ExoTAC Report on Starshade S5 Milestone #4 Review

January 18, 2019

A telecon review of the Milestone #4 Final Report for the Starshade Technology to TRL 5 Activity (S5) was held on January 17, 2019. With one exception (DM), all of the ExoTAC members were able to participate in the telecon.

Milestone #4 deals with the lateral formation sensing and control of the starshade's orbital position when viewed by the space telescope being used to image and characterize exoplanets around nearby stars, whose light is being blocked by the starshade. The nominal space telescope assumed is the 2.4-m WFIRST design, though the Milestone work is relevant for any roughly 2.4-m space telescope operating at L2. The nominal starshade (NI2-24) has 24 petals and a tip-to-tip diameter of 26 m, producing a dark shadow with a 4.4-m diameter at the telescope.

The Milestone #4 objective is to validate the sensor model by demonstrating that the lateral position offset accuracy of the starshade can be measured to within a flight equivalent of +/- 30 cm (with a goal of +/- 10 cm), and that a control system simulation using that validated sensor model can demonstrate lateral position control to within +/- 1 m. The approach used to validate these sensing requirements assumes a 1 Hz measurement rate as well as white noise from all sources and is performed by a combination of analytic, numerical, and experimental data, with the intent to develop a flight-capable sensor model adapted to the space environment. The control requirement is intended to show that this sensing model can be used in the space environment, even with pessimistic performance assumptions for formation flying.

Analytical work was used to predict the size of the Poisson spot (spot of Arago) for the nominal starshade petal design. This prediction was then confirmed (and the brightness of the spot determined) with detailed numerical modeling of the entire optical path of the starshade and telescope. The numerical model was used to generate a library of predicted images when the starshade and telescope are aligned or near alignment. An image-matching algorithm was used to measure the displacement if any of the starshade from the telescope's optical axis.

Lab testing was performed with the Starshade Lateral Alignment Testbed (SLATE) at JPL, and it was used to validate the numerically predicted image library (for the red and green science bands) and the function of the image matching algorithm. A "2D disk-deadbanding" algorithm for formation flying was developed, using a noise-magnified version of the blue science band simulation model and other pessimistic assumptions, to derive the thruster firings needed to maximize the drift time between successive thruster firings. This work showed that science data could be taken in the roughly 10 minute time spans between thruster firings, even in the worst case.

The ExoTAC raised concerns during the review on several issues. One was the problem with sensing when blue science data is being taken, when the sensing algorithm operates in the red band, with decreased throughput and larger spots compared to the other science bands. As a result, the SLATE test bed could not demonstrate the same sensing accuracy as was shown in the red and green science bands. The S5 response was that this was not thought to be a real concern, due to the non-flight-like environment of the SLATE experiments, e.g., the need for correcting flat-fielding errors and the noisy camera used.

Another question raised was whether or not a position stability requirement might need to be flowed down to complement the position knowledge error derived to guide this technology development milestone. The ExoTAC requests that this concern be considered in the future but as part of normal engineering development work by the S5 team. Similarly, in response to ExoTAC questions the S5 team clarified that the simulation completed to satisfy this technology development work did not consider any starshade flexible body effects, nor did it impose any practical constraints on permissible thruster firings, such as single pulse magnitudes or pulse train frequency exclusions. The S5 team assumes damping of the starshade vibrations following thruster firings is sufficient or could be enhanced such that the control simulations completed for this milestone remain valid. The ExoTAC concurred but requested the S5 team conduct sensitivity analyses in the future course of engineering development to help formulate what kind of impacts to the drift time science would occur when allowing for thruster constraints imposed by flexible body effects that can't be fully damped out.

Overall, the ExoTAC believes that Milestone #4 has been fully met and congratulates the entire team on their excellent efforts to advance the technology readiness levels of the elements in the S5 activity. Precision lateral control over thousands of kilometers is an unprecedented requirement, and essential for starshade operation. Achieving this first of fifteen S5 Milestones serves as a confidence builder for the entire S5 activity.

We also note that by virtue of the successful achievement of Milestone #4, the Exoplanet Exploration Program's Technology Gap List item S-3 on "Lateral Formation Sensing" is retired.

We thank Kendra Short, Stefan Martin, Michael Bottom, Thibault Flinois, and the other S5 team members for their presentations and comments during the review.

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