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Cataclysmic Variables from SDSS: A Review and A Look Forward to LSST

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Abstract

The past and current projects of the Sloan Digital Sky Survey are reviewed in the context of applicability and results for cataclysmic variables. Ongoing and future time domain surveys that will have impact on the field are also briefly discussed.

Keywords: cataclysmic variables - dwarf novae - intermediate polars - polars - optical - photometry - spectroscopy.

1 Introduction

Cataclysmic variables (CVs) have been discovered in a variety of ways, with the largest numbers of new systems coming from survey work. The mode of operation and the limiting magnitude of each survey determines the different types of CVs that are discovered. The Palomar-Green survey (Green et al. 1986) used blue color to find objects that were brighter than 16th magnitude, hence it found many bright novalike systems. X-ray surveys such as ROSAT (Voges et al. 1999) identified those systems with high X-ray flux, hence many polars and intermediate polars were found. The Hamburg Survey (Hagen et al. 1995) searched for emission line objects down to about 18th magntitude, finding SW Sex stars, intermediate polars and long period dwarf novae. The Sloan Digital Sky Survey (SDSS) used both photometry (to 22nd magnitude) and spectroscopy (to 19th magnitude) to identify all types of CVs, especially those with low accretion rates and orbital periods below the gap (Szkody et al. 2011). Current and future surveys are concentrating on variability as a means of identification and as a result are turning up many dwarf novae. The combination of all of these results will ultimately end in a better understanding of the total space density of all types of CVs.

2 SDSS

The SDSS project (York et al. 2000) began taking data in 2000 and has continued to the present time, undergoing changing modes of operation and target selection. The past results on CVs from this survey, as well as current and future plans are summarized below.

2.1 SDSS I,II legacy survey

SDSS I started with a goal to photometrically survey the entire north galactic cap, as well as obtain spectra of a selected subset of objects within what is termed the Legacy Survey. In addition to the north cap, a 2.5 degree wide stripe centered on the celestial equator (Stripe 82) was also included (see Figure 1). The initial plan for completion in 5 years was extended (SDSS II) in order to finish the original footprint so the Legacy encompassed the years 2000-2008 and the final entire database was released as Data Release 7 (DR7; www.sdss.org/dr7/). This database includes imaging data of 230 million objects, using 54 second integrations in 5 filters (ugriz). Based on the colors obtained, targets (primarily quasars and galaxies) were selected by a variety of groups, within restrictions of fiber spacing, brightness limits, etc. for 1 hour integration spectra with wavelength coverage from 3800-9200Å at a resolution of about 2000. Plug plates were than drilled and threaded to accomodate 640 fibers resulting in 1.37 million spectra in DR7, including 225 thousand stars.

Since the sources receiving spectra were determined by color, and CVs have a broad range of colors (Szkody et al. 2003), the main source of CV spectra turned out to be objects taken from quasar loci, which span a broad range of colors outside the main sequence footprint. The resulting computer and eye searches of all the Legacy spectra for Balmer lines turned up 285 CVs which included 30 Polars, 6 IPs and 9 systems containing pulsating white dwars. A list of these sources can be found in Szkody et al. (2011) as well as on the web with links to the spectra (http://www.astro.washington.edu/users/szkody/cvs/). From 2000-2011 extensive followup on more than 300 nights was conducted on this list by many observers using APO, La Palma, USNO, Steward, MDM, MMT observatories. As a result of this work, 151 orbital periods were determined that allowed specific classification of these objects and how they fit into population models. Gänsicke et al. (2009) used 126 of the periods known at that time to reach major conclusions that enforced the magnetic braking model and confirmed the population synthesis predictions of Howell et al. (2001): i.e. the majority of the disk accreting systems exist below the period gap and a period spike appears at the minimum period. The SDSS results showed that the discrepancies in the past were primarily due to selection effects that favored the discovery of bright, long period systems, while SDSS was able to uncover the larger population of faint sources. However, the percentages under the gap are slightly less and the period spike occurs at a slightly longer period than predicted so adjustments to the angular momentum losses are needed (Knigge 2011).

The fainter magntitude limit reached by SDSS also revealed large numbers of accreting pulsators and Low Accretion Rate Polars (LARPs). Of the 16 known accreting pulsators, 9 were found in the Legacy survey. All of these showed broad Balmer absorption lines surrounding the emission, providing a clear optical signature of the white dwarf. Followup optical and UV results on the set of accreting pulsators has led to three major results. The first is that the instability strip is much wider than H atmosphere pulsating white dwarfs (ZZ Ceti) (Szkody et al. 2010). Arras et al. (2006) attribute this to the existence of a He instability strip as well as hydrogen. Because many of the accreting white dwarfs in this wide instability strip are observed not to pulsate, followup long term observations were conducted. This led to the second result that objects can stop pulsating, usually after an outburst, but sometimes when no outburst has occurred! e.g. SDSS0745+45 (EQ Lyn, Mukadam et al. 2013). Third, in followup observations with HST, it was discovered that the pulsation that was present after outburst in V455 And appeared in the emission lines, not the continuum, presenting problems for a physical mechanism (Szkody et al. 2013).

Of the 9 known LARPs, 7 were found in SDSS. These objects have prominent humps due to cyclotron harmonics at high fields and low optical depth (Wickramasinghe & Ferrario 2000). Finding LARPs in SDSS data is not easy as the dependence of the harmonics on field strength moves them into different regions of color space. Schmidt et al. (2005) calculated the SDSS color ranges for various fields but there has as yet been no systematic search to find all the candidates. They estimate these could be a major contribution to the magnetic white dwarf population.

Several groups are using the SDSS database to further understand the properties of the known CVs and to find further ones. A large HST program led by Boris Gänsicke is obtaining UV spectra of 40 CVs (including 12 discovered by SDSS) to characterize the temperature of the white dwarf and the mass accretion rates over a variety of orbital periods and compositions. When combined with Gaia distances, the masses of these white dwarfs will also be determined, leading to improved understanding of the evolution of close binaries. Carter et al. (2013) discovered 29 new CVs in doing spectroscopic followup of AM CVn candidates selected by color in the photometric database. Breedt and Gänsicke (2011) are obtaining spectra of the faintest CVs in SDSS that are being discovered by CRTS (see section below).

2.2 SDSS II: SEGUE and SN

Besides the Legacy extension, SDSS II (2005-2008) contained the Sloan Extension for Galactic Understanding and Exploration (SEGUE) and a supernova survey. These results are contained in DR8.

The main goal of SEGUE was to explore the Milky Way, including its structure, history, kinematics, evolution and dark matter by mapping the positions, velocities, composition and temperatures of 240,000 stars (see Figure 1 for the coverage compared to Legacy). While this survey mainly targetted white dwarfs and giants, several CVs were included as their colors matched those of white dwarfs.

The SN survey involved repeated imaging of the same region of the sky (Stripe 82) during 3 months of each year. The repeat imaging over 275 deg^2 with about 20 measurements on each object identified hundreds of new transient sources (Sako et al. 2008). While the main goal was identifying SN, other types of variable stars were also found. The analysis of all the light curves of variable objects is ongoing and may include some CVs. A catalog of 13,051 variable sources brighter than g=20.5 from 1998-2007 Stripe 82 data is in Sesar et al. (2007). Bhatti et al. (2010) provide a catalog of light curves for 221,842 point sources for half of the entire Stripe 82 data.

2.3 SDSS III: SEGUE-2, BOSS, APOGEE and MARVELS

SDSS III (2008-2014) continues the SEGUE project and adds 3 new enterprises. SEGUE-2 obtained spectra of 119,000 stars with a concentration on the stellar halo with distances of 10-60 kpc. These data appeared in DR8 while DR9 updated the stellar parameters and added catalogs. The Baryon Oscillation Spectroscopic Survey (BOSS) updated the SDSS fibers to 1000 and is producing spectra of many galaxies and quasars. While the target selection is not as optimal as it was in the

Legacy survey, there are a few CVs which emerge in the spectra. DR9 was the first public release of BOSS spectra, while DR10 contains the latest data. The APO Galactic Evlution Experiment (APOGEE) uses IR spectra to observe red giants throughout the Galaxy. The first data appear in DR10. Finally, the Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS) is monitoring the radial velocities of 11,000 bright stars to look for planets.

2.4 SDSS IV: the future

Plans are underway to extend SDSS from 2014-2020 with a continuation that involves APOGEE-2, eBOSS and MaNGA. APOGEE-2 will continue the Milky Way exploration using APO and extend to the south with a 2.5m telescope at Las Campanas. eBOSS will continue BOSS but add 2 segments of interest to CVs: a Time-Domain Spectroscopic Survey (TDSS) that will obtain spectra of 100,000 variable sources and the Spectroscopic Identification of ERosita Sources (SPIDERS). Mapping Nearby Galaxies at APO (MaNGA) will obtain spatially resolved spectra of 10,000 nearby galaxies.

3 Current Surveys

Several surveys are now ongoing and searching for objects that vary. The Catalina Real-Time Transient Survey (CRTS; Drake et al. 2009) consists of 3 telescopes: a 1.5m on Mt. Lemmon, a 0.7m on Catalina and a 0.5m at Siding Springs. At the time of this meeting, 1022 potential CVs with outburst magnitudes brighter than 17 were posted on the web page *nesssi.cacr.caltech.edu/catalina/BrightCV.html.* This page has a column that denotes whether the object is in the SDSS photometric database and provides a direct link to SDSS. Since most of the objects were found at outburst, the quiescent magnitudes tend to be very faint (20-22nd mag) and therefore difficult to followup spectroscopically. Several groups are now following up on the CRTS sources (Woudt et al. 2012; Thorstensen & Skinner 2012). As noted above, Elme Breedt is also leading a project using Gemini and other large telescopes to categorize the faintest CRTS sources that have 5 color photometry in SDSS.

The Panoramic Survey Telescope & Rapid Response System (PanSTARRS1) is using an 1.8m telescope on Haleakala, Hawaii to complete a 2010-2013 northern sky transient survey which observes the available sky several times a month (Tonry et al. 2012). One of the 12 key projects involves variables and explosive transients. A data release is planned for 2014 and a second telescope is under development.

The Palomar Transient Factory (PTF) involves the Palomar 48 in Schmidt telescope to image the sky from 2009-2014 to a magnitude of 21 on timescales from minutes to years to find new transients and variables, including CVs (Rau et al. 2009). Recent improvements (called iPTF) have led to pipeline products that provides candidates within 30 minutes for spectroscopic followup. The followup spectroscopy is accomplished with the Palomar 1.5m and other telescopes and some of that is available in WISeREP (Yaron & Gal-yam 2012).

SkyMapper is a robotic 1.35m survey telescope in Siding Springs, Australia that is imaging the entire southern sky 36 times over 5 years in a series of 6 filters to 22nd mag that will provide spectral types of stars as well as variability information (Keller et al. 2007). The data will be made public through the Virtual Observatory.

In addition to these single, wide-field telescope surveys, there are 2 all-sky surveys which are using 2-4 cameras to image the sky. One is the All Sky Automated Survey (ASAS) which images the entire sky to 14th mag in V and I bands from Las Campanas, Chile and Haleakala, Maui (Pojmanski 1997). The other is the Mobile Astronomical System of Telescope-Robots (MASTER) which images to 19th mag at sites from Russia and Argentina (Lipunov et al. 2010).

4 The Future: LSST

The future for investigation of variability lies with the Large Synoptic Survey Telescope (LSST). This 8.4m telescope situated in Chile will image 18,000 $\deg^2$ of sky about 1000 times over 10 years (2020-2030). It uses 6 filters and will reach r = 24.5 mag on single nights and 27.5 on co-added images. The survey will produce alerts within minutes of observation as well as long term catalogs that will be made public. Details may be found in the online Science Book (http://www.lsst.org/lsst/scibook). This survey will go several magnitudes fainter than SDSS and should be able to find the population of period bounce systems that are predicted by models, as well as find unusual long term variability such as found by Honeycutt et al. (2003) during their long term monitoring with Roboscope. However, the difficulty lies in planning spectroscopic followup for 24-25 mag objects, which will require a lot of observing time on the largest telescopes available. Time series photometry for short period, low amplitude variables will still be possible, but the problems of smart classification to pick out interesting variables from the multitude each night and the ensuing spectral confirmation remain to be solved.

5 Conclusions

The SDSS has provided a significant database of CVs including a consistent set of medium resolution spectra for 285 systems and a photometric database that likely contains many more at faint magnitudes down to 22. Due to the fainter magnitude limit compared to previous surveys, followup observations resulted in a large change in the observed orbital period distribution of CVs that has resolved some discrepancies in close binary evolution. Current and future surveys rely on discoveries based primarily on variability, and so uncover large numbers of dwarf novae. As these surveys push further into the galactic plane and to fainter magnitudes with larger telescopes, the true space density of CVs and the distribution among types will become better known. However, the detailed information that comes from spectroscopy will be difficult to obtain for the faintest systems.

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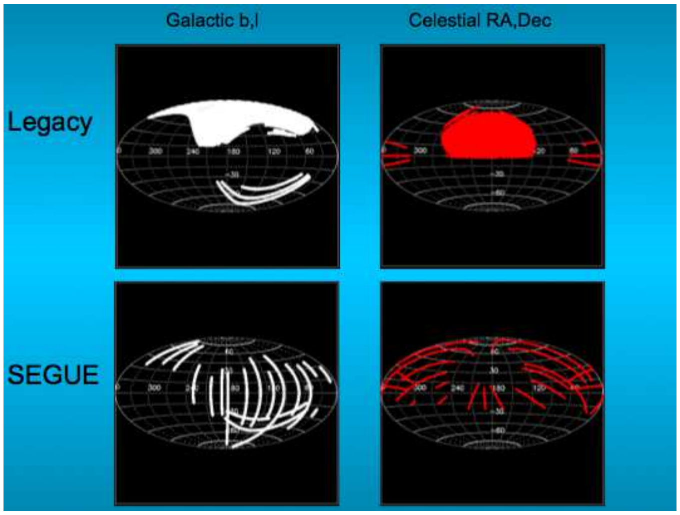

Figure 1: The sky coverage of the Legacy and SEGUE surveys in galactic (left) and celestial (right) coordinates, from www.sdss.org/dr7.

DISCUSSION

LINDA SCHMIDTOBREICK: Wouldn't you expect the pulsating white dwarfs in accreting systems to be hotter than single white dwarfs? Due to accretion, you would get a thin hot layer that influences the measured temperature but not necessarily the pulsation.

PAULA SZKODY: Yes, most accreting white dwarfs are indeed observed to be hotter than single white dwarfs. However, there are several parameters that could affect the pulsations (instability strip) in these accreting white dwarfs besides the temperature. The accreting ones are spun up by the accretion and the composition of the atmosphere is different due to the mass transfer from the secondary. Right now, we don't have enough data to distinguish which of these parameters are determining whether an accreting white dwarf will pulsate or not.