A Self-Stabilizing Metasurface Laser Sail To Explore The Stars

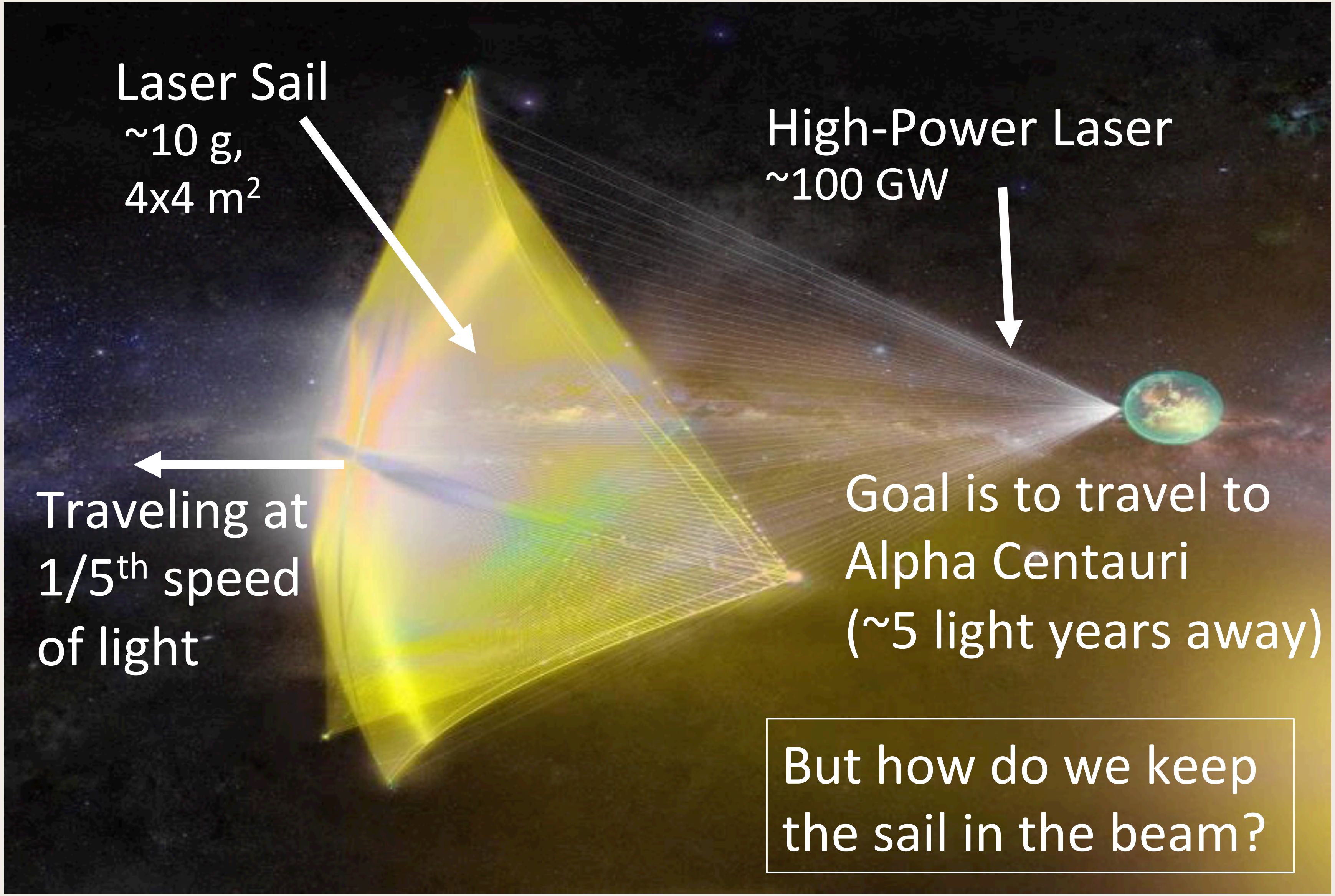
Joel Siegel

University of Wisconsin Madison

Physics Department

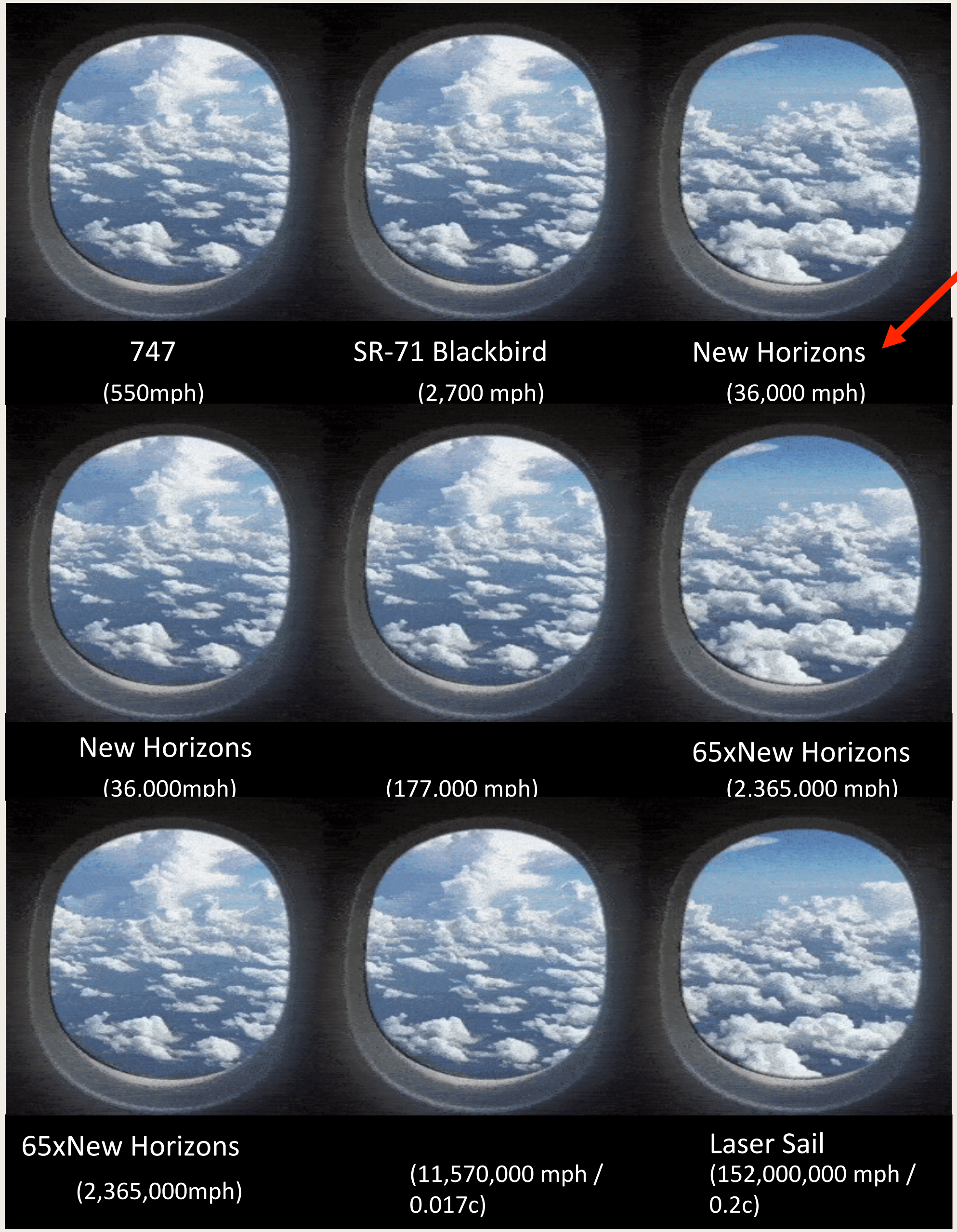
7/19/19

Laser Propelled Spacecraft



Starshot Breakthrough Initiative

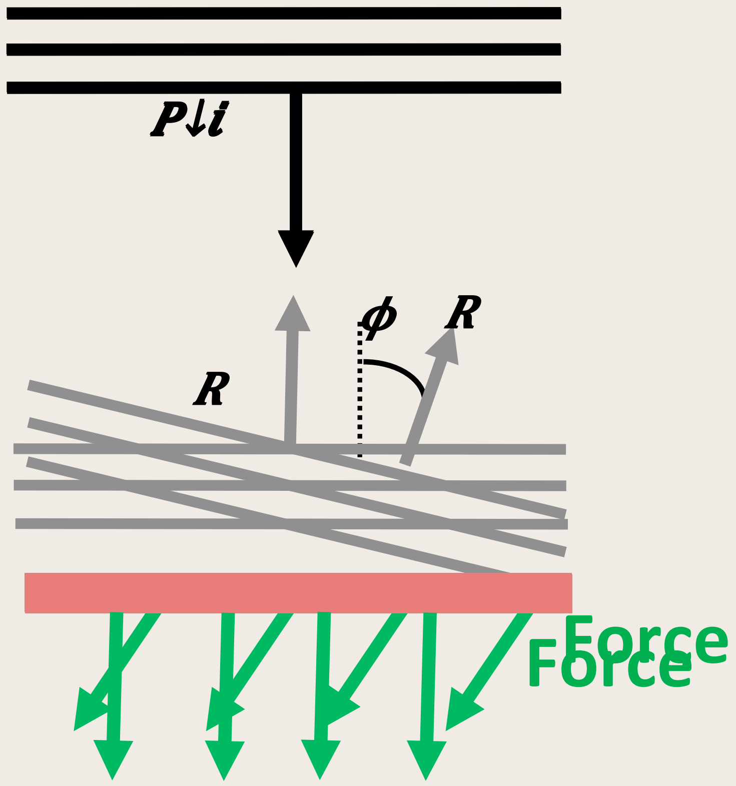
How fast is 1/5th the speed of light?



- Took the first close up pictures of Pluto in 2015
- One of the fastest man made objects

Gif from Clay Bavor

Optical Forces



Laser Sail

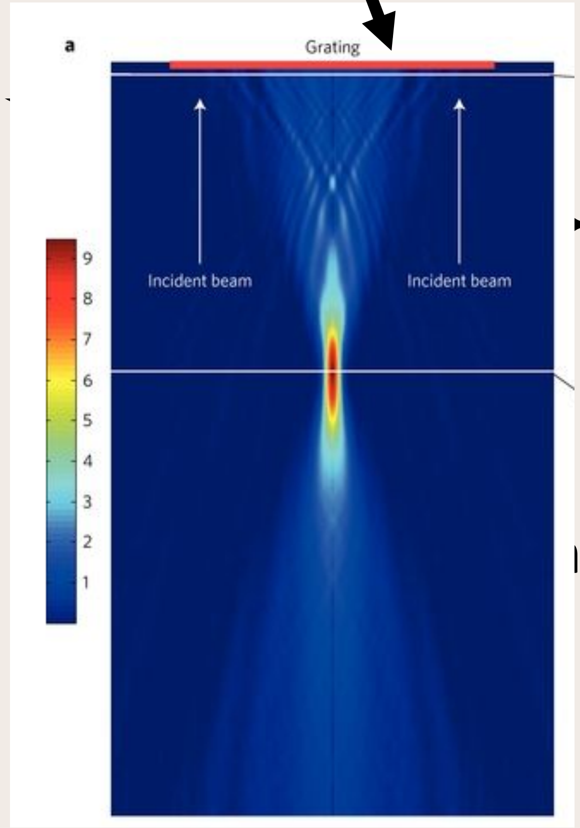
Force is determined by the reflected/refracted light

If we control how the light reflects/refracts, we can control the optical forces

Metasurface Based Laser Sail

- Thin, lightweight structure with subwavelength scattering elements
- Controls the phase and magnitude of reflected/refracted light

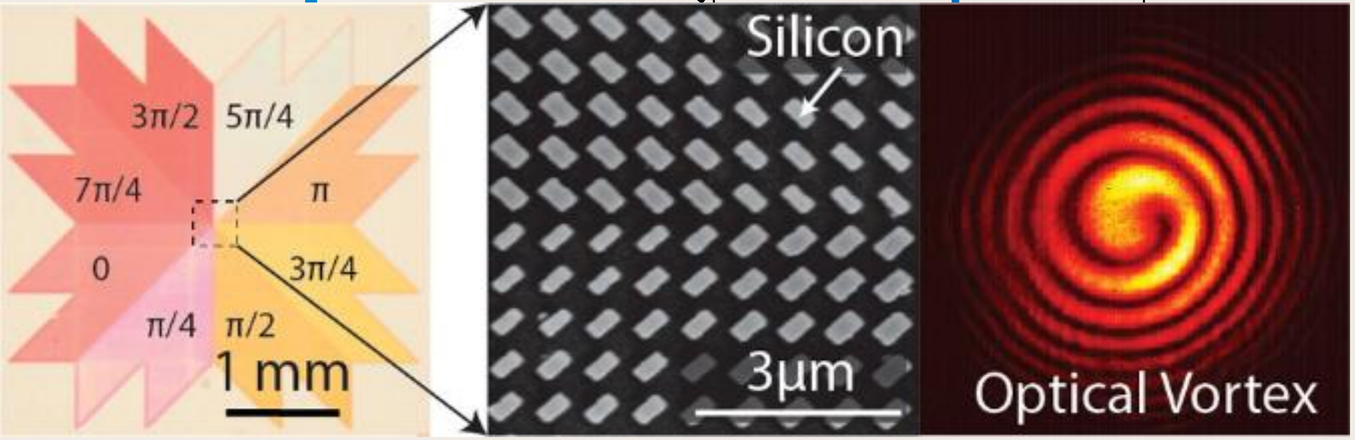
Reflective Metasurface Focusing Lens



~cm

D. Fattal, et. al., Nature Photonics 4, 466 (2010).

Optical Vortex Beam Creation

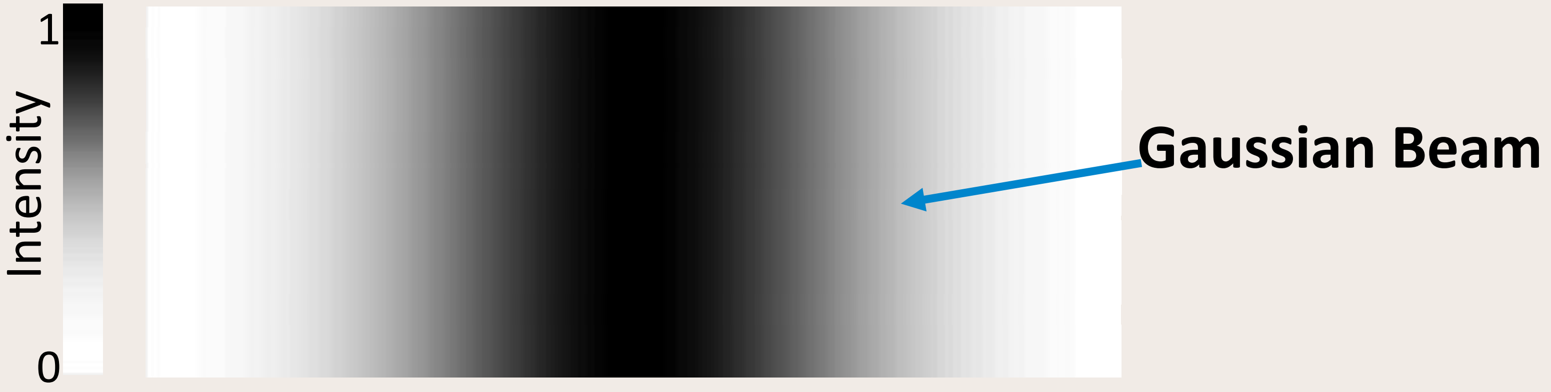


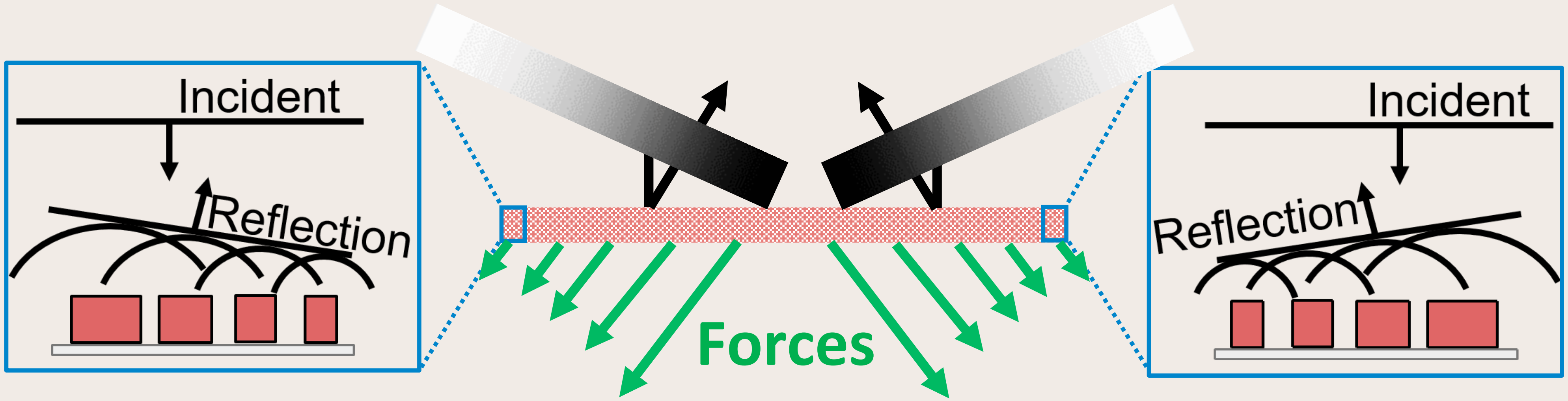
Metasurface Beam Steering

Y. Yang, et. al. Nanoletters 14, 1394 (2014).

Arbitrary wave-fronts can be generated with a metasurface

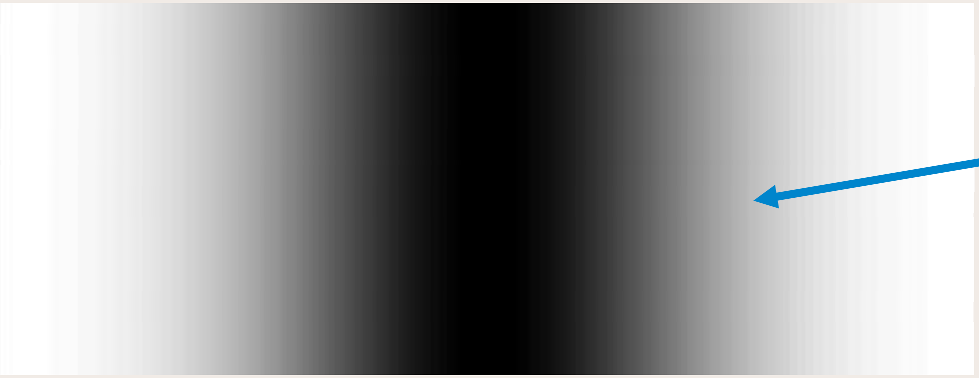
Metasurface Example





Example Metasurface

Metasurface Motion



Gaussian Beam

Motion can be described by:

$$m\frac{\partial^2 \delta}{\partial t^2} = C_1 \delta + C_2 \theta$$

$$I\frac{\partial^2 \theta}{\partial t^2} = C_3 \delta + C_4 \theta$$

Dynamic Force Coefficients

Offset

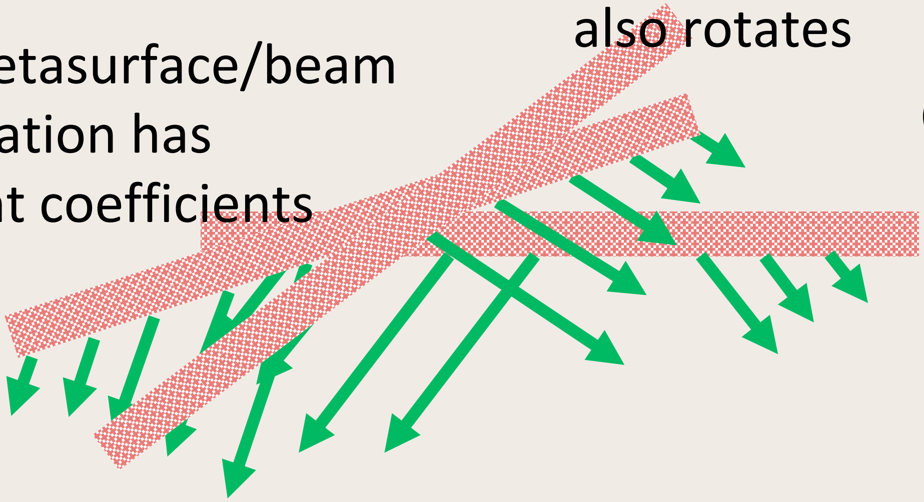
Rotation

Each metasurface/beam combination has different coefficients

Moves back, but also rotates

Metasurface flies away

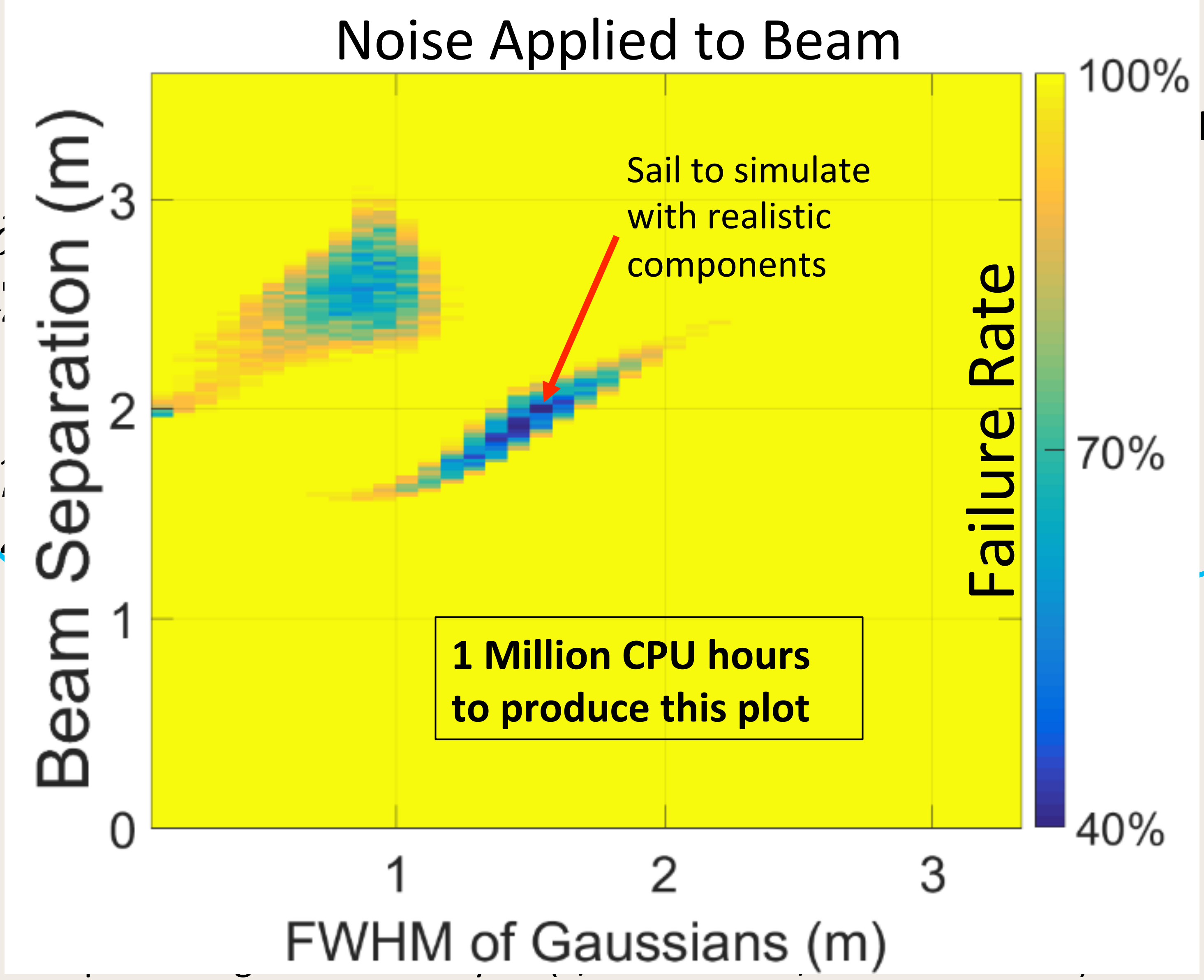
Offset the Metasurface



Example Metasurface

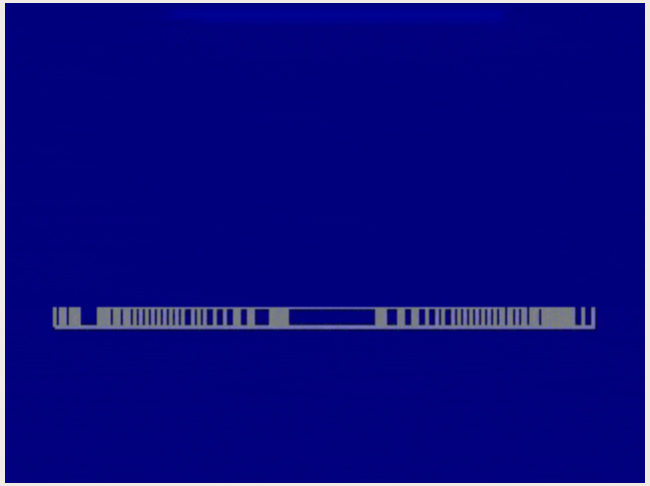
How can we control these coefficients to make a metasurface that is stable?

Designing a Stable Sail



nts

Simulate that sail using realistic components

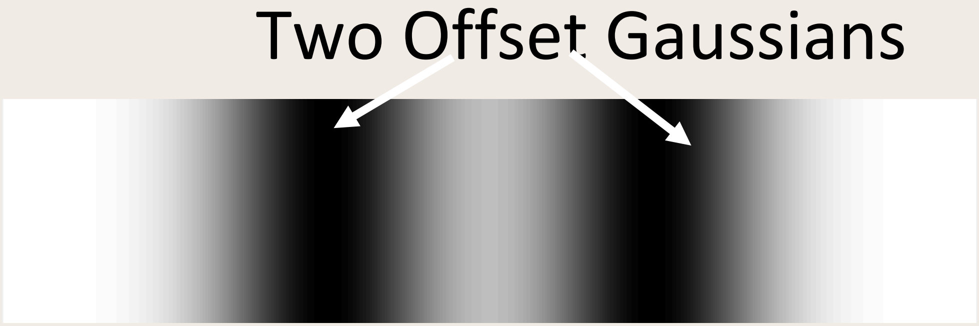


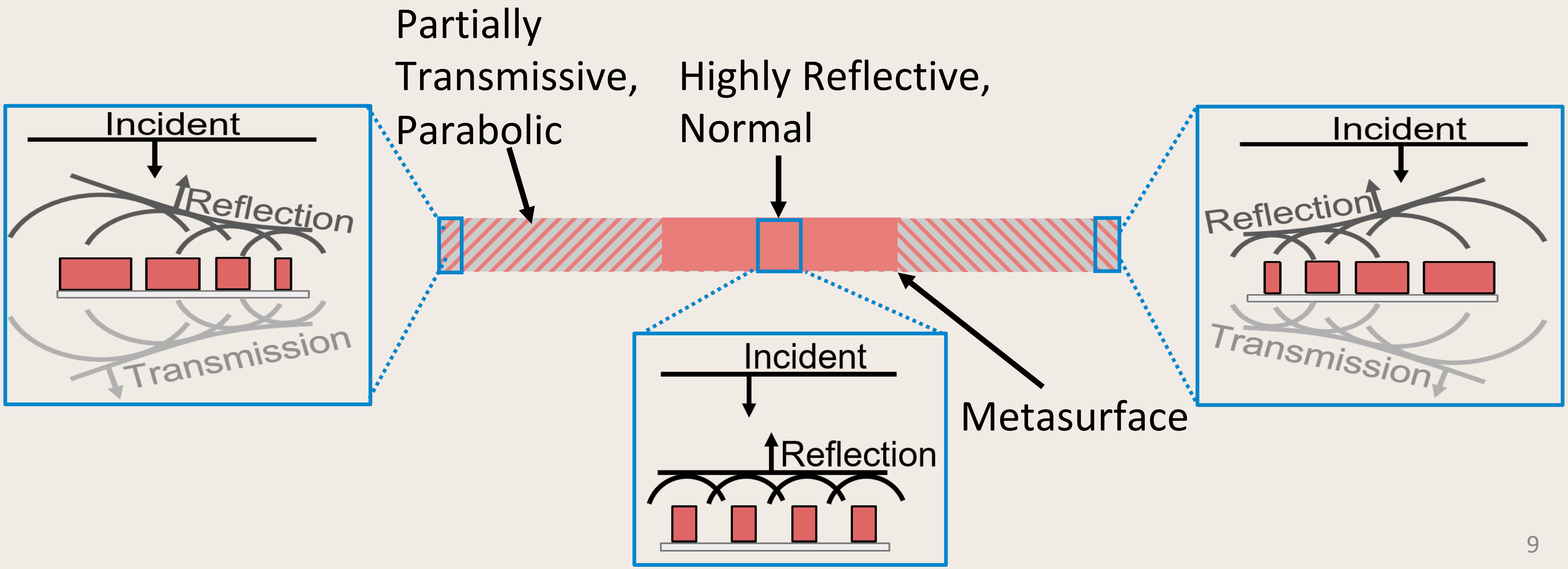
- Requires 1 large computation
  - Sail design chose from previous stage
- Computation Requirements
  - 80 CPUs
  - 500 GB of RAM
  - 5 GB of Disk
- Output is ~5 GB

Needed HPC to run– which introduced me to HTC

Idealized Metasurface to Generate Stable Coefficients

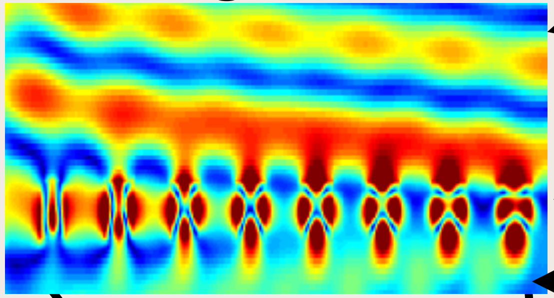
Inverted Cat Eye (ICE) Metasurface





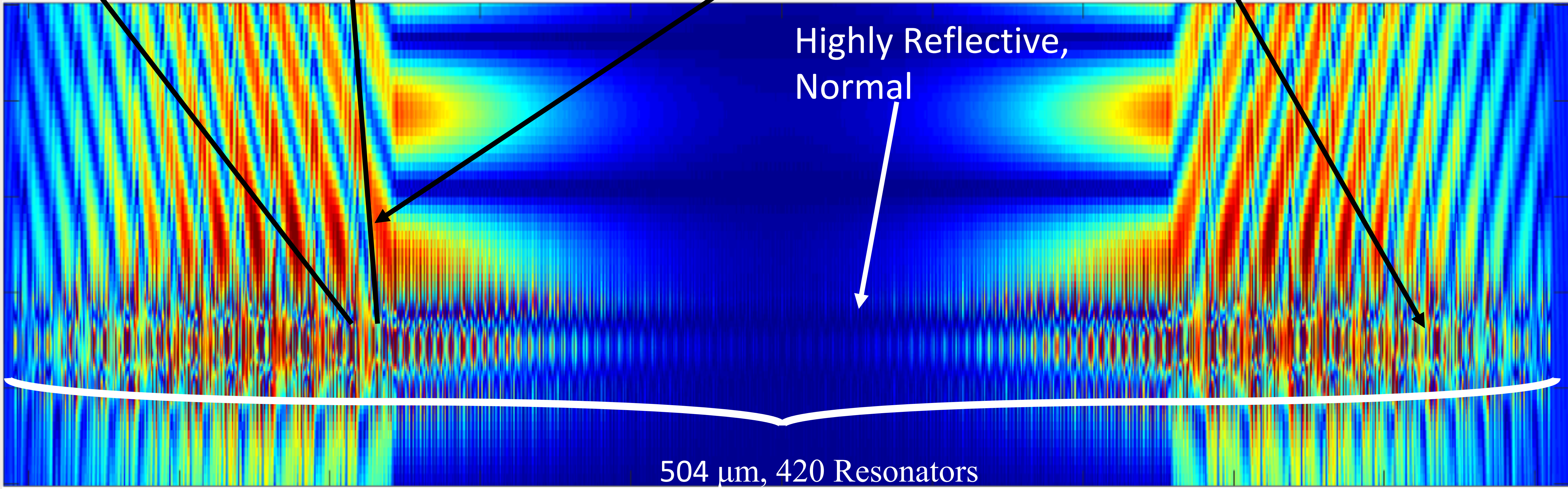
Full-Wave Simulation

Steering the Beam

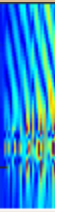


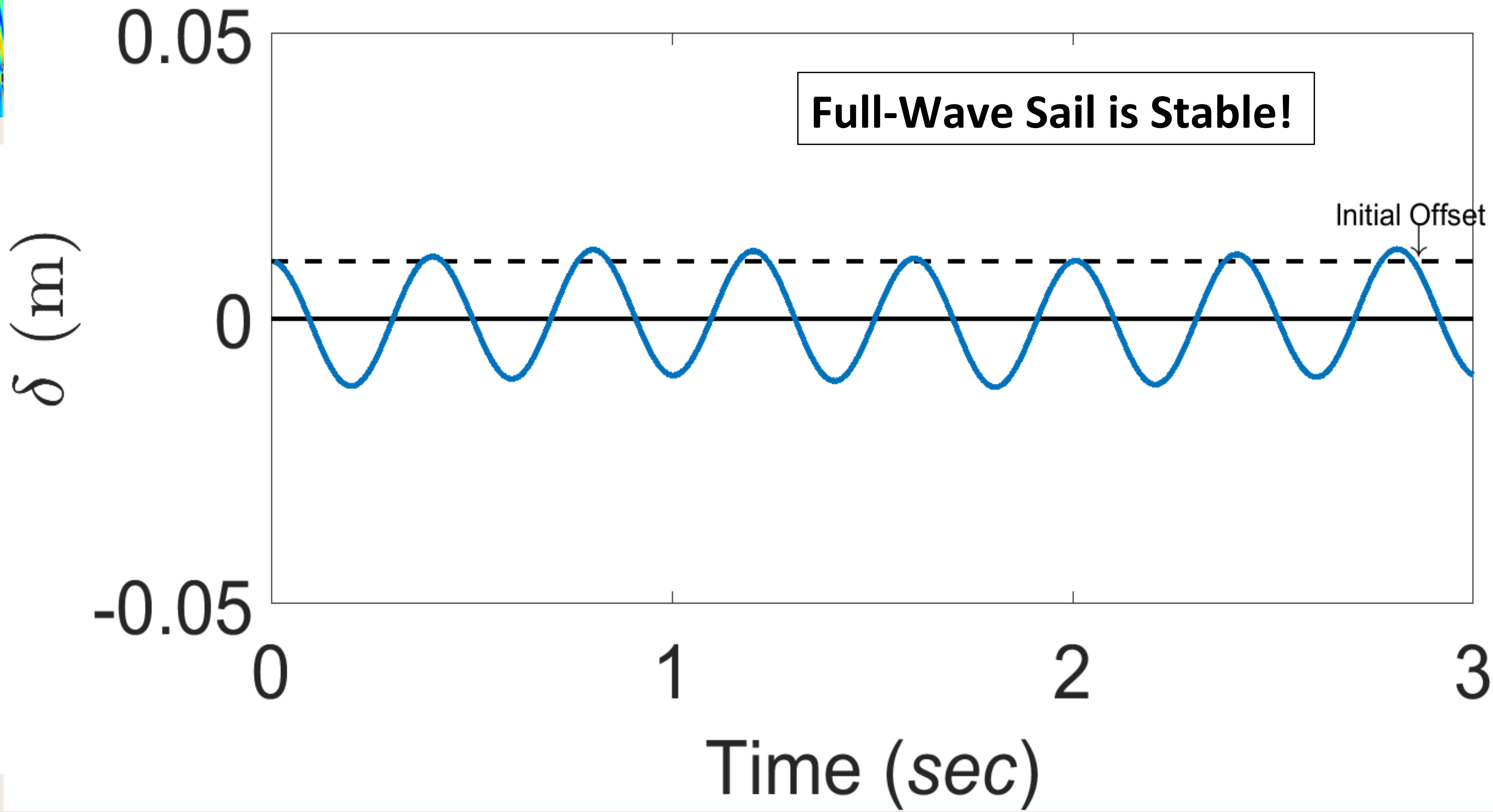
Simulated ICE Metasurface

Partially Transmissive, Parabolic



Local Optical Forces on Metasurface





What’s next?

- Incorporate optimization techniques that take advantage of throughput computing
- Algorithmically generate a sail based on a set of dynamic force coefficients
- Use optimization based metastructures to improve efficiency of structures

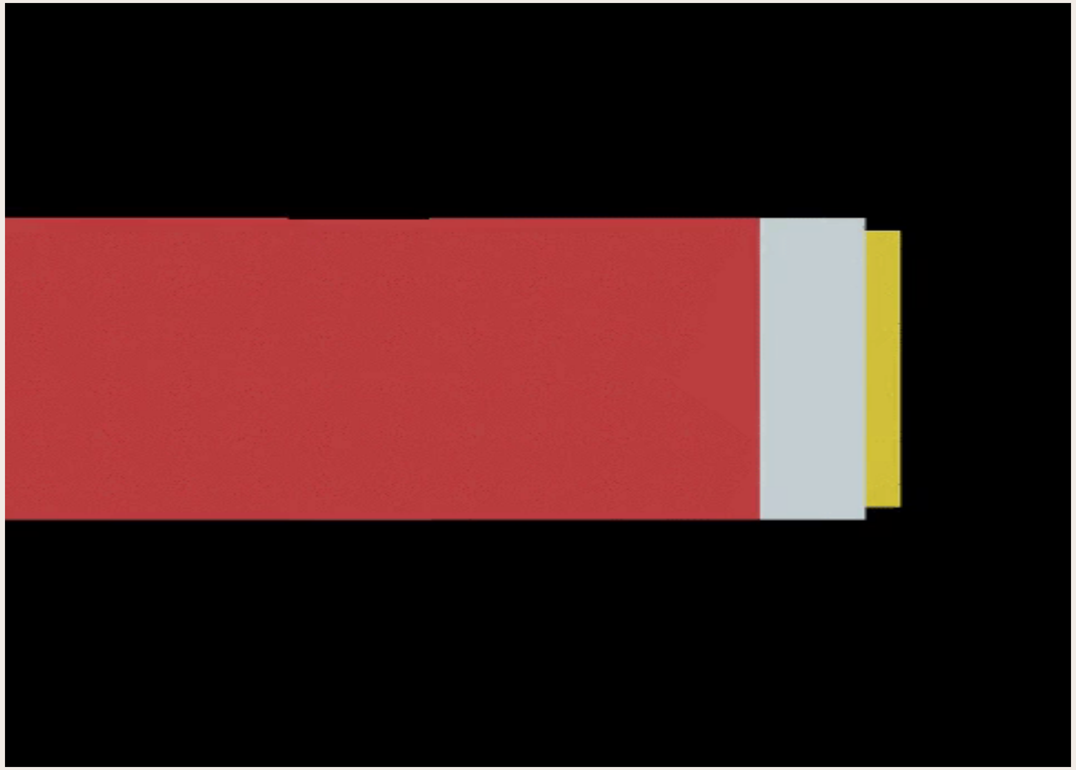


Figure courtesy of Greg Holdman

Acknowledgments

- Big Thank You to Christina Koch and Lauren Michael for helping me learn to use CHTC

<u>Collaborators</u>
Anthony Wang – UCLA (formerly UW Madison)
Mikhail A. Kats –UW Madison
Sergey Menabde –KAIST
Min Seok Jang –KAIST

More details can be found in our recent paper:
Self-Stabilizing Laser Sails Based on Optical Metasurfaces, ACS Photonics