Time-dependent search for neutrino emission from Mrk 421 and Mrk 501 observed by the HAWC gamma-ray observatory with the ANTARES data

Mukharbek Organokov$^1$, Thierry Pradier$^1$

$^1$Institut Pluridisciplinaire Hubert Curien, CNRS, France

mukharbek.organokov@iphc.cnrs.fr, thierry.pradier@iphc.cnrs.fr

Introduction

The VHE extragalactic sky is dominated by emission from blazars$^2$, a class of a radio-loud AGN$^3$. Two blazars, Mrk 421 and Mrk 501, the brightest and closest BL Lac objects known, at luminosity distances $d_L = 134$ Mpc with redshift $z = 0.031$ and $d_L = 143$ Mpc with redshift $z = 0.033$ respectively, are the first and the second extragalactic objects discovered in the TeV energy band. This analysis focuses on the search of spatial/temporal correlation between neutrinos (ν) detected by ANTARES and γ-ray emission from flares detected by HAWC from these blazars in the period November 2014 – April 2016, and reported in$^6$.

ANTARES and HAWC

The ANTARES$^4$ telescope designed to search for high-energy neutrinos ($E_\nu > 100$ GeV) from astrophysical sources by detecting the Cherenkov light emission of neutrino-induced charged particles in the very deep waters of the Mediterranean Sea. The HAWC$^5$ telescope was designed to search for high-energy γ-rays ($100$ GeV < $E_\gamma < 100$ TeV) from astrophysical sources by detecting the Cherenkov light emission of gamma-ray-induced charged particles in extensive air showers.

The ANTARES data sample: Covered period: November 26$^{th}$, 2014 – April 20$^{th}$, 2016 (MJD 56988-57497)

Effective detector livetime: 5017 days, covers same period of observation as HAWC.

Time-dependent search method

• An unbinned likelihood-ratio maximization method$^6$.

For a given direction in the sky and at a given time to determine the relative contribution of background and signal components.

$$\ln(L) = -\frac{1}{2} \sum (N_{\text{obs}} - N_{\text{model}})$$

→ $S_i$ and $B_i$: signal and background PDFs for an event i, at time $t$, energy, declination $\delta$;

→ $S_i$: $P_s(\omega) \cdot P_B(\nu) \cdot P_\delta(t)$

→ $B_i$: $P_B(\omega) \cdot P_B(\nu) \cdot P_\delta(t)$

→ $N_{\text{obs}}$ and $N_{\text{model}}$: unknown signal events and known background rate (a priori when building the L)

→ The energy PDF for the signal event is produced according to the studied energy spectra: $E^{-2.0}$, $E^{-2.25}$, $E^{-2.5}$ exp($-E/1$ PeV) for both sources and extra $E^{-2.25}$ for Mrk 501.

→ The signal time PDF shape is extracted directly from the γ-ray light curve assuming a proportionality between the γ-ray and the ν fluxes. Several flare selection conditions considered: all pass thresholds: average flux, average flux × 3σ, average flux × 2σ.

→ Test Statistic: Evaluated by generating pseudo-experiments simulating background and signal around the considered source. $L_{\text{nu}}$ is maximized w.r.t $N_\nu$ parameter.

Light curves of blazars

Analysis performance

• Injection of neutrinos ideally only on the selected flare periods ⇒ raise loss of neutrinos, because the probability to arrive outside this period ⇒ derived $N_\nu$ required for discovery for the selected peaks is then rescaled as if like neutrinos injected on all flares.

• Conversion $N_\nu \rightarrow F$, the equivalent source flux, is done through the acceptance of the detector.

Results

• Neutrino energy flux sensitivities at 90% C.L.

→ lowest flux with all flares.

Ex.: Mrk 421 with $E^{-2.0}$

5σ level discovery fluxes vs threshold vs $\Lambda$

→ lowest flux with average flux ≤ 2σ flares.

Ex.: Mrk 421 with $E^{-2.0}$

90% C.L. flux sensitivities vs threshold vs $\Lambda$

Conclusion

The HAWC detector operates nearly continuously and it is currently the most sensitive wide FOV γ-ray telescope in the very promising HE band ~ 0.1 and ~ 100 TeV. Therefore, it opens prospects to study the most energetic astrophysical phenomena in the Universe as well as to understand the mechanisms that power them and endeavor to break the mystery of their origin. Taking into account the flare timing information given by γ-ray observations should improve the efficiency of the search for a ν counterpart with ANTARES. The next generation KM3NET neutrino telescope will provide more than an order of magnitude improvement in sensitivity. Therefore, such sources are promising candidates as HE ν emitters for an improved future time-dependent search.

References

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