

DETERMINATION OF STELLAR PARAMETERS FOR FGK-DWARF STARS: THE NIR
APPROACH

by

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A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy
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Dedication

*To Linnea, Henriette, Rico, and Else
For always supporting me*

Acknowledgements

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Abstract

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Chapter 6

Future work

Appendix A

SWEET-Cat update of 50 planet hosts

Table A.1: Derived parameters for the 50 stars in our sample. The S/N was measured by ARES.

Star	T_{eff} [K]	$\log g$ [cgs]	[Fe / H]	ξ_{micro} [km/s]	ξ_{micro} fixed?	Instrument	S/N
BD -11 4672	4553 ± 75	4.87 ± 0.51	-0.30 ± 0.02	0.14 ± 0.07	yes	FIES	487
BD +49 828	5015 ± 36	$2.87 \pm 0.09^{\text{a}}$	-0.01 ± 0.03	1.48 ± 0.04	no	FIES	567
GJ 785	5087 ± 48	4.42 ± 0.10	-0.01 ± 0.03	0.69 ± 0.10	no	HARPS	801
HATS-1	5969 ± 46	4.39 ± 0.06	-0.04 ± 0.04	1.06 ± 0.08	no	UVES	155
HATS-5	5383 ± 91	4.41 ± 0.22	0.08 ± 0.06	0.91 ± 0.14	no	UVES	158
HAT-P-12	4642 ± 106	4.53 ± 0.27	-0.26 ± 0.06	0.28 ± 0.63	no	FIES	185
HAT-P-24	6470 ± 181	4.33 ± 0.27	-0.41 ± 0.10	1.40 ± 0.03	yes	UVES	158
HAT-P-39	6745 ± 236	4.39 ± 0.47	-0.21 ± 0.12	1.53 ± 0.04	yes	UVES	127
HAT-P-42	5903 ± 66	$4.29 \pm 0.10^{\text{a}}$	0.34 ± 0.05	1.19 ± 0.08	no	UVES	130
HAT-P-46	6421 ± 121	$4.53 \pm 0.14^{\text{a}}$	0.16 ± 0.09	1.67 ± 0.18	no	UVES	208
HD 120084	4969 ± 40	$2.94 \pm 0.14^{\text{a}}$	0.12 ± 0.03	1.41 ± 0.04	no	ESPaDOnS	852
HD 192263	4946 ± 46	4.61 ± 0.14	-0.05 ± 0.02	0.66 ± 0.12	no	HARPS	415

Table A.1: continued.

Star	T_{eff} [K]	$\log g$ [cgs]	[Fe / H]	ξ_{micro} [km/s]	ξ_{micro} fixed?	Instrument	S/N
HD 219134	4767 ± 70	4.57 ± 0.17	0.00 ± 0.04	0.59 ± 0.24	no	ESPaDOnS	725
HD 220842	5999 ± 39	$4.30 \pm 0.06^{\text{a}}$	-0.08 ± 0.03	1.21 ± 0.05	no	FIES	459
HD 233604	4954 ± 46	$2.86 \pm 0.11^{\text{a}}$	-0.14 ± 0.04	1.61 ± 0.05	no	FIES	314
HD 283668	4841 ± 73	4.51 ± 0.18	-0.74 ± 0.04	0.16 ± 0.61	no	FIES	592
HD 285507	4620 ± 126	4.72 ± 0.61	0.04 ± 0.06	0.74 ± 0.43	no	UVES	239
HD 5583	4986 ± 35	$2.87 \pm 0.09^{\text{a}}$	-0.35 ± 0.03	1.62 ± 0.04	no	FIES	933
HD 81688	4903 ± 21	$2.70 \pm 0.05^{\text{a}}$	-0.21 ± 0.02	1.54 ± 0.02	no	^b	1350, 860
HD 82886	5123 ± 18	$3.30 \pm 0.04^{\text{a}}$	-0.25 ± 0.01	1.16 ± 0.02	no	^c	1198, 1294
HD 87883	4917 ± 68	4.53 ± 0.19	0.02 ± 0.03	0.46 ± 0.21	no	ESPaDOnS	753
HIP 107773	4957 ± 49	$2.83 \pm 0.09^{\text{a}}$	0.04 ± 0.04	1.49 ± 0.05	no	UVES	218
HIP 11915	5770 ± 14	4.33 ± 0.03	-0.06 ± 0.01	0.95 ± 0.02	no	HARPS	709
HIP 116454	5042 ± 72	4.69 ± 0.15	-0.16 ± 0.03	0.71 ± 0.17	no	UVES	412
HR 228	5042 ± 42	$3.30 \pm 0.09^{\text{a}}$	0.07 ± 0.03	1.14 ± 0.04	no	UVES	400
KELT-6	6246 ± 88	$4.22 \pm 0.09^{\text{a}}$	-0.22 ± 0.06	1.66 ± 0.13	no	FIES	374
Kepler-37	5378 ± 53	4.47 ± 0.12	-0.23 ± 0.04	0.58 ± 0.13	no	FIES	205
Kepler-444	5111 ± 43	4.50 ± 0.13	-0.51 ± 0.03	0.37 ± 0.15	no	FIES	675
mu Leo	4605 ± 94	$2.61 \pm 0.26^{\text{a}}$	0.25 ± 0.06	1.64 ± 0.11	no	ESPaDOnS	354
ome Ser	4928 ± 35	$2.69 \pm 0.06^{\text{a}}$	-0.11 ± 0.03	1.55 ± 0.04	no	FIES	1168
omi UMa	5499 ± 52	$3.36 \pm 0.07^{\text{a}}$	-0.01 ± 0.05	1.98 ± 0.06	no	ESPaDOnS	527
Qatar-2	4637 ± 316	4.53 ± 0.62	0.09 ± 0.17	0.63 ± 0.83	no	UVES	97
SAND364	4457 ± 104	$2.26 \pm 0.20^{\text{a}}$	-0.04 ± 0.06	1.60 ± 0.11	no	UVES	220
TYC+1422-614-1	4908 ± 41	$2.90 \pm 0.12^{\text{a}}$	-0.07 ± 0.03	1.57 ± 0.05	no	FIES	506
WASP-37	5917 ± 72	4.25 ± 0.15	-0.23 ± 0.05	0.59 ± 0.13	no	FIES	232
WASP-44	5612 ± 80	4.39 ± 0.30	0.17 ± 0.06	1.32 ± 0.13	no	UVES	125
WASP-52	5197 ± 83	4.55 ± 0.30	0.15 ± 0.05	1.16 ± 0.14	no	UVES	125
WASP-58	6039 ± 55	4.23 ± 0.10	-0.09 ± 0.04	1.12 ± 0.08	no	FIES	310

Table A.1: continued.

Star	T_{eff} [K]	$\log g$ [cgs]	[Fe / H]	ξ_{micro} [km/s]	ξ_{micro} fixed?	Instrument	S/N
WASP-61	6265 ± 168	$4.21 \pm 0.21^{\text{a}}$	-0.38 ± 0.11	1.44 ± 0.02	yes	UVES	163
WASP-72	6570 ± 85	4.25 ± 0.13	0.15 ± 0.06	2.30 ± 0.15	no	UVES	174
WASP-73	6203 ± 32	$4.16 \pm 0.06^{\text{a}}$	0.20 ± 0.02	1.66 ± 0.04	np	^d	193,231
WASP-75	6203 ± 46	$4.42 \pm 0.22^{\text{a}}$	0.24 ± 0.03	1.45 ± 0.06	no	UVES	189
WASP-76	6347 ± 52	$4.29 \pm 0.08^{\text{a}}$	0.36 ± 0.04	1.73 ± 0.06	no	UVES	165
WASP-82	6563 ± 55	$4.29 \pm 0.10^{\text{a}}$	0.18 ± 0.04	1.93 ± 0.08	no	UVES	239
WASP-88	6450 ± 61	$4.24 \pm 0.06^{\text{a}}$	0.03 ± 0.04	1.79 ± 0.09	no	UVES	174
WASP-94 A	6259 ± 34	$4.34 \pm 0.07^{\text{a}}$	0.35 ± 0.03	1.50 ± 0.04	no	UVES	356
WASP-94 B	6137 ± 21	$4.42 \pm 0.05^{\text{a}}$	0.33 ± 0.02	1.29 ± 0.03	no	UVES	397
WASP-95	5799 ± 31	$4.29 \pm 0.05^{\text{a}}$	0.22 ± 0.03	1.18 ± 0.04	no	UVES	247
WASP-97	5723 ± 52	4.24 ± 0.07	0.31 ± 0.04	1.03 ± 0.08	no	UVES	219
WASP-99	6324 ± 89	4.34 ± 0.12	0.27 ± 0.06	1.83 ± 0.12	no	UVES	249
WASP-100	6853 ± 209	$4.15 \pm 0.26^{\text{a}}$	-0.30 ± 0.12	1.87 ± 0.02	yes	UVES	166

^a Spectroscopic $\log g$.^b Weighted average of ESPaDoNS and FIES results. The parameters are (FIES in parantheses): $T_{\text{eff}} = 4870(4934) \pm 30(29)$, $\log g = 2.50(2.73) \pm 0.14(0.05)$, $[\text{Fe} / \text{H}] = -0.26(-0.19) \pm 0.03(0.02)$, and $\xi_{\text{micro}} = 1.50(1.59) \pm 0.03(0.03)$.^c Weighted average of ESPaDoNS and FIES results. The parameters are (FIES in parantheses): $T_{\text{eff}} = 5124(5121) \pm 22(29)$, $\log g = 3.30(3.31) \pm 0.05(0.07)$, $[\text{Fe} / \text{H}] = -0.25(-0.24) \pm 0.02(0.02)$, and $\xi_{\text{micro}} = 1.15(1.17) \pm 0.03(0.04)$.^d Weighted average of UVES and FEROS results. The parameters are (FEROS in parantheses): $T_{\text{eff}} = 6313(6162) \pm 61(37)$, $\log g = 4.26(4.14) \pm 0.15(0.06)$, $[\text{Fe} / \text{H}] = 0.22(0.19) \pm 0.04(0.03)$, and $\xi_{\text{micro}} = 1.85(1.61) \pm 0.08(0.04)$.

Table A.2: Previous parameters from SWEET-Cat.

Star	T_{eff} [K]	$\log g$ [cgs]	[Fe / H]	ξ_{micro} [km/s]	Reference
BD-114672	4475 ± 100	4.10 ± 0.36	-0.48 ± 0.05	0.67 ± 0.16	Moutou et al. (2015)
BD +49 828	4943 ± 30	2.85 ± 0.09	-0.19 ± 0.06	...	Niedzielski et al. (2015b)
GJ 785	5144 ± 50	4.60 ± 0.06	0.08 ± 0.03	...	Howard et al. (2011)
HATS-1	5780 ± 100	4.40 ± 0.08	-0.06 ± 0.12	...	Penev et al. (2013)
HATS-5	5304 ± 50	4.53 ± 0.02	0.19 ± 0.08	...	Zhou et al. (2014)
HAT-P-12	4650 ± 60	4.61 ± 0.02	-0.29 ± 0.05	...	Lee et al. (2014)
HAT-P-24	6373 ± 80	4.29 ± 0.04	-0.16 ± 0.08	...	Kipping et al. (2010)
HAT-P-39	6340 ± 100	4.16 ± 0.03	0.19 ± 0.10	...	Hartman et al. (2012)
HAT-P-46	6120 ± 100	4.25 ± 0.11	0.30 ± 0.10	$0.85 \pm ...$	Hartman et al. (2014b)
HAT-P-42	5743 ± 50	4.14 ± 0.07	0.27 ± 0.08	...	Boisse et al. (2013)
HD 120084	4892 ± 22	2.71 ± 0.08	0.09 ± 0.05	1.31 ± 0.10	Sato et al. (2013a)
HD 192263	4906 ± 57	4.36 ± 0.17	-0.07 ± 0.02	0.78 ± 0.12	Tsantaki et al. (2013)
HD 219134	4699 ± 16	4.63 ± 0.10	0.11 ± 0.04	0.35 ± 0.19	Motalebi et al. (2015)
HD 220074	3935 ± 110	1.30 ± 0.50	-0.25 ± 0.25	1.60 ± 0.30	Lee et al. (2013)
HD 220842	5920 ± 20	4.24 ± 0.02	-0.17 ± 0.02	...	Hébrard et al. (2016)
HD 233604	4791 ± 45	2.55 ± 0.18	-0.36 ± 0.04	...	Nowak et al. (2013)
HD 283668	4845 ± 66	4.35 ± 0.12	-0.75 ± 0.12	0.02 ± 0.30	Wilson et al. (2016)
HD 285507	4503 ± 73	4.67 ± 0.06	0.13 ± 0.01	...	Quinn et al. (2014)
HD 5583	4830 ± 45	2.53 ± 0.14	-0.50 ± 0.18	...	Niedzielski et al. (2016)
HD 81688	4753 ± 15	2.22 ± 0.05	-0.36 ± 0.02	1.43 ± 0.05	Sato et al. (2008)
HD 82886	5112 ± 44	3.40 ± 0.06	-0.31 ± 0.03	...	Johnson et al. (2011)
HD 87883	4958 ± 44	4.56 ± 0.06	0.07 ± 0.03	...	Valenti and Fischer (2005)
HIP 107773	4945 ± 100	2.60 ± 0.20	0.03 ± 0.10	...	Jones et al. (2015)
HIP 11915	5760 ± 4	4.46 ± 0.01	-0.06 ± 0.00	...	Bedell et al. (2015)
HIP 116454	5089 ± 50	4.59 ± 0.03	-0.16 ± 0.08	...	Vanderburg et al. (2015)
HR 228	4959 ± 25	3.16 ± 0.08	0.01 ± 0.04	1.12 ± 0.07	Sato et al. (2013b)

Table A.2: continued.

Star	T_{eff} [K]	$\log g$ [cgs]	[Fe / H]	ξ_{micro} [km/s]	Reference
KELT-6	6102 ± 43	4.07 ± 0.06	-0.28 ± 0.04	...	Collins et al. (2014)
Kepler-37	5417 ± 70	4.57 ± 0.01	-0.32 ± 0.07	...	Barclay et al. (2013)
Kepler-444	5046 ± 74	4.60 ± 0.06	-0.55 ± 0.07	...	Campante et al. (2015)
mu Leo	4538 ± 27	2.40 ± 0.10	0.36 ± 0.05	1.40 ± 0.10	Lee et al. (2014)
ome Ser	4770 ± 10	2.32 ± 0.04	-0.24 ± 0.02	1.34 ± 0.04	Sato et al. (2013a)
omi UMa	5242 ± 10	2.64 ± 0.03	-0.09 ± 0.02	1.51 ± 0.07	Sato et al. (2012)
Qatar-2	4645 ± 50	4.60 ± 0.02	-0.02 ± 0.08	...	Bryan et al. (2012)
SAND364	4284 ± 9	2.20 ± 0.06	-0.02 ± 0.04	...	Brucalassi et al. (2014)
TYC+1422-614-1	4806 ± 45	2.85 ± 0.18	-0.20 ± 0.08	...	Niedzielski et al. (2015a)
WASP-37	5940 ± 55	4.39 ± 0.02	-0.40 ± 0.12	...	Simpson et al. (2011)
WASP-44	5400 ± 150	4.48 ± 0.07	0.06 ± 0.10	...	Anderson et al. (2012)
WASP-52	5000 ± 100	4.58 ± 0.01	0.03 ± 0.12	...	Hébrard et al. (2013)
WASP-58	5800 ± 150	4.27 ± 0.09	-0.45 ± 0.09	...	Hébrard et al. (2013)
WASP-61	6250 ± 150	4.26 ± 0.01	-0.10 ± 0.12	...	Hellier et al. (2012)
WASP-72	6250 ± 100	4.08 ± 0.13	-0.06 ± 0.09	1.60 ± 0.10	Gillon et al. (2013)
WASP-73	6030 ± 120	3.92 ± 0.08	0.14 ± 0.14	1.10 ± 0.20	Delrez et al. (2014)
WASP-75	6100 ± 100	4.50 ± 0.10	0.07 ± 0.09	1.30 ± 0.10	Gómez Maqueo Chew et al. (2013)
WASP-76	6250 ± 100	4.13 ± 0.02	0.23 ± 0.10	1.40 ± 0.10	West et al. (2016)
WASP-82	6490 ± 100	3.97 ± 0.02	0.12 ± 0.11	1.50 ± 0.10	West et al. (2016)
WASP-88	6430 ± 130	4.03 ± 0.09	-0.08 ± 0.12	1.40 ± 0.10	Delrez et al. (2014)
WASP-94 A	6170 ± 80	4.27 ± 0.07	0.26 ± 0.15	...	Neveu-VanMalle et al. (2014)
WASP-94 B	6040 ± 90	4.26 ± 0.06	0.23 ± 0.14	...	Neveu-VanMalle et al. (2014)
WASP-95	5630 ± 130	4.38 ± 0.03	0.14 ± 0.16	...	Hellier et al. (2014)
WASP-97	5640 ± 100	4.43 ± 0.03	0.23 ± 0.11	...	Hellier et al. (2014)
WASP-99	6180 ± 100	4.12 ± 0.03	0.21 ± 0.15	...	Hellier et al. (2014)
WASP-100	6900 ± 120	4.04 ± 0.11	-0.03 ± 0.10	...	Hellier et al. (2014)

Bibliography

- Adamów, M., Niedzielski, A., Villaver, E., Wolszczan, A., and Nowak, G.: 2014, *A&A* **569**, A55
- Adibekyan, V., Delgado-Mena, E., Figueira, P., Sousa, S. G., Santos, N. C., González Hernández, J. I., Minchev, I., Faria, J. P., Israelian, G., Harutyunyan, G., Suárez-Andrés, L., and Hakobyan, A. A.: 2016, *A&A* **592**, A87
- Adibekyan, V. Z., Benamati, L., Santos, N. C., Alves, S., Lovis, C., Udry, S., Israelian, G., Sousa, S. G., Tsantaki, M., Mortier, A., Sozzetti, A., and De Medeiros, J. R.: 2015, *MNRAS* **450**, 1900
- Adibekyan, V. Z., Figueira, P., Santos, N. C., Mortier, A., Mordasini, C., Delgado Mena, E., Sousa, S. G., Correia, A. C. M., Israelian, G., and Oshagh, M.: 2013, *A&A* **560**, A51
- Adibekyan, V. Z., Sousa, S. G., Santos, N. C., Delgado Mena, E., González Hernández, J. I., Israelian, G., Mayor, M., and Khachatryan, G.: 2012, *A&A* **545**, A32
- Aerts, C., Christensen-Dalsgaard, J., and Kurtz, D. W.: 2010, *Asteroseismology*, Springer-Verlag
- Anderson, D. R., Collier Cameron, A., Gillon, M., Hellier, C., Jehin, E., Lendl, M., Maxted, P. F. L., Queloz, D., Smalley, B., Smith, A. M. S., Triaud, A. H. M. J., West, R. G., Pepe, F., Pollacco, D., Ségransan, D., Todd, I., and Udry, S.: 2012, *MNRAS* **422**, 1988
- Andreasen, D. T., Sousa, S. G., Delgado Mena, E., Santos, N. C., Lebzelter, T., Mucciarelli, A., and Neil, J. J.: 2017a, *A&A* **585**, A143
- Andreasen, D. T., Sousa, S. G., Delgado Mena, E., Santos, N. C., Tsantaki, M., Rojas-Ayala, B., and Neves, V.: 2016, *A&A* **585**, A143
- Andreasen, D. T., Sousa, S. G., Tsantaki, M., Teixeira, G. D. C., Mortier, A., Santos, N. C., Suárez-Andrés, L., Delgado Mena, E., and Ferreira, A. C. S.: 2017b, *A&A* **600**, A69
- Balachandran, S.: 1990, *ApJ* **354**, 310
- Barclay, T., Rowe, J. F., Lissauer, J. J., Huber, D., Fressin, F., Howell, S. B., Bryson, S. T., Chaplin, W. J., Désert, J.-M., Lopez, E. D., Marcy, G. W., Mullally, F., Ragozzine, D., Torres, G., Adams, E. R., Agol, E., Barrado, D., Basu, S., Bedding, T. R., Buchhave, L. A., Charbonneau, D., Christiansen, J. L., Christensen-Dalsgaard, J., Ciardi, D., Cochran, W. D., Dupree, A. K., Elsworth, Y., Everett, M., Fischer, D. A., Ford, E. B., Fortney, J. J., Geary, J. C., Haas, M. R., Handberg, R., Hekker, S., Henze, C. E., Horch, E., Howard, A. W., Hunter, R. C., Isaacson, H., Jenkins, J. M., Karoff, C., Kawaler, S. D., Kjeldsen, H., Klaus, T. C., Latham, D. W., Li, J., Lillo-Box, J., Lund, M. N., Lundkvist, M.,

- Metcalfe, T. S., Miglio, A., Morris, R. L., Quintana, E. V., Stello, D., Smith, J. C., Still, M., and Thompson, S. E.: 2013, *Nature* **494**, 452
- Bedding, T. R., Mosser, B., Huber, D., Montalbán, J., Beck, P., Christensen-Dalsgaard, J., Elsworth, Y. P., García, R. A., Miglio, A., Stello, D., White, T. R., De Ridder, J., Hekker, S., Aerts, C., Barban, C., Belkacem, K., Broomhall, A.-M., Brown, T. M., Buzasi, D. L., Carrier, F., Chaplin, W. J., di Mauro, M. P., Dupret, M.-A., Frandsen, S., Gilliland, R. L., Goupil, M.-J., Jenkins, J. M., Kallinger, T., Kawaler, S., Kjeldsen, H., Mathur, S., Noels, A., Silva Aguirre, V., and Ventura, P.: 2011, *Nature* **471**, 608
- Bedell, M., Meléndez, J., Bean, J. L., Ramírez, I., Asplund, M., Alves-Brito, A., Casagrande, L., Dreizler, S., Monroe, T., Spina, L., and Tucci Maia, M.: 2015, *A&A* **581**, A34
- Bertaux, J. L., Lallement, R., Ferron, S., Boonne, C., and Bodichon, R.: 2014, *A&A* **564**, A46
- Blackwell, D. E. and Shallis, M. J.: 1977, *MNRAS* **180**, 177
- Bochanski, J. J., Hawley, S. L., Covey, K. R., West, A. A., Reid, I. N., Golimowski, D. A., and Ivezić, Ž.: 2010, *AJ* **139**, 2679
- Boisse, I., Hartman, J. D., Bakos, G. Á., Penev, K., Csubry, Z., Béky, B., Latham, D. W., Bieryla, A., Torres, G., Kovács, G., Buchhave, L. A., Hansen, T., Everett, M., Esquerdo, G. A., Szklenár, T., Falco, E., Shporer, A., Fulton, B. J., Noyes, R. W., Stefanik, R. P., Lázár, J., Papp, I., and Sári, P.: 2013, *A&A* **558**, A86
- Bonfils, X., Delfosse, X., Udry, S., Forveille, T., Mayor, M., Perrier, C., Bouchy, F., Gillon, M., Lovis, C., Pepe, F., Queloz, D., Santos, N. C., Ségransan, D., and Bertaux, J.-L.: 2013, *A&A* **549**, A109
- Brucalassi, A., Pasquini, L., Saglia, R., Ruiz, M. T., Bonifacio, P., Bedin, L. R., Biazzo, K., Melo, C., Lovis, C., and Randich, S.: 2014, *A&A* **561**, L9
- Bryan, M. L., Alsubai, K. A., Latham, D. W., Parley, N. R., Collier Cameron, A., Quinn, S. N., Carter, J. A., Fulton, B. J., Berlind, P., Brown, W. R., Buchhave, L. A., Calkins, M. L., Esquerdo, G. A., Fűrész, G., Gråe Jørgensen, U., Horne, K. D., Stefanik, R. P., Street, R. A., Torres, G., West, R. G., Dominik, M., Harpsøe, K. B. W., Liebig, C., Calchi Novati, S., Ricci, D., and Skottfelt, J. F.: 2012, *ApJ* **750**, 84
- Campante, T. L., Barclay, T., Swift, J. J., Huber, D., Adibekyan, V. Z., Cochran, W., Burke, C. J., Isaacson, H., Quintana, E. V., Davies, G. R., Silva Aguirre, V., Ragozzine, D., Riddle, R., Baranec, C., Basu, S., Chaplin, W. J., Christensen-Dalsgaard, J., Metcalfe, T. S., Bedding, T. R., Handberg, R., Stello, D., Brewer, J. M., Hekker, S., Karoff, C., Kolbl, R., Law, N. M., Lundkvist, M., Miglio, A., Rowe, J. F., Santos, N. C., Van Laerhoven, C., Arentoft, T., Elsworth, Y. P., Fischer, D. A., Kawaler, S. D., Kjeldsen, H., Lund, M. N., Marcy, G. W., Sousa, S. G., Sozzetti, A., and White, T. R.: 2015, *ApJ* **799**, 170
- Casagrande, L., Portinari, L., and Flynn, C.: 2006, *MNRAS* **373**, 13
- Cayrel, R.: 1988, in G. Cayrel de Strobel and M. Spite (eds.), *The Impact of Very High S/N Spectroscopy on Stellar Physics*, Vol. 132 of *IAU Symposium*, p. 345

- Chaplin, W. J., Kjeldsen, H., Christensen-Dalsgaard, J., Basu, S., Miglio, A., Appourchaux, T., Bedding, T. R., Elsworth, Y., García, R. A., Gilliland, R. L., Girardi, L., Houdek, G., Karoff, C., Kawaler, S. D., Metcalfe, T. S., Molenda-Żakowicz, J., Monteiro, M. J. P. F. G., Thompson, M. J., Verner, G. A., Ballot, J., Bonanno, A., Brandão, I. M., Broomhall, A.-M., Bruntt, H., Campante, T. L., Corsaro, E., Creevey, O. L., Doğan, G., Esch, L., Gai, N., Gaulme, P., Hale, S. J., Handberg, R., Hekker, S., Huber, D., Jiménez, A., Mathur, S., Mazumdar, A., Mosser, B., New, R., Pinsonneault, M. H., Pricopi, D., Quirion, P.-O., Régulo, C., Salabert, D., Serenelli, A. M., Silva Aguirre, V., Sousa, S. G., Stello, D., Stevens, I. R., Suran, M. D., Uytterhoeven, K., White, T. R., Borucki, W. J., Brown, T. M., Jenkins, J. M., Kinemuchi, K., Van Cleve, J., and Klaus, T. C.: 2011, *Science* **332**, 213
- Christensen-Dalsgaard, J., Kjeldsen, H., Brown, T. M., Gilliland, R. L., Arentoft, T., Frandsen, S., Quirion, P.-O., Borucki, W. J., Koch, D., and Jenkins, J. M.: 2010, *ApJL* **713**, L164
- Collins, K. A., Eastman, J. D., Beatty, T. G., Siverd, R. J., Gaudi, B. S., Pepper, J., Kielkopf, J. F., Johnson, J. A., Howard, A. W., Fischer, D. A., Manner, M., Bieryla, A., Latham, D. W., Fulton, B. J., Gregorio, J., Buchhave, L. A., Jensen, E. L. N., Stassun, K. G., Penev, K., Crepp, J. R., Hinkley, S., Street, R. A., Cargile, P., Mack, C. E., Oberst, T. E., Avril, R. L., Mellon, S. N., McLeod, K. K., Penny, M. T., Stefanik, R. P., Berlind, P., Calkins, M. L., Mao, Q., Richert, A. J. W., DePoy, D. L., Esquerdo, G. A., Gould, A., Marshall, J. L., Oelkers, R. J., Pogge, R. W., Trueblood, M., and Trueblood, P.: 2014, *AJ* **147**, 39
- Czekala, I., Andrews, S. M., Mandel, K. S., Hogg, D. W., and Green, G. M.: 2015, *ApJ* **812**, 128
- Dekker, H., D’Odorico, S., Kaufer, A., Delabre, B., and Kotzlowski, H.: 2000, in M. Iye and A. F. Moorwood (eds.), *Optical and IR Telescope Instrumentation and Detectors*, Vol. 4008 of *Proceedings of the SPIE*, pp 534–545
- Delfosse, X., Bonfils, X., Forveille, T., Udry, S., Mayor, M., Bouchy, F., Gillon, M., Lovis, C., Neves, V., Pepe, F., Perrier, C., Queloz, D., Santos, N. C., and Ségransan, D.: 2013, *A&A* **553**, A8
- Delrez, L., Van Grootel, V., Anderson, D. R., Collier-Cameron, A., Doyle, A. P., Fumel, A., Gillon, M., Hellier, C., Jehin, E., Lendl, M., Neveu-VanMalle, M., Maxted, P. F. L., Pepe, F., Pollacco, D., Queloz, D., Ségransan, D., Smalley, B., Smith, A. M. S., Southworth, J., Triaud, A. H. M. J., Udry, S., and West, R. G.: 2014, *A&A* **563**, A143
- Donati, J.-F.: 2003, in J. Trujillo-Bueno and J. Sanchez Almeida (eds.), *Solar Polarization*, Vol. 307 of *Astronomical Society of the Pacific Conference Series*, p. 41
- Ducati, J. R.: 2002, *VizieR Online Data Catalog* 2237
- Favata, F., Micela, G., and Sciortino, S.: 1997, *A&A* **323**, 809
- Figueira, P., Oshagh, M., Adibekyan, V. Z., and Santos, N. C.: 2014, *A&A* **572**, A51
- Frandsen, S. and Lindberg, B.: 1999, in H. Karttunen and V. Pirola (eds.), *Astrophysics with the NOT*, p. 71
- Gillon, M., Anderson, D. R., Collier-Cameron, A., Doyle, A. P., Fumel, A., Hellier, C., Jehin, E., Lendl, M., Maxted, P. F. L., Montalbán, J., Pepe, F., Pollacco, D., Queloz, D., Ségransan, D., Smith, A. M. S., Smalley, B., Southworth, J., Triaud, A. H. M. J., Udry, S., and West, R. G.: 2013, *A&A* **552**, A82

- Gómez Maqueo Chew, Y., Faedi, F., Pollacco, D., Brown, D. J. A., Doyle, A. P., Collier Cameron, A., Gillon, M., Lendl, M., Smalley, B., Triaud, A. H. M. J., West, R. G., Wheatley, P. J., Busuttil, R., Liebig, C., Anderson, D. R., Armstrong, D. J., Barros, S. C. C., Bento, J., Bochinski, J., Burwitz, V., Delrez, L., Enoch, B., Fumel, A., Haswell, C. A., Hébrard, G., Hellier, C., Holmes, S., Jehin, E., Kolb, U., Maxted, P. F. L., McCormac, J., Miller, G. R. M., Norton, A. J., Pepe, F., Queloz, D., Rodríguez, J., Ségransan, D., Skillen, I., Stassun, K. G., Udry, S., and Watson, C.: 2013, *A&A* **559**, A36
- Gonzalez, G., Carlson, M. K., and Tobin, R. W.: 2010, *MNRAS* **403**, 1368
- Gonzalez, G. and Laws, C.: 2000, *AJ* **119**, 390
- Gray, D. F.: 2005, *The Observation and Analysis of Stellar Photospheres*, 3rd ed.
- Griffin, R. and Griffin, R.: 1967, *MNRAS* **137**, 253
- Grundahl, F., Fredslund Andersen, M., Christensen-Dalsgaard, J., Antoci, V., Kjeldsen, H., Handberg, R., Houdek, G., Bedding, T. R., Pallé, P. L., Jessen-Hansen, J., Silva Aguirre, V., White, T. R., Frandsen, S., Albrecht, S., Andersen, M. I., Arentoft, T., Brogaard, K., Chaplin, W. J., Harpsøe, K., Jørgensen, U. G., Karovicova, I., Karoff, C., Kjærgaard Rasmussen, P., Lund, M. N., Sloth Lundkvist, M., Skottfelt, J., Norup Sørensen, A., Tronsgaard, R., and Weiss, E.: 2017, *ApJ* **836**, 142
- Gustafsson, B., Edvardsson, B., Eriksson, K., Jørgensen, U. G., Nordlund, Å., and Plez, B.: 2008, *A&A* **486**, 951
- Hartman, J. D.: 2010, *ApJL* **717**, L138
- Hartman, J. D., Bakos, G. Á., Béky, B., Torres, G., Latham, D. W., Csubry, Z., Penev, K., Shporer, A., Fulton, B. J., Buchhave, L. A., Johnson, J. A., Howard, A. W., Marcy, G. W., Fischer, D. A., Kovács, G., Noyes, R. W., Esquerdo, G. A., Everett, M., Szklenár, T., Quinn, S. N., Bieryla, A., Knox, R. P., Hinz, P., Sasselov, D. D., Fűrész, G., Stefanik, R. P., Lázár, J., Papp, I., and Sári, P.: 2012, *AJ* **144**, 139
- Hartman, J. D., Bakos, G. Á., Torres, G., Kovács, G., Johnson, J. A., Howard, A. W., Marcy, G. W., Latham, D. W., Bieryla, A., Buchhave, L. A., Bhatti, W., Béky, B., Csubry, Z., Penev, K., de Val-Borro, M., Noyes, R. W., Fischer, D. A., Esquerdo, G. A., Everett, M., Szklenár, T., Zhou, G., Bayliss, D., Shporer, A., Fulton, B. J., Sanchis-Ojeda, R., Falco, E., Lázár, J., Papp, I., and Sári, P.: 2014a, *AJ* **147**, 128
- Hartman, J. D., Bakos, G. Á., Torres, G., Kovács, G., Johnson, J. A., Howard, A. W., Marcy, G. W., Latham, D. W., Bieryla, A., Buchhave, L. A., Bhatti, W., Béky, B., Csubry, Z., Penev, K., de Val-Borro, M., Noyes, R. W., Fischer, D. A., Esquerdo, G. A., Everett, M., Szklenár, T., Zhou, G., Bayliss, D., Shporer, A., Fulton, B. J., Sanchis-Ojeda, R., Falco, E., Lázár, J., Papp, I., and Sári, P.: 2014b, *AJ* **147**, 128
- Hébrard, G., Arnold, L., Forveille, T., Correia, A. C. M., Laskar, J., Bonfils, X., Boisse, I., Díaz, R. F., Hagelberg, J., Sahlmann, J., Santos, N. C., Astudillo-Defru, N., Borgniet, S., Bouchy, F., Bourrier, V., Courcol, B., Delfosse, X., Deleuil, M., Demangeon, O., Ehrenreich, D., Gregorio, J., Jovanovic, N., Labrevoir, O., Lagrange, A.-M., Lovis, C., Lozi, J., Moutou, C., Montagnier, G., Pepe, F., Rey, J., Santerne, A., Ségransan, D., Udry, S., Vanhuyse, M., Vigan, A., and Wilson, P. A.: 2016, *A&A* **588**, A145

- Hébrard, G., Collier Cameron, A., Brown, D. J. A., Díaz, R. F., Faedi, F., Smalley, B., Anderson, D. R., Armstrong, D., Barros, S. C. C., Bento, J., Bouchy, F., Doyle, A. P., Enoch, B., Gómez Maqueo Chew, Y., Hébrard, É. M., Hellier, C., Lendl, M., Lister, T. A., Maxted, P. F. L., McCormac, J., Moutou, C., Pollacco, D., Queloz, D., Santerne, A., Skillen, I., Southworth, J., Tregloan-Reed, J., Triaud, A. H. M. J., Udry, S., Vanhuyse, M., Watson, C. A., West, R. G., and Wheatley, P. J.: 2013, *A&A* **549**, A134
- Hellier, C., Anderson, D. R., Cameron, A. C., Delrez, L., Gillon, M., Jehin, E., Lendl, M., Maxted, P. F. L., Pepe, F., Pollacco, D., Queloz, D., Ségransan, D., Smalley, B., Smith, A. M. S., Southworth, J., Triaud, A. H. M. J., Udry, S., and West, R. G.: 2014, *MNRAS* **440**, 1982
- Hellier, C., Anderson, D. R., Collier Cameron, A., Doyle, A. P., Fumel, A., Gillon, M., Jehin, E., Lendl, M., Maxted, P. F. L., Pepe, F., Pollacco, D., Queloz, D., Ségransan, D., Smalley, B., Smith, A. M. S., Southworth, J., Triaud, A. H. M. J., Udry, S., and West, R. G.: 2012, *MNRAS* **426**, 739
- Hinkel, N. R., Young, P. A., Pagano, M. D., Desch, S. J., Anbar, A. D., Adibekyan, V., Blanco-Cuaresma, S., Carlberg, J. K., Delgado Mena, E., Liu, F., Nordlander, T., Sousa, S. G., Korn, A., Gruyters, P., Heiter, U., Jofré, P., Santos, N. C., and Soubiran, C.: 2016, *ApJS* **226**, 4
- Hinkle, K., Wallace, L., and Livingston, W.: 1995a, *Publications of the ASP* **107**, 1042
- Hinkle, K. H., Wallace, L., and Livingston, W.: 1995b, in A. J. Sauval, R. Blomme, and N. Grevesse (eds.), *Laboratory and Astronomical High Resolution Spectra*, Vol. 81 of *Astronomical Society of the Pacific Conference Series*, p. 66
- Howard, A. W., Johnson, J. A., Marcy, G. W., Fischer, D. A., Wright, J. T., Henry, G. W., Isaacson, H., Valenti, J. A., Anderson, J., and Piskunov, N. E.: 2011, *ApJ* **730**, 10
- Huber, D., Silva Aguirre, V., Matthews, J. M., Pinsonneault, M. H., Gaidos, E., García, R. A., Hekker, S., Mathur, S., Mosser, B., Torres, G., Bastien, F. A., Basu, S., Bedding, T. R., Chaplin, W. J., Demory, B.-O., Fleming, S. W., Guo, Z., Mann, A. W., Rowe, J. F., Serenelli, A. M., Smith, M. A., and Stello, D.: 2014, *ApJS* **211**, 2
- Husser, T.-O., Wende-von Berg, S., Dreizler, S., Homeier, D., Reiners, A., Barman, T., and Hauschildt, P. H.: 2013, *A&A* **553**, A6
- Jofré, P., Heiter, U., Soubiran, C., Blanco-Cuaresma, S., Worley, C. C., Pancino, E., Cantat-Gaudin, T., Magrini, L., Bergemann, M., González Hernández, J. I., Hill, V., Lardo, C., de Laverny, P., Lind, K., Masseron, T., Montes, D., Mucciarelli, A., Nordlander, T., Recio Blanco, A., Sobeck, J., Sordo, R., Sousa, S. G., Tabernero, H., Vallenari, A., and Van Eck, S.: 2014, *A&A* **564**, A133
- Johnson, J. A., Clanton, C., Howard, A. W., Bowler, B. P., Henry, G. W., Marcy, G. W., Crepp, J. R., Endl, M., Cochran, W. D., MacQueen, P. J., Wright, J. T., and Isaacson, H.: 2011, *ApJS* **197**, 26
- Jones, M. I., Jenkins, J. S., Rojo, P., and Melo, C. H. F.: 2011, *A&A* **536**, A71
- Jones, M. I., Jenkins, J. S., Rojo, P., Olivares, F., and Melo, C. H. F.: 2015, *A&A* **580**, A14
- Kaufer, A., Stahl, O., Tubbesing, S., Nørregaard, P., Avila, G., Francois, P., Pasquini, L., and Pizzella, A.: 1999, *The Messenger* **95**, 8

- Kippenhahn, R. and Weigert, A.: 1994, *Stellar Structure and Evolution*, Springer-Verlag
- Kipping, D. M., Bakos, G. Á., Hartman, J., Torres, G., Shporer, A., Latham, D. W., Kovács, G., Noyes, R. W., Howard, A. W., Fischer, D. A., Johnson, J. A., Marcy, G. W., Béky, B., Perumpilly, G., Esquerdo, G. A., Sasselov, D. D., Stefanik, R. P., Lázár, J., Papp, I., and Sári, P.: 2010, *ApJ* **725**, 2017
- Kirkpatrick, J. D., Henry, T. J., and McCarthy, Jr., D. W.: 1991, *ApJS* **77**, 417
- Kjeldsen, H. and Bedding, T. R.: 1995, *A&A* **293**, 87
- Kopparapu, R. K., Ramirez, R., Kasting, J. F., Eymet, V., Robinson, T. D., Mahadevan, S., Terrien, R. C., Domagal-Goldman, S., Meadows, V., and Deshpande, R.: 2013, *ApJ* **765**, 131
- Kunitomo, M., Ikoma, M., Sato, B., Katsuta, Y., and Ida, S.: 2011, *ApJ* **737**, 66
- Kupka, F. G., Ryabchikova, T. A., Piskunov, N. E., Stempels, H. C., and Weiss, W. W.: 2000, *Baltic Astronomy* **9**, 590
- Kurucz, R.: 1993, *ATLAS9 Stellar Atmosphere Programs and 2 km/s grid. Kurucz CD-ROM No. 13. Cambridge, Mass.: Smithsonian Astrophysical Observatory, 1993*. 13
- Lebzelter, T., Seifahrt, A., Uttenthaler, S., Ramsay, S., Hartman, H., Nieva, M.-F., Przybilla, N., Smette, A., Wahlgren, G. M., Wolff, B., Hussain, G. A. J., Käuff, H. U., and Seemann, U.: 2012, *A&A* **539**, A109
- Lee, B.-C., Han, I., and Park, M.-G.: 2013, *A&A* **549**, A2
- Lee, B.-C., Han, I., Park, M.-G., Mkrtichian, D. E., Hatzes, A. P., and Kim, K.-M.: 2014, *A&A* **566**, A67
- Lindgren, S., Heiter, U., and Seifahrt, A.: 2016, *A&A* **586**, A100
- Mayor, M., Pepe, F., Queloz, D., Bouchy, F., Rupprecht, G., Lo Curto, G., Avila, G., Benz, W., Bertaux, J.-L., Bonfils, X., Dall, T., Dekker, H., Delabre, B., Eckert, W., Fleury, M., Gilliotte, A., Gojak, D., Guzman, J. C., Kohler, D., Lizon, J.-L., Longinotti, A., Lovis, C., Megevand, D., Pasquini, L., Reyes, J., Sivan, J.-P., Sosnowska, D., Soto, R., Udry, S., van Kesteren, A., Weber, L., and Weilenmann, U.: 2003, *The Messenger* **114**, 20
- Mayor, M. and Queloz, D.: 1995, *A Jupiter-mass companion to a solar-type star*
- McWilliam, A.: 1990, *ApJS* **74**, 1075
- Mortier, A., Santos, N. C., Sousa, S., Israelian, G., Mayor, M., and Udry, S.: 2013a, *A&A* **551**, A112
- Mortier, A., Santos, N. C., Sousa, S. G., Adibekyan, V. Z., Delgado Mena, E., Tsantaki, M., Israelian, G., and Mayor, M.: 2013b, *A&A* **557**, A70
- Mortier, A., Sousa, S. G., Adibekyan, V. Z., Brandão, I. M., and Santos, N. C.: 2014, *A&A* **572**, A95
- Motalebi, F., Udry, S., Gillon, M., Lovis, C., Ségransan, D., Buchhave, L. A., Demory, B. O., Malavolta, L., Dressing, C. D., Sasselov, D., Rice, K., Charbonneau, D., Collier Cameron, A., Latham, D., Molinari, E., Pepe, F., Affer, L., Bonomo, A. S., Cosentino, R., Dumusque, X., Figueira, P., Fiorenzano, A. F. M., Gettel, S., Harutyunyan, A., Haywood, R. D., Johnson, J., Lopez, E., Lopez-Morales, M., Mayor, M., Micela, G., Mortier, A., Nascimbeni, V., Philips, D., Piotto, G., Pollacco, D., Queloz, D., Sozzetti, A., Vanderburg, A., and Watson, C. A.: 2015, *A&A* **584**, A72

- Moutou, C., Lo Curto, G., Mayor, M., Bouchy, F., Benz, W., Lovis, C., Naef, D., Pepe, F., Queloz, D., Santos, N. C., Ségransan, D., Sousa, S. G., and Udry, S.: 2015, *A&A* **576**, A48
- Neuforge-Verheecke, C. and Magain, P.: 1997, *A&A* **328**, 261
- Neveu-VanMalle, M., Queloz, D., Anderson, D. R., Charbonnel, C., Collier Cameron, A., Delrez, L., Gillon, M., Hellier, C., Jehin, E., Lendl, M., Maxted, P. F. L., Pepe, F., Pollacco, D., Ségransan, D., Smalley, B., Smith, A. M. S., Southworth, J., Triaud, A. H. M. J., Udry, S., and West, R. G.: 2014, *A&A* **572**, A49
- Newton, I.: 1687, *Philosophiae Naturalis Principia Mathematica. Auctore Js. Newton*
- Ngo, H., Knutson, H. A., Hinkley, S., Bryan, M., Crepp, J. R., Batygin, K., Crossfield, I., Hansen, B., Howard, A. W., Johnson, J. A., Mawet, D., Morton, T. D., Muirhead, P. S., and Wang, J.: 2016, *ApJ* **827**, 8
- Nicholls, C. P., Lebzelter, T., Smette, A., Wolff, B., Hartman, H., Käuff, H.-U., Przybilla, N., Ramsay, S., Uttenthaler, S., Wahlgren, G. M., Bagnulo, S., Hussain, G. A. J., Nieva, M.-F., Seemann, U., and Seifahrt, A.: 2017, *A&A* **598**, A79
- Niedzielski, A., Villaver, E., Nowak, G., Adamów, M., Kowalik, K., Wolszczan, A., Deka-Szymankiewicz, B., Adamczyk, M., and Maciejewski, G.: 2016, *A&A* **588**, A62
- Niedzielski, A., Villaver, E., Wolszczan, A., Adamów, M., Kowalik, K., Maciejewski, G., Nowak, G., García-Hernández, D. A., Deka, B., and Adamczyk, M.: 2015a, *A&A* **573**, A36
- Niedzielski, A., Wolszczan, A., Nowak, G., Adamów, M., Kowalik, K., Maciejewski, G., Deka-Szymankiewicz, B., and Adamczyk, M.: 2015b, *ApJ* **803**, 1
- Nowak, G., Niedzielski, A., Wolszczan, A., Adamów, M., and Maciejewski, G.: 2013, *ApJ* **770**, 53
- Önehag, A., Heiter, U., Gustafsson, B., Piskunov, N., Plez, B., and Reiners, A.: 2012, *A&A* **542**, A33
- Penev, K., Bakos, G. Á., Bayliss, D., Jordán, A., Mohler, M., Zhou, G., Suc, V., Rabus, M., Hartman, J. D., Mancini, L., Béky, B., Csubry, Z., Buchhave, L., Henning, T., Nikolov, N., Csák, B., Brahm, R., Espinoza, N., Conroy, P., Noyes, R. W., Sasselov, D. D., Schmidt, B., Wright, D. J., Tinney, C. G., Addison, B. C., Lázár, J., Papp, I., and Sári, P.: 2013, *AJ* **145**, 5
- Piskunov, N. E., Kupka, F., Ryabchikova, T. A., Weiss, W. W., and Jeffery, C. S.: 1995, *A&A Supp.* **112**, 525
- Quinn, S. N., White, R. J., Latham, D. W., Buchhave, L. A., Torres, G., Stefanik, R. P., Berlind, P., Bieryla, A., Calkins, M. C., Esquerdo, G. A., Fűrész, G., Geary, J. C., and Szentgyorgyi, A. H.: 2014, *ApJ* **787**, 27
- Ramírez, I., Allende Prieto, C., and Lambert, D. L.: 2013, *ApJ* **764**, 78
- Ramírez, I., Fish, J. R., Lambert, D. L., and Allende Prieto, C.: 2012, *ApJ* **756**, 46
- Ramírez, I. and Meléndez, J.: 2005, *ApJ* **626**, 465

- Santos, N. C., Adibekyan, V., Figueira, P., Andreasen, D. T., Barros, S. C. C., Delgado-Mena, E., Demangeon, O., Faria, J. P., Oshagh, M., Sousa, S. G., Viana, P. T. P., and Ferreira, A. C. S.: 2017, *ArXiv e-prints*
- Santos, N. C., Israelian, G., and Mayor, M.: 2004, *A&A* **415**, 1153
- Santos, N. C., Sousa, S. G., Mortier, A., Neves, V., Adibekyan, V., Tsantaki, M., Delgado Mena, E., Bonfils, X., Israelian, G., Mayor, M., and Udry, S.: 2013, *A&A* **556**, A150
- Sato, B., Izumiura, H., Toyota, E., Kambe, E., Ikoma, M., Omiya, M., Masuda, S., Takeda, Y., Murata, D., Itoh, Y., Ando, H., Yoshida, M., Kokubo, E., and Ida, S.: 2008, *PASJ* **60**, 539
- Sato, B., Omiya, M., Harakawa, H., Izumiura, H., Kambe, E., Takeda, Y., Yoshida, M., Itoh, Y., Ando, H., Kokubo, E., and Ida, S.: 2012, *PASJ* **64**
- Sato, B., Omiya, M., Harakawa, H., Liu, Y.-J., Izumiura, H., Kambe, E., Takeda, Y., Yoshida, M., Itoh, Y., Ando, H., Kokubo, E., and Ida, S.: 2013a, *PASJ* **65**
- Sato, B., Omiya, M., Wittenmyer, R. A., Harakawa, H., Nagasawa, M., Izumiura, H., Kambe, E., Takeda, Y., Yoshida, M., Itoh, Y., Ando, H., Kokubo, E., and Ida, S.: 2013b, *ApJ* **762**, 9
- Simpson, E. K., Faedi, F., Barros, S. C. C., Brown, D. J. A., Collier Cameron, A., Hebb, L., Pollacco, D., Smalley, B., Todd, I., Butters, O. W., Hébrard, G., McCormac, J., Miller, G. R. M., Santerne, A., Street, R. A., Skillen, I., Triaud, A. H. M. J., Anderson, D. R., Bento, J., Boisse, I., Bouchy, F., Enoch, B., Haswell, C. A., Hellier, C., Holmes, S., Horne, K., Keenan, F. P., Lister, T. A., Maxted, P. F. L., Moulds, V., Moutou, C., Norton, A. J., Parley, N., Pepe, F., Queloz, D., Segransan, D., Smith, A. M. S., Stempels, H. C., Udry, S., Watson, C. A., West, R. G., and Wheatley, P. J.: 2011, *AJ* **141**, 8
- Smiljanic, R., Korn, A. J., Bergemann, M., Frasca, A., Magrini, L., Masseron, T., Pancino, E., Ruchti, G., San Roman, I., Sbordone, L., Sousa, S. G., Tabernero, H., Tautvaišienė, G., Valentini, M., Weber, M., Worley, C. C., Adibekyan, V. Z., Allende Prieto, C., Barisevičius, G., Biazzo, K., Blanco-Cuaresma, S., Bonifacio, P., Bragaglia, A., Caffau, E., Cantat-Gaudin, T., Chorniy, Y., de Laverny, P., Delgado-Mena, E., Donati, P., Duffau, S., Franciosini, E., Friel, E., Geisler, D., González Hernández, J. I., Gruyters, P., Guiglion, G., Hansen, C. J., Heiter, U., Hill, V., Jacobson, H. R., Jofre, P., Jönsson, H., Lanzafame, A. C., Lardo, C., Ludwig, H.-G., Maiorca, E., Mikolaitis, Š., Montes, D., Morel, T., Mucciarelli, A., Muñoz, C., Nordlander, T., Pasquini, L., Puzeras, E., Recio-Blanco, A., Ryde, N., Sacco, G., Santos, N. C., Serenelli, A. M., Sordo, R., Soubiran, C., Spina, L., Steffen, M., Vallenari, A., Van Eck, S., Villanova, S., Gilmore, G., Randich, S., Asplund, M., Binney, J., Drew, J., Feltzing, S., Ferguson, A., Jeffries, R., Micela, G., Negueruela, I., Prusti, T., Rix, H.-W., Alfaro, E., Babusiaux, C., Bensby, T., Blomme, R., Flaccomio, E., François, P., Irwin, M., Koposov, S., Walton, N., Bayo, A., Carraro, G., Costado, M. T., Damiani, F., Edvardsson, B., Hourihane, A., Jackson, R., Lewis, J., Lind, K., Marconi, G., Martayan, C., Monaco, L., Morbidelli, L., Prisinzano, L., and Zaggia, S.: 2014, *A&A* **570**, A122
- Snedden, C. A.: 1973, *Ph.D. thesis*, THE UNIVERSITY OF TEXAS AT AUSTIN.
- Soubiran, C., Le Campion, J.-F., Brouillet, N., and Chemin, L.: 2016, *A&A* **591**, A118
- Sousa, S. G., Santos, N. C., Adibekyan, V., Delgado-Mena, E., and Israelian, G.: 2015, *A&A* **577**, A67

- Sousa, S. G., Santos, N. C., Israelian, G., Mayor, M., and Monteiro, M. J. P. F. G.: 2007, *A&A* **469**, 783
- Sousa, S. G., Santos, N. C., Israelian, G., Mayor, M., and Udry, S.: 2011, *A&A* **533**, A141
- Sousa, S. G., Santos, N. C., Mayor, M., Udry, S., Casagrande, L., Israelian, G., Pepe, F., Queloz, D., and Monteiro, M. J. P. F. G.: 2008, *A&A* **487**, 373
- Takeda, Y., Sato, B., and Murata, D.: 2008, *PASJ* **60**, 781
- Torres, G., Andersen, J., and Giménez, A.: 2010, *Astronomy and Astrophysics Reviews* **18**, 67
- Torres, G., Winn, J. N., and Holman, M. J.: 2008, *ApJ* **677**, 1324
- Tsantaki, M., Andreasen, D. T., Teixeira, G. D. C., Sousa, S. G., Santos, N. C., Delgado-Mena, E., and Bruzual, G.: 2017, *MNRAS* **555**, A150
- Tsantaki, M., Sousa, S. G., Adibekyan, V. Z., Santos, N. C., Mortier, A., and Israelian, G.: 2013, *A&A* **555**, A150
- Valenti, J. A. and Fischer, D. A.: 2005, *ApJS* **159**, 141
- Valenti, J. A. and Piskunov, N.: 1996, *A&A Supp.* **118**, 595
- Vanderburg, A., Montet, B. T., Johnson, J. A., Buchhave, L. A., Zeng, L., Pepe, F., Collier Cameron, A., Latham, D. W., Molinari, E., Udry, S., Lovis, C., Matthews, J. M., Cameron, C., Law, N., Bowler, B. P., Angus, R., Baranec, C., Bieryla, A., Boschin, W., Charbonneau, D., Cosentino, R., Dumusque, X., Figueira, P., Guenther, D. B., Harutyunyan, A., Hellier, C., Kuschnig, R., Lopez-Morales, M., Mayor, M., Micela, G., Moffat, A. F. J., Pedani, M., Phillips, D. F., Piotto, G., Pollacco, D., Queloz, D., Rice, K., Riddle, R., Rowe, J. F., Rucinski, S. M., Sasselov, D., Ségransan, D., Sozzetti, A., Szentgyorgyi, A., Watson, C., and Weiss, W. W.: 2015, *ApJ* **800**, 59
- West, R. G., Hellier, C., Almenara, J.-M., Anderson, D. R., Barros, S. C. C., Bouchy, F., Brown, D. J. A., Collier Cameron, A., Deleuil, M., Delrez, L., Doyle, A. P., Faedi, F., Fumel, A., Gillon, M., Gómez Maqueo Chew, Y., Hébrard, G., Jehin, E., Lendl, M., Maxted, P. F. L., Pepe, F., Pollacco, D., Queloz, D., Ségransan, D., Smalley, B., Smith, A. M. S., Southworth, J., Triaud, A. H. M. J., and Udry, S.: 2016, *A&A* **585**, A126
- Wilson, P. A., Hébrard, G., Santos, N. C., Sahlmann, J., Montagnier, G., Astudillo-Defru, N., Boisse, I., Bouchy, F., Rey, J., Arnold, L., Bonfils, X., Bourrier, V., Courcol, B., Deleuil, M., Delfosse, X., Díaz, R. F., Ehrenreich, D., Forveille, T., Moutou, C., Pepe, F., Santerne, A., Ségransan, D., and Udry, S.: 2016, *A&A* **588**, A144
- Wolszczan, A. and Frail, D. A.: 1992, *Nature* **355**, 145
- Zhou, G., Bayliss, D., Penev, K., Bakos, G. Á., Hartman, J. D., Jordán, A., Mancini, L., Mohler, M., Csubry, Z., Ciceri, S., Brahm, R., Rabus, M., Buchhave, L., Henning, T., Suc, V., Espinoza, N., Béky, B., Noyes, R. W., Schmidt, B., Butler, R. P., Shectman, S., Thompson, I., Crane, J., Sato, B., Csák, B., Lázár, J., Papp, I., Sári, P., and Nikolov, N.: 2014, *AJ* **147**, 144
- Zieliński, P., Niedzielski, A., Wolszczan, A., Adamów, M., and Nowak, G.: 2012, *A&A* **547**, A91