Old Data, New Forensics: The First Second of SN 1987A Neutrino Emission

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2306.08024 w/ Beacom, Roberts, Capozzi

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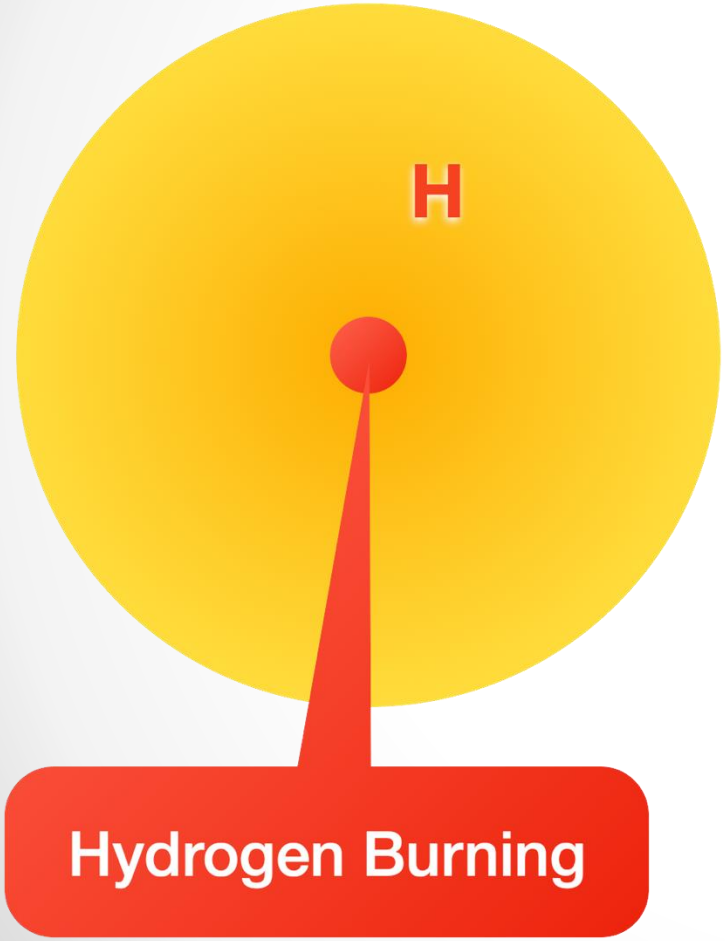
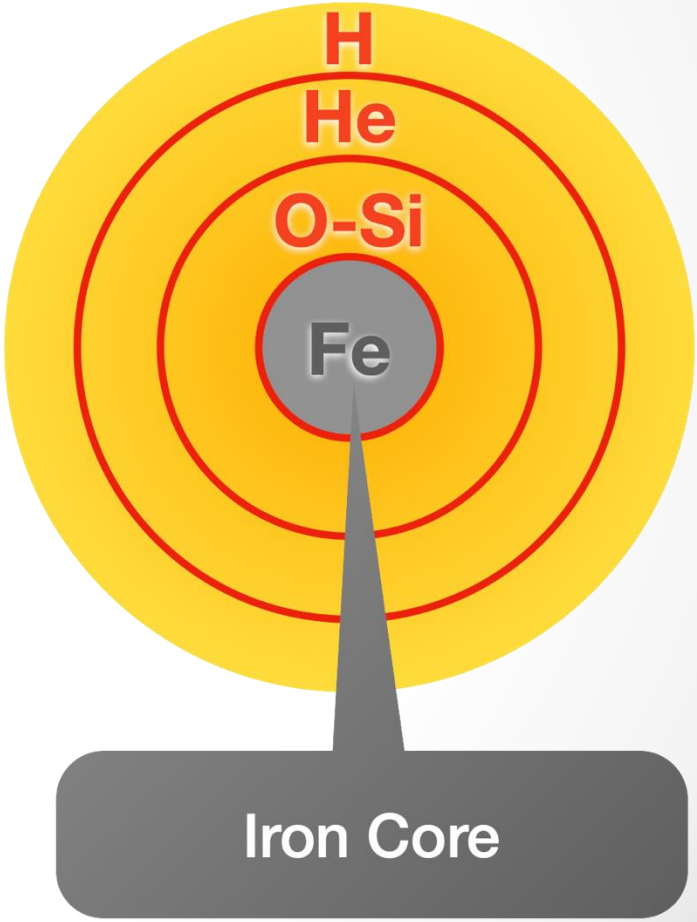
Core-Collapse Supernovae

The end of massive stars (> 8 $M_\odot$)

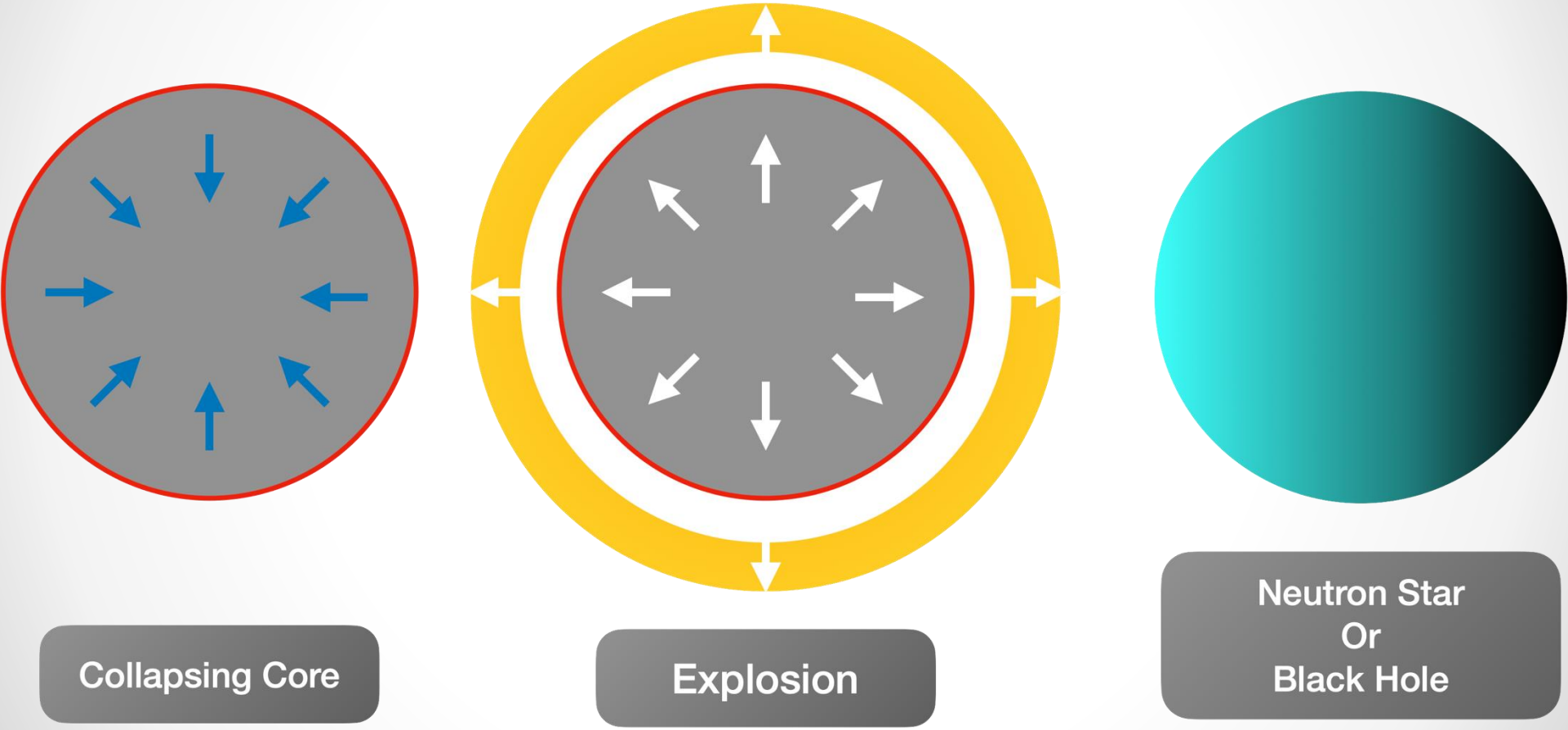




Figures remade from Raffelt's talk

Core-Collapse Supernovae

The end of massive stars ($> 8\ M_\odot$)



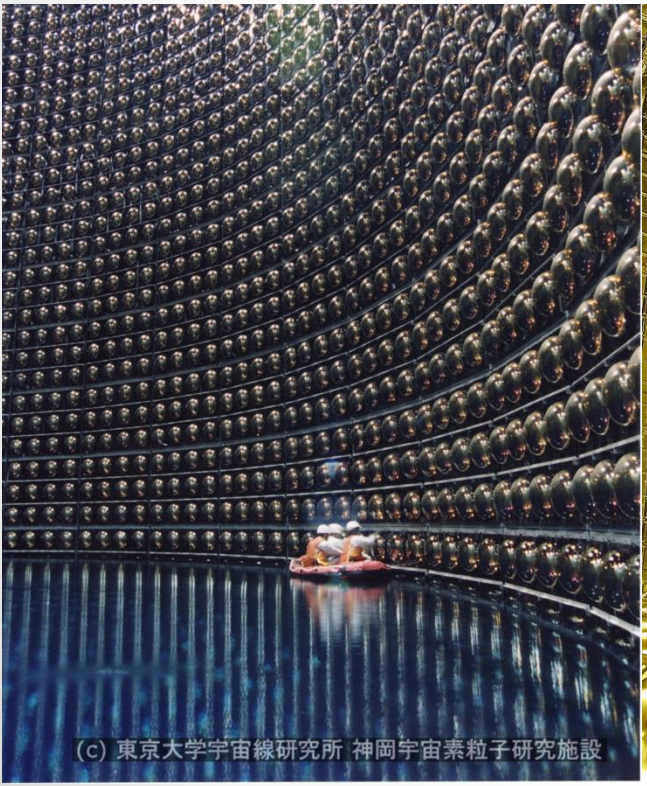
Figures remade from Raffelt's talk

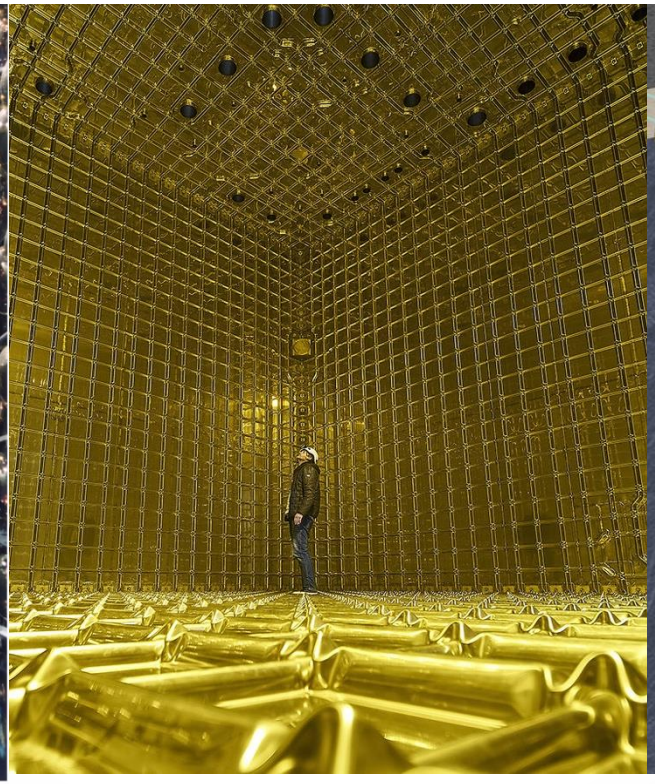
WHY?

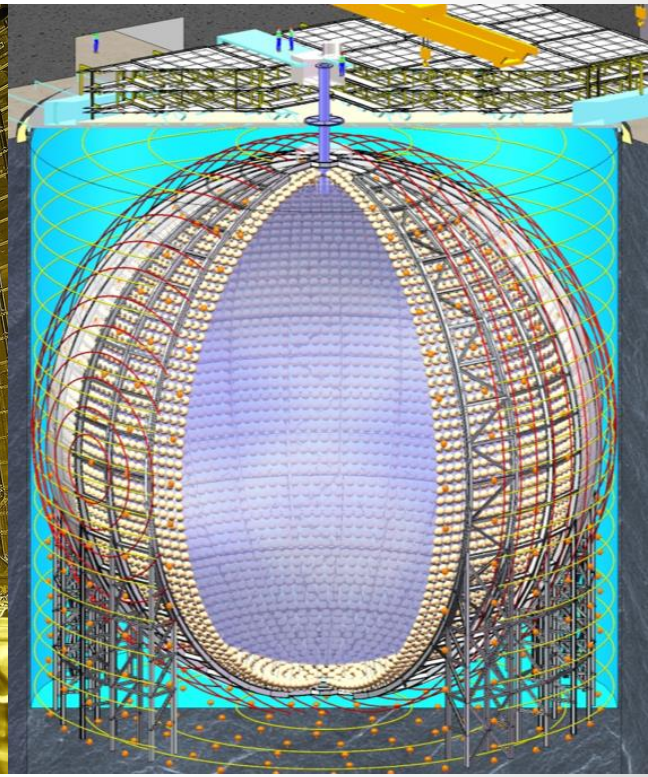
- How do massive stars die?
- Production sites of heavy elements
- Possible production sites of light particles
- Supernova remnants--acceleration of cosmic rays
- Properties of neutron stars/pulsars, black holes

Compute theoretically, measure experimentally

We May Have Only One Chance







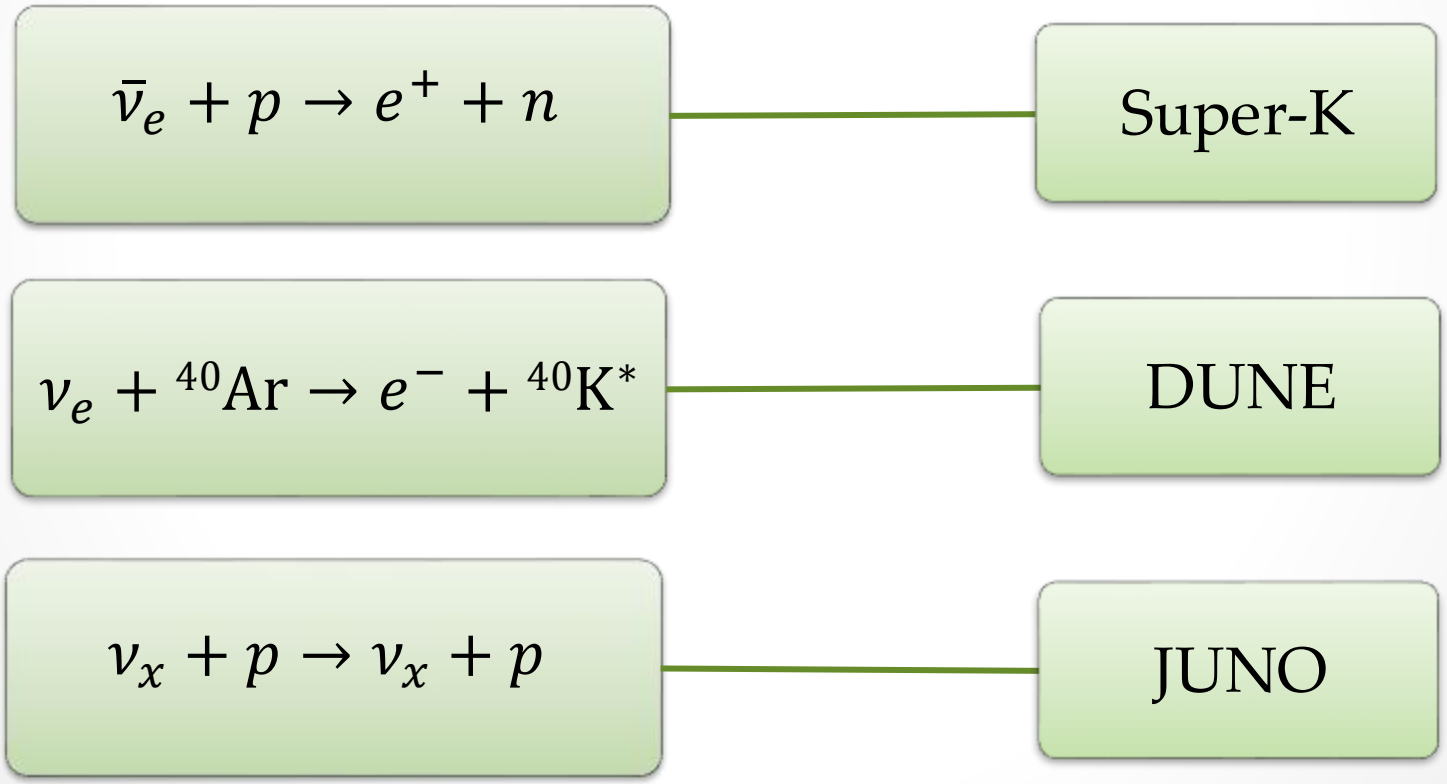
Not clear whether there will be successors

We Need All Three Experiments

Distinct detection channels

Large cross sections

Multi-10 kton



SN 2030?

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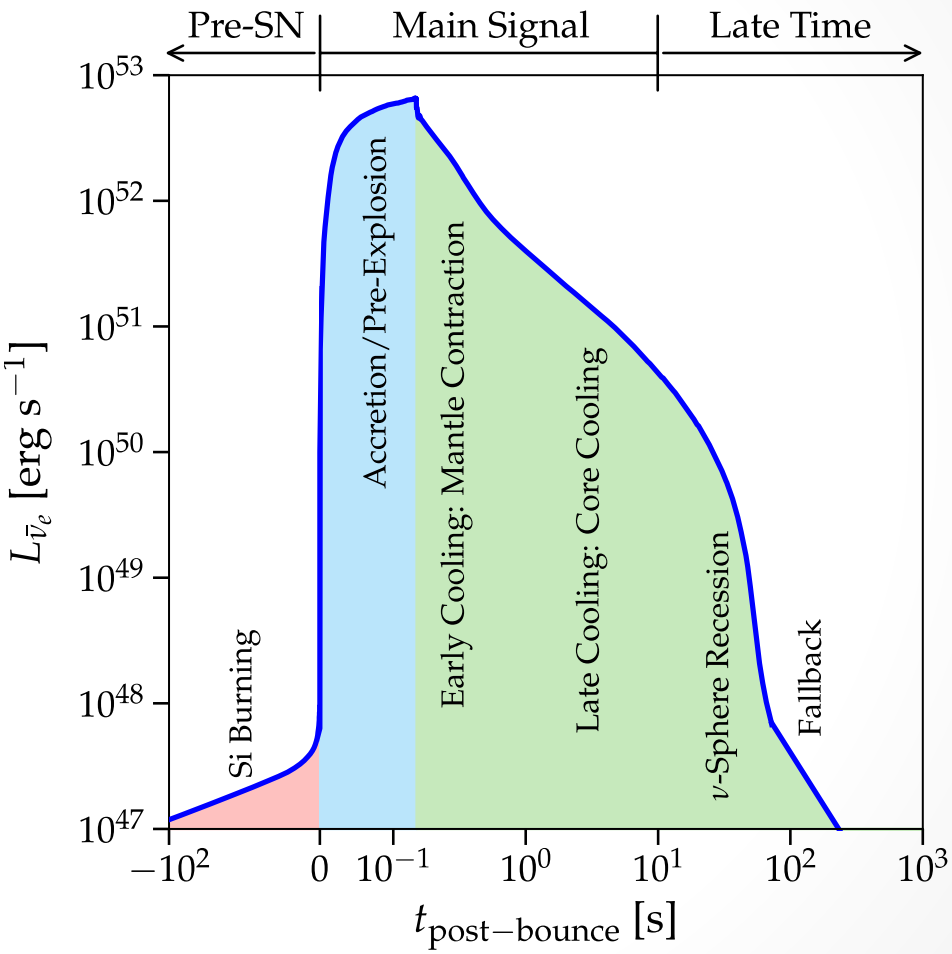
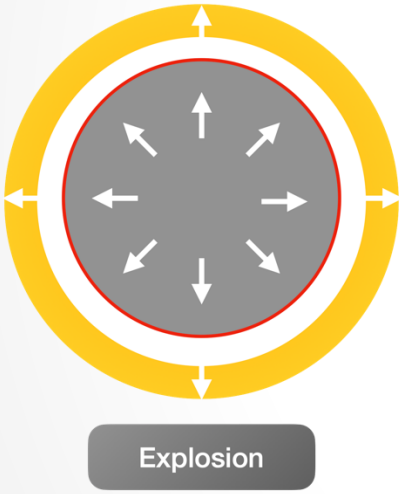
Are We Ready??

Basic Features of SN Neutrinos



SL, Roberts & Beacom, 2020

Basic Features of SN Neutrinos



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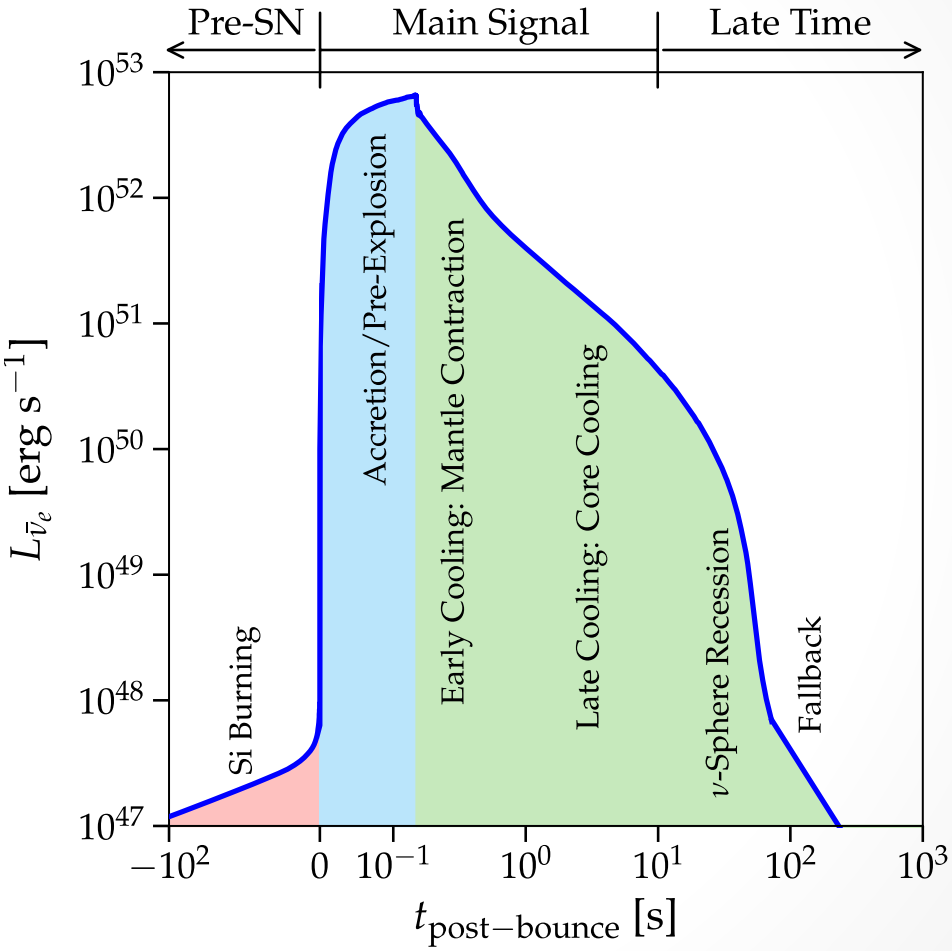
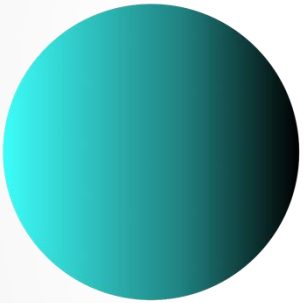
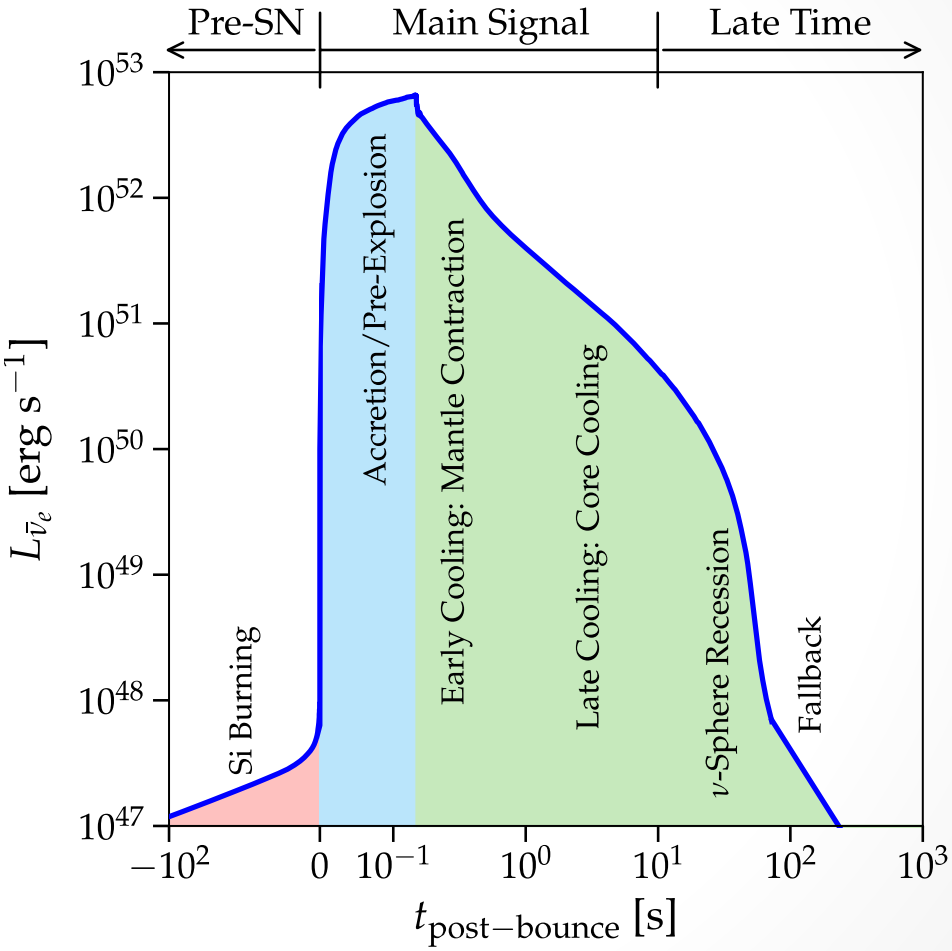


Basic Features of SN Neutrinos





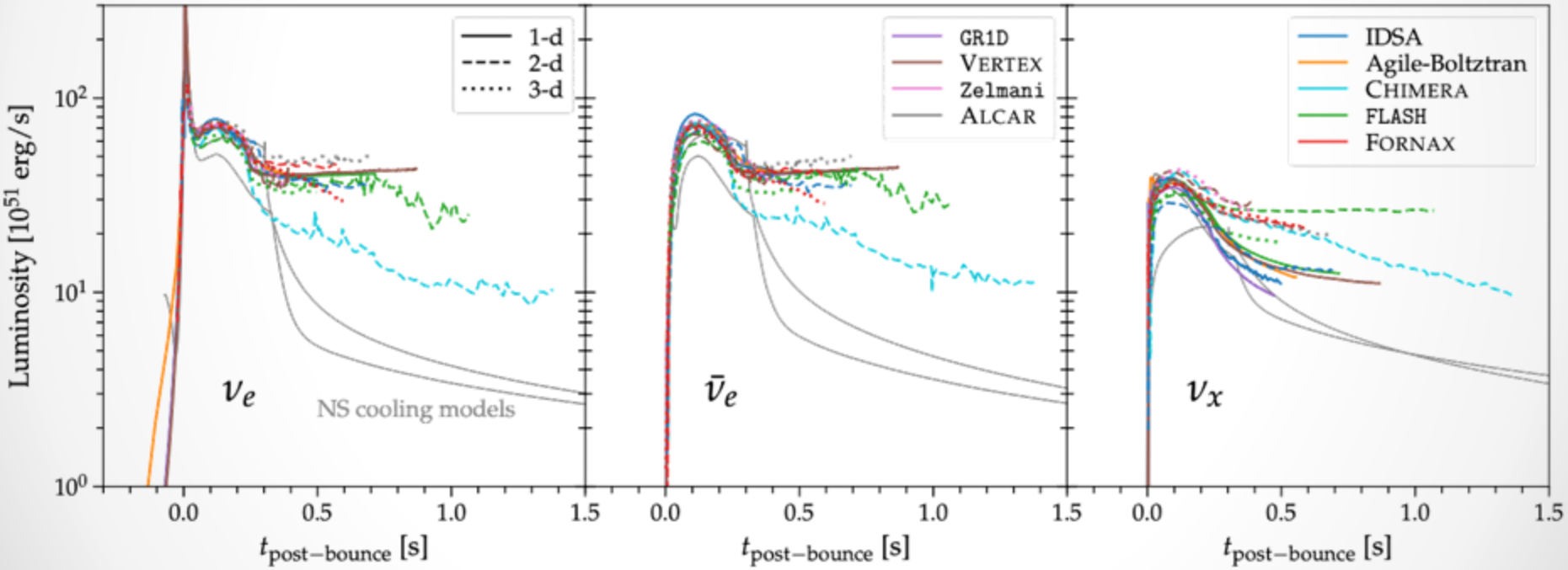
SL, Roberts & Beacom, 2020

Explosion Neutrinos

Simulation Status

Intense efforts for decades, focus of multi-d studies

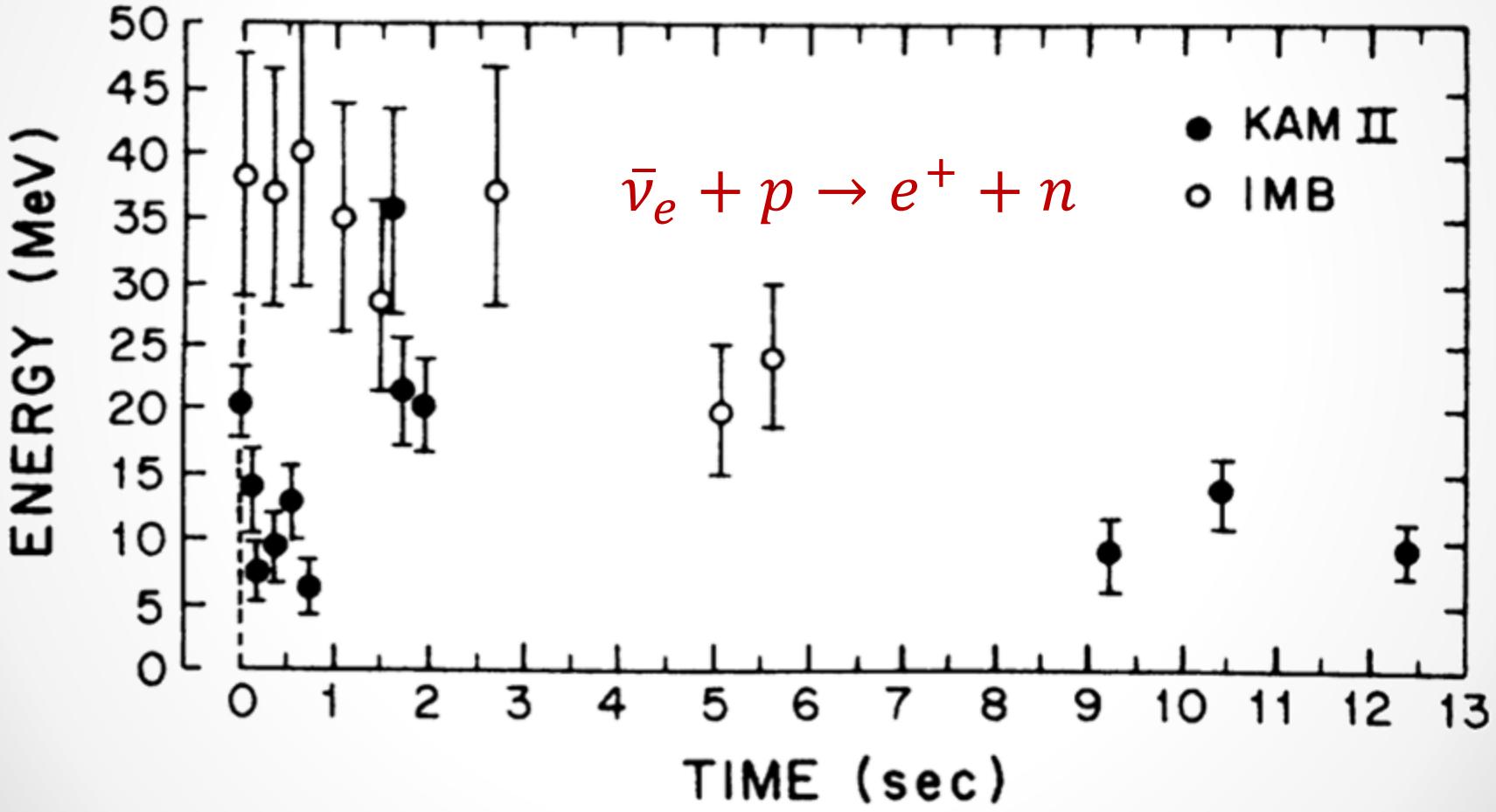
SL, Beacom, Roberts, Capozzi, 2023



$20M_\odot$ well studied, less so for other progenitors

We Have Data: SN 1987A!

Large Magellanic Cloud, 50 kpc away



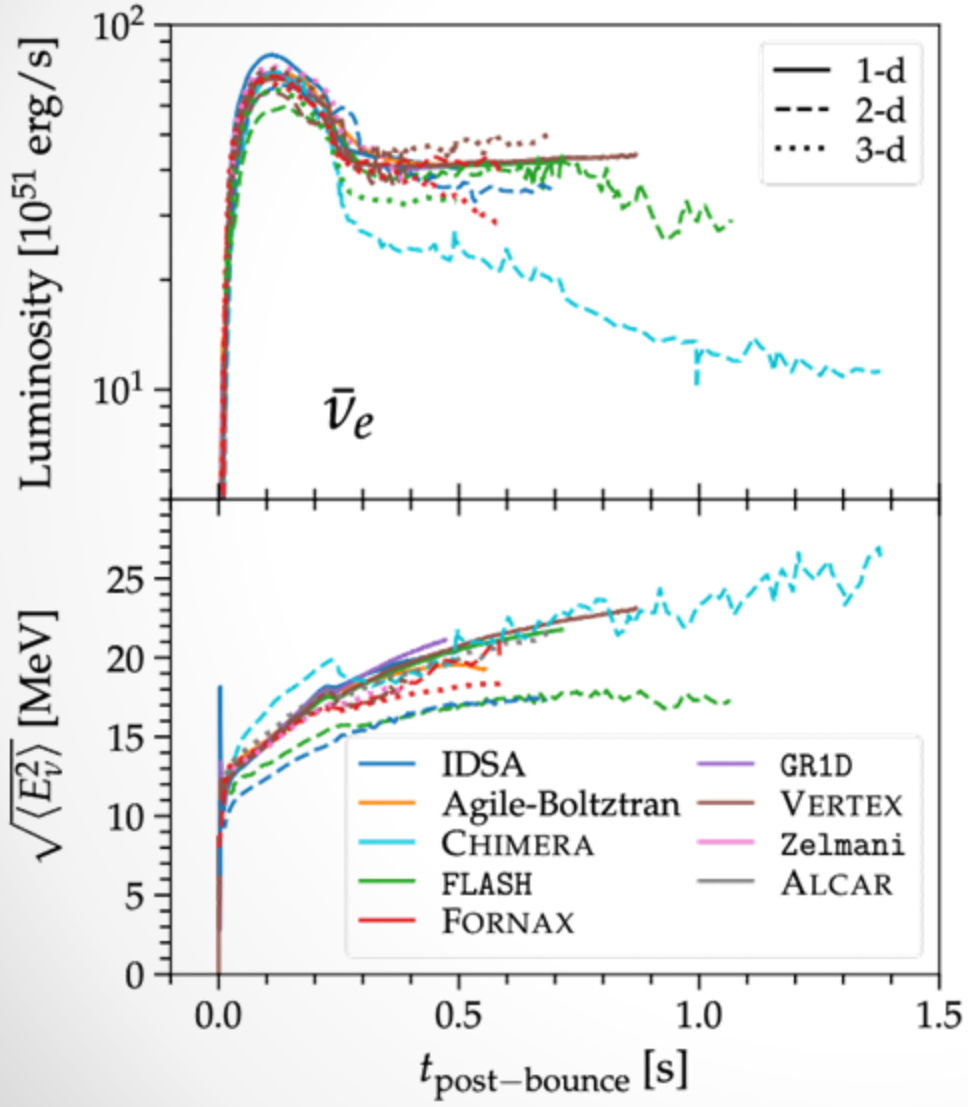
Kamioka-II 1988

Supernova 1987A by Arnett, Bahcall, Kirshner, Woosley

The results for the temperature, the cooling time scale, and the $\bar{\nu}_e$ flux are consistent with the standard picture of stellar collapse that is based upon detailed numerical models and on analytic arguments. The success of this simplified "standard" model suggests that it will be difficult to use the neutrino events observed from SN 1987A to establish more detailed models. The observations of SN 1987A have triumphantly confirmed the schematic picture of core collapse. The observational test of such a complex phenomenon is a great achievement. However, the data are not sufficient to discriminate between equations of state or to validate specific detailed models. There is no need to invoke new particle physics or complicated

Is this true??

Let's Compare!



- Straight out of simulation, no oscillation
- $\bar{\nu}_e$ only
- 20 $M_\odot$
- All models in the last 10 years

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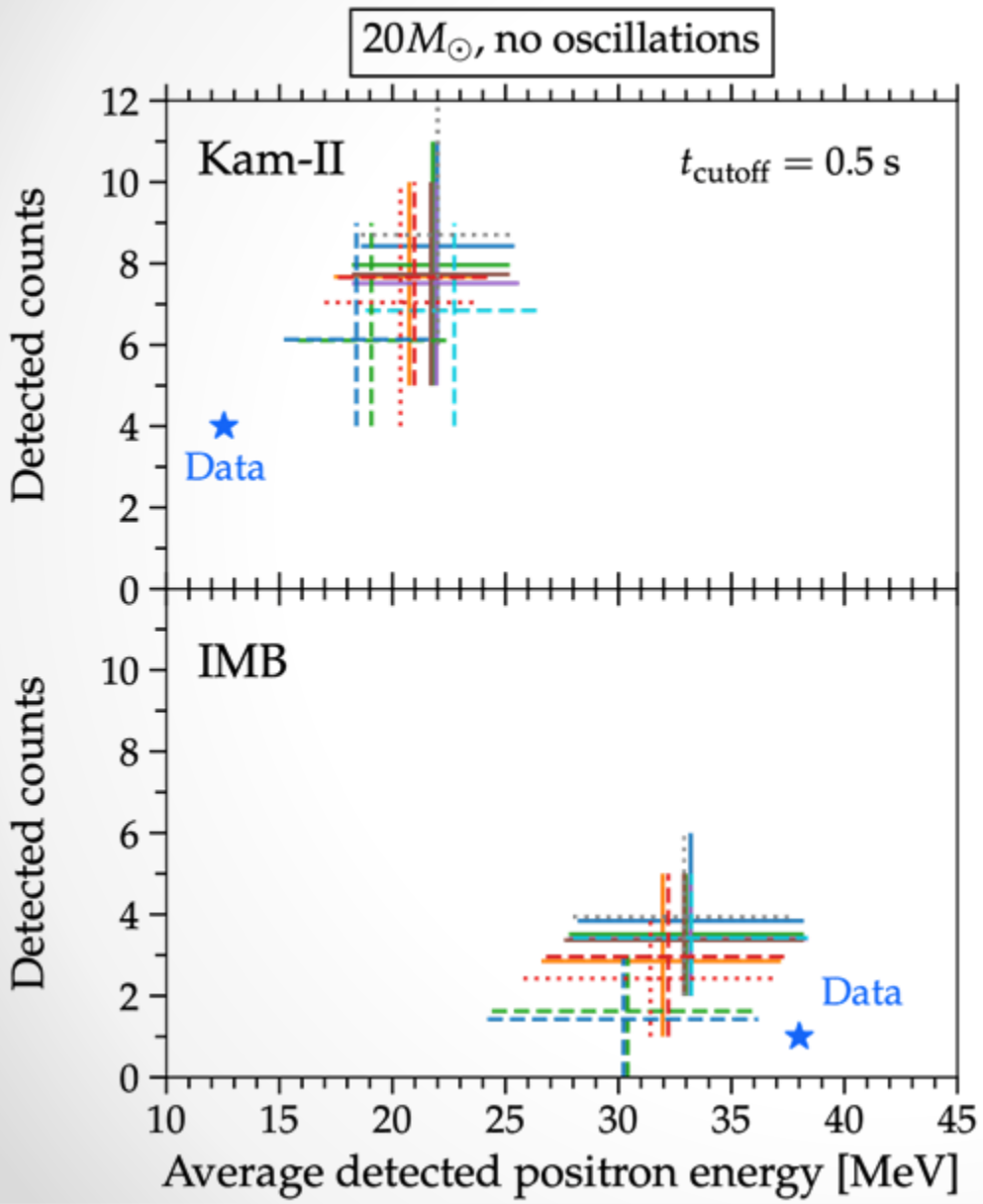
First Look at the Results



- Model simulation vs. 87A data
- Cut off all predictions and data at 0.5 s
- Forward modeling
- Error bars 1σ

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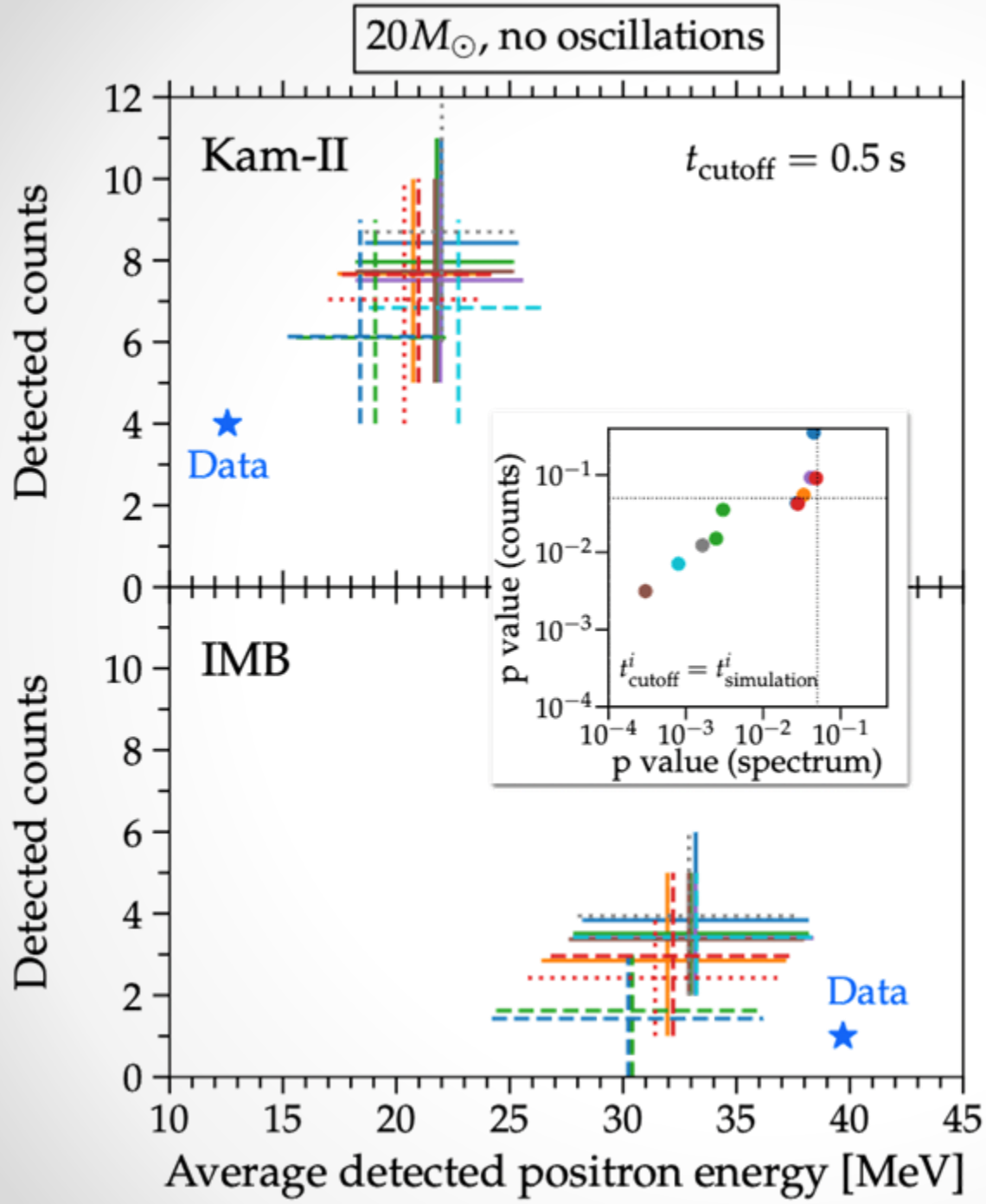

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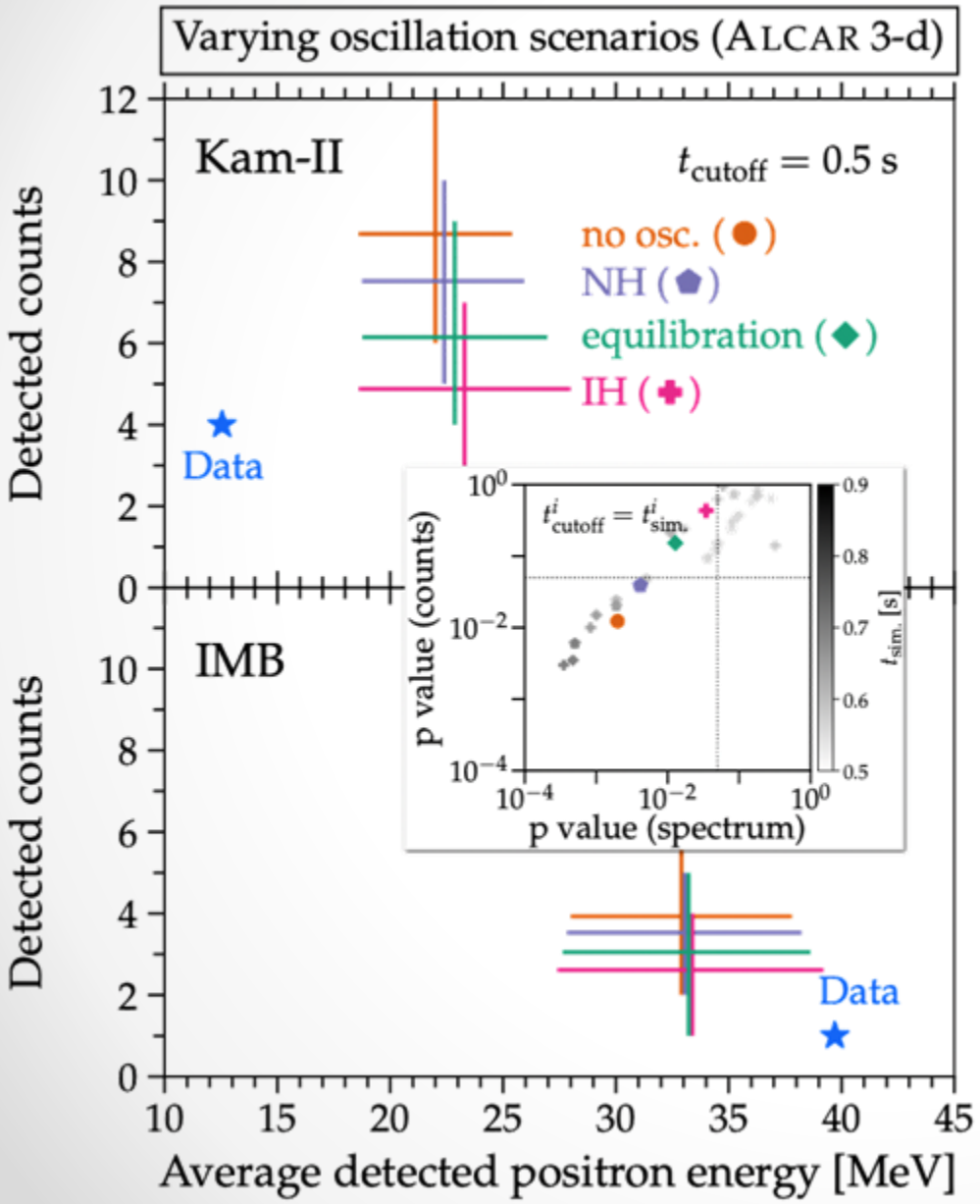
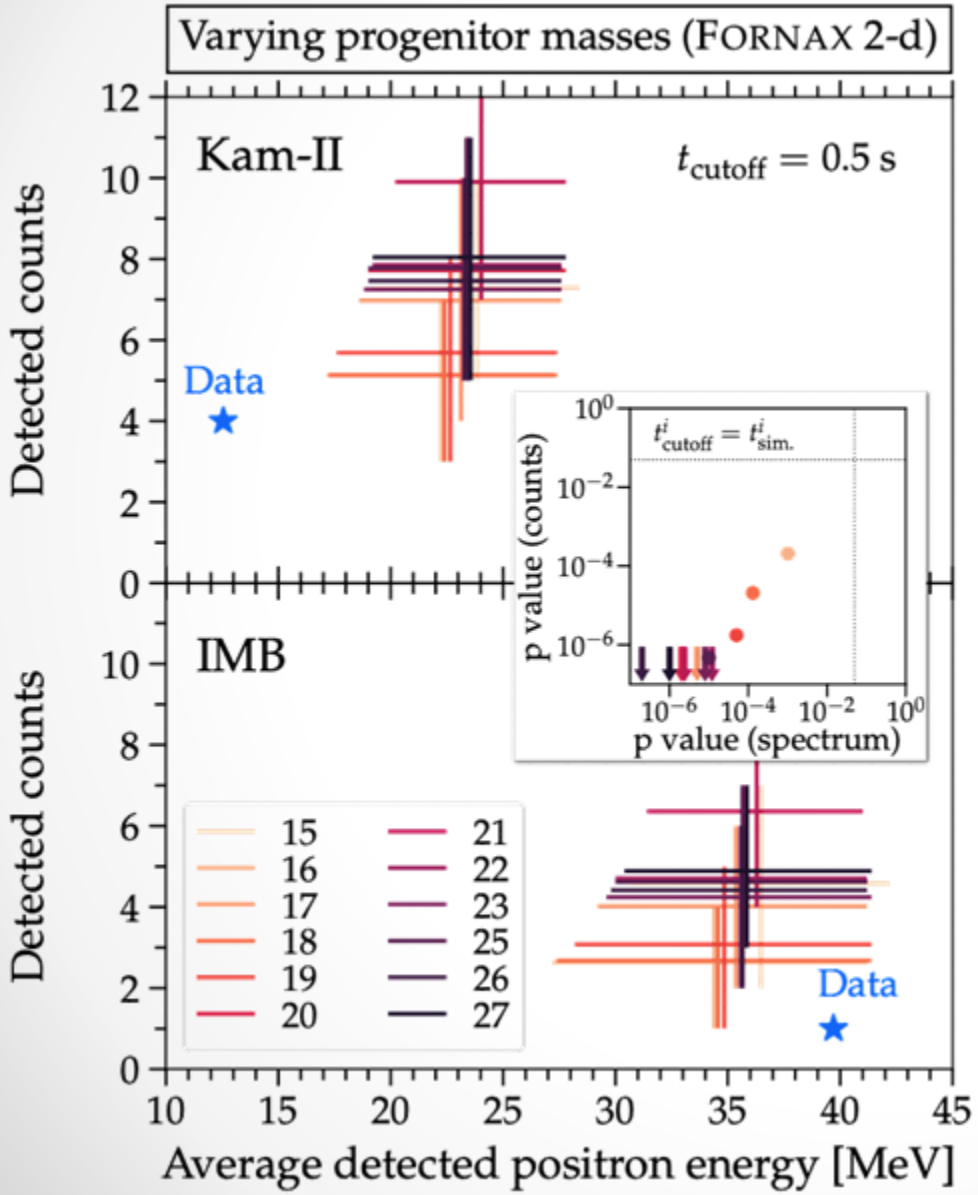
No model is compatible with data

Could Oscillation Fix This?



- How supernova ν oscillate is an unsolved problem
- Lowers the count, increases the temperature
- Not likely to be a solution

Could It Be Different Progenitors?



- We do not know the progenitor mass for 87A
- Probably roughly between 15-30$M_\odot$
- Not likely to be a solution

What Does This Mean?

- Flux seems high, temperature seems high
- Not definitive, simulation runtime too short
- Need further studies
  - Longer runtime
  - More progenitors
  - Neutrino oscillation implemented into simulation

Conclusions

- We need to get ready for SN 2030
- The neutrino luminosities predicted by simulations show general agreement with each other in the first second
- They generally disagree with 87A data
- Hope to stimulate further work