PHYSICAL AI IN SPACE

& THE ORBITAL DATA CENTER ECONOMY

A Global Market & Economic Review

Markets · Unit Economics · Company Landscape · Planetary Operations · Policy · Scenarios to 2035

Review draft · Data as of 5 August 2026

Compiled from ~90 primary and trade sources across English, Chinese, Japanese, French, German, Italian and Russian coverage. Companion Excel database: space_physical_ai_database.xlsx (83 company/program records).

Contents

1. Executive Summary

The space economy crossed **$626 billion in 2025**[1] and is projected to reach $1.0–1.8 trillion by the mid-2030s[2,3]. Within it, two deeply linked theses are moving from paper to hardware: **orbital data centers** — solar-powered compute placed in orbit to escape terrestrial power, land, and cooling constraints — and **Physical AI** — artificial intelligence embodied in machines that sense, move, and manipulate the physical world. This review argues they are one story: above the Kármán line there is no labor pool, so Physical AI is not a substitute for the space workforce; it **is** the space workforce, at any price.

2025–2026 marked the sector's transition from concept to demonstration. Starcloud flew the first data-center-class GPU (an NVIDIA H100) and trained the first model in orbit[17]; Axiom and Kepler placed the first commercial free-flying data-center nodes in space[25,26]; China's Three-Body/Star-Compute constellations put more than 30 compute satellites in orbit and ran a general-purpose LLM on one of them[28,30]; SpaceX filed for up to **one million** compute satellites and revealed its 150 kW AI1 design[20,21]; Blue Origin filed for 51,600[22]; and Google published the most rigorous public engineering study (Project Suncatcher), pegging economic viability at launch prices below ~$200/kg[13,14]. Meanwhile the servicing economy had its own breakout: Northrop's MRV robotic servicer launched to GEO with DARPA robotic arms[58,59], China apparently completed the first GEO-to-GEO satellite refueling[63], Varda flew and recovered six manufacturing-reentry capsules[69,70], and Starlink executed over **355,000 autonomous collision-avoidance maneuvers** in a single year — the largest deployed Physical-AI behavior in existence[79].

The economics remain the fulcrum. Published parity thresholds for orbital compute cluster tightly at **$100–300/kg** to LEO[13,44,47], against today's ~$1,500–3,600/kg — a 10–30× gap that only Starship-class reuse can close. Bulls point to ~8× solar yield in dawn-dusk orbit, demonstrated COTS-chip radiation tolerance, and $600–725 billion of annual terrestrial AI capex colliding with multi-year grid queues[13,49,50]. Skeptics counter with radiator mass ("the physics tax"), unrepairability, inter-satellite bandwidth, and a ~10^6:1 gap between filed ambition and flying hardware[18,19,44,45]. Both are right about different timescales: the honest base case is megawatts by 2028, single-digit gigawatts by the early 2030s, and a real option on far more if launch costs fall on schedule.

Our synthesis: treat orbital compute as a **launch-cost derivative** with an embedded Physical-AI multiplier. Every credible path — assembling arrays, replacing failed GPUs, refueling tugs, deorbiting debris, mining regolith — runs through autonomous robots. The companies in the companion database that own flight-proven autonomy and manipulation are therefore levered to every scenario, including the ones where orbital data centers disappoint.

Key number	Value (as of Aug 2026)	Source
Global space economy (2025)	$626.4B; ~78% commercial	Novaspace [1]
2035 projections	$1.01T by 2034 (Novaspace) / $1.8T by 2035 (McKinsey-WEF, real 2023$)	[2][3]

Key number	Value (as of Aug 2026)	Source
Launch cost, F9 vs targets	~$1,500–3,600/kg today; Starship target $100–200/kg	[11][12][13]
Orbital-DC parity threshold	$100–300/kg (multiple independent analyses)	[13][44][47]
Orbital compute flying today	<0.1 MW aggregate (est.) vs >100 GW of stated ambition	[18][20]
Deployed vs announced gap	~10^6 : 1	[18]
Starlink autonomous maneuvers	355,000+ in year to May 2026 (~3× 2024 rate)	[79]
In-space servicing market	$3.3B (2025) → $5–12B by early 2030s (analyst range)	[74][101]
Physical AI enabling-stack market	$1.5B (2026) → $15.2B (2032), 47% CAGR	[77]
SpaceX IPO (Jun 12, 2026)	$135/share; $1.78T IPO valuation; ~$2.1T day-one cap	[57]

Table 1 — Headline numbers. Full sourcing in Appendix D.

2. Scope, Definitions & Method

Physical AI here means AI systems that act on the physical world through machines — robotic manipulation, autonomous mobility and rendezvous, onboard perception and decision-making, and fleet-scale autonomous operations. We track both the narrow enabling-stack market that analysts size (chips, sensors, actuation, robot software — $1.5B in 2026 growing at 47%/yr[77]) and the broader economic footprint that shows up inside other industries' P&Ls, from $5 trillion humanoid forecasts[78] to the autonomy that operates 11,000 satellites.

Orbital data centers (ODCs) are space-based facilities for general-purpose or AI compute and data storage — from edge processors on relay satellites through free-flying GPU nodes to proposed gigawatt constellations. We include lunar/cislunar data storage. **Space logistics and servicing** covers orbital transfer vehicles, satellite life extension and repair, refueling, debris removal, space situational awareness, reentry/downmass logistics, and cislunar delivery.

Method. Five parallel research tracks were compiled on 4–5 August 2026: (i) the orbital-DC landscape; (ii) logistics/servicing companies; (iii) space robotics and planetary operations; (iv) market sizing and unit economics; and (v) a non-English sweep across Chinese, Japanese, French, German, Italian, Korean and Russian sources, which surfaced programs largely absent from US coverage (Shanghai's Xingshu Plan[31], CASC's Tiangong Kaiwu resource program, Japan's Space Strategy Fund allocations[95], Orbital Lasers' Series A[100]). Roughly 90 primary sources are cited; claims resting on single or machine-translated sources are flagged in the companion database. Figures for private companies are as reported by cited outlets and should be treated as indicative.

3. The Space Economy in 2026: Baseline & Capital

Novaspace puts the 2025 space economy at **$626.4B**, with commercial activity at roughly 78% and government spending of $137.4B — for the first time majority-defense (54%)[1,5]. Downstream, space-enabled services remain the largest slab ($236B growing to $323B by 2034). Projections diverge more on definitions than on optimism: Novaspace sees $1.01T by 2034 (5.5% CAGR)[2]; McKinsey/WEF project $1.8T by 2035 in real 2023 dollars (9% CAGR), with "reach" applications — logistics, mobility, agriculture riding on PNT and EO — growing faster than the space "backbone" itself[3].

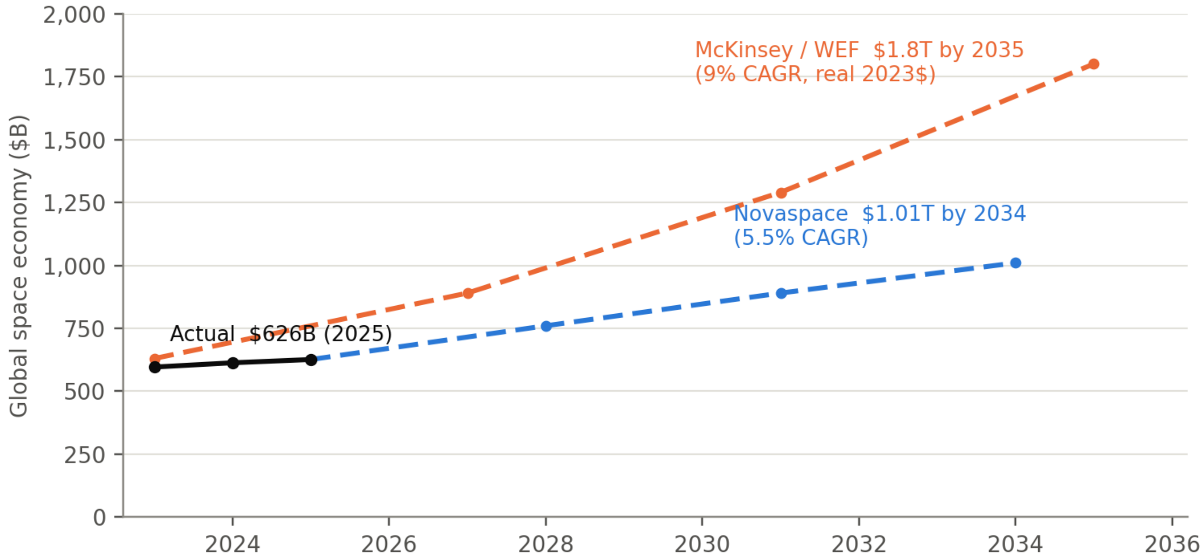

Figure 1 — The space economy: actuals vs the two most-cited projections. Definitions differ; both are annual revenue.

Launch is the master variable. 2025 set records: 329 orbital launch attempts (+25% YoY) and ~3,200 tonnes to orbit, two-thirds of it SpaceX[9,10]. Falcon 9 list pricing sits near $2,700–3,600/kg; Starship V3 — flying, but at only 1–2 flights per quarter as of mid-2026 — targets $100–200/kg at maturity, with Google modeling a ~20% learning rate reaching <$200/kg by the mid-2030s[12,13]. Government budgets tell a defense-led story: US Space Force FY2026 tops $40B including Golden Dome funds[6], NASA landed at $24.4B after Congress rejected deep proposed cuts[7], and ESA's Bremen ministerial subscribed a record €22.1B for 2026–28[8].

Capital reset the sector's ceiling in 2026. Space Capital counted a record $55.3B of private investment in 2025 and $31.6B in Q2 2026 alone[54]; Seraphim logged consecutive record quarters[55,56]. The watershed was the **SpaceX IPO**: priced June 11–12, 2026 at $135/share — a $1.78 trillion offering valuation — SPCX closed its first day up 19% at a ~$2.1 trillion market capitalization, instantly a top-six US company[57]. The listing simultaneously validated space as an asset class and concentrated it: one firm now spans launch, broadband, and (via its AI1 filing) orbital compute. Post-IPO drawdown into the July lockup-expiry window — amplified by a Starship Flight 13 launch abort — was the sector's first lesson in public-market beta.

4. Physical AI: The Workforce Above the Kármán Line

On Earth, Physical AI competes with human labor, so adoption is a cost-curve story. In orbit the comparison collapses: EVA hours are scarce, dangerous, and confined to two stations; everything else — assembly, repair, refueling, inspection, capture, mining — is robotic or does not happen. That inversion makes space simultaneously the **hardest proving ground** for Physical AI (radiation, thermal swings, light-lag that defeats teleoperation, no repair depot) and its **purest market** (no labor substitute, unbounded willingness to pay for capability).

4.1 What has actually flown

Flight heritage — not renders — is the discriminator. The deepest lineage is MDA's: Canadarm2 and Dextre have operated on the ISS for over two decades, and the CA$1B Canadarm3 is in build[91]. GITAI operated dual 1.5 m autonomous arms **outside** the ISS in March 2024, completed its S3 servicing-satellite flight model in June 2026 — then delayed its own flagship demo to 2028+ after winning US Space Force interceptor-prototype work, a telling sign of where money is pulling the field[90]. Motiv built the arm Perseverance uses on Mars; Honeybee's drills operated on the lunar surface during Blue Ghost 1[80]. The July 21, 2026 launch of DARPA/Northrop's MRV carried two 7-jointed dexterous arms to GEO — the first US robotic servicing mission in that orbit, arriving ~2027 for a planned decade of repairs, relocations and propulsion-pod installs[58,59]. On the software side, edge-AI has moved from cubesat demos (ESA Φsat, Ubotica CogniSAT, JPL's in-orbit Dynamic Targeting retasking[93]) to a platform play: NVIDIA's Space Computing line (Mar 2026) targets orbital Jetson/IGX deployments with Starcloud, Kepler, Axiom, Planet and others[92].

Capability	Proven in flight (operator, when)	Still unproven in flight
Robotic manipulation — station	Canadarm2/Dextre daily ops since 2001/2008 (MDA); GITAI dual arms outside ISS (2024)[90,91]	Untethered free-flyer manipulation at commercial scale
Robotic manipulation — GEO	MRV launched with dual DARPA 7-DoF arms (Jul 2026; arrival ~2027)[58]	Actual commercial repair revenue (first ops ~2027)
Docked life extension	MEV-1/-2: dock, station-keep, undock, redeploy (2020–25)[60]	Multi-client rapid re-tasking
Satellite-to-satellite refueling	SJ-25→SJ-21 in GEO, ~5 months docked (2025–26)[63]	Western equivalent (APS-R FY2027; Orbit Fab shuttles)
Autonomous RPO / inspection	ADRAS-J to 15 m of a tumbling stage (2024–26)[61]; Starfish RPO with Impulse Mira (2025)	Capture of a non-cooperative tumbling object
Fleet-scale autonomy	Starlink: 355k+ collision-avoidance maneuvers/yr[79]	Cross-operator coordinated traffic management
Planetary surface manipulation	Perseverance arm (Motiv, 2021–); Honeybee drills on the Moon (2025)[80]	Long-duration lunar-night ops; multi-robot teams (CADRE flies on IM-3)
In-space manufacturing	ISS: metal 3D printing (Airbus 2024), bioprinting/pharma (Redwire), Varda crystallization × 6 flights[69,70]	Free-flyer assembly of large structures (Arkisys ~2027)

Table — Physical AI in space: the flight-heritage frontier as of August 2026.

4.2 Autonomy at fleet scale — the quiet headline

The largest Physical-AI system in existence is not a humanoid: it is Starlink's collision-avoidance autonomy, which executed **207,152 maneuvers in the December 2025–May 2026 half-year and over 355,000 in twelve months** — roughly 40 maneuvers per satellite per year, triple the 2024 rate, screening at a 3-in-10-million collision-probability threshold[79]. This matters economically because every orbital-capacity model assumes it: MIT's source-sink carrying-capacity estimate of ~12.6 million satellites in

LEO is conditional on exactly this class of active management[105], and CO_2-driven thermospheric contraction is projected to cut safe capacity 50–66% by 2100[106]. Autonomy is what keeps the $n^2\sigma v$ collision arithmetic — and with it the entire megaconstellation economy — on the stable branch of the Kessler curve[107].

4.3 Market sizing: the stack vs the footprint

MarketsandMarkets sizes the Physical-AI enabling stack at $1.50B (2026) rising to **$15.24B by 2032** (47.2% CAGR)[77] — a deliberately narrow definition covering the chips-to-software layer. The economic footprint is far larger and lands in other columns: Morgan Stanley's $5T-by-2050 humanoid scenario[78], Goldman's more conservative $38B-by-2035, and in space, the servicing/ISAM complex (§7) that GAO notes has already absorbed >$2B of US government demonstration spending against a stubborn chicken-and-egg demand problem[76]. Our working view: in space, Physical AI value is best measured not as a market but as a **tax rate on everything else** — every gigawatt of orbital compute, every constellation, every lunar base pays it.

4.4 The industrial stack: manufacturing and assembly

Between edge autonomy and gigawatt ambitions sits the least glamorous, most consequential layer: making and assembling things in orbit. Today's working examples are small and real — Redwire's ISS pharmaceutical crystallization and bioprinting lines, Airbus's first metal parts 3D-printed in orbit (2024), and Varda's six recovered manufacturing capsules[69,70]. The next rung is structural: Arkisys's ground-demonstrated modular "Port" (first launch ~2027), Airbus's assembly roadmap, and the robotic in-orbit assembly that both ASCEND's 1 GW design and any multi-gigawatt compute cluster quietly assume[38]. The cautionary tale is governmental: NASA cancelled both OSAM-2 (2023) and OSAM-1 (2024) after overruns — while the DARPA-commercial hybrid RSGS survived to fly[58]. The lesson the market has drawn: in-space industrialization advances when a paying operator, not a cost-plus program, owns the robot.

5. Orbital Data Centers: The Global Landscape

Twenty-two companies and programs now credibly claim the category (companion database, Tab 1). They stratify into four tiers: **flying hardware** (Starcloud, Kepler/Axiom, China's Three-Body/Star-Compute, HPE's ISS precursor); **funded near-term builders** (Cowboy Space, Sophia, Madari, Lonestar, NTT/Space Compass); **hyperscale filings** (SpaceX's 1M-satellite AI1 constellation, Blue Origin's 51,600-satellite Project Sunrise, Google's Suncatcher prototypes); and **state-anchored programs** (China's 2,800-satellite Star-Compute plan and Shanghai's new 1,000-satellite Xingshu Plan[31], the EU's ASCEND study[38]).

Region	Flagship efforts	Status	Stated scale
United States	Starcloud; SpaceX AI1; Google Suncatcher; Blue Origin Sunrise; Axiom ODC; Cowboy Space; Relativity (launcher)	H100 flown; first free-flyer nodes; two mega-filings	5 GW cluster; 1M sats (+100 GW/yr); 51,600 sats
China	Zhejiang Lab Three-Body; ADA Space Star-Compute; Shanghai Xingshu; MIIT policy + CAICT committee	30+ compute sats flying; LLM run in orbit; national coordination	2,800 sats by 2035; 1,000-sat city programs; >¥250B market by 2030
Japan	NTT/Space Compass space-DC roadmap (IOWN photonics); JAXA Space Strategy Fund	Optical-relay procurement signed 2026; behind original 2025 schedule	GEO relay backbone → staged space DCs
Europe	Thales Alenia ASCEND (12-partner consortium); D-Orbit orbital cloud	Feasibility positive; €300M program proposed; edge tier flying	1 GW EU capacity by 2050
Middle East	Madari Space (UAE); Ramon.Space (IL)	Pilot Q3 2026; rad-hard compute lines	Sovereign EO edge → cislunar
Canada	Kepler optical relay + NVIDIA compute	Operational (33 sats; 40 Jetson modules)	Compute grows per tranche

Table 2 — Orbital data center landscape by region. Full records with funding and sources in the database.

5.1 Eighteen months that created an industry

Date	Event
May 14, 2025	China launches first 12 Three-Body/Star-Compute satellites (~5 POPS, 100 Gbps laser links)[28,32]
Nov 2, 2025	Starcloud-1 launches: first NVIDIA H100 in orbit[17]
Nov 4, 2025	Google announces Project Suncatcher + engineering paper[13,14]
Nov 2025	ADA Space runs Alibaba Qwen3 — first general LLM inference on an operational satellite
Dec 10, 2025	Starcloud trains nanoGPT in orbit — first model trained in space[17]
Jan 8, 2026	SpaceX files FCC application for up to 1,000,000 compute satellites[20]
Jan 11, 2026	Axiom ODC Nodes 1–2 + Kepler optical Tranche 1 launch — first commercial free-flying DC nodes[25]
Feb–Mar 2026	Altman calls space DCs "ridiculous"; Huang: "poor economics… cooling is the bottleneck"[52,53]

Date	Event
Mar 16, 2026	Kepler commissions NVIDIA-powered orbital cloud; NVIDIA launches Space Computing line[26,92]
Mar 19, 2026	Blue Origin files Project Sunrise: 51,600 satellites[22]
Mar 30, 2026	Starcloud raises $170M Series A at $1.1B valuation[16]
May 11, 2026	Aetherflux rebrands Cowboy Space; $275M Series B at $2B; rocket-as-datacenter architecture[27]
Jun 9, 2026	SpaceX reveals AI1 (150 kW compute satellite) + Gigasat factory plan[21]
Jul 18–24, 2026	Shanghai unveils Xingshu Plan (1,000 sats); Three-Body constellation adds embodied-intelligence test sats[31,33]
H2 2026 (pending)	Starcloud-2 (Blackwell B200, Oct); Madari pilot (Q3); Cowboy power-beaming demo

Table 3 — Orbital compute timeline, mid-2025 to August 2026.

Two structural observations. First, **compute-adjacent infrastructure is arriving before the compute**: optical relay (Kepler, Space Compass), edge processors, and standards. Second, the field's biggest names disagree in public — Musk claims space is "the lowest-cost place to put AI" within 2–3 years[21]; Bezos says gigawatts in 10–20[23]; Altman and AWS's Matt Garman dismiss near-term economics[52]; NVIDIA sells to all sides while Huang calls the economics poor "right now"[53]. When the principal beneficiaries of the hype are its loudest skeptics, discount rates matter.

6. The Economics of Orbital Compute

The case reduces to one arbitrage: continuous, land-free solar power against the cost of getting mass to orbit and keeping it working. A dawn-dusk sun-synchronous orbit yields up to **8×** the annual energy of the same panel at mid-latitudes, at >95% capacity factor with no batteries, land, permits, or water[13,15]. Terrestrial AI infrastructure meanwhile costs $30–45M per MW fully loaded, faces 18–36-month (to 10-year) grid interconnect queues, and will absorb $600–725B of hyperscaler capex in 2026 alone[49,50]. Orbit's pitch: energy at ~$0.002/kWh equivalent[15], if — and only if — launch, thermal, and reliability costs cooperate.

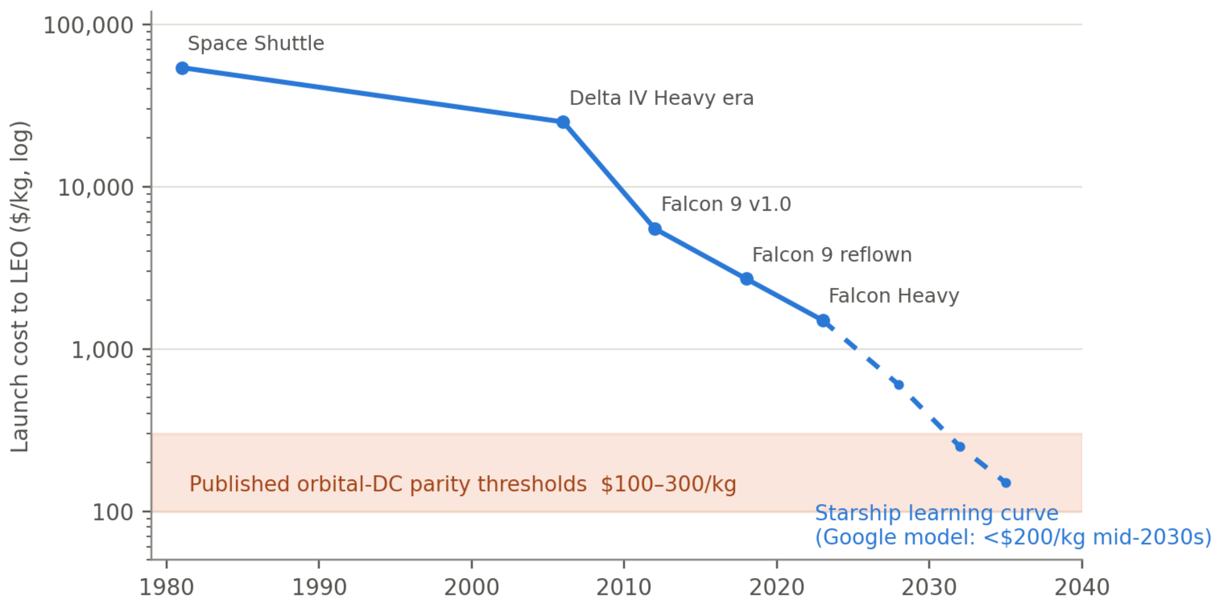

Figure 2 — Launch cost to LEO vs the published orbital-DC parity band ($100–300/kg). The entire industry is a bet on the dashed segment.

6.1 Where the independent analyses converge

Strip away advocacy and the quantitative studies agree on the shape of the problem. **Google's Suncatcher paper**: at ≤$200/kg, launch+operations ≈ $810/kW-yr — inside the $570–3,000/kW-yr range of terrestrial data-center energy — with COTS TPUs proton-tested to ~2.7× a five-year mission dose and 1.6 Tbps optical links benched[13]. **Forethought's** independent model finds parity at ~$250/kg for space-solar-vs-off-grid and ~$100/kg for full competitiveness, flags a ~40% hardware overbuy from unrepairable failures, and notes the FAA's current launch-licensing ceiling would need a ~35× increase[44]. **Aravolta** lands at ~$200/kg with repairability as the binding constraint[47]. Against these, today's ~$1,500–3,600/kg says the trade is 10–30× out of the money — which is precisely why every serious player words its roadmap in Starship-cadence conditionals.

6.2 The skeptics' arithmetic

Thermal. In vacuum, every watt must leave by radiation (Stefan–Boltzmann). A 700 W H100 needs ~1.4 m² of radiator at 60°C — growing ~40% over five years as surfaces degrade; a 40 kW rack needs ~80 m²; 100 MW implies ~2,500 such assemblies[19]. Radiators and arrays end up 65–70% of satellite mass. Flown radiator heritage runs ~14–17 kg/m²; the bulls' business cases assume advanced deployables at 3–10× better specific power[44,45]. Nanjangud's re-costing of Starcloud's 40 MW reference — ~900–1,100 tonnes of radiators, 17–22 launches rather than one — is the sharpest published rebuttal[45].

Reliability & radiation. No one fixes a GPU in orbit (Altman's point[52]). Estimated on-orbit failure rates near 9%/yr imply ~20% of accelerators dark within 26 months; five-year satellite lives clash with 1–2-year terrestrial refresh cycles; Google's own data shows HBM irregularities beginning at 2 krad — acceptable for inference, a real question for training[13,18,42]. **Bandwidth.** Fleet laser links run 100–200 Gbps against terabit-class data-center fabrics; Suncatcher's 1.6 Tbps bench demo is the state of the art, and ground-segment egress remains a choke point — pushing near-term orbital compute toward inference and preprocessing rather than frontier training[13,51]. **Aggregate cost.** ABI Research estimates today's all-in orbital TCO at ~78× terrestrial — while still forecasting 1.54 effective GW by 2035, a usefully honest pairing of present absurdity with future plausibility[43].

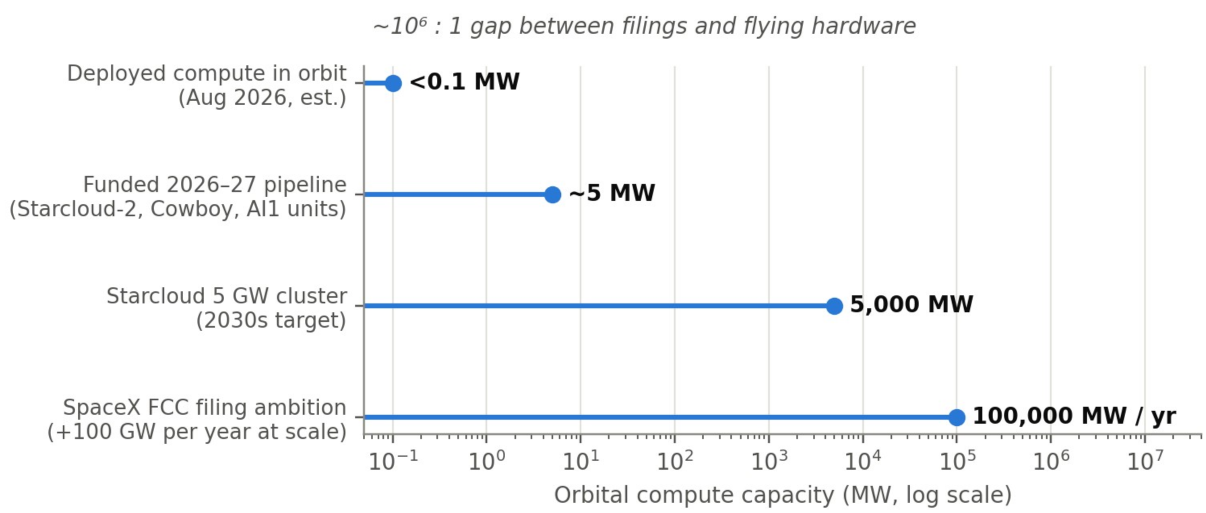

Figure 3 — Ambition vs hardware, August 2026. Filings exceed flying capacity by roughly six orders of magnitude.

6.3 Demand-side reality check

The bull case does not require beating terrestrial compute everywhere — only capturing overflow demand that grids cannot serve. US AI capacity needs are projected to triple by 2031[43]; interconnect queues in key metros run to a decade[49]; and Handmer's margin argument — inference tokens sell for ~100× marginal cost, so even 2×-terrestrial orbital costs preserve ~98% gross margins — reframes the question from cost parity to **elasticity of supply**[48]. The bear case answers: nuclear restarts, gas turbines, and grid buildout are also racing, and a 3–5-year orbital deployment cycle competes against terrestrial capacity that can break ground tomorrow. Both arguments are about timing, not physics.

7. Space Logistics, Transport & Maintenance: The Enabling Economy

If orbital compute is the skyscraper, logistics and servicing are the roads, cranes, and maintenance crews — and in 2025–26 this layer produced harder milestones than the compute layer it will serve. The companion database (Tab 2) profiles 37 organizations across six segments: orbital transfer, life extension/servicing, refueling, debris removal and SSA, reentry/downmass, and cislunar delivery.

Segment	2025–26 proof points	Leaders (flight-proven)
GEO life extension & robotic servicing	MEV-1 completed first commercial GEO undock (Apr 2025)[60]; **MRV/RSGS launched Jul 21, 2026** with dual DARPA arms + 3 propulsion pods[58,59]	Northrop SpaceLogistics; Astroscale (LEXI in dev)
Refueling	China's SJ-25→SJ-21 apparent first GEO-to-GEO refueling (docked ~5 months, separated by Jan 2026)[63]; USSF adopts Orbit Fab RAFTI standard; Northrop PRM flies on MRV	CASC/SAST; Orbit Fab; Astroscale APS-R (FY2027)
Orbital transfer	Impulse: 3 Mira missions flown, >$1B raised, Helios (LEO→GEO in hours) booked for 2027[65,66]; D-Orbit: 17 ION missions + €120M ESA RISE GEO servicer[67]	Impulse, D-Orbit, Exotrail; Momentus surviving
Debris removal & SSA	Astroscale ADRAS-J completed 15 m inspection of derelict stage (Mar 2026)[61]; first positive gross profit; ClearSpace-1 slipped to ~2028[99]; LeoLabs record $60M bookings[103]	Astroscale; LeoLabs; KMI (ISS-tested capture)
Reentry / downmass	Varda: six capsules flown & recovered, 20 more booked[69,70]; Europe's two 2025 capsule attempts both lost (TEC, Atmos)[71,72]; Dream Chaser still unflown[73]	Varda (only serial operator)
Cislunar delivery	Blue Ghost 1: first fully successful commercial lunar landing (Mar 2025)[80]; IM-2 tipped[81]; ispace M2 crashed[82]	Firefly; Intuitive Machines (partial)
Rapid mobility & dynamic space ops	True Anomaly's VICTUS HAZE RPO exercise entered flight ops (Jun 22, 2026) after $650M raised[109]; Blue Ring pathfinder flown (Jan 2025) — 3,000–4,000 m/s ΔV multi-orbit bus with onboard AI compute[110]; Helios booked for LEO→GEO-in-hours from 2027[66]	True Anomaly; Impulse; Portal; Blue Origin

Table 4 — The servicing economy's 2025–26 scorecard: real operations, real failures.

Market sizing spans definitions: satellite servicing at $3.3B (2025) → $7.1B by 2033 (Grand View[74]); on-orbit servicing alone $2.4B → $5.1B by 2030 (MarketsandMarkets[101]) or $9B by 2032 (Allied[75]); the broad ISAM complex $135B by 2040 (Allied[75]). GAO's sober counterpoint: >$2B of US government demo spending has not yet produced a self-sustaining commercial market, with demand still anchored to government missions[76]. The capital market disagrees selectively — Impulse's $500M Series D, Varda's $187M at ~$500M, Turion's $75M — while weaker players consolidated (Katalyst absorbing Atomos; Momentus's near-death; NorthStar's modest $300M SPAC).

The strategic read: **2026 is to servicing what 2015 was to reusable launch** — the year the reference missions flew. When MRV reaches GEO (~2027) and begins commercial repairs alongside China's demonstrated refueling capability, satellite design assumptions (single-fuel-load, disposable) begin to unwind, and with them the replacement-demand model underlying much of today's manufacturing revenue.

7.1 Sidebar: rapid mobility & dynamic space operations

A distinct agility segment has crystallized around the US Space Force doctrine of "dynamic space operations" and "maneuver without regret" — repositioning across and between LEO, MEO and GEO at operational tempo rather than Hohmann patience. Orbital mechanics forces a three-way split in how firms buy that agility: **fast chemical** (Impulse's Helios: ~4 t from LEO to GEO in under a day, booked from 2027[65,66]), **high-efficiency thermal** (Portal's solar-thermal Supernova, hours-class repositioning at far better propellant economy), and **efficient-but-slow electric** (Exotrail, D-Orbit — logistics-grade, not tactical). The purest expression is **True Anomaly**: its Jackal "space superiority" vehicle and Mosaic effect-driven autonomy — operators set objectives, the spacecraft plans and executes maneuver and response in real time — reached $650M raised in April 2026, and its VICTUS HAZE tactically-responsive rendezvous exercise entered live flight operations on June 22, 2026[109]. At the heavy end, **Blue Ring** pairs 3,000–4,000 m/s of ΔV and 4,000+ kg of payload with onboard edge/AI compute — a mobility bus that is also a compute node[110].

Two dependencies make this a Physical-AI story rather than a propulsion story. First, agility is effectively **ΔV × autonomy ÷ decision latency**: a ground-in-the-loop maneuver cycle takes hours an adversary's spacecraft does not grant, so terminal-phase RPO guidance (Starfish's CEPHALOPOD, Mosaic) and AI-accelerated low-thrust trajectory search are the binding technologies, with Starlink's 355,000 autonomous maneuvers/yr as the fleet-scale existence proof[79]. Second, repeatable maneuver is a propellant-logistics statement — "without regret" only holds if tanks refill — which routes the whole doctrine back through the refueling economy (RAFTI, APS-R, PRM) and explains why China's SJ-25→SJ-21 GEO refueling demonstration[63] was read on both sides of the Pacific as a mobility milestone, not a servicing one.

The underlying maneuver economics are packaged as a second interactive companion, **orbital_maneuver_ops.html** (Appendix C): a mission planner that solves any LEO↔MEO↔GEO transfer from the vis-viva and rocket equations, and a pursuit/evasion mode that makes the latency term tangible. Three results anchor the segment. A plane change is the currency of surprise — a 10° tilt costs ~1,340 m/s at LEO but only ~540 m/s at GEO, so loitering in-plane beats sprinting to it. **MEO is underpriced high ground**: from an equatorial 20,200 km parking orbit, GEO is only ~790 m/s away, versus ~3.9–4.8 km/s from LEO. And urgency is linear — repositioning ΔV scales as 1/time, so a GEO longitude shift that costs 37 m/s over two weeks costs 511 m/s in a single day. The same law, reversed, prices evasion: dodging a 10 km miss costs 0.12 m/s with 24 hours' warning but 11 m/s with fifteen minutes — a ~90× penalty set entirely by decision latency, which is why autonomy, not propellant, is the binding constraint in a duel.

8. The Orbital Combat Economy: A Doctrinal Net Assessment

The rapid-mobility segment of §7.1 is, at bottom, a military-economic phenomenon, and its logic reads directly off the maneuver prices. This section treats those prices as a combat-economics model — an open-source, doctrinal net assessment in the tradition of published counterspace surveys[111,112], built from two-body orbital mechanics and the documented 2025–26 programs, not from any operational source. The organizing insight is that orbital engagement is **logistics-limited**: unlike terrestrial forces already in contact, an orbital asset must spend finite, largely non-renewable ΔV to bring an effect to bear, and that wallet does not refill without a depot. Three consequences follow — ΔV is ammunition, orbital position is terrain, and decision latency is tempo — and together they make the outcome of most engagements legible before they begin. Engagements therefore end not in destruction but at **Winchester** (bingo propellant): whoever can impose an effect for fewer m/s, more times, prevails.

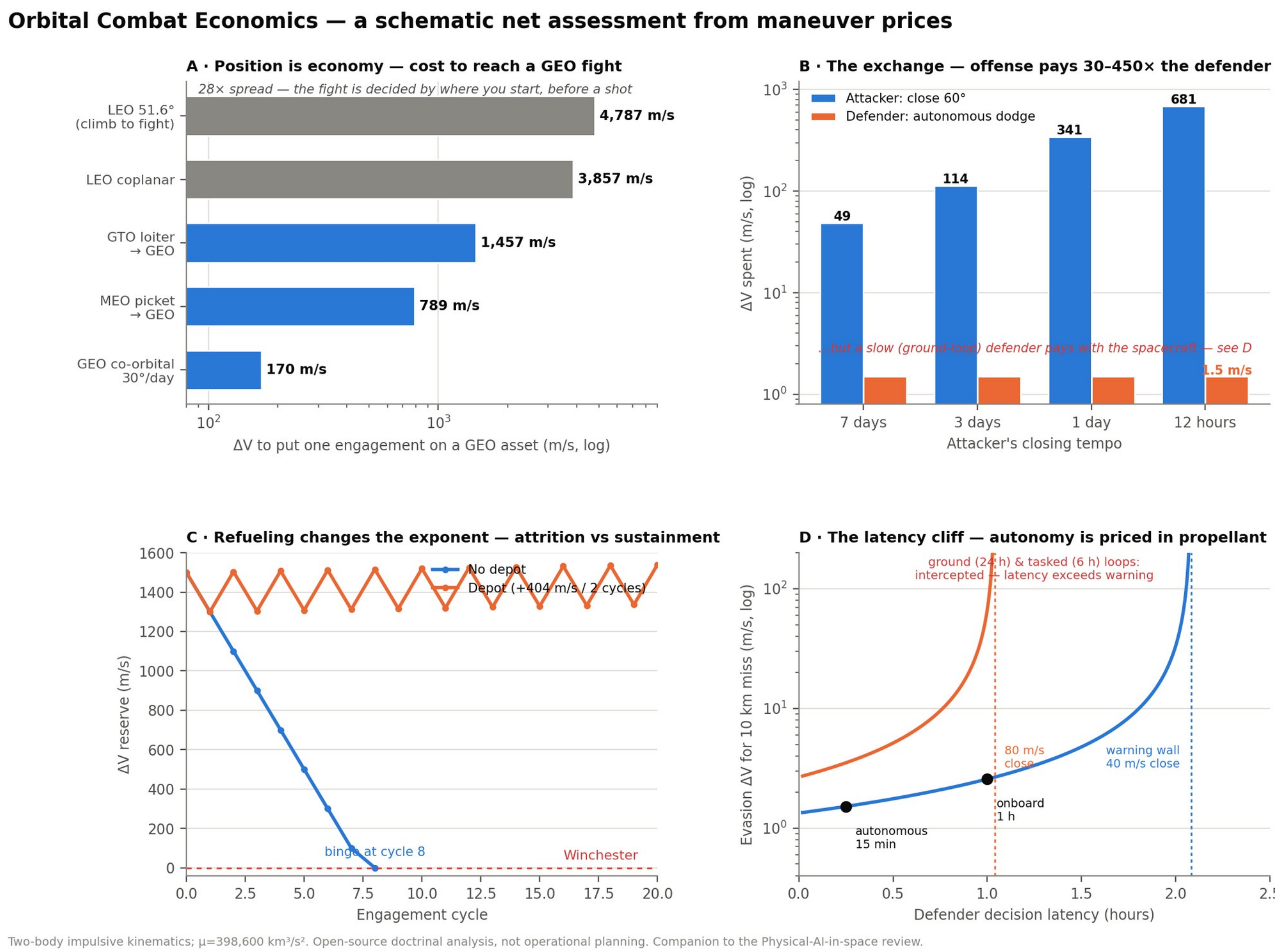

Figure 4 — Orbital combat economics, computed from the maneuver prices. A: the cost to reach a GEO engagement spans 28× by starting position. B: against an autonomous defender, offense pays 30–450× the evasion cost. C: a propellant depot converts an 8-engagement attrition curve into indefinite sustainment. D: evasion ΔV explodes as decision latency approaches the warning window, and past it the defender cannot react at all. Schematic two-body model; see Appendix C for the interactive companion.

Four laws organize the assessment. **First, position is economy.** The ΔV to put one engagement on a GEO asset spans 28× purely by starting orbit — 4,787 m/s climbing from a 51.6° LEO, 789 from an equatorial MEO perch, 170 from co-orbital GEO — while mid-fight plane changes stay unaffordable (a 10° tilt at LEO is ~1,340 m/s, most of a tactical wallet). The fight is decided by pre-positioning, before anyone maneuvers. **Second, the high ground is coverage, not altitude.** A co-orbital GEO picket can hold only ±35° of the belt at risk within a day for a 200 m/s reserve, so covering the full belt takes roughly six pickets; a single MEO vehicle laps the entire GEO belt by Keplerian drift about once a day and dives for 789 m/s when it chooses, while GEO defenders cannot cheaply climb to punish it — a ≈6:1 coverage economy that is the quantified case for the emerging MEO layer. **Third, autonomy is priced in propellant.** Evasion ΔV scales as 1/(warning − latency): against an autonomous defender, offense pays 30–450× the defender's ~1.5 m/s dodge, but the relation has a cliff — once a decision loop is longer than the warning window (about two hours at 300 km detection and 40 m/s closing), the defender cannot react and pays with the spacecraft. A 24-hour ground loop and a 6-hour tasked loop are both dead on arrival; onboard AI and autonomous RPO survive for single-digit m/s. **Fourth, refueling changes the exponent.** A 1,500 m/s wallet goes Winchester after ~8 engagement cycles; an SJ-style +404 m/s refill every couple of cycles turns attrition into indefinite sustainment. RAFTI/PRM standardization and the SJ-25→SJ-21 refueling demonstration[63] are therefore strategic acts, not maintenance.

Factor	Advantage accrues to	Computed price
Starting position	Higher / in-plane (MEO perch, GEO co-orbital)	up to 28× in reach cost (170 vs 4,787 m/s)
Belt coverage	The high ground (MEO over GEO)	≈6:1 per vehicle (1 MEO ≈ 6 GEO pickets)
Decision latency	The lower (autonomous) side	30–450× in evasion ΔV; interception once latency > warning
Logistics	The refueled (depot-access) side	attrition (~8 engagements) → sustainment

Table 5 — Who wins an orbital engagement, and the price of each edge. All four favour the pre-positioned, autonomous, refuelled side — which is precisely the capability stack the rapid-mobility firms of §7.1 are racing to field.

8.1 Stability: the same equations, two readings

Whether this balance is dangerous is a question on which serious analysts divide, and the division is about weighting rather than facts. Those who read the economics as **destabilizing** note that cheap agility, autonomy, and the inherent ambiguity of rendezvous — an inspector and an attacker fly identical approaches until the final seconds — compress decision time toward the reflexive, and that a fuelled maneuvering asset is a use-it-or-lose-it piece that degrades if it waits, rewarding the first mover. The historical rhyme is the pre-1914 mobilization timetable: when the advantage of going first is large and legible, crises resolve toward going first. Those who read the same facts as **stabilizing** counter that the dominant defensive move is simply to dodge — reversible, non-kinetic, harming no one and creating no debris — and that better space situational awareness widens the warning window, which by Panel D directly raises the price of surprise and pushes engagements back into the cheap-to-defend regime. Both camps are reading the same curves; they disagree on how first-mover advantage trades against transparency.

One firebreak follows from the companion debris model rather than opinion: **kinetic anti-satellite attack is self-deterring.** A destructive intercept in a GEO or dense-LEO compute shell seeds exactly the $n^2\sigma v$ cascade Appendix B lets the reader trigger, denying the orbit to the attacker and its allies for centuries. The maneuver competition is therefore pushed toward non-kinetic effects — shadowing, dazzling, signal interference, positional denial — which are more ambiguous but bounded in physical destruction. The candidate rules of the road that fall out of this framework — keep-out volumes, pre-notification of close approach, shared SSA to widen warning, and norms against kinetic testing (several states have already declared moratoria) — are, in the language of Figure 4D, all ways to move engagements left along the latency curve, into the region where defense is cheap and surprise is expensive. This review takes no position on which regime states should adopt; it observes only that the physics rewards transparency and penalizes kinetic escalation.

The investment corollary restates §13's thesis in a security register: value accrues not to the maneuvering platforms themselves but to the capabilities every scenario in Table 5 must rent — space situational awareness (which prices surprise), refueling standards and depots (which set the exponent), and flight-proven autonomy (which sets tempo). These are the same "tax collectors" the commercial analysis favours, which is why the servicing, SSA, and autonomy names in the companion database are levered to the defense build-out as much as to the commercial one.

9. Planetary Operations Review

Roughly **40 robotic spacecraft** currently operate beyond Earth orbit. Every one is a Physical-AI datapoint: light-lag makes autonomy mandatory, and the 2025–26 record shows both its progress and its price.

8.1 Mars

Asset / program	Status (Aug 2026)
Perseverance + Curiosity	Active; Perseverance holds 30+ sealed samples incl. the Cheyava Falls potential-biosignature core
Mars Sample Return (NASA-ESA)	Effectively terminated — Senate appropriators declined to fund the existing program (Jan 2026); samples stay on Mars indefinitely[85]
Tianwen-3 (China MSR)	In spacecraft construction; launch ~2028, samples back ~2031 — now positioned to return Mars samples first[86]
ESA Rosalind Franklin	NASA contributions formally in implementation (Apr 2026); launch 2028, landing 2030
ESCAPADE (NASA/Blue Origin)	Twin smallsats launched Nov 2025 on New Glenn (booster landed); Mars arrival 2027

Table 6 — Mars operations. The strategic headline: US sample retreat vs Chinese advance.

8.2 The Moon

The 2025 commercial scorecard — one full success (Firefly's Blue Ghost 1, 14 days of surface ops[80]), one tip-over (IM-2 at the south pole[81]), one crash (ispace's Resilience, laser-rangefinder failure[82]) — says lunar landing autonomy remains genuinely hard. **Artemis II flew crewed around the Moon April 1–10, 2026**, splashing down 2.9 miles from target with dramatically improved heat-shield behavior, keeping Artemis III on the books for 2027[84]. The pipeline into 2027 is the densest in history: Chang'e-7 (delivered to its spaceport, targeting H2 2026 with a hopping probe for shadowed craters[83]), Blue Ghost 2 to the far side, IM-3 (carrying JPL's CADRE autonomous rover trio and AstroForge's asteroid rideshare), Astrobotic's Griffin-1 with Astrolab's FLIP rover, VIPER revived on Blue Origin's second Blue Moon MK1[88], and NASA's $219M/$220M lunar-terrain-vehicle awards to Astrolab and Lunar Outpost[89].

8.3 Small bodies & deep space

China's Tianwen-2 reached quasi-moon Kamoʻoalewa in July 2026 ahead of a touch-and-go sampling and ~2027 return[87]. Psyche executed its Mars gravity assist (May 2026) after resolving its propulsion anomaly; ESA's Hera arrives at the DART impact site in December 2026; Lucy's Donaldjohanson flyby succeeded (Apr 2025). Commercial asteroid ambitions were humbled — AstroForge's Odin was lost en route in 2025; its Vestri rendezvous attempt rides IM-3 — while CASC's new "Tiangong Kaiwu" program (Jan 2026) laid out a state roadmap from Chang'e-8 ISRU (2029) toward asteroid extraction at 2040-scale.

10. Regional Landscape & Policy

United States pairs the deepest capital markets (SpaceX at ~$2T, record VC[54,57]) with a defense pull now strong enough to distort commercial roadmaps — GITAI's postponed servicing demo[90] and Golden Dome's $25B are the same story told twice. Regulatorily, the FCC absorbed two unprecedented compute-constellation filings while the FAA moved to streamline launch environmental reviews — even as its ~145-launch/yr licensing ceiling sits ~35× below fast-scenario needs[44].

China is running an industrial policy for space compute that has no Western equivalent: MIIT's "systematic planning" posture, a CAICT-coordinated committee spanning 100+ organizations, a Beijing innovation center for satellite AI chips and thermal systems, and a projected >¥250B domestic market by 2030[29,30]. Beneath policy sit three operating constellation programs (Three-Body, Star-Compute, Xingshu[31]), the SJ-25/SJ-21 refueling first[63], commercial servicing entrant Sustain Space[64], and a lunar/resource roadmap (Chang'e-7/8, Tiangong Kaiwu) synchronized with its Five-Year Plan. The gap between announced POPS and audited capability is real — but the coordination advantage is realer.

Japan built the servicing sector's first genuine business result — Astroscale's first positive gross profit and ¥30.6B raise with JSAT/Hulic as strategic investors[62] — alongside a ¥1T Space Strategy Fund[95], NTT's methodical space-DC roadmap[36,37], and new entrants like Orbital Lasers (laser de-tumbling, ¥3B Series A[100]). **Europe** leads on rules and lags on hardware: the ASCEND study validated a 1 GW climate-positive orbital DC by 2050[38] but no demonstrator is funded; ClearSpace-1 slipped to ~2028[99]; both 2025 reentry-capsule attempts failed[71,72]; and the draft **EU Space Act** remained stuck in Council with every member state holding scrutiny reservations as of May 2026[94]. Standouts: D-Orbit's €120M ESA GEO-servicing contract[67] and The Exploration Company's reported >$2B valuation talks. **Elsewhere**: India converted its SPADEX docking success into a 2028 Chandrayaan-4 path with SSA (Digantara[97]) and refueling-interface (OrbitAID) startups; Korea's KASA opened its first OTV budget line[96]; the UAE's Madari is the Gulf's first orbital-DC entrant[39]; Russia's Sfera program consolidated amid funding complaints, with no visible compute or servicing initiative[98].

11. Risk Register

- **Launch-cost schedule risk (dominant).** Every orbital-compute business case discounts a Starship price curve that has not yet materialized — mid-2026 cadence is 1–2 flights/quarter against models assuming thousands/yr[12,44]. A three-year slip in $/kg moves every breakeven right by roughly the same amount.
- **Thermal-mass physics.** Radiator specific power must improve 3–10× over flown heritage for bull-case masses; otherwise radiators, not chips, are the payload[19,44,45].
- **Reliability without repair.** ~9%/yr accelerator attrition and 5-yr asset lives vs 1–2-yr terrestrial refresh force overbuild and freeze architectures — unless in-orbit servicing (§7) matures on schedule, which is itself the Physical-AI bet[18,44].
- **Debris & carrying capacity.** Filings totaling >1M satellites enter an environment already generating 355k avoidance maneuvers/yr[79]; capacity is management-

conditional[105] and shrinking with thermospheric contraction[106]. A single bad conjunction cascade in a compute shell would reprice the sector's insurance and its politics simultaneously[107]. Appendix B presents an interactive companion model of exactly this arithmetic.

- **Bandwidth ceiling.** Until multi-Tbps optical mesh + ground egress scale, orbital compute is inference-shaped; training-class interconnect remains unproven[13,51].
- **Demand rerating.** If terrestrial power constraints ease (nuclear, gas, efficiency) or AI capex cools, orbit's overflow demand evaporates ahead of its cost curve[50].
- **Concentration & governance.** One ~$2T firm spans launch, broadband and compute filings; Brookings flags the feasibility gap itself as a governance risk — spectrum and orbital slots claimed by paper constellations[46]. Regulatory fragmentation (stalled EU Space Act[94]) adds jurisdictional arbitrage.
- **Geopolitical bifurcation.** Parallel US/China compute-and-servicing stacks with dual-use ambiguity (GEO refueling, RPO) raise both escalation risk and compliance cost for every commercial operator[63].

12. Scenarios & Outlook to 2035

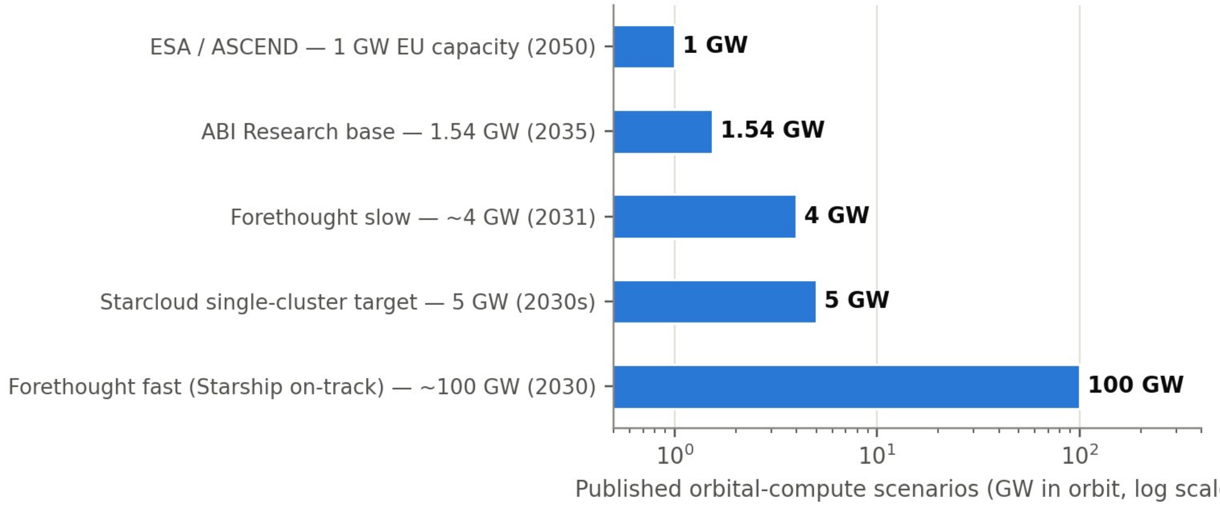

Figure 5 — Published orbital-compute scenarios (log scale). The spread is a launch-cost bet, not a physics dispute.

Scenario	Assumptions	2030	2035	Physical-AI implication
Bear — “niche edge”	Starship $/kg stalls >$800; radiators stay ~15 kg/m²; AI capex cools	<0.2 GW; edge/defense only	<1 GW	Servicing market stays government-anchored; autonomy value accrues to constellations & lunar programs
Base — “megawatts to gigawatts”	$200–400/kg by ~2032; inference-first workloads; optical mesh scales	0.5–1 GW cumulative	1.5–5 GW (ABI 1.54; Forethought-slow 4)	Servicing/refueling become standard ops; robotic assembly demos; $10B+ servicing market
Bull — “power plant in the sky”	≤$150/kg + 1,000s of launches/yr; advanced radiators fly; training-class links	~100 GW/yr additions begin (Forethought-fast; SpaceX claim)	Terawatt trajectory; in-space assembly mandatory	Physical AI becomes the constraint: robotic assembly, servicing and debris control gate growth

Table 7 — Scenario matrix synthesized from ABI, Forethought, Google, Starcloud and SpaceX filings{13,15,20,43,44}.

11.1 Signposts to watch (next 18 months)

- **Starcloud-2 (Oct 2026):** does a Blackwell-class node run at full power — fixing Starcloud-1’s radiator shortfall — and hold customers’ SLAs?[16]
- **Starship:** cadence × published pricing; the first credible <$1,000/kg external quote resets every model[12].
- **MRV at GEO (~mid-2027):** first commercial robotic repair — the servicing market’s “Falcon 9 landing” moment[58].

- **Google's Planet-built prototypes (early 2027)** and any published radiation/thermal telemetry — the first peer-reviewable orbital-DC data[13].
- **China:** Star-Compute batch cadence toward 1,000 sats by 2030, and whether POPS claims convert to sold capacity[28,30].
- **Starship ship-to-ship propellant transfer:** unlocks the heavy-cargo cislunar economy — still unflown as of Aug 2026[102].
- **FAA licensing ceiling & EU Space Act:** the regulatory throughput that fast scenarios silently assume[44,94].
- **Capital discipline:** post-SPCX drawdown behavior — whether record 2026 inflows[54,56] survive the first orbital-compute disappointment.

13. Conclusions

1. The theses are one thesis. Orbital data centers, space logistics, and planetary operations all reduce to the same input: machines that can work in places humans cannot. Physical AI is the space economy's labor supply, and its maturity curve — not solar flux, not chip supply — sets the sector's speed limit.

2. Hardware has started telling the truth. In eighteen months the orbital-compute question moved from "could it work?" to "at what $/kg, with what radiators, at what reliability?" — questions with numeric answers arriving on knowable dates (Starcloud-2, Suncatcher prototypes, Starship cadence). The 10^6:1 ambition-to-hardware gap will compress from both directions.

3. The servicing economy is the safer branch of the same bet. Whether or not gigawatt compute arrives on schedule, the 2025–26 record — MRV launched, GEO refueling demonstrated, six Varda recoveries, ADRAS-J's inspection, 355k autonomous maneuvers — says orbital operations are industrializing now. Its revenue is nearer, its physics kinder, and every compute scenario needs it.

4. Watch China's coordination, not just its claims. Three constellation programs, a national committee, a refueling first, and a Five-Year-Plan-synchronized resource roadmap constitute the most complete state strategy for the orbital economy anywhere. The West's answer is capital depth and SpaceX's cost curve. The 2030 landscape depends on which compounds faster.

5. For builders and investors, the asymmetric positions are in the tax collectors, not the skyscrapers: autonomy software with flight heritage, manipulation and refueling standards (RAFTI/PRM), optical interconnect, SSA, high-cadence reentry, and thermal hardware — the capabilities every scenario must rent.

Appendix A — Companion Database Guide

The Excel companion (**space_physical_ai_database.xlsx**) contains 83 sourced records: **Tab 1 — Orbital Data Centers** (22 companies/programs from flying hardware to filings); **Tab 2 — Logistics & Servicing** (39 organizations across OTVs, rapid mobility/dynamic space operations, life extension, refueling, debris/SSA, reentry, cislunar); **Tab 3 — Robotics & Physical AI** (22 manipulation, autonomy, manufacturing and humanoid programs). Each record carries HQ, founding year, build description, status, flight heritage, funding with dates, 2025–26 milestones, partners, roadmap, and abbreviated source URLs; status cells are color-coded (green = flying/operational, amber = development/study, dark amber = distressed). Claims resting on single or machine-translated sources are marked [UNVERIFIED] and should be re-confirmed before external publication.

Appendix B — The Orbital Debris Environment Console

The debris-risk arithmetic in §4.2 and §11 — spatial density n(h), flux $\Phi = n \cdot \sigma \cdot v$, the kinetic-theory collision rate $\frac{1}{2} n^2 \langle \sigma v \rangle V$, the NASA standard breakup model, and the Kessler source–sink criterion — is packaged as an interactive companion to this review: **orbital_debris_ops.html**, a single-file 3-D console (Three.js + SGP4) delivered alongside this document. It propagates 62 real objects from current two-line element sets (ISS, Tianhe, Hubble, Envisat, GOES-16, and Starlink/GPS/OneWeb samples, plus debris from the Fengyun-1C and Cosmos-1408 ASAT tests and the 2009 Iridium–Cosmos collision) over a 22,000-point background population shaped to the tracked catalog's altitude-density profile. A live physics panel recomputes every quantity above for any altitude shell; a source–sink cascade mode — calibrated to today's ~0.18 catastrophic collisions per year — compresses time to a year per second and lets the reader inject a Fengyun-scale ASAT breakup and watch the n^2 feedback pull the density profile off its baseline. The console can also refresh its element sets live from CelesTrak in the browser.

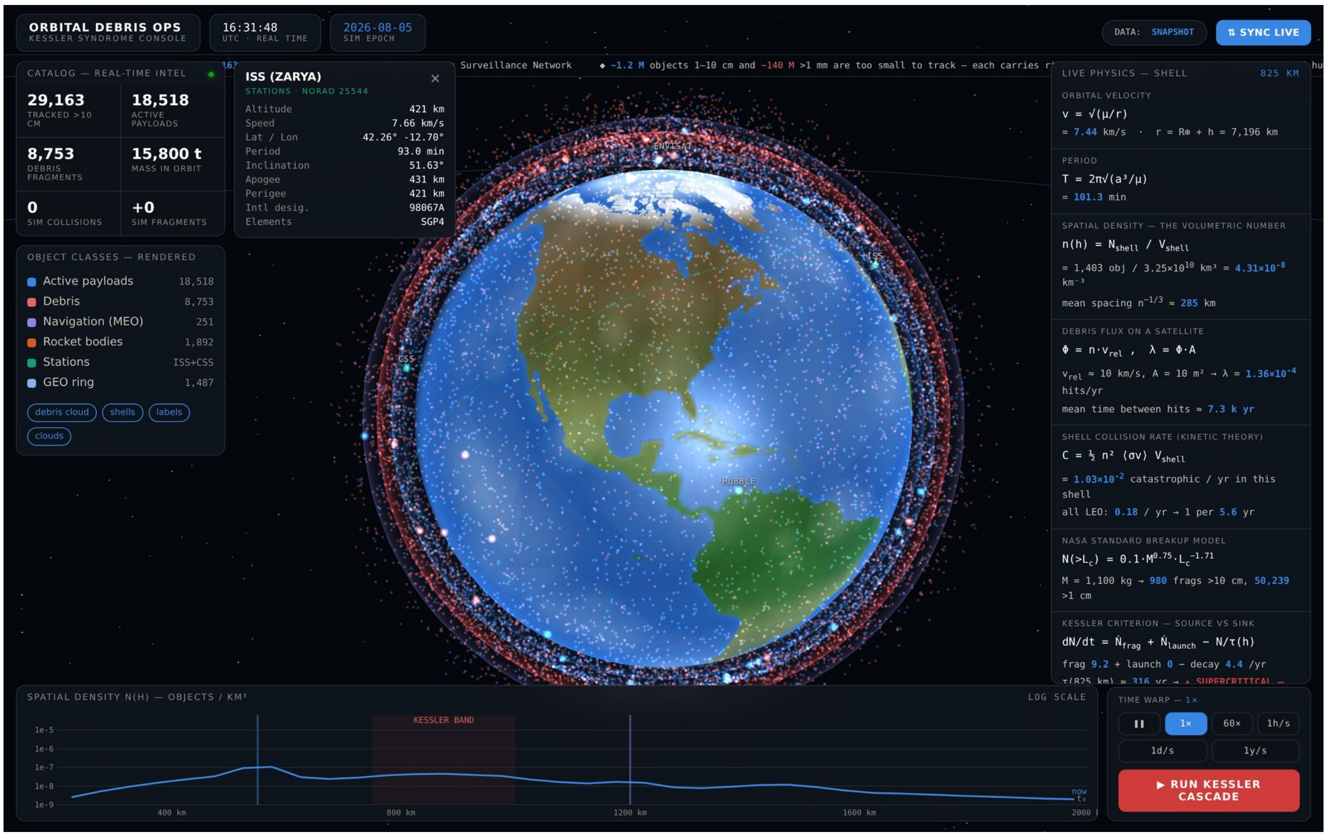

Figure B-1 — Baseline environment (Aug 2026 snapshot): real SGP4-propagated objects, catalog-shaped debris cloud, live physics for the 825 km shell ($n = 4.3\times10^{-8}$ km^{-3}; mean spacing ≈ 285 km; all-LEO rate 0.18/yr → 1 per 5.6 yr).

Figure B-2 — Cascade mode, +1.3 simulated years after two ASAT injections at 875 km: tracked objects 29,163 → 33,509, +2,448 fragments >10 cm, all-LEO collision rate 0.18 → 0.30/yr, and the live density curve (solid) lifted above the t_0 baseline (dashed) through the 300–900 km band.

The console's shell model is deliberately simple — 36 shells, circular-orbit kinetics, drag lifetimes from a solar-cycle-mean table, NASA breakup fragment counts — and is intended for intuition, not prediction; the peer-reviewed treatments remain Kessler's stability analysis[107] and MIT's MOCAT source–sink capacity work[105]. Its qualitative lesson matches theirs: above ~700 km the atmospheric sink collapses, so density added there — by ambition or by accident — is effectively permanent on human timescales.

Appendix C — The Rapid-Mobility Maneuver Console

The maneuver economics of §7.1 — vis-viva circular speeds, Hohmann transfers with an optimally split plane change, Edelbaum low-thrust spirals, the rocket equation, and the GEO repositioning urgency law — are packaged as a second single-file companion to this review: **orbital_maneuver_ops.html** (Three.js), delivered alongside this document. Its Mission Planner solves any origin-to-destination transfer across LEO, SSO, MEO and GEO for a chosen vehicle and propulsion type (storable, methalox, solar-thermal, nuclear-thermal, or electric), animates the transfer along its true conic, and reports ΔV required against the vehicle's rocket-equation ΔV "wallet," transfer time, propellant burned, and how many times the move can be repeated — with a refuel button that demonstrates how a single propellant top-up converts the exponential into a linear subscription. A Pursuit/Evasion mode makes the latency term tangible: for a given detection range and closing speed, it shows which defender decision loops (ground, tasked, onboard-AI, autonomous) can react in time and what evasion ΔV each requires.

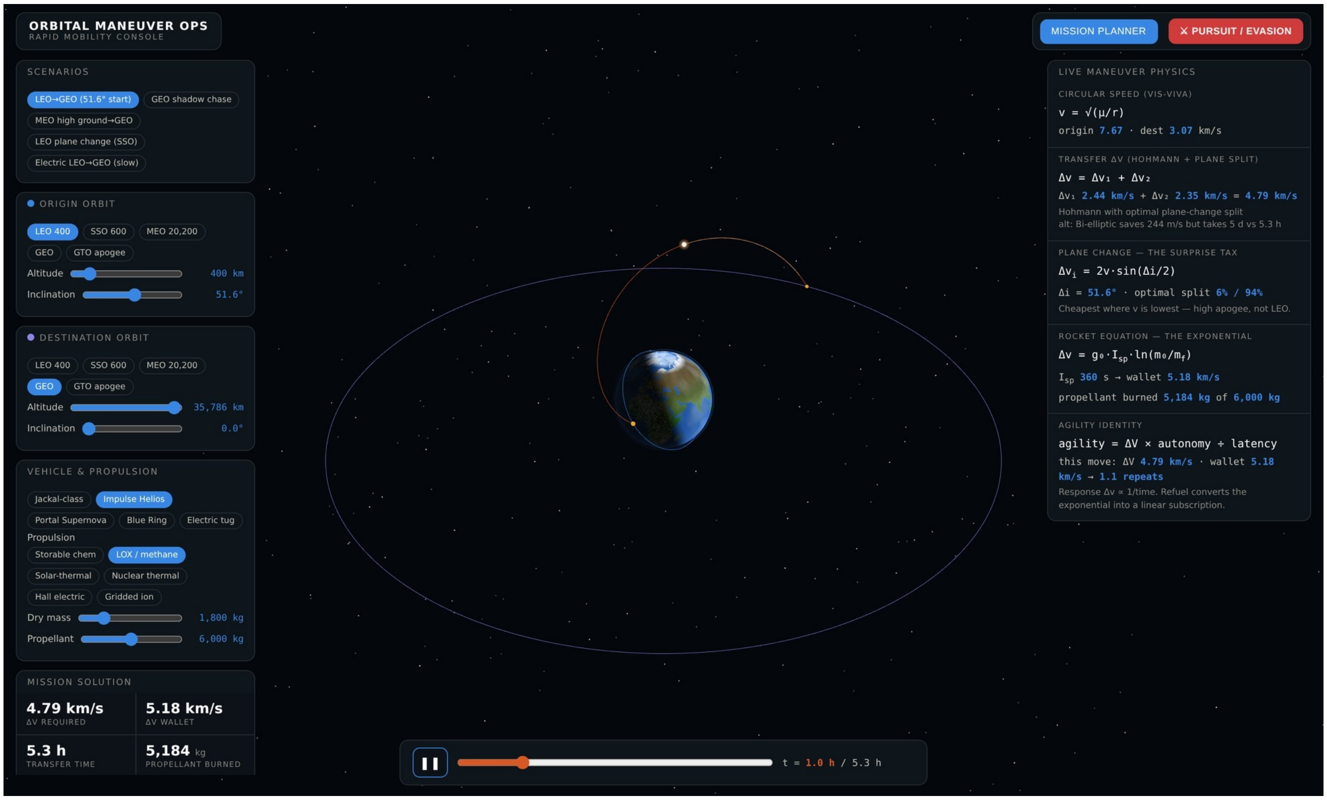

Figure C-1 — Mission Planner: LEO (51.6°) → GEO on an Impulse-Helios-class vehicle. Optimal Hohmann-plus-plane-change solution 4.79 km/s in 5.3 h (the panel also notes the slower bi-elliptic alternative), against a 5.18 km/s propellant wallet — feasible with ~1.1 repeats. The transfer ellipse is flown live.

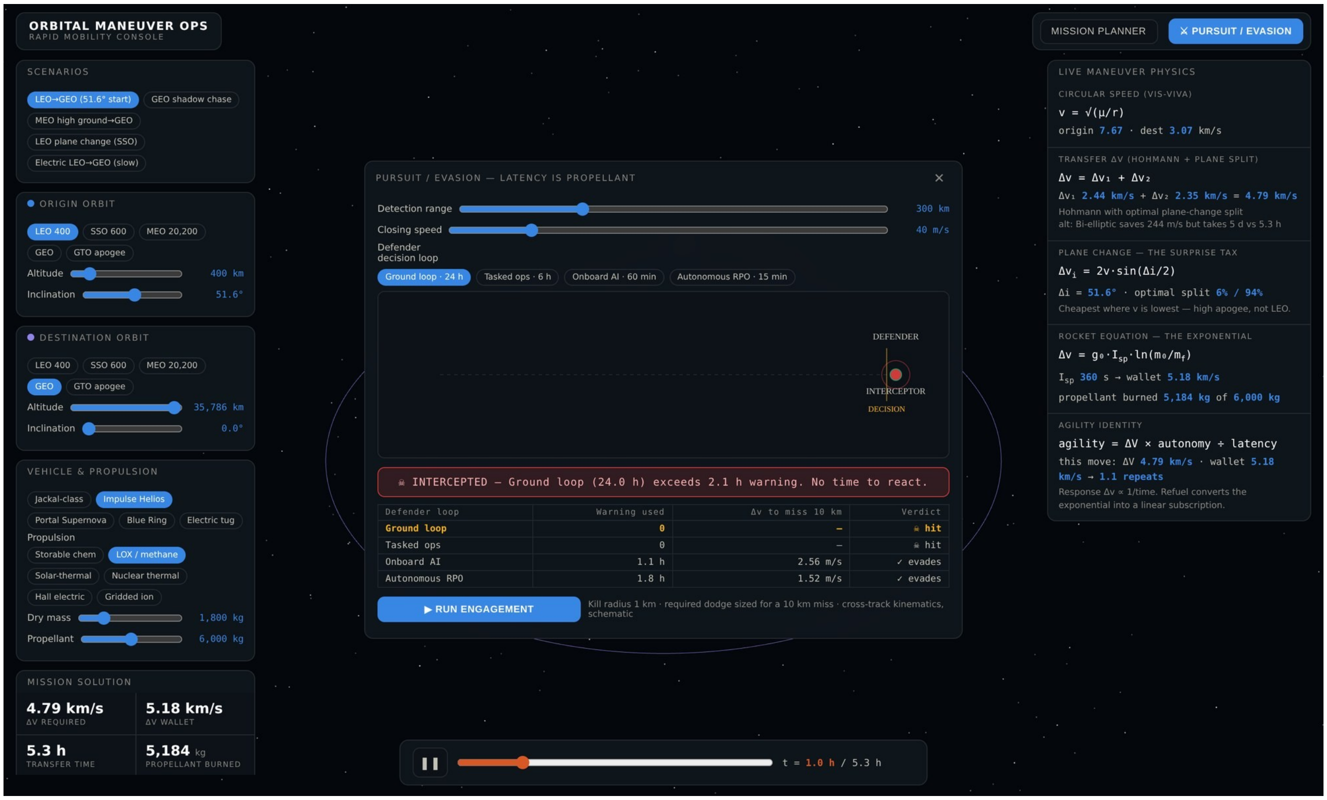

Figure C-2 — Pursuit/Evasion: identical geometry (300 km detection, 40 m/s closing), four defender decision loops. A 24-hour ground loop is intercepted outright; onboard AI evades for 2.56 m/s and autonomous RPO for 1.52 m/s. Propellant cost is set entirely by decision latency — the quantitative core of "agility = ΔV × autonomy ÷ latency."

As with the debris console, the model is deliberately schematic — two-body impulsive kinematics, a blended-inclination transfer arc, and cross-track evasion geometry — intended to build intuition about the trade space, not to design missions. Its lesson restates §7.1 in numbers the reader can vary: the side that decides in seconds forces the side that decides in hours to pay the plane-change and urgency premiums, or lose the engagement with full tanks.

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