EPSC Abstracts
Vol. 6, EPSC-DPS2011-432, 2011
EPSC-DPS Joint Meeting 2011

Directed follow-up strategy of low-cadence photometric surveys in Search of transiting exoplanets. A Bayesian approach for adaptive scheduling

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Abstract

We propose a novel approach to utilize low-cadence photometric surveys for exoplanetary transit search. Even if transits are undetectable in the survey database alone, it can still be useful for finding preferred times for directed follow-up observations that will maximize the chances to detect transits [2].

1. Introduction

Posterior detections of the transits of HD 209458b and HD 189733b in *Hipparcos* Epoch Photometry [1] [5] motivated us to examine *Hipparcos* Epoch Photometry data to look for a way to utilize this survey and similar low-cadence photometric surveys, to detect exoplanets.

In order to predict the best possible future observing times that will maximize the probability of sampling a transit in low-cadence surveys, we chose to use Bayesian inference methods, and especially the Metropolis-Hastings (MH) algorithm. We use a simplified (BLS-like) transit light curve model that is parametrized by five quantities, i.e., the period, phase, and width of the transit, and the flux levels in-transit and ex-transit.

The first step in our proposed procedure is to apply the MH algorithm to the low-cadence survey measurements of a target star, and to produce posterior probability distribution functions of the orbital elements. The next step is to assign to each point in time the probability that a transit will occur at that time. Calculating this probability is easy using the posterior distributions we found in the first stage.

Performing the follow-up observations at the times directed by the algorithm is the final step of the strategy. A combination of both the 'old' data from the survey and the new observations at the directed time eliminates periods that do not fit our new state of knowledge. The procedure is repeated until we detect a transiting planet, or exclude its existence.

2. Directed follow-up of HD 209458

We demonstrate the approach through simulations based on the *Hipparcos* Epoch Photometry data base, and the transiting planets whose transits were already detected there (HD 209458b, HD 189733b), using previous knowledge of the orbital elements of the transit [1]. We show that without any prior information regarding the orbital elements of the planets, it would have been possible to use the available data base of *Hipparcos* to direct follow-up observations for both stars and thus detect the planetary transits in minimal observational effort [2].

Fig. 1 shows an example of the resulting posterior distributions for the orbital period and the transit depth of HD 209458. The most likely period is $P \approx 3.52$ d, which is consistent with the known period of HD 209458b [1], while the other probable periods are spurious periods that fit the data as well, due to the low-cadence of the survey. We examine the most probable time to observe the star in a follow-up observation. The follow-up predictions (the Instantaneous Transit Probability (ITP) function) are shown on the right panel of Fig. 1. The time that was most preferred by our predictions indeed fits inside a transit, meaning it would have been possible to detect the transit with only one follow-up observation conducted after *Hipparcos*, using our proposed strategy.

The final step of the strategy is to perform follow-up observations according to the most significant peak of the ITP. Since the time that has elapsed since *Hipparcos* cause the ITP peaks to be smeared out, we cannot perform current follow-up observations for significant ITP peaks found using the algorithm. Instead, we simulated such observations at a time closer to the completion of the *Hipparcos* mission, and then combined them with the *Hipparcos* data, to recalculate the ITP.

The new histograms of the period and transit depth

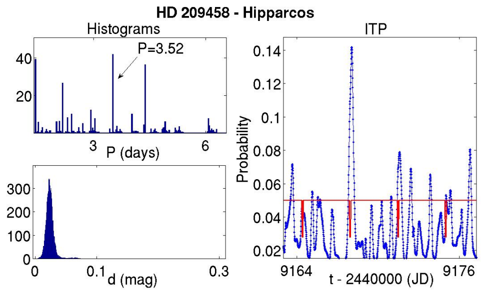

Figure 1: HD 209458 - Left: Histograms of the posterior probability distribution functions of the orbital period and the transit depth found using the MH algorithm for the *Hipparcos* measurements of the star. Right: ITP function for the first year after *Hipparcos* observations, compared with the known transit light curve [1].

for the combined data sets are presented on the left panel of Fig. 2. It is clear that the first observation that could have been preformed using the directed follow-up would have been enough to detect the transit, since the histograms are centered around the parameters of the planetary transit of HD 209458b. The simulated new observation exclude all the spurious periods which the MH algorithm proposed based on the *Hipparcos* data alone. The new ITP that relies on both *Hipparcos* and the new simulated observation fits perfectly with the planetary transit of HD 209458b, and with a high ITP value, which indicates a high detection probability (right panel of Fig. 2).

We performed some sanity checks where we examined test cases where no transit signal appears in the data, and found that the strategy would not prioritize this kind of data for follow-up observations.

3. Summary and Conclusions

We proposed a novel approach to the design of follow-up observations of low-cadence photometric surveys, in a way that will maximize the chances to detect planetary transits. Examples of such surveys are *Hipparcos*, *ASAS*, and *Gaia* as *Hipparcos* successor.

At this stage the simulations we have presented are a feasibility test, based on *Hipparcos* Epoch Photometry. Using *Hipparcos* in such fashion to detect planets is already impractical, due to the long time that elapsed since the completion of the mission. Therefore, we applied our strategy to *Gaia* [4] simulations of known transiting exoplanets [Dzigan & Zucker, in prep]. We found that altough *Gaia* photometry is not

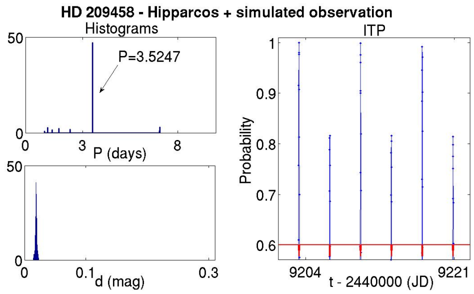

Figure 2: HD 209458 - combined data sets of *Hipparcos* and the simulated observation. The simulation generated four single measurements at the directed time by the ITP most significant peak. According to the known light curve of the transit this peak fits mid-transit time. Left: Histograms of the orbital period and the transit depth found using the MH algorithm for the combination of the data sets. Right: ITP for the first year after the simulation, compared with the known light curve of the transit [1].

aimed for detecting exoplanets, is cases where at least five transit observations are detected by the telescope, a detection will be possible using MH algorithm, and in cases where only three transit observations are detected by the telescope (a possibility which is highly probable for short period planets according to simulations of *Gaia* scanning law), the directed follow-up strategy will be used to prioritize the stars and will enable detecting the transits in minimal follow-up observations. Thus, the approach will hopefully significantly increase the yield of exoplanetary transits detected, thanks to Gaia.

References

[1] Castellano T., Jenkins J., Trilling D. E., Doyle L., Koch D., APJ, Vol. 532, pp. L51-L53 2000.

[2] Dzigan, Y., & Zucker, S. 2011, arXiv:1105.5393

[3] ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200

[4] Eyer L., Mowlavi N., Varadi M., Spano M., Lecoeur-Taibi I., Clementini G., 2009, in SF2A-2009: Proc. Annual meeting of the French Society of Astronomy and Astrophysics, Heydari-Malayeri M., Reyl'E C., & Samadi R., ed., p. 45

[5] Hébrard, G., & Lecavelier Des Etangs, A., A&A, Vol. 445, pp.341-346 2006