ExoTAC Report on Starshade S5 Milestone #5A Review

April 21, 2020

A telecon review of the Milestone #5A Final Report for the Starshade Technology to TRL 5 Activity (S5) was held on April 17, 2020. All of the ExoTAC members were able to participate in the telecon.

The Milestone #5A objective is to show that a petal subsystem with shape critical features can be fabricated, assembled, and shown to preserve the pre-launch shape accuracy to within +/- 70 microns after multiple cycles of deployment and thermal cycling. The petal width is judged to be the critical dimension that must be stable in order to preserve the starshade contrast, and is being held to a +/- 26 ppm (+/- 34 microns) requirement out of a total KPP5 error budget of +/- 92 microns. The other major error source is manufacture (+/- 41 microns), which will be the subject of Milestone #5B. Lab testing was performed with a single petal subsystem ½ the length of a flight petal with ¾ of the flight width. A custom-built thermal chamber was used for the thermal cycling experiments and a custom-built hub was built for the stowage and unfurling exercises. Position measurements were performed with a MicroVU Excel machine, with a repeatability error of 7.8 microns. The testing performed in 2019 suffered from relatively large thermal variations in the MicroVU machine due to ambient room temperature variations. This was remedied for the 2020 testing, which involved 50 thermal cycles and 5 deploy cycles, but which still required data corrections for the thermal response of the MicroVU machine's steel tape ruler. After corrections, the petal-width bias measured in the experiments was determined to be no worse than +/- 5 ppm, with a maximum uncertainty of +/- 12 ppm, consistent with meeting the Milestone #5A goal of +/- 26 ppm.

The ExoTAC raised concerns during the review on several issues that should be addressed in the Final Report, as follows:

1) Future work needs to clarify the shape errors that could arise from the many other disturbances that will occur to the entire starshade system beyond the deployment and thermal cycling disturbances considered here.

2) The fact that only a single petal subsystem was constructed and tested means that the variations to be expected from an ensemble of petals cannot be reliably verified on the basis of the work performed on this Milestone.

3) Use of an Invar "meter stick" or some other approach instead of the steel tape would calibrate the thermal corrections that need to be applied to the MicroVU measurements, or at least serve as a check on the success of the correction process.

4) Please add language, as was confirmed in our telecon, that the AI&T & Storage error allocation of 26 ppm is meant to include all errors within this category of which the present work reported herein are just a subset.

5) Please consider adopting a standard optical error budgeting approach of correlated and uncorrelated error sources as bias and random errors, respectfully (with split allocations as needed for intermediate types of error sources) and use that in each MS report to clearly identify the allocations and suballocations the work addresses, while describing the rationale for that focus and acknowledging work needed to address remaining related error sources and allocations.

6) Please add language that the team recognizes and is working as part of another MS these two items:
    a. After initial ground shape validation following build but before stowed qualification dynamic and thermal testing the starshade will likely undergo shape changes. Those sources of error are not in the scope of the milestone's work but will be addressed in some future activity.
    b. After final ground shape verification of each petal following stowed ground acceptance dynamic and thermal testing the flight system will be subjected to launch, ascent and thermal (survival) conditions prior to deployment for science operations. Those sources of error are not in the scope of the milestone's work but will be addressed in some future activity.
7) Sect 3.1 last para please add for clarity further description of rationale for what has been excluded from being "shape critical features" for the deploy cycles (e.g., ignoring petal latch features) and for the deployed thermal cycles (e.g., no longerons in test article)

Notes for further consideration from Steve Ridgeway:

I think that there are several things that combine to make Table 1 and related discussion difficult to follow. The table caption is fairly clear, but terminology in the text and in the table sets the reader on the wrong path and we found it difficult to climb out of that.

1. "Bias" is used in a non-standard way, and worse, in a misleading way. I urge you to rewrite the paper to not use this term.

2. "Bias" sounds like an error with respect to an absolute standard. But here the error to the standard is tracked elsewhere, in the "manufacture" category. The error studied here is only a change in the shape from the manufactured shape, whatever that is.

"Global" sounds like it refers to the entire starshade. but after listening, I think it refers to a useful and simple characterization of the size change of one petal with a single parameter.

So I would call the quantity something like "Median petal-width change of test article accumulated during AI&T and storage". In my opinion, words like this would cause the reader to assess their understanding of the table and more easily get it right.

3. The problem with "random" is that it sounds like it should refer to the result of measuring many petals. but as I understand it, it is the higher order terms of the petal width error after removing the median value. So I would suggest calling it, "Petal width additional RMS error about median error".

4. Also, I would include the clarification (reminder) in the table caption that only one petal was measured - again, redundancy to keep reader on track. That raises the implicit question of whether errors are correlated or not from petal to petal. I heard in the discussion that this has been considered, but I found the discussion went somewhat against my intuition. I recommend that this issue should be mentioned near the table, and either directed to further discussion, or reserved for the future.

5. There are multiple places in the paper where it is said rather explicitly that the headroom in an observed stability term is margin on that term. I think those statements should be deleted unless the case is made that all other terms appear under other allocations.

Overall, the ExoTAC believes that Milestone #5A has been met and congratulates the entire team on their efforts to advance the technology readiness levels of the elements in the S5 activity.

We thank Flora Mechentel, David Webb, Doug Lisman, and the other S5 team members for their presentations and comments during the review.

Exoplanet Exploration Program TAC Members

Alan Boss (Chair), Carnegie Institution

Rebecca Oppenheimer, American Museum of Natural History

Joe Pitman, Heliospace Corporation

Lisa Poyneer, Lawrence Livermore National Laboratory

Stephen Ridgway, NSF’s National Optical-Infrared Astronomy Research Laboratory