

Extraterrestrial Data Centers and the Gravitational Pull From Unresolved Legal and Regulatory Issues



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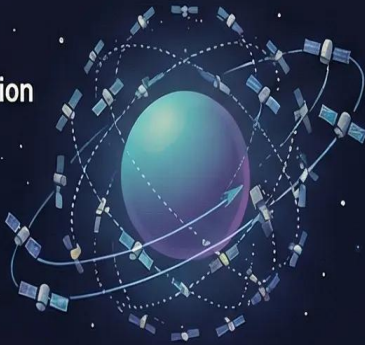
The Orbital Cloud: AI's Next Frontier

As terrestrial AI demand outstrips Earth's power and cooling capacities, a new "space race" for orbital data centers has emerged. By leveraging constant solar energy and the vacuum of space for passive cooling, companies are building a decentralized cloud infrastructure beyond the atmosphere to support the next generation of AI.

Building the Orbital Infrastructure

SpaceX's Million-Satellite Constellation

A massive filing to the FCC seeks approval for 1 million AI-processing satellites.

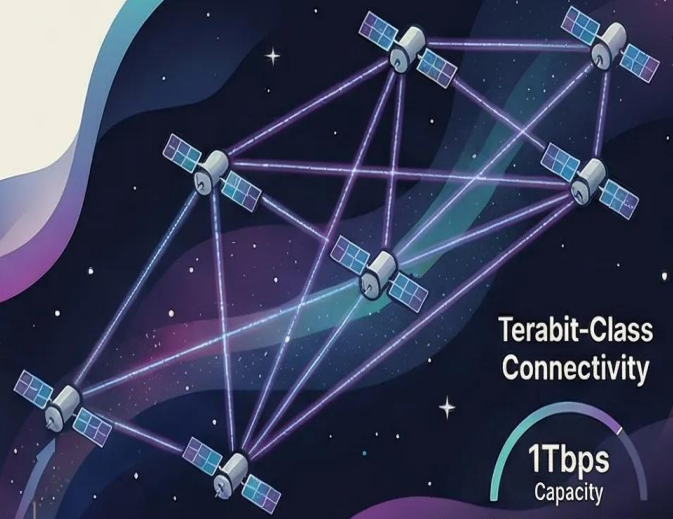


High-Reliability Space Hardware

New AMD Class Y SoCs are engineered to survive harsh radiation for 13-year missions.



AMD Class Y SoCs



Terabit-Class Connectivity

1Tbps Capacity

High-speed laser links for mesh networking, Starlink V3 satellites.

The Terrestrial Bottleneck

30x Increase in Power Demand

US AI data center power usage is projected to surge from 4GW to 123GW by 2035.



105°C
(Earth-bound GPUs)

The Cooling Crisis

Earth-bound GPUs reach 108°C, space provides an "infinite heat sink" via radiative cooling.



Unfiltered Solar Energy

Space-based solar arrays are 80% more efficient and operate without weather or night cycle interruptions.

Upcoming Space-Based Computing Milestones



2025 (In-Orbit Test Complete): Starcloud-1 | NVIDIA H100 GPU



2027 (Prototype Launch): Google Project Soncatcher | Tensor Processing Units (TPUs)



2027 (Deployment): AxQDC Node (ISS) | Phison SSDs & Microchip SoCs

The Main Points

Ever growing demand for cloud storage and AI applications has stimulated a gold rush proliferation of terrestrial data centers (“TDCs”).

The Court of Public Opinion has quickly pivoted from disinterest, or support to “not in my backyard,” and even “not on my planet you bastards.”

A growing list of concerns: upward pressure on retail electricity, water, and residential housing prices, environmental harm, likely market domination of AI markets by a few “Big Tech” incumbents, and doubts whether data centers support the local economy after the initial construction phase.

Shifting data centers from earth to space has become an alternative touted as solving concerns without generating new ones. In sun synchronous, low Earth orbit, orbiting data centers (“ODCs”) may have comparatively less environmental impact and lower power and coolant costs.

The Main Points

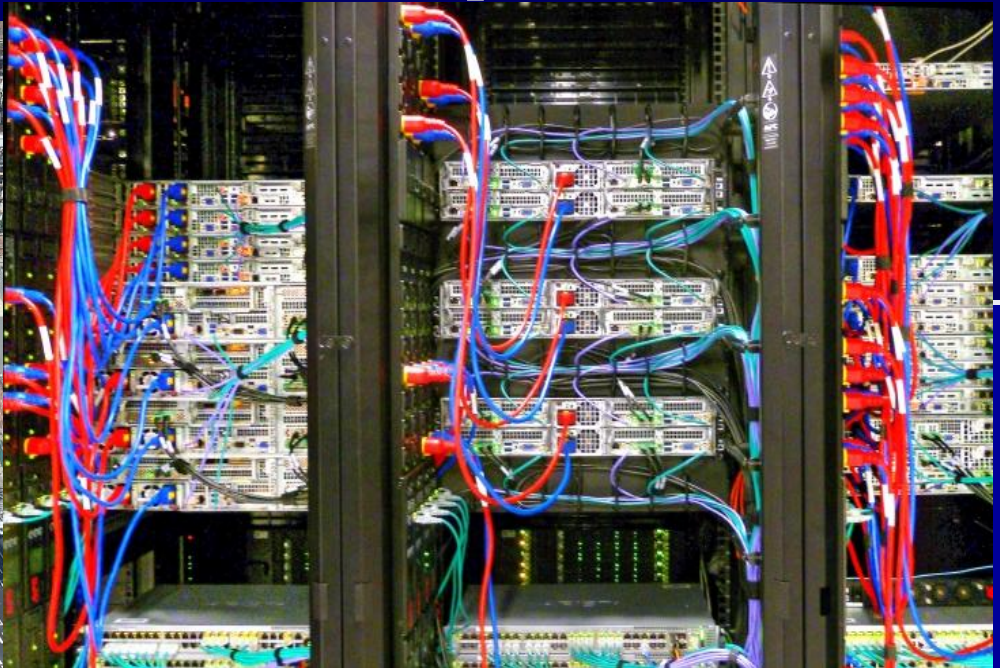
However, there are many countervailing factors, largely ignored or discounted, including rising regulatory, space governance, and treaty compliance costs.

This presentation provides a SWOT analysis and assesses future ODC viability.

ODC exuberance may migrate to cautious optimism based on more realistic assessment of risks and rewards. Space is not a deregulatory safe harbor.

Challenges include: unavoidable government oversight; spectrum and orbital coordination obligations, spacecraft collision potential, proliferating space debris, weaponization of space as a likely new theater of warfare questions; whether AI will become profitable; and recognition that operating in space does not eliminate all environmental and other fears, uncertainties, and doubts.

Four Phases in Data Center Development



Four Phases in Data Center Development



ORBITAL DATA CENTER A TYPICAL CONFIGURATION

This illustration shows a possible configuration of a large-scale data center operating in low Earth orbit. All systems are designed for autonomous operation with robotic maintenance.

ROBOTIC MAINTENANCE SYSTEMS
Robotic arms and drones inspect, repair, and replace components.

SOLAR ARRAYS
Generate tens of megawatts of clean electricity.

ENERGY STORAGE
Batteries and supercapacitors store energy for eclipse periods and peak loads.

THERMAL RADIATORS
Reject waste heat into space using large, high-efficiency radiator panels.

HIGH-BANDWIDTH LASER COMMUNICATIONS
Low-latency links to ground stations around the world.

SERVER MODULES
Thousands of blade servers housed in radiation-shielded racks. Hot aisles face cooling plates.

STRUCTURAL TRUSS
Provides strength while minimizing mass.

ATTITUDE CONTROL
Reaction wheels and thrusters keep the station stable and maintain its orbit.

POWER MANAGEMENT
Distributes and conditions power for all systems.

GROUND STATION NETWORK
Laser links provide high-bandwidth, low-latency connections to users and cloud networks worldwide.

INSIDE A SERVER MODULE
Row after row of high-density servers with liquid cooling and hot-aisle containment.

www.Communitine.com



ODC Exuberance

“I actually think that the cost of deploying AI in space will drop below the cost of terrestrial AI much sooner than most people expect. . . . I think it may be only two or three years.” Elon Musk, (Feb. 5, 2026); <https://www.youtube.com/watch?v=BYXbuik3dgA&t=6s>; see also, <https://www.npr.org/2026/04/03/nx-s1-5718416/ai-data-centers-in-space-spacex-elon-musk>; <https://www.cnn.com/2026/02/04/business/elon-musk-orbiting-ai-data-center-plans>

“The only place you can really scale is space. Once you start thinking in terms of what percentage of the sun’s power you are harnessing, you realize you have to go to space. You can’t scale very much on earth.” *Id.*

“[I]f launch costs to LEO reach \$200/kg, then the cost of launch amortized over spacecraft lifetime could be roughly comparable to [terrestrial] data center energy costs, on a per-kW basis.” Blaise Agüera y Arcas, et al, *Towards a future space-based, highly scalable AI infrastructure system design* (Nov. 22, 2025); <https://arxiv.org/pdf/2511.19468> (Google sponsored research)

Multiple forecasts of a 10-20 yr. timeline, including Jeff Bezos “I originally expected it would be 30-50 years before it would be cheaper in space, but I ran quantitative numbers twice and both times they predicted only 10 to 11 years. . . . So [I] think @JeffBezos’ estimate of 10-20 years is spot-on. Dr. Phil Metzger; <https://x.com/DrPhiltill/status/1987478347480273407?s=20>; see also, <https://www.wsj.com/tech/now-tech-moguls-want-to-build-data-centers-in-outer-space-a8d08b4b>

Major Technology Developments

Declining spacecraft construction and launch costs (from \$60,000/kg for the Space Shuttle, to \$1500-5000/kg using SpaceX; \$100-500/kg anticipated).

Launch equipment reuse.

New markets and segmentations, e.g., satellite direct to handset; Earth Stations in Motion.

Proliferating launch options (small vehicles carry up to 2000 kg into LEO; medium vehicles carry 2000-20,000 kg; heavy vehicles carry 20,000 kg+).

Applicability of Moore's Law and Metcalf's Law.

Satellite situational awareness, collision avoidance, and maneuverability.

New and expanded orbital options, Sun synchronous LEO, MEO, Deep Space TDRSS, Cis lunar, lunar polar.

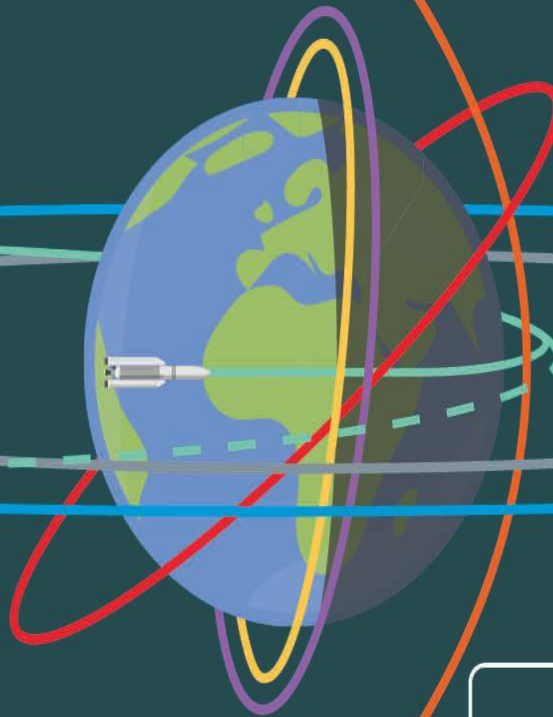
Types of Earth Orbits



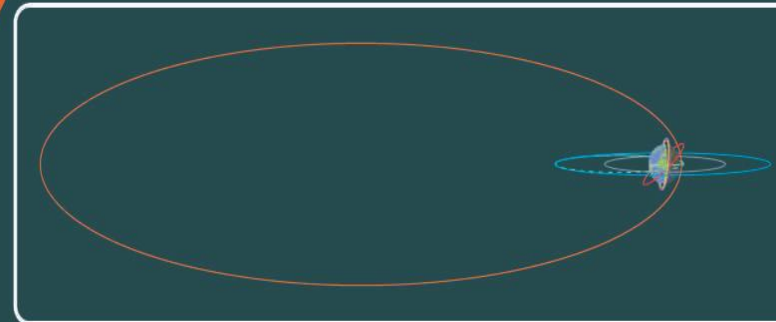
WHIZZING AROUND EARTH

Types of orbit

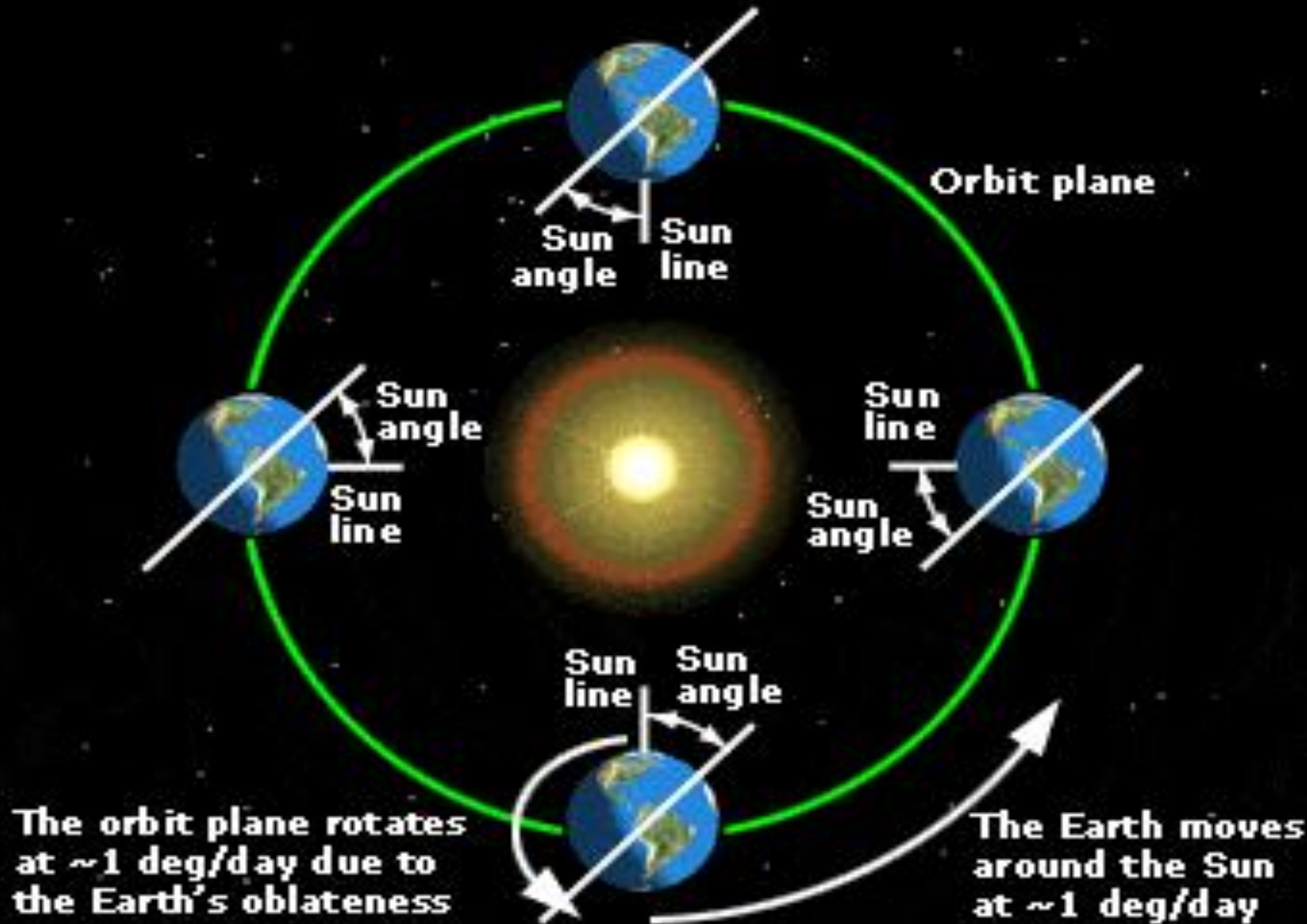
- Geostationary orbit (GEO)
- Highly eccentric orbit (HEO)
- Geostationary transfer orbit (GTO)
- Medium Earth orbit (MEO)
- Polar orbit (PO)
- Sun synchronous orbit (SSO)
- Low Earth orbit (LEO)
- Altitude above Earth surface



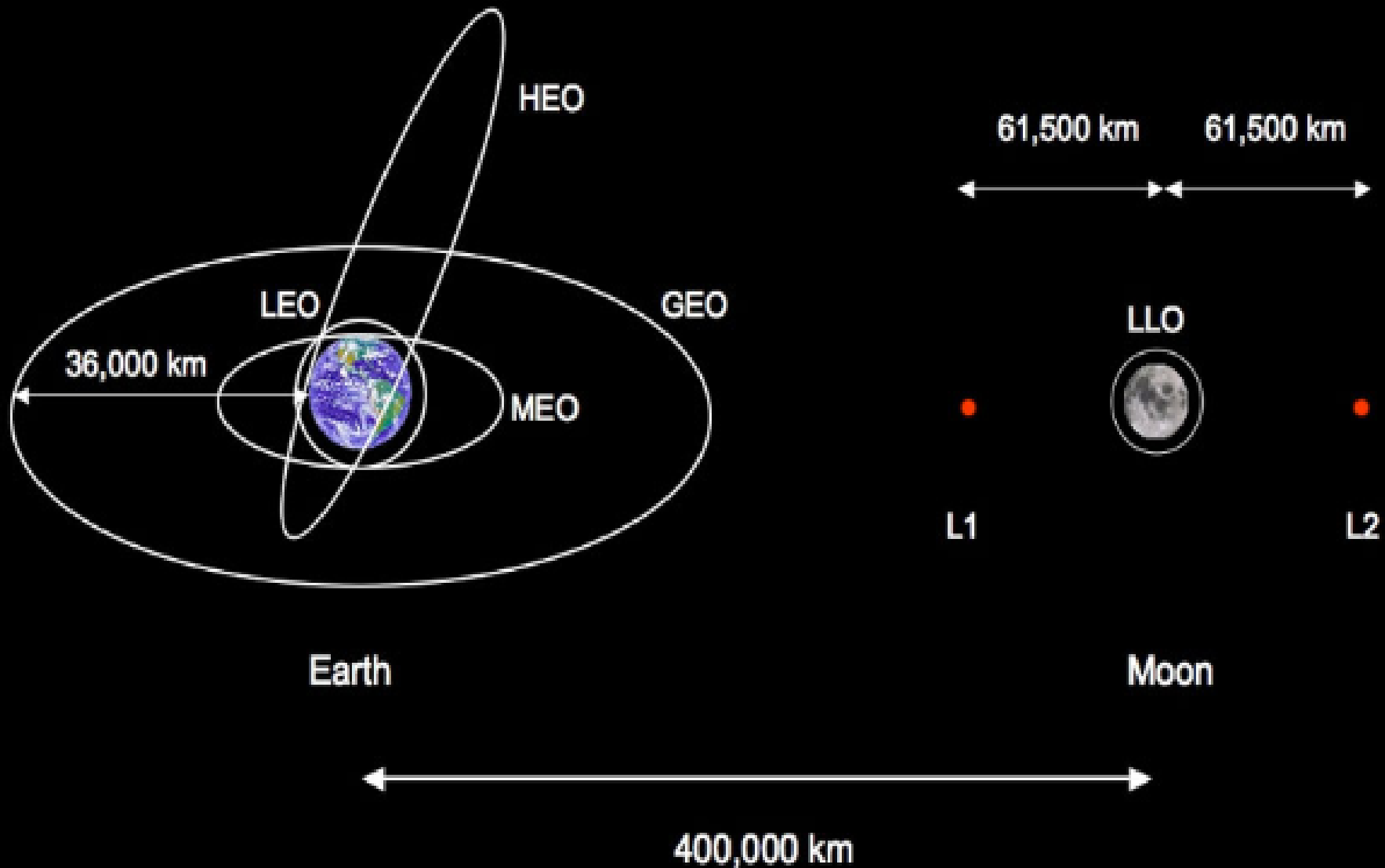
5 000 km 10 000 km 15 000 km 20 000 km



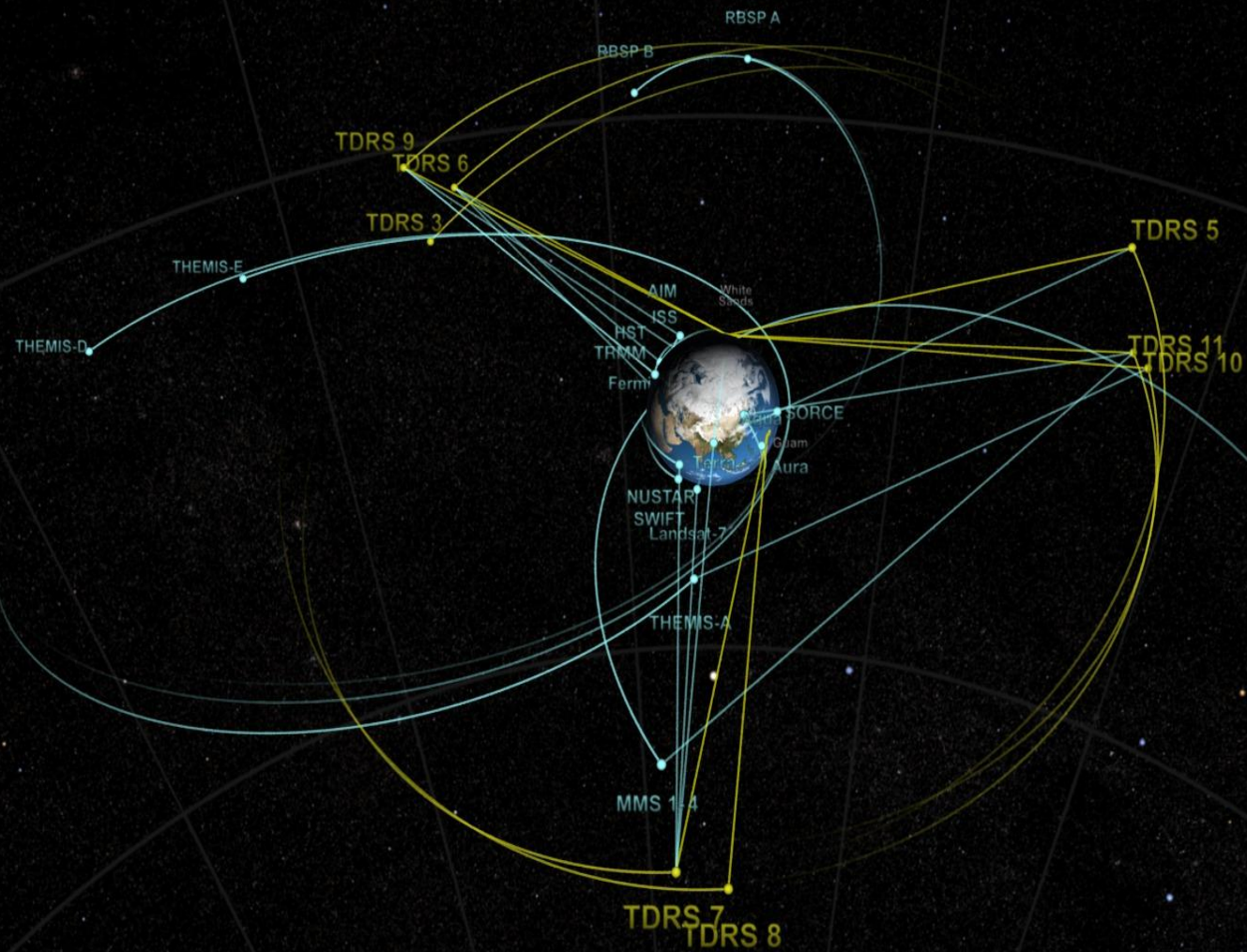
Sun Synchronous Low Earth Orbit



Map of Cislunar Space



Tracking and Data Relay Satellites



Emerging Space Commerce Trends

Insatiable demand for cloud computing, machine learning, storage, and AI stimulate extraordinary, unanticipated electricity, water, and real estate requirements.

Rising terrestrial costs, environmental concerns, congestion, and scarcity make space options perceived as comparatively more attractive and potentially less costly.

Willingness of government agencies to rely more heavily on private ventures for service.

Increased market entry in existing market segments and development of new ones, e.g., broadband, backhaul, middle mile/kilometer carriage, satellite direct to handset, earth stations in motion, sensors/IoT, Narrowband Non-Terrestrial Networks.

Business plans assuming the construction, launch, and ease of coordinating orbits and spectrum requirements by constellations of small satellites possibly exceeding 1 million.

Data Centers in Space Case Study

Technical Background

ODCs will use sun synchronous orbits, 300-1200 mi./1931 km above earth, to tap solar energy continuously. This location lies at the dividing line separating day and night areas on earth. Even if each satellite will need much less power than larger terrestrial facilities, it still will require vastly larger solar power collectors than what existing satellites use.

The satellites also will need large external radiators to absorb internal heat and radiate it out as infrared energy. Additional chemical components may be used to dispel heat.

Satellites will use high-speed laser (optical) communications for high-bandwidth data links between spacecraft and with terrestrial gateway stations. Additionally, the satellites will communicate with higher geostationary satellites for relays and backup to ensure ongoing connectivity.

Latency comparable to TDCs expected.

Major Components of an ODC

Modular Compute Units (Servers): Compact, often commercial-off-the-shelf hardware or specialized radiation-hardened modules designed to survive high-vibration launches and operate in microgravity and high radiation environment.

Satellite Bus Structure: The chassis that houses all components, providing structural support, pointing capability, and management systems.

Power Generation & Storage (Solar/Batteries): Large solar arrays for generating electricity (operating with high efficiency due to 24/7 sunlight).

Passive/Active Thermal Management: Systems consisting of passive radiators, heat pipes, and cold plates that conduct heat from computing elements directly into deep space to maintain optimal operating temperatures.

High-Bandwidth Communication System: Optical links (lasers) for fast data transmission between satellites and radio frequency antennas (e.g., Ka-band, 26.5 GHz to 40 GHz) for communication with ground stations.

Propulsion System: Thrusters needed to perform station-keeping maneuvers to combat atmospheric drag and maintain proper orbital altitude.

Autonomous Operations & AI Software: Advanced software designed to manage operations, perform diagnostic checks, and handle repairs with minimal human intervention.

Major Differences From TDCs

Cooling: Instead of using air conditioning or water, ODCs use conductive spreading to move heat to external panels, which radiate it into the vacuum of space.

Radiation Protection: Components are either physically shielded or, in modern approaches, use software-based redundancy to handle errors caused by cosmic rays and “solar weather.”

Redundancy: Because repairs are impossible, ODCs will have “triple modular redundancy” (three identical systems in parallel) to prevent data loss.

Much larger length and breadth to support more solar arrays and heat disbursement.

More antennas pointing upward, to geostationary relay satellites, laterally via laser inter-satellite links to other data center satellites, and downward to terrestrial gateways and Telemetry, Tracking and Command earth stations.

Likely Space Situational Awareness to detect possible collision risks and some maneuvering capabilities to avoid a collision.

SWOT Analysis—TDCs

Strengths: TDCs use modularity and scalability for interconnected Graphics Processing Units (GPUs), servers, and other equipment handling massive parallel processing workloads, primarily for cloud storage, AI, and high-performance computing.

As AI demand increases, terrestrial operators can incrementally add equipment and increase power/coolant capacity. Current data centers, span over 10,000 square feet, use over 5000 servers, and consume at least 100 megawatts of power, sufficient to serve several hundred thousand residences. Hyperscale centers massively larger and power consumptions exceeds 1 Gigawatt.

TDCs connect to the existing broadband networks via fiber optic cables offering best in class transmission speed, lowest latency, and maximum scale economies.

Weaknesses: Massive use of electricity, water, and real estate exemplify the aspiration of Big Tech to manage—if not dominate—the growing role of information processing and AI in the global economy. Some of the richest and most flamboyant entrepreneurs, as well as key information ventures, such as Google, Microsoft, X, Amazon, Meta, Equinix, Digital Realty, and NTT Global Data Centers, have invested over \$350 billion in 2025 and the total projected by 2030 is approximately \$7 trillion.

SWOT Analysis—TDCs

Weaknesses (cont.): The Court of Public Opinion has severely pushed back on TDC construction, based on legitimate concerns that investors do not solely bear the full cost of growth, such as higher electric rates that utilities justify based on vastly higher aggregate demand.

Other concerns appear overwrought: data centers are a physical embodiment of how many people consider themselves unable to force Big Tech firms to accept regulatory guardrails that could abate the potential for AI development to cause substantial adverse societal harm, such as rampant unemployment and existential risk.

Opportunities: Data center investors expect to profit handsomely from their massive investment, based on the credible premise that AI will revolutionize many market segments and trigger substantial opportunities for both cost savings and new profit centers.

Threats: Public pushback can translate into litigation, legislation, increasingly burdensome permitting and regulation, and sour public relations that collectively can jeopardize the viability or timeline for adding new hyperscale projects. Pursuing space orbiting alternatives, in large part, results from growing opposition to ever larger and numerous TDC proposals.

SWOT Analysis—ODCs

Strengths: ODCs conceptually offer solutions to many terrestrial concerns: lower power, coolant, and possibly litigation and regulatory costs.

Laser inter-satellite links and LEO may match or improve latency. Integration with both geostationary satellites and terrestrial fiber optic networks can enhance reliability and overall efficiency in delivering cloud computing and AI services.

As the public has less knowledge about the negative externalities probably generated by ODCs, a more receptive attitude might support faster authorizations and less regulatory oversight than now applied to TDCs.

Widespread public pushback less likely, because harm is not locale specific, except for launch sites.

Uncertainty about the applicability of international treaties and domestic laws may facilitate aggressive first mover pursuits based on the premise that it's better to ask for forgiveness than permission and moving fast/breaking things enhance the odds for commercial success.

SWOT Analysis—ODCs

Weaknesses: Limited proof of concept test and demonstration projects so far.

Probable higher total capex and opex driven by spacecraft launches, less cost-per-square-foot efficiency, inability to scale, make upgrades, or repairs, and risk of component damage from radiation, geomagnetic storms, sunspot cycles, and overheating.

Unrealistic regulatory safe harbor expectations.

Questions whether orbiting satellite constellations, even with ongoing replacements and integration with geostationary orbiting satellites and existing terrestrial networks, can match TDC efficiency gains, including total available processing capabilities, bandwidth, and bit transmission speeds.

Opportunities: At least some significant, achievable comparative advantages, efficiencies, and cost savings likely vis a vis TDCs.

Probable public relations benefits accruing from perception of enhanced “green” ecological benefits, e.g., near zero carbon generation once in orbit, zero water consumption, and self-generated electricity.

SWOT Analysis—ODCs

Opportunities (cont.): Potentially significant first mover/market preemption and synergy gains, particularly for incumbent LEO network operators, such as SpaceX.

Major regulatory arbitrage and safe harbor chances due to ambiguity in outer space treaties and international law, domestic regulatory lag, and willingness of governments to incubate a developing technology.

Market leadership in orbiting data centers contributes to space supremacy and competition between China, Russia, and the U.S.

Threats: Data center investment is high risk/high reward, with extremely large sunk, startup costs.

Massive increase in LEO satellite launches raises the odd for collisions, especially when sun synchronous satellites converge above the earth's poles. 10 satellites, currently in polar orbit around the Moon, require continuous collision monitoring with 40 “red alarm” warnings within 18 months.

SWOT Analysis—ODCs

Threats (cont.)

ODCs add light pollution that interferes with astronomy and other types of scientific research.



SWOT Analysis—ODCs

Threats (cont.)

One current cost estimate show a wide cost disparity: “If you run the numbers honestly, the physics doesn't immediately kill it, but the economics are savage. It only gets within striking distance under aggressive assumptions, and the list of organizations positioned to even try that is basically one.” <https://andrewmccalip.com/space-datacenters>

Orbital solar data center : US \$51.1 billion

Non-recurring engineering (NRE) and
Replacement and replenishment (Repl): 11.6

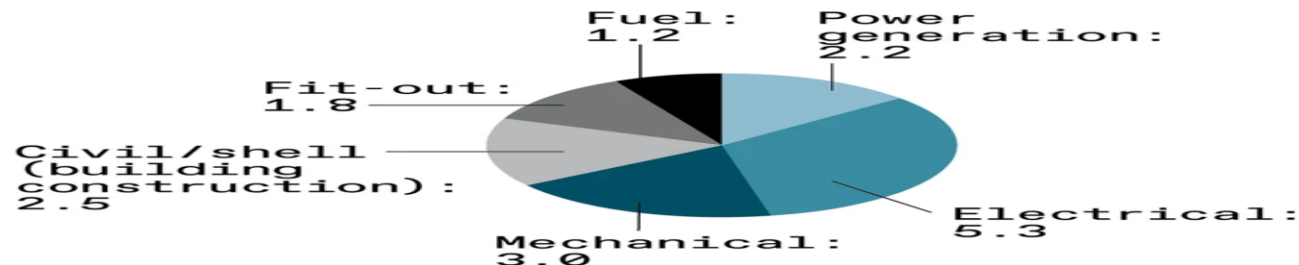
Operations
(1% per
year): 1.2



Billions
of dollars

Cost per watt: \$51.10

Terrestrial data center : US \$16 billion



Billions
of dollars

Cost per watt: \$16.00

Source:
Andrew McCalip

SWOT Analysis—ODCs

Threats (cont.): Space debris proliferation, without any mitigation efforts so far, contributes to collision risks and the cascading effect of even more debris, i.e., Tragedy of the Commons and Kessler Syndrome.

Uncertainty whether existing UN and ITU spacecraft registration, space governance, space resource and spectrum management, and five space treaties can achieve consensus and adequate safeguards.

The combination of many more spacecraft launches, and deorbiting, will generate toxicity and pollution having uncertain effects in space and Earth's atmosphere.

Risk of overlapping jurisdictional claims, but also “race to the bottom” regulatory forbearance competition and “flags of convenience” creating unlikely “paper” projects still requiring preliminary coordination with incumbents and more likely ventures.

Legal, Regulatory, and Governance Uncertainties

While the five space treaties have several, major deficiencies (e.g., lack of enforcement power, no financial incentives for debris mitigation and best practices, inapplicability to private ventures, inability to future proof terms) ODCs are not exempt.

~~Regulatory enforcement complicated by satellites, terminals, handsets, and earth stations in motion.~~

Proving harm cause and effect may be impossible, especially for space debris lacking known provenance.

UN and ITU consensus building, timely conflict anticipation and resolution, efficiency, responsiveness to changed circumstances, jurisdiction, and overall efficacy deemed inadequate leading some nations to pursue unilateral remedies.

Data centers combine telecommunications signal transmission with content storage and information processing. Unclear whether and how current law and regulations will apply to ODCs. Potential areas include: intellectual property, tort liability, privacy and data protection, export controls, environmental protection, including noise, light, launch emissions, and debris vaporization pollution, national security, and AI.

Prospects For and Against Regulatory Forbearance

In the U.S. EU, and other nations regulatory authority has been limited and narrowly focused, mostly executing responsibilities established in the space treaties.

Recently, the U.S. Federal Communications Commission, imposed more time-sensitive responsibilities on satellite operators to deorbit decommissioned spacecraft.

On the other hand, the FCC has limited the scope of environmental assessments required of new service applicants. The National Environmental Policy Act of 1969 (“NEPA”), 42 U.S.C. §§ 4321–4347, explicitly requires the FCC to evaluate the environmental impact of radio signal emissions, including the potential effects of radio towers on migratory birds, historic preservation, flood plains, Indian religious sites, and nearby neighborhoods. See 47 C.F.R. § 1.1307 *et seq.*

The Commission narrowly interprets NEPA and has exempted or reduced the environmental assessment burden for many types of signal transmitters. For example, when the FCC considered an application from SpaceX to lower the orbital height of additional Starlink satellites, the Commission did not require an environmental impact study under NEPA.

FCC has under consideration further reduction in NEPA applicability.

Prospects For and Against Regulatory Forbearance

The D.C. Circuit Court of Appeals in *Viasat, Inc. v. FCC*, 47 F. 4th 769 (D.C. Cir. 2022) rejected Viasat's argument that the FCC should have assessed the environmental impact of lower orbits as well as the potential for increased space debris that would not fully vaporize when deorbiting. The court determined that Viasat lacked standing in the case, because it claimed potential for economic harm, causing it to incur higher operating costs due to increased spacecraft collision risks and orbital crowding.

NEPA only addresses the potential for environmental harm that could affect a larger constituency.

Unless and until space activities are deemed to have a direct and significant impact on the earth atmosphere below, the FCC will maintain its forbearance.

Necessary But Unlikely Space Governance Reforms

Space governance and policies require intergovernmental cooperation and a shared mission. Weaponization and commercialization of space further fragments global consensus, e.g., treating space as a shared commons.

The 5 space treaties are not compulsory and lack enforcement. They need substantial revision reflecting vast changes since enactment. Key amendments: explicit requirements not to generate more space debris; financial incentives for debris removal; recognition of private ventures as key stakeholders; legitimizing commercial use, but not to the detriment of non-space faring or later market entrants; establishing use it or lose it spectrum and orbital plane deadlines; speeding up spectrum planning/allocation, satellite constellation coordination, and dispute resolution; and mandate a duty of care and certain financial responsibility for collisions.

The UN and ITU need to prepare for a massive increase in the number of spacecraft, especially in low Earth and sun synchronous orbit. They cannot ration or limit access, but the Tragedy of the Commons/Kessler Syndrome necessitates compulsory collision avoidance, e.g., situational awareness, and ejection of decommissioned spacecraft into deep space or complete vaporization

National laws also need to address other potential negative externalities of space commerce including atmospheric toxification from aerosols and particles generated by deorbiting spacecraft, light pollution, and property damage from falling debris on earth.

Anything Wrong With This Picture?



Source: <https://insideclimatenews.org/news/26102025/virginia-data-center-capital-ai-boom/>

Preliminary Conclusions

Current ODC enthusiasm may decline with more realistic timelines, cost estimates, risk assessments, and likely degree of regulatory exposure.

Launches of test and demonstration/proof of concept ODCs will occur in the near future, but much uncertainty whether a realistic business case can be made for many projects.

Even Starlink might have floated its 1 million smallsat “Orbital Data Center System”, to boost its reputation and preempt competitors. SpaceX’s application seeks FCC waivers that would normally impose construction and service commencement deadlines, technical disclosures, and coordination with other later filing applicants.

Vastly more LEO and sun synchronous orbiting spacecraft and will test whether ITU spectrum and orbital plane coordination can effectively manage potentially conflicting registrations and signal interference.

Several underemphasized and ignored risks require prudent assessment including: spacecraft collision potential; proliferating space debris; development of AI profit centers and cost savings; go it alone space governance initiatives, such as the U.S. Artemis Accords; and recognition that operating in space does not eliminate environmental and other fears, uncertainties, doubts, and concerns triggered by TDCs.