Feeding Compact Objects: Accretion on All Scales
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High Speed Optical Photometry of LMXBs and CVs

Paul A. Mason[1], Edward L. Robinson[2], Sebastian Gomez[1], Emmanuel Gonzalez[1], Isaac D. Lopez [1], Lorena Monroy [1], and Alex Price [1]

[1]Department of Physics, University of Texas at El Paso, 500 West University Avenue, El Paso, Texas 79968 USA
email: paason@nmsu.edu

[2]Department of Astronomy, University of Texas at Austin, 1 University Station, Austin TX, USA

Abstract. High speed photometry of several accreting binaries was obtained using the McDonald Observatory 2.1m telescope and ARGOS CCD photometer. A broad-band filter (BVR) was used in order to maximize flux and maintain a short (1-10s) integration time on faint targets. Such observations obtained over several years allow for variability study over time scales covering many orders of magnitude. Observations and analysis for several binaries are summarized.

Keywords. X-ray Binaries, Cataclysmic Variables, Optical Photometry

1. V1727 Cygni - An LMXB in a Triple System

V1727 Cygni is a transient LMXB containing a neutron star, currently in quiesence. Thorstensen (1979) measured its optical light curve during outburst and obtained a period of 5.24 hours, interpreted as the orbital period of the binary. V1727 Cygni is a hierarchical triple system with an F class star in wide orbit about the close LMXB pair (Bothwell, 2008). We have detected a sinusoidal variation with a period of 0.10912971 ± 0.00000063 days, which we interpret as ellipsoidal variations at an orbital period of 0.21825942 ± 0.00000126 days. The fractional amplitude is 0.00321 ± 0.00014 with zero phase of the sine curve at HJD 2455443.6750 ± 0.0016 (Price *et al.* 2012). All of the data from 19 nights are phased with this ephemeris and are shown in Fig. 1.

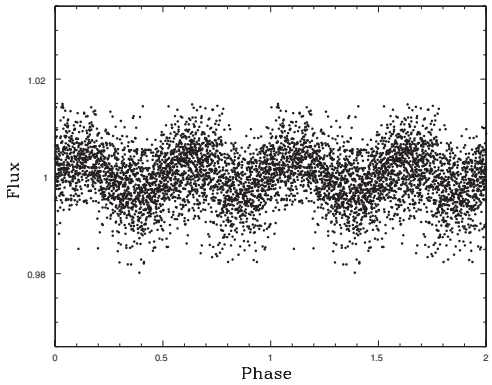

Figure 1. V1727 Cygni: Broad band optical (BVR filter) photometry collected over 19 nights is shown phased with the orbital period given in the text.

2. J1118+480 - A Black Hole LMXB

The black hole LMXB J1118+480 was observed on 30 nights from 2004 to 2012. Example data from one run, six nights, are shown in Fig. 2. Integration times were 10 seconds and a broad band (BVR) filter was used. All light curves display similar orbital modulation interpreted as ellipsoidal variations. On the first night, the mean brightness was lower than on the subsequent nights and there is low level flickering. Flickering is observed predominately during the bright phases of the orbital variation. As seen in Fig. 2, the minima on the forth and sixth nights of data are only slightly higher than the minima on the first night. However the bright phase intensity and high speed flickering intensity increased substantially. From 2010 and 2011 data, a period study yielded P = 0.08496672 ± 0.00000024 days, corresponding to one-half of the orbital period, with a zero point crossing (negative to positive) of T(zero) = 2455324.60280 ± 0.00025 HJD (Monroy *et al.* 2012).

3. PSR J1023+0038 - An LMXB with a Pulsar Primary

Optical observations of the low-mass X-ray binary PSR J1023+0038 are presented. CCD photometry was collected with 10 second integrations. Data were obtained during seven nights in February 2011 and January 2012. The light curves are quite similar to those obtained in previous studies, allowing a systematic period study of new data combined with three epochs of published light curves, covering a span of 8 years. An unambiguous period of 0.1980962(4) days is derived, in agreement with Archibald *et al.* (2010).

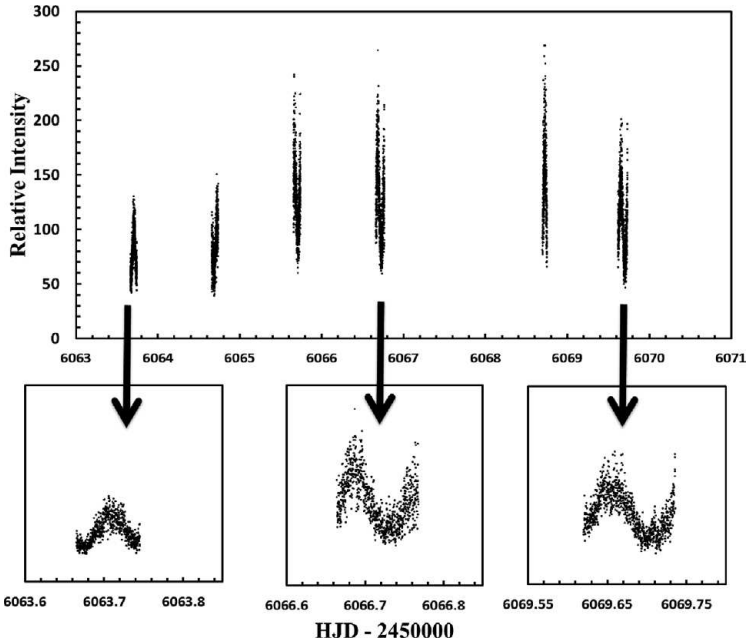

Figure 2. J1118+480: The top panel shows one run of data covering six nights. Three of those nights are shown with an expanded scale in the bottom three panels. On the first night, the mean brightness was lower than on the subsequent nights and there is low level flickering. The middle and right lower panels show intense flickering and a significantly higher mean brightness.

4. V1055 Orionis (= 4U 0614+091) - An Ultra-Compact Binary

V1055 Orionis (= 4U 0614+091) is thought to be an ultra-compact binary containing a neutron star primary accreting from a white dwarf companion. Froning *et al.* (2012) obtained HST-COS spectra showing strong CIV and OV emission lines. High-speed broadband optical observations were obtained on 14 nights in 2010, 2011, and 2012. The nightly mean brightness remained quite stable over the dataset. The light curve is dominated by complex oscillatory behavior reminiscent of the beating of hidden frequencies. A variety of photometric periods have been previously reported and none are found to be coherent periods in our dataset. Rather, a given night exhibits short lived quasi-periodic variations covering a variety of time scales, especially 10-40 min and even as long as two hours. This short period variability combined with recent spectroscopic abundance studies suggests that the likely donor in this binary is a white dwarf. Six nights of data are shown in Fig. 3.

5. FL Ceti - The Shortest Period Eclipsing Polar

We used a 1 second integration time to observe the eclipsing cataclysmic variable FL Ceti in order to resolve the extremely rapid variations during eclipse ingress and egress (O'Donoghue *et al.* 2006). FL Ceti is a polar. Our photometry clearly shows that the the majority of the optical flux originates from two very small accretion regions at the foot-points of the magnetic field. Example data from one run are shown in Fig. 4. An expanded view of one eclipse is shown in the bottom panel.

Our observations of UW CrB presented in this talk and excluded herein are presented by Mason *et al.* (2012). This work is supported by the NSF/PAARE grant No. 0958783.

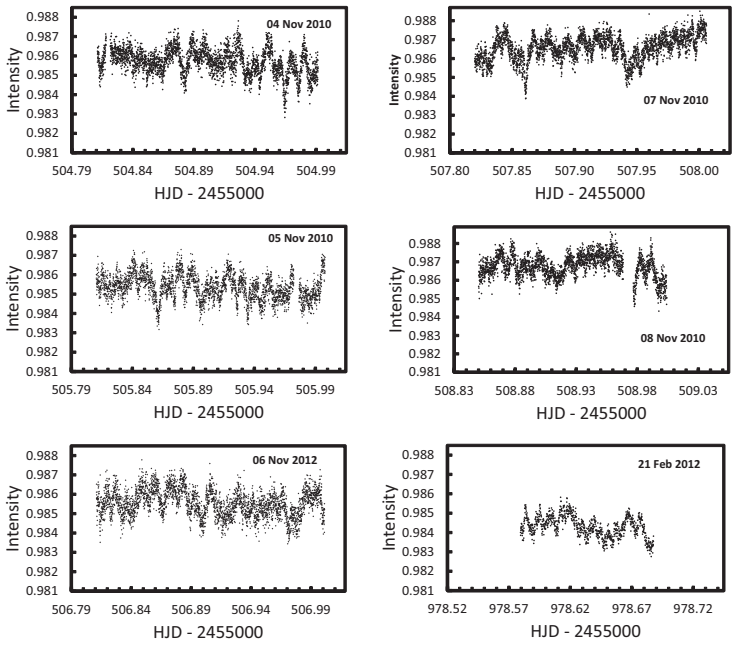

Figure 3. Light curves of V1055 Orionis on six nights in 2010 and 2012. The system varies at time scales from a few seconds to a few hours, especially in the 10 to 40 minutes range. We have not found any persistent period that might be attributed to an orbital modulation.

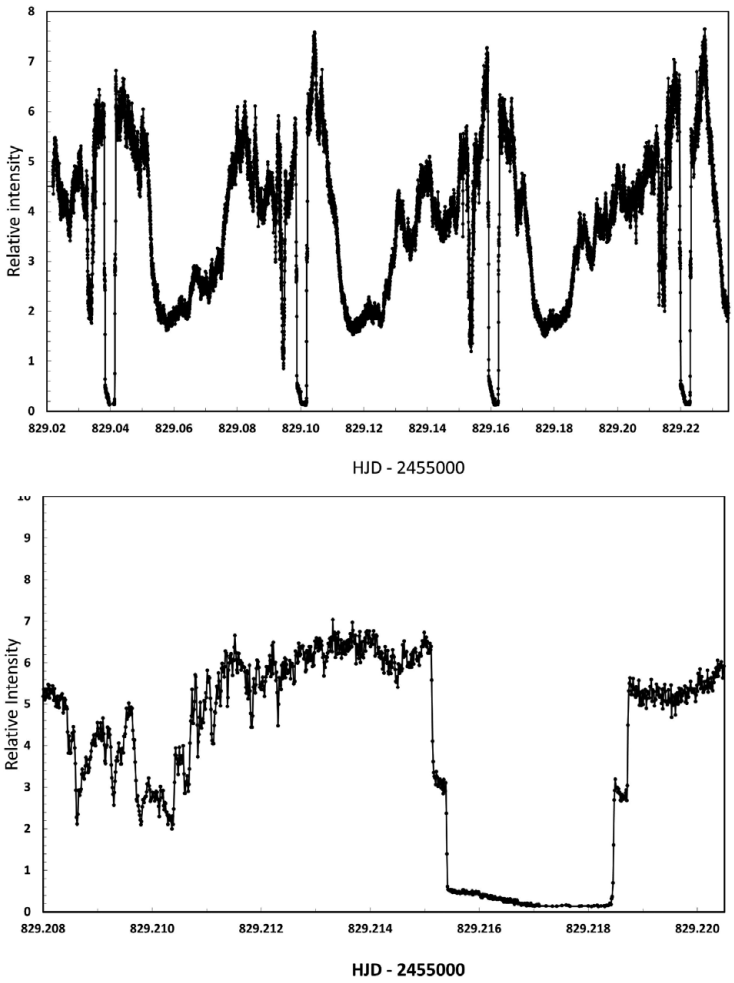

Figure 4. Optical (BVR) observations of the shortest period eclipsing polar FL Ceti. There is a sharp drop, $\sim 3s$, to a mid-level pause and another sharp drop showing only the uneclipsed part of the white dwarf. Thus, the vast majority of the optical light originates from two very small magnetic accretion regions on the surface of the white dwarf. After eclipse of the second spot, the white dwarf is progressively eclipsed, leaving only the faint light of the secondary during total eclipse. Eclipse egress features are similar to ingress, except that the appearance of the white dwarf occurs quicker than its disappearance.

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