Solar On-orbit Welder for Assembly, Repair, and Manufacturing

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Partner

NASA SBIR Phase II Project
Contract # 80NSSC23CA077

Technical Monitor:
Zachary Courtright | Marshall Space Flight Center

Technology Portfolio

Solar Concentrators
NSF SBIR Phase I - SCUforAM
NASA SBIR Phase I & II - LAMA
Colorado Grant - SmallSat

U.S. Patent 11,162,713
1 US Patent Pending

Regolith Resource Extraction
NASA SBIR Phase I - SCORCHER
NASA SBIR Phase I & II - FaRROE
NASA SBIR Phase I & II - MORRE

3 US, 2 Int'l Patents Pending

Solar Manufacturing and Construction
NSF SBIR Phase II - SAM
NASA SBIR Phase I, II & III - SEER
NASA SBIR Phase I & II - SOWARM
NASA SBIR Phase I - RE4CH

U.S. Patent 11,162,713
3 US, 2 Int'l Patents Pending

Software for Modeling and Optimization
NASA SBIR Phase I & II - Terra
NASA SBIR Phase I & II - THM
NASA SBIR Phase I & II - PSI
NASA STTR Phase I - LLPDT

Open-Source Software
Trade Secret Optimal Process Parameters

OUTWARD TECHNOLOGIES

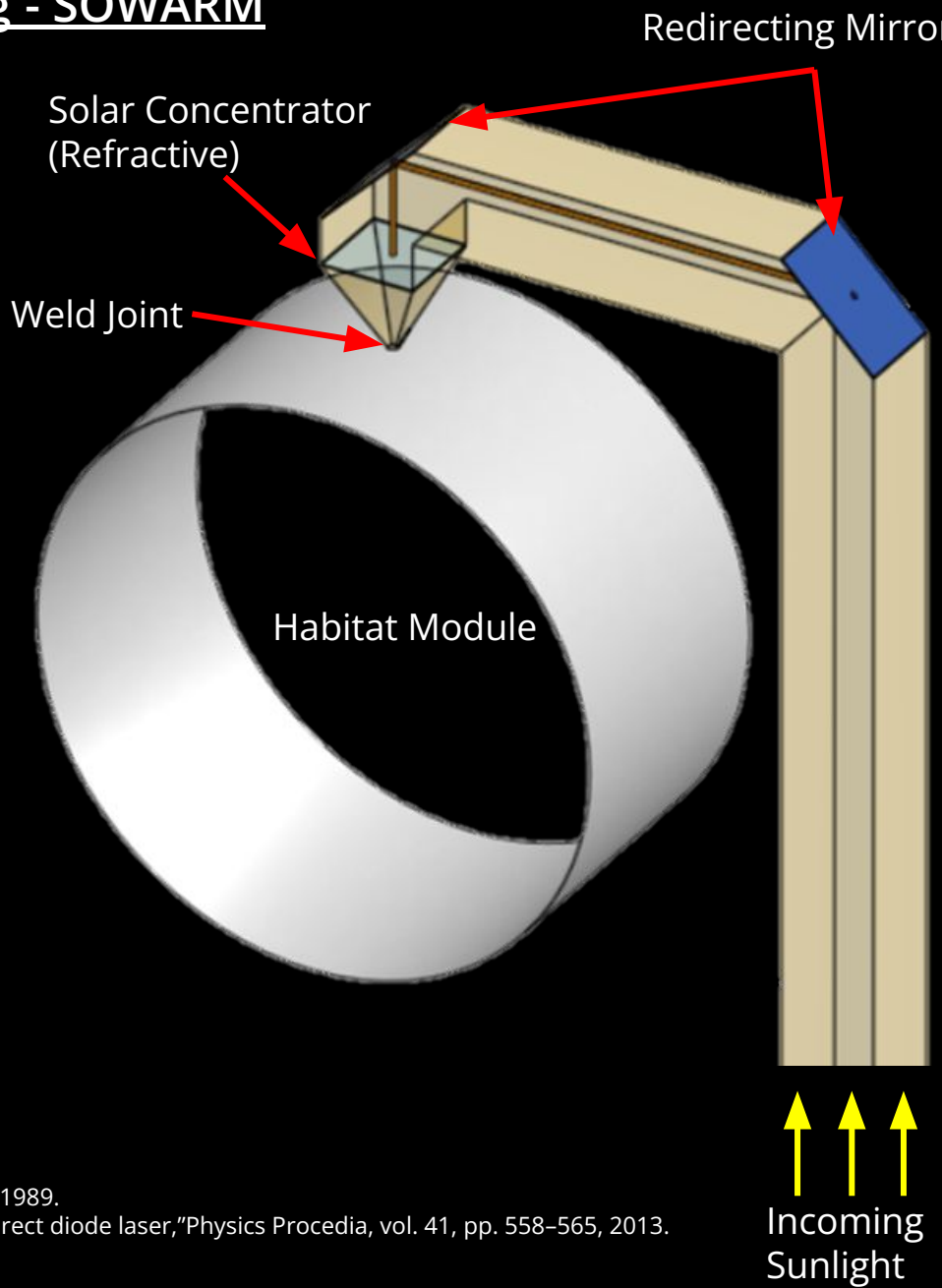
Outward Technologies

- Lean startup team with 12 engineers and scientists
- 6,300 sq ft shop and lab space
- Fenced in pad for solar testing
- Established track record for fast, inexpensive, high-quality tech advancement
- Deep understanding of concentrated solar energy, regolith processing, space system development
- Working with world experts in many fields
- Strong university ties

OUTWARD TECHNOLOGIES

Solar On-orbit Welder for Assembly, Repair, and Manufacturing - SOWARM

- Weld structural components and large habitats
  - Redirecting mirrors enable welding entire circumference of a habitat module
- Weld non-conductive materials like thermoplastics and ceramics
- >10 W/mm^2 energy density for welding metals
- **Drastically reduced system mass compared to conventional welding systems**
  - 2.5 kW-17 kW potential power reduction compared to arc[1] and laser[2] welding systems
  - No active cooling system required for heat source
    - Terrestrial 6 kW laser welder chiller = 100 kg +
- Multiple subsystems implemented for controlling weld properties and Heat Affected Zone
  - **Improves overall welding efficiency for light-based welding processes**

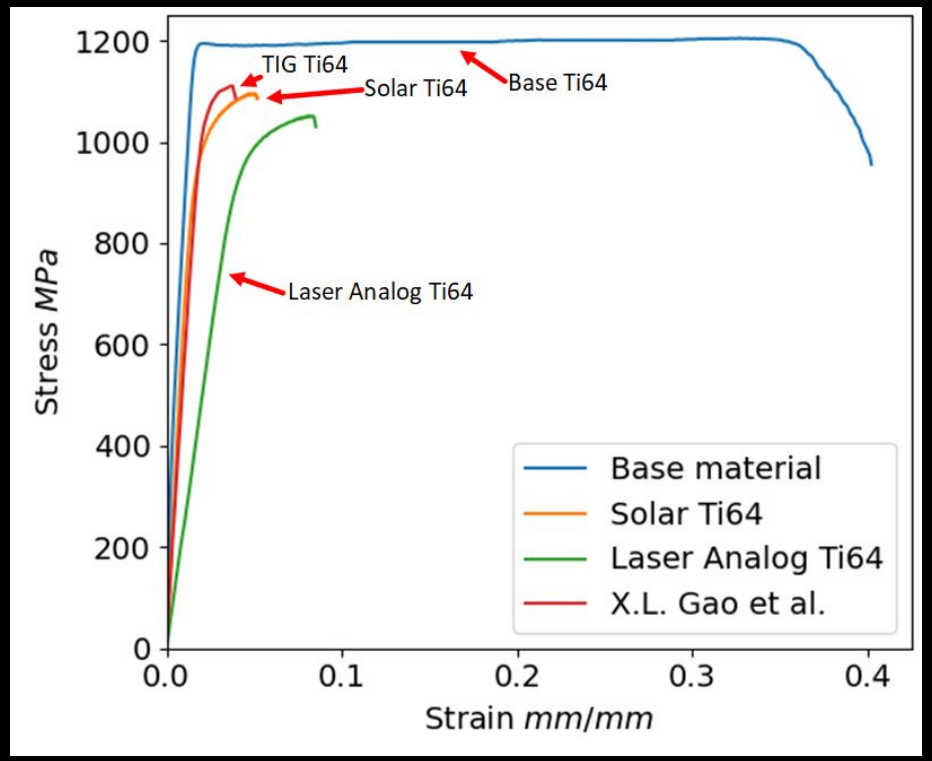


[1]J. K. Watson and G. D. Schmittgrun, "Extra-Vehicular Activity Welding Experiment." 21-Aug-1989.
[2]G. C. Rodrigues, M. Cuypers, E. F. Sichani, K. Kellens, and J. R. Duflou, "Laser cutting with direct diode laser,"Physics Procedia, vol. 41, pp. 558–565, 2013.

OUTWARD TECHNOLOGIES

Solar Welding Current State - TRL 5

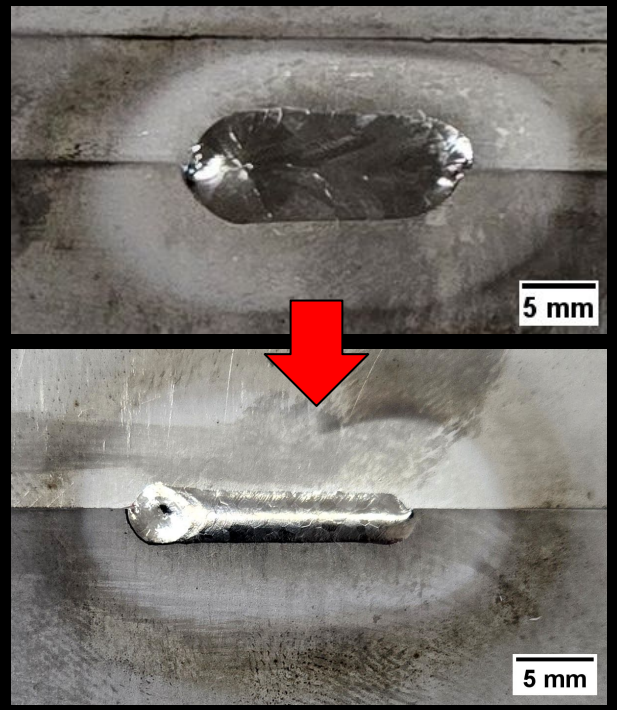
- Solar weld joint efficiencies so far (optimizing process):
  - Up to 87% for Grade 2 Titanium (1mm thick, no filler)
  - Up to 88% for Ti64 Titanium Alloy (1mm thick, no filler)
  - Up to 33% for 6061-Al (3.18mm thick, no filler) - Not optimized
  - Up to 30% for 6061-Al (6.35mm thick, with filler) - Not optimized
  - Up to 33% for PEEK (1.59mm thick, no filler) - Not optimized

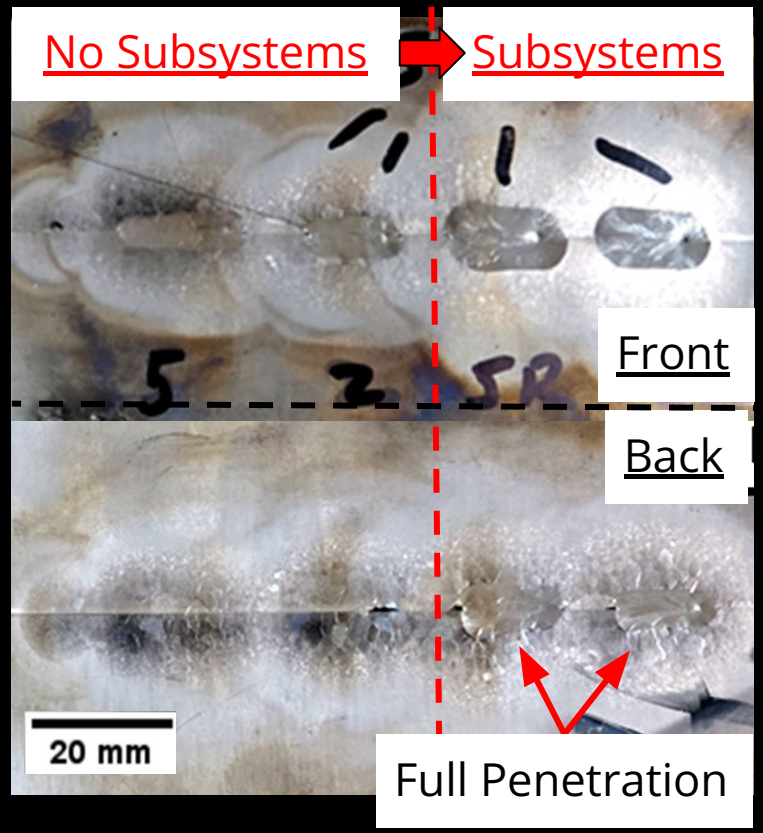


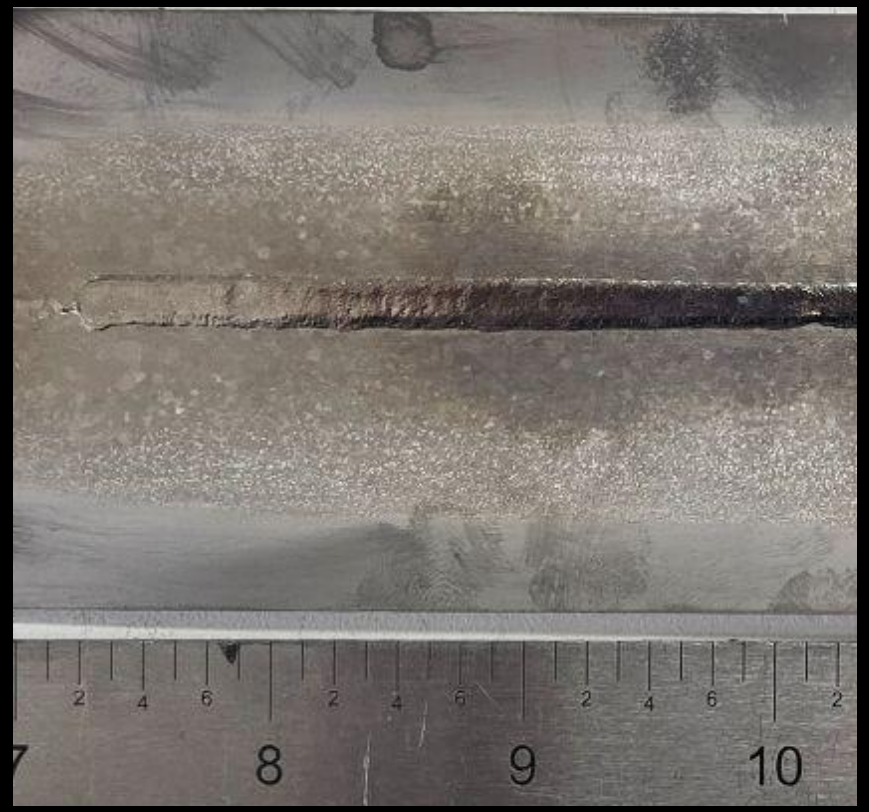
OUTWARD TECHNOLOGIES

Weld Control Subsystems

- Multiple mechanical subsystems for controlling weld properties
  - Improves overall welding efficiency for solar AND laser welding processes!! ⇒ Terrestrial applications!!
    - Lower-power welding
    - Faster welding speeds
    - Deeper penetration
    - Improved weldability of reflective materials



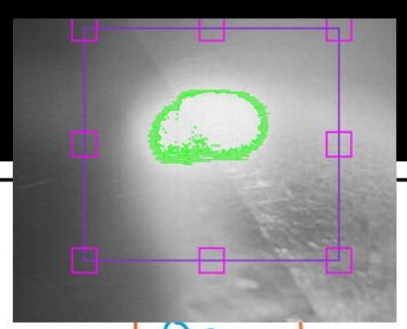


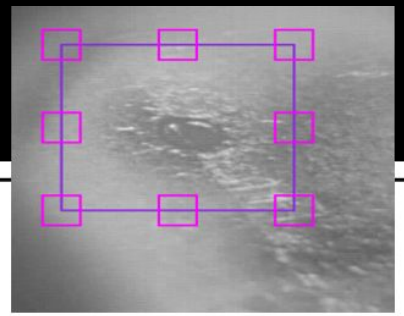


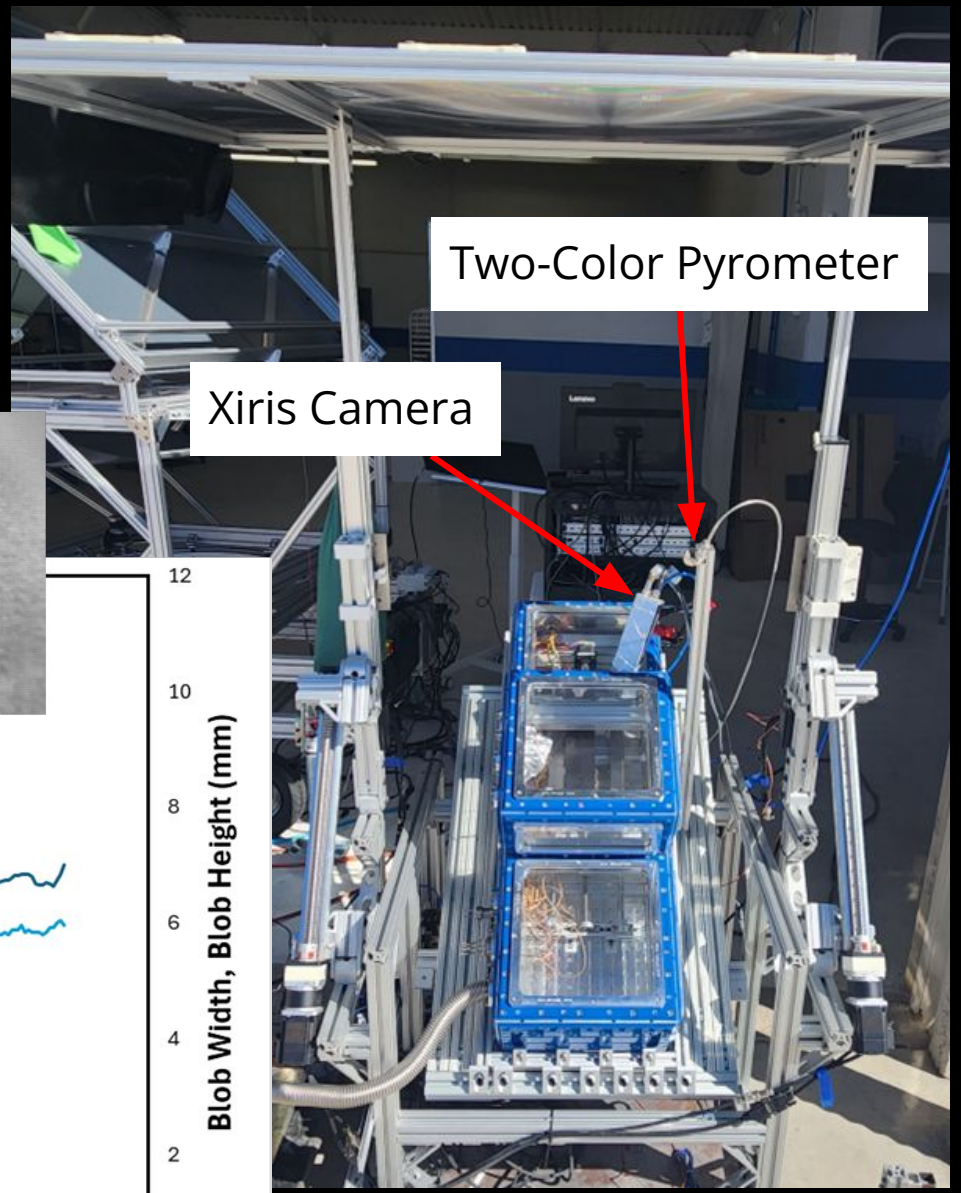
OUTWARD TECHNOLOGIES

In-Situ Process Monitoring and Closed-Loop Control

- Xiris high-dynamic-range welding camera
  - Melt pool formation and properties
- Two-color pyrometer
  - Temperature monitoring
  - Blind to solar spectrum



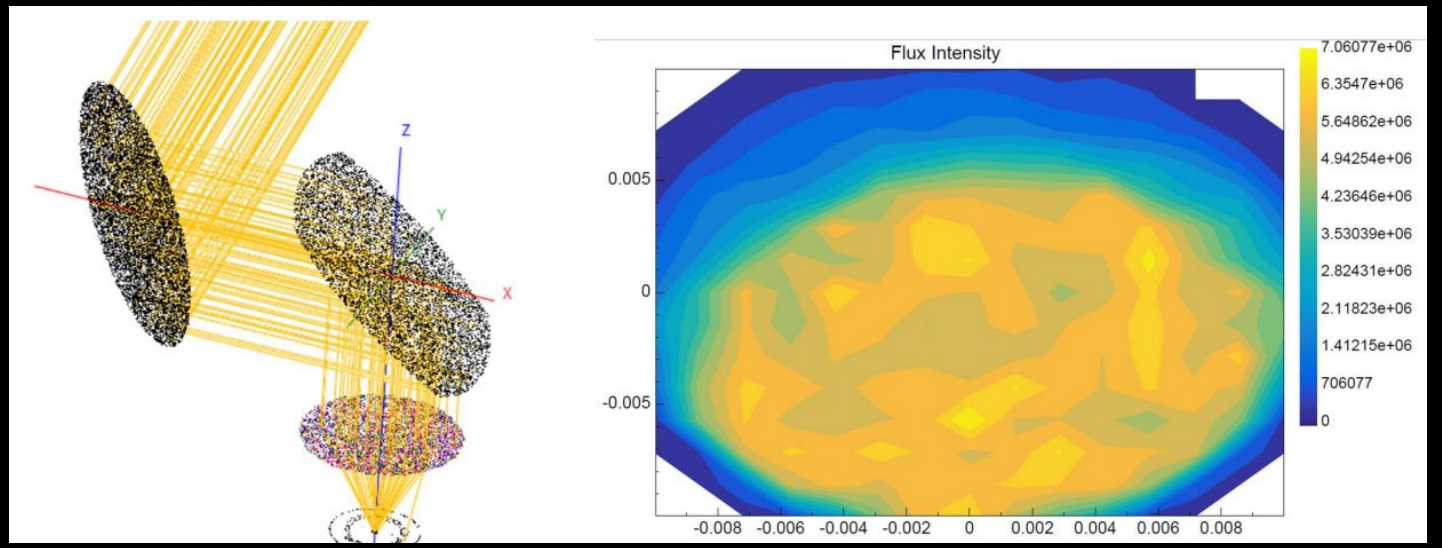


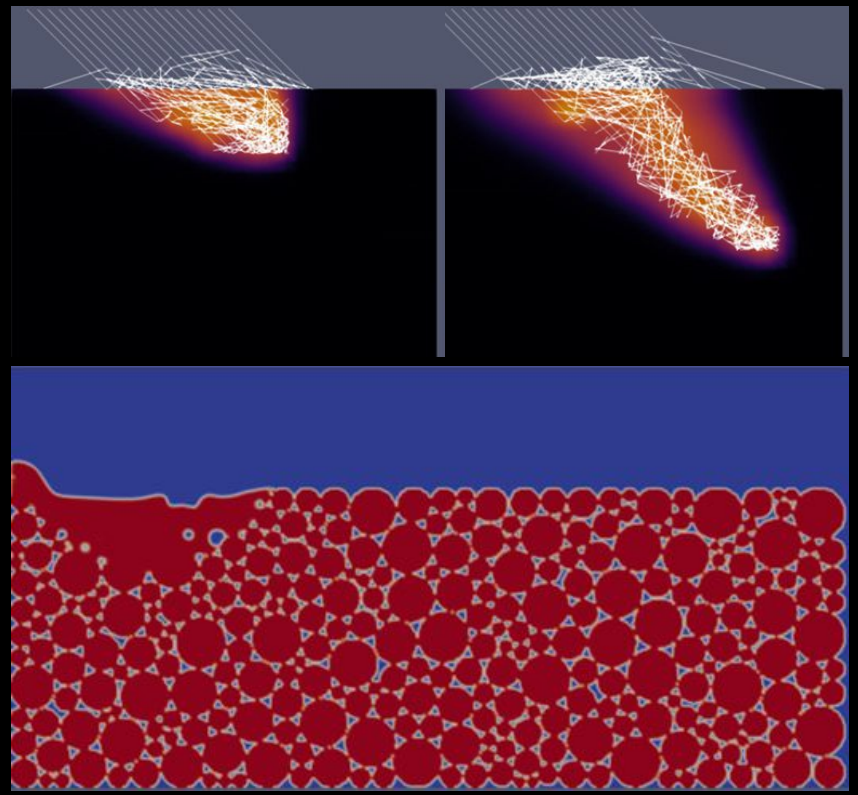


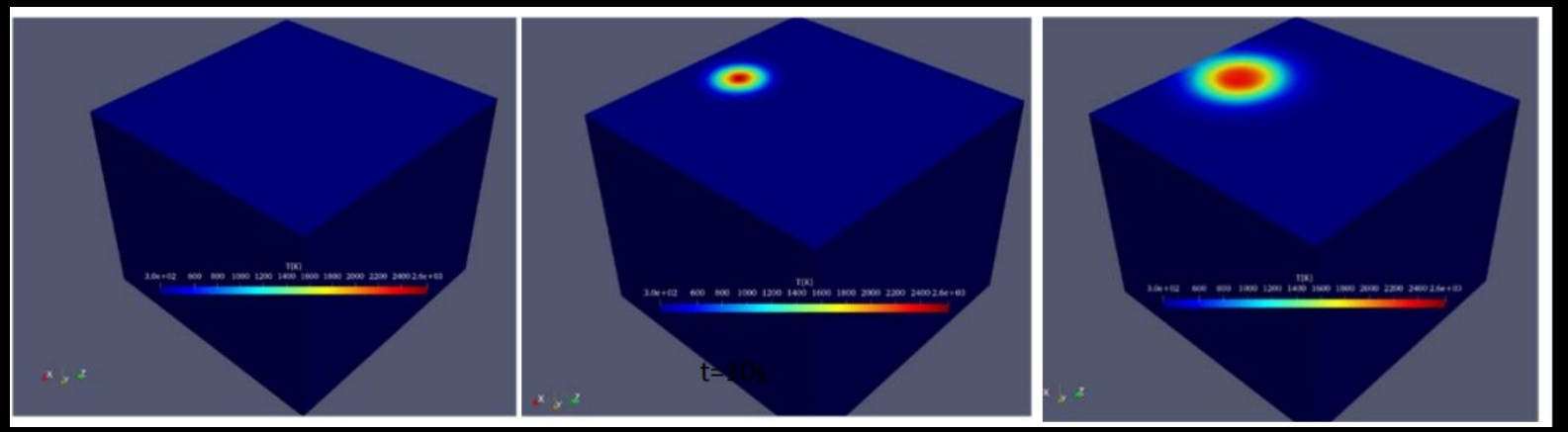
OUTWARD TECHNOLOGIES

Digital Twin Development

- Multiple models under development
  - Solar ray-tracing model
  - CFD model of melt pool
  - ROS2 Mechanical model
- Process development and operations planning
- Automation Development



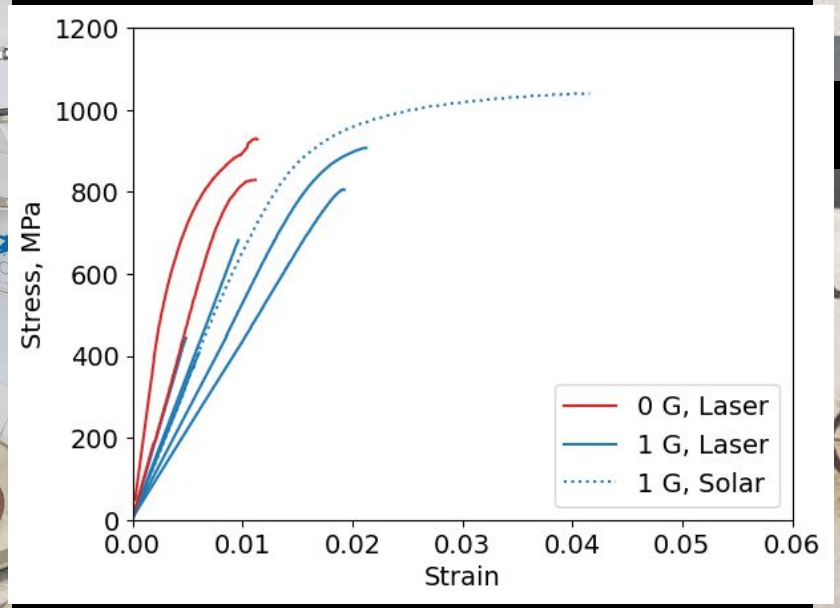




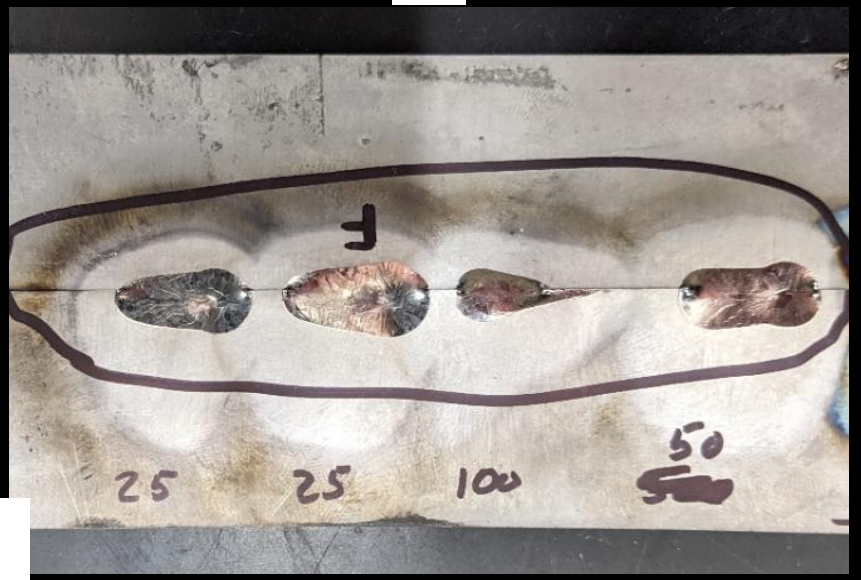
OUTWARD TECHNOLOGIES

Reduced Gravity Flight Testing

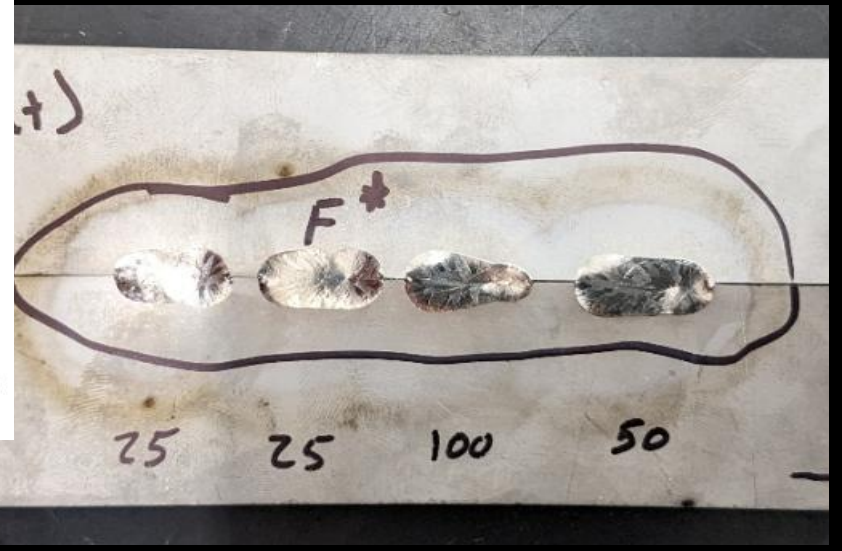
- Success!
- Used laser welder conditioned to match concentrated solar energy spot
- Effect of microgravity on solar welding seems minimal
  - Experienced more blow-through, but could be experimental conditions
  - Similar visual properties
  - Similar strength



0-G



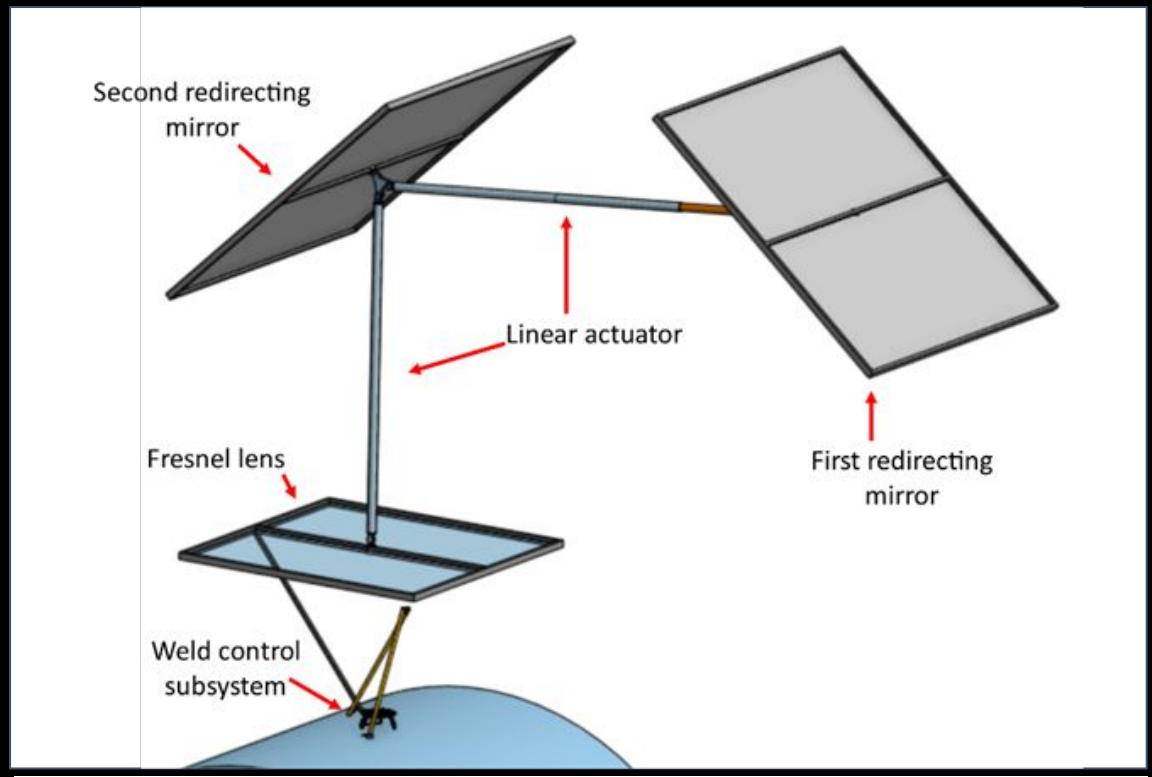
1-G

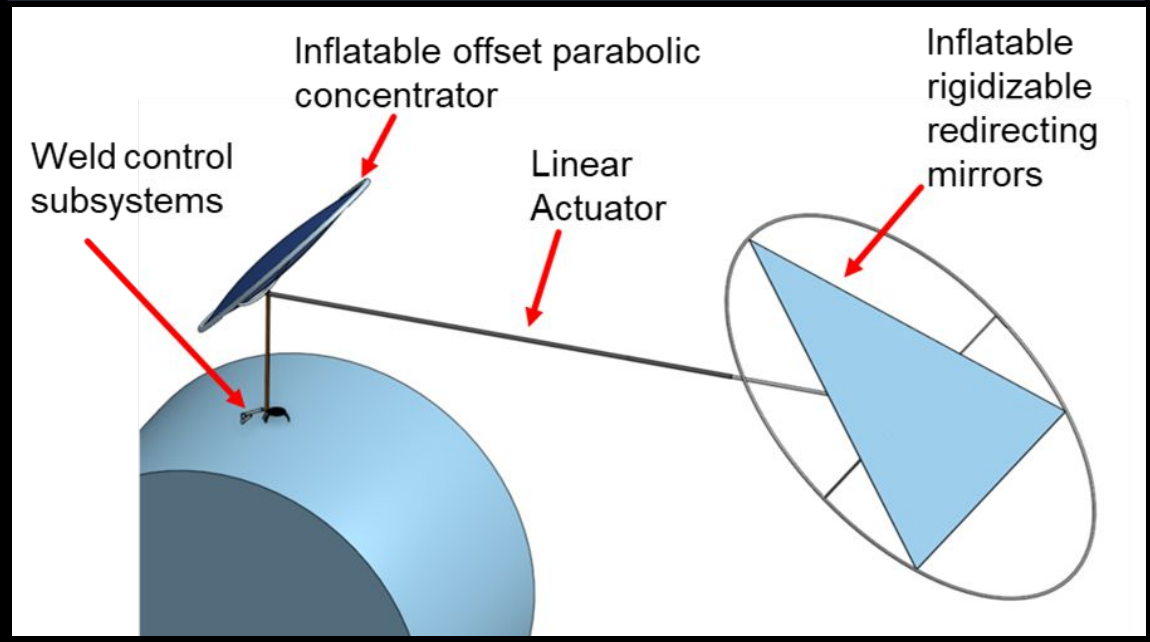


OUTWARD TECHNOLOGIES

Full Scale System Design

- Mechanical design support provided by Moog
- 5 kW Rigid refractive concentrator system estimates:
  - Power = 232 W
  - Mass = 38 kg
  - Stowage volume = 0.05 m^3
- 5 kW Inflatable reflective concentrator system estimates:
  - Concentrator design support provided by L'Garde
  - Power = 197 W
  - Mass = 24 kg
  - Makeup gas requirement = 0.32 kg per year minimum
  - Stowage volume = 0.03 m^3
- 2 kW Terrestrial laser welder (for reference)
  - Power = 6.5 kW
  - Mass = 55 kg



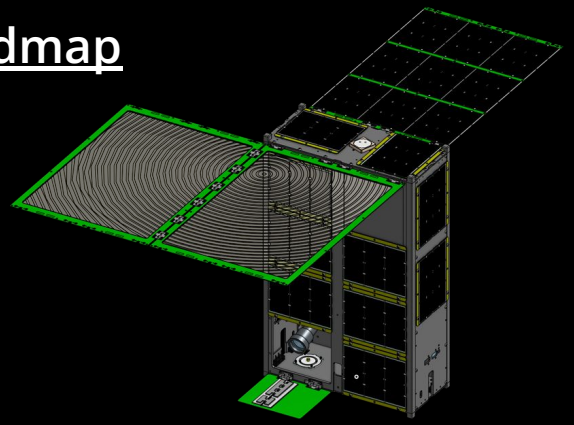


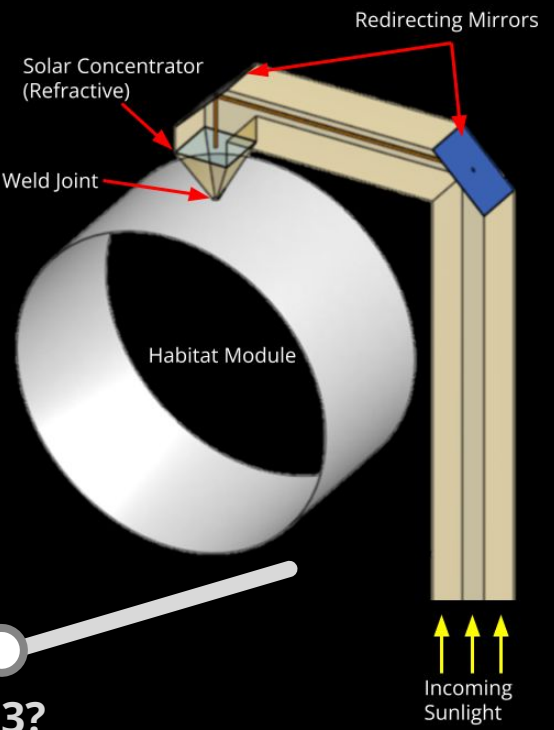
MOOG

L·GARDE
CELEBRATING 50 YEARS OF SMART SPACE TECHNOLOGY

OUTWARD TECHNOLOGIES

Solar Welding Technology Development Roadmap





2023

TRL 4
Phase I feasibility demonstration

2024

TRL 5
ZeroG flights using laser analogue (vacuum + microgravity)

2026

TRL 6
SmallSat demonstration payload

2027

TRL 7
Space station hosted demonstration payload

2029

TRL 8
Space station hosted solar welding testbed

203?

TRL 9
Complete SOWARM system deployed

OUTWARD TECHNOLOGIES

Solar Welding Market Opportunities

Lunar Transfer

- HLS/Transfer Vehicle maintenance

GEO

- Servicing vehicle utility
- Space-based power platform assembly/maintenance

MEO/Transfer

- Servicing vehicle utility
- Tug maintenance and utility

LEO/SSO

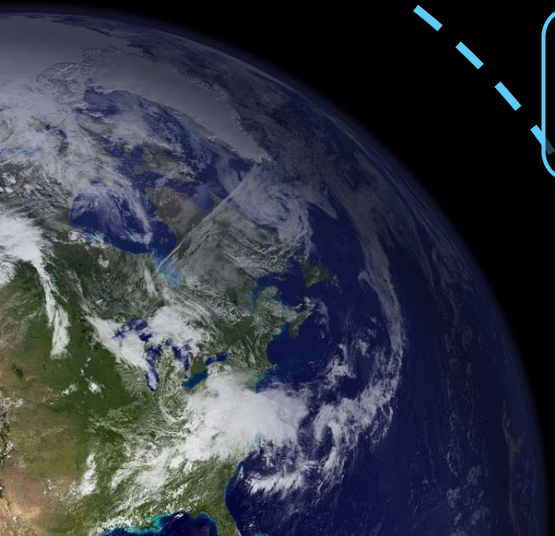
- Space station assembly/maintenance
- Persistent platform assembly/maintenance
- Early microgravity factory assembly/maintenance

NRHO/Cislunar

- Lunar gateway maintenance
- Relay maintenance

L2

- Great Observatories assembly/maintenance
- JWST maintenance



OUTWARD TECHNOLOGIES

Solar Welding System Architecture - Opportunities for Collaboration

- Andrew Brewer - abrewer@outward.tech
- Alan Carter - acarter@outward.tech

System Inputs:
- Raw materials
- Filler rods
- Mobility Platform
- Deployable Solutions

Operational Needs:
- Sensing and Perception
- Autonomous operation
- Navigation and propulsion
- Workpiece manipulation
- Thermal regulation
- Space-rated components
- Optics servicing

Post-Production Needs:
- Non-destructive evaluation
- Delivery and installation

Customers!

OUTWARD TECHNOLOGIES