TPF Interferometer Architecture Studies

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1. Architecture Options
2. Figures of Merit
3. Strawman Configurations
Architecture Studies Objective

Science Performance

Minimum Science Mission (~30 stars)  Full Science Mission (~150 stars)

Implementation Platform

Structurally Connected Interferometer (SCI)

Formation Flying Interferometer (FFI)

Architecture

?  OASES 1331

Dual Chopped Bracewell (DCB)

Chopped Degenerate Angel Cross (DAC)

Darwin: bow-tie

Choose an Architecture to support the two missions

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Nulling Architectures Options

- Bracewell
- Chopped Dual Bracewell (hi-res)
- Chopped Dual Bracewell (lo-res)
- Angel Cross
- Degenerate Angel Cross (DAC)
- Chopped Degenerate Angel Cross (DAC)
- Darwin: bow-tie
- Laurance
- Mariotti
- OASES 1331
- OASES 1221
Figures of Merit

- Ability to isolate planet signal
  - Exo-zodi suppression
  - Instrumental background suppression
- Practical Configuration
  - Beam combiner complexity
- Ability to examine an adequate number of stellar systems
  - Resolution
  - Sensitivity

Resolution and Signal-to-Noise Ratio
Nulling Architectures Options that Support Phase Chopping

Chopped Dual Bracewell (hi-res)

Chopped Dual Bracewell (lo-res)

Darwin: bow-tie

Chopped Degenerate Angel Cross (DAC)

Laurance

Mariotti

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Nulling Architectures Options Remaining

Hi-Lo-Res Chopped Dual Bracewell

Darwin: bow-tie

Chopped Degenerate Angel Cross (DAC)
# Figures of Merit

- **Performance**
  - Adequate number of stars
  - Exo-zodi suppression
  - Instrumental background suppression

- **Complexity/Difficulty**
  - **Beam combiner complexity**

- **Risk and robustness**

- **Cost and Utility**

Chopping
Dual Chopped Bracewell Beamcombiner

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

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# Figures of Merit

<table>
<thead>
<tr>
<th>Terrestrial Planet Finder Mission</th>
<th>JPL</th>
</tr>
</thead>
</table>

## Performance
- Number of stellar systems
- Exo-zodi suppression
- Instrumental background suppression

## Complexity/Difficulty
- **Beam combiner complexity:**
  - Dual Chopped Bracewell has the simplest beamcombiner

## Risk and robustness

## Cost and Utility
Performance Models

- Interferometer Performance Model (IPM)
  - Rigorous model of a single observation
  - Connects instrument Level 3 engineering requirements to a signal-to-noise performance on a single canonical planetary system, e.g. sun at 10 parsecs
- Star Selectors Analysis
  - Uses simplified and parametrized model of the instrument sensitivity (based on the IPM)
  - Accounts for non-SNR limitations of the instrument
  - Works on the entire star list to determine the number of measurable stars
Interferometer Performance Model (IPM) flowdown to level 3 milestone complete

A self consistent set of assumptions, constrains and requirements that can be use as a starting reference point by the design teams
**SCI Baseline: Minimum Mission**

- Under current implementation assumptions SCI Baseline achieves the Minimum Mission Requirement (30 stars)

**CONFIGURATION SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Array length</th>
<th>Baseline</th>
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<tbody>
<tr>
<td>36</td>
<td>JPL</td>
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<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>DCB hi/lo res</th>
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<tbody>
<tr>
<td>Chop response (right-left)</td>
<td>0.87/0.77</td>
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<tr>
<td>Chop de-modulation efficiency (~Ndet)</td>
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<tr>
<td>BeamCombiner efficiency (on top of ideal)</td>
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<tr>
<td>Apertures Locations Factor (x=bs/s)</td>
<td>0.25</td>
</tr>
<tr>
<td>Collecting area (m^2)</td>
<td>32.2</td>
</tr>
<tr>
<td>Number of apertures</td>
<td>4</td>
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<tr>
<td>Apertures diameter (m)</td>
<td>3.2</td>
</tr>
</tbody>
</table>

**IMPLEMENTATION ASSUMPTIONS**

- Inner Working Distance (fraction of 1st peak at 10um) | 1 |
- Sky coverage (+/- degrees) | 45 |
- Internal throughput | 0.05 |
- Optics transmission | 0.2 |
- Det Response | 0.5 |
- Number of detectors (Ndet) | 1 |
- Null floor | 1.0E-06 |

**OBSERVATION PARAMETERS**

- planet surface area | 0.5 Earth |
- planet distance from star | 0.7 Mid+Z |
- Required SNR (shot noise only) | 7 |
- Bandwidth (um) | 7-17 |
- Completeness | 95% |
- Number of visits | 3 |
- Orbit inclination factor | 1.29 |
- Time available for integration | 1 year |
- Max single observation time | 7 days |
- LZ flux density | 13.7 Mjy/sr @ 12um |

**PERFORMANCE METRICS**

- Number of stars (req=30) | 54 |
- F | 7 |
- G | 20 |
- K | 27 |
Statistics of the Minimum Mission

Histograms of star sets

Detection times

- All Stars
- Eligible (sky cov, type, binarity)
- Observable (+resolution)
- Measured (+int time)

Stellar distance (pc)

Detection time (hrs)

0.001 1

10 100

0 5 10 15 20 25 30

Array Length (m)
Full Mission FFI Performance Considerations

- Sensitivity for further out stars (strongest signal)
  - Favors Dual Chopped Bracewell (q2)
- Stellar leakage Nearby stars (low noise)
  - Favors $\theta^4$ architectures, e.g. Darwin bow-tie
<table>
<thead>
<tr>
<th>Options</th>
<th>1-D Chopping Dual Bracewell hi-lo-res, 3.5 m</th>
<th>2-D DARWIN (1.5 m)</th>
<th>2-D Dual Chopped DAC (3.5 m)</th>
<th>Supporting Documents</th>
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<tbody>
<tr>
<td>MUSTS</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td>D.2</td>
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<td>Exo-zodi suppression</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td></td>
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<tr>
<td>Feasible beamcombiner</td>
<td>v</td>
<td>v</td>
<td>v</td>
<td></td>
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<td>Equal pathlengths</td>
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<td>v</td>
<td>v</td>
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<td>Instrument background suppression?</td>
<td>v</td>
<td>v</td>
<td>v</td>
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<td>In one plane</td>
<td>v</td>
<td>v</td>
<td>v</td>
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<td>Top Discriminators</td>
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<td>Performance</td>
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<td>Number of stars</td>
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<td>Speed=beam combiner efficiency+ sky response+collecting area</td>
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<td>1</td>
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<td>Unambiguous planet position?</td>
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<td>0</td>
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<tr>
<td>Complexity/Difficulty</td>
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</tr>
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<td>Beamcombiner Complexity</td>
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<td>-3</td>
<td>-3</td>
<td>-2</td>
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<td>Beam transport complexity</td>
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<td>0</td>
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<td>Concept Maturity</td>
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<td>-1</td>
<td>-2</td>
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<td>Fuel usage</td>
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<td>0 (?=)</td>
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<td>0</td>
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<td>&quot;D.3&quot; and see comment</td>
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<td>Robustness and Risk</td>
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<td>Cost and Utility</td>
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<td>Equal size collectors</td>
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<td>0</td>
<td>-1</td>
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<td>Legacy (scalable to future missions)</td>
<td>0</td>
<td>1</td>
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**Criteria**

- Terrestrial Planet Finder Mission
- A NASA Origins Mission

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What about Stellar Leakage?

Although stellar leakage is the dominant noise source for nearby stars, it is NOT a problem for observation of nearby stars.

More distant stars, which we need to pick up for a full mission, are NOT leakage dominated.
What would it take to see 150 stars? Details of the exam.

**Configuration**
- **Full**: FFI
- **Min**: 36 m SCI

**Architecture**
- **Full**: hi-lo DCB
- **Min**: hi-lo DCB

**Aperture diameter**
- **Full**: 4.0
- **Min**: 3.2

**Sky Coverage**
- **Full**: 45
- **Min**: 45

**Throughput**
- **Full**: 7%
- **Min**: 5%

**Number of detectors**
- **Full**: 2
- **Min**: 1

**Total available time**
- **Full**: 1.5 years
- **Min**: 1 year

**Min FF Length**
- **Full**: 60
- **Min**: NA

**Number of Stars**
- **Full**: 149
- **Min**: 52

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A self-consistent, but not necessarily practical example.

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What would it take to see 150 stars? Star Statistics

config = "DCB_lo_res"  
TwoConfigs = 1  
FF = 1

Resolution selector:  
IWD = 1  
Sky coverage(deg)  
SkyHalfAngle = 45  
Dapm = 4

With an SCI array set at  
FFI operating with Lmin =  
L_J_SCI = 89  
L_J_FFminL = 61

Measured stars: number  
N_meas_stars_All = 149  
types  
N_F = 72  
N_G = 44  
N_K = 33

Spectroscopy  
N_earth = 0.1  
N_stars_spectr = 14

A NASA Origins Mission

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## Parameters used as input to Strawman Design

<table>
<thead>
<tr>
<th>Feature</th>
<th>Interferometer</th>
<th>Coronagraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR/visit</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Inner HZ</td>
<td>0.7 “AU”</td>
<td>0.7 “AU”</td>
</tr>
<tr>
<td>IWA/IHZ</td>
<td>1/1.29</td>
<td>1</td>
</tr>
<tr>
<td>IWA Defined</td>
<td>$\frac{3 \lambda}{4 L_o}$ (for hi-res Bracewell)</td>
<td>$\frac{3 \lambda}{L_o}$</td>
</tr>
<tr>
<td>IWA</td>
<td>43 mas for 36m structure</td>
<td>82 mas for 6m aperture</td>
</tr>
<tr>
<td>$\lambda_o$</td>
<td>10 µm</td>
<td>0.8 µm</td>
</tr>
<tr>
<td>Outer HZ</td>
<td>1.5 “AU” (not yet a filter)</td>
<td>1.5 “AU” (not yet a filter)</td>
</tr>
<tr>
<td>Visits (for completeness)</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Total time for survey</td>
<td>Elapsed observing time is 1 yr out of 2 calendar yrs</td>
<td>Elapsed observing time is 1 yr out of 2 calendar yrs</td>
</tr>
<tr>
<td>Planet surface area</td>
<td>Half earth</td>
<td>Half earth</td>
</tr>
<tr>
<td>Field Of Regard (from anti sun)</td>
<td>+/- 45 deg</td>
<td>+/- 85 deg</td>
</tr>
</tbody>
</table>
What’s Next

- For the Architecture Team

- Next presentation: Curt