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INFLUENCE OF LIGHT-CURVE SAMPLING ON THE PERIODICITY DETERMINATION IN CASE OF SUBPARSEC SUPER-MASSIVE BLACK HOLE BINARIES

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Abstract. Here we explore the periodicity determination in the light curves of super-massive binary black holes (SMBBHs) considering different observation sampling during a monitoring period. We use a theoretical model of an SMBBH system which assumes that the variability in the light curves is due to dynamical effects. We simulate several observational light curves assuming different cadences, and estimate the periodicity using the Lomb-Scargle (LS) algorithm. We found that the lack of observational data could reduce the significance level of periodicity determination, but still a rough periodicity could be estimated.

1. INTRODUCTION

In the case of merging galaxies, one can expect that subparsec super-massive binary black holes (SMBBHs) are present in their central parts (Begelman et al. 1980). Many galaxies are observed to be in a collision, and they potentially have a SMBBH in their center. One can expect that even the sub-parsec SMBBHs may be very often in the centers of merging galaxies, however, the problem is to detect these objects. E.g. direct imaging in the high resolution radio observations could be potentially a good method for SMBBH detection (see e.g. Burke-Spolaor 2011, Roland et al. 2013), but only on the kpc scale distances between the components (see Fu et al. 2011).

On the other hand, it seems that sub-parsec scale SMBBHs may be possibly detected using the spectral characteristics, in which one can expect to see dynamical signature of binary orbital motion (see e.g. Gaskell 1983, Tsalmantza et al. 2011, Shen & Loeb 2010, Eracleous 2012, Popović 2012, Bon et al. 2012, Simić & Popović 2016, Li et al. 2019, Kovačević et al. 2019, Popović et al. 2020), especially in the case in which both black holes (BHs) in a binary system have accretion discs and emit broad lines (see for a review, Popović 2012).

Here we continue our investigation of the detection of possible periodicity in the SMBBHs light curves. We explore the perspective of monitoring of active galactic nuclei (AGN) in large surveys and possibility to find good candidates for SMBBHs. Particularly in this work we consider influence of different observation sampling to determination of the periodicity, that is expected to be present in the SMBBHs light curves.

2. THE MODEL OF THE SMBBH SYSTEM

We consider the system in which both components have accretion discs, and each disc is surrounded with its broad line region (BLR), and a common BLR, as shown in Figure 1. We describe briefly the main concepts of the theoretical model, but more details will be given in Simić et al. (2020). We accept the model of a standard optically

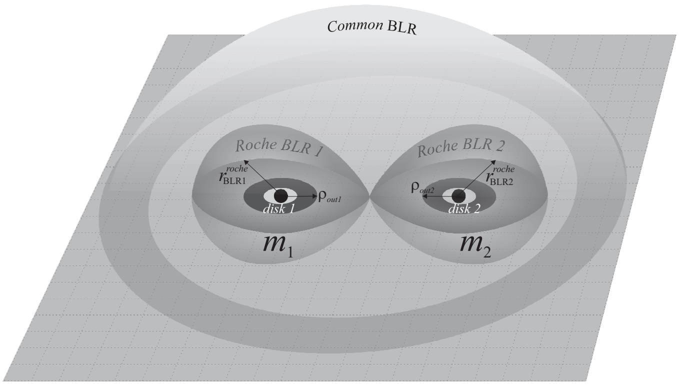

Figure 1: SMBBH system in the compact configuration, with designated BLR of particular components (BLR1 and BLR2) inside each Roche lobe, with an additional common BLR, located outside of Roche lobes.

thick, geometrically thin, black body accretion disc (see Pringle & Rees 1972, Shakura & Sunyaev 1973, Novikov & Thorne 1973), and we take that the effective temperature as a function of the radius from the center is as given in Woo et al. (2014). The BLR can have different geometries (see e.g. Sulentic et al. 2000), but we assume that it is homogeneously distributed around the BH disc. The BLR inner radius is very close to disc outer radius and spans a few tens of light days in diameter, while keeping probably spherical shape around the BH and disc. This region is photoionized by the X-ray and UV radiation from the accretion disc. We estimate the BLR size by using the empirical formulas given in Kaspi et al. (2005), i.e. using the continuum luminosity at 5100Å (for Hβ line emitting region).

Taking the dynamical effects of an SMBBH system we assume that the total line emitting region is actually composed from three different BLRs. First two regions are defined by the local Roche lobes of each component in the SMBBH system (BLR1 and BLR2), and third is a circumbinary region that is surrounding both components (common BLR), as shown in Fig. 1. As we can see, BLRs defined by Roche lobes are moving and following the host BH component, whereas the common BLR is static. We also connect the line intensities and width of each BLR component with the total

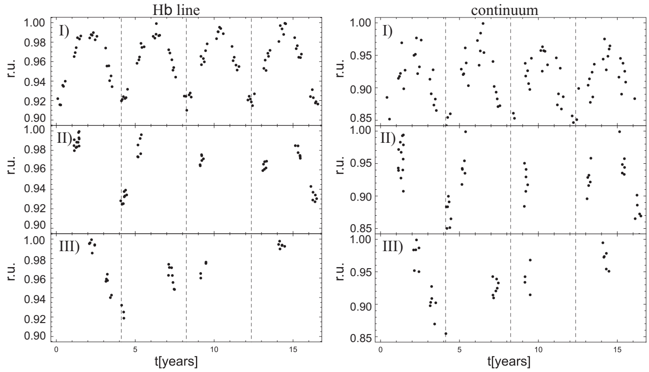

Figure 2: Light curves for emission in Hβ (left panel) and continuum (right panel) of SMBBH system during four full rotation. Presented luminosity scaled to its maximal values.

component masses.

We model the total emitted spectra in a wide wavelength range, from the UV to the IR band, but here we only consider the variability of the region around the Hβ line. First, we model the spectra in the Hβ wavelength band, then we measure the Hβ and continuum at λ5100Å luminosity. We take four full orbits, and consequently find the light curves of the total Hβ emission and continuum at λ5100Å.

3. RESULTS AND DISCUSSION

We distinguish three different cases: I) when observations are made in the first half of the year, randomly once per month for entire time period of $4 \times P_{orb}$, II) when observations are made in the first half of the randomly chosen year with the number of observing years reduced by half in comparison to case I), and III) with significantly reduced number of observations and random cadence in total observed time.

During the orbital motion of SMBBH system, we expect to observe dynamical variation of the luminosity in line and continuum. However, this variability could be masked by many different reasons, like enormous line width, high mass ratio system, or some other issues. In case of very compact sub-parsec SMBBHs, imprinted dynamical variability is the only way to detect such systems. In order to test how quantity and quality of observations influence the periodicity determination, we examine spectral features (Hβ line and continuum at $\lambda = 5100$Å) in details. First, we compute luminosity in a given spectral range for continuum and line segment during four full rotation of the binary system, see Fig. 2. We can see variation of luminosity in the line (left panel) and continuum (right panel), with luminosities scaled to their maximal value. Continuum variability (Fig. 2, right panel) has similar variation as in line, since in this case the Hβ line is broad enough and affect continuum measurement at $\lambda = 5100$Å.

We apply Lomb-Scargle (LS) to compute orbital periods of SMBBHs. We generated periodograms (Fig. 3) for each observational case for Hβ line and continuum. As we can see, peaks of the periodogram curves are placed at the extracted orbital period of the SMBBH system.

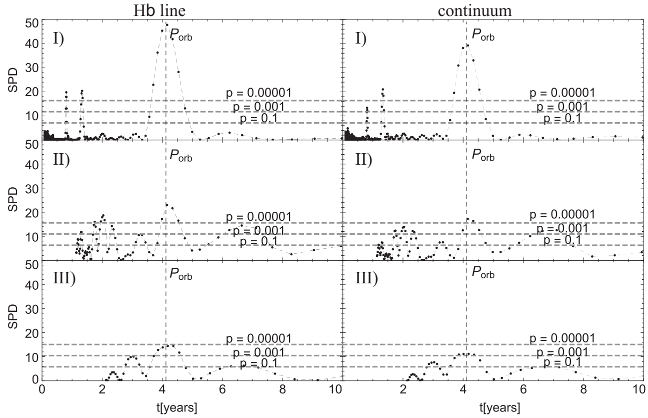

Figure 3: Periodograms for Hβ line and continuum flux in case of SMBBH system. Horizontal dashed lines present significance level lines.

We found that the lack of observational data, i.e. poor sampling of light curves, could reduce significantly the certainty of periodicity determination, however, a rough estimate of periodicity is still possible. More details on the model and perspectives of the periodicity estimates and detection of possible SMBBH systems in AGN light curves will be given elsewhere.

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