Machine-Learning X-ray Lightcurve Profiling

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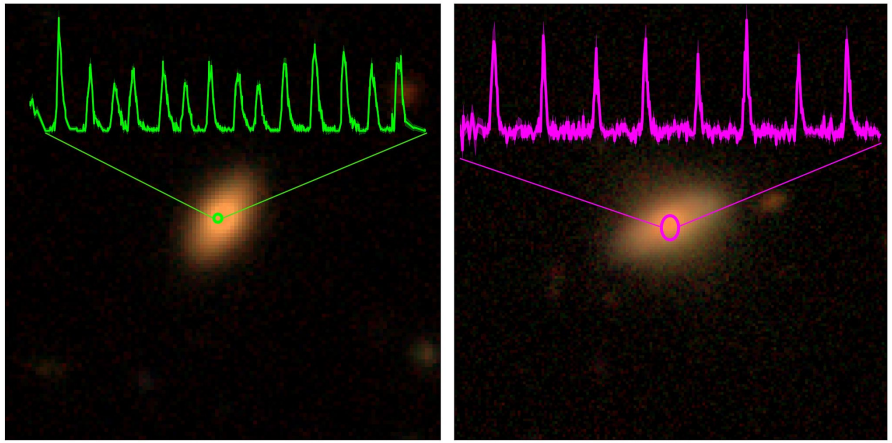
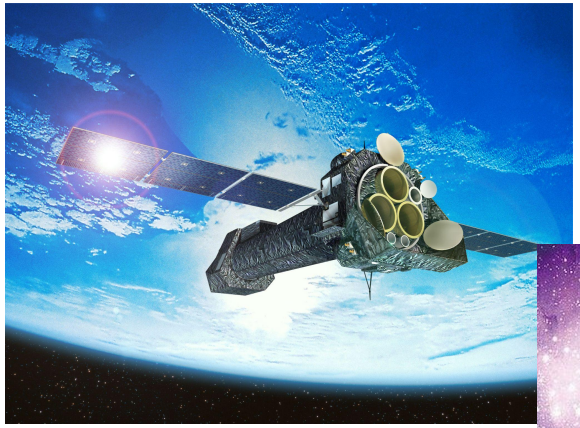
Journée IA@IRAP - octobre 2025

Why classify X-ray lightcurves?

Expand populations



Quasi-Periodic Eruptions
Credit: MPE; optical image: DESI Legacy Imaging Surveys/D. Lang (Perimeter Institute)



XMM-Newton. Credit D. Ducros

NewAthena
Credit: ESA/IRAP/CNRS/UT3/CNES/Fab&Fab

Credit: Myrabella / Wikimedia Commons

Comme une aiguille dans une botte de foin…

Previously…

RAS Techniques and Instruments

RASTAI **2,** 238–255 (2023)
Advance Access publication 2023 May 18

https://doi.org/10.1093/rasti/rzad015

Searching for quasi-periodic eruptions using machine learning

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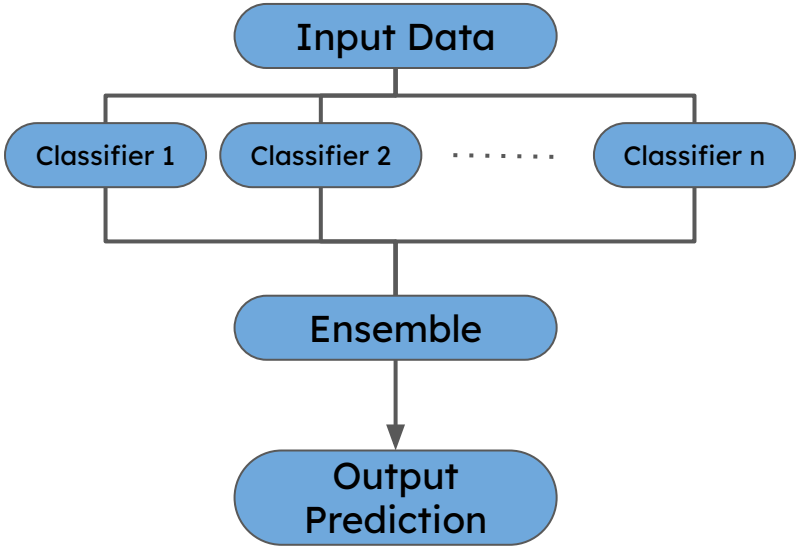
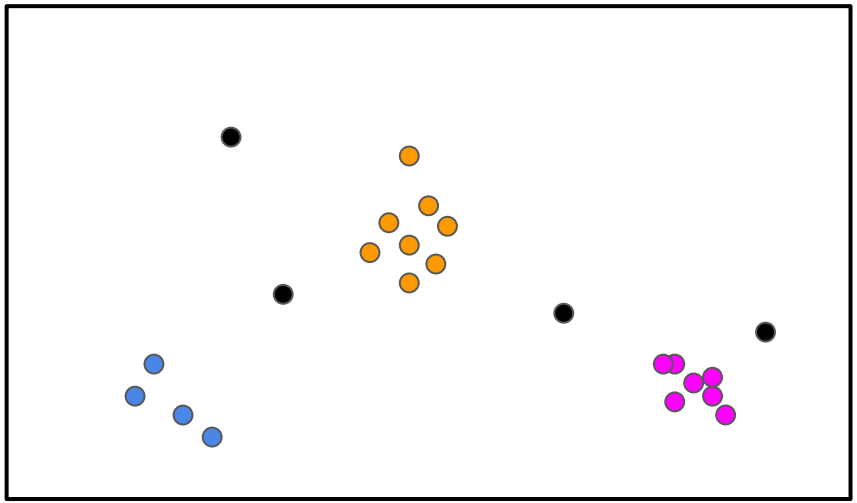
The End Goal(s)…

Ensemble classifier





Anomaly detection

Phenomena of interest

Quasi-Periodic Eruptions (AGN)

Quasi-Periodic Oscillations (AGN & XRBs)

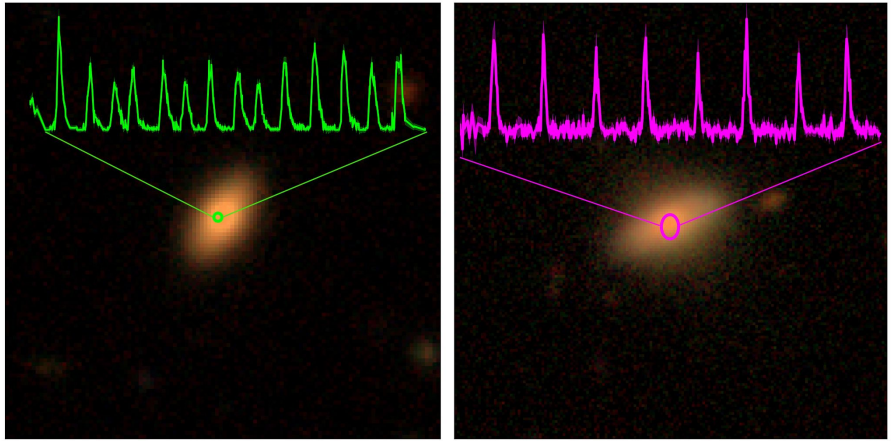
Type-1 X-ray bursts (NS LMXBs)

Orbital X-ray Modulation (CVs)

Eclipses (Binaries)

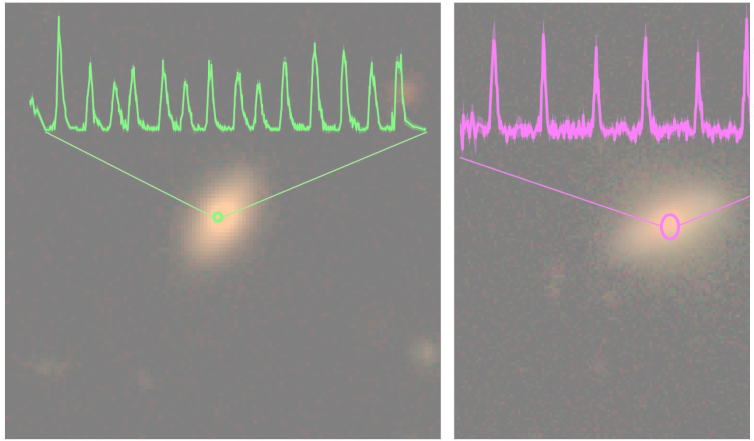
The list goes on…

Phenomena of interest

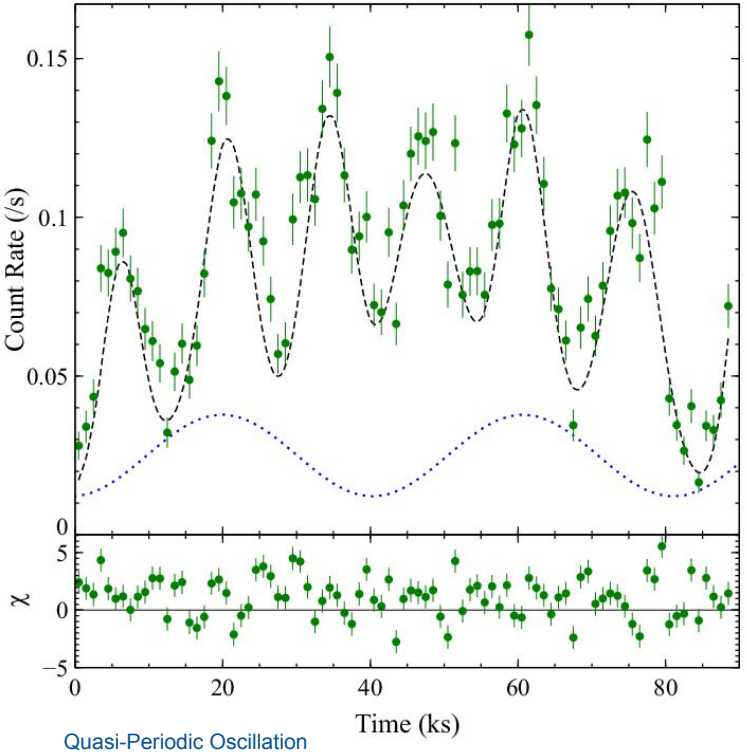


Quasi-Periodic Eruptions
Credit: MPE; optical image: DESI Legacy Imaging Surveys/D. Lang (Perimeter Institute)

Phenomena of interest

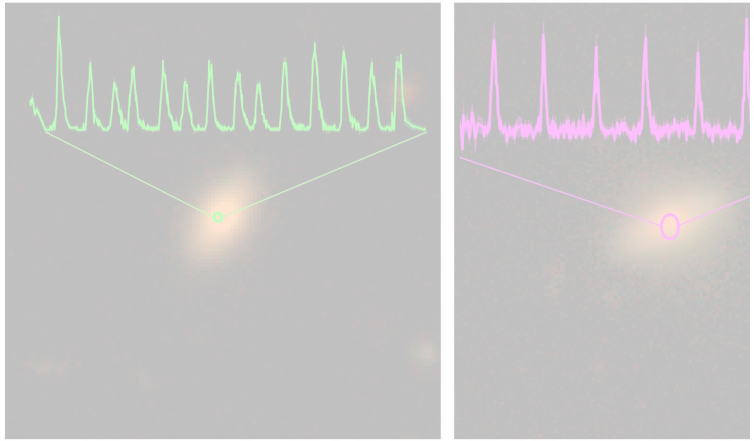


Quasi-Periodic Eruptions
Credit: MPE; optical image: DESI Legacy Imaging Surveys/D. Lang (Perimete

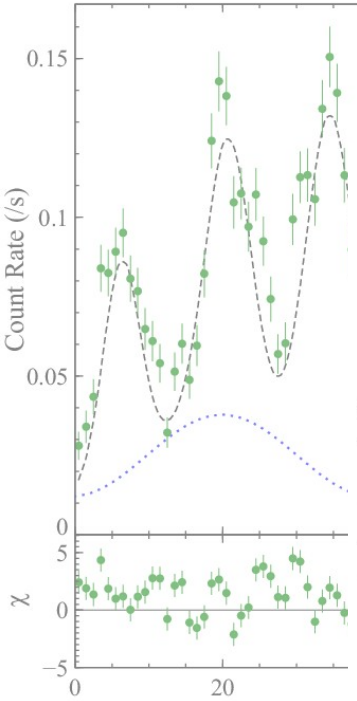


Quasi-Periodic Oscillation
Credit: Webbe and Young, 2023, MNRAS, 518, 3428

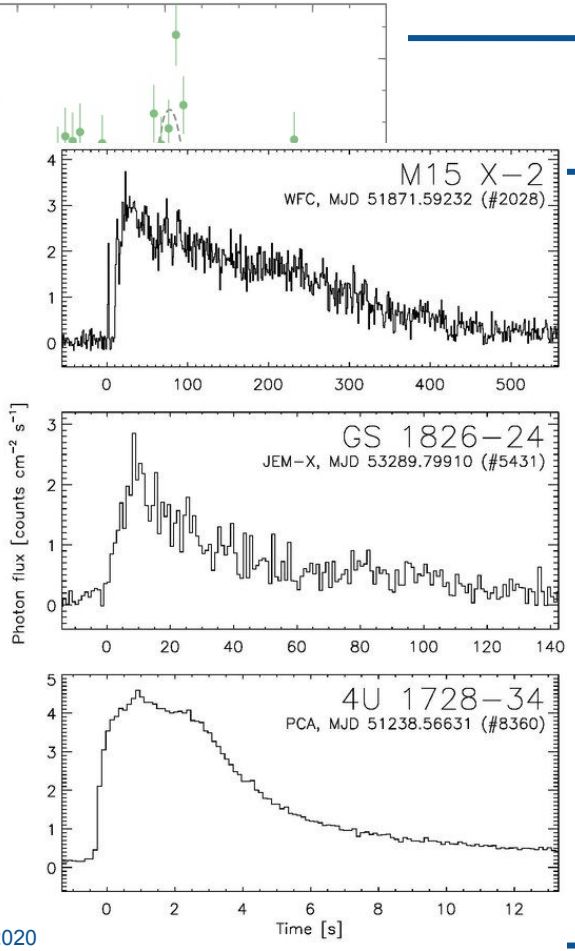
Phenomena of interest



Quasi-Periodic Eruptions
Credit: MPE; optical image: DESI Legacy Imaging Surveys/D. Lang (Perimete



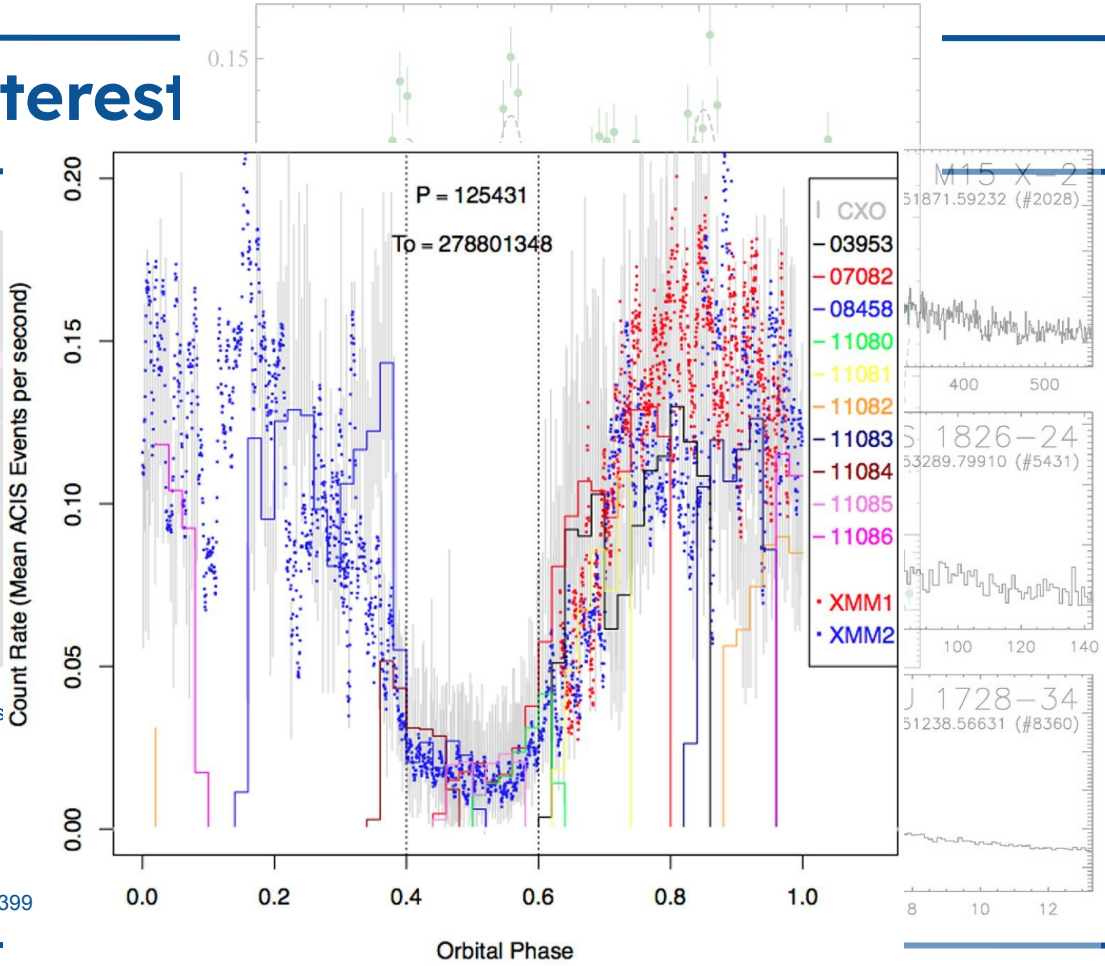
Quasi-Periodic Oscillation
Credit: Webbe and Young, 202



Type-1 X-ray Burst
Credit: Galloway et al. 2020
10.3847/1538-4365/ab9f2e

Phenomena of interest

Quasi-Periodic Eruptions
Credit: MPE; optical image: DESI Legacy Imaging Surveys

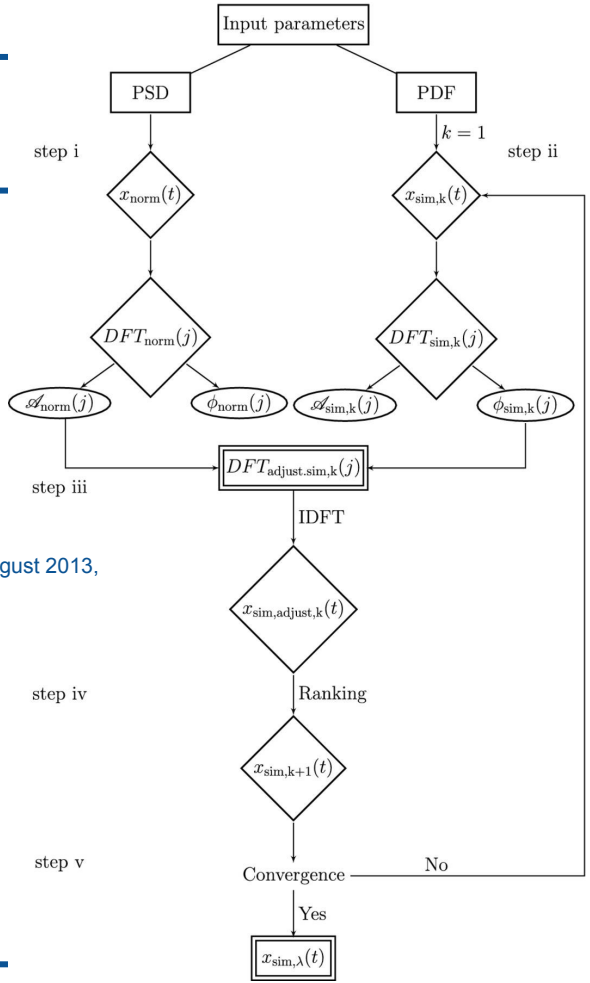


Eclipsing Binary
Credit: Laycock et al., 2015, MNRAS, 446, 1399

Building Training Data

Lightcurve Simulation - Emmanoulopoulos 2013

Class imbalance?



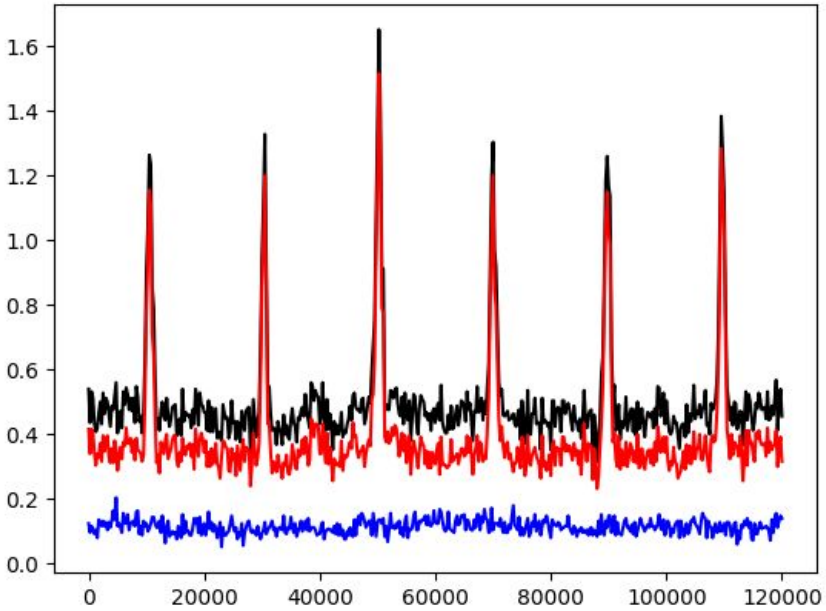
Emmanoulopoulos et al., August 2013, MNRAS, 433, 2, p907

Feature extraction

Three energy bands

- Full 0.2-12 keV
- Soft 0.2-2 keV
- Hard 2-12 keV

42 features per band



QPEs - Training Data classification

SKlearn

Supervised Learning

- Support Vector Machine
- Gradient-Boosted Tree
- Neural Network
- AdaBoost Classifier
- Random Forest
- Extra-Trees Classifier

Hyper-parameter tuning - Grid search

QPEs - Training Data classification

SKlearn

Supervised Learning

- Support Vector Machine
- Gradient-Boosted Tree
- Neural Network
- AdaBoost Classifier
- Random Forest -> 99%+ accuracy
- Extra-Trees Classifier

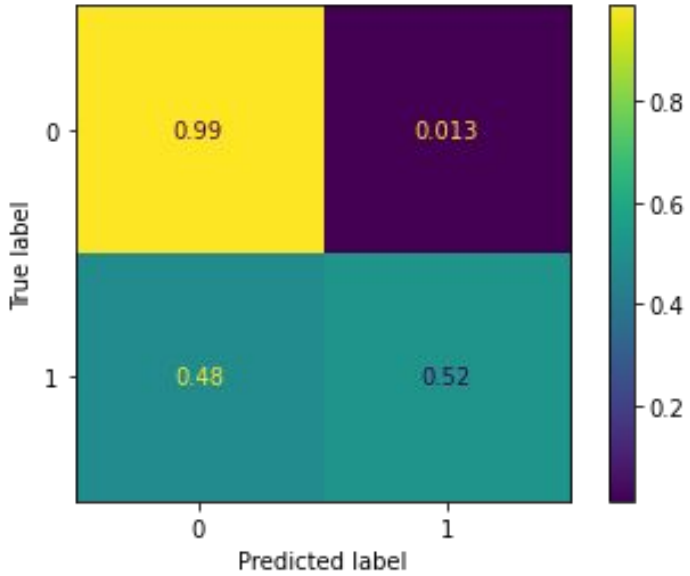
Hyper-parameter tuning - Grid search

QPEs - Real LC predictions

Application to 99 real lightcurves, including 24 known QPE lightcurves

(All but one) False negatives for single eruption observations.

Previously required thresholding.



QPE Feature clustering

Features extracted for all XMM-DR14 PPS lightcurves

~15000 observations, ~280000 detections

KMeans

DBSCAN

Where are QPE sources?

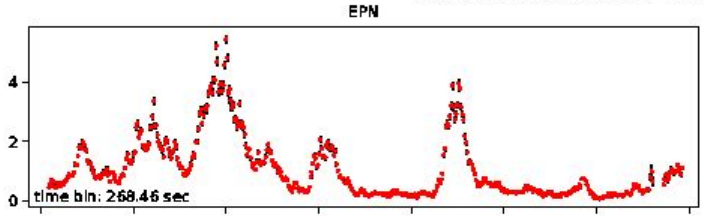
Any interesting outliers?

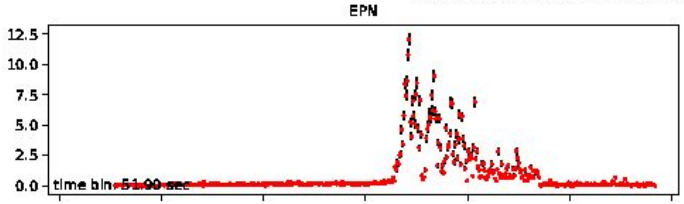
Application to entire dataset

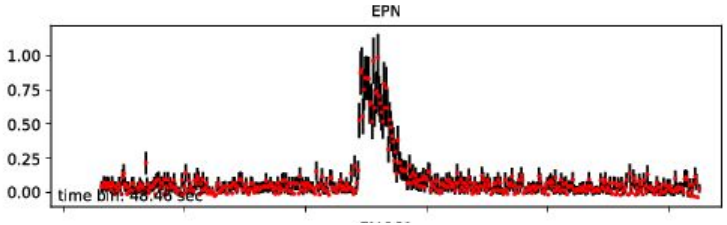
~55000 classed as QPE, dropping to ~3000 with P(QPE) = 0.9

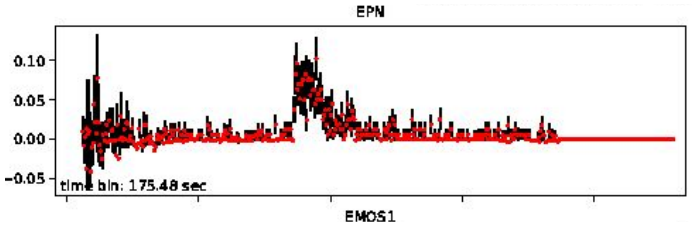
Top candidates include:

- Eclipsing CV
- Variable Stars
- Variable AGN
- High Proper Motion Stars


EPN
4
2
0
time bin: 268.46 sec


EPN
12.5
10.0
7.5
5.0
2.5
0.0
time bin: 51.90 sec


EPN
1.00
0.75
0.50
0.25
0.00
time bin: 48.46 sec


EPN
0.10
0.05
0.00
−0.05
time bin: 175.48 sec
EMOS1

Application to entire dataset

~55000 classed as QPE, dropping to ~3000 with P(QPE) = 0.9

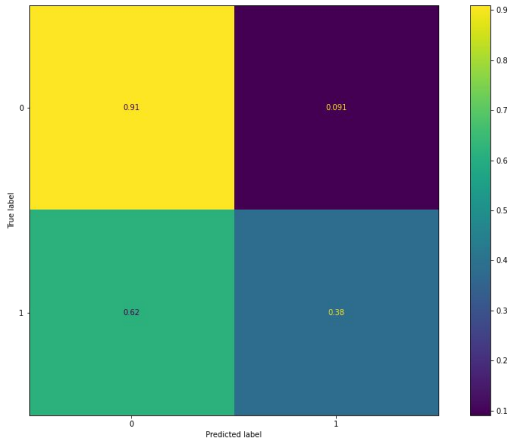
Next step - Cross-match with GLADE

High false positive rate? Training set balance?

Next steps

QPO classifier, preliminary results:

Accuracy ~ 60%



High false positive rate for real observations. Real QPOs or not?

Extension and the future

Fine-tune QPO detection

Other phenomena - Do you have a favourite?

Ensemble and multi-class classifiers

VAE for feature generation

Very open to any suggestions!