FM Leo – the tale of twins

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First spectroscopic and new photometric observations of the eclipsing Algol-type binary FM Leo are presented. The results of the orbital solution from radial velocity curves are combined with those derived from the light-curve analysis to derive orbital and stellar parameters. JKTEBOP**, Wilson-Devinney binary modeling codes and two-dimensional cross-correlation (TODCOR) method were applied for the analysis. With masses and radii determined better than 1% and 4 %, respectively, we compared the observations with current stellar evolution models interpolated for this system and found the evolutionary status and age of FM Leo.**

1. Spectroscopy

Spectroscopic observations were performed with the Cassegrain-focus spectrograph at the 1.9 m telescope of the David Dunlap Observatory (DDO; R ~ 20 000) and the 0.4 m Poznań Spectroscopic Telescope (PST; R ~ 35 000; echelle). The data reduction was performed with IRAF package. In order to determine radial velocities of components, one- (FXCOR) and two- (TODCOR) dimensional cross-correlation techniques have been used.

The spectra were cross-correlated against various templates and by using different procedures. In the case of one-dimensional correlation we used as a template the spectrum of HD 102870, which is of similar spectral type (F9V) as FM Leo. In the case of two-dimensional correlation we used the synthetic spectrum created by the ATLAS9 (Castelli & Kurucz, 2003) for a star with an effective temperature of 6400 K, solar metallicity, and rotational velocity of 8 km s^{-1}. The cross-correlation was performed with the TODCOR method (Zucker & Mazeh, 1994).

Mean formal error of measurements in the case of two-dimensional correlation σ = 0.6965 km s^{-1} was smaller than in the case of one-dimensional correlation σ = 1.425 km s^{-1}, so we used the TODCOR result as the final one.

Using the procedure that fits a double-keplerian orbit to radial velocity measurements and minimises the χ^2 function with Levenberg-Marquardt algorithm we obtained RV curves with RMS of fitting σ_1=1.129 km s^{-1} for the primary and σ_2 =1.604 km s^{-1} for the secondary. Final radial velocity curves are shown in Fig. 1.

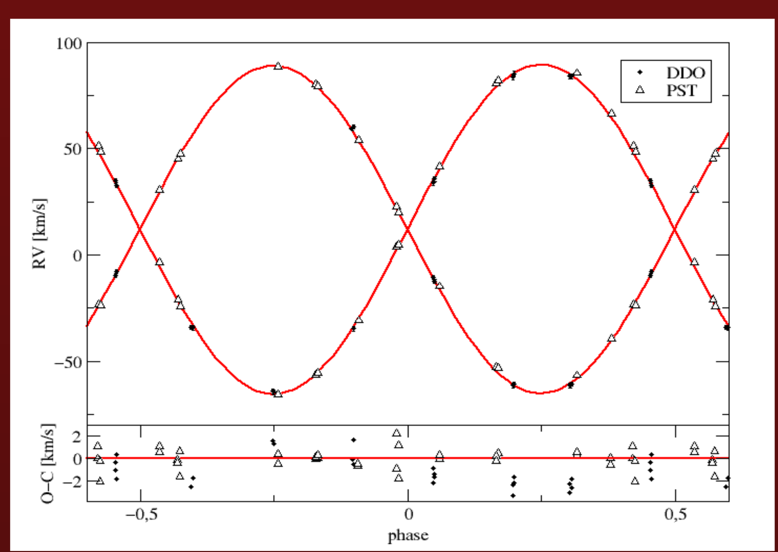

Figure 1: RV curves of FM Leo derived by using the two-dimensional correlation (TODCOR).

2. Photometry

FM Leo was first identified as an Algol type binary with a maximum, out-of-eclipse *V*-band magnitude of *V* = 8.467± 0.016 mag in the Hipparcos catalogue (Perryman et al., 1997).

A total of 324 *V*-band measurements of the object were gathered during the ASAS-3 survey (Pojmański, 2002). Mean error of measurements is σ = 0.017 mag. The resulting light-curve exhibits periodic eclipses with depth of 0.5 mag. We supplemented the long-term photometry from ASAS with additional *V*-filter observations of moments of eclipses: 2655 mesurements with exposure time of 5 s obtained with 0.4 m telescope (Kielce) and 46 measurements with exposure time of 40 s obtained with 1 m Elizabeth telescope in SAAO.

Using *JKTEBOP,* procedure by John Southworth (Southworth et al., 2004a,b), we fit the model to photometric observations. We held the mass ratio *q* derived from the preliminary solution from *PHOEBE* (Prsa & Zwitter, 2005) fixed and orbital period *P*, ephemeris timebase T_0, light scale factor, orbit inclination *i*, surface brightness ratio, sum, and ratio of the radii adjusted with initial values from *PHOEBE*. Additionally we used the same procedure for a bootstrapping error analysis. The final light-curve of FM Leo is shown in Fig. 2. We obtained RMS of fitting of σ = 0.02 mag.

To calculate the absolute dimensions of the system we used the *JKTEBOP* procedure - *JKTABSDIM*, the code in which careful attention is paid to correctly errors propagation.

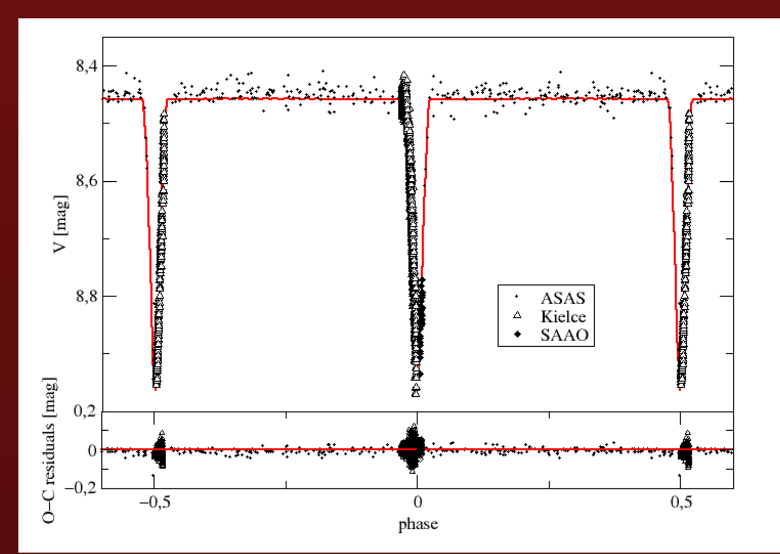

Figure 2: *V* light-curve of FM Leo.

3. Results

A full compilation of stellar and orbital parameters of FM Leo obtained by using mentioned codes is presented in Table 1. As one can see, we were able to reach 1% level of uncertainty in masses and 3% in radii.

Table 1. Absolute dimensions of FM Leo. Surface gravity acceleration is denoted with log *g*, where *g* is given in cgs units

Parameter	Primary	Secondary	Unit
T_0	HJD 2452499.182 ± 0.002		
P	6.728606 ± 0.000006		d
e	0		
γ	11.87 ± 0.13		km s^{-1}
i	87.98± 0.06		deg
a	20.631 ± 0.052		$R_\odot$
K	76.619 ± 0.273	78.463 ± 0.284	km s^{-1}
M	1.318 ± 0.007	1.287 ± 0.007	$M_\odot$
R	1.648 ± 0.043	1.511 ± 0.049	$R_\odot$
L	1.806 ± 0.086	1.617 ± 0.102	$L_\odot$
T_{eff}	6316 ± 240	6190 ± 211	K
log g	4.124 ± 0.023	4.189 ± 0.028	

4. Comparison with stellar models

To prove the solution for both components we compared them with current stellar evolution models - evolutionary tracks for certain masses and checked if a single isochrone fits both stars simultaneously. We interpolated evolutionary tracks at the measured masses of primary (M_1 = 1.318 $M_\odot$) and secondary (M_2 = 1.287 $M_\odot$) component using Yonsei-Yale code (Yi et al., 2001) for solar metallicity and α-enhancement of zero. The tracks on log *T* - log *g* plane are illustrated in Fig. 3a. The parameters of both components are consistent with evolutionary tracks for given masses.

To estimate the age of the system and prove obtained parameters we considered four different sets of theoretical isochrones: Yonsei-Yale, Padova (Marigo et al., 2008), and Geneva (Lejeune & Schaerer, 2001; Fig. 3 b,c,d) for various ages and metallicities. We obtained the best fit for ages in the range of 2-4 Gyr and assumed metallicity of *Z* = 0.018. The location of two components of FM Leo on the various planes suggests the age of the system about 3 Gyr.

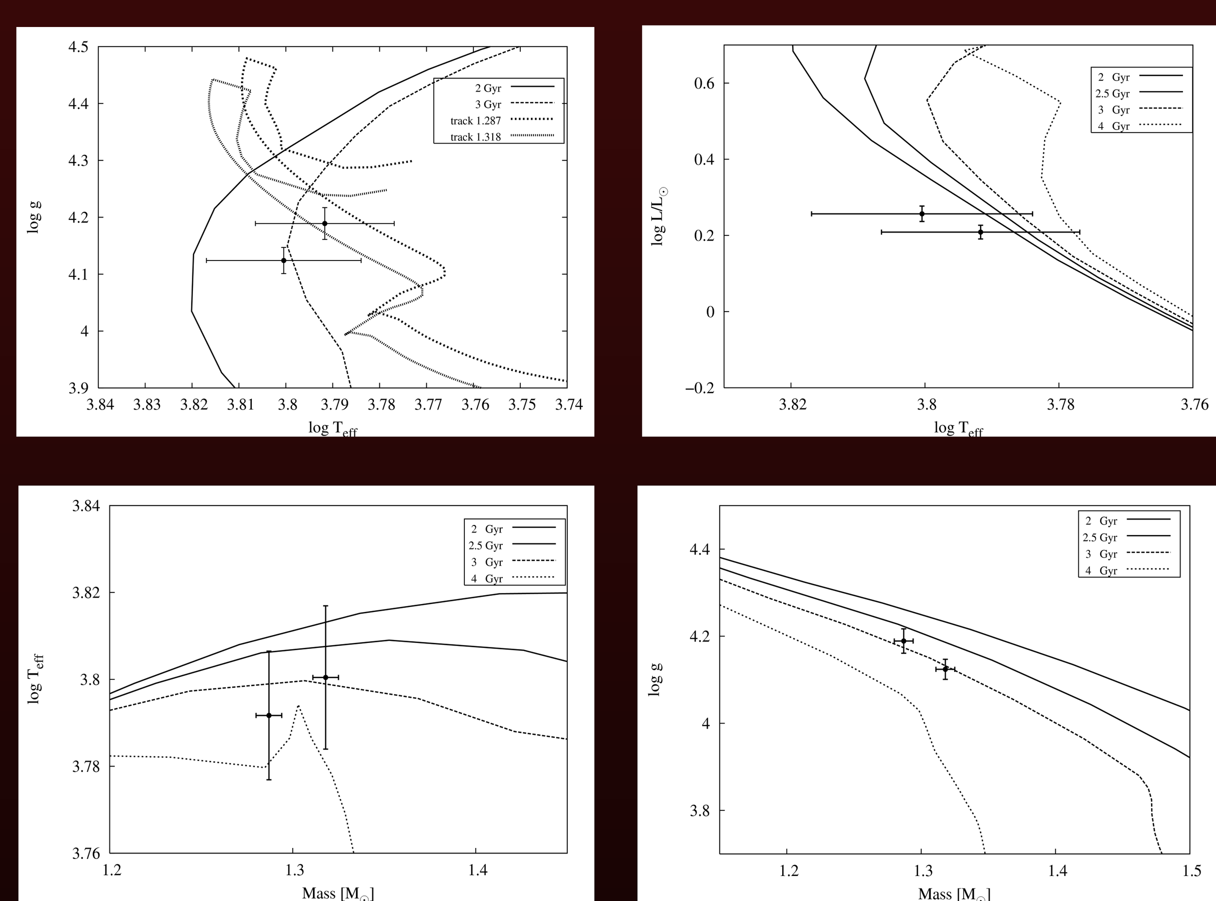

Figure 3: The location of components of FM Leo on several planes: (a): log *T* – log *g*. (b): log *T* – log *L*, (c): *M* – log *T*, (d): *M* – log *g*, is compared with Yonsei-Yale isochrones. The adopted age for isochrones is 2, 2.5, 3, 4 Gyr. Solar metallicity was assumed.

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