S5 Assessment Review: Recommended Changes and Dispositions

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S5 Assessment Review Process

The S5 Assessment Review was held on Monday, September 23. The morning session was devoted to listing and discussing proposed changes to the S5 plan as received from the ExoTAC, the TSWG, the SIP face-to-face meeting of September 18-19, and the S5 team members themselves. The afternoon session was devoted to scoping and categorizing the proposed changes.

At the request of TSWG chair Simone d'Amico, a second, more formal presentation of the TSWG's recommended changes to S5 was delivered to the S5 Project Manager on October 10. These recommended changes have been incorporated into this proposal list.

On November 12, S5 briefed NASA HQ on this proposal list and its disposition plan. The Remote Occulter mission concept was also briefed to HQ during this meeting.

Accepted Recommendations

These proposed changes are consistent with S5's current scope, L1 deliverables, and resources, and are accepted by S5 without further comment:

- *More thoroughly document the S5 error budget and KPPs*
- *Publicly document the mechanical architecture design trade*
- *Document starshade's dynamic response against mission requirements*
- *Analyze contrast stability terms in the error budget*
- *Analyze effect of contamination on edge scatter*
- *Analyze effect of contamination on reflected bright bodies*
- *Analyze and document the on-sky starshade calibration approach*
- *Investigate alternative mask fabrication techniques*
- *Investigate the sensitivity of the starshade error budget flow-down to exozodi level and structure*
- *Design and support community data challenges to use state-of-the-art retrieval methods to increase fidelity of KPP's traceability to scientific objectives*

More thoroughly document the S5 error budget and KPPs

Publicly document the mechanical architecture design trade

Document starshade's dynamic response against mission requirements

These tasks are generally motivated by comments from many quarters that assumptions and trades made by S5 are often obscure. A better understanding of these underlying assumptions and trades would help the SIP advise S5 on how to bring starshade technology to TRL5, and would help the Decadal Survey judge the maturity of starshade technology for future flight missions.

Analyze contrast stability terms in the error budget

Analyze effect of contamination on edge scatter

Analyze effect of contamination on reflected bright bodies

The S5 team understands these proposed changes to encompass variations in the instrument contrast over time scales long compared to integration times for exoplanet images, such that the calibration of the instrument cannot be assumed constant from image to image. Accumulated micrometeoroid damage would be one potential mechanism for such slow contrast changes. The scope would be to more thoroughly understand and document the contrast variation, along with proactive distribution of the results to the interested astrophysical community.

Analyze and document the on-sky starshade calibration approach

The S5 team understands this to encompass the steps that must be taken during a mission to calibrate the starshade contrast sufficiently to enable exoplanet imaging with the signal to noise ratio required by the starshade mission concepts. Frequency of calibrations and properties of candidate calibration stars would fall within the scope of this task.

Investigate alternative mask fabrication techniques

S5 understands this task to apply for the masks required to demonstrate TRL5, and also for masks required for possible post-TRL5 studies using a longer testbed. This is already a very active line of investigation for the TRL5 masks required to demonstrate milestone 2, and a backup vendor (UC San Diego) can now produce high quality masks for S5.

Investigate the sensitivity of the starshade error budget flowdown to exozodi level and structure

Design and support community data challenges to use state-of-the-art retrieval methods to increase fidelity of KPPs' traceability to scientific objectives

These proposals are similar in their attempt to validate the S5 error budget with better understanding of high SNR exoplanet detection and characterization. The TSWG is currently determining scope for the data challenges, which will likely include some exozodi variation in the challenge datasets.

Recommendations Requiring ApD Approval

These proposed changes are consistent with S5's current scope, but require revisions to L1 deliverables, additional resources*, or both:

- *Better model and understand vector diffraction effects on starshade contrast*
- *Fund more focused/directed material test facility*
- *Extend the SIP*
- *Investigate edge coatings and alternative edge technologies to reduce solar glint*
- *Build a longer optical testbed at the XRCF or some other location*

*requests requiring additional resources will be directed to the SOP and PPBE processes as appropriate.

Better model and understand vector diffraction effects on starshade contrast

This has been requested of S5 by the ExoTAC, and S5 is very actively working on this issue already, both with experiments at the Princeton testbed and with models. Both the requirements and completion date of milestone 2 have changed from the baseline plan, and the milestone is now scheduled to be complete in June 2020.

Fund more focused/directed material test facility

The material testing needed for starshade mechanical development is by necessity contracted to a very few vendors with adequate facilities, but these vendors are not engaged at a level that meets S5 needs in a timely or convenient manner. This task would set up a facility and staff dedicated to material testing of starshade component materials. This could be done with one of the current vendors, or with new industrial or academic vendor, or within NASA itself.

- This proposal will be given a cost/benefits analysis by S5 and the result brought to HQ during the next PPBE cycle.

Extend the SIP

The SIP can be extended both in current scope, and by keeping it active beyond 2020. The SIP vendor subcontracts could yield tangible improvements in S5's demonstrating its technology milestones. Many of the tasks described in this report could be executed within the SIP, for example as student projects. The TSWG identified several specific tasks within this rubric: data challenges and hackathons, academic interactions through Capstone Design classes and/or graduate research funding, and funding/organizing a special issue of SPIE JATIS.

This proposal will be given a cost/benefits analysis by S5 and the result brought to HQ during the next PPBE cycle. The special JATIS issue is already being arranged by the TSWG.

Investigate edge coatings and alternative edge technologies to reduce solar glint

This edge coating investigation is already underway as an SIP subcontract with Zecoat. Other solar glint suppression techniques have been proposed, such as ‘stealth edges’. The stealth edge technique would require a nonspinning starshade, which would require new thermal analyses and pointing control and would affect KPP allocations in the error budget.

- This proposal will be given a cost/benefits analysis by S5 and the result brought to HQ during the next PPBE cycle.

Build a longer optical testbed at the XRCF or some other location

This would definitely be valuable for post-TRL5 work on optical suppression, but unlikely to be needed for TRL5. A study on the requirements for a longer testbed would be inexpensive, but the testbed itself would likely cost a few $M. S5 is currently has planned scope to evaluate what V&V could be done in a longer testbed and what properties that testbed must have.

- We recommend that S5 perform its evaluation, and bring any plan to build a new testbed to HQ through the SOP and PPBE processes.

Recommendations We Redirect Outside S5

These proposed changes are outside S5's scope, and are better directed to other parties:

- *Find uses for starshades other than exoplanetary system studies*
- *Understand how S5 optical sensitivity scales up to Remote Occulter and down to mDOT mission sizes*
- *Understand how the thrust impulse and thermal environments and mechanical design together impact sensitivity for Remote Occulter and mDOT*
- *Given the current landscape of starshade concepts, survey and assess TRL of required and enabling technologies, including precision and fuel efficient formation-flying and orbit control in earth orbits (LEO to cis-lunar)*
- *In-space assembly design and trade study*
- *Investigate starshade refueling*

Find uses for starshades other than exoplanetary system studies

While the question is interesting, this task has no clear relation to demonstrating TRL5 for any starshade technology, and so would distract from S5's core purpose. This recommendation would better be directed to NASA's Physics of the Cosmos and Cosmic Origins Programs.

Understand how S5 optical sensitivity scales up to Remote Occulter and down to mDOT mission sizes

Understand how the thrust impulse and thermal environments and mechanical design together impact sensitivity for Remote Occulter and mDOT

Given the current landscape of starshade concepts, survey and assess TRL of required and enabling technologies

These proposed changes all relate to missions other than the current S5 reference missions of Starshade Rendezvous and HabEx. These are relatively straightforward to do, but require significant time and resources. We recommend these task be considered by the ExEP within its State of the Program exercise, and/or by the ExEP technology office within its biennial technology assessment.

In-space assembly design and trade study

The S5 baseline mechanical design has a high probability of demonstrating TRL5, and S5 has already determined that developing two parallel mechanical architectures is unaffordable in the baseline budget. The in-space assembly concept for starshades is so new that its enabling technologies and their TRLs is still unknown.

- We recommend that the ExEP consider evaluating the enabling technologies and TRLs for starshade in-space assembly as part of its biennial technology assessment.

Investigate starshade refueling

Refueling would be a clear advantage to any starshade mission, but refueling is already very actively investigated elsewhere in NASA.

- We recommend that S5 contact the GSFC team doing RESTORE-L and associated refueling technology development, to communicate to them special starshade mission needs, and learn from them enabling features for refueling that could impact starshade design.

Recommendations without Disposition

Preselecting target stars

The idea is that the yield of starshade exoplanet missions would be enhanced by focusing observations on stars already known to have rocky planets in habitable zones through transit or RV observations. This recommendation does not appear to be actionable at this time.

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