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Stellar apoplexy, convalescence and recovery: The life cycles of cataclysmic variable stars.

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1. Introduction

White dwarf stars are usually thought of as rather tame objects, exhausted of nuclear fuel and with nothing to do but slowly cool down for the rest of the life of the Universe. This is true for single white dwarfs, but those in close binary stars are allowed no peace at all. Close binary in this context means stars so close to each other that gas can pass from one to the other in a stream. A white dwarf accreting mass from its companion in this way is destined for a troubled life – until the companion has whittled itself down to a mere Jupiter and stops generously giving itself away.

The physics of accretion onto a white dwarf was first worked out by Leon Mestel in the 1950s. The interior of a white dwarf is composed of degenerate gas, which behaves differently from ordinary ('perfect') gas – in particular, when it is heated it does not expand. Energy put into a degenerate star therefore does not change the pressure equilibrium – until the temperature rises to the point (the Fermi Temperature) when degeneracy is removed, leaving a perfect gas that is enormously hotter than it would be if in hydrostatic equilibrium, which therefore rapidly expands.

White dwarfs are the hydrogen-exhausted cores of old red giants. They therefore do not contain any supply of easily accessible nuclear energy and are completely stable. But pouring hydrogen-rich gas from its companion onto the surface of a white dwarf sets up an explosive situation – as the accreted layer thickens it is heated by the compression of its own weight, and becomes more dense. Eventually the bottom of the layer, which by now is at a depth where the gas is at least partially degenerate, becomes sufficiently hot and dense that nuclear reactions start – these are the same proton-proton chain reactions that fuel the sun. The result is a thermo-nuclear runaway – as in a hydrogen bomb: as the temperature rises the nuclear reaction rates increase, heating the gas even more. The result is that the basal layers of the accreted gas expand at the velocity of sound, ejecting the gas that has been accreted. This is a *nova*.

Having expanded its overburden the white dwarf's troubles are not over. In effect it has regained the giant structure that it had earlier in life, but it cannot find the equilibrium it had when it was a giant. Now its envelope is expanding at greater than escape velocity, and the pressure at the base of the hydrogen layer has dropped so nuclear reactions soon turn off. A small part of the expanded envelope falls back onto the white dwarf, but most escapes as nova ejecta. When the wind of gas has dropped sufficiently, accretion from the companion starts again and the whole cycle repeats. For the first hundred years or so after the explosion the white dwarf surface cools from the high temperature it reached at the peak of the thermonuclear runaway.

The above is a simplified view of our current understanding of the nova process – it is one of cycling between two unstable states. I want now to concentrate on the observational side of nova studies, which can be fitted into the above evolutionary context. There are many types of cataclysmic variable (CV) star, e.g., dwarf novae, nova-like variables, magnetic systems (known as polars and intermediate polars). With the exception of one group (the AM CVn stars, which transfer helium) all consist of binaries of short orbital period transferring hydrogen onto a white dwarf primary. The different types are defined by their long-term light curves or by the strength of their magnetic fields, but, from what has been said above, all the hydrogen systems will go through the nova experience – and so novae should not be thought of as a distinctly different type of CV – every other type is what a CV is while it is not being a nova.

2. Nova Eruptions

Novae are visibly spectacular because they result in a typically 10 000-fold increase in brightness of a previously well-behaved star. The rapidity of the rise adds to the excitement – if you are on the wrong side of the Earth this can make the difference between success and failure to discover a particular nova. The rapid rise is a result of the thermonuclear runaway – novae are the largest hydrogen bombs that the Universe makes. It is no accident, therefore, that many of the most comprehensive computations of nova explosions have been made at Los Alamos. Such calculations require supercomputers capable of following the details of the many nuclear reactions, and the hydrodynamics of the ejection. Although the best physics known is used, there is still a significant discrepancy between the predicted mass ejected – about a few x 10^{-5} solar mass, and what is observed – about 2 x 10^{-4} solar mass. Also, novae are considerably brighter at maximum than the models predict. Worse still, at the observed accretion rates, white dwarfs should not explode so violently. There are therefore some very important pieces of physics missing from the models.

The speed of decrease in luminosity after maximum depends on the rate of ejection and how much gas was ejected – and both of these depend quite sensitively on the mass of the white dwarf. White dwarfs that are near the upper limit of what is possible – the Chandrasekhar Limit of 1.4 solar masses – are both massive and very small in radius. The result is that the force of gravity at their surface increases rapidly with approach to the Chandrasekhar Limit, and so less mass has to be accumulated before it is sufficiently compressed to be ignited. The consequence is that nova explosions can then occur as frequently as once or twice per century – which explains the occurrence of the Recurrent Novae. As is seen from the above explanation, all novae are actually recurrent, but only those that have recurred in the roughly 150 years since proper records started can enter the class of Recurrent Novae. Only about 10 novae are listed as recurrent. A few of these have red giant secondaries, which pour mass onto the white dwarf at a higher rate than do ordinary dwarfs, which again shortens the time it takes to accrete the critical mass.

It is estimated that there are about 35 novae every year in our Galaxy, but because the Galaxy is such a dusty place only about 5 of them are detected. This total is arrived at indirectly: by looking at the spiral galaxy M87, for which observations with the Hubble Space Telescope (made for unrelated reasons) have resulted in the discovery of over 400 novae, and at the Andromeda Galaxy, M31, where systematic nova searches are often made. Seen from the outside the losses due to interstellar extinction are easier to estimate. The numbers for the two galaxies are then scaled by the ratio of their masses to that of our Galaxy.

The majority of very bright, i.e. naked eye, novae are still found by amateurs who specialise in nova hunting. I have to include Bill Liller in this category – he is a retired professional astronomer living in Chile, works with a small telescope and a 35 mm camera, and is one of the most prolific of nova discoverers of the past decade. But most of the well-known discoverers have been complete amateurs – for example, the late George Alcock of Peterborough, England, discovered 5 novae, including Nova Herculis 1991, which he found as a 5th magnitude star while observing from his lounge, looking through the window pane with binoculars.

An historically very important nova was Nova Pictoris 1925, found at magnitude 2.4 by R. Watson, a 'telegrapher' going to work before dawn in Beaufort West one morning. The nova was still rising, and Watson was in a special position to alert the professional astronomers, with the result that Harold Spencer Jones, H.M. Astronomer at the Cape, was able to catch the rise to maximum and to carry out the most detailed spectroscopic study of a nova made to that time.

Nowadays the professional armoury extends way beyond spectroscopy and optical photometry. Observations in the infrared and satellite ultraviolet show that the post-maximum decline in optical brightness is very misleading. Most novae maintain a constant total (bolometric) luminosity for weeks or months after outburst, but the peak of their emitted flux moves steadily into the ultraviolet. This is because the ejected shell gradually becomes transparent, enabling us to see deeper in, and eventually to the very hot white dwarf itself. The deep dips that occur for weeks or months on the decline of some novae are caused by the condensation of dust in the expanding and cooling shell – the dust grains absorb optical light and are heated, and then radiate the heat in the infrared.

Novae also emit X-Rays during eruption – caused largely by the rapidly expanding shell colliding with circumstellar or interstellar gas. Another source of X-Rays that may last for a few years is the steady nuclear burning of accreting hydrogen that can occur near the surface of the greatly heated white dwarf after the eruption. This produces what is called a Super Soft X-Ray Source. It is also predicted that they should emit gamma rays due to the decay of radioactive elements formed in the nuclear reactions that occur during the thermonuclear runaway. The predicted fluxes have been just below what is possible to detect from balloon and satellite-born detectors, but are within the grasp of the new *INTEGRAL* satellite – but only if a nova erupts within about a kiloparsec of the Earth during the lifetime of the satellite.

3. Convalescence

I next must deal with the part of a nova life cycle that interests me most – the long recovery process after the eruption, when the white dwarf is collecting enough mass and courage to have another go. First I need to explain in more detail the basic mechanisms that operate in a CV.

3.1 The driving mechanism in a CV

The reason that the companion star loses mass is that it slightly overflows its Roche Lobe. The latter is a mathematical surface surrounding individual stars in binary systems, and is computed from the twin effects of gravitational attraction and centrifugal force. The Roche Lobe simply denotes the largest surface that a star can fit into before it begins to spill has out of the place (known as the Inner Lagrangian Point, or L_1) that is nearest to its companion. The slightest excess of size outside this surface and mass flows across the surface of the star to L_1 and thence in a stream towards the white dwarf. If the white dwarf is not strongly magnetic then the stream forms a disc around it and steadily spirals down to its surface. Where the infalling stream hits the disc a Bright Spot is produced – it is a region of shock waves caused by the supersonic impact of the stream.

The rate at which gas pours out of the secondary is determined by several interesting bits of physics. The transfer of gas from the lower to the higher mass component results, through conservation of angular momentum, in increasing the distance between the two stars. If that were all that was involved, the Roche Lobe would increase in size as the separation increased and the secondary would no longer overflow the Lobe, cutting off the mass transfer. But there is a constant drain of angular momentum out of the orbits of close binaries, which results in a steady decrease in separation – more than enough to counter the increase arising from the transfer – so the mass transfer is able to continue.

Therefore it is the loss of angular momentum from the orbit that drives the mass transfer process. Currently we know two mechanisms that drain angular momentum – one is a prediction of General Relatively (GR) – namely that a binary star loses angular momentum through radiation of gravitational waves. Gravitational waves have not been directly observed yet (but they should within a couple of years when the newly built detectors are fully operational). The angular momentum loss is proportional to the fifth power of the orbital frequency, so the shortest period binaries are the ones that are affected most. For orbital periods of about two hours and less the evolution of the orbit, and the transfer of mass, is a direct consequence of GR.

The second mechanism is the same one that has slowed the Sun's rotation. When the Sun was young, judging by observations of young stars of about the same mass as the Sun, it would have rotated quite rapidly – with a rotation period of just a few days. Its slow rotation now, with its 28-day period, is the result of angular momentum lost during its lifetime. This is caused by the combination of the Solar Wind and the Sun's magnetic field. The solar wind carries away mass but it also carries away angular momentum, and the latter is greatly enhanced because the wind is ionised, so the escaping gas has to follow the Sun's magnetic field lines, which rotate with the Sun. All the while the particles stay on the field lines (which is out to about the distance of the Earth from the Sun) they must be sped up by the Sun – that is, they extract its angular momentum.

The same mechanism is in operation in CVs. The magnetic fields of the Sun and other dwarf stars are generated by a self-acting dynamo that arises through rotation. The secondary star in a CV is forced through tidal interaction to rotate with the same period as the binary, i.e. hours rather than days, which means it will be quite strongly magnetic and its stellar wind will also be quite strong. The magnetic braking effect extracts angular momentum from the secondary star, but as

2003MNSSA..62...74W

this is tidally locked to the orbital revolution the angular momentum is extracted from the orbit.

There is a third mechanism that can affect the rate of mass transfer, and this one is of great relevance to the effect of a nova explosion on a CV. Magnetic braking and GR operate all the time, but for a hundred years or more after a nova explosion the white dwarf cools from a temperature of about 100 000 K immediately after the nova down to 20 000 K. Having such a high luminosity white dwarf close to the secondary star heat its atmosphere to high temperatures (typically tens of thousands of degrees), which expands the atmosphere and causes it to overflow the Roche Lobe by a greater amount. A post nova is therefore in a state of irradiation-enhanced mass transfer for a century of more.

Yet another effect comes into play here. The gas that falls down onto the white dwarf converts its kinetic energy of infall into thermal energy when it hits the surface of the star. There is therefore a positive feedback mechanism – the greater the rate of transfer the hotter the white dwarf becomes and the more the atmosphere of the secondary is heated and expanded, this sounds like a recipe for disaster – a runaway could occur. But as the transfer rate goes up the accretion disc has to pass the mass through it, and this heats and thickens the disc – which shields the atmosphere of the secondary from the heat of the white dwarf. There is thus a self-regulating mechanism that prevents the mass transfer runaway.

3.2 Pre- and Post-Novae

We are now ready to interpret a somewhat unusual observation, namely, for most novae the brightness immediately before the explosion is the same as the brightness that they settle down to when the effects of the nova explosion have worn off. It is worth explaining how we know this, because it has implications for some future nova. When a nova has appeared and its position has been accurately measured, its progenitor is looked for on existing sky survey plates. For bright novae it is almost always possible to find the star before it exploded – for example Nova Delphini 1967 shows as a 12th magnitude star on photographs taken before 1967, and this is the magnitude it has returned to. Its spectrum and photometric properties now are those of a typical nova-like variable. In a few cases it has been possible to find such pre-novae on objective prism plates, and their spectra are also typical of nova-likes.

The nova-likes are CVs with high rates of mass transfer – the white dwarf is greatly heated by the infalling gas and so part of the cause of the high rate is irradiative heating of the secondary. This is why the brightness before and long after the nova explosion are so similar. Before the eruption the system was in an equilibrium state, most of its brightness being accretion luminosity (dominated by the bright accretion disc), and after the heated white dwarf has cooled down it returns to that equilibrium state.

The implications are of some interest. The reason that most novae explode from nova-like systems is because those are the CVs where the mass is accreting at the greatest rate onto the white dwarf, and so those are the objects where the critical mass needed for explosion is most likely to be reached. That means that among the nova-likes that we currently know, one may soon become a nova. A regrettable fact is that no star that we have previously identified as a CV has ever become a nova (this does not apply, of course, to the repeat explosions of recurrent novae). Even though we have identified perhaps 50 nova-likes not one of them has become a nova since they were discovered (which for most of them is only in the past 20 years).

What this suggests is that the true population of nova-likes is very much greater than the 50 or so that we currently know.

When a previously recognised and well-studied nova-like does become a nova this will be very valuable because we will be able to measure the change in orbital period before and after explosion – such a change occurs because the ejected gas carries mass and angular momentum away. Only in one case, Nova Mon 1939, has the increase in period been measured – and this was done by measuring its brightness on so many pre-eruption archived survey plates that its deep eclipse could be detected and the orbital period measured.

Regrettably, there are still many quite bright nova-likes that have never been properly studied at all. For example, KQ Mon is at magnitude 12.0 – 13.0 and has never had an orbital period determined

3.3 Orbital humps, superhumps and magnetic rotators

There are more topics that I must explain before I can describe the program of photometry of old novae that we have been carrying out at Sutherland over the past few years. Periodic modulations of brightness of old novae can arise through several different mechanisms. The most obvious is that if the nova remnant has a high orbital inclination then we will observe eclipses, which immediately tell us the orbital period. There can be orbital modulation even in the absence of eclipses – caused by variations of the aspect at which view the Bright Spot as the binary rotates.

A more subtle effect is that of superhumps. Some dwarf novae in outburst show large amplitude periodic humps that have periods a few percent longer than the orbital periods. These were discovered about 25 years ago, and were at last explained as a direct result of the accretion disc becoming elliptical in shape. The superhumps are seen in superoutbursting dwarf novae; the accretion disc is forced into the elliptical shape because of the tidal influence of the companion, which is usually only strong enough for the short orbital period systems – periods less than about 3 hours. Any CV that has a short orbital period and a high rate of mass transfer can be expected to show superhumps. There are a few nova-likes that fit these requirements, and as a result they possess Permanent Superhumps – the superhumps in dwarf novae last only while the star is in outburst (and hence has a high rate of mass transfer).

Finally, CVs in which the white dwarf is highly magnetic can show brightness modulations at the rotation period of the white dwarf (in many cases the period is not that of the white dwarf – instead it is the period of rotation of the white dwarf as seen at the secondary; think of the former as the sidereal period and the latter as the synodic period).

The result of all this is that if a periodic modulation in the brightness of a CV is observed one still has to work out which of the above causes are responsible. Sometimes all three modulations may be present in the same star.

4. Recovery

The "recovery" referred to here is not the

2003MNSSA..62...74W

recovery of the star from the effects of the nova explosion – it is the recovery by us of the old nova by use of high speed photometry. Of course, most novae that have been discovered in the past 50 years or so have been followed down to their quiescent magnitudes, and most older novae have been identified by using the accurate measurements of their positions made at the time of their explosion. A few old novae have been mis-identified or not identified at all, on the basis of their positions; as all CVs flicker quite rapidly, and this is almost unique to CVs, it is possible to make correct identifications purely on the basis of flickering activity. Although we have made a few such corrections and new identifications, this is not what I want to describe. Rather I want to talk about the variety of properties we are finding among the old novae. So the "recovery" I am describing is really a photometric survey of old novae, most of them faint and never previously observed at high time resolution.

4.1 High Speed Photometry

At the Sutherland observing station of the South African Astronomical Observatory we are fortunate to have a state-of-the art high speed photometer. This was designed and built by Dr Darragh O'Donoghue in the Department of Astronomy at UCT during the early 1990s. It was paid for by funds that I was able to raise from the University and the then Foundation for Research Development. It was quite expensive – the CCD chip costing about £20 000 – taking all the equipment funding for two years. But is was motivated on the grounds that it would be the piece of equipment that would carry us well into the next millennium – which it is doing.

By use of the "frame-transfer" and on-chip binning technique we are able to use short integration times – it can take a few seconds to read out the charge stored on a CCD, but the charge can be moved from one part of the chip to another in a millisecond. So we expose only half of the chip to the sky and then move that electronic image to the other half where it can be read out while the first half is taking another picture. We can use integrations as short as 4 seconds and display the images as they are read out. Giving up the real time display allows very much shorter integrations.

Used on the 74-inch Radcliffe telescope at Sutherland we can produce light curves with 30 second time resolution at about 20th magnitude, and can reach 21st magnitude with about 2 min time resolution.

Because the technique is differential – we compare the brightness of the variable star with constant stars on the chip – we can work through thin cloud and also in very crowded fields. The latter was the prime motivation to move to CCD technology – most novae lie near the Galactic Plane or are in the Galactic Bulge and so are part of the Milky Way. At Sutherland we not only use the ~ 50% of time that is properly photometric, we can also use almost of the additional 25% that has traditionally been called spectroscopic time.

In the twenty-five years of photoelectric photometry I did at Sutherland before the advent of the CCD photometer I was limited to stars brighter than about 18th magnitude, and in non-crowded fields. The UCT CCD Photometer has, as planned, enabled us to reach the limiting magnitudes of each of the telescopes, and observe in the heart of the Milky Way. The "UCT CCD CV Survey" has concentrated on faint CVs, and old novae in particular. One reason for this is to determine orbital periods for novae.

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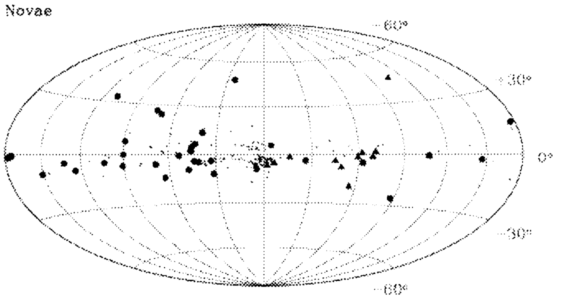

Figure 1.

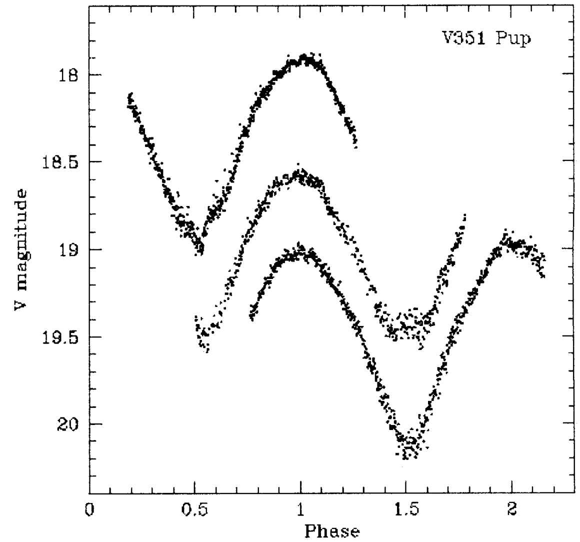

Figure 2.

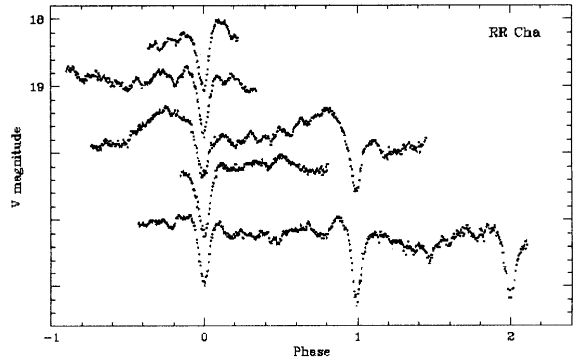

Figure 3.

To determine periods, whether of orbital humps, superhumps or rotational modulations, we compute Fourier Transforms of the light curves. The significant peaks in such Transforms show the presence of coherent periodicities. This type of analysis can be performed on line at the telescope, which means that objects not showing significant signals can be abandoned for more interesting sources; this increases the efficiency with which the telescopes can be used.

4.2 The Old Novae

In 1997, at about the time that the Survey was started, there were some 24 novae with known reliable orbital periods less than one day. Few of these had been determined from southern hemisphere observations. There are now 49 periods known (Table 1 overleaf), of which 11 of the southern ones were determined in the UCT Survey. The distribution of known periods on the sky is now more evenly shared between the northern and southern celestial hemispheres (Figure 1). The Survey has also added four new rotational periods to the list.

Finally we arrive at the point where we can display examples of the light curves of some of the old novae.

In V351 Pup (Figure 2), which is a fairly recent nova (1991), we see the presence of a large 'reflection effect' – caused by heating of the face of the secondary pointing towards the still hot primary. Only the reflection effect is capable of providing such a large amplitude of brightness variation – one side of the secondary may be at a temperature of ten or twenty thousand degrees, while the other side is only a few thousand degrees. It is an example of an orbital modulation of brightness, without eclipses. The light curve closely resembles that of Nova Cyg 1975 a few years after its eruption. As that star turned out to be strongly magnetic, we have some hopes that V351 Pup will also show the signature –

Table 1. Orbital periods of novae

Star	**Date**	**Magnitude range**	P_{orb} **(hours)**	P_{rot} **(min)**
RW UMi	1956	6 — 18.5	1.418	
GQ Mus	1983	7.2 — 18.3	1.425	
CP Pup	1942	0.5 — 15.2	1.474	
V1974 Cyg	1992	4.2 — 16.1	1.950	
RS Car	1895	7.0 — 18.0	1.977*	
DD Cir	1999	7.7 — 20.2	2.339*	11.2*
V Per	1887	9.2 — 18.5	2.571	
QU Vul	1984	5.6 — 17.5	2.682	
V2214 Oph	1988	8.5 — 20.5	2.804	
V630 Sgr	1936	1.6 — 17.6	2.831*	
V351 Pup	1991	6.4 — 19.0	2.837*	
V4633 Sgr	1998	7.4 — >20	3.014	
DN Gem	1912	3.5 — 16.0	3.068	
V1494 Aql	1999	4.0 — >16	3.232	
V1668 Cyg	1978	6.7 — 19.8	3.322	
V603 Aql	1918	-1.1 — 11.8	3.324	62.9 (?)
DY Pup	1902	7.0 — 19.6	3.336*	
V1500 Cyg	1975	2.2 — 18.0	3.351	
V909 Sgr	1941	6.8 — 20	3.36	
RR Cha	1953	7.1 — 18.4	3.362*	32.5*
RR Pic	1925	1.0 — 12.1	3.481	
V500 Aql	1943	6.6 — 17.8	3.485	
V382 Vel	1999	2.7 — 16.6	3.508	
V533 Her	1963	3.0 — 14.8	3.53	1.06
WY Sge	1783	5.4 — 20.7	3.687	

circularly polarised light – of magnetism within a few years.

In RR Cha, Nova Cha 1953 (Figure 3), we see three phenomena simultaneously. The system is obviously eclipsing, which enables us to determine the orbital period very straightforwardly, but it will be noticed that there are also large humps that move around in orbital phase – this is the signature of a superhump, which is confirmed by Fourier analysis. And finally, in some of the light curves a repetitive hump at about one seventh of the orbital period is seen. Fourier transforms of the light curves show this to be a stable modulation (of somewhat variable amplitude) with a period of 32.5 minutes, which is the signature of rotation of a magnetic primary. Subsequent to out discovery, Drs Stephen Potter and Pablo Rodriguez-Gil, working at Sutherland, have found RR Cha to have strong circular polarisation, which confirms then presence of a magnetic field.

(Table 1 continued)

Star	Date	Magnitude range	P_{orb} (hours)	P_{rot} (min)
OY Ara	1910	6.0 — 17.5	3.731	
V1493 Aql	1999	10.4 — >21	3.74	
V992 Sco	1992	8.3 — 19.1	3.686*	
V4077 Sgr	1982	8.0 — 22	3.84	
DO Aql	1925	8.7 — 16.5	4.026	
V849 Oph	1919	7.3 — 17	4.146	
DQ Her	1934	1.3 — 14.6	4.647	1.18
CT Ser	1948	7.9 — 16.6	4.68	
T Aur	1891	4.2 — 15.2	4.906	
V446 Her	1960	3.0 — 17.8	4.97	
V533 Her	1963	3.0 — 15.0	5.04	
HZ Pup	1963	7.7 — 17.0	5.11	20.0
AP Cru	1936	10.7 — 18.1	5.12*	30.6*
HR Del	1967	3.5 — 12.3	5.140	
V1425 Aql	1995	7.5 — >19	5.419	86.5
BY Cir	1995	7.2 — 17.7	6.76*	
V838 Her	1991	5.4 — 15.4	7.143	
BT Mon	1939	8.5 — 16.1	8.012	
V368 Aql	1936	5.0 — 15.4	8.285	
QZ Aur	1964	6.0 — 17.5	8.580	
DI Lac	1910	4.6 — 15.0	13.050	
V841 Oph	1848	4.2 — 13.5	14.50	
V723 Cas	1995	7.1 — >18	16.638	
CP Cru	1996	9.2 — 19.7	22.7*	
V373 Sct	1975	7.1 — 18.6	—	43.0*

*New orbital periods and rotation periods determined in the UCT Survey.

DD Cir, which was the very fast Nova Cir 1999, is the faintest nova remnant that we have found to be of particular interest. In Figure 4 (overleaf) we see that it has eclipses of moderate depth, with an upwardly convex light curve between the eclipses. We interpret this shape as being caused by reflection effect – in this case not very strong because the primary has cooled rapidly since the eruption. Fourier Transforms show that there is in addition a persistent brightness modulation at about 670 s, which again is the signature of a magnetic primary. All of this is happening at about 20th magnitude! Furthermore, from the speed class of the nova we estimate that within a few years it will settle down at about 23rd magnitude, which will make it much more difficult to observe.

In Figure 5 (overleaf) we show one night's observation of V992 Sco (Nova Sco 1992), showing an orbital modulation at 3.68 h but

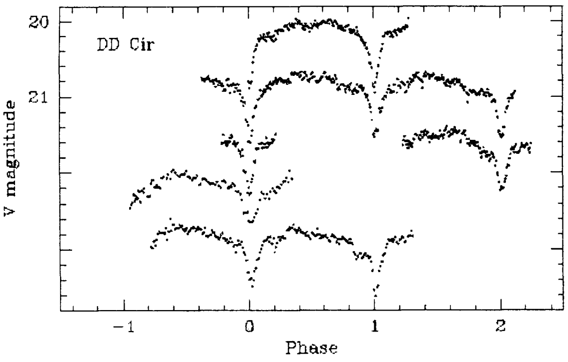

Figure 4.

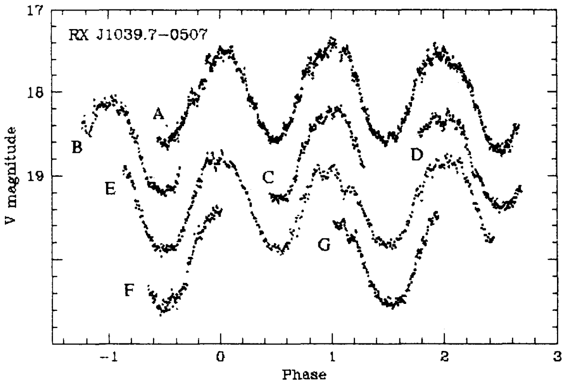

Figure 6.

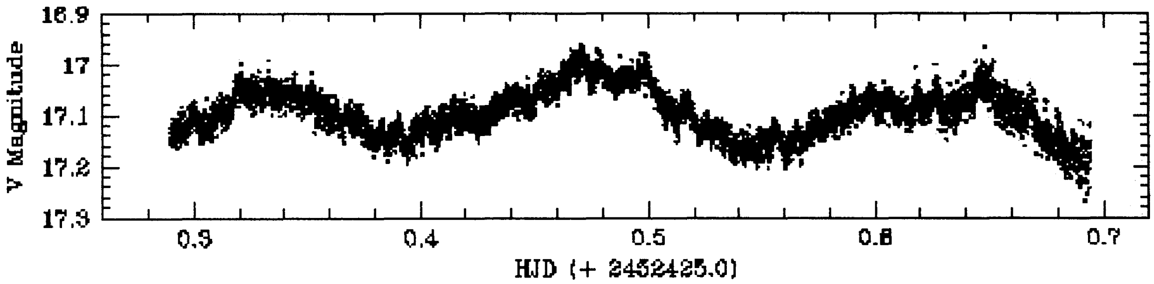

Figure 5.

no eclipses – the system is evidently not highly enough inclined to produce eclipses.

Finally, in Figure 6 we show the light curve of an X-Ray source, RX J1039.7-0507, discovered by the *ROSAT* satellite and classified as a CV from its optical spectrum. Again the large amplitude of the light modulation, which has a period of 1.574 h, is indicative of a reflection effect, which in turn suggests a very hot primary. The wiggles on the light curve turn out to be periodic and show that the primary has a rotation period of 24.07 min. Such a hot primary suggests that this star was a nova not long ago – but went unrecorded at the time. It might have reached about 8th magnitude, but because it is far from the Galactic bulge (it has Galactic latitude 45° and Galactic longitude 253°) it is not in the primary direction in which surveys for novae are made, and was probably missed for that reason.

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