

Developing a spectral analysis code for the future diffuse supernova neutrino background studies

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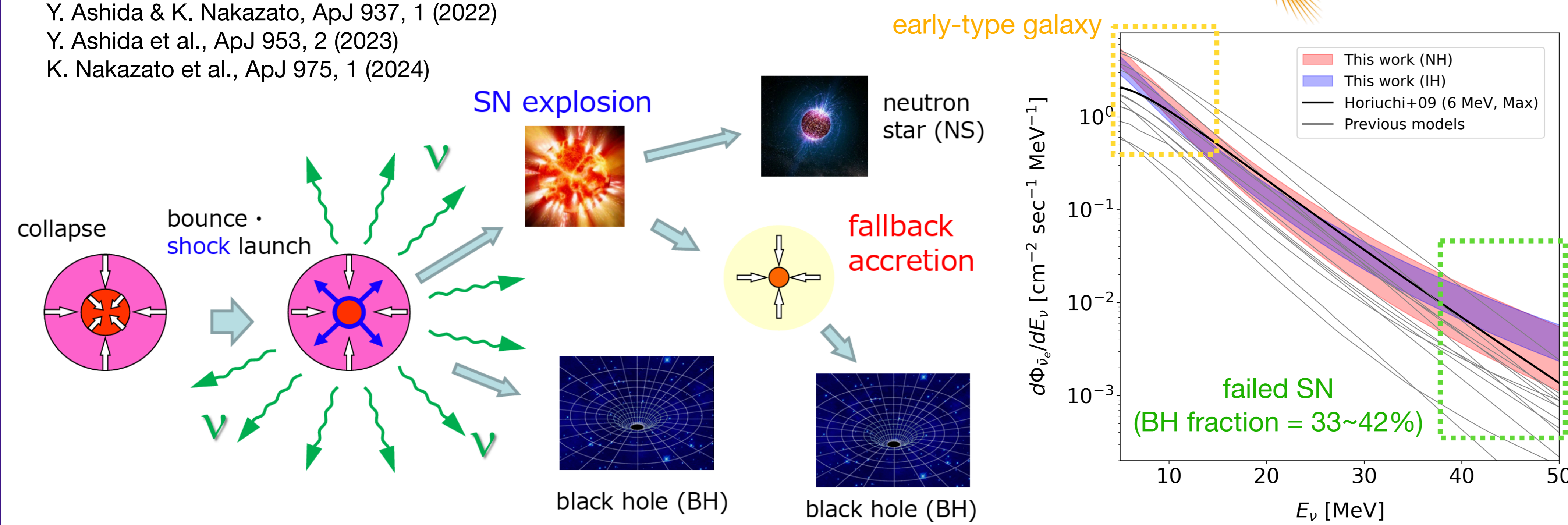
Poster #37



1. Diffuse Supernova Neutrino Background

- Diffuse Supernova Neutrino Background (DSNB)** = the accumulated flux of neutrinos from stellar core collapse over the cosmic history
- There are a variety of factors that affect the DSNB flux scale and shape, among which are **fate of stellar collapse** and **galactic chemical evolution**.

Y. Ashida & K. Nakazato, ApJ 937, 1 (2022)
Y. Ashida et al., ApJ 953, 2 (2023)
K. Nakazato et al., ApJ 975, 1 (2024)



2. Experimental Searches

Water Cherenkov	Liquid Scintillator
<ul style="list-style-type: none"> Good scalability (O(10) kton → O(100) kton) Small light yield <ul style="list-style-type: none"> higher energy threshold worse reconstruction performance Background modeling <ul style="list-style-type: none"> Insensitive to low energy hadronic particles More chains for muon spallation isotopes Smaller reference dataset for neutrino interactions 	<ul style="list-style-type: none"> Worse scalability (O(1) kton → O(10) kton) Large light yield <ul style="list-style-type: none"> lower energy threshold good reconstruction performance Background modeling <ul style="list-style-type: none"> Sensitive to almost any particles Less chains for muon spallation isotopes A lot of scintillation-based neutrino cross section measurement results available
<p>Hyper-K</p>	<p>KamLAND</p>
<p>Directional emission (42 deg opening angle in water)</p>	<p>Isotropic emission</p>

- Super-K has been the world-leading experiment (see **S. Fujita's poster (#360)** for the latest search result).
- The next generation large detectors are operating now or soon.
- DSNB observation over the wide energy range** is essential for astrophysical studies.

3. CARNE for Spectrum Analysis

- Need to get prepared for a full use of available dataset from multiple future detectors.
- Another demand comes from the theoretical field as they would like to investigate their own models with realistic experimental assumptions.
 - We are developing a dedicated spectral fitting code, **Code for Analyzing Relic NEutrinos (CARNE)**.

CARNE

- Statistical model:** an extended unbinned likelihood
- Observable:** energy (~reconstructed)
- Flow:**

- Prepare probability density functions (PDFs) of each signal and background.
- Produce N_{obs} events based on PDF, detector size, operation time, and analysis efficiency etc (as a toy dataset); in (signal+)background hypothesis, $N_{\text{obs}} = (N_{\text{sig,nom}} + N_{\text{bkg,nom}})$.
- Calculate likelihood for each toy dataset by scanning N_{sig} and N_{bkg} , and normalize each likelihood by the maximum likelihood to obtain **Test Statistic (TS)**.
- From each toy, get expected sensitivity or discovery potential based on Wilks' theorem.

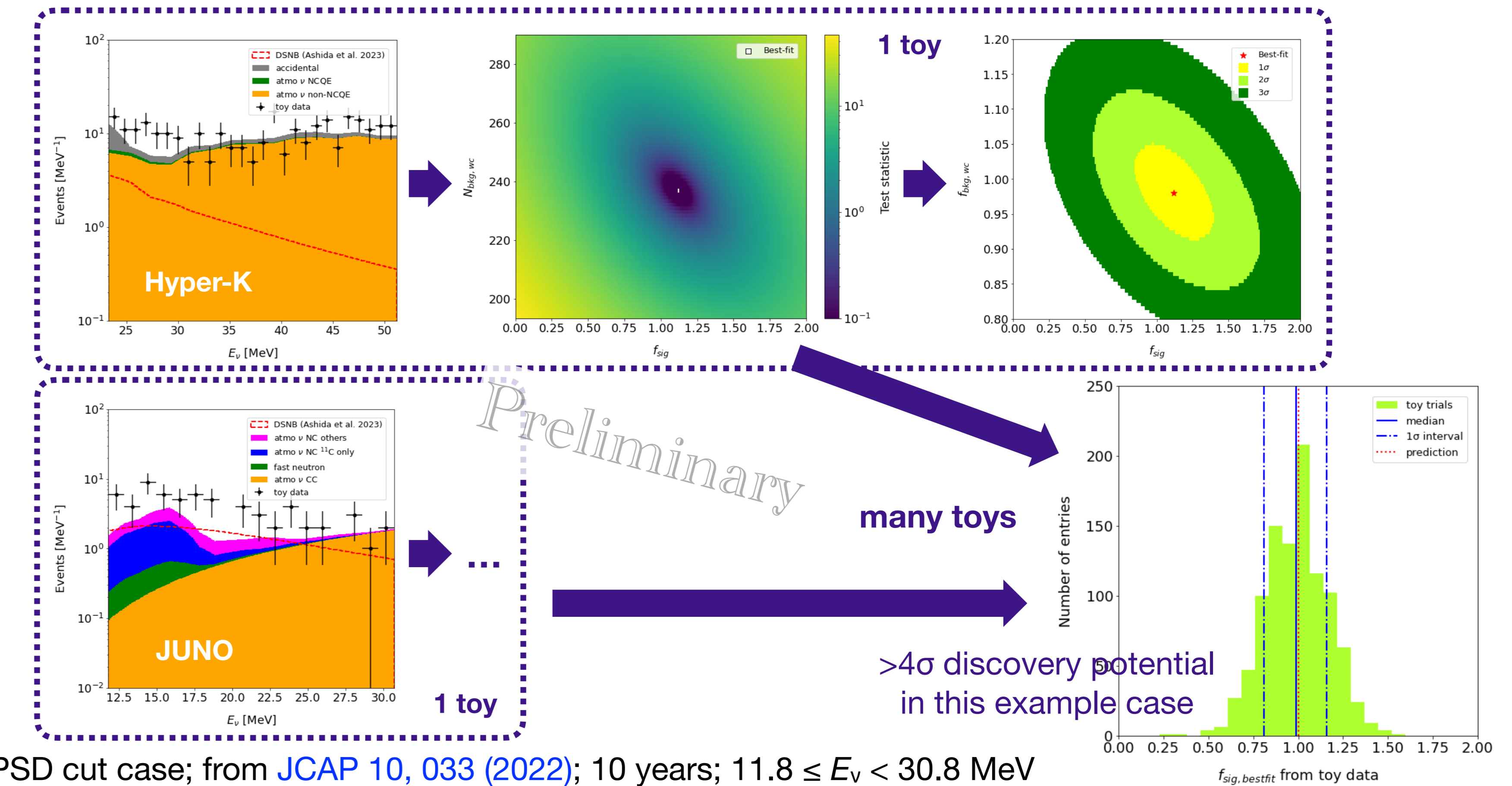
$$L(E_i; N_{\text{sig}}, N_{\text{bkg}}) = \frac{e^{-(N_{\text{sig}}+N_{\text{bkg}})}}{N_{\text{obs}}!} \prod_{i=1}^{N_{\text{obs}}} [N_{\text{sig}} P_{\text{sig}}(E_i) + N_{\text{bkg}} P_{\text{bkg}}(E_i)] \times \prod_{\theta} \exp\left\{-\frac{1}{2} \left(\frac{\theta - \theta_0}{\sigma_{\theta}}\right)^2\right\}$$

TS = $-2 \ln \left(\frac{L}{L_{\text{max}}}\right)$

Poisson term for statistics (i: event ID)
pull term for systematics ($\theta \sim \alpha, \beta, f_j$; PDF shift/shape, bkg norm etc)

4. Demonstration

Extrapolated from SK-IV (PRD 104, 122002 (2021)); 7 years; $23.3 \leq E_{\nu} < 51.3$ MeV



Considered a loosen PSD cut case; from JCAP 10, 033 (2022); 10 years; $11.8 \leq E_{\nu} < 30.8$ MeV

5. Summary & Prospects

- DSNB is a unique probe of astrophysics and particle physics.
- Next generation detectors are operating now or soon with their own search energy window.
- Making full use of available data from multiple detectors is essential in the next era.
- We are developing a dedicated spectral fitting code, **CARNE**, for the future DSNB studies.
- Will sophisticated the code, aiming its public release and technical paper publication of this summer.