The Terrestrial Planet Finder Coronagraph for the Next Decade

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NASA’s plan for a large-scale observatory to directly detect and characterize terrestrial planets has been significantly delayed by funding shortfalls. It appears more likely that a smaller, focused extra-solar planet mission could fly in the next decade. Mission modeling studies show that a 1.5 m aperture coronagraphic telescope could detect and characterize a handful of Earth-like planets and many Jupiter-class planets. The technology for the giant-planet portion of the mission, including a contrast ratio of $2 \times 10^{9}$ in 10% bandwidth light, is in hand and no fundamental roadblocks remain. External occultor technology is less mature but once developed, a formation-flying occultor could join the telescope in orbit to form a powerful exo-planet characterization observatory.

**Coronagraph Technologies**

- Optical vortex coronagraph: @ 2.4 μm in air (Arizona/JPL)
- Visibility nuller 15% bandwidth @ 3.5 μm in air (JPL)
- PAH monochromatic @ 2 μm in air (Subaru)
- Visibility nuller monochromatic at 3.5 μm in air (JPL)
- Occultor broadband @ 2.5 μm in air (JPL)
- Shaped pupil mask 15% bandwidth @ 4 μm in vac. (Princeton/IHT)
- Shaped pupil mask monochromatic @ 4 μm in vac. (Princeton/IHT)
- 4th order band limit mask 2% bandwidth @ 4 μm in vac. (JPL/IHT)
- Occultor broadband mask monochromatic @ 4 μm in vac. (JPL/IHT)

**Finding Planet 1 (FB1): Case Study**

Band-limited 8th-order Mask
Excellent aberration rejection. Modest throughput. 8 m x 3.5 m aperture (JWA – 60 mas = 4.6 μarcsec) Large throughput; high resolution reduces contribution of exo-ozoids. Mission Modeling Tools Which stars to look at, how long, how deep. Results: Detailed engineering studies show we meet thermal, vibration, and pointing requirements. No show-stoppers. Detects Earth, 390 Jupiters (τ = 1)

**Relative Merits of a Small Aperture Telescope**

- Telescope does not deploy.
- Simple thermal shield deployment.
- Standard solar panel and solar sail deployments.
- Simplified Observational Scenario
- Line-of-site effect for image subtraction
- Circular aperture means no need for multiple rolls about line of sight
- Stiffer Telescope
- Greatly reduces gravity sag relative to FB1
- Stiff structure relative to FB1 to reduce beam walk and aberrations
- End-to-end testing looks feasible
- No major new facilities
- Easily fits in low-cost launch vehicles.
- BUT, stability requirements are MUCH tighter for small IWA
- Researcher support for smaller more straightforward mission.
- Obviously, fewer planets can be detected and characterized.

**Aberration Sensitivity at 2 μarcsec**

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<th>Exposures</th>
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**SUMMARY**

- We are exploring several approaches to TPF-C including 4 classes of internal coronagraphs, and the external occultor.
- For internal coronagraphs, only PIAA could potentially enable operation at 2 μarcsec where several terrestrial planets could be detected.
- If this approach is successfully developed, it can find up to ~6 Earth-like planets (for PIAA = 1) and requires an ultra-stable 1.5 μarcsec telescope.
- Phased approach may yield the best overall science return, and could be affordable over time.