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New Methodology for the Reanalysis of Low Signal Small Bodies

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Abstract

Most small bodies are faint and often produce low quality lightcurves. Using tools from statistics and signals analysis we can improve the signal-to-noise ratio and period detection of archived lightcurves. We emphasize reanalyzing scientifically interesting targets and known binaries.

1. Introduction

Ground based observations of minor planetary objects such as asteroids and comets is an inexpensive and effective way to investigate the history and evolution of our solar system. One particular investigation involves measuring the change in brightness of an object over time, its lightcurve. Under normal conditions a small body is approximated, to first order, by a tri-axial ellipsoid. The rotation of a body varies the reflective area of the object, producing a lightcurve whose amplitude varies with the reflective area. The rotational period can be determined by observing these variations. Additional amplitude variations can indicate the object's shape as well as major surface features such as craters. There may also be additional variation which occurs regularly but with a different period than that of the rotation, indicating the presence of a moon or secondary object. This secondary period, in conjunction with Kepler's equations and additional estimates of volume obtained from infrared flux measurements, provide bulk density estimates of the body; together with spectral type and meteorite analogues, this can be used to estimate the object's porosity [1].

We adapt tools developed over the past decade in the fields of statistics and signals processing to improve the analysis of photometric lightcurve data. Some of these routines, such as wavelet period analysis, are less sensitive to noise compared with traditional Fourier techniques. Other techniques, such as those based on Bayesian statistics, are able to reduce the apparent level of the noise based on information contained within the signal as well as prior information on the construction of the signal.

2. Methodology

In our analysis, when the complete photometric dataset is present, we use new centering techniques to improve the SNR of our photometry. We then take these lightcurves, or ones obtained from the archive, and use Bayesian statistics in denoising the data to further improve the signal to noise ratio. Accurate approximations for the periods present will then be generated from Szego polynomials, to be used as the starting points in phase dispersion minimization. The resulting periods are then compared to a wavelet transformation to investigate whether the period is localized or possibly changing in time.

2.1. Denoising

Bayesian denoising, based on Bayesian statistics, estimates the denoised values from the structure of the recorded data and prior knowledge on how the signal is constructed; it has been shown to reproduce signals more faithfully than other techniques [2].

2.2. Wavelet Period Analysis

Wavelets use a system of basis functions which are localized in the time domain with primary span of the basis functions proportional to the size of the feature, i.e. frequency, in consideration. This is similar to a windowed Fourier Transform, but with the width of the window proportional to the frequency of the transform, allowing investigations at specific time and amplitude scales.

2.3. Szego Polynomial Frequency Analysis

Determining periodicities with methods such as Fourier and wavelet analysis is done by a process analogous to guess and check. The signal is projected on a basis of a particular frequency, producing a coefficient representing how prevalent that frequency is. This is reliant on testing the correct period and is sensitive to high levels of noise. Szego polynomials [3] offer an approach where the end result will asymptote to any frequencies which are present, independent of large numbers of iterations.

2.4. Phase Dispersion Minimization

In phase dispersion minimization, [4] the time value associated with each data point is mapped to a modulus of some primary period, creating a set of phase values ranging from zero to one. A median filter is then applied to the data to create a model from which residuals can be calculated. The period is then varied with a minimizer to determine which value produces the lowest residuals.

3. 549 Jessonda

As an example of a reanalyzed lightcurve, 549 Jessonda has a published period from the lightcurve database of 0.124 days, seen in Figure 1. We then create a low order Szego polynomial with this data to look for periodicities and note a post transformation period at 0.231 days. Using a minimizer on our phase dispersion routine near the Szego result we find a minimum at 0.247 days with a phase curve shown in Figure 2. We find this curve more likely for two reasons. First it is bi-modal, a typical trait of asteroid rotation curves. Secondly, and more importantly, while our minimizer does find a local minimum at the published period (0.097), the minimizer finds a lower value (0.075) at a period 0.247 days.

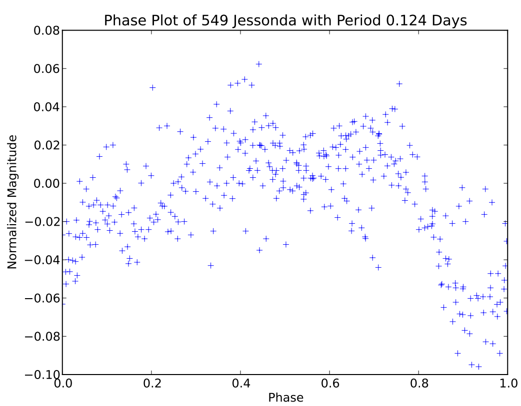

Figure 1: Phase plot of 549 Jessonda using the published period of 0.124 days

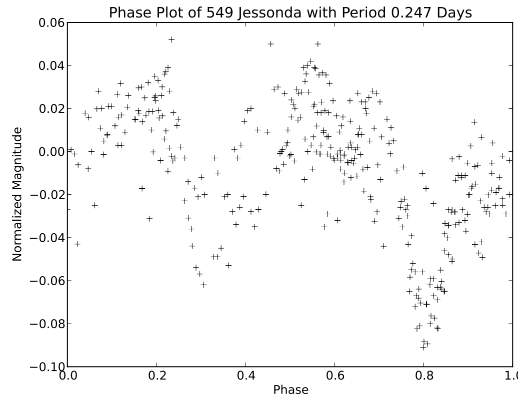

Figure 2: Phase plot of 549 Jessonda using a period of 0.247 days

4. Summary and Conclusions

We find that new and adapted tools can successfully interpret periodicities in low quality small body lightcurves. These estimates can then be used for spin statistics, planning missions, or discovering and estimating binary properties.

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