ARGO-YBJ Experiment: Gamma Ray Astronomy results

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1. Search for Gamma Ray Bursts

The data collected by the ARGO-YBJ detector [1] in scaler mode have been analysed to search for signals from GRBs in coincidence or with some delays with respect to the prompt emission detected by satellites. Presentely ARGO-YBJ analysed 102 bursts, the largest sample of GRBs on ground in the GeV range. Up to now statistically significant GeV signals of GRB counterpart were not detected and the fluence upper limits reached values as low as $10^{-5}\ erg/cm^2$ in the $1-100\ GeV$ range [2]. Also the shower mode data have been used in a stacked analysis to put significant upper limits on the GRB fluence up to $1\ TeV$ [3].

2. Gamma ray sources

The search of γ-sources is performed using the data collected in shower mode. According to the Moon shadow analysis the detector Point Spread Function (PSF) is Gaussian for $N_{hit} \geq 100$ while an additional Gaussian is required to describe the PSF at lower multiplicities. The angular resolution for cosmic ray showers is $\sim 1.6°$, $0.82°$ and $0.66°$ for $N_{hit} \geq 40$, 100 and 300, respectively. By means of proper simulations the angular resolution for γ-induced showers has been evaluated $30-40\%$ better because of the more defined profile of the showers. The background is calculated with two different methods (time swapping and equizenith) with consistent results.

With the data analysed up to now 3 sources have been identified (Crab Nebula, Markarian 421, MGRO J1908+06) and the detection sensitivity is around 0.5 Crab unit in one year. Other hot spots are going to become statistically significant collecting more data. Sensitivity enhancement and new results are also expected thanks to more sophisticated analyses (mainly gamma/hadron separation) in progress. Furthermore the continuous data taking in a large FoV allowed the observation of transient gamma-phenomena which the Cherenkov telescopes were not in condition to see.

2.1. Markarian 421 (Mrk 421)

This Active Galatic Nucleus (AGN) is the first source detected by ARGO-YBJ (Fig. 1, top). During the flare in July and August 2006 ($E_\gamma > 0.8\ TeV$) the measured flux was 4 times higher than the Crab flux. In the first half of June 2008 another flare occurred, it has been studied from optical to 100 MeV γ-rays, and only partially up to TeV energies [4], since the moonlight hampered the Cherenkov telescope observations during the second and most intense phase of the emission. ARGO-YBJ data are available also during this second flare completing the multifrequency observations [5]. The signal intensity was about 6 Crab units ($E_\gamma > 1\ TeV$) on June 11-13, with a significance of 4.2 standard deviations. In those days ARGO-YBJ measured the following spectrum:

$$dN/dE = (3.2 \pm 1.0)\times 10^{-11}\,(E/2.5\ TeV)^{-2.1\pm0.7} \times e^{-\tau(E)}\ \gamma/cm^2/s/TeV$$

where $e^{-\tau(E)}$ is the term due to Extragalactic Background Light [6]. This spectrum does not confirm the estimate by I. Donnarumma et al. (see [4]). Its shape is consistent with the measurement by Whipple in 2000 and 2001 during a similar flare.

In February 2010 a third Mrk 421 flare was observed by ARGO-YBJ. We would like to stress that the data collected on February 16 were enough to see the source with a significance of $\sim 5\ \sigma$. This was the first time that an array observes a VHE gamma source just in one day.

A long monitor of Mrk 421 has been also performed [7] and the γ-signal shows a good correlation with X-ray emission (Fig. 1, center) without significant time delay. The TeV spectrum hardens when the flux increases (Fig. 1, bottom) according to Whipple [8]. This results are fully compatible with a γ-flux due to Synchrotron Self Compton (SSC) emission.

2.2. MGRO J1908+06

With 3-years data ARGO-YBJ observed (significance $> 5\ \sigma$) this source discovered by Milagro in 2007. The best ARGO-YBJ value for the

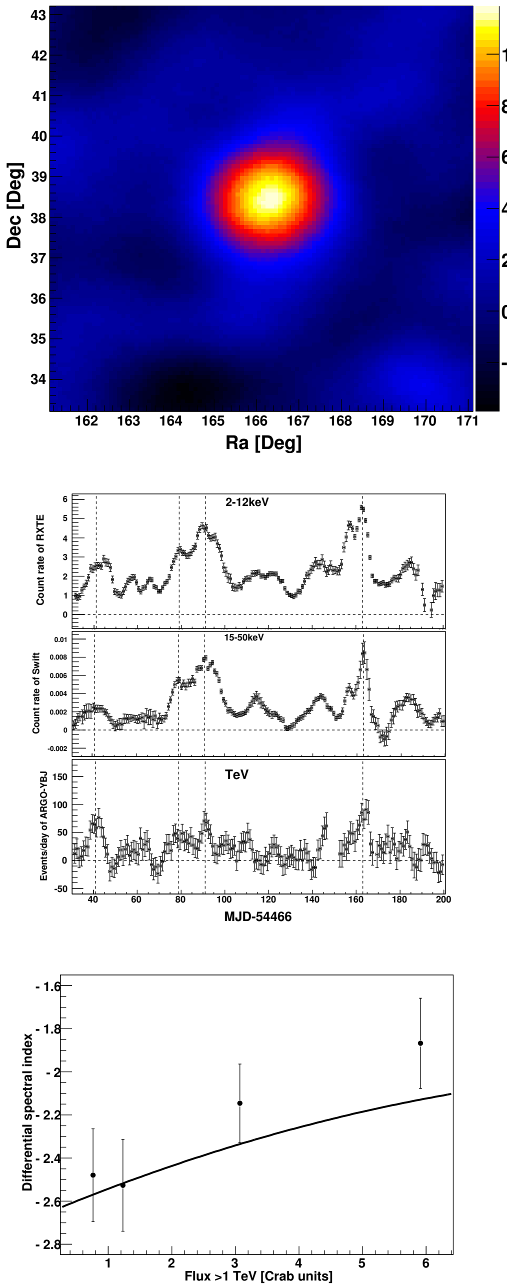

Figure 1. Mrk 421. Top: Significance map. Center: Light curve in different energy bands according to ASM/RXTE, BAT/Swift and ARGO-YBJ, respectively. Bottom: Spectral index as a function of gamma flux. The solid line is the function suggested by the Whipple experiment [8].

source extension is $\sigma_{ext} = 0.69° \pm 0.25°$. The measured spectrum is in agreement with the Milagro measurement, but only marginally consistent with HESS measurement, being the ARGO-YBJ flux a factor 3-4 higher. This result can be explained by the worst angular resolution by Milagro and ARGO-YBJ with respect to HESS, assuming a signal contamination of other extended sources close to the object measured by the HESS telescope. Another possible explanation is a variability of the source. However a long-term monitor based on the ARGO-YBJ data has shown that the signal is consistent with a stable flux, on time scales ranging from few days to months.

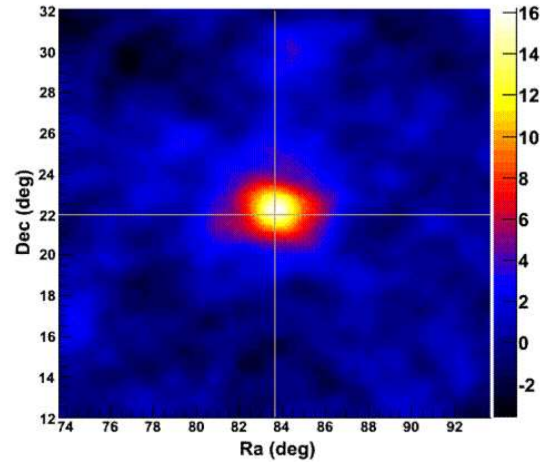

Figure 2. Crab nebula. Significance map.

2.3. Crab Nebula

ARGO-YBJ observed ($\sim 16.2\,\sigma$ in ~ 800 days, Fig. 2) also the so-called "standard candle" of γ-astronomy. The measurement of the spectrum resulted fully compatible with those by other experiments:

$$dN/dE = (3.62 \pm 0.29)\times 10^{-11}\,(E/TeV)^{-2.55\pm 0.10}\;\gamma/cm^2/s/TeV$$

In September 2010 an unexpected flare from Crab Nebula was detected by Agile and Fermi-LAT [9] in the band $0.1 - 10\ GeV$. The flare was visible also in the ARGO-YBJ data [10]. A flux increase by a factor of 3-4 compared to the non-flaring status has been detected both in the GeV and TeV range. Indeed ARGO-YBJ detected the source with a statistical significance of $4.8\,\sigma$ (Fig. 3, top) instead of $0.96\,\sigma$ as expected in 8 days for the steady regime. The statistics does not allow to calculate the spectrum but the signal is essentially at low hit-multiplicities and then we can infer that the spectrum is soft (mainly $E_\gamma < 1\ TeV$). The bottom plot of Fig. 3 shows the light-curve in the flare period with 10-day and 2-day bins. Since 2007 ARGO-YBJ never observed similar excesses. The probability that the 10-day excess is a fluctuation of the steady flux is 7×10^{-6}. Taking into account the trials the probability increases at $\sim 10^{-3}$.

Cherenkov telescopes did not confirm the ARGO-YBJ measurement [11]. Taking into account the different longitudes of the detectors and the 12-hours variability observed in the GeV range [12] this discrepancy can be explained assuming a similar variability at the TeV energy.

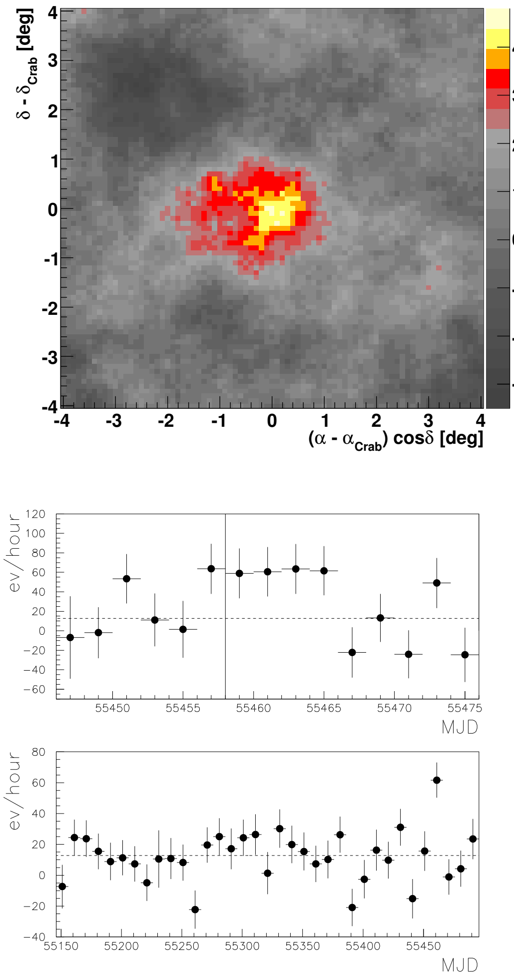

Figure 3. Crab Nebula. Top: Significance map in the flare days. Bottom: Light curves with 2-day bins (up) and with 10-day bins (down). The vertical line indicates the start time of the GeV-flare, the horizontal lines indicate the steady *TeV* emission.

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