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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University of Porto

Dedication

To Linnea, Henriette, and Rico

For always supporting me

Acknowledgements

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Abstract

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Chapter 1

Introduction

Ever since the dawn of time, the humankind have looked at the stars and wondered if we are alone in this Universe. To answer this question, one must look toward the field of extrasolar planets (exoplanets). This is a rapidly growing field in astronomy and science in general. Since the first confirmed discovery of an exoplanet around a millisecond pulsar in 1992 by Wolszczan and Frail (1992) and three years later, the more interesting exoplanet 51 Peg b discovered around a solar-type star by Mayor and Queloz (1995), more than 3600 exoplanets have been discovered at the time of writing, July 2017[1].

With the discoveries of exoplanets, the main focus is now mainly on finding the twin of Earth, that is a planet that can harbour life as we know it. However, it is not enough to simply discover small rocky exoplanets. Accurate and precise determination of the stellar parameters are crucial as the planetary parameters (radius, mass, bulk density, etc.) are directly derived from their host's parameters.

In this chapter there will be a general introduction to exoplanets, detection methods, and characterisation (Section 1.1). Then a throughout introduction on the exoplanet host stars (Section 1.2), which is the main focus on this thesis. While learning about host stars, and stars in general, the results have wide-spread applications, where some will briefly be discussed in the end of this chapter (Section 1.3) before an introduction on what this thesis will consists of (Section 1.4).

1.1 Exoplanets

The holy grail in the field of exoplanets is to find the first exoplanet with life. This is by no means an easy task. To give an idea of the difficulty of detecting life on an exoplanet, one must understand all the difficulties to simply detect and confirm an exoplanet. This will shortly be described in the sections below

1.1.1 Detecting exoplanets

There are sex ways of detecting exoplanets, some with advantages over others. In combination with each other, one can potentially learn a lot about the exoplanet(s).

It is important to note, that different things might mimic planetary signals, however they will not be described in this thesis. The confirmation of an exoplanet often happen, when two techniques are able to detect the same exoplanet.

[1] http://exoplanet.eu/

1.1.1.1 Transit method

The most successful method, if based on numbers of exoplanets detected, is the transit method. This is a well-known method in astronomy, however only used in the last decade for detecting exoplanets. Before this, it has been used extensively for finding and characterising binary stars. The difference here is, that the exoplanet does not radiate (or at least very little radiation). An example of an exoplanet transiting a star can be seen in Figure 1.1.

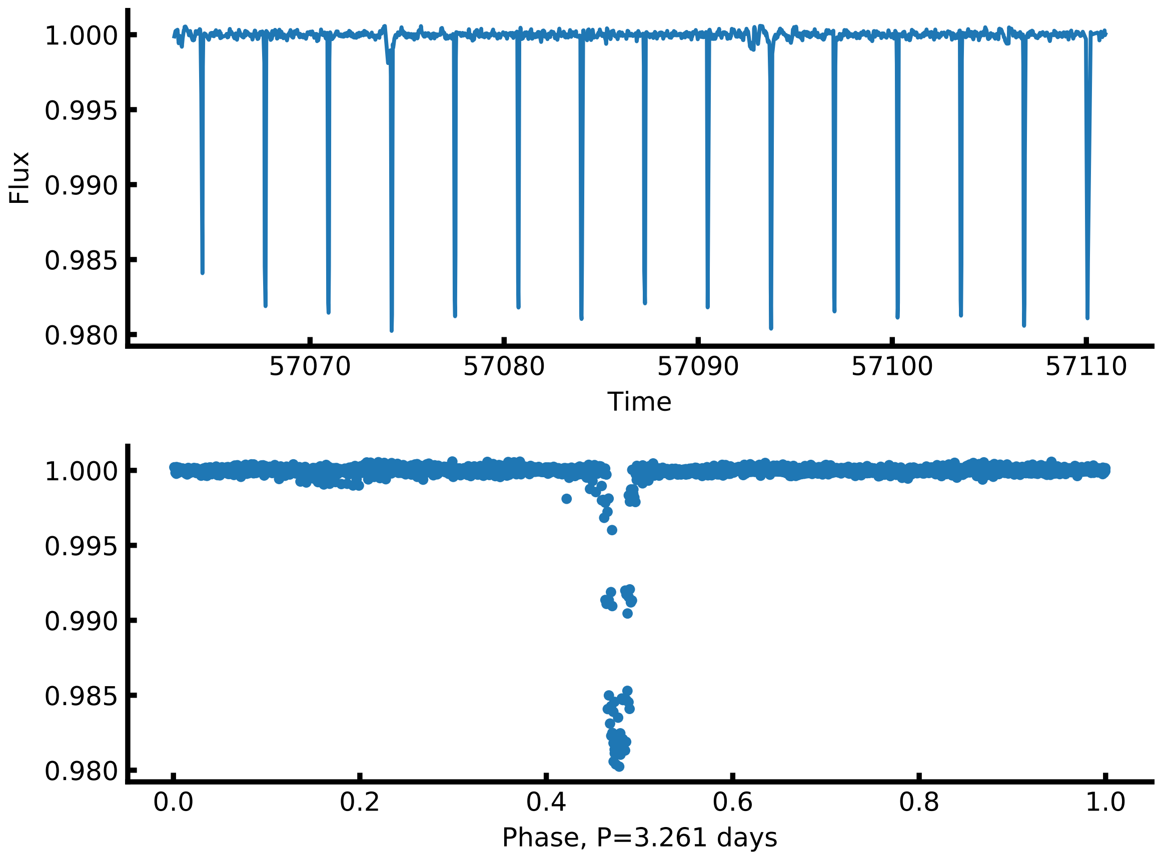

Figure 1.1: *Upper plot*: The lightcurve of a star with an exoplanet transiting. *Lower plot*: The phase curve of the above lightcurve.

As an exoplanet orbit a star, it might transit its host as seen from an observer here on Earth. This signal might be detected if the star's brightness is being monitored as a periodic signal. The decrease in brightness as the planet transit the star is directly related to ration between the stellar radius R_* and the planetary radius R_p:

$$k = \sqrt{\frac{R_p}{R_*}}, \tag{1.1}$$

where k is the depth of the transit compared to the total stellar brightness.

It is possible to obtain the radius of an exoplanet with this method. However, detailed analysis of the phase curve of an exoplanet can reveal the surface temperature of the exoplanet. The transit described above is also known as the primary transit. If it is possible to detect the secondary transit, that is when the exoplanet goes behind the star as seen from Earth, the difference in light (planet + star right before secondary transit compared to just star) gives the flux of the planet and thus the surface temperature. This is a difficult task as secondary transits are intrinsic faint.

1.1.1.2 Radial velocity method

The radial velocity method is the indirect study of the motion of the host star using the Doppler effect caused by an orbiting exoplanet. This together with the transit method described above is by far the most successful methods to detect and characterise exoplanets. The periodic signal created by the exoplanet on the host star depends on the mass ratio between the star M_* and the planet M_p:

$$K = \frac{28.4329\,\mathrm{km/s}}{\sqrt{1-e^2}} \frac{M_p \sin i}{M_{\mathrm{Jup}}} \left(\frac{M_* + M_p}{M_\odot}\right)^{-2/3} \left(\frac{P}{1\,\mathrm{year}}\right) \tag{1.2}$$

where K is the semi-amplitude of the sinusoidal, e is the eccentricity, i is the inclination, P is the orbital period, and M_{Jup} is the mass of Jupiter. Since $M_* \gg M_p$, the term $M_* + M_p \simeq M_*$ in order to simplify the equation. Often a circular orbit is assumed, $e = 0$.

1.1.1.3 Direct imaging

1.1.1.4 Astrometry

1.1.1.5 Transit timing variation

1.1.1.6 Microlensing

1.2 Planet host stars

With the present diversity of exoplanets it becomes increasingly important to get an accurate and precise characterisation of the planets in order to study them in samples and on an individual level. An accurate and precise characterisation can give us an idea whether the planet is rocky, composed of water or gaseous.

1.3 Applications from knowing the stars

1.4 This thesis

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 ± 0.09[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 ± 0.10[a]	0.34 ± 0.05	1.19 ± 0.08	no	UVES	130
HAT-P-46	6421 ± 121	4.53 ± 0.14[a]	0.16 ± 0.09	1.67 ± 0.18	no	UVES	208
HD 120084	4969 ± 40	2.94 ± 0.14[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
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 ± 0.06[a]	-0.08 ± 0.03	1.21 ± 0.05	no	FIES	459
HD 233604	4954 ± 46	2.86 ± 0.11[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 ± 0.09[a]	-0.35 ± 0.03	1.62 ± 0.04	no	FIES	933
HD 81688	4903 ± 21	2.70 ± 0.05[a]	-0.21 ± 0.02	1.54 ± 0.02	no	[b]	1350, 860
HD 82886	5123 ± 18	3.30 ± 0.04[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 ± 0.09[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

Table A.1: continued.

Star	$T_{\rm eff}$ [K]	$\log g$ [cgs]	[Fe /H]	$\xi_{\rm micro}$ [km/s]	$\xi_{\rm micro}$ fixed?	Instrument	S/N
HR 228	5042 ± 42	$3.30 \pm 0.09^{\rm a}$	0.07 ± 0.03	1.14 ± 0.04	no	UVES	400
KELT-6	6246 ± 88	$4.22 \pm 0.09^{\rm a}$	-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	$2.61 \pm 0.26^{\rm a}$	0.25 ± 0.06	1.64 ± 0.11	no	ESPaDOnS	354
ome Ser	4928 ± 35	$2.69 \pm 0.06^{\rm a}$	-0.11 ± 0.03	1.55 ± 0.04	no	FIES	1168
omi UMa	5499 ± 52	$3.36 \pm 0.07^{\rm a}$	-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	$2.26 \pm 0.20^{\rm a}$	-0.04 ± 0.06	1.60 ± 0.11	no	UVES	220
TYC+1422-614-1	4908 ± 41	$2.90 \pm 0.12^{\rm a}$	-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
WASP-61	6265 ± 168	$4.21 \pm 0.21^{\rm a}$	-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	$4.16 \pm 0.06^{\rm a}$	0.20 ± 0.02	1.66 ± 0.04	np	[d]	193,231
WASP-75	6203 ± 46	$4.42 \pm 0.22^{\rm a}$	0.24 ± 0.03	1.45 ± 0.06	no	UVES	189
WASP-76	6347 ± 52	$4.29 \pm 0.08^{\rm a}$	0.36 ± 0.04	1.73 ± 0.06	no	UVES	165
WASP-82	6563 ± 55	$4.29 \pm 0.10^{\rm a}$	0.18 ± 0.04	1.93 ± 0.08	no	UVES	239
WASP-88	6450 ± 61	$4.24 \pm 0.06^{\rm a}$	0.03 ± 0.04	1.79 ± 0.09	no	UVES	174
WASP-94 A	6259 ± 34	$4.34 \pm 0.07^{\rm a}$	0.35 ± 0.03	1.50 ± 0.04	no	UVES	356
WASP-94 B	6137 ± 21	$4.42 \pm 0.05^{\rm a}$	0.33 ± 0.02	1.29 ± 0.03	no	UVES	397
WASP-95	5799 ± 31	$4.29 \pm 0.05^{\rm a}$	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

Table A.1: continued.

Star	T_{eff} [K]	$\log g$ [cgs]	[Fe /H]	ξ_{micro} [km/s]	ξ_{micro} fixed?	Instrument	S/N
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 ± 0.26[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): $T_{\mathrm{eff}} = 4870(4934) \pm 30(29)$, $\log g = 2.50(2.73) \pm 0.14(0.05)$, $[\mathrm{Fe}/\mathrm{H}] = -0.26(-0.19) \pm 0.03(0.02)$, and $\xi_{\mathrm{micro}} = 1.50(1.59) \pm 0.03(0.03)$.

[c] Weighted average of ESPaDoNS and FIES results. The parameters are (FIES in parantheses): $T_{\mathrm{eff}} = 5124(5121) \pm 22(29)$, $\log g = 3.30(3.31) \pm 0.05(0.07)$, $[\mathrm{Fe}/\mathrm{H}] = -0.25(-0.24) \pm 0.02(0.02)$, and $\xi_{\mathrm{micro}} = 1.15(1.17) \pm 0.03(0.04)$.

[d] Weighted average of UVES and FEROS results. The parameters are (FEROS in parantheses): $T_{\mathrm{eff}} = 6313(6162) \pm 61(37)$, $\log g = 4.26(4.14) \pm 0.15(0.06)$, $[\mathrm{Fe}/\mathrm{H}] = 0.22(0.19) \pm 0.04(0.03)$, and $\xi_{\mathrm{micro}} = 1.85(1.61) \pm 0.08(0.04)$.

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