No.97 **Mar. 2022**

ISSN 0917-2211

Variable Star Bulletin

Gaia22ayj: outburst from a deeply eclipsing 9.36-min binary?

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Received 2022 Mar. 24

Abstract

Gaia22ayj (=ZTF19aagmvuk) was detected as a transient on 2022 March 3 both by the Gaia satellite and the Zwicky Transient Facility (ZTF). I analyzed the past public ZTF data and found that Gaia22ayj showed coherent large-amplitude double-wave variations with a period of 0.00649910257(13) d = 9.36 min. The period can be either from the spin period of the white dwarf or the orbital period of the binary. I consider the latter possibility more likely based on the light curve resembling an eclipsing binary and on the stability of the profile. The presence of an outburst lasting at least ~1 d suggests that this system has an accretion disk. If Gaia22ayj is indeed an eclipsing binary with a period of 9.36 min, this is the shortest orbital period ever measured in eclipsing accreting binaries and is the shortest record of a system with a dwarf nova-type outburst. The presence of an outburst is unusual for an AM CVn system with this orbital period and this object might be in the turn-on phase of the mass-transfer. If the ultrashort orbital period of Gaia22ayj is confirmed, this object would an ideal target to detect period variations within several years to confirm its evolutionary state and to identify the future evolutionary consequence.

Gaia22ayj is a transient detected by the Gaia Photometric Science Alerts Team[1]. The object was detected at 17.01 mag on 2022 March 3. Five Gaia observations between March 3.112 and 4.038 UT showed significant short-term variations between 16.55 and 17.01. The object had been registered as a variable ZTF19aagmvuk[2] by the Zwicky Transient Facility (ZTF: Masci et al. 2019). The same outburst was detected in outburst by ZTF and the Transient Alert Broker Lasair (Smith et al. 2019) reported r=16.09 on March 3.399 UT. The Gaia EDR3 position, magnitudes and parallax $08^{\rm h}\,25^{\rm m}\,26\overset{\rm s}{.}528$, $-22^\circ\,32'\,12\overset{''}{.}34$ (J2000.0), BP=19.570, RP=18.461 and ϖ=0.43(22) mas, respectively (Gaia Collaboration et al. 2021).

Using the ZTF public data[3], I found coherent short-period variations in time-series ZTF observations on 2019 Jan. 10 (T. Kato, vsnet-alert 26674[4]; figure 2). Phase dispersion minimization (PDM: Stellingwerf 1978) analysis yielded a period of 0.006500(7) d with two different maxima and minima in one cycle (figure 3). I have confirmed that this period can express the entire ZTF light curve as well. The orbital period was refined using the Markov-Chain Monte Carlo (MCMC)-based method introduced in Kato et al. (2010). The resultant ephemeris is

$$\mathrm{Min\ I\ (BJD)} = 2458699.17927(1) + 0.00649910257(13)E. \qquad (1)$$

The phase-folded light curve of the entire ZTF data (excluding the Lasair data) is shown in figure 4. This period express all the observations very well.

[1] <http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia22ayj/>.

[2] <https://lasair.roe.ac.uk/object/ZTF19aagmvuk/>.

[3] 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>.

[4] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26674>.

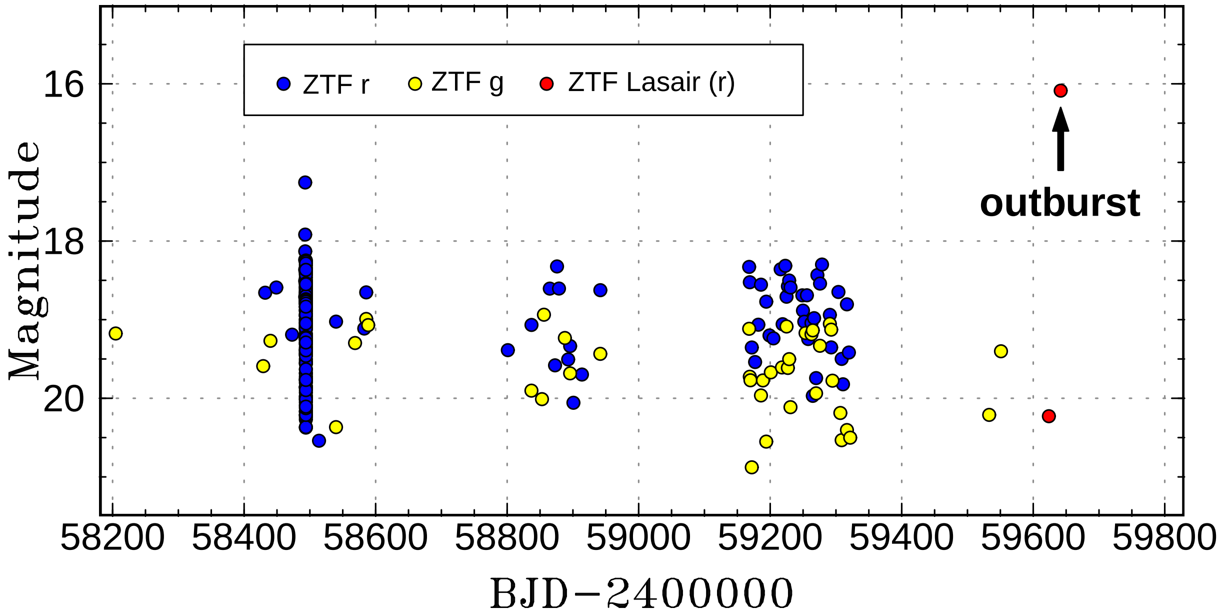

Figure 1: Long-term ZTF light curve of Gaia22ayj. An outburst was detected on 2022 March 3.

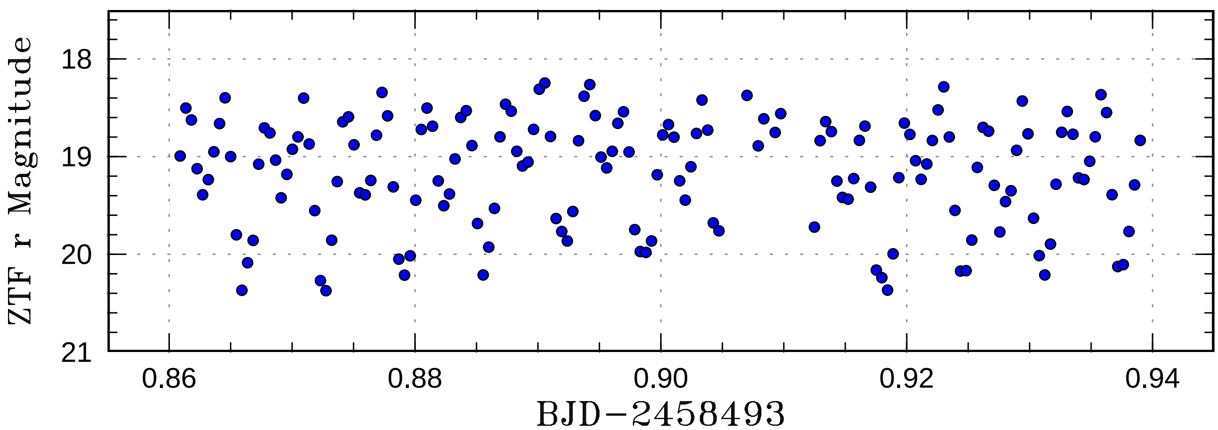

Figure 2: ZTF light curve of Gaia22ayj on 2019 Jan. 10. Periodic short-period variations are clearly seen.

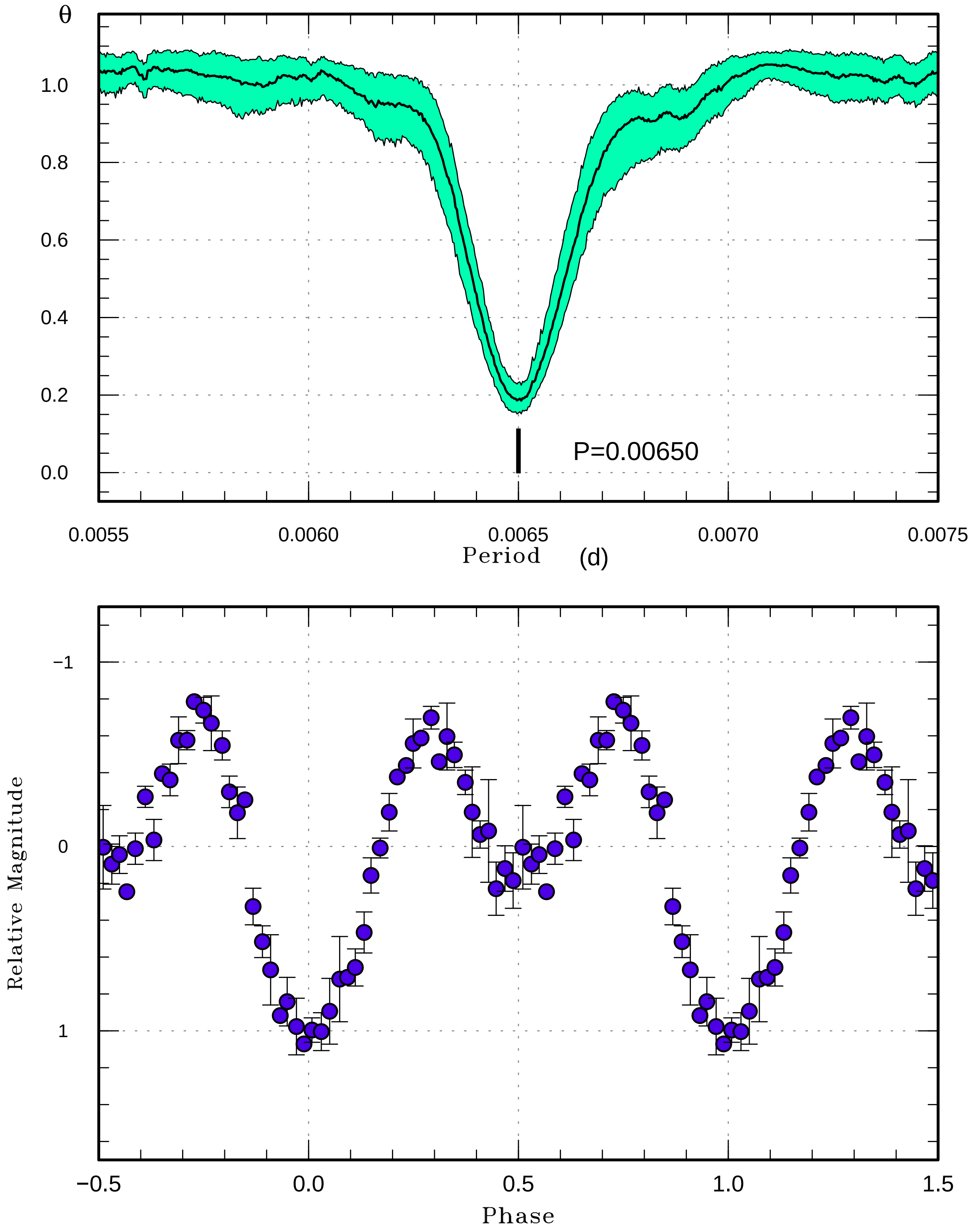

Figure 3: PDM analysis of Gaia22ayj using the ZTF data on 2019 Jan. 10. (Upper): PDM analysis. (Lower): mean profile. The epoch and period were from equation (1).

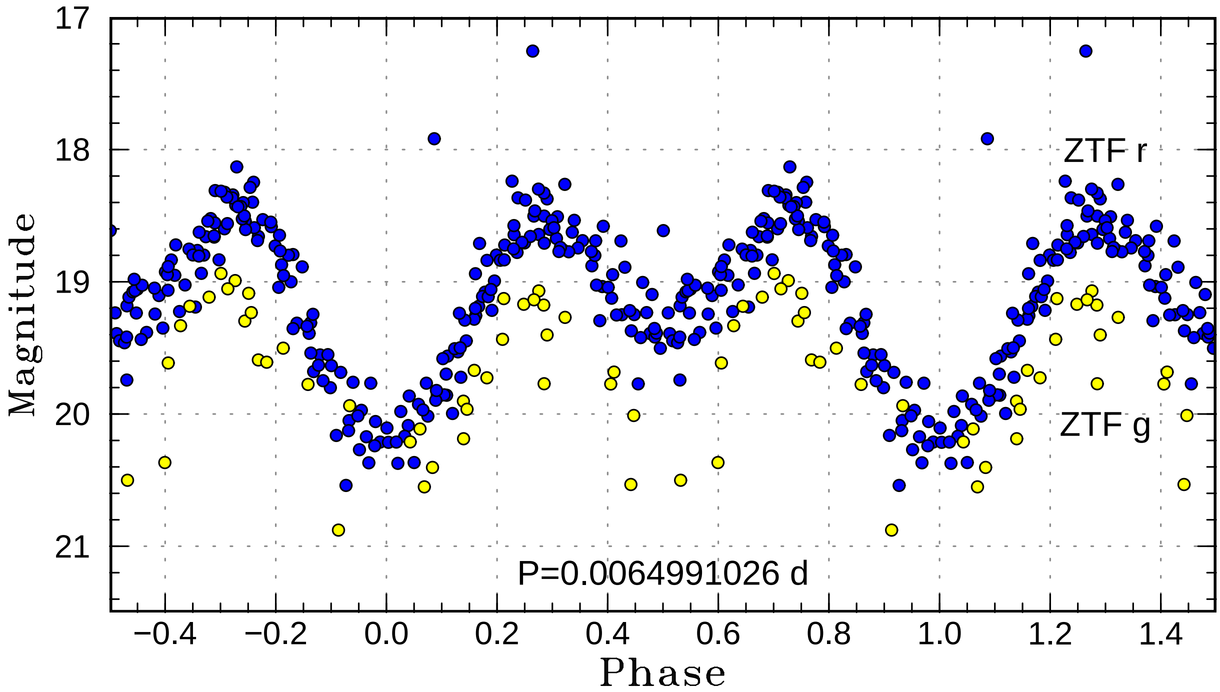

Figure 4: The phase-folded light curve of the entire ZTF data. The epoch and period were from equation (1).

The resultant period of 0.0064991026 d = 9.36 min is very short. Although this could be the spin period of a binary containing a white dwarf, such as in the white dwarf pulsar AR Sco (Marsh et al. 2016; Stiller et al. 2018) and candidate white dwarf pulsars ZTF J185139.81+171430.3 = ZTF18abnbzvx (Kato and Kojiguchi 2021; Klingler and Pavlov 2021; Pavlenko and Sosnovskij 2021), ASASSN-V J205543.90+240033.5 (Kato 2021; Kato et al. 2021; Wagner et al. 2021), and more recently GLEAM-X J162759.5−523504.3 (Katz 2022). The profile of variations in Gaia22ayj and the constancy of the profile, however, do not look similar to those of white dwarf pulsars.

The phase-folded light curve rather suggests a β Lyr-type or W UMa-type eclipsing binary with different minima. The slightly brighter second maximum is suggestive of the O'Connell effect (O'Connell 1951). The only such short-period (9.36 min) binaries known to us are AM CVn stars composed of white dwarfs [For a review of AM CVn stars see e.g. Solheim (2010)]. Among AM CVn stars, two short-period systems HM Cnc (5.36 min) and V407 Vul (9.48 min) are considered to be direct impact accretors without forming an accretion disk (Marsh and Steeghs 2002; Ramsay et al. 2002). The third shortest system ES Cet (10.3 min) has recently been shown to have an accretion disk (Bąkowska et al. 2021). Aside from these accreting systems, an eclipsing binary with a period of 6.91 min (ZTF J153932.16+502738.8) is also known (Burdge et al. 2019).

If Gaia22ayj is indeed an accreting 9.36-min eclipsing binary, this object is the shortest period known such an object (the record up to now was ES Cet). The presence of eclipses in ES Cet was confirmed only by rotational disturbance in the profiles of emission lines (Bąkowska et al. 2021), and not yet by photometry. Gaia22ayj would be very important case due to the very large amplitudes of photometric variations. Following the interpretation of an eclipsing binary, the large depths of the eclipses require that the system is seen almost edge-on and the brightness of the two components do not differ greatly. A simplified calculation suggests that a luminosity ratio of ∼0.4 could reproduce the observed difference in depths of the minima. With this orbital period, the Doppler beaming is expected to be an order of 1%(=0.01 mag) (Zucker et al. 2007) and would be detectable by high-precision photometry.

The presence of an outburst lasting nearly 1 d in Gaia22ayj suggests the presence of instability in the accretion disk, rather than a short-lived flare or an accretion event as seen in in intermediate polars. The detection in X-rays by the Swift X-ray telescope (1SWXRT J082526.4−223212: D'Elia et al. 2013) is compatible with an accreting binary. The presence of an accretion disk makes Gaia22ayj similar to ES Cet. The disks in short-period AM CVn stars, like ES Cet, are considered to be thermally stable due to the high mass-accretion rate considering the standard evolutionary path in which the mass transfer is driven by gravitational wave radiation and the mass-losing white dwarf fills the Roche lobe (Tsugawa and Osaki 1997; Kotko et al. 2012). The case of Gaia22ayj appears to be different. If Gaia22ayj is indeed an AM CVn-like object, it might be in the turn-on phase of the mass-transfer before reaching the period minimum (Deloye et al. 2007; Solheim 2010).

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 21K03616. The author is grateful to the ZTF team for making their data available to the public. We are grateful to Naoto Kojiguchi for helping downloading the ZTF data. This research has made use of the AAVSO Variable Star Index and NASA's Astrophysics Data System.

Based on observations obtained with the Samuel Oschin 48-inch Telescope at the Palomar Observatory as part of the Zwicky Transient Facility project. ZTF is supported by the National Science Foundation under Grant No. AST-1440341 and a collaboration including Caltech, IPAC, the Weizmann Institute for Science, the Oskar Klein Center at Stockholm University, the University of Maryland, the University of Washington, Deutsches Elektronen-Synchrotron and Humboldt University, Los Alamos National Laboratories, the TANGO Consortium of Taiwan, the University of Wisconsin at Milwaukee, and Lawrence Berkeley National Laboratories. Operations are conducted by COO, IPAC, and UW.

The ztfquery code was funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement n°759194 – USNAC, PI: Rigault).

We acknowledge ESA Gaia, DPAC and the Photometric Science Alerts Team (http://gsaweb.ast.cam.ac.uk/alerts).

List of objects in this paper

ES Cet, HM Cnc, AM CVn, β Lyr, W UMa, V407 Vul, 1SWXRT J082526.4−223212, ASASSN-V J205543.90+240033.5, Gaia22ayj, GLEAM-X J162759.5−523504.3, ZTF J153932.16+502738.8, ZTF J185139.81+171430.3, ZTF18abnbzvx, ZTF19aagmvuk

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Editor Seiichiro Kiyota
e-mail: skiyotax@gmail.com