THE UNIVERSITY OF WARWICK

Period evolution in AM CVns

Chris Copperwheat

T. Marsh, D. Steeghs, V. Dhillon, S. Littlefair

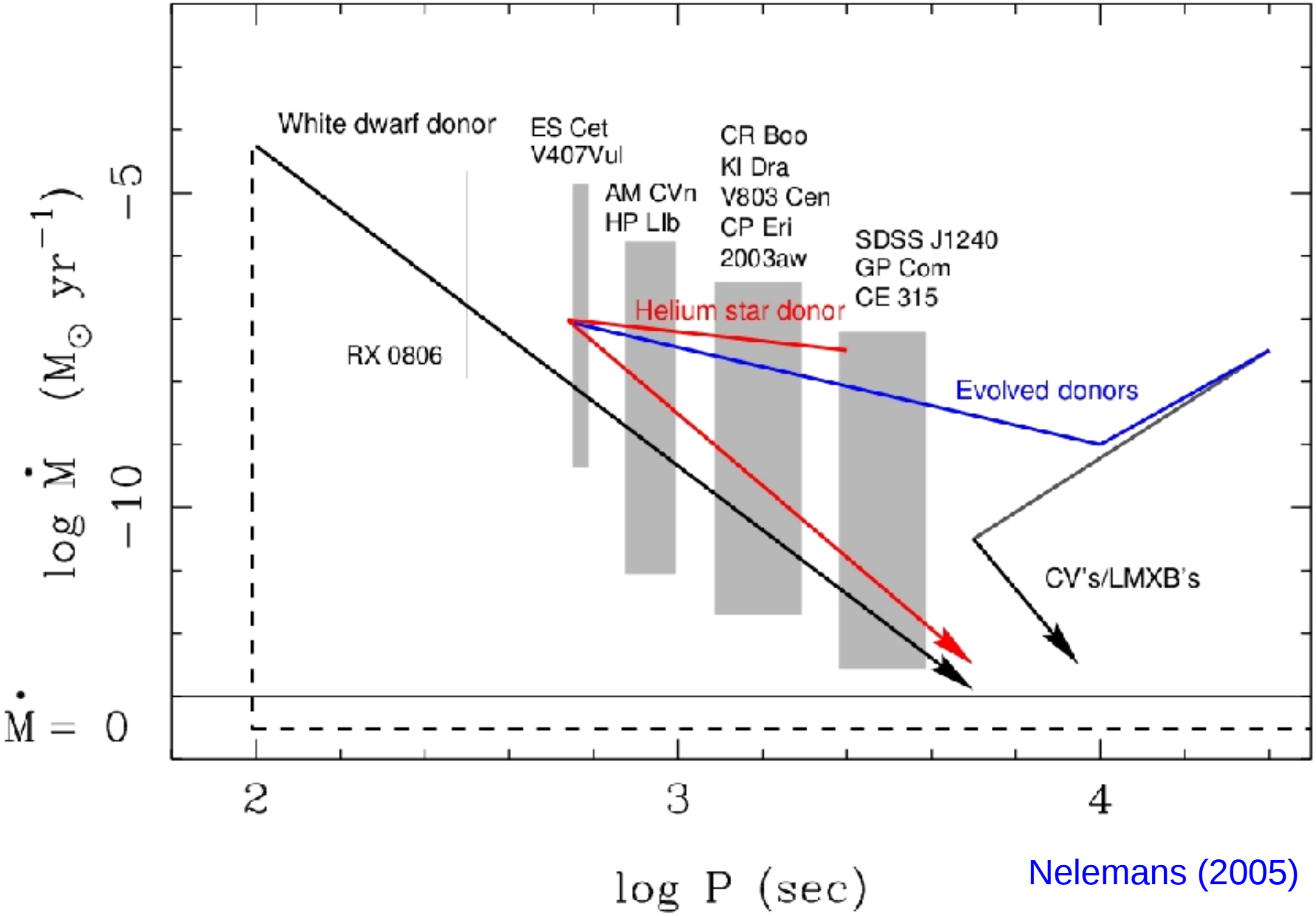
Target list

- The two ultracompact binaries with the shortest orbital periods:
  - HM Cnc (P = 321s; Israel et al. 1999; Ramsay et al 2002)
  - V407 Vul (P = 569s; Motch et al. 1996; Ramsay et al. 2000)

- ES Cet (P = 10min; Warner & Woudt 2002):
  - The next shortest period system - unambiguously an accreting AM CVn

- SDSS 0926+3624 (P=28min; Anderson et al. 2005):
  - The only known eclipser = the most precise timings

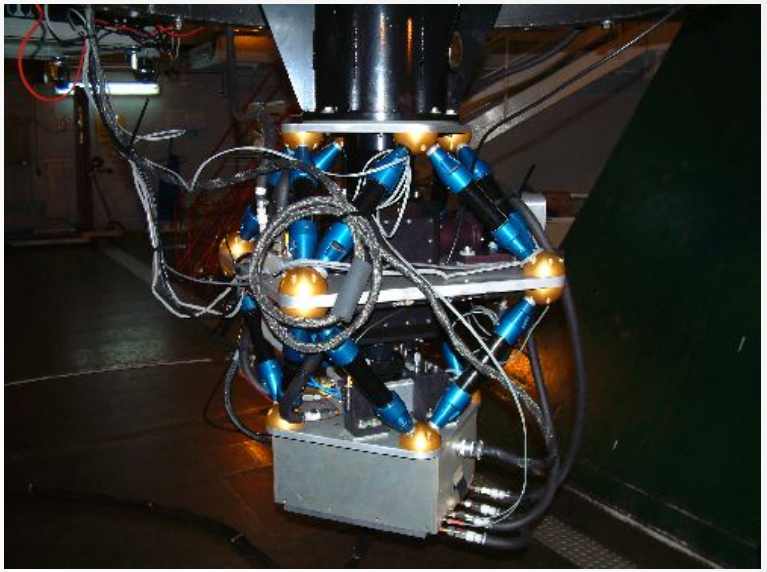
AM CVn period evolution



Nelemans (2005)

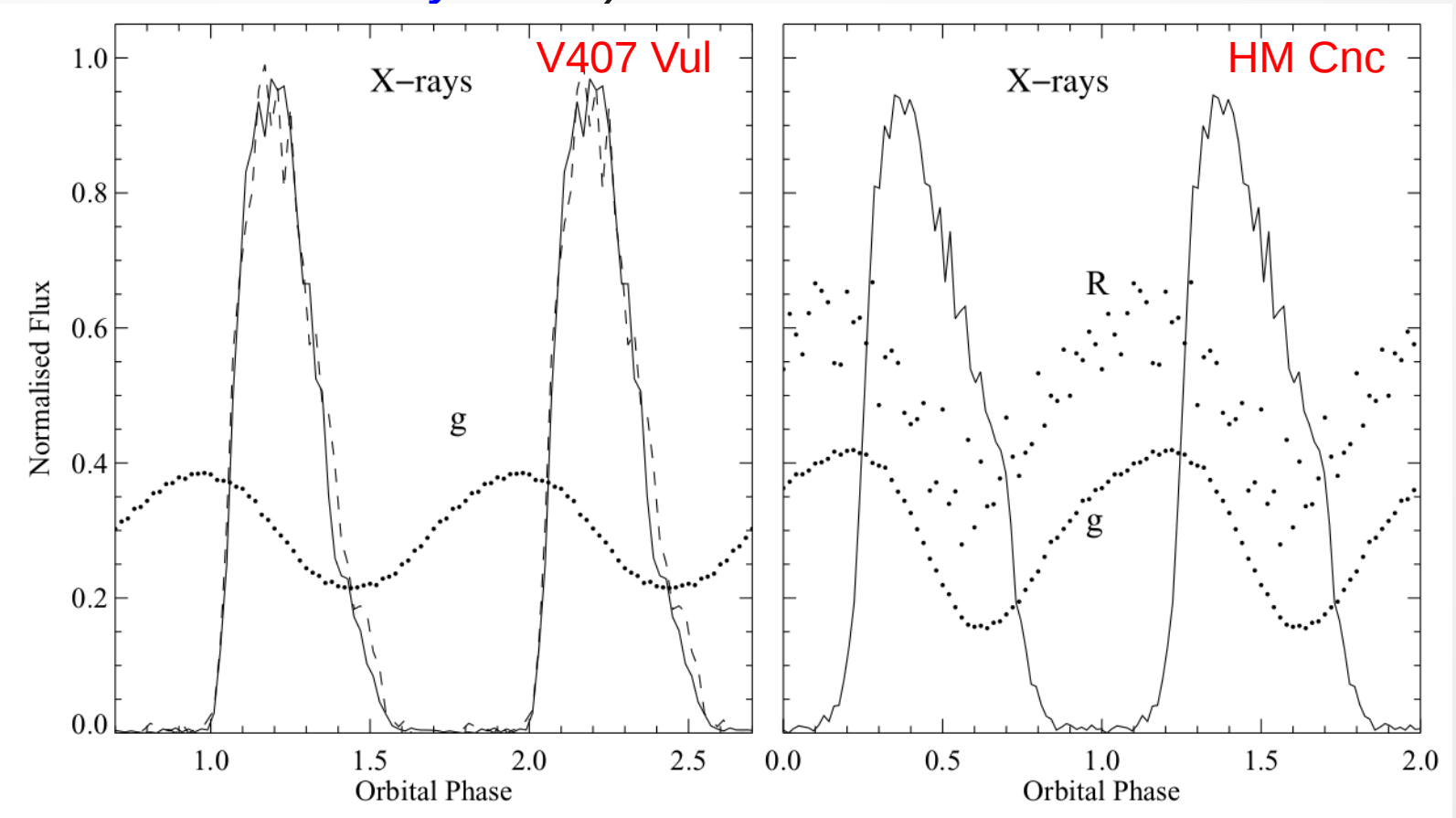
ULTRACAM

- High-speed CCD photometer (Dhillon et al., 2007)
- Simultaneous observation in Sloan u', g' and r' or i'
- Frame transfer CCDs – dead time ~25ms
- These observations obtained on the 4.2m WHT and the 3.6m NTT



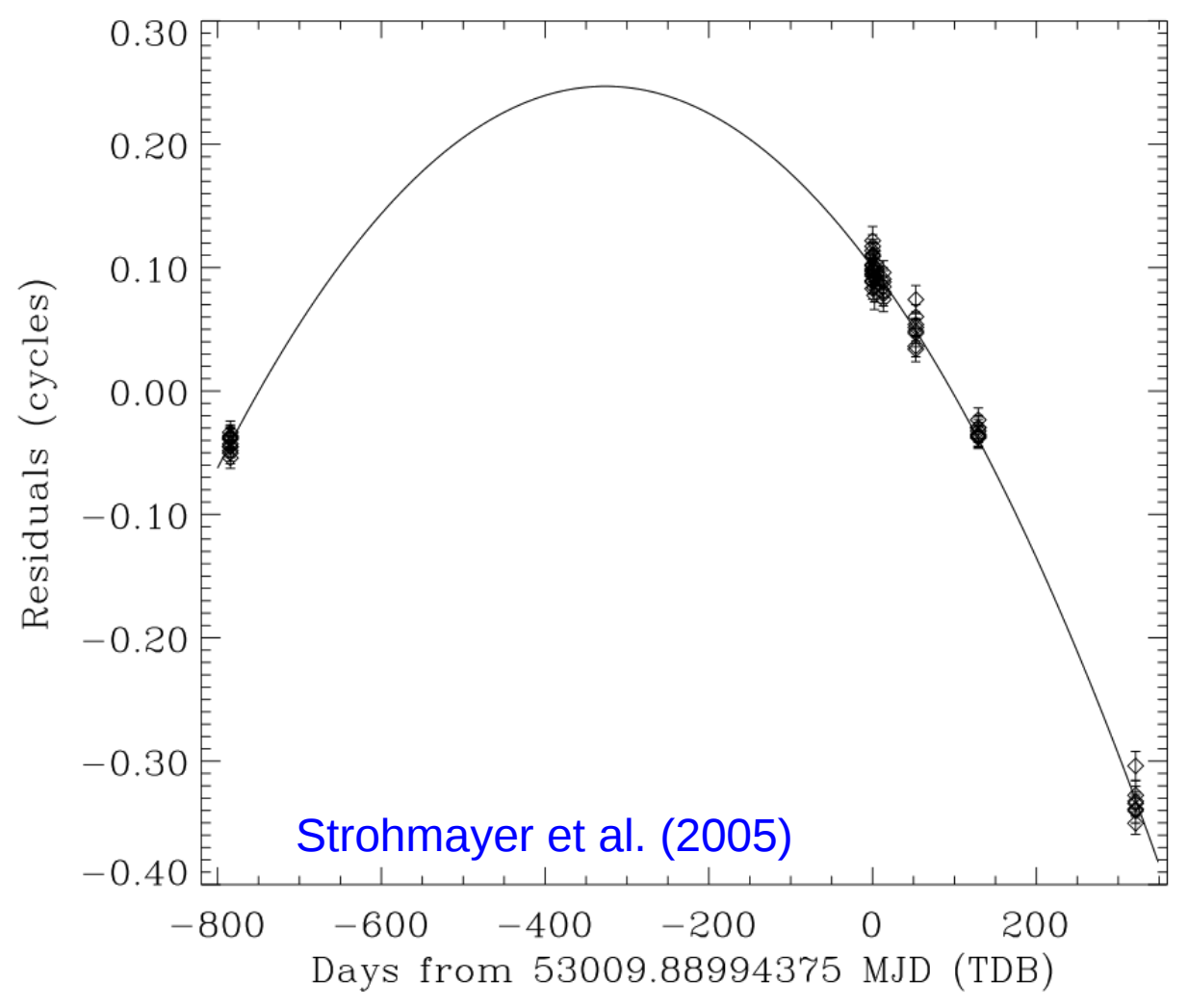
HM Cnc and V407 Vul

- Models
  - Intermediate polar (Motch et al. 1996; Israel et al. 1999)
  - Unipolar inductor (Wu et al. 2002)
  - Direct impact accretion (Nelemans et al. 2001; Marsh & Steeghs 2002; Ramsay 2002)



Barros et al. (2007)

Orbital frequency derivatives



$\dot{\nu} = 3.63 \pm 0.06 \times 10^{-16}\,\mathrm{Hz\,s^{-1}}$

Where $\nu = 1/P_{orb}$

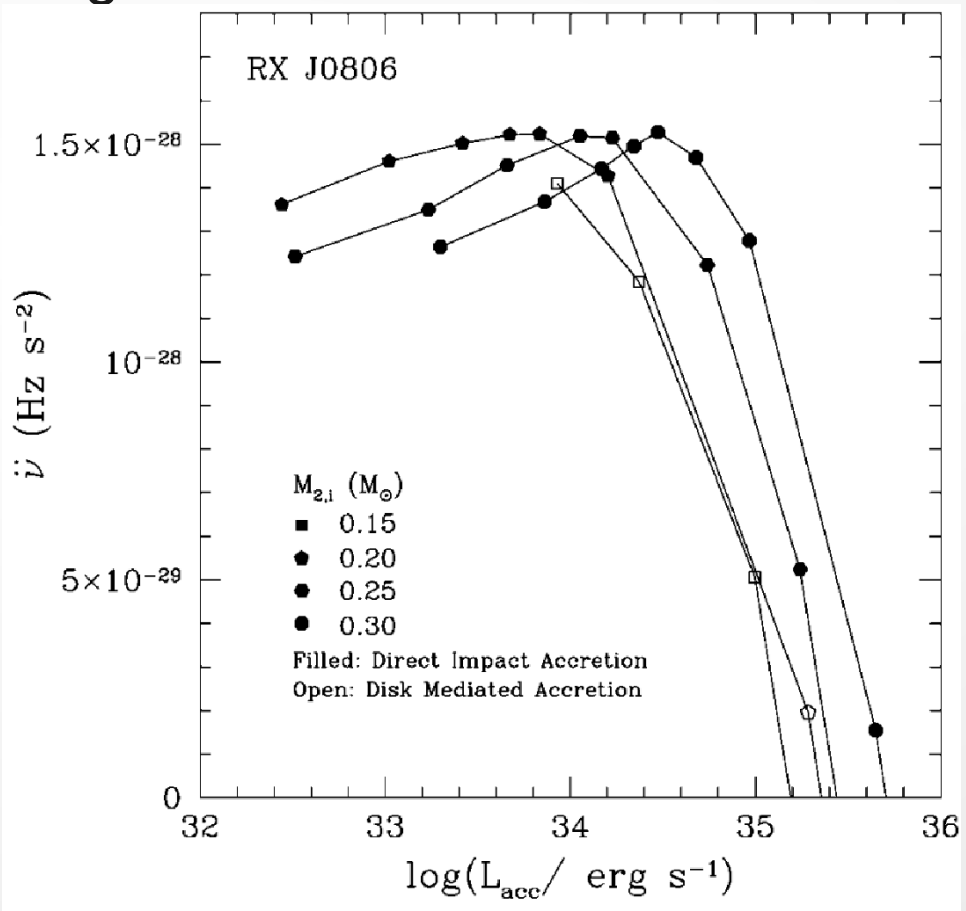
Similar spin-up detected in V407 Vul: $\dot{\nu} = 9.9 \pm 1.9 \times 10^{-18}\,\mathrm{Hz\,s^{-1}}$

Ramsay et al. (2005, 2006); Barros et al. (2007)

Accretion models not ruled out

- HM Cnc and V407 Vul in mass transfer turn-on phase
- Mdot is significantly smaller than secular rate -> $\dot{\nu} > 0$ (D'Antona et al. 2006)

- $\ddot{\nu}$ term a means of distinguishing between models (Deloye & Taam 2006)

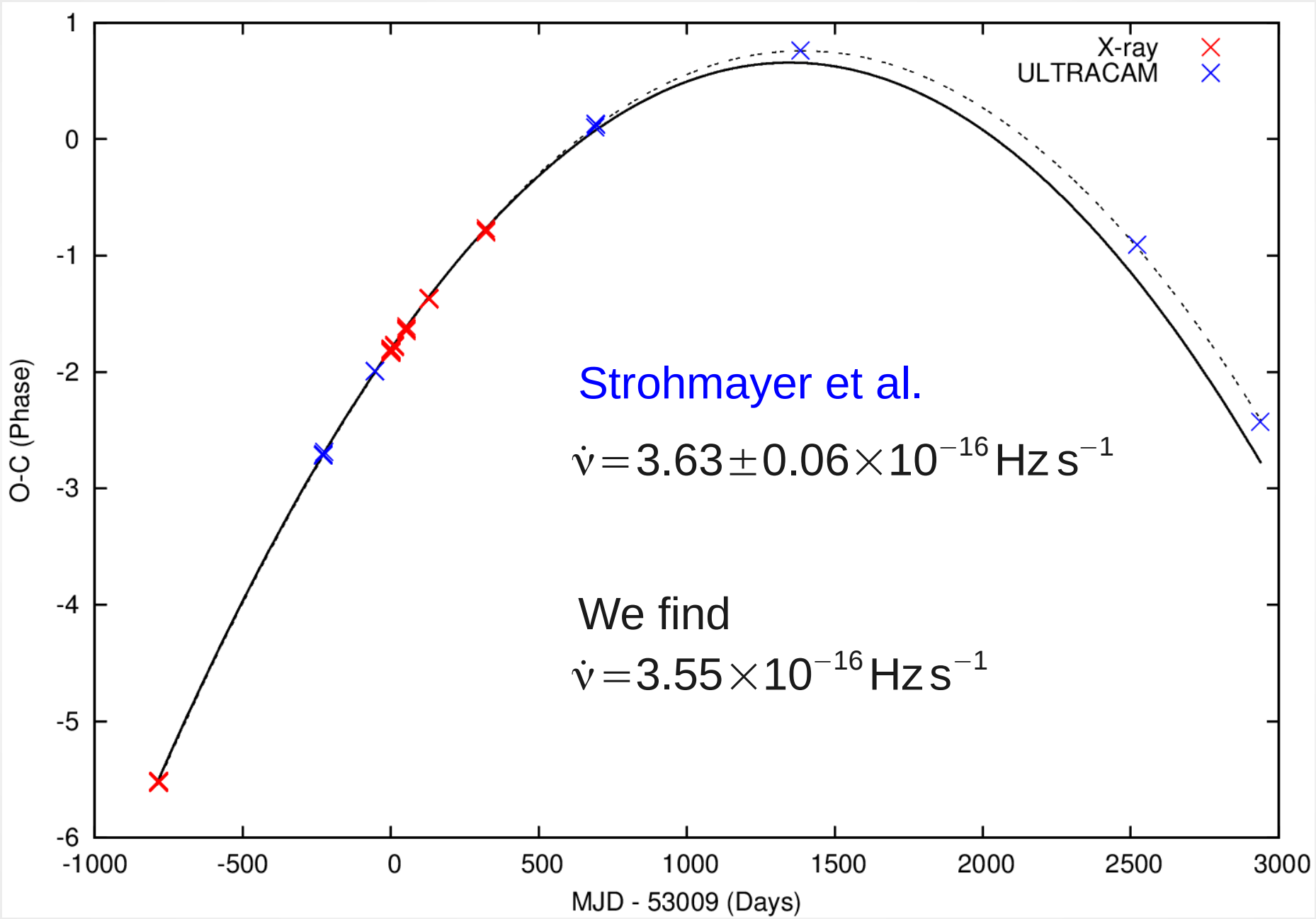


ULTRACAM observations

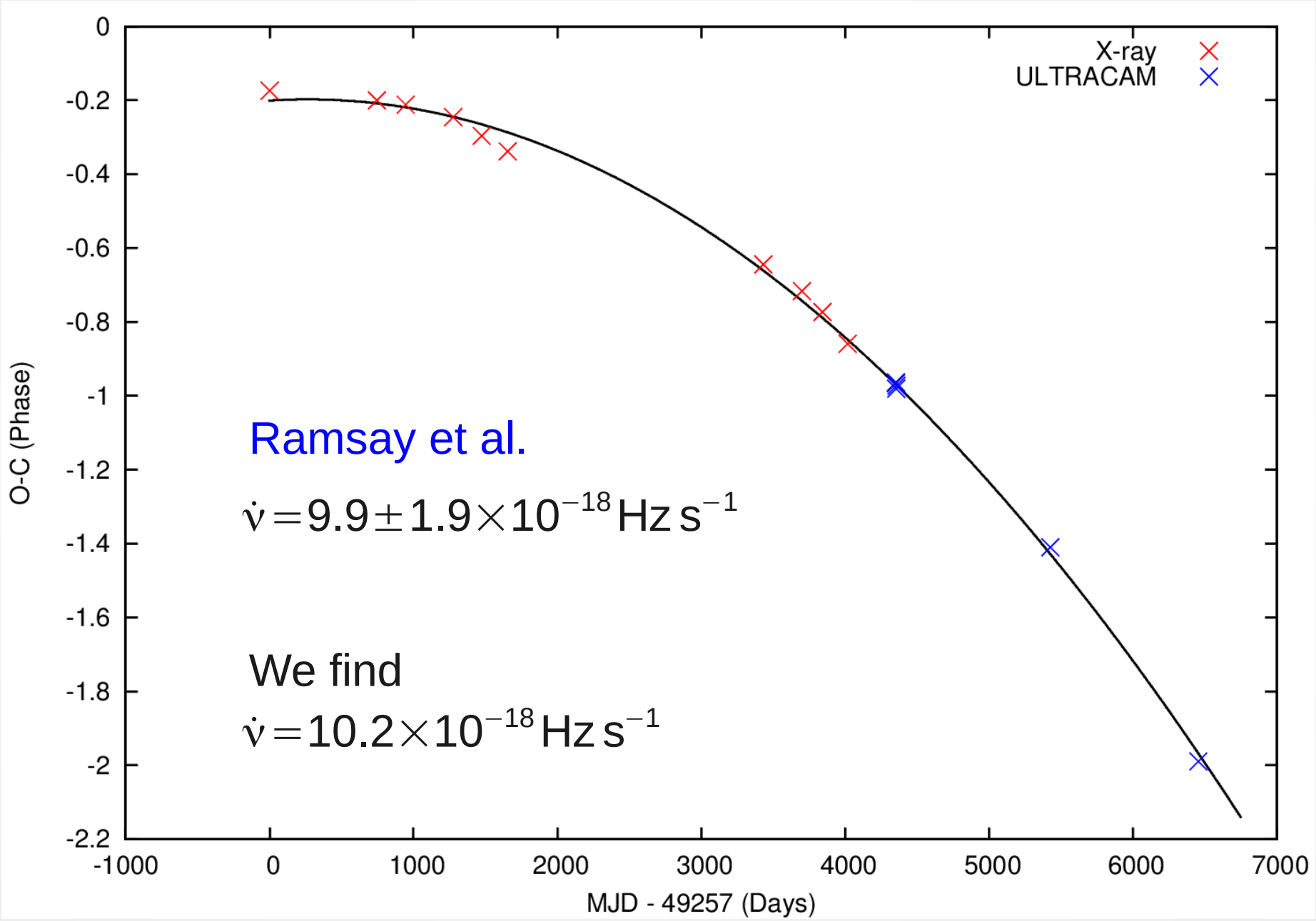
- HM Cnc
  - 05-2003, 11-2003, 11-2005, 10-2007, 12-2010, 01-2012
- V407 Vul
  - 05-2003, 08-2005, 08-2008, 05-2011
- Runs typically ~1h or longer, with 6-10s exposure times simultaneous in u',g',r'/i'
- Light curves fitted with sinusoids to obtain timings
- Dataset fitted with timing solution

$$\phi(t) = \nu(t - t_0) + \dot{\nu}(t - t_0)^2/2 + ...$$

HM Cnc (O-C)


X-ray
ULTRACAM
O-C (Phase)
MJD - 53009 (Days)
1
0
-1
-2
-3
-4
-5
-6
-1000
-500
0
500
1000
1500
2000
2500
3000
Strohmayer et al.
$\dot{\nu} = 3.63 \pm 0.06 \times 10^{-16}\,\mathrm{Hz\,s^{-1}}$
We find
$\dot{\nu} = 3.55 \times 10^{-16}\,\mathrm{Hz\,s^{-1}}$

V407 Vul (O-C)


X-ray
ULTRACAM
O-C (Phase)
MJD - 49257 (Days)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-1000
0
1000
2000
3000
4000
5000
6000
7000
Ramsay et al.
$\dot{\nu} = 9.9 \pm 1.9 \times 10^{-18}\,\mathrm{Hz\,s^{-1}}$
We find
$\dot{\nu} = 10.2 \times 10^{-18}\,\mathrm{Hz\,s^{-1}}$

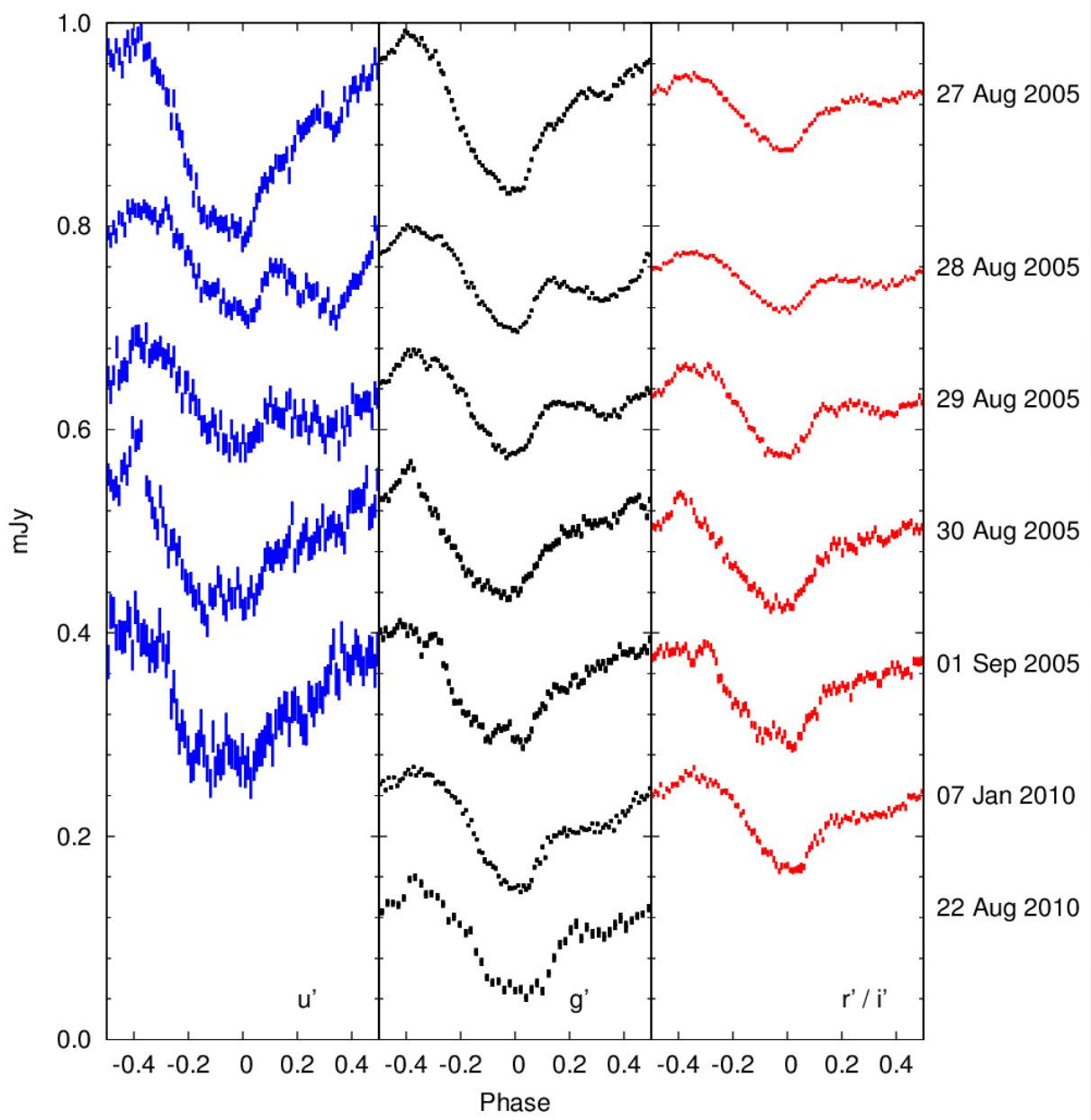
ES Cet

- 620s optical modulation (Espaillat et al. 2005)
- Spectroscopic confirmation that this is the orbital period (Steeghs et al., in prep)
- Orbital period only 51s greater than V407 Vul, so ES Cet potentially connects the two shortest period systems to the rest of the AM Cvn population
  - ES Cet also in the mass transfer turn-on phase?
  - On the long-term and stable AM CVn path of lengthening period?

ES Cet observations

- WHT+ULTRACAM observations in u', g' and r'/i'
  - 08-2005, 01-2010, 12-2010 and 01-2012
  - Exposure times ~2-4s
- WHT+ACAM in Sloan g
  - Aug 2010, 5s exposure
- SAAO 1.9m + UCT CCD photometer
  - 38 observations between 10-2001 and 10-2009
- Center for Backyard Astrophysics (CBA)
  - 21 observations between 01-2002 and 01-2010

ES Cet light curves

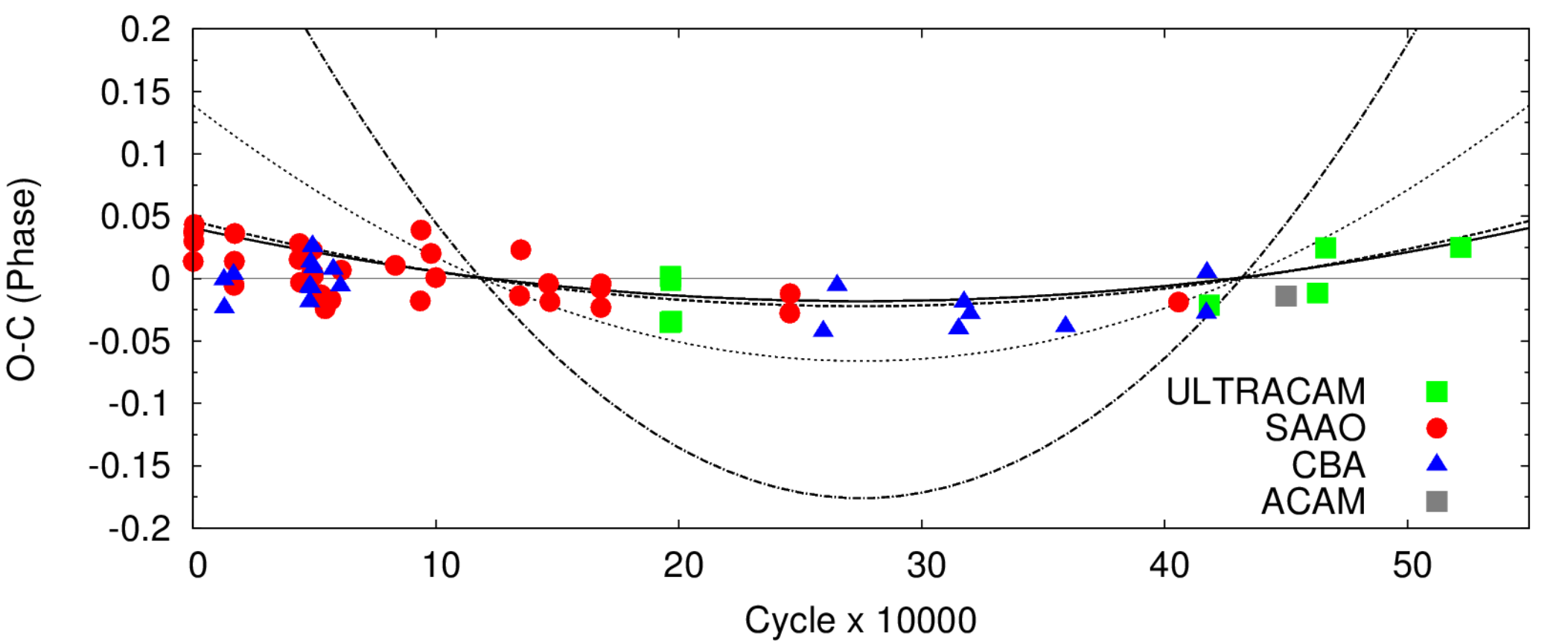


ULTRACAM

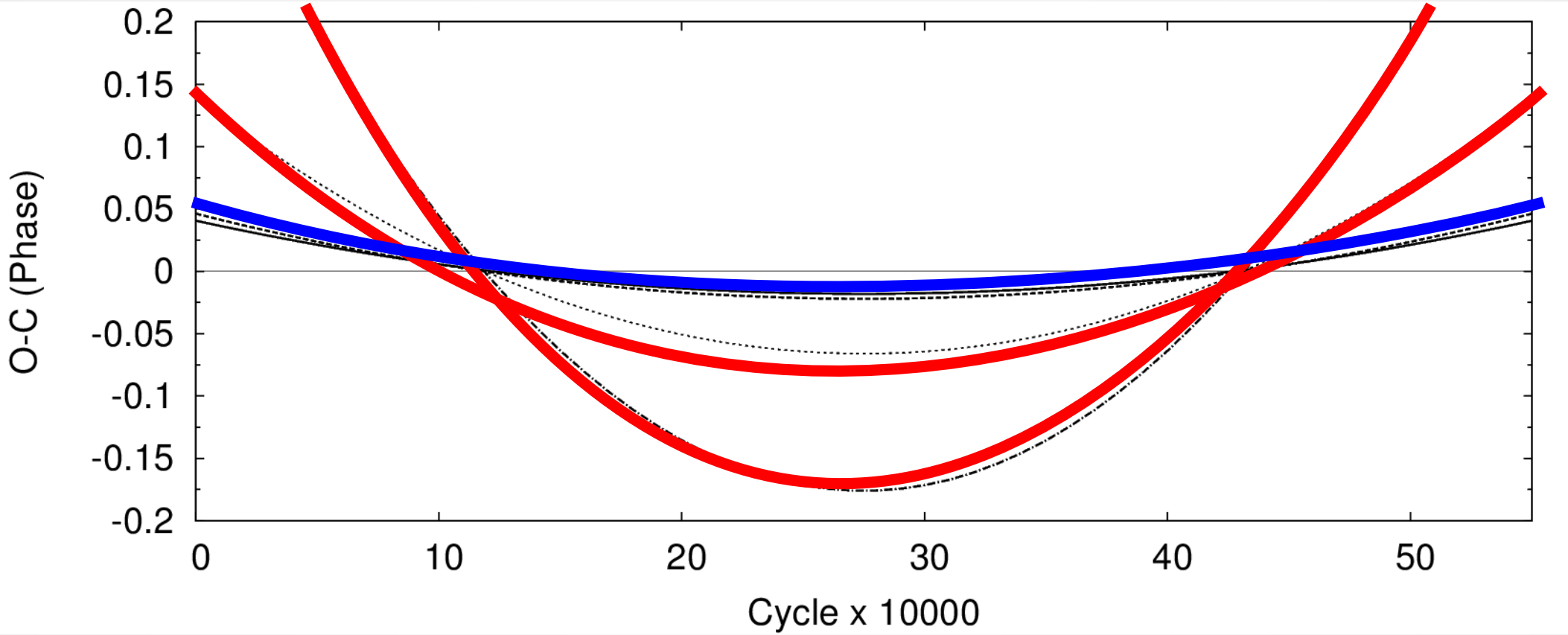
ACAM

Copperwheat et al. (2011)

ES Cet (O-C) plot



ES Cet (O-C) plot

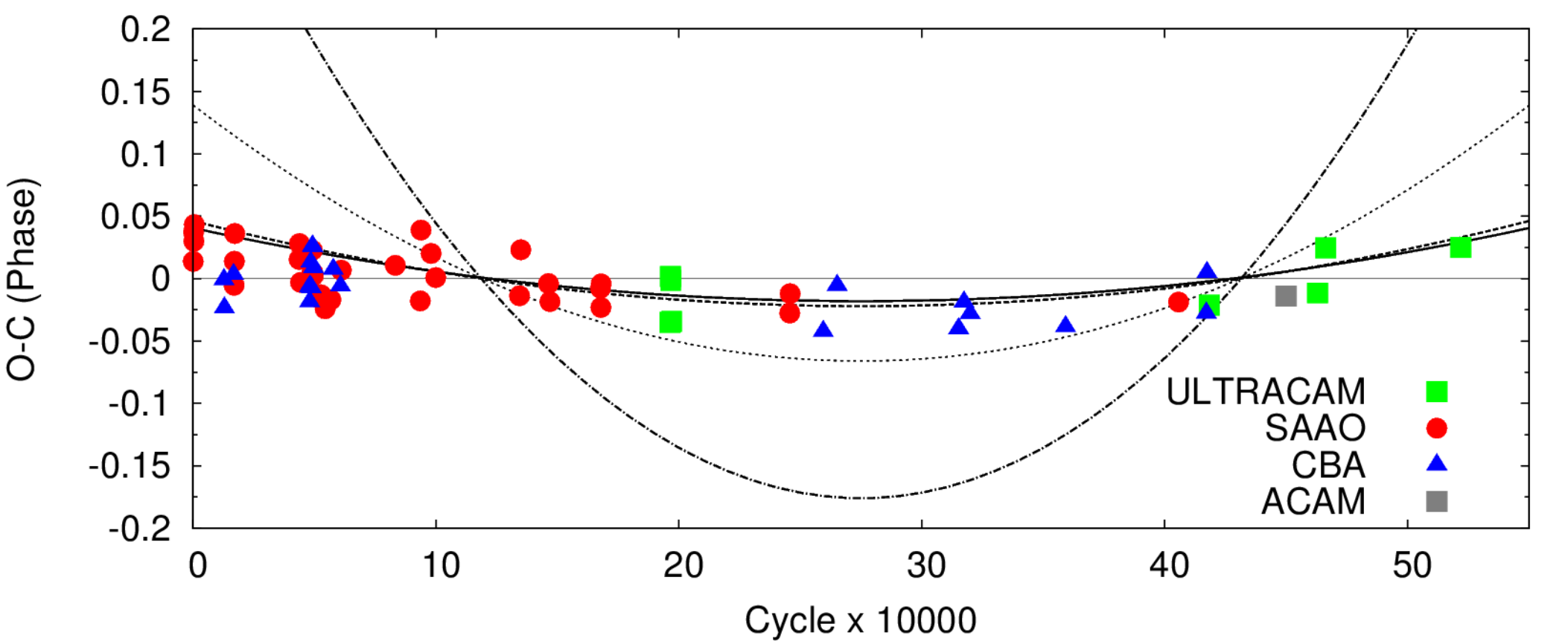


Fully degenerate donor (M_2 = 0.062 $M_\odot$)

M-R relation from He-star formation channel (M_2 = 0.26 $M_\odot$)

Donor response to mass loss -0.28 > ξ_2 > 0

ES Cet (O-C) plot

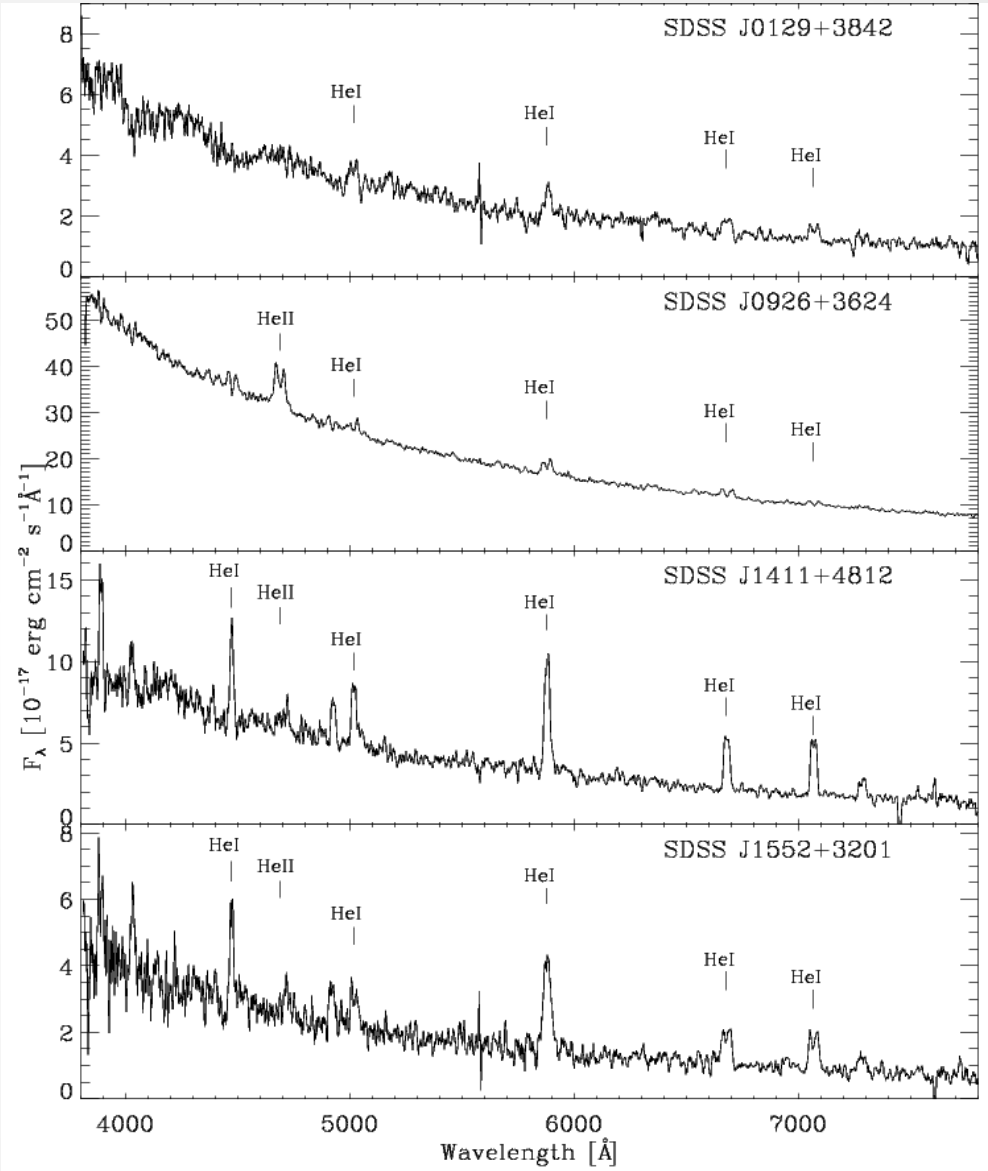


ES Cet summary

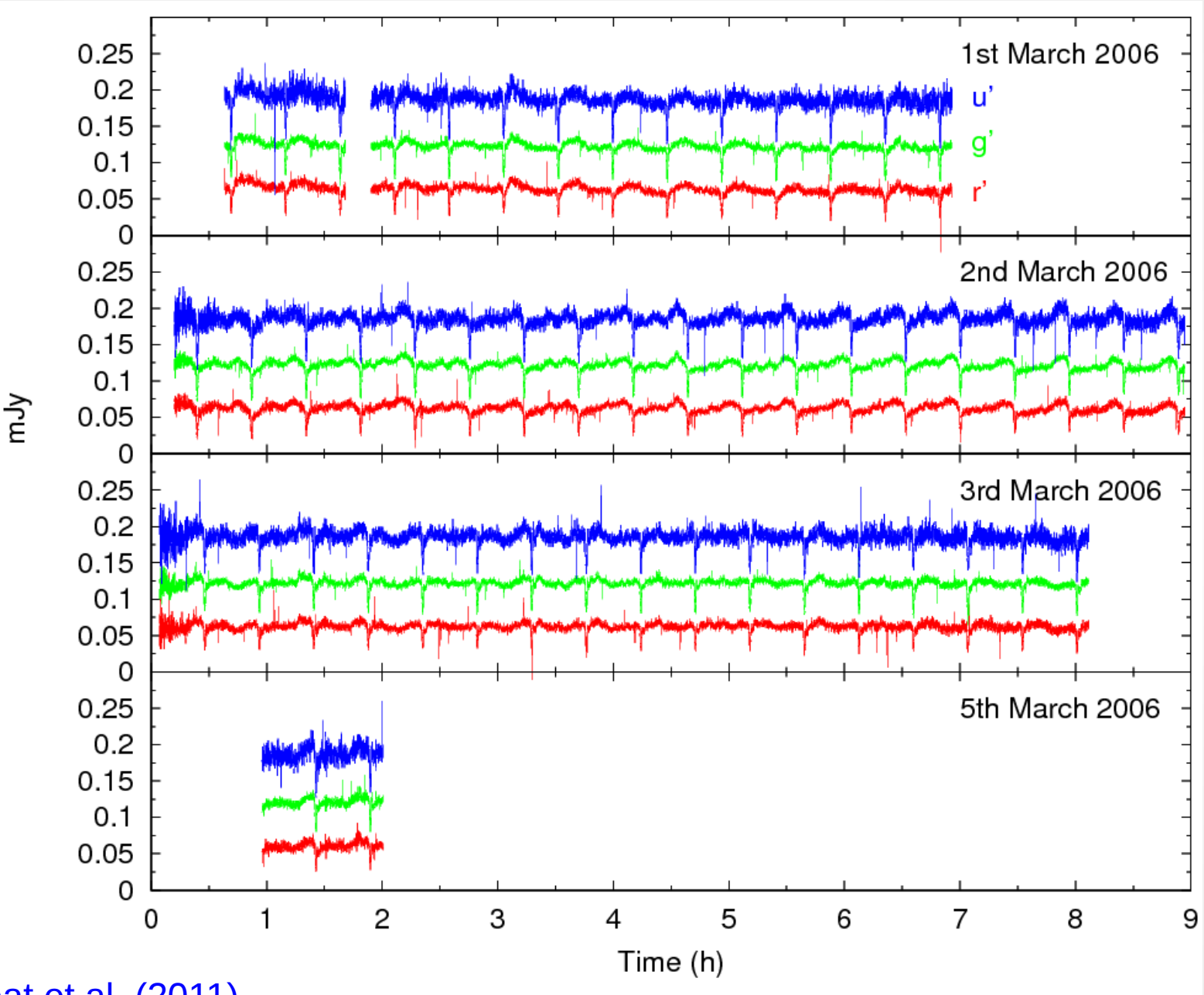
- Any underlying deviation from a linear ephemeris still masked by the ~20s scatter in the timings
- We can rule out some models, and conclude a donor mass close to the zero temperature mass – double white dwarf formation channel
- Alternatively, Mdot significantly shorter than the secular rate – ES Cet links HM Cnc and V407 Vul to the longer period AM CVns

SDSS J0926+3624

- One of 4 AM CVn stars in the SDSS reported by Anderson et al (2005)
- *P* = 28 min
- *g′* = 19.3 out of eclipse
- ~1 min eclipses
- Three epochs of ULTRACAM data obtained between 03-2006 and 01-2012. Exposure times ~2-4s

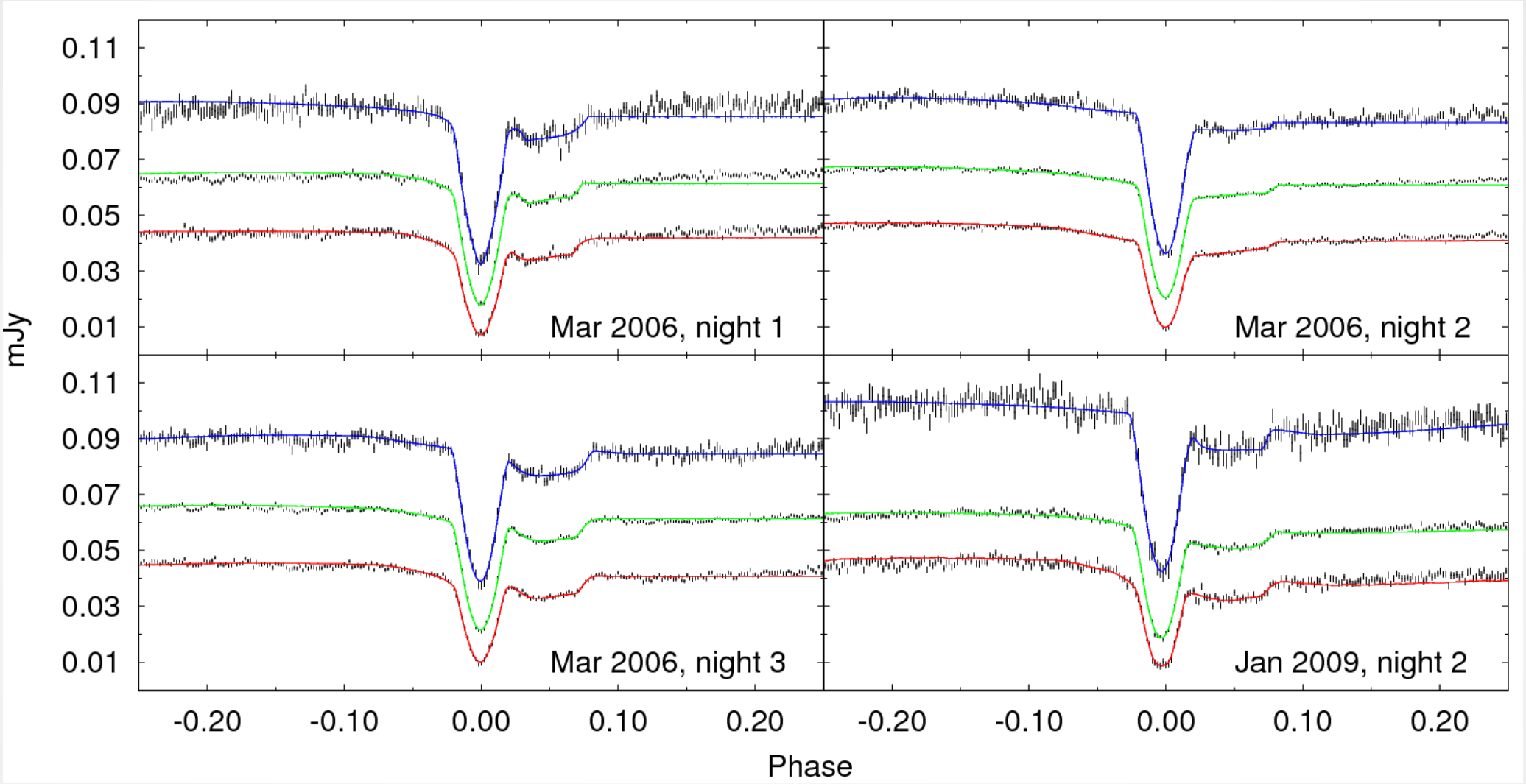


Light curves – March 2006



Copperwheat et al. (2011)

Model fits



- Light curve fitting using TRM's LCURVE software (see appendix of Copperwheat et al., 2010)

Parameter determinations

- Minimisation and uncertainty determination using Markov Chain Monte Carlo (MCMC) method

  $q = M_2 / M_1 = 0.043 \pm 0.004$

  $i = 82.5 \pm 0.3$ deg

  $R1/a = 0.035 \pm 0.002$

- The accreting white dwarf M/R relation obtained using the Bergeron et al. (1995) cooling models

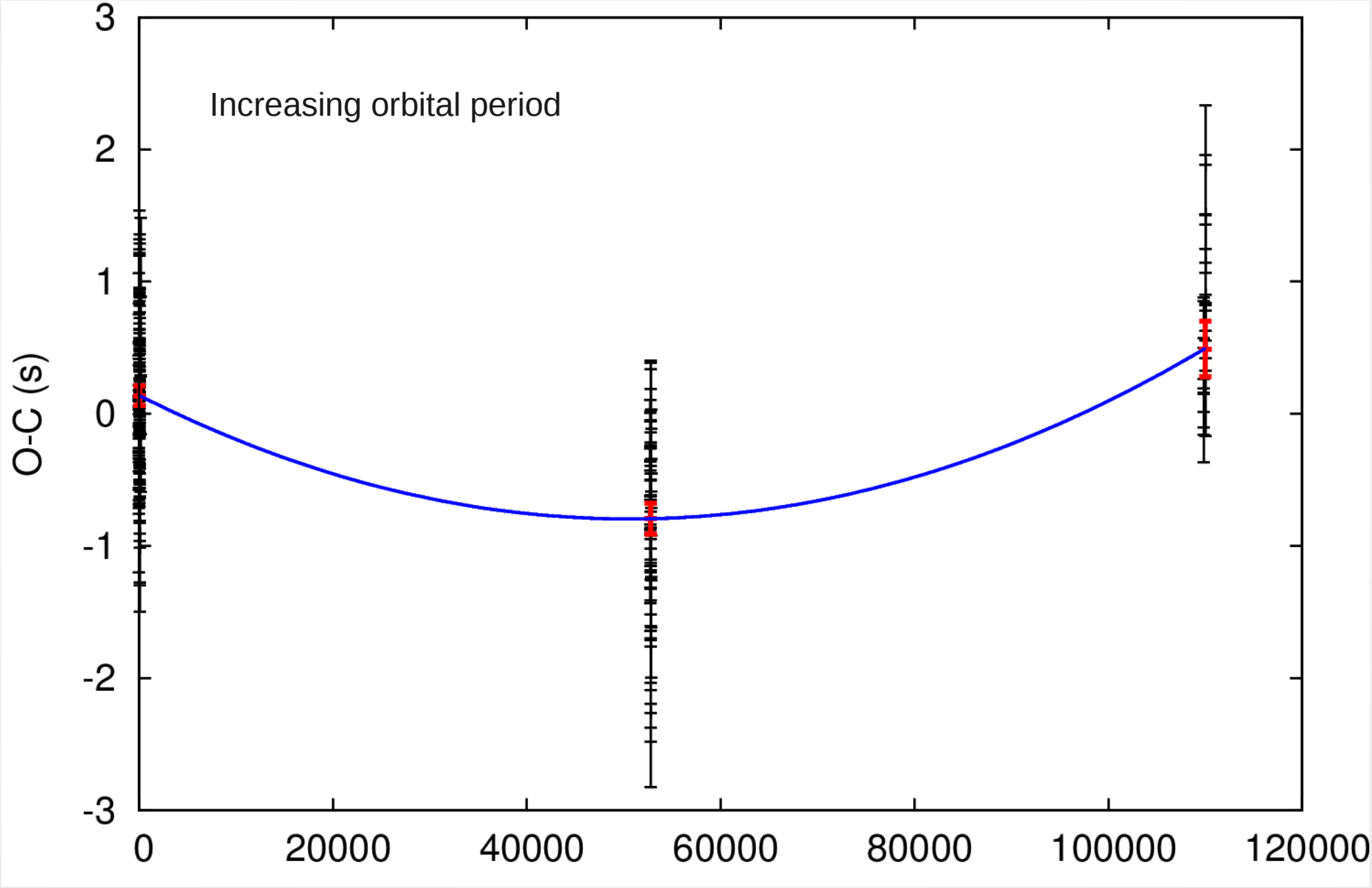
  $T_{eff} \sim 17{,}000K$

  $M_1 = 0.82 \pm 0.04\ M_{\odot}$

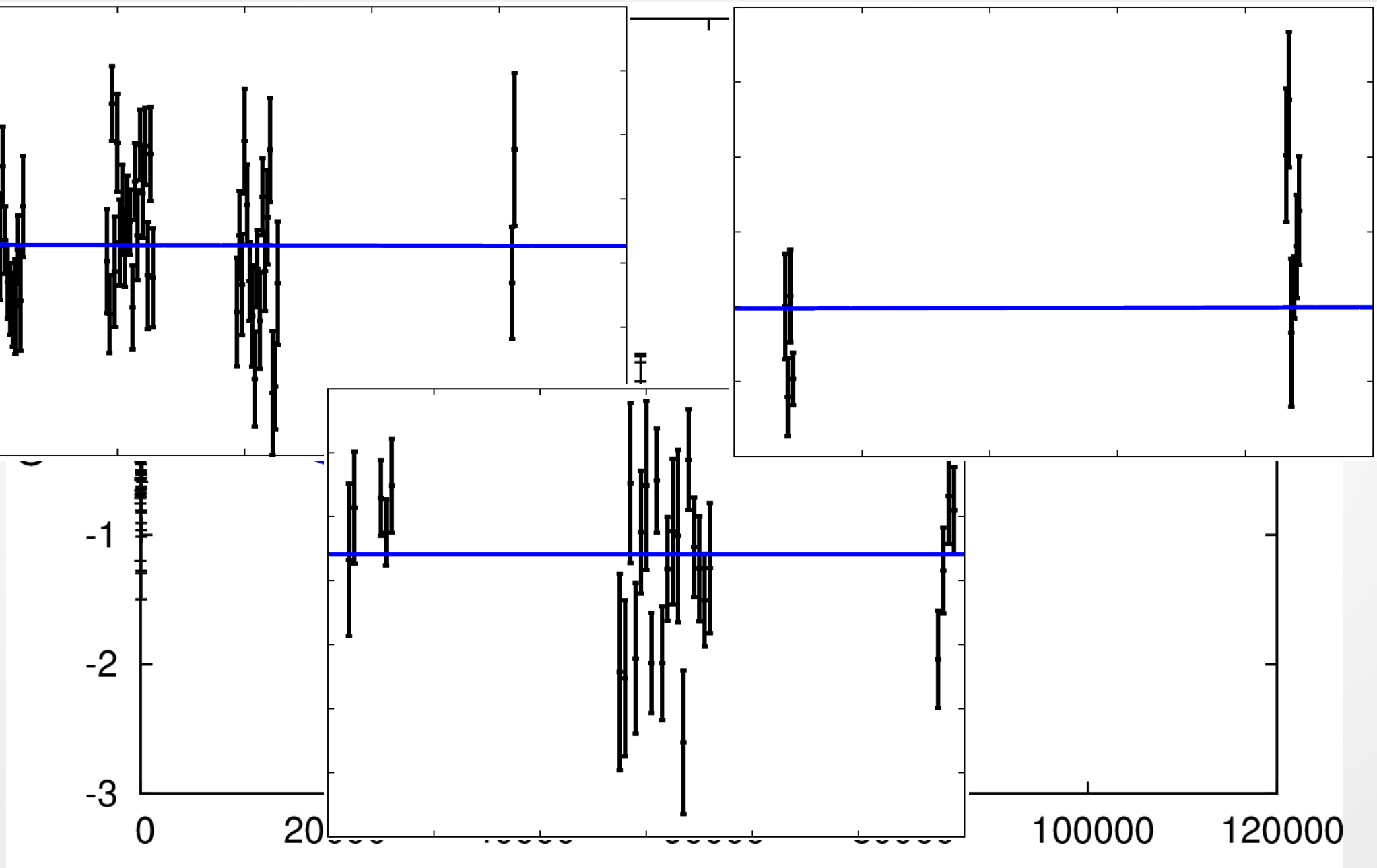
  $R_1 = 0.010 \pm 0.002\ R_{\odot}$

- $M_2 = 0.035 \pm 0.005\ M_{\odot}$ and $R_2 = 0.047 \pm 0.002\ R_{\odot}$ - A fully degenerate donor in this system would have $M_2 \sim 0.02\ M_{\odot}$

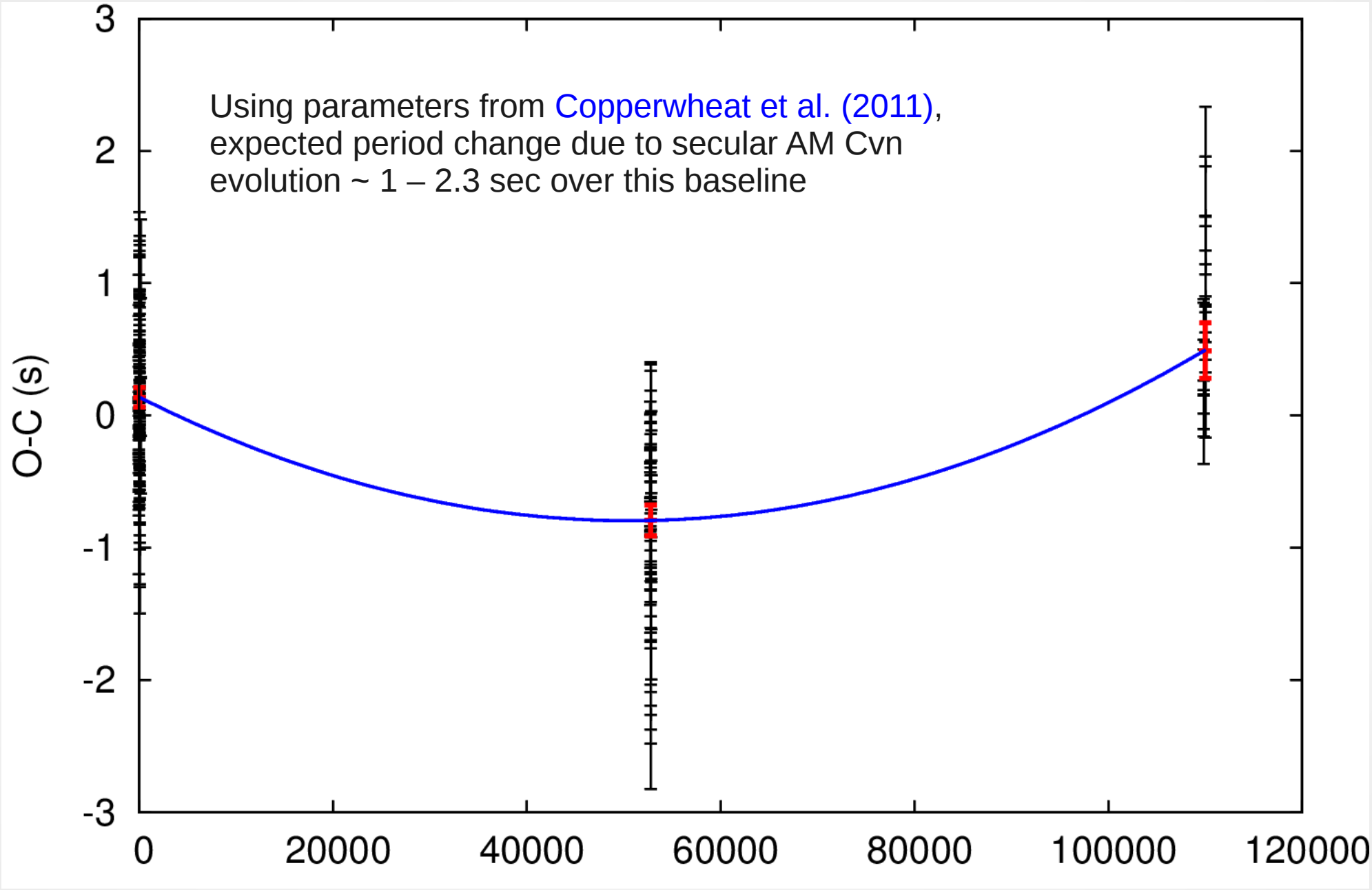
SDSS 0926 (O-C) plot



SDSS 0926 (O-C) plot



SDSS 0926 (O-C) plot



Conclusions

- ~10yr of monitoring HM Cnc and V407 Vul shows the spin up rate to remain consistent with the original X-ray determinations
- $\ddot{\nu}$ will be an important diagnostic, but we are still some years away from being able to constrain this parameter

- ES Cet shows a constant period over 10+ years
- Donor in ES Cet fully degenerate or system in turn-on phase

- Orbital period in SDSS 0926+3624 is lengthening, and in line with the expected secular rate.

(O-C) for all four systems