28 mins

White Dwarfs in Binary Systems

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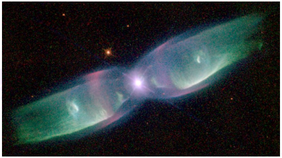
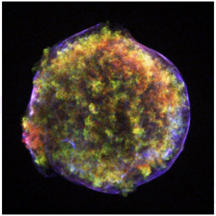
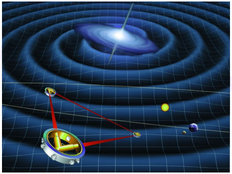
Collaborators: Steven Parsons, Madelon Bours, Boris Gänsicke, Stelios Pyrzas, Danny Steeghs, Chris Copperwheat, Vik Dhillon, Stu Littlefair







White dwarfs in binaries . . .

- the sites of classical nova and Type Ia supernova explosions;
- provide easily-observed examples of accretion, both discs and magnetically-dominated;
- widened range of white dwarf properties (bulk composition, mass, spin, surface pollution, magnetism);
- precision parameters of white dwarfs and their companions;
- dominant gravitational wave sources for eLISA.

Types & Numbers

Type	Number known	Total in Galaxy ($\times 10^6$)
Accreting WD+MS (CVs)	3000	2 – 10
WD+MS (detached)	2300	100 – 300
WD+WD	100	100 – 300

(other combinations possible: WD+RG, WD+sdB, WD+NS, . . .)

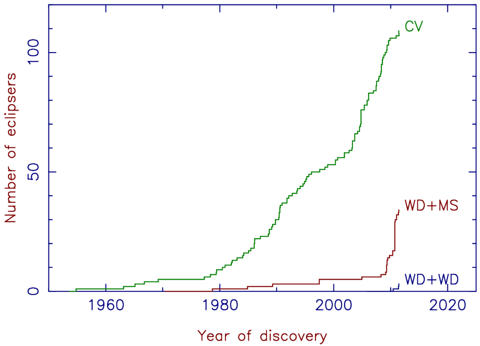
Progress:

In 2000 we knew of 4 eclipsing WD+dM stars; we now know 86.

The Rise of White Dwarf Binaries

Progress has been driven by spectroscopic and variability surveys (SDSS, CSS, PTF).

GAIA & LSST will have a major future impact. e.g. GAIA will find $\sim$ 300,000 WDs with $G < 19$ cf $\sim$ 10,000 today.



Number of eclipsers known vs time, up to 2011

Talk Plan

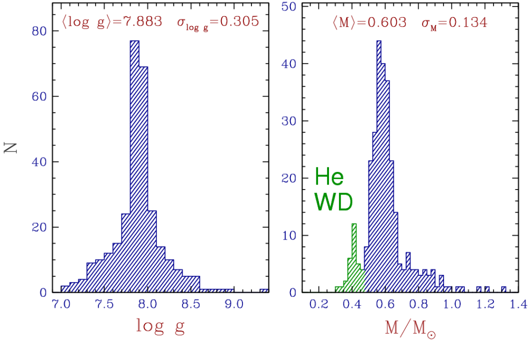
- Precision parameters, white dwarf masses in binaries
- Circumbinary debris, timing & planets
- Recent highlights

Some background on single white dwarfs

Physics of Stark broadening + optical spectra → $T_{\rm eff}$ and $\log g$.

Physics of degenerate matter, evolutionary model + $T_{\rm eff}$ and $\log g$ → mass and cooling age

Narrow mass distribution from mass loss on AGB.

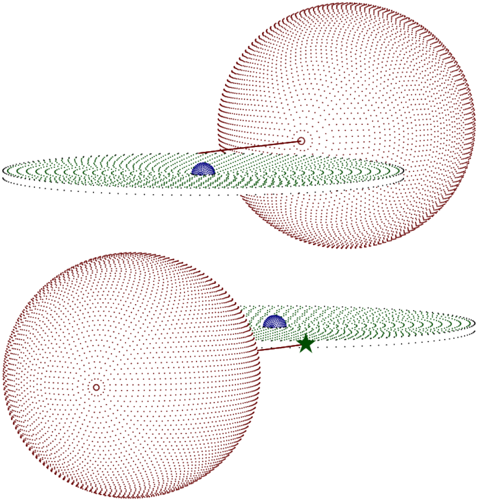


Liebert et al (2005)

Growing white dwarfs

A key problem of Type Ia SN models is how to ensure long-term increase of the mass of white dwarfs. CVs are usually ruled out because it is believed that nova explosions remove most of the accreted mass.

Through precision measurements we can test this observationally.

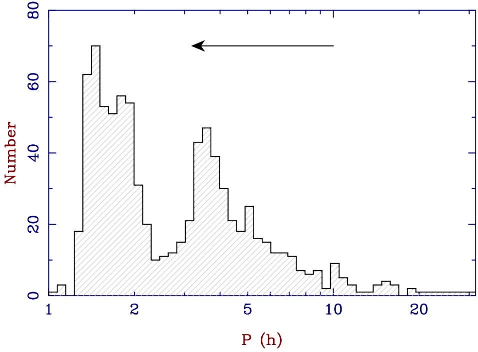


Evolution of CVs

Mass transfer implies a shortening orbital period. If white dwarf masses grow or decrease with time, expect a stratification of white dwarf mass with period.

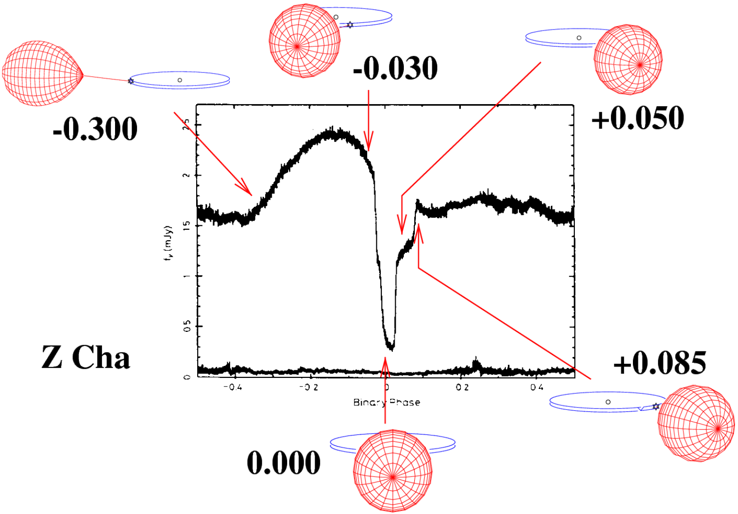
Due to nova explosions, expect mass to decrease along with the period

Only become testable in past few years from new systems from the SDSS.



Orbital period distribution of CVs

Measuring the masses of CV components



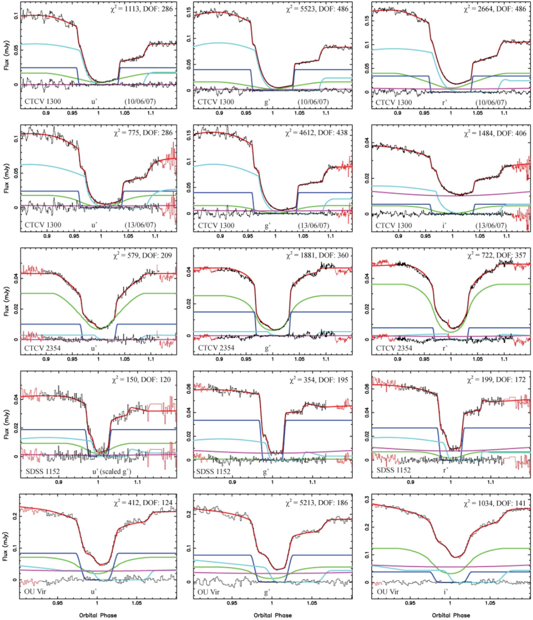
(Work of the 1980s by Wood, Horne, Smak, Cook, Warner)

Only widely applicable after SDSS & CRTS discoveries.

Light curve modelling $\Rightarrow M_W$, M_R and T_W

Savoury et al (2011)

Typical cadence 2 – 6 sec, $g = 17 – 20$. Requires 3 – 8 m aperture telescopes & repeat observations to beat flickering.



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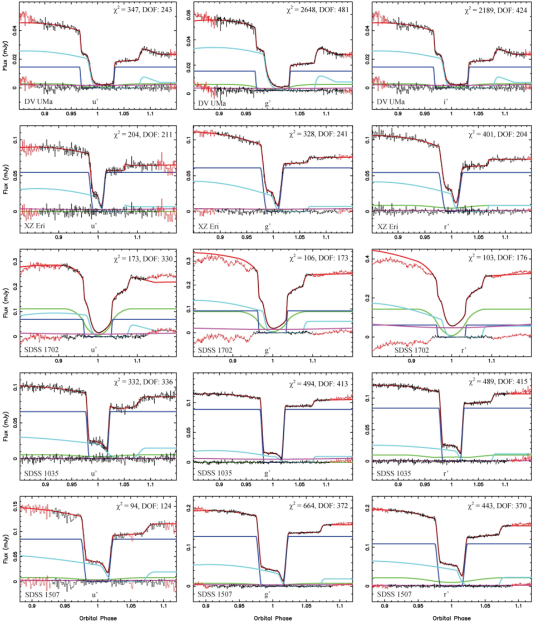

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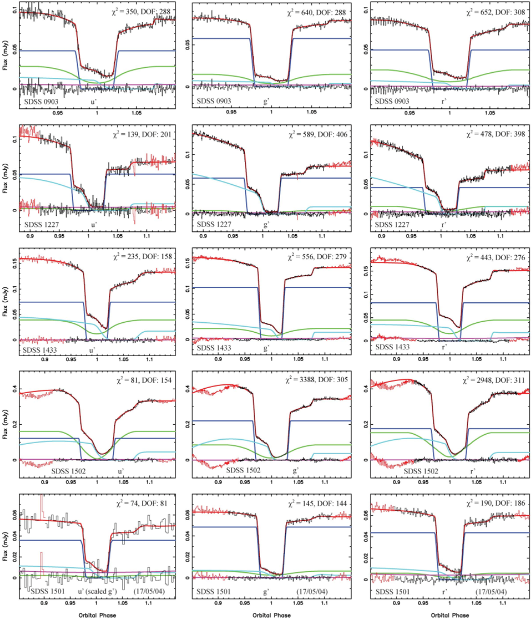
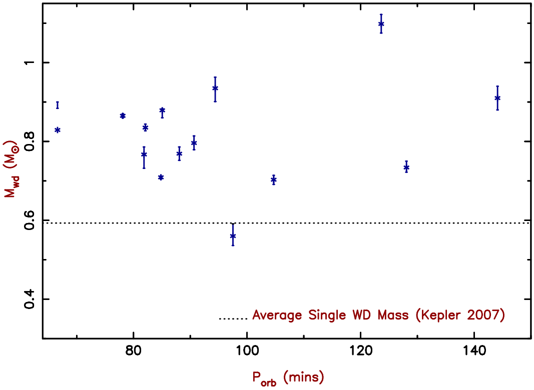


Masses of white dwarfs in CVs

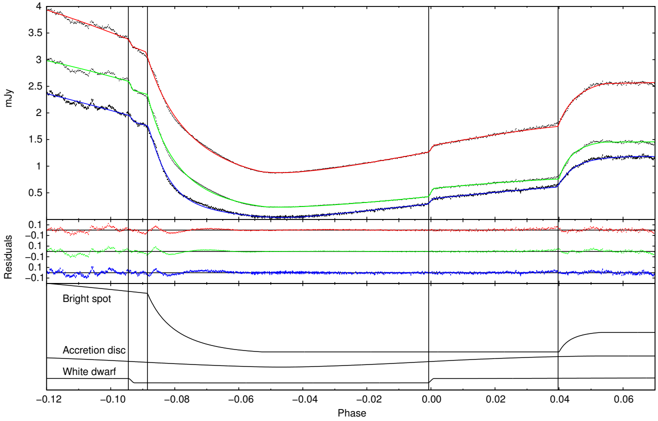
No clear evidence for stratification with period, but CV white dwarfs are massive cf isolated white dwarfs.

[NB. WDs in CVs tend only to be easily seen at the short period end, so many of these may have evolved from longer periods where $\dot{M}$ is higher.]



Savoury et al (2011)

$1.1\,\mathrm{M}_\odot$ white dwarf in the system IP Peg



Copperwheat et al (2010): massive white dwarf is small and eclipsed in just 10 seconds.

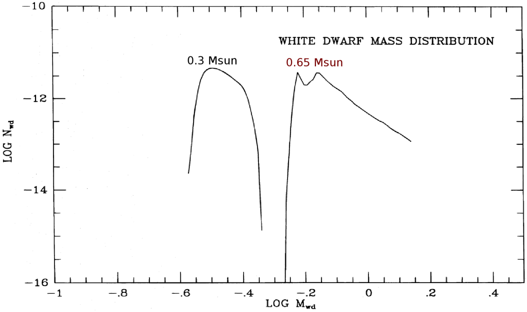
The problem of CV white dwarf masses

The high-masses of the white dwarfs in CVs are hugely problematic.

Could they be high from birth due to evolutionary effects?

Why are there no low mass He white dwarfs, which are expected in abundance? ⟶

Test with detached "pre-CVs".

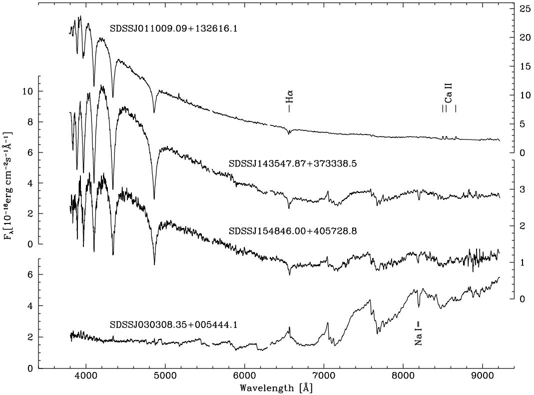


Politano (1996), predicted white dwarf mass distribution in CVs at birth. Those on the left are He white dwarfs.

Detached WD+MS systems

Simple systems with spectra which are a combination of white dwarfs and M dwarfs.

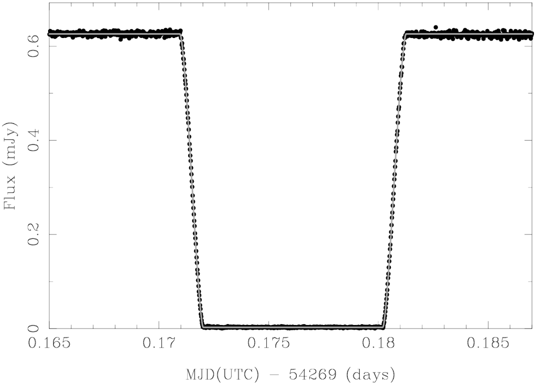
Around 2300 now known, mostly from SDSS, with 86+ eclipsers.



Pyrzas et al (2009), spectra of 4 eclipsing WD/dM systems.

Detached eclipsers

Eclipsing WD+dM binaries enable exquisite measurements (VLT+ULTRACAM here)

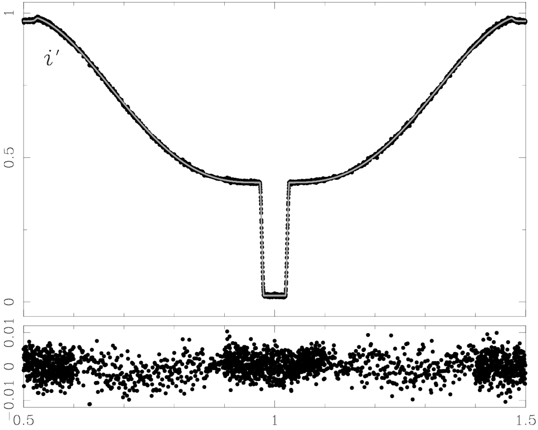


Parsons et al (2010a), GK Vir, a hot WD + 0.1 $M_\odot$ dM eclipser.

Detached eclipsers

In the best cases, complete solution of M_W, R_W, M_R, R_R and i is possible. e.g NN Ser

$$
\begin{aligned}
M_W &= 0.535 \pm 0.013\,\mathrm{M}_\odot \\
R_W &= 0.0211 \pm 0.002\,\mathrm{R}_\odot \\
M_R &= 0.111 \pm 0.004\,\mathrm{M}_\odot \\
R_R &= 0.149 \pm 0.002\,\mathrm{R}_\odot \\
i &= 89.6^\circ \pm 0.2.
\end{aligned}
$$

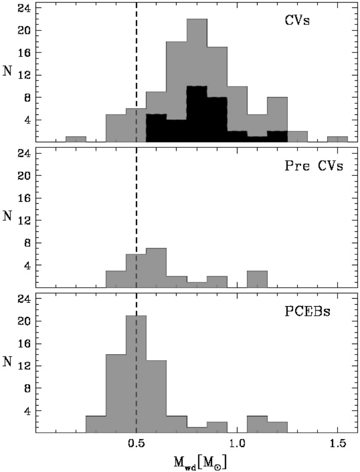


Parsons et al (2010b), NN Ser.

White Dwarf mass: CVs vs pre-CVs

The masses of WDs in pre-CVs (and related post-CE binaries) are not systematically large.

The CV white dwarf mass problem remains. Hard to avoid conclusion that white dwarf masses in CVs do in fact grow with time.

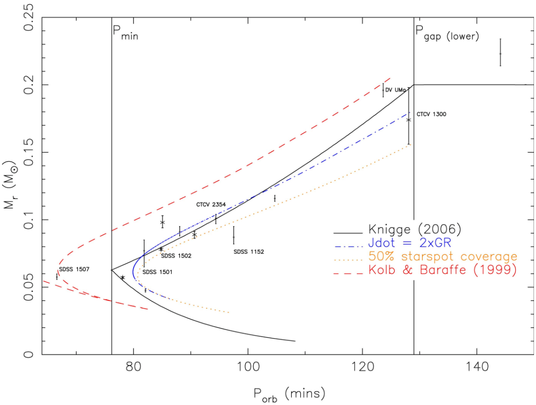


Zorotovic et al. (2011)

Side product I. brown dwarf donor stars

Nice side-products are precise masses of the mass donors.

These are close to predictions of binary evolution models, and constrain the long-term angular momentum loss rate.

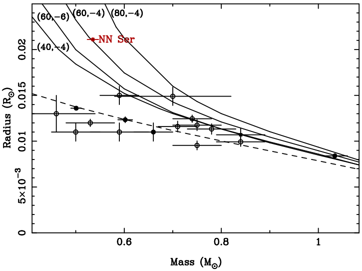


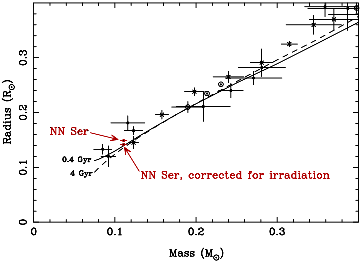
Savoury et al (2011)

Side product II. Electron degeneracy EoS

The best mass–radius measurements test structure models of white dwarfs and very low mass stars (and, potentially, brown dwarfs).

Parsons et al (2010b)





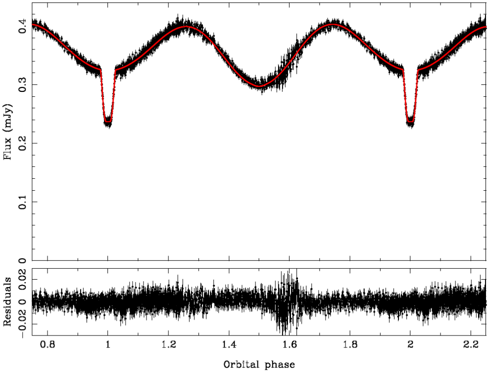
Side product III. Ancient systems

Starting to find systems with cool, very old white dwarfs.

In the system on the right, a feeble star of just $0.13\,\mathrm{M}_\odot$ outshines its "white" dwarf companion.

With $T \approx 3600\,\mathrm{K}$, the latter has been cooling for 9.5 Gyr

Such white dwarfs are hard to characterise when isolated.



Parsons et al (2013)

Talk Plan

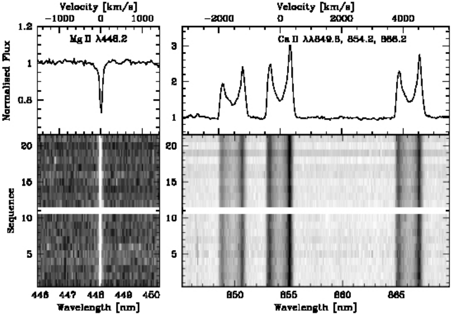
- Precision parameters, white dwarf masses in binaries
- Circumbinary debris, timing & planets
- Recent highlights

White dwarf debris disks

The existence of debris disks around some single white dwarfs is now well-established.

Signatures: polluted atmospheres; emission lines from accretion disks; excess IR flux from dust.

Thought to be asteroidal in composition, and to imply the presence of planetary perturbers.



Metal (Mg) pollution and accretion disc emission (CaII) of the single white dwarf SDSS1228+1040 (Gänsicke et al 2006).

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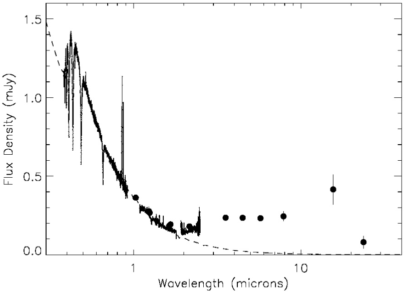
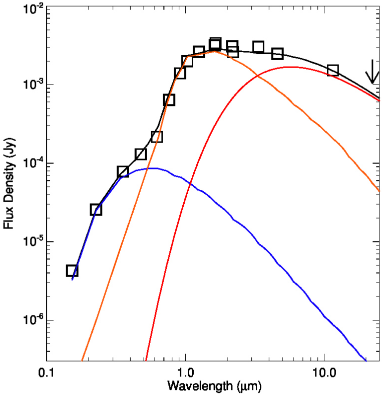


IR dust emission from the debris disk around SDSS1228+1040 (Brinkworth et al 2009).

Circumbinary debris?

Similar evidence for debris disks around white dwarf binary stars has been largely unconvincing as it is vulnerable to intrinsic binary effects.

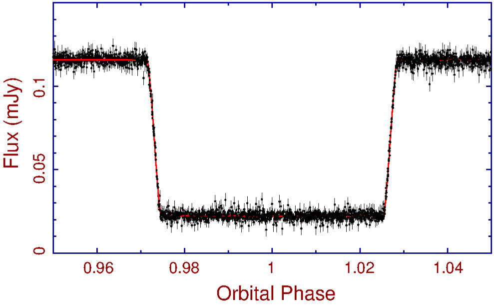
Witness the case of SDSS J0303+0054, a $P = 3.2\,\text{h}$, WD+dM eclipser.



Apparent debris disk emission around the WD+dM binary SDSS0303+0054 (Debes et al 2012)

SDSS0303+0054: optical eclipse

The system is optically indistinguishable from other WD+MS eclipsers, so accretion does not appear at first sight to be responsible for the IR excess.



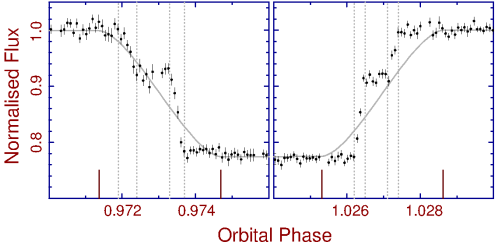
Eclipse of the white dwarf in SDSS g' (WHT+ULTRACAM), (Parsons et al 2013).

SDSS0303+0054: near infrared eclipse

However, the NIR (K_S) eclipse of the white dwarf shows that the IR excess comes from concentrated spots of emission on the white dwarf.

$\Longrightarrow$ cyclotron emission from magnetic poles accreting from the M star companion's wind.

...not circumbinary debris.



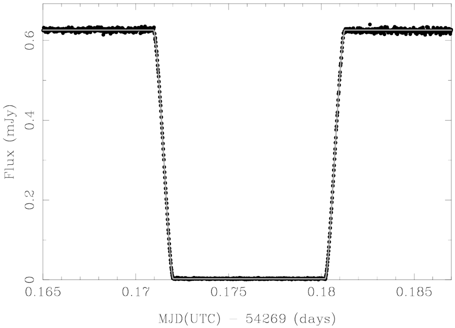
Eclipse of the white dwarf in K_S (VLT+HAWKI), (Parsons et al 2013).

Circumbinary planets via timing

Eclipsers enable precise period measurement. Potential to directly measure angular momentum loss (gravitational radiation, magnetic braking).

A steady rate of period change $\dot{P}$ alters the times of eclipse by a quadratic function of time

$$\Delta t = \frac{1}{2}\frac{\dot{P}}{P}t^2.$$



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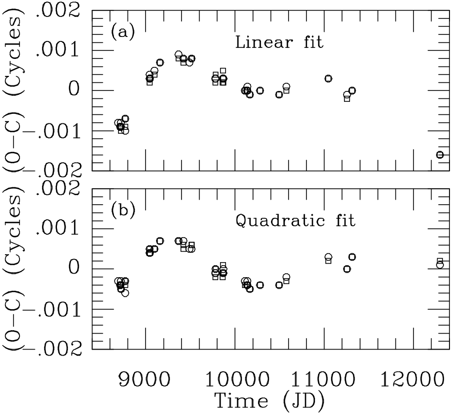
In practice, rather erratic variations always seem to be the rule. $\longrightarrow$



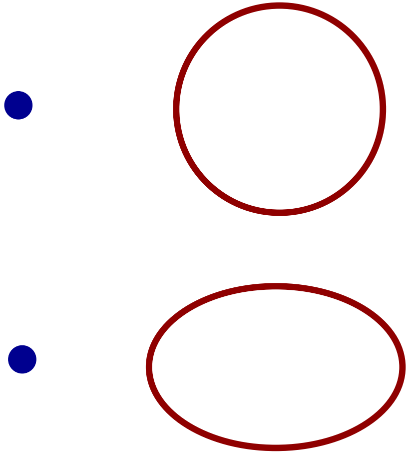
Period changes in WD/dM system QS Vir, O'Donoghue et al (2003)

Applegate's Mechanism

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

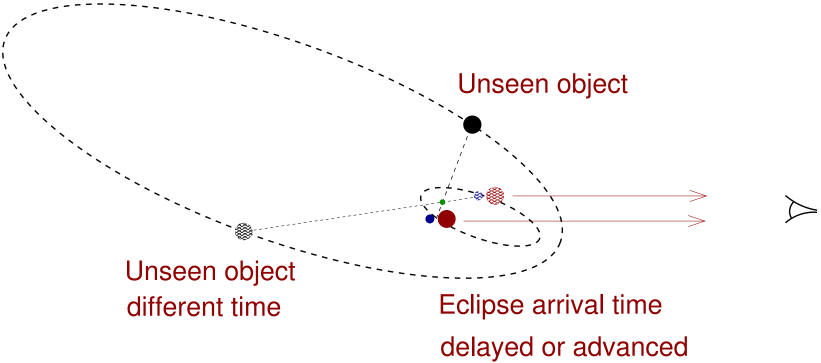
No angular momentum is lost in the process; it is not a driver of evolution.

Applegate's mechanism does require energy however.

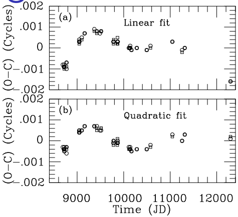


Variations in quadrupole moment change the gravitational attraction between the stars

Perturbation by “third” bodies



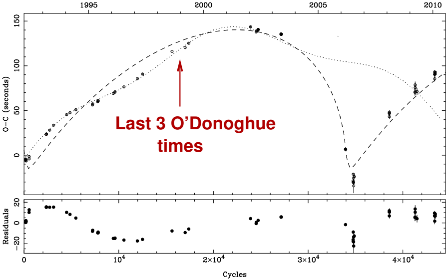
Stress-testing Applegate



Some systems show too large a period change for Applegate's mechanism to work.

Here the eclipses in QS Vir are seen to arrive $\sim 200\,\mathrm{sec}$ earlier than expected from O'Donoghue et al.'s data.

Seems certain that there is a "third body" orbiting the binary, in this case a brown dwarf



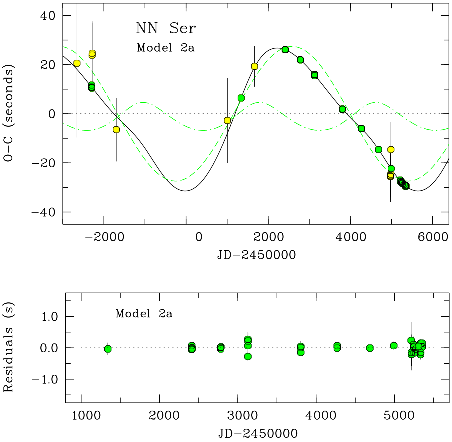
QS Vir, Parsons et al (2010)

Two planets around NN Ser

The M dwarf in the 3.1 h binary NN Serpentis is so feeble, that it does not even have the oomph to drive its much smaller timing changes via Applegate.

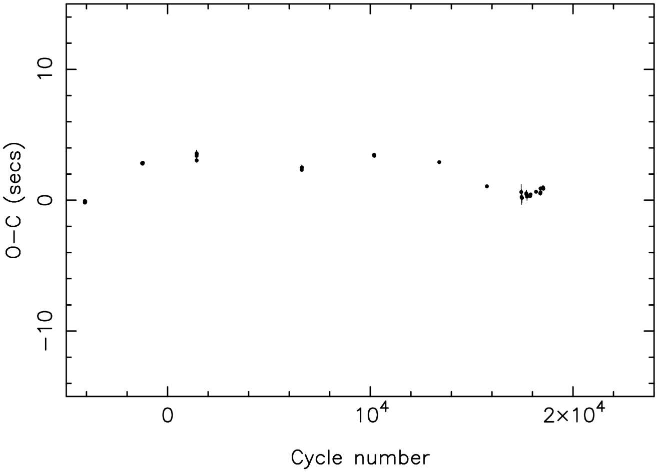
Instead, two planets, with masses of 6.9 and and 2.2 M_J in 15.5 and 7.7 yr orbits provide an excellent fit.

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



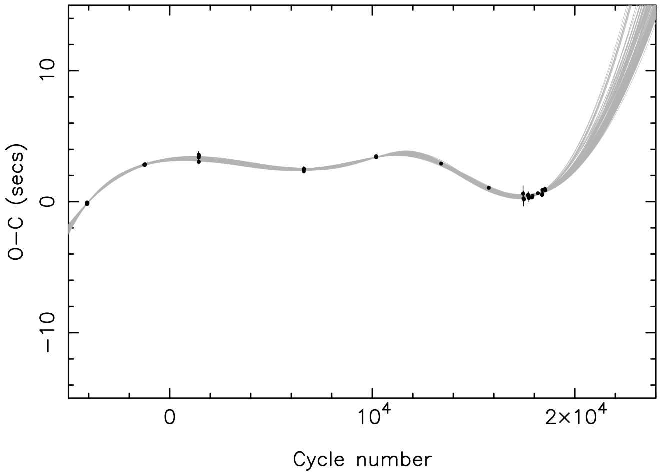
Two planet fit to NN Ser times, Beuermann et al (2010)

Extrapolating NN Ser . . .



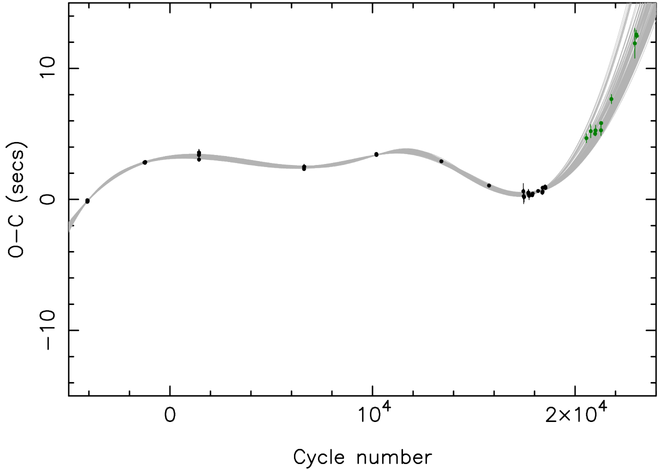
Last 10 years of data from Beuermann et al (2010)

Extrapolating NN Ser . . .



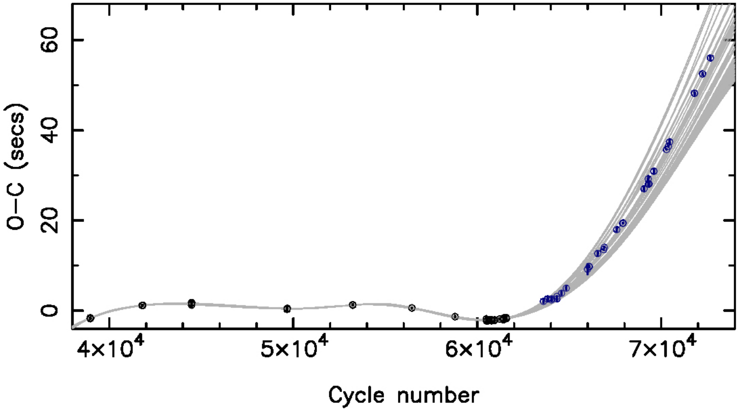
Last 10 years of data plus MCMC sample of possible orbits.

Extrapolating NN Ser . . .



. . . with 2 years of new data

Up to May 2014, expanded scale



First successful prediction of eclipse times based upon planetary orbit model (Marsh et al 2014)

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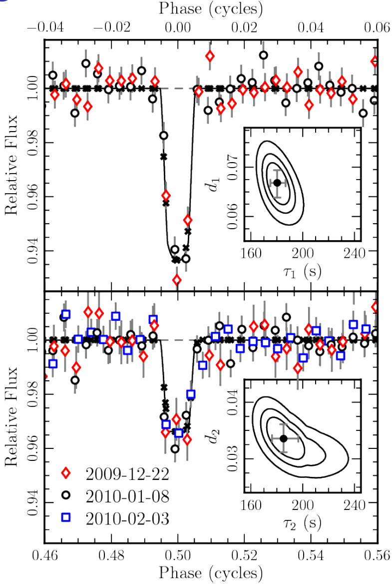
NLTT 11748, first eclipsing double white dwarf

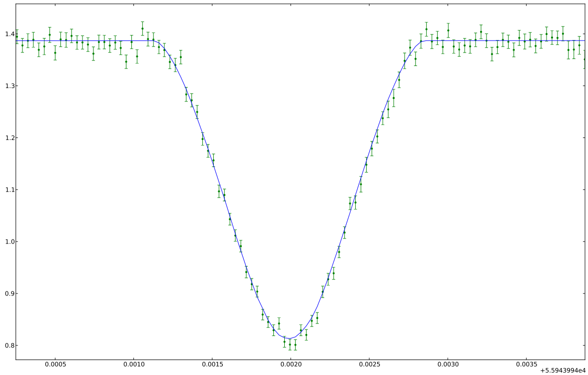
A $0.2\,M_\odot$ and $0.7\,M_\odot$ pair of white dwarfs in a 5.6-hour, $i = 89.9^\circ$ orbit.

6% and 3% deep eclipses.

Steinfadt et al. (2010), Kaplan et al. (2014)



CSS 41177, second known DWD eclipser



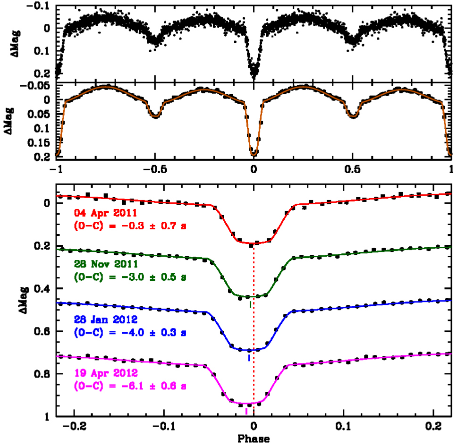
40% & 10% deep eclipses, lasting 2 minutes. Two $\sim 0.3\,\mathrm{M}_\odot$ helium white dwarfs, $P = 2.8$ hour orbit.

Parsons et al (2011), Bours et al (2014)

SDSS J0651+2844, fourth DWD eclipser

Brown et al. (2011) discovered a remarkable $P = 12.7$ minute eclipsing DWD.

GWR-driven decay detected after a little more than one year: one of the two best eLISA "calibrators" known.



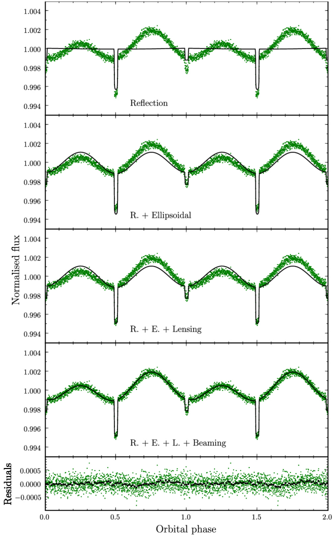
Hermes et al. (2012)

New data, new effects: beaming & lensing

KPD 1946+4340 is an WD+sdB binary. Component stars are radiative and stable.

Kepler data show eclipses and ellipsoidal modulation, but also Doppler beaming and gravitational lensing (although degenerate with other parameters).

Bloemen et al (2010)

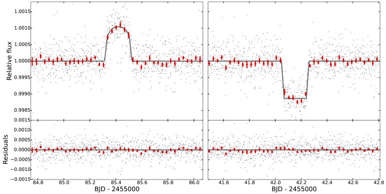


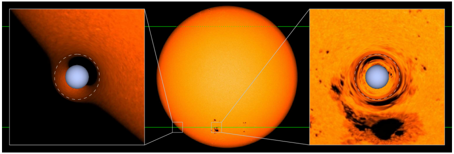
Indisputable lensing

KOI-3278 shows apparent transits of an Earth-sized object, once every $P = 88$ days, raising the interest of planet hunters.

In fact, the dips are eclipses of a $0.63\,\mathrm{M}_\odot$ white dwarf which half-a-cycle later lenses its companion G star.

Kruse & Agol (2014)





Conclusions

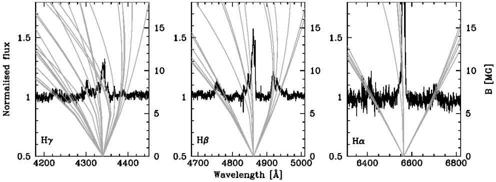
- Large surveys have hugely increased the number of white dwarf binaries known.
- Many new eclipsers discovered leading to high-precision parameters.
- The white dwarf masses in CVs emerging from this are in serious discord with theory.
- Some detached systems show timing anomalies which appear to imply circum-binary planets.
- High-quality data are revealing white dwarfs in hard-to-find locations and subtle new physical effects.

SDSS0303+0054: Zeeman-split line emission

The system provides the second-known example of Zeeman-split line emission from a white dwarf.

This leads to a surface field of $B \sim 8\,\mathrm{MG}$. This is moderately strong by white dwarf standards. The system is a likely progenitor of the. "intermediate polar" class of CVs.

. . . but no debris disk.

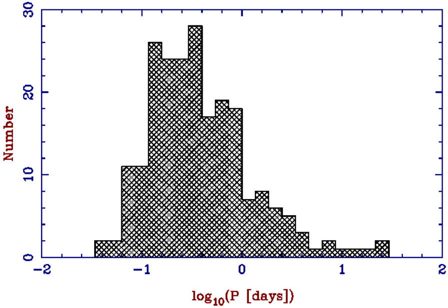


Parsons et al (2013)

Common envelope efficiency

Most post-CE WD+MS binaries have orbital periods short of one day.

These can be matched with common envelope efficiency $\alpha_{\rm CE} = 0.2 - 0.3$ (Zorotovic et al. 2010)



Periods from Ritter & Kolb