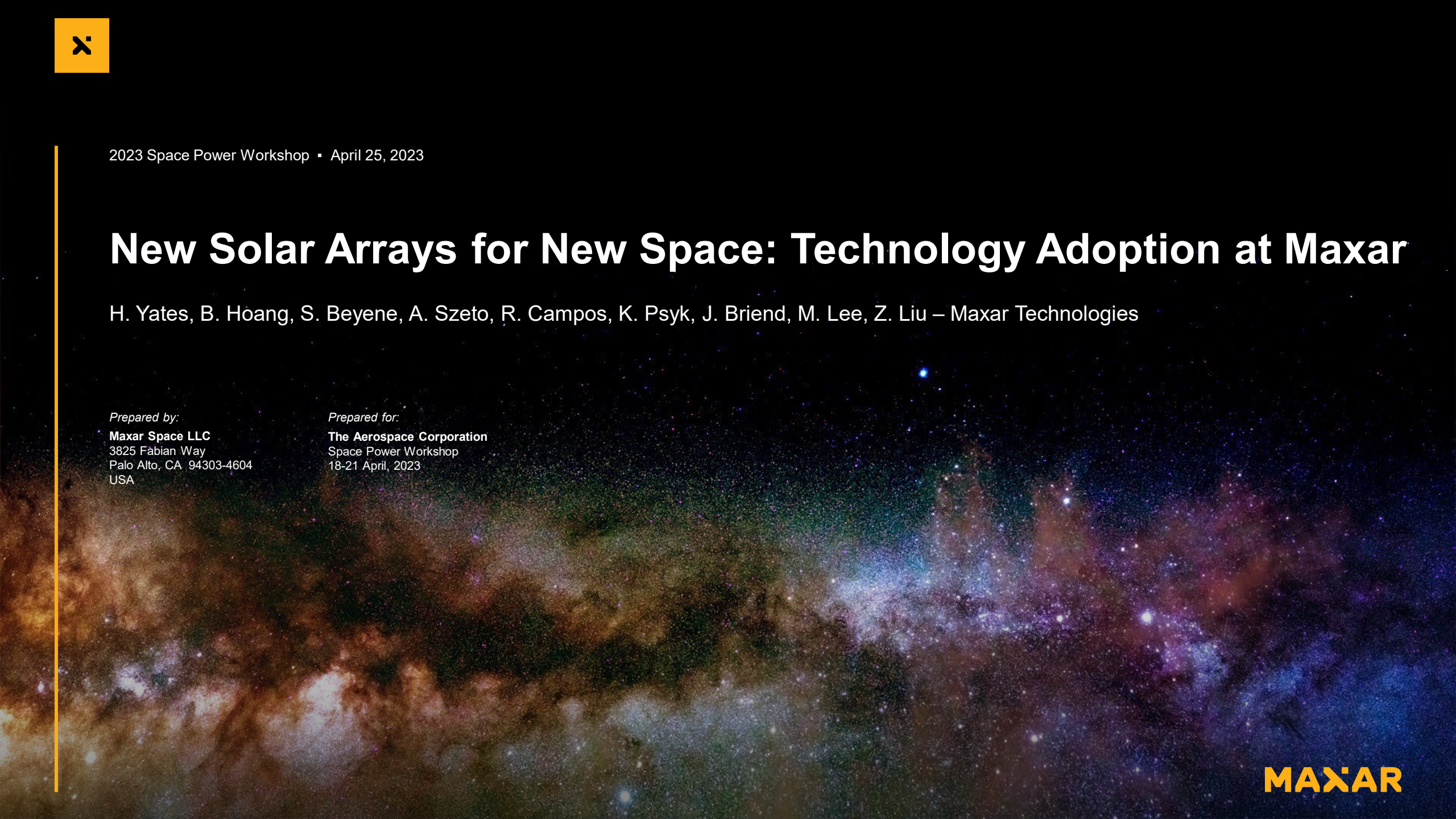

2023 Space Power Workshop ▪ April 25, 2023

New Solar Arrays for New Space: Technology Adoption at Maxar

H. Yates, B. Hoang, S. Beyene, A. Szeto, R. Campos, K. Psyk, J. Briend, M. Lee, Z. Liu – Maxar Technologies

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What does New Space mean to Maxar?

In this changing Space 2.0 economy, how has Maxar evolved and adapted?

Commercial GEO communication satellites? ***Yes, some smaller and more frequent*.**

US DOD and NASA programs? ***Yes, building on heritage 1300 bus*.**

LEO constellations? ***Yes, yes, yes, yes, yes, yes, yes, yes, yes, and yes……..***

Imaging constellation? ***Yes, current top priority*.**

Who will be left standing when the dust settles? ***Wrong question*.**

How many more can we help to stand up *before* the dust settles?
Let's bring on and develop as many new and interesting solar array technologies as we can

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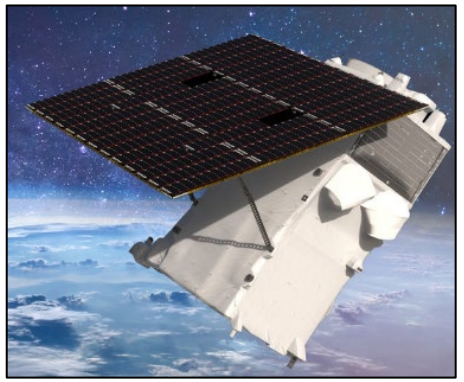
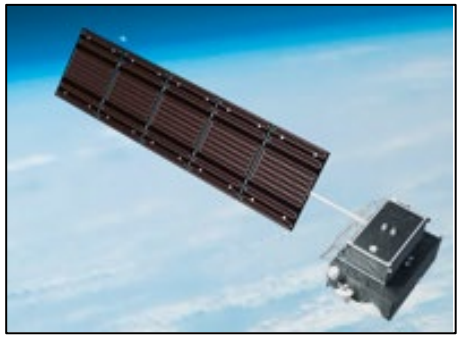
Three Low Earth Orbit (LEO) programs at Maxar

- WorldView Legion: Maxar 500 bus
  - Next generation commercial LEO-optical constellation to improve upon the existing WorldView spacecraft providing imagery over Ukraine and elsewhere



- Tranche 1 Tracking Layer (T1TRK): Maxar 300 Bus
  - One of many programs in support of the Space Development Agency's Proliferated Warrior Space Architecture
  - Maxar as a sub providing spacecraft bus to L3-Harris



- Proliferated Low Earth Orbit (pLEO): Maxar 300 Bus
  - Multiple studies / pursuits for commercial missions with up to hundreds of spacecraft in LEO, to be built and launched on very aggressive schedules

Each has unique design drivers leading toward new photovoltaics and novel materials

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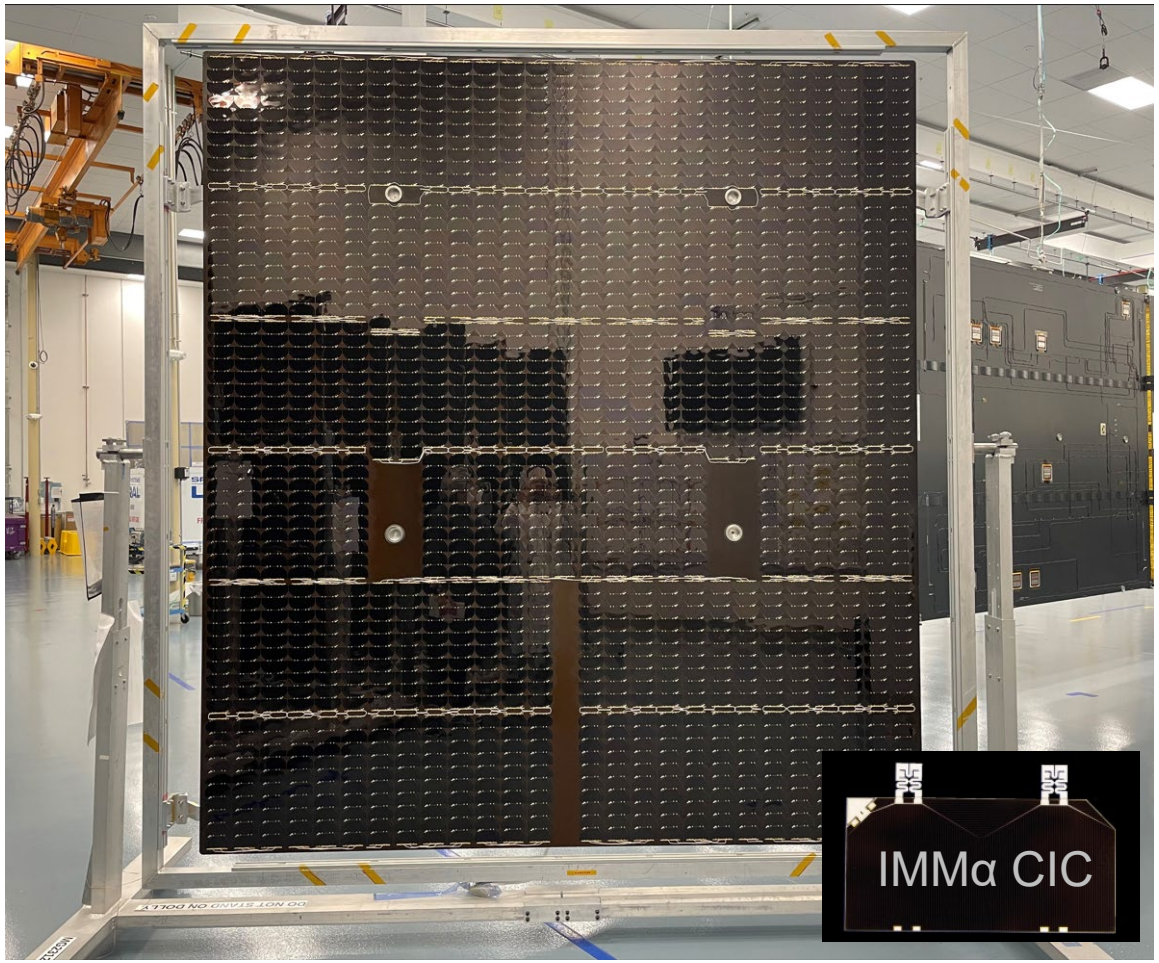
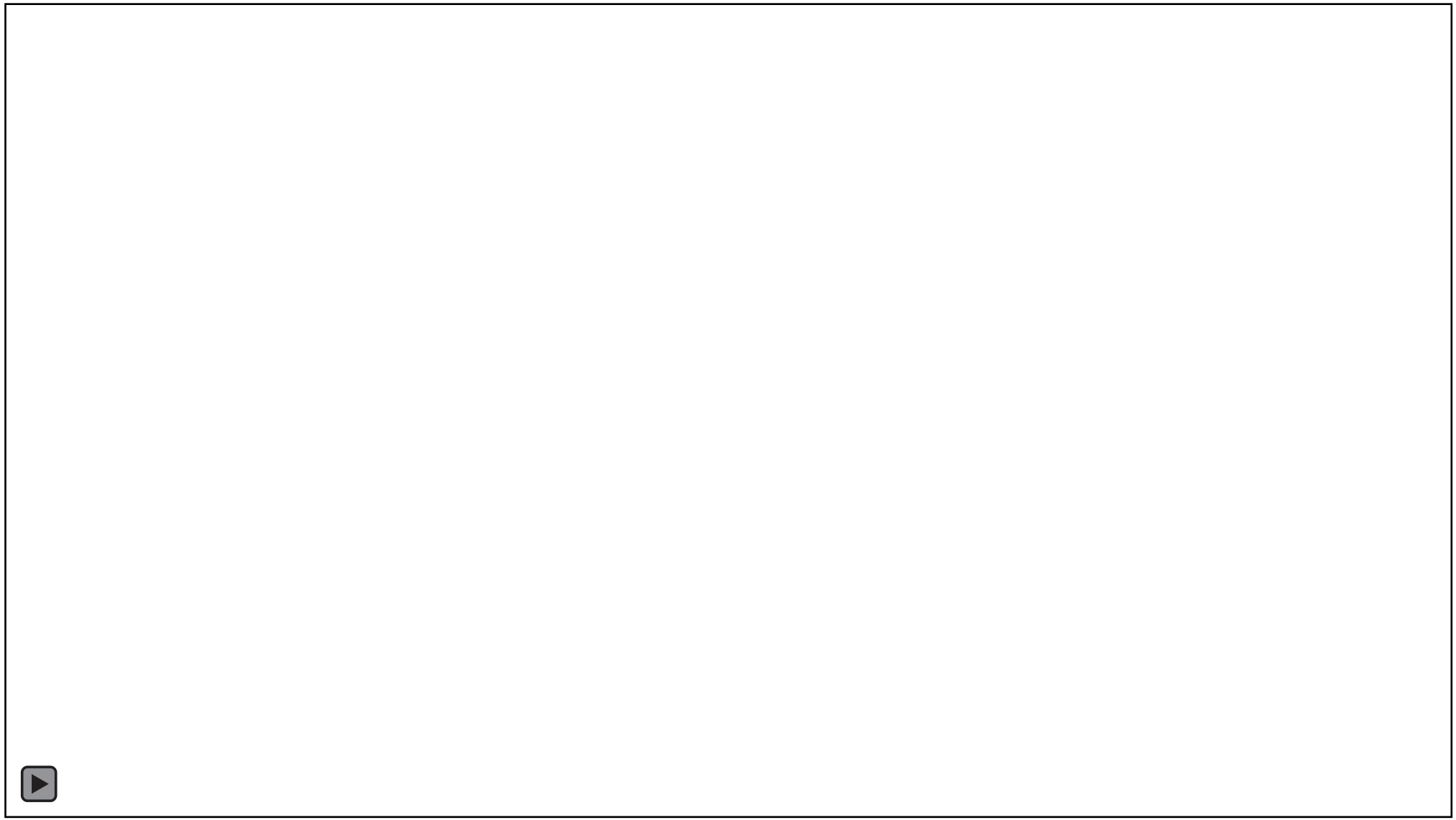
WorldView Legion solar array design

- Solar Array design drivers for LEO Optical payload
  - High stiffness
  - Low mass
  - High efficiency
- Inverted Metamorphic (IMM) α solar cell by Rocket Lab
  - 32% BOL efficient
  - Approx. 32% lighter CIC than equivalent ZTJ
- Solar Array Specs
  - Single-panel wing
  - 156 strings of 10 CICs each, 26 circuits
  - 1651 W at 34 V at EOL (10.5 yrs)
  - Panel is 240cm x 265cm
  - < 25 kg
  - Includes thermal and ATOX coatings



Low-mass solar cells and stiff panels enable increased slew rates and faster image capture

WorldView Legion solar array deployment

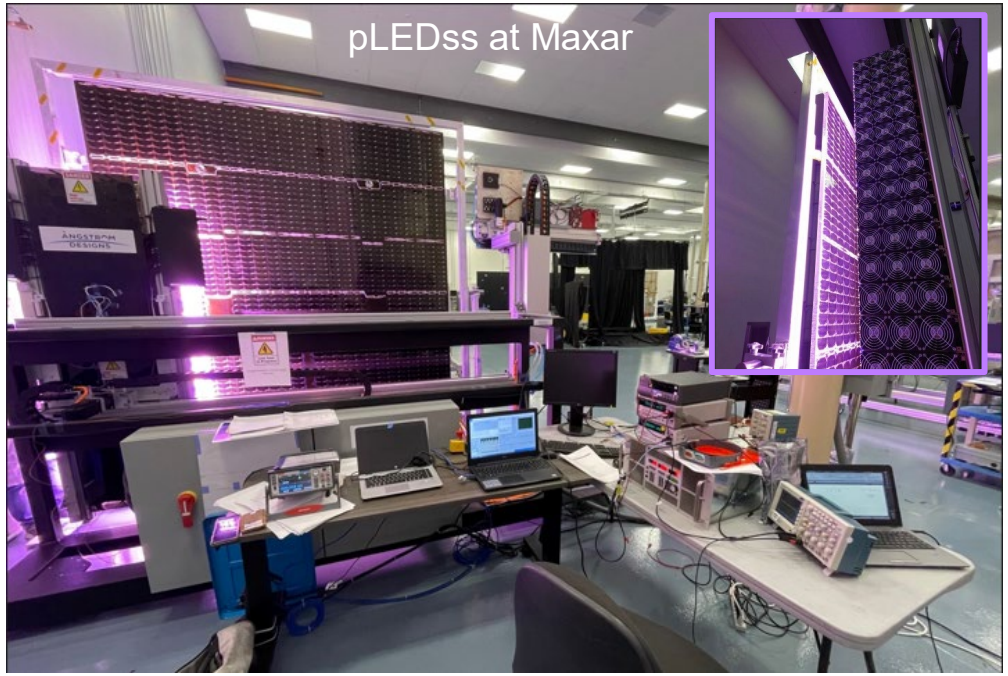


WorldView Legion solar array lessons learned

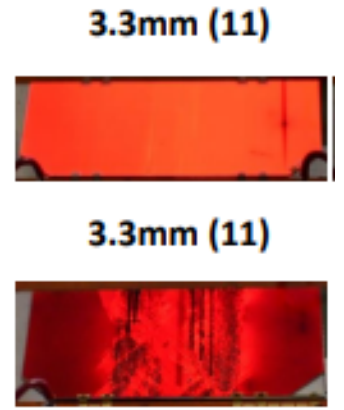
- New PVA tech can mean new problems
  - Defect categories not seen before
  - Production and assembly challenges to work through
  - More sensitive to conditions previously thought benign
  - New test methods may be needed

- New PVA tech can mean new opportunities
  - Increased flexibility
  - Potential for increased compatibility with new materials and structures
  - Improved tolerance to certain types of damage/defects
  - Other – i.e. we're still learning

- Also, the common definition of what is a CIC / SCA is evolving, and so related assumptions need to be checked and challenged



EL Image vs. Mechanical Displacement*



The AIAA industry standards exist for a reason – shortcut them at your peril, but also don't blindly follow – always ask "why am I doing this?"

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*Source: "Bend Testing of IMM and Triple Junction Solar Cells", David M. Wilt[1], Ryan Beauchemin[2], Clay McPheeters[3], Paul Sharps[3], Neil Snyder[4], Cody Griffee[5] and Michael Peterson[1]. [1]AFRL, [2]ATA, [3]SolAero Technologies, [4]Shaffer, [5]Loadpath. 7th WCPEC, June 15, 2018.

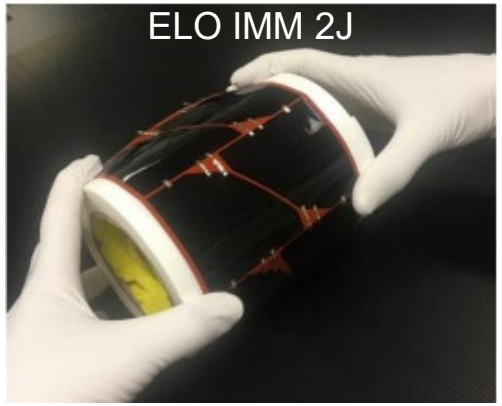
Path forward for Maxar with IMM and similar solar cells

- IMM β by Rocket Lab
  - ~ 34% AM0 BOL Efficiency
  - Qualification ongoing
  - Working with Martin Materials as a second coverglass source

- 4G32 by Azur Space
  - As thin as 90 microns
  - 32% AM0 BOL Efficiency
  - Performance metrics comparable to IMM at wing level

- IMM ELO by MicroLink Devices
  - Epitaxial Liftoff process
  - Allows re-use of host wafer
  - Reduced production cost
  - Working on coverglass alternates as well as with Martin Materials

4G32



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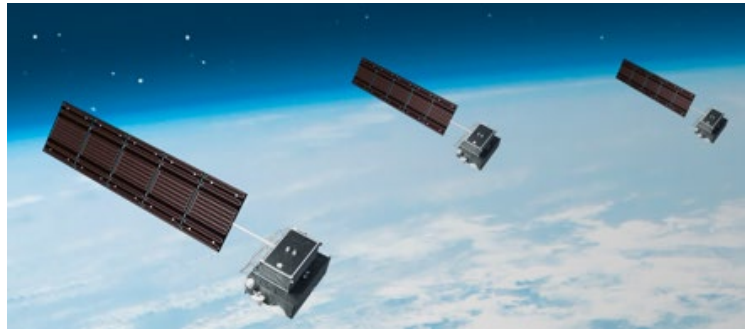
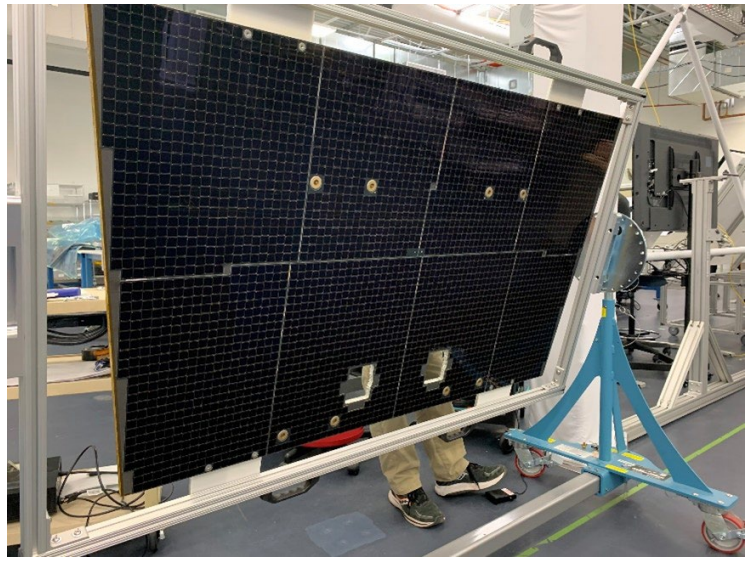
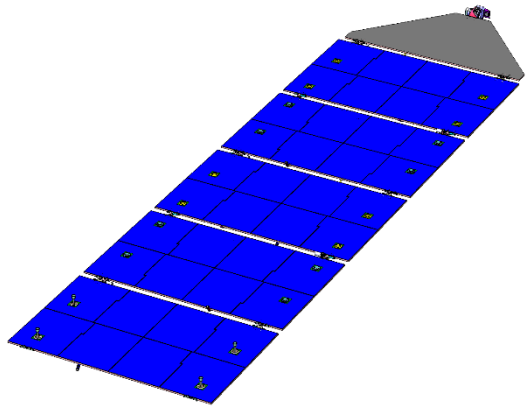
Tranche 1 Tracking Layer (T1TRK) solar array design

- Solar Array design drivers
  - OISLs = no yaw steering = beta mechanism
  - Payload = large radiator = single wing
  - Single wing with beta + jitter-sensitive payload = small and light = GaAs
  - Quick-turn schedule + 10's of spacecraft = max automated production
- Surface Mount Technology (SMT) by Sierra Space
  - 30% BOL efficient 3G30 cell by Azur Space
  - An all backside contact solar cell with through-wafer-via connections enable standard commercial electronics pick and place assembly
- Solar Array Specs
  - Single wing of 5 panels
  - 306 cells per matrixed string
  - 2522 W at 30.0 V at EOL (5 years)
  - Panels are 107cm x 180cm
  - 65 kg







SIERRA SPACE

Surface Mount Technology and automated production enable compressed design schedule

Surface Mount Technology (SMT) module assembly

SMT Video

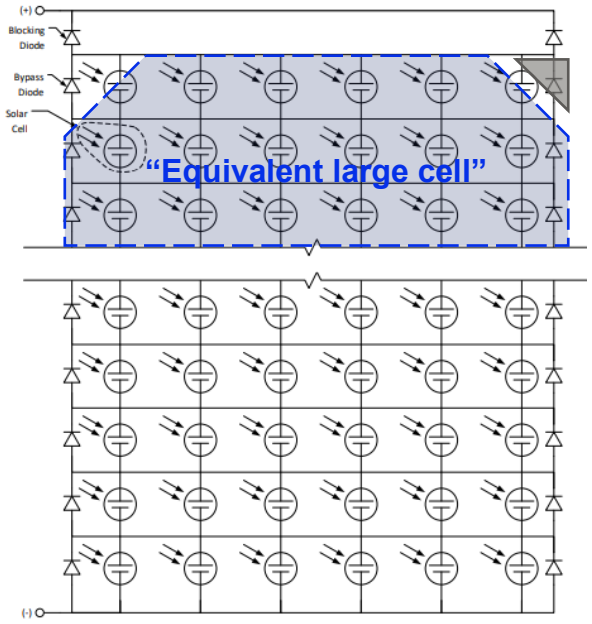
- SMT Solar cells are received on reels with 5 bin classifications
- Electrical attachment material is screened onto the PCB and automatically inspected prior to cell placement
- Cells are placed automatically through pick and place and moved into the reflow oven
- After reflow, automated AM0 testing, EL, and diode checks are completed
- Automated conveyor moves the power module from start to finish with zero touch labor

Automated module assembly and test support quick-turn programs with aggressive schedules

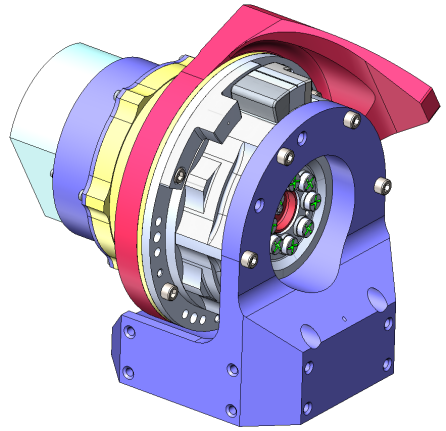
T1TRK solar array design considerations

- Matrix stringing offers new benefits but requires “outside the CIC” thinking
  - Multiple parallel connections can mitigate effects of single failures
  - Low overall string current (due to small cell size) and lack of interconnects/end terminations reduces ESD concerns
  - Matrix wiring yields improved shading performance and reduced sensitivity to degradation or open cell failures
- Beta mechanism adds complexity and more interfaces to manage
  - Sierra Space provides the beta axis mechanism (BAM) as a turnkey solution with the solar array
  - Mechanical and electrical interfaces are communicated through ICD and specifications
  - Sierra Space provides the complete structural analysis and verification of the BAM and solar arrays - Maxar defines the operational scenarios
- The hold down release mechanisms (HDRM) are provided by Sierra Space
  - HDRM location is jointly defined between Sierra Space and Maxar
  - Preload and structural dynamics are analyzed and verified at Sierra Space
  - Need to consider shock limitations of bus units on adjacent structure!

pLEO Goal: Suppliers provide turnkey (bolt-on) commercial solutions



Matrix Stringing



Beta Axis Mechanism

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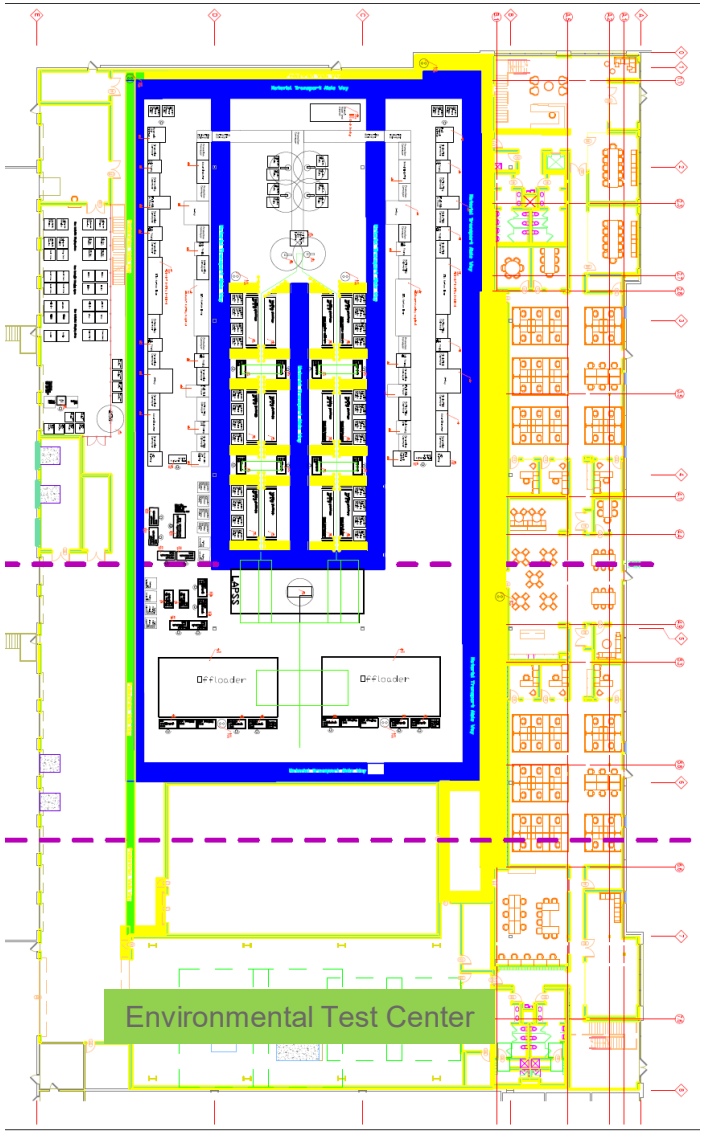
Path forward for Maxar with SMT and Sierra Space

- Conduct modified qualification program tailored to T1TRK to validate SMT matrix design and bypass diode configuration
- Continue working with Sierra Space on T1TRK as they expand production into new facility – new dedicated 70,000 sq ft facility will be online Q1/2024
- Take advantage of SMT modularity and module design to re-use as building block for other programs
- Broaden supply chain for key SMT components to further reduce execution risk

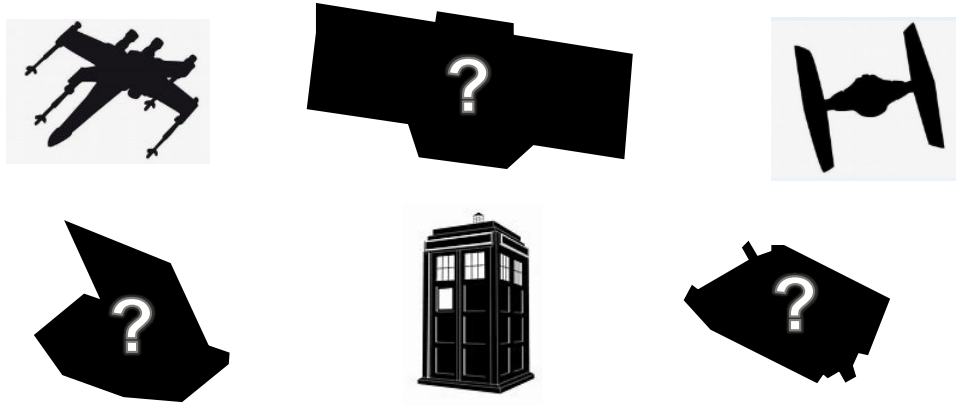
Significant investment in large volume production of solar arrays



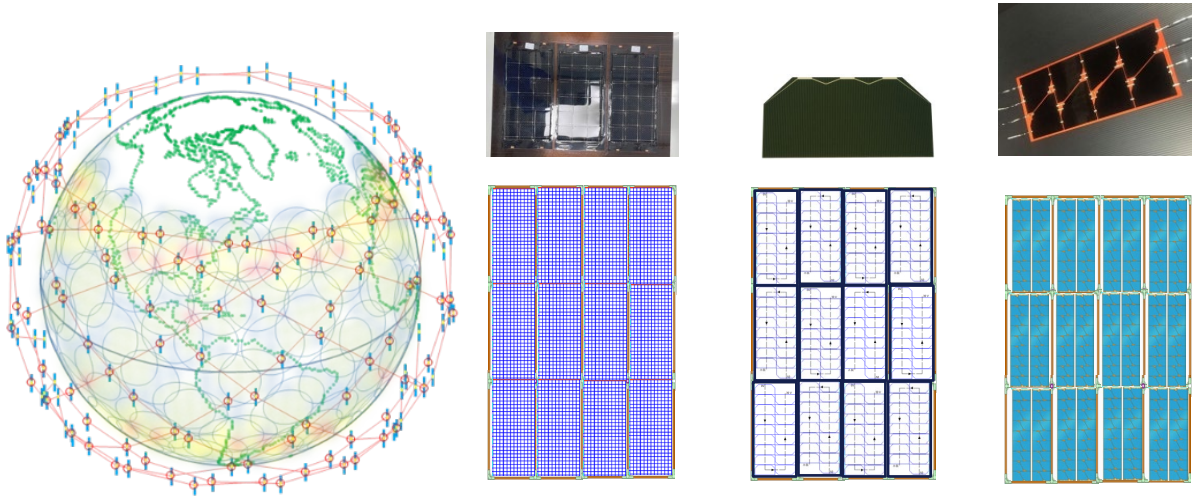
Dedicated 70K sq ft solar array factory

Proliferated Low Earth Orbit (pLEO) solar array design(s)

- Solar Array design drivers for pLEO
  - Solar array is single largest driver of bus cost
  - Ludicrous production rates
  - Insane production volumes



- Multiple sources / hybrid arrays
  - DragonSCALES Silicon modules by mPower
  - Epitaxial Liftoff (ELO) IMM modules by MicroLink
  - Multiple module assembly and wing partners
  - Standard module footprint
  - Standard mechanical interfaces



- Production rates in the tens of ship sets per month
  - Novel solar panel and wing structures

Need for high volume and rapid production drives move to new components, materials and processes

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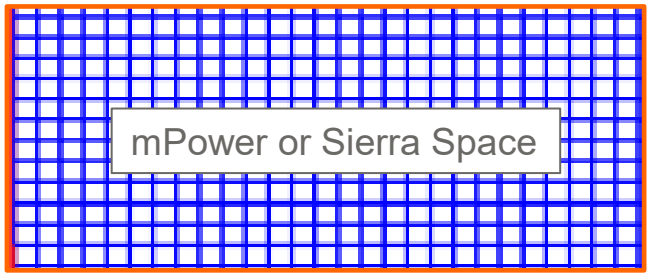
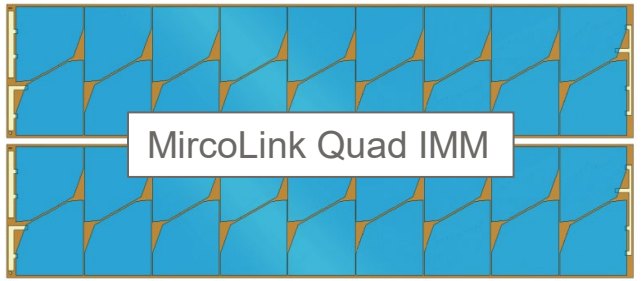
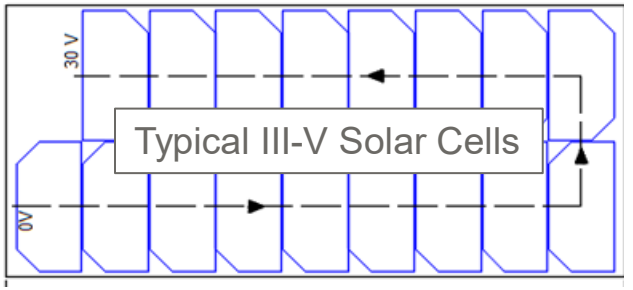
Maxar standard module design

~ 58 cm x 29 cm, +/- 1 cm

- For pLEO designs using 30 V strings, Maxar is driving toward a common Solar Power Module (SPM) footprint across multiple suppliers
- Form factor applies to potential wing structure providers as well
- Allows modules from different suppliers to be mechanically interchangeable on a single wing design
- Drives wing structure providers to design around a standard geometry with common hinge and hold down interfaces
- Objective it to have multiple wing designs and suppliers compatible with a common spacecraft bus structure
- As new PVA technology comes online and performance improves, modules with this technology can be “drop-in” to existing without extensive re-qual of entire panels / wings
- Potential to service 100 V EPS as well with 3 modules in series, depending on design, mission, and voltage margin





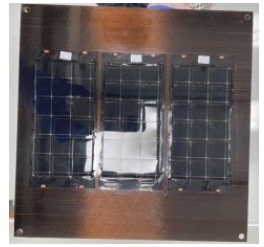


58 cm x 29 cm seems to work as a standard 30 V footprint for most solar cell types

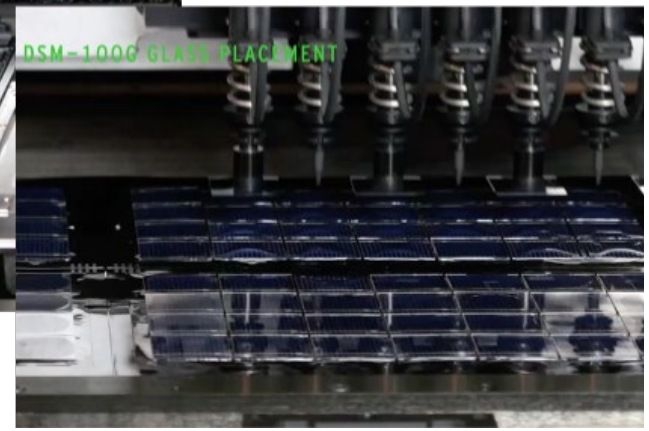
pLEO Solar Array Development: mPower Technology's DragonSCALES

- Risk mitigation coupons completed 35k thermal cycles
  - Multiple generations of contact systems
  - Multiple substrate types
  - Partially funded by Maxar
- Radiation annealing characterization
  - Extensive DOE – 3 rounds completed with multiple cells per condition (over 1,200 hours to date)
  - Different advanced cell structures to evaluate for space environment
  - Common packaging and contact system
- Flight heritage
  - 3 satellites to date for Lynk Global – operational since April 2022
  - Innovation flight demonstration with OneWeb
- Actively delivering and ramping production for LEO constellations, space logistics and lunar missions

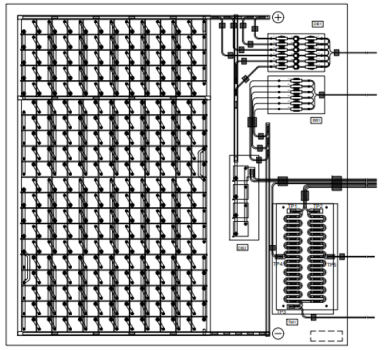
Risk Mitigation
Thermal Cycle Coupon



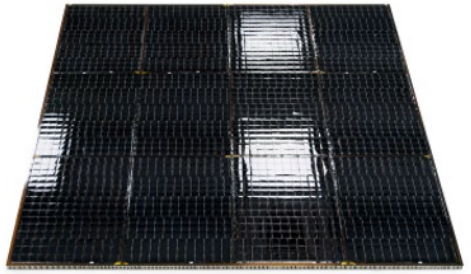
Automated SPM Fabrication



Maxar LC Coupon



EM Panel (non-Maxar)



DragonSCALES to be used on future pLEO missions at Maxar

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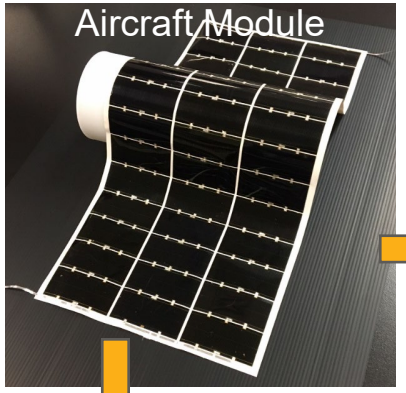
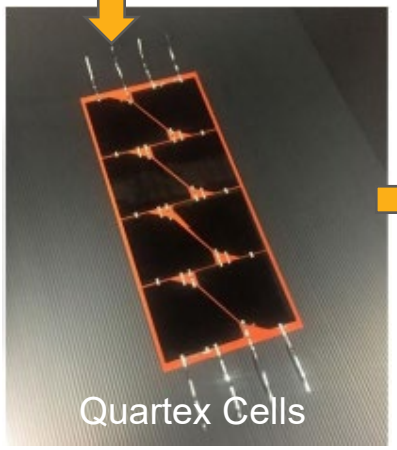
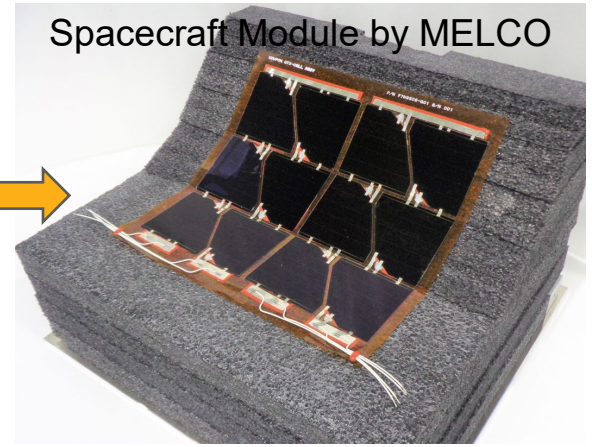
pLEO Solar Array Development: MicroLink Devices ELO IMM

- Established microchip manufacturer
- 26 + 70 Days High Altitude Long Endurance “flight heritage”
  - +30 °C to -68 °C, ~at 19 km
- AIAA qualification for space ongoing
- Space packaging in development
  - Characterizing alternative cover solutions
- Manufacturing partners to help scale production
  - Sharp
  - MELCO
- Plans in place to expand production for large constellations
  - Able to use idle reactors of partner companies for adjacent products
  - Maintaining proprietary ELO process in-house



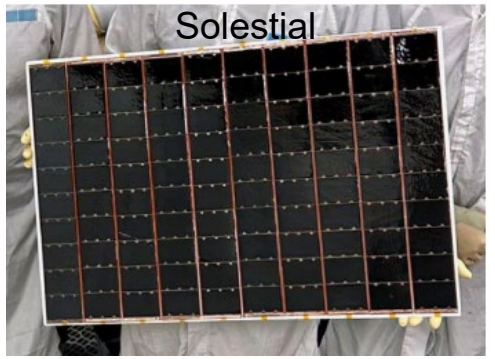


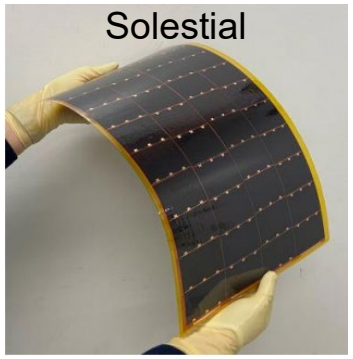


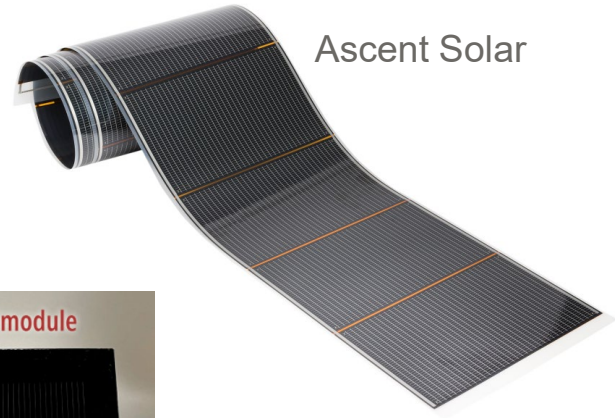
MicroLink modules to be used on future pLEO missions at Maxar

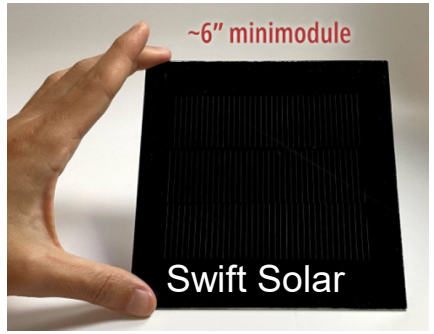
Other PVA / SPM products in development for pLEO

- Solestial
  - Thin Silicon modules
  - Qualification ongoing
  - Flight demo in 2023
  - Transitioning to dedicated production facility
- Ascent Solar
  - CIGS modules produced roll-to-roll
  - Moving to high-volume Perovskite production
  - Space packaging development ongoing
  - Flight demo in 2023
- Swift Solar
  - Perovskite solar cells
  - Large 6” x 6” cells in development
  - Transitioning to dedicated production facility









~10% EOL efficiency may be “good enough” for some high-volume / low-cost missions

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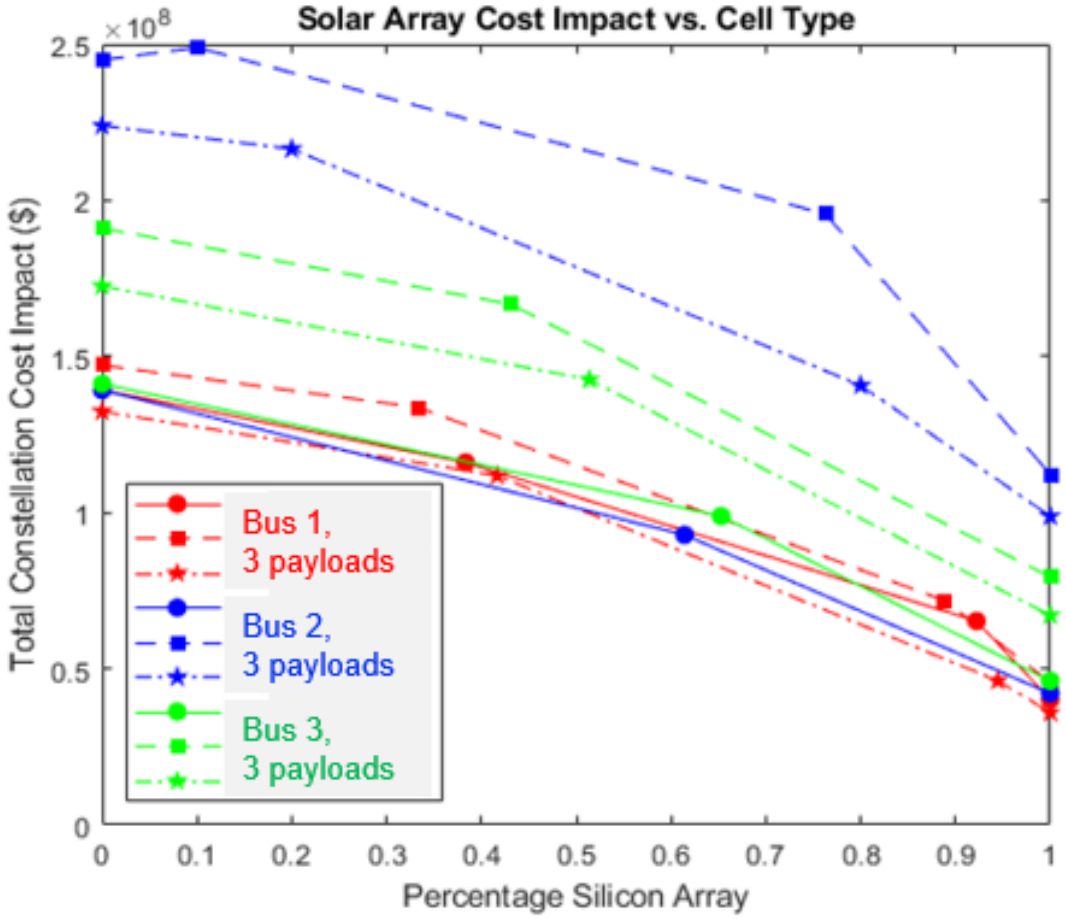
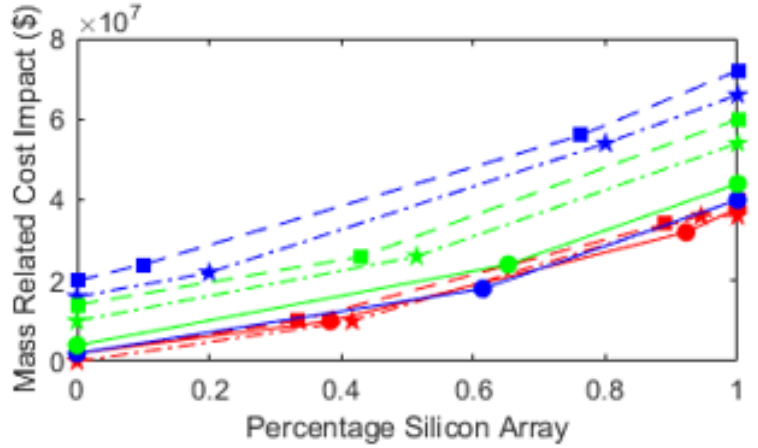
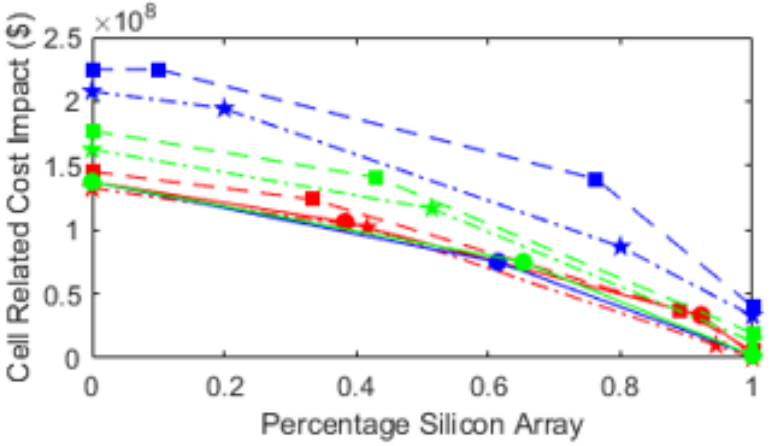
Silicon vs. Conventional III-V solar cell types

- Cost and mass of hybrid Si/III-V solar arrays as a function of % Si for nine different spacecraft configurations
  - Applies to a specific orbit and mission and assumes latest industry pricing for standard space product





Mass Impact vs. Cell Type (III-V v Si)



Cost Impact vs. Cell Type (III-V v Si)

At the constellation level, Si can be worth it despite larger wings and higher mass

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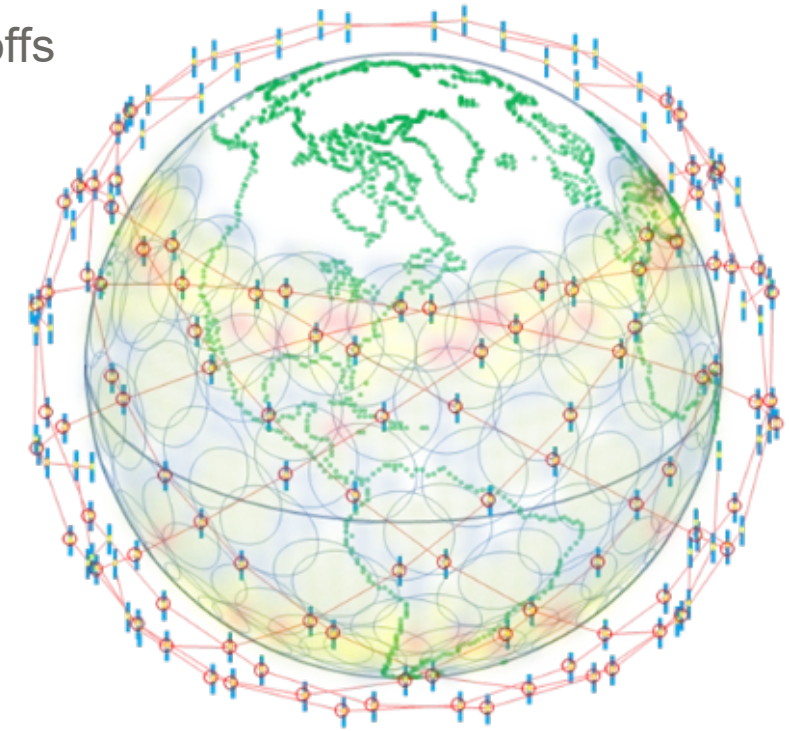
Key Takeaways

- Many more than the three LEO applications shown – there seems to be increasing demand on the horizon
- Exploring new materials and processes from adjacent industries with robust supply chains
- A complete wing solution is best, so that we can limit interfaces and handoffs
- We need a different mix of quicker, better, cheaper for each application
- Welcome new technologies but don't throw out the "old ways"
- Maxar standard SPM is 58 x 29 cm (give or take)
- Automation is a game changer



Maxar is open to considering all new solar array tech – please reach out!

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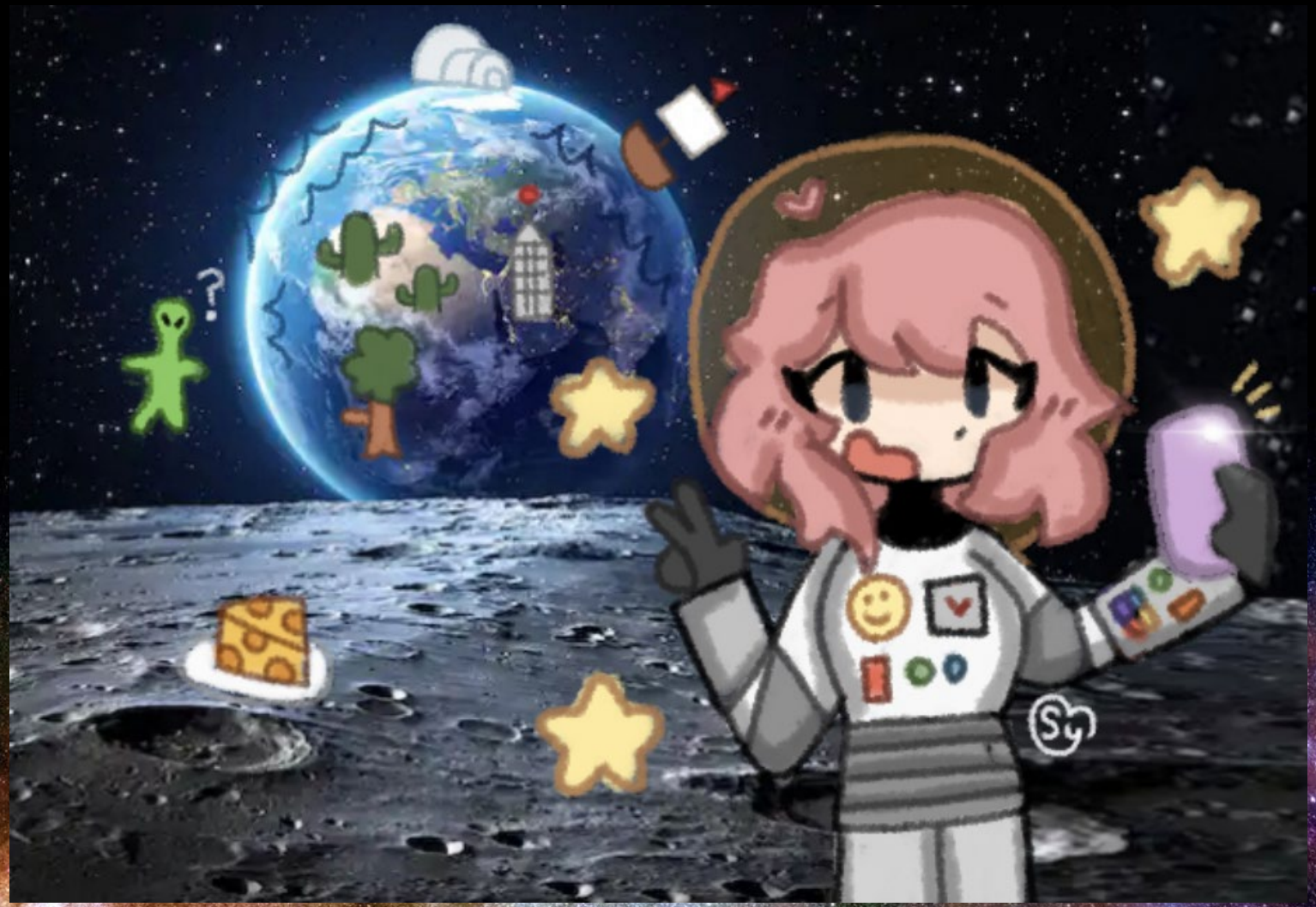
“Space Girl” by Sloane Yates



THANK YOU!

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MAXAR.COM