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ASASSN-15cm: an SU UMa star with an orbital period of 5.0 hours

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Abstract

ASASSN-15cm had been identified as a dwarf nova with an orbital period of 5.0 hours and a hot, luminous secondary of of a spectral type around K2.5 in the previous study. Using the Zwicky Transient Facility (ZTF) data, the Asteroid Terrestrial-impact Last Alert System (ATLAS) forced photometry and the All-Sky Automated Survey for Supernovae (ASAS-SN) Sky Patrol data, I found that this object underwent a superoutburst in 2019. I obtained a refined orbital period of 0.2084652(3) d and a superhump period of 0.2196(1) d, which gave a mass ratio q=0.22. Modeling of quiescent ellipsoidal variations yielded an inclination of i=55°, consistent with the lack of eclipses during outbursts. The object adds another example of SU UMa stars above or in the period gap containing a secondary with an evolved core, and has the longest orbital period among the established ones. ASASSN-15cm showed relatively regular superoutbursts with a supercycle of 849(18) d between 2015 and 2022, and the next superoutburst is expected to occur in the early half of 2024. Coordinated detailed observations during the next superoutburst are expected to better clarify the nature of this object.

1 Introduction

ASASSN-15cm was discovered as a dwarf nova by the All-Sky Automated Survey for Supernovae (ASAS-SN: Shappee et al. 2014) at V=15.8 on 2015 January 31. The ASAS-SN team noted that the Catalina Real-time Transient Survey (CRTS, Drake et al. 2008)[1] had detected previous outbursts. Thorstensen et al. (2016) performed spectroscopic and photometric studies of this object and obtained an orbital period ($P_{\rm orb}$) of 0.208466(2) d using the CRTS data. Spectroscopy by Thorstensen et al. (2016) indicated a secondary of a spectral type of K2.5±2.5, hot and luminous for a cataclysmic variable (CV) with this $P_{\rm orb}$ Based on the long $P_{\rm orb}$, the object was implicitly assumed to be an SS Cyg star and no special attention has been paid to search for an SU UMa-type signature. [For general information of CVs and subclasses, see e.g., Warner (1995). For a review of dwarf novae, including SU UMa stars, see e.g., Osaki (1996)].

2 Data

I used the Asteroid Terrestrial-impact Last Alert System (ATLAS: Tonry et al. 2018) forced photometry (Shingles et al. 2021) and the Zwicky Transient Facility (ZTF: Masci et al. 2019)[2] data together with ASAS-SN Sky Patrol data (Kochanek et al. 2017).

3 Results and Discussions

[1] <http://nesssi.cacr.caltech.edu/catalina/>.

[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>.

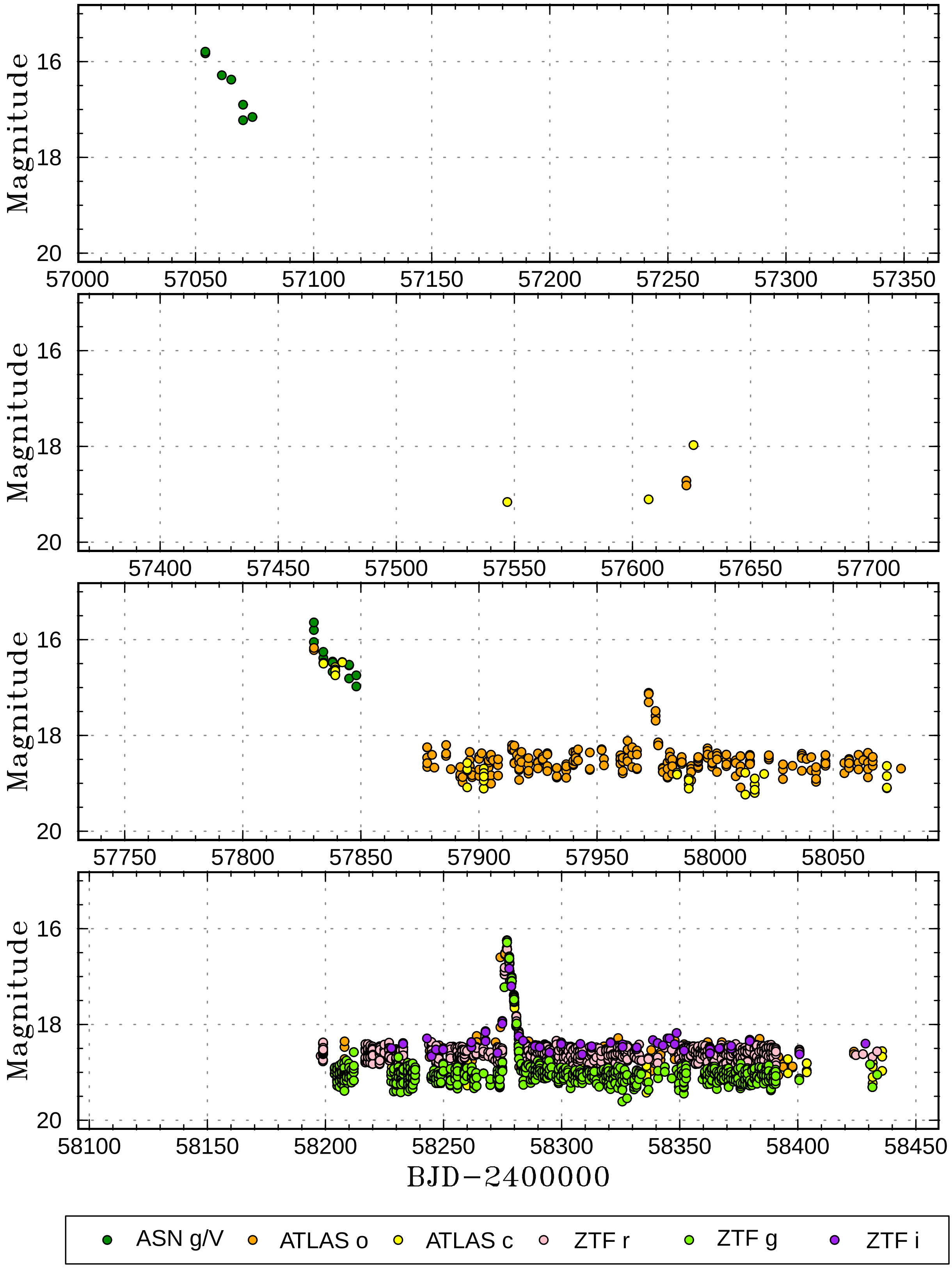

Figure 1: Light curve of ASASSN-15cm in 2015–2018.

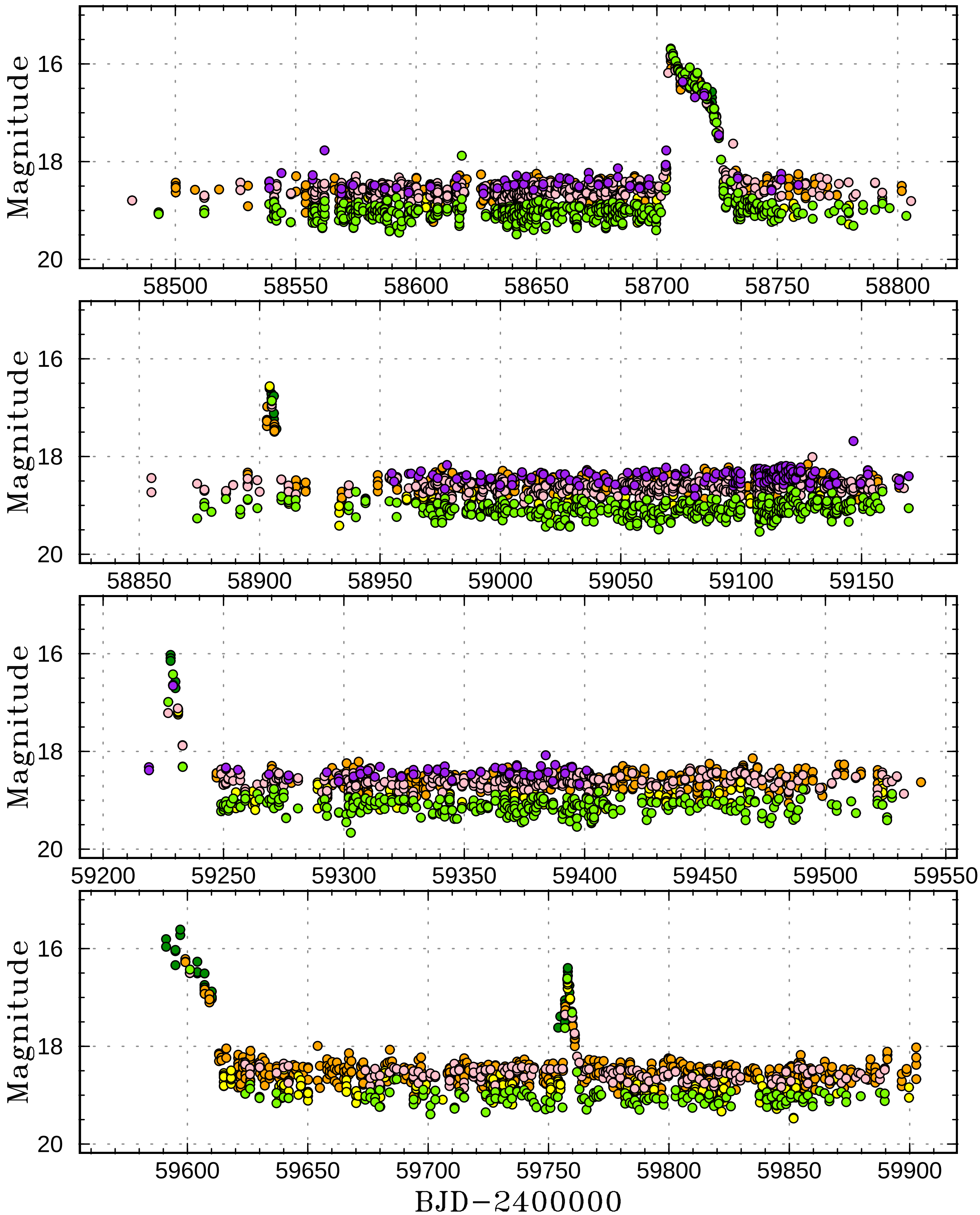

Figure 2: Light curve of ASASSN-15cm in 2019–2022. The symbols are the same as in figure 1.

3.1 Superoutbursts and superhumps

In figures 1 and 2, I show the light curve of ASASSN-15cm in the 2015–2022 seasons. ASAS-SN data did not reach 18.0 mag and quiescent parts was not recorded. In all these surveys, there were false bright detections and they were removed by comparing with the data obtained on the same nights by the same or other surveys. Upper limit observations were not plotted to avoid the figures to be too crowded.

The initial outburst in 2015 (first panel of figure 1) corresponds to the initial announcement of the outburst detection by the ASAS-SN team. I noticed that a long outburst in 2019 (first panel of figure 2) had a shape similar to an SU UMa-type superoutburst. This outburst was composed of a linearly fading initial part and a subsequent part with a scatter in the light curve (figure 3). Using these data after removing the trend by locally-weighted polynomial regression (LOWESS: Cleveland 1979), a phase dispersion minimization (PDM, Stellingwerf 1978) analysis yielded a strong superhump signal (figure 4) having a period of 0.2196(1) d with its error determined by the methods of Fernie (1989) and Kato et al. (2010). This period analysis had been proven to be useful for sparse, but with multiple samples in the same night, data such as ATLAS observations (Kato 2023). Note that the entire part was analyzed and possible variation in the superhump period (e.g. Kato et al. 2009) may have affected the result. There was no hint of the orbital modulation during the superoutburst.

ASASSN-15cm showed long outbursts (likely superoutbursts) relatively regularly: in 2015 (BJD 2457054), in 2017 (BJD 2457830), in 2019 (BJD 2458706) and in 2022 (BJD 2459591), where BJD values refer to the peaks of the outbursts (figures 1, 2). These long outbursts could be expressed by a period (supercycle) of 849(18) d within errors of 41 d. This result suggests that superbursts in ASASSN-15cm occur very regularly, and the 2019 superoutburst was unlikely an exceptional phenomenon. The next superoutburst is expected to occur in the early half of 2024 (around BJD 2460417) and coordinated detailed observations are desirable. The supercycle of 849 d is fairly long and this implies a low mass-transfer rate.

The object also showed normal outbursts. These outbursts were relatively slowly rising and could be inside-out outbursts. The small number of normal outbursts also supports the low mass-transfer rate (Ichikawa and Osaki 1994; Osaki 1996).

3.2 Orbital period and variation in quiescence

Using ATLAS and ZTF data (all bands combined), a PDM analysis of the quiescent part yielded an orbital period of 0.2084652(3) d (figure 5), in very good agreement with the value by Thorstensen et al. (2016). The quiescent light curve consists of prominent ellipsoidal variations, which are expected from the hot and luminous secondary (Thorstensen et al. 2016). The zero phase was chosen to be BJD 2457553.8461 to match figure 15 in (Thorstensen et al. 2016). This zero phase corresponds to the inferior conjunction of the secondary. Multicolor phase-averaged light curves are shown in figure 6. The maximum at phase 0.7–0.8 (possibly corresponding to the hot spot, but the O'Connell effect cannot be excluded) becomes brighter in the r and g bands than in the i band.

3.3 Mass ratio and orbital parameters

The observed fractional superhump excess $\epsilon \equiv P_{\rm SH}/P_{\rm orb}-1$, where $P_{\rm SH}$ represents the superhump period, is 0.053. Assuming that $P_{\rm SH}$ represents the period of stage B superhumps [for superhumps and stages, see Kato et al. (2009)], the semi-empirically derived $q = M_2/M_1$ is 0.22 (table 4 in Kato 2022). Although I do not explicitly give an error estimate, the error is expected to be an order of 0.01 [see Kato (2022) for the derivation process]. This appears to fit the observations fairly well since q <0.25–0.33 is required to show superhumps during outbursts (Whitehurst 1988; Murray et al. 2000). The regularity of superoutbursts (subsection 3.1) provides a support to the q value not too close to the borderline, i.e. not close to 0.3 or larger.

This q is very different from $q \sim$0.6 suggested in Thorstensen et al. (2016).[3] This constraint by Thorstensen et al. (2016) on q was based on a combination of the observed K_2 velocity and the constraint on the inclination allowing a large amplitude of ellipsoidal variations, which could not be comfortably modeled without introducing artificially increasing gravity darkening and decreasing the disk contribution excessively (Thorstensen et al. 2016). The second assumption (negligible contribution from the disk) required for modeling at least appears to be satisfied considering the low mass-transfer rate inferred from the long supercycle (subsection 3.1).

Using Ellipsoidal Modulation Light Curve Generator by M. Uemura (2006), which was based on Orosz and Bailyn (1997a,b), I obtained ellipsoidal variations similar to the ZTF light curves in figure 6. I used $T_{\rm eff}$=5000 K,

[3] The modest lower limit of q=0.1 by Thorstensen et al. (2016), however, turned out to be an excellent choice after the identification of this system as an SU UMa star.

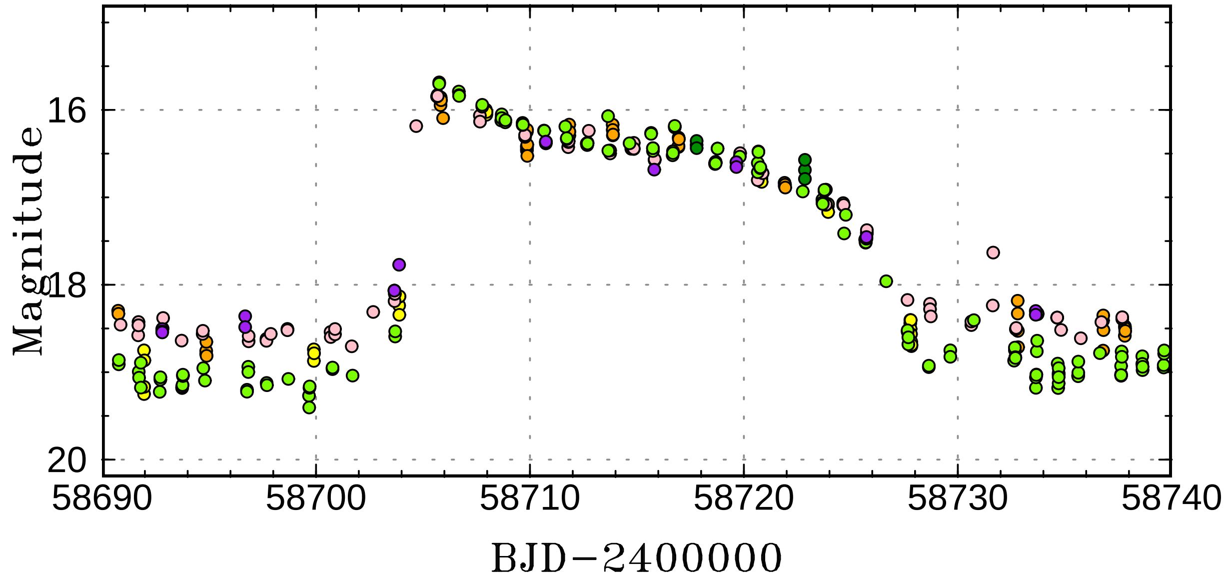

Figure 3: Enlargement of the light curve of the 2019 superoutburst. The symbols are the same as in figure 1.

log g=4.5 and gravitational darkening and limb-darkening coefficients given in Claret and Bloemen (2011) (solar metallicity and a microturbulent velocity of 2 km s^{-1} as typical values were used, since I do not have information for them; however, they have little effect on the result). With these parameters, the primary with a mass of 0.7 $M_\odot$ can reproduce the observed K_2=229 km s^{-1}.

3.4 SU UMa stars above or in the period gap

SU UMa stars above the CV period gap are relatively rare, since CVs with long periods have larger q values, which make the 3:1 resonance in the disk difficult to achieve. The present finding in ASASSN-15cm adds another example of SU UMa stars above or in the period gap containing a secondary with an evolved core. The known such systems include OT J002656.6+284933 (=CSS101212:002657+284933, $P_{\rm SH}$=0.13225 d, Kato et al. 2017), ASASSN-18aan ($P_{\rm orb}$=0.149454 d, Wakamatsu et al. 2021) and likely ASASSN-19ax ($P_{\rm SH}$=0.1000 d, Kato et al. 2021a) following the identification of QZ Ser (but near the lower border of the period gap with $P_{\rm orb}$=0.08316 d) as an SU UMa star with an anomalously hot and luminous secondary (Thorstensen et al. 2002). V363 Lyr ($P_{\rm orb}$=0.185723 d, Kato 2021) might be another example, although the superhump-like signal recorded in this system may have not been the same as in other SU UMa stars. Another group of SU UMa stars above the period gap, but apparently lacking evidence of a secondary with an evolved core, contains BO Cet ($P_{\rm orb}$=0.139835 d, Kato et al. 2021b; Kato 2023) and possibly MisV1448 ($P_{\rm SH}$=0.2275 d, vsnet-alert 24912,[4] Kojiguchi et al. in preparation). The status of ASASSN-14ho ($P_{\rm orb}$=0.24315 d, Kato 2020) still requires observational confirmation. Lists of long-$P_{\rm orb}$ SU UMa stars or CVs with an anomalously warm secondary can be found in Wakamatsu et al. (2021) and Kato et al. (2021a). A search for superhumps in long-$P_{\rm orb}$ systems with a secondary with an evolved core would be an interesting challenge.

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[4] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/24912>.

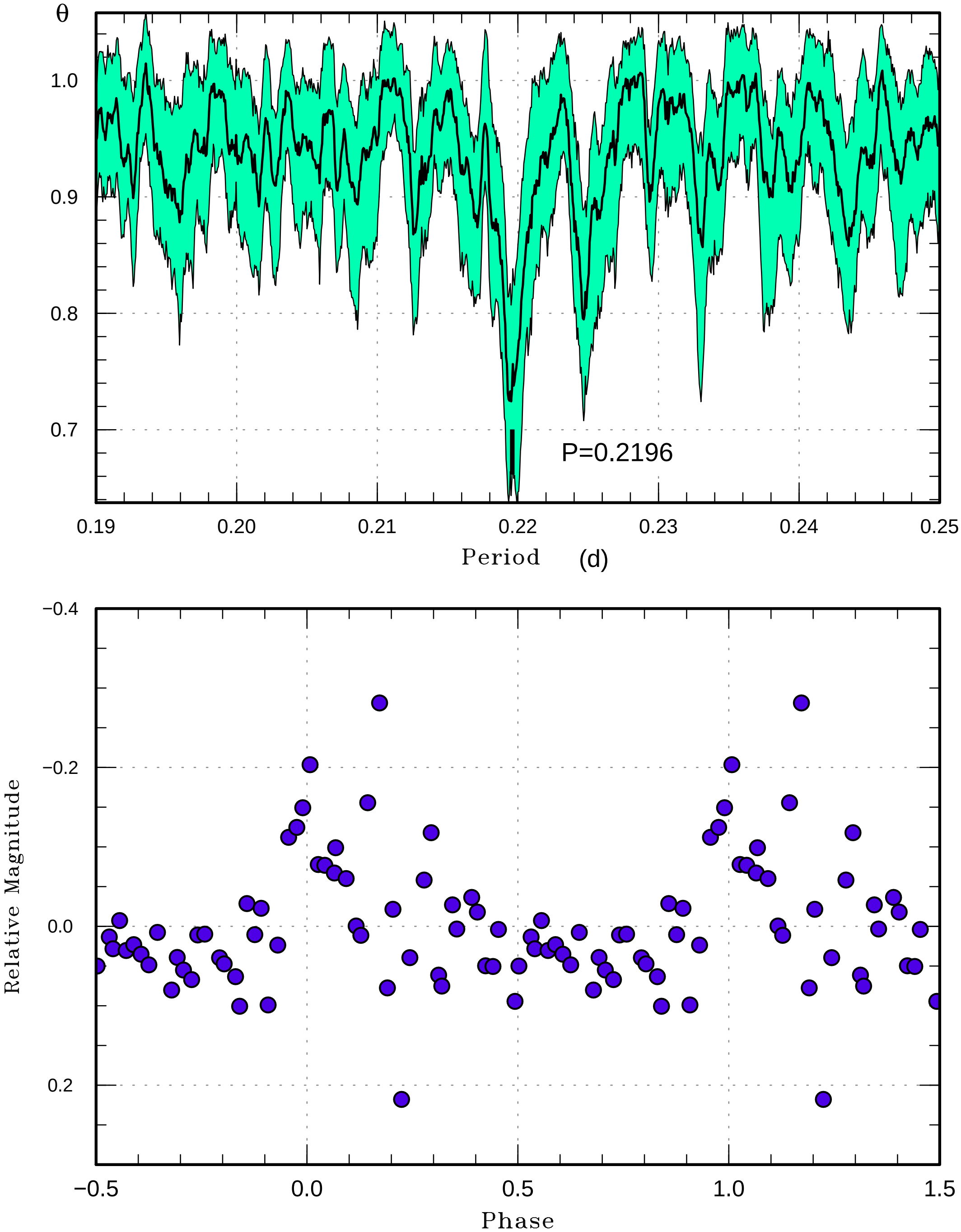

Figure 4: Superhumps of ASASSN-15cm in 2019 (interval BJD 2458705.6–2458726.7). (Upper): PDM analysis. The bootstrap result using randomly contain 50% of observations is shown as a form of 90% confidence intervals in the resultant θ statistics. (Lower): Phase plot.

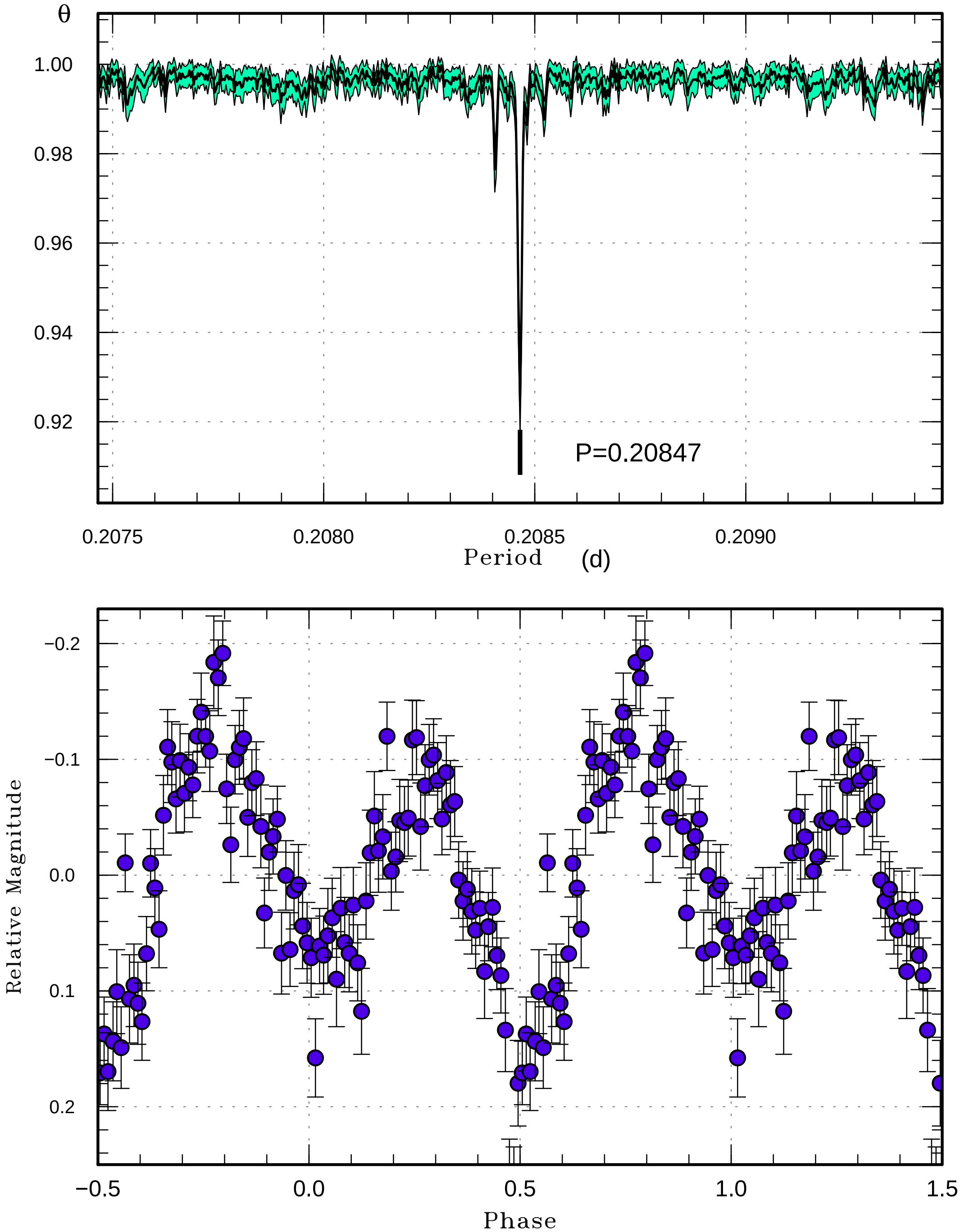

Figure 5: Orbital profile of ASASSN-15cm in quiescence using ATLAS and ZTF data. (Upper): PDM analysis. (Lower): Phase plot. Prominent ellipsoidal variations are present. The zero phase was chosen to be BJD 2457553.8461 to match figure 15 in Thorstensen et al. (2016). This zero phase corresponds to the inferior conjunction of the secondary.

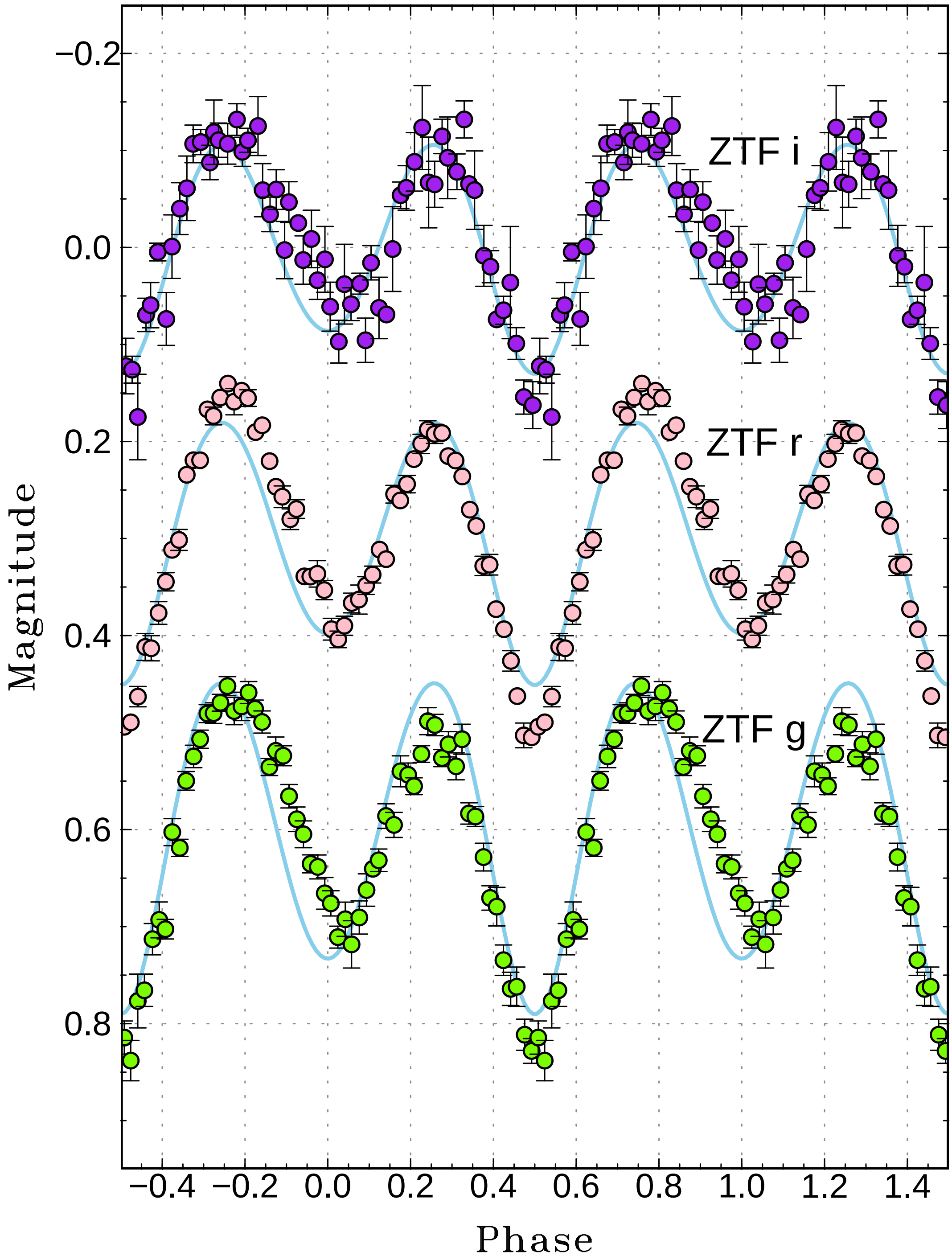

Figure 6: Orbital profile of ASASSN-15cm in quiescence using multicolor ZTF data. The zero phase is defined as the same as in figure 5. The plots were shifted by 0.3 mag between different bands. The solid curves represent ellipsoidal variations expected for q=0.22 and i=55° (see text).

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List of objects in this paper

BO Cet, V363 Lyr, QZ Ser, SU UMa, ASASSN-14ho, ASASSN-15cm, ASASSN-18aan, ASASSN-19ax, CSS101212:002657+284933, MisV1448, OT J002656.6+284933

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