



2nd LAMOST-Kepler workshop LAMOST in the era of large spectroscopic survey

Gianni Catanzaro

STUDIES OF CLOSE BINARY SYSTEMS TRIGGERED BY LAMOST-KEPLER SURVEY

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SELECTION OF THE SAMPLE

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Astronomy
&
Astrophysics

Activity indicators and stellar parameters of the *Kepler* targets An application of the ROTFIT pipeline to LAMOST-*Kepler* stellar spectra^{★,★★}

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J. R. Shi⁶, Y. Wu⁶, and H. T. Zhang⁶

Table A.3. Stellar parameters for the whole sample of LAMOST spectra.

Spectrum	HJD (-2 450 000)	KIC	Designation	S/N _r	RA °	DEC °	<i>SpT</i>	<i>T_{eff}</i> (K)	err	log <i>g</i> dex	err	[Fe/H] dex	err	<i>RV</i> (km s ⁻¹)	err	<i>v sin i</i> err	P(χ^2)
spec-56083-IF04_B56083_sp12-240.fits	6083.2758	1 002 134	J194236.51+465436.2	52	295.6521606	46.9100761	K0II	4762	98	2.74	0.17	-0.01	0.12	0.2	19.4	< 120	0
spec-56083-IF04_B56083_sp11-028.fits	6083.2758	1 008 415	J194104.02+470135.0	110	295.2667847	47.0263977	K2III	4619	79	2.64	0.13	0.12	0.11	-6.5	17.8	< 120	0
spec-56083-IF04_B56083_sp11-209.fits	6083.2758	1 014 763	J193708.62+470632.9	23	294.2859192	47.1091385	F2V	6110	101	4.07	0.12	0.03	0.13	-23.9	24.1	< 120	0
spec-56083-IF04_B56083_sp11-210.fits	6083.2758	1 014 871	J193837.77+470814.8	56	294.6574097	47.1374626	M3III	3531	87	1.09	0.12	-0.05	0.10	-56.8	55.9	< 120	0
spec-56094-kepler05F56094_sp01-243.fits	6094.2989	1 023 665	J192153.09+364634.8	20	290.4712219	36.7763596	F8	5914	264	4.09	0.16	-0.54	0.31	-35.5	31.2	< 120	0
spec-56094-kepler05B56094_sp01-243.fits	6094.2131	1 023 745	J192158.43+364638.9	50	290.4934692	36.7774773	K2III	4471	92	2.37	0.16	-0.17	0.13	28.7	18.1	< 120	0
spec-56094-kepler05B56094_2_sp01-243.fits	6094.2537	1 023 848	J192205.31+364715.1	51	290.5221558	36.7875481	K3III	4466	100	2.41	0.20	-0.01	0.11	-122.3	18.1	< 120	0
spec-56094-kepler05B56094_2_sp01-207.fits	6094.2537	1 024 114	J192221.97+364643.2	63	290.5915527	36.7786751	K1III	4800	123	2.91	0.27	-0.12	0.15	-94.5	18.2	< 120	0
spec-56094-kepler05F56094_sp01-212.fits	6094.2989	1 024 464	J192240.76+364638.6	12	290.6698608	36.7773972	K3V	4308	228	2.43	0.55	-0.11	0.18	-5.8	69.3	328	78
spec-56094-kepler05B56094_sp01-219.fits	6094.2131	1 024 986	J192308.20+364527.1	277	290.7842102	36.7575302	K4III	4266	103	2.08	0.14	-0.06	0.11	-15.7	17.3	< 120	0
...
spec-56930-KP192323N501616V03_sp07-169.fits	6930.0216	10 920 086	J192724.49+481910.4	111	291.8520830	48.3195560	F6V	6439	57	4.12	0.11	-0.03	0.13	-35.9	18.3	< 120	0
...
spec-56918-KP192323N501616V_sp07-152.fits	6918.0333	10 920 130	J192729.65+482148.4	96	291.8735830	48.3634720	K1.5III	4655	92	2.60	0.14	-0.03	0.11	4.7	18.3	< 120	0
...

Probability that *RV* variations have a random occurrence (Press et al. 1992)

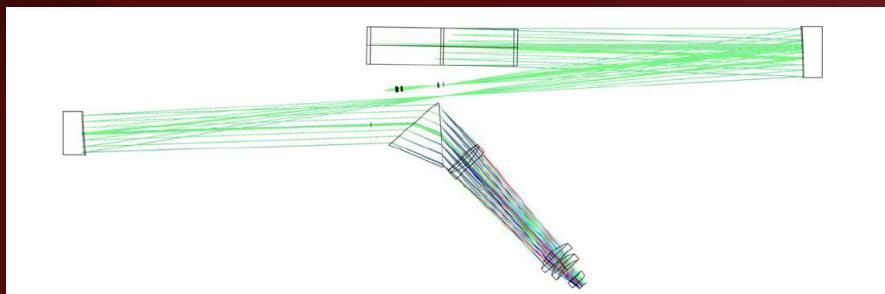
CAOS: CATANIA ASTROPHYSICAL OBSERVATORY SPECTROPOLARIMETER



91 cm telescope dome



91 cm telescope

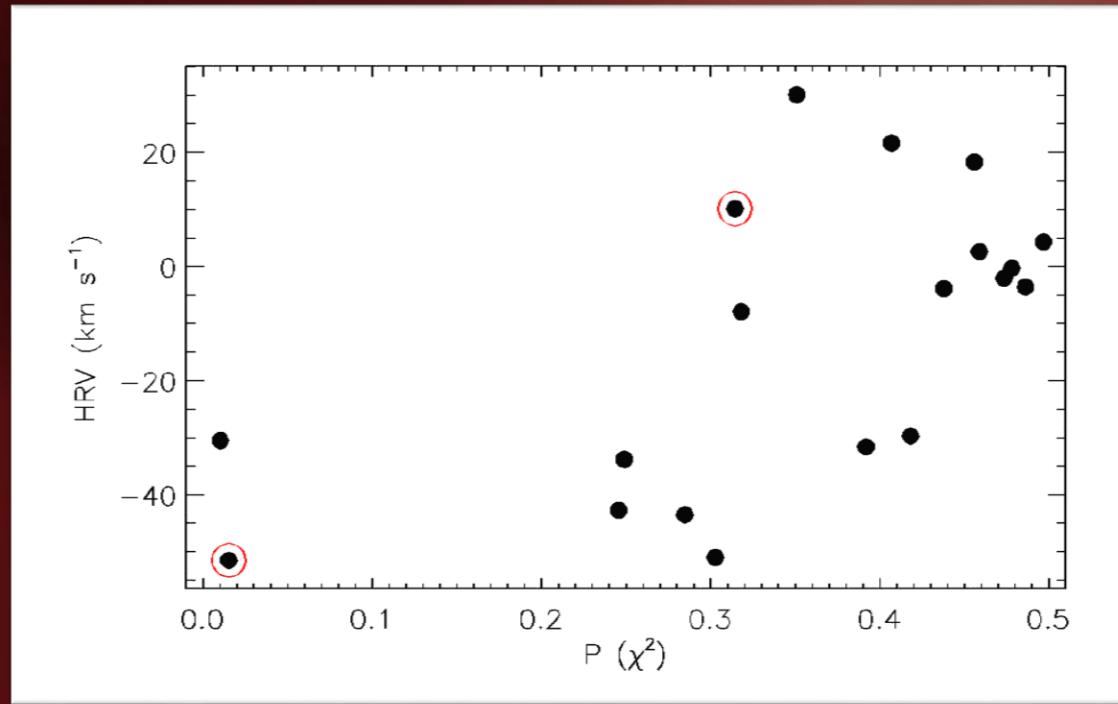


CAOS optical layout

$$\left\{ \begin{array}{l} R=55000 \\ 3750 - 11000 \text{ \AA} \\ \text{snr} = 60 \text{ for } v=10 \text{ with } T_{\text{exp}} = 1h \end{array} \right.$$

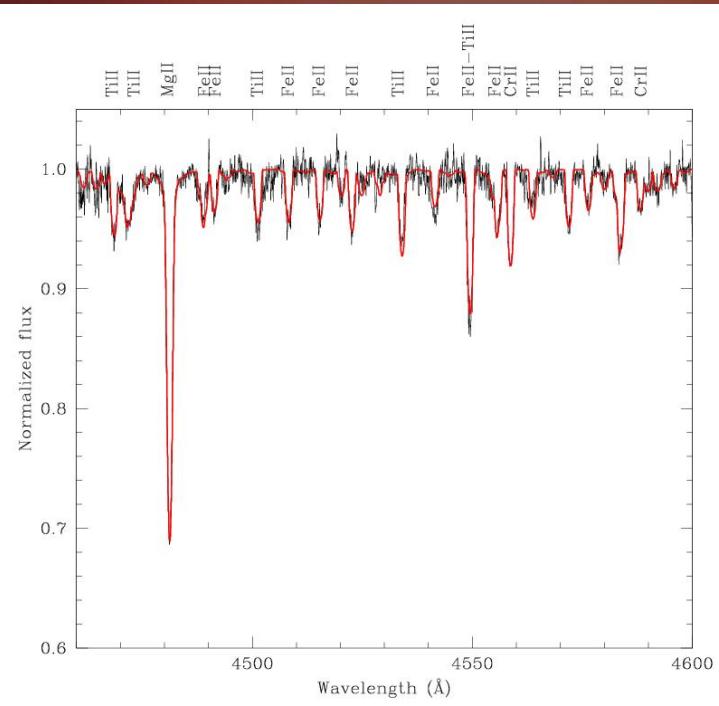
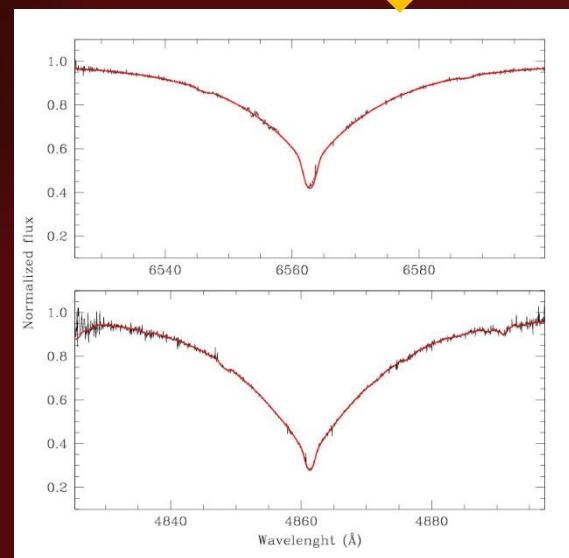
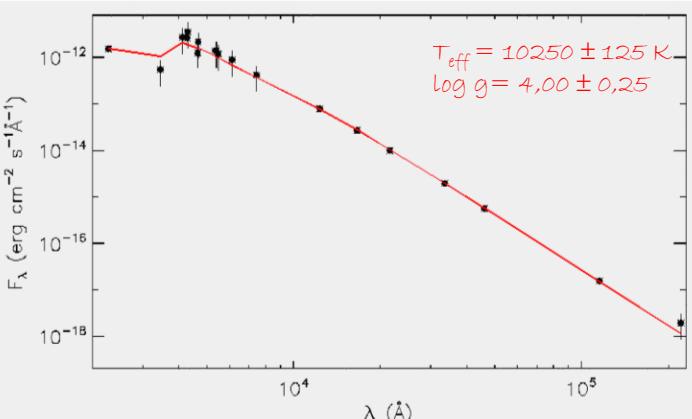
SELECTION OF THE SAMPLE

Selection Criteria	
$V < 10$ mag	
$P(\chi^2) < 0.5$	
$T_{\text{eff}} > 6000$ K	
Sp: F-A-B	



KIC	Sp Type	HJD (d)	SNR	T_{eff} (K)	$\log g$ (cm s ⁻²)	[Fe/H] (sun)	HRV (km s ⁻¹)	$P(\chi^2)$
5219533	A6m	56570,9769	169	7835 ± 327	$3,88 \pm 0,11$	$-0,09 \pm 0,13$	$10,1 \pm 22,3$	0,3143
		56800,3279	108	7920 ± 194	$3,88 \pm 0,12$	$-0,11 \pm 0,12$	$45,9 \pm 29,5$	0,3143
7599132	B9.5III	56432,2613	435	11251 ± 860	$3,99 \pm 0,12$	$-0,03 \pm 0,11$	$11,6 \pm 17,9$	0,0152
		56570,0049	372	10719 ± 372	$3,95 \pm 0,12$	$-0,10 \pm 0,12$	$-51,5 \pm 18,9$	0,0152

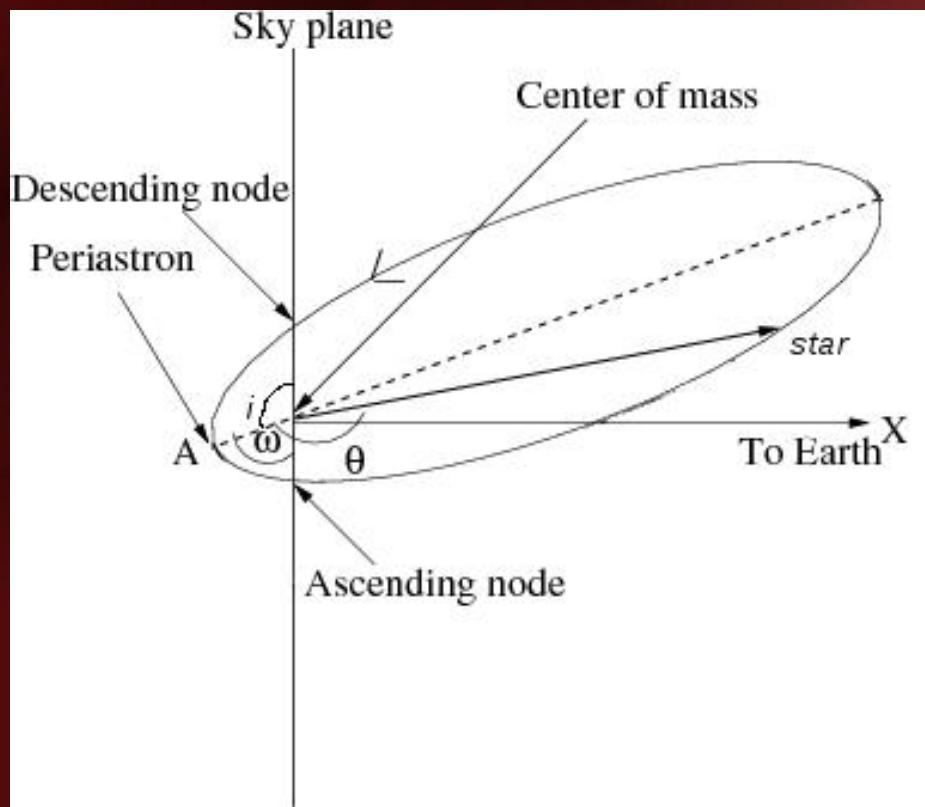
KIC7599132 (HD 180757) AN ELLIPTICAL VARIABLE IN A CLOSE SB1 SYSTEM



Solar chemical abundances have been used for all identified spectral lines, with the exception of silicon 0.5 dex more than the Sun

SPECTROSCOPIC VARIABILITY: CAOS@OACT

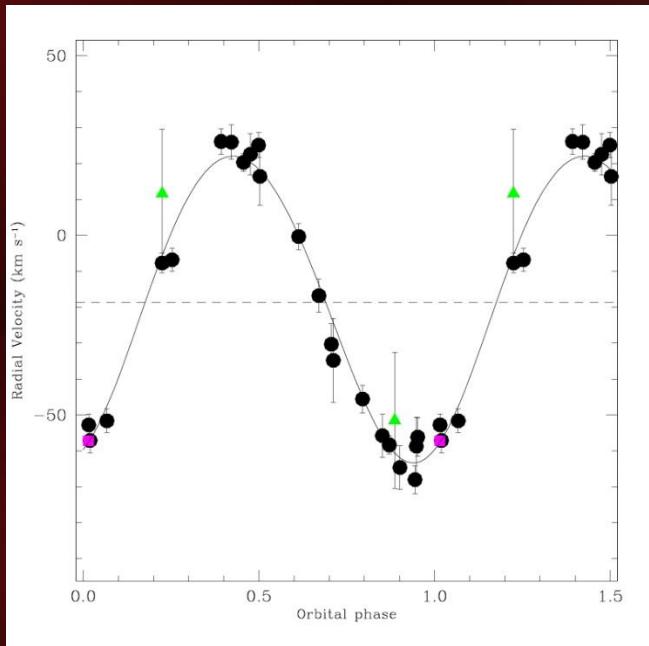
$$V_{\text{rad}} = \gamma + \frac{2\pi a \sin i}{P\sqrt{1-e^2}} [\cos(\theta + \omega) + e \cos \omega]$$



γ = velocity of centre of mass
 a = semi-major axis
 i = inclination between plane of sky and plane of orbit
 P = orbital period
 e = eccentricity
 θ = position angle
 ω = orientation

SPECTROSCOPIC VARIABILITY: CAOS@OACT

Radial velocity curve of **KIC 7599132**



Black dots → CAOS (catanzaro et al., 2017)
 Green triangles → LAMOST (Frasca et al., 2016)
 Magenta square → FRESCO (catanzaro et al., 2010)

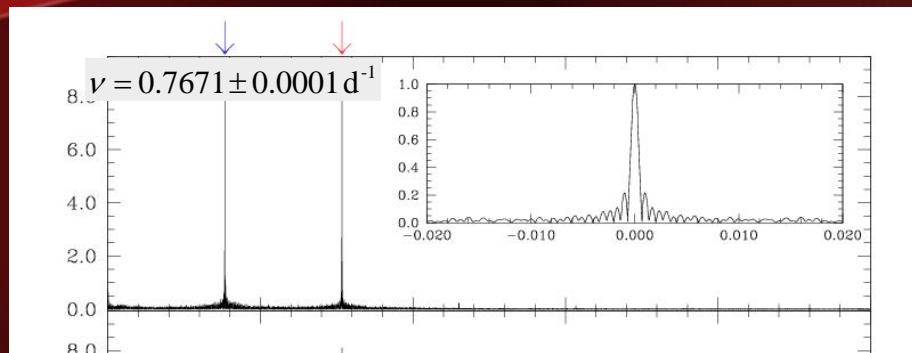
P	$1,30364 \pm 0,00006$ d
T	$2457611,764 \pm 0,027$
e	$0,03 \pm 0,05$
ω	$343^\circ \pm 7^\circ$
κ	43 ± 4 km s ⁻¹
γ	-19 ± 3 km s ⁻¹
$a \sin i$	$1,1 \pm 0,1 R_\odot$
$f(m)$	$0,011 \pm 0,003 M_\odot$

$$f(m) = \left(\frac{M_2}{M_1 + M_2} \right)^2 M_2 \sin^3 i$$

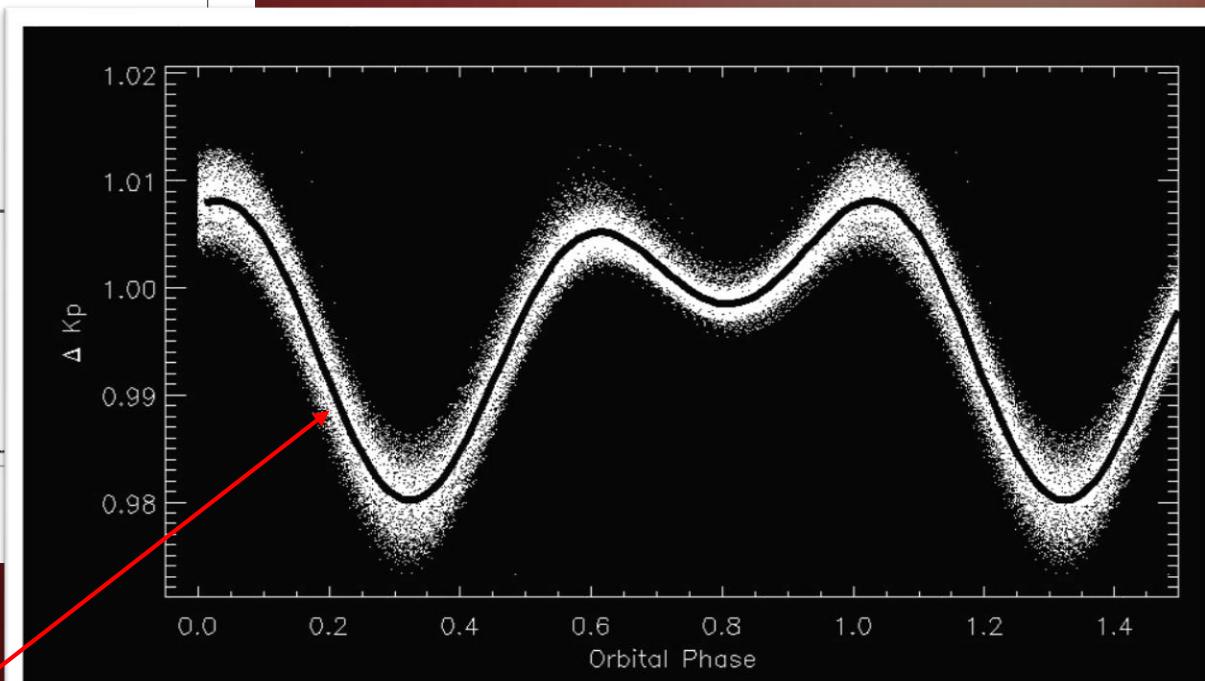
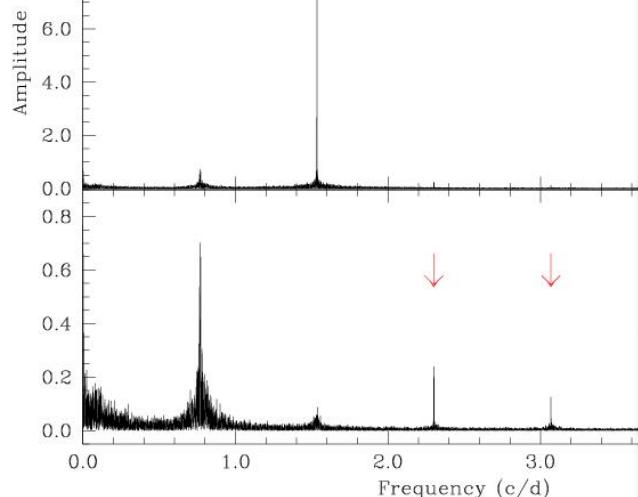
PHOTOMETRIC VARIABILITY: KEPLER Q0→Q17

65859 long-cadence data
 1471 days
 PDC (Pre-search Data Conditioning)

$$P = 1.3036 \pm 0.0002 \text{ day}$$



Amplitude



Following Kopal (1959) and Morris (1985)

$$L_1(\varphi) = \sum_{n=0}^3 C_1(n) \cos(n2\pi\varphi + \vartheta_n)$$

KEPLER LIGHT CURVE ANALYSIS

$$L_1(\varphi) = \sum_{n=0}^3 C_1(n) \cos(n2\pi\varphi + \vartheta_n)$$

The amplitude of the $\cos(2\varphi)$ term can be expressed as

$v\sin i$ from spectral lines

Third Kepler's law

Mass function from fitting of radial velocities

$$\frac{qR_1^3 \sin^2 i}{a^3} = -\frac{3.07C_1(2)(3-u_1)}{(\tau_1+1)(15+u_1)}$$

$C_1(2)$ from fit of light curve
 u_1 limb darkening
 τ_1 gravity darkening
 (Claret & Bloemen, 2011)

$M_1 = 2.9 M_\odot$ (from spectroscopy)
 $q = M_2/M_1$



System of 4 equations in 4 unknowns

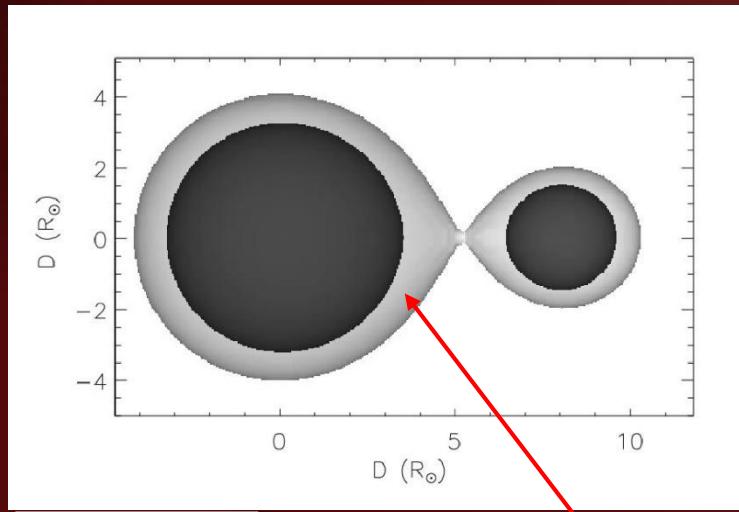
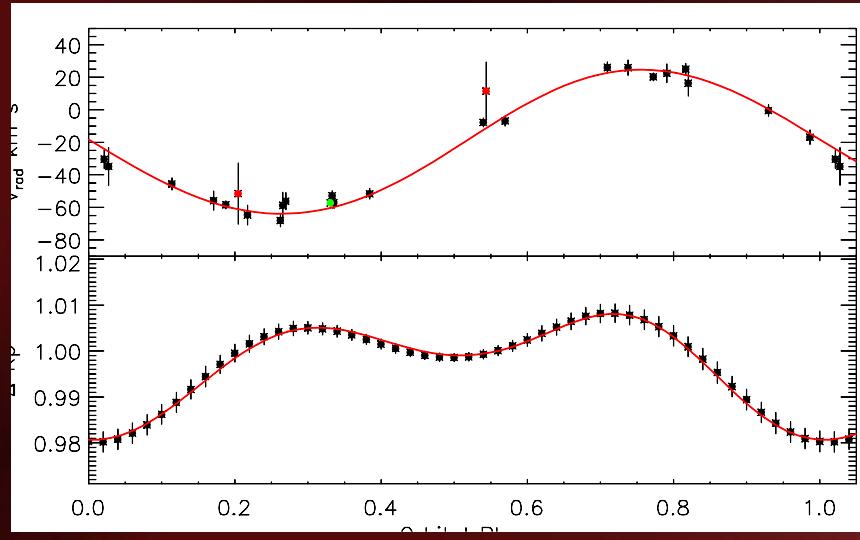
$$R_1 = 2.3 \pm 0.1 R_{\text{sun}}$$

$$q = 0.25 \pm 0.01$$

$$a = 7.71 \pm 0.02 R_{\text{sun}}$$

$$i = 40^\circ \pm 2^\circ$$

COMBINING SPECTROSCOPY AND PHOTOMETRY WITH PHOEBE



$\phi=0,25$

Roche Lobe

	Primary	Secondary
e	0.035 ± 0.005	
JD_0	57611.347 ± 0.002	
P [days]	1.30364 ± 0.00006	
a [R_\odot]	7.8 ± 0.1	
q	0.24 ± 0.01	
i [$^\circ$]	$40 \pm 2^\circ$	
$\Omega(L_1)$	2.42 ± 0.02	
$\Omega(L_2)$	2.18 ± 0.02	
T_{eff} [K]	10200 ± 150	≤ 5000
M [M_\odot]	3.0 ± 0.1	0.7 ± 0.1
Ω	2.75 ± 0.02	2.62 ± 0.02
R [R_\odot]	3.2 ± 0.2	1.6 ± 0.2
M_{bol}	-0.23 ± 0.07	5.38 ± 0.03

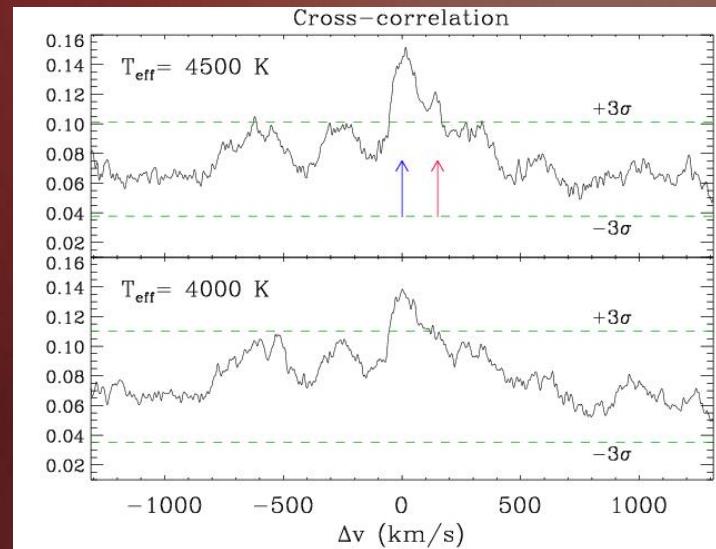
Only an upper limit

Further constraints for the secondary component

	Primary	Secondary
e		0.035 ± 0.005
JD_0		57611.347 ± 0.002
P [days]		1.30364 ± 0.00006
a [R_\odot]		7.8 ± 0.1
q		0.24 ± 0.01
i [$^\circ$]		$40 \pm 2^\circ$
$\Omega(L_1)$		2.42 ± 0.02
$\Omega(L_2)$		2.18 ± 0.02
T_{eff} [K]	10200 ± 150	≤ 3000
M [M_\odot]	3.0 ± 0.1	0.7 ± 0.1
Ω	2.75 ± 0.02	2.62 ± 0.02
R [R_\odot]	3.2 ± 0.2	1.6 ± 0.2
M_{bol}	-0.23 ± 0.07	5.38 ± 0.03

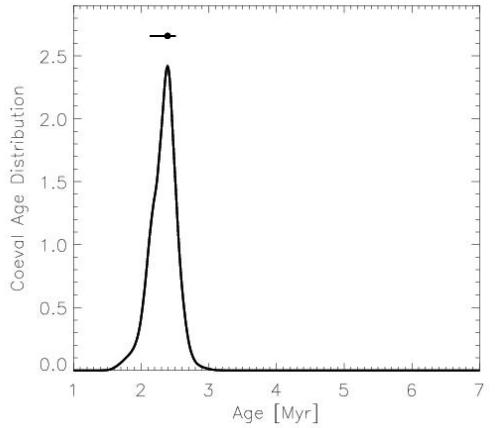
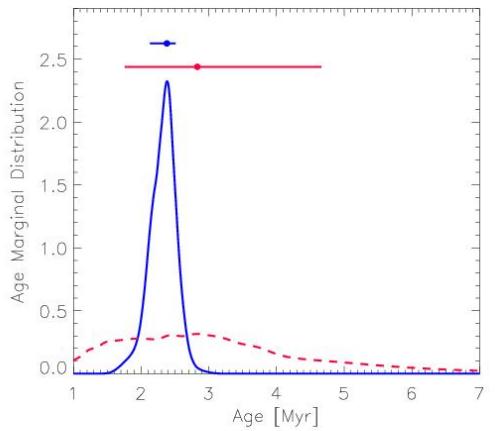
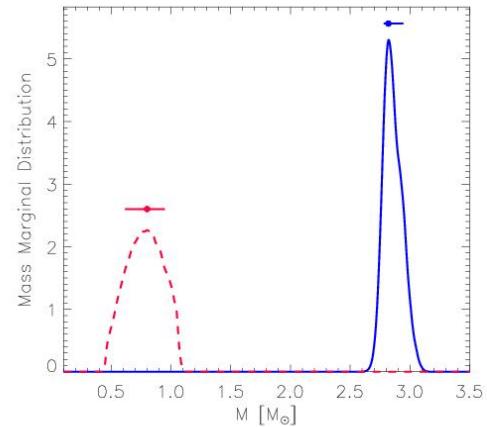
Upper limit for secondary
 $T_{\text{eff}} \leq 4000$ K

Theoretical simulation



ESTIMATION OF MASSES AND AGE WITH BAYESIAN ANALYSIS

Evolutionary models computed with
PROSECCO code (Tognelli et al, 2015,
2016)



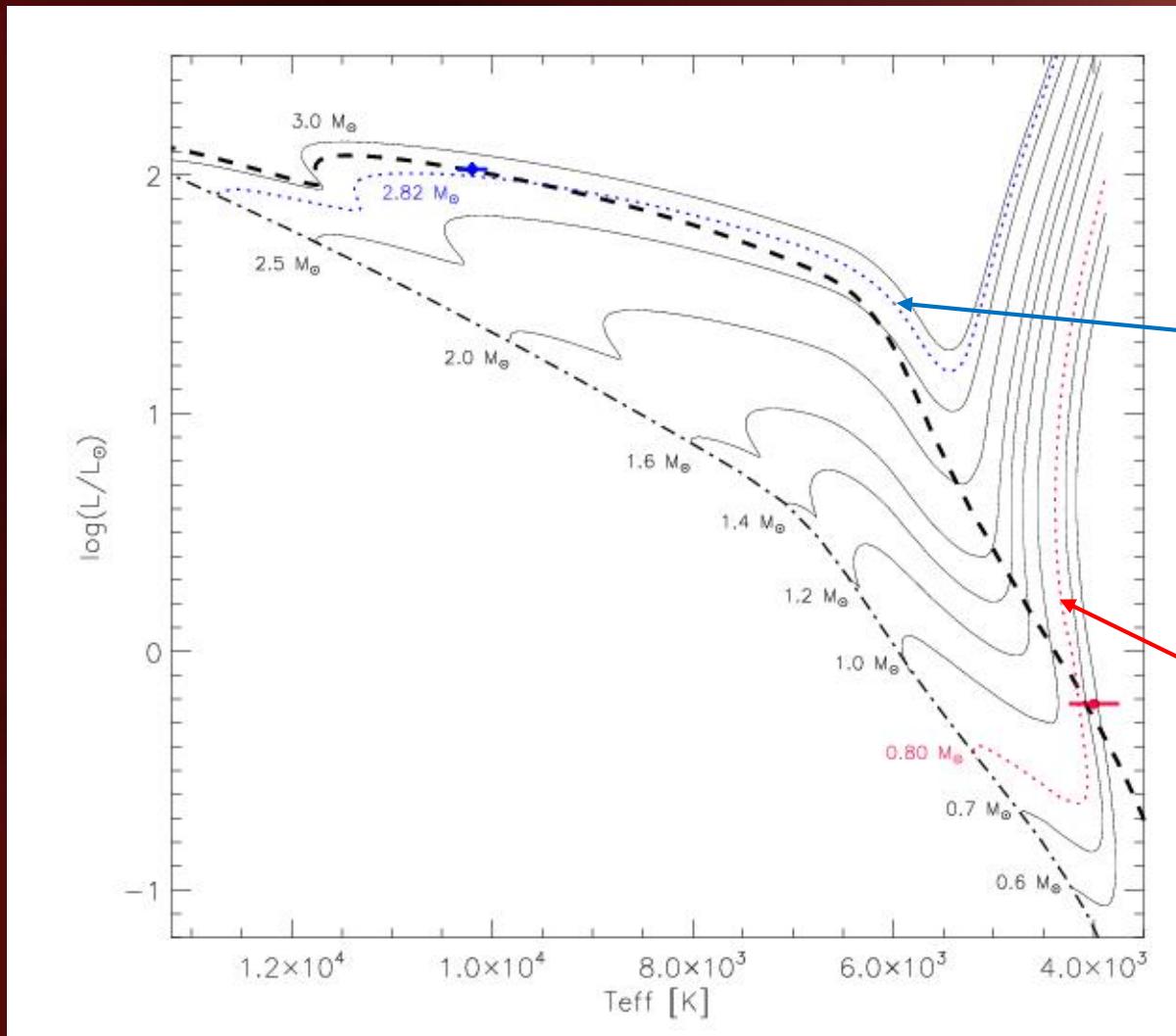
$$M_1 = 2.82^{+0.12}_{-0.04} M_{\text{sun}}$$
$$\tau_1 = 2.38^{+0.13}_{-0.25} \text{ Myr}$$

$$M_2 = 0.80^{+0.15}_{-0.19} M_{\text{sun}}$$
$$\tau_2 = 2.83^{+1.83}_{-1.07} \text{ Myr}$$

$$q = \frac{M_2}{M_1} = 0.28 \pm 0.07$$

$$\tau_s = 2.39^{+0.12}_{-0.26} \text{ Myr}$$

POSITION IN THE HR DIAGRAM



PROSECCO evolutionary tracks from PMS to the ZAMS ($[Fe/H]=0$)

Evolutionary track for the primary

Evolutionary track for the secondary

KIC 7599132: an elliptical variable in a close SB1 system^{*}

G. Catanzaro¹†, A. Frasca¹, M. Giarrusso^{2,1}, F. Leone^{2,1}, E. Tognelli^{3,4},
M. Munari¹, S. Scuderi¹

¹ INAF-Osservatorio Astrofisico di Catania, Via S.Sofia 78, I-95123, Catania, Italy

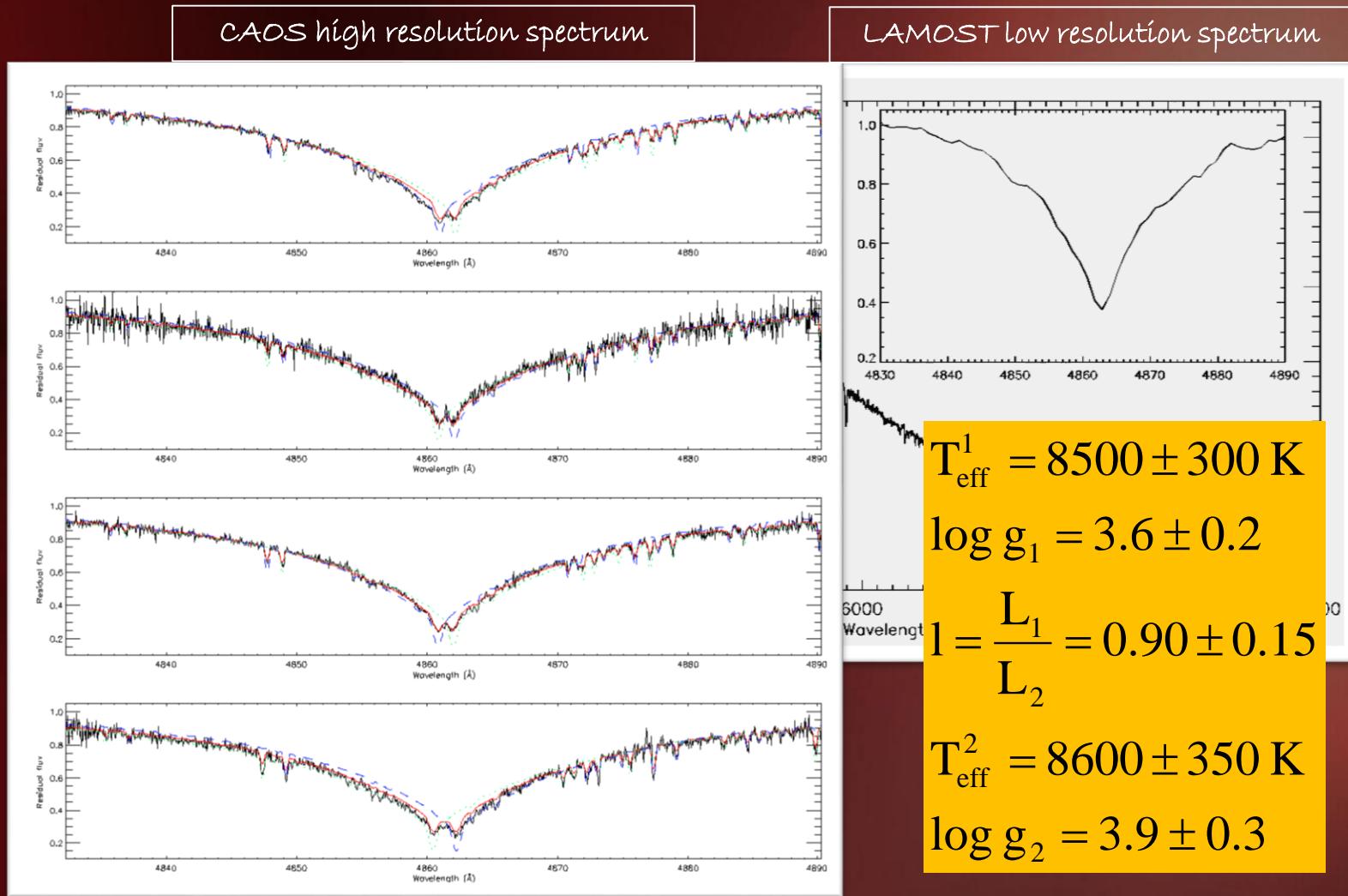
² Universitá degli studi di Catania, Via S.Sofia 78, I-95123, Catania, Italy

³ Osservatorio Astronomico di Teramo, via M. Maggini, I-64100, Teramo, Italy

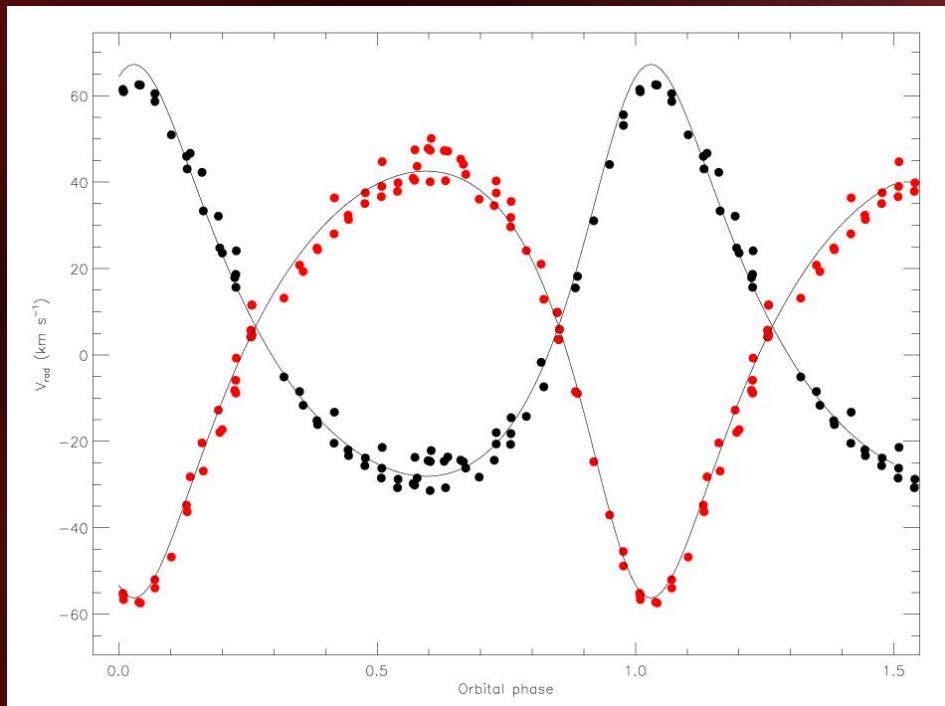
⁴ INFN, Sezione di Pisa, Largo Bruno Pontecorvo 3, I-56127, Pisa, Italy

Accepted Received ; in original form

KIC5219533 (HD 226766) A NEW HIERARCHICAL TRIPLE SYSTEM



RADIAL VELOCITY CURVES OF THE SB2 SYSTEM HD226766 A,B



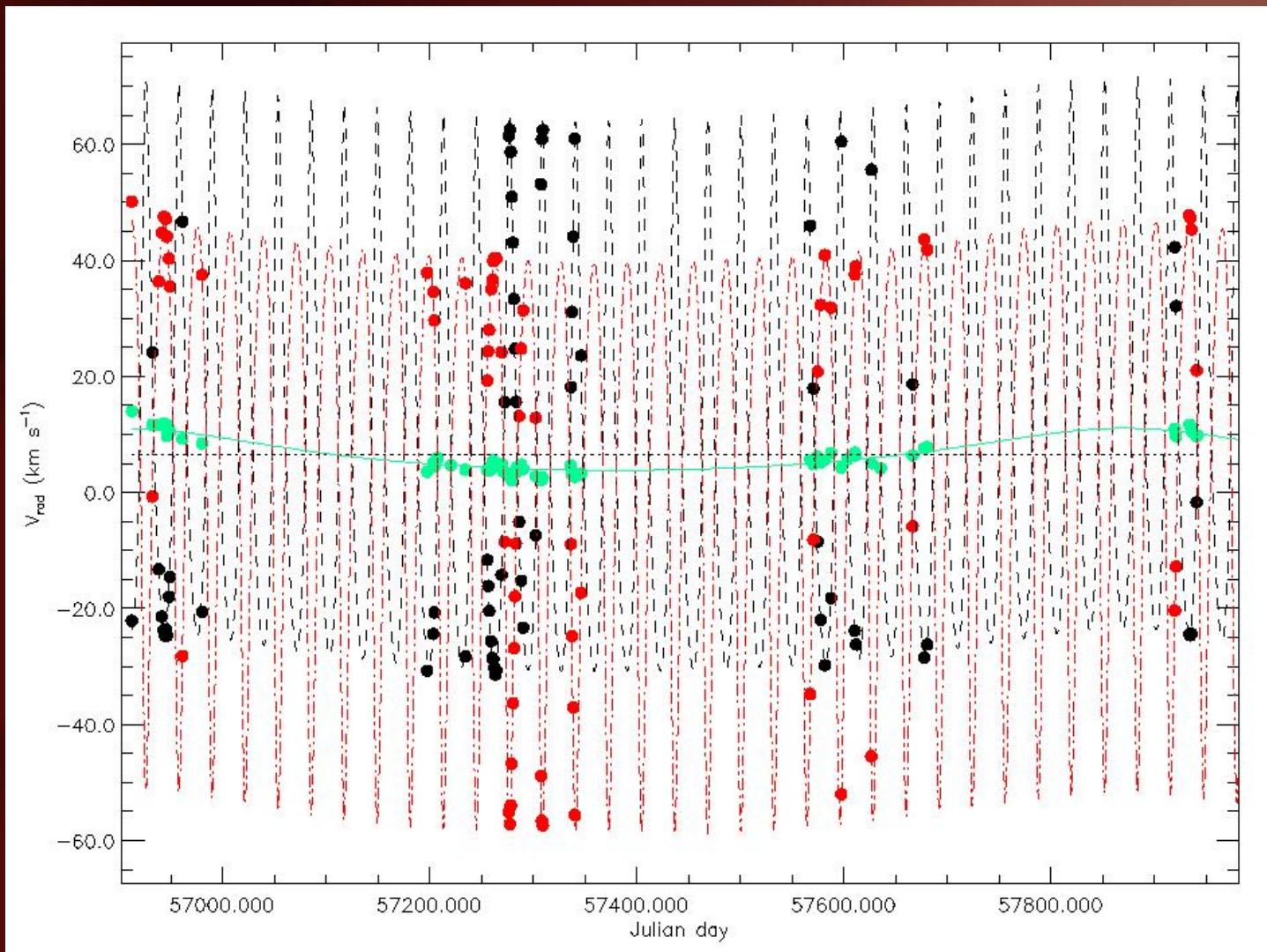
P	31,912 d
T	2457948,026
e	0,28
ω	0°
K_A	46,5 km s $^{-1}$
K_B	50,3 km s $^{-1}$
γ	5,9 km s $^{-1}$
$a_A \sin i$	28,1 R_\odot
$a_B \sin i$	30,5 R_\odot
M_A/M_B	1,1

Too dispersion around the fit

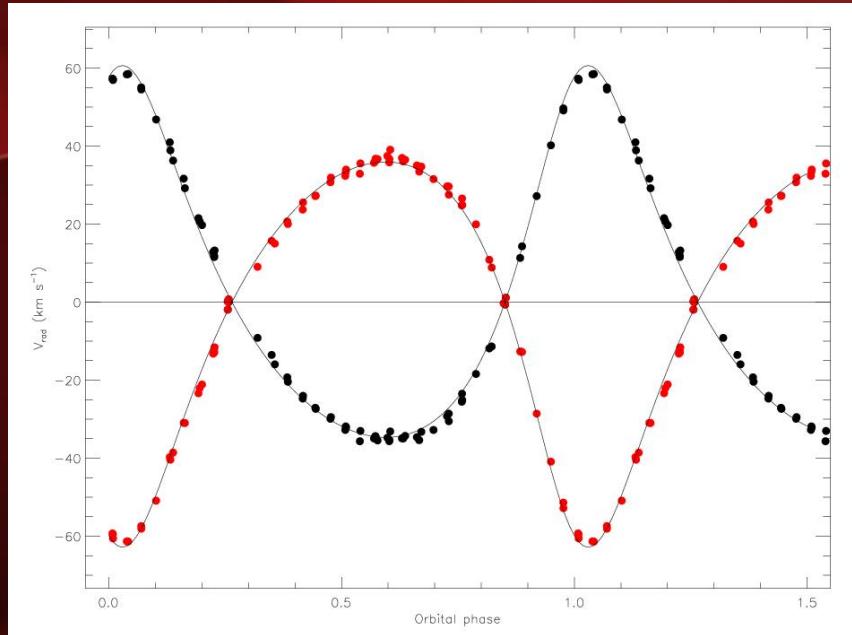
Third component



SIMULTANEOUS FIT OF THREE COMPONENTS



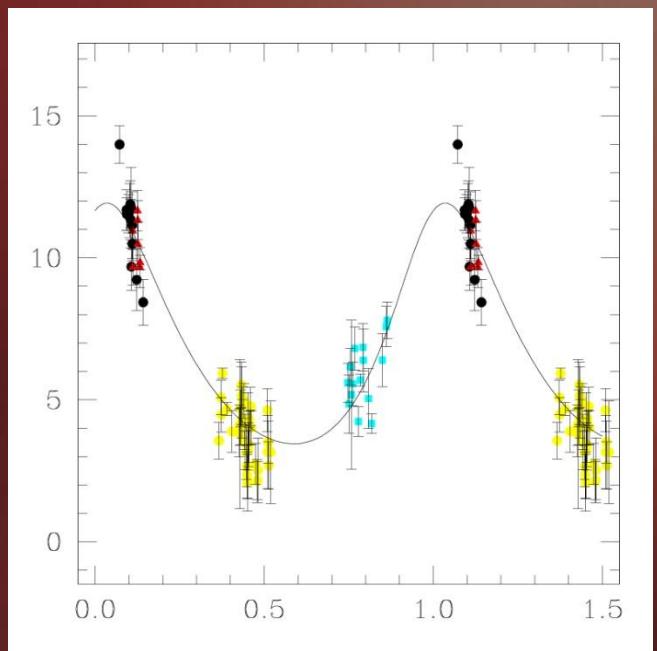
$\mathcal{H}D226766\ A, B$



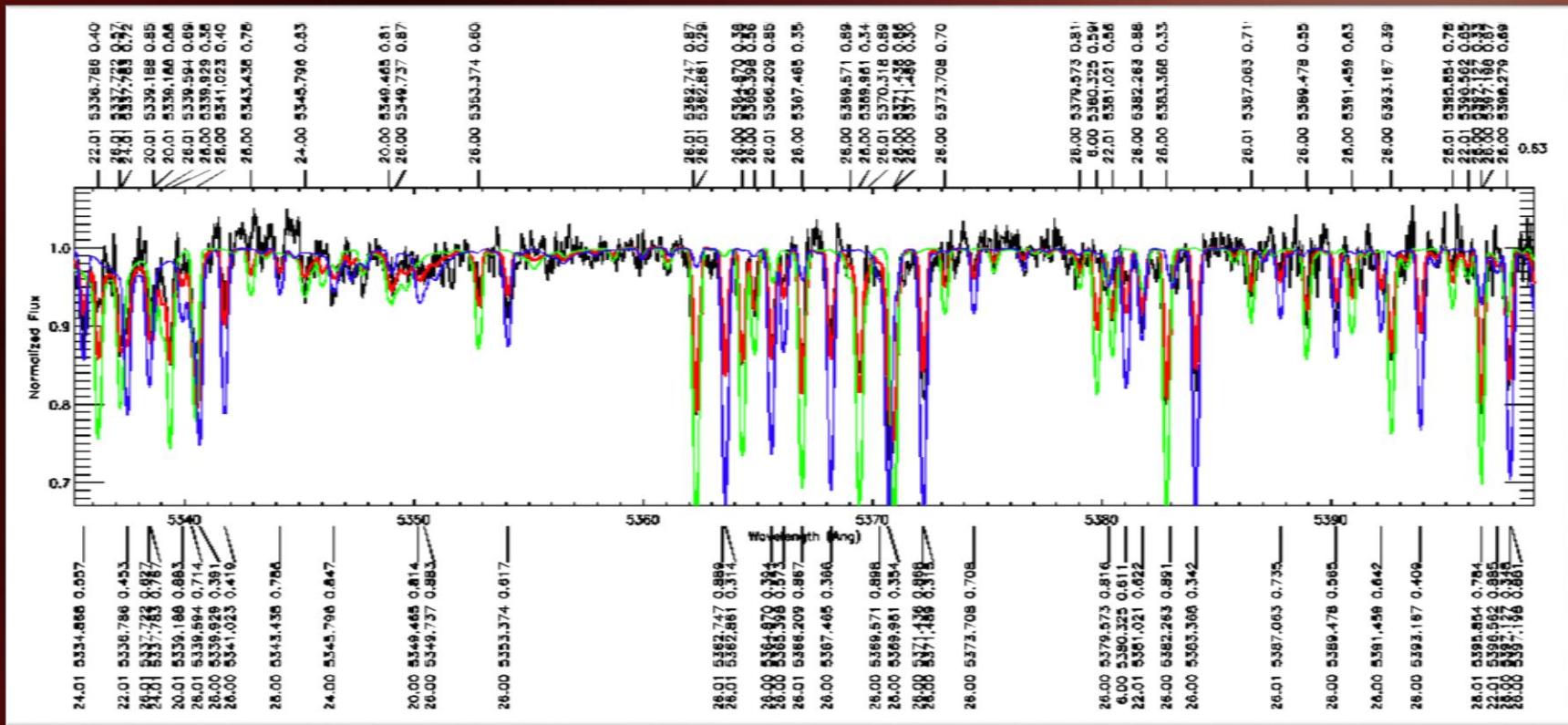
P	31,915 d
T	2457946,343
e	0,29
ω	340°
K_A	47,7 km s ⁻¹
K_B	49,4 km s ⁻¹
γ	6,6 km s ⁻¹
$a_A \sin i$	28,7 R_\odot
$a_B \sin i$	29,8 R_\odot
M_A/M_B	1,04

$\mathcal{H}D226766\ C$

P	970 d
T	2457812,308
e	0,23
ω	3°
K	3,6 km s ⁻¹
γ	6,8 km s ⁻¹
$a \sin i$	2,2 R_\odot
$f(m)$	$1,6 \cdot 10^{-7} M_\odot$



MULTI-COMPONENT ABUNDANCE ANALYSIS



Thanks for your attention