Using Neural Networks to Detect Black Hole Dark Matter

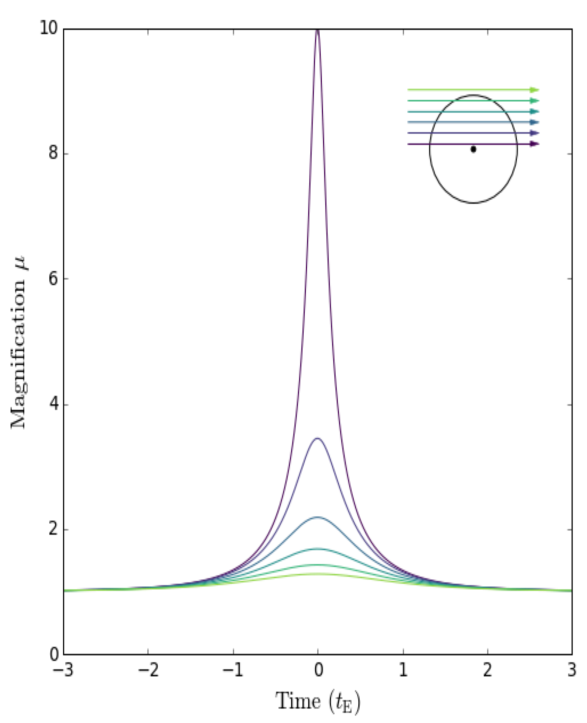
DSSI DATA SCIENCE SUMMER INSTITUTE

Ryan Dana (UC Berkeley), William Dawson (LLNL)

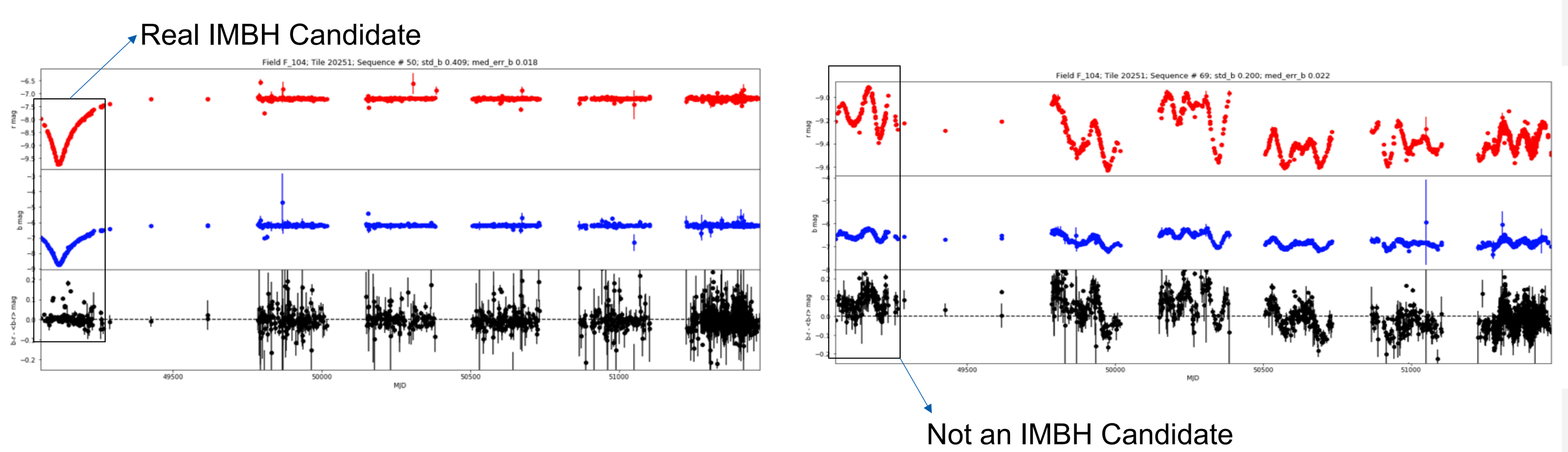
Lawrence Livermore National Laboratory

Is dark matter just black holes?

- Black holes with Mass of Range (10^2-10^6)M☉ could make up all dark matter.
- LIGO has found supporting evidence for black holes as dark matter. [cite Bird et al. 2016], but it is an indirect probe.
- Gravitational microlensing is the most direct probe of black holes.
- While the microlensing signal can be completely physically modeled, other stellar variability is not easily modeled and is a dominant systematic.



- **We are attempting to use deep neural nets to overcome this modeling limitation and detect intermediate mass black holes.**

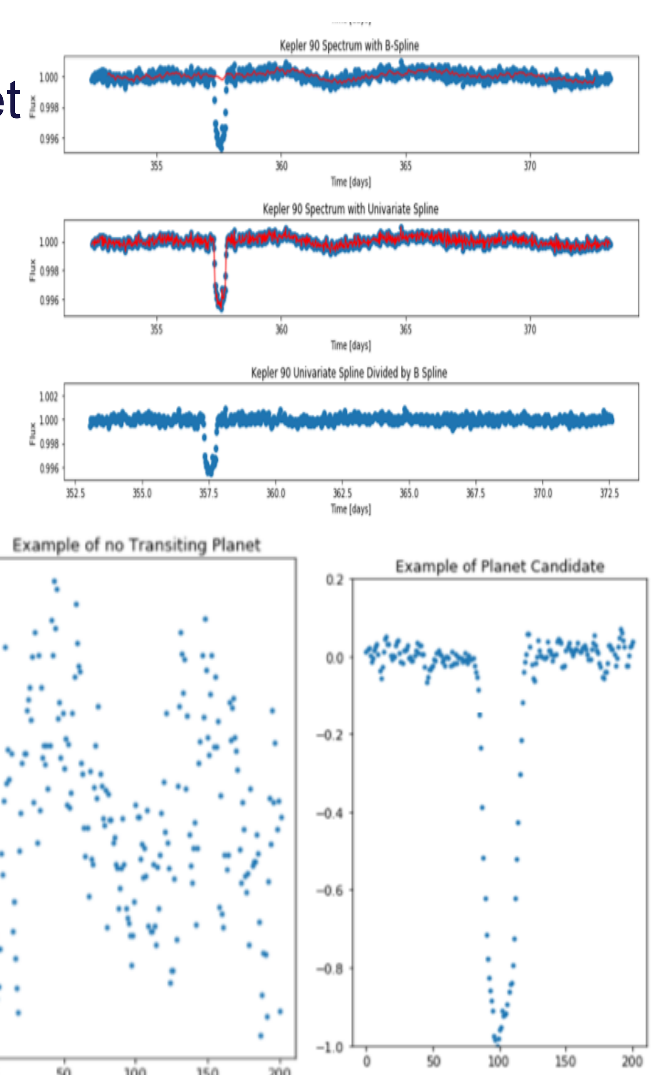


The left figure displays the achromatic nature of Microlensing events. The magnification of an event event its directly correlated to the distance to the transit.

Motivation and Background

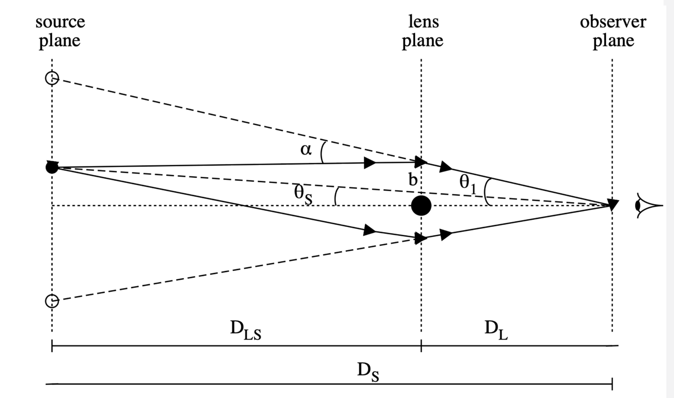
In 2017, the Google Brain (Shallue et al.) team were able to develop an advanced deep learning model to detect exoplanets. Using NASA's autovetter catalog as training labels, the model accurately predicted threshold crossing events as exoplanets, and was then able to discover new exoplanets.

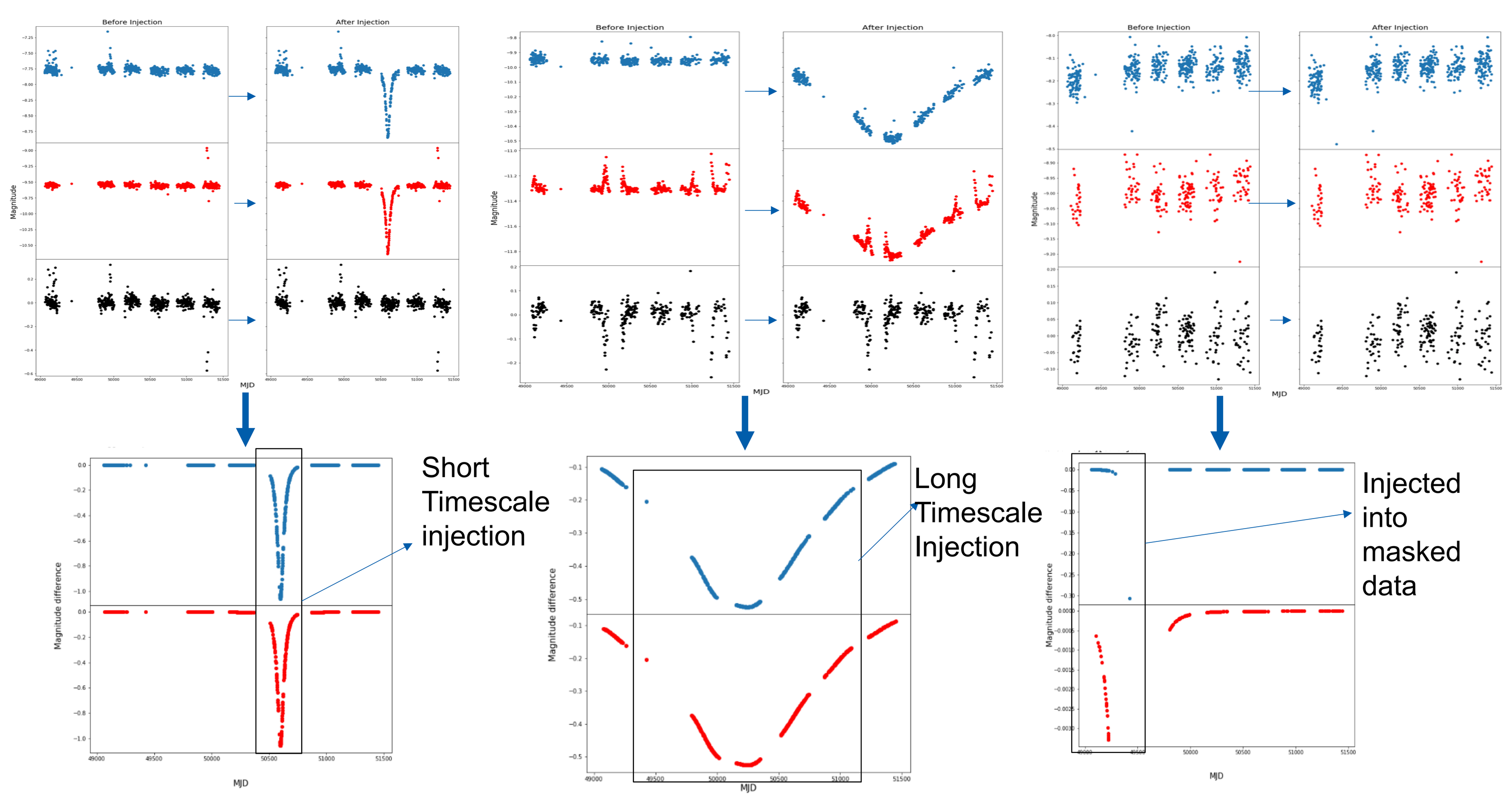
Given the similarities between exoplanet and black hole transit photometry, we investigate deep learning's effectiveness on discovering new black holes.



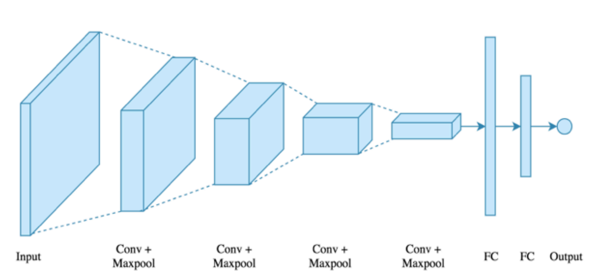
The Training Problem: Synthetic Microlensing Events

- With so few examples of microlensing events, how could we possibly train a model?
- By randomly simulating parameters based on empirical priors we can inject synthetic microlensing events





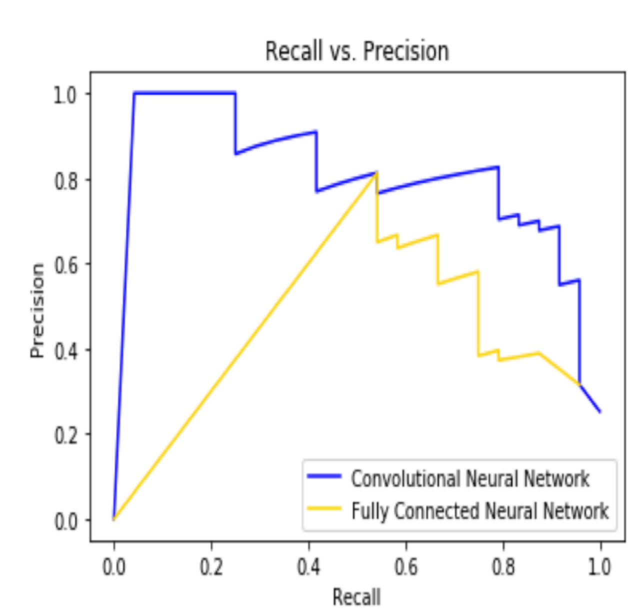
The top figure displays how microlensing works and the following 6 figures display the result of simulating microlensing events, and seeing what gets captured, some are short timescale, some are long timescale, and some are not caught by the algorithm, and hence are thrown out



$$Precision = \frac{TP}{(TP+FP)}$$

$$Recall = \frac{TP}{(TP+FN)}$$

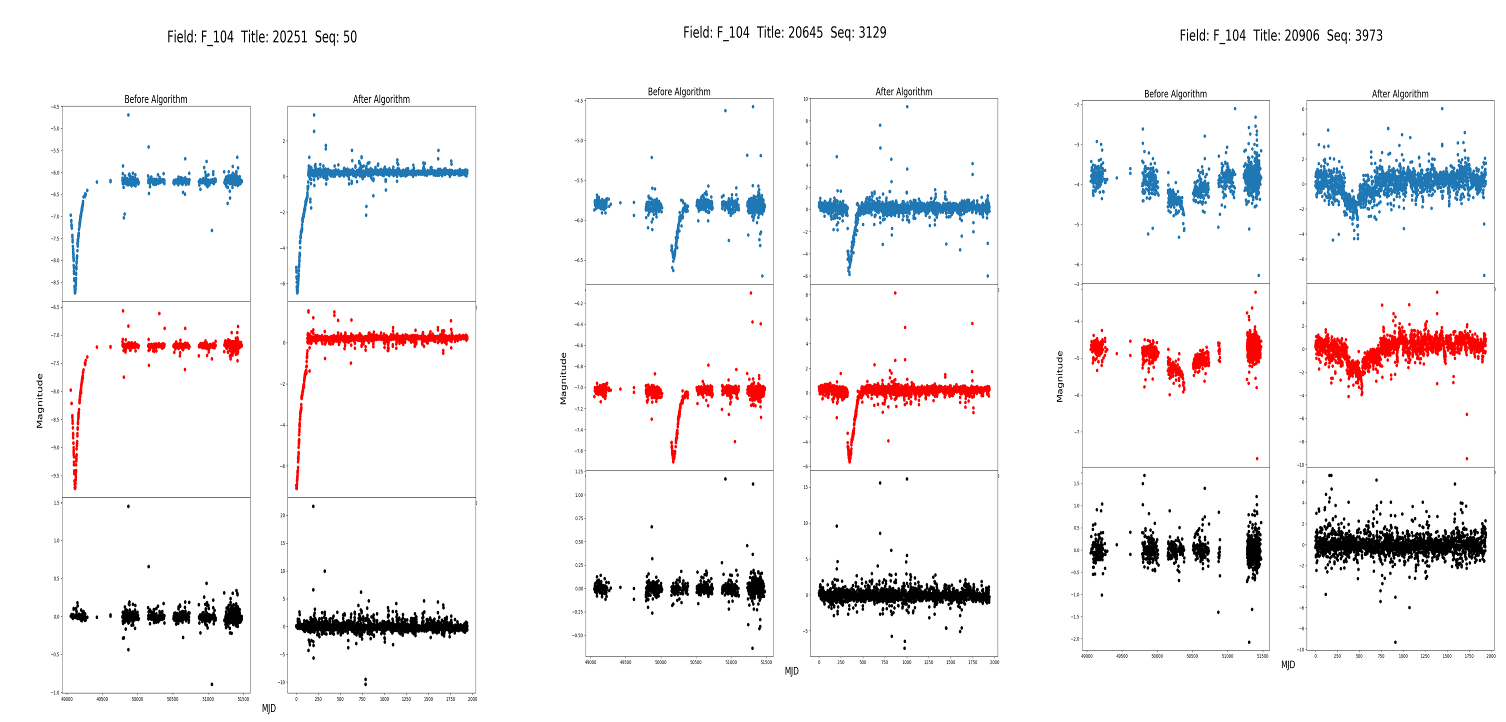
$$Accuracy = \frac{TP+TN}{Total}$$



- Thinking of the different color bands as RGB pixels, we can input them into a Convolutional Neural Network
- The goal will be to see if the network can pick out astrophysical anomalies that are present in the Blue and Red band, but not in the Color Band.
- The metrics I will try to maximize are Precision, Recall, and Accuracy
  - Precision is the proportion of Black Hole candidates that were actually correct
  - Recall is the proportion of Black Hole Candidates discovered out of the population of candidates

Using the Model for Anomaly Detection

Now that the model is good at finding Black Holes with high recall without losing accuracy, we ran the data on Field 104 to see if it found existing microlensing events, and if it could find new ones.



These Figures are examples of good "Candidates" outputted by the model. The Model was able to detect a previously known IMBH candidate, and these other candidates were found organically through the model. These other candidates were also discovered using other methods of MACHO.

Conclusions and Collaborators

Conclusions:

- Synthetic microlensing events were successful at training a model to find real microlensing events
- Deep Learning can become an effective tool to quickly find new candidates
- It takes roughly 90 Minutes to parse through a field on a typical computer

Next Steps:

- Train a model on synthetic events to make a model learn and predict masses of events (to specifically find IMBH candidates)
- Use the LC to dramatically increase the efficiency and size of the model, and run through more fields to find potentially new candidates

Collaborators:

- William Dawson (LLNL)
- George Chapline (LLNL)
- Nathan Golovich (LLNL)
- Michael Medford (UCB/LLNL)

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