TPF-C: Size and Completeness

Sarah Hunyadi and Stuart Shaklan
Jet Propulsion Laboratory, California Institute of Technology

Robert Brown
Space Telescope Science Institute

The Terrestrial Planet Finder Coronagraph (TPF-C) is required to find 30 terrestrial planets, provided that each star has such a planet. This requirement may be evaluated using program completeness [1,2], the cumulative sum of habitable zone search space observed over the duration of the mission. Beyond meeting mission goals, program completeness is used to compare different types of coronagraph designs.

In this study we compare the program completeness of different coronagraph designs:

1) TPF-C FB-1 design,
2) Phase induced amplitude apodization (PIAA),
3) Optical Vortex Coronagraph (Vortex), and
4) New Worlds Observer external occulter (NWO).

For all cases we assumed a habitable zone populated with 10,000 Earth-like pseudo planets uniformly distributed in semi-major axis and having an orbital ellipticity in the range [0, 0.1]. The exozodi level was chosen to be equivalent to the mean Solar System zodi level over the entire habisphere. The central wavelength of interest was 550 nm with a bandpass of 110nm. The throughput for the different mask designs is shown in Table 1.

The TPF-C FB-1 mission design baseline is an 8 × 3.5m elliptical primary mirror with a band-limited 8th order occulting mask. An elliptical mirror allows larger habitable zone coverage in one direction, but requires additional rolls and integration time to circularize the inner working angle. The PIAA, Vortex and NWO designs may be able to utilize a 4m telescope, though this is still under study. Therefore, we simulated program completeness with this reduced-size concept.

For FB-1, PIAA and Vortex, potential targets were required to be at least 95 degrees from the sun. We also assumed 1 hour of overhead per target to account for slew time between targets.

For NWO, we assume a single occulter with the overhead shown in Table 1 and up to 1 full day of integration time per target. We assume that NWO can detect planets at a contrast ratio of 26 magnitudes, while the other designs achieve up to delta magnitude 25.5. We also restricted the potential observable region to a 15 degree latitudinal slew from the previously viewed star. This restriction was combined with an additional constraint on sun-angle that limited the potential targets to be between 45 and 95 degrees from the sun. The results for all cases are shown in the table below.

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[1] Brown, R. A., Hunyadi, S. L., and Shaklan, S. B., A DRM for *TPF-C*: A Design Reference Mission for the Coronagraphic *Terrestrial Planet Finder*.
http://sco.stsci.edu/tpf_downloads/TPF-C_DRM.pdf

[2] Hunyadi, S. L., Shaklan, S. B., and Brown, R. A. Single Visit Completeness Optimization *(submitted to ApJ, April 2006)*.

Table 1: Completeness simulation results.

	Long Axis (m)	Ellipticity	IWA (mas)	IWA (λ/D)	Overhead (hrs)	Throughput	Completeness	# Targets
FB-1	8	Elliptical	65.5	4	1	11%	31.97	66
PIAA	4	Circular	56.7	2	1	28%	70.14	140
PIAA	4	Circular	70.9	2.5	1	28%	50.59	104
PIAA	4	Circular	85.1	3	1	28%	35.25	75
PIAA	4	Circular	99.3	3.5	1	28%	25.02	56
PIAA	4	Circular	113.4	4	1	28%	17.34	33
Vortex	4	Circular	56.7	2	1	23%	65.73	133
Vortex	4	Circular	70.9	2.5	1	23%	48.01	99
Vortex	4	Circular	85.1	3	1	23%	34.12	71
Vortex	4	Circular	99.3	3.5	1	23%	24.46	54
Vortex	4	Circular	113.4	4	1	23%	17.33	33
NW0	4	Circular	65.5	*	312	80%	23.01	58
NW0	4	Circular	65.5	*	480	80%	18.45	41

* The IWA for NW0 is based on the mask size and distance from the telescope, not λ/d

The Vortex and PIAA methods at 3 λ/D achieve scientific gain greater than or equal to that of our baseline FB-1 design (at 4 λ/D). These results depend on our ability to demonstrate reliable reduction of the inner working angle (IWA) for these devices. The NWO design may also be able to achieve similar results through the use of multiple or larger external occulters. Further completeness studies will implement variable throughput over the coronagraph field of view to account for different throughput levels at different working angle locations.