An evaluation of the effects of non-uniform exo-zodiacal dust distributions on planetary observations

Dmitry Savransky, N. Jeremy Kasdin, Robert J. Vanderbei[a]

[a]Princeton University, Princeton, NJ USA

Abstract

As the push for a dedicated direct exoplanet imaging mission intensifies, and numerous mission concepts are drafted and refined, a growing concern has been that not enough attention has been paid to the effects of exozodiacal light. As most mission simulations have assumed uniform or smoothly varying exozodi levels, there exists a danger that a potential future planet imager will be unable to succeed in its mission due to 'clumped' exozodi. We have used our existing framework for evaluating the capabilities of direct planet imagers to simulate the effects of non-uniform exozodi on mission outcomes, including modeling the increased integration time that may be required, and the possibility of increased false positives.

Historical Distribution of Local Zodiacal Dust Levels

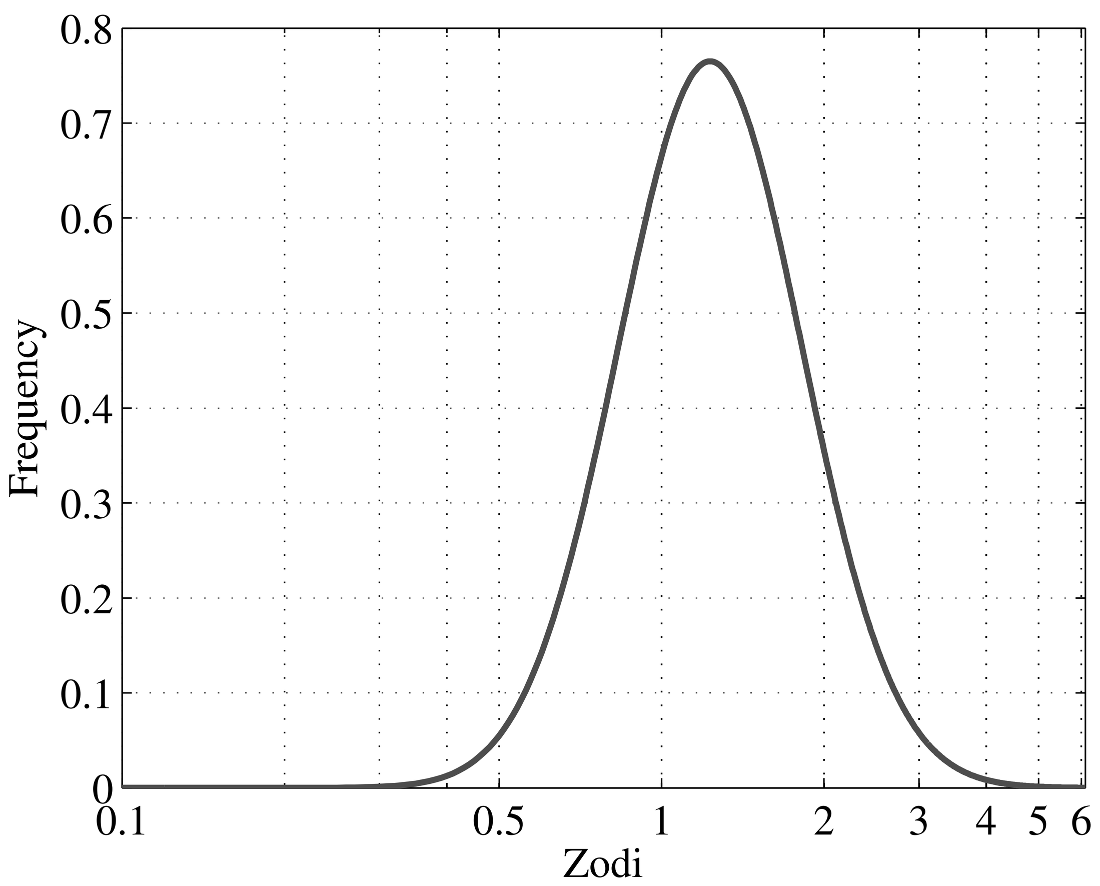

Figure: Historical distribution of solar system zodiacal dust levels. [Kuchner and Farley, 2008]

- Measurements of seafloor sediment isotope concentrations imply that the historical distribution of zodiacal dust in the solar system (over the last 80 Myr) is log normal, with a mean of 1.55 (current) zodi.
- 95% of solar analogs should have zodiacal dust levels in the range of 0.7 to 3.3 zodi if their asteroid and comet populations are similar to those of our solar system.
- For mission with a goal of detecting Earth-like planets, we must consider at least this range of exozodi levels.

Importance of Exo-zodiacal Dust

- One of the most important factors in mission planning is deciding when to stop an observation.
- Decision of whether a planet exists in the field of view is based on bayesian detection algorithm, and depends on estimate of the background (non-planet) signal.
- Exozodi is a major, usually unknown contributor to the background.
- We can calculate the required integration time for planetary detection and spectral characterization for a list of real targets, assuming different exozodi levels. [Kasdin and Braems, 2006, Savransky and Kasdin, 2008]

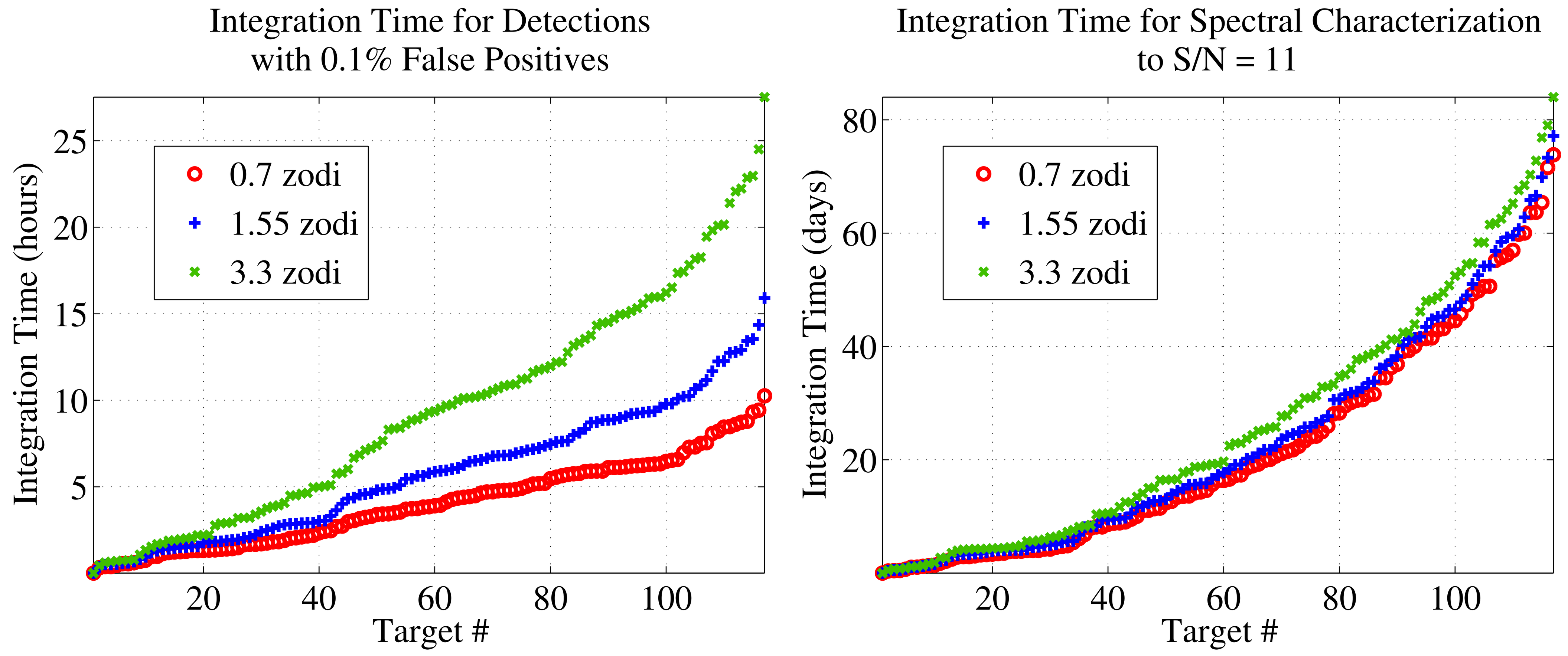

Figure: Integration times for planetary detection with 0.1% false positives, and spectral characterizations with S/N = 11 at the 760nm O_2 feature with resolving power R = 70. The planet is assumed to be 25 magnitudes fainter than the target star, and targets are ordered with decreasing magnitude. The legend numbers are the assumed exozodi levels in zodi.

References

- Kasdin, N. J. and Braems, I. (2006). Linear and bayesian planet detection algorithms for the terrestrial planet finder. *ApJ*, 646:1260–1274.
- Kuchner, M. and Farley, K. (2008). The Historical Distribution of Zodiacal Dust Levels and its Implications for the Direct Detection of Exoearths.
- Savransky, D. and Kasdin, N. J. (2008). Design reference mission construction for planet finders. In J. M. Oschmann, J., de Graauw, M. W. M., and MacEwen, H. A., editors, *Space Telescopes and Instrumentation 2008: Optical, Infrared, and Millimeter*, volume 7010 of *Proc. SPIE*. SPIE.

Exozodi Effects on Mission Science Yield

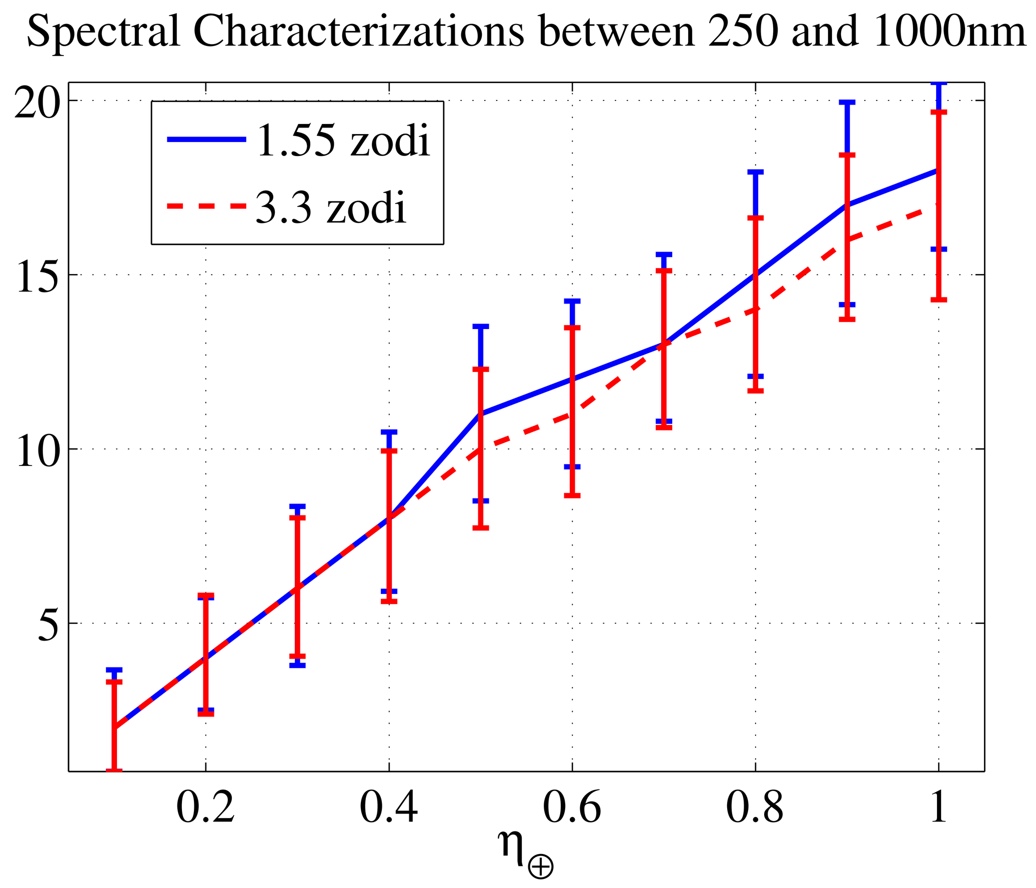

Figure: Total number of spectral characterizations to S/N = 11at the 760nm O_2 feature with resolving power R = 70.

- Generate ensembles of mission simulations for the THEIA mission concept (4m primary diameter telescope and free-flying occulter with 5 year mission and 117 targets).
- Assume varying zodi levels, and frequency of Earth-like planets ($\eta_\oplus$).
- The lines represent median values for 100 simulations at each value of $\eta_\oplus$. Error-bars represent the one-sided deviations of each distribution. The legend numbers are the exozodi levels in zodi.

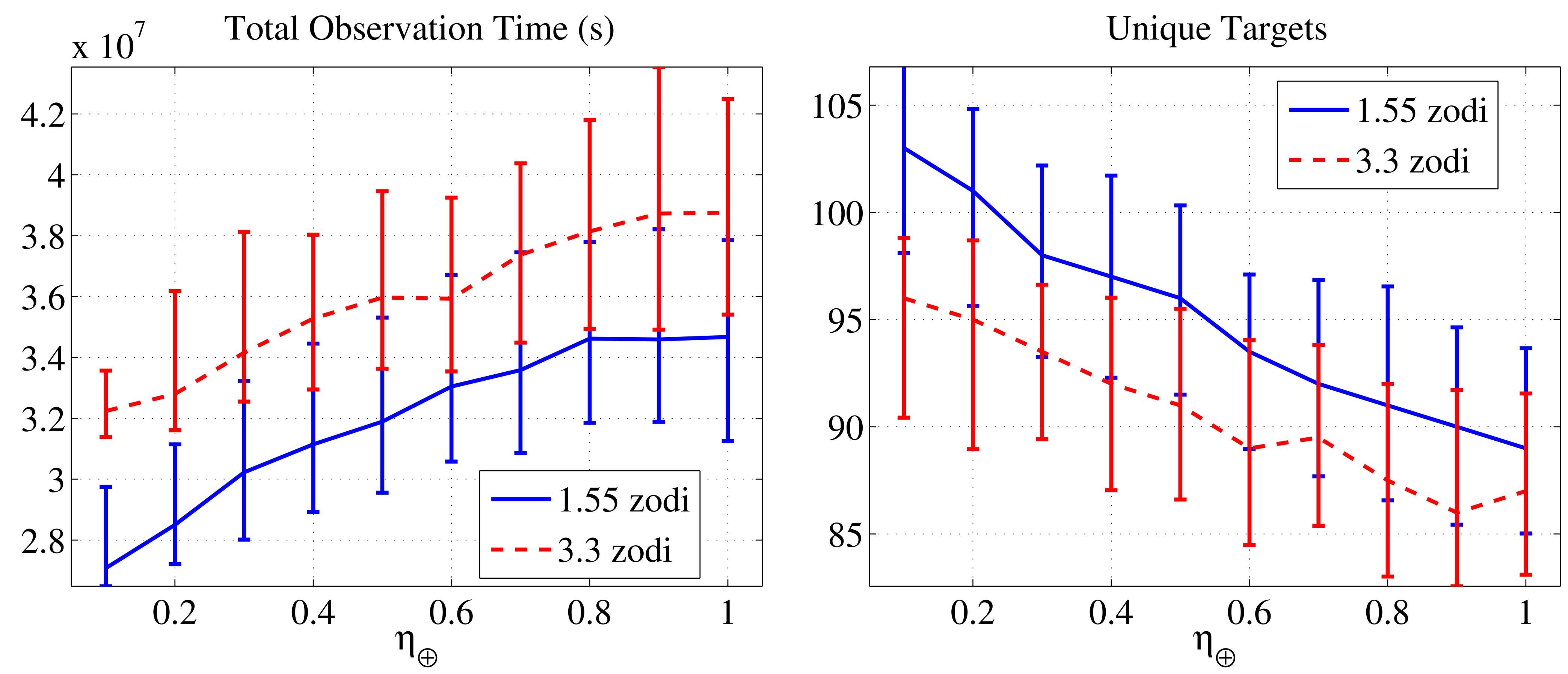

Figure: (a)Total time for planet-finding/characterizing observations over the length of a mission. (b) The number target stars observed at least once in the course of the mission.

Effects of Confusion

- If background cannot be estimated or is non-uniform ('clumped zodi'), false positives will be generated (a planet signal will be 'detected' when no planet exists).
- We model this by increasing the number of false positives generated in simulation while leaving the same integration time.
- False positives decrease overall mission science yield since time is spent resolving them, lowering available observation time for planet-finding.

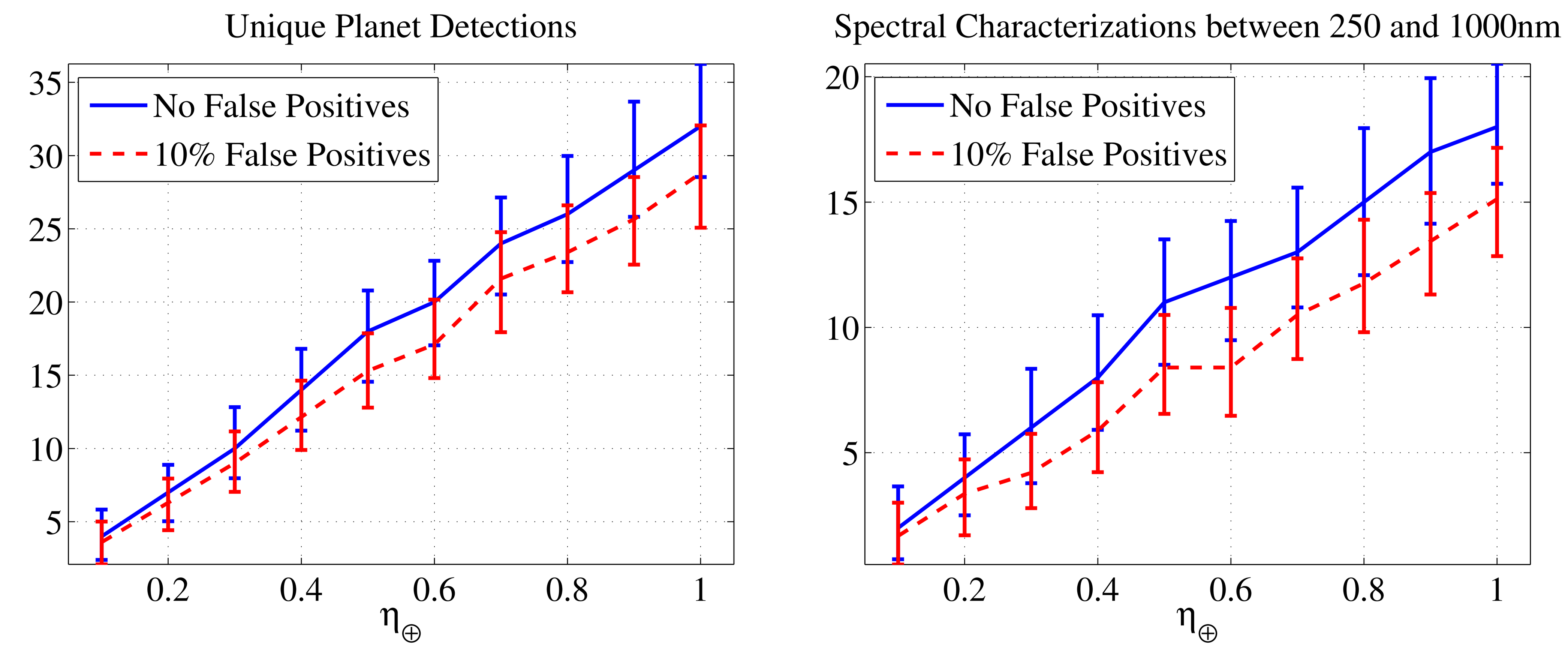

Figure: (a) Number of unique planets found. (b) Number of full spectral characterizations. The two simulations were run with a false positive rate set sufficiently low to produce no false positives, and with a simulated 10% false positive rate.