CATACLYSMIC VARIABLES

BRIAN WARNER
Department of Physics and Astronomy
Dartmouth College
Hanover, NH 03755

and

Department of Astronomy
University of Cape Town
Rondebosch 7700
South Africa

The cataclysmic variables, comprising the classical novae, dwarf novae and nova-like variables, provide the amateur variable star observer with the greatest opportunities for important and indispensable contributions to the current progress of astronomy. The brightest classical novae are almost always discovered by those dedicated observers who search the sky on every clear night, leaving only the fainter novae to be found through photographic patrols of selected regions such as the general direction towards the center of the Galaxy. The very brightest novae are sufficiently rare (one every five or ten years) that significant technological progress is made in the interim to result in the discovery of new phenomena from each of them. In order to cover adequately the final rise and the maximum phases of classical novae the earliest possible discovery of bright novae remains of great benefit.

The statistics of classical nova discoveries (e.g. Warner 1986) suggests that in the past many novae were missed which reached apparent magnitudes brighter than sixth. Nowadays probably the only unrecorded bright novae will be fast novae that happen to occur in parts of the sky near to the sun, but in the last century the majority of novae evidently went unnoticed - the first nova discovered in the nineteenth century was Nova Ophiuchi 1848, and in the remainder of the century fewer than twenty more were recorded.

The dwarf novae, although erupting several times a year, are mostly fainter than ninth magnitude at maximum light, which made their early discovery a difficult and slow process. The first, U Gem, was found by J. R. Hind in 1855 and the second, SS Cyg, was discovered in 1896 by Miss L. D. Wells. Hind was a semi-professional at the time of his discovery of U Gem, but he used the same techniques of searching for and observing variable stars as are used by modern visual observers. In fact, the contemporary body of amateur variable star observers keep alive the techniques and traditions of the visual observers (professional and amateur) of the pre-photographic era. The identification of SS Cyg came from inspection of Harvard Observatory patrol plates, and this method of discovery has been used for almost all of the hundreds of currently known dwarf novae. However, the large range (2-8 magnitudes), frequent outbursts and unpredictability of dwarf novae have from the beginning caught the imagination of the amateur observers. As a result, for a few dwarf novae records extend back for about a century and for many more useful, and in some cases almost complete, coverage extends back for thirty years or more. See Figure 1.

There has in the past been no possibility that professional astronomers could monitor photoelectrically the 100 or more brightest dwarf novae: as a result almost everything that is known about the long term behavior of dwarf novae has come from analysis of data provided by the amateur observers. Current progress in technology is such that it is conceivable that within ten years all-sky photoelectric monitoring down to say 15th magnitude will be possible. Even if one or two such instruments are put into operation, the continuity of light curves that is a characteristic of the wide geographical spread of the network of visual observers will not be achieved. Amateur visual and photoelectric observations will remain essential for a long time.

Over the years professional astronomers' interests in cataclysmic variables have waxed and waned. Early studies were primarily concerned with the forms and classification of classical novae, the classification and interpretation of their spectra, and with statistical descriptions of the long term outburst light curves of dwarf novae. It was early found by Humason (1938) that the spectra of nova remnants are characterized by blue continua and hydrogen emission lines. Later work (see review by Warner (1976)) demonstrated that the dwarf novae at quiescence have very similar spectra. As an extension of these studies the class of objects known as nova-like variables was recognized - such stars have spectra like classical novae or dwarf novae at quiescence but have no recorded eruptions.

In the mid-1950's M. F. Walker discovered that at quiescence all of the cataclysmic variables show variations in brightness, of low amplitude (a few tenths of a magnitude), on time scales of minutes. He also discovered that some of these stars are eclipsing binaries. The suspicion that all cataclysmic variables may be short period binaries led R. P. Kraft in the early 1960's to carry out a systematic spectroscopic survey with the 200-inch reflector. With his verification of their double nature, and the numerous indications that one of the components is always a white dwarf, came the realization that a classical nova explosion is the result of a thermonuclear explosion in the outer layers of the white dwarf, caused by transfer to it of hydrogen-rich gas from the companion star. During the 1960's it was generally assumed that the dwarf novae are miniature versions of the classical novae.

For some time after Walker's and Kraft's pioneering surveys (summarized in Kraft (1963) and Warner (1976)) the cataclysmic variables were to a large extent ignored. Their study was revived around 1970 by the technological progress that had resulted both in more efficient photomultipliers and in the application of minicomputers to the acquisition of data at the telescope (Warner 1971). In this way photometry with high time resolution could be carried out. See Figures 2 and 3. This era of "high speed photometry" resulted in the discovery of a range of unexpected phenomena - and also to the realization of the importance of accretion discs in the cataclysmic variables. Mass leaving the secondary star passes through such an accretion disc before reaching the white dwarf. Because of viscous heating it turns out that in the majority of cataclysmic variables most of the radiation in the ultraviolet and visible comes from their accretion discs. For these objects the AAVSO is really the AAADO - The American Association of Accretion Disk Observers.

From the mid-1970's x-ray and far-UV satellites rapidly revealed that the cataclysmic variables are energetic sources. Of equal importance for cataclysmic variables studies was the recognition of a much more energetic class of binary stars, of which Scorpii X-1 is the prototype, in which the compact star component is a neutron star: the x-ray binaries. Because the x-ray and far-UV properties of these stars are dominated by the properties of their accretion discs, the theoretical and observational study of discs has become a growth industry in the past decade. The vast data banks on the long term variations of cataclysmic variables, built up by the AAVSO and the Variable Star Section of the RAS of New Zealand, become source material for analysis in ways undreamt of by the early observers, who studied classical novae and dwarf novae solely for their interest *per se*.

Furthermore, real-time interaction between amateurs and professionals has become commonplace: satellites are often used for "target of opportunity" observations of outbursts of dwarf novae. In order to select an object for study the satellite users rely on intensive monitoring over a limited interval of time by the international corps of amateur observers. Selection is made on the basis of information received via telephone, telegram or telex. In most cases subsequent interpretation of the satellite data relies heavily on the overall light curve produced from the visual observations. (Satellite users are not the only consumers of current information on cataclysmic variables: ground-based astronomers often make use of the previous night's visual observations to eliminate the need to search for a star in outburst and thereby save valuable and hard to obtain time on a large telescope). There are few other scientific disciplines in which such extensive and essential knowledge is provided by non-professionals. In astronomy we have a mutually rewarding and satisfying relatioship.

Apart from the obvious importance of continuing the observational record of dwarf and classical novae, on what areas should the amateur observer of cataclysmic variables concentrate? The answer to such a question will vary according to current knowledge or speculation on the structure and evolution of these stars. To a large extent the classical novae at minimum light have been neglected by both professionals and amateurs. Only about a dozen nova remnants (other than the recent novae that are still fading) are brighter than magnitude 15.5 so this is a task for large instruments. An example of the contribution made in this subject is the work of W. H. Steavenson and B. M. Peek, praised by Payne-Gaposchkin (1977). See Figure 4. The possible rewards include detection of dwarf nova-like outbursts of the kind seen in GK Per (Nova Per 1901), which commenced some 40 years after the nova explosion. Such changes from nova remnant to dwarf nova have great importance to current work on the evolution of cataclysmic variables.

Another phenomenon to be sought is the gradual fading of a nova remnant long after it has reached its normal quiescent state. The oldest recovered novae (Nova Vul 1670 and Nova Sge 1783) have both diminished to uncharacteristically faint magnitudes. It is currently suspected that many, perhaps all, novae will fade away after a century or so in stable postnova states. Study of such a decline will help to explain the cause of the variations in the rate of mass-transfer from the secondaries of cataclysmic variables.

The nova-like variables, of which there are now many known brighter than 14th magnitude, are worthy of persistent monitoring. Some of them have faint states, falling fairly rapidly by two or more magnitudes. No light curve is yet available for the transition from high to low states, and more photometric and spectroscopic studies are required during this time, so a collaborative effort between amateur and professional is overdue. Three kinds of nova-like variable show the two-state phenomenon: (i) the magnetic cataclysmic variables (AM Her stars, or Polars), of which only AM Her, VV Pup and EF Eri are brighter than 14th magnitude in their high state, (ii) the Intermediate Polars, of which five are bright enough to monitor relatively early (TV Col, m_v = 13.5; V426 Oph, m_v = 12.4; FO Aqr, m_v = 13.5; AO Psc, m_v = 13.3; V1223 Sgr, m_v = 13.2), and (iii) the MV Lyr stars, which are included in Table I.

Before its explosion, almost every nova has been found on archival photographic patrol plates to have been a nova-like variable. Thus Nova Del (1967) appears on plates taken earlier in the century as a 12.1 magnitude nova-like variable, but it had not been discovered as such prior to the 1967 explosion. In fact, no **previously known** variable has become a nova. Yet at least four novae this century have erupted from bright nova-like variables: GK Per (1901), m_v = 12.3; HR Del (1967), m_v = 12.1. There must be a good chance that before the end of the century an **already known** nova-like variable will become a nova. The brightest of these stars, many of which are already on AAVSO or RASNZ observing lists, are given in Table I.

Among these stars are bright novae that erupted in the past but were unrecorded. These cannot be expected to explode again for at least millennia. But also among these stars, if our surveys are reasonably complete (which, unfortunately, is probably not the case: the brightest, IX Vel, was only discovered in 1983!), will be one of the next spectacularly bright novae. We cannot say that the next one will certainly come from among the bright nova-likes: Nova Cyg (1975) was unobservable at m_v > 21 until a few weeks before it exploded.

A daily watch on these nova-like variables should result in the earliest possible notice of the rise of a classical nova. It may be possible to get an early warning of the impending explosion: Robinson (1975) has drawn attention to the record of the archival plates which shows that some prenovae have brightened by up to two magnitudes during the year or so prior to explosion. See FIgure 5. Any nova-like variables showing such a steady rise would be worthy of almost hourly attention by visual observers! In the meantime, the professionals should make sure that all of the bright nova-likes are thoroughly studied; in this way there is some hope that for the first time a well-studied object will become a nova. At the moment there are still a few stars in Table I for which even orbital periods are not yet known.

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REFERENCES

Humason, M. L. 1938, **Astrophys. Journ. 88**, 237.
Kraft, R. P. 1963, **Adv. Astron. Astrophys. 2**, 43.
Payne-Gaposchkin, C. 1977, in **Novae and Related Stars**, Reidel, p.3.
Robinson, E. L. 1975, **Astron. Journ. 80**, 515.
Warner, B. 1971, **Int. Astron. Union Colloquium No. 15**, p.144.
__________ 1976, **Int. Astron. Union Colloquium No. 73**, p.85.
__________ 1986, in **Classical Novae**, ed. A. Evans & M. F. Bode, Wiley, in press.

TABLE I

The Brightest Nova-like Variables

IX Vel	9.6	UX UMa	12.8	PG 2133 +115	14.0
V385 Sgr	10.4	KQ Mon	13.0	V751 Cyg	14.0
RW Sex	10.8	V795 Her	13.0	V363 Aur	14.2
TT Ari	11.1	HS Vir	13.0	LX Ser	14.4
CL Sco	11.2	RW Tri	13.2	PG 1717 +413	14.4
QU Car	11.4	VY Scl	13.2	RX LMi	14.4
MV Lyr	12.5	CM Del	13.4	V1315 Aql	14.4
V442 Oph	12.6	KR Aur	13.5	V794 Aql	14.5
V592 Cas	12.8	AC Cnc	13.8	V425 Cas	14.5
				V380 Oph	14.5

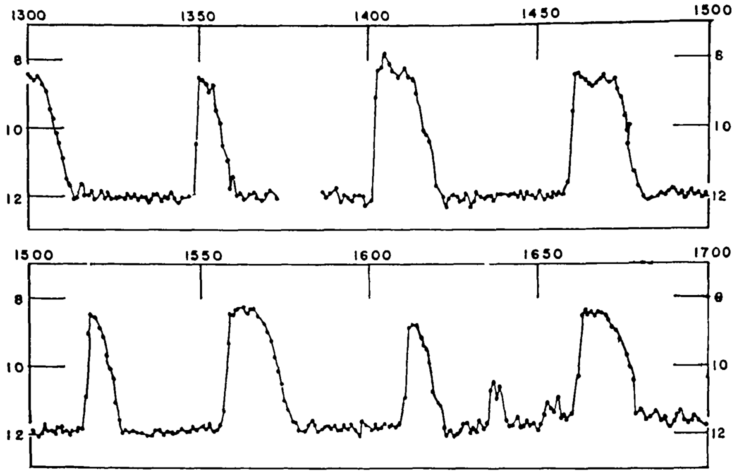

Figure 1. Light curve for SS Cygni in 1972, drawn from AAVSO observations. Note the almost complete coverage, which is typical since the discovery of this star in 1896. Adapted from **J.R.A.S. Canada 67**, 158, 1973.

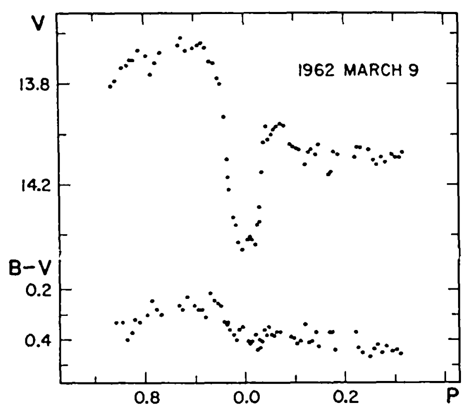

Figure 2. Photoelectric light curve of U Geminorum at minimum light, showing eclipse at time resolution characteristic of photometry in the 1960s. From **Astrophys. Journ. 142**, 1051, 1965.

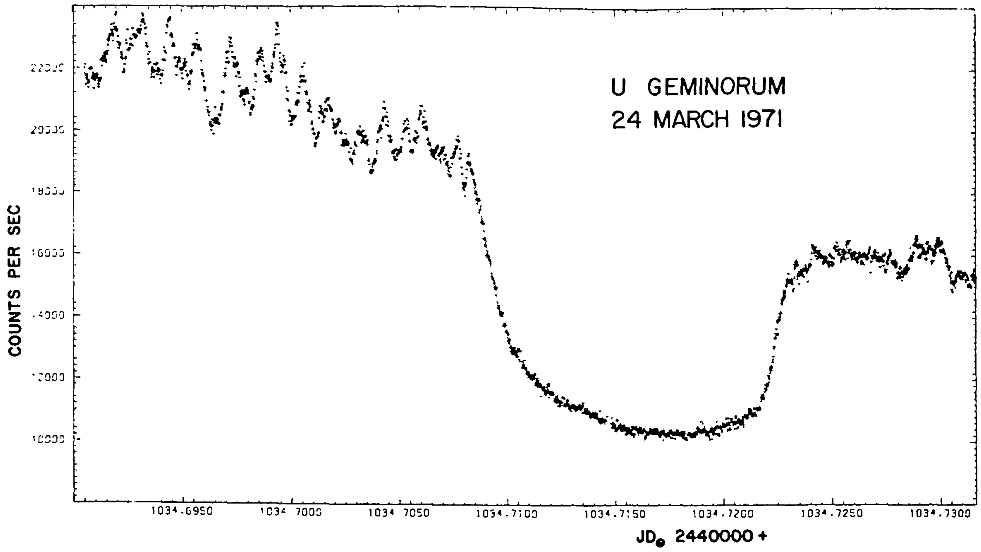

Figure 3. Photoelectric light curve of U Geminorum at minimum light, showing eclipse at time resolution characteristic of photometry with improved technology of the 1970s. From Warner (1976).

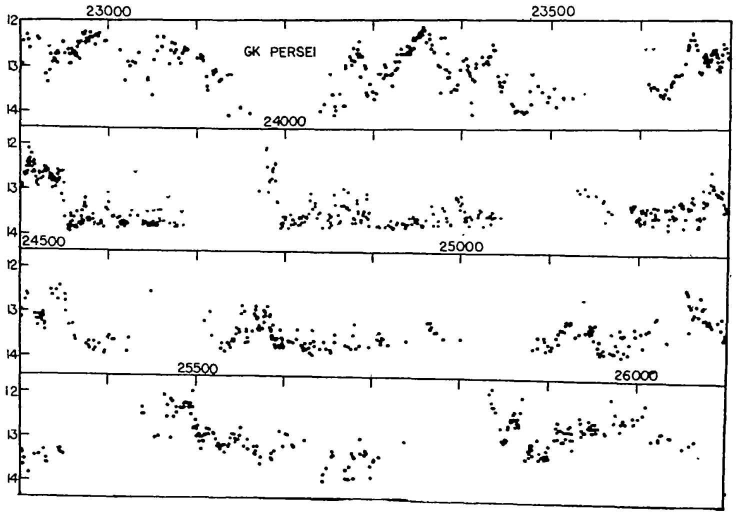

Figure 4. Visual observations of Nova Persei 1901 at minimum light, by W. W. Steavenson and B. M. Peek. From Payne-Gaposchkin (1977).

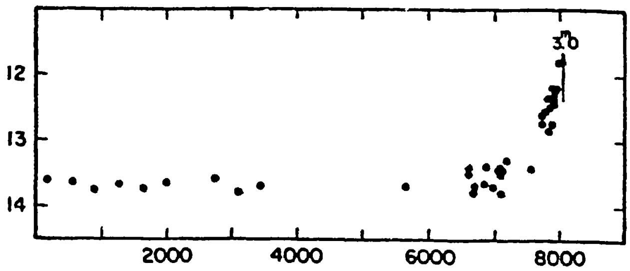

Figure 5. Rise in brightness of V533 Her prior to its classical nova eruption in 1963. From Robinson (1975).