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SNEWPY: A Data Pipeline from Supernova Simulations to Neutrino Signals

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Software

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Summary

Current neutrino detectors will observe hundreds to thousands of neutrinos from a Galactic supernova, and future detectors will increase this yield by an order of magnitude or more. With such neutrino data sets, the next Galactic supernova will significantly increase our understanding of the explosions of massive stars, nuclear physics under extreme conditions, and the fundamental properties of neutrinos. However, there is a gulf between supernova simulations and the corresponding signals in detectors, making comparisons between theory and observation, as well as between different detectors, very difficult. SNEWPY offers a unified interface for hundreds of supernova simulations, a large library of flux transformations on the way towards the detector, and an interface to SNOwGLoBES (Scholberg & SNOwGLoBES Contributors, 2021), allowing users to easily calculate and compare expected event rates from many supernova models in many different neutrino detectors.

Statement of need

SNEWPY is an open-source software package which bridges the gap between simulations of supernova neutrinos and the corresponding signals (neutrino events) one would expect from neutrino detectors here on Earth. The package, written in Python, is built upon NumPy (Harris et al., 2020) and SciPy (Virtanen et al., 2020), and makes use of Astropy (Astropy Collaboration et al., 2013, 2018) for model I/O and unit conversions.

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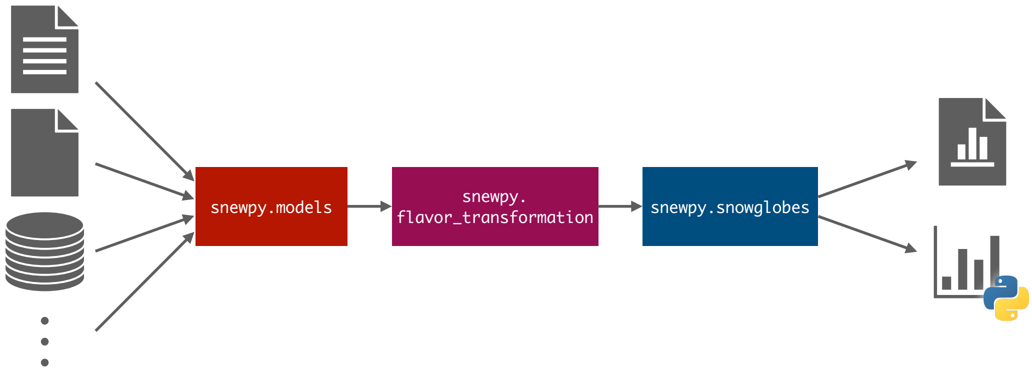

Figure 1: Flowchart showing the complete SNEWPY pipeline. SNEWPY supports a wide variety of input formats and can output results as plots or as a Python dictionary for further analysis.

SNEWPY consists of three main modules that together form a complete simulation pipeline (see Figure 1). The first module, `snewpy.models`, interfaces with supernova simulation data sets in different formats to extract the neutrino emission produced in the supernova as a function of time, energy, angle, and neutrino flavor. The `snewpy.flavor_transformation` module then convolves the neutrino spectra with a prescription for neutrino flavor transformation in the mantle of the star and during propagation to Earth. The third module, `snewpy.snowglobes`, interfaces with SNOwGLoBES itself: First, it can generate either a time series of neutrino spectra at Earth—the "neutrinocurve"—or the spectral fluence. The module is then able to run the generated data files through SNOwGLoBES, which computes the expected event rates in different neutrino detector models, before collating the output from SNOwGLoBES into a signal data file per detector per interaction channel.

Instead of using it as a complete simulation pipeline, SNEWPY can also be integrated into other software thanks to its modular design. For example, the supernova event generator sntools (Migenda et al., 2021) recently incorporated SNEWPY as a dependency to provide access to a broad range of supernova models and flavor transformations.

In addition to the source code, SNEWPY comes with data from several hundred simulations kindly provided by various modeling groups, a script for generating a spectral fluence from an analytic prescription, and several Jupyter notebooks illustrating its capabilities. While SNEWPY has been developed explicitly for the SuperNova Early Warning System, SNEWS 2.0 (Al Kharusi et al., 2021), its object-oriented design makes the addition of new supernova models and flavor transformations straightforward. We expect that it will prove broadly useful to modelers and theorists interested in what neutrino detectors will observe from a supernova simulation, as well as experimentalists wishing to evaluate the sensitivity of their detector to supernova neutrinos.

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