UGRP2026, September 30th 2026

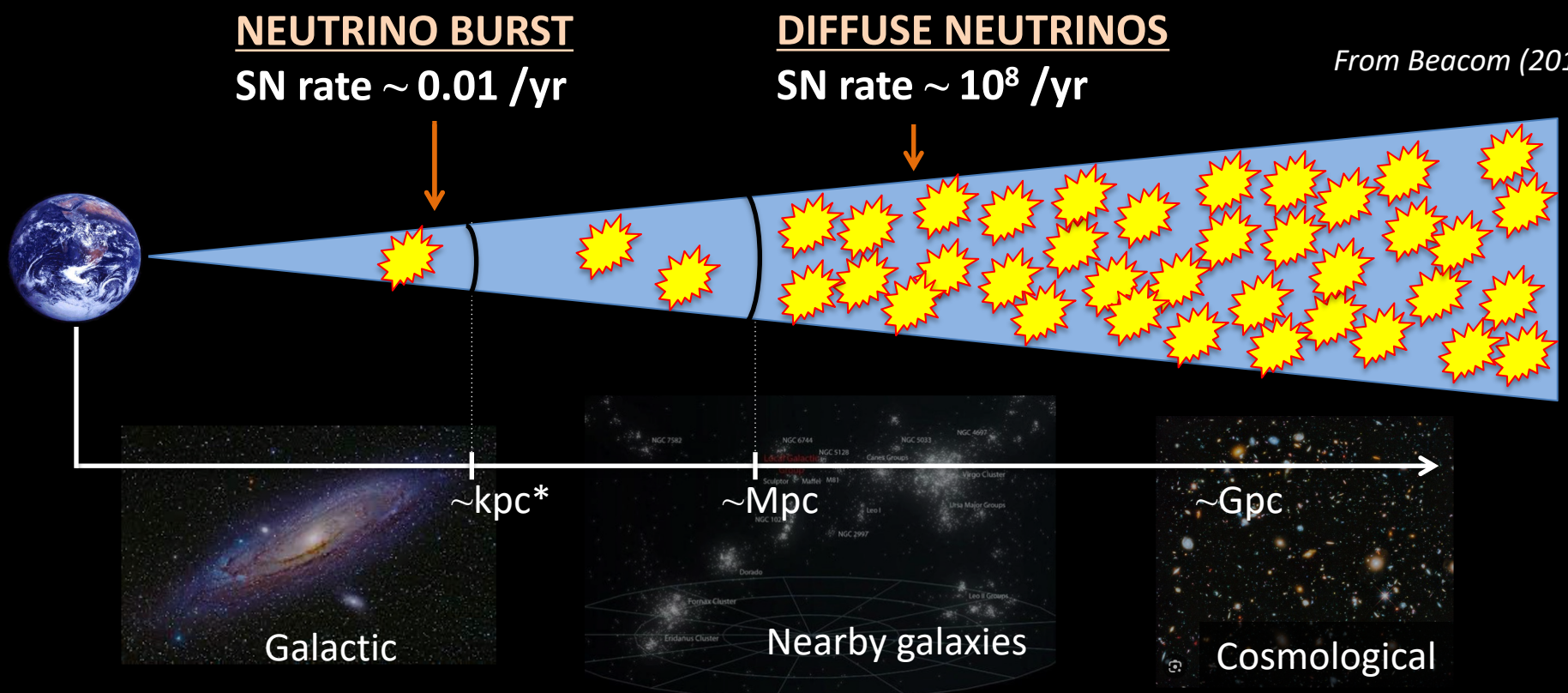
DSNB Theory

Shunsaku Horiuchi

Institute of Science Tokyo
Virginia Tech
Kavli IPMU

Image credit: NASA/ESA

Future supernova neutrinos



Features:

- Wait For nature's cooperation
- Precision multi-messenger observations on 1 progenitor
- Surprises?

Features:

- Guaranteed signal (no waiting)
- Many progenitors, population studies
- Cosmological distances
- Surprises?

Diffuse supernova neutrinos

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

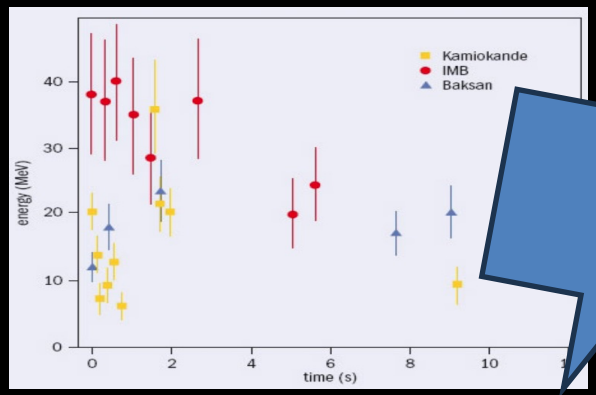
Neutrino detector capabilities

Time-integrated neutrino emission

Rate of massive star core collapse

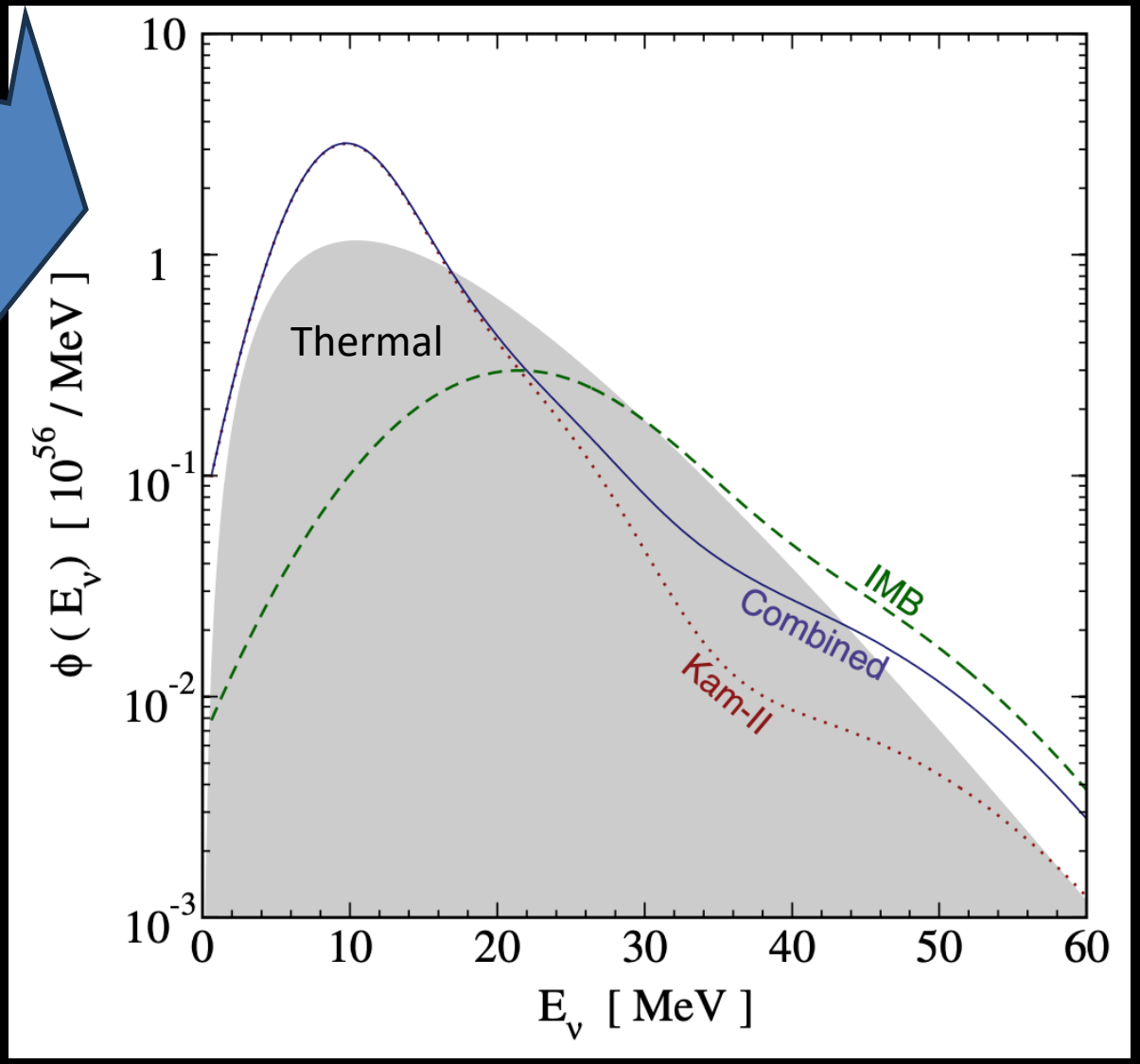
Guidance from data

Look to SN1987A for guidance





Yuksel & Beacom (2007)
See also Krauss (1987),
Bahcall (1987), Vissani (2015)



Guidance from simulations

Look to simulations for guidance:

- Rapid sophistication
- Simulations routinely explode stars
- Code comparisons

O'Connor et al (2018)

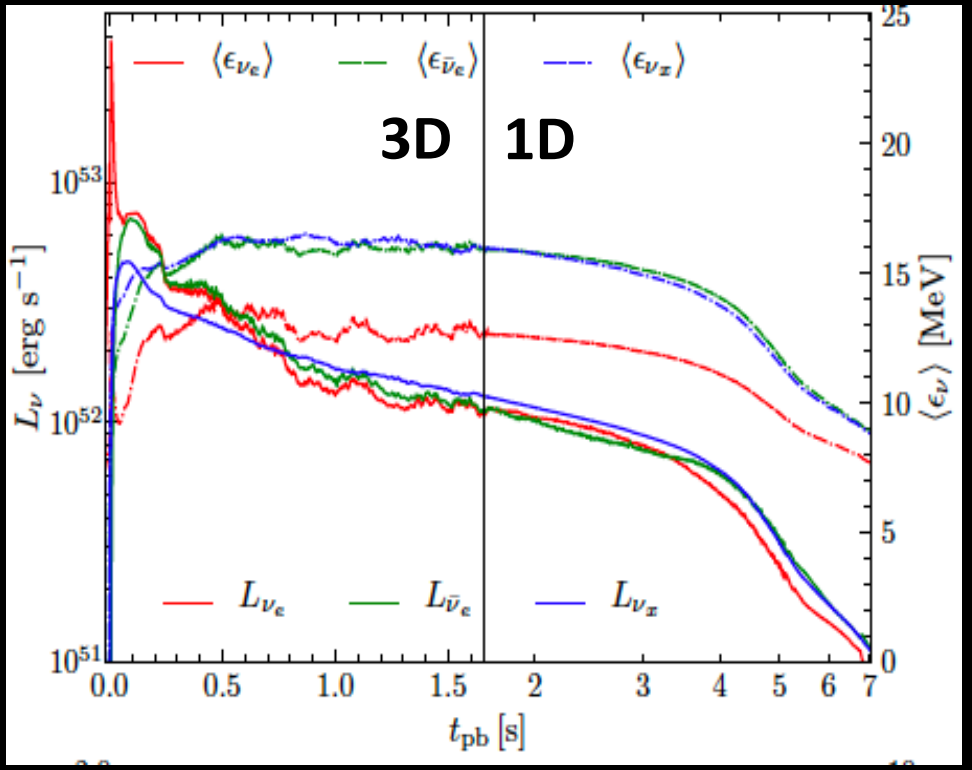
Challenges:

- Mostly still < 1 sec
- Sparsely sampled progenitors

Wishlist:

1. Coverage over long durations
2. Coverage over many progenitors
3. Account for black hole formation, other channels

Challenging, but much progress

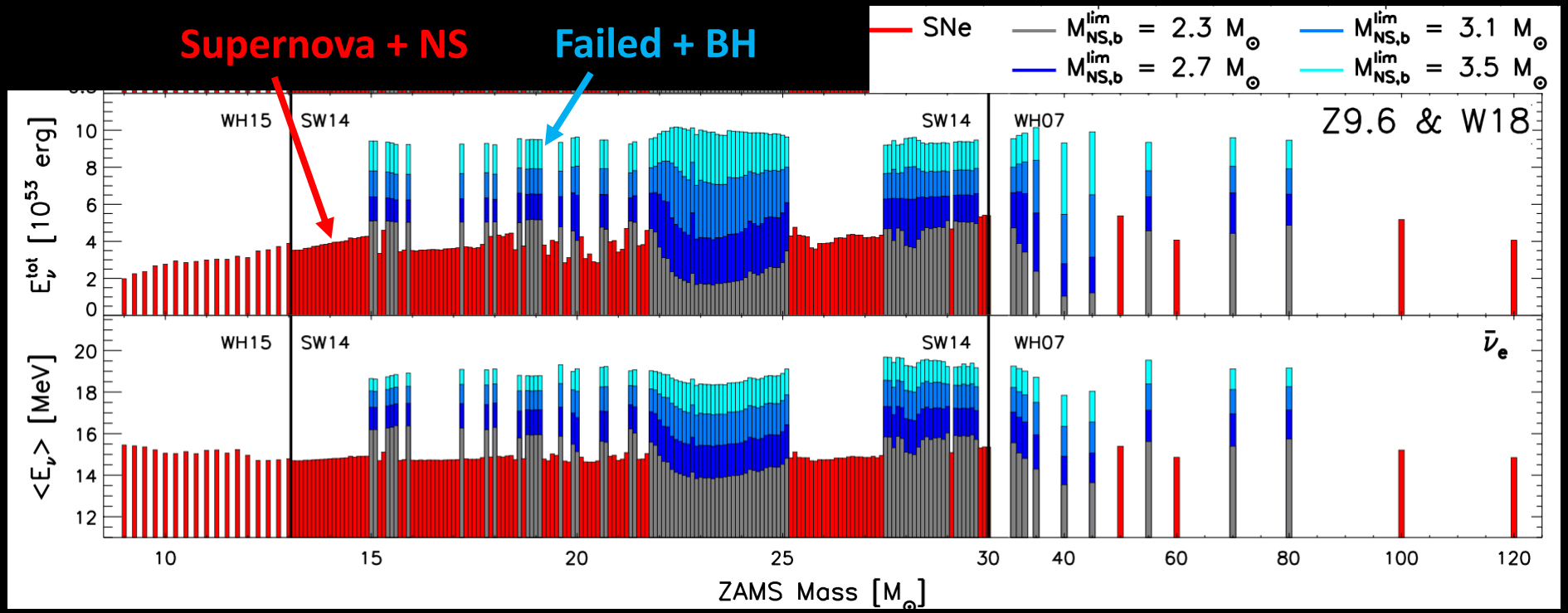


Bollig et al (2021)

Spherical models

Long-term (~10 sec) predictions for multiple progenitors

1. Spherical, calibrated central neutrino engines



Kresse et al (2021)

+ 4 other engine models (calibrated to Crab and SN1987A)

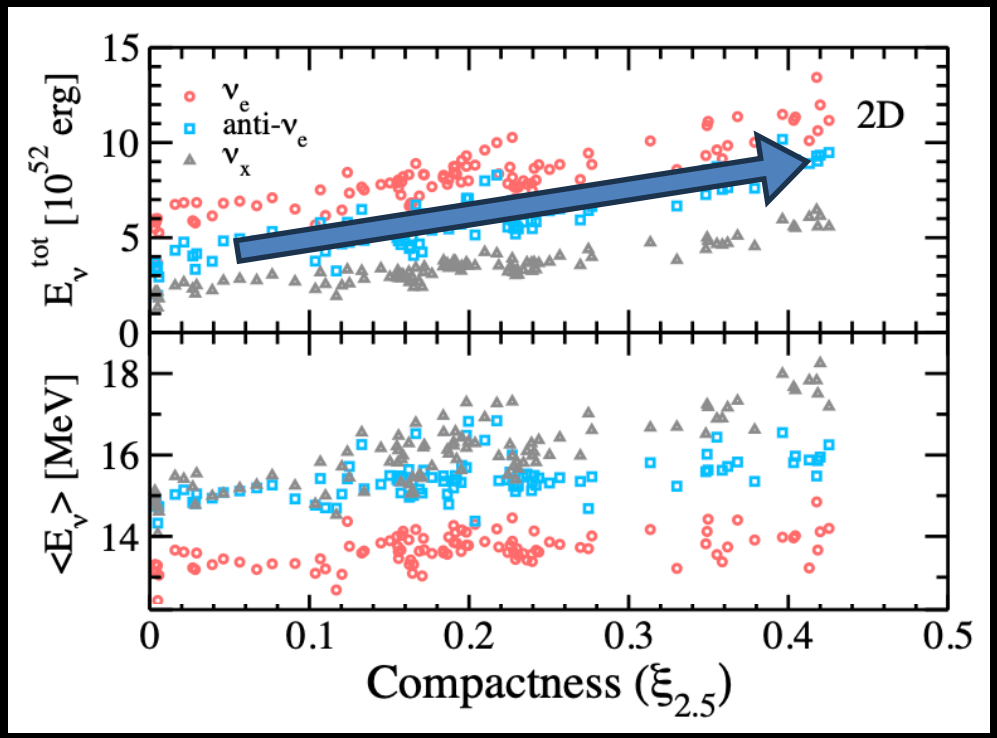
See also, Ugliano et al (2012), Sukhbold et al (2016)

Beyond spherical models

Long-term (~10 sec) predictions for multiple progenitors

1. Spherical, calibrated central neutrino engines
2. Axis-symmetric + simple cooling

Simulations until ~1 sec, analytic model after that



Horiuchi et al (2018), based on Nakamura et al (2015); see Ekanger et al (2022) for updates

Compactness:
Captures the density structure of the progenitor, which impacts mass accretion evolution

$$\xi_M = \left. \frac{M/M_\odot}{R(M_{\rm bary} = M)/1000\,{\rm km}} \right|_t$$

- Higher ξ → higher Mdot
- Lower ξ → lower Mdot

O'Connor & Ott (2013)

Beyond spherical models

Long-term (~10 sec) predictions for multiple progenitors

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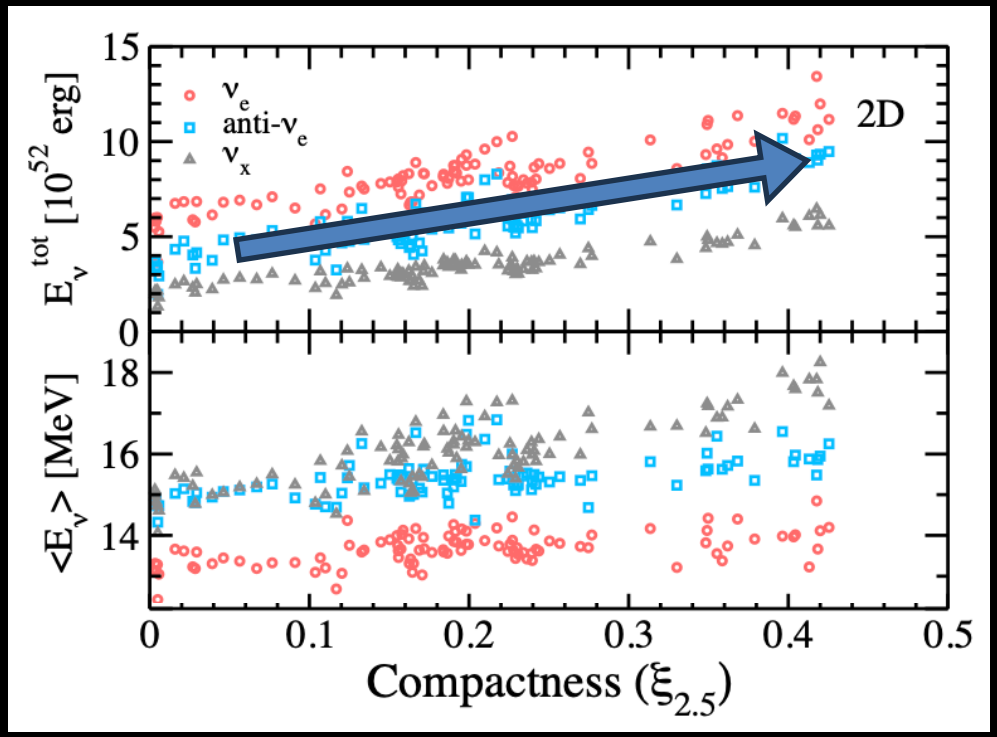
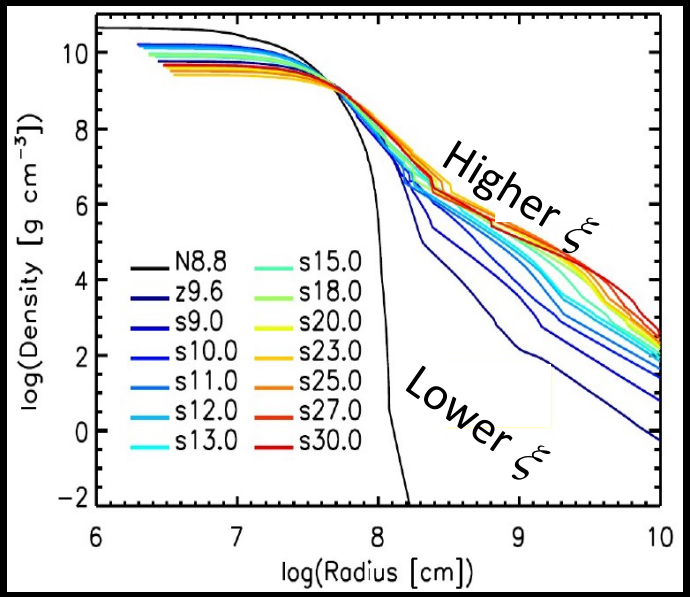


Horiuchi et al (2018), based on Nakamura et al (2015); see Ekanger et al (2022) for updates

Compactness:



O'Connor & Ott (2013)

Neutrino emission synthesis

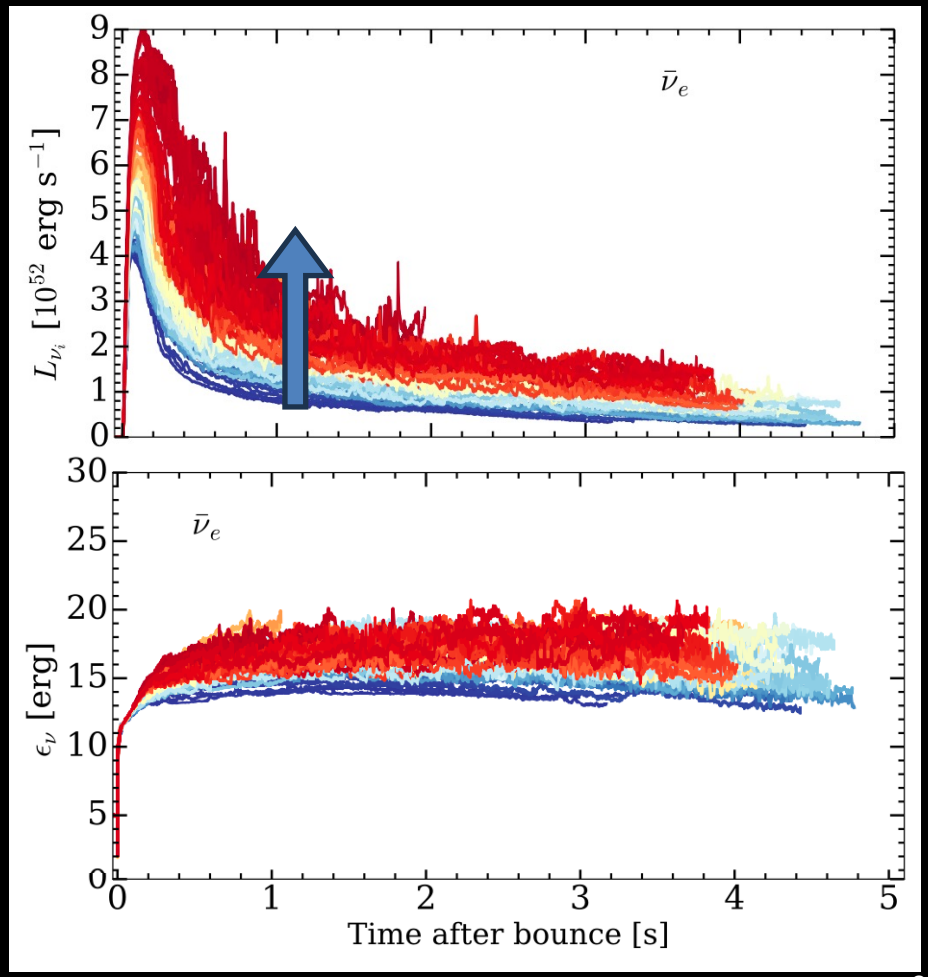
Long-term (~10 sec) predictions for multiple progenitors

1. Spherical, calibrated central neutrino engines
2. Axis-symmetric + simple cooling
3. Large sets of numerical models

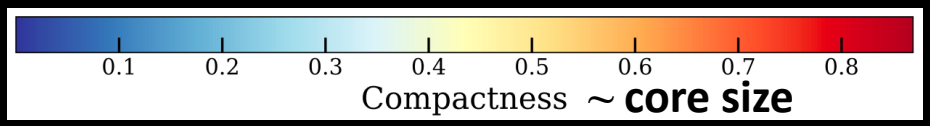
e.g., Nagakura et al (2021), Vartanyan & Burrows (2023), Choi et al (2025), …

Supports importance of progenitor (eg compactness).

see also, O'Connor & Ott (2011), Nakamura et al (2015), Horiuchi et al (2016)



Vartanyan & Burrows (2023)

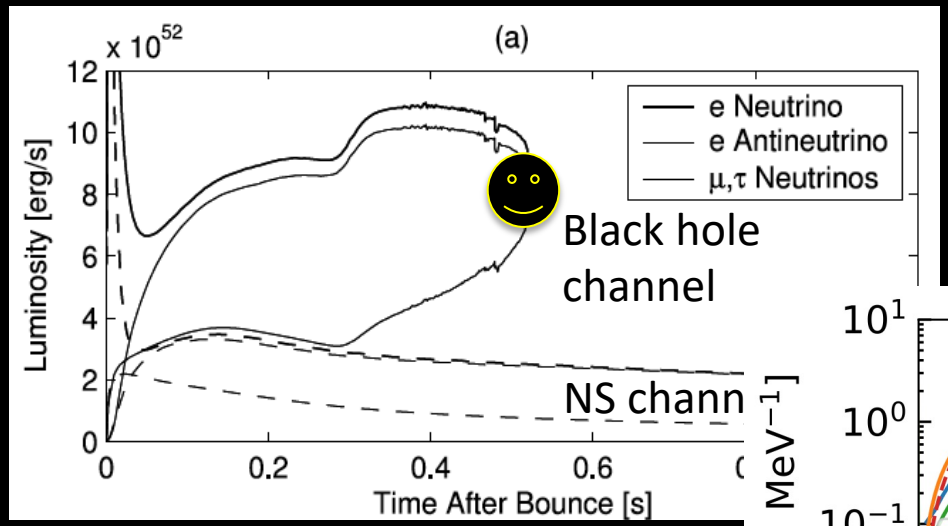


Guidance from simulations: black holes

Black hole formation

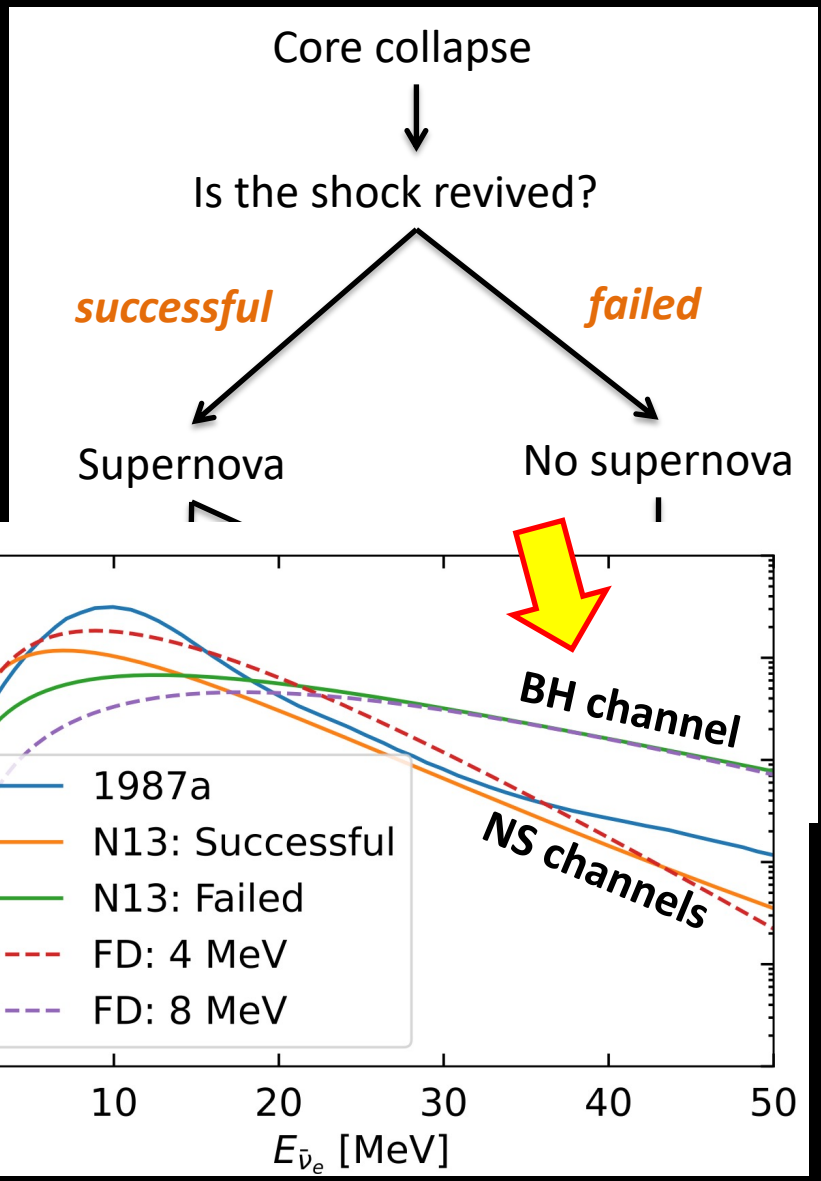
Some massive stars collapse to black holes

Liebendoerfer et al (2004)



- Neutrino luminosities are high
- But don't last as long ☹

➔ **Time-integrated, produces a systematically higher-energy spectrum**



Ando, Ekanger, Horiuchi, Koshio (2023)

Black hole channel

Long-term predictions for multiple progenitors

Neutrino emission

Larger cores (=compactness)

→ higher L_ν but shorter duration

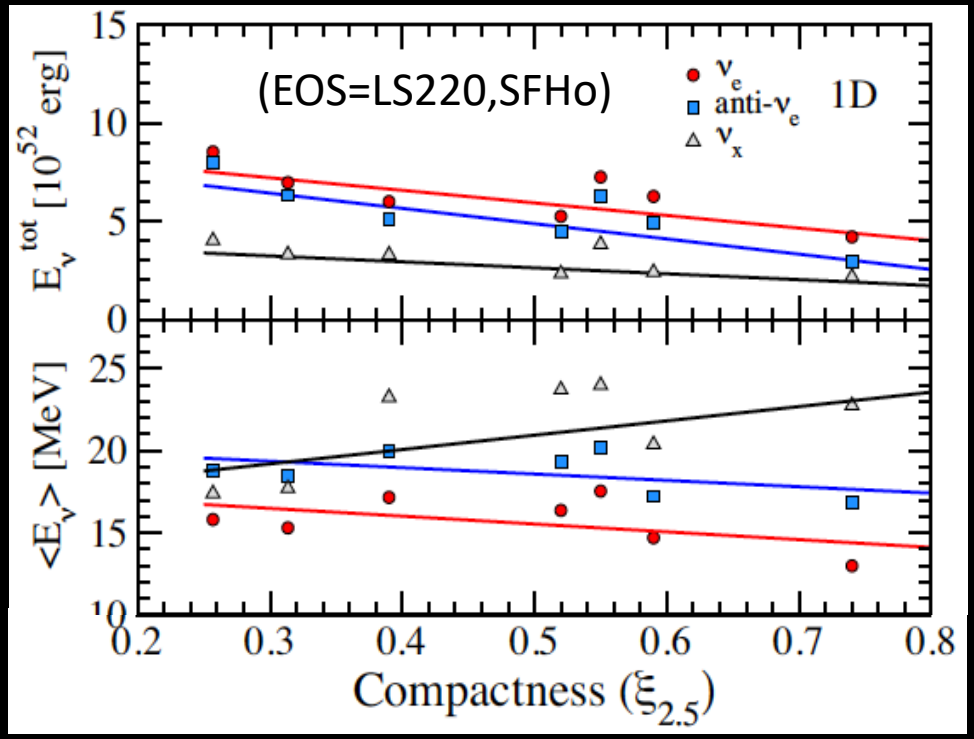
→ net decline (except ν_x)

Dependence on explosion mechanism

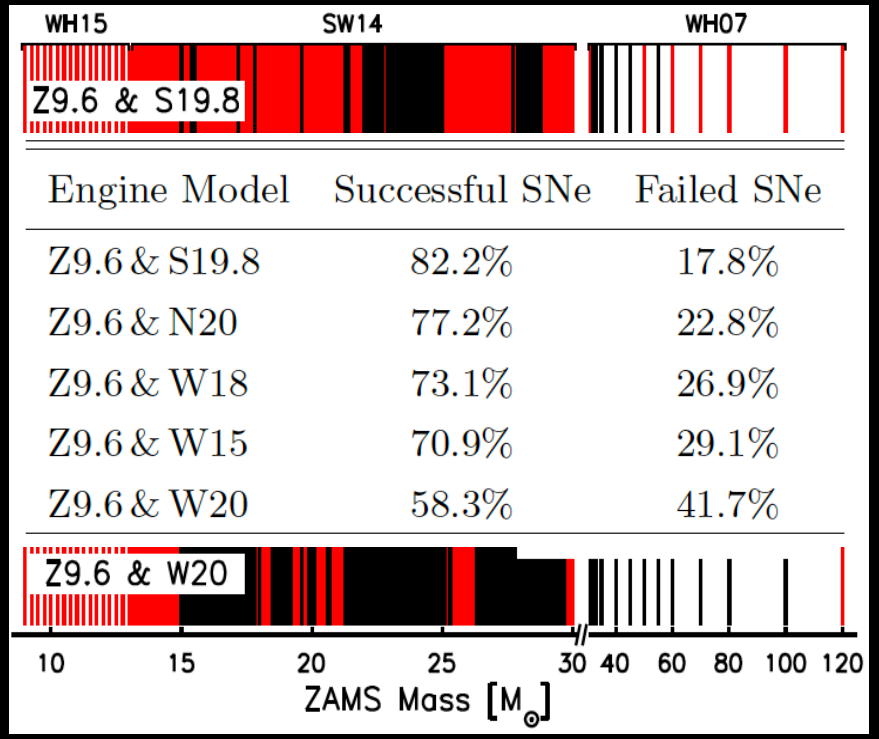
More power engine

→ more neutrino

→ less black hole formation



Horiuchi et al (2018)



Engine Model	Successful SNe	Failed SNe
Z9.6 & S19.8	82.2%	17.8%
Z9.6 & N20	77.2%	22.8%
Z9.6 & W18	73.1%	26.9%
Z9.6 & W15	70.9%	29.1%
Z9.6 & W20	58.3%	41.7%

e.g., calibrated 1D engine, Kresse et al (2021)

Diffuse supernova neutrinos

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

Neutrino detector capabilities

Time-integrated neutrino emission

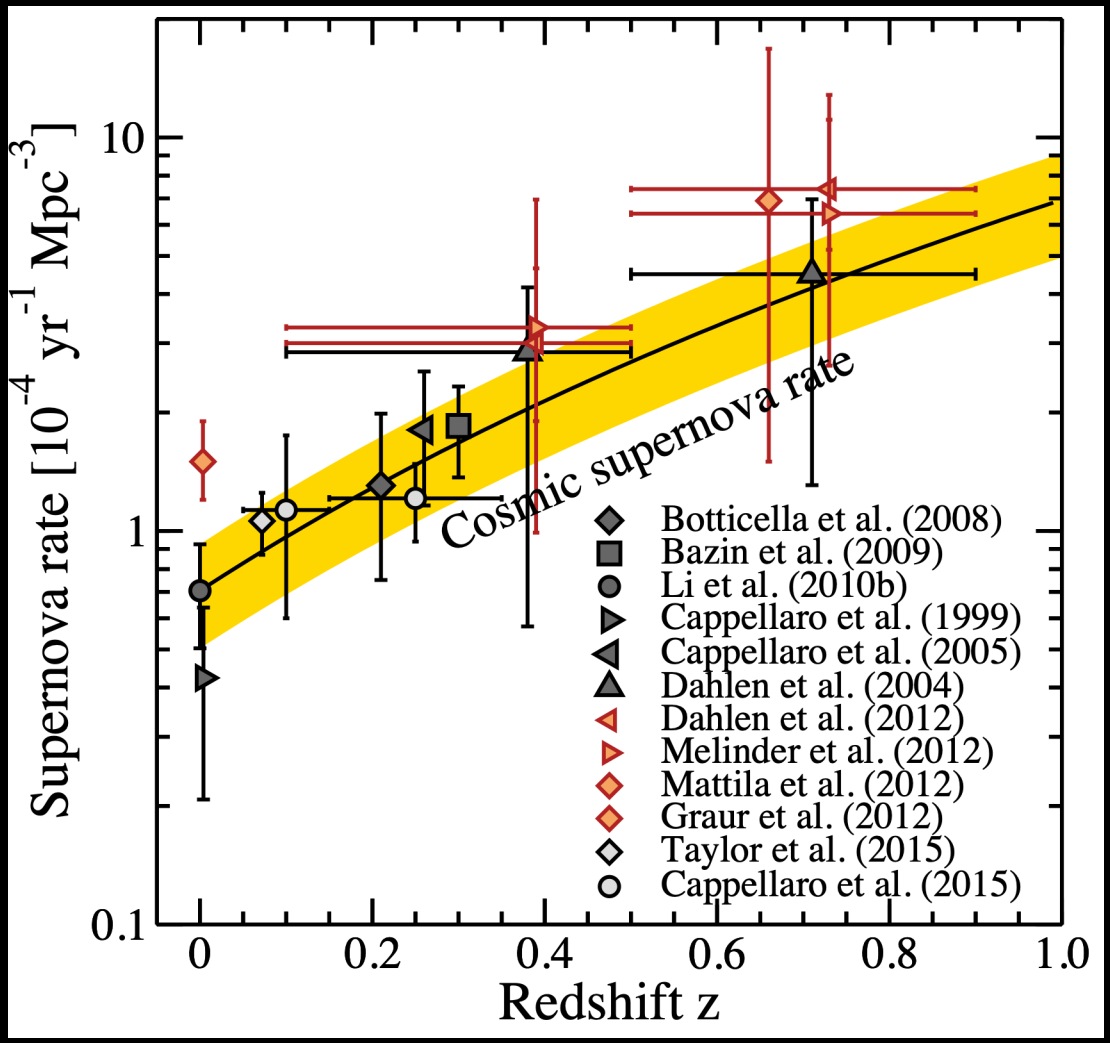
Rate of massive star core collapse

Core-collapse supernova rate

Direct measurements

- Important redshift range (z<1) observed by surveys
  - Different survey strategy, sample size, dust correction, supernova luminosity function

But: supernova rate only gives the exploding core collapse rate



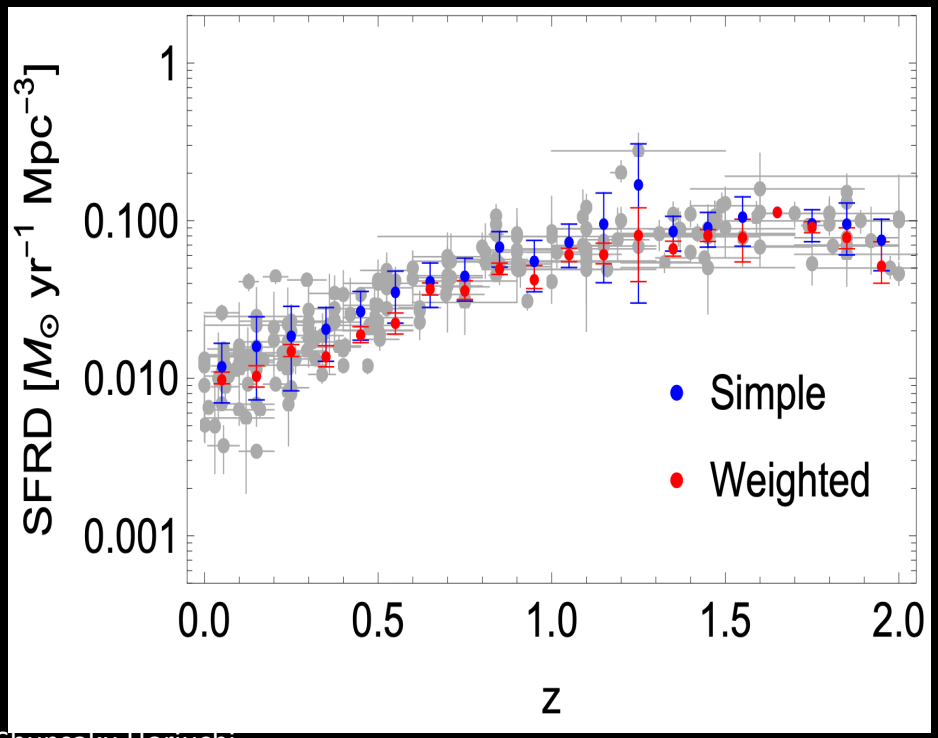
Updated from Horiuchi et al (2011)

Rate of cosmic core collapse

Since core-collapse progenitors have short lifetimes:

$$\left(\frac{dN}{dt}\right)_{\substack{\text{stellar}\\\text{birth}}} = \left(\frac{dN}{dt}\right)_{\substack{\text{bright}\\\text{collapse}}} + \left(\frac{dN}{dt}\right)_{\substack{\text{dark}\\\text{collapse}}}$$

Well-measured Improving



Star formation rate:

- ✓ Measured by many groups, many wavebands, many data sets
- ✓ Many cross checks
  - Background light from stars
  - Stellar density evolution
  - Metallicity evolution

Ekanger et al (2024), see also
Madau & Dickinson (2014), Hopkins & Beacom (2006)

Rate of cosmic core collapse

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Well-measured | Improving | Frontier

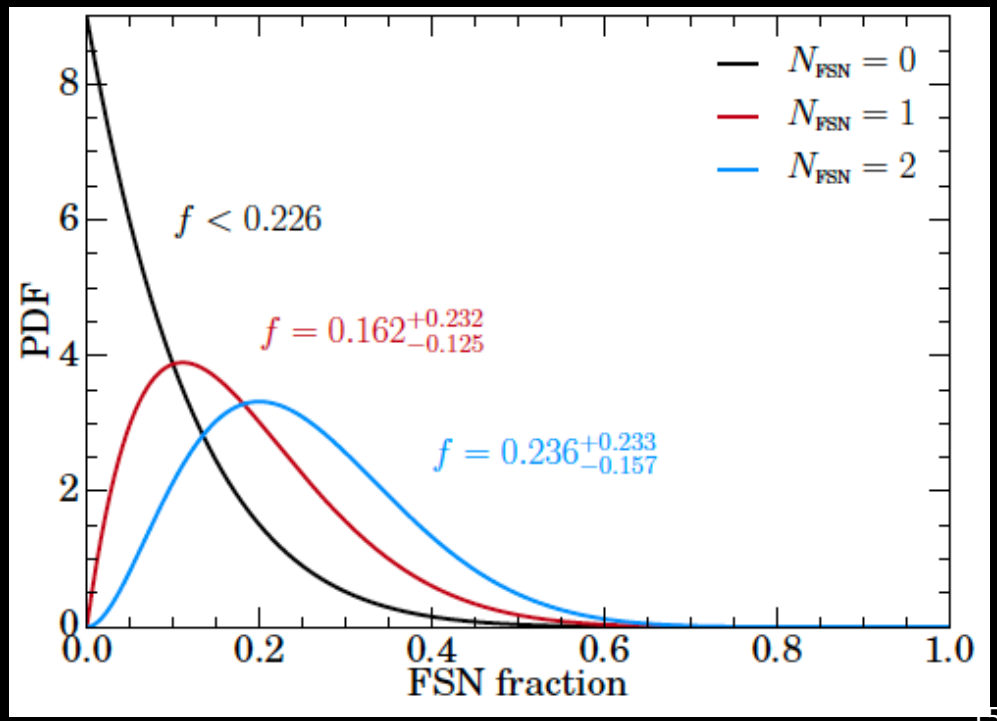
Collapse to black holes

1. Inferred by mismatch of stellar birth rate and supernova rate

   Eg Strigari et al (2008), Horiuchi et al (2011), Mathews et al (2014), Yuksel & Kistler (2014), Graur et al (2015), Ekanger et al (2024), …

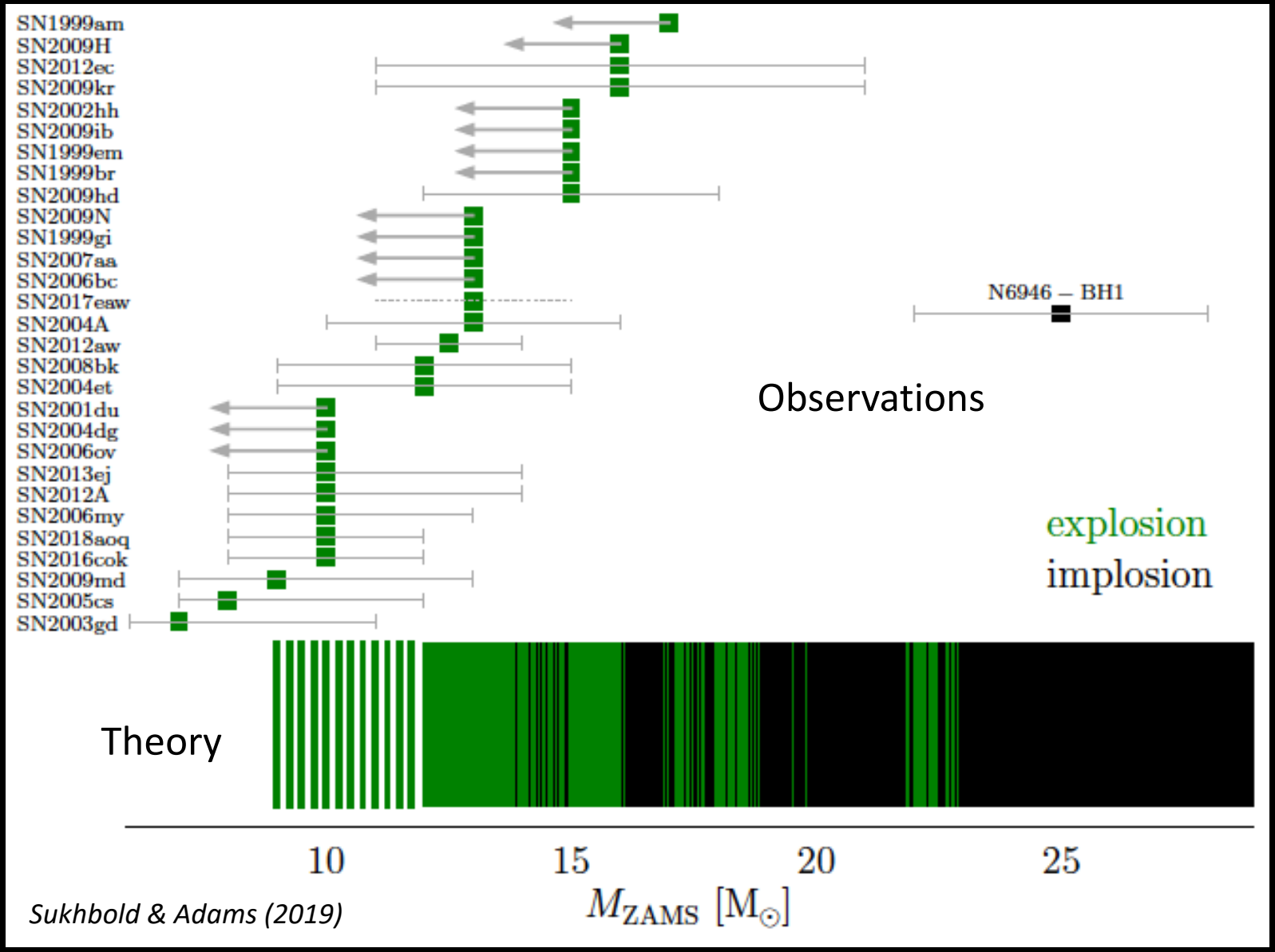
2. Candidates of disappearing stars

   Kochanek et al (2018), Gerke et al(2015), Adams et al (2017), Reynolds et al (2016), Neustadt et al (2021)



Neustadt et al (2021)

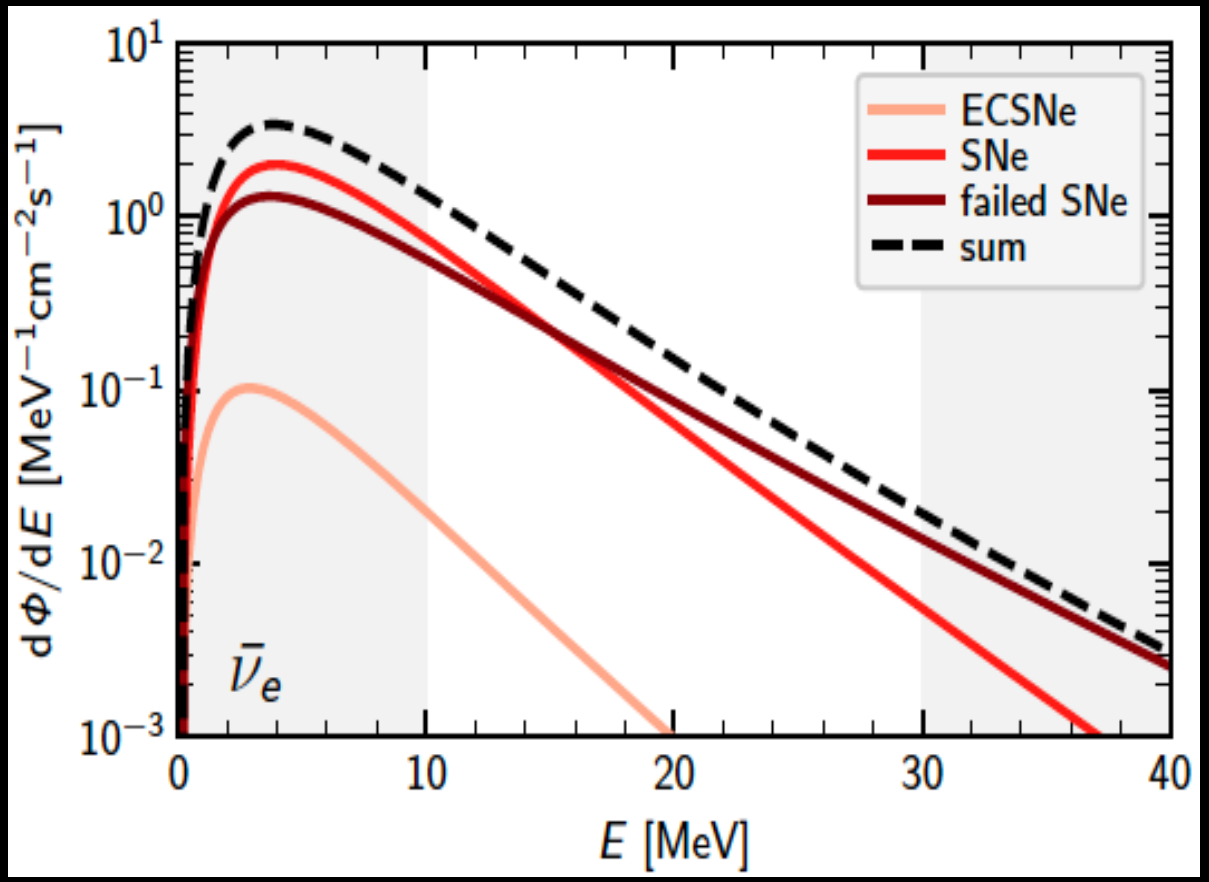
Potential emerging picture



Sukhbold & Adams (2019)

DSNB predictions

Common to separate 3 populations. (uncertainties not shown)



Review & public code to estimate the neutrino flux (*pyDSNB*)

https://github.com/shinichiroando/PyDSNB

Ando, Ekanger, Horiuchi, Koshio (2023)

See also: Lunardini (2009), Lien et al (2010), Yang & Lunardini (2011), Keehnn & Lunardini (2012), Nakazato (2013), Mathews et al (2014), Yuksel & Kistler (2015), Nakazato et al (2015), Hidaka et al (2016), Priya & Lunardini (2017), Moller et al (2018), Horiuchi et al (2018), Sing & Rentala (2021), Kresse et al (2021), Horiuchi et al (2021), Ashida & Nakazato (2022), Ekanger et al (2022), Ziegler et al (2023), Martínez-Miravé et al (2024), Ekanger et al (2024), MacDonald et al (2025), Lunardini et al (2025)

Uncertainties (an attempt)

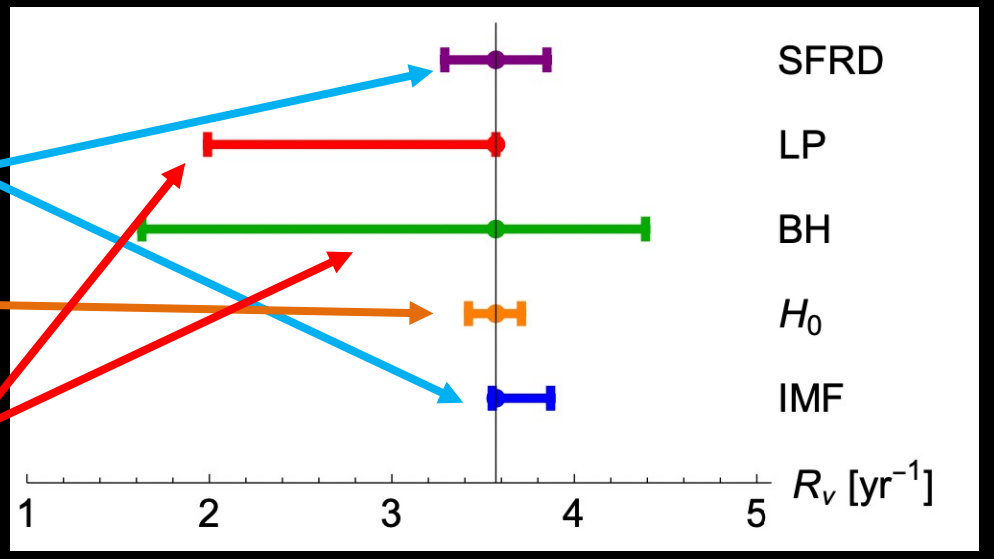
Some attempts at the error budget:

Most likely to learn about supernova physics

Core collapse rate

Cosmology

Neutrino emission

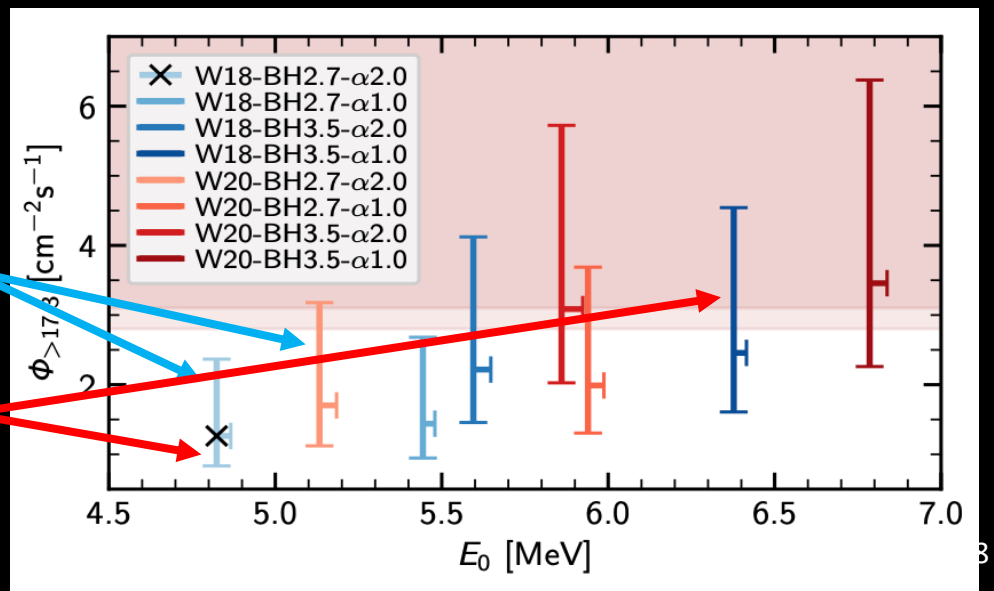


Ekanger et al (2024)

➔ **In the future, likely to learn about black hole channel**

Different supernova model

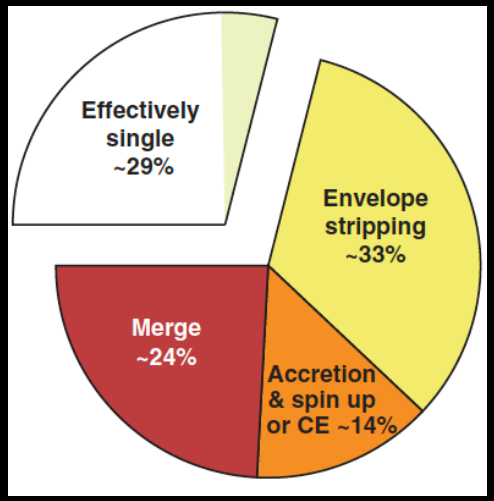
DifferentBlack hole mass



Kresse et al (2021)

Various effects

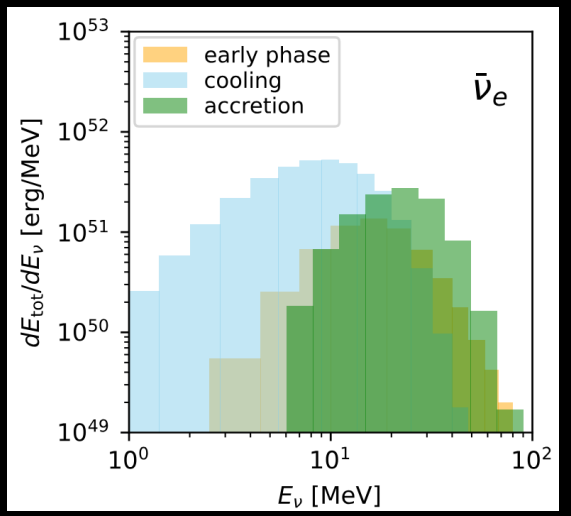
Stellar binaries: are common and can affect progenitors



Horiuchi et al (2021)
Lunardini et al (2025)

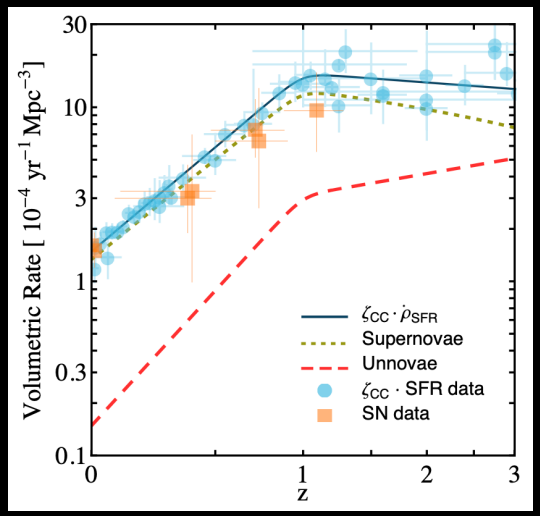
Fall back channel: can be large contribution if black hole takes time to form

Nakazato et al (2024)



Black holes: may be more commonly formed at high redshifts. EOS dependence

Yuksel & Kistler (2014)
Nakazato et al (2020)
Ashida et al (2023)



Neutrino decay: competitive probes of decay times ~10^{10} s/eV

de Gouvea et al (2020)

Non-Universal IMF: hints of environmental dependence

Zieger et al (2022), Ashida et al (2023)

DM-ν interactions

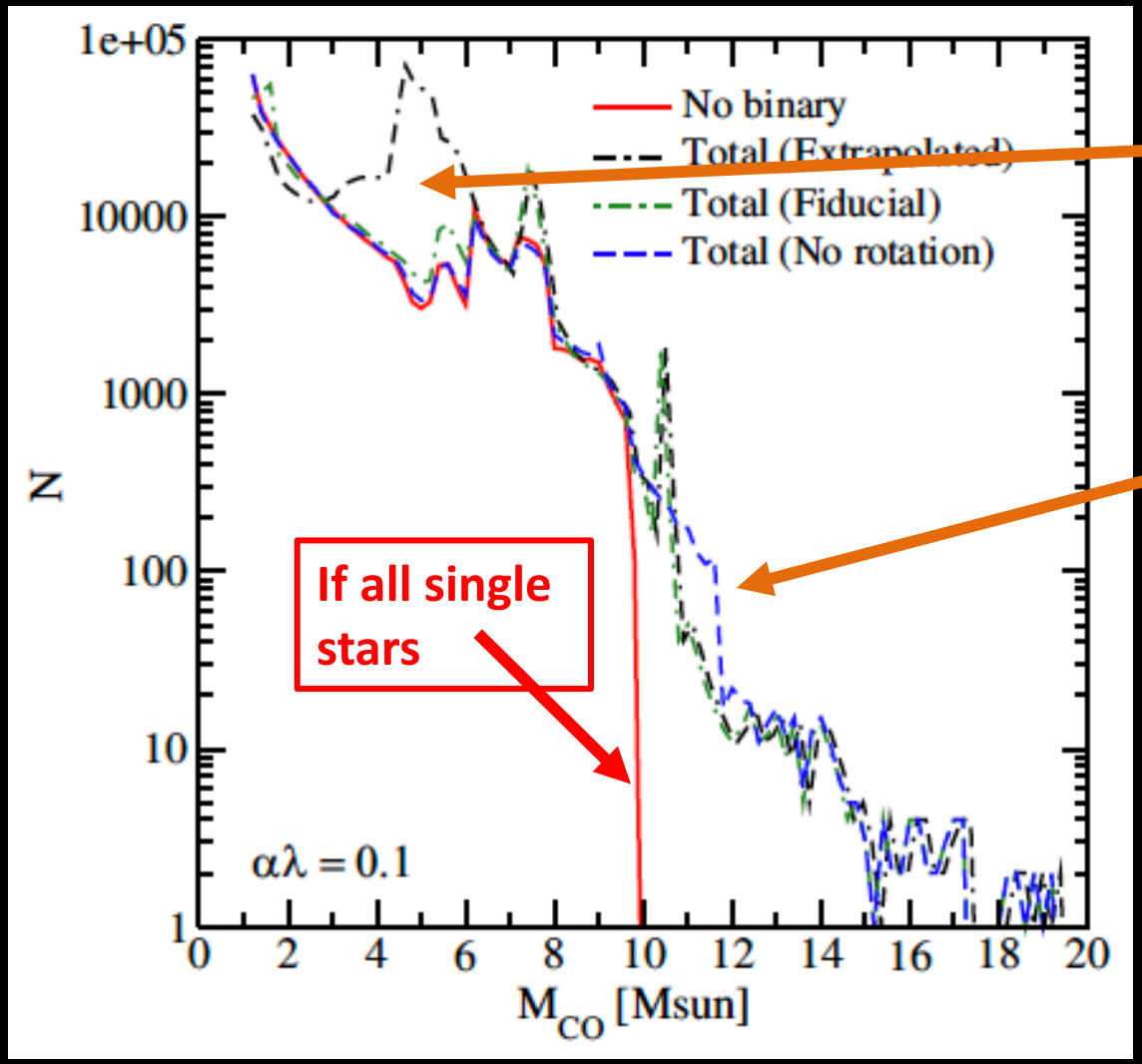
Eg, Farzan & Palomares-Ruiz (2014), Das et al (2024)

Late-time ν mass generation

de Gouvea et al (2022)

Binary effects on the DSNB

Binary effect creates more and higher mass cores for collapse



Horiuchi et al (2021)

Boost to number of progenitors due to mergers: ~25% more progenitors

Boost to masses of progenitors due to mergers and mass transfers (at the expense of donor's mass)

Effect on DSNB is ~10-20%, (up to ~70% under certain assumptions)

See also, Kinugawa et al (2024), Lunardini et al (2025)

More black hole effects on the DSNB

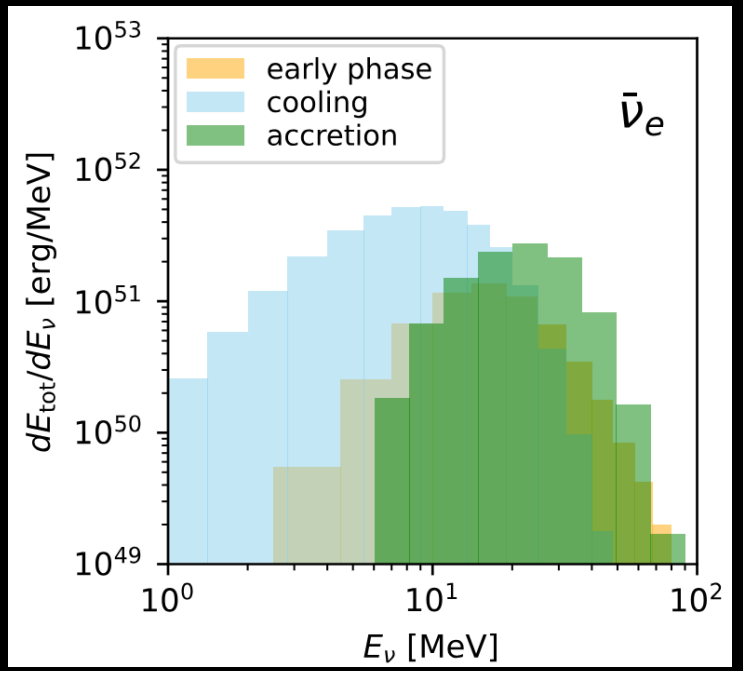
Many unknows (which is a good thing)

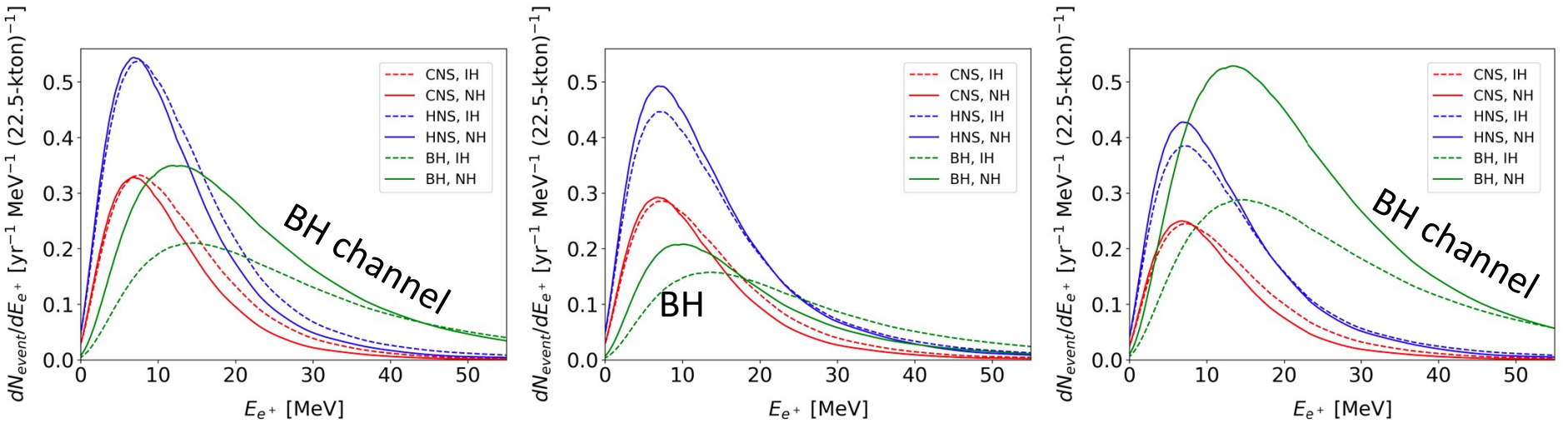
- Fraction may be large
- Impacted by EOS dependence
- Enhanced by late-time accretion

Effect on DSNB can be up to factor of 2

Nakazato et al (2024)

Ashida & Nakazato (2022)





(a) Togashi EOS (b) LS220 EOS (c) Shen EOS

stiffer

Final remarks

The diffuse supernova neutrino background is a guranteed signal

- ✓ We know supernovae are occuring
- ✓ We know supernovae emit copious neutrinos

Many interesting input physics being worked out

- ✓ Supernova rates: connection to broad astronomy
- ✓ Neutrino emission: connection to simulation, explosion mechanism
- ✓ Black hole physics: connection to simulation, EOS, galaxy evolution

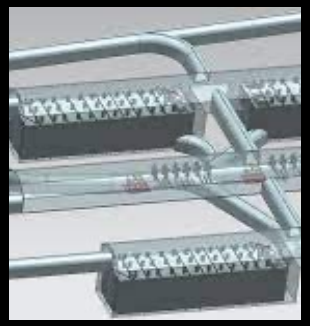
Broad implications for discovery

- ✓ This will be the first confirmed extraterresterial neutrinos since solar and SN1987A neutrinos, this time over cosmological distances

thank you!

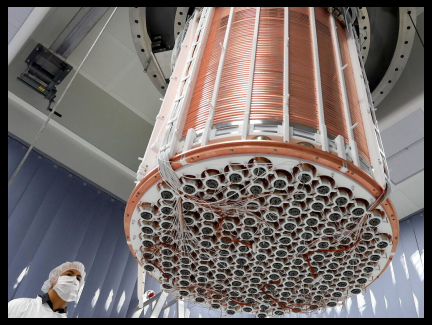
BACKUP

Beyond nuebar flavor



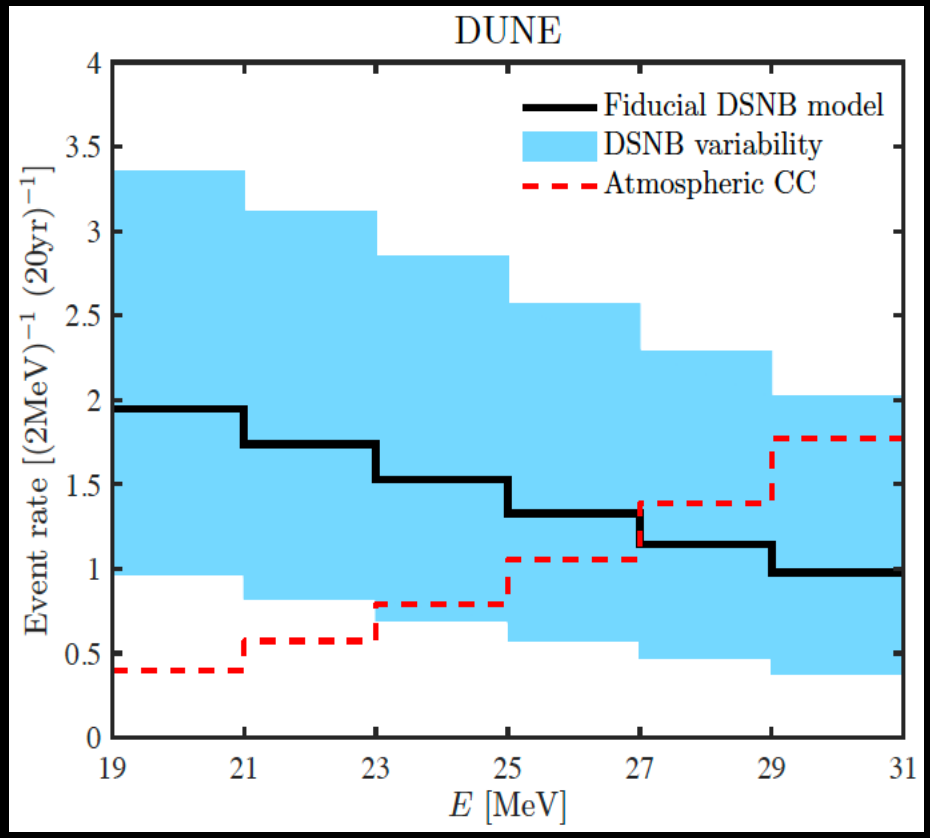
DUNE

- 40k ton lq Ar
- Signal & bkg studies ongoing
- CC int. for nue

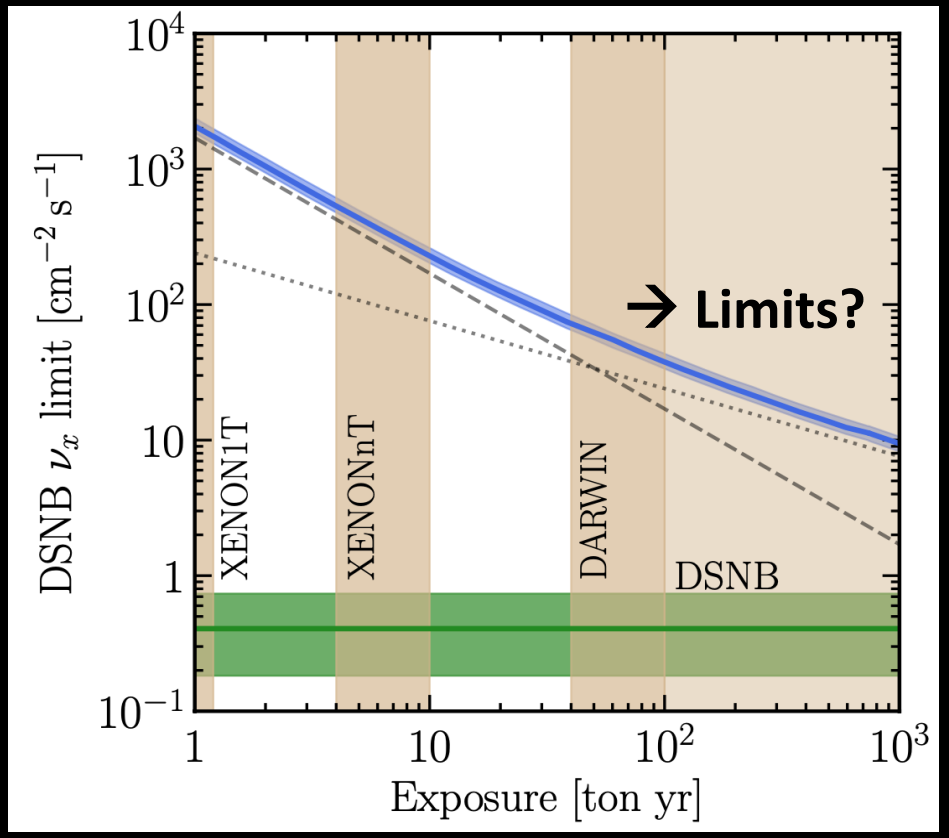


Direct DM detector

- Xe or Ar targets
- Solar & atm. bkgs
- CEνNS for all flavor



Moller et al (2018)



Suliga et al (2022)

Detection with geological minerals?

Use old rocks?

- Natural solid-state track detectors
- R&D of fast nm resolution mapping of macroscopic samples



Competitive exposure

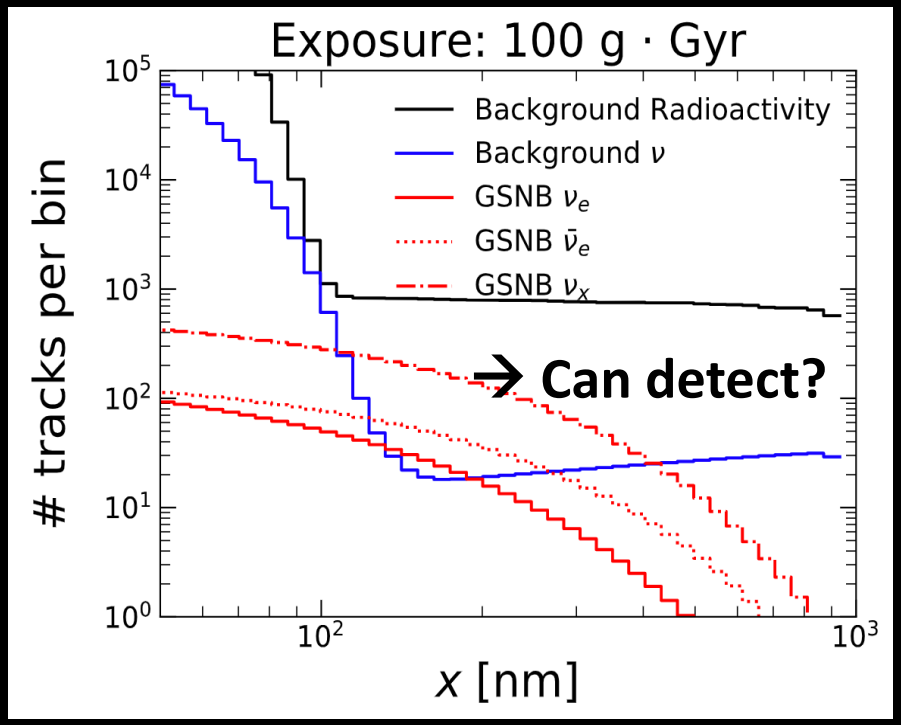
100 grams over 10^9 yr = 10^5 t yr

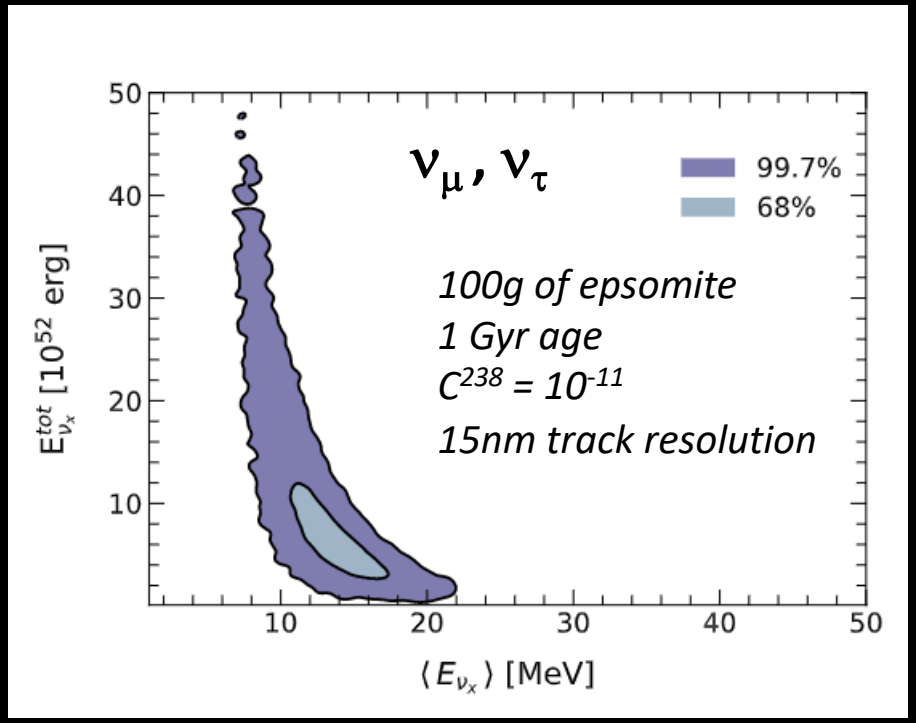
All flavors

CEνNS relevant for MeV neutrinos

Records thousands of core collapse

Duration >> inverse of Galactic supernova rate

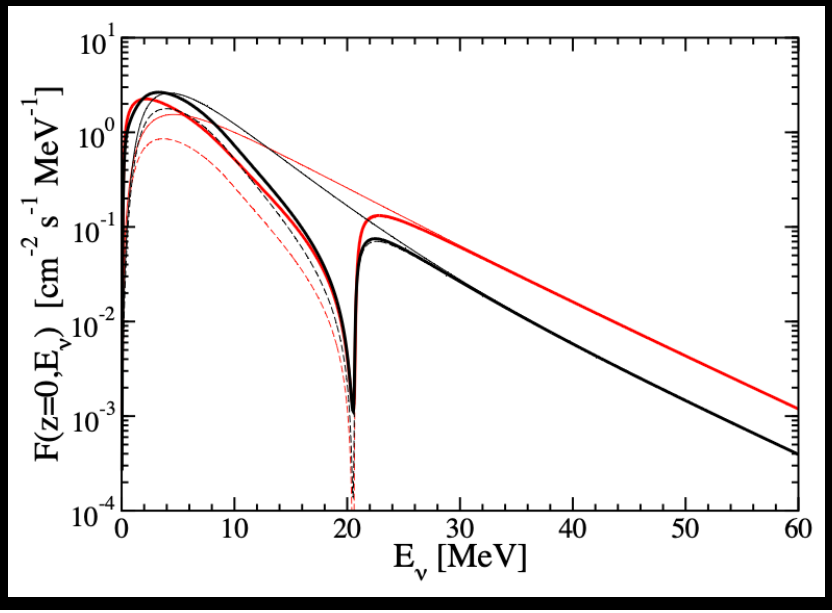




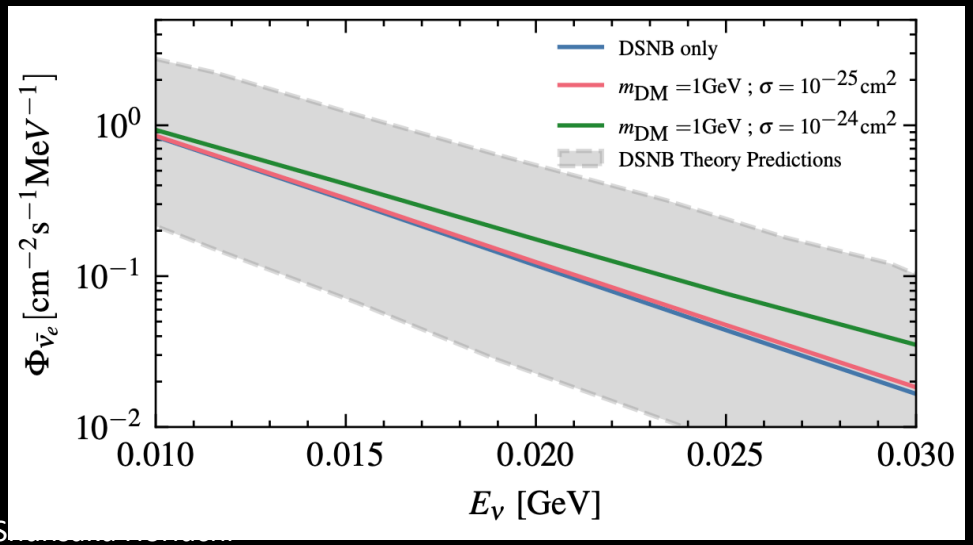
Baum et al (2022)

Examples: new physics probe

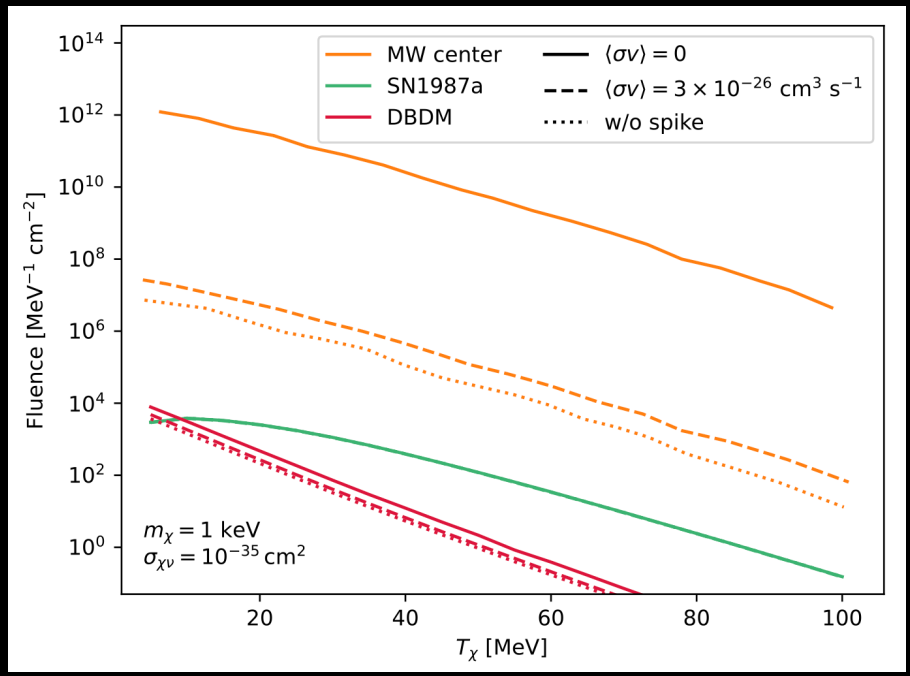
Effect on supernova neutrino flux



Farzan & Palomares-Ruiz (2014)



Signal of boosted dark matter



Lin & Wu (2025)

Chauhan et al (2025)