SUPERMASSIVE BLACK HOLE BINARY CANDIDATE PG1302-102: OSCILLATIONS AND PERTURBATION IN THE PHOTOMETRIC LIGHT CURVE

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ABSTRACT

PG 1302-102 shows periodic variability, which makes this object one of the most promising supermassive black hole binary candidates. Interestingly, a newly collected data shows an interesting pattern which was interpreted as a decrease in the significance of periodicity, which may suggest that the binary model is less favorable. We present detailed analysis of photometric PG 1302-102 light curve including 1) a supermassive black hole binary system model in which a perturbation in the accretion disk of a more massive component is present; 2)our 2DHybrid method for periodicity detection in the light curves.

Our model explains well observed light curve, using a slight perturbation of a sinusoidal feature, and predicts that a slightly larger period than previously reported, of about 1899 days, could appear due to a cold region in the disk of a more massive component of a close, unequal-mass (q=0.1) black hole binary system. According to our model, one could expect that light curve follows the pattern of a sinusoid-like shape within a few years, which could be observed by sky surveys.

Using our 2DHybrid method for periodicity detection, we calculated that the periods in the observed (1972 ± 254 days) and modeled (1873 ± 250 days) light curves are within 1σ, which is also consistent with result from our physical model and with previous findings. Thus, the periodic nature and its slight fluctuation of the light curve of PG 1302-102 are explained by our physical model and confirmed by our 2DHybrid method for periodicity detection.

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INTRODUCTION

Graham et al. (2015) report an evidence of a binary system with a ~4 yr rest-frame period based on the analysis of data from the Catalina Real-Time Transient Survey (CRTS). Recently, new clues to its variability have emerged. Namely, it seems that adding recent observations from the All-Sky Automated Survey for Supernovae (ASAS-SN), which are analyzed in detail by Liu et al. (2018), shows that the evidence for periodicity decreases, and that further new observations would clarify the significance of the SMBHB model.

The first aim of our work is to model the optical light curve with a perturbation in the disk of the more massive component in the SMBHB (L. C. Popović & S. Simić 2020, in preparation), which slightly perturbs the sinusoidal signal, and to forecast the light-curve variability in the next few years. The reason for choosing such an approach is that the standard SMBHB model assumes that an accretion disk surrounds at least a more massive black hole and that the outcoming variability and structural changes are determined by dynamical characteristics of the disk, as well as the interaction of the SMBHB-disk system (Lobanov & Roland 2005). The second aim is to test our newly proposed hybrid method for oscillation detection in the light curves of quasars (which was presented in Kovačević et al. 2018), on both observed and modeled light curves.

Gaussian-like Disk Perturbation—Model

Applied perturbation changes in time the disk temperature profile:

$$T^{\rm pert}_{\rm eff}(R,t) = T_{\rm eff}(R) + T_{\rm eff}(R)\cdot\delta T(t),$$

$$\delta T(t) = P_{\rm int}\cdot\exp\left[-\frac{(t-t_{\rm pert})^2}{P^2_{\rm dur}}\right],$$

$$T_{\rm eff}[{\rm K}] = 2\cdot 10^5\left(\frac{10^8}{m_i}\right)^{1/4}\left(\frac{R_{\rm in}}{R}\right)^{3/4}\left(1-\sqrt{\frac{R_{\rm in}}{R}}\right),$$

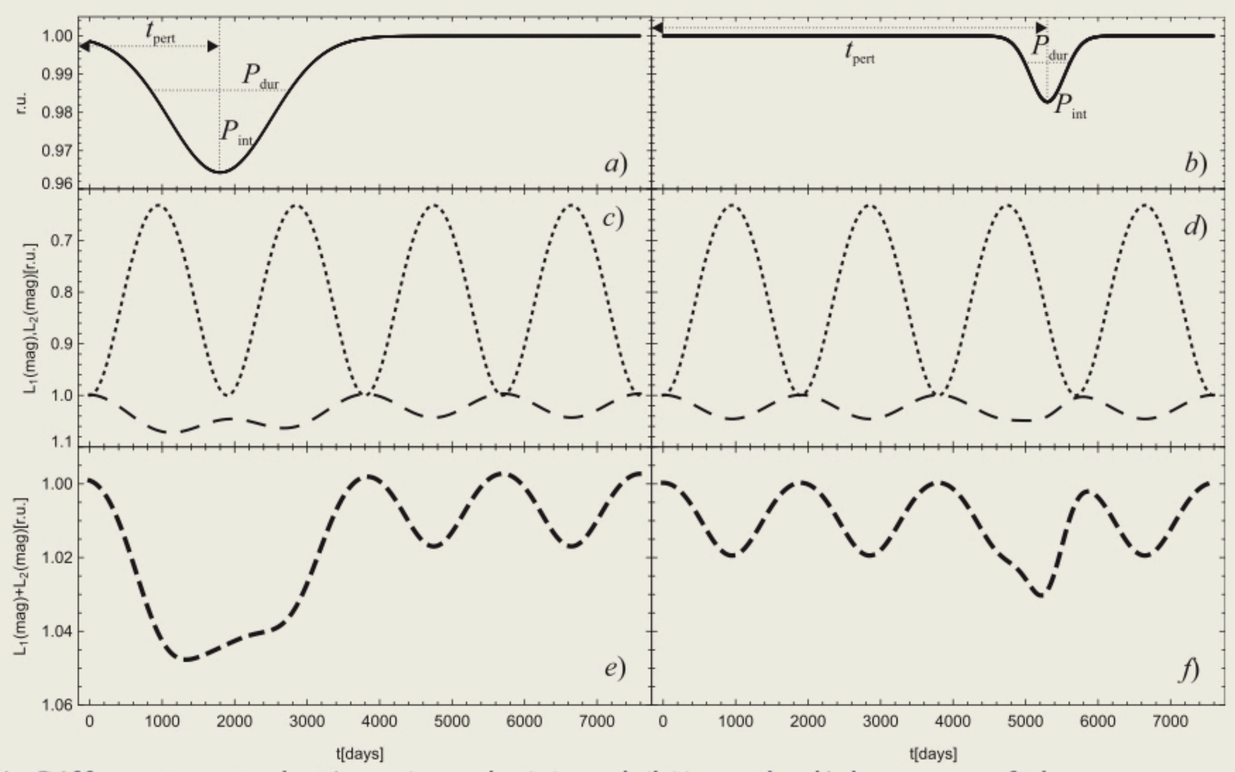

Figure 1. Different perturbations (panels (a) and (b)) on the light curve of the more massive component (panels (c) and (d)) and the resulting light curves (panels (e) and (f)).

Modeling Light Curve

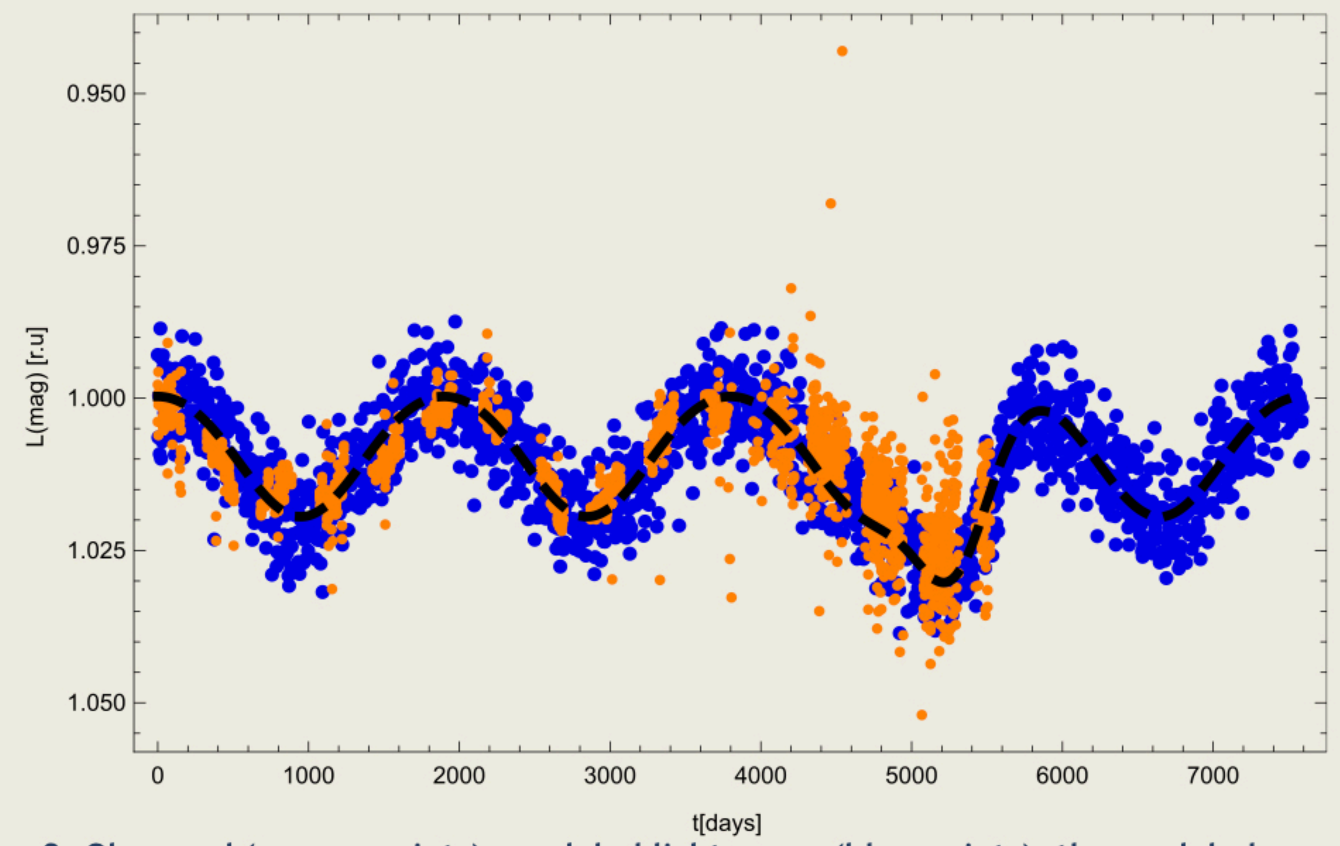

Figure 2. Observed (orange points), modeled light curve (blue points), the modeled curve without white noise (dashed black line).

Table 1

Inferred Parameters of the Model of the SMBHB System with Gaussian Perturbation in the Accretion Disk of the More Massive Component, Defined in Section 2.

m_1 ($10^8 M_\odot$)	m_2 ($10^8 M_\odot$)	a (pc)	e	$t_{\rm pert}$ (days)	$P_{\rm int}$ (%)	$P_{\rm dur}$ (days)	P (days)	AIC	BIC	$\rm AIC_{np}$	$\rm BIC_{np}$	$\rm AIC_{nc}$	$\rm BIC_{nc}$
1	10	0.015	0	5300	1.7	330	1899	−4135	−4125	−3793	−3787	−3028	−3025

Note. Parameters AIC, BIC, $\rm AIC_{np}$, $\rm BIC_{np}$, and $\rm AIC_{nc}$, $\rm BIC_{nc}$ measure the quality of the perturbed, nonperturbed, and pure noise models, respectively (see text).

DETECTED PERIODIC OSCILLATIONS

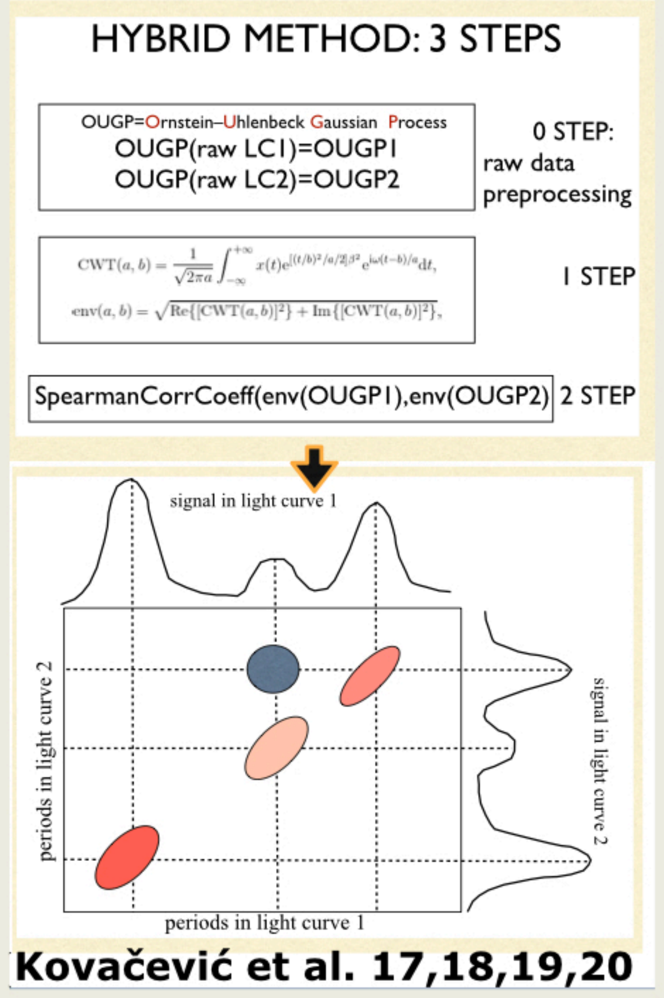

Figure 3. Scheme of 2DHybrid method.

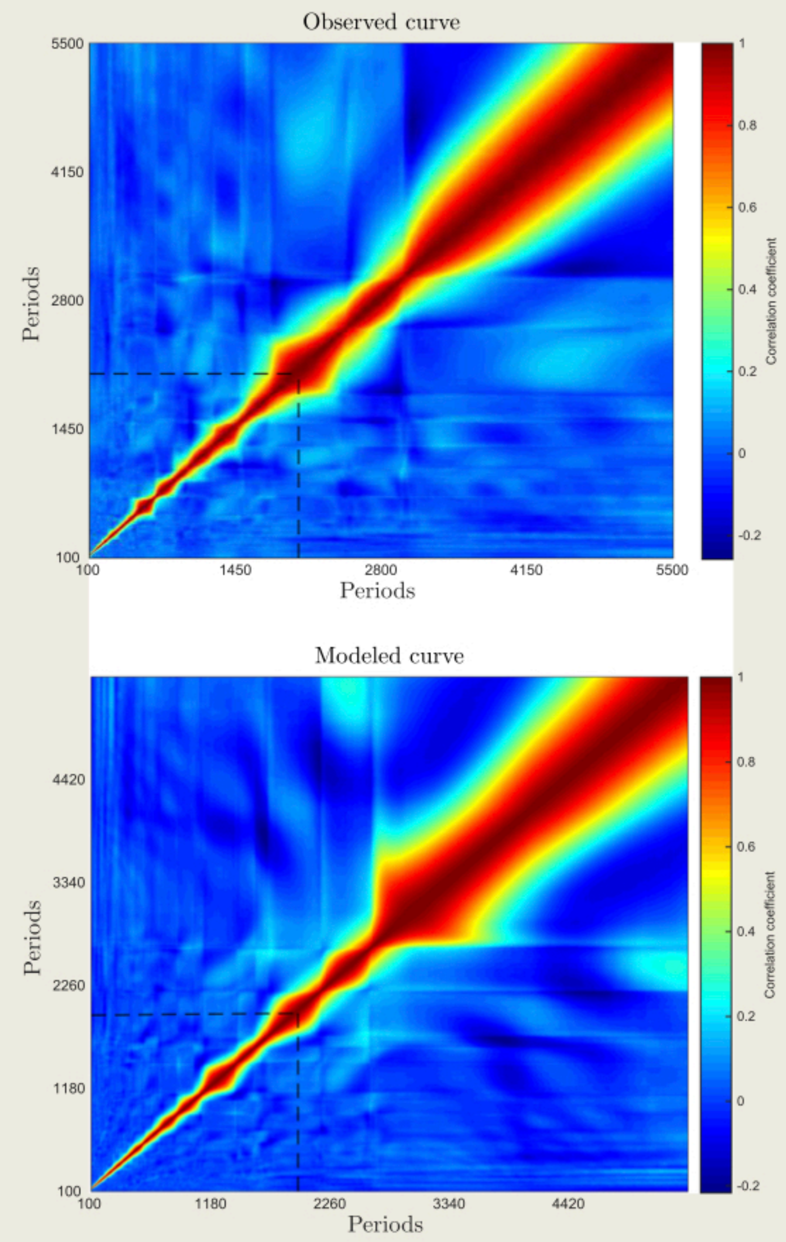

Figure 4. 2D correlation map of all oscillatory patterns within the total observing time range of 100-5500 days, for the preprocessed observed light curve (top) and modeled light curve (bottom). Both axes represent periods (in days) in the curve.

Table 2

Best-fitting Parameters and Their Standard Deviations of the Sinusoid Fitted to the Detrended Observed Data, Defined by Equation (6) in Section 3.

A	P (days)	φ (rad)	B	$\chi^2_{\rm red}$
0.123 ± 0.003	1950 ± 150	4.74 ± 0.84	−0.018 ± 0.003	1.09

Note. The parameter $\chi^2_{\rm red}$ is the reduced χ^2 value of the fit.

CONCLUSIONS

We develop one possible physical model that could explain the variability of the optical flux and a slight perturbation of the sinusoidal feature of the optical light curve of PG 1302-102 reported in Liu et al. (2018). The dynamical properties of PG 1302-102 are described by the model of the orbital motion in the SMBHB system and the attenuation due to a cold spot in the accretion disk around the more massive black hole. The model recovered an orbital period of 1899 days. Second, the 2D correlation maps of oscillatory patterns in the observed and modeled light curves are determined with our hybrid method for periodicity detection. The inferred periods are 1972± 254 days and 1873±250 days in the observed and modeled light curves, respectively.

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