THE IMPACT OF RE-ENTERING SATELLITES ON ATMOSPHERIC CHEMISTRY AND EARTH‘S CLIMATE

STUDY ANALYSIS & REPORT BY OHB & LEIBNIZ INSTITUTE OF ATMOSPHERIC PHYSICS

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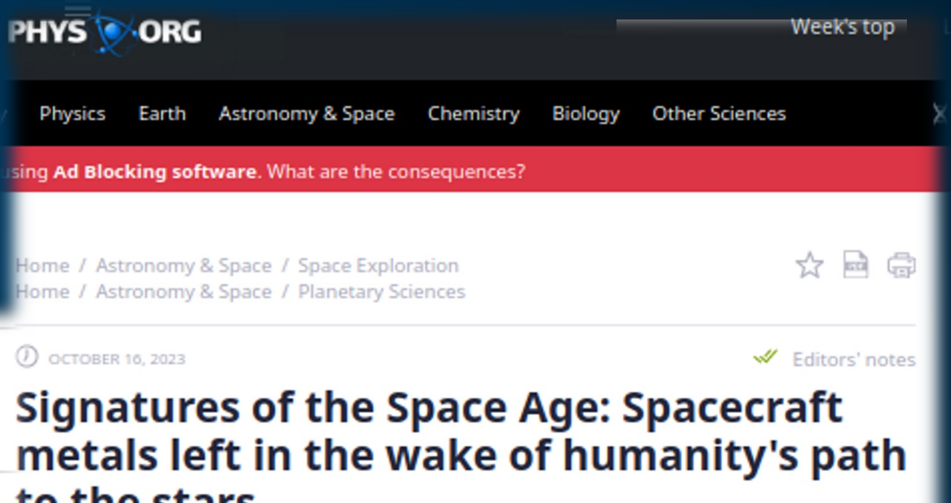
NATURAL VS ANTHROPOGENIC INFLUX

STATUS QUO

- <u>Natural sources injection masses</u>
  - **~ 12000 t/yr**
    (11500 t by particles less than 10E-2)
  - Mass influx varies ± 6000 – 25000 t/yr
  - 47% Non-metallic
    41% Metallic
    13% Metalloid elements
    8% not-assigned
- <u>Current anthropogenic injection</u>
  - **~ 890 t/yr (in 2019)**
    - 87% rocket bodies (702t)
      primary Al-alloys, CFK, unburned propellant
- <u>OHB future anthropogenic estimation</u>
  - **Satellites 4000 t/yr**
    primary Al-alloys, Fe- and Ni-alloys, Si, Ti, Mg, Cu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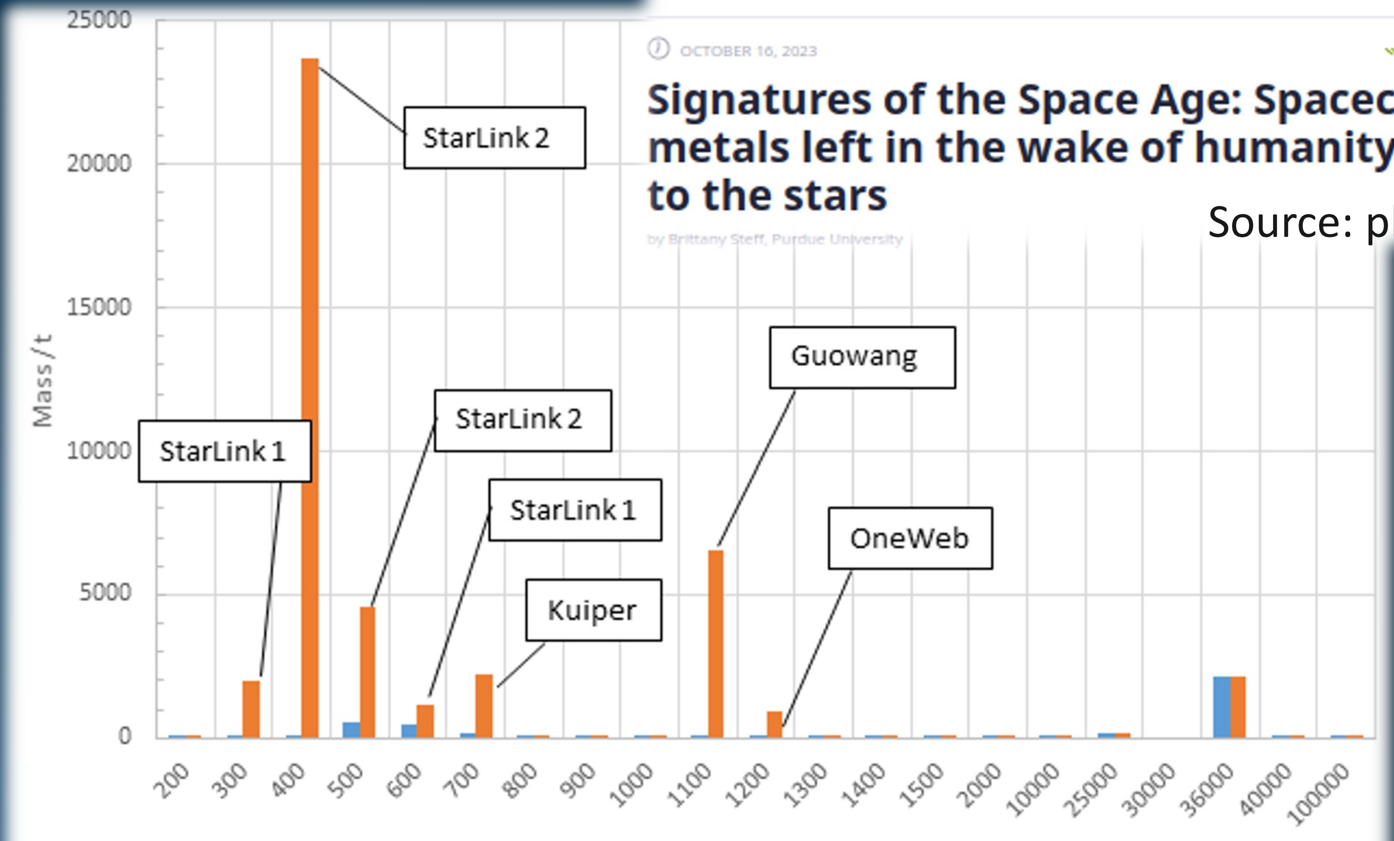
Source: phys.org



internal records/estimations

SATELLITE RE-ENTRY CONCEPT

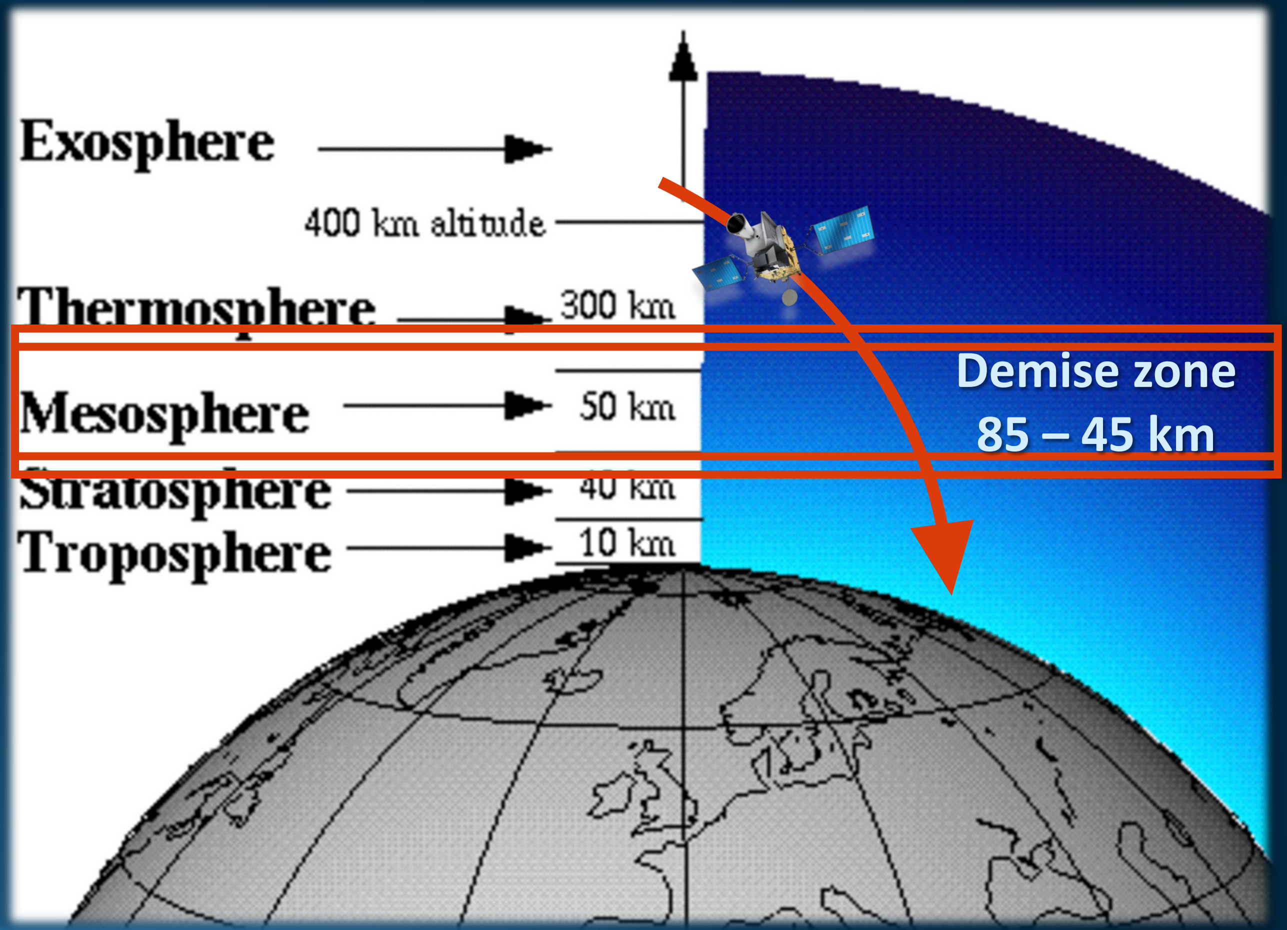
STATUS QUO – NECESSITY OF ACTION

Atmosphere and reentry trajectory concept

- Main Demise Zone is in Mesosphere and Stratosphere

- Relevant forces and degree of demise can be simulated
  Calculation based on:
  - Standard Global Reference Atmospheric Model
    I.e.: atmospheric density as a function of geodetic altitude relative to an oblate Earth.
  - Complex dependencies on spacecraft design, i.e. drag coefficient for cylindrical, spherical, boxes, and flat

- Atmospheric impact is different for controlled re-entry and uncontrolled re-entry



ENVIRONMENTAL CONCERNS OF RE-ENTERING SATELLITES

STATUS QUO – AVAILABLE STUDIES

- MIT: Comparing meteor and rocket atmospheric emissions
  - provides extensive literature review and explores overlaps of the effects of deorbiting space debris with known atmospheric processes coming from aircrafts, meteors and rockets

- ARA & ATISPADE study - Focused on de-orbiting satellites
  - ATISPADE Report concludes that the ozone depleting and global warming effect of deorbiting satellites is negligible in contrast to the negative environmental effect of rocket launchers. The highest Antarctic local ozone concentration change reached about ~0.05%, which is negligible in contrast to the impact of anthropogenic activities causing a global ozone loss (3-4%)

- Few more studies on the impact of space industry on the atmosphere
  - Not all publicly available

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ENVIRONMENTAL CONCERNS OF RE-ENTERING SATELLITES

STATUS QUO – IMPACT ON ATMOSPHERIC CHEMISTRY AND EARTH CLIMATE

Future increasing space traffic in LEO will cause a greater need for cleaning the orbits after satellites EoL via de-orbiting strategies.

- Higher number of ablating structures could cause potentially harmful emissions damaging the atmosphere

Environmental concerns of de-orbiting satellites:

- Ozone depletion
- Global climate change due to radiative forcing
- (toxic) materials reaching ground
- Interactions with high altitude cloud formation
- Disturbance of ionosphere (e.g. radio transmissions)
- Consequences for upper atmosphere measurements

INJECTION OF ANTHROPOGENIC MATERIALS INTO THE ATMOSPHERE

TECHNICAL PART – MAIN POLLUTANTS

Effect of Re-entering Satellites on the upper stratosphere and the mesosphere-lower thermosphere (MLT Region)

Main pollutants due to re-entering:

- Al and aluminum alloys
- Carbon containing materials (CCM)
- NO as the result of combustion

Three types of injection compounds:

- Atoms and molecules (direct chemical impact)
- Aerosols (radiative forcing and catalytic impact)
- Ground-reaching parts (thermal NO)

INJECTION OF ANTHROPOGENIC MATERIALS INTO THE ATMOSPHERE

TECHNICAL PART – **NITROGENOXIDE (NO)** INFLUX SCENARIOS - CALCULATED BY CTM-IAP MODEL

Frictional heating during re-entry generates NO that affects the ozone concentration.

Four scenarios were modelled for atmospheric NO influx:

- No anthropogenic mass injection
  Run (1): unperturbed run
  represents the **unaffected atmosphere** (i.e., no additional NO input).

- Current anthropogenic mass injection
  Run (2): mass of objects re-entered in 2021
  Re-entry of 515 objects with a total mass of **271.1 t/yr**.

- Future anthropogenic mass injection
  Runs (3) and **(4)** future prospective scenarios
  1251 t/yr and 4033 t/yr intruded mass of objects, consequently of NO.

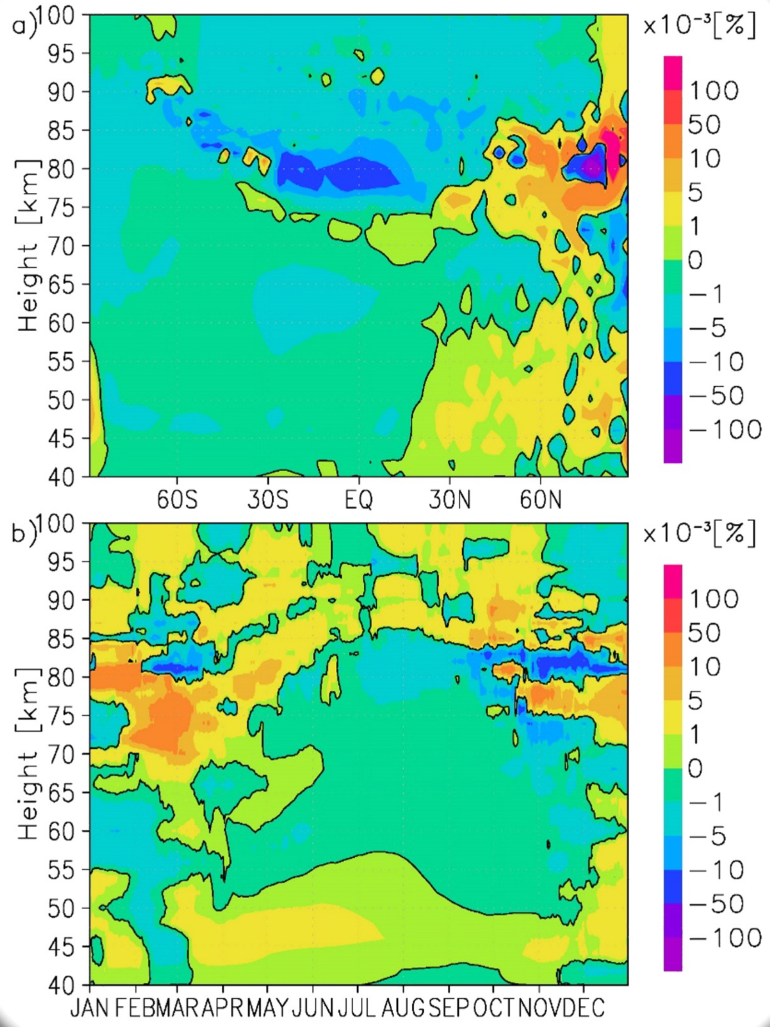

Figure shows deviations in ozone concentration for Run (4) with an injection of **4033 tons per year** intruded mass of objects in Decembre and 53.75° N

(injection estimates from Schulz and Glassmeier, 2021)

INJECTION OF ANTHROPOGENIC MATERIALS INTO THE ATMOSPHERE

TECHNICAL PART – **NITROGENOXIDE (NO)** INFLUX SCENARIOS - CALCULATED BY CTM-IAP MODEL

Nitrogenoxide (NO) Influx model results

- Prediction of negative *AND* positive effects on ozone of no more than ~0.05%.

Distributions of effects are strongly non-linear and have latitudinal and seasonal dependence but are still low.

Variation of ozone concentration during anthropogenic material injection (~0.05%)
-> small in comparison to natural ozone variation (seasonal (~50%) and solar cycle changes (~5%))

Moreover: Production of NO by re-entry is much smaller than ground-based anthropogenic production changes.

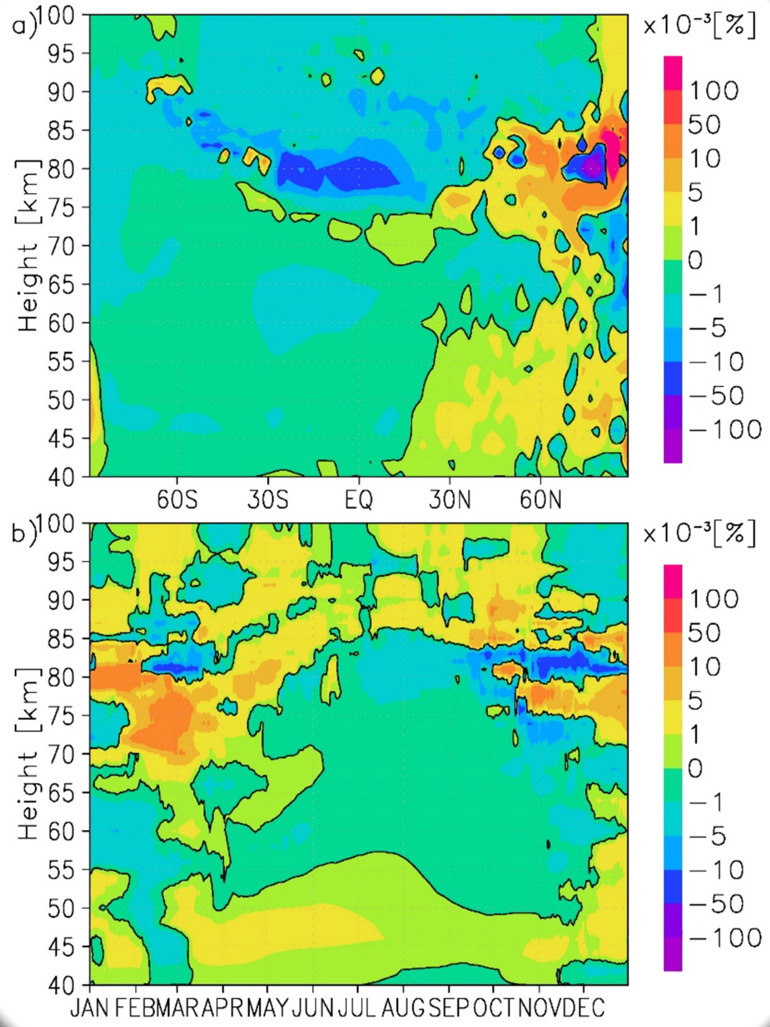

Figure shows difference in deviations in ozone concentration for Run (4) with an injection of **4033 tons per year** intruded mass of objects in Decembre and 53.75° N

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INJECTION OF ANTHROPOGENIC MATERIALS INTO THE ATMOSPHERE

TECHNICAL PART – EFFECTS BY **AL_2O_3** AND **CARBON AEROSOLS** – LITERATURE STUDY

- In the atmosphere, **Al_2O_3** will further condensate and form larger (Al_2O_3)n clusters (aerosols).
  - Aerosols absorb solar radiation, modify the thermal regime of the stratosphere and mesosphere

> - Effect estimated to be **10^{-3} W/m²** on global annual scale.
> - Natural variations of the total solar irradiance due to season is 1321W/m² - 1412W/m² (says by about **90W/m²**) and due to solar cycle is 1360W/m² to 1362W/m² (says by about **2W/m²**)

- **Carbon** aerosols modify radiative balance and consequently determine the thermal regime of the atmosphere.
  - BC aerosols act as catalysts for ozone chemistry.

> - Expected radiative effect by intruded aerosols (black carbon & aluminum alloys), estimated to be **small compared to the natural variability**
>   **Natural variability** = solar radiation due to the Earth's rotation around the Sun & to solar cycle.

INJECTION OF ANTHROPOGENIC MATERIALS INTO THE ATMOSPHERE

TECHNICAL PART – FUTURE EXTENSION NEEDED FOR A **COMPLETE** ANALYSIS

- **Shown**: dedicated analysis/estimation for intrusion of NO and aerosol radiative effects
- **Needed**: More and/or improved process understanding determined by laboratory experiments and model extensions, e.g.,
  - Combustion model for re-entering anthropogenic bodies
  - Model of Al_2O_3 condensation
  - Model of chemistry on aerosols
  - Interactive coupling between chemical-dynamical responses and radiation
  - composition and gasification rates of re-entering object
  - 3D aerosol distributions by size and concentrations
  - the optical properties of aerosols
  - chemical processes on aerosols surface
  - among others …

OHB INVOLVEMENT AND PROJECTS

Further work to be done by the community

- **Debris mitigation strategies**
- **Active debris removal strategies and concepts**
- **Design for demise and removal**

- Controlled vs uncontrolled re-entry and atmospheric impacts (and impact on ocean at point nemo)
- Space debris modelling, M/OD Hazard
- Identification of all materials in a spacecraft and their impact on the atmosphere
- Consideration of climate change induced alteration atmospheric composition

OHB-Involvement & Projects	Person of Contact
Zero Debris Charter	Kate Lahaie and Christiane Bergemann
OHB Space Debris Centre	Charlotte Bewick, Kate Lahaie
PoC-1 as steppingstone for RVD in-orbit	Marc Scheper, Birk Wollenhaupt and Laura Schumacher
Design for Demise (D4D)	Bradley Lockett and Britta Ganzer
DRAMA, Space Debris Modelling, M/OD Hazard	Bayrem Zitouni and Sara De Masi

THANK YOU
& TAKE CARE!

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ATMOSPHERIC IMPACT OF DE-ORBITING OBJECTS

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