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Influence of stellar variability on the determination of the radius during a transit of an exoplanet

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Abstract. Stellar variability can affect the estimate of an exoplanet radius measured during a transit. We developed a transit light curve model which includes stellar spots. It appears that, if spectro-photometric technique is used, spots and faculae have to be considered to conclude on atmospheric detection and characterization. When using a model including spots, characterization of Hot-Jupiter atmosphere around active stars is possible with this technique, provided a signal to noise ratio up to 10^5. For Earth-size planets a long-term parallel photometric follow up monitoring the stellar activity is required to compensate the error due to the stellar variability.

1. MODELLING THE STELLAR ACTIVITY

Spectro-photometry is widely used to search for exoplanet atmospheric signature because it is much more sensitive than spectroscopy [1]. However, stellar activity can introduce bias. Spots and faculae in the surface of the stars modulate rotates with it. This rotation changes the visibility of the spots and faculae and therefore can change the luminosity of the star. To modulate this effect we define a parameter f_λ as follow:

$$f_\lambda \equiv \frac{F_*(\lambda) - F_{quiet}(\lambda)}{F_{quiet}(\lambda)} \tag{1}$$

Where F_* is the observed flux of the star and F_{quiet} is the reference flux of the star, taken when the star have no spots neither faculae. We calculated the spectral dependence of this parameter assuming that the stellar variability is due to the rotation of spots 1000 K cooler than the photosphere. The spots and the photosphere are assumed to be blackbodies:

$$f_\lambda = \left(\frac{R_{spot}}{R_*}\right)^2 \left(1 - \frac{I_\lambda\left(T_{spot}\right)}{I_\lambda\left(T_*\right)}\right) \tag{2}$$

R_{spot} is the radius of the spot and I_λ the specific intensity of the blackbody. For a starspot covering 2% of the stellar surface, f_λ varies from 1.5% in the visible to 0.5% in the infrared.

2. HOW DOES IT INFLUENCE THE DETERMINATION OF THE RADIUS RATIO?

When a planet transits an active star, it can occult a part of the star of different brightness than its average brightness. Then the observed flux during the transit must be written:

$$F_{obs} = F_0\left(1 + f_\lambda\right) - F_0\left(\frac{R_p}{R_*}\right)^2 \tag{3}$$

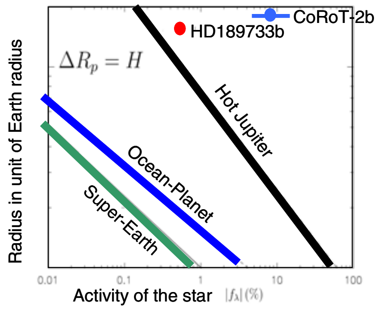

Figure 1. If a planet is on the right of the separation line, stellar activity affects the atmospheric characterization.

If we estimate the radius ratio from the conventional formula $F_{obs} = F_0 - F_0(R_p/R_*)^2$ we make an error in the estimation of the radius of :

$$\frac{\Delta\left(R_p/R_*\right)}{\left(R_p/R_*\right)} \approx -\frac{f_\lambda}{2} \tag{4}$$

If the error on the estimate of the radius is bigger than one scale height of the atmosphere of the planet, it can leave on qualitative errors on the determination of the atmosphere composition. Figure 1 show a graph where, knowing the radius of the planet and the mean activity of the star, one can see if stellar activity must be corrected for the study of the atmosphere.

3. HOW CAN WE CORRECT THESE EFFECTS?

We found two methods for correcting these biases:

During the partial phases of the transit, there is a signature of the presence of spots on the stellar surface. Then one can fit the light curve with a model based on equation (3) and determine the filling factor fl and the true radius ratio. Unfortunately, the signature is very faint and one needs a signal to noise ratio up to 10^5 for Hot-Jupiter and 10^7 for Super-Earth to make it detectable.

The second method is to be used when such a big signal to noise ratio can't be obtained. Then, one needs to use a photometric follow up of the star to determine the parameter f_λ (see equation (1)) and correct the biases using equation (4). There will be remaining errors because the reference flux F_{quiet} can't be measured. If stellar spots and not faculae cause the main variability of the stellar photometry, the maximum observed flux should be used as the reference. We used this method to correct observations of HD189733b made with Spitzer [2, 3].

References

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