Data Analysis and Machine Learning Education in the Physics Department at the University of Illinois

Mark Neubauer

University of Illinois at Urbana-Champaign

APS DSECOP Workshop

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Origins of my DS/ML course in Physics

The idea for developing a course in data analysis and ML applications for our undergraduates grew out of townhall discussions ~6 years ago in our department

- At the time, there were no such courses in our Physics department (now there are several)
- Data science was on the rise, especially driven by the revolution around machine learning
- Students recognize the high value of training at the intersection of data science, AI and physics

I pitched this new course in 2017 at our PAB meeting & taught in Fall 2018, Spring 2019, Fall 2019, Spring 2022

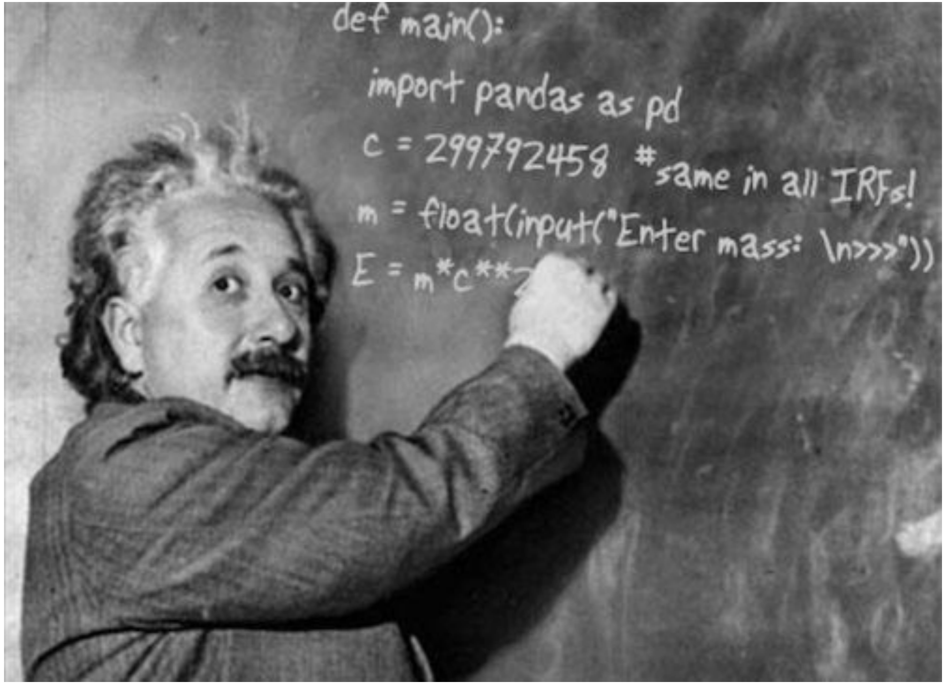
Course website: http://illinois-mla.github.io/syllabus

PHY 398MLA

Data Analysis & ML Applications for Physicists

Topical focus:

- Techniques for analysis and interpretation of scientific data
- Machine learning principles and applications to physics



Technical approach:

- Open everything
- Minimize coding focus: Data Science to advance Physics is the goal

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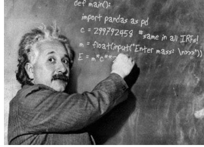

Motivation

- We live in a data-centric world, with people and machines learning from vast amounts of data.
- Early-career physicists need a solid understanding in the basics of data analysis, data-driven inference and machine learning, and a working knowledge of modern tools and techniques from data science

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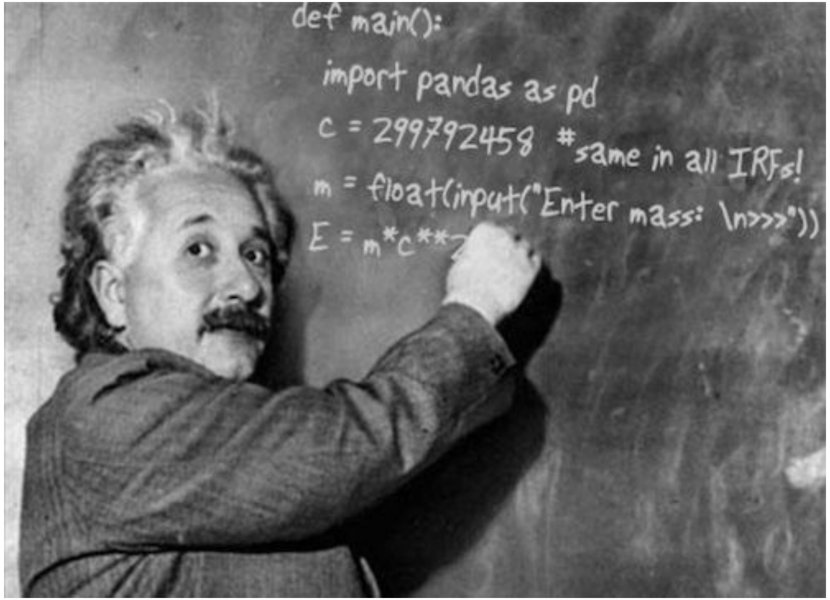
Why do this in Physics?

- Data science is an exploding area both academia and industry
  - E.g. we find that many problems in physics map to vision problems amenable to automation via ML methods
- Many of the future (and current) jobs will be in this area



- Physics students need a solid foundation in data analysis & interpretation to do research. They need this education and training to be productive in science and thrive as the next generation of leaders

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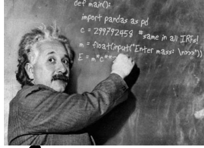

Data Analysis & ML Applications for Physicists

Structure

- ❖ Two credit-hour course
- ❖ One 2 hour lecture each week
  - o Attendance and class participation are mandatory
- ❖ 8 Homework assignments
  - o New problems posted ~weekly, due within 1 week
- ❖ A final project based on analysis of open science data

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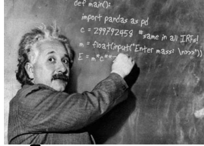

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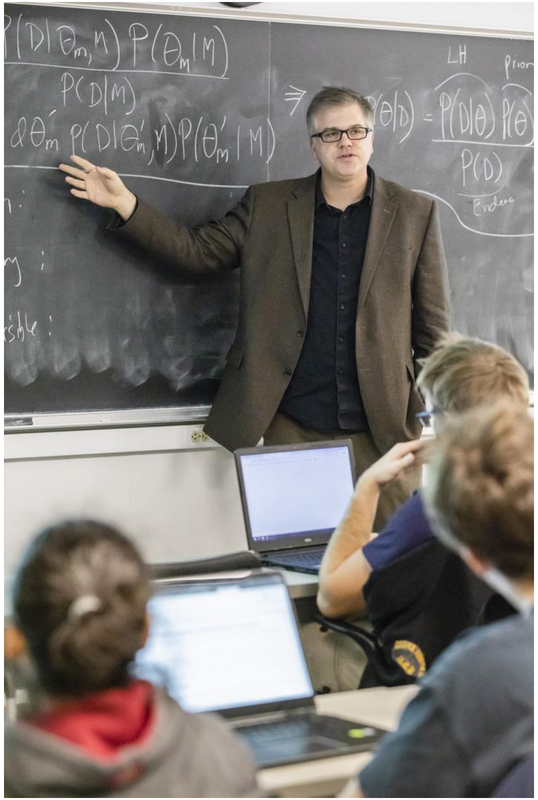
Pedagogy in Motion

- At the center of the course is *scientific data*
  - Students learn how to analyze it, simulate it, gain insight from it, and get machines to learn from it
- Students acquire a working knowledge of DS tools
  - All lecture materials, homework and projects are python-based within in Jupyter notebooks (.ipynb)
  - Materials are managed within a Github organization
    - Students submit homework (.ipynb) to their private Github repo. Homework is managed by nbgrader
  - In-class time is a mixture of collective listening and active learning with *in-situ* coding exercises



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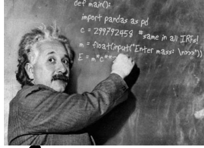

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PrairieLearn PHYS 398MLA Issues Questions Sync / Spring

Access | Assessments | Files | Gradebook | LTI

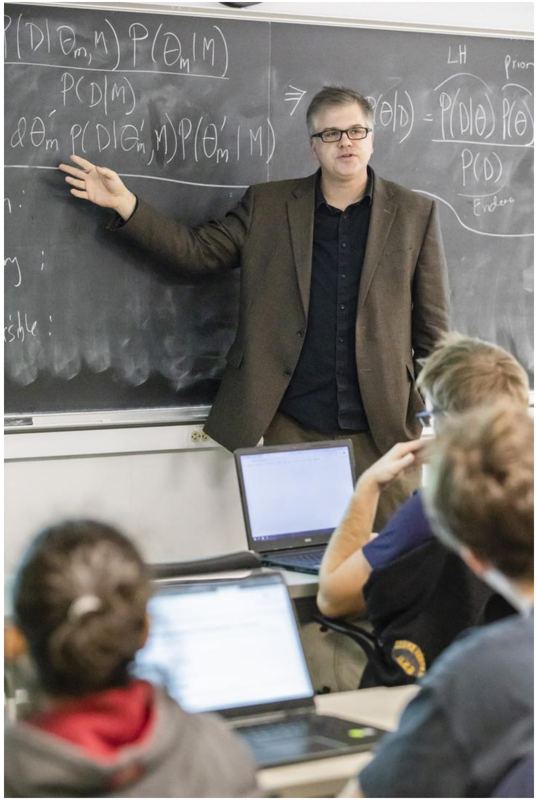
Assessments

		AID
Lecture Activities		
L1	Lecture 01	lectures/lecture01
L2	Lecture 02	lectures/lecture02
L3	Lecture 03	lectures/lecture03
L4	Lecture 04	lectures/lecture04
L5	Lecture 05	lectures/lecture05
L6	Lecture 06	lectures/lecture06
L7	Lecture 07	lectures/lecture07
L8	Lecture 08	lectures/lecture08
L9	Lecture 09	lectures/lecture09
L10	Lecture 10	lectures/lecture10
L11	Lecture 11	lectures/lecture11
L12	Lecture 12	lectures/lecture12
L13	Lecture 13	lectures/lecture13
L14	Lecture 14	lectures/lecture14

PrairieLearn is **an online problem-driven learning system for creating homeworks and tests**

- Developed by **the University of Illinois** in 2014

Course Projects		
P1	Final Project	projects/FinalProject
Homeworks		
HW1	Homework 01	homework/homework01
HW2	Homework 02	homework/homework02
HW3	Homework 03	homework/homework03
HW4	Homework 04	homework/homework04
HW5	Homework 05	homework/homework05
HW6	Homework 06	homework/homework06
HW7	Homework 07	homework/homework07
HW8	Homework 08	homework/homework08



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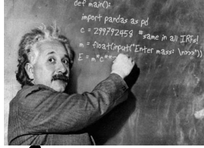

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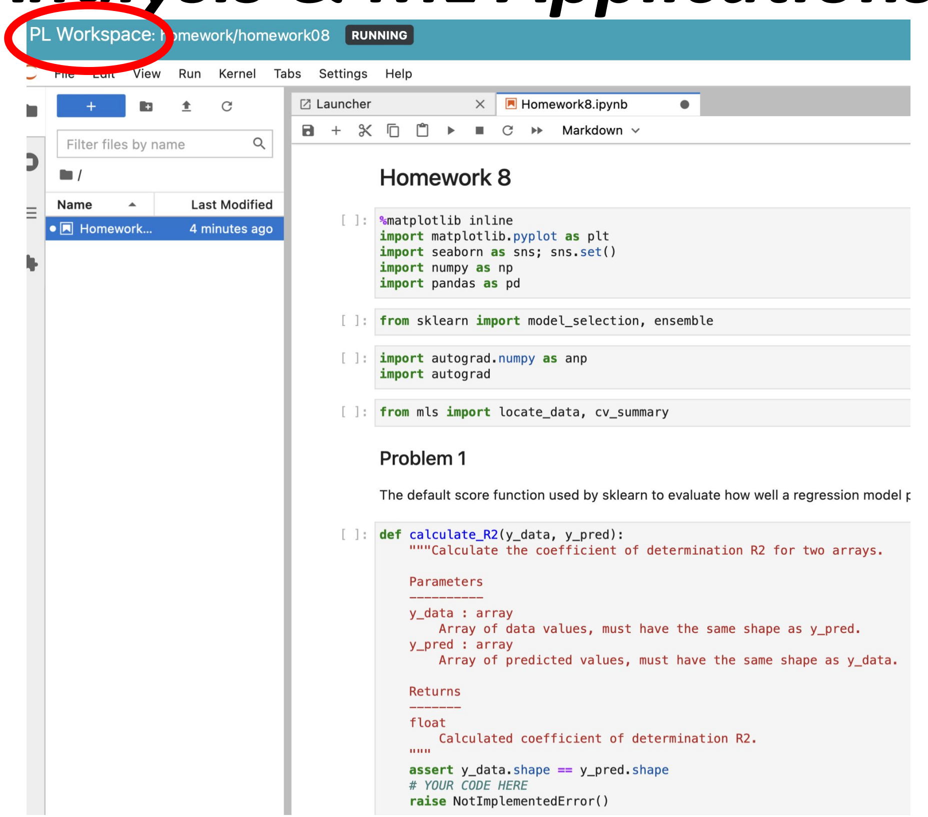
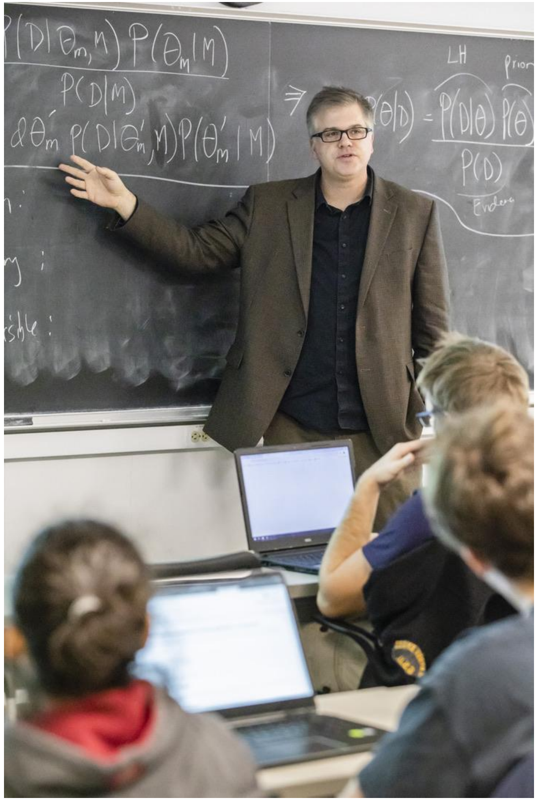
PrairieLearn Workspaces allow students to work in persistent remote containers via in-browser frontends such as VS Code and JupyterLab.

Workspace questions are integrated with the standard PrairieLearn autograding pipeline.

The remote containers are configured by instructors to provide *[custom, uniform environments per question](#)*.





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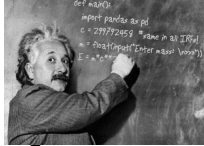
Docker container:
https://github.com/illinois-mla/phys-398-mla-image



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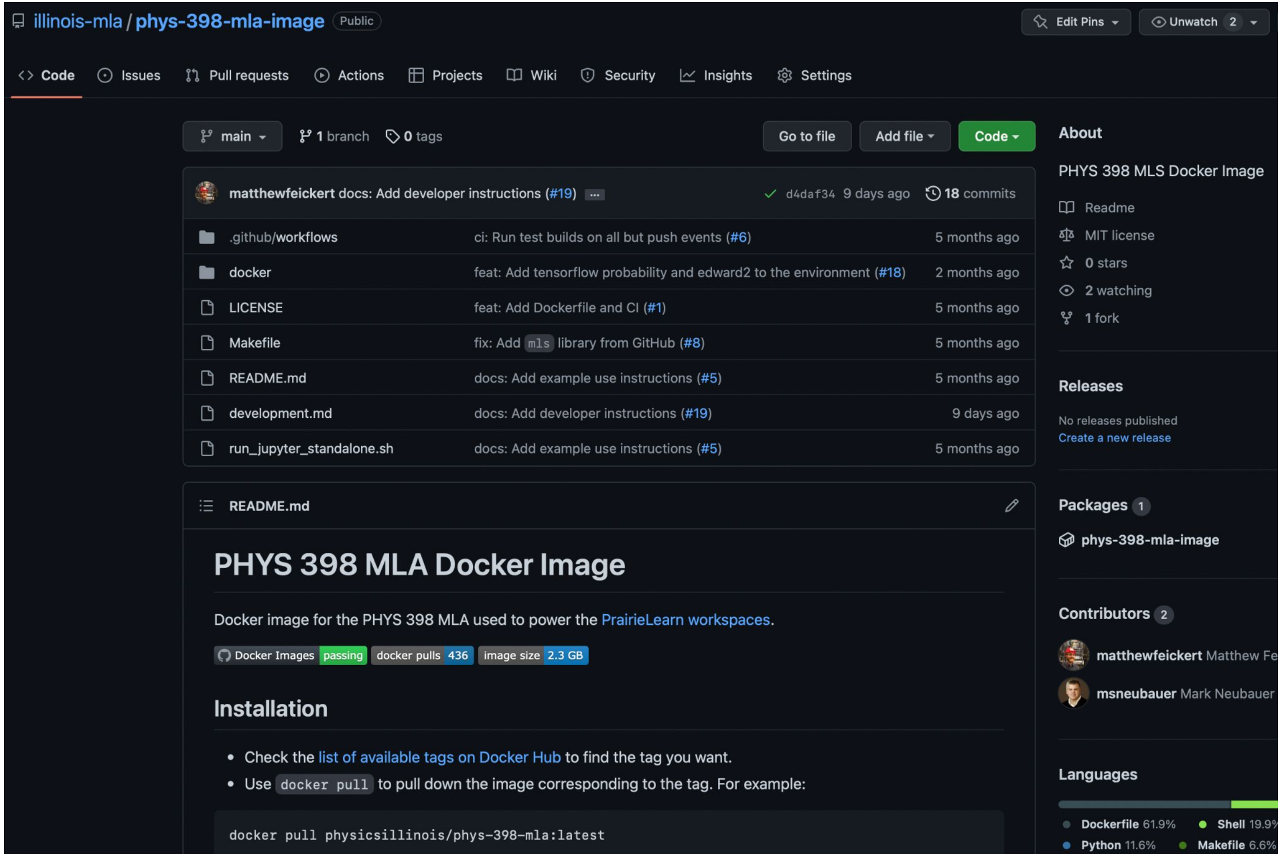

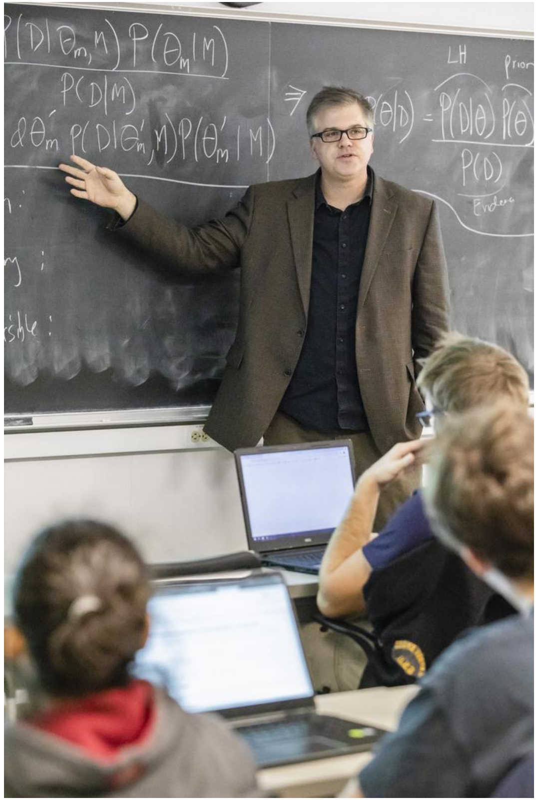

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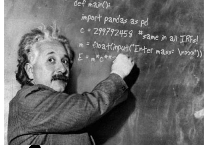

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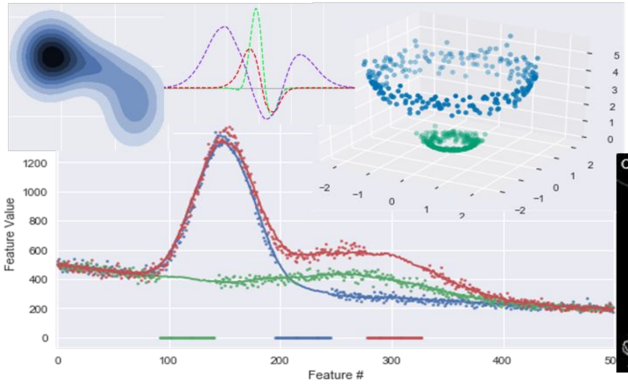
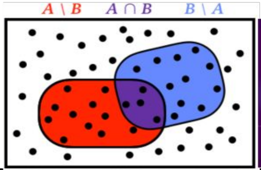
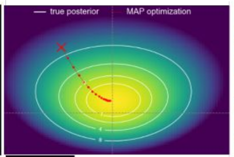
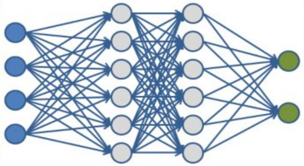
Topics

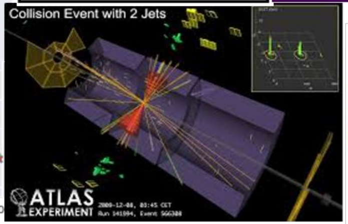
1) *Handling and Visualizing Data*
2) *Finding structure in data*
3) *Measuring and reducing dimensionality*
4) *Adapting linear methods to nonlinear problems*
5) *Estimating probability density*
6) *Probability theory*
7) *Statistical methods*
8) *Bayesian statistics*
9) *Markov-chain Monte Carlo in practice*
10) *Stochastic processes and Markov-chain theory*
11) *Variational inference*
12) *Optimization*
13) *Computational graphs*
14) *Probabilistic programming*
15) *Bayesian model selection*
16) *Learning in a probabilistic context*
17) *Supervised learning in Scikit-Learn*
18) *Cross validation*
19) *Neural networks*
20) *Deep learning*

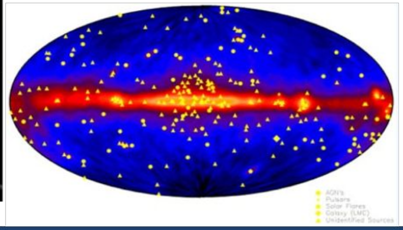


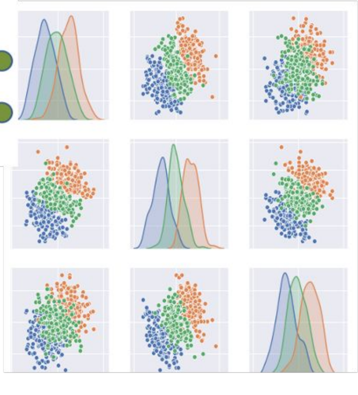












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Some challenges:

- Coding is new for many students. Many are unfamiliar with Python, Git, Jupyter notebooks, etc … → provide ample resources/examples
- Challenge to keep notebooks working over years (e.g. TF API changes, …) and the software packages/tools current
- Modules for physics applications (thanks to DSECOP Fellows!)
- Access to GPU resources for training deep neural network models

Work in progress:

- Developing an advanced version for MEng in Instrumental Physics @ Illinois

https://a3d3.ai