

Perspectives of DSNB neutrino researches in modern detectors

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DSNB

Diffuse Supernova Neutrino Background is the flux of neutrinos and antineutrinos from SN bursts, which occurred through the Universe history.

The DSNB flux could be represented as:

$$\frac{d\varphi}{dE_\vartheta} = \int_0^{z_{max}} dz \frac{N_{SN}(E(z+1)) R_{SN}}{H_0 \sqrt{(z+1)^3 \Omega_M + \Omega}}$$

Supernova rate

Individual supernova emission spectrum

Hubble constant

redshift

Relative density of matter

Relative density of dark matter

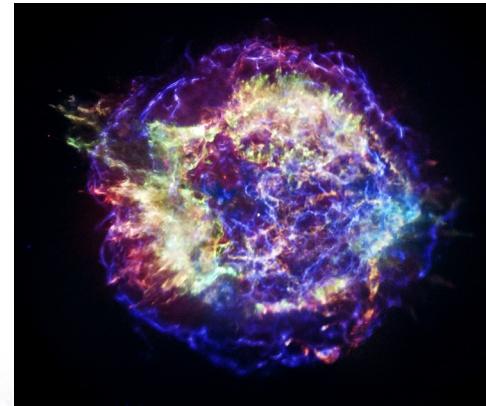
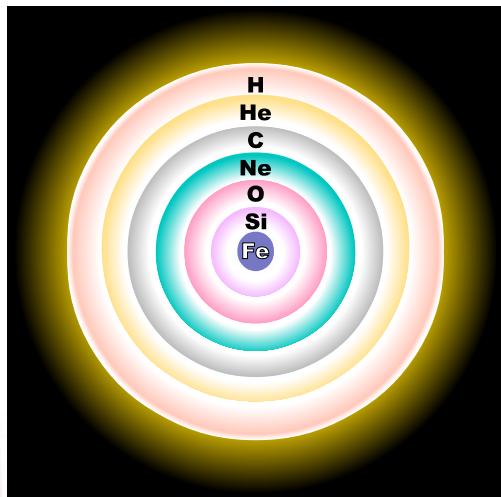
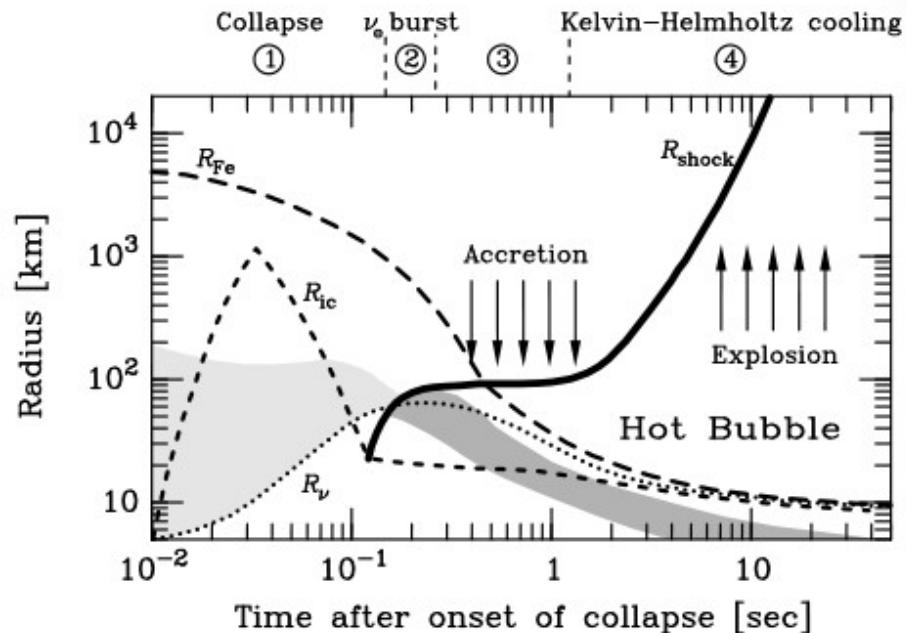
The diagram illustrates the components of the DSNB flux equation. A red box encloses the equation $\frac{d\varphi}{dE_\vartheta} = \int_0^{z_{max}} dz \frac{N_{SN}(E(z+1)) R_{SN}}{H_0 \sqrt{(z+1)^3 \Omega_M + \Omega}}$. Two terms in the equation are circled in red: $N_{SN}(E(z+1)) R_{SN}$ and $H_0 \sqrt{(z+1)^3 \Omega_M + \Omega}$. Arrows point from the labels "Individual supernova emission spectrum" and "Relative density of dark matter" to the circled term $N_{SN}(E(z+1)) R_{SN}$. Arrows point from the labels "Hubble constant" and "Relative density of matter" to the circled term $H_0 \sqrt{(z+1)^3 \Omega_M + \Omega}$. An arrow points from the label "Supernova rate" to the rightmost part of the equation.

Supernova core-collapse

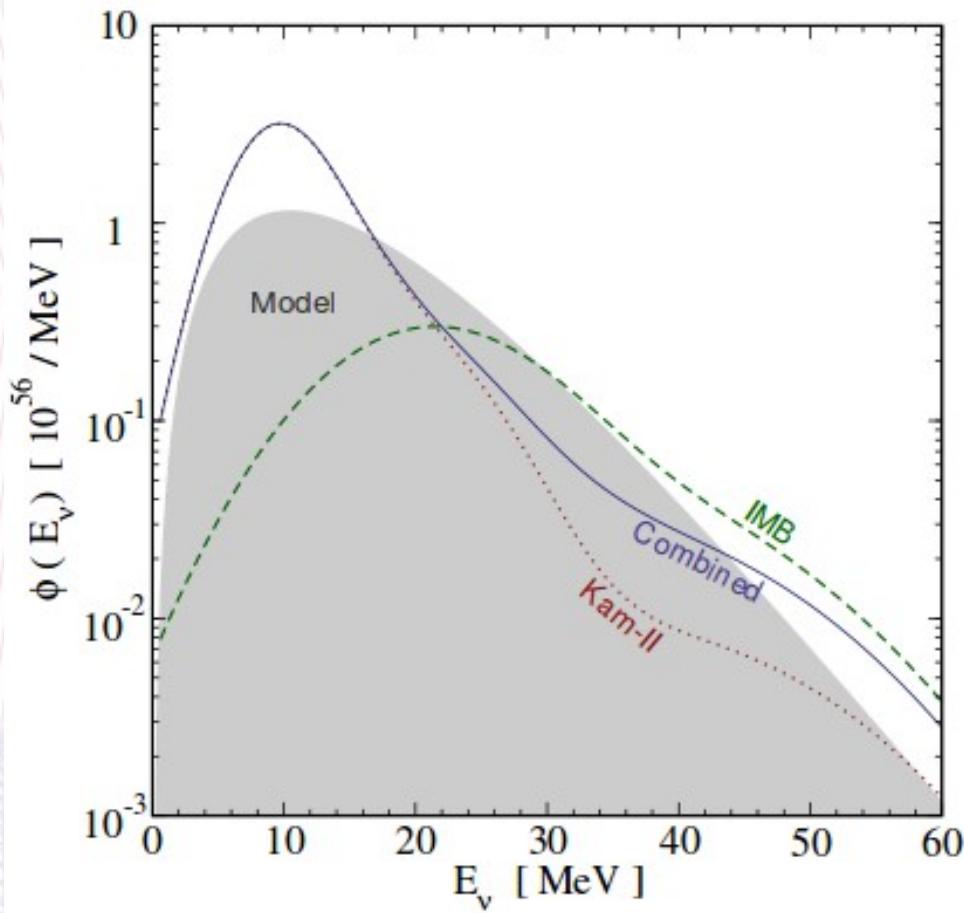
- $M \geq 8M_*$;
- $E = 3 \cdot 10^{53}$ erg;
- $\rho_0 = 3 \cdot 10^9 \text{ g cm}^{-3}$;

Core-collapse stages:

- 1) Collapse;
- 2) Prompt-shock and break-out (ν_e burst);
- 3) Matter accretion and matter cooling;
- 4) Cooling of progenitor star;



Why DSNB neutrinos are important?



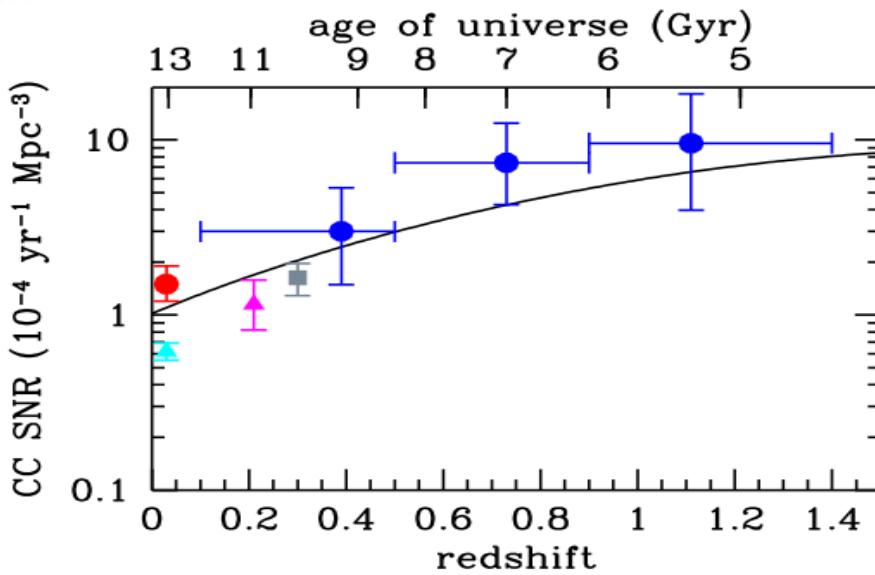
- SN 1987A was detected by Baksan, Kamiokande II (Kam-II) and Irvine-Michigan-Brookhaven (IMB) detectors;
- It is expected that SN spectrum is thermal, but neutrino spectrum was different from thermal distribution;

Possible explanations:

- neutrino-mixing among various flavours;
- neutrino decay;
- neutrino-neutrino interactions;
- new physics;

Why DSNB neutrinos are important?

SFR(Star formation rate function) describes the fractional growth rate of stellar mass in galaxy.

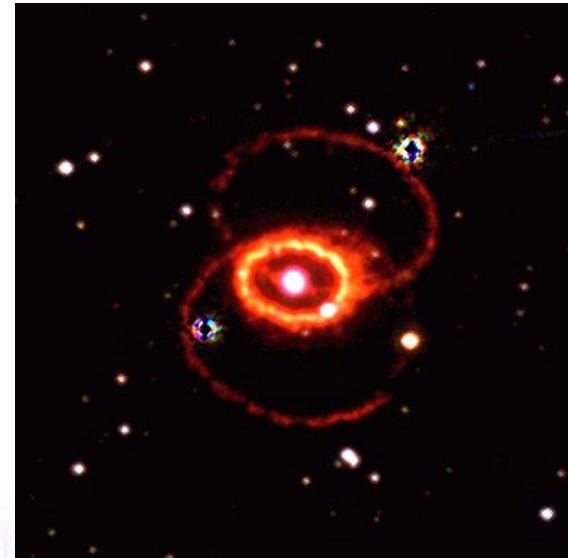


Why do we search for supernova bursts?

Supernovae bursts is an independent way to determine the star formation history of the Universe and metallicity production rate inside stars.

Why do we research DSNB?

SN core-collapse is a very rare event in our Galaxy: 1-3 Supernovae per century! *(Last supernova was in 1987)*



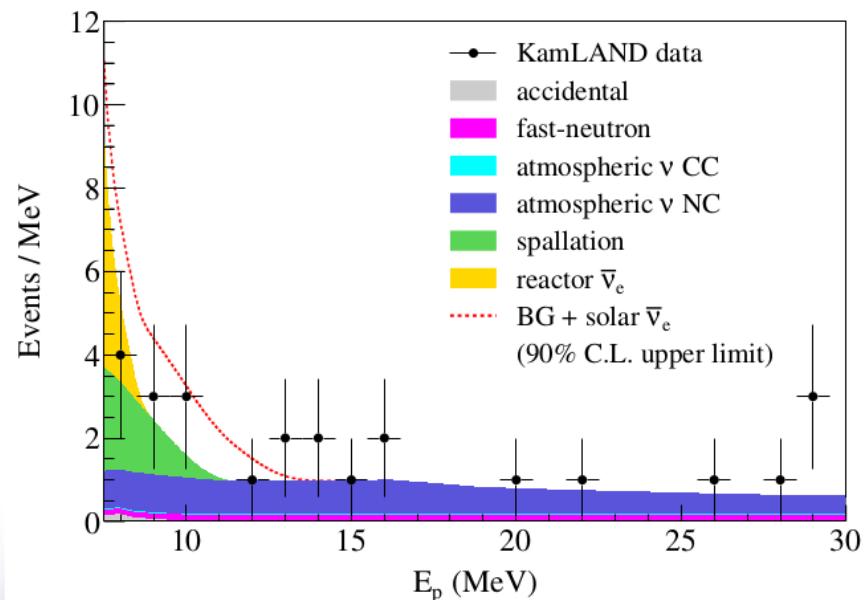
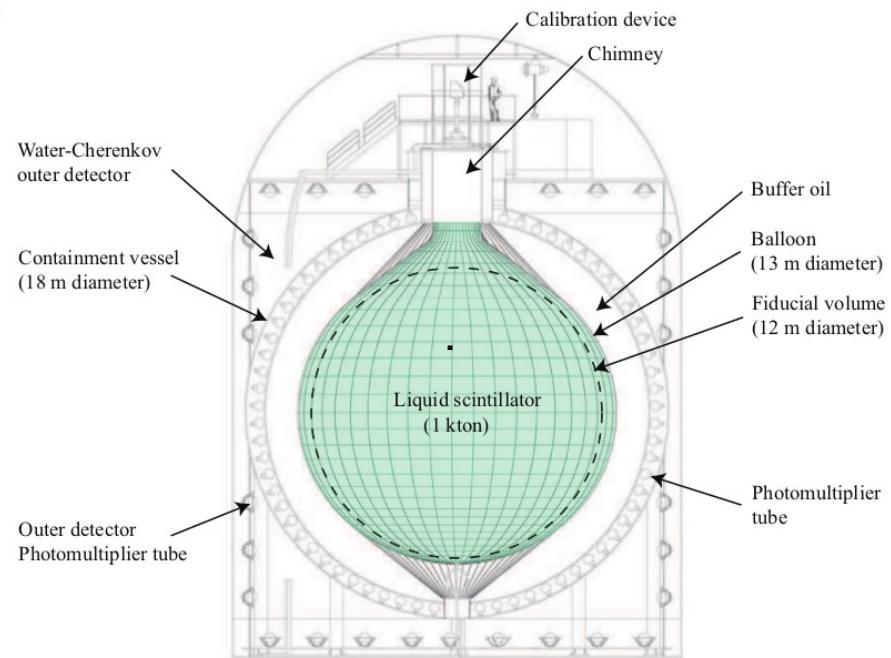
KamLAND $\bar{\nu}_e$

- Liquid scintillator detector
- 2700 m.w.e.
- Target mass is 1 kton
- Backgrounds:
 - 1) random coincidence;
 - 2) antineutrinos from reactors;
 - 3) cosmogenics isotopes;
 - 4) atmospheric neutrinos;

$$\bar{\nu}_e + p \rightarrow e^+ + n.$$

Upper limit for diffuse supernova electron antineutrino flux:

139 cm⁻² s⁻¹ 90% C.L.



SNO $\bar{\nu}_e, \nu_e$ $\nu_e + d \rightarrow p + p + e^-$



- Backgrounds:

- 1) Solar 8B neutrinos;
- 2) Atmospheric neutrinos;

Upper limit for DSNB **electron neutrino** flux in $22.9 \text{ MeV} < E < 36.9 \text{ MeV}$ energy range:

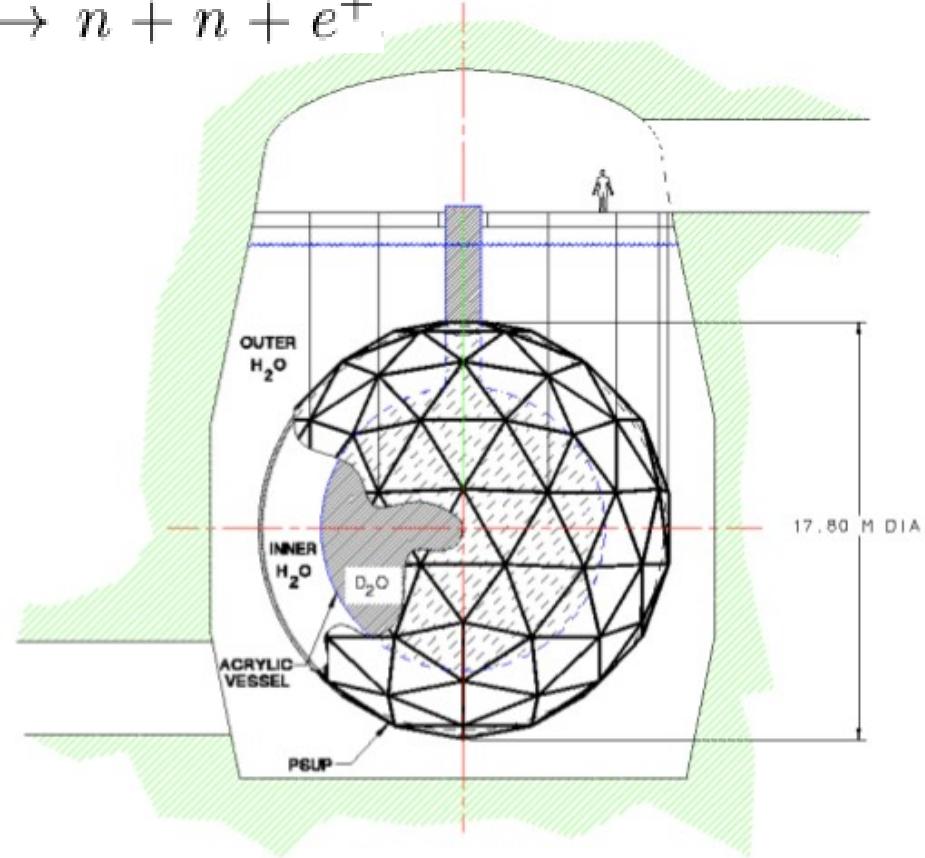
$70 \text{ cm}^{-2}\text{s}^{-1}$ 90% C.L.

- Model-independent upper limit for electron antineutrinos from unknown sources:

$2 \cdot 10^6 \text{ cm}^{-2}\text{s}^{-1}$ $4 \text{ MeV} < E < 8 \text{ MeV}$

$3.4 \cdot 10^4 \text{ cm}^{-2}\text{s}^{-1}$ $E > 14.8 \text{ MeV}$

90% C.L.



- heavy water Cherenkov detector;
- 6010 m.w.e.
- target mass is 1 kton;

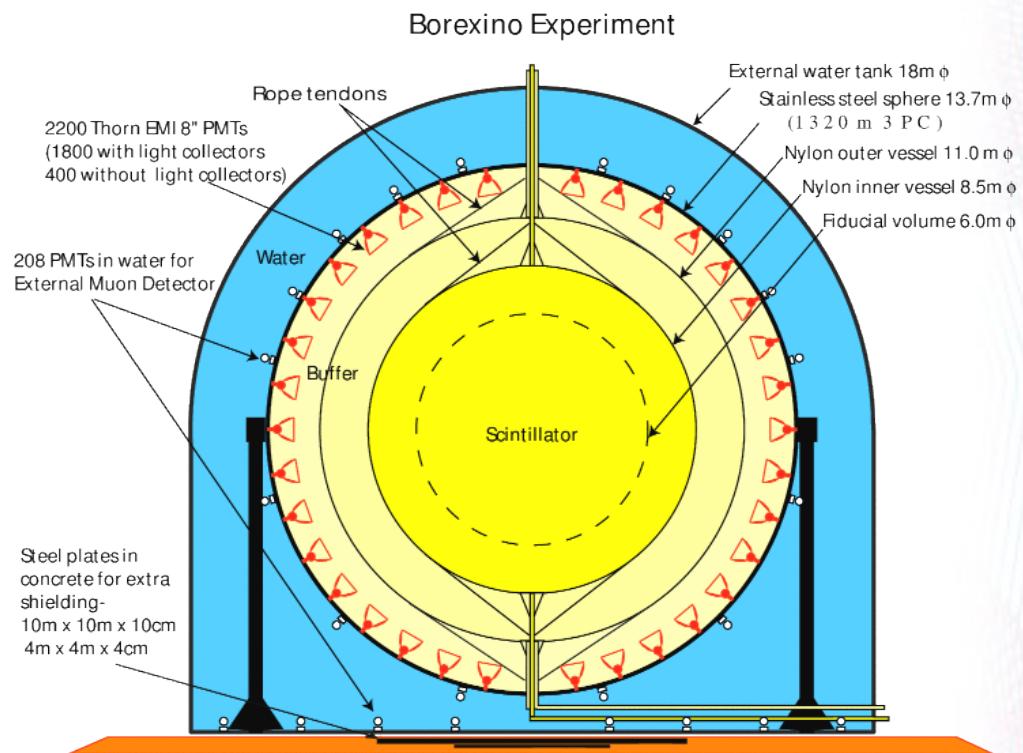
Borexino $\bar{\nu}_e$, ν_e

$$\bar{\nu}_e + p \rightarrow e^+ + n.$$

- Backgrounds:
 - 1) Antineutrinos from reactors;
 - 2) Geo-antineutrinos;
 - 3) Atmospheric neutrinos;
 - 4) Radioactive isotopes;
- Upper limit for electron antineutrino flux from unknown sources:

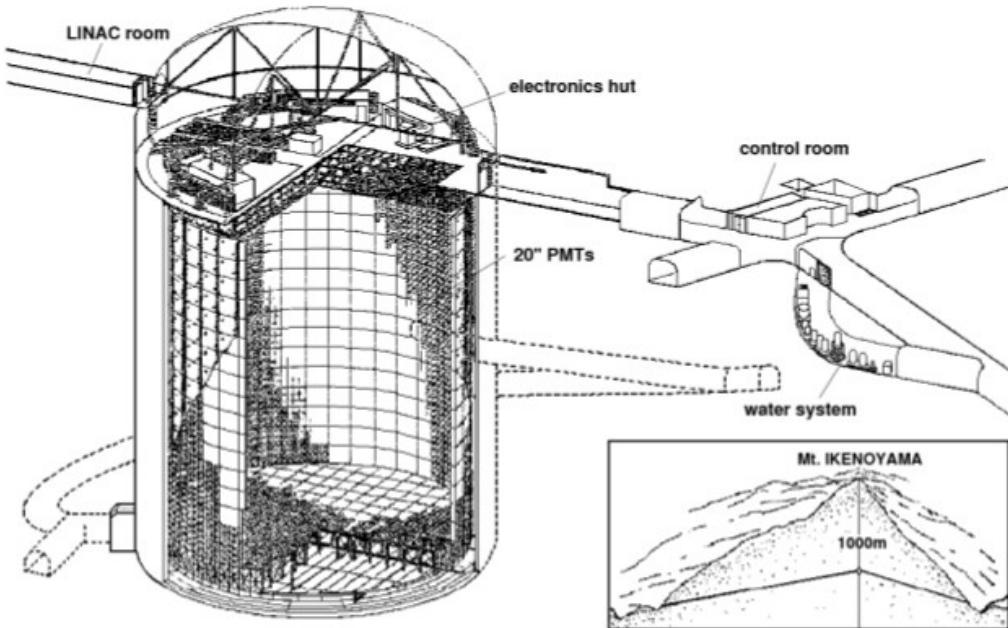
760 cm⁻²s⁻¹ 90% C.L.

in 1.8 MeV < E < 17.8 energy range



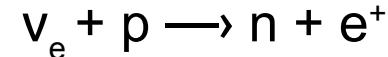
- Liquid scintillator detector;
- 3800 m.w.e.
- Target mass is 280 ton;

Super-Kamiokande $\bar{\nu}_e$



- Water Cherenkov detector
- 2700 m.w.e.
- Fiducial volume 22.5 kton

- Inverse beta-decay reaction:



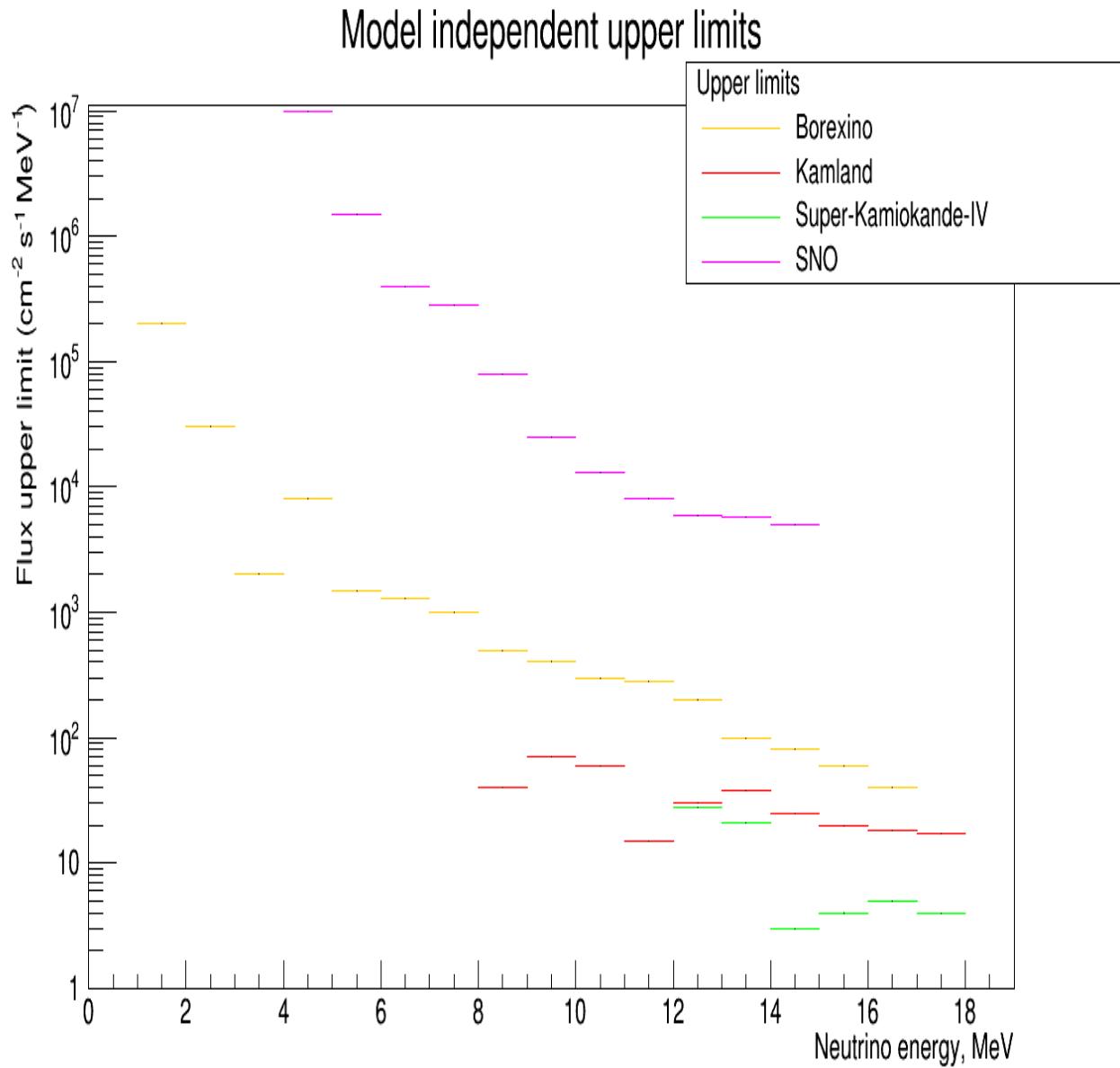
- Backgrounds:

- 1) Atmospheric neutrinos;
- 2) Solar neutrinos;
- 3) Muon induced spallation products;

- Upper limit: $2.9 \text{ cm}^{-2} \text{s}^{-1}$
90% C.L.

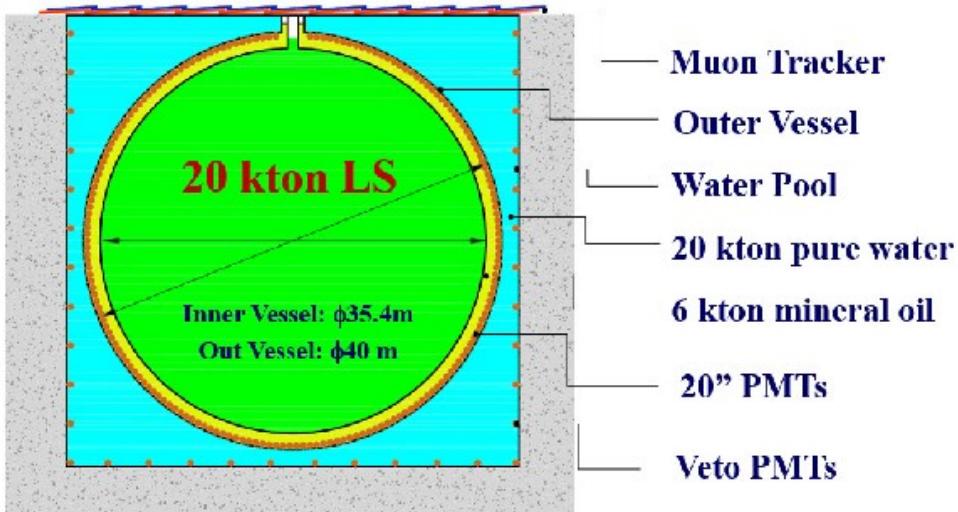
- for $E > 17.3 \text{ MeV}$;

Summary of upper limits for electron antineutrino fluxes for different detectors



JUNO $\bar{\nu}_e, \nu_e$

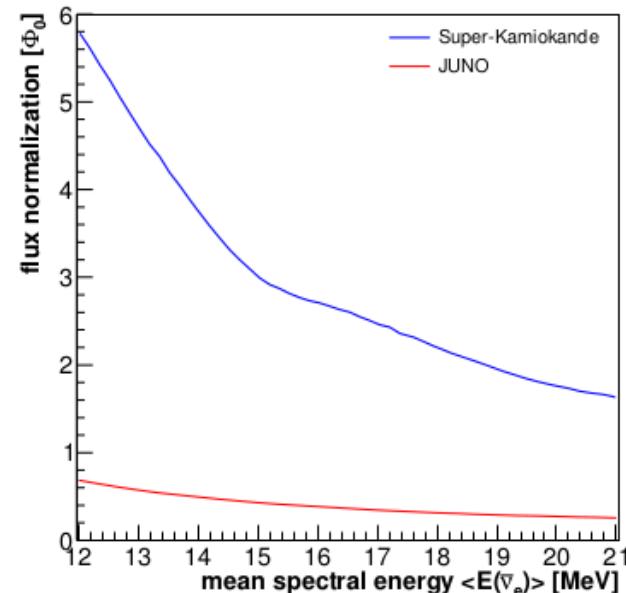
$$\bar{\nu}_e + p \rightarrow e^+ + n.$$



- Liquid scintillator detector;
- Target mass is 20 kton;

- Backgrounds:
 - geo and reactor antineutrinos;
 - Cosmogenic isotopes;
 - Atmospheric neutrinos CC and NC interactions;
 - Fast neutrons;
- Upper limit for DSNB electron antineutrinos flux:

0.2 cm⁻²s⁻¹ 90% C.L.



Conclusion

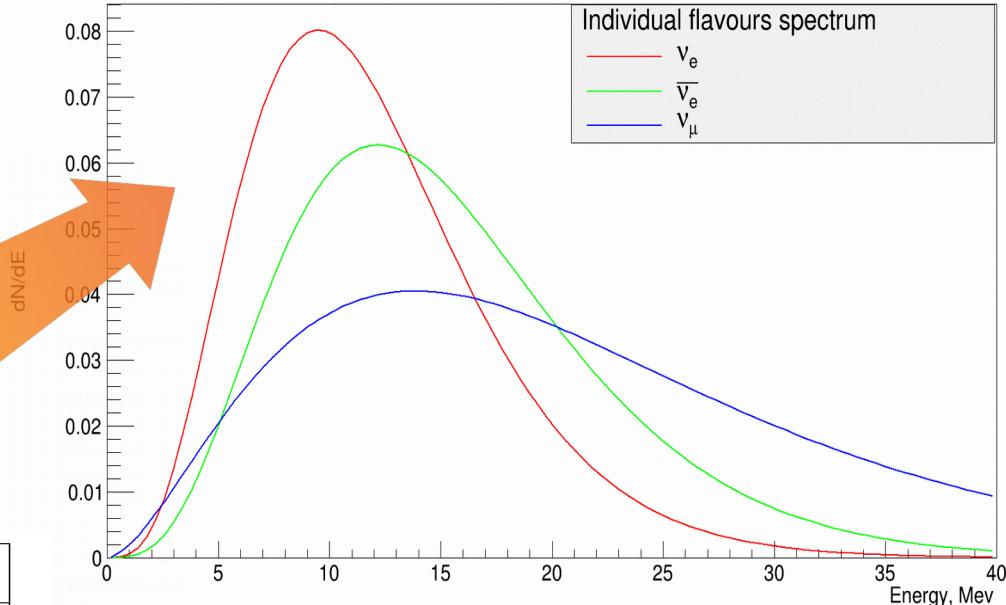
- DSNB neutrinos are guaranteed sources of information about cosmic core-collapse rate and neutrino emission from supernova.
- DSNB neutrinos have not been detected yet, only upper limits were set on the flux in energy range from 1.8 MeV to 40 MeV. The best current limit on DSNB electron antineutrino flux ($2.9 \text{ cm}^{-2} \text{ s}^{-1}$) was set by Super-Kamiokande.
- It is expected that future detectors like JUNO will be able to detect DSNB signal or improve upper limits on DSNB neutrino fluxes during next 10 years.

Backup slides

Neutrino emission spectra

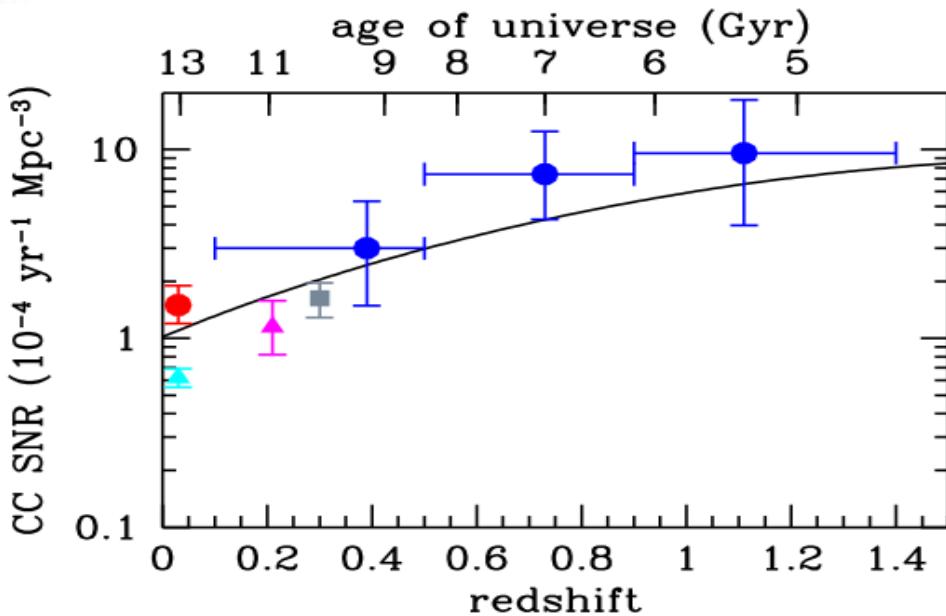
$$\frac{dN}{dE} \cong \frac{(1 + \alpha_\omega)^{1+\alpha_\omega} L_\omega}{\Gamma(1 + \alpha_\omega) E_{0\vartheta}^2} \left(\frac{E_\vartheta}{E_{0\vartheta}}\right)^{\alpha_\omega} e^{-(1+\alpha_\omega)E_\vartheta/E_{0\vartheta}}$$

- L_w is total luminosity of bounce;
- E_ν is energy of neutrinos;
- $E_{0\nu}$ is average energy of neutrinos predicted by some model;
- α_ω is numerical parameter obtained from SN spectrum fit;
- There are MC simulations by several groups:



Model	Mass [M_\odot]	$\langle E_{\nu_e} \rangle$ [MeV]	$\langle E_{\bar{\nu}_e} \rangle$ [MeV]	$\langle E_{\nu_x} \rangle$ [MeV]	$\beta_{\bar{\nu}_e}$	β_{ν_x}
LL [46]	20	12.0	15.4	21.6	3.8	1.8
TBP [47]	11	10.0	11.4	14.1	3.7	2.2
	15	10.0	11.4	14.1	3.7	2.2
	20	10.0	11.9	14.4	3.6	2.2
KRJ [48]	—	13.0	15.4	15.7	4.2	2.5

Supernova rate



$$R_{sn} = R_{-4} 10^{-4} \text{ yr}^{-1} \text{ Mpc}^{-1} \begin{cases} (1+z)^{3.28}, & z < 1 \\ (1+z)^{-0.26}, & 1 < z < 4.5 \\ (1+z)^{-7.8}, & z > 4.5 \end{cases}$$

SN rate represents the function dependent of redshift z and proportional to Star Formation Rate (SFR):

$$R_{SF}(z) \propto \begin{cases} (1+z)^\beta, & z < 1 \\ (1+z)^\alpha, & 1 < z < 4.5 \\ (1+z)^\gamma, & 4.5 < z, \end{cases}$$

$$R_{SF}(z) \propto \frac{a + bz}{1 + (z/c)^d}$$

where $\alpha, \beta, \gamma, a, b, c, d$ are numerical parameters;

Also, we adopt that stars are distributed in the Universe according to the Salpeter initial mass function:

$$R_{SN} = \frac{\int_{8M_\odot}^{125M_\odot} dm \phi(m)}{\int_{0.5M_\odot}^{125M_\odot} dm m \phi(m)} R_{SF}(z) \simeq 0.0122 M_\odot^{-1} R_{SF}(z)$$

where: $\phi \propto m^{-2.35}$