Determination of the Nature and Classification of BW Sculptoris.

Peter Starr, 19 May 2012

ABSTRACT

I report the results from the analysis of photometric observations of the first ever recorded superoutburst of BW Sculptoris (BW Scl) and conclude it to belong to the WZ Sagittae (WZ Sge) class of dwarf novae and part of the GW Librae (GW Lib) class of stars. Observations were compared to the recent superoutbursts of WZ Sge in 2001 and GW Lib in 2007.

The star was observed 8 magnitudes higher than its quiescent 16th magnitude on October 21 2011. It declined on the outburst plateau for 21 days at a rate of 0.13 magnitudes per day, and then dipped sharply in under three days with a gradual long decline to quiescence, all typical of WZ Sge type dwarf novae in outburst.

The first days of the outburst exhibited a complicated lightcurve however early superhumps were present that declined in amplitude as seen in other WZ Sge dwarf novae. This reveals that the accretion disk had spread out in the outburst to radius where a 2:1 resonance occurs causing the early superhumps. Each day the amplitude of the superhumps diminished as the accretion disk was shrinking until at day 11 the superhumps returned strongly in the form of common superhumps as the accretion disk reached a radius where a 3:1 resonance could occur. This is also a characteristic of WZ Sge dwarf novae.

The common superhumps reduced in amplitude until the end of the dip after 25 days. Very high amplitude late superhumps occurred at this stage and continued for weeks as the star faded to quiescence. Notably absent though were the rebrightenings or echo outbursts exhibited by the WZ Sge 2001 superoutburst as well as by many other Sge type dwarf novae. However these were absent in the 1946 WZ Sge superoutburst as well as the GW Lib superoutburst of 2007.

Fourier analysis determined the superhump period to be 79.12 minutes, a 1.15% excess to the orbital period giving a precession rate of 4.77 days with the orbital period. The superhump period was found to be variable throughout all parts of the superoutburst. Another strong signal was detected at 39.26 minutes and is the harmonic of the superhump period.

GW lib stars are part of the WZ Sge type dwarf novae class however they exhibit non-radial pulsations in their lightcurve when in quiescence. This was reported by Uthas in 2012 from quiescent observations. No radial pulsations were observed when the star was settling back to quiescence however this is not surprising considering how hot the white dwarf would be form the accretion process during the superoutburst. Recent observations 200 days after the superoutburst do show a periodicity that Uthas had reported that was concluded to be a non radial pulsation. A quiescent superhump at 89 minutes was also observed at a similar period as reported by Uthas.

BW Scl is a highly evolved cataclysmic variable star and is at ‘the period minimum’. Theory predicts that 70% of cataclysmic variable stars should have passed the period minimum but very few have
been found due to their intrinsic faintness. BW Scl is one of these and categorising short period cataclysmic variable stars helps understand their evolutionary theory.

**AIMS**

BW Scl is a magnitude 16 star in the constellation Sculptor. It was first observed in 1990 as an x-ray source in the ROSAT Survey [Abbott, Fleming & Pasquini, 1997], and as a bright UV source in the Hamburg/ESO Survey [Augusteijn & Wisotski, 1997]. The General Catalogue of Variable Stars [GCVS] categorises BW Scl as a “Nova Like” variable star, the AAVSO categorises BW Scl as UGWZ +ZZ type CV, and more recently Uthas et al [2012] as a member of the GW Lib class of CVs.

On the 21st of October 2011, Michael Linnolt observed BW Scl at magnitude 9 [AAVSO]. The AAVSO issued a special notice (261) for variable stars observers to monitor this event to help categorise BW Scl. Amateur astronomers around the world observed BW Scl nightly for 2 months and submitted CCD and visual observations to the AAVSO database.

The aim of this project is to determine the nature and classify BW Scl in the Cataclysmic Variable Zoo of variable stars. This is to be done by;

1. Examining the literature to determine
   a. What CVs are, and their structure,
   b. The mechanisms involved in accretion
   c. Establish the different types of CVs and their characteristics,
   d. The evolution CVs and how the different CV types fit into this.
2. Examining the literature on the discovery of BW Scl as a CV.
3. Examine the literature to date on further observations and understandings of BW Scl
4. Download and analyse photometric data including my own photometric data on the recent first ever observed superoutburst of BW Scl.
   a. Determine characteristics from the data in order to help classify BW Scl (periodicities, amplitudes, superhumps)
5. Download data of the superoutbursts of WZ Sge and GW Lib to determine if there are any similarities to BW Scl.

Analysis of the profile of the long term light curve in outburst as well as the determination of periodicities and light curve profile in nightly observations may shed light onto the classification of this CV. Orbital and super hump periods for this star can also be determined from the light curves as well the observations of the individual components of the system (white dwarf, accretion disk, bright spot, and secondary star) may be seen if eclipses are present in its outburst state. Different classes of CVs may be different steps in the evolution of CVs. Studying and classifying individual systems like BW Scl help the understanding of evolution of CVs. Understanding CVs is important to revealing the physics in mass transfer and accretion disks about compact objects. Understanding accretion disks in CVs can help the understanding of accretion disks in protostars and higher energy systems such as black holes in HXMBs and super massive black holes in active galactic nuclei (AGN).

**WHAT ARE CATACLYSMIC VARIABLE STARS?**

Cataclysmic variable stars are semidetached binary stars consisting of a near main sequence secondary red dwarf star which is transferring mass to a primary white dwarf star [Warner, 1995].
Mass is transferred by a stream of gas from the secondary which forms an accretion disk about the primary star. A bright spot appears where the stream interacts with the disk. A boundary layer occurs around the white dwarf where material is transferred from the disk to the white dwarf. All of these components contribute to the light observed from a cataclysmic variable star. The observed light is variable on long time scales as outbursts and novae, medium timescales as orbital humps and eclipses in high inclination systems, and short time scales of seconds as flickering.

The entire system can fit well within the volume of the Sun and therefore have short orbital periods which range between 80 minutes and six hours [Dillon, 2006]. This closeness results in the tidal and rotational distortion of the red dwarf which causes it to be tidally locked to the primary star.

![Figure 1: Artists depiction of a cataclysmic variable star and its components [Uthas]](image)

JR Hind was the first to observe a CV, U Gem, as a blue variable star [Warner, 1995]. He noticed a 9th magnitude star where none was recorded previously in 1855. This was of most interest at the time as it was all other variables known were red. It faded but was rediscovered by Pogson in 1857 again at 9th magnitude which showed this star was no ordinary nova. JR Hind and Pogson had observed a CV in outburst. Since this time U Gem has been observed almost continually by amateur astronomers around the world.

T Leo was next to be observed in 1865, then SS Cygnus in 1896 [Warner, 1995]. When the General Catalog of Variable Stars was first published in 1948, 92 CVs were known. By 1984, 342 were known and published in the 4th edition of GCVS. With the advent of surveys like Hamburg and SDSS, hundreds more have been detected.

CVs are unable to be resolved in telescopes. Their structure was determined by observing CVs at high inclination. The components of the system are observed to eclipse each other revealing their relative sizes and luminosity. One example is the CV Z cha. Its lightcurve shows clearly the ingress and egress of the white dwarf behind the secondary star a short sharp decline in brightness indicating a bright but very compact object. The orbital period of the CV can be determined by repeating eclipses. An orbital hump is visible attributed by the bright spot on the edge of the accretion disk coming into view as the system rotates. The accretion disk is also observed to eclipse.
Spectroscopy of CVs reveal emission lines. Systems in quiescence show Balmer lines indicating hydrogen in a low ionisation states. Systems with high accretion rates show He II lines indicating higher ionisation state. Eclipsing systems show double peaked lines caused by the Doppler affect from a rotating accretion disk. Radial velocity measurements can determine the orbital periods of these systems and are much more reliable than the period determined photometrically. Spectra of the central white dwarf reveals broad absorption lines in the UV caused by the extreme pressures on the surface of the white dwarf. The temperature of the white dwarf can also be determined [Gansicke et al, 2005].

Observations in the X-ray spectrum reveal information in the boundary layer close to the white dwarf. Infra red observations sometimes reveal the secondary star [Mennickent, Diaz, Tappert, 2004]. In most systems it is hardly seen and contributes little light to the system. Some systems have revealed a reflection effect on the secondary caused by the hotter accretion disk [Hellier, 2001].

It was Brian Warner who developed the current model of CVs which was derived from eclipsing systems such as U Gem and Z Cha. He revealed that the light observed was a combination of the primary and secondary stars, an accretion disk and a bright spot of the accretion disk. The lightcurve of Z Cha revealed these components each of which were eclipsed.

CVs are noticed by their variations in brightness. Large increases by several magnitudes due to outbursts, variations due to eclipses in high inclination CVs showing their bright spot as an orbital hump, and the short sharp eclipse of the white dwarf, and small variations known as flickering which occur over one minute intervals at 0.01 – 0.2 magnitudes [Warner, 1995]. The secondary is rarely observed and contributes very little light to the lightcurve but is noticed when it eclipses the white dwarf, accretion disk and bright spot. In some cases a reflection effect is observed on the secondary as the hot white dwarf star heats up one side of the secondary star. Their spectra are observed to have broad double peaked Balmer emission lines due to the Doppler affect of a rotating accretion disk. They are observed in X-rays as material accretes onto the white dwarf, and are bright UV sources due to the hot white dwarf. Some light variations in low accreting systems are due to non radial pulsations of the white dwarf if they lie in the instability strip [Warner & Zyl, 1998]. These white dwarfs are known as zz ceti systems.

The physical process competing are magnetic braking by stellar winds, angular momentum loss through emission of gravitational radiation, mass loss, complexities from magnetic fields [Hellier, 2001].

**TYPES OF CATAclySMIC VARIABLE STARS**

**Classical novae** only have one observed outburst. The outburst is an increase in magnitude between 6 and 19 magnitudes. The largest are fast novae which also decay fast. Slow novae have small amplitudes but can take years to fade. They occur by a runaway thermonuclear process from material accreted onto the WD. All dwarf Novae will produce classical novae over periods of thousands of years as matter builds up on the white dwarf causing a runaway thermonuclear reaction [Warner 1995].

**Dwarf Novae** have outbursts 2 to 5 magnitudes. However some like WZ Sge go up to 8. Intervals between outbursts range from 10 days to decades. The duration for them is 2 to 20 days. Individual
DN has a similar pattern and don’t vary over the entire range. No shell of material is ejected like in novae.

There are 3 subtypes;

1. **Z Cam stars**, which have protracted standstills about 0.7 mag below max brightness, where outbursts cease for tens of days to years

2. **SU Uma Stars**, which have occasional superoutbursts which the star is 0.7 magnitudes higher than the normal outbursts between. The superoutburst is 3 times longer. They exhibit superhumps in the superoutbursts.

   **A WZ Sge Types**

   WZ Sge stars are a subclass of the SU Uma dwarf novae. They have orbital periods close to the Period Minimum meaning they are highly evolved. WZ Sge itself has a red dwarf mass of 0.06 solar masses and an orbital period of 82 minutes indicating that it’s at the latter stages of its evolution [Smak, 1993].

   They differ from other SU Uma types by only exhibiting superoutbursts and have reoccurrence times of decades instead of months. WZ Sge had superoutbursts in 1913, 1946, 1978, and 2001 [Kato, 2009]. The superoutbursts last much longer with the main plateau lasting approximately 30 days. The amplitude of the superoutburst is also much higher than of normal SU Uma stars with amplitudes of ~ 8 magnitudes.

   Their superoutbursts also differ from normal SU Uma stars by having double peaked superhumps in the early in the outburst that is close to the orbital period [Kato, 2002]. The superhump period shortens towards the end of the plateau. This is thought to be due to a 2:1 resonance with the disk [Osaki 2002]. Superhumps are also present after the plateau but have longer periods than the orbital period. This is caused by a 3:1 resonance.

   They have reoccurring rebrightening or ‘echo outburst’ events which vary in number with different WZ Sge stars. WZ Sge exhibited this in 1978 and in 2001, but was absent in 1946 [Patterson, etal, 2001]. It is not clear what causes these rebrightenings but may be due to significant material left on the disk after the main outburst and the viscosity of the disk close to a critical level between high and low viscosities [Kato, 2009]. An extreme case was SDSS J080434.20+510349.2 which had 11 rebrightenings in its first observed outburst in 2006. This star also exhibit non radial pulsations making it part of the GW Lib class of CV as well [Kato, 2009].
GW Lib Types

Lone white dwarfs with hydrogen rich atmospheres that lie in the ‘instability strip’ in the HR diagram (11,500 to 13,200 K) are observed to exhibit non radial pulsations which can be observed in the light curve of the white dwarf [Kepler & Nelan, 1993]. These stars are classed as ZZ Ceti stars. Pulsating stars vary in brightness as the star expands and contracts. The instability strip is a narrow range of temperatures depending on luminosity on the HR Diagram. If a star is in that region it will pulsate varying in brightness. Classical Cepheids, RR Lyrae stars, and d scuti stars are examples of stars in the instability strip.

Henrietta Leavitt discovered the period – luminosity relationship of Classical Cepheids showing that the absolute magnitude is proportional to the log of its period. Cepheids are used as a ‘yardstick’ for measuring distances to nearby galaxies. Understanding the mechanisms of pulsating stars is important as Classical Cepheids are used as a ‘rung in the ladder’ for other distance measures. Accurate distance measures to galaxies are important, as using this with the red shift puts constraints on the Hubble Constant determining the age of our Universe and the rate of expansion.

ZZ ceti stars exhibit non radial pulsations. Radial pulsation is where the star keeps its spherical shape but increases and decreases in radius. Non radial pulsations are variations in the shape of a star’s surface where some areas expand and others contract. These are p-mode oscillations. ZZ Ceti stars exhibit g-mode oscillations.
which are produced by gravitational forces acting on the interior, where it is the interior of the star that moves back and forth. The periods range from a few seconds to a couple of minutes [Uthas, 2012].

Non radial pulsations have been detected in the white dwarfs of some cataclysmic variable stars. Normally this would not be detected due to the competing light from the accretion disk. However in systems where the accretion rate is very low, the white dwarf is the main source of luminosity. The first recognised is GW Lib [Warner & van Zyl, 1998] with periods of 378.72 and 648.07 seconds. GW Lib was first observed as an outburst with a large amplitude and at the time was thought to be a nova. It was realised while observed in quiescence that it was a CV with a low accretion rate and would exhibit outbursts decades apart similar to the WZ Sge type CVs. Several others have now being found including BW Scl and are grouped into a class called GW Lib stars Uthas, 2012].

GW Lib stars have surface temperatures higher than their ZZ ceti counterparts and are not in the instability strip but are over a wider range from 10500 K to 15,000K [Szkody etal, 2010]. White dwarfs in CVs would be hotter than lone white dwarfs of the same age and mass due to the transfer of hot hydrogen from the accretion disk.

Not all low accreting CVs exhibit non radial pulsations. For example, the WZ Sge type CV, EG Cancri, is 12300K and is in the instability strip shows no variability as would be expected. It is not clear why this is the case [Szkody etal, 2010]. Also low accreting CVs just out of outburst do not exhibit pulsations. They take several years to cool sufficiently to move back into the instability strip [Szdody etal, 2010].

This has been noticed in some CVs particularly ones of very low accretion, for example GW Lib. These stars however do not lie in the instability strip. This is due to the accretion of material onto the white dwarf making them appear hotter and brighter than they would otherwise be.

3 U Gem stars, which include the remainder.

Recurrent Novae are like classical novae but have repeat eruptions. A shell of material is ejected.

Nova like variables includes all non eruptive CVs. It is probable that they are eruptive but have never been observed to do so. Most have emission line spectra

Magnetic CVs have their disks disrupted partially or totally by the magnetic field of the WD. There are 2 classes, Intermediate Polars and Polars. They will not be discussed and further here.
MECHANISMS INVOLVED WITH ACCRETION

Roche Lobe Geometry

When 2 stars in a binary orbit are considered point masses, there is a region of gravitational equipotential. That is a test particle will feel equal gravity from both stars in this region.

These regions about each of the stars are called a Roche Lobe. The size of the Roche lobe is determined by the masses of the two stars and their separation.

![Figure 5: Roche Lobe geometry in a binary star system (Dillon, 2008)]

There are 5 Lagrangian points where gravitational forces cancel out. If the secondary star fills this Roche Lobe, gas can then leave the star through the inner Lagrangian point (L1) and move to a lower gravitational point, i.e. the primary star.

This process occurs in the secondary star in CVs because of their thermal instability. Thermal instability results from previous mass loss which was fast enough that the star cannot adjust its radius to suit the lower mass quick enough. As a result the secondary star fills its Roche Lobe and gas leaves the inner Lagrangian point and is transferred to the white dwarf.

As the secondary star is in asynchronous orbit, the inner Lagrangian point is also in motion. The gas leaving this point has angular momentum because of this motion. A circular stream will result around the white dwarf primary star forming an accretion disk.

Accretion Disks

Accretion disks are one of the most common structures. All stars probably form from disk like structures, are found in CVs such as dwarf novae, X-ray binaries (XRBs) containing neutron stars and black holes, active galactic nuclei (AGN) such as quasars and blazars.

Dwarf novae are common and are found relatively close to us which allows astronomers to study the properties of accretion disks. They offer test grounds for theories which can be extended to the higher energetic systems of XRBs and AGN.

Systems with magnetic fields of $10^5$ to $10^8$ gauss prevent accretion disks from forming [Warner, 1995].
In non magnetic CVs material from the secondary star forms an accretion disk about the primary white dwarf star. Material gradually spirals in towards the white dwarf losing potential energy and angular momentum and radiating this as light. The disk contributes a large part of the light observed from a CV. The light is proportional to the product of the star masses and inversely proportional to their distance apart [Warner 1995].

\[ L = 0.5 \times G \frac{M_{\text{wd}}}{R_{\text{wd}}} \]

The rate at which mass migrates depends on the viscosity of the accretion disk.

In high viscosity disks the mass transfer is high and this produces the dominant source of light in the system. These CVs have orbital periods of 3 hour or more. They do not have major outbursts as they are essentially in outburst continually. These systems are known as Nova Like variables.

In low viscosity disks the mass transfer is low and produces less light, leaving the white dwarf as the dominant source of light. The mass transfer through the disk to the white dwarf is thought to be less than what is transferred from the secondary to the bright spot on the edge of the accretion disk. Mass builds up in these systems and the accretion disk changes from a low viscosity state to a high viscosity state where material is transferred rapidly to the white dwarf. This is an outburst. The system settles back down into a low viscosity state and the CV is said to be in quiescence. This process repeats periodically. These systems are the Dwarf Novae. Some CVs are borderline between viscosity states, and can change from one to the other. These are known as Z Cam CVs. This would indicate that the mass transfer rate from the secondary can be variable.

At the boundary layer, material is slowed down losing kinetic energy before it accretes onto the white dwarf. Here half of the luminosity of the system is generated here.

**Outbursts**

Outbursts are observed by a rapid increase of 3 to 5 magnitudes in brightness. This is due to an increase in temperature of the accretion disk to \( \sim 20,000\text{K} \) [Warner, 1995]. They may last a few days to a number of weeks. They are repetitive and repeat on intervals from weeks to decades. As mentioned above they are caused by an increase mass flow across the disc to the white dwarf when the viscosity of the accretion disk increases. They generally start from one location in the disk. There are the ‘inside out’ outbursts which start from the inner edge of the disk and spread out, and the outside in outbursts starting on the edge of the disk [Osaki 1996].

**Superoutbursts**

SU Uma stars are characterised by normal outbursts but also periodically have superoutbursts. Superoutbursts are brighter than normal outbursts and last longer. They are start as a normal outburst but are brighter and more stable as the disk reaches a 3:1 resonance with the secondary star [Whitehurst, 1988]. This can only occur with secondary stars of low mass where \( q < 0.33 \) as in SU Uma stars [Whitehurst, 1988]. Osaki [1989] proposed a model that during a normal outburst not all of the material is transferred to the white dwarf. The total angular momentum of the disk increases with the increase in mass and makes the disk spread out to a larger radius. This gets larger with each
successive normal outburst until a point is reached where the radius reaches a critical value at the 2:1 resonance with the secondary star. At this point the disk becomes tidally unstable and a superoutburst occurs. The disk is ellipsoidal due to tidal action from the secondary star and the outer disk precesses with the orbital period. This is observed as a superhump. Superhumps are only visible in superoutbursts, except for a few stars in quiescence (e.g. BW Scl [uthas, 2012]). They are unusual in that they have a slightly longer period (~ 2-3%) than the orbital period.

Patterson [2005] conducted a study on 200 dwarf Nova and found superhumps existed only in systems where the secondary star / white dwarf mass ratio (q) is less than 0.25 and none at all above 0.36. Systems between 0.36 and 0.25 had a gradual decline in the number that exhibited superhumps.

**EVOLUTION OF DWARF NOVAE**

The understanding of the evolution of CVs is still in its infancy. CVs are thought to have evolved from wider binaries (~50 solar radii, [Warner, 1985] of main sequence stars. As the more massive star evolves into a red giant it overflows its Roche Lobe and both stars share a common envelope of gas.

In turn the period of the binary and separation decrease due to friction. The common envelope expands to form a planetary nebula and eventually dissipates leaving a white dwarf primary and main sequence secondary in a detached state with no mass transfer from secondary to primary with an orbital period of a few hours.

The separation and orbital period of the binary star decrease further primarily due to magnetic braking. In this process the secondary star has an ionised stellar wind. The wind gets caught up in the star’s magnetic field and co rotates with the star before being flung off into space. Angular momentum is lost and this forces the star to rotate slower. As the stars in CVs orbit synchronised with the stars rotation, the distance between the stars must decrease [Verbunt & Zwann, 1981]. The orbital period decreases to 3 hours. The mass loss is in the order of $10^{-9}$ to $10^{-8}$ solar masses per year [Howell, 2001].

At a 3 hour orbital period, the secondary star changes from having a radiative core and a convective envelope to a star that is fully convective resulting in a loss of its magnetic field. The binary star becomes detached meaning that there is no mass transfer to the white dwarf primary star. The orbital period still shrinks due to gravitational radiation from the warping of space and the orbit will shrink to 2 hours. There are very CVs observed with periods between 2 and 3 hours, and this is known as ‘The Period Gap’ as illustrated in figure 6. With no bright accretion disk, these stars are faint and difficult to observe, hence the low numbers known.
With an orbital period of 2 hours, the diameter of the secondary is the Roche lobe boundary and mass is then transferred again to the white dwarf through the inner Lagrangian point, which further reduces the orbital period. These are the Dwarf Nova stars, U Gem type and SU Uma type. The mass transfer is slower and CVs spend most of their evolutionary time at this stage (~2.8 x 10^{10} years). Theory predicts that 99% of CVs should have orbital periods of less than 2 hours [Kolb, 1993].

The orbital period shrinks further until the secondary star loses so much mass that fusion in the core ceases (< 0.08 solar masses) and the star becomes degenerate like a white dwarf. The period of the CV is now down theoretically to 65 minutes. In reality no CVs have been observed at this period with the lowest at 82 minutes.

The orbital period now increases. These CVs are termed ‘period bouncers’. Population models predict that 70% of CVs should be at this stage [Kolb, 1993] however this is not observed. This is due to a selection affect as they are quite faint and are usually only noticed when they are in outburst, e.g. WZ Sge & GW Lib. BW Scl is another right at the minimum period.

Recent surveys like the Sloan Digital Sky Survey have uncovered many faint new CVs. Orbital periods have been determined and most are found near the period minimum but not the number predicted by theory.

One can see that by knowing the orbital period of a CV one can deduce what stage of evolution the CV is in.

Over time much material builds up on the surface of the white dwarf. The material becomes degenerate under the intense pressure and heat builds up. Eventually a thermonuclear runaway occurs and the system becomes a classical Nova ejecting a shell of material outwards. This should reoccur for all CVs and the rate of this would depend on the mass of the white dwarf. Most DN would have a Nova every few thousand years, but some can be in decades for the higher mass CVs. These are the Recurrent Novae. These higher mass systems are close to the Chandrasekhar limit of 1.4 solar masses, then these are candidates for type 1a supernovae.

**BW Scl**

BW Sculptoris (BW Scl) is a variable star listed as ‘nova like’ in The General Catalog of Variable Stars (GCVS). The AAVSO list BW Scl as a suspected WZ Sge cataclysmic variable star (UGWZ + ZZ).

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*Figure 6: Orbital periods of CVs [simostronomy web]*

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WZ Sge stars are a subclass of SU Uma stars. They have orbital periods near the minimum period and are faint due to their very low accretion rate. SU Uma stars have a series of normal outbursts followed by a superoutburst and repeating that pattern. WZ Sge stars have no normal outbursts but only superoutbursts and they reoccur over decades. The superoutbursts have large amplitudes in the order of 8 magnitudes.

ZZ refers to ZZ ceti stars which exhibit non-radial pulsations.

BW Scl has never been observed in outburst until October 2011.

DISCOVERY OF BW SCULPTORIS

BW Scl was first observed as a soft x-ray source (RX J2353.0-3852) in the ROSAT all-sky survey. The optical counterpart was observed in 1992 as with a V magnitude of 16.5 [Abbott, Fleming, Pasquini, 1997]. Periods of 87.4 minutes and 38 were observed however in 1994 no periods were observed. Spectra revealed broad double peaked Balmer lines indicative of an accretion disk at high inclination and very similar to the short period SU Uma type cataclysmic variable, WZ Sagitae. Abbott, Fleming, and Paquini [1997] concluded that BW Scl was a non magnetic cataclysmic variable with a low mass transfer rate or perhaps an intermediate polar CV with a long white dwarf spin rate.

BW Scl was independently discovered as a bright UV source, HE2350-3908, in the Hamburg / ESO Survey. Augusteijn & Wisotski, [1997], determined an orbital period of 78.226 minutes with radial velocity measurements. Photometry also showed periodicity at 78 minutes. At the time this is the shortest period CV known, again similar to that of WZ Sge type stars and indicative of a CV that is highly evolved.

A search was conducted to detect the red dwarf secondary star by infra red spectroscopy but none was found perhaps due to the red dwarf of being a very low mass due to its short orbital period and the accretion disk dominating the infra-red. [Mennickent, Diaz, & Tappert, 2004]

The Hubble Space telescope observed BW Scl in 2005 and found that the white dwarf was the main light source particularly in the UV consistent of what would be expected from a CV with a low accretion rate. The temperature determined was 14,800K +900K [Gansicke etal,2005]. This is hotter than expected for a lone white dwarf and this lends evidence that it is a CV as accretion of material onto the white dwarf has heated it up.

An accurate orbital period was determined from measuring radial velocities and is 78.22639 +/- 0.00003 minutes [Uthas, 2012]. Periods of 10 and 20 minutes were observed in photometric data and is thought to be due to non radial pulsations like observed in ZZ Ceti stars. It has double peaked emission lines indicative of an accretion disk. It also exhibits a quiescent superhump at 87 minutes and may arise from a 2:1 orbital resonance in the accretion disk. Other periods are tabled below.

<table>
<thead>
<tr>
<th>Frequency (cycles / day)</th>
<th>Period (min)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.50± 0.01</td>
<td>87.27</td>
<td>Quiescent superhump, slightly nonstable</td>
</tr>
<tr>
<td>18.40811 ± 0.03</td>
<td>78.23</td>
<td>Orbital period</td>
</tr>
<tr>
<td>32.98 ± 0.01</td>
<td>43.66</td>
<td>Harmonic of superhump</td>
</tr>
<tr>
<td>36.81622 ± 0.03</td>
<td>39.11</td>
<td>Harmonic of orbital period</td>
</tr>
<tr>
<td>50.5 ± 0.5</td>
<td>28.5</td>
<td>Period signal – weak</td>
</tr>
<tr>
<td>69.55 ± 0.03</td>
<td>20.7</td>
<td>Non radial pulsation (NRP)</td>
</tr>
<tr>
<td>103.55 ± 0.03</td>
<td>13.90</td>
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</tr>
</tbody>
</table>
The quiescent superhump is 11% greater than the orbital period. It was noticed to change from night to night and sometimes not there at all. The superhump is unusual in that they are normally seen at outburst and they are normally around 3% greater than the orbital period. However it has been observed in AI Com previously [Patterson 1996] which is another short period CV with a low q ratio. It maybe that in low q ratio systems the Roche Lobe is large and this has a tidal affect on the accretion disk causing it to precess [Patterson, 1996]. Uthas concludes that BW Scl is a GW Lib type star due to the non radial pulsations, low accretion rate.

**Superoutburst of BW Scl**

BW Scl was discovered bright on the 21st of October 2011 by Mike Linnolt at visual magnitude 9.6 and confirmed an hour later by A Plummer at visual magnitude 9.4 [AAVSO]. The previous observation was on the 13th of October 2011, 8 days previous by Josch Hambsch [AAVSO]. The AAVSO issued a ‘special notice’ immediately to take time series observations to determine the nature of BW Scl considering the conflicting identification and being its first observed outburst.

The peak brightness was recorded at V magnitude 8.9 on the same day by Peter Starr [AAVSO]. If the two initial visual magnitudes observed by Linnolt and Plummer are accurate, the outburst was observed on the rise. Both observers are very experienced and respected. The time series data I collected on that night averaged flat to a slight increase in brightness (taking out the orbital cycles). Observations continued later that day by several observers on the other side of the world showing a decline in brightness. This would indicate the superoutburst started either late on the 20th or early 21st October UT.

Fourteen observers around the world took 29,789 filtered differential CCD photometric observations and submitted them to the AAVSO for 2 months after the discovery. Josch Hambsch of Belgium and me contributed 95% of the observations. Observations by Hambsch were taken from an observatory in South America [Hambsch, private communication 29/4/12], and my own in Australia resulting in a wider spread of observations.

**ANALYSIS OF SUPEROUTBURST DATA**

Photometric Data for BW Scl was downloaded from the AAVSO website as a text file containing the Julian date, magnitude, error, filter used, if the data was transformed, standard star name and magnitude, and comparison star and magnitude, air mass, and reference star chart. The same was downloaded for WZ Sge and GW Lib. The text file was converted to a Microsoft Excel file in order to show time series graphs and perform calculations.

All data that is submitted to the AAVSO must include reference stars used with their assigned magnitude as well as instrumental magnitudes of a check star in order to calculate errors. Data that is of a high error is not accepted. However this data will have biases with different observers using different equipment and observing from different sites.
For example, comparing the results of Hambsch and my own have a difference in 0.1 magnitudes. On private communication with Hambsch [29/4/2012] the difference is primarily due to the brand of filter. I use custom scientific filters and Hambsch uses Baader. Another observer at the same site as Hambsch uses Custom Scientific filters and has the same difference in results. One of the observer’s data was not considered as the errors were consistently too large and was contaminating amplitude results.

The date stamping for each observation could also be in error depending on how each observer’s computer determined the time and how often they update it. On private communication with Hambsch [29/4/2012] who provided the majority of the observations, his observations were calibrated using Dimension 4 [ThinkingMan] as was my data. This software synchronises the time of Windows based operating systems with time servers around the world and timing should be accurate within a few milliseconds. Analysis of data where timing is important such as determining frequencies was performed on Hambsch’s data and my own.

Fourier analysis was used to determine periodicities in the downloaded time series data. Any signal that varies with time such as time series photometric series can be represented by a series of sines and cosines (Fourier series) of varying frequencies. Each sinusoid derived has a specific amplitude and phase. This is applied to time series photometric data by multiplying each point in the time series by

\[ F(\nu) = \int f(t)e^{i2\pi \nu t} dt \]

\( f(t) \) is data in the time domain

\( F(\nu) \) is data in the frequency domain

\( \nu \) is the frequency

\( dt \) is the time interval between data points

for a specific frequency. The results for all points in the time series are summed and this gives on point in the power spectrum. This is repeated for all frequencies and a power spectrum results. The power spectrum can be depicted on a graph as frequency versus amplitude^2.

The power spectrum will show a number of peaks corresponding to the frequency of each sine wave needed to form the photometric lightcurve. The analysis will show periodicities in the data. Frequency is converted back to time and time period for each repeating pattern can be determined.

The range of meaningful frequencies that can be determined depends on the sampling rate, i.e. the time between each CCD exposure. The sampling frequency must be more than twice the maximum frequency. The maximum frequency is known as the Nyquist frequency and twice this number is the Nyquist sampling rate. If the sampling rate is too low (less than the period being determined), incorrect frequencies will be determined. These are called ‘aliases’. It is ideal to have sampling points evenly spaced and to cover many periods. Data taken from consecutive nights can also cause aliasing as the sampling is not evenly spaced.

A computer program called Period 04 was used to analyse the data [Lend & Breger]. Data in the form of Julian date and corresponding magnitude is imported as a text file. A Fourier analysis is performed on the data. The program recommends a Nyquist frequency to use. A figure just below that number

14
is selected. The program calculates the main frequency and generates a graph of frequencies versus amplitude. Further analysis is performed on the residuals to find further frequencies in the data. The program performs a least squares calculation and calculates uncertainties.

Figure 7 shows the superoutburst lightcurve for BW Scl, GW Lib, and WZ Sge. All data is with a Johnson V filter. The thickness of the curve is caused by orbital variations with BW Scl plus a spread in results due to different observers.
Figure 7: Superoutburst light curves of a) BW Scl 2011 [AAVSO], B) GW Lib 2007 [AAVSO], C) WZ Sge 2001 [Patterson, 2002]

The light curves can be divided into 4 sections, the rise to outburst, the first decline known as ‘the plateau’, a rapid dip in brightness, and a slow decline to quiescence. Parameters of the light curves are summarised in table 2.

<table>
<thead>
<tr>
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<th>BW Scl</th>
<th>GW Lib</th>
<th>WZ Sge</th>
</tr>
</thead>
<tbody>
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<td>Date of Outburst (JD)</td>
<td>2455855.81458*</td>
<td>2454203.097**</td>
<td>2452114.344***</td>
</tr>
<tr>
<td>Years since previous outburst</td>
<td>Unknown</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Outburst amplitude (V magnitudes)</td>
<td>8</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Plateau length (days)</td>
<td>21****</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Plateau amplitude (V magnitudes)</td>
<td>2.5****</td>
<td>3.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Plateau average decline rate (magnitudes/day)</td>
<td>0.13</td>
<td>0.13</td>
<td>0.10</td>
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<tr>
<td>Sharp decline at the end of the plateau (V magnitudes)</td>
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<td>3.4</td>
<td>2.3</td>
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<tr>
<td>Rebrightenings (echoes)</td>
<td>0</td>
<td>0</td>
<td>Multiple</td>
</tr>
</tbody>
</table>

Table 2: Lightcurve parameters for BW Scl, WZ Sge, GW Lib

* AAVSO Alert Notice 449 [AAVSO]

** AAVSO Alert notice 349 [AAVSO]

*** AAVSO Alert Notice 286 [AAVSO]

**** Date of outburst not observed so plateau length and amplitude is a minimum value.

**Rise to Outburst**

GW Lib and WZ Sge show a very rapid rise into outburst. This was not captured with BW Scl but this is expected to be the case as this is observed in all SU Uma star outbursts. All three stars have show a rise of 7 to 8 magnitudes and are typical of all WZ Sge type dwarf novae. Each rise to outburst has been consistent for WZ Sge with 7.0 photographic in 1908, 8.0 in 1946, 8.1 in 1978, and 8.1 in 2001 [AAVSO alert 286].

**Plateau**

BW Scl then has a gradual decline at 0.13 V magnitudes per day for 21 days and is similar in the light curves for GW Lib and WZ Sge. This region of the lightcurve is called a ‘plateau’ and is typical of all
WZ Sge type dwarf novae. All three light curves reveal a thickening of the curve. This is due to the onset of ‘common superhumps’ in all three cases. This is also typical also of WZ Sge type dwarf novae.

Figure 8 illustrates the lightcurve I captured on the first night the outburst was reported. The lightcurve is very complicated and shows several repeating features of peaks, troughs and standstills. Over successive days many of these features disappear and new ones appear. It’s not clear what the cause of each feature is but they are likely to be caused by the accretion disk as most of the light in an outburst comes from the accretion disk [Warner, 1995]. As the system rotates different light sources come into view or maybe eclipsed.

The superhump observed here in BW Scl (K) early in the outburst has an amplitude of 0.25 V magnitudes. These are called an ‘early superhump’ [Kato, 1996] or an outburst superhump [Patterson, etal 2002].

WZ Sge also shows a complicated lightcurve but is observed on day 3 though day one data is a bit sparse so hard to tell. It exhibits a double peak in the superhump and has an amplitude of 0.5 V magnitudes. The difference in amplitude maybe that WZ Sge is at a higher inclination (75° [Osaki & Meyer, 2001] than BW Scl.

GW Lib does not exhibit this at all or is at a very low amplitude (see appendix A). This is perhaps due to that GW Lib has lower inclination (11.2° [Spaandonk, 2010]) than BW Scl and WZ Sge and so orbital characteristics do not make themselves apparent.

Kato [1996] explains the early superhumps as a premature form of the common superhumps that appear later in the plateau. Osaki and Meyer [2001] disagree as the early superhumps in WZ Sge repeat along with the primary secondary orbital period. Kato’s early superhumps would have a different period slightly longer than the orbital period as observed with common superhumps.
My data on BW Scl clearly shows the early superhumps in BW Scl are precessing supporting Kato’s view (see figure 9). A Fourier transform was performed using Period 04 for all my data in the first day of outburst which covered 2.5 orbital periods. A frequency of 17.8294574 ± 0.000837 cycles per day was determined. This equates to 80.80 ± 0.35 minutes for the superhump period compared to the binary orbital period of 78.22 [Uthas, 2012]. This is different to WZ Sge where its early superhumps are in phase with the orbital period of the binary.

Osaki and Meyer [2001] explain these early superhumps in WZ Sge stars due a 2:1 tidal resonance of the accretion disk which causes the accretion disk to become truncated. When the outburst occurs, the accretion disk spreads out to a larger radius where the 2:1 tidal resonance occurs. Two tidal spiral arms form out of phase by 0.5. As the accretion disk is not totally edge on one tidal arm will be more prominent than the other with one arm causing the superhump and the other the smaller hump visible in WZ Sge (see appendix 2 for WZ Sge lightcurve for day 3). In the Fourier analysis above there is a second frequency at 36.76 cycles per day that has a period half of that of the superhump frequency. This second frequency can be explained by Osaki and Meyer’s model.

Patterson [1996] however proposes that outburst superhumps are due to an increase in mass flow from the secondary star causing a super hot spot on the edge of the accretion disk similar to a normal hot spot observed in quiescence in high inclination Su Uma stars like Z Cha and U Gem. This model is unlikely as there is no mechanism proposed why an increased mass flow would occur and due to its position on the edge of the accretion disk compared to the position of the donor secondary star (60° [Osaki and Meyer, 2001]. The second frequency at 0.5 phases from the main frequency maybe due to the super hot spot on the opposite side of the disk. It is not as strong being on the other side of the disk. In the days after outburst the superhump diminishes and the second frequency is stronger perhaps meaning the disk is becoming less viscous and more transparent enabling the super bright spot to be seen more clearly on the opposite side of the disk.

Superhumps typically have a sharp rise and a slower decline. The slow decline is observed but the sharp rise is obscured by the contamination of another light source that contributes two peaks (G & I) and makes the main superhump appear as a triple hump. Perhaps the light source on the edge of the accretion disk is made up of multiple hot spots or caused by several tidal disturbances in the accretion disk.

The large minima maybe due to the accretion disk being partly obscured by the relatively larger secondary red dwarf star and also due to the truncated shape of the accretion disk resulting in less of the accretion disk visible.

One unusual feature is ‘B’. There is a standstill and a very sharp drop in brightness which is very short and another standstill. This may be due to something very bright and compact like the white dwarf or the hot boundary layer around the white dwarf. This is seen in eclipsing SU Uma stars such as Z cha and OY Car which I have observed myself previously. The white dwarf could be eclipsing behind the accretion disk. The periods are variable which would occur as the outer part of the accretion disk is elliptical and probably varies in size over time. It is most noticeable in the 2nd orbit, with a magnitude drop of 0.6 V magnitudes in 1.25 minutes. It is 0.3 phases ahead of the early superhump maximum. In WZ Sge the early superhump is 0.3 phases behind the white dwarf eclipse. The feature is not observed in subsequent days as the disk cools and reduces in size.

A phase diagram of this first lightcurve is depicted below in figure 9. The phase being the orbital period of the primary / secondary of 78.22639 minutes derived from radial velocity measurements [Uthas, 2012].
Figure 9: First 2 orbital periods of BW Scl at the start of the recorded outburst

Figure 10: Frequency plot from Period 04 of the first 2.5 orbits of BW Scl after outburst. Arrow points at main frequency of 17.8294574 cycles per day and the second at 36.0465 cycles per day.

Data observed at the end of day 1 produced a superhump period of $77.45 \pm 0.24$ minutes. The superhump period appears to be variable. Variability for the outburst is illustrated in figure 11 and a table in appendix 3.

An analysis was done on each day’s data and the daily average superhump period determined. The results are tabled in appendix 3 and graphically represented in figure 11. The main frequencies were averaged at 18.23 cycles per day and 36.69 cycles per day for the entire outburst. This corresponds to periods of 79.12 minutes and 39.26 minutes compared to the orbital period of 78.22 minutes. 79.12 minutes is the average period of the superhump. This is typical of WZ Sge type dwarf novae where the superhump period is slightly longer than the orbital period.

The superhump signal was not always the strongest signal. During each day in the plateau up to day 10 the amplitude of this signal decreased and was surpassed by the signal 39.26 minutes. This occurred again after the common superhumps appeared.
Other frequencies were observed but were not present every day including periods at 26, 54, and 72 minutes which were more common and generally when the amplitude for the superhump was weak. Appendix 5 shows several frequency charts determined from Period 04 at critical stages in the outburst.

Using Patterson’s theory [1996] of the super hotspot, this is likely due to the bright spot on the disk causing the superhump shining back through the accretion disk. As the system is not edge on this signal is almost always seen. It appears to get stronger when the amplitude of the superhumps decrease and may mean that the disk is becoming less viscous and more transparent enabling the signal to be stronger. Using Osaki and Meyer’s theory [2001] of two tidal arms causing the early superhumps, the second frequency is due to a second tidal arm in the accretion disk 0.5 out of phase.

![BW Scl Daily Superhump Period](image)

On subsequent days after the initial outburst, the amplitude of the lightcurve and the early superhumps diminishes in size and the second frequency of 36 cycles per day (superhump harmonic) becomes stronger than the superhump frequency of 18 cycles per day. This is shown in the frequency diagrams in appendix 5.

This is caused by the tidal arms in the accretion disk removing angular momentum from the accretion disk and over time reduces the size of the accretion disk. Appendices 1 and 2 show this for the 3 stars where the curve is much flatter at day 10 than at day 1. Figure 12 shows how amplitude has changed over the entire outburst to quiescence and shows a gradual decline in amplitude from day 1 to day 10.

Figure 12 shows at day 11 after the outburst there is a sharp increase in amplitude for BW Scl. This is observed in WZ Sge and GW Lib and can be seen in their light curves in appendices 1 & 2. All three dwarf novae are now exhibiting strong common superhumps. This is common with all WZ Sge type stars. The reduction in the size of the accretion disk reaches a critical point where a 3:1 resonance occurs. The disk is truncated and common superhumps appear. These superhumps are a different shape than the early superhumps with a sharp rise and a slower decline. There are not as many other dips and troughs as seen in the first few days of outburst but as time progresses other periodicities become visible and the amplitude of the superhumps decreases. Appendix 5 shows the frequency charts before and after the onset of the common superhumps. On day 17 the superhumps
split which is also observed in WZ Sge at the same time (appendix 2). No data was available for GW lib on that day.

The arrival of the common superhumps coincided with an observed change in superhump period for BW Scl which increased to a period of 82 minutes (figure 11). Over time these superhumps reduce in size and figure 11 shows the superhump period trending to decrease. It is interesting to note that the common superhumps are strong in all 3 dwarf novae as it is with all WZ Sge stars and this is regardless of the orbital inclination of the system. This was not the case at all with the early superhumps.

Appendix 2 shows the common superhumps in WZ Sge are much higher in amplitude than BW Scl and GW Lib (Appendix 1) which are very similar. Perhaps orbital inclination is producing this effect but does not explain why BW Scl and GW lib are similar.

Appendix 4 shows charts of relative brightness versus time for the entire outburst and for the plateau of each of the three stars.

The plateau for BW Scl shows an exponential decline that is interrupted three times with a small jump in brightness at 8, 11, and 15 days after the initial outburst. Day 11 coincides with the formation of the common superhumps and a large change in amplitude.

The plateau for WZ Sge had a very linear decline in brightness for the first 14 days dropping in brightness 0.3 times per day.

The plateau for GW Lib shows a slight exponential decline from outburst to day 2, then a shift to a linear decline from day 4 to day 7, then a more pronounce exponential decline to day 23.

**The Dip**

The plateau is followed by a sharp decline in brightness by 2.5 magnitudes in under 3 days. Again this is typical of WZ Sge types. There was no change in the trend of the superhumps other than they were diminishing in size and on a downward slope.

The dip is a transition from outburst to quiescence. The sudden drop in brightness is due to the disk shrinking, cooling and changing from a viscous to a non-viscous state.

**Post Dip**

After the dip, BW Scl slowly fades to quiescence. This is observed as well in GW Lib but not so in WZ Sge. The 2001 outburst of WZ Sge has a number of rebrightenings, also called ‘echo outbursts’. This also occurred in the 1978 superoutburst and is a typical feature of WZ Sge types where the number of echoes is wide and varied. No rebrightenings were observed in the 1948 superoutburst however and we will have to wait for further superoutbursts in the decades to come to see if both BW Scl and GW Lib exhibit rebrightenings.

Appendix 4 illustrates the different rate of decline in brightness as the stars fade into quiescence. BW Scl and GW Lib have a slow decline with a positive shaped curve, whereas WZ Sge has a faster decline with a negative shaped curve. This is a fundamental difference but it is not clear why this occurs.
The amplitude changes for BW Scl were calculated for each day after normalising all of the data and centreing on zero. This is depicted in figure 8 with the lightcurve of BW Scl overlayed. It can be seen that the amplitude reduces right from the start of the outburst. On day 11 the amplitude increases and this coincides with an offset in the lightcurve which is one of the three mentioned above. This offset is also observed in GW Lib and WZ Sge with an increase in amplitude and the onset of strong superhumps.

The amplitude more than doubles after the dip and becomes more erratic with it getting larger and smaller. These are the superhumps returning but they are much larger that the early and common superhumps. These are termed ‘late superhumps’. It is interesting to note but maybe coincidental that this fluctuation appears in the same portion of the lightcurve as the rebrightenings observed in WZ Sge and many others like EG Cancri. There is no rebrightening in BW Scl though and maybe that’s because the brightness is dropping much faster than WZ Sge does after the dip.

![BW Scl, Amplitude Changes](image)

Figure 12: Normalised data illustrating the changes in amplitude of BW Scl over time after the outburst.

Appendix 5 shows the frequency charts for quiescence. The superhump signals are strong but their period varies. Other frequencies present themselves, in particular one at 53, 66, and 83 cycles per day. With the white dwarf becoming the more dominant source of light, periodicities maybe the result of the white dwarf. The frequencies observed do not match the non-radial pulsations observed listed in table 1, and nor is the very late superhump at 87 minutes. The white dwarf will still be very hot and possibly years before this settles down and perhaps non radial pulsations will not be seen at a later stage.

I took some more photometric observations in 3 nights in May 2012 of BW Scl as it comes back to our skies. The star is very faint at magnitude 16. It is revealing a double humped lightcurve. Fourier analysis (see appendix 5) reveals a period of 89.9 minutes and it appears to be this superhump at 87 minutes that Uthas etal, [2012] reported. Also there is a signal at 22 minutes. This might be the non-
radial pulsation that Uthas et al. reported. There are other frequencies as well but further monitoring this season will give more clues of their repeatability.

Figure 13: Amplitude changes of BW Scl during the superoutburst.

CONCLUSION

I report the light curves of the BW Scl superoutburst of October 2011 and comparison with WZ Sge type dwarf novae WZ Sge and GW Lib.

BW Scl behaves like a typical WZ Sge type dwarf nova with a rapid rise in brightness of 8 magnitudes, a 21 day long plateau where early superhumps are visible due a 2:1 resonance of the accretion disk early in the plateau which diminish before common superhumps are revealed once the accretion disk shrinks to a 3:1 resonance. The superhumps have shallower amplitude than those of WZ Sge but significantly more than GW Lib. This can be explained by the different inclinations of each system. There is a sharp dip in brightness typical of WZ Sge type dwarf nova followed by a long fading into quiescence where large amplitude late superhumps begin.

The lightcurve of BW Scl immediately after outburst is very complex with many repeating patterns and is difficult to determine what the cause of each feature is. This was observed and reported with the 2001 outburst of WZ Sge as well. There is a hint of the primary white dwarf star being eclipsed in three successive orbits by the accretion disk due its very sharp decline, though this is not certain. The presence of early superhumps is clear.

The superhumps (early, common, and late) are out of phase with the orbital period which was found to vary from 77.3 minutes to 85.3 minutes where they became double humped. The average superhump period was 79.12 minutes which is 1.15% longer than the orbital period and results in the superhump precessing at an average rate of 4.77 days with the orbital period. This is typical of WZ Sge type dwarf novae, however WZ Sge itself has early superhumps that are equal to its own orbital period which is definitely not the case with BW Scl.
BW Scl differs from WZ Sge in that no rebrightenings occur after the dip as observed in many WZ Sge type dwarf novae. However none were observed in the 1946 superoutburst of WZ Sge and no rebrightenings were observed in the GW Lib 2007 superoutburst. This characteristic may not be a certain prerequisite for a WZ Sge type dwarf nova and it is not clear of the mechanism of why rebrightenings occur. BW Scl also differs like GW Lib also does in the rate of decline to quiescence. BW Scl and GW Lib have a very slow fading where as WZ Sge has a decline curve of opposite shape having a fast rate in decline.

No periods were found in the decline to quiescence that matches the non-radial pulsations reported by Uthas in 2012. This is not surprising as the white dwarf would be extremely hot with the accretion of material from the superoutburst. Recent observations however 200 days after the outburst do show a period very close to that reported by Uthas as well as a very late quiescent superhump.

I conclude that BW Scl is a WZ Sge type dwarf nova as well as part of the GW Lib class of stars. I reject the classification in the General catalogue of Variable Stars of a Nova like variable.

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simostronomy web, accessed 12 may 2012,


Thinkman, www.thinkman.com


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<td>2455883.4</td>
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<td></td>
<td>2455883.5</td>
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<td></td>
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<td></td>
<td>2455883.7</td>
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<td></td>
<td>2455883.8</td>
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V mag

- 14.05
- 14.25
- 14.45
- 14.65
APPENDIX 2

BW Scl Day 1

V mag

WZ Sge Day 1

V magnitude

BW Scl Day 10

V mag

WZ Sge Day 3

V magnitude

WZ Sge Day 11

V magnitude
BW Scl  Day 28  

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APPENDIX 3:

Table of results from fourier analysis with Period 04 of photometric data from each day of Hambsch’s observations.

Frequency 1 has the highest amplitude except for the frequency 2 values in red where they are the strongest frequency. Errors are calculated from the Period 04 software.

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<th>Day after Outburst</th>
<th>JD</th>
<th>Frequency 1</th>
<th>Period</th>
<th>Error</th>
<th>Percent difference to orbital period (78.22 mins)</th>
<th>Frequency 2</th>
<th>Period</th>
<th>Error</th>
<th>Percent of orbital period</th>
<th>Percent of Superhump period</th>
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<tr>
<td></td>
<td></td>
<td>Cycles per day</td>
<td>Mins</td>
<td>± mins</td>
<td>Cycles per day</td>
<td>Mins</td>
<td>± mins</td>
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<td>37.07865</td>
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<td>50.6%</td>
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**Average**

|   | 18.23 | 79.12 | 1.15% | 36.69 | 39.26 | 50% | 50% |
BW Scl Plateau

Days after outburst

Brightness decrease compared to Day 1

\[ y = 0.9454e^{0.1011x} \]

\[ y = 1.4769e^{0.1097x} \]

\[ y = 1.0743e^{0.1216x} \]

GW Lib Outburst 2007, Plateau

Days after outburst

Relative Brightness

\[ y = 0.9417e^{0.4192x} \]

\[ y = 0.5516x + 0.4321 \]

\[ y = 2.1351e^{0.0907x} \]

WZ Sge 2001 Outburst Plateau

Days after outburst

Relative Brightness

\[ y = 0.2606x + 0.6607 \]

\[ y = 0.7185x - 7.1109 \]

\[ y = 0.2314x^2 - 9.3079x + 100.92 \]
Appendix 5

Frequency charts from Period 04 at different stages of the outburst. All are using Hambsch’s data except the last two which is Peter Starr’s. Apologies for the clarity but is a limitation to the software.

Initial outburst days 1 to 3.

The early superhumps are strong at this stage and that is seen at the strong frequency of 18.4347826 cycles per day (78.1 minutes) at amplitude 0.0404556271. The second signal is at 36.826087 cycles per day (39.1 minutes) at amplitude 0.0267926332.

Days 5 to 9. This is where the early superhumps have decrease greatly in amplitude. Above you can see the superhump signal much less prominent at 36.826087 cycles per day (39.1 minutes) with an amplitude of 0.0211351308.

The stronger signal is now at 18.4395501 cycles per day (78.1 minutes) with an amplitude of 0.0211351308. The broader patterns are due to the superhump period changing from cycle to cycle.
Days 11 to 15 represent the emergence of strong common superhumps. The superhump period varied as before but the strongest signal was at 18.1967213 cycles per day (79.1 minutes) with an amplitude of 0.0778064004.

The second signal was at 17.9859485 (80.1 minutes) which is really the same superhump.

The third signal is 36.4051522 cycles per day (39.6 minutes) with an amplitude of 0.0166657648.

Days 16 to 21. This is the end of the Plateau before the dip. The superhumps are diminishing in size but still strong and appears as the stronger signal at 18.1669011 cycles per day (79.3 minutes), amplitude 0.0377375869. The superhump period is moving around from cycle to cycle creating several frequencies.

2\textsuperscript{nd} signal is at 36.310361 cycles per day (39.7 minutes), amplitude 0.0191894277Another signal though week comes into play and appears on different days from this point on and has a frequency of 54.899203 cycles per day (26.2 minutes), amplitude 0.0061369043
Days 23 to 28.

This is after the completion of the sharp dip and fading into quiescence and the onset of the late superhumps which have the highest amplitude. The frequency chart here also shows the superhump period changing but is strongest at a frequency of 18.1146859 (79.5 minutes) and amplitude of 0.0813330715.

The second frequency was close to 18 being the superhump again.

The 3rd frequency is 36.8097617 (39.1 minutes) of amplitude 0.038125089

The frequency of 54.7279639 (26.3 minutes) is seen again here with an amplitude of 0.0149997437

Other frequencies are starting to appear now as the dwarf novae fades.

Days 41 to 45 using Peter Starr’s data.
Well into the quiescence now with the superhump signal still strong and varying at 17.2865999 and amplitude 0.0775726056.

The second signal is at frequency 36.695279, amplitude 0.0502375993.

The frequency at 53.1235098 (27.1 minutes) is there as well as 83.237959 (17.3 minutes), 43.2522651 (33.3 minutes), 66.5951359 (21.6 minutes), 96.8764902 (14.9 minutes).

Day 207 and 208

Observations I recently did, so in quiescent mode now.

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<td>33.74175</td>
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Appendix 6

BW Scl Observations contributed by:

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<th>BHQ BOHLSEN, TERRENCE</th>
<th>AUSTRALIA, VSS</th>
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