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STARE Transit Detection Capabilities

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Abstract. We evaluate the transit detection capabilities of the STARE experiment in a real observing run. To this end, artificial transits have been added to 480 light curves of stars from STARE data, varying their amplitudes, periods and phases. A matched filter algorithm was then applied for the transit search. Detection probabilities of over 60% can be mantained for transits of 20 mmag depth for periods up to 4 days, with tolerable false alarms counts.

1. Introduction

Ground-based transit searches are a promising method to detect giant extrasolar planets. Several on-going projects are now under that path, and some new projects are quickly being developed. The STARE project (URL in references), which detected the first transits of an extrasolar planet around a solar type star (Charbonneau et al 2000), uses a 9.9 *cm*, $6.1 \times 6.1\ deg^2$ Schmidt telescope to obtain high precision photometry of several thousands of stars in the galactic plane, with magnitudes typically between $9.5 < R < 13$. Built and initialy tested at HAO (Boulder, CO), it is currently observing from the Observatorio del Teide at the Canary Islands. It was moved there in June 2001, and the first set of light curves from a field pointing at Cygnus (centered at SAO 69072, $RA = 19h54m42s$, $DEC = +36°59'44''$) is currently under analysis, looking for real transits. To have an estimation of what we are able to achieve with real data, we present the results of an exercise, following the one outlined by Doyle et al. (2000), that consists in inserting artificial transits in real light curves and measuring the recovery percentage, as a function of the period and amplitude of the inserted transits.

2. The Data

The first set of light curves obtained from Observatorio del Teide begins at JD= 2452118.7 and spans aproximately 90 nights. The field is extremely crowded, obtaining up to 100000 detections of stars above a threshold of 5σ above the mean sky value with the DAOPHOT find routine, in a 5 exposures averaged

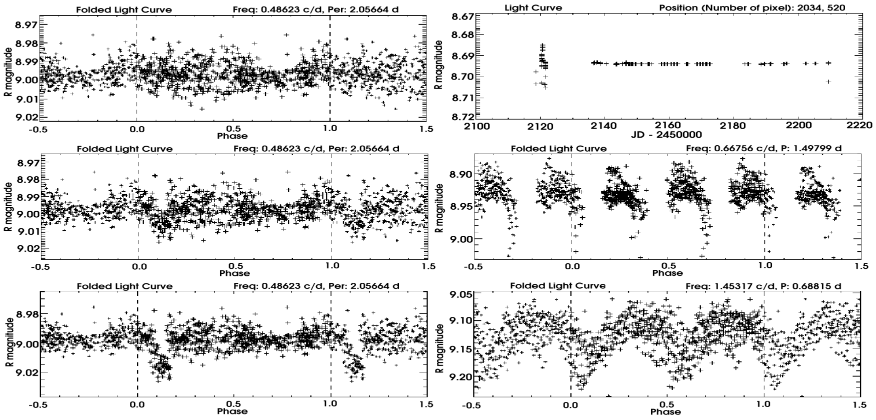

Figure 1. Left (from top to bottom): folded light curves of one sample star, with no transits, 10 mmag and 20 mmag transits. Right (from top to bottom): different examples of false alarms that are easily discarded by visual inspection of the light curves: a star close to the CCD edge, extinction correction not fully accomplished, and an eclipsing binary, which produces a high value of the maximum detection statistics.

image. The exposure time employed was 107s. With a readout time of approximately 13 s this gives roughly one point in the light curves every two minutes. All the data were taken in the R filter, but color information was also obtained for data reduction, after B and V images. Data were averaged in 15 min bins, to decrease the dispersion of the points, as well as to reduce the amount of data and the computing efforts. The final data consist of light curves of the $\approx$ 14000 brightest stars. We used the second 480 brightest stars that didn't saturate in our images for this exercise.

The next step was to add artificial transits to these 480 stars. Square transits with a fixed duration of 3 hours were added, and new sets of light curves were obtained, with transit depths of 20 and 10 mmag, for 9 different periods ranges (from $P \approx 0.5$d to 5d, in 0.5d blocks). Thus, we ended with 18 sets of 480 light curves in which to apply the matched filter algorithm for transit detection. Each set of 480 stars consisted of 10 subsets of 48 stars with equal transit period and random uniformly distributed phases, with the period being incremented by 0.05d in each subset. We can see in Figure 1 (left) how transits of different amplitude show in the light curve of one star, folded with the period of the transit.

3. Results of the Artificial Transit Search

The matched filter transit search algorithm folds the light curve in a set of periods and phases and then measures the correlation between the folded light curve and that of a modeled transit shape. It then provides as a condensed output a maximum detection statistical value (MDSV) of the different correlations between the transit shape and the folded light curve, together with the period and

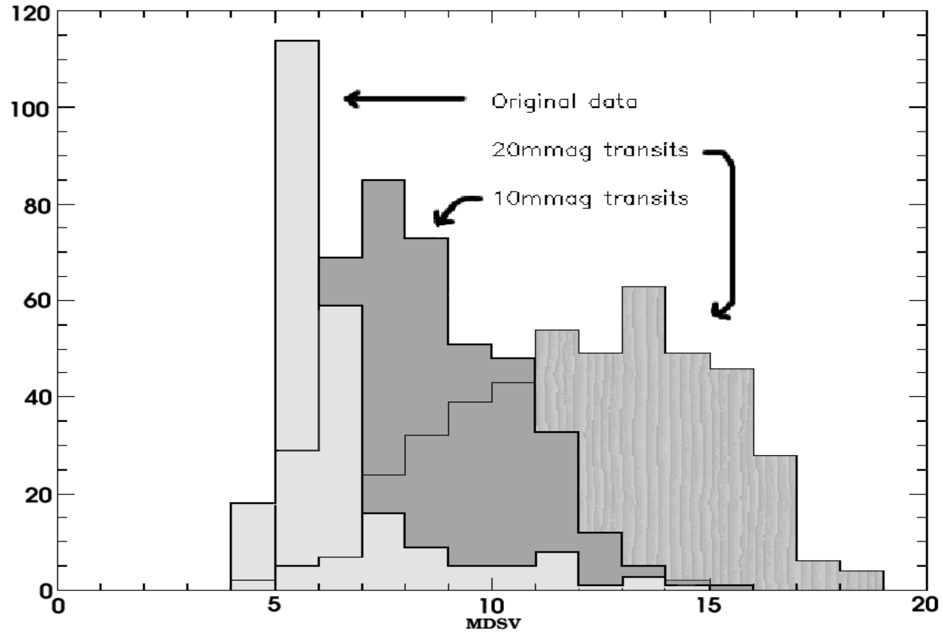

Figure 2. Histograms of the maximum detection statistical value (MDSV) for the three sets of data. The period range used for the transit search was [2.0,2.5]d. From these histograms, one can choose a threshold value of the detection statistic as a function of the number of false alarms one wants to accept.

phase at which this occurs. If we plot histograms of the MDSV for a limited period range search, we obtain results like those of Figure 2.

With these histograms, one can have an idea of the threshold to choose in order to have an estimation of the number of false alarms one has to inspect to see if they are indeed transits. In this work, we call false alarm everything that produces a value of MDSV above the threshold, and is not a transit. According to this definition, variable stars and poor-quality light curves (with close-to-edge effects, or extinction corrections not fully accomplished) will then be considered false alarms. In Figure 1 (right) we plot some real examples of false alarms obtained from the original set of light curves. Many of these cases can easily be discarded by visual inspection. With this information, one can have an idea of how many stars in the whole Cygnus field will yield false alarms when we fix the threshold.

The result of the transit search in the light curves is summarized in Figure 3. With threshold values of 9 or 10, the total number of false alarms in the whole field will still be not so big as to make a visual inspection of the light curves something impossible. The threshold of 10 will yield to approximately 800 false alarms, while the value of 9 leads to 1100 in the 14000 stars observed at the Cygnus field.

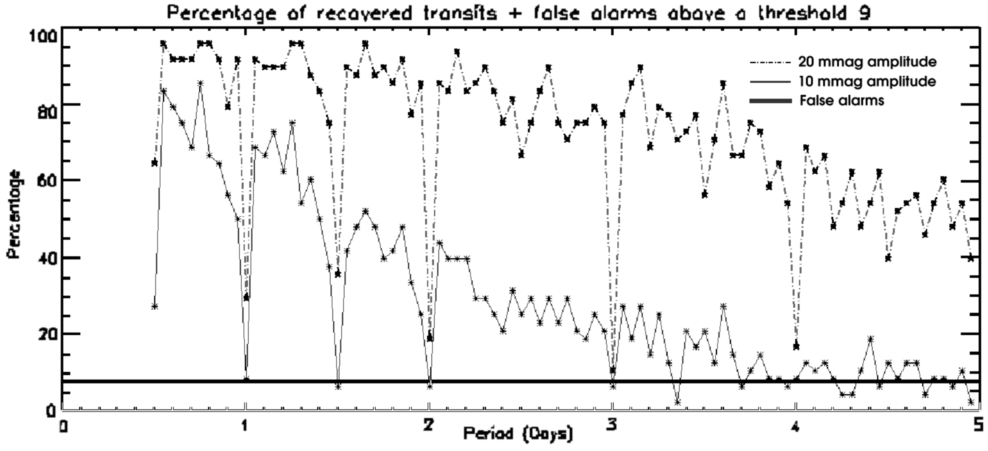

Figure 3. Percentages of recovered transits above a threshold of 9 as a function of the period of the transit added. Each point is the percentage from a 48 stars sample. The mean value of false alarms (as defined in the text) in the whole period range is represented as the horizontal solid line. The low values at the integer and half-integer periods are because these periods are ignored by our transit search algorithm, to avoid false alarms due to daily gaps.

4. Conclusions and Future Work

The detection capabilities of STARE in real data strongly depend on the period of the searched transit, as well as on the amplitude. In these data, the detection probability of a 20 mmag transit with a period between 4 and 4.5 days is roughly the same as the detection of a 10 mmag transit in the 1-1.5 days range. The use of a threshold of 9 instead of 10, while increases the false alarms, also rises the detection probabilities a value of around 10% at both transit depths.

Our next step will be the application of this acquired knowledge to the whole observed field of Cygnus, to obtain a set of transit candidates to be confirmed.

Work is currently being done to combine data from several sites. With these combinations, it should be possible to raise these detection probabilities considerably.

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http://www.hao.ucar.edu/public/research/stare/stare.html