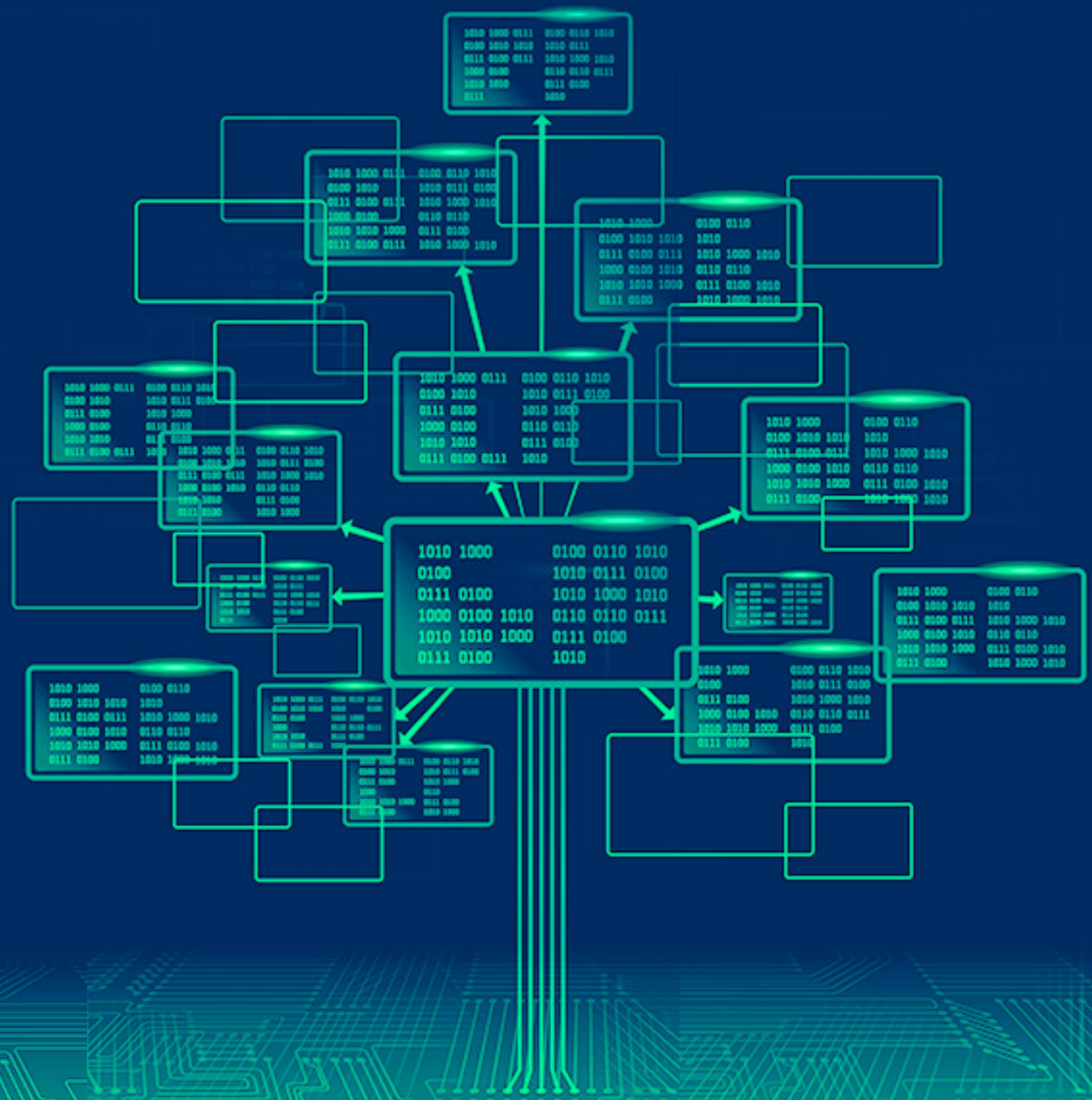
MACHINE LEARNING para clasificación automática de estrellas binarias de rayos X: preparación para la Misión espacial THESEUS

Elisa Nespoli, Adrián Pérez-Suay, Pere Blay, Julia Suso, Juan Fabregat, José Luis Gasent-Blesa, Javier Navarro-González

ESENCIA
Centro de Estudios en Ciencia de Datos e Inteligencia Artificial

viu Universidad Internacional de Valencia



theseus
transient high energy sky and early universe surveyor

1er Workshop de Investigación Centro ESenCIA - 30/01/2025

THESEUS/M7: contribution from Valencia

within the Spanish consortium

- THESEUS Scientific Contribution
- XGIS Simulator
- XGIS Imaging System Design
- Machine learning techniques applied to scientific data related to the THESEUS goals

WHY X-RAY BINARIES?

- ☑ High variability across timescales from msec to years in periodic, quasi-periodic, or aperiodic domains.
- ☑ Diverse types exist, classified from phenomenology and nature of the counterpart.

The phenomenology of X-ray emission from XRBs is broad and varied, making their classification a complex goal.

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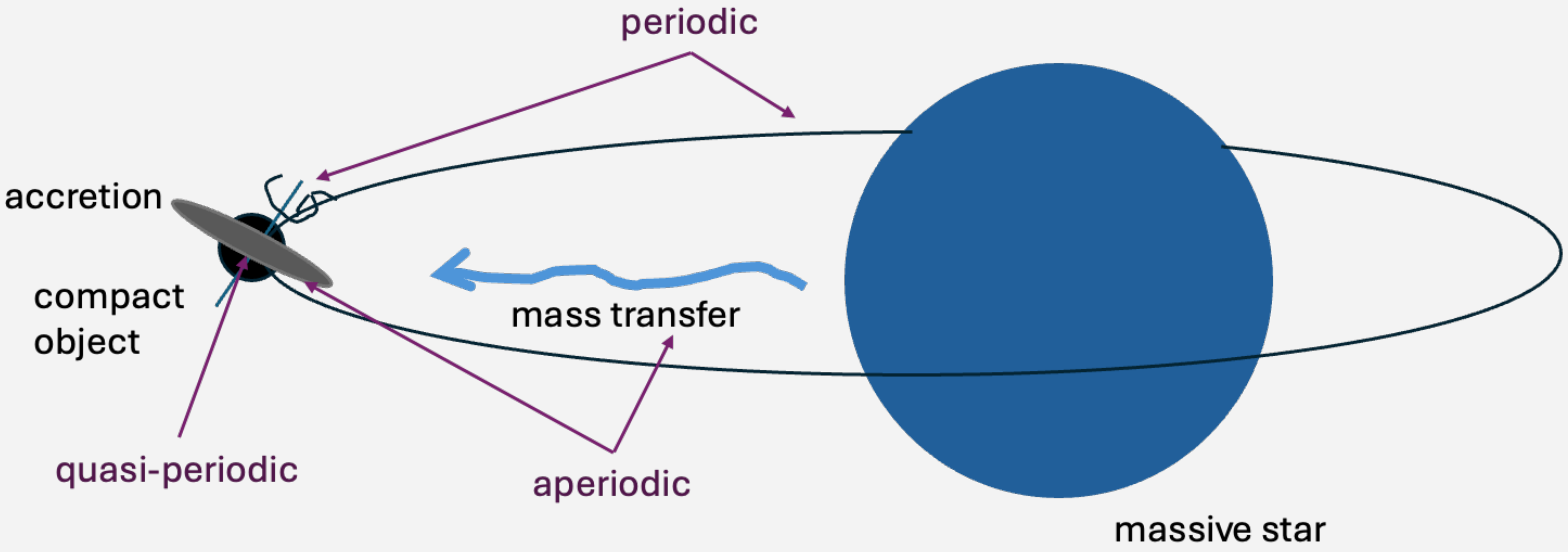
X-ray binaries: compact object (NS, BH, WD) +

- Low mass X-ray binaries: solar mass or less massive stars as counterpart.
- High mass X-ray binaries: > 8 solar masses counterpart.
- Intermediate systems > systems that may not fit in the previous categories.

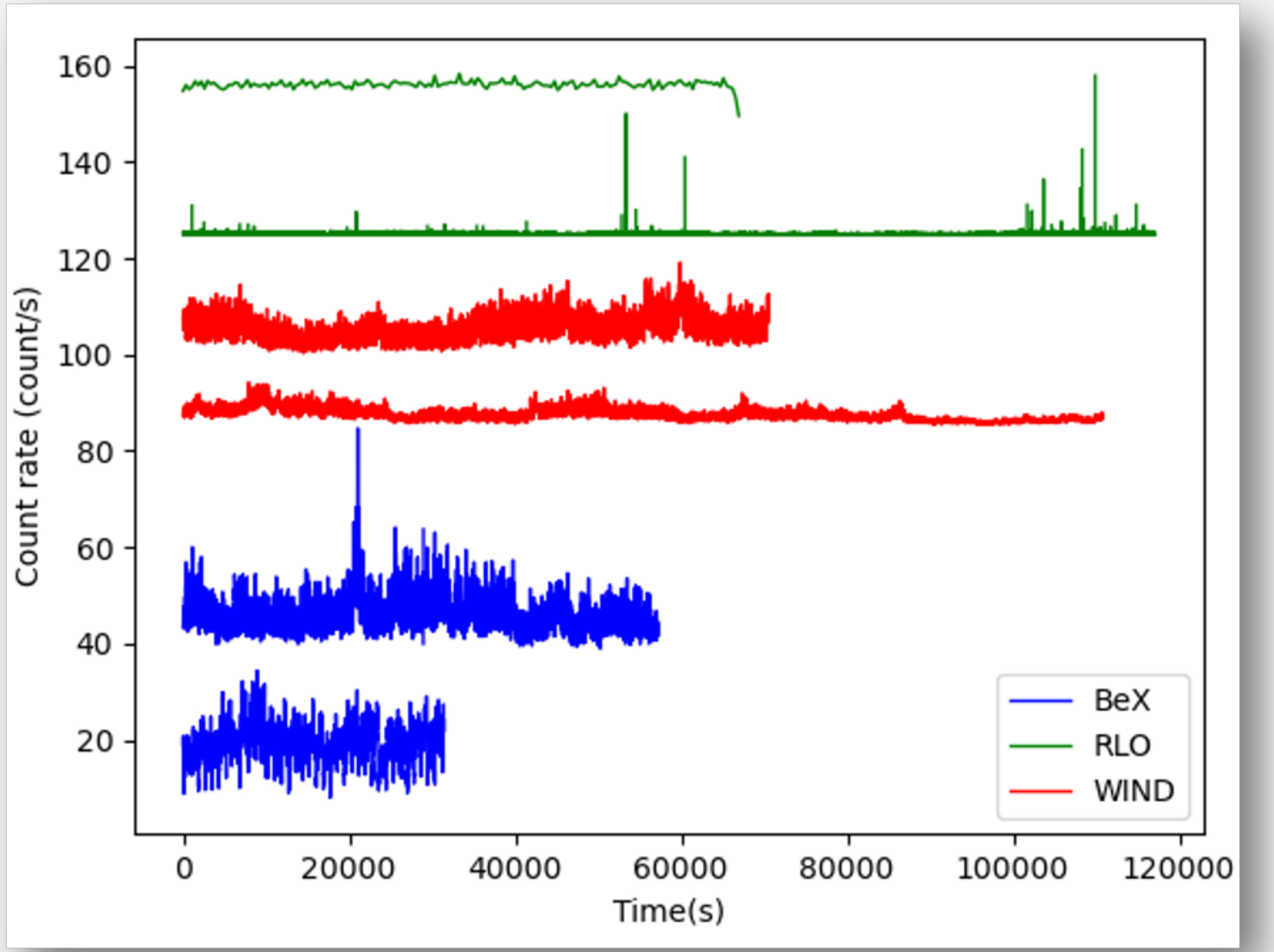
This work, as first approach, is focused on High Mass X-Ray Binaries.

HIGH-MASS X-RAY BINARIES

Variability (periodic, QPO or aperiodic) yields lots of information about the system and the physical processes taking place.



HIGH-MASS X-RAY BINARIES



Examples of light curves (XMM/EPIC) for High-Mass X-Ray Binaries with three types of mass transfer:

- Roche-lobe overflow
- Stellar wind accretion
- Accretion from the circumstellar disk of a Be star

The challenge is to classify HMXBs according to the type of mass transfer.

WHY MACHINE LEARNING?

Automatic classification of X-ray binaries is ideal to be addressed with ML techniques for several reasons:

- Large amount of data: huge datasets are ideal for training ML algorithms, as the more information available, the better the models can learn.
- Data complexity: ML techniques are capable of handling this complexity and learning patterns even in noisy or difficult-to-interpret data.
- Non-linear features: The relationships between the features of X-ray binaries and their classes can be non-linear or difficult to model using traditional analytical methods. ML algorithms, such as neural networks, can learn these non-linear relationships and capture complex patterns in the data.
- Ability to adapt: ML algorithms are flexible and can adapt to different types of data (observation duration, sampling frequency, instrument sensitivity, etc.).
- Feature discovery: In many cases, it can be difficult to determine which specific features of the light curves in the X-ray range are important for classification.

PREVIOUS RESULTS IN THE LITERATURE

The application of Machine Learning techniques, still a very recent tool of analysis in astrophysical applications, has proven effective in the classification of X-ray sources, even with a limited number of labelled sources and without additional information from optical and infrared catalogues.

Nevertheless, a general lack of a systematic analysis of variability emerges from previous works, which opens to a large area for further studies and improvements

See, for instance:

- Pérez-Díaz, V., et al., MNRAS 528, 4852–4871 (2024)
- De Beurs, Z., et al., ApJ 933-116 (2022)
- De Luca, A., et al., A&A 650, A167 (2021)

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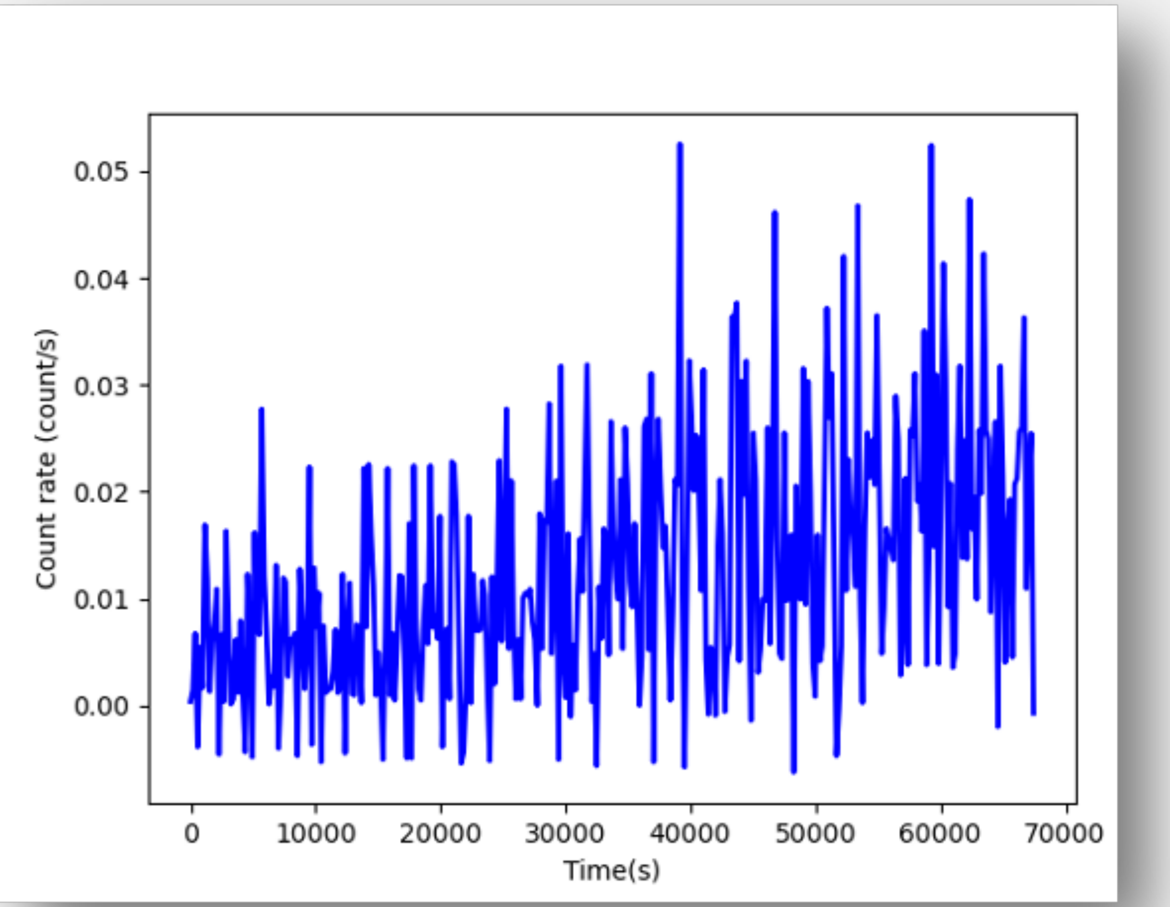
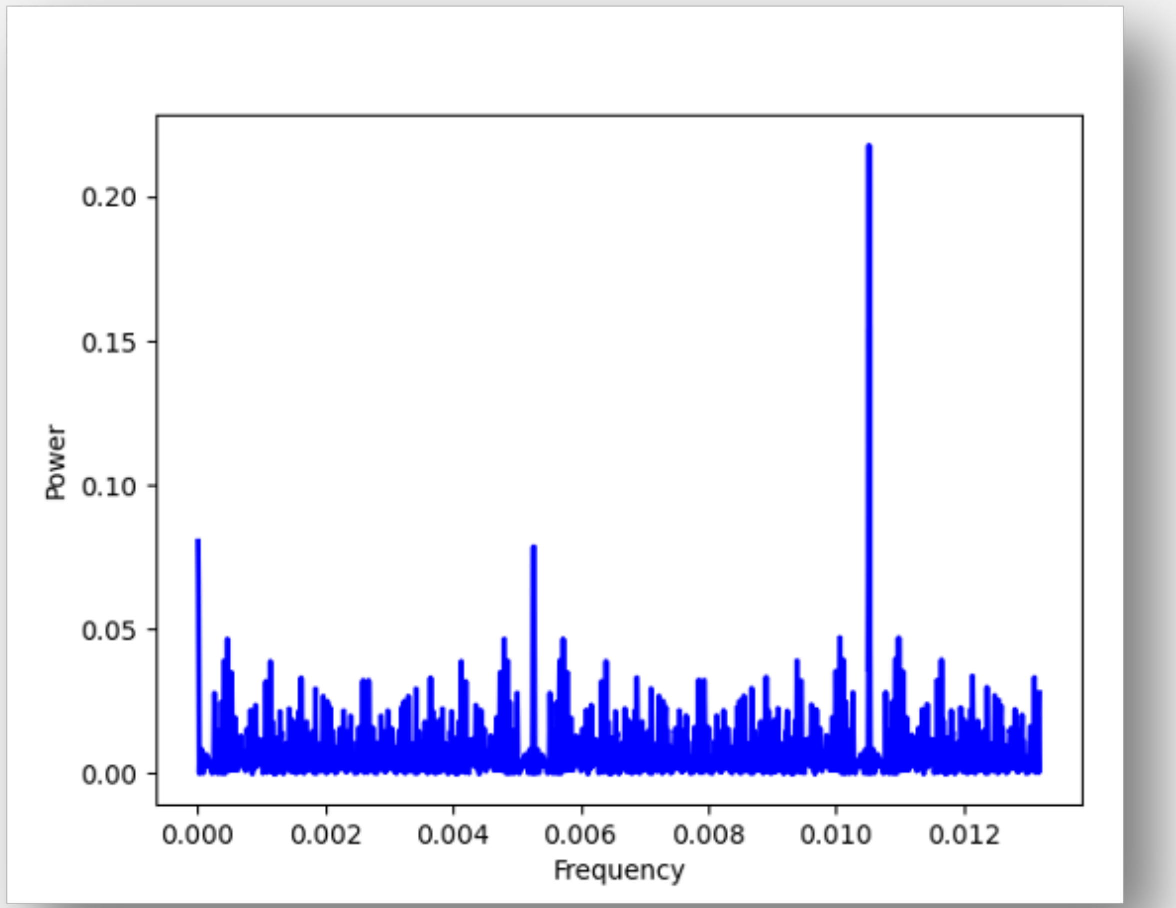
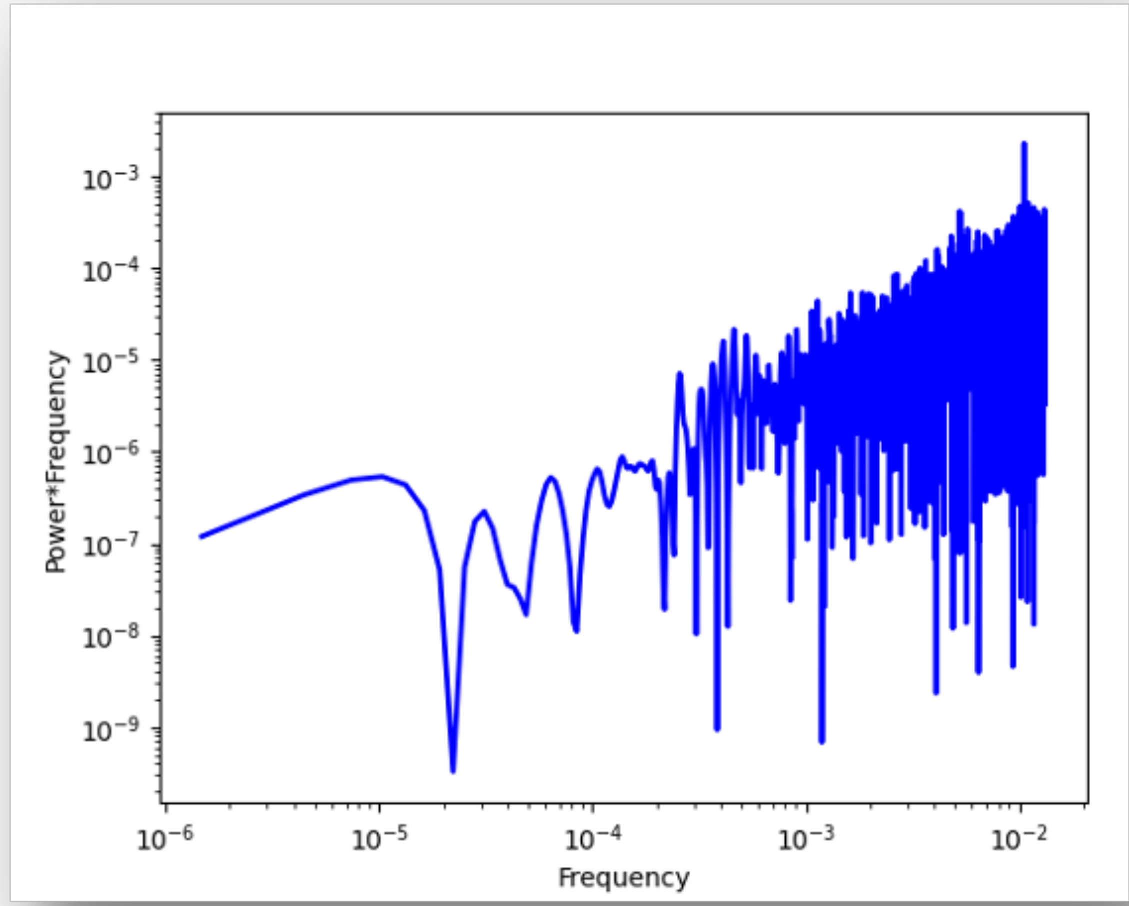
DATASETS



light curves



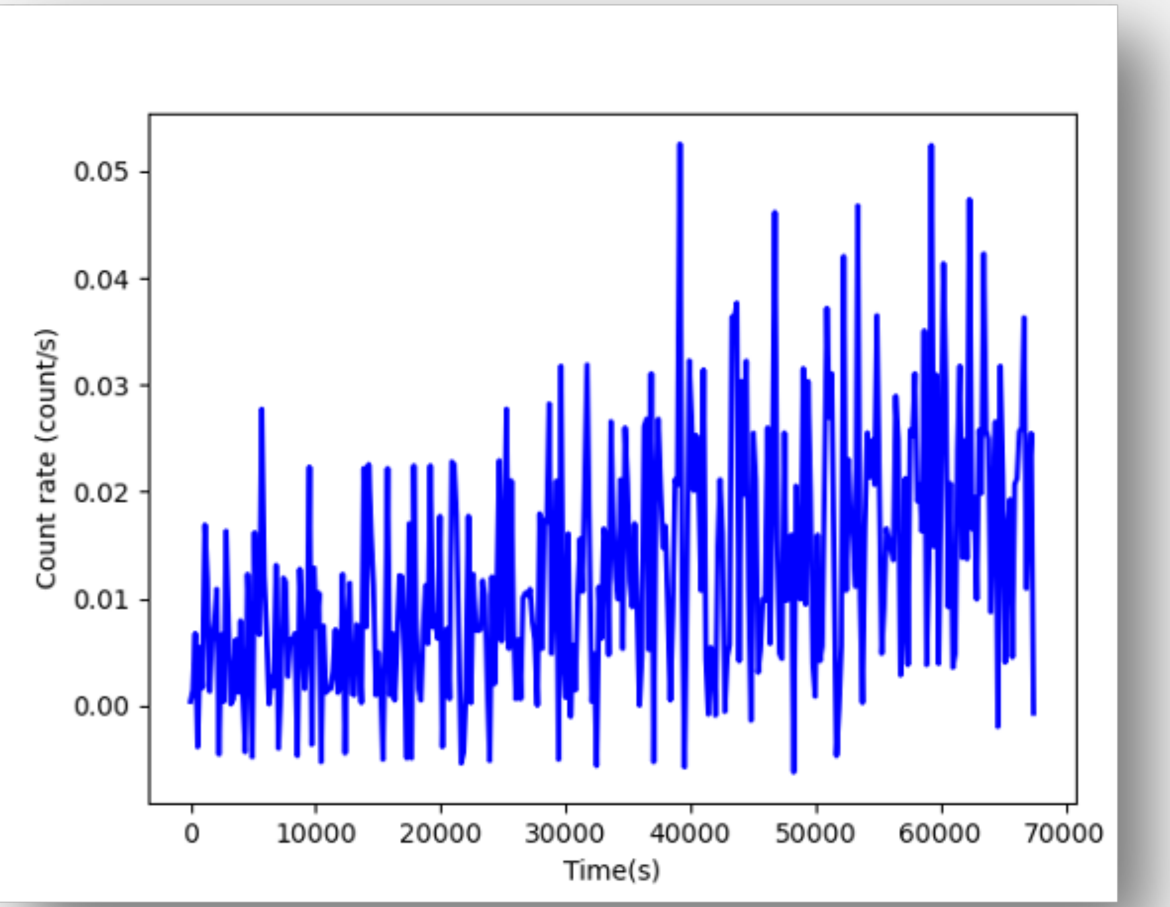
Lomb-Scargle Periodograms



Power spectral density (PSD)

Our final goal is to combine information from all of them to classify the targets, by using different ML approaches.

DATASETS



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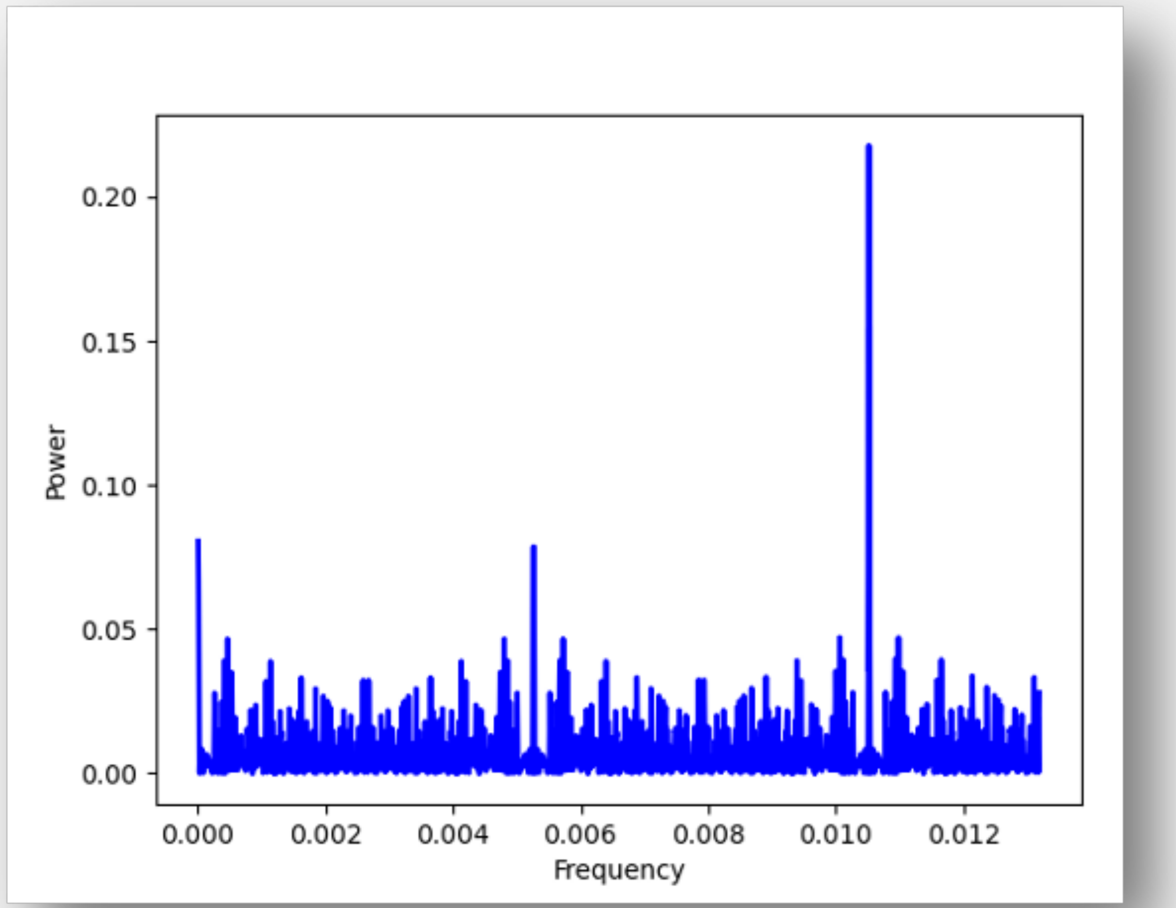

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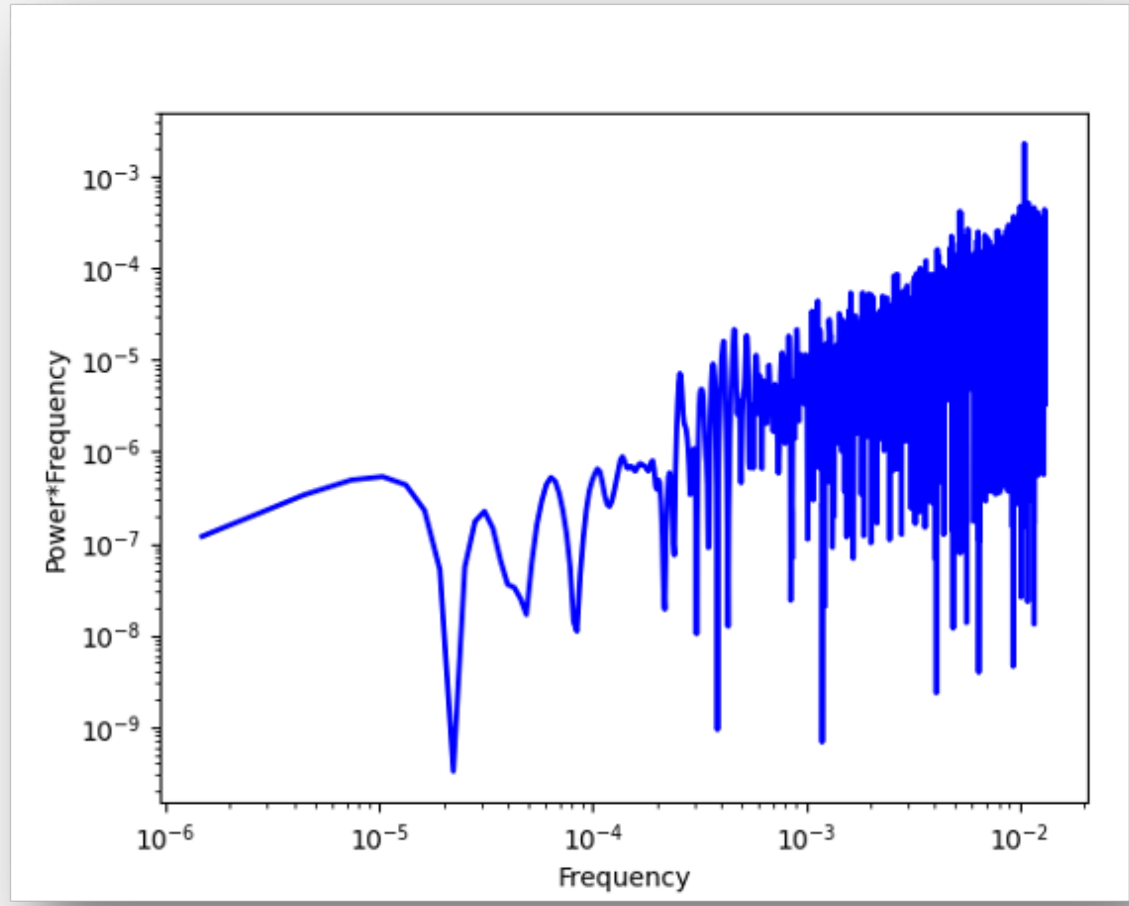

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To include the largest amount of data, we used a multi-mission approach (similar energy range 2-12 keV): XMM-Newton, MAXI, Swift (in progress).

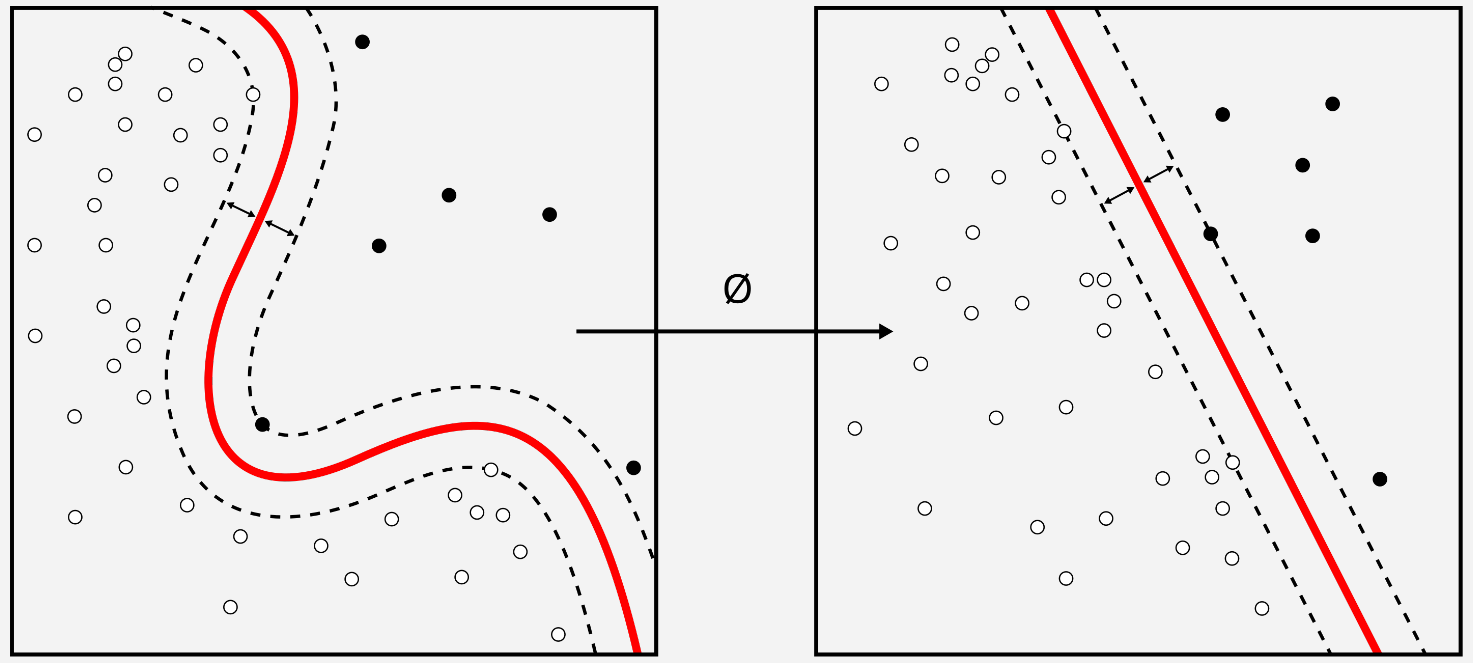
METHODOLOGY

Data are divided into two sets:

- 66% for training
- 33% for testing

Imbalanced learning: number of elements in each class is not equal (15, 93, 129 members for each class for XMM).

First tests with supervised classification methods:



non-linear methods
(KNN, Kernel SVM)

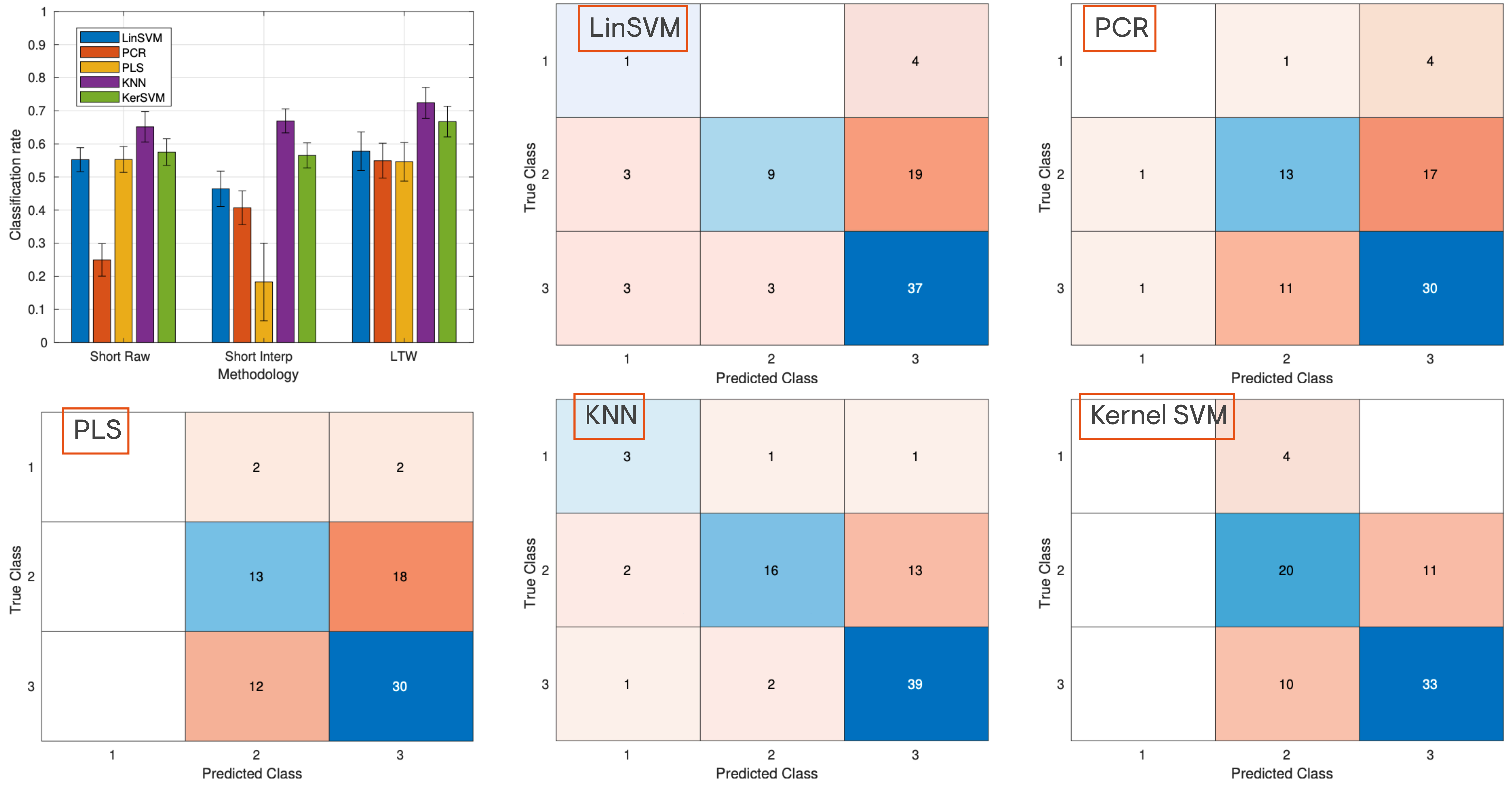
linear methods
(linear SVM, PLS, PCR)

RESULTS

XMM
Light curves

CLASES:

1. Roche-lobe overflow
2. Stellar wind accretion
3. BeX



RESULTS

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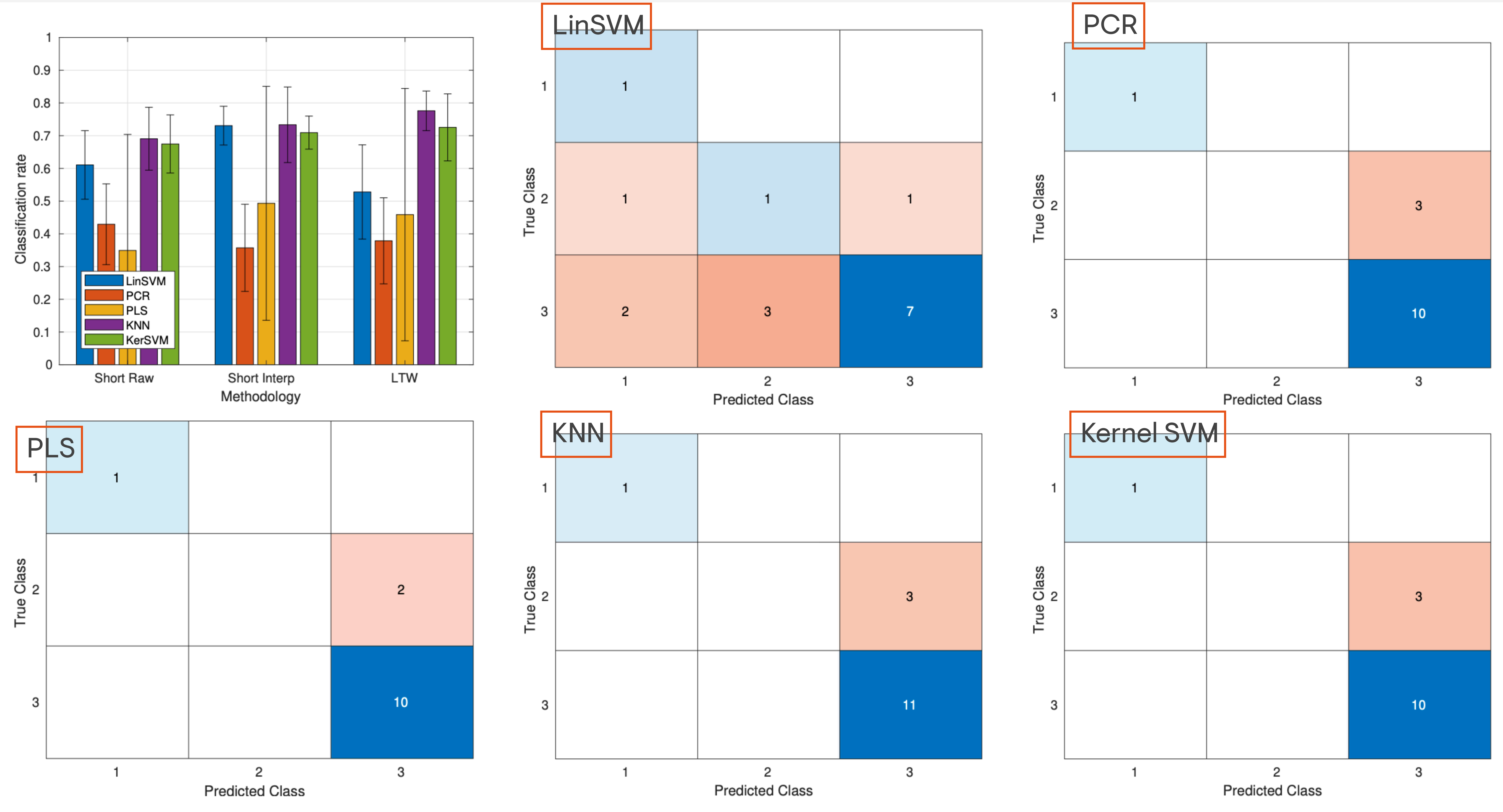
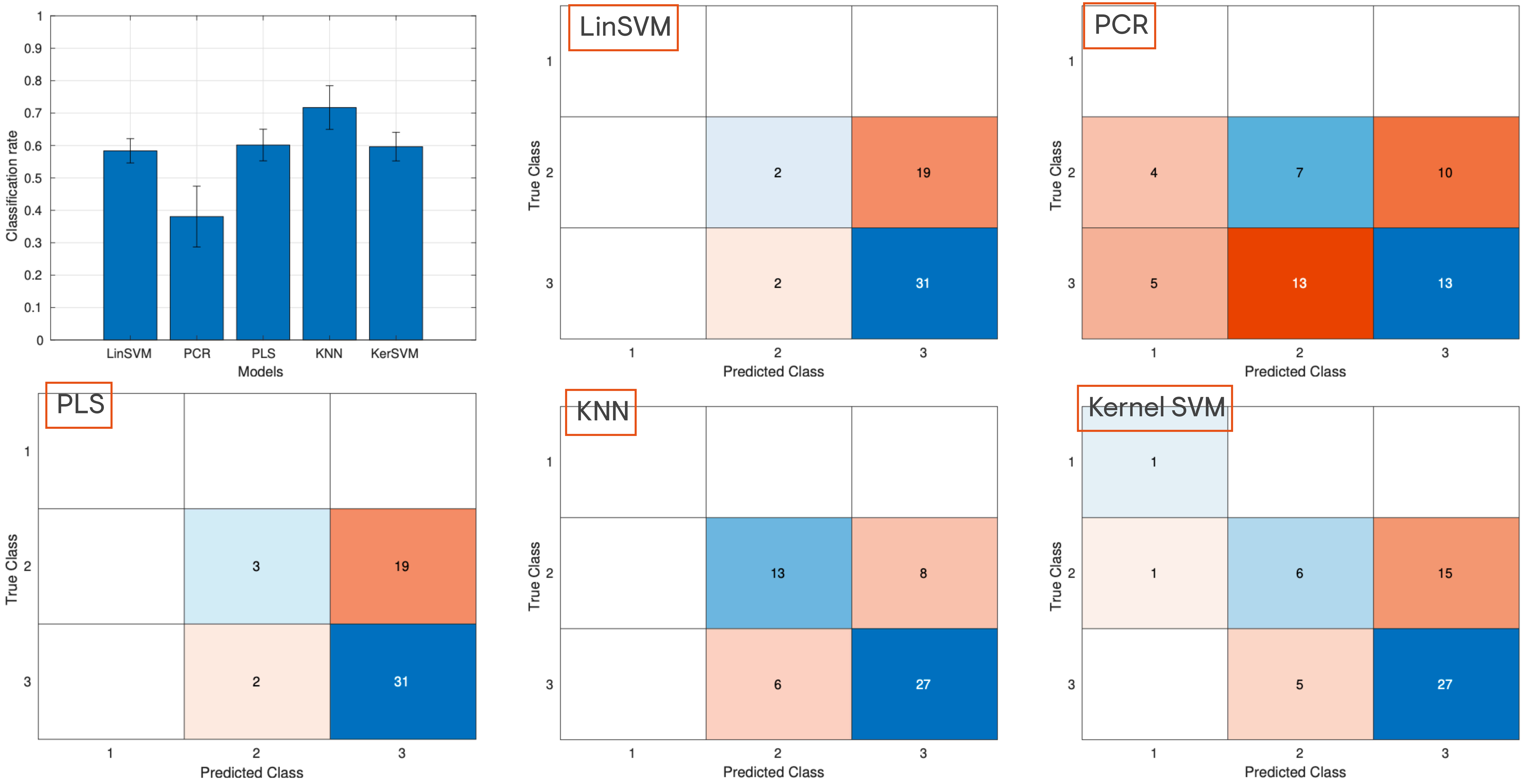


RESULTS

XMM PSDs



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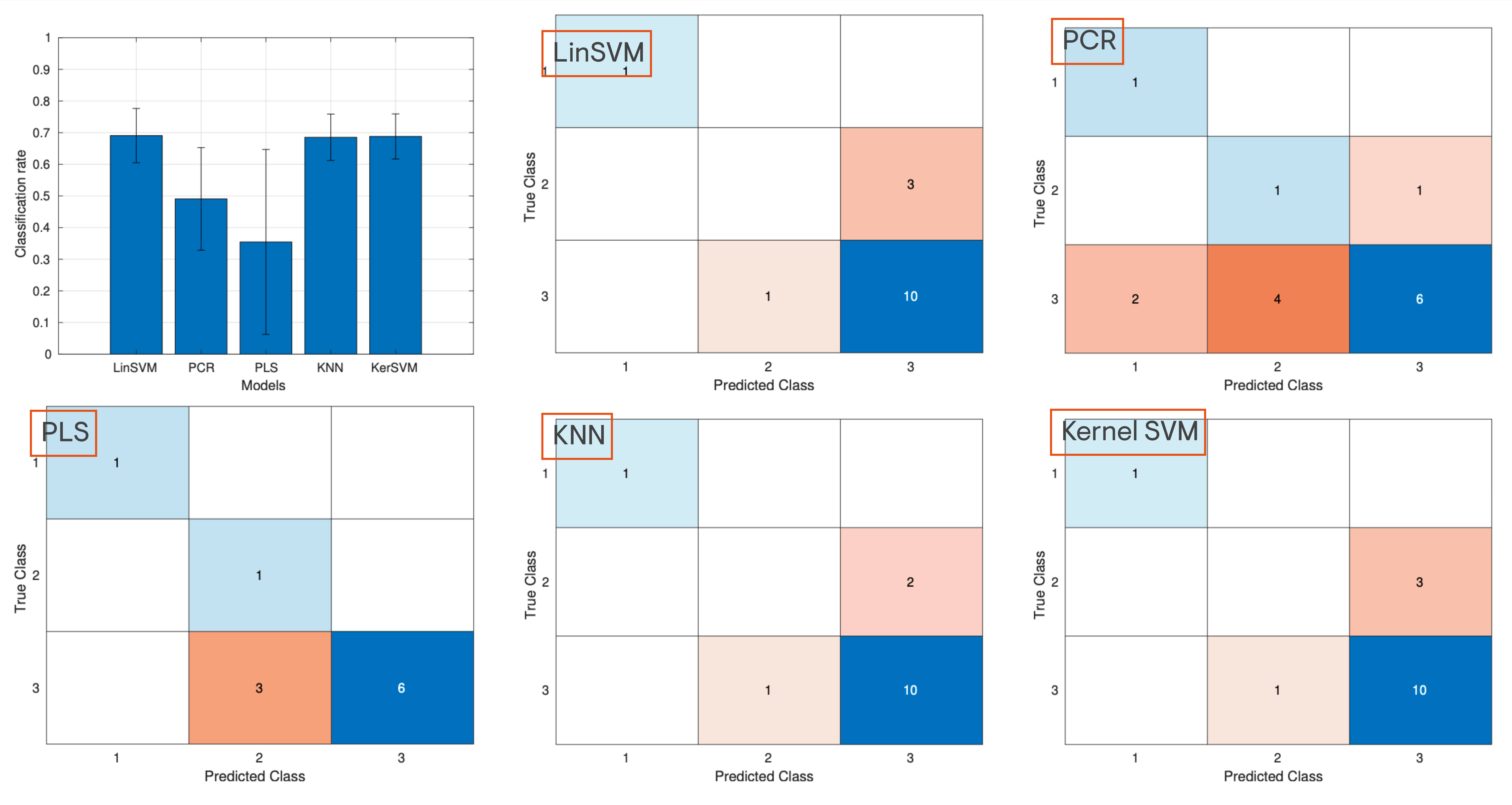

ADDITIONAL WORK

Data

- Including L-S periodograms (ongoing)
- Including data from additional missions: SWIFT (ongoing), RXTE/ASM, INTEGRAL/JEM-X, GINGA, GRO
- Extending the work to all XRBs
- Employing simulated THESEUS data

Models

- Improving current models in order to maximize the accuracy
- Applying neural network models
- Exploring the feasibility of real-time identification of targets as soon as they are observed by THESEUS.

CONCLUSIONS

- Within the THESEUS science, X-ray binaries are a key topic.
- The use of ML techniques provides advantages to identify and classify Galactic X-ray binaries. These techniques are well suited to problems where large amounts of data have to be analysed.
- This preliminary work is focused on High Mass X-Ray Binaries.
- Five ML techniques have been applied to light curves and PSDs from XMM-Newton and MAXI .
- Preliminary results are promising:
  - ☑ light curves allow for a more accurate classification than PSDs
  - ☑ KNN provides the best results… to be confirmed…