# GOCE & Aeolus re-entries

## 6th International Space Debris Re-Entry Workshop

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# Mission descriptions: GOCE & Aeolus

## GOCE

## Aeolus

# Mission descriptions: GOCE & Aeolus

| | GOCE (Gravity field & steady-state Ocean Circulation Explorer) | Aeolus |
|---|---|---|
| **Launch** | March 2009 | August 2018 |
| **Purpose** | High precision measurement of Earth‘s gravity field (geoid) | Global wind profile measurements up to 30 km |
| **Orbit** | Polar, sun-synchronous, 260 km -> 224 km | Polar, sun-synchronous, 320 km -> 280 km |
| **Earth Observation programme** | ESA‘s living planet Earth Explorer programme | ESA‘s living planet Earth Explorer programme |
| **Nominal life time** | 20 months, extended | 39 months, extended |
| **Solar cycle** | | |
| **Re-entry type** | Uncontrolled | Assisted |
| **Last telemtry received** | At ~115 km on 11th November 2013 | At ~150km on 28th July 2023 |
| **S/C passivation** | No | Yes |

# End of Life (EoL) strategy: GOCE

- S/C designed for a drag environment, i.e. GOCE experience was very different from deorbiting a more conventional S/C…

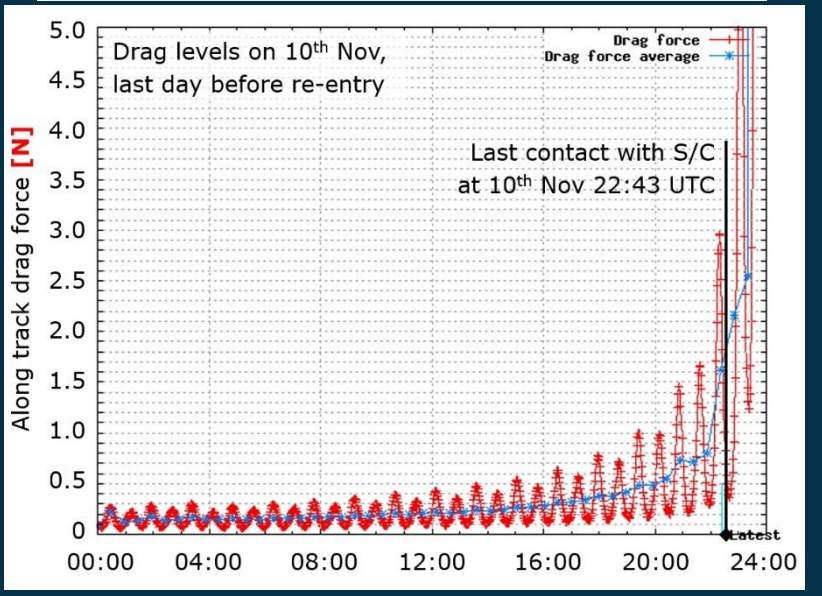
# End of Life (EoL) strategy: GOCE

Basic premise:

- Re-entry unavoidable once out of Xenon for electric propulsion (21-Oct-2013)
- S/C not designed for performing a controlled re-entry
- Objective: “[..] operate GOCE as long as possible in the decay phase, i.e. up to when [..] the performance of S/C or G/S does not allow to continue.”

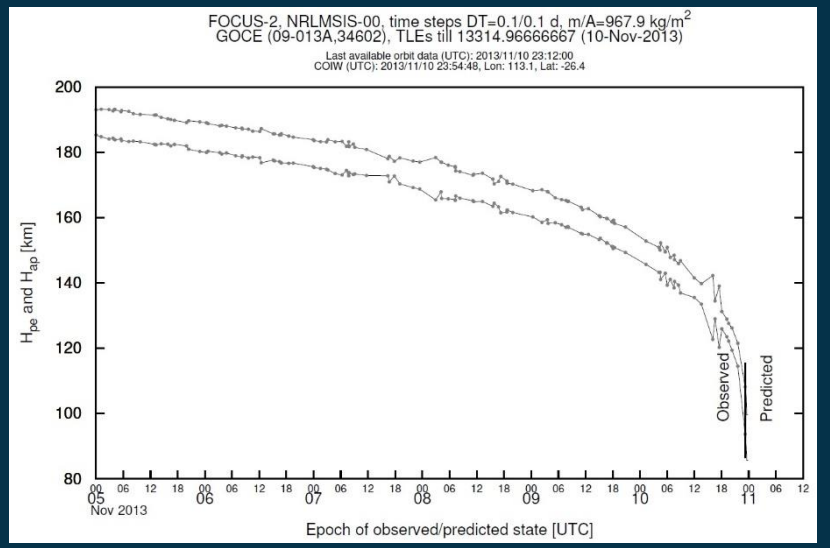
Outcome:

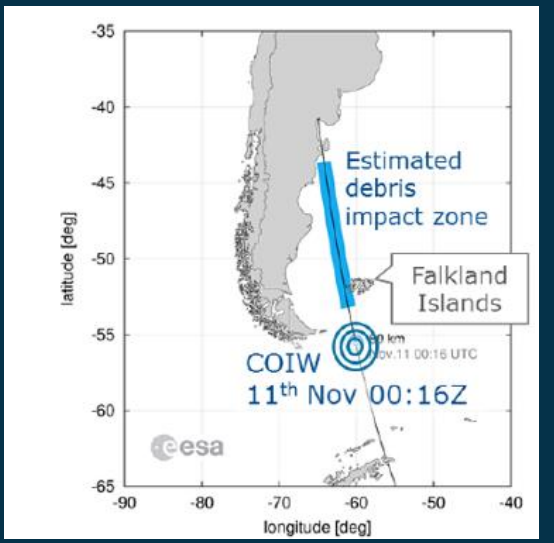
- Re-entry early on 11-Nov-2013
- S/C performance far exceeded expectations – still functional when seen at last station pass at roughly 115 km altitude, about 1.5h before break up
- S/C attitude stable thanks to passive aerodynamic stabilisation (torques induced by atmospheric drag above magnetotorquers capability)
- Stable solar/geomagnetic activity during deorbiting: no problems tracking the S/C

# End of Life (EoL) strategy: GOCE

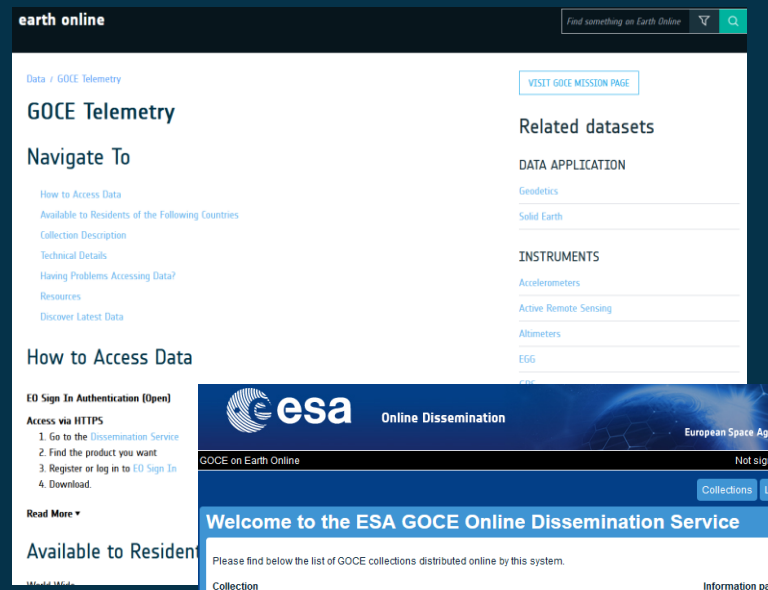
**The S/C was more aerodynamic than thought – re-entry later than expected**




# Available Data

- S/C telemetry received until approx. 115 km (S/C not passivated)
  - Thermal/power
  - Ground station tracking data
  - GPS (SSTI), Star Tracker, magnetometer and magnetorquers
  - Specifics: non conventional S/C AOCS design (drag free attitude orbit control system using acceleration data from the gradiometer payload)
- SDO/FD data:
  - TIRA tracks, DRAMA model, re-entry predictions
  - attitude and orbits from FD until the very end
- Accessible via ESA tools including a tailored re-entry data set:
  - https://earth.esa.int/eogateway/catalog/goce-telemetry
  - https://earth.esa.int/eogateway/missions/goce/goce-re-entry-dataset
  - End of Mission report, GO-RP-ESC-FS-6268



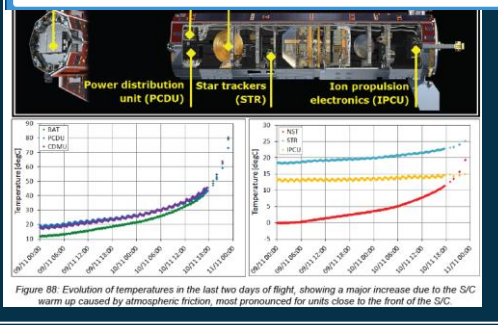
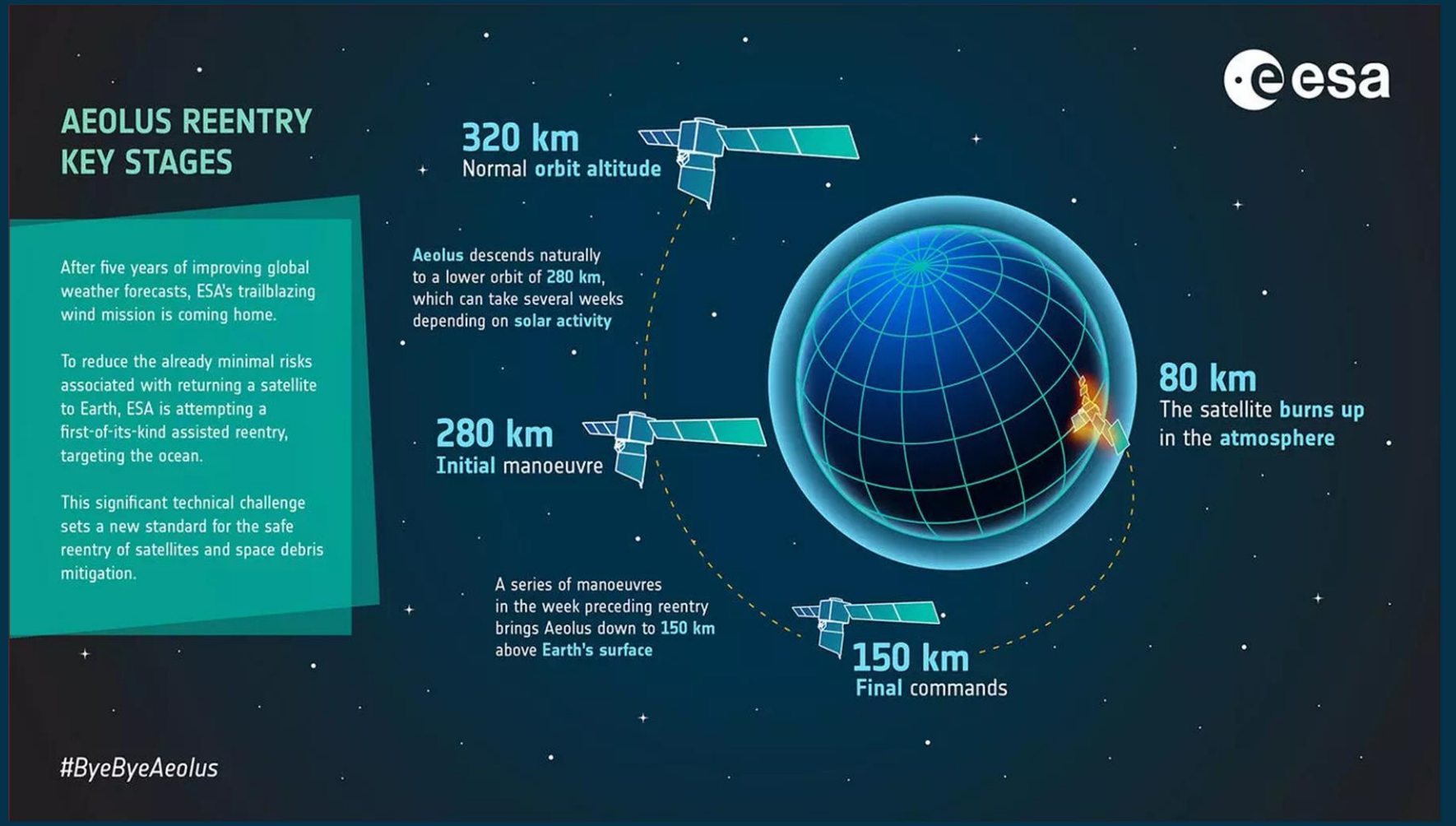




Figure 88: Evolution of temperatures in the last two days of flight, showing a major increase due to the S/C warm up caused by atmospheric friction, most pronounced for units close to the front of the S/C.

# End of Life (EoL) strategy: Aeolus

Assisted Natural Re-entry: in between controlled re-entry and uncontrolled re-entry



# End of Life (EoL) strategy: Aeolus

Basic premise:

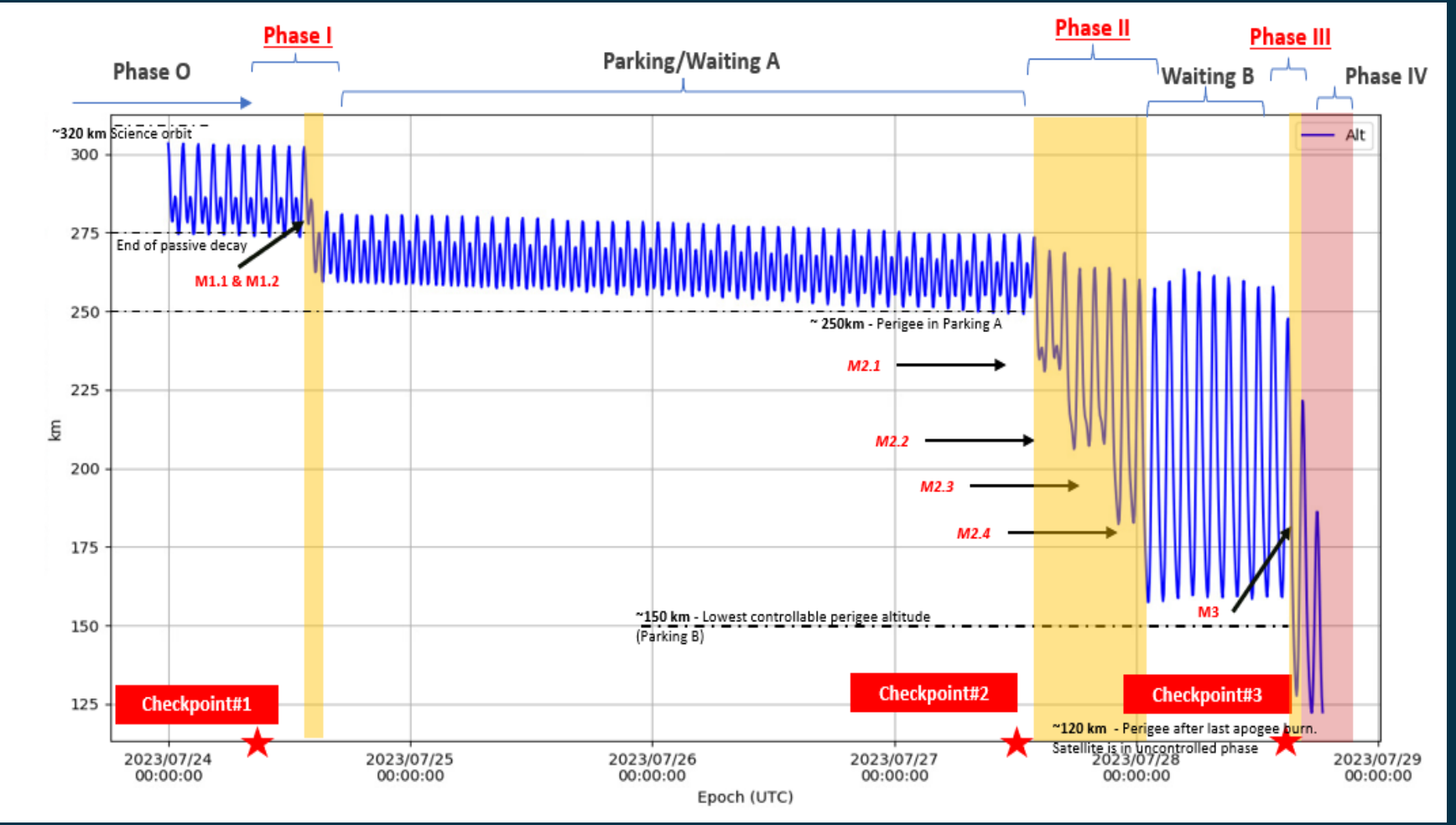
- Follow the best effort obligation to minimise the global casualty risk associated to a re-entry below the currently applicable threshold of 1/10000.
- Use the remaining fuel to deorbit the satellite and shorten the time spent in the protected LEO region after end of mission.
- Proof of concept of an assisted re-entry for a mission not designed for active re-entry operations.

Outcome:

- Re-entry on 28-July-2012 after a 4 days active manoeuvring campaign of the S/C
- A number of platform anomalies encountered on the way down & need to implement a special drag compensating attitude due to unexpected excessive thrusting at lower altitudes
- S/C passivated after the final maneouvre with a last station pass at roughly 145 km altitude, about 2.5h before break up
- Aeolus reentered within 0.23 rev. (1σ) from target location
- The global casualty risk was further reduced to 1.2·10-6, 150 better than uncontrolled and well within ESA's Policy

# End of Life (EoL) strategy: Aeolus

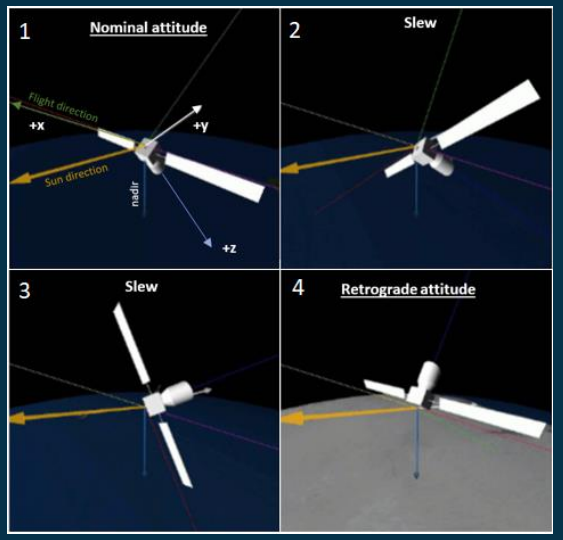
Assisted Natural Re-entry: in between controlled re-entry and uncontrolled re-entry

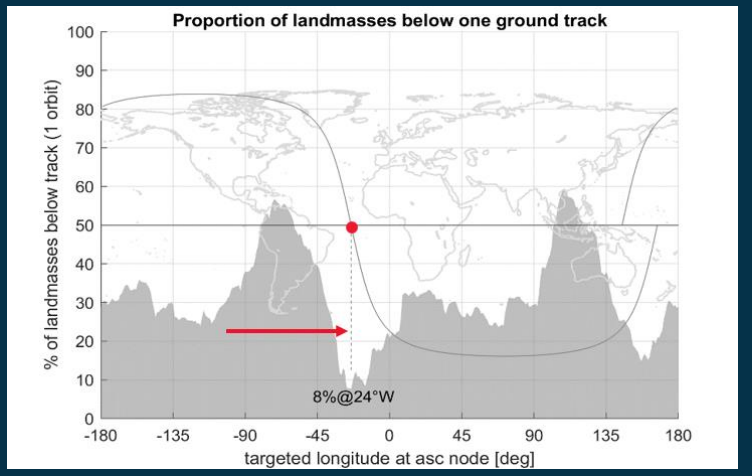


# End of Life (EoL) strategy: Aeolus

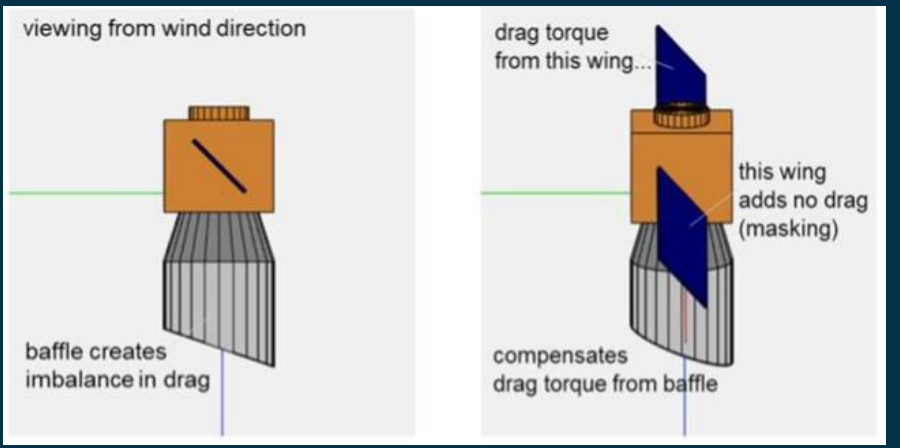
## Challenges

- Moving start date of the active re-entry phase
- Execution of the large retrograde manoeuvres (never done in-flight, max. delta-v = 3m/s)
- GPS convergence after large manoeuvres
- Nominal attitude control until 250 km perigee and need to activate so called Equilibrium Attitude
- Behaviour of the thruster control mode (TCM)
- Atmosphere density models as expected?
- Retrieval of final telemetry recorded data for final Orbit Determination
- Will it reenter as we expect?




[Credit: Airbus]

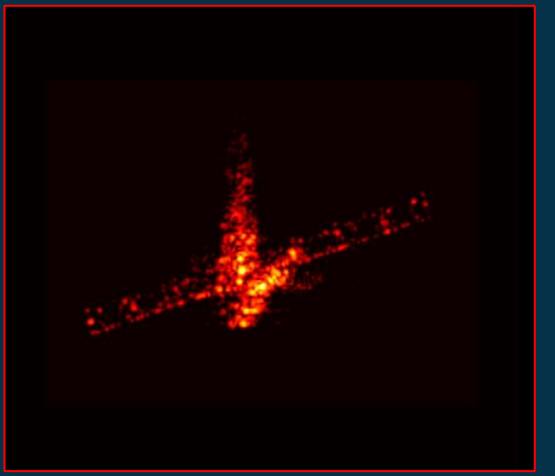



[Credit: Airbus]

# End of Life (EoL) strategy: Aeolus

Final phase of re-entry

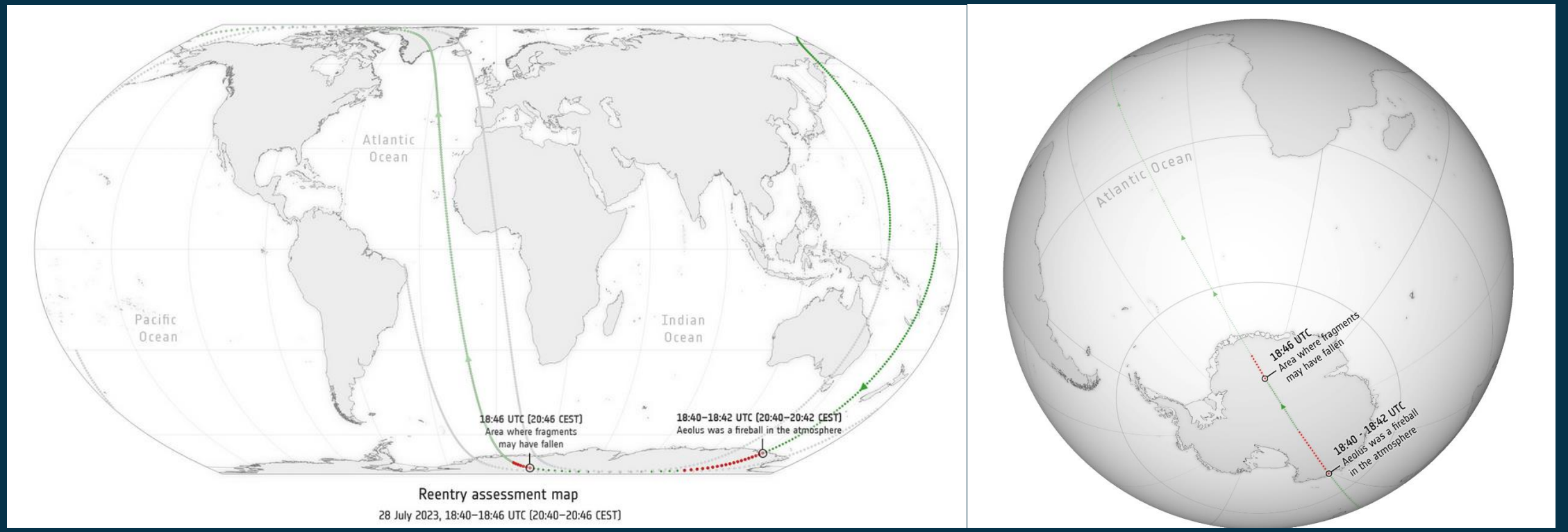
- last real-time telemetry received @15:10z and last telecommand executed time-tagged @15:43z - 28th July 2023
- Transition to Space Debris Office Coordination (SDO)
- TIRA from the Fraunhofer Institute for the High Frequency Physics and Radar Techniques (Germany) could observe the satellite after the last contact and following the last M3 burn
    - S/C confirmed tumbling after passivation
    - < 1 second time offset vs Flight Dynamics computed orbit
- New Orbit Determination was possible and allowed SDO to perform a preliminary reentry prediction for 18:48UTC already at 17:19 UTC and very close to final location



[Credit: Fraunhofer Institute]

# End of Life (EoL) strategy: GOCE

**USSPACECOM confirmed reentry @18:46 UTC 28th July 2023 over Antarctica close to entering the Atlantic Ocean on the predicted corridor**



# Available Data: Aeolus

- S/C temeletry received until approx. 150 km (S/C was passivated)
  - Ground station tracking data
  - Thermal/power
  - GPS, Star Tracker, magnetometer, Reaction Wheels were switched off below 250km
  - S/C was tumbling in it‘s final stage (not available in direct S/C TM)
- SDO/FD data:
  - TIRA track after last manoeuvre, DRAMA re-entry model, FD orbit and manoeuvre information and calibration
- Currently available via ESA internal tools and ESA internal reports. Please reach out in case of interest.

# Available Data: general

- What S/C data would the re-entry community be interested in that could be collected across past & future missions?
- How to generalize the data across missions (if possible and sensible)?
- What example data from the two presented missions would you be interested in?

| | GOCE | Aeolus |
|---|---|---|
| **Re-entry dynamics** | X | X |
| **Thermal data** | X | X |
| **AOCS data** | X | X |
| **Drag profiles** | X | |
| **Re-entry predictions** | X | X |
| **Flight Dynamics attitude and orbit data** | X | X |
| **What else?** | … | … |

# Thank you

## Contact:

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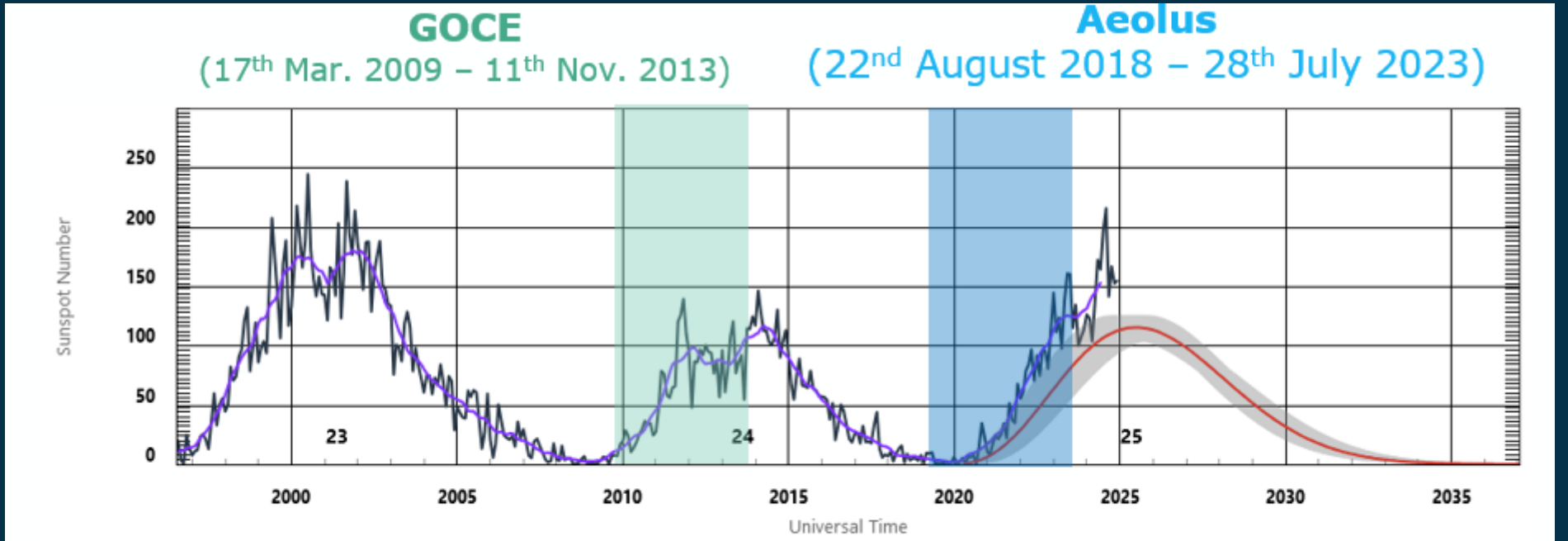
# EXTRA




*Observed and predicted Solar Cycle*

*Source: https://www.swpc.noaa.gov/products/solar-cycle-progression*