Methodology of experimental search for neutrinos from solar flares in Borexino detector

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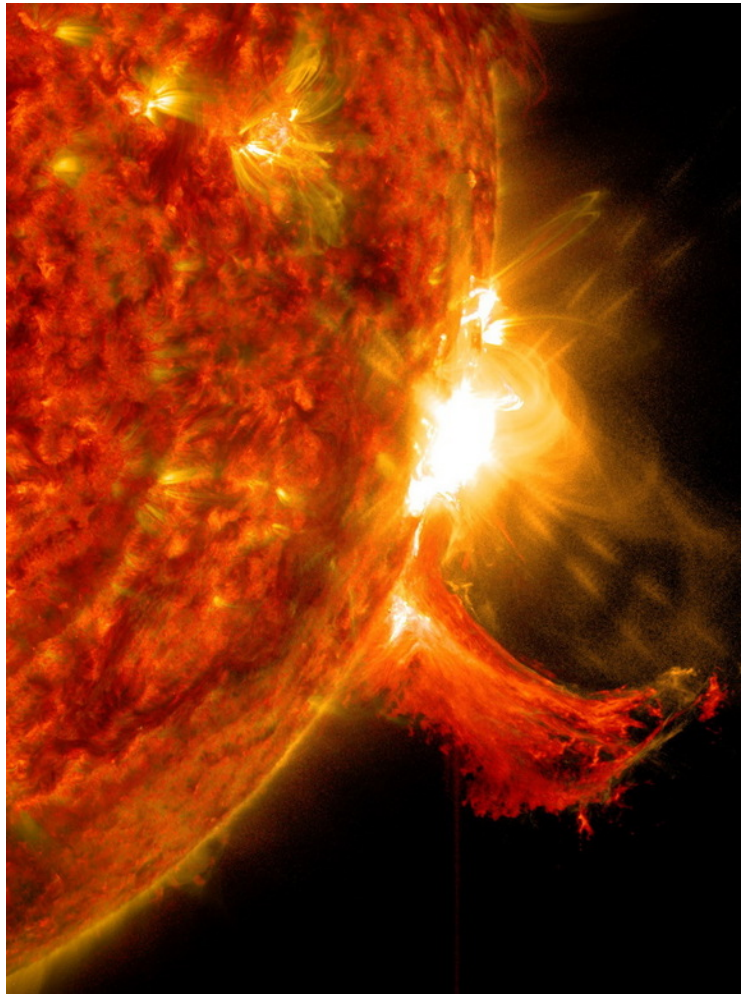
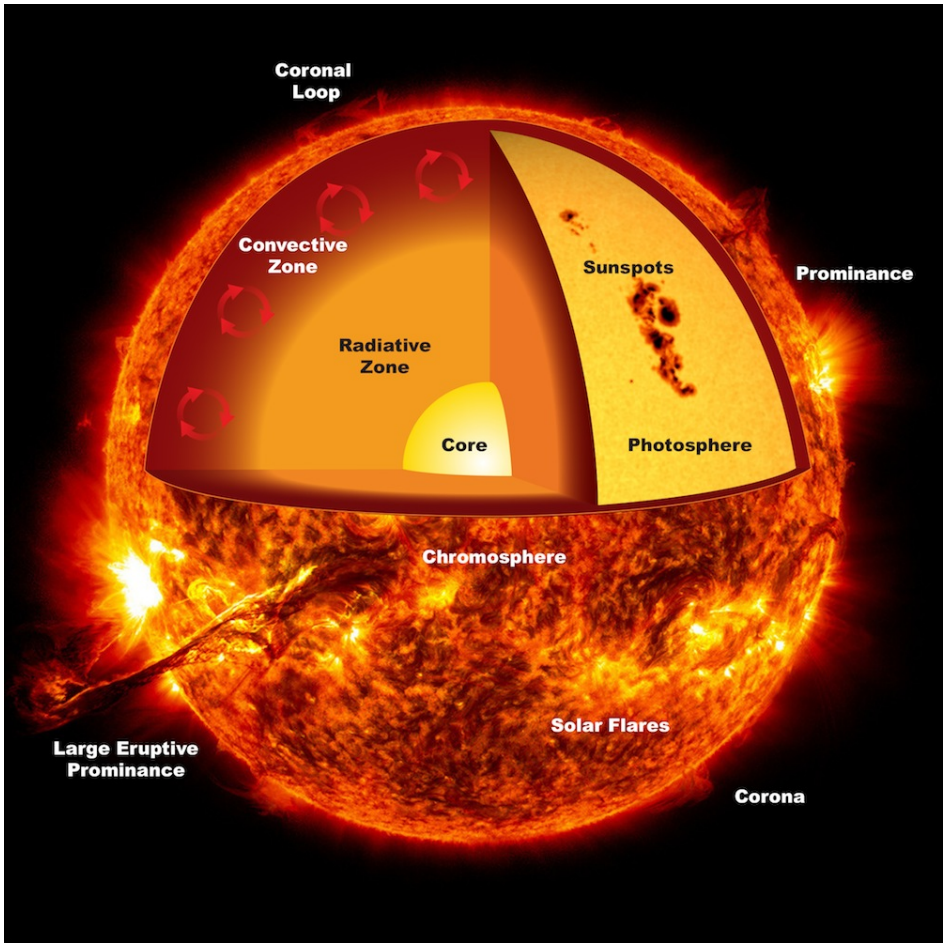
Solar Flares

Solar flare is sudden variation in brightness near the Sun's surface

- The source of energy released in solar flare is restructuring magnetic fields
- Solar flares take place in active regions of Sun's surface (near the sunspots)
- Processes during solar flare involve all layers of solar atmosphere (photoshere, chromosphere and corona)



Solar Flares



X-rays:

- produced through bremsstrauhlung of accelerated electrons in chromospere and transit region
- give the starting time of the flare

γ-rays:

- produced by nuclear deexcitation, neutron capture, positron annihilation and pion decay
- may be delayed with respect to X-rays and then give the end time of the flare

Solar flares detection by satellites

GOES satellite

RHESSI satellite

Low geocentric orbit

- RHESSI: X-ray and γ-ray
- Fermi: X-ray and γ-ray
- Hinode: optical, EUV, X-ray

Geosynchronous orbit

- GOES: X-ray
- SDO: EUV

Heliocentric orbit (L_1)

- WIND (Konus): hard X-ray and γ-ray

Solar flare neutrinos

Neutrinos in solar flares may possibly be born in the following processes:

$$p+p \rightarrow \begin{cases} \Delta^{++} + n \rightarrow p + n + \pi^+ \\ \Delta^{+} + p \rightarrow \begin{cases} p + p + \pi^0 \\ p + n + \pi^+ \end{cases} \end{cases}$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Relevance of solar flare neutrinos searches

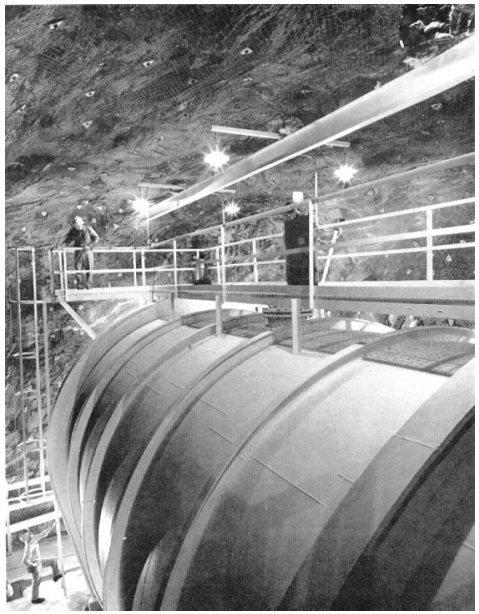
Any result will give us more precise knowledge about solar flare mechanisms and updated information about:

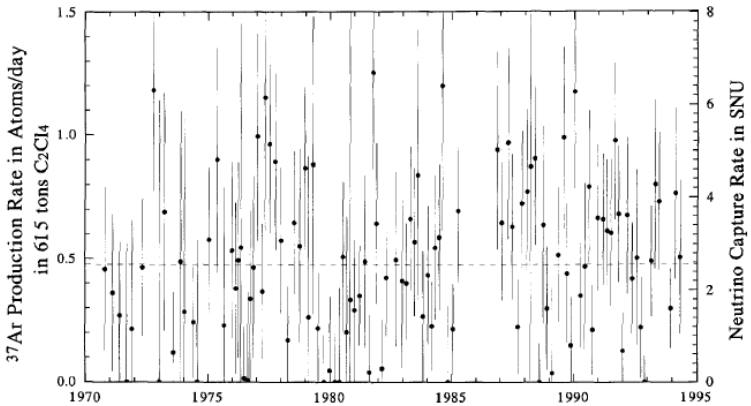
- particle acceleration in flares
- flare process itself
- solar flare neutrinos flux and energy spectrum

History of solar flare neutrinos searches

The Homestake experiment

- The detector - 380 m^3 tank of perchloroethylene. It was located in USA
- Main goal was to measure total flux of solar neutrinos with energies above 0.8 MeV





Solar flare neutrino search

- In 1988 the excess of detected neutrino events in correlation with the powerful solar flares in 1972 and 1981 was reported

History of solar flares neutrinos searches

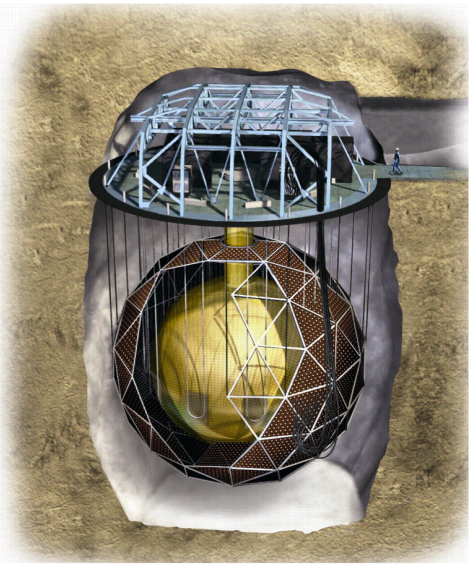
Kamiokande experiment

- Kamiokande is water Cherenkov detector that contained 3000 tons of pure warer + 1500 tons of water in veto. It was located in Japan
- Main goal was the search for proton decay

Solar flare neutrino search

- No significant neutrino signal in correlation with solar flares was found in period from 1983 to 1988

History of solar flares neutrinos searches

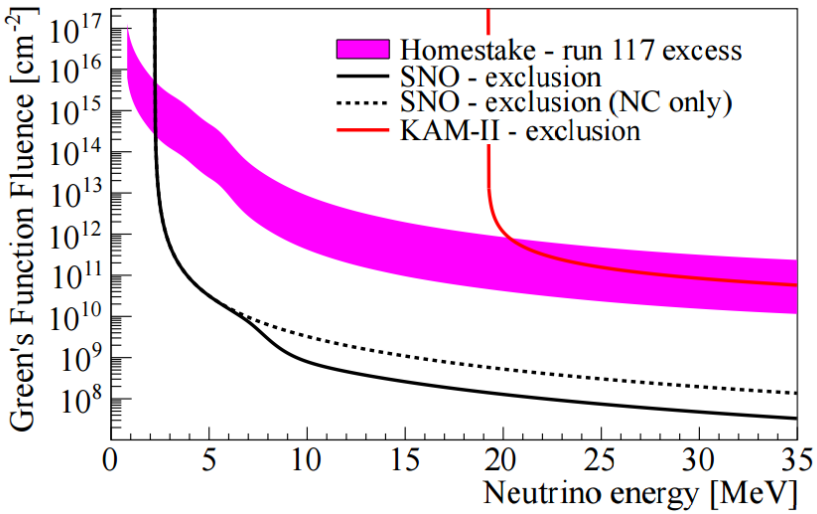


The SNO experiment

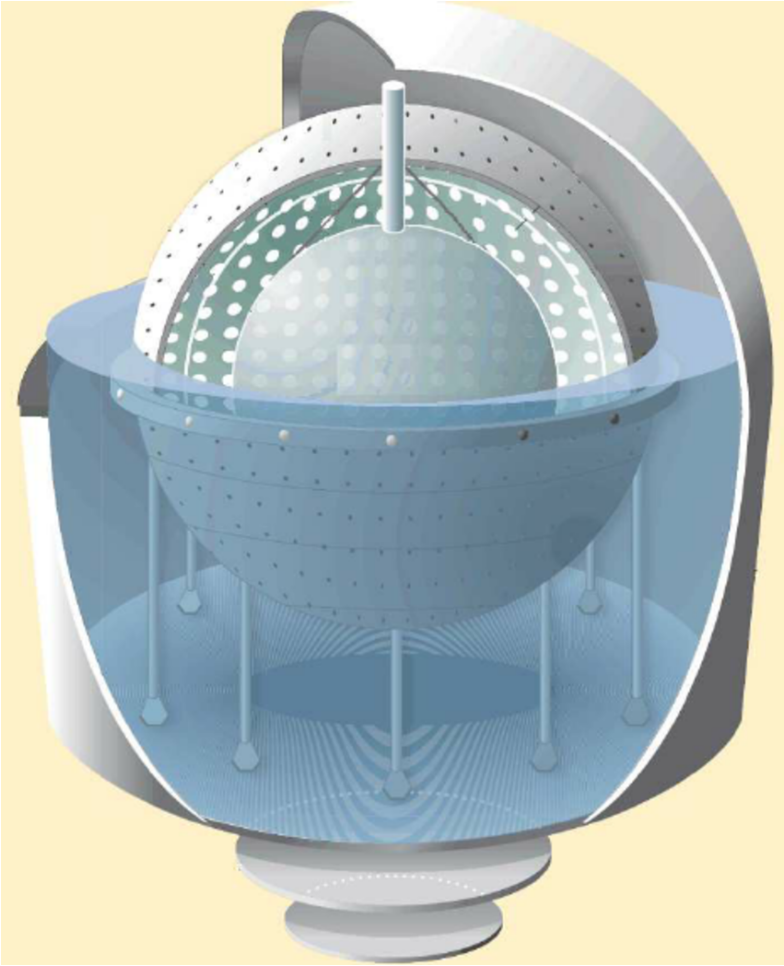
- SNO is one kton pure heavy water detector that was located in Canada
- Main goal was to study solar neutrino flux

Solar flare neutrino search

- No excess of neutrino events in time windows connected with solar flares was found
- Fluence upper limits for neutrinos from solar flares were obtained



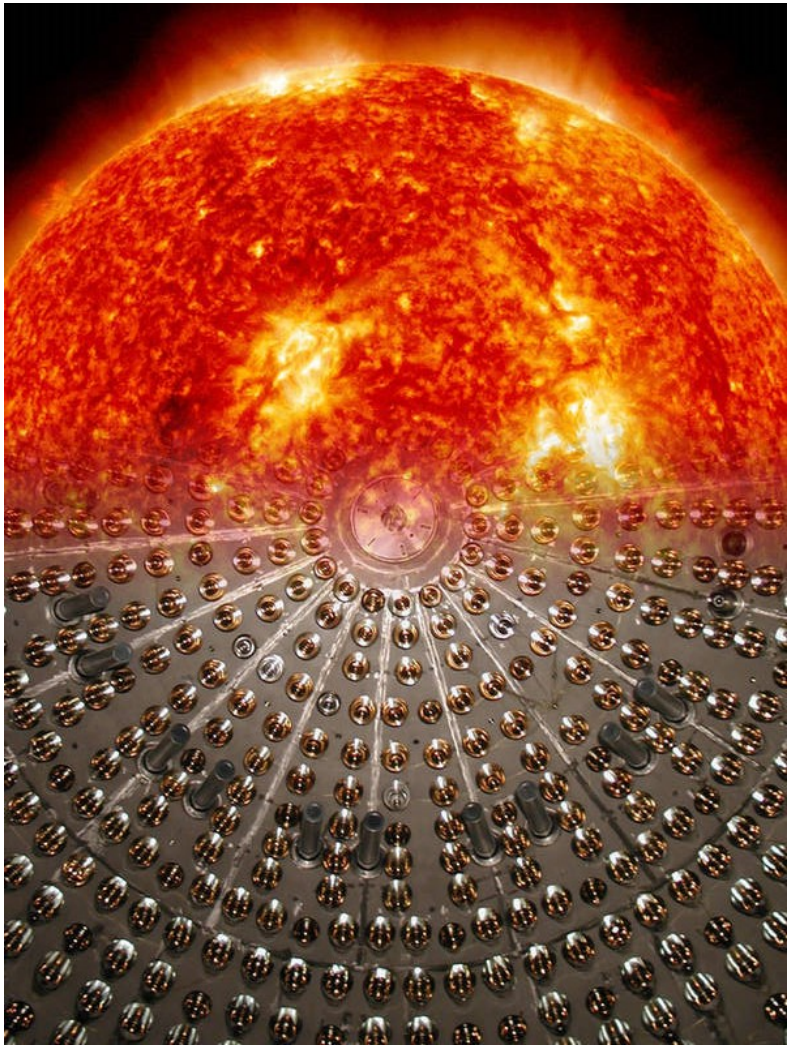
Borexino detector



- Borexino is a 278 tons liquid organic scintillator neutrino detector placed in Italy
- The main goal is spectroscopy of solar neutrino below 1 MeV
- Secondary goals are studies of atmospheric and geo-neutrinos and also neutrinos from different astrophysical sources

Borexino advantages in solar flare neutrino searches

- Data taking period: from 2007 to nowadays.
  It covers more than a half of 11-year solar cycle including the maximum of solar activity
- Two semi-independent data taking systems.
  This allows us to extend energy region and to use some advanced software algorithms
- Opportunity to improve upper fluence limits for lower energies for electron neutrinos



Detection of solar flare neutrinos in Borexino

Neutrino-electron scattering

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

Signal in detector - single point-like event

Burst of events

Signal in detector - group of single events

- split a time scale to equal intervals
- multiplicity - number of singles in one interval
- high multiplicities $\rightarrow$ burst of single events

Detection of solar flare neutrinos in Borexino

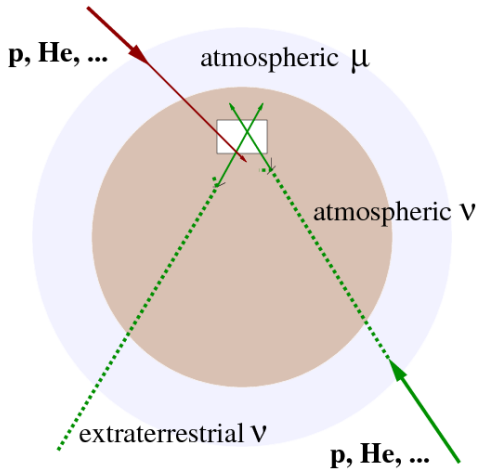
Reactions on carbon

$$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$$

$${}^{12}N \rightarrow {}^{12}C + e^+ + \nu_e$$

Threshold energy $E_{th} = 17.8$ MeV
Signal in detector - single event with energy above the threshold

Upward-going muons



Signal in detector - muons going from the ground

- high muon rate
- possibility to search for muon neutrinos from solar flares

Solar flares databases and correlation time window

- Combined database from several satellites (RHESSI, GOES, Hinode, Fermi) is used
- Only the most powerful solar flares (M and X classes) are used in analysis

- Time windows length depends on solar flare duration
- These windows contain periods before and after moment of solar flare registration
- Additional time windows for background rate calculation

Summary

- Main points of solar flares nature were stated
- Opportunities of neutrino emission during solar flares were considered
- History of searches for solar flare neutrinos on Earth were reviewed

- The search for neutrinos from solar flares is now in progress in Borexino collaboration
- We are looking for variations in detected neutrino signal correlated with the most powerful solar flares
- In case of abscence of any correlations fluence upper limit for solar flare neutrinos will be set

Back-up slides

Solar flares classification

Solar flares are classified according to the peak flux of 100 to 800 picometre X-rays near Earth.

Class	Flux (W/m^2)
A	$< 10^{-7}$
B	$10^{-7} - 10^{-6}$
C	$10^{-6} - 10^{-5}$
M	$10^{-5} - 10^{-4}$
X	$> 10^{-4}$