Time-Series Photometric Surveys: Some Musings

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1 Introduction

Time-Series surveys are designed to detect variable, transient, rare, and new astronomical sources. They aim at discovery with a goal to provide large samples of "this and that". They are not designed to provide detailed study or analysis of individual objects. Detected sources are classified as variable if they show light and/or motion variations above some survey threshold. We ignore here changes due to uninteresting phenomena such as seeing or focus. What a survey delivers as a variable (or a constant) source critically depends on the photometric precision obtained and the process of data calibration and light curve processing. Observations in different Galactic locations and obtained with different filters (wavelengths) will find different populations of constant and variable sources.

Given the above complexities and nuances of time-series surveys, their interest lies in the sources they discover, especially the variable sources. Of these, the interesting sources are the prime driver of large efforts involving source classification, especially in near real-time. Note "interesting" can mean that a source is rare, highly variable, well understood, poorly understood, capable of follow-up, etc.

Source classification is a complex problem but can become manageable and even highly successful if one limits the total parameter space in which classification is attempted. For example, for a specific time sampling, certain classes of object will or will not be detectable. (This is not as clear cut as it sounds. For example, low amplitude periodic signals, not obvious in the data, can be teased-out of datasets that are long compared to the period.) Total time coverage is another example to consider. Attempts to classify sources from a survey of 30 days in total length with template models for many-hundred day semi-regular variables would be non-productive. Rise and fall times and light curve shape are additional temporal factors to keep in mind. Classification will always improve in accuracy as the number of samples for any given source increases.

Finally, the survey photometric precision will greatly limit the type of variable source that can be detected. Most modern large-area surveys will deliver a bright source single measurement photometric precision near 0.01-0.005 magnitude, with better results planned through co-addition. Controlling systematics using a standard observing protocol and consistent data pipeline reduction procedures will be the keys to reaching these precision limits.

2 Two Illustrative Examples

To illustrate some of thees points, I provide two examples. In the first you see the importance of time-sampling, both cadence-to-cadence as well as longevity. I doubt many could identify the source in the top panel of Figure 1 as a RR Lyrae star of ∼0.5 day period. In fact, this source might be identified as a lower amplitude variable with a period near 1 day.

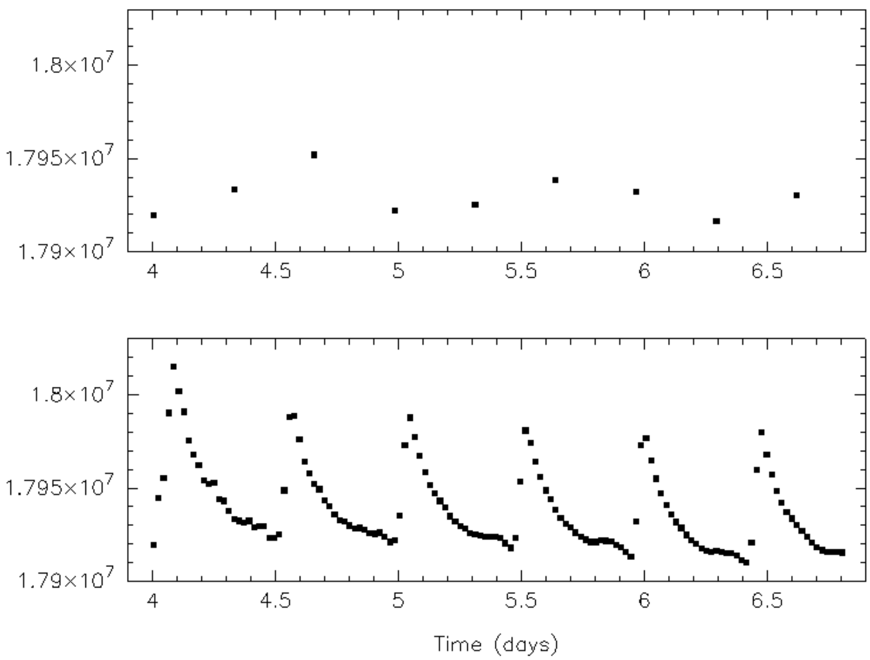

Figure 1: RR Lyrae star observed by the K2 mission during science verification tests. The top panel shows the light curve sampled every 7.5 hours - a proxy for a "once per night sampling". The bottom panel shows the full temporal resolution, sampled every 30 minutes, confirming a ∼0.5 day RR Lyrae star.

In the second example, we are interested in transient sources. Transients are important as they often represent astrophysically interesting sources, such as supernovae, rare objects such as TOADs (Howell et al., 1995), or new astronomical discoveries. Figure 2 shows a recent example of a source that was believed to be interesting based on its very blue color selection and a past observation revealing outburst-like behavior. However, upon the onset of a detailed Kepler monitoring program, the source

(BOKS 45906, Feldmeier et al., 2011) was found to be very faint (near 22nd magnitude) and boring. That is, it showed essentially a complete lack of "interesting variations". After nearly a year of observation, BOKS 45906 redeemed itself, showing large amplitude, transient behavior and rapid flaring. This highly variable source fell back into obscurity about 1.5 years later, again becoming "boring". Today we believe the object is some sort of short period (56.5 min) interacting binary (Ramsay et al., 2013).

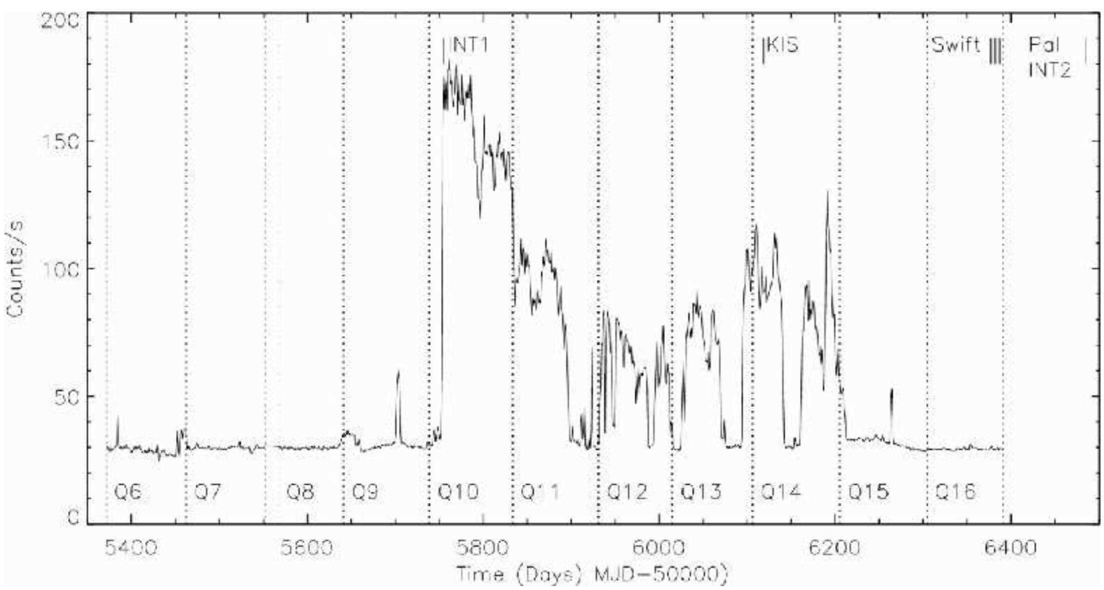

Figure 2: The Kepler light curve of the interacting binary star BOKS 45906, covering 1000 days, sampled every minute but plotted as 1 day bins. The time unit is in MJD - 50000.0. Note the long period (first year of data) showing effectively no variation - a boring source - followed by the rapid transient behavior (post day 5750). Suddenly, BOKS 45906 became very interesting!

3 Predicting Variable Sources in a Survey

Variability in a survey is dominated by low-amplitude, non-periodic sources. Periodic variables, such as pulsating stars or eclipsing binaries, make up only about 10% of all variables observed. This one fact alone has large ramifications for source classification, as non-periodic sources are tremendously difficult to categorize, especially the multitude with low modulation amplitudes. The number of variable sources, both periodic and non-periodic, that a survey will detect appears to be a universal function (see Howell 2008; Tonry et al., 2005) and, assuming relatively good sampling, is related to the survey's photometric precision in magnitudes (σ) as follows (Fig. 3):

$$\%\text{Variable} = -23.95(\log\sigma) - 39.52.$$

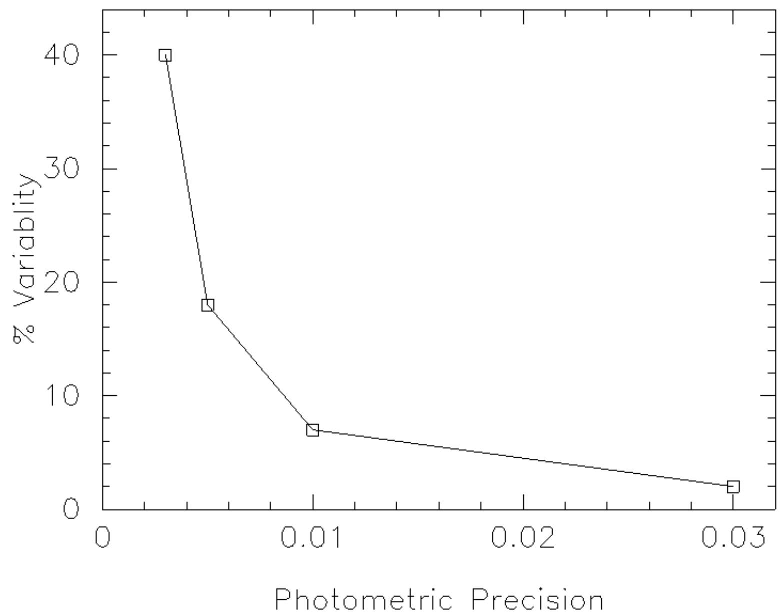

Figure 3: Survey variability fraction can be predicted. We show the universal relationship of the percentage of sources that will be found to be variable (both periodic and non-periodic) vs. the best photometric precision (mag) of the survey.

4 Conclusions

Our expectations for the findings and results from a survey, whatever they might be, are sometimes wrong. Surveys all have biases. Keep them in mind and try to avoid them in your thinking or at least realize they are present. Surveys are wonderful large-scale experiments. Some lessons learned, based on trail and error and their pitfalls as well as their successes, are as follows.

Variable objects are often highly useful probes of fundamental properties in astrophysics. Remember, just because a source is variable does not mean that it is periodic; don't confuse the two. Only $\sim$10% of all variable objects will be periodic. The periodic sources, however, are much more easily classified and often much more astrophysically important and useful. The non-periodic variables, while in the vast majority, are the least understood. Perhaps they are full of potential, waiting to teach us much about the universe.

One can predict the percentage of variables that a survey will detect using an apparently robust relationship. Such predictions are highly useful in order to assess the intrinsic value of a survey and allow data collection and analysis requirements to be specified (e.g., Ridgway et al., 2014). Such a ubiquitous function is probably telling us something very important about the nature of variability.

Spectroscopy of discovered variables may not always provide an answer as to source identification. Some sources, especially those with small intrinsic photometric variations, may not be spectroscopically variable. Remember, traditional analysis techniques tend to yield traditional results. New and different analysis techniques, such as sonification of variability (Tutchton, R., et al., 2012) may help to reveal new insights.

Keep Watching the Skies!

I'd like to thank my many collaborators on the Kepler/K2 team as well as those many others with whom I have variable relations. I'd particularly like to acknowledge the *Hot-Wired* organizers for their initial idea and continued effort to bring together the diverse talents that are needed to study and understand the transient universe.

References

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