Search for neutrino emission of gamma-ray flaring blazars with the ANTARES telescope

Damien Dornic (IFIC/Valencia/Spain)

ICRC Beijing – August 2011
THE ANTARES EXPERIMENT

- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking PMTs, axis at 45° to vertical;
- 2475 m deep.

- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs
- 40 km cable to shore

Junction Box

25 storeys, 348 m
14.5 m
100 m
~ 70 m

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TIME-DEPENDENT ANALYSIS

Use the time information provided by other multimessenger experiments (Swift, Fermi, HESS…) directly in the analysis:
  * Space-time coincidences reduce effectively the background
  * Improve the discovery potential over a time integrated search

→ Method: unbinned search using likelihood ratio (triggered ⇔ 1 free parameter, $n_s$)

\[
\lambda = \sum_{i=1}^{N_{\text{event}}} \log \frac{P(x_i | H_{\text{sig+bkg}})}{P(x_i | H_{\text{bkg}})}
\]

\[
\lambda = \sum_{i=1}^{N_{\text{event}}} \log \frac{\frac{n_s}{N} P_{\text{sig}} (\alpha_i, \delta, t_i) + \left(1 - \frac{n_s}{N}\right) P_{\text{bkg}} (\alpha_i, \delta)}{P_{\text{bkg}} (\alpha_i, \delta)}
\]

Optimization: minimum neutrino flux to have a 5 sigma discovery

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MC nu+anu

γ-ray LC

Signal: $P_{\text{sig}} (\alpha_i, \delta, t_i) = P_{\text{dir}} (\alpha_i, \delta) \times P_{\text{time}} (t_i)$

Noise: $P_{\text{bkg}} (\alpha_i, \delta, t_i) = (\Omega(\alpha_i, \delta))^{-1} \times P_{\text{time}} (t_i)$

Extracted from data

(2008 data ~61 days)
**INGREDIENTS**

**Angular resolution:** 0.4 ± 0.1 degree  
Estimated from MC, but constrained using data

**Comparable to IceCube,** despite much smaller size detector => advantage of water over ice

Upgoing event selection using the track fit quality parameter, $\Lambda > -5.4$ + the error estimate of the track, $\beta < 1^\circ$

Distribution for upgoing events of lambda in both data and atmospheric Monte Carlo samples
TIME DISTRIBUTIONS

Once normalized to an integral equal to 1, the distribution for all reconstructed events is used as the time PDF for the background.

Selected events ($\Lambda > -5.4 + \beta < 1^\circ$)
PERFORMANCES

→ Analysis of 2008 ANTARES data (4 months from September to December)
→ Performance: average number of events required for a $5\sigma$ discovery (50% prob) produced in one source as a function of the width of one flare period.

![Graph showing performance improvement](image)

Improvement by a factor 2-3 compared to a standard analysis
γ-RAY FLARING BLAZARS

Fermi LAT data:
Many sources show important time variabilities at HE …

→ Search for signal from blazars AGN – candidate sources for UHECR
p-γ or p-p interactions ➔ strong correlation between γ-ray and neutrino fluxes
+ Larger photon density + Larger magnetic field ➔ enhancement of the neutrino production

[No HESS, MAGIC and VERITAS TeV flare found in the end of 2008]
FLARE IDENTIFICATION

**Fermi LAT data**: Identification of the flare periods on AGNs

1) $\gamma$-ray sources: Variable and energetic blazars
2) 1-day binned light curve (fit files from Fermi website)
3) Flare (↔ HE state) periods: robust and simple method
   - Extraction of a baseline + error
   - Prior: $(\text{flux-erflux}) > \text{(baseline+2*sigma)} + \text{flux} > \text{(baseline+3*sigma)}$
   - Duration: add consecutive points to the prior $(\text{flux-erflux}) > \text{(baseline+sigma)}$
     add +/- 0.5 day to each flare (1-day binned LC + uncertainties models)

PKS1510-089

3C279

3C454.3
| Source       | visibility | timePDF (MJD+54000)                                                                 | Live time (day) | N(5σ) | Nobs | Fluence U.L. GeV/cm² |
|--------------|------------|-------------------------------------------------------------------------------------|-----------------|-------|------|---------------------|
| 0208-512     | 1.0        | 712-5, 722-4, 745-7, 750-2, 753-7, 764-74, 820-2                                    | 8.8             | 4.5   | 0    | 2.8                 |
| 0235+164     | 0.41       | 710-33, 738-43, 746-64, 766-74, 785-7, 805-8, 810-2                                | 24.5            | 4.3   | 0    | 18.7                |
| 1510-089     | 0.55       | 716-9, 720-5, 726-35, 788-90, 801-3                                              | 4.9             | 3.8   | 0    | 2.8                 |
| 3C273        | 0.49       | 714-6, 716-8, 742-5                                                              | 2.4             | 2.5   | 0    | 1.1                 |
| 3C279        | 0.53       | 749-51, 787-809, 812-5, 817-21, 824-6                                            | 13.8            | 5.0   | 1    | 8.2                 |
| 3C454.3      | 0.41       | 713-51, 761-5, 767-9, 784-801                                                    | 30.8            | 4.4   | 0    | 23.5                |
| OJ287        | 0.39       | 733-5, 752-4, 760-2, 768-70, 774-6, 800-2, 814-6                                  | 4.3             | 3.9   | 0    | 3.4                 |
| 0454-234     | 0.63       | 743-5, 792-6, 811-3                                                              | 6.0             | 3.3   | 0    | 2.9                 |
| WComae       | 0.33       | 726-9, 771-3, 790-2, 795-7, 815-7                                                | 3.9             | 3.8   | 0    | 3.6                 |
| 2155-304     | 0.68       | 753-5, 766-8, 799-801, 828-30                                                    | 3.1             | 3.7   | 0    | 1.6                 |
Results from the 2008 data (61 days):

$\Rightarrow$ 1 neutrino compatible with the time/space
distribution ($\Delta \alpha = 0.56^\circ$) of 3C279 with
probability 10% after trials

$\Rightarrow$ Compatible with background fluctuations
SUMMARY

✓ First time-dependent search for cosmic neutrinos using a subsample of 2008 ANTARES data
✓ Transients: time-dependent more sensitive than standard point-source search
✓ Search applied to 10 very bright and variable Fermi LAT blazars. Most significant correlation of a flare: 3C279 for which 1 neutrino event is detected in time/space coincidence with the gamma-ray emission (10% probability).

Data analysis in progress:
Nearly 3000 neutrino candidates detected since the beginning of 2008

γ-ray sky: variable
Very important flares detected by Fermi the last 2 years