi-major axis $a = 0.^\circ33$ and a semi-minor axis $b = 0.^\circ33$, whereas the overall AGILE error circle, taking into account systematic errors, has a radius $r = 0.^\circ58$.

The top panel in Fig. 1 shows the γ-ray light curve with 1 or 2 day resolution for photons of energy above 100 MeV. The downward arrows represent 2-σ upper limits. During the September observation, we note that S5 0716+714 is detected at high significance on 1-day timescales, while other days have upper limits that are significantly lower, clearly indicating strongly variable γ-ray activity.

The average γ-ray flux above 100 MeV during the period 2007 September 7–12 is $F_{E>100\ \mathrm{MeV}} = (97 \pm 15) \times 10^{-8}$ photons cm^{-2} s^{-1} (see Fig. 5) with a peak level of $F_{E>100\ \mathrm{MeV}} = (193 \pm 42) \times 10^{-8}$ photons cm^{-2} s^{-1}, and shows an increase in flux by a factor of four in three days. The peak level γ-ray flux above 100 MeV, observed in mid September, was the highest ever detected from this source.

Super-AGILE observed S5 0716+714 during 2007 September 7–12 for a total on-source net exposure time of 335 ks. The source was not detected (above 5-σ) by the Super-AGILE Iterative Removal Of Sources (IROS) algorithm, which was applied to the image in the 20–60 keV energy range. A 3-σ

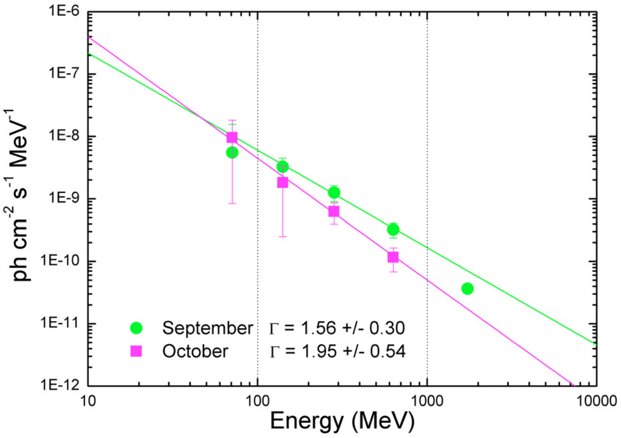

Fig. 2. Gamma-ray photon spectrum of S5 0716+714 during the high state of mid-September 2007 (green line) and the low state of end October 2007 (magenta line).

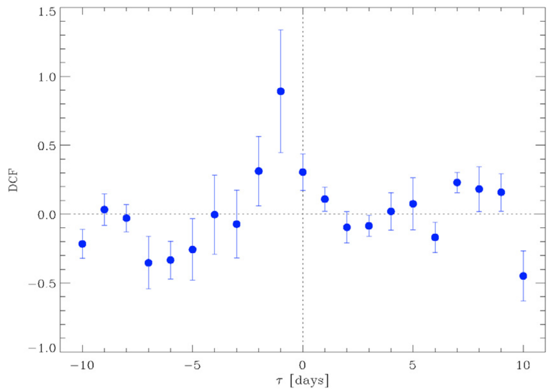

Fig. 3. Discrete correlation function (DCF) between the γ-ray and R-band light curves for S5 0716+714 in September–October 2007.

upper limit of 10 mCrab was derived from the observed count rate by a study of the background fluctuations at the position of the source and a simulation of the source and background contributions with IROS.

A comparison between the γ-ray and optical light curves is shown in Fig. 1; the bottom panel shows the R-band optical light curve obtained by the GASP-WEBT. The results of the GASP-WEBT multifrequency monitoring of 0716+714 in September–October 2007 are presented in Villata et al. (2008)[3].

The source in mid-October showed increasing optical flux, which reached a peak of F_R = 45.7 mJy on October 22.2 (Villata et al. 2008); at that time S5 0716+714, even if rather off-axis (∼50° from the axis) was seen by AGILE to have a high γ-ray flux. In particular, between 2007 October 22 12:33 UT and October 23 12:06 UT, the maximum likelihood analysis measured a flux of $F_{E>100\ \mathrm{MeV}} = (203\pm75)\times10^{-8}$ photons cm^{-2} s^{-1} at a significance level of 4.0-σ. We note, however, that AGILE has a high particle background at high off-axis angles, and that the exposure time is relatively short (only one day of observation).

After this flaring episode, AGILE observed the source with a dedicated repointing at an off-axis angle of ∼15° between October 24 9:47 UT and November 1 12:00 UT. During this entire period, the AGILE-GRID detected a γ-ray flux above 100 MeV at a significance level of 6.0-σ with a lower average flux of $F_{E>100\ \mathrm{MeV}} = (47 \pm 11) \times 10^{-8}$ photons cm^{-2} s^{-1}.

During the September–October observations, AGILE measured S5 0716+714 to have two different levels of activity. The γ-ray spectrum during the high activity state of mid-September can be fitted with a power-law of photon index $\Gamma = 1.56 \pm 0.30$, while during the AGILE October ToO the source was in a low γ-ray activity state and the photon index of the differential energy spectrum was $\Gamma = 1.95 \pm 0.54$ (see Fig. 2). The photon index was obtained with the least squares method by considering only three energy bins: 100–200 MeV, 200–400 MeV and 400–1000 MeV.

4. Discussion

To analyze the gamma-optical correlation, we have applied the Discrete Correlation Function (DCF; see Edelson & Krolick 1988; and Hufnagel & Bregman 1992) to the γ-ray and R-band light curves. The DCF is a statistical method developed to analyze unevenly sampled data sets. The R-band flux densities were averaged over 0.1 day bins to smooth the intranight variability. The result is shown in Fig. 3. The DCF displays a significant peak (DCF ∼ 0.9) for a time-lag of –1 day. Notwithstanding the large uncertainty due to poor γ-ray sampling, this result suggests a possible delay in the γ-ray flux variations with respect to optical variations of the order of 1 day. The uncertainty in the delay can be estimated by Monte Carlo simulations based on the "flux randomization/random subset selection" method (see Peterson et al. 2001; Raiteri et al. 2003). By performing 2000 simulations we derived a 1-σ uncertainty level in the lag of 1.1 days.

In Fig. 1, it is clear that most of the DCF signal originates from the quasi-simultaneity of the γ-ray and optical peaks of late October (JD ∼ 2 454 396-397). As for the September AGILE detection, the strong γ-ray flare lacks strictly simultaneous optical observations since it occurred at both the start of the GASP operation and the optical observing season.

We note that when the γ-ray fluxes are $\lesssim 120 \times 10^{-8}$ photons cm^{-2} s^{-1}, the corresponding optical flux densities are around 25–30 mJy. In contrast, the October γ-ray peak reaching $\sim 200 \times 10^{-8}$ photons cm^{-2} s^{-1} has an optical counterpart of 40–45 mJy (see Fig. 1). This suggests that a significant optical event occurred at the same time as the γ-ray flare and in September was missed. Moreover, while the ratio between the high and low γ-ray flux levels is about 2.5, in the optical band the same ratio is of the order of 1.5. Hence, the gamma variability appears to depend on the square of changes in optical flux density. This would favour 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 then be due to the light travel time of the synchrotron seed photons that scatter the energetic electrons.

The Spectral Energy Distribution for the AGILE and GASP-WEBT data of September 2007 is shown in Fig. 4 as green dots. The blue dashed line shows a simple SSC model that fits simultaneous observations of a ground state (see Tagliaferri et al. 2003, and references therein) and non-simultaneous EGRET data (empty blue circles). Because the high state of mid-September 2007 cannot be fitted by a one-zone SSC component alone, we used a model with two SSC components.

To the first SSC component that reproduces the ground state, we add a second SSC component that dominates the optical and γ-ray bands. Both the components are reproduced with a double power-law electron distribution: the spectral index is p_{low} from

[3] In addition to the data presented there, we show new GASP data for a couple of nights.

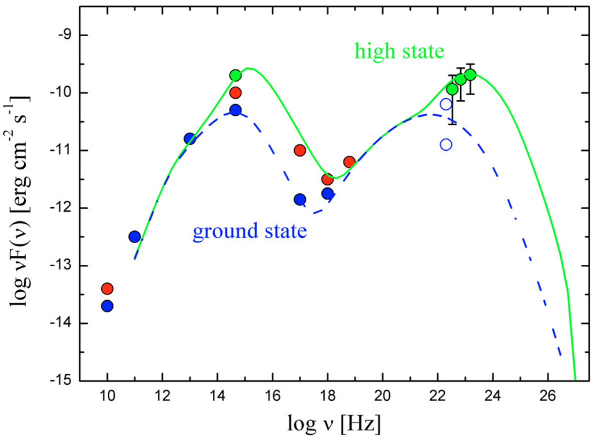

Fig. 4. The SED of S5 0716+714, including GASP-WEBT optical data quasi-simultaneous with a AGILE-GRID gamma-ray observation in September (green dots). Historical data over the entire electromagnetic spectrum relative to a ground state of the source and EGRET non-simultaneous data are represented with blue dots. Red dots represent historical data simultaneous with a high X-ray state.

Table 1. Parameters for the two SSC components.

	1st SSC comp	2nd SSC comp	Units
δ	14	25	
Γ	7.5	15	
R	40	40	[10^{15} cm]
B	1	0.5	[G]
$\gamma_{\min}$	200	3×10^3	
$\gamma_{\rm break}$	4×10^3	6×10^3	
$p_{\rm low}$	2.0	2.0	
$p_{\rm high}$	4.8	4.8	
$n_{\rm e}$	2.2	0.8	[cm^{-3}]
θ	2	2	[deg]

$\gamma_{\min}$ to $\gamma_{\rm break}$ and $p_{\rm high}$ above $\gamma_{\rm break}$. The parameters of the two SSC components are reported in detail in Table 1.

We cannot exclude a second component due to an external seed photon field, for example mirrored by a putative broad line region, which could also account for the possible 1 day time lag. Nevertheless, the large amplitude of γ-ray variability with respect to that of the optical favors a SSC explanation.

The luminosities observed in the optical and γ-ray ranges are both 10^{48} erg s^{-1}, with a dissipated power in the jet rest-frame of $2 \times 10^{43}(\delta/15)^{-4}$ erg s^{-1}. This output is significantly large with respect to other BL Lacs, and we estimate a global power transported into the jet $L_{\rm tot} > 3 \times 10^{45}$ erg s^{-1}. This may exceed the maximum power generated by a spinning black hole of mass $10^9\ M_\odot$ in most widely known models (see e.g. Cavaliere & D'Elia 2002).

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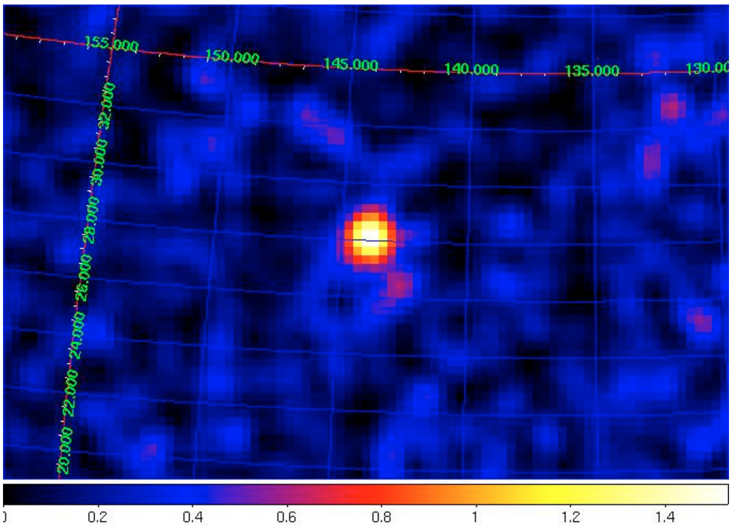

Fig. 5. Gaussian-smoothed counts map of S5 0716+714 in Galactic coordinates integrated over the observing period of most intense activity (2007 September 7 14:24 UT – 2007 September 12 12:00 UT) with the source at about 15° off-axis.