EPSC Abstracts
Vol. 6, EPSC-DPS2011-406, 2011
EPSC-DPS Joint Meeting 2011

Potential biases in the detection of planets with TTVs

M. López-Morales (1) and E. García-Melendo (1,2)
(1) Institut de Ciéncies de L'Espai, Campus UAB, Fac. Ciéncies, Torre C5 p2, 08193 Bellaterra, Barcelona, Spain
(2) Fundació Privada Observatori Esteve Durán, 08553 Seva, Barcelona, Spain

Abstract

The Transit Timing Variations (TTVs) technique is a powerful tool to detect additional planets in transiting systems, however planets with large TTVs could be missed by current transit search algorithms. If the period of the TTVs, P_{TTV}, is longer than the time baseline of the observations and its amplitude, A_{TTV}, larger than the timing precision of the data, transiting planet candidates are detected, but with incorrect ephemerides. If P_{TTV} is shorter than the observations time span and A_{TTV} is large enough, constant period search algorithms find an average period for the system, and altered transit durations and depths once light curves are folded. Also, for a large enough A_{TTV}, the transits can get diluted by photometric dispersion. Such detection biases could explain the observed statistical differences between the number of multiple systems among planets detected via other techniques and those detected via transits.

1. Introduction

The presence of other planets in a transiting system can be inferred by TTVs with amplitudes as large as several tens of minutes, e.g. [1,2,3]. Those theoretical predictions have been now confirmed by the detection of TTVs in the multiple-transiting planet systems Kepler-9 [4] and Kepler-11 [5]. However, it is surprising that there are fewer TTV detections of systems with single-transits than multiple-transits systems, since the former are geometrically more likely. The apparent scarcity of single-transit systems was also noticed by [6], who showed how one third of the non-transiting planets discovered at the time were in multi-planet systems. Here we explore some potential transit search systematics that could explain such single-transit system detection biases.

2. Transit search algorithms

Transit planet candidates in current planet search surveys are identified via search algorithms adapted to the specific characteristics of each survey. All ground-based surveys use the Box-fitting Least Square (BLS) algorithm [7] or some modified version of it. BLS folds the light curves over series of periods, and fits the folded curves with narrow box-shaped functions until finding the best least-square fit. The CoRoT mission algorithms [8,9,10,11], follow approaches such as correlations with sliding transit templates, box-shaped signal searches, wavelet transformations or BLS. Some of these algorithms work with folded data, while others use the unfolded light curves. However, all the algorithms, except for [9] and [11] search for strictly periodic signals. Finally, the Kepler mission uses a custom-made transiting pipeline (TPS), which applies a wavelet-based, adaptive matched filter to minimize noise effects, followed by a transit waveform (box-shape-like function) to search for individual transit events in the unfolded data. TPS folds the transit candidate events at strict periodicities, not accounting for TTVs. However, because of the continuous monitoring of targets, the pipeline does flag systems with significant TTVs (e.g. Kepler-9, Kepler-11).

3. Model simulations

We conducted model simulations to assess the effectiveness of current search algorithms for transiting planets with significant TTVs. Our model is a Jupiter-size planet orbiting a Sun-like star with a period P_p = 3.6235 days, impact parameter $b = 0$, a linear limb darkening of 0.61 and 1.3% depth. We simulated series of transits with the length of the observing blocks, observing cadence, photometric dispersion of the light curves, σ_{ph}, and amplitude and period of the TTVs, A_{TTV} and P_{TTV}, as variable parameters. A_{TTV} is defined as a fraction of the orbital period of the planet, or equivalently, a fraction of the orbital phase. For the

TTVs we assume a simple periodic model of the form

$$T_{mid} = T_0 + nP_p + A_{TTV} P_p \sin\left(\frac{2\pi}{P_{TTV}} nP_p\right), \quad (1)$$

where P_{TTV} is in days, n is the number of elapsed orbits with respect to an arbitrary initial transit epoch, T_0, and T_{min} is the mid-transit time of each transit.

We tested values of $A_{TTV} \in [0.0025, 0.02]$, and $P_{TTV} \in [25, 360]$ days. For the simulations we used observational parameters typical of both ground-based and space-borne surveys. Each synthetic light curve is then folded over a range of trial periods, like in BLS algorithms, until the best period is found. Example results are shown in Figures 1 and 2.

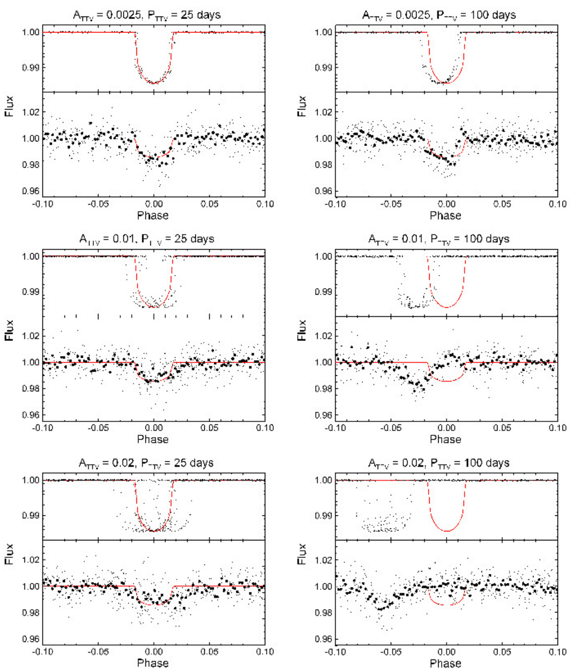

Figure 1: Effect of TTVs for 90-day observing blocks. Top curves in each panel are model Kepler data ($\sigma_{ph} = 10^{-4}$); bottom curves are model ground-based data ($\sigma_{ph} = 8 \times 10^{-3}$). Solid circles are the ground-based model data binned over 0.002 phase intervals.

4. Results

In all simulated cases, a BLS-type algorithm detects transit-like dips for $A_{TTV} \leq 0.02$. However, the characteristics of the curves change with of A_{TTV} and P_{obs}, i.e. the length of the observing blocks. When $P_{TTV} < P_{obs}$ (fig.1, left column), the algorithms find the correct orbital period, but the transits widen and

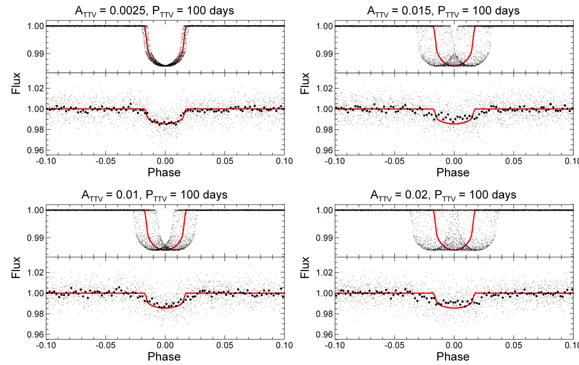

Figure 2: Same as Fig.1, but with 3-year observing blocks, like Kepler.

get shallower as A_{TTV} increases. While the effect will be discernible in Kepler-like data, those transiting planet candidates will be most likely mistaken by grazing binary eclipses in data from ground-based surveys. For $A_{TTV} \gg 0.02$ the transits get completely diluted in typical ground-based data. When $P_{TTV} > P_{obs}$, the algorithms find a perfect transit shape, but an erroneous period and T_0 zero epoch. When $P_{TTV} \sim P_{obs}$ (fig.1, right column), algorithms simultaneously yield a wrong ephemeris and shape-deformed transits. Figure 2 illustrates $P_{TTV} < P_{obs}$, but for 3-year observing blocks. and shows more clearly how the shape of the transits get altered with A_{TTV} . In the case of $A_{TTV} = 0.01$, for example, the folded ground-based light curve resembles a "V" shape, typical of binary star false positives.

References

[1] Miralda-Escudé, J. 2002, ApJ, 564, 1019

[2] Agol E. et al. 2005, MNRAS, 359, 567

[3] Holman, M.J. & Murray, N.W. 2005, Science, 307, 1288

[4] Holman, M.J. et al. 2010, Science, 330, 51

[5] Lissauer, J. J. et al. 2011, Nature, 470, 53

[6] Fabrycky, D.C. 2009, IAU Symposium v253, p173-179

[7] Kovács, G. et al. 2002, A&A, 391, 369

[8] Moutou, C. et al. 2005, A&A, 437, 355

[9] Régulo, C. et al. 2007, A&A, 467, 1345

[10] Carpano, S. & Fridlund, M. 2008, A&A, 485, 607

[11] Renner, S. et al. 2008, A&A, 492, 617