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Subtle flickering in Cepheids: *Kepler* and *MOST*

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Abstract. Fundamental mode classical Cepheids have light curves which repeat accurately enough that we can watch them evolve (change period). The new level of accuracy and quantity of data with the *Kepler* and *MOST* satellites probes this further. An intriguing result was found in the long time-series of Kepler data for V1154 Cyg the one classical Cepheid (fundamental mode, P = 4.9 d) in the field, which has short term changes in period (≃20 minutes), correlated for ≃10 cycles (period jitter). To follow this up, we obtained a month long series of observations of the fundamental mode Cepheid RT Aur and the first overtone pulsator SZ Tau. RT Aur shows the traditional strict repetition of the light curve, with the Fourier amplitude ratio R_1/R_2 remaining nearly constant. The light curve of SZ Tau, on the other hand, fluctuates in amplitude ratio at the level of approximately 50%. Furthermore prewhitening the RT Aur data with 10 frequencies reduces the Fourier spectrum to noise. For SZ Tau, considerable power is left after this prewhitening in a complicated variety of frequencies.

Keywords. stars: variables: Cepheids, pulsation, *Kepler*, *MOST* satellite photometry

1. Introduction

The quality and quantity of satellite data is revealing subtle features in Cepheid pulsation. Specifically, we discuss here recent findings from two long series of observations by the *Kepler* and *MOST* satellites.

2. *Kepler* observations

There is only one classical Cepheid (V1154 Cyg) in the *Kepler* field, and it is a fundamental mode pulsator with a period of 4.9 d. Analysis of the *Kepler* data by Derekas *et al.* (2012) found small cycle to cycle variations of the period. Typically the period excursions might be 20 minutes and last up to 15 cycles before the sign of the period change ($\dot{P}$) reverses.

3. *MOST* observations

To look further for the small fluctuations made visible by the long continuous strings of accurate satellite data, we observed two Cepheids with the *MOST* satellite (Walker *et al.* 2003, Matthews *et al.* 2004). Motivation for the structure of the observation request is provided by known period changes in Cepheids (Fig. 1). The data taken from Szabados (1983) show the well known increase in period fluctuations with period or luminosity of the Cepheid. This is consistent with period changes ($\dot{P}$) determined by evolution through the instability strip, with more luminous stars evolving more quickly. The exception to the

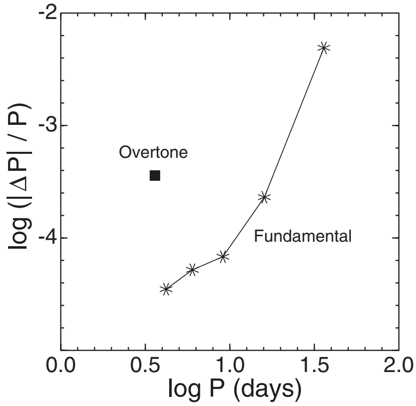

Figure 1. Fractional period change (absolute value) as a function of the log of the pulsation period in days. Fundamental mode pulsators (binned) are denoted by asterisks; overtone pulsators are a filled square.

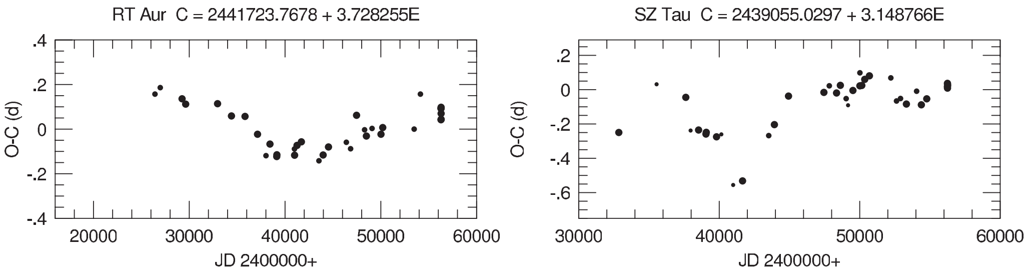

Figure 2. The long-term period variations (O−C diagrams: O−C in days as a function of Julian date − 2 400 000) for RT Aur (left) and SZ Tau (right). As is typical of their pulsation modes, the variation for RT Aur is smooth, where for SZ Tau it is both positive and negative and also constant for a long period. Symbol size denotes the significance of the O−C value.

trend, however, is the group of Cepheids pulsating in an overtone mode which apparently show unusually large period jitter rather than the smooth and continuous evolution of fundamental mode pulsators.

For the *MOST* observations we wanted to contrast the behavior of a fundamental mode pulsator (RT Aur) with a first overtone pulsator (SZ Tau). The background information on $\dot{P}$ is shown in Fig. 2. For RT Aur the period change O−C (observed minus computed) diagram has a decrease followed by an increase, which is typically fitted with a parabola. For SZ Tau, the O−C diagram shows both increasing and decreasing periods, as well as about 10 000 days when it remains constant.

The *MOST* observations (Evans *et al.*, in preparation) phased for pulsation period are shown in Fig. 3. For RT Aur, the observations were interleaved with another target, resulting in gaps in the light curve. However, the light curve repeats very precisely from cycle to cycle. For SZ Tau, the overtone pulsator, only the maximum of the phased light curve is shown. This emphasizes the fact that there are variations in maximum brightness from cycle to cycle (also easily visible at minimum light). A small instrumental signal (differing earthshine through the satellite orbit) is seen in Fig. 3b, which is being removed through additional processing.

The data from the two stars was subjected to a number of comparisons. In Fig. 4, the Fourier spectra are shown after pre-whitening for a Fourier fit of 10 terms. The instrumental signal is seen at the orbital frequency ($\simeq$14 d^{-1}). The Fourier series describes

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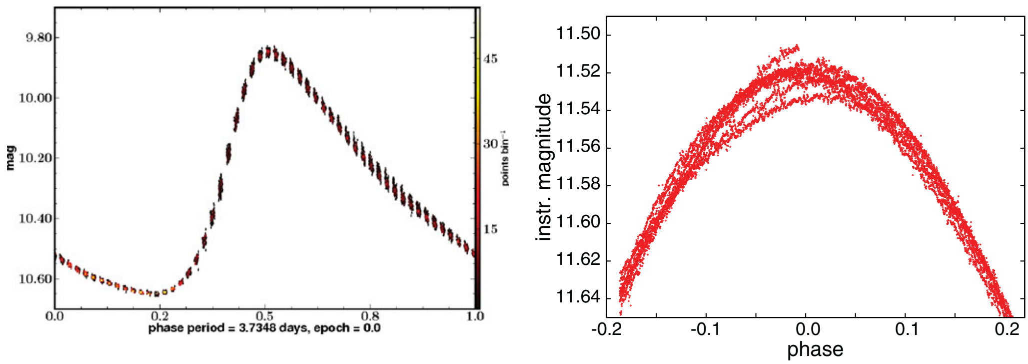

Figure 3. The *MOST* light curves (magnitudes as a function of pulsation phase) for RT Aur (left) and SZ Tau (right). The RT Aur figure also shows points per bin on the right side scale. The RT Aur observations were interleaved with another target, resulting in the gaps in the data. Only the maximum light is shown for SZ Tau, emphasizing the variation in brightness between cycles.

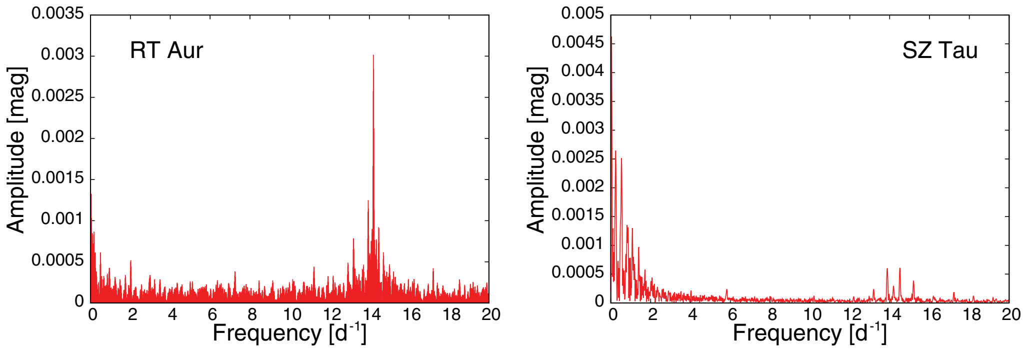

Figure 4. The Fourier spectra of the *MOST* data of RT Aur (left) and SZ Tau (right). The data for both stars have been prewhitened by a Fourier series with 10 terms. In both stars the instrumental signature is seen at about 14 d^{-1}. For RT Aur, little power is left at low frequencies. For SZ Tau, power still remains in a complicated set of low frequencies.

the fundamental mode pulsator (RT Aur) well and little power is left at low frequencies. In SZ Tau, on the other hand, power still remains in a complicated set of low frequencies, indicating that the single periodicity does not fully describe the pulsation.

The Fourier parameters themselves were compared for the two stars. As an example, Fig. 5 shows the amplitude ratio R_{21} changes for the six cycles observed for each of the stars. For RT Aur, the variation is estimated to be 3%. For SZ Tau the variation is much larger (45%). The variation in Fig. 5 (right) is typical of the variation in other Fourier coefficients of the overtone Cepheid.

Thus the *MOST* observations show that the overtone pulsator SZ Tau has a larger variability in the parameters we examined, or a larger instability in the pulsation than the fundamental mode Cepheid.

4. Summary

We present here a brief summary of the period changes or possible period changes in classical Cepheids and the characteristics of pulsation which they suggest. Most probably the $\dot{P}$ which we observe results from a combination of causes.

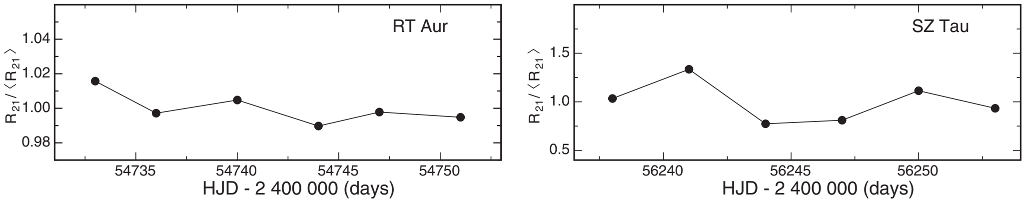

Figure 5. Representative Fourier parameters for the *MOST* data ($R_{21}/\langle R_{21}\rangle$ as a function of HJD - 2 400 000) for each of the six cycles observed, with RT Aur on the left and SZ Tau on the right. We estimate that the $R_{21}/\langle R_{21}\rangle$ parameter varies by 3% in RT Aur and 45% in SZ Tau.

• Evolution through the instability strip: This would have $\dot{P}$ in one direction (at least for a century of observations).

• Light-time effects in binaries: $\dot{P}$ would be cyclic but with a long period. (Known Cepheid binaries have orbital periods longer than 1 year in the Milky Way.)

• Mass loss: $\dot{P}$ would be in one direction,

• Star spots and rotation: $\dot{P}$ would be cyclic and roughly periodic as spots come and go.

The two phenomena discussed here have the following characteristics:

– Flickering $\dot{P}$ (*Kepler*): It is cyclic and reasonably short term. It could be due either to a pulsation phenomenon or star spots.

– Instability in overtones (*MOST*): This seems to be most probably pulsation related.

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