

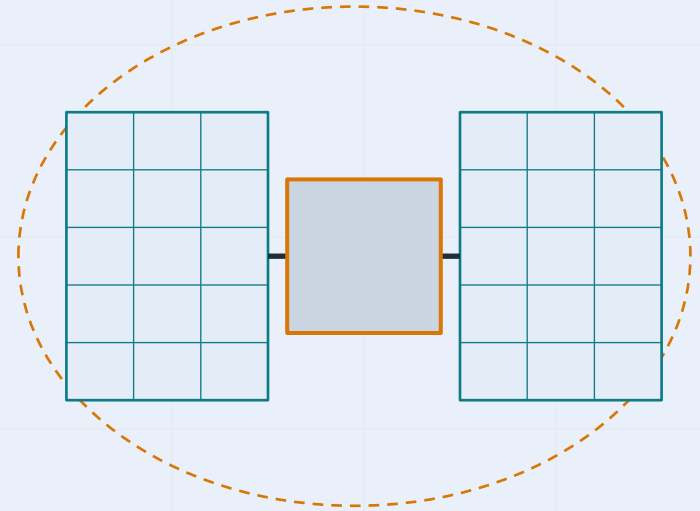
The next space race – PV in orbit

From silicon to gallium arsenide to perovskites

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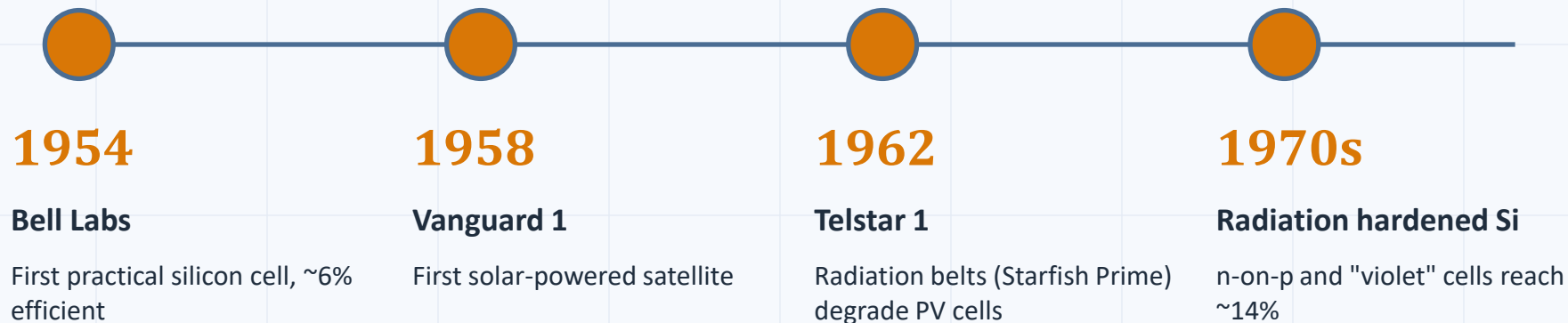
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SCHEMATIC: ROLL-OUT ARRAY SATELLITE

The silicon era, 1954 to the 1970s



The transformation: gallium arsenide

Better physics

Direct bandgap of ~ 1.42 eV, closely matched to sunlight. Strong absorption means only microns of material.

Better in orbit

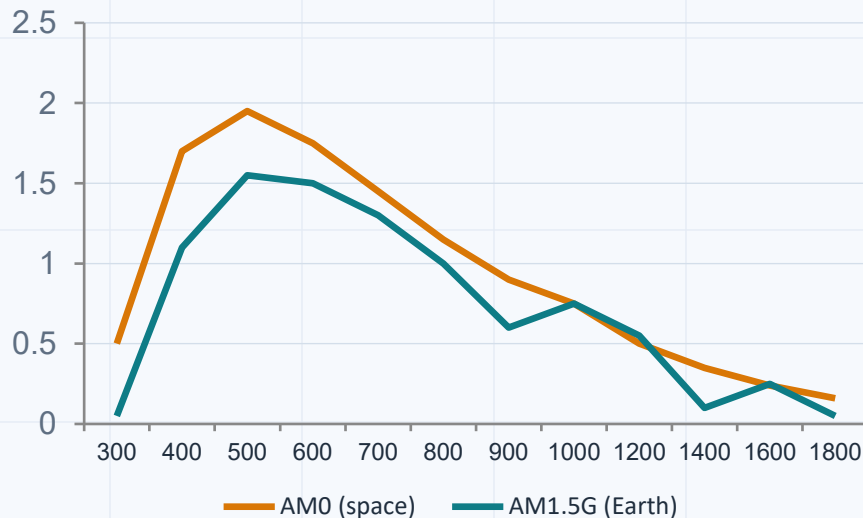
Lower temperature coefficient penalty and better radiation tolerance than silicon.

Key enablers

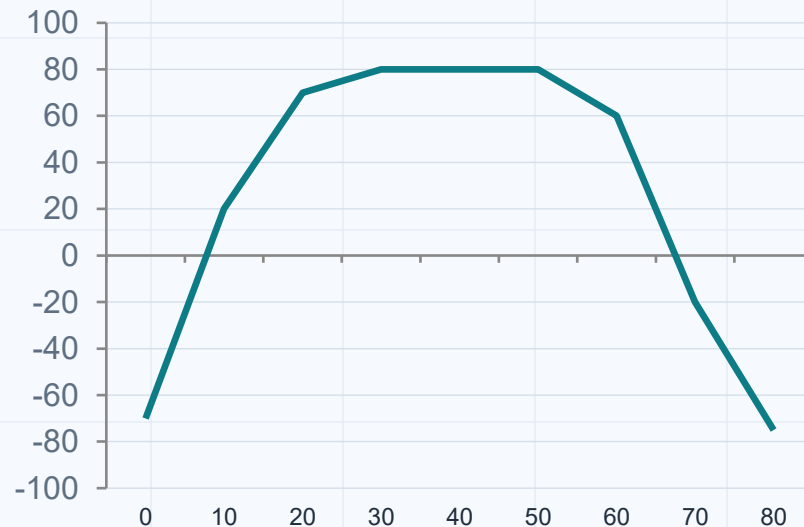
AlGaAs/GaAs heterostructures (Alferov and others), then MOCVD epitaxy in the 1980s.

The space environment: light and heat

Spectral irradiance (W/m²/nm) vs wavelength (nm), schematic



One LEO orbit (~90 min): cell temperature (C), illustrative



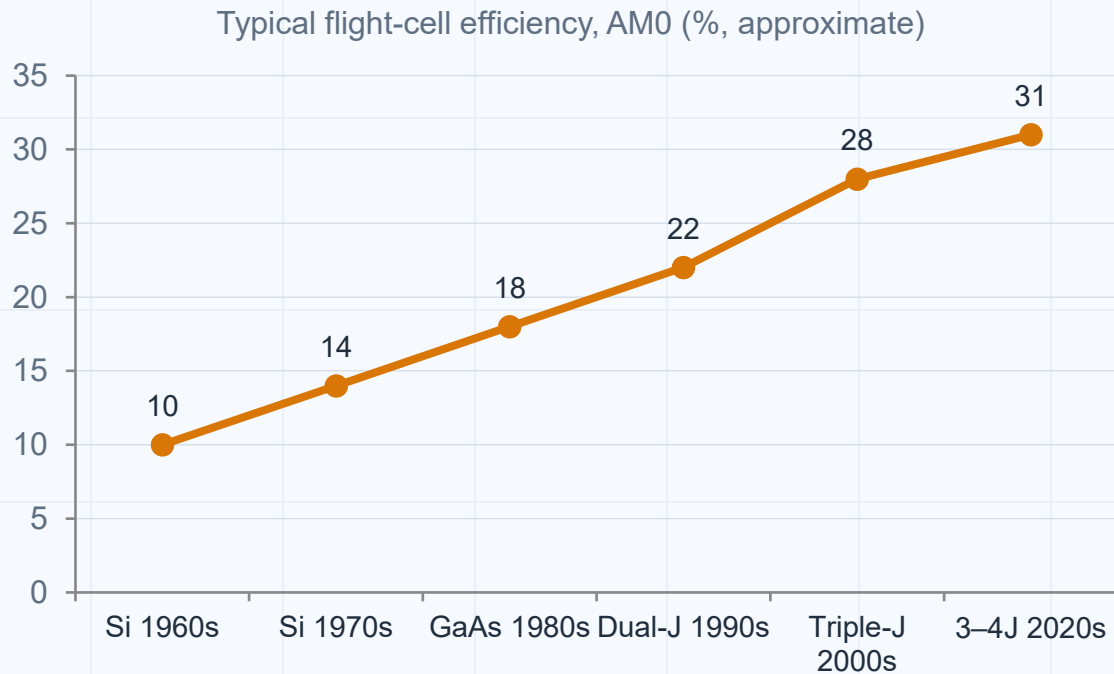
AM0 ~1,360 W/m² vs AM1.5G 1,000 W/m² | UV ~5-7% of AM0 | ~16 orbits/day = ~5,800 thermal cycles/yr

Radiation testing: environment and methods

Test	Source and range	What it probes	Metric
Electron	~1 MeV e-, fluence ladder up to ~1E15-1E16 e/cm ²	Displacement damage, 1 MeV-equivalent fluence	P _{max} , I _{sc} , V _{oc} vs fluence
Proton	~0.05-10 MeV, several energies	Trapped and solar-event protons; low energies stop in the stack	Degradation vs energy and dose
Total ionizing dose	Co-60 gamma	Polymers, adhesives, encapsulants, substrates	Optical and mechanical change
UV	AM0-matched UV lamps	Photochemical damage, transmission loss	P _{max} , transmittance
Recovery	Repeat I-V at set delays after exposure	Ion-migration healing and annealing	P _{max} vs time

Reference standards: AIAA S-111 (cells) | AIAA S-112 (panels) | ECSS-E-ST-20-08C

Multijunction cells pushed efficiency past 30%



Triple junction

GaInP / GaAs / Ge is the mainstream high-performance device.

Heritage

Mars rovers Spirit and Opportunity, and nearly every GEO satellite.

Silicon comeback: p-type PERC in LEO

LIGHT v v v

Front grid + SiNx anti-reflection

n+ emitter (front junction)

p-type wafer (bulk): Ga- or B-doped

Al₂O₃ / SiNx rear passivation

Local Al rear contacts (laser openings)

Why silicon

Terrestrial supply chain; module cost ~\$0.1/W.

Why p-type

Better electron tolerance than n-type in tests.

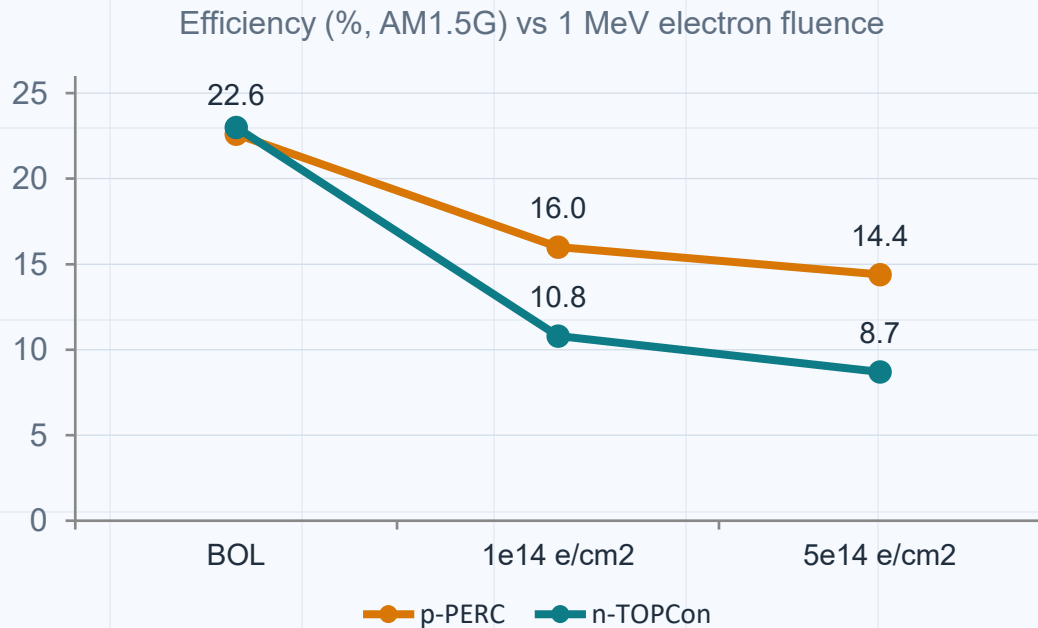
The trade-off

Short-life LEO satellites; bigger arrays offset lower efficiency.

Simplified p-PERC cross-section (not to scale)

SpaceX does not publish its cell spec: PERC is the cell class, not a confirmed part. Sources: Li et al. 2026; Starlink filings.

Measured: p-PERC vs n-TOPCon



0.64

p-PERC remaining factor at 5e14 e/cm²
(~3-5 yr LEO)

0.38

n-TOPCon remaining factor at the same
fluence

Source: Li et al., Sol. Energy Mater. Sol. Cells 296 (2026) 114062. Commercial cells, AM1.5G.

Potential of p-type heterojunction (HJT)

Cell (5-yr LEO)	BOL, AM0 est. (%)	EOL, 4 um polyimide (%)	EOL, cover glass (%)
p-PERC (commercial)	20.8	12.6	17.2
n-TOPCon (commercial)	21.2	6.4	16.3
p-HJT, p-PERC-like (assumed)	23.0	14.0	19.1
p-HJT with healing (upside, assumed)	23.0	18.4	21.8

Why p-type HJT could help

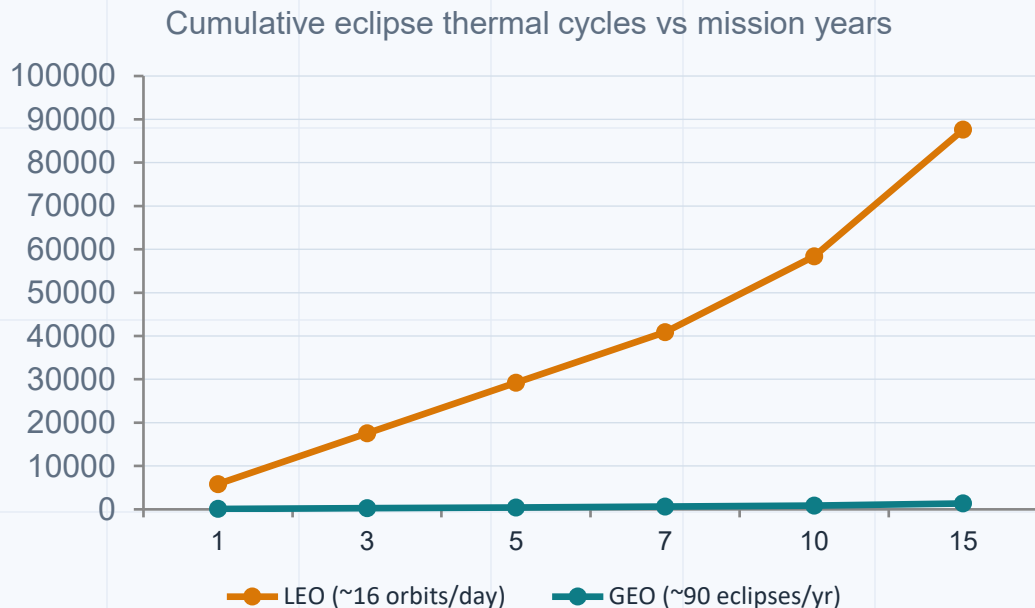
Ga-doped p-type wafers resist radiation; low-temp HJT suits thin wafers; ultrathin HJT reported to self-heal above ~65 C.

Open questions

No p-HJT flight heritage: HJT rows are assumptions, not data. Needs proton and combined-stress tests.

BOL = AM1.5G x 0.92 (my scaling). p-PERC/n-TOPCon EOL: paper fits at extrapolated dose rates. HJT rows: assumptions.

Expected thermal cycling: LEO vs GEO



~29,000

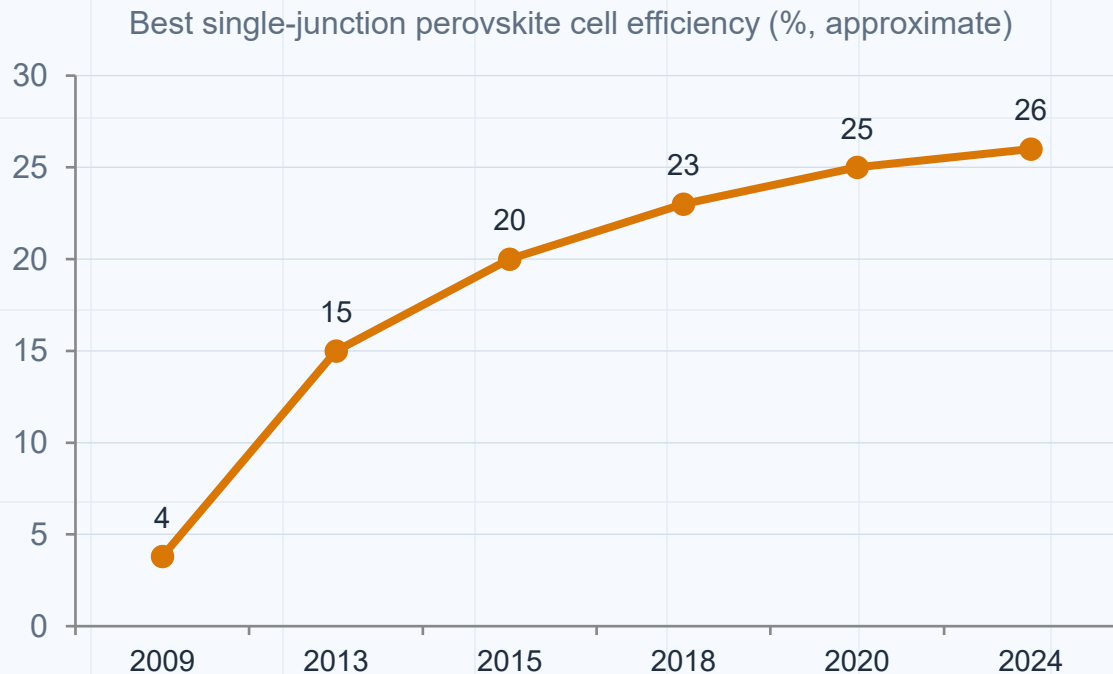
LEO thermal cycles in a 5-year mission

200

cycles in the terrestrial IEC 61215 test (-40 to +85 °C)

Typical qualification range: LEO ~ -100 to +100 °C | GEO down to ~ -180 °C (mission-specific)

Enter perovskites: a very fast climb



3.8 → 26%

in ~15 years, single junction

>34%

perovskite/silicon tandem cells

Why perovskites suit space

Ultra-light

Absorber only a few hundred nm thick

Tunable bandgap

Enables tandems with silicon or CIGS

Radiation tolerant

Ground proton and electron tests show good retention and partial recovery

Vacuum helps

No moisture or oxygen to degrade the material

Flexible and printable

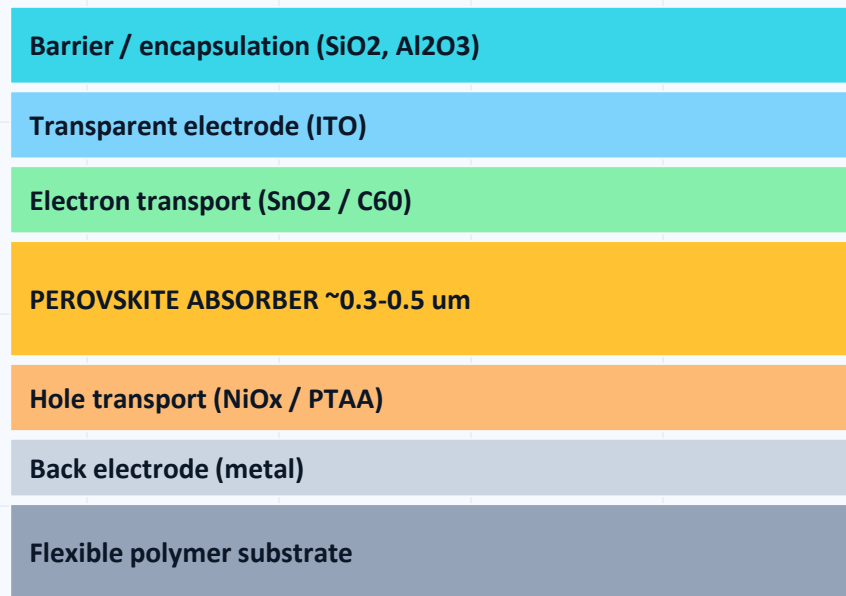
Roll-to-roll processing, roll-out arrays

Low-cost route

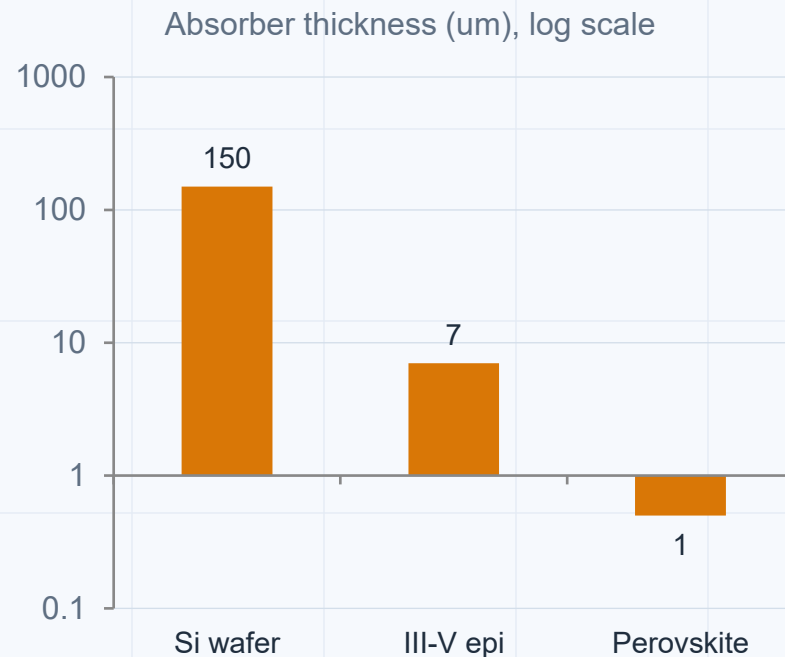
Solution processing, no epitaxy wafers

Anatomy of a flexible perovskite cell

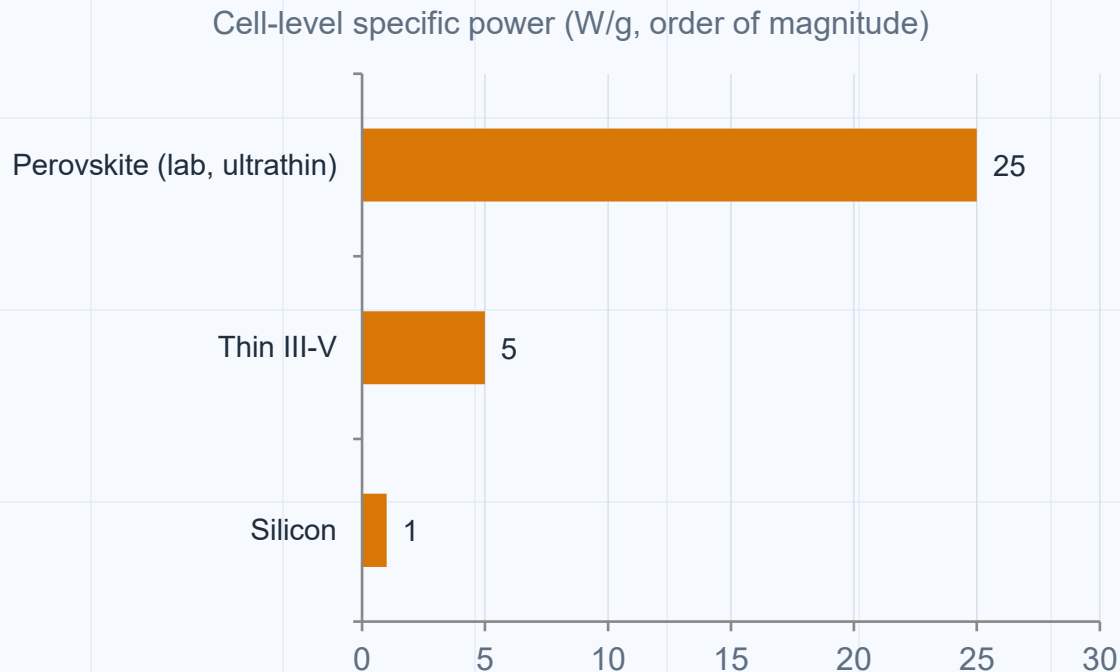
LIGHT ∇ ∇ ∇



n-i-p order shown; p-i-n reverses the transport layers



The specific power opportunity



Note

Cell-level lab numbers only. Substrates, barriers and structure reduce array-level values considerably.

The challenges

Stability

UV, ion migration and heat can degrade cells

Thermal cycling

~16 orbits a day: ~5,800 cycles a year

Encapsulation

Light, transparent barrier against atomic oxygen, UV, outgassing

Scale-up

Uniform, defect-free square-metre modules

Lead content

Handling, containment and regulation

Qualification

Little flight heritage; no agreed space standards

Technology comparison

Parameter	Silicon	GaAs multijunction	Perovskite
Bandgap (eV)	1.12	1.9 / 1.4 / 0.67 (3J)	1.2-2.3, tunable
Absorber thickness	~50-150 um	~5-10 um epi on Ge	~0.3-0.5 um
AM0 efficiency	~14-20%	~30-32%	Lab >25% (AM1.5); AM0 lower
Cell specific power	~1 W/g	~2-5 W/g	>20 W/g (lab foils)
Radiation	Moderate	Good	Promising; recovery reported
Cost	Low	Very high	Low (potential)
Maturity	Flight-proven	Flight-proven	Early: ground tests, first demos

Who buys: potential customers

SpaceX / Starlink

Reported switch from GaAs to silicon; building in-house cell capacity

Other constellations

Amazon (Kuiper/Leo), Eutelsat OneWeb, Telesat, Chinese mega-constellations

GEO and military

Airbus, Thales Alenia, Boeing, Northrop Grumman, Lockheed

Government agencies

NASA, ESA, JAXA, DoD; also early perovskite test flights

Orbital data centres

SpaceX/xAI, Google, Starcloud, Axiom and others

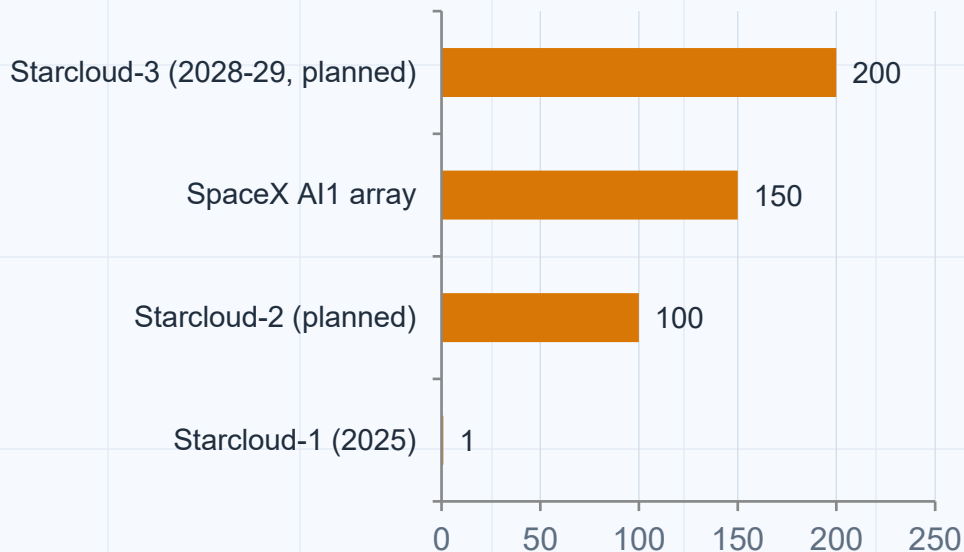
Vertical integration

Large players (think SpaceX) may fabricate their own cells rather than buy

Sources: press reports and company filings; Starlink silicon switch widely reported by industry commentary.

Orbital data centres: a new demand driver??

Power per satellite (kW): reported figures and plans



SpaceX: FCC filing for up to 1M satellites; AI1 design has a 150 kW array at 250 W/m² (~18% of AM0)

Starcloud: H100 demo flown Nov 2025; filing for up to 88,000 satellites

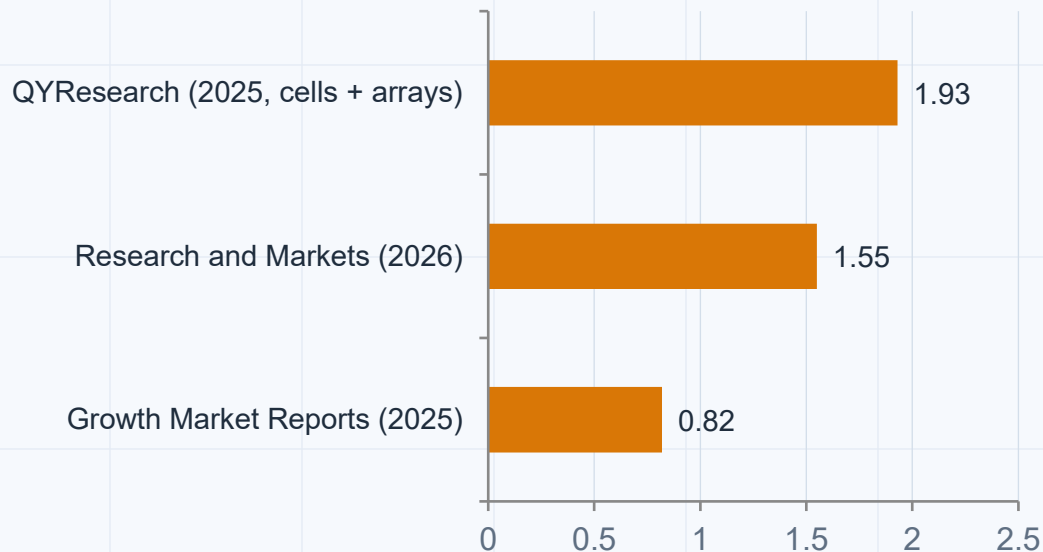
Google Suncatcher: 81-satellite cluster, 2027 prototype with Planet

Skeptics: cost per Watt and heat rejection remain unproven

Sources: SpaceX AI1 reporting, TechCrunch (FCC filing), Starcloud and Google announcements; plans may change.

Market size: a small market today

Analyst estimates of the space solar market (\$B)



\$0.8-1.9B

estimated annual market, 2025-26 (scope varies)

~12%

typical projected CAGR (about \$2.4B by 2030 in one report)

Sources: Research and Markets 2026; QYResearch; Growth Market Reports. Indicative only.

Space: the final frontier

- Silicon proved space solar; radiation and efficiency limits pushed the shift to GaAs
- III-V multijunctions deliver 30%+ efficiency, at high cost
- Perovskites promise very high specific power and low-cost, flexible formats
- Stability, encapsulation, scale-up and qualification decide whether they fly

Is the next space race PV in space?