Neutrinos from Core-Collapse SNae

Kate Scholberg, Duke University
CCSN Workshop, Pasadena, March 2016
When a star's core collapses, ~99% of the gravitational binding energy of the proto-nstar goes into ν's of all flavors with ~tens-of-MeV energies

(Energy *can* escape via ν's)

Mostly ν-ν̅ pairs from proto-nstar cooling

**Timescale:** *prompt* after core collapse, overall Δt~10’s of seconds

A. Mezzacappa
Expected neutrino luminosity and average energy vs time

**Vast information in the flavor-energy-time profile**


- **Early:** deleptonization
- **Mid:** accretion
- **Late:** cooling

Note: visible supernova may not show up for hours or days
Multimessenger signals

K. Nakamura et al., MNRAS 2016
What can we learn from the next neutrino burst?

**CORE COLLAPSE PHYSICS**
- explosion mechanism
- proto nstar cooling,
- quark matter
- black hole formation
- accretion, SASI
- nucleosynthesis

**NEUTRINO and OTHER PARTICLE PHYSICS**
- $\nu$ absolute mass (not competitive)
- $\nu$ mixing from spectra:
  - flavor conversion in SN/Earth (mass hierarchy)
  - other $\nu$ properties: sterile $\nu$'s,
    - magnetic moment,...
- axions, extra dimensions,
  - FCNC, ...

**input from neutrino experiments**

**from flavor, energy, time structure of burst**

**input from photon (GW) observations**

**+ EARLY ALERT**
<table>
<thead>
<tr>
<th>Current main supernova neutrino detector types</th>
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<tbody>
<tr>
<td><strong>Water</strong></td>
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<tr>
<td><img src="image1" alt="Water Detector" /> <img src="image2" alt="Water Detector" /></td>
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<tr>
<td><strong>Scintillator</strong></td>
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<td><strong>Argon</strong></td>
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<td><img src="image4" alt="Argon Detector" /></td>
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<td><strong>Lead</strong></td>
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<td><img src="image5" alt="Lead Detector" /></td>
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<td>+ some others (e.g. DM detectors)</td>
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In particle physics, an “event” is *not* this...

It’s an individual *recorded neutrino interaction*:

- Few times $10^{-5}$ ergs
- ~$10^{52-53}$ ergs

E.g., “the IMB neutrino detector saw 8 events from 1987A”
Water Cherenkov detectors

Inverse Beta Decay (CC) dominates

\[ \bar{\nu}_e + p \rightarrow e^+ + n \]

\( E_{\text{thr}} = 1.8 \text{ MeV} \)

Pointing from neutrino-electron elastic scattering

G. Raffelt
Super-Kamiokande Water Cherenkov detector in Mozumi, Japan

- 50 kton of ultrapure water
- 13,000 photomultiplier tubes
- 40 m high, 17 m radius
- 1 km underground

40 m high, 17 m radius

13,000 photomultiplier tubes

50 kton of ultrapure water

1 km underground
Detection efficiency

- Sensitivity to full Galaxy (and somewhat beyond)
- Few to 10° pointing within this range

Pointing*

*SK-Gd upgrade will improve this by reducing isotropic bg
Next generation: Hyper-Kamiokande

374 kton fiducial volume
Design & site-selection underway
~100,000 events!
mostly electron antineutrinos
Hyper-K detection probabilities

K. Nakamura et al., MNRAS 2016
Long string water Cherenkov detectors

~kilometer long strings of PMTs in very clear water or ice (IceCube, ANTARES)

Nominally multi-GeV energy threshold... but, may see burst of low energy (anti-) $\nu_e$'s as coincident increase in single PMT count rate

Map overall time structure of burst by tracking the glow