New Stellar Companion to Exoplanet Host Star Kepler-83

F. M. Rica,
Grupo Astronómico Orión, C/José Ruíz Azorín, 14, 4º D, E06800 Mérida (Spain), email: frica0@gmail.com

ABSTRACT

In this article I study the recently discovered new wide (ρ = 22.1”) stellar companion, with common proper motion and common parallax, of Kepler-83 exoplanet host star located at about 397 pc. Kepler-83 is a K7V star with 3 planets discovered in 2012-2014. The new companion is a red and faint star (*G* = 18.09 mag.) of spectral type M3V separated by about 8887 AU from Kepler-83. Using *Gaia* DR3 astrometric data, the relative and projected velocity of the new companion was calculated. The low significance relative velocity is lower than the escape velocity, which suggests a physical relation.

1. INTRODUCTION

This paper continues my study of new companions to exoplanet host stars in JDSO (see Rica 2020 reporting the new companion to WASP 3 AB). In this article, I report a new stellar companion to the exoplanet host star Kepler-83 that I discovered several years ago (and unpublished at that time) that was recently reported by Mugrauer (2019).

Kepler-83 is a faint star (*G* = 15.77 mag) of poor metallicity located in the Lyra constellation and observed by Kepler Space Telescope. It was reported as a Kepler candidate multiple transiting planets host star in 2011 (Lissauer et al. 2011). According to the literature, Kepler-83 is a rotating variable of M0V type located at 397 ± 4 pc (*Gaia* DR3) with small proper motion ($\mu(\alpha)$ = +1.90 ± 0.03 and $\mu(\delta)$ = -13.63 ± 0.03 mas yr^{-1}). Currently, Kepler-83 is listed as having 3 close orbiting small planets.

Mugrauer (2019) searching for stellar companions in *Gaia* DR2, reported the faint companion as *G* = 18.09 mag at 22.08 arcsec from Kepler-83 (Illustration 1). This binary star is currently not listed in the WDS catalog. In this work, I characterize this faint companion (and the exoplanet host star) and its relative motion with respect to Kepler-83.

In Section §2, I describe the star Kepler-83 and its exoplanets. In Section §3, I detail the astrophysical characterization of the wide stellar companion and estimate for the first time its spectral type. Relative astrometric measures are detailed in Section §4. In Section §5, I describe the dynamical study of the new stellar companion with respect to Kepler-83.

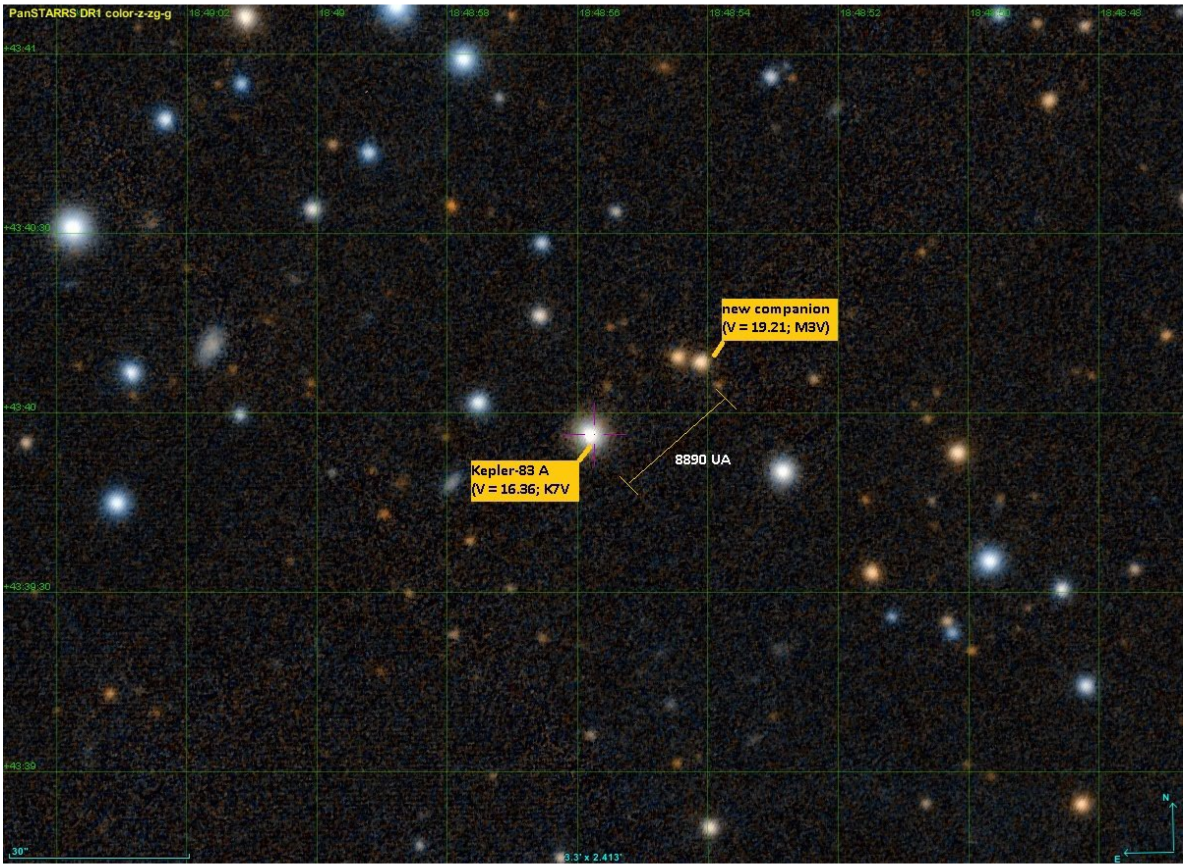


Illustration 1. Kepler-83 and the new faint companion (Pan-STARRS DR1 image). Image obtained using Aladin Sky Atlas.

2. KEPLER-83

Kepler-83, the main component of the stellar system (hereafter Kepler-83 A) is a faint star (G = 15.77 mag) with metallicity [Fe/H] of about -0.25, located at the Lyra constellation and observed by the Palomar Observatory in 1951 in POSS photographic plates. Later the 2MASS (in 1998) and the Pan-STARSS (in 2012) surveys imaged it with CCD images. The *Kepler* Space Telescope started the "famous life" of Kepler-83 A in 2011 (Lissauer et al. 2011) when it was listed as a Kepler's candidate multiple transiting planets host star. According to the literature, Kepler-83 A is a rotating variable of M0V type located at 397 ± 4 pc (*Gaia* DR3) with small proper motion. **Table 1** lists the astrophysical properties for the components of this stellar system.

2.1 Effective Temperature

Astronomical literature shows several values for the effective temperature. SIMBAD shows a M0V spectral type. **Table 2** lists most of the references found in the literature (two of them, with T_{eff} > 4500K, were rejected).

Table 2 .Effective Temperature for Kepler-83 A

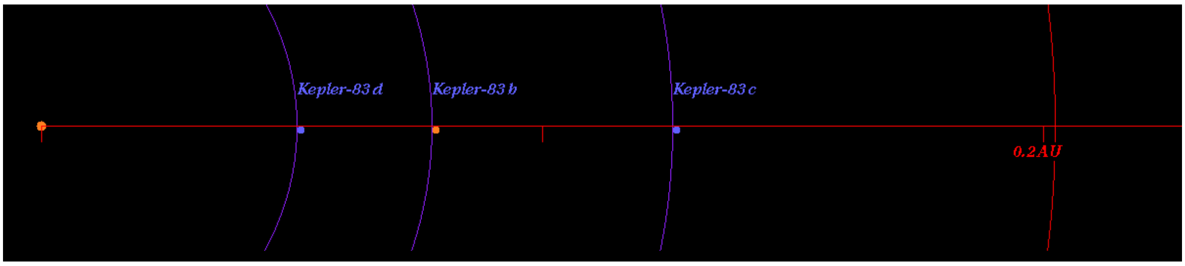
T_{eff} [º K]	Reference	Spectral Type
3893 ± 100	Muirhead, Hamren, Schlawin et al. (2012)	M0V
3907 ± 100	Muirhead et al. (2014)	M0V
4003 ± 57	Mann, Gaidos, Ansdell (2013)	[K8V]
4051	Borucki, Koch, Basri et al. (2011)	[K7V]
4100 ± 50	Martinez-Rodriguez, Caballero, Cifuentes et..al. (2019)	[K7V]
4250 ± 100	Furlan, Ciardi, Cochran et al. (2018)	[K6V]

From these T_{eff} values, spectral types within square brackets were estimated in this work using the Mamajeck table[1].

The Pan-STARRS colors (transformed to *B*, *V*, *I* standard photometry using the transformation of Kostov & Bonev (2017)), the *Gaia*-DR3 photometry (transformed to *V* and *I* standard photometry using the Gaia Data Release 3 Documentation release 1.1[2]) and 2MASS photometry (see Table 1) were also used to obtain a T_{eff} = 4070 K and a spectral type of K7V, which is in good agreement with literature. The procedure used consisted of comparing the *V* magnitude and the *B* - *V*, *V* - *I*, *J* - *H* and *H* - *K* colors (taken into account their errors) for Kepler-83 A with those listed in the Mamajeck table (Version 2019.3.22). The data with a minimum χ^2 was chosen. An Excel tool designed by the author was used. Using all the literature information, this work assumes a spectral type of K7V.

2.2 The exoplanets

Kepler-83 has 3 planets orbiting very close to the host star (between 0.05 and 0.13 AU) and they were discovered by the *Kepler* satellite in 2011 (Lissauer et al. 2011) and 2014 (Rowe et al. 2014). The planets are about 4 and 6 times smaller than Jupiter. Berger et al. (2020) estimated about 1.9 and 2.6 radii of the Earth. Judkovsky, Ofir & Aharonson (2022) determined a sub-Earth density for all the planets ranges with 3.3 and 6.4 Earth masses.



Ilustration 2. The exoplanets of Kepler-83. Credits: http://www.exoplanetkyoto.org/exohtml/Kepler-83.html

3. CHARACTERIZING THE NEW STELLAR COMPANION KEPLER-83 B

Mugrauer (2019) reported for the first time the presence of a faint stellar companion (*G* = 18.09 mag.) at about 22 arcsec from Kepler-83. He estimated T_{eff} = 3495 K (in excellent agreement with *Gaia* data) and a stellar mass of 0.38 $M_{\odot}$. The *Gaia* DR3 catalog lists this faint star as a common parallax and proper motion stellar companion, suggesting physical relation. In addition, *Gaia* estimated T_{eff} = 3517 ± 23 K, log g = $4.8^{+0.06}_{-0.16}$ and [Fe/H] = $-0.35^{+0.10}_{-0.08}$.

In this work I used the Mamajeck table (Version 2019.3.22) to obtain the astrophysical properties of the secondary star. The T_{eff} from the literature matches with a M2.5V red dwarf.

The 2MASS (bands *J, H* and K_s; Skrutskie et al. (2006)), the *Gaia* DR3 (bands *G*, G_{Bp} and G_{Rp}) and Pan-STARRS PS1 (bands *g, r, z*; Flewelling et al. (2016), Chambers et al. (2016)) photometric data were used, producing 9 total photometric points. I performed a transformation of *Gaia*-DR3[3] and Pan-Starss photometry to V and I standard system (Kostov & Bonev 2017). The companion is a very faint star of *V* = 19.21 ± 0.07 of *V* - *I* = +2.44 ± 0.07. Using an excel tool built by me, I compared the *V* and *G* magnitudes and several photometric colors (*V - I, J – H, H – K, G – Rp* and *Bp – Rb*) for Kepler-83 B with those listed in the Mamajeck table. The entry from the table with a

[1] http://www.pas.rochester.edu/~emamajek/EEM_dwarf_UBVIJHK_colors_Teff.dat. Most of the content of this table was incorporated into Table 5 of Pecaut & Mamajek (2013).

[2] https://gea.esac.esa.int/archive/documentation/GDR3/Data_processing/chap_cu5pho/cu5pho_sec_photSystem/cu5pho_ssec_photRelations.html

[3] Gaia Data Release 3 Documentation release 1.1 https://gea.esac.esa.int/archive/documentation/GDR3/Data_processing/chap_cu5pho/cu5pho_sec_photSystem/cu5pho_ssec_photRelations.html

minimum χ^2 was chosen. A spectral type of M3V, $T_{\rm eff}$ = 3400 K and 0.36 $M_\odot$ was determined, in excellent agreement with the literature.

This is the first time the spectral type of B component is published in the literature. Assuming a face-on (i = 0 deg) and circular (e = 0) orbit, an orbital period of approximately 840,000 years was calculated which corresponds to a change in positional angle of 0.0004 deg yr^{-1}. For an edge-on orbit, the separation will change up to 0.1-0.2 mas yr^{-1}. From *Gaia* DR3 data, no significant relative motion was detected.

The exoplanet host star Kepler-83 (K7V mag. G = 15.77; distance 397 ± 4 pc) has a new faint companion (G = 18.09) located at 22.08 arcsec (8887 AU at the distance of the system) with a position angle of 303.28 deg (*Gaia* DR3). Berger el al. (2018) estimated a reddening of Av = 0.06 mag using a 3D reddening map. In this work I calculated the reddening in the line of sight using the maps of Schlafly and Finkbeiner (2011). The resulting values were scaled to the initial distance using the formula published by Anthony-Twarog, and Twarog (1994). In addition to this, I also calculated the reddening using the Stilim web[4]. Both reddening values are in excellent agreement, E(B - V) of 0.03 (Av = 0.08 mag.) with the literature.

For the *Gaia* parallax and distance Listd in Table 1, I took into account the systematic offset of -0.03 mas (Lindegren et al. 2018). This is the value of the mean offset but the exact offset for a combination of magnitude, colour, and position may be different by several tens of µas. For this reason I added quadratically the mean offset to the parallax listed by *Gaia*.

Table 1
Astrophysical data for the components of Kepler-83 system

	A	B	Reference
Designations	Kepler-83 2MASS J18485580+4339562	2MASS J18485409+4340084	
α_{2000}	18h 48m 55.805s	18h 48m 54.103s	*Gaia* DR3
δ_{2000}	+43° 39' 56.03"	43° 40' 8.15"	*Gaia* DR3
V	+16.36 ± 0.03 [a)]	+19.21 ± 0.07 [a)]	
V - I	+1.64 ± 0.06 [a)]	+2.44 ± 0.07 [a)]	
G	+15.770 ± 0.003	+18.090 ± 0.003	*Gaia* DR3
J	+13.74 ± 0.02	+15.50 ± 0.06	2MASS
H	+13.08 ± 0.02	+14.88 ± 0.07	2MASS
K	+12.95 ± 0.02	+14.60 ± 0.09	2MASS
$\mu(\alpha)$ [mas yr^{-1}]	+1.90 ± 0.03	+1.83 ± 0.12	Gaia DR3
$\mu(\delta)$ [mas yr^{-1}]	-13.63 ± 0.03	-13.77 ± 0.14	Gaia DR3

[4] https://stilism.obspm.fr/

Spectral type	K7V[d)]	M3V [d)]	
Parallax [mas]	2.52 ± 0.04	2.45 ± 0.10	*Gaia* DR3
Distance [pc]	397 ± 4	408 ± 17	
[Fe/H]	-0.25 ± 0.12 [c)]	…	
Mass [M⊙]	0.59 [c)]	0.38[e)] 0.36[d)]	
T_{eff} [K]	4100 ± 50[d) f)]	3517 ± 23 [c)] 3495 [e)] 3410 [d)]	
Log g		4.76 ± 0.06 [b)]	

Notes. a) transformation of Gaia-DR3[5] and PanStarss photometry to standard system (Kostov & Bonev, Bulgarian Astronomical Journal 28 · 2017); b) Gaia DR3; c) Average of literature values; d) this work; e) Mugrauer (2019); f) Berger et al. (2018).

4 NEW ASTROMETRIC MEASUREMENTS

POSSI-O photographic plates taken in 1951 and 1955 were measured in this work using the REDUC software, programmed by the French astronomer Florent Losse. This software is widely used by the non-professional double star community and in the normal mode REDUC obtains very good centroid calculation even for badly shaped and overexposed stars, like those relatively bright stars on POSS photographic plates. The typical astrometric error when stellar components are not saturated in these plates is of 0.30” in ρ.

In addition to this, AR and DEC astrometric of the catalogs 2MASS, Pan-STARRS and *Gaia* DR3 for both stars were used to obtain relative positions theta and rho which are listed in **Table 3**. A Monte Carlo simulation was applied (using the AR and Dec astrometric errors listed in the catalogs) to obtain errors in theta and rho.

Table 3. Astrometric data for Kepler-83

Epoch	θ [°]	σ ["]	Source
1951.669	303.4 ± 0.8	21.42 ± 0.30	POSSI-O
1955.554	304.1 ± 0.8	21.86 ± 0.30	POSSI-O
1998.426	303.2 ± 0.2	22.20 ± 0.07	2MASS
2012.53	303.3 ± 0.1	22.07 ± 0.03	Pan-STARRS
2016.00	303.28	22.08	*Gaia* DR3

5 DYNAMICAL STUDY OF THE NEW STELLAR COMPONENT

From the astrometric data of *Gaia* DR3 a very small relative motion of 0.16 ± 0.11 mas yr^{-1} (0.30 ± 0.20 km s^{-1}) of the new companion with respect to Kepler-83 was determined. This is 1% of the total proper motion suggesting a common proper motion nature. From stellar masses, an escape velocity (assuming face-on and circular orbit) of 0.43 km s^{-1} was calculated. As the projected relative motion is smaller than escape velocity we can conclude a possible gravitational relation of Kepler-83 and the new stellar companion. The high quality astrometric parameters of *Gaia* (`ASTROMETRIC_EXCESS_NOISE` and RUWE) show a good astrometric fit for both stellar components. From *Gaia* DR3 data I determine the dynamical parameter for Kepler-83 (see **Table 4**).

[5] Gaia Data Release 3 Documentation release 1.1
https://gea.esac.esa.int/archive/documentation/GDR3/Data_processing/chap_cu5pho/cu5pho_sec_photSystem/cu5pho_ssec_photRelations.html

Table 4.
Dynamical parameters for Kepler-83

Epoch	2016
θ (deg)	303.28
ρ (arcsec)	22.08
s (AU)	8887
dx/dt (mas yr^{-1}) [E-W]	-0.07 ± 0.12
dy/dt (mas yr^{-1}) [N-S]	-0.14 ± 0.14
Δμ (mas yr^{-1})	0.16 ± 0.11
V_x (km s^{-1}).[E-W]	-0.13 ± 0.23
V_y (km s^{-1}).[N-S]	-0.27 ± 0.26
V_{tot} (km s^{-1})	0.30 ± 0.20
V_{esc_max} (km s^{-1})	0.43 ± 0.01
Mass A (Msun)	0.59
Mass B (Msun)	0.38
Parallax (mas)	2.52 ± 0.03

Acknowledgment

I am grateful to Frank Smith for the English language review of this paper.

This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

The Pan-STARRS1 Surveys (PS1) and the PS1 public science archive have been made possible through contributions by the Institute for Astronomy, the University of Hawaii, the Pan-STARRS Project Office, the Max-Planck Society and its participating institutes, the Max Planck Institute for Astronomy, Heidelberg and the Max Planck Institute for Extraterrestrial Physics, Garching, The Johns Hopkins University, Durham University, the University of Edinburgh, the Queen's University Belfast, the Harvard-Smithsonian Center for Astrophysics, the Las Cumbres Observatory Global Telescope Network Incorporated, the National Central University of Taiwan, the Space Telescope Science Institute, the National Aeronautics and Space Administration under Grant No. NNX08AR22G issued through the Planetary Science Division of the NASA Science Mission Directorate, the National Science Foundation Grant No. AST-1238877, the University of Maryland, Eotvos Lorand University (ELTE), the Los Alamos National Laboratory, and the Gordon and Betty Moore Foundation.

This research has made use of "Aladin sky atlas" developed at CDS, Strasbourg Observatory, France

References

Anthony-Twarog B. J., Twarog B. A., 1994, AJ, 107, 1577
Berger T.A. orcid , Huber D., Gaidos E. et. al., 2018, ApJ, 866, 99B
Berger, T. A. et al., 2020, AJ, 160, 108B
Borucki W.J. , Koch D.G., Basri G. et al., 2011, ApJ, 736, 19B
Chambers et al., 2016, arXiv: 1612.05560
Flewelling et al., 2016, arXiv: 1612.05243
Furlan E. , Ciardi D. R., Cochran W. D. et al., 2018, ApJ, 861, 149F
Judkovsky Y., Ofir A. and Aharonson O., 2022, AJ, 163, 91J
Kostov, A. & Bonev, T., 2017, Bulgarian Astronomical Journal, 28

Lindegren L. et al., 2018, A&A, 616, A2
Lissauer J. J. , Ragozzine D., Fabrycky D. C. et. al., 2011, ApJS, 197, 8L
Mann A.W. , Gaidos E., Ansdell M., 2013, ApJ, 779, 188M
Martinez-Rodriguez H., Caballero J. A., Cifuentes C. et. al., 2019, ApJ, 887, 261M
Mugrauer, M., 2019, MNRAS, 490, 5088M
Muirhead P. S., Hamren K., Schlawin E. et al., 2012, ApJ, 750L, 37M
Muirhead P. S. et al., 2014, ApJS, 213, 5M
Pecaut & Mamajek, 2013, ApJS, 208, 9
Rica, F. M., 2020, JDSO, 16, 449
Rowe, J. F. et al., 2014, ApJ, 784, 45R
Schlafly & Finkbeiner, 2011, ApJ, 737, 103
Skrutskie M. F. et al., 2006, AJ, 131, 1163