Hubble 2017 [1]

Predicting The Diffuse Supernova Neutrino Background

Andrew Caruso

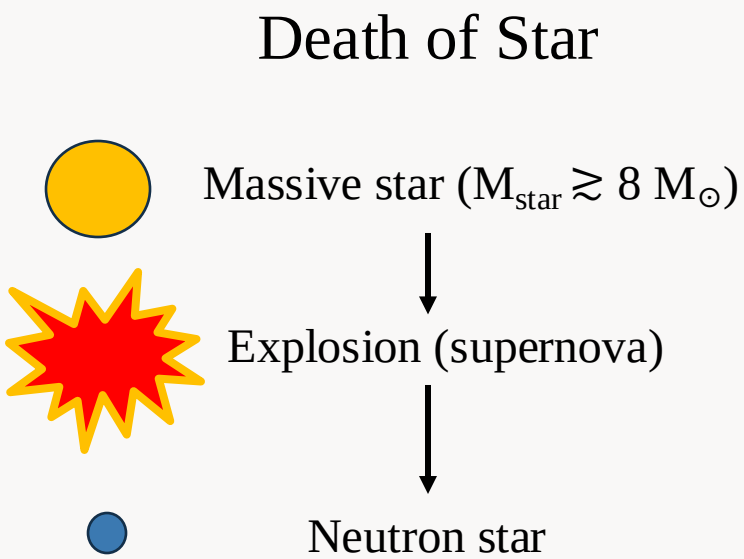
In Collaboration with Shunsaku Horiuchi, Volodymyr Takhistov, & Tomoya Kinugawa

VIRGINIA TECH

Center for Neutrino Physics Day

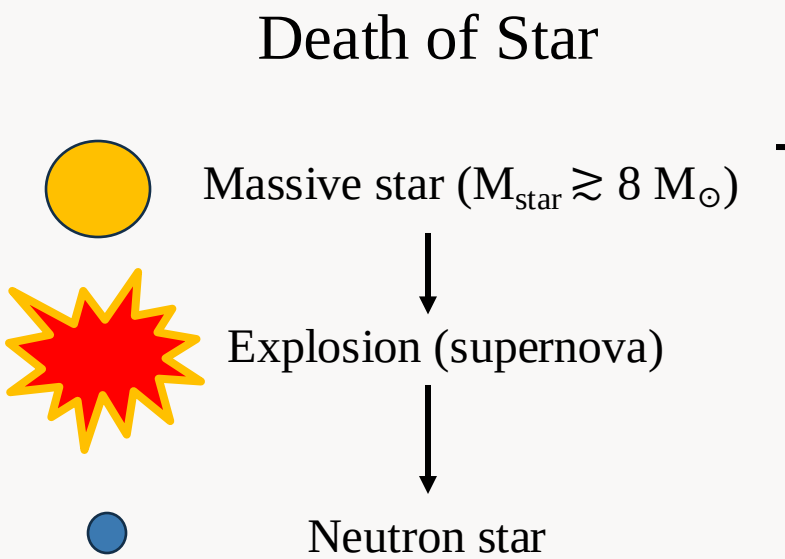
December 13, 2024

Core-collapse Supernovae



Andrew
Caruso

Core-collapse Supernovae



Lots of neutrinos and some photons

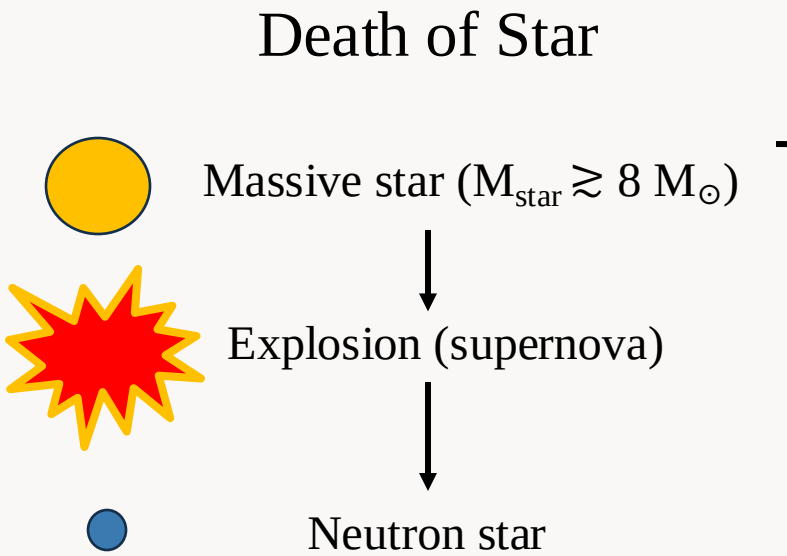
Neutrinos luminosity ~ Photon luminosity x 10^6

Outshine entire visible universe!

Carry away ~10^{53} erg (99% of gravitational binding energy)

Andrew Caruso

Core-collapse Supernovae



Lots of neutrinos and some photons

Neutrinos luminosity ~ Photon luminosity x 10^6

Outshine entire visible universe!

Carry away ~10^{53} erg (99% of gravitational binding energy)

Have we detected supernova neutrinos?

Supernova Neutrino Detection

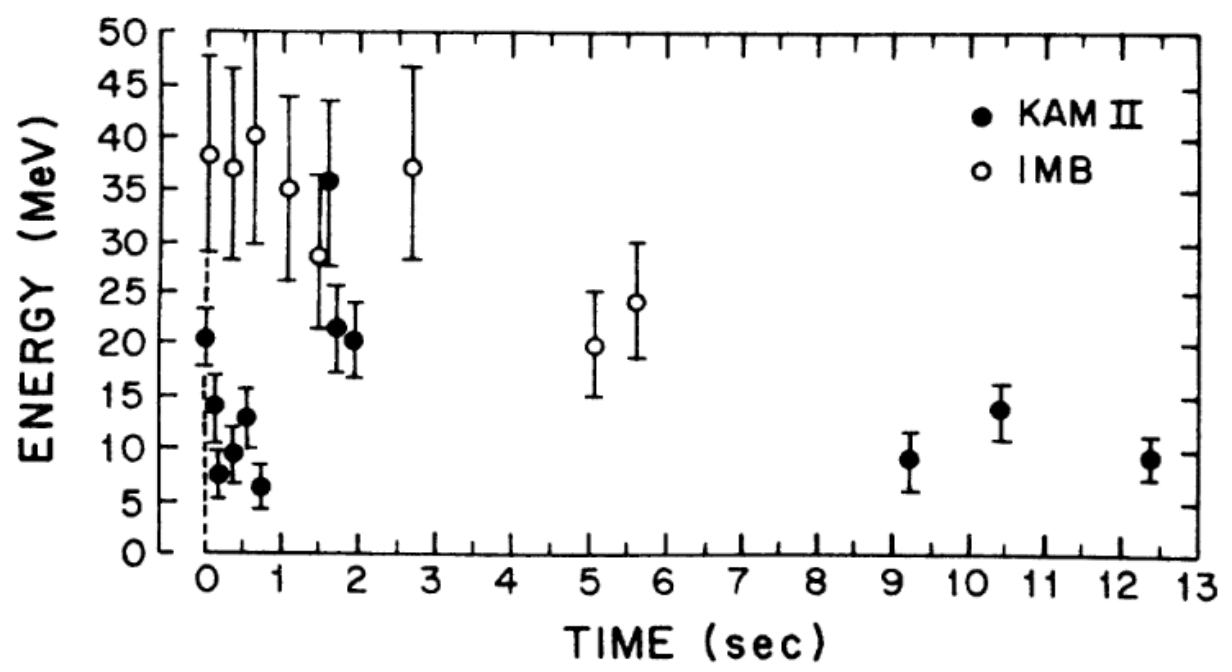
Yes!

Supernova Neutrino Detection

Yes!

SN1987a

- 55 kpc away from Large Magellanic Cloud
- 12 events at Kamiokande-II
- 8 events at Irvine-Michigan-Brookhaven



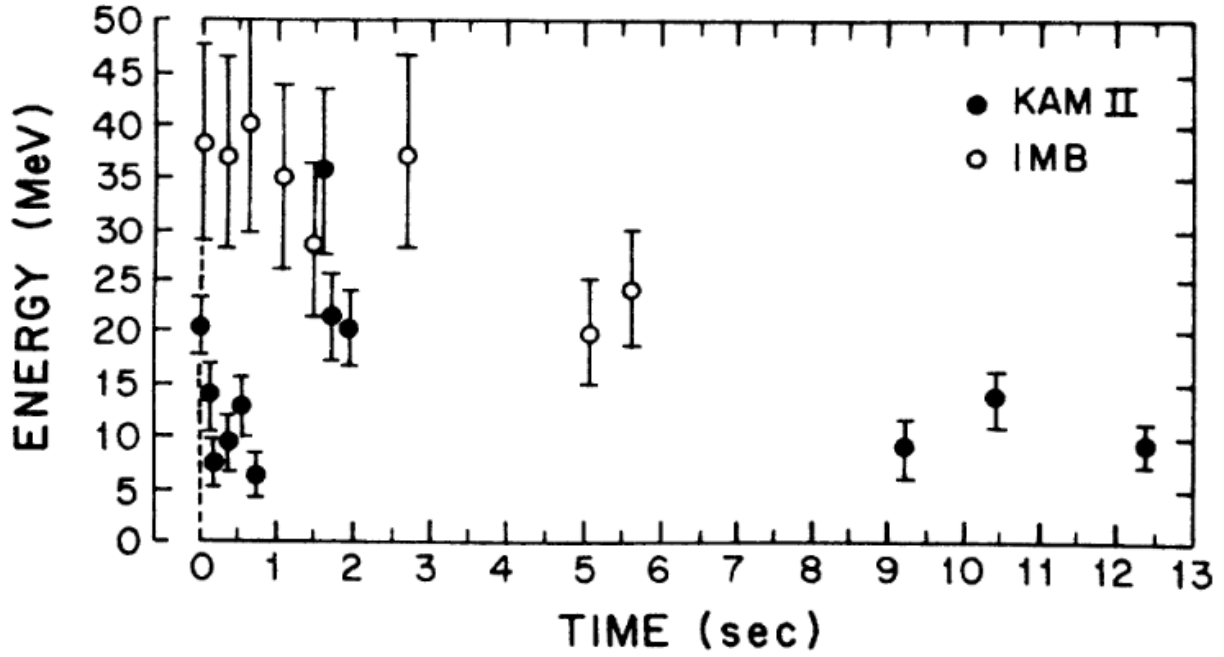
Hirata et al. 1988 [2]

Supernova Neutrino Detection

Yes!

SN1987a

- 55 kpc away from Large Magellanic Cloud
- 12 events at Kamiokande-II
- 8 events at Irvine-Michigan-Brookhaven



Hirata et al. 1988 [2]

Confirms average neutrino energy ~15 MeV for total energy ~3×10^{53} erg

But there is a slight issue…

Issue and Resolution

We have not detected supernova neutrinos ever since then!

- Predicted **local** rate of supernova: ~1-2 per century
- Supernova yields neutrinos

Issue and Resolution

We have not detected supernova neutrinos ever since then!

- Predicted **local** rate of supernova: ~1-2 per century
- Supernova yields neutrinos

Solution:

Look at **ALL** supernovae in past → Diffuse Supernova Neutrino Background (DSNB)

Expected:

1. Exist
2. Isotropic
3. Time independent

Issue and Resolution

We have not detected supernova neutrinos ever since then!

- Predicted **local** rate of supernova: ~1-2 per century
- Supernova yields neutrinos

Solution:

Look at **ALL** supernovae in past → Diffuse Supernova Neutrino Background (DSNB)

Expected:

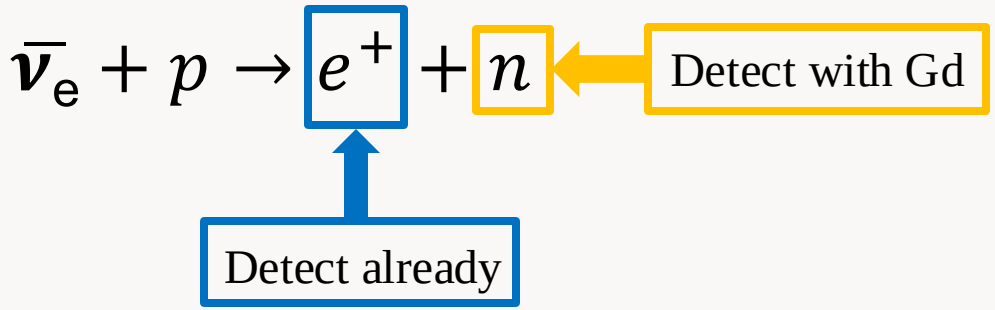
1. Exist
2. Isotropic
3. Time independent

Not yet detected but can we do it?

Hunt for the DSNB

Super-Kamiokande

- Water Cherenkov neutrino detector
- Gadolinium (Gd) doped water



Super-Kamiokande Collaboration 2021 [3]

Hunt for the DSNB

Super-Kamiokande

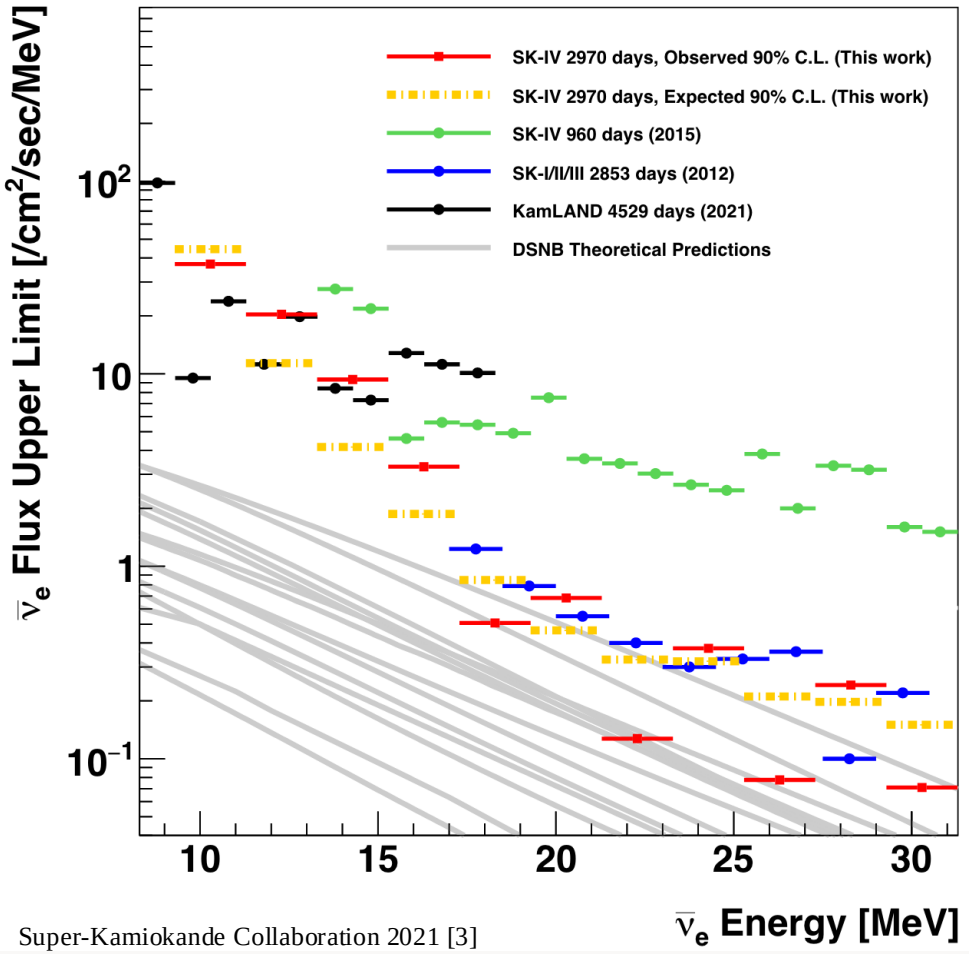
- Water Cherenkov neutrino detector
- Gadolinium (Gd) doped water

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Detect with Gd

Detect already

Already excluding some theoretical models!



Super-Kamiokande Collaboration 2021 [3]

Hunt for the DSNB

Super-Kamiokande

- Water Cherenkov neutrino detector
- Gadolinium (Gd) doped water

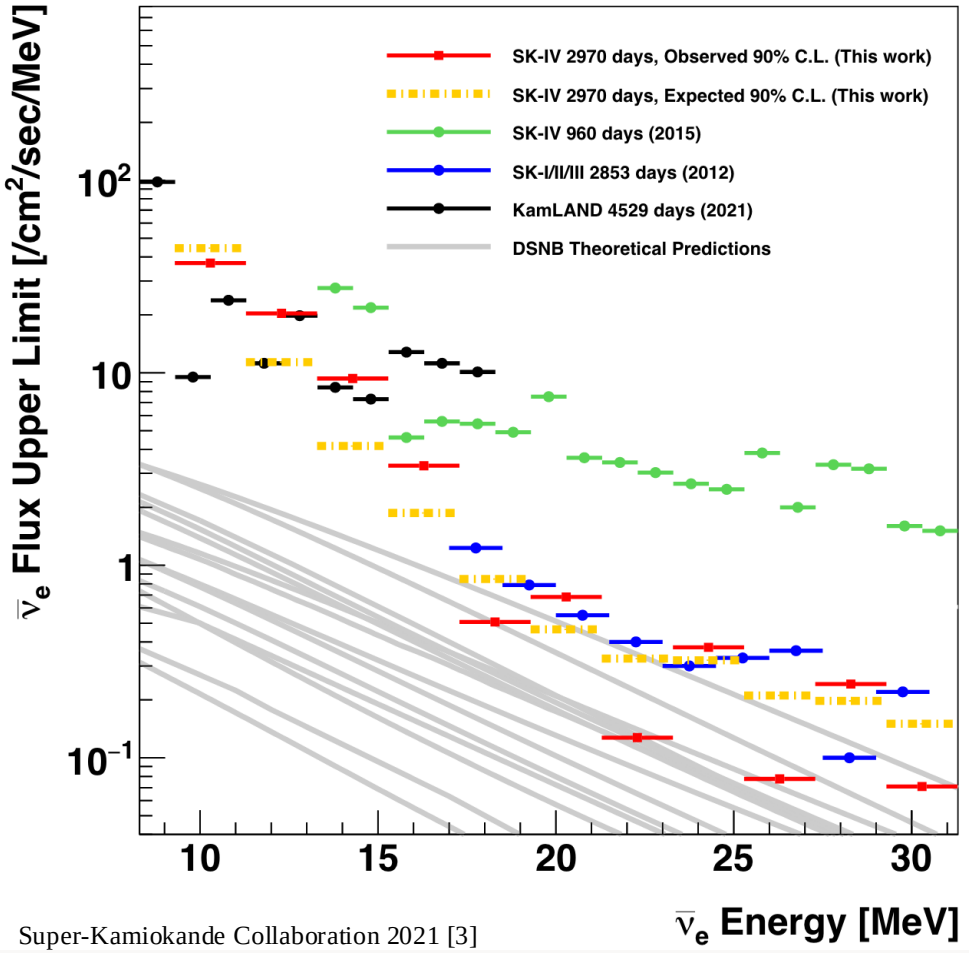
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Detect with Gd

Detect already

Already excluding some theoretical models!

But supernovae are NOT that simple.



Super-Kamiokande Collaboration 2021 [3]

Previous DSNB Prediction

Recent prediction by Horiuchi et al. 2021 [4]

- Included binary systems since most stars are in pairs

Previous DSNB Prediction

Recent prediction by Horiuchi et al. 2021 [4]

- Included binary systems since most stars are in pairs

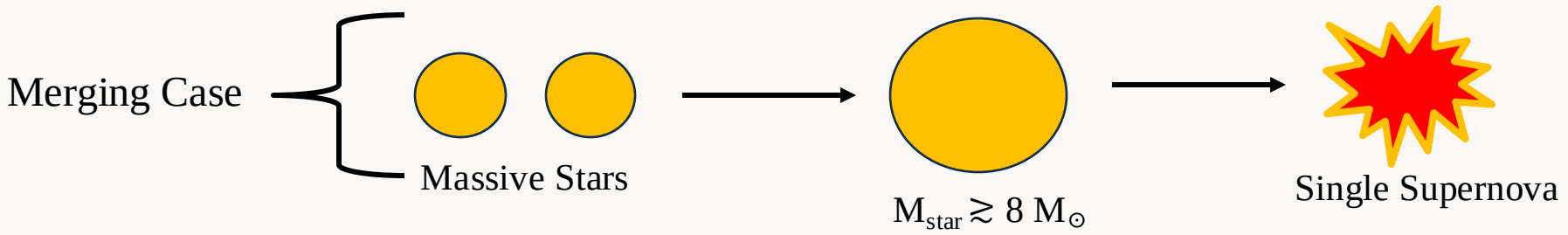
Merging Case

Non-merging Case

Previous DSNB Prediction

Recent prediction by Horiuchi et al. 2021 [4]

- Included binary systems since most stars are in pairs

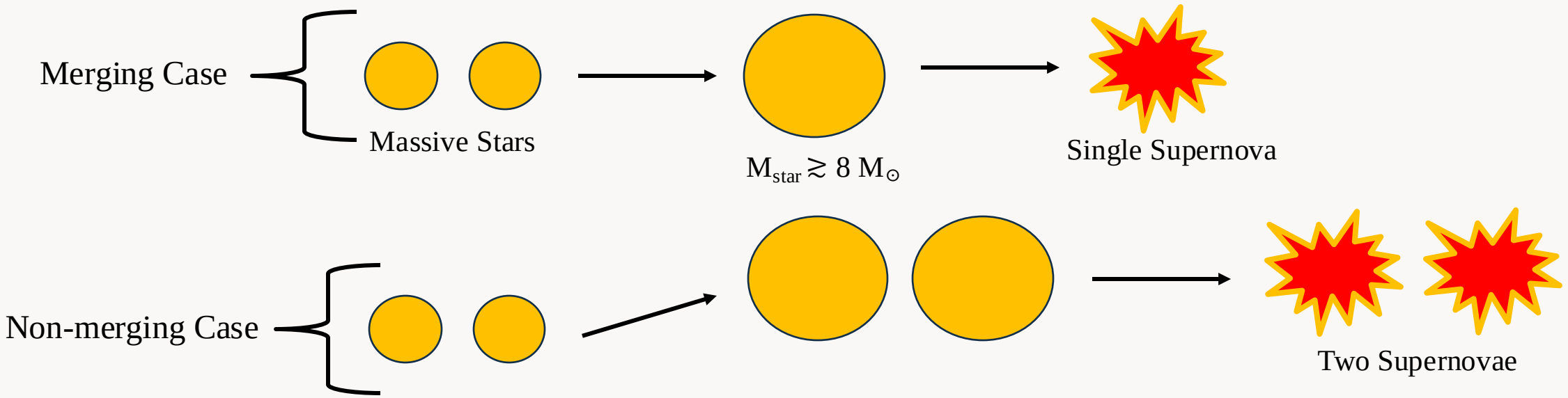


Non-merging Case

Previous DSNB Prediction

Recent prediction by Horiuchi et al. 2021 [4]

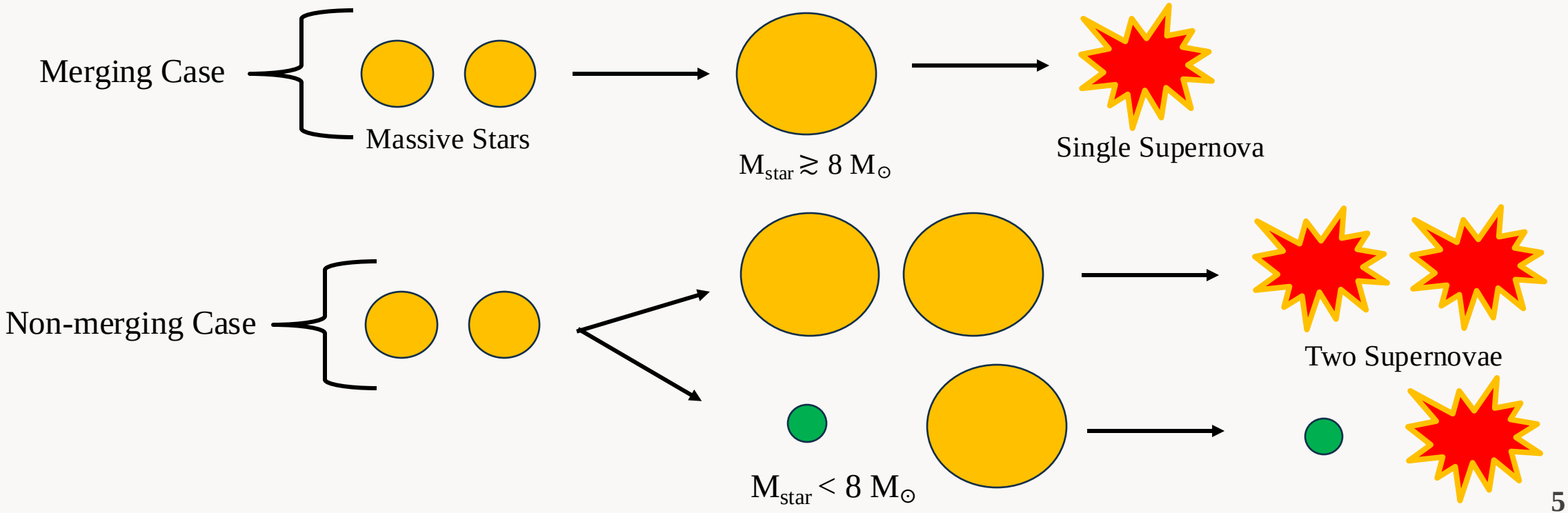
- Included binary systems since most stars are in pairs



Previous DSNB Prediction

Recent prediction by Horiuchi et al. 2021 [4]

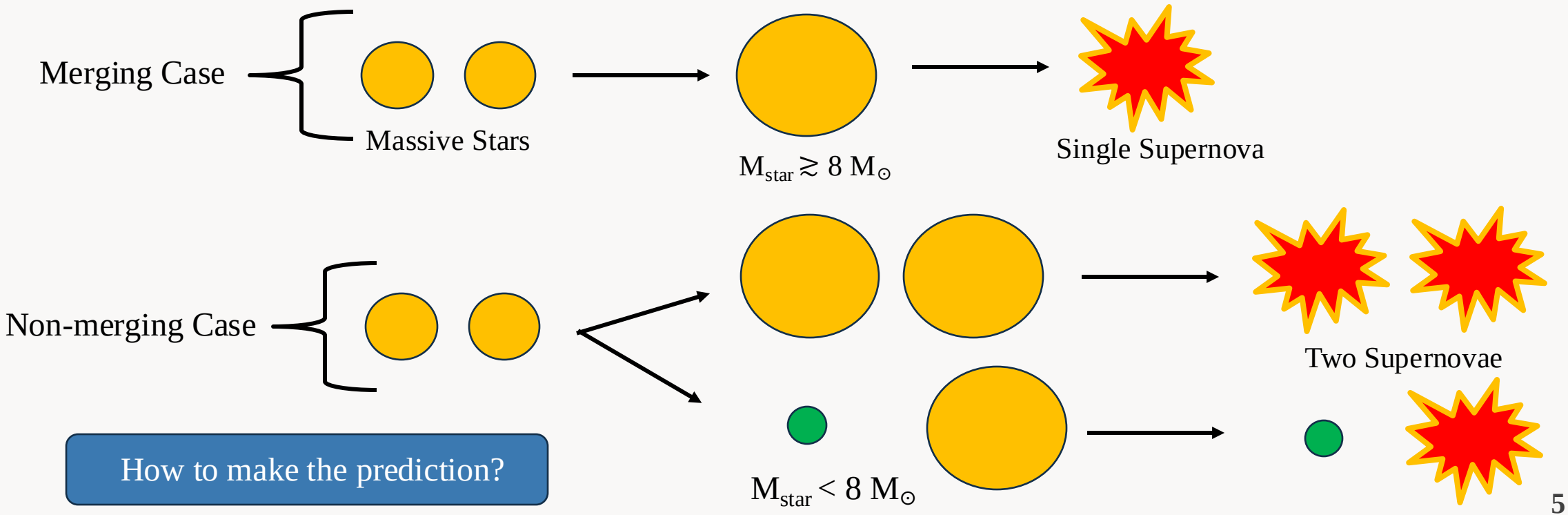
- Included binary systems since most stars are in pairs



Previous DSNB Prediction

Recent prediction by Horiuchi et al. 2021 [4]

- Included binary systems since most stars are in pairs



How to make the prediction?

Previous DSNB Prediction

By calculating the DSNB flux

Has three ingredients:

$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}\, dz$$

Previous DSNB Prediction

By calculating the DSNB flux

Has three ingredients:

$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}\, dz$$

Previous DSNB Prediction

By calculating the DSNB flux

Has three ingredients:

$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}\,dz$$

Supernova rate

Previous DSNB Prediction

By calculating the DSNB flux

Has three ingredients:

Neutrino spectrum

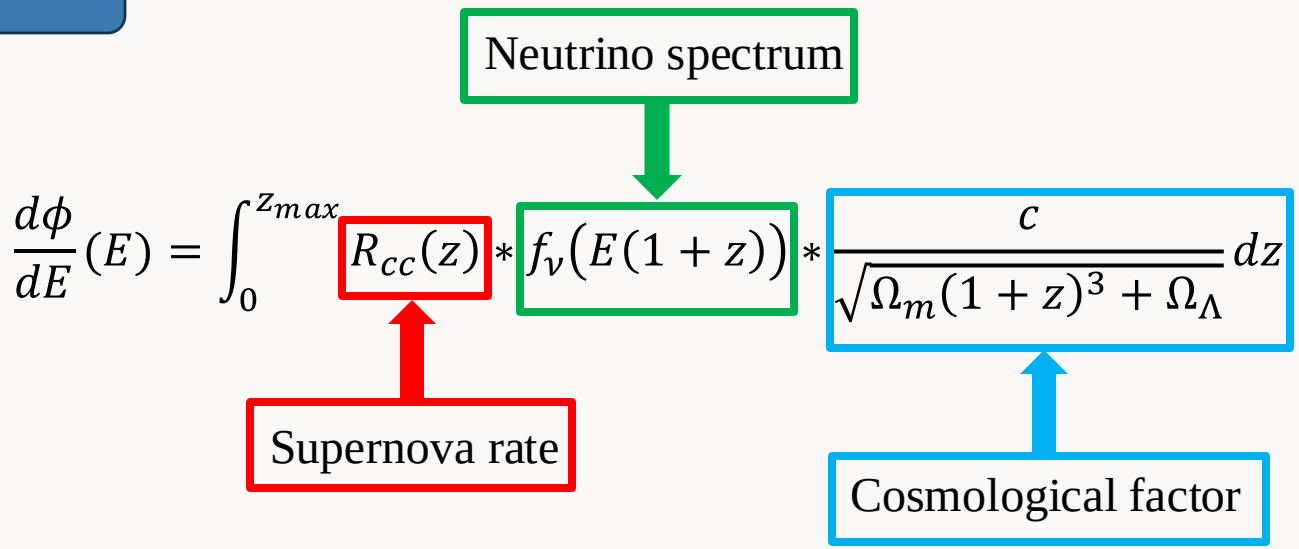
$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}\,dz$$

Supernova rate

Previous DSNB Prediction

By calculating the DSNB flux

Has three ingredients:



Previous DSNB Prediction

By calculating the DSNB flux

Has three ingredients:

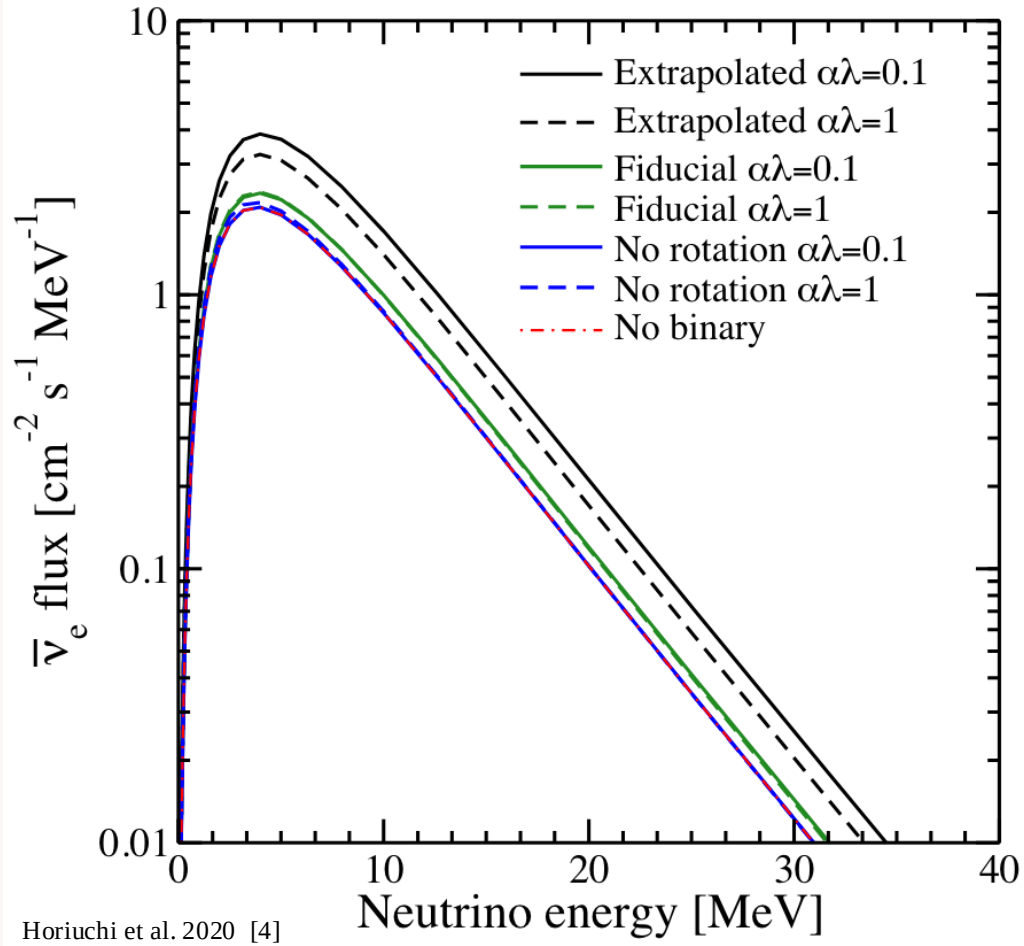
Neutrino spectrum

$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}} dz$$

Incorporate binary populations into average neutrino spectrum

Previous DSNB Prediction

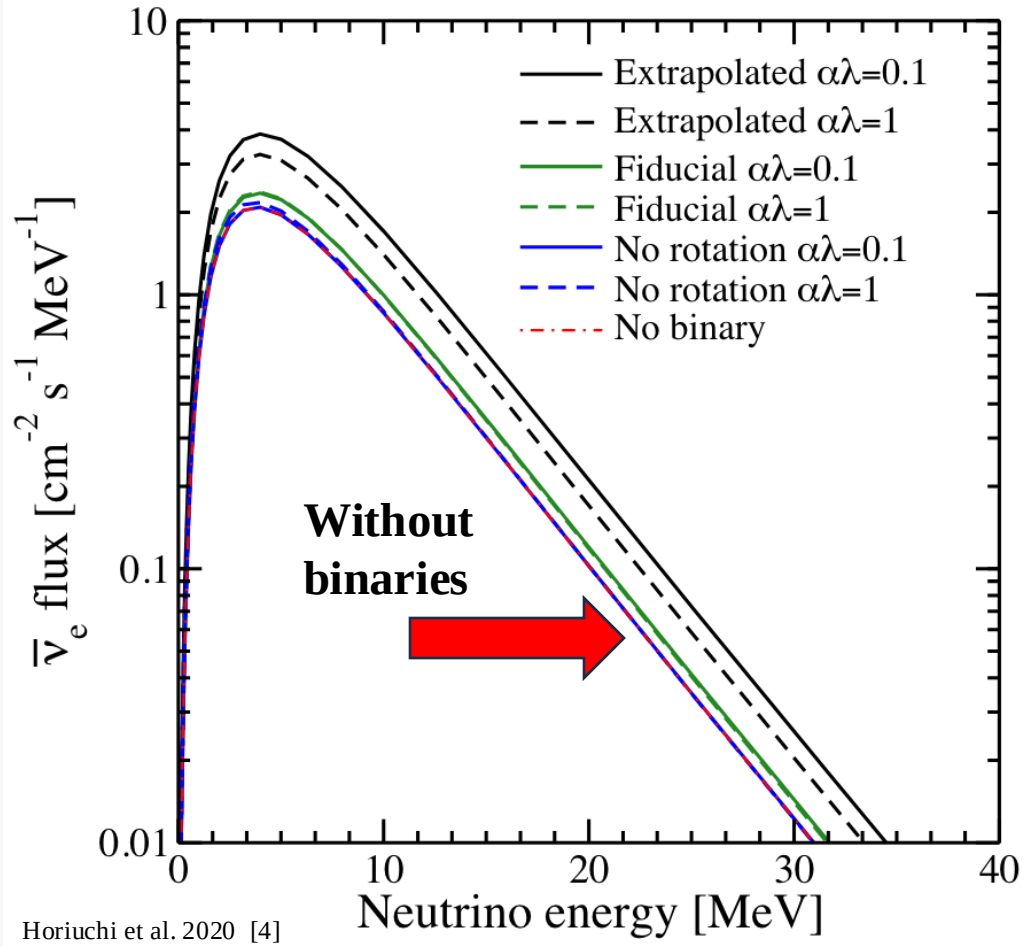
DSNB flux from $\bar{\nu}_e$



Horiuchi et al. 2020 [4]

Previous DSNB Prediction

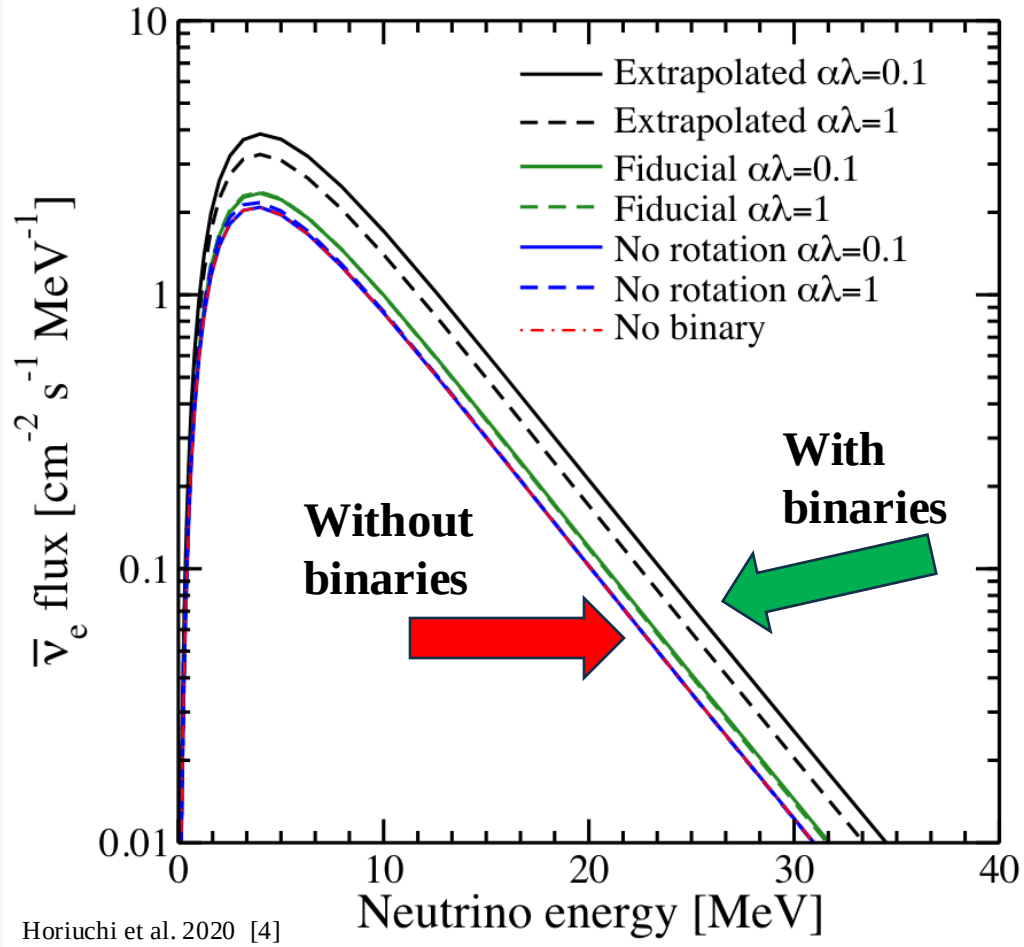
DSNB flux from $\bar{\nu}_e$



Horiuchi et al. 2020 [4]

Previous DSNB Prediction

DSNB flux from $\bar{\nu}_e$

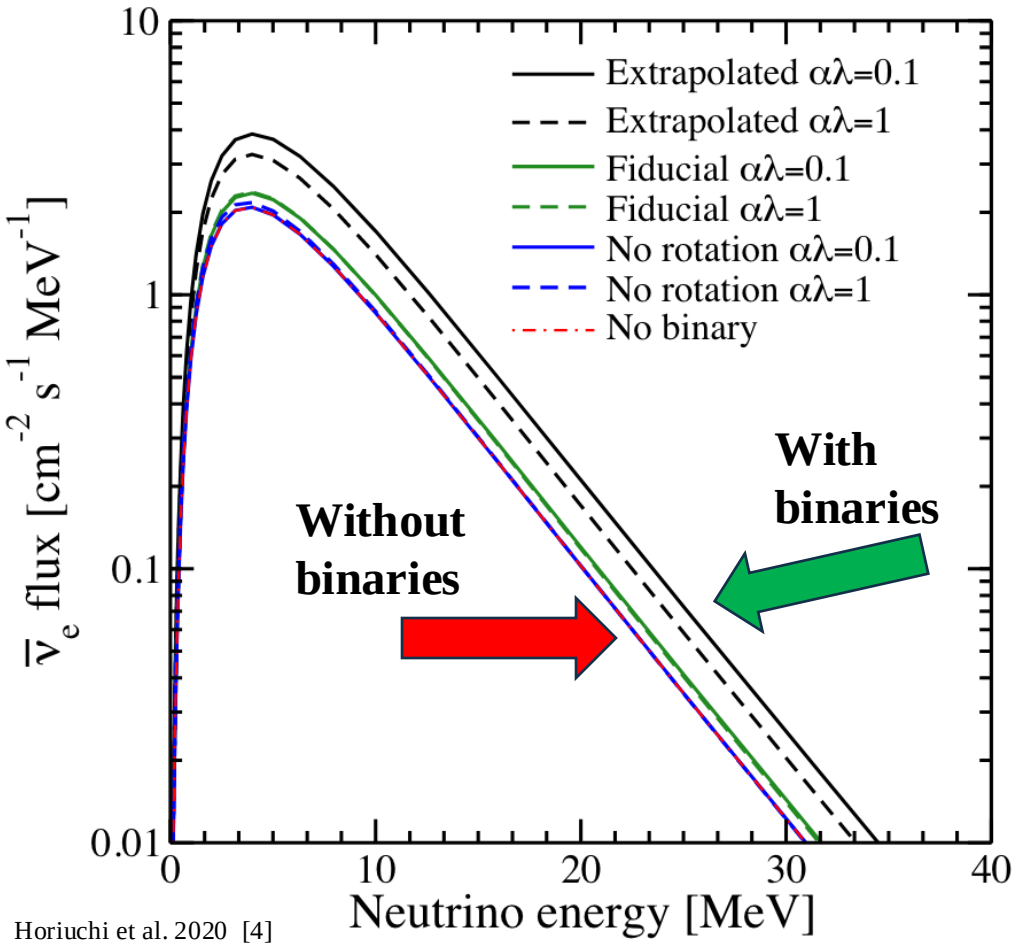


Horiuchi et al. 2020 [4]

Previous DSNB Prediction

DSNB flux from $\bar{\nu}_e$

With binaries DSNB flux increases

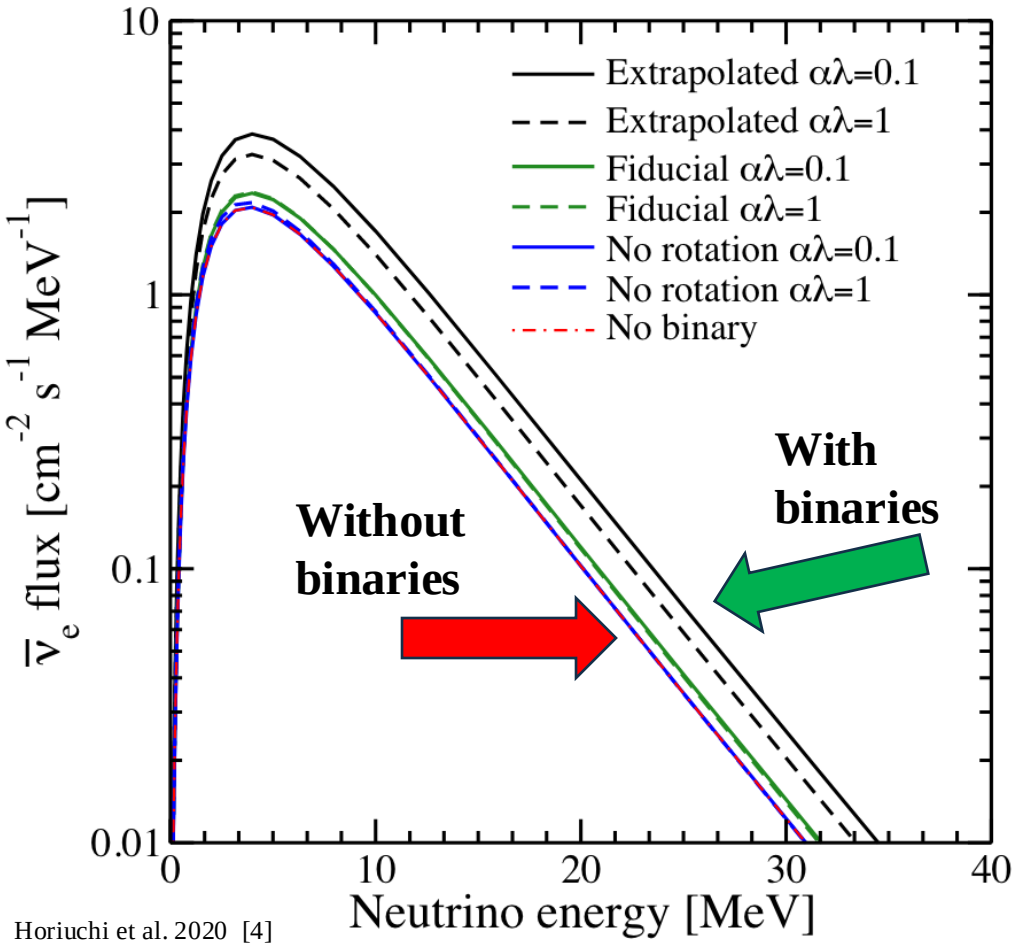


Horiuchi et al. 2020 [4]

Previous DSNB Prediction

DSNB flux from $\bar{\nu}_e$

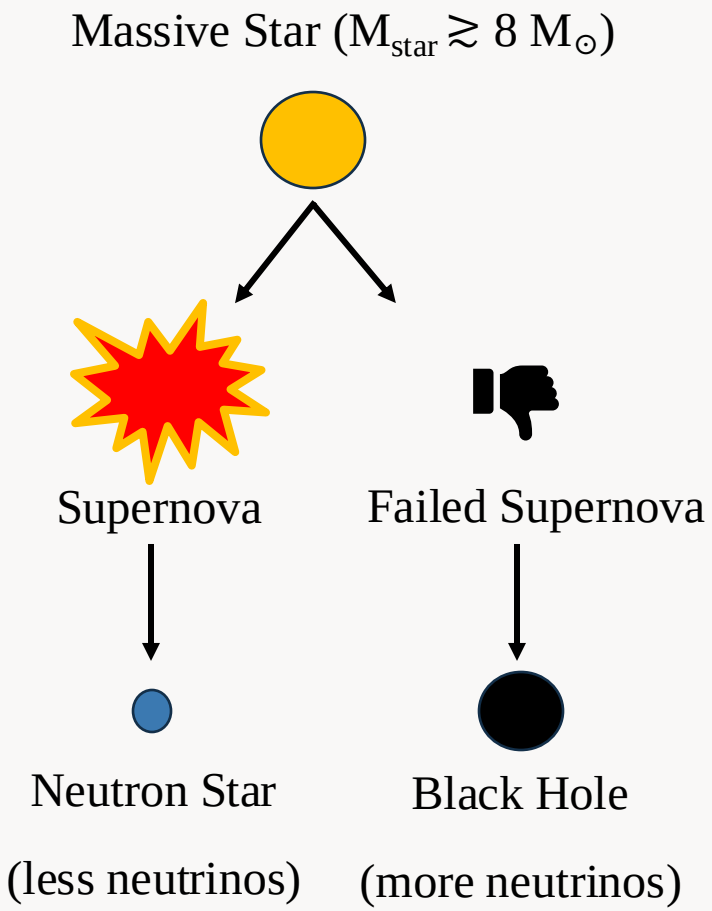
With binaries DSNB flux increases



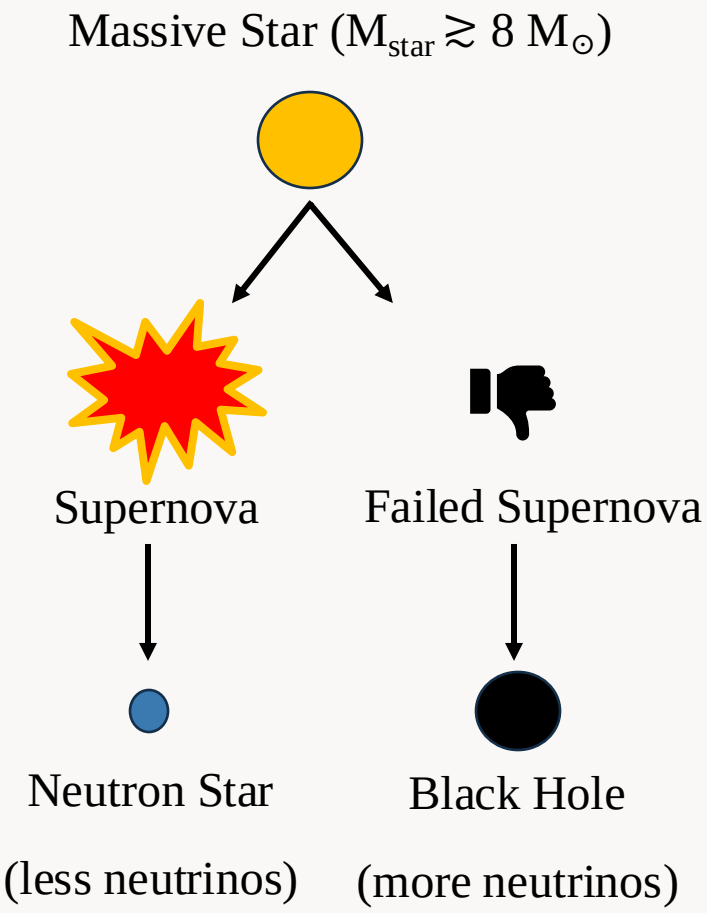
Horiuchi et al. 2020 [4]

What if black holes form instead of neutron star?

Core-collapse Supernovae Evolution III



Core-collapse Supernovae Evolution III

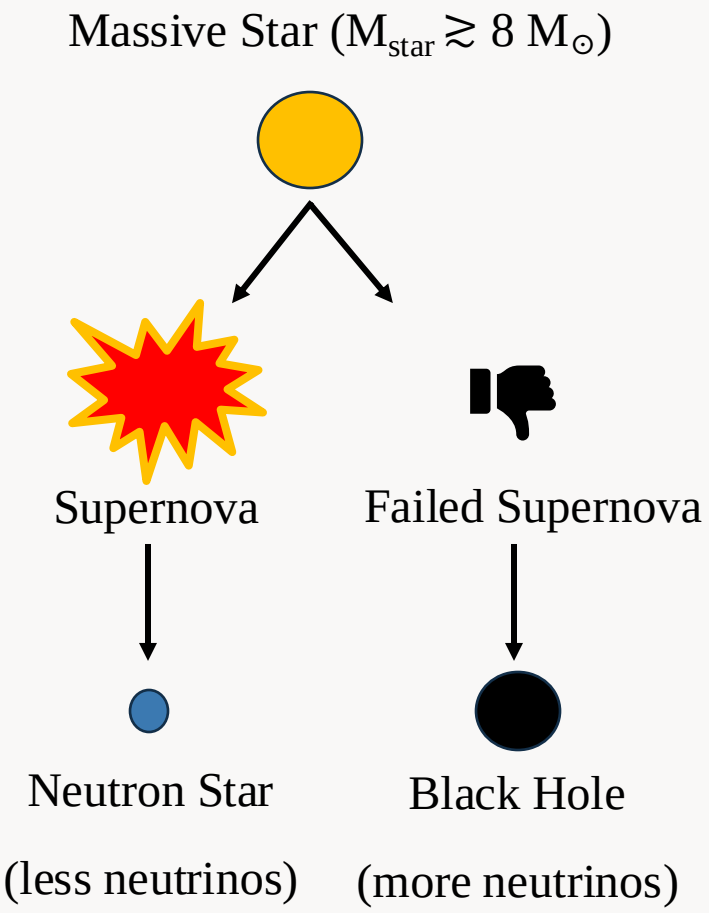


Can include with binaries for new prediction

via the average neutrino spectrum

$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}\,dz$$

Core-collapse Supernovae Evolution III



Can include with binaries for new prediction via the average neutrino spectrum

$$\frac{d\phi}{dE}(E) = \int_0^{z_{max}} R_{cc}(z) * f_\nu\big(E(1+z)\big) * \frac{c}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}\,dz$$

But we do not know how many supernovae form black holes vs neutron stars?

Current Project

Use two sets of simulated data:

Supernova simulations

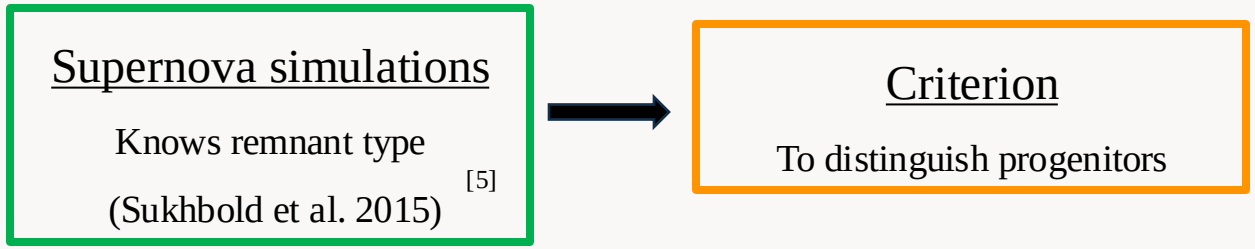
Knows remnant type

(Sukhbold et al. 2015) [5]

[4]

Current Project

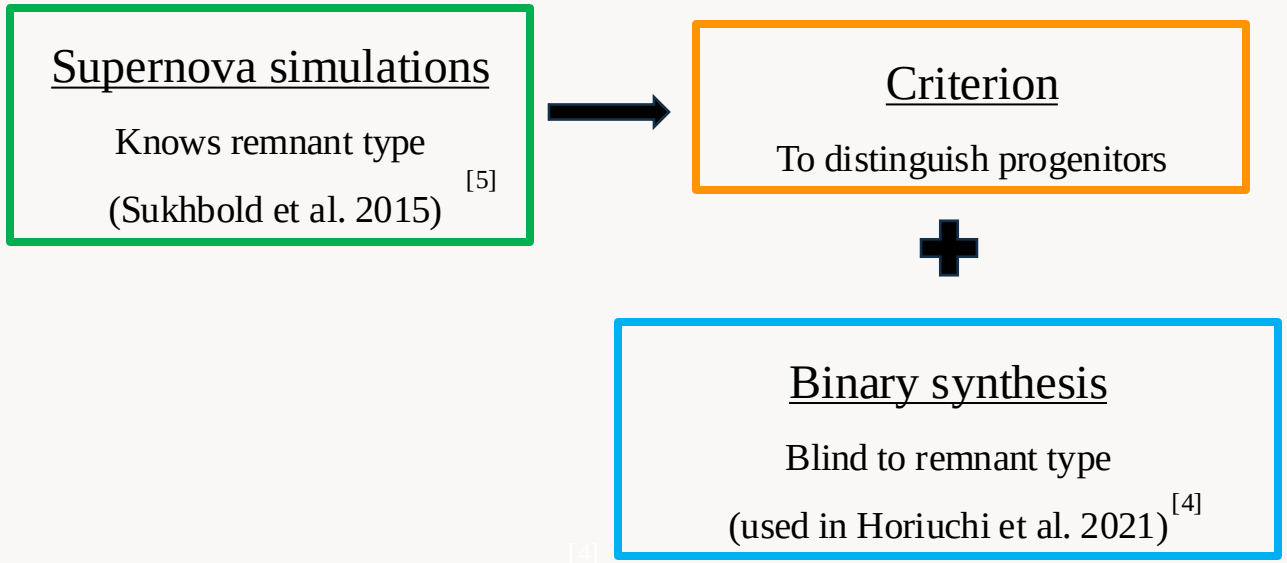
Use two sets of simulated data:



[4]

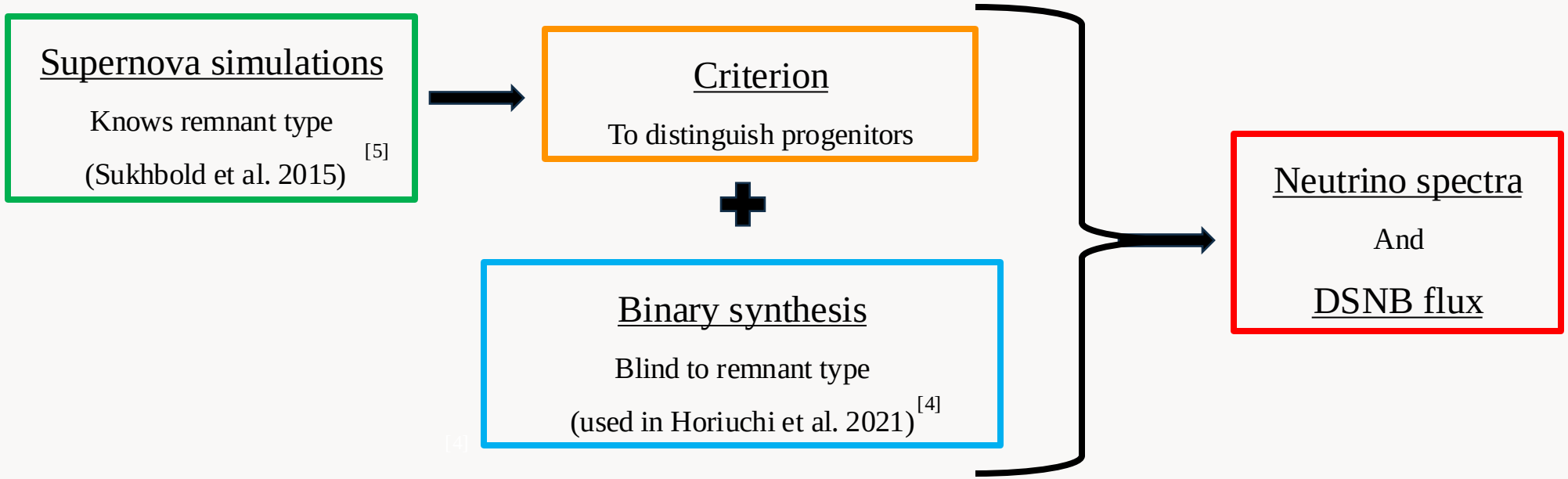
Current Project

Use two sets of simulated data:



Current Project

Use two sets of simulated data:



Current Project

Preliminary result (not at Earth):

Criterion:

Progenitors with M_{co} {
- $> 5\ M_{\odot}$ form black hole
- $\leq 5\ M_{\odot}$ form neutron star

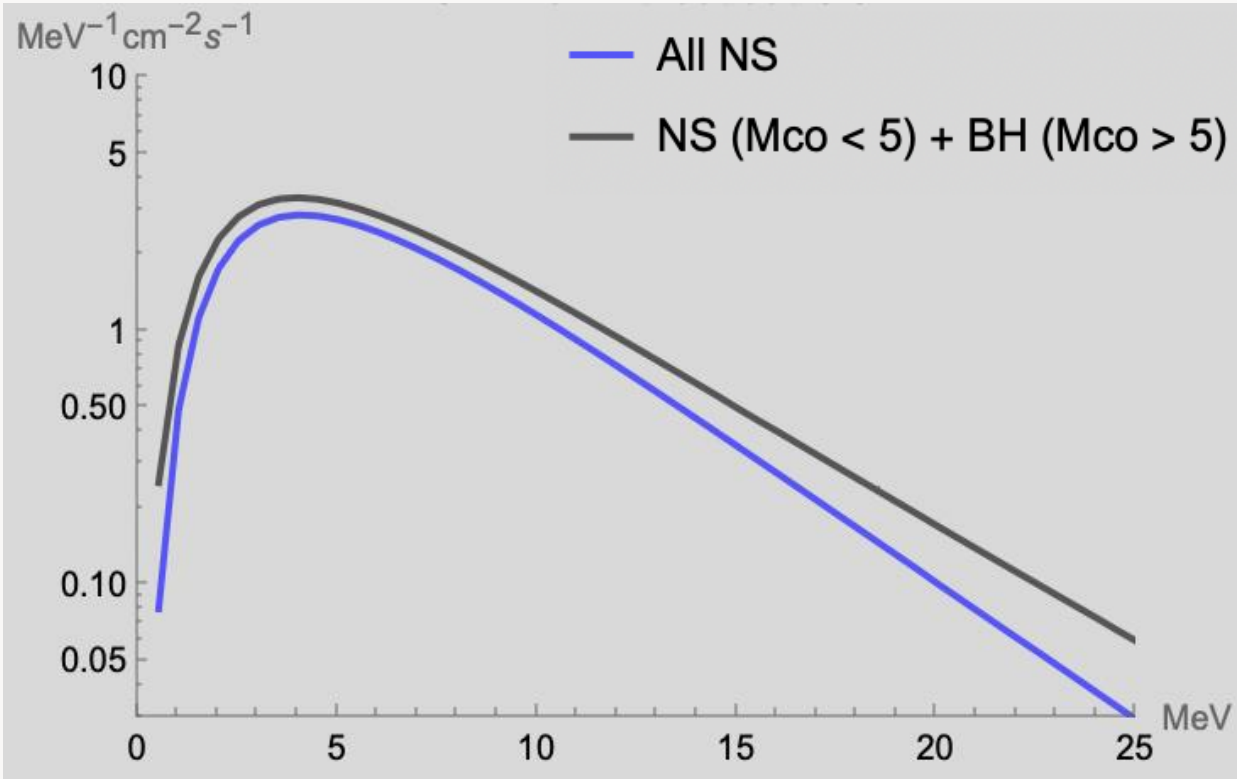
[4]

Current Project

Preliminary result (not at Earth):

Criterion:

Progenitors with M_{co} { $> 5\ M_{\odot}$ form black hole ; $\leq 5\ M_{\odot}$ form neutron star



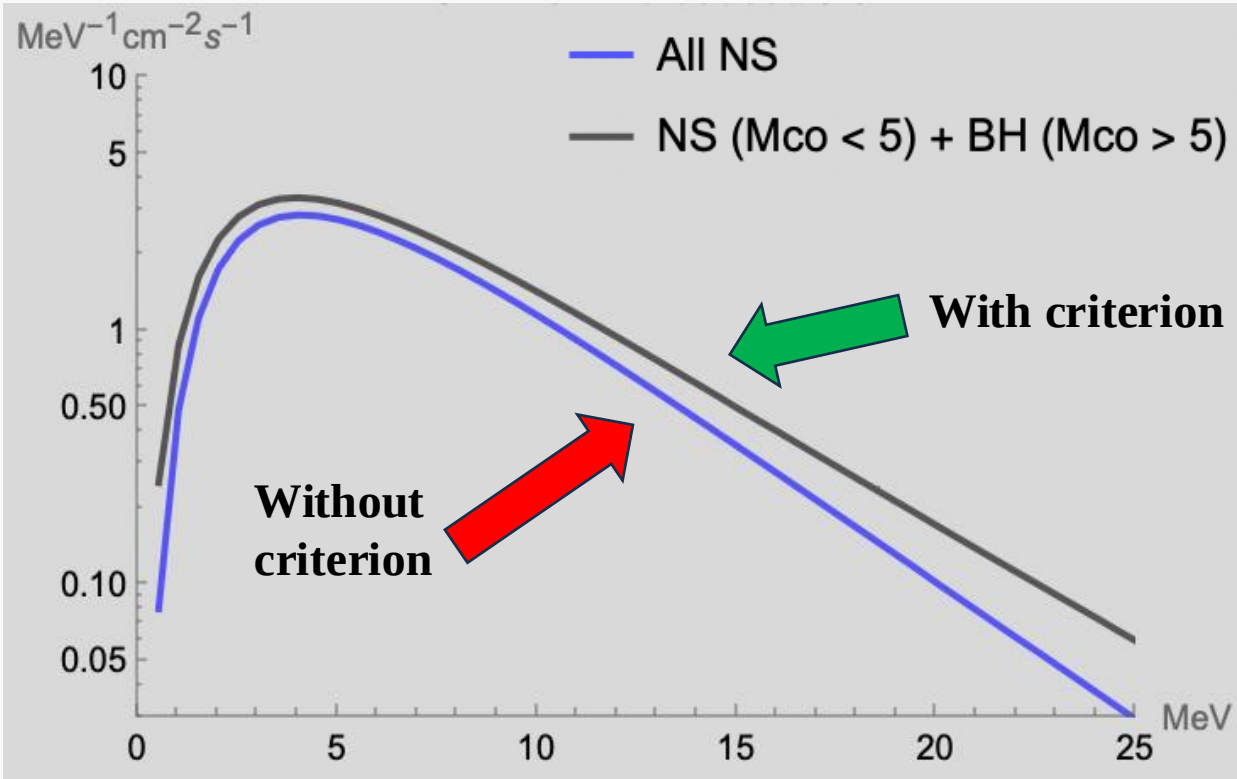
[4]

Current Project

Preliminary result (not at Earth):

Criterion:

Progenitors with M_{co} { $> 5\ M_{\odot}$ form black hole ; $\leq 5\ M_{\odot}$ form neutron star



[4]

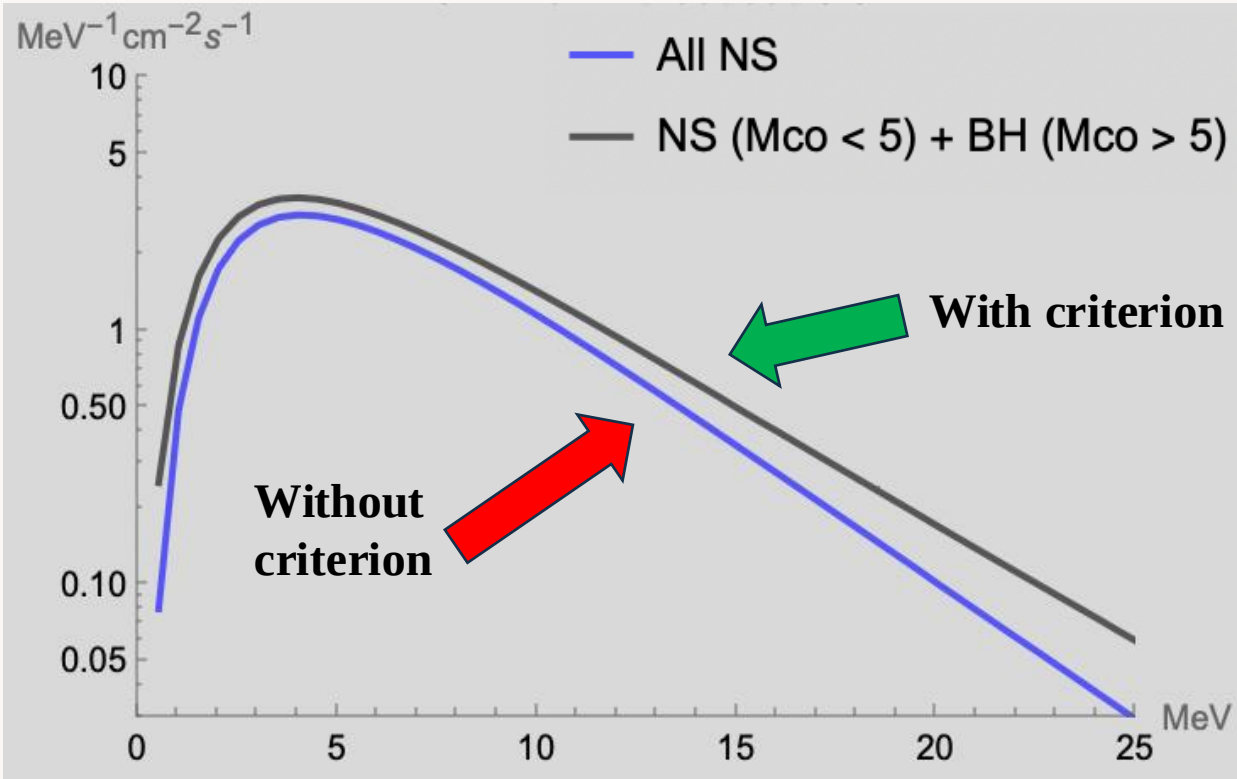
Current Project

Preliminary result (not at Earth):

Criterion:

Progenitors with M_{co} { $> 5\ M_{\odot}$ form black hole ; $\leq 5\ M_{\odot}$ form neutron star

Inclusion of black hole formation with binary population may increase DSNB flux



SUMMARY

SUMMARY

1. The diffuse supernova neutrino background is worth the search

SUMMARY

1. The diffuse supernova neutrino background is worth the search

2. Better theoretical predictions are necessary

SUMMARY

1. The diffuse supernova neutrino background is worth the search

2. Better theoretical predictions are necessary

3. On verge of discovery of the DSNB

SUMMARY

1. The diffuse supernova neutrino background is worth the search

2. Better theoretical predictions are necessary

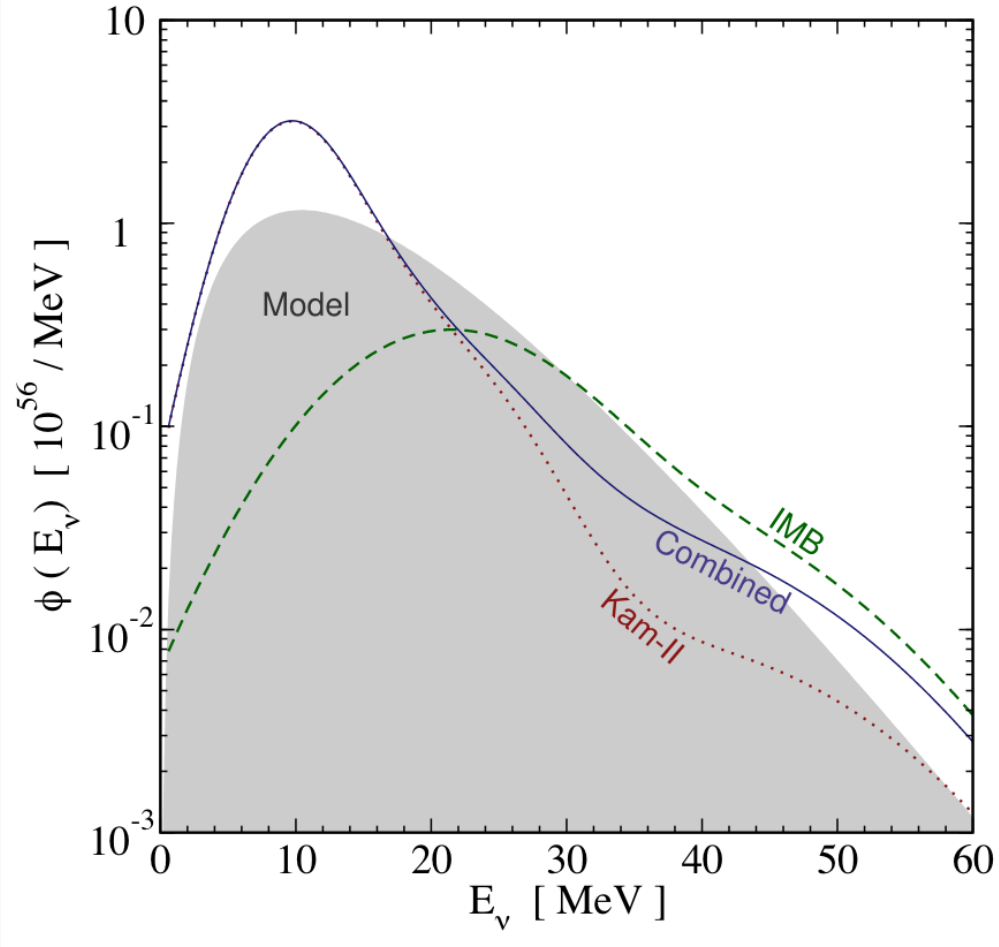
3. On verge of discovery of the DSNB

Questions?

Supernova Neutrino Detect (EXTRA)

Model assumes:

1. Fermi-Dirac spectrum
2. Neutrino energy = 15 MeV
3. Time integrated Luminosity = 5×10^{52} erg

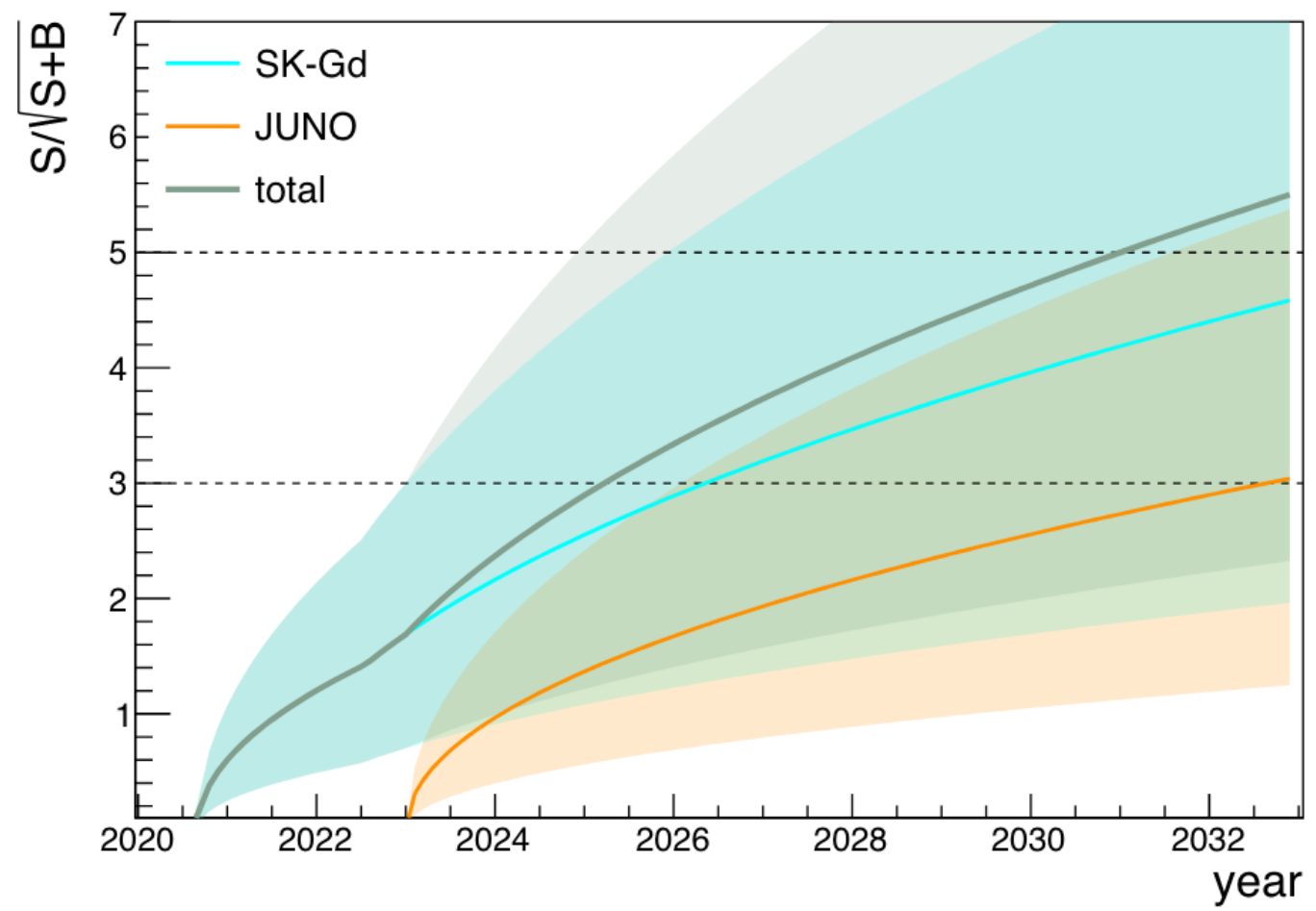


Yüksel & Beacom 2007 [a]

Hunt for the DSNB (EXTRA)

Reach ~5σ by 2030s with

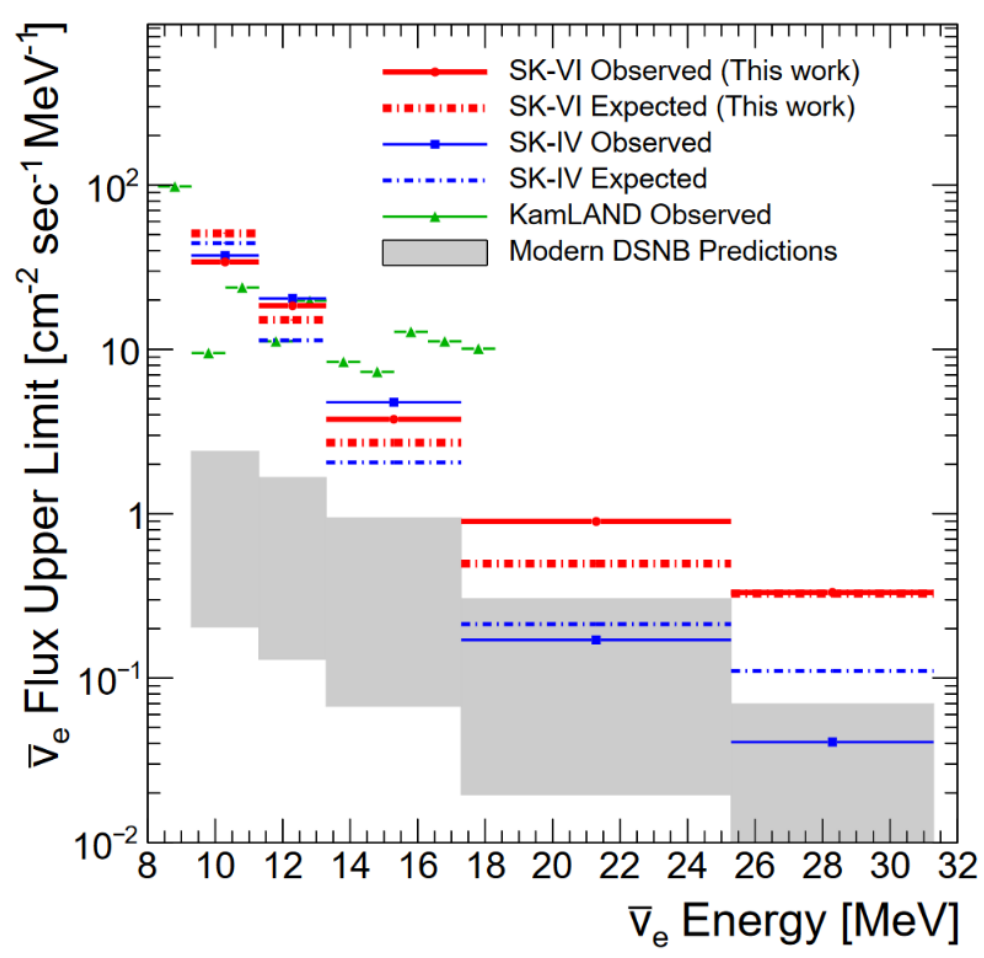
SK-Gd and JUNO



Li et al. 2022 [b]

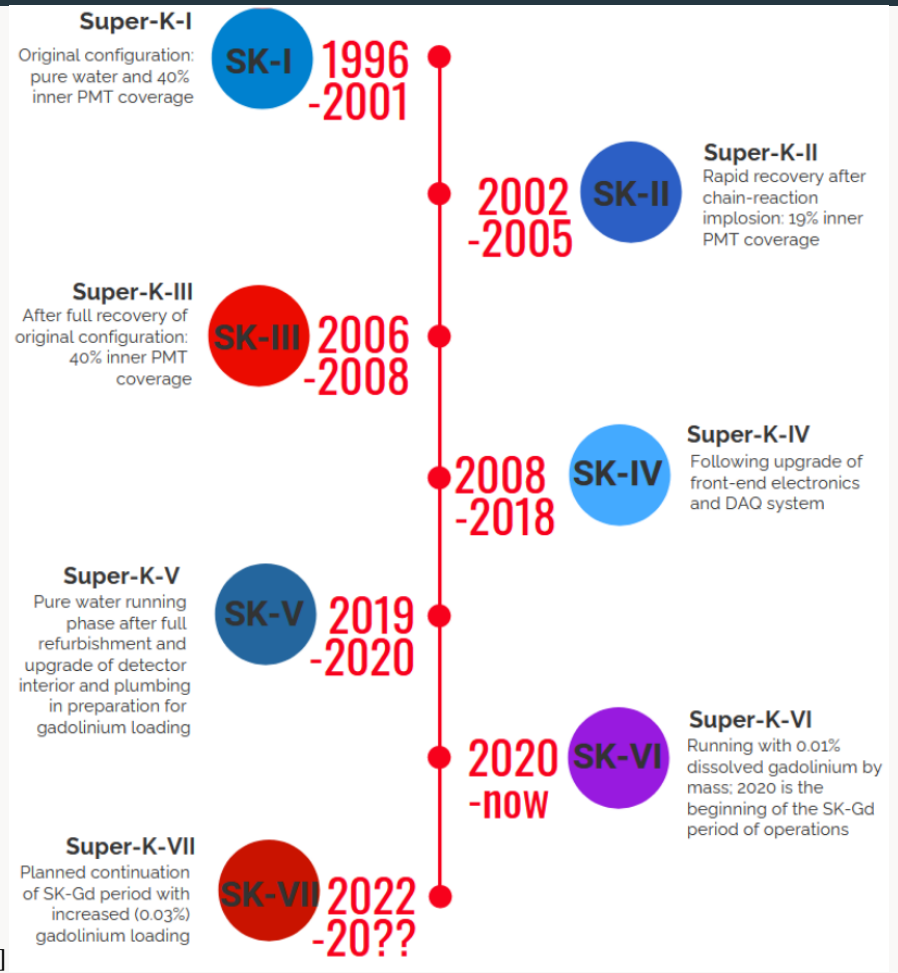
Hunt for the DSNB (EXTRA)

SK-IV bounds are stronger than SK-VI



Santos 2022 [b]

Hunt for the DSNB (EXTRA)



Santos 2022 [b]

References

[1] https://hubblesite.org/contents/media/images/2017/08/3987-Image.html

[2] https://arxiv.org/abs/astro-ph/0702613v3

[3] https://arxiv.org/abs/2109.11174

[4] https://arxiv.org/abs/2012.08524

[5] https://wwwmpa.mpagarching.mpg.de/ccsnarchive/data/SEWBJ_2015/index.html

[a] https://arxiv.org/abs/astro-ph/0702613

[b] https://arxiv.org/abs/2201.12920

[c] https://arxiv.org/abs/2405.07900