WFIRST
Exoplanets Parallel Session: Demonstration of Starshade Technologies

November 18th 2014

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Northrop Grumman Starshade History

OCCULT STARLIGHT

Concepts & Performance Simulation

New Worlds Occultor Designed for High Contrast

- Occultor is a true binary optic
- Transmission is unity or near unity
- Edge obstruction from solid disk is suppressed by cancellation
- Inspired VanderLau Fowler
- Precision null plane cancels power in first order
- Various optimization strategies
- Per given optical disk: 400 nm - 700 nm
- In a well-crafted disk
- 7 cm is the length of the occultor

Mission design

1/1000th scale Indoor Testing

NGC Astro Aerospace Reflector-based Deployment Demo

1/100th scale Field Tests

2004

2005-2006

2008

2010

2013

Deployment Stills

Courtesy of NASA JPL

2014
Purpose of Optical Performance Testing

Critical Technologies

**Performance Verification and Modeling**
- Predict diffraction performance at better than $10^{-12}$ precision
- Validate that models are accurate to this level

**Precision Deployment and Shape Control**
- Build structure that meets shape requirements
- Deploy accurately and with high reliability
- Maintain shape during on-orbit disturbances such as jitter and thermal gradients

**Stray Light Control**
- Mitigate scattering of sunlight off edge of starshade petals
- Control transmission of sunlight and starlight through membrane

**Long Distance Formation Flying**
- Sense cross-track alignment errors between starshade and telescope
- Control starshade position relative to telescope line of sight

- Optical performance verification is a critical technology for the starshade
  - Starshade must block the light of the central star by more than $10^{10}$ – cannot be tested on the ground at full scale, given required separation
  - Modeling will be key to validating the mission performance
  - Optical diffraction modeling effort has been under way for many years – must be verified with test measurements
Field Testing 2014

NASA JPL / Northrop Grumman
100th Scale Starshade

Light Sources
Testing Engineering Sensitivities – Flawed Starshade Performance

- Added “flaws” to Starshades to mimic in-space errors and validate models
- 6 families of flaws applied to two designs
- Models predicted performance with field test dimensions
Comparison of Simulations to Field Data

- Shown here is a Hypergaussian Starshade with a range of petal width variations
  - Clockwise from 9:00 position: -5%, -2%, and -3%
  - Starshade stand obscures the true effects of the -4% petal
- Simulations predict equal brightness flaws on each side of the petal
  - Differing brightness in field test likely due to misalignment
  - Preliminary match to model points to a source shift down and to the right

<table>
<thead>
<tr>
<th>Change in Petal Width</th>
<th>-2%</th>
<th>-3%</th>
<th>-5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted Contrast</td>
<td>0.4-4×10⁻⁶</td>
<td>0.5-7.4×10⁻⁷</td>
<td>0.1-1.7×10⁻⁵</td>
</tr>
<tr>
<td>Estimated Contrast</td>
<td>1×10⁻⁶</td>
<td>1.5-2.3×10⁻⁶</td>
<td>3.2-5.5×10⁻⁶</td>
</tr>
</tbody>
</table>
**Best Contrast Result to Date – Hypergaussian Starshade**

- Image is a combination of 20, 5 sec images
- The curve is cross section through the image, averaging over a 65 pixel wide strip
- ND1 Planet ($7 \times 10^{-6}$), ND2 Planet ($6 \times 10^{-7}$), and ND3 Planet ($4 \times 10^{-8}$) LEDs are indicated, a 4th LED is present ($\leq 10^{-8}$)

<table>
<thead>
<tr>
<th>Distance from center</th>
<th>70&quot;</th>
<th>100&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Background</td>
<td>$7.7 \times 10^{-8}$</td>
<td>$5.5 \times 10^{-8}$</td>
</tr>
<tr>
<td>3σ Contrast Upper Limit</td>
<td>$2.1 \times 10^{-8}$</td>
<td>$1.5 \times 10^{-8}$</td>
</tr>
</tbody>
</table>
Best Contrast Result to Date – IZ5 Starshade

- Image is a combination of 39, 5 sec images
- The curve is cross section through the image, averaging over a 65 pixel wide strip
- ND1 Planet (7x10^{-6}), ND2 Planet (6x10^{-7}), and ND3 Planet (4x10^{-8}) LEDs are indicated, a 4^{th} LED is present (\leq 10^{-8})

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<tr>
<td>Mean Background</td>
<td>1.1x10^{-7}</td>
<td>7.8x10^{-8}</td>
</tr>
<tr>
<td>3\sigma Contrast Upper Limit</td>
<td>4x10^{-8}</td>
<td>1.6x10^{-8}</td>
</tr>
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</table>
Small Starshade

- The feasibility of small Starshades were tested
  - ~12” diameter compared to the 24” used for most of the testing
  - Tests the Starshade at closer to the space mission optics 4x Fresnel Number compared to 16x Fresnel Number
  - Alignment was possible and good images could be taken
  - ND1 Planet \((7 \times 10^{-6})\), ND2 Planet \((6 \times 10^{-7})\), and ND3 Planet \((4 \times 10^{-8})\) LEDs are indicated, ND4 LED is also present \((\leq 10^{-8})\)
Future Tests

• Results from this test indicate that tests to space-like Fresnel Number are possible
  – 20cm Starshade, star at 4km, Starshade at 2km gives a Fresnel number of 20
  – For most recent test, placed LED station at 4km to measure seeing during the night
  – Alignment stable enough – expect to get enough reliable measurements during an observing run (hours of total integration time)