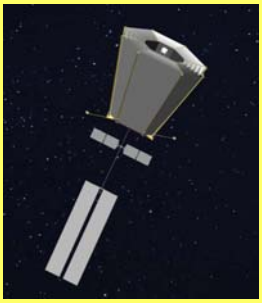

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

TPF Coronagraph Instrument Design

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Requirements and Observing Scenario

Table 1. TPF-Coronagraph Contrast Error Budget Requirements.

	Requirement	Comment
Static Contrast	6.00E-11	Coherent Terms
Contrast Stability	2.00E-11	Thermal + Jitter
Instrument Stray Light	1.50E-11	Incoherent light
Inner Working Angle	4 λ/D_{long}	57 mas at λ=550 nm, D_{long} = 8 m
Outer Working Angle	48 λ/D_{short}	1.5 arcsec at λ=550 nm, D_{short} = 3.5 m
Bandpass	500-800 nm	Separate observ. in three 100 nm bands.

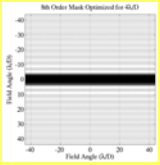
Observing Scenario:

Acquire Target
Set Wave Front
Observe Target (I1)
Rotate 30 deg about LOS
Observe Target (I2)
Compute difference image I2 – I1

} Stability is required during this sequence.

Pupil Shape

Image Plane Mask



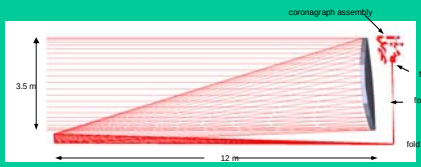
Bar-code Pupil Mask

Xinetics 64x64 DM

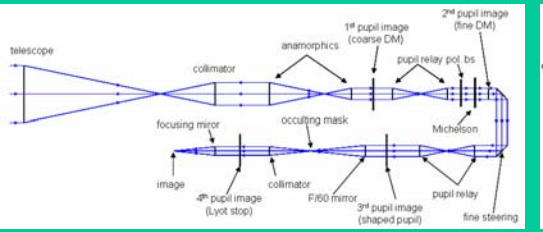
Instrument Architecture

- Primary Mirror Shape
  - 'Band-aid' – nearly rectangular
- Image Plane Mask
  - 8th order HEBS glass mask, linear, mask throughput = 70%
  - Lyot throughput = 45%
- Shaped-pupil Mask
  - 'Bar-code' mask, IWA = 4 λ/D, Airy throughput = 25%
- Polarization
  - PBS cubes split the light into to separate channels, each with its own coronagraph and wave front control system
- Wave Front Control
  - DM format = 96 x 96 actuators, 1 mm pitch
  - Michelson DM configuration controls 96 x 96 λ/D dark hole
- Detectors
  - Imaging camera and spectrometer (R = 70).
  - Instrument Concept Studies are underway.

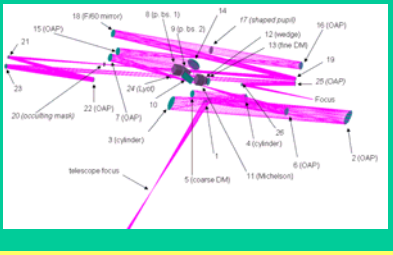
Telescope and Instrument



Functional Layout



Optical Layout

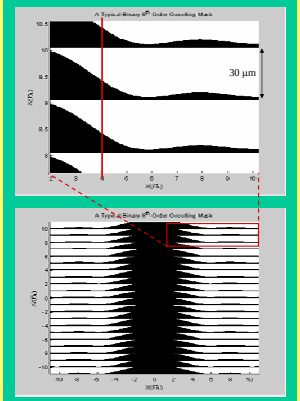


- Coronagraph Trades
  - Lyot and Shaped Pupil coronagraphs are complementary
    - Lyot coronagraphs have good discovery space and efficiency
    - Shaped pupil coronagraphs have better stability and potentially less chromaticity and polarization issues
  - PIAA based coronagraphs appear to have many attractive properties and their evaluation continues.
    - But diffraction and the need for apodization may be limitations.
  - Visible Nuller performs nulling in the pupil. May offer an advantage chromatically but it is otherwise disadvantaged by its combined limited discovery space and high aberration sensitivity.
- Wavefront Control Architecture Trades
  - Michelson I/F configuration enables full complex pupil control but its amplitude compensation is chromatically limited
  - Multi-conjugate configurations are also being considered
- Telescope architecture co-optimization with starlight suppression system is vital to ensure the achievement of broadband contrast.

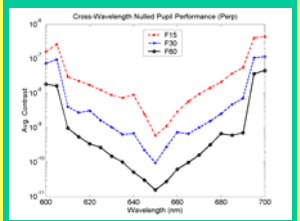
Coronagraph Trades

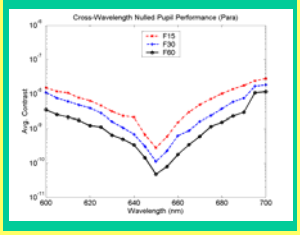
Property	Occulter / Lyot	Shaped Pupil	PIAA	Visible Nuller
Practical IWA	3.0-3.5 λ/D	3.5-4.5 λ/D	2.0-3.0 λ/D ?	3.0-3.5 λ/D
Stop Efficiency	40-60%	10-25%	~100%	40-60%
Immediate Discovery Space*	>90% Constrained by occulter	40-60% Constrained by limited diffraction shaping	> 90% Constrained by field dependent aberrations	<50% Constrained by fringe pattern and fiber attenuation
Minimum Primary Mirror Dimensions	6x3.5 m	8x3.5 m	< 6x3.5 m	6x3.5 m
SM Despace Stability	20 nm	20 nm	200 nm ??	1 nm
Implementation Complexity	Low	Low	Moderate	High
Critical Issue	Complex errors induced at a focal plane may limit broadband utility	Interaction between high-angle diffraction and high-frequency speckles	Fabrication of optical components. Diffraction?	Implementation complexity

Binary Masks?

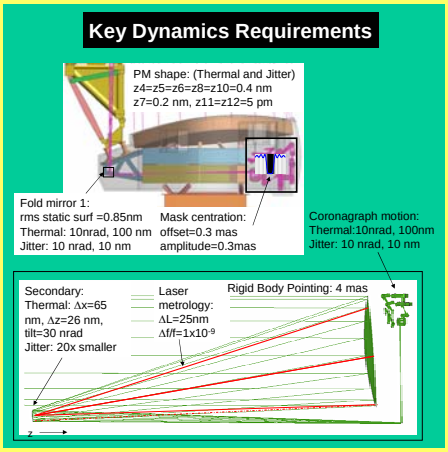


- Simulation: Use DM to compensate for mask performance at 650 nm.
  - Each polarization nulled separately at 650nm.
  - 1000 nulling cycles applied.
- What is the broadband performance?

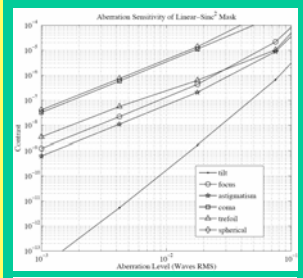




Key Dynamics Requirements



Aberration Sensitivity



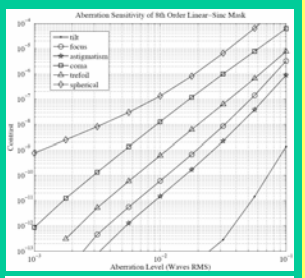
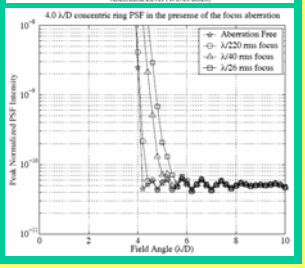


Table: 1: Allowed RMS Wave Front for Contrast 1e-12 at 4λ/D

Aberration	8th Order	4th Order	Relaxation Ratio
Tilt	4.3e-2	2.7e-3	16
Focus	3.8e-3	2.9e-5	132
Astigmatism	5.3e-3	1.0e-5	132
Coma	1.0e-3	5.6e-6	185
Trefoil	2.3e-3	1.7e-5	132
Spherical	3.5e-5	4.9e-6	7.2

Note. — Aberration units are waves rms at 550 nm.