# The Diffuse Supernova Neutrino Background

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DPG-Tagung 4. März 2008

# Outline

# What is the DSNB and why would we be interested in it?

- Core-collapse Supernovae (SNe) are the most luminous Neutrino sources of the universe ($3 \times 10^{53}\mathrm{erg}$)
- Only a handful neutrinos observed from one SN until now (SN1987A)
- Today‘s detector technology would measure thousands of events but galactic SNe are rare statistical events
- Look for the convolved flux of all past SNe instead - The DSNB

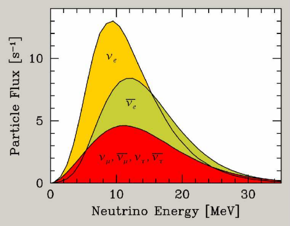
- What could we learn?
  - About SN physics in general
  - About the SN history ⇒ star formation history
  - About neutrino properties
- DSNB Flux:

$$\frac{dF}{dE_0}(E_0) = \int_0^{z_{max}} \frac{\frac{dn}{dE_1}(E_0(z+1))R_{\mathrm{SN}}(z)dz}{H_0\sqrt{(z+1)^3\Omega_{m,0}+\Omega_{\Lambda,0}}},$$

original $\nu$-spectrum $\frac{dn}{dE_1}(E)$, supernova rate $R_{\mathrm{SN}}(z)$

# Individual SN neutrino spectrum

- Delayed explosion mechanism: neutron star binding energy $E_\mathrm{b} \approx 3 \times 10^{53}\mathrm{erg}$ released in $\nu$
- Different simulations: Garching group, Lawrence Livermore, Thompson Burrows & Pinto and others
- Example *[Keil,Raffelt,Janka astro-ph/0303226]*:

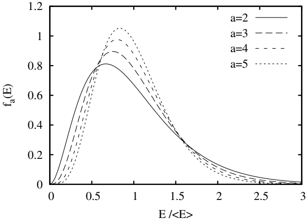


- Roughly thermal spectra can be fitted to an analytic distribution (a-fit):

$$f_a(E) = \frac{1}{c_a}\left(\frac{E}{\overline{\overline{E}}}\right)^a \exp\left[-(a+1)\frac{E}{\overline{\overline{E}}}\right],$$

- pinching factor $a$ describes deviation from Maxwell-Boltzmann distribution

# Individual SN neutrino spectrum

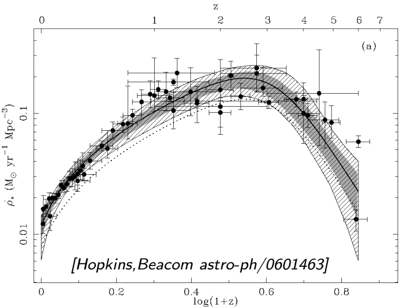


- Only interested in $\bar{\nu}_e$ easiest to detect (water cherenkov detectors, inverse beta decay)
- Oscillations *[Lunardini,Smirnov hep-ph/0302033]* can be neglected: Differences between simulations larger than difference between $(\bar{\nu}_\mu, \bar{\nu}_\tau)$ and $\bar{\nu}_e$ spectra
- Uncertainties in $E_\mathrm{b}$ due to uncertainties in neutron star masses and equation of state
- SN1987A analyses *[Yuksel,Beacom07], [Loredo, Lamb astro-ph/0107260]*: $(E_{\mathrm{tot},\overline{\nu_e}} = 84 \times 10^{51}\mathrm{erg})$; $(< E_{\nu_e} >= 9 \pm 1.5\mathrm{MeV})$
- These references and the simulations can be summarized:
  - $E_{\mathrm{tot},\bar{\nu}_\mathrm{e}} = 50^{+50}_{-20} \times 10^{51}$ erg
  - $\overline{E}_{\overline{\nu_e}} = 17^{+5}_{-8}$ MeV
  - $a_{\overline{\nu_e}} = 3.1 \pm 1.2$

# The supernova rate

- Direct measurements of $R_{\mathrm{SN}}$, both locally *[Cappellaro&al01]* and up to $z \approx 1$ *[Dahlen&al04]*. Problem: Low statistics, dust extinction
- Indirect observation by using the star formation rate (SFR) $\psi_*(z)$: $R_{\mathrm{SN}} \propto \psi_*$
  - UV-light: Young stars produce UV-light; dust extinction!
  - Emission-lines: Massive, early-type stars emit $H_\alpha$ line; dust extinction
  - Far infrared: Dust absorbs UV-light and reemits it in the Far infrared
  - Radio: Synchrotron radiation from CC SN; no dust extinction
  - X-ray: X-ray binaries; indirect
  - many more...
- Uncertainties in the conversion factor between SN rate and SFR due to uncertain critical mass $(7 - 10 M_\odot)$

# The supernova rate



*[Hopkins,Beacom astro-ph/0601463]*

- Parameterize $R_{\mathrm{SN}}$ as follows:
    - $R_{SN} = R^0_{\mathrm{SN}}(1+z)^\beta$ for $z < 1$
    - $R_{SN} = 2^{(\beta-\alpha)}(1+z)^\alpha$ for $z > 1$
- $\beta = 2.5 \pm 1.5$ *[Hogg 01], [Hopkins,Beacom06]*
- $\alpha = 0 \pm 2$ (large scatter in opinions)
- $R^0_{\mathrm{SN}} = 0.7^{+1.9}_{-0.3} \times 10^{-4}\,\mathrm{yr}^{-1}\,\mathrm{Mpc}^{-3}$ (dust extinction)

# Detectors

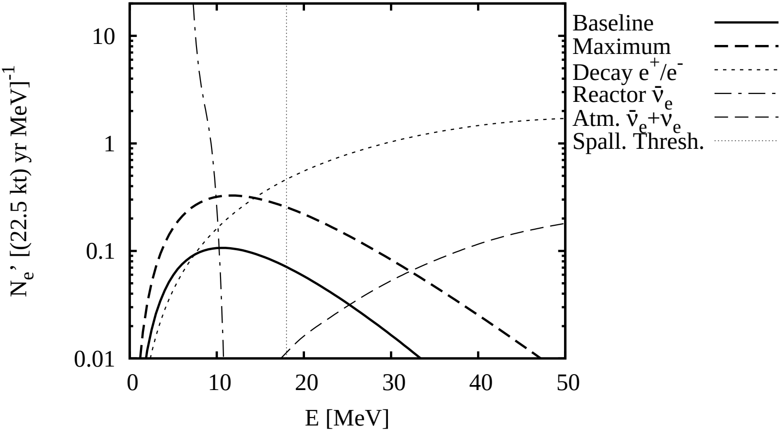
- detection cross section $\bar{\nu}_e p \rightarrow n e^+$ scales $\propto E_\nu^2$
- Water cherenkov detectors: SKs limit on the DSNB: $< 1.2 \bar{\nu}_e cm^{-2} s^{-1}$ and less than 3 events/yr above $19.3 MeV$ *[Malek&al03]* ($< 30 \bar{\nu}_e cm^{-2} s^{-1}$ total, our baseline: $8^{+22}_{-5} \bar{\nu}_e cm^{-2} s^{-1}$, 0.33 events/yr at SK from 18–40 MeV)
- Gadolinium Trichloride $\mathrm{GdCl}_3$ detection proposed; Coincidence measurement with neutron *[Beacom&Vagins03]*
- New megaton-class detectors: Hyper-K; UNO with fiducial volume of 1150Mt and 445 kt (respectively) proposed. 170 events in 5 years in (8–40) MeV (baseline case, UNO)
- Large liquid scintillation detectors like Low Energy Neutrino Astronomy (LENA) detector would use coincidence measurements; $\approx$ 10 events per year for (10–25 MeV) *[Wurm&al'07]*

# Backgrounds

- Reactor $\bar{\nu}_e$: At the SK site negligible at $E > 12 MeV$
- Atmospheric $\bar{\nu}_e$: Important from about $30 MeV$
- Spallation: Cosmic Ray Muons split $O$-atoms, daughter products decay via beta-dacay, mimic a $\bar{\nu}_e$-event. Reduceable, but not to arbitrarily low energies. Current SK-limit: $19.3 MeV$
- Sub-Cherenkov-muons: Muons from atmospheric neutrinos with a kinetic energy smaller than $50 MeV$, do not emit Cerenkov-light and cannot be detected, but decay into electrons $\Rightarrow$ background to the DSNB.
- Spallation and sub-Cherenkov-muons can be further reduced by coincidence measurement (liquid scintillator, Gadolinium technique)

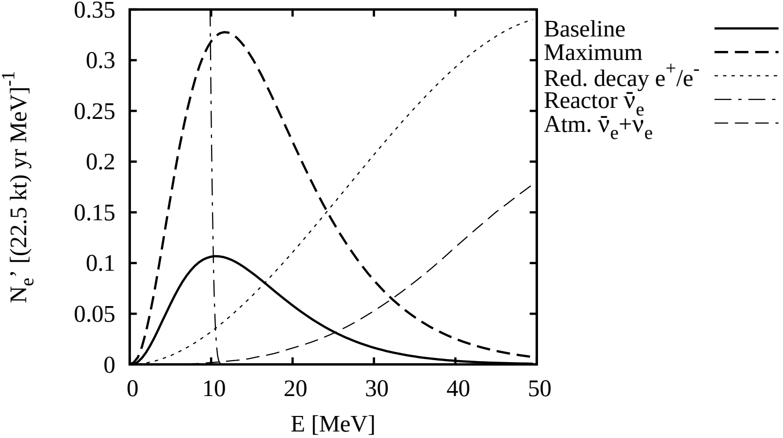
# Backgrounds

## Current situation

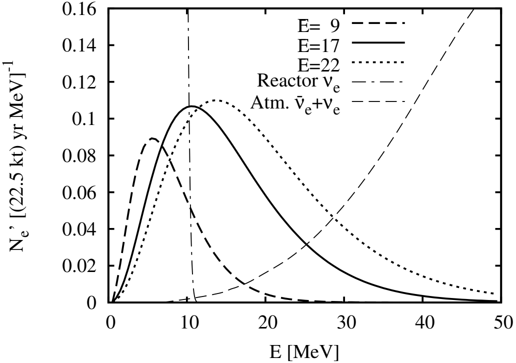


# Backgrounds

Possible future situation

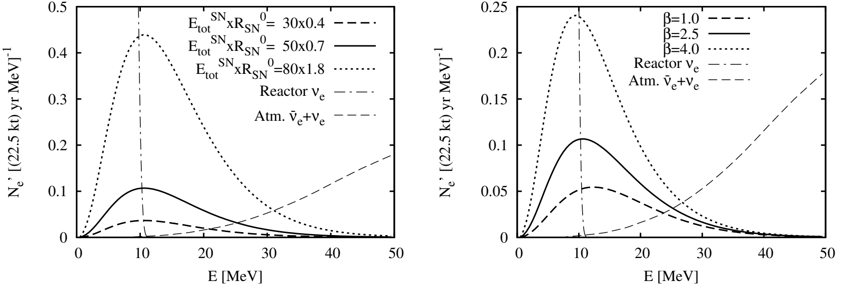


# What can we realistically learn?



- In absence of galactic SN: Future SFR observations might constrain $\beta \approx 2 - 3 \Rightarrow \overline{E}_{\mathrm{SN}}$ constrained to ±2 MeV (5 yrs, megaton) ⇒ Important probe for SN simulations

# What can we realistically learn?



- Case of a Galactic SN: very accurate knowledge (1–5%) of $E_{\rm tot}^{\rm SN}$; SFR measurements might determine $\beta$ to 25% $\Rightarrow$ Determine $R_{\rm SN}^0$ to 25% from the DSNB (5 years megaton detector performance).
- Only measurement placing an *upper* bound on $R_{\rm SN}^0$, not affected by dust extinction.

# Summary

- What can the DSNB tell us about?
  - In case of no galactic SN: SN physics ($\overline{E}_{\mathrm{SN}}$), upper bound on SN and SF history
  - In case of galactic SN: Stringent bounds on the SN and Star Formation History
  - Other neutrino properties not covered in this talk, like decay rates
- Detection technique and Background reduction crucial
- Rough estimates:
  - Detection propably possible within 10 years, including Gadolinium Detection technique or liquid scintillators
  - Good statistics with Megaton-class detectors in maybe 10-20 years