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Modeling transiting exoplanet and spots For interferometric study

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Abstract. Up to now, many techniques have been developed to detect and observe exoplanets, the radial velocity (RV) method being the most prolific one. However, stellar magnetic spots can mimic an exoplanet transit signal and lead to a false detection. A few models have already been developed to constrain the different signature of exoplanets and spots, but they only concern RV measurements or photometry. An interferometric approach, with high angular resolution capabilities, could resolve this problem.

Optical interferometry is a powerful method to measure accurate stellar diameters, and derive fundamental parameters of stars and exoplanets minimum masses. We have built an analytical code able to calculate visibility moduli and closure phases of stars with a transiting exoplanet, to be compared with a star with no exoplanet. From the difference of interferometric signal, we can derive the presence of the exoplanet, but this requires that the star is resolved enough. We have tested this code with current available facilities like VEGA/CHARA and determined which already discovered exoplanets systems can be resolved enough to test this method.

To make a more general study, we also tested different parameters (exoplanet and stellar diameters, exoplanet position) that can lead to a variation of the minimum baseline length required to see the exoplanet signal on the visibility modulus and the phase. Stellar spots act in the same way, but the difference of local intensity between an exoplanet transit and a spot can easily be studied thanks to the interferometric measurements.

Keywords. Exoplanets, magnetic spots, optical interferometry

1. Introduction

The detection and characterization of exoplanets has been one of the fastest developing fields in Astrophysics since the discovery of the first exoplanet by Mayor & Queloz (1995). However, this detection can be disturbed by stellar activity. Magnetic spots and bright plages can mimic an exoplanetary signals, leading to a false detection.

For example, Lagrange *et al.* (2010) have studied the impact of magnetic spots on RV measurements of a Solar-like star to verify if an Earth-like planet located on the habitable zone could be detected. They found that a good temporal sampling is necessary to remove the spots' signatures from RV measurements as they can be of higher ampltitude than the exoplanet's one. Meunier *et al.* (2010) made an equivalent study but on bright plages and found that it does not affect the exoplanets detection.

Understanding stellar activity is not only important for exoplanets search, but also because it gives information about stellar structure and evolution, without forgetting that the study of exoplanets, spots and stars are complementary. We could cite for example Sanchis-Ojeda *et al.* (2012)'s work, who used magnetic spots to derive the equatorial alignement of Kepler−30's three exoplanets. Contrary to them, Silva-Valio & Lanza (2012) used the planetary transit of Corot−2a to study spots at the surface of its host star.

Most of previous interferometric studies on exoplanets have been performed in the infrared domain. For instance, Matter *et al.* (2010) made an attempt to detect the signal of Gliese 86b using MIDI/VLTI and AMBER/VLTI, but a lack of precision prevented us to measure it. Zhao *et al.* (2008, 2011) have simulated the effects of exoplanets on closure phases using MIRC/CHARA. Again, instrumental issues prevented us to succeed. Some attempts with MIRC/CHARA have also been made to do direct imaging of spots (e.g., Monnier *et al.* 2012 ; Baron *et al.* 2012).

Most limitations in this field are then the angular resolution and instrumental limitations. Optial interferometry can be a solution. Direct imaging with big telescopes or infrared interferometry is resolving enough to separate planet and star but not to characterize the star. Optical interferometry has a much better angular resolution since the wavelength is smaller than in IR. As photometry and spectroscopy are operating in the optical domain, optical interferometry would also be a complementary method.

We propose to probe the capabilities of an optical interferometer, VEGA/CHARA, to measure the signal of an exoplanet and a magnetic spot. We also present a more general study using a fictive interferometer. For this, we have built a numerical code called `COMETS` (*COde for Modeling ExoplaneTs and Spots*) using analytical formulae allowing to model a dark transiting exoplanet (modelled as a dark disk) and/or a magnetic spot (umbra and penumbra modelled as a dark disk and a dark ring respectively). Thus we can measure the interferometric observables (visibility, phase and closure phase) for the different cases.

2. VEGA/CHARA capabilities

2.1. *VEGA/CHARA*

VEGA (Mourard *et al.* 2009) is a Visible spEctoGrAph and interferometer located at Mount Wilson, California. It uses the CHARA array's telecopes, which longest separation between one pair reaches 331 m. The six 1 meter-telescopes arranged in a Y-shape allows a good repartition of baselines and thus a good u,v coverage. VEGA operates at high (30000) or medium (6000) resolution in the wavelength range 450 − 850 nm. It has a maximum angular resolution of 0.3 milliarcseconds (mas), which gives the opportunity to resolve a large number of targets. Particularly, we have observed ten stars hosting planets, which are part of a catalog of 42 exoplanet hosts stars, measured their angular diameters with a precision of $\sim 2.4\%$ and derived their parameters (mass, effective temperature) (Ligi *et al.* 2014, in prep.). Reaching the first zero of the visibility function is the first step to measure stellar activity in interferometry. Figure 1 shows the squared visibility curve of HD190360, which hosts two exoplanets and is part of our catalog. We can see that the measurements reach the first zero of visibility, thus we could constrain its limb-darkened diameters : 0.78 ± 0.01 mas.

2.2. *Exoplanet and spot signatures*

`COMETS` simulates a transiting exoplanet as a dark disk of intensity 0, whereas spots are considered hotter ($\sim 500 - 1000$K colder than the star's photosphere) and are thus represented by an umbra (a dark disk) and a penumbra (a ring sourrounding the umbra) of intensity proportional to their temperature. Using CHARA baselines and VEGA specificities, the code measures the corresponding observables. Taking an ideal case, i.e.

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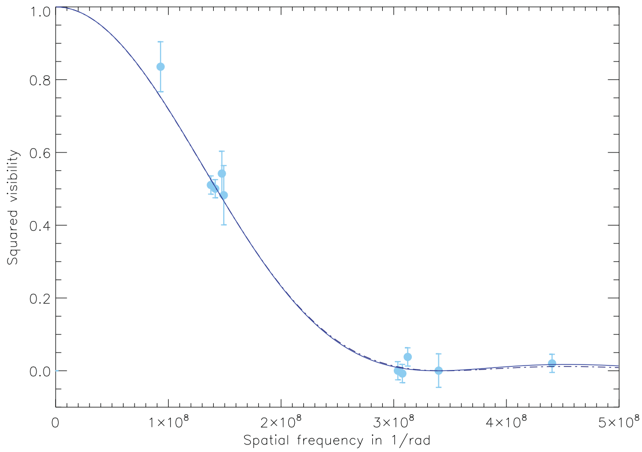

Figure 1. Squared visibility of HD190360 obtained with VEGA/CHARA. The points represent the data and the solid and dotted-dashed lines represent the uniform disk and the limb-darkened disk model respectively (Ligi *et al.* 2014, in prep.).

a star of 1 mas of angular diameter, so it is well resolved by VEGA, we measured the corresponding interferometric observables with one of the two features. Even with a very small exoplanet or spot (e.g., $\sim$ 0.015 mas), a weak signal is seen on the closure phase but not on the visibility curve. However, with an exoplanet or spot ten times bigger, the signal can be observed on both observables. Thus, we calculated the minimum baseline length required to measure such signals. CHARA baselines are sufficient as long as the exoplanet is bigger than 0.09 and 0.13 mas, which provoques a signal of 1% or 2% on the visibilities respectively. Closure phases measurements allow to detect smaller exoplanets with a minimum signal of 2°. Resolving the star is of course the first condition to measure the signal of an extra feature, but the closure phase measurement is also an important condition. Unfortunately, VEGA cannot measure closure phases yet. We see that the limiting factor is also the accuracy of the measurements.

3. Disentangling between exoplanets and magnetic spots

Both exoplanet and spot have a signature on interferometric observables, which differs because of their different shapes. To disentangle between an exoplanet and a spot signature, we have plotted the Airy function in the u,v plane of a star with a transiting exoplanet and a spot (Figure 2). We can see that the Airy figure is disturbed by the presence of a spot and we can notice two important points. Firstly, the first lobe of visibility is a quite perfect disk, which means that the visibility is not perturbed by the presence of an exoplanet or a spot. Thus, one has to measure beyond the first lobe to measure the signature of an the exoplanet or spot. Secondly, the source is not well resolved beyong the first lobe (the visibility does not reach the zero value), and this phenomenon is emphasized by the presence of the spot.

With a fictive interferometer, we cannot measure closure phases but phases only (as triplets of telescopes cannot be defined anymore). However, phases react the same. When the system is not resolved, the signal on the phase is maximum. Spots and exoplanets also induce different variations of the phase, which also help desentangling between both.

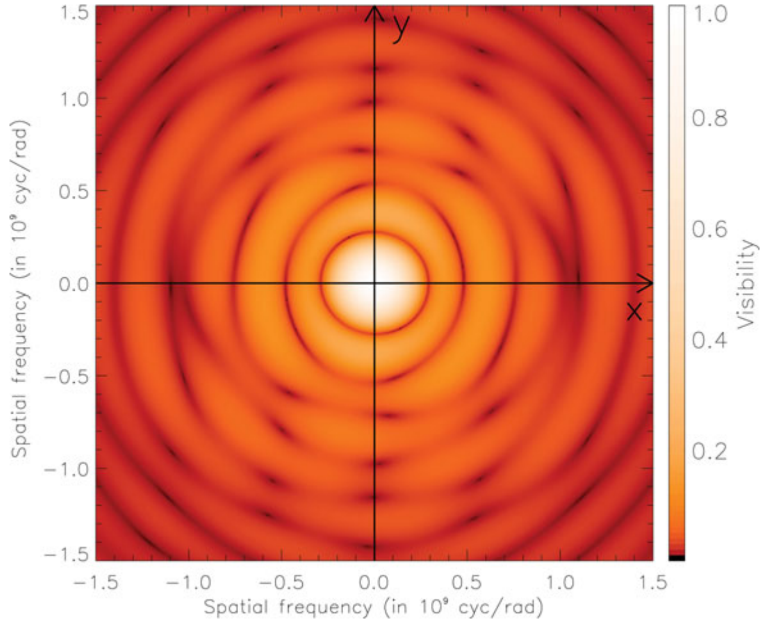

Figure 2. Airy figure of a 1 mas star with a 0.15 mas transiting exoplanet and a 0.15 mas magnetic spot (Ligi *et al.* 2013, in prep.).

4. Conclusion

Transiting exoplanets and magnetic spots have a signature in optical interferometry. Even if they are not measurable with VEGA/CHARA yet, it will be possible soon. VEGAS, *VEGA Second generation*, will measure closure phases and will be be equiped with adaptative optics. It will also be able to observe brighter objects with a better SNR. All this combined will allow to measure exoplanets and spots signatures.

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