University of Stuttgart
Institute of Space Systems

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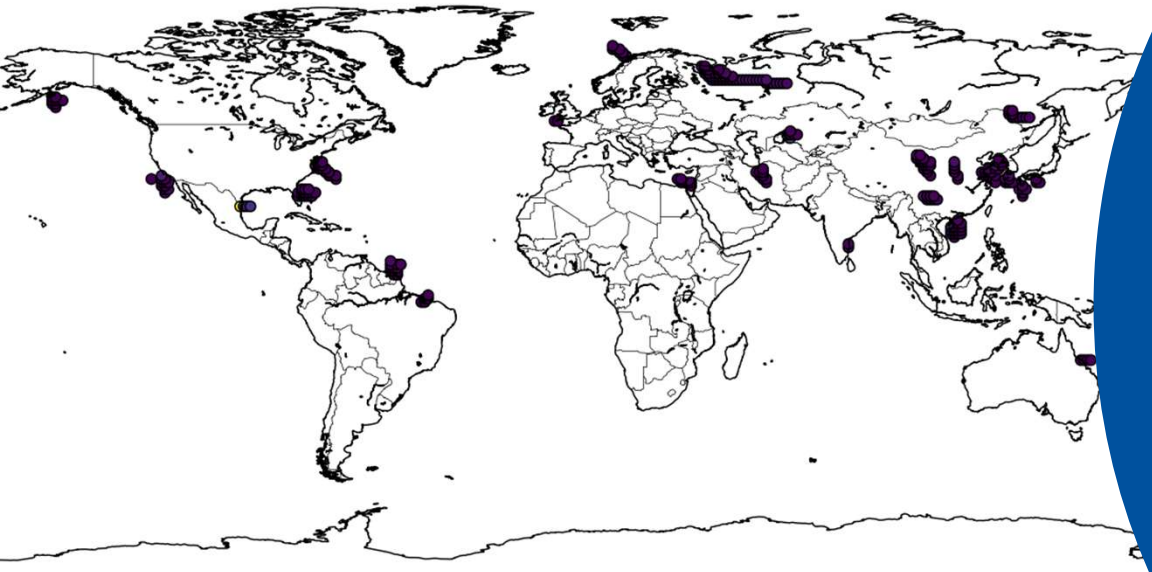

# Development of space transportation launch and re-entry emission inventories for 2019-2025 and analysis of the chemical interaction with the atmosphere

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Constantin Traub, Stefanos Fasoulas

Clean Space Days 2026
ESA ESTEC Noordwijk
1st July 2026

With funding from the:
Federal Ministry of Research, Technology and Space

## Emission Calculation Tools (GNU Affero General Public License)

Launch Emission Assessment Tool (LEAT)

- Trajectory calculation
- Own Trajectory files implementation
- Emission calculation based on
  - Predefined emission index (including all literature values)
  - NASA CEA (external free license)
  - Cantera

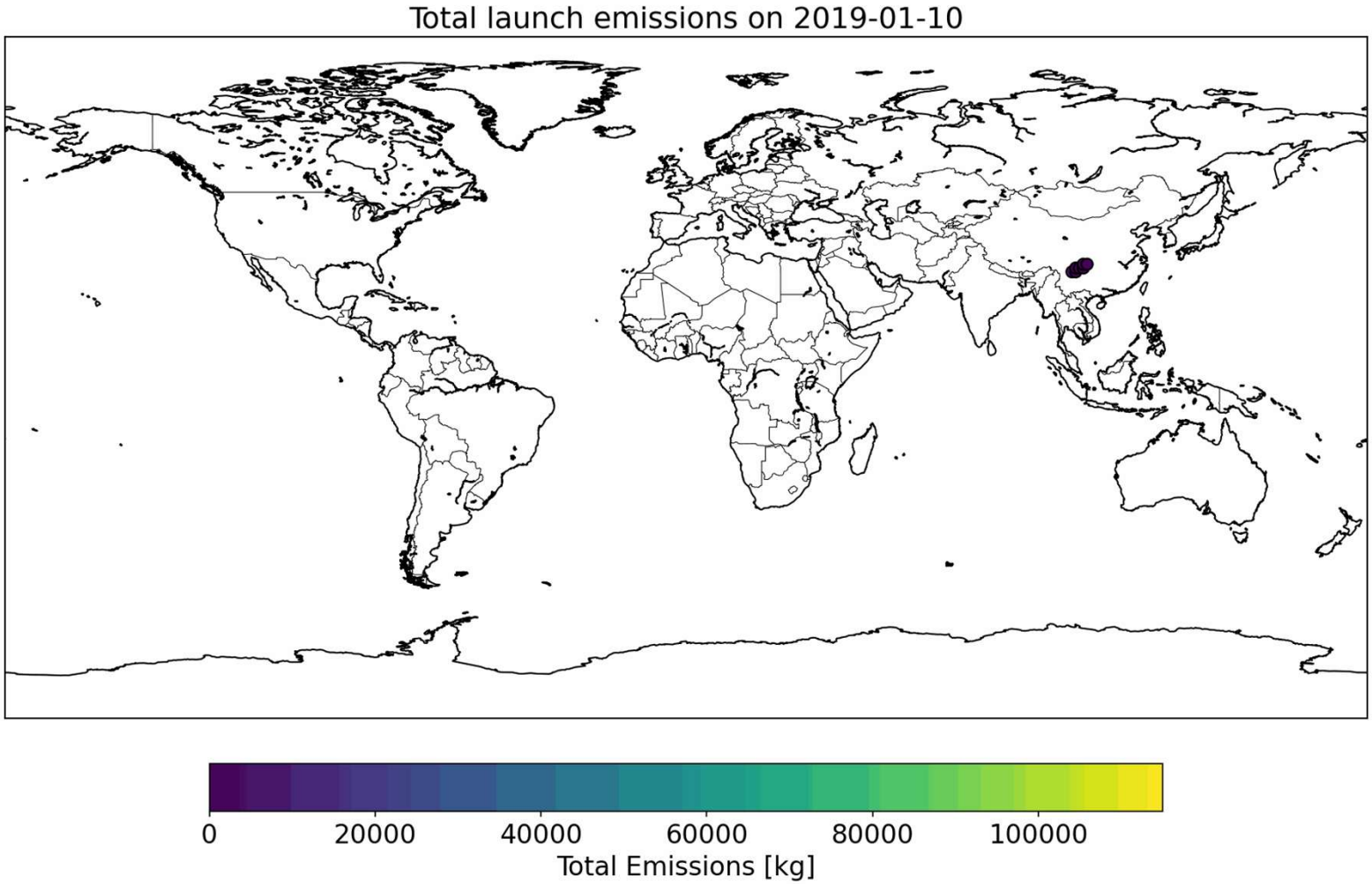
Repo: https://github.com/lcasts/LEAT

Re-entry Emission Assessment Tool (REAT)

- DRAMA destructive or (Semi-) ballistic trajectory calculation
- Own Trajectory /DRAMA/ SCARAB/ DEBRISK files read in
- NOx emission calculation based on
  - NASA CEA (external free license)
  - Cantera
- Structural emission calculation based on
  - Predefined emission index
  - NASA CEA (external free license)

Repo: https://github.com/lcasts/REAT

# Launch Emission – Worldwide 2019-2025

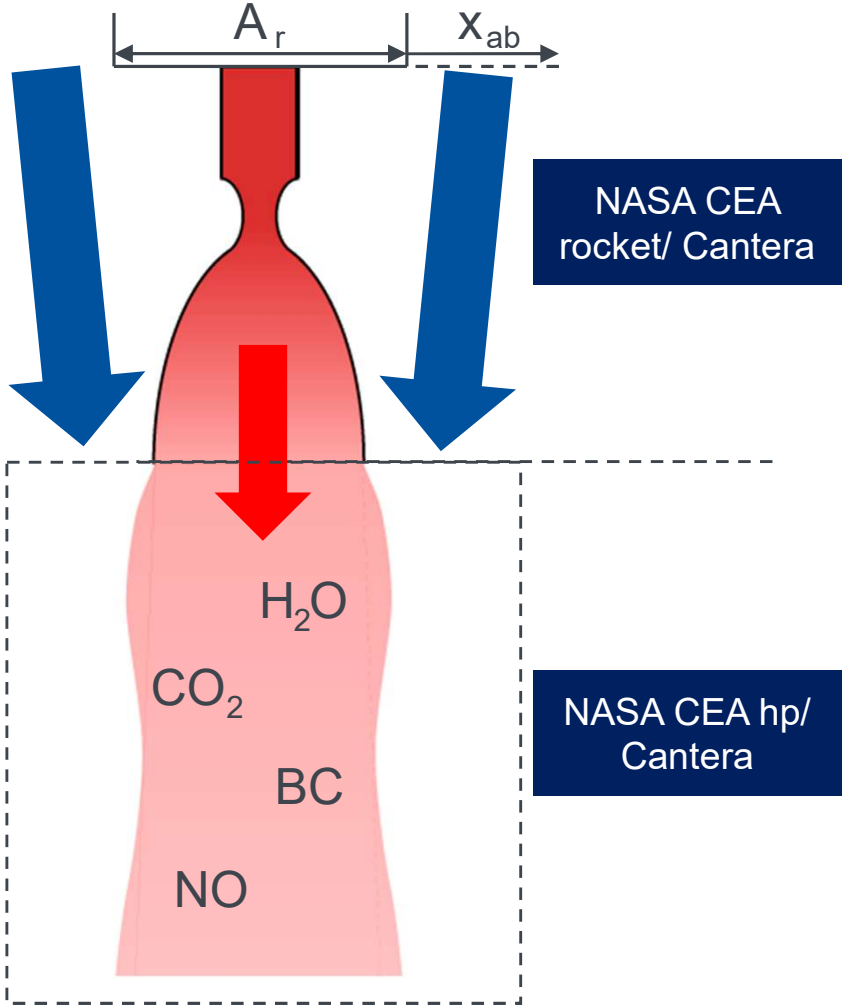



- Launch data from GCAT[1]
- Launcher data from literature
- Unknowns handled with stage optimization
- Specific engine data for launchers > 10 launches
- General data for most engines, mixture ratio of propellants



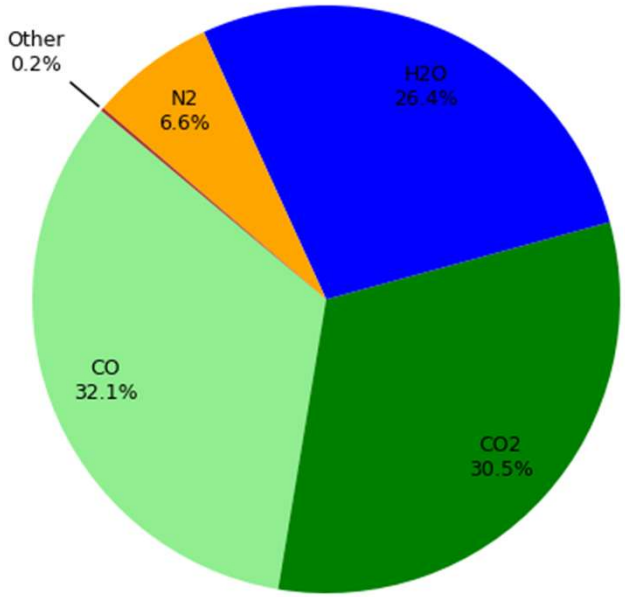
1) McDowell, J. C.: General Catalog of Artificial Space Objects Release 1.8.0 under CC-BY licence

# Launch Emission – Uncertainties in emission calculation

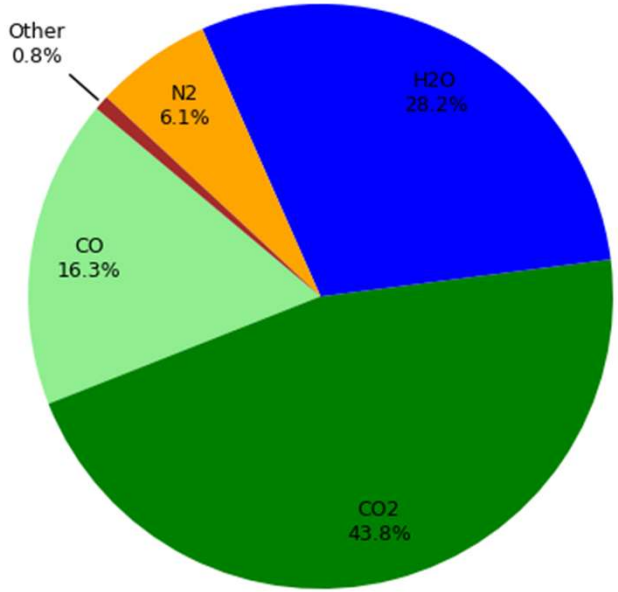



NASA CEA rocket/ Cantera

NASA CEA hp/ Cantera

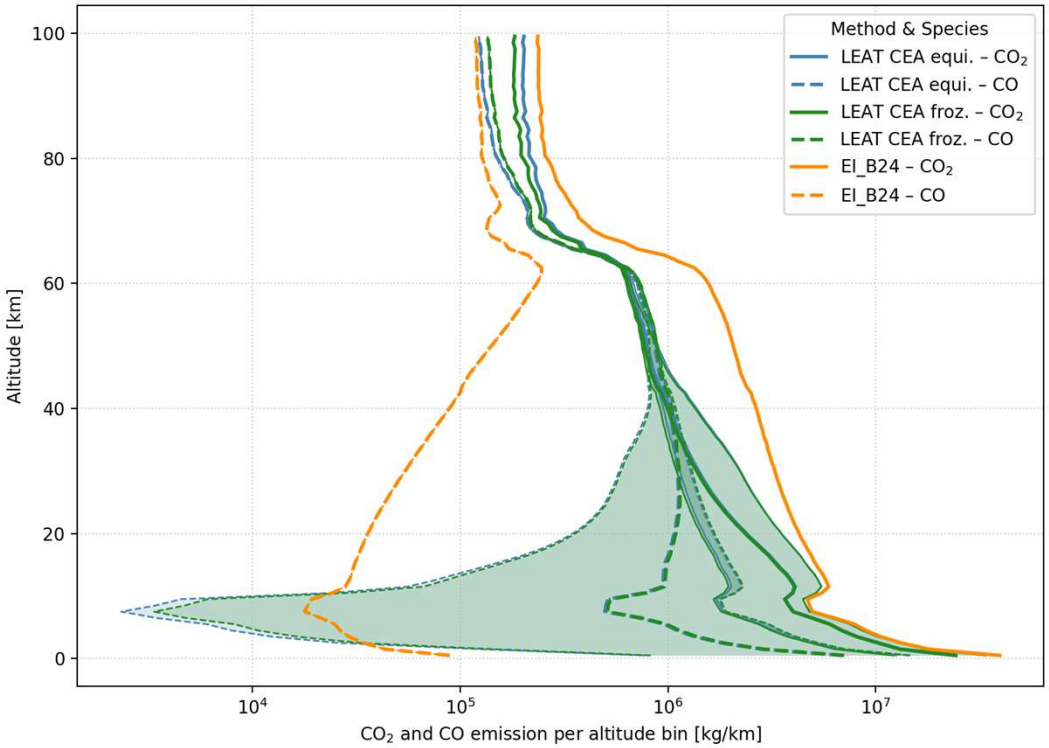


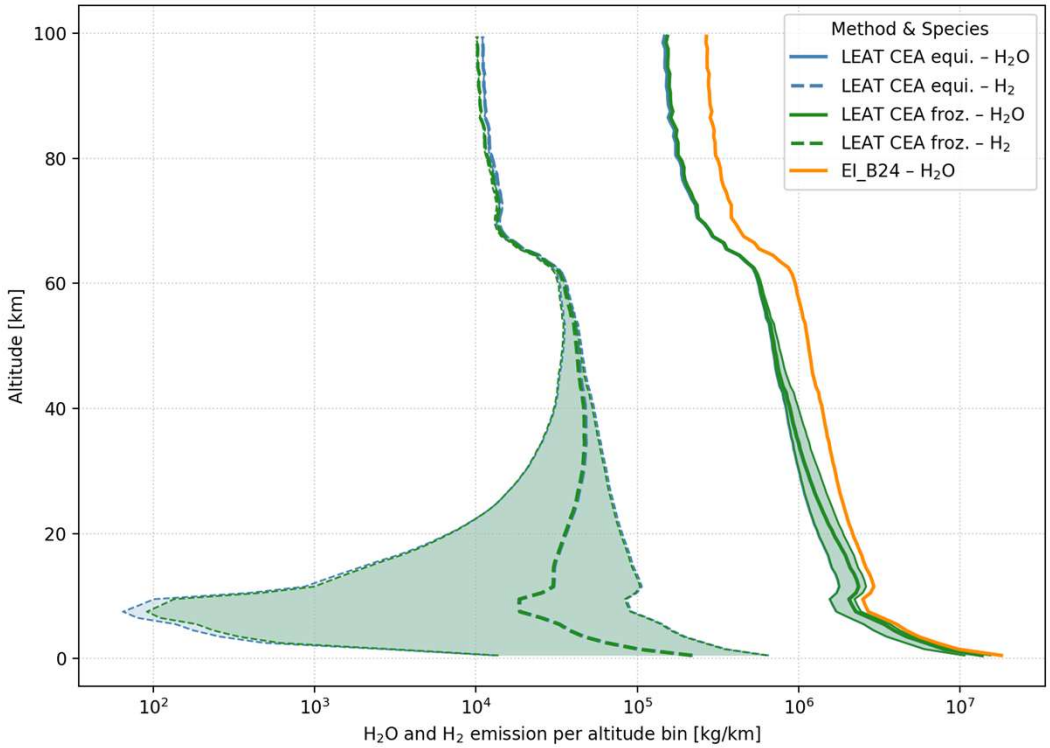

$x_{ab}$ = 1.2




$x_{ab}$ = 8

# Launch Emission – Uncertainties in emission calculation



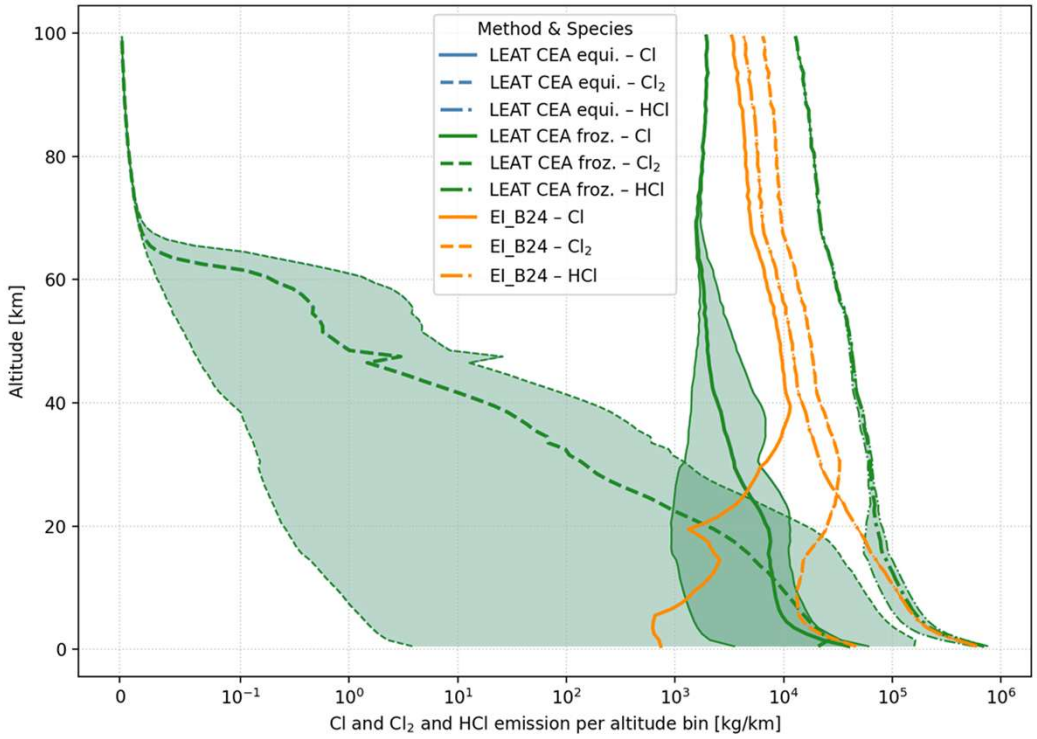



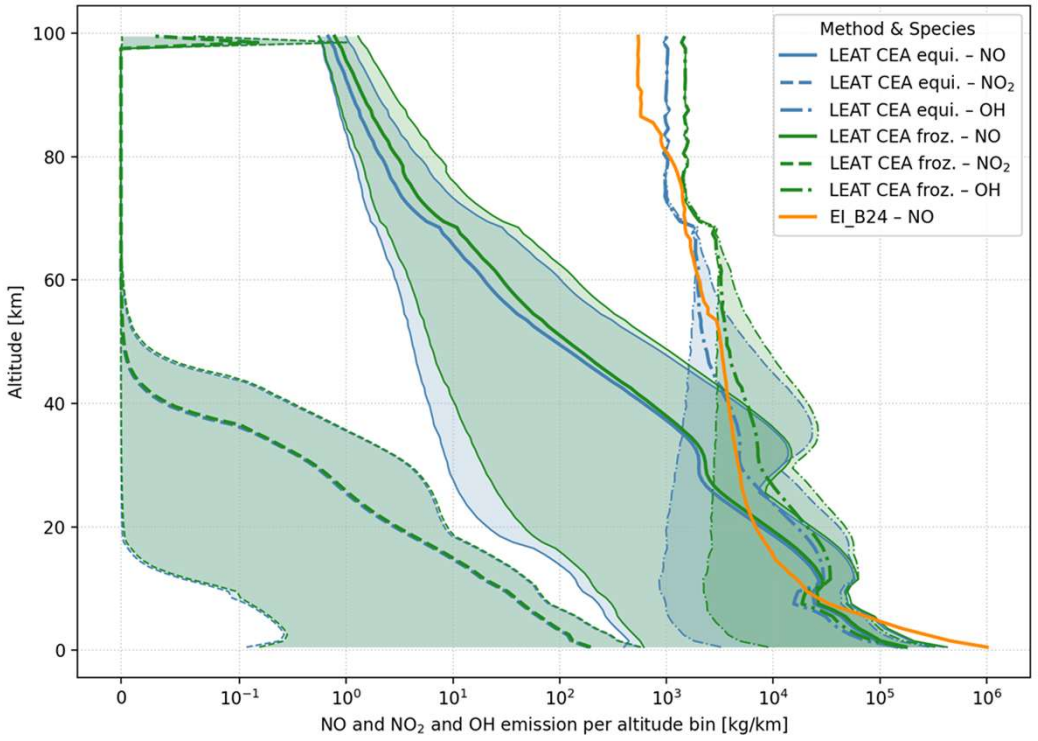

Variation of ambient air mass flow for afterburning with reference trajectories

→ significant uncertainty for minor species

→ Underestimation of CO in with emission indices

# Launch Emission – Uncertainties in emission calculation



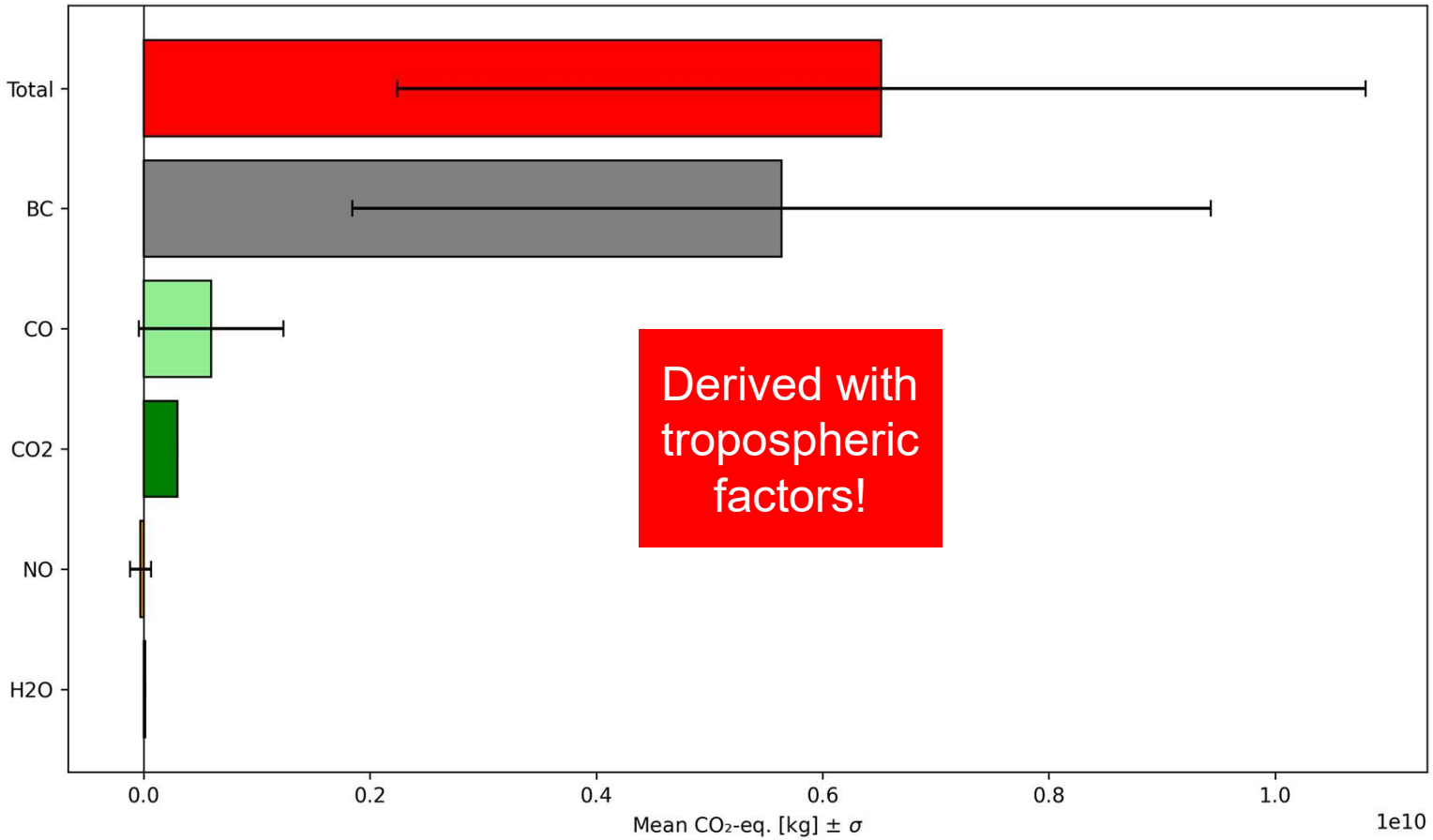




Variation of ambient air mass flow for afterburning with reference trajectories

→ more $Cl_2$ and NO emission with emission indices

→ significant OH emission

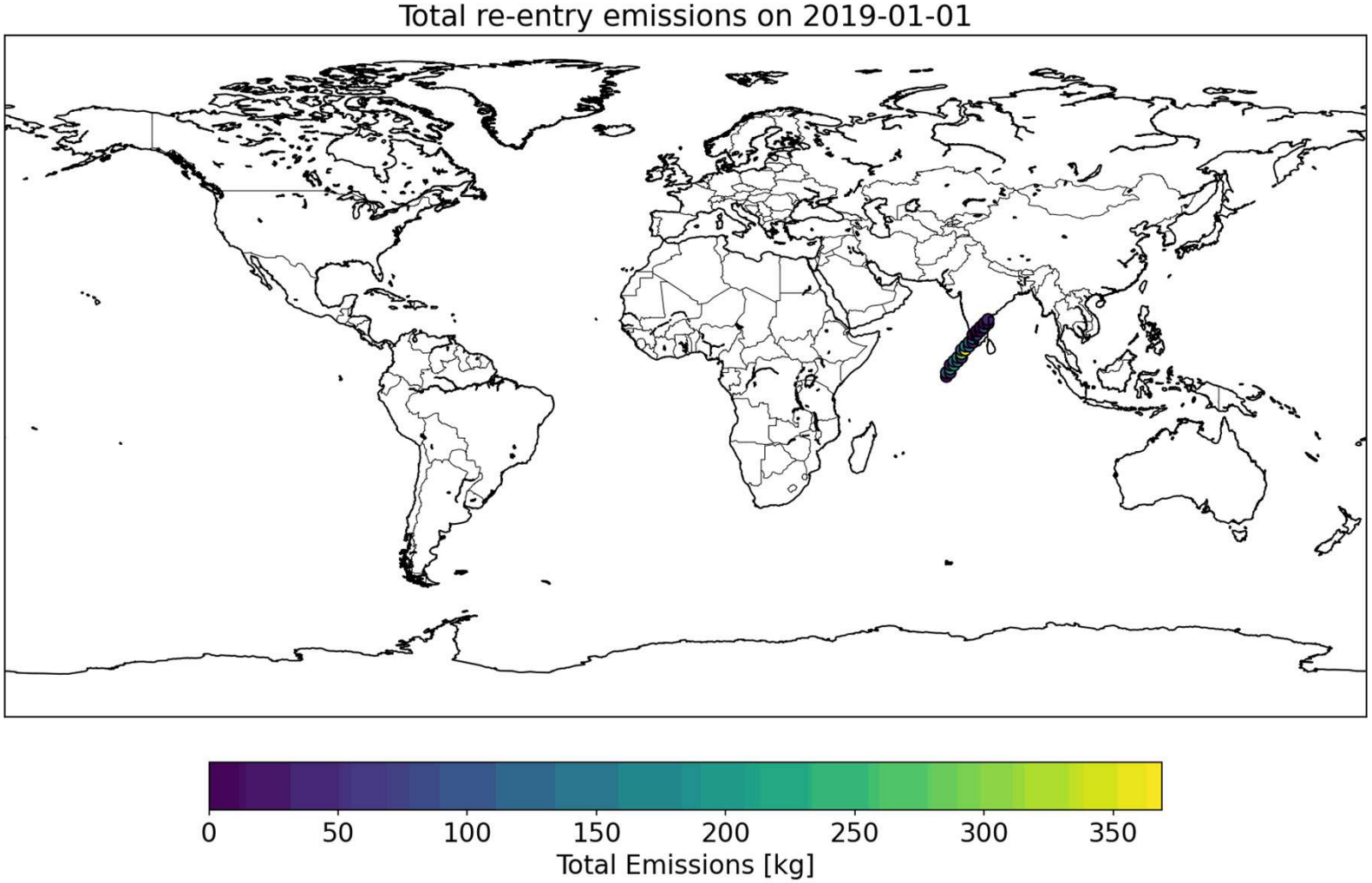
# Launch Emission – Worldwide launches 2019 - 2025




- 373.207 – 445.476 t of emission 2019 - 2025
- Growth of 450% 2019 to 2025
- 0.04 – 0.05 % of emission of aviation in 2019

- Impact derived with tropospheric characterization factors from IPCC and Lee et al.
- Impact of 0.1 – 0.6 % of aviation in 2018

# Rocket Bodies Re-entry Emission – Worldwide 2019-2025



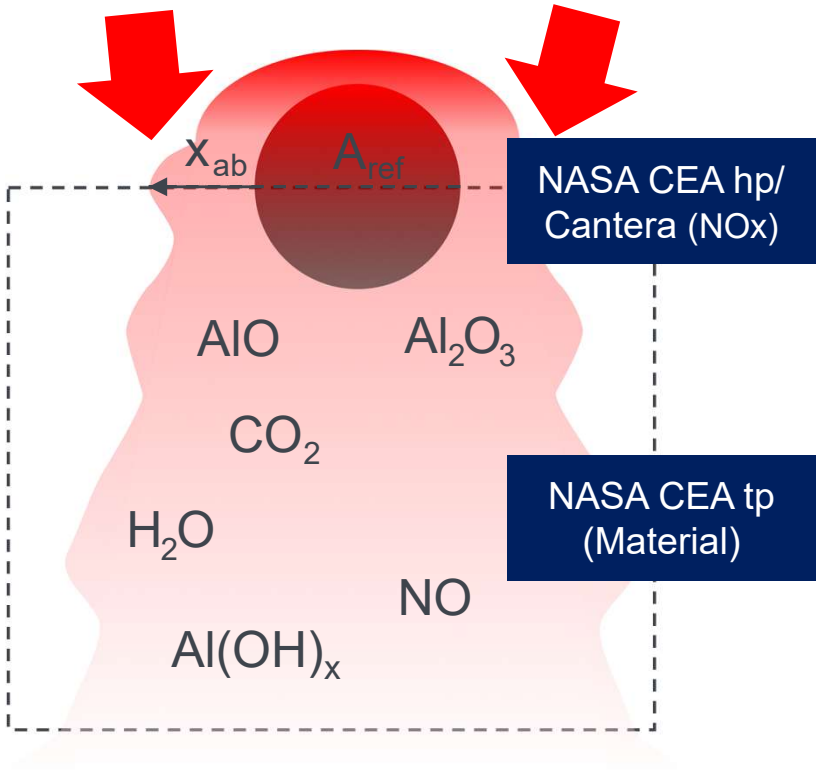

- Re-entry data from GCAT[1] & Spacetrack
- Stage data from literature & JCAT
- Adaption of mass, diameter, length
- Literature data for mass and material share
- General data except Falcon 9/Ariane 6

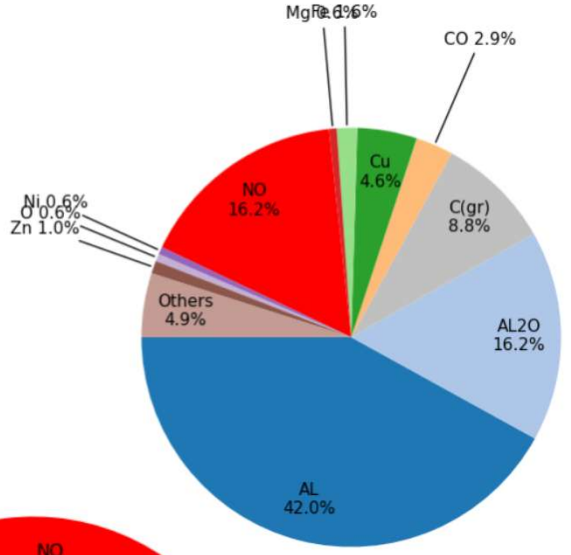
Results



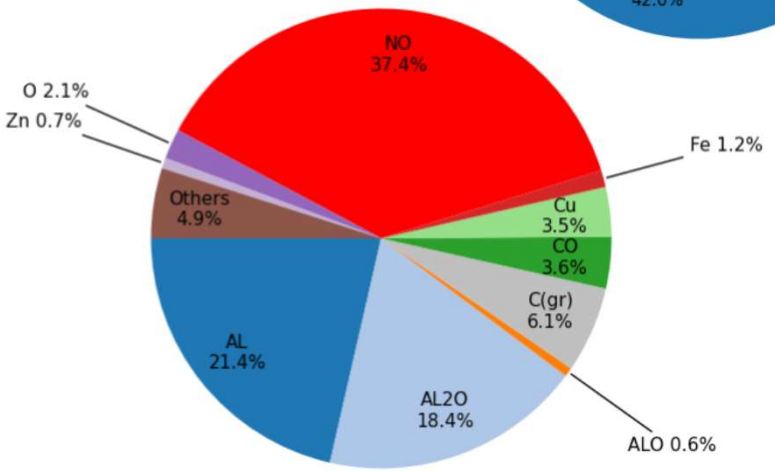
1) McDowell, J. C.: General Catalog of Artificial Space Objects Release 1.8.0 under CC-BY licence

# Re-entry Emission – Uncertainties in emission calculation



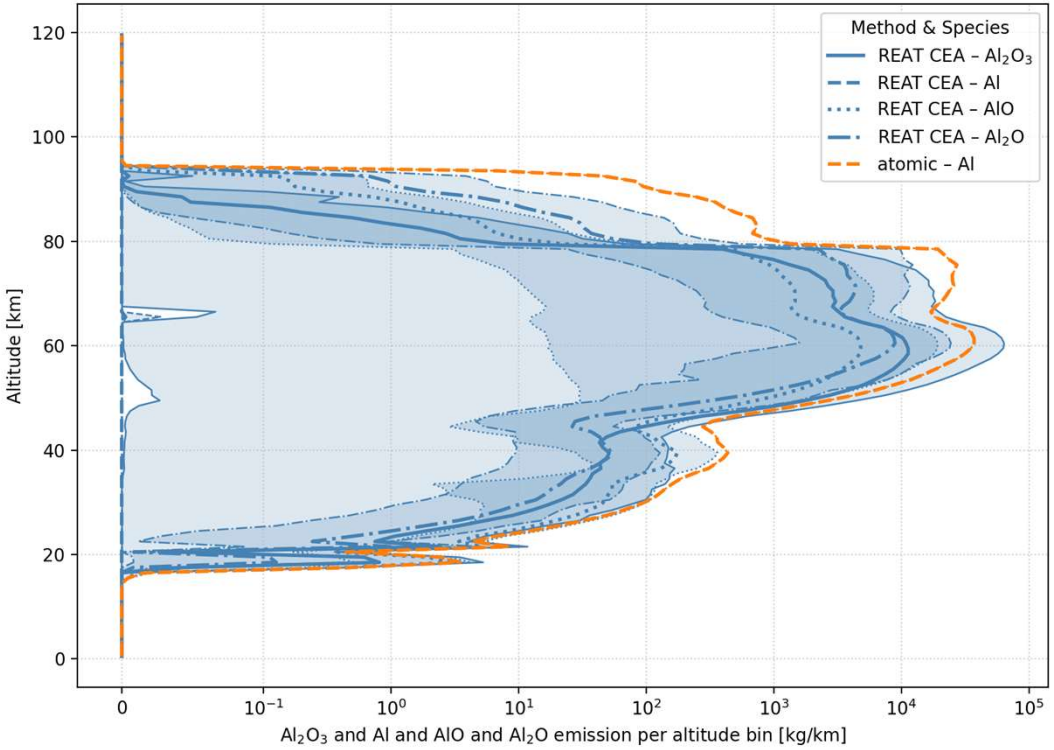



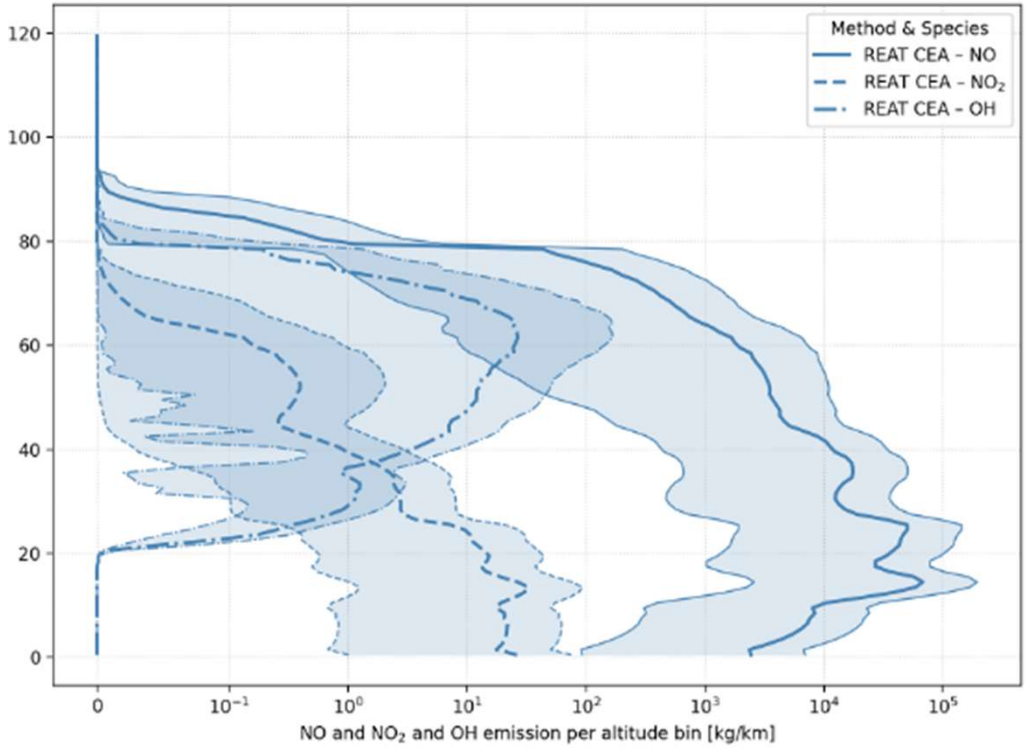

$x_{ab} = 2$




$x_{ab} = 4$

# Re-entry Emission – Uncertainties in emission calculation



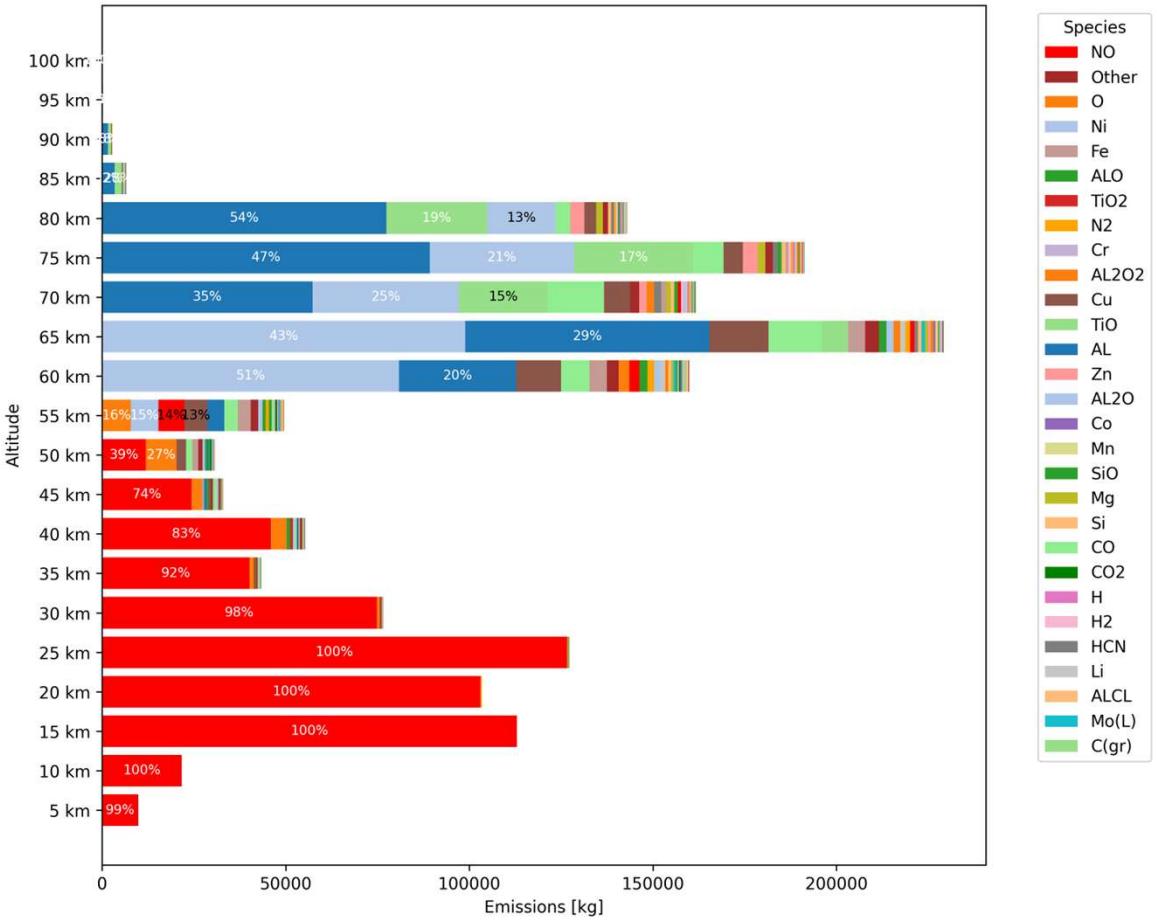




Variation of ambient air mass flow for demise

→ relatively low impact on oxidation of $Al_x$

→ lower peak for NO/NO2 than for metallic emission

# Re-entry Emission - Worldwide rocket bodies emissions 2019 - 2025




- 1000 t of structural emission 2019-2025
- NOx in the same order of magnitude
- 0.2 – 1 % of launch emission
- A lot of different possible species, **which exactly is still unknown!**
- **Might have significant impacts already in ppbv concentration → research gap**

# Project Outlook & Acknowledgements

German Space Agency, funding reference 50RL2180 / 50RL2580

Supported by:

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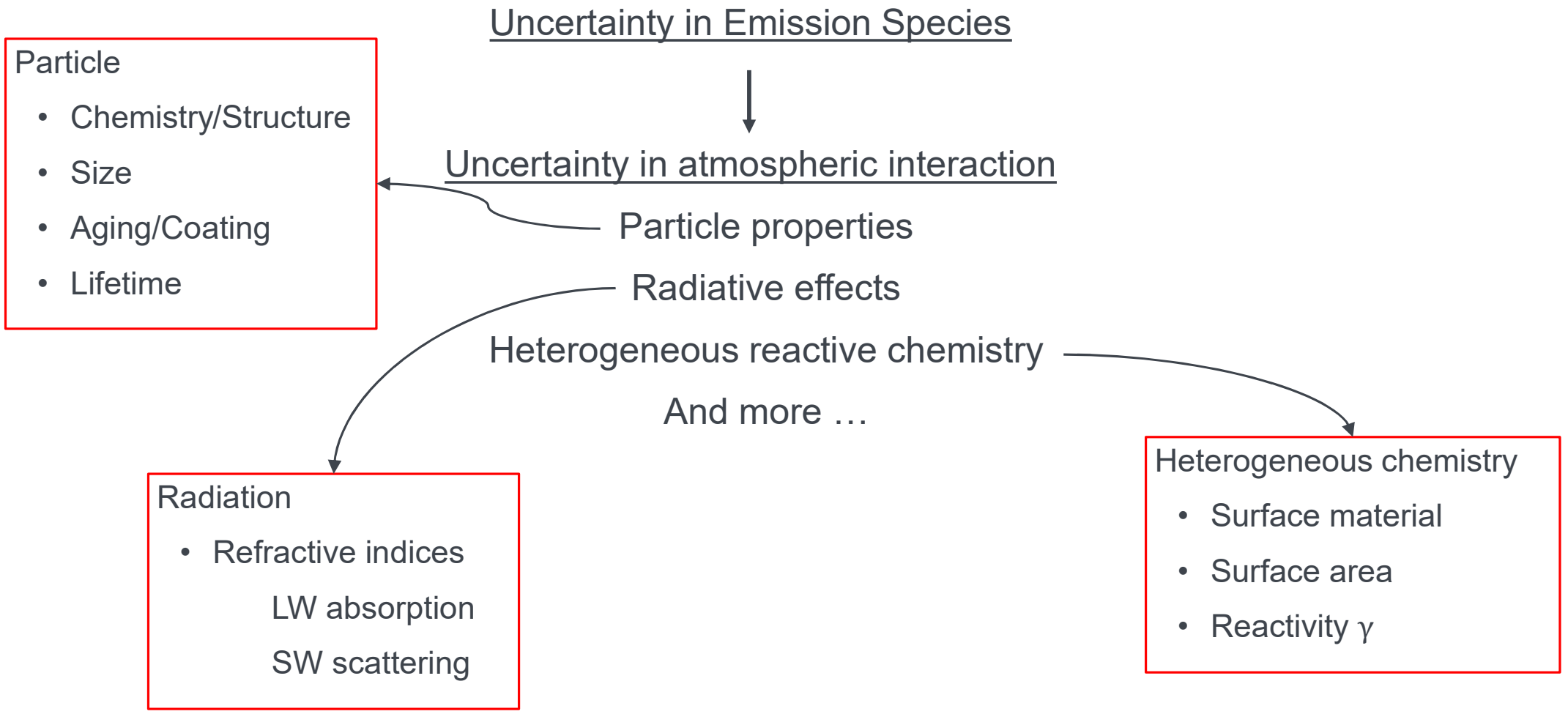
With funding from the:

Federal Ministry of Research, Technology and Space

- Further development of the LEAT-REAT-Framework → SLICE

- ***Analysis of the impacts of spaceflight emissions in the upper atmosphere***
- Setup of reaction database of emission's interaction with atmospheric species

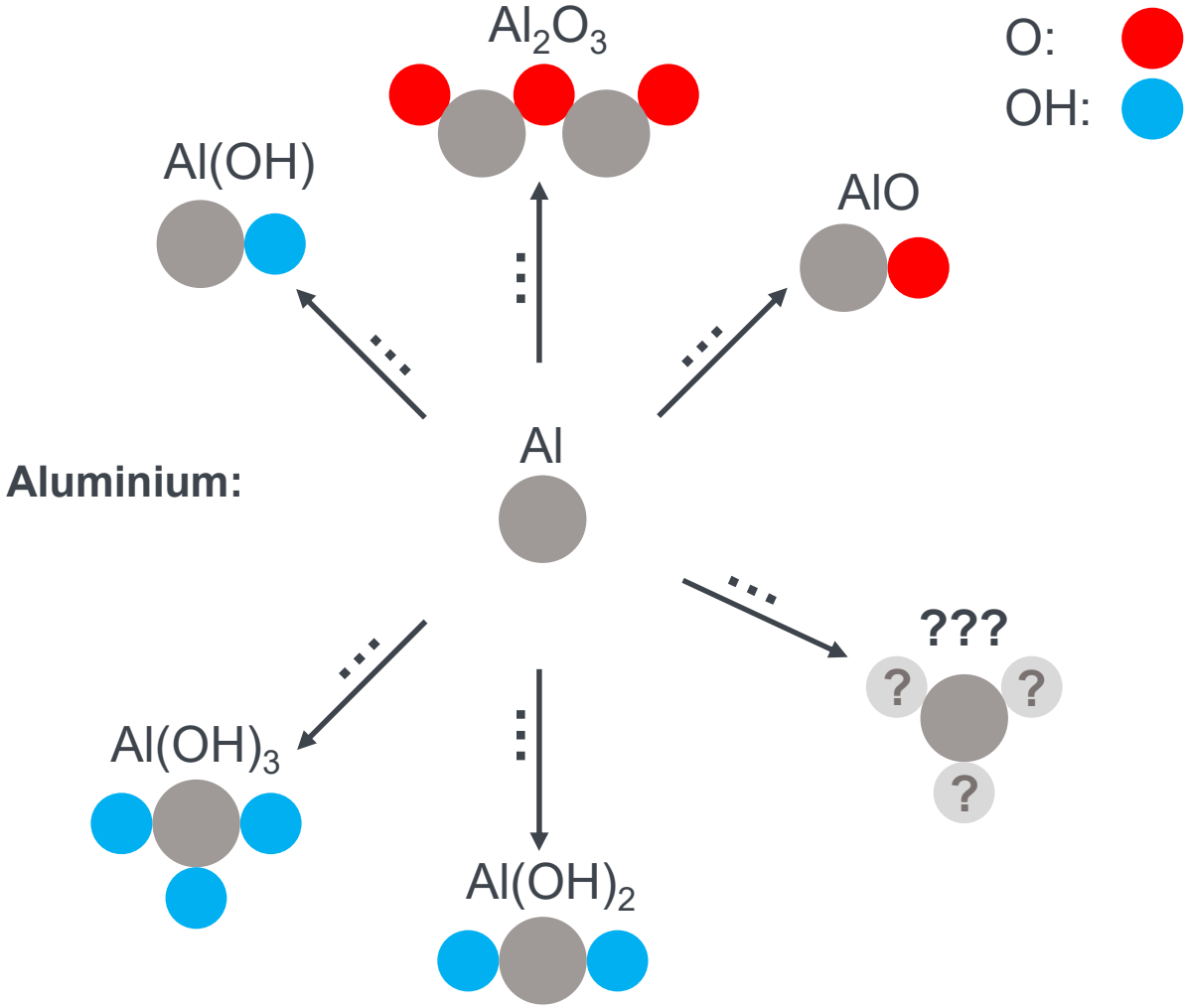
# Atmospheric Interaction Uncertainty



# High Altitude Reaction Chemistry

- Highly uncertain!
- Metallic emissions' reactions mostly unknown $\sim f(p, T, c)$

- Reaction Database:
  - Ti ⇢ ???
  - Cu ⇢ ???
  - Co ⇢ ???
  - ⋮



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- Further development of the LEAT-REAT-Framework → SLICE

- ***Analysis of the impacts of spaceflight emissions in the upper atmosphere***
- Expansion of reaction database of emission's atmospheric interaction
- Development of reaction networks

- Exchange of knowledge through network of experts → 4th Workshop on LCA of STS

# 4th Workshops on life cycle assessment of STS at the University of Stuttgart

- Experts from politics, space agencies, industry and research
- Exchanging knowledge about the environmental impacts of STS

- **September 1st – 3rd, 2026**
- Working groups on:
  1. Eco-design/LCA methodology
  2. Emissions assessment
  3. Atmospheric interaction

- **Registration closed**

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# Thank you!


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