The BAA VSS Long Term Polar Monitoring Programme

The first five years, 2006–2011

Gary Poyner

A report of the Variable Star Section. Director: R. D. Pickard

A programme of observation to monitor the long term optical behaviour of a small group of magnetic cataclysmic variable stars (Polars) has been set up and run by the Variable Star Section of the British Astronomical Association. Here we present the results of the first five years of our study – 2006 to 2011 – in the form of lightcurves for 17 of the 18 objects on the programme.

Introduction

Cataclysmic variables (CVs) are close binary systems where mass transfer between a white dwarf (WD) and a Roche Lobe-filling late main sequence star takes place. AM Her stars (or Polars) are CVs in which the WD has a magnetic field strong enough to synchronise the orbit of the WD and secondary star, and also prevents the formation of an accretion disc. Instead we see an accretion stream, which follows the magnetic field lines towards the WD, and impacts on the surface at one or sometimes both poles. Polars do not undergo outbursts as in dwarf novae, but rather undergo high and low states of luminosity.

The BAAVSS long term polar monitoring programme (hereafter 'Polar Programme') was conceived in 2006 following an article in BAA VSS *Circular* 129 by Prof Boris Gaensicke, Warwick University, describing the magnetic CVs and how they are the key to understanding the physical nature of the donor star within the system. Prof Gaensicke concluded his article by saying:

'*However, so far the interest in these stars has remained very feeble. It would be of great scientific interest if more CCD observers would add Polars to their regular monitoring targets, so that within a few years high quality lightcurves such as that of AM Her would be the norm, rather than the exception, for a substantial number of the known Polars. Only at that point would we have a chance to cast some light on the activity cycles of their donor stars, which is an important task for our general understanding not only of Polars, but of CVs in general*'.[1]

An opportunity had therefore presented itself for amateurs to partake in a programme to monitor a select few of these magnetic variable stars, where the resulting data would be viewed with interest by professional astronomers. A new observing programme for the VSS was raised by the author with the VSS Director who immediately agreed to the idea. Consultation with Prof Gaensicke then followed, and eventually a list of 18 stars whose long term variability was not known with any certainty was produced.

Table 1 lists these stars together with some basic information. It was agreed that the author would coordinate the programme.

Observers

Charts were prepared using photometry already available from either Dr Arne Henden (American Association of Variable Star Observers, AAVSO) or obtained by Roger Pickard. A number of these preliminary sequences were later updated by efforts undertaken by Mike Simonsen and the AAVSO chart team. These charts are readily available from either the BAAVSS or AAVSO web pages.

Observers were asked to make discrete CCD measurements or make visual observations of as many objects as possible each night, and to continue doing so indefinitely. Time series CCD observations were not required, as much of the information (orbital period, modulations) which can be obtained by such methods was already known. However Ian Miller did report several time series observations showing eclipses and orbital modulations in several systems.

The observers who participated in the project are listed in Table 2. Apart from visual observations, XG also used the remote telescopes of the Bradford Robotic Telescope[2] and the AAVSO Sonoita Research observatory (SRO)[3] to obtain data. In the table, C= clear (unfiltered), V= V-band, R= R-band and I= I-band filtered photometry.

Table 1. The Polar Programme stars

Star	*RA(2000)*	*Dec (2000)*	*Mag.max.*	*Mag.min.*	P_{orb} *(d)*
FL Ceti	01 55 43.4	+00 28 06	14.7p	17.6p	0.060516
AI Trianguli	02 03 48.6	+29 59 26	15.5V	18.0V	0.191745
V1309 Orionis	05 15 41.4	+01 04 40	15.2V	17.3V	0.332612
BY Camelopardalis	05 42 48.8	+60 51 31	14.6V	17.5V	0.139753
EUVEJ0854+390	08 54 14.2	+39 05 40	15.5C	<17.0C	0.078681
GG Leonis	10 15 34.7	+09 04 42	16.5V	18.8V	0.055471
WX Leonis Minoris	10 26 27.5	+38 45 01	?	17.5	0.116389
AN Ursae Majoris	11 04 25.7	+45 03 14	13.8B	20.2B	0.079753
ST Leonis Minoris	11 05 39.8	+26 06 28	15.0V	17.2V	0.079089
AR Ursae Majoris	11 15 44.6	+42 58 22	13.3V	16.5V	0.080501
DP Leonis	11 17 15.9	+17 57 42	17.5B	19.5B	0.062363
EU Ursae Majoris	11 49 55.7	+28 45 07	16.5B	——	0.062600
MR Serpentis	15 52 47.2	+18 56 29	14.9V	17.0V	0.078798
AP Coronae Borealis	15 54 12.3	+27 21 52	16.8B	——	0.105462
1RXSJ161008+035222	16 10 07.5	+03 52 33	15.9V	——	0.132200
V2301 Ophiuchi	18 00 35.6	+08 10 13	16.1V	21.0V	0.078480
V884 Herculis	18 02 06.5	+18 04 44	14.5V	——	0.078480
QQ Vulpeculae	20 05 41.9	+22 39 58	14.5B	15.5B	0.154520

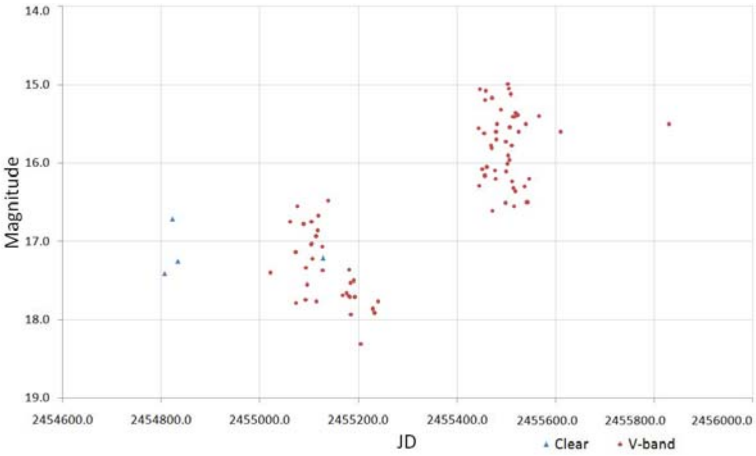


Figure 1. Lightcurve of FL Cet.

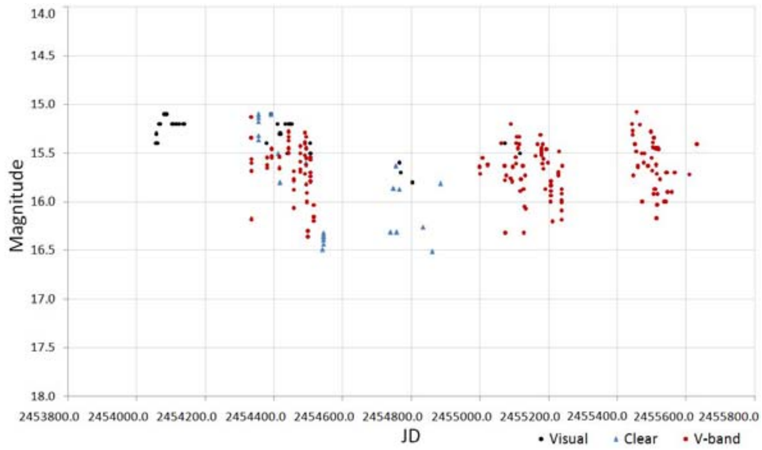


Figure 2. AI Tri. High or intermediate state with ~1 mag orbital modulations.

Results

From the period 2006 September to 2011 September, 12,871 visual and CCD observations were reported to the VSS database on the Polar Programme stars, presented here in the form of lightcurves. All the data extracted from the BAAVSS database, with the accompanying set of lightcurves, have been sent to Prof Gaensicke.

Table 3 lists a summary of activity observed during this five year period. The 'state', whether high, intermediate or low is shown, along with the time taken where appropriate for the transition from one to the other.

The light curves of Polars can be difficult to interpret, as unlike their dwarf nova cousins, large orbital variations are apparent from even a cursory glance at the graph. These orbital 'modulations' are probably caused by the changing aspect of the dominant light source in the system – the accretion stream and to a much lesser extent the impact area on the white dwarf polar region. Along with eclipses, which are observed in a number of the objects on the programme, these modulations can make the lightcurve look very strange indeed.

FL Cet: 88 observations. Observer XG. V-band. Figure 1

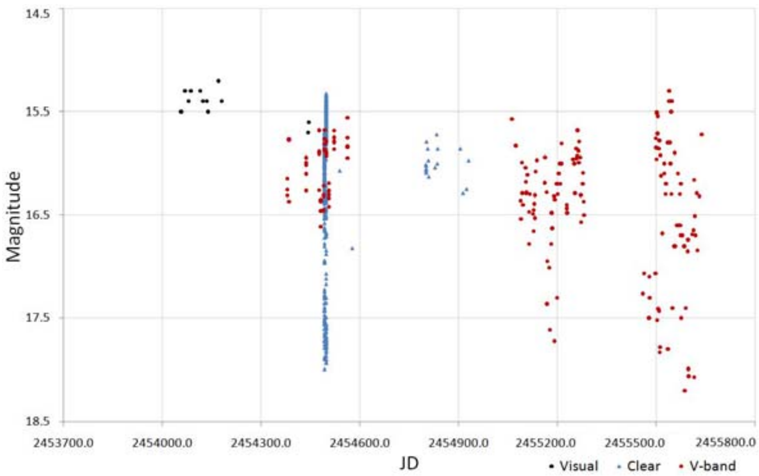
FL Cet is the shortest period eclipsing polar yet to be discovered. The orbital period (P_{orb}) is 0.060516d (1.45h) with deep eclipses of ~5 magnitudes of just 6.5 minutes duration.[4] The eclipses show up in the lightcurve as scattering. However a very obvious rise to high state was recorded in 2010 September when FL Cet peaked at *V*= 15.0. The rise to high state traversed a large seasonal gap of 200d, during which time data were not available, so it is not possible to determine the exact time the rise began or how long it took. The previous high state had occurred in 2007, and was recorded by the Catalina Real Time Transient Survey.[5] At the time this report is being prepared (2011 October), FL Cet remains in high state. In low state FL Cet is ~17.5V.

Table 2. Observers

Observer	*Code*	*Instrument*	*Method*	*Location*
David Boyd	DDB	40cm SCT	CCD (C&V)	W. Challow, Oxon.
Chris Jones	CPJ	45cm Newt.	Visual	W. Hanningfield, Essex
Ian Miller	MZ	40cm SCT	CCD (C&V)	Swansea
Roger Pickard	PI	30cm SCT	CCD C,V,R,I)	Shobdon, Herefordshire
Gary Poyner	XG	35cm SCT, 51cm Newt.	CCD (C&V) & Visual	Birmingham
Jeremy Shears	SFY	10.2cm OG	CCD (C)	Bunbury, Cheshire

AI Tri: 217 obs. Observers MZ, XG. Visual, Clear & V-band. Figure 2

AI Tri has one of the longest orbital periods known amongst polars – 0.191745d (4.6h), and emits most of its energy in X-rays. There is also the possibility that the system switches from one-pole to two-pole accretion.[6] During our study AI Tri was seen to be at high or intermediate state, varying between *V*= 15.0 and 16.5 and displaying large orbital modulations.



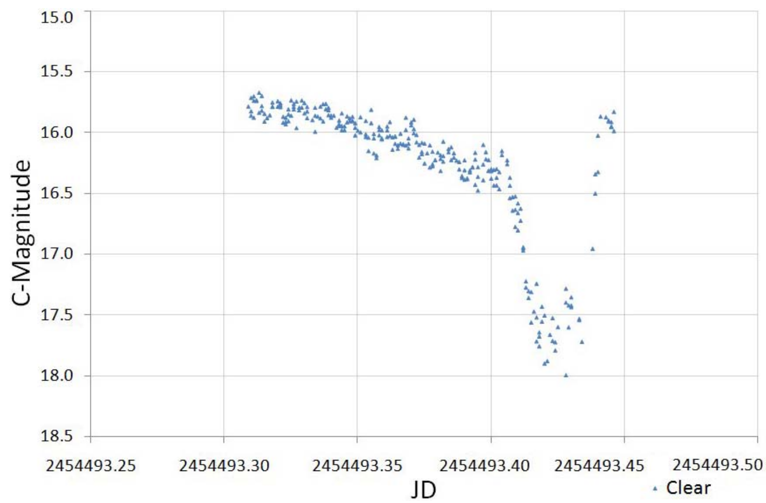


Figure 3. *(top)* V1309 Ori. Deep eclipses with a gradual decline in intrinsic magnitude. **Figure 3a.** *(bottom)* V1309 Ori eclipse *(Miller)*

Table 3. A summary of results from data obtained during 2006–2011

Star	*State seen*	*Transition*	*Comments*
FL Cet	Low/high	unknown	Rise through seasonal gap
AI Tri	High/intermediate	Slow	
V1309 Ori	High/low	Slow	
BY Cam	High		
EUVEJ0854+390	Low/high/low		Sparse data
GG Leo	High/low	Fast ~100d	
WX LMi	Intermediate/low		High state unknown
AN UMa	Low/high	Fast ~30d	
ST LMi	High/low	Fast	Active
AR UMa	High/Low	Fast	Active (2006-2008)
DP Leo	Low		Below 18.0V
EU UMa	High/Low		Poorly defined low state
MR Ser	High/Intermediate/Low		Transition covering seasonal gaps
AP CrB	High/Low?	Fast?	Rapid transition?
1RXSJ161008+035222	High/Low	Slow	Large modulations
V2301 Oph	High/Low	Slow ~500d	
V884 Her	High or intermed./low	Fast decline with slower rise	Unprecedented high state. Active.
QQ Vul	High/Intermediate		Steady

itself the difference is only 1%. Low states are of prime importance, as only at this time can the donor star be observed unhindered.

EUVE J0854+390: 374 obs. Observers MZ, SFY. Clear and V-band. Figure 5

Discovered spectroscopically from the EUVE (Extreme Ultraviolet Explorer) survey[9] and reported by Christian *et al.* in 2001,[10] the long term optical behaviour of this object remains poorly understood. VSS data is patchy. Some time series observations have been carried out by Miller, and show a modulation in excess of *C*=1.5 magnitudes (see BAA VSS *Circular* 127, 2006 March, for observations of orbital modulations by J. Shears). Our data show a rise from *C*= 16.6 mean in 2005 December to *C*= 15.5 mean in 2007 January, fading to *C*= 16.7 mean by 2008 February and recovering slightly to *C*= 16.5 by 2009 March. However large seasonal gaps are present in the data, and observations are 'light'. Further observations of this system are needed.

V1309 Ori: 771 obs. Observers MZ, XG. Visual, Clear and V-band. Figures 3 & 3a.

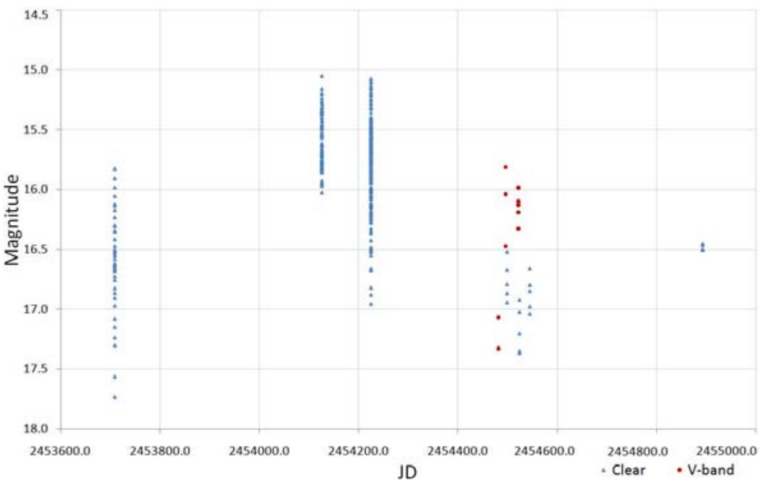
V1309 Ori has the longest orbital period yet seen in polars – 0.332612d (7.98h). It is also a deeply eclipsing system resulting in the total eclipse of the white dwarf.[7] Our data include eclipses observed by MZ (Figure 3a), which show a depth of *C*= 2.0 magnitudes and a gradual ingress, followed by a steeper egress. Applying a linear trend to the V-band data for the period covered, we see a gradual decline of *V*= 0.8 magnitudes in the intrinsic brightness of the system.

BY Cam: 647 obs. Observers CPJ, XG. Visual. Figure 4

Apart from AM Her, the prototype star in this class, BY Cam is one of the brightest polars and one of the most well observed by amateurs. The lightcurve presented here shows data for the period 1995 November – 2011 September, as the object has been under constant observation since 1995 by XG. Low states are rarely seen, the last being a reported *V*= 17.5 in 1989 January/February by Szkody *et al.*[8] BY Cam is an asynchronous polar, where the WD has a rotation period that is independent of the whole system, although in BY Cam

GG Leo: 29 obs. Observer XG. Visual, clear and V-band. Figure 6

Fortuitously GG Leo was caught fading to low state just as the first observations were made for the programme. The star faded from



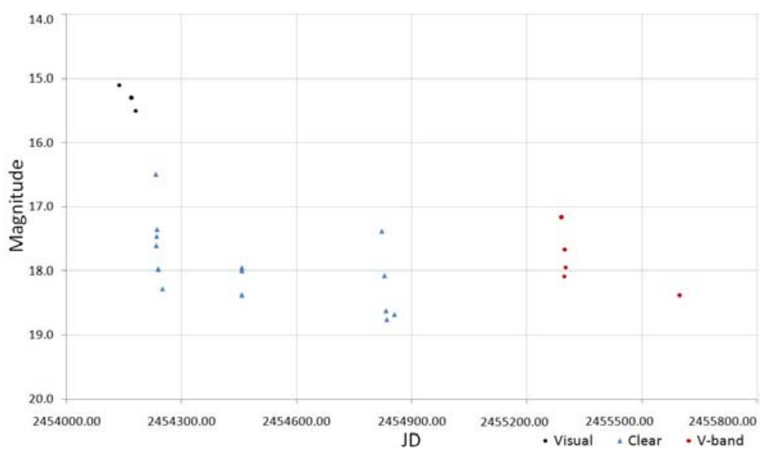


Figure 5. *(top)*. EUVEJ0854+390 showing large orbital modulations.
Figure 6. GG Leo. Fortuitously caught fading to low state.

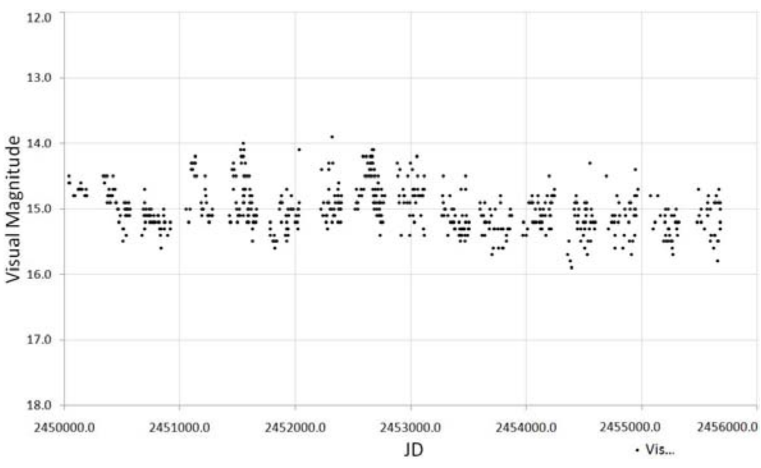
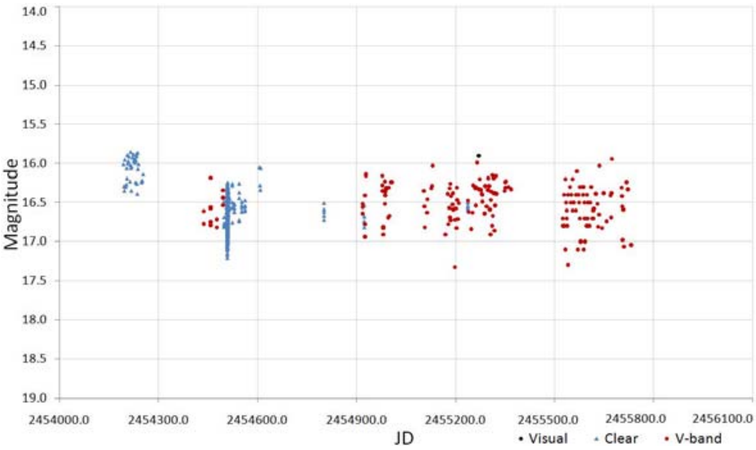


Figure 4. Lightcurve of BY Cam. One of the brightest polars.



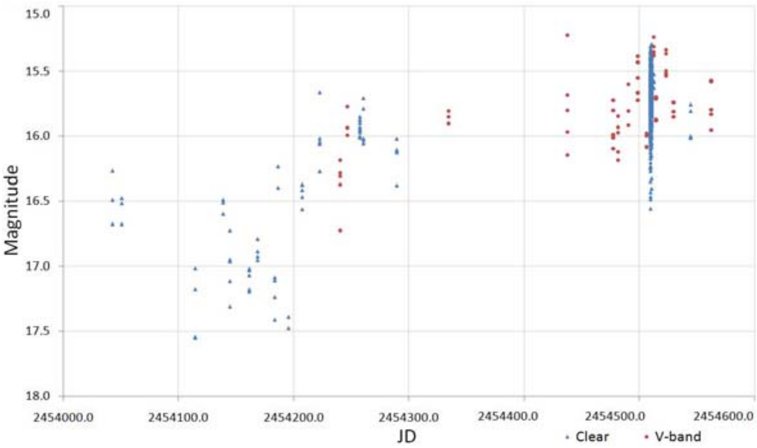


Figure 7. *(top).* Lightcurve of WX LMi.
Figure 8. AN UMa showing orbital modulations and rise to high state.

15.2 visual to *C*= 18.4 in 100 days during 2007, and remains in low state ~*V*= 18.0 at 2011 September.

WX LMi: 1,167 obs. Observers MZ, XG. Visual, Clear and V-band. Figure 7

Unusually for this class of object, WX LMi is a very low mass accretion polar, and is possibly accreting mass from a stellar wind rather than a stream. It may also be a detached (pre-Polar) system. The high state is unknown, which is the primary reason why this object was added to the programme. If a high state were detected, then this would disprove the detached binary theory.[11] Our data show the system in intermediate to low state, with orbital modulations of the order of one magnitude.

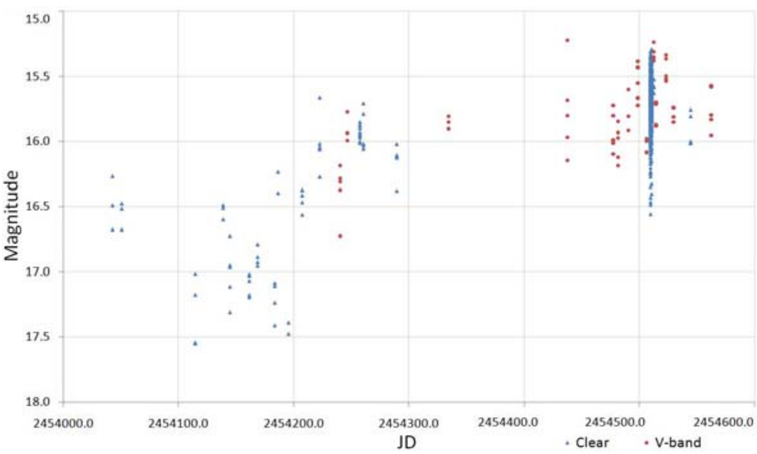
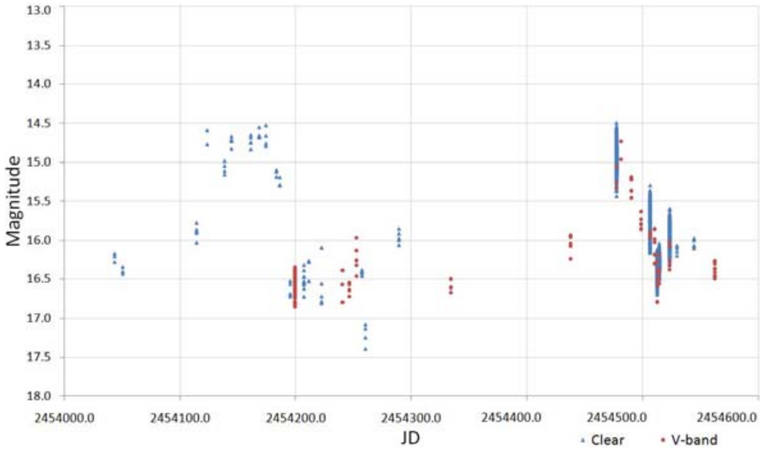


Figure 9. ST LMi. Large orbital modulations and decline to low state.



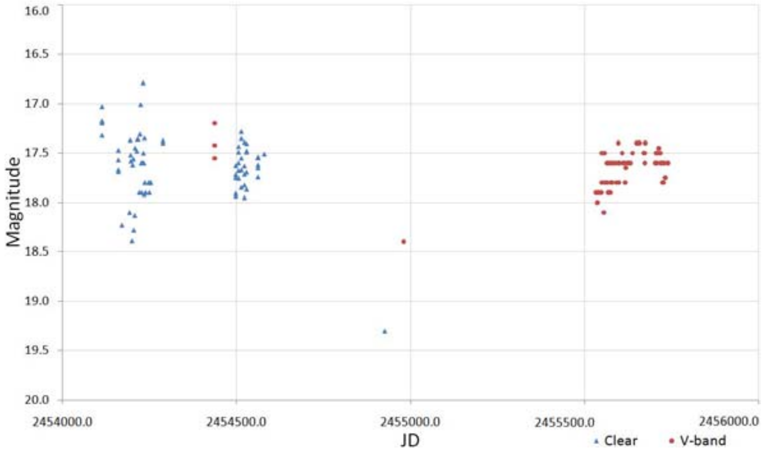


Figure 10. *(top).* AR UMa.
Figure 11. *(bottom).* EU UMa.

AN UMa: 673 obs. Observer MZ. Clear and V-band. Figure 8

Miller's data shows AN UMa to rise from low state of *C*= 17.5 in 2007 March to high state of *V*= 15.7 by 2007 May where it has remained until 2011 September. Time series observations also show orbital modulations (typical in these systems) of ~one magnitude, and using the Anova method in *Peranso*[12] gives a period of 114.91±1.6m, consistent with the published modulation period for AN UMa (Table 1).[13]

ST LMi: 3,483 obs. Observers MZ, XG. Visual, clear and V-band. Figure 9.

ST LMi is a (mainly) single-pole accretor with a P_{orb} of 0.079089d (1.9h), although accretion does occur to the second pole at times. This is one object whose long term lightcurve has been studied in some depth, most notably with RoboScope (a 0.41-m automated telescope located in Central Indiana) data providing a photometric study from 1990–2004.[14,15] Visual observations dating back to 1998 from XG have been added to the lightcurve in order to extend our observational coverage. ST LMi entered low state in 2008 January after spending the period 1998–2007 in a high state of brightness of *mv*= 15.5–16.0. A brief low state ended in 2009 June when the brightness increased to *V*= 15.5, followed by a further return to low state in 2009 October to present. Miller reports time series observations of orbital modulations consistent with the published P_{orb}.

AR UMa: 1,824 obs. Observers MZ, PI. Clear and V-band. Figure 10

AR UMa is a strong magnetic polar, with a P_{orb} of 0.080501d (1.93h) – very close to the lower limit of the period gap. Our data show an

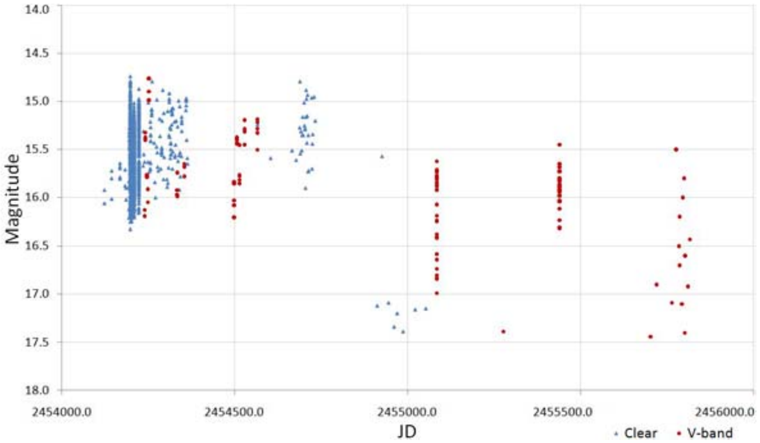


Figure 12. MR Ser. Large orbital modulations and a decline to low state with partial recovery.

active system, with two well defined high states peaking at *C*= 14.5 in 2007 January and 2008 January, and one well observed low state of *V*= 16.7 from 2007 April–December. VSS data only cover the period 2006–2008.

DP Leo: 183 obs. Observer XG. V-band

DP Leo has been in low state during our period of observation, with only seven positive observations of *V*= ~18.5.

EU UMa: 149 obs. Observers MZ, XG. Clear and V-band. Figure 11

EU UMa remains a faint and elusive object for amateur study. With a high state of *V*= 17.5 and a low state below magnitude 19 or 20, one can understand why there is sparse data. A single data point suggests one low state in 2009 April, when EU UMa faded below *C*= 19.5, recovered to V=18.4 by 2009 May after which an observational gap appears in the data until 2010 December when we see EU UMa back in high state.

MR Ser: 1,629 obs. Observers MZ, XG. Clear and V-band. Figure 12

MR Ser remained in high state (*V*= ~15.5) from 2007 April–2009 April. We then see a fade of two magnitudes to low state (*C*= 17.3) by 2009 March until a slight recovery to *V*= ~16.5 by 2009 September where the brightness level has remained. Miller reports C band time series resulting in orbital modulations at the published P_{orb} of 0.078798d (1.89h).

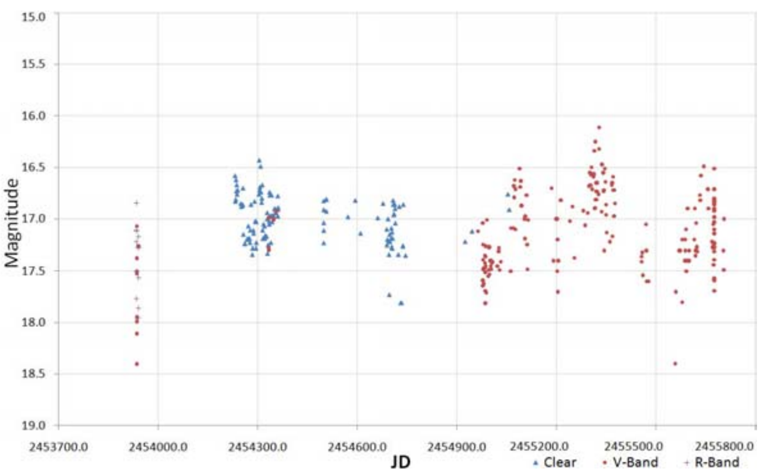


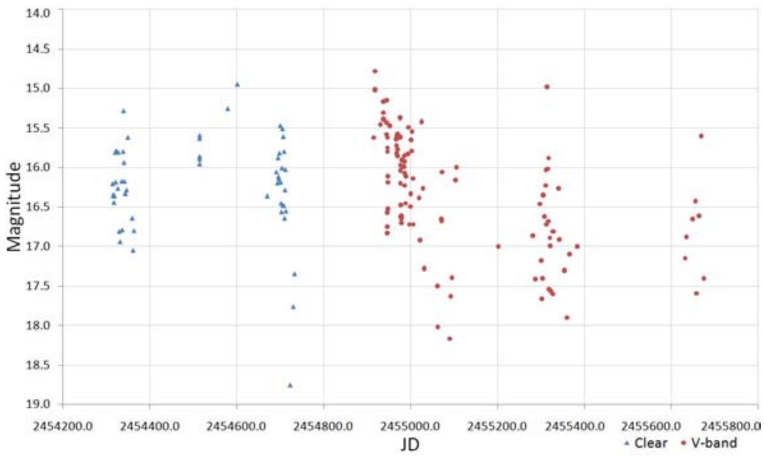
Figure 13. Lightcurve of AP CrB.

AP CrB: 333 obs. Observers MZ, PI, XG. Clear, V-band and R-band. Figure 13

AP CrB is a period gap CV, with a P_{orb} of 0.105462d (2.75h), very close to the upper edge of the gap (the period gap lies between orbital periods 2 and 3 hours, where very few CVs are found). It is a high magnetic field polar with an apparent low or non-existent accretion rate when in low state.[16] AP CrB is an active system. Our data show an amplitude of *V*= 16.0–17.5. It is not clear whether the variations are due to an orbital modulation or a rapid switching between high and low state as suggested in Tovmassian *et al.*[16] Period gap CVs are interesting to follow as they give an indication as to CV evolution, and AP CrB may provide us with answers to period gap polars over time.

1RXS J161008+035222: 181 obs. Observers MZ, XG. Clear and V-band. Figure 14

One of the most poorly observed of all AM Her stars. First identified as a magnetic CV in 2000 by Jiang *et al.*, the published P_{orb} of 0.132200d (3.17h) is by no means a certainty and to the author's knowledge, no optical lightcurve has yet been published. Our data show large orbital variations in excess of 1.5 magnitudes. The catalogued high state is *V*= 15.9, but the lightcurve suggests a somewhat brighter figure of *V*= ~15.5. The mean magnitude has decreased from *V*= 15.6 mean in 2009 May to *V*= 17.2 mean by 2011 April where it has remained. This is a slow progression to low state, if indeed this is what we are seeing. Hopefully observations over the next five years may prove to be enlightening, providing more observers add the star to their programmes.



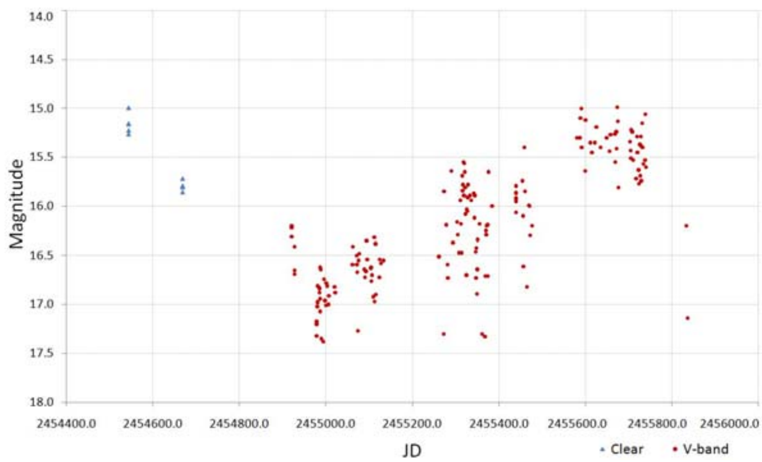
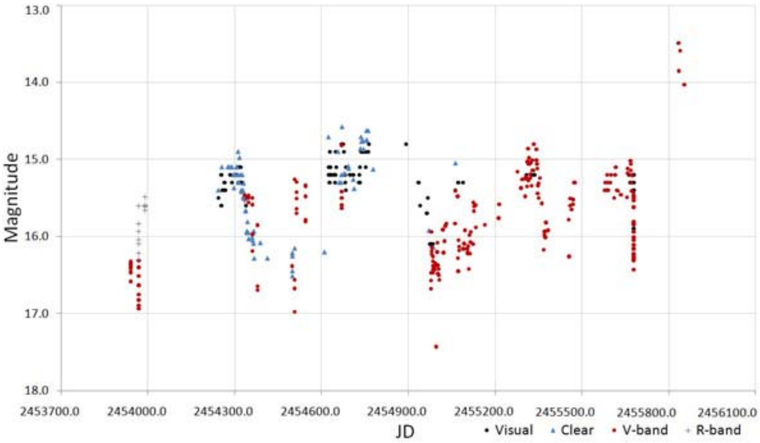


Figure 14. *(top).* 1RXSJ161008+035222
Figure 15. *(bottom).* V2301 Oph.



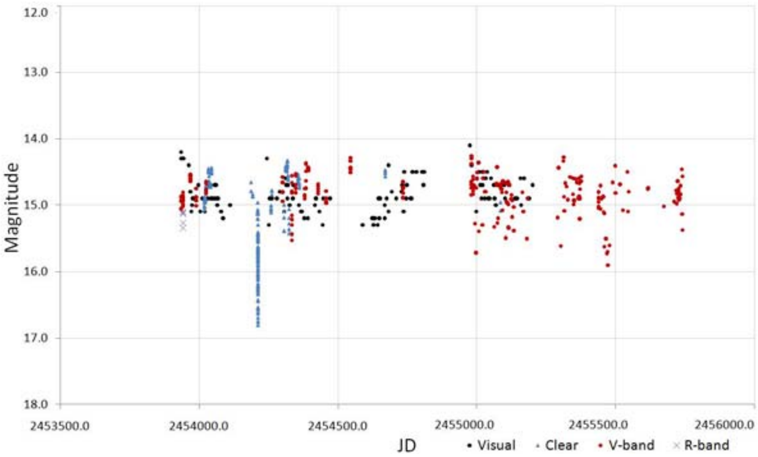


Figure 16. *(top).* Lightcurve of V884 Her showing the unprecedentedly high state observed in 2011.
Figure 17. *(Bottom).* QQ Vul

V2301 Oph: 188 obs. Observers MZ, PI, XG. Clear and V-band. Figure 15

First identified as a magnetic CV in the late 1980s, V2301 Oph was initially thought to be an intermediate polar (IP), as observations seemed to show the presence of a small accretion disc. It wasn't until 1998 that it was conclusively identified as an AM Her object with one of the weakest magnetic fields known, and an eclipsing object in both the optical and X-ray.[17] Our data show a fade from high state in 2008 March at C= 15.3 to low state V= 17.0 by 2009 May, followed by a steady rise back to high state by 2011 April. We then have a long seasonal gap until 2011 September where a fade to low state is seen, and V= 17.14 is recorded on October 1.

V884 Her: 380 obs. Observers MZ, PI, XG. Visual, clear, V-band & R-band. Figure 16

Next to AR UMa, V884 Her has the strongest magnetic field known in this class of object. The P_{orb} has been measured as 0.078480d (1.88h), but because of a lack of an observed low state, neither stellar component has yet to be detected in the optical light curve.[18] Schmidt *et al.*[19] also suggest a 1–2 mag change in optical brightness due to 'accretion activity', and we do indeed see this in our data, along with the system spending much of its time during our observational study in an intermediate state of brightness. This was the case until mid October 2011 when observations from the AAVSO's SRO-50 telescope were belatedly sent to observers. Examination of the images obtained by XG, and images recorded independently by PI show a much brighter 'high state' than the recorded value of V= 14.5. On Sep 29.219 UT a V= 13.49 was recorded, fading to V= 14.03 by Oct 19.828. This to our knowledge is an unprecedented level of brightness previously unseen within this system. We can have no idea as to when this 'outburst' state began, because of the gap between observations from June to September, but hopefully we can cover the decline and any further irregularities in the optical light curve which may result from this high brightness level.

QQ Vul: 555 obs. Observers DDB, MS, PI, XG. Visual, Clear, V-band & R-band. Figure 17

QQ Vul has benefited over the years from long term photometric studies, not least from a Moscow plate survey obtained from 1962–1982, and a *Roboscope* survey from 1991–2001.[19] In both cases the lightcurves of the optical behaviour of QQ Vul match our own. However whilst the *Roboscope* survey is now complete, we hope to continue for the foreseeable future. Our data show a steady mean magnitude of V= 14.7 superimposed on to which can be found variations in the order of V= 1.0 mag and C= 1.5 mag. These dips vary with time, and do not follow the 0.154520d (3.7h) orbital period of the system. These dips are probably due to cyclotron beaming or grazing occultations of the (single) accretion pole.[20] At no time in our study did QQ Vul enter low state.

Conclusion

Although the objects on this BAAVSS programme are well known to professional astronomers in that the orbital, primary and secondary star information is known in some detail, the long term study of these objects and how they behave photometrically over a period of time remains a grey area. The purpose of this programme is to fill in some of those gaps. This has in a small way been achieved by the detection in late 2011 of an unprecedentedly bright high state in V884 Her. One might be tempted to say that the detection was due solely to V884 Her being monitored as part of this programme. Although the response from observers – especially CCD users – has been far from enthusiastic for this project, the small group of active participants has provided good coverage for most stars and excellent coverage for a few.

In view of the interesting data obtained during this 5 year period and described in this paper, it has been agreed to extend the Polar Programme for a further 5 years. The author very much hopes that more observers will join in observing these interesting, and astrophysically significant, objects.

Acknowledgments

The author wishes to thank Prof Boris Gaensicke, Dept of Physics and Astronomy, Warwick University, for his help and encouragement in setting up this programme, and the continued advice he has given over the last five years. Also Andy Wilson and Clive Beech, database secretaries of the BAAVSS, who extracted the data for the 18 objects in the study from the relevant database. The referees Jeremy Shears and Dr Chris Lloyd, for their helpful advice and useful suggestions. The AAVSO for the use of the 35cm SCT and later the 50cm Newtonian reflector at their Sonoita Research Observatory, Arizona, from which all the author's V-band data were obtained. Mike Simonsen of the AAVSO, for updating sequences for objects on the programme, and BAAVSS Director Roger Pickard for his useful comments and correction of errors in the text. The author's visual observations are partly supported by a BAA Ridley Grant. This research has made use of NASA's Astrophysical Data System.

Address: 67 Ellerton Road, Kingstanding, Birmingham B44 0QE. *[garypoyner@blueyonder.co.uk]*

References

1 BAAVSS *Circular* 129, 2006 September
2 The Bradford Robotic Telescope. **www.telescope.org**
3 SRO. **http://www.sonoitaobservatories.org/sonoita_research_observatory.html**
4 Schmidt *et al.*, 'Unveiling the puzzle of the eclipsing polar SDSS J015543.40 +002807.2 with XMM and optical photometry/spectro polarimetry', *ApJ.*, **620**, 422–431 (2005)
5 Drake *et al.*, *ApJ.*, **696**, 870 (2009)
6 I. Traulsen *et al.*, 'X-ray spectroscopy and photometry of the long period polar AI Tri with XMM Newton', **http://arxiv.org/abs/1004.1629v1** (2010)
7 A. Staude *et al.*, 'System parameters of the long period polar V1309 Ori', **http://arxiv.org/abs/astro-ph/0105362v1** (2001)
8 Szkody P., Downes R. & Mateo M., *PASP* **102**, 310 (1990)
9 **http://www.ssl.berkeley.edu/euve/**
10 Christian D. J. *et al.*, *IBVS* 5032, **http://www.konkoly.hu/cgi-bin/IBVS?5032** (2001)
11 Gaensicke B. *et al.*, 'Monitoring the long term variability of CVs from the Hamburg Quasar Survey', **http://deneb.astro.warwick.ac.uk/phsdaj/HQS_Public/HQS_Public.html**
12 Vanmunster T., *Peranso*, **http://www.peranso.com**
13 Ramsay *et al.*, 'ROSAT observations of AN UMa and MR Ser: the status of the soft X-ray excess in AM Her stars', *MNRAS* **270**, 692–702 (1994)
14 Kafka *et al.*, 'A photometric study of the cataclysmic variable ST LMi during 2005–2006', *ApJ.*, **133** (2007)
15 Kafka & Honeycutt, 'High/Low states in magnetic cataclysmic variables', *ApJ.*, **130** (2005)
16 Tovmassian G. H. *et al.*, 'The new cataclysmic variable RX J1554.2+2721 in the period gap', **http://arxiv.org/abs/astro-ph/0110048v1** (2001)
17 Thomas & Steiman–Cameron, 'V2301 Ophiuchi: An X-ray bright eclipsing AM Herculis object', *ApJ.*, **515**, 404–413 (1999)
18 Schmidt *et al.*, 'The cyclotron fundamental exposed in the high field magnetic variable V884 Herculis', *ApJ.*, **553**, 823–831 (2001)
19 Kafka & Honeycutt, 'The puzzling optical light curve of the polar QQ Vulpeculae', *AJ*, **125** (2003)
20 Robert Smith, *private communication*, 2010 April

Received 2011 October 26; accepted 2012 January 25