Pulse Profile Decomposition

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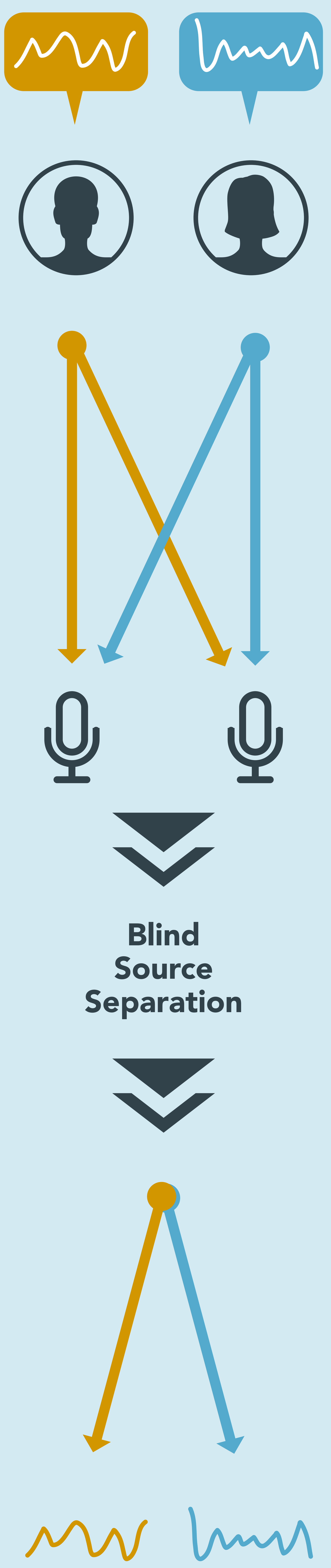
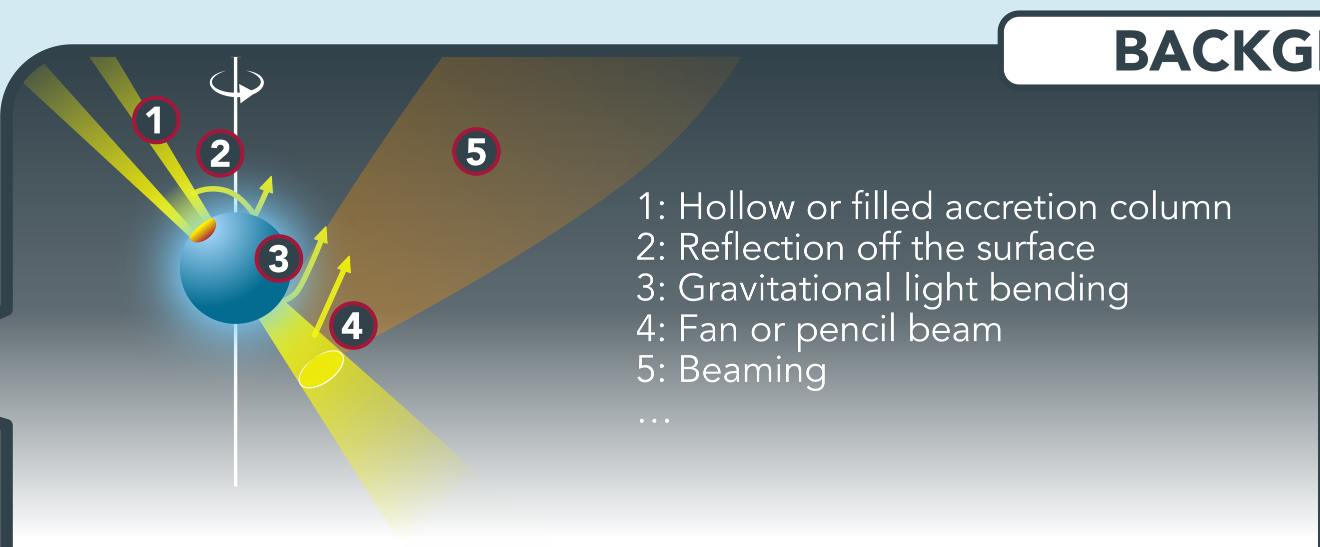
Contact me here during conference (and after)



BACKGROUND



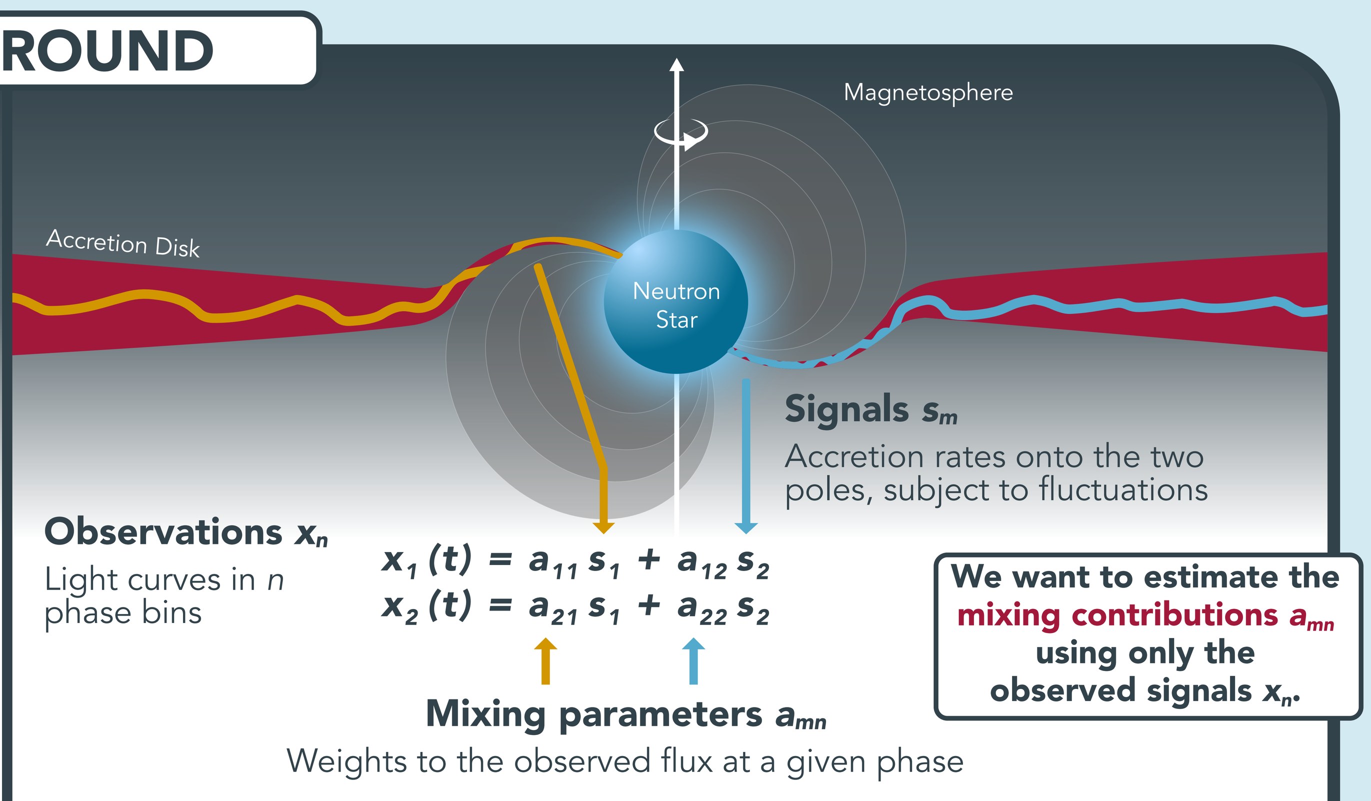
The pulse profiles of accreting X-ray pulsars depend on

1) the **geometry of the system,**
2) the **emission region** close to the neutron star, and
3) how the matter is diverted by the magnetic field in the **inner accretion disk**.

At a given pulse phase, we can see a **mixture** of the emission of **both poles at the same time.** This can occur because of one or the combination of a number of phenomena, e.g. the type of accretion column (if present), gravitational light bending, beaming, reflection…

The problem is:

We still don't know the contributions of the individual poles and their intrinsic emission properties!

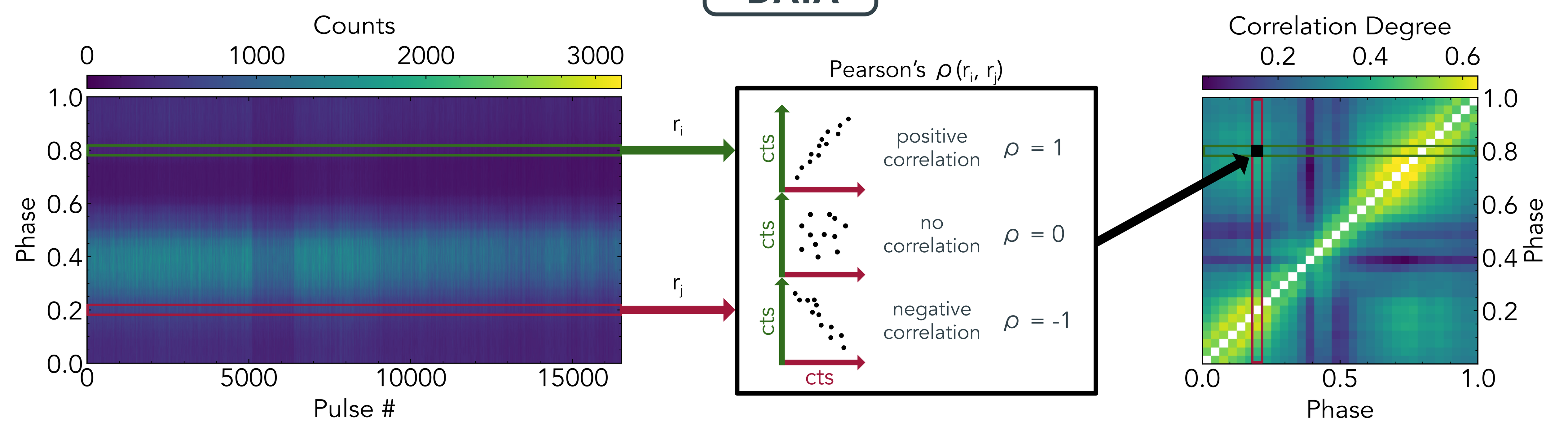


A fluctuating accretion rate leads to a uniquely variable emission of the two poles. We exploit this to **disentangle the contributions of the individual poles** using a blind source separation (BSS) method called non-negative matrix factorisation (**NMF**).

For this, we consider that the observed flux in any given pulse phase is a **mix** of the **two signals**, which are **weighted** by the **intensity** of the emission of each pole - the single-pole pulse profile.

When correlating light curves at different phases, we expect to see a **higher** degree of **correlation**, if the radiation emerged at a **single pole** and **lower correlation**, if it is a **mix** of two separate poles.

DATA

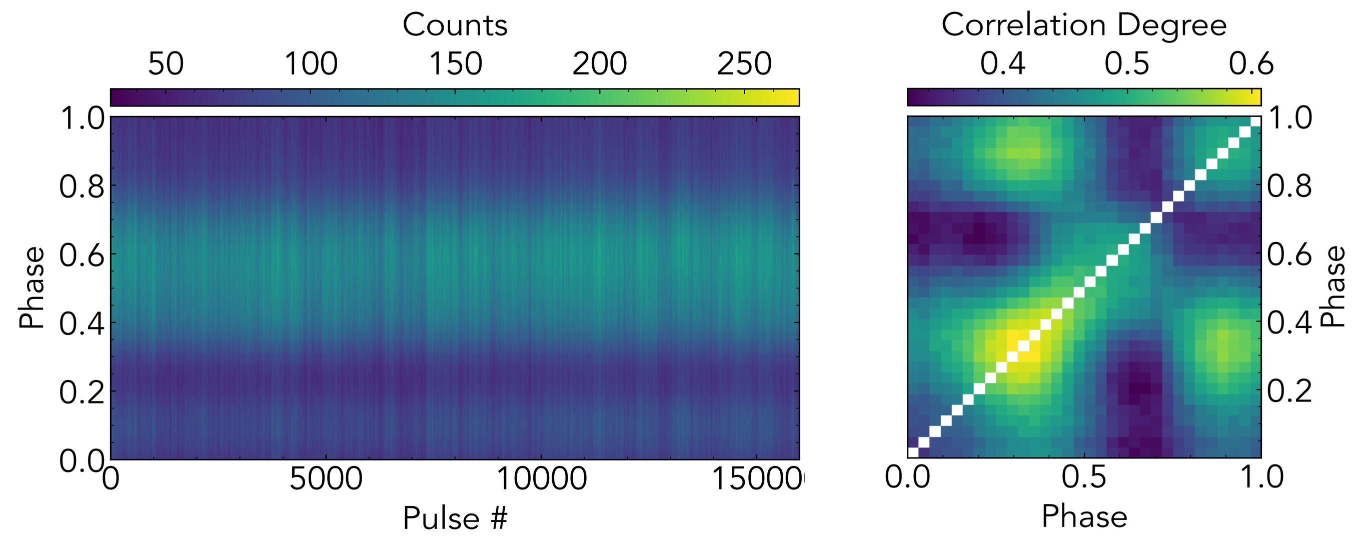


Example of a phase matrix showing **pulse-to-pulse variability**. The data shows an observation of **Cen X-3** made by RXTE/PCA. Each row is a light curve at a given phase.

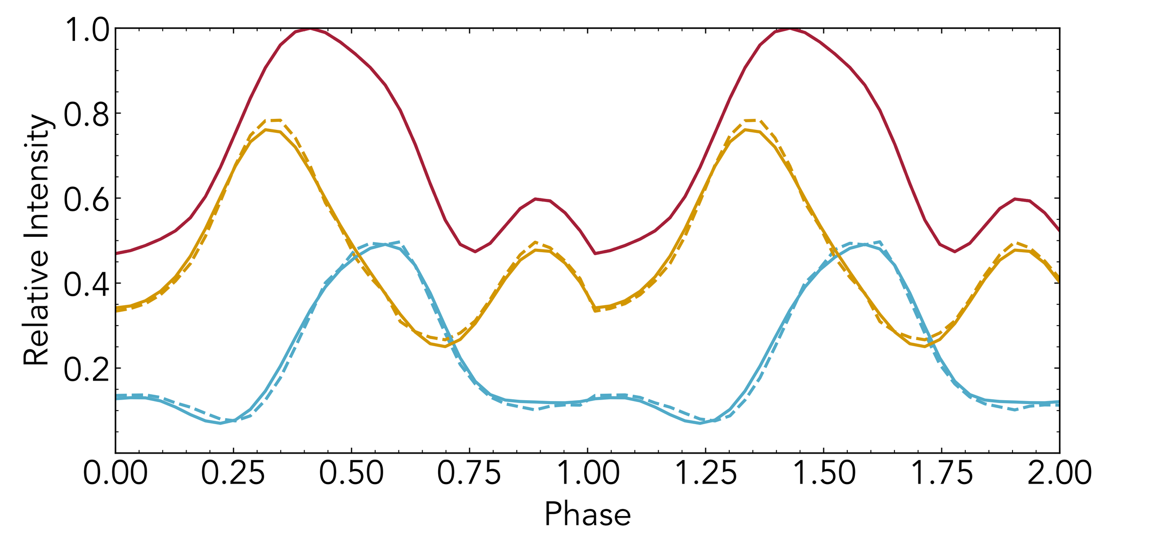
Pearson's correlation coefficient measures the linear correlation between two datasets (here: light curves at given phases).

The **correlation matrix** clearly shows some **structure** and is not flat, supporting the idea that the **signals are independent** and the NMF method should work.

VERIFICATION

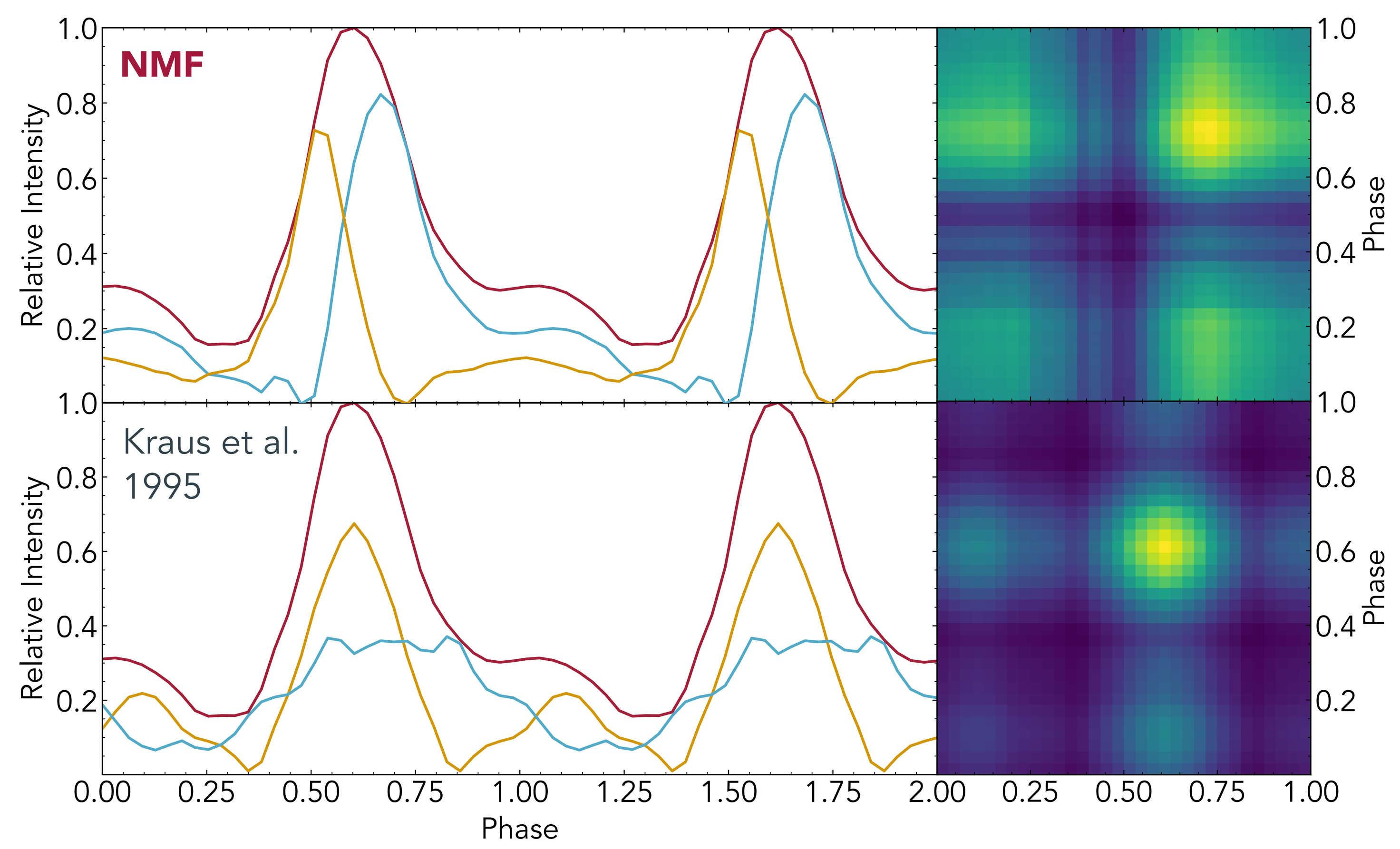


Simulated phase matrix (left) and correlation matrix (right). The simulated light curves are based on a broken power law with break frequency at the pulsar spin period and known single-pole pulse profile contributions.



Input weights/single-pole pulse profiles (solid blue and yellow) and the recovered weights (dashed). We were able to recover the original profiles of the simulation well using the NMF method.

RESULTS



The **decomposition results** of Cen X-3 (left panel) using NMF show that the primary peak is composed of **two distinct peaks** of approximately **equal amplitude**. The two profiles are notably **asymmetric** in phase and the **narrow** character of the peaks points toward **pencil beams.** The auto-correlation matrix (right panel) replicates the main features of the observed correlation matrix (see Section "Data").

The results of the analysis of the same data with the method by **Kraus et al. 1995** shows entirely different results. Our results are **incompatible** with their **assumption** that both single-pole pulse profiles are **symmetric**. The auto-correlation matrix also exhibits features at other phases compared to the observed matrix.

We conclude that NMF is a valuable new tool to analyse and decompose pulse profiles and a next step is the modelling of the decomposition results.

References: Phenomenology of accreting pulsars: Bildsten, et al. 1997 and Fürst, et al. 2019; Emission regions on neutron stars: Basko & Sunyaev, 1976; Mushtukov & Tsygankov 2022; Sasaki et al. 2010; Decomposition method: Kraus, et al. 1995; Application to Cen X-3: Kraus, et al. 1996; Noise in accretion disks: Lyubarskii, 1997; NMF algorithm: Lee, Seung 1999; NMF implementation in Python: Pedregosa, et al. 2011