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

G. Morello (1,2), I. P. Waldmann (1) , G. Tinetti (1), G. Peres (2), G. Micela (3) and I. D. Howarth (1)
(1) Department of Physics and Astronomy, University College London, UK, (2) Dipartimento di Fisica e Chimica, Universitá degli Studi di Palermo, Italy, (3) INAF - Osservatorio Astronomico di Palermo (giuseppe.morello.11@ucl.ac.uk / Fax: +44-(0)20-76797153)

## Abstract

Blind source separation techniques are used to reanalyse two exoplanetary transit lightcurves of the exoplanet HD189733b recorded with the IR camera IRAC on board the Spitzer Space Telescope at 3.6$\mu$m during the "cold" era. These observations, together with observations at other IR wavelengths, are crucial to characterise the atmosphere of the planet HD189733b. Previous analyses of the same datasets reported discrepant results, hence the necessity of the reanalyses. The method we used here is based on the Independent Component Analysis (ICA) statistical technique, which ensures a high degree of objectivity. The use of ICA to detrend single photometric observations in a self-consistent way is novel in the literature. The advantage of our reanalyses over previous work is that we do not have to make any assumptions on the structure of the unknown instrumental systematics. Such "admission of ignorance" may result in larger error bars than reported in the literature, up to a factor 1.6. This is a worthwhile trade-off for much higher objectivity, necessary for trustworthy claims. Our main results are (1) improved and robust values of orbital and stellar parameters, (2) new measurements of the transit depths at 3.6$\mu$m, (3) consistency between the parameters estimated from the two observations, (4) repeatability of the measurement within the photometric level of $\sim 2 \times 10^{-4}$ in the IR, (5) no evidence of stellar variability at the same photometric level within 1 year.

## 1. Introduction

Observations of exoplanetary transits are a powerful tool to investigate the nature of planets around other stars. Transits are revealed through periodic drops in the apparent stellar brightness, due to the interposition of a planet between the star and the observer. The shape of an exoplanetary transit lightcurve depends on the geometry of the star-planet-observer system and the spatial distribution of the stellar emission at the wavelength at which observations are taken [8]. Multiwavelength transit observations can be used to characterise the atmospheres of exoplanets, through differences in the transit depths, typically at the level of one part in $\sim 10^4$ in stellar flux for giant planets [5, 10, 12]. For this purpose, the diagnostic parameter is the wavelength-dependent factor $p = r_p/R_s$, i.e. the ratio between the planetary and the stellar radii (or $p^2$, so-called transit depth).

The exoplanet HD189733b is one of the most extensively studied hot Jupiters: the brightness of its star allows spectroscopic characterisation of the planet's atmosphere. The 3.6$\mu$m transit depth for the exoplanet HD189733b has been debated in the literature. Different analyses of the same dataset, including two simultaneous Spitzer/IRAC observations at 3.6$\mu$m and 5.8$\mu$m, have been used to infer the presence of water vapour in the atmosphere of HD189733b [3, 11], or to reject this hypothesis [6]. [7] reported the analysis of a second Spitzer/IRAC dataset at 3.6$\mu$m using the same techniques. Their new estimates of the planet's parameters were significantly different from those reported previously by the same authors [6]; the discrepancies were attributed by the authors to variations in the star. Although stellar activity may significantly affect estimates of exoplanetary parameters from transit lightcurves [2, 4], the method used to retrieve the signal of the planet also plays a critical role. The analyses mentioned above were all based on parametric corrections of the instrumental systematics, and are thus, to some degree, subjective. Recently, nonparametric methods have been proposed to decorrelate the transit signals from the astrophysical and instrumental noise, and ensure a higher degree of objectivity. [13, 14] suggested algorithms based on Independent Component Analysis (ICA) to extract information of an exoplanetary atmosphere from Hubble/NICMOS and Spitzer/IRS spectrophotometric datasets.

In this paper we adopt a similar approach to detrend the transit signal from photometric observations by using Point Spread Functions (PSFs) covering multiple pixels on the detector. We apply this technique to re-analyse the two observations of primary transits of HD189733b recorded with Spitzer/IRAC at 3.6$\mu$m (channel 1) in the “cold Spitzer” era. We present a series of tests to assess the robustness of the method and the error bars of the parameters estimated. Critically, by comparing the results obtained for the two measurements, we discuss the level of repeatibility of transit measurements in the IR, limited by the absolute photometric accuracy of the instrument and possible stellar activity effects. We discuss the reliability of our results for orbital and stellar parameters in the light of previous multiple 8$\mu$m observations [1].

## 2. ICA using pixel-lightcurves

The main novelty of the algorithms we use here is their ability to detrend the transit signal from a single photometric observation of just one primary transit. This is possible because, during an observation, there are several pixels detecting the same astrophysical signals at any time, but with different scaling factors, depending on their received flux, their quantum efficiency, and the instrument PSF. We performed an ICA decomposition over several pixel-lightcurves, i.e. the time series from individual pixels, in order to extract the transit signal and other independent components (stellar or instrumental in nature). Further details are reported in [9].

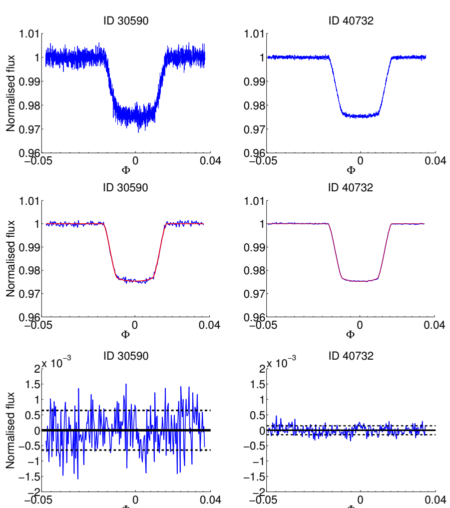


Figure 1: (Top panel): transit time series extracted using the $5 \times 5$ array, considering all the independent components. (Middle panel): (blue) the same series, binned by nine points, (red) relative best model fit. (Bottom panel): residuals between the extracted time series and the model. Dashed black lines indicate the standard deviations of the residuals.

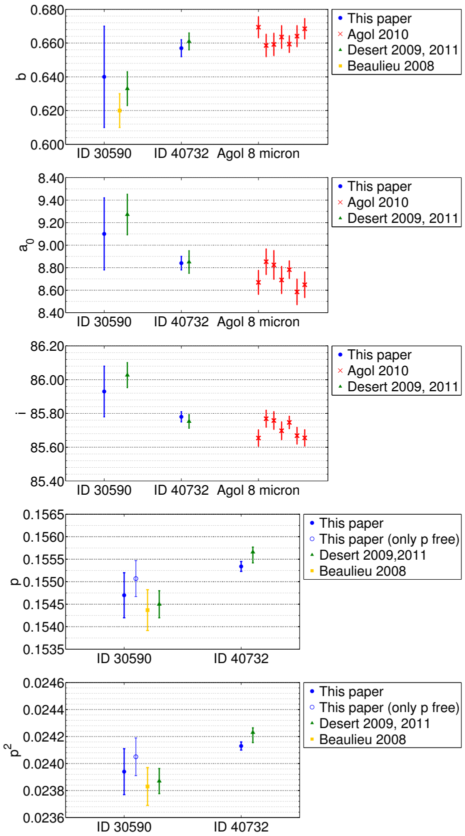


Figure 2: From top to bottom: Comparisons of the parameters $b$, $a_0$, $i$, $p$, $p^2$, obtained in this paper and in the others discussed here.

## 3. Summary and Conclusions

We have introduced a blind signal-source separation method, based on ICA, to analyse photometric data of transiting exoplanets, with a high degree of objectivity; a novel aspect is the use of pixel-lightcurves, rather than multiple observations.

We have applied the method to a reanalysis of two Spitzer/IRAC datasets at 3.6$\mu$m, which previous analyses found to give discrepant results, and obtained consistent transit parameters from these observations. We suggest the large scatter of results reported in the literature arises from the use of parametric methods to detrend the transit signals, neglecting the relevant uncertainties, and correlations between parameters in the lightcurve fit.

We found values for the orbital parameters that are in excellent agreement with those found by [1], based on Spitzer/IRAC observations at 8$\mu$m.

We are applying this method to other observations at 3.6 and 4.5$\mu$m. Preliminary results are promising.

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