Observational Window Functions in Planet Transit Searches

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Abstract: Window functions describe the probability that an existing planetary transit is detectable in one's data as a function of orbital period. A variety of observing strategies and astrophysical parameters influence this probability in different ways. We give a quantitative insight into this relatively big parameter space spanned by aspects such as the observing cadence, depth and duration of planetary transit, number of nights in an observing run, etc. In our simulations of window functions, we explicitly address non-correlated (gaussian or white) noise and correlated (red) noise and discuss how these two different noise components affect window functions in different manners. We furthermore discuss the consequence of competing effects on transit detectability, and we examine the efficiency of a few selected surveys with respect to certain regions of parameter space.

Introduction

The signal-to-noise ratio (SNR) of a transit detection can be approximated by the following equation (Pont et al. 2006):

$$SNR = \sqrt{\frac{depth^2 n^2}{\sum_{k=1}^{N_{tr}} n_k^2 \left(\frac{\sigma_w^2}{n_k} + \sigma_r^2 \right)}}$$

- **depth**: depth of transit signal.
- **n**: total number of data points observed during all transits.
- **N_{tr}**: total number of transit that occurred during the observing run.
- **n_k**: total number of data points observed during k-th transit.
- **σ_w**: white noise level of photometry.
- **σ_r**: red noise level of photometry.

- **white noise**: uncorrelated gaussian noise (mostly photon & sky noise).
- **red noise**: correlated noise (weather, seeing, tracking, etc), does not follow simple error statistics, independent of brightness or number of observational epochs.

Due to the low signal depth, transits can typically only be detected for the bright stars in one's sample. Though photon noise dominates the white noise portion, red noise is particularly relevant in this regime.

The SNR is dependent on parameters set by observing strategy as well as astrophysical parameters. When the SNR exceeds a threshold SNR, a transit is detectable in the data. For a given period, the value of $P_{detection}$ indicates what fraction of transit phase angles would lead to the detection of the transit.

Unless otherwise indicated, the default parameter values used here are:

- **SNR_detection**: ~ 7.
- **Planet**: Jupiter mass & radius.
- **Star**: solar mass & radius.
- **Observing Run**: 60 consecutive nights.
- **Night**: 8 hours continuous observing.
- **Observing Cadence**: 5 minutes
- **σ_w**: 0.005 mag
- **σ_r**: 0 (**blue line**) ; 0.002 mag (**red line**)

We show the dependence of observational window function upon several parameters. In this presentation, we require that at least two transits were sampled, we assume central transits, uninterrupted observing, circular orbits, and that the number of data points detected in transit is much lower than the number of data points out of transit.

White Noise versus Red Noise

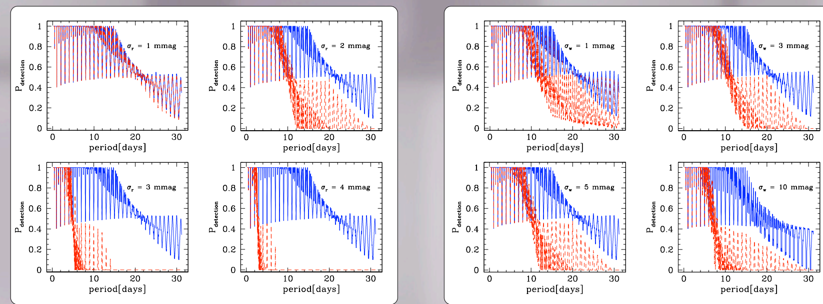

Fig. 1: The consequence of varying the amounts of **red noise (left panel)** and **white noise (right panel)** are illustrated. Parameter values are given in the **light blue box.** In the left panel, white noise is held constant The **blue (solid)** line indicates σ_r=0, the **red (dashed)** line shows different values for σ_r (fixed at 2 mmag in the right panel). **Red noise is by far the dominant noise source in typical ground-based transit surveys, especially at longer periods, showcasing the need for data detrending.**

Observing Run Length

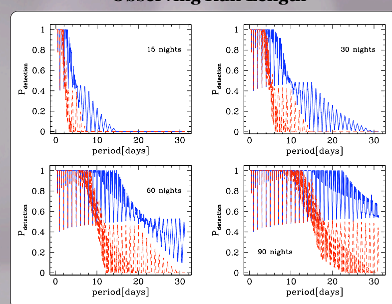

Fig. 2: Influence of **Observing Run Length** (given in respective panel) upon $P_{detection}$, e.g., to increase number of monitored fields in a given number of nights. Parameter values are given in the **light blue box.** The **blue (solid)** line indicates σ_r=0, the **red (dashed)** σ_r=2 mmag. **A careful analysis is required before deciding how to optimally allocate a given number of nights to a variable number of target fields to monitor.**

Observing Cadence

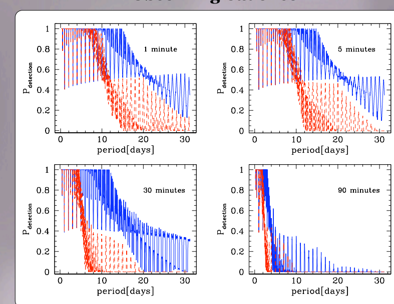

Fig. 3: Influence of **Observing Cadence** (e.g., as a result of moving back and forth between targets) upon $P_{detection}$, given in respective panel. Parameter values are given in the **light blue box. To increase number of monitored targets, it may be worth switching targets on short time scales, if telescope tracking/pointing is very good.**

Transit Depth

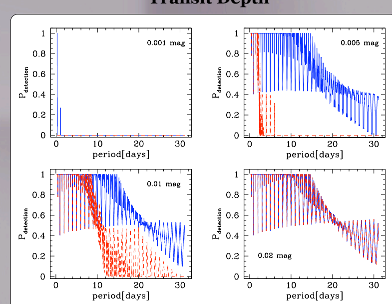

Fig. 4: Influence of **Transit Depth** upon $P_{detection}$, given in respective panel. Parameter values are given in the **light blue box.**. The **blue (solid)** line indicates σ_r=0, the **red (dashed)** σ_r=2 mmag. **Earth-sized planets are not detectable in ground-based transits. When transit depth >> σ_r, the influence of red noise decreases and eventually disappears.**

Length of Night

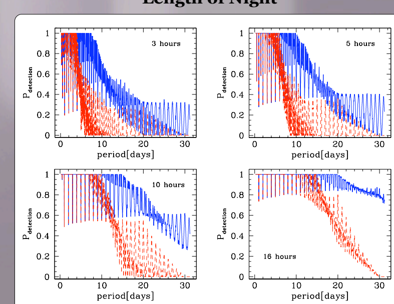

Fig. 5: Influence of **Length of Night** (e.g., as a result of cycling through targets) upon $P_{detection}$, given in respective panel. Parameter values are given in the **light blue box.** The **blue (solid)** line indicates σ_r=0, the **red (dashed)** σ_r=2 mmag. **As the night becomes longer, the spikes in $P_{detection}$ become smaller and disappear for uninterrupted observing.**

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References:
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- von Braun & Ciardi 2008, IAU Proc, 249, 93
- von Braun et al. 2009, ApJ, submitted