A UNIQUE LOW MASS ECLIPSING BINARY DISCOVERED BY COROT IN NGC2264

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The young open cluster, NGC 2264, was observed by CoRoT for 24 days continuously in 2008. The search for young eclipsing binaries (EBs), which can be used as calibrators of evolutionary models for pre-main sequence stars, was one of four key science motivations behind this set of observations.

In December 2011 and January 2012, CoRoT re-observed NGC 2264, accompanied by Spitzer, Chandra, MOST and a host of ground-based observatories. This continuous simultaneous photometric and spectroscopic dataset is unprecedented in studying a young star forming region.

We present a particularly interesting system, which shows not only stellar eclipses but also out-of-eclipse variations. We believe these variations are, at least in part, due to a circumbinary disk obscuring light from the central stars. The stellar component of this system consists of a 0.68 $M_\odot$ primary and a 0.52 $M_\odot$ secondary. The orbital period of the binary is 3.87 days.

1. CoRoT Lightcurve

The CoRoT space satellite takes time series photometry in a broad 300-1000nm bandpass with a time sampling of 512 seconds. The CoRoT lightcurve from the 2008 observations (fig. 1a) shows out-of-eclipse variations in addition to the stellar eclipses.

The amplitude and evolutionary timescale of these variations make it extremely difficult to reproduce with stellar activity models alone.

We are looking into alternative possibilities, such as a combination of occultations by a warped circumbinary disk[5] and accretion-related variability.

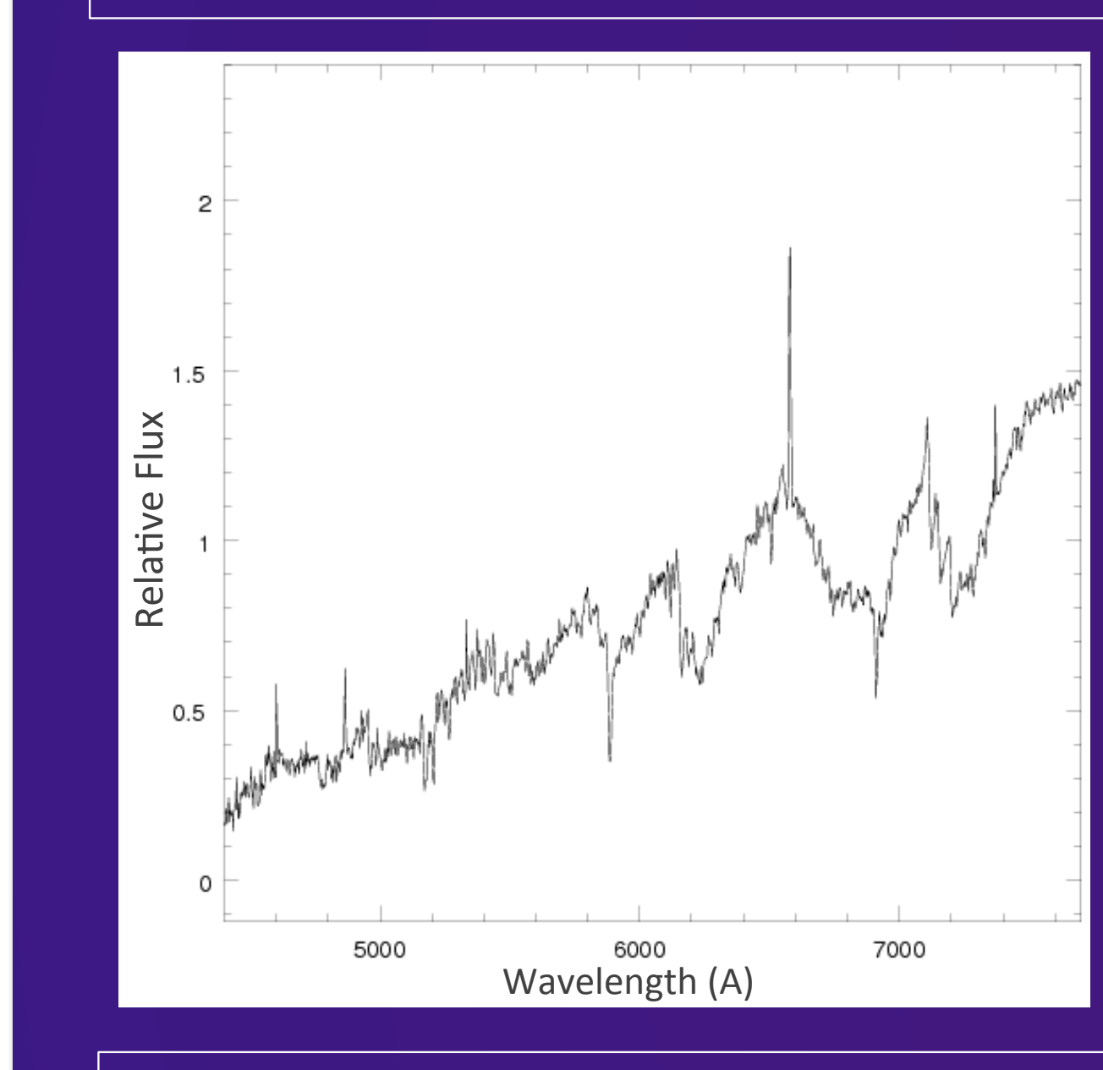

Figure 2: Low resolution optical spectra around Hα showing the deep molecular absorption bands of TiO. The spectral type is M2V.

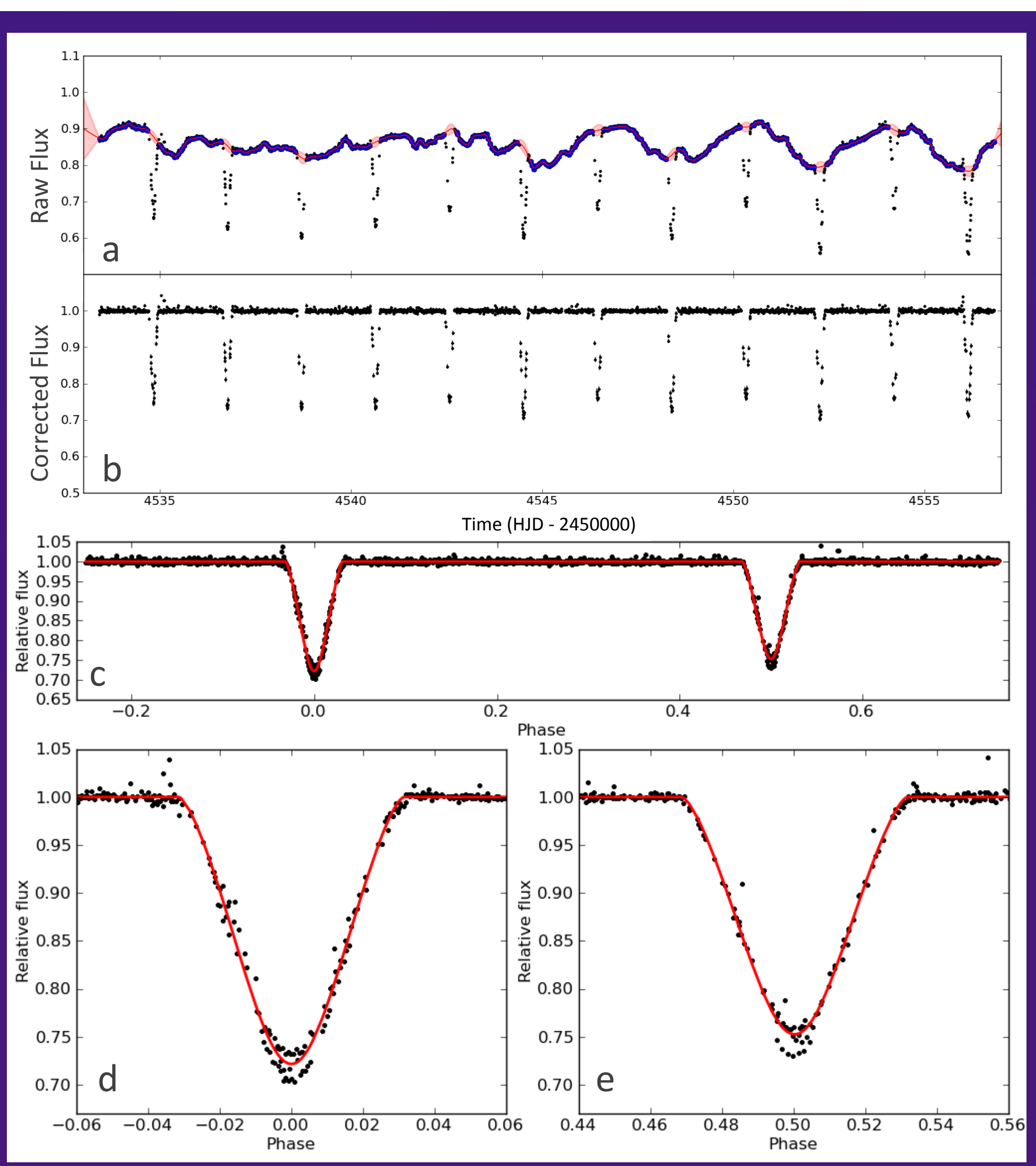

Figure 1: a) CoRoT lightcurve from the 2008 observations with Gaussian Process modelling of the out-of-eclipse (OOE) variability. b) removing the OOE variability ready for stellar eclipse modelling with JKTEBOP. c) phase folded lightcurve from (b) with the JKTEBOP best fit (red). Zoomed in regions around primary (d) and secondary (e) eclipses show the best fit through the eclipses.

2. Modelling of Lightcurves

To extract useful information on the binary components from the lightcurve, we first need to remove the out-of-eclipse variability. We fit and remove this variability using Gaussian Processes[2] (GPs) (see Fig 1a).

We model the resulting lightcurve (Fig 1b) using JKTEBOP[1] (see Fig 1c ,d, e and Table 1), specifying a quadratic limb darkening description with coefficients set according to surface temperature and log*g* estimates from stellar atmospheric models[4].

Even with GP modelling, residual scatter in the folded lightcurve during eclipse (Figs 1d and e) is seen. This is currently unresolved.

Parameter	Best Fit Value	1σ error
P (days)	3.874814	0.000080
M_1 ($M_\odot$)	0.683	0.020
M_2 ($M_\odot$)	0.521	0.016
R_1 ($R_\odot$)	1.327	0.048
R_2 ($R_\odot$)	1.105	0.048
a (AU)	0.051355	0.000037
i (degs)	85.27	0.12
T_0 (HJD)	2454536.76315	0.00028
Surface Brightness Ratio	0.8616	0.0045
e	0.0041	0.0026
ω (degrees)	276.9	6.6
L_2/L_1	0.61	0.10
K_1 (kms^{-1})	62.2	1.4
V_0 (kms^{-1})	17.1	1.3
K_2 (kms^{-1})	81.5	2.0

Table 1: The Eclipsing Binary fundamental parameters and orbital elements. Parameters determined through lightcurve modelling have associated MCMC errors whereas fundamental parameters and those determined from radial velocities have formal errors.

3a. Spectra

A single low-resolution optical spectrum around Hα (Fig 2) was obtained with the 2.2m CAHA telescope at Calar Alto confirming the spectral type of the object as M2V. We then obtained multiple moderate resolution spectra with INT/IDS (3 epoch, near-IR), WHT/ISIS (6 epoch, near-IR) and VLT/FLAMES (21 epoch, optical, around Hα) in order to measure radial velocities by cross correlation (Fig 3) and derive a radial velocity orbit (Fig 4 & Table 1).

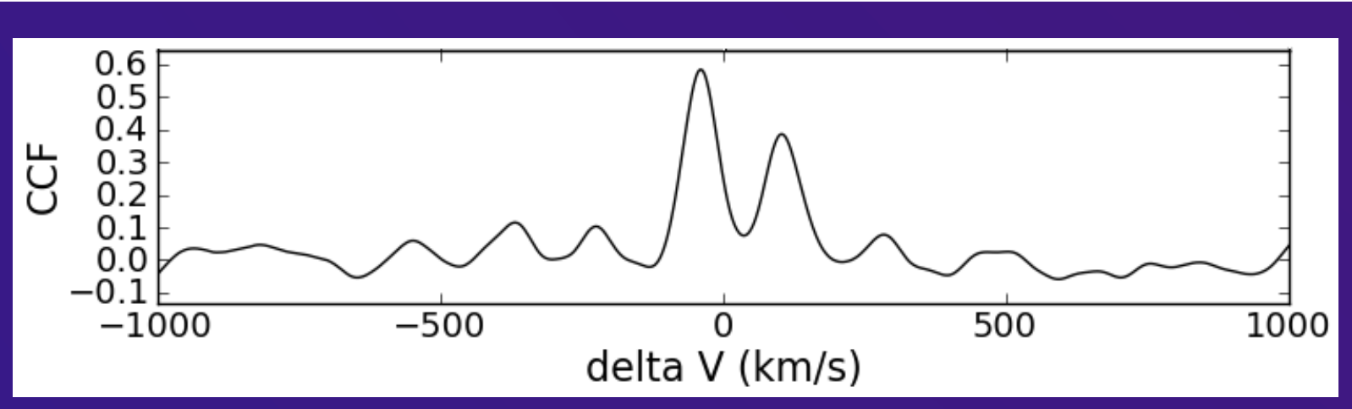

Figure 3: Cross-correlation function using MARCS[3] model spectra (Teff = 3800 K, log*g* = 4.0) showing the velocities of the primary (~-50kms^{-1}) and secondary (~100kms^{-1}) stars.

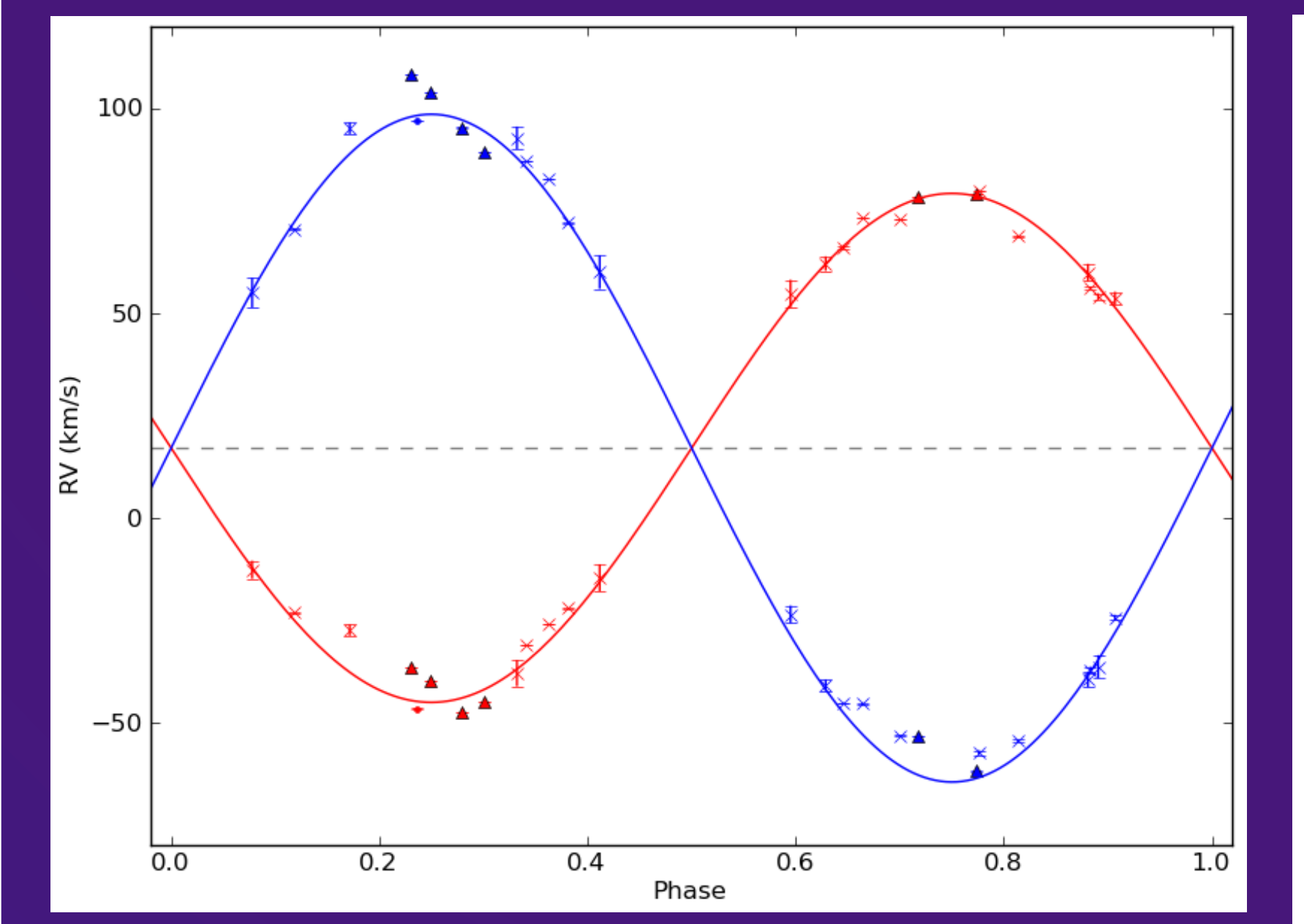

Figure 4: Radial velocity curve for the primary (red) and secondary (blue) stars. The curves represent the best fit solutions. IDS spectra are represented with dots, ISIS with triangles and FLAMES with crosses. The horizontal dashed line depicts the systemic velocity of the system.

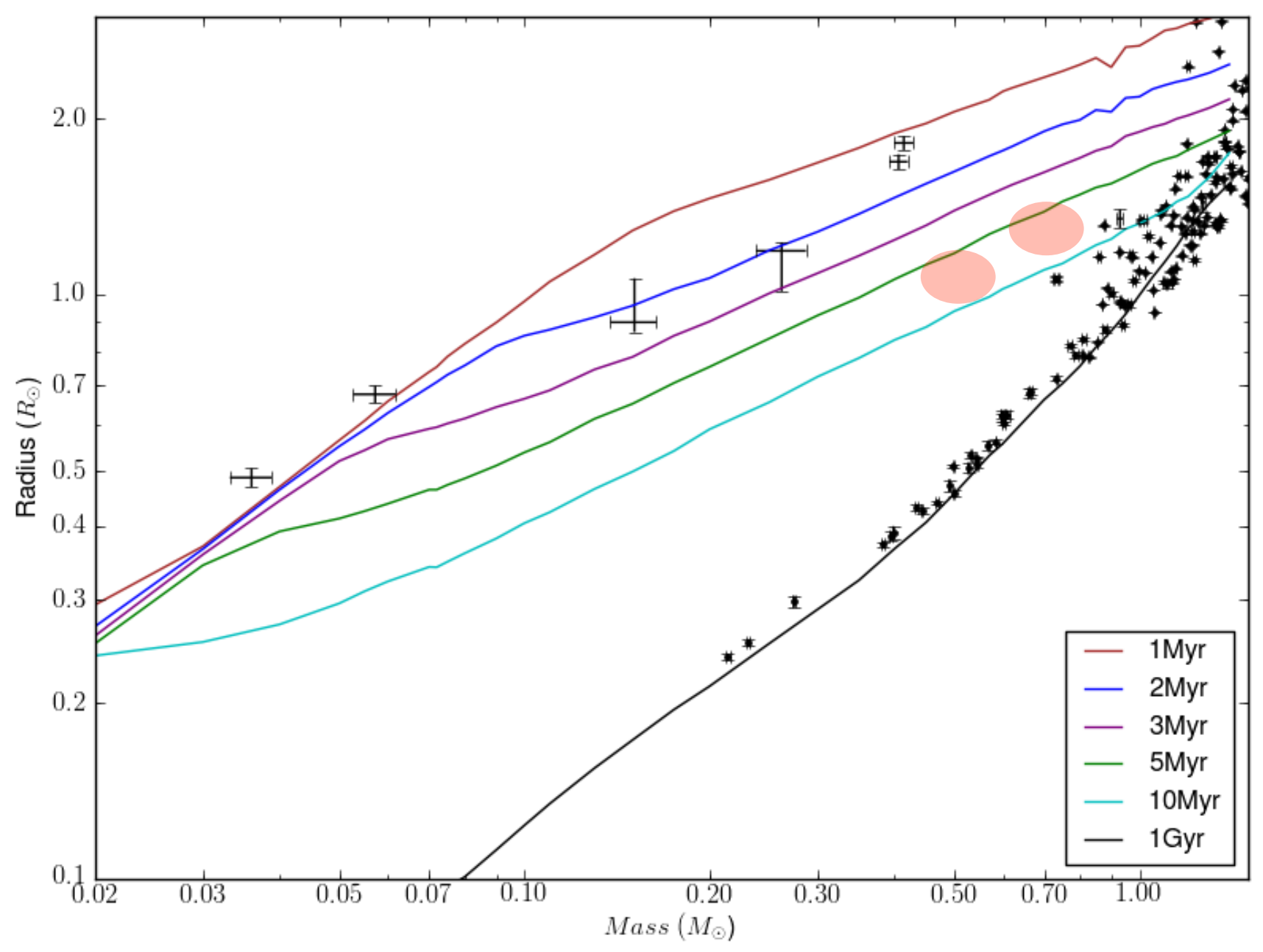

Figure 6: The Mass-Radius relation for low mass EBs. The Baraffe et al.[6] model isochrones at 1Myr (brown line), 2Myr (blue), 3Myr (purple), 5Myr (green), 10Myr (cyan) and 1Gyr (black line) are shown. Black points depict known EBs[7] and this system is shown by the red shaded regions.

3b. Hα Emission

The sequence of FLAMES spectra, which spans nearly 3 months (04/12/11 - 24/02/12), can also be used to monitor the profile of the Hα line, which is a diagnostic of accretion from the circumbinary disk onto one or both of the stars. Broad Hα wings are present during certain phases of the binary orbit, but not others, suggesting non-steady accretion which may be controlled in part by the binary orbit.

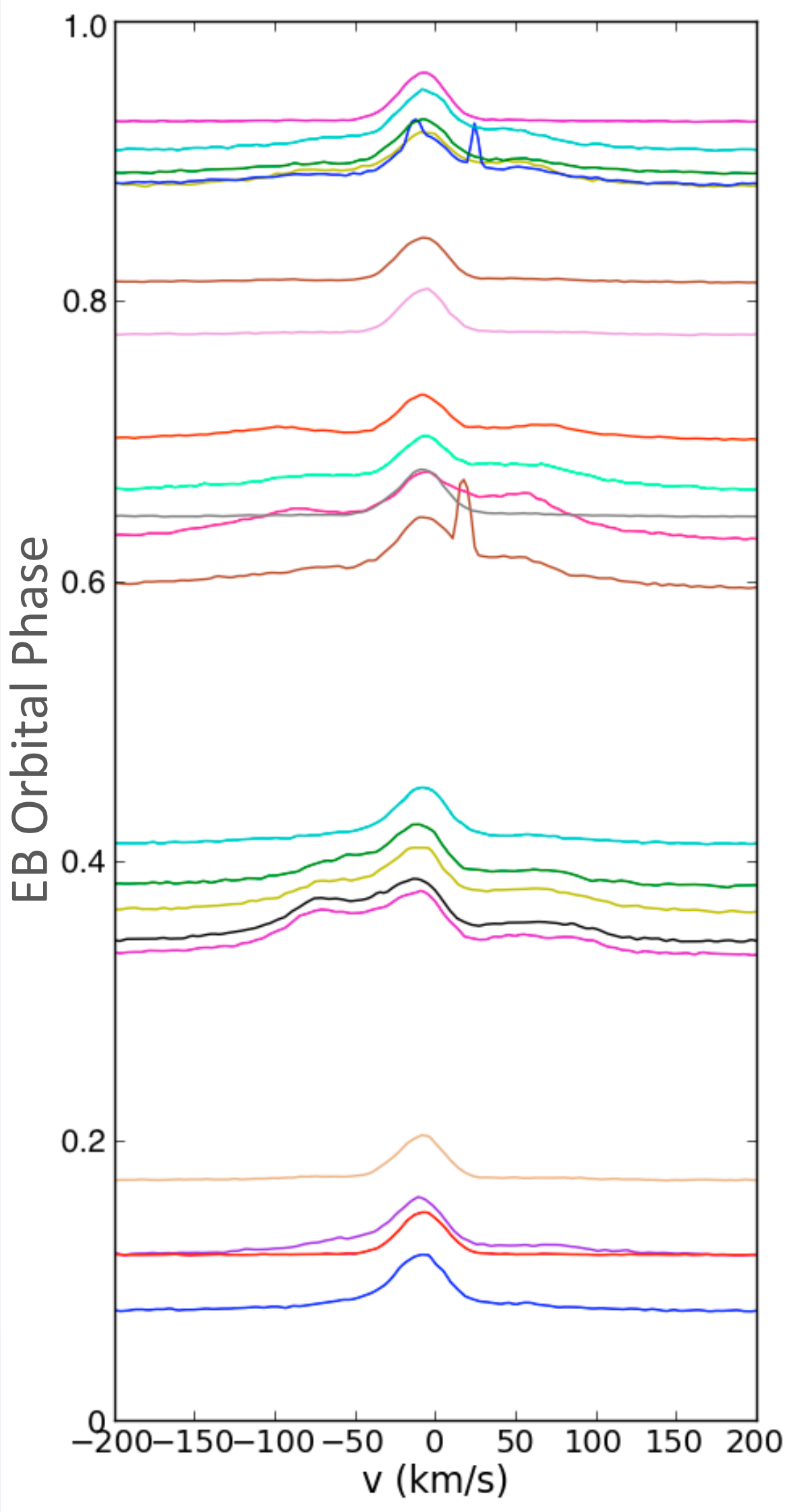

Figure 5: Hα emission feature relative to the systemic rest velocity as a function of the EB orbital phase. The different colours are simply to aid viewing.

4. Fundamental parameters

Masses and radii for young, detached, double-lined EBs, such as this, can be determined model independently and are very valuable in testing pre-main sequence stellar evolutionary models where we currently have very few constraints (see Fig 6).

5. Current and Future Work

Lightcurves from the 2011/2012 observations are shown in Figs 7 & 8. Simultaneous observations with CoRoT (spanning 38 days) and Spitzer (Channel 1: 23 days, Channel 2: 28 days) (Fig 7) show that the out-of-eclipse variability is still present in addition to the stellar eclipses. These will be analysed jointly with the FLAMES spectra, and with CFHT light curves (Fig 8) obtained the following month, to refine the parameters of the central binary components and to investigate the source of the out-of-eclipse variability in more detail.

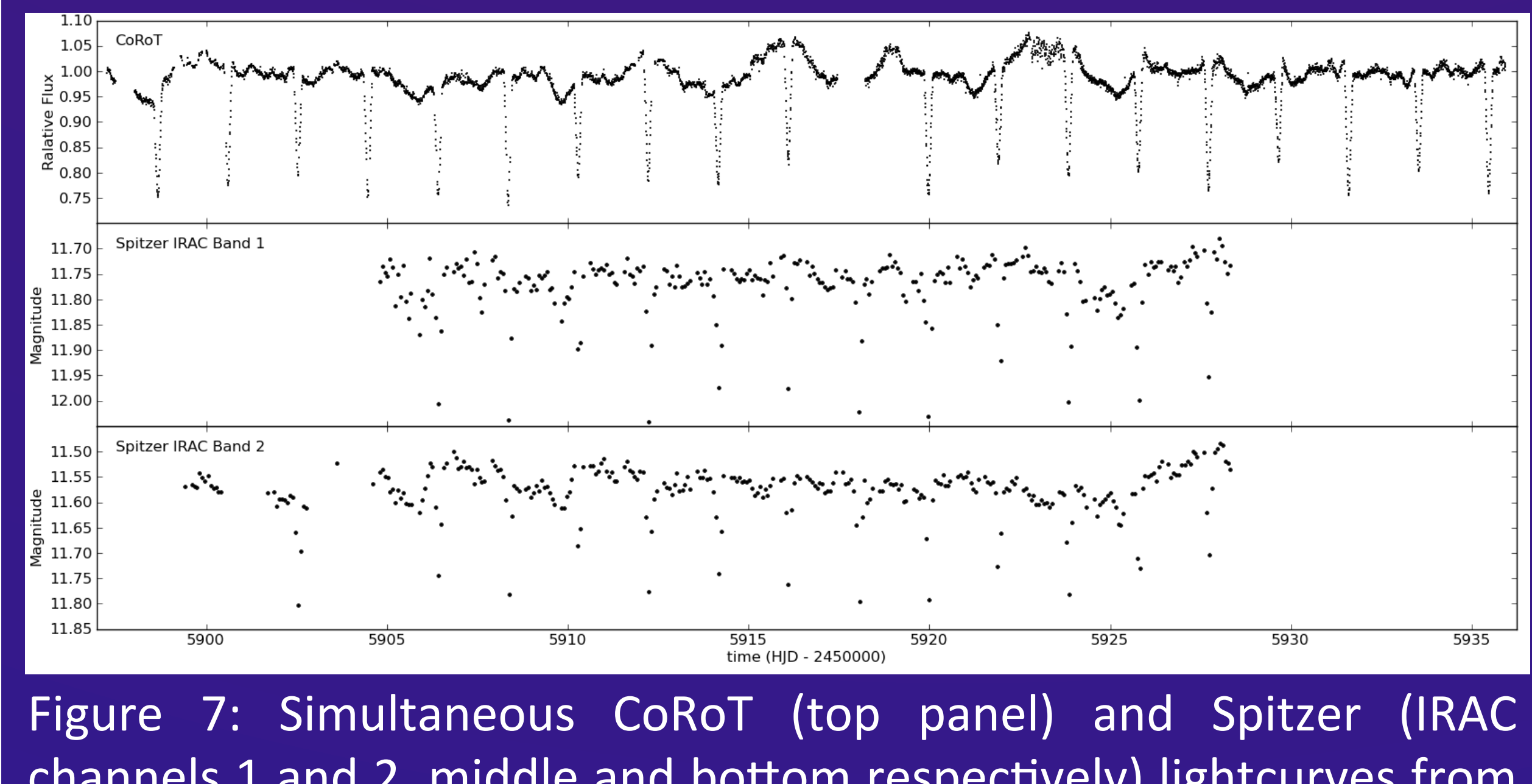

Figure 7: Simultaneous CoRoT (top panel) and Spitzer (IRAC channels 1 and 2, middle and bottom respectively) lightcurves from the 2011/2012 All show out-of-eclipse variability in addition to the stellar eclipses.

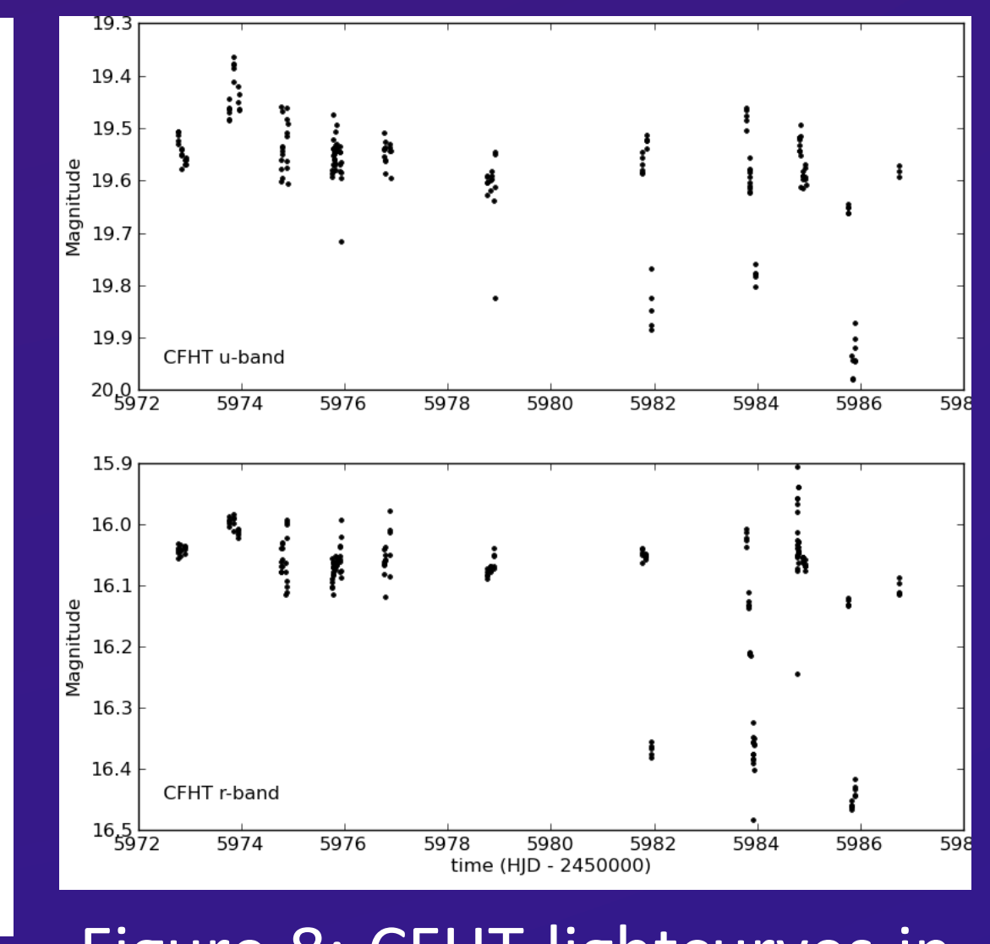

Figure 8: CFHT lightcurves in the u-band (top) and r-band (bottom).

References

[1] Southworth et al. 2004, MNRAS, 351,1277S
[2] Gibson et al. 2012, MNRAS, 419,2683G
[3] Gustafsson et al. 2008, A&A, 486,591
[4] Sing, 2010, A&A, 510, 21
[5] Bouvier et al. 2007, A&A, 463,1017
[6] Baraffe et al. 1998, A&A, 337, 403
[7] http://www.astro.keele.ac.uk/~jkt/debdata/debs.html

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