Tech Brief:

Orbital Debris: Situational Awareness, Collision Avoidance, and Debris Mitigation

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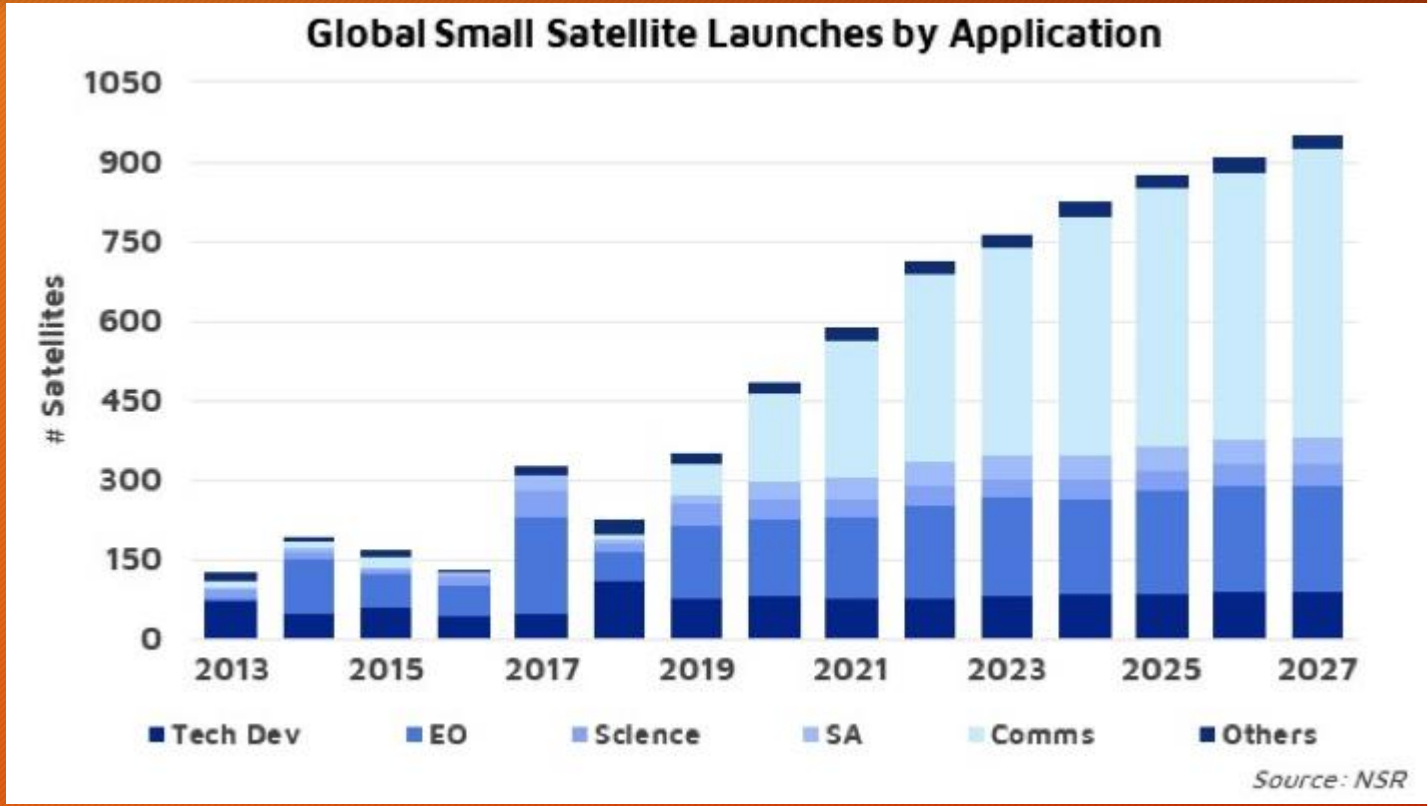
The Magnitude of the problem

Increasing Launches and Payloads Drive Debris



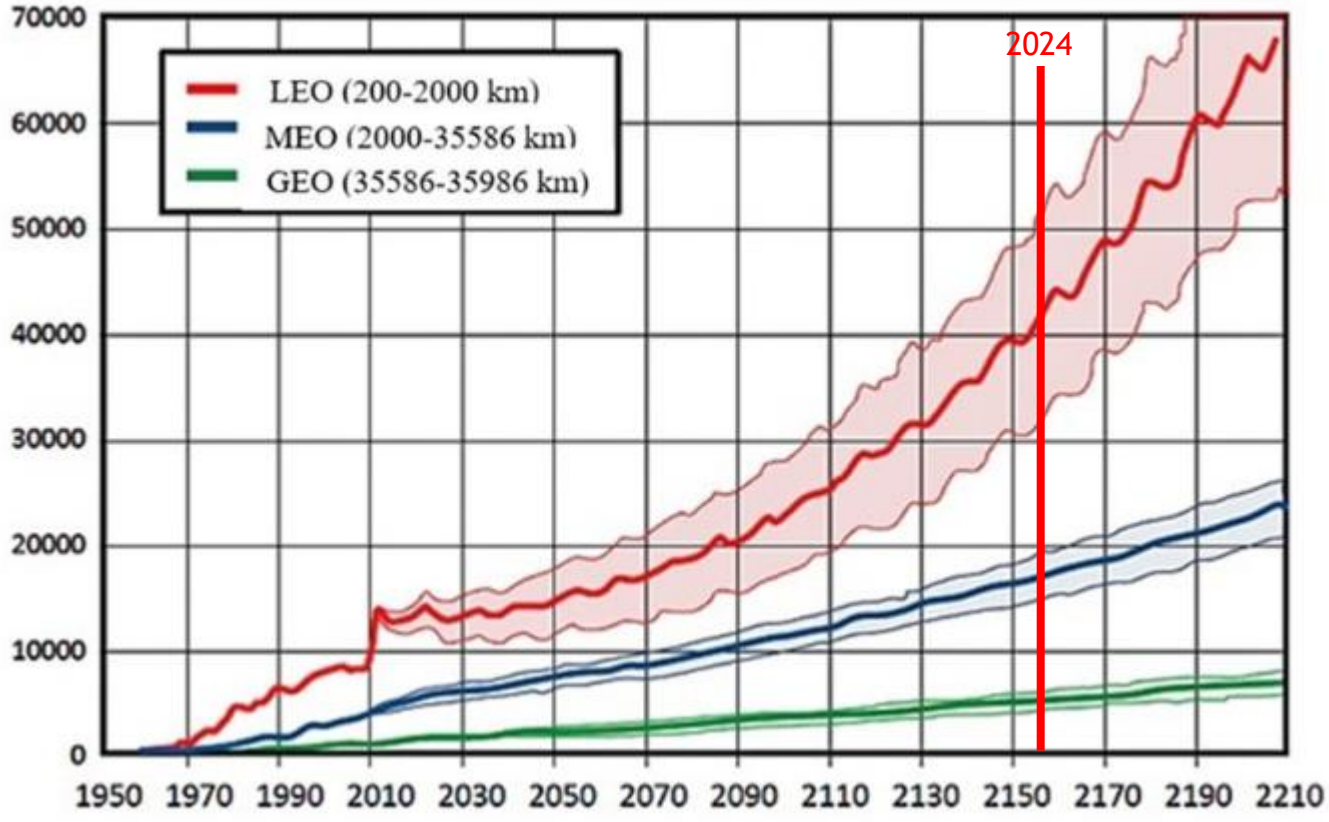
> 2,500 satellites will be launched every year between now and 2031, driven by commercial constellations

Starlink:

- 5,500 Satellites launched at end of 2023
- Approval by FCC for 12,000 satellites
- Starlink has a new request for 30,000
- 50% of all active satellites

As of 06/2023	Starlink Gen 1				Starlink Gen 2	
Missions	V1.0	Group 2	Group 3	Group 4	Group 5	Group 6
Orbit	550 km at 53°	570 km at 70°	560 km at 97.6°	540 km at 53.2°	530 km at 43°	
Satellites launched	1665	408	243	1637	541	86
Satellites reentered	178	3	10	68	2	7
Satellites in operational orbit	1423	152	233	1544	306	30

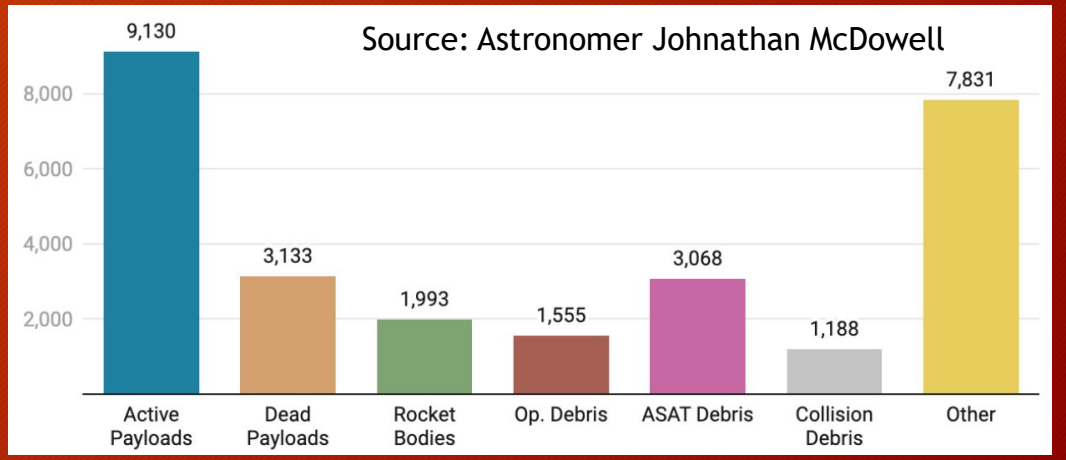
The Growth in Space Debris



Source: Research Gate -Elizaveta Abramova

Operational changes are required to limit space debris. Failing this, debris density will grow & collisions between objects could cause a cascade of collisions creating more debris.

"The Kessler Syndrome"

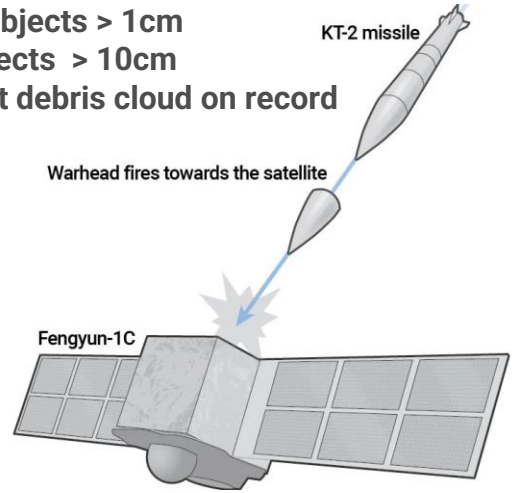


Sources of Space Debris

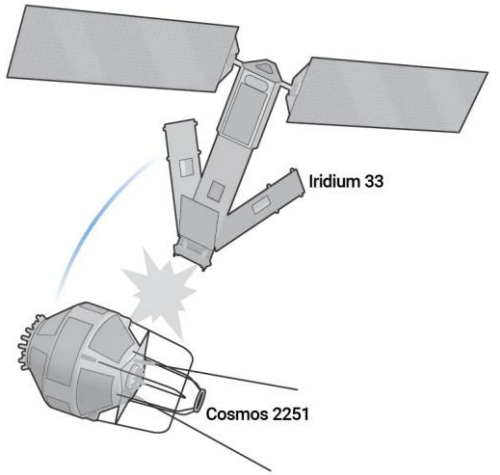
- The delivered payload from a successful launch
  - The Mission is the Debris unless it can be “deorbited”
- Upper stages of launch boosters and orbit transfer motors
- Other mission hardware launch adapters, lens covers, etc.
- Explosion or remnant rocket bodies and space craft
- Collison between satellites and other space debris
  - Example Iridium 33 and Cosmos 251
- Intentional anti-satellite weapons tests
  - Example KT-2 missile & Fengyun-1C weather satellite

These collisions increased the Space Surveillance Network tracked orbital debris by almost one third.

2007, China tests an anti-satellite missile
300K objects > 1cm
3K Objects > 10cm
Largest debris cloud on record



February 10, 2009 first Satellite Collision
~2k Objects > 10cm created



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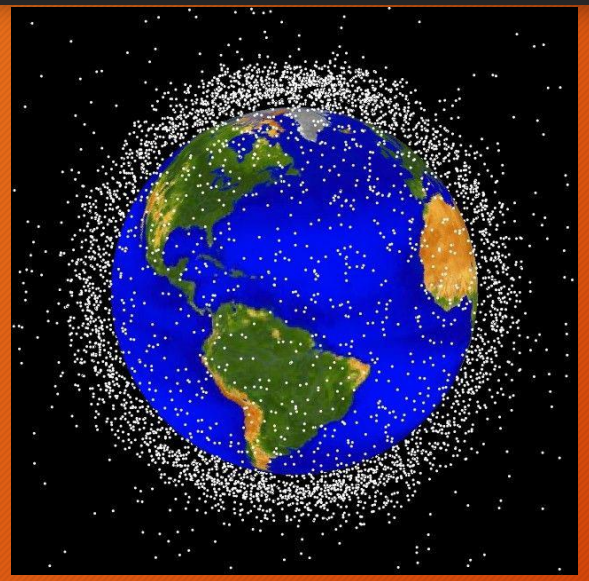
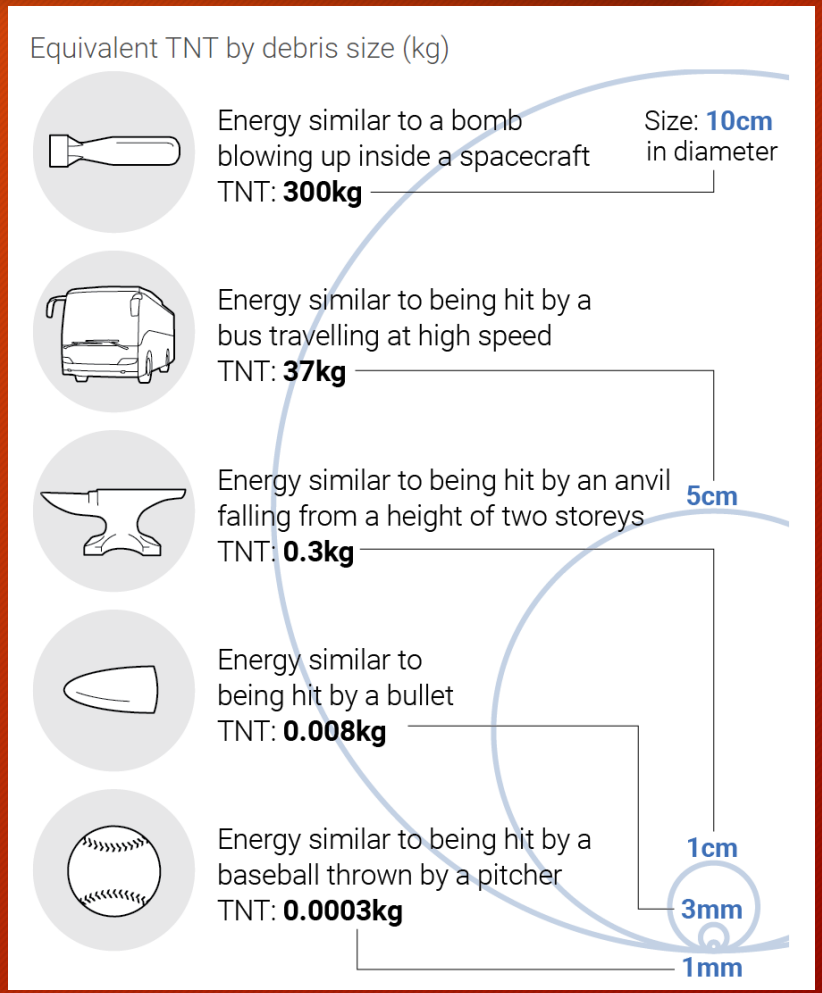
Mass Combined with High Velocity = High Destructive Power



- As of December 31, 2023 27,898 orbital debris >10cm
- 500,000 pieces of debris >1cm but < 10cm
- 100 Million pieces > than 1mm
- Average velocity 28,000 km/h (17,000 mph)



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Object/Debris Tracking

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Tracking Orbital Space Debries

- 18th Space Defense Squadron – USSF Space Domain Awareness unit (in conjunction with NASA)
  - Operates the US Space Surveillance Network (SSN)
  - SSN is a world wide network of 30+ ground-based radars and optical telescopes, plus 6 satellites in orbit (Pathfinder SSBS)
  - Near-Earth (NE) tracking- observing satellites, space debris and other LEO objects
  - Deep Space (DS) tracking- generally for asteroids and comets
  - Cataloges and Tracks >30K near earth objects > 10cm
- China, Russia, and EU perform similar tracking functions
  - Limited sharing of object data bases (which is disappointing)

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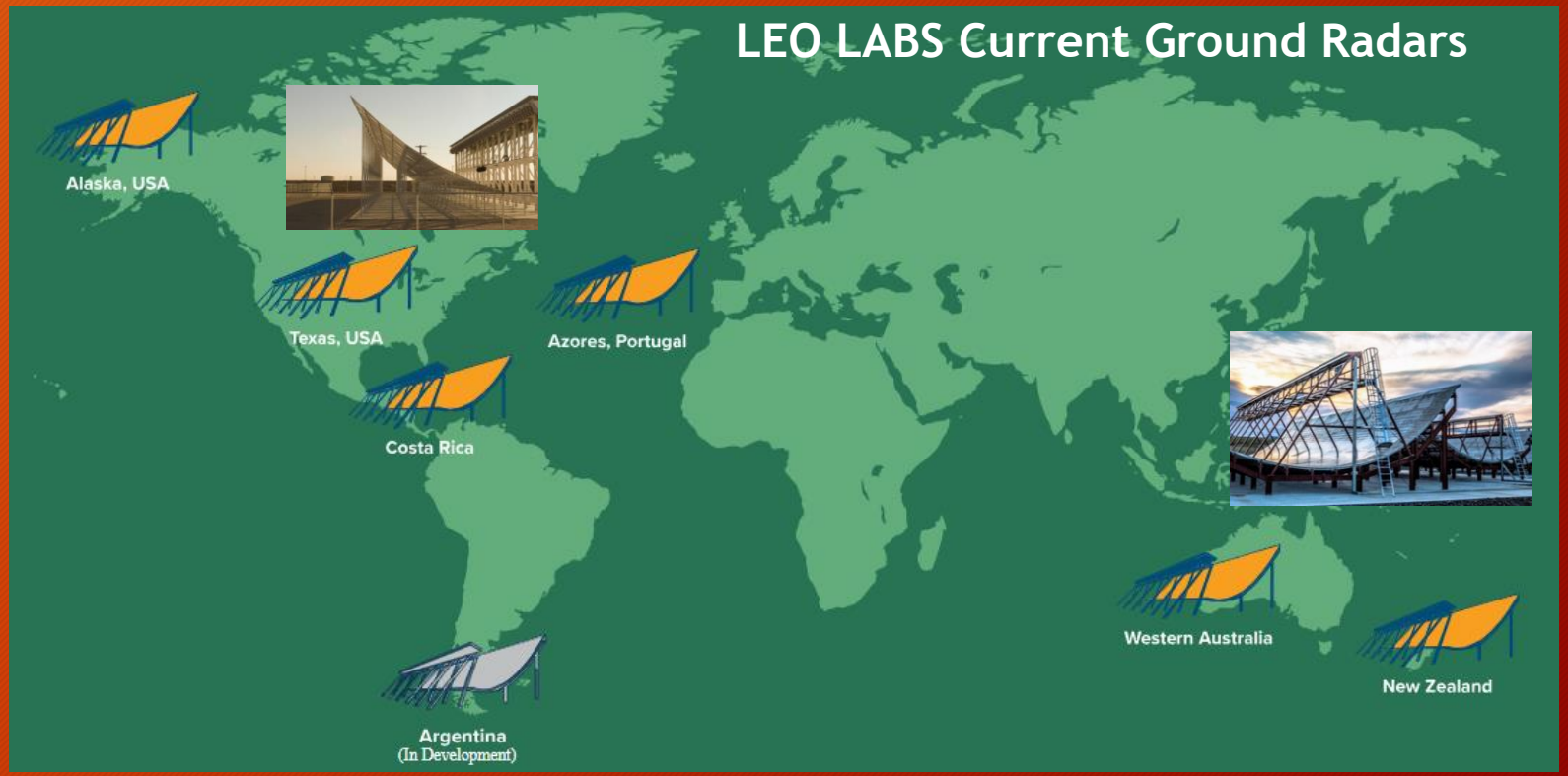
US Space Surveillance Network

- In addition to ground based radar and optical sites, the SSN has satellite components:
  - Sapphire (Canadian military satellite – joint program)
  - Space Based Space Surveillance (SBSS) "Pathfinder satellites"
  - Geosynchronous Space Situational Awareness Program (GSSAP) satellites

Commercial LEO Debris Tracking: LEO LABS

- LEO Labs provides Tracking and Collision Avoidance As A Service
  - Conjunction Alerts and post maneuver assessment
  - Mission planning and assessment
  - Space Domain Awareness
    - Tracking of any and all launches deployed objects
- Six S-Band and UHF Phased Array Radars with plans for 20
  - Track objects as small as 2 cm
- Current System capabilities
  - Track new satellites in orbit within hours of deployment
  - Revisit satellites multiple times a day
  - Avoidance Alerts and Risk Assessment



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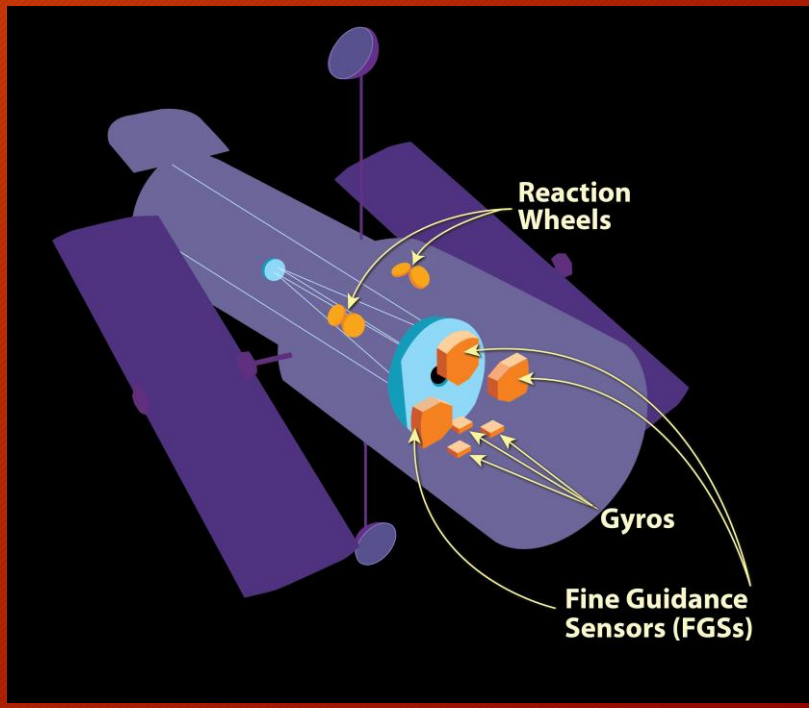
Debris Avoidance

Collision Avoidance:
Mission Planning and Non-Thruster Techniques

- A vast majority of satellites and vehicles have no thrusters
- Mission Planning and Simulation identify launch and orbit profiles that minimize probability of collision large objects in the SSN catalog or services by LEO labs and others.
- For LEO satellites atmospheric drag can be used to alter orbit and avoid collision
  - Satellite orientation used to alter between low-drag and high-drag configurations to decelerate and avoid collision – simple rotation
- Satellite and spacecraft orientation systems like Magnetorquers, Reaction wheels, etc., can modify orbit with inertia

Orbital Changes can lead to Future Collison Events
Simulation and Planning is required

Satellite Orientation Control



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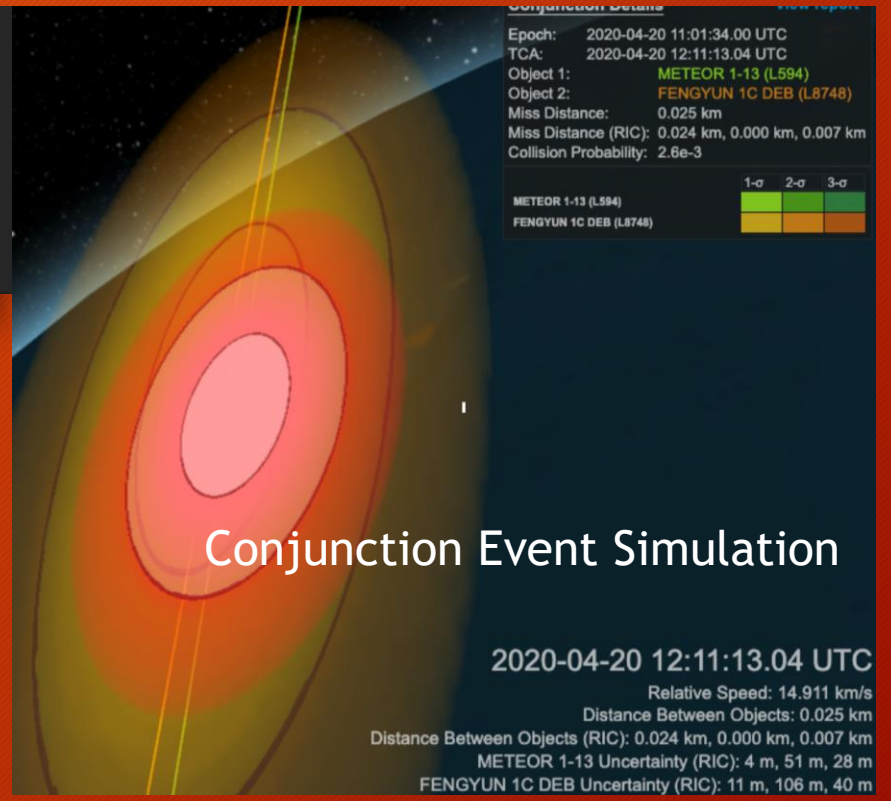
Collision Avoidance: Spacecraft with Onboard Thruster

- Space craft with thrusters can perform debris avoidance maneuvers
  - Small maneuvers are executed several hours before the time of the conjunction (collision)
  - Manned space craft like the ISS require about 5 hours to plan and execute
- The International Space Station (ISS) will execute maneuvers when:
  - Probability of collision is greater than 1 in 100,000, and not result in significant impact to mission objectives.
  - If it is greater than 1 in 10,000, a maneuver will be conducted unless it will result in additional risk to the crew.
  - For small debris impact, ISS has Whipple shielding to resist damage
- ISS has conducted 29 debris avoidance maneuvers since 1999, including three in 2020.



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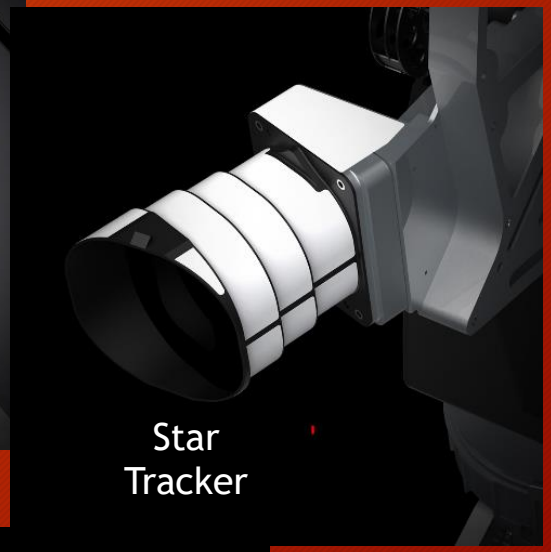
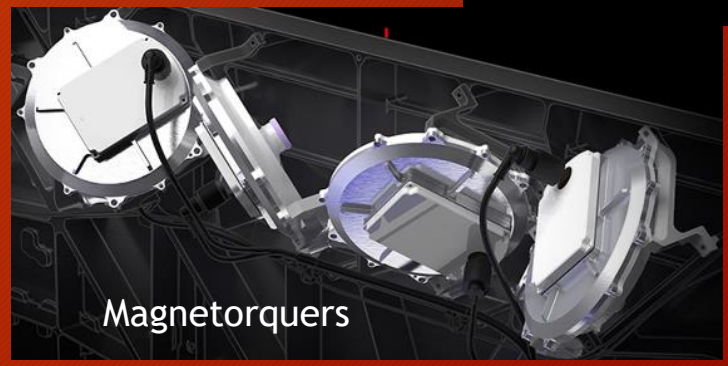
Autonomous Collision Avoidance – Starlink
and All Future/Evolving Mega Satellite Constellations

- Starlink, since inception has used automated collision avoidance
  - ~50,000 automated maneuvers since inception
  - ~1M estimated by 2028 as constellation grows
- Starlink Collison Avoidance Components:
  - Krypton Ion thrusters – Maneuvering
  - Star Tracker – Precision location & Orientations
  - Magnetorquers– Attitude and Orientation control
- From FCC Starlink filings:

"Starlink utilizes an automated collision avoidance system, ingesting data from the 18th Space Control Squadron … Satellites can autonomously evaluate risk and plan avoidance maneuvers, without human input"





Debris Reduction and Removal

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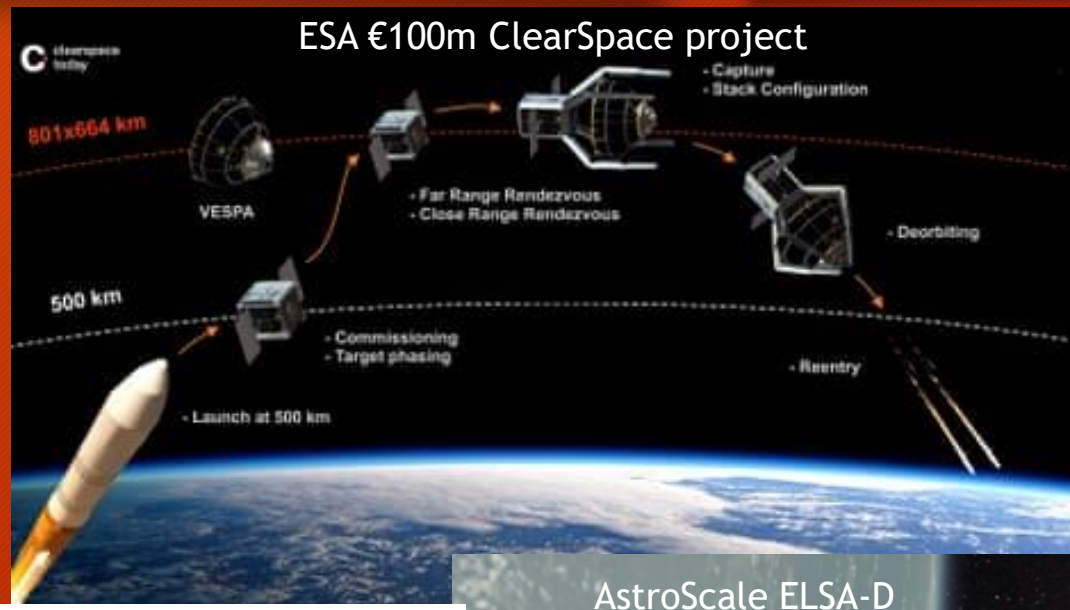
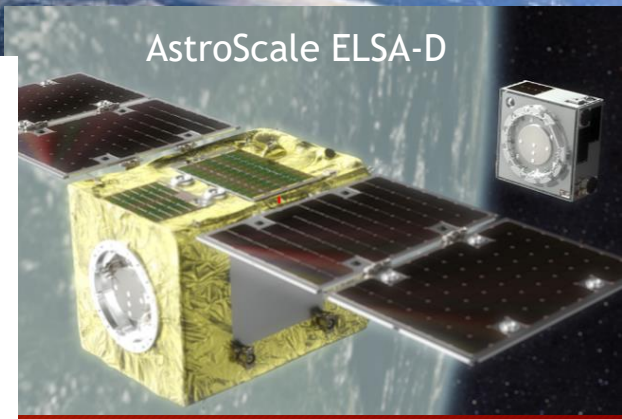
Decreasing Space Debris – New Regulation

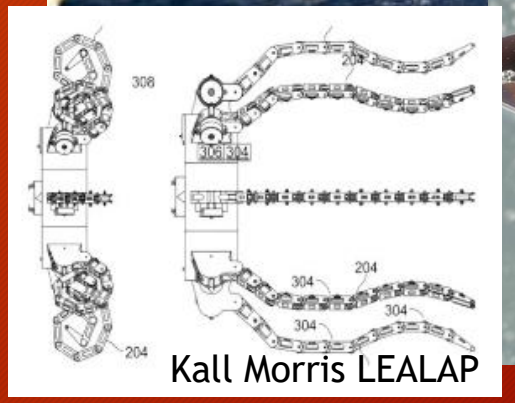
- The United States is defining stringent limits to Space Debris especially for space craft in orbits < 2000 Km
  - 2019 update: US Government Orbital Debris Mitigation Standard Practices
  - September 20, 2022 FCC report: Space Innovation; Mitigation of Orbital Debris in the New Space Age
- Specific changes
  - **Disposal:** 25 year deorbit policy moved to **5 Years**
    - Increased requirements for thrusters of LEO space craft
  - **Operations:** Required Selection of Safe Flight Profile and operational Orbit Configuration
  - FCC will apply US standards to any LEO communications system to get US Market Access

Space Debris Removal & Mission Extension

- Debris Removal and Mission Extension are gaining commercial and government funding, for example:
  - **ClearSpace**
    - 2025 ESA Mission on 100kg Vespa
  - AstroScale
    - ELSA-D, End-of-Life Services by AstroScale Demonstration program
  - **Surrey Satellite Technology Ltd**
    - RemoveDEBRIS CubeSat demonstration
  - **Northrop Grumman**
    - **Mission Extension Vehicle 2 - refuel intellsat 10-02**
  - **Kall Morris Incorporated**
    - **Spinning debris removal demonstration**
    - **Lealap (spacecraft), REACCH (arms), TUMBLEYE (orientation)**
- **And the list continues to grow …**







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