The first quintuple system found with the K2 Mission

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There were some 3000 binaries discovered in the Kepler main mission, and there is a growing collection of binaries that have been found to date in the 2-wheel extension of the Kepler mission, called 'K2'. Among this impressive collection of mostly eclipsing binaries, some 220 triple stars have been detected, mostly through eclipse timing variations, but some via 3rd-body eclipses. In addition to the large sample of triple-star systems, a number of higher-order multiple star systems have also been discovered using Kepler data plus follow-up ground-based observations, like the quadruple systems KIC 4247791 (Lehmann et al. 2012) and KIC 7177553 (Lehmann et al. 2016), or the quintuple system KIC 4150611 (Shibahashi & Kurtz 2012, Prsa et al. 2016). We report on the first quintuple star system found in the K2 fields, and one of the few that contain two eclipsing and spectroscopic binaries.

Photometry

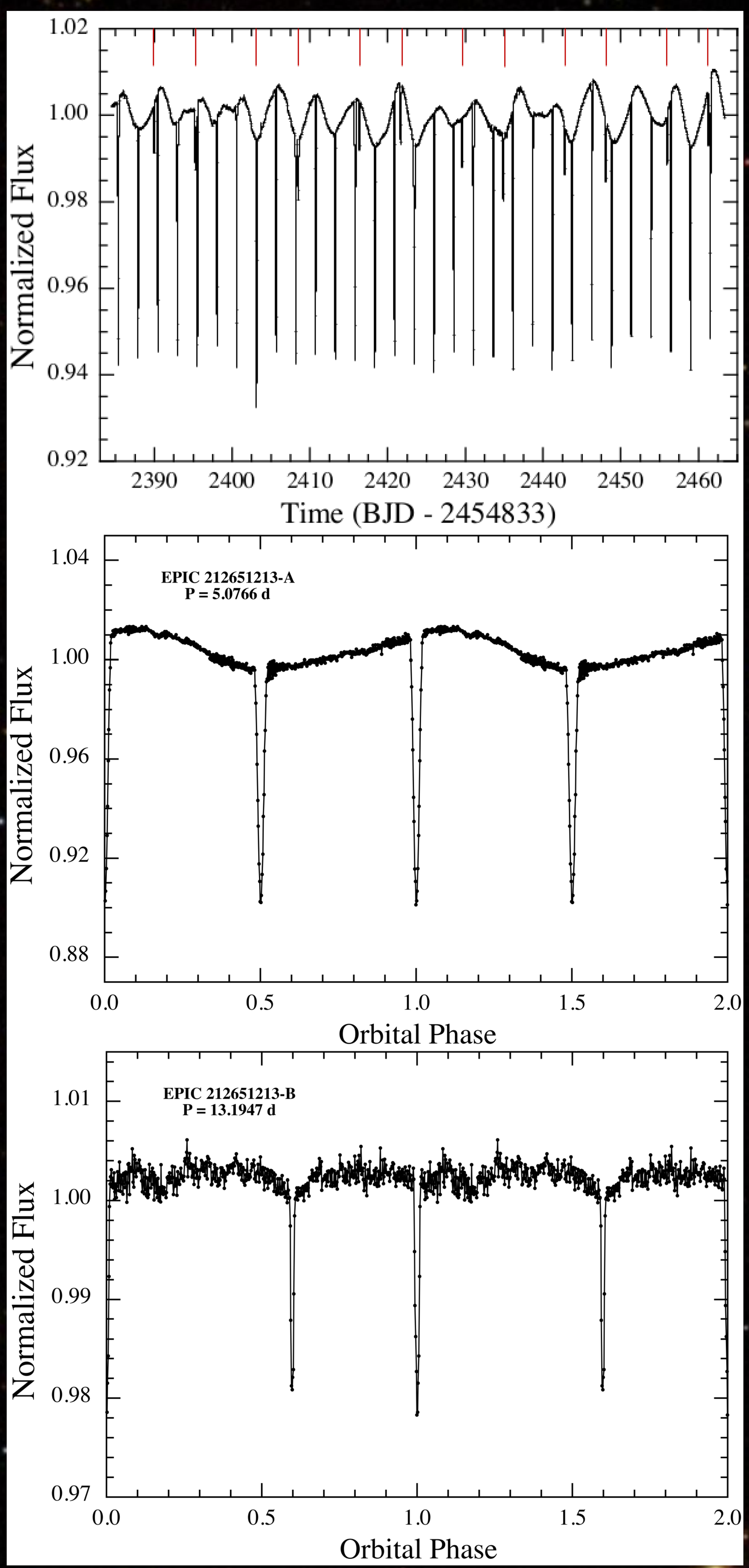

Fig. 1. K2 flux data for E1213 (top) and the disentangled and folded light curves for the 5-day circular binary ‚A' and the 13-day eccentric binary ‚B'.

The SDSS image in the background shows EPIC 212651**213** and EPIC 212651234. Both stars exhibit the same two sets of eclipses (Fig. 1) in the K2 data. Keck AO imaging (Fig. 2) and Speckle interferometry with the WIYN telescope at Kitt Peak resolve the image of E1213 into two images (binaries ‚A' and ‚B' hereafter) at 0.09 arcsec, whereas E1234 seems to be a single star.

Spectra have been taken with the Coude spectrograph at the 2-m telescope of the Thüringer Landessternwarte (TLS) Tautenburg, the TRES spectrograph at the 1.5-m telescope on Mt. Hopkins, and the ACE spectrograph at the 1-m telescope of the Konkoly Observatory. Their analysis showed that E213 is an SB3 star, showing the lines of both components of binary ‚A' (circular orbit) and of one component of binary ‚B' (eccentric orbit). The orbits were determined from the radial velocities (RVs) measured from 27 spectra using cross correlation with a synthetic template (Fig. 3).

Spectrum analysis for stars 1 to 3 was performed by applying the spectrum synthesis method to the TLS spectrum showing the largest RV separation of the components (Fig. 4). Atmospheric parameters of E1234 were determined from the six TRES spectra.

Spectroscopy

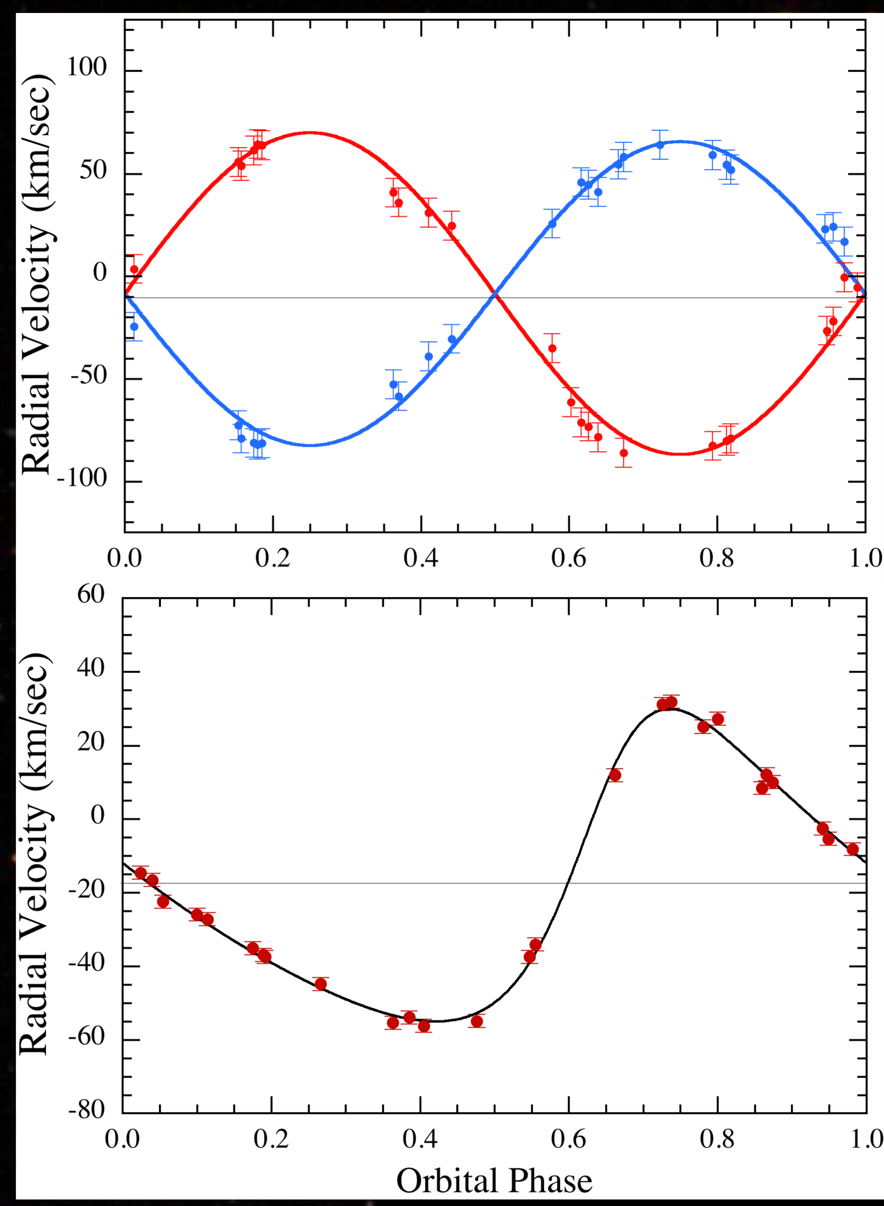

Fig. 3. RVs measured for the ‚A' binary (top) and the ‚B' binary (bottom). The solid curves are the best fitting orbital solutions (blue for the primary and red for the secondary star of binary ‚A').

Keck AO Imaging and Speckle Interferometry

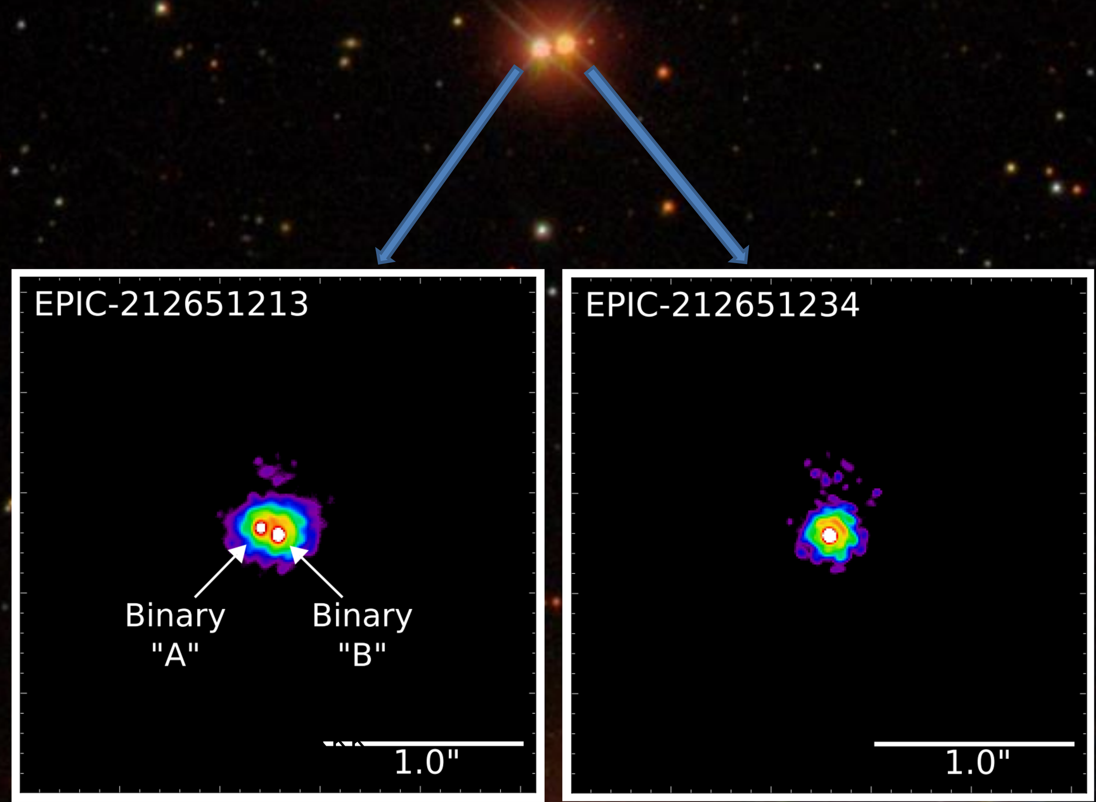

Fig. 2. Keck-AO images in the K_s-band.

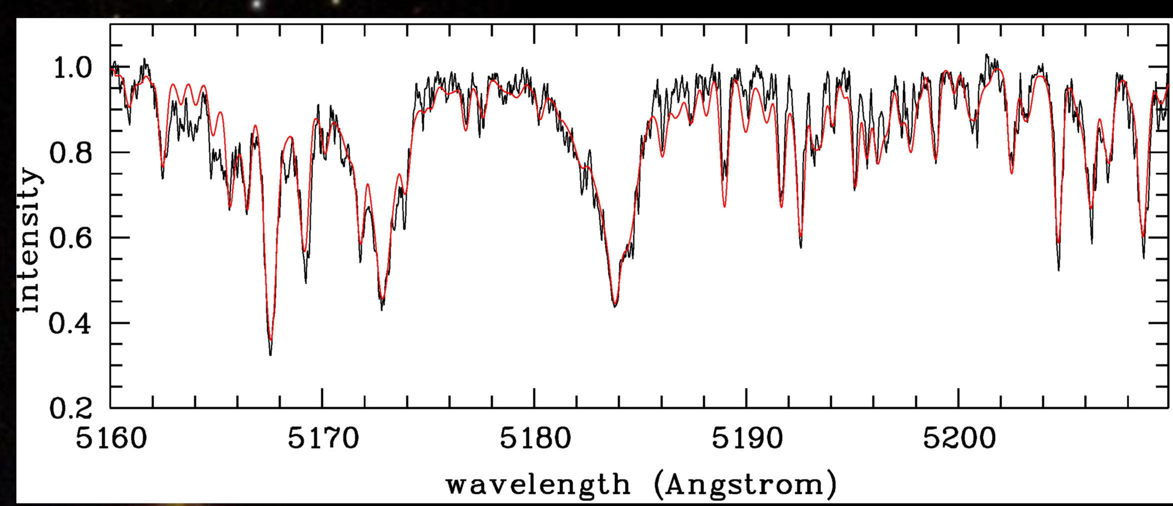

Fig. 4. Part of the composite spectrum of E1213 (black) together with the best fitting combination of synthetic spectra (red colour).

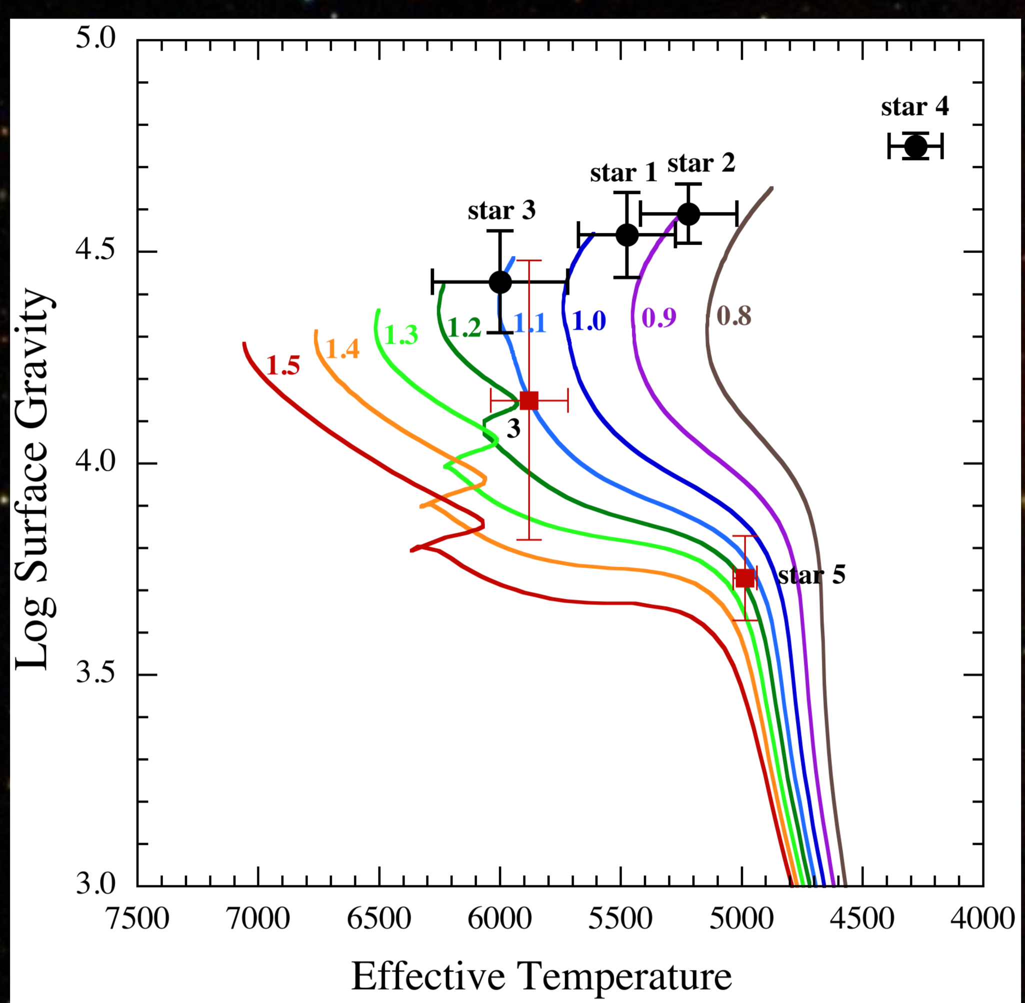

Fig. 5. Yonsei-Yale evolution tracks for stars of 0.8 to 1.5 solar masses. The black circles are the locations of stars 1 to 4 as determined from the Monte Carlo analysis. The red squares for stars 3 and 5 are based on spectrum analysis.

Stellar parameters

Radial velocities → mass functions for stars 1, 2, 3
Light curve → orbital inclination for ‚A' and ‚B'
Speckle → relative fluxes of ‚A' and ‚B'

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Monte Carlo error propagation technique: Evaluate this information + using Yonsei-Yale tracks (Fig. 5) to get the masses, radii, T_{eff}, and logg of stars 1 to 4. Results are listed in Table 1. Parameters of star 5 were obtained from spectrum analysis. From the photometric parallax we obtain a distance of 260+-50 pc.

Table 1. Orbital and stellar parameters derived for the five stars in the hierarchical quintuple system.

Parameter	E1213 + E1234 = Binary 'D'				
a (AU)	~ 2800				
	E1213 = Binary 'C'				E1234
P_{orb} (yr)	65 ± 20				
a (AU)	25 ± 5				
	Binary 'A'		Binary 'B'		
P_{orb} (d)	5.07655 ± 0.00003		13.1947 ± 0.0004		
i (°)	85.7 ± 0.5		85.8 ± 0.1		
a ($R_\odot$)	7.61 ± 0.20		10.51 ± 0.07		
e	$\lesssim 0.02$		0.325 ± 0.006		
	Star 1	Star 2	Star 3	Star 4	Star 5
M ($M_\odot$)	0.94 ± 0.06	0.89 ± 0.05	1.09 ± 0.07	0.64 ± 0.03	
R ($R_\odot$)	0.86 ± 0.12	0.80 ± 0.09	$1.07^{+0.17}_{-0.11}$	0.57 ± 0.03	
T_{eff} (K)	5475 ± 200	5250 ± 200	6000 ± 280	4280 ± 110	4990 ± 50
$\log g$ (cgs)	4.54 ± 0.10	4.59 ± 0.07	$4.43^{+0.10}_{-0.16}$	4.75 ± 0.03	3.73 ± 0.10
$v \sin i$ (kms^{-1}	13 ± 5	7 ± 6	14 ± 2		2.7 ± 0.5

Conclusions

From the relative RV between binaries ‚A' and ‚B', their projected separation, and an upper limit for the relative radial acceleration, we can estimate an orbital separation between ‚A' and ‚B' of 25+-5 AU and an orbital period of 65+-20 years. It means that a phase change in the binary ‚C' orbit can be observed from further RV and high-resolution imaging in a couple of years from now. From the projected separation on the sky and the derived distance, we estimate the physical projected separation between E1213 and E1234 to about 2800 AU. The equal RVs of both stars and the very small difference in proper motion of only 3.4 mas/year leads to the plausible conclusion the E1213 and E1234 are themselves gravitationally bound. We therefore conclude that we observe a hierarchical quintuple system consisting of two eclipsing binaries where one is in a circular and one in an eccentric orbit, and a fifth star in a distant orbit.

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