OV BOOTIS: FORTY NIGHTS OF WORLD-WIDE PHOTOMETRY

Barret, Douglas & douglasbarret70@gmail.com
Brincat, Stephen & stephenbrincat@gmail.com
Boardman Jr, James & jboardmanjr@gmail.com
Buczynski, Denis & buczynski8166@btinternet.com
Campbell, Tut & jmontecamp@yahoo.com
Cejudo, David & davcejudo@gmail.com
Cook, Lew & lew.cook@gmail.com
Cook, Michael J. & michael.cook@newcastleobservatory.ca
Collins, Donald & dcollins@warren-wilson.edu
de Miguel, Enrique & edmiguel63@gmail.com
Dubois, Franky & astrosun@skynet.be
Dvorak, Shawn & sdvorak@rollinghillsobs.org
Kroes, Anthony J. & akroes@netnet.net
Lemay, Damien & damien.lemay@globetrotter.net
Licchelli, Domenico & domenico.licchelli@le.infn.it
Novak, Rudolf & rudolf.novak@gmail.com
Oksanen, Arto & arto.oksanen@jklsirius.fi
Patterson, Joseph & jop@astro.columbia.edu
Roberts, George & georgeroberts0804@att.net
Seargeant, Jim & jimsarge@gmail.com
Slauson, Douglas & dmslauson@netscape.net
Stone, Geoff & geofstone@earthlink.net
Ulowetz, Joe & joe700a@gmail.com
Vanmunster, Tonny & tonny.vanmunster@gmail.com
Wood, Matt & matt.wood@tamuc.edu
Walt Cooney & waltc111@att.net

ABSTRACT

Among the ~1000 known cataclysmic variables, only one appears to belong to the "Galactic halo" - the Population II stars. We report round-the-world photometry of this star (OV Boo) during March-April 2017, when it staged its first certified dwarf-nova outburst. Brightenings on archival plates in 1906 and 1984 suggest a recurrence period near 30 years. The star is remarkable for its short binary period (67 minutes), high proper motion, metal-poor composition, substellar secondary, sharp white-dwarf eclipses, and nonradial pulsations. Something for everybody…… and it even had the good manners to erupt in northern springtime, when it transits near local midnight. Move over, SS Cyg and WZ Sge; there's a new celebrity in town!

FORGET THIS NEXT PARAGRAPH (perhaps for the regular-journal paper to follow)

In March-April 2017, the first-recorded outburst of the dwarf nova OV Bootis occurred. OV Bootis is a unique star. Certified by its high proper motion, low abundance of metals, and oddly short orbital period (67 minutes), it is the only known Population II star among the several thousand known cataclysmic variables. We report on our campaign of time-series photometry during the first 40 days of outburst. The outburst light curve generally resembled those of “WZ Sagittae stars” - dwarf novae with a very low accretion rate. The star showed outburst orbital humps, superhumps, and periodic eclipses. The eclipse timings wandered early and late with respect to a constant-period ephemeris. This was probably due to a large elliptical and precessing disk which formed during the outburst..

1. **INTRODUCTION**

As of 2017, several thousand cataclysmic variables (CVs) are known, including ~1200 of known orbital period. Essentially all the orbital periods are short (<1 day), and most are very short (<3 hours). By definition, every CV has a Roche-lobe-filling “secondary star” transferring matter to a white dwarf, and accretion onto the white dwarf powers the luminosity. The “Roche-lobe-filling” condition implies a relation between orbital period and the density of the secondary: $P\sqrt{\rho}$ = constant. A few CVs (~40) have ultrashort periods – in the range 5-40 minutes – and those secondaries must therefore be of very high density. Spectroscopy of these stars shows a nearly pure helium spectrum, and the secondaries are very likely helium white dwarfs. That explains their very high density. This was lucidly explained long ago by Faulkner (1971) and Faulkner, Flannery & Warner (1972).

But the other 97% of CVs show a minimum period of ~80 minutes. In fact there's a big pile-up of CVs right around 77-82 minutes (“period spike”). This is basically because the secondaries are hydrogen-rich main-sequence stars, and the smallest possible star (~0.085 solar masses) has the highest possible density – and hence the shortest orbital period, since $P\sqrt{\rho}$ = constant. So we were quite shocked to find a CV with strong hydrogen emission lines and an orbital period of 67 minutes, far below the minimum period. This was SDSS J150722.30+523039.8 (Szkody et al. 2003). Mercifully, the Russians gave it a traditional variable-star name: OV Bootis.

You might think that since 0.085 Mo stars are the densest main-sequence stars, you could explain this oddity by merely hypothesizing a secondary of still lower mass – a brown dwarf. But not so. Lacking the central concentration of more massive “stars” (spherical self-gravitating objects), brown dwarfs are of *lower* density. By way of illustration, consider Jupiter – not quite a brown dwarf, but sufficient to illustrate the point. Jupiter has a mean density around 1 g/cc, like the Sun. But main-sequence stars obey roughly R~M^1, and hence ρ ~ M/R^3 ~ M^{-2}. Get the idea? Low-mass stars have densities far greater than the Sun (~100x greater, for the R~M^1 assumption). So the secondary in OV Boo is basically a low-mass star... and the spectrum is dominated by hydrogen, so the weirdly short orbital period cannot be explained by supposing it's a helium star.

So we zeroed in on this star and gave it a full photometric and spectroscopic study (Patterson, Thorstensen, and Knigge 2008). We learned the masses and radii of white dwarf and secondary, and the orbital inclination. The total eclipse of the white dwarf, along with the very high orbital inclination (85 degrees), permits very accurate measurement of these quantities. Most significantly, we measured the parallax and proper motion, which showed it to have – by a wide margin – the highest proper motion of any CV. This suggested that it might be a member of the Galactic Halo. We followed through with a study of its ultraviolet spectrum, which showed it to be significantly deficient in heavy elements: ([Fe/H] < -1.2; Uthas et al. 2011). This seemed to confirm its credentials as a Population II star – the only one known among all CVs.

Theoretical Pop II stars are slightly smaller, by ~10%, than Pop I stars of the same mass. This is because much of the opacity in the outer layers of Pop I stars comes from "metals" (elements beyond helium), and opacity tends to bloat a star. Pop II stars lack metals. Density scales as M/R^3, so at a fixed mass, that 10% translates to ~ 30% greater density. A 30% increase in ρ means a 15% increase in √ρ. Since P√ρ = constant, this means a 15% decrease in P. Thus the minimum orbital period for a Pop II CV should be ~15% shorter, or about 67 minutes.

Well, that's pretty good… and consistent with everything else known about this star (high proper motion, low abundance of metals). A remaining question is whether the unusual abundances might have an effect on outbursts.   In March 2017, we had an opportunity to find out. This paper reports our time-series photometry over the first 40 days of OV Boo's first recorded outburst.

2. OBSERVATIONAL TECHNIQUES

Most of the data reported here comes from the Center for Backyard Astrophysics, a global network of telescopes cooperating in campaigns of time-series photometry of variable stars (CBA: Patterson 2006, de Miguel et al. 2016). The network now includes ~20 telescopes, spread sufficiently over the Earth to give very long time series relatively untroubled by local weather and daily aliasing. Our typical telescope is a 35 cm reflector, equipped with a CCD camera and recording images every 30-60 s for many hours per night. Most of the data is unfiltered (white-light, or perhaps more correctly "pink", with an effective wavelength near 6000 A) differential photometry, although we always obtain some coverage in *V* light to express results on a standard scale if needed. Data from several telescopes are then spliced together to form a one-night light curve, with minimal gaps. We take advantage of overlaps in data to determine additive constants which put all our measurements on one instrumental scale (usually that of the most prolific or best-calibrated observer). These constants are usually in the range 0.01-0.05 mag, probably due to variations in transparency and camera sensitivity. Most telescopes use the same comparison star, although we also use data with other comparisons (requiring larger and more uncertain additive constants) if there is sufficient overlap. In this case we frequently used the AAVSO “115” star (GSC 3868-1067, V=11.482) and “143” star (GSC.3868-1068, V=14.290)

Research programs on faint stars with small telescopes often use white light, to enable high time resolution with good signal-to-noise. In the case of cataclysmic variables, it usually makes good astrophysical sense too, since the underlying sources of light are broad-band emitters (accretion disk, white dwarf). It is common practice to report magnitudes as “C” (or often “CV”, though we will avoid this term for obvious reasons): the result of differential photometry in clear light, added to the comparison star's known *V* magnitude. This is also our practice. However, because the white-light passbands are typically ~4000 A wide, the effective wavelengths of the variable and comparison stars can easily be 500 A apart. Therefore, C/CV magnitudes are not *V* magnitudes. We nevertheless prefer the C/CV scale and use it here, because it is our natural measurement scale, and because it accurately expresses the true changes in light.

Since an instrumental scale is not fully reproducible, a standard *V* magnitude is more desirable for archival purposes. For “good” comparison stars ($B-V<1.0$), our *C* magnitudes transform to *V* magnitudes via

$$\Delta V = \Delta C + 0.37\ \Delta(\mathrm{B-V}),$$

which implies ΔV = -0.20 in this case, where the variable is assumed (and observed) to have $B-V$ near 0.0. The latter assumption is pretty good for the great majority of cataclysmic variables accreting at a high rate – including OV Boo in outburst.

Atmospheric extinction is significant for us, because the program stars are usually much bluer than comparison stars (although we avoid very red stars, which are the bane of all stellar photometry). We know from experience that this differential extinction amounts to ~0.06 mag/airmass for most CVs. Nevertheless, in the spirit of keeping human hands off the data as much as possible, we usually make *no correction for extinction*.

The summary observing log for the first 40 days of outburst is given in Table 1. (A “night” denotes a time-series of good quality lasting at least 3 hours.)

3. THE OUTBURST

On 15 March 2017, the star was reported to be at magnitude 11.4 in the photographic sky patrol of Masaru Mukai (no relation to Koji Mukai, the famous X-ray astronomer). This was the first-ever recorded outburst. Within a few hours, telescopes around the world turned to the star, mostly with time-series photometry.

Yadda, yadda, yadda (expect to complete in 2 days)