JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Diffractive Solar Sailing NIAC Phase III

PI: Amber Dubill (JHU/APL)

Co-I's: Dr. Grover Swartzlander (RIT), Les Johnson (NASA MSFC)

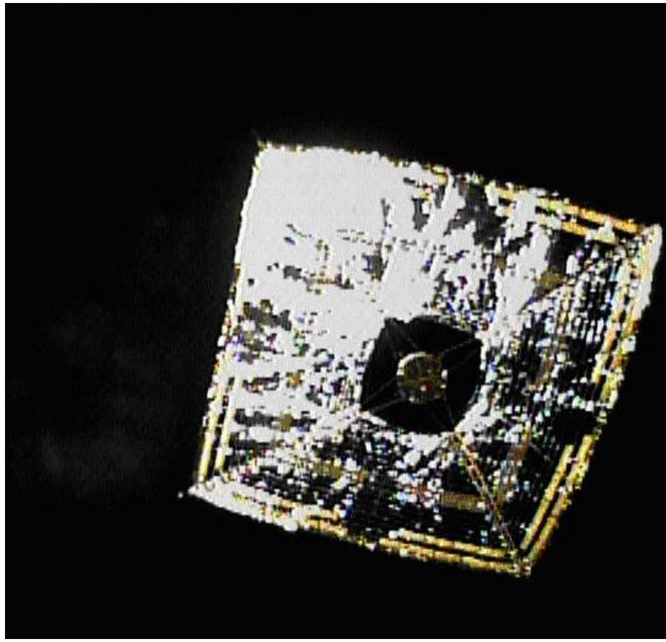
Collaborators: Dr. Angelos Vourlidas (JHU/APL), Dr. George Ho (JHU/APL), Dr. David Shrekenhamer (JHU/APL)

Comparison of Past Solar Sailing Missions

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

	IKAROS	NanoSail D2	LightSail 2	NEA Scout
Organization	JAXA	NASA MSFC	Planetary Society	NASA MSFC/JPL
Central Body	Sun	Earth	Earth	Sun
Year of Launch	2010	2010	2019	2021
Sailcraft Mass (kg)	319	4	5.1	16
Sail Mass (kg)	15	1.35	0.48	3.6
Sail Area (m^2)	196	10	32	86
Areal Density (kg/m^2)	1.628	0.400	0.159	0.186
Attitude Control Method	Cold Gas Thrusters	Passive Magnets	1 Reaction Wheel and Torque Rods	Sliding Mass Table and Reaction Wheels
# of Boom	0	4	4	4

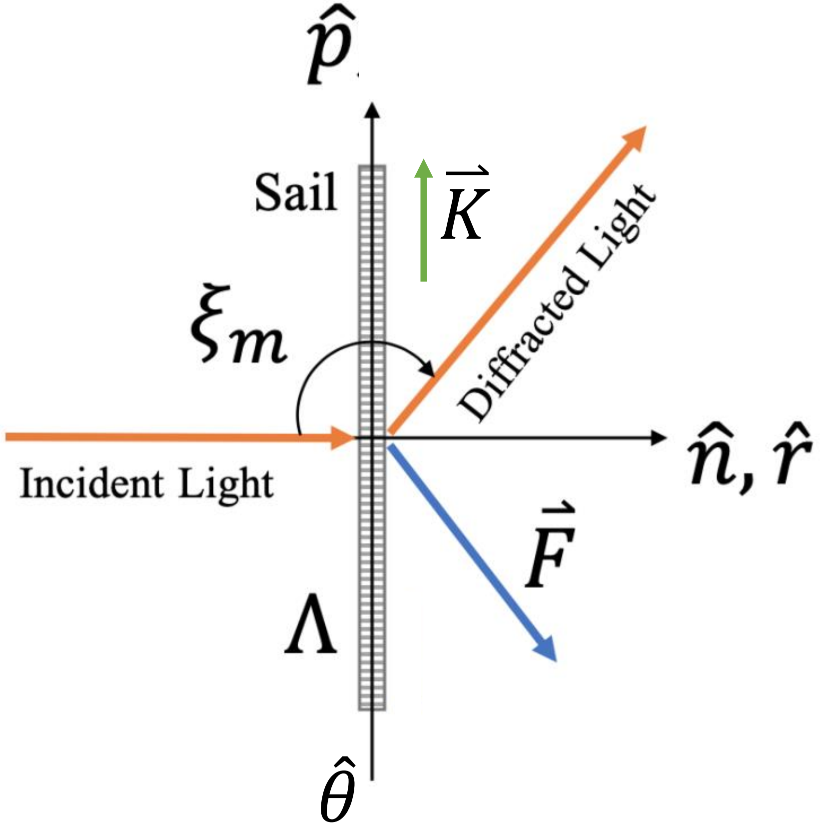
*Not included is Solar Cruiser, est. 2025 Launch



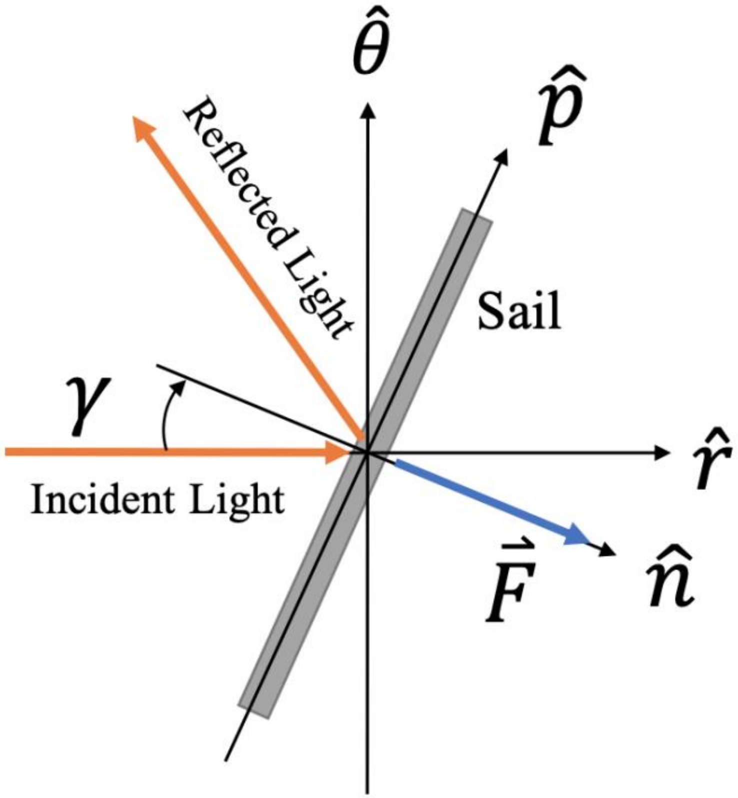
JAXA's IKAROS circa 2010 after deployment

1. Spencer, D., Johnson, L., and Long, A., "Solar sailing technology challenges," *Aerospace Science and Technology* , Vol. 93, 2019.

Diffractive Solar Sailing Concept

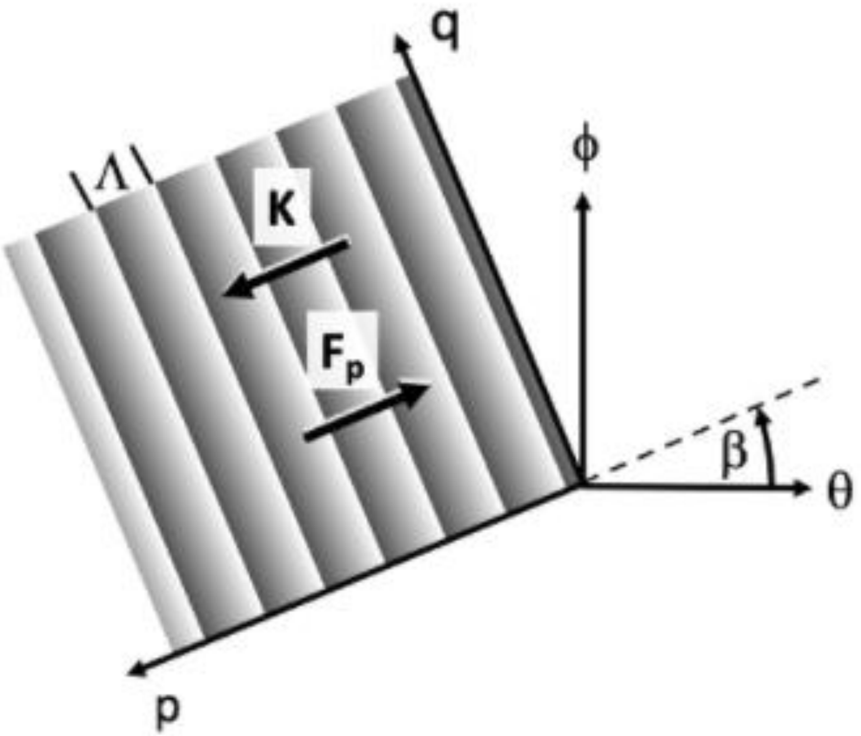


Diffractive

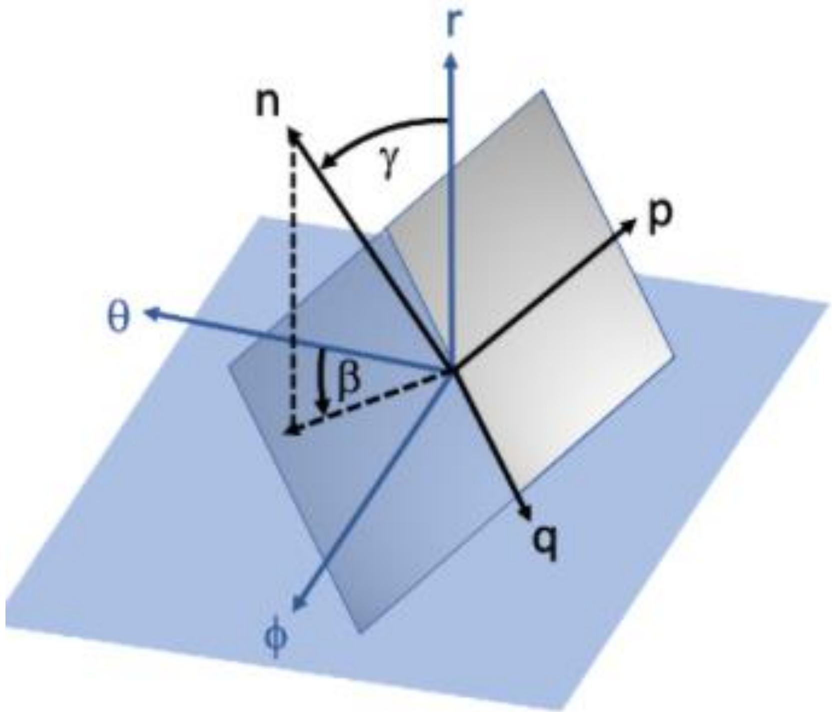


Reflective

Diffractive Solar Sailing Concept



Diffractive



Reflective

NASA Innovative Advanced Concepts

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Phase I
$175,000 – 9 months
12 to 18 awards per year

Phase II
$600,000 – 24 months
6 to 8 awards per year

Phase III
$2 million – 24 months
1 award per year

NIAC
NASA Innovative Advanced Concepts

In 2019, NIAC introduced Phase III proposals-
We were selected as the 5th NIAC Phase III award!

(*FY22 numbers, have been different in past)

Primary Investigators

Co-I: Dr. Grover Swartzlander

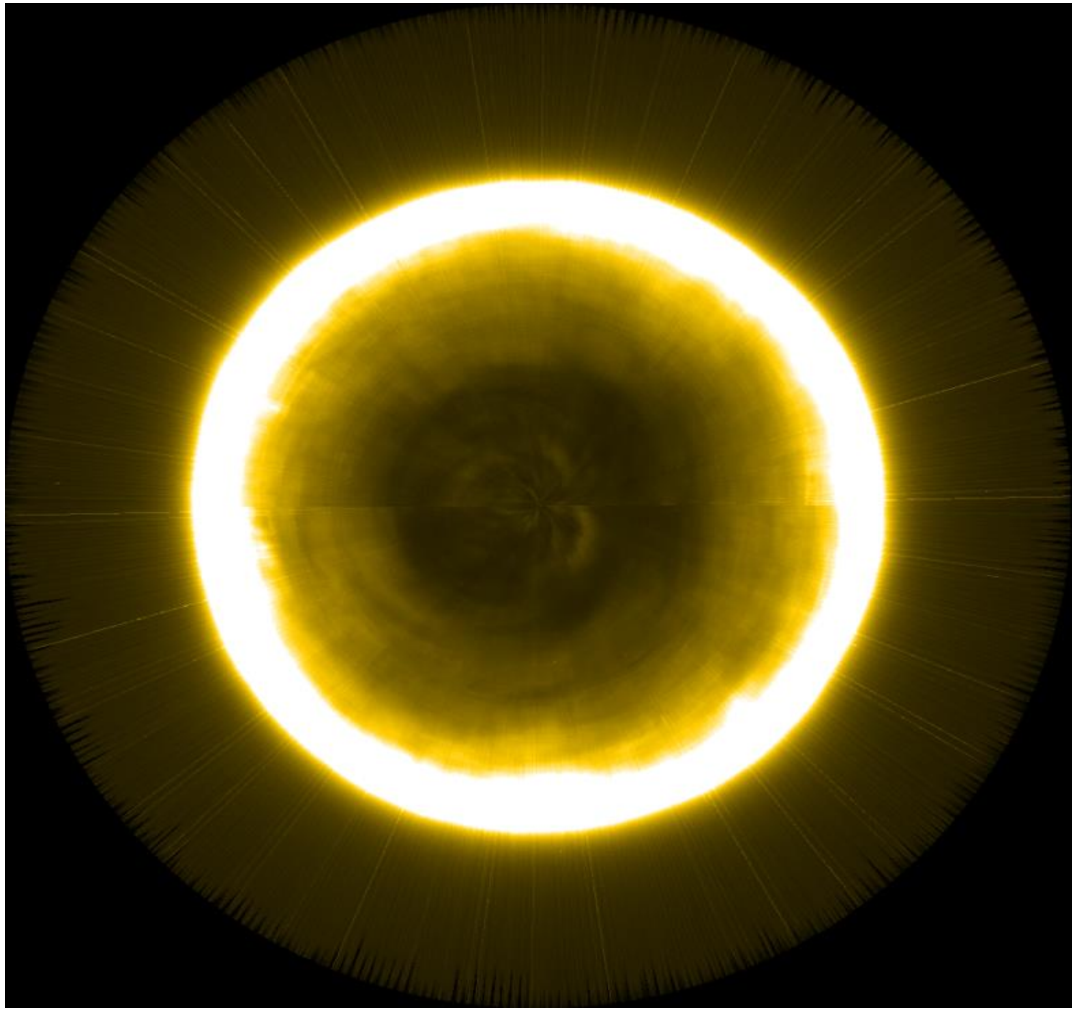
PI: Amber Dubill

Co-I: Les Johnson

- Phase I awarded to Dr. Swartzlander @ RIT in 2018
- Phase II awarded to Dr. Swartzlander @ RIT in 2019
- Phase III awarded to Amber Dubill @ JHU/APL in 2022

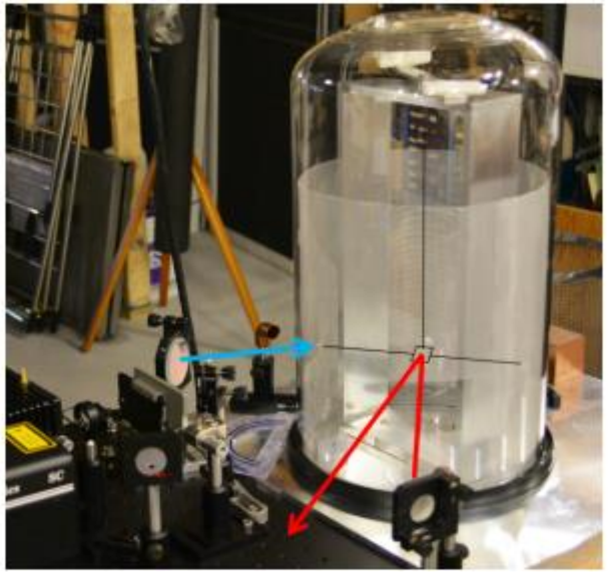
Heliophysics – Solar Polar Imagers

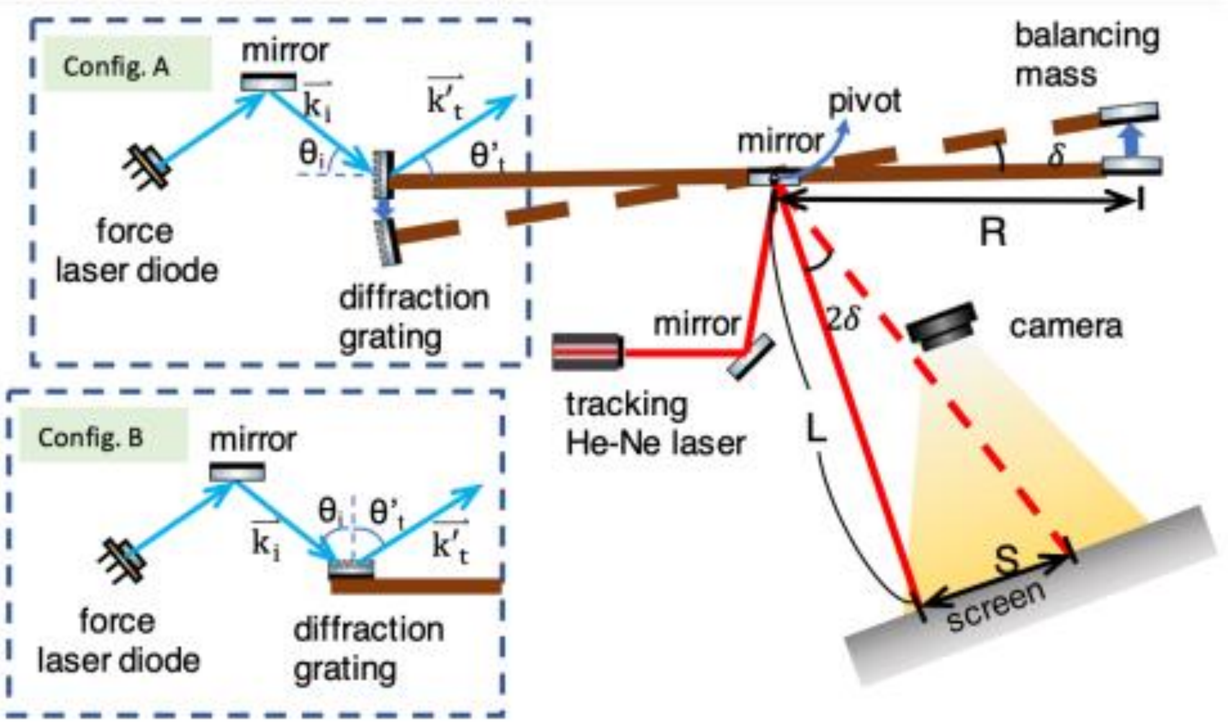
- There is a scientific need for more heliophysics missions
  - 2013 Decadal Survey for Solar and Space Physics
  - Upcoming Decadal Survey of which APL is heavily involved
  - Community interest in multi-view simultaneous observations
  - Interest in space weather prediction and alert systems
- These missions particularly are advantageous with solar sails
  - Thrust increases exponentially as orbital radius to Sun decreases
- Ulysses has been the only mission with a focus on the solar poles
  - No imaging
  - 1.3 AU to use Jupiter gravity assist
- Solar Polar Orbiter
  - Launched in February 2020
  - 7 years to achieve 24 degree inclination
  - 2 gravitational assists – Venus and Earth



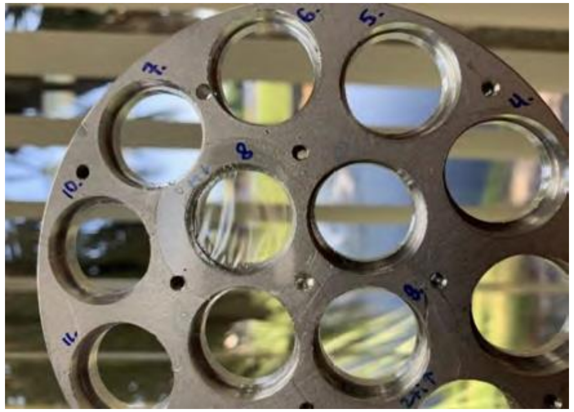
Picture of solar pole stitched together from Proba-2 data

Previous Research

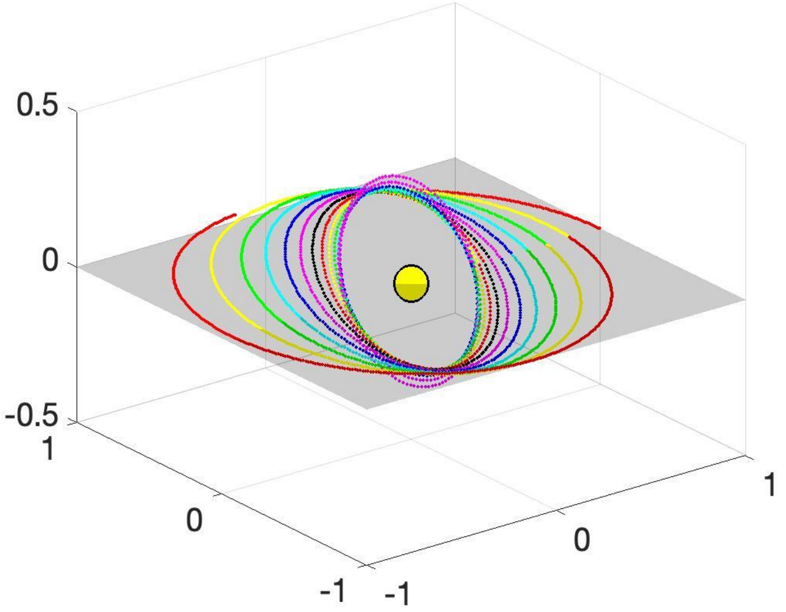


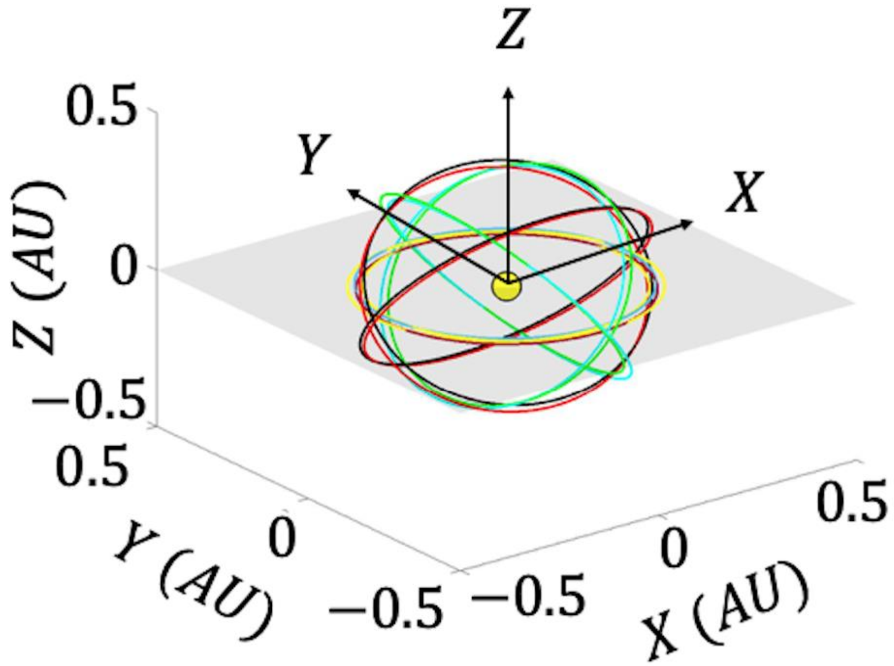


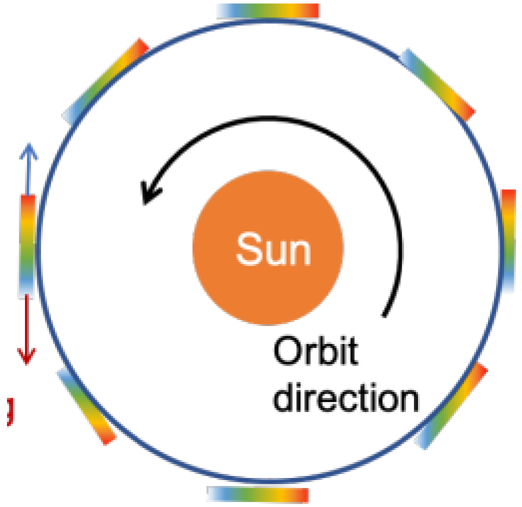
- Performed radiation pressure testing using a torsion oscillator on narrow band diffractive gratings at RIT
- Diffractive gratings were also subjected to space weather testing at NASA MSFC

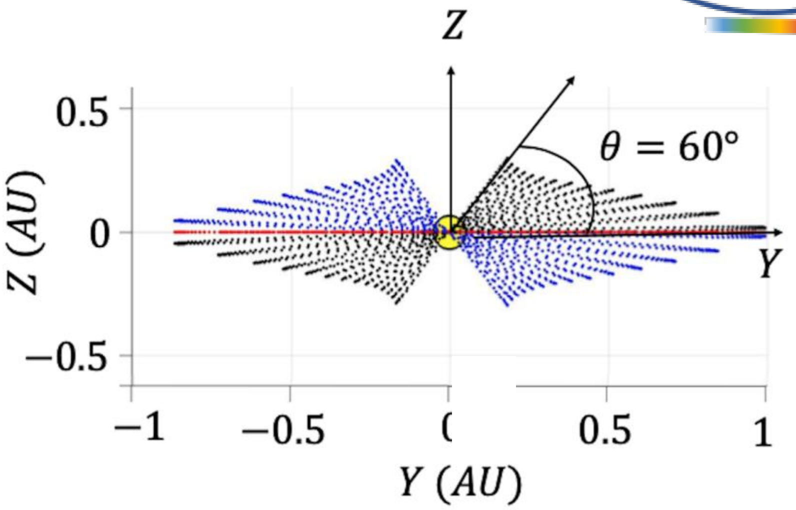


Previous Research





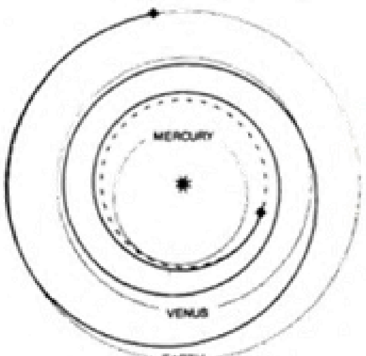




- NEA Scout like sailcraft with over twice the sail side length (20 m x 20 m sail), 6U, and 14kg
- Simple solar polar orbiter constellation of 12 satellites at 60º at 0.32 AU in 6 years
- Non-Optimized Roll Maneuver

Previous Research

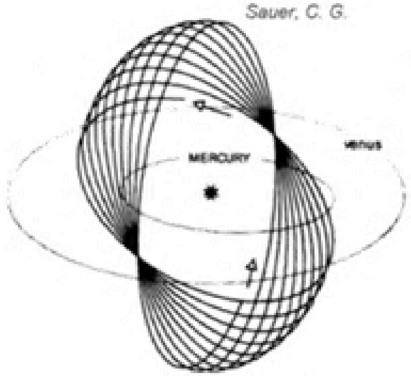
- Solar Polar Imager: Diffractive vs. Reflective Study performed by NASA Marshall's ACO
- Final orbit: 0.48 AU at inclination of 75 degrees
- Traditional reflective sailcraft is assumed 7000 m^2, though bus structure had to spin to avoid boom buckling
- Increased efficiency of diffractive sail concept showed a 6050 m^2 sail was needed to accomplish the same mission. This size sail did not require spinning to avoid boom buckling



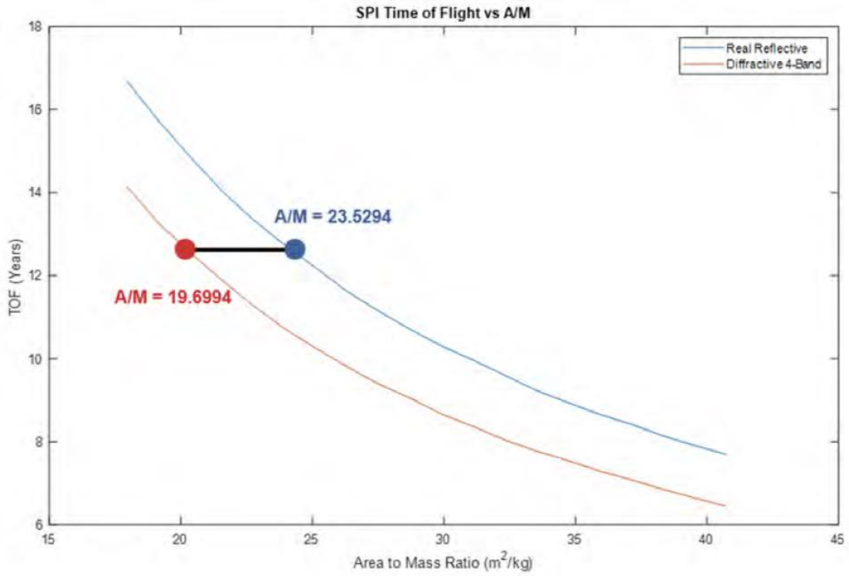
AAS 99-336
Sauer, C. G.

Spiral in "pumping" from 1 AU to 0.48 AU with zero C3

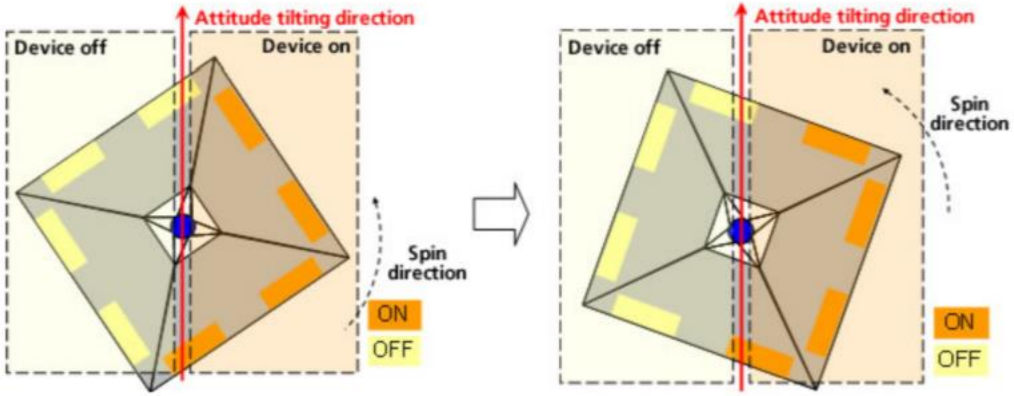
Beginning orbit is 1 AU circular



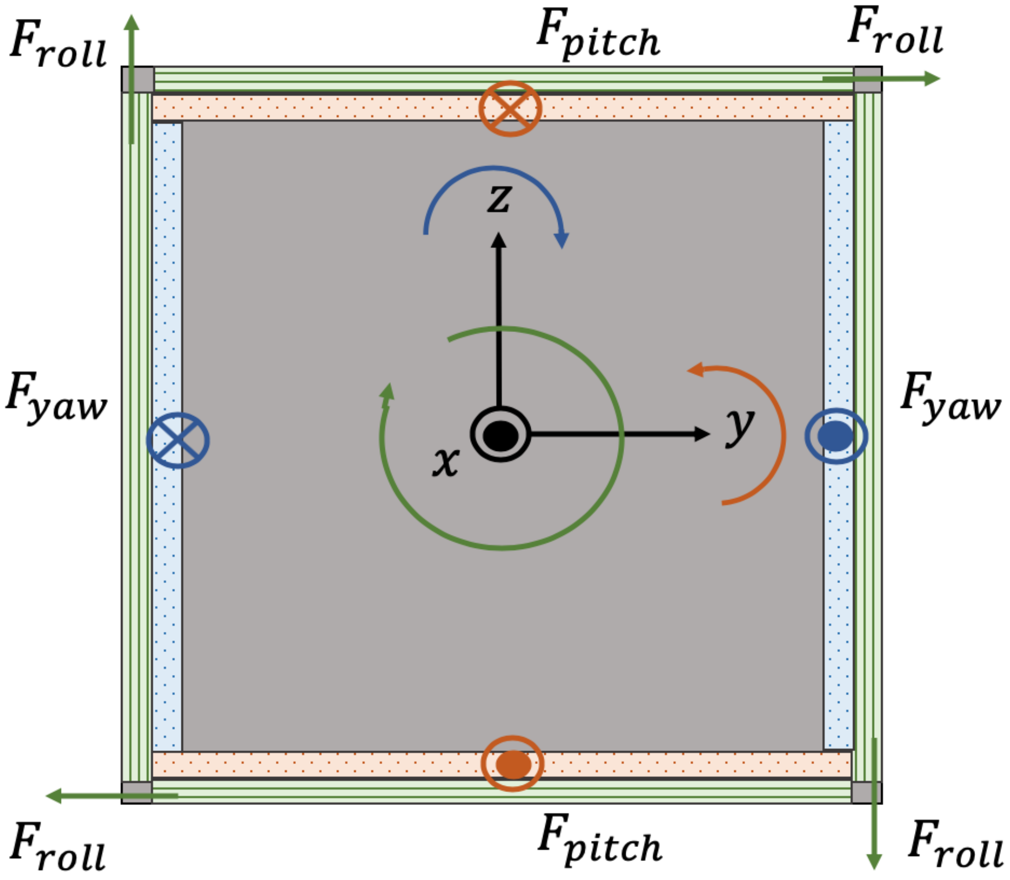
Perform solar sail "cranking" from 0 – 75 deg inclination (w.r.t. ecliptic)

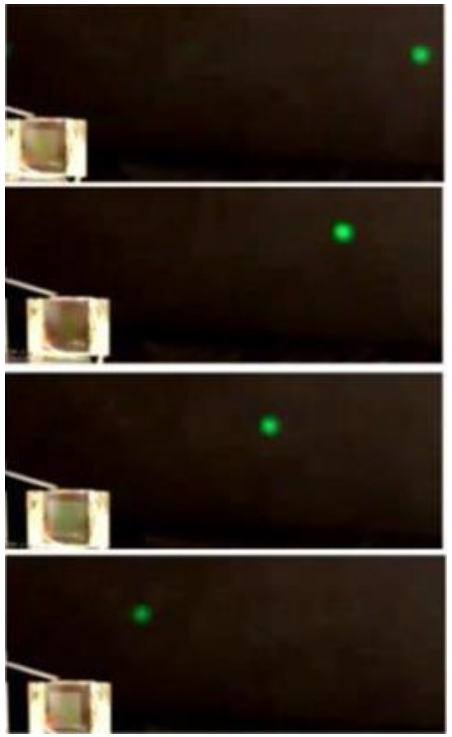


Electro-Optical Devices: GNC



- Potential to use modified theory of IKAROS' tested Reflectivity Control Devices (RCD's)
- Diffractive gratings would be able to control offsets in all 3 axis unlike before
- Two methods: area control or switchable optics (beam steering)





Planned Work 2022-2024

Period of Performance started Oct 2022

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Key Areas of Development

- Improvement in efficiency of gratings for broadband solar spectrum
- Manufacturing of sail material and scaling to large areas
- Complete characterization of realistic diffractive sail dynamics
- Space qualification of diffractive sail materials

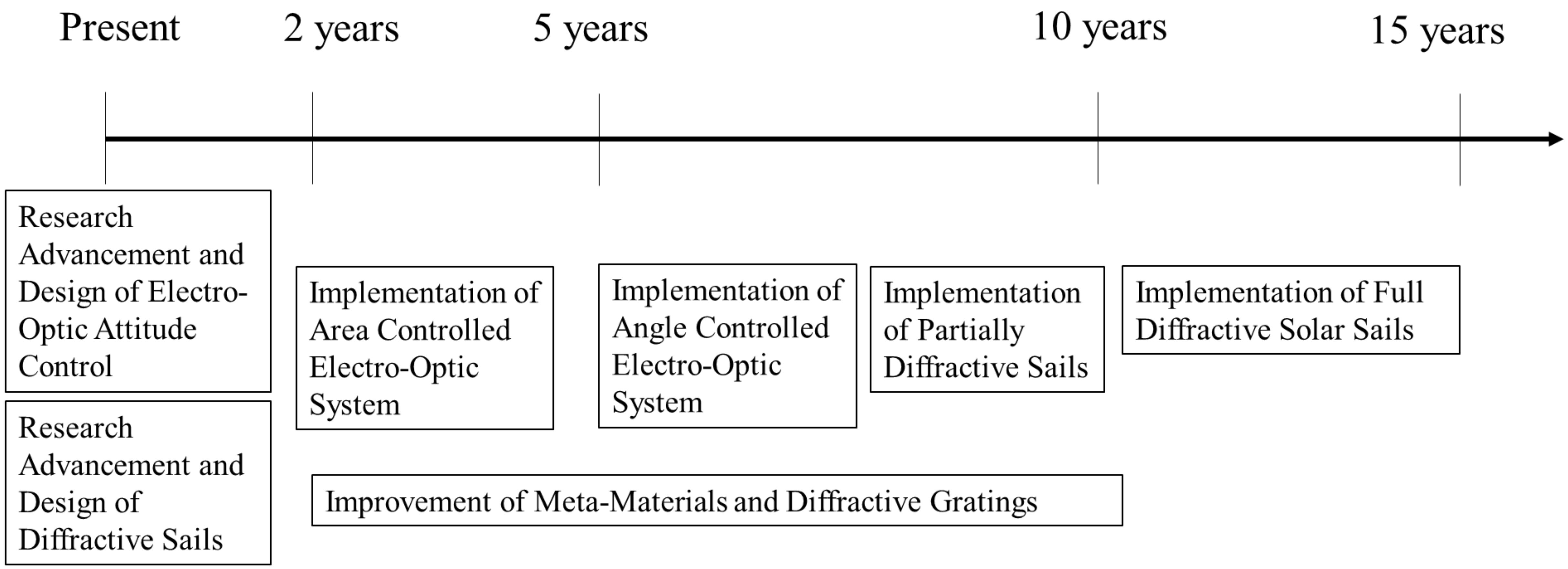
Fiscal Year 1

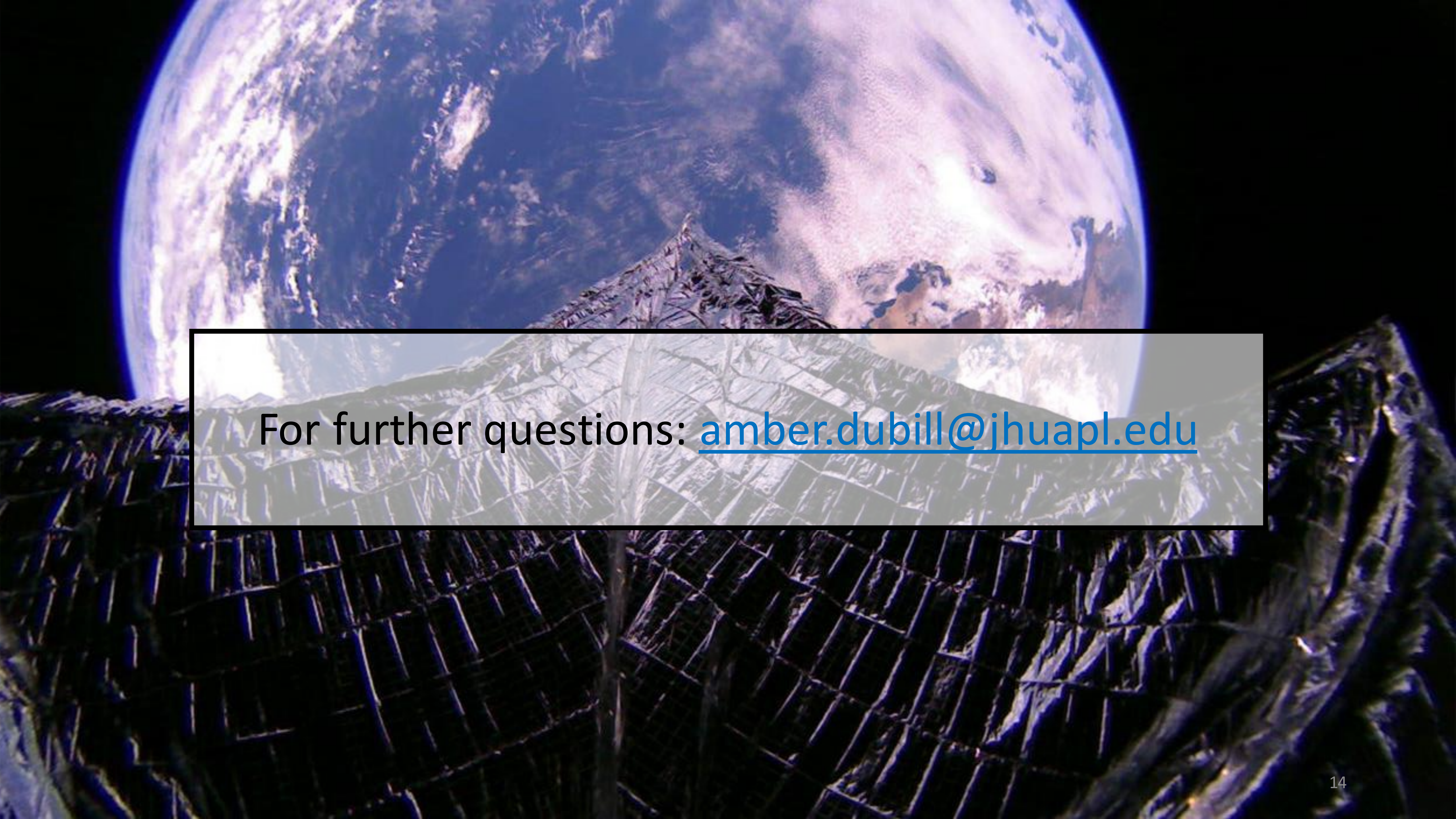
- Design, optimize, and analyze broad band diffractive grating samples x2
- Manufacture samples x2
- Perform optical and radiation pressure measurements x2
- Subject samples to space weather testing
- Fully characterize the force from grating designs

Fiscal Year 2

- Selection of heliophysics payload suite
- Mission trajectory and design for constellation of Solar Polar Orbiters
- High level sailcraft design
- Attitude control and determination trades of sails
- Final report

Potential Development Roadmap





For further questions: amber.dubill@jhuapl.edu