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MODELING AND DETERMINING ORIGINS  
OF SIGNALS FOUND IN RADIAL  
VELOCITY DATA

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## Abstract

Thanks to the current *TESS* space mission, the number of exoplanets with both precise radius and mass measurements is continually growing, providing more promising candidates for the next era in the exoplanet field of atmosphere characterization. A key ingredient is to understand all the signals that appear in the data, to ensure that we obtain the correct planetary parameters. I was involved in developing the `juliet` package, which allows for easy model comparison between models of combined transit and radial velocity datasets. The methodology is based on modern statistical concepts, such as Bayesian statistics, Nested Sampling, and Gaussian Processes, which are presently gaining popularity among the community. Within the CARMENES consortium, I was heavily engaged in demonstrating how to construct the appropriate models and also how to interpret the results. Hence, for this thesis, I present a guideline on how to build an intuition using this code, covering the small nuances and common misconceptions.

I employed `juliet` on a variety of planets/systems: TOI-150 b, one of the most eccentric transiting hot Jupiters known to date whose obliquity can be measured; TOI-163 b, another hot Jupiter with an inflated radius ideal for future atmospheric characterization in the *JWST* continuous viewing zone; TOI-1201 b, currently one of the most optimal transiting mini-Neptunes for atmospheric characterization to aid in determining the origins of these planets; and AD Leo, a case study of a highly-active star that continues to puzzle how stellar activity influences radial velocity measurements as it often masquerades as a planet. These projects showcase the wide application of the code as well as the importance of implementing the correct methodology to contribute well-constrained planetary parameters. To end the thesis, I discuss the need for a better understanding of how stellar activity affects radial velocities to better mitigate the effects, and as well I urge the community to take a standardized approach for modeling in order to avoid misleading interpretations.

## Zusammenfassung

Dank der aktuellen Weltraummission *TESS* wächst die Zahl der Exoplaneten mit präzisen Radius- und Massenmessungen kontinuierlich an und liefert viele weitere vielversprechende Kandidaten für die kommende Ära im Bereich der Atmosphärencharakterisierung von Exoplaneten. Ein wichtiger Bestandteil ist dabei ein tiefgehendes Verständnis aller Signale, die in den Daten auftauchen, um sicherzustellen, dass wir die richtigen Planetenparameter bestimmen. Ich war an der Entwicklung des `juliet`-Pakets beteiligt, das einen einfachen Vergleich zwischen verschiedenen Modellen für kombinierte Transit- und Radialgeschwindigkeitsdatensätze ermöglicht. Die Methodik basiert sich auf modernen statistischen Konzepten wie Bayessche Statistik, Nested Sampling und Gaußschen Prozessen, die alle derzeit in der Fachwelt an Popularität gewinnen. Innerhalb des CARMENES-Konsortiums war ich in diesem Zusammenhang maßgeblich daran beteiligt anderen zu erklären, wie man die entsprechenden Modelle konstruiert und wie man die Ergebnisse interpretiert. Daher präsentiere ich in dieser Arbeit einen Leitfaden der helfen soll eine Intuition für den Code zu bekommen und der all die kleinen Feinheiten und häufigen Missverständnisse abdeckt.

Ich habe `juliet` für die Charakterisierung einer Vielzahl von Planetensystem eingesetzt: TOI-150 b, einer der exzentrischsten transitierenden heißen Jupiter, der bisher bekannt ist und dessen Achsneigung gemessen werden kann; TOI-163 b, ein weiterer heißer Jupiter auf

einer kreisförmigen Umlaufbahn und mit einem aufgeblähten Radius, der ideal ist für die zukünftige atmosphärische Charakterisierung in der CVZ von *JWST*; TOI-1201 b, derzeit einer der am besten zur atmosphärischen Charakterisierung geeigneten transistierenden Mini-Neptune, der dabei helfen kann die Herkunft dieser Planeten weiter zu untersuchen; und AD Leo, eine umfangreiche Fallstudie eines hochaktiven Sterns, die sich mit dem Rätsel beschäftigt, wie stellare Aktivität in den Radialgeschwindigkeitsmessungen Signale planetarischen Ursprungs vortäuschen kann. Diese Projekte zeigen sowohl die breite Anwendung der Software als auch die Wichtigkeit eine korrekte Methodik zu implementieren, um präzise Planetenparameter zu erhalten. Zum Abschluss der Arbeit diskutiere ich die Notwendigkeit eines besseren Verständnisses darüber wie stellare Aktivität Radialgeschwindigkeiten beeinflusst, um so den Einfluss besser korrigieren zu können. Weiterhin fordere ich dazu auf, mehr Fokus auf einen standardisierten Ansatz für die Modellierung zu legen um so irreführende Interpretationen zu vermeiden.

# Contents

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<b>LIST OF FIGURES</b>	5
<b>LIST OF TABLES</b>	7
<b>1 Introduction</b>	<b>9</b>
1.1 Discovering new exoplanet worlds	10
1.2 Transit method	10
1.2.1 Parameters obtained	11
1.2.2 The all-sky <i>TESS</i> survey	13
1.2.3 Follow-up efforts	14
1.3 Radial velocity method	16
1.3.1 Extremely precise RVs	17
1.3.2 Parameters obtained	18
1.3.3 RV complications	18
1.3.4 RV variability due to stellar activity	19
1.3.5 The CARMENES survey	23
1.4 CARMENES- <i>TESS</i> synergy	24
1.5 Exoplanet demographics	26
1.5.1 Host stars	26
1.5.2 Hot Jupiters	26
1.5.3 Super-Earths and mini-Neptune	28
1.6 Thesis overview	29
<b>2 Statistical concepts in the realm of detecting exoplanets</b>	<b>31</b>
2.1 Motivation	31
2.2 Bayesian statistics	31
2.2.1 Bayes' theorem	32
2.2.2 Choosing a prior	35
2.2.3 Model comparison	37
2.3 Nested Sampling	38
2.4 Gaussian processes	40
2.4.1 Why do we need GPs?	41
2.4.2 GPs in a nutshell	41
2.4.3 Kernel choice	43

<b>3</b>	<b>A toolbox for detecting and modeling signals</b>	<b>47</b>
3.1	Motivation . . . . .	47
3.2	Detecting . . . . .	48
3.2.1	GLS periodograms . . . . .	48
3.2.2	Aliasing . . . . .	49
3.3	Modeling with <code>juliet</code> . . . . .	50
3.3.1	What is <code>juliet</code> ? . . . . .	50
3.3.2	Instrumental jitter and offsets . . . . .	51
3.3.3	Parametrizations . . . . .	52
3.3.4	Performing transit-only, RV-only, and joint fits . . . . .	56
3.3.5	Additional applications and case studies . . . . .	59
<b>4</b>	<b>TOI-150 b and TOI-163 b: two transiting hot Jupiters, one eccentric and one inflated, revealed by <i>TESS</i> residing close to the <i>JWST</i> CVZ</b>	<b>63</b>
4.1	Motivation . . . . .	63
4.2	Context . . . . .	64
4.3	Data . . . . .	65
4.3.1	<i>TESS</i> transit photometry . . . . .	65
4.3.2	Transit photometric follow-up . . . . .	66
4.3.3	Spectroscopic follow-up . . . . .	69
4.3.4	Gemini/DSSI speckle images . . . . .	71
4.4	Stellar parameters . . . . .	72
4.5	Analysis and results for TOI-150 and TOI-163 . . . . .	75
4.5.1	Flux contamination possibility . . . . .	77
4.5.2	Instrumental detrending & jitter terms . . . . .	78
4.5.3	Final model parameters . . . . .	79
4.5.4	Signals in the residuals . . . . .	79
4.6	Further analysis . . . . .	82
4.6.1	Stellar density prior . . . . .	82
4.6.2	Search for secondary eclipses . . . . .	82
4.7	Discussion . . . . .	82
4.7.1	The two systems . . . . .	82
4.7.2	Eccentricity of TOI-150 b . . . . .	84
4.7.3	Secondary eclipses, transmission spectroscopy, and RM effect . . . . .	85
4.8	Summary and conclusions . . . . .	87
4.9	RV data . . . . .	87
<b>5</b>	<b>TOI-1201 b: a mini-Neptune transiting a bright and relatively young M dwarf</b>	<b>91</b>
5.1	Motivation . . . . .	91
5.2	Context . . . . .	91
5.3	<i>TESS</i> photometry . . . . .	93
5.4	Ground-based observations . . . . .	95
5.4.1	Follow-up seeing-limited transit photometry . . . . .	95
5.4.2	Long-term photometric monitoring . . . . .	96
5.4.3	High resolution spectroscopy with CARMENES . . . . .	96



5.5	Stellar properties . . . . .	97
5.5.1	Basic astrophysical parameters . . . . .	97
5.5.2	The stellar host and its companion . . . . .	97
5.5.3	Rotation period . . . . .	99
5.6	Analysis and results . . . . .	104
5.6.1	Transit-only modeling . . . . .	104
5.6.2	RV-only modeling . . . . .	105
5.6.3	Joint modeling . . . . .	109
5.6.4	Radial velocities of the companion . . . . .	110
5.7	Discussion and future prospects . . . . .	114
5.8	Conclusions . . . . .	118
5.9	Appendix . . . . .	118
5.9.1	Two-planet model . . . . .	118
5.9.2	Additional figures . . . . .	119
5.9.3	Priors and posteriors . . . . .	119
<b>6</b>	<b>AD Leonis: stable radial-velocity variations at the stellar rotation period</b>	<b>129</b>
6.1	Motivation . . . . .	129
6.2	Context . . . . .	130
6.3	AD Leo . . . . .	131
6.3.1	Stellar parameters . . . . .	131
6.3.2	Photometry . . . . .	134
6.3.3	Hypothetical binary . . . . .	134
6.4	Spectroscopic data . . . . .	135
6.4.1	CARMENES . . . . .	138
6.4.2	HARPS-South . . . . .	138
6.4.3	HIRES . . . . .	138
6.4.4	Additional data from the literature . . . . .	139
6.5	Analysis and results . . . . .	140
6.5.1	Stellar binarity . . . . .	140
6.5.2	Aliasing in HIRES data . . . . .	141
6.5.3	Spectroscopic variability . . . . .	142
6.5.4	Wavelength dependence of RV signal . . . . .	142
6.5.5	Other activity indicators . . . . .	144
6.5.6	Time dependence of the RV signal . . . . .	144
6.5.7	Spectral lines affected by stellar activity . . . . .	147
6.6	Discussion and future studies . . . . .	152
6.7	Conclusions . . . . .	153
6.8	Appendix . . . . .	154
6.8.1	RV data . . . . .	154
6.8.2	Stellar activity . . . . .	154
<b>7</b>	<b>Conclusions and future outlook</b>	<b>161</b>
7.1	Summary . . . . .	161
7.1.1	Promising targets for follow-up studies . . . . .	161
7.1.2	Investigating stellar activity in RV data . . . . .	163

*Contents*

7.2	Future outlook . . . . .	164
7.2.1	Homogeneous studies . . . . .	164
7.2.2	Understanding stellar activity in RVs . . . . .	164
	<b>Bibliography</b>	<b>169</b>
	<b>Acknowledgements</b>	<b>189</b>

## List of Figures

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1.1	Schematic of idealized transit light curve . . . . .	12
1.2	Sky coverage map of the transiting <i>TESS</i> mission and bandpass coverage comparing <i>TESS</i> and <i>K2</i> . . . . .	14
1.3	Schematic of the radial velocity method, showcasing the stellar and planetary body gravitational influence on each other. . . . .	16
1.4	Schematic demonstrating the degeneracy of planetary mass and inclination for the RV method . . . . .	20
1.5	Schematic of a cool spot co-rotating on the stellar surface . . . . .	21
1.6	Exoplanet demographic plot of planetary mass versus orbital period . . . . .	27
2.1	Distribution of the number of published articles with the word “Bayes” included from 2005-2020. . . . .	32
3.1	Theoretical light curves for three impact parameters $b$ and with varying limb-darkening effects. . . . .	53
3.2	Phase-folded transits and LDC posterior distributions for TOI-1201 b when the LDCs are not shared . . . . .	54
3.3	Posterior distributions of eccentricity from transit-only, RV-only and joint fits	60
3.4	Posterior distributions of $P$ and $t_0$ from transit- and RV-only runs for TOI-1201 b . . . . .	61
4.1	All transit data and phase-folded transits for TOI-150 b . . . . .	67
4.2	All transit data and phase-folded transits for TOI-163 b . . . . .	68
4.3	BIS-RV correlation plots for TOI-150 b and TOI-163 b . . . . .	70
4.4	RV time series and phase-folded RVs for TOI-150 b . . . . .	71
4.5	RV time series and phase-folded RVs for TOI-163 b . . . . .	71
4.6	Speckle images for TOI-163 . . . . .	72
4.7	Planetary radius versus planetary equilibrium temperature and versus planetary mass for known hot Jupiters . . . . .	83
4.8	Orbital eccentricities as a function of planetary orbital period for known hot Jupiters . . . . .	83
4.9	Distributions of the FOM for both transmission spectroscopy and secondary eclipses for known transiting hot Jupiters . . . . .	86
5.1	<i>TESS</i> TPF plot for TOI-1201 for sectors 4 and 31. . . . .	94

List of Figures

5.2	Posterior probability density for the estimated stellar rotation period for TOI-1201 . . . . .	102
5.3	GLS periodograms of the various stellar activity indicators from the CARMENES spectroscopic data for TOI-1201. . . . .	103
5.4	GLS periodograms of the RV residuals after subtracting different models for TOI-1201. . . . .	109
5.5	All transit data and phase-folded transits for TOI-1201 b . . . . .	111
5.6	RV time series and phase-folded RVs for TOI-1201 b . . . . .	112
5.7	Transmission spectroscopy metric (TSM) as a function of J magnitude for currently known transiting exoplanets around M dwarfs with a measured mass. . . . .	116
5.8	Mass-radius diagram for currently known transiting exoplanets around M dwarfs with a measured mass. . . . .	117
5.9	Phase-folded <i>TESS</i> light curve exhibiting the stellar rotation period for TOI-1201 . . . . .	120
5.10	GLS periodograms of the RVs and various stellar activity indicators from the CARMENES spectroscopic data for the companion of TOI-1201 . . . . .	121
5.11	RV-only posterior distributions of the minimum mass of TOI-1201 b as a function of model choice . . . . .	124
5.12	Posterior distributions for the transiting planet TOI-1201 b . . . . .	125
5.13	Posterior distributions for the dSHO-GP on the CARMENES RVs . . . . .	126
5.14	Posterior distributions for the long-term signal . . . . .	127
6.1	Time series of all available RV data for AD Leo . . . . .	136
6.2	GLS periodograms of the CARMENES VIS, CARMENES NIR, and combined RV datasets for AD Leo . . . . .	137
6.3	RV time series of CARMENES VIS and CARMENES NIR for AD Leo . . . . .	139
6.4	S-BGLS periodograms for HIRES RV data for AD Leo . . . . .	141
6.5	RV-CRX correlation plots for HARPS-S, CARMENES VIS, and CARMENES NIR for AD Leo . . . . .	143
6.6	RV semi-amplitudes as a function of wavelength for the wavelength chunks from HARPS and the CARMENES VIS and NIR spectographs for AD Leo . . . . .	143
6.7	Phase-folded RVs for the optical and near-infrared RV instruments for AD Leo . . . . .	148
6.8	Spectral line analysis for AD Leo . . . . .	149
6.9	GLS periodograms of the stellar activity indicators for AD Leo . . . . .	154
6.10	BIS-RV correlation plots for AD Leo . . . . .	159
6.11	Correlation plots as in Tal-Or et al. (2018) for AD Leo . . . . .	160