Planets around Post Common-Envelope Binaries

Tom Marsh

Department of Physics, University of Warwick

Responsible for most of the work: Madelon Bours, Steven Parsons
Post Common-Envelope Binaries (PCEBs)

SDSS: \textbf{2300+} detached white dwarf / main-sequence binaries (Rebassa-Mansergas+ 2012)

CRTS: $\sim 100$ eclipsers (Parsons+ 2013; Drake+ 2014)

\textit{A decade ago: just 5}

Orbital periods of eclipsing WD/MS binaries. Compact systems with separations $\sim 1 – 10 \text{R}_\odot$
Eclipsing white dwarfs can be timed precisely: can measure eclipse times to $< 0.05 \text{s}$. Jupiter moves the Sun by $\sim 2 \text{s}$.

(No sniggering, pulsar people.)

PCEB timing is sensitive to $\ll M_J$ circum-binary planets on solar system-scale orbits.

30-mins in the life of GK Vir, a hot WD + $0.1 M_\odot$ dM eclipser Parsons+ (2010).
Perturbation by “third” bodies

Unseen object

Unseen object
different time

Eclipse arrival time
delayed or advanced

PCEBs are so compact that this a simple Rømer delay, not a TTV-like orbital dynamics effect.
All that glisters is not gold

Period variations in PCEBs (and other binaries) have been known for years. Only recently has it become fashionable to infer planets.

Long, long ago, in the era BP, there lived the dreaded “Applegate”

Applegate (1992) suggested that period variations can be driven by variations in the quadrupole moment of the MS star driven by internal angular momentum exchange.

Applegate is not without cost: it needs power.

Variations in quadrupole moment change the gravitational attraction between the stars.
NN Ser, 3.1 h WD+dM binary. Variations too large for feeble 0.11 \( M_{\odot} \) M star to drive (Brinkworth+ 2006).

Two planets, with masses of 6.9 and 2.2 \( M_J \) in 15.5 and 7.7 yr orbits provide an excellent fit.

...but is this just a visit from Mr G. Ive-Me-Enough-Free-Parameters-And I-Will-Fit-Anything?

Two planet fit to NN Ser times, Beuermann+ (2010)
NN Ser, up to May 2014

![Graph showing data points on a cycle number vs. O-C (secs) plot, with cycles marked for 2011 and 2012.](image-url)
NN Ser, up to May 2014

![Graph](image)

- Predictive power (update of Marsh+ 2014; also Beuermann+ 2013)

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Predictive power . . . (update of Marsh+ 2014; also Beuermann+ 2013)
NN Ser, dynamical stability

Grey: $< 10^5$ y; Red: $> 10^5$, $< 10^6$ y; Blue: $> 10^6$ y
PCEB Eclipse Timing (PET) Project

- Tracking $\sim 80$ systems with the Liverpool Telescope + RISE, Thai National Telescope + ULTRASPEC, and WHT & NTT + ULTRACAM observations.

- $\sim 500$ eclipses observed to date

- Period changes detected in 30 systems, but 19 out of 21 with $\geq 4$ y coverage.

- Observing WD+WDs, WD+BDs, WD+dMs, CVs. Large range of $L_2 (> 10^4 \times )$ & $R_2/a$ to test Applegate.
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Brown Dwarfs?

V471 Tau

\[ O - C \text{ (sec)} \]

\[ \text{Time [years]} \]
Brown Dwarfs?

RX J2130.6+4710

![Graph showing data over time](image)
Brown Dwarfs?

SDSS J1435+3733

$O - C$ (sec) vs. Time [years]
Planets?

NN Ser

![Graph showing data points over time]

Time [years] vs. $0 - C$ (sec)
Planets?

GK Vir

Time [years]
Planets?

CSS 080502

![Graph showing data points with error bars, labeled with axes: Time [years] and 0 - C (sec).]
Nothing?

CSS 09704

\[ 0 - \Delta C \text{ (sec)} \]

Time [years]
Nothing?

SDSS J1035+0551

$O - C$ (sec) vs Time [years]
Nothing?

CSS 03170

\[ 0 - C \text{ (sec)} \]

Time [years]
Errr . . . ??
Errr . . . ??

HU Aqr

Time [years]

O - C (sec)
This is CSS 41177, one of 5 known double white dwarf eclipsers. (Parsons+ 2011, Bours+ 2014). Many more (> 100) of these should come from GAIA & LSST. They should be excellent clocks.
Conclusions

- PCEBs enable detection of circum-binary planets through timing.

- Majority of systems show $\dot{P}$ after 4+ years timing.

- Planets work for NN Ser, but definitely not for others. At the same time, little support for Applegate.
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- **Qs**: current stability? pre-CE stability? survival through the CE? first vs second gen. planets? CE fallback discs? if not planets or Applegate, then what? (Mustill+ 2013; Zorotovic & Schreiber 2013; Bear & Soker 2014)

Future:
- Better clocks: WD+WDs and WD+BDs.
- Independent evidence: direct imaging, astrometry.
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  - Better clocks: WD+WDs and WD+BDs.
  - Independent evidence: direct imaging, astrometry.