

# Towards precise predictions of the Diffuse Supernova Neutrino Background

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VIRGINIA  
TECH.<sup>®</sup>



# Outline

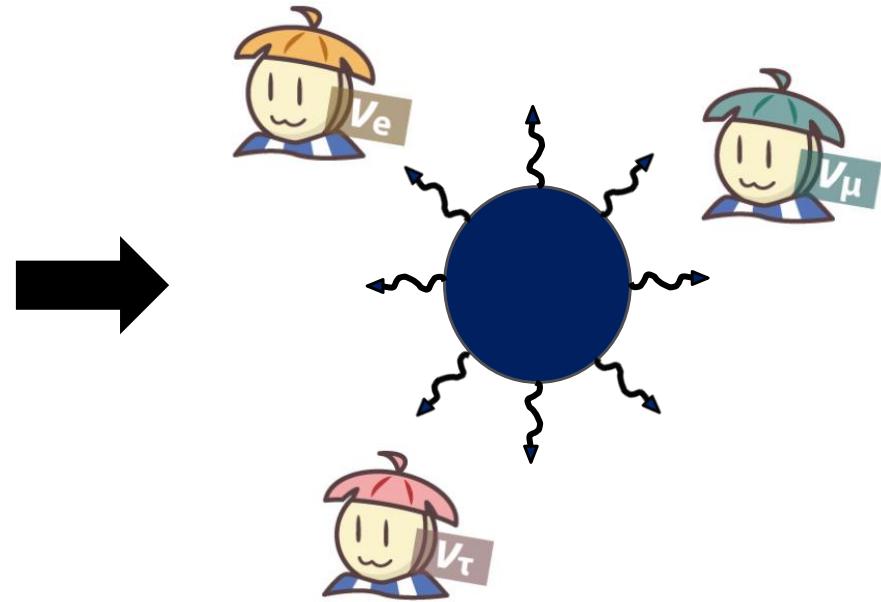
- What is the DSNB?
- DSNB ingredients
  - 1. Detection thru IBD
  - 2. Supernova neutrino emission
  - 3. Core-collapse rate
- Predicted rates of the DSNB at Super-K
- PyDSNB public code

# Supernova neutrinos

SN1987A: only detection so far of supernova neutrinos



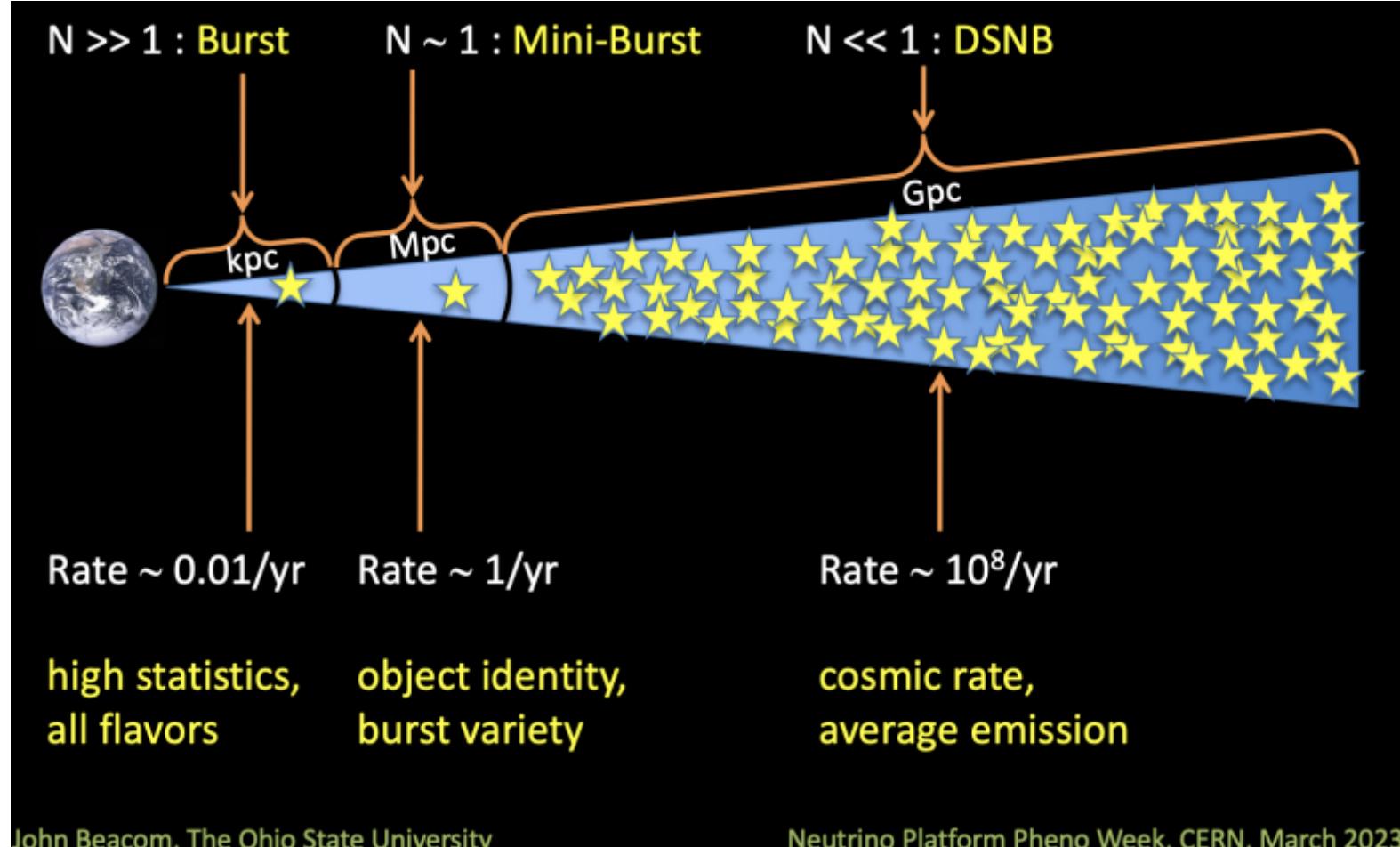
$10^{58}$  neutrinos of  $\sim 10$  MeV



From <https://higgstan.com/>

# Diffuse Supernova Neutrino Background (DSNB)

- Isotropic, diffuse background of all supernova neutrinos
- Guaranteed signal



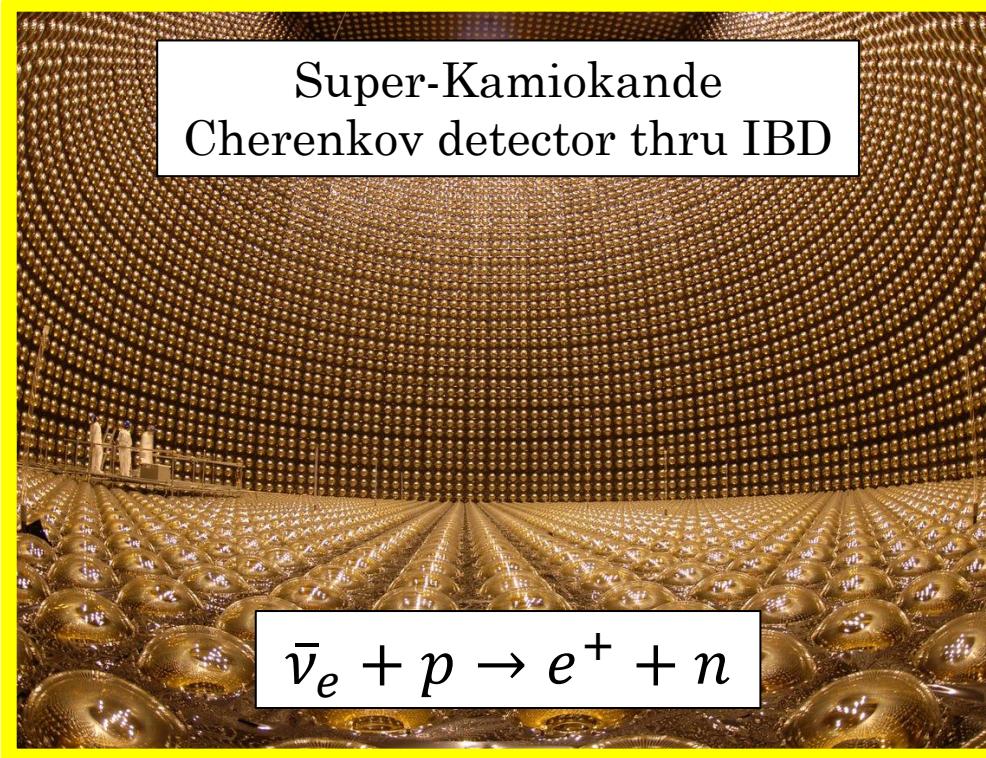
# DSNB Ingredients and Uncertainty

$$R_\nu = N_t \int dE \sigma_{\text{IBD}} \int dz c \frac{dN}{dE'} (1+z) R_{CC} \left| \frac{dt}{dz} \right|$$

- [1] Abe et al. (2021)
- [2] Ekanger et al. (2022)  
[arXiv:2206.05299](https://arxiv.org/abs/2206.05299)
- [3] Madau & Dickinson (2014)

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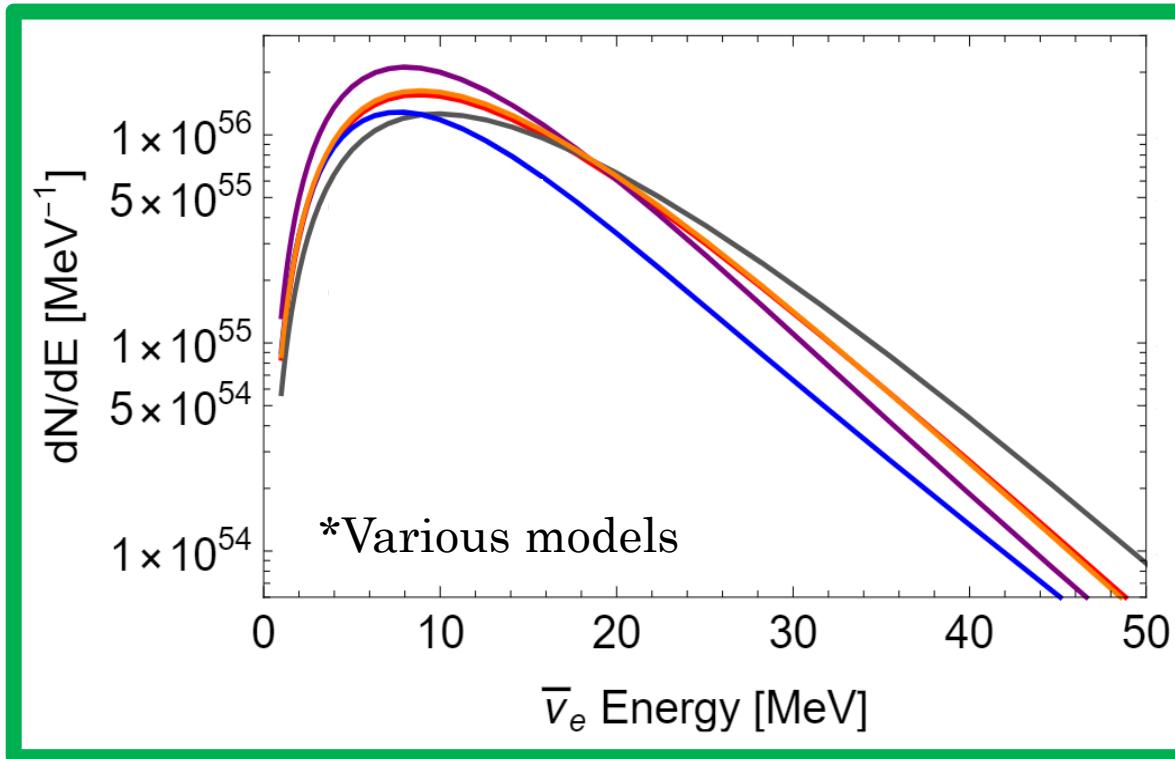
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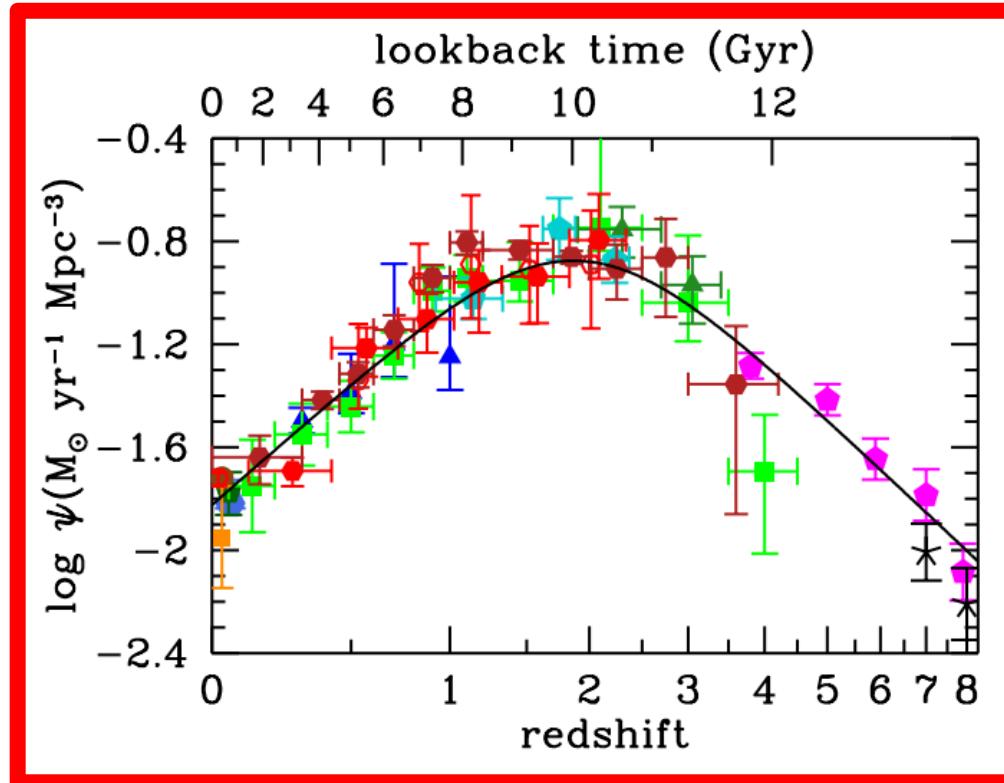


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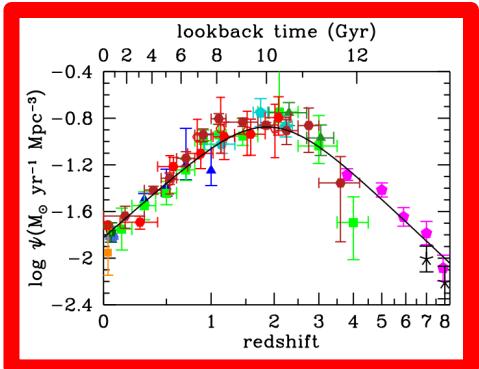
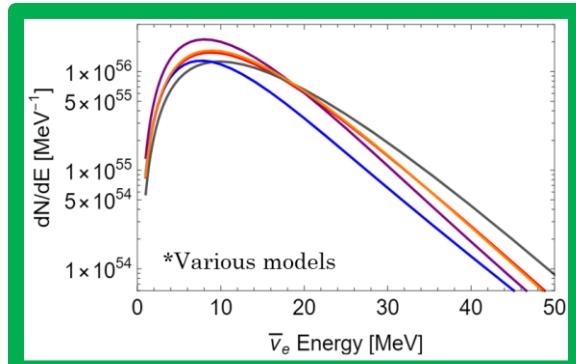
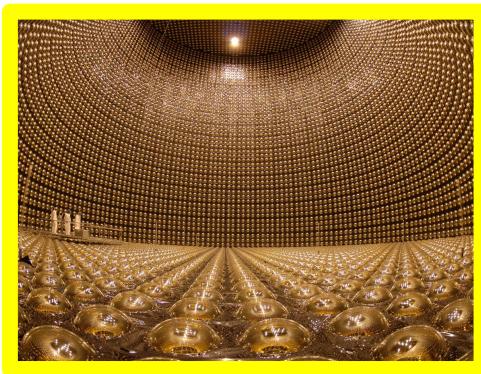
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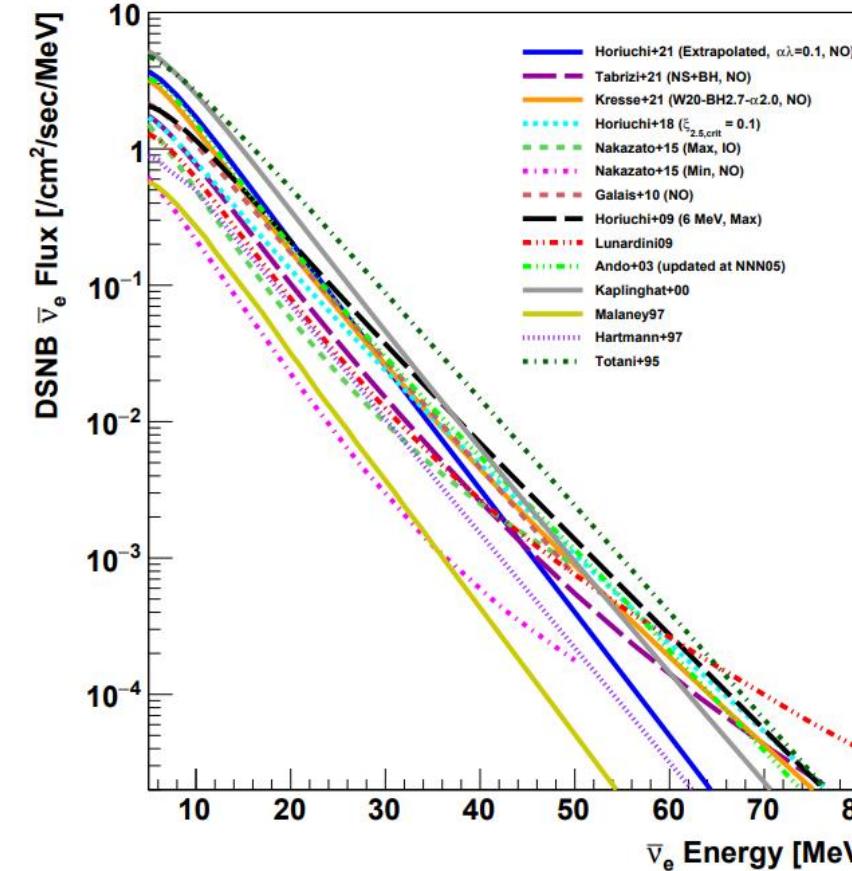
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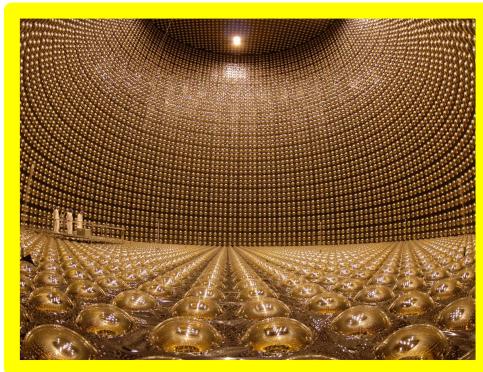
Factor of  $\sim 10$  in overall flux predictions



[1]

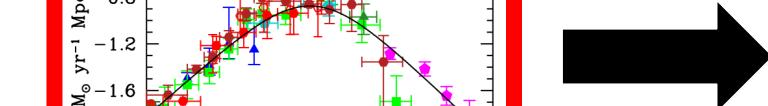
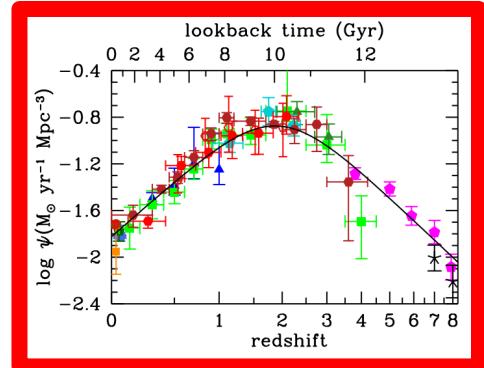
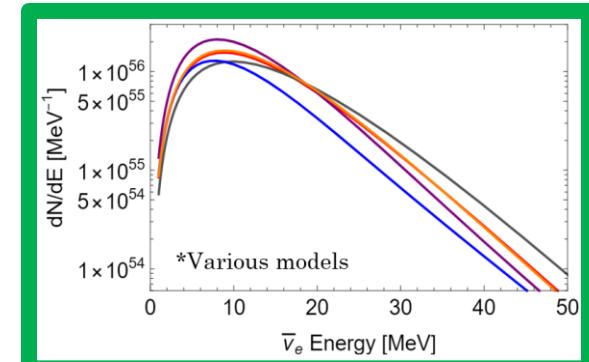
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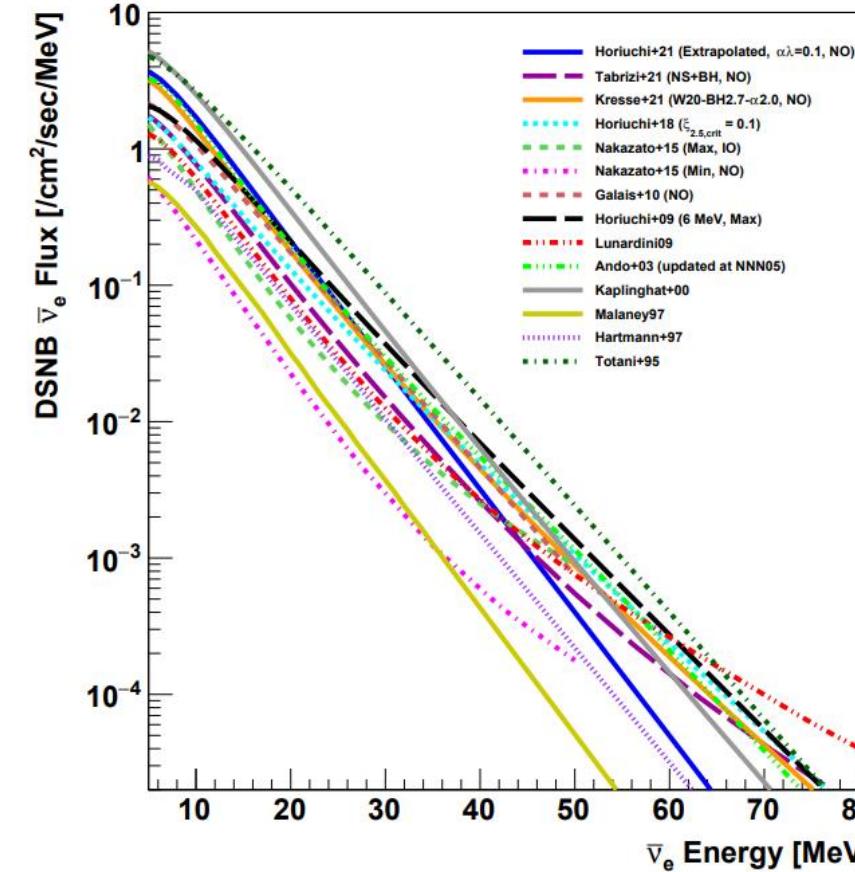


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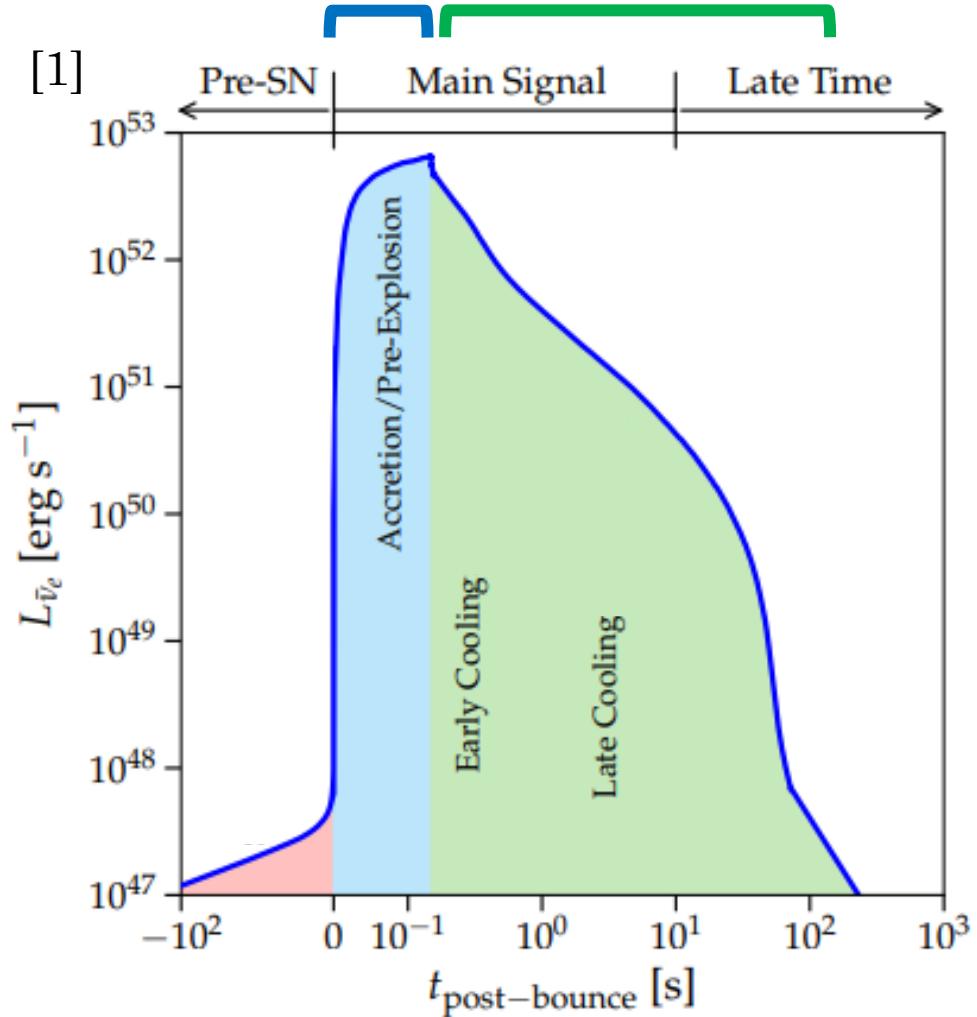


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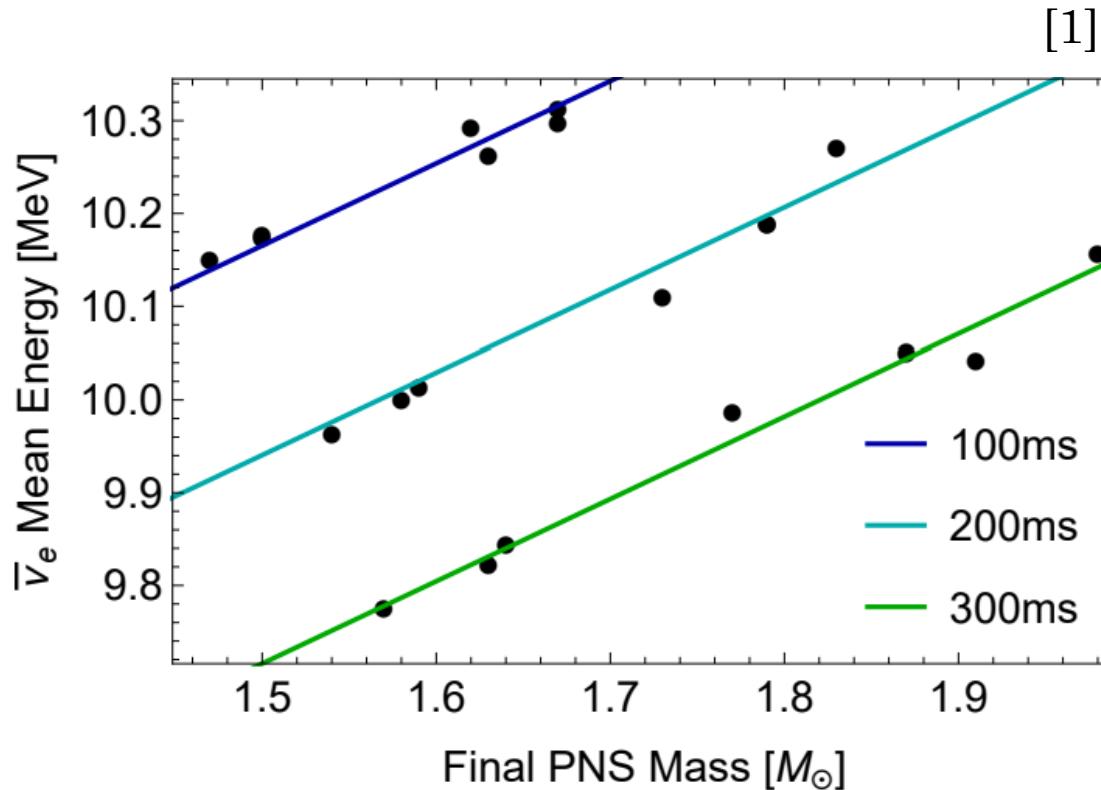
# Neutrino Emission



- Spectrum from time-integrated signal
- Early signal:
  - High luminosity, high mean energy from accretion
- Late signal:
  - After shock revival, PNS cools
  - Luminosity and mean energy decrease
  - > 50% of energy liberated
- SN1987A only case of SN neutrinos  
→ Look to simulations

# Late-time Neutrino Emission

- Early phase is well simulated in 3D
- > 50% of energy liberated occurs > 1 s
- Late phase neutrino emission depends on:
  1. Shock revival time
  2. Final PNS mass



[1] Ekanger et al. (2022), [arXiv:2206.05299](https://arxiv.org/abs/2206.05299)

# Late-time Neutrino Emission

[2] [3]

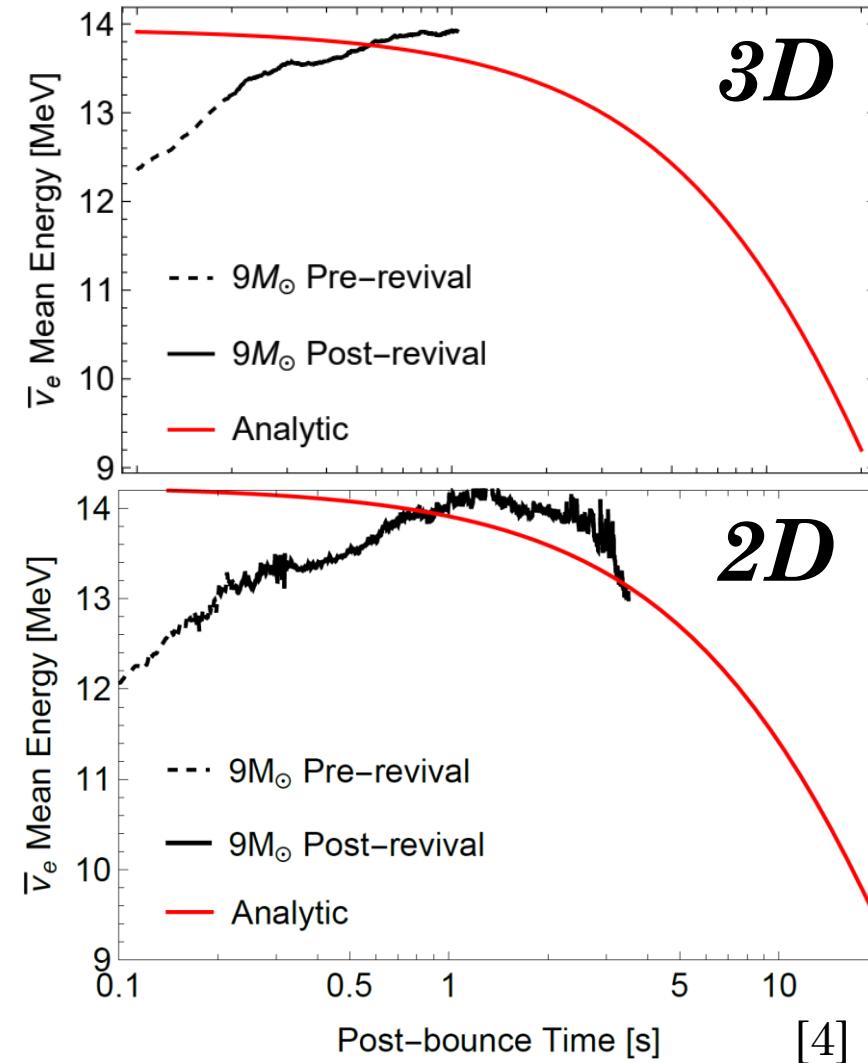
- Estimate late phase with analytic model
  - Tuned to match available data (< 1 s)
  - Use red function after black sim data
- Can do for 3D, but doesn't match well
- Works for 2D, more data is available

[1] Suwa et al. (2021)

[2] Burrows et al. (2019)

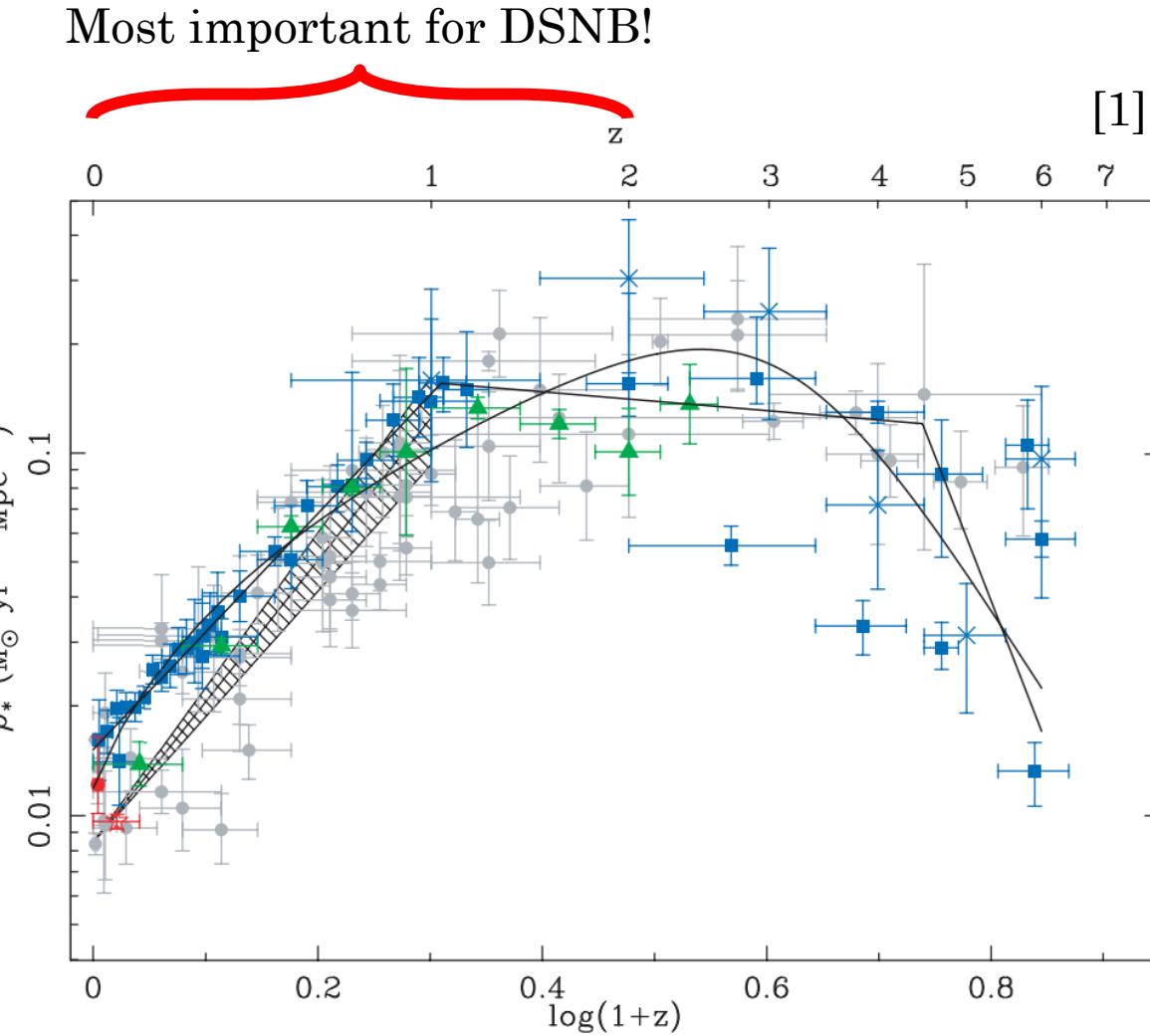
[3] Ekanger et al. (2022), [arXiv:2206.05299](https://arxiv.org/abs/2206.05299)

[4] Nagakura et al. (2021)



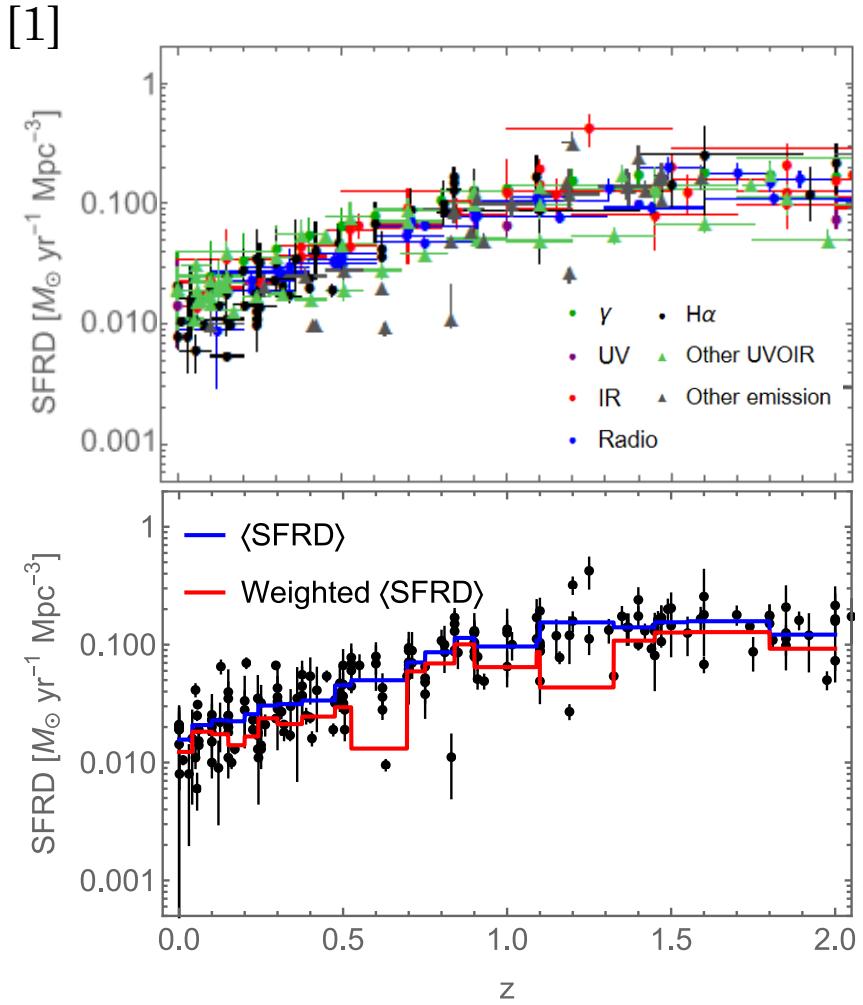
# Star Formation Rate

- Proxy for core collapse rate,  $R_{\text{cc}}$
- Measured thru IR, UV, H $\alpha$ 
  - Others include optical, radio,  $\gamma$ , other emission lines
- Collect recent measurements
  - Reduce uncertainty
  - Data driven estimates



[1] Hopkins and Beacom (2006)

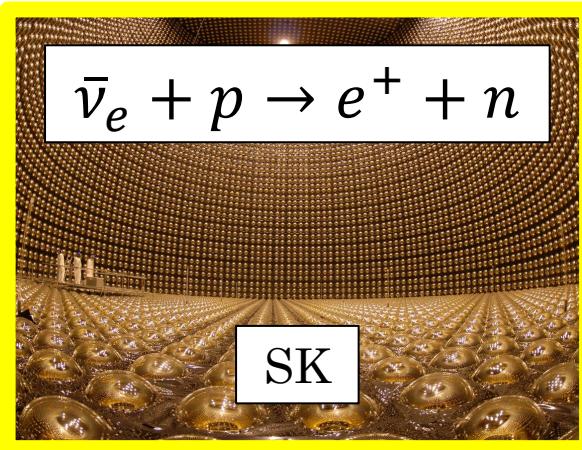
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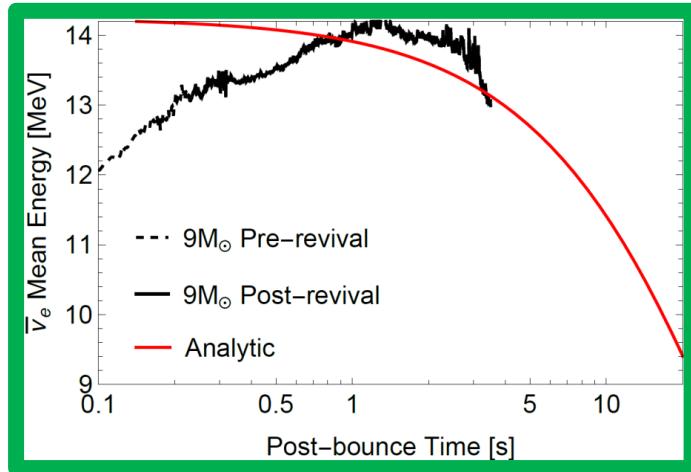
- Data agrees well across indicators
  - Some “other emission” outliers
  - Still investigating
- Bin data
- Average bins two ways
  - Simple and weighted average
  - Good agreement

[1] Ekanger et al. (in prep)

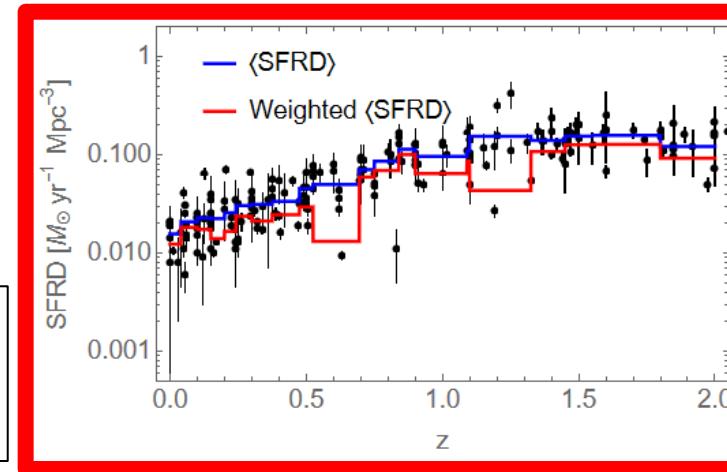
# DSNB Rate at Super-Kamiokande



Core collapse rate  
inferred from updated  
star formation rate

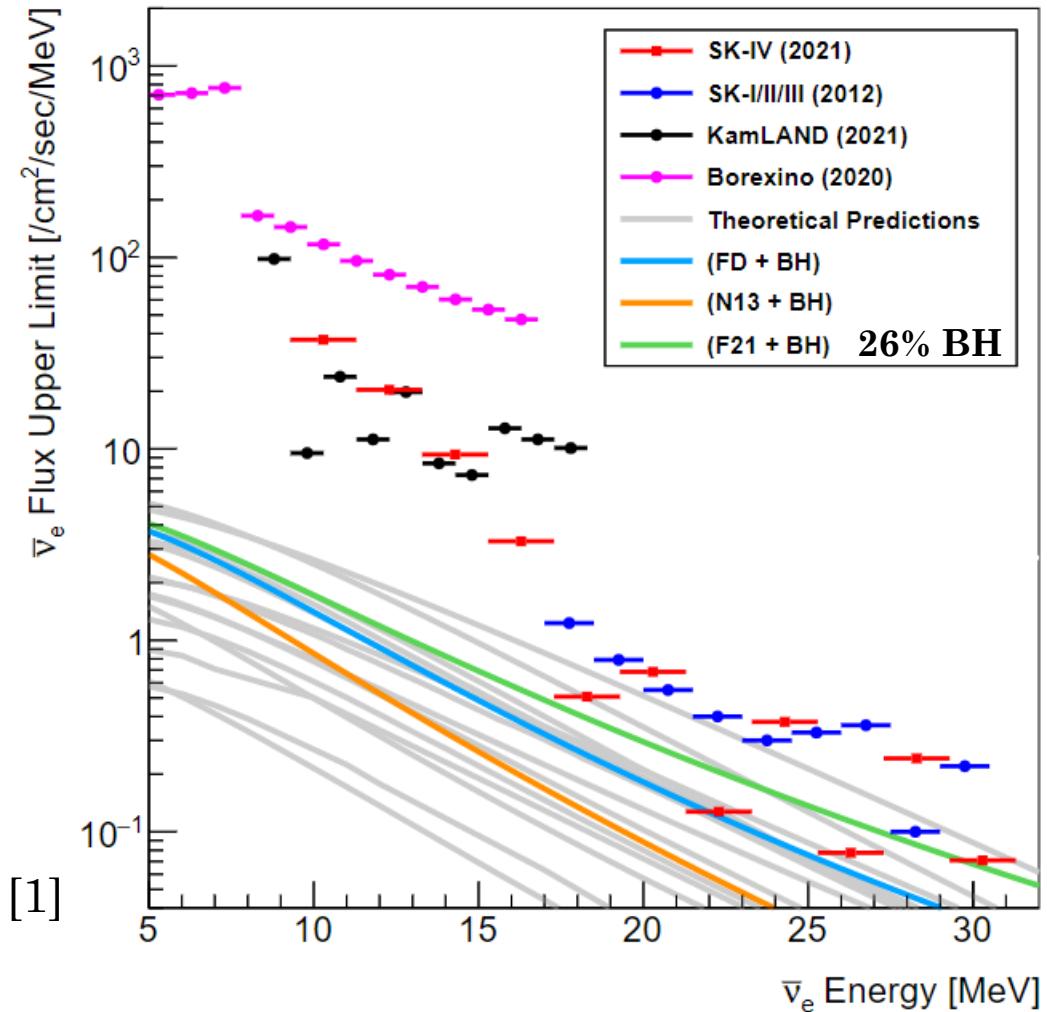


Weighted-average neutrino spectrum  
(16 successful SNe + failed)



~0.5 – 2 *events/yr*  
depending on NO/IO,  
binning, late phase

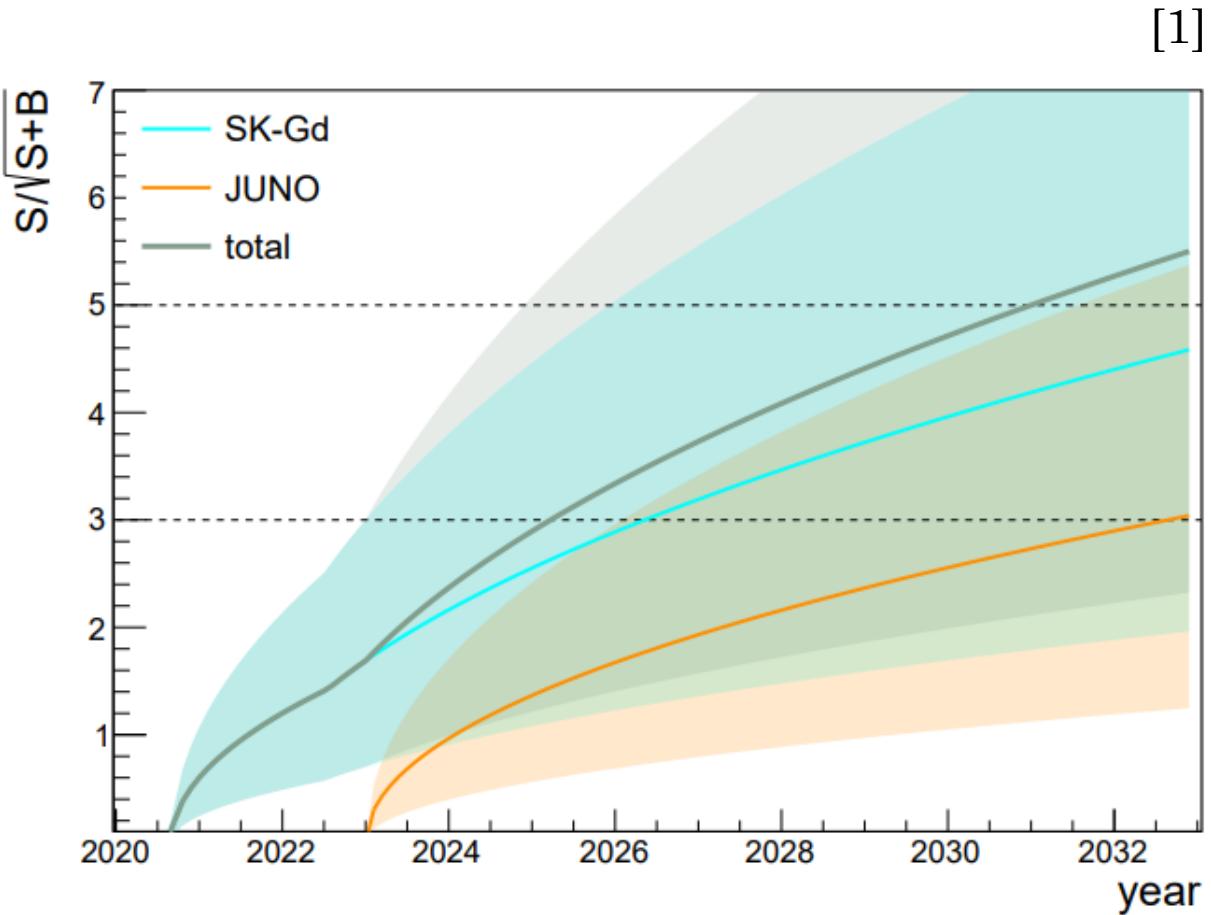
# PyDSNB!



- Publicly available code to model DSNB
  - *Coming soon*
- Choices when modeling:
  - Neutrino emission
  - Initial mass function
  - Failed SNe fraction
  - Other inputs
- SK disfavoring some models
  - Blue, orange, green from PyDSNB

# Summary

- Neutrino emission modeling improving
  - Including late phase
- Star formation rate uncertainty decreasing
- We estimate  $\sim 0.5 - 2 \text{ events/yr}$
- Significant detection in the next  $\sim 10$  years
  - SK-Gd, JUNO, others like HK
- Public PyDSNB code available soon



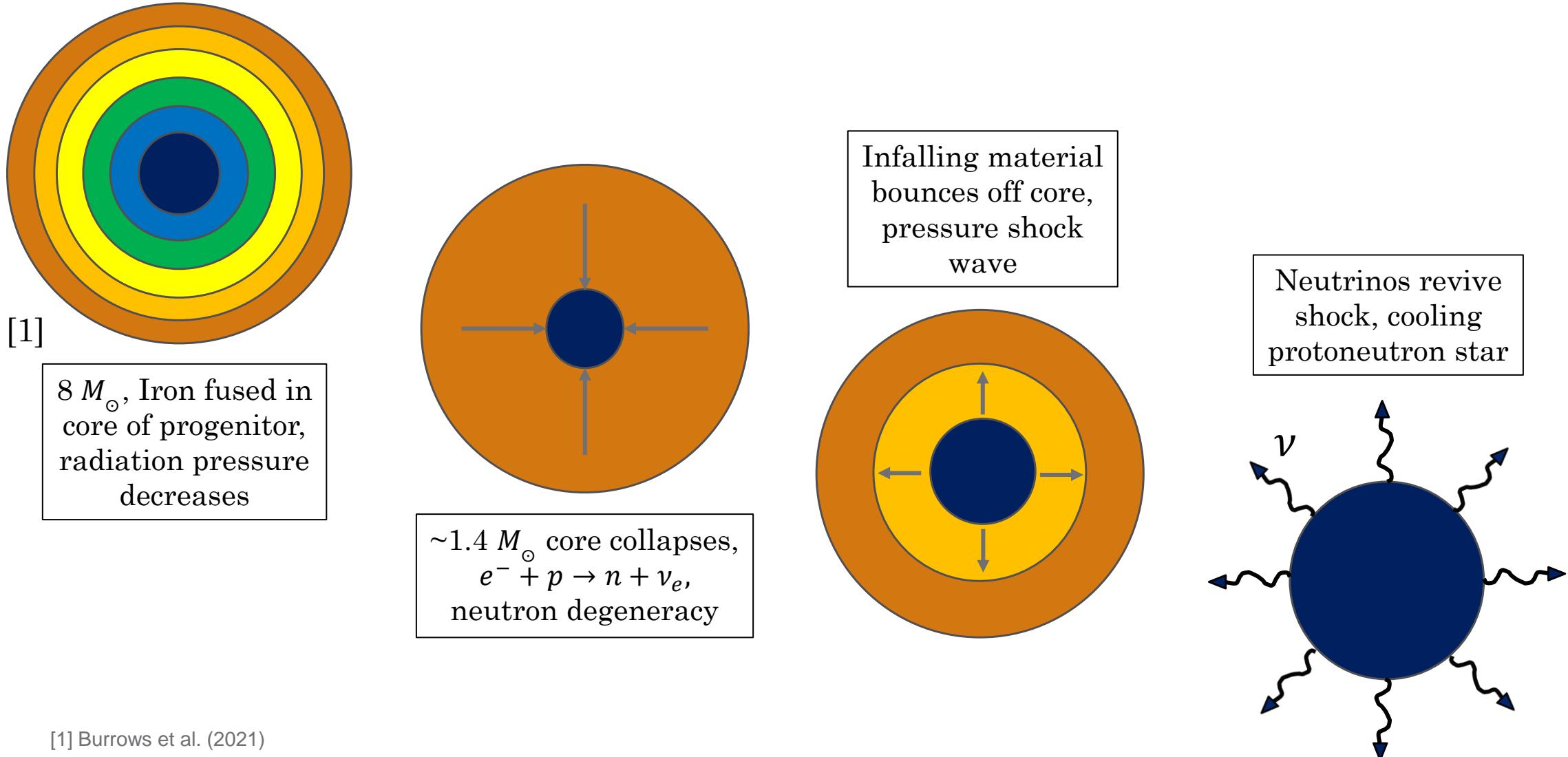
[1] Li et al. (2022)

Thank you!

# Backup



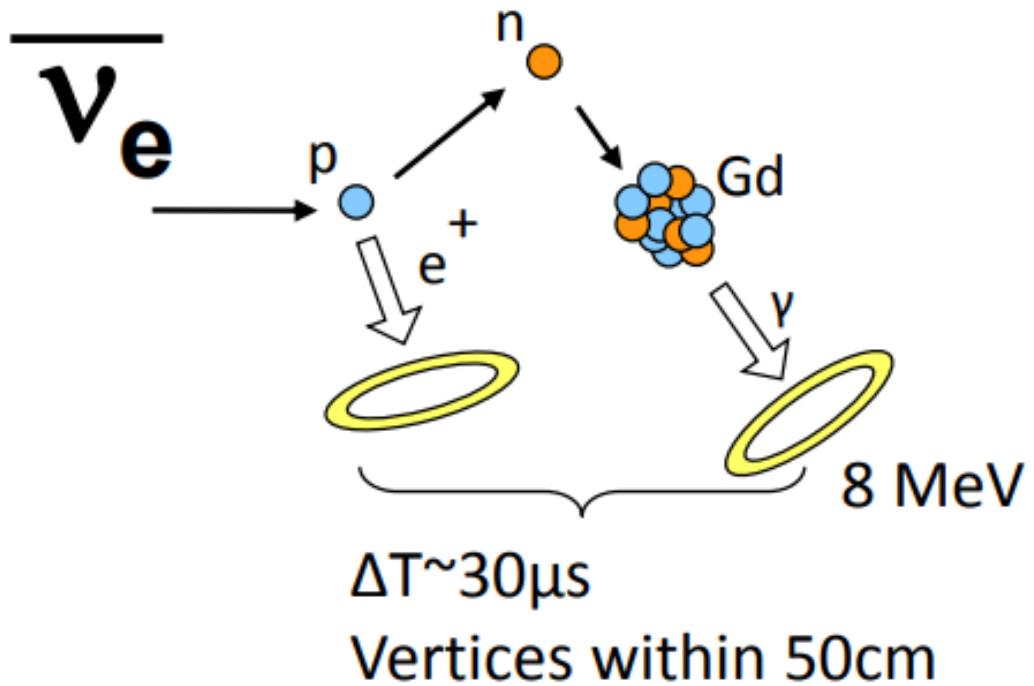
# Supernovae and Neutrinos



[1] Burrows et al. (2021)

# Detection

- Detectable at SK thru IBD
  - $\bar{\nu}_e + p \rightarrow e^+ + n$
  - Gadolinium upgrade (SK-Gd)
- Hyper-K is successor of SK  
~10 times bigger volume
- JUNO is a scintillator detector



# Some equations

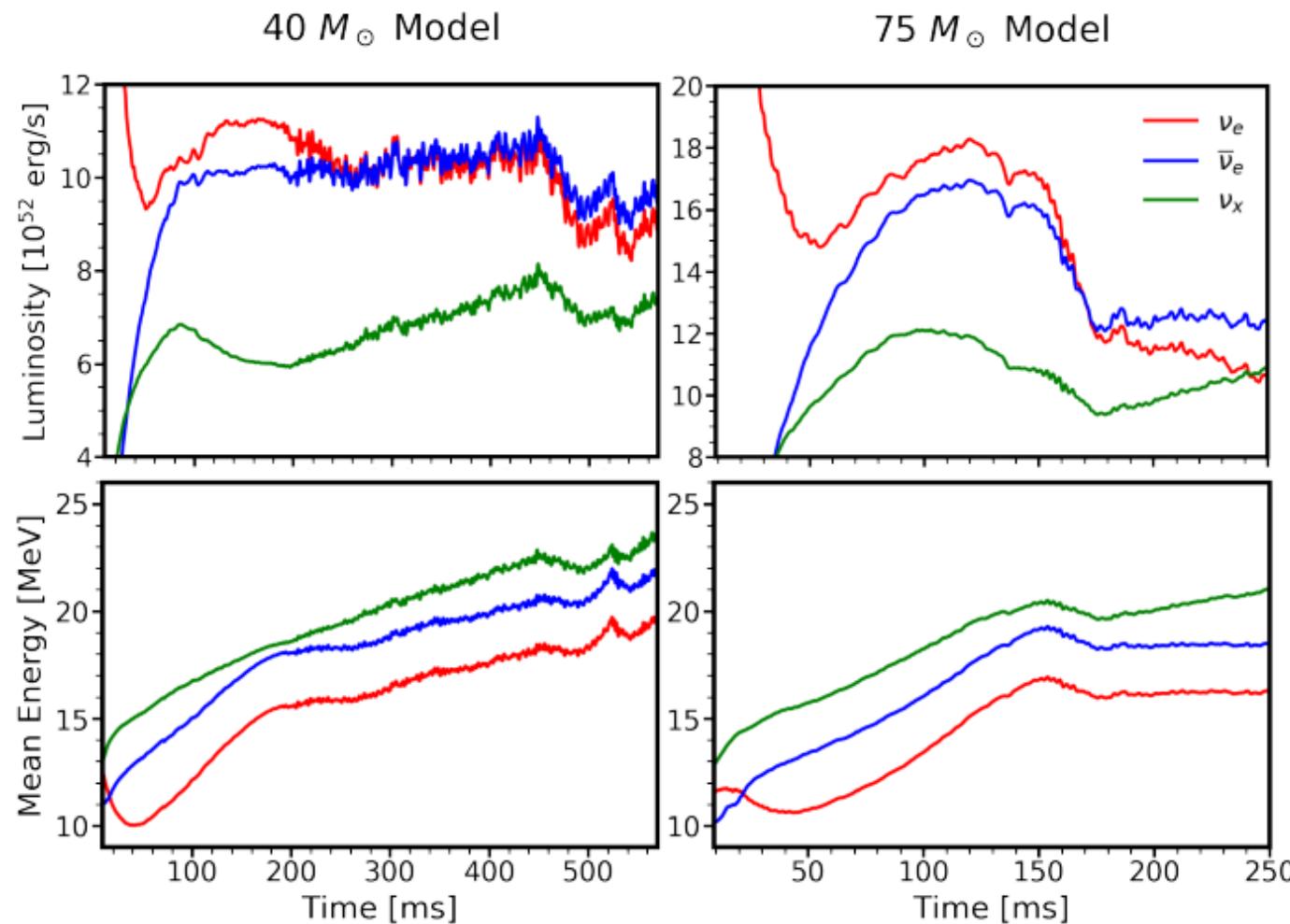
- SFRD  $\rightarrow$  CCR

$$R_{\text{CC}} = \dot{\rho}_*(z) \frac{\int_{M_{\text{Min}}}^{M_{\text{Max}}} \psi(M) dM}{\int_{0.1M_{\odot}}^{M_{\text{Max}}} M \psi(M) dM}$$

- Progenitor-weighted Neutrino spectrum

$$\frac{dN}{dE} = \sum_i \frac{\int_{\Delta M_i} \psi(M) dM}{\int_{M_0}^{M_f} \psi(M) dM} f_i(E)$$

# BH forming case – failed SNe



# Neutrino interactions

Reaction	References
$\nu e^\pm \rightleftharpoons \nu e^\pm$	Mezzacappa and Bruenn (1993a), Cernohorsky (1994)
$\nu A \rightleftharpoons \nu A$	Horowitz (1997), Bruenn and Mezzacappa (1997)
$\nu N \rightleftharpoons \nu N$	Bruenn (1985), Mezzacappa and Bruenn (1993b), Burrows and Sawyer (1998), Horowitz (2002), Carter and Prakash (2002), Reddy et al. (1999)
$\nu_e n \rightleftharpoons e^- p$	—, Burrows and Sawyer (1999)
$\bar{\nu}_e p \rightleftharpoons e^+ n$	—, Burrows and Sawyer (1999)
$\nu_e A' \rightleftharpoons e^- A$	Bruenn (1985), Mezzacappa and Bruenn (1993b), Langanke et al. (2003)
$\nu \bar{\nu} \rightleftharpoons e^- e^+$	Bruenn (1985), Pons et al. (1998)
$\nu \bar{\nu} NN \rightleftharpoons NN$	Hannestad and Raffelt (1998)
$\nu A \rightleftharpoons \nu A^*$	Langanke et al. (2008)
$\nu_{\mu,\tau} \bar{\nu}_{\mu,\tau} \rightleftharpoons \nu_e \bar{\nu}_e$	Buras et al. (2003a)
$\bar{\nu}_{\mu,\tau} \bar{\nu}_e \rightleftharpoons \bar{\nu}_{\mu,\tau} \bar{\nu}_e$	Buras et al. (2003a)