Space debris modelling and IADC lessons learned

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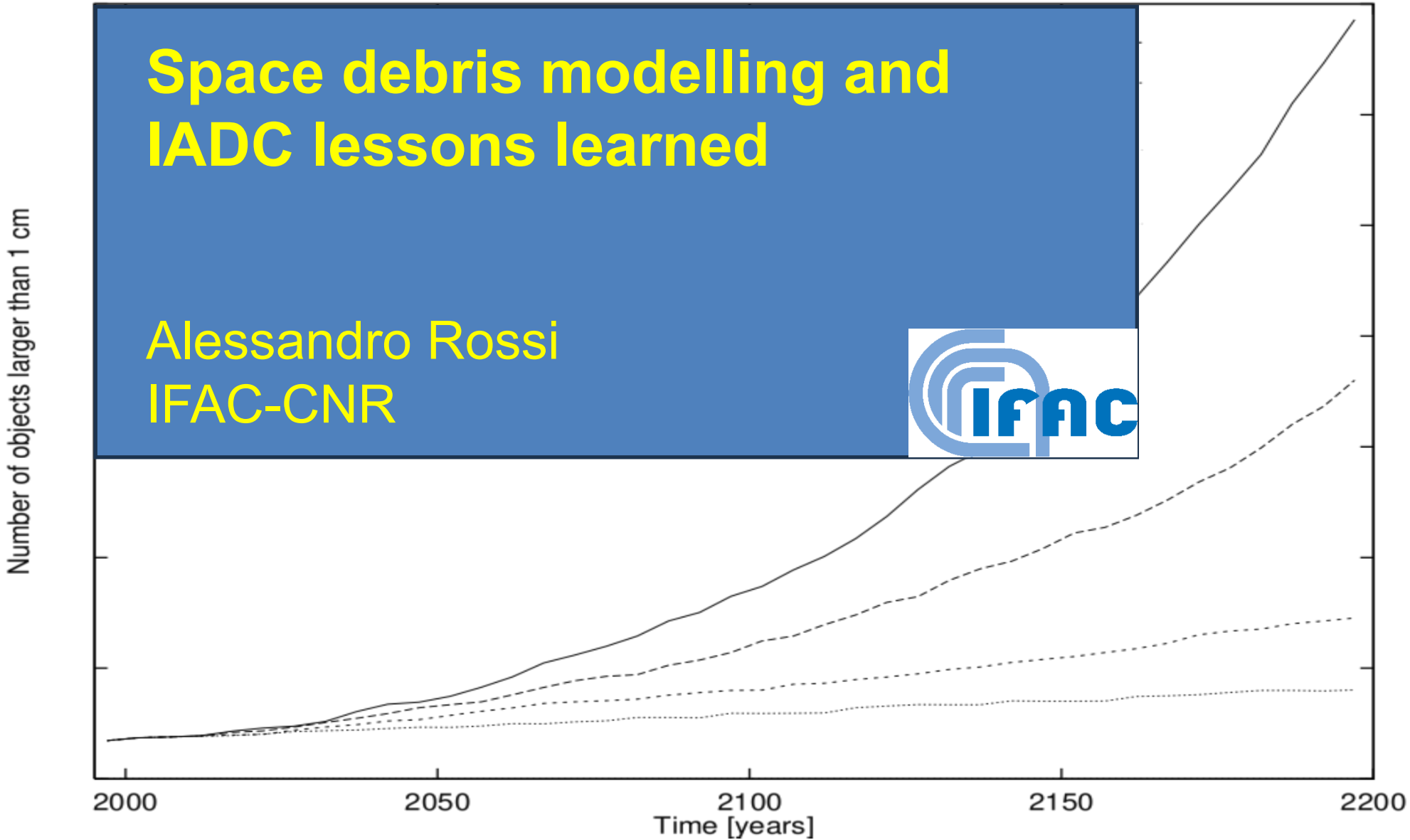

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- The opinions expressed in this presentation are personal opinions of the speaker
- They do not reflect any IADC official position
- This presentation was not coordinated within the IADC

Inter-Agency Space Debris Coordination Committee

(www.iadc-home.org)

- October 25, 1993: First ToR established by the four founding members (NASA, RKA, Japan, and ESA) in Kaliningrad (Russian Federation) during the 10th IADC Meeting.

- Four technical Working Groups (+ a Steering Group):

  - WG1: measurements
  - WG2: environment and database
  - WG3: protection
  - WG4: mitigation

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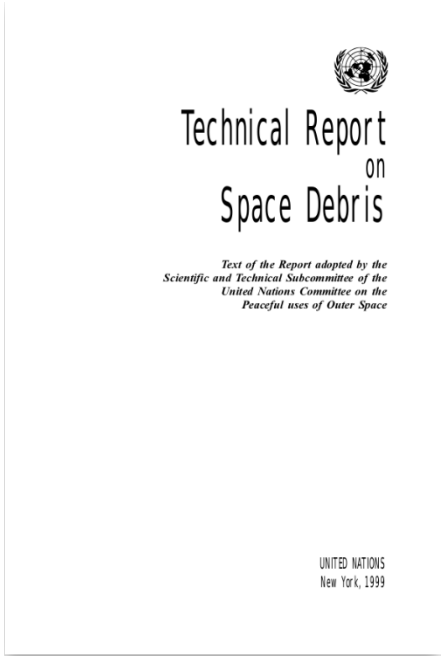
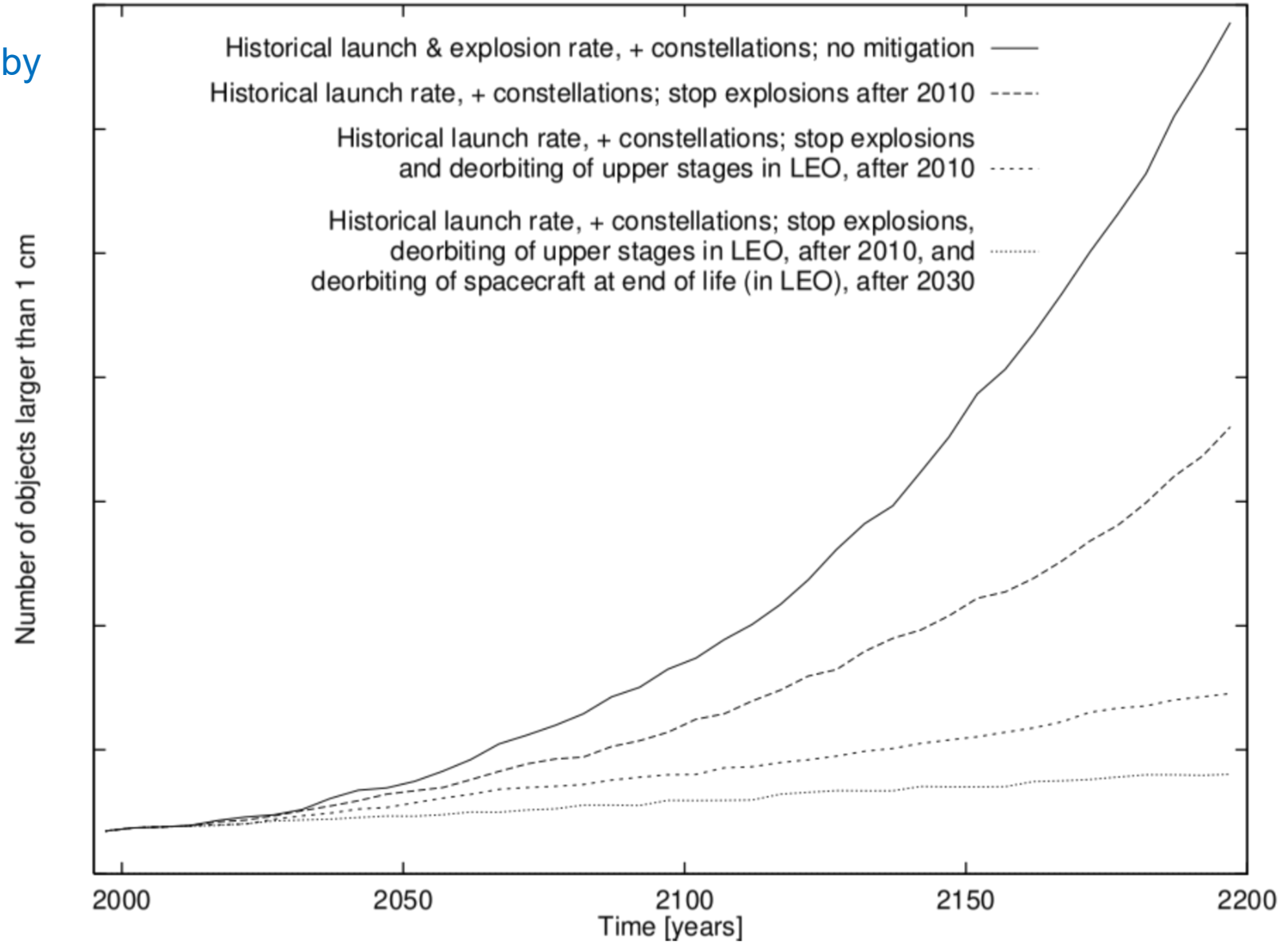
IADC achievements (modelling and mitigation)

- The IADC is an authoritative *technical* forum.
- Among the plethora of documents and reports produced:
  - *IADC Space Debris Guidelines*
  - *IADC Support Document to the Guidelines*
  - *IADC Protection Manual*
  - *IADC Statement on Large Constellations*
  - *IADC Environmental Report*
  - ……
- The IADC has a direct link with the UN COPUOS (Committee on the Peaceful Uses of Outer Space) for technical matters.

IADC results obtained by simulations with SDM, used for the "*United Nations - Technical Report on Space Debris*", 1999





Why 25?

"Spacecraft or orbital stages that are terminating their normal operations in orbits that pass through the LEO Protected Region, or have the potential to interfere with the LEO Protected Region, should be de-orbited, in order of preference, by

1. *performing a direct re-entry or*
2. *where appropriate manoeuvre into a decay orbit with residual orbital lifetime limited to be as short as practicable and no more than a maximum of 25 years."*

IADC Space Debris Mitigation Guidelines (IADC-02-01 Rev. 4)

Why 3 %?

Why 3 %? The European deficit limit

Each European country in the EU must keep its government deficit within 3 % of its Gross Domestic Product (GDP).

(A deficit of a nation occurs when the government's annual spending exceeds its revenue, meaning it spends more money than it collects through taxes and other income sources within a specific fiscal year. This shortfall requires the government to borrow money, which contributes to the national debt.)

The European deficit limit is essentially a **stability constraint** introduced when European countries adopted the euro as a common currency.

The basic concern was the following:

- if many independent governments share the same currency but borrow without limits, the financial instability of one country can affect all the others.

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The basic concern was the following:

- if many independent governments share the same currency but borrow without limits, the financial instability of one country can affect all the others (we share the same space, any instability we create will affect all the other users).

Why 3 %? The European deficit limit

In a monetary union:

- countries no longer control their own currency
- cannot independently print money
- cannot devalue exchange rates
- and share a common central bank

So fiscal policy (government spending and borrowing) became one of the few remaining national macroeconomic tools.

The deficit rule was intended to prevent a situation in which:

- governments accumulate debt too rapidly
- markets lose confidence
- interest rates rise
- and the entire monetary union becomes unstable.

Why 3 %? The key mathematical idea

The debt sustainability is described through the evolution of *the debt-to-GDP* ratio:

$$d = \text{public debt} / \text{GDP}$$

The important quantity is not debt alone, but whether debt grows faster than the economy itself.

A simplified dynamics equation is:

$$\Delta d \approx \text{deficit} - (\text{economic growth effect})$$

or more precisely:

$$\Delta d = (r-g)\, d + p$$

where:

- d = debt / GDP ratio,
- r = interest rate on debt,
- g = nominal economic growth,
- p = primary deficit (i.e., difference between a government's total revenues (excluding interest payments) and its non-interest expenditures. It indicates how much the government is borrowing to cover its current expenses rather than using its own income).

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- p = primary deficit.

This resembles a stability equation in dynamical systems:

- **deficits act as a forcing term increasing debt**
- **growth acts as a stabilizing dilution term**
- **interest rates can amplify instability**

Why 3 %? The key mathematical idea

You can think of the system as a feedback-controlled network.

The euro area is a coupled system of states sharing:

- one monetary field
- one central bank
- but multiple independent fiscal sources.

Unconstrained deficits were viewed as potentially destabilizing perturbations capable of propagating through the entire network.

The deficit ceiling was therefore introduced as a global stability constraint intended to keep trajectories inside a “safe operating region”.

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What is the "*safe operating region*" for space capacity?

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The deficit ceiling was therefore introduced as a global stability constraint intended to keep trajectories inside a "safe operating region".

Why 3 %? The key mathematical idea

The rough reasoning was:

If: debt is around 60% of GDP, nominal GDP grows around 5% per year,

then:

$$0.05 \times 0.60 = 0.03$$

Meaning:

the economy “naturally” expands by about 5% of GDP each year, so a 3% deficit would keep the debt ratio approximately constant.

This was not a deep economic, physical law or rigorous theorem.
It was more a pragmatic engineering threshold.

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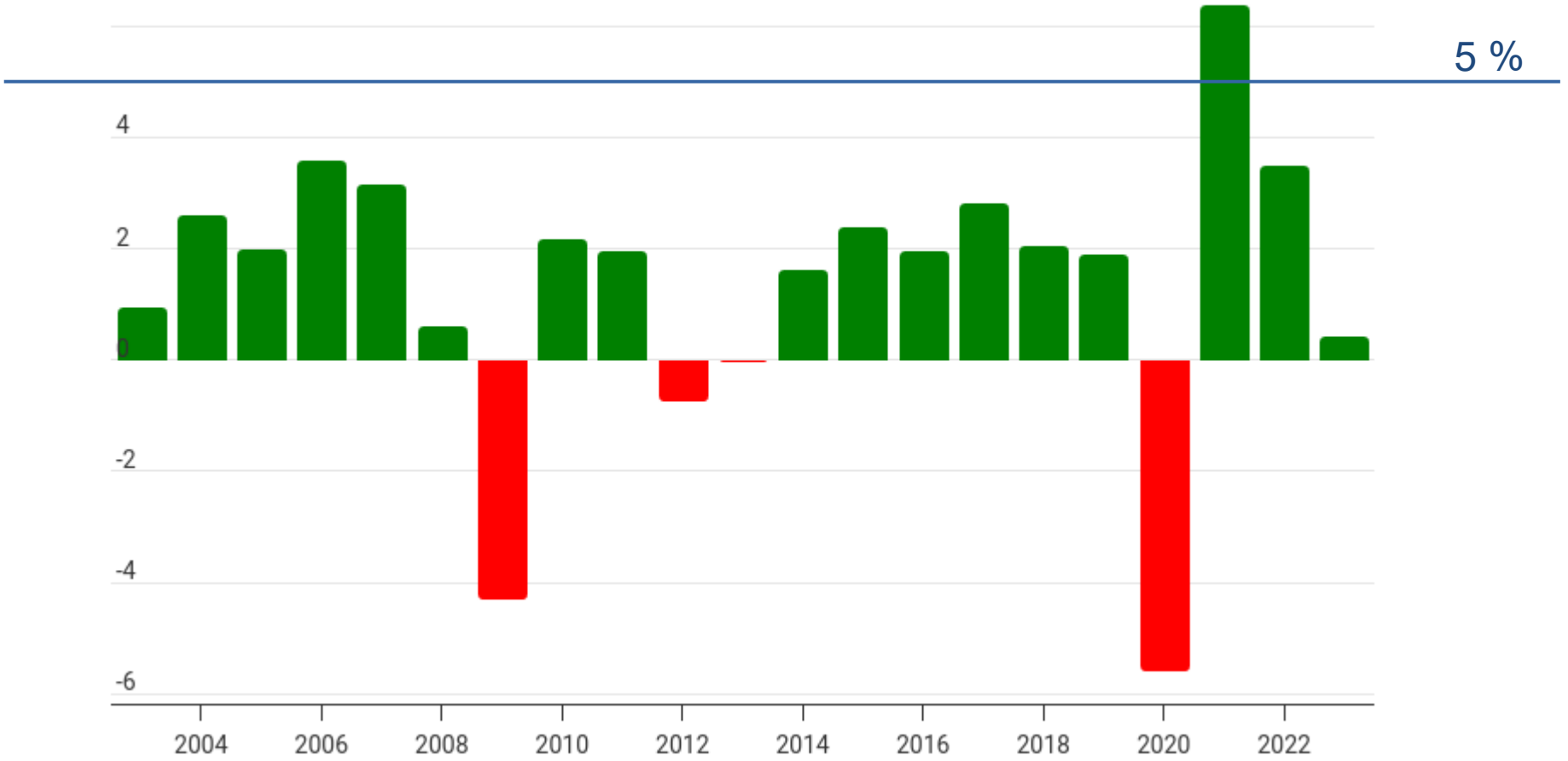
Why 3 %?

Annual percentage growth of EU GDP

+ 6.36 % Post-COVID rebound



https://www.macrotrends.net/global-metrics/countries/euu/european-union/gdp-gross-domestic-product

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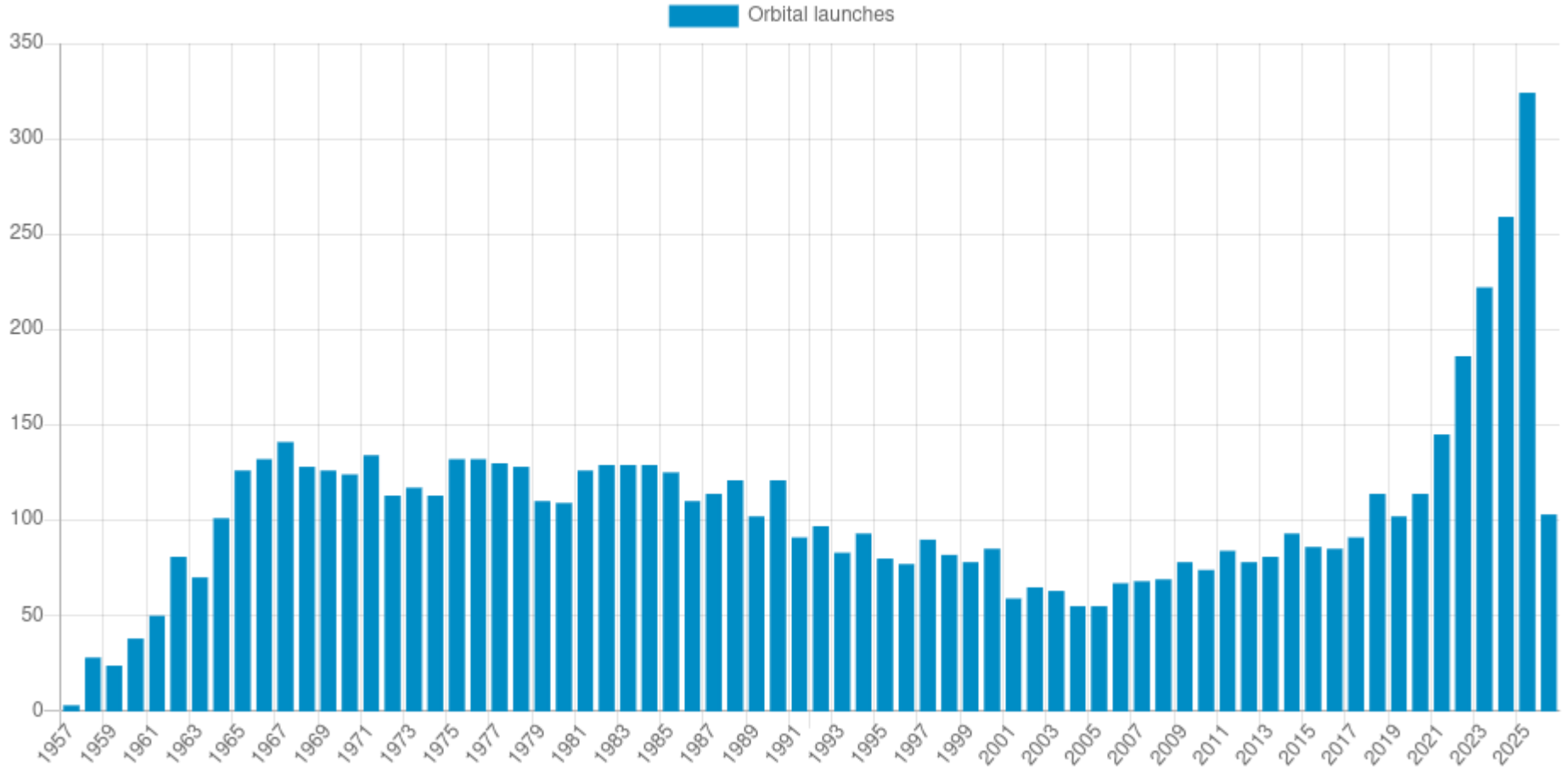
It was more a pragmatic engineering threshold, BASED ON EXTENSIVE LONG TERM SIMULATIONS CAMPAIGNS of the space debris environment.

- It was a compromise between the environment preservation (in terms of growth of the debris population, future collisions, etc) and the energetic considerations (Delta V needed for the de-orbiting maneuver) linked to the operational lifetime of a payload
- E.g., in simulations where direct reentry (0-year) was compared to 25-year deorbiting, in elliptical disposal orbits, an average increase of ~ 24 % in the needed Delta V necessary (e.g., A. Rossi, *Journal of Spacecraft and Rockets*, 39, 2002).

What's new?



https://spacestatsonline.com/launches/

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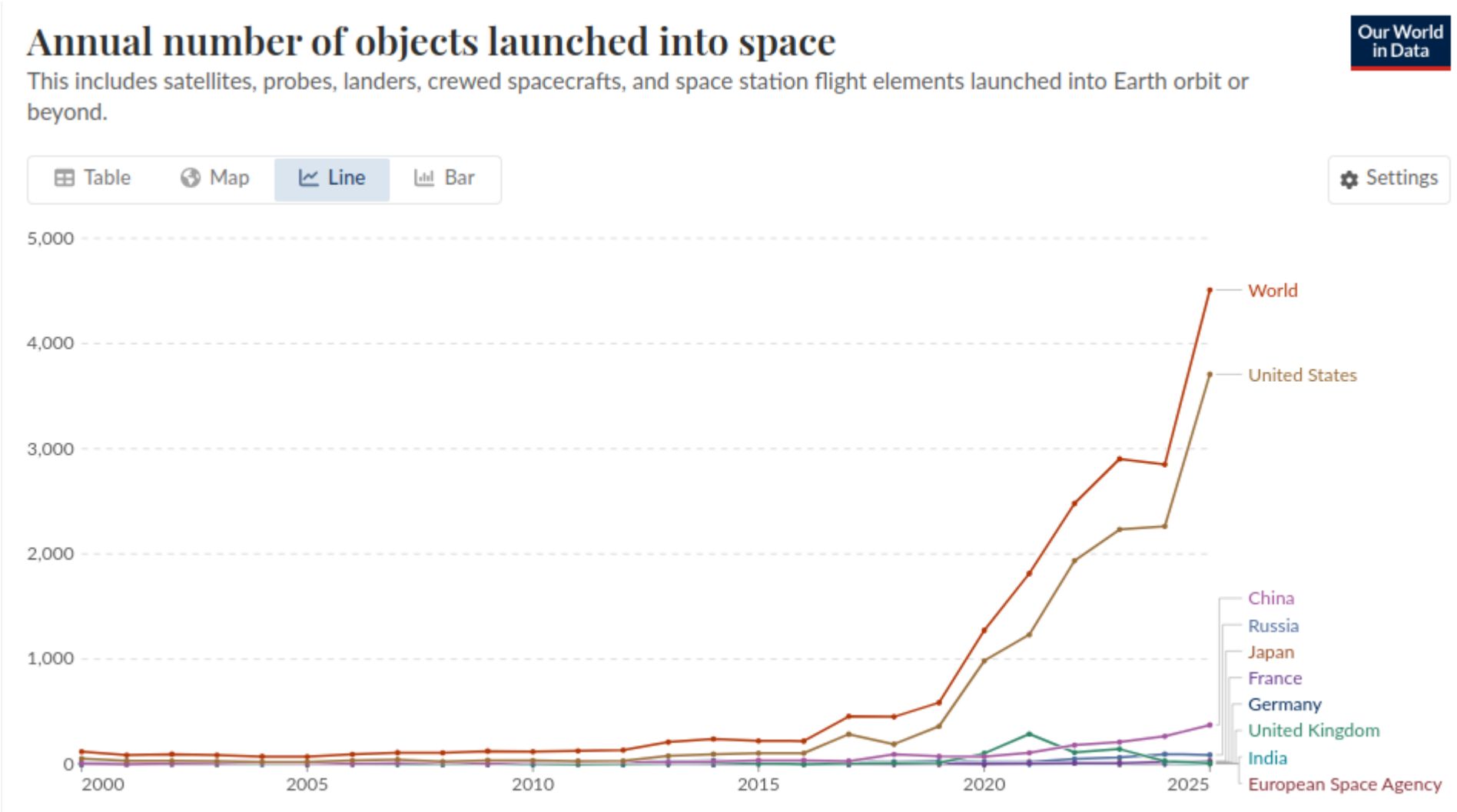
Annual number of objects launched into space
This includes satellites, probes, landers, crewed spacecrafts, and space station flight elements launched into Earth orbit or beyond.
Our World in Data
Table
Map
Line
Bar
Settings
5,000
4,000
3,000
2,000
1,000
0
2000
2005
2010
2015
2020
2025
World
United States
China
Russia
Japan
France
Germany
United Kingdom
India
European Space Agency

What's new? The role of IADC in the present worldwide scenario

- IADC is an authoritative *technical* forum.
- The changes in the space *economy* and in the *political* scenarios make the IADC role even more important on one side, while making its job harder.
- The IADC should work (IMHO) (and, indeed, is working) on:
  - Improved guidelines
  - Improved guidelines for large constellations

What's new? The role of IADC in the present worldwide scenario

- Improved guidelines for large constellations

PARAMETERS FOR CONSTELLATION MODELING COMPARISON

CHARACTERISTIC	DESCRIPTION
Background Environment	Taken from the Benchmark LEO Comparison Case (See Session 5)
Numbers of Spacecraft (S/C) / Planes	1. 50 S/C equally distributed in 5 planes (10 / plane) 2. 350 S/C equally distributed in 10 planes (35 / plane)
Constellation Altitude	1. Low Altitude = 800 km 2. High Altitude = 1400 km
Constellation Design / Architecture Characteristics	S/C Mass = 800 kg; Orbit Inclination = 80°; S/C Lifetime = 8 years; Probability of S/C Design Failure during Mission Life = TBD; Number of S/C per upper stage (U/S) = TBD
Mitigation Options (Constellations Only)	1. Postmission Deorbiting of S/C and U/S; Passivation after Mission 2. No Mitigation
Projection Time	100 years (2000 – 2100)

What's new? The role of IADC in the present worldwide scenario

- Improved guidelines for large constellations

From: Minutes of the Working Group 2 Meeting Held at the 16th IADC, Toulouse, France, November 3 – 6, 1998

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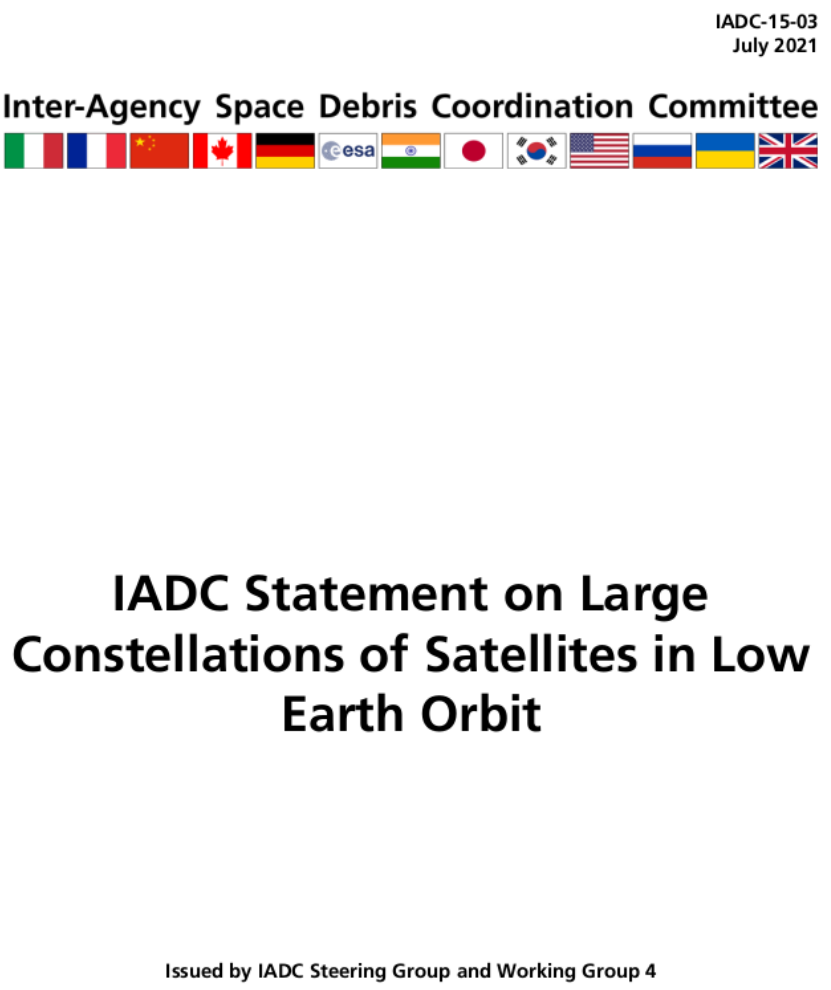

What's new? The role of IADC in the present worldwide scenario

- IADC is an authoritative *technical* forum.
- The changes in the space *economy* and in the *political* scenarios make the IADC role even more important on one side, while making its job harder.
- The IADC should work (IMHO) (and, indeed, is working) on:
  - Improved guidelines
  - Improved guidelines for large constellations
  - Communication and outreach (E.g.: *IADC Report on the status of the space debris environment*)

What's new? IADC and this meeting

- Long term simulations models are, and will remain, a basic tool for the evaluation of the effectiveness of space policies and mitigation measures. E.g.: what is the role of Lethal Non-Trackable particles?
    - Space capacity should be instrumental in identifying, in a more rigorous way, what is the "*safe operating region*" for the space environment:
        - What is a sustainable environment (not only for space operations: e.g., "Dark and quite skies")?
        - What is our "3 %" (or our 1.5 degrees)? I.e., identify an *as rigorous as possible* measure of a sustainable environment.
- IADC is actively working on the subject of environmental indexes, incorporating efforts from several different delegations and approaches, to answer the above questions.