Resonant neutrino self-interactions in astrophysical spectra

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Work w/
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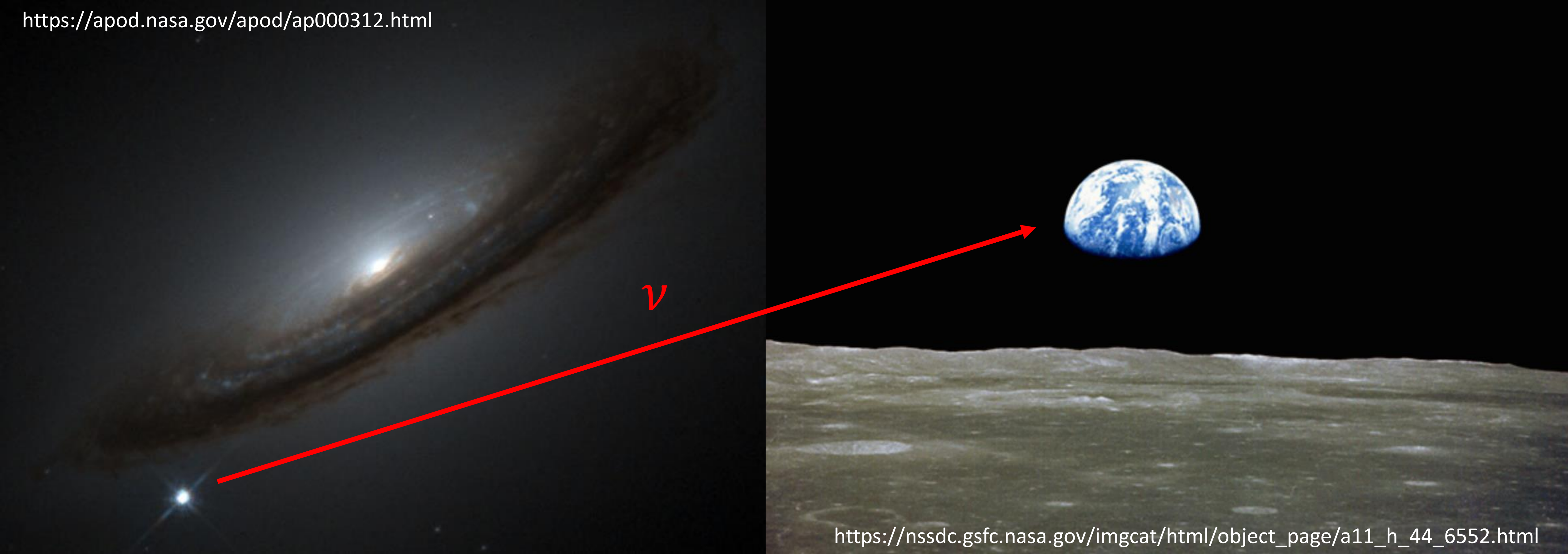
CCS, JH, MK, Phys. Rev. D 103, 023527, arXiv:2005.05332

Motivations

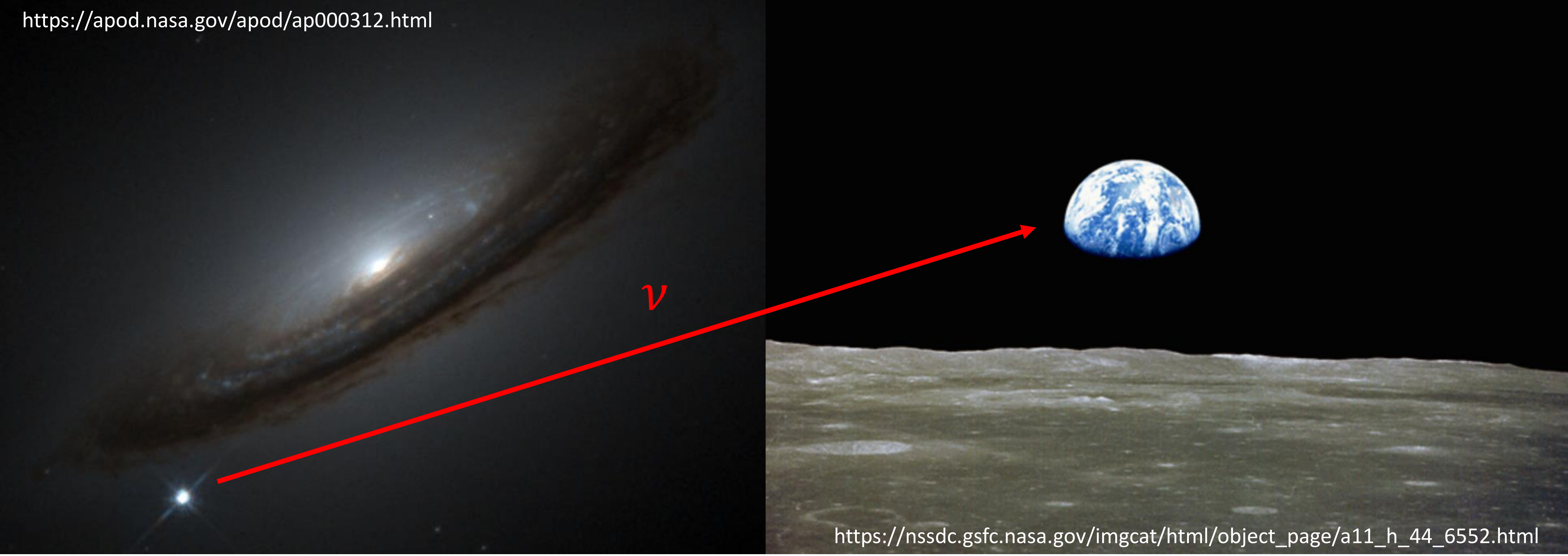
- It's tough to constrain some neutrino properties (e.g. ν_τ interactions)
- Neutrino self-interactions are popular to consider: $\mathcal{L}_{int} = g_{ij}\phi\nu_i\nu_j$

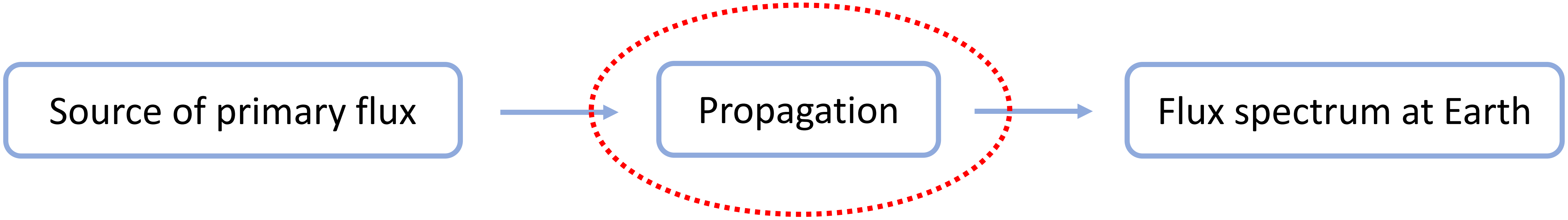
  e.g. Araki et al. 1409.4180 & 1508.07471, Barenboim et al. 1903.02036, Jones & Spitz 1911.06342,
  Ng & Beacom 1404.2288, Bustamante et al. 2001.04994, Blinov et al. 1905.02727,
  Mazumdar et al. 2011.13685, Carpio et al. 2104.15136, Das & Ghosh 2011.12315, Choudhury et al. 2012.07519

- Existing / upcoming neutrino experiments
  (Super-K, IceCube, POEMMA, …)

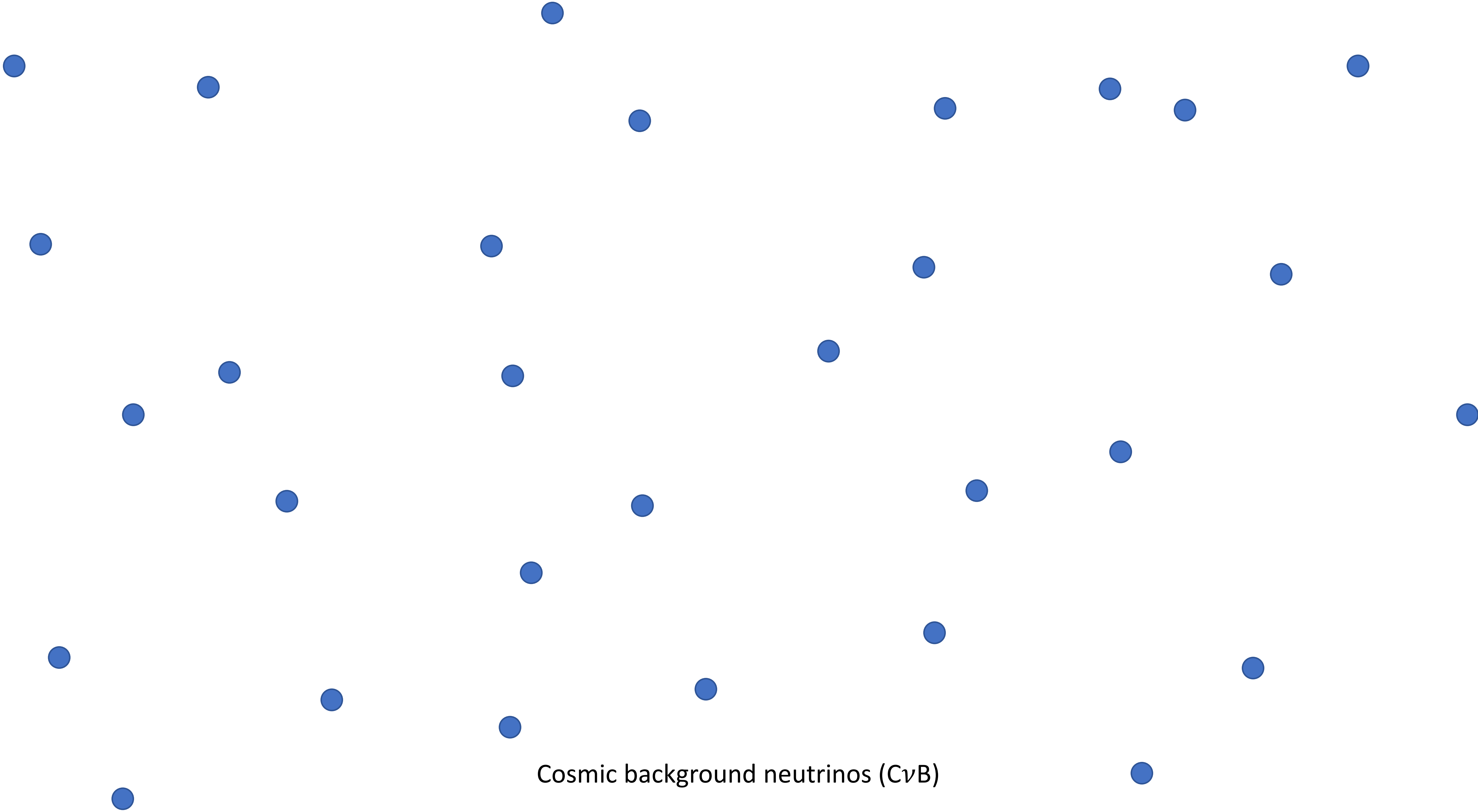


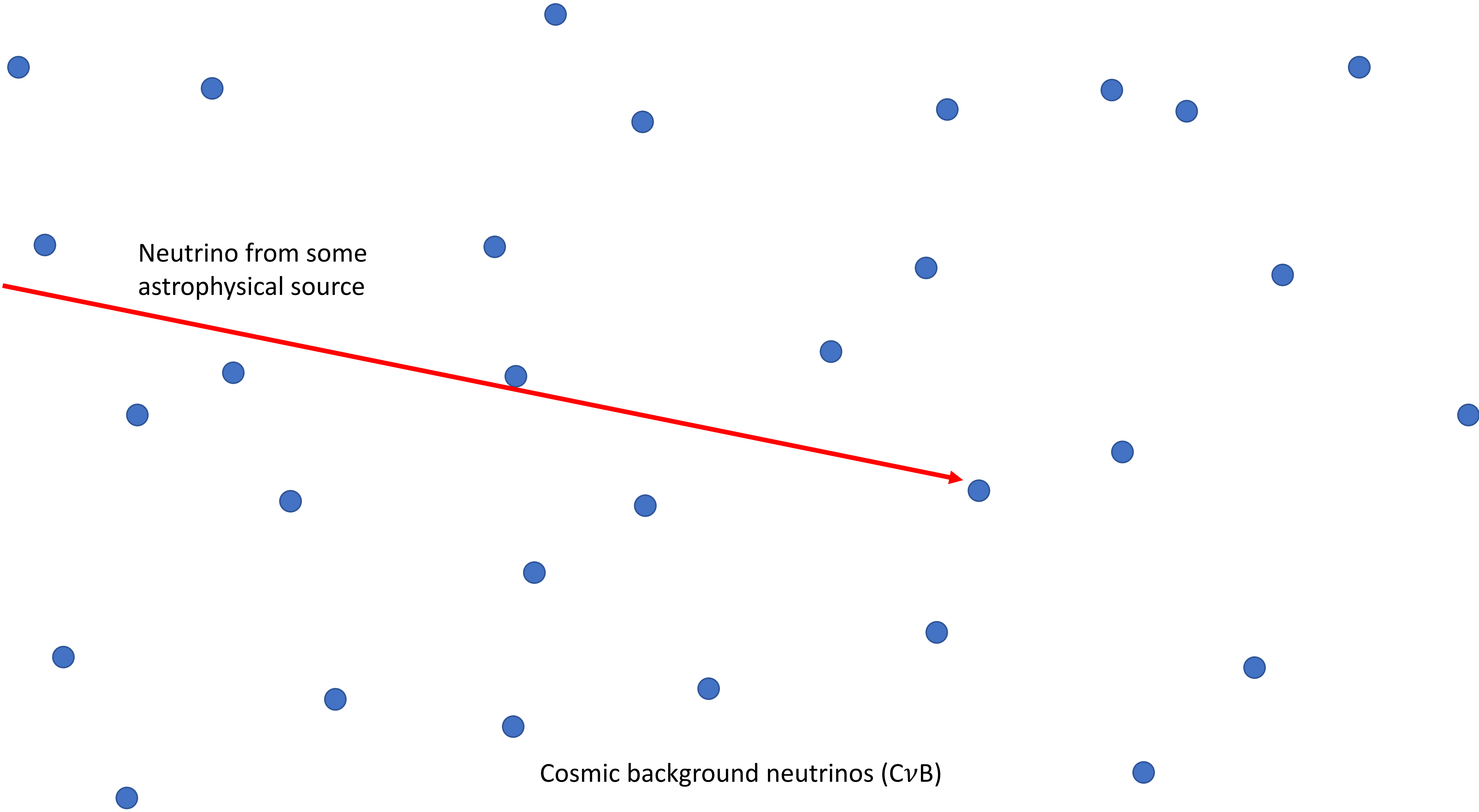
Source of primary flux → Propagation → Flux spectrum at Earth





Possible scattering on CνB


Cosmic background neutrinos (CνB)


Neutrino from some
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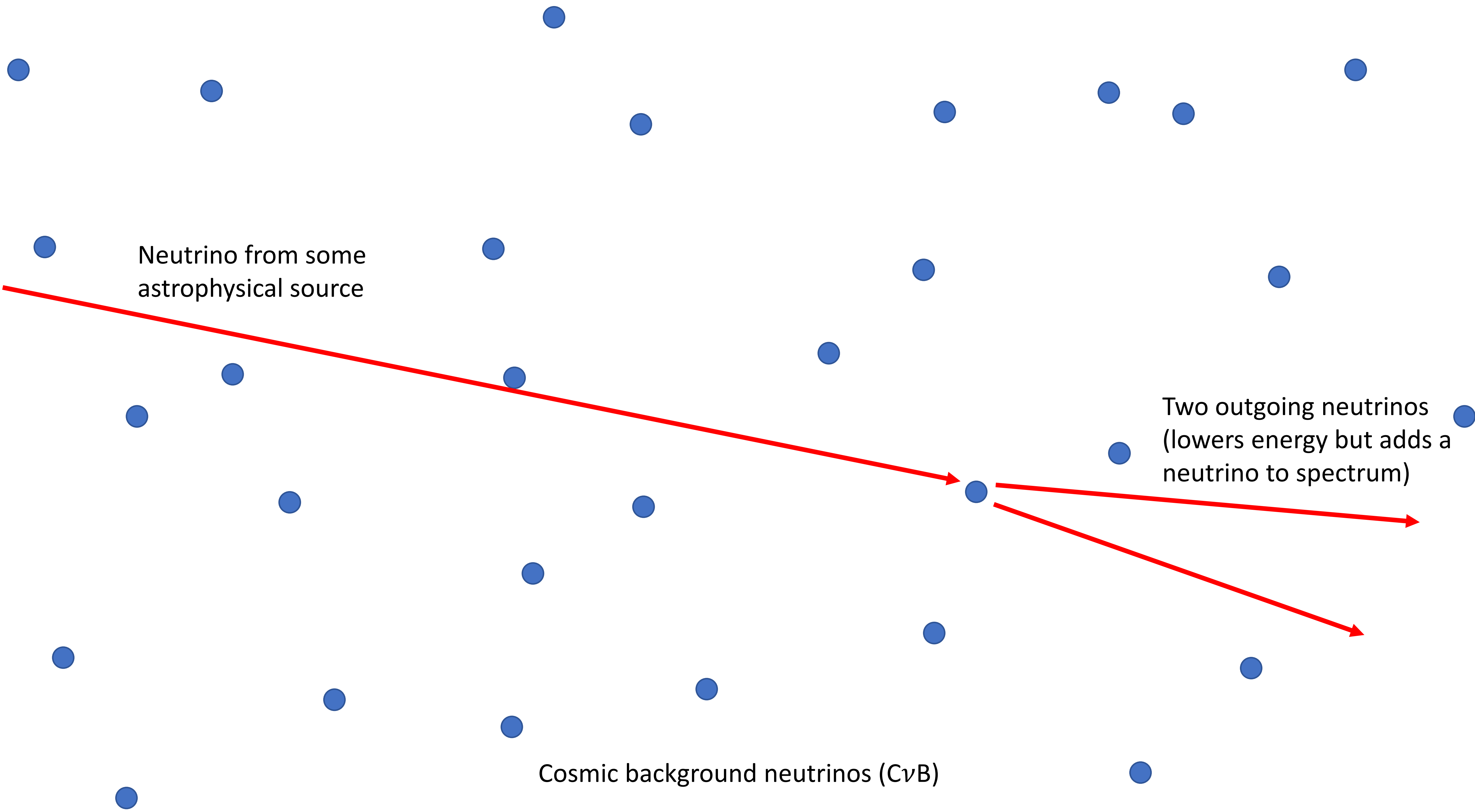
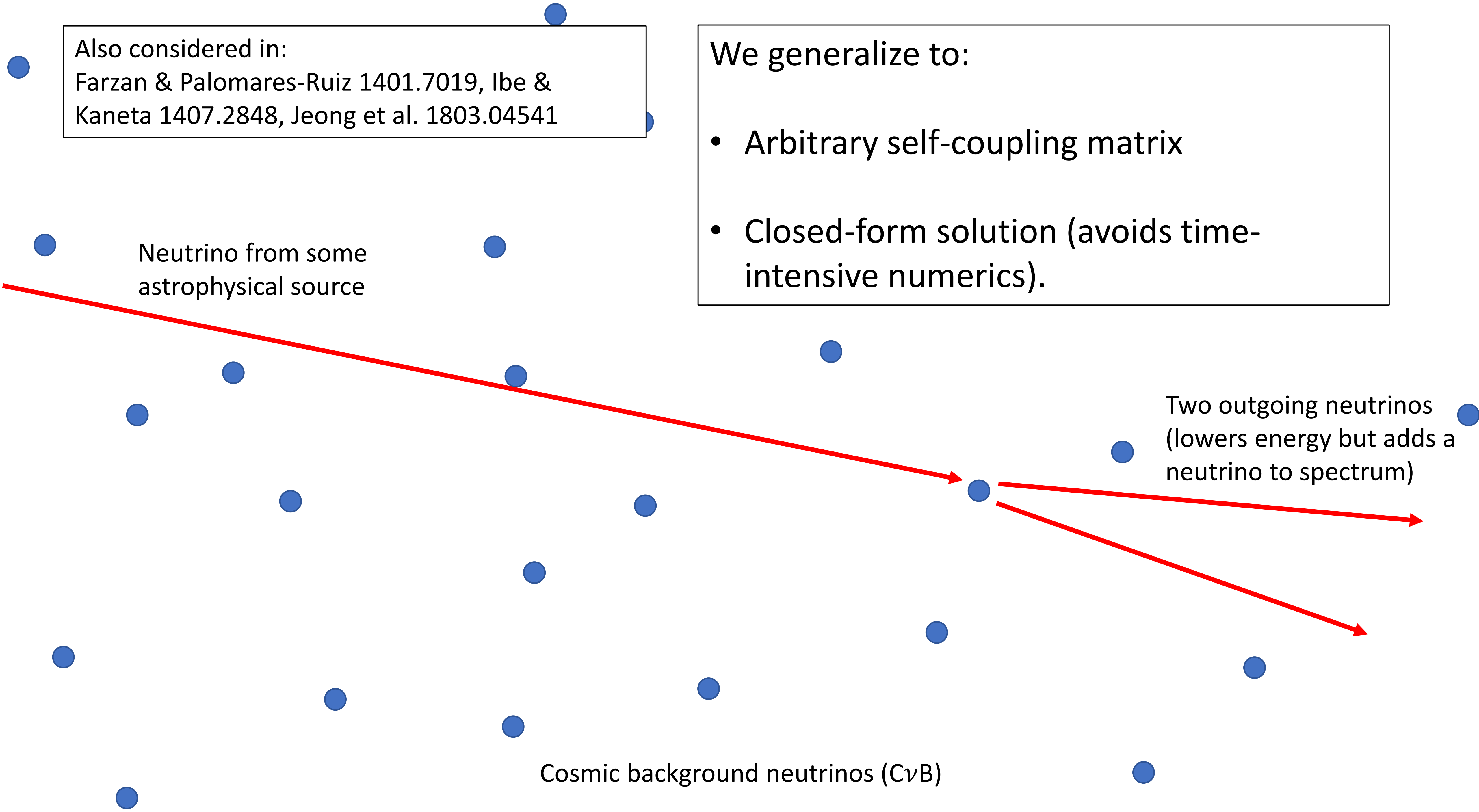
Cosmic background neutrinos (CνB)


Neutrino from some astrophysical source
Two outgoing neutrinos (lowers energy but adds a neutrino to spectrum)
Cosmic background neutrinos (CνB)

Also considered in:
Farzan & Palomares-Ruiz 1401.7019, Ibe & Kaneta 1407.2848, Jeong et al. 1803.04541

We generalize to:

- Arbitrary self-coupling matrix
- Closed-form solution (avoids time-intensive numerics).



Boltzmann equations for evolution of neutrino flux

$$\frac{\partial \Phi_i}{\partial t} = H\Phi_i + HE\frac{\partial \Phi_i}{\partial E} + S_i(t, E)$$

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- $\frac{\partial \Phi_i}{\partial t}$: $\Phi_i(t, E)$ = specific flux of ν_i (number per conformal time, per comoving area, per energy)
- $H\Phi_i + HE\frac{\partial \Phi_i}{\partial E}$: Expansion
- $S_i(t, E)$: Source term for primary flux.

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Boltzmann equations for evolution of neutrino flux

$$\frac{\partial \Phi_i}{\partial t} = H\Phi_i + HE\frac{\partial \Phi_i}{\partial E} + S_i(t,E) - \Gamma_i(t,E)\Phi_i + S_{tert,i}(t,E)$$

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- $\Gamma_i(t,E)\Phi_i$: Scattering events remove neutrinos from the primary spectrum. (Γ is rate.)
- $S_{tert,i}(t,E)$: The tertiary source term represents reinjection of neutrinos after scattering.

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Expansion

Source term for primary flux.

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Neutrino self-interactions found here

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Resonant $\nu - \nu$ scattering

- Resonant scattering dominant – we take a Breit-Wigner form.

- In many cases, this can be well-approximated as a delta function (e.g. width less than detector energy resolution).

Result for multiple flavors, arbitrary self-coupling matrix

$$\Phi_i(t,E) = \int_{-\infty}^{t} dt' \left(\frac{a(t)}{a(t')}\right) e^{-\tau_i(t',t,E)} \tilde{S}_i\left(t', \frac{a(t)}{a(t')} E\right)$$

Optical depth depends on form of neutrino self-coupling matrix...

$\tilde{S}_i = S_i + S_{tertiary}$,
w/ tertiary source dep. on self-coupling matrix, and $\tilde{S}_i$ evaluated at higher resonant energy, ...

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Details here are pretty involved for such a short talk... See paper.

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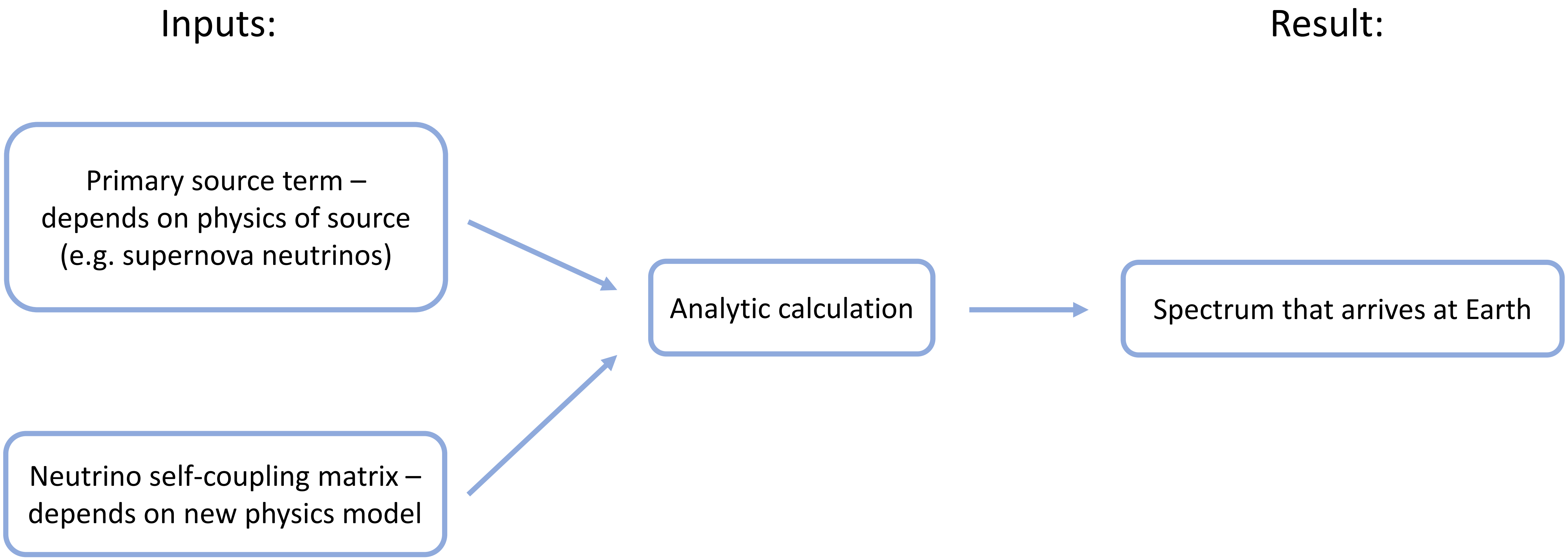

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Inputs:

Could apply to a wide range of scenarios.

Result:

Primary source term – depends on physics of source (e.g. supernova neutrinos)

Neutrino self-coupling matrix – depends on new physics model

Analytic calculation

Spectrum that arrives at Earth

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Is it really a closed-form solution?

Yes! But have to be careful with implementation…

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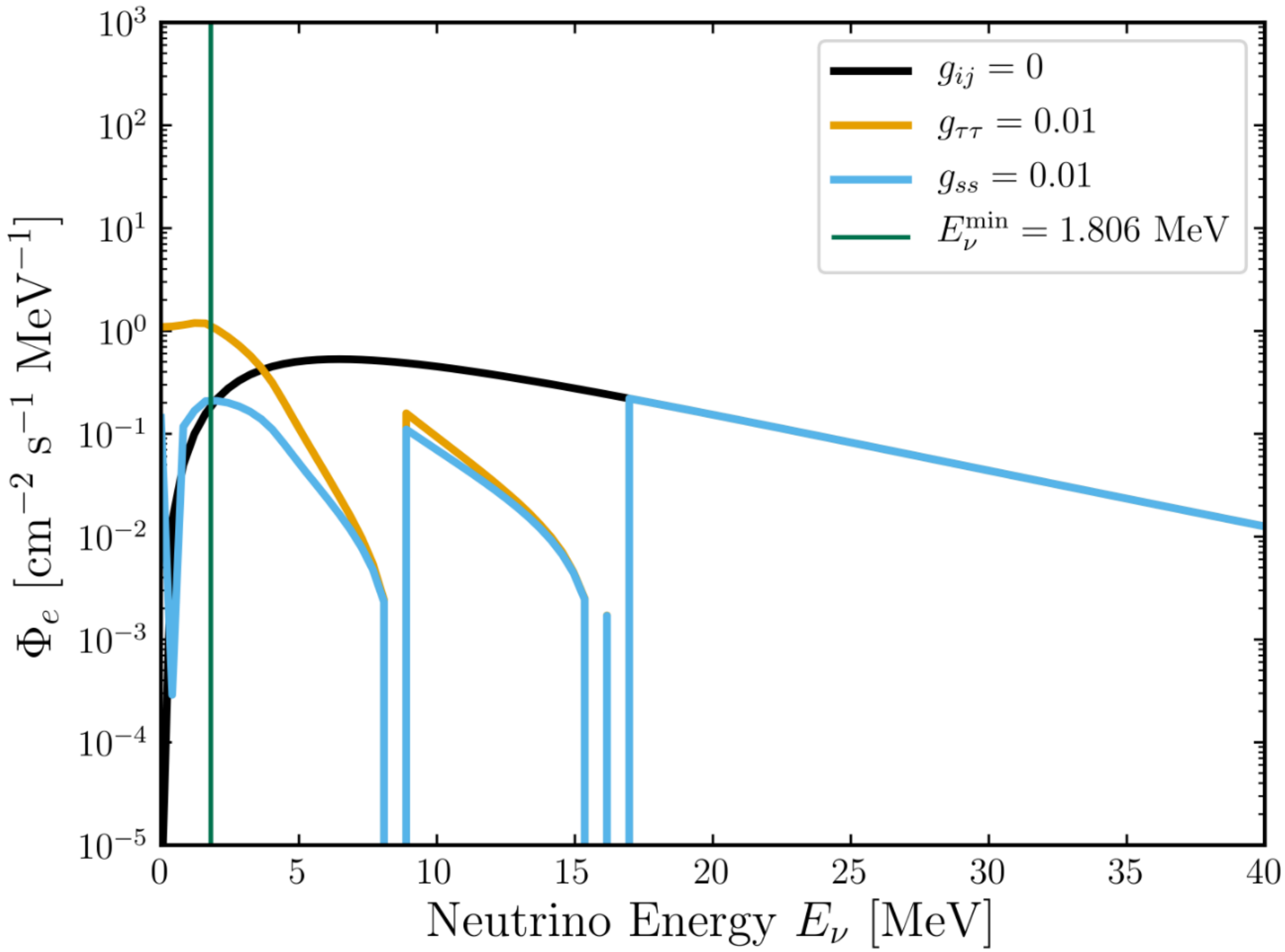
Example: Diffuse Supernova Neutrino Background (DSNB)



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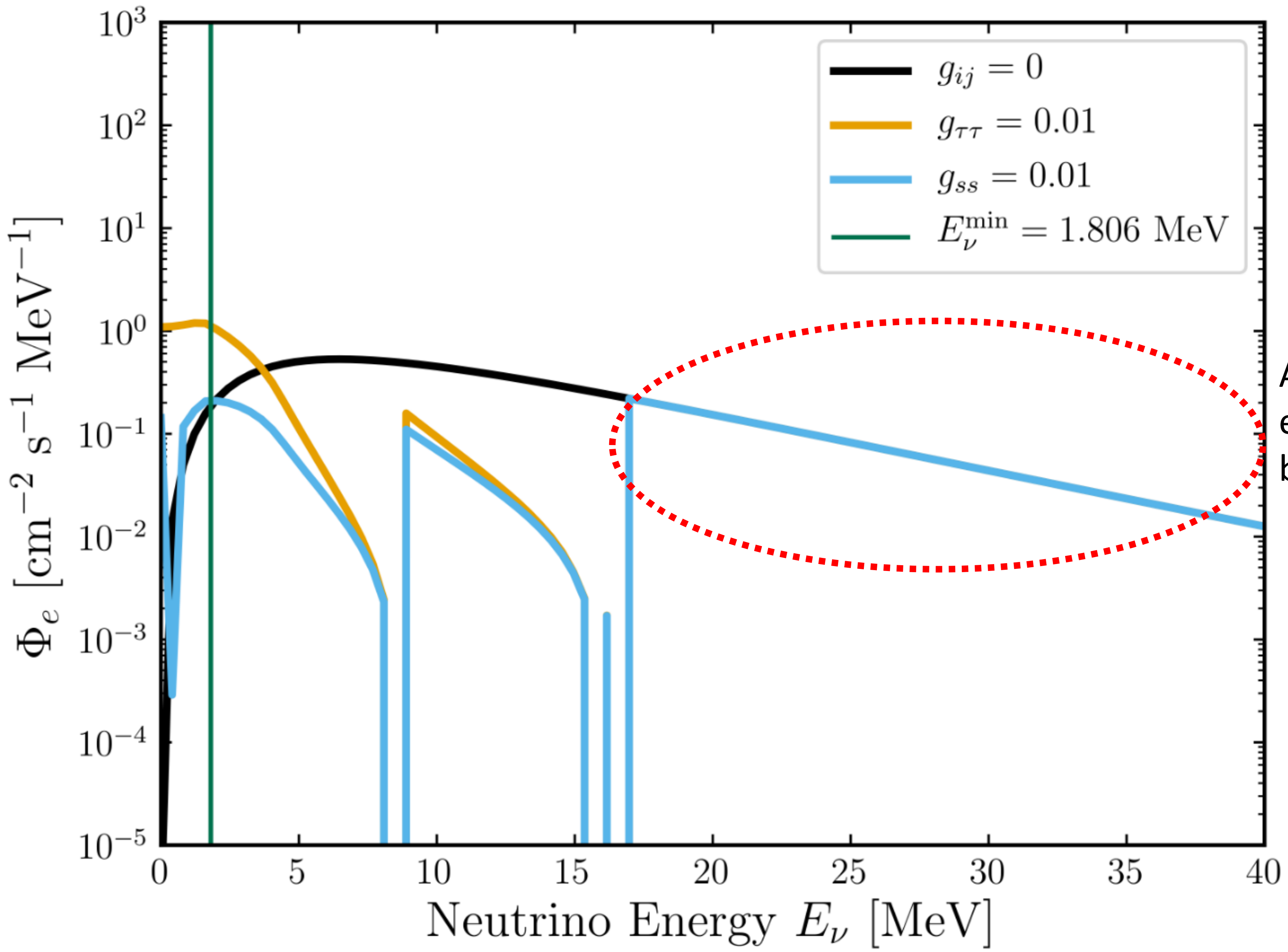

Above highest resonant energy, spectrum unaffected by self-interactions.

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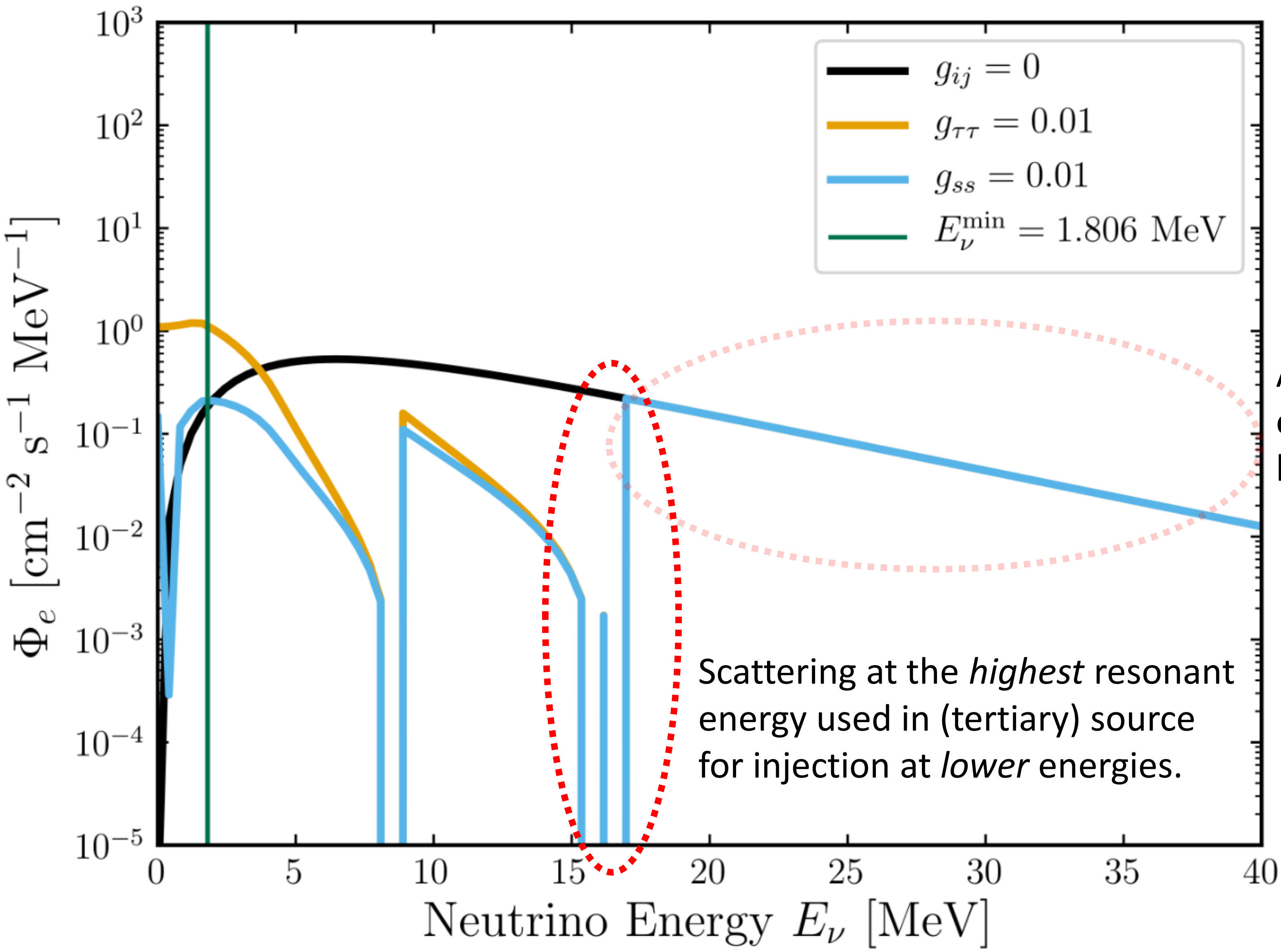

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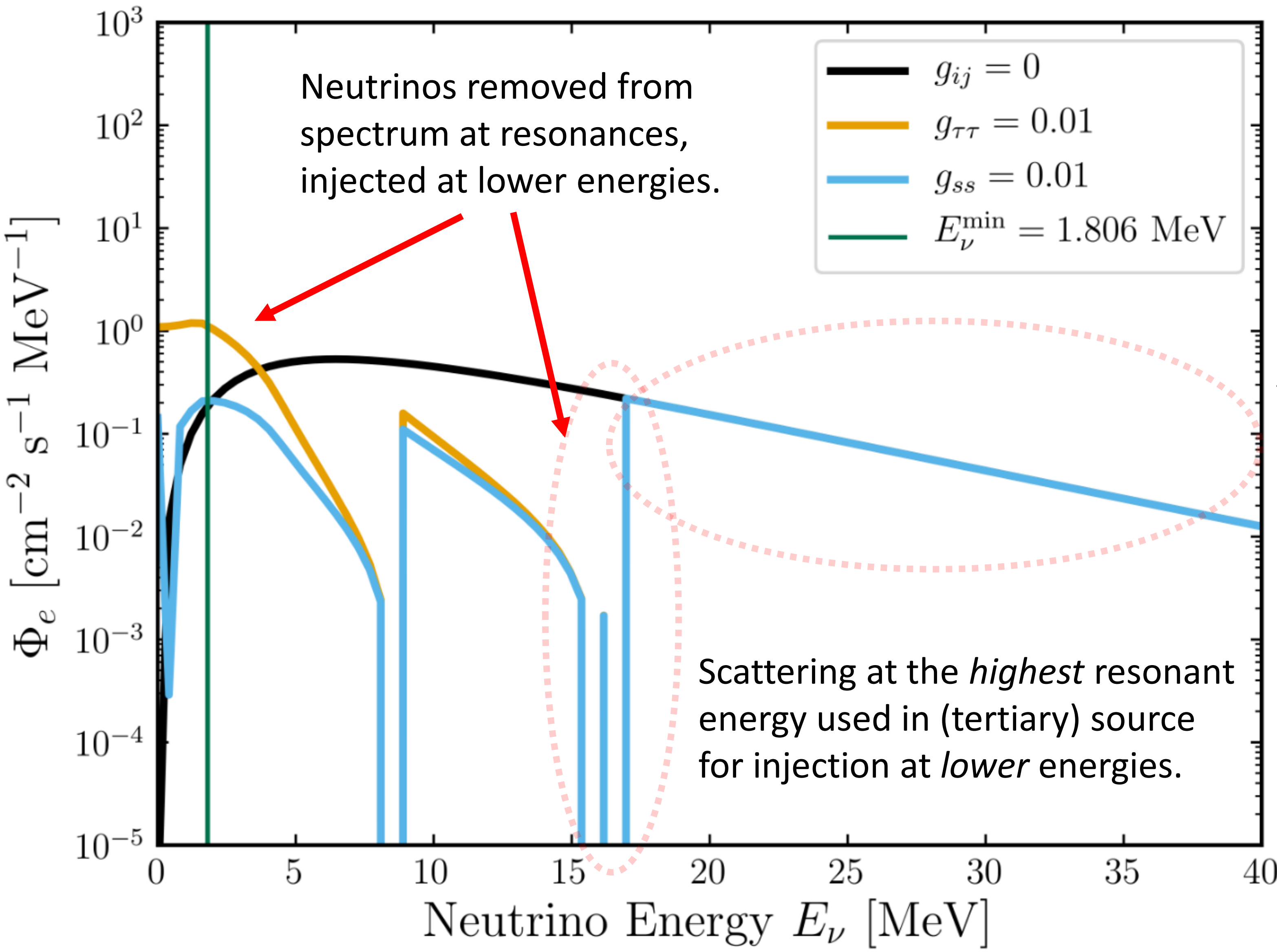

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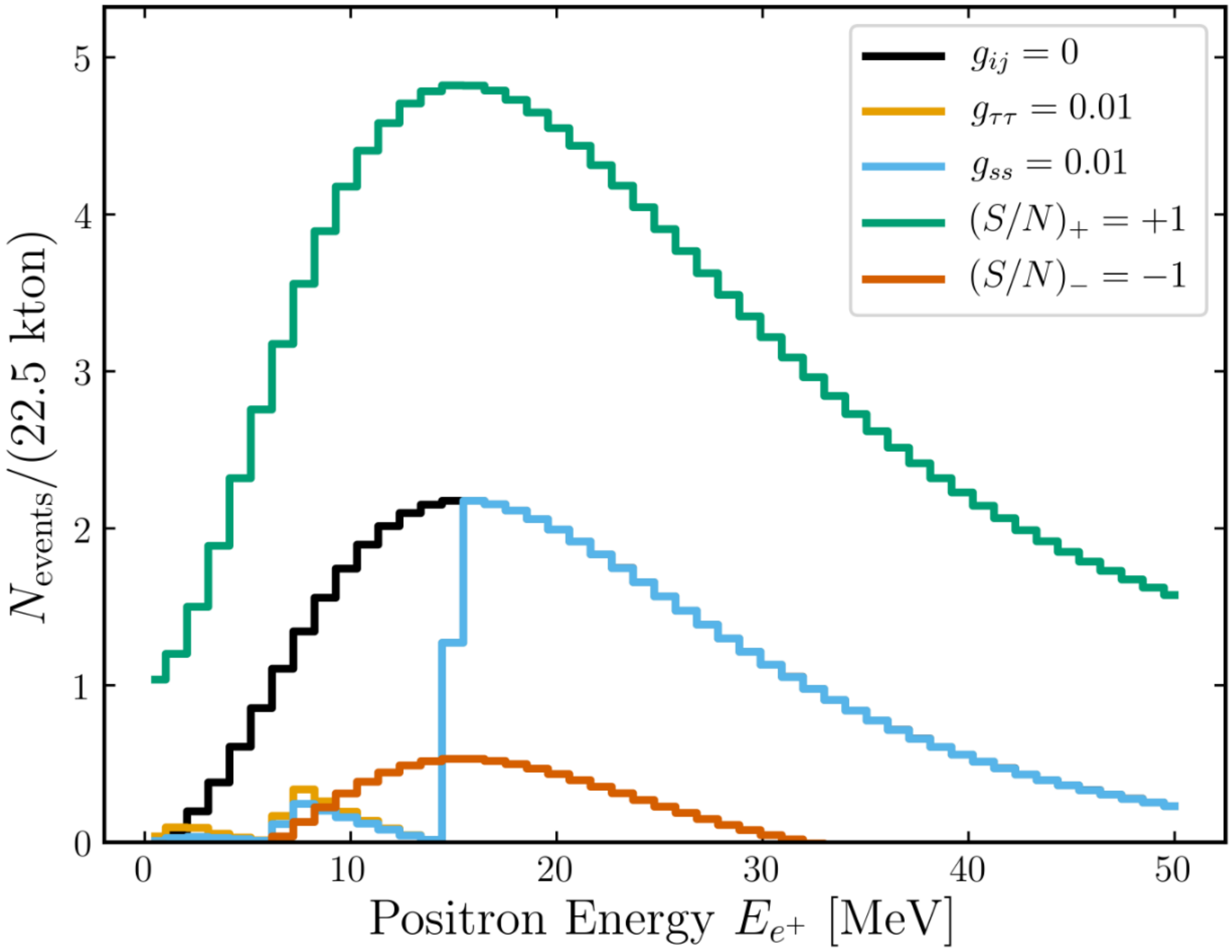
Event rates, +/- 1 sigma for 10 years at Super-K w/ gadolinium.

Comparison with expected spectrum at T = 8 MeV in absence of self-interactions.



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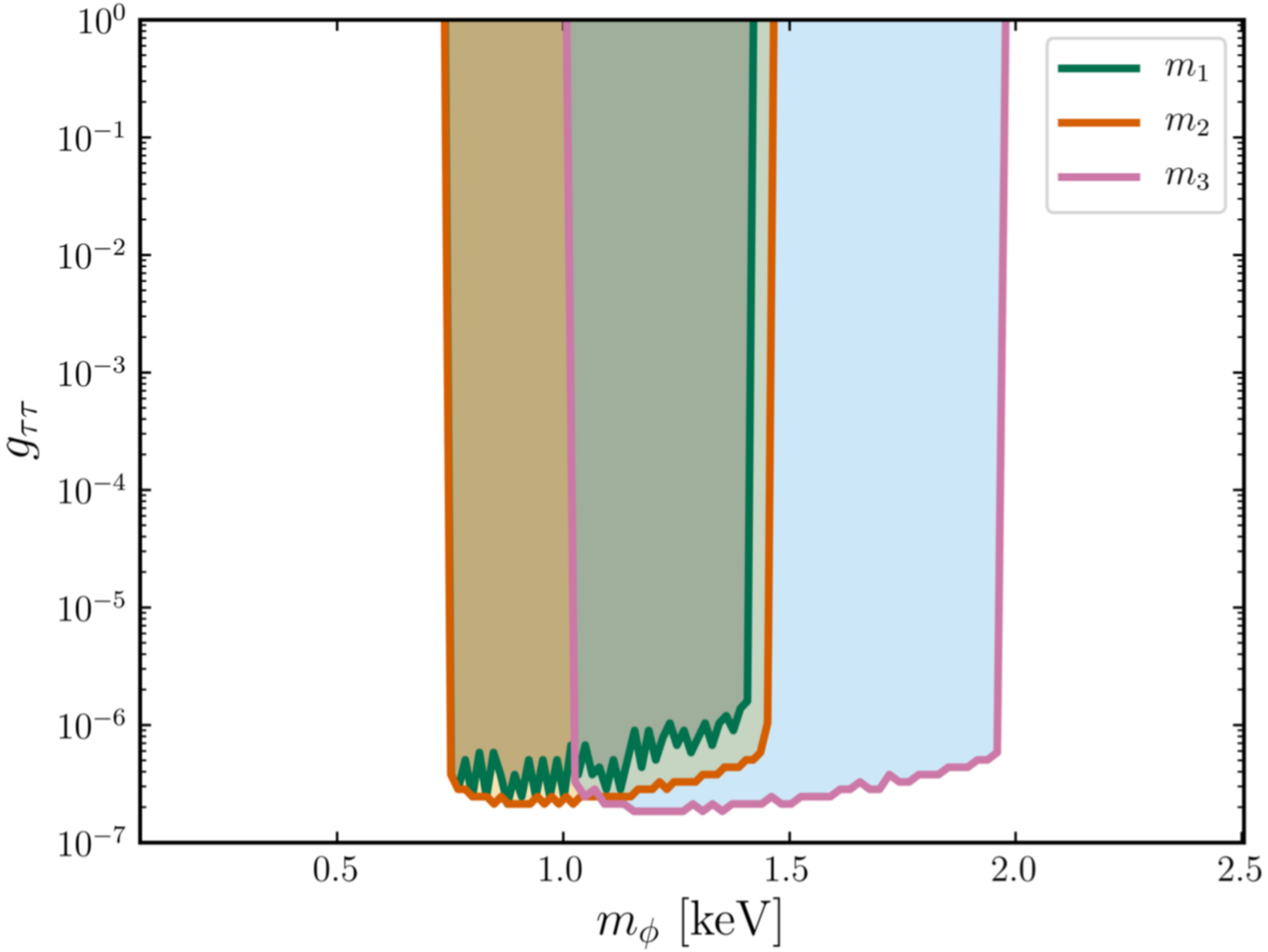
Forecasted 1-sigma constraints on coupling & scalar mediator, for 10 years at Super-K w/ gadolinium.



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Summary

- Efficient way to calculate observed spectra, given a source and model of neutrino self-interactions.

- Observation of the DSNB by Super-K can constrain neutrino self-interactions with $\sim$ keV masses.

- (In paper) High-Energy Astrophysical Neutrinos at IceCube: can constrain $\sim$ MeV mediators.

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