Insights into Accretion in Cataclysmic Variables Gleaned from Kepler/K2

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A Cataclysmic Variable:

- is a close binary system
- has a white dwarf primary
- has a cool low mass secondary
- actively transfers mass
CV Types

B<1MG
- outbursts

Disk System

B=1-10MG
- mostly high state

B>10 MG
- high, low states
- WD spin = orbit

Polar

LARP
- all low state

Intermediate Polar
- WD spin ~ 1/10 orbit
DISK ACCRETION

Dwarf nova outbursts

Outburst or high state

Quiescence or low state

MAGNETIC ACCRETION

High and low states

White dwarf

9000-4000 K

10^8 K

Cool supersonic accretion flow

Hot subsonic settling flow

White dwarf photosphere

Soft X rays and UV

Magnetic field line

Hard X rays

X-rays
## Timescales for Kepler/K2 Studies

<table>
<thead>
<tr>
<th>Variability</th>
<th>Typical Timescale</th>
<th>Amplitude (mag)</th>
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<tr>
<td>Flickering</td>
<td>sec – min</td>
<td>tenths</td>
</tr>
<tr>
<td>WD pulsation</td>
<td>4–10 min</td>
<td>0.01–0.1</td>
</tr>
<tr>
<td>AM CVn orbital period</td>
<td>10–65 min</td>
<td>0.1–1</td>
</tr>
<tr>
<td>WD spin (intermediate polars)</td>
<td>20–60 min</td>
<td>0.02–0.4</td>
</tr>
<tr>
<td>CV orbital period</td>
<td>10 min–10hrs</td>
<td>0.1–4</td>
</tr>
<tr>
<td>Accretion Disks</td>
<td>2–12 hrs</td>
<td>0.4</td>
</tr>
<tr>
<td>AM CVn Outbursts</td>
<td>1–5 days</td>
<td>2–5</td>
</tr>
<tr>
<td>Dwarf novae Outbursts</td>
<td>4 days–30 yrs</td>
<td>2–8</td>
</tr>
</tbody>
</table>
Some of what we have tried to learn from 10 yrs of Kepler/K2 data~ 25/110 CVs

1. Disk systems
   • disk changes before, during & after outburst
   • white dwarf pulsations after outburst

2. Magnetic systems
   • mass transfer changes from low to high state
   • spin changes during orbit and long term
   • activity in pre-polars
Outbursts and Disk Changes

Kepler light curves show a variety of outburst behaviors in frequency and shape of outbursts
Short period systems (P< 2 hrs with M2/M1<0.25) show Superoutbursts, Superhumps. Matt Wood derived properties of disks from SPH simulations of Kepler V344 Lyr data.
HS Vir

$P_{\text{orb}}=1.8\text{hr}$

K2-6

K2-17

Normal outbursts build up in amplitude before a SOB (some fail)
MLS0359+17 (SDSS0359 +17) K2-4 LC (30 min)

Feb 2 – Apr 24, 2015  \( P_{\text{orb}} = 1.9 \text{ hr} \)

MLS0359 – first eclipsing dwarf nova with an SOB

\[ P = 1.91 \text{ hr (115 min)} \]

1.3 mag eclipse

K2-4 – SC (1 min) at quiescence

Highly variable hot spot
No orbital hump for 4 orbits prior to SOB

-Littlefield et al. 2018
Orbital hump and eclipse egress shift toward earlier phases after SOB implies disk shrinkage after outburst as predicted by TTI (Osaki 1989)
K2-7  V729 Sgr  Ramsay et al. 2017

*P=4.16 hr, shallow eclipse
*most frequent outbursts for P> gap
* neg SHs at quiescence

Eclipse shifts to shorter P during outbursts due to lack of hot spot at outburst
SDSS 1238-03 (V406 Vir) K2-10


8.5 hr brightness increases (thermal instability in disk?)

40 min (1/2 P_{orb}) modulation (due to spiral shocks)
GW Lib- dwarf nove $P_{\text{orb}}=76\text{min}$, WD pulsations at 230, 380, 650 sec at quiescence K2-15 (10 yrs after SOB), $P=19\text{ min}$, 4 hrs, 273 sec in UV only during peak of 4 hr
Boris Gaensicke PI HST UV – 9 orbits + 39 Swift obs during K2-15

273 sec pulse shows up only during peak of 4 hr modulation!

Conclusions:
19 min is fundamental mode
4 hr either modulation of accretion rate or pulsation?
Systems with Magnetic WDs

- IP FO Aqr reveals spin changes
- Polar Tau4 shows low-high state change
- Pre-polar V1082 Sgr shows activity
K2-3 Intermediate Polar FO Aqr
1 day of SC observations
$P_{\text{orb}} = 4.85 \text{ hr}$  $P_{\text{spin}} = 20.9 \text{ min}$

Accuracy of spin determination from K2 comparable to decades of normal observations – K2 showed FO Aqr is spinning down
FO Aqr

Amplitude of spin lowest at phase 0, highest at 0.7
Tau4, first Kepler Polar - K2-13 P=1.6hr, B~20MG

See Colin Littlefield poster #84

Low state for ~70 days

Transition to high state in ~8 days
Activity in pre-polar V1082 Sgr P=20.8 hr, 29 days cyclic lows and highs

See Gagik Tovmassian poster #96
Summary of Kepler/K2 Results

- amplitude and shape of outbursts shows buildup of disk, activity prior to an SOB, shrinks after
- hot spot changes as the 3:1 resonance is reached
- eccentric disk develops in a few hours
- new modes are observed in accreting pulsating WDs after a superoutburst and last for a decade
- the changover from a low to high accretion state in a polar takes place in ~ week
- spin period and amplitude changes in IPs
- a pre-polar can have accretion activity
We will miss the long, uninterrupted cadence of Kepler/K2 for CV work!

TESS will partly help but then?