POPULATION STUDIES OF CATACLYSMIC VARIABLES

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Cataclysmic variables (CVs) are idiosyncratic objects, but progress can be made by studying groups of them. To do this, one must identify samples that are representative of their true properties. Because of the wide variety of physics that occurs in CVs, they have a complex phenomenology in which effects are still being discovered (e.g. permanent superhumps: Patterson & Richman 1991). CV outbursts have their own complex phenomenology (but see Osaki 1995a,b and this volume, for ideas on unification for dwarf novae), so it is unwise to rely on outburst properties to give unbiased samples.

One wants to identify CVs by some property common to all of them. One such property is flickering; another is color excess. CVs are very blue, especially in the ultraviolet, with $U - B < -0.46$ for 95% of CVs (Bruch & Engel 1994). This color index also defines inclusion in the Palomar-Green (PG) survey (Green, Schmidt & Liebert 1986), and a preliminary list of PG CVs was given by Green et al. (1982). My Ph.D. thesis (Ringwald 1993) completed this work, being the first optically selected complete sample of CVs at high latitude. At the same time, Andy Silber was writing his Ph.D. thesis on an X-ray-selected sample of CVs, from the *HEAO-A1* MC-LASS survey (Silber 1992). One might say I was Andy's optical counterpart.

The Palomar-Green catalog includes 1715 objects of all types (QSOs, sdBs, WDs) in its complete sample. Of these, 70 were listed by Green et al. (1986) as candidate CVs, having emission lines at Galactic velocities, or energy distributions with $f_\nu \approx 0$. Follow-up spectra were obtained of all 70 candidates. Of these, 30 were found to be genuine CVs. Five more CVs were found, but were excluded from the complete sample, since they were seen by the PG survey only because they were in outburst when Green was exposing his films on the 18-inch Palomar Schmidt telescope. The rest of the candidates, some 35 objects, were found not to be CVs. Many were misidentified sdB and other hot, high-gravity stars, with several binaries (including, but not limited to, PG 1114+187, PG 1119+147, BE UMa, NN Ser, KQ Peg = PG 2240+193, and PG 2300+166), two compact emission-line galaxies (PG 1136+581 = Mrk 1450 and PG 0947+462 = Mrk 125), and one planetary nebula nucleus (PG 1712+493).

Because it selects by color and not by outburst properties, the PG survey found new classes of CVs not showing conspicuous outbursts. These include the dreaded SW Sex stars (Thorstensen et al. 1991; Dhillon, this volume), faint nova-likes with mysterious but consistent behavior. Of 30 PG CVs, five are SW Sex stars. Nine are dwarf novae and three are magnetic: the SW Sex stars are not 'peculiar', as claimed by most of the discovery papers. All but WX Ari (Hellier, Ringwald & Robinson 1994) are eclipsing.

Another new class of stars from the PG survey are RZ LMi and ER UMa (PG 0948+344 and PG 0943+521, respectively: Robertson, Honeycutt & Turner 1994, 1995; Kato & Kunjaya 1995). These are low-amplitude dwarf novae with cycles that repeat unusually coherently, for dwarf novae. HS Vir = PG 1341−079 is another low-amplitude dwarf nova, with outbursts rising only 1.5 mag brighter than quiescence (Kato et al. 1995).

Permanent superhumps have been found in several nova-likes, including BK Lyn = PG 0917+342 (Skillman & Patterson 1993), V795 Her = PG 1717+413 (Patterson & Skillman 1994), and PG 1633+115 (Misselt & Shafter 1995). That these nova-likes are those in the PG catalog with the shortest orbital periods (1.80, 2.60, and 3.94 h, respectively) is consistent with the theory that superhumps are tidally induced (Whitehurst 1988), resulting from the high mass ratios short-period CVs should have.

An unbiased sample allows ensemble properties to be determined. The complete sample from the PG survey gives a space density of $6\,10^{-6}$ pc^{-3}. This is about ten times higher than previous estimates of $7 \pm 3.5\,10^{-7}$ pc^{-3} (Della Valle & Duerbeck 1993), $8\,10^{-7}$ pc^{-3} (Downes 1986), $7\,10^{-7}$ pc^{-3} (Patterson 1984), and $1\,10^{-6}$ pc^{-3} (Warner 1974). Nearly all the excess space density from the PG survey is from the least luminous CVs.

This space density suggests a recurrence time between novae of 15 000 yr, or about ten times longer than for the low-latitude sample of Downes (1986), assuming $D_{\rm N}/T = 3.8\,10^{-10}$ pc^{-3} yr^{-1}, where $D_{\rm N}$ is the average space density and T is the average recurrence time (Duerbeck 1984), assuming that all CVs have classical nova outbursts at some time. This may not be so if CVs are in two populations, one in the Galactic disk and one in the bulge (Della Valle et al. 1992). Because of the PG survey's relatively bright average limiting magnitude, the PG CVs extend only about one scale height away from the Galactic plane, so nearly all are in the disk.

The fraction of magnetic PG CVs is 3/30 (10%); the AM Her systems MR Ser and AN UMa, and the DQ Her star YY Dra. This contrasts with 28% from the X-ray-selected sample of Silber (1992), and 2% for the ratio of magnetic white dwarfs to field white dwarfs (Schmidt & Liebert 1987).

In response to a poster shown at the San Diego meeting (Ringwald 1994), several observers, including Hellier et al. (1994) and Misselt & Shafter (1995), obtained time-resolved photometry of many PG CVs. All systems in the complete sample have now had sufficient phase coverage to determine the fraction of eclipsing CVs: 7/30 (23%) eclipse. Silber (1992) also obtained a fraction of 23% for his X-ray-selected sample; an isotropic distribution should have 14%. Silber suggested this to be evidence of massive white dwarfs, although the fraction for the PG CVs can be turned into an isotropic distribution if one excludes the SW Sex stars.

The cumulative surface density of the PG CVs is $d \log n(B)/dB = 0.35$ mag^{-1} over $14.4 \leq B \leq 16.2$, where $n(B)$ is the number of CVs per square degree per B magnitude. This is similar to the surface density of sdO and sdB stars (Green et al. 1986). The orbital period distribution is like that of the *HEAO A-1* CVs, except that the 'AM Her spike' is less pronounced; it differs significantly from the distribution for the AM Her stars found by *ROSAT* (Kolb & de Kool 1993).

Other population studies of CVs include the Kitt Peak-Downes survey (Downes 1986), which was optically selected near the Galactic plane. Deep high-latitude UV-excess surveys are in progress, including the Edinburgh-Cape survey (Stobie et al. 1992), which reaches to $B \sim 18$, and the Montréal-Cambridge survey (Demers et al. 1987), which reaches to $B \sim 17.5$. These surveys will be statistically cleaner than the PG survey, since their cutoff can be held at $B = 16.5$; the limiting magnitude in the PG survey changes from field to field, between $B = 15.49$ and 16.67. They may also avoid problems with incompleteness suspected of the PG survey, since most objects were near the detection limit of Green's Schmidt films.

A sample of high-latitude CVs, selected by variability, was compiled from the GCVS by Howell & Szkody (1990), intending to explore CVs in the Galactic halo. Despite selection effects and incompleteness, it has found many of the faintest, nearest CVs (Howell, Szkody & Cannizzo 1995).

Shafter (this volume) reviews studies of CVs in M31 and other galaxies. Searches for CVs in globular clusters are ongoing with *HST* (Paresce & de Marchi 1994). Perhaps too few CVs are present (Shara, Bergeron & Moffat 1994; Shara et al. 1995), but the case is not yet clear (Cool et al. 1995).

Another, different sort of survey has been carried out by Ringwald, Naylor & Mukai (1996), to explore the behavior through time in novae that had outbursts between 1783 and 1986. Essentially, they don't do anything: there is no sign of the secondary stars, as one might expect if novae went into hibernation. High-excitation lines such as He II λ4686 Å have comparable strengths in centuries-old novae and in novae just out of the nebular phase, suggesting that the white dwarfs or disks stay hot for centuries.

There has been work on detached post common-envelope binaries, often wrongly called pre-cataclysmic binaries (Ritter 1986a), which have turned up in the EUV surveys of *ROSAT*/WFC (Pounds et al. 1993) and *EUVE* (Bowyer et al. 1994). The first Ph.D. thesis on these objects will soon appear (Catalán 1995), surely establishing these objects as a part of the astrophysical landscape. Theory includes work on selection effects, begun by Ritter (1986b), and on population modeling (Kolb 1993; also this volume).

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