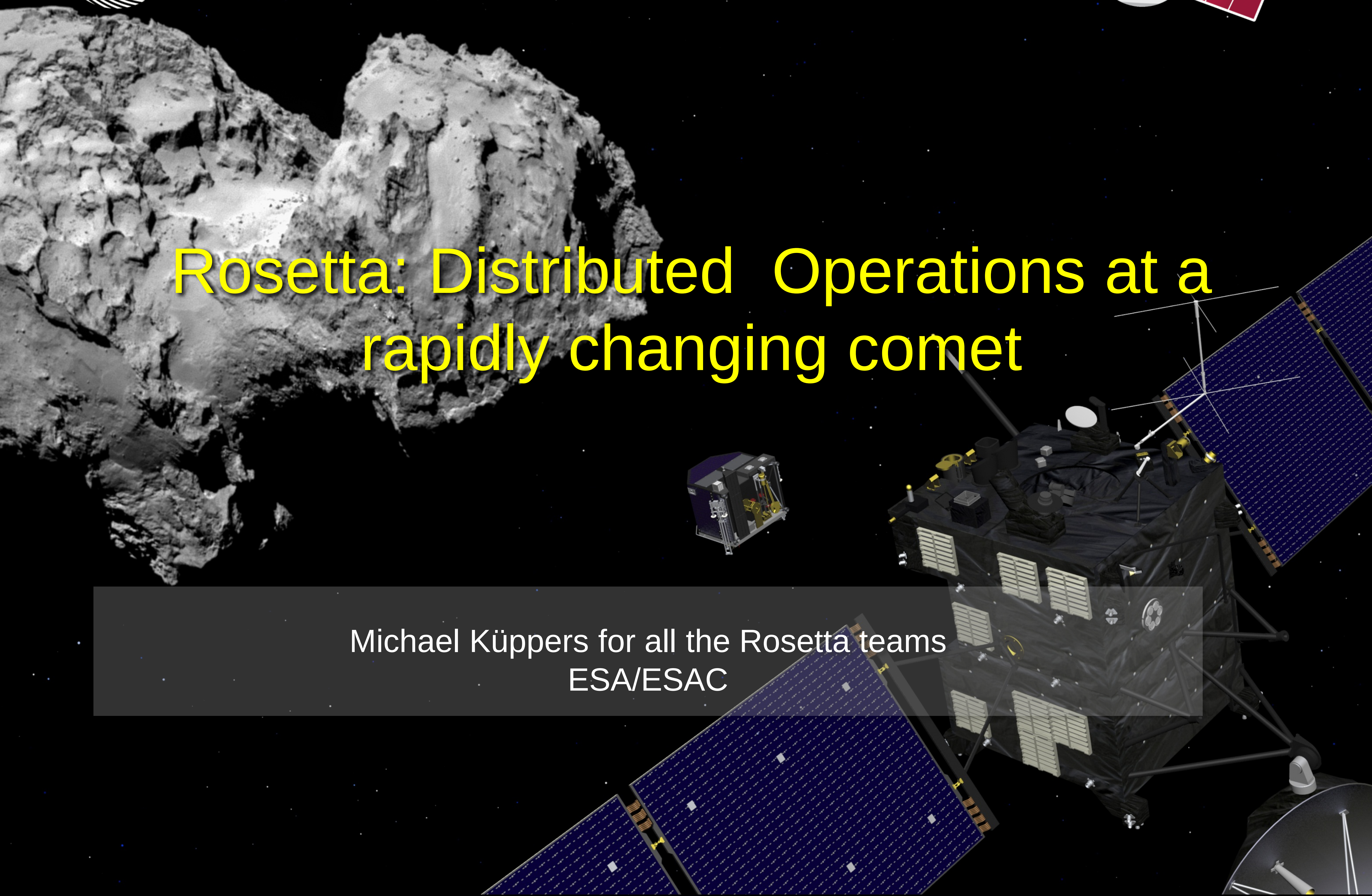
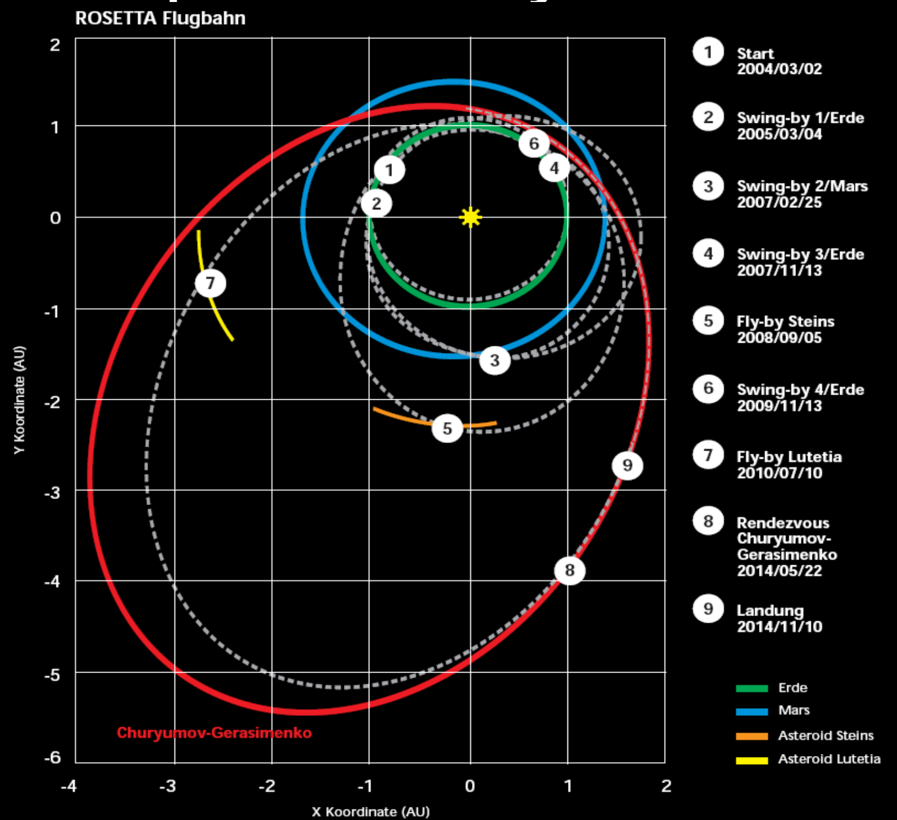


Rosetta: Distributed Operations at a rapidly changing comet

Michael Küppers for all the Rosetta teams
ESA/ESAC

Rosetta Firsts: An exploratory mission

- First rendezvous with a comet
  - ❑ First spacecraft in the inner coma of a comet
- First landing on a comet
  - ❑ Requires quick exploration of the cometary environment to prepare for landing
- Largest heliocentric distance (at the time) for a solar-powered spacecraft
  - ❑ Huge solar panels increase sensibility to cometary environment
  - ❑ Required 2.5 years hibernation



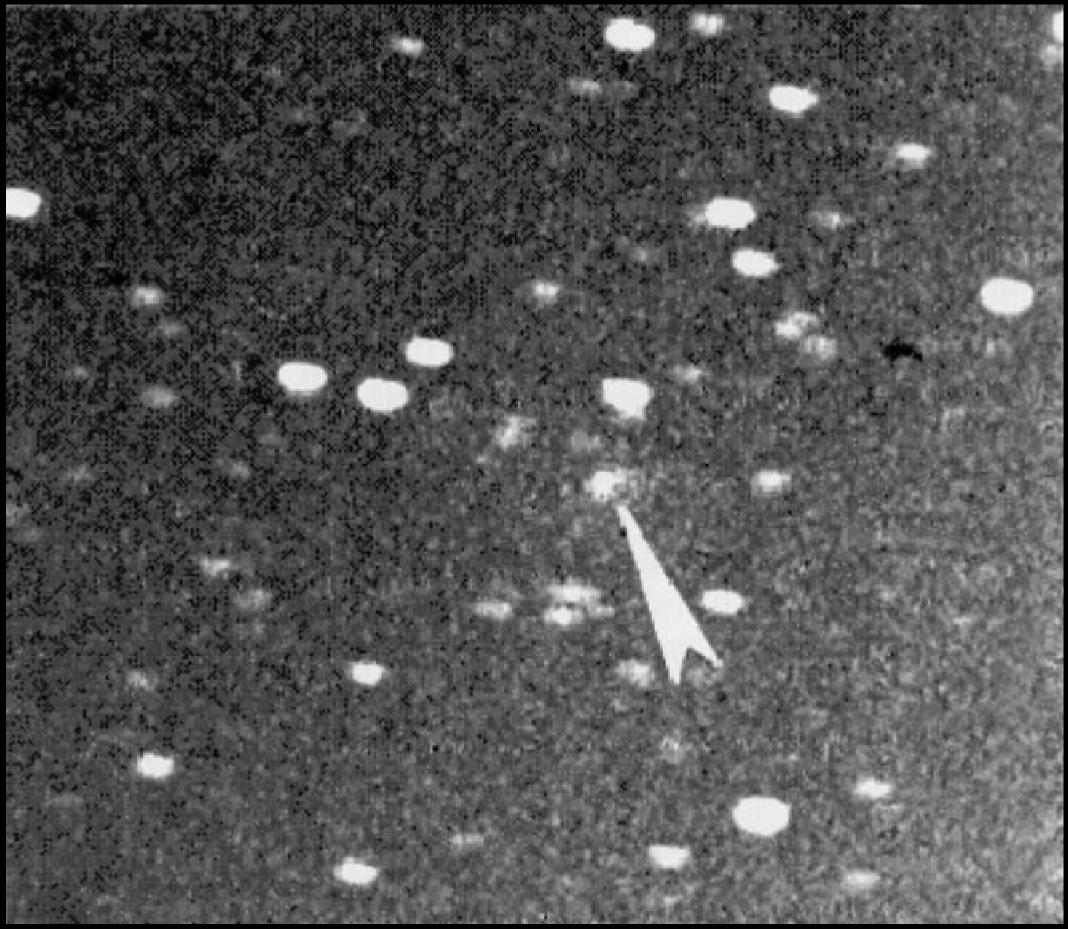
Topics

- Knowledge of the comet before arrival at Rosetta
- Rosetta distributed ground segment
- Rosetta Ground segment
- Preparation for landing
- Long-lead planning of operations in a dynamic environment
- The accident
- Short-lead planning of operations in a dynamic environment
- End of mission
- Conclusion

Knowledge before arrival: Orbit and Spin

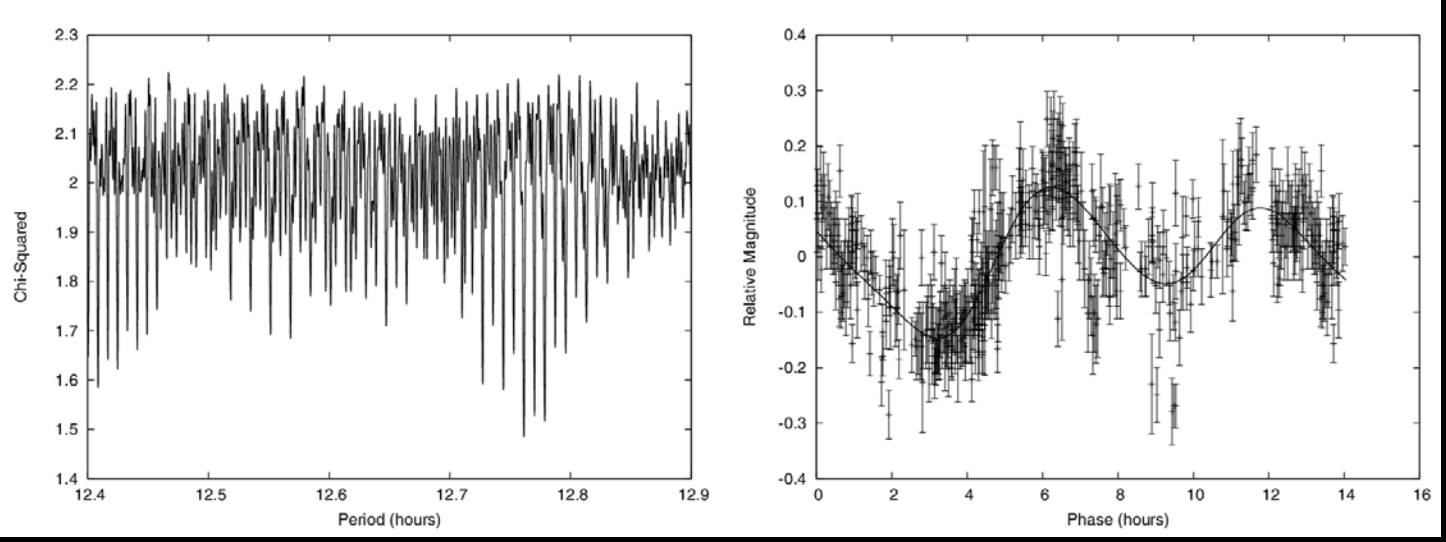
- **C/G was observed on 7 perihelion passages from 1969 to 2008**
  - ❑ **Trajectory well known**
- **Spin period measured before 2008 perihelion**
  - ❑ **Period may (and did) change during perihelion**
- **Direction of spin axis approximately known**

Discovery image of comet C/G in 1969

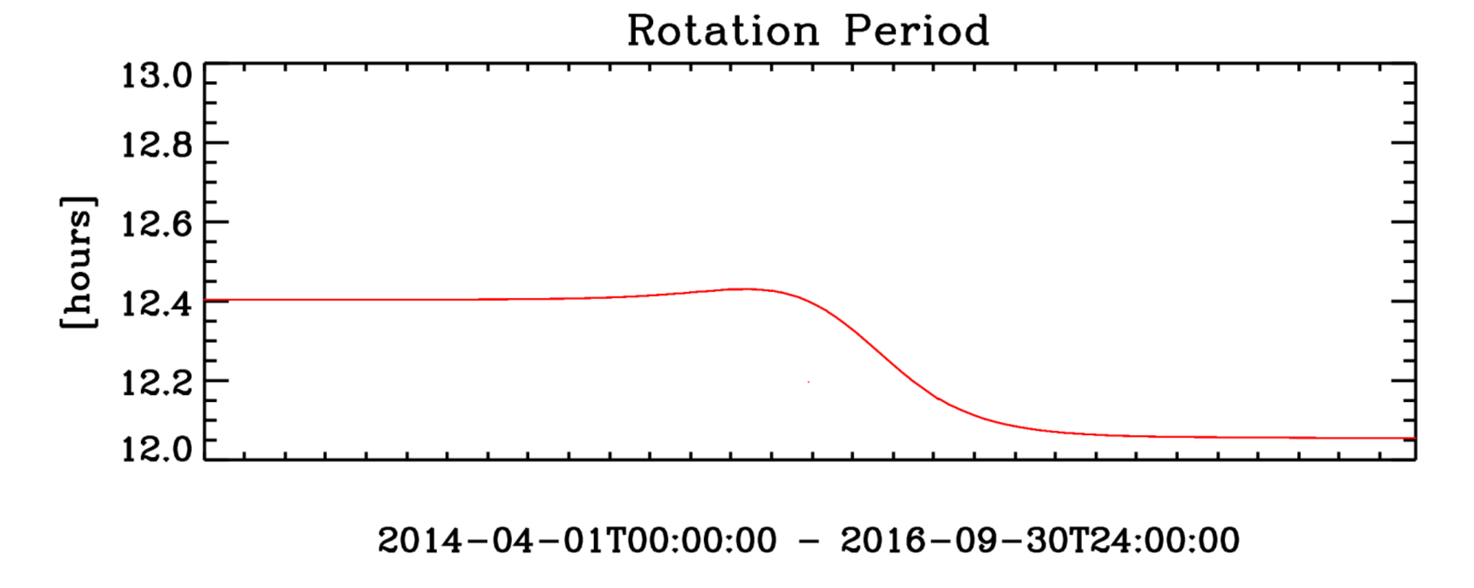


Taken from Lamy et al. 2006

12.76 hour period from data taken in 2006/2007



Taken from Lowry et al. 2012



Measured spin period vs. time by Rosetta

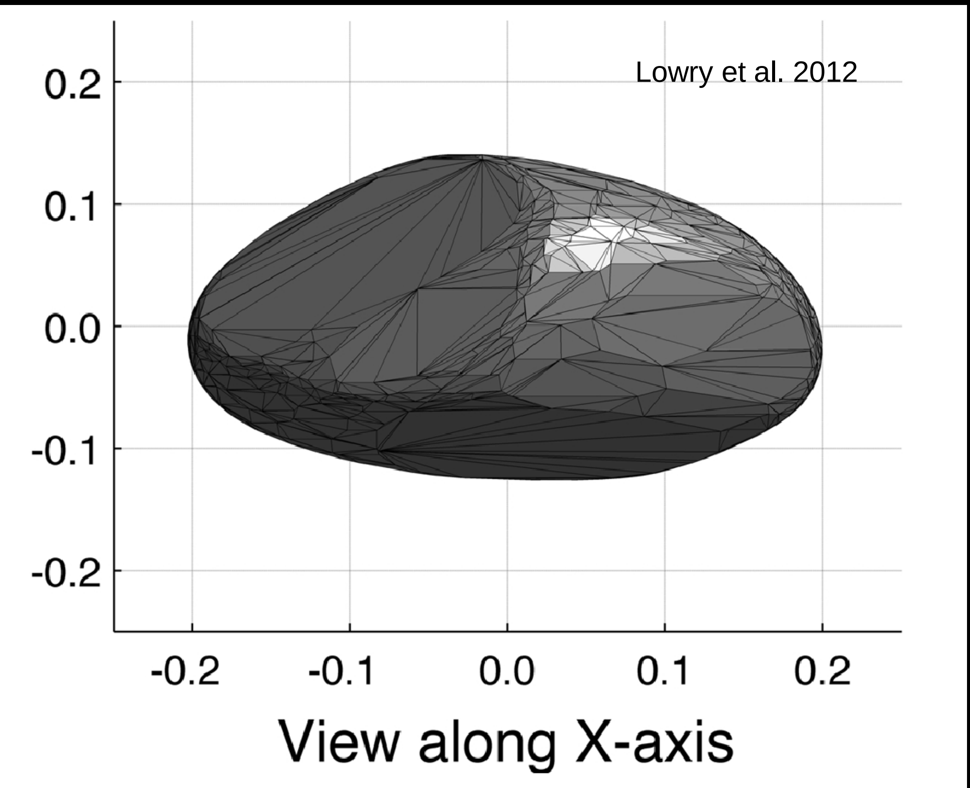
- ❑ **Decreases by approx. 20 minutes/orbit**

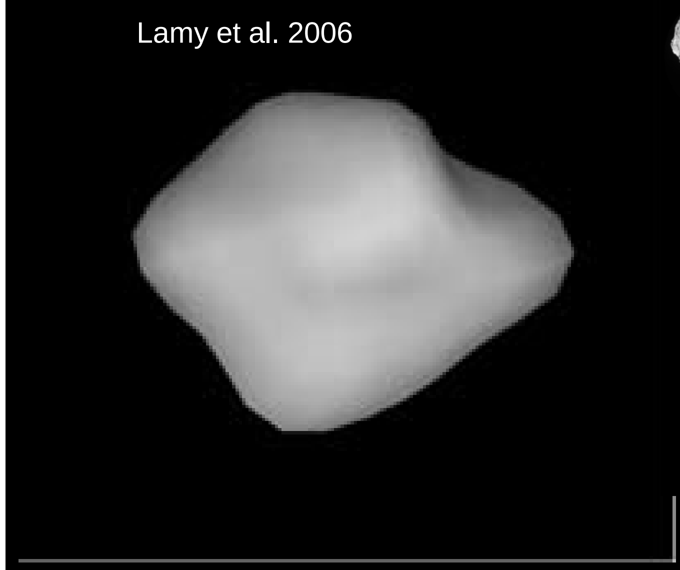
Knowledge before arrival: Size, Shape, Volume, mass, density

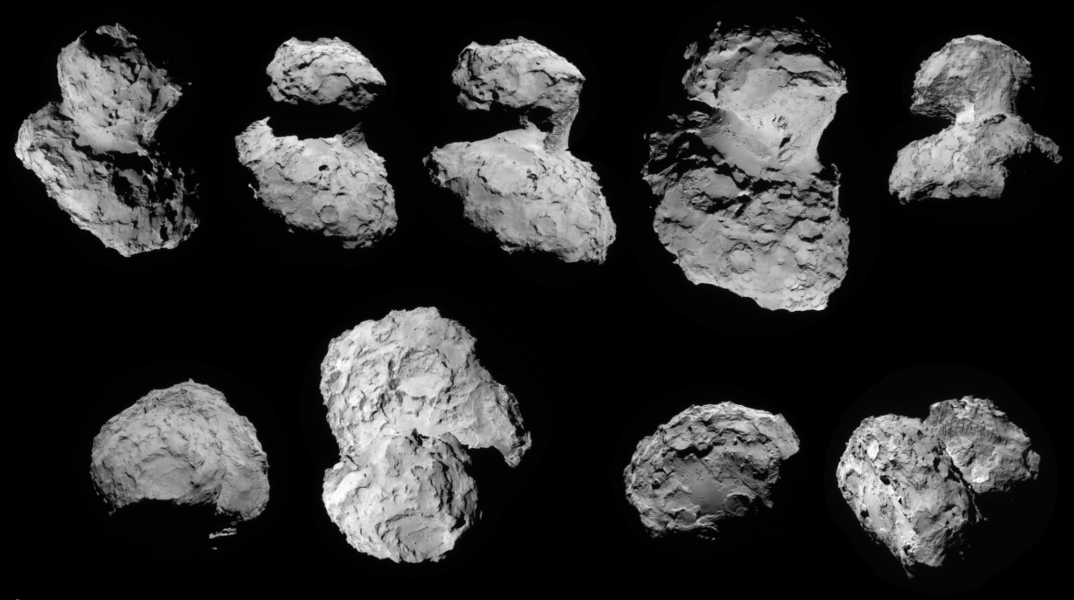
- Size (radius ~ 2km) determined from HST and groundbased observations
- Shape from remote observations not unique (unknown)
- Mass determined from non-graviational forces
- Volume overestimated from inaccurate shape => density underestimated

Models

Rosetta at C/G



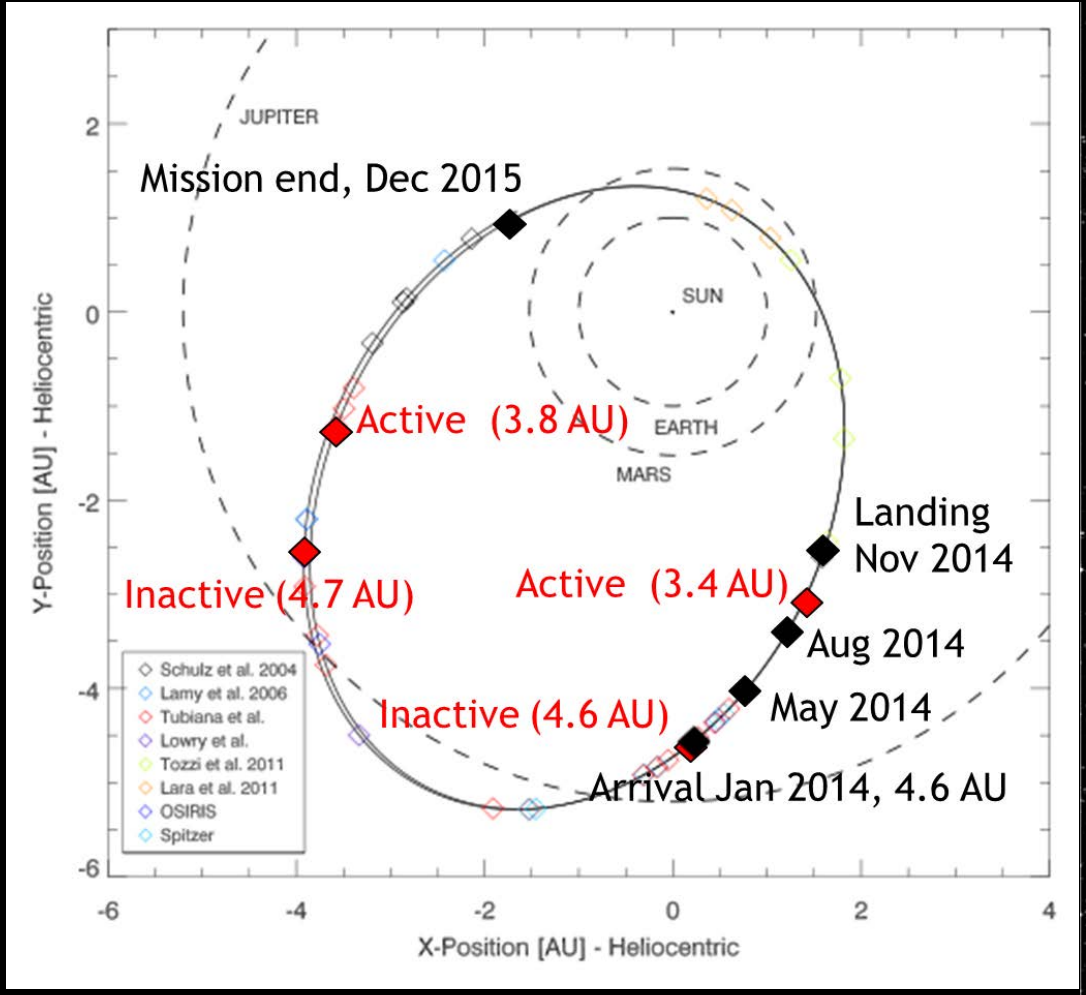




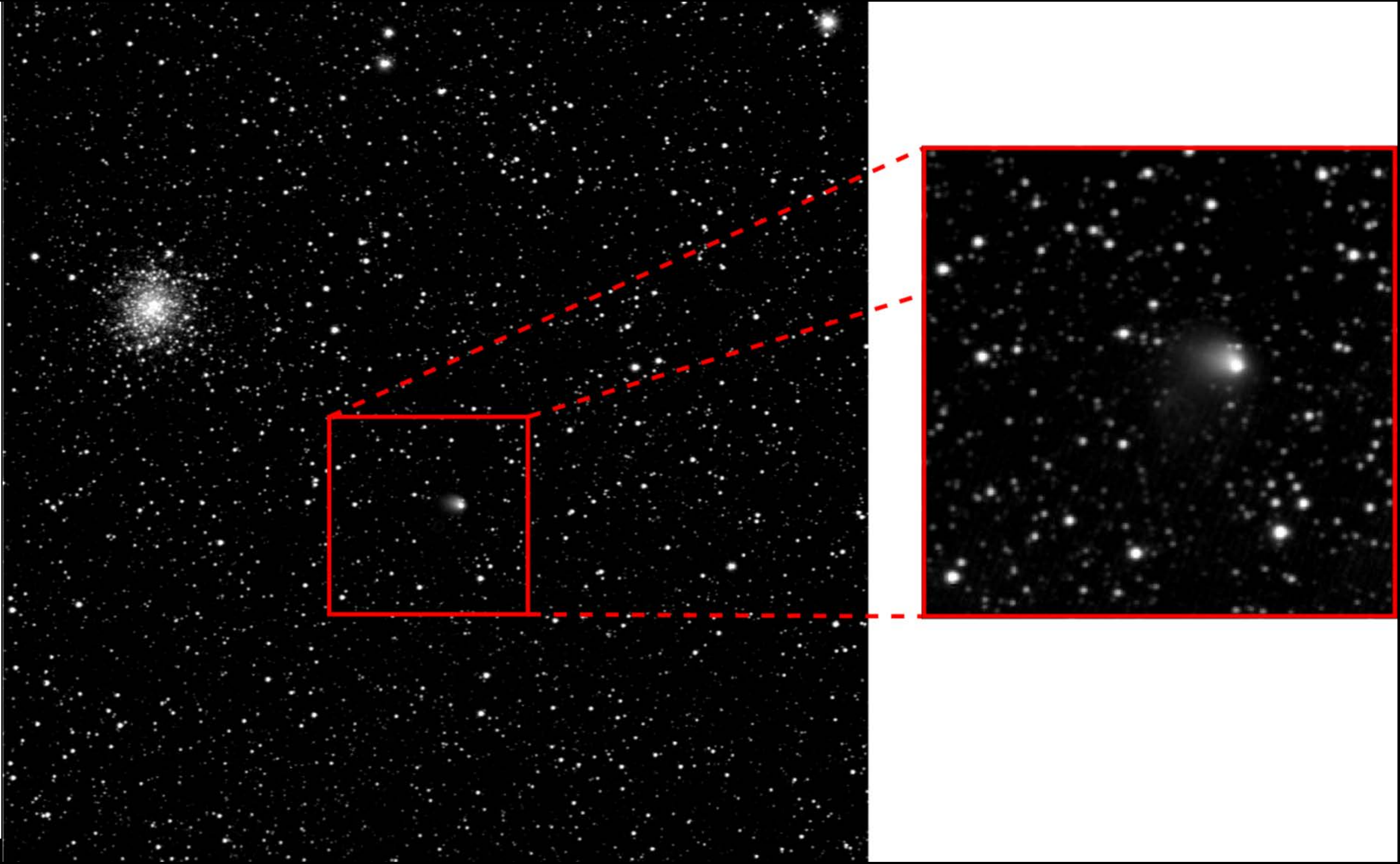
Knowledge before arrival: Activity

- Observations between selection of comet C/G for Rosetta (2003) and arrival provide global dust and gas activity over orbit
- Conditions in the inner coma, where Rosetta was expected to spend most of the time, were laregely unknown

Activity over orbit from groundbased observations

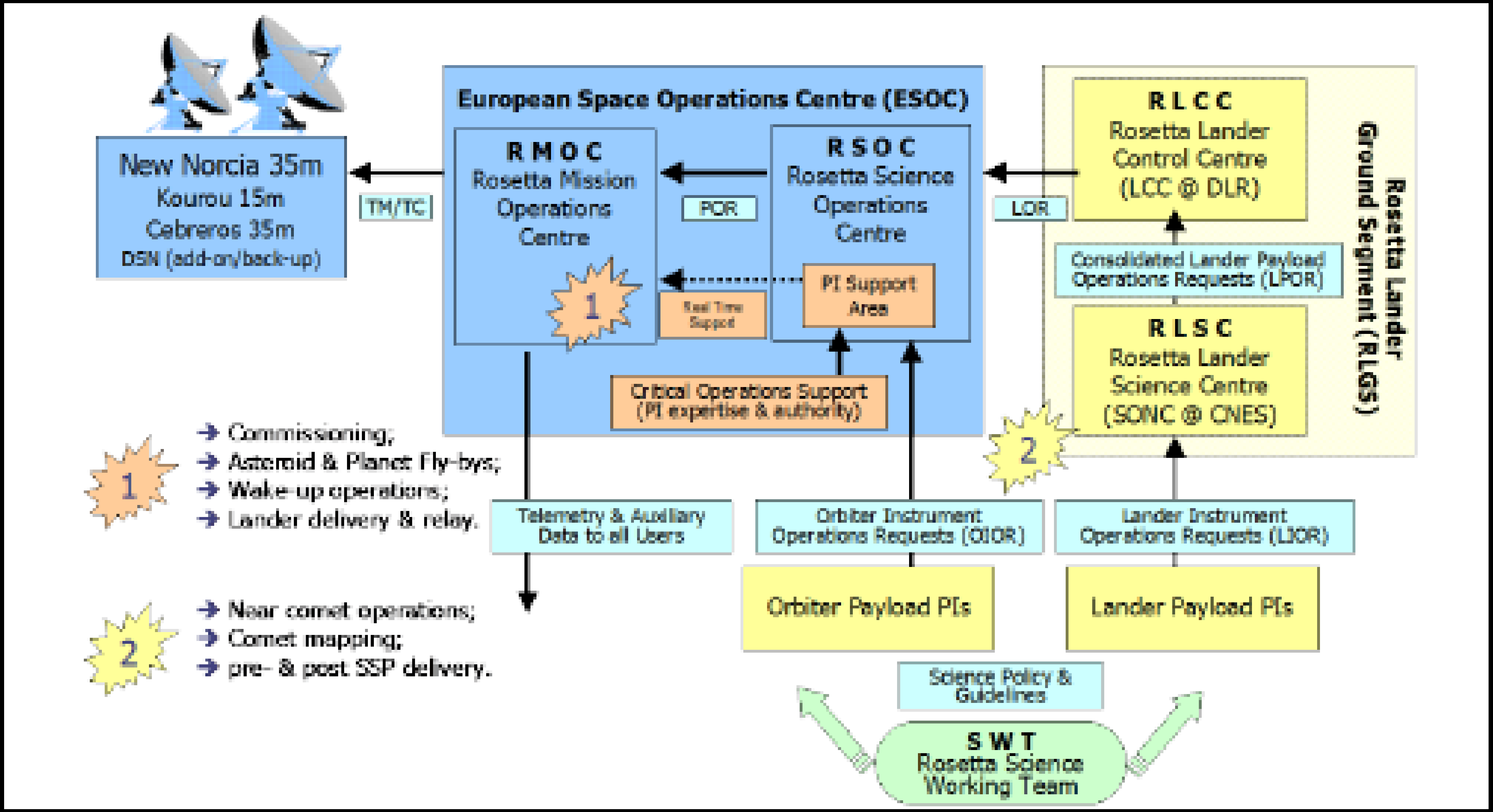


Cometary outburst seen by OSIRIS on 30 April 2014, at 4.1 AU from the sun



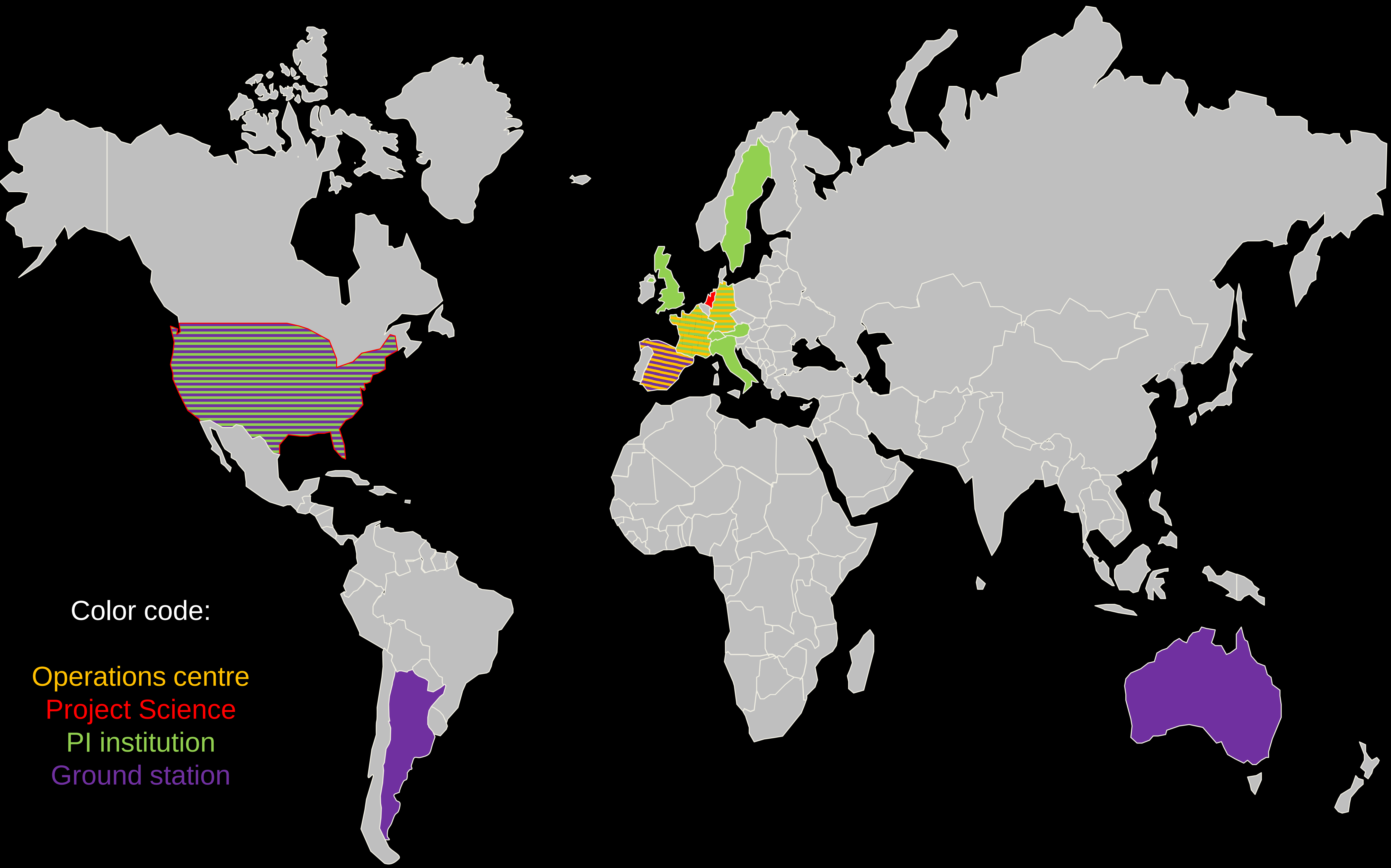
Source: C. Snodgras

Rosetta Ground Segment



Taken from Mission Implemantation Plan

Distributed ground segment



Color code:

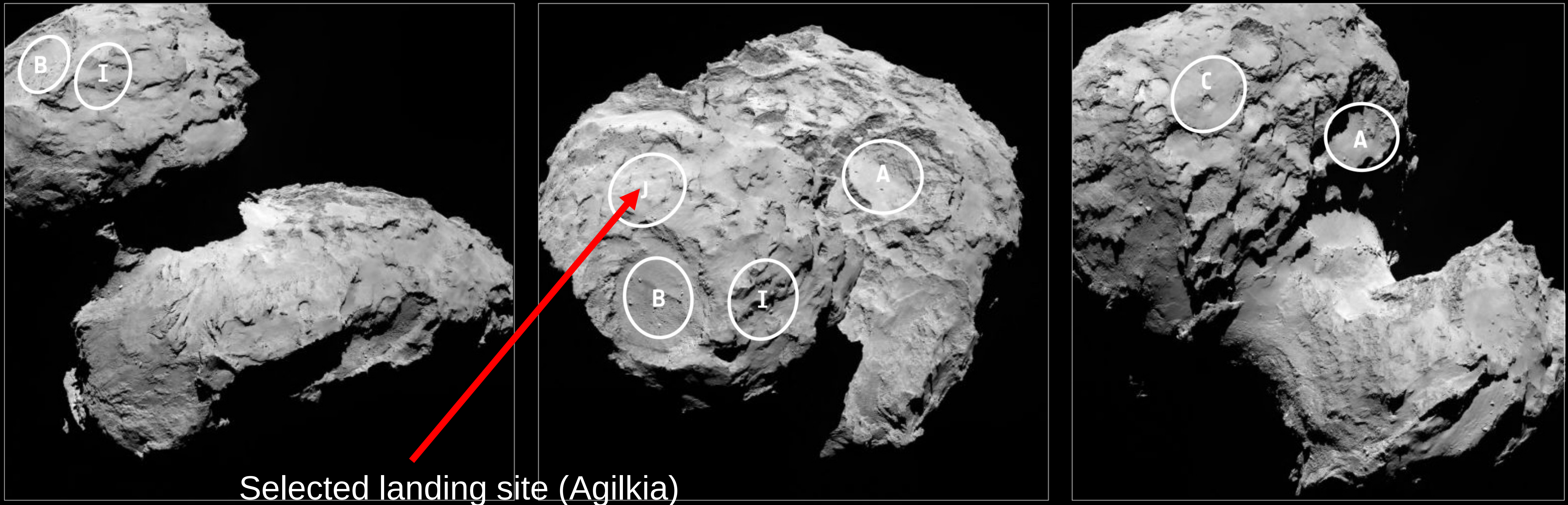
Operations centre
Project Science
PI institution
Ground station

Arrival: Mapping the nucleus to find a spot for the lander

- Initial characterisation from 50-100 km
- Global mapping from 30km
- Close observtation from 10-20 km
- Data processing as fast as possible for landing site selection

All this was prescribed by mission operations as prelanding was an engineering phase

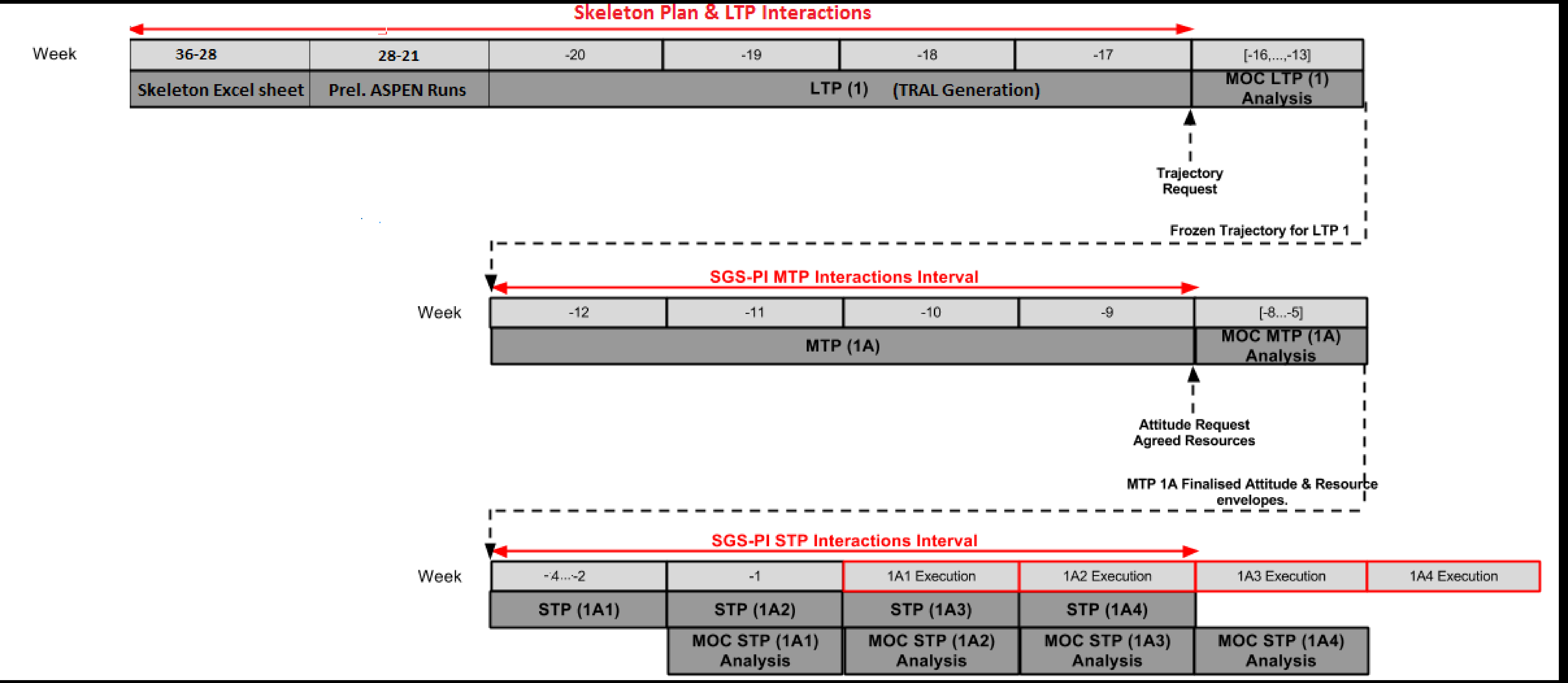
Landing site candidates



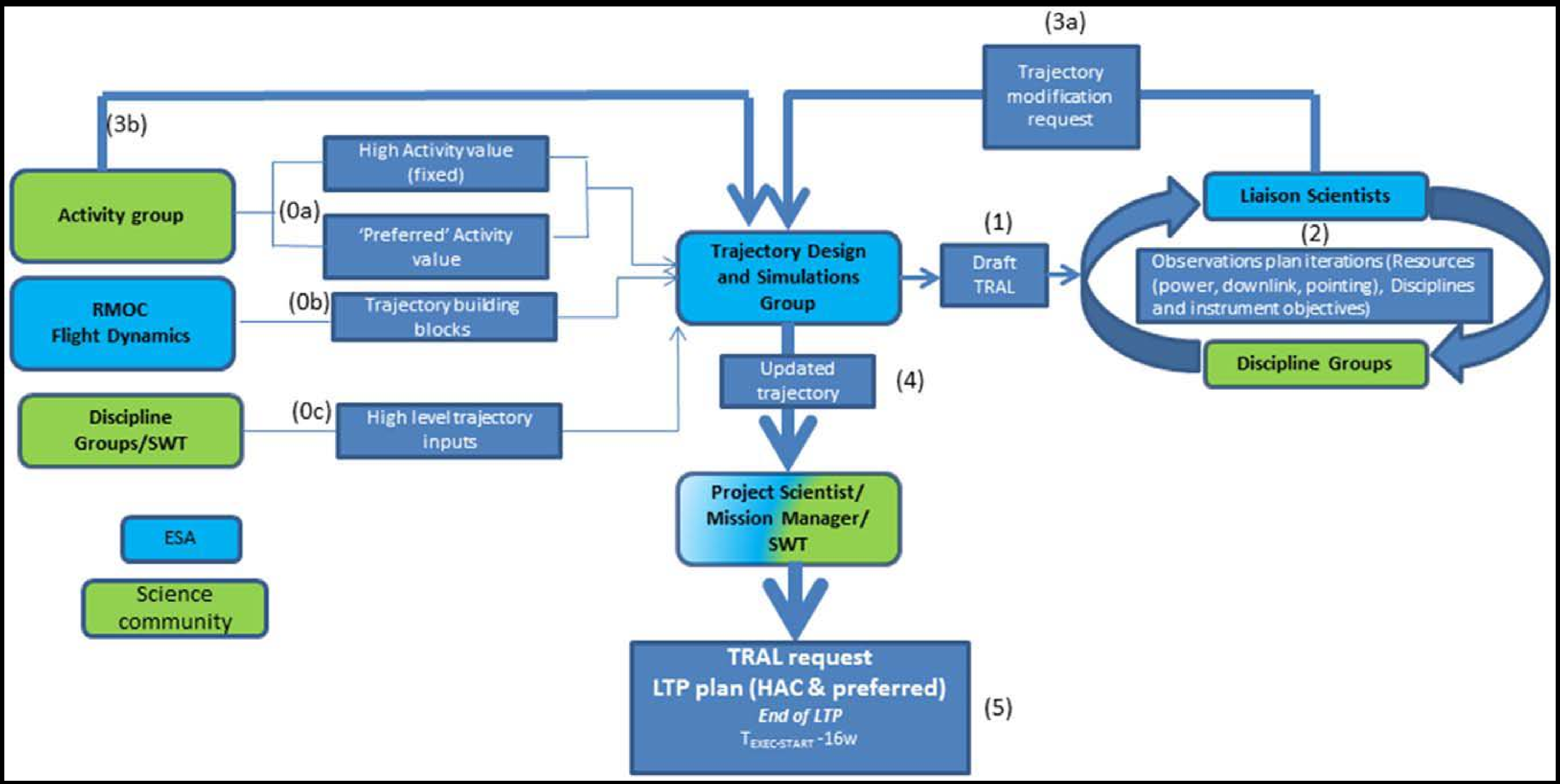
Rosetta landing

Rosetta operations after Philae landing

- Spacecraft trajectory fixed 4 months before the start of a 4 month period
- Spacecraft attitude fixed 8 weeks before the start of a 4 week period
- Commanding fixed 1 week before the start of a 1 week period

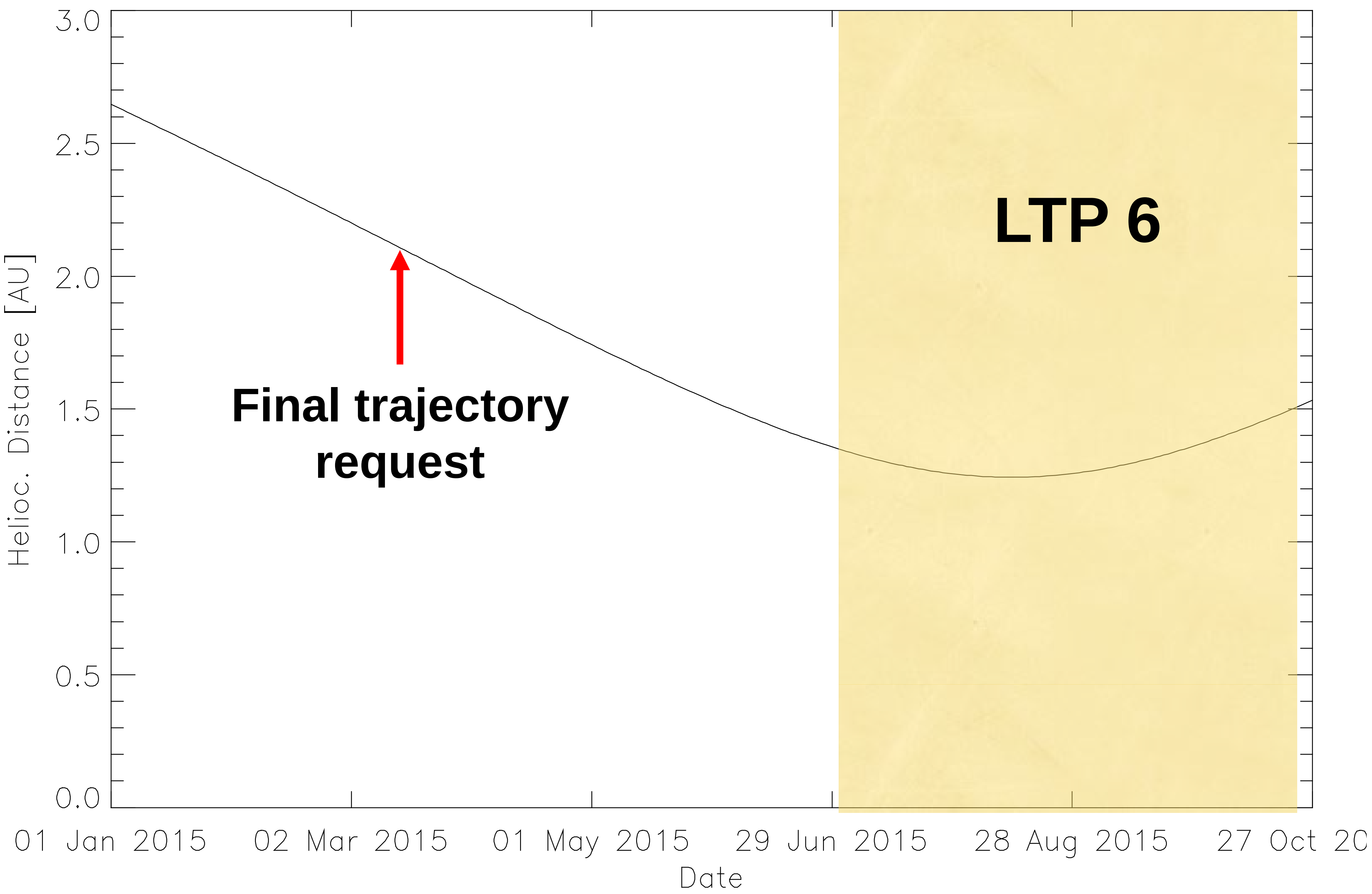


LTP high level planning



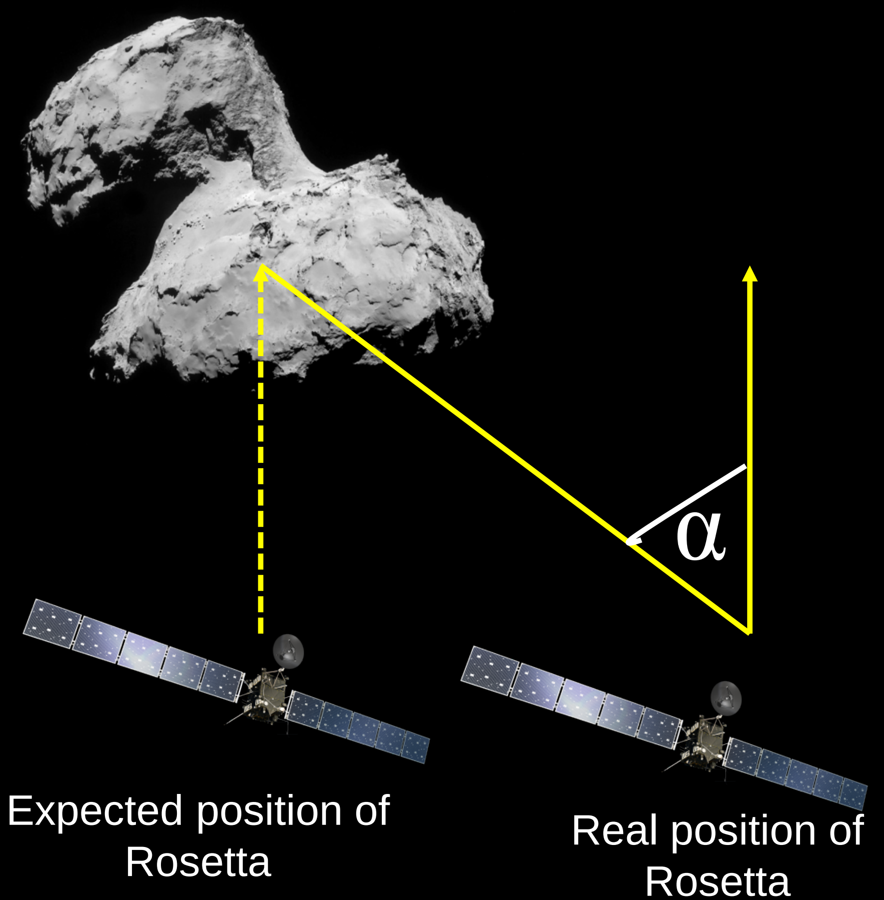
Source: Vallat et al., Acta Astronautica

Heliocentric orbit vs. planning cycle

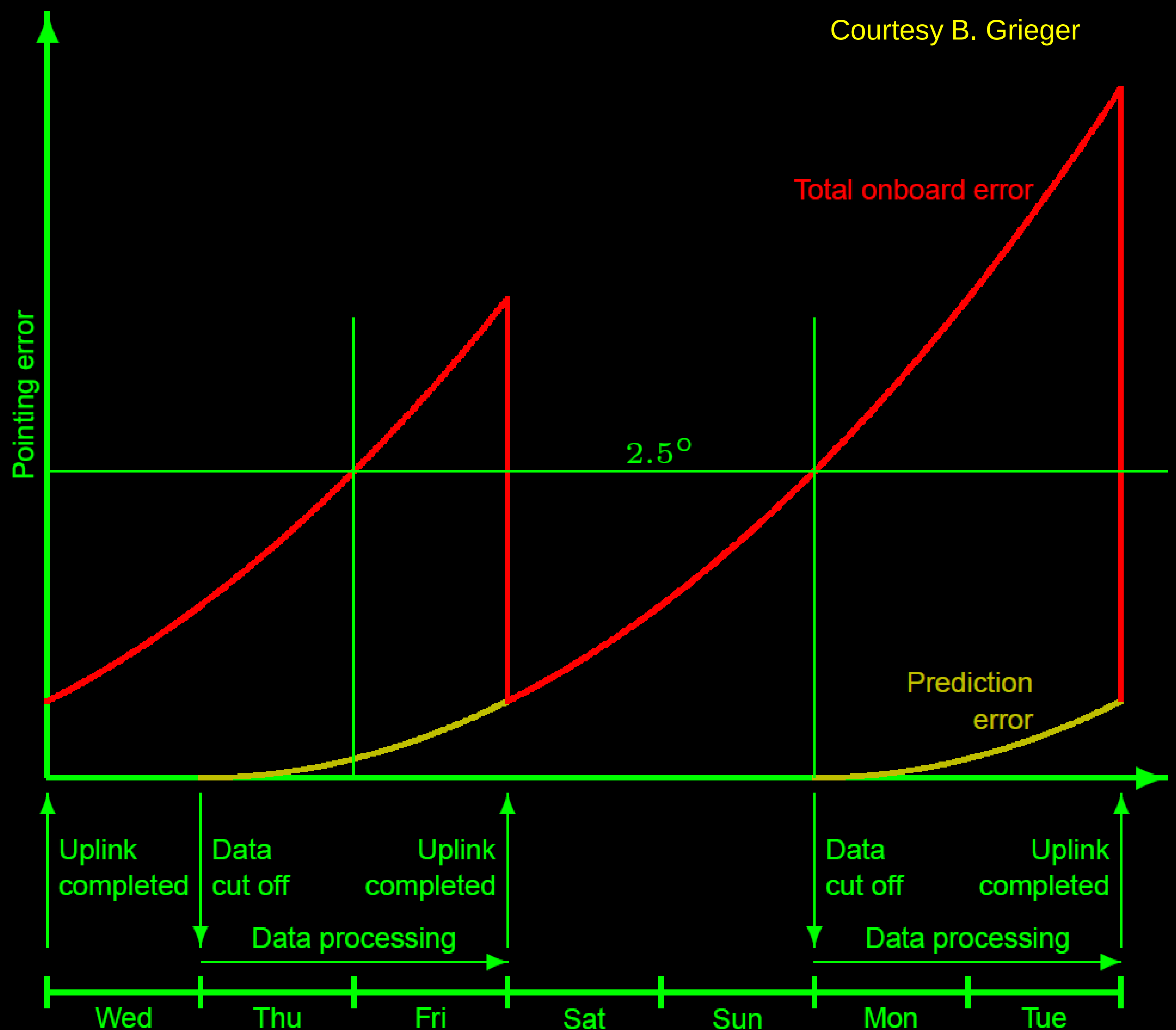


Expected limitations of trajectories: pointing error

- Trajectories are to be defined according to science goals
  - ❑ But which trajectories can be flown under increasing comet activity? The limit is that the position (or comet pointing) error needs to be small enough so that Rosetta can be navigated – that's what we thought……

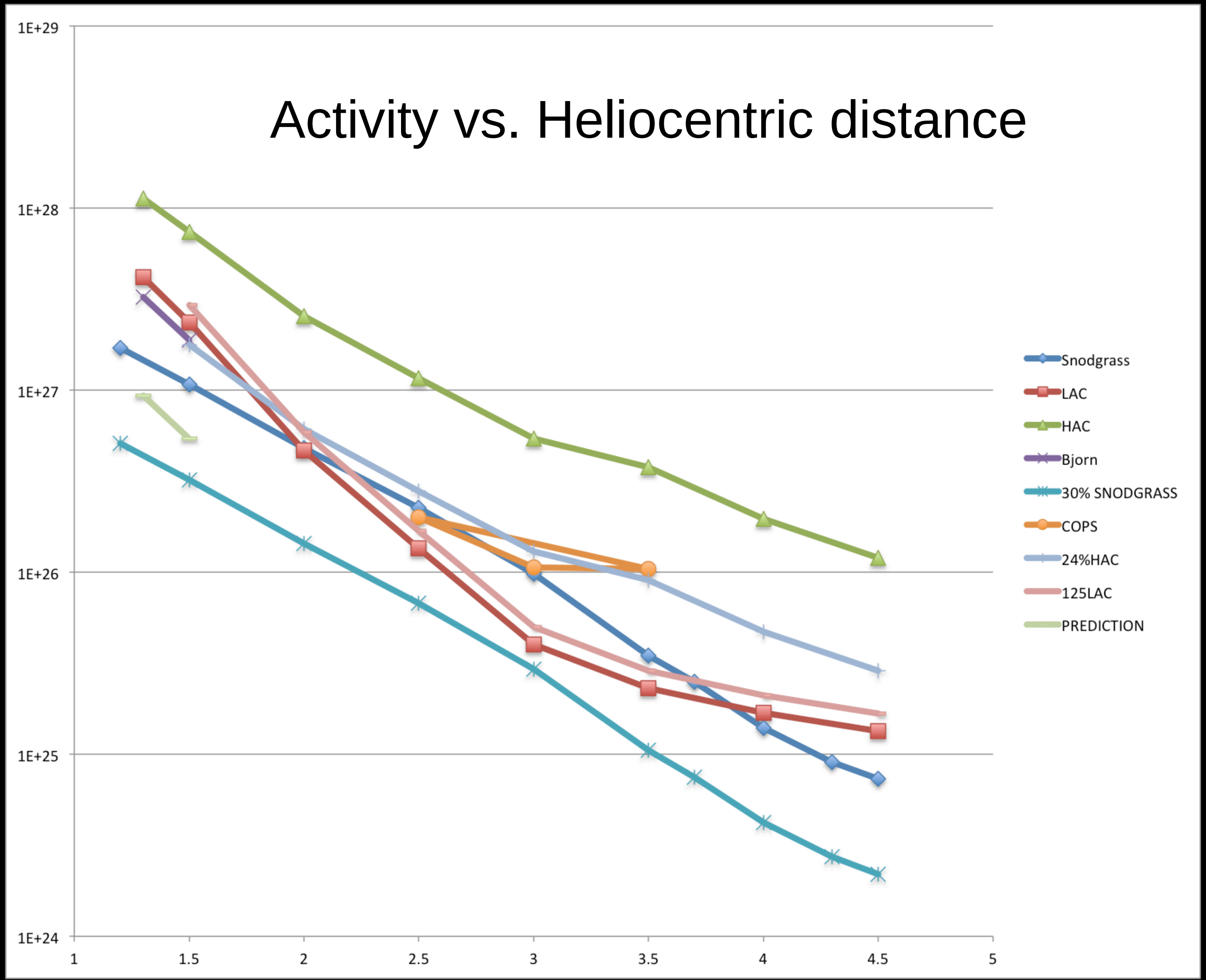


α: Pointing error

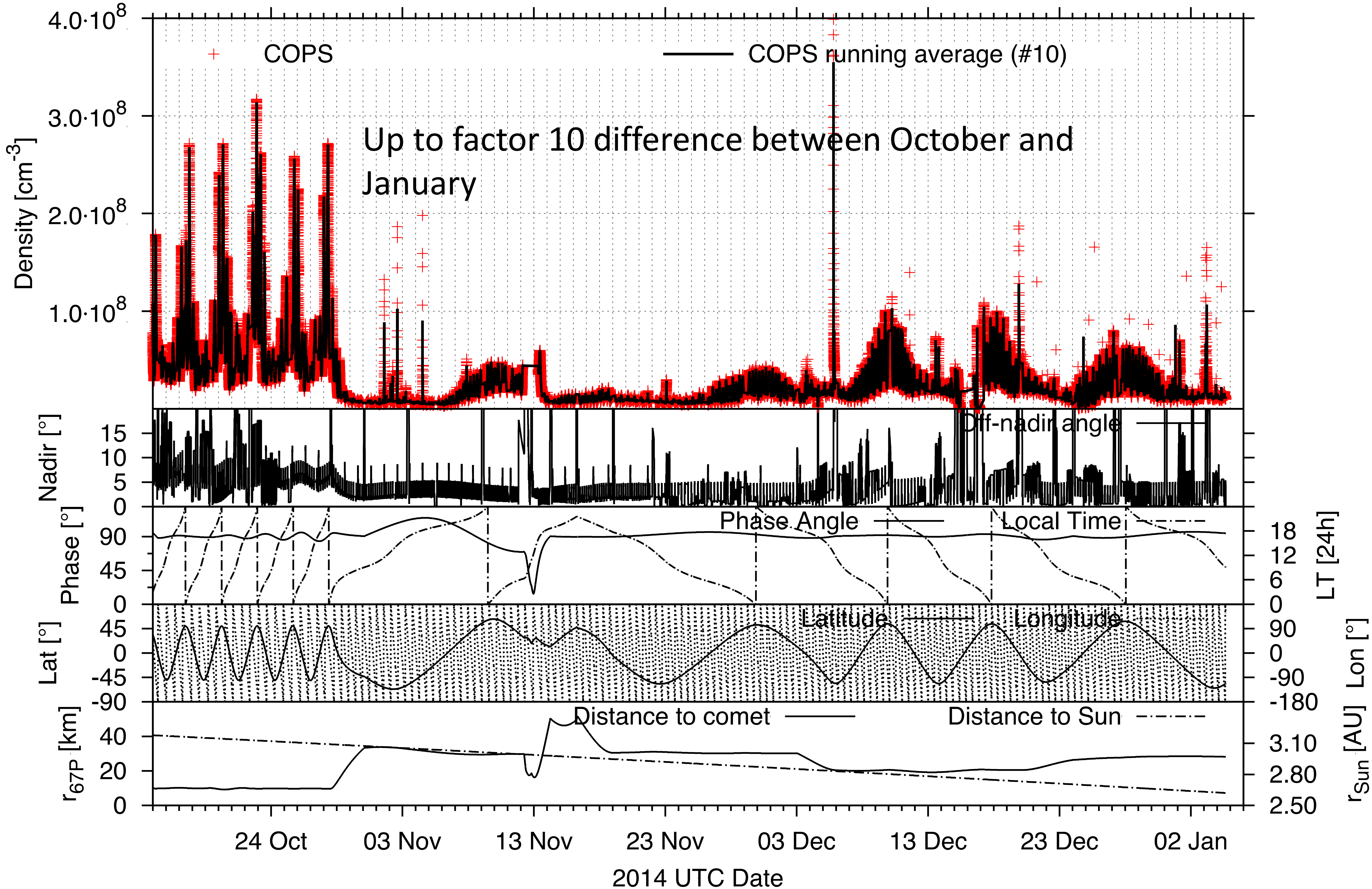


How to estimate pointing error?

- Pointing error depends on manoeuvre error and predictability of comet activity
  - ❑ How to predict comet activity (and its predictability) several months in advance?
  - ❑ "Solution": Define a best guess "preferred case" to be flown and a pessimistic High Activity Case as fallback
- A working group of experts was established to define the preferred case



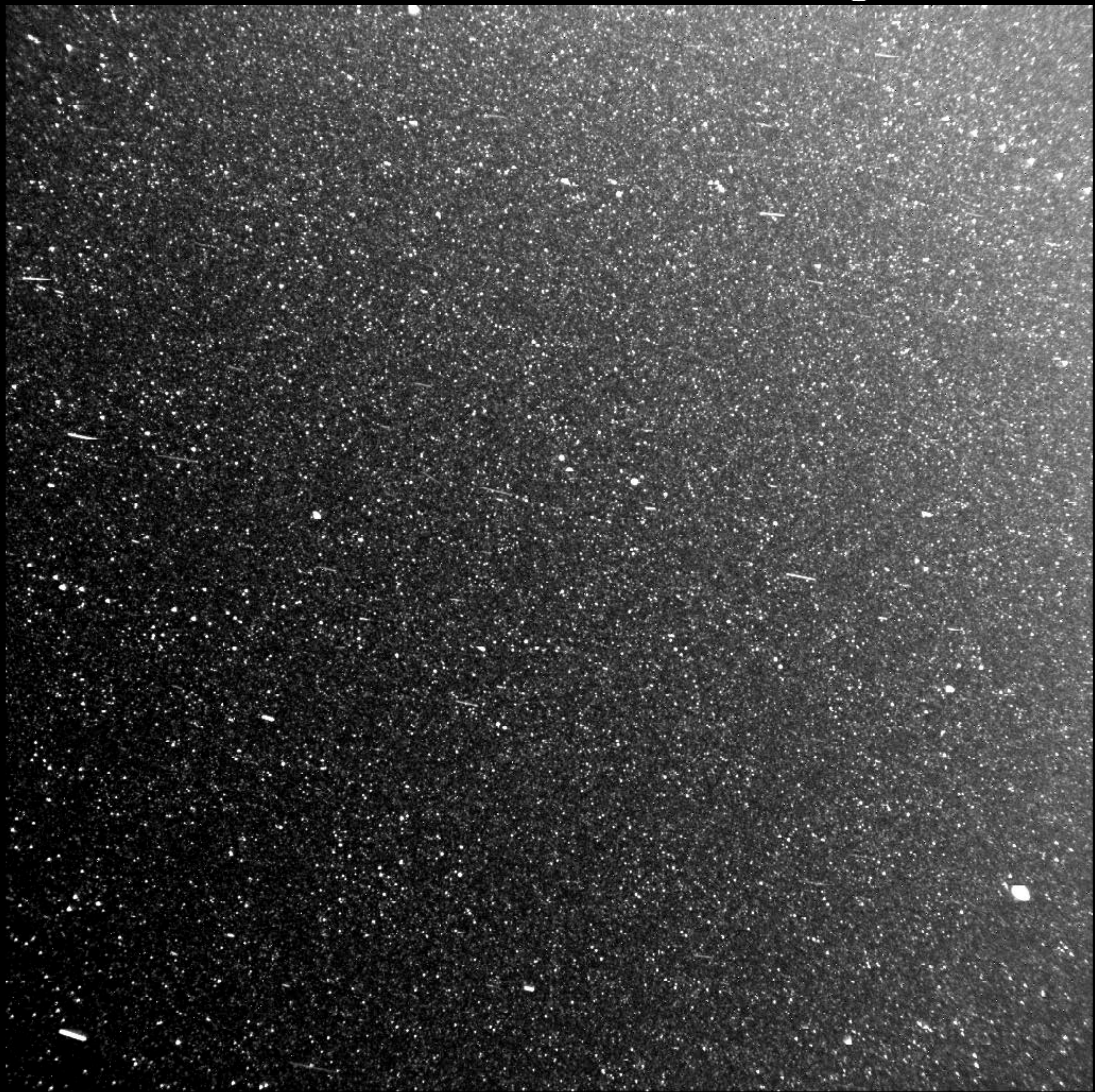
Are the trajectories too conservative?



The 28 March 2015 flyby

- While more demanding trajectories were discussed, the spacecraft entered safe mode during a close flyby
  - ❑ Close to loss of attitude control
  - ❑ Problems already during previous flyby
- What had happened?

Star tracker image

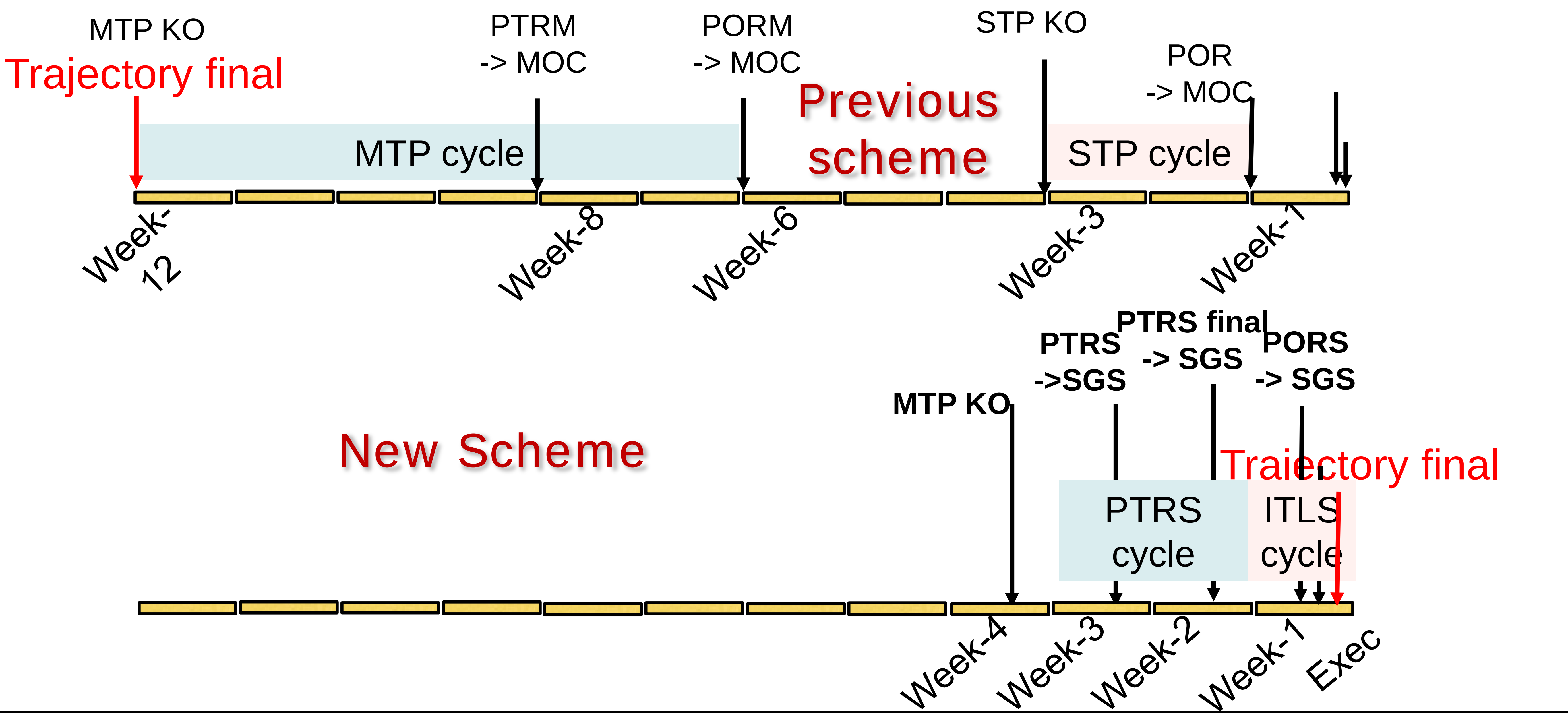


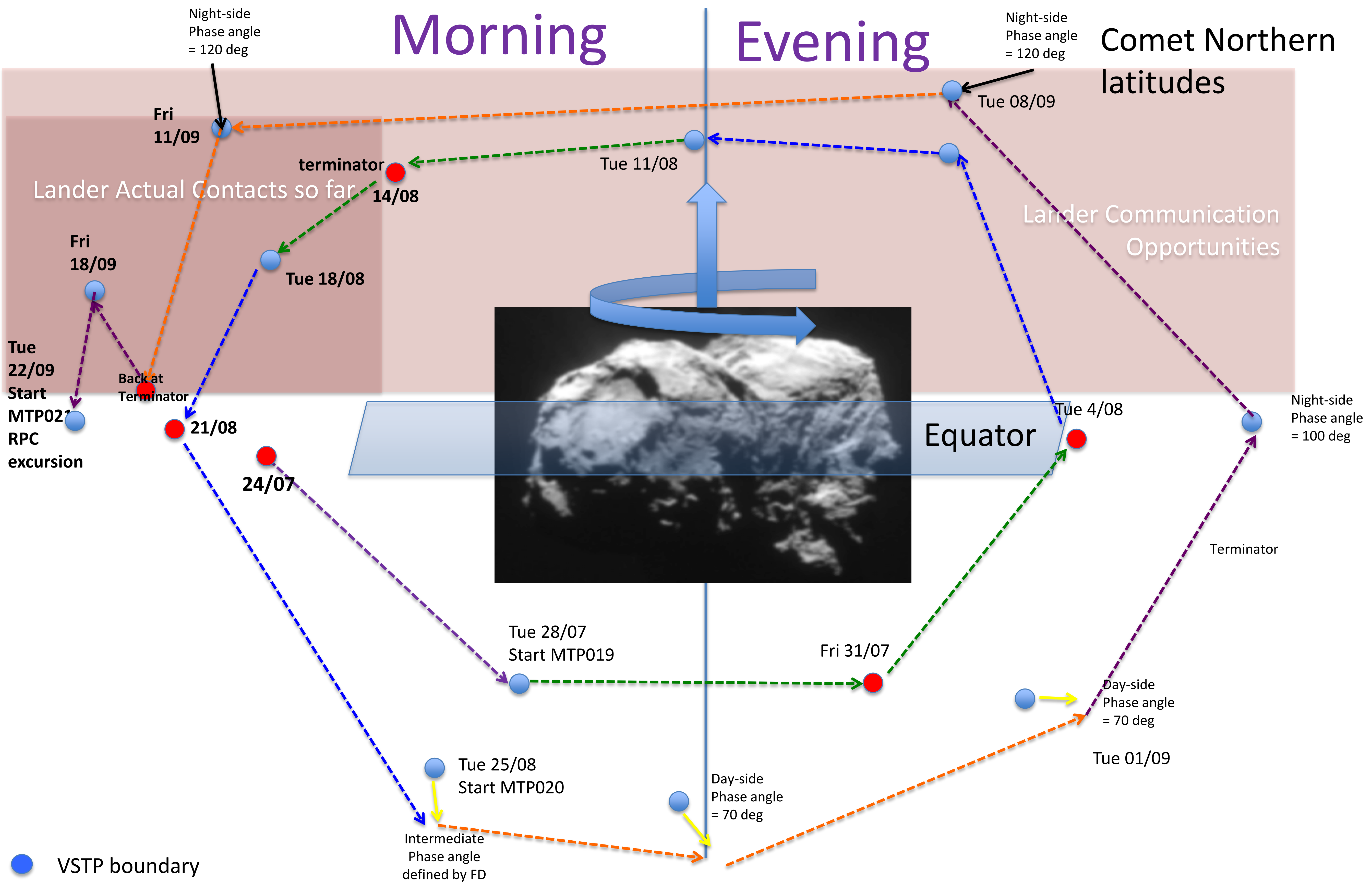
- Large number of dust particles confuse the star trackers
  - ❑ Only a few percent of the objects in the image are stars

A completely new way of operating

- Analysing the issues, the conclusion was quickly drawn that a long-term prediction of flyable trajectories is not possible for the perihelion passage

=> A completely new operations scheme was born





VSTP boundary

Requiring SWT decision [see table for decision date and where Lander inputs needed]

Comet Southern latitudes

Note 1: First Southern arc lattitude to evening can be adjusted (current going to lattitude 0 - equator)

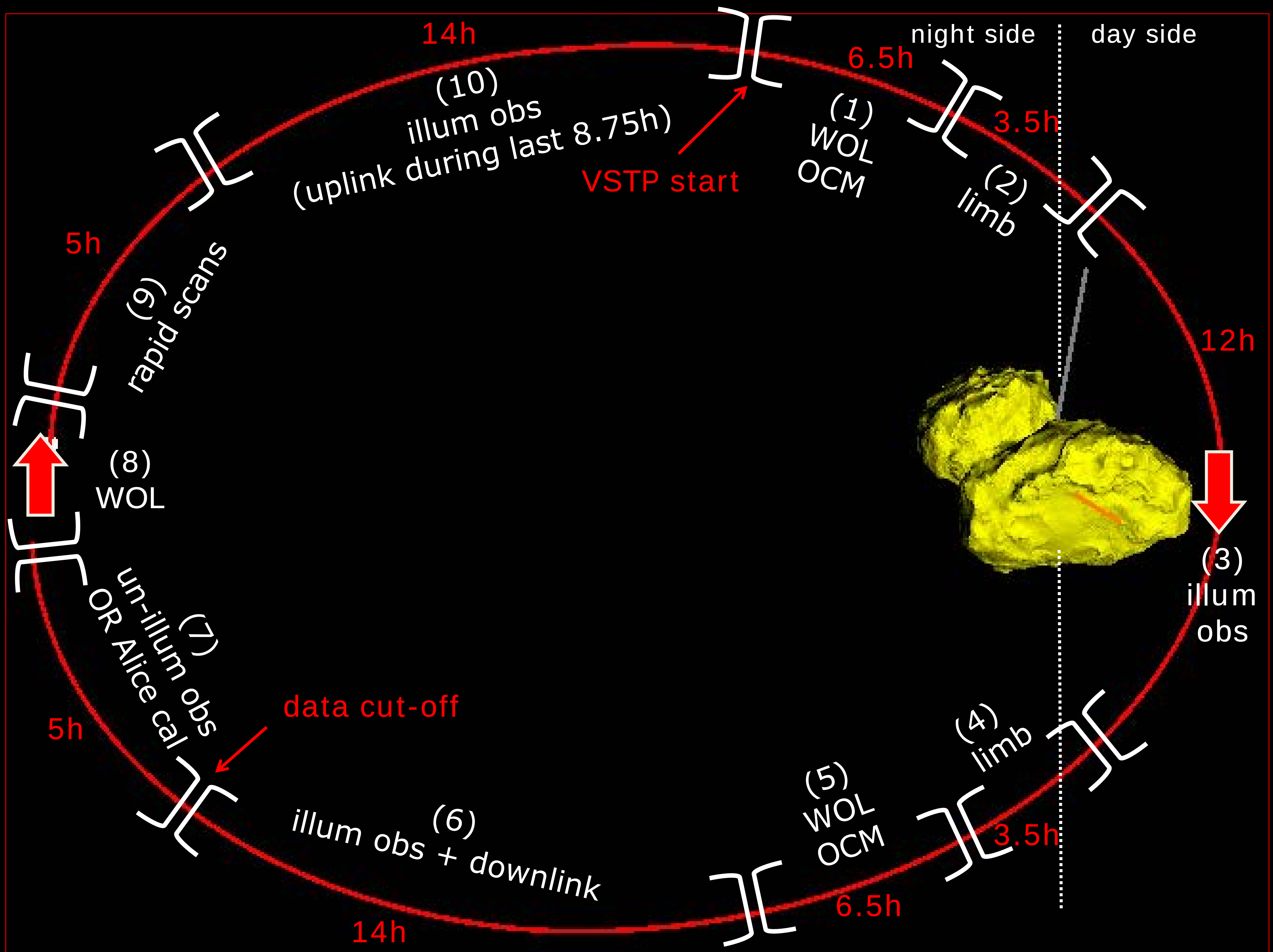
Note 2: VSTP legs for “orbit” (consisting of 7 VSTPs) around Comet can be adjusted

→ Trajectory segment covering 1 VSTP [3 - 4 days]

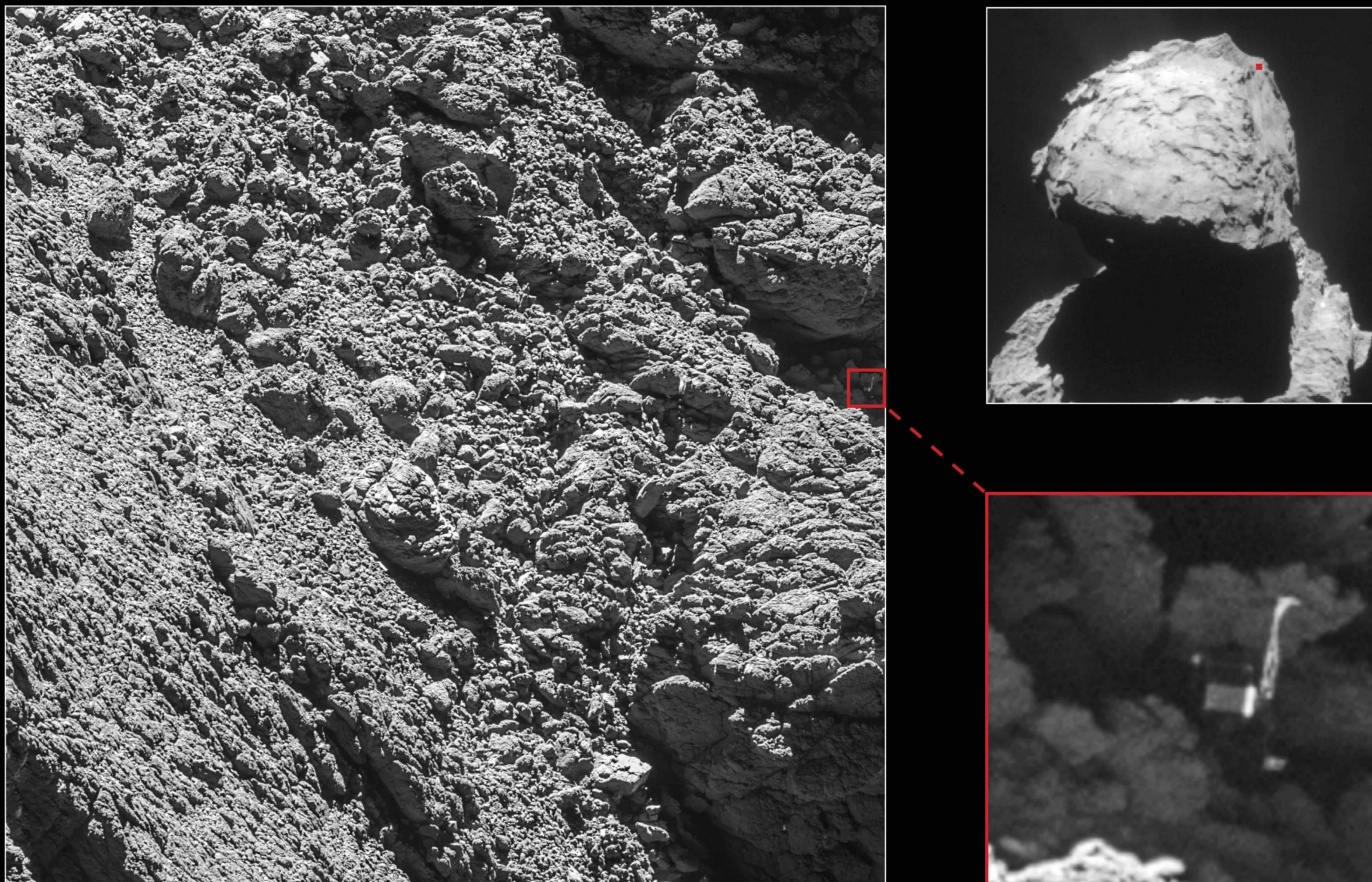
End of mission: Getting closer

- Elliptic orbits with 3 days orbital period
  - Corresponds to large semimajor axis of 10.5 km
- Increasing eccentricity with time
  - Pericentre down to < 2 km from surface
- Required highly constrained pointing
  - Predefined repeatable pointing profile
- Required further (slight) increase in turn-around times

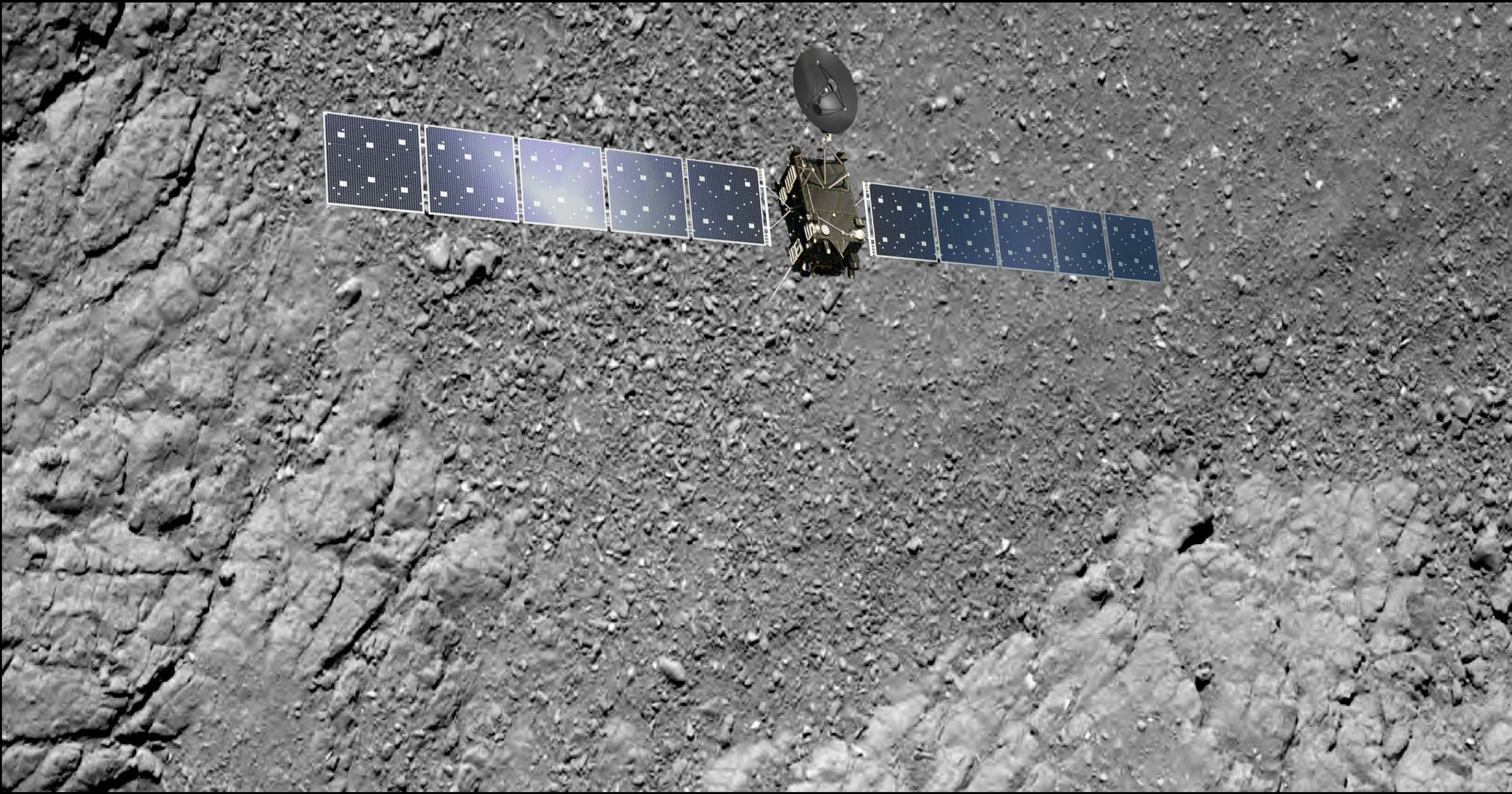
End of Mission orbits



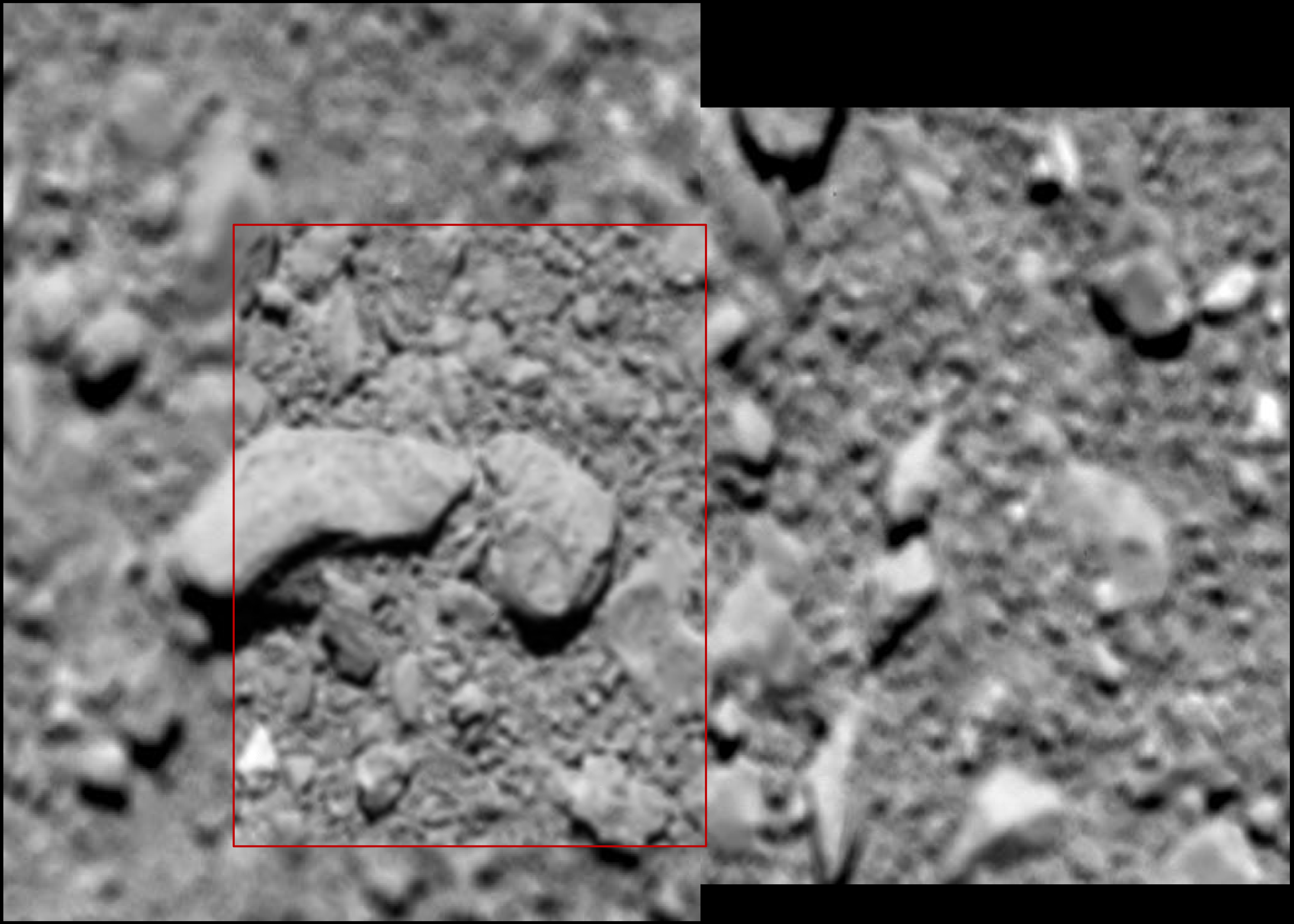
Philae found!



End of mission



Last images



Conclusions

- For an ESA cornerstone mission, a distributed ground segment is a fact

- Don’t allow processes to become overly complex due to the ground segment being highly distributed
  - ❑ Large number of parties involved does not preclude quick turnaround

- Adapt the planning process to the pecularities of the mission