Exocomet Hunting with Neural Networks

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UK & Ireland Discs Meeting 2024

Introduction

Exocomets

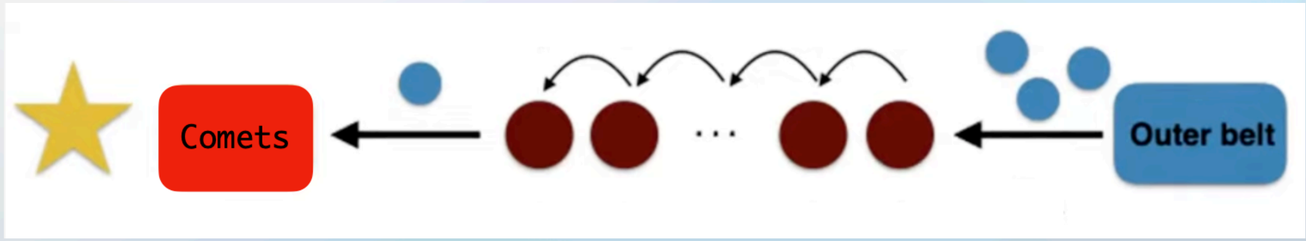
Exocomets: analogues of solar system comets.

- Composed of ice, dust, and rocky material

Why do we study detections of exocomets?

- Links towards the architecture of planetary systems.
- Trends of exocomet host stars?

The Solar System comet Hale-Bopp



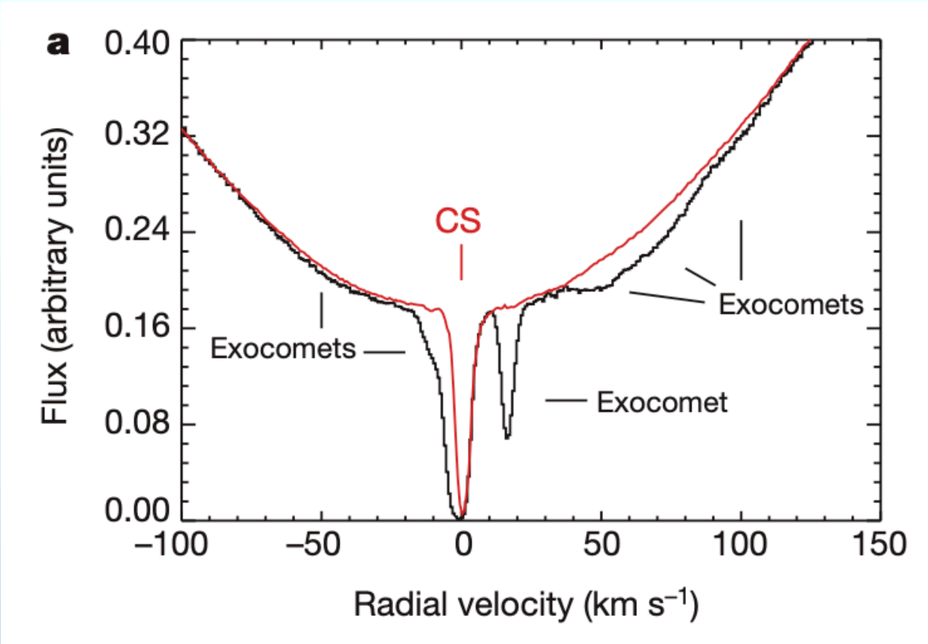
Adapted from Marino et al. 2018

Introduction

Exocomets - Detection Methods for Transiting Exocomets

Spectroscopy

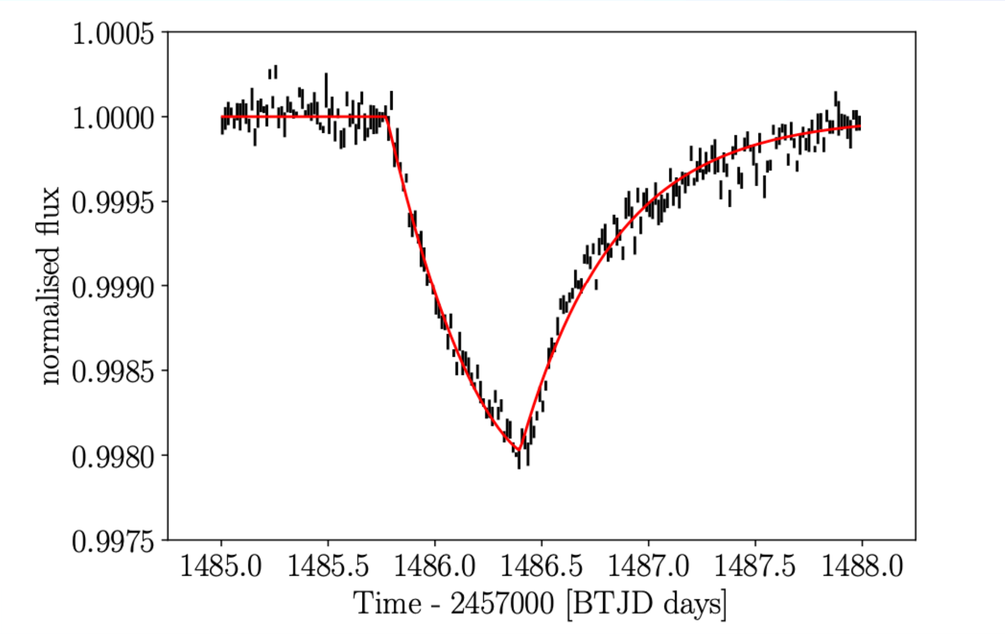
- Variable absorption features in spectral lines.
- HARPS, FEROS



Kiefer et al. 2014

Photometry

- Upside-down shark fin-like transits.
- Kepler, TESS



Zieba et al 2019; Strøm et al. 2020

Methods

How do we search for exocomets?

Methods included:

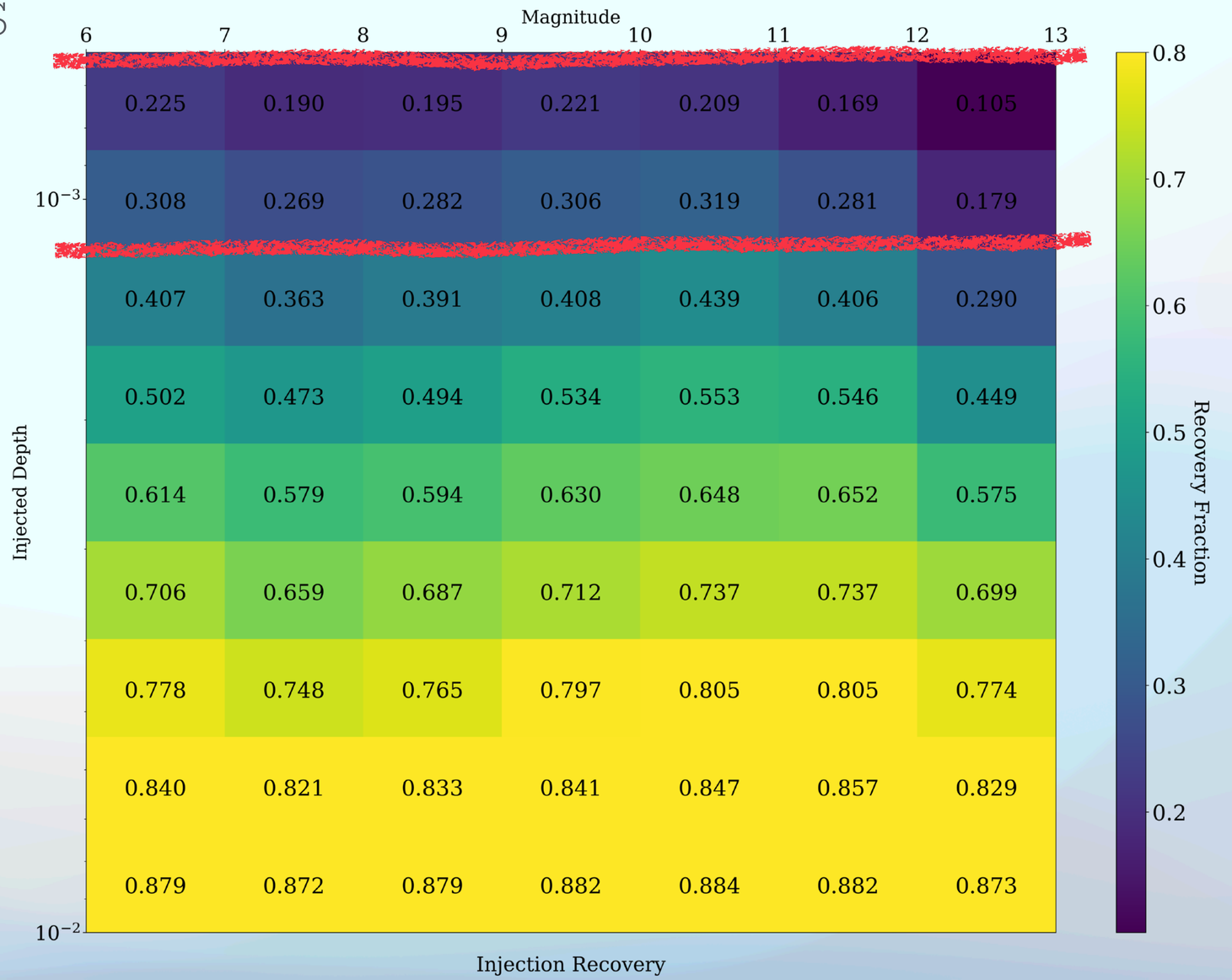
See poster #19!

- Visual searches through lightcurves (Rappaport et al 2018)
- “Classical” automated methods (Kennedy et al. 2019, Norazman et al. in prep).
  - ***The main science goals:*** Determine the occurrence rates of exocomet events; what is the relationship between these detections and the stellar age/spectral-type of host system?

Methods

Classical Techniques; Results

- ***Kepler occurrence rates***: 3/200,000 stars observed over 4 years (Kennedy et al 2019).
- ***TESS occurrence rates:*** *6/9,000,000 stars observed over 1 month (Norazman et al. in prep)*
- *Putting this together, exocomet occurrence rates in TESS are roughly 1/10,000 stars per year.*



Methods

Classical Techniques; Limitations

Why do we need to improve detection techniques?

- Distributions and thresholds are based on a very small sample of previous detections.
- Systematics/detrending may have prevented real detections.

Machine learning as a potential <u>efficient</u> solution:

- Convolutional Neural Networks (CNN)
  - Works well for 2D (image classification) or 1D (exoplanet science) data
  - A key advantage is that the CNN can focus on the shape of exocomet transits.

Tey et al 2023,
Valizadegan et al 2021

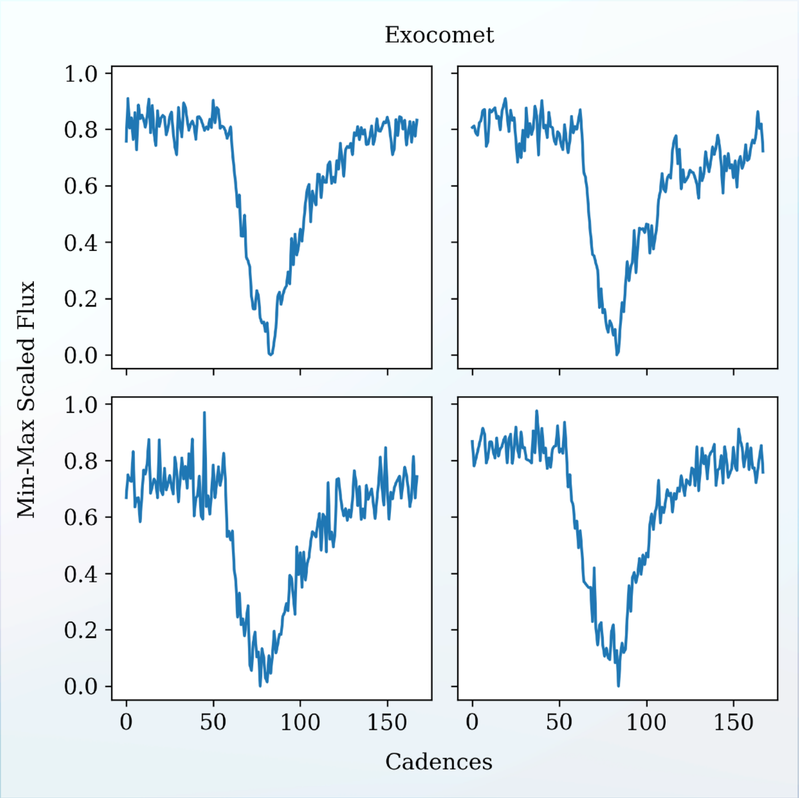
Methods - Machine Learning

Training Set

Since the known number of exocomet systems is still few, we generate a synthetic training set by injecting exocomet models into real TESS lightcurves.

We also insert:

- Binaries (Prsa et al 2021)
- Synthetic binaries
- Synthetic exoplanets
- Stellar variability



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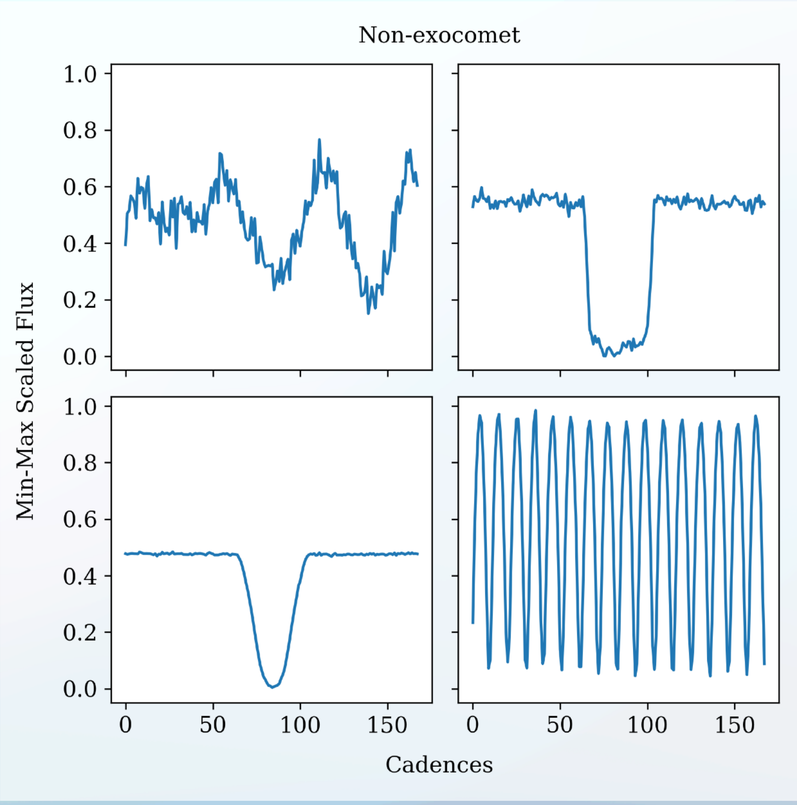
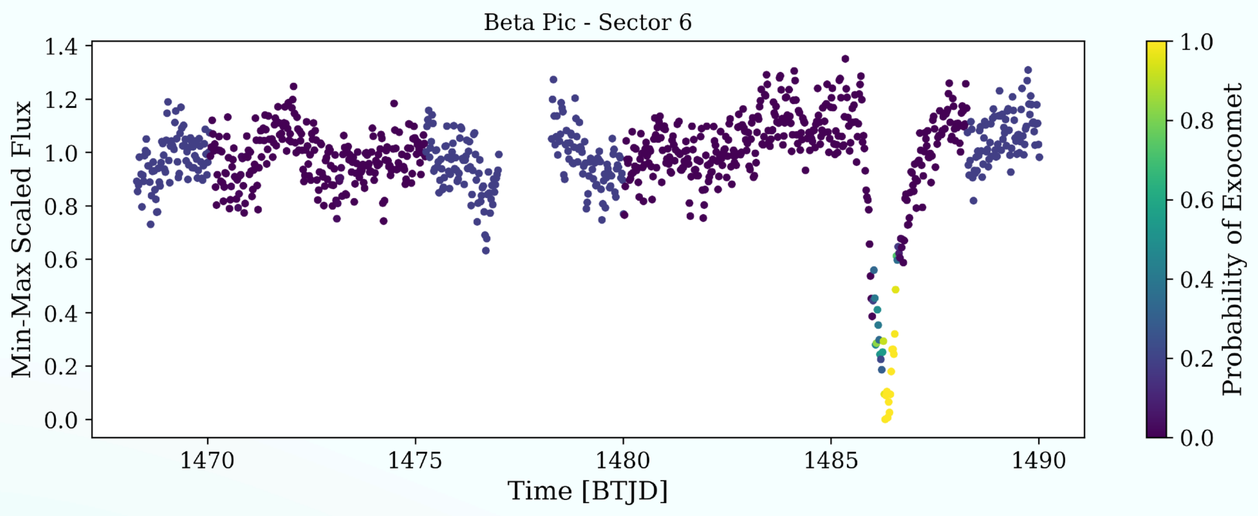
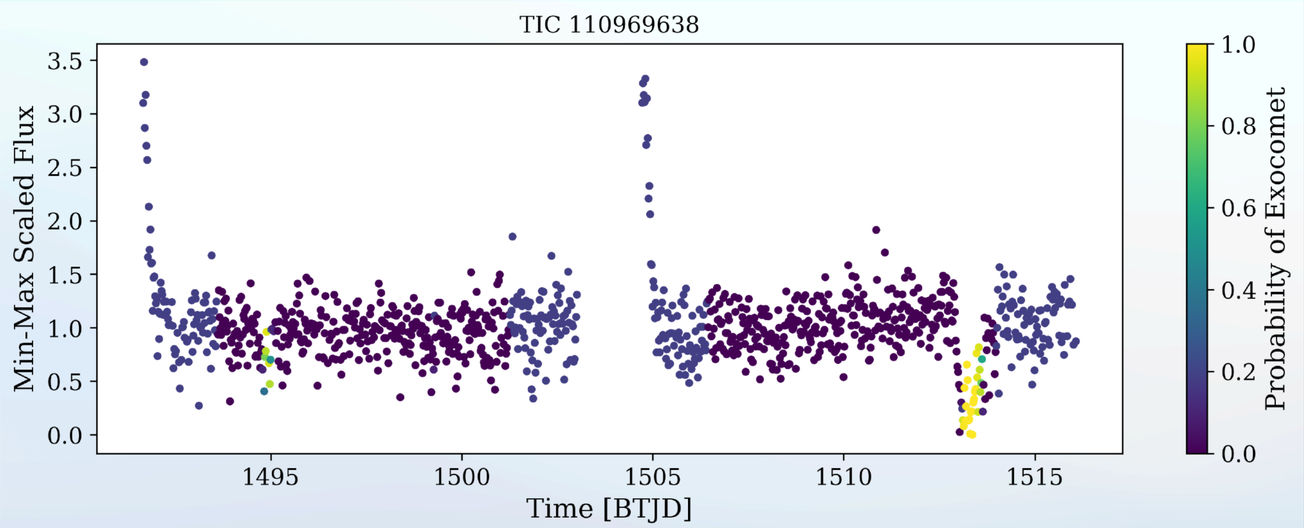


Preliminary Results

Validating our CNN models - Predictions on real data





- Our CNN recovers transits for most of the exocomet candidates to date.
- Goal: Re-analyse the first two years of TESS (~14m lightcurves) and compare with results of classical method.

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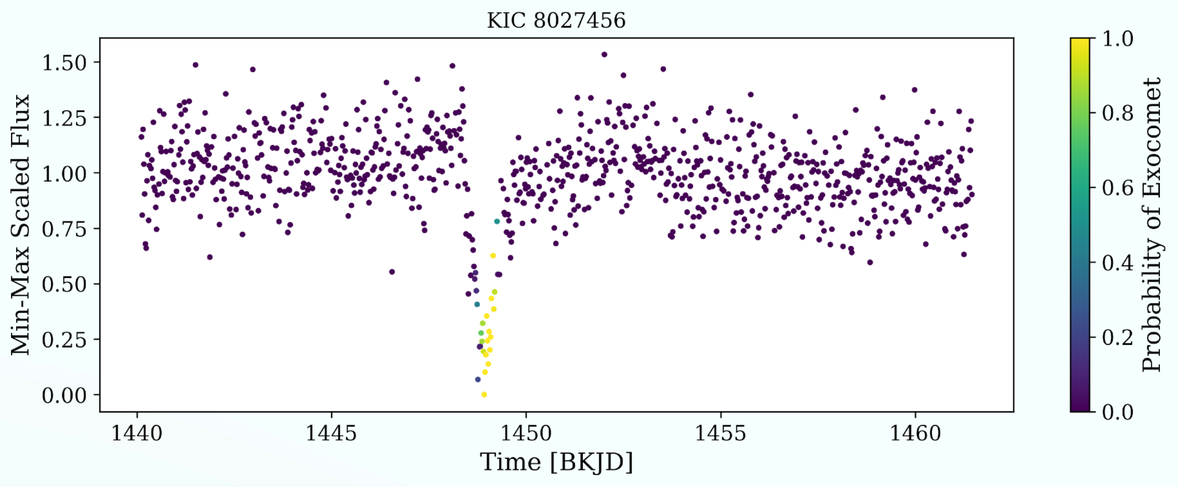

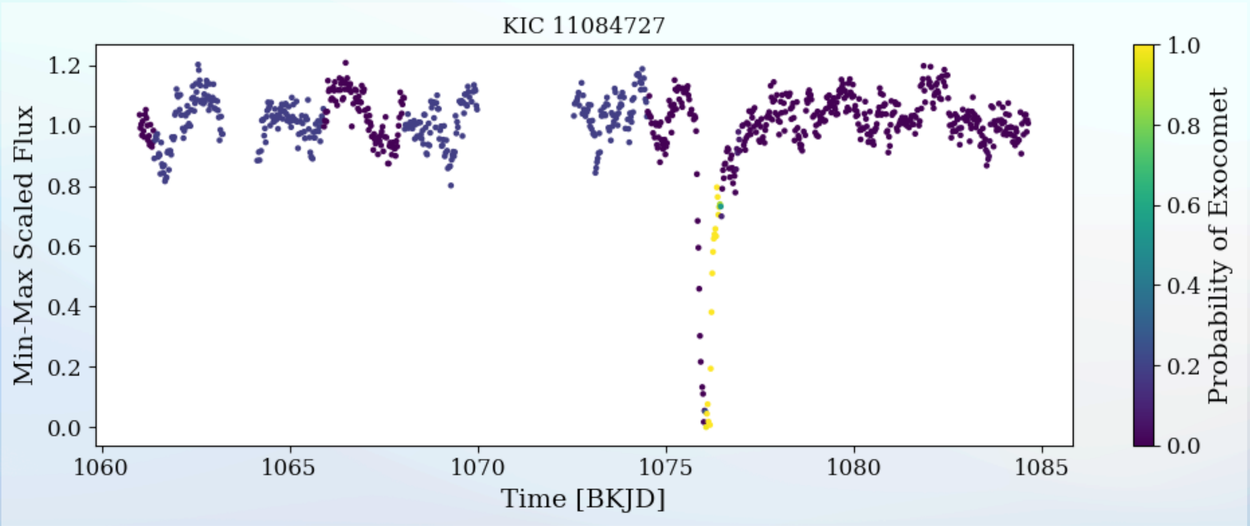

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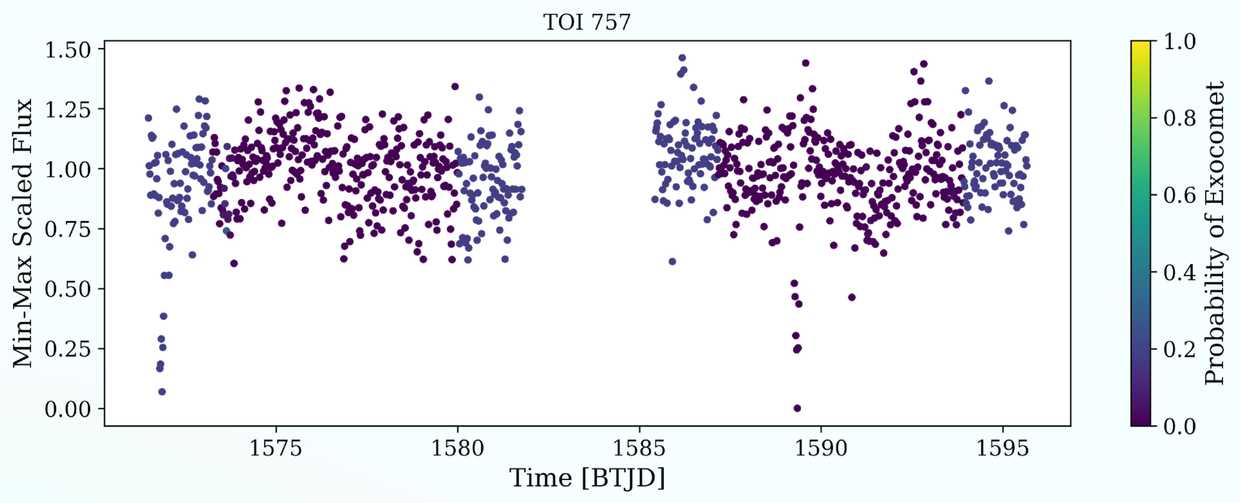

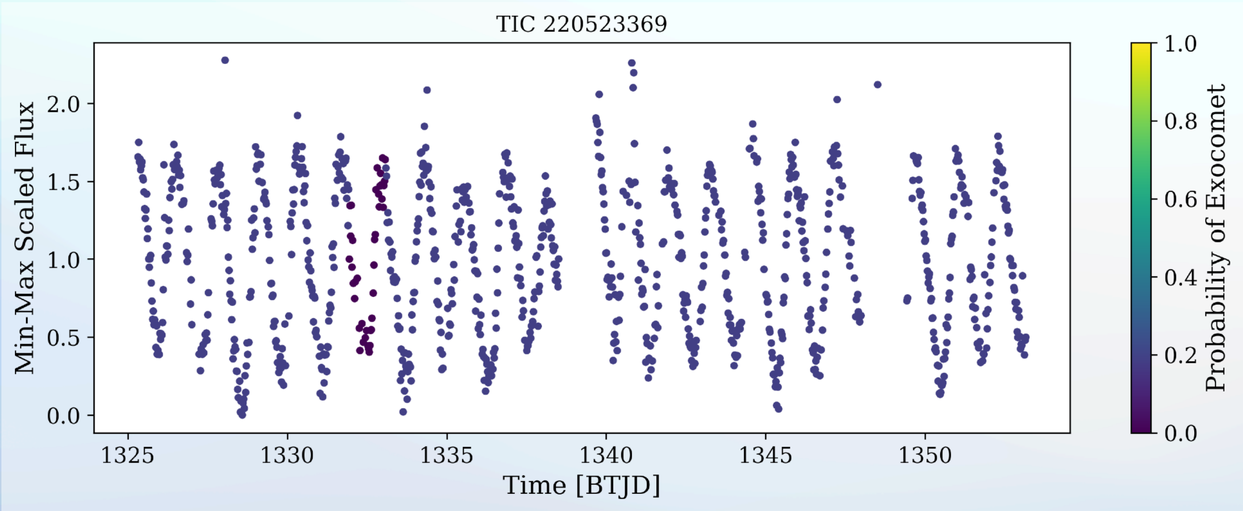

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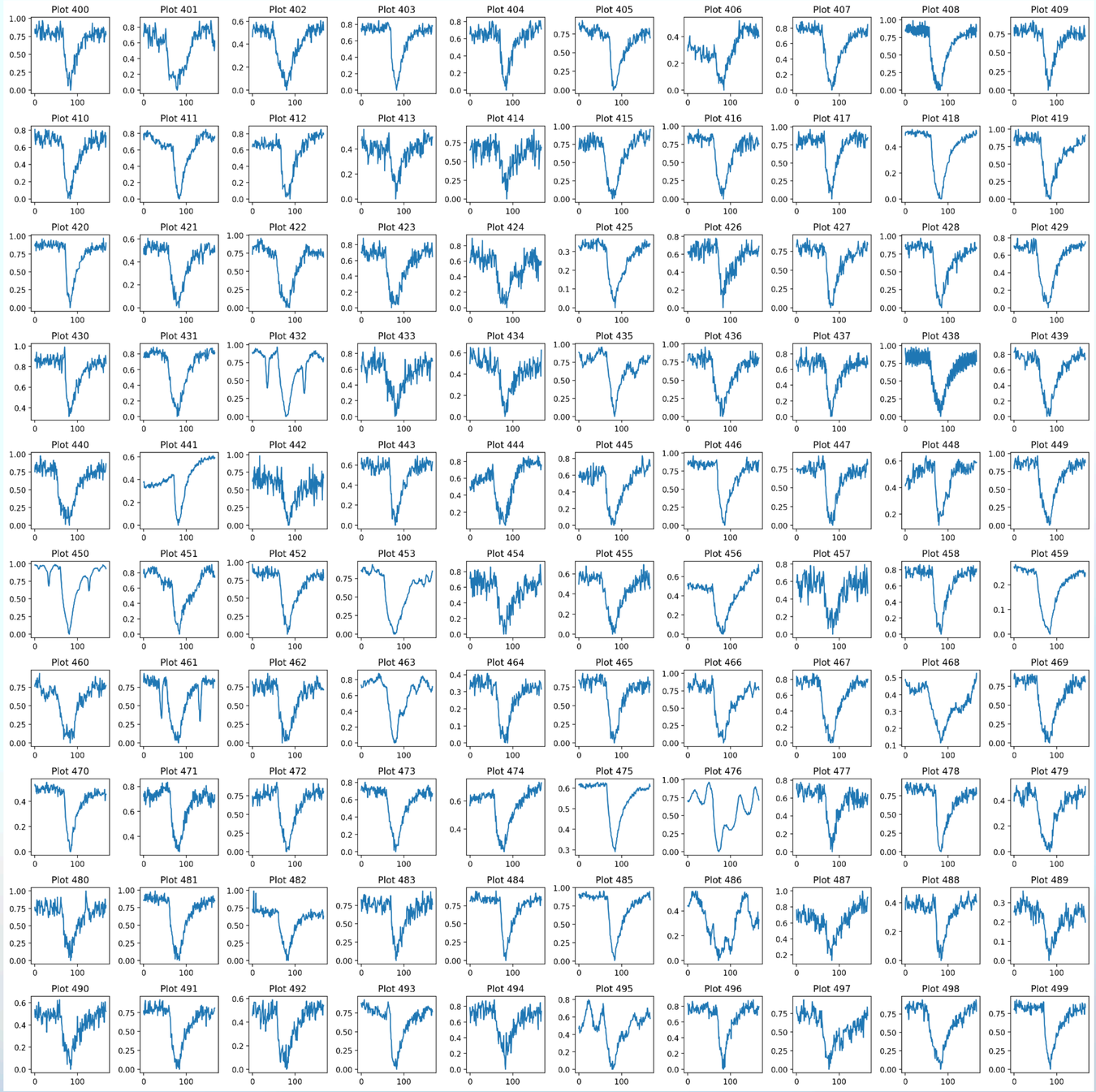
Conclusions

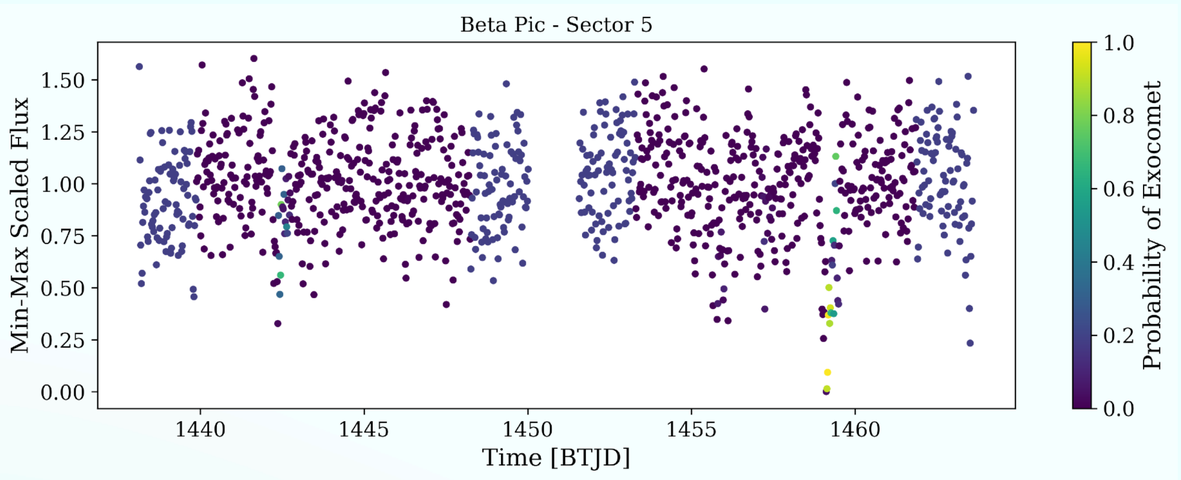
- The number of exocomets in photometry is still only a handful.
- Large-scale searches are well underway.
- Classical automated approaches have found new exocomet candidates
  - But it may have its limitations, so we are trying an independent method (i.e: CNN)
- The CNN can be trained well by injecting exocomet models into real data.
  - Our CNN recovers most most transits from the known candidates - a good sign!

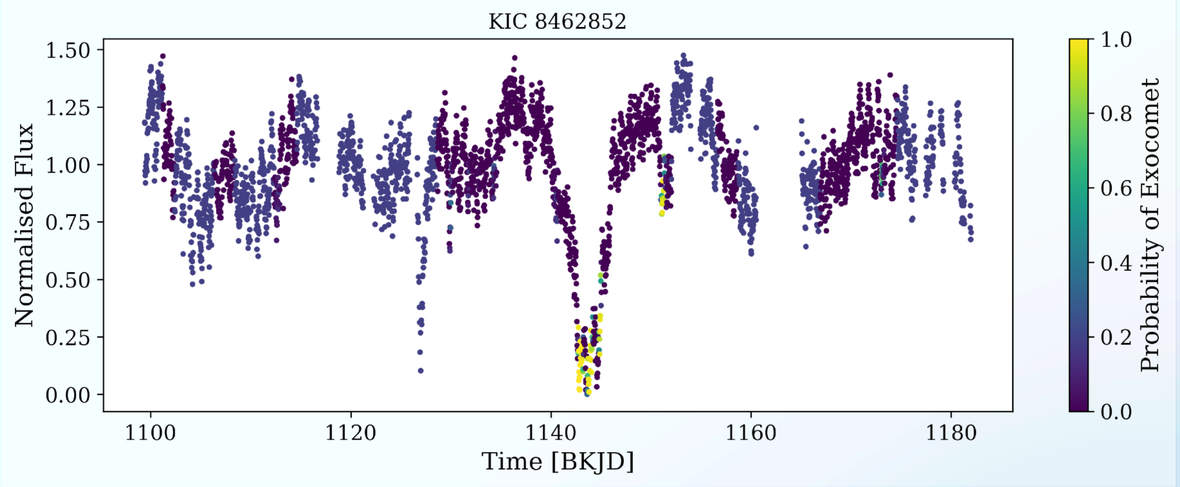
Extra slides - Example of Training Set

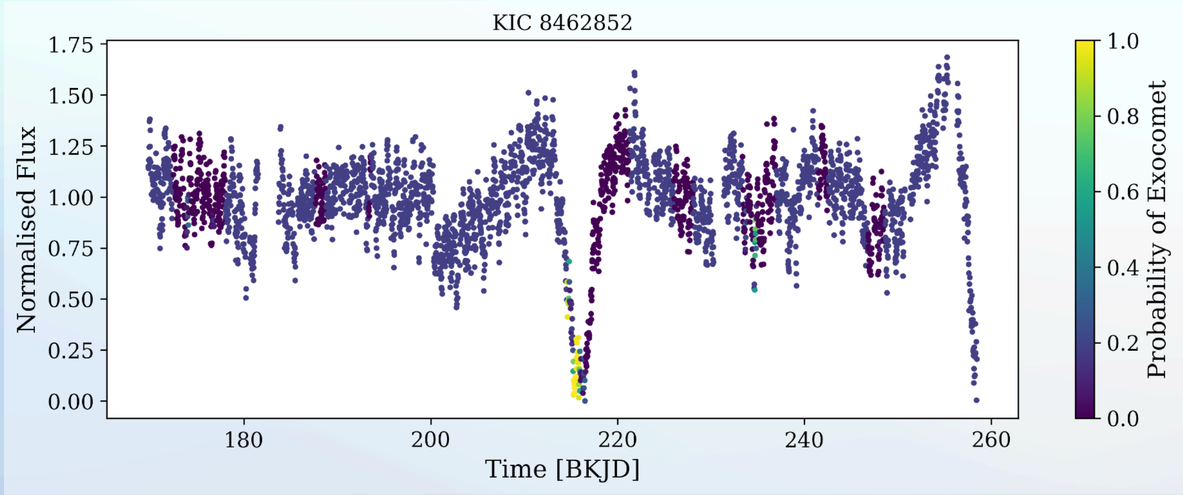


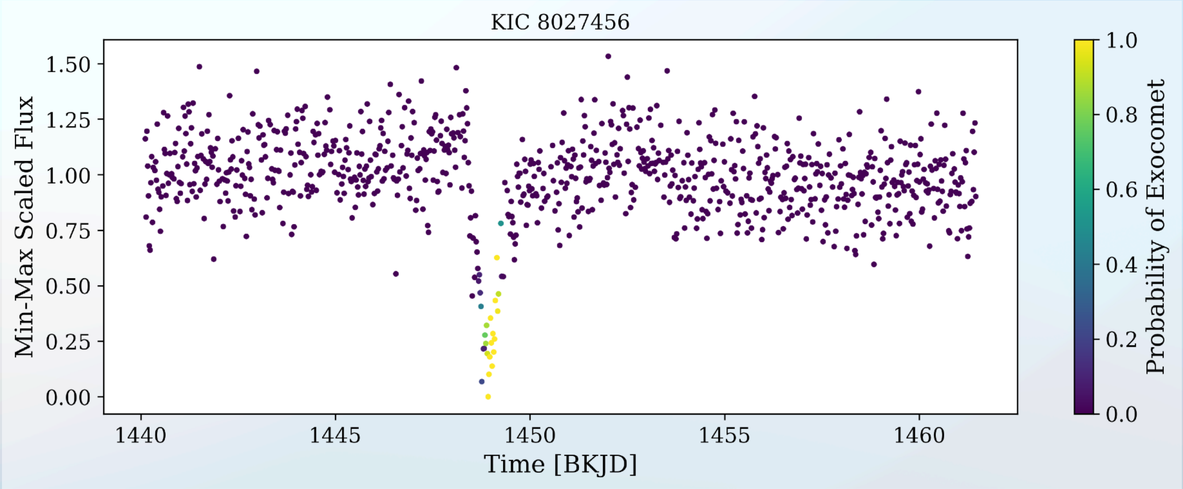
Extra slides

More predictions on real data









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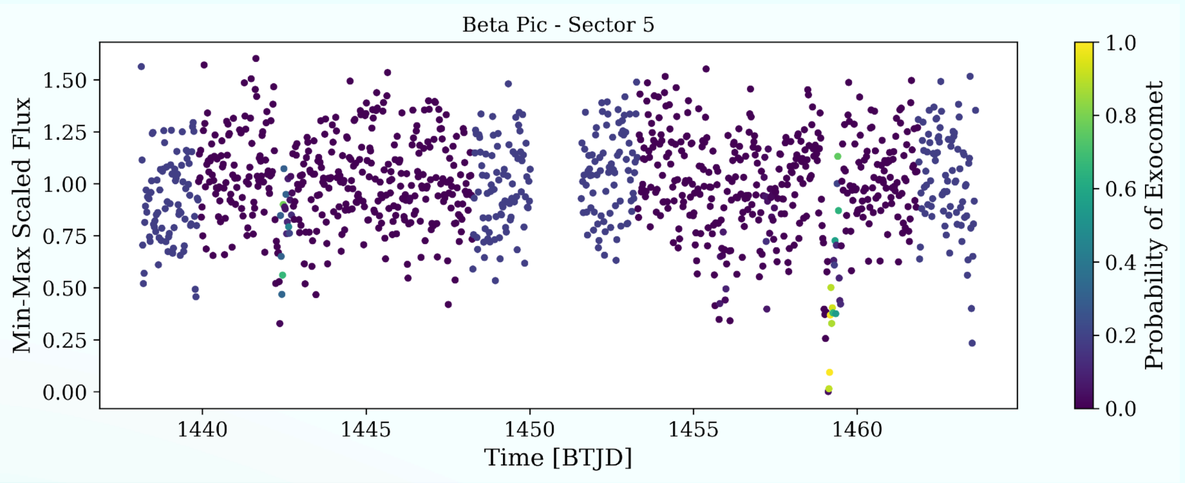
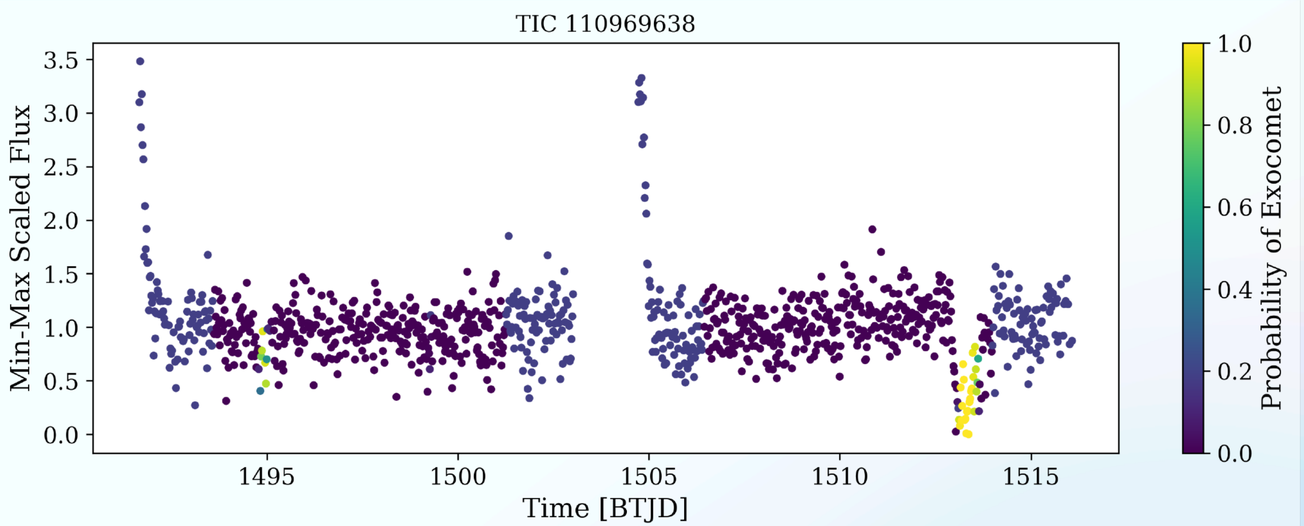
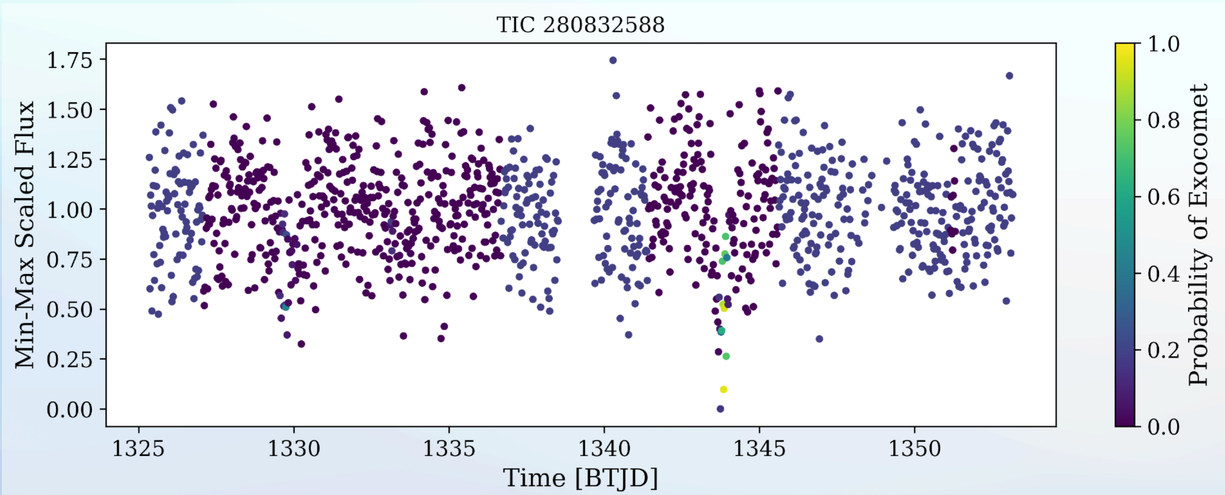
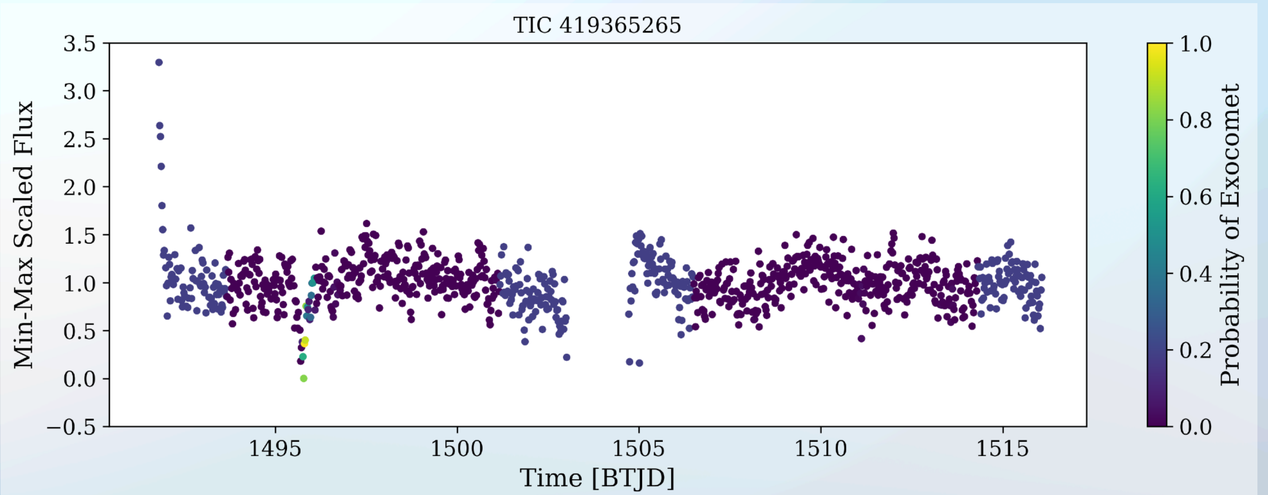


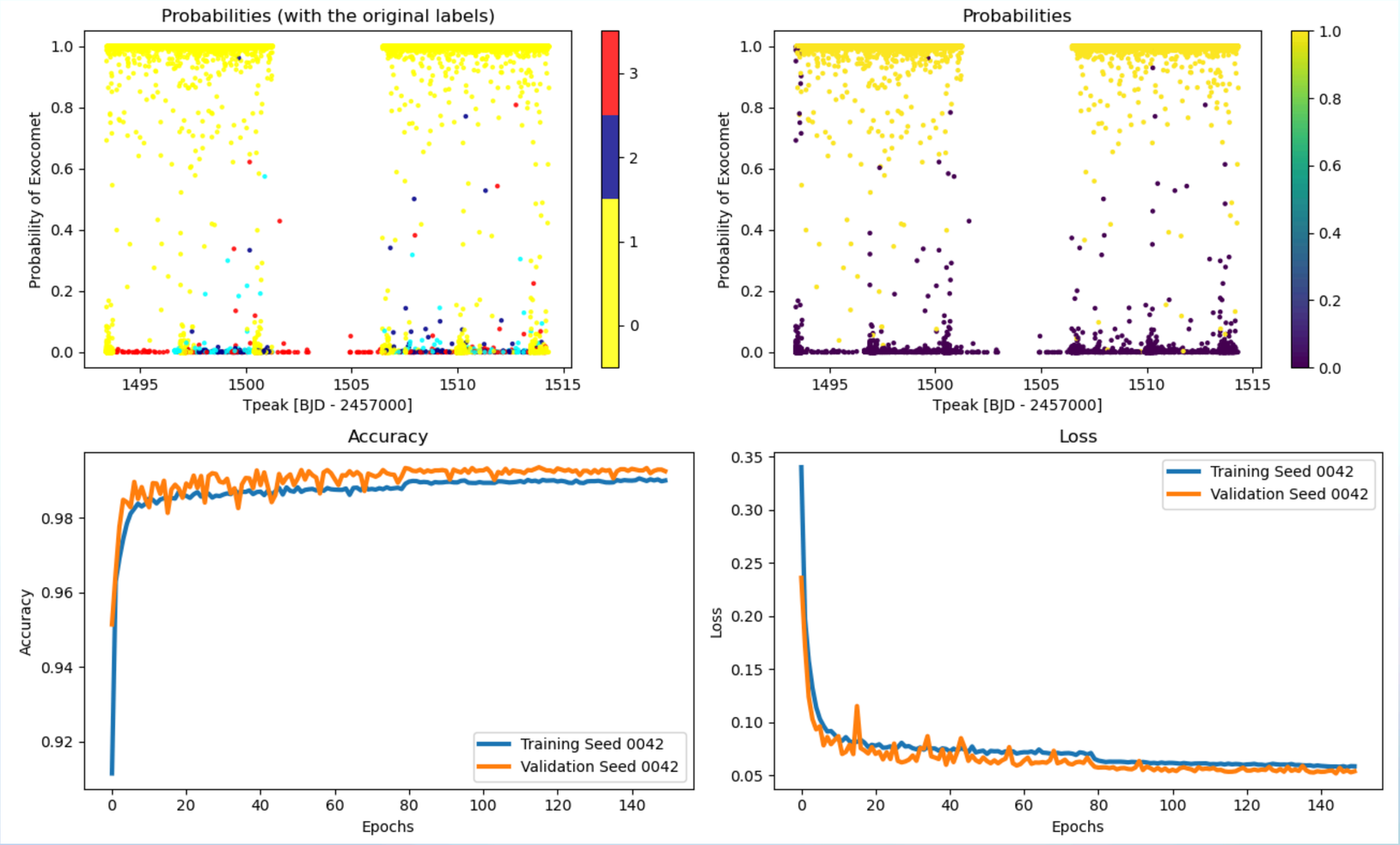






Extra Slides

CNN Performance



Accounting for overfitting:

- Dropout
- L2 Regularisation
- ReduceLROnPlateau
- Early Stopping
- Ensembling

Extra Slides

Can you detect a Solar System comet?

- Hale-Bopp and 1/P Halley could be possible if you consider their dust production, since a recent paper (Luk'yanyk et al 2024) has determined the similarities between the Beta Pic exocomets and these Solar System comets.

- BUT, Hale-Bopp itself is an "outlier" in the taxonomy of Solar System comets in that it is a much more active comet - more typical comets are not like Hale-Bopp.