前兆から超新星爆発の初期段階にわたるニュートリノ放出の系統的な調査と親星モデルとの相関調査

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2026/3/9-10 第12回超新星ニュートリノ研究会@プラサ ヴェルデ

I will submit the paper soon…

Comprehensive Neutrino Light Curves and Spectra: From Pre-supernova Evolution to Early Supernova Phase

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Uncertainty in SN progenitor models

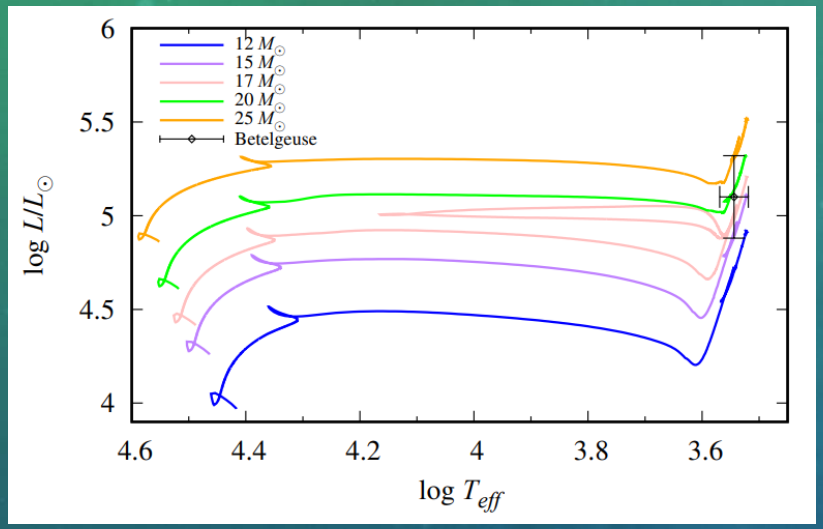
✓We have a “standard model”
but advanced stages of massive stars are uncertain

✓ Uncertainty of progenitor models

- physics: boundary mixing, mass loss,
  nuclear reaction, magnetic field,
  rotation, binary interaction
- numerical treatment: MLT, nuclear network size,
  special resolution, time resolution

Constraints on progenitor models

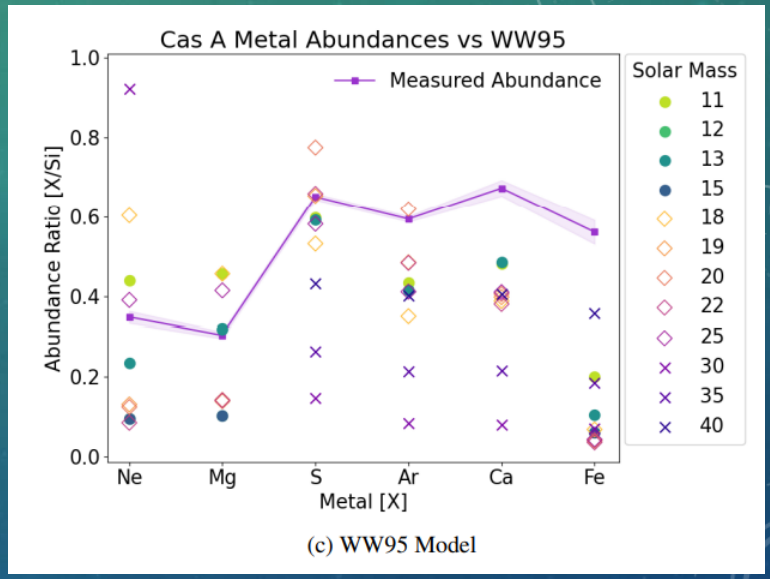
✓direct observation
→ luminosity & color



Luo2022

✓SNR spectrum

Braun2019



✓SBO lightcurve & spectrum

✓SN shock-CSM interaction

✓Nebula phase spectrum

- Only surface information
- Coupling between model uncertainties (SN, nucleosynthesis)

Advantage & drawback of preSN ν

Recent observational development

➡ long precise observation of neutrinos!

preSN ν : neutrino emission before core bounce

<u>Advantages</u>

✓direct evidence of progenitor interiors:

independent of uncertainties of SN models & nucleosynthesis

✓ SN alert: a several days before explosion

<u>Drawbacks</u>

✓ very low event rates: detection range 1kpc

(40 candidates)

Motivation

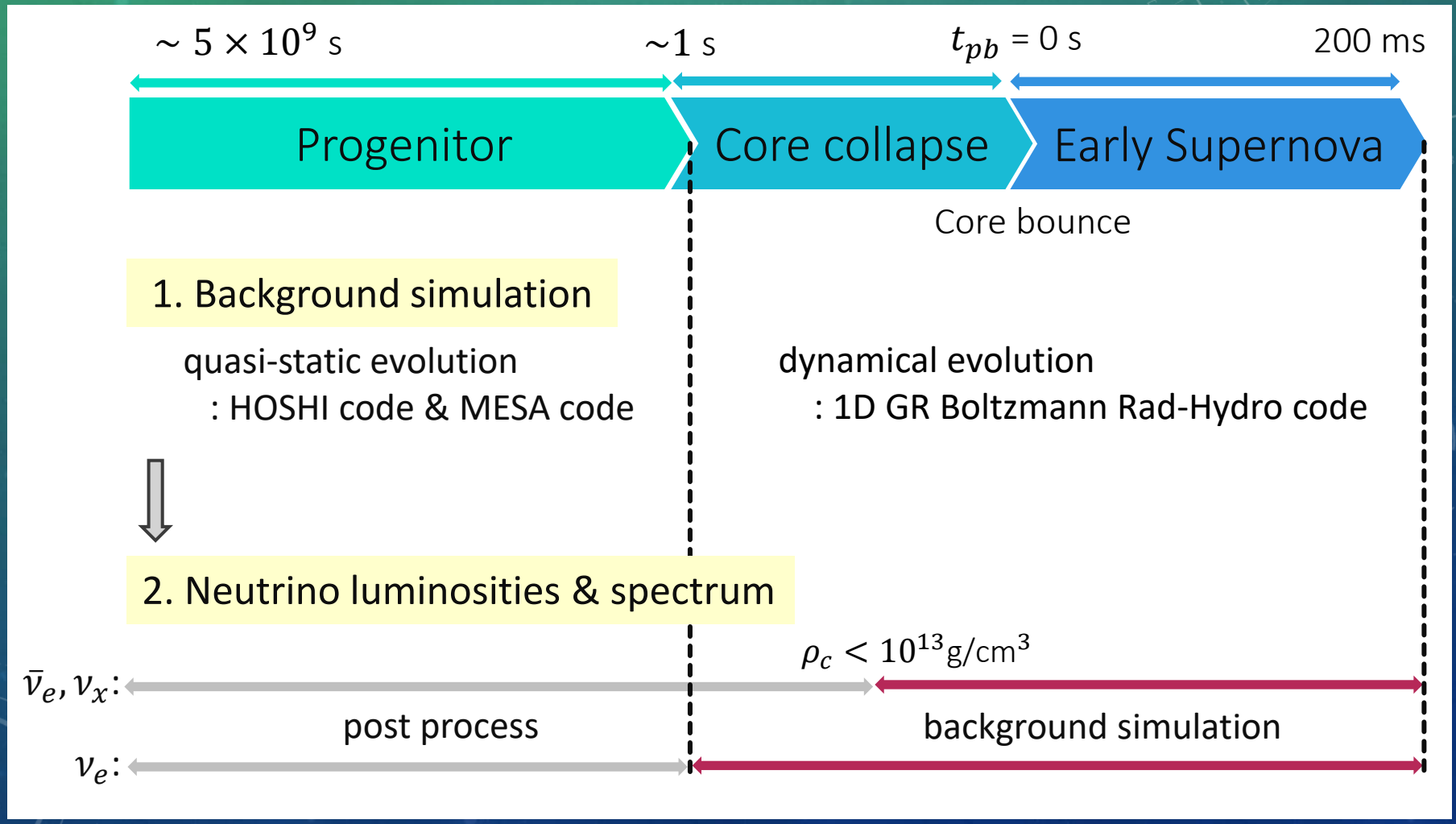
Can we place the constraints on progenitor models by the combination of preSN ν and SN ν observations?

- Calculation of long-term neutrino luminosities and spectra
- Investigation of key progenitor parameters having a relation with neutrino emission for each phases
- Discussion of the synergy with both of preSN ν and SN ν observations

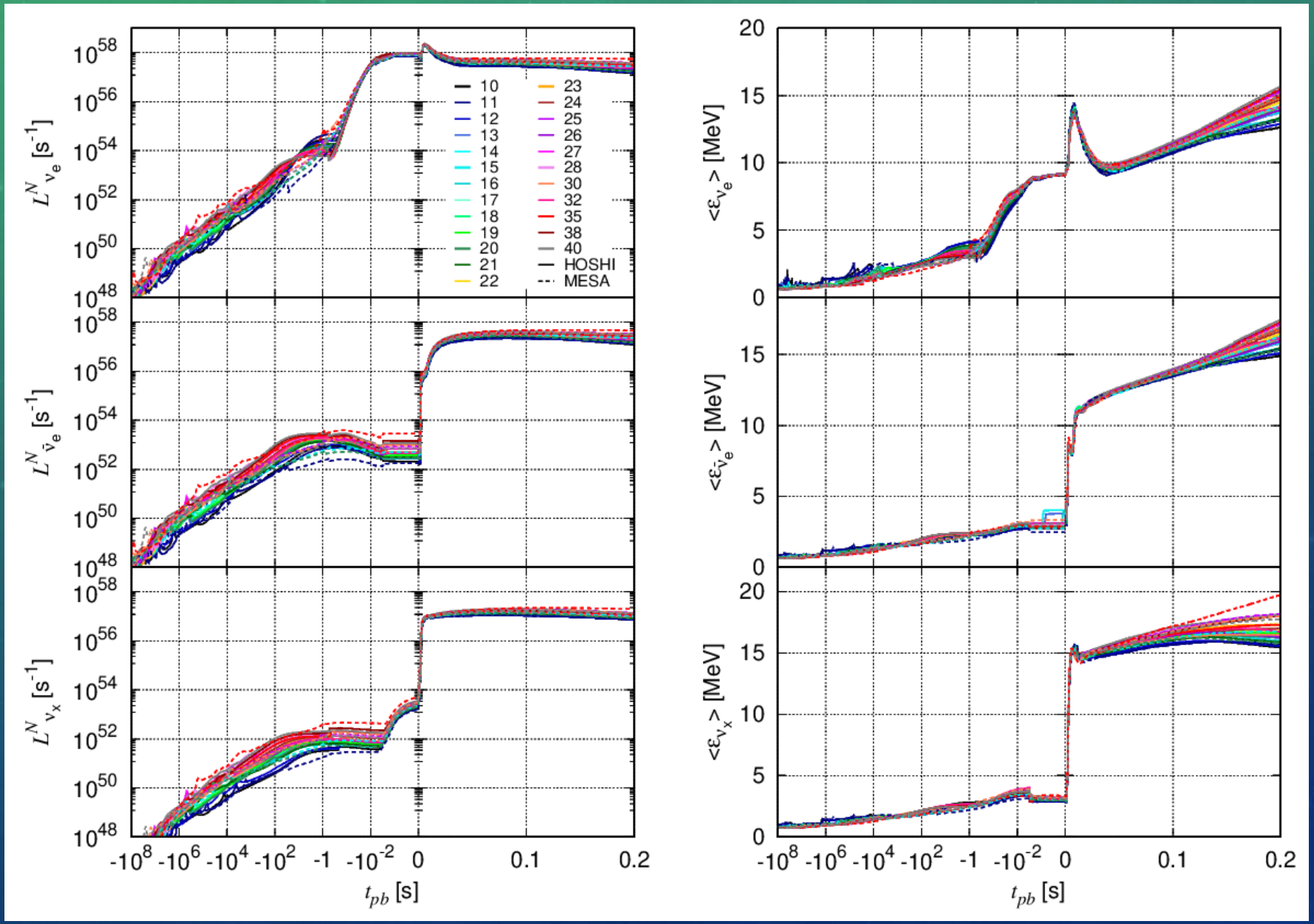
Methods

✓30 models (solar metallicity, 10 – 40$M_\odot$, single star)

HOSHI: 23 models, MESA: 7 models



Luminosities & average energy



Neutrino data are available!

Zenodo: https://zenodo.org/records/18886215
Github: https://github.com/Chinami1229/massivestar-neutrino-data.git

Data release v1.0: Neutrino luminosities and spectra for "Comprehensive Neutrino Light Curves and Spectra: From Pre-supernova Evolution to Early Supernova Phase"

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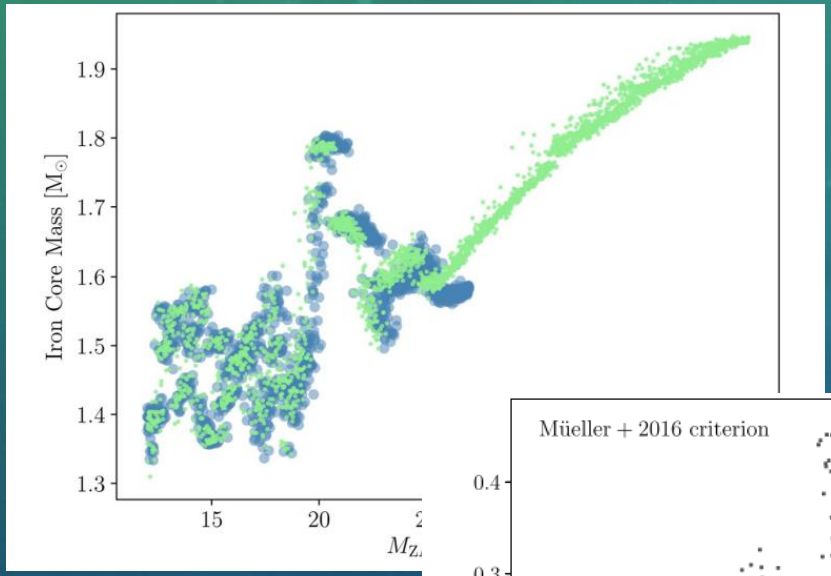
✓Time evolution of neutrino number luminosities

average energy

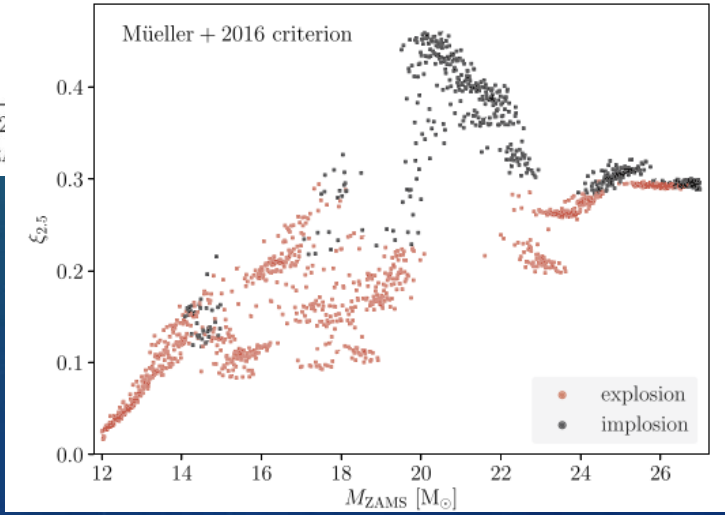
energy specra

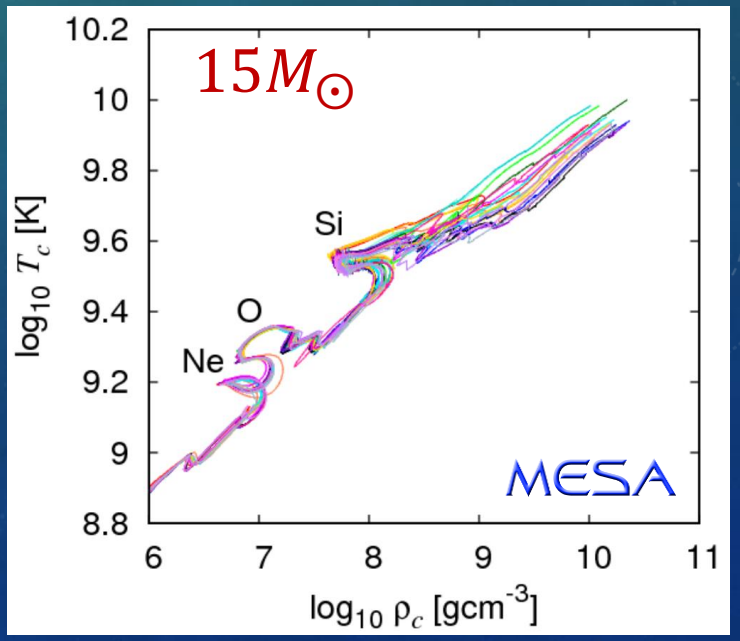
M_{ZAMS} is not a good index!

- ✓ M_{ZAMS} is not corelates with the properties of SN
  ex. Fe core mass / explodability
- ✓ One of parameters for numerical stellar evolution



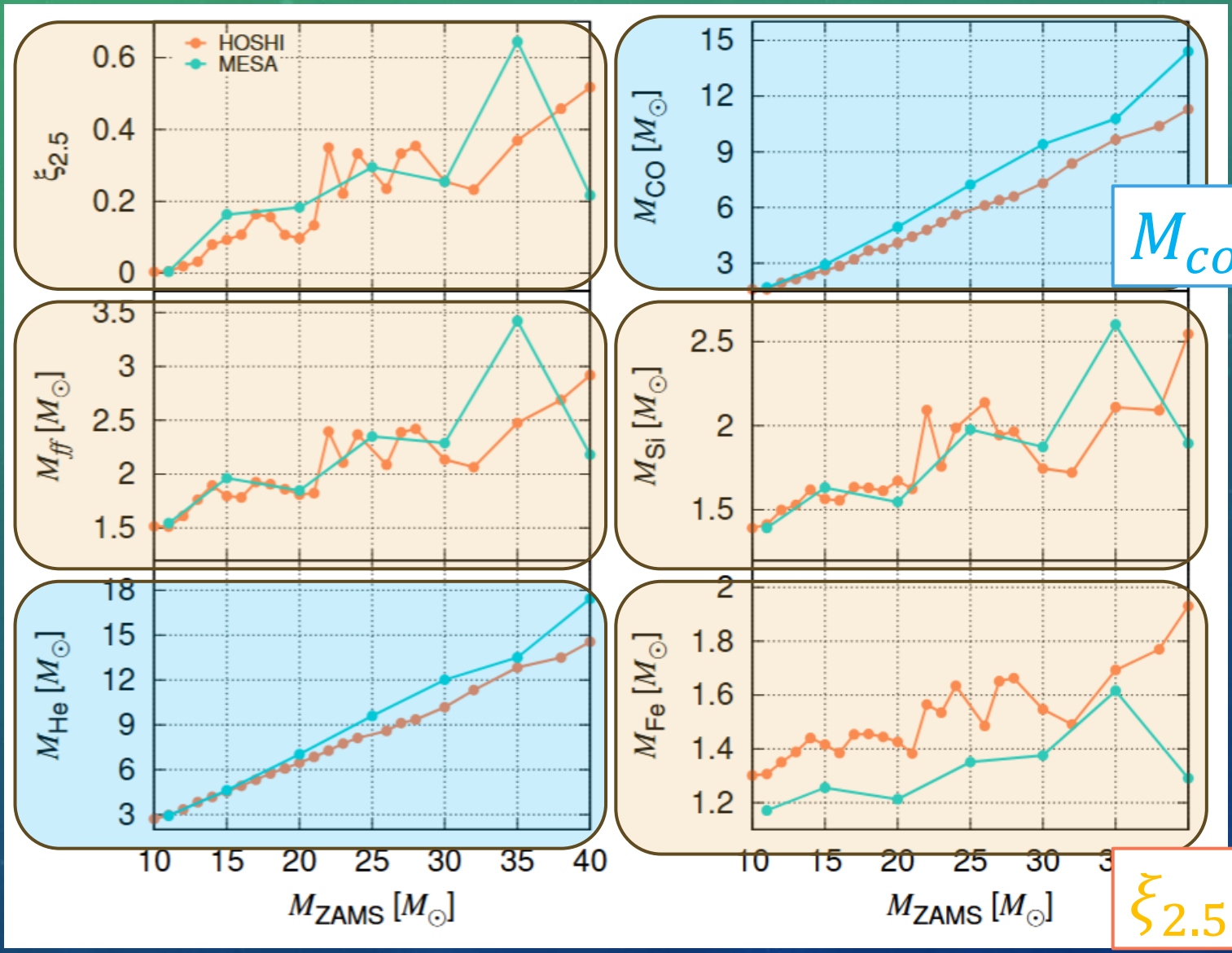
Sukhbold2018





Kato 2020

What's other candidates?

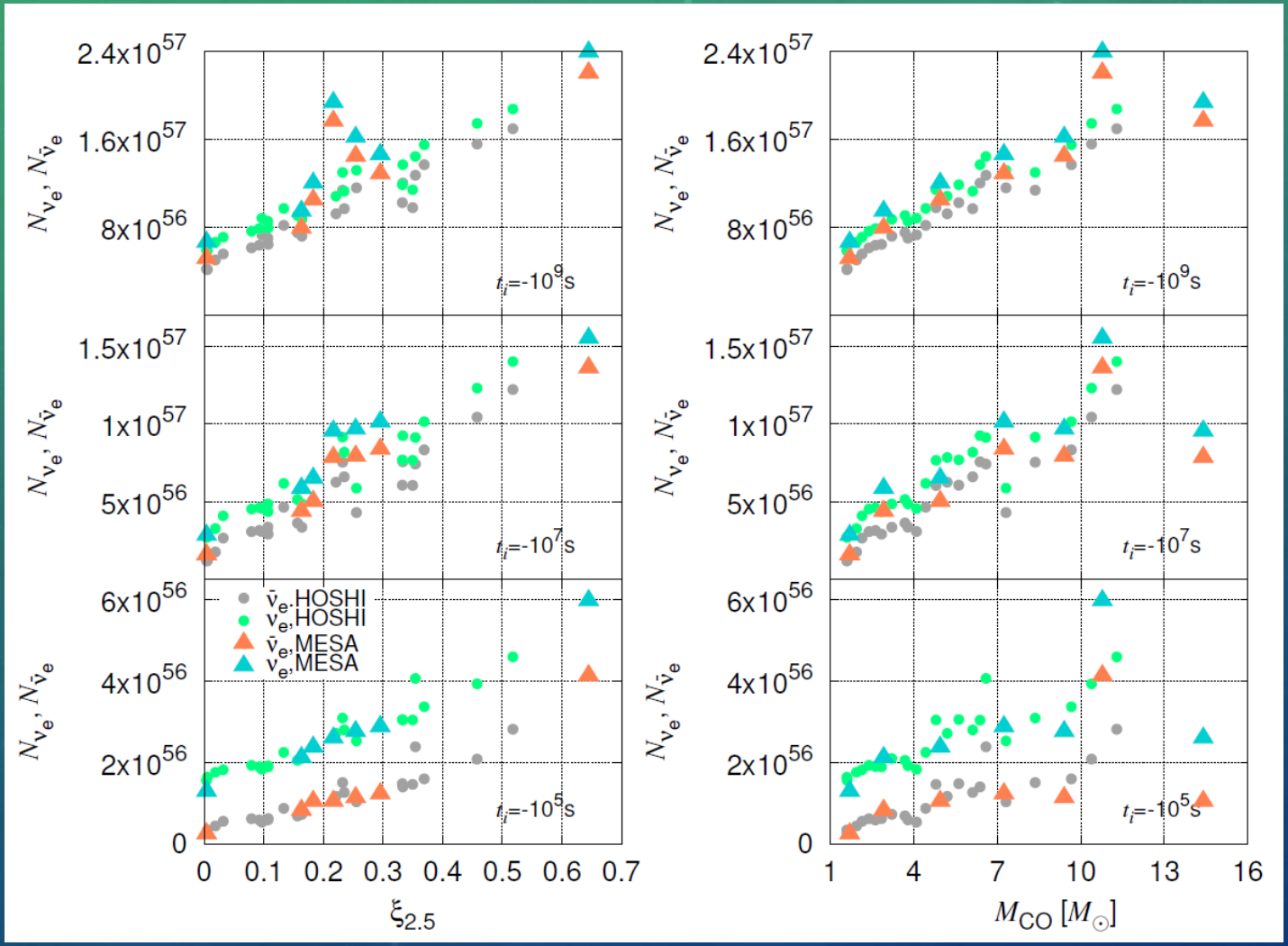


M_{co} type

$\xi_{2.5}$ type

@collapse

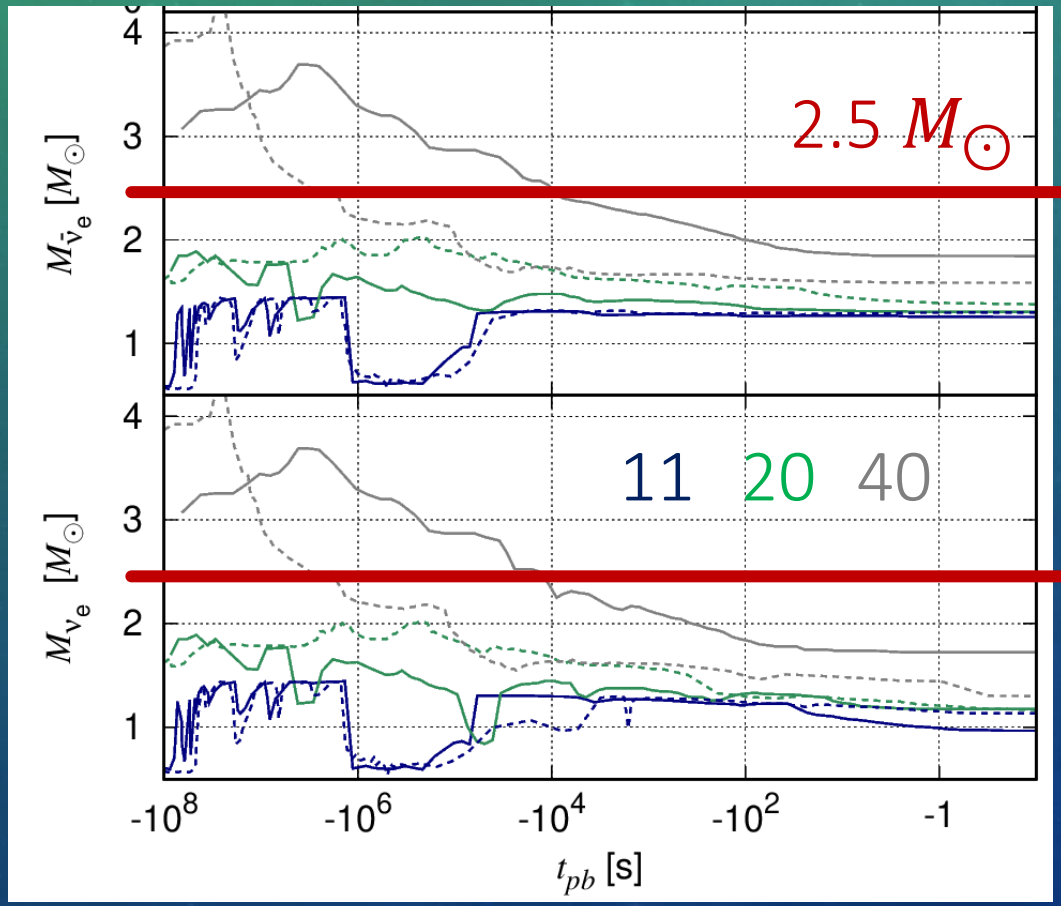
preSN ν vs Mco/$\xi_{2.5}$

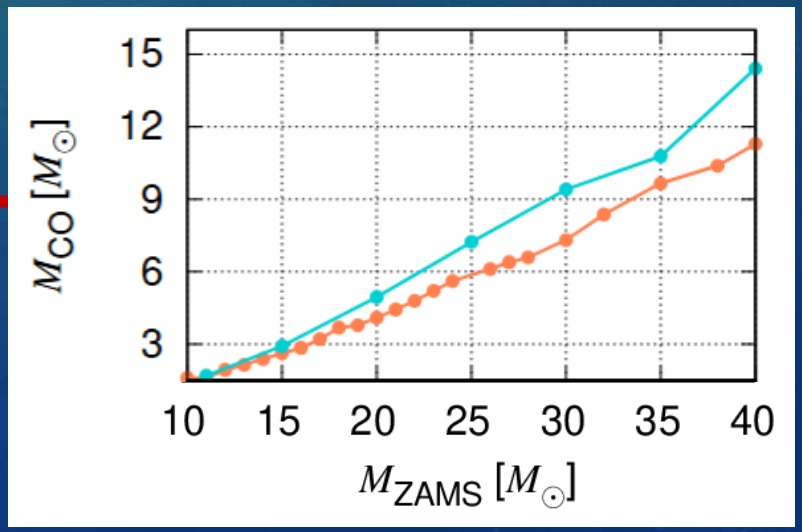


- ✓ $\xi_{2.5}$: neutrino emission just before core collapse
- ✓ M_{CO}: long-term neutrino emission

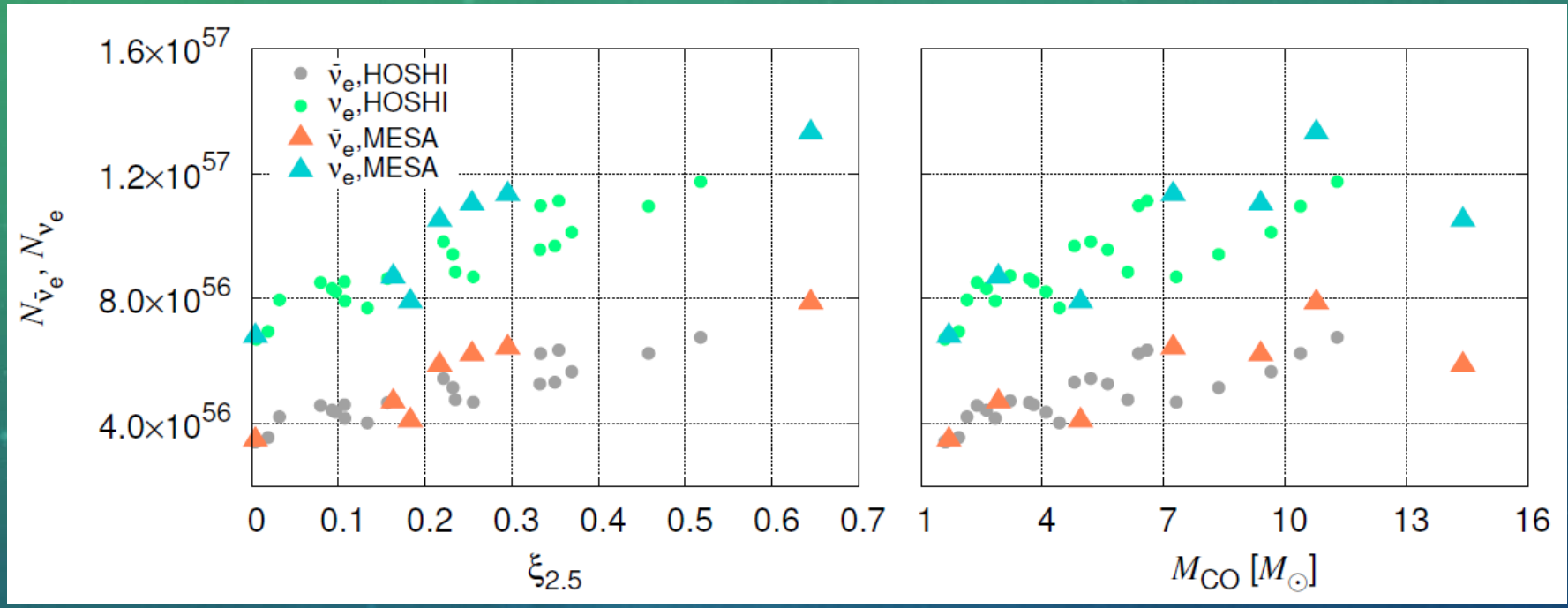
Neutrino emission region vs $M_{\rm CO}$ & $\xi_{2.5}$

- ✓ ν emission region: M_{ν_e}, $M_{\bar{\nu}_e}$
- ✓ $M_{\nu} \sim M_{\rm CO}/\,\xi_{2.5}$ ➡ strong correlation





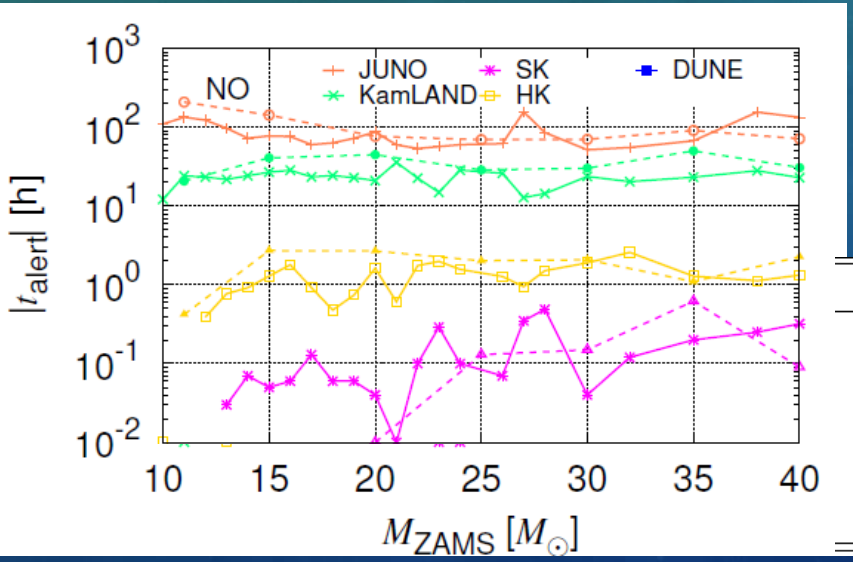
Early-SN ν vs Mco/$\xi_{2.5}$



- ✓ $\xi_{2.5}$ correlation: strong
- ✓ M_{CO} correlation: weak

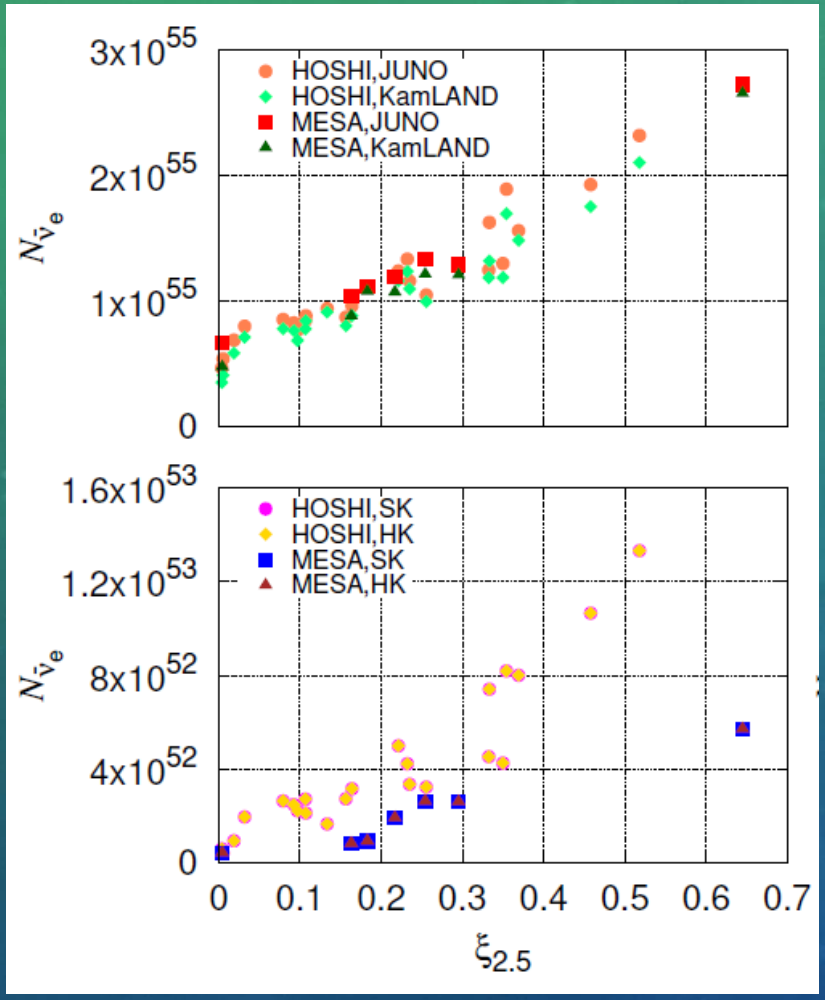
In practical scenarios

- ✓ For practical observations
  neutrino oscillation / neutrino energy threshold / first detection time (alert time)
- ✓ alert time estimation: False Alarm Method
  time window: 24h, FAR: 10/yr, distance: 200pc

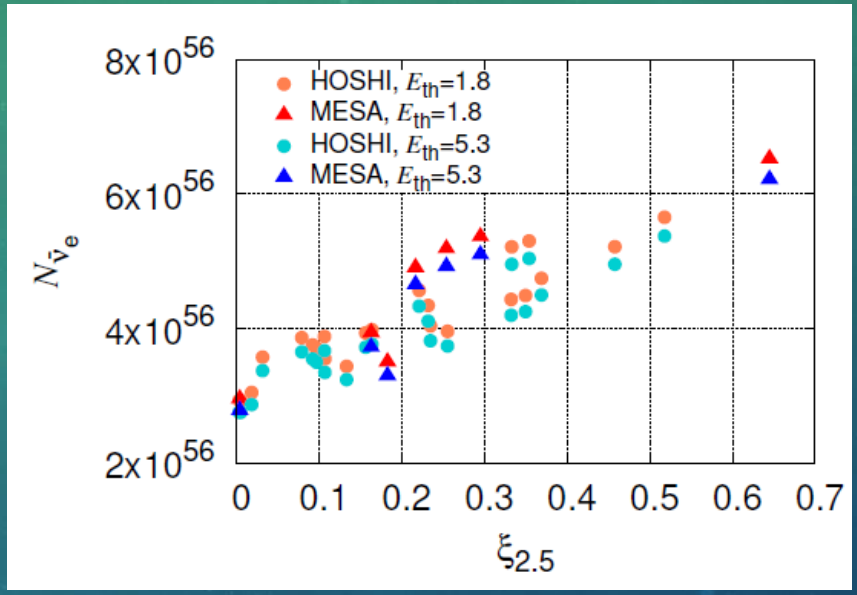


Detector	volume [kt]	energy threshold (E_{th}) [MeV]	BG [day^{-1}]
SK	32	5.3	25
HK	260	5.3	200
KamLAND	1	1.8	0.1
JUNO	20	1.8	20
DUNE	70	8	200

Correlations persist under practical conditions



preSN

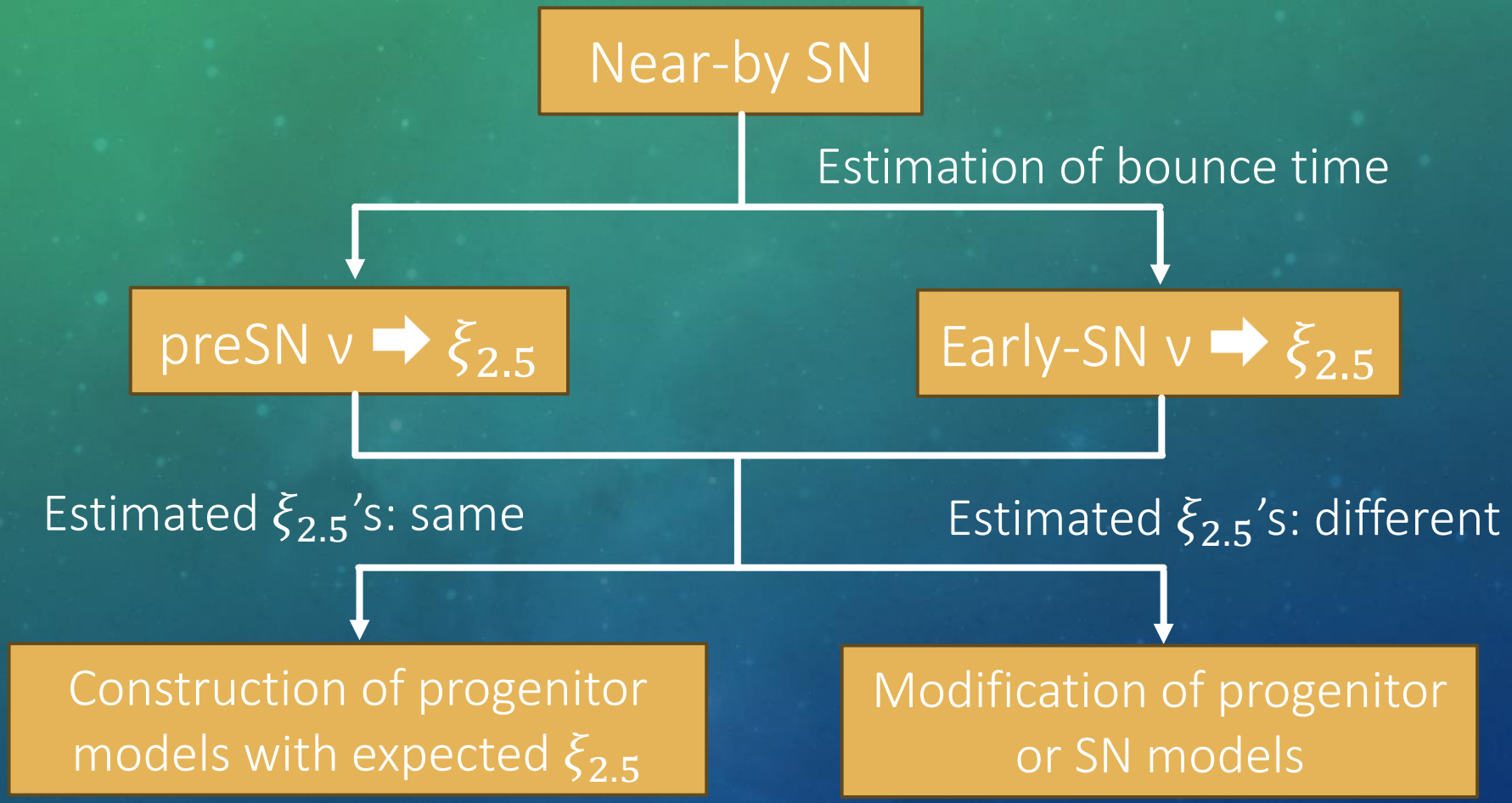


Early-SN

※ We assume the total number of neutrinos can be fully reconstructed

➡ future detailed discussion

Synergy of preSN/SN ν observations



Independent estimation by preSN and SN ν observations

➡ better feedback for progenitor & SN models!

Summary & Future works

✓Uncertainties in advanced stages of progenitor models

➡ long-term observations of preSN/SN neutrinos for near-by progenitors

✓To calculate neutrino luminosities and spectra from preSN to early-SN phases systematically

✓ $\xi_{2.5}$ correlates with neutrino emission both with late stellar evolutionary stages and early-SN phases

➡ better observational feedbacks for progenitor models

Do correlations persist

✓ if physics and numerical inputs for stellar evolution calculations are changed?

✓ if more realistic discussion for neutrino observations?