ISSRDC

International Space Station
Research & Development Conference

July 29 - August 1, 2024
Boston, MA

#ISSRDC

*In-Space Production Applications I*

# **Revolutionizing Space Manufacturing:** *Insights and Recent Results from Manufacturing Glass Aboard the ISS*

*And Yes, there will be data from our first draw*

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NASA
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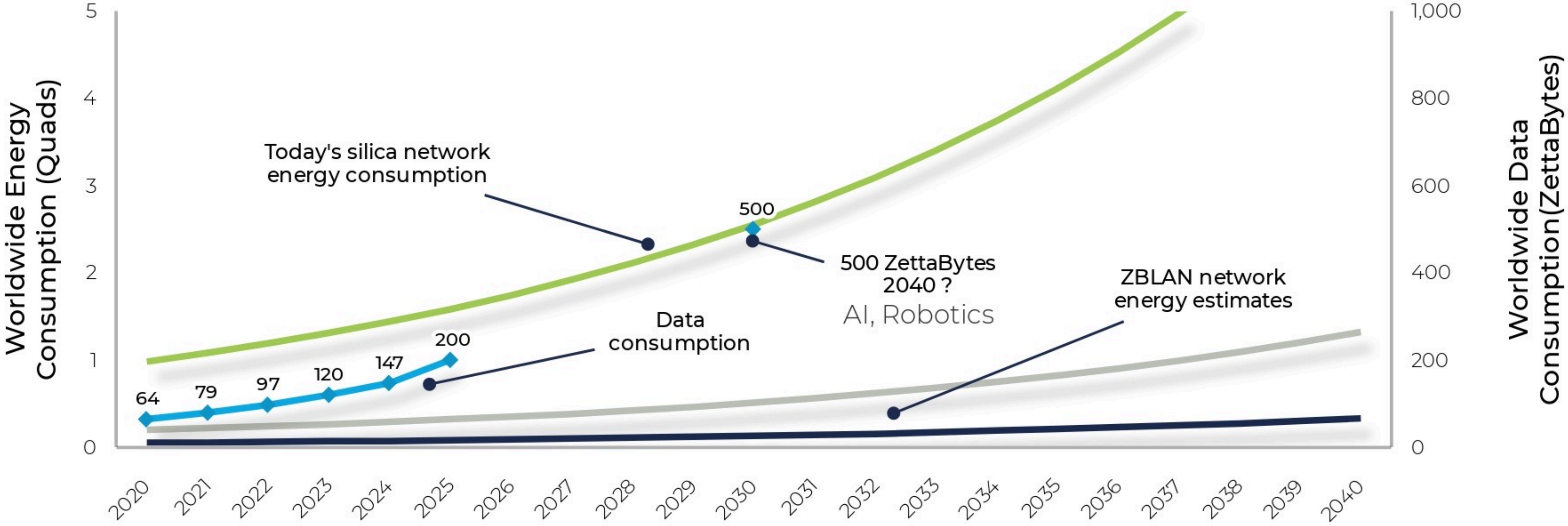
## The Data/Energy Crunch

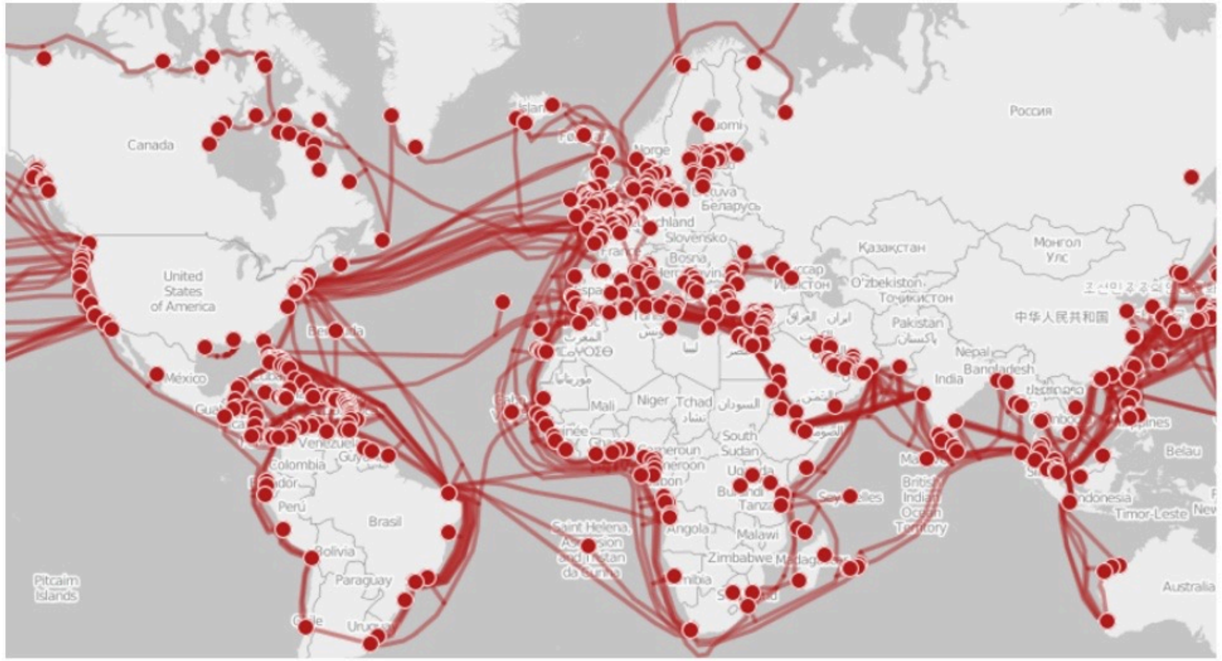
# Global data consumption is doubling every 2 to 3 years

Global optical network uses 1 - 1.5% of global electricity usage; ~4% of CO2 emissions



## Size of the Network

# Repeaters every 40 to 50 km




*1.4 MILLION KM OF UNDERSEA OPTICAL CABLE IN 2023, UP FROM 1.2 IN 2022 1.2M; HEADED TO 2M 2030*

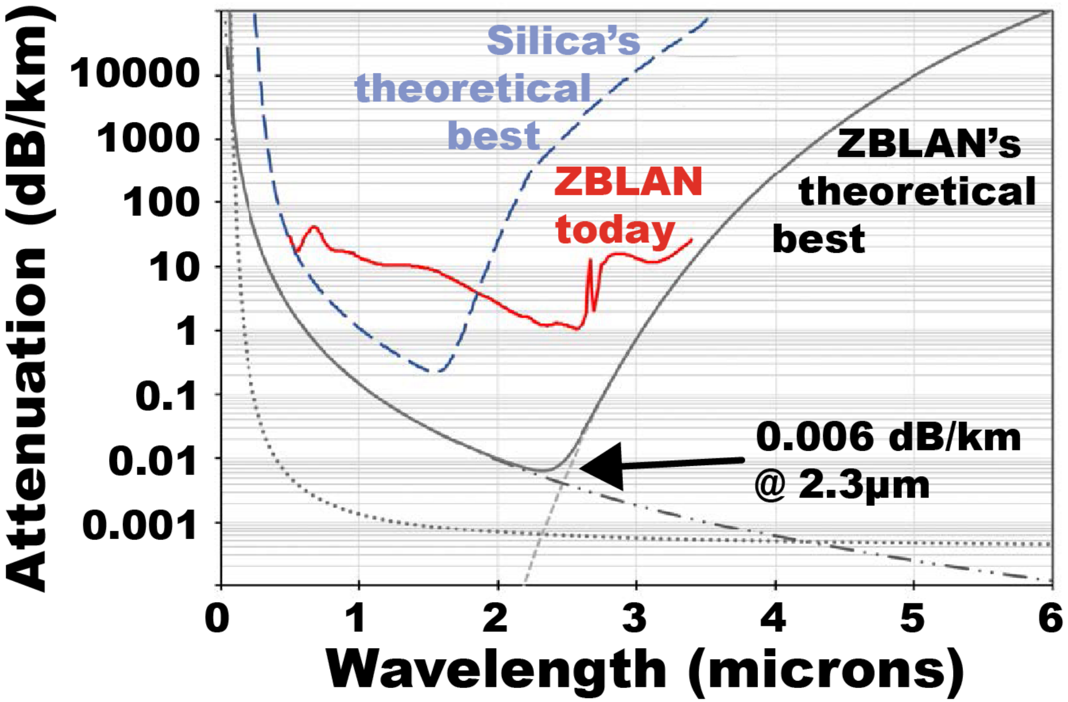

$10 billion boom over next few years

- 78 systems go online (300,000 kilometers)
- Level of growth not seen in over 20 years

# ZBLAN's Material Advantage over Silica

## ZBLAN's **better spectral efficiency** drives lower energy costs & **increased ROI**

- Spectra efficiency
  - Attenuation & more bands (figure)
  - Non-linear effects, dispersion, gain flatness
- ZBLAN network could transmit
  - 30X more data compared to silica
  - 10X-100X further w/out amplification
- **But manufacturing low attenuation ZBLAN has been challenging … a problem microgravity uniquely addresses**




2020, SPIE, Breaking the Silica Ceiling: ZBLAN-based Opportunities for Photonics Applications

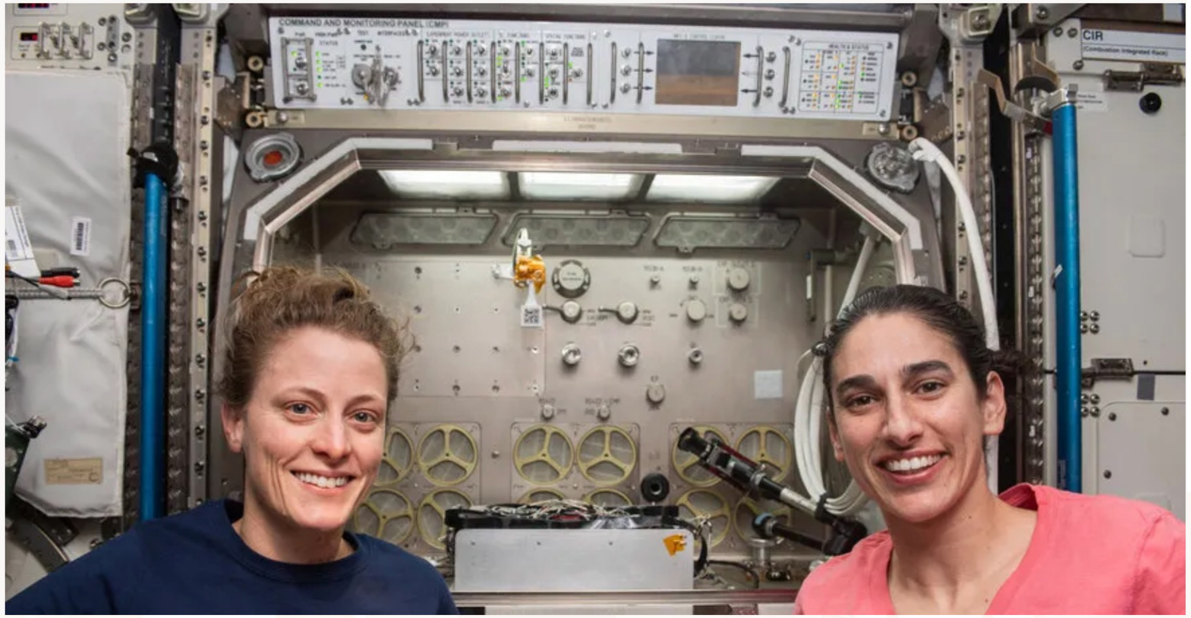
# Space Manufacturing Milestone

## Making history – 11.8 kilometers of fiber drawn on the ISS

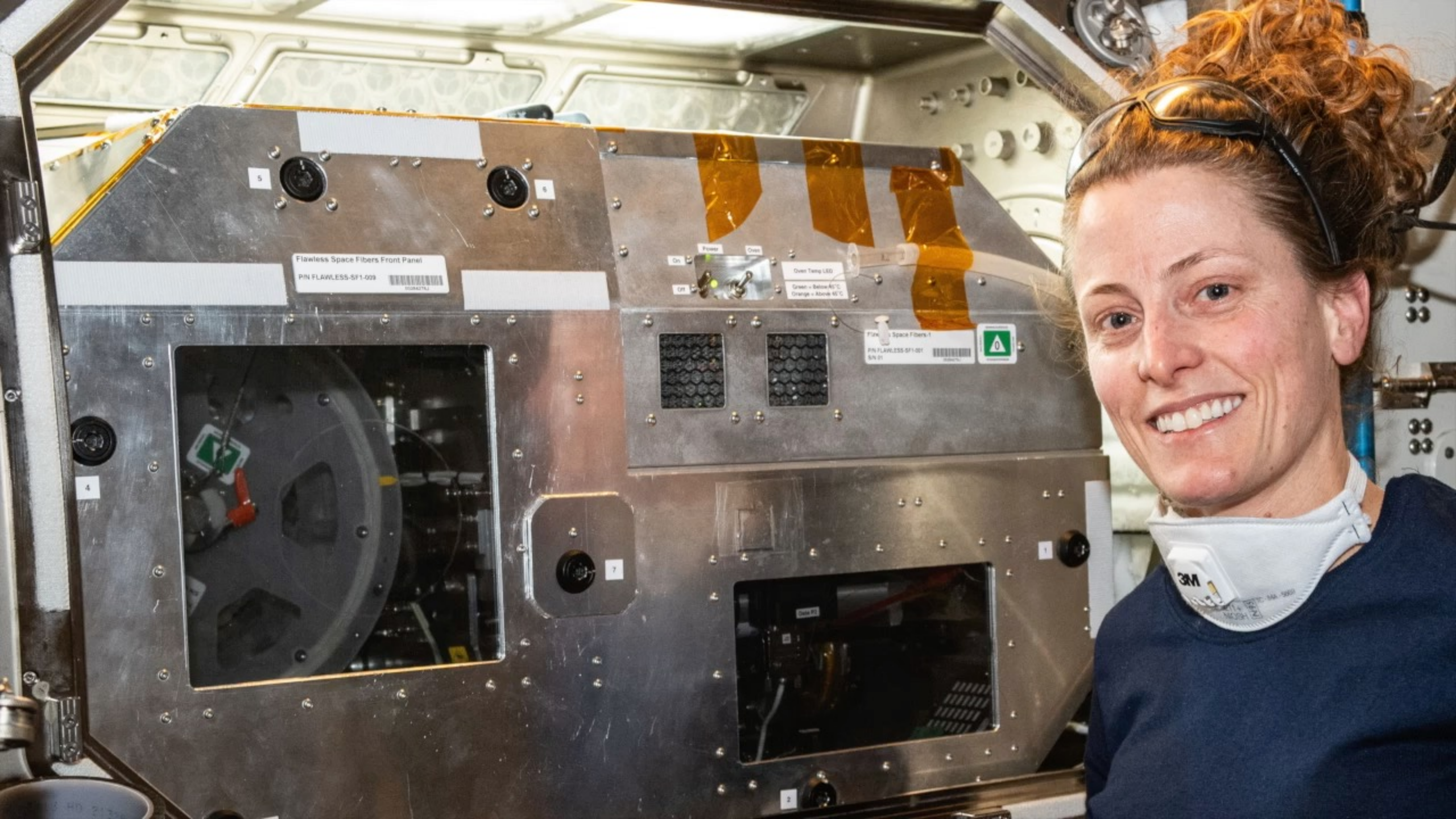
### Flawless Photonics Kicking Glass

Silicon Valley startup produces more than 5 kilometers of ZBLAN in two weeks

Debra Werner February 23, 2024




"For in-space manufacturing, Flawless Photonics' accomplishment "**is in a class by itself**," Lynn Harper, strategy lead for NASA ISS InSpace Production Applications, told *SpaceNews*."


Flawless Space Fibers Front Panel
P/N FLAWLESS-SF1-009
Power
Oven
On
Off
Oven Temp LED
Green = Below 45°C
Orange = Above 45°C
P/N FLAWLESS-SF1-001
S/N 01
5
6
4
7
1
2
3M

# Characterization Overview

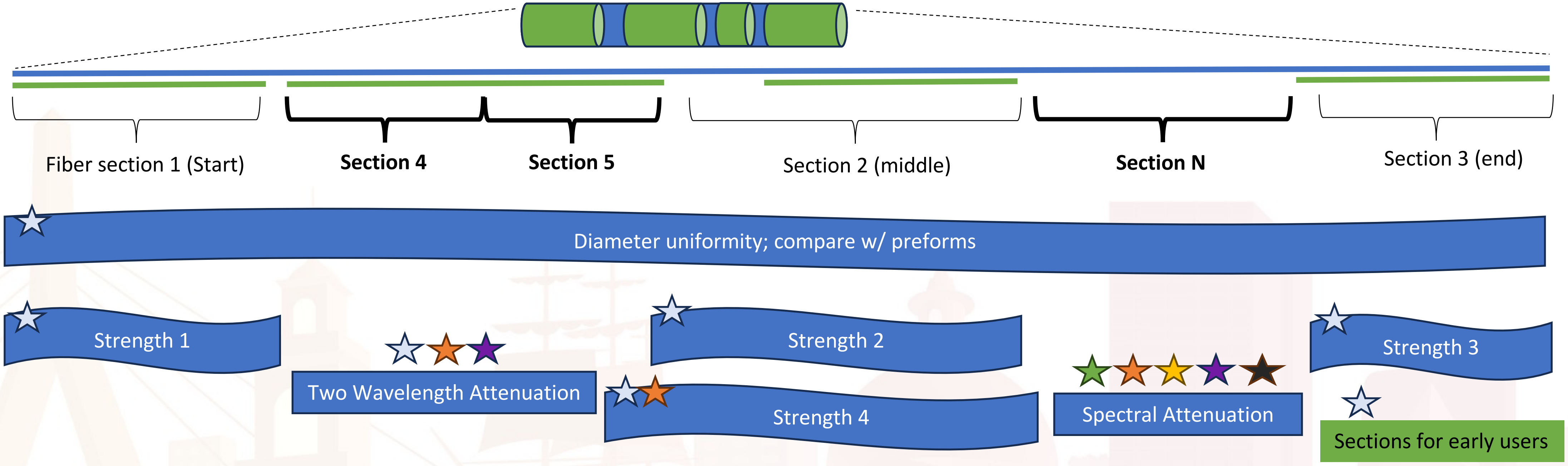
Space-drawn
Earth-drawn
Compare 0g & 1g Quality

## Identify 1g & 0g process and quality differences

Measurements Planned by:

- UoW
- UoA
- DTU
- IPHT
- NRL
- FP

| 19 Preforms Drawn In-Space | |
|---|---|
| 6 Undoped Preforms | 2 Preforms (dopant 1) |
| 5 Rods | 6 Preforms (dopant 1) |

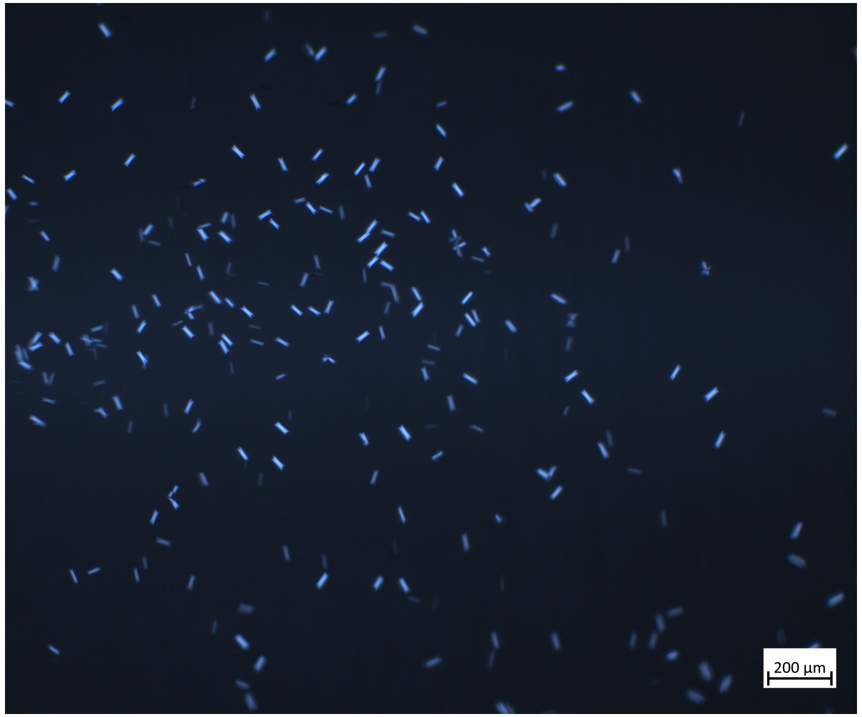


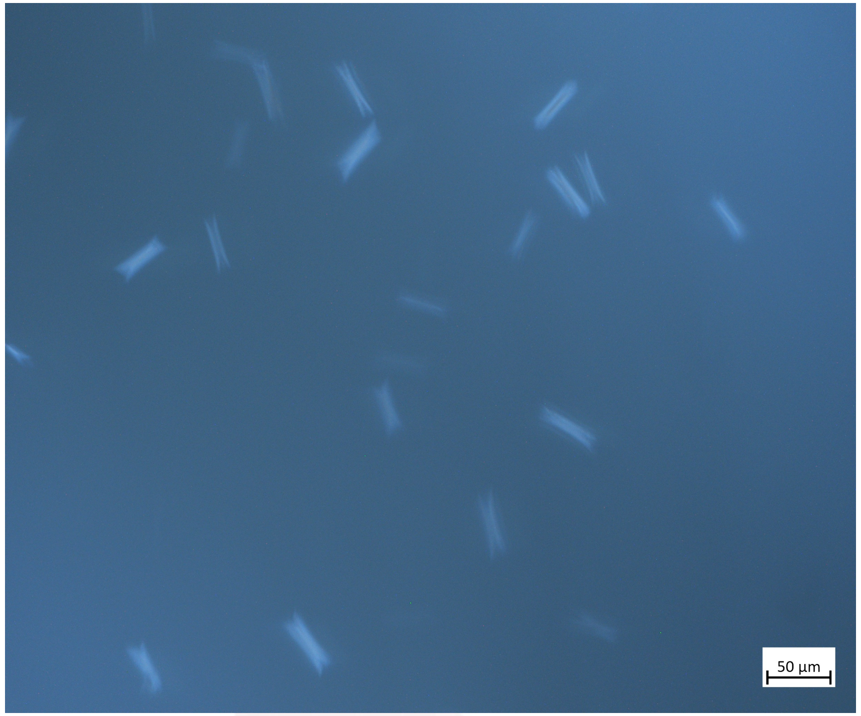

LuxIMPULSE
esa

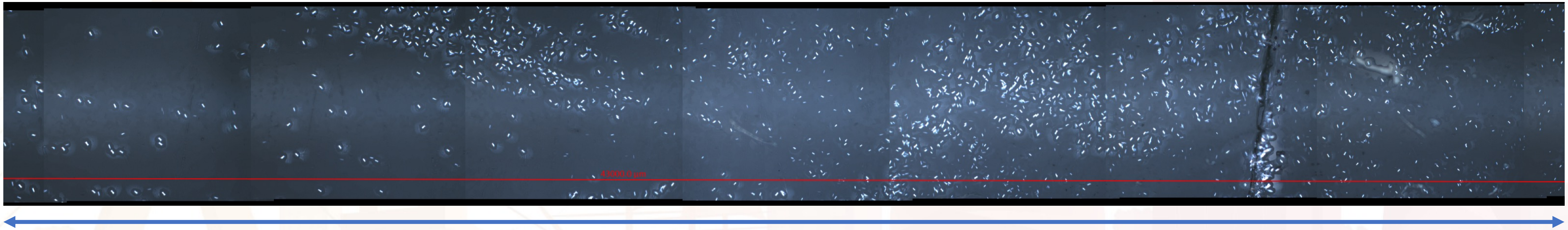
# Defect Characterization

Crystals in ZBLAN glass

- Polarized light
- Extended Depth of Field
- Tiles function – stitch 50 x 70mm pictures together



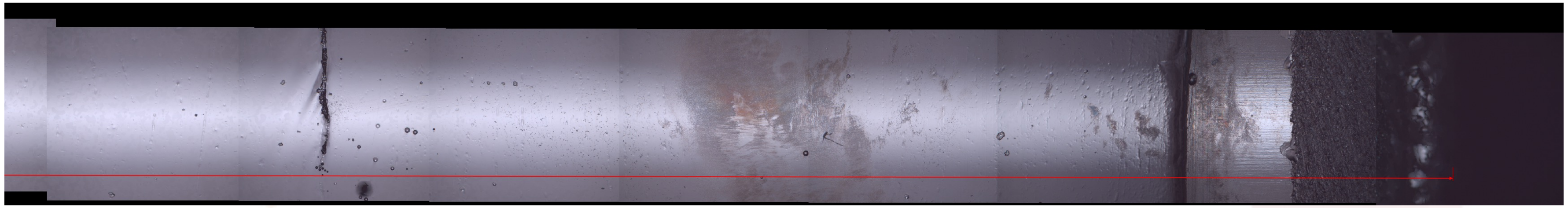



43 mm

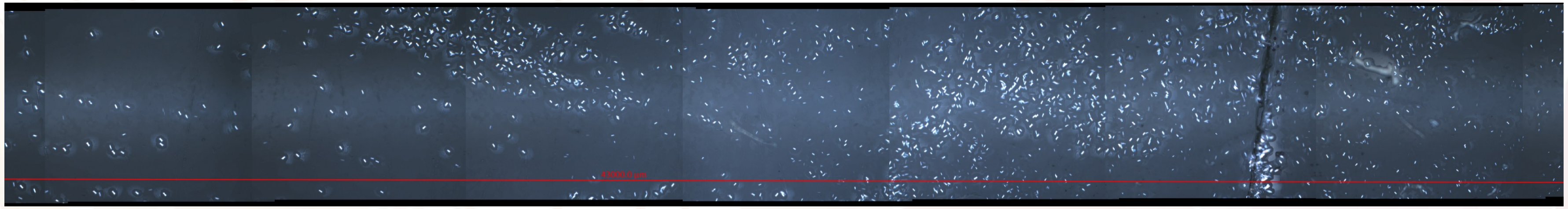
# Preform Characterization

Detect and position defect in the ZBLAN preforms

Bubbles and voids in preform core



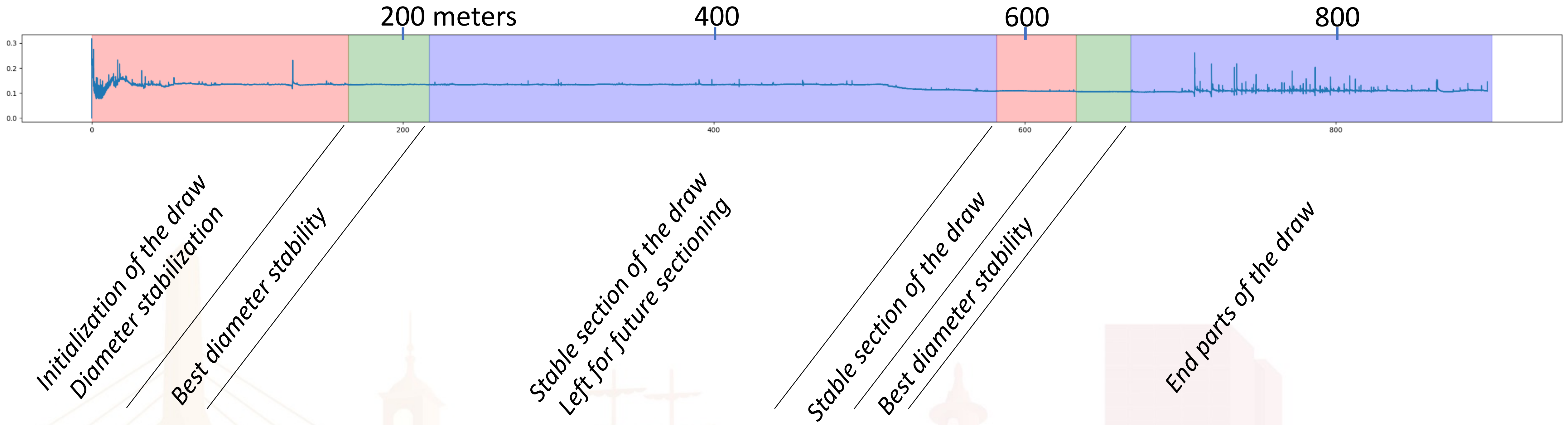
Surface defects



Crystals in glass

# Diameter Variation Drawn on the ISS

Collected diameter and length data onboard the ISS

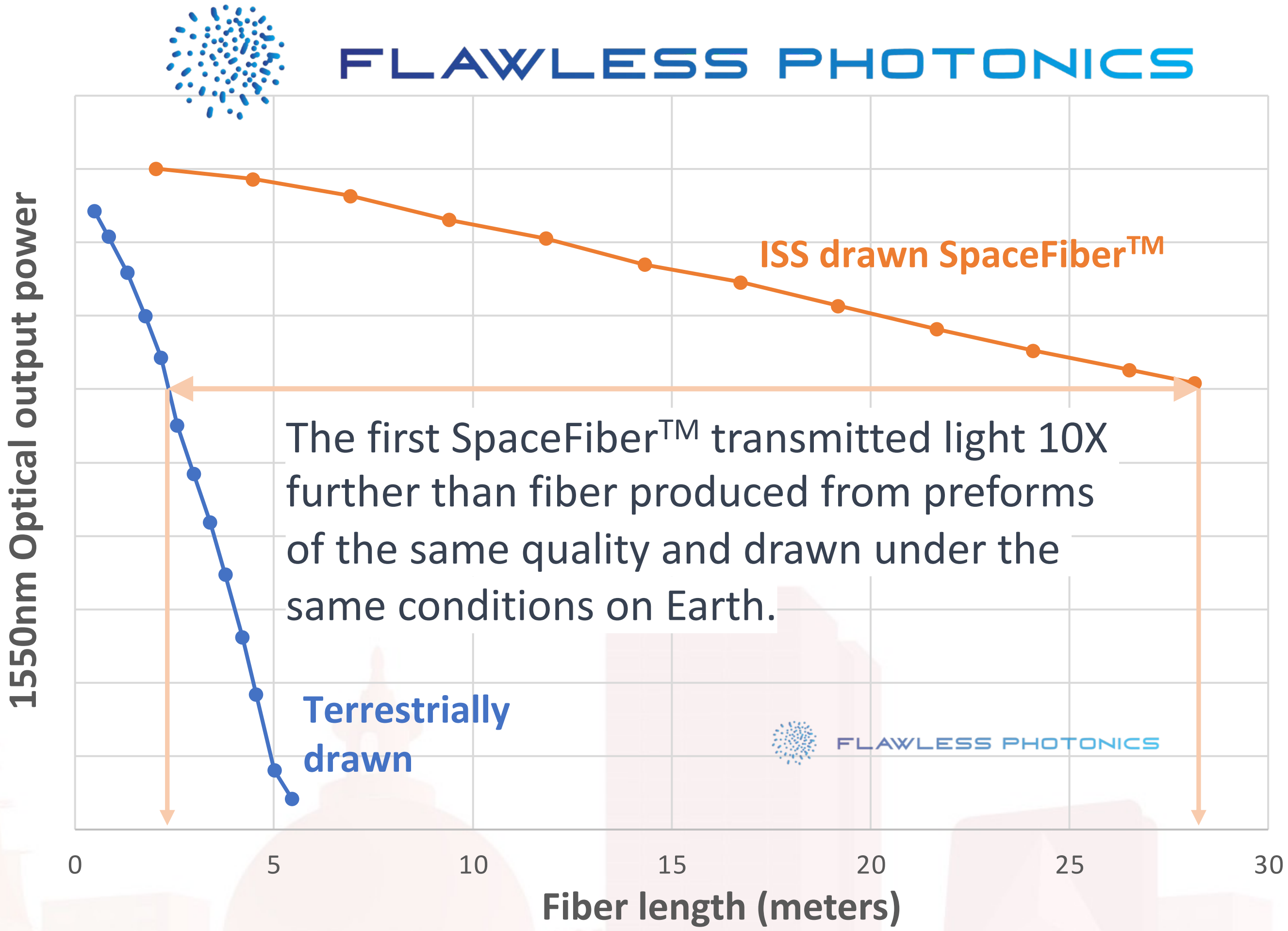



- Diameter and length analysis informs sectioning of fiber
- Need long draws to achieve stability

# SpaceFiber™ vs Terrestrial Fiber Measurement

Flawless Photonics' 1st fiber measurements are encouraging but need more statistical relevance

- Attenuation of the microgravity drawn fiber improved
  - One measurement, need statistics
  - Similar quality starting preforms
- Ongoing fiber measurements
  - 11,800 meters being screened
  - Similar samples will be measured by 6 independent organizations, including NRL, Universities, Labs
    - Cutback at 2- & multi-wavelength
    - Strength
    - Attenuation by optical time-domain reflectometer (OTDR)



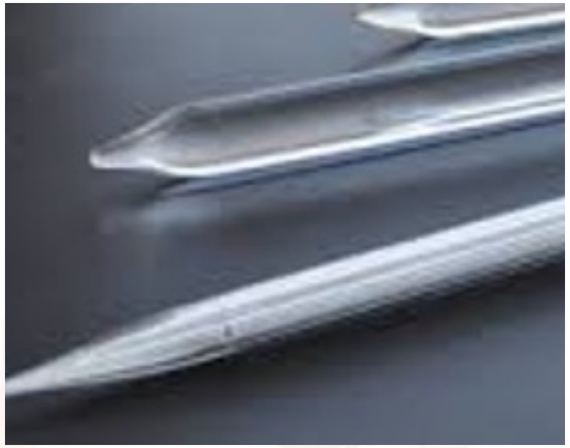

ZBLAN Multimode fiber attenuation

# Producing Better Fiber

## From Powder to Fiber: Key Stages of Fiber Production

**FLAWLESS' COMPETITIVE ADVANTAGE**
Autonomy, Materials/Glass Science

Purify the Powder



Make the Preform

Draw the Fiber

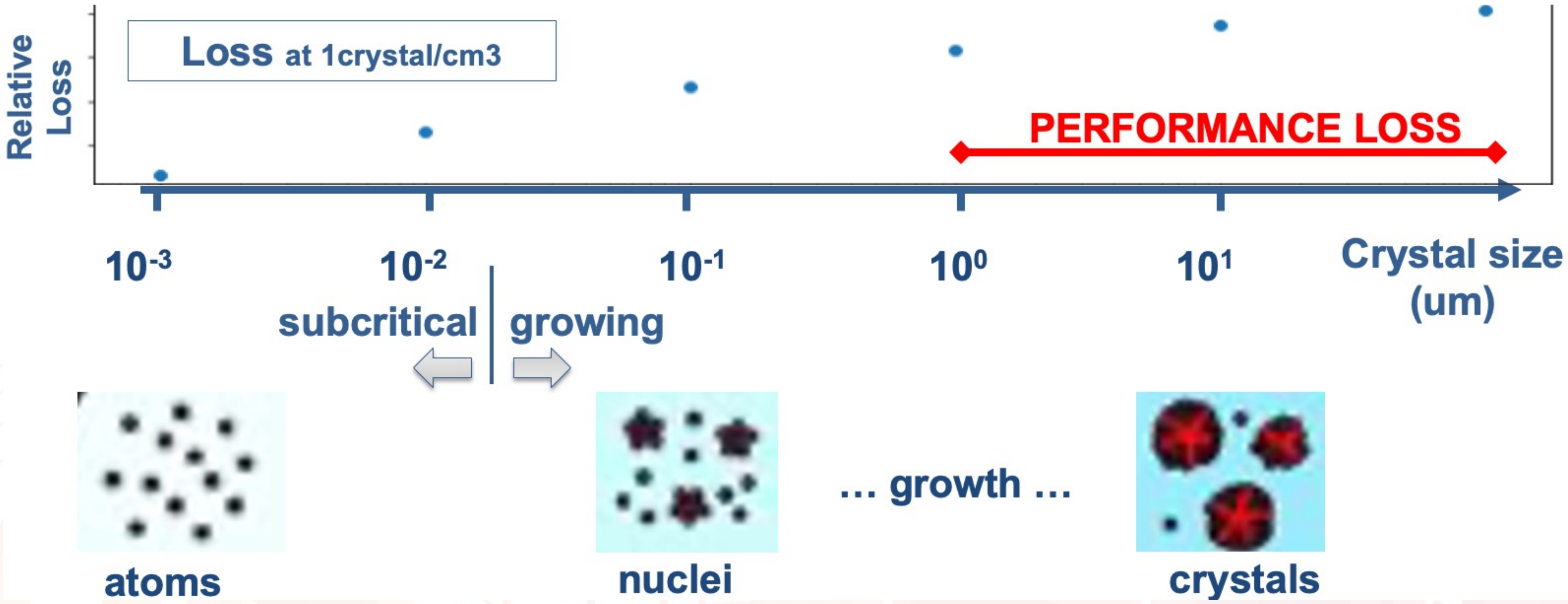
Coat and Protect

**Control over the quality and purity of the starting material, the preform, drawing, and coating processes all directly influence the final fiber's performance**

## What is the science underpinning microgravity manufacturing

As nuclei grow into crystals, they scatter light (performance loss)

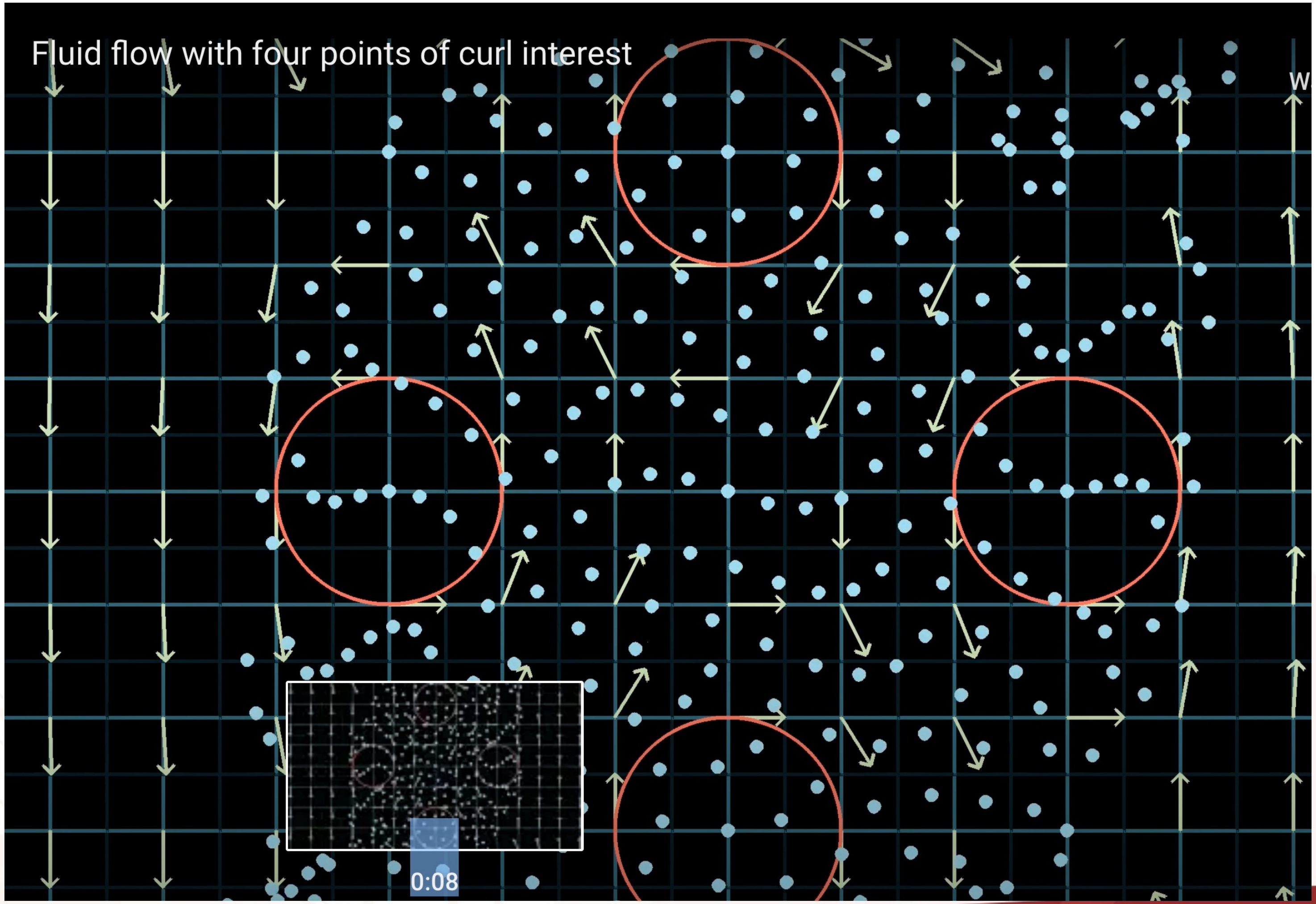
Flawless Photonics & LLNL scientists modeled 1G and microgravity N/G



# Microgravity suffers no convection

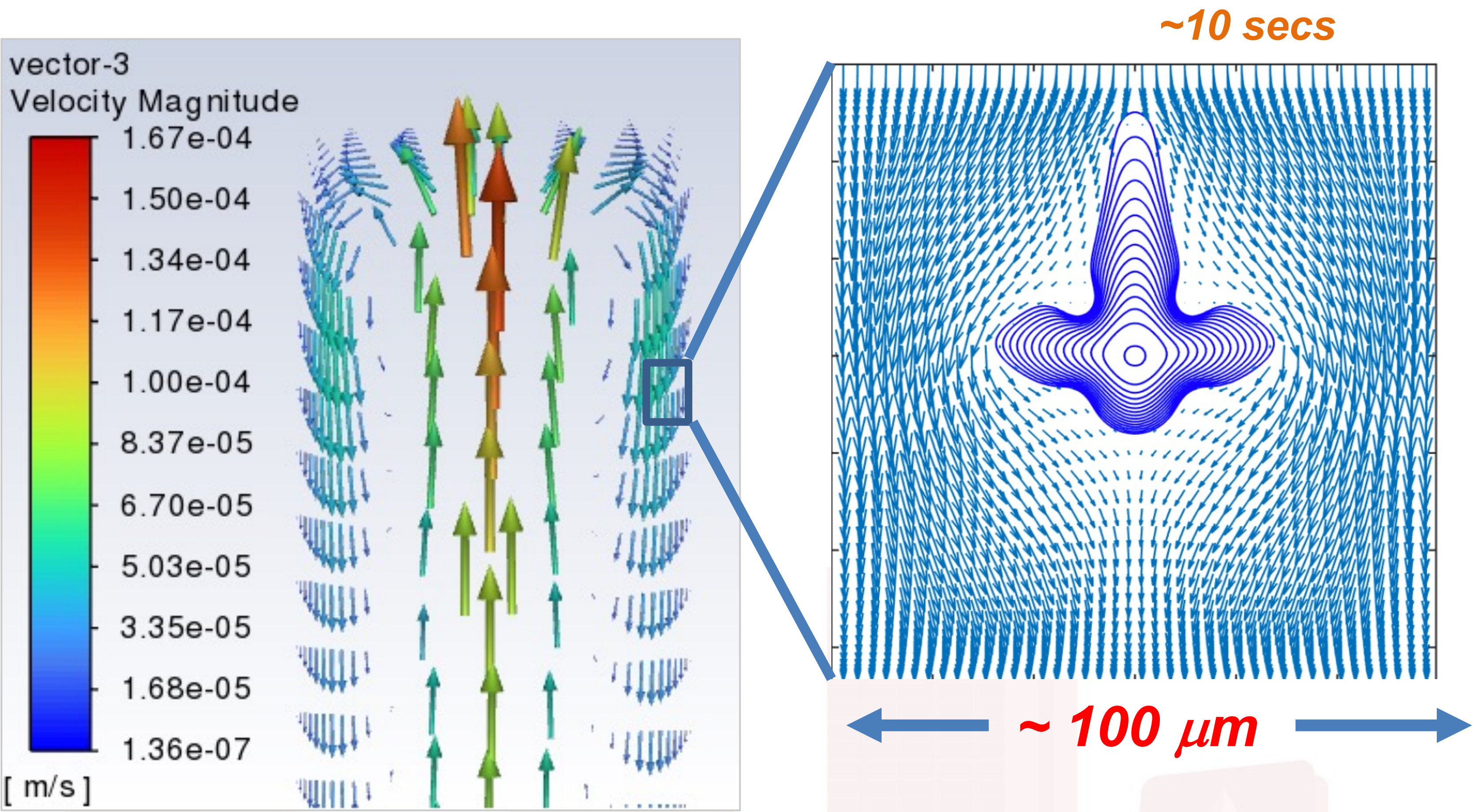
While 1g convection leads to ion velocity vector field, or eddy currents, i.e., curl

Boundary layer where velocity filed contains curl (red circles)



## Gravity & Convection

- Convection - brings fresh solute to the growing crystal embryo
- In micro-gravity, convection is suppressed (no buoyancy)
- Coupling CFD with phase-field for crystal growth under convection flow

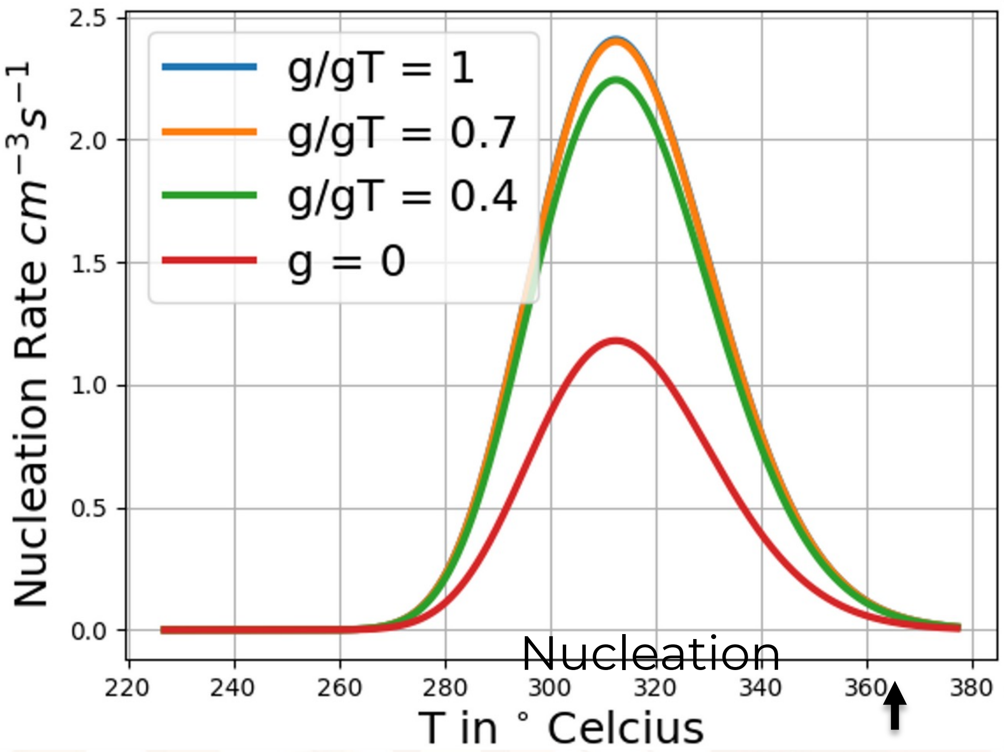


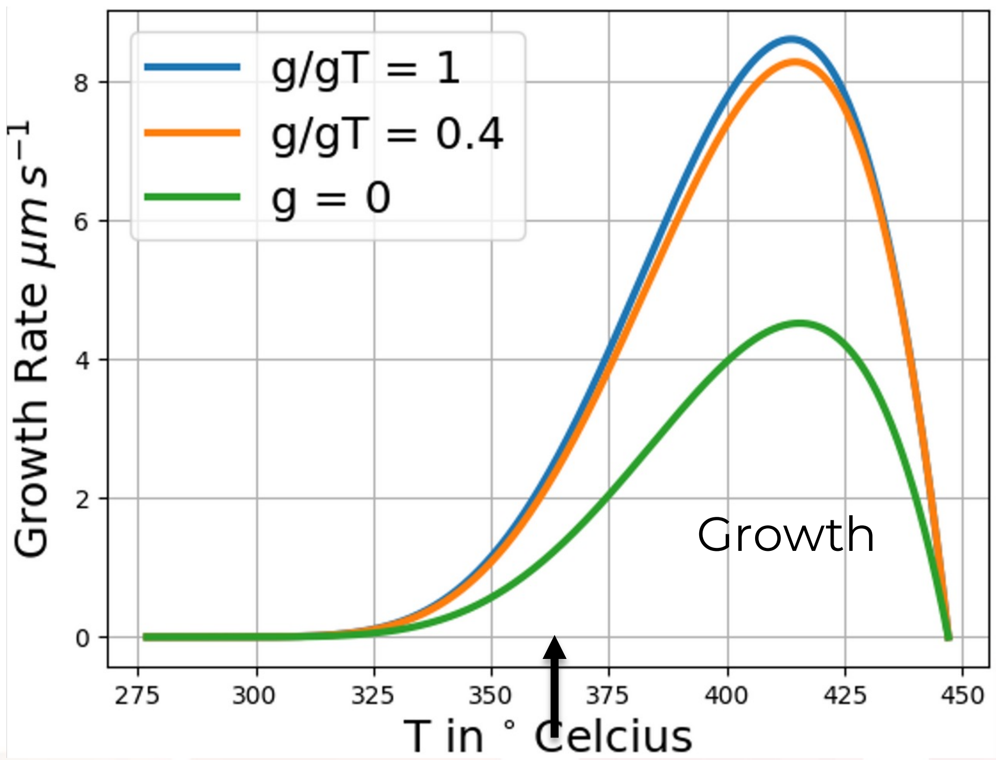

ZBLAN Mold Modeling

# Nucleation and growth (N/G) occur in different temp. ranges

As glass cools from melt, in passes through growth and then nucleation temperatures

Microgravity slows N & G rates (fresh solute is not brought to embryo or crystal)



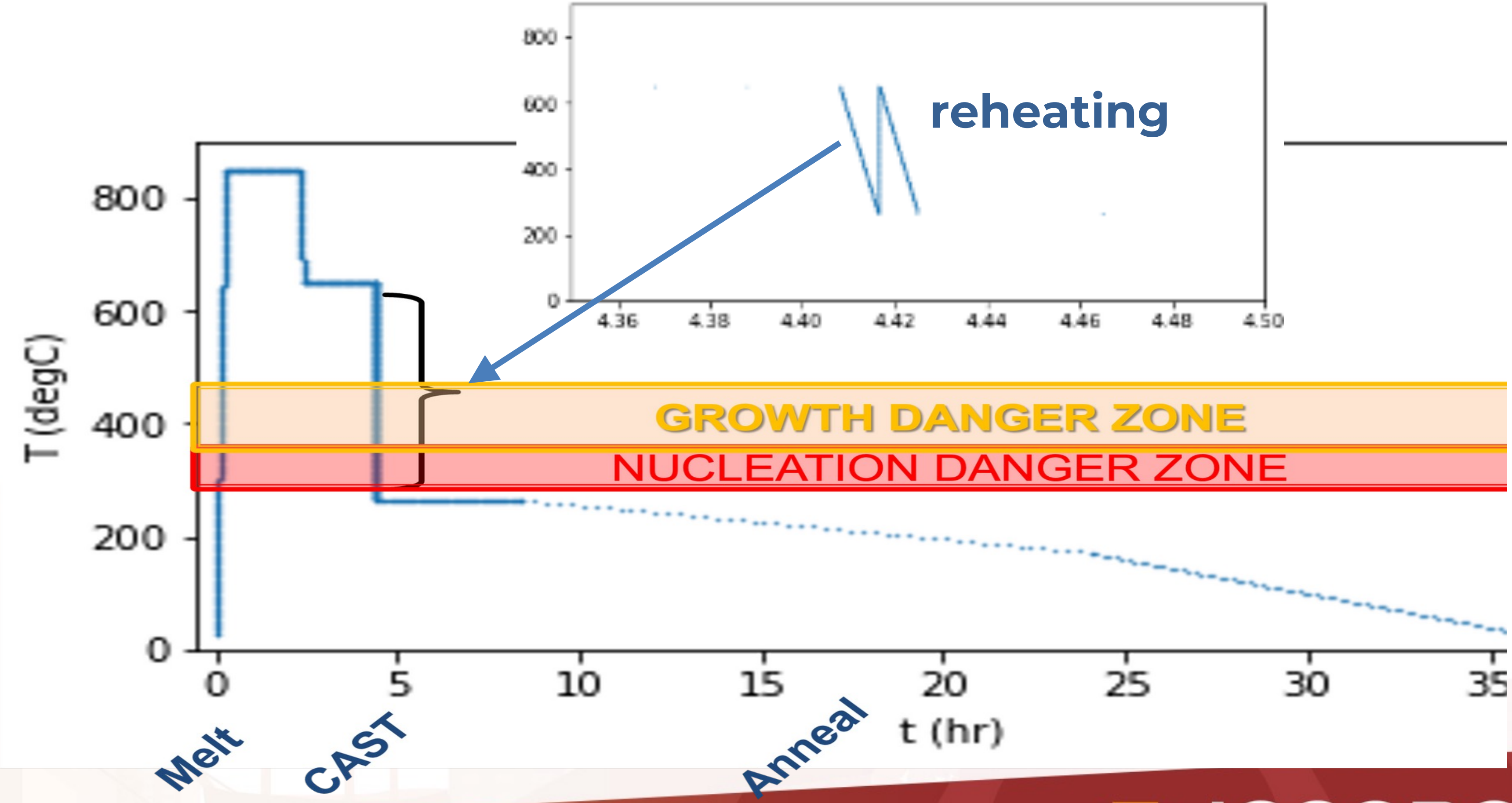




Unit Gravity Model follows Carter, S. F., and J. M. Parker. Glass technology 31.6 (1990): 245-255.

# Primary Defects Form when Reheating

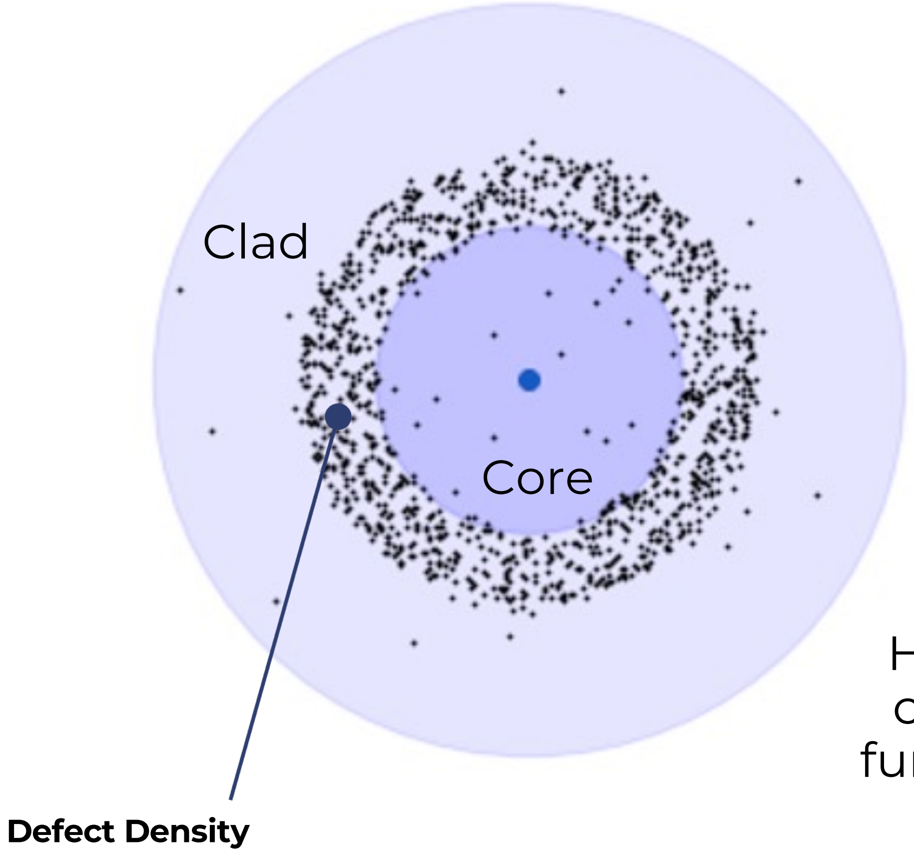
Predicts position, size distribution & volume concentration of defects from thermal profile

Reheating - Glass passes through danger zones TWICE

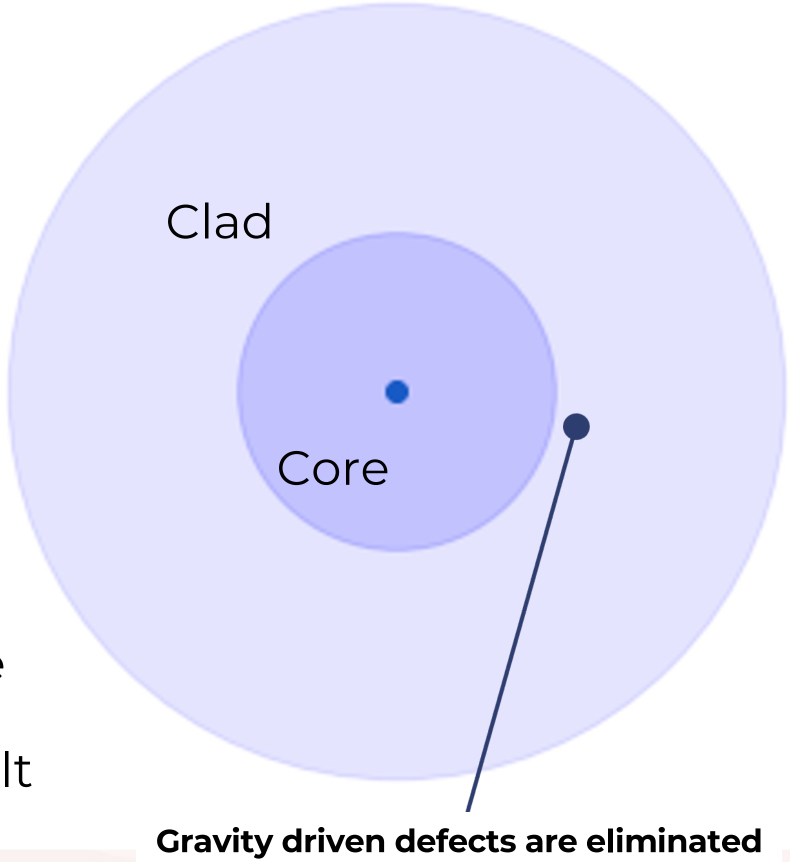


# Microgravity Manufacturing – Eliminates convectional nucleation and growth

Terrestrially Drawn Fiber




Microgravity Drawn Fiber

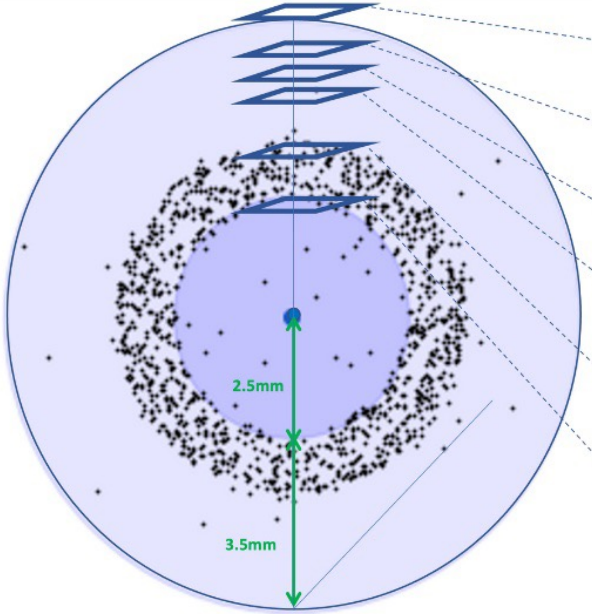



High-performance computing model funded by DOE, built with LLNL SMEs

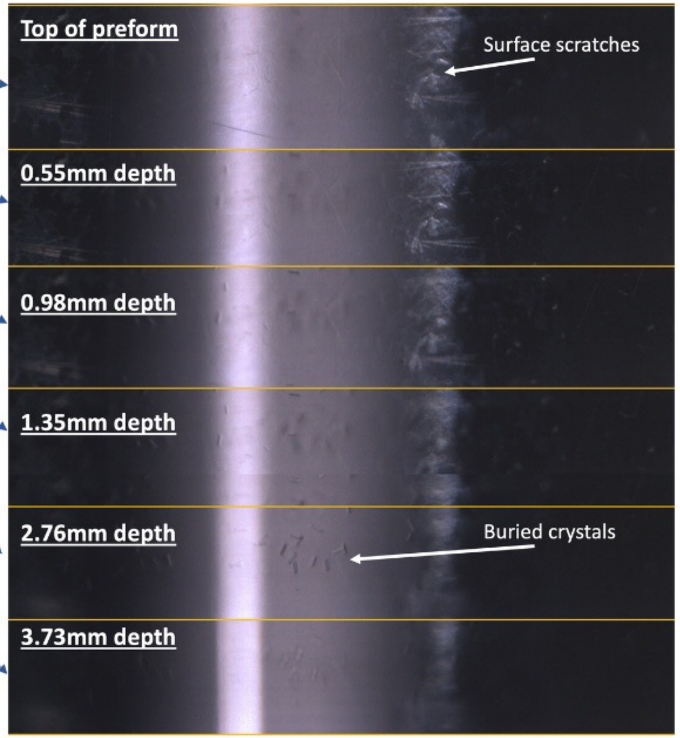
# Initial 1G Model Validation

## Location Validation

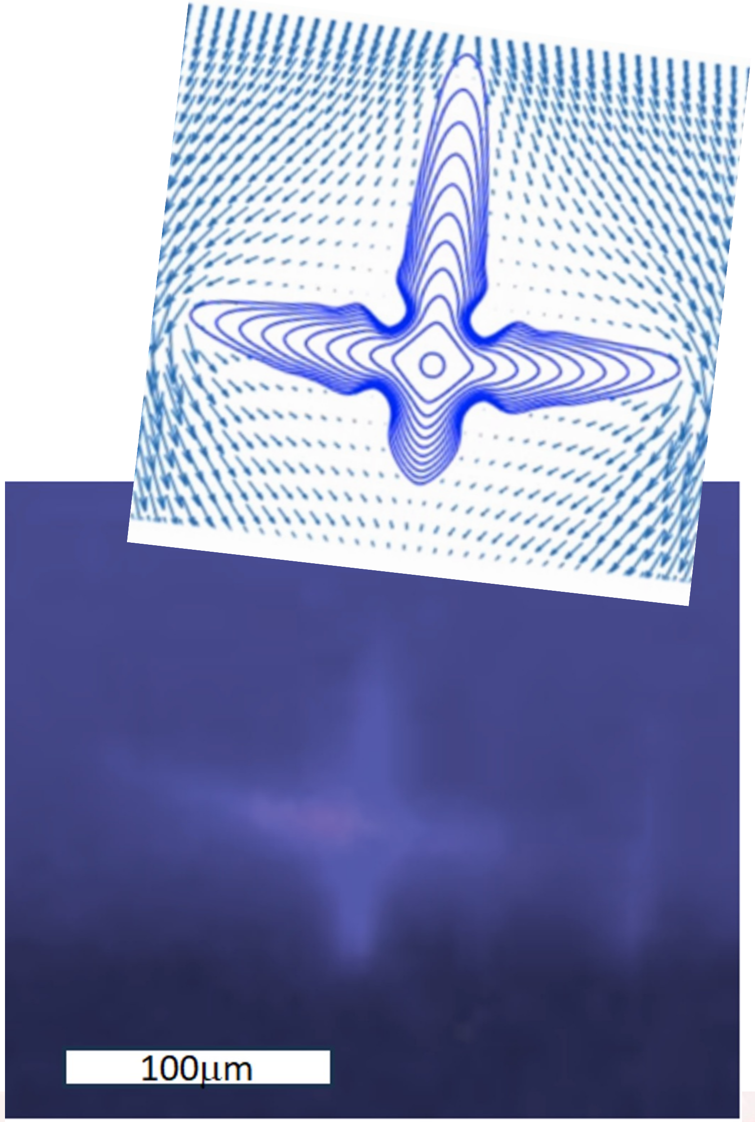
Relative crystal concentration predicted by model:




Micrographs of preform modeled at depths shown




## Defect Shape Validation

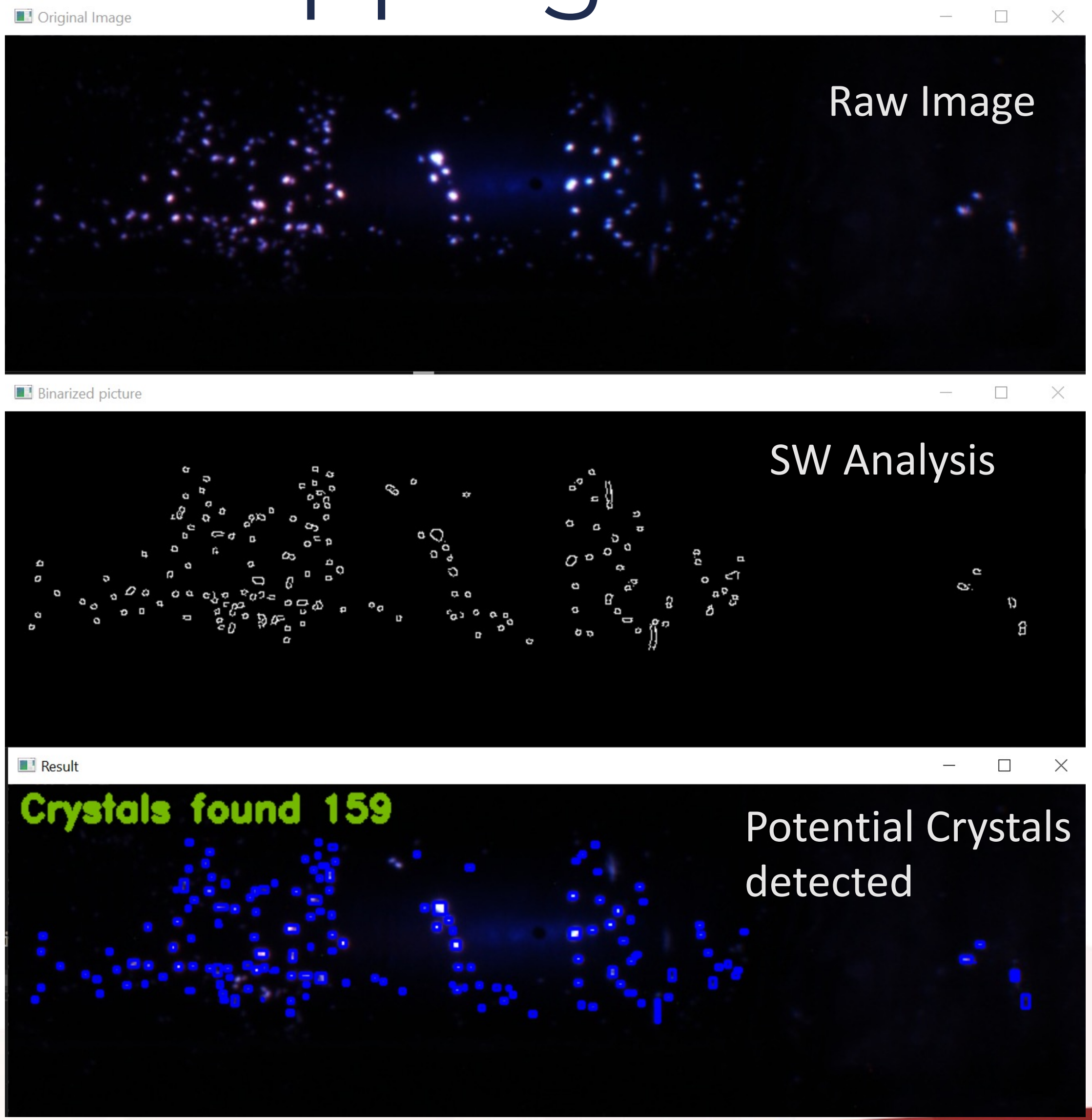


# Developed In-situ defect mapping

For use InSpa Preform Maker

- Crystal image detection
  - Process image by smoothing, histogram analysis, edge detection
  - Classify based on shape and size

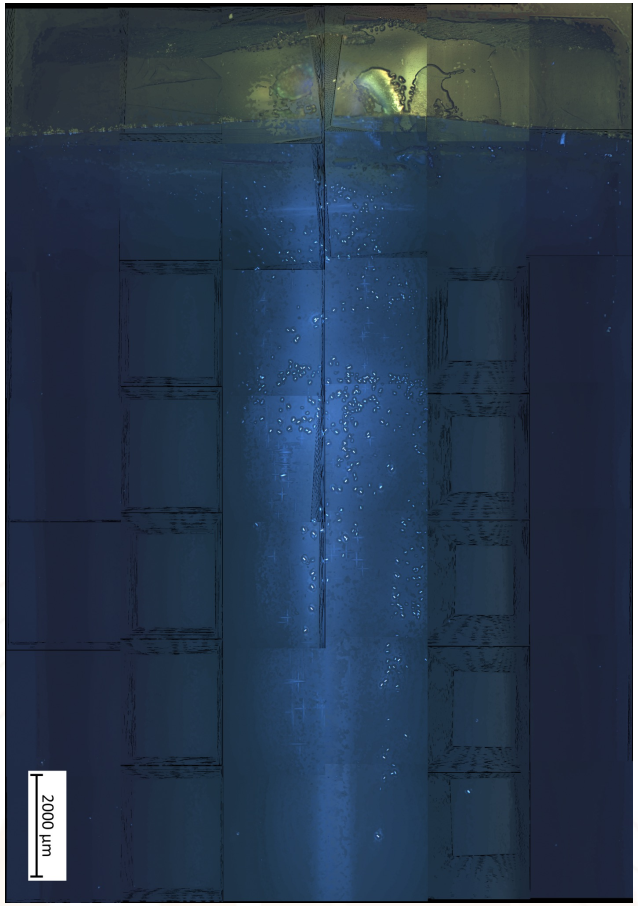
- Developing in-line monitoring to characterize preform during the annealing step
  - Analyze different process recipes
  - Choose the best for final mfg step



# In-Situ Optical Characterization Development

## Optical microscopy analysis of crystals in preforms compares well with in-situ method

Optical microscope reflected light



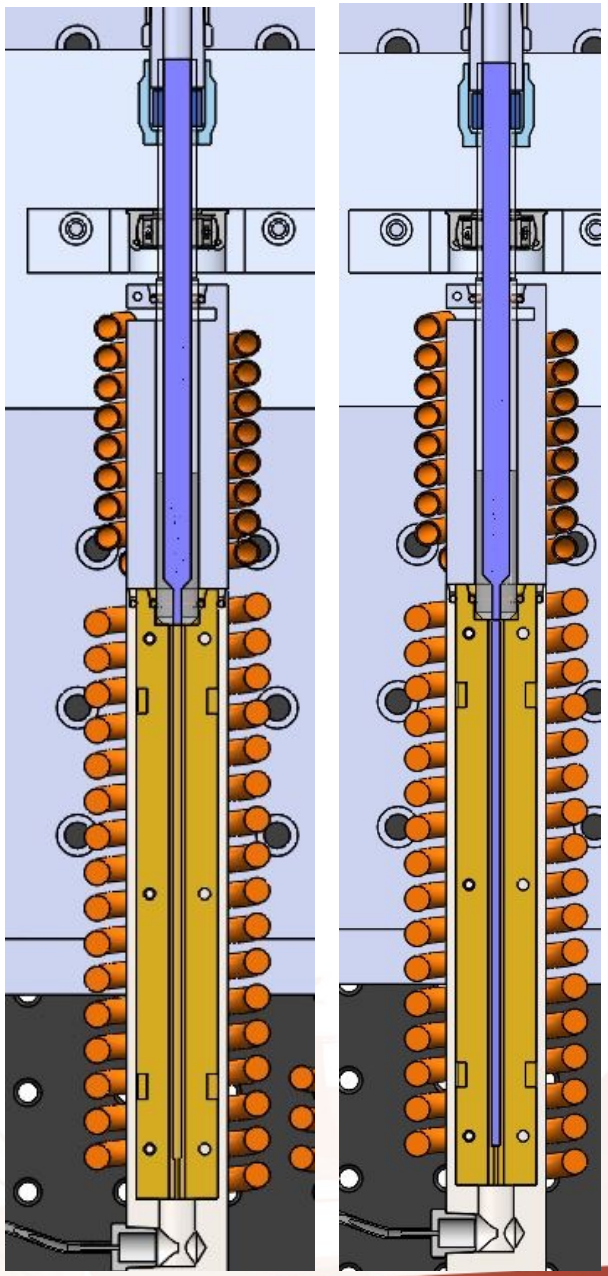

Optical microscope transmitted light

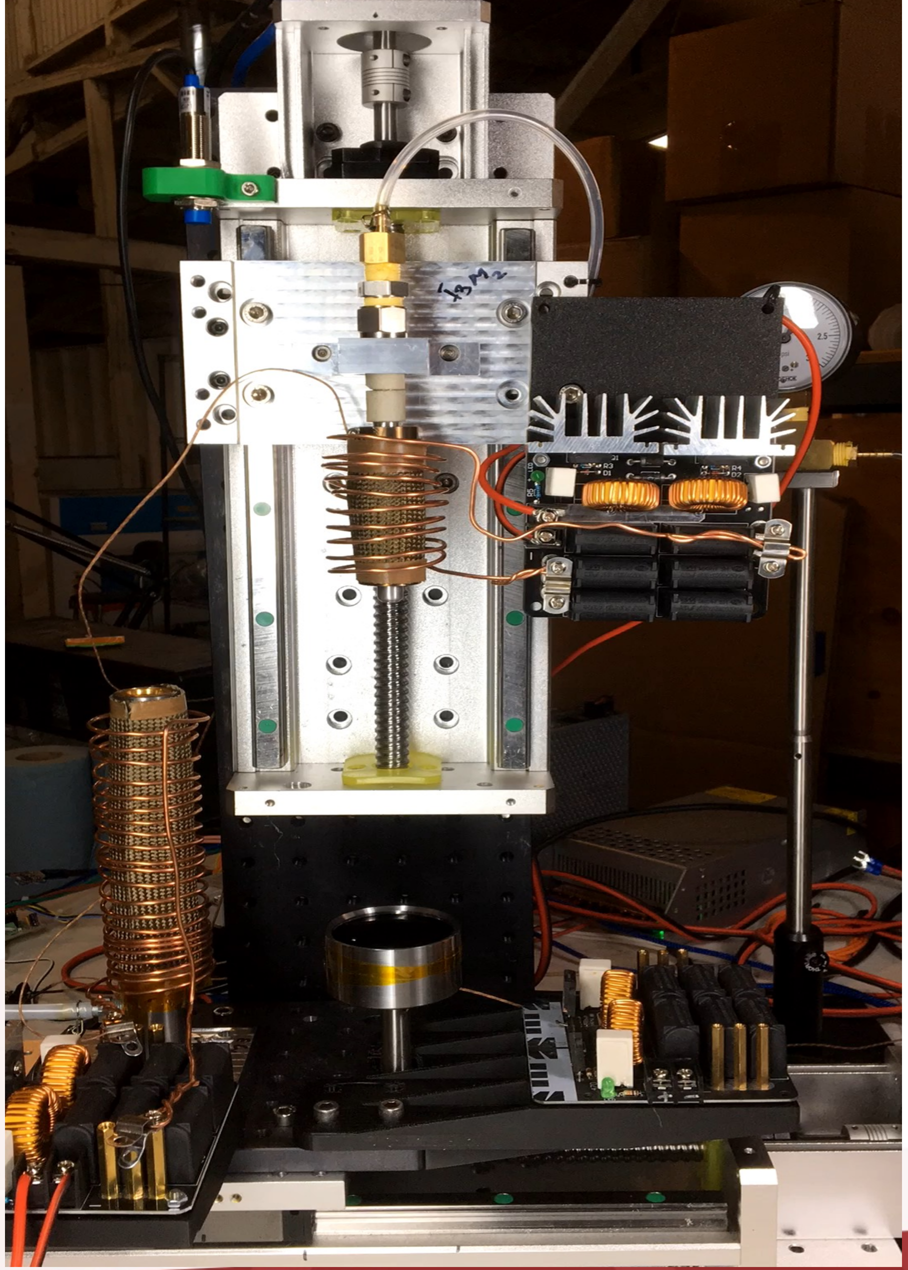

In-situ Method

## Core injection

Goal: Perform reheating in microgravity

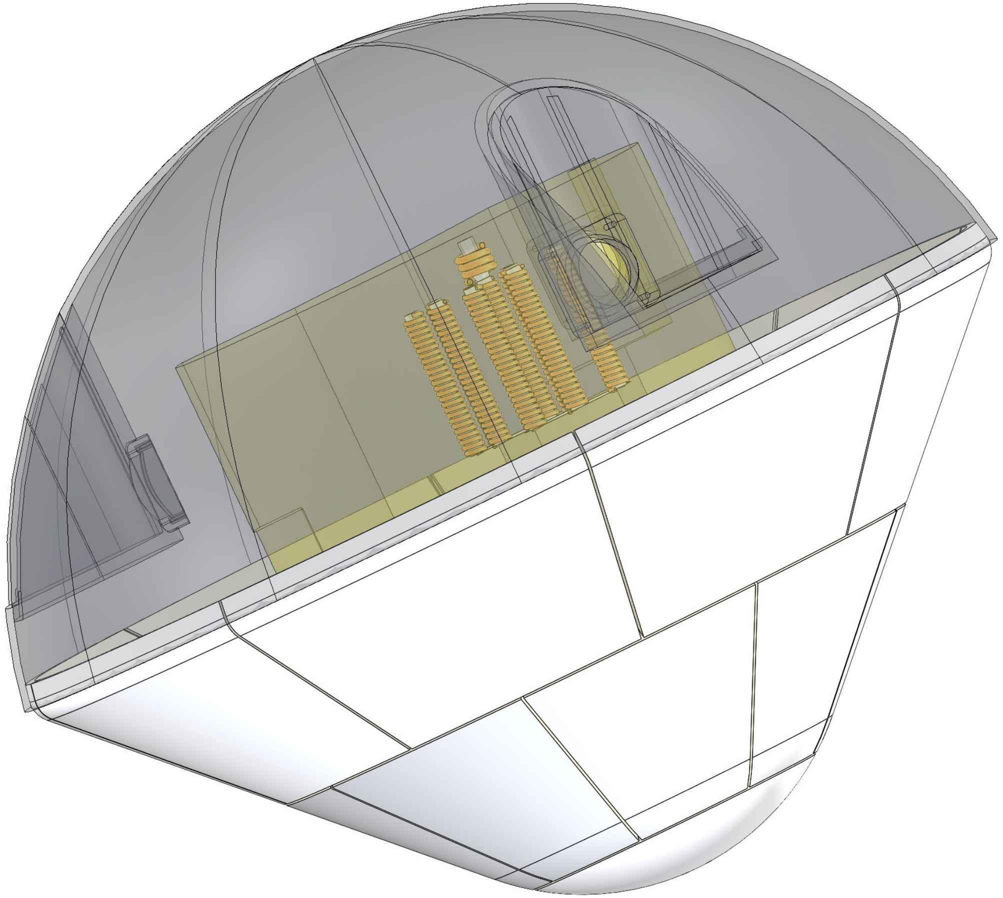
- Melted and injected a plurality of surrogates including tellurite glass
- Next, move to ZBLAN
- Process demonstrated core injection





## Decreasing costs, and increasing reentry cadence make InSPA viable now

Well addressed by the private sector (Varda, Axiom, Orbital Reef, VAST, etc.)



## The Team

# Experts in glass manufacturing, optics, systems, and telecom

Rob Loughan

Founder & President

Michael Vestel, Ph.D.

CTO

David Shoup

CFO/Telco SME

Hubert Moser, Ph.D.

Sr. Dir. Engineering

Alex Hallock, Ph.D.

Dir. Product & Materials

Heike Ebendorff, Ph.D.

ZBLAN SME & Advisor

SRI International

Berkeley UNIVERSITY OF CALIFORNIA

Stanford University

THE UNIVERSITY of ADELAIDE

OHB LUXSPACE

Lawrence Livermore National Laboratory

## The Current Capabilities

# Expertise in Automation, Material Processing, Glass Science

**Growing from 13 Ph.D.s & 24 Total Technical Staff**

| R&D Focus | Capability | Team (FTE/PhD) |
|---|---|---|
| Process Development | Making glass on a small scale | 4/3 |
| Automation | Single preforms<br>Drawing fiber<br>Fiber QC | 18/7 |
| Purification | Sublimation<br>Chelation, test quantities | 6/6 |
| Spaceflight | Fiber drawing,<br>Preform on ISS | 15/5 |
| Products | Dark comms,<br>Lasers,<br>Prototypes | 3/2 |

→

| Expansion |
|---|
| Increase glass from 100s of grams to kg |
| Highly automated processes, multiple preforms in parallel |
| Dedicated purification facility (kg / week) |
| Equipment permanently in orbit |
| Disrupting the market |

## Thank-you to our Partners

Actively delivering to our government customers

NASA In-Space Applications

DoD - AFWERX

European & Luxembourg Space Agencies

Australian Research Council

DoE High Performance Computing

CASIS Integration & Flights

Advanced MFG

# The Future of Optical Fiber – Made in Microgravity

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Chief Technology Officer

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