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Advancing Space Power: XTE+ 3J Technologies and Site-wide Manufacturing Innovations

Christine Y. Wang, Philip Chiu, David Nguyen, Angelica Davancens, Tiffany Quach, Christopher Fetzer, and Daniel Law

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Outline

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- **Spectrolab Introduction**
- **32.6% XTE+ Qualification**
  - XTE+ variants: GEO / LEO advantages
  - Qualification of panel adhesive
- **Quadruple Junction (QJ) Cell Development**
- **Factory Modernization and Improvements**
  - Automated 2D welder for CIC assembly
  - Automated coverglass bonding tool
  - Robotic system for adhesive dispensing and trimming
- **Summary**

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Spectrolab Introduction

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- **Spectrolab, Inc. : Founded 1956, Sylmar, CA**
  - **70th anniversary**: employee pride, customer loyalty
  - Boeing subsidiary; 260+ employees; 180,000 ft^2 on 6 acres
  - Historical leader in US space solar cell manufacturing
  - Footprint in commercial, DoD, NASA/Civil, and proprietary
- **2025 Highlights**
  - Qualified XTE+, automated CG bonding tool, new panel adhesive
  - Expanded solar power module (SPM) assembly
  - Over 98% on-time delivery, quality, performance
- **2026 Future**
  - QJ entering qualification
  - Automation in modular panel assembly
  - Alternative panel substrates: Kapton & FR4 SPM, 3D-printed wing

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Product & Technology Roadmap

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Online now

Coming Soon

Cells

- XTE+ 32.6% (3J) ✓
- Quad Junction (QJ) High V Cell
- Cell w/ Co-Planar Diodes

Assembly

- Partial Automated SPM Assembly / Inspection ✓
- Rapid Cure Adhesive ✓
- Rapid Modular Assembly / Alternate Substrates
- Turn-key Wings (1-2kW to larger solar arrays)

Expansion

- Additional Factory Capacity through CIC / SPM
- Whole Factory Capacity Expansion

2024	2025	2026	2027	2028	2029

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Scope of XTE+ Products

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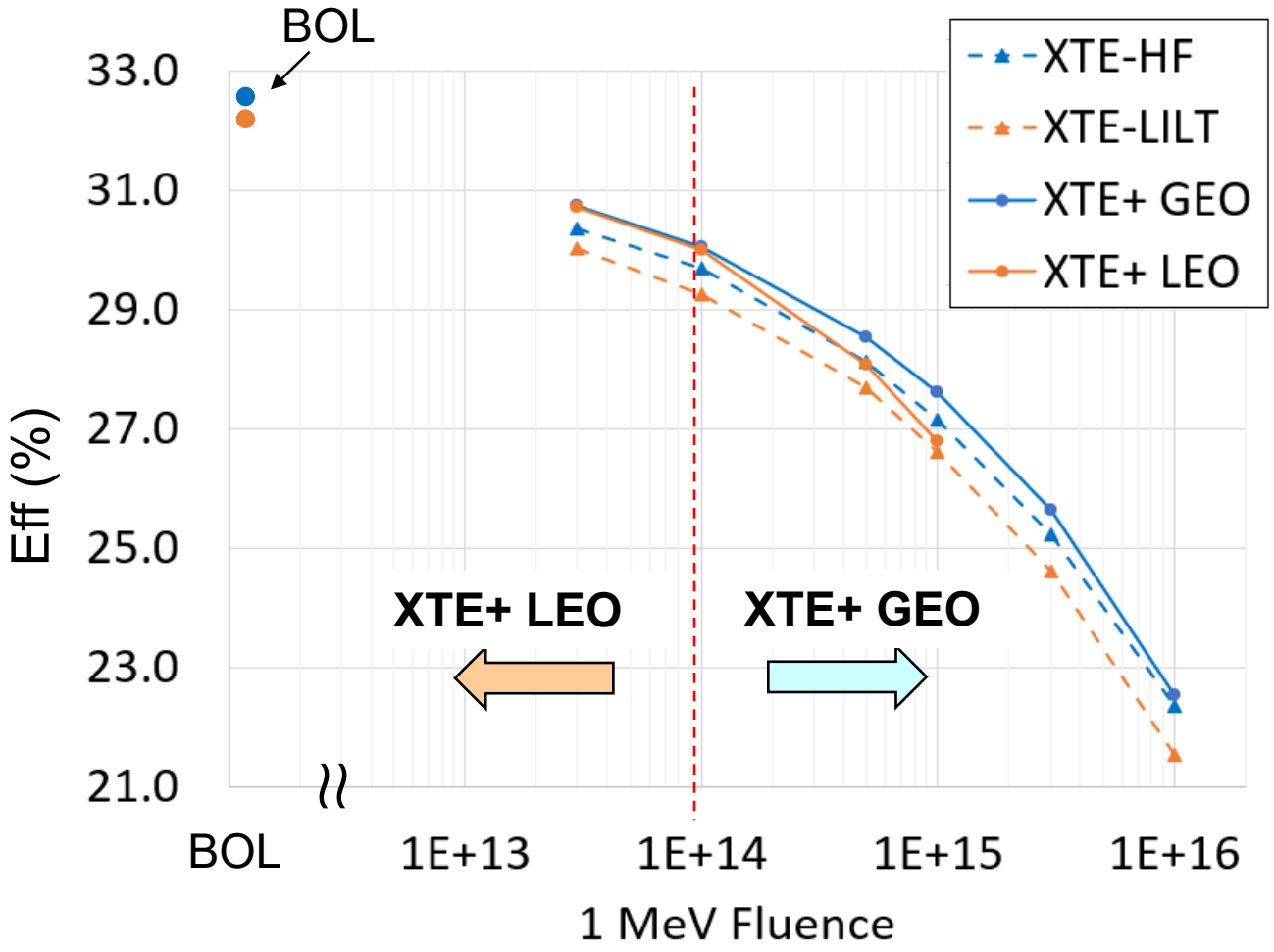
- XTE+ is a family of two **3J** products optimized for different environments

Product name	Fluence (1-MeV e^-/cm^2)	Application
XTE+ LEO	≤1e14	LEO constellation
XTE+ GEO	>1e14	Traditional GEO and MEO

- Improved wafer process flow, increased throughput, lower cost
- Fully qualified to AIAA S-111-2014 standard
- In production, available cell size 27 – 80 cm^2



XTE Plus offers 2-3% efficiency boost over XTE in both BOL and EOL

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XTE+ GEO Electrical Characterization

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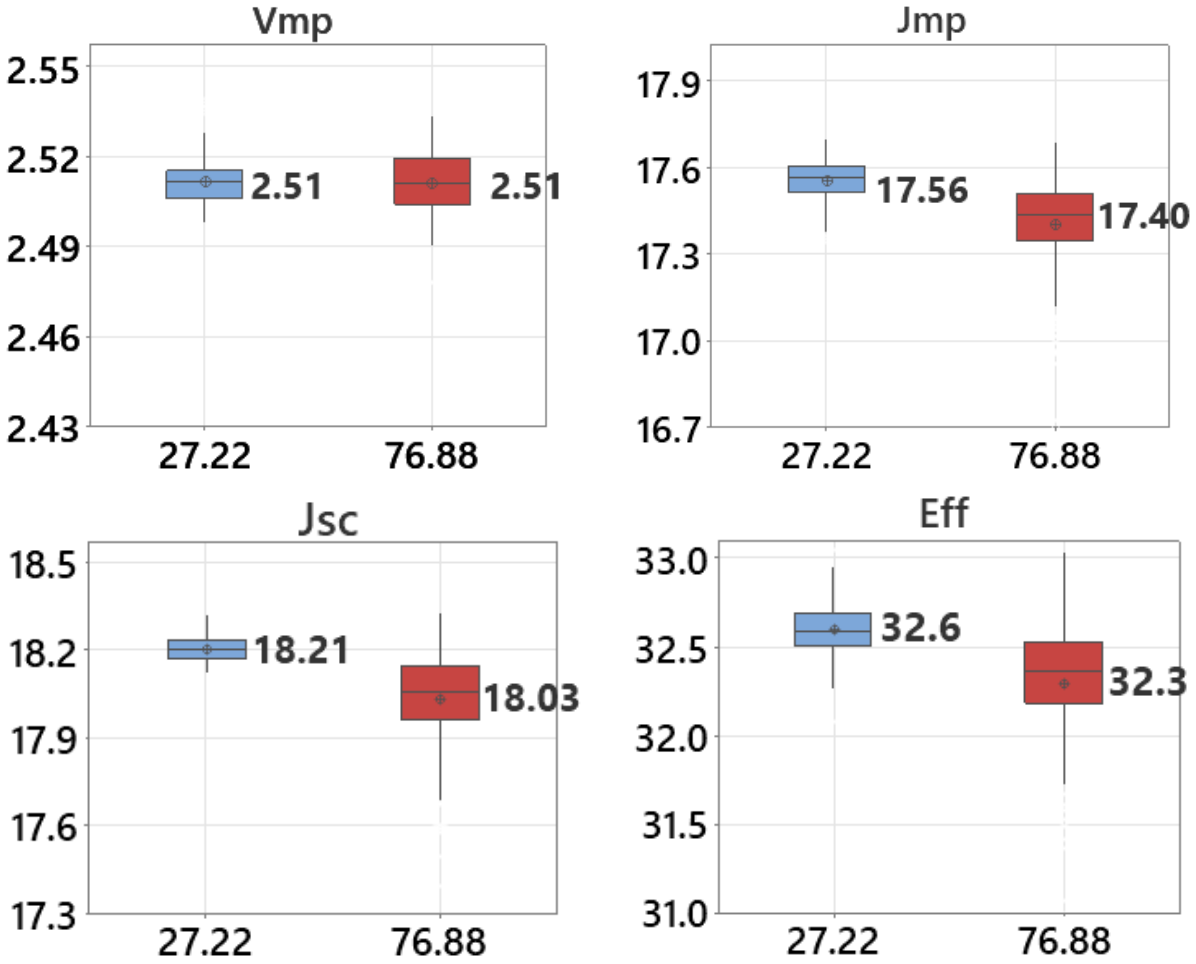
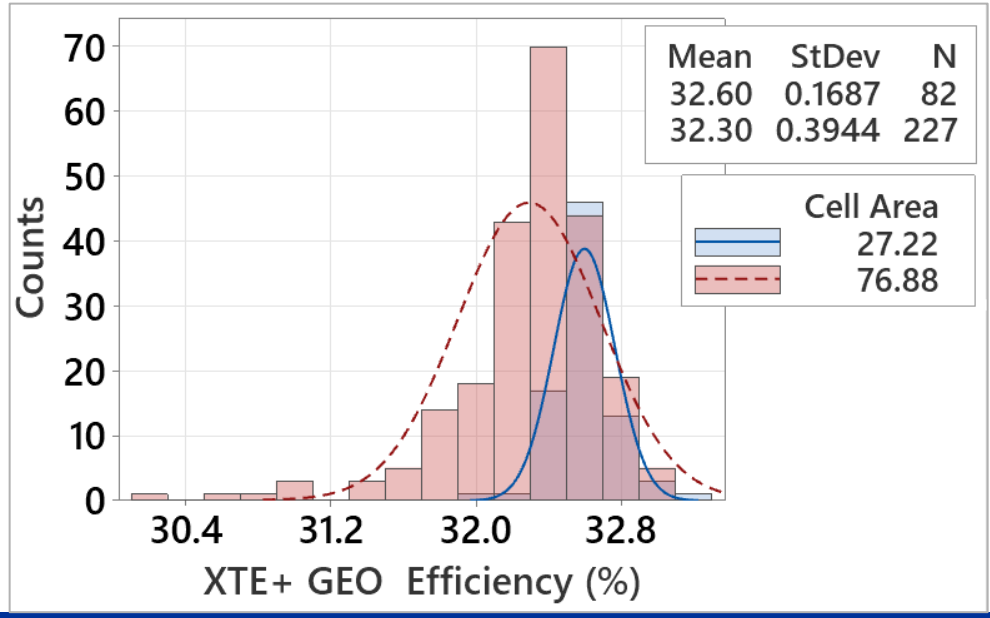


- 27.22 and 76.88 cm^2 cells were used in the qual
- XTE+ GEO has a median cell efficiency of **32.6**%. Compatible current density.



XTE+ GEO achieves 32.6% BOL efficiency: Industry leading

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XTE+ LEO Electrical Characterization

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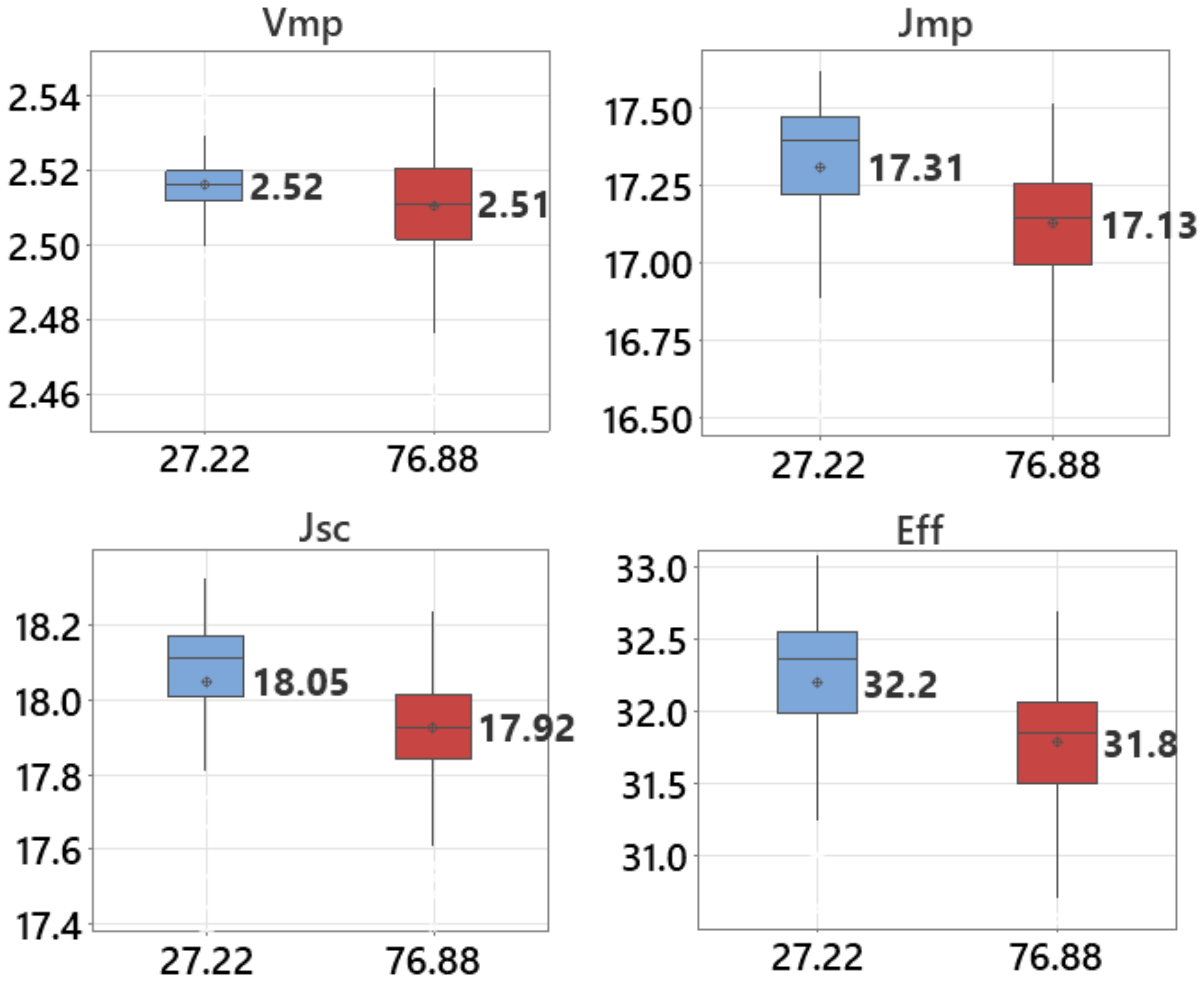
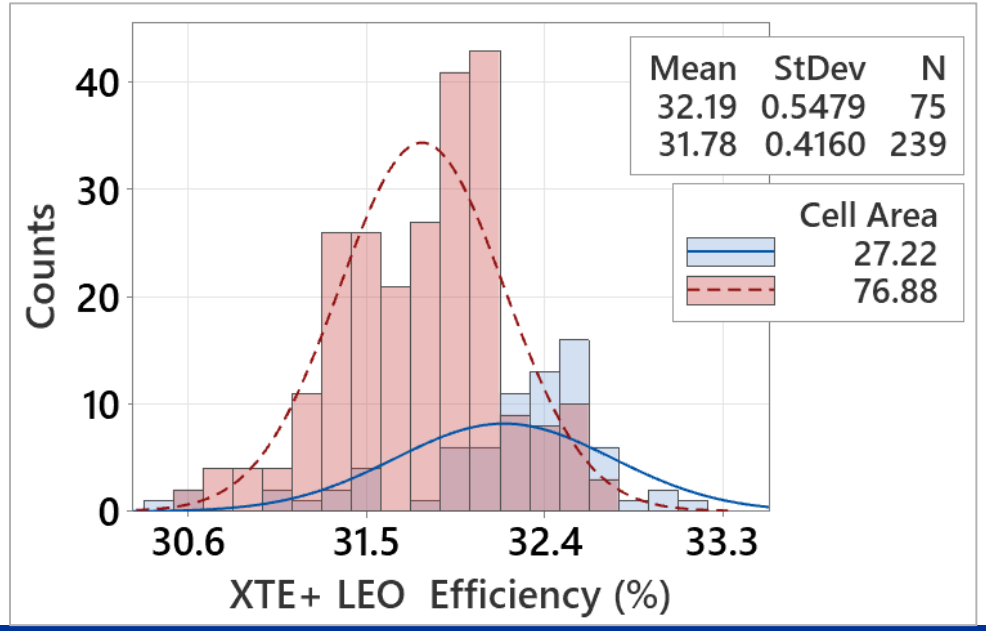


- Designed with LEO constellation in mind
- Lower cost option for low fluence applications
- BOL efficiency is **32.2**%



XTE+ LEO achieves 32.2% BOL efficiency with lower cost

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Environmental qualification details

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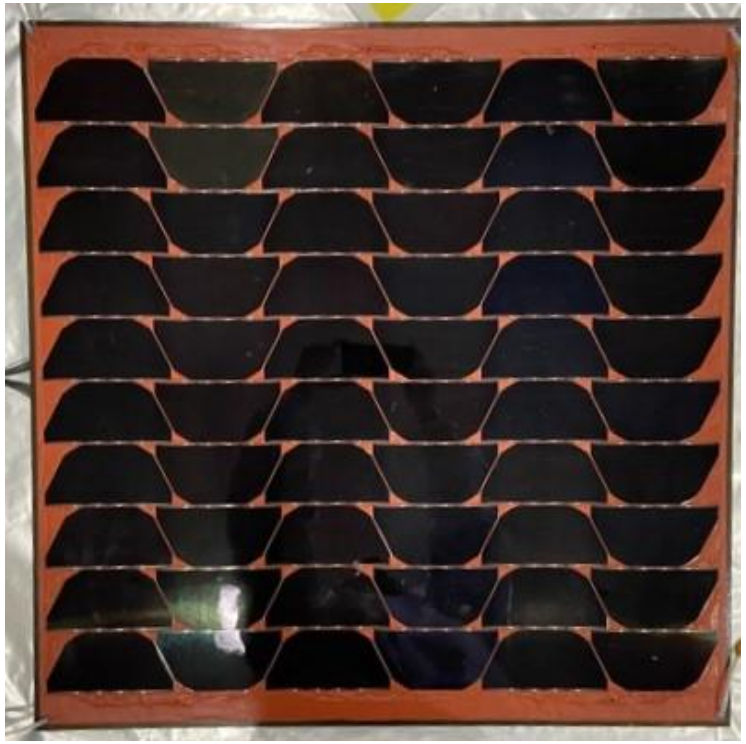
- Multiple coupons were made in the qual event.
- Ambient thermal cycling (**2000 cycles**, +140°C –175°C)
- Thermal vacuum cycling (**8 cycles** +140°C to –175°C)
- Cycling **test breaks** at 100, 1000, 2000 cycles, and after 8 cycles of TVAC
- **LAPSS** at 28°C and 80°C

- Passed visual inspections at each test break and passed all test events for LAPSS.



XTE Plus passed gate review for product qualification, ready for production

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Qualification of New Panel Adhesive

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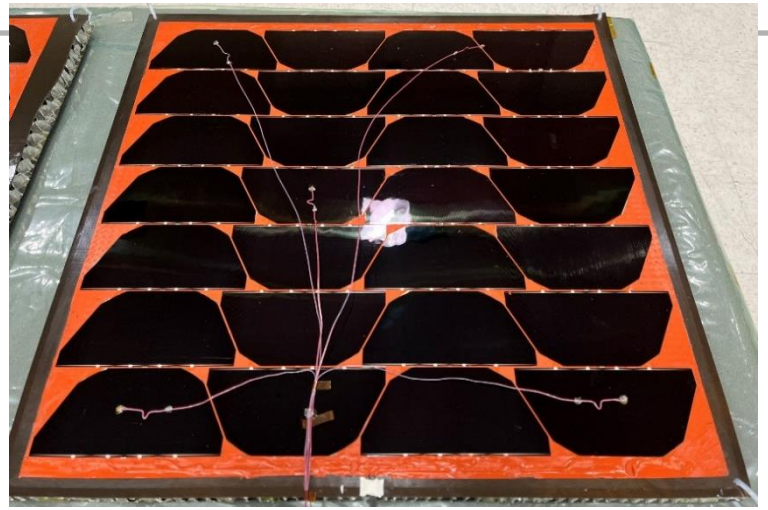
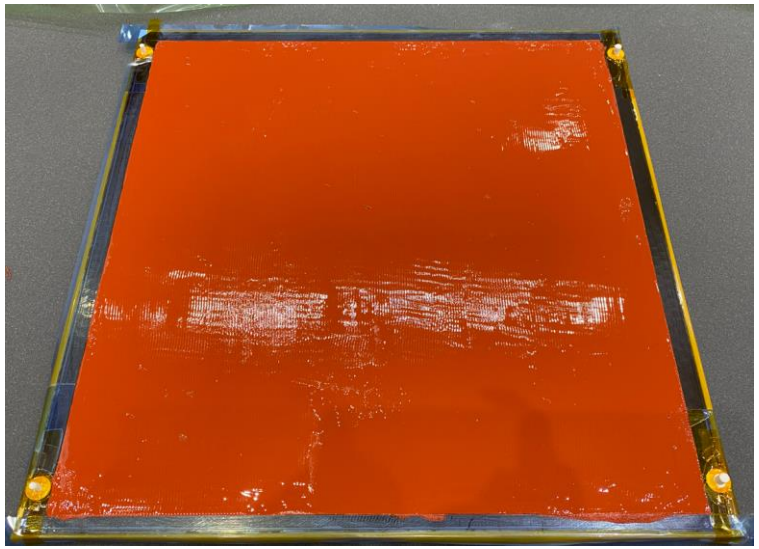
- New panel adhesive provides a **major cycle-time benefit** versus heritage process. Cure-time reduction of **>90%**.
- **Qualification test** performed on rigid and flex/SPM coupons for full and patterned bond, as well as backside component configurations, all passed required evaluations.
- **ESD testing** of aged coupon showed no Permanent Sustained Arc (PSA) in fully grouted adjacent-string gaps up to 110 V and 2.8 A.
- **Post-ESD testing** showed no measurable change in Isc, Pmp, DIV response, or insulation resistance.





New adhesive passed qualification and ready for production use.

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Large-area QJ Cell Test Build – Cell Performance

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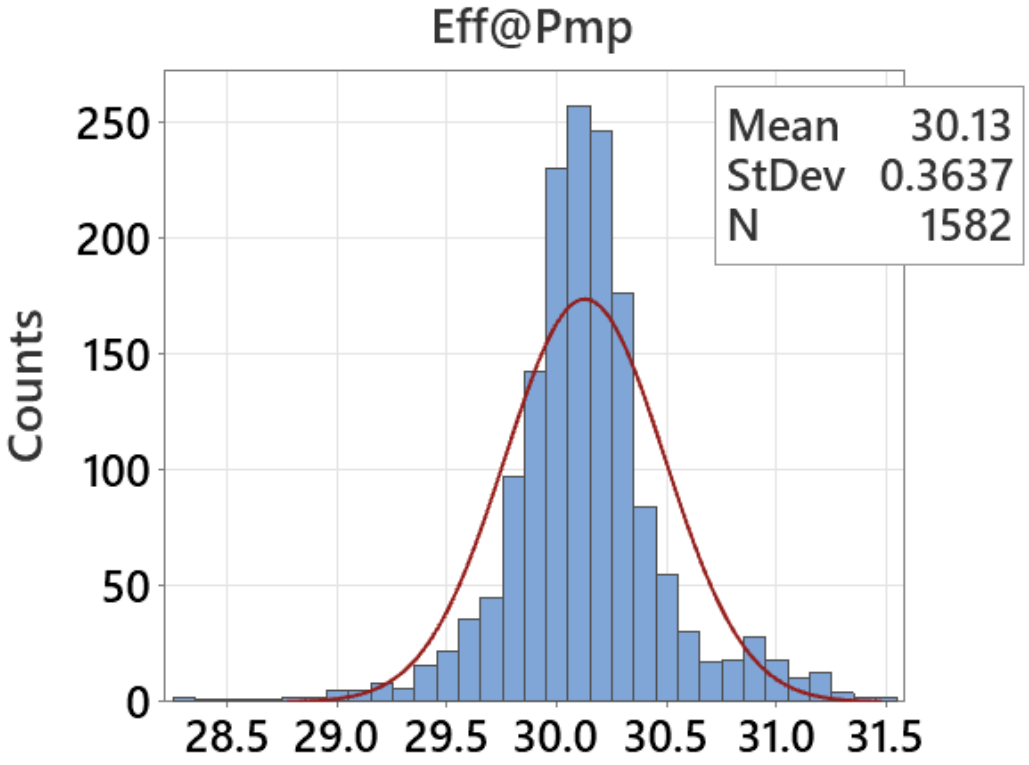
- Specialize in **high V**, small area, low ESD applications
- Built with XTE+ wafer process
- Large area QJ cells (27.22 and 76.88 cm^2) averaged 30.1% BOL efficiency

Voc	Vmp	Jsc	Jmp	FF
4.059	3.691	11.597	11.041	0.866

- Nominal LIV performance observed when subject to all space standard inspections and testing
- Working on full qualification to AIAA S-111-2014 standard by 2027



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Cell w/Co-planer Diode + Automated Welder

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- From prototype to new product (2027)
  76.88 cm^2 cell with co-planer diode.
  - New tooling
  - New process flow
  - Coupons for thermal cycles

- Multiple modules, 2-dimensional welding for front side, back side, and diode welding
- 3x throughput capacity increase
- Reduce labor content
- Plan to complete system build and software integration for acceptance test in 4Q2026

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Automated Coverglass (CG) Bonding

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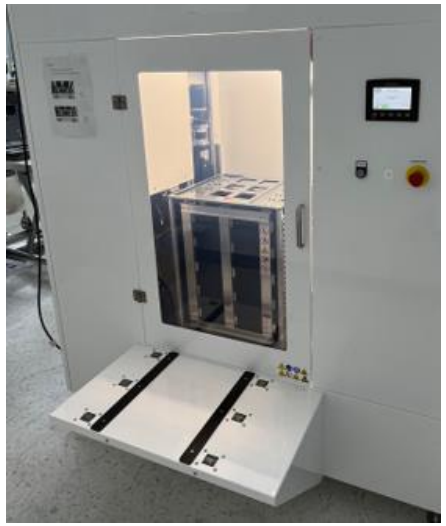

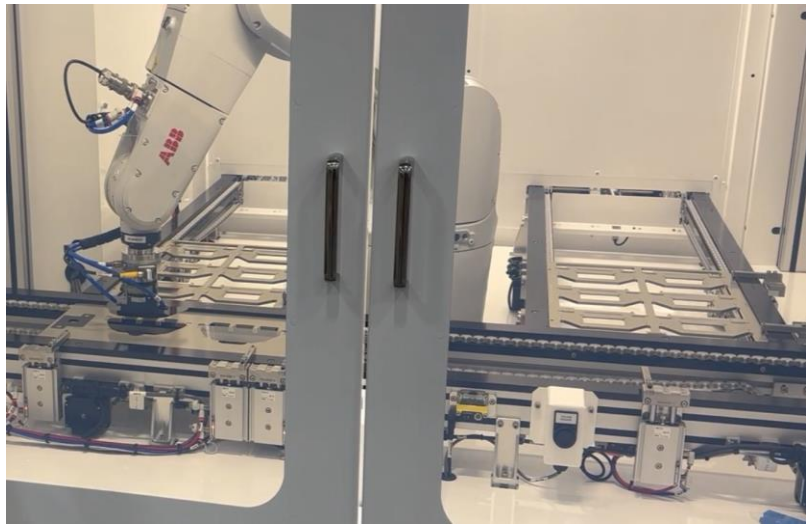

Automated Parts Loading → Automated Dispensing (Two dispensers) → Automated Bonding (Two bonders) → Cure and unload

- More controlled adhesive mix/dispense
- More consistent bonding thickness and cleanliness
- Reduction of labor hours and FOD related attrition

Started pilot production runs in Dec. 2025 with a ramp up to gain experience.

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Automated SPM Trimming and Adhesive Dispense

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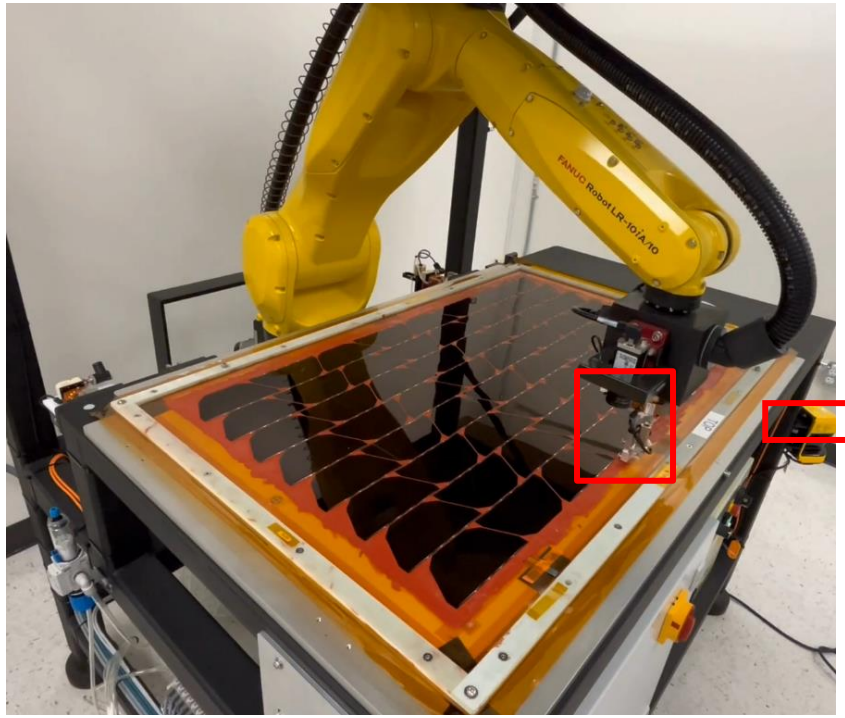
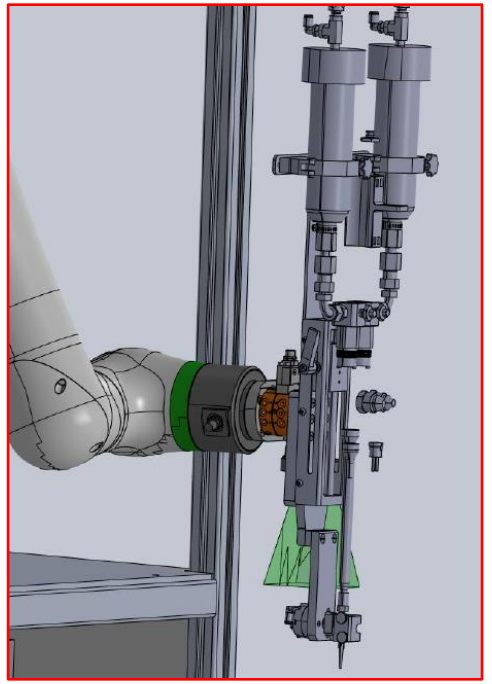
- One robot arm platform, dual end effectors for dual purposes:
- Offers accuracy in robot movement and vision system
- On site 3Q 2026



1. **Trimming**
   - Process time reduction
   - Enhanced safety

2. **Adhesive Dispensing**
   - Accurate dispense pattern
   - Mix-on-demand



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Summary

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- Spectrolab has fully qualified our XTE+ 3J solar cell product.
  - XTE+ GEO achieved BOL efficiencies of 32.6%, providing a 2–3% relative improvement over the legacy XTE cells.
  - XTE+ LEO is a lower cost option for low fluence applications.
  - New panel adhesive enabling significant cycle time reduction.
- Early QJ cell builds showed consistent electrical performance across different cell sizes. Cell with co-planer diode is on the way.
- Spectrolab is also advancing factory automation through coverglass bonding, CIC welding, and robotic trimming / adhesive dispense.

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Acknowledgements

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- Many talented hands make this all possible. Thank you to all the talented technicians, engineers, and leaders at Spectrolab
- Thank you to Boeing for enabling Spectrolab to drive the leading edge of Space PV
- Thank you to the AFRL, Space Force, the Title-III Office, and the Aerospace Corporation for their collaboration on developing the future of Space PV

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