Underground megatons detectors: Solar v Flares and Andromeda SN prompt v -GW discover
D. Fargion-Rome University1, INFN, Italy

- A first, few MeVs Solar Neutrino Astronomy was opened by Davis, SK, Gallex, SNO last four decades.
- Supernova neutrino 1987A Astronomy was oneshoot event two decades ago.
- UHE GeVs- TeVs (Muon) Neutrino Astronomy are masked by abundant atmospheric neutrino noise. Maybe soon ICECUBE may rise clustering.
- UHE Cosmogenic Tau Neutrino in EeV energy, via Tau Airshowers in AUGER is within horizons a few years from now.
- Supernovae Relic background via Gadolinium at edge.
- Solar tens MeVs Neutrino Flare is low energy guaranteed, but not too rare, new solar Astronomy testing in principle all Neutrino Flavours Astronomy, at SK or UNO detection mass thresholds: for energetic events muons and taus might be born too.

SN neutronization neutrinos versus GW detecting neutrino mass splitting
No one but 6 Neutrinos
The lepton thresholds
Neutrino events by SN 1987A in LMC in KII

![Graph showing neutrino events energy vs. relative time](image)

*Image of Supernova 1987A*
Supernova Neutrinos

Expected for Super-KAMIOKANDE at 10kpc, (ν-oscillation effects not included)

(1987)
Additional Anti-Matter signals from Solar Flare: (as OSSE Neutrons June 1991) an earlier and rarest Anti-Neutron (above threshold 6.5 GeV) signal in GLAST followed by more abundant Neutrons and latest protons
From half century ago..1956
Neutron Solar Flare (J.Simpson)
In one hour tenfold CR neutrons→ almost half a day CR→ 3-4 neutrino
atmospheric expected → 3-4 from Solar Flare?

Detecting Solar Neutrino Flare and Flavors
by D.Fargion:
JHEP 0406 (2004) 045

D.Fargion,F.Moscato
" Muon and Tau Neutrinos Spectra from Solar Flares",
Chin. J.
Flare-Supernova 1987A energy Fluence Ratio

\[
\frac{\Phi_{FL}}{\Phi_{SN}} \gtrsim \frac{E_{FL}}{E_{SN}} \left(\frac{d_{SN}}{d_{\odot}}\right)^2 \gtrsim \frac{1}{30} \left(\frac{E_{FL}}{10^{32} \text{ erg}}\right)\left(\frac{E_{SN}}{3 \cdot 10^{53} \text{ erg}}\right)^{-1}
\]  

(1.1)

\[10^{32} \text{ erg} \sim \geq E_{FL} \geq 10^{31} \text{ erg}\]  

(2.1)

\[
\Phi_{FL} = 3.5 \cdot \eta \cdot 10^4 \text{ erg cm}^{-2} \left(\frac{E_{FL}}{10^{32} \text{ erg}}\right)
\]  

(1.2)
Neutrino event expected in SK from SN $^{1987A}$ versus SOLAR FLARE = 242 : 30 = 8

**TABLE IV:** Signal totals for various processes in representative supernova detectors at 10 Kpc [39]. $\nu_\mu$ represents $\nu_\mu$, $\nu_\tau$, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>SNO</th>
<th>Superkamiokande</th>
<th>LVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\nu}_e$ p</td>
<td>331</td>
<td>5310</td>
<td>342</td>
</tr>
<tr>
<td>$\nu_e e^-$</td>
<td>12</td>
<td>77.6</td>
<td>8.04</td>
</tr>
<tr>
<td>$\bar{\nu}_e e^-$</td>
<td>6</td>
<td>16.9</td>
<td>1.49</td>
</tr>
<tr>
<td>$\nu_\mu e^-$</td>
<td>7</td>
<td>49.9</td>
<td>3.28</td>
</tr>
<tr>
<td>$\nu_e O$ (CC)</td>
<td>3</td>
<td>36.0</td>
<td>-</td>
</tr>
<tr>
<td>$\bar{\nu}_e O$ (CC)</td>
<td>3</td>
<td>45.5</td>
<td>-</td>
</tr>
<tr>
<td>$\nu_x$ C</td>
<td>-</td>
<td>-</td>
<td>22</td>
</tr>
<tr>
<td>$\nu_e d$ (CC)</td>
<td>81.9</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$\bar{\nu}_e d$ (CC)</td>
<td>66.7</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$\nu_e d$ (NC)</td>
<td>35.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$\bar{\nu}_e d$ (NC)</td>
<td>37.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$\nu_\mu d$ (NC)</td>
<td>200</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Core-Collapse Astrophysics with a Five-Megaton Neutrino Detector

Matthew D. Kistler,1,2 Hasan Yüksel,1,2 Shin’ichiro Ando,3 John F. Beacom,1,2,4 and Yoichiro Suzuki5,6

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(Dated: October 10, 2008)

The legacy of solar neutrinos suggests that large neutrino detectors should be sited underground. However, to instead go underwater bypasses the need to move mountains, allowing much larger contained water Čerenkov detectors. Reaching a scale of ~5 Megatons, the size of the proposed Deep-TITAND, would permit observations of “mini-bursts” of neutrinos from supernovae in the nearby universe on a yearly basis. Importantly, these mini-bursts would be detected over backgrounds without the need for optical evidence of the supernova, guaranteeing the beginning of time-domain MeV neutrino astronomy. The ability to identify, to the second, every core collapse would allow a continuous “death watch” of all stars within ~5 Mpc, making previously-impossible tasks practical. These include the abilities to promptly detect otherwise-invisible prompt black hole formation, provide advance warning for supernova shock-breakout searches, define tight time windows for gravitationalwave searches, and identify “supernova impostors” by the non-detection of neutrinos.

<table>
<thead>
<tr>
<th></th>
<th>32 kton (SK)</th>
<th>0.5 Mton (HK)</th>
<th>5 Mton (Deep-TITAND)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 kpc (Milky Way)</td>
<td>$10^4$</td>
<td>$10^5$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>1 Mpc (M31, M33)</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3 Mpc (M81, M82)</td>
<td>$10^{-1}$</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

Fargion D.-TAUP-01-07-2009-Rome
Solar Flares are energetic and not too rare.
Why so much interest for the 20° January Solar Flare for Neutrinos?
GAMMA Spectra on 20 Jan. 2005

Figure 3. a–c: Some wide-band RHESSI time profiles (red). Green dash-dotted line shows start of TRACE observations. Black dashed line marks a weak enhancement of 25–300 keV emission. Red dotted line shows part of its time profile enlarged ten-times. c–f: Some SONG time profiles smoothed over 13 points (blue; the 200–800 keV channel has not been smoothed).
The neutral-pion signature: a clear trace of a LOWER BOUND of charged pions

Figure 7. High-resolution RHESSI (red) and wide-range SONG (blue) spectra recorded during the hardest flare emission. Vertical dash-dotted line shows the high-energy part of the SONG spectrum where the $\pi^0$-decay emission dominates. Shading shows uncertainties.
Super Kamiokande Bounds

Electron neutrino spectrum (\(\nu_e\))

Solar neutrino spectrum:
- pp
- \(^{7}\)Be
- \(^{13}\)N
- \(^{15}\)O
- \(^{17}\)F
- \(^{8}\)B
- pep
- atm
- SRN relic

Neutrino energy (MeV):
- \(10^1\) to \(10^6\)

Neutrino flux (cm\(^{-2}\)s\(^{-1}\)MeV\(^{-1}\)):
- \(10^{12}\) to \(10^4\)
neutrino $\nu_\mu$ differential number flux (after oscillation)
neutrino $\nu_\mu$ differential number flux (after oscillation)

MEGATON

$\nu_e$

$\nu_\mu$

$\nu_\tau$

atm

upward

downward

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Correct cross section

\[ \sigma \propto E_V^2 \]

\[ \nu_e \text{ on proton} \]
\[ \nu_e \text{ on electron} \]
neutrino $\nu_\mu$ differential number flux (after oscillation)

$\nu_e$, $\nu_\mu$, $\nu_\tau$

MEGATON
neutrino $\nu_\mu$ differential number flux (after oscillation)

5 MEGATON TITAND

$\nu_e$  $\nu_\mu$  $\nu_\tau$
neutrino $\nu_\mu$ differential number flux (after oscillation)
neutrino $\nu_\mu$ differential number flux (after oscillation)

- **ICECUBE**

- $\nu_e$
- $\nu_\mu$
- $\nu_\tau$

- $\nu$ fluxes from different sources:
  - pp
  - $^7$Be
  - $^7$Be
  - $^{13}$N
  - pep
  - $^{15}$O
  - $^{17}$F
  - $^8$B
  - hep

- Energy (MeV) vs. flux (cm$^{-2}$ s$^{-1}$ MeV$^{-1}$)
Best signals: by Anti Neutrino $\bar{\nu}_e$ before mixing

neutrino $\bar{\nu}_e$ differential number flux
(before mixing)
SK Anti $\nu_e$ after in SK

neutrino $\bar{\nu}_e$ differential number flux (after mixing)

$\nu_e$

$\nu_\mu$

$\nu_\tau$
The SK Detector

50000 tons ultra-pure water
22500 tons fiducial volume
1 km overburden = 2700 m.w.e.
The low energy ν-e elastic scattering
Still points back To the Sun

12 MeV solar ν
492 MeV atmospheric electron $\nu$

Note diffuse edge of ring from electron produced by $\nu_e$-nucleon interaction.
603 MeV atmospheric muon $\nu$

Note sharp edge of ring from muon produced by $\nu_\mu$-nucleon interaction
$$E_{\nu_{\mu}} \geq \Delta M \cdot (1 + \frac{\Delta M}{2m_p}) \simeq 3.46 \text{ GeV},$$

where \(\Delta M = m_{\tau} + m_{n} - m_p\)

Our first estimate on the neutrino number events detection at the Super-Kamiokande II Laboratory for horizontal or hidden flare is found to be:

$$N_{ev\bar{\nu}_e} \simeq 0.63\eta_e \left(\frac{<E_{\nu}>}{35 \text{ MeV}}\right) \left(\frac{<E_{FL}>}{10^{31} \text{ erg}}\right); \text{ and } N_{ev\nu_{\mu}} \simeq 3.58 \left(\frac{<E_{\nu_{\mu}} >}{200 \text{ MeV}}\right) \left(\frac{<E_{FL}>}{10^{31} \text{ erg}}\right)\eta_{\mu},$$

where \(\eta \simeq 1, E_{\nu_{\mu}} > 113 \text{ MeV.}\) Any large neutrino flare event record might also verify the expected neutrino flavour mixing leading to \(\frac{\eta_{\mu}}{\eta_e} \simeq \frac{1}{2}\) and to

$$N_{ev\bar{\nu}_\mu} \simeq N_{ev\bar{\nu}_e} \simeq 2 \left(\frac{<E_{\nu_{\mu}} >}{200 \text{ MeV}}\right) \left(\frac{<E_{FL}>}{10^{31} \text{ erg}}\right); \text{ and } N_{ev\nu_{\mu}} \simeq N_{ev\nu_e}$$

as well as a comparable, \(\nu_e, \nu_{\mu}, \bar{\nu}_e, \bar{\nu}_{\mu}\) energy fluence and spectra. A surprising \(\tau\) appearance may occur for a hard \((E_{\nu_{\mu}} \rightarrow E_{\nu_{\tau}} \simeq > 4 \text{GeV})\) flare spectra.

Highest energetic solar particles
Milagro Observation of >10 GeV Particles from Sun on 20 Jan 2005

- GOES proton data
  - >10 MeV
  - >100 MeV

- Milagro scaler data
  > 10 GeV protons
  ~1 min rise-time
  ~5 min duration

Milagro Observed > 10 GeV from the Solar Energetic Particle events on
- 6 November 1997
- 14 July 2000
- 15 April 2001
- 20 January 2005
Flavor Neutrino Mixing by neutrino mass splitting:

The rare Tau Appearance because of large Oscillation Lengths versus Earth Diameter

\[ L_{\nu_\mu-\nu_\tau} = 2.48 \cdot 10^9 \text{cm} \left( \frac{E_\nu}{10^9 \text{eV}} \right) \left( \frac{\Delta m^2_{ij}}{(10^{-2} \text{eV})^2} \right)^{-1} \ll D_{\oplus\oplus} = 1.5 \cdot 10^{13} \text{cm} \]

The allowable neutrino tau appearance from the Sun
A first SK Tau $\nu$ candidate event (~3 GeV)

(Still Fully Contained)
Super-Kamiokande Preliminary
1289.4 days

The pion-signature

![Graph showing the pion-signature analysis with data points and error bars.](image)
Probability Meaning

The recent solar flare on October-November 2003 as large as the one on Sept. 29th, 1989 might be an exceptional source of cosmic, gamma, neutron rays and neutrinos as well. Their minimal event number at Super-Kamiokande $N_{\nu_{\mu}} \simeq N_{\nu_e} \simeq 2\left(\frac{E_{\nu}}{100\text{ MeV}}\right)\left(\frac{E_{\nu}}{10^{31}\text{ erg}}\right)$; $N_{\nu_{\mu}} \simeq N_{\nu_e}$ is near or above unity. The noise signal of energetic atmospheric neutrinos at the Japanese detector is nearly 5.8 event a day time corresponding to a rate $\Gamma \simeq 6.710^{-5}\text{s}^{-1}$. The minimal and the largest predicted event number ($1 \div 5$) $\eta$, ($\eta \leq 1$) within the narrow time gate defined by the sharp X burst onset (100s), are above the noise. Indeed the probability to find by chance one neutrino event within a 1 - 2 minute $\Delta t \simeq 10^2\text{s}$ in that interval is $P \simeq \Gamma \cdot \Delta T \simeq 6.7 \cdot 10^{-3}$. For a Poisson distribution the probability to find $n = 1, 2, 3, 4, 5$ events in a narrow time window might reach extremely small values: $P_n \simeq \frac{P^n}{n!} = (6.7 \cdot 10^{-3}, 2.25 \cdot 10^{-5}, 5 \cdot 10^{-8}, 8.3910^{-11}, 1.1 \cdot 10^{-13})$. Therefore the very possible presence of one or more high energetic (tens hundred MeVs) positron (or better positive muons) as well as any negative electron or muon, in Super-Kamiokande at X-flare onset time may be a well defined and most brilliant signature of the solar neutrino flare. A surprising discover by $\tau$ appearance of the complete mixing may occur by hard ($E_{\nu_{\mu}} \rightarrow E_{\nu_{\tau}} \simeq 4\text{GeV}$) flare spectra. Its most recognizable signature occurs by a rare $\pi^0$ production, (by the common hadronic $\tau$ decay), and its pion consequent decays into mono-cromatic $\gamma$ whose relics are consequent $e^+, e^-$ relativistic pairs production.
Why Solar Neutrino Flare have not been yet observed? Maybe because of low density acceleration target.
Summary: Physica Scripta 2006 versus 2008

neutrino $\nu_e$ differential number flux
(before mixing)
Conclusions:

1) Nearly equal electron-muon neutrino Flux Flare
2) A first ANTI-Neutrino signal in electron-positron tracks
3) A Hard electron neutrino spectra than SN ones
4) A first Muon appearence in harder spectra above 400 MeV
5) A rarest Tau appearence in harder spectra, 4 GeV,
6) Few events in future HK might occur in Oct –Nov 2003
    A probable transient event on 20 January 2005
7) A Solar Neutrino and Anti Neutrino Flare Astronomy
    must be born almost garanteed in larger Gd-UNO (440 kton)
    and-or HSK and Deep TITAND.
8) More Solar Flare than SN at the edge.
9) The rare Andromeda SN neutronization neutrino delay
    versus GW may test neutrino mass splitting.
Thank You for the attention
Forbush after all…

Figura 14.2: Tipiche diminuzioni di Forbush. La curva in basso rappresenta la componente
Present - Future Neutrino Detectors versus FLARE
HK and UNO

<table>
<thead>
<tr>
<th>Detector</th>
<th>$E_{\text{th}}$ (MeV)</th>
<th>($a_E, b_E$)</th>
<th>Fiducial mass (kton)</th>
<th>$N_{\nu_e}^{\text{det}}$ ($D = 10$ kpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Čerenkov</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SK[48, 49]</td>
<td>5</td>
<td>(0.47, 0)</td>
<td>32</td>
<td>5,900 - 9,990</td>
</tr>
<tr>
<td>(H$_2$O)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNO[50, 51]</td>
<td>4</td>
<td>(0.35,0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$O</td>
<td></td>
<td></td>
<td>1.4</td>
<td>260 - 440</td>
</tr>
<tr>
<td>D$_2$O</td>
<td></td>
<td></td>
<td>1.0</td>
<td>80 - 160</td>
</tr>
<tr>
<td>Scintillator</td>
<td>2.6</td>
<td>(0,0.075)</td>
<td>1.0</td>
<td>240 - 400</td>
</tr>
<tr>
<td>KamLAND [52]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N12+PC+PPO)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Čerenkov</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HK[33]</td>
<td>5</td>
<td>(0.5,0)</td>
<td>540</td>
<td>100,000 - 170,000</td>
</tr>
<tr>
<td>(H$_2$O)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNO [55]</td>
<td>5</td>
<td>(0.5,0)</td>
<td>650</td>
<td>120,000 - 203,000</td>
</tr>
<tr>
<td>(H$_2$O)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scintillator</td>
<td>2.6</td>
<td>(0.1,0)</td>
<td>30</td>
<td>7,500 - 12,600</td>
</tr>
<tr>
<td>LENA [35]</td>
<td>(PXE)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE I: The relevant $\bar{\nu}_e$ detection parameters for some of the present and proposed detectors. In the last column we give the expected range for the number of charged current $\bar{\nu}_e$ events from a Galactic SN at 10 kpc, assuming the neutrino oscillation pattern discussed in sect 3B. The larger (smaller) numbers correspond to SN model 1 (model 2).
Anti mu after

neutrino $\bar{\nu}_\mu$ differential number flux
(after mixing)
Solar Standard Model: a noisy neutrino electron sky
Flux Number

\[ \log\left[ \frac{\text{Flux}}{(\text{erg cm}^{-2} \text{s}^{-1} \text{sr}^{-1})} \right] \]

\[ \log(E/eV) \]

- CMB
- IR
- Radio
- Cosmological Massless \( \nu \)
- UV
- Cosmic SuperNova \( \nu \)
- Atmospheric \( \nu_\mu \)
- CR
- AGN \( \nu \)
- WB limit
- HiRes1
- HiRes2
- AGASA
Neutron and Gamma…and Neutrinos?

Solar Neutron Events of October-November 2003

K. Watanabe¹, M. Gros², P. H. Stoker³, K. Kudela⁴, C. Lopate⁵, J. F. Valdés-Galicia⁶, A. Hurtado⁶, O. Musalem⁶, R. Ogasawara⁷, Y. Mizumoto⁷, M. Nakagiri⁷, A. Miyashita⁷, Y. Matsubara¹, T. Sako¹, Y. Muraki¹, T. Sakai⁸, and S. Shibata⁹

ABSTRACT

During the period when the Sun was intensely active on October-November 2003, two remarkable solar neutron events were observed by the ground-based neutron monitors. On October 28, 2003, in association with an X17.2 large flare, solar neutrons were detected with high statistical significance (6.4σ) by the neutron monitor at Tsumeb, Namibia. On November 4, 2003, in association with an X28 class flare, relativistic solar neutrons were observed by the neutron monitors at Haleakala in Hawaii and Mexico City, and by the solar neutron telescope at Mauna Kea in Hawaii simultaneously. Clear excesses were observed at the same time by these detectors, with the significance calculated as 7.5σ for

neutrino $\nu_e$ differential number flux
(after mixing)
Neutrino muon before mixing

neutrino $\nu_\mu$ differential number flux
(before mixing)