SAG 18 Starshade Metrics Update

1/2/2017

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Introduction

• Goal of ExoPAG SAG 18 is to define how performance metrics for starshades are being used in the community
• SAG18 started with a survey to ask the community what metrics they’ve been using and how they’re being used
  – Thank you to everyone who provided inputs
• Group led by Charles Lawrence of JPL is tackling similar questions, focused on a plot of testbed performance from Exoplanet office technology appendix
• Slides are a summary of the inputs/ discussion so far
• Aim is not to narrow down to one metric – there are many different metrics that may be useful for different situations
  – Establish consensus on definitions, differences, and applications of each metric
Thanks to all the inputs to this work

• SAG 18 co-chair Maggie Turnbull

• Inputs to SAG 18 survey
  – Ashley Baldwin, Dominic Benford, Jim Breckinridge, Robert Brown, Eric Cady, Shawn Domagal-Goldman, Anthony Harness, Joe Harrington, Aki Roberge, Tyler Robinson, Stuart Shaklan, Nick Siegler, Chris Stark, Steve Warwick, Sloane Wiktorowicz

• Lawrence starshade discussion group
1) Fractional Planet Brightness

Astrophysical property of the targets of interest – purely scientific definition

<table>
<thead>
<tr>
<th>Factor</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual light</td>
<td>Brightness of planet</td>
</tr>
<tr>
<td>Region of interest</td>
<td>N/A</td>
</tr>
<tr>
<td>Unsuppressed starlight</td>
<td>Brightness of star</td>
</tr>
<tr>
<td>PSF</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- **Pros:** Defines properties of target of interest
- **Cons:** Not related to imaging system or test

- **NB:** Name from Turnbull et al. 2012, other names “Planet-Star contrast”, “Planet Flux Ratio”
2) Raw Contrast

Straightforward calculation of average contrast in the focal plane

<table>
<thead>
<tr>
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<th>Method</th>
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<tbody>
<tr>
<td>Residual light</td>
<td>Average starlight irradiance in region of interest</td>
</tr>
<tr>
<td>Region of interest</td>
<td>Aperture/ pixel/ annulus in focal plane</td>
</tr>
<tr>
<td>Unsuppressed starlight</td>
<td>Average irradiance of unblocked star in equivalent aperture</td>
</tr>
<tr>
<td>PSF</td>
<td>No correction</td>
</tr>
</tbody>
</table>

- **Pros:** Simple to calculate in test data
- **Cons:**
  - Includes effects of imaging system (telescope), not just starshade
  - Doesn’t consider PSF of planet (mostly coronagraph concern)
  - Doesn’t consider unblocked PSF (issue for starshade tests)
  - Unclear how to interpret if performance is background-limited

- **Variant is RMS contrast:** $N \sigma$ of background (instead of average) in region of interest
- **Pros:**
  - Simple to calculate in test data even when background limited
  - Assesses ability to detect planet against background noise
- **Cons:**
  - Not necessarily measuring effect of starshade itself (in case where non-starshade effects limit background noise)
3) Aperture-Corrected Contrast

Correct contrast for over-resolved PSF in starshade tests

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<td>Residual light</td>
<td>Average starlight irradiance in region of interest</td>
</tr>
<tr>
<td>Region of interest</td>
<td>Aperture/ pixel/ annulus in focal plane</td>
</tr>
<tr>
<td>Unsuppressed starlight</td>
<td>Average irradiance of unblocked star in equivalent aperture</td>
</tr>
<tr>
<td>PSF</td>
<td>Convolve image by lower-resolution PSF (or ratio of lower to higher res. PSFs)</td>
</tr>
</tbody>
</table>

- **Pros:** Compare starshade images over-resolved in tests to each other and to likely flight systems
- **Cons:**
  - Extra calculation that is model dependent
  - Test images likely still at higher F# than flight

Properly-Resolved Test Image

![Properly-Resolved Test Image](samuele.png)

Over-Resolved Test Image

![Over-Resolved Test Image](glassman.png)
Corrects contrast for planet PSF

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<th>Factor</th>
<th>Method</th>
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<tbody>
<tr>
<td>Residual light</td>
<td>Average in raw image or peak of limiting speckle after processing</td>
</tr>
<tr>
<td>Region of interest</td>
<td>Aperture/ pixel/ annulus in focal plane</td>
</tr>
<tr>
<td>Unsuppressed starlight</td>
<td>Average irradiance of unblocked star in equivalent aperture</td>
</tr>
<tr>
<td>PSF</td>
<td>Correct for effect of system on point source in region of interest</td>
</tr>
</tbody>
</table>

- **Pros:** Assess detectability of planet through full imaging system
- **Cons:**
  - Extra calculation that is model dependent
  - Doesn’t consider unblocked PSF (issue for starshade tests)
- For coronagraphs: brightness of a planet in region of interest, with the planet light equal to the residual starlight in the aperture. Brightness of planet uses models of effect of system on off-axis source.
- For starshades: calculate unsuppressed starlight as the average in aperture if the star was centered on the region of interest (with starshade in place)
5) Suppression

Total light entering the telescope

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<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual light</td>
<td>Integrated light in pupil with starshade in place</td>
</tr>
<tr>
<td>Region of interest</td>
<td>N/A</td>
</tr>
<tr>
<td>Unsuppressed starlight</td>
<td>Integrated light in pupil without starshade</td>
</tr>
<tr>
<td>PSF</td>
<td>N/A</td>
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</tbody>
</table>

**Pros:**
- Telescope agnostic – useful for assessing and comparing tests with geometries that vary significantly from the flight system (unique for starshades)
- Quantitative measure of total amount of stray light entering the system

**Cons:**
- Can be dominated by background sources, therefore can be difficult to measure in lab/field
- Difficult to translate into planet detectability in an absolute sense
- No meaningful coronagraphic equivalent – must be translated to something like contrast to compare techniques
Starshade Radius

• Another important parameter that was raised by the Lawrence group is defining the radius of the starshade
  – \( r_{1.0} \) = radius at petal tips
  – \( r_{0.5} \) = radius at the 50% transmission point
  – \( r_e \) = radius at the 1-1/e transmission point

• Relationships between these can vary depending on starshade design
  – Multiple radius values should be provided with each design/test article if possible

• Starshade radius and any other factor derived from that (e.g. F#, IWA) should also be labeled with which radius was used
THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN