

National Aeronautics and
Space Administration



Bio-inspired Materials and Processes for Aerospace Environments

Biocene 2023: Transforming Materials
Cleveland, Ohio

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NASA EXPLORES



Space Exploration

- Land humans on the Moon
- Long-term exploration for human missions to Mars
- Enable new scientific discoveries about the Earth, our Sun, our Solar System and beyond

Climate

NASA's climate mission is to observe, understand, and address climate change through science, exploration and innovation for the benefit for all.

Source: Description of NASA's climate mission from "Advancing NASA's Climate Strategy" 2023



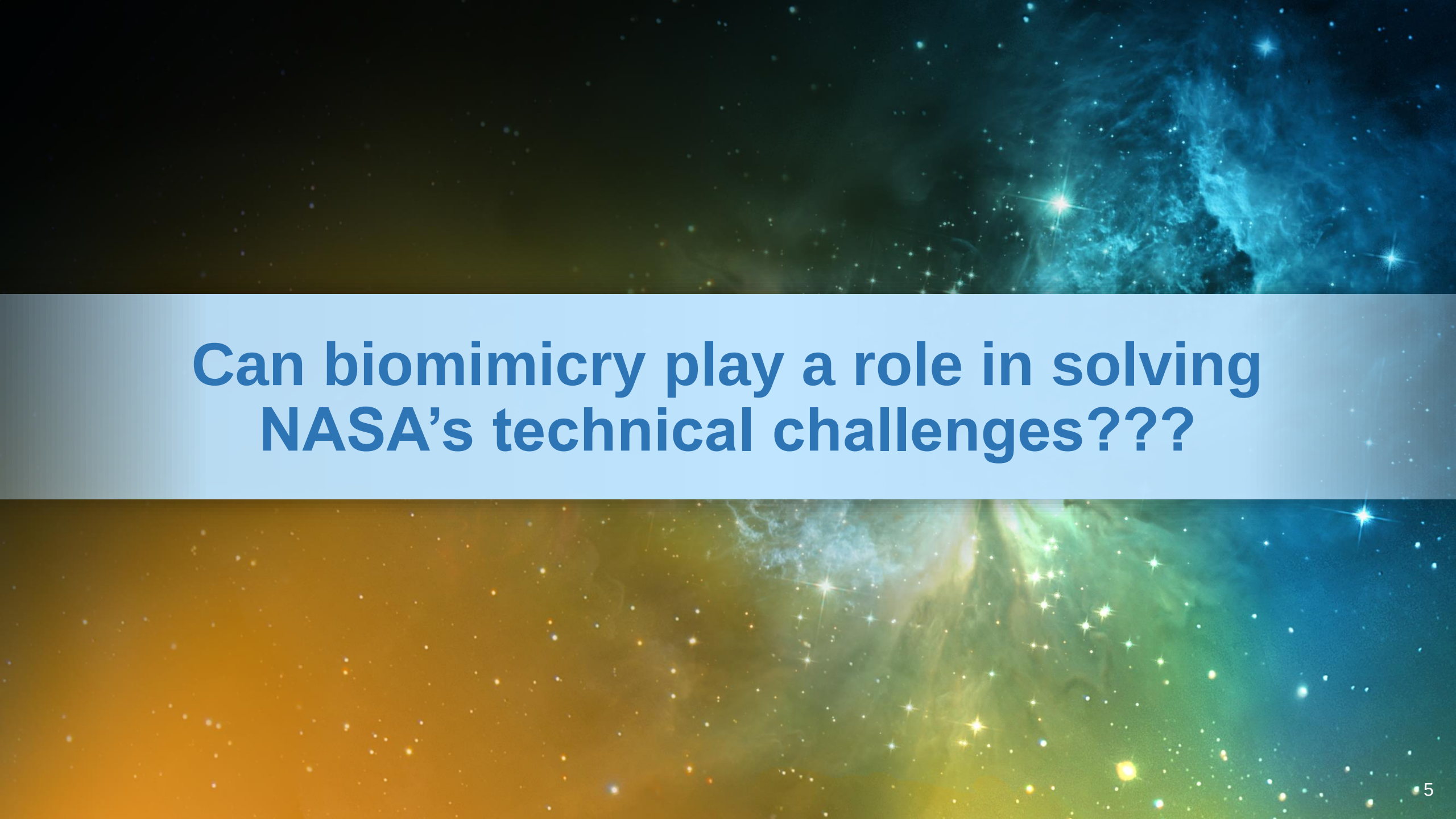
Aeronautics

Environmental Impact of Aviation

- Currently accounts for 2 – 2.5% of global CO₂ emissions
- Fuel significant driver of the cost of air transportation
- Pursuing approaches to balance sustainability and affordability

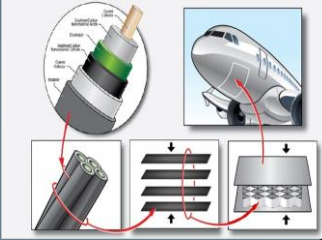
NASA's electrified aircraft propulsion efforts entail targeting system-level improvements in efficiency and achieving carbon-neutral growth by 2050.



The background of the slide is a composite image of space. The top half features a dark blue and black space filled with numerous small, bright stars and a prominent, wispy blue nebula on the right side. The bottom half is a gradient of orange and yellow, also filled with stars and a faint, glowing greenish-yellow nebula on the right. A semi-transparent light blue horizontal band runs across the middle of the image, containing the text.

**Can biomimicry play a role in solving
NASA's technical challenges???**

Multi-functional Materials

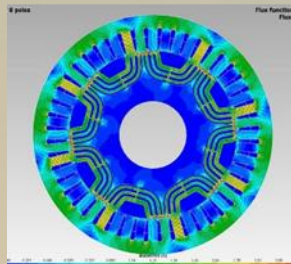


Power and Propulsion



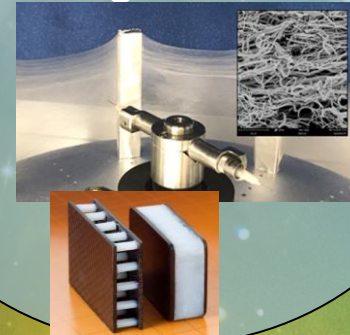
Thermal Management

Materials for Aerospace Power and Propulsion



Computational-modeling

Lightweight Structures



Materials Sustainability Efforts in Aviation

- Sustainable Manufacturing of Aircraft
- Goal: Lessen the environmental impacts of materials used for air transportation
- Studying use of bio-based materials for sustainability and recyclability of aircraft composite parts

Image credit: NASA

Technical challenge: Electrical insulation longevity

Biological Model: Self-healing

Mechanisms of self-healable materials

- Extrinsic
- Intrinsic



(12) **United States Patent**
Parrish

(54) **SELF-HEALING WIRE INSULATION**

(75) Inventor: **Clyde F. Parrish, Trinity, FL (US)**

(73) Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration, Washington, DC (US)**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 991 days.

(21) Appl. No.: **11/856,218**

(22) Filed: **Sep. 17, 2007**

(65) **Prior Publication Data**

US 2008/0234463 A1 Sep. 25, 2008

(10) **Patent No.: US 8,119,238 B2**
(45) **Date of Patent: Feb. 21, 2012**

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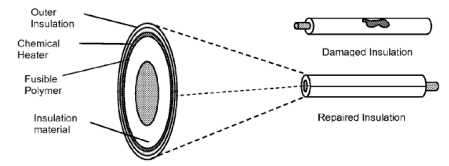
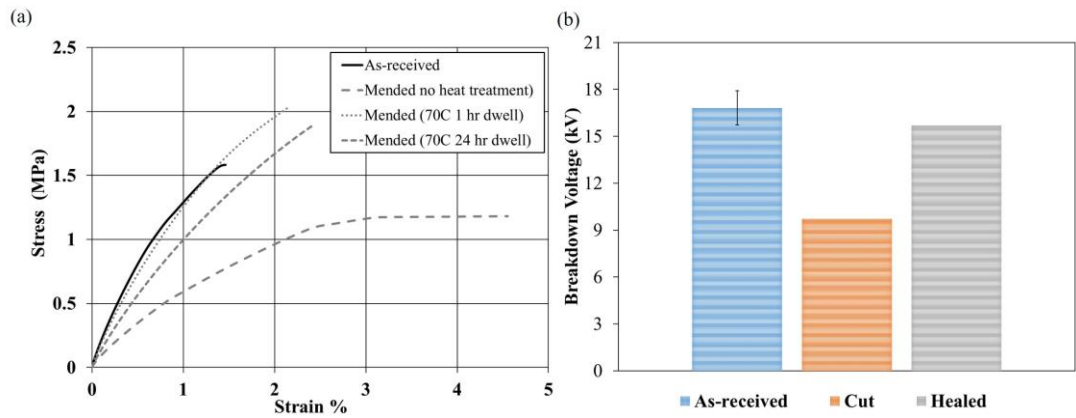


FIG. 1



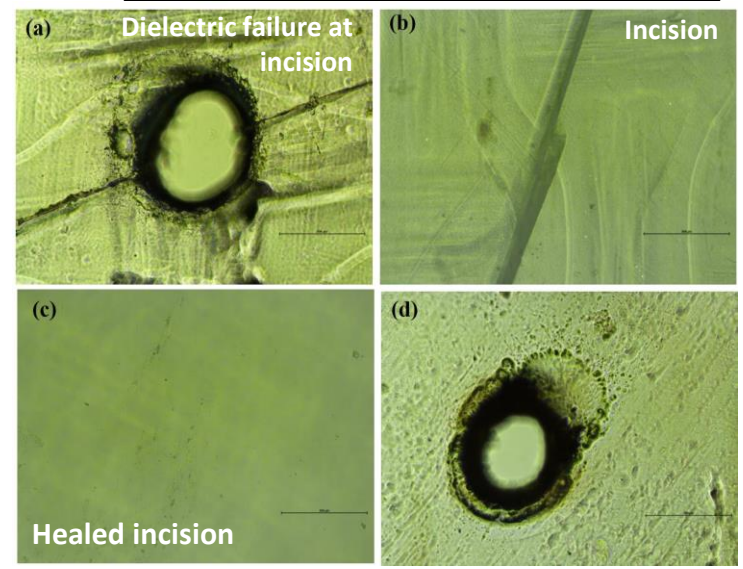
FIG. 2



Sodium ionomer, ethylene methacrylic acid copolymer

Contains ionic crosslinks
(Reversible bonds)

Low thermal properties



Williams, Tiffany. 2022. "Advancing research efforts in biomimicry to develop nature-inspired materials, processes for space exploration and more efficient aircraft" In *Biomimicry for Aerospace: Technologies and Applications* by Shyam, Eggermont, Hepp,

Re-establishment of ionic crosslinks led to over 95% recovery of mechanical and dielectric properties

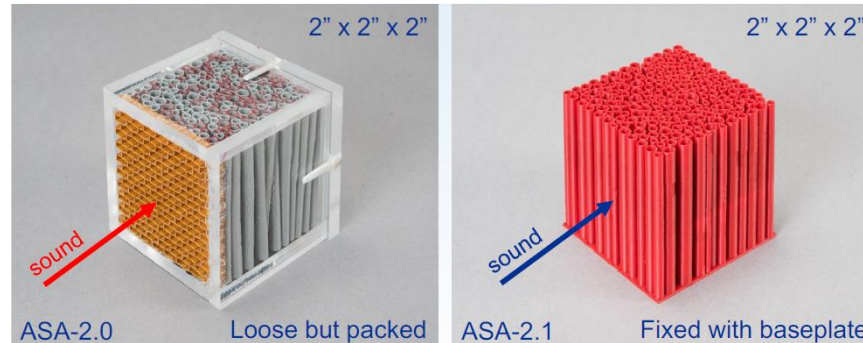
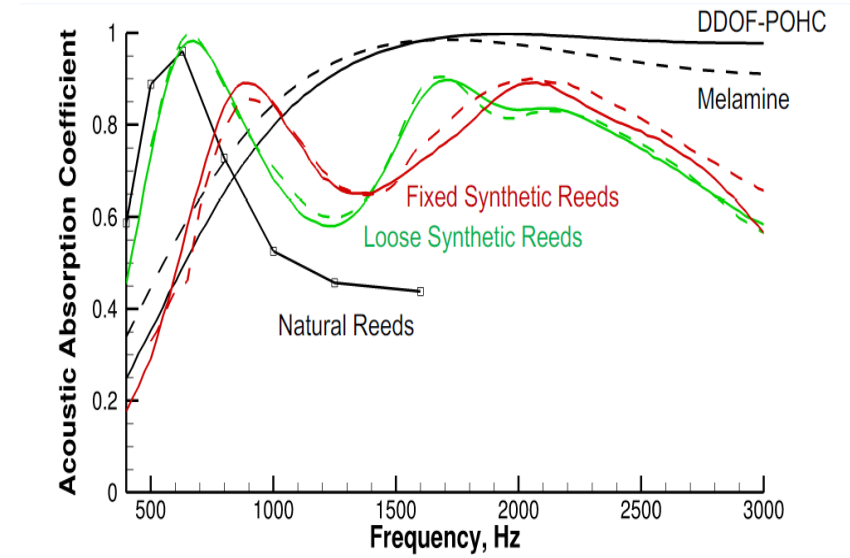
Technical challenge:
Noise

Biological model:
Natural reeds



Common reed, *Phragmites australis*

Image Source: Ohio Department of Natural Resources



Prototype of acoustic absorbers inspired by natural reeds

Courtesy: Danielle Koch/ NASA GRC

Technical Challenge: Aircraft icing

Airframe Icing

Caused by water content in clouds and precipitation
Reduced lift
Increased weight and drag

Airfoil icing

Creates mechanical vibrations
Alters aerodynamic efficiency

Ice crystal ingestion

May lead to power loss
Poses safety concerns

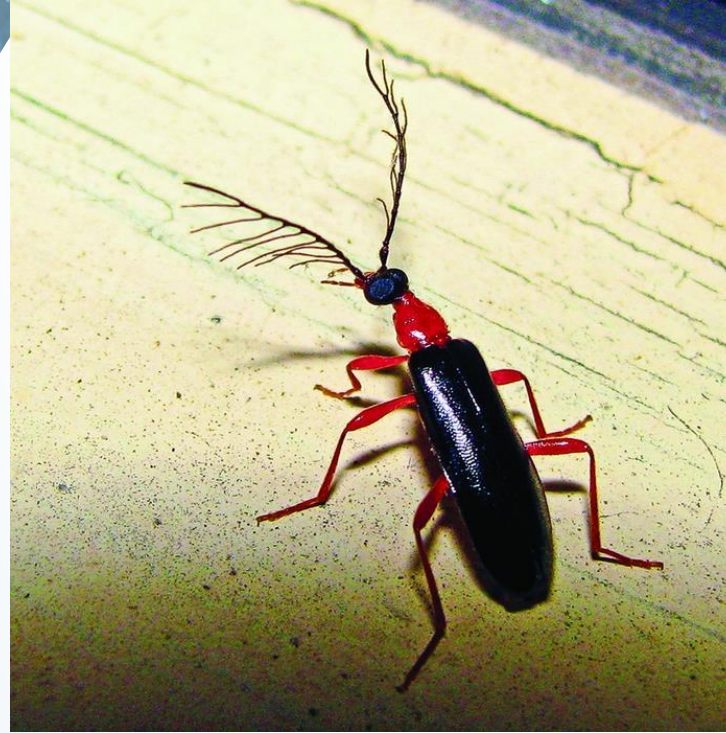
Current mitigation strategies:

- Antifreeze spray – environmental concerns
- Pneumatic or heating for inflight ice removal – power and weight



Image credit: NASA

Biological model: Protein mimicry



Dendroides canadensis
Credit: Flickr/kestrel360

Can prevent freezing

Popular in biology and medicine, rare in materials science

Insects, fish, plants thrive in Arctic environments

Antifreeze (glycol) proteins or protein ice nucleators give some species ability to prevent freezing

A photograph of Apollo 17 mission commander Eugene Cernan inside a lunar module. He is wearing a white flight suit with a red collar and a headset. The background shows the interior of the module with various instruments and a window. A large white curved shape on the right side of the image contains text.

Sustainable lunar dust mitigation strategies

Lunar dust during Apollo era

- Instrumentation overheating
- Abrasion
- False readings
- Vision obscuration
- Respiratory issues

Dust mitigation strategy

Brushes

May require both active and passive mitigation approaches

Affinity toward dust mitigation strategies requiring least power consumption

Multiple bio-inspired approaches may be employed

Self-actuation

Electro-active stimuli responsive polymers

Technical Challenge: Microbial fouling and contamination

Biological model: Functional surfaces

Occurrence of microbial fouling in aerospace

Metal corrosion in jet fuel tanks

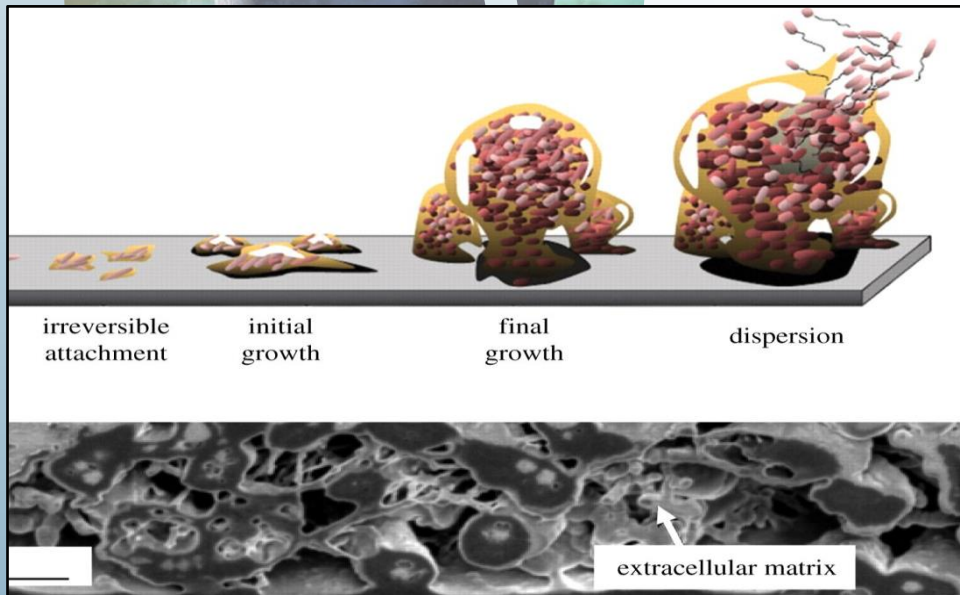
Fuel filter blockage

Fires and explosions

Biodeterioration in SRB parachute recovery systems

Water handling systems on ISS

Biofilm growth and corrosion of stainless-steel surfaces in microgravity conditions



Monroe D (2007) Looking for Chinks in the Armor of Bacterial Biofilms. PLoS Biol 5(11): e307. <https://doi.org/10.1371/journal.pbio.0050307>



Microscale
ridges believed
to reduce
biofouling

MARINE LIVES RESIST BIOFOULING THROUGH MICRO-TEXTURED SURFACE



Technical challenge: Limitations in synthetic fiber reinforcement

Common types: carbon fiber, fiberglass, aramid (Kevlar), hybrids

Fiber directions unidirectional and bidirectional

Layup: quasi-isotropic plies, biaxial and triaxial braid

Carbon fiber – very brittle, low bend radius

Challenges: Difficult to make high strength composites with complex geometries; often a toughness and stiffness trade-off; environmental durability

Biological Model: Conch shell



Curved reinforcement with plywood-architecture

Superior strengthening (crack deflecting, bridging, and branching) compared to synthetic fiber reinforced composites

Allows the conch to obtain its pyramid shape

Li and Li demonstrated a 30% increase in fracture toughness in parts made from curved lamellae compared to straight lamellae sections



Advanced materials processing techniques are needed

Challenges

- Scalability
- Precision
- Cost
- Durability

Potential processing solutions

- Polymer synthesis
 - Self- and LBL- assembly
 - Polymeric nanobrushes
- Additive manufacturing
- Nanolithography

Natural systems form under benign conditions

(attractive for in-space manufacturing)

NASA's Space Technology Research Institutes (STRIs)



Two five-year projects
awarded at \$15M in
2017

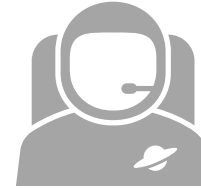
Renewed to 2025



Center for the Utilization of
Biological Engineering in
Space (CUBES)



Image credit: NASA



Targeted destinations: Moon and
Mars

Biological engineering and
biomanufacturing in space

Exploit inherent mass, power, and
volume potential of space
biotechnology over traditional
approaches

Berkeley
UNIVERSITY OF CALIFORNIA



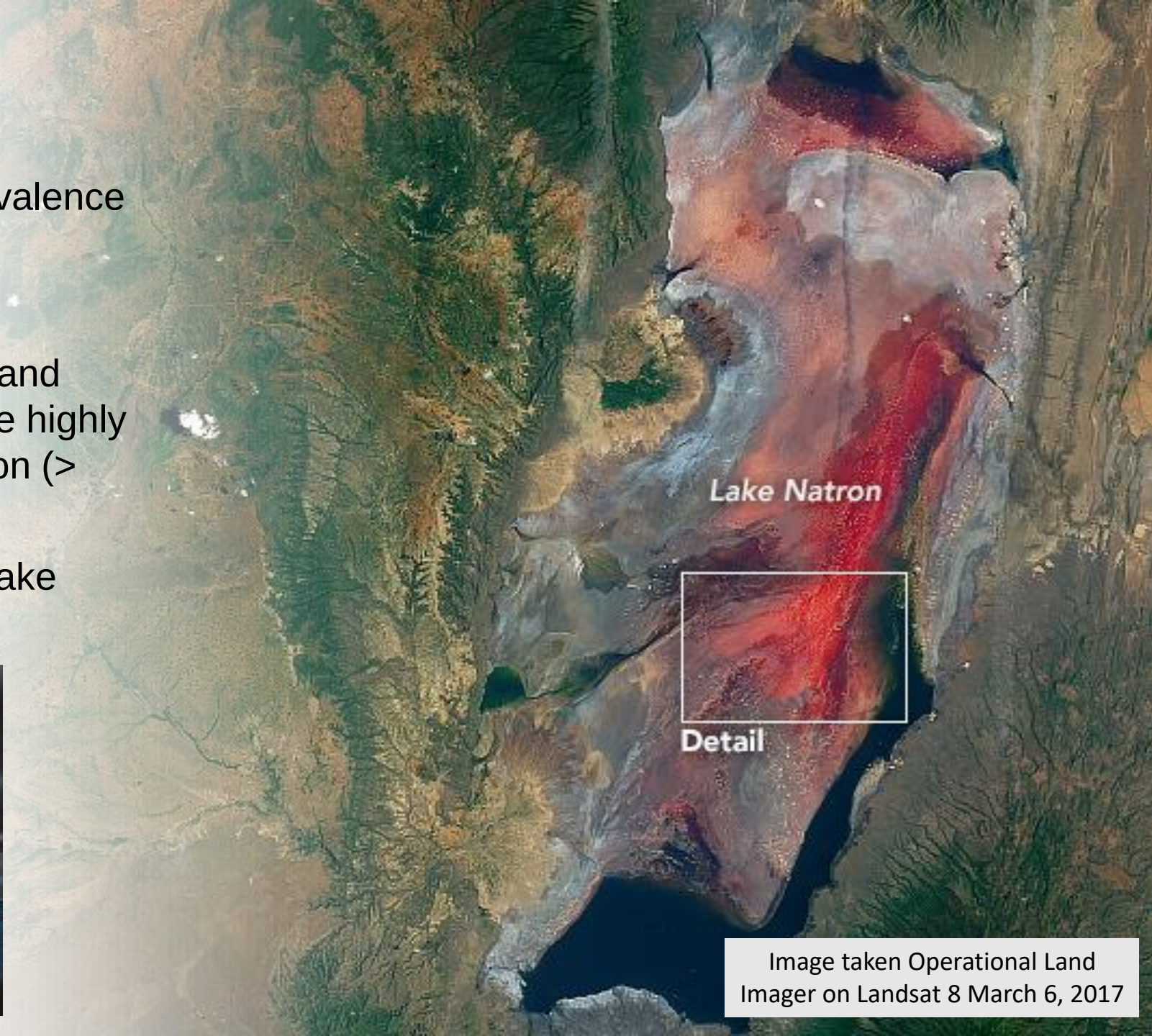
UC DAVIS

UF | UNIVERSITY of
FLORIDA

Stanford
University

Taxonomic Biases

- Understudied species due to its prevalence in extreme terrestrial climates
- Lake Natron – Arusha, Tanzania
- Only lesser flamingoes, certain fish and bacteria can survive and thrive in the highly corrosive environment of Lake Natron (> pH 9)
- Millions of lesser flamingoes fly to Lake Natron to breed



A banner for NASA STEM Engagement featuring four panels: a child wearing goggles, a woman looking at a screen, two people in a kart, and a man holding a model airplane. The text "NASA STEM Engagement" is overlaid on the left side.

NASA STEM Engagement



INSPIRE - ENGAGE - EDUCATE - EMPLOY
The Next Generation of Explorers

Opportunities for Collaboration

- Advanced Air Vehicles Fellowship Program
- University Leadership Institute (ULI) Program
- NASA Space Technology Graduate Research Opportunity (NSTGRO)– Graduate Students
- Space Technology Research Opportunities for Early Career Faculty Grants
- Space Technology Research Opportunities – Early-Stage Innovations Grants (Faculty)
- NASA EPSCoR
- **NASA Postdoctoral Fellowship Program**

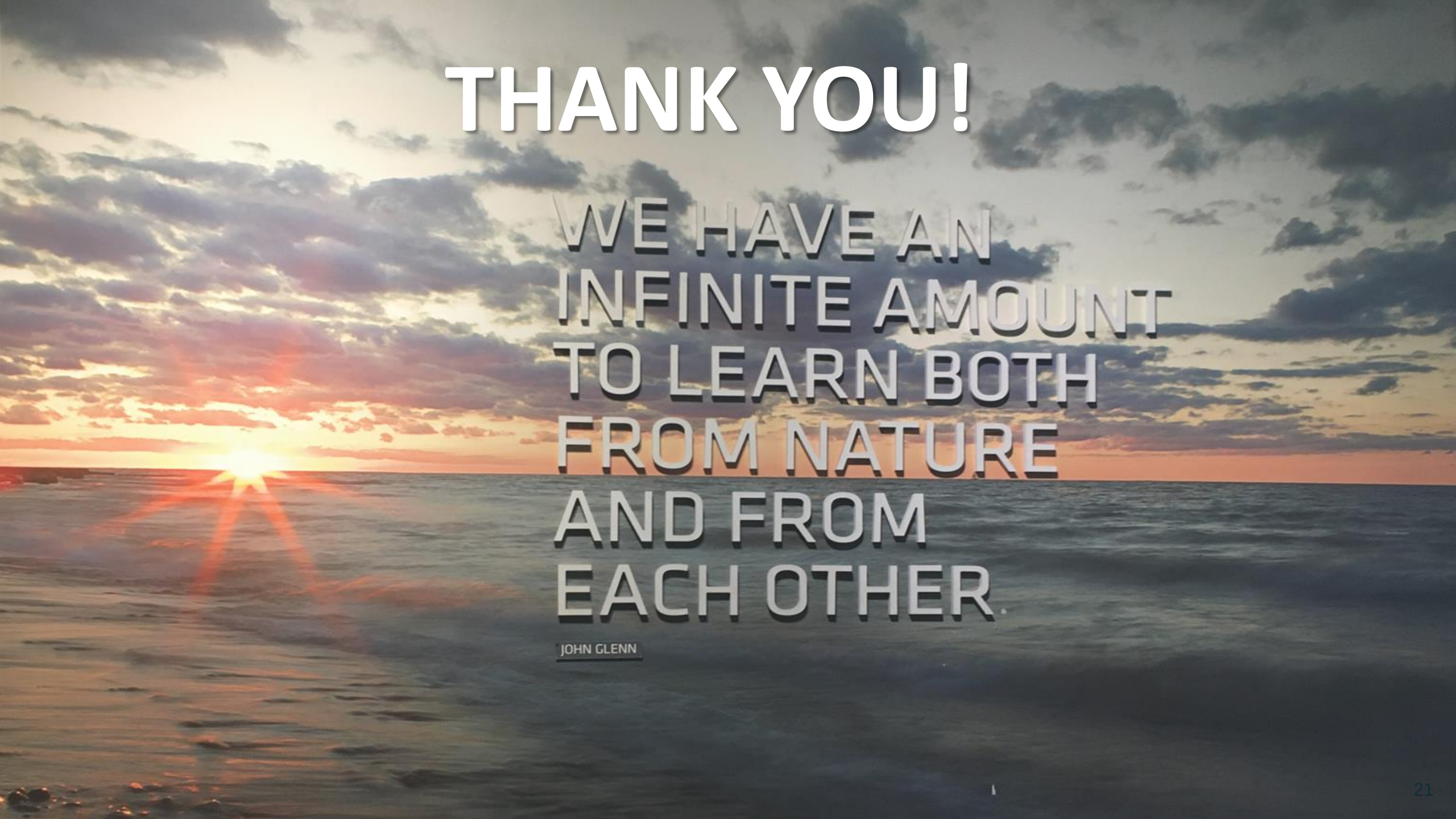
A vibrant space-themed background featuring a large blue planet with a ring system, a yellow planet, a brown planet, and a bright yellow sun. The background is filled with stars and nebulae, creating a cosmic atmosphere. A large white curved shape is overlaid on the right side of the image, framing the text.

Conclusions

- Numerous opportunities for biomimicry to enable advancements in space exploration and aeronautics
- Advancements in materials processing techniques needed
- Multiple paths to partner with NASA

Acknowledgements

NASA CAS Projects, Aeronautics Research Mission Directorate

A full-page background image showing a sunset over a body of water. The sun is low on the horizon, creating a bright orange glow and lens flare effects. The sky is filled with scattered clouds, some of which are illuminated by the setting sun. The water in the foreground is dark and calm.

THANK YOU!

WE HAVE AN
INFINITE AMOUNT
TO LEARN BOTH
FROM NATURE
AND FROM
EACH OTHER.

JOHN GLENN