Outline

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2. Transient Point Sources
3. GRB Analysis
4. $\mu$-quasar Analysis
5. AGN Analysis
6. Conclusions
The ANTARES Neutrino Telescope
The ANTARES Neutrino Telescope

ANTARES is a Neutrino Telescope placed underwater in the sea bed of the Mediterranean Sea at the south of Toulon (France)
The ANTARES Neutrino Telescope

- String-based detector;
- Downward-looking (45°) PMTs;
- 2475 m deep;

- 12 detection lines
- 25 storeys/line
- 3 PMTs/storey
- 885 PMTs

40 km cable to shore
Detection Mechanism

Atmospheric muons \( \sim 10 \) per second

Atmospheric neutrinos few per day

Cosmic neutrinos few per year (may be)

- Atm muons: quite easy to remove (zenith + quality cuts)
- Atm neutrinos: irreducible isotropic background, low energy
ANTARES Performance

- 12-line data taking since 2008
- ~7000 detected neutrinos
- Median angular resolution 0.3-0.4° above ~10 TeV
- Effective area ~1m² @30 TeV
- Visibility of 3/4 of the sky, most of the galactic plane
- Real-time data processing
Transient Analyses

- ANTARES can perform a wide range of analyses
- Point Source analyses: discovering of astrophysical neutrino sources
- **Multi-messenger study**: Variable light emission sources time info as expected time for neutrino signal
- Improved performance with respect to not using time info at all

![Signal needed for a 5σ evidence the 50% of the times VS flare length](image-url)
Transient Physics

- Motivation: link CR/ν/γ via Fermi mechanism
- “Leptonic”, “Hadronic” and “Lepto-Hadronic” models
- Open questions over jet composition: relativistic fraction, maximum energies, CRs and UHECRs origin...

![Diagram of transient physics](image_url)
Transient Physics

Coincidence of $\gamma$ and neutrino emission: different transient sources can be analyzed

1. **GRBs**: Most energetic known events in the Universe (sec ↔ days)
2. **$\mu$-quasars**: Galactic variable sources (hours ↔ months)
3. **AGNs**: Extra-galactic variable sources (hours ↔ months)
Optical Counterparts

Supported by multi-wavelength telescope observations:

- **Satellites**: Rossi RXTE/ASM and Swift BAT/XRT for X-Rays and FermiLAT for γ-Rays
- **IACT**: HESS, MAGIC, VERITAS for HE and UHE γ-Rays
GRB selection

- Stacked GRBs within 2008 – 2011
- Long GRB selection only (short GRB class much less understood)
- 296 long GRBs (6.55 hours)
- Multi-messenger info provided by FERMI, SWIFT and GCN (Gamma-ray Coordinates Network) alerts.

Sky distribution of the selected 296 gamma-ray bursts in equatorial coordinates. The photon fluence of each burst is indicated by the colors.
GRB analysis

- Extended Maximum Likelihood search quality cut optimized per GRB highest discovery probability
- GRB simulations of expected neutrino fluence: NeuCosmA [Hümmer et al. (2010)] and Guetta [Guetta et al. (2004)] model spectra
- Quality cut optimized for NeuCosmA model

NeuCosmA and Guetta spectra. Thick: sum of the 297 individual spectra

Sample of discovery power curves for GRB110918
GRB results

- No event found in stacked GRB search windows
- Expected events: 0.48 (Guetta), 0.061 (NeuCosmA), 0.05 (bkg)
- Improvement in ANTARES upper limits with respect previous analysis

Upper limits @90% C.L. (dashed) for Guetta and NeuCosmA
Grey: previous limit, 40 GRBs (Adrián-Martínez et al., 2013 / JCAP 1303 (2013) 006)
μ-quasar selection

- Six μ-quasars with X-ray or γ-ray outbursts in the 2007-2010 satellite data:
  - Circinus X-1
  - GX339-4
  - H 1743-322
  - IGRJ17091-3624
  - Cygnus X-1
  - Cygnus X-3

- ν-search for 4 black hole binaries split in two:
  - during hard X-ray states: “slow” steady jet
  - during transition hard ↔ soft: “fast” discrete ejection
- Cyg X-3: γ-ray outburst using Fermi/LAT data
- Cir X-1: X-rays + orbital phase/jet connection
μ-quasar selection

ANTARES skymap for the 3058 neutrino candidates in the case of a $\lambda_{cut} > -5.2$ in equatorial coordinates (ANTARES events and studied μ-quasars)
μ-quasar analysis

- ANTARES data period 2007 - 2010 (813 live time days)
- Multi-messenger info provided by SWIFT, ROSSI and FERMI.
- Optimization cuts selects 3058 neutrino candidates ($\lambda_{cut} > -5.2$) and 5709 neutrino candidates ($\lambda_{cut} > -5.4$)

X-ray light curves of GX 339-4 between 2007 and 2010 (hard state and hard to soft transition filled areas)
μ-quasar results

- No neutrino found in time coincidence with μ-quasars
- Upper limits on neutrino flux (F.C. @90% C.L.)

<table>
<thead>
<tr>
<th>Source</th>
<th>nsig</th>
<th>Livetime (days)</th>
<th>Fluence U.L. 90% C.L.</th>
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<td>GX 339-4 (HS)</td>
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<td>H1743-322 (TS)</td>
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<td>IGRJ17091-3624</td>
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<td>21.3</td>
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<td>Cyg X-1 (HS)</td>
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<td>Cyg X-1 (TS)</td>
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<tr>
<td>Cyg X-3</td>
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<td>5.7</td>
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AGN selection

- First AGN ANTARES analysis (Astropart. Phys. 36 (2012) 204)
- High variability, brightness and visibility Fermi blazar sources (reported in 1FGL and LBAS catalogs)

<table>
<thead>
<tr>
<th>Source</th>
<th>Class</th>
<th>Redshift</th>
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AGN analysis

- From September 6th to December 31st, 2008 (60.8 hours)
- $\gamma$-Ray light curves from FERMI.

$\gamma$-Ray light curve sample for 3C 279 during studied period
AGN results

- One neutrino event compatible with 3C 279 in time and direction ($\Delta \alpha = 0.56^\circ$) $\rightarrow$ post trial value 10%
- Upper limits on neutrino flux (F.C. @90% C.L.)

<table>
<thead>
<tr>
<th>Source</th>
<th>$n(5\sigma)$</th>
<th>$n_{\text{obs}}$</th>
<th>Fluence U.L. 90% C.L.</th>
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<tr>
<td>AO 0235+164</td>
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<tr>
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<tr>
<td>WComae</td>
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<tr>
<td>PKS 1510-089</td>
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<td>3C 454.3</td>
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<tr>
<td>PKS 2155-304</td>
<td>3.7</td>
<td>0</td>
<td>1.6</td>
</tr>
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</table>

Neutrino event during 3C 279 flare
AGN analysis prospects

Updated analysis 2008 - 2012:

- Multi-messenger data: Fermi and IACT (HESS/MAGIC/VERITAS)
- Selection of 41 sources and 6 specially significant flares from FERMI photon counting data
  - Inclusion of IACT bibliography collected flares
  - Developed a Maximum Likelihood Block method for denoising FERMI photon counting light curves for flaring states identification
  - Various energy spectra taken in consideration: $E^{-2}$, $E^{-2}$ with cutoffs @1 TeV and 10 TeV, $E^{-1}$
  - Implementation of a possible lag in $\nu/\gamma$ signal in the likelihood for avoid missing short flares
  - ...

- Unblinding in process
AGN analysis prospects

Photon counting map and light curve for 3C 279 from Sep’08 to Dec’11
### AGN analysis prospects

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- ...
- **Unblinding in process**
Conclusions

1. ANTARES is the biggest neutrino telescope underwater and the biggest in the northern hemisphere.

2. High duty cycle and an instantaneous field of view of $2\pi$, including the galactic center.

3. Transient and multi-messenger analyses are performed.


5. First results on $\mu$-quasar analysis with ANTARES (2007-2010).

Thank you for your attention