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A new look at the Spitzer primary transit observations of the exoplanet HD189733b

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Abstract

New blind source separation techniques are used to analyse uniformly eight primary transit lightcurves of the exoplanet HD189733b recorded with the infrared camera IRAC on board the Spitzer Space Telescope at $3.6\mu m$. The observations were performed between 2006 and 2011: two of them were obtained in the"Cold Spitzer" regime, the others were taken in the "Warm Spitzer" period.

The techniques we used to process the data are based on an Independent Component Analysis (ICA) approach, i.e. a computational method to disentangle the 'original source signals' from a set of observations/recordings in which they are mixed. ICA assumes only the mutual statistical independence and the non-gaussianity of the source signals. Our objective was to extract the transit components by removing instrumental systematic effects and possibly other sources of astrophysical noise, such as background and stellar activity. The novelty of the algorithms used is their ability to extract the exoplanet signal in a single observation.

In this presentation we will present the results obtained, detail the methods adopted and critically discuss the conclusions of our work by comparing said results to the ones obtained in the literature.

1. Introduction

Exoplanetary transit lightcurves contain a great deal of information about the transiting planets: i.e. the orbital period (P), the ratio between the planet's and star's radii ($p = r_p/R_s$), the orbital inclination (i), the ratio between the orbital semimajor axis and the star's radius ($a_0 = a/R_s$), the orbital eccentricity (e) and the argument of periastron (ω). In principle, it is possible to extract all these parameters from the lightcurves, provided we know certain properties of the host star. High-precision measurements are used to obtain additional information; in particular:

- small variations of the orbital parameters can be used to detect other perturbing objects (exoplanets, stellar companions, exomoons);
- the wavelength dependence of the apparent planet's radius, may be used to infer the atmospheric properties of the exoplanet.

To probe the exoplanet atmosphere, the accuracy required is at the limit of the current instrumental capabilities ([4]) and at the same level of possible stellar activity effects ([1]). Because of these difficulties, some results in the literature have been quite controversial: the claim for water vapour in the atmosphere of HD189733b based on differential photometric data in the IR was one of those ([2]; [3]). Most controversies originate from the corrections for instrumental systematics, which are often beyond the limit of the well-known instrumental calibration ([3]; [4]). Clearly the parameterisations adopted play a critical role here. In this work, we have corrected for systematics using blind, non-parametric methods, in order to have a high degree of objectivity and also better chances to separate the effects due to stellar activity ([5]).

2. The ICA pixel-lightcurves method

The Independent Component Analysis (ICA) performs a transformation from a set of observed signals to an equipotent set of maximally independent components. To effectively disentangle the source signals, at least an equal number of observations of the same phenomenon is required. In the context of exoplanetary transit lightcurves two possibilities have been considered ([4];[5]):

- simultaneous lightcurves of the same transit at different wavelengths;

- lightcurves of different transits of the same exoplanet, recorded with the same instrument at the same wavelength.

Even if stars can be approximated by point sources, the instrument is purposefully de-focused to spatially spread the stellar point spread function (PSF) over several pixels. In Spitzer observations the positions of the target stars on the detector are quite stable to within a pixel, so that there are several pixels detecting the astrophysical signals at any time. We analysed the simultaneously - observed - lightcurves of those individual pixels as mixed signals from which we extract the independent components, among which there is the transit one. These lightcurves contain the same astrophysical components, which is not guaranteed for non-simultaneous ones.
To have a qualitative idea of the efficiency of the proposed method, we show in Figures 1, 2 and 3 the raw lightcurves of the first three observations analysed and the relative transit components extracted. Different approaches were used to validate the robustness of the method and to estimate the error bars. In this way, we could infer whether a discrepancy between two observations taken at different times was most likely “real” or “artificial”.

3. Figures

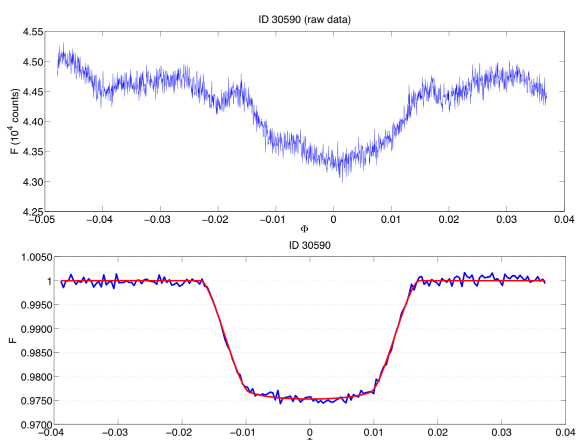

Figure 1: Top: raw lightcurve of observation ID30590; Bottom: the extracted eclipse component (blue) and relative model (red)

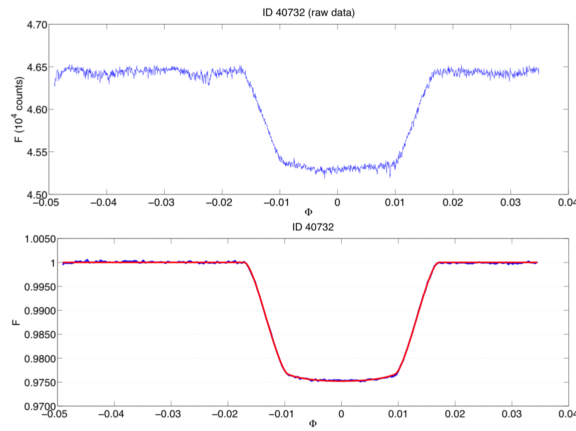

Figure 2: Top: raw lightcurve of observation ID40732; Bottom: the extracted eclipse component (blue) and relative model (red)

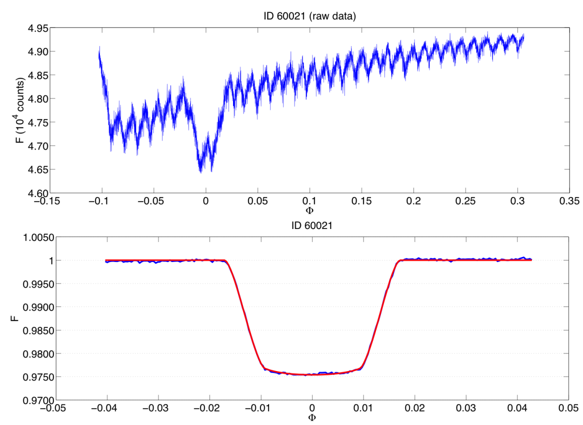

Figure 3: Top: raw lightcurve of observation ID60021; Bottom: the extracted eclipse component (blue) and relative model (red), using part of the data

4. Summary and Conclusions

- A new blind source separation method based on ICA is proposed here to analyse photometric data of transiting exoplanets, with a high degree of objectivity.

- It uses pixel-lightcurves and does not need different observations, but just one with multiple pixels. This fact is rather pleasant both for conceptual physical reasons and for its wide applicability.

- Our method is tested on eight lightcurves of the primary transit of HD189733b recorded with

Spitzer-IRAC at $3.6\mu m$; most of them are very noisy, making the tests rather robust.

- The method was used successfully to compare non-simultaneous observations.

As in other blind decorrelation techniques, the minimality of assumptions and objectivity, are counterbalanced by larger error bars compared to the ones obtained with parametric techniques ([5]). The efficiency of the method proposed clearly depends on the kind of systematics present in the observations. More work will be done in the future to extend the applicability of the method to other observations and/or to reduce the error bars.

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