Tech Brief:
Orbital Data Centers – Logistics

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Orbital Data Centers vs Terrestrial Data Centers

Factor	Space-Based Data Centers	Terrestrial Data Centers
Energy Availability	Continuous, uninterrupted solar power (polar orbit) gigawatt-scale potential ($0.01 per kWh)	Dependent on local grids; rising energy constraints ($0.05 to $0.15 per kWh)
Cooling Efficiency	Radiant cooling in vacuum of space - efficient heat dissipation (weight	Requires massive water and/or HVAC systems; costly
Latency	High latency for Earth-bound users; good for orbital edge computing	Low latency; close to users and fiber networks
Scalability	Vast physical space; no land constraints	Limited by land, zoning, and environmental impact. Ocean/Submerged data centers as an alternative
Deployment Cost	**Highly sensitive to Launch Costs**, early-stage technology with resulting R&D costs	Mature, cost-optimized industry
Environmental Impact	Reduces Earth-based energy/water use; but has launches emissions and **end-of-life disposal issues**	High energy and water consumption; noise and land use issues
Silicon - GPU/CPU	Early reuse of exiting silicon (radiation issues), industry maturity will require rad hardening and power savings	Commercial CPU/GPU optimized for terrestrial deployment - not optimized for power savings

High-Density Modular "Compute Tiles“ Space-based data center architecture [Thales Alenia Space]

Key Stake Holder Constellation Plans

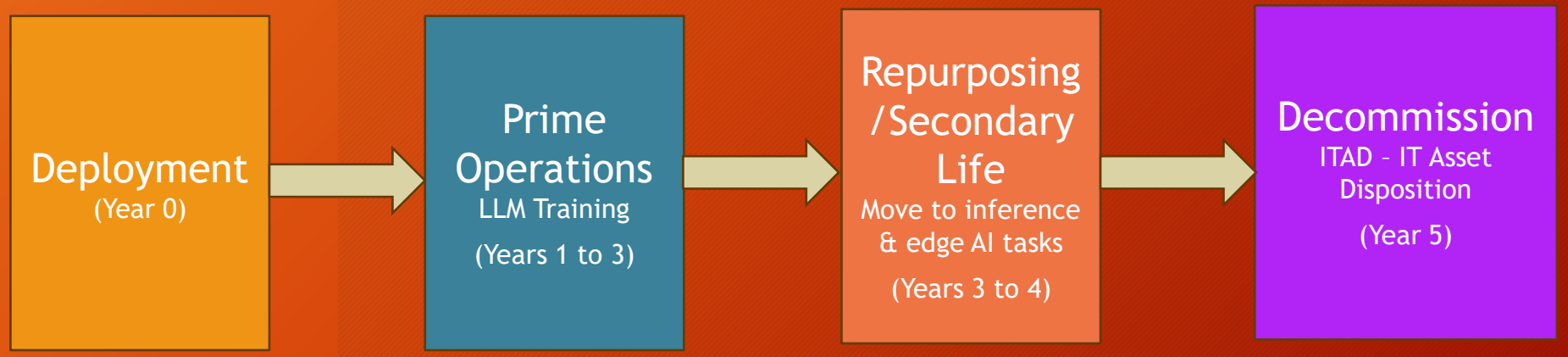
Polar Dusk-Dawn Line Orbit [Starcloud]

Company/ Constellation	FCC Filing	Number of Satellites	Planned Orbital Planes
SpaceX	X	1,000,000	500 – 2,000 km Polar & 30 degree 50Km (between orbital planes)
Starcloud	X	88,0000	600-850 km Polar (multiple orbital planes)
Blue Origin /Amazon "Project Sunrise"	X	51,600	500 and 1,800 km Polar (multiple orbital planes)
Google with Planet Labs "Project Suncatcher"	N/A	N/A	Orbital AI edge commuting tests of Google TPU AI ASIC
Technology Dev. Companies: Sophia Space, Axium Space, Aetherflux … and more coming	N/A	N/A	TBD

Space-based data centers filings are 2 orders of magnitude greater (100x) than current Mega- communication constellations

AI Data Center Compute Life Cycle

- AI Data Center Blade Lifespan ~ **5 years**
- Performance Obsolescence (The "Nvidia" Effect)
  - Each AI chip generation offers 4x to 5x improvement in processing power
  - A 3-year-old AI chip can be made functionally obsolete (e.g., Nvidia H100 to GB200/Blackwell)

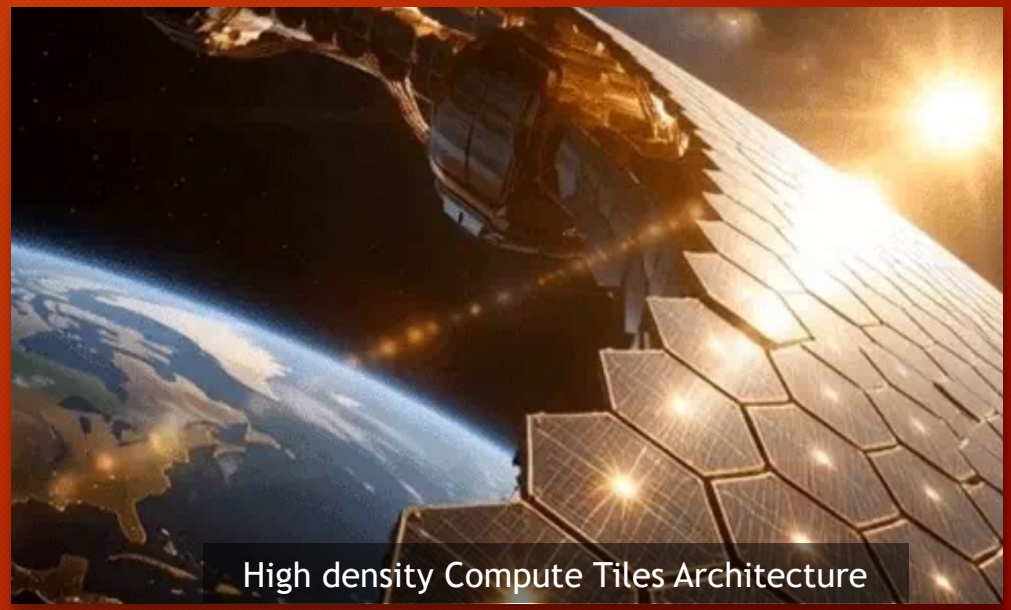


Compute Lifespan and Replacement is a Significant Logistics Issue
What about decommissioning? *Deorbiting pollution or Parking Orbit Junk*

Space Data Center Design

- Three factors drive Space Data Center Design
  - **AI ASIC power consumption:** 1.5kw moving to 3kw per ASIC
  - **Solar Panel Area:** 400 to 600 W/m^2 acts as a sun shield for the radiator
  - **Radiator:** (sunshield @ 27 deg C) 450 W/m^2 one sided to 900 W/m^2 two sided – ammonia fused for heat transfer
- Space-Based Constellation Architectures
  - Distributed "Compute Constellations" (Mesh Networks)
    - Clusters of modular laser-linked AI satellites act as an orbiting node
    - Multiple nodes on multiple orbiting planes make the constellation
    - Proposed by: SpaceX, Google Suncatcher, & Starcloud (Stem & Leaf)
  - High-Density Modular "Compute Tiles”
    - Large-scale satellite node composed of integrated AI ASIC(s), Solar, cells and radiator tiles
    - Multiple nodes on multiple orbiting planes make the constellation
    - Proposed by Sophia Space, and Axiom Space
- Hybrid Earth-Space Architecture for the entire system
  - Edge AI in LEO, non-latency-sensitive workloads in SPACE, and latency-sensitive tasks in EARTH-based data centers
- Sun Suunchronus Orbits (polar dusk-dawn) from 500km to 2000km
  - Majority of constellations will be above 700km for lower drag, decreased fuel budget, and long orbital life (25+ years at 700km to >1000 years at 2000km)

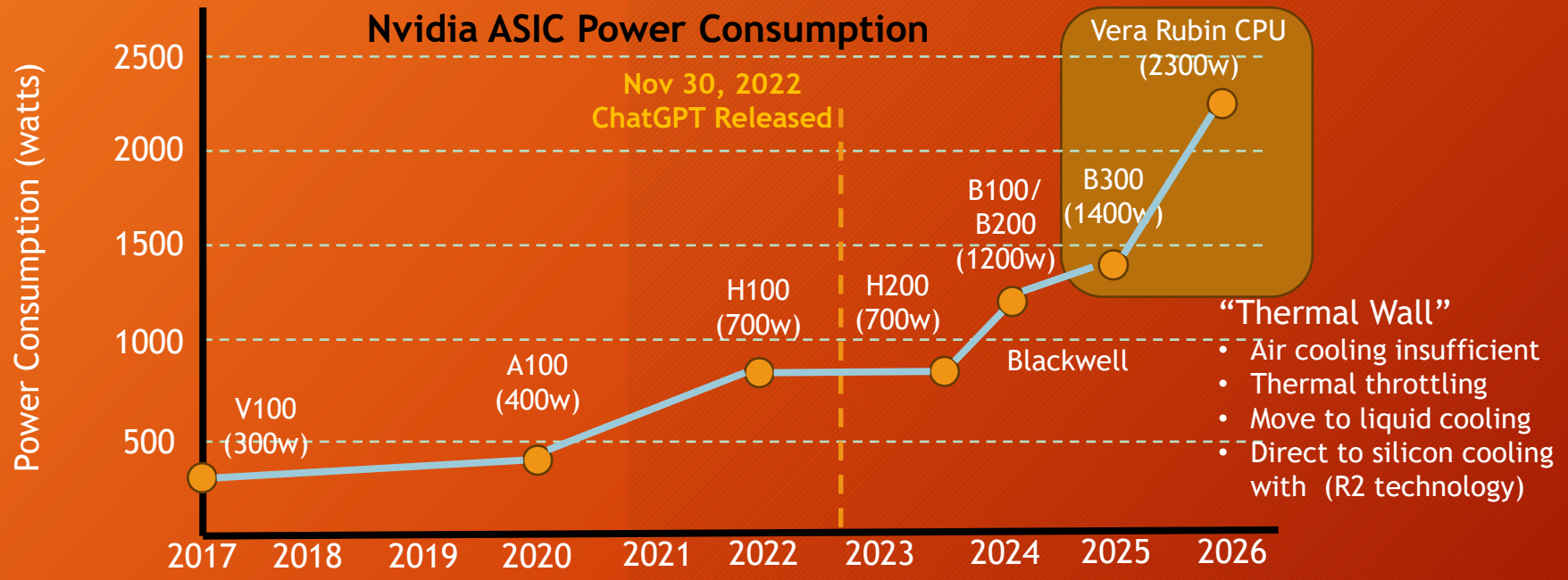
Distributed Modular Compute Constellation



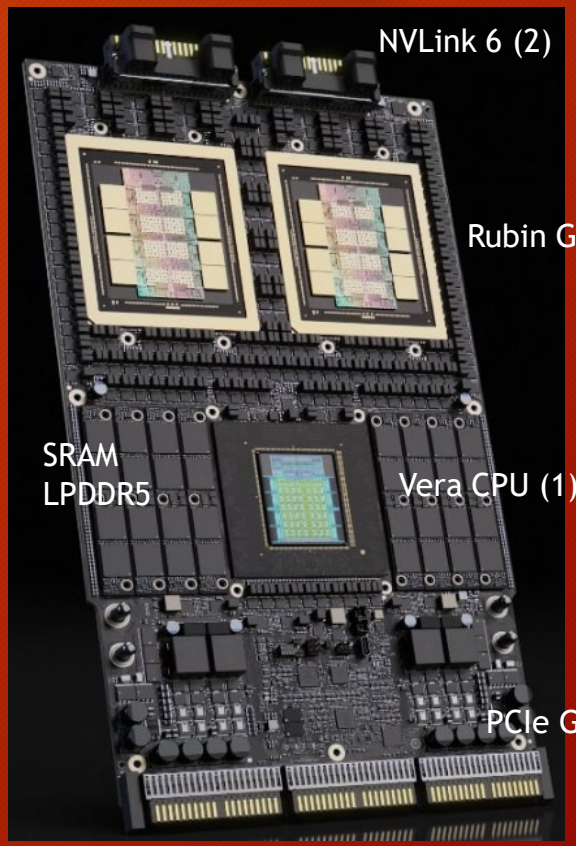
High density Compute Tiles Architecture

AI ASIC Power Consumption: The Driver of All Space-Base Data Center Design

- Horizontal & future wafer scale integration are driving 40% increase in AI CPU ASIC Platform power per year - **Focus is on Performance NOT Power**
  - Power is increasing despite Moore's Law improvements in silicon process nodes
- Each kW of power drives 2.5 m^2 solar and 2.25 M^2 single sided radiator
- Note: Intel, AMD, SpaceX/Tesla, Google, & Amazon have significant multi-generation AI ASIC programs



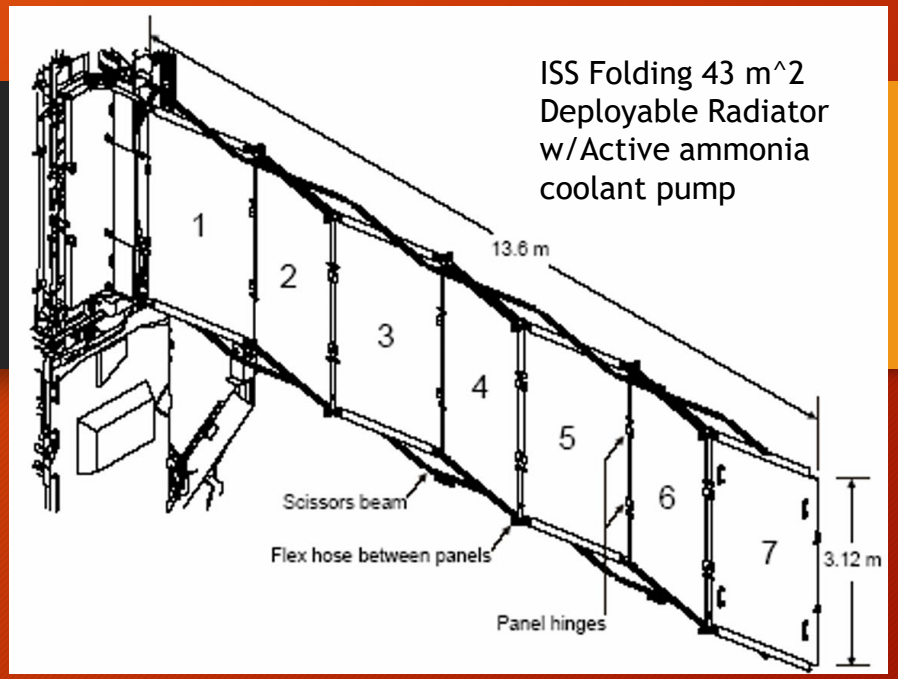
"Thermal Wall"
- Air cooling insufficient
- Thermal throttling
- Move to liquid cooling
- Direct to silicon cooling with (R2 technology)

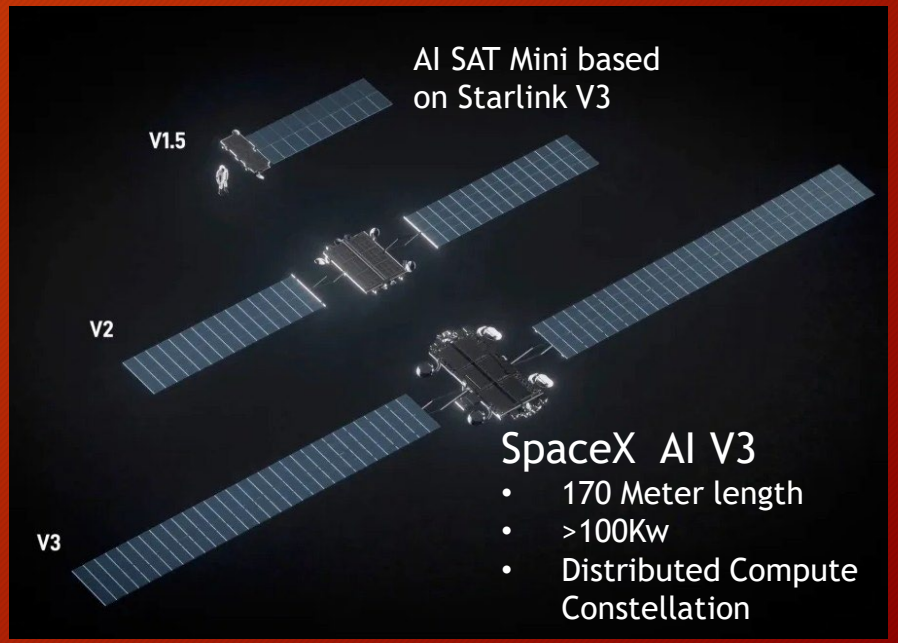


Vera Rubin Super Chip Platform based on TSMC's 3nm (N3P) [Nvidia]

Space-Based Radiators

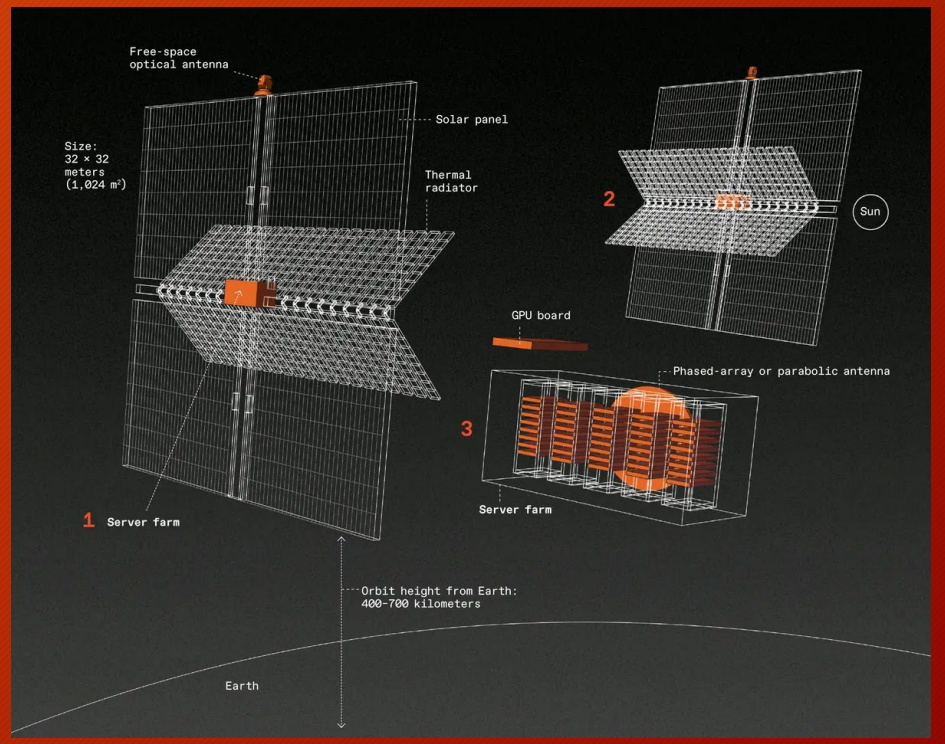
- Cooling in space is based on infrared radiation
- Solar cells are used as a sun block, providing shade for the radiators (-270 deg C)
- Radiators use Passive or Active heat pipes to distribute heat to the Radiators using Aluminum-ammonia or copper-water working solutions
  - **Passive Heat Pipes** are based on a capillary wick structure to operate in zero gravity
    - **Oscillating Heat Pipes (OHPs):** passive radiators improve weight and performance
    - **Advantage:** Reliable, long life, no active parts, minimum weight, no power load
    - **Disadvantage**: Designed for a fixed thermal load (not variable)
  - **Active Heat Pipes** are based on pumps to move the working fluid
    - **Loop Heat Pipes (LHPs): Capable of transferring higher heat loads over longer distances with high efficiency**
    - **Advantage:** Allows for variable load, more efficient, higher thermal load
    - **Disadvantage**: complex with moving parts, lower reliability, energy use
  - Modern/Lightweight (Carbon-Carbon) radiators 2kg per m^2





Orbital Life Cycle:
A case for modular design in-orbit servicing

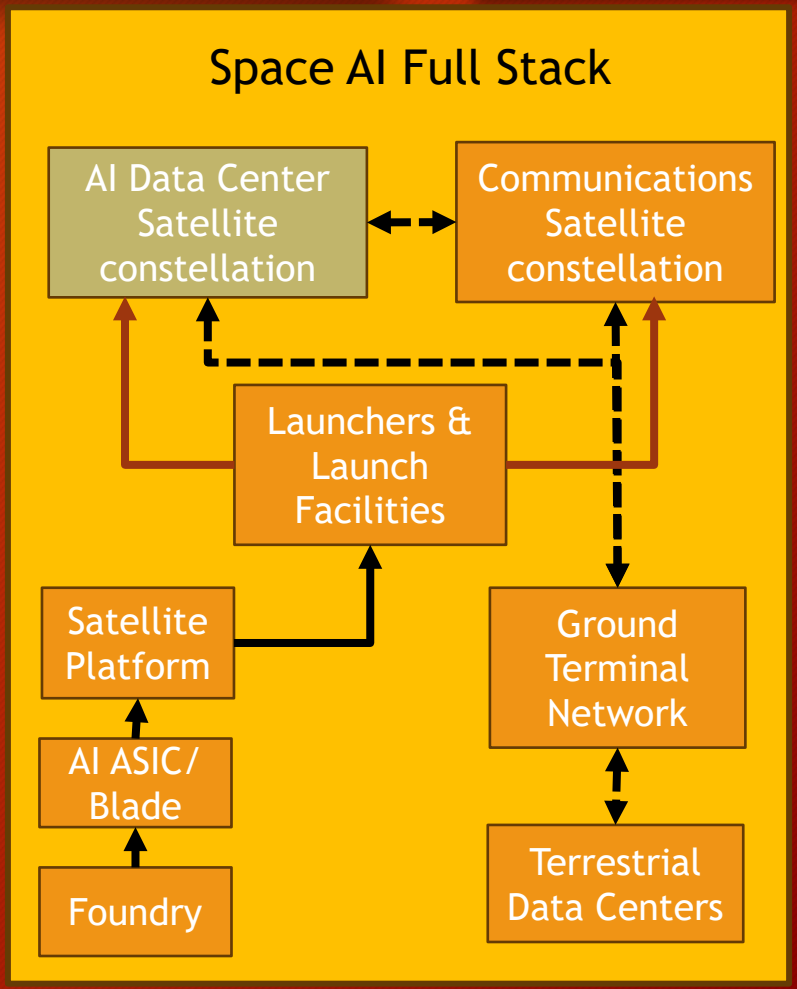
- Majority of space data center satellites will be in orbits between 700 to 2000 Km
  - 25 years till 1000s of years before orbit decay
- Solar Cells, Radiators, have 15 to 25-year lifespan
- AI CPU/Blade, Free Space optics,& station keeping propellant have short lifespans Short Lifespan components (~5 Years):
- Clearly a modular design using solar cells/radiators as a backbone skeleton could cut down decommissioning waste
  - A 5-year replacement cycle using am in -orbit replaceable server farm module
  - The old module would be decommissioned (deorbit or parking orbit) and replaced by a new module
  - The replacement module would upgrade CPU/Free Space Optics recharge propellant and radiator working fluid
- A modular replaceable architecture will reduce the mass to orbit life cycle costs



Large-scale Data Center Satellite with Replaceable Server Farm module

The Vertical Integration Advantage

- Launch costs of <$300/kg are required for an economically viable space data center deployment
  - In the near-term, SpaceX Starship and the next generation Blue Origin are only launch vehicles that can meet launch cost goals(an 8x reduction from current launch costs)
- SpaceX and Amazon/Blue Origin can leverage their “full stack” capabilities to deliver the vision the space-based data center vision:
  - Launch vehicles and launch cadence build out their respective constellations
  - Exiting satellite communications and ground station network Starlink & Amazon LEO
  - Terrestrial Data Centers and AI business and partnerships
  - Mature, well-funded custom AI chipset development programs
- Despite these leveraged capabilities, large opportunities exist in the ecosystem and niches:
  - Chipsets and Foundries: TSMC, Intel, Nvidia, AMD, etc.
  - Earth Observation edge compute AI (Nvidia Jetson-Orin & Thor, & alternates)
  - Full-stack supply chain – optical terminals, thrusters, etc
  - Alternate launch services: Rocket Labs, Firefly, etc.
- Breaking news - Google/Alphabet rumored to be in talks with SpaceX for launch and communications services for its own Space -ased Data centers

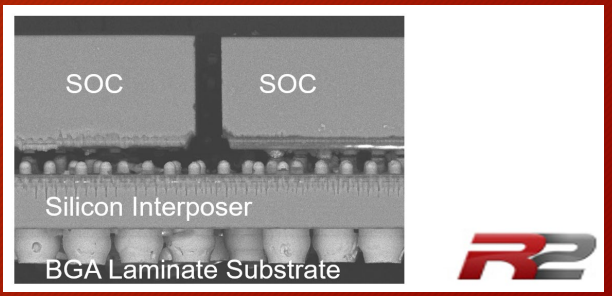


Custom Space-Based AI/CPU – Why Terafab?

- Early Space Applications are testing existing Core and Edge AI ASICs
  - Design for Performance Not Power Savings
  - Physical Shield and ecrror detection and correction SW
- Custom AI ASICs using advanced fab tech (e.g. R2 silicon Imposer), & advance system wide ECC offer significant power and radiationa effect improvements
  - R2 silicon imposer reduces power consumption by 50%
  - R2 tech licensed by Intel & Samsung
- SpaceX $130M+ Terrafab project will use Intel A14 (1.4nm) process technology
  - Armed with R2 technology – double the compute power for a given AI satellite Power configuration

Radiation Effects on 2n m ASICs

- **Single Event Effects (SEE):** single high-energy particle note strike
- **Multi-Bit Upset (MBU):**single strike with multiple failures and ECC failure
- **Single Event Latch-up (SEL):** Hardware failure/destruction
- **Total Ionizing Dose (TID):** cumulative damage from long-term exposure – causes power leakage



Thank You

Space is the new theater of war, and EO Reconnaissance and Edge AI are critical for US and Allied deterrence. Find out more in my new book:

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