Performance study of interferometric small-sats to detect exoplanets: Updated exoplanet yield and application to nearby exoplanets

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INTRODUCTION

Nulling interferometry is considered as one of the most promising solutions to spectrally characterize rocky exoplanets in the habitable zone of nearby stars. It provides both high angular resolution and starlight mitigation. It requires however several technologies that need to be demonstrated before a large interferometry space-based mission flies. A small-sat mission is a good technological precursor. Based on a Bracewell architecture[1], this unique satellite can demonstrate some key components (null capability, fiber injection, achromatic phase shifter). Scientific capabilities of such a mission are presented. An exoplanet detection yield is derived, and we show that the detection of exoplanets around nearby stars is feasible.

Three configurations are considered (Tab. 1):
2 CubeSats and a PROBA-size family satellite

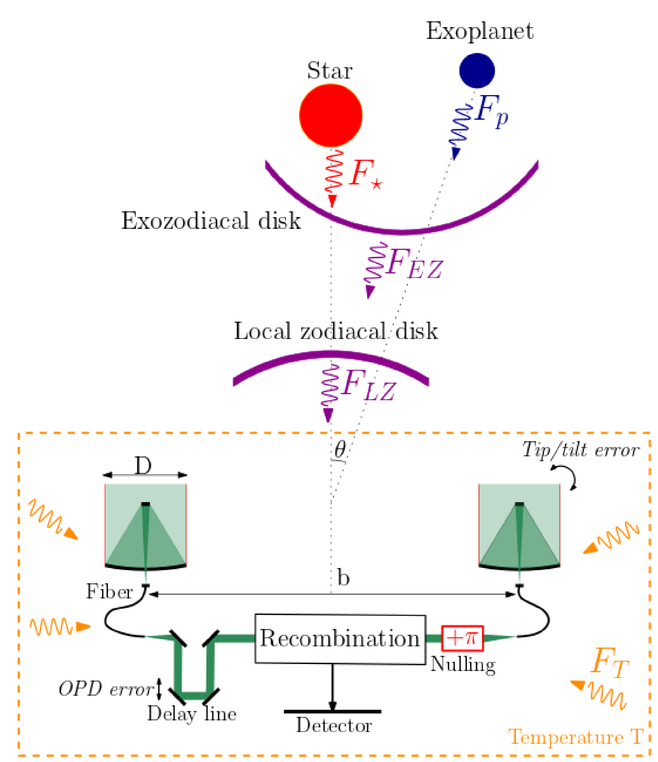


Fig. 1: Schematic presentation of a Bracewell nulling interferometer, represented with the main noise sources used in our radiometric budget. $F_\star$ - the stellar flux; F_p - the planetary flux; F_{EZ} - the exozodiacal flux; F_{LZ} - the zodiacal flux; F_T - the thermal flux of the instrument (temperature T).

	CubeSat 6U	CubeSat 12U	PROBA-size
Size	0.6 x 0.1 x 0.1 m	1.1 x 0.1 x 0.1 m	1 m^3
Baseline length	0.5 m	1.0 m	5.0 m
Pupil diameter	0.08 m	0.08 m	0.25 m

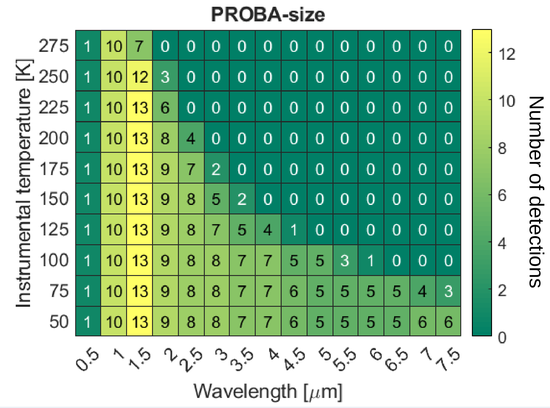
Tab. 1: Three small-sat configurations considered in this study.

METHODS

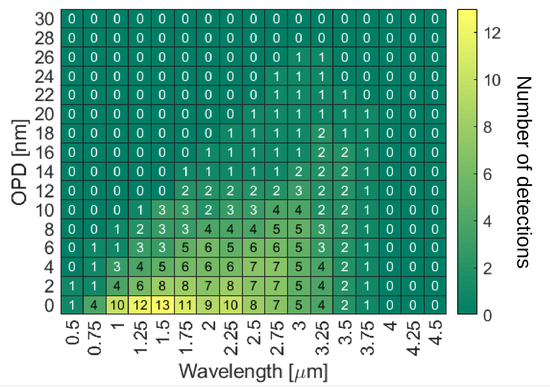
We consider the **28 nearest known exoplanet**. From a radiometric budget[2], the integration time to reach a Signal-to-Noise Ratio (SNR) of 5 is computed. Three main parameters are presented below for the PROBA-size configuration :

- **Effect of the instrumental temperature**
- **Impact of the residual optical path difference (OPD)**
- **Impact of the RMS differential tip/tilt angle**

(a)



(b)



(c)

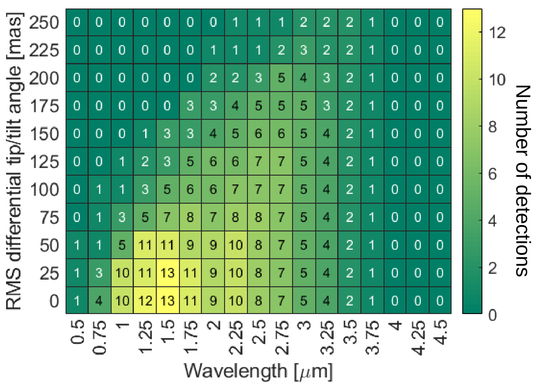


Fig. 2-3-4: Number of detected planets out of the 28 nearest exoplanets with the PROBA-size configuration (Tab. 1) as a function of the operating wavelength (resolution parameter, R = 1.2) and the
(a) the instrumental temperature.
(b) the residual OPD
(c) the RMS differential tip/tilt angle

A planet is considered as detected if the SNR is a least 5 with an integration time of 24 hours.
150 K is considered for case (b) and (c).

RESULTS

- PROBA-concept can not detect all the 28 nearest exoplanets, even with low instrumental temperature. Some planets are too distant from their host star and are out of outer working angle (0.514λ/D)
- **The instrumental temperature has a very limited impact in the 0.5-3.0 µm range. Even at 250 K, it is not the main noise contributor**
- **Only 2 nm of residual optical path difference are sufficient to lost half of the detection at 1.5µm**
- **Above 50 mas, the number of detections starts to decrease to only half of the maximum detection value.**

CONCLUSIONS

1. The instrumental temperature at constant operating wavelength has a lower impact has previously thought
2. Constraints are strong on instrumental stability. Only a few nm of OPD is sufficient to drastically decrease the number of detections. The tip/tilt accuracy is also very stringent
3. CubeSat configurations have very little chance to detect known exoplanets in the vicinity of the Earth.

If the goal is to characterize at least several exoplanets, a larger mission, as a PROBA-one, is needed. It will avoid any uncertainties and will detect exoplanets with more confidence.

REFERENCES

1. Bracewell, R. N., “Detecting nonsolar planets by spinning infrared interferometer,”Nature274(5673), 780(1978). [doi:10.1038/274780a0]
2. Dandumont, C., Defrère, D., Kammerer, J., Absil, O., Quanz, S. P., and Loicq, J., “Exoplanet detection yield of a space-based Bracewell interferometer from small to medium satellites,”Journal of Astronomical Telescopes, Instruments, and Systems6(3), 1 – 20 (2020).

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