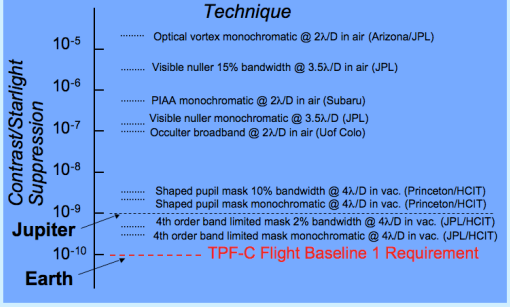
National Aeronautics and Space Administration

The Terrestrial Planet Finder Coronagraph for the Next Decade

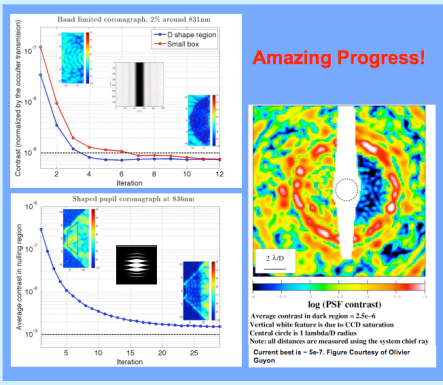
Stuart B. Shaklan, Marie B. Levine, Sarah Hunyadi
Jet Propulsion Laboratory, California Institute of Technology

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 2x10^9 in 10% bandwidth light, is in hand and no fundamental roadblocks remain. External occulter technology is less mature but once developed, a formation-flying occulter could join the telescope in orbit to form a powerful exo-planet characterization observatory.

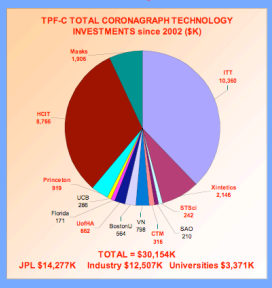
Coronagraph Technologies



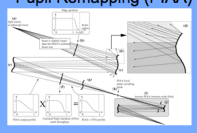
Amazing Progress!



Community Effort

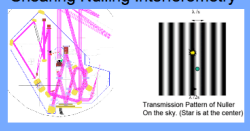


Pupil Remapping (PIAA)



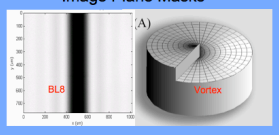
Potentially closest to 'ideal'; high throughput, small IWA, challenging optics, unknown WFC issues.

Shearing Nulling Interferometry



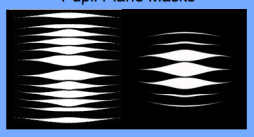
No optics in image plane, most complicated to implement, throughput and IWA similar to band-limited mask

Image Plane Masks



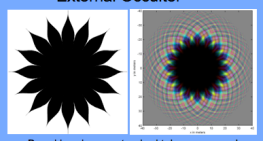
Band-Limited Mask has best performance so far, good aberration rejection, hard to achromatize, moderate throughput

Pupil Plane Masks



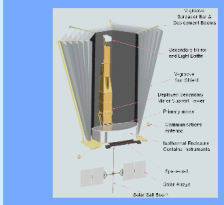
Easy to manufacture, easy to achromatize, simplest design, low throughput, large IWA.

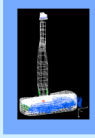
External Occulter

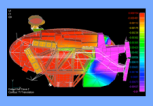


Broad band, uses standard telescope, good inner working angle, large floppy structure, limited mobility, very few revisits

Flight Baseline 1 (FB1): Case Study





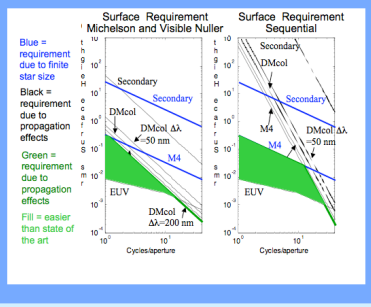


Band-limited 8th-order Mask
Excellent aberration rejection.
Modest throughput.

8 m x 3.5 m aperture
IWA = 60 mas = 4 λ/D
Large throughput, high resolution reduces contribution of exo-zodi.

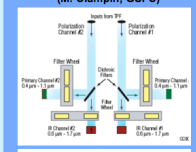
Mission Modeling Tools
Which stars to look at, how long, how deep.

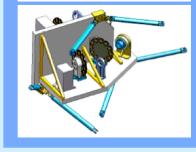
Results
Detailed engineering studies show we meet thermal, vibration, and pointing requirements.
No show-stoppers.
Detects 41 Earths, 390 Jupiters (η=1)



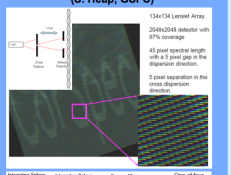
Instrument Concept Studies

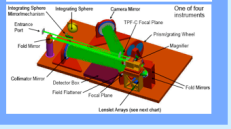
CorCam:
Multi-band Photon-Counting Camera
(M. Clampin, GSFC)



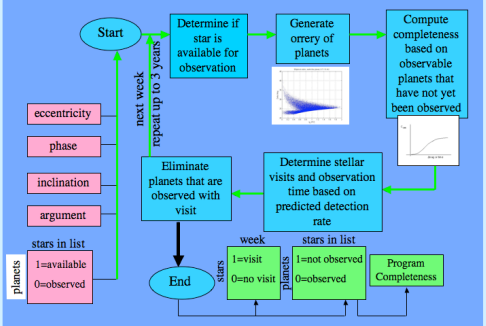


CorSpec:
Integral Field Unit Spectrometer
(S. Heap, GSFC)





Mission Studies: Observational Completeness



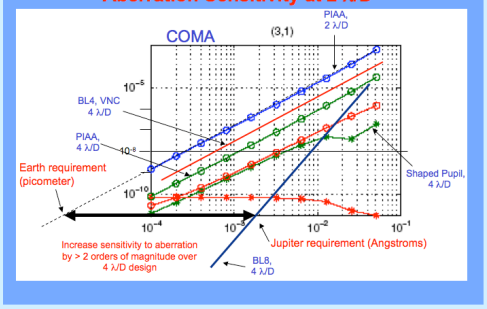
Predicted # Discoveries for η = 1

Type	IWA (λ/D_{max})	Primary Mirror	# Earths	# Targets	# Jupiters	# Targets
BL8	4	8 m x 3.5 m	41	85	390	680
PIAA	4		73	140	580	800
BL8/SP	3.5	4 m	19	36	320	540
PIAA	3.5	4 m	25	56	460	580
Ext. Occ.		JWST	25	62	71	78
BL8/SP	3.5	1.5 m	2.3	5	82	154
PIAA	2.5	1.5 m	4.5	9	105	186
PIAA	2	1.5 m	6	11	115	195

Relative Merits of a Small Aperture Telescope

- Telescope does not deploy.
  - Simple thermal shroud deployment
  - Standard solar panel and solar sail deployments
- Simplified Observational Scenario
  - Line-of-site dither for image subtraction
  - Circular aperture means no need for multiple rolls about line of sight
- Stiffer Telescope
  - Greatly reduce gravity sag relative to FB1
  - Stiffer 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
  - Orders of magnitude tighter requirement on low-order aberrations
  - Lower throughput and smaller aperture, so integration times grow.
- Obviously, fewer planets can be detected and characterized.

Aberration Sensitivity at 2 λ/D



A Phased Approach to Detecting Earths

- Fly small coronagraph (<$1B)
  - Detects and characterizes many Jupiters and does disk science with *existing* technology.
  - With breakthroughs it can find a few Earths
  - Optimized instrument suite for detection and characterization
- Follow a few years later with an occulter (additional $$$)
  - Can observe the systems most likely to harbor Earths.
  - Allows time to develop external occulter technologies.
  - Telescope angular resolution comparable to JWST (80 mas) preserves reasonable Inner Working Angle.
- This follows a natural progression of using proven, low-risk technology for larger, more accessible planets, followed by the application of future technology to study Earth-like planets.
  - White paper submitted to ExoPTF.

SUMMARY

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

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California