Detecting Late-Time Neutrinos from Core-Collapse Supernovae

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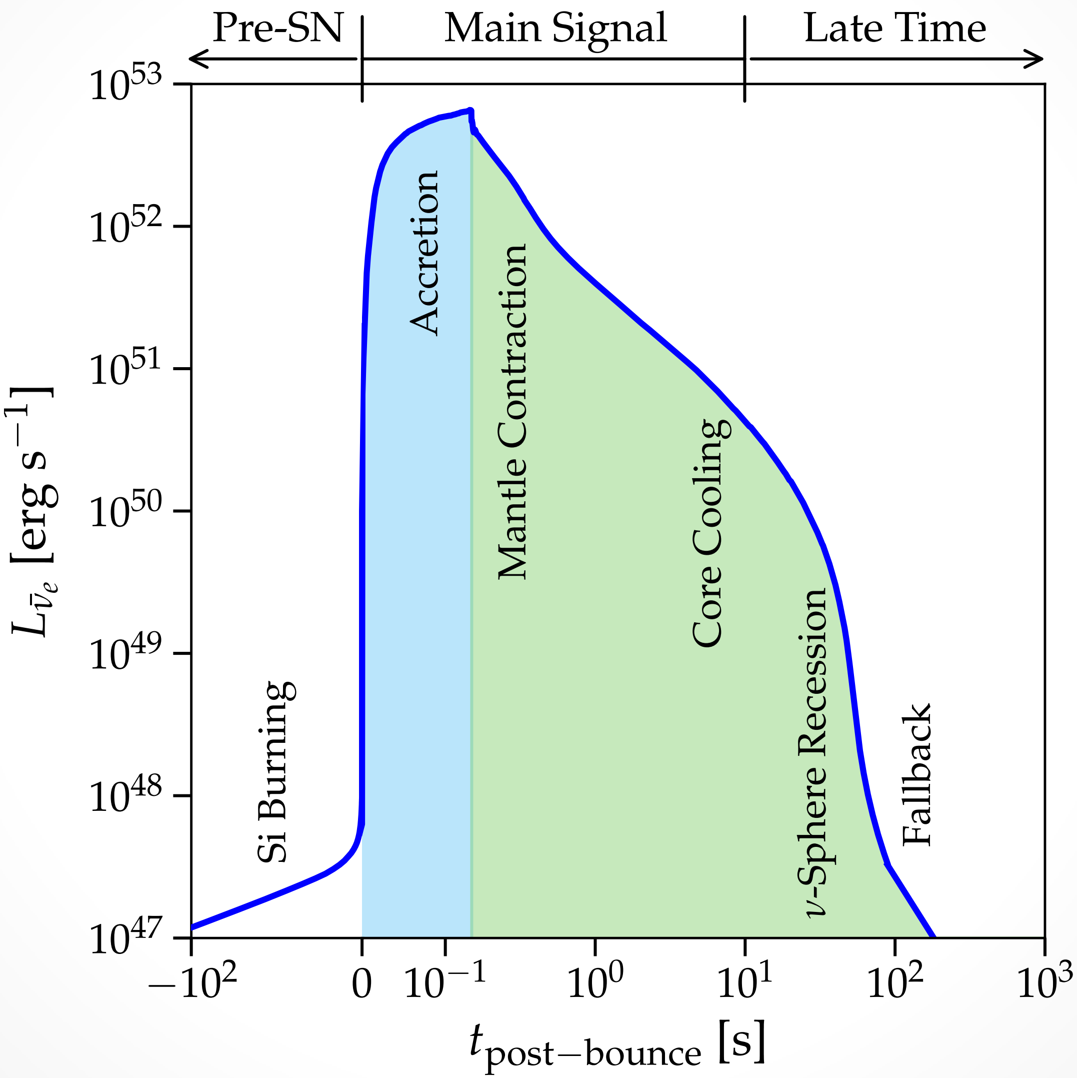
Collaborators: L. Roberts, J. Beacom

Timescale of A SN



Open Questions

- Is Neutrino Heating the Explosion Mechanism?
- How Do Neutrinos Oscillate In Dense Environment?

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- How Do Neutrinos Oscillate In Dense Environment?
- What Are the Yields of Heavy Elements?
- What Is the Equation of State of a NS?
- What Remnant Forms From A SN Explosion?

SN Cooling Neutrinos

…

Input -- Simulation

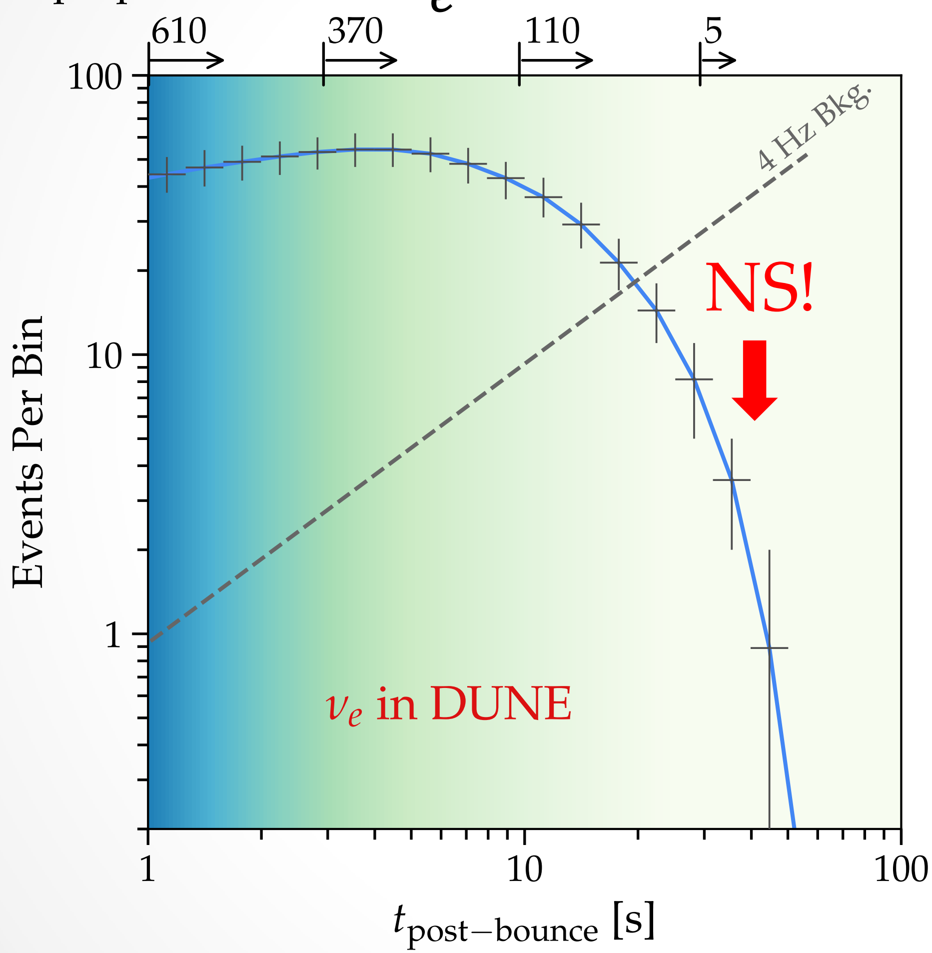
Luke Roberts

- 1D
- Goes Out to ~ 100 s
- No Convection
- 15 Solar Mass

ν_e Signal Rate

Li, Roberts & Beacom, in prep

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

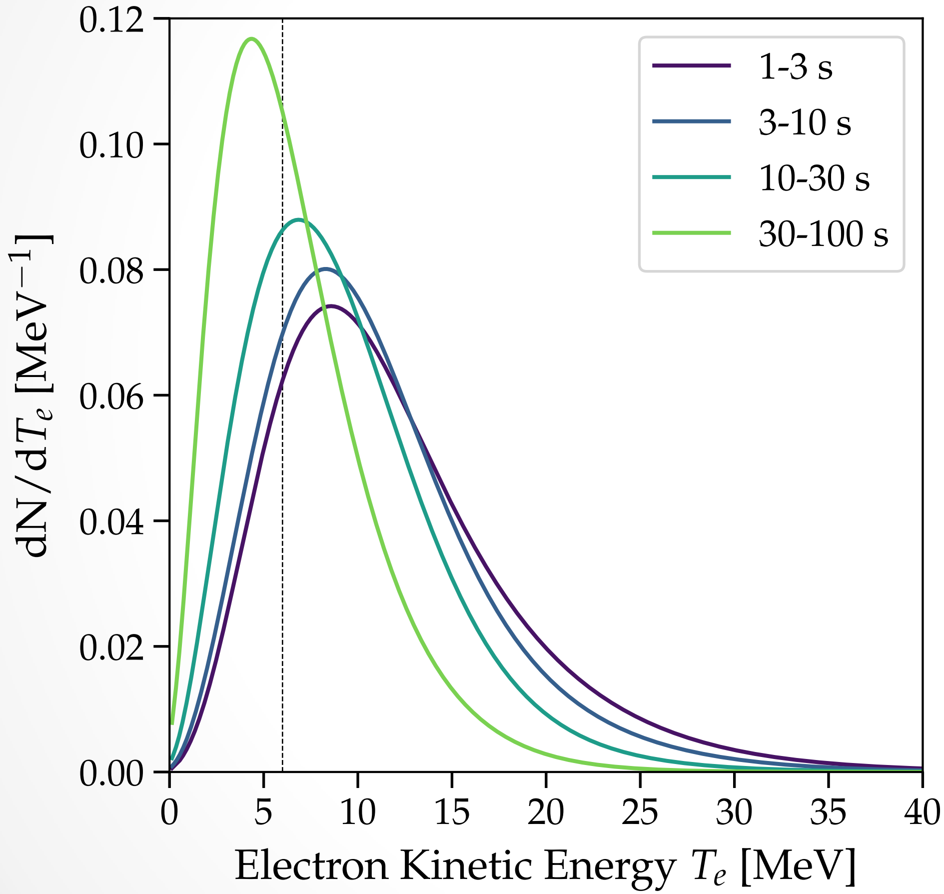


- Inputs:
  - 10 kpc SN
  - 40 kton
  - 6 MeV Threshold
  - Neutron Capture Background

Plenty of Events to Late Time in DUNE!

ν_e Energy Spectrum

$$\nu_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}^*$$



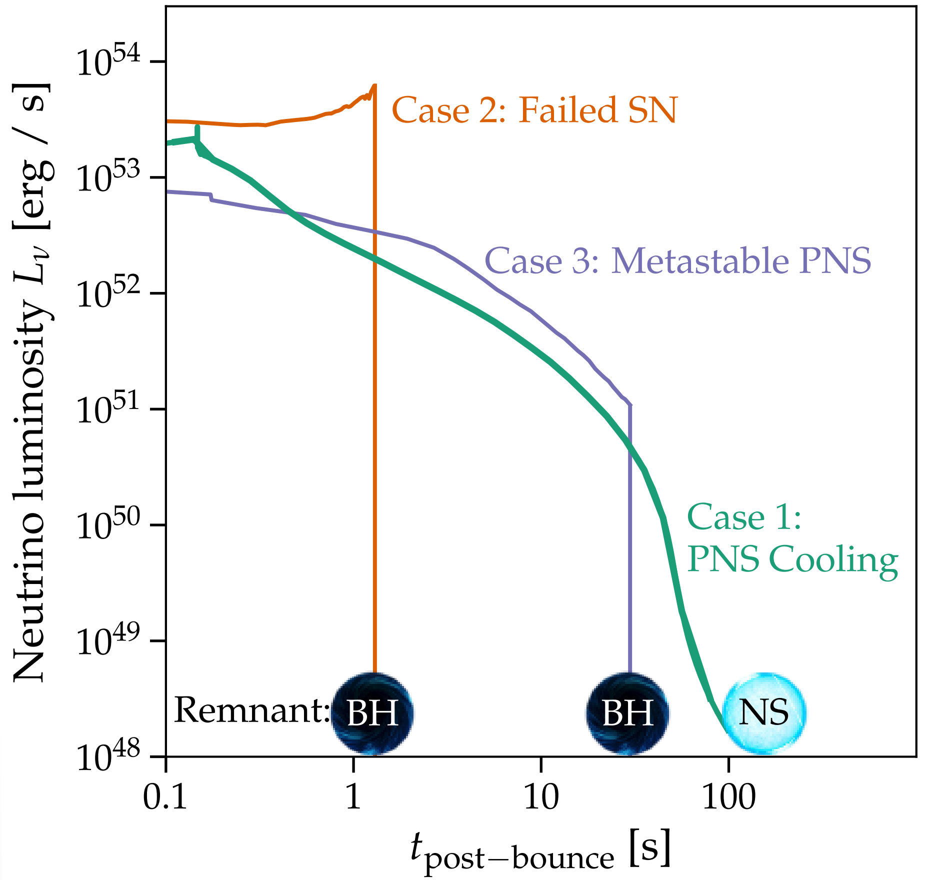
- $E_e = E_{\nu_e} - Q - \Delta\text{E}$
- Threshold Close to Spectrum Peak

Li, Roberts & Beacom, in prep

Detection Threshold Needs to Reach ~ 6 MeV

Alternative Outcome -- BH

Different Mechanisms for BH Formation

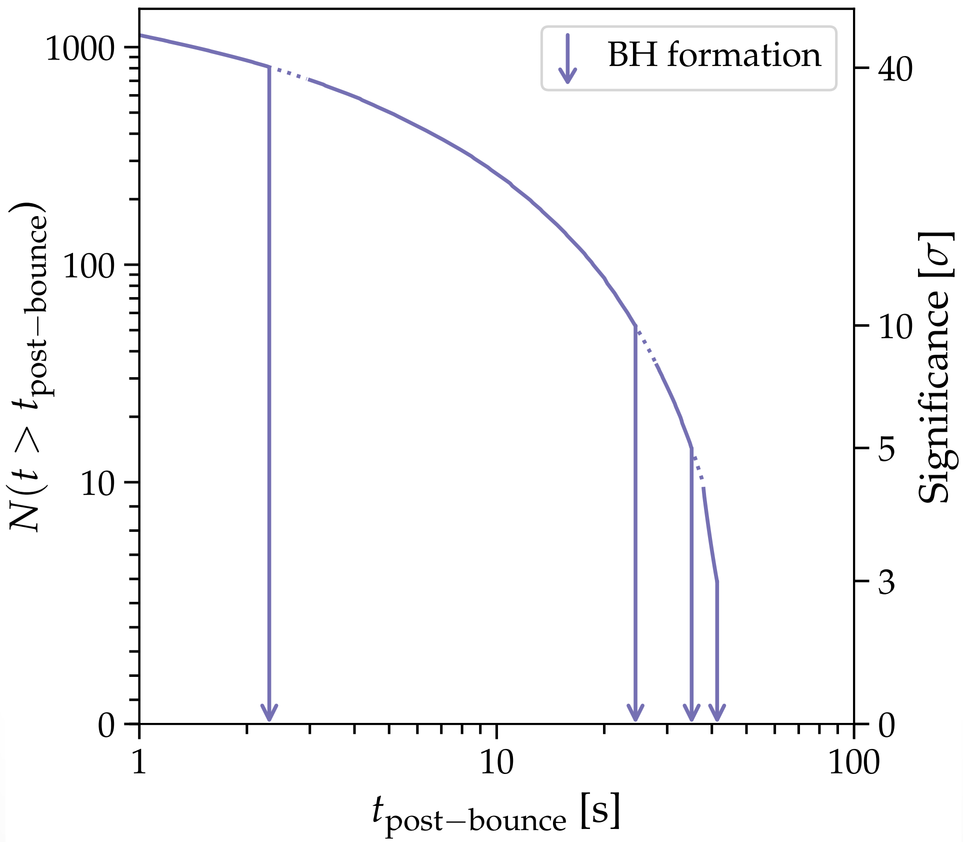


Li, Roberts & Beacom, in prep

BH May Form at Late Times

Detecting BH Formation

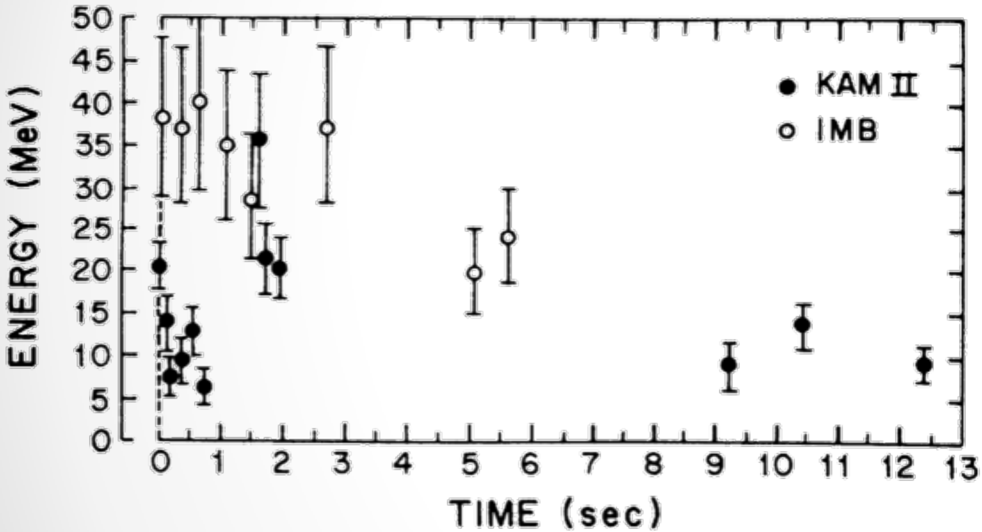
Detection Significance of BH Formation

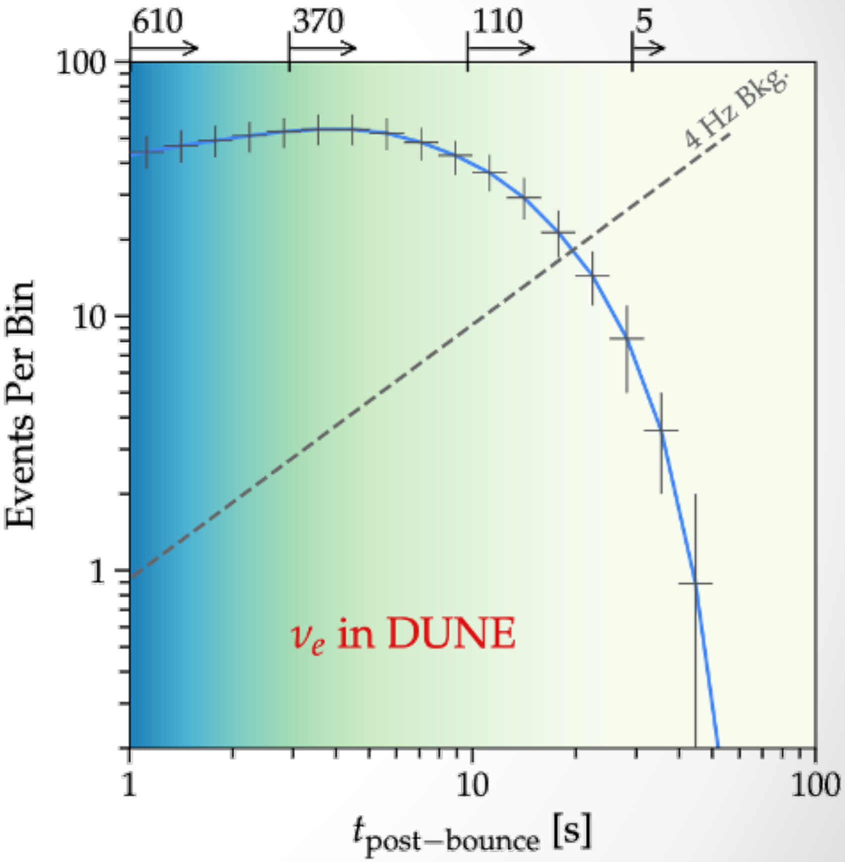


Li, Roberts & Beacom, in prep

We Can Detect BH Formation at Late Times

Conclusions





Backup

Galactic Core-Collapse SN

How Often?

$$3.2^{+7.3}_{-2.6}$$

Adams et al, 2013

$$2.8^{+0.6}_{-0.6}$$

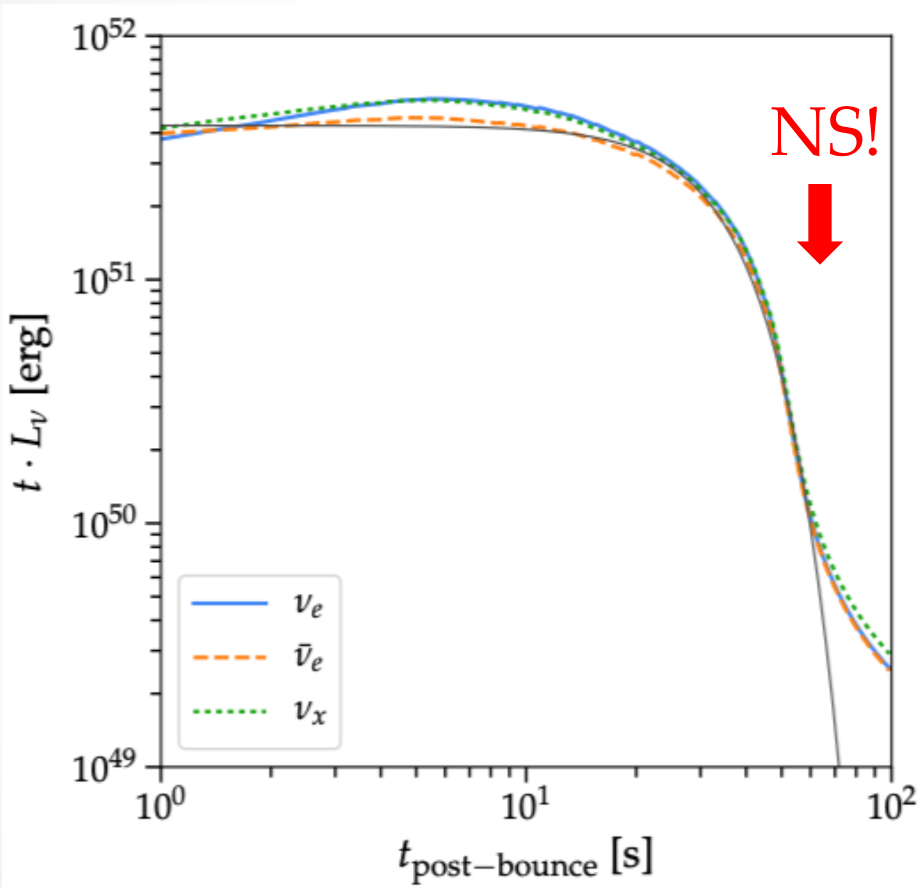
(With A Systematic Uncertainty of A Factor of ~2)

Li et al, 2011

Per Century

Cooling Neutrinos

Neutrino Luminosity



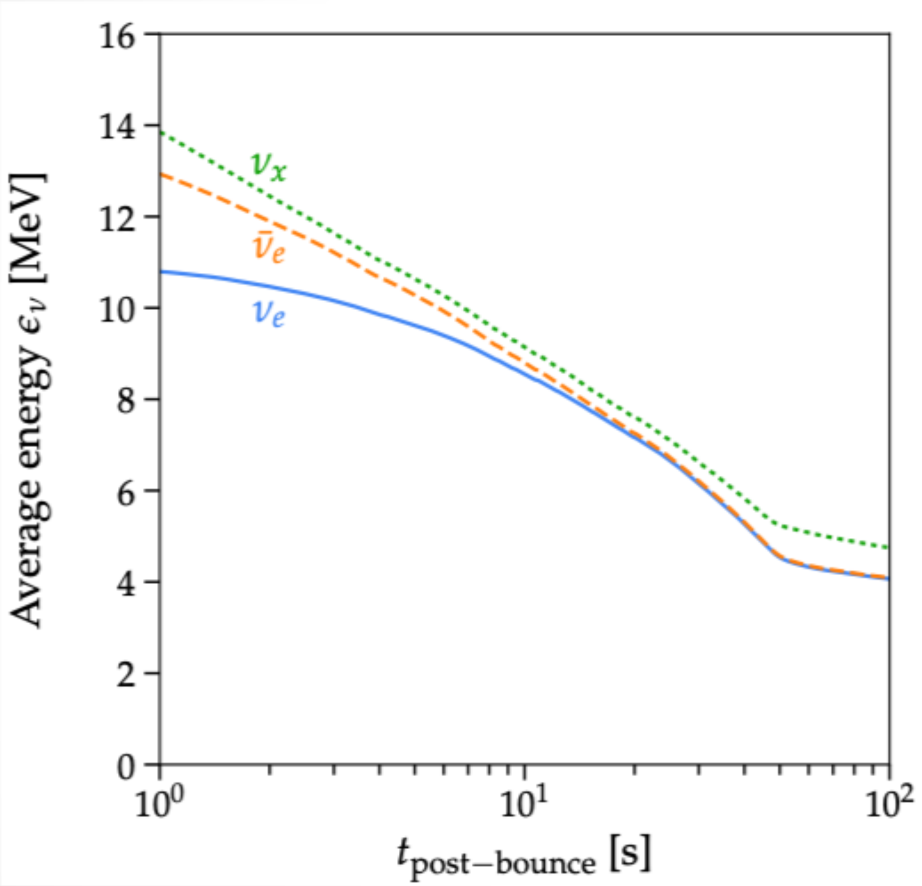
- 1/t Behavior Surprising
- Connects SN and NS
- Moderate Mixing Effect

Li, Roberts & Beacom, in prep

Cooling Neutrinos Are Interesting & Robust!

Cooling Neutrinos

Neutrino Energy



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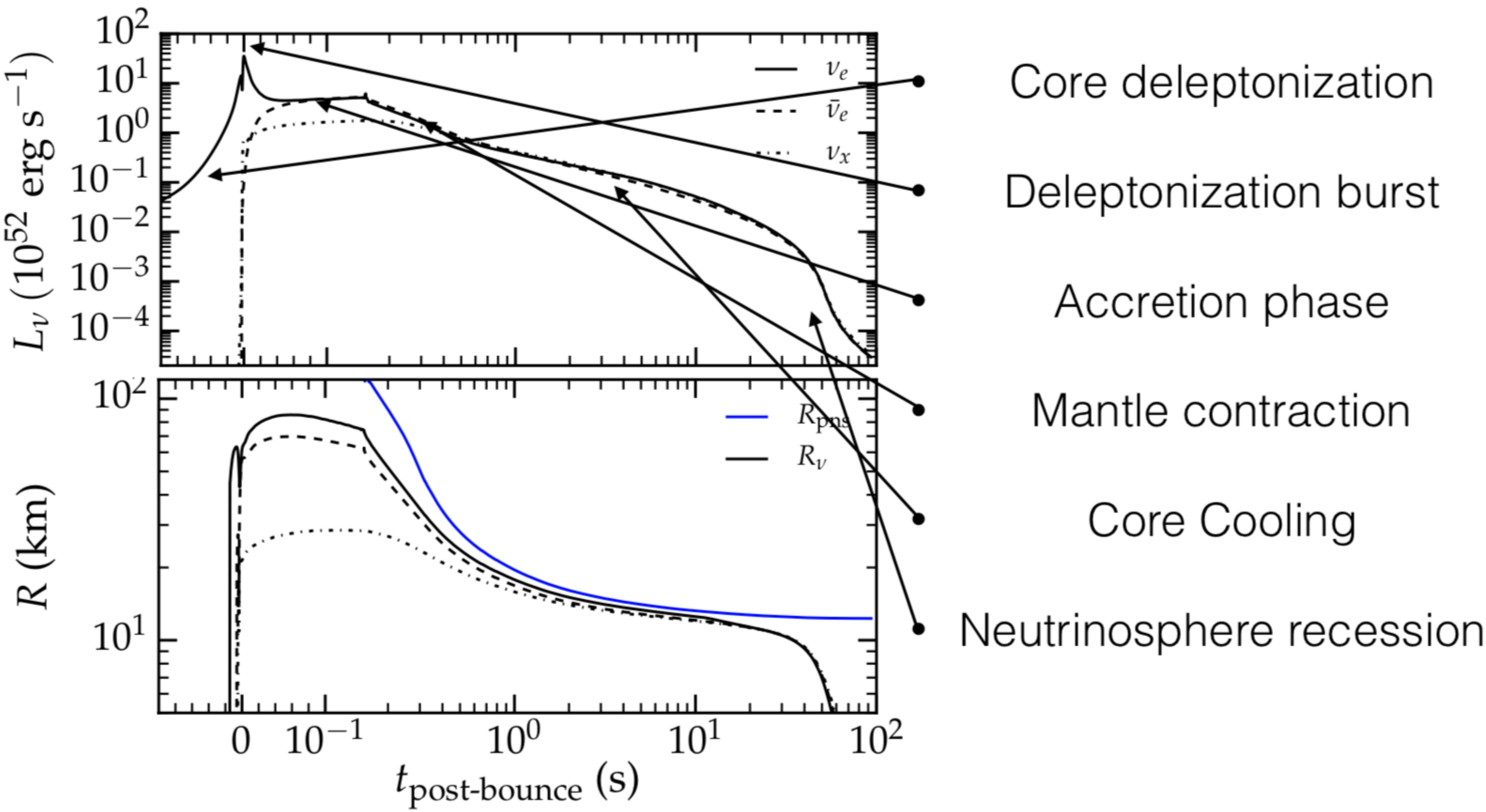
Cooling Neutrinos Are Interesting & Robust!

Anatomy of the Neutrino Signal



ν_e Signal Rate

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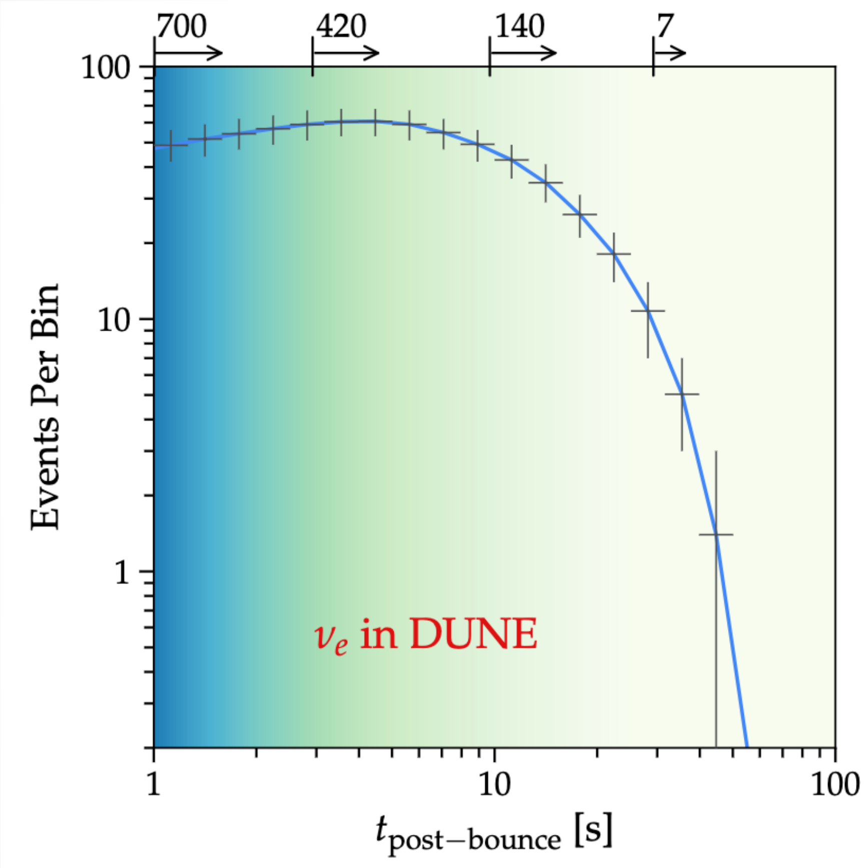

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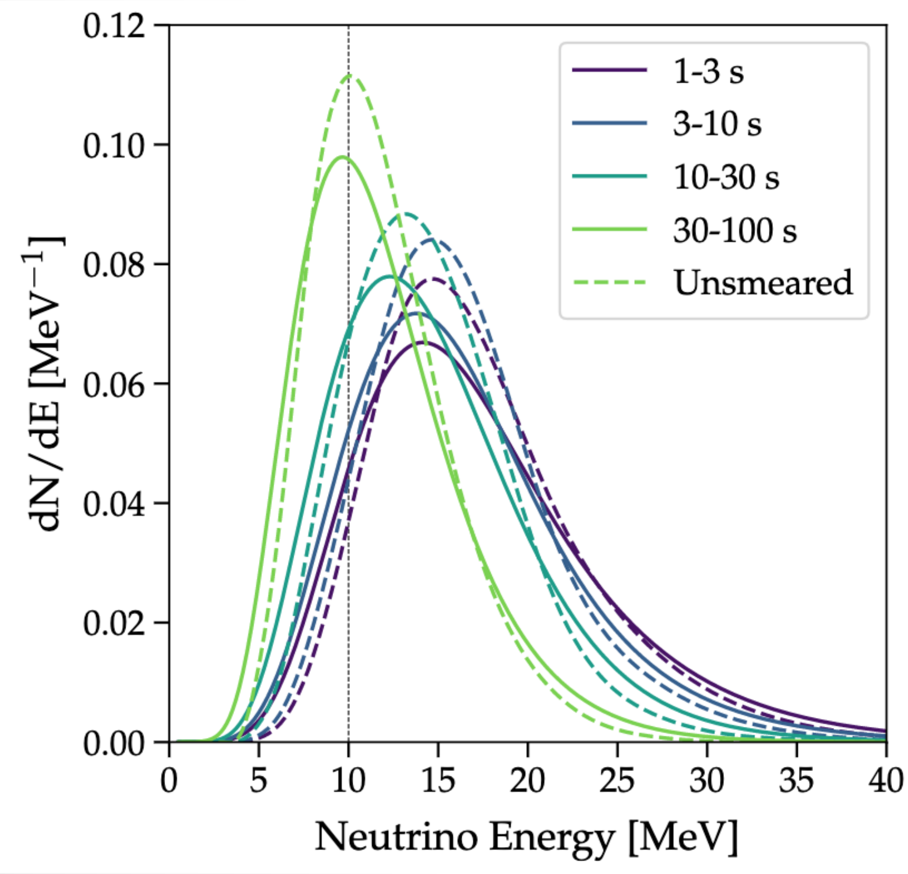

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Detection Threshold Needs to Reach ~ 10 MeV

Cross Section Studies

PHYSICAL REVIEW C **80**, 055501 (2009)

Weak-interaction strength from charge-exchange reactions versus β decay in the $A = 40$ isoquintet

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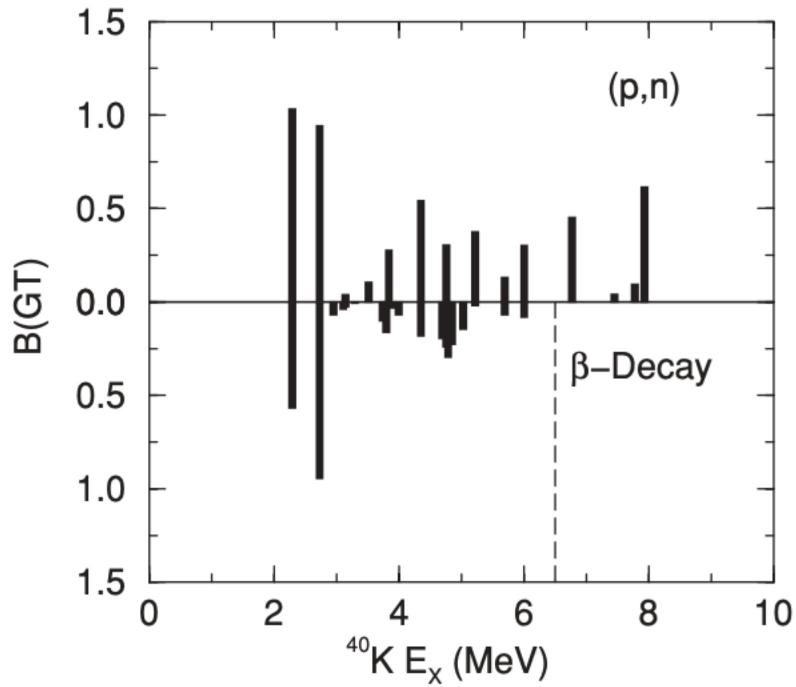
(Received 29 February 2008; revised manuscript received 1 July 2009; published 19 November 2009; publisher error corrected 24 November 2009)

We report a measurement of the Gamow-Teller (GT) strength distribution for ^{40}Ar → ^{40}K using the $0^\circ(p,n)$ reaction. The measurement extends observed GT strength distribution in the $A = 40$ system up to an excitation energy of ~8 MeV. In comparing our results with those from the β decay of the isospin mirror nucleus ^{40}Ti, we find that, within the excitation energy region probed by the β-decay experiment, we observe a total GT strength that is in fair agreement with the β-decay measurement. However, we find that the relative strength of the two strongest transitions differs by a factor of ~1.8 in comparing our results from (p,n) reactions with the β decay of ^{40}Ti. Using our results we present the neutrino-capture cross section for ^{40}Ar.

Cross Section Studies

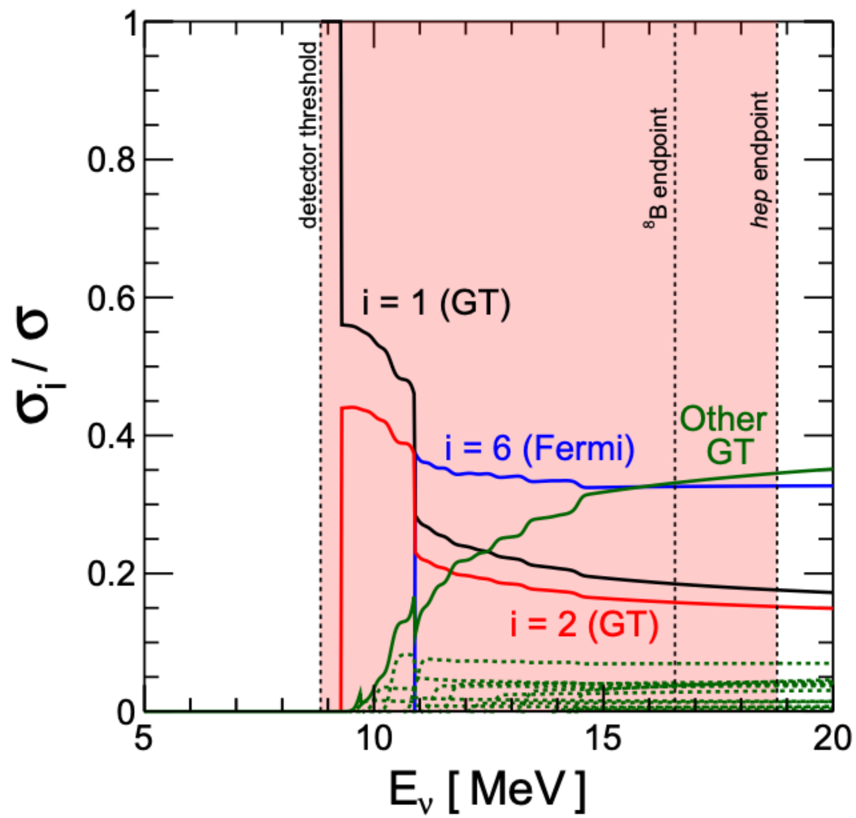


Cross Sections

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

Capozzi et al., 2018

i	ΔE_i [MeV]	B_i(F)	B_i(GT)
1	2.333		1.64
2	2.775		1.49
3	3.204		0.06
4	3.503		0.16
5	3.870		0.44
6	4.384	4.00	
7	4.421		0.86
8	4.763		0.48
9	5.162		0.59
10	5.681		0.21
11	6.118		0.48
12	6.790		0.71
13	7.468		0.06
14	7.795		0.14
15	7.952		0.97
total		4.00	8.29



Difficult Theoretically and Experimentally