ANTARES neutrino telescope

-18 km

-2500 m
**ANTARES**

- String-based detector;
- Downward-looking (45°) PMTs;
- 2500 m deep;
- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

40 km cable to shore

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XRB, γRB: hadronic?

GeV-TeV γ-ray detections => emission of outflow containing particles accelerated away from the compact object up to relativistic speeds. HE radiations -> interaction of this outflow with wind/radiation of the companion star.

Cosmic rays can also be accelerated together with the electrons but are more difficult to see (less radiation, longer acceleration time...).

The non-thermal emission of the system is surely dominated by leptonic processes but a hadronic component could also be present (not necessary to have jets).

As usual only few indications of hadronic component in XRB, only few cases:


Detection of neutrinos => smoking gun for the presence of hadronic processes
Neutrinos from XRB

**Hadronic models**


Neutrinos from XRB, γRB

1st analysis: Looking for a point-like source signal using 9 years of data [2007-2015, 2423.6 days] - all-flavour neutrino search ($\nu_e+\nu_\mu+\nu_\tau$)

<table>
<thead>
<tr>
<th>Name</th>
<th>$\delta[\degree]$</th>
<th>$\alpha[\degree]$</th>
<th>$\mu_{\text{sig}}$</th>
<th>$\Phi_0^{90%}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CirX-1</td>
<td>-57.17</td>
<td>230.17</td>
<td>–</td>
<td>0.84</td>
</tr>
<tr>
<td>GX339-4</td>
<td>-48.79</td>
<td>255.70</td>
<td>–</td>
<td>0.63</td>
</tr>
<tr>
<td>LS5039</td>
<td>-14.83</td>
<td>276.56</td>
<td>–</td>
<td>1.19</td>
</tr>
<tr>
<td>SS433</td>
<td>4.98</td>
<td>287.96</td>
<td>–</td>
<td>0.99</td>
</tr>
<tr>
<td>HESSJ0632+057</td>
<td>5.81</td>
<td>98.24</td>
<td>2.7</td>
<td>2.40</td>
</tr>
</tbody>
</table>

<= small fluctuation <2σ

(in units of $10^{-8}$ GeV cm$^{-2}$ s$^{-1}$)
Gain in sensitivity by looking at space/time correlation (~2-3)
Choose the more appropriate periods to look for neutrinos
Neutrino emission is assumed to be correlated with hard X-ray outbursts (natural in the case of μ-quasars).

Selection of 36 XRBs exhibiting outburst periods between 2008-2016 from the Swift and MAXI catalogues, extended with RXTE/ASM data when available.

In Transition State periods, even more favourable conditions but difficult to be identified. So, we have used ATels and papers as references.

$P_{\text{sg}}(t)$ sample for GX 1+4, made up with flares registered by SWIFT, Rossi and MAXI.
Source and flare selection: γRBs

HE emission due to interaction of pulsar wind with the intense stellar wind of the companion massive star.

Four γ-RBs compatible with ANTARES up-going visibility selected:


<table>
<thead>
<tr>
<th>Name</th>
<th>RA (°)</th>
<th>DEC (°)</th>
<th>Period (days)</th>
<th>Flaring phase</th>
<th>Periastron (MJD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1FGL J1018.6–5856</td>
<td>154.7</td>
<td>-58.9</td>
<td>16.58±0.02</td>
<td>0.70–0.40</td>
<td>55387.5±0.4</td>
</tr>
<tr>
<td>HESS J0632+057</td>
<td>98.2</td>
<td>+5.8</td>
<td>315±5</td>
<td>0.20–0.45</td>
<td>54587.0±0.5</td>
</tr>
<tr>
<td>LS 5039–63</td>
<td>276.6</td>
<td>-14.8</td>
<td>3.91±8·10⁻⁵</td>
<td>0.45–0.95</td>
<td>51942.59±0.05</td>
</tr>
<tr>
<td>PSR B1259–63</td>
<td>195.7</td>
<td>-63.8</td>
<td>1236.7±2·10⁻⁵</td>
<td>0.92–0.08</td>
<td>55545.0±0.5</td>
</tr>
</tbody>
</table>

(TeV measurements for **LS 5039–63**)

**Cyg X–3** XRB detected outbursting at γ-ray energies by Fermi-LAT (A. Bodaghee et al., ApJ 2013). Flaring periods: ON/OFF periods Y+ and Y− reported in the reference + #ATel 8591 and 9502.
Preliminary sensitivities

All-flavour time-dependent point-like source search using 2008-2016 data (2412 days).

=> Preliminary sensitivities using only muon neutrino sample (+30% including all-flavour neutrinos)

\[
\frac{dN}{dE} = \Phi_0^{90\%} (E/\text{GeV})^{-2}
\]

\[
F^{90\%} = \Delta t \int_{E_{5\%}}^{E_{95\%}} E \cdot \frac{dN}{dE} \cdot dE
\]

<table>
<thead>
<tr>
<th>Name</th>
<th>RA</th>
<th>DEC</th>
<th>(\Phi_{0}^{90%})</th>
<th>(10^{-6} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} )</th>
<th>(\Phi_{90%})</th>
<th>(10^{-6} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1FGL J1018.6−5856</td>
<td>154.7</td>
<td>-58.9</td>
<td>0.5</td>
<td>6.8</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>HESS J0632+057</td>
<td>98.2</td>
<td>-5.8</td>
<td>1.6</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>LS 5039−63</td>
<td>276.6</td>
<td>-14.8</td>
<td>1.1</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>PSR B1259−63</td>
<td>195.7</td>
<td>-63.8</td>
<td>3.0</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Cyg X−3</td>
<td>308.1</td>
<td>+41.0</td>
<td>146</td>
<td>18</td>
<td>18</td>
<td>18</td>
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<tr>
<td>SWIFT J1139.2−6227</td>
<td>234.8</td>
<td>-62.5</td>
<td>S(#1)</td>
<td>50</td>
<td>6.6</td>
<td>6.6</td>
</tr>
<tr>
<td>SWIFT J1745.1−2624</td>
<td>266.3</td>
<td>-26.4</td>
<td>S(#1)</td>
<td>10</td>
<td>9.6</td>
<td>9.6</td>
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<tr>
<td>SWIFT J1842.5−1124</td>
<td>280.6</td>
<td>-11.4</td>
<td>S(#1)</td>
<td>4.8</td>
<td>10</td>
<td>10</td>
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<tr>
<td>SWIFT J1910.2−0546</td>
<td>287.6</td>
<td>-5.8</td>
<td>S(#1)</td>
<td>29</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>V404 Cyg</td>
<td>306.0</td>
<td>33.9</td>
<td>S(#1)</td>
<td>29</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>XTE J1752−223</td>
<td>268.1</td>
<td>-22.3</td>
<td>S(#1)</td>
<td>22</td>
<td>17</td>
<td>17</td>
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<tr>
<td>XTE J1810−189</td>
<td>272.6</td>
<td>-19.1</td>
<td>S(#1)</td>
<td>22</td>
<td>17</td>
<td>17</td>
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<tr>
<td>XTE J1946+274</td>
<td>296.4</td>
<td>27.4</td>
<td>S(#1)</td>
<td>48</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>
In the case of Cyg X-1, non-thermal emission of Cyg X-1 comes from static corona model without presence of relativistic outflows (Romero et al, A&A 2010).

Preliminary sensitivities


Cyg X-1

Circ X-1


\( \Gamma > 22, \theta < 3^\circ, D=9.4 \text{ kpc} \)

Circ X-1


\( 1.076<\Gamma <5, \theta < 20^\circ, D=7.8 \text{ kpc} \)

MAXI J1659-152
In the case of $\mu$-quasar: we use the model of Levinson et al, PRL 2001, Distefano et al, ApJ 2002, to constrain the parameter space

$\Rightarrow$ Prediction of the neutrino energy flux based on the radio luminosity of the jets observed in radio during flares.
In Zhang et al. MNRAS (2010), neutrinos are produced in p-γ interactions assuming primary spectrum of the injected particles in the jets has spectral indexes $-1.8 > \alpha > -2.0$ and that the ratio between proton and electron energy is equal to 1 and 100.
In the case of XRB without relativistic jets, Anchordoqui et al. ApJ (2003) predict that protons can be accelerated in the gaps in the magnetosphere of accreting NS and can impact onto the accretion disk, finally producing high-energy neutrinos under specific conditions of disk density.
2nd generation KM3NeT telescope

**ORCA:** South of Toulon [construction 2017-2020]: Low-energy array 3-300 GeV
=> Neutrino oscillation properties (mass hierarchy), dark matter, low-energy astro...

**ARCA:** South of Sicily [construction 2016-2023]: High-energy array 300 GeV-30 PeV
=> Astronomy, dark matter...

~30-50 better than ANTARES at high-energy
Conclusions

• ANTARES: 11 years of continuous data-taking. Still the best neutrino observatory to study the southern sky (GC region)

• Search for all-flavour neutrinos in space/time correlation with XRB and γRB.
  ⇒ The limits start to arrive to the level where we can constrain the “optimistic” hadronic models

• The construction of KM3NeT has started in Italy (ARCA) and in France (ORCA).