Detecting extragalactic SNe @ South Pole

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Why South Pole

• IceCube „lab“ has been completed – significant (positive) experience with deployment & operation

• Very clear, pure & stable detection medium

• Cost-effective option for Megaton instrumented volume with 10 MeV threshold
Detecting nearby supernovae

Kistler et al.

Generic neutrino prediction (scaling from SN1987A)

$10 \text{ Mton} \Rightarrow \geq 2 \text{ SNe/yr}$!
SN Science with neutrinos

• Directly probe of core collapse, e.g. black hole vs neutron star
• Rate of SNe (e.g. no dust obscuration)
• Neutrino-mass hierarchy & QCD phase transition.
• Early triggers for follow-up to catch very early phase.
• Gravitational detectors: Coincident search ~3000 times more significant.

SN 1987A
Gravitational Collapse: Black Hole vs Neutron Star

Yang, Lunardi, arXiv:1103.4628v1

NS formation: TBP-Model, LL-Model

dark SNe from Black Hole formation

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Detector consideration

3000 photons for 15 MeV neutrino
⇒ very dense instrumentation needed

Simulation using IceCube software:
- 2200 – 2500 m depth
- 61 strings
- variable string spacing
- Variable number of sensors
  (23000 – 91000 HQE 10'' PMTs)
- ν-events: \( N_{\text{hits}} \geq 5 \)
Shallow ice?

• In the early nineties, 4 AMANDA (A) strings where deployed between 800-1000 m
Shallow ice?

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Random walk:

\[
\mu(d) \propto \frac{1}{d} e^{-d/\sqrt{\lambda_{att}}}
\]

\[
\lambda_{att} = \sqrt{\lambda_{absorb} \lambda_{scat}} / 3 \approx 7 \text{m}
\]
Detector simulation (shallow ice)

Special simulation:
• 61 strings
• 300 m long strings
• 23000 10'' HQE-PMTs

ν-events: $N_{\text{hits}} \geq 5$
Effective volume for SN neutrinos as a function of string spacing for $N_{\text{hits}} \geq 5$

- **61 strings**
- **Shallow & 22875 sensors**
- **Deep & 91500 sensors**
- **Deep & 22875 sensors**
Supernova Detection rate

Supernova Rate

Detection probability

SNe detections per year for diffuse ice with $N_\nu \geq 3$ assuming observed SN rate:

Rate based on star formation: $\sim 10$ yr$^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>$N_\nu \geq 3$</th>
<th>$N_\nu \geq 10$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBP model</td>
<td>3.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Dark SNe (0.1 of all)</td>
<td>1.4</td>
<td>0.15</td>
</tr>
</tbody>
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PINGU - Phased IceCube Next Generation Upgrade

Utilizing existing infrastructure & experience for a large, low energy neutrino-detector

First stage ("PINGU-I")
- ~20 extra strings for $E_{\text{thresh}} \sim 1$ GeV
- WIMP search, $\nu$-oscillation,...
- test bed for new technologies

Second stage ("PINGU-II")
- New photon detection technology, $E_{\text{thresh}} \sim 10$ MeV
- Costs comparable to IceCube
- supernovae, proton decay,...

Proto-Collaboration forming, if interested:
http://www.mailman.srv.ualberta.ca/mailman/listinfo/beyonddc
R&D for larger/cheaper photo-sensors

- KM3Net-like design by P. Kooijman et al.
- WLS as light catchers?
- IceCube DOMs
- Abalone PMTs, Ferenec et al.
Conclusion

• IceCube/DeepCore provides a unique „lab“ infrastructure to exploit physics at lower energies
• 8 (10) Mtons for SN neutrinos for 61 deep (shallow) strings with 9 (2) $10^4$ IceCube-DOMs
• R&D for larger/cheaper photo sensors ongoing
• 3-10 SNe yr$^{-1}$ → A novel perspective for astronomy and fundamental physics!

PINGU proto-collaboration – if interested sign mailing list:
http://www.mailman.srv.ualberta.ca/mailman/listinfo/beyonddc