Observational Window Functions in Planet Transit Searches

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Abstract: Window functions generally describe, as a function of period, the probability that an existing planetary transit is observed for a given observing strategy. We show the dependence of this probability upon several strategy parameters, such as observing cadence, transit duration, length of observing run, and others. Since the definition of a transit detection is directly related to the signal-to-noise ratio of the observations, we discuss the white noise case as well as statistically correlated (red) noise implications and considerations.

Introduction

The signal-to-noise ratio (SNR) of a transit detection can be approximated by the following equation (Pont et al. 2006, MNRAS, 373, 231):

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

- **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.

In the theoretical absence of any red noise, this equation reduces to:

$$SNR_w = \frac{depth}{\sigma_w}\sqrt{n}$$

The SNR is thus 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 window function indicates what fraction of transit phase angles would lead to the detection of the transit.

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. Typical ground-based numbers are as follows:

- **SNR_detection**: 8 - 10.
- **depth**: 0.01 mag.
- **σ_w**: 0.003 - 0.01 mag
- **σ_r**: 0.002 - 0.005 mag

We show the dependence of observational window function upon several parameters. We note that in this presentation, in contrast to other window functions, we only use the SNR criterion to quantify detections, and do not require that, e.g., a full transit be observed or that data from at least two or three different transits be sampled.

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White Noise versus Red Noise

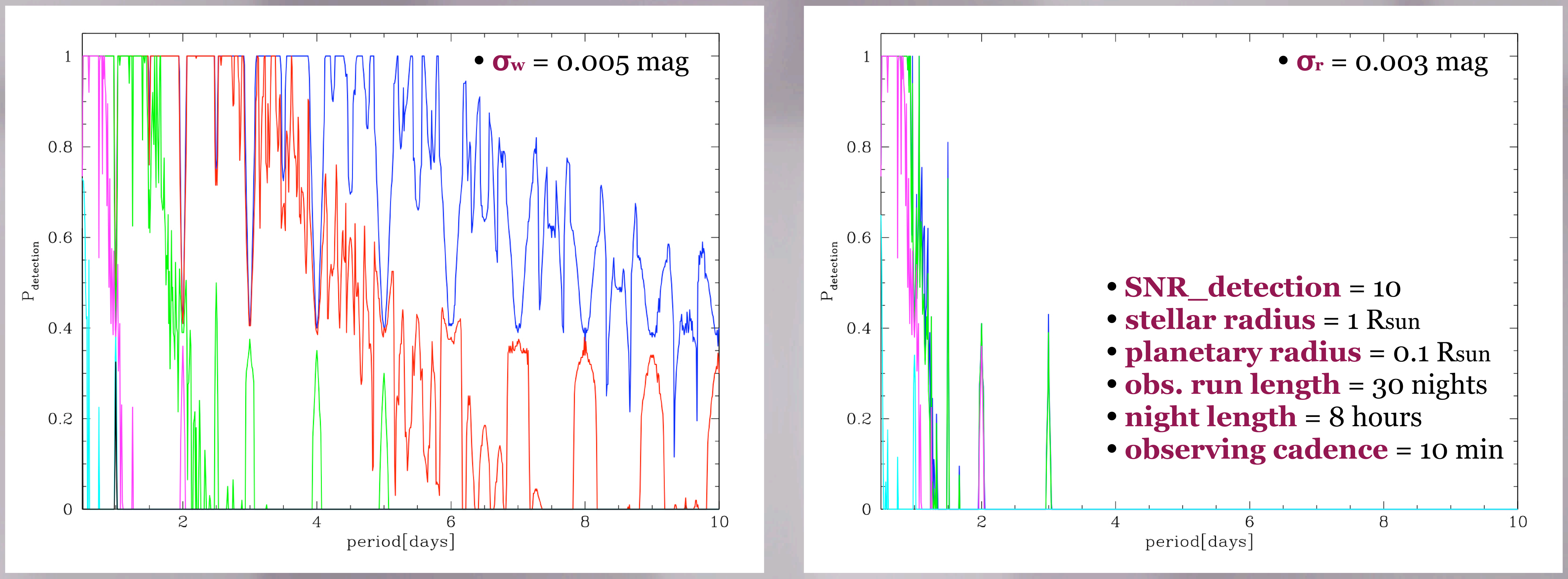

Fig. 1: The consequence of varying the amounts of **red noise (left panel)** and **white noise (right panel)** are illustrated. The ordinate represents the probability with which an existing transit is detected in the data as a function of orbital period, given the listed survey parameters. In the **left panel**, σ_w is held constant at 5 mmag, and **red noise** is set to **zero (dark blue)**, **1 mmag (red)**, **2 mmag (green)**, **3 mmag (pink)**, **4 mmag (light blue)**, and **5 mmag (black)**. In the **right panel**, σ_r is held constant at 3 mmag, and **white noise** is set to **1 mmag (dark blue)**, **2 mmag (green)**, **5 mmag (pink)**, and **10 mmag (light blue)**. Other parameters used for both panels are listed in the bottom right corner of the right panel. **Red noise is by far the dominant noise source in typical ground-based transit surveys.**

Observing Run Length

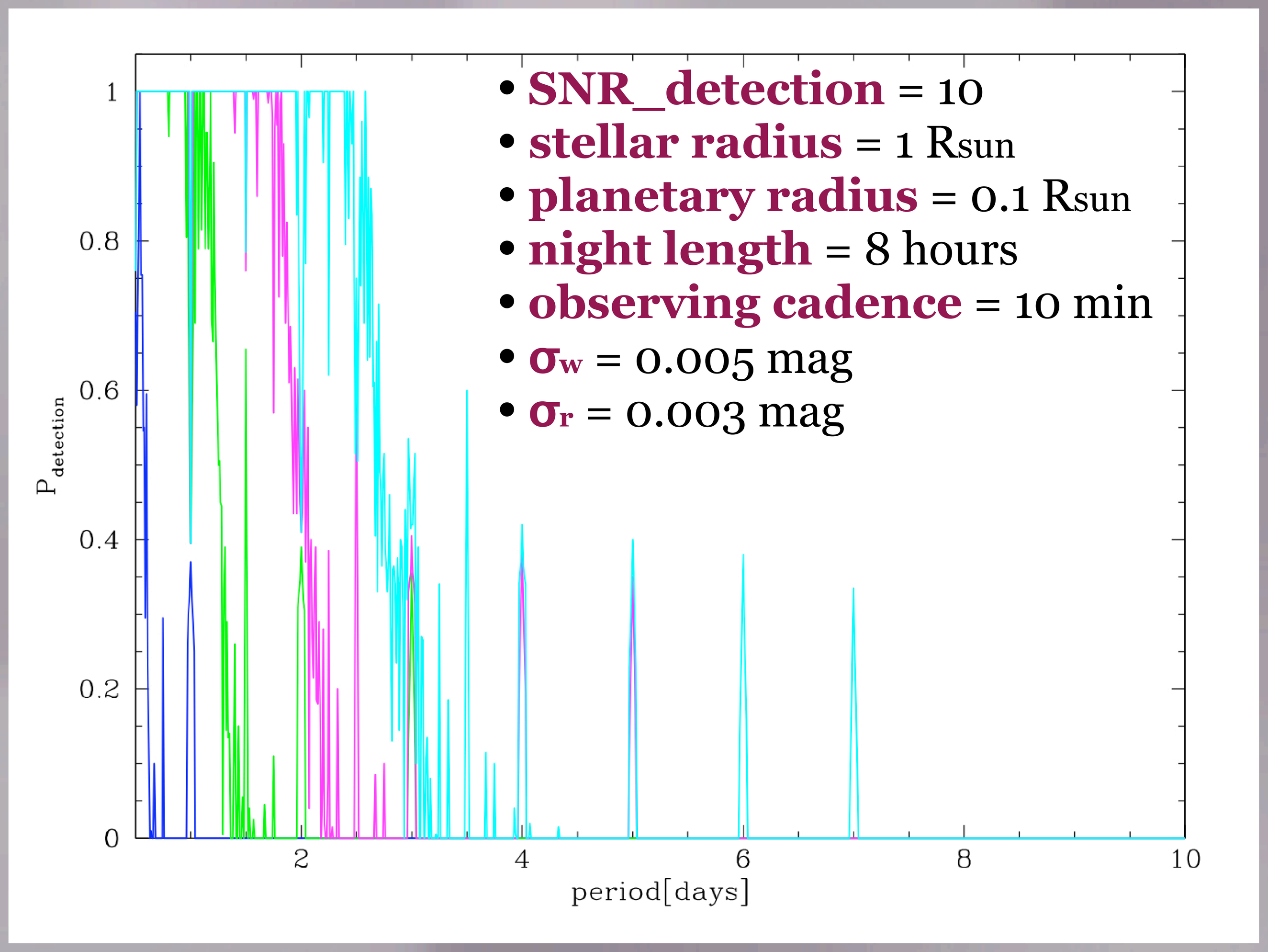

Fig. 2: Influence of **Observing Run Length** upon transit detection probability. All parameters held constant are listed in the panel. The number of consecutive observing nights is set to **20 (dark blue)**, **40 (green)**, **60 (pink)**, and **80 (light blue)**.

Observing Cadence

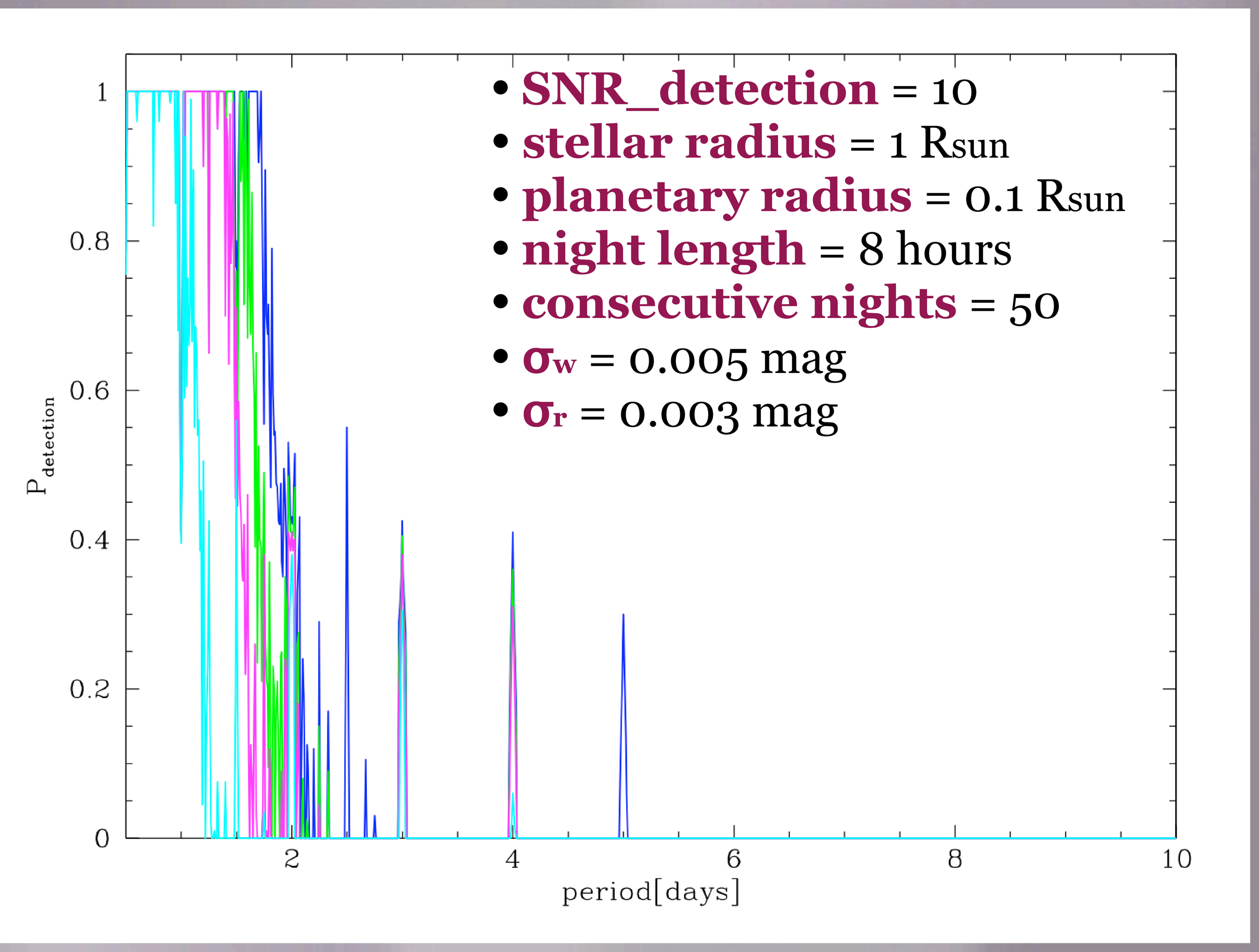

Fig. 3: Influence of **Observing Cadence** (e.g., as a result of moving back and forth between targets) upon transit detection probability. All parameters held constant are listed in the panel. Observing cadence is set to **5 min (dark blue)**, **10 min (green)**, **15 min (pink)**, and **30 min (light blue)**.

Transit Duration

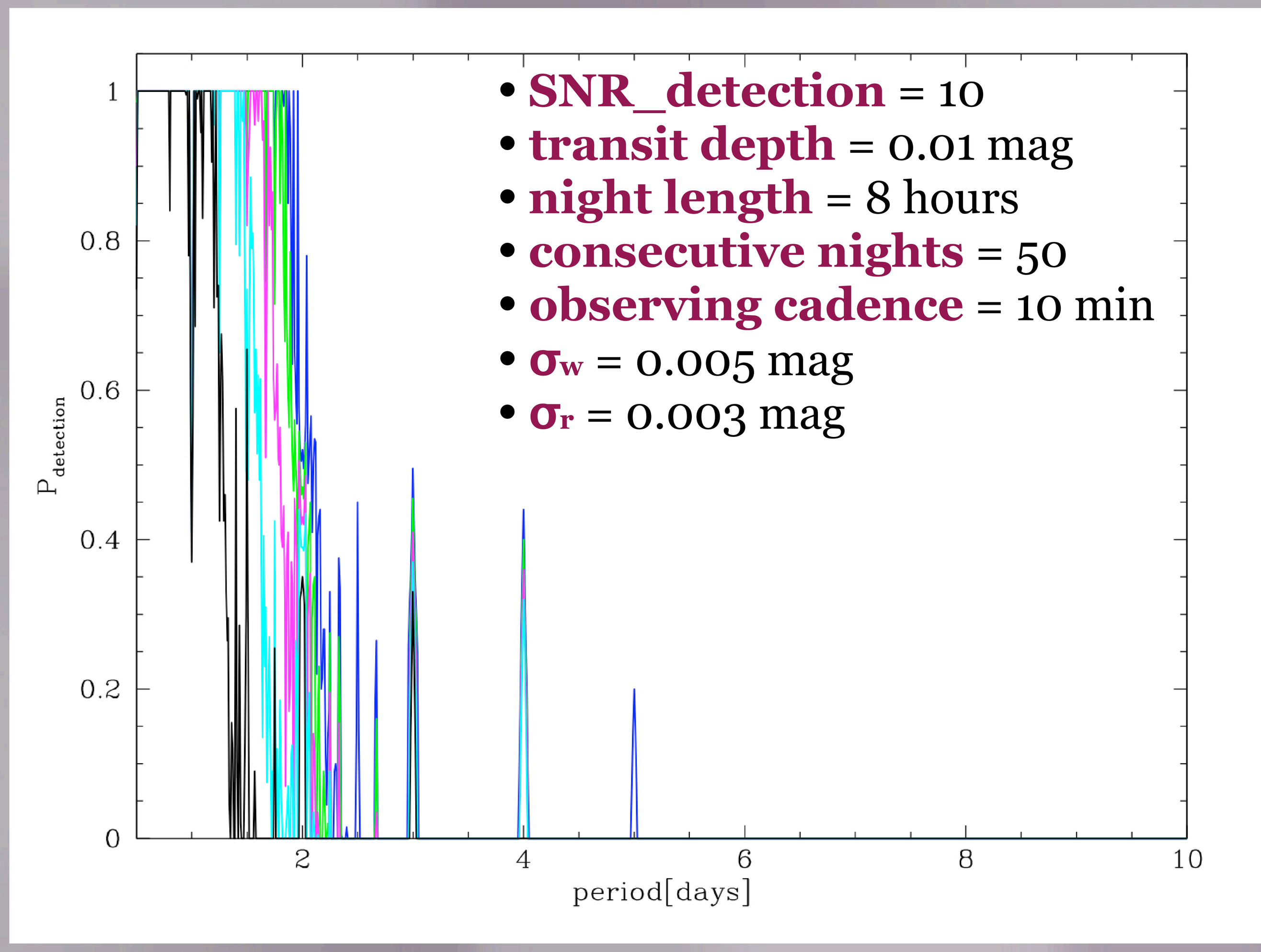

Fig. 4: Influence of **Transit Duration** (e.g., as a result of non-central transit) upon transit detection probability. All parameters held constant are listed in the panel. Transit duration is set to **5h (dark blue)**, **4h (green)**, **3h (pink)**, **2h (light blue)**, and **1h (black)**.

Length of Night

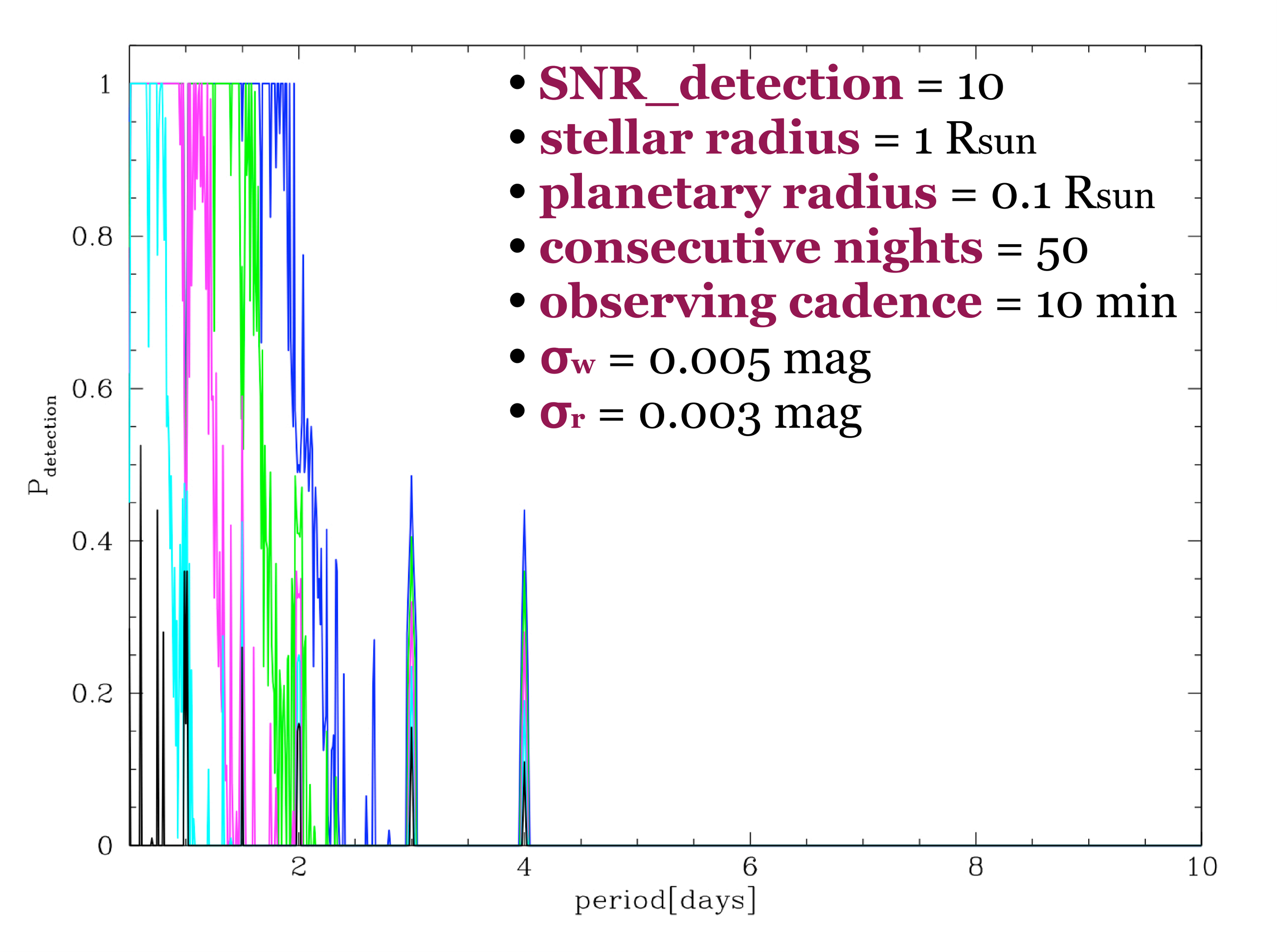

Fig. 5: Influence of **Length of Night** (e.g., as a result of cycling through targets) upon transit detection probability. All parameters held constant are listed in the panel. Length of night is set to **10h (dark blue)**, **8h (green)**, **6h (pink)**, **4h (light blue)**, and **2h (black)**.