Fine detrending of raw Kepler and MOST photometric data of KIC 6950556 and HD 37633

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Abstract. We present a simple phenomenological method for detrending of raw Kepler and MOST photometry, which is illustrated by means of photometric data processing of two periodically variable chemically peculiar stars, KIC 6950556 and HD 37633. In principle, this method may be applied to any type of periodically variable objects and satellite or ground based photometries. As a by product, we have identified KIC 6950556 as a magnetic chemically peculiar star with an ACV type variability.

Key words: data processing, Kepler and MOST photometry, chemically peculiar stars, stars individual: KIC 6950556, HD 37633

Introduction

Nowadays, the amazing accuracy of nearly continuous photometric observations made from space satellites enables us to study subtle details in the light variations of variable stars. However, raw space photometric data contain different systematic trends associated with the spacecraft, detector and environment rather than the target. To exploit maximum information hidden in the satellite photometry, we need to eliminate all these trends as good as possible. We have developed a way of detrending raw photometry using appropriate phenomenological models of the real light curve modulated by instrumental effects. To display the efficiency of the method, we have processed raw photometric data of two strictly periodic CP stars with smooth light curves obtained by the Kepler and MOST satellites.

1. Kepler - KIC 6950556

KIC 6950556 (= 2MASS J19294376+4229306; 12.751 ± 0.024 mag) was classified by McNamara et al.(2012) as a B-type binary or a star whose light curve is dominated by rotation. Furthermore, it was preliminarily identified as an ellipsoidal (ELL) variable star candidate with a period of 1.5116 d by Balona et al.(2015). According to the double-wave light changes and

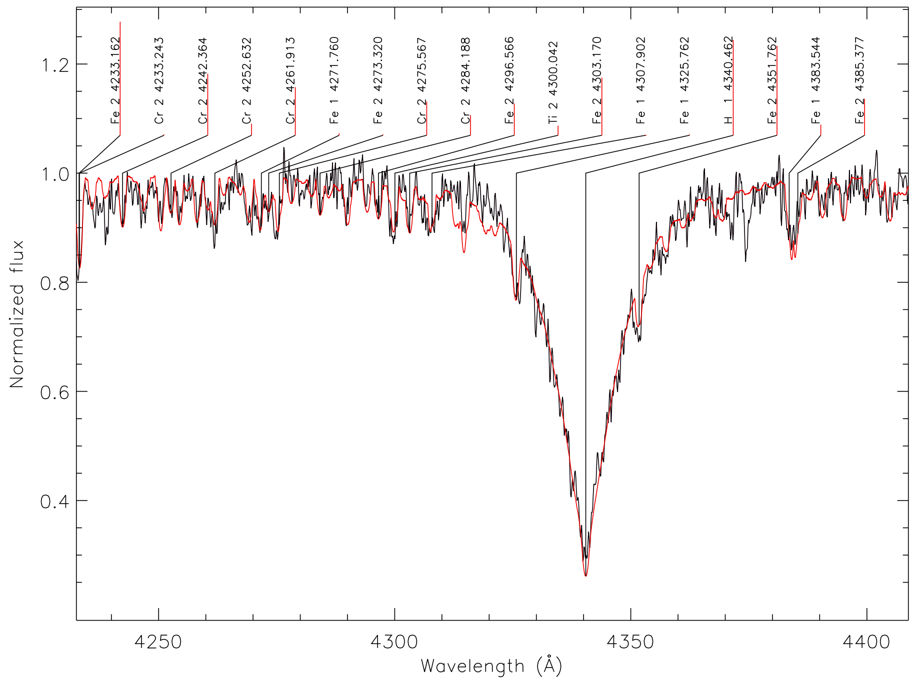

Fig. 1. A part of the spectrum of SiCr CP2 star KIC 6950556, fitted by the atmosphere model with an effective temperature of 11 000 K, $\log g = 4.0$, and enhanced abundances of chromium, iron, and silicon.

the effective temperature, we also assumed ACV (α_2 CVn) variability. The classification of KIC 6950556 as a magnetic chemically peculiar star was subsequently confirmed by our analysis of two newly obtained spectra in the spectropolarimetric mode using the 6m telescope of Special Astrophysical Observatory of the Russian Academy of Science, Nizhnii Arkhyz (see Fig. 1).

Spectral analysis of spectrograms shows that KIC 6950556 is B8-9 V star with an effective temperature of $T_{\rm eff} = 11\,000(700)$ K, $\log g = 3.5 - 4.0$, and a projected rotational velocity $V \sin i = 60(10)\,\mathrm{km\,s^{-1}}$. Assuming a typical radius of the stars with such parameters $R = 2.4\,\mathrm{R}_\odot$ (according to tables in Harmanec(1988)) we can also estimate the inclination angle $i \doteq 50°$. The observed spectrum is apparently peculiar due to strong overabundance of chromium, iron, silicon, and underabundance of helium and calcium. If overabundant elements are distributed unevenly on the surface of the rigidly rotating star, they should form photometrically contrasting spots causing light variability of the star.

The photometric analysis was based exclusively on raw Kepler data (Q0-Q17) which exhibit a scatter of 32 mmag as processed by the Kepler pipeline

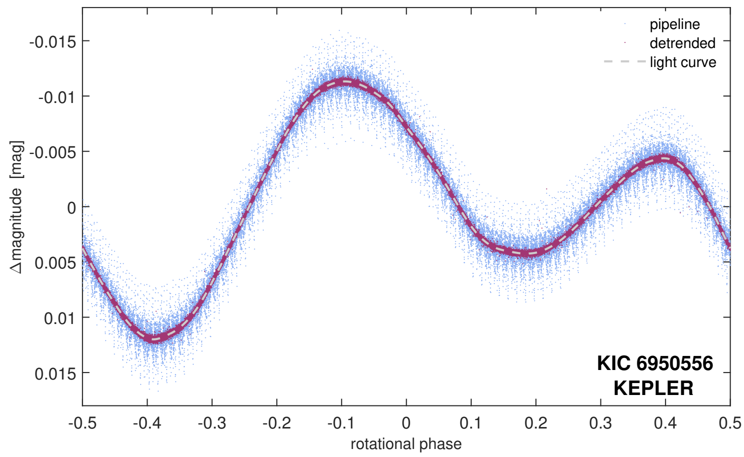

Fig. 2. Phased light curve of KIC 6950556, based on photometric data detrended by the Kepler pipeline (powder-blue dots) and data detrended by our code (magenta dots). The dashed grey line is a fit of the light variations by a harmonic polynomial of the 35-th order.

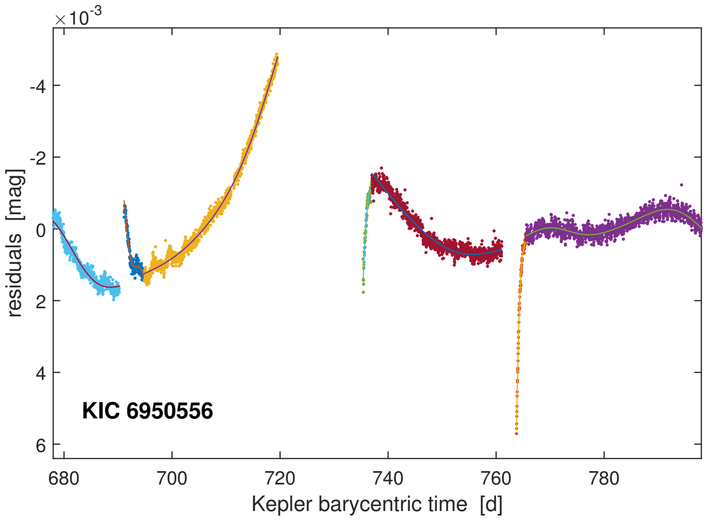

Fig. 3. Detail view of seven residual segments fitted by special function series.

Jenkins et al.(2010). Such a preprocessed set of 64 793 individual observations of KIC 6950556 exhibits a scatter of 1.0 mmag - see Fig. 2.

The detailed analysis of the light residuals indicates a very strong correlation of adjacent points (see Fig. 3) which can be removed by fine detrend-

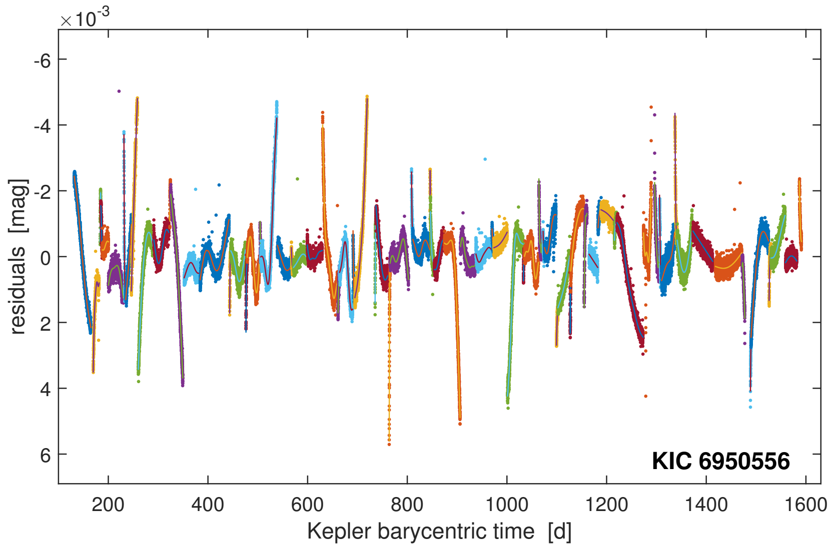

Fig. 4. Residuals fitted by 75 smooth lines.

ing. Residuals were divided into 75 intervals of uneven lengths and fitted by series of special quasi-orthogonal functions Mikulášek & Gráf(2005) of 0 to 7-th orders (see Fig. 4). After the detrending, which is described by 256 free parameters, we obtained a corrected light curve with a scatter of 0.13 mmag, which is close to the expected limit of accuracy of the Kepler satellite photometry. The detailed description of the mathematics of the detrending procedure will be published elsewhere.

The light curve itself was fitted by a harmonic polynomial of the 35-th order (see Fig. 2). The accuracy (5×10^{-7} mag) and reliability of the detrended light curve is sufficient for deriving the positions of photometric spots on the surface of the rotating star. The complex shape of the light curve with unequally high maxima in the double-wave Morris(1985)see e.g. also do not support the classification of KIC 6950556 as an elliptical variable star or B-type binary Balona et al.(2015), McNamara et al.(2012).

We also refined the period of the star to: $P = 1.511\,785\,08(4)$ d, which seems to be fairly constant: $\dot{P} = 1(2) \times 10^{-10}$. It should be noted that the accuracy of the period rate determination of 2×10^{-10} is high enough to reveal all presently known CP stars exhibiting variable periods Mikulášek et al.(2014), Mikulášek et al.(2015).

2. MOST - HD 37633

The MOST B9Vp CP2 star HD 37633 (= V1147 Ori) was identified as a variable star by North(1982). Later, North(1984) published its period $P = 1.5718$ d and light curves of the star in the Geneva system. Our pho-

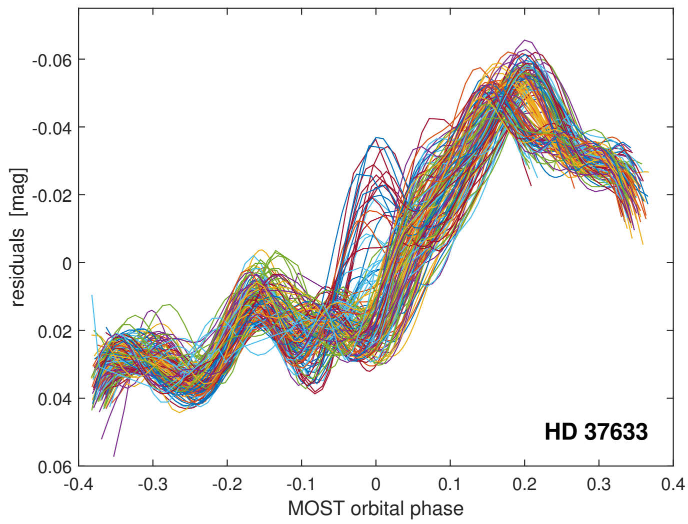

Fig. 5. Residuals plotted versus the MOST orbital phase. Each of the 146 MOST passages were fitted by its own curve.

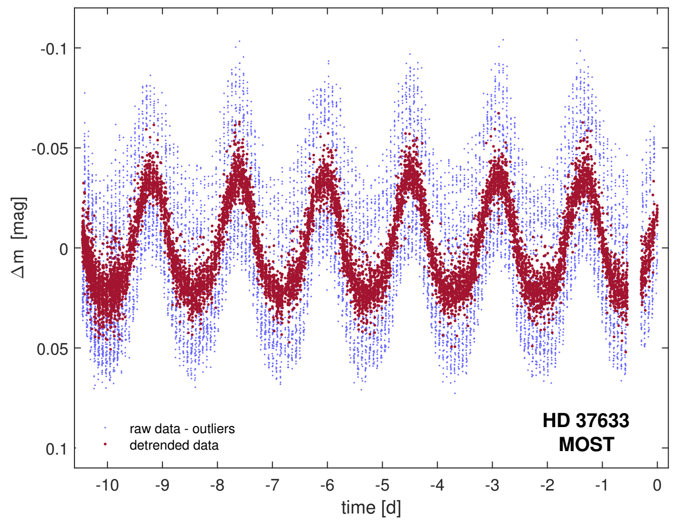

Fig. 6. Phased light curve of HD 37633 defined by its raw photometric data (powder-blue dots) and data detrended by our code (magenta dots).

tometric analysis was based on 10 572 raw MOST measurements obtained during 10.5 d (6.7 photometric cycles). We fitted the raw measurements by a harmonic polynomial of the 5-th order using a robust regression suppressing the influence of outliers Mikulášek et al.(2003). The residuals, having an amplitude of 0.1 mag, are strongly correlated with the phase of the orbital revolution of the MOST satellite (101.48 min); nevertheless each of the 146 passages differs from each other.

Consequently, we modelled the individual course of each observational interval using linear combination of 14 special functions mentioned above (see Fig. 5). Subtracting these trends, which are correlated with the MOST orbital period, we obtained detrended magnitudes defining the light curve with a scatter of 75 mmag (see Fig. 6). 207 measurements were deleted. The data filtered by the MOST pipeline Hareter et al.(2008) have the same scatter as our detrended data, but the number of deleted measurements is larger: 497.

3. Conclusions

We have shown that the proposed way of the phenomenological detrending of raw Kepler and MOST data is able to improve light curves of periodically variable stars considerably. The outlined method can be used also for the final processing of ground based (ASAS, Pan-STARRS, and SuperWASP) as well as satellite based (BRITE, CoRoT, and PLATO) data. The phenomenological detrending can be essentially applied to all variable objects whose periods and light curves are constant or regularly changing. That is valid for all rotators (CP stars, elliptical stars, spotted star, asteroids), eclipsing systems (binaries or stars transited by their planets), and several types of pulsators (RR Lyr stars, cepheids, δ Sct stars, and so on), among variable objects.

Simultaneously, we have revealed that the Kepler star KIC 6950556 is definitely a common CP2 star with an effective temperature of 11 000 K, $\log g = 4.0$, and enhanced abundances of chromium, iron, and silicon, rotating with a constant period of $P = 1.511\,785\,08(4)$ d. The observed light variability is then caused by the incidence of two or more photometric spots on its surface.

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