# International Neutrino Summer School 2021

# Core Collapse Supernova Neutrinos Mini Project Group B

Suggested by: Prof. Kate Scholberg




# Overview of Project


- Neutrinos emitted during core-collapse supernovae  provide an important window into understanding such phenomena
- Rates of interactions between different neutrino flavors and target particles need to be understood in order to take advantage of this signature

- “Back-of-the-envelope” calculations can give an idea of the order of magnitude of expected interaction events
- SNOwGLoBES software allows for more precise interaction rate estimates for expected and detected events and for different detector configurations and theoretical flux models,

# Warmups

$$\text{Flux} \times \text{Cross Section} \times \text{No. of targets} = \text{No. of Interactions}$$

- ***ESTIMATE:*** *Number of solar neutrino interactions in a typical human body over a human lifetime*
- ***ASSUMPTIONS:***
  - *All interactions are neutrino-electron elastic scattering*
  - *Human body is made of water*
  - *Mass of human body is 80 kg*
  - *Average human lifespan is 80 years*
  - *Solar neutrino flux is about $2 \times 10^6$ cm$^{-2}$s$^{-1}$*

$$(2 \times 10^6\ \mathrm{cm^{-2}s^{-1}}) \times (5 \times 10^{-44}\mathrm{cm^2}) \times (6.74 \times 10^{37}\mathrm{s\ electrons})) = 6.8\ \text{interactions}$$

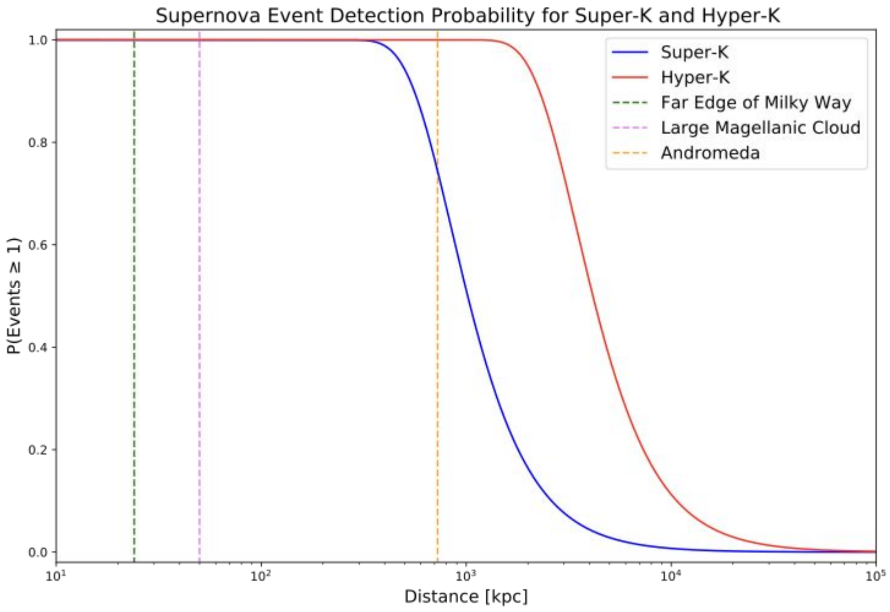
- ***ESTIMATE:*** *Number of $\upsilon_e - {}^{40}\mathrm{Ar}$ CC neutrino interactions in a 40-kton liquid-argon detector for a core collapse at center of Milky Way AND in M31*
- **Milky Way:**

$$(1.38 \times 10^{12}\ \upsilon_e\ \mathrm{cm^{-2}}) \times (2 \times 10^{-41}\mathrm{cm^2}) \times (6 \times 10^{32}\ {}^{40}\mathrm{Ar\ nuclei}) = 17{,}500\ \text{interactions}$$

- **M31:**

$$(1.68 \times 10^{8}\ \upsilon_e\ \mathrm{cm^{-2}}) \times (2 \times 10^{-41}\mathrm{cm^2}) \times (6 \times 10^{32}\ {}^{40}\mathrm{Ar\ nuclei}) = 2.1\ \text{interactions}$$

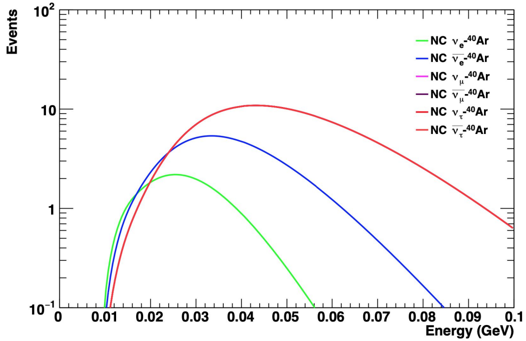
# Warmups, cont.

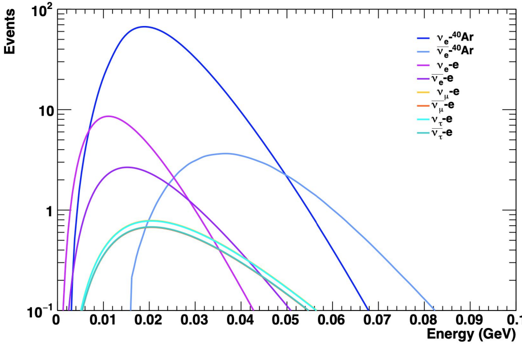


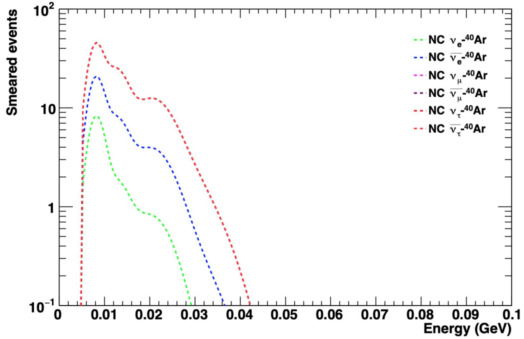

- ***PLOT:*** *Probability of recording at least one event as a function of distance out to 100 Mpc for Super-K and Hyper-K*
- ***ASSUMPTIONS:***
  - *7000 neutrinos will be recorded by Super-K on average for a core-collapse supernova at 10 kpc*
  - *Super-K is a detector made of 22.5 ktons of water*
  - *Hyper-K is a detector made of 374 ktons of water*
  - *All interactions are from inverse $\beta$-decay*

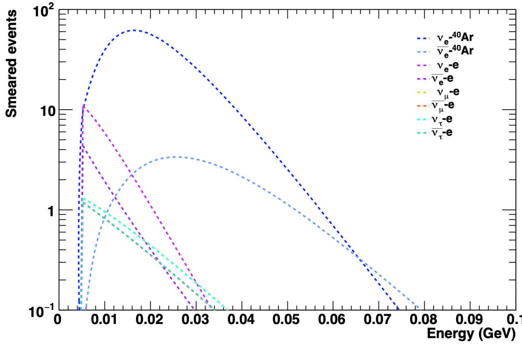
# Interaction Rates in Liquid Argon with SNOwGLoBES

## Livermore model for a 40 kt Liquid Argon Detector



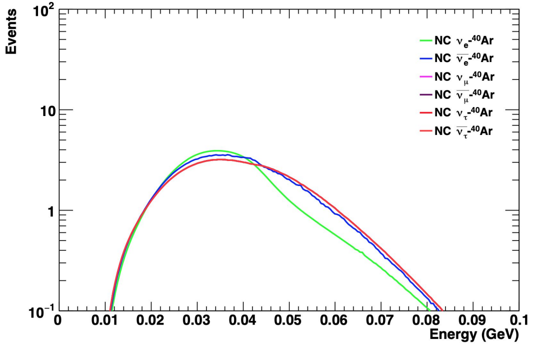



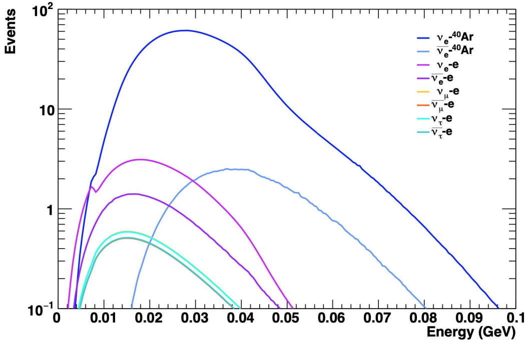



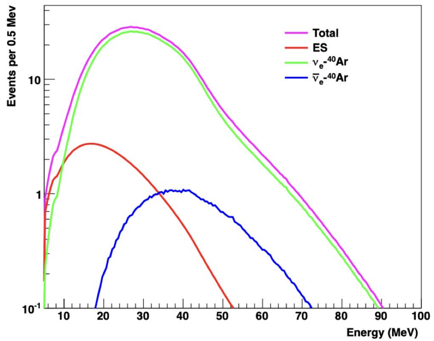
# Interaction Rates in Liquid Argon

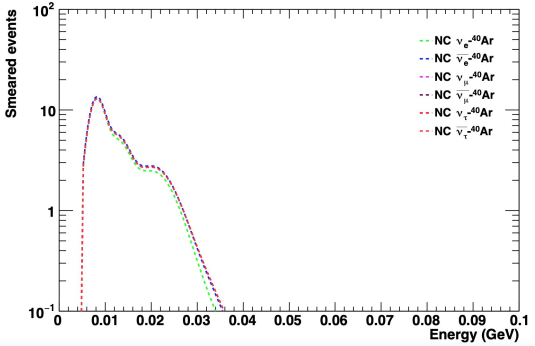
**GVKM model for a 40 kt Liquid Argon Detector**
(Gava-Kneller-Volpe-McLaughlin)

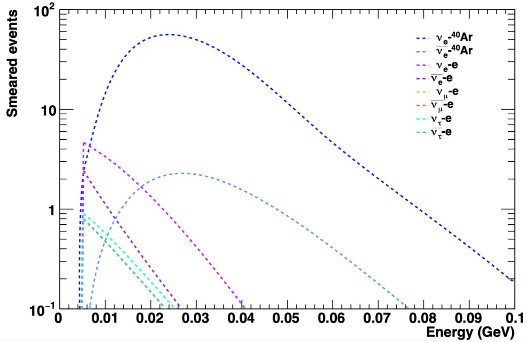
**SNOwGLoBES manual (GVKM)**

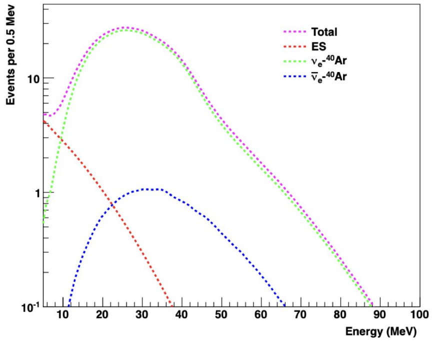


# Comparing Livermore and GVKM flux models

Livermore (10.1086/305364) (1997):

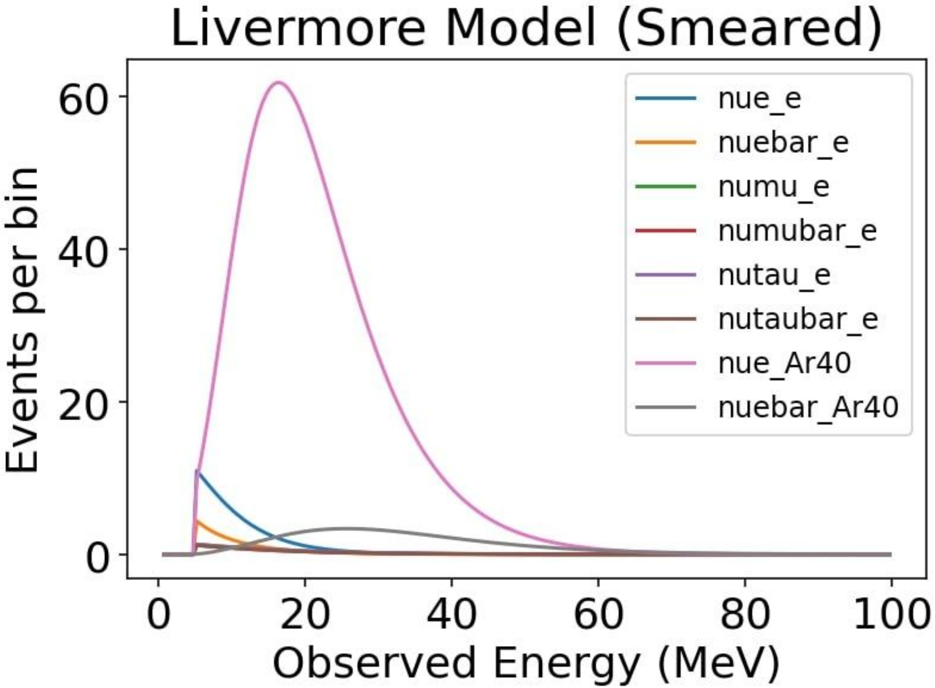
- model of the SN1987A
- One dimensional simulation is performed from the onset of the collapse to 18 seconds after the core bounce in a consistent way

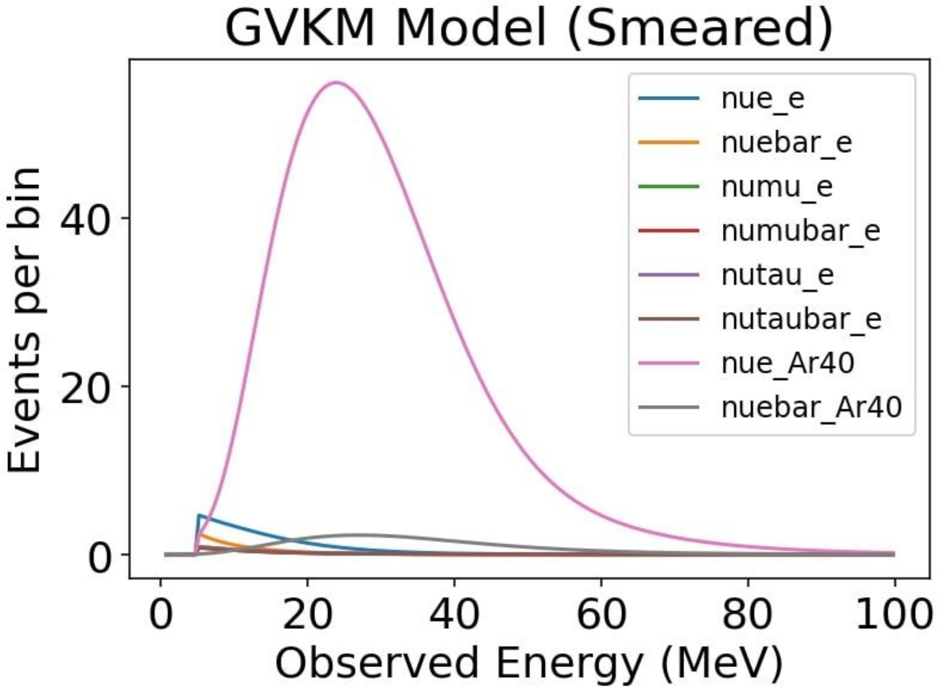
GVKM (10.1103/PhysRevLett.103.071101)(2009)

- evolves the neutrino wavefunctions up to a radius using supernova density profiles at different times during the supernova explosion
- Neutrinos will go through multiple matter resonance areas.

Events for Argon channel in 40kt Argon Detector

| Flux Model | Livermore | GVKM |
|---|---|---|
| Total ES: | 341 | 206 |
| Total NC: | 4079 | 1314 |
| Total events: | 7291 | 4970 |




GVKM ([10.1103/PhysRevLett.103.071101](https://doi.org/10.1103/PhysRevLett.103.071101))(2009)

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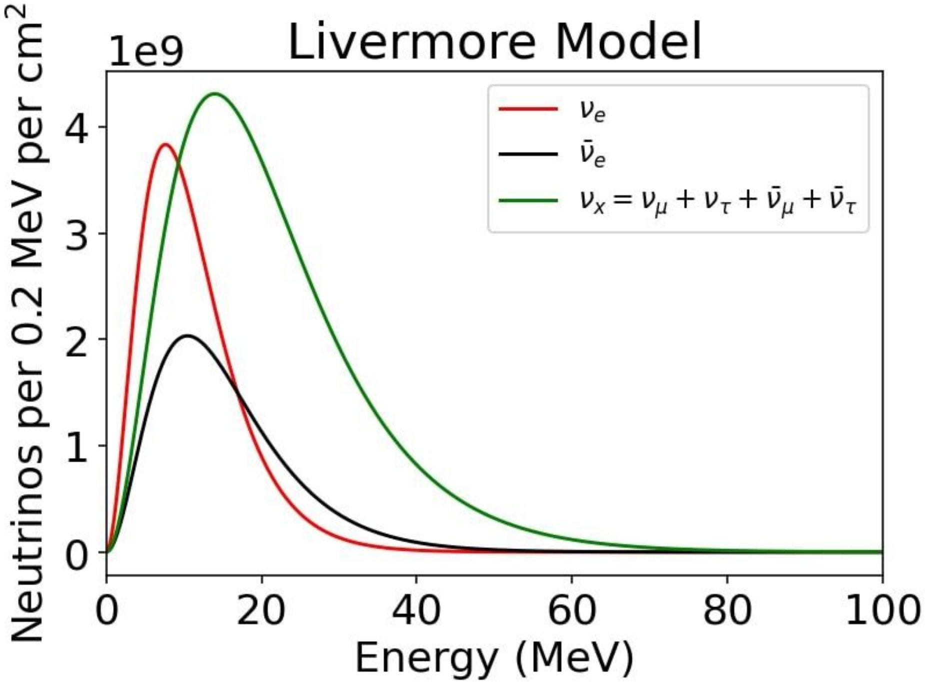


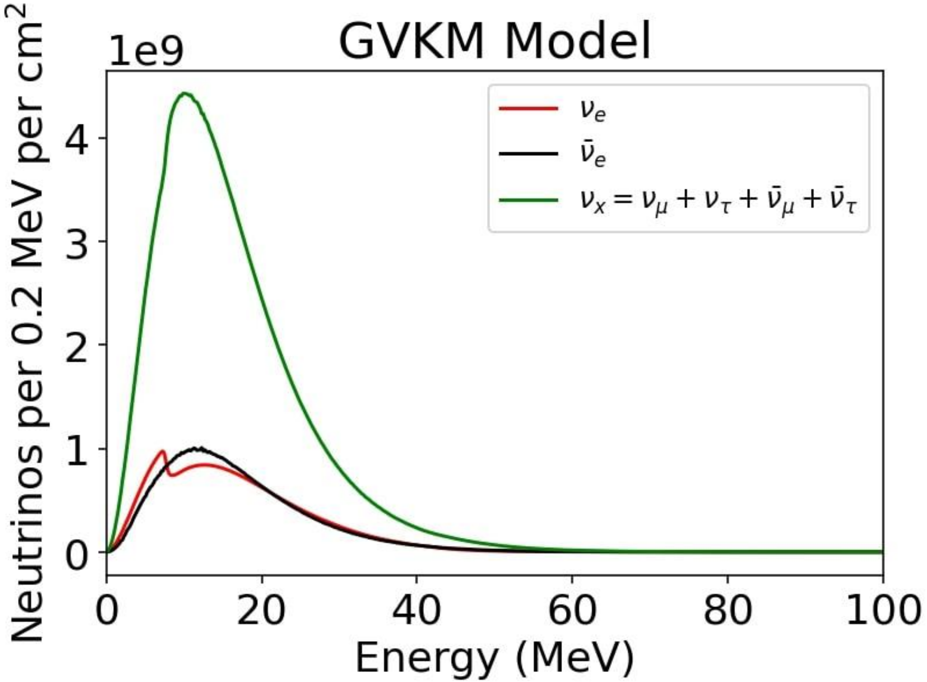


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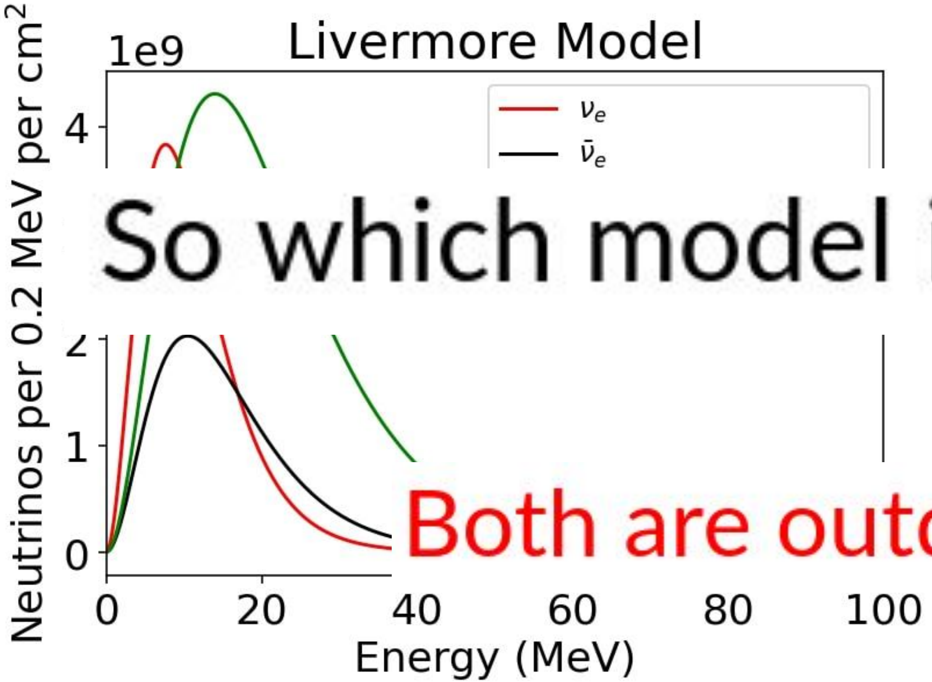


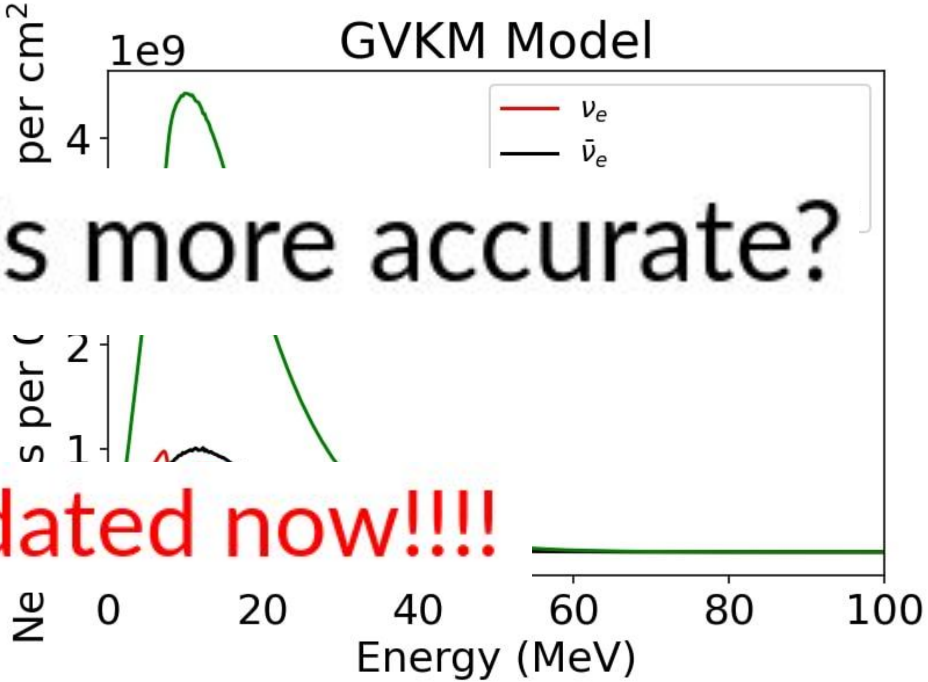


# So which model is more accurate?

**Both are outdated now!!!!**

Planning for modern set of models for SNOwGLoBES soon
\- Prof. Kate Scholberg

- Neutrinos will go through multiple matter resonance areas.

| | | |
|---|---|---|
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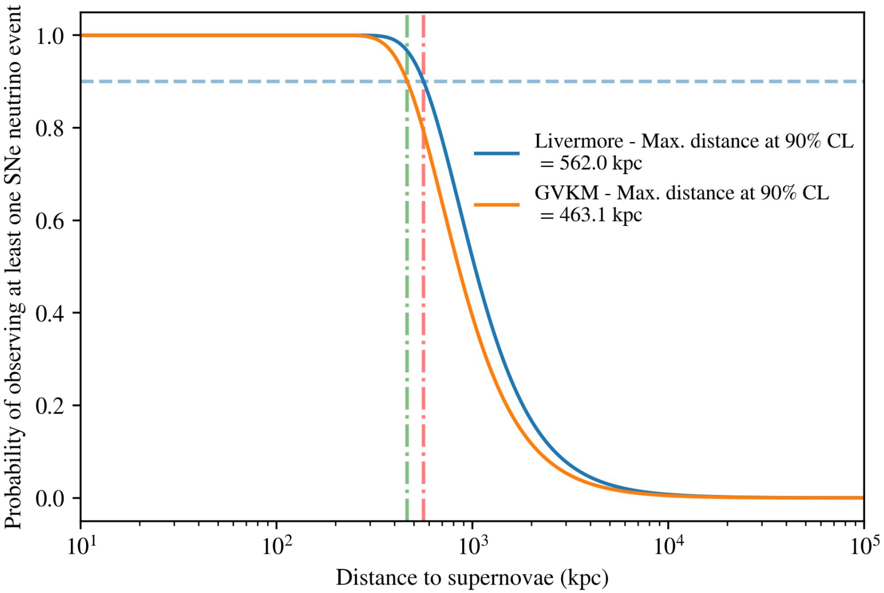
# Detection Probability with Distance in Liquid Argon

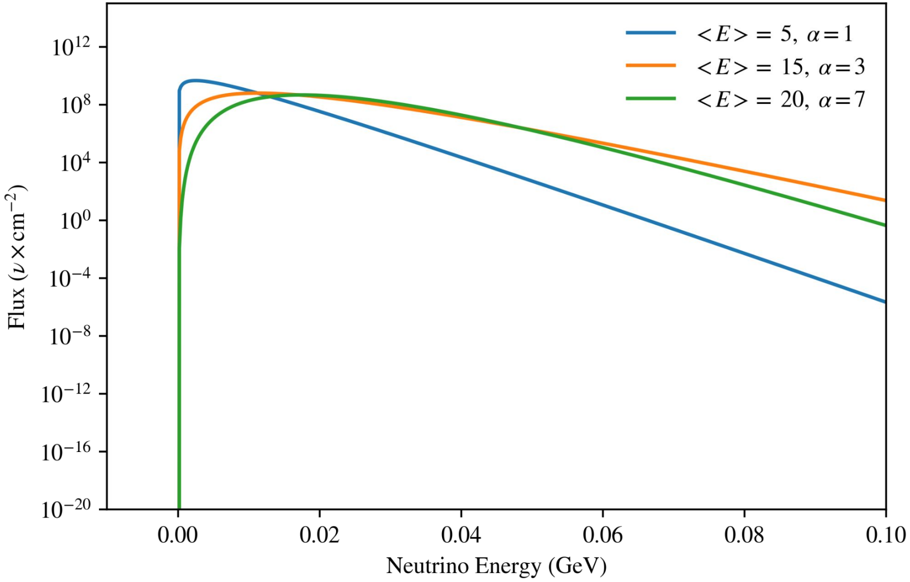
Large discrepancy between models!



# Garching Parameterization

- Garching model (1211.3920) (2012)
  - Simplified SN flux model that allows parameterization
  - Can well reproduce features that can be observed in detectors
  - Allows broad testing of detection capability without knowing underlying model details

$$\phi(E_\nu) = \mathcal{N}\left(\frac{E_\nu}{\langle E_\nu \rangle}\right)^{\alpha} \exp\left[-(\alpha+1)\frac{E_\nu}{\langle E_\nu \rangle}\right]$$



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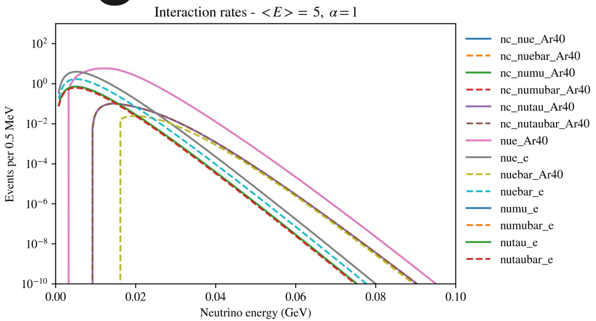


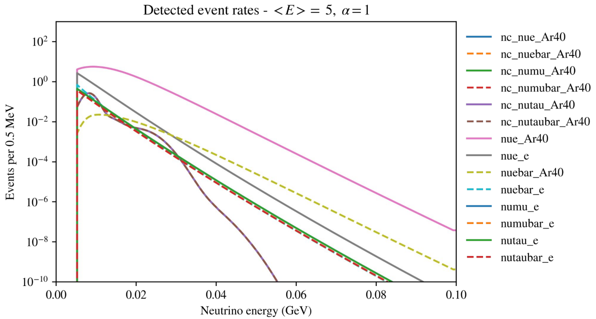


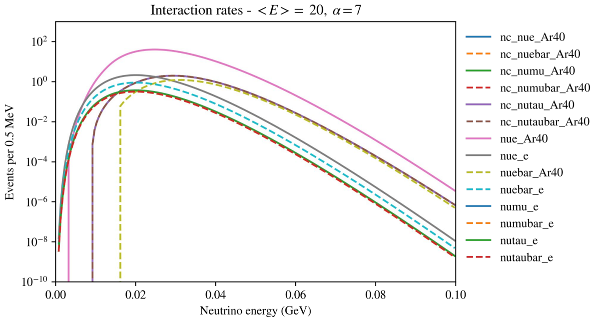


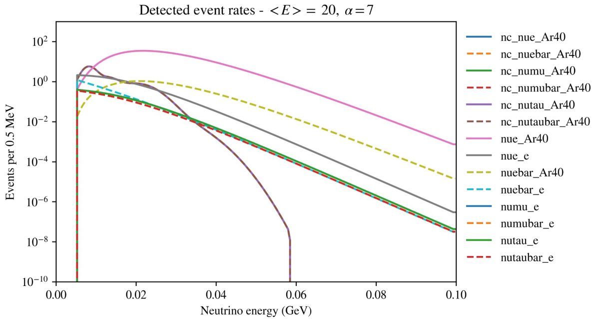

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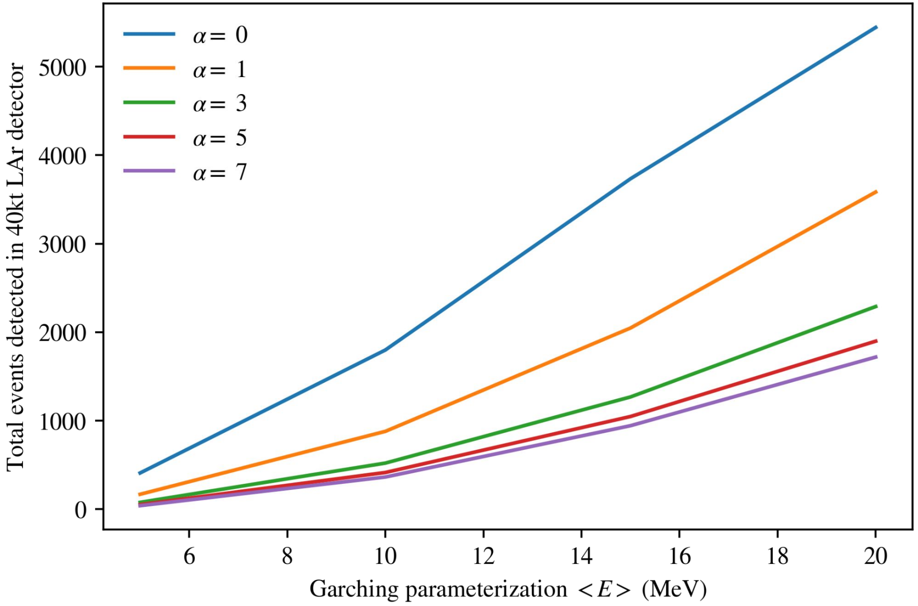
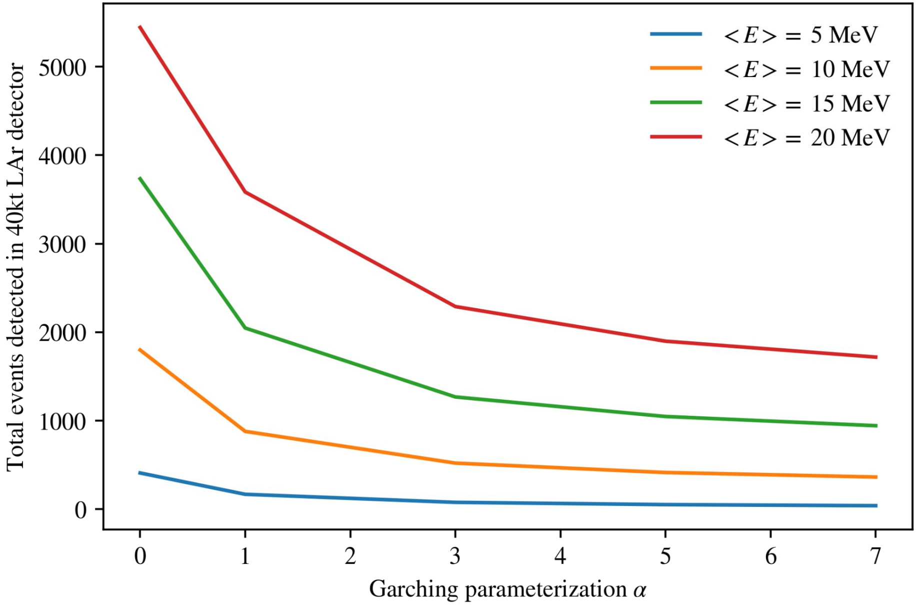
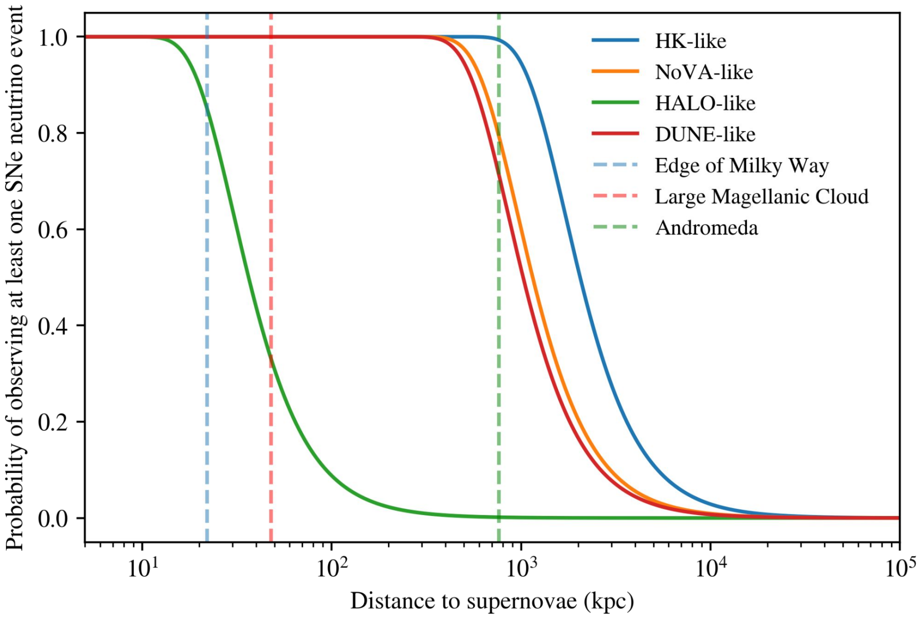


# Comparing Different Detector Types



## Conclusions

SNOwGLoBES is a powerful software that can help to improve physicists' understanding of the expected signature from core collapse supernovae based on different flux parametrizations, supernova neutrino models, and detector parameters.

Thank you!