Planning and Scheduling for Space Applications Part I

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Presentation Outline (Part I)

- What is Mission Planning?
  - Definition
  - Mission Planning Functionality
  - Mission Planning in the Ground Segment
  - Typical Planning Cycle
- Ground Based Planning Systems
  - Mission planning
  - Science operations planning
  - Ground Stations Allocation
  - Navigation: contact planning

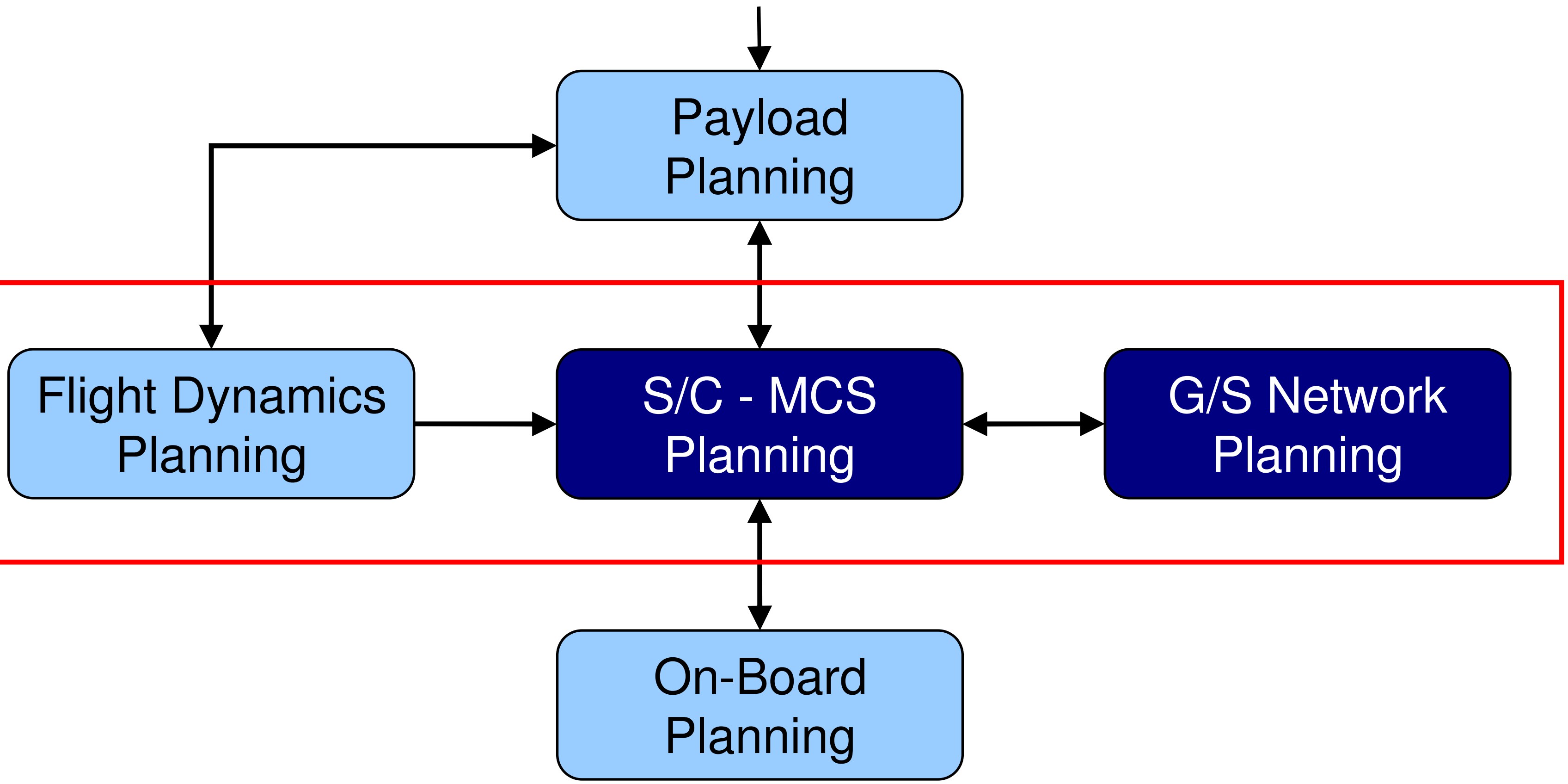
Presentation Outline (Part I)

- Modelling and Genericity
  - Typical mission planning system features
  - Planning problems definition and modelling approaches
  - Characteristics of space applications
- On-Board Mission Planning
  - Rationale
  - Examples of applications
  - On-line planning strategies

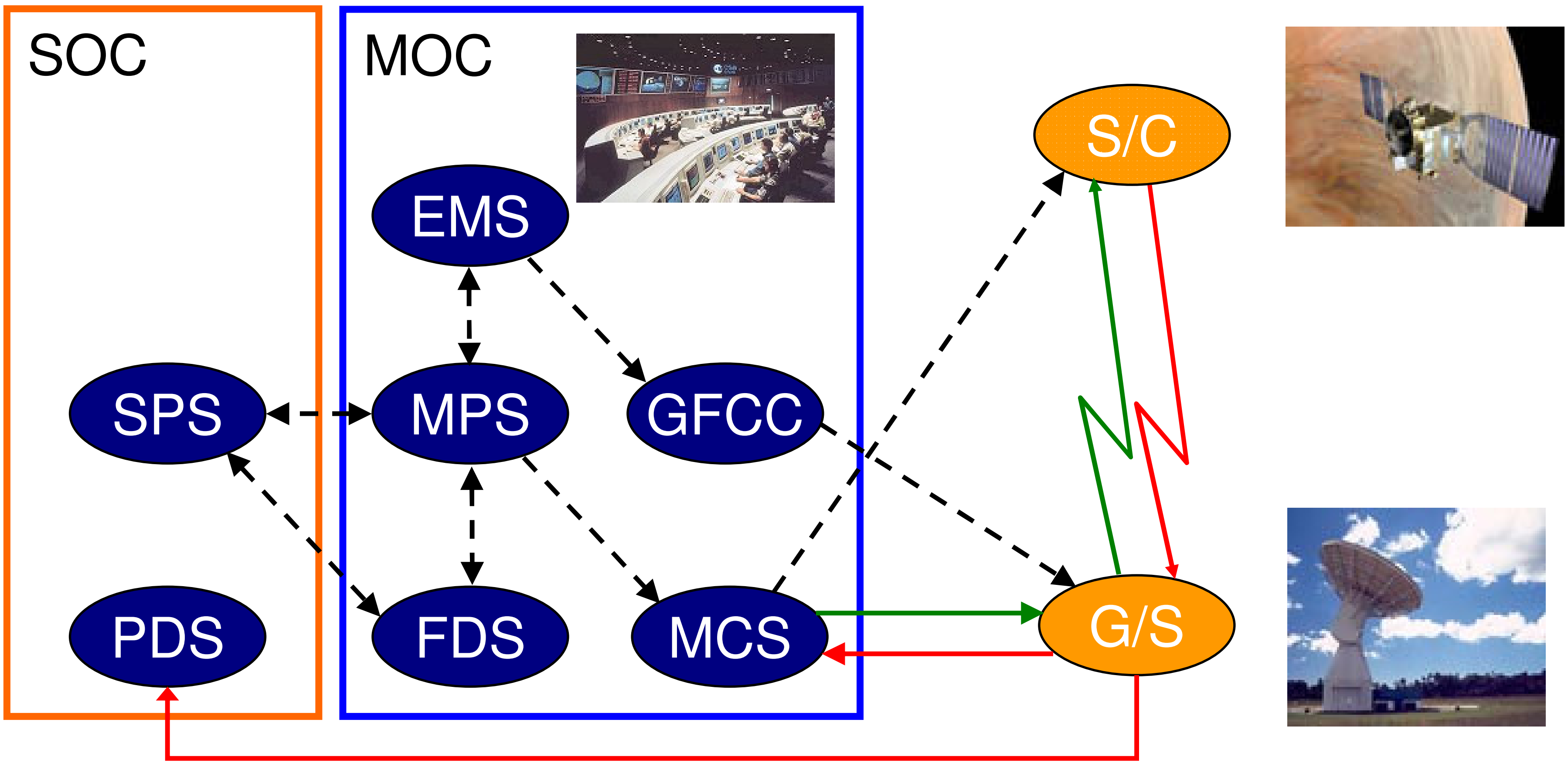
(A) Definition

- Mission Planning covers the *generation of timelines of activities* to be carried out by the various entities of the mission in order to achieve its goal
- The Mission Planning functionality is *distributed* in the ground (and sometimes space) segment
- The Mission Planning activity is supported by *Mission Planning Systems (MPS)*, automated or not

Mission Planning Functionality



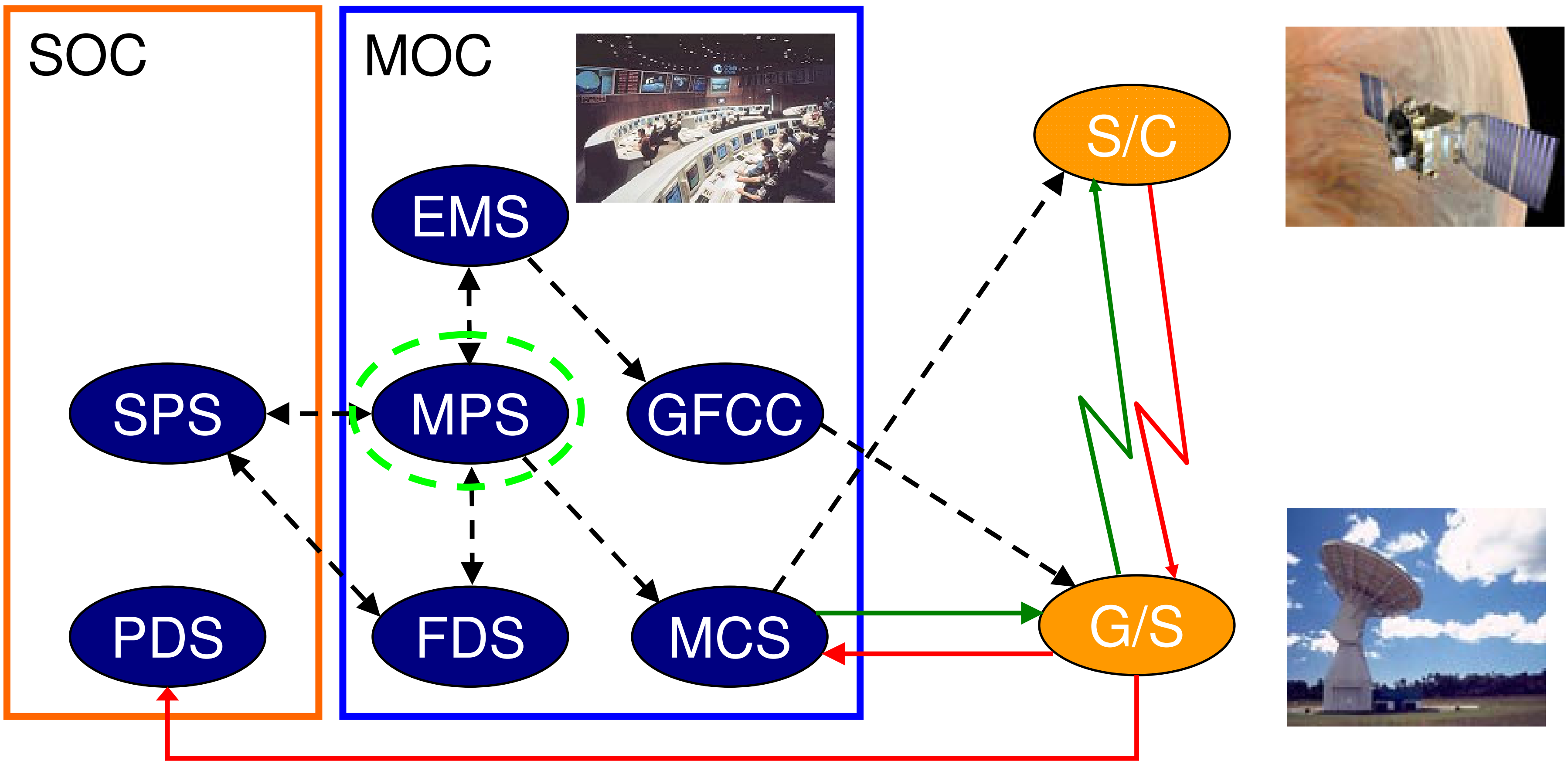
Mission Planning in the Ground Segment



Typical Planning Cycle

- Long-Term Planning
  - Months or years prior to execution
  - Based on low-level accuracy of incomplete data
  - Checking at high-level the feasibility of the plan objectives
  - Booking of the resources at high-level
- Medium-Term Planning
  - Typically 1-3 months prior to execution
  - Based on complete data
  - Focus on maximising the mission return, i.e. the science return, service availability
- Short-Term Planning
  - Typically less than a month prior to execution
  - Based on complete data, regularly updated to increase accuracy
  - Ensure a safe execution of the plan

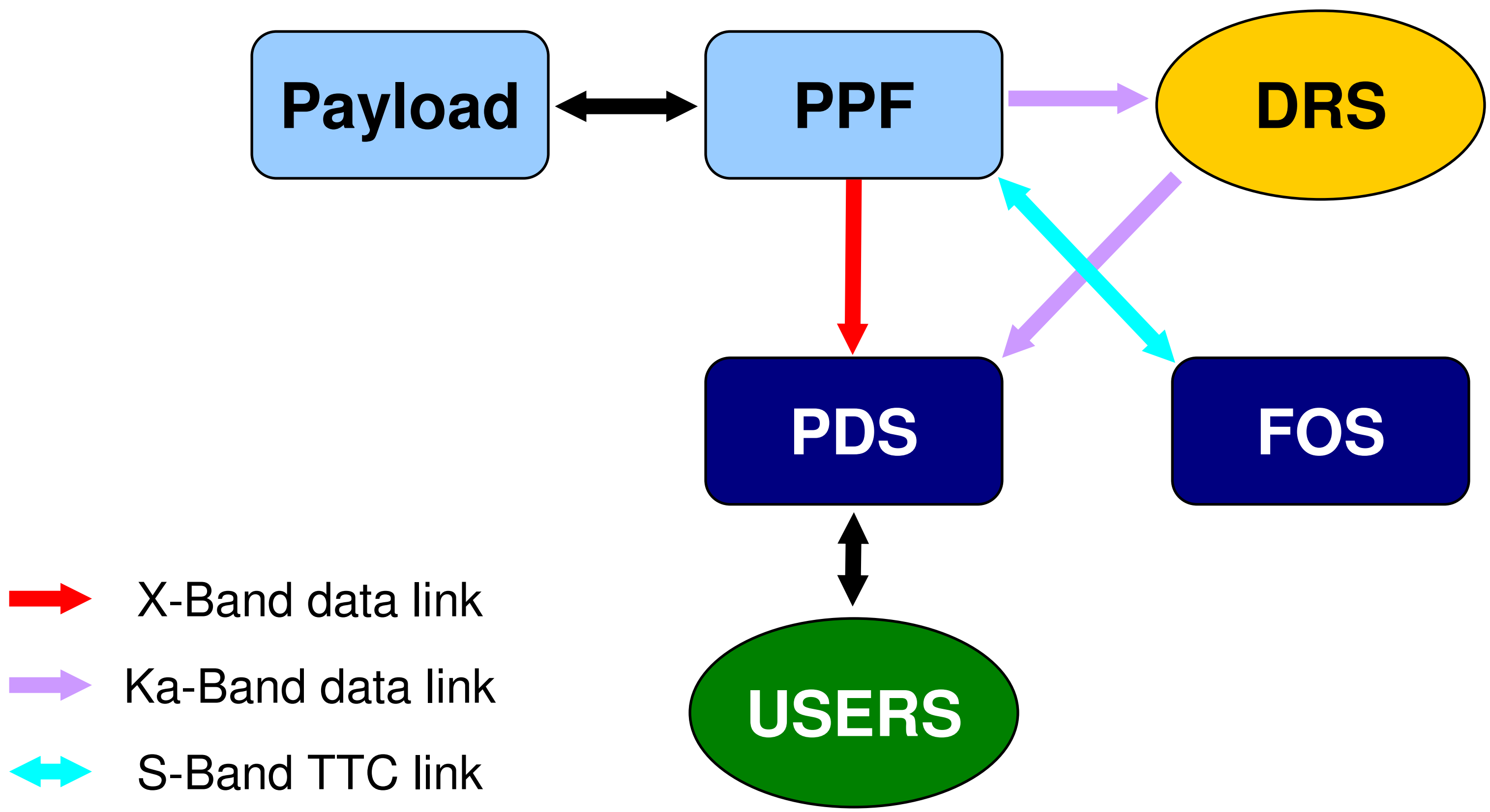
Mission Planning System



Earth Observation – ENVISAT

- ESA's advanced polar-orbiting Earth observation satellite
- launch in March 2002
- successor of ERS-1 and ERS-2
- large payload (9 instruments)
- complex Data Management System
- measurements of the atmosphere, ocean, land, and ice
- Originally five year period mission

Envisat Mission Architecture



Typical Planning Steps

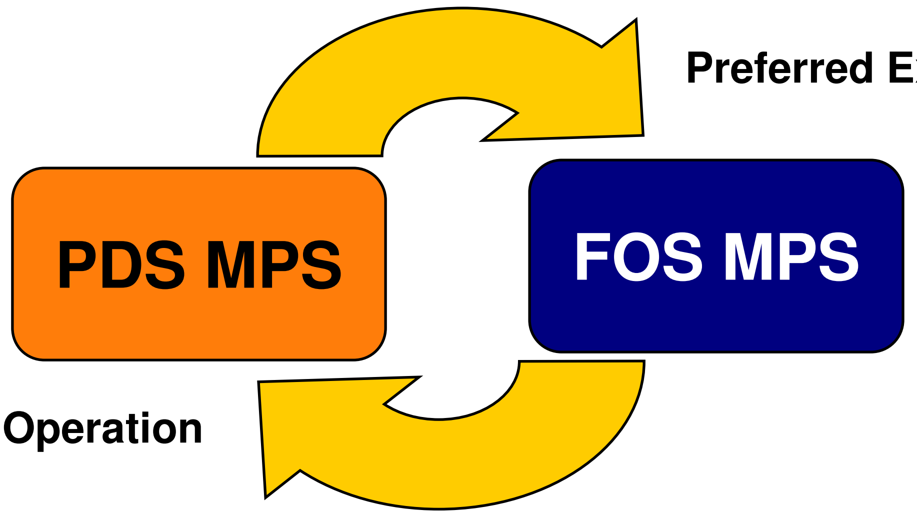
- **Reference Orbit Timeline Generation** — Orbit propagation, zone visibilities, station Visibility, illumination Conditions, etc.
- **Observation Requests Implementation** — Generation of opportunity windows for observations
- **Observation Requests Selection** — Selection of observations based on priority and quality within resource constraints (data storage, power, thermal)
- **Post-processing** — Link Selection, switches selection, etc.

Envisat FOS Mission Planning

- Plan the spacecraft operations in accordance to the Preferred Exploitation Plan within the defined satellite and ground constraints
- Coordinate with the planning function of the DRS ground segment
- Provide the plan to the PDS planning function to enable PDS to schedule data acquisition facilities and payload data handling stations
- Generate the command schedule for the spacecraft and for the commanding/monitoring ground station
- Generate timeline event information for usage by the operators of the mission control system
- Report on the success of the planning and execution of the operations with respect to the plan

Envisat Planning Concept

Preferred Exploitation Plan



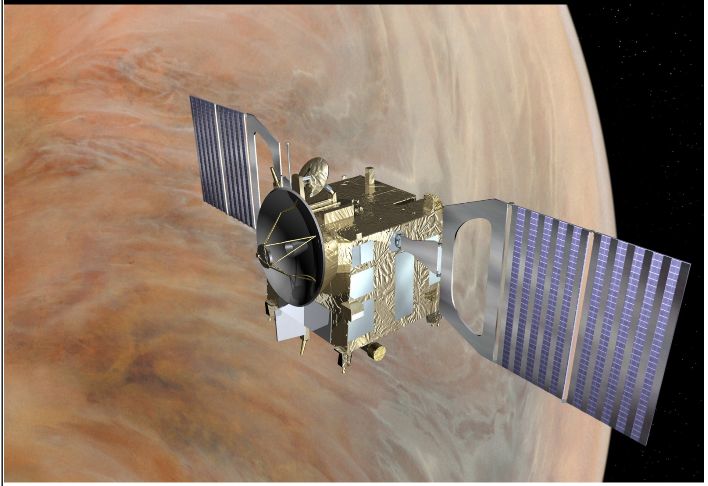
Detailed Mission Operation Plan

- Planning of observation requests
- Acquisition schedules generation

- Planning/Checking of observation requests
- Data Management System planning (Solid State Recorders, links, acquisitions, etc.)
- Spacecraft and commanding/monitoring station schedule generation

Planetary Science – Mars/Venus-Express

- First ESA mission to Mars
- Study the surface and the atmosphere of Mars
- Was assumed to be a lander data relay …
- Launch in June 2003 from the Baikonur Cosmodrome



- First ESA mission to Venus
- Study of the atmosphere, the plasma environment, and the surface of Venus
- Launched in November 2005 from the Baikonur Cosmodrome

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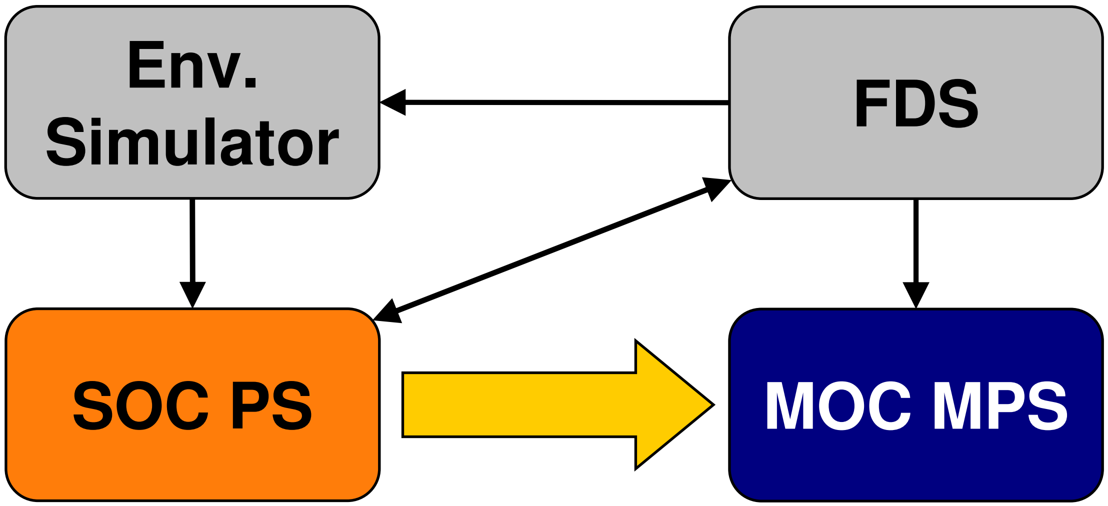
Mars/Venus-Express Planning Concept



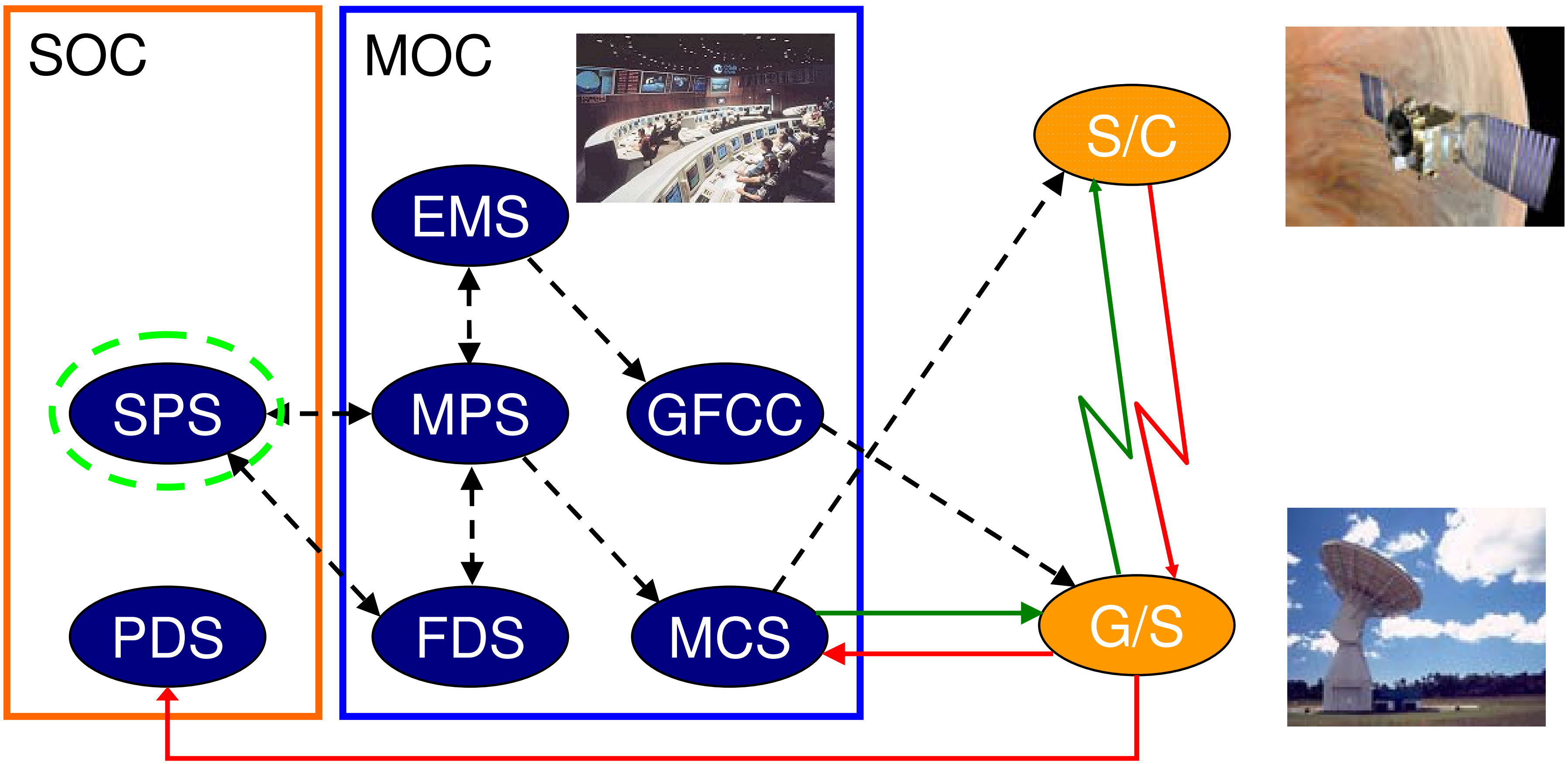
- Planning of science requests in order to maximise the science return

- Orbiter operations constraint checking
- Complex modelling of resources (thermal, power, memory)
- Spacecraft and station schedule generation

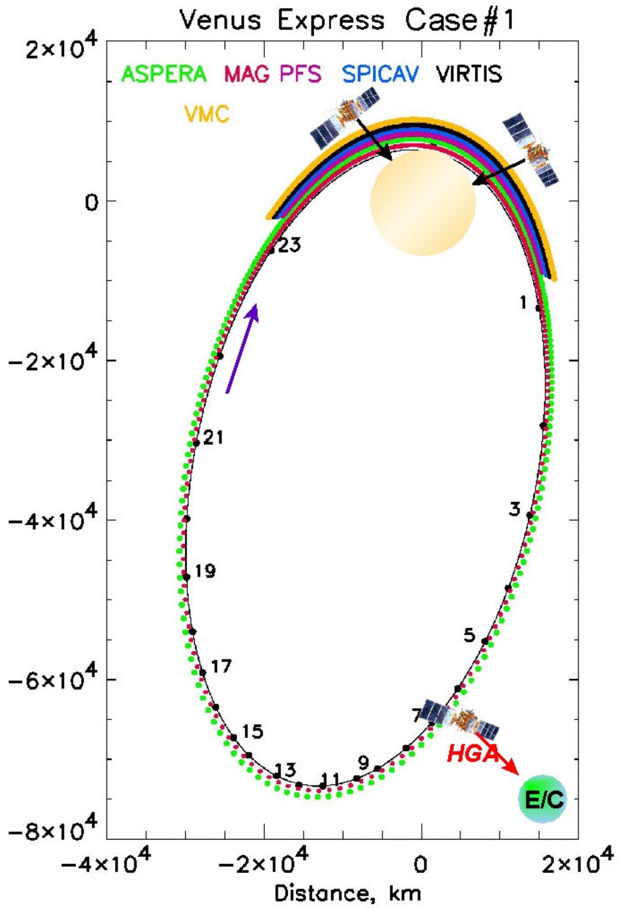
Mars/Venus-Express MOC Planning

- Check that external requests for observations do not exceed the resources (e.g. power, data) available to the spacecraft.
- Plan the Mars Express spacecraft operations according to the requests for operations generated by the Flight Control Team (FCT) and Flight Dynamics
- Generate the command schedule for the spacecraft and for the commanding/monitoring ground station
- Generate timeline event information for usage by the operators of the mission control system
- Report on the success of the planning and execution of the operations with respect to the plan

Mission Planning System



Mars/Venus-Express SOC Planning



- Identification of the Target of Opportunity Windows for the various observations requested by the Principal Investigators (PI's)
- Selection of the observations that maximize the mission return within the resource profiles
- Transfer of pointing timeline to FDS for checking
- Transfer of final science plan to MOC MPS for consolidation and final schedule generation

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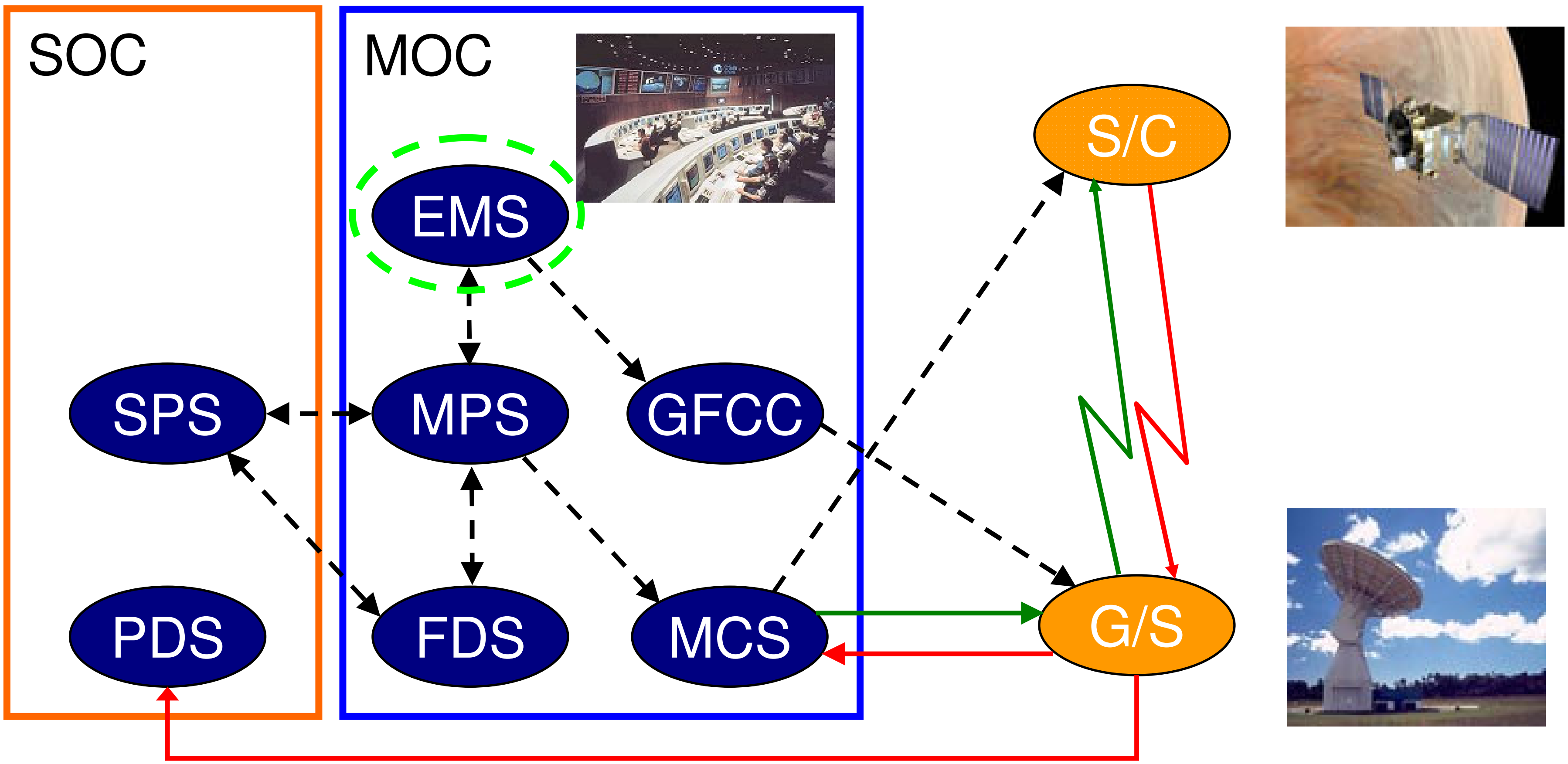
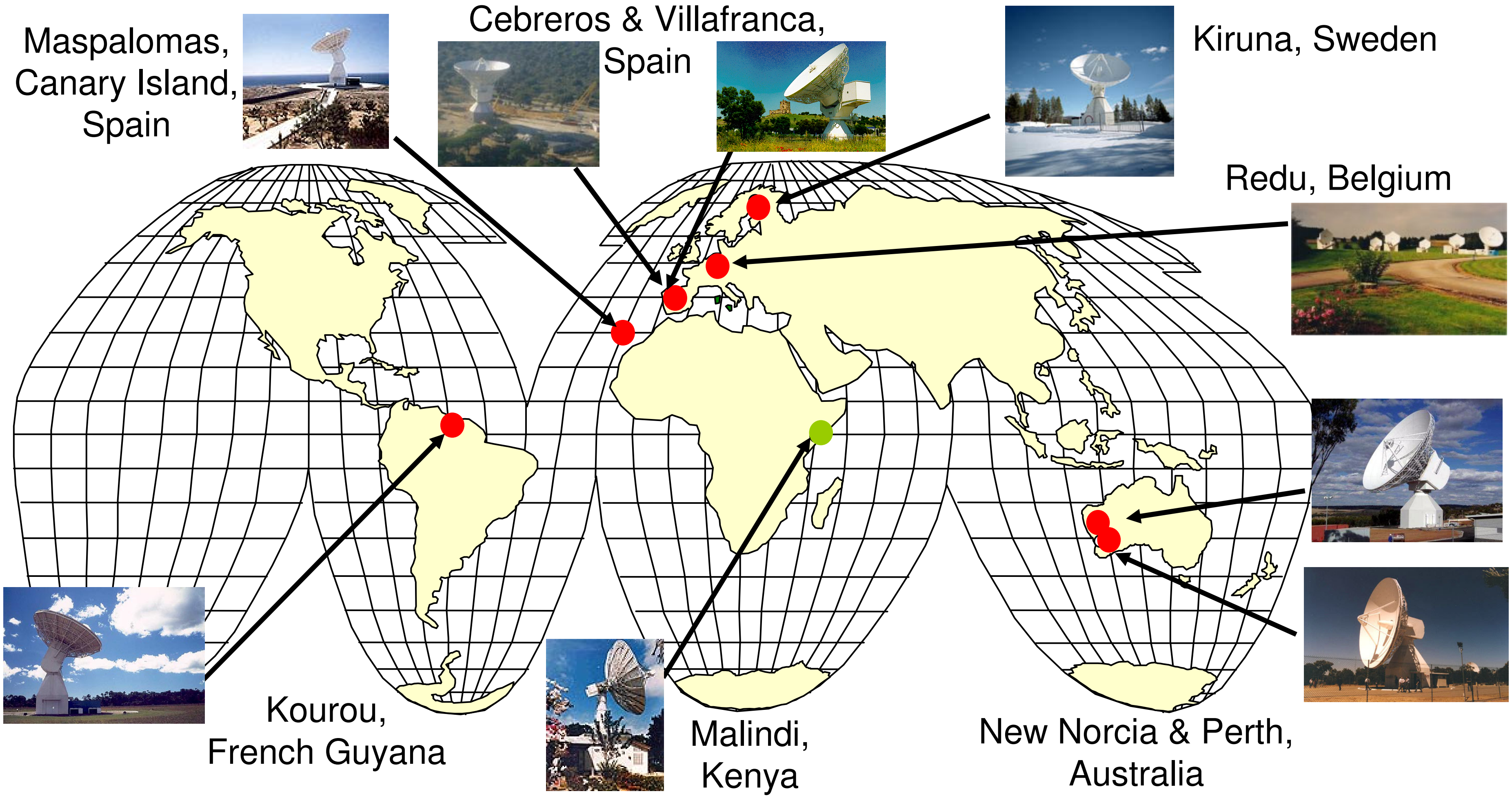
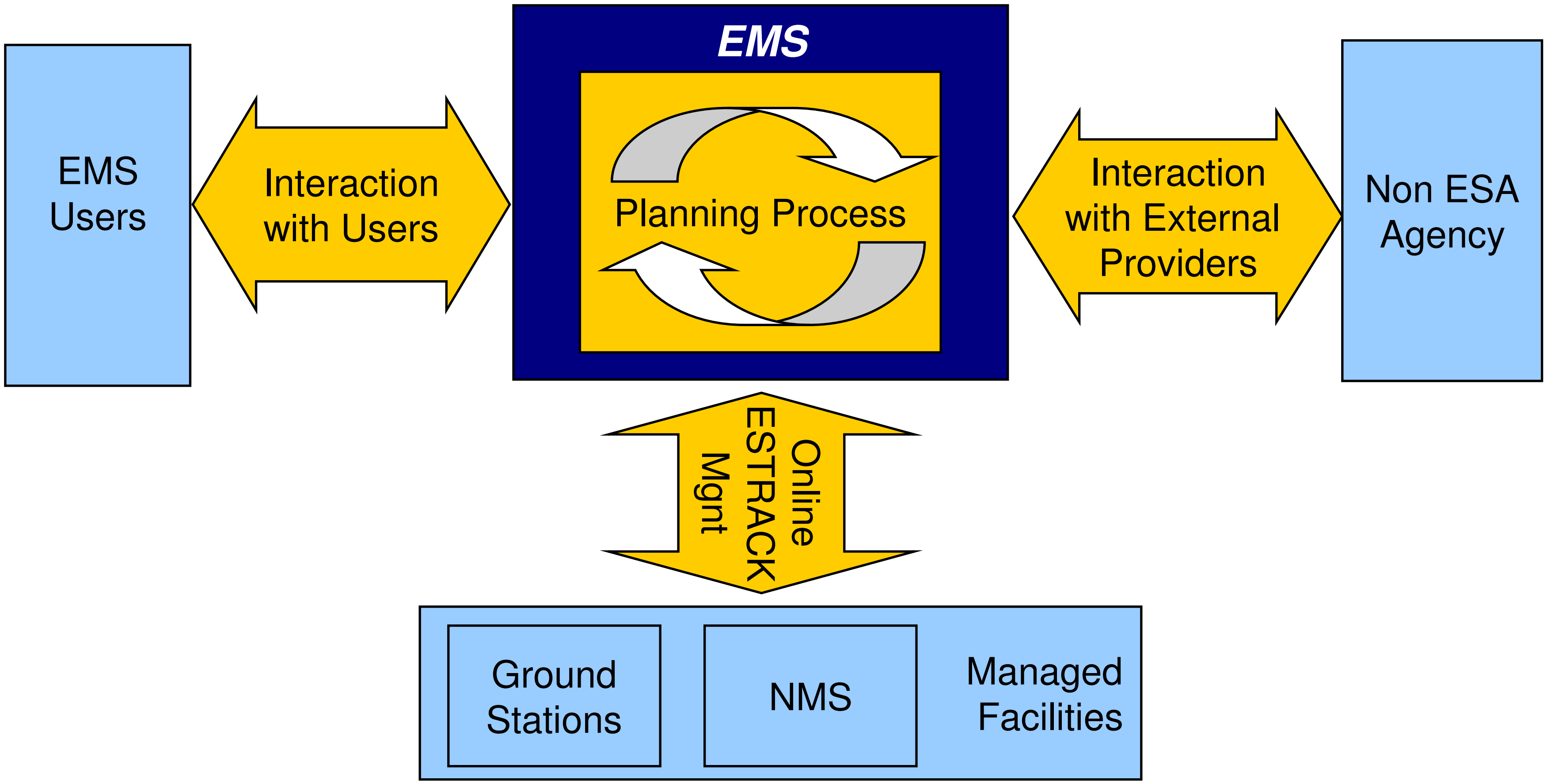
Mission Planning System



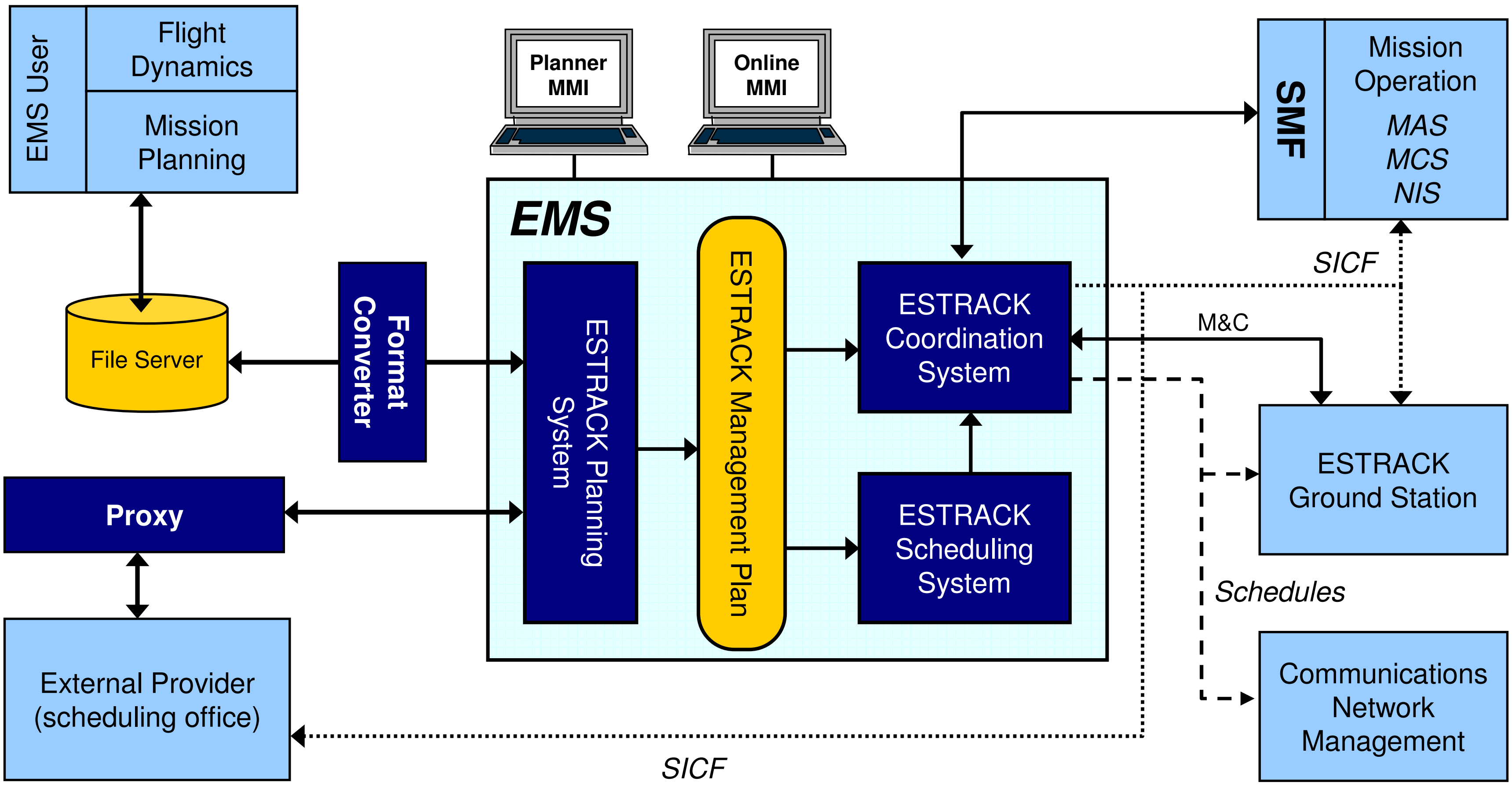
ESTRACK – ESA Tracking Network Overview



ESTRACK Management & Scheduling System



EMS in more details



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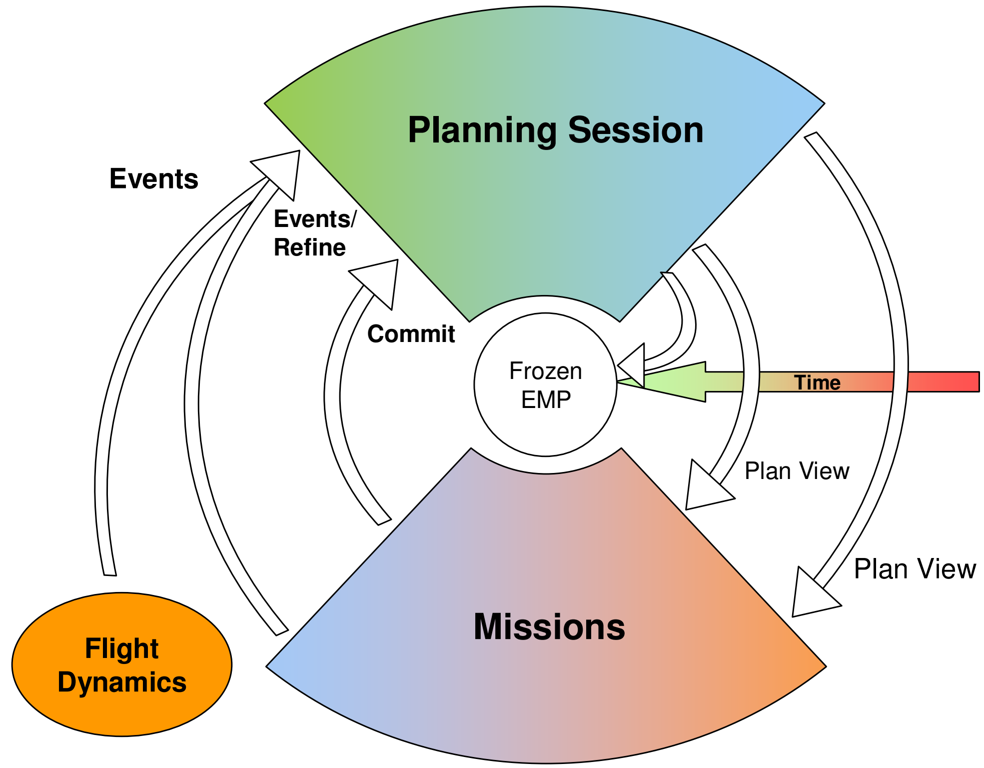
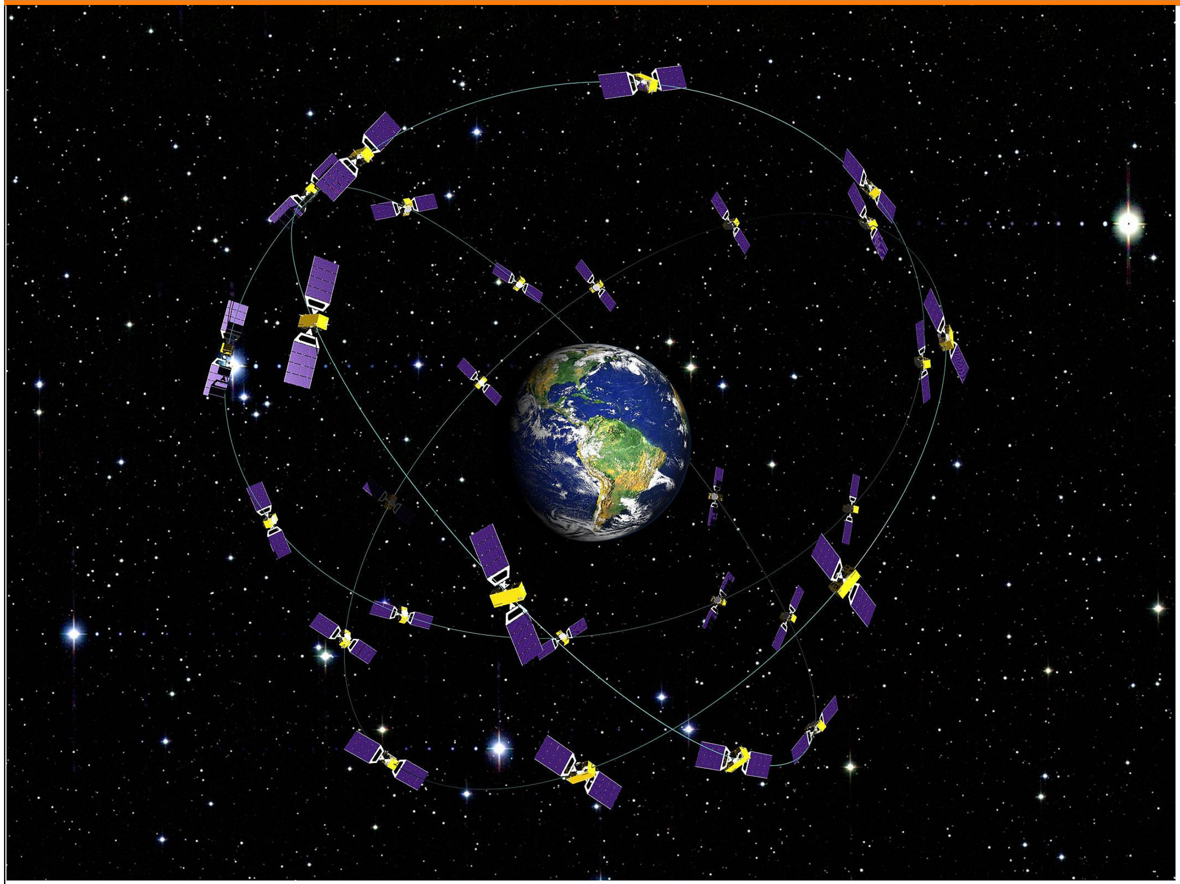
Dynamic use of the system

- Three levels
  - EMS system
  - Planning session
  - Planning run
- Plans are frozen one week before execution

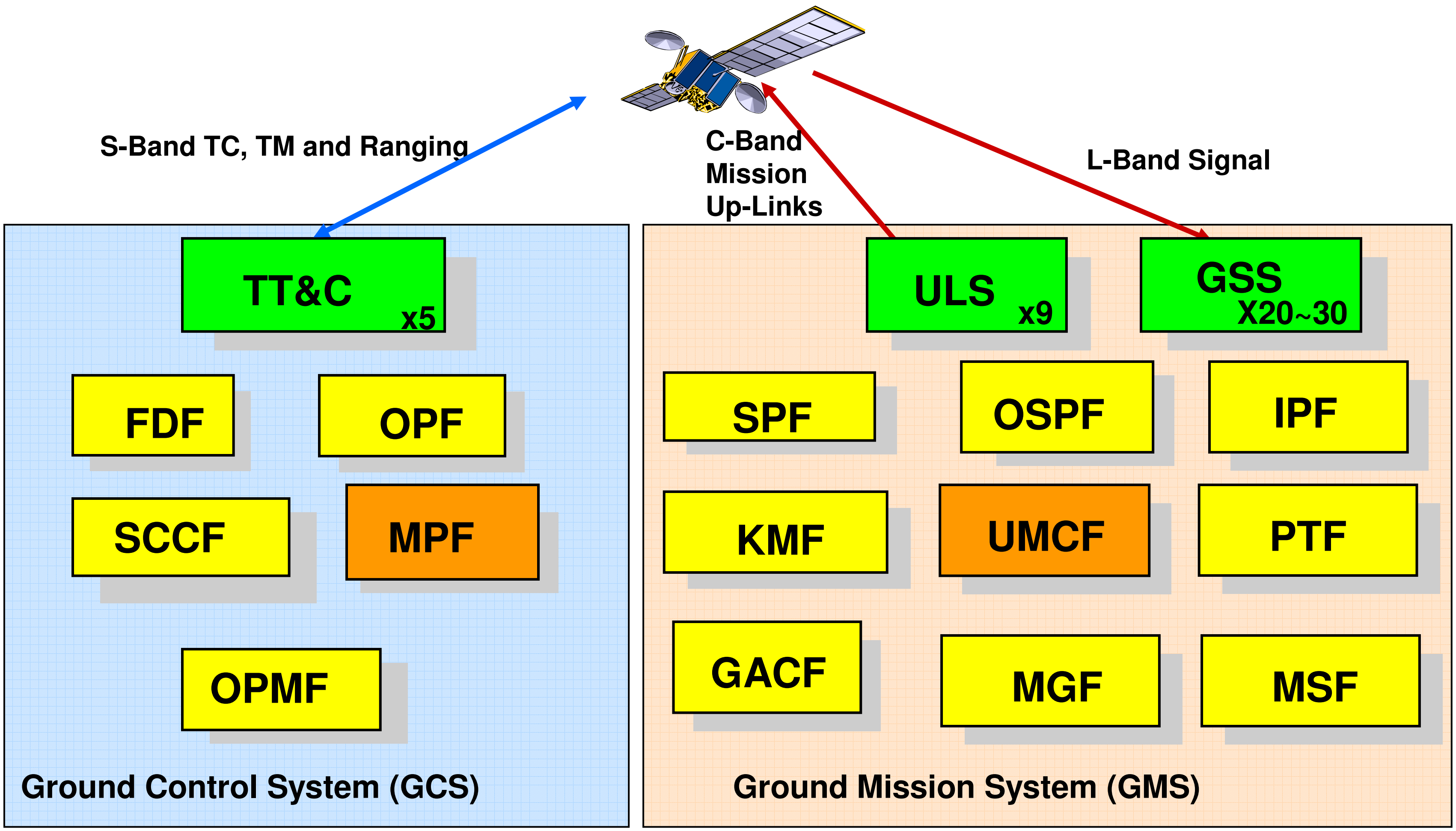


Navigation – Galileo



- European initiative to build a global positioning and navigation system
- Constellation of 30 MEO satellites
- 2 sub-constellations for service provision (navigation and integrity)

Galileo Ground Segment



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Galileo Planning Concept

- Covers planning of all system resources of both space and ground segment
- Operation to be planned
  - TT&C tracking and maintenance
  - ULS tracking and maintenance
  - On-Board S/C activities (ITC, TTC)
  - MCS activities (workspace planning, periodic archiving, configuration of client applications)
  - Special Operations (OBSM, On- Board Tests, Manoeuvre, Maintenance slots)
- 2 distinct planning processes
  - Control planning (MPF)
  - Uplink Scheduling (UMCF)

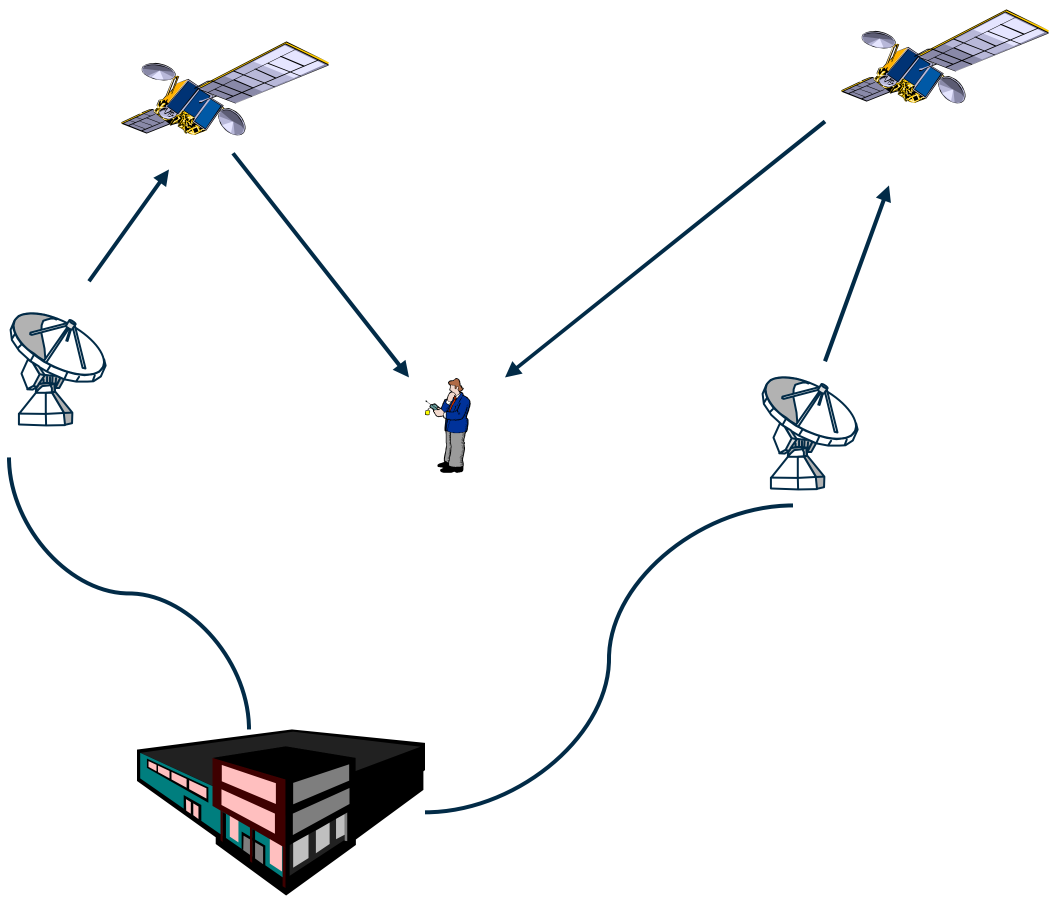
Galileo Contact Planning

- Contacts between the S-band TT&C stations and the satellites support the satellite routine operations and maintenance activities
- Contacts between the C-band ULS's and the satellites support the navigation and integrity services
- Independent problems with different characteristics

C-Band ULS Contact Planning

- Permanent contact with at least one ULS stations for each satellite of the integrity sub-constellation
- Contact of given duration at interval (specified in minutes or orbits; default: 1 min contact every 100 min) for each satellite of the navigation sub-constellation
- Each ULS station has a maximum of 4 heads
- Independent integrity paths to the user must be available
- Time for pre-pass operations and station handover must be included
- Integrity sub-constellation and visibility segments for the satellites of the sub-constellation are provided

Independent Paths to the User



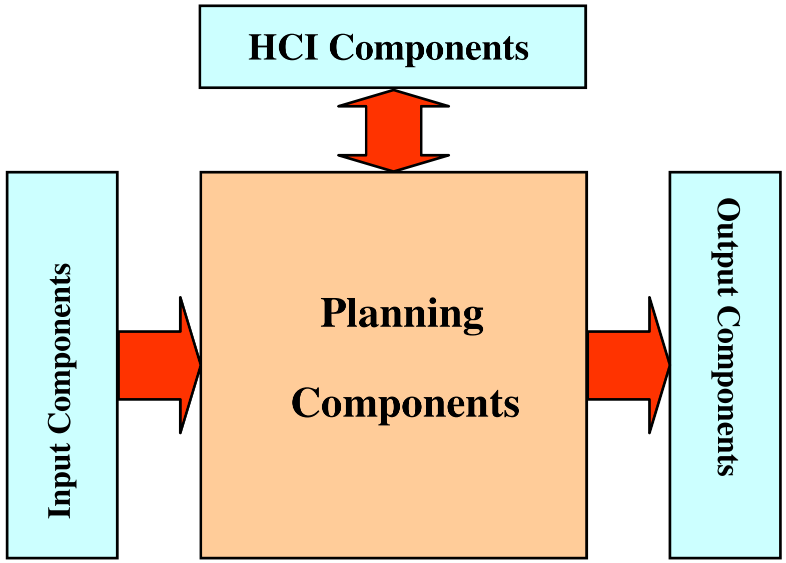
C-Band ULS Contact Planning

Ground software development at ESA

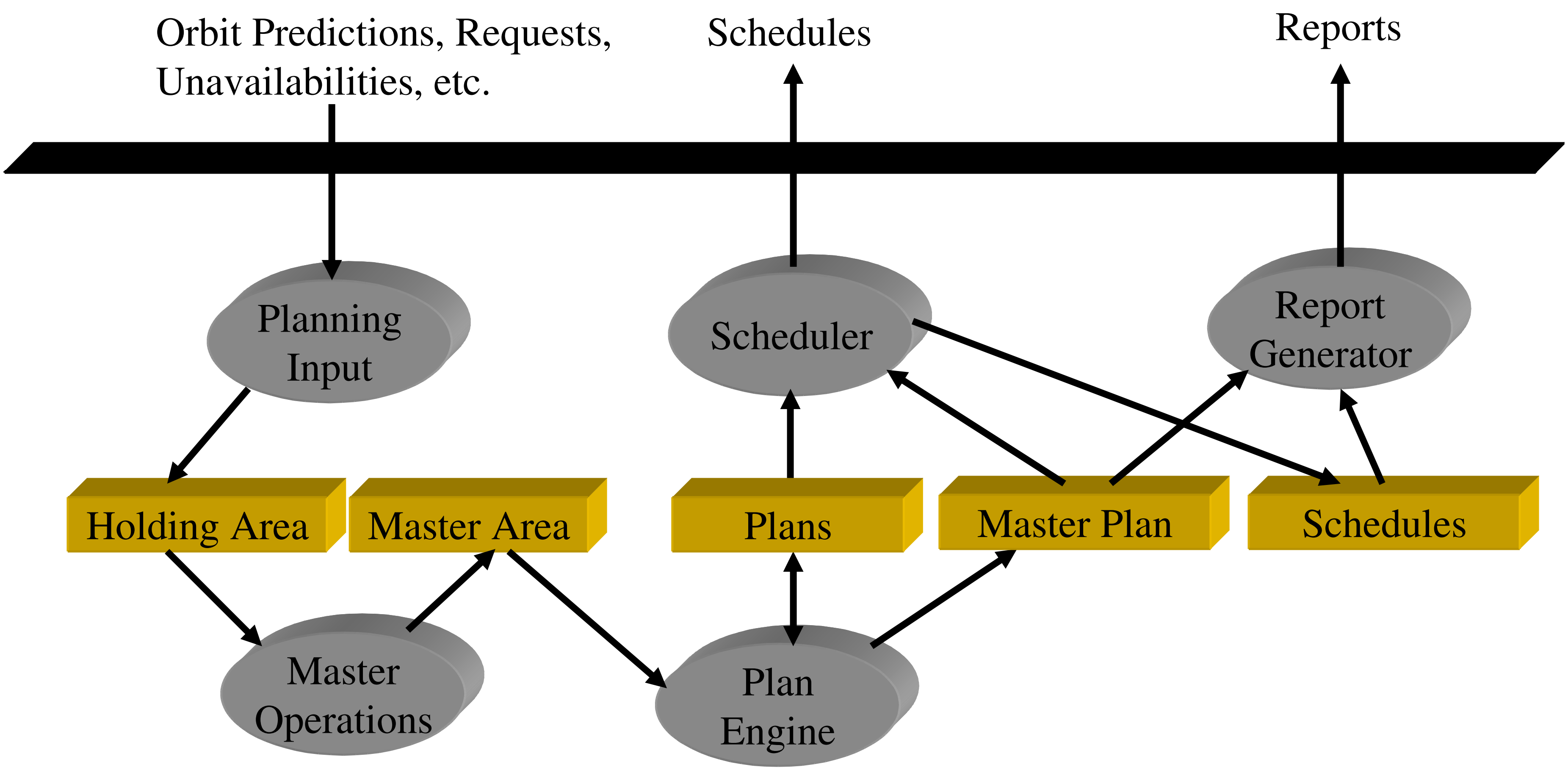
1. ESA issues a statement of work
2. Companies issue a bid
3. ESA selects a consortium
4. Software development
5. Testing and validation
6. Maintenance and upgrades

Modelling and Genericity
Mission planning systems framework: EKLOPS

- Kernel of configurable components
  - Based on results of ESA's study programmes on Generic Mission Planning
  - Provides the core of the functionality
  - Reduces the effort required for validation
- Design model close to the User's perception of the problem
  - No impedance mismatch between specification and design model
  - Control of impact of changes to the specification



Mission planning system design Functionalities

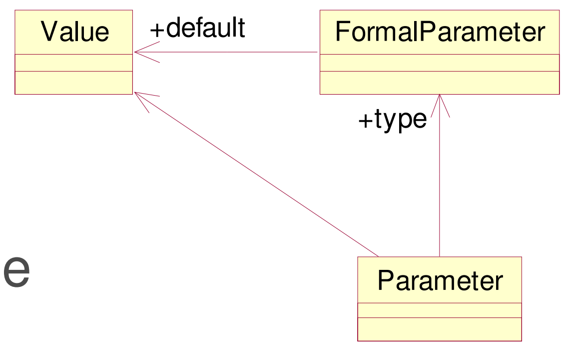


Mission planning system design
Basic Design Features

- Libraries of configurable C++ components
  - Mission Planning domain representation (plan, activity, resource, etc.)
  - Rule-based engine
  - XML-based system configuration
  - I/O filters (ingestion of input data, scheduling, reporting)
  - Human Computer Interface components (Timeline display, Resource Profile displays, Etc.)
- Routines for orbital data interpretation (zone visibility, station visibility, etc.)
- Planning of observation requests and generation of executable schedules for various targets (spacecraft, stations, personnel)
- Designed in UML with code skeleton generation

Mission planning system design
Key Elements

- Adaptive Object Model
- Function is defined through metadata
- Parameter model to represent metadata
- Variable aspects of a mission are configurable (activities, occurrences, commands, rules)
- Configuration data held in database – XML interface
- Rule Based system
- Rule definition language
- Integration of a distributed planning system



Mission planning system design
Language for Mission Planning

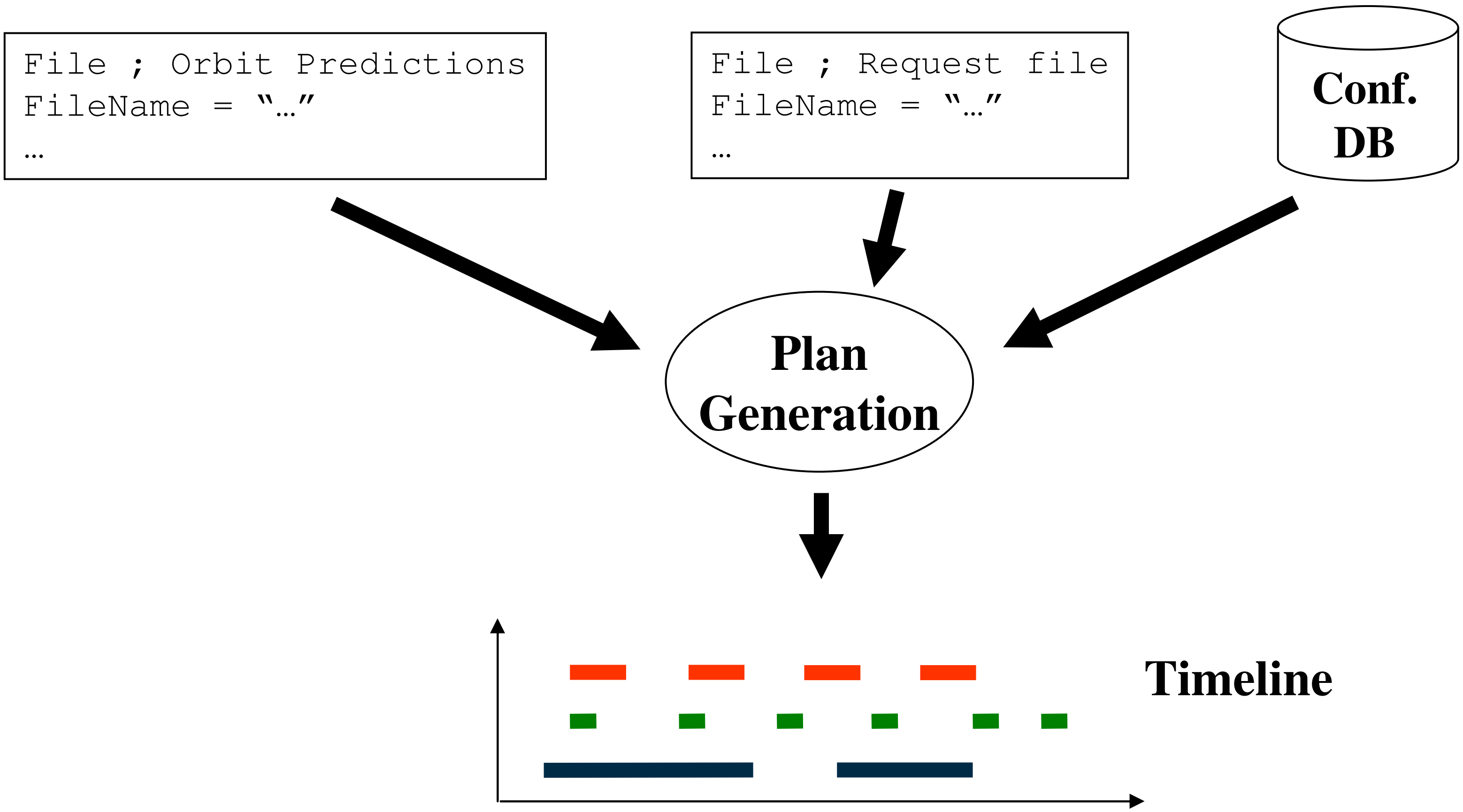
- Result of an ESA study to develop a MPS Domain Specific Language (DSL)
- Language to express planning constraints
- A rule can be defined without modifying the code
- Expressions are translated to XML
- XML configuration

Mission planning system design
Logical Language Summary

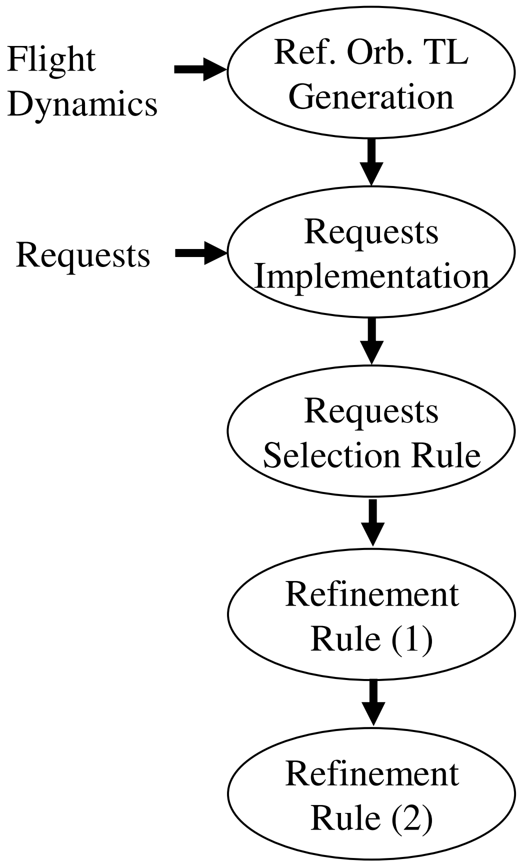
- Selectors for items on the plan: *activity, fact, nextFact, lastFact*
- Temporal predicates: *precedes, meets, overlaps, inRange*
- Comparison operators: *==, <>, <, >, >=, <=*
- Mathematical Operators: +, -, *, /
- Logical connectors: *AND, NOT*
- Variables: *?X*

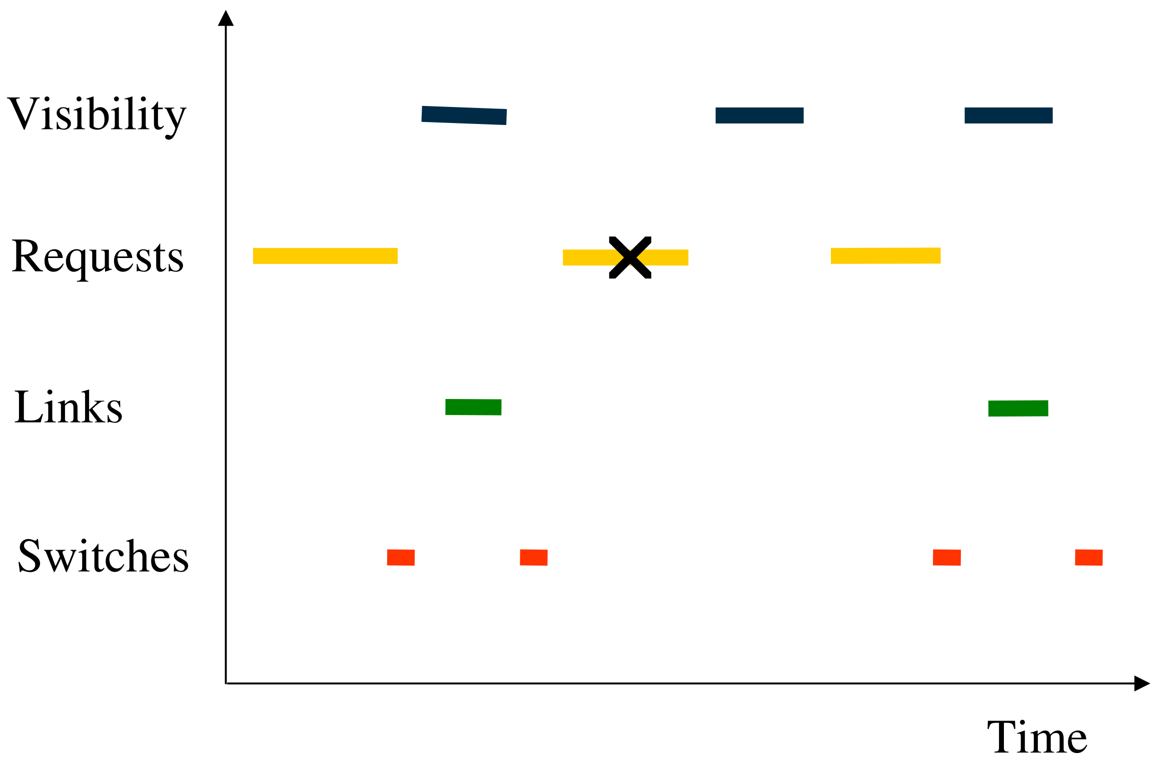
```
fact(?id1, target_visibility, TARGET A, ?tvS, ?tvE)
^ fact(?id2, target_illumination, TARGET A, ?tiS, ?tiE,)
^ overlaps( ?tiS, ?tiE, ?tvS, ?tvE, ?toS, ?toE )
-> activity( ?newId, operation_A, TOW, ?toS, ?toE)
```

Mission planning system design
Example Planning Logic

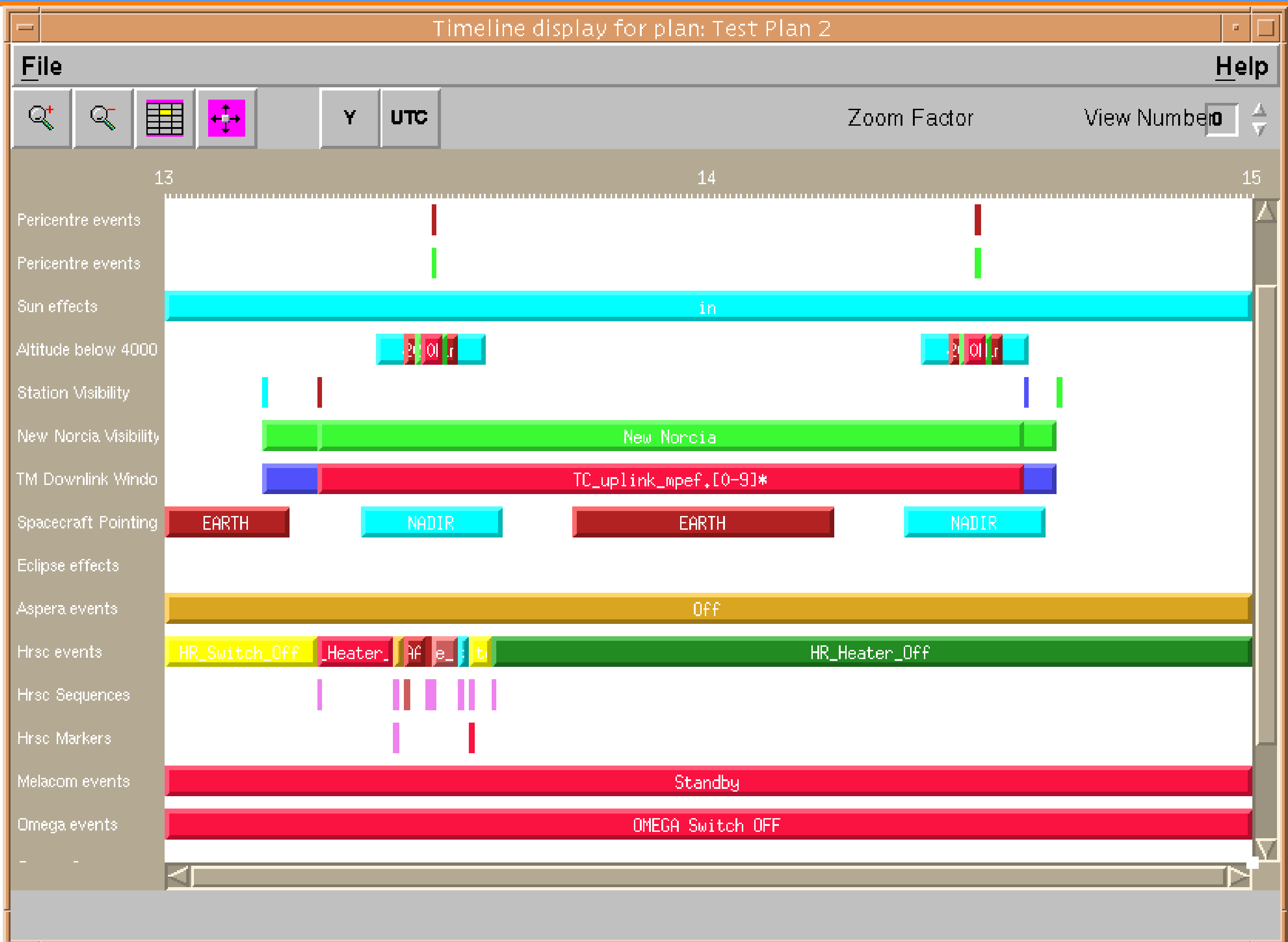


Mission planning system design
Planning Process

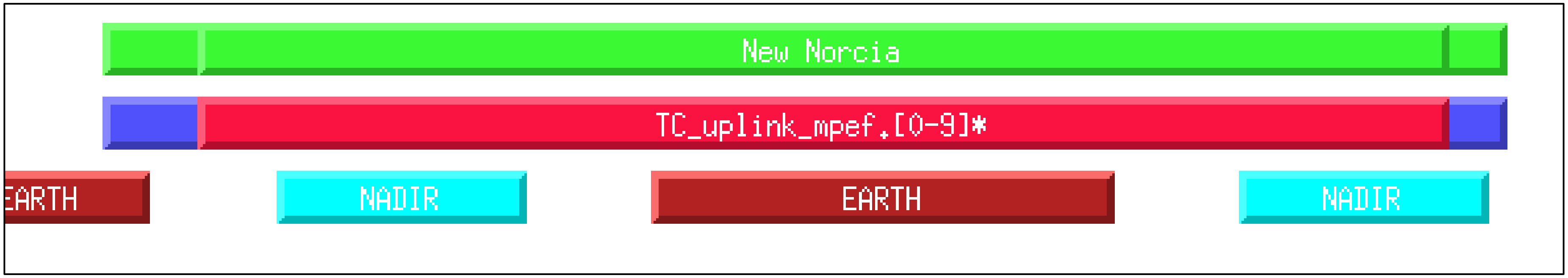




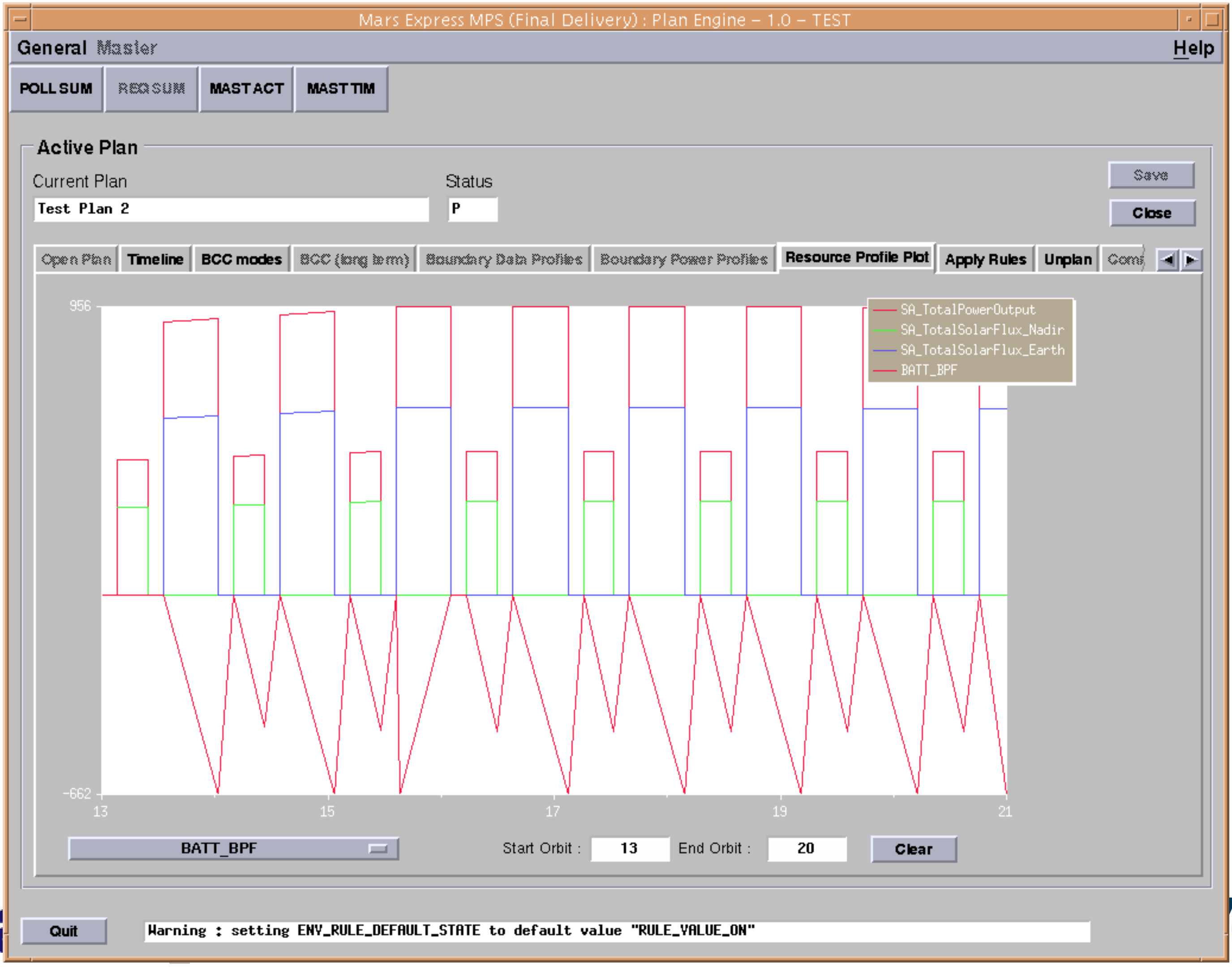
Mission planning system design
Timeline Display



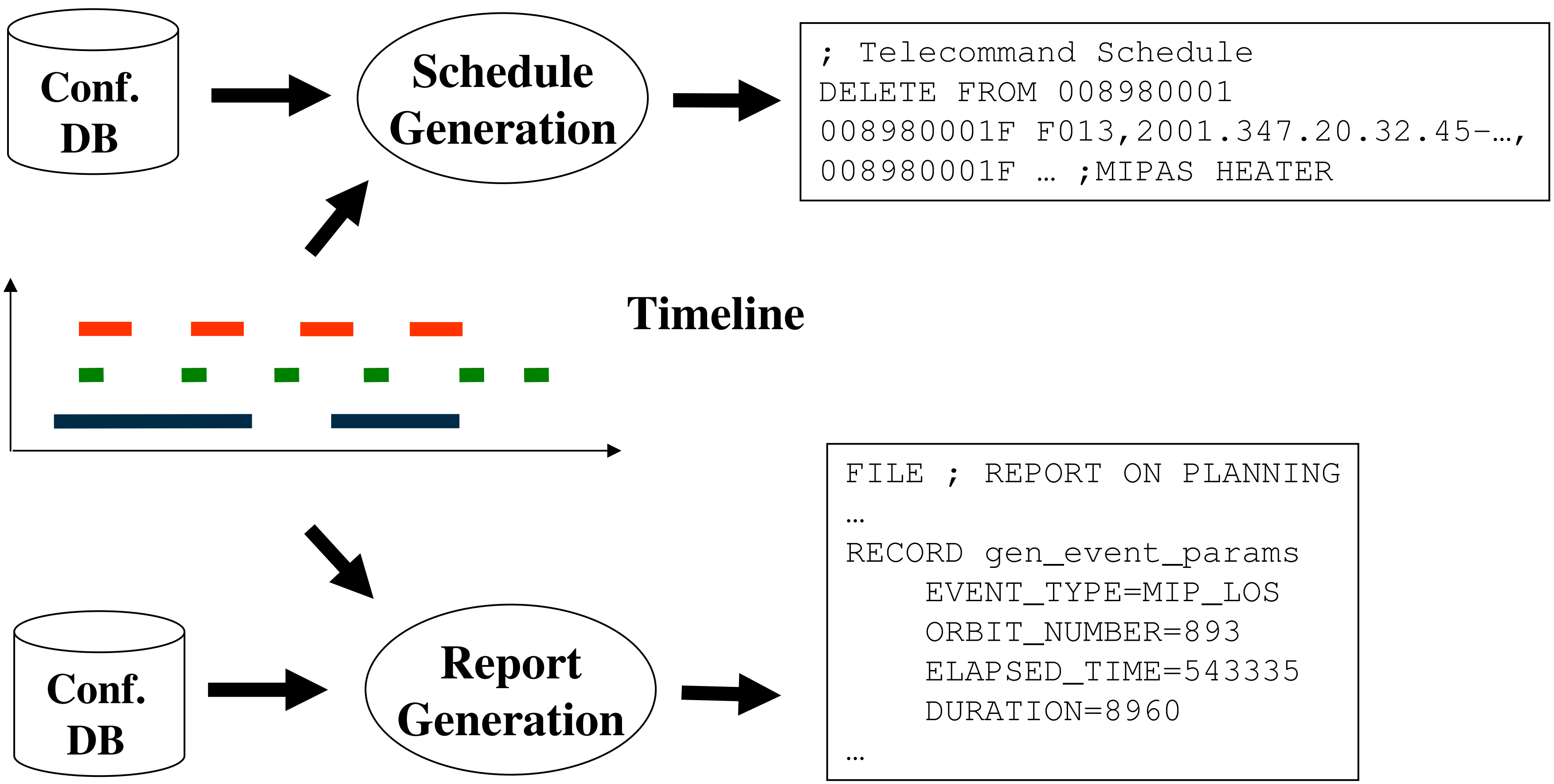
Mission planning system design
Timeline Display (detail)



Mission planning system design
Resource Profile Display



Mission planning system design
Scheduling and Reporting



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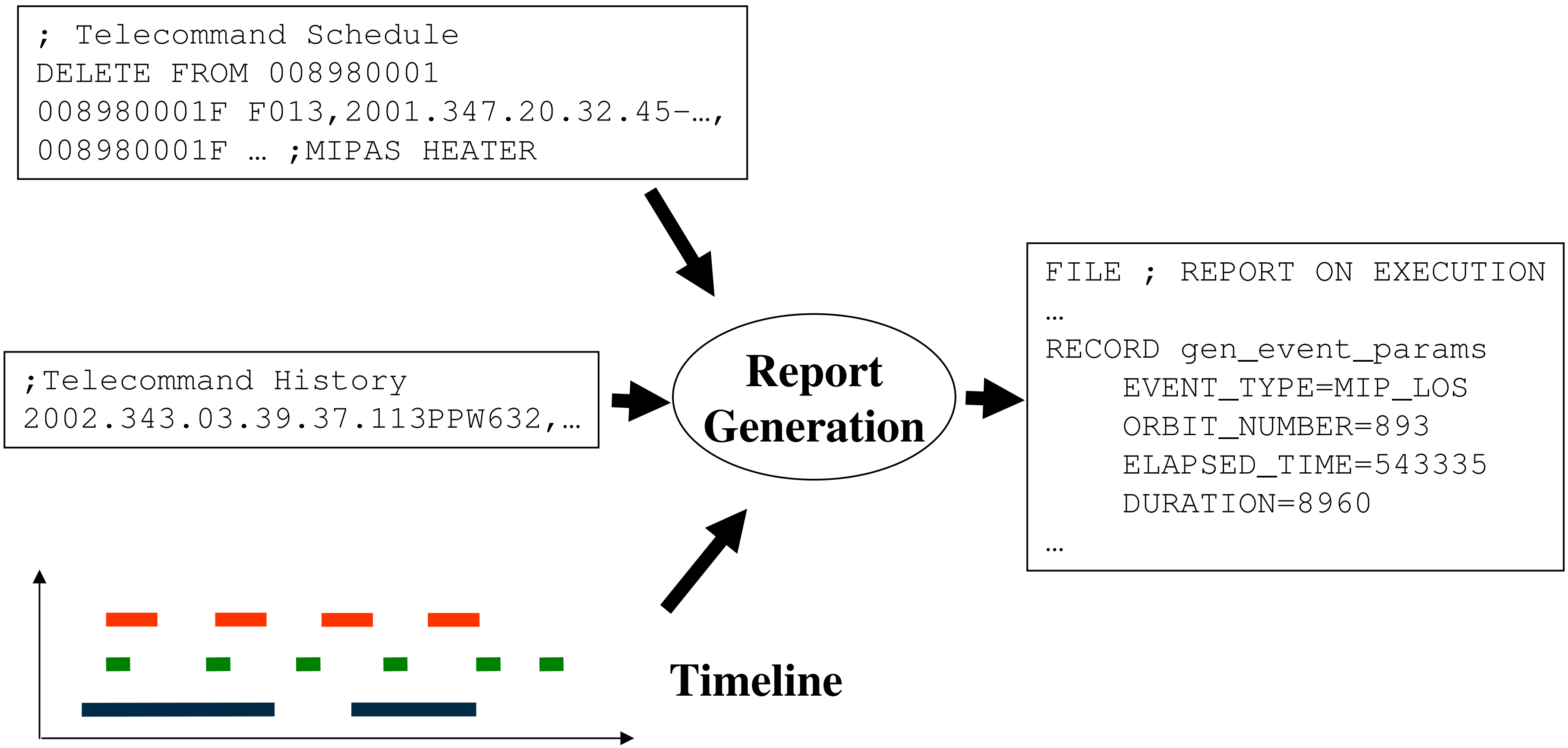
Mission planning system design
Reporting after Execution



Modelling and Genericity
Planning problems definition and modelling approaches

- Representation
  - Classical planning: goals, actions, domain
  - + time – temporal planning
  - + resources -> scheduling
  - + uncertainty -> probabilistic / fuzzy / conformant planning
  - + criteria -> optimisation
- Context
  - Localisation of the planning agent in the system
  - Off-line / On-line
- Complexity
  - Plan validation
  - Plan existence
  - Plan creation
- Solving
  - Often translation into a different representation
  - Search; different search spaces
  - Optimisation

Modelling and Genericity
Example of planning problem: domain

```
(define (domain vehicle)
 (:requirements :strips :typing)
 (:types vehicle location fuel-level)
 (:predicates (at ?v - vehicle ?p - location)
              (fuel ?v - vehicle ?f - fuel-level)
              (accessible ?v - vehicle ?p1 ?p2 - location)
              (next ?f1 ?f2 - fuel-level))

 (:action drive
   :parameters (?v - vehicle ?from ?to - location
                ?fbefore ?fafter - fuel-level)
   :precondition (and (at ?v ?from)
                      (accessible ?v ?from ?to)
                      (fuel ?v ?fbefore)
                      (next ?fbefore ?fafter))
   :effect (and (not (at ?v ?from))
                (at ?v ?to)
                (not (fuel ?v ?fbefore))
                (fuel ?v ?fafter))
 )
)
```

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Modelling and Genericity
Example of planning problem: problem

```
(define (problem vehicle-example)
 (:domain vehicle)
 (:objects
      truck car - vehicle
      full half empty - fuel-level
      Paris Berlin Rome Madrid - location)
 (:init
      (at truck Rome)
      (at car Paris)
      (fuel truck half)
      (fuel car full)
      (next full half)
      (next half empty)
      (accessible car Paris Berlin)
      (accessible car Berlin Rome)
      (accessible car Rome Madrid)
      (acessible truck Rome Paris)
      (accessible truck Rome Berlin)
      (accessible truck Berlin Paris)
 )
 (:goal (and (at truck Paris)
             (at car Rome))
 )
)
```

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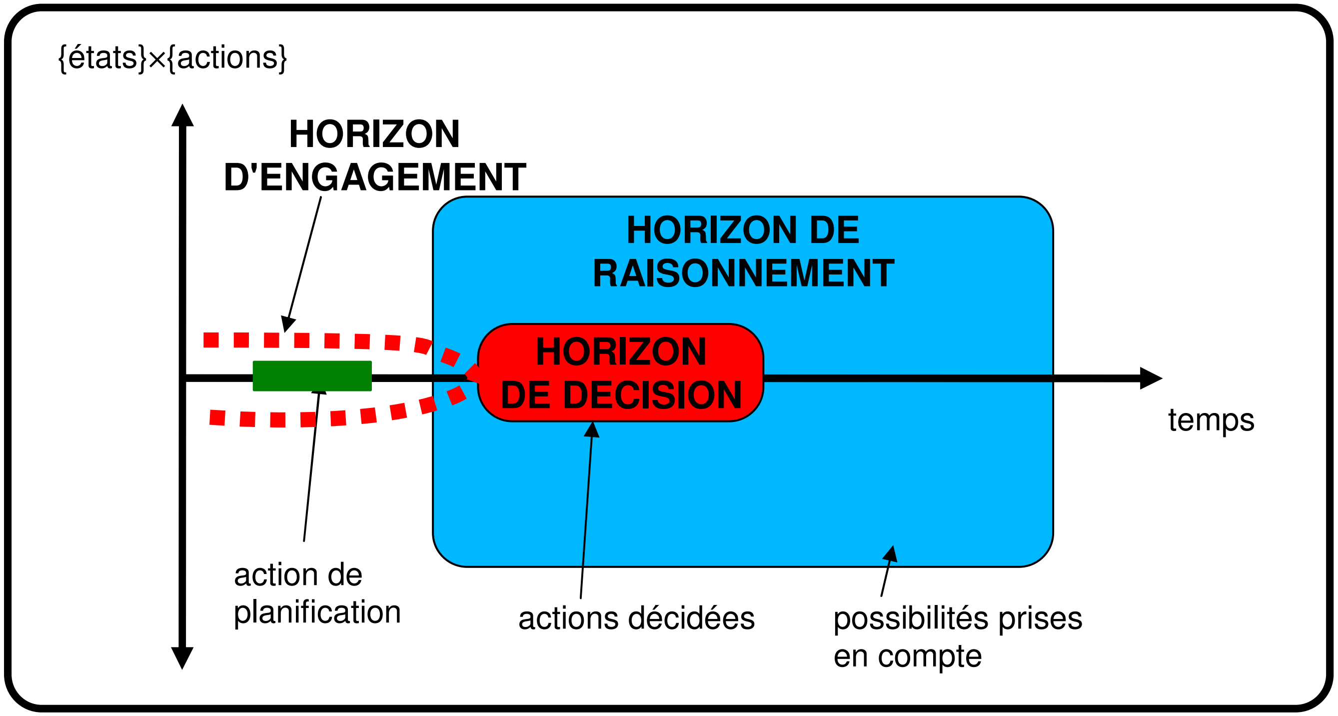
Situation temporelle de l'action de planification



Modelling and Genericity Characteristics of space applications

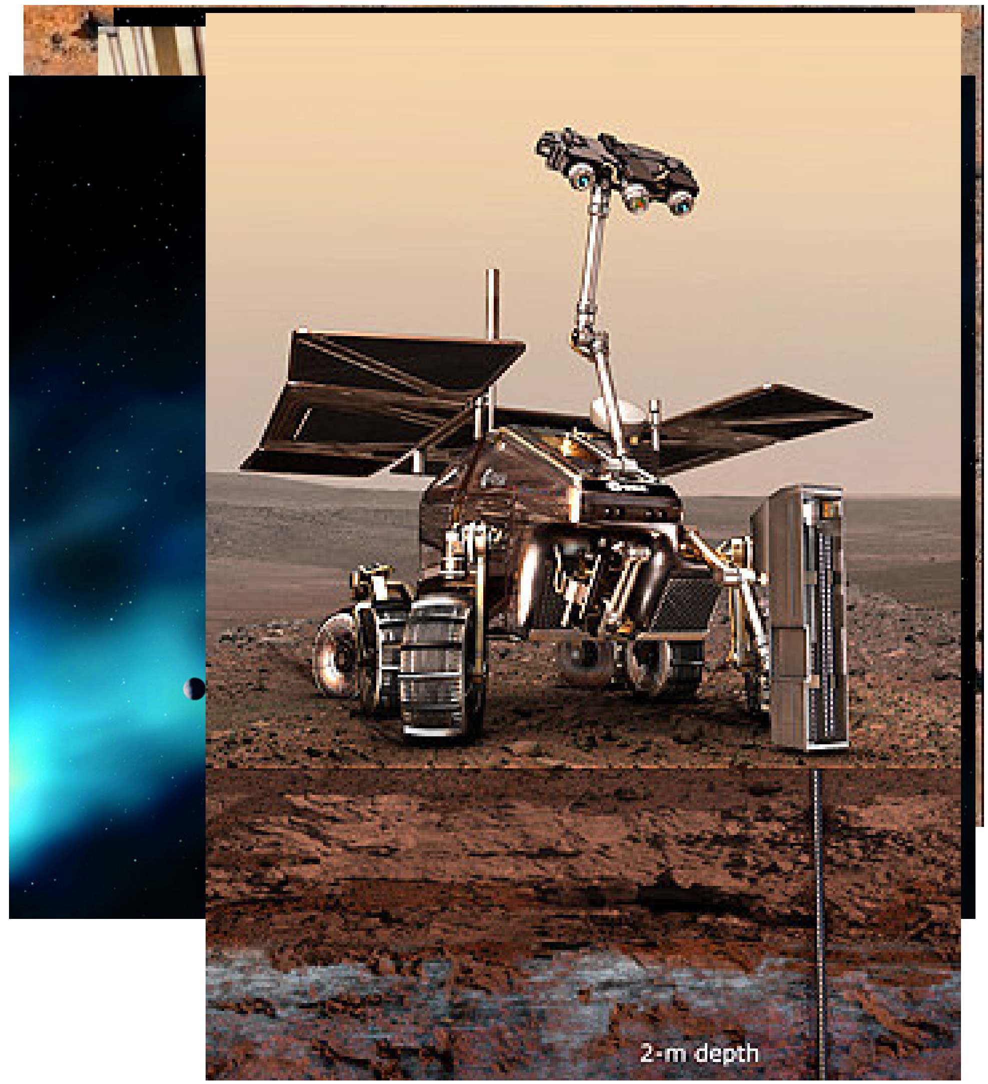
- All extensions may be necessary
  - Goals *observe zone A*
  - Actions *switch on instrument I*
  - Time *during 11 seconds*
  - Resources *power, memory, instruments*
  - Uncertainty *cloud coverage of the zone to observe*
  - Criteria *high priority*
  - Real-time context (on-board) *next opportunity in 5 minutes*
  - + complex transitions models *slew duration between angle a and angle b*
  - + hierarchy of tasks *heat up instrument, observe, store data*
  - + exogenous events *illumination periods*
- High complexity
- ESA initiative for AI planning framework (APSI)
  - Provide representations
  - Provide interfaces with solvers

On-Board Mission Planning Rationale

- Re-distribution of planning capabilities
- Ratio reactivity requirements and uncertainty / communications
  - Ex: watching satellites
- Improve scientific productivity
  - Ex: on-board resource optimisation
- Lower the cost of the ground segment
  - Ex: on-board AOCS

On-Board Mission Planning
Implementations / prototypes / future projects

- Past
  - Deep Space One (NASA)
  - Earth Observing One (NASA)
  - Mars Exploration Rovers (NASA)
  - Proba One (ESA)
  - Demeter (CNES)
- Prototyped
  - Beagle (ESA)
- Future projects
  - Exomars (ESA)
  - Formations



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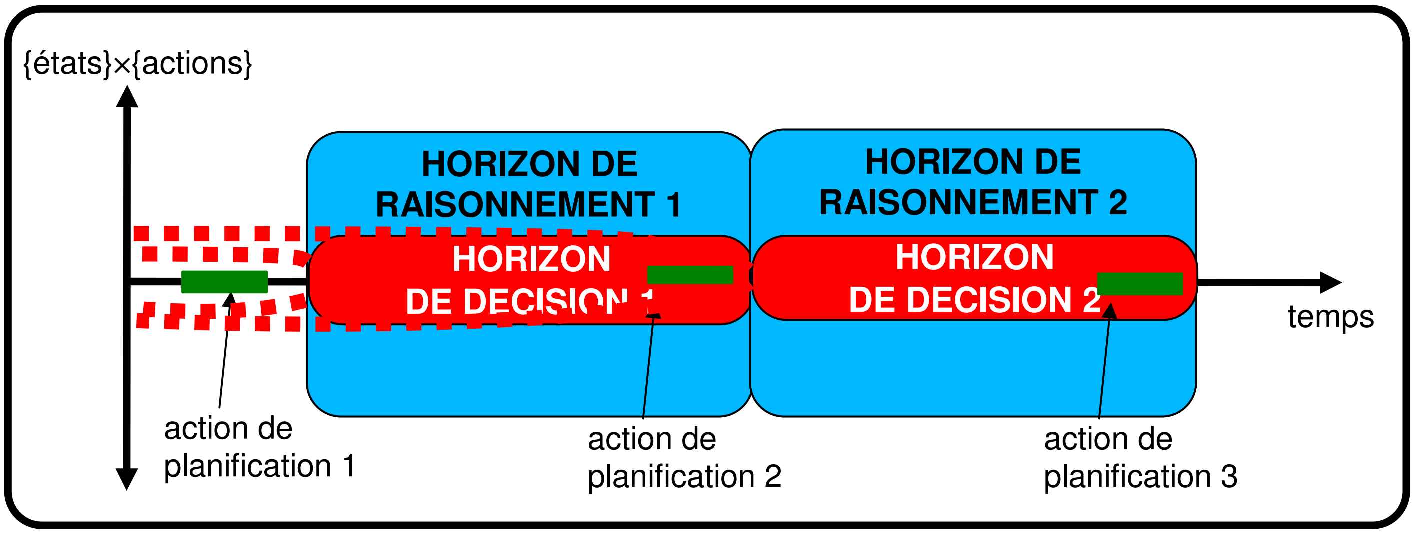
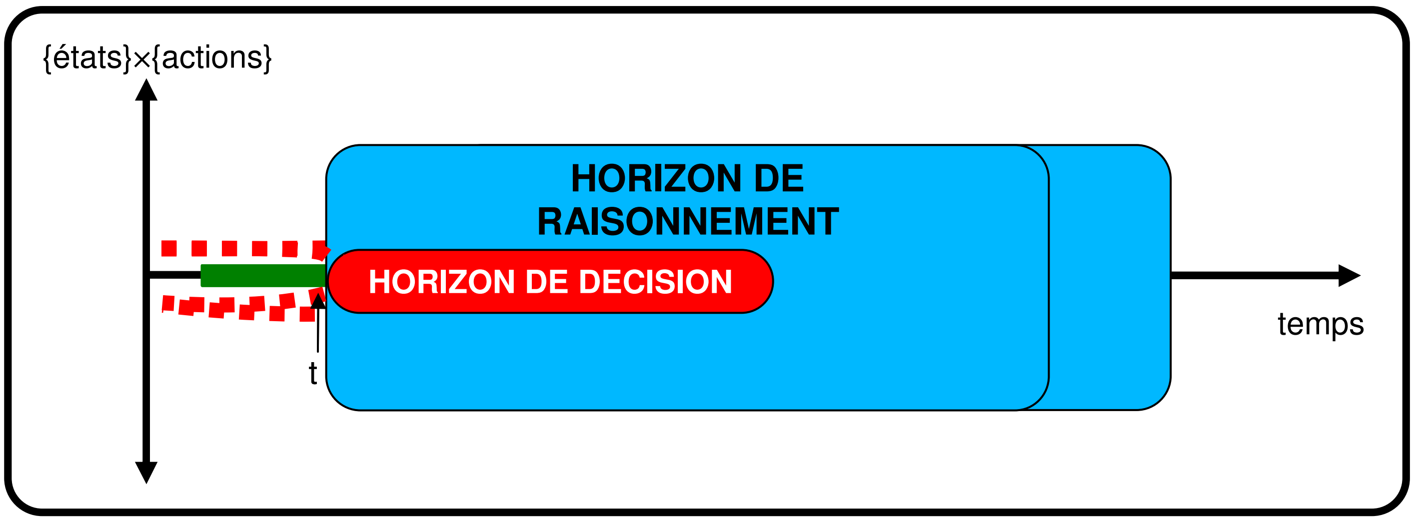
On-Board Mission Planning
Planning on Deep Space One



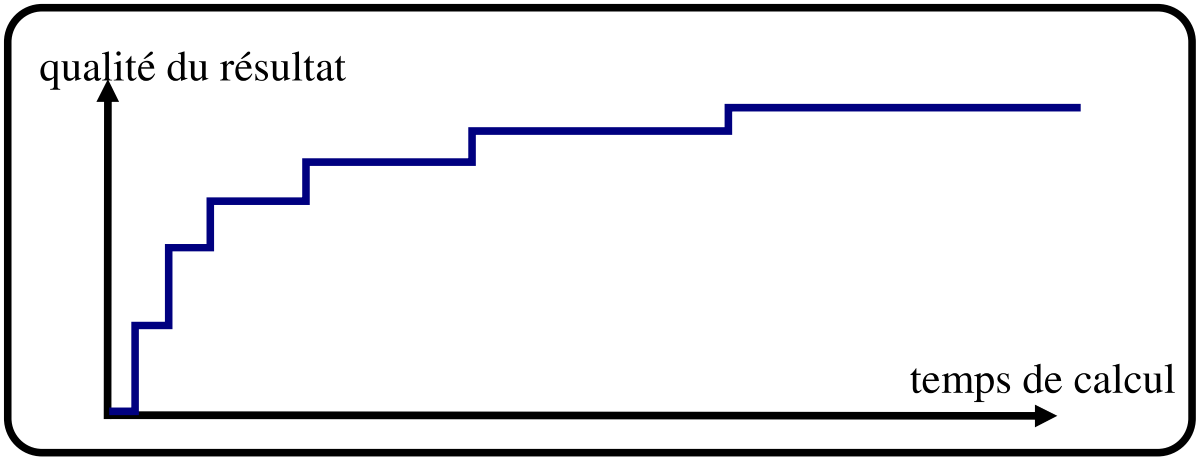
On-Board Mission Planning
Planning on Earth Observing One



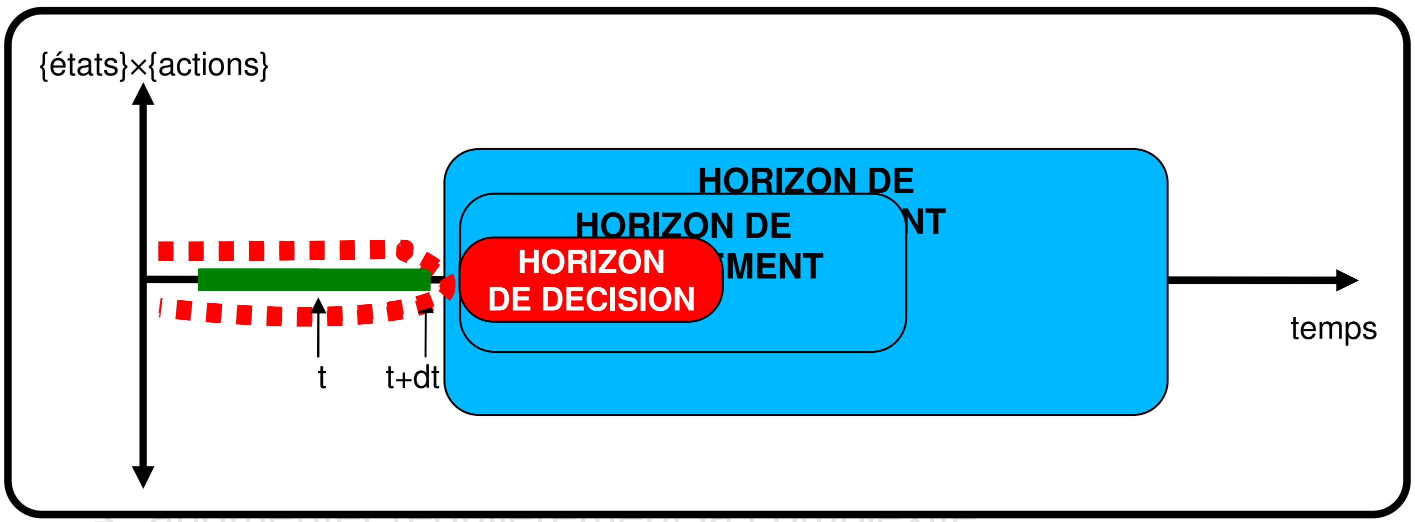
On-Board Mission Planning
Planning in highly dynamic contexts

- Produce a valid decision on time
- Policies
- Decision rules
- Anytime algorithms
  - Ex. Local search

Anytime algorithms



On-Board Mission Planning
Planning in highly dynamical contexts



- augmenter régulièrement la complexité
- lorsqu'un instant de décision est atteint, utiliser le résultat courant pour décider de l'action à entreprendre