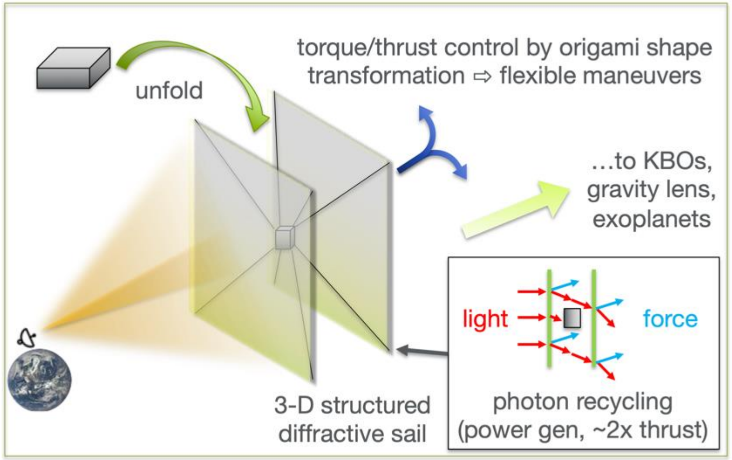
Origami-inspired Diffractive Sail for Directed Energy Propulsion



Origami-based design enables 3-D shaped diffractive sails that can expand, maneuver, and recycle photons for breakthrough propulsion.

Research Objectives

- **Goal:** Develop an **origami-inspired diffractive sail propulsion** system to unlock the maximum potential of diffractive sail propulsion for KBO exploration and interstellar travel.
- **Innovation:** Origami-inspired 3-D shaped diffractive sails enable **effective photon recycling** for thrust enhancement and power generation via used photons. The origami-based shape transformation offers **large expansion rate for sail deployment** and **flexible orbit maneuver capability**. Diffractive sails can be designed to ensure **passive beam-riding stability**.
- **Comparison to SOA**: Improved understanding of **underlying multi-physics processes of 3-D shaped diffractive sails**, their propulsive performance, and system design methodologies.
- **Entry TRL 1:** some basic principles known/formulated.
- **Exit TRL 3:** detailed mathematical models; proof-of-concept design and performance evaluation; experimental validation of critical components.

Approach

- **Task 1. Multi-physics Mathematical Modeling:** Develop **multi-physics, semi-analytical models** that capture the effect of sail deformation and multiple diffraction on the net thrust and torque.
- **Task 2. Proof-of-Concept System Design:** Formulate a **proof-of-concept of the proposed propulsion system** and evaluate its propulsive performance. Develop systematic methodologies for computational design of the propulsion system.
- **Task 3. Experimental Validation:** Conduct **laboratory experiments to assess the validity** of the models and proof-of-concept design from Tasks 1 and 2.
- **Key metrics for evaluation:** spacecraft thrust-to-mass ratio, passive laser-riding stability, effective deviation angle, and time-of-flight for solar system escape.

Potential Impact

- **Fundamental physical understanding.** Improved understanding of **fundamentals of diffractive sail propulsion** under deformation and multiple diffraction.
- **Computational system design.** Novel **methodologies for computational deign of the propulsion system**, including co-design of microscopic gratings, 3-D sail shape, folding patterns, possible transformation states, and flight trajectories.
- **Experimental procedure.** New insights into experiment design and hardware setup for **measuring small forces caused by light diffraction** acting on deformed, 3-D shaped sails.
- **Science impact.** Innovative means for exploring KBOs, solar gravity lens, and exoplanets within a human lifetime.
- **Extension to similar concepts.** Produced models and findings applicable to diffractive sails propelled by sunlight or hybrid of sunlight and lasers.