SAG 18 Starshade Metrics Update

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Introduction

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- 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

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- 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
  - Jon Arenberg, Web Cash, Tiffany Glassman, Anthony Harness, Jeffrey Jewell, Charles Lawrence, Doug Leviton, Stefan Martin, Charley Noecker, Stuart Shaklan, Ann Shipley, Steve Warwick, Ben Zeiger

1) Fractional Planet Brightness

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Astrophysical property of the targets of interest – purely scientific definition

Factor	**Method**
Residual light	Brightness of planet
Region of interest	N/A
Unsuppressed starlight	Brightness of star
PSF	N/A

- 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

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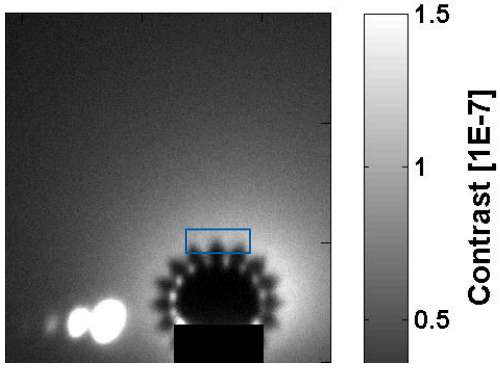
Straightforward calculation of average contrast in the focal plane

Factor	Method
Residual light	Average starlight irradiance in region of interest
Region of interest	Aperture/ pixel/ annulus in focal plane
Unsuppressed starlight	Average irradiance of unblocked star in equivalent aperture
PSF	No correction

- 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: Nσ 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

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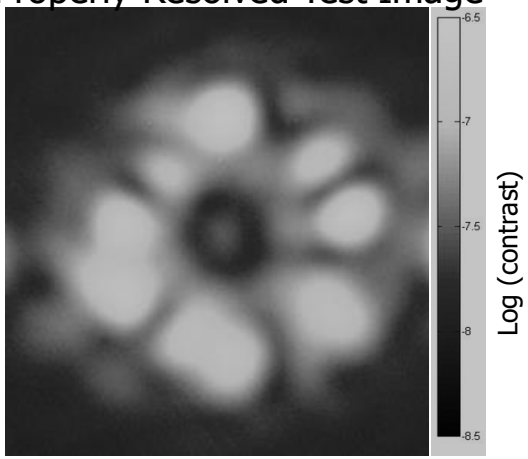
Correct contrast for over-resolved PSF in starshade tests

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

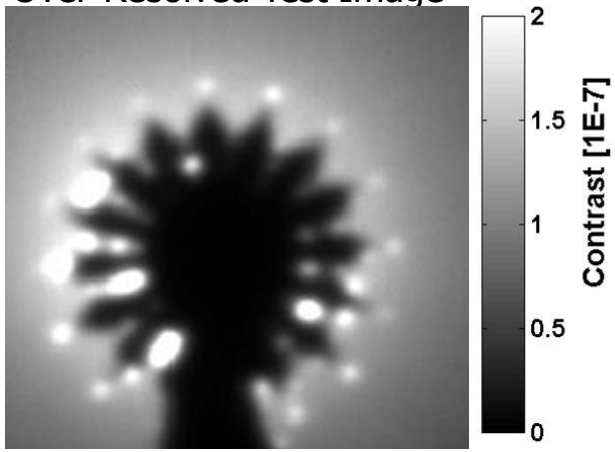
- Pros: Compare starshade images over-resolved in tests to each other and to likely flight systems
- Cons:
  - Extra calculation that is model dependent
  - Test images likely still at higher F# than flight

Properly-Resolved Test Image



Samuele, et al. 2010, SPIE, 7731, 51

Over-Resolved Test Image



Glassman, et al. 2014, SPIE, 9143

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Corrects contrast for planet PSF

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

- 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

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Total light entering the telescope

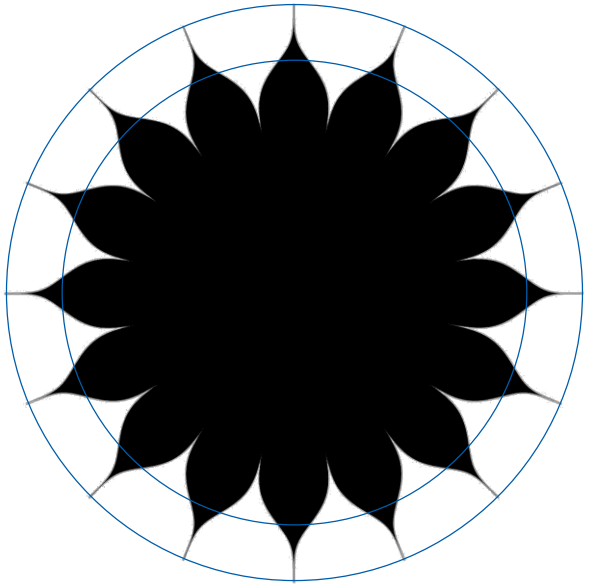
Factor	Method
Residual light	Integrated light in pupil with starshade in place
Region of interest	N/A
Unsuppressed starlight	Integrated light in pupil without starshade
PSF	N/A

- 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

Approximate $r_{1.0}$ and r_e for a Hypergaussian starshade



Ratio of $r_{1.0}$ and r_e could look very different for a numerically determined shape

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