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Gaia19bxc: possible polar below the period minimum

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Abstract

Gaia19bxc is a transient detected on 2019 May 9 by the Gaia Photometric Science Alerts Team. I analyzed the past public Zwicky Transient Facility (ZTF) data and found that Gaia19bxc has a period of 0.04473647(3) d and two different maxima in one cycle. This object also showed high and low states in the ZTF data. Based on the high amplitude (2.0 mag) of the short-term variations, short period, almost zero color indices between the different ZTF bands and the absence of a longer period, I classified it to be a likely polar. There has been no established polar below the period minimum of cataclysmic variables (CVs) and Gaia19bxc could be the first such an object. CVs below the period minimum usually have a secondary star with a stripped evolved core and Gaia19bxc is expected to have a similar secondary. If this is indeed the case, Gaia19bxc could become a highly magnetized exotic ultracompact binary during its secular evolution.

Gaia19bxc is a transient detected by the Gaia Photometric Science Alerts Team[1]. The object was detected at 19.28 mag on 2019 May 9 and was reported as a "variable Gaia source brightens by 2 mag". The object stayed bright for months after this according to the Gaia light curve. The object is located at $17^{\rm h}\ 31^{\rm m}\ 58\overset{\rm s}{.}468$, $+27^\circ\ 09'\ 36\overset{''}{.}12$ (J2000.0) has BP=20.570(188), RP=19.726(142) and a parallax ϖ=0.565(772) mas (Gaia Collaboration et al. 2021). The American Association of Variable Stars (AAVSO) Variable Star Index (VSX: Watson et al. 2006) classified it as a possible dwarf nova (UG:). The Zwicky Transient Facility (ZTF: Masci et al. 2019) listed it as a suspected variable star (Ofek et al. 2020). I analyzed the light variation using the ZTF public data[2].

The long-term variation is shown in figure 1. The object apparently shows high and low states and the variation is not that of a dwarf nova. A phase dispersion minimization (PDM: Stellingwerf 1978) analysis of the ZTF data after removing the global trend using locally-weighted polynomial regression (LOWESS: Cleveland 1979) yielded a period of 0.04473647(3) d (figure 2). There were two maxima of different amplitudes in one cycle. The amplitude of the variation was very large, reaching 2.0 mag. The phased light curve of the bright state is shown in figure 3. The phased light curve for the intermediate state is shown in figure 4. The profile was almost the same between different states and the colors between the different ZTF bands were almost zero. The phased light curve of the low state could not be examined due to the small number of observations. The SDSS colors (Ahumada et al. 2020) at four different epochs had $u-g$ of +0.1 to +1.6 and $i-z$ of +0.0 to +0.9. The $u-g$ values seem to be redder than many polars, although individual measurements were apparently affected by large-amplitude, short-term variations. The large variation was already apparent in the SDSS data (g=21.56–23.04).

[1] <http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia19bxc/>.

[2] The ZTF data can be obtained from IRSA <https://irsa.ipac.caltech.edu/Missions/ztf.html> using the interface <https://irsa.ipac.caltech.edu/docs/program_interface/ztf_api.html> or using a wrapper of the above IRSA API <https://github.com/MickaelRigault/ztfquery>.

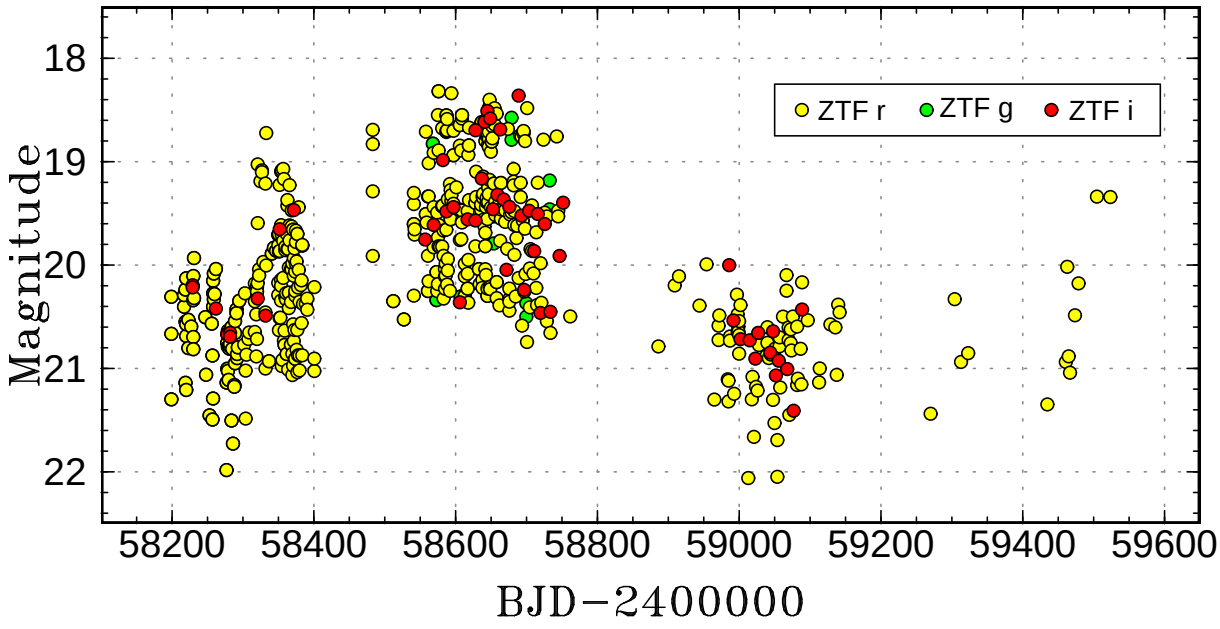

Figure 1: Long-term ZTF light curve of Gaia19bxc.

No known type of pulsating variables has such a large amplitude and a short period at the same time. The flat maximum is not characteristic to a short-period pulsating variable. The ZTF colors (almost zero color indices) suggest a blue object like a cataclysmic variable (CV). The period is then either the spin period of an intermediate polar (IP) with a very large amplitude as in Romanov V48 (Kato and Romanov 2022), the spin period of a white dwarf pulsar like AR Sco (Marsh et al. 2016; Stiller et al. 2018) and candidates (Kato and Kojiguchi 2021; Kato et al. 2021), or the orbital period ($P_{\rm orb}$) of a polar. The presence of high and low states is also compatible with a polar. I could not find a longer period (corresponding to $P_{\rm orb}$ for an IP) as in Romanov V48. If the object is indeed a polar, this is very unusual. The $P_{\rm orb}$ is far shorter than the "period minimum" of CVs (Kolb 1993; Gänsicke et al. 2009; Knigge et al. 2011; Kato 2022),

There are several CVs below the period minimum. One notable case is OV Boo with $P_{\rm orb}$ of 0.046258 d (Littlefair et al. 2007; Patterson et al. 2008; Uthas et al. 2011; Patterson et al. 2017). OV Boo has a large space velocity (against the Solar system) and is considered to be a population II CV (Patterson et al. 2008). It is possible that OV Boo is on the standard evolutionary sequence of population II CVs. There is no good distance estimate for Gaia19bxc and a possibility for a population II CV is not readily excluded.

There are several hydrogen-rich CVs below the period minimum. The best known example are V485 Cen with $P_{\rm orb}$=0.040995 d (Augusteijn et al. 1996), EI Psc with $P_{\rm orb}$=0.044567 d (Thorstensen et al. 2002) CRTS J174033.4+414756 with $P_{\rm orb}$=0.045048 d (Kato et al. 2014) and SBS 1108+574 with $P_{\rm orb}$=0.03845 d (Littlefield et al. 2013). EI Psc is renowned to have a hot, luminous secondary for this $P_{\rm orb}$ (Thorstensen et al. 2002). These objects are considered to have a secondary star with a stripped evolved core and are also referred to as EI Psc stars. It has been theoretically shown that CVs with $P_{\rm orb}$ shorter than the period minimum (including AM CVn stars) can be formed if the core of the secondary star starts evolving in the early phase of their evolution as CVs (see e.g. Nelemans et al. 2010; Podsiadlowski et al. 2003).

The lack of systems below the period minimum among hitherto discovered polars is striking considering the number of EI Psc-type objects for non-magnetic CVs [see figure 3 in Belloni et al. (2020)], although there appears to be no specific reason why there is no EI Psc-like object having a strongly magnetized white dwarf. 1RXS J035410.4−165244 = RBS 490 was suggested to be a polar with a possible $P_{\rm orb}$ of 46 min = 0.032 d by a radial-velocity study (Thorstensen et al. 2006; Harrison and Campbell 2015). The most recent observation suggested a photometric $P_{\rm orb}$ of 0.0703 d (Joshi et al. 2022). I, however, could not find a significant period around these periods in this system using the ZTF data. The He II line is weak for a polar in the spectrum and the field strength appears to be low even if it is indeed a polar (Joshi et al. 2022).

If Gaia19bxc is indeed confirmed to be a polar by polarimetry, X-ray observations and spectroscopy, it will be the first object below the period minimum. Since the distance is poorly known, it is not easy to tell whether this

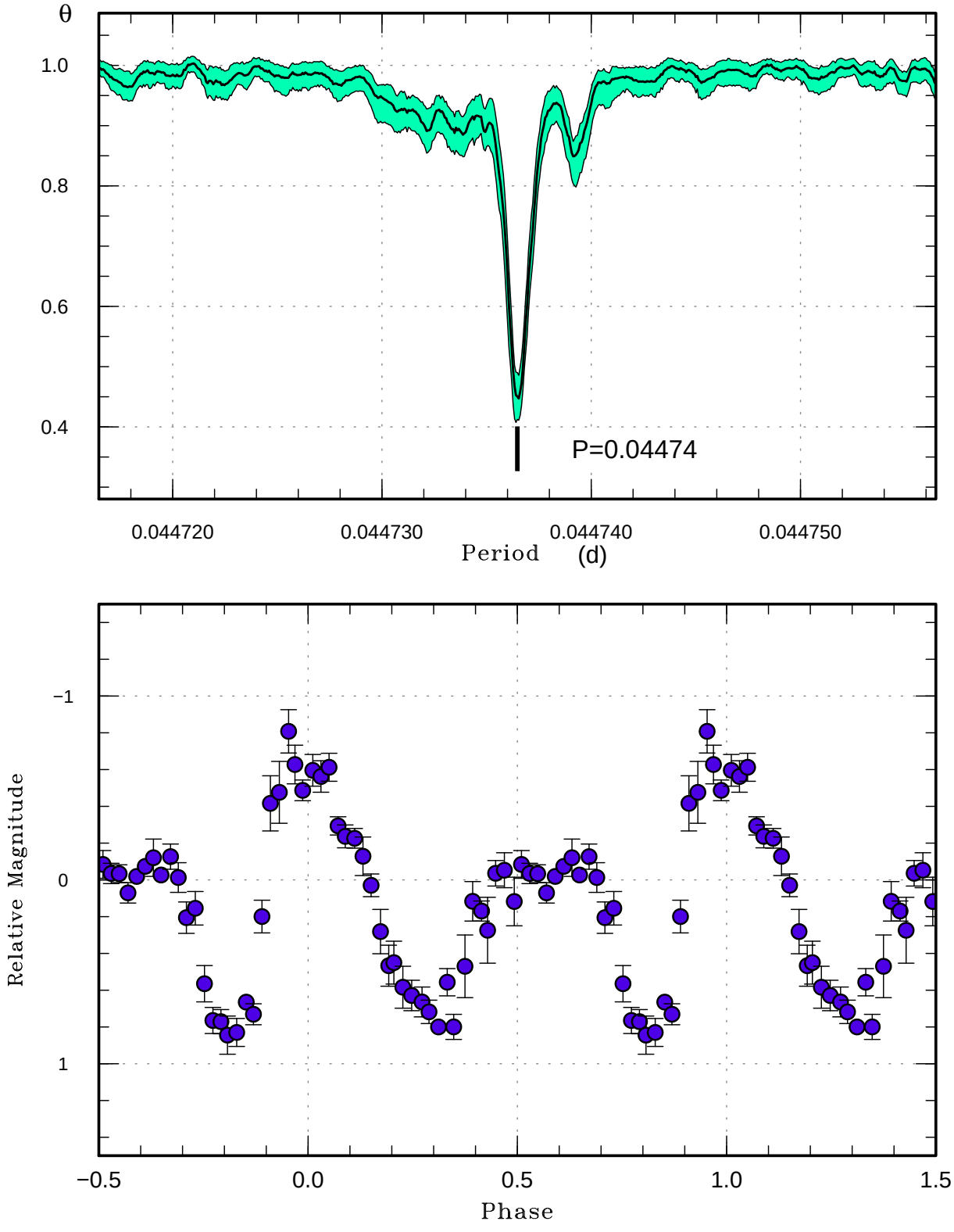

Figure 2: PDM analysis of Gaia19bxc using the ZTF data. (Upper): PDM analysis. The bootstrap result using randomly contain 50% of observations is shown as a form of 90% confidence intervals in the resultant θ statistics. (Lower): mean profile. 1σ error bars are shown.

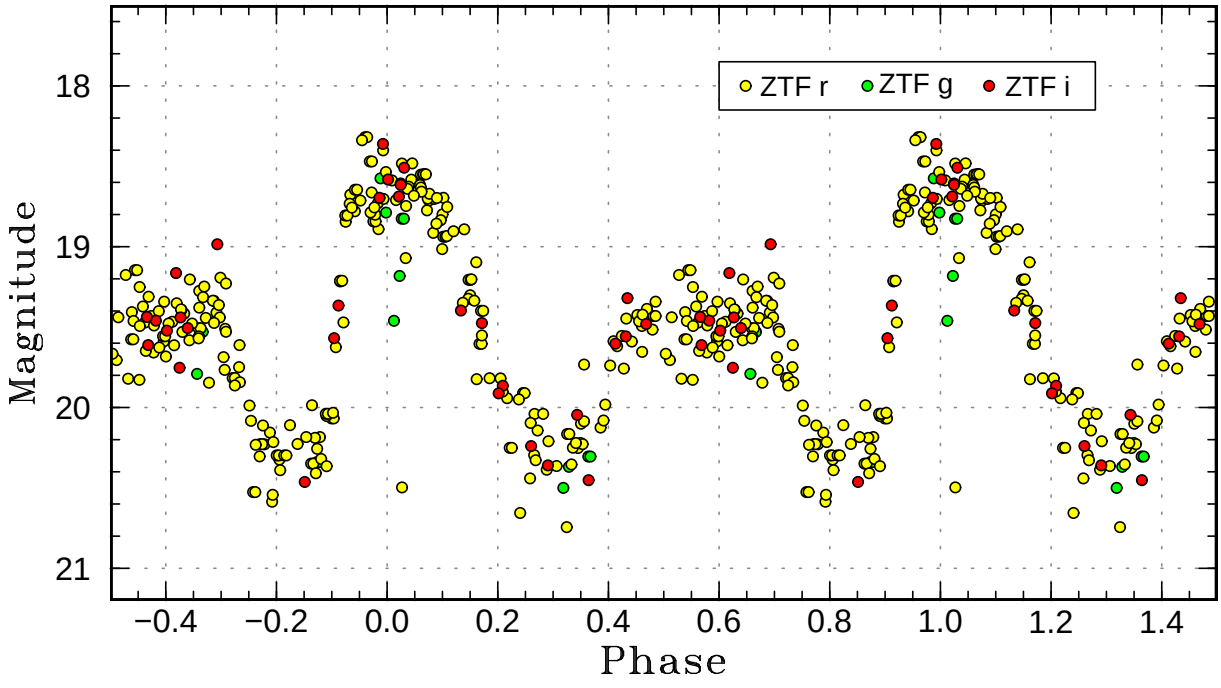

Figure 3: The light curve of Gaia19bxc in high state (BJD 2458500–2458800) using the ZTF data folded by the 0.04473647(3) d The zero epoch was chosen as BJD 2458563.005.

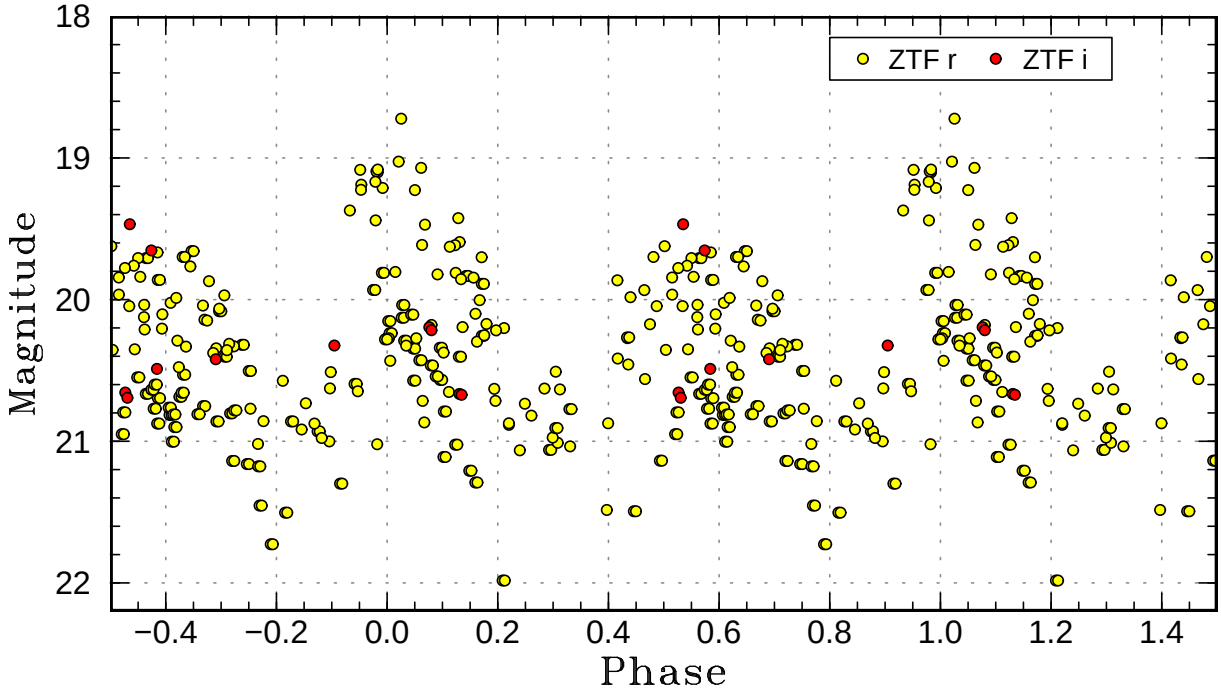

Figure 4: The light curve of Gaia19bxc in intermediate (before BJD 2458400). The period and epoch are the same as in figure 3.

object has a secondary with an evolved core from photometric data. Such a secondary, however, might explain the relatively red $u-g$ color (the $u-g$ color of EI Psc is +0.8). If this possibility is indeed the case, Gaia19bxc could become a highly magnetized exotic ultracompact binary during its secular evolution.

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List of objects in this paper

OV Boo, V485 Cen, AM CVn, EI Psc, AR Sco, 1RXS J035410.4−165244, CRTS J174033.4+414756, Gaia19bxc, RBS 490, Romanov V48, SBS 1108+574

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