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Cadence optimisation and exoplanetary parameter sensitivity

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Abstract. To achieve maximum planet yield for a given radial velocity survey, the observing strategy must be carefully considered. In particular, the adopted cadence can greatly affect the sensitivity to exoplanetary parameters such as period and eccentricity. Here we describe simulations which aim to maximise detections based upon the target parameter space of the survey.

Keywords. methods: data analysis – planetary systems – techniques: radial velocities

1. Introduction

Large-scale radial velocity surveys for extra-solar planets require a great deal of planning, particularly in terms of instrument considerations and the selection of targets. The duration of the survey will affect the sensitivity of the survey to different regions of period space. Additionally, the cadence of the observations affect the detection of short and long period planets and the overall planet yield. We present simulations of different observing strategies and demonstrate the change in sensitivity to a planetary period, mass, and eccentricity. These results are used to calculate the relative frequency of planet detections for various ranges of orbital parameters. By simulating a selection of cadence configurations, the optimal cadence for a given survey duration and observing constraints is estimated. The techniques presented here may be applied to a wide range of planet surveys with limited resources in order to maximise planet yield.

2. Simulation Framework

To investigate the detection efficiency properties of various radial velocity observing programs, we constructed a suite of simulated datasets using a FORTRAN code which also performs the analysis, as described by Kane, Schneider, & Ge (2007). The parameters of the initial simulation are based upon those of the Multi-object APO Radial-Velocity Exoplanet Large-Area Survey (MARVELS) (Ge *et al.* 2006). The stellar properties were estimated from Tycho-2 stars selected for observation by MARVELS for 60 separate fields. The noise model for the simulation was produced from the current and planned performance of the instrument and used to generate the radial velocity data. The cadences were defined by the number of observations per month during bright time. An example cadence can be conveniently expressed as 888, meaning 8 observations per month for 3 consecutive months. Since we are concerned with exoplanet parameter sensitivity, each dataset was injected with a planetary signature, the parameters of which were randomly chosen from a uniform distribution including mass, period, and eccentricity. In this way, > 4 million datasets were produced for each cadence simulation. Figure 1 represents an example simulated dataset, showing the radial velocity amplitudes and noise model.

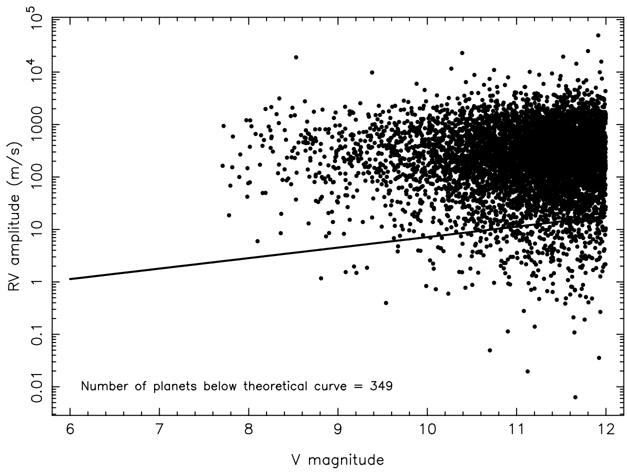

Figure 1. Radial velocity amplitudes of the planetary signatures along with the noise model for a small sample of datasets.

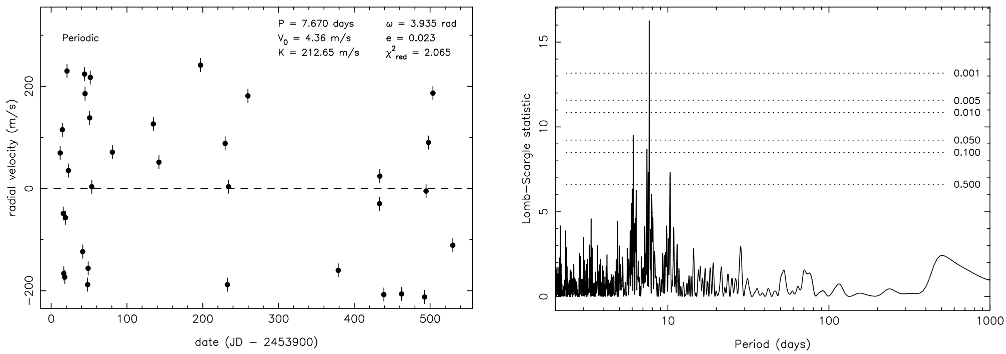

Figure 2. A simulated dataset for an 18 month cadence configuration (left) along with the accompanying periodogram (right).

3. Detection Criteria

The code written for the task of sifting planet candidates from the data uses a weighted Lomb-Scargle (L-S) periodogram to detect a periodic signal. The number of false detections resulting from this technique depends upon the periodic false-alarm probability threshold one adopts as the detection criteria. We selected this threshold for each cadence by producing a large number of datasets with no planets injected, then executing a Monte-Carlo simulation to determine that threshold which yields the required maximum number of false detections. In addition, we distinguish between those detections with unique and ambiguous periods based on the number of significant peaks in the periodogram.

Shown in Figure 2 (left) is a typical dataset from an 18 month cadence simulation. Figure 2 (right) also shows the corresponding periodogram where the dotted lines indicate various false-alarm probabilities.

4. Cadence Results and Planet Yield

For each cadence configuration, the simulated datasets were passed through the described detection algorithm and the results sorted by period, eccentricity, and sensitivity

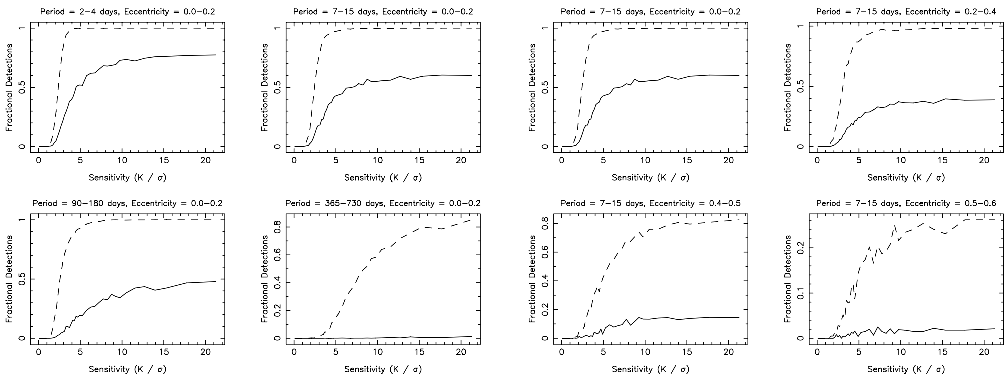

Figure 3. Detection efficiency results for the 888 cadence configuration, with the 4 plots on the left showing sensitivity variation with period, and the 4 plots on the right showing sensitivity variation with eccentricity.

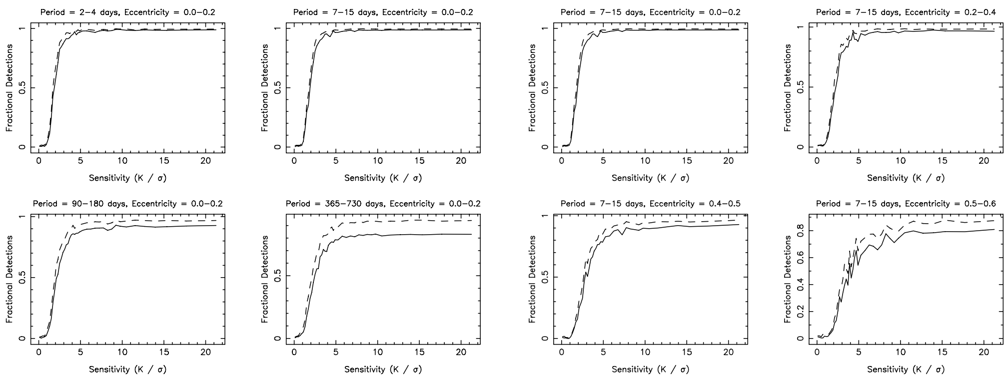

Figure 4. Detection efficiency results for the 771111111000222222 cadence configuration, with the 4 plots on the left showing sensitivity variation with period, and the 4 plots on the right showing sensitivity variation with eccentricity.

(K/σ). The results for the 888 simulation are shown in Figure 3, where the dashed line indicates all detections and the solid line indicates only unique period detections. The four plots on the left show the period dependence for a circular orbit and the four plots on the right show the eccentricity dependence for a period range of 7–15 days. The detection efficiency of the 888 cadence performs moderately well for short-period planets with relatively circular orbits, but suffers greatly in the long-period and mid-high eccentricity regimes.

A far superior plan is to use slightly more measurements spread over a much longer time-scale. An example of this is an 18 month cadence with 33 measurements distributed in a cadence configuration described as 771111111000222222. The results of this simulation are shown in Figure 4 in which it can be seen that the detection efficiency for both period and eccentricity fare significantly better than in the 888 case.

A large number of cadence configurations have been investigated in this manner. Given the parameter sensitivities derived from the cadence simulations, we can now use the known distribution of exoplanetary parameters to calculate the planet yield for each cadence. Table 1 shows the planet yield predictions, unique and total detections, from a subset of the cadences which, given uncertainties in stellar properties, provides a useful comparison. Included in this table is a simulation in which the measurements were

Table 1. Sample of cadence simulations performed with planet yields.

measurements	cadence	unique	total
15	111111111000111111	31	41
24	741111111000111111	88	94
33	771111111000222222	173	200
33	36 months uniform	184	187

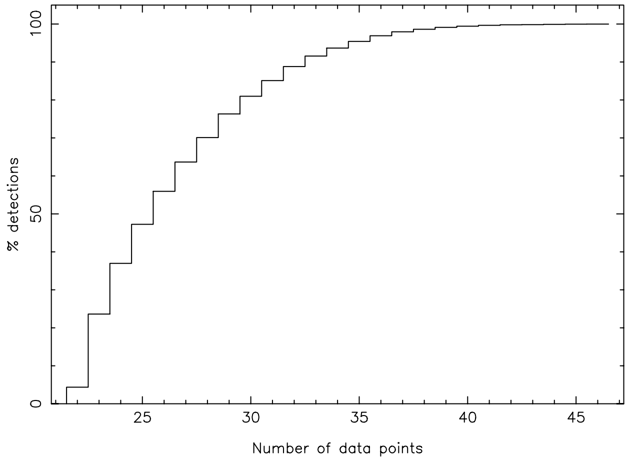

Figure 5. Cumulative histogram of the number of unique detections per measurement bin for a given cadence.

distributed uniformly over a 36 month period, avoiding monsoon seasons such as those experienced in Arizona.

There is a clear trade-off between the number of measurements and the number of unique detections. The choice of cadence therefore largely depends upon the amount of follow-up resources available. Figure 5 is a cumulative histogram of the number of unique detections for a given cadence. Beyond 30–35 data points, the fractional increase in unique detections becomes negligible, therefore suggesting that it would be most useful for increasing planet yield to change targets beyond this point.

5. Conclusions and Future Work

These simulations show that the choice of observing cadence can have a major impact on the exoplanetary parameter sensitivity. For example, reducing the number of measurements from 33 to 15 has a devastating impact on the planet yield. Furthermore, restricting the 33 measurements to 18 months rather than 36 months increases the sensitivity to short-period planets. The detection of mid-high eccentricity planets are biased against by the current algorithm, but this is being addressed by investigating the inclusion of higher order fourier terms. Since there is a continuum of possible cadence configurations, techniques to perform a more systematic search of cadence "parameter space" are being developed to determine optimal cadence solutions.

References

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