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.

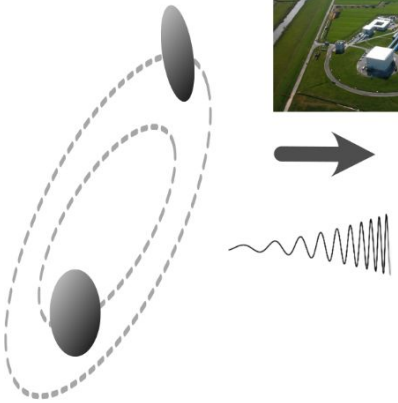
In particular, we are focused on development to improve and characterize transient source detection(s) by **gravitational-wave detectors** such as Advanced LIGO, Virgo and KAGRA.

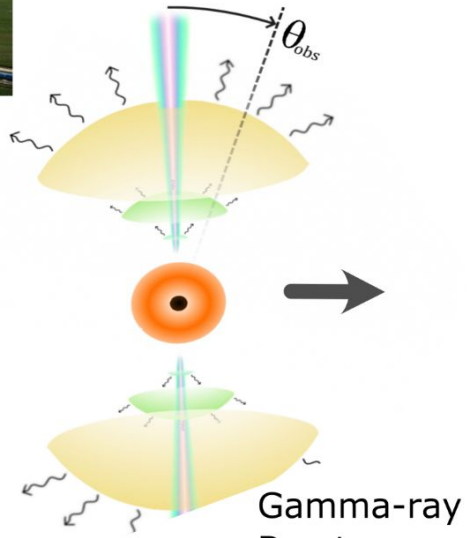
Associated with such transient source detections/candidates, we are contributing to the preparations for the follow-up by **optical facilities** such as the Zwicky Transient Facility of these events, beginning early 2023.

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

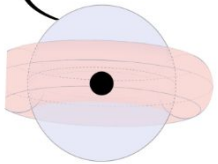
Compact Binaries





Kilonovae

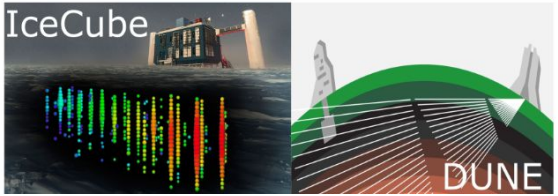
Remnant



Dynamical ejecta

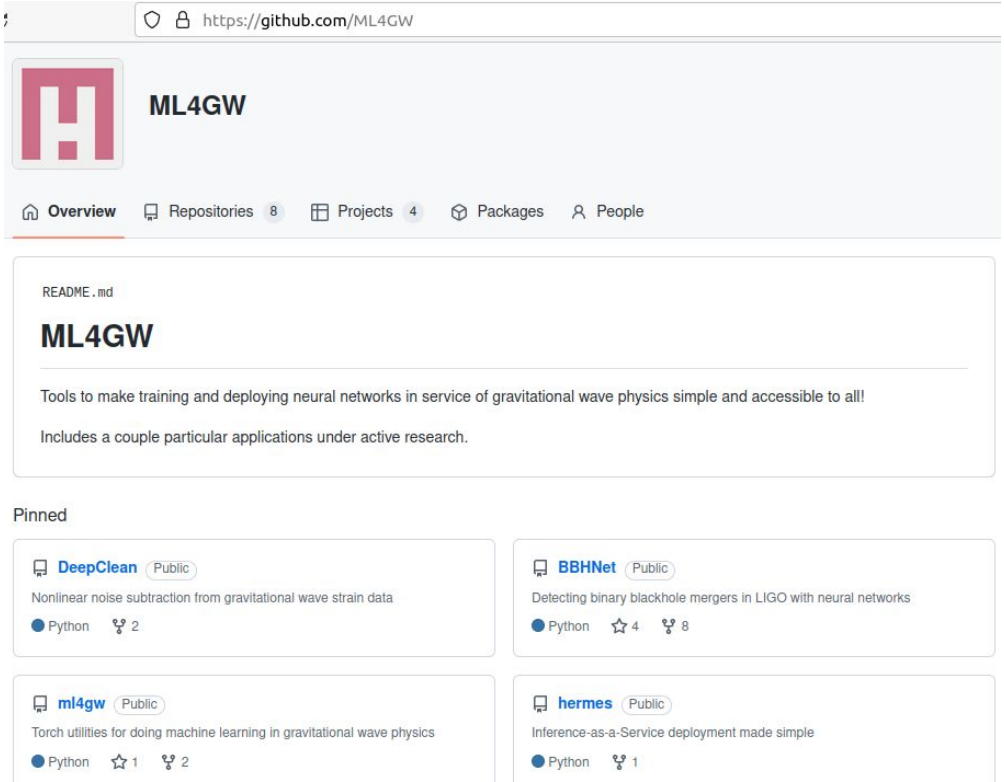
Stellar Collapse

Gamma-ray Bursts



Gravitational Waves

Group meetings: Thursdays 8:30-9:30 Central Time, Fridays 2-3 Central
~3 faculty, 3 postdocs, 6 grad-students, ~2 post-bac/undergraduates
Top-level github work area: ML4GW



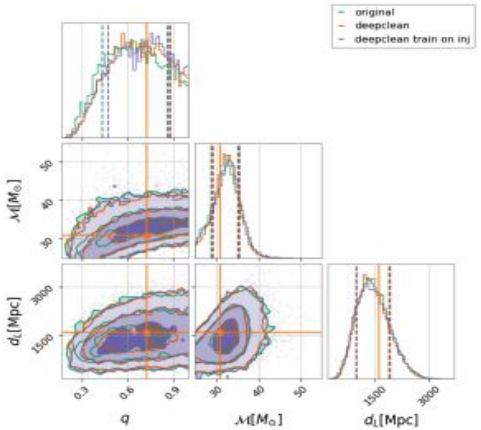
Main focus: Extending the inference-as-a-service (IaaS) prototype and using it to implement a real-time noise subtraction pipeline (DeepClean) for use in the upcoming fourth observing run (O4) of LIGO-Virgo-KAGRA on dedicated hardware at the detector sites. Work continues on gravitational-wave transient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

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

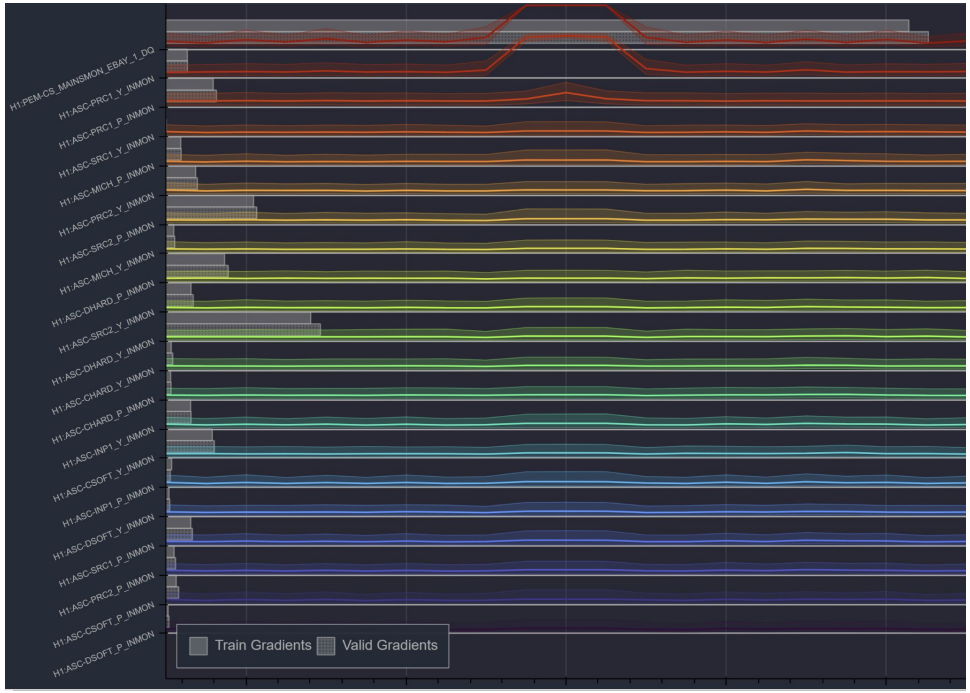
Gravitational Waves – Denoising work

Compact binary parameter estimation (PE) on the MDC data.

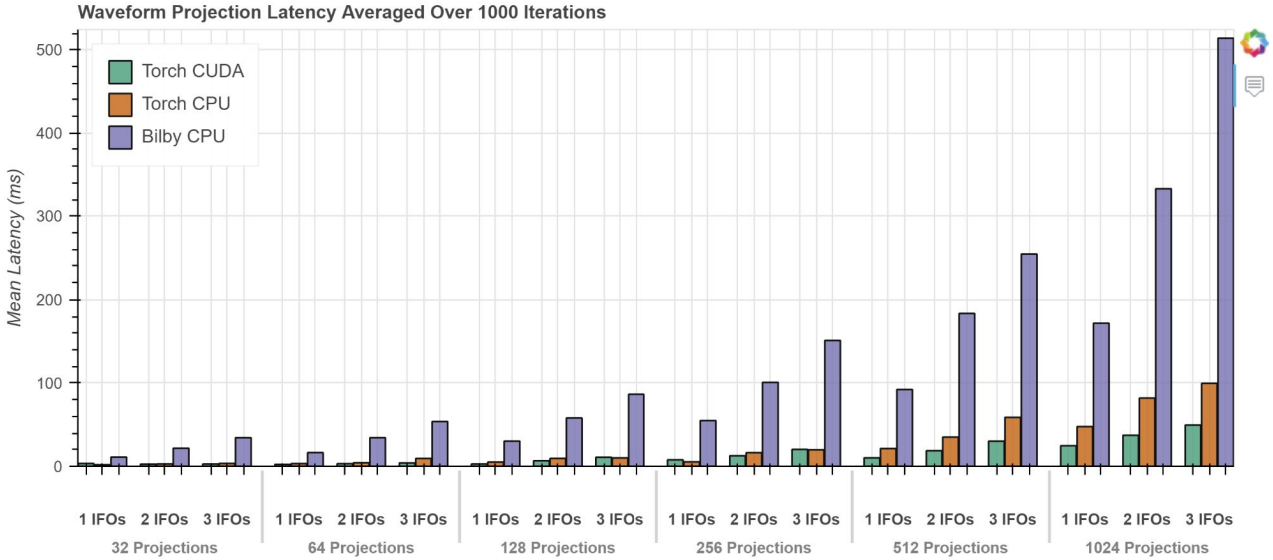
- 20 days O3 data + 25000 simulated GW signals (BBH, BNS and NSBH)
- PE performed after the subtraction of 60 Hz noise with DeepClean
- Unbiased parameter recovery.



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



BBHNet - Accelerated projection of gravitational waveforms to interferometer responses, allowing for faster augmentation at training time. Broader applications to other machine learning applications and beyond - being composed into standalone library https://github.com/ML4GW/ml4gw

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/

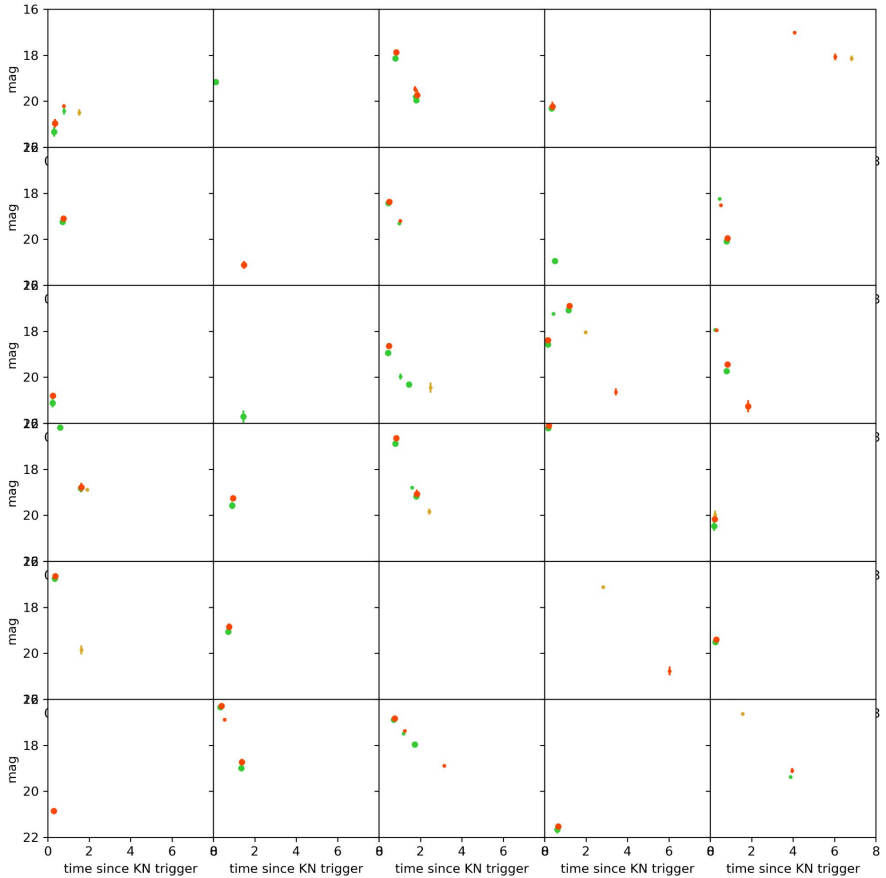
Optical Astronomy – Activities

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

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)
- 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."

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
- Goal: Running noise subtraction online on MDC (Monte Carlo data) and then O4 data

Optical Astronomy

- Developing telescope triggering and analysis toolkit and distributing to other teams (discussion with Rubin in use for their ToOs, discussion with Australians for O4, etc.)
- Used framework for follow-up of a high energy neutrino
- Goal: First end-to-end Fermi GRB and then gravitational-wave event

Neutrinos

- Developing new fast reconstruction tools for supernova burst pointing in DUNE and 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

Outcomes, Achievements, and Objectives

Accelerated AI Algorithms for Data-Driven Discovery

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Neutrinos

- Developing new fast reconstruction tools for supernova burst pointing in DUNE -> **new working group formed;** 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

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.

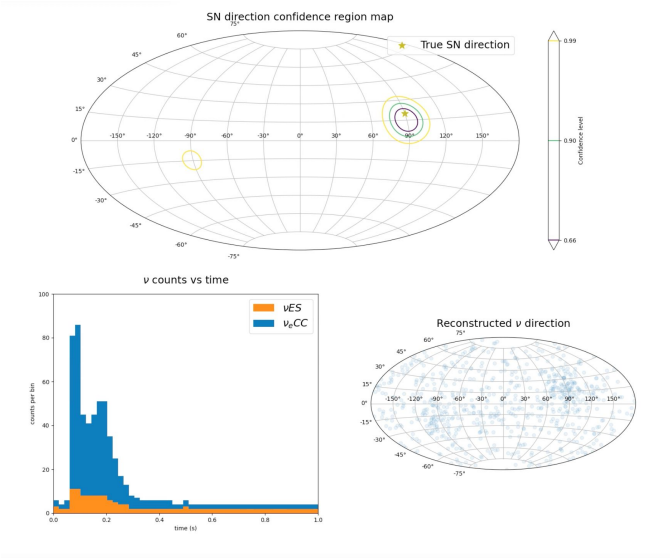
On the development of educational experiences

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

DUNE supernova burst pointing studies @ Duke

- Grad student Josh Queen
  - Toy pointing study and animation to learn the physics & reco issues



- Post-bacc Van Tha Bik Lian starting on DUNE: 1DCNN autoencoder project for raw LArTPC waveforms
- Postdoc Janina Hakenmüller on DUNE and COHERENT