Detection of Periodic Variability in Simulated QSO Light Curves

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Introduction

Modern surveys of the sky, such as the Sloan Digital Sky Survey (SDSS), have collected huge amounts of data (20 TB for SDSS), requiring the development of automated analysis methods. The Large Synoptic Survey Telescope (LSST) will gather even more data than the SDSS did (one SDSS equivalent per night), and identify several million QSOs. This requires a search method for candidate eclipsing binary QSOs that can be applied to these very large data sets. Recently the author participated in research which employed the Lomb-Scargle periodogram (Lomb 1976, Scargle 1982, Horne & Baliunas 1985) to test ~9000 spectroscopically confirmed QSOs from SDSS Stripe 82 (S82) for periodic variability (see McLeod et al. 2010, hereafter M10). Periodic variability has been suggested as one of the observational characteristics of a binary black hole system (Komossa 2003).

Goal

The Lomb-Scargle periodogram software developed for the research reported in M10 could be useful for searching for periodic variability in a large population of QSOs. This algorithm needs to be tested for possible use with the LSST, to see whether it can be used to identify candidates for further examination in the LSST data set. If a large set of light curves were constructed, it would be possible to determine the likely number of QSOs exceeding the false alarm probability, and other features of the output from this software.

Creation of Light Curves

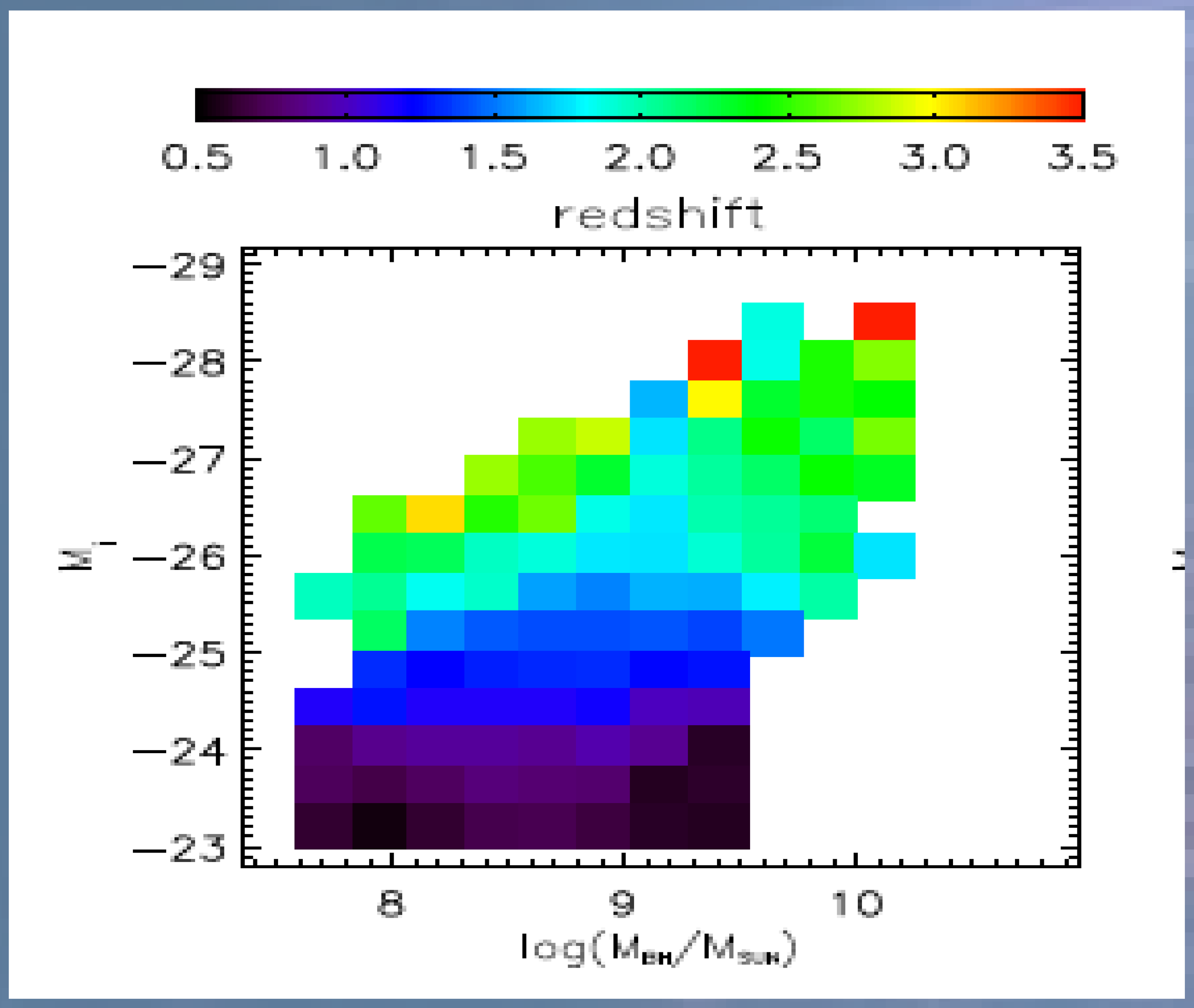

Figure 1

Approximately 1x10^6 QSO light curves were generated using the damped random walk model (Kelly et al., 2009; Kozlowski et al., 2010; M10) as follows. The input parameters to the model were the characteristic time scale, *tau*, and the rms variability on long time scales, or structure function, *sf*. These input parameters were determined using the scalings with black hole mass (M_{BH}), absolute magnitude (M_i), and redshift found by M10. These physical parameters were drawn from the distribution shown in Figure 1. After generating ~83,500 well-sampled light curves, each light curve was resampled to the 12 different simulated r-band LSST cadences from Delgado et al. (2006; ~200 observations spread over 10 years) to obtain ~1x10^6 total light curves.

After the light curves were generated in this fashion, each light curve was analyzed with the Lomb-Scargle periodogram method. If the maximum power spectral density value was above the level given by the false alarm probability, *fap*, then the curve became part of a set used for further examination.

Results

We found that for high *fap* values, the actual number of light curves which exceeded the *fap* level was less than the theoretical value by an appreciable amount. For a *fap* value of 5%, there were 13,294 (1.3%) light curves that exceeded that level, for a *fap* value of 1%, there were 4696 (0.47%), and for a *fap* value of 0.1%, there were 1035 (0.1%).

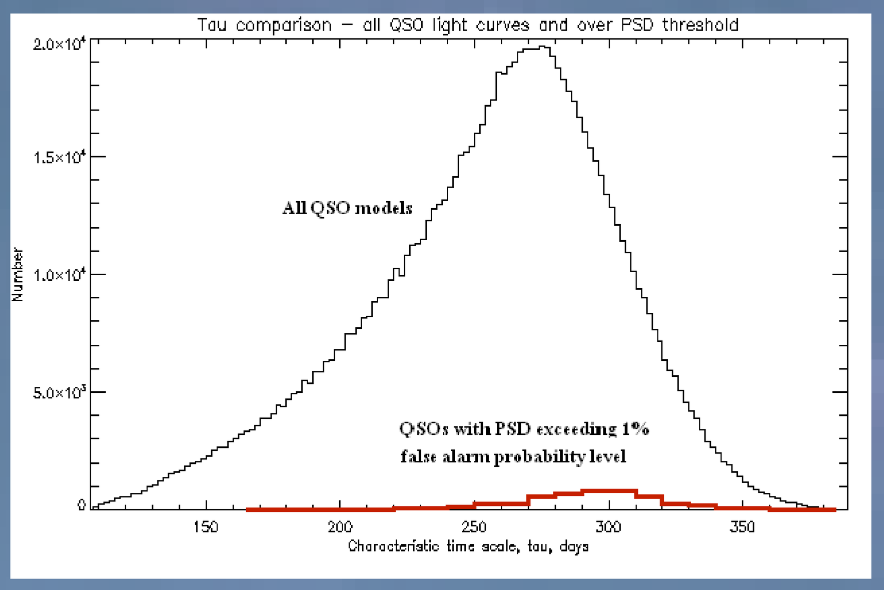

Figure 2

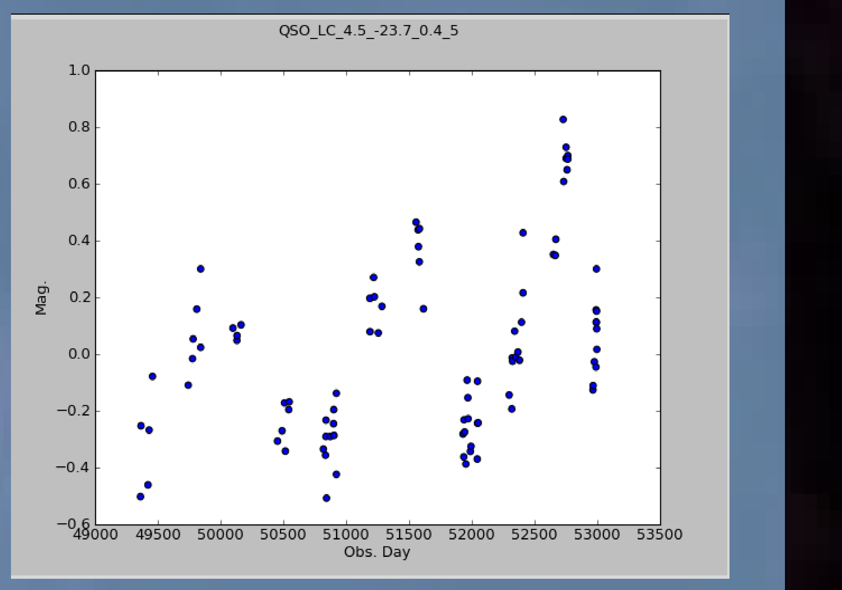

Figure 3

Figure 2 shows that values of *tau* for QSO models with PSD exceeding the 1% *fap* level (red histogram) are distributed differently than those for all the QSO models (black histogram). This bias is due to the fact that when *tau* is long, only a few "oscillations" are observed over the duration of the light curve, causing the periodogram to mistake the damped random walk behavior for a periodic behavior. Figure 3 shows an example light curve with *tau* = 346.5 days, and a supposed, significant period of 1374.75 days.

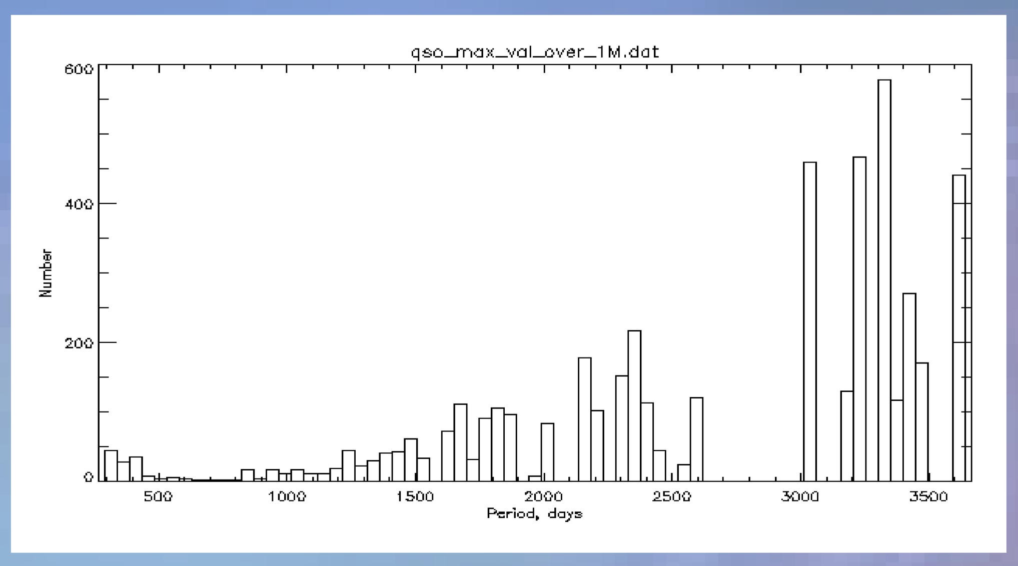

Figure 4

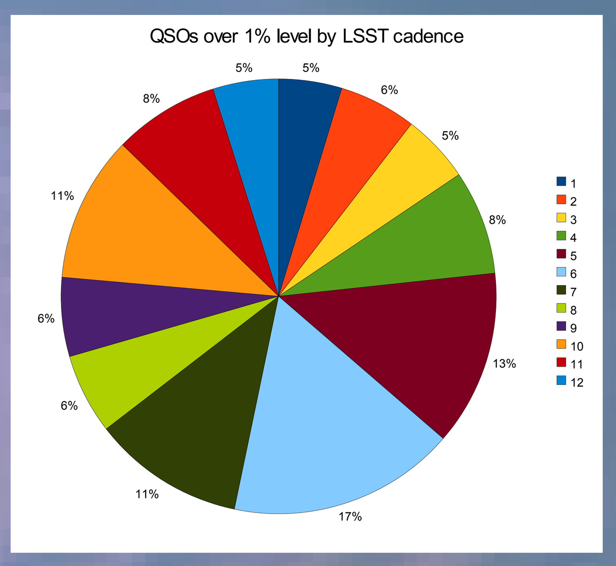

Figure 5

Figure 4 shows the distribution of the periods found by the Lomb-Scargle software. This value is taken as the frequency at which the maximum PSD value has exceeded the 1% *fap* level. It should be understood that this histogram is a superposition of all 12 cadences. Since each cadence has a different overall duration and pattern, the histograms for individual cadences are much simpler. The likelihood of a PSD maximum clearly decreases with decreasing period values. Figure 5 shows the comparative percentages of the number of QSO models found to exceed the 1% *fap* level for each of the cadences. There is a marked difference between the various cadences here, showing that some of the cadences allow many more periodogram results for which the 1% *fap* level is exceeded. Therefore, the results obtained by using the Lomb-Scargle periodogram method can be greatly influenced by the pattern of the observations used.

Conclusions

This work shows that the Lomb-Scargle periodogram method may be useful for detecting potentially periodic behavior in QSO light curves in a large-scale survey such as the one to be carried out by the LSST. However, even with *fap* as small as 0.1%, the large LSST sample would yield 1,000 **false** candidates, which are biased to longer variability time scales for individual accretion disks. Therefore, the future claims for binary black holes based on Lomb-Scargle analysis of LSST light curves will have to be interpreted with caution. Candidates identified by this method would have to be examined individually.

References

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