Multi-messenger Astronomy: Major Goals

MMA PIs: Coughlin, Graham, Scholberg, Hanson, Katsavounidis, Harris

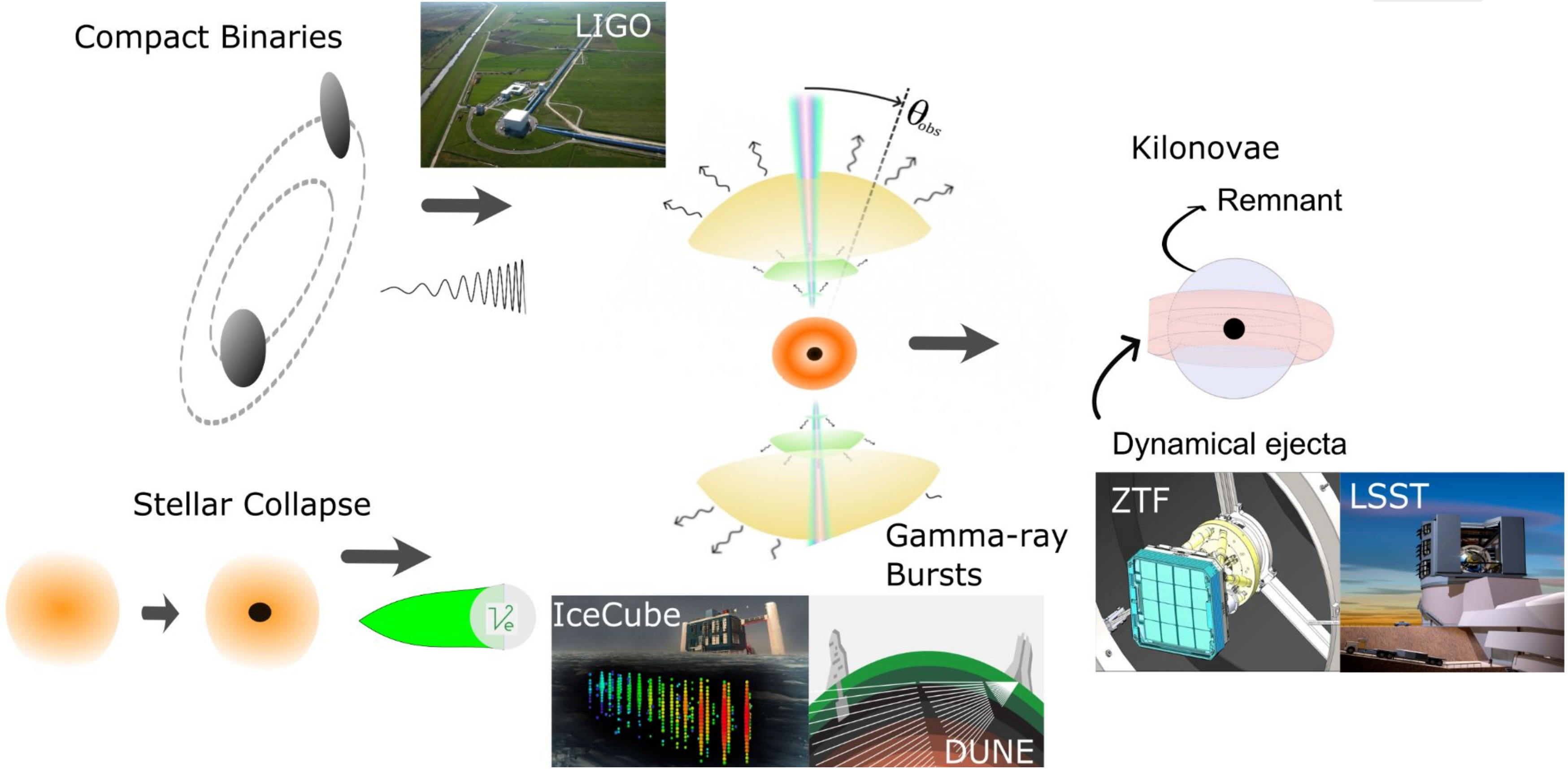
The **Multi-Messenger Astronomy (MMA)** pillar is currently revolved around preparation for ongoing and forthcoming observing runs by the astronomical facilities.

In particular, we are focused on development to improve and characterize transient source detection(s) by **gravitational-wave detectors** such as Advanced LIGO, Virgo and KAGRA.

Associated with such transient source detections/candidates, we are contributing to the preparations for the follow-up by **optical facilities** such as the Zwicky Transient Facility of these events, beginning early 2023.

An additional direction is development of low-latency triggering and pointing algorithms for supernova burst **neutrino direction**, in the context of DUNE, the SuperNova Early Warning System as well as reconstruction algorithms in IceCube.

Multi-messenger Astronomy: Major Goals



Joint MMA Efforts

Monthly PI Meetings

- High level planning discussions

Monthly MMA group meetings

- February 20: 10 minute presentations by members from each pillar, group discussion of strategies to promote more cross-pillar discussions
- March 20: Presentation from Alec Gunny on ML4GW
- April 24: Presentation from Niharika Sravan on observing scenarios plus follow-up optimization

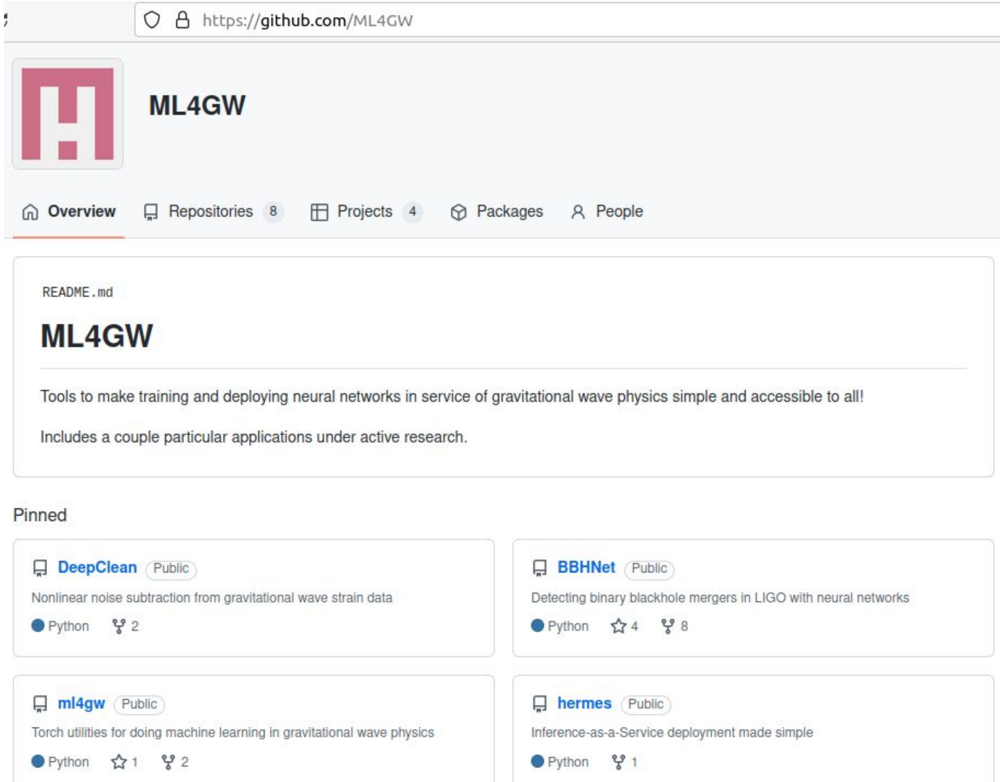
Gravitational Waves

Accelerated AI Algorithms for Data-Driven Discovery

Group meetings: Thursdays 8:30-9:30 Central Time, Fridays 9:30-10:30 Central

~3 faculty, 3 postdocs, 6 grad-students, ~2 post-bac/undergraduates

Top-level github work area: ML4GW

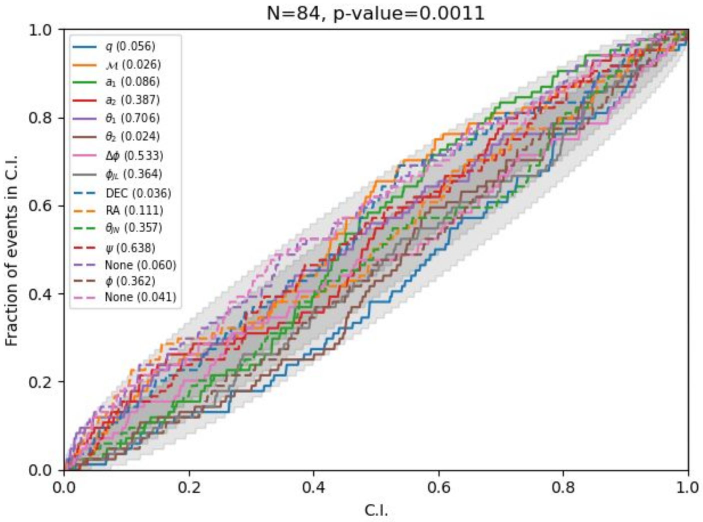


Main focus: Extending the inference-as-a-service (IaaS) prototype and using it to implement a real-time noise subtraction pipeline (DeepClean) for use in the upcoming fourth observing run (O4) of LIGO-Virgo-KAGRA on dedicated hardware at the detector sites. Work continues on gravitational-wave transient detection and source parameter estimation.

Public releases with ongoing Continuous Integration (CI) development of the associated IaaS libraries via main github area.

Gravitational Waves – Denoising work

Compact binary parameter estimation (PE) on the O3 MDC gives unbiased estimates.



Improvements in detectability estimated using GstLAL pipeline - preliminary results shows improvements after the subtraction of 60 Hz power-line noise

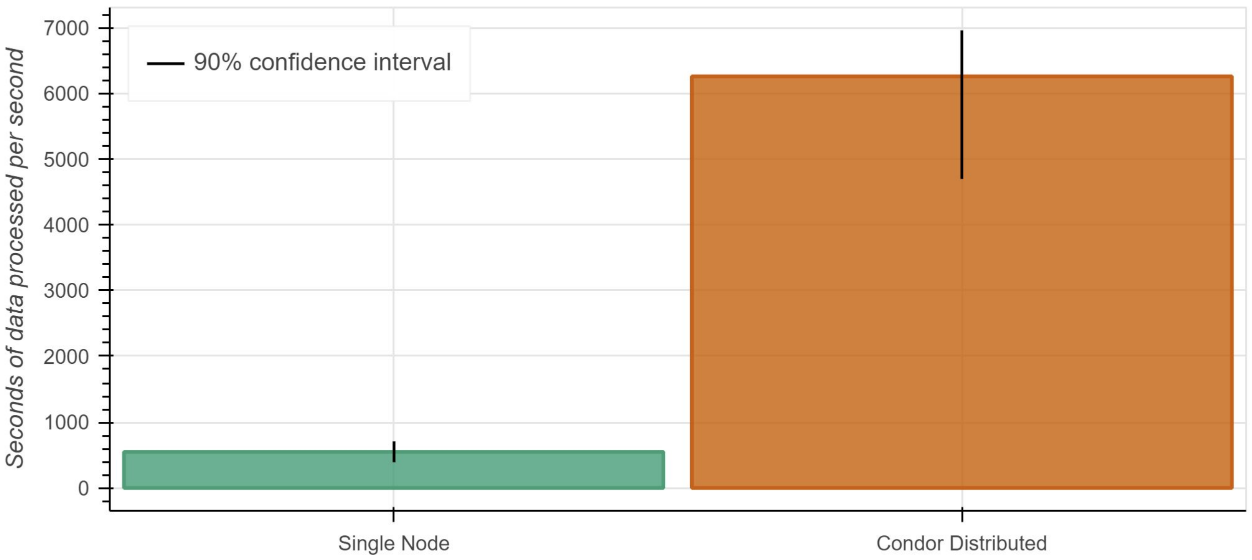
DeepClean - Channel-wise coherence and saliency map analysis, accelerated on GPU. Approximates the "importance" of each channel to strain noise estimate

Gravitational Waves – Detection work

Extending inference-as-a-service model to distribute inference across nodes in LIGO data grid.

This has led to >10x increase in throughput using a single 8 GPU node for serving, with simplified client code.

Robust infrastructure will allow for further scaling to many GPU-enabled nodes.



Optical Astronomy

Group meetings: Tuesdays 11:30-12:30 Central Time, Wednesdays 12-1 Central (ZTF Internal)

Tuesday: ~1 faculty, 2 postdocs, 5 grad students, 2 postbac/undergraduates

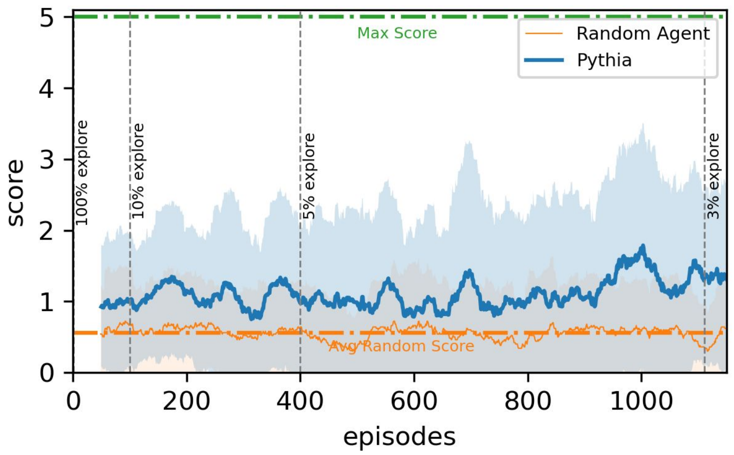
Wednesday: ~4 faculty, 4 postdocs, 6 grad students, 2 postbac/undergraduates

Goal: Developing and implementing ML-assisted follow-up for gravitational-wave counterparts, including injection pipelines to simulate gravitational-wave counterparts such as kilonovae and gamma-ray burst afterglows, and contaminants such as shock breakout supernovae with realistic observing scenarios.

NMMA software released publicly here:
https://github.com/nuclear-multimessenger-astronomy/nmma

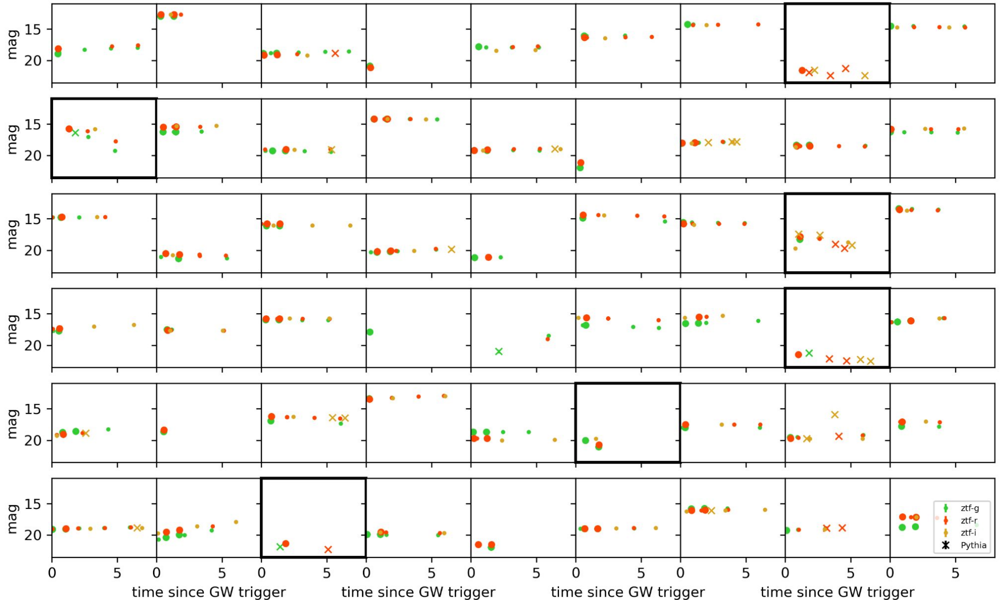
With documentation here:
https://nuclear-multimessenger-astronomy.github.io/nmma/

Optical Astronomy – Activities



Pythia: SARSA agent (linear VFA and TD(0) target) to maximize additional photometric follow-up in ZTF g, r, or i allocated to KNe v. contaminants

- Agent 3x better than random. 80% of KNe receive at least one follow-up photometry
- Overall prefers i filter on days 1-2 and r filter after
- Confuses KNe with GRB afterglows on days 2-4 and SNe on days 4-6
- Human benchmarking in progress. Paper in prep. Code: https://github.com/niharika-sravan/Pythia



Transitioning to deep Q networks:

- Developing environment in Gymnasium to attach to DQN agent in tf-agents.

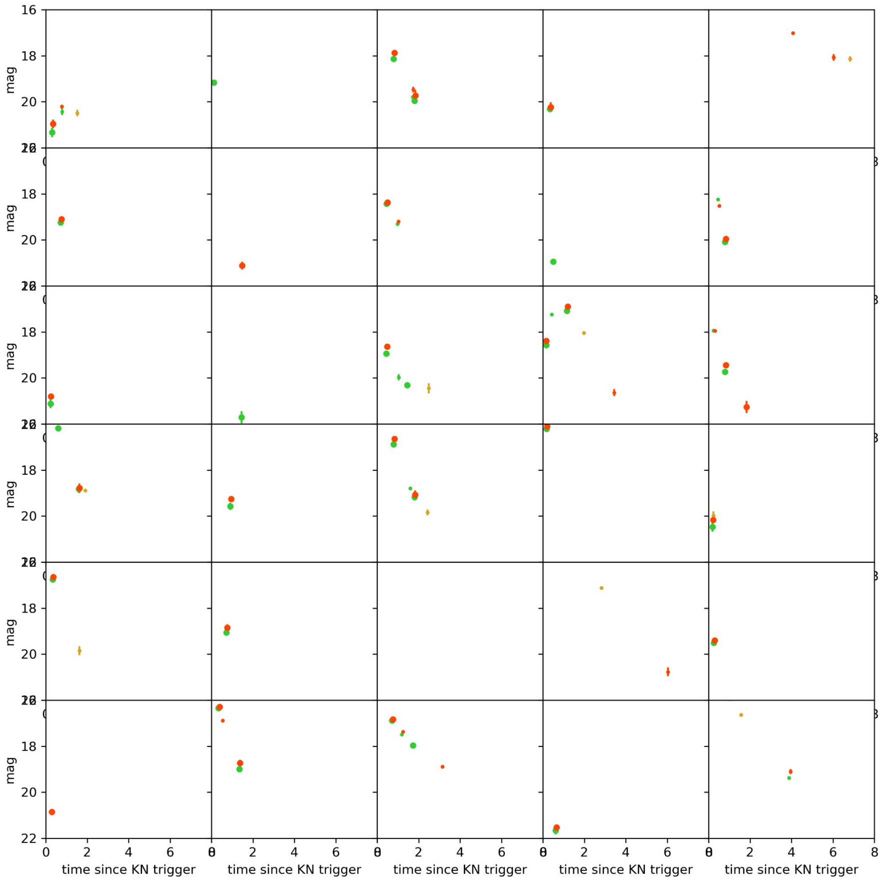
Optical Astronomy – Activities

Ready: training light curves for kilonovae from Binary Neutron Star (BNS) and Neutron Star-Black Hole (NSBH) mergers (10k each) and contaminants including gamma-ray burst afterglows, shock breakout, thermonuclear and core-collapse supernovae, expected from ZTF during LIGO 4th observing run (O4).

Pythia: SARSA agent (linear VFA and TD(0) target) to maximize additional photometric follow-up in ZTF g, r, or i allocated to KNe v. contaminants

Learns on-line in a simulated environment. State/action featurization leverages CNN-autoencoder using LCs only

Currently >2x more accurate than random



To the right: Samples from training dataset for contaminant GRB afterglows as observed by ZTF in g, r and i. Larger datapoints are due to ToO observations.

Neutrinos

Accelerated AI Algorithms for Data-Driven Discovery

DUNE/SNEWS/COHERENT

Faculty: Kate Scholberg
Postdoc: Janina Hakenmüller
Grad student: Joshua Queen
Post-bacc: Van Tha Bik Lian
Specific projects now underway:

- new fast SNB pointing working group led by Hakenmüller (weekly meetings)
    - First paper draft indicating DUNE pointing capability starting collab review
    - Starting implementation on in-situ computing setup
    - ICEBERG data this summer
- VTB Lian working on denoising raw DUNE waveforms w/autoencoder

Group meetings on zoom: Fridays 4 pm Eastern Time + other collaboration-specific meetings

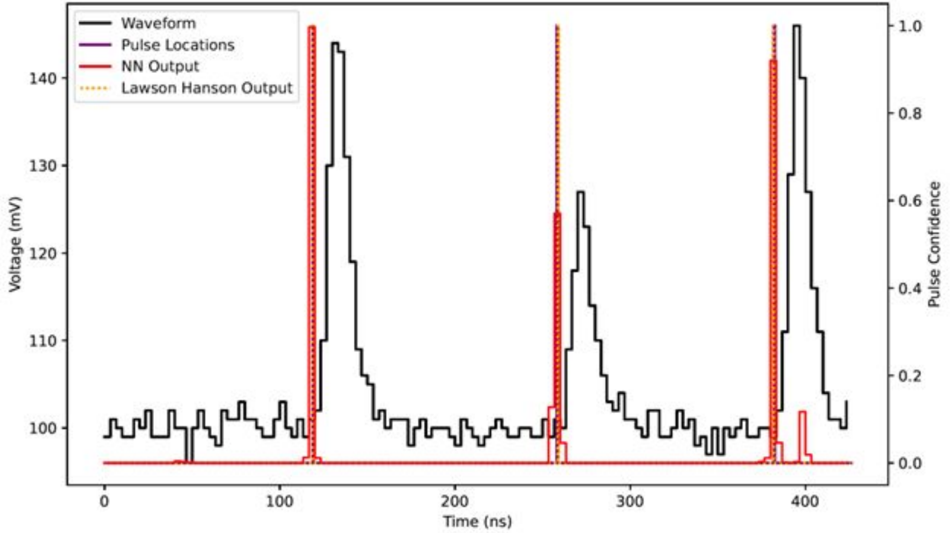
IceCube

- Finally! A Postdoc! B. Ty joins IceCube A3D3 group
    - PhD. Physics 2022
    - Experience with Verilog / VHDL
    - Will pick up from Josh Peterson's work on ML waveform unfolding in FPGA
- Josh is wrapping up hardware work - transition to "thesis mode."

Neutrinos

IceCube

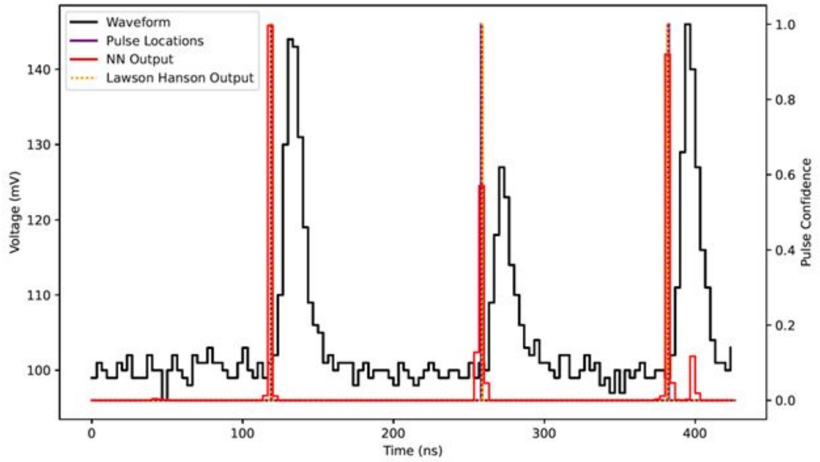
- Goal: Use small neural networks tp process PMT voltage waveforms in GPU or FPGA
- Developed a 1D CNN for finding populated voltage waveform bins and a small neural network for searching populated bins for photon hits
- Both networks combined have a total of about 65,000 trainable parameters
- Ported PMT voltage waveform deconvolution algo to Xilinx/Vitris
- Goal: Use high level synthesis tools to deploy wavedeform algorithm on FPGA accelerator card (single copy successful, need ~100 in parallel as goal)

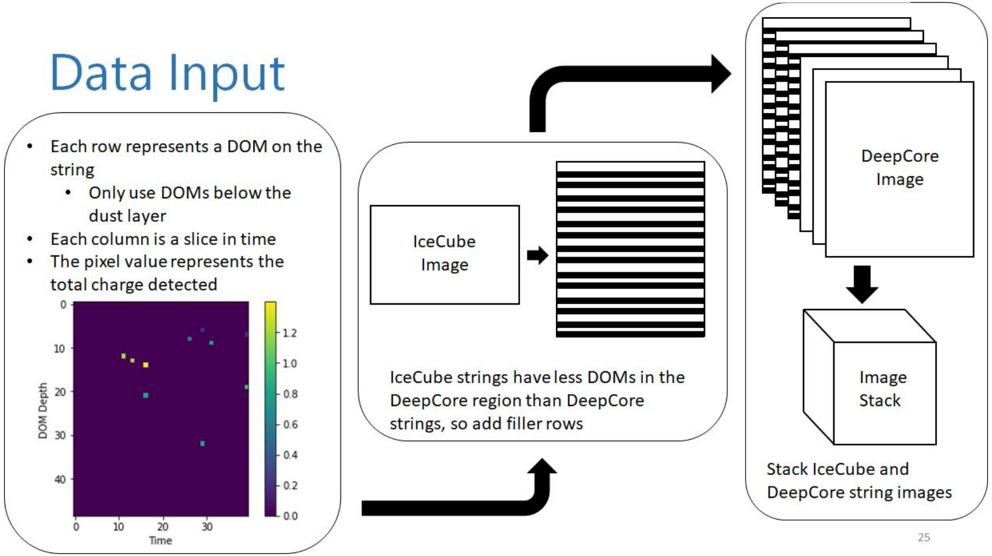


Neutrinos

IceCube

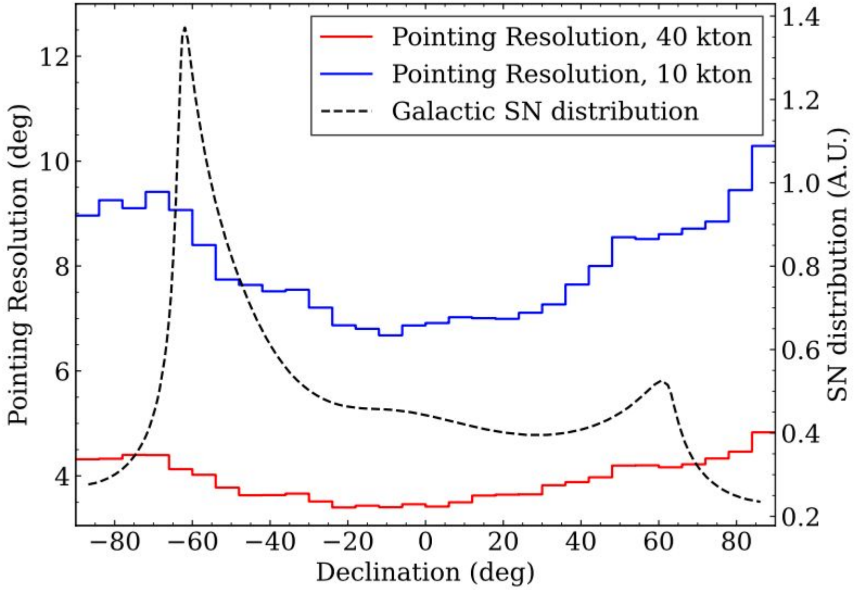
- Started bi-weekly/monthly meetings with Vladimir to talk about HLS issues
- Testing Vitris-based implementation for “standard” algorithm
- Creating CNN for Neutrino oscillation studies
- 1D CNN for waveform deconvolution still development

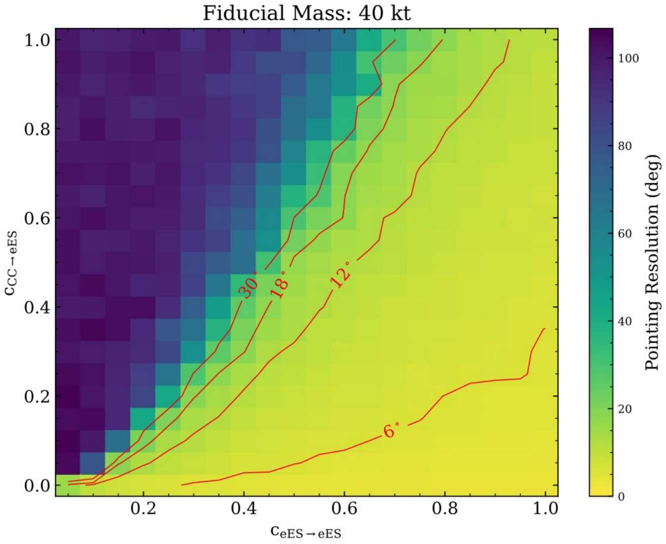




Neutrinos

- *Preliminary* (**internal** technical note in DUNE working group circulation… do not propagate…) evaluation of DUNE pointing capability
- Non-ML proof-of-concept so far: paper starting DUNE collab review process (wg review)
- Depends on “channel tagging” (event classification)-> ML effort
- Next steps: implement in in-situ compute setup
- New: PINNS-AIHEP effort: ICEBERG data @ FNAL this summer (Janina/Josh)





Janina Hakenmueller, James Shen (now grad at Penn), Josh Queen, Kate Scholberg

Outcomes, Achievements, and Objectives

Gravitational waves
- Bringing in other data analysis pipelines (e.g., detection/classification, parameter estimation and interferometer controls) within the International GW network (IGWN) into the inference as a service framework
- Established connections with the NYCU-Taiwan, AEI, UvA, UWA and Cardiff groups (Accelerating Physics with ML@MIT very helpful for this)
- Goal: Running noise subtraction online on ER/O4 data (ER = 4/24, O4 = 5/24); running BBHNet offline over O4a, online during O4b

Optical Astronomy
- Software stack to trigger ZTF on neutrinos and GRBs established as working; ready for ER/O4
- Goal: finish paper on observing scenarios / follow-up strategy implications / data set

Neutrinos
- Developing new fast reconstruction tools for supernova burst pointing in DUNE -> new working group underway**, first sim/reco results;** waveform unfolding in IceCube
- Goal: ML-based channel-tagging for fast pointing reco for DUNE; accelerated unfolding algorithms on the surface for new ML based reconstruction algorithms for IceCube

Accelerated AI
Algorithms for
Data-Driven
Discovery

Thank you!

Impact

On the development of the principal discipline(s) of the project:

All three pillars are very well integrated into and driving the growth of their respective communities

On other disciplines

With the gravitational-wave work, we have curated and provided a data set to test novel regression algorithms against, and will be doing something similar for the detection work. On the optical side, we are creating a novel fast transient focused data set with Bayesian inference posteriors provided; we are also enabling the observing scenarios for the next gravitational-wave observing run. All of these provide unique data sets for others to test out algorithms with.

On the development of human resources

The projects all have significant graduate student and undergraduate involvement in a variety of forms, with post-docs and graduate students the point of contacts for a number of deliverables.

On the development of educational experiences

The data sets being curated will be used in the ZTF Summer School and in a variety of classes taught by the A3D3 professors.

Institutional resources that form infrastructure
N/A