Technische Universität Braunschweig

IGEP TU Braunschweig Institut für Geophysik und extraterrestrische Physik

Significance of the anthropogenic mass influx into Earth's atmosphere compared to the natural influx

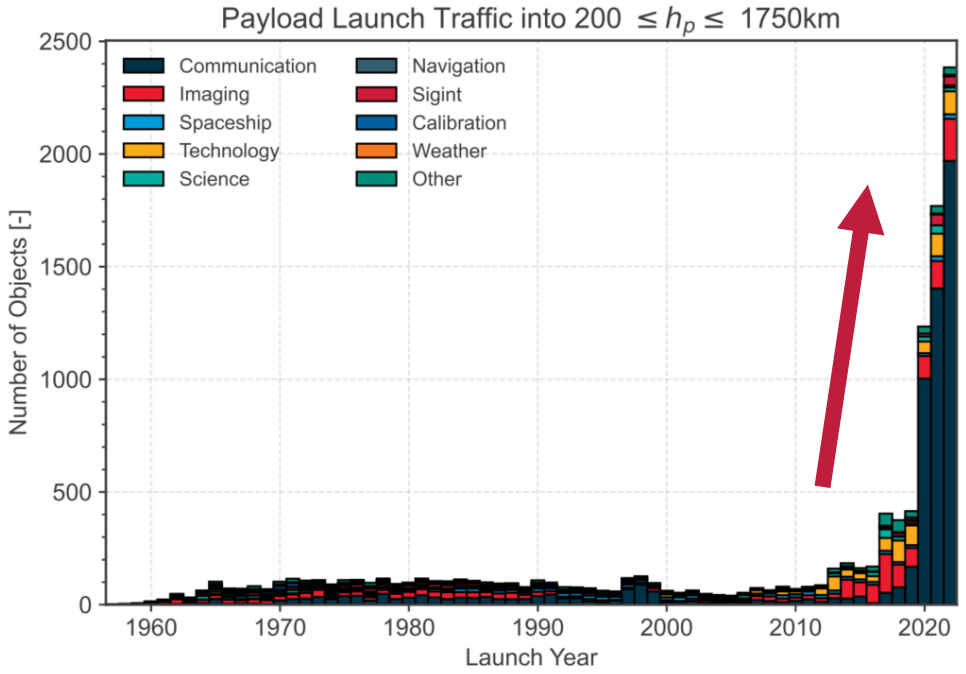
***Leonard Schulz**, Karl-Heinz Glassmeier*

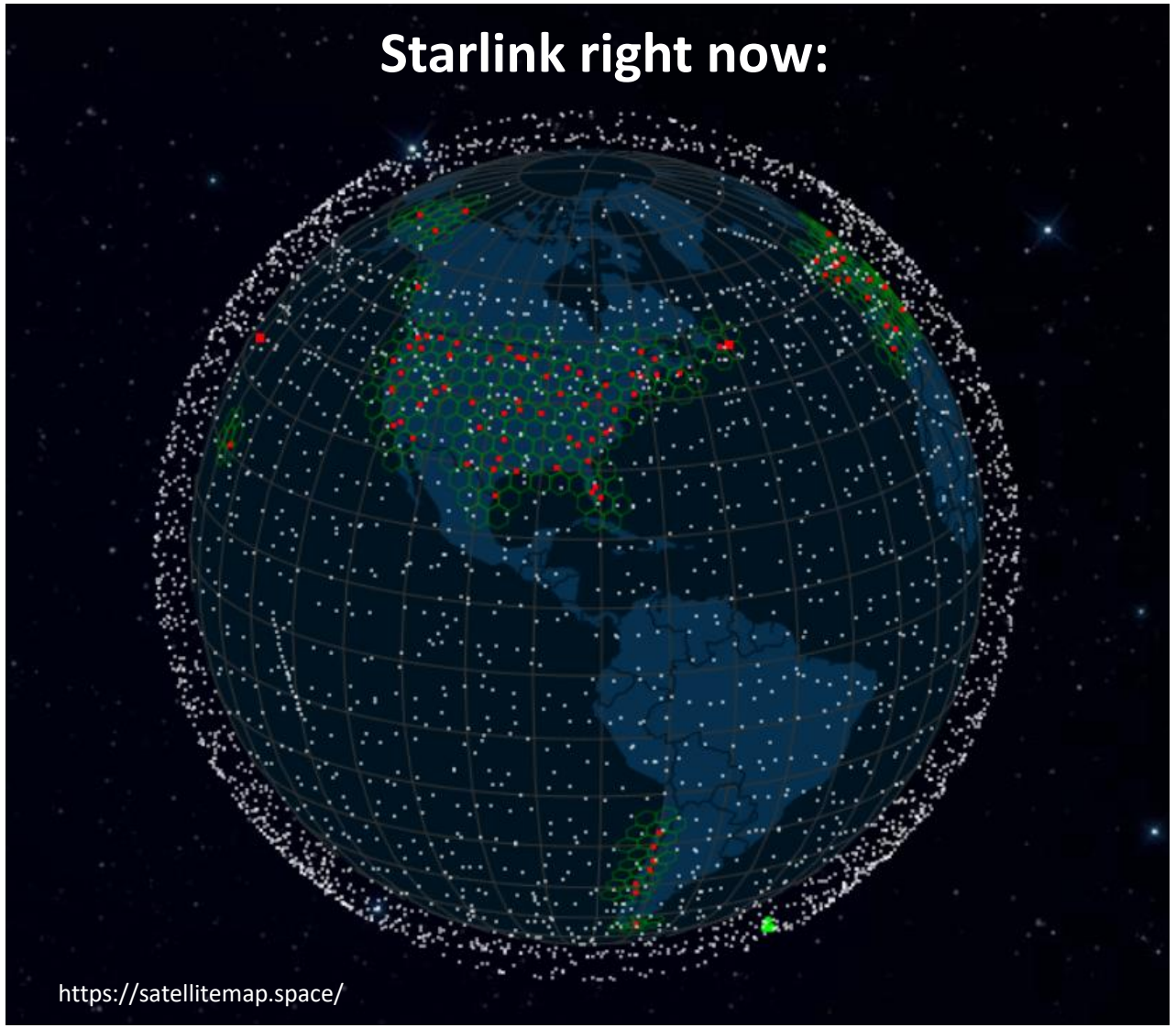
Images: https://sky.rogue.space/ [09.12.2022] Right: https://spaceexplored.com/wp-content/uploads/sites/10/2022/02/Starlink-satellite-puerto-rico-reentry-kevinizooropa.png [09.12.2022]

The Surge of the Space Industry: Satellite Mega-Constellations

- Drastic increase in launch activity and commercialization

- More than 100,000 satellites proposed; 58,000 additional satellites by 2030





The Problem with the Current Zero Debris Approach

Space debris is a problem:

- Possible chain reaction of collisions
- Whole orbits might become unusable

→ Solution for LEO: spacecraft **re-enter the atmosphere**

- To minimize ground risk → Design-for-demise

→ ESA Zero Debris Charta

→ A focus on space and the ground, leaving out the atmosphere completely!

→ Use of Earth's atmosphere as a waste bin! → **Space waste**

→ **Space – The new junkyard?**

What goes up will come down again…

Increasing number of spacecraft + obligated re-entry:

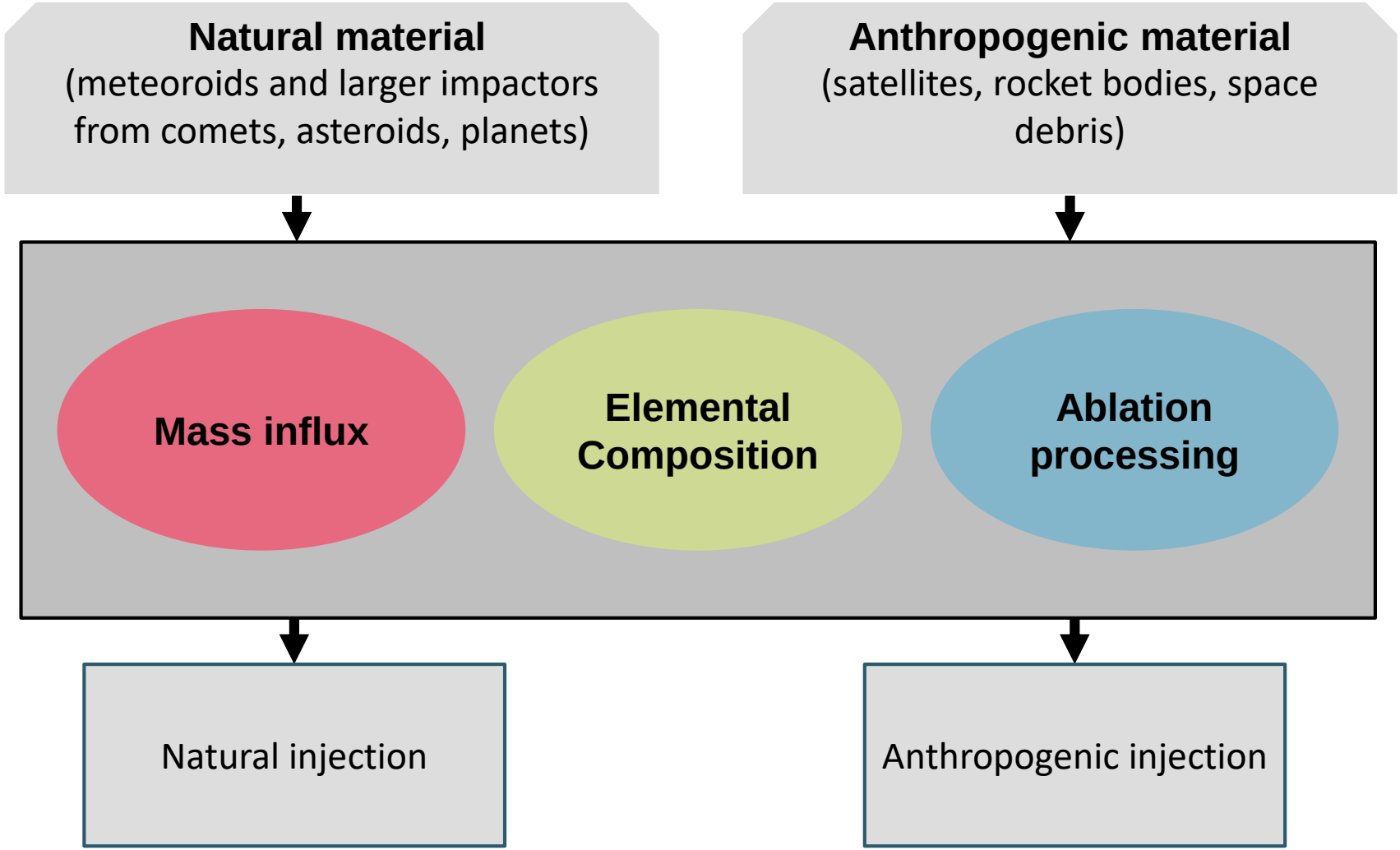
→ Is the **anthropogenic injection** of matter into Earth's atmosphere **significant** compared to the **natural injection**?

→ If it is, are there **environmental impacts** on Earth's atmosphere?

Left: https://spaceexplored.com/wp-content/uploads/sites/10/2022/02/Starlink-satellite-puerto-rico-reentry-kevinizooropa.png, Right: Tuvix72/YouTube

Method

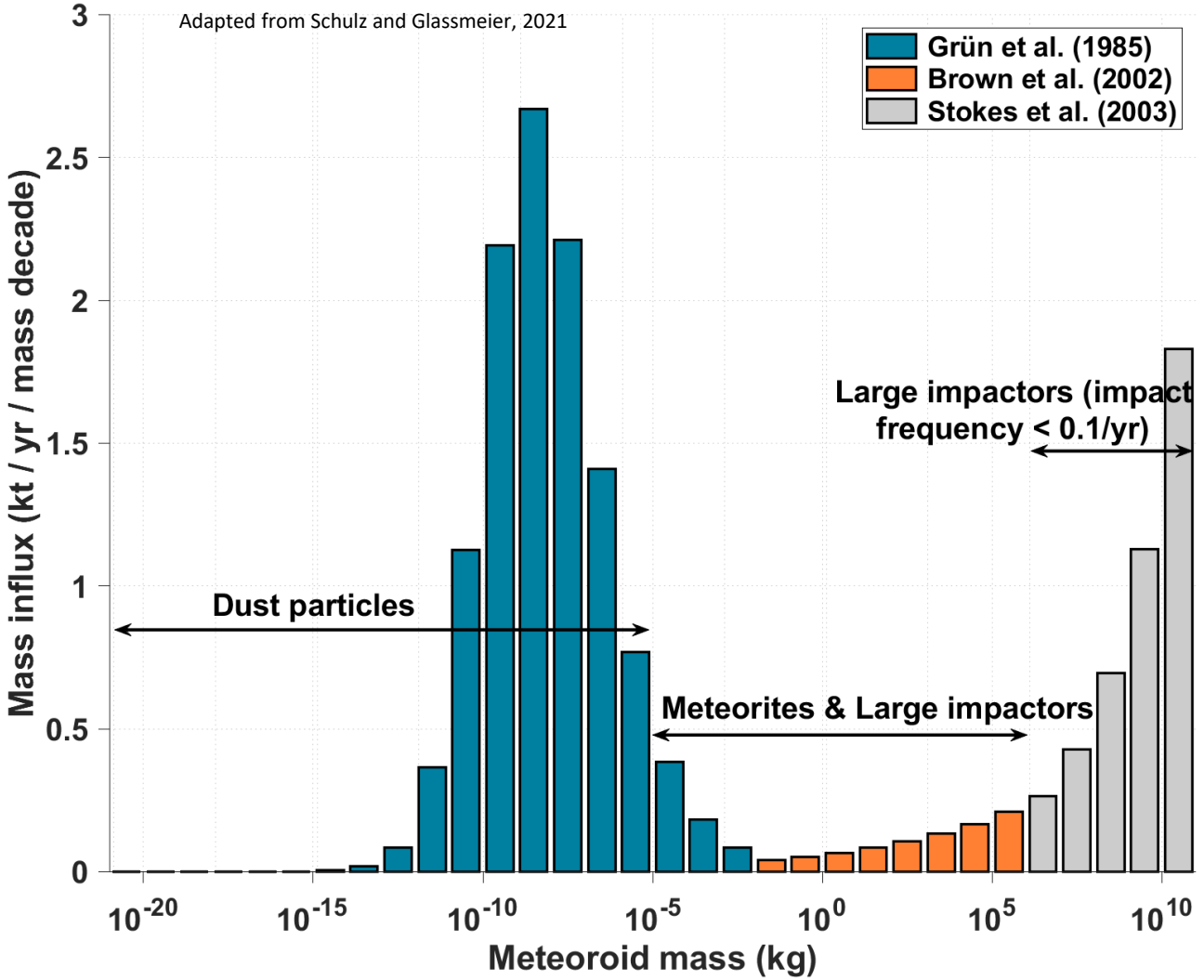
Schulz & Glassmeier, Advances in Space Research, 2021



Mass: Natural Input

- Mass input estimates differ largely, but a lot of studies have strong biases
- Only consider impactors at least hitting Earth every ten years

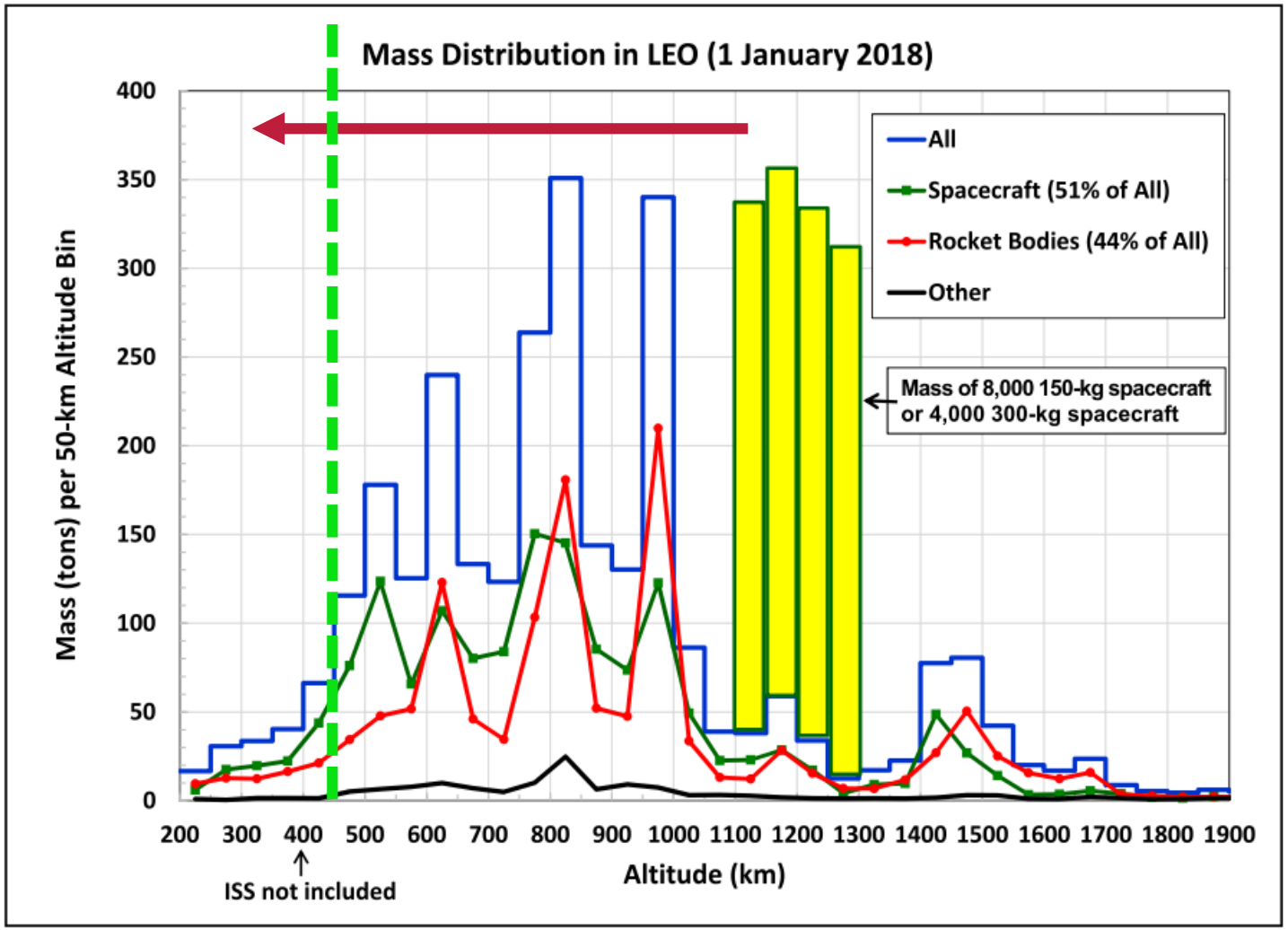
→ **Around 12.4 kt enter Earth's atmosphere every year (error of factor 2)**



Mass: Current (2019) Anthropogenic Input

- Everything below 450 km reenters within a year
- Suborbital stages have to be considered as well!

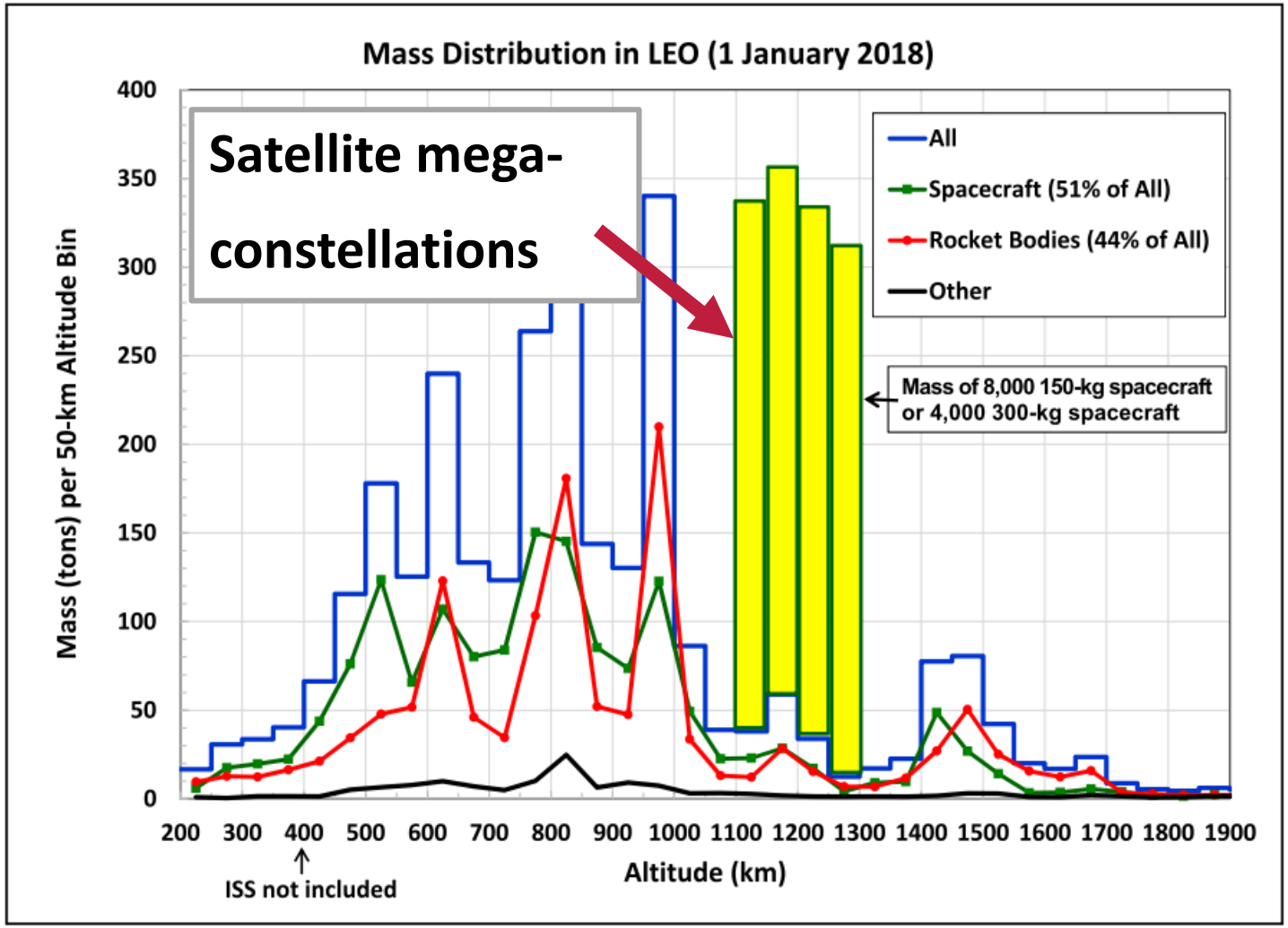
→ **Today (2019) about 0.89 kt/yr** reenter Earth's atmosphere



Mass: Future Anthropogenic Input

Satellite mega-constellations: **Over 110,000 satellites** proposed → Drastic increase in mass flux in the future!

2 future scenarios



Mass: Future Anthropogenic Input

Satellite mega-constellations: **Over 110,000 satellites** proposed → Drastic increase in mass flux in the future!

Scenario 1 (most probable)	Scenario 2 (worst case)
Today's influx + some satellite mega-constellations	2x today's influx + large portion of satellite mega-constellations
Every 5 years: Additional **19400 satellites** 590 upper stages 440 suborbital stages	Every 5 years: Additional **75000 satellites** 2000 upper stages 1500 core stages
Total mass influx: 2.7 kt/yr	**Total mass influx: 8.1 kt/yr**

→ The current and future annual mass influx is significant compared to the natural mass influx!

But is the injection significant, too?

Composition: Natural Input

Different composition depending on origin!

High abundance of **minerals**

Main elements **O, Fe, Si, Mg, C**

Dust particles

Mainly **cometary** origin → Modelled after IDP composition

Larger meteoroids

Mainly of **asteroid** origin

→ Modelled after meteorite composition found on Earth

Composition: Anthropogenic Input

Differentiation between satellites, rocket upper stages and core stages

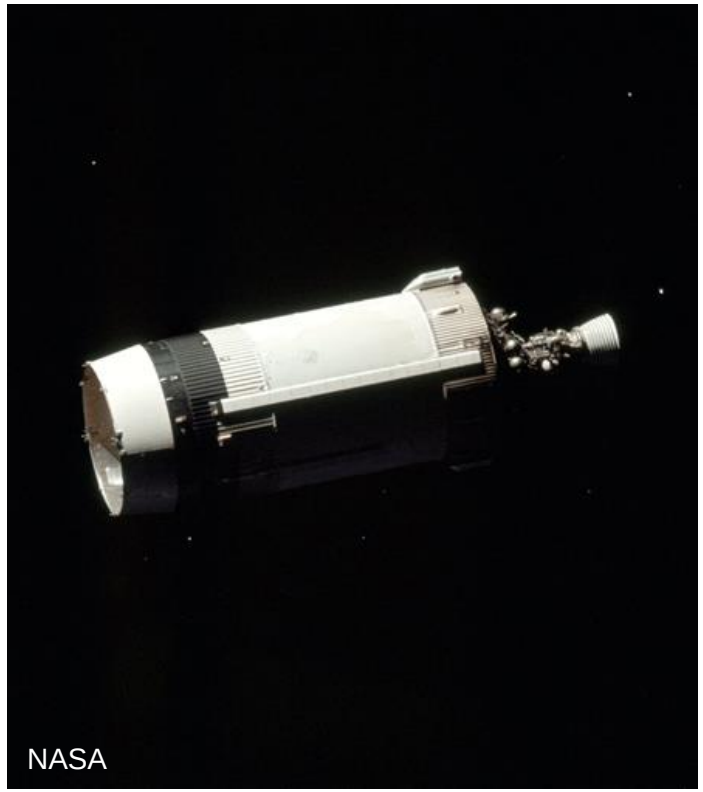
Use of **alloys** and light metals is predominant

Main elements **Al, Fe, Ni**

Satellites

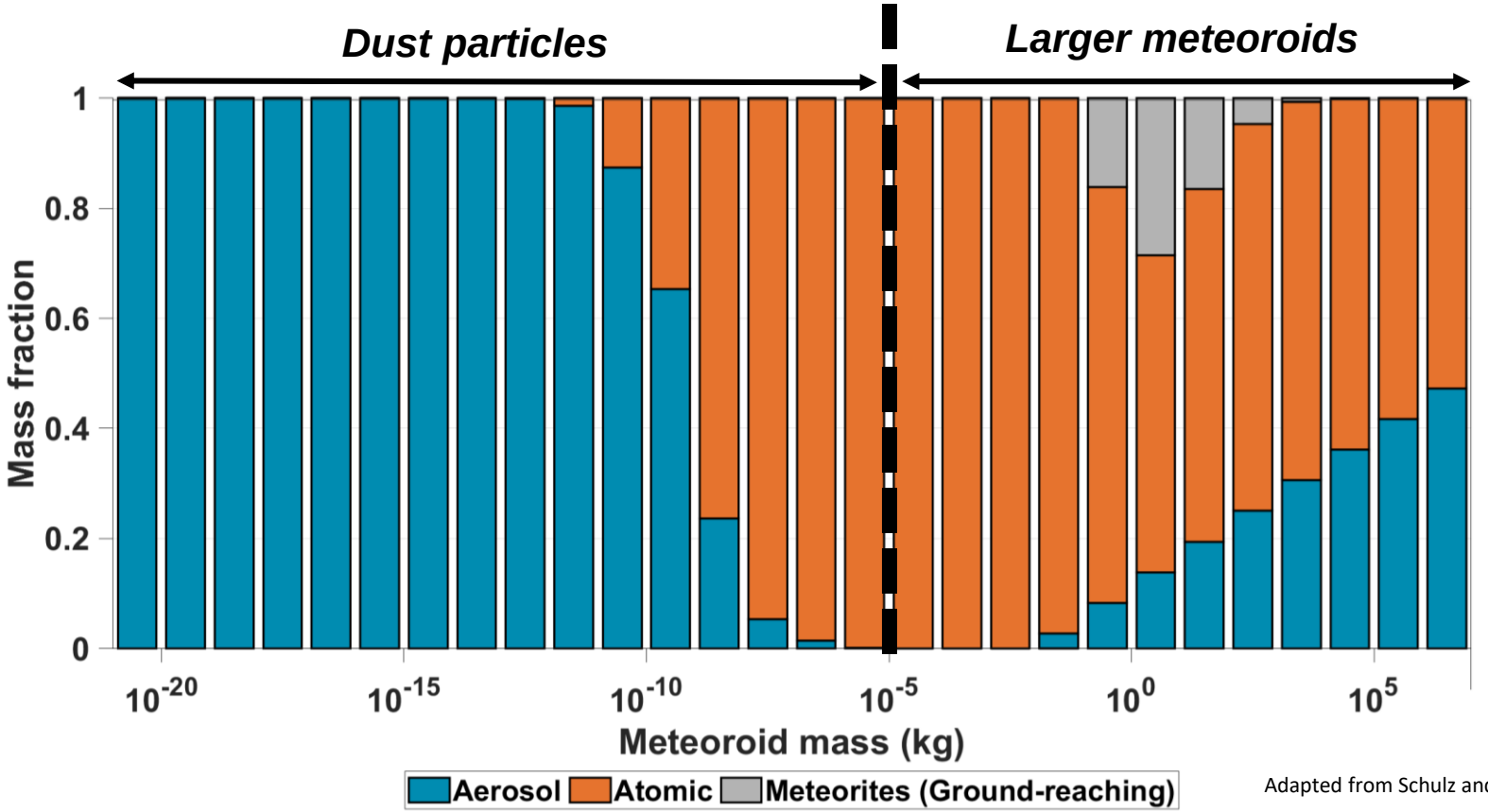
Suborbital stages

Upper stages



Ablation processing: Natural Input

- Three different ablation products: Vapor **(atomic),** small particles **(aerosols),** surviving **(ground-reaching)**
- Mass-dependent ablation modelling and observational data provide first estimate:



Adapted from Schulz and Glassmeier, 2021

Ablation Processing: Anthropogenic Input

Compared to natural input:

- Lower entry speed
- Shallower entry angles
- “Porous” design
- Design-for-demise: Predetermined break-up points

→ **Higher survival fraction**: 20% for satellites, 35% for upper stages, 70% for suborbital stages

→ **Higher aerosol fraction**: 75% of ablated mass

- Constellation satellites are expected to burn up completely

Resulting Estimates and Significance

Combination of mass, elemental composition and ablation product:

- **Today**, the anthropogenic injection amounts to **2.8%** (0.35 kt/yr) compared to natural injection
- But: **Metals** at **7.5%; aerosols** at **6.7%! Disproportional increase.**
- With future mega-constellations, the anthropogenic fraction increases largely:

1. **Probable Scenario**: **12.8%** (1.6 kt/yr) compared to the natural injection.

   Metals at 29.4%, aerosols at 30.2%.

2. **Maximum Scenario**: Nearly **40%** (4.9 kt/yr) compared to the natural injection.

   Metals at 90%, aerosols at 94%.

Resulting Estimates and Significance

The anthropogenic injection of some metal elements even prevails the natural injection:

- **Aluminum**: **Today, 160%** compared to natural injection

  In the future: **6 to 18 times** the natural injection!

- **Copper**: **Today, 700%** compared to natural injection

  In the future, **18 to 50 times** the natural injection!

- Additional elements now and in the future

→ Human-made injection of matter into Earth's atmosphere is significant and can in some cases even dominate over the natural meteoric injection

Murphy et al., 2023 – Observational Confirmation

Observations:

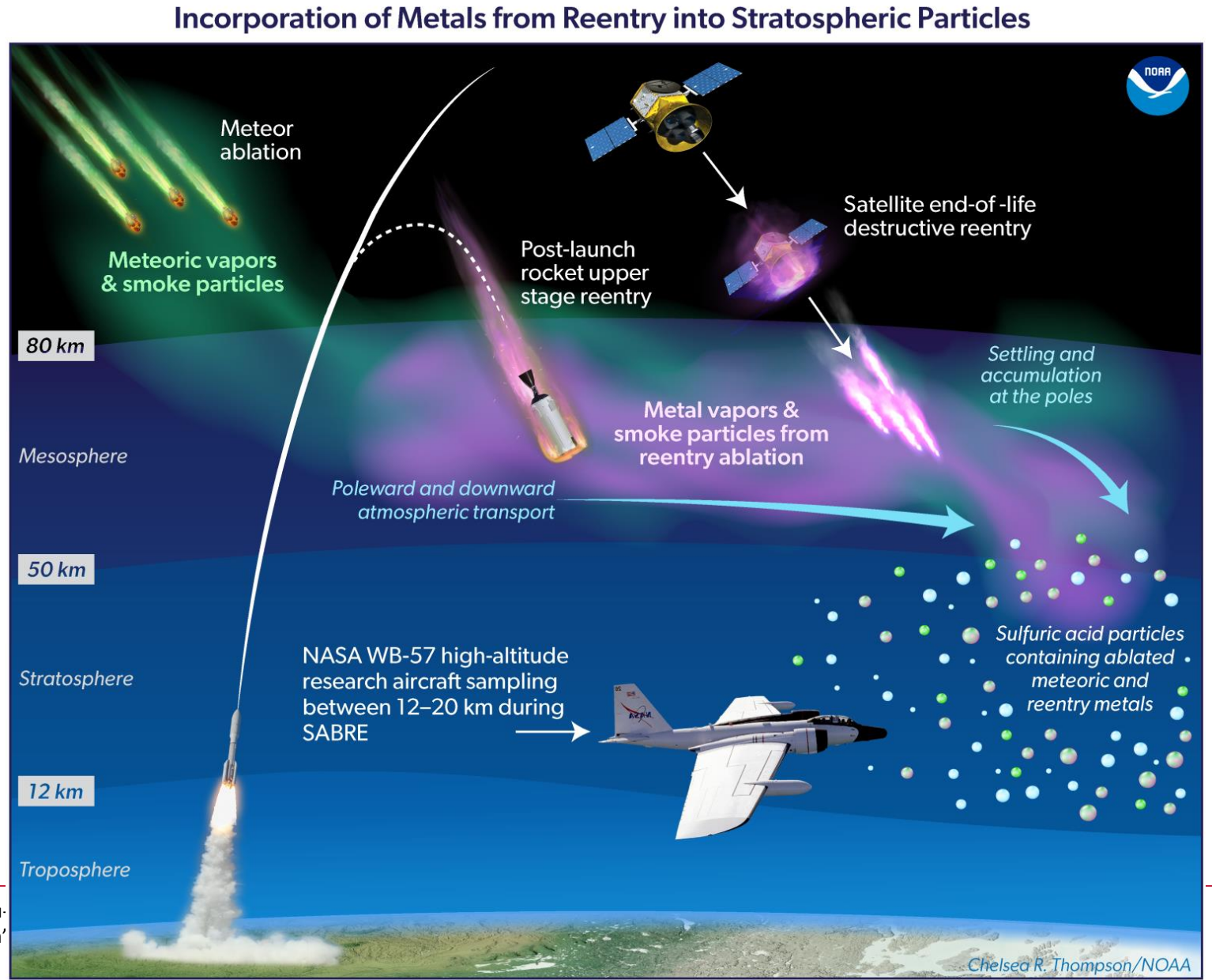
- Space debris remnants in stratospheric aerosol particles

→ Details in Daniel Murphy's talk!

Fit to our theoretical calculations:

- Dominating **Al, Cu** and **Li** mass
- Input of a **whole zoo of metals**, that are very scarce in meteoric input
- Relative mass ratio of **Cu/Al = 0.12**+-0.06 compared to 0.1 theoretical estimation
- **70% of Al** is from **spacecraft**

→ **Observational validation of our modeling!**



Possible Atmospheric Impacts

- Influences on **mesospheric** and **stratospheric chemistry**
- **Catalytic destruction of ozone**
- Increased **cloud formation** due to more condensation nuclei
- **Radiative forcing** due to aerosols

→ **We should do something about that, right now!**

Possible Atmospheric Impacts

- Influences on **mesospheric** and **stratospheric chemistry**
- **Catalytic destruction of ozone**
- Increased **cloud formation** due to more condensation nuclei
- **Radiative forcing** due to aerosols

→ We should do something about that, right now!

A short look back to the past:

- **Climate change**
- **Plastic pollution of the oceans**
- **Ozone depletion**

A Possible Way Forward

Scientists

- **Quantification** of atmospheric impacts!
- Better quantification of injection!
- → **Modelling** (re-entry, whole atmosphere)
- → **Observations** (sounding rockets, atmosphere dipping missions, etc.)
- → Give input on appropriate actions

A Possible Way Forward

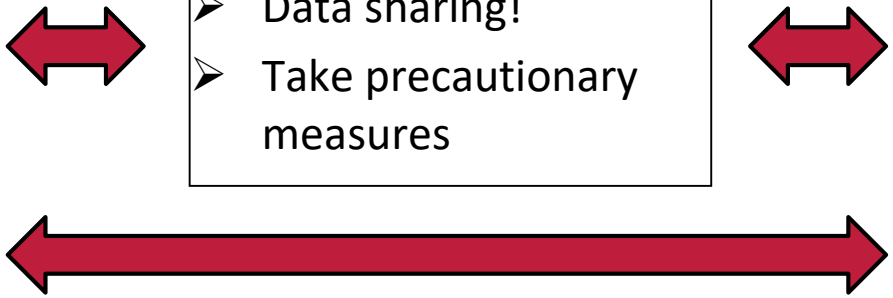
Shutler et al., Nature Geoscience, 2022: Atmospheric impacts of the space industry require oversight:

Take everybody on board!

Work together!

Scientists

- **Quantification** of atmospheric impacts!
- Better quantification of injection!
- → **Modelling** (re-entry, whole atmosphere)
- → **Observations** (sounding rockets, atmosphere dipping missions, etc.)
- → Give input on appropriate actions



Industry

- Data sharing!
- Take precautionary measures

Politicians

- Protect the upper atmosphere through regulation
- Transnational policy effort (UN)
- Finance scientific studies

→ **Achieve sustainability of space travel!**