NEW ATHENA RISING

From tools to analysis
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HIGH RESOLUTION SPECTROSCOPY

What does that actually mean?

Orbital modulations

Doppler shifts

Emission lines

More complexity - More insight!

A lot can be done with current instruments while we prepare for New-Athena

HMXBs are ideal laboratories for exploiting high-resolution spectroscopy.

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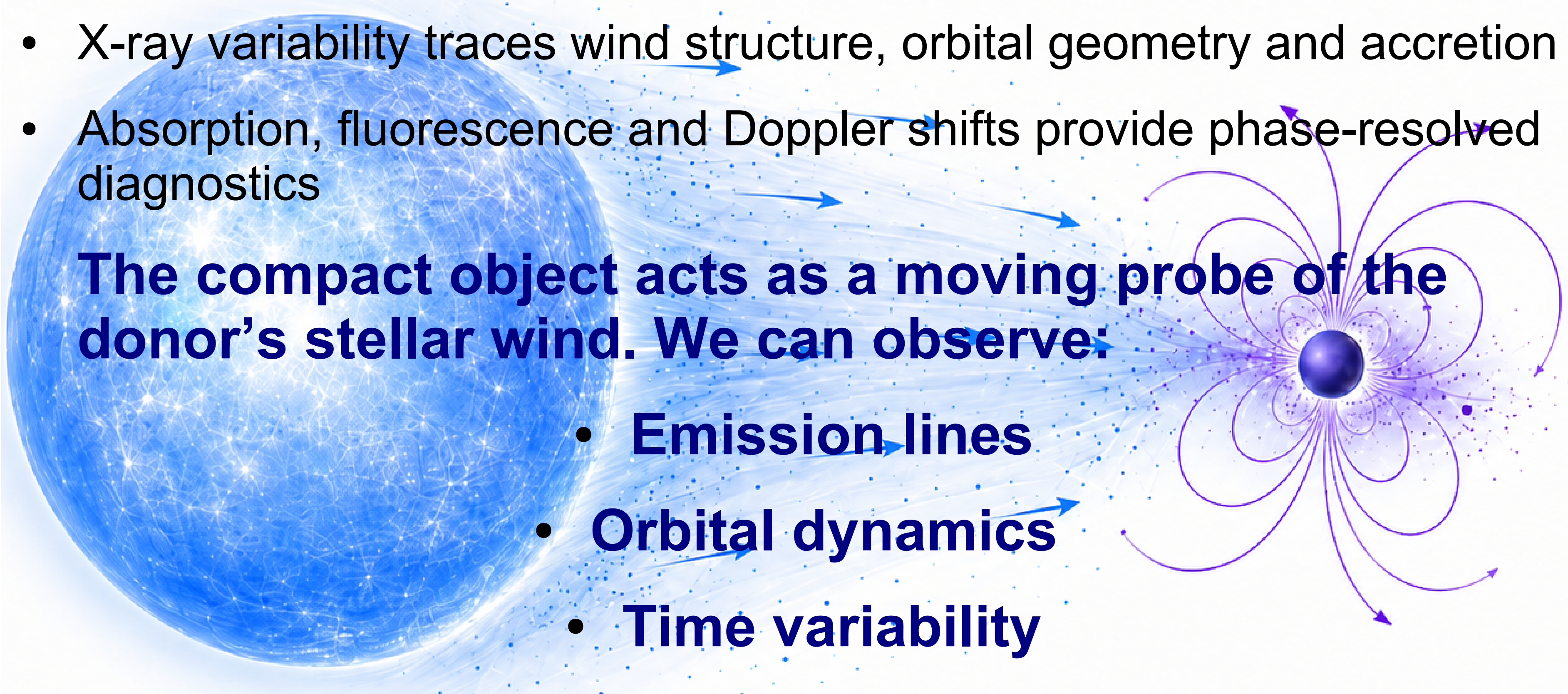
Context: high-mass X-ray binaries



- O/B-type donor + compact object embedded in a dense stellar wind
- X-ray variability traces wind structure, orbital geometry and accretion
- Absorption, fluorescence and Doppler shifts provide phase-resolved diagnostics

The compact object acts as a moving probe of the donor's stellar wind. We can observe:

- **Emission lines**
- **Orbital dynamics**
- **Time variability**

Let us now see how these diagnostics can be explored through code and results.

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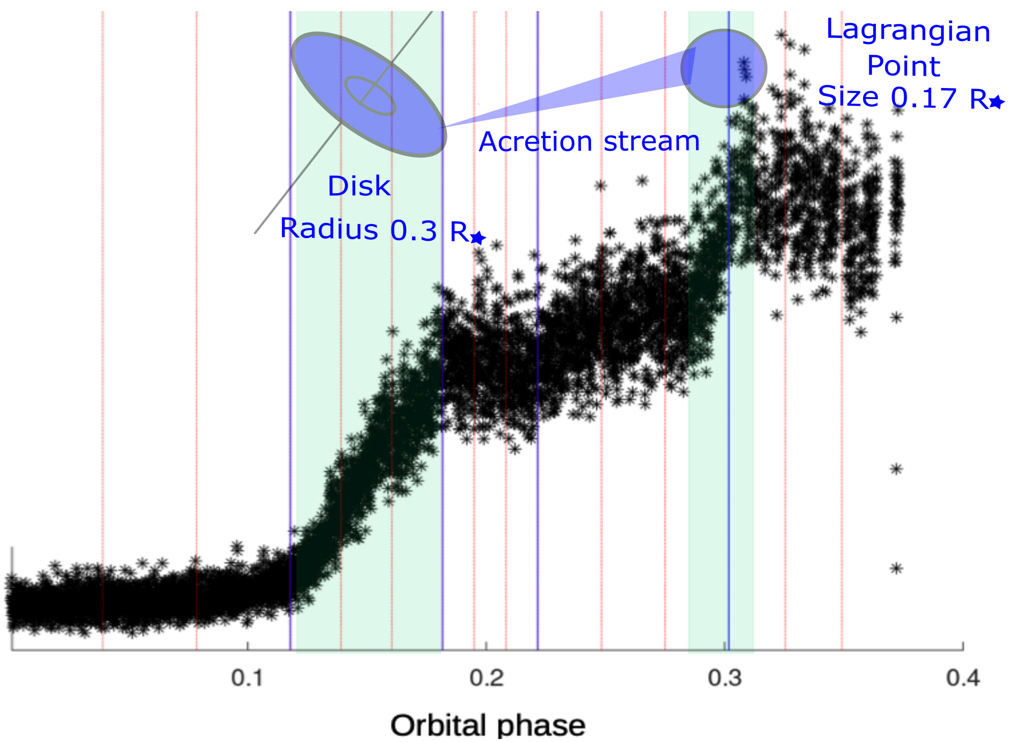
The disc-fed system Cen X-3

Low-hard / high-soft transitions
Eclipsing system



Properties of the Cen X-3 System	
Donor Star	
MK type	O6–8 III
M_{opt}	$20.2^{+1.8}_{-1.5}\ M_\odot$
R_*	$12.1 \pm 0.5\ R_\odot$
Neutron Star	
M_{NS}	$1.34^{+0.16}_{-0.14}\ M_\odot$
Spin period	4.79 s
Orbit	
Orbital period	2.087139842(18) d
Inclination i	$72°{}^{+6}_{-5}$
Semimajor axis a	$1.58^{+0.05}_{-0.04}\ R_*$

Examples on an Chandra observation taken in the state transition during the egress

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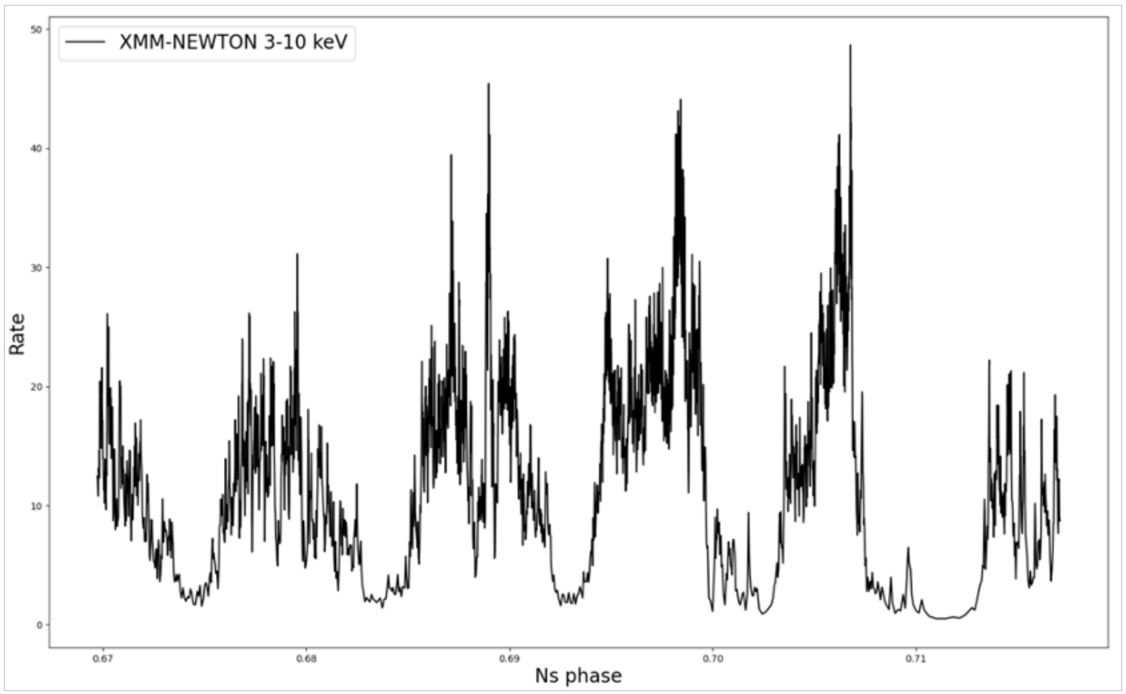
The magnetar-candidate HMXRB 4U 0114+65

One of the slowest known neutron stars.
Every pulse is different
The source exhibits rich time variability



Properties of the 4U 0114+65 System	
Donor Star	
Spectral type	B1 Ia (V* V662 Cas)
M_{opt}	$\sim 23 \pm 3\ M_{\odot}$
R_{*}	$\sim 37 \pm 5\ R_{\odot}$
$\dot{M}_{w}$	$\sim (1-3) \times 10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}$
v_{∞}	$\sim 800-1000\ \mathrm{km\ s}^{-1}$
β (wind)	$\sim 0.8-1.0$
Neutron Star	
M_{NS}	$1.4 \pm 0.2\ M_{\odot}$
Spin period	~ 2.6 h ($\sim 9.36 \times 10^{3}$ s)
Surface B-field	$\sim 10^{14}$ G ? (magnetar candidate)
Orbit	
Orbital period	11.598 ± 0.005 d
Inclination i	$\sim 40° - 60°$ (not eclipsing)
Semimajor axis a	$\sim 1.34-1.65\ R_{*}$

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Examples on a set of 9 Chandra observations
in different orbital phases

Orbital modulations python package

GETTING STARTED

Getting started

Usage

EXAMPLES

Time Phase Relation Theoretical

Doppler Theoretical in four scenarios

Density Through the Orbit and Absorption Column

Density and Ionization Parameter in the Orbital Path of Radiation

Ionization Map of 4U0114+65

Ns pulse shape in Vela X-1

Fe XXV Doppler Shifts Cen X-3

FUNCTIONS

CONTRIBUTE

/ GETTING STARTED

The Journal of Open Source Software

xraybinaryorbit

X-ray binaries are truly fascinating! In these extreme environments, a compact object—either a neutron star or black hole—draws in matter from a companion star, producing intense X-ray emissions. These systems offer a unique window into extreme physics, from the effects of strong gravity and relativistic jets to the presence of intense magnetic fields.

Orbital modulations are observed in nearly all X-ray binary systems. These variations arise from the orbital motions of the system, driven by the relative velocities of the two stars and their changing configurations with respect to each other and the observer.

To aid in the study of these modulations, we introduce **xraybinaryorbit** —a user-friendly Python package designed to simplify the analysis of orbital modulations in X-ray binaries. Whether you are studying the orbital parameters or working to refine your data analysis, this tool is built to help you extract the most from your observations.

If you have any questions or need assistance, please feel free to reach out: graciela.sanjurjo@ua.es.

Getting started

Installation

You can install the package directly from PyPI using pip: **pip install xraybinaryorbit**.

Or download the code from here.

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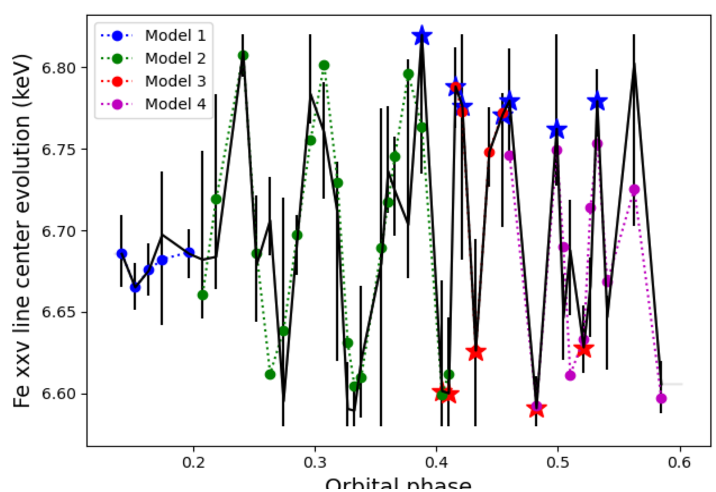
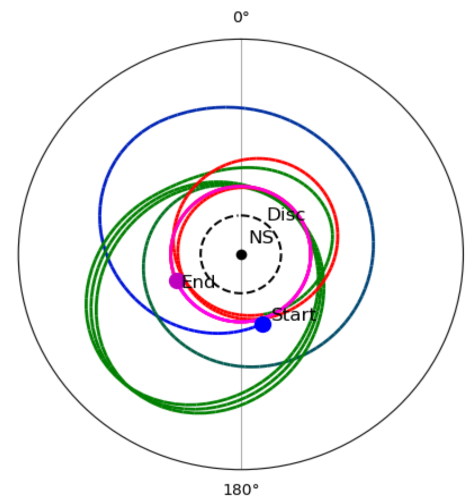
https://xragua.github.io/xraybinaryorbit/

pip install xraybinaryorbit

Ballistic movement around the NS in state transition of Cen X-3

The Fe XXV emission lines show energy shifts with respect to their expected rest-frame values. We fitted these shifts with **fit_disc_ps()** from **xraybinaryorbit**, allowing us to infer the trajectory of the emitting plasma.





Model	r^2	Semi-Major Axis ($R_\star$)	Eccentricity	Period (s)	Inclination (°)
1 (Blue)	0.6	0.90 ± 0.05	0.4 ± 0.3	36000 ± 15000	74 ± 3
2 (Green)	0.7	0.91 ± 0.05	0.45 ± 0.08	13000 ± 130	76.0 ± 0.8
3 (Red)	1.0	0.62 ± 0.13	0.27 ± 0.14	6000 ± 60	81 ± 6
4 (Magenta)	0.7	0.52 ± 0.02	0.003 ± 0.002	6300 ± 50	66 ± 6

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NH to constrain wind parameters in 4U 0114+65

Using **fit_nh_ps()** from **xraybinaryorbit,** we fitted the integrated column density traversed by the neutron-star radiation along the line of sight for three different orbital phases corresponding to three different observations.

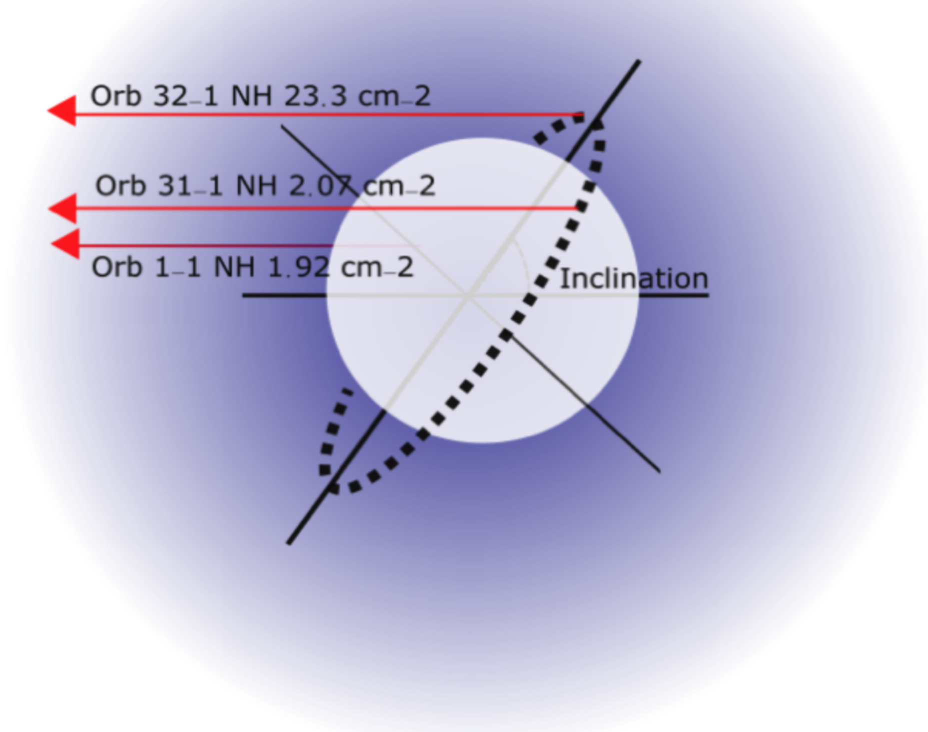
The fit, based on a particle swarm algorithm, allowed us to infer the orbital inclination and the stellar-wind mass-loss rate.

Inclination:

$$40 \pm 3^{\circ}$$

Mass-loss rate:

$$(8.6 \pm 1.7) \times 10^{-7}\, M_{\odot}\, \mathrm{yr}^{-1}$$



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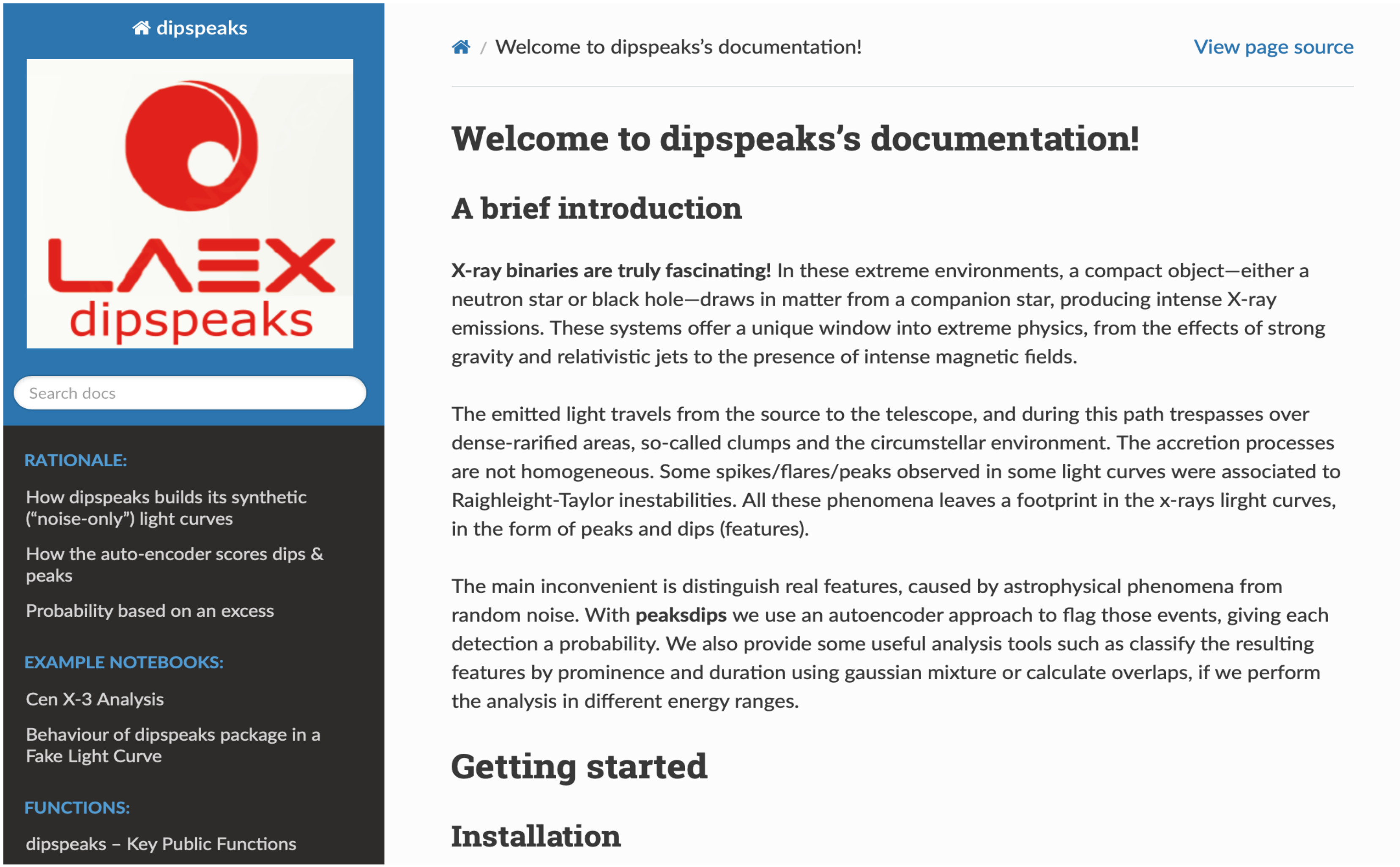
Dips and spikes in light curves


dipspeaks

LAEX dipspeaks

Search docs

RATIONALE:

How dipspeaks builds its synthetic (“noise-only”) light curves

How the auto-encoder scores dips & peaks

Probability based on an excess

EXAMPLE NOTEBOOKS:

Cen X-3 Analysis

Behaviour of dipspeaks package in a Fake Light Curve

FUNCTIONS:

dipspeaks – Key Public Functions

/ Welcome to dipspeaks’s documentation!

View page source

Welcome to dipspeaks’s documentation!

A brief introduction

X-ray binaries are truly fascinating! In these extreme environments, a compact object—either a neutron star or black hole—draws in matter from a companion star, producing intense X-ray emissions. These systems offer a unique window into extreme physics, from the effects of strong gravity and relativistic jets to the presence of intense magnetic fields.

The emitted light travels from the source to the telescope, and during this path trespasses over dense-rarified areas, so-called clumps and the circumstellar environment. The accretion processes are not homogeneous. Some spikes/flares/peaks observed in some light curves were associated to Raighleight-Taylor inestabilities. All these phenomena leaves a footprint in the x-rays lirght curves, in the form of peaks and dips (features).

The main inconvenient is distinguish real features, caused by astrophysical phenomena from random noise. With **peaksdips** we use an autoencoder approach to flag those events, giving each detection a probability. We also provide some useful analysis tools such as classify the resulting features by prominence and duration using gaussian mixture or calculate overlaps, if we perform the analysis in different energy ranges.

Getting started

Installation

https://xragua.github.io/dipspeaks/

pip install dipspeaks

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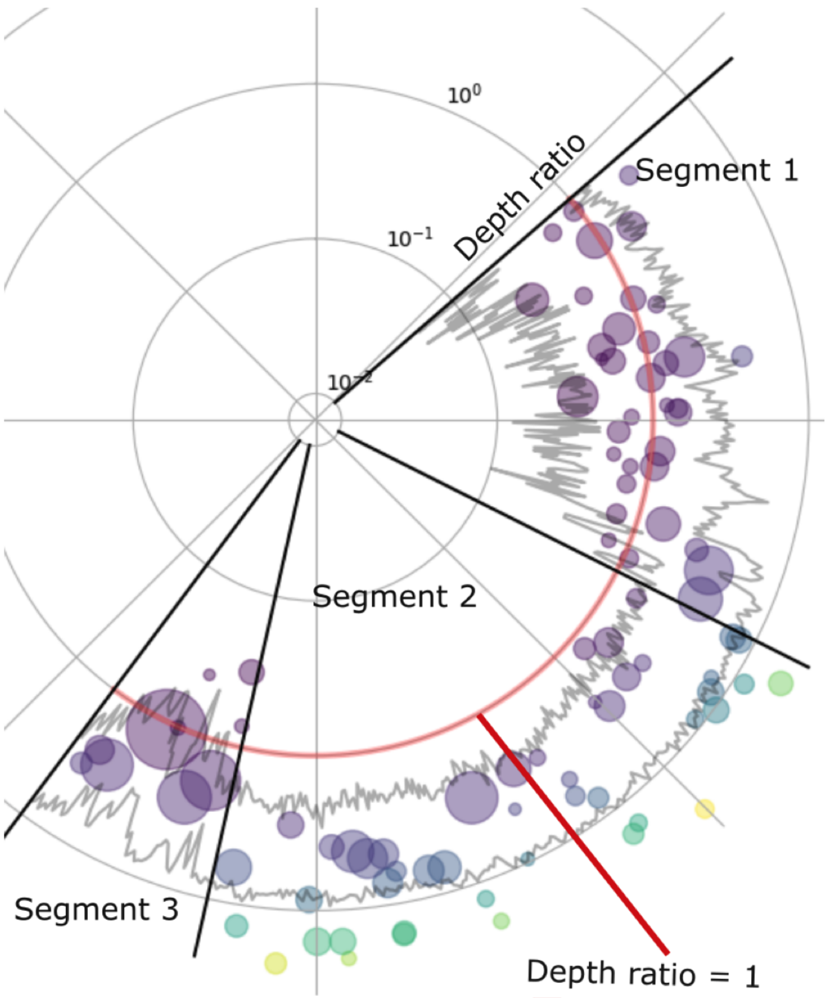
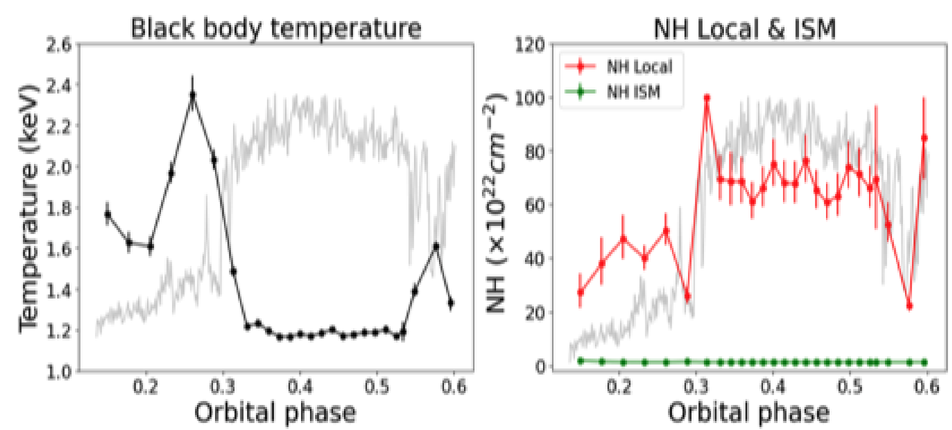
Arrival of train of clumps in transition state of Cen X-3



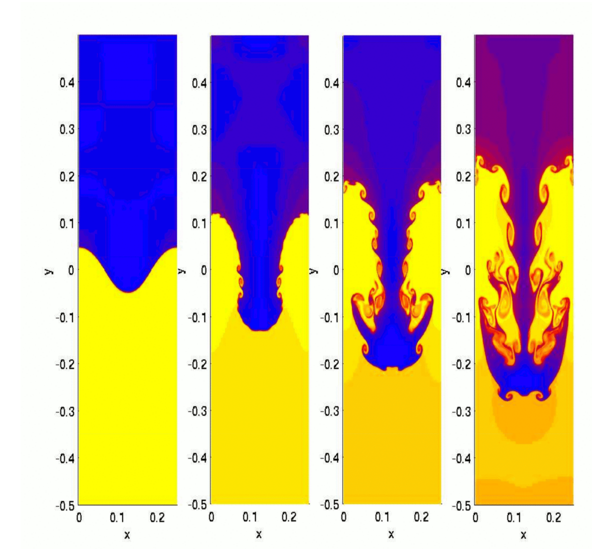
Chandra observation in the transition state (low-hard to high soft)

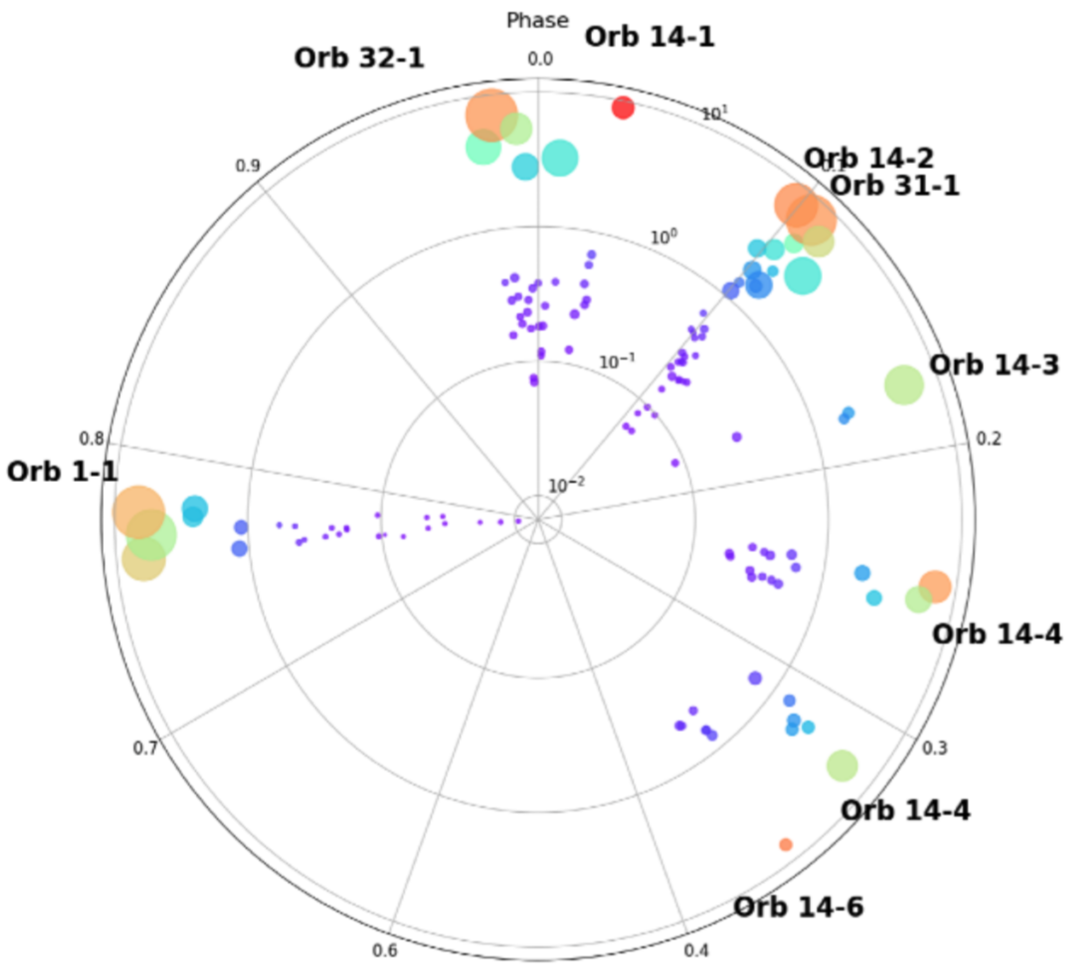
Clump candidates: dips pronounced in the low energy range.

We detected clump candidates in transition state, accompanied by plasma cooling and enhanced absorption



Spikes compatible Rayleigh–Taylor instabilities in 4U 0114+65





9 Chandra observations in different orbital phases.

Spikes caused by accretion: best in the high-energy range.

Spikes compatible with RTI-driven accretion were observed in this set of observations.

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EMISSION LINE DETECTION

Public in repository https://github.com/xragua

In collaboration with Luis Abalo

LAEX

BLiSS

GETTING STARTED

- Main features
- Getting started
- License

EXAMPLE

EMISSION LINES EXAMPLE

FUNCTIONS

CONTRIBUTE

REFERENCES

/ GETTING STARTED

BLiSS – Blind Line Search System

BLiSS (Blind Line Search System) is an open-source Python package for finding emission lines in spectra without telling the code where to look first.

In other words: a **real blind line-search algorithm** — you only need your spectrum.

BLiSS was designed to simplify and speed up spectral analysis in X-ray astronomy. Instead of manually inspecting spectra, guessing candidate energies, and testing lines one by one, **BLiSS** performs an automatic search for statistically significant emission features and then cross-matches them with atomic transitions.

The package combines Gaussian line-profile fitting, statistical scoring, and database-based identification using XSTAR atomic data. It is especially useful when the continuum is complex, uncertain, or simply not the main focus of the analysis.

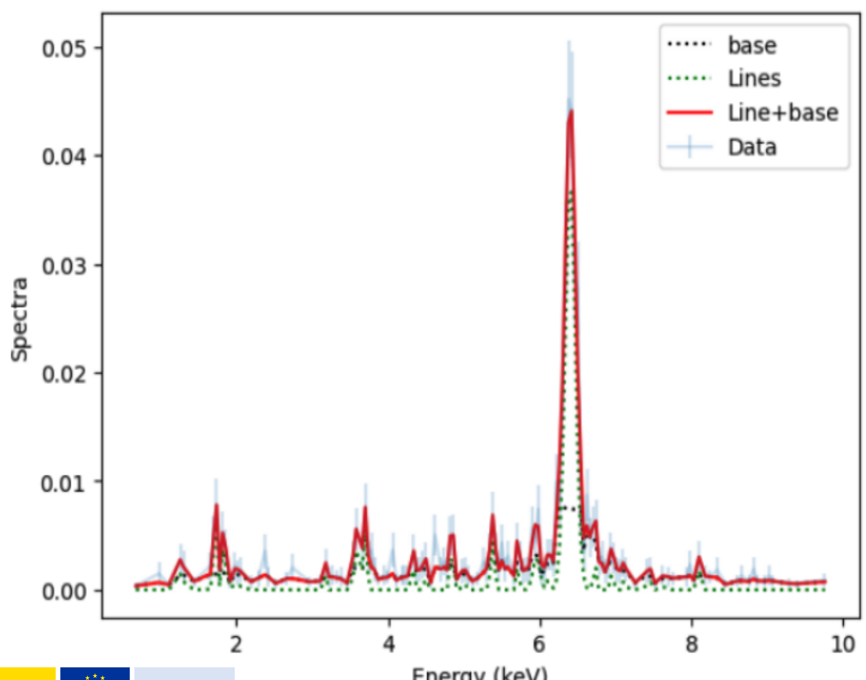
Although **BLiSS** was developed for X-ray spectra, the core idea is more general: if you have spectral data with uncertainties, BLiSS can help you search for emission features in a systematic and reproducible way.

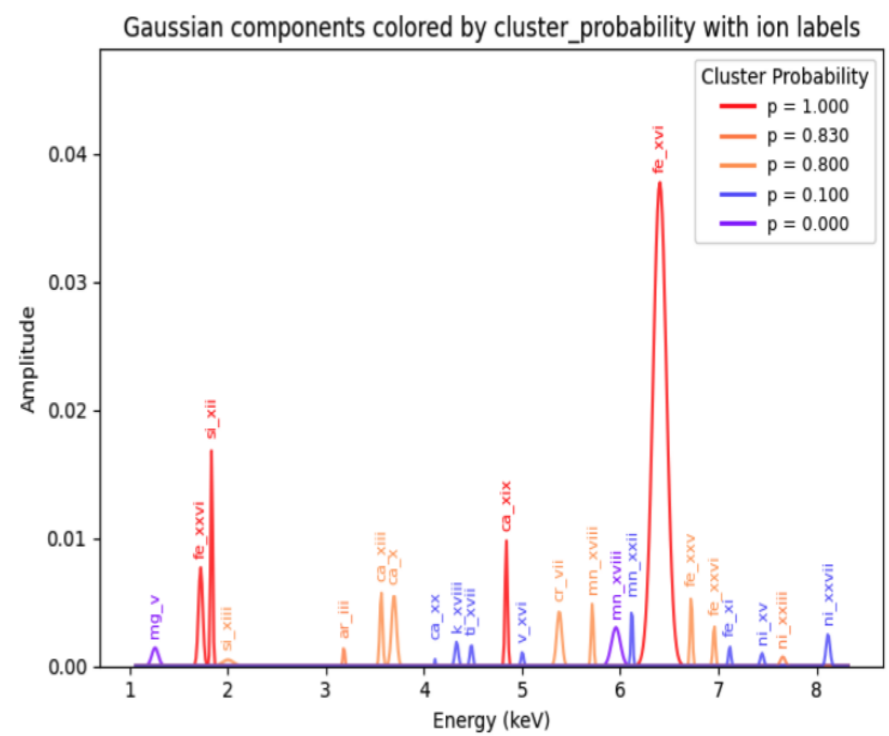
BLiSS (BLIND SEARCH SYSTEM)

CREATED TO BE **REALLY** BLIND:

You only need your spectra:

Continuum independent
Line-list independent
Probabilities estimated with Gaussian mixture models
Line identification for a given Doppler velocity window





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Take-home message:

Current high-resolution X-ray data already allow us to test tools and methods in preparation for **NewAthena**.

HMXBs provide natural laboratories for orbital, wind, and accretion diagnostics, making them especially well suited for high-resolution X-ray analysis.

Open tools such as **xraybinaryorbit**, **dipspeaks**, **BLiSS**, and many others can help make this analysis more reproducible, systematic, and accessible.

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