Overview of Neutrino Cross Sections

John Beacom, The Ohio State University

Evolving Perspective

Long past:

"If [there are no new forces] ---- one can conclude that there is no practically possible way of observing the neutrino." Bethe and Peierls, Nature (1934)

Recent past:

Solar neutrino problem?
Atmospheric neutrino problem?
Large neutrino masses?
Exotic neutrino properties?

Now just neutrino engineering? NO, actually.

Basic Message

• We have a newly emergent picture of neutrino properties, interactions, and applications, and it is broad, detailed, and fascinating.

• We now want to ask questions that are more precise, interconnected, and challenging.

• Many of our practical and profound questions require better knowledge of neutrino interactions.

We need multiple new experiments on neutrino interactions, covering a large dynamic range.

What Changed?

- The key factor-of-2 issues have been solved, and there is new interest in absolute measurements.

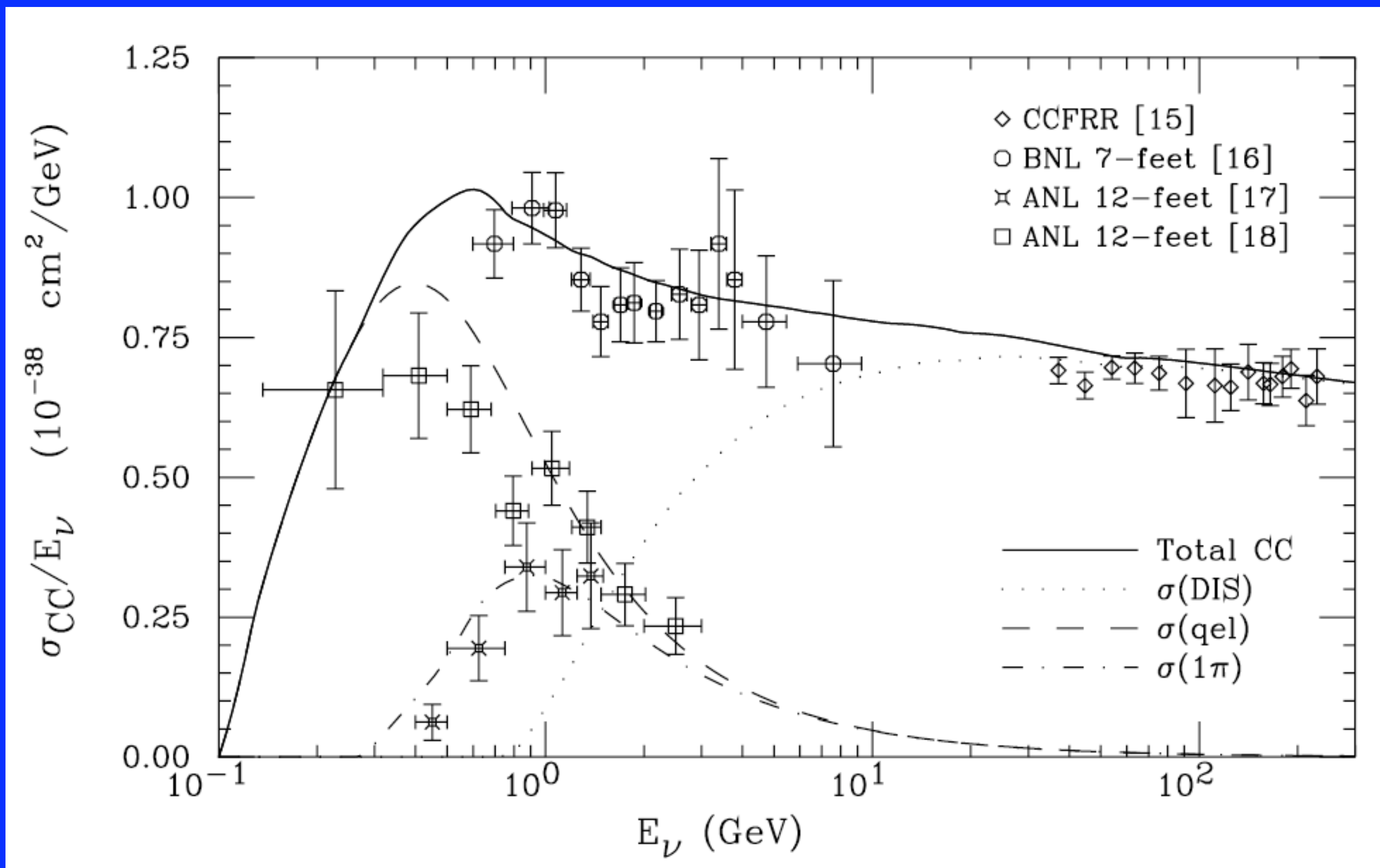
- Yes, the solar and atmospheric results were a factor ~ 2 *below* the expected weak rates, but without knowing why, we couldn't be sure of our calculations in other physical situations.

- The capabilities and coverage of detectors has radically improved, and is continuing.

- There are new and exciting prospects for doing astrophysics - for example, a first detection of the Diffuse Supernova Neutrino Background.

Scale Overview

- Inadequate data, sometimes only bubble-chamber
- Hard to separate nucleus, nucleon, and quark pieces



Lipari, Lusignoli, Sartoga, PRL 74, 4384 (1995)

Neutrino-Nucleus

- Hydrogen: the Ur weak interaction cross section
- Deuteron: precisely calculated, poorly measured
- Carbon: the easy part is easy, but not the rest; well measured by LSND, but theory contentious
- Iron, Iodine: crude data agrees with theory
- Gallium: ~ 1 MeV data only, but agrees with theory
- No measurements for He, O, Ne, Cl, Ar, Pb, ...
- Don't ask about angular distributions, spectra, neutron emission, gamma de-excitation, ...

Rising Interest

- APS Neutrino Study: measuring neutrino cross sections is essential to maximize impact of program

- New results from K2K and MiniBooNE

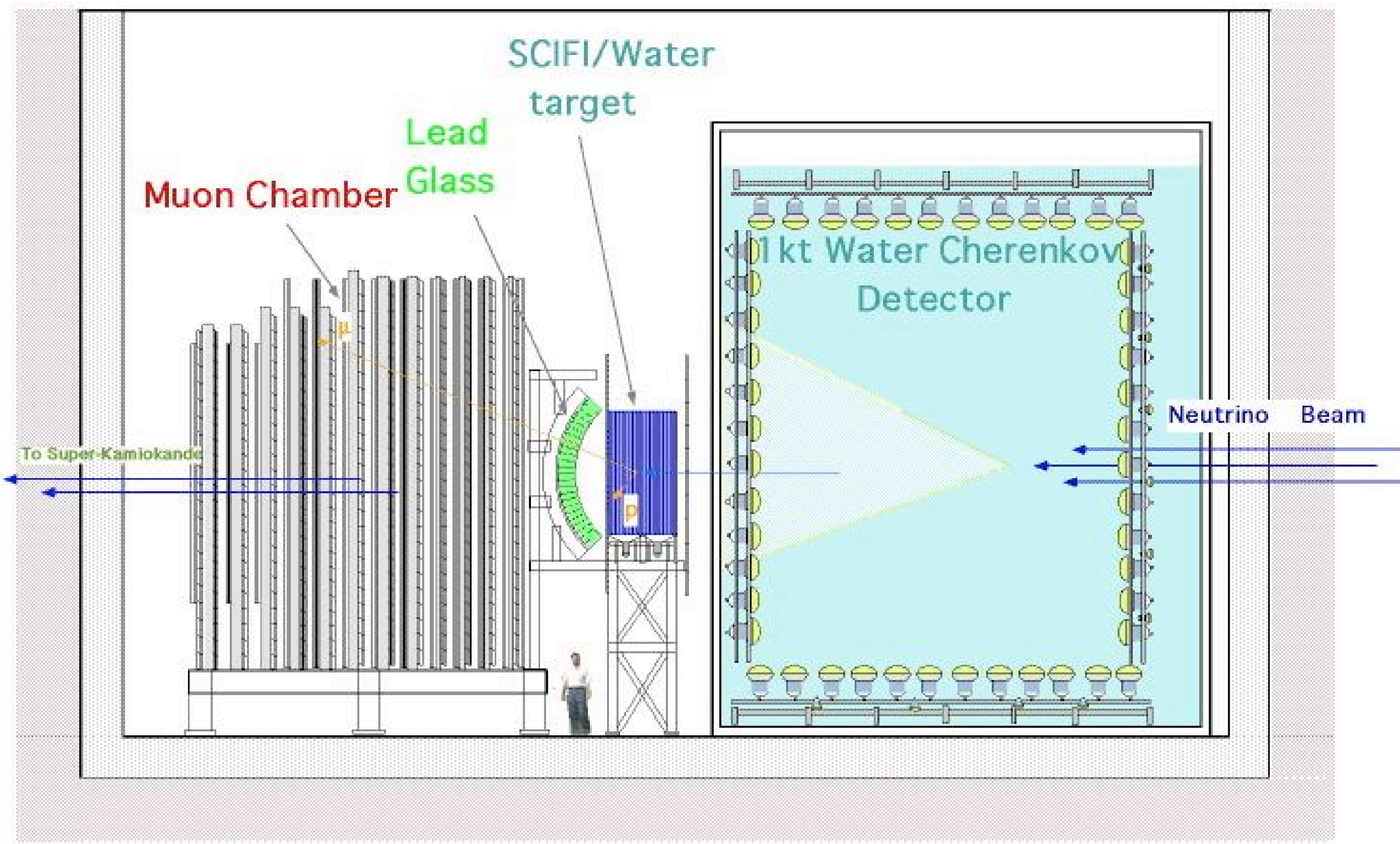
- Lots of new proposals:
  Below 0.1 GeV: nu-SNS
  0.5-1.5 GeV: Scibar@FNAL, FINESSE, Argon, ...
  2-20 GeV: MINERVA

- Strong efforts on organizing past neutrino data, Monte Carlo code development, measuring related hadronic production and electron scattering data, reinvigorated theoretical interest, ...

What Do We Need?

- Total charged- and neutral-current cross sections
- Charged lepton energy and angular distribution
- Struck nucleon energy and angular distributions
- Same for pions
- Rescattered nucleons, at least neutron counts
- Nuclear de-excitation gamma rays
- Delayed nuclear decays

K2K Detector(s)



Focus on Supernovae

A new opportunity to attack the supernova problem:

- Neutrinos are now under control (we think)

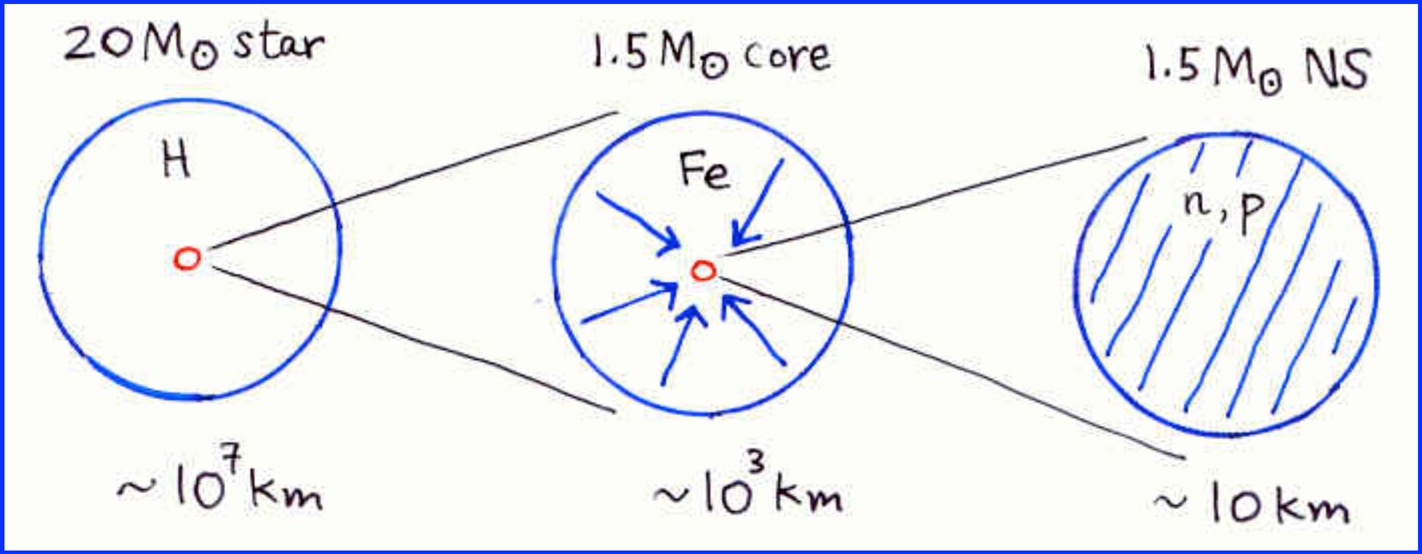
- Intense efforts on numerical modeling

- Very rapidly improving astronomical data

- Excellent prospects for getting neutrino data, with the Diffuse Supernova Neutrino Background

We need better neutrino cross sections to match

Supernova Energetics

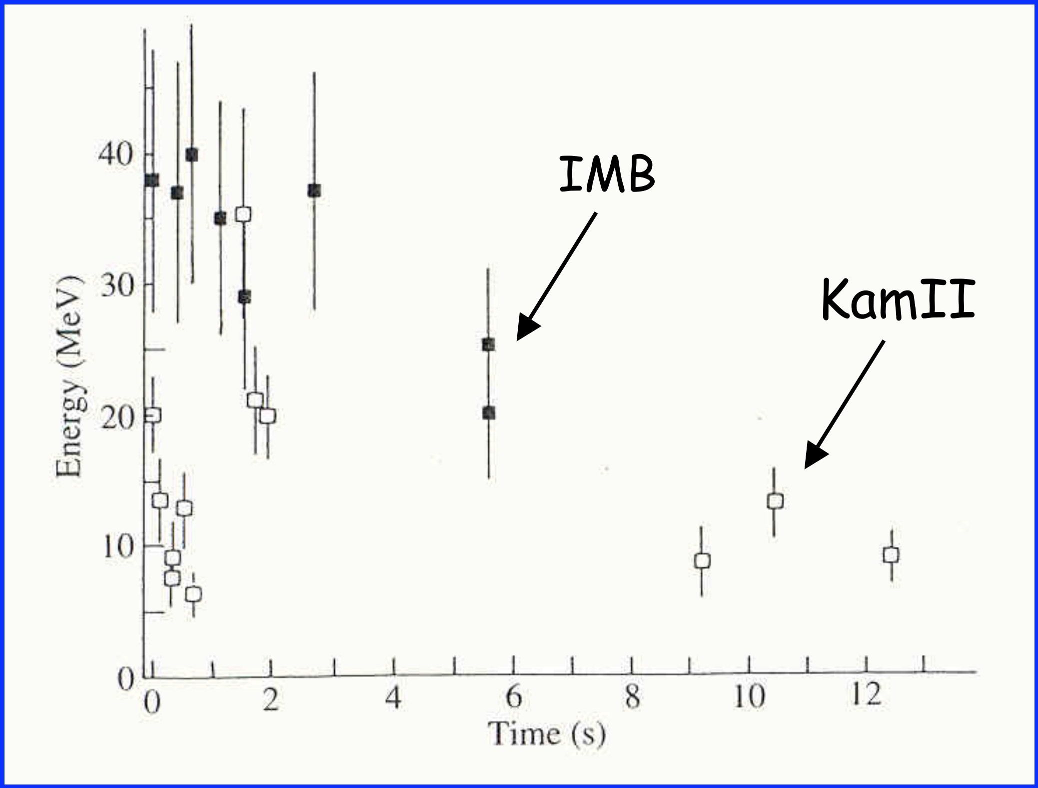


$$\Delta E_B \simeq \frac{3}{5}\frac{G M_{NS}^2}{R_{NS}} - \frac{3}{5}\frac{G M_{NS}^2}{R_{core}} \simeq 3\times10^{53} \text{ ergs} \simeq 2\times10^{59} \text{ MeV}$$

K.E. of explosion $\simeq 10^{-2}\,\Delta E_B$

E.M. radiation $\simeq 10^{-4}\,\Delta E_B$

Supernova Neutrino Detection



SN1987A :

$\sim 20\ \ \bar{\nu}_e p \rightarrow e^+ n$ events

SN200?? :

$\sim 10^4$ *CC* events

$\sim 10^3$ NC events

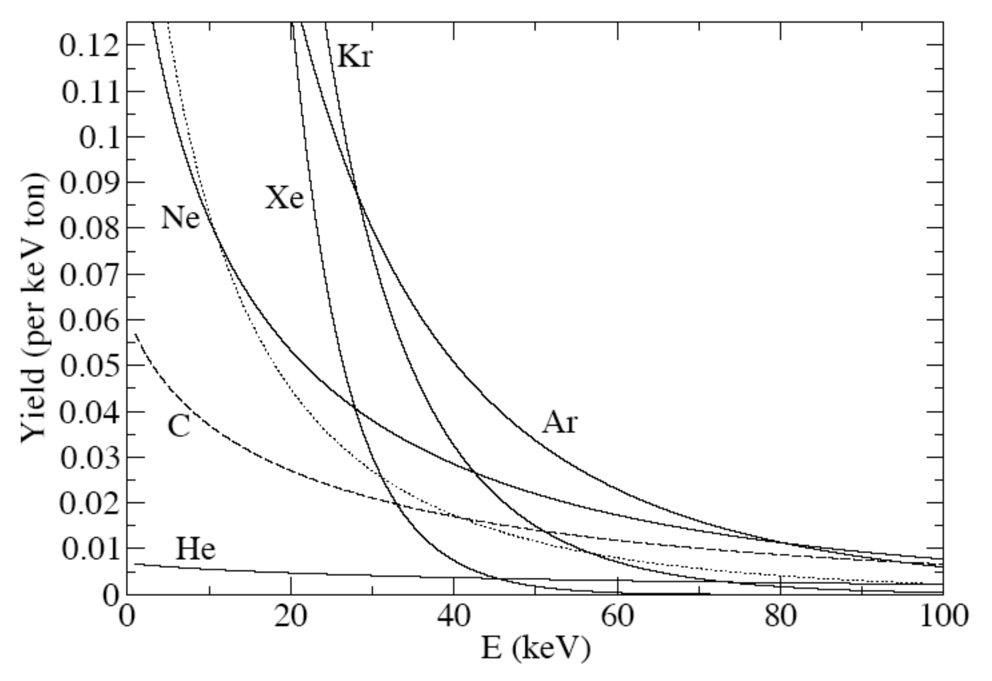
Supernova physics (models, black holes, progenitors…)

Particle physics (neutrino properties, new particles, …)

Neutronization and Opacity

- Electron capture on nuclei important, which affects the supernova and also the nue burst; see, e.g., Hix et al., PRL 91, 201102 (2003)

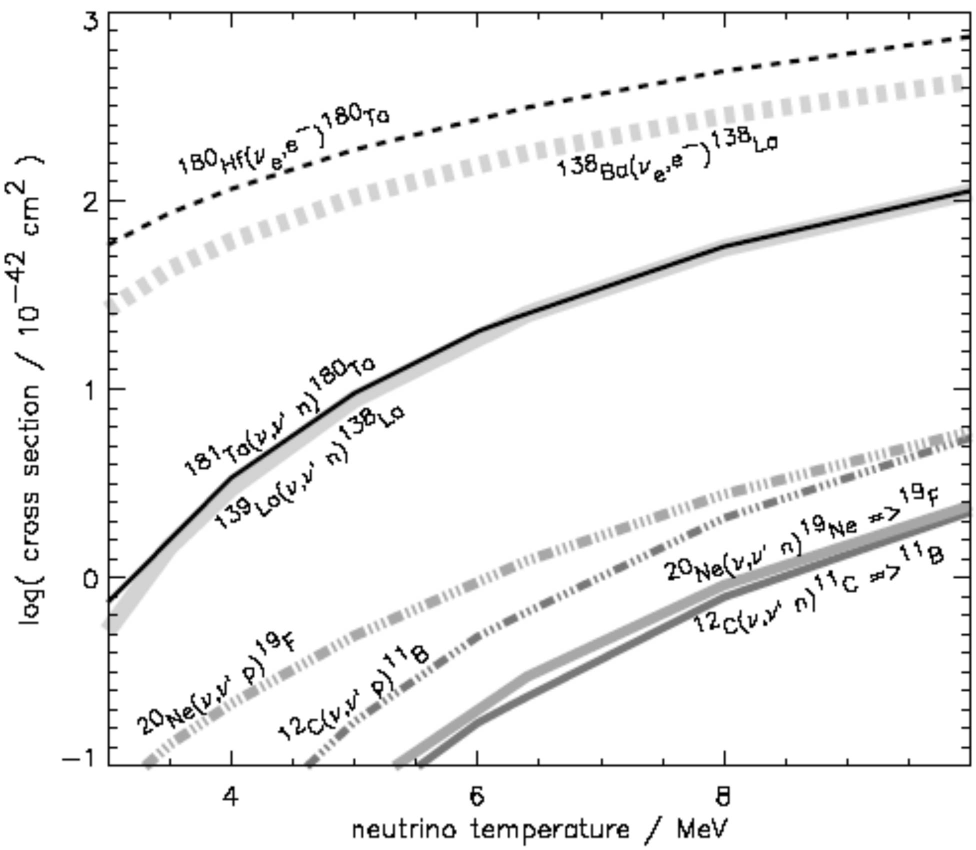
- Neutrino-nucleus coherent scattering is an important part of the opacity; it might also allow a detection channel



Horowitz, Coakley, McKinsey, PRD 68, 023005 (2003)

Neutrino Nucleosynthesis

FIG. 1: Dominant neutrino process cross sections for production for ^{11}B, ^{19}F, ^{139}La, and ^{180}Ta as a function of neutrino temperature (degeneracy parameter $\alpha = 0$).



Use supernova models and neutrino-nucleus cross sections to predict isotope yields and compare to data; this constrains the neutrino spectra

Heger et al., PLB 606, 258 (2005)

Supernova Burst Detection

Assume a Galactic supernova at 10 kpc

Yields in 22.5 kton Super-Kamiokande:

$\simeq 8000 \quad \bar{\nu}_e + p \rightarrow e^+ + n$

$\simeq 700 \quad \nu + {}^{16}O \rightarrow \nu + \gamma + X \quad (E = 5 - 10\ \mathrm{MeV})$

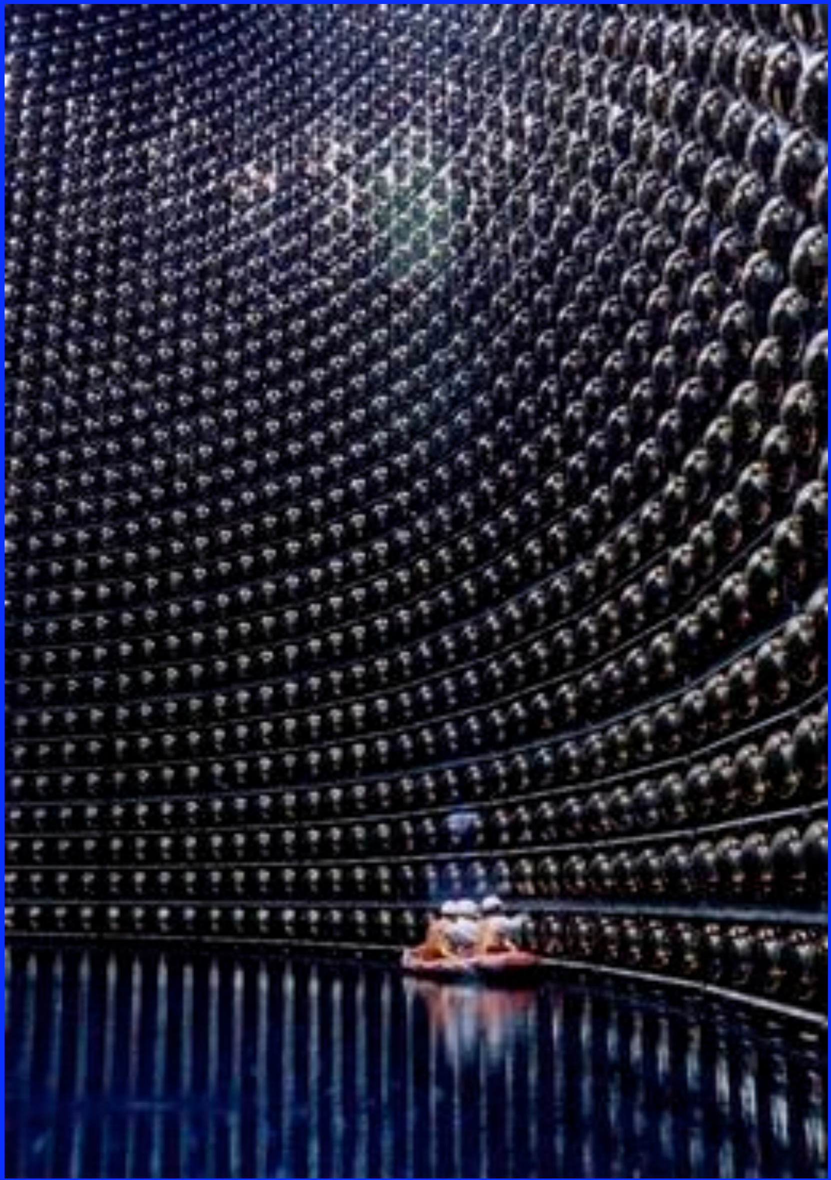
$\simeq 300 \quad \nu + e^- \rightarrow \nu + e^- \quad (e^-\ \text{is forward})$

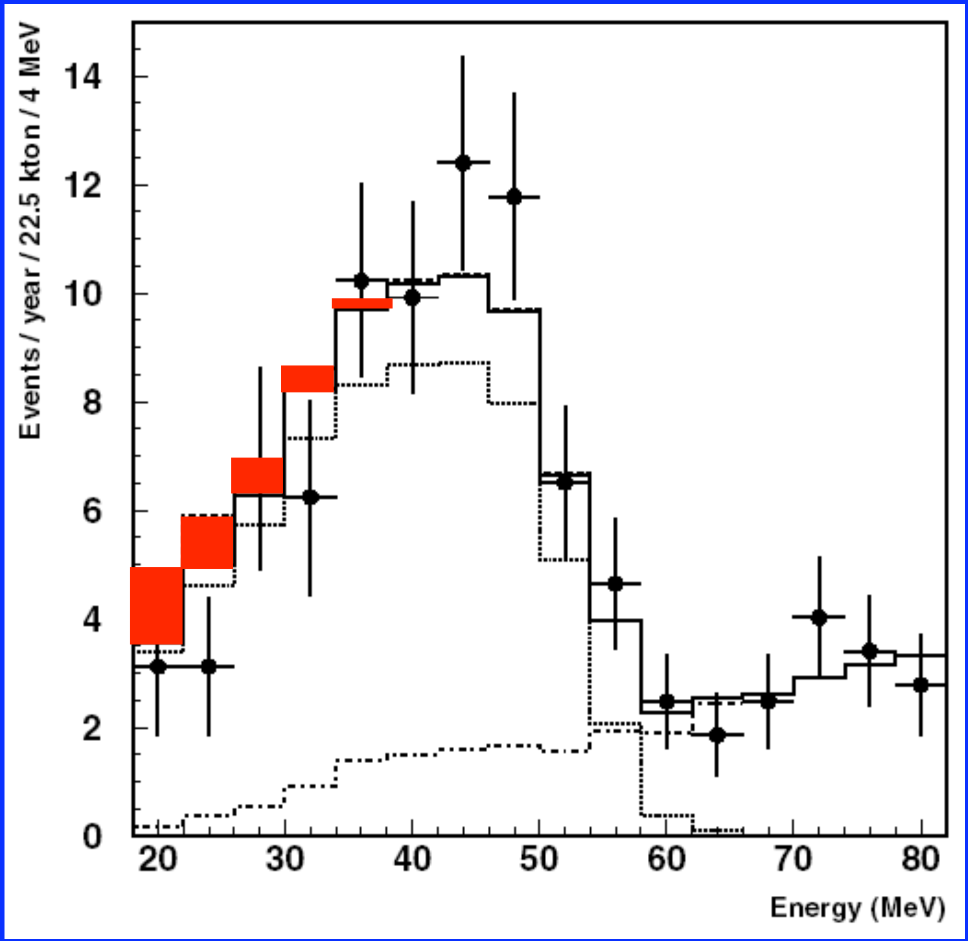
$\sim 100 \quad \nu_e + {}^{16}O \rightarrow e^- + X \quad \text{(buried)}$

$\bar{\nu}_e + {}^{16}O \rightarrow e^+ + X$

Rates on oxygen important, if they can be isolated

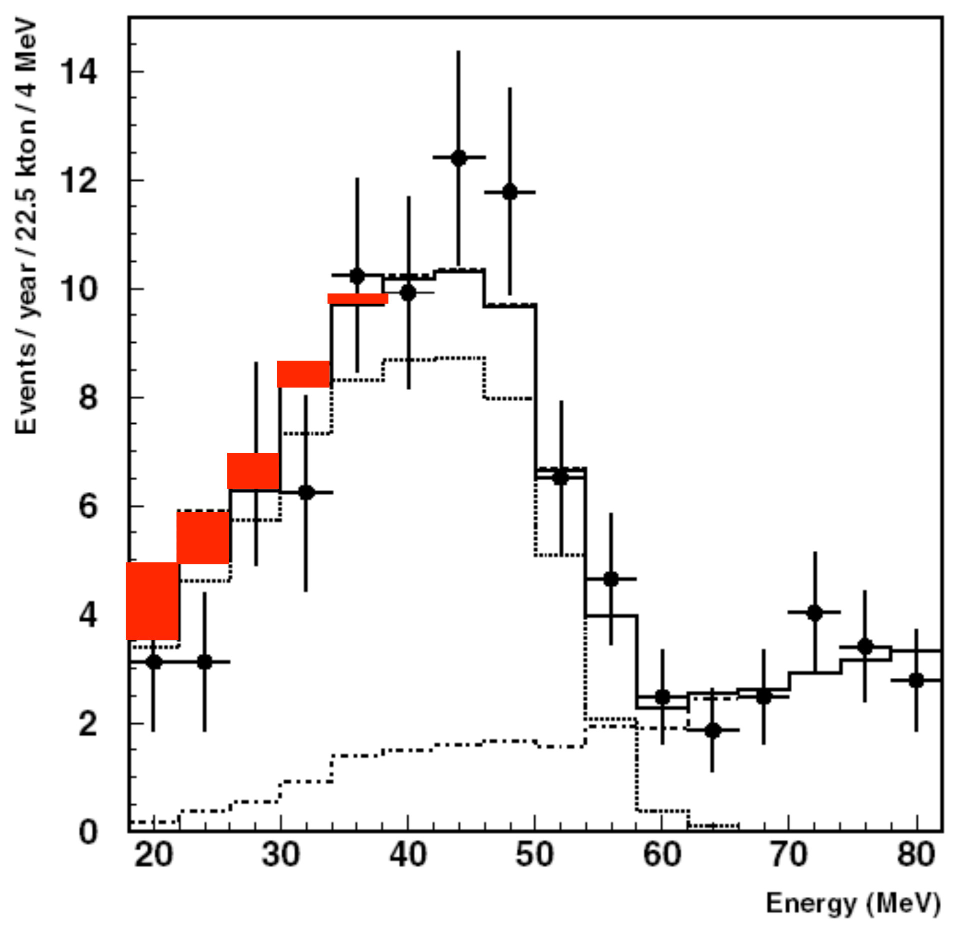
Super-Kamiokande

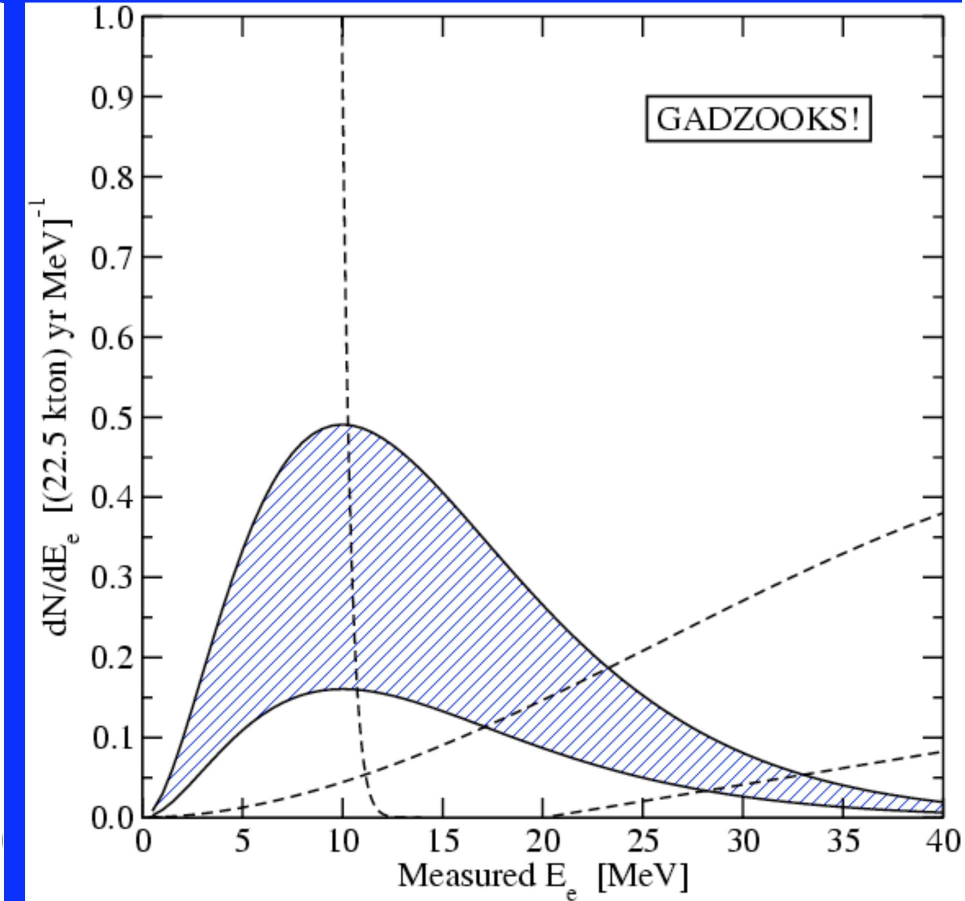




Malek et al. (SK), PRL 90, 061101 (2003)

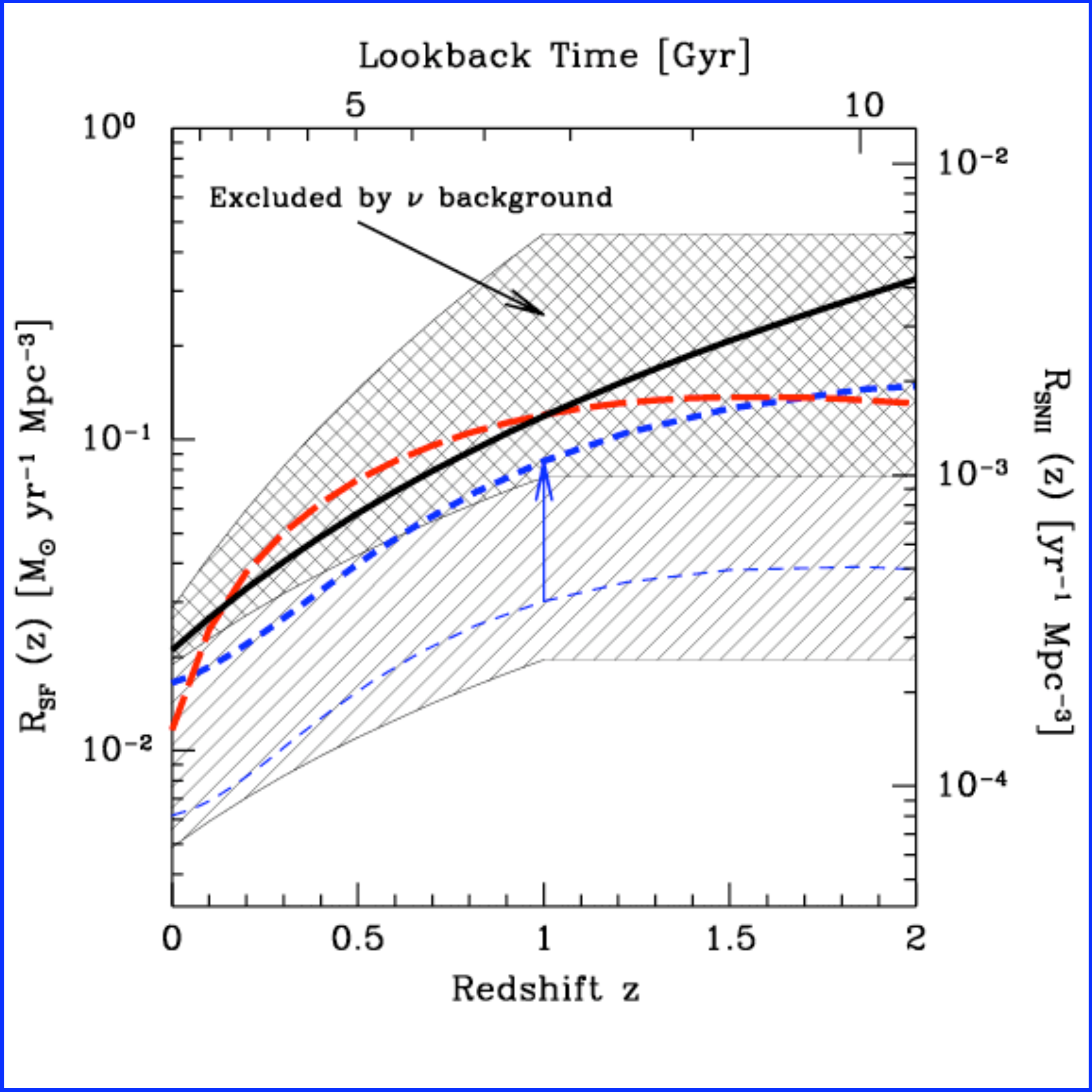
Spectrum With GADZOOKS!





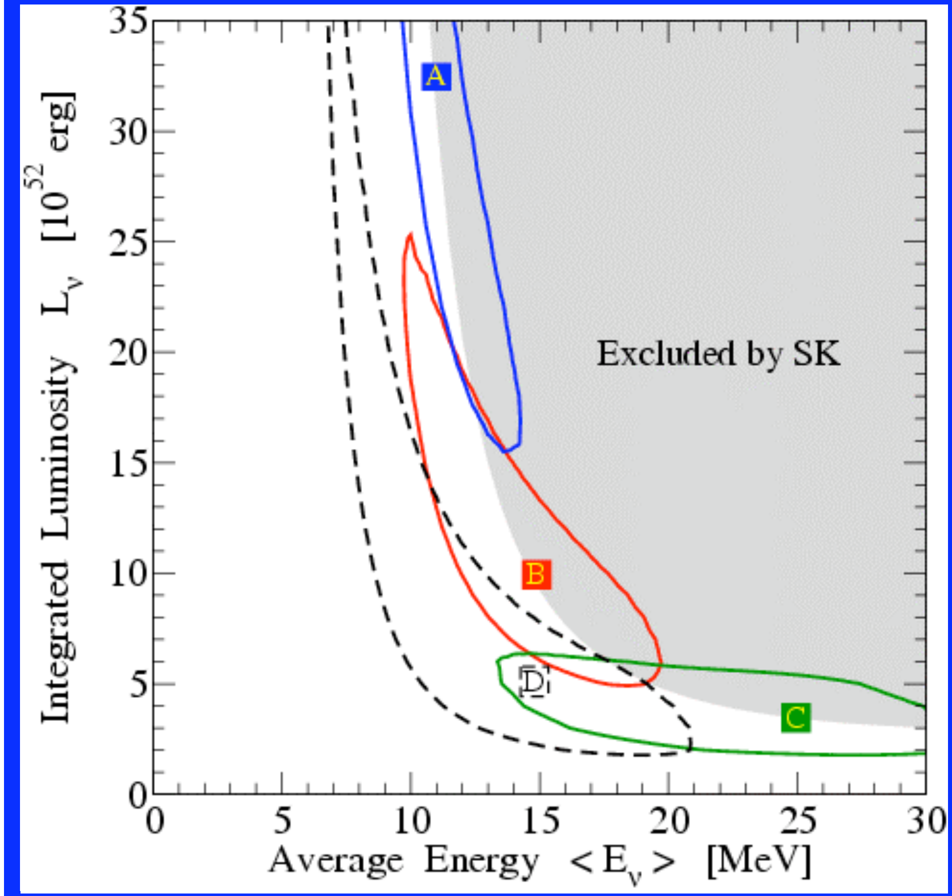
Beacom and Vagins, PRL (2004) [hep-ph/0309300]

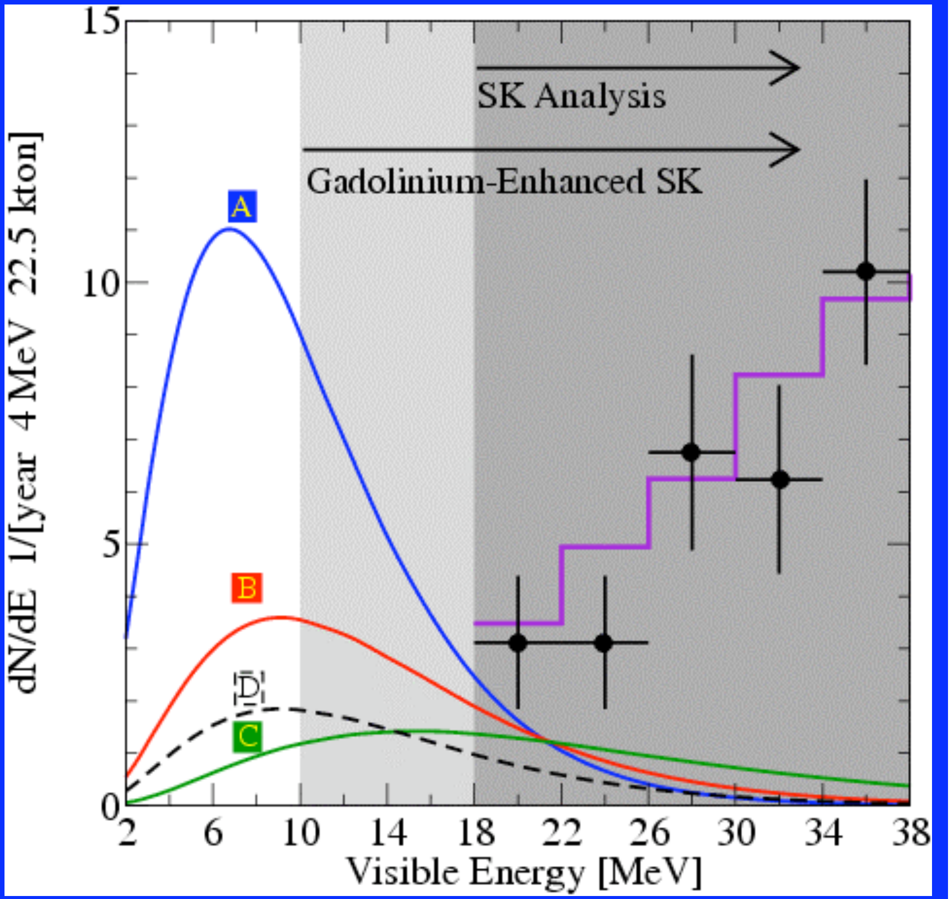
Cosmic Star Formation Rate



Strigari, Beacom, Walker, Zhang, astro-ph/0502150

Future DSNB Detection



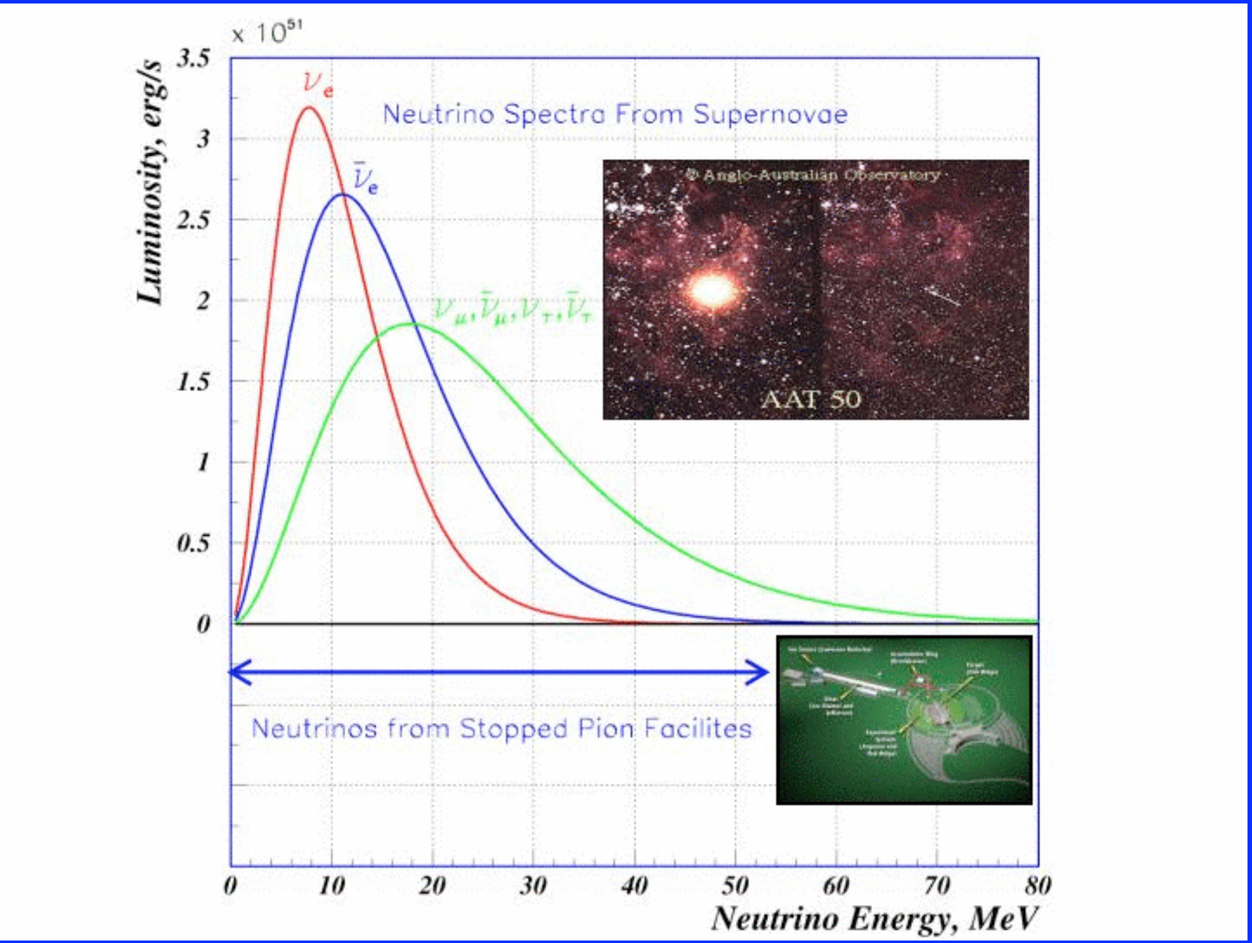


Yuksel, Ando, Beacom, astro-ph/0509297

nu-SNS Proposal

SNS produces abundant pions as a byproduct.

Pion and muon decays produce 0-50 MeV neutrinos.



homogeneous detector for: D, C, O, I, ...

segmented detector for: Al, Fe, Pb, Ta, ...

Conclusions

- We need better neutrino cross sections to match the great leaps forward in understanding neutrino properties, developing new detectors, and making connections to astrophysics - Need new experiments.
  - 2-20 GeV regime: see Niculescu
  - Strange spin of the proton: see Tayloe, Miyachi
  - Liquid Argon development: see Fleming
  - 10-50 MeV regime: see Cianciolo
  - Coherent nuclear scattering: see Scholberg
  - Connection to neutrino properties: see Friedland