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Spectrolab's Pathway Forward:
Modular Solutions for Bespoke Space Power Needs

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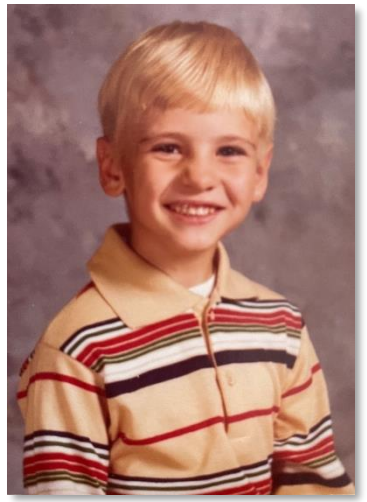
Outline

- A Bit of History
- Spectrolab's Historical Focus / Pathway Forward
- Roadmap
- XTE and XTE-PLUS Family Adoption
- Quad Junction (QJ)
- Solar Power Modules
- Applying Six Sigma to Panel Assembly
- Extending SPM to Concept to More Environments
- Accelerating Production
- Conclusions



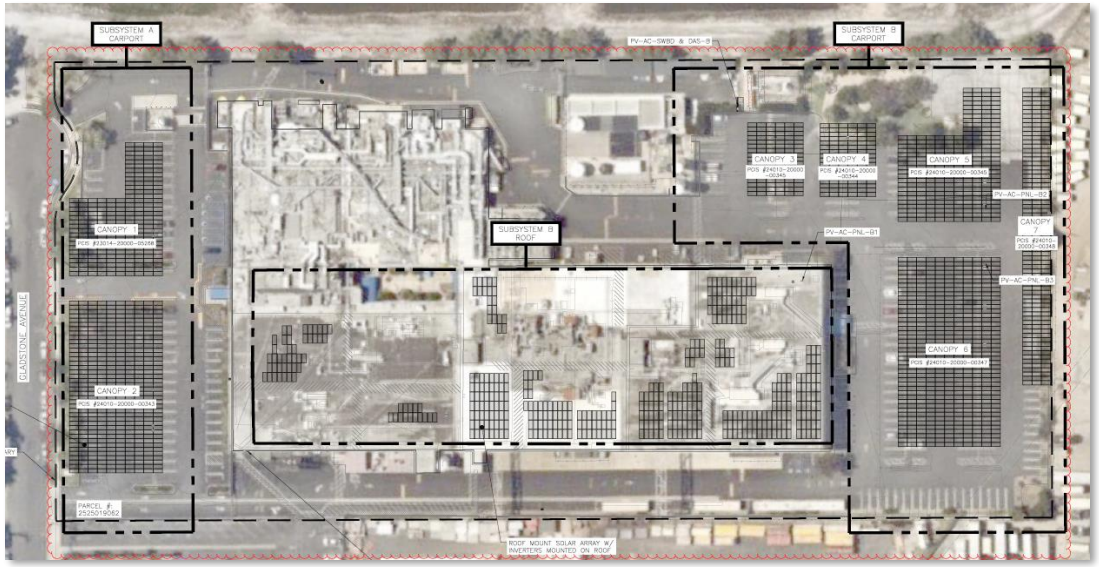
Me: Age 5, 1st grade (1977)

Our Vision:
To power a brighter future for humanity through reliable and innovative solutions for the exploration and protection of Earth and Space.

A Bit of History

Bill Yerkes: Spectrolab president (‘72-’75) and creator of the solar module and many influential solar technologies and companies (1934 to 2014)*

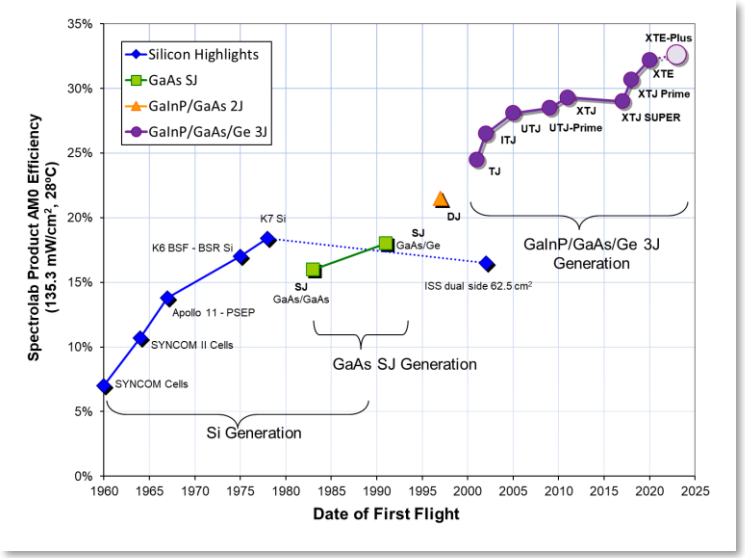
- Low-cost, durable module of PV cells and Al screen printing of cells
- Modularity is key to terrestrial PV adoption
- Space PV industry has pursued customization rather than commoditization
- Modules returning to power Spectrolab



1.3 MW_{DC} ground mount system being installed in Sylmar
2,225 solar modules, ECD Q4-25

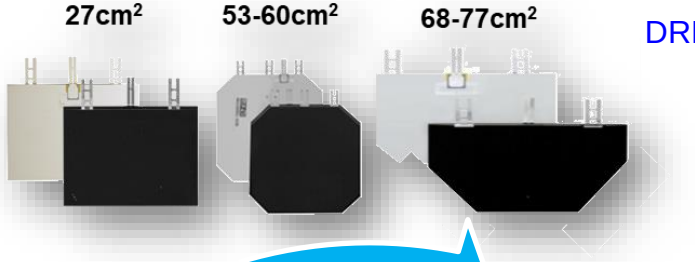
*From Space to Earth: The Story of Solar Electricity (Perlin, 2002)
Photo from Santa Barbara Independent, accessed 3/25/25

Spectrolab's Historical Focus



Deep cell development knowledge

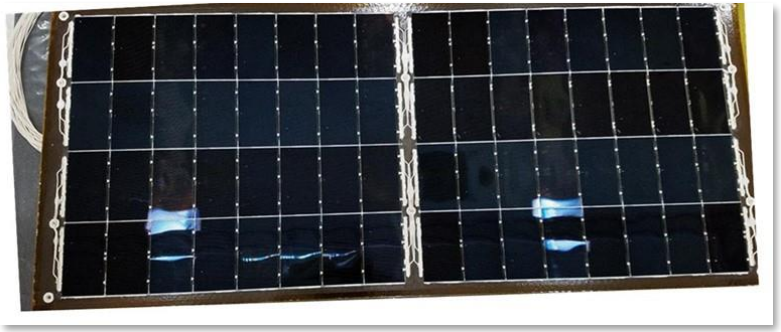
Wing assembly capability to >30kW/SS



Fungible Cells/CICs

High Reliability Testing

DRB & Automated inspection on every cell; defect tracking



Extensive qualification & flight heritage designs
Up to 88,000 thermal cycles,
LEO.GEO, MEO, Interplanetary orbits

High Power per unit area, custom panels

Proven processes, people and validation in and post-process

Delivering power as promised on orbit

Increased Cell Efficiency

Historical efforts for high reliability and maximum power delivers highly tailor-made products

Space PV is a Bespoke World Evolving Toward Commoditization

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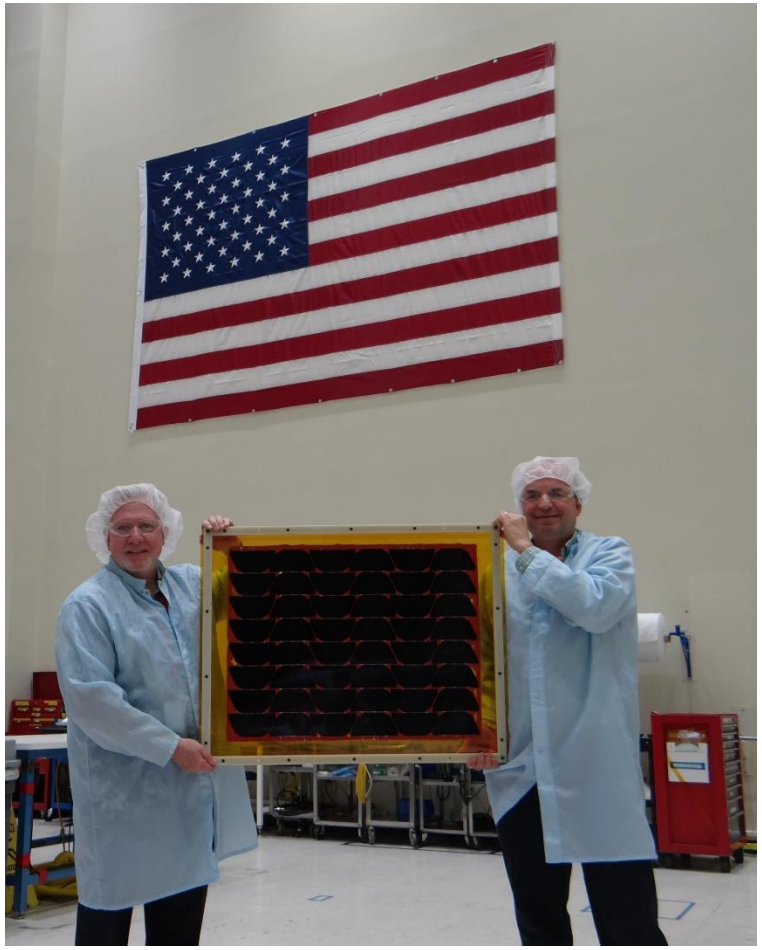
- The market is changing and now is valuing faster acquisition
- Modularity at higher levels in assembly; Solar Power Module (SPM)
- SPM Design:
  - Human scale, modular build of strings of cells on a membrane
  - Interchangeable
  - Attachment to flexible or rigid substrates
  - Integration step after string build; parallel manufacture
  - Decreases time and cost to build standard units
- Delivered over 310 kW with 177 kW in orbit; >2000 flight SPMs produced
- Today, few wing designs built around SPM/string modularity; many more emerging



ISS SPM (~143W BOL, 28C) of
42 XTJ Prime Cells

Spectrolab is designing our factory around SPM based solutions going forward

Product & Technology Roadmap

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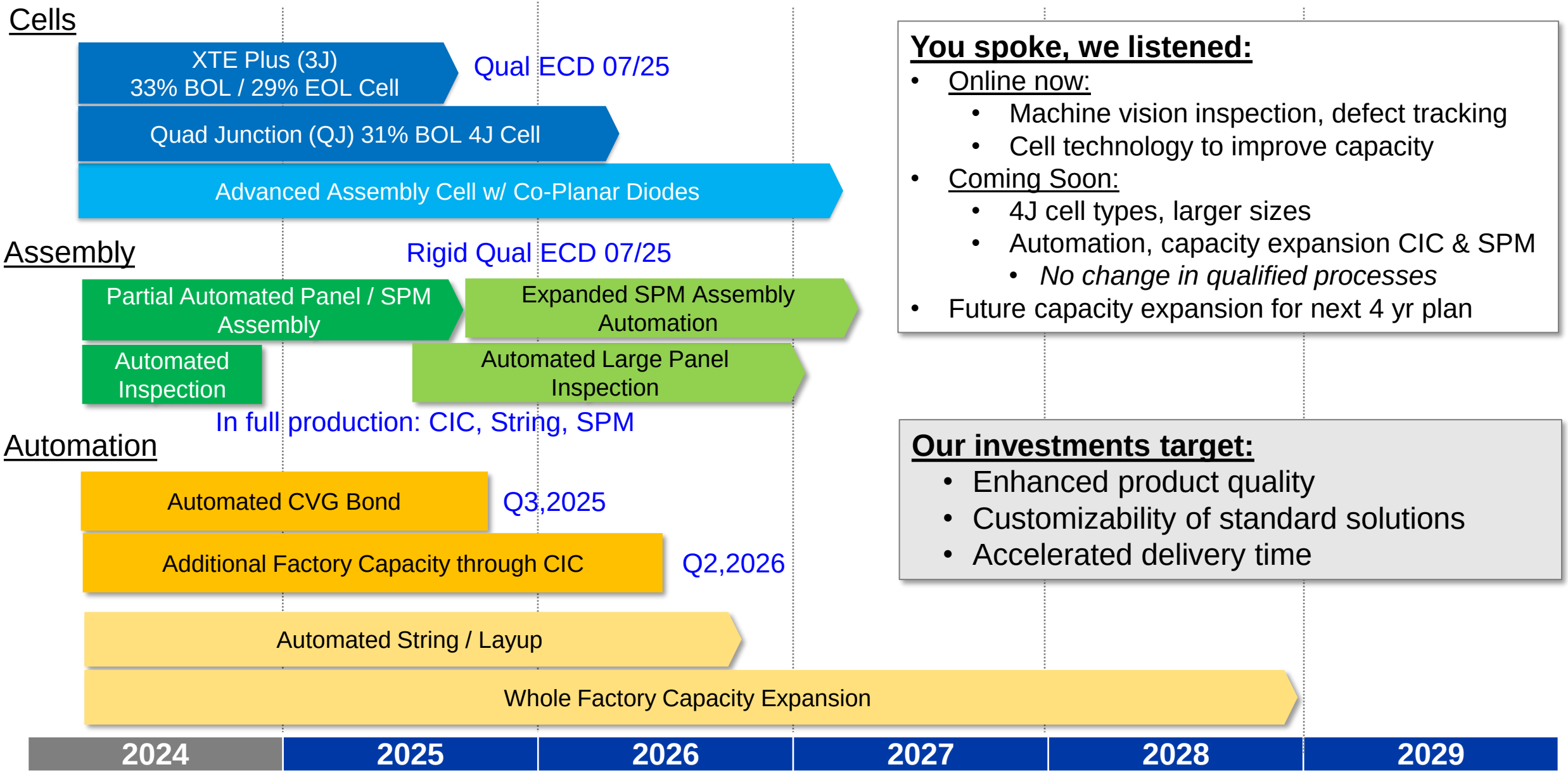

You spoke, we listened:

- Online now:
  - Machine vision inspection, defect tracking
  - Cell technology to improve capacity
- Coming Soon:
  - 4J cell types, larger sizes
  - Automation, capacity expansion CIC & SPM
    - *No change in qualified processes*
- Future capacity expansion for next 4 yr plan

Our investments target:

- Enhanced product quality
- Customizability of standard solutions
- Accelerated delivery time

XTE and XTE Plus Family

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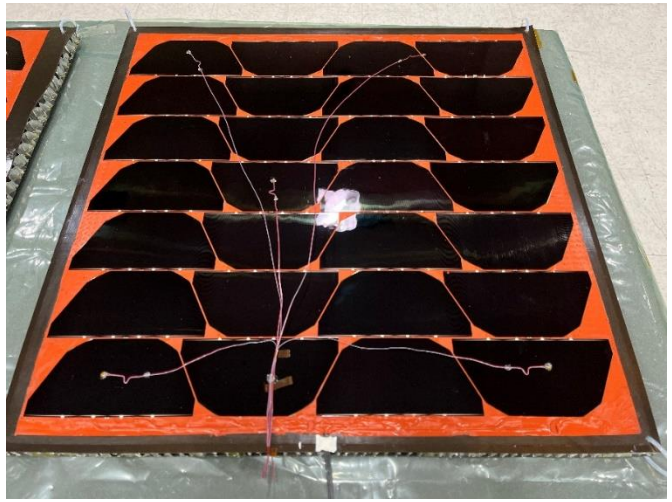
- XTE Family is the flagship of SPL production today for SuperCells
  - XTE-SF at 31.8% for 135,000 cells
  - XTE-HF at 31.8% for 65,000 cells

- XTE-PLUS Qualification to AIAA S-111-2014 is nearly complete (ECD 7/25)
  - GEO and LEO versions at 32.3% and 31.8% respectively, near 33% for smaller form-factors

XTE-PLUS 76.88 cm^2 cell Qual LIV Data:

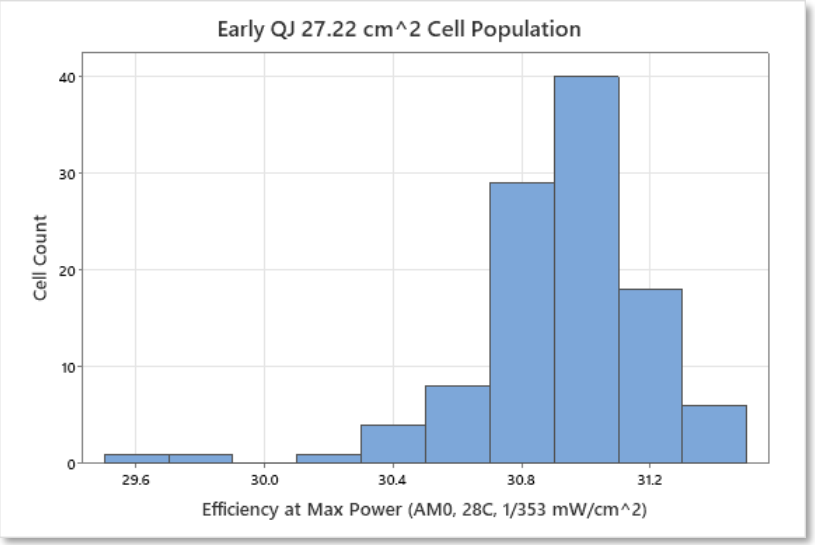
Type	V_{oc} [V]	V_{mp} [V]	I_{mp} [A]	I_{sc} [A]	Eff@$_{mp}$ [%]
GEO	2.808	2.511	1.338	1.386	32.3
LEO	2.806	2.511	1.317	1.378	31.8

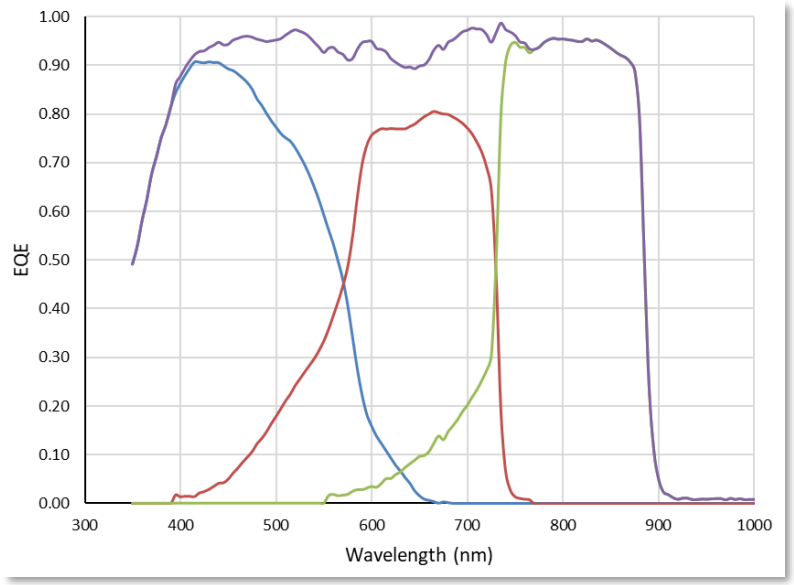
Similar performance to XTE-HF with increased factory throughput



XTE-PLUS rigid coupons built by automation, thermal cycling now (ECD 7/25); GEO conditions; 2000 cycles (+140/-175C), T-VAC and Survival cycles.

Quad Junction (4J) Coming 2026





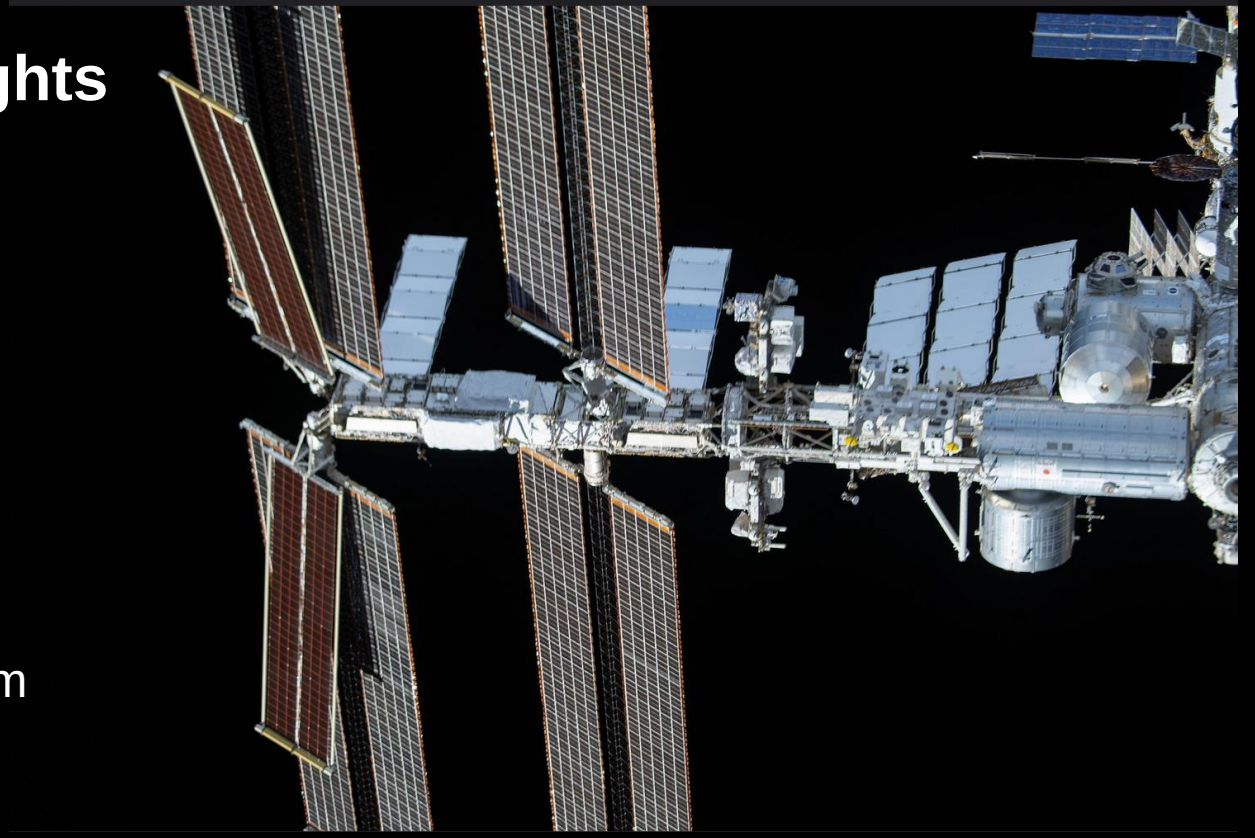
- Quad Junction (QJ) in engineering confidence testing today.
  - 31% efficiency at bare cell, 28ºC
  - Lattice matched AlGaInP/AlGaAs/GaAs/Ge design
  - Offers greater flexibility for SPM / Wing design

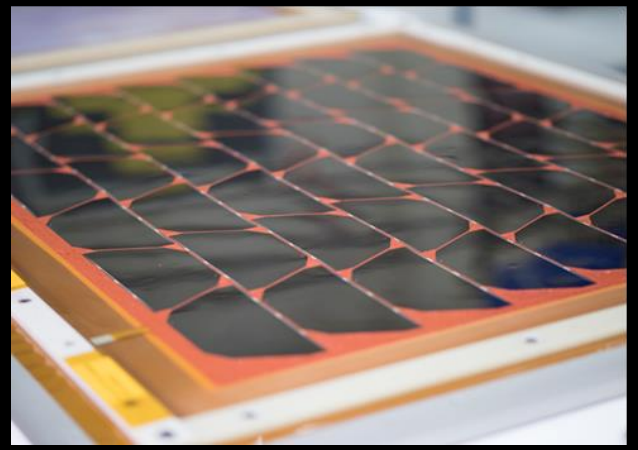
- Testing Highlights
  - Cell/CIC LIV testing at Spectrolab and Aerospace, (+/- 0.5%)
  - Early testing of very large cells : Mega Cell
  - Non annealed radiation retention NP_{mp} of 0.88, 1e15 1 MeV e-/cm^2
  - S-111/S-112 qualification testing start in Q4-25
  - Campaign for flight testing in 2026

Cell Area [cm^2]	V_{oc} [V]	V_{mp} [V]	I_{mp} [A]	I_{sc} [A]	$Eff_{@mp}$ [%]
27.22	4.094	3.729	0.305	0.323	30.9
138.57	4.090	3.673	1.528	1.609	30.0

Spectrolab Solar Power Modules Highlights

- Delivering SPMs since 2017
  - Fully qualified for flight conditions
    - LEO 55,000 cycles (+120ºC/-65ºC)
    - LEO Environment ESD testing
    - GEO 2,000 cycles (+125ºC/-175ºC)
  - 177 kW on orbit, 59 kW launch in ‘25
  - Delivered over 2000 SPMs to date; 310 kW
  - Full, constant-rate production line
  - Automated inspection capability with vision system

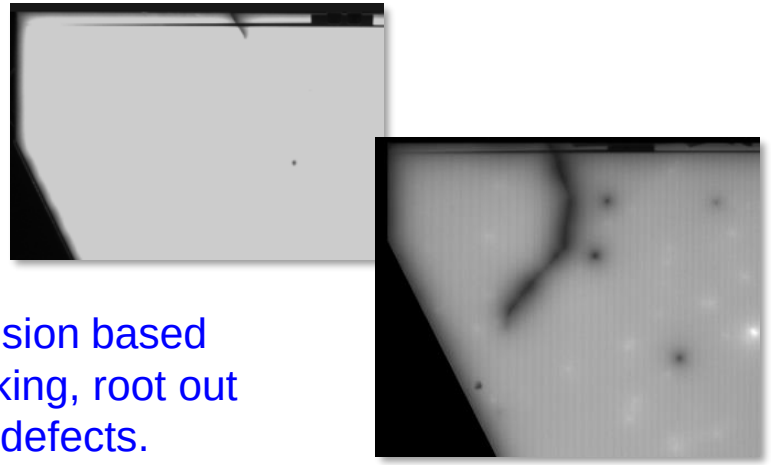




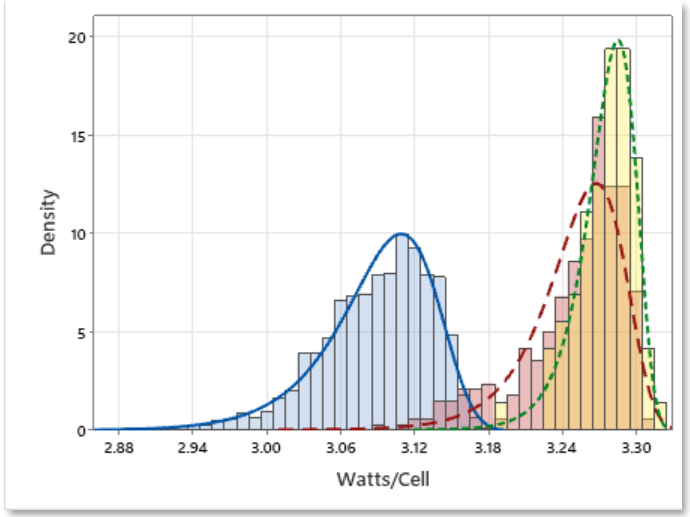
- Multiple designs in production
  - Kapton sheet based, thin conductor pickup tabs
  - 100V and 160V bus
  - 42 to 63, 76.88 cm^2 cells (XTJ-Prime, XTE-SF, and XTE-HF)
  - 143 to 210W per SPM

For more: Matt LaPointe’s talk in Wednesday Energy Generation II

Applying 6-Sigma to Panel Assembly

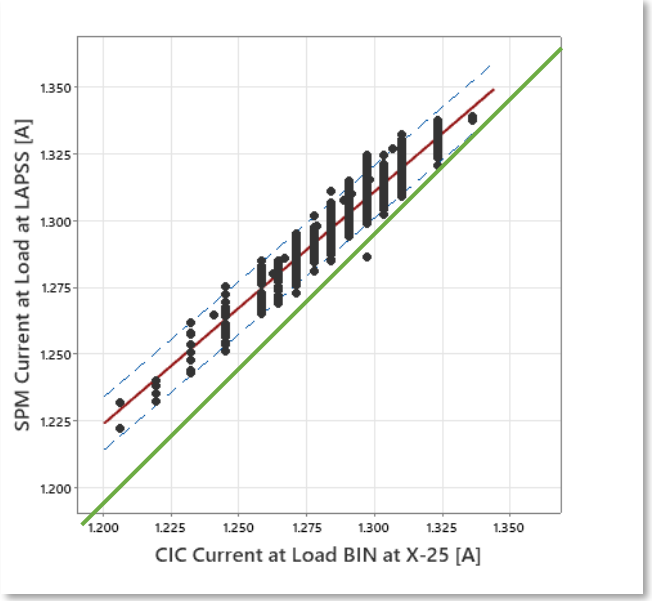


Machine Vision based defect tracking, root out sources of defects.



LAPSS of all SPMs and all cell types

Correlation between LAPSS and CIC LIV



Predictability of SPM performance at delivery, regardless of cell type or SPM design

Looking to reduce product acceptance testing opportunities

Extending SPMs More Missions

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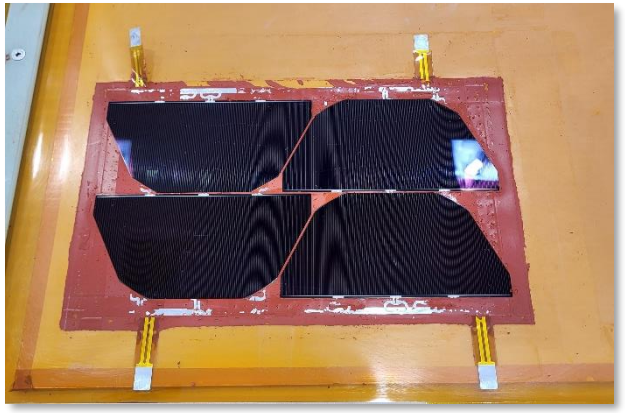
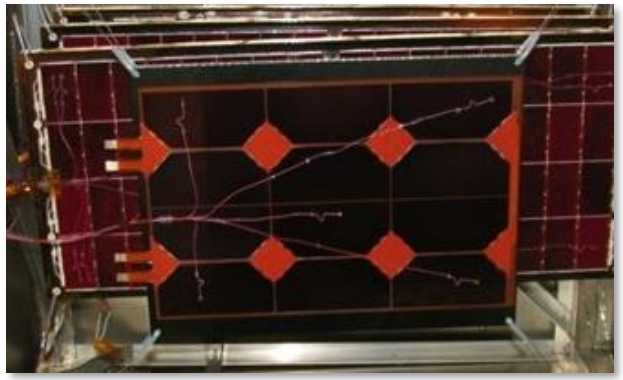
- Engineering testing completed on:
  - ESD testing on SPMs and XTE cells – in current XTE QDD*
  - Bonded to rigid substrate : passed 2,600 cycles (+140ºC/-175ºC)
  - Automated build SPMs – completed 500 cycles to (+140ºC/-175ºC)
  - Intentional fractured cell SPMs – completed 1000 cycles (same T's) + vibe test

- In GEO qualification now for Redwire's ROSA platform
  - Lifecycle Coupon (LC) APTC / TVAC to 5,295 cycles (+125ºC/-175ºC); 10 cryocycles to -210ºC
  - Combined Effects coupon – Life thermal cycles, UV soak, Radiation, ESD Test Pre/Post

Automated Build Coupons (complete)



CE Coupon (In test)



SPM on Rigid Coupon (Complete)

(*Spectrolab SPW 2024 talk by Jesse Matossian)

Acceleration Coming

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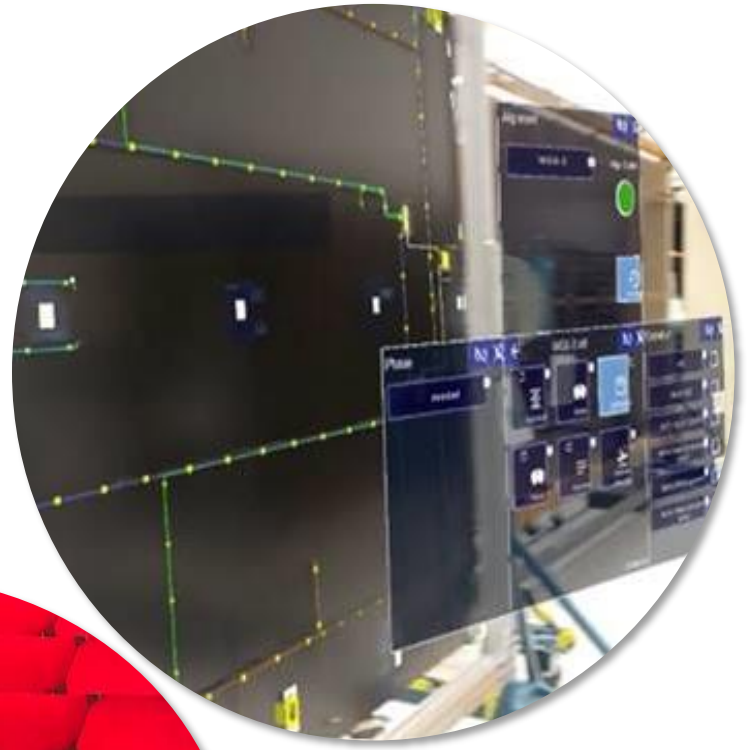
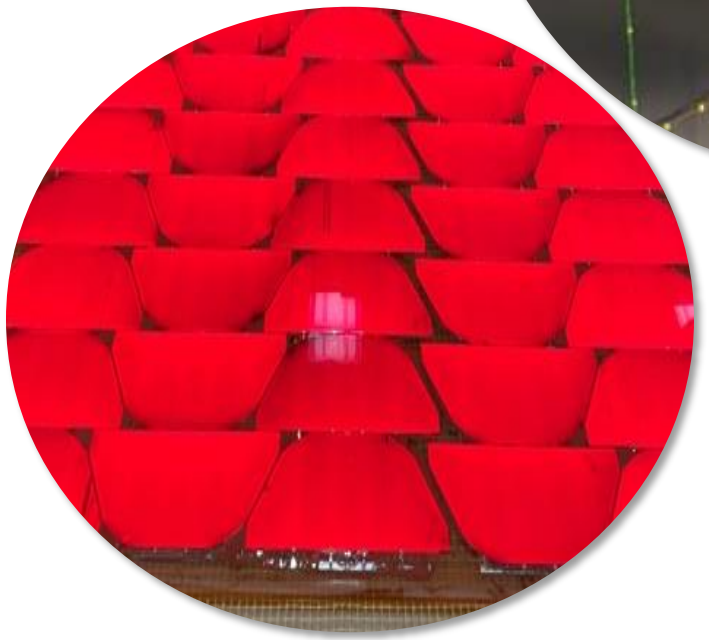
SPM focused plan for the factory

Development in the works today:

- Augmented reality build & QA
- Accelerated build cycle time
- Novel SPM materials
- Automated SPM fabrication
- Factory capacity expansion

More on the horizon





Our investments target:

- Enhanced product quality
- Customizability of standard solutions
- Accelerated delivery time

Summary

- Modular Solar Power at Spectrolab – 1.3MW$_{DC}$ System being installed
- Modularity provides a pathway forward for an industry demanding rapid acquisition
- XTE-PLUS Qualification completing ECD 07/25 and includes automation-built coupons
- Quad Junction (QJ) at 31% coming in 2026, evaluating 138 cm^2 cells
- Built and delivered over 310kW of Solar Power Modules
- Volume experience applies 6-sigma tools to panel assembly
- SPMs being extended to more wing systems, materials, environments
- Focusing factory on SPM plan forward, acceleration coming

Thank You

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REDWIRE

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.

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