

## AGILE detection of variable gamma-ray activity from the blazar S5 0716+714 during September–October 2007

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We report the  $\gamma$ -ray activity from the Intermediate BL Lac S5 0716+714 during 2007 September–October observations by the AGILE satellite, coincident with a period of intense optical activity of the source monitored by GASP–WEBT.

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

Over the period 7–12 September, AGILE detected  $\gamma$ -ray emission from the source at a significance level of  $9.6\text{-}\sigma$  with an average flux ( $E > 100$  MeV) of  $(97 \pm 15) \times 10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ , increasing by a factor of at least four within three days. No emission was detected by Super-AGILE in the energy range 18–60 keV, with a  $3\text{-}\sigma$  upper limit of 10 mCrab in 335 ksec. The  $\gamma$ -ray flux of S5 0716+714 detected by AGILE is the highest ever detected for this blazar and one of the most intense  $\gamma$ -ray fluxes detected from a BL Lac object. The Spectral Energy Distribution (SED) of mid-September seems to be consistent with the synchrotron self-Compton (SSC) emission model, but only by including two SSC components with different variability.

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  $\text{cm}^{-2} \text{s}^{-1}$  at a significance level of  $6.0\text{-}\sigma$ .

The  $\gamma$ -ray flux during both AGILE pointings appears to be highly variable on timescales of 1 day.

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## 1. Introduction

The source S5 0716+714 was classified by Biermann (1981) as a BL Lac object, because of its featureless optical spectrum and high linear polarization. The optical continuum is so featureless that every attempt to determine the spectroscopic redshift of the source has failed; however, very recently through optical imaging of the underlying galaxy was estimated a redshift of  $z = 0.31 \pm 0.08$  (Nilsson et al. 2008).

The source belongs to the Intermediate BL Lac class according to its Spectral Energy Distribution. In fact, observations by BeppoSAX (Tagliaferri et al. 2003) 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, 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 the contemporary presence of a slowly variable Compton component and a fast and 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 has been analyzed by Raiteri et al. (2003), while the EGRET telescope onboard *CGRO* (Hartman et al. 1999) detected S5 0716+714 several times in the  $\gamma$ -rays (Lin et al. 1995). The integrated flux above 100 MeV varied between  $(13 \pm 5)$  and  $(53 \pm 13) \times 10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ .

We present the analysis of the AGILE data obtained during the S5 0716+714 observations in September–October 2007, in particular two flaring episodes: the first in mid-September, the other on 22–23 October 2007. Preliminary results were communicated in Giuliani et al. (2007) and a more detailed analysis is presented in Chen et al. (2008, in preparation).

The strong  $\gamma$ -ray flare detected by AGILE in mid-September triggered observations by the GLAST-AGILE Support Program (GASP) of the WEBT<sup>1</sup> (see Carosati et al., 2007). About one month later the GASP observed a new very bright phase of the source, triggering Swift as well as new AGILE 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 AGILE and Swift observations in October 2007 are discussed in Giommi et al. (2008). Throughout this paper the quoted uncertainties are given at the  $1-\sigma$  level, unless otherwise stated.

## 2. AGILE Observations and Data Analysis

The AGILE scientific Instrument (Tavani et al. 2008) is very compact and combines four active detectors yielding broad-band coverage from hard X-rays to  $\gamma$ -rays: a Silicon Tracker optimized for  $\gamma$ -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 0.35–100 MeV energy band (Labanti et al. 2006) and a segmented Anticoincidence System (Perotti et al. 2006).

<sup>1</sup><http://www.oato.inaf.it/blazars/webt/>; see e.g. Villata et al. (2007)

In September, the AGILE satellite was performing its Science Verification Phase and 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  $\sim 16.9$  days<sup>2</sup>.

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  $\sim 8.1$  days.

Level-1 AGILE-GRID data were analyzed using the AGILE Standard Analysis Pipeline as described in detail in Vercellone et al. (2008). Counts, exposure and Galactic background  $\gamma$ -ray maps are created with a bin size of  $0.3 \times 0.3$  for  $E > 100$  MeV. To reduce the particle background contamination we selected only events flagged as confirmed  $\gamma$ -ray events (*filtercode=5*) and all events collected during the South Atlantic Anomaly (SAA) were rejected (*phasecode=18*). We also rejected all the  $\gamma$ -ray events whose reconstructed directions form angles with the satellite-Earth vector smaller than  $80^\circ$  (*albrad=80*), reducing the  $\gamma$ -ray Earth Albedo contamination by excluding regions within  $\sim 10^\circ$  from the Earth limb.

The average  $\gamma$ -ray flux as well as the daily values were derived according to 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.

### 3. Results

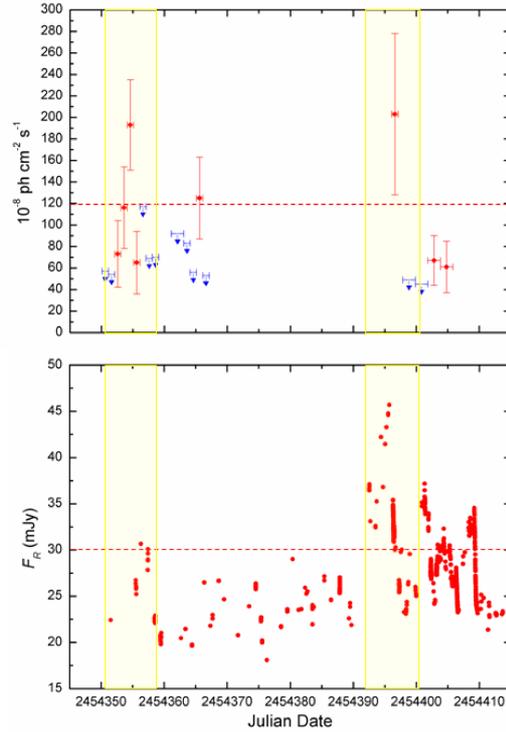
S5 0716+714 was detected by the GRID instrument onboard AGILE in the period 7–12 September 2007, with the source at about  $15^\circ$  off-axis, at a significance level of  $9.6\text{-}\sigma$  with an average  $\gamma$ -ray flux of  $F_{E>100 \text{ MeV}} = (97 \pm 15) \times 10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ , as derived from a maximum likelihood analysis. The peak level of the  $\gamma$ -ray flux is  $F_{E>100 \text{ MeV}} = (193 \pm 42) \times 10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ , showing an increase of the flux by a factor four within three days; this flux is the highest ever detected from S5 0716+714.

Super-AGILE observed S5 0716+714 between 7 and 12 September 2007 for a total on-source net exposure time of 335 ksec and the source was not detected above  $5\text{-}\sigma$  by the Super-AGILE Iterative Removal Of Sources (IROS) applied to the image, in the 20–60 keV energy range. A  $3\text{-}\sigma$  upper limit of 10 mCrab was obtained 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  $\gamma$ -ray and optical light curves is shown in Figure 1: the top panel shows the  $\gamma$ -ray light curve with 1 or 2 day resolution for photons above 100 MeV, the bottom panel shows the  $R$ -band optical light curve as 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). During the September observation the  $\gamma$ -ray flux of the source appears to be highly variable on timescales of 1 day.

Moreover, S5 0716+714 in mid-October shows increasing optical flux, reaching 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 ( $\sim 50^\circ$  from the axis) was seen by AGILE to have a high  $\gamma$ -ray flux. In particular, between

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



**Figure 1:** In the top panel, AGILE–GRID  $\gamma$ -ray light curve with 1-day or 2-day resolution for fluxes in units of  $10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$  for  $E > 100$  MeV . The downward arrows represent  $2\text{-}\sigma$  upper-limits. In the bottom panel, the  $R$ -band optical light curve as observed from GASP-WEBT. The mean flux density level is highlighted with horizontal red dashed line. The yellow shaded regions indicate the two high activity periods of the source in the  $\gamma$ -ray band.

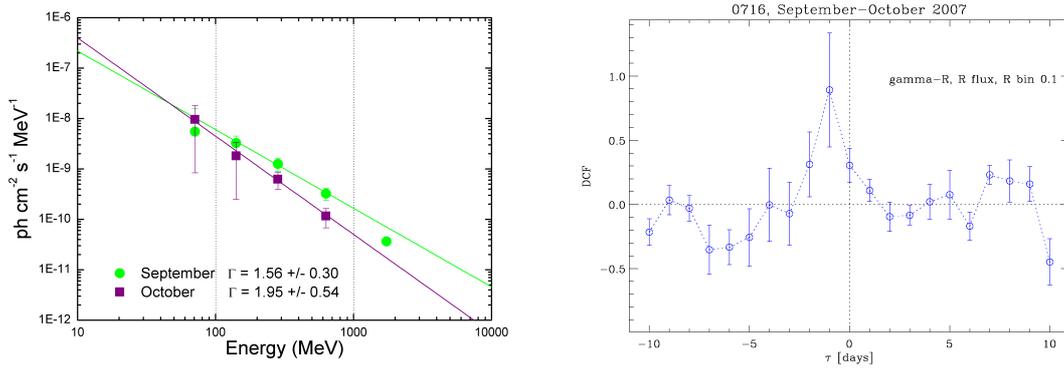
2007 October 22 12:33 UT and October 23 12:06 UT the maximum likelihood analysis provides a significance of  $4.0\text{-}\sigma$  with a flux of  $F_{E>100\text{MeV}} = (203 \pm 75) \times 10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ . Note, however, that AGILE has a high particle background at high off-axis angles, and that the exposure time is relatively short.

After this flaring episode AGILE observed the source with a dedicated repointing during the period between October 24 9:47 UT and November 1 12:00 UT, and over the entire period detected a  $\gamma$ -ray flux above 100 MeV at a significance level of  $6.0\text{-}\sigma$  with a lower average flux of  $F_{E>100\text{MeV}} = (47 \pm 11) \times 10^{-8}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ .

During the September–October observations AGILE detected S5 0716+714 at two different levels of activity. The  $\gamma$ -ray spectrum during the high activity state of mid-September can be fitted with a power law with a photon index of  $\Gamma = 1.56 \pm 0.30$ , while during the October ToO the source was in a low  $\gamma$ -ray activity state and the photon index of the differential energy spectrum is  $\Gamma = 1.95 \pm 0.54$  (see Fig. 2, left panel). The photon index was obtained with the weighted least squares method considering only 3 energy bins: 100–200 MeV, 200–400 MeV and 400–1000 MeV.

#### 4. Discussion

To analyze the gamma-optical correlation we applied the Discrete Correlation Function (DCF;



**Figure 2:** *Left panel:* 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 (purple line). *Right panel:* Discrete correlation function (DCF) between the  $\gamma$ -ray and  $R$ -band light curves for S5 0716+714 in September-October 2007.

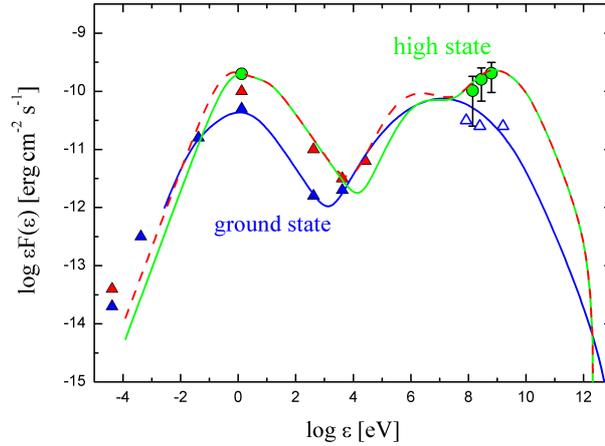
see Edelson & Krolick 1988; Hufnagel and Bregman 1992; Peterson 2001) to the  $\gamma$ -ray and  $R$ -band light curves. The  $R$ -band flux densities were averaged over 0.1 day bins to smooth the intranight variability. The DCF is a statistical method that was developed to analyze unevenly sampled data trains. The DCF displays a significant peak (DCF  $\sim 0.9$ ) at a lag of -1 day (Fig. 2, right panel). Despite the large uncertainty due to poor  $\gamma$ -ray sampling, this result suggests a possible delay of the  $\gamma$ -ray flux variations with respect to the optical ones on the order of 1 day. Looking at Fig. 1, one can see that most of the DCF signal comes from the quasi-simultaneity of the  $\gamma$ -ray and optical peaks of late October (JD  $\sim 2454396$ -397).

We notice that when the  $\gamma$ -ray fluxes are  $\leq 120 \times 10^{-8}$  photons cm<sup>-2</sup> s<sup>-1</sup>, the corresponding optical flux densities are around 25–30 mJy. In contrast, the October  $\gamma$ -ray peak reaching  $\sim 200 \times 10^{-8}$  photons cm<sup>-2</sup> s<sup>-1</sup> has an optical counterpart of 40–45 mJy (see Fig. 1). This suggests that a strong optical event simultaneous to the  $\gamma$ -ray flare was missed in September, since it occurred at the beginning of the optical observing season as well as the start of the GASP activity.

The gamma variability seems to depend on the optical flux density changes roughly quadratically and 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. In this case, the 1-day time lag in the high-frequency peak emission found from the DCF could be due to the light travel time of the synchrotron seed photons which scatter the energetic electrons.

The Spectral Energy Distribution with the AGILE and GASP-WEBT data of September 2007 is shown in Figure 3 as green dots. The blue solid line shows a simple SSC model fitting simultaneous observations of a ground state (see Tagliaferri et al. 2003 and references therein) together with non-simultaneous EGRET data (empty blue triangles). 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. Without simultaneous X-ray data the spectrum is poorly constrained, then we show two models: one with a high hard X-ray state (red dashed line) and one with a low hard X-ray state (green solid line).

The first SSC component dominates in the optical and X-ray bands and it is reproduced with a double power law electron distribution: the spectral index is  $p_{low} = 2$  from  $\gamma_{min}$  to  $\gamma_{break}$  and



**Figure 3:** The SED of S5 0716+714 including GASP-WEBT optical data quasi-simultaneous with AGILE-GRID  $\gamma$ -ray observation in September 2007 (green dots). Historical data over the entire electromagnetic spectrum relative to a ground state of the source together with EGRET non-simultaneous data is represented with blue triangles. Red triangles represent historical data simultaneous with a high X-ray state.

$p_{high} = 4.5$  above  $\gamma_{break}$ . For the high X-ray state model  $\gamma_{min} = 500$ , while the low X-ray state model has  $\gamma_{min} = 700$ ; in both cases  $\gamma_{break} = 10^3$ . The density at the spectral break is  $n_e = 40 \text{ cm}^{-3}$ , the blob radius  $R = 2 \times 10^{16} \text{ cm}$  and the magnetic field  $B = 3 \text{ Gauss}$ .

The second SSC component contributes primarily to the gamma range of the SED and, to a lesser extent, to the optical emission. The electron distribution is a single power law with  $p = 4.5$ ,  $\gamma_{min} = 4 \times 10^3$  and  $n_e = 50 \text{ cm}^{-3}$ . The blob radius is  $R = 10^{16} \text{ cm}$  and the magnetic field  $B = 1.3 \text{ Gauss}$ . Both blobs are moving with bulk Lorentz factor  $\Gamma = 15$ , at an angle of  $3^\circ$  with respect the line of sight.

We cannot exclude a second component due to an external seed photon field (e.g. mirrored by a putative broad line region) which could also account for the possible 1-day time lag, but the large amplitude of  $\gamma$ -ray variability with respect to that of the optical one favours a SSC explanation.

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## References

- [1] P. L. Biermann, H. Duerbeck, A. Eckart, et al. *Observations of six flat spectrum sources from the 5 GHz survey*, *ApJ* **247L**, 53 (1981)

- [2] D. Carosati, V. M. Larionov, L. Larionova, et al. *GASP detection of an optical flare of the blazar S5 0716+71*, *ATel* **1223** (2007)
- [3] R. A. Edelson, & J. H. Krolik, *The Discrete Correlation Function: a new method for analyzing unevenly sampled variability data*, *ApJ* **333**, 646 (1988)
- [4] M. Feroci, et al. *SuperAGILE: the hard X-ray Imager for the AGILE space mission*, *NIM A* **581**, 728 (2007) [astro-ph/07080123]
- [5] E. Ferrero, S. J. Wagner, D. Emmanoulopoulos, L. Ostorero *Disentangling the synchrotron and Inverse Compton variability in the X-ray emission of the intermediate BL Lac object S5 0716+71*, *A&A* **457**, 133 (2007) [astro-ph/0607023]
- [6] L. Foschini, G. Tagliaferri, E. Pian, et al. *Simultaneous X-ray and optical observations of S5 0716+714 after the outburst of March 2004*, *A&A* **455**, 871 (2006) [astro-ph/0604600]
- [7] P. Giommi, et al. *AGILE and Swift simultaneous observations of the blazar S5 0716+714 during the bright flare of October 2007*, *A&A* in press (2008) [astro-ph/08061855]
- [8] A. Giuliani, et al. *AGILE detection of a gamma-ray source possibly associated with Blazar TXS 0716+714*, *ATel* **1221** (2007)
- [9] R. C. Hartman, et al. *The Third EGRET Catalog of High-Energy Gamma-Ray Sources*, *ApJS* **123**, 79 (1999)
- [10] B. R. Hufnagel, & J. N. Bregman, *Optical and radio variability in blazars*, *ApJ* **386**, 473 (1992)
- [11] C. Labanti, et al. *The mini-calorimeter of the AGILE satellite*, *Proc. SPIE* **6266**, 62663Q (2006)
- [12] Y. C. Lin, D. L. Bertsch, B. L. Dingus, et al. *EGRET observations of the BL Lacertae objects 0716+714 and 0521-365*, *ApJ* **442**, 96 (1995)
- [13] J. R. Mattox, et al. *The EGRET detection of quasar 1633 + 382*, *ApJ* **410**, 609 (1993)
- [14] K. Nilsson, et al. *Detection of the host galaxy of S5 0716+714*, *A&A* accepted for publication (2008) [astro-ph/08070203]
- [15] F. Perotti, et al. *The AGILE anticoincidence detector*, *NIM A* **556**, 228 (2006)
- [16] B. P. Peterson, *Variability of Active Galactic Nuclei*, in *Advanced Lectures on the Starburst-AGN Connection Proc. Conf. Tonantzintla* (2001)
- [17] M. Prest, G. Barbiellini, G. Bordignon, et al. *The AGILE silicon tracker: an innovative  $\gamma$ -ray instrument for space*, *NIM A* **501**, 280 (2003)
- [18] C. M. Raiteri, M. Villata, G. Tosti, et al. *Optical and radio behaviour of the BL Lacertae object 0716+714*, *A&A* **402**, 151 (2003) [astro-ph/0302518]
- [19] G. Tagliaferri, M. Ravasio, G. Ghisellini, et al. *The BL Lac objects OQ 530 and S5 0716+714. Simultaneous observations in the X-rays, radio, optical and TeV bands*, *A&A* **400**, 477 (2003)
- [20] M. Tavani, G. Barbiellini, et al. *The AGILE space mission*, *NIM A* **588**, 52 (2008)
- [21] S. Vercellone, A. W. Chen, A. Giuliani, et al. *AGILE Detection of a Strong Gamma-Ray Flare from the Blazar 3C 454.3*, *ApJ* **676**, L13 [astro-ph/08021709]
- [22] M. Villata, C. M. Raiteri, T. J. Balonek, et al. *The unprecedented optical outburst of the quasar 3C 454.3. The WEBT campaign of 2004-2005*, *A&A* **464L**, 5 (2007) [astro-ph/0603386]
- [23] M. Villata, C. M. Raiteri, V. M. Larionov, et al. *Multifrequency monitoring of the blazar 0716+714 during the GASP-WEBT-AGILE campaign of 2007*, *A&A* **481L**, 79 (2008) [astro-ph/08023012]