Searches for Neutrino Point Sources with AMANDA and IceCube

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Astronomical Messengers

Astrophysical beam dump

Log(E) GeV

Neutrinos
Photons
Protons

p
π^0
π^+, π^-
ν_μ
ν_e
γ
µ
e
IceCube

IceTop

Currently 40 Strings

2007-08: 18 Strings

2006-07: 13 Strings

2005-06: 8 Strings

2004-05: 1 String

In-Ice Array

80 Strings
60 Modules
17 m between modules

AMANDA

19 Strings
677 Modules

Optical Cherenkov Detection
The IceCube Collaboration
32 Institutions, ~250 members
Moon Shadow

4.2σ deficit of events from direction of moon in the IceCube 40-string detector (3 months of data) confirms pointing accuracy

Calibration with moon ~monthly with completed IceCube detector
Upgoing Events

IceCube 22 String:
5114 neutrino candidates in 276 days livetime

AMANDA: 6595 $\nu$ candidates in 3.8 live-years
Search for Extraterrestrial Neutrinos

- Use unbinned maximum-likelihood search method
  - Incorporate event angular resolution and event energy estimate

\[ L(\vec{x}, n_s, \gamma) = \prod_{i=1}^{N} \left( \frac{n_s}{N} S_i + (1 - \frac{n_s}{N}) B_i \right) \]

\[ \lambda = -2 \cdot \text{sign}(\hat{n}_s) \cdot \log \left[ \frac{L(\vec{x}, 0)}{L(\vec{x}, \hat{n}_s, \hat{\gamma})} \right] \]
AMANDA All-Sky Search

Max Significance
\( \delta = 54^\circ, \alpha = 11.4h \)
\( 3.38\sigma \)

95 of 100 data sets randomized in RA have a significance \( \geq 3.38\sigma \)

<table>
<thead>
<tr>
<th>Source</th>
<th>( \mu_{90} )</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab</td>
<td>9.27</td>
<td>0.10</td>
</tr>
<tr>
<td>MGRO J2019+37</td>
<td>9.67</td>
<td>0.077</td>
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<tr>
<td>Mrk 421</td>
<td>2.54</td>
<td>0.82</td>
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<tr>
<td>Mrk 501</td>
<td>7.28</td>
<td>0.22</td>
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<tr>
<td>LS I +61 303</td>
<td>14.74</td>
<td>0.03</td>
</tr>
<tr>
<td>Geminga</td>
<td>12.77</td>
<td>0.0086</td>
</tr>
</tbody>
</table>

\( E^2\Phi < \mu_{90} \times 10^{-11} \text{ TeV cm}^{-2} \text{ s}^{-1} \)

The probability of obtaining \( p \leq 0.0086 \) for at least one of the 26 sources is 20%
AMANDA Milagro Stacking Search

Improves per-source flux sensitivity and discovery potential by a factor of 4 compared to a fixed-point search for any of the six sources

AMANDA: Minor upward fluctuation (p = 20%)
Search of the Galactic Plane with IceCube-22 + AMANDA

Optimized for low energy
No significant excess observed
IceCube 22 String

Hottest spot found at r.a. 153°, dec. 11°

pre-trial p-value: $7 \cdot 10^{-7}$ (4.8 sigma)
est. nSrcEvents = 7.7  est. gamma = 1.65

Accounting for all trials, p-value for analysis is 1.34%  (2.2 sigma).

At this significance level, consistent with fluctuation of background.
Out of 10,000 trials of scrambled data sets, 67 (0.67%) have a test-statistic (max \( \text{I} \ll \text{h Ratio} \) or \( p \)-value of hottest spot) more significant than that found in the data.

Including trial factor of two since the analysis with the a priori list was also performed, the \textbf{post-trials} \( p \)-value is \( \sim 1.34\% \).

Future IceCube data will test the possibility that the hotspot is a source unless it is a \textbf{one-time occurrence}.  

None of the events contributing most strongly to the hotspot are closer together than 10 days. Events are distributed roughly evenly in time over the year.

Neither analysis finds any significant single cluster of events in time.
Conclusions

• New methodology and increasing detector size are improving the current neutrino point source sensitivity

• No evidence of neutrino point sources observed by AMANDA in 3.8 years of livetime.

• The hotspot observed by IceCube-22 will be tested with data from IceCube-40