The power of wavelets in analysis of transit and phase curves in presence of stellar variability and instrumental noise II. Accuracy of transit parameters

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ABSTRACT

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An error was found in the data compilation pipeline used in the study of parameter stability using the wavelet-based noise filtering technique. As a consequence, the uncertainty of one of the fitting parameters (the impact parameter) was overestimated by a factor of ~ 3. Here we present the corrected version of the corresponding figures. We note that the conclusion from the original work still holds true.

In Kálmán et al. (2023), we presented a study on the stability of certain parameters that are used to described the transit of an exoplanet against time-correlated noise. We utilized two different software, FITSH (Pál 2012) and TLCM (Transit and Light Curve Modeller; Csizmadia 2020), the latter of which uses the wavelet-based noise filtering technique of Carter & Winn (2009).

In TLCM, the transits are parametrized via the so-called conjunction parameter (Csizmadia 2020):

\[ b' = \frac{a}{R_S} \left(1 - e^2 \cos i\right) \]

where \( a \) is the semi-major axis, \( R_S \) is the stellar radius, \( e \) and \( i \) denote the orbital eccentricity and inclination (measured from the line of sight), respectively, and \( \omega \) is the argument of periastron. For circular orbits (\( e = 0 \) that were considered in Kálmán et al. (2023), this expression is simplified to the commonly used definition of the impact parameter

\[ b = b'|_{e=0} = \frac{a}{R_S} \cos i \]

Given that \( b' \) is used in the light curve fitting, only the corresponding uncertainty (\( \Delta b' \)) is estimated directly from the posteriors, as described in Csizmadia (2020), while the uncertainty of \( b (\Delta b) \) is calculated by error propagation from \( a/R_S \) (an independent fitting parameter describing the transits) and \( i \) (derived from Eq (2)). The uncertainty propagation is done via a Monte Carlo simulation. As a consequence, \( \Delta b \) is generally greater than \( \Delta b' \).

In Kálmán et al. (2023), we mistakenly reported findings based on \( b \pm \Delta b \) instead of \( b' \pm \Delta b' \). Although the expectation values are the same (\( b' = b \)), this influenced the calculation of variance, skewness, and kurtosis of the resultant distribution of the parameters \( b' \) and \( \omega = \frac{2 \pi a}{R_S} \left(1 - e^2\cos i\right) \) due to the propagation of uncertainty of the fitting based on TLCM in the original paper. In this corrigendum, we rectify that oversight, using the same datasets that were already described in detail in Kálmán et al. (2023).

Using \( \Delta b'^2 = 2\Delta b'^2 \) to compute the distribution shown in the bottom row of Fig. A. 4. of Kálmán et al. (2023) instead of \( \Delta b'^2 = 2\Delta b^2 \), we calculated the histograms shown in Fig. 1. We note that only these two distributions are affected by the oversight expressed. We find that the variance of the (squared) impact parameters (left panel of Fig. 1) increases from 0.682 to 4.881, and the skewness and kurtosis change from \(-0.617\) and 1.688 to \(-0.654\) and 1.937, respectively. In essence, this implies that the uncertainty of the conjunction parameter is underestimated by TLCM in this particular case by a factor of ~ 2 (since for a Gaussian distribution we would expect a variance of 1, corresponding to a standard deviation of 1). The other two metrics remain relatively unchanged. We also find that the variance, skewness, and kurtosis of the distribution of the \( \omega \) parameter in the wavelet-based noise handling case change from 0.098, –0.337, and 0.927 to 0.437, –0.564, and 1.474, respectively. Similarly to \( b^2 \), the most significant change occurs in the second statistical moment, implying that the distribution of the relative errors of the \( \omega \) parameter are overestimated by a factor of 1.5 (after accounting for the uncertainty propagation).

The changes presented here still allow us to argue for the clear benefits of the wavelet-based handling time-correlated (“red”) noise when compared to a method without noise handling, retaining the principal findings of Kálmán et al. (2023).

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Fig. 1. Distribution of the differences between the input parameters and the fitted parameters without noise filtering (red) and with the wavelet-based noise filtering (blue) for $b^2$ and $\omega$, the fitting parameters of the software package FITSH. These are in principle the same as the bottom row of Fig. A. 4. of Kálmán et al. (2023), with the uncertainty of the fitting parameter ($b')$ used for the calculation of the blue histograms. The medians, variances, skewnesses, and kurtoses of the distributions are also shown.

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