Modeling the TPF Interferometer

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June 25, 2004

SPIE Astronomical Telescopes and Instrumentation
Glasgow, Scotland
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Overview of the TPF-I modeling plan
Modeling Challenges

• “The Model” has to say go for launch
  – It also has to explain “funny” things on orbit
• Large
• Tiny
• Complicated
• Cryo
• Novel
• Multiple Organizations
Other architectures under consideration
Formation Flying Interferometer - Collector

Five Layer Sunshield

15.3 m

Spacecraft Bus

4 m Diameter Primary Mirror
Formation Flying Interferometer - Combiner

Beam Combiner

Five Layer Sunshade

15.3 m

Spacecraft Bus
The Approach

Today: Bucket Brigade

Future: IMOS-based Observatory Simulation
Map of the TPF Modeling Bucket Brigade

TELESCOPE

INSTRUMENT

ENGINEERING BUS

OBSERVATORY

PROJECT TRADES MODEL

OPTICS

CAD

FEM

THERMAL

CONTROLS

DISTURBANCES

GSFC

JPL

BALL

OK?

Yes CDR

No
Some Simple Things to Aid Integration

1. A plan
2. Common coordinate systems
3. Common software applications (or export formats that are compatible with other applications)
4. Common node meshes
5. A good description of the design baseline
6. A library that is subject to configuration management
Some Other Models to Integrate

- Disturbance Sources
  - Reaction Wheels
  - Thrusters
  - Cryo cooler
  - Actuators
  - Micrometeoroid impacts
- Natural Environments
  - Local Zodi
  - Exo Zodi
  - Target Planetary Systems
- Stray Light
- Detectors
- Planetary Signal Extraction
- Cost
- Risk
Other Helpers

- University of Arizona (N. Woolf et al)
  - Planetary Signal Extraction
- Massachusetts Institute of Technology (D. Miller, J. Wertz, et al)
  - Optical element perturbations
  - Cost
  - Risk
- University of Colorado (L. Peterson et al)
  - Dynamics of cryo structures
- Lockheed Martin
- Northrop Grumman
- European Space Agency
  - Performance of architectures
  - More later
Observatory Simulation
Some Things We’ve Already Learned

• It will be a challenge to . . .
  – Distinguish multiple planets within a star system
  – Achieve 40 K temperatures on optical surfaces
  – Fit a full formation of a Dual Chopped Bracewell array on a single launch vehicle

• Optical throughput margin is healthy

• Stray light effects limit the maximum separation between spacecraft

• Designing TPF-I is fun
Some Work Ahead

- First assessment of whether the error budget can be achieved
  - Need a complete suite of stand-alone models
- Detailed thermal analysis of the sub-40 K portion of the instrument
- Planet signal extraction
- New FFI architecture(s)
Thank you.

Questions?
Backup
Some of the additional presentations about the TPF and Darwin interferometers at this conference

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Speaker</th>
<th>Paper #</th>
<th>Paper Title</th>
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<tbody>
<tr>
<td>Monday</td>
<td>2:00 p.m.</td>
<td>Mennesson</td>
<td>5491-16</td>
<td>Expected science capabilities of the TPF interferometer</td>
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<tr>
<td>Tuesday</td>
<td>8:30 a.m.</td>
<td>Fridlund (ESA)</td>
<td>5491-26</td>
<td>Darwin and TPF technology and prospects</td>
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<td>Tuesday</td>
<td>8:30 a.m.</td>
<td>Henry</td>
<td>5491-30</td>
<td>Terrestrial Planet Finder interferometer architecture, mission design, and technology development</td>
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<td>Lay</td>
<td>5491-32</td>
<td>Architecture selection and optimization for planet-finding interferometers</td>
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<td>Miller</td>
<td>5491-33</td>
<td>Current Status of the TPF formation flying interferometer concept</td>
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<td>Noecker</td>
<td>5491-40</td>
<td>TPF control system requirements for structurally connected and formation flying interferometers</td>
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<td>Tuesday</td>
<td>1:30 p.m.</td>
<td>Pedreiro</td>
<td>5491-41</td>
<td>Control and vibration mitigation for structurally connected Terrestrial Planet Finder Interferometer</td>
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<td>Tuesday</td>
<td>5:30 p.m.</td>
<td>poster</td>
<td>5495-43</td>
<td>Structural Configuration for the Terrestrial Planet Finder Structurally Connected Interferometer Concept</td>
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<td>poster</td>
<td>5487-183</td>
<td>The potential of conductive waveguides for nulling interferometry</td>
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<td>Thursday</td>
<td>11:10 a.m.</td>
<td>Coulter</td>
<td>5487-55</td>
<td>NASA's Terrestrial Planet Finder Mission</td>
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<td>Thursday</td>
<td>11:10 a.m.</td>
<td>? (ESA)</td>
<td>5487-56</td>
<td>A comparison of architectures for Darwin/TPF</td>
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<td>Unwin</td>
<td>5487-57</td>
<td>Terrestrial Planet Finder: science overview</td>
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<td>5487-58</td>
<td>Terrestrial Planet Finder technology development</td>
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<td>5491-188</td>
<td>Deformable mirror based adaptive nuller demonstration in the near-IR</td>
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<td>5491-189</td>
<td>Stellar suppression with interferometer arrays</td>
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<td>5491-190</td>
<td>A cryogenic mid-IR nuller for TPF</td>
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<td>5491-211</td>
<td>Terrestrial Planet Finder cryogenic delay line</td>
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<td>Wallace</td>
<td>5491-96</td>
<td>Mid-IR interferometric nulling for TPF</td>
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<td>5491-97</td>
<td>The impact of systematic errors on nulling interferometers</td>
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<td>Levine</td>
<td>5497-18</td>
<td>Integrated modeling approach for the Terrestrial Planet Finder Mission</td>
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<td>Henry</td>
<td>5497-19</td>
<td>Modeling the TPF Interferometer</td>
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</table>
Motivation

- With just a single harmonic, the image reconstruction is highly ambiguous
- Cannot distinguish between:
  - Small planet at large offset
  - Large planet at small offset
  - Multiple planets

- Hardest when inside the first stripe
Observations

• If planets are close, algorithms tend to find one planet in between
• Algorithms find large planets well
• Large planets suck photons out of small ones
• There wasn’t one system with planets that the algorithms didn’t make look interesting - suggests that we won’t miss worthwhile systems, and revisit information will help resolve ambiguities
• Algorithms find planets where there are none (Case 1)
Planet Signal Extraction
• The top figure shows an earthlike system at 15 pc, on a background of exozodiacal light (log scale in brightness).

• The lower figure shows the results given by two planet detection algorithms, imposed on the original planet positions. The planets are scaled by their flux, and the solutions by their confidence level.
Case 1

No planet, 10 pc, 5 EZ

- Star
- Original planet
- Ball CC/CLEAN
- Velu/Ken

Graph showing positions in x (mas) and y (mas) with markers for different scenarios.
Case 2

One planet, 10 pc, 5 EZ

Star
Original planet
Ball CC/CLEAN
Velu/Ken

y (mas)

x (mas)
Case 4

Two planets, 15 pc, 1 EZ

- Star
- Original planet
- Ball CC/CLEAN
- Velu/Ken
Case 12

Face-on solar system: Four planets, 15 pc, 1 EZ

Star
Original planet

y (mas)

x (mas)
Case 12

Face-on solar system: Four planets, 15 pc, 1 EZ

- Star
- Original planet
- Ball CC/CLEAN
- Velu/Ken

The diagram shows a plot of an exoplanet system, with markers indicating the positions of the stars and planets. The x-axis represents the x (mas) coordinates, ranging from -300 to 300, and the y-axis represents the y (mas) coordinates, ranging from -300 to 300.