Classification of Hard X-ray Light Curves of Black Hole Binary Transients

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Abstract

We have systematically analyzed hard X-ray light curves of transient black hole binaries taken by Swift/BAT (15−50 keV) and MAXI (3−20 keV), searching for common morphological properties among different light curves. To that end, we have applied a technique widely used in data science, such that virtual "distance" between two lightcurves is defined to quantify their similarities, and "tree diagram" is made to classify all the observed lightcurves. Consequently, we have found that the lightcurves in 15−50 keV are classified into distinct groups based on their morphologies, while such a classification is not clear in the 3−20 keV light curves. This suggests that hard X-rays are more likely to reflect distinct types of the accretion processes in black hole binaries than soft X-rays.

Key words: black holes: light curves – MAXI – BAT – Data Science

1. Introduction

Black hole transients exhibit varieties of X-ray light curves in terms of their morphologies, presumably reflecting various aspects of different accretion processes. However, our current understanding of the physical mechanisms behind these varieties is very limited.

Both Swift/BAT and MAXI routinely produce and publicly release the X-ray light curves of bright black hole transients. These light curve datasets will provide a unique opportunity to carry out systematic and unbiased studies of the black hole X-ray transient phenomena. Here, we are going to apply techniques that are proven effective in various fields of "data sciences", and try to classify X-ray light curves of black hole transients based on their morphologies.

2. Data Analysis and Results

We use the Swift/BAT (15–50 keV) and MAXI (3–20 keV) publicly available X-ray light curve datasets. We choose the following black hole (candidate) sources; 4U1630–472, GX339–4, H1743–322, MAX J1305–704, MAXI J1543–564, MAXI J1659–152, MAXI J1836–194, MAXI J1910–057 and XTE J1752–223. For each pair of all the BAT light curves, we calculate their Dynamic Time Warping (DTW) distance, which is known to be an effective measure to quantify their similarities (Hayashi et al. 2013); we did the same for the MAXI lightcurves. A merit of using the DTW distance is that it can find morphological similarities between two light-curves even if they have different intensities or stretched in the time direction. Based on these DTW distances, we performed the clustering analysis to construct "tree diagrams" for BAT and MAXI light curves separately. On the tree diagram, light curves which are more similar in shape are located closer.

Consequently, the BAT tree diagram (Figure 1) shows several distinct clusters, while MAXI tree diagram (not shown) does not show such clear clustering. This indicates that hard X-ray is more likely to reflect characteristics of accretion process than soft X-ray, whatever the physical mechanisms behind. Looking at the BAT tree diagram and those light curves belonging to each cluster, we notice the following; besides a few "outliers", ordinary light curves are divided into those having "double-peaks" (Figure 2, top-left) or "single-peak". The single-peak light curves are further divided into "fast-decay" (top-right), "fast-rise" (bottom-right) and "slow-decay" (bottom-left) types.

Physical mechanisms behind these classifications are unclear yet. Also, it is curious why hard X-ray light curves are more effectively classified than soft ones. In order to study their physical origins, we are investigating for correlations between the light curve morphological types and black hole parameters, such as black hole mass, binary parameters, luminosities and spectral states.

References

Hayashi, F. et al. 2013, Journal of Space Science Informatics Japan: Vol.2, p.19

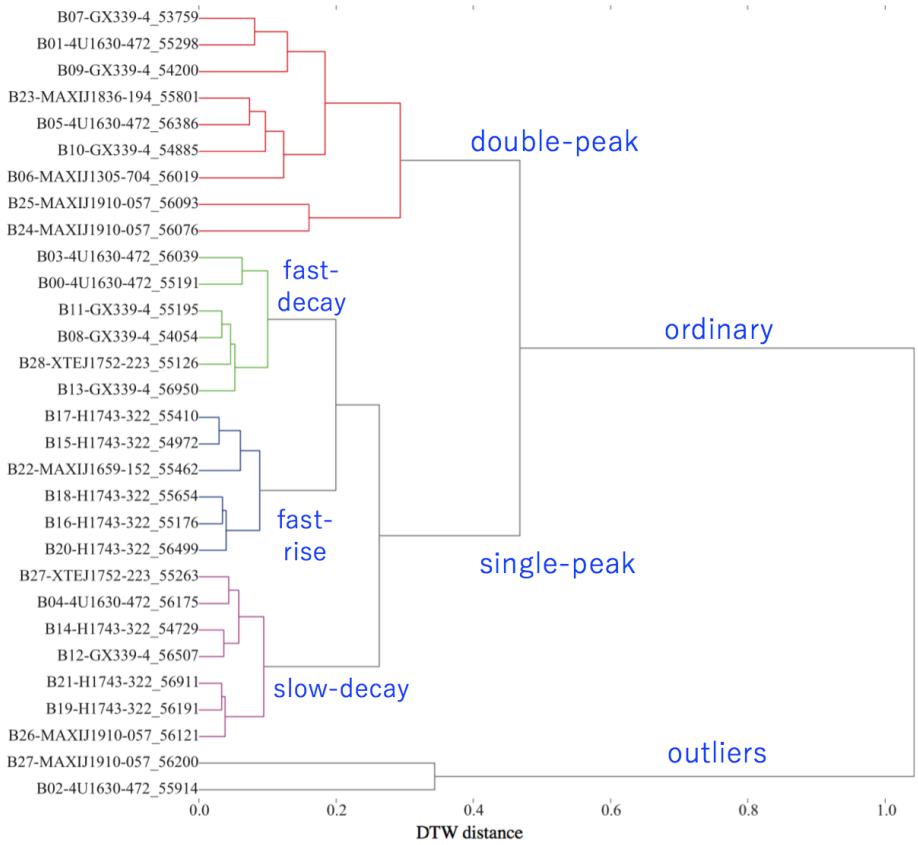

Fig. 1. A tree diagram to show classification of the black hole light curves taken by Swift-BAT.

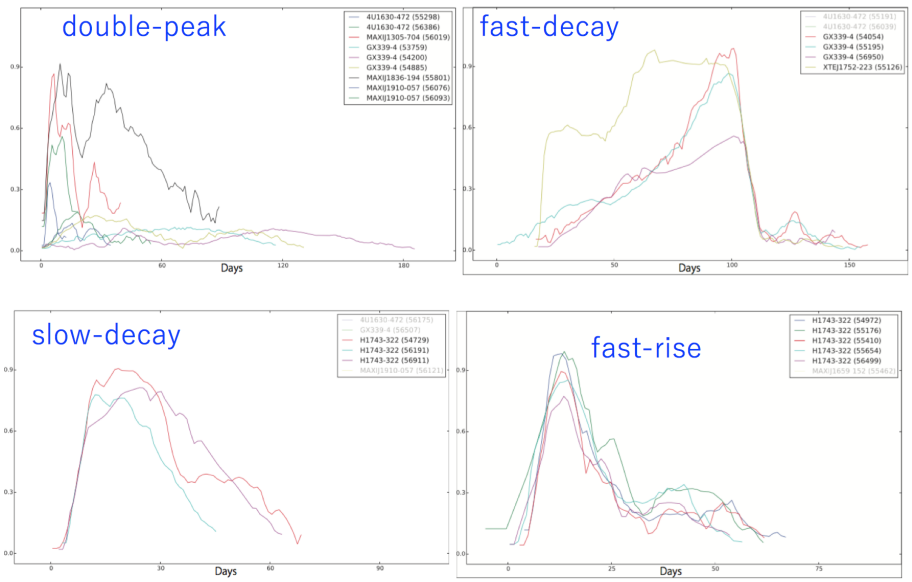

Fig. 2. Four representative examples of classification of the Swift-BAT lightcurves.