A3D3 Postbac Update

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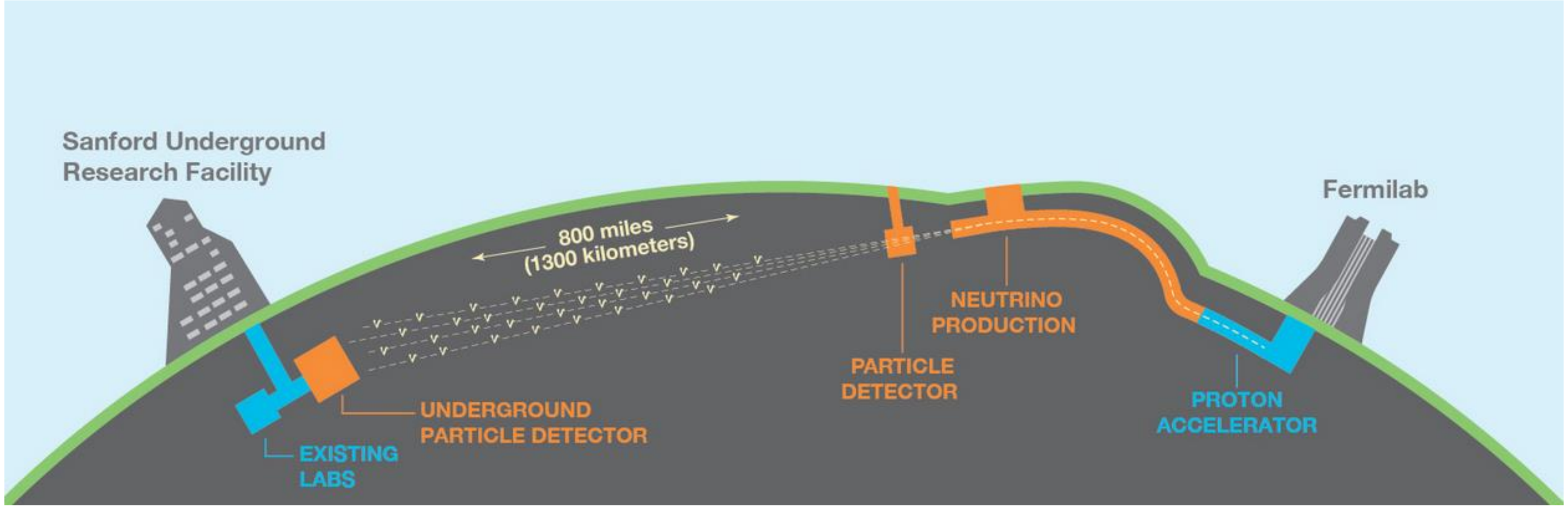
Overview

1. Background Info
2. Ongoing work
3. Everything else (extracurriculars)

1. Background Info

Deep Underground Neutrino Experiment (DUNE)

- The Deep Underground Neutrino Experiment (DUNE); underground in Lead, South Dakota
- Can detect neutrinos from core-collapse supernova – uniquely sensitive to electron neutrinos
- DUNE also has a day job: Long Baseline Experiment



How To Find a Core-Collapse Supernova (Before It Finds You)

99% of energy from core-collapse SN carried away by neutrinos

First detection of neutrinos from core collapse supernova: SN 1987A

As a star gets close to the end of its lifetime neutrinos are released during:

1. Matter infall
2. Burst
3. Remnant

We expect a SN to go off in our galaxy once every few decades

If we can detect the neutrinos from matter infall in these supernovae, we can “find” them before the electromagnetic shock arrives

Detection channels

DUNE's detectors are liquid argon time projection chambers (LArTPC)

Two main detection channels I am considering in my project

- Charge Current (CC) absorption of electron neutrinos on Ar40

$$\nu_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}$$

- And election elastic scattering (eES)

$$\nu_X + e^- \rightarrow \nu_X + e^-$$

We are looking at electrons: different event channels (and the energies of individual events) have different recoil energy and angular distributions, and thus different pdfs

Negative Log Likelihood

- SN direction is reconstructed from neutrino events and their pdfs using the maximum likelihood estimation method

$$-\log \mathcal{L}(\hat{d}_{SN}) = -\sum_i \log p(E_i, \hat{d}_i; \hat{d}_{SN})$$

- We account for a lot of events in our map constructions, taking the negative log of the likelihood allows us to use a sum instead of a product
- We use negative log likelihoods to construct sky map from events
  - Point on map with maximal likelihood of detecting a SN has the minimal negative log likelihood

Why healpy?

healpy is a Python package for handling pixelated data on the sphere

- Based on a C++ library: Hierarchical Equal Area isoLatitude Pixelization (HEALPix)
- Originally developed to process Cosmic Microwave Background data
- Useful functions allowing you to:
  - convert between sky coordinates and pixel indices
  - apply coordinate transformations
  - upgrade and downgrade map resolution
  - Read and write maps to disk in FITZ format

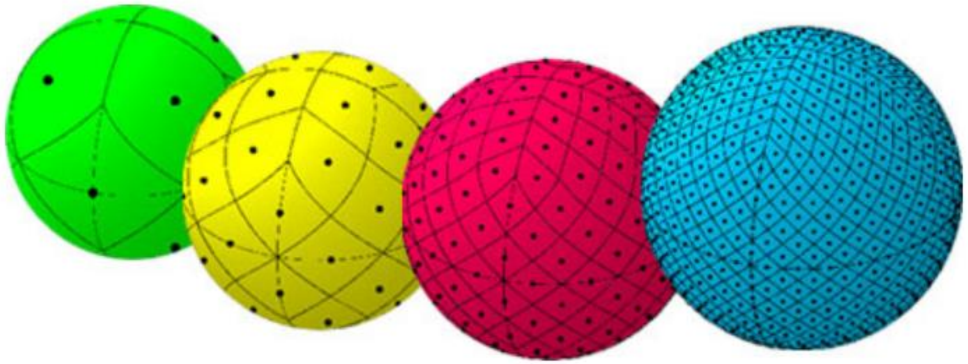


Image citation: NASA JPL

Goals

We want to go from events in our detector to points on the sky:

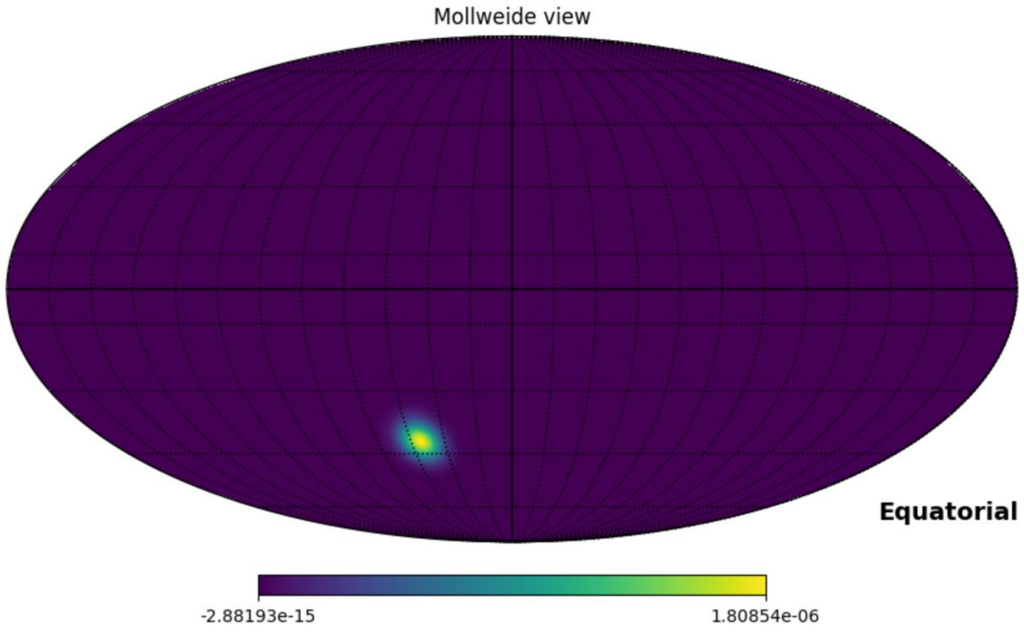
1. Account for coordinate transformations from local altitude/azimuth to a right ascension and declination we can give to astronomers
2. Create negative log likelihood sky maps using healpy
3. Quantify quality of maps with 90% confidence interval
4. Consider how pointing quality varies with isotropic background
5. Generate pre-supernova signals and time-series likelihood map
6. See if this approach can be improved with ML algorithm

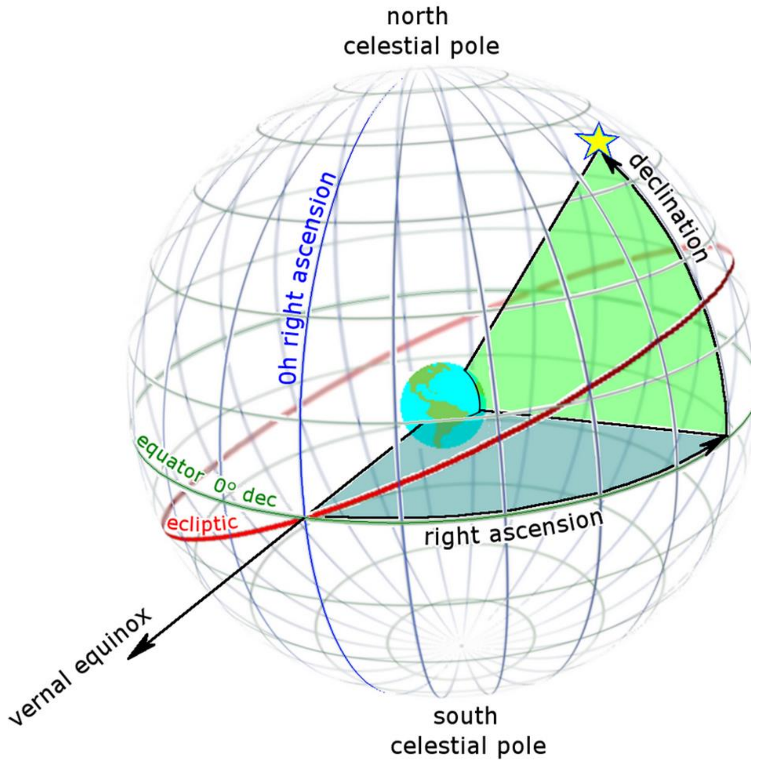
2. Ongoing work

Toy Model

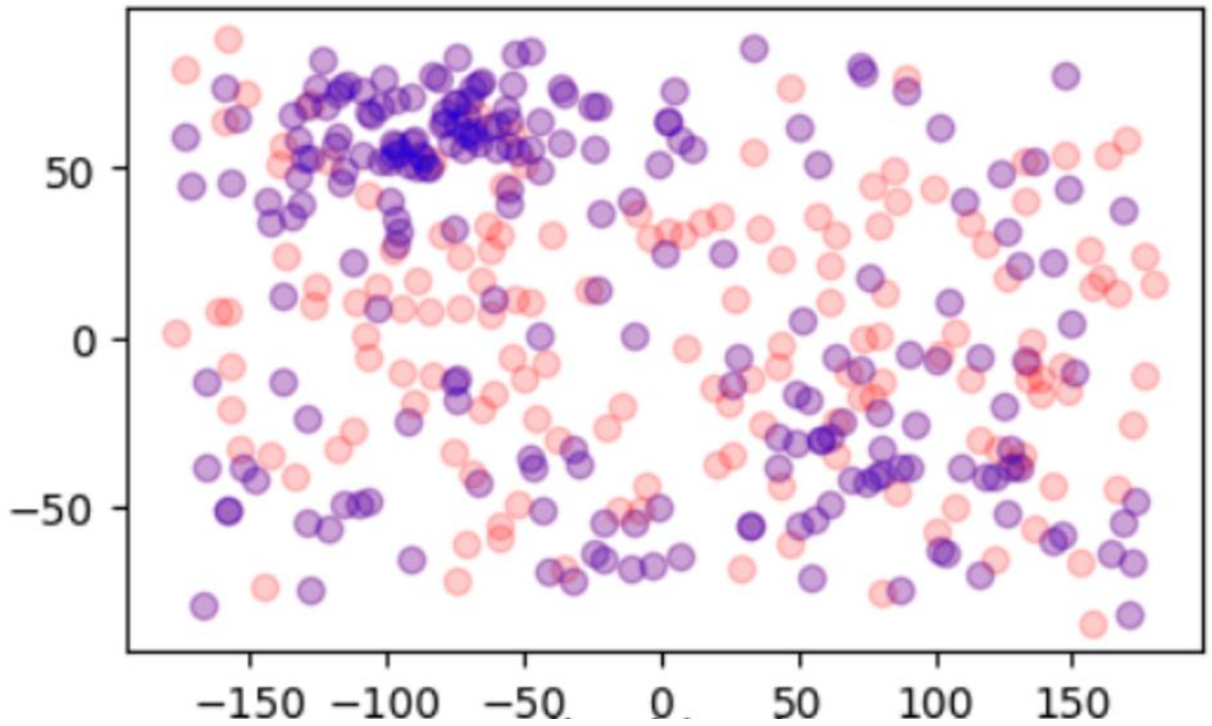
First task: created a toy model to make maps in healpy and takes in an altitude/azimuth, time, elevation, and latitude/longitude of Sanford (DUNE's site) and translates that to right ascension and declination

- Plots a gaussian beam in RA/Dec direction

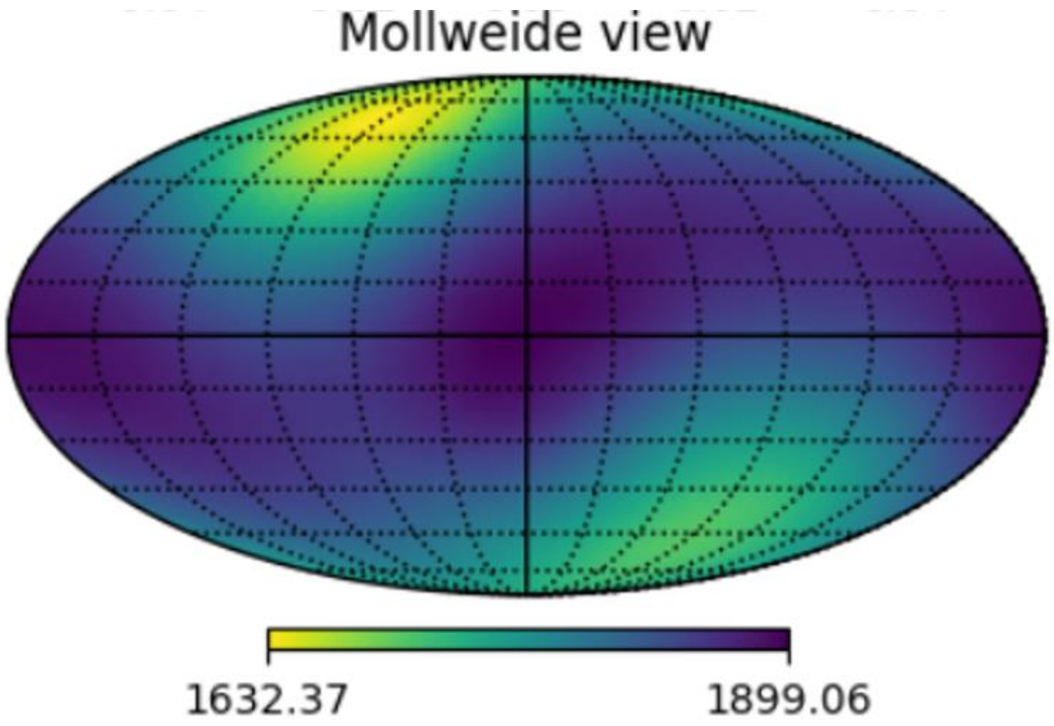




Create negative log likelihood maps

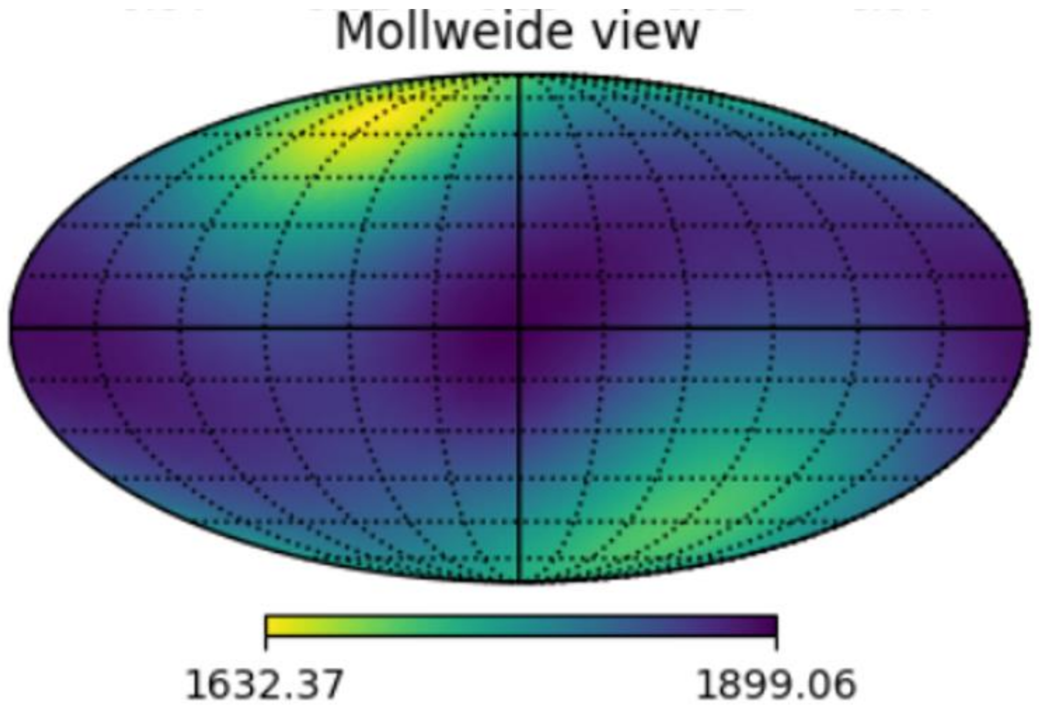


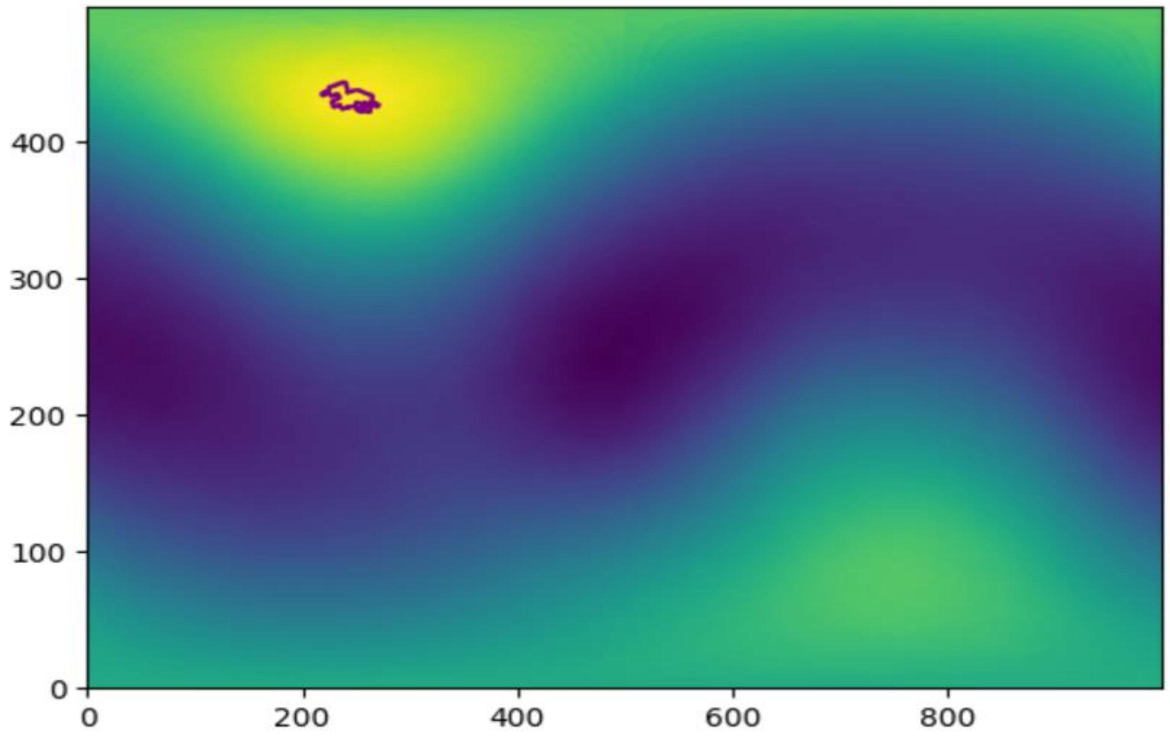
eES events (purple) and CC events (red)



Quantify quality

- Read map out as 2D numpy array, and from there can create a CDF





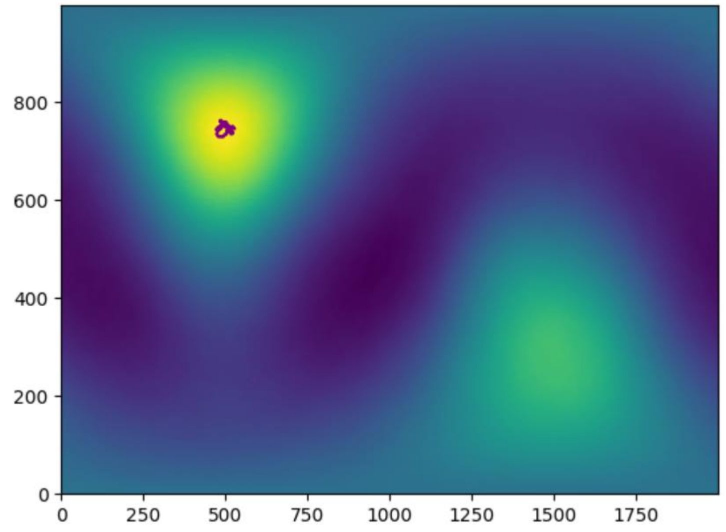
Adding background

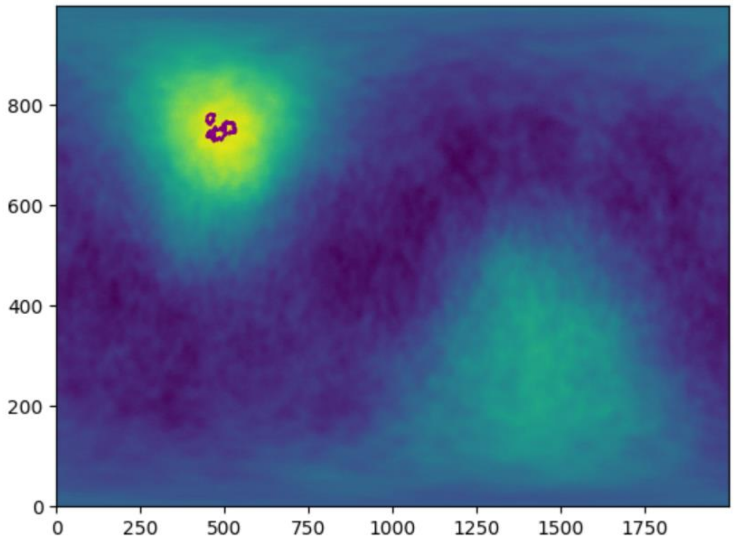
- Simple Monte Carlo to sample points on a sphere
- Background events are very low energy compared to eES and CC events
  - Noise from the detector, cavern
- Initial response to introduction of background gave us trouble: sky fraction not changing as expected
  - Largely due to the pdf distribution we assumed

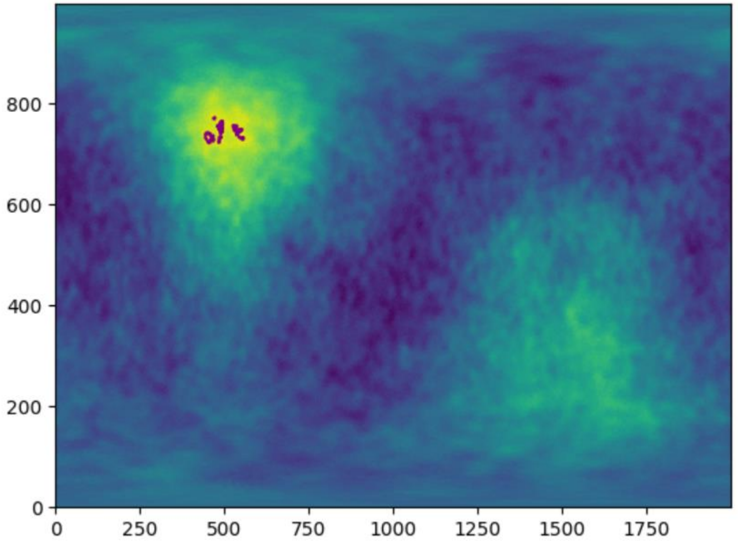
Burst + 1k background

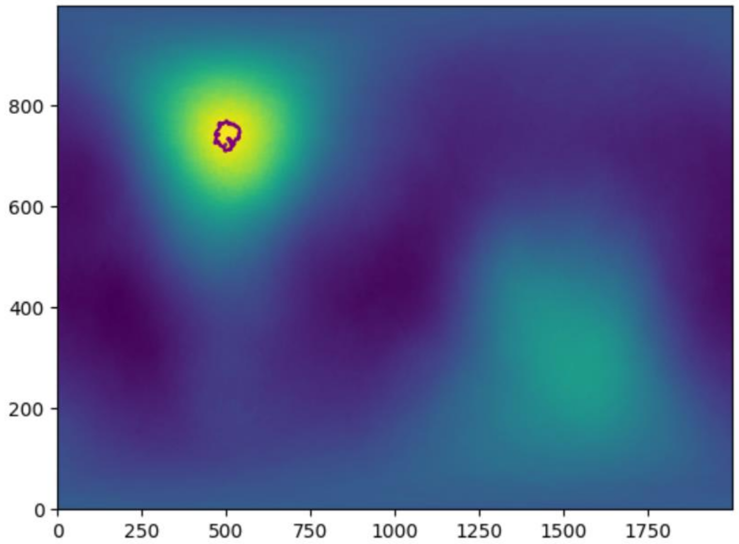
Burst + 2k background

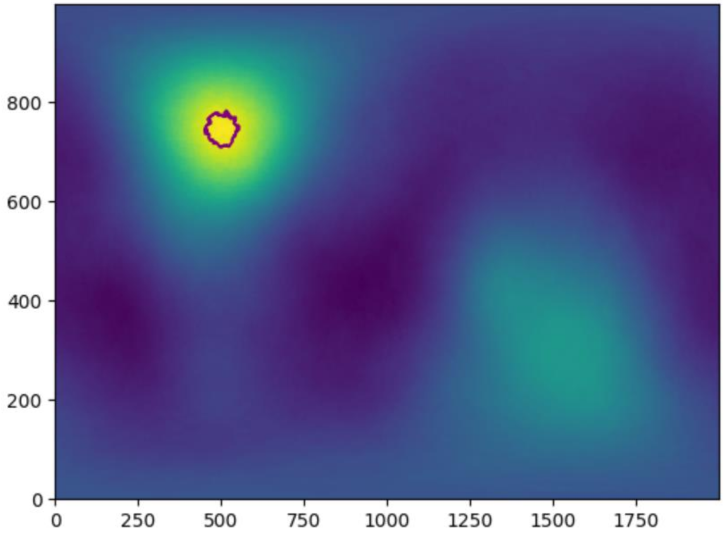
0 background (burst only)











Future Work

- Generate pre-supernova signals and time-series likelihood map
- See if this approach can be improved with ML approach

3. Everything else