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# IMPACT OF STELLAR ACTIVITY ON THE DETERMINATION OF STELLAR PARAMETERS WITH INTERFEROMETRY

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**Abstract.**
With the new space missions dedicated to exoplanet detection and characterization, like PLATO, CHEOPS, TESS, the determination of stellar parameters with high accuracy becomes more and more essential. However, direct or indirect estimations of stellar parameters are affected by stellar activity (magnetic spots, bright plages, granulation) that introduces bias that lower those parameters accuracy. Improving the sensitivity and resolution of future interferometers will allow enlarging the number of common targets of space and ground instruments, and accessing the accuracy needed to distinguish between planetary signals and stellar activity signals. After presenting how visible interferometry contributes to the direct and accurate determination of stellar parameters and thus planetary ones, the impact of stellar activity on interferometric observables and stellar parameters will be presented. Finally, solutions to distinguish between exoplanet and spot signals will be discussed.

Keywords: Stellar physics, exoplanets, stellar activity, interferometry

## 1 Introduction

Our knowledge of stars hosting exoplanets constitutes the basics of our comprehension of extra-solar systems. Particularly, the accurate determination of stellar radius allows a direct determination of planetary ones when exoplanets transit their star, which gives access to many other planetary parameters, like their density or composition provided radial velocity measurements or orbital parameters are also available. Figure 1 (Fressin et al. 2012, Fig. 3) shows the expected composition of transiting exoplanets, which cannot be precisely determined because of the large error bar on their radius and mass. It is even more true for planets different from that found in our solar system, whose composition is not determined (e.g., the super-Earth HD97658 b (Howard et al. 2011) and the sub-Neptune GJ1214 b (Valencia et al. 2013)). However, for most exoplanets, the host star radius is determined through totally model-dependent methods, and their values can differ according to the models used.

Radial velocity (RV) and transit measurements are the most prolific methods in exoplanet discovery. They respectively provide the ratio of the minimum mass of exoplanet to the stellar mass ($M_{\rm p}\sin(i)/M_\star$) and the ratio of the exoplanet and stellar radii ($R_{\rm p}/R_\star$). Those ratios are generally known to better than 1% precision. Therefore, to obtain the planetary radius and mass with such an accuracy, we need to reach this accuracy on the stellar radius and mass. Beyond the difficulty to reach such precision and exactitude with stellar models, stellar activity (magnetic spots, bright plages, granulation) adds noise on RV and transit measurements, but also on direct measurements of stellar parameters, that can in turn add a bias in derived stellar and planetary parameters. With the development of the sensitivity of interferometers, it will become possible to detect weaker signals from the stars including signals of stellar activity. Then, it will be necessary to relate each signal to its physical origin to distinguish between activity and exoplanet signals, which will enable the characterization of both phenomena. In particular, we will have to tackle signals containing the signature of stellar activity and will have to extract them in order to make exact and accurate estimation of stellar and planetary parameters.

In Section 2 we describe how space mission and ground-based instruments together can lead to a better characterization of stars and exoplanets and in Section 3 we show how this characterization can be impacted by stellar activity.

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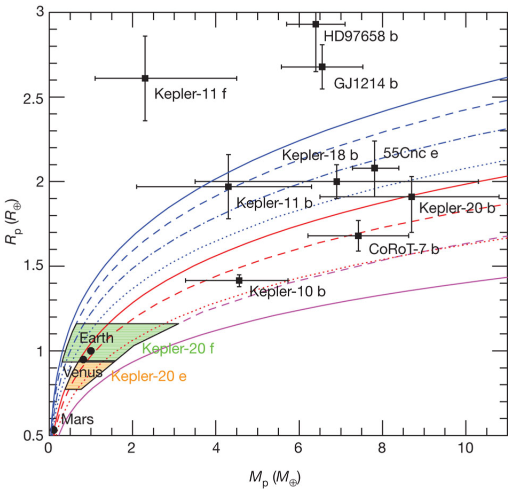

**Fig. 1.** Mass versus radius relation for small planets (Fig. 3, Fressin et al. 2012). The curves represent theoretical constant-temperature mass-radius relation : water ice (solid blue), MgSiO3 perovskite (solid red), iron (solid magenta). The non-solid lines are mass radius relations for differentiated planets (see Fressin et al. 2012, for details).

## 2 Determining accurate stellar parameters with combined methods

The next decade will be marked by the development of space missions whose goal is both the characterization of stars and exoplanets. For instance, PLATO mission (Rauer & Catala 2012) has been selected by ESA and should be launched in 2024. The goal of this mission is to detect and characterize exoplanets in the solar neighbourhood thanks to the transit method and to measure stellar seismic activity to precisely determine their age together. The goal of CHEOPS mission (Broeg et al. 2013) is to characterize Earth-sized to Neptune-sized planets with very high precision photometry, whereas TESS mission (Ricker et al. 2010) will discover planetary transits.

However, the scientific exploitation of these missions will be greatly reinforced with independent measurements achieved from the ground. Indeed :

- the transit method allows obtaining the planetary radius if the stellar radius is known. Currently, the ratio between the planetary and stellar radii provided by photometry is more precise than the measurement of stellar radii by a factor 10 ;

- moreover, seismic data together with a direct measurement of the stellar radius bring a better accuracy on ages ($< 10\%$, see e.g. Lebreton & Goupil 2014) and stellar masses ($< 3\%$, see e.g. Creevey et al. 2007). Indeed, the determination of global stellar parameters can be derived from asteroseismology but uncertainties and the difficulties in identifying the modes of oscillation, particularly in classical pulsators, remain. The interferometric radius decreases these uncertainties and help constraining the models used in asteroseismic studies (Cunha et al. 2007).

The stellar radius takes part in the determination of many other parameters through stellar modelisation. All of this highlights the necessity of its very precise and direct determination. This actually applies to every stellar parameters together. Indeed, we need an accurate knowledge of host stars, in particular their age, to get a clear vision of the story of star-planet systems. Contrary to previous missions CoRoT and *Kepler*, which discovered exoplanets around very faint stars, and whose parameters are thus very difficult to constrain with ground instruments, the targets of these missions will be bright stars, which means accessible with interferometry. It will therefore be possible to accurately determine their radius and thus planetary radii and masses. Indeed, interferometry allows the direct determination of angular diameters with a precision better than 2% (and sometimes 1%) (see e.g. Ligi et al. 2012). Combined with the distance, we obtain a direct estimation of the radius, which means as independent of models as possible, and exact. Currently, the accuracy on the distance significantly limits the accuracy on stellar radii but Gaia will soon provide (mid 2016) distances with an accuracy better than 2%, that will allow reaching an accuracy better than 2% on stellar radii.

## 3 Tackling stellar activity

At the same time, the study of stellar activity (dark spots, bright plages, granulation) is becoming increasingly important in this context. Beyond the fact that it helps understanding stellar structure and evolution, it is of primordial importance in the quest for exoplanets, for three main reasons: (i) it can allow the improvement of the signal/noise ratio and the detection of smaller, terrestrial-like planets for both RV and transit techniques, (ii) it permits the achievement of a better knowledge of the fundamental parameters of the star (radius, age etc.), which has a significant impact on the characterization of the detected planets, (iii) it has an impact on habitability studies because stellar activity is a crucial parameter for the evolution of a planet atmosphere and climate. Stellar activity is known to add a jitter in RV measurements (Lagrange et al. 2010; Meunier et al. 2010; Oshagh et al. 2013) that can mimic exoplanetary signatures and also impacts interferometric observables (Chiavassa et al. 2012, 2014). Some attempts have been made to detect this signature on infrared interferometry (Matter et al. 2010; Zhao et al. 2008, 2011), but never in visible wavelengths.

The code `COMETS` (*COde for Modeling ExoplaneTs and Spots*, Ligi et al. 2014) aims at studying the impact of exoplanets and magnetic spots on interferometric observables (squared visibilities, phases) and allows comparing the results with current available facilities like VEGA/CHARA (Mourard et al. 2009; Ligi et al. 2013) considering realistic achievable precisions.

In this paper, Ligi et al. (2014) present a pionier work exploring the influence of the parameter space (exoplanet position, exoplanet diameter, spot temperature and star diameter) on the minimum baseline length (MBL) required to detect the transiting exoplanet signal on the squared visibility and the phase. The variation of the MBL as a function of the parameters is similar in the presence of an exoplanet or of a spot. However, the spot's temperature causes a contrast with the photosphere which is different from the contrast caused by a transiting exoplanet, which enables to distinguish between the two. The MBL as a function of the parameters can be fitted by an analytical law from which a general formula is derived.

Figure 2 shows the phases corresponding to different configurations : a single star, a star with a transiting exoplanet of various diameters and/or a spot. The star with a spot and/or an exoplanet has a different signal from that of a single star. When the spot and the exoplanet have the same size (left panel), the exoplanet signal (in red) is generally higher than the spot one (in orange) from the $3^{rd}$ lobe of visibility, but it is mixed up with the spot signal until the $2^{nd}$ lobe. When the exoplanet is smaller (right panel), its signal is lower than the signal of the spot, even if its contrast with the stellar photosphere is higher. This shows the difficulty to disentangle between spot and exoplanet. In this latter case, the signal induced by both spot and exoplanet in the $2^{nd}$ lobe is hardly higher than the signal induced by the spot alone. The exoplanet signal is thus hard to extract, unless measurements from the $4^{th}$ lobe are possible. On the contrary, when $\theta_s = \theta_p$, the signal provoked by both spot and exoplanet is higher by a few degrees than the signal of the spot alone, and reaches a few degrees from the $2^{nd}$ lobe that should be detectable with existing baselines. For both cases, not taking into account the spot leads here to a bad interpretation of the signal, like a bigger transiting planet, and highlights the necessity of observing the star out of the transit to characterize the stellar activity, that could be substracted from the signal recorded during the transit time to allow the characterization of the exoplanet.

According to these simulations, existing baseline lengths are sufficient to detect the signal of a transiting Jupiter or a small spot, but instruments need to reach accuracies better than 0.5% on squared visibilities and $1^\circ$ on phases to achieve this goal, which is beyond current instrument accuracies. Measurements in the second lobe of visibility is essential because exoplanet signals can only be seen at these spatial frequencies. Then, phase measurements would allow the characterization of exoplanets more easily, provided that the signal to noise ratio is sufficient to measure this second order observable. Exoplanets and spots do not have the same interferometric signatures, but their signals are mixed up during the transit (see Fig 2). Combining photometric or velocimetric measurements with interferometric ones could be a solution to distinguish between both signals. We have shown that this is possible if the planet crosses the star in few hours/days, provided that the transit time is sufficient to get a detectable signal on interferometric observables. Conversely, observing out of the transit directly provides information about stellar activity.

Other effects should not be forgotten, like the granulation, as shown by Chiavassa et al. (2014) who use realistic three-dimensional radiative hydrodynamical simulations obtained with the Stagger-Grid (Magic et al. 2013) to study its impact on interferometric observables. The granulation perturbs closure phase measurements in particular from the second lobe of visibility, depending on the spectral type, the interferometric instrument used and the wavelength probed. Its signal can also be mixed with a transiting exoplanet signal but they could be differenciated at specific wavelengths (optical or infrared).

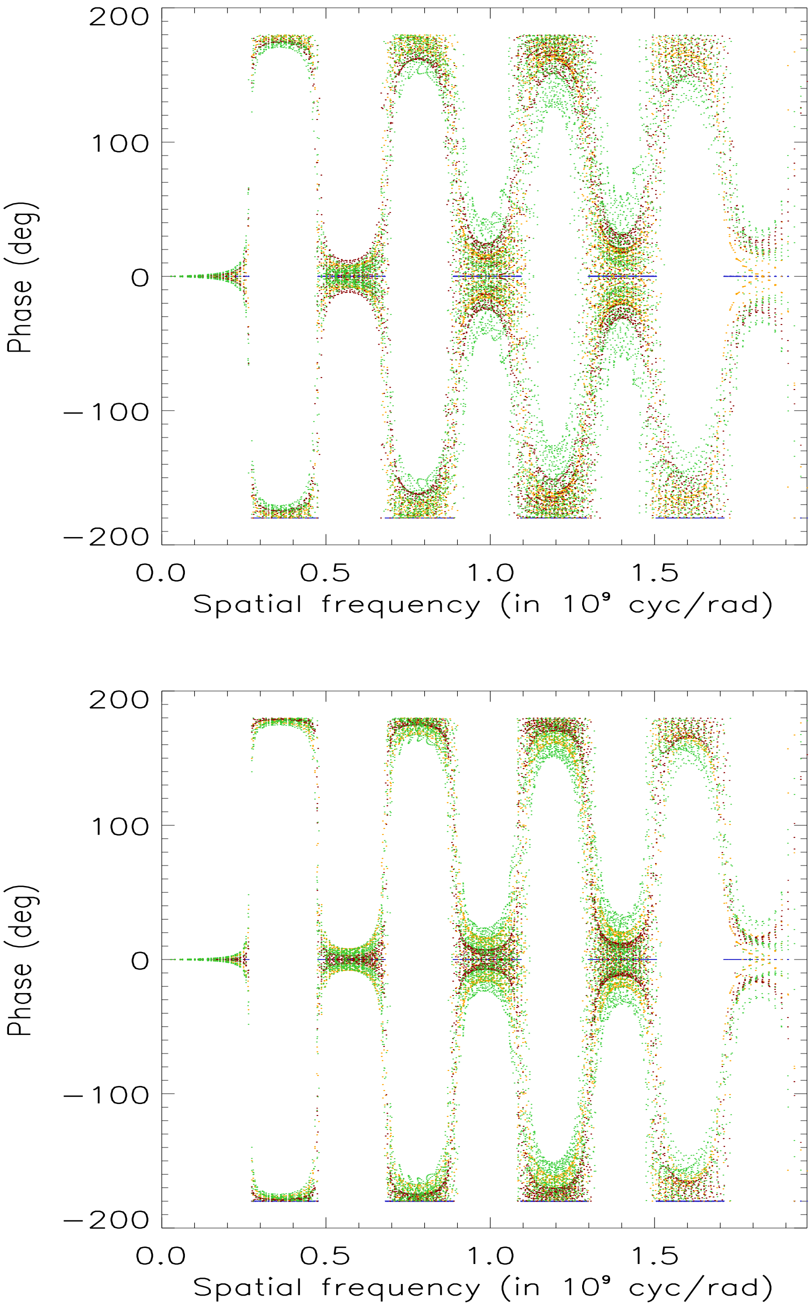

**Fig. 2.** Phases of a single star (blue), a star with a spot (orange) at (0.2, 0.2) mas, a star with a transiting exoplanet (red) at (0.2, 0.0) mas on the stellar disk and a star with both (green). The spots diameter is $\theta_s = 0.10$ mas and the stars diameter is 1 mas. The exoplanets diameter is either $\theta_p = 0.10$ mas (upper panel) or $\theta_p = 0.05$ mas (bottom panel).

## 4 Conclusion

The synergy between star and planet studies will be greatly developed in the next years which should lead to a better knowledge of exoplanets but also of stellar systems in general. The combination of measurements from space and ground based instruments will provide a better characterization of stellar radii, masses and ages, and thus allow the determination of exoplanet composition and age with unprecendented precision. Interferometry is essential to determine stellar parameters, but it will also be able to tackle stellar activity if instrument sensitivities are developed enough. This is essential to extract exoplanet signals and eliminate false positives. Then, the questions of habitability of exoplanets can be addressed with a better knowledge and efficiency.

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