PI and Point of Contact:
Christine Gregg (NASA Ames Research Center)
christine.e.gregg@nasa.gov

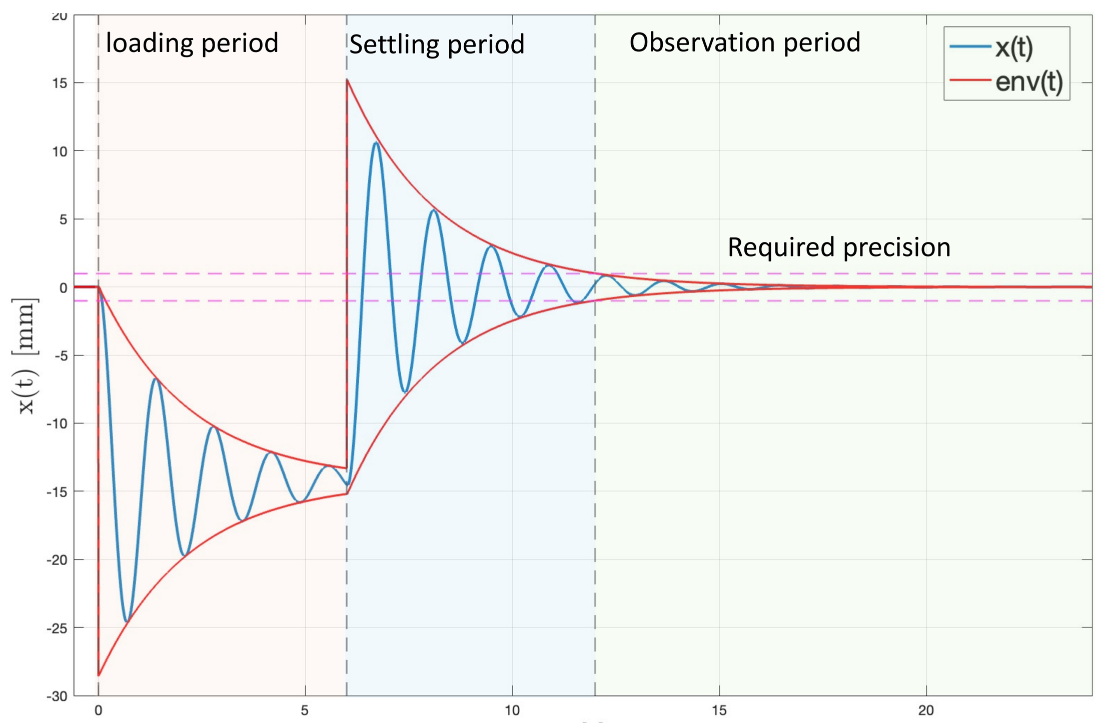
Metashade

Dynamically Stable Large Space Structures via Architected Metamaterials

Project Co-Is:
Alan Cassell (NASA Ames Research Center),
Serife Tol (University of Michigan),
Ellen Arruda (University of Michigan),
Dan Sirbu (NASA Ames Research Center),
Othman Oudghiri-Idrissi (University of Texas at Austin)

Innovation

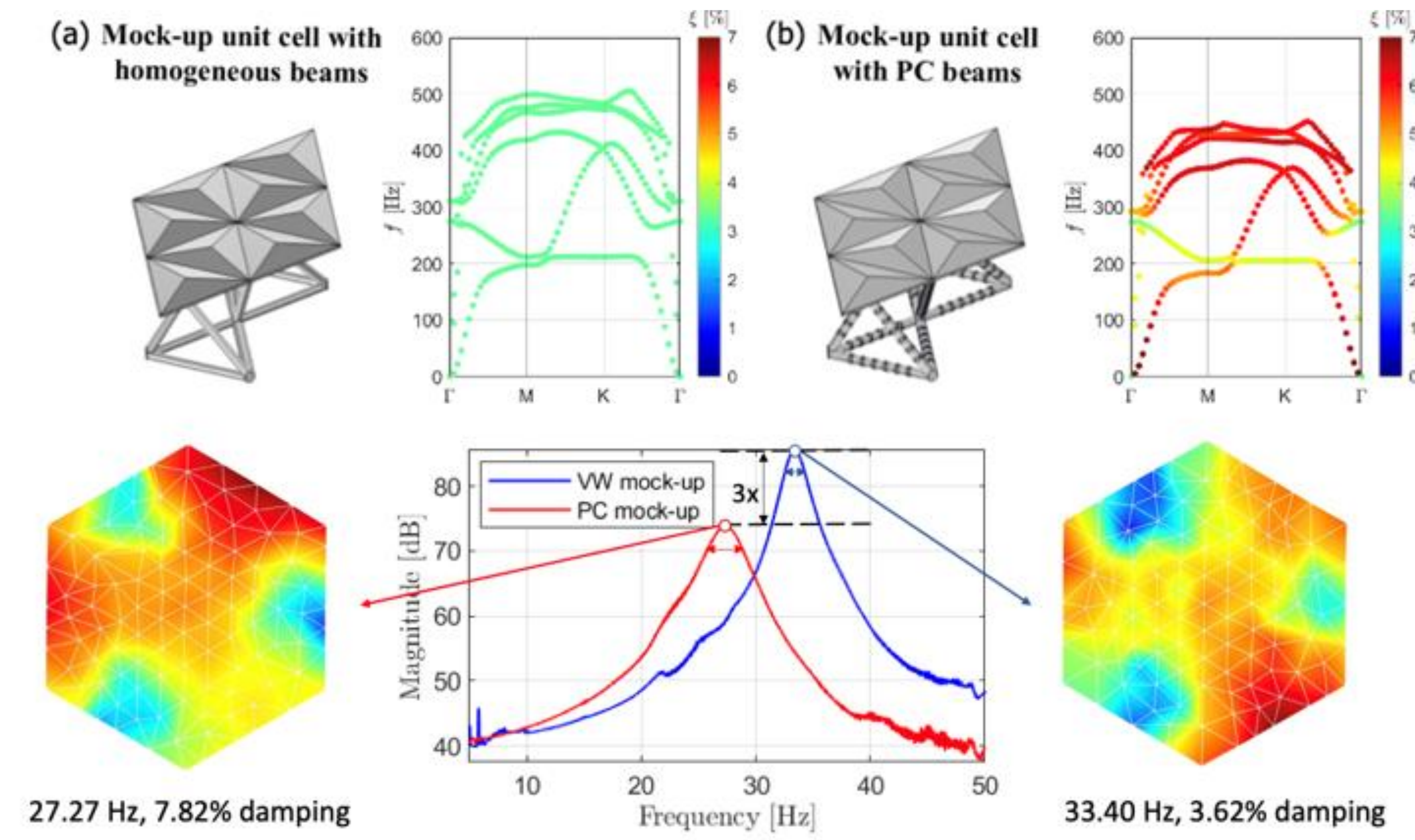
- Compared to state-of-the-art starshade structures, dissipative metamaterial designs do not trade stiffness for enhanced damping, allowing faster settling times. This can reduce overall mass while maintaining high precision and overall performance, especially for structures in dynamics limited applications.
- Band gaps in metamaterials can be tailored to suppress the most problematic modes associated with the periodic pulsed loading of starshades during operation
- Novel starshade structures that leverage dissipative metamaterials can create lower-mass structures that meet challenging dynamic operational loading requirements (see figure)
- Ultra-light, ultra-stable precision starshades at >100m would transform NASA's ability to detect exoplanets in the habitable zone



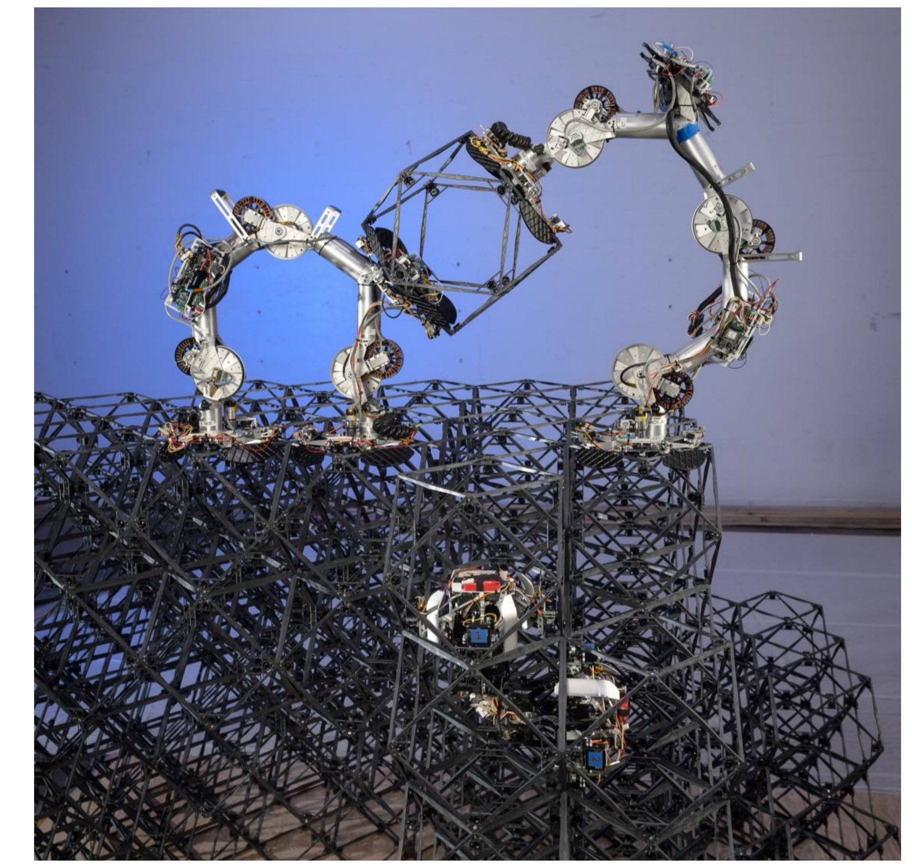
Single degree of freedom representation of the dynamic requirements due to station keeping loading of the mission concept, which features earth-based telescopes operating with an earth-orbiting starshade.

Technology

- Metamaterial designs can increase damping while maintaining structural stiffness
- Operation-induced vibrations can be suppressed by tuning band gaps
- Robotic assembly enables the application of these technologies to large-scale space structures without the design restrictions of deployables



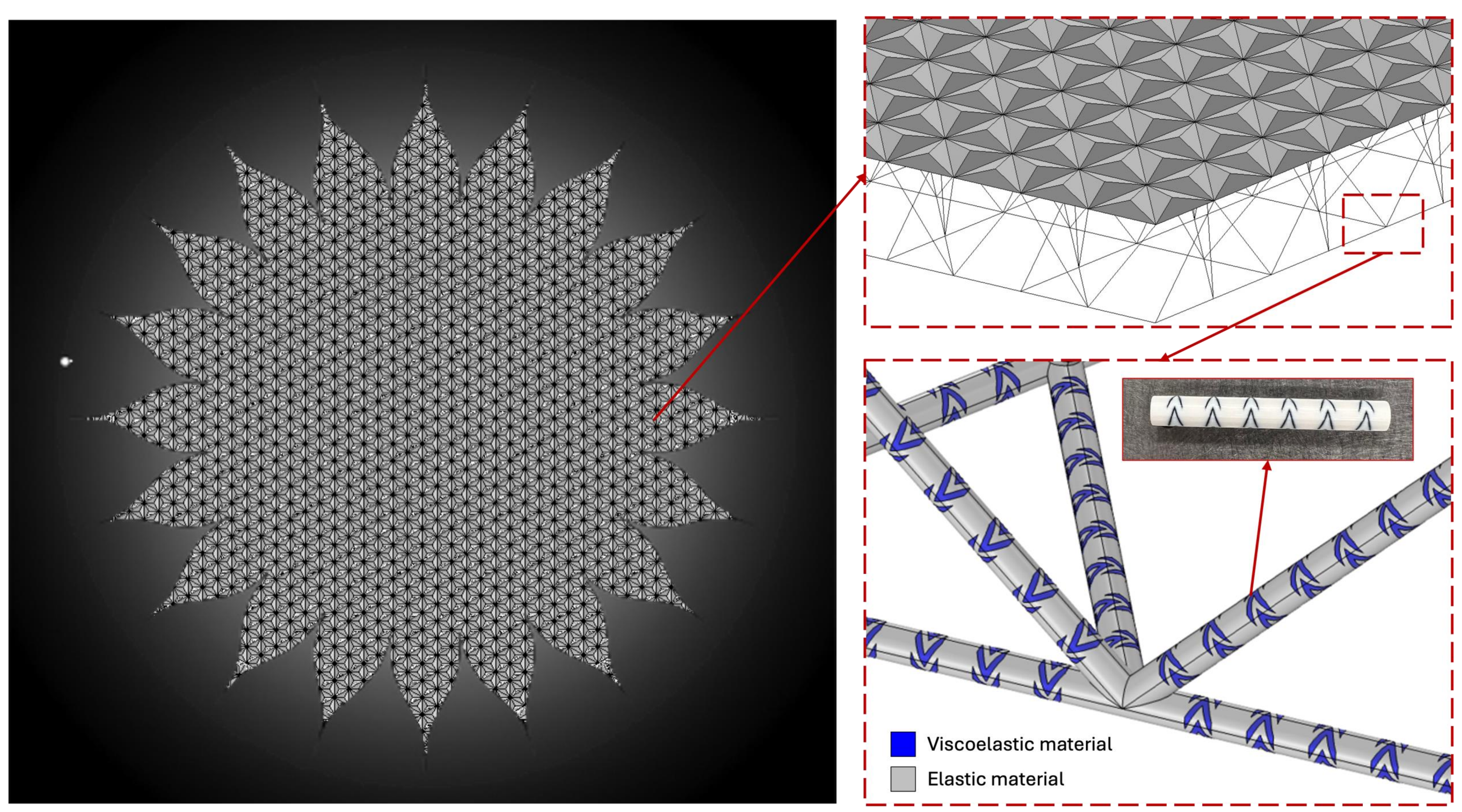
Prior Art: Dispersion and damping levels of prototype solar array unit cell with (a) homogenous VeroWhite beams and (b) phononic crystal beams. The damping level in the VW and PC-based arrays is ~3% and ~6%, respectively. The experimental structural tests of the solar array verify this prediction.



Prior Art: Autonomous *construction robots from the NASA ARMADAS project can enable small robots to assemble large metamaterial structures.*

Mission

- We propose a mission concept for habitable zone exo-planet discovery utilizing a 100m starshade made from periodic dissipative metamaterial architectures
- Structure will be assembled on orbit, integrating metamaterial modules, creased plates occulting layers, and petal structures (which may be hybrid assembly/deployed)



Concept image of the assembled starshade with metadamping metamaterial modules.

Phase I Study Approach

- Evaluate 100m starshade design based on dissipative metamaterials and phononic crystals, focusing on vibrational amplitude, settling time, and system mass, comparing performance to published baseline designs and deployable shade scaling
- Develop a mission concept for 100m starshade
- Develop preliminary plan for sub-scale test of critical system subcomponents

Ames Research Center
UNIVERSITY OF MICHIGAN
TEXAS The University of Texas at Austin
NIAC NASA Innovative Advanced Concepts

References:

[1] Oudghiri-Idrissi, O., Lu, W.C., Vijayachandran, A.A., McInerney, J., Poli, A., Danawe, H., Mao, X., Arruda, E., Waas, A. and Tol, S., 2024. In-space manufacturable solar array structures integrating metamaterial technologies, part I: Design approaches, numerical modeling, and experimental validation. In AIAA SCITECH 2024 Forum (p. 0827).
[2] Vijayachandran, A.A., Oudghiri-Idrissi, O., Lu, W.C., McInerney, J., Poli, A., Mao, X., Arruda, E., Tol, S. and Waas, A., 2024. In-space Manufacturable Solar Array Structures Integrating Metamaterial Technologies, Part II: Numerical Models and Design Optimization. In AIAA SCITECH 2024 Forum (p. 1263).
[3] Vijayachandran, A.A., Oudghiri-Idrissi, O., Danawe, H., Mao, X., Arruda, E., Tol, S. and Waas, A.M., 2024. Free vibration of thin, creased elastic plates: Optimization and scaling laws. Thin-Walled Structures, 195, p.111393.
[4] Lu, W.C., Oudghiri-Idrissi, O., Danawe, H. and Tol, S., 2023, June. Design optimization of 3d printed chiral metamaterials with simultaneous high stiffness and high damping. In Society for Experimental Mechanics Annual Conference and Exposition (pp. 95-98). Cham: Springer Nature Switzerland.
[5] C. E. Gregg et al., "Ultralight, strong, and self-reprogrammable mechanical metamaterials," Sci. Robot., vol. 9, no. 86, p. eadi2746, Jan. 2024, doi: 10.1126/scirobotics.adi2746.