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NORTHROP GRUMMAN

SAG 18 Proposal: Metrics for Direct Imaging with Starshades

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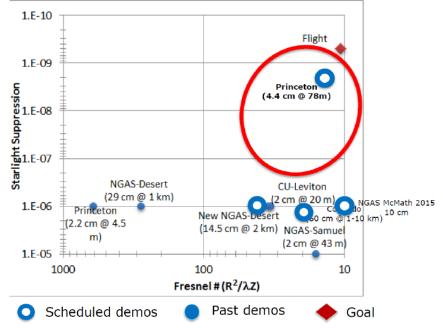# Inconsistent Definitions of Starshade Performance

Various terms for starshade performance are used in…

- Starshade technology development requirements:

Starshade Technology Gap List

ID	Title	Description	Current Capabilities	Needed Capabilities
S-2	Optical Perf Demo and Model Validation	Experimentally validate the equations that predict the contrasts achievable with a starshade.	3×10^{-10} contrast at 632 nm, 5 cm mask, and ~500 Fresnel #; validated optical model 9×10^{-10} contrast at white light, 58 cm mask, and 210 Fresnel #	Experimentally validated models of contrast to $< 10^{-10}$ in scaled flight-like geometry with Fresnel numbers ≤ 20 across a broadband optical bandpass.

(row label: onstration and Validation)

- Plots to compare testbed results:

- However…
  - Terms are often used inconsistently
  - There is no detailed definition of what is meant by contrast or suppression

from 2016 Exoplanet Technology Plan

SAG18 Goals

A standard definition of performance that is agreed upon by the community would allow unbiased comparisons between separate tests and between tests and flight requirements

Primary goal:

1. Create a standardized definition(s) of starshade performance

As part of evaluating this standard, consider how it will be used to…

2. Define mission performance requirements

3. Determine needs for ground tests to do performance verification and model validation for flight

4. …

1. Starshade Performance Definitions

- Two terms for starshade performance are contrast and suppression

	Contrast	Suppression
Definition	Residual starlight at the location of the planet in the image plane	Total starlight entering the telescope aperture in the pupil plane
Pros	Directly linked to planet detectability	Completely independent of telescope
Cons	Dependent on extraneous test variables such as telescope resolution	Not directly linked to planet detectability/ doesn't take advantage of distribution of light

- Need to add more detail to definitions in order to come up with an agreed-upon performance metric

1. Define a "corrected performance" metric

- Can a "corrected performance" metric be defined that will provide an unbiased comparison of various test and flight scenarios?

- New metric should be based off of existing metrics where possible
  - Previous definitions of performance achieved in testbeds /required for planet detection e.g. Useful Throughput (Guyon et al. 2006), Q (Brown & Burrows 1990), Krist (2016), tests by several starshade groups
  - SAG 19 will work in parallel to define a similar metric focused on coronagraphs

- Standard astronomical techniques for detecting faint sources will be referenced where applicable

- Starshade metrics should be unique only where some aspect of the residual stray light from starshades requires a new approach

1. "Corrected Performance" in image plane

- If performance is measured in the image plane – i.e. some type of "corrected contrast"

- Should contrast be calculated at a standard location in the image?
  - For example, an annulus near the petal tips
  - Fixes IWA relative to the starshade angular size
  - Or let this float to allow the definition of IWA to be adjusted based on performance?

- For tests where there is no off-axis object in the field, must define method of determining level of residual starlight in an image pixel
  - Average flux – with or without background subtraction
  - Statistical measure of the noise in the pixels (e.g. StDev)
  - Simulation of point source detectability limit in the image

- If the test image is over-resolved compared to a flight-like configuration, can the image be post-processed to compensate?
  - If so, a standardized method of compensation should be determined

1. "Corrected Performance" in pupil plane

- If performance is measured in the pupil plane – i.e. some type of "corrected suppression"

- If a test measures the shadow directly, then this is simple to define
  - Misses a lot of information about what's happening in the test
  - Flight system won't be measuring in the pupil plane

- If a test only measures the image plane, then the suppression must be calculated by summing over an area in that image
  - What area of the image is included?
  - What features can be masked off?
  - What radius should the area extend to?
  - If there is a smooth background present in the image, can it be subtracted either as a constant level or a smooth distribution before the image is summed?

2. Define Flight Performance Requirements

- Part of evaluating this metric will be its usefulness in defining mission requirements – i.e. the required "performance level" in order to detect a planet at a given Δmag and angular separation

- This could be a simple definition i.e. "performance" $<10^{-xx}$ outside the IWA

- Should required performance be equal to the planet?
    - Doesn't take into account any advantage of any advanced image-processing techniques

- Could required performance be brighter than the planet?
    - Takes advantage of post-processing techniques
    - Could depend on structure of background light (uniform, along the edge of the starshade, speckles)
    - Could depend on techniques to use diversity of background light (spectral or time variability that is different from planets)
    - Definitely depends on evolving ability to pull faint objects from bright backgrounds

3. Ground Tests Requirements

- Another consideration in evaluating the metric will be its usefulness in deciding what level of performance is required for ground tests

- Assumption is ground test will fall short of flight performance in some way
  - How much projection of performance is acceptable? Get within 10X of flight requirement? 2X?
  - How much correction is acceptable? Correct for images that are over-resolved by a factor of 50? Factor of 2?
  - Etc.

- Gets into technology development goals of tests and how this relates to mission risk and Technology Readiness Levels

- This is definitely a stretch goal for this SAG

Please join SAG 18

- If you haven't already done so, please contact us to join the SAG
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- Also please send suggestions for possible definitions and/ or questions to explore

- We'll set up a first telecon meeting soon

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