Terrestrial Planet Finder Coronagraph

Virginia Ford, Anthony Hull, Stuart Shaklan, Marie Levine, Andrew Lowman, Eri Cohen

Jet Propulsion Laboratory, California Institute of Technology
Earth- Finding Missions

Primary Science Objective:
Detect and characterize Earth-like planets

Method:
- Survey stars near Earth
- Detect planets orbiting the stars as points of light
- Determine whether planets possess an atmosphere using low resolution spectroscopy
- Analyze the spectrum for biomarkers of life

Additional Sciences:
- Study giant planets
- Study planetary atmospheres
- Image other celestial objects
- Study star and planet formation
- Study the formation and evolution of galaxies
- Observe galaxies with black holes
- Observe the center of our galaxy

TPF Coronagraph

TPF-I
(MWIR Interferometer)
Formation Flying
or Structurally Connected

TPF-Science Working Group

TPF-C
(Visible Coronagraph)
TPF Coronagraph Organization

TPF Coronagraph

A NASA Origins Mission

TERRESTRIAL PLANET FINDER MISSION

TPF

DESIGN TEAM

KEY
System Management
Coronagraph System Leaders
JPL Design Team Participants
Outside Design Team Participants
JPL Technology Area Leaders

Optics, Electronics, Structures, Modeling Coord., Detector Engineering, Collimation

CORONAGRAPH SCIENTIST
John Trauger

Coronagraph Systems
Virginia Ford, Manager

TECHNOLOGY DEVELOPMENT

FL4

NASA 0

Mission
Technology Demonstration Mirror

TPF primary mirror features:
- ellipse: 6-10 m major axis x 3.5-4.5m minor axis
- Off-axis paraboloid
- Surface accuracy specified based on spatial frequency

TDM features:
- Circular, 1.8m CA, F no. 2.11
- Off-axis paraboloid
High Contrast Imaging Testbed

- Guest Testing of Coronagraph Concepts
- Wavefront stability - Angstroms
- Stable Vacuum Environment - μKelvin temperature stability, vibration isolated
- Flexible layout for trying alternate concepts
  Goal: Contrast = 10^{-10} at Q=1, 0.2
  = DI/I

TPF Coronagraph
Masks and Stops

• Activities:
  - Theoretical performance predictions and comparisons
  - Modeling – including substrate interactions, diffraction effects, tolerances
  - Fabrication of devices
    • Successful HEBS glass devices
    • Other methods tried with limited success so far
Modeling Efforts

TPF Coronagraph
Integrated Modeling Process Flow

- C (4λ/D)
- Beam Walk
- DM - LOS Pupil Shear
- Occulting spot boresight

Test Case Metrics
- Optical Code Development (MACOS)
  - Code Validation & Numerical Accuracy

Optical Model
  - Optical Sensitivity Analysis
  - Optical Parametric Error Model
  - Integrated Parametric Error Model
  - Validated Parametric Error Model

Thermo-Mech Model
- System Response: thermal & dynamic
  - Sensitivity to Design Params
  - Mitigations Optimization

Environmental Effects
- Geometry, materials, stiffness, CTE, creep, property variations, property accuracy, radiation, hysteresis, DM actuator perf, PM actuation, orthotropy, hygroscopy, ...

Environmental Effects
- Orbit slews, ops ...
- RWA
- Thermal gradients
- Thermal transients
- Microdynamics ...

Baseline Mission
- Code Validation & Numerical Accuracy
  - Orbit slews, ops ...

Test Case Design

End-to-End Simulations

 Inputs/definitions
 Optical analysis
 Thermo-mech analysis
 Analysis outputs

Multiple modeling efforts
Validation by comparison of HCIT performance and to each other
Full end-to-end performance model is goal for flight hardware design
Code development to ensure accuracy and efficiency
Other Technology areas

- Visible Nulling Coronagraph

- Contracts:
  - University solicitations
    - Technology Topics
  - Industry solicitations
    - TDM
    - Deformable mirror development
  - Telescope Front End Study – RFP due out Wednesday
  - Technology topics – due out by end of August
Strawman Design relation to Schematic

Deployed Secondary w/tower, metrology and 6 DOF actuators

Deployed Telescope Baffle/Inner Thermal Shield

Deployed V-groove Thermal Shields (4 plus telescope baffle) - 3 degree separation between layers

Primary mirror: 6m x 3.5m (3.5 m dimension shown) - active surface correction

Instruments: Coronagraph Sensor and Spectrograph

Undeployed structure that holds "flexible" deployables: Baffle/Inner Thermal Shield; V-groove Thermal Shields

Communication Antenna

Dynamic Isolation

Thermal Isolation

Instrument Electronics

Deployed Solar Array (10 m²)
Design Team parameters

Science Requirements

<table>
<thead>
<tr>
<th>Key Parameter</th>
<th>Full TPF</th>
<th>Minimum TPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Stars Visited</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>0.3 to 1.1 µm</td>
<td>0.5 – 1.0 µm</td>
</tr>
<tr>
<td>Angular Resolution at $\lambda = 0.5$ µm</td>
<td>10 mas</td>
<td>30 mas</td>
</tr>
<tr>
<td>Inner Working Distance</td>
<td>30 mas</td>
<td>63 mas</td>
</tr>
<tr>
<td>Outer Working Distance</td>
<td>2000 mas</td>
<td>1000 mas</td>
</tr>
<tr>
<td>Contrast</td>
<td>$10^{-10}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>Stability timescale</td>
<td>4 sec</td>
<td>10 sec</td>
</tr>
</tbody>
</table>

Error Budget

- Contrast: $1.00E-10$
- Background (contrast): $1.80E-11$
- WFE (contrast): $6.53E-11$
- Source-related Scattering: $1.00E-11$
- Dynamic/Thermal Error: $4.88E-11$
- Static Error: $1.66E-11$
- Rigid Body Beamwalk: $2.88E-12$
- Mask Leakage: $4.78E-12$
- Structural Deformation: $2.18E-12$
- Amplitude Uniformity (lifetime): $1.66E-12$
- Leakage Due to Dynamics: $2.91E-11$
- Leakage Due to Thermal Effects: $2.91E-11$
- Structural Deformation: $2.08E-12$
- Deformation of Optics: $6.38E-12$
- Structural Deformation aberrations: $9.38E-12$
- Scattering from Other Sources: $6.00E-12$

TPF Coronagraph

4 August 2003 Virginia Ford - 1
Strawman Design

Terrestrial Planet Finder Mission

Fully-deployed Observatory

Deployed except for Thermal shields and light baffle

TPF Coronagraph
Stowing sequence in Delta IV Heavy

Folded in clam-shell support

Installed in clam-shell support

In launch vehicle shroud

TPF Coronagraph

4 August 2003 Virginia Ford - 1