

Space Security in the 21st Century

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Nuclear Risk, Technological Disruption, and
International Conflict in an Age of Turbulence
64th ISODARCO Course
15 January 2026

Outline

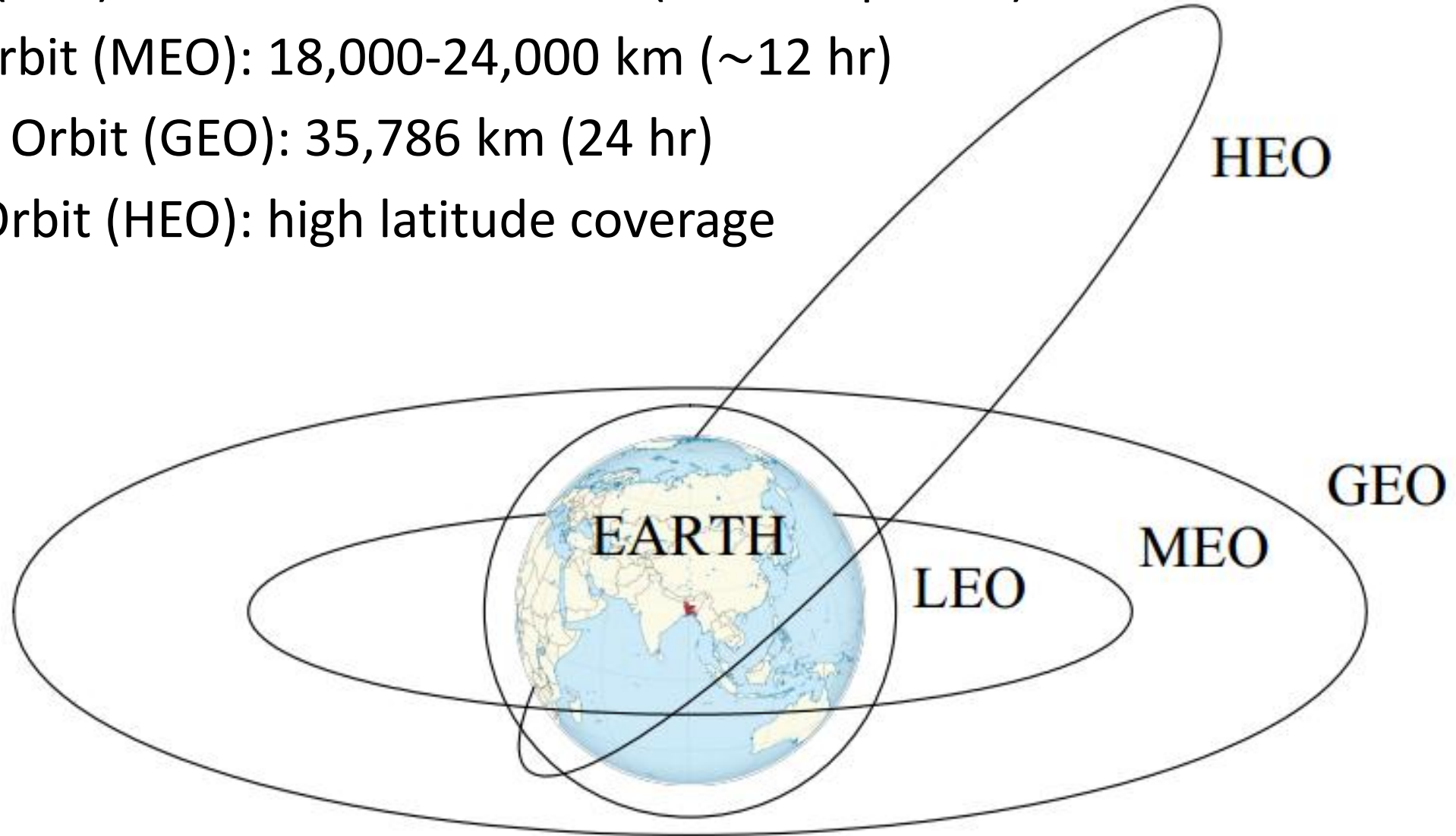
- Satellite missions and orbits
- Recent trends in space technology
 - Large constellations of small satellites in low-Earth orbit
- Implications for security and stability
- History of space arms control
- Anti-satellite weapons (ASATs)
- Space debris

Military Satellite Missions

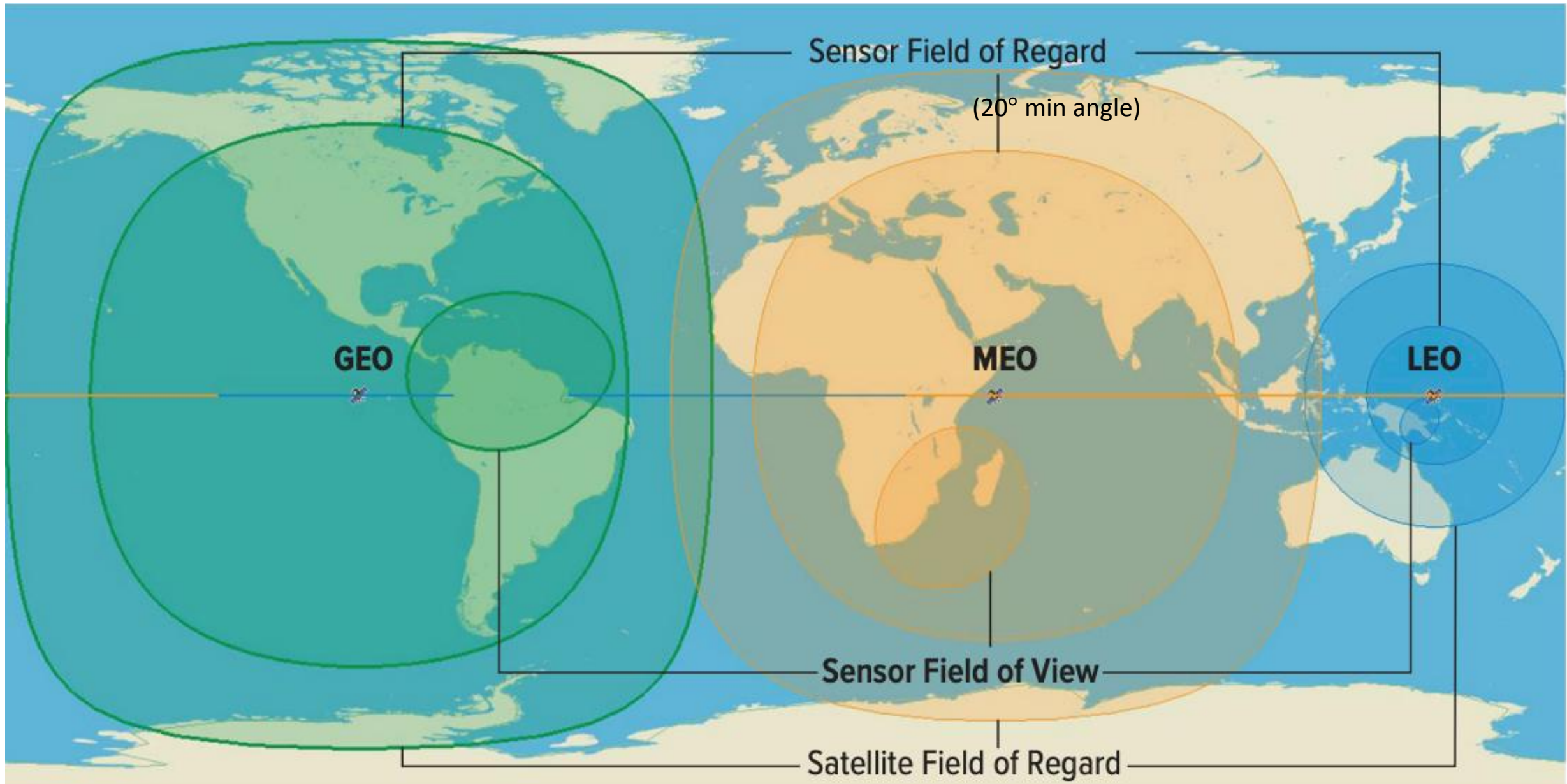
- Observation
 - Intelligence, Surveillance, and Reconnaissance (ISR)
 - Electro-optical (IMINT)
 - Electronic signals (SIGINT, ELINT)
 - Radar (SAR, MTI)
 - Weather
 - Ballistic missile detection and tracking
 - Nuclear burst detection
- Communication
 - Nuclear and conventional command and control
- Position, Navigation, and Timing (PNT)

Satellite Orbits

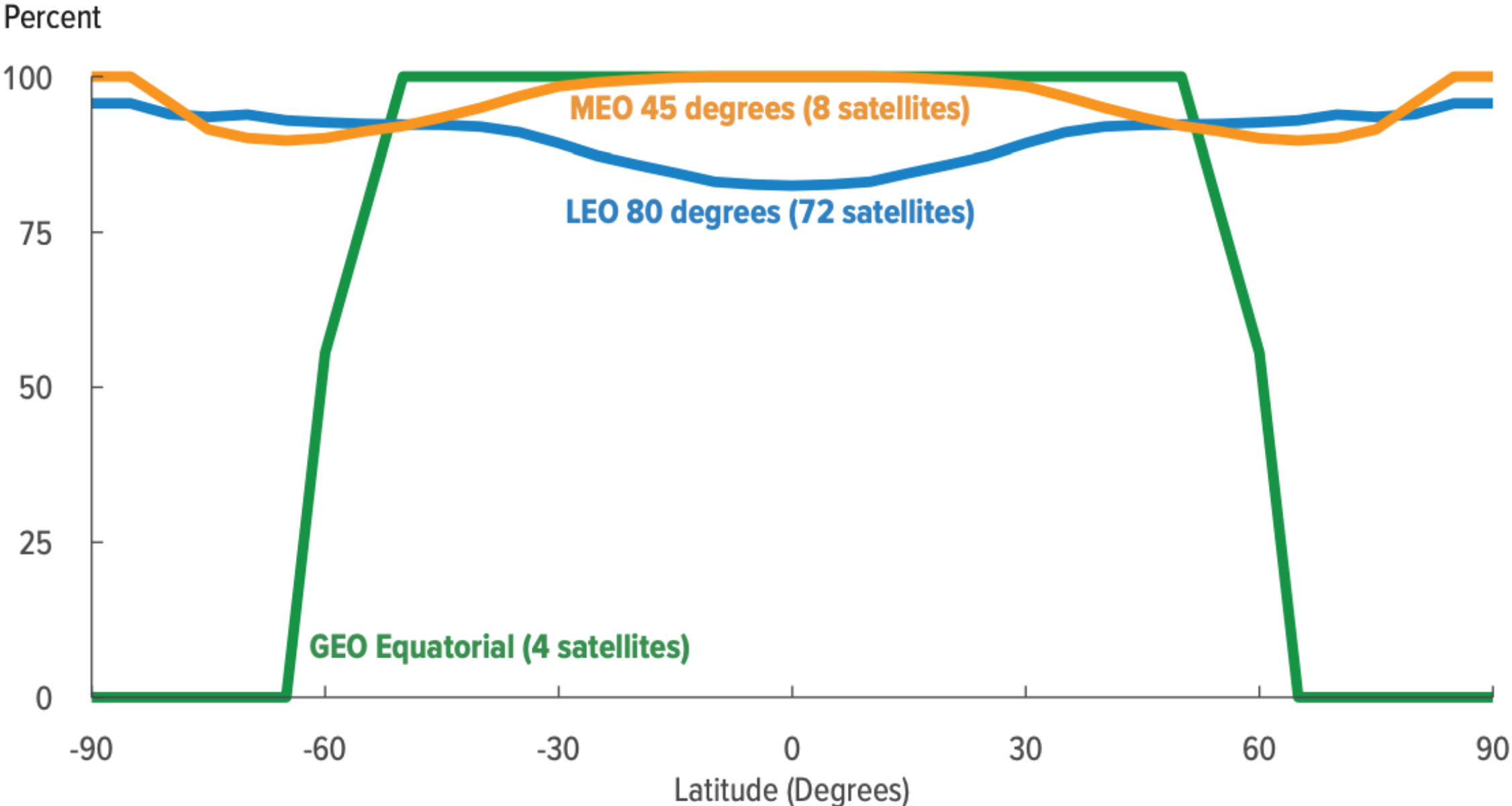
- Low-Earth Orbit (LEO): 300-2000 km altitude (1.5-2 hr period)
- Medium-Earth Orbit (MEO): 18,000-24,000 km (~12 hr)
- Geosynchronous Orbit (GEO): 35,786 km (24 hr)
- Highly Elliptical Orbit (HEO): high latitude coverage



Satellite and Sensor Field of Regard



Satellite Constellation Coverage



Space Systems and Nuclear Operations

- GEO
HEO

{

 - Early-warning satellites to detect and track ballistic missile launches; attack assessment; BMD; provide option to launch under attack
 - Communication satellites to transmit orders to/between mobile command posts, submarines, bombers, mobile ICBMs
- MEO

{

 - Navigation satellites for submarine, bomber, mobile ICBM location
 - Nuclear burst detection for attack assessment
- LEO

{

 - ISR systems to identify and locate targets
 - Electro-optical, electronic/signals, radar (SAR, GMTI)

Satellites by Mission and Orbit (2025)

	LEO	MEO	GEO	HEO	Total
Number in orbit	13,000	170	670	63	14,000
Observation	1,400	5	60	20	1,500
Navigation	120	120	33	3	280
Communication	11,600	45	575	40	12,300

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300 a decade ago

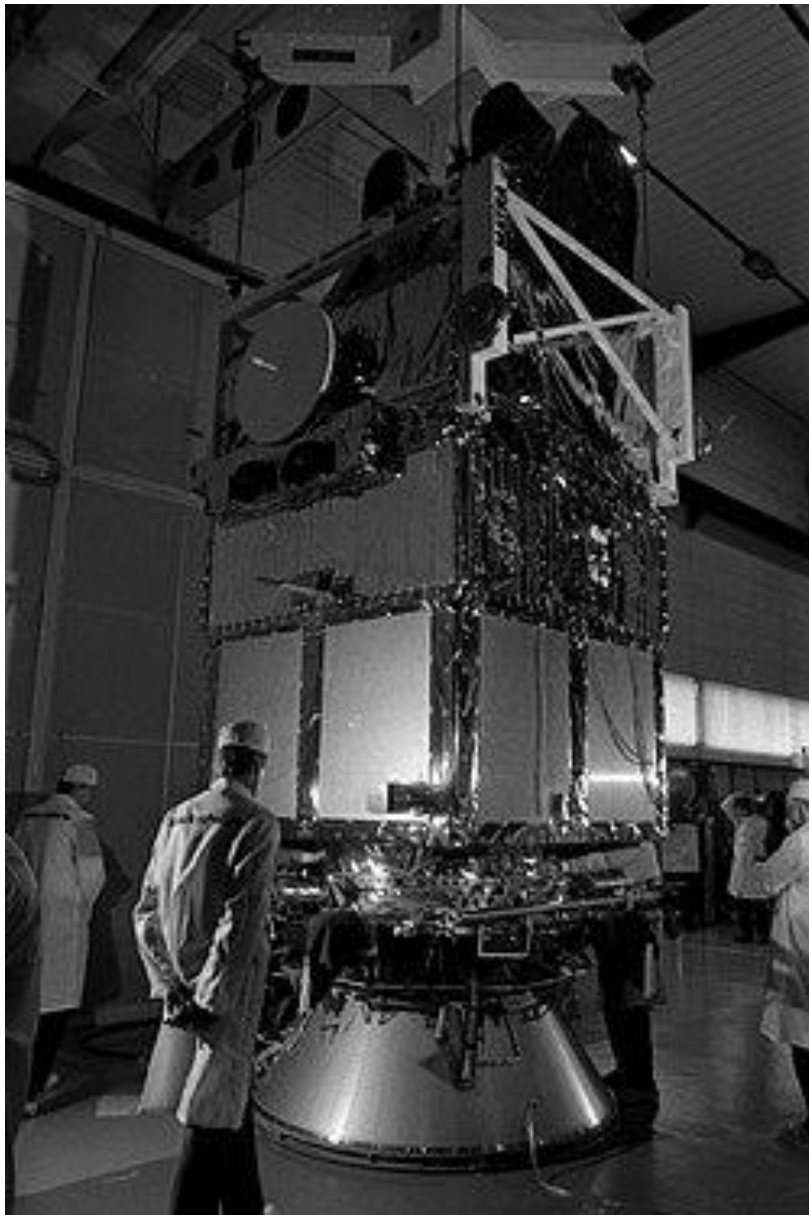
doubled in 3 yr

zero 3 yr ago

Trends in Space Technology

- Increase in sensor and on-board processing capabilities; decrease in mass and power requirements; decrease in power supply mass
- Major reductions in satellite cost; major increases in capability
 - SPOT (\$200M / 2000 kg; 10 m) → SkySat (\$2.0M / 100 kg; 0.5 m)
 - Iridium (\$50M / 690 kg; 5 Mps) → Starlink (\$0.3M / 300 kg; 1 Tbs)
- Major reduction launch costs
 - Shuttle (\$50,000/kg) → Falcon Heavy (\$1500/kg) → Starship (\$500/kg)
- Dramatic increase in satellites to orbit
 - 100/yr in 2000-2010 → 3000/yr in 2025

SPOT-1
(1869 kg, 10 m res)



SkySat-1
(83 kg, 0.5 m res)



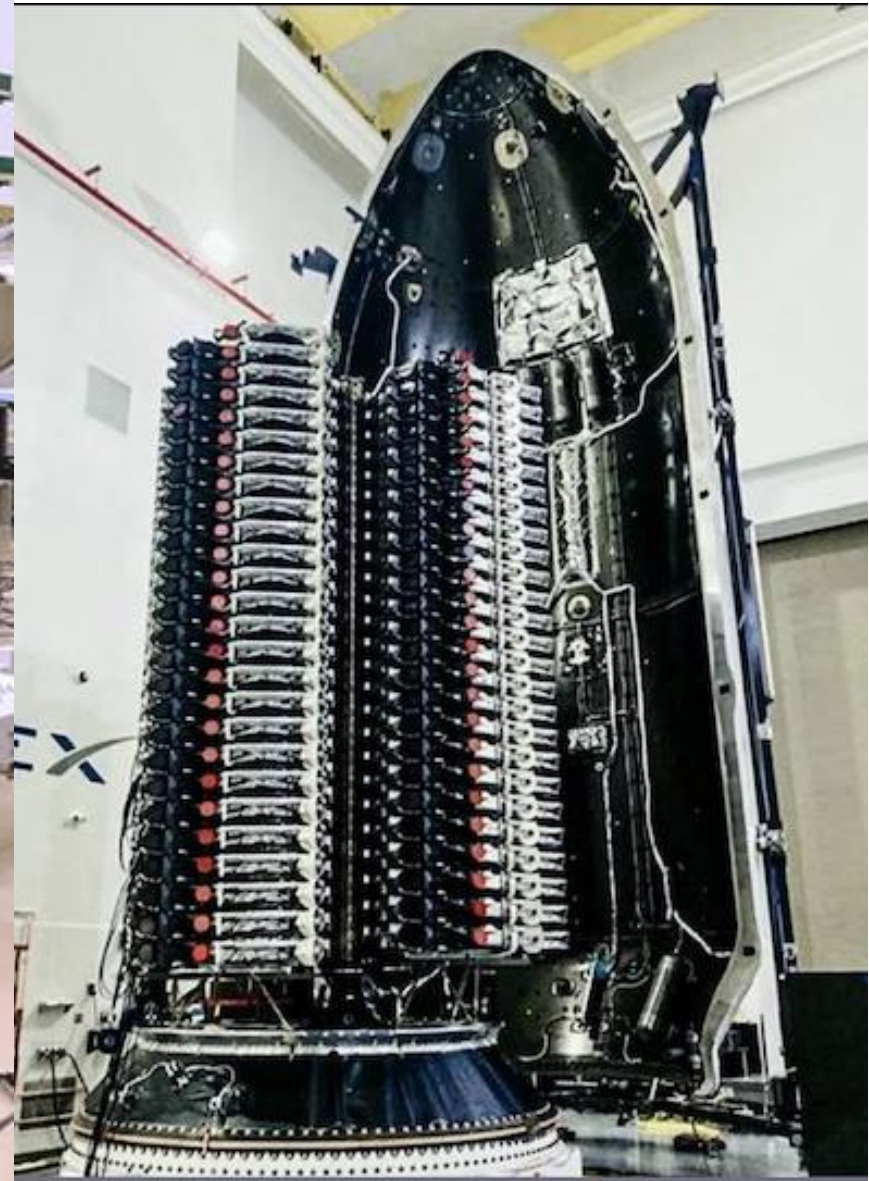
Galaxy-10
(3475 kg, 1 Gbps)



Iridium (1st gen)
(689 kg, 5 Mbps)



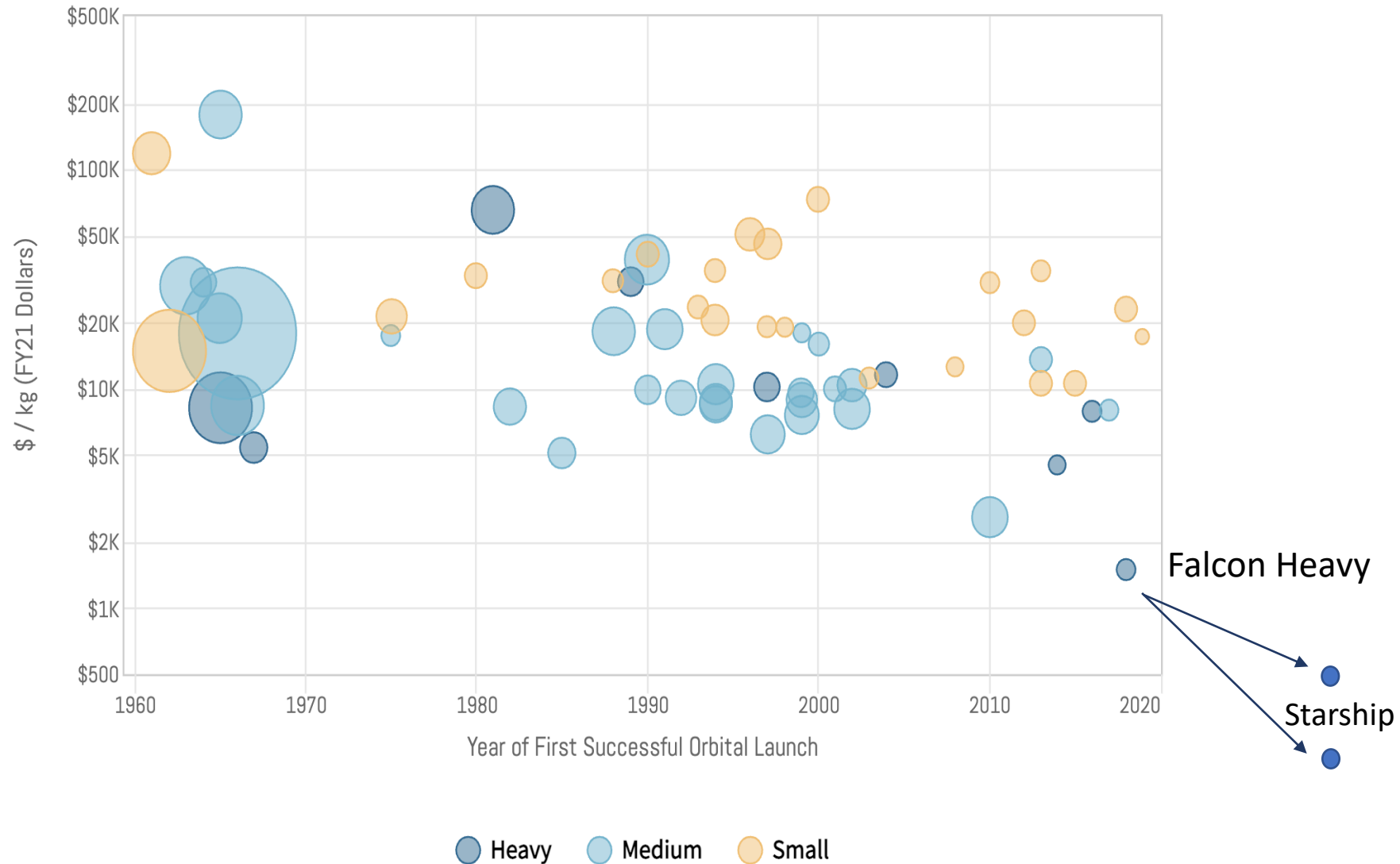
21 Starlink v1
(260 kg, 1 Tbs each)



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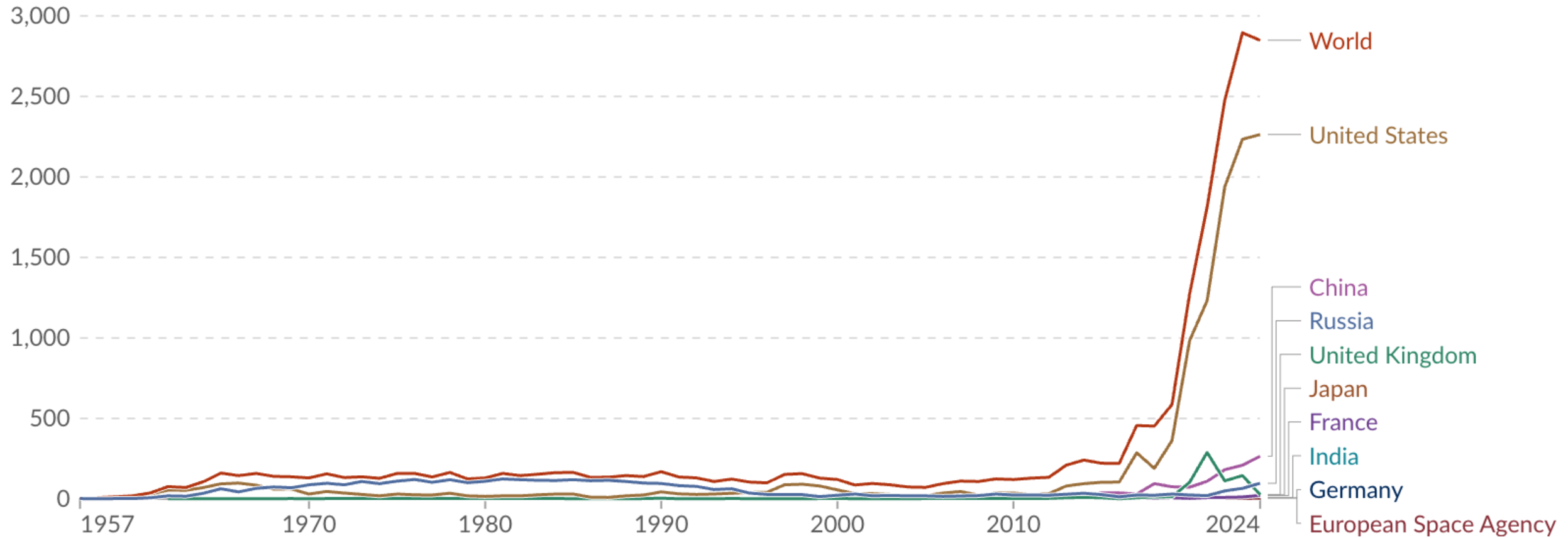
Launch Cost Fell 10x in 20 years



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Rate of Satellite Launch Increased 30x in a Decade



Examples of Large Constellations in LEO

- Planet observation satellites
 - 400+ Dove and SuperDove (6 kg), 3-5 m resolution; image Earth daily
 - 21 SkySat (100 kg), 0.5-m resolution; 6 revisits/d; \$2 million each
 - 32 Pelican (200 kg), 0.3-m resolution; 12-30 revisits/d; \$5 million each
- SpaceX Starlink communications satellites
 - 230-300 kg satellites at about 550 km altitude, \$300,000 each
 - 60 per launch (Falcon 9) → 400 per launch (Starship)
 - 8500 operational; launch approval for 12,000; plans for 42,000

Commercial → Military

- Space Development Agency and National Defense Space Architecture (now “Proliferated Warfighter Space Architecture”) established in 2019
- Large constellations of low-cost satellites in LEO organized into “layers”:
 - Transport: communication
 - Tracking: ballistic and hypersonic missiles
 - Navigation: using transport-layer satellites
 - Battle management: data processing and integration on all satellites
 - Custody: ISR using existing commercial and military satellites
 - Emerging capabilities: space domain awareness...
- 126 transport and 28 tracking by mid-2026 (tranche 1); an additional 200 transport and 72 tracking by mid-2029 (tranche 2)...

Emerging Capabilities

- Space-based radar
 - Can provide continuous (day-night, all-weather) surveillance of air and ground
 - SAR combined with AI/ML could enable automatic target identification
 - MTI could enable tracking of moving vehicles
- IR sensors in LEO
 - Allows multiple views of missiles and warheads from various angles; could improve midcourse discrimination for missile defense
- Space-based interceptors
 - Too expensive to defend against even salvo launch of 10 ICBMs
 $(1600 \text{ SBI/int-att})(2 \text{ int-att/ICBM})(10 \text{ ICBM})((\$20\text{M}/5 \text{ yr})/\text{SBI}) \approx \$3 \text{ trillion over 25 y}$
 - Easily defeated using faster-burning ICBMs (burnout below 100 km in 50 s)
 - May stimulate plans to destroy attack SBI or blind sensors with nuclear weapons
 - SBI would be potent ASAT weapons

Impacts on Strategic Stability

Positive

- Large constellations of small satellites in LEO can provide essential attack warning, communication, navigation services
- Very robust to degradation from ASAT attacks; can be rapidly reconstituted
- Should makes ASAT attack less attractive, bolster confidence in the survivability of satellites capabilities

Negative

- Could lead Russia and China to plan nuclear attacks on satellite systems
- Persistent ISR for detecting and tracking mobile and relocatable targets could decrease survivability of nuclear forces and command and control

Space Force general: Commercial satellite internet in Ukraine showing power of megaconstellations

by Sandra Erwin — May 11, 2022

A lesson from the Ukraine war is the resiliency provided by large proliferated constellations, said Gen. David Thompson

WASHINGTON — During a Senate Armed Services Committee hearing May 11, Sen. Tom Cotton (R-Ark.) asked Space Force officials if any lessons could be drawn from the war in Ukraine about the role of commercial satellites in armed conflicts.

One lesson is the resiliency provided by large proliferated constellations, said Gen. David Thompson, vice chief of space operations of the U.S. Space Force.

US Military Says SpaceX Handily Fought Off Russian Starlink Jamming Attempts

 South China Morning Post

China military must be able to destroy Elon Musk's Starlink satellites if they threaten national security

- Researchers call for development of anti-satellite capabilities including ability to track, monitor and disable each craft
- The Starlink platform with its thousands of satellites is believed to be indestructible

WAR IN UKRAINE

U.S. says Russia launched a space weapon in the path of an American satellite

The Kremlin accused Washington of disinformation Wednesday, while it conducted exercises to simulate the use of tactical nuclear weapons in a likely warning to the West over Ukraine.



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2024 Elections

Exclusive: Russia attempting to develop nuclear space weapon to destroy satellites with massive energy wave, sources familiar with intel say

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US Tells Allies Russia May Launch Anti-Satellite Nuclear Weapon Into Space This Year

- Russia says it has no plans to deploy nuclear weapons in space
- Weapon would target communications satellites, not people



By —
John
Leicester,
Associated
Press

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Intelligence agencies suspect Russia is developing anti-satellite weapon to target Starlink service

World Dec 22, 2025 1:52 PM EST

Two NATO-nation intelligence services suspect Russia is developing a new anti-satellite weapon to target Elon Musk's Starlink constellation with destructive orbiting clouds of shrapnel, with the aim of reining in Western space superiority that has helped Ukraine on the battlefield.

Intelligence findings seen by The Associated Press say the so-called "zone-effect" weapon would seek to flood Starlink orbits with hundreds of thousands of high-density pellets, potentially disabling multiple satellites at once but also risking catastrophic collateral damage to other orbiting systems.

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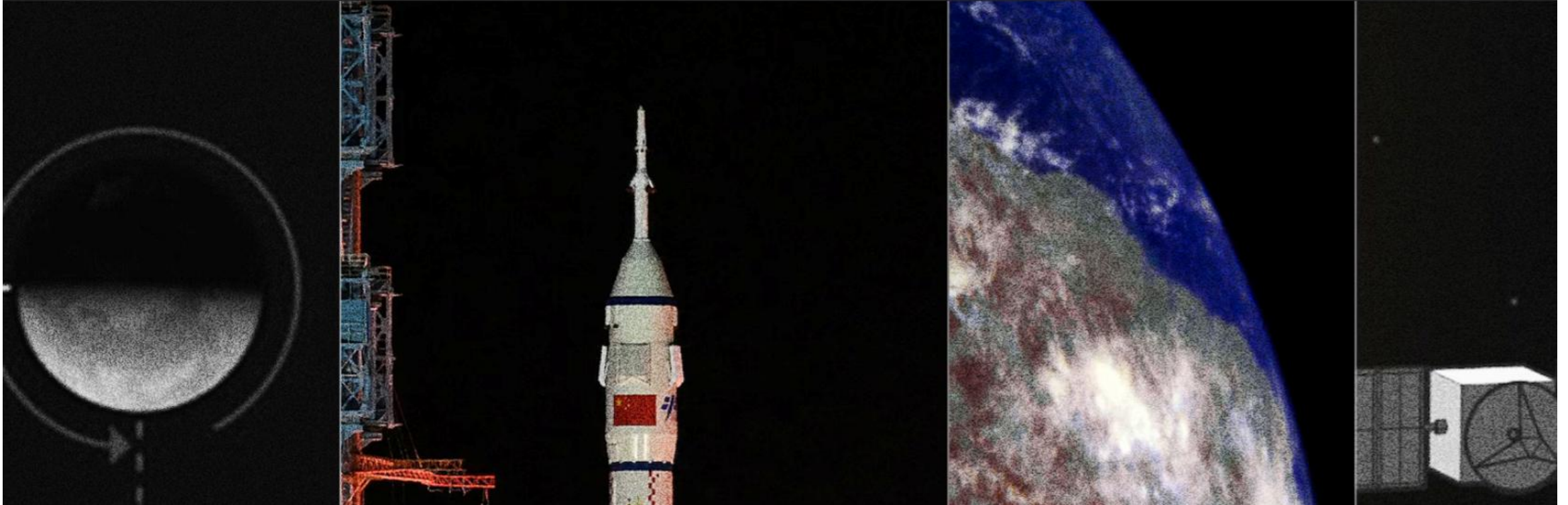


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SPACE

WHY U.S. AND CHINESE SATELLITES ARE 'DOGFIGHTING' IN ORBIT



Sanctuary or Theater of War?

- 1957-62: Proposals to ban the use of space for military purposes
 - Little progress because of inspections proposed by US, linkage to general and complete disarmament by USSR
- 1959-60: U.S. deploys CORONA photoreconnaissance; TRANSIT navigation; GRAB electronic intelligence; MIDAS early warning sats
 - Strong US interest in legitimizing use of space for intelligence and defense support missions
- Interest/concern about “orbital bombardment” dissipated
 - Orbital delivery inferior to ballistic missiles
- Outer Space Treaty (1967)

Outer Space Treaty (1967)

- Exploration and use of space shall be carried out for benefit of all countries and shall be the province of all mankind
- Space shall be free for exploration and use by all States
- Space not subject to national appropriation by any means
- States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies
- Moon and celestial bodies used only for peaceful purposes; prohibits testing weapons or establishing military bases
- States are responsible for national space activities whether carried out by governmental or non-governmental entities
- States shall be liable for damage caused by their space objects
- States shall avoid harmful contamination of space and celestial bodies

Sanctuary or Theater of War?

- Satellites provide key capabilities to support military operations—particularly for US, which has operations far from its national territory
- Satellites increasingly attractive targets, particularly for Russia, China, and other potential US adversaries
- Satellites are inherently vulnerable
 - Predictable orbits; limited ability to maneuver, harden, or defend
 - Even large constellations are easier/cheaper to destroy than replace
- Countries may be deterred from large-scale ASAT attacks
 - Destructive attacks generate debris that can render regions of space unusable for many years
 - Nuclear explosions in space would destroy many satellites, including those of the attacking nation

Anti-Satellite Weapons

Satellite Destruction

- Direct-ascent: air/sea/ground-launched missile that delivers kinetic kill or explosive warhead to satellite
- Co-orbital: missile delivers ASAT into same orbit as target satellite
- Space mine: co-orbital ASAT that maneuvers into proximity to target satellite, ready to destroy target on command

Satellite Interference or Damage

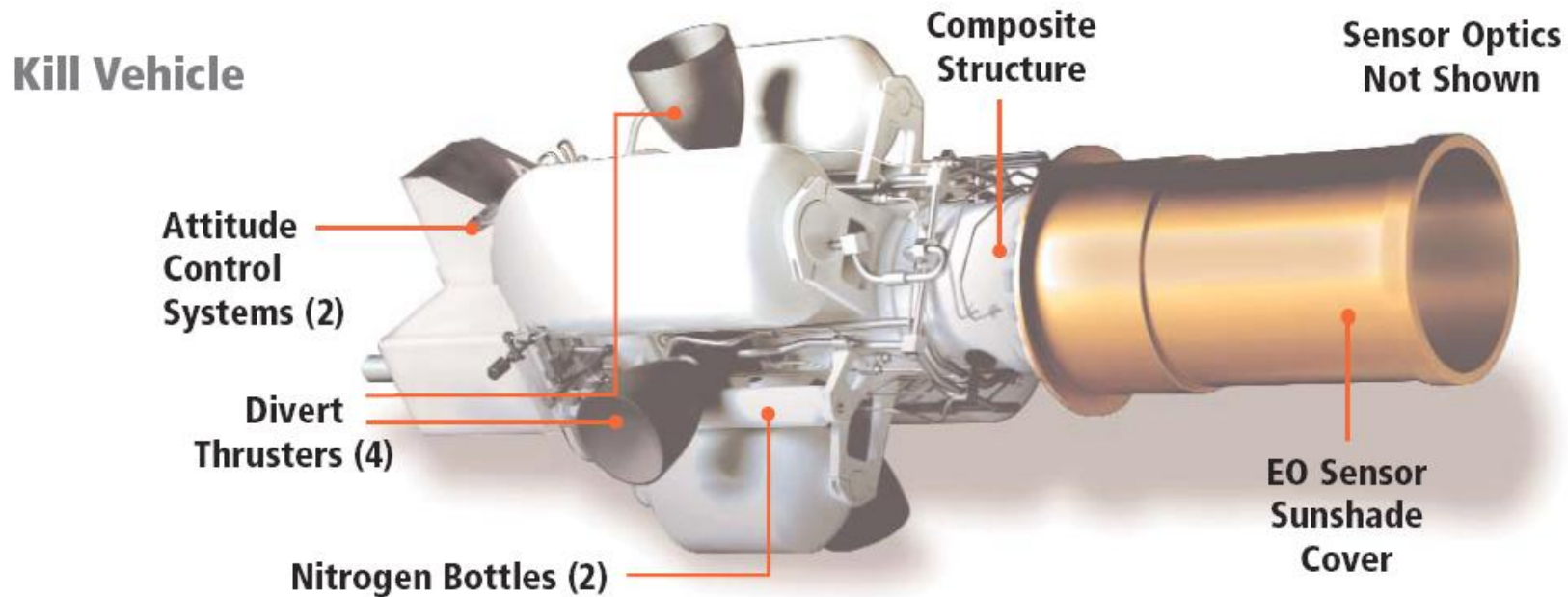
- Jamming or spoofing downlinks or uplinks
- Cyber attack
- Laser dazzling or blinding optical sensors; heating
- Physical interference using systems developed for satellite maintenance

Direct-ascent ASAT Advantage

- Δv required to reach 300-1000 km altitude is 2-3x less than Δv required to place a satellite in orbit at the same altitude
 - ASAT rocket can be 3-4x smaller than satellite launch vehicle for a given payload mass
- ASAT payload (kinetic kill vehicle) can be much lighter and less expensive than target satellites
 - Similar to EKV developed for GMD (65 kg) and Aegis SM-3 (10-20 kg)
 - At 10 km/s, 10-kg KKV has KE = 500 MJ $\approx$ 120 kg TNT
- Cost to deliver one 100-kg satellite to LEO is roughly the same as the cost to deliver 30-40 ASATs (10-kg KKV)
- Even for large constellations of small and inexpensive satellites, the cost-exchange ratio favors the attacker

Kinetic Energy ASAT

- Booster rocket lifts the ASAT kill vehicle to satellite altitude
- On-board sensor and thrusters are used to home on satellite
- Destroys satellite by colliding with it
- Similar in concept to U.S. missile defense kill vehicle:



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Anti-Satellite Weapons

United States

- 1959-75: Existing air-launched missiles and ABM interceptors adapted to direct-ascent nuclear ASAT mission; low priority
- 1982-85: Air-launched direct-ascent kinetic-kill ASAT; tested 13 Sep 1985, creating 1000+ pieces of orbital debris (last deorbited 19 yr later)
- 1985: Congress bans destructive tests; ASAT cancelled in 1988
- 1997: USAF tests MIRACL laser on satellite, damaging sensor; program ended in 2011
- 2008: US uses modified SM-3 to destroy disabled satellite; 174 pieces of trackable debris (last deorbited 20 mo later)
- 2022: US proposes banning destructive ASAT tests

Anti-Satellite Weapons

Soviet Union / Russia

- 1963-93: Soviet development of co-orbital ASAT; first successful test in 1968, operational in 1973; decommissioned in 1993
- 2009: Russia begins development of direct-ascent ASAT; tested on 15 Nov 2021; 1800 pieces of trackable orbital debris (5 still in orbit)

China

- 2003: Development begins on direct-ascent ASAT; tested against weather satellite on 11 Jan 2007; 4000 trackable debris (2800 still in orbit)

India

- 2010: announces development of direct-ascent ASAT; tested against microsatellite on 27 March 2019; 270 pieces of trackable debris (last deorbited 39 mo later)

January 2007 Chinese Test of Kinetic Energy Interceptor Against FY-1C Satellite



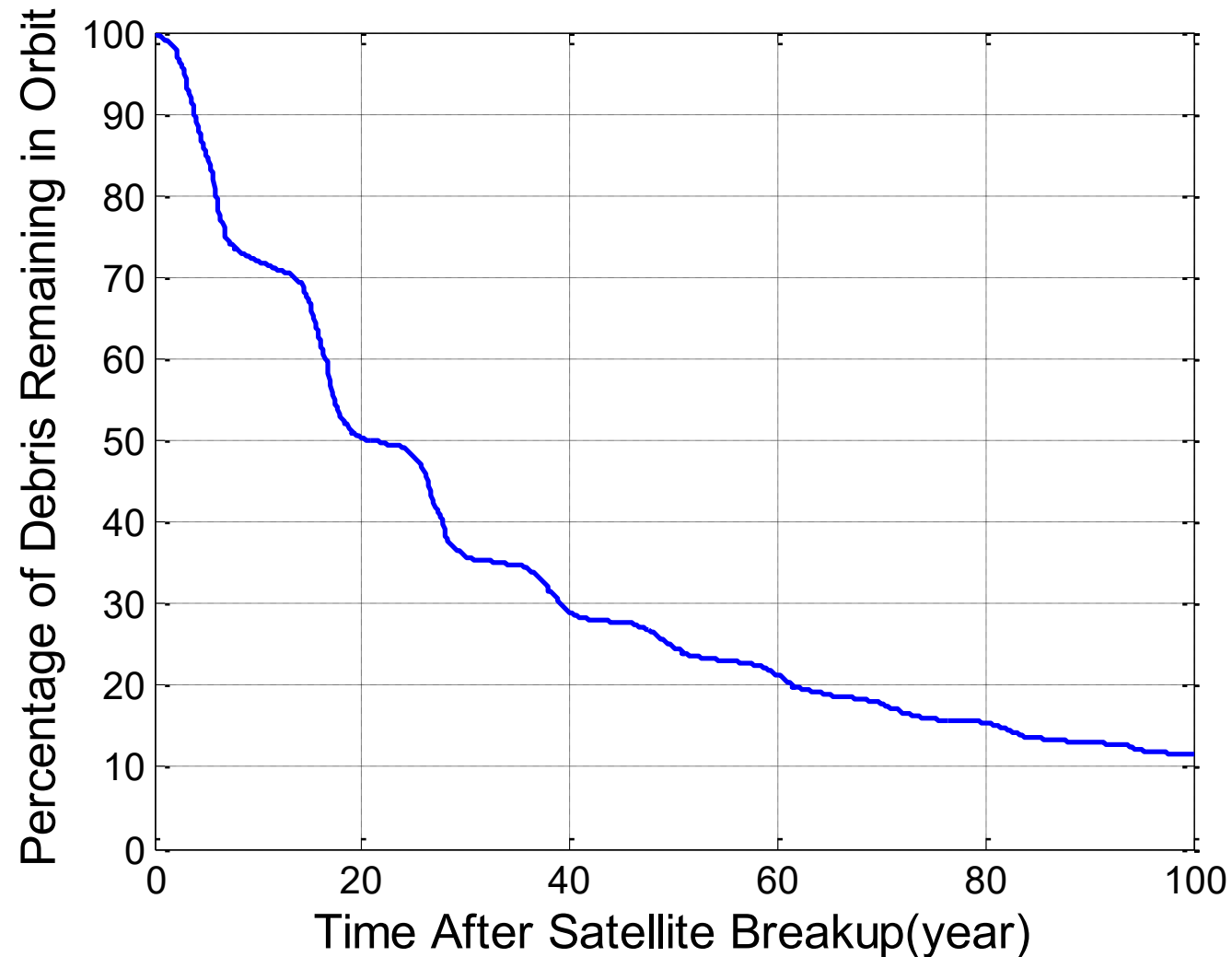
Dry mass = 850 kg

Body dimensions: 1.42 m x 1.42 m x 1.2m

Total length: 10.5 m

Destroyed by a homing KE interceptor at an altitude of 850 km

Lifetime Estimates of Debris from Chinese Test



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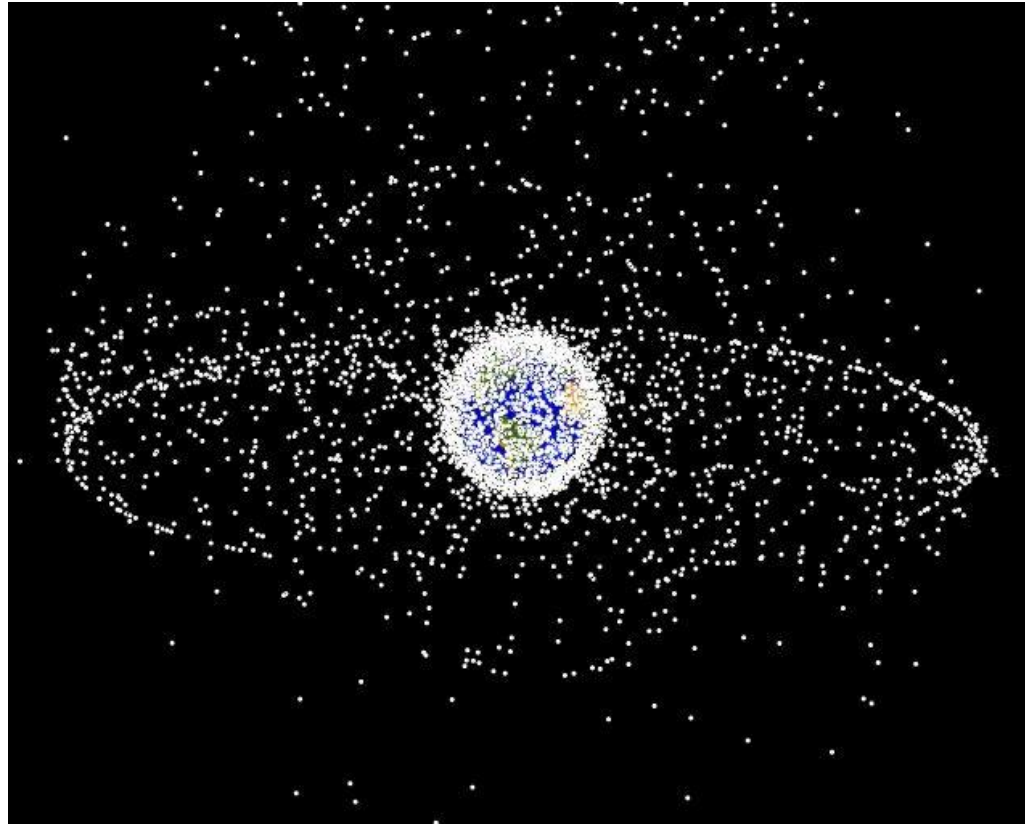
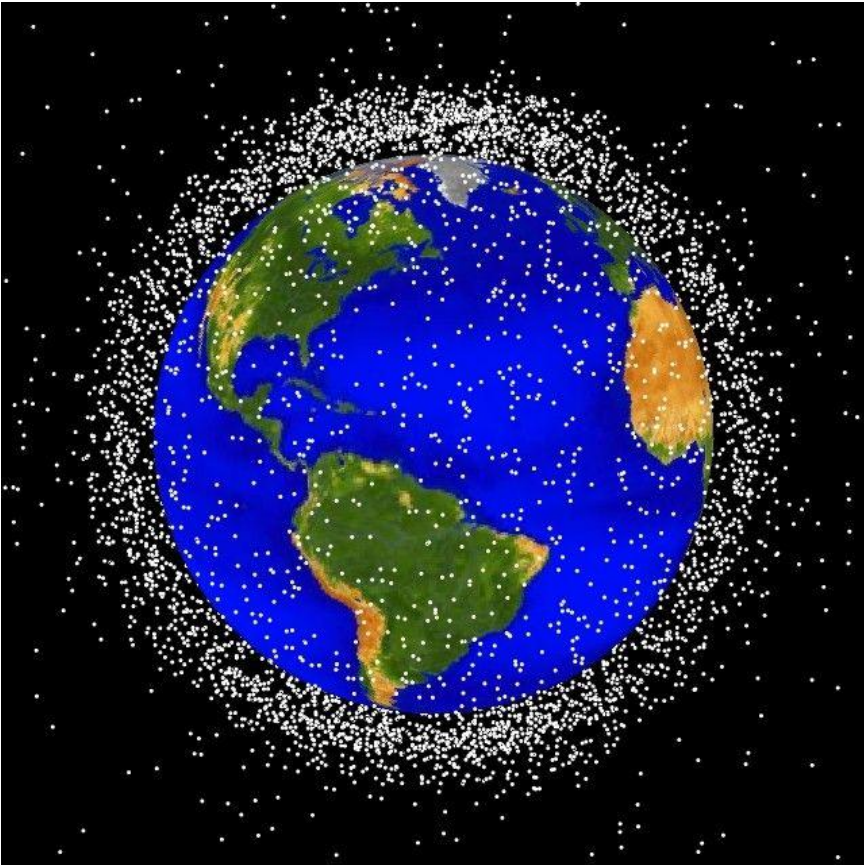
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Space Debris

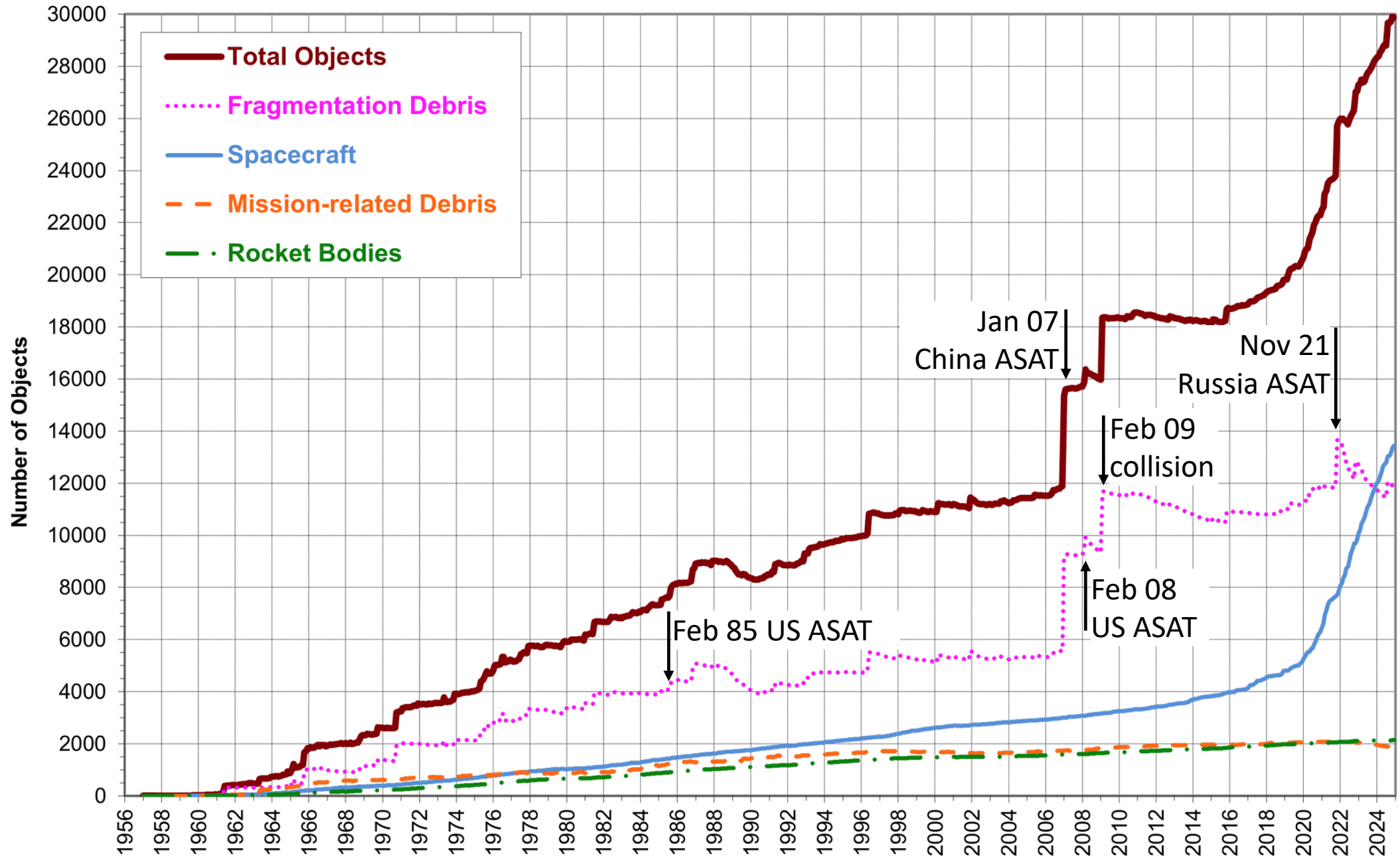
- Rocket stages and defunct satellites
- Fragments from breakup of satellites, rocket stages
- Discarded equipment; bolts and other hardware released during deployment of satellites



Cataloged Debris

- The US tracks objects in space with radar and optical sensors in the Space Surveillance Network (SSN)
 - Can track objects in LEO larger than 5-10 cm in size
 - Can track objects in GEO larger than ~1 m in size
- U.S. keeps a catalog of objects—currently 30,000 in orbit
- To be in the catalog:
 - object must be tracked by SSN
 - object's origin must be known
- Total number of debris objects is much larger than the number in the catalog; ~1 million pieces greater than 1 cm at all altitudes

Catalogued Objects in Earth Orbit (>5-10 cm)



Ownership of Catalogued Objects (4 June 2025)

	Satellites	Debris	Total
United States	9779	4757	14536
Russia	1575	5056	6631
China	889	4557	5446
United Kingdom	717	1	718
France	120	519	639
Japan	201	96	297
India	112	83	195
ESA	104	26	130
Others	1158	87	1245
Total	14655	15182	29837

Collision Between Satellites (Feb 2009)

Collide at 11.6 km/s
relative velocity at
790 km altitude

Kosmos-2251 satellite
(950 kg)



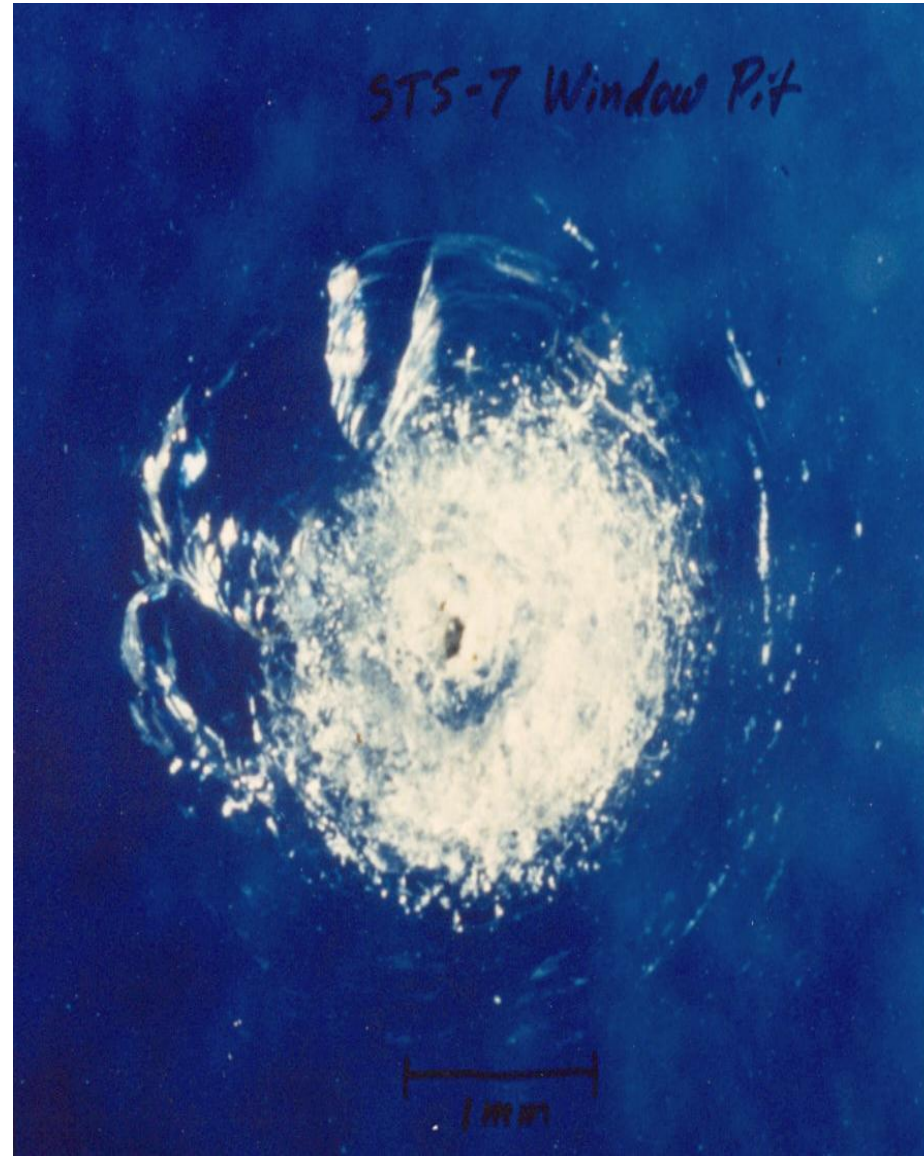
Iridium satellite
(560 kg)

2300 pieces
tracked debris
(1100 still in orbit)

Total vs. Cataloged Debris

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Crack in Space Shuttle Window from Paint Fleck



“Kessler Syndrome”

- First described in 1978 paper by NASA scientist Donald Kessler, “Collision Frequency of Artificial Satellites: The Creation of a Debris Belt.”
- Collision frequency increases as square of the number of objects in orbit.
- If number of objects doubles, the collision frequency increases by a factor of four. These collisions create additional debris objects, which further accelerate the collision frequency.
- At a certain point, the collision frequency is so high and growing so rapidly that satellite lifetime in an orbital belt becomes unacceptably short, and even the risk of transit through the debris belt becomes unacceptably high

Recommendations

- Debris from ASAT testing has increased the threat to satellites, but that threat is still relatively small and manageable. Testing or use of destructive ASAT weapons against satellites should be prohibited.
- Satellite collisions have been rare, but will become more frequent as the satellite population increases. Space situational awareness must be improved and procedures adopted to provide timely warning and collision avoidance.
- International debris mitigation guidelines should be made mandatory, with enforcement mechanisms.
- Methods to remove debris should be developed.