

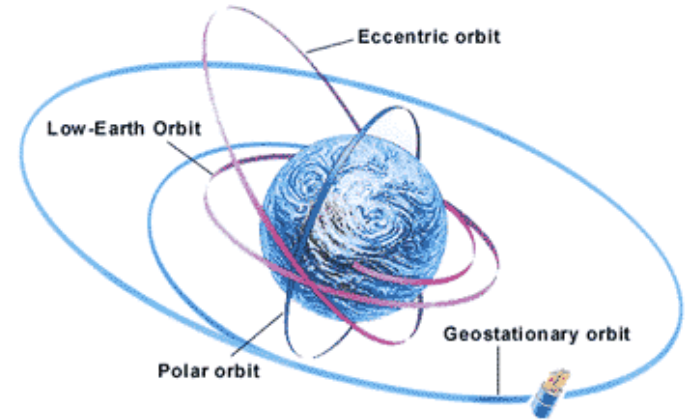
Congestion-Tipping Model for Earth Orbits

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Agenda

- Earth orbits as limited, natural resources
 - Definition
 - Cause-problem-symptom relationship
- Determining factors for congestion
- Debris classes
- The Congestion-Tipping Model
 - Model specifications
 - Model equation
 - Results
- Prospects for Future Studies



Determining factors for congestion

What makes an operator re-consider operations in an orbit?

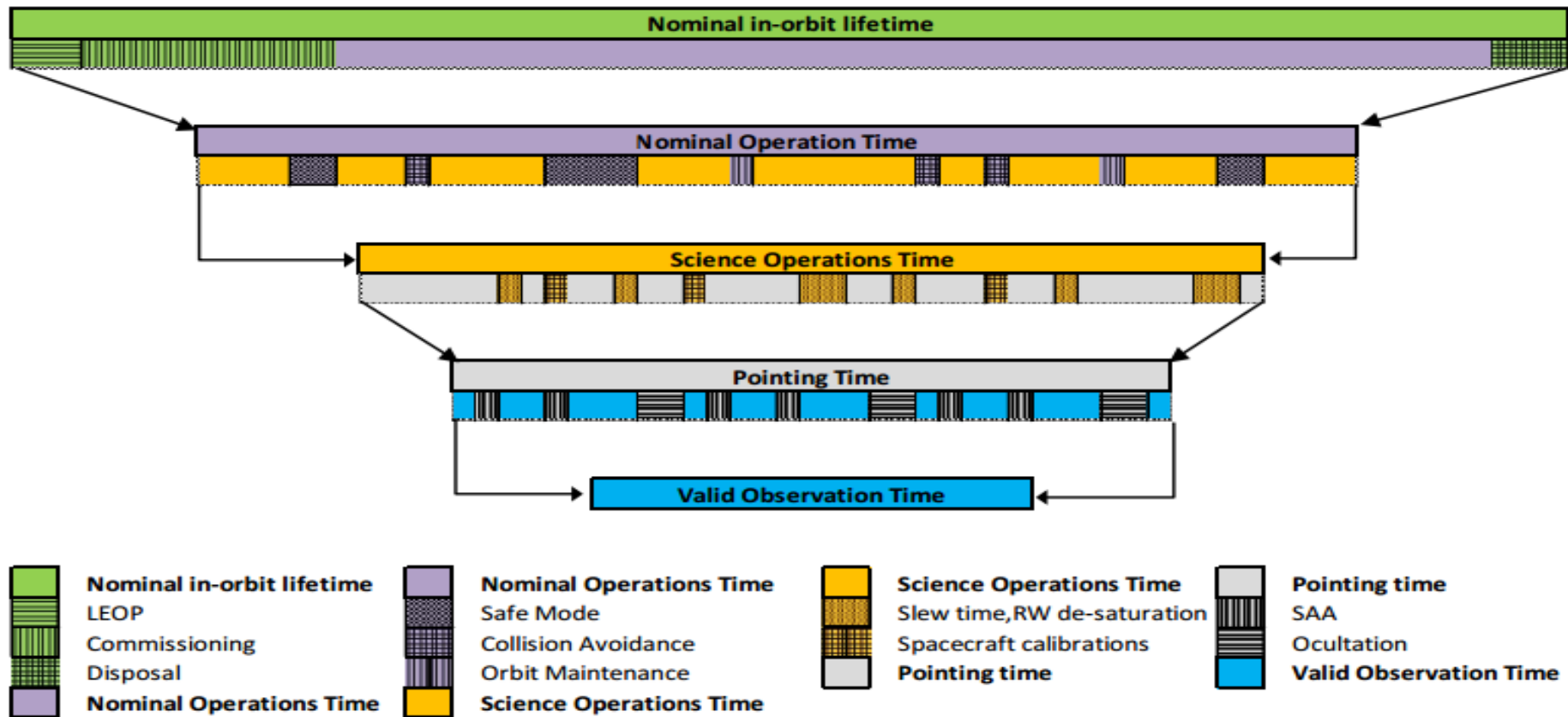
- Operational overheads - Negligible
 - Cost of Ground-Station (GS) services
 - Assembling a critical team for conjunction analysis
- On-board capacity - Negligible
 - Quantity of fuel on-board
 - Capacity of thrusters on-board
- Service interruptions - Not disapproved

3 classes of debris

Table 2: Space debris classes and risk mitigation strategy

Debris class	Risk mitigation strategy
Detectable debris (catalogued + observable)	CAMs
Undetectable debris (larger than 1 cm)	<i>Blindspot</i>
Undetectable debris (1 cm and smaller)	Shielding





Note 1: Allocations are scale representative, they are provided only for conceptual reference.

Note 2: Science calibrations are considered Valid observation time since the related data will also be scientifically analysed.

Figure 2-1: Schematic representation of the times definition

Detectable debris population

Mission downtime allowed \times *1 Julian year* = *no. of CAMS_(year)* \times *CAM duration*

R.H.S. > L.H.S.

Undetectable debris population

ACP_w - *ACP_d* = *Remaining probability*

Remaining probability = *Acceptable collision probability margin*

R.H.S. > L.H.S. **→ Beginning of the congestion-tipping point**

*ACP – Average Collision Probability

Case Specifications



- Earth orbit: Sun Synchronous Orbit (SSO)
- Region: 450 – 1000 km belt
- Number of active satellites: 261 (excl. classified missions) *
- Scenario: Business As Usual (BAU)
- Criteria for terminating operations: Service interruption resulting from CAMs
- **Note: only looking at catastrophic collisions (i.e., energy-to-mass ration > 40 J/g)**

* Source: DISCOS, UCS, SpaceTrack



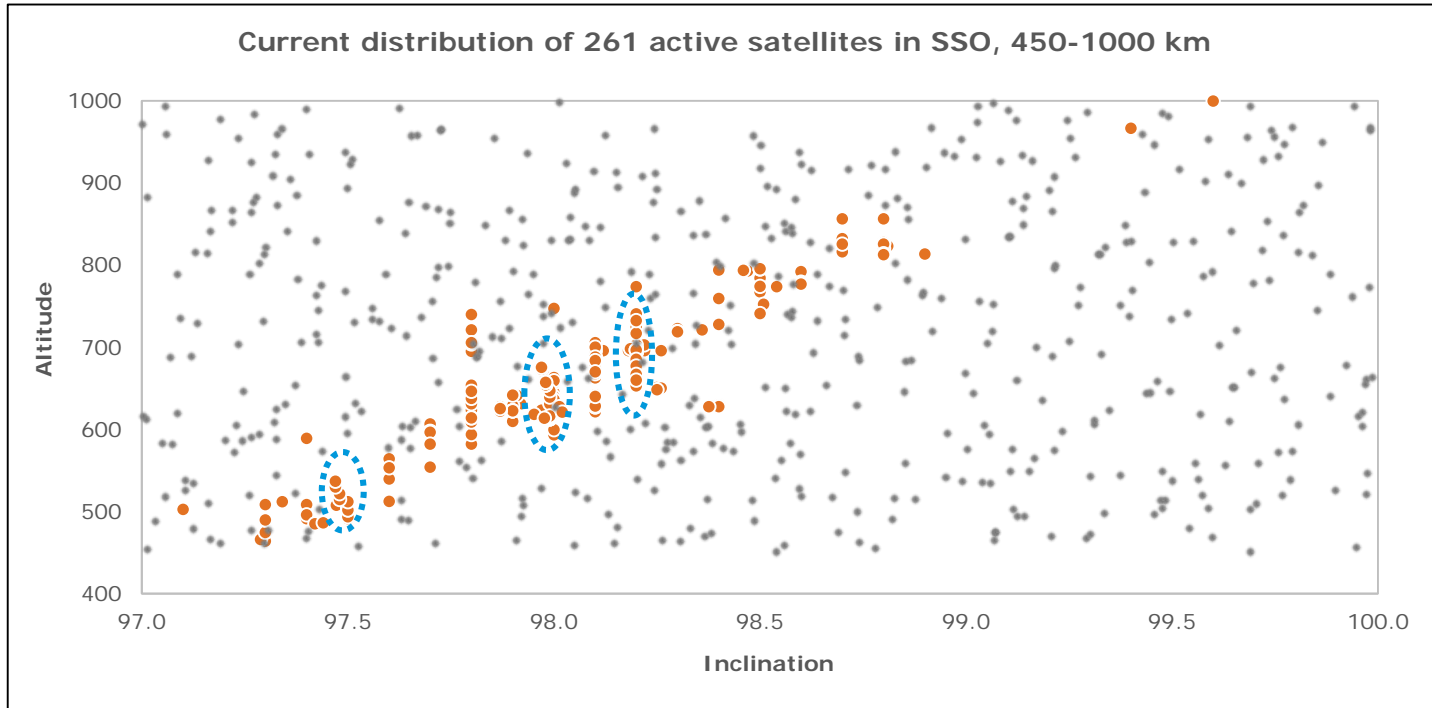
Detectable debris

- CAM duration: **3 hours**
- Mission downtime allowed: **1% of nominal operation time**
solely for CAMs

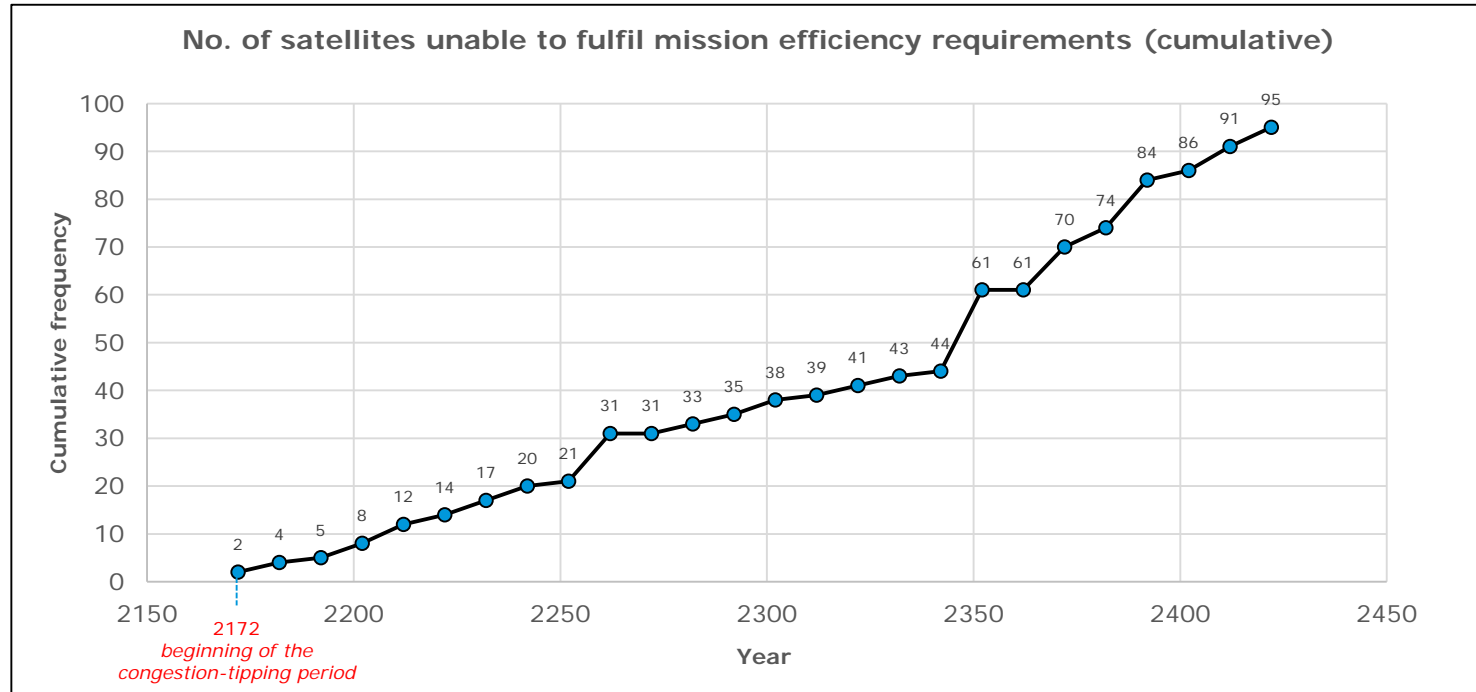
Undetectable debris

- Accepted Collision Probability Margin **1%**

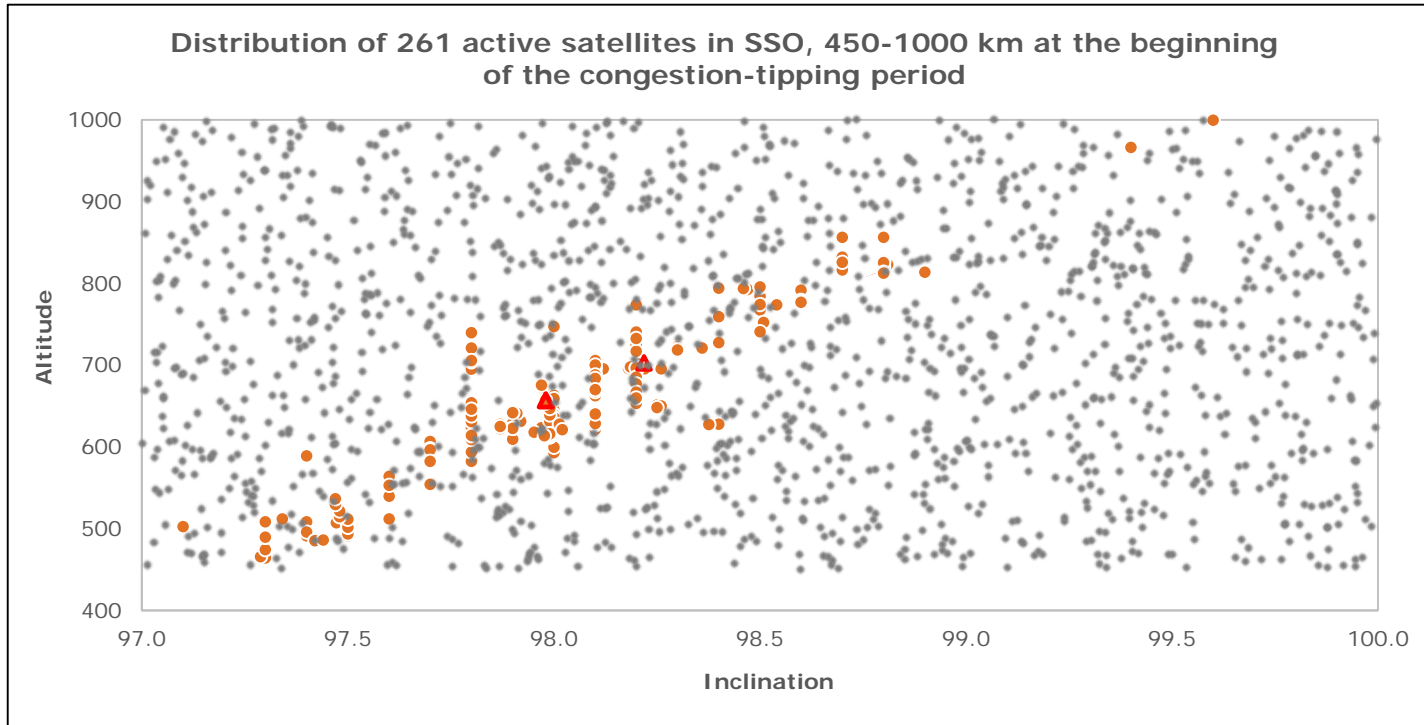
Population Density in SSO, 450-1000 km belt, in 2017



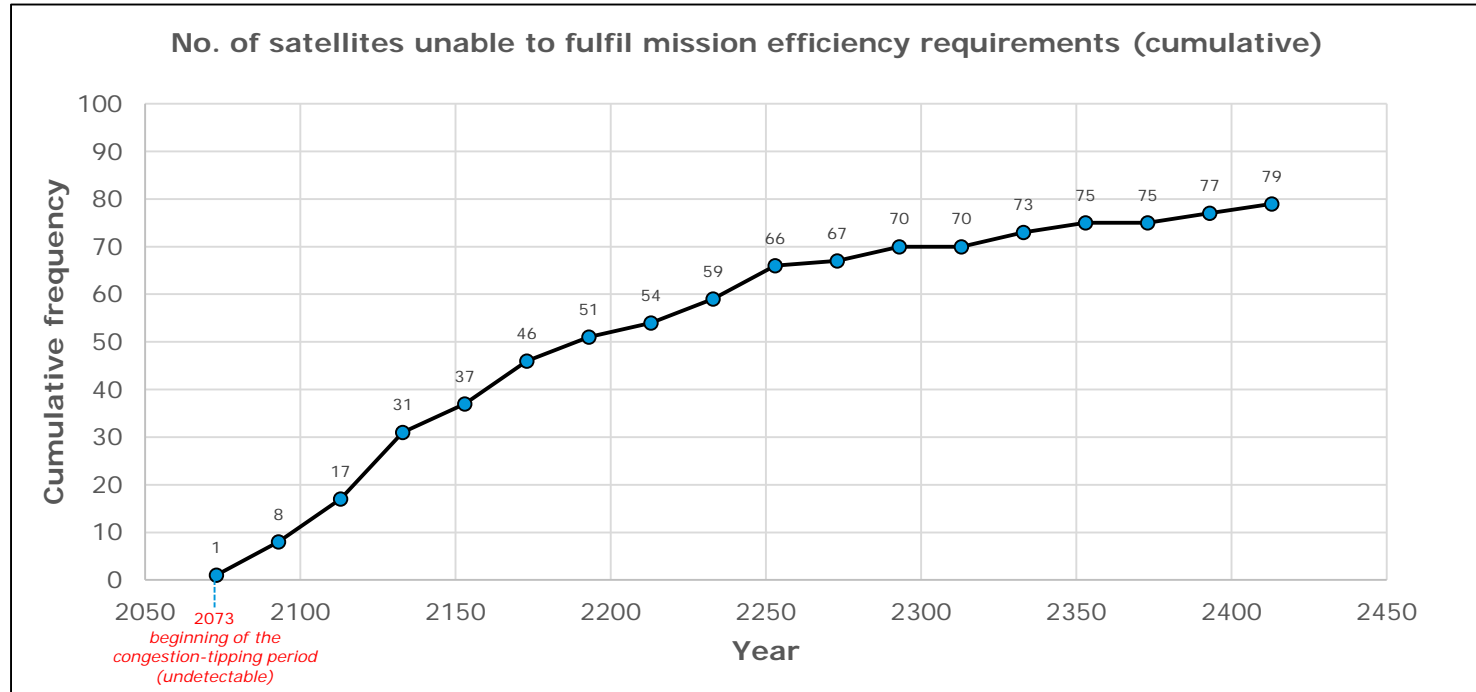
The congestion-tipping period for SSO begins in the year 2172



Population Density in SSO, 450-1000 km belt, in 2172



The risk posed by undetectable debris could bring the congestion-tipping period ~100 years sooner



Prospects for Future Studies



- Objects < 1 cm
- Combined effect of all 3 debris classes
- Other scenarios – Partial & Full mitigation
- Megaconstellations
- Other factors of congestion, say, on-board propellant
- Complimentary study on the valuation of Earth orbits



The Congestion-Tipping Model

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