ExoTAC Report on Starshade S5 Milestone #3 Review

January 17, 2020

A telecon review of the Milestone #3 Final Report for the Starshade Technology to TRL 5 Activity (S5) was held on January 15, 2020. All of the ExoTAC members were able to participate in the telecon.

Milestone #3 deals with the need to demonstrate that solar light that is scattered (reflected and/or diffracted) by the finite thickness edges of a starshade is no brighter than visual magnitude 25, i.e., no brighter than the expected brightness of an Earth-like planet seen in reflected light around a nearby solar-type target star. These "solar glint lobes" would have only diffracted light, not reflected light, for an ideal starshade with infinitely thin edges. The challenge is then to design, fabricate, and test the scatter off realistic edges that replicate the planned flight configurations for starshades intended for use with either WFIRST or a HabEx-like mission.

The testing involved bend and release cycling, given the need to stow and deploy the starshade petals, which are initially wound around a spool, and thermal cycling (+105 C to -125 C), based on the expected number of cycles. Half-scale (0.5 m) test articles were subjected to both bending and thermal cycling. Smaller coupons were subjected to thermal cycling only. The test articles were constructed of amorphous metal bonded to substrates, with nominal sine-wave shapes along the edges. The terminal radius achieved for the amorphous metal edges was less than 1 micron in radius, intended to minimize the reflected light component of the solar glint lobes.

The test articles and coupons were tested for edge scattering on a multi-angle scatterometer (coupons only) and on a single-angle scatterometer (coupons and edge segments), the latter including polarization. Results for coupons on the MAS and the SAS showed good consistency. The test articles showed about 41% more scatter than the coupons, thought to result from non-optimal assembly with the epoxy bonding. On-sky performance was predicted based on the MAS results with the SISTER modeling tool and showed 5% (0.05 mag) agreement with an analytical model for a diffraction-only test case. The environmental cycling (bending and thermal) produced little degradation (about 3%) in scattered light. Testing with a ZeCoat-edge coupon shows that a considerable reduction in scattered light (perhaps a factor of 10) might be possible, and this option is being pursued at present.

The main results are that the average solar glint at the IWA for a HabEx or WFIRST starshade is expected to be fainter than 25 visual magnitudes in blue light (425 nm to 552 nm). This average brightens slightly to V = 24.6 in green light (615 nm to 800 nm), with 40% of the IWA meeting the V = 25 goal at a specific sun angle. Improved manufacturing of the test articles to achieve the coupon results would allow the green band to fully achieve the milestone goal. Applying anti-reflective edge coatings such as ZeCoat could also result in full compliance with the goal.

The ExoTAC requests that more information be made available about the information plotted in the Backup Charts 25 and 27, perhaps in tables to be inserted into the Final Report where those edge scatter figures appear in Appendices D and E. Our concerns deal with the source of the peaks in these figures, e.g., whether there are systematic errors due to mounting the coupons in non-blackened brackets for scatterometer testing, as well as manufacturing issues with the test articles.

The ExoTAC also requests that the explanation for the SCSR of 1.41 being caused by manufacturing problems be clarified in the Final Report where the value is listed (Table 4 on p. 28), if that is indeed the likely cause. Further work by the S5 team should help clarify the situation (see the suggestions below, particularly regarding Chart 19).

Overall, the ExoTAC believes that Milestone #3 has been met and congratulates the entire team on their excellent efforts to advance the technology readiness levels of the elements in the S5 activity. The careful documentation of sample preparation and of testing methods are particularly appreciated. We note, however, that for this edge scatter technology maturation to advance the ExoTAC believes that future Milestones need to reflect a revisit and change to the assumed Stressing Condition for the edges based on the results of this work, as further explained in the suggestions below as well as in the discussions at the meeting.

We thank Stuart Shaklan, Evan Hilgemann, Dylan McKeithen, Douglas Lisman, Stefan Martin, David Webb, and the other S5 team members for their presentations and comments during the review.

Suggestions for future work from Joe Pitman:

Chart 3

- Future work needs to consider higher frequency cycling effects, such as vibrations.

Chart 7

- Future work could use these same 0.5m long otherwise full-scale articles with symmetry and anti-symmetry BC's at one end to be actual full-scale test results.

Chart 8

- Request that the internal member loads/stresses developed in these test articles be compared to the estimated DLL's for the petal edges to understand more clearly whether or not we've met the Stressing Condition definition of TRL test criteria.

Chart 12

- Suggest adding evidence (such as the correlation with model predicts) of actions or measurements taken that firm up there was minimal leakage or losses.

Charts 26, 27, and 36

- Please provide more detailed and direct comparison of the pre to post environmental testing changes in the scatter, in direct support of the defined MS as well as to inform the technology maturation work strategies going forward, including considering annealing of the materials as well as making more refined measurements in the future.

Chart 19

- From materials presented and associated discussions it appears the environmental testing completed on the test articles might have made no difference in the scatter characteristics, both in the test articles directly and in the system analyses completed, meaning that environments tested are not the Stressing Condition required to be achieved in TRL maturation testing per NPR 7120.8. Instead it appears the far larger cause and likely Stressing Conditions of scatter for these edges is in the manufacturing, assembly and repair processes used in these test articles. Please add additional details to support these two assertions if they hold and please consider describing the best path forward to meet TRL maturation criteria.

- Please assess and provide evidence for what the Stressing Condition and Relevant Environments are to mature the technology for Petal Edges going forward.

A number of typos were found in the Report by Steve Ridgway, as follows:

Figure 11 (report): p. 13 - "Orange boxes are data." – There are no orange boxes.

Section 7.1.2 (report): p. 29 - "the full range solar"

Section 7.1.3 (report): p. 31- "segments segments"

Section 7.1.4 (report): p. 32 - "SISTER gint generation"

Tables 6,7,8 (report): p. 32-33 - The data columns headings referring to Figure 24 are somewhat ambiguous; a few more words would help.

Section 7.2.2 (report): p. 35 - "The exozodiacal light level is currently specified at the median expected level of 4 zodis" – I believe that during the conference this was amended to 3 zodis.

Appendix A (report): p. 37 – "edge segment must be meet"