ON THE DATA REDUCTION OF WET OBSERVATIONS

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Abstract. It is demonstrated how the length of a continuous time-series of photometric data and their gaps affect the power spectrum of a Fourier Transform of the data. It is shown that second order effects of the atmospheric extinction – the dependence of the extinction coefficient on spectral type of a star and on the air mass – cannot be ignored. The ignoring of these effects results in aliases at frequencies lower than 200 μHz . A modification of the extinction correction procedure is proposed.

Key words: methods: data analysis – atmospheric effects – techniques: photometric: WET

1. INTRODUCTION

The Whole Earth Telescope (WET) was established in 1986 as a world-wide network of cooperating astronomical observatories to obtain uninterrupted time-series measurements of short-period variable stars (white dwarfs and hot subdwarfs). WET works as a single astronomical instrument with many operators around the globe. The technological goal is to resolve multi-periodic oscillations observed in these objects into their individual components (Nather et al. 1990). The scientific goal is to construct accurate theoretical models of the target objects, constrained by their observed oscillations. Using the models, fundamental astrophysical parameters of these stars can be derived.

The aim of this study is to investigate, how the length of continuous time-series of photometric data and their gaps affect the power spectrum of the Fourier Transform (FT) of the data, and to examine the extinction correction procedure applied for the reduction of WET observations.

Fig. 1. Fourier power spectra of the three simulated photometric data runs. The solid lines in both panels correspond to the simulated light curve covering 94500 s time span without gaps. The dashed line in panel (a) corresponds to the simulated light curve covering 31500 s time span without gaps, while that in panel (b) corresponds to the simulated light curve covering 94500 s with two gaps between different runs.

2. IMPORTANCE OF CONTINUOUS LONG TIME-SERIES PHOTOMETRY

Multi-site WET observations enable observers to obtain continuous long time-series of photometric data, in most cases avoiding gaps caused by the diurnal cycle. FT of such long time-series gives us power spectrum with narrow peaks at really existing pulsation frequencies, thus enhancing the resolving power of oscillation frequencies and excluding aliases.

In order to demonstrate, how the results of FT depend upon the length of photometric dataset and the presence or absence of different gaps, we have simulated the primary data run covering a time span of 31500 s. Using this dataset we have formed two larger datasets, each of 94500 s duration – one with two gaps and another without gaps. The light curves were constructed as a sum of two time-variable functions with the frequencies: 1300 μHz with an amplitude of 20 mmag and 1430 μHz with an amplitude of 25 mmag (Pakštienė & Solheim 2003). The results of FT of the mentioned three time-series of photometric data are shown in Figure 1.

The power spectra in panel (a) of Figure 1 show that longer time-series yield narrower frequency peaks, thus enabling to resolve closer frequencies of oscillations. In addition, the noise of the power spectra for longer time-series is much lower. Panel (b) shows that gaps in the time-series of photometric data generate aliases or false peaks, thus decreasing the precision of data analysis. However, they have no effect on the amplitude and frequency of the real peak. So, our results confirm the conclusion that longer continuous time series of data allow to avoid aliasing and achieve a higher resolution of oscillation frequencies of the variable star. This conclusion is the main argument in favor of multi-site observing campaigns, like WET.

Fig. 2. Illustration explaining the wavy structure of the light curve after the linear extinction correction with the QED program: (a) the dependence of extinction on air mass; (b) observations transformed by the standard QED extinction correction procedure.

3. THE NOISE CAUSED BY THE REDUCTION PROCESS

WET observations usually are processed for each night separately using the standard reduction program QED (Clemens 1993). This program allows one to follow and control step by step all the reduction procedure on-line. The observed data, after the subtraction of the sky background and the correction for the response non-linearity, are corrected for atmospheric extinction. The QED program assumes that there is a linear dependence between the photon counts and the air-mass at which the star is observed. The program allows us to fit the extinction coefficient in such a way that the light curve of the target star during a night is more or less flat after the extinction correction. If after the extinction correction the star gets brighter with increasing air mass, this means that the applied extinction coefficient is too large. On the other hand, if the corrected light curve shows that the star is dimming with the air mass, this means that the applied extinction coefficient is too small.

Even if the transparency of the atmosphere during a night is stable, the extinction coefficient is variable due to the Forbes effect, i.e., the extinction vs. air mass dependence is curved (Figure 2). In this case the QED method gives a wavy run of counts. Such waves in the light curve of the target star will give an additional noise at low frequencies during FT.

In most cases when the reduced light curve is not flat because of extinction variations during a night or because of other reasons, for the curve flattening the QED program uses an additional polynomial fitting. A fourth order polynomial enables one to flatten the light curve considerably, however, with some residual waves (Pakštienė & Solheim 2003). Such waves cause an additional noise in FT at

frequencies lower than 200 μHz .

If observations were carried out through clouds, and the light curve is strongly curved, then the ratio of photon counts of the target star and a nearby comparison star should be taken. Clouds usually add a grey extinction which can be considered the same for both stars. If the cloud effect is not removed, then FT gives a strong noise which can increase or decrease the real amplitudes. The waves on the light curve disappear when the real dependence of the extinction coefficient on air mass is used and the extinction is calculated for every moment of observation. The real dependence of the extinction on air mass can be estimated using the synthetic extinction coefficients calculated for different air masses (Pakštienė & Solheim 2003).

In the case when the ratio of photon counts of the target star and the comparison star is used, it is important to take into account the difference of spectral classes of these stars (the second-order extinction effect). In the next section we will discuss a possibility to determine spectral type of a comparison star from WET observations themselves.

4. ESTIMATION OF SPECTRAL TYPE OF THE COMPARISON STAR

For the extinction correction we need to know the spectral type of the comparison star (spectral type of the WET target star usually is known). We propose to estimate the spectral type of the comparison star in the following way.

(1) Synthetic extinction coefficients for the spectral type of the target star (white dwarf or OB subdwarf) are to be calculated with the mean seasonal or instantaneous atmospheric transmittance curve and used for every moment of observations.

(2) Synthetic extinction coefficients for the comparison star are to be calculated for the same atmospheric transmittance curve, but for different spectral types.

(3) Then the extinction coefficients for every observational moment of the comparison star are used for different chosen spectral types. If the spectral type of the comparison star is chosen correctly, the count ratio of the target star (T) and the comparison star (C) as a function of time during a night should be constant (Figure 3). If the accepted spectral type is wrong, we get some dependence of the ratio versus time. The form of the dependence may be used for estimation of the unknown spectral type of the comparison star.

Fig. 3. Determination of spectral type of the comparison star (C) with the extinction correction for synthetic observations assuming different spectral types for the comparison star: (a) the assumed spectral type, F0 V, is wrong, (b) the assumed spectral type, G0 V, is correct. Spectral type O V is assumed for the target star (T).

5. CONCLUSIONS

The WET is a very useful tool for obtaining long time-series of photometric data with a small number of gaps. Such data allow us to avoid additional noise in the FT power spectra, to resolve more pulsation frequencies and to determine more exact values of these frequencies and their amplitudes.

The standard QED program used for processing of WET observations gives too small extinction corrections in the Earth's atmosphere. As a result, the real extra-atmospheric magnitudes of the target stars cannot be obtained. However, QED gives right pulsation amplitudes for frequencies above $200 \mu\text{Hz}$. The amplitude values are influenced mostly by other kinds of noises, like the electronic noise, small variations of atmospheric transparency due to clouds, fluctuations of the sky brightness, etc. Most important is to reduce the photon noise of the star itself by increasing the exposure length or by using a larger telescope.

For the increase of the reduction accuracy to outside the atmosphere we propose to use synthetic extinction coefficients calculated for each moment of observation. In two-channel observations, when the target star and the comparison star are observed at the same time, the extinction effects may be avoided by taking the ratio of counts of both stars. However, in this case the differences of spectral types of stars must be taken into account.

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