Jet Propulsion Laboratory
California Institute of Technology

JPL Document D-94003

TECHNOLOGY DEVELOPMENT FOR EXOPLANET MISSIONS

Technology Milestone Whitepaper

Starshade Stray Light Mitigation through Edge Scatter Modeling and Sharp-Edge Materials Development

Suzanne Casement, Principal Investigator
Northrop Grumman
Webster Cash (University of Colorado)
Tiffany Glassman, Steve Warwick

15 December 2014

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

1. Objective

In support of NASA's Exoplanet Exploration Program and the Technology Development for Exoplanet Missions (TDEM) component of NASA's Strategic Astrophysics Technology (SAT) solicitation, this whitepaper explains the purpose of the TDEM Milestone for the evaluation of edge scatter from starshades, specifies the success criteria against which the milestone will be evaluated, describes the differences between the test implementation and future flight implementation of the starshade, and outlines the milestone demonstration procedure. The tasks identified in this white paper are consistent with the scope of initial proposal submitted in March, 2013, updated as much as feasible to reflect new data and research results.

2. Milestone Description

Technology milestones serve to gauge the developmental progress of technology for a space-based mission and the mission's readiness to proceed from pre-formulation to formulation. The completion of the milestone described here is to be documented in a report by the Principal Investigator and reviewed by NASA HQ.

The following milestone addresses the mitigation of broadband light from the Sun scattered off the starshade edge into the telescope. This milestone will include simulation development and sample testing to determine if there is a hardware implementation that meets requirements derived from the simulation.

The milestone is stated as follows:

> *"Develop a scattered light simulation and use it to derive requirements for the edge radius of curvature and scattering properties;*
> *Build and test at least two sharp-edge samples to evaluate the feasibility of flight-compatible materials being fabricated to the derived requirements and how well such a sample performs compared to the predictions of the simulation."*

We recognize that diffraction has been identified as a significant component to the stray light from a starshade edge by Martin et al. (2013), providing an equivalent contribution to the scattered light for small radius of curvature edges. However, we have not included this in the scope of our milestone directly as it was not in the original proposed scope for the simulation development. To the extent possible within our available budget and schedule, we will include the diffraction component in the analyses, and to the extent that it is present, it will be measured in the test of the sharp-edge samples.

3. Background and Current State of the Art

An external occulter mission (or starshade) is one of the methods being studied to be able to detect and characterize extra-solar planets around nearby stars. Several teams are studying the requirements for such a mission and identifying the technical challenges that must be addressed if such a mission were to be undertaken. The Exoplanet Exploration Program (ExEP) released a prioritized list of the technical challenges facing a starshade-based mission [Lawson et al. 2013], the number one challenge being control of stray light. This is because the contrast ratio between the planet and its host star is ~25 magnitudes [Turnbull et al. 2012] and the potential target stars range in brightness from magnitude 2 to 7. Thus for the faintest target stars, the planet brightness would be ~32 magnitudes.

One source of stray light is from the parent star leaking past the starshade. This is addressed by the design and construction of the starshade and is the focus of other technology development efforts. A second contribution is from the light from our Sun that scatters from the edge of the starshade. This must also be controlled so that it doesn't swamp the light of the target exoplanets. Because of the geometry of the system, only the very edge of the starshade is visible to both the Sun and the

Telescope (see Figure 1). However since the starshade is 10s of meters in diameter, this can still add up to a large area. Controlling sunlight scattering from this edge, through a combination of making the edge narrow and making it black, is the focus of this TDEM.

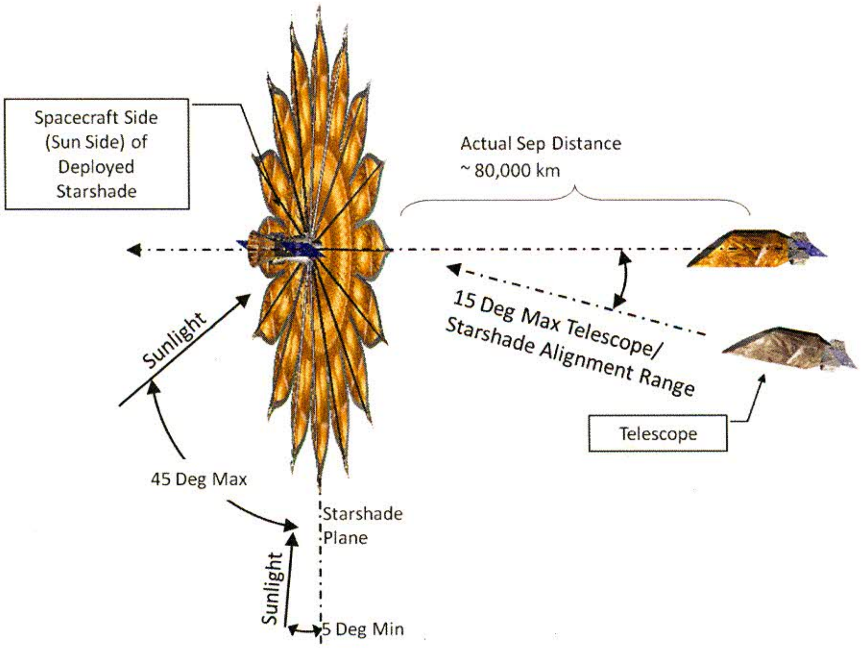

Figure 1: The geometry of the starshade system ensures that only the edge of the starshade is lit by the Sun and also visible to the telescope. The angles shown above are typical operating ranges for a starshade mission.

Our initial TDEM proposal was based on modeling and analysis published in two papers [Arenberg et al. 2007 and Casement et al. 2012] which suggested that a modest edge radius of curvature (25 – 100 microns) would be sufficient to reduce the scattered light to an acceptable level for a Flagship mission (such as the one described by Turnbull et al. 2012). More recent analysis [Martin et al. 2013], published after our submission, suggests that diffraction is the dominant contributor to the stray light originating from the Sun and that scattered sunlight would drive the edge radius of curvature (ROC) down to a few microns. The modeling results are significantly different between the two studies. Casement et al. show that the scattered light provides a reduction of Solar flux by ~57 magnitudes using an edge ROC of 50 microns and the scattered light properties of Graphite Polycyanate, with the BRDF (Bidirectional Reflectance Distribution Function) as given in Figure 2. Using a 1% Lambertian surface results in a reduction of Solar flux by ~ 61 magnitudes. This disagrees dramatically with the Martin et al. result which shows that the Solar flux is only reduced by ~50 magnitudes assuming a Lambertian scattering surface with 10% reflectivity and a 10 micron edge ROC. Even accounting for the difference in reflectivity used in each model (1% v. 10%, equivalent to 2.5 magnitudes) there is still a very large disconnect of at least 9 magnitudes, as our edges are also significantly thicker. By performing this work, we intend to resolve the differences between these two sets of models. In addition, we will identify materials which can meet the optical property requirements indicated from the model and can do so after surviving launch and exposure to the space environment. Testing of sharp edged samples performed in this work will help validate the models.