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Long-lasting high state of the high-field polar AR UMa

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Abstract

Using ASAS-SN Sky Patrol Photometic Database and Asteroid Terrestrial-impact Last Alert System (ATLAS) data, I found that the high-field polar AR UMa entered a long-lasting high state in 2022 October. This object is renowned for its small duty cycle, and short-lived high states have only been occasionally seen since the discovery. It appears that the present long-lasting high state is the first recorded one at least in the last 30 years and probably even more. Before entering the current long-lasting high state, this object showed three short-lived high states, which might have been precursors to the current state. Before these short-lived high states, the object had been in a low state for 8 years and probably more. I refined the orbital period to be 0.08050066(1) d. The object is still bright and current phenomenon provides a unique opportunity to study accretion processes onto a strongly magnetized white dwarf and to study the mechanism of maintaining the long-lasting high state.

There was an extremely soft X-ray transient 1ES 1113+432 discovered from observations by Imaging Proportional Counter of the Einstein Observatory in 1979 (Remillard et al. 1994). At that time, no optical object brighter than V=16 within 2 arcmin of the X-ray location was found. The object was high above the Galactic plane and a classical X-ray nova seemed unlikely. Remillard et al. (1994) obtained optical imaging and found a very blue object within 1.2 arcmin radius of the X-ray error circle. This optical counterpart (V=16.5) had already been known as a semiregular (SR) variable star (Kholopov et al. 1985; Meinunger and Wenzel 1968), which was originally discovered by Hoffmeister (1963) as an RR Lyr star (SON 7744) with a range of 14.5–16 mag. Remillard et al. (1994) obtained spectra, determined the orbital period (1.9322 hr = 0.08051 d) and detected "outburst"-like variations on historical plates. Remillard et al. (1994) identified this object to be a polar (AM Her star) [see e.g., Cropper (1990) for a review of polars] which spends most of the time in low-accretion states. Referring to the manuscript of Remillard et al. (1994), Wenzel (1993) re-examined the plates which were used to give the earlier SR-type classification. It turned out difficult to determine the variability type in the 1960s when the great diversity of cataclysmic variables (CVs) was still unknown. It is also worth noting that AR UMa was not selected as a CV by ROSAT (Voges et al. 1999), which was/is known to be very efficient in discovering polars. AR UMa should have spent too much time in low states to be detected even by ROSAT as a CV. This object was then shown to be the first high-field magnetic CV with a field strengh of ∼230 MG (Schmidt et al. 1996).

While inspecting of ASAS-SN Sky Patrol Photometic Database (ASAS-SN V2.0: Hart et al. 2023; Shappee et al. 2014), I noticed that AR UMa had entered a long-lasting high state starting from 2022 October. This brightening had been independently detected by Yutaka Maeda on 2023 February 21 (14.1 mag, unfiltered CCD), but apparently escaped detection by visual monitoring. I immediately issued an alert (vsnet-alert 27706)[1] on 2023 May 3, when ASAS-SN V2.0 observations had ended on April 26. After confirming that the Asteroid Terrestrial-impact Last Alert System (ATLAS: Tonry et al. 2018) forced photometry (Shingles et al. 2021) recorded this object still bright in May, I issued a follow-up notice (vsnet-alert 27708)[2]. Campaigns by the VSNET (Kato et al. 2004) and VSOLJ teams (cf. vsnet-alert 27719)[3] and by the AAVSO[4] were launched. Although time-resolved

[1] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/27706>.
[2] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/27708>.
[3] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/27719>.
[4] <https://www.aavso.org/aavso-alert-notice-824>.

photometric data have been reported, I primarily deal with the behavior of AR UMa leading to the current bright state in this article.

The light curve since 2013 using ATLAS, ASAS-SN (not V2.0) and Zwicky Transient Facility (ZTF: Masci et al. 2019)[5] observations is shown in figures 1 and 2. Several ASAS-SN observations were omitted as noises by comparing with observations on the same night. Before this, there had been some observations reported to VSOLJ and VSNET. There was no evidence for a long-lasting high state in 2009–2013, although observations were fragmentary. There were short-lived high states in 2007 January to March and in 2008 January, both detected by Ian Miller by snapshot CCD observations (see also Schmidt et al. 1999 for the light curve). Observations before them were not ideal and visual observations since 1997 reporting magnitudes of 15.0–16.0 probably referred to the low state. There was a documented short-lived high state in 1996 December (Schmidt et al. 1999). It appears that the high state starting from 2022 October is the first long one since the discovery. According to Wenzel (1993), low states were predominant and only six high states since 1961 (spanning 32 years) had been detected almost like dwarf nova outbursts. There may have not been a long-lasting high state even since the discovery of this object as a variable star.

There were three short-lived brightening events in 2021 May, 2022 April and likely in 2022 June (figure 2) despite the long absence (nearly 8 yr) of a similar event before them. These short-lived events may have been precursors to the present high state. Although it has been argued that long-lasting low states already challenge the theories (Breedt et al. 2012), whether these short-lived brightening events reflected gradually increasing mass-transfer or such precursors could initiate some sort of positive feedback to maintain the high state may be an interesting theoretical topic.

The orbital profile during the low states before 2022 October is shown in figure 3. The ASAS-SN, ATLAS and ZTF data were combined after removal of the long-term trends by locally-weighted polynomial regression (LOWESS: Cleveland 1979). The period wes determined using the phase dispersion minimization (PDM: Stellingwerf 1978) method, whose error was estimated by the methods of Fernie (1989); Kato et al. (2010). Strong ellipsoidal variations are apparent [see Schmidt et al. (1996); Howell et al. (2001)]. The difference between the primary and secondary maxima was much smaller in Schmidt et al. (1996) and Howell et al. (2001) because they used infrared bands. In drawing the phase-averaged light curve, I used the following ephemeris determined from these data:

$$T_0(\mathrm{BJD}) = 2458786.470(1) + 0.08050059(2)E. \tag{1}$$

This period agrees with the one 0.08050074(12) d by Schmidt et al. (1999) from radial-velocity observations. The difference in the zero phases between this and Schmidt et al. (1999) (zero crossing by radial-velocity observations) corresponds to a 0.076 orbit after 103304 orbital cycles. Assuming that the present photometric minimum is equivalent to the zero crossing phase, the improved orbital period is 0.08050066(1) d, which can be considered as the current best determination of the period of this binary.

The orbital profile during the current high state is shonw in figure 4. ZTF data for this interval are not yet publicly available and ATLAS and ASAS-SN data were combined. Although the statistic is worse than the low-state profile, a bump at phase 0.2–0.3 appeared.

Acknowledgements

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This work has made use of data from the Asteroid Terrestrial-impact Last Alert System (ATLAS) project. The ATLAS project is primarily funded to search for near earth asteroids through NASA grants NN12AR55G, 80NSSC18K0284, and 80NSSC18K1575; byproducts of the NEO search include images and catalogs from the survey area. This work was partially funded by Kepler/K2 grant J1944/80NSSC19K0112 and HST GO-15889, and STFC grants ST/T000198/1 and ST/S006109/1. The ATLAS science products have been made possible

[5] 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>.

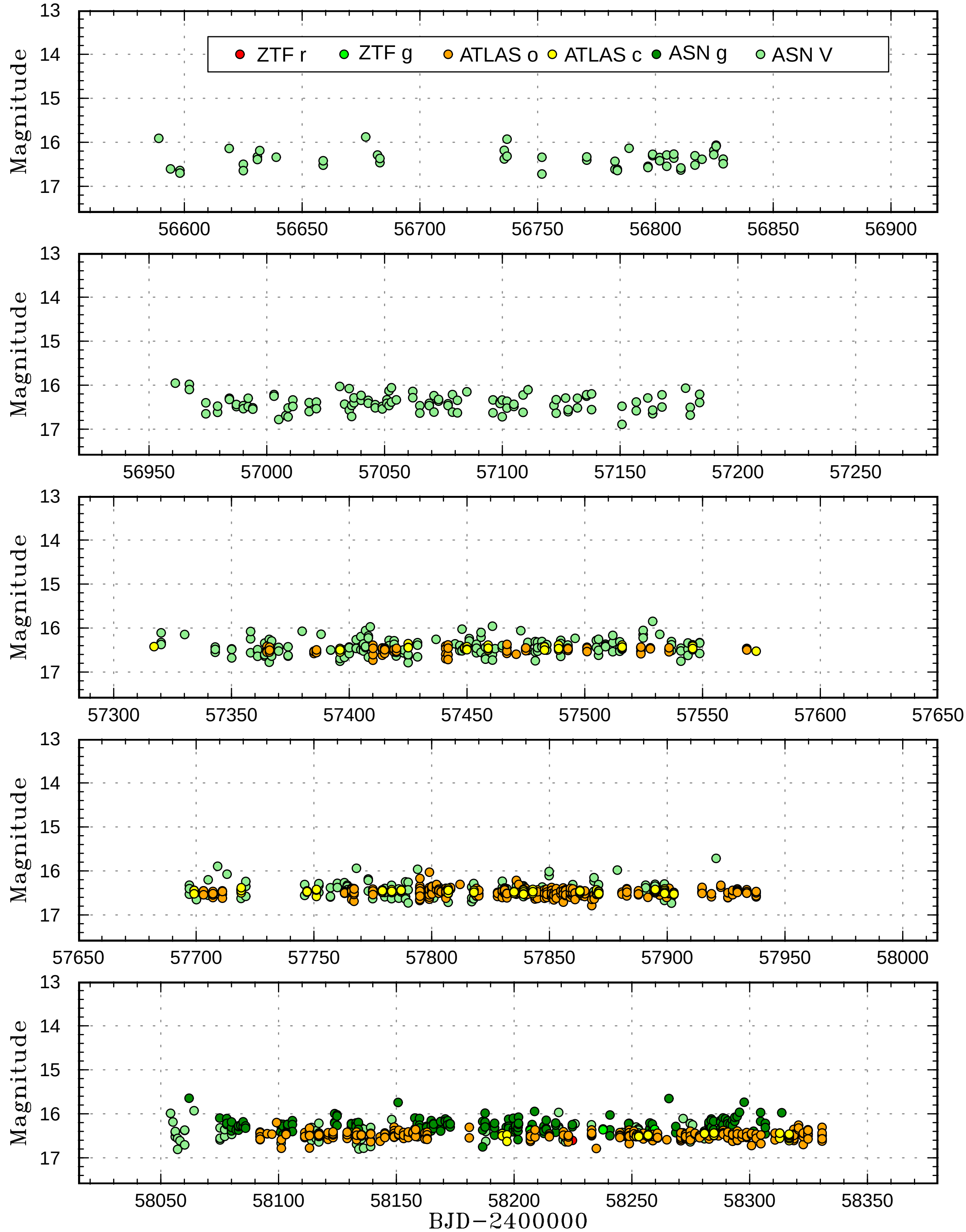

Figure 1: Light curve of AR UMa in 2013–2018. The object was in low state. The symbols used in figure 2 are also displayed.

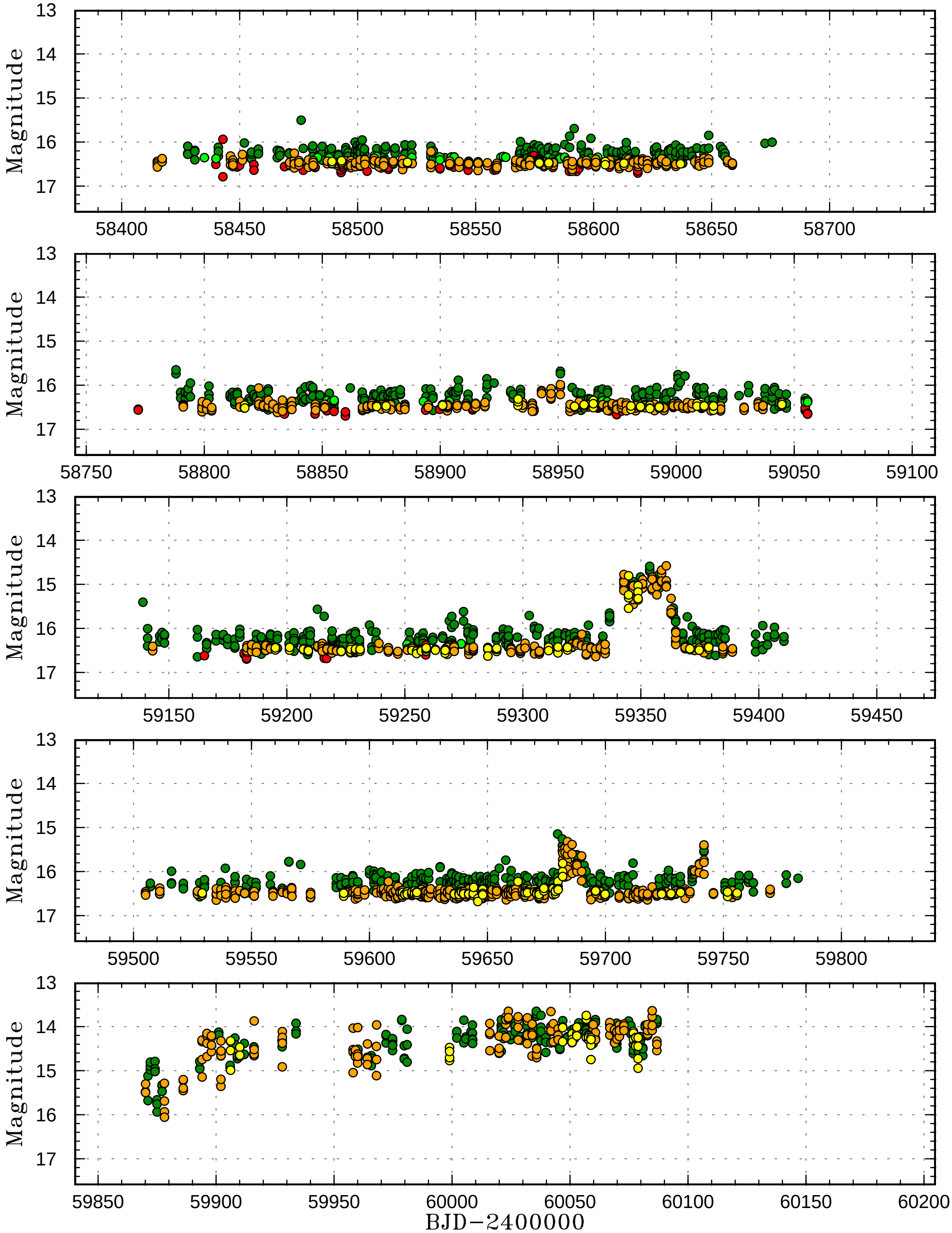

Figure 2: Light curve of AR UMa in 2018–2023. The symbols are the same as in figure 1. Transient high states were seen in the third and fourth panels. The object entered a long-lasting high state in the last panel.

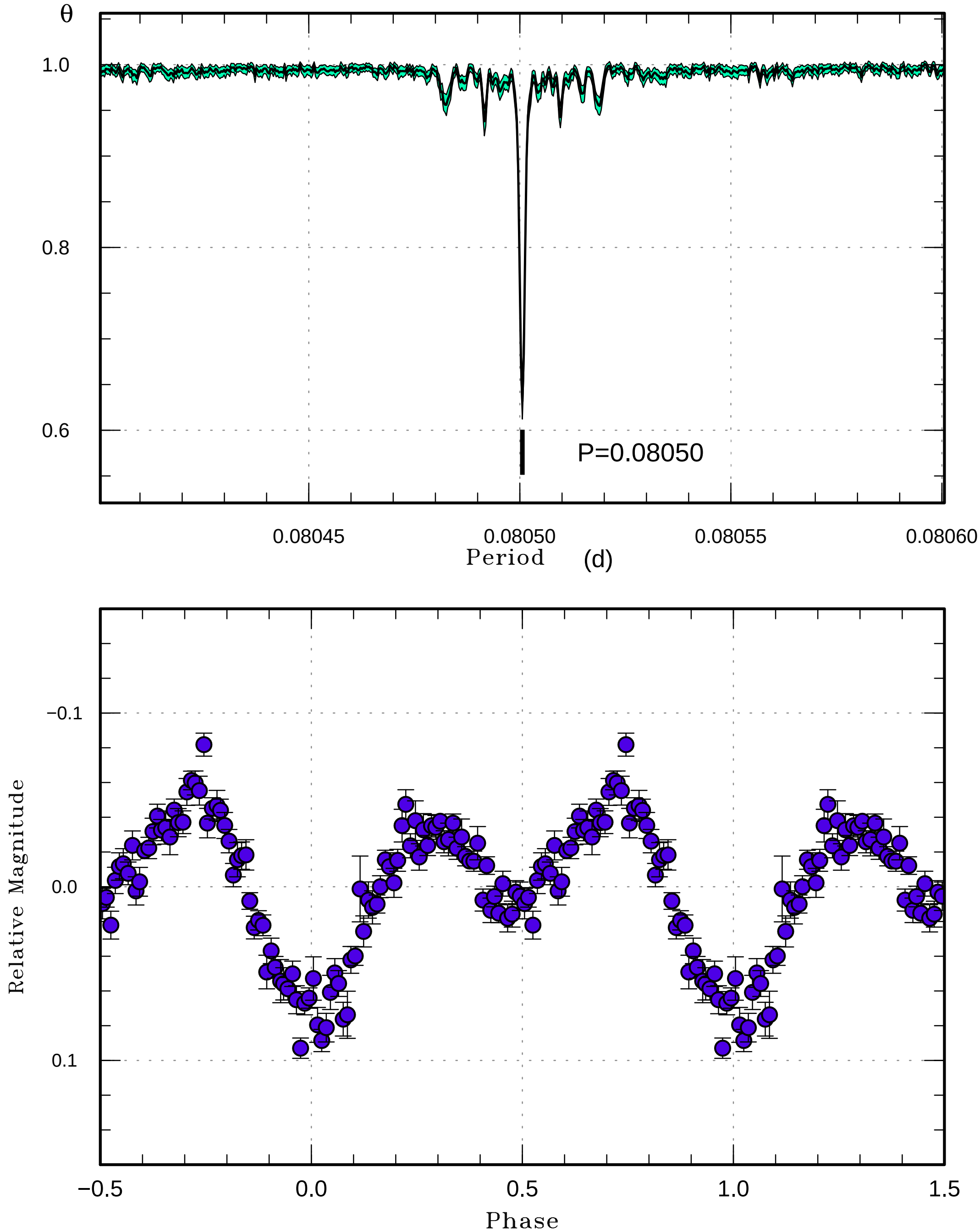

Figure 3: Orbital profile of AR UMa in low states. (Upper): PDM analysis. The bootstrap result using randomly contain 50% of observations is shown as a form of 90% confidence intervals in the resultant θ statistics. (Lower): Phase plot.

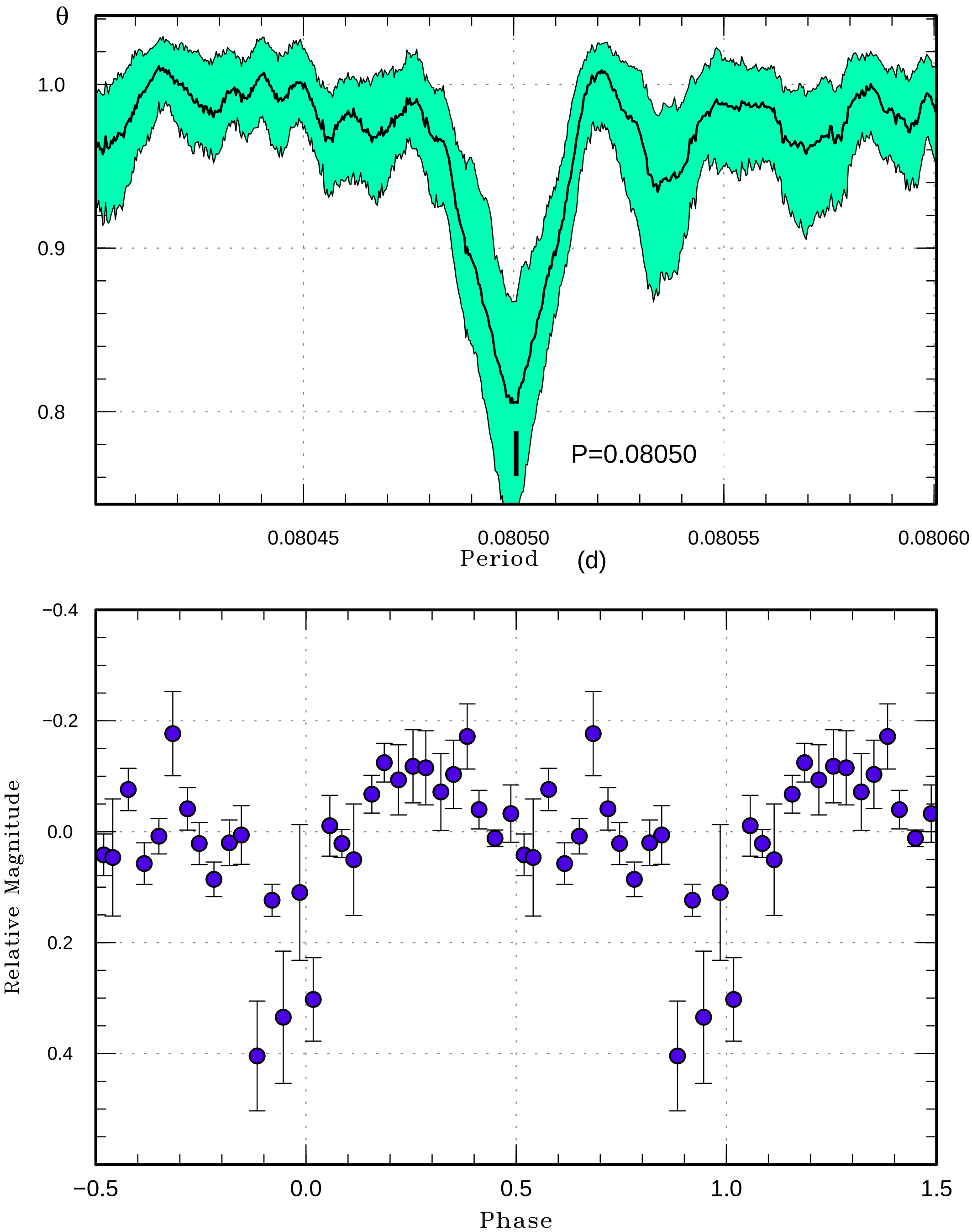

Figure 4: Orbital profile of AR UMa in the current high state. (Upper): PDM analysis. (Lower): Phase plot.

through the contributions of the University of Hawaii Institute for Astronomy, the Queen's University Belfast, the Space Telescope Science Institute, the South African Astronomical Observatory, and The Millennium Institute of Astrophysics (MAS), Chile.

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List of objects in this paper

AM Her, RR Lyr, AR UMa, 1ES 1113+432, SON 7744

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