DOPPLER BEAMING IN THE KEPLER LIGHT CURVES OF KPD 1946+4340 AND KOI 74

UNDER EMBARGO!

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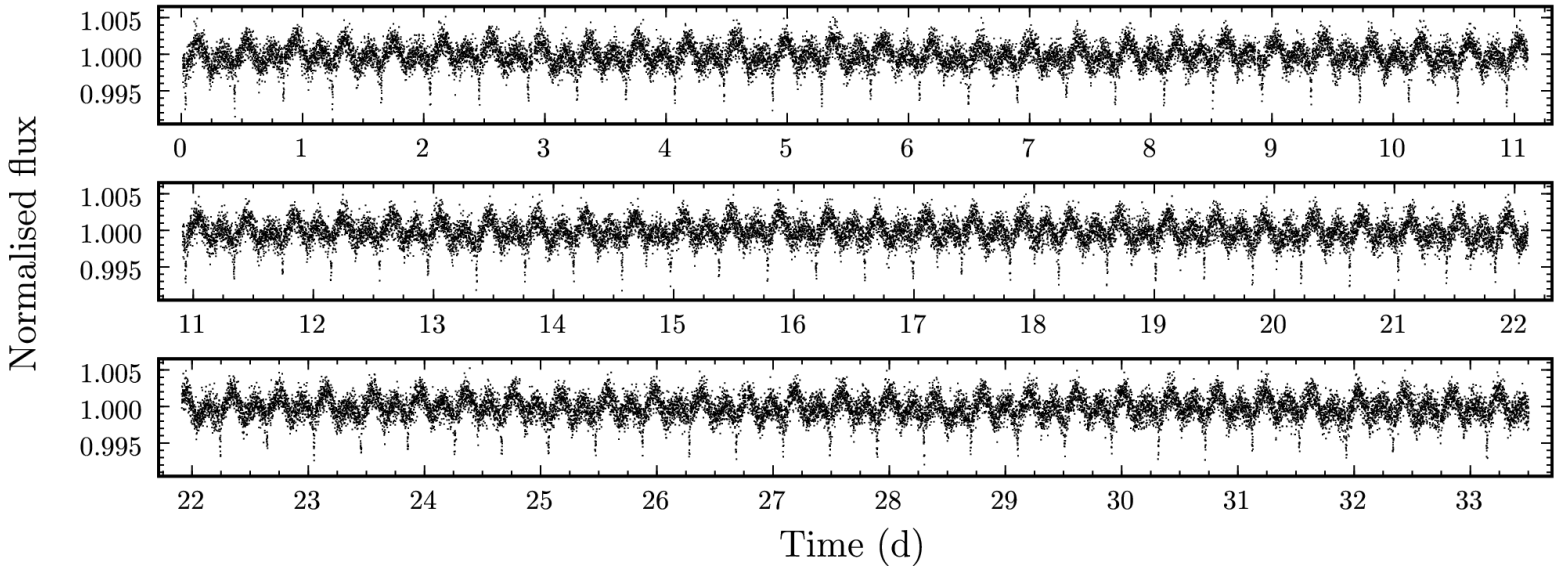
17th European White Dwarf Workshop, 16-20 August 2010, Tübingen

KPD 1946+4340

- sdB+WD binary, P_{orb} = 0.4 d, eclipsing
- Q1 short cadence *Kepler* data [KIC 7975824]:
  59s sampling, 33d time span



Spectroscopy of KPD1946

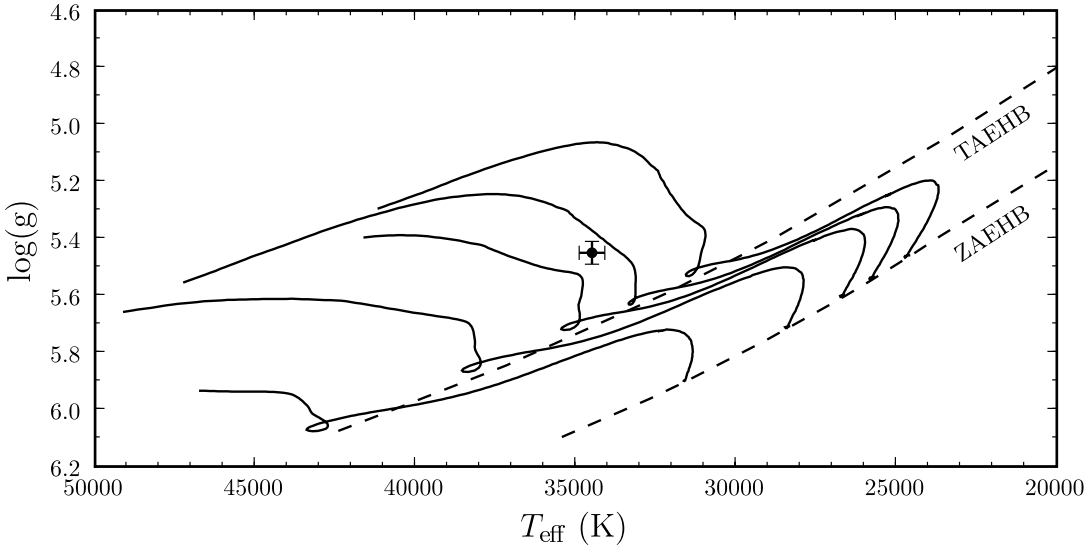
- Radial velocities [Morales-Rueda et al. 2003 + 11 new NOT spectra]:

  $K_1 = 164.0 \pm 1.9$ km/s

- Spectroscopy [G. Fontaine & E. Green]:

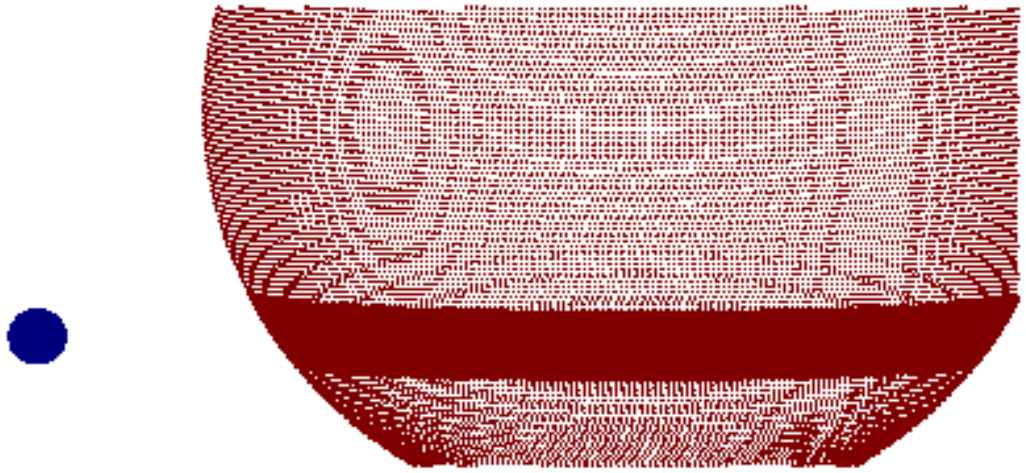
  $T_{eff} = 34\,730 \pm 220$ K log(g) = 5.43 ± 0.04

- Post-EHB
  (shell He-burning)



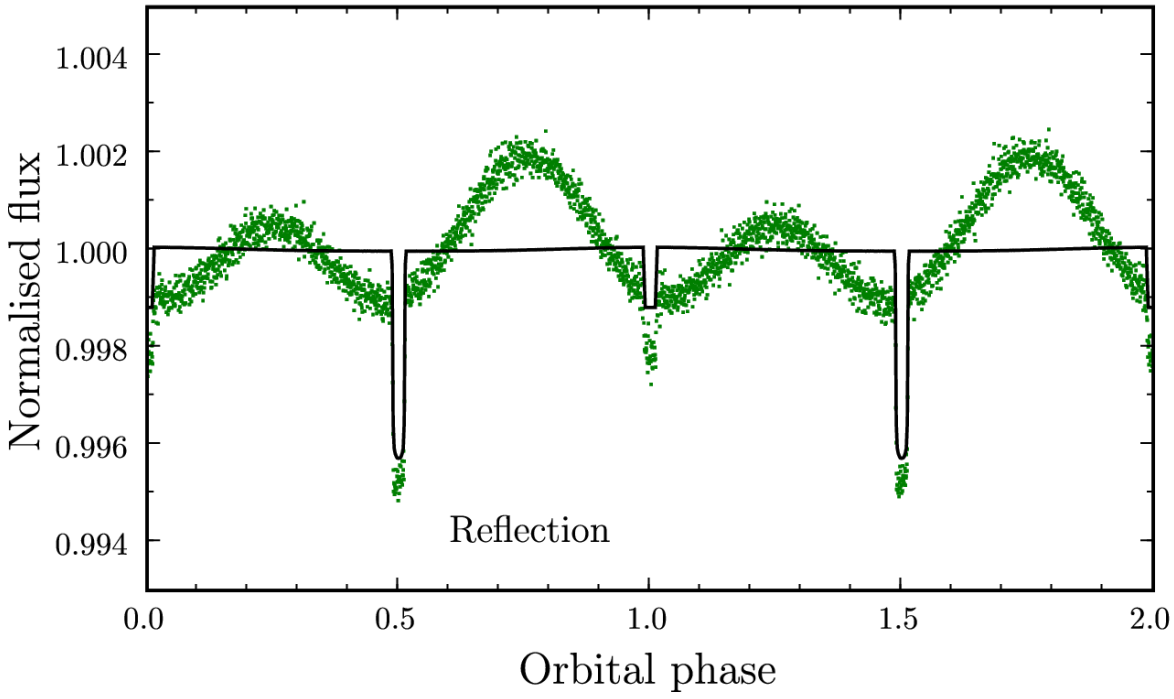
Modelling the binary LC

- LCURVE [TOM MARSH]
- 100 000 grid points on sdB, 3000 on WD
- Adaptive grids (denser strip on sdB during eclipse)



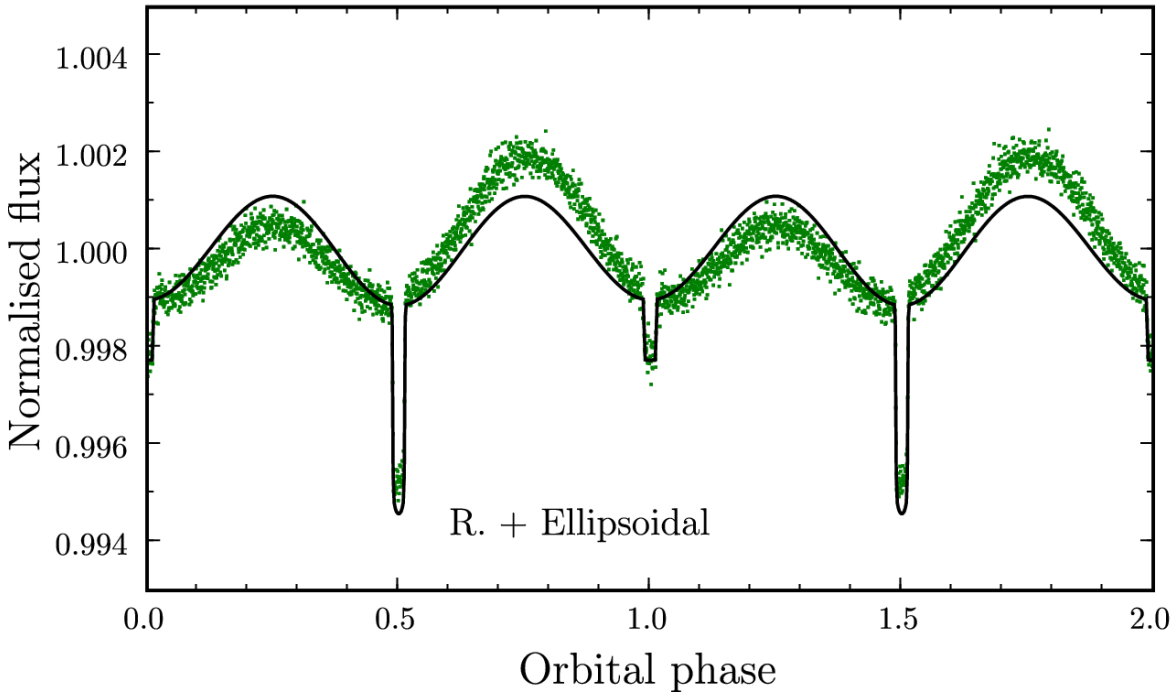
Modelling the LC of KPD1946

Eclipses + reflection



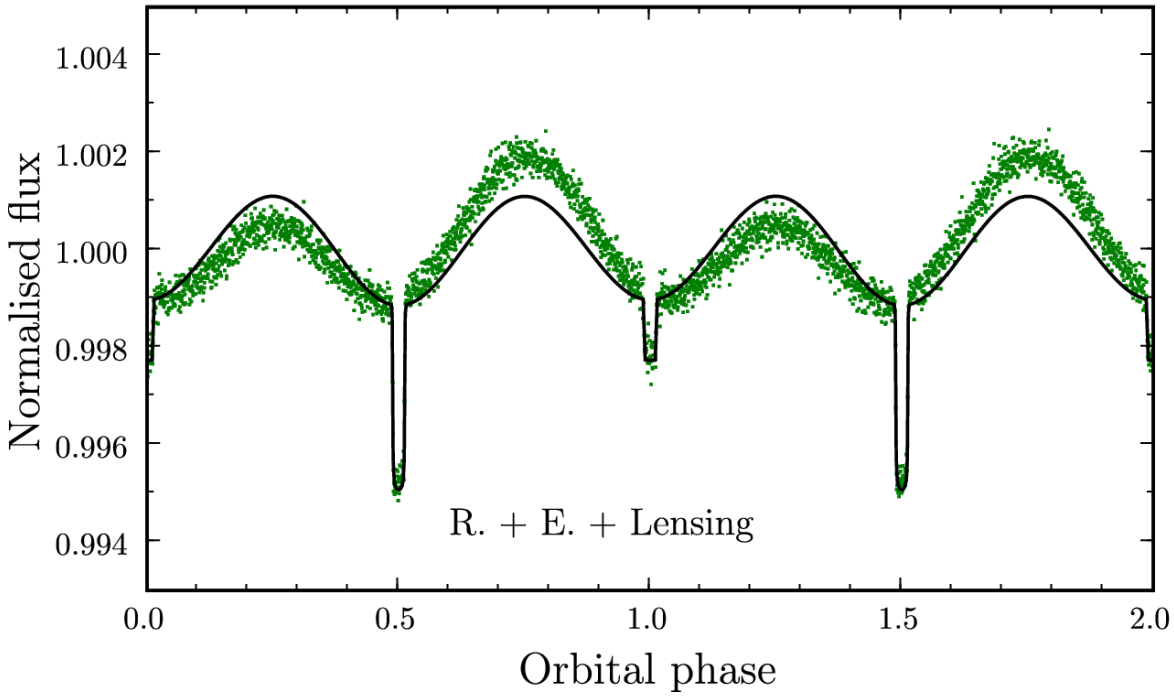
Modelling the LC of KPD1946

Eclipses + reflection + ellipsoidal



Modelling the LC of KPD1946

Eclipses + reflection + ellipsoidal + lensing



Doppler beaming

- Flux increase/decrease due to velocity of stars in orbit

$$F_\lambda = F_{0,\lambda}\left(1 - B\frac{v_r}{c}\right) \qquad B = 5 + \mathrm{d}\ln \mathrm{F}_\lambda/\mathrm{d}\ln\lambda$$

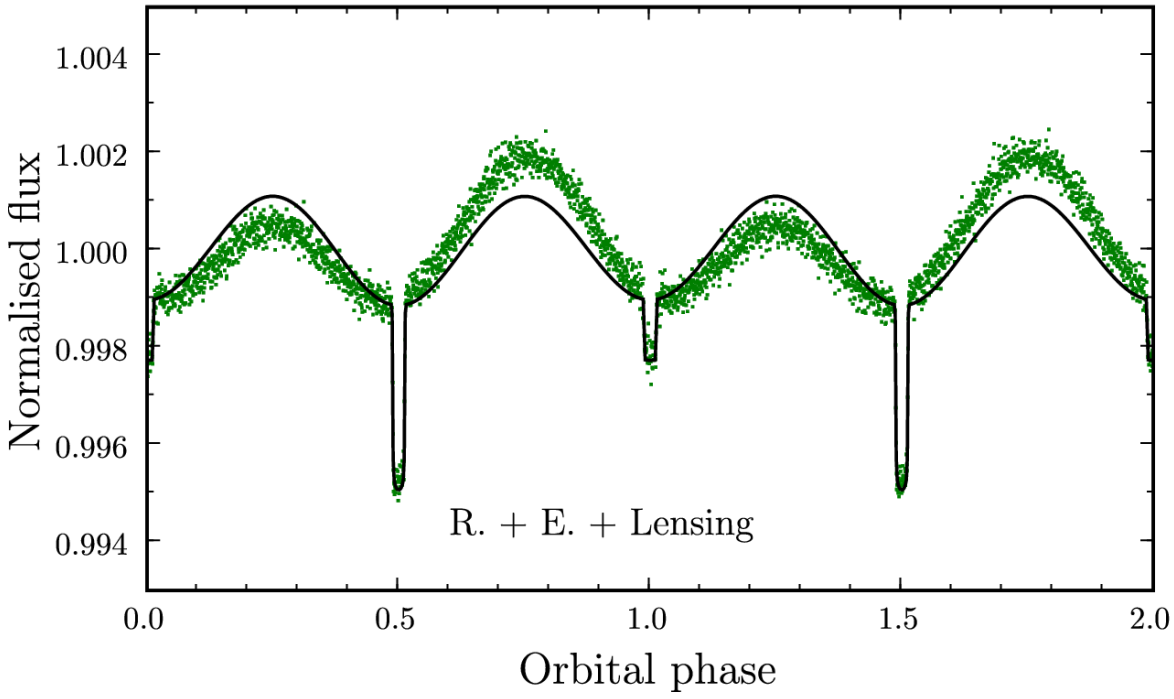
- Expected in Kepler LCs
  [LOEB & GAUDI 2003; ZUCKER ET AL. 2007: 'beaming binaries']
- Detected in long cadence Kepler light curve of KOI 74
  [VAN KERKWIJK ET AL. 2010]
- *Kepler* bandpass photon weighted factor from atmosphere model (depends on assumed metallicity etc.!):

$$\langle B\rangle = \frac{\int \epsilon_\lambda \lambda F_\lambda B\, d\lambda}{\int \epsilon_\lambda \lambda F_\lambda\, d\lambda} = 1.30 \pm 0.03$$

(components: aberration +2, photon arrival rate +1, Doppler shift -1.7)

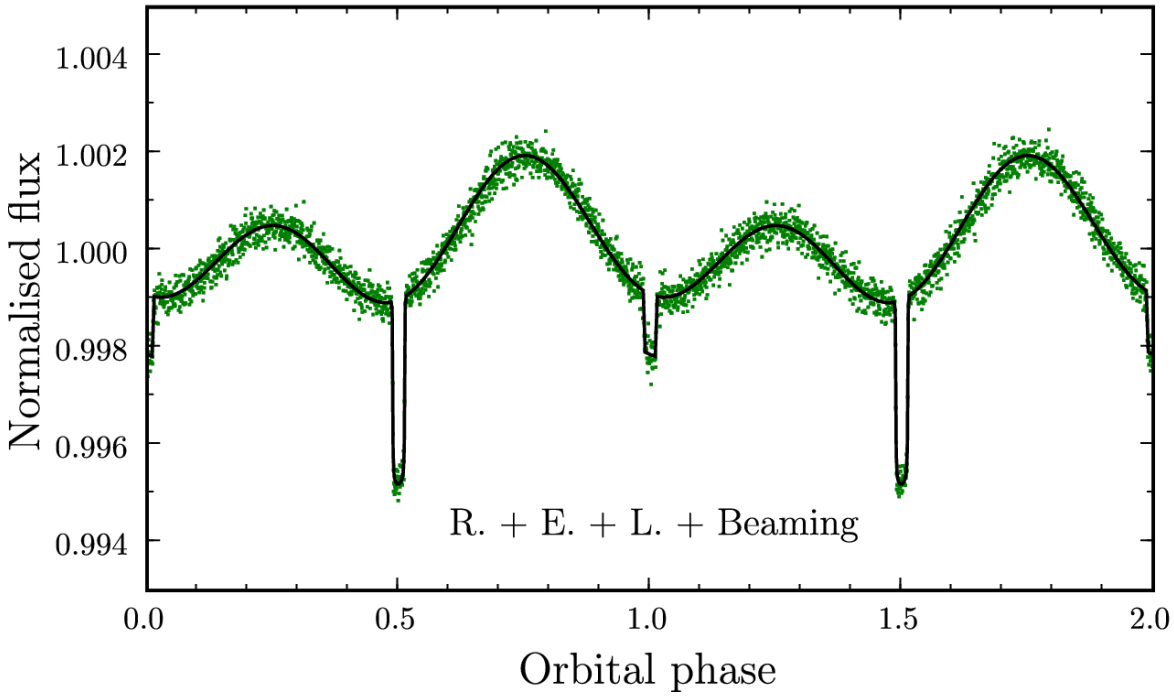
Modelling the LC of KPD1946

Eclipses + reflection + ellipsoidal + lensing



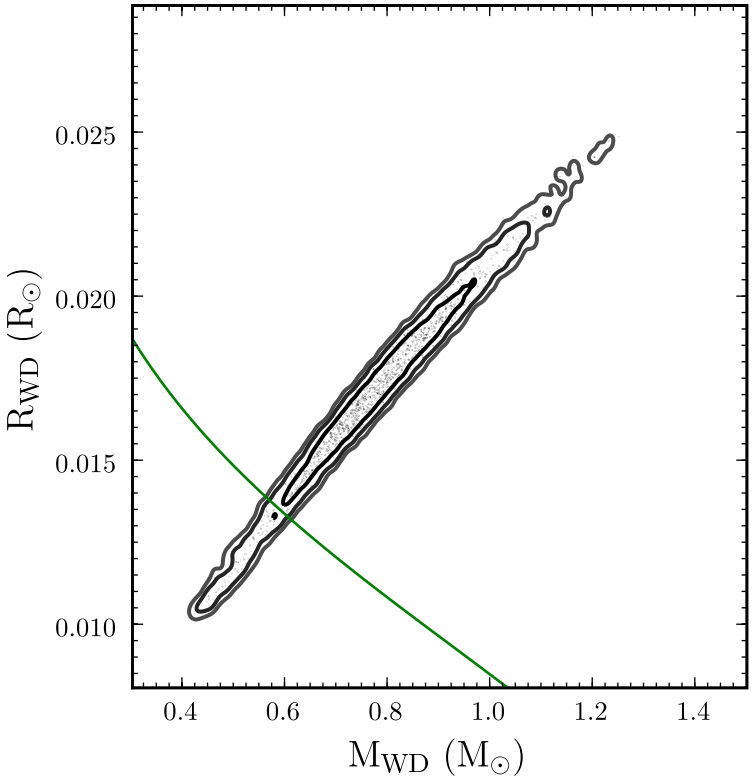
Modelling the LC of KPD1946

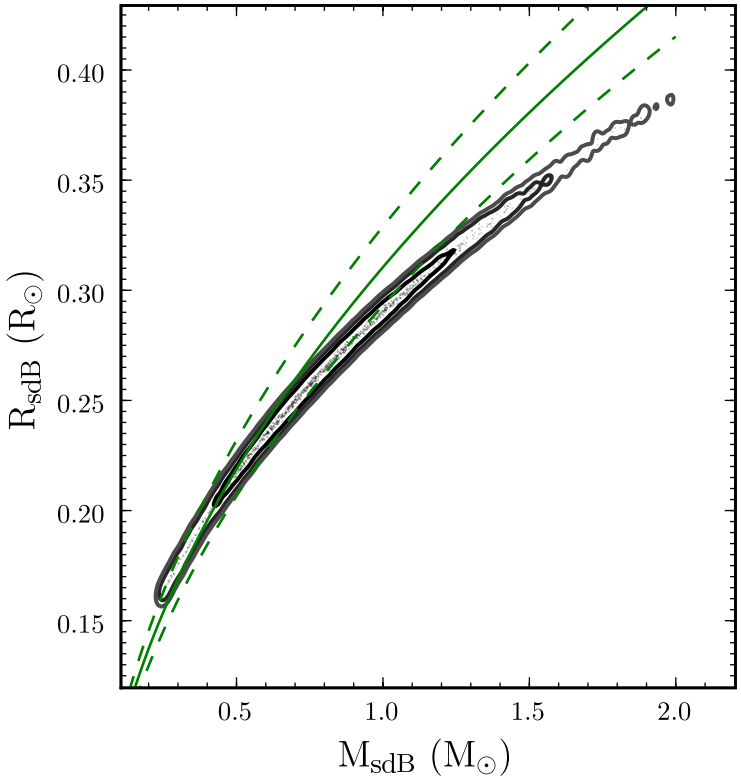
Eclipses + reflection + ellipsoidal + lensing + beaming



MCMC results for KPD1946

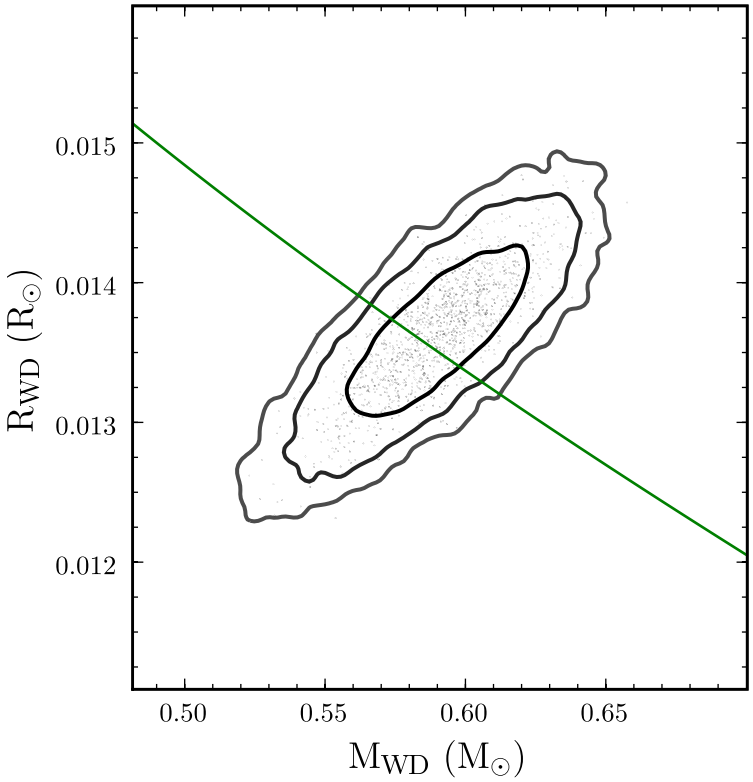
M-R relations for WD (left) and sdB (right)

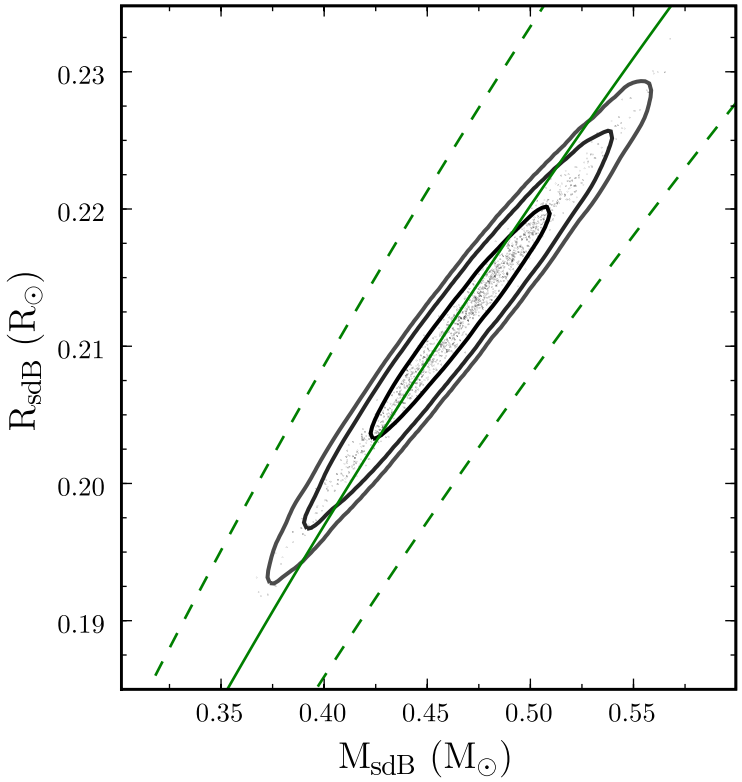




MCMC results for KPD1946

M-R relations with Eggleton's WD M-R constraint





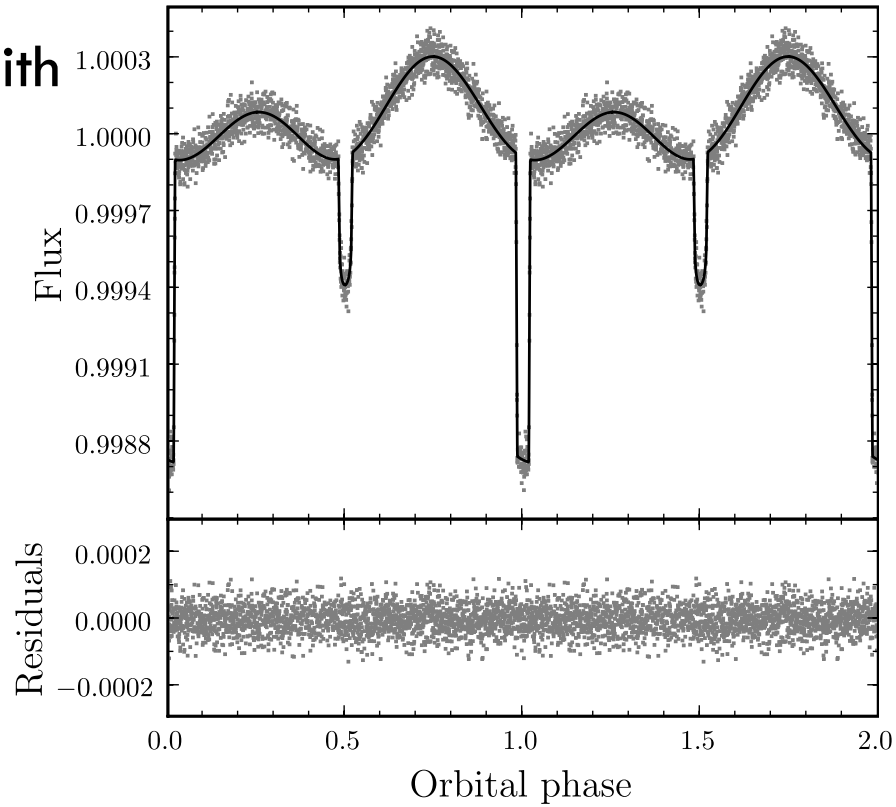
MCMC results for KPD1946

	Primary (sdB)	Secondary (WD)
$P_{\rm orb}$ (d)	$0.40375026(16)$	
q	1.27 ± 0.06	
i (deg)	87.14 ± 0.15	
R ($R_\odot$)	0.212 ± 0.006	0.0137 ± 0.0004
M ($M_\odot$)	0.47 ± 0.03	0.59 ± 0.02
$T_{\rm eff}$ (K)	$34{,}500 \pm 400$	$15{,}900 \pm 300$

sdB parameters	Photometry	Spectroscopy
K_1 (km/s)	168 ± 4	164.0 ± 1.9
log(g)	5.452 ± 0.006	5.43 ± 0.04
v sin(i) (km/s)	26.6 ± 0.8 (assuming corotation)	26.0 ± 1.0 (Geier et al. 2010)

KOI 74

- Q0+Q1 long cadence *Kepler* data, 30m sampling, 43 days
- P_{orb} = 5.2 d
- ROWE ET AL. 2010: 'A1-star with unusual transiting companion'
- VAN KERKWIJK ET AL. 2010:
  - Low mass WD companion
  - Doppler beaming
    → $K_{1,phot}$ = 14.7 ± 1.0 km/s
- Hermes@Mercator spectra:
  → $K_{1,spec}$ = 15.7 ± 1.0 km/s
  → v sin(i) = 164 ± 9 km/s



Beaming binaries

S. ZUCKER ET AL., 2007, APJ 670, 1326

- Beaming expected in hundreds of Corot & Kepler binary light curves
- Weighted *difference* between beaming variability of two stars
- Dominant over ellipsoidal variability and reflection at long enough orbital periods

THE THREE PERIODIC PHOTOMETRIC EFFECTS FOR SAMPLE BINARY CONFIGURATIONS

		P = 10 days			P = 100 days		
PRIMARY	SECONDARY	Ellipsoidal	Reflection	Beaming	Ellipsoidal	Reflection	Beaming
F0	G0	3.9×10^{-4}	4.8×10^{-4}	6.4×10^{-4}	3.9×10^{-6}	2.2×10^{-5}	2.9×10^{-4}
F0	K0	3.4×10^{-4}	4.1×10^{-4}	8.3×10^{-4}	3.4×10^{-6}	1.9×10^{-5}	3.8×10^{-4}
G0	K0	1.9×10^{-4}	2.1×10^{-4}	6.6×10^{-4}	1.9×10^{-6}	9.6×10^{-6}	3.1×10^{-4}

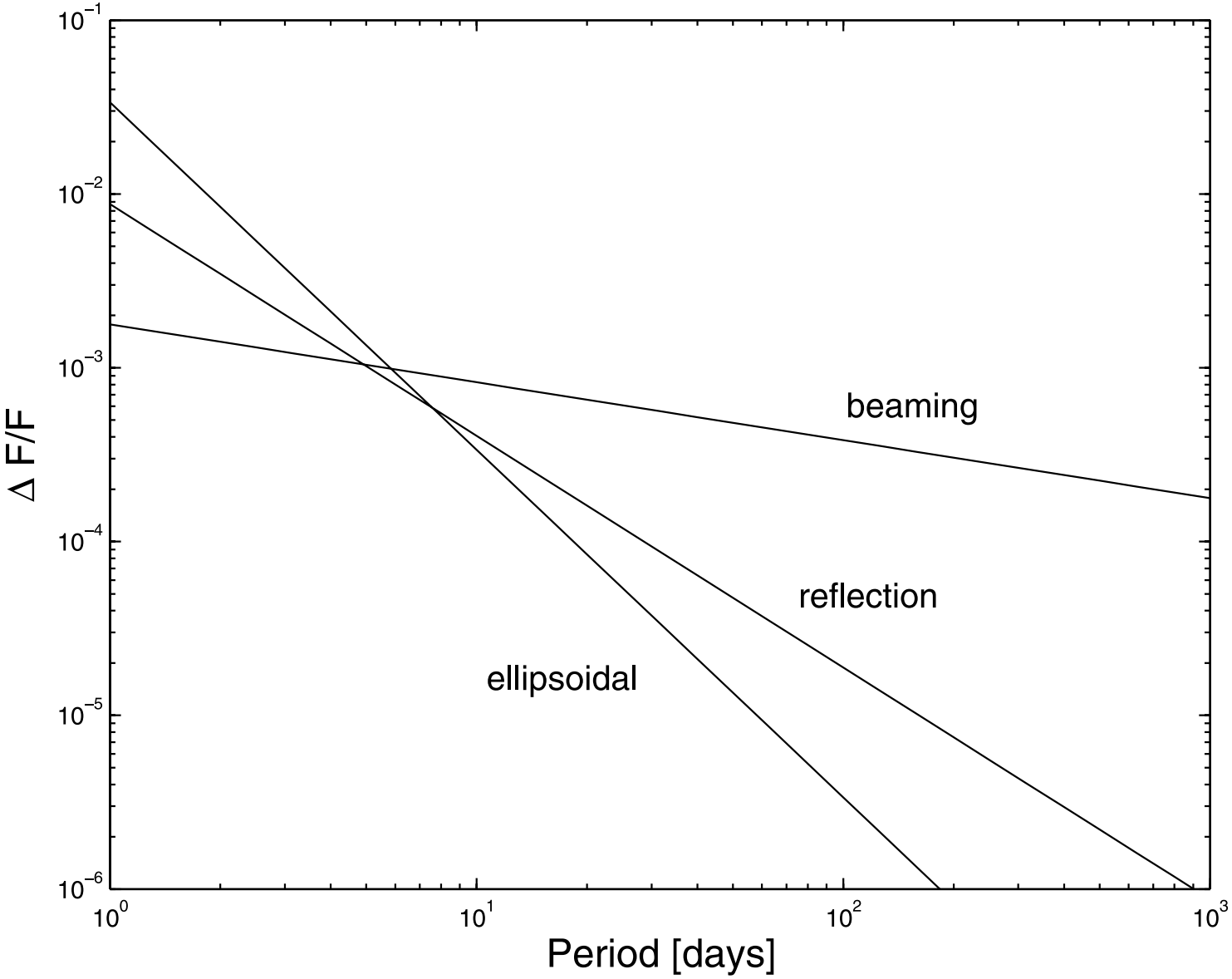
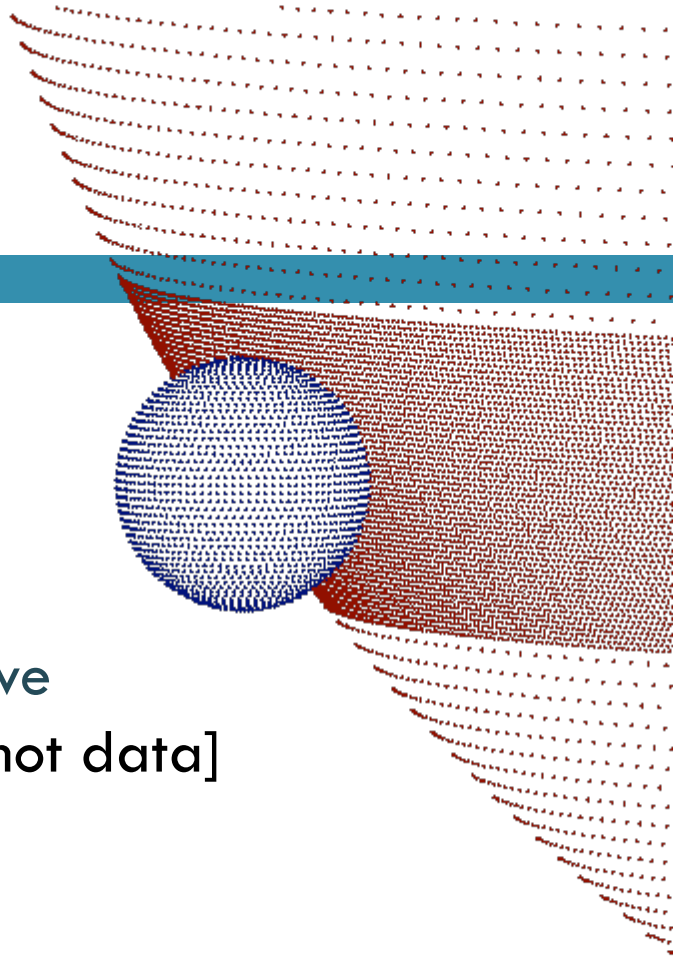


FIG. 1.—The three periodic photometric effects for an F0–K0 binary star in a range of periods.

Summary



KPD 1946+4340

- Modelled superb Kepler short cadence binary light curve using LCURVE
- Doppler beaming → photometric RV curve
  [largest source of uncertainty is models, not data]
- Very accurate system parameters,
  fully consistent with spectroscopic results

KOI 74

- Photometric K_1 consistent with spectroscopic K_1
- Modelling complicated by large vsini

Many thanks to my collaborators!

***Kepler* observations of the beaming binary KPD 1946+4340**

S. Bloemen[1⋆], T. R. Marsh[2], R. H. Østensen[1], S. Charpinet[3], G. Fontaine[4], P. Degroote[1], U. Heber[5], S. D. Kawaler[6], C. Aerts[1,7], E. M. Green[8], J. Telting[9], P. Brassard[4], B. T. Gänsicke[2], G. Handler[10], D. W. Kurtz[11], R. Silvotti[12], V. Van Grootel[3], J. E. Lindberg[8,13], T. Pursimo[8], P. A. Wilson[8,14], R. L. Gilliland[15], H. Kjeldsen[16], J. Christensen-Dalsgaard[16], W. J. Borucki[17], D. Koch[17], J. M. Jenkins[18], T. C. Klaus[19]

Under embargo!

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