The Ground Segment:
Science and Mission Operations

Presentation Outline

Introduction

Part I – Generic Ground Segment tasks

– Lunch Break –

Part II – The Ground Segment through the various phases

What?
Who?
Where?
When?
How?

Long-Term Plan

System Requirements

Trend Analysis

Performance Verification

Constraint Avoidance

Instrument Calibration

Analysis Software

User Support

Data Processing

Spacecraft commanding

Instrument Activity Plan

Health Monitoring

Instrument commanding

On-board software updates

AOCS Calibration

Anomaly Resolution

Quick-Look Analysis

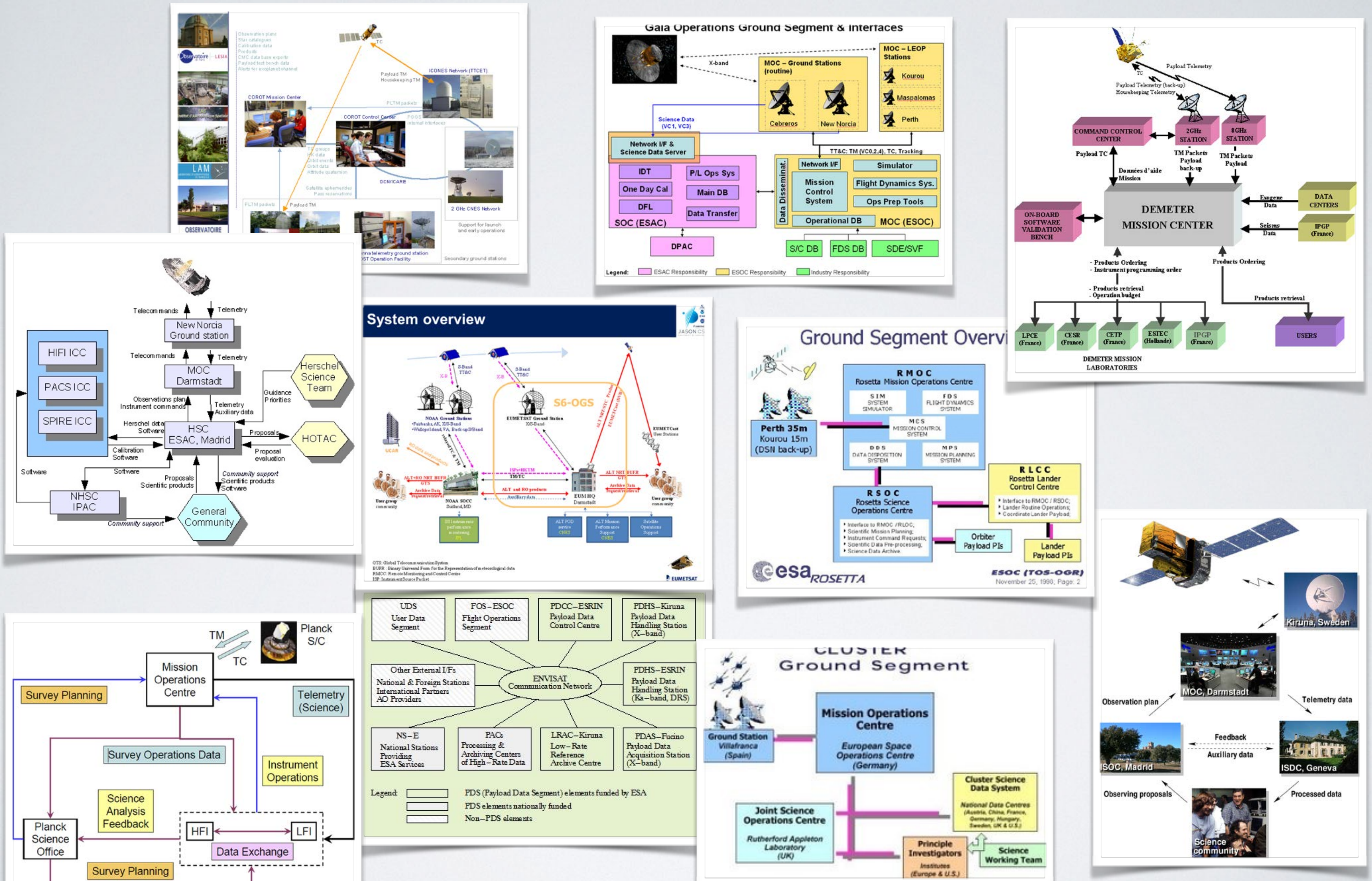
Legacy Archive

Interface Definitions

Operational Repository

Spacecraft disposal

There are many ways to design a Ground Segment …



… and there is no simple right or wrong way …

One size does NOT fit all!

Factors that will influence the ground segment set-up:

- Size and complexity of the spacecraft & instruments. Higher complexity ➟ more players involved.
- Complexity of operations concept: scanning survey (e.g., Planck, Gaia) vs, complex flight and pointing efforts (Rosetta).
- Complexity of data processing effort, mostly routine (e.g., Swift XRT) or very elaborate (Planck, Gaia).
- Financial and political considerations – who is ready to pay for what?

… but there are common tasks across all

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Which ones can you think of?

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… but there are common tasks across all

Spacecraft Communication

Spacecraft Control & Flight Dynamics

Instrument Control

Health & Status Monitoring

Instrument Maintenance & Calibration

Observation Planning

Data Processing

Data Storage & Archiving

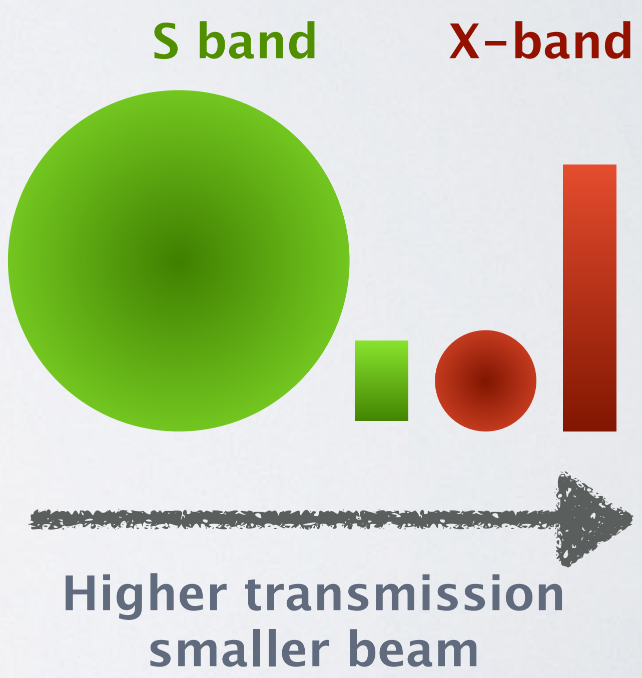
User Support

Ground Station Network

Essential lifeline to the satellite. Sometimes taken “for granted” as infrastructure by scientists, but major effort (and cost factor) in background.

Questions to consider / Issues to resolve:

- Data rate requirements (usually never enough to make instruments happy).
- Orbital coverage. Ability to track without interruptions.
- Technology: tried & trusted vs. latest development. Possible obsolescence for long-duration missions.
- Higher frequency bands ➟ higher transmission rates but smaller beam width (more critical requirements on antennae).



Ground Station Network

- Further questions to consider / Issues to resolve:
  - Availability of back-up options for times of servicing, outages, special circumstances.
  - Interference, from ground or from other satellites.
  - Changing data rate with distance, especially for solar systems missions.
  - Possible interference by the Sun!

Mission Control

Platform and payload control – steering the satellite.

Careful evaluation of all telecommands sent to the space mission.

Safety evaluation of all planned operations.

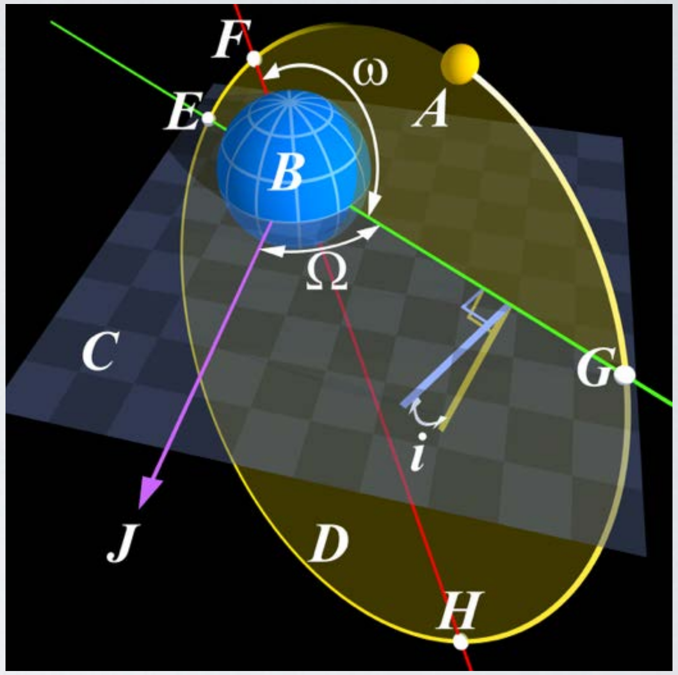
Problem resolution: procedures for all foreseen cases, mechanisms to deal with the unforeseen.

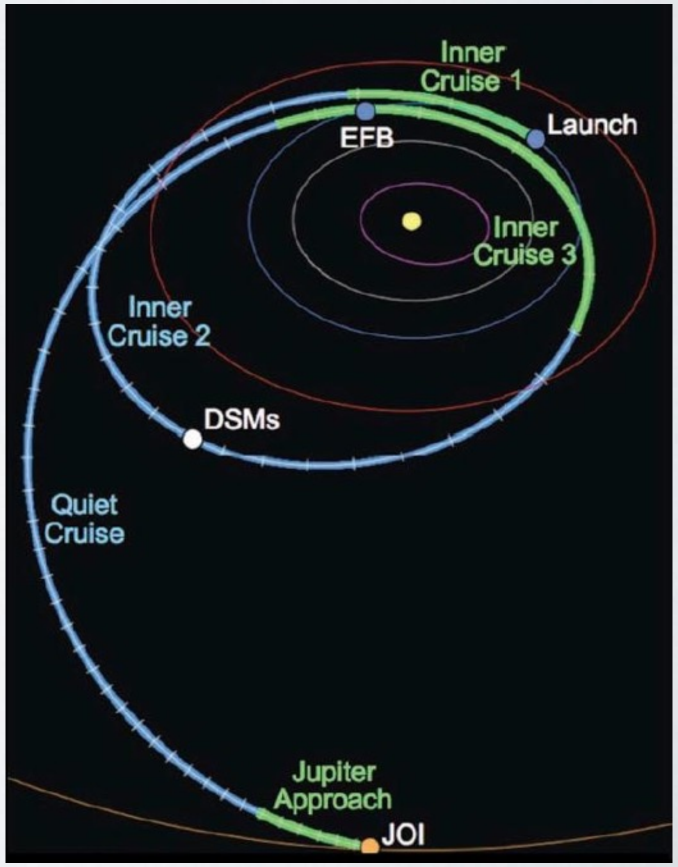
Flexibility and redundancy. Experts at work or on-call, often enough 365/24.

Flight Dynamics

Experts in orbital mechanics and satellite control.
Often PhDs in mathematics. Involved in:

- mission studies (operations concept, which orbits are possible and make sense).
- Detailed planning: verification of safe satellite movements.
- Orbit control & maintenance – every change of angular momentum **is** a change of orbit.
- In recent years: disposal strategies to avoid space-debris.





Instrument Control

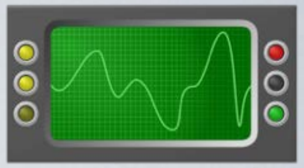
Space instruments are complex: A typical scientific satellite has over 20 000 control parameters (similar to modern jet aircraft) that control on-board systems, functions and settings. Each must be carefully configured.

Commands and parameters are grouped into command sequences and instrument modes to structure the complexity.

Database of telemetry commands and parameters built up over years before launch as instruments are defined and developed. After launch updated to adapt to realities of space. Mission critical to have this correct!

Often complex interactions with multiple parties (instrument teams, spacecraft controllers, science planners) to implement changes. Strict change control essential. (At ESA) new sequences are checked with a spacecraft simulator.

Health & Status Monitoring



Many things can go wrong in space. Don’t get upset about Single Event Upsets. 😉

A smoothly running mission = All problems are found quickly and can be treated with known procedures.

➥ Spacecraft and instruments need to be continuously checked for functioning.

Multiple levels of checking:

- Mission Control checks housekeeping parameters (e.g., temperatures, voltages, power consumption, data rates, etc. etc.) and compares to pre-defined limits ➟ alerts in case of exceeded limits.
- Data processing and instrument centres repeat checks (e.g. for warnings) and do more long-term analysis.
- Also need to verify that observations went as planned.

Health & Status Monitoring

Instrument Maintenance and Calibration

No instrument remains completely stable. Many factors influence instrument behaviour, e.g.:

- Radiation damage & charge disposal
- Stark temperature contrasts
- Micro-meteorites & tiny space debris
- Mechanical vibrations (launch! but also later by thermal distortions)
- Higher background than expected (somehow very common …)

➥ Usually major efforts in early mission to adapt instrument settings to behaviour in space. May well involve on-board software updates (never trivial).

➥ Long-term effort to follow instrumental evolution and derive calibration.

Observation Planning – solving the puzzle

Goal: make best use of available time for science, addressing all **scientific requirements** and taking into account all **scientific** and **technical** constraints.

➥ This very quickly turns into a multi-dimensional puzzle.

Very different time scales:

- Long-term planning: High-level schedule for campaign, year, full mission.
- Mid-term planning: Detailed schedule for some weeks or months.
- Short-term planning: actual planning data with detailed commanding. Last adaptions to actual orbit and other constraints.
- Re-planning: changing plans due to scientific or technical needs. Target of Opportunity observations, lost data, changes in Ground Stations. Changing environment for solar system (Rosetta's comet).

Observation Planning – Getting the inputs

Depending on mission type, various ways to obtain scientific requirements.

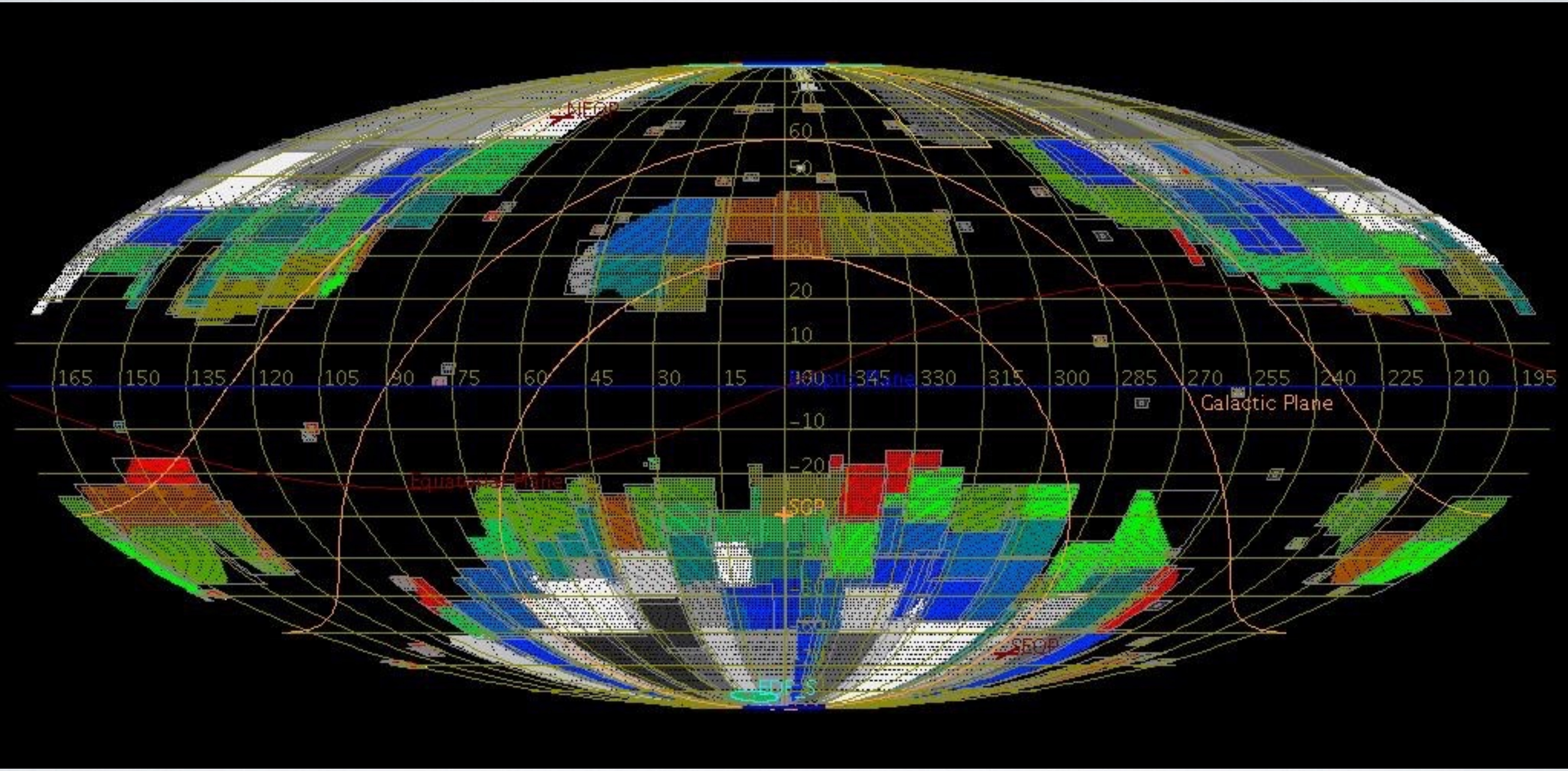
Survey Missions: Overall plan developed & refined before launch.

Experiment: List of activities, experiments set up before launch, later updated at regular intervals.

Exploration Mission: Large parts pre-approved before arrival at object, then updated (often very significantly), based on results of observations.

Observatory: Some core science usually pre-defined, rest obtained from regular calls for proposals, with most interesting selected by a committee.

Example mission-long plan: Euclid



Observation Planning – Scientific constraints

Sufficient time for measurements.

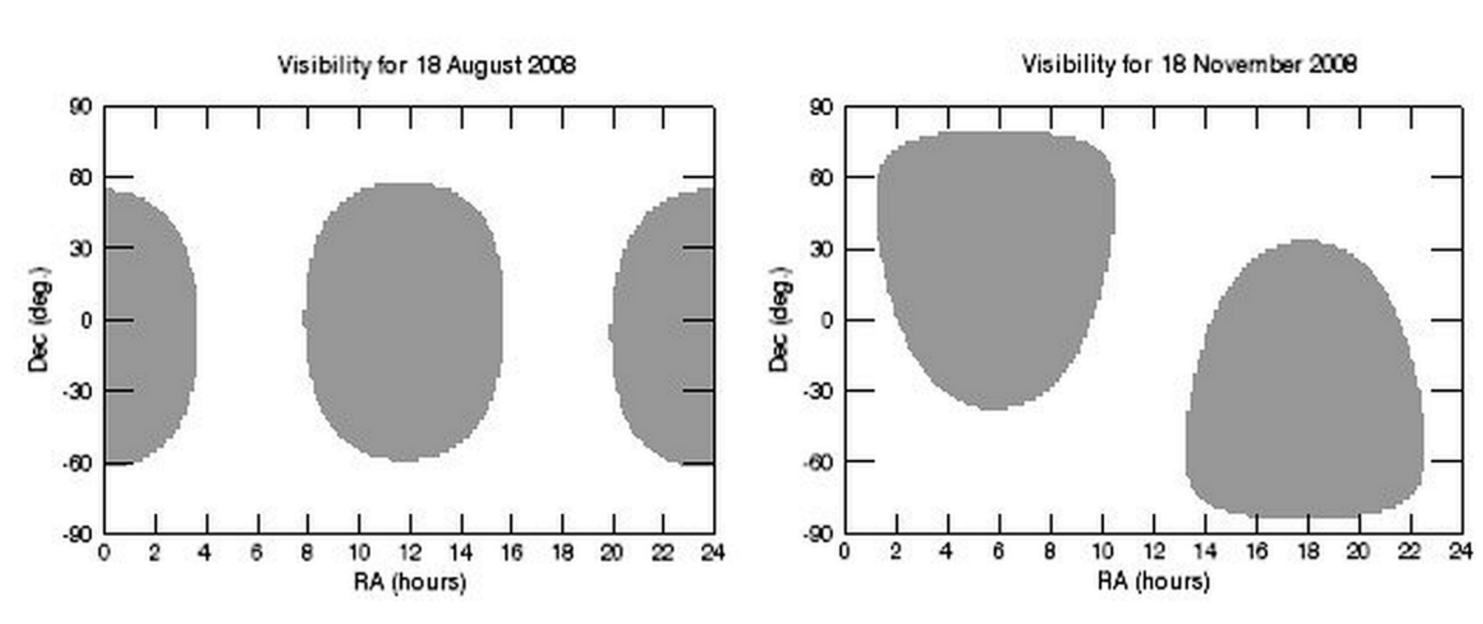
Correct sequence of data taking (filters, exposure times, instruments in use).

Correct pointing direction

Additional, specific time constraints:

- Driven by object under study (orbital phase, rotation phase, illumination, …)
- Simultaneous data with other observatories.
- Distances to object (for solar system)
- Radiation or thermal environment.

Observation Planning – Technical constraints



Avoidance zones around Sun, moon or other bright sources for instruments or star trackers.

Anti-sun constraint from need to have solar panels illuminated.

➥ At any given moment only part of the sky (or target) is visible.

Limitations on available power for certain operations.

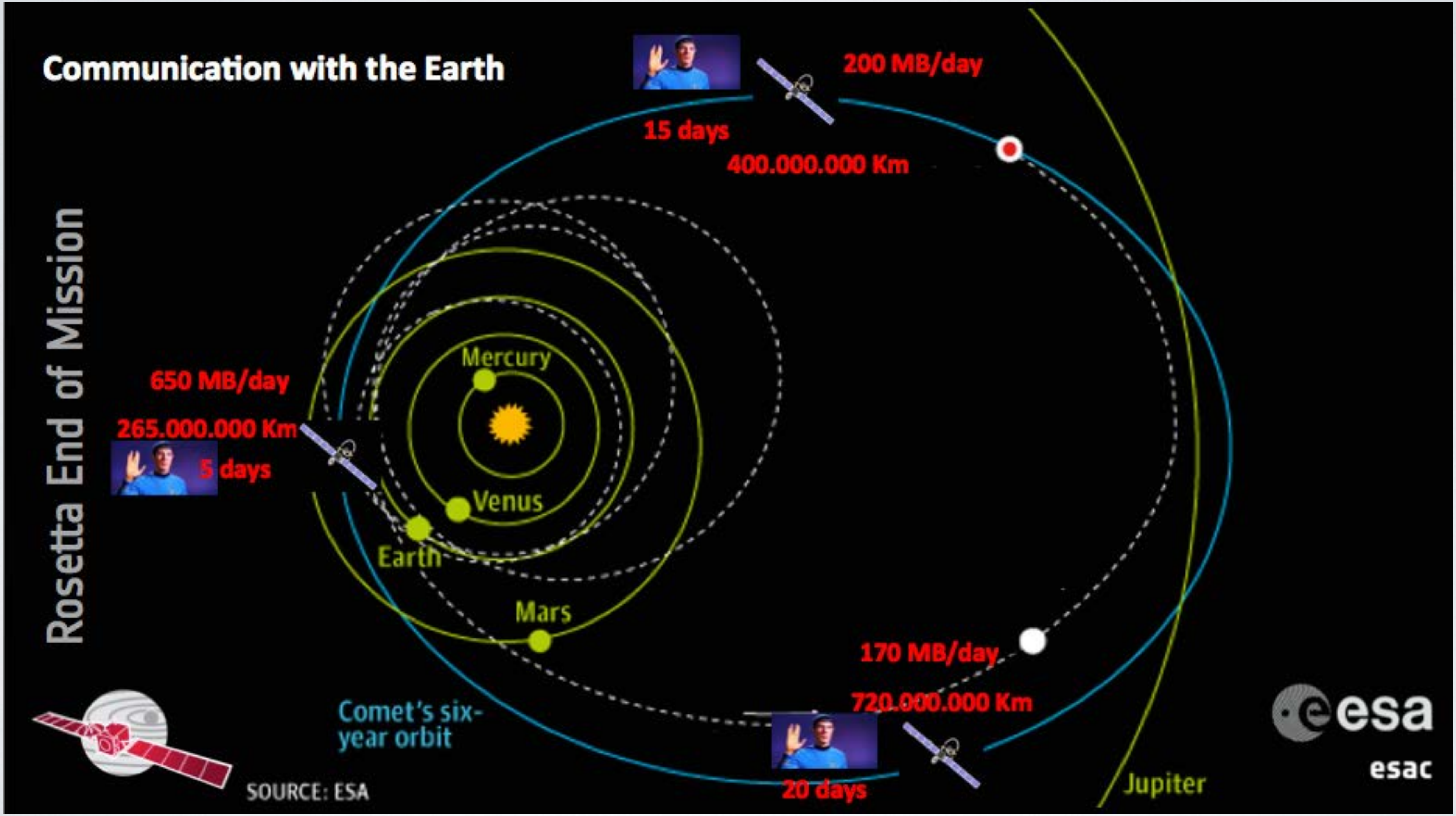
Limited on-board storage of data, limited data transmission rate.

Restrictions on simultaneous operation of instruments.

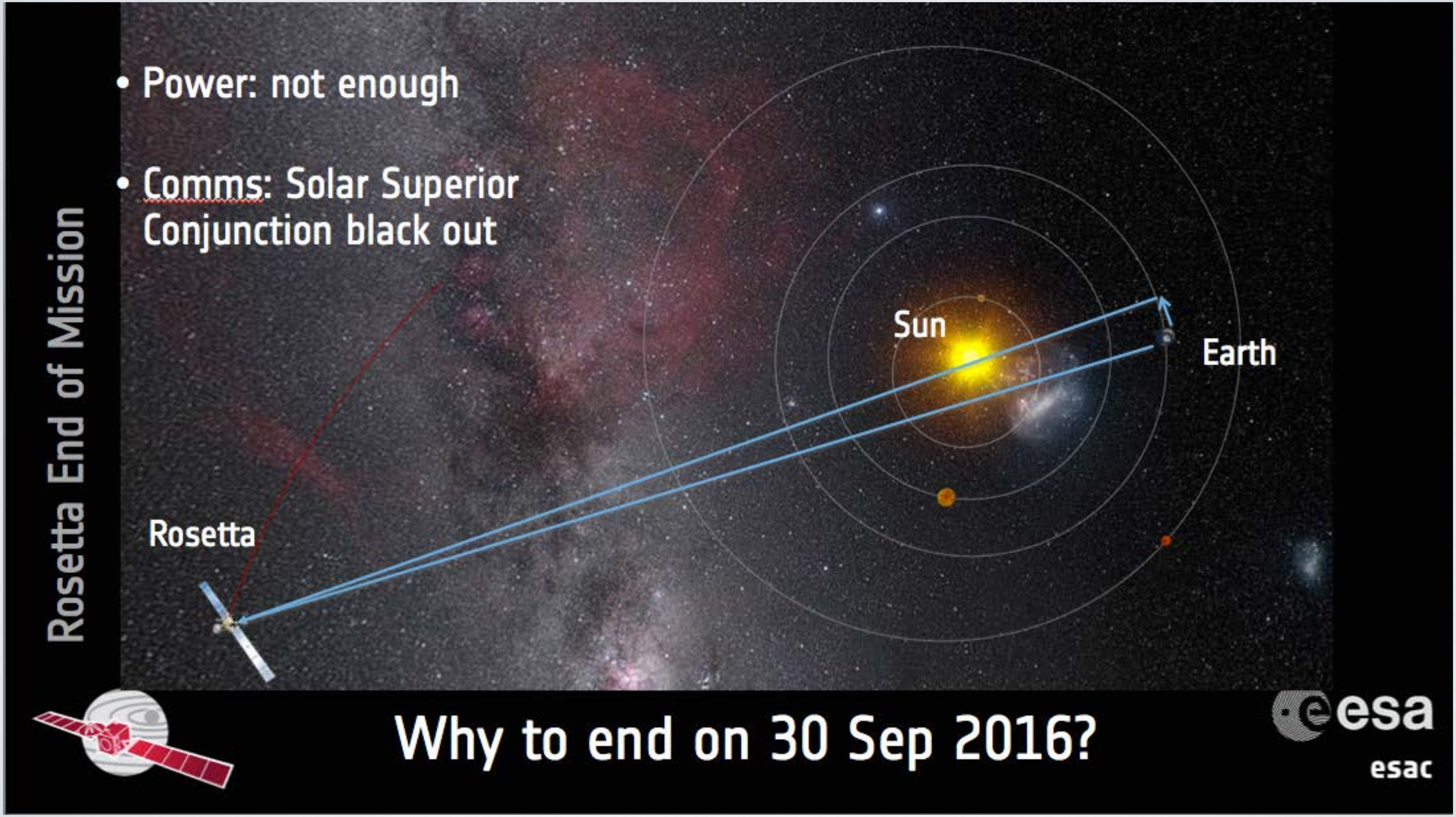
Minimisation of fuel expenditure ➟ prolong the satellite's life.

Ground station availability and location.

Download rates from Rosetta at the comet



End Rosetta Mission – Technical Constraints



Data processing – from telemetry to information

Essential element of mission success. Usually defined in 'levels', but with no standardised nomenclature. Essential steps:

- From telemetry to 'raw' science data, useable by more or less common analysis tools. Often the hardest to set up correctly, as very intricate.
- Incorporation of 'auxiliary' data (attitudes, planning information, …)
- Verification of health and status, Good-Time Intervals.
- Quick-look analysis – interesting science results and effective status monitoring.
- Standard data processing, raw data to scientific data products. Wide range of different approaches for latter (what is useful?, what can be done?).
- Ingestion in repositories and archives.

➟ **See presentation by Roland Walter.**

Archive – not just some (big) amount of disk space

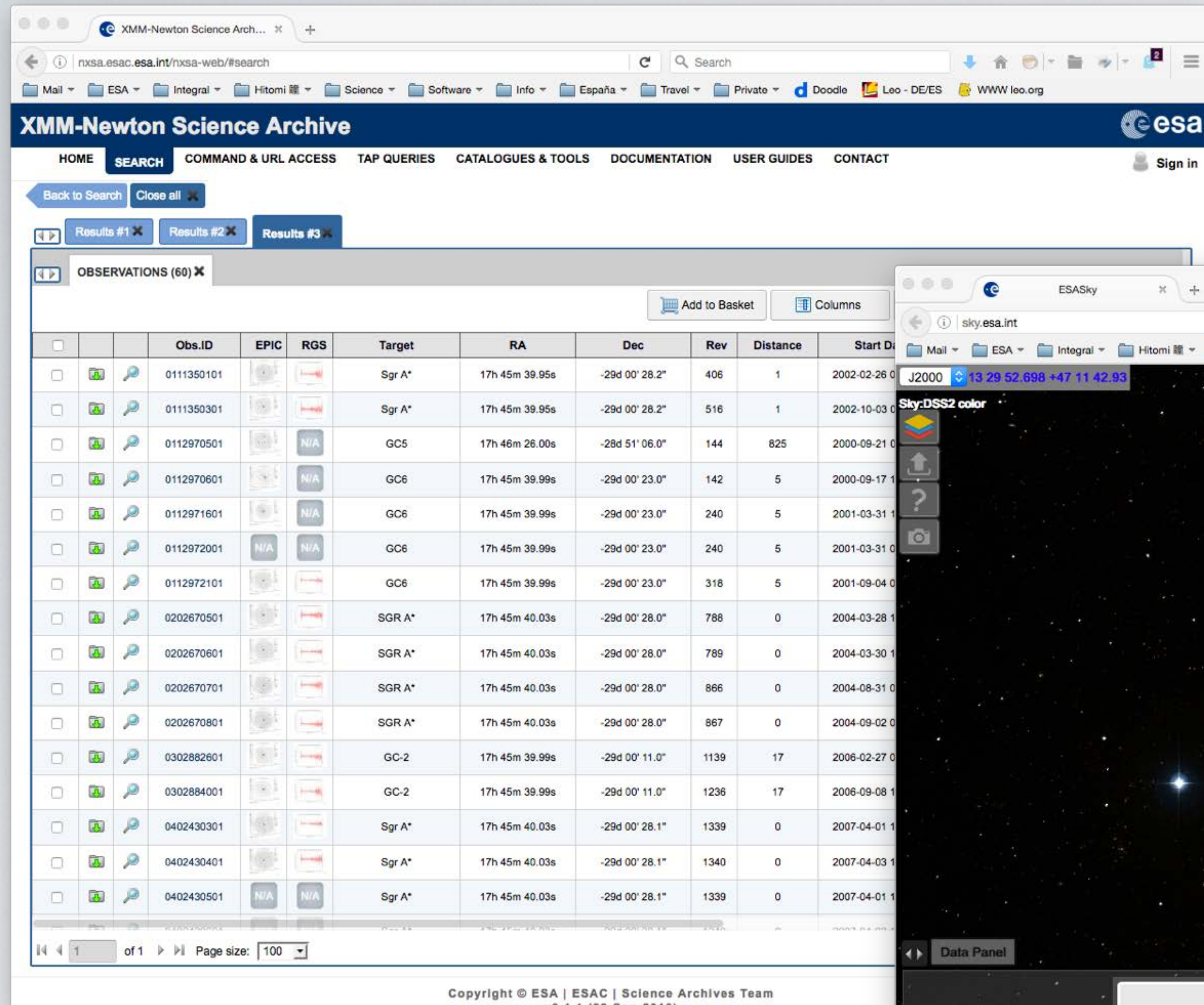
Sometimes neglected in the past. Now recognised as essential part of a mission's actual success.

Beyond immediate usage an Archive adds the 4^{th} dimension, time, to research.

Many questions to consider from the early phases of mission development:

- Operational vs Legacy Archive, different needs for different users in content, speed, access methods, … Who will be the users in the long run?
- What gets archived (telemetry? converted data, high-level)?
  Who provides which kind of data? When? How exactly?
  Which meta data is required to find information later.
- Interfaces: for humans and machines, both will be required.
- Long-Term Preservation: archive storage technology, regular re-copying (how long for validation?). What about software?

Archive Interfaces keep evolving



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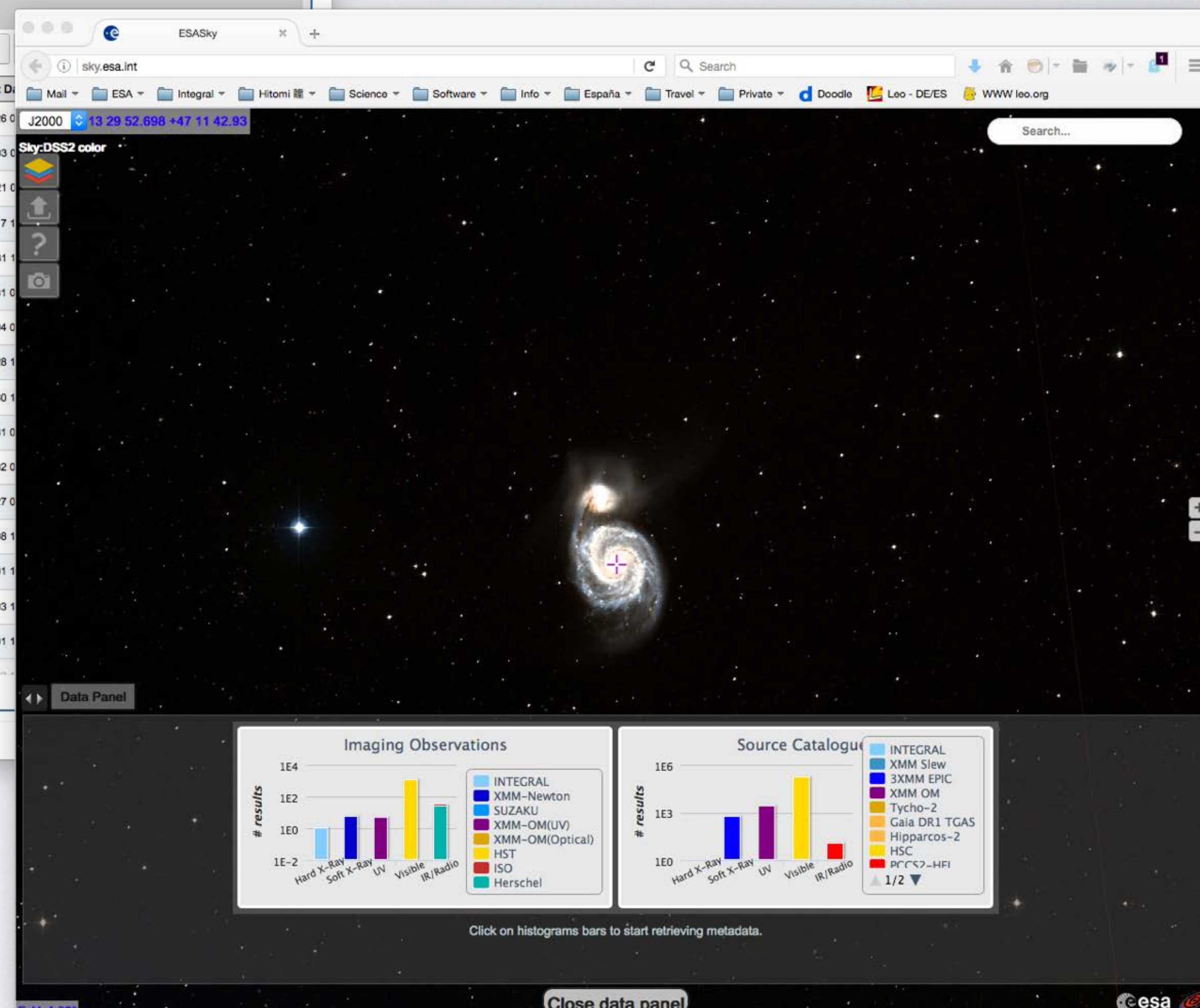
sky.esa.int



User Support – engaging the world

Sometimes still treated as an 'afterthought', but good user support helps your mission in the long run. Consider different stakeholders! Typical needs:

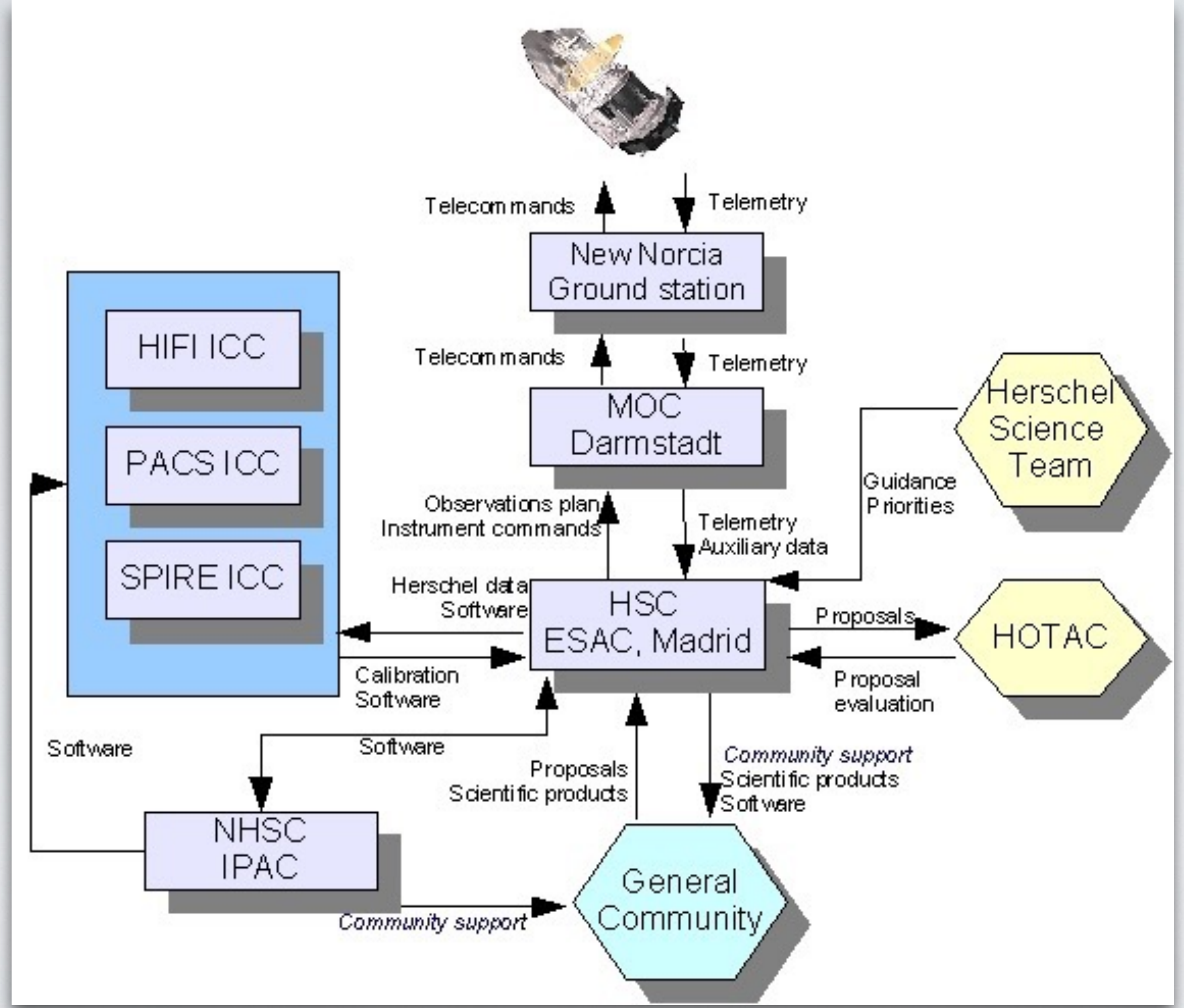
- **Comprehensible documentation**
  Specialists don't tend to write easy to understand documentation. Need to have someone address user needs for mission description, Frequently-Asked Questions, use cases, etc. etc.

- **Help-Desk**
  A simple way to get questions answered. Must be 'manned', i.e., someone must feel explicitly responsible for answers. Currently by web tools & email, this may well evolve.

- **Newsletters, Web pages, Outreach**
  Inform users pro-actively about mission news.

Modern technology makes it easy to have geographically distributed user support, involving people in many centres.

Example: Herschel Ground Segment



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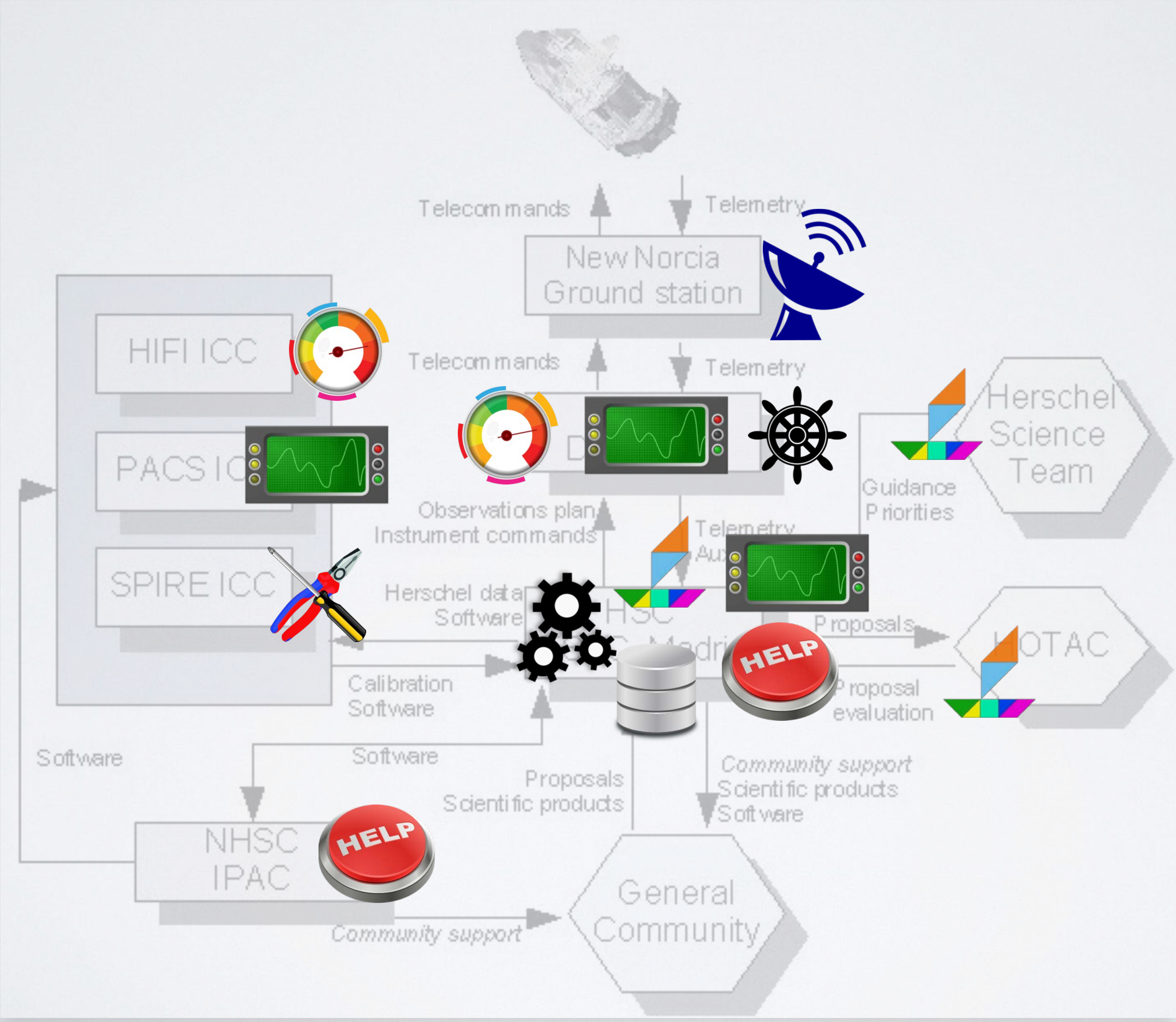
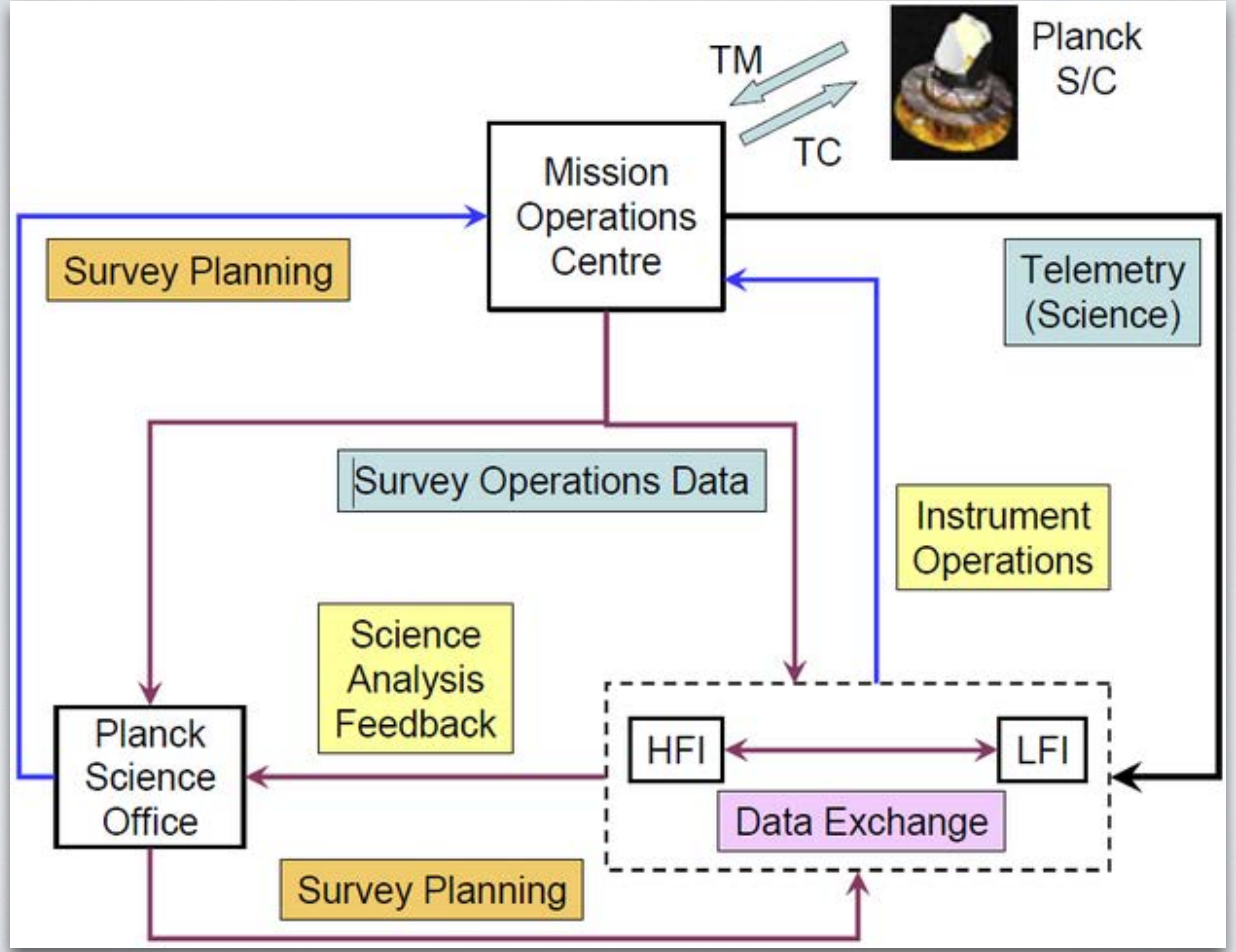
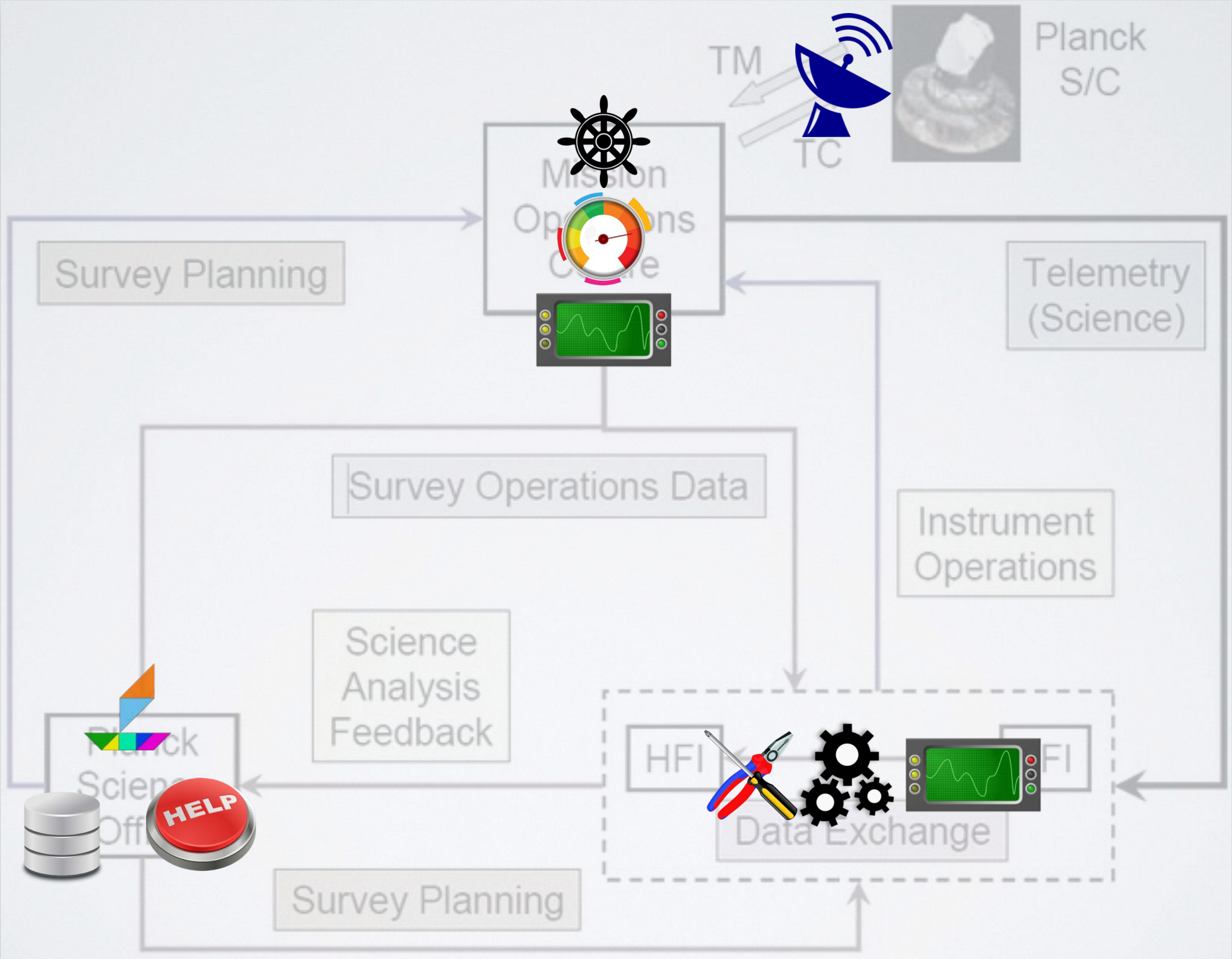


Example: Planck Ground Segment



Example: Planck Ground Segment



Operational Phases

Which ones would you consider?

Operational Phases

Study/Design – Getting the structure right, early

Develop/Implement – Building what you need, when you need it

Early Operations – When you find which assumptions were wrong …

Routine Operations – If you ever reach a state of routine …

Extended Operations – Dwindling resources & knowledge

Post-Operations – Assuring the Legacy

Study/Design – Understanding users & constraints

Need to understand **real scientific requirements**, e.g.:

- Sensible observing strategies
- Complexity of configuring the instruments
- User priorities in case of conflicts
- Frequency and speed of updates to settings

Specifying real requirements is difficult for anyone. Usually many interactions required and scientific expert knowledge in Ground Segment helps.

Also need to grasp **technical and financial constraints**, e.g.:

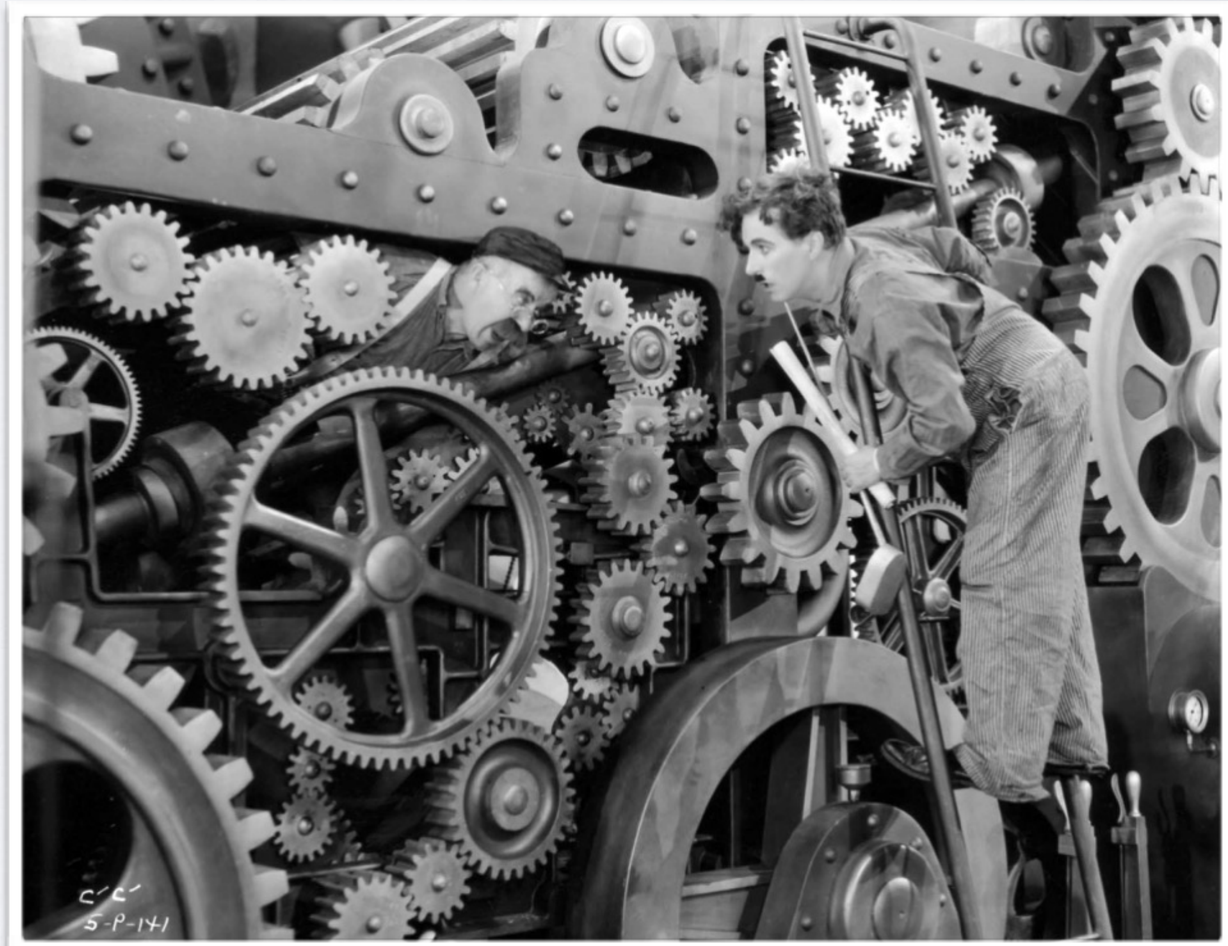
- Frequency of interactions with satellite
- Data volumes being exchanged and stored, connection speeds
- Required interfaces and their complexity
- Affordable staffing levels at various centres

Develop/Implement - Keeping up …

Development should go hand-in-hand with satellite project, but possibly starting slowly.

Missions in Earth Orbit need full Ground Segment shortly after launch. Solar system missions can have years of drift time with little interactions.

Busy satellite & instrument builders can be difficult to convince to interact with Ground Segment while building and testing.



Test, test, test … with as realistic data as possible. End-to-end tests before launch with full spacecraft at assembly being commanded by Mission Control and rest of system executed as much as possible.

Warning: tests always get squeezed for time, one usually pays for this after launch with added stress.

Early Operations – When the real fun begins

(To my knowledge) no mission ever behaved exactly as expected!

Expect the unexpected and to have a lot of issues to resolve.

Changes to instrument operations, planning schemes, interfaces, … all is possible – but changes should remain well controlled.

Real strain on interfaces in centralised design, usually short-cuts with teams directly in Mission Control.

➥ Some risk of divergence between defined systems and quick ad-hoc solutions.

Routine Operations – relax & refine

For some missions (not all!) routine operations set in after the first year(s):

- Fewer open problems, number goes down;
- routine procedures for repeating problems;
- experience with real-life instruments;
- time to handle long-standing issues.

But:

- less people available (or for less of their time);
- expectation to need less resources in “smooth sailing mode”.

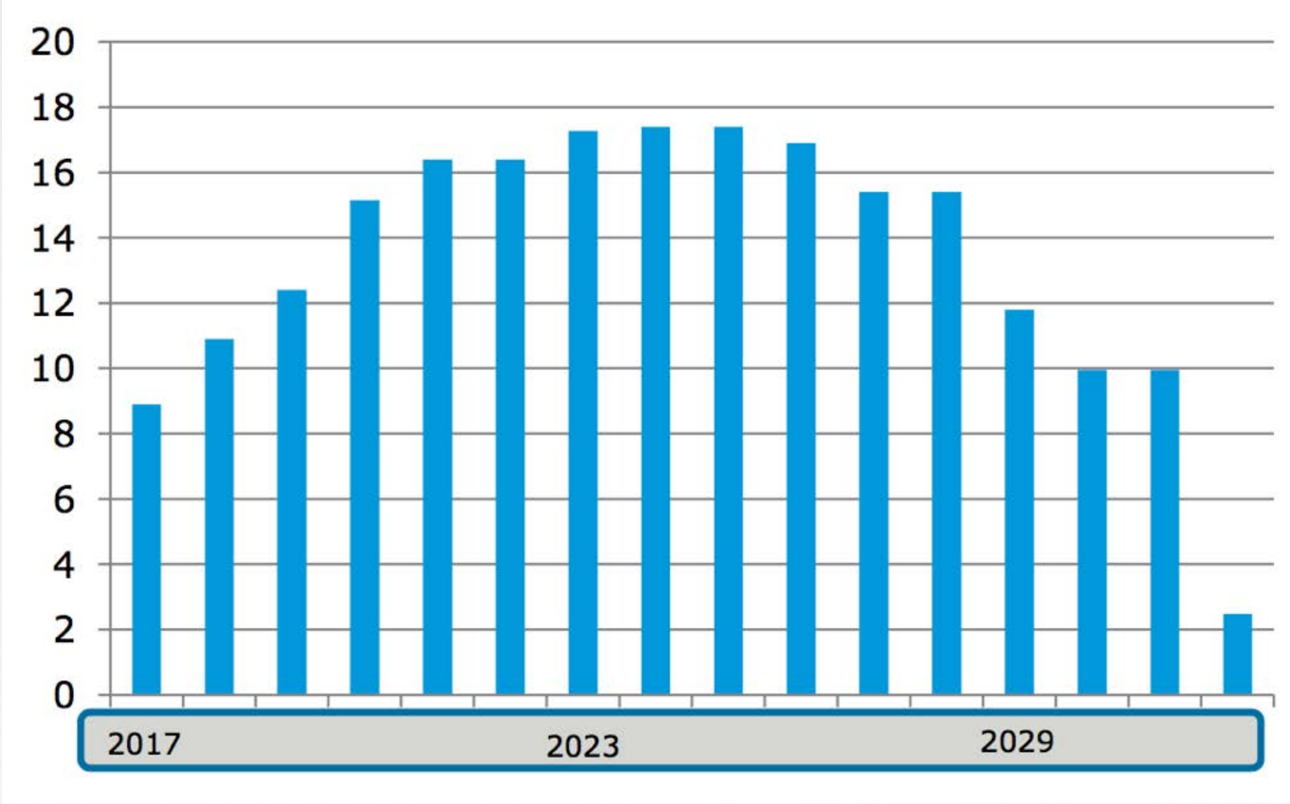
➥ Good time to streamline operations already, using the experience. Less effort, more chances for improved operational abilities.

Extended Operations – a challenge of its own

Many space missions function (much) longer than their nominal time – great!

A year of operations is a few % of the original cost.

But: now there is definitely pressure to bring operations costs down. Some things can be simplified, others not. May need to re-think Ground Segment structure and split of tasks and responsibilities.



Expected manpower profile for a future ESA mission's SOC

Also: ageing spacecraft and instruments can lead to new challenges (example: Cluster without working batteries).

Post-Operations – Assuring the Legacy

End of data taking ≠ End of Mission!

Final data taken still needs to be processed. Usually attempt at 'final' calibration and frequently re-processing.

Legacy Archive to be populated!
Make it ready for the future.
Consider how to maintain the ability to analyse your data for many more years.

Mission description to be completed (catching up to reality in documentation).

Lessons learned for future missions.

Summary

Mission Operations and Science Operations include many different roles,which all need to be considered.

Make it as simple as possible, but not more so. Launching a normal satellite is expensive, not using it well, a waste.