CASSIOPeiA SPS

Advantages for Commercial Power

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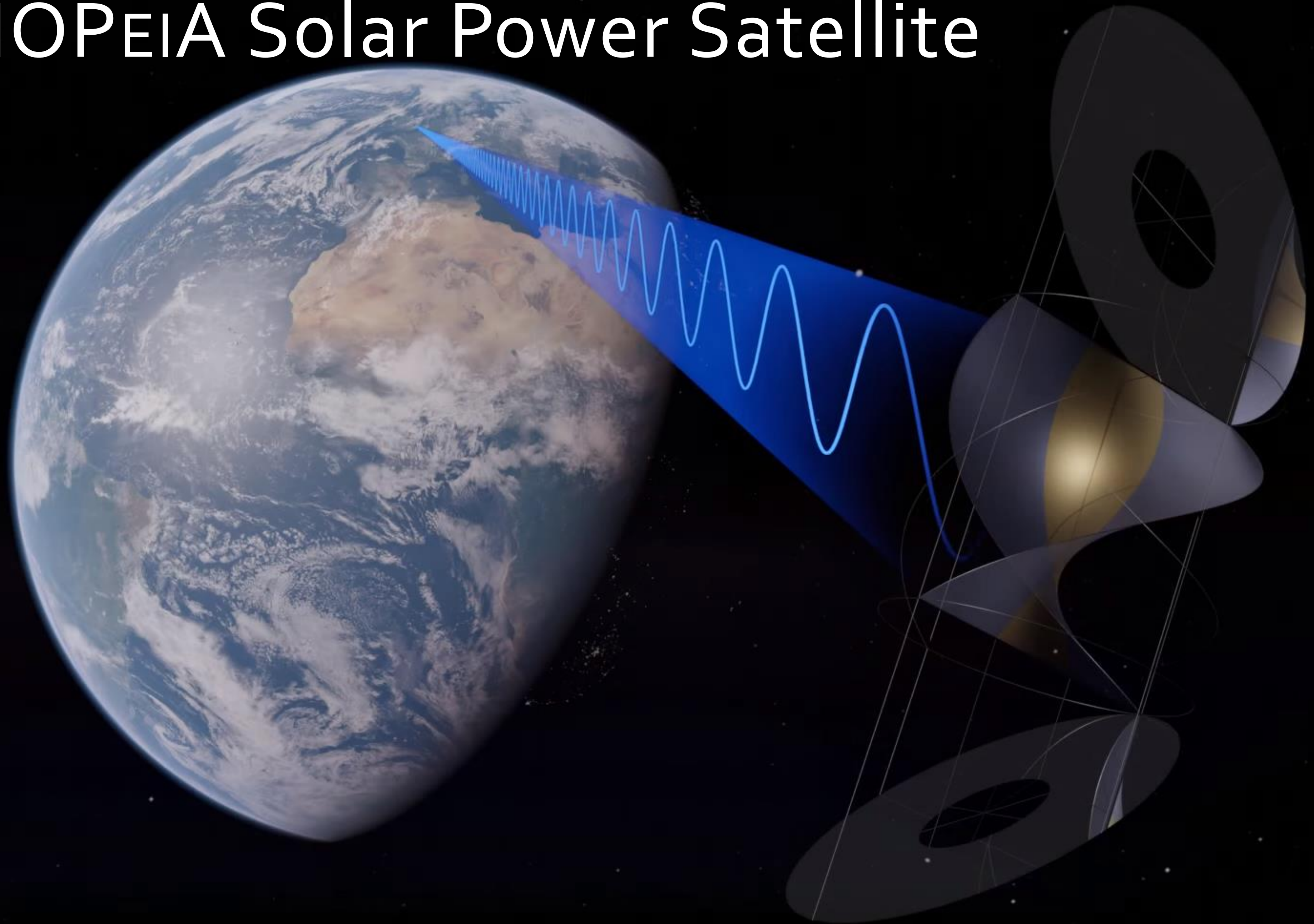
INTERNATIONAL ELECTRIC

ISDC 2022 – May 26th 2022

CASSIOPeiA Solar Power Satellite



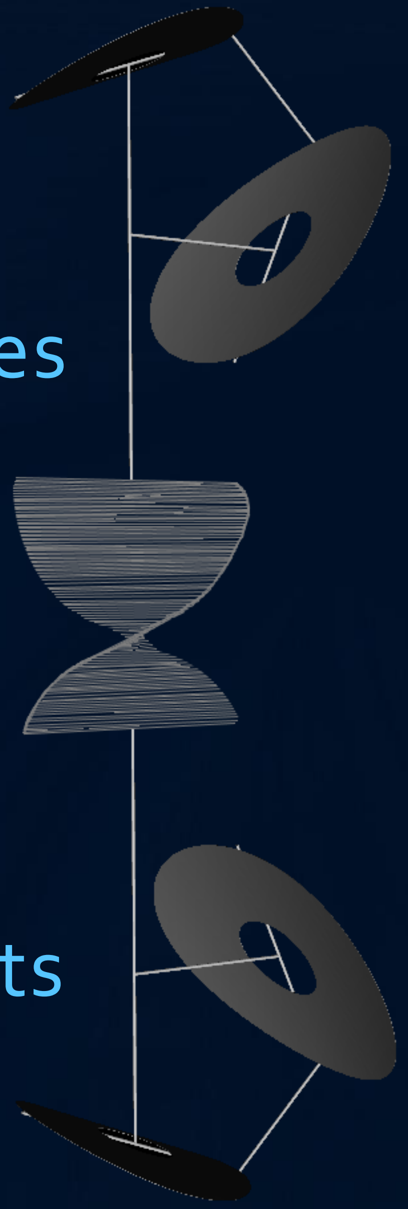
Constant Aperture, Solid-State, Integrated, Orbital Phased Array

Why Don't We Already Have Space Solar Power?

- Historic high cost of space launch
- 1970's oil crisis postponed by 50 years
- Inability to commence at smaller power scales

So Why Is Now The Right Time?

- New-Space RLVs are slashing costs
- Imperative of Climate/Energy emergencies
- PV / RF materials & technology improvements
- CASSIOPEIA mass & scalability advantages



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The Reusable Space Launch Revolution

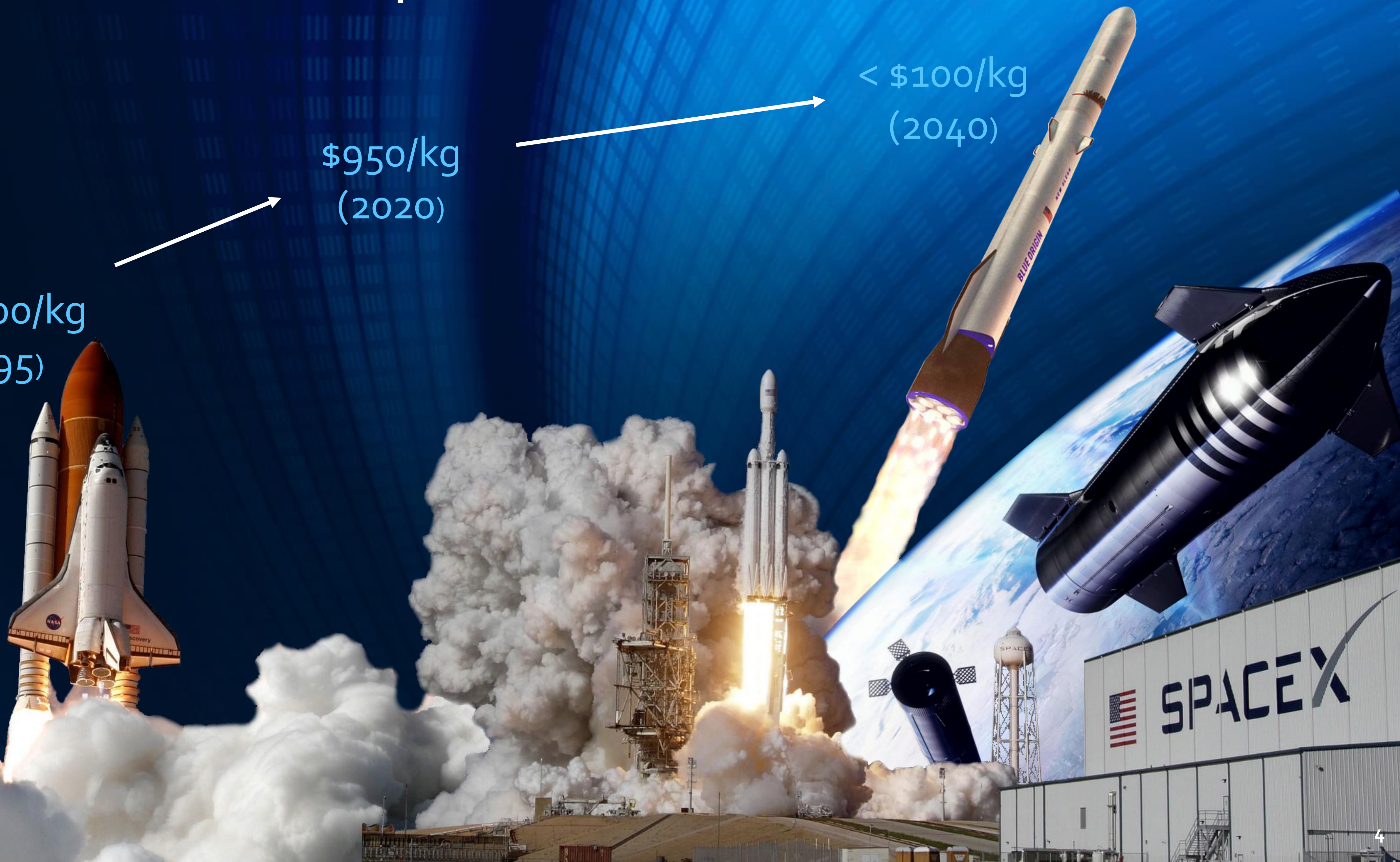
[LEO payload launch costs]

$85,000/kg (1981)

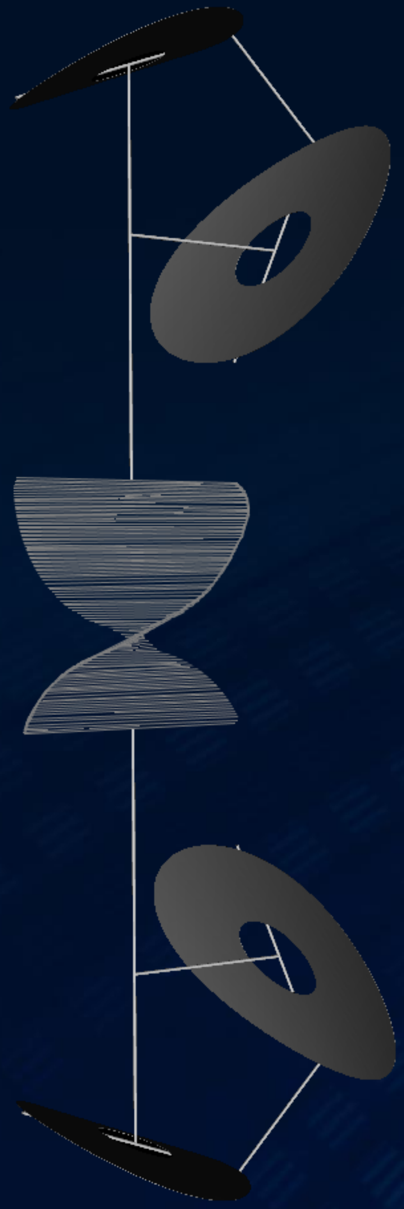
$27,000/kg (1995)

$950/kg (2020)

< $100/kg (2040)

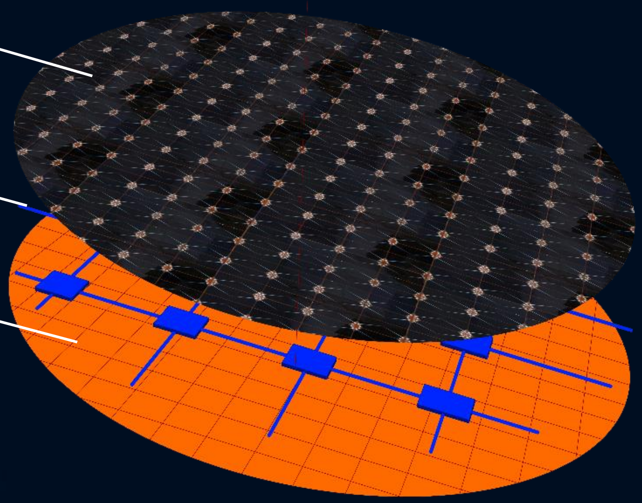


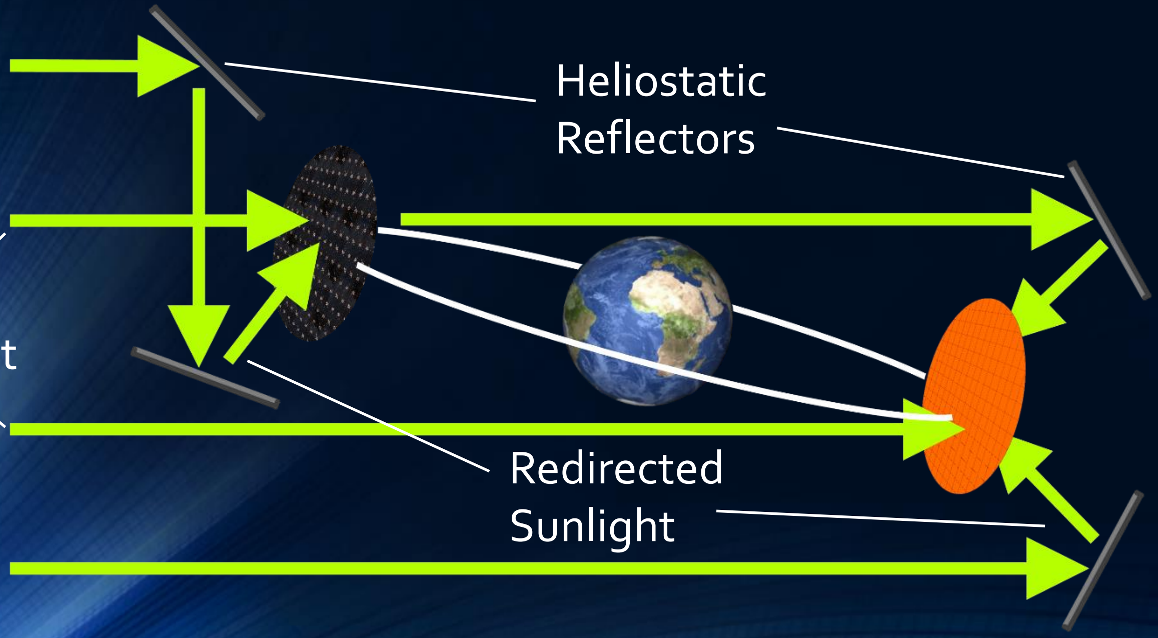
Key Requirements for Commercial Space Solar



- Payload launch costs are already viable ✓
- Maximise Specific Power – 1 MW/tonne aspiration
- Maximise Utilisation – ideally 24/365 dispatchable; batteries are too expensive, too resource intensive
- Start smaller, not gigawatts from GEO – more investable from outset, with earlier returns
- Modular assembly across all scales – advantage of mass production, proven technology
- Operable in multiple orbits – global marketplace

Towards High Specific Power – Sandwich Panels





- PV and RF apertures matched; power distribution measured in mm and volts, not kilometres and kilovolts ✓
- Reduced mass through shared structure, elimination of electro-mechanical articulated joints ✓
- Solar concentration increases PV efficiency ✓
- Direct sunlight on transmit face is unwanted thermal load, limiting concentration to 3-suns approx. ✗
- Sunlight converges from wide, variable angle – preventing use of High Concentration PV (HCPV) ✗
- Earth-facing, high-inertia sandwich panel restricts to circular orbits ✗

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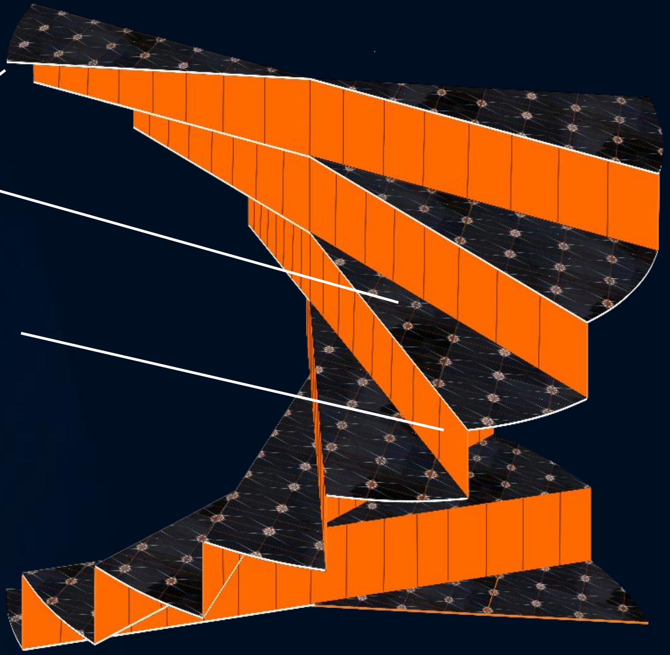
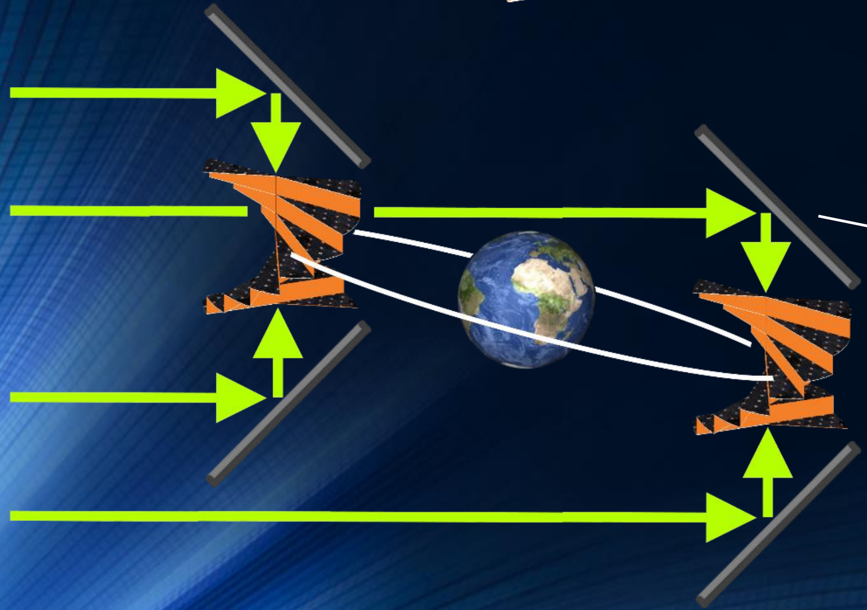
Highest Specific Power – CASSIOPEIA Array





- All the advantages of a Sandwich Panel ✓
- Further mass reduction through elimination of excess reflector area, heliostat bearings, motors, etc. ✓
- Doubled solar aperture increases power without additional structure ✓
- Minimal direct sunlight; 4-sun system concentration within thermal limits ✓
- Retained collimation enables power & efficiency gains of HCPV ✓
- Sun-facing, solid-state design circumvents momentum constraints for operation in all useful circular and Highly Elliptical Orbits (HEOs) ✓

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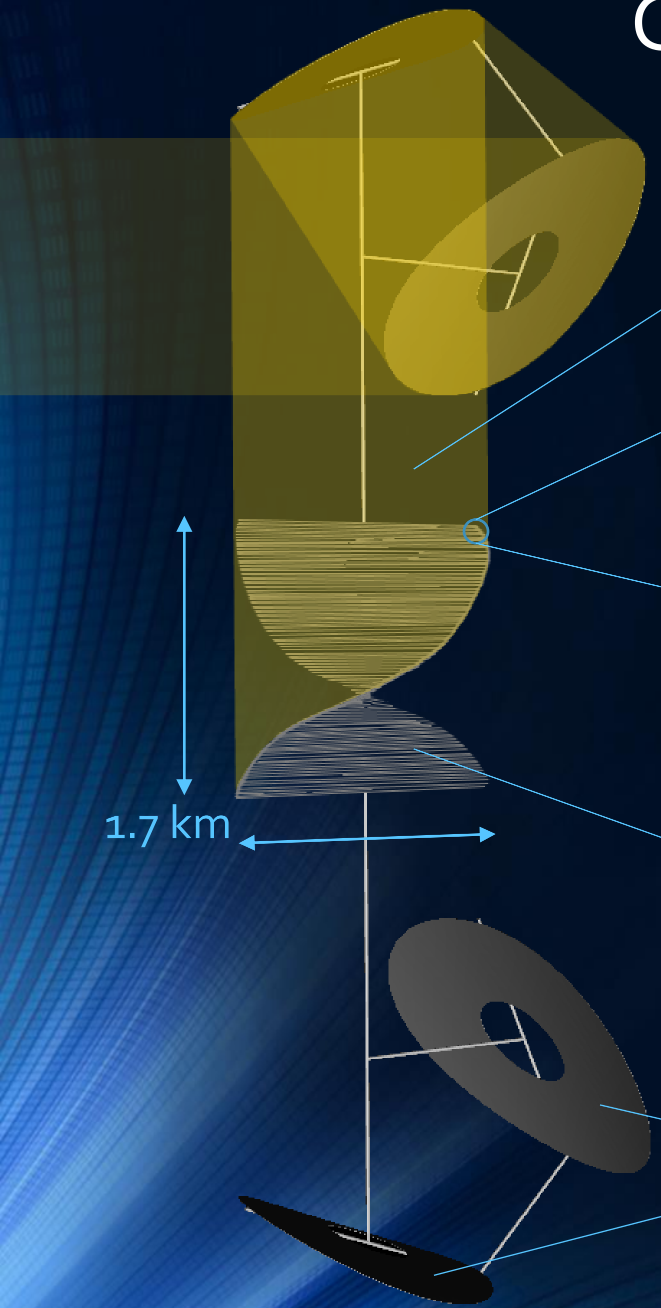
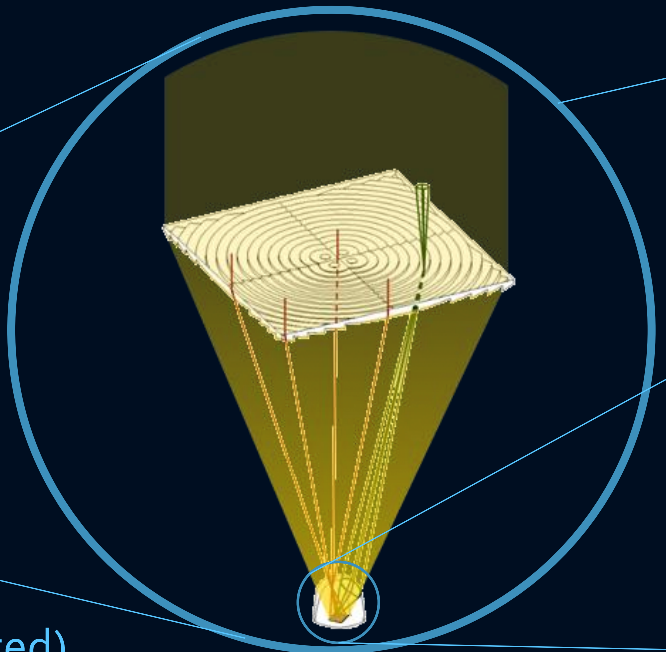
CASSIOPeiA SPS Can Achieve 1 MW / tonne ✓



×2 concentrated, collimated sunlight

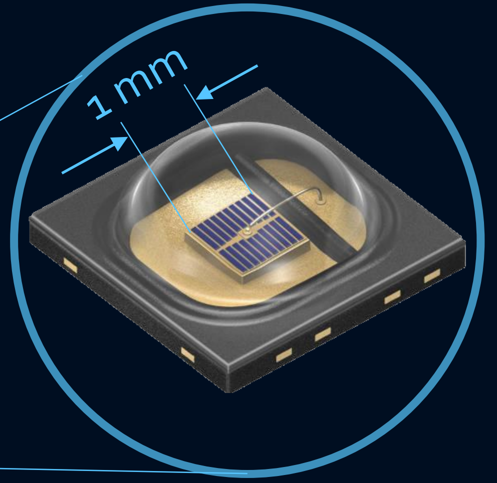
Helical array (patented) comprises 50,000 thin PV/RF layers, always edge-on to the Sun

Solid-State Symmetrical Concentrator (SSSC):
Conical, non-rotating thin film solar reflectors (patent pending)



Further ×250 microscale solar concentration

15 billion H-CPV chips



Main SPS Features:

- 2,000 tonnes in GEO (with other orbits & scales), rotating once-per-year to always face the Sun.
- 11.3 GW sunlight concentrated by dual primary reflectors, re-collimated by secondary reflectors.
- Novel helical antenna (GB2563574) electronically steers through 360° to target the rectenna.
- 2 GW delivered to grid, on-demand, 24/365

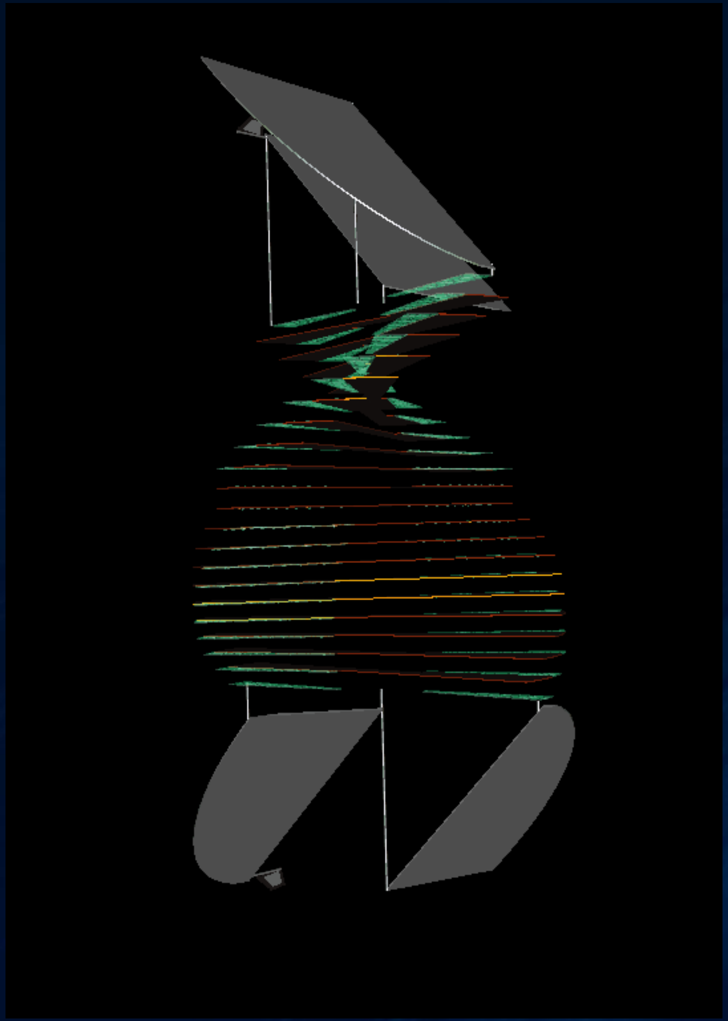
Considerations for Smaller-Scale Microwave SBSP

- **Surface peak RF intensity:** the regulatory limit* becomes the economic optimum, having minimum rectenna area
- **For linked solar and RF apertures:** at any given wavelength and beaming distance there results an optimum beaming power – typically gigawatt(s) at GEO distance
- **Only three options exist to downscale SPS power:**
  1. Reduce wavelength – with significant atmospheric losses above 10 GHz / below 3 cm (5.8 GHz may be preferable limit)
  2. Reduce beaming distance, i.e. non-geostationary orbits
  3. Provide concept variants with differing solar:RF aperture ratios

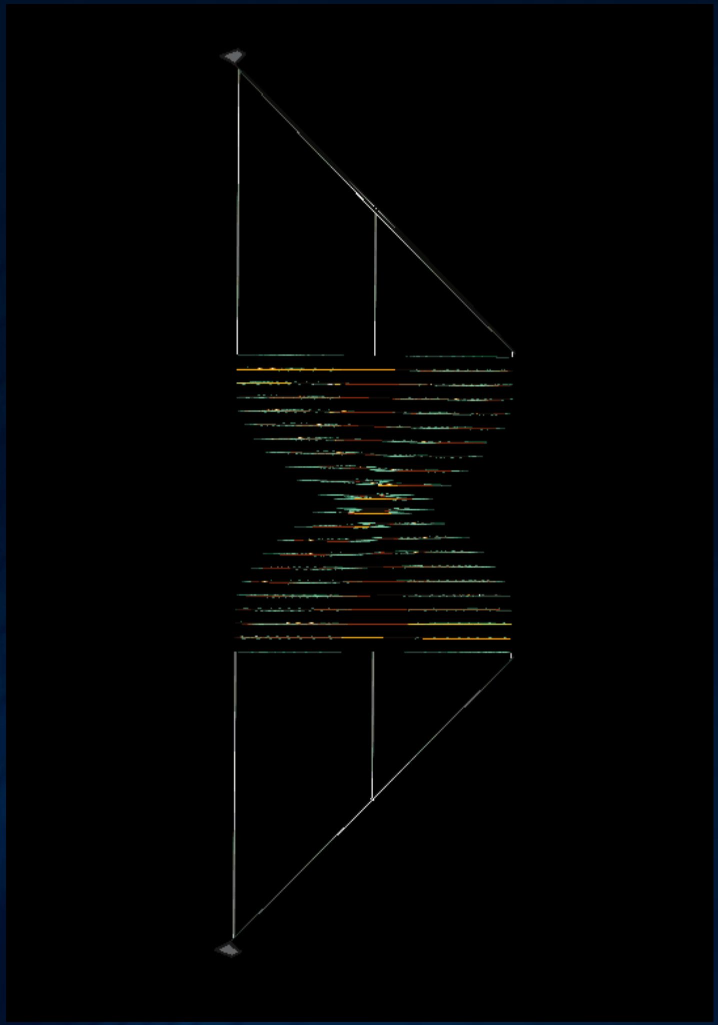
[* 230 W/m^2 RF is likely]

CASSIOPeiA SPS Reflector Variants

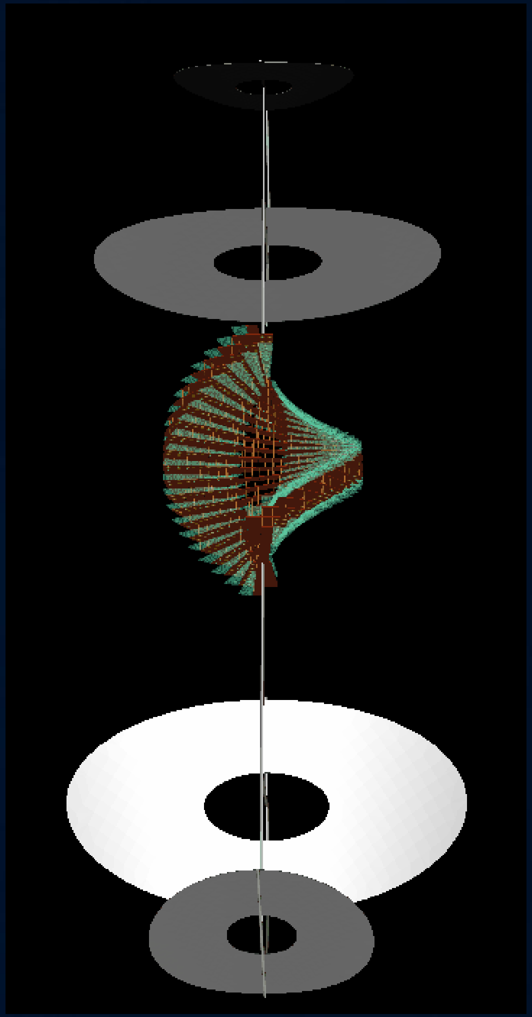
Planar Quadrant (1-sun)



Planar Full (2-sun)



SSSC (4-sun)



[SSSC: Solid-State Symmetrical Concentrator – Patent Filed WO 2019/162679]

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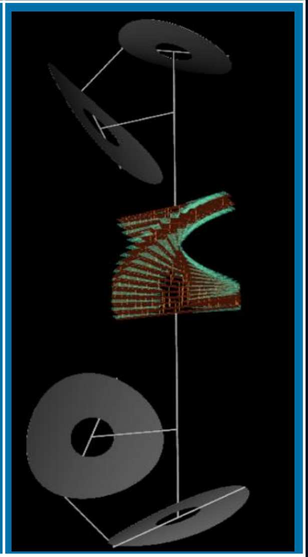
CASSIOPeiA SPS Variants & Power Scalability ✓

VARIANT

x4 Concentrator:

Highest specific power, approaching 1 MW per tonne.

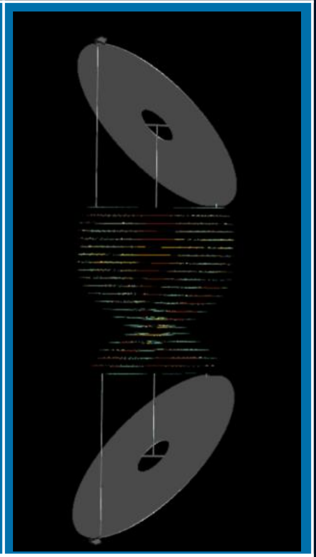
Best for highest power, lowest energy costs.



x2 Full Planar:

Good specific power, approaching 800 kW per tonne.

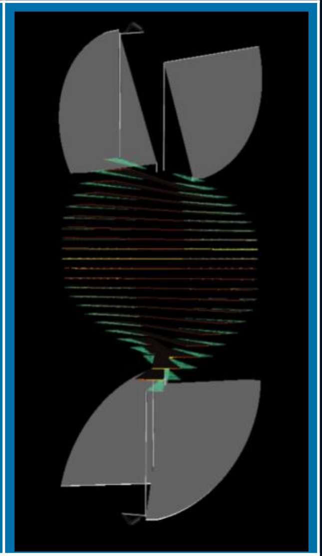
Optimises at medium power levels.



x1 Quad-Planar:

Lower specific power, approaching 660 kW per tonne.

Best for minimum mass, lowest capital costs.



Relative optimised delivered power for each variant from a particular orbit, at selected microwave frequency:

	x4 Concentrator	x2 Full Planar	x1 Quad-Planar
2.45 GHz	100%	72%	53%
5.8 GHz	42%	30%	22%

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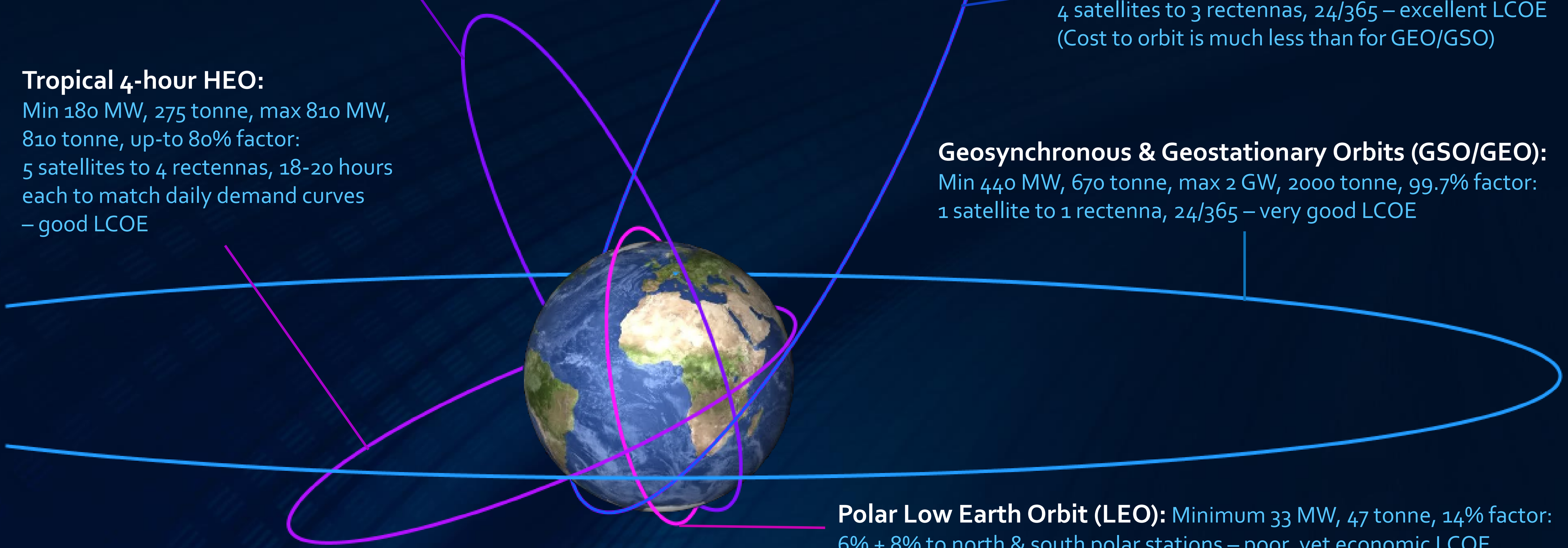
CASSIOPeiA Orbits for Commercial Power Delivery ✓

North/South 4-hour Highly Elliptical Orbit (HEO):
Min 180 MW, 275 tonne, max 810 MW, 810 tonne, 53% factor:
4 satellites to 3 rectennas, 52 hours/day shared flexibly, including 24 hours to one region – reasonable LCOE

North/South 8-hour HEO: Min 310 MW, 470 tonne, max 1.4 GW, 1400 tonne, 75% factor:
4 satellites to 3 rectennas, 24/365 – excellent LCOE
(Cost to orbit is much less than for GEO/GSO)

Tropical 4-hour HEO:
Min 180 MW, 275 tonne, max 810 MW, 810 tonne, up-to 80% factor:
5 satellites to 4 rectennas, 18-20 hours each to match daily demand curves – good LCOE

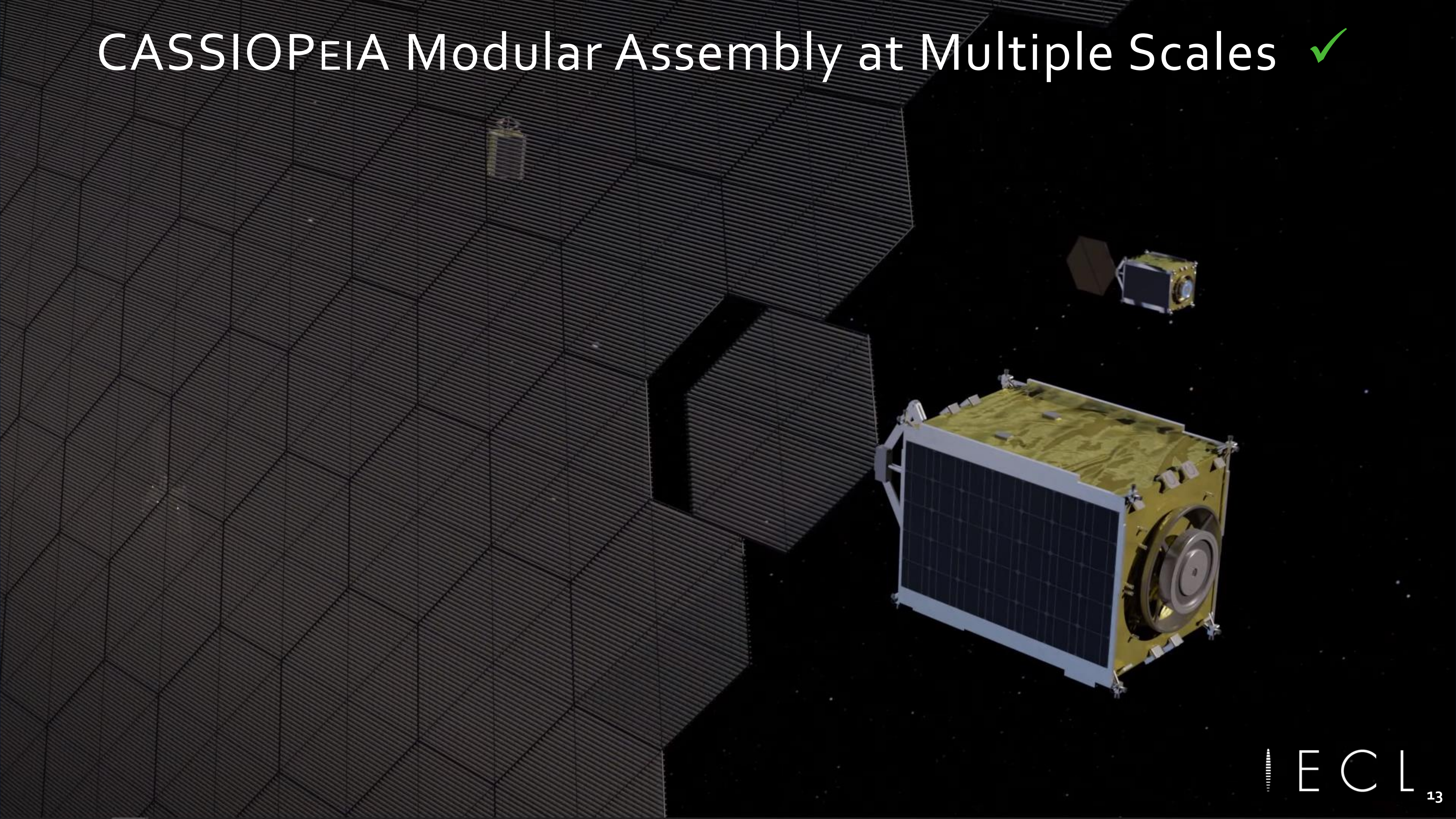
Geosynchronous & Geostationary Orbits (GSO/GEO):
Min 440 MW, 670 tonne, max 2 GW, 2000 tonne, 99.7% factor:
1 satellite to 1 rectenna, 24/365 – very good LCOE



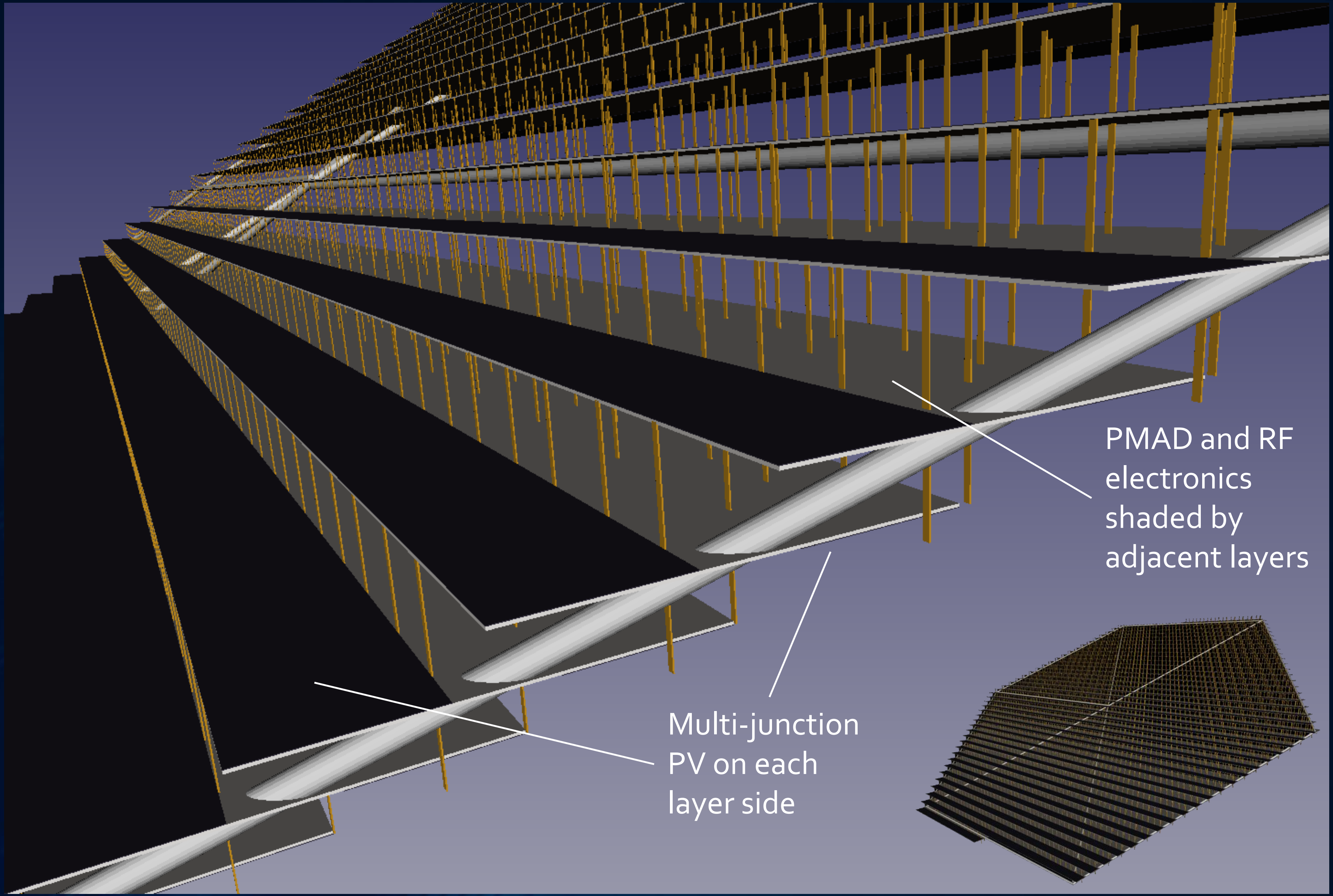
Polar Low Earth Orbit (LEO): Minimum 33 MW, 47 tonne, 14% factor:
6% + 8% to north & south polar stations – poor, yet economic LCOE

[Orbits are to scale]

CASSIOPeiA Modular Assembly at Multiple Scales ✓

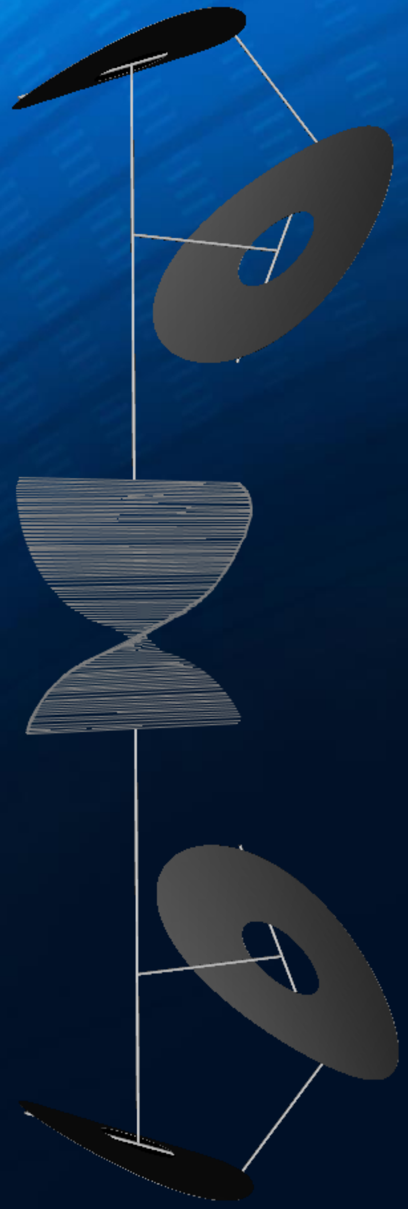


CASSIOPeiA Metre-Scale Module Close-up (PV Variant)



Requirements Met for Commercial Space Solar

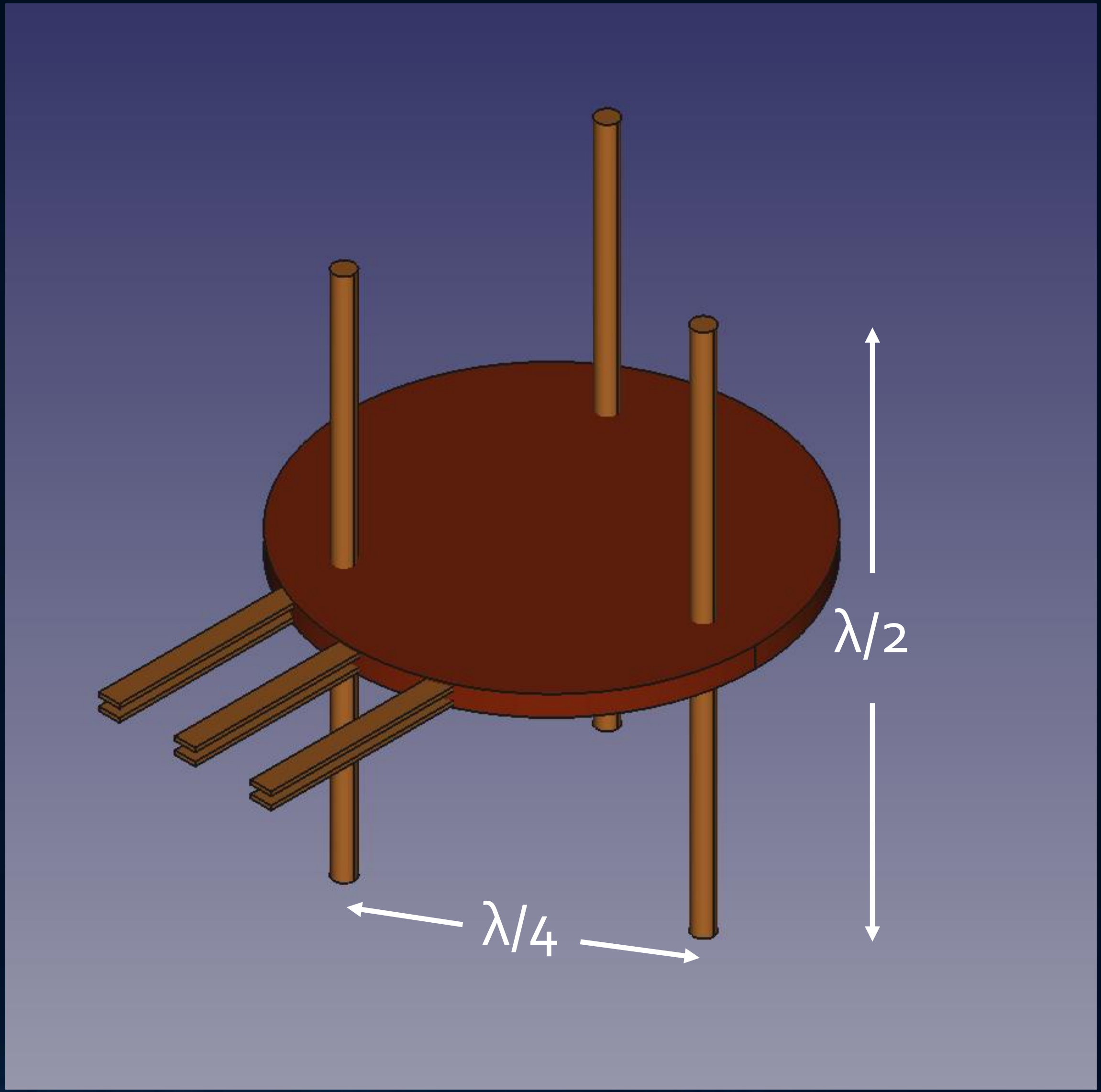
- Payload launch costs are already viable ✓
- Maximise Specific Power – 1 MW/tonne ✓
- Maximise Utilisation – 18 to 24 hours per day ✓
- Start smaller, not gigawatts – 180 MW ✓
- Modular assembly across multiple scales – small number of mass-produced module types ✓
- Operable in multiple orbits – including HEOs ✓



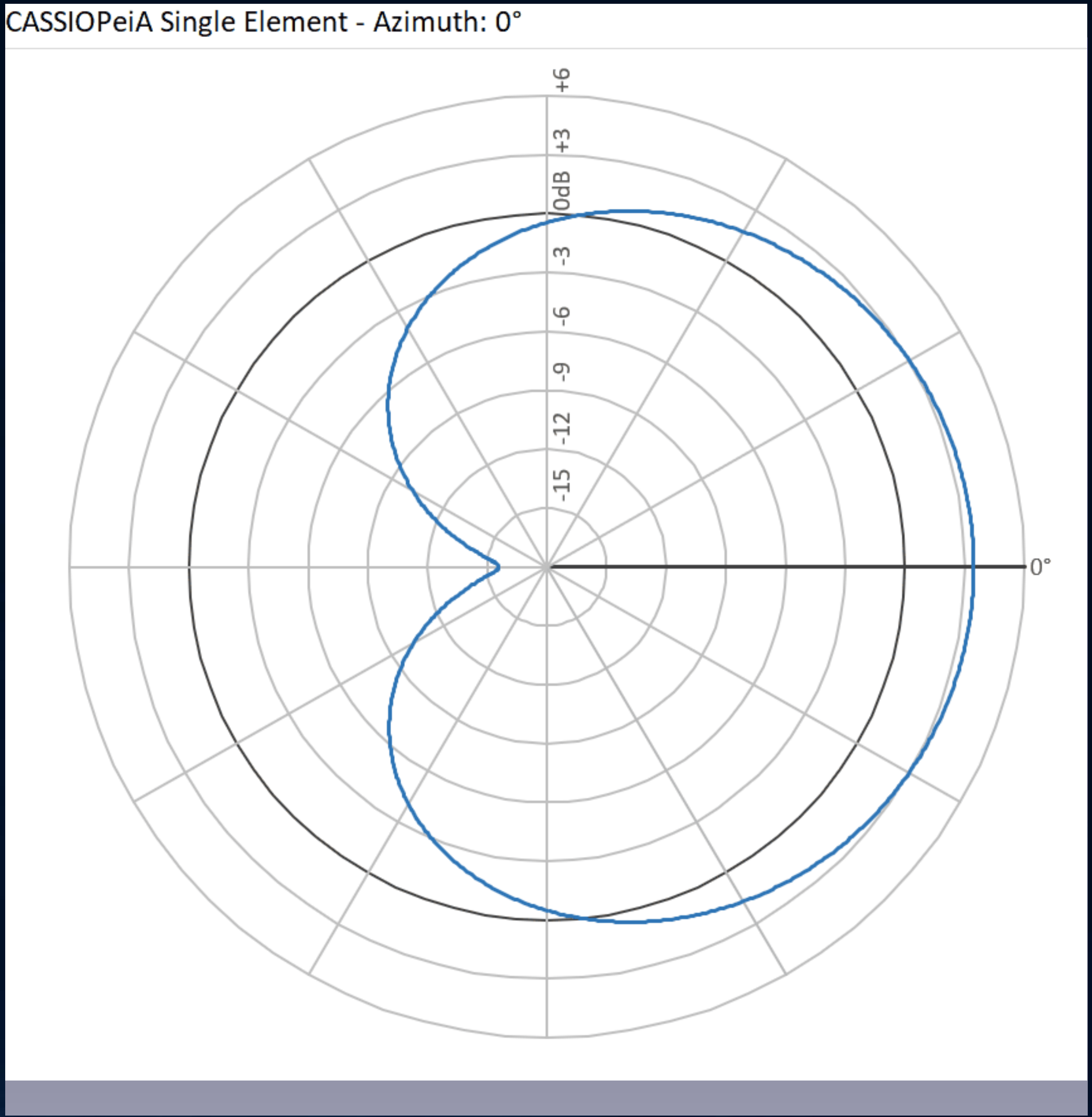
Questions?

Supplementary:

360° Steering at RF Element Scale



360° Steering at RF Element Scale



Cardioid Pattern:

Steerable null replaces the rear reflector (necessary with other phased array designs)

CASSIOPeiA Constant Aperture Phased Array

56x88 Elements – Independently Validated: U. Strathclyde, UK