Spurious One-Month and One-Year Periods in Visual Observations of Variable Stars

John R. Percy

Department of Astronomy and Astrophysics and Dunlap Institute for Astronomy and Astrophysics, University of Toronto, 50 St. George Street, Toronto, ON M5S 3H4, Canada; john.percy@utoronto.ca

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Abstract Visual observations of variable stars, when time-series analyzed with some algorithms such as DC-DFT in VSTAR, show spurious periods at or close to one synodic month (29.5306 days), and also at about a year, with an amplitude of typically a few hundredths of a magnitude. The one-year periods have been attributed to the Ceraski effect, which was believed to be a physiological effect of the visual observing process. This paper reports on time-series analysis, using DC-DFT in VSTAR, of visual observations (and in some cases, V observations) of a large number of stars in the AAVSO International Database, initially to investigate the one-month periods. The results suggest that both the one-month and one-year periods are actually due to aliasing of the stars' very low-frequency variations, though they do not rule out very low-amplitude signals (typically 0.01 to 0.02 magnitude) which may be due to a different process, such as a physiological one. Most or all of these aliasing effects may be avoided by using a different algorithm, which takes explicit account of the window function of the data, and/or by being fully aware of the possible presence of and aliasing by very low-frequency variations.

1. Introduction

In the course of time-series analyses of AAVSO visual observations of red giants (such as Percy and Long 2010) and T Tauri stars (such as Percy *et al.* 2010), we have found many stars with periods at or close to one year, and occasionally one synodic month (hereinafter "one month"—29.5306 days). We attributed the one-year periods to the Ceraski effect—a physiological effect which is described thus by Gunther and Schweitzer (undated): "when two stars of equal brightness are aligned so that the line-of-stars is perpendicular to the line-of-eyes, an observer may systematically see the 'upper' star brighter than the 'lower' one." Sharonov (1933) carried out an experimental study of the effect, and found that it can be as large as 0.3 magnitude in the most extreme cases.

How might such an effect occur? Here's a simple example. Suppose a northern observer was measuring Betelgeuse every night with the unaided eye, relative to Rigel as a comparison star. At the beginning of the observing season in August, he/she would be observing Orion as it rose, when Betelgeuse and Rigel are at approximately the same altitude, and the line-of-stars is parallel to the line-of-eyes (to use Gunther and Schweitzer's terminology), which we assume to be horizontal. There would be no Ceraski effect. At the end of the observing season, in April, he/she would be observing Orion as it set, when Betelgeuse is at a much higher altitude than Rigel. The line-of-stars is now perpendicular to the line-of-eyes. According to the Ceraski effect, Betelgeuse would be seen artificially brighter than Rigel. In fact, differential extinction might add to the effect. Since this would be a seasonal effect, it would have a one-year period.

I initially hypothesized that the one-month periods were caused by a variant of the Ceraski effect: depending on the position of the moon in the sky, during its monthly cycle, observers will tend to observe a variable in different parts of the sky, with a different orientation of the line-of-stars to the line-of-eyes. A post on the AAVSO Visual Observing forum, asking if this seemed reasonable, resulted in many views but no replies.

In the end, my initial hypothesis about the nature and cause of the one-month periods turned out to be almost certainly incorrect. My efforts also led me to a reconsideration of the nature and cause of the one-year periods, and the Ceraski effect. The pathway to my conclusion was not a direct, linear one; I am "telling it as it was," for the benefit of other users of visual data, and of VSTAR and similar time-series analysis packages.

2. Data and analysis

I used visual observations from the AAVSO International Database (AID; Kafka 2015) of the selected groups of stars described below and the DC-DFT routine in the AAVSO software package VSTAR (Benn 2013). DC-DFT, or date-compensated discrete Fourier transform (Ferraz-Mello 1981) is a common implementation of Fourier analysis, a topic that is discussed in detail in Templeton (2004), a reference which is freely available on the AAVSO website. I occasionally used Johnson V observations from the AID, to compare the results with those from visual observations—for instance, to determine whether "spurious" peaks were solely in the visual data, and therefore possibly due to the visual observing process. I generally scanned periods at a resolution of 0.01 or 0.001 day.

3. Results and discussion

3.1. The incidence of one-month signals

To study the incidence of one-month periods, I initially used visual observations of a sample (Table 1) of 50 carbon and oxygen red giants which Percy and Huang (2015) had been analyzing for other purposes. To avoid confusion, I used only those stars which had pulsation amplitudes less than 0.20

Table 1. One-month periods and their amplitudes in Red Giants.

Star	*P (d)*	*Δv (mag.)*	*Star*	*P (d)*	*Δv (mag.)*
RY Cam	29.574	0.025	V UMi	none	≤ 0.008
RY Cnc	29.489	0.037	VY And	29.109	0.059
AA Cas	none	≤ 0.015	AQ And	29.530	0.024
SS Cep	29.502	0.013	V Aql	29.550	0.019
DM Cep	29.490	0.032	U Cam	29.834	0.030
TZ Cyg	29.516	0.015	ST Cam	29.530	0.020
CT Del	29.494	0.042	X Cnc	29.530	0.021
CZ Del	29.483	0.025	Y CVn	29.533	0.018
EU Del	29.527	0.010	WZ Cas	29.473	0.013
S Dra	29.605	0.046	RV Cyg	29.548	0.081
TX Dra	none	≤ 0.010	SV Cyg	29.583	0.043
Y Gem	29.613	0.033	TT Cyg	29.541	0.019
SW Gem	29.548	0.030	AW Cyg	29.481	0.030
X Her	29.519	0.017	V460 Cyg	29.526	0.037
ST Her	29.497	0.034	RY Dra	29.523	0.019
UW Her	none	≤ 0.010	UX Dra	29.526	0.025
g Her	29.525	0.012	U Hya	29.533	0.022
RX Lep	29.526	0.017	Y Hya	29.511	0.033
SV Lyn	29.594	0.026	T Lyr	29.530	0.039
SZ Lyr	29.809	0.033	W Ori	29.536	0.030
SW Mon	none	≤ 0.035	RX Peg	29.552	0.058
V UMa	29.638	≤ 0.020	TX Psc	29.503	≤ 0.015
RY UMa	29.619	0.016	S Sct	29.524	0.026
RZ UMa	29.552	0.041	Y Tau	29.531	0.046
ST UMa	29.574	0.011	VY UMa	29.510	0.009

magnitude (an arbitrary number); most had pulsation amplitudes less than 0.10 magnitude.

In 40 out of 50 stars, there was a peak at or close to a period of one month, or a frequency of 0.03386 cycle/day (c/d). In the other 10 stars, any one-month period was at the noise level, so only an upper limit could be specified. The stars in Table 1 from RY Cam to V UMi are normal M-type giants; those from VY And to VY UMa are carbon stars.

3.2. In search of the cause—alias periods?

In a further effort to understand the nature of the one-month periods, I analyzed visual data on other samples of stars in the AID. R CrB stars had substantial one-month signal amplitudes, here given in magnitudes: U Ant (0.070), S Aps (0.040), U Aqr (0.091), UV Cas (0.011), UW Cen (0.123), DY Cen (0.033), R CrB (0.075), V Cra (0.080), WX Cra (0.053), Y Mus (≤ 0.010), RT Nor (0.037). However, when I analyzed a long stretch of observations of R CrB when it was constant at maximum, the amplitude of the one-month signal was much smaller.

It was at this point that I began to wonder if the one-month signal was a one-month *alias* of very low-frequency (VLF) variability, on a time scale of thousands to tens of thousands of days. One-*year* aliases are well-known. They occur because of the one-year temporal periodicity in the times of observation, that is, the window function of the data. There are times of year when it is difficult or impossible to observe the star, so there are seasonal gaps in the data. The alias frequencies differ from the true frequency by ± N / 365.25 c/d where the strongest alias is normally N = 1. The seasonal gaps are usually quite visible in the light curve, as seen in VSTAR or in the AAVSO Light Curve Generator.

One-*month* aliases might occur for the same reason as one-*year* aliases: there are times of the month when the star might be difficult to observe, due to moonlight, and therefore less likely to be observed, especially if the star is near the ecliptic. These gaps are less obvious in the light curve, but are definitely there. As a check, I looked at the observations of Antares, near the ecliptic. During the 0.15 of the month when the moon was near Antares, only 0.04 of the observations were made.

Indeed, the one-*year* signals might also be alias periods, caused by VLF variations, rather than due to the Ceraski (physiological) effect. We discuss this possibility below.

3.3. Alias periods and the window function

In retrospect: if I had thought about VLF variability in red giants, and/or had been using a different Fourier-analysis routine, I would have been aware of the possibility of one-month and one-year aliases as being part of the *window function* of the dataset (for example, Templeton 2004; Lenz and Breger 2005). The window function, for discretely-sampled data, describes the inherent periodicities in the times of observation, and shows how a true signal at a frequency f "leaks" into other frequencies—the alias frequencies. The window function is centered at f = 0. Often, it is used by being applied to the strongest peak in a Fourier spectrum to determine which weaker peaks are likely to be aliases of it, especially in the case of short-period variables in which there are strong one-*day* aliases. In the present case, we are dealing with an aliased signal with a frequency f which is very close to but not equal to zero. This, in an ideal case, would result in a *pair* of alias periods, separated by 2f. Non-periodic VLF variability would produce more complex aliasing structure (such as in Figure 1).

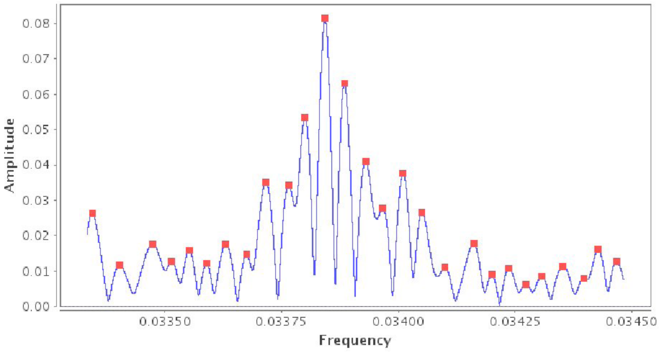

Figure 1. The DC-DFT power spectrum (amplitude in magnitudes versus frequency in c/d) of the pulsating red giant RV Cyg, which shows very slow variations, with a nominal frequency of 0.000027 c/d and an amplitude of 0.36 mag. The spectrum shows a pattern of alias periods around one month, and separated by a frequency of about 0.000027 c/d. The blue curve is the spectrum; the red points are the peaks or "top hits."

The present project began with AAVSO data and specific software (VSTAR) which can be and is used by amateur or professional astronomers or students, and this paper is particularly addressed to these users. VSTAR does not explicitly calculate the window function of the data being analyzed, though the equivalent can be done approximately (as long as VLF variability is present) by calculating the Fourier spectrum from f = 0.00 to f = 0.04 c/d (Figure 2). Also, this project began with a study of what turned out to be the alias periods, rather than with a study of the true VLF peaks, which were not obvious

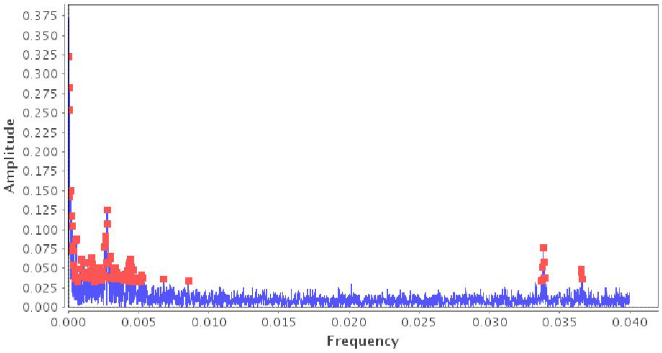

Figure 2. The DC-DFT power spectrum (amplitude in magnitudes versus frequency in c/d) of the pulsating red giant RV Cyg, from f = 0.00 to f = 0.04 c/d. The pattern is approximately equivalent to the window function of the star. See text for further discussion.

to me when I began. In this sense, this project was carried out "in reverse."

3.4. Other results

In the course of arriving at the eventual (probably) correct conclusion about the one-month periods, I carried out several sets of analyses which, in the end, are not directly relevant, but are listed here.

- Stars with long, strong, coherent periods such as S Per (807 days) and VX Sgr (756 days) and AH Sco (738 days) show conspicuous two-peak alias signals at the expected (almost) one-month periods.
- Stars with strong but non-periodic VLF variations, such as R CrB stars, show a more complex aliasing pattern around one month.
- At high resolution, a typical red giant such as RV Cyg shows a complex aliasing pattern around one month (Figure 2).
- Stars near the ecliptic (such as R Cnc, S Vir, T Sgr, and R Gem) show a stronger aliasing amplitude, relative to the amplitude of the aliased signal, than stars further away from the ecliptic (such as R Dra, S UMa, R UMa, and T Cam).
- Stars which are not expected to have VLF variability (such as δ Cep and η Gem) show little or no signal around one month.
- The aliasing effect does not depend, significantly, on the brightness of the star, all other factors being the same.
- Constant stars should not show alias periods around one month. Four stars which were classified as constant in the AAVSO's old Validation File were studied (CI Ori, Z Gem, S Cha, RY Peg); they actually showed VLF signals, and aliases around one month. Compared with the stars in Table 1, RY Peg was an unusual case: the VLF amplitude was 0.29 magnitude and the amplitude of the one-month alias was 0.17 magnitude, which was much larger than usual, relative to the VLF amplitude. I am not sure why.
- Returning to the 50 stars in Table 1, I found that all of these stars showed VLF signals, almost always non-periodic. The aliasing patterns were complex (such as in Figure 1). Whether the VLF variations are real, or due to small changes in the assumed magnitudes of the comparison stars over time, is not clear.

3.5. Is the one-year Ceraski effect due to aliasing?

I re-analyzed the stars which Percy and Long (2010) identified as having a period at or near one year: SV Aur, RT Car, IZ Cas, AD Cen, DM Cep, XY Lyr, T Cyg, SV Cyg, V449 Cyg, CT Del, and WY Gem. In each case, the standard DC-DFT scan showed a peak (or pseudo-peak) at a very low frequency—0.000100 c/d or less. The amplitude of this peak was typically 5 to 10 times that of the peak which was at or near one year. It thus appears probable that the Ceraski effect is not primarily due to a physiological effect, but is partly or wholly due to one-year aliasing of VLF variability of the star. Investigators still need to be aware of these spurious one-year periods, whatever their cause. As Percy and Huang (2015) have shown, they can lead to incorrect conclusions about multiperiodicity in stars, and about the period distribution in the stars under study.

3.6. Final comments

As a test of the hypothesis that the one-month and one-year periods were due to aliasing of VLF variability of the stars, Dr. Matthew Templeton (AAVSO Science Director) kindly analyzed the VX Sgr data using two different methods: DC-DFT as in VSTAR, and a program using the Roberts *et al.* (1987) CLEAN algorithm. The latter takes explicit account of the window function of the data, and is therefore not subject to aliasing. The one-month periods are not present in the latter spectrum, and the one-year periods—if they exist—are close to the noise level. This one example supports the hypothesis that the peaks occur because the DC-DFT program does not take account of the temporal sampling of the data, which can result in aliasing. CLEANest (Foster 1995), an implementation of CLEAN, is available at https://www.aavso.org/software-directory .

I began the study of periods near one month because I thought that they might be analogous to the periods near one year which were thought to be due to a physiological effect of the visual observing process—the Ceraski effect. It now appears that *both* may be primarily or wholly due to aliasing of the star's VLF variability.

If the star has a more moderate period—tens or hundreds of days, for instance—it may still show one-month aliases, whose frequencies are separated from the true frequency by ± N / 29.5306 c/d where N is usually 1. These aliases will not be close to one month but, like one-cycle-per-year aliases, can be confused with true periods. Figure 3 shows the power spectrum of S Aql, with a period of 146 days. There is a complex system of one-month and one-year aliases.

4. Conclusions

Visual observations have been known, for a century, to contain signals at or close to one year. This so-called Ceraski effect was believed to be due to a physiological effect of the visual observing process. AAVSO visual and V data may also contain a signal at a period at or near one month (29.5306 days). Initially, I thought that the one-month signals were also due to a physiological Ceraski effect, but this study suggests that, in most cases, they are primarily or wholly due to one-cycle-per-

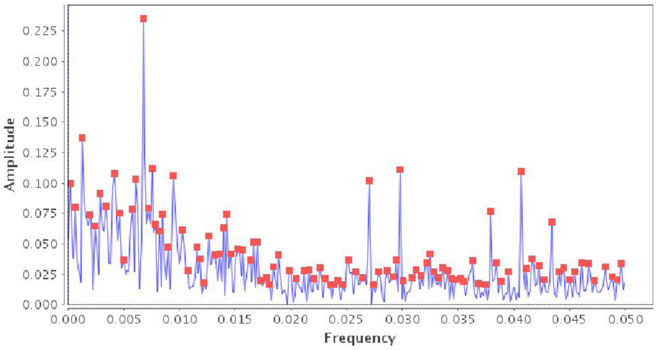

Figure 3. The power spectrum (amplitude in magnitudes versus frequency in c/d) for S Aql, which has a period of 146 days, or a frequency of 0.006849 c/d. There are one-month aliases around 0.027-0.030 and 0.038-0.043 c/d, each with one-year alias peaks.

month aliasing of VLF variability of the star. The amplitudes of the alias peaks are lower, by a factor of 5 to 10, than that of the VLF variability. This study also suggests that, in many or most cases, the one-*year* signals are not due to a physiological effect, but are due to one-cycle-per-year aliasing of VLF variability of the star. A very small (less than 0.02 magnitude) one-month or one-year physiological effect is not ruled out. In any case, these alias or spurious signals must not be confused with true periods in the star. The main goal of this paper is to stress this fact to other users of visual data, especially if using VSTAR.

5. Acknowledgements

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