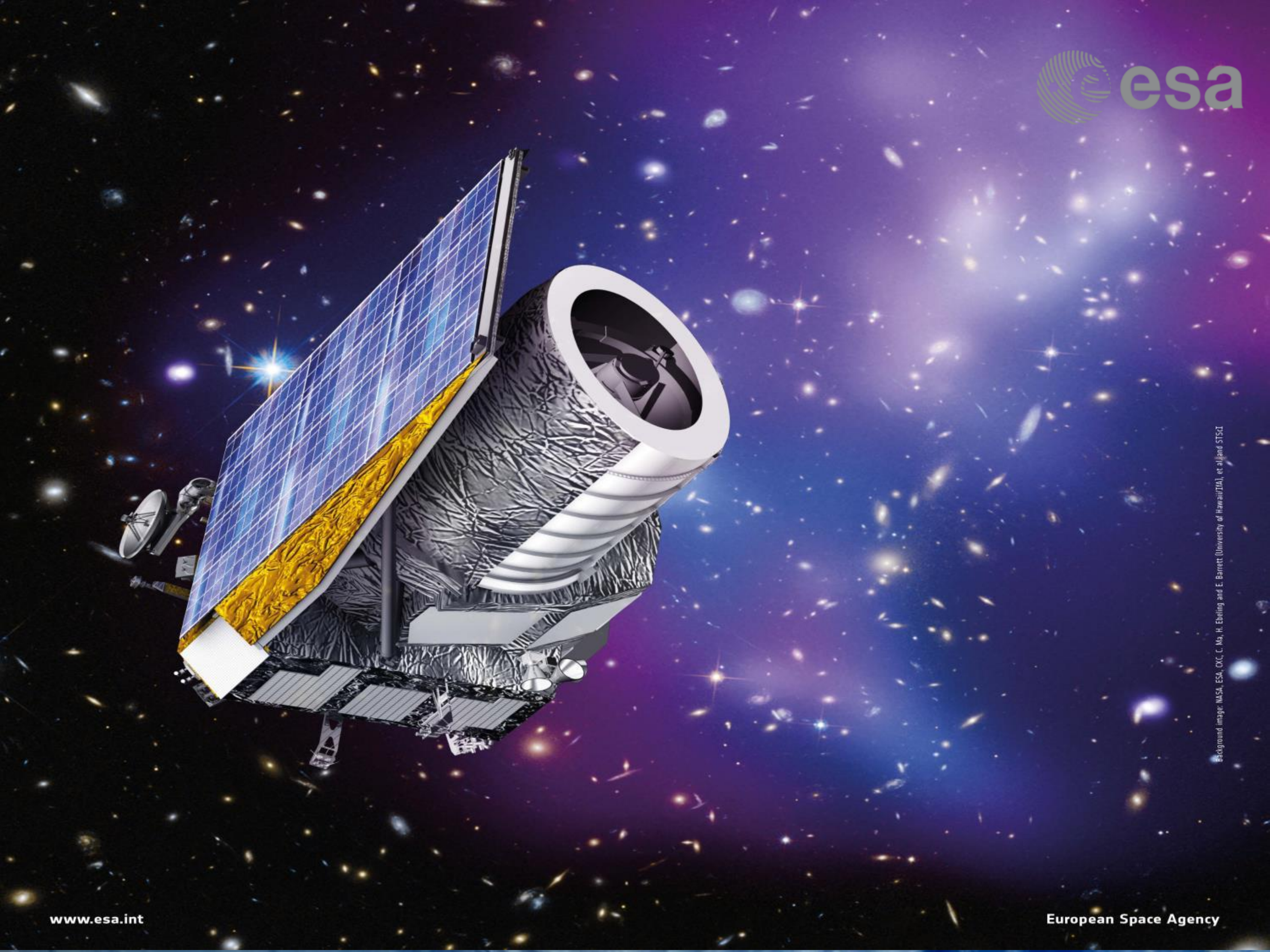
MBSE approach for the Euclid mission: Benefits and lessons learned (so far)

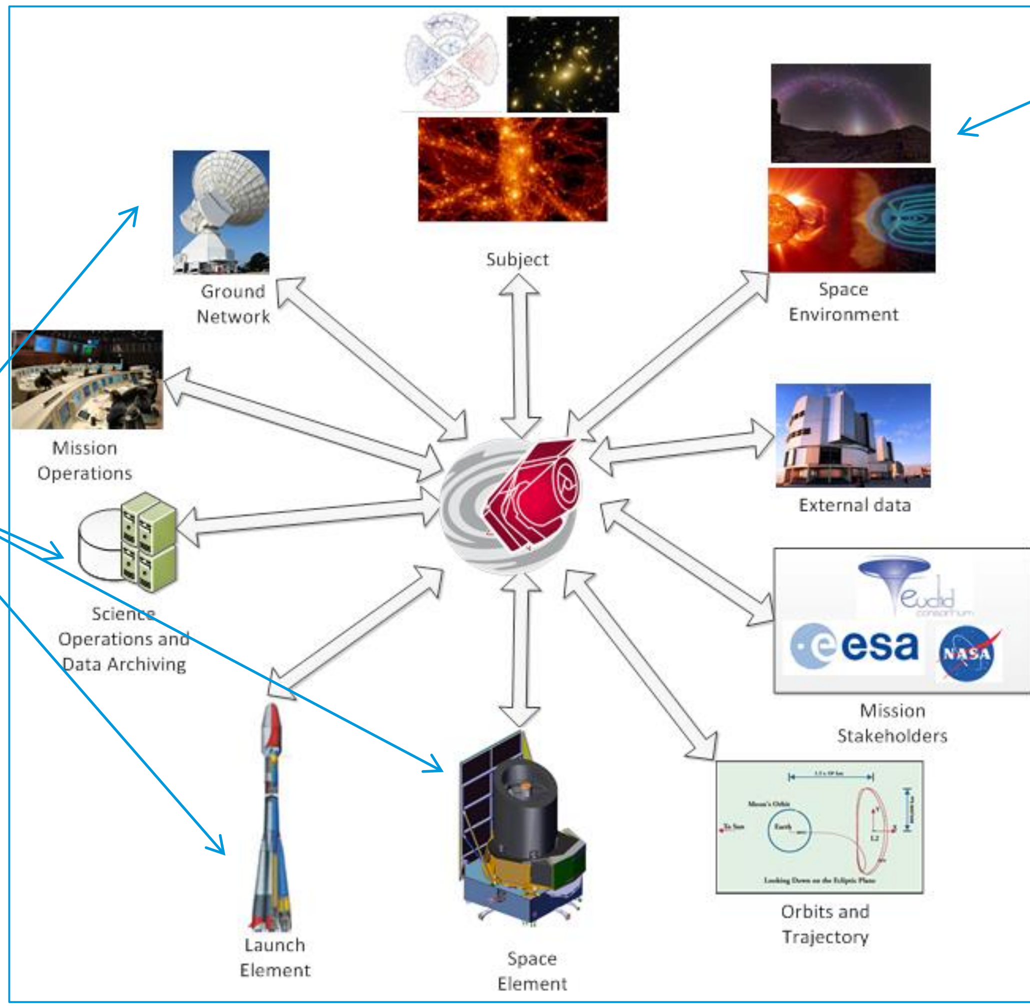
J. Lorenzo Alvarez, H. Metselaar, M. Kretzenbacher (ESA)

INCOSE IW 2017, Torrance, CA, 28-31 Jan 2017


esa
Background image: NASA, ESA, CXC, C. Ma, H. Ebeling and E. Barrett (University of Hawaii/IfA), et al. and STScI
www.esa.int
European Space Agency

Mission Complexity definition

Mission context



Multiple configured elements

Architectural complexity

High number of requirement interrelations

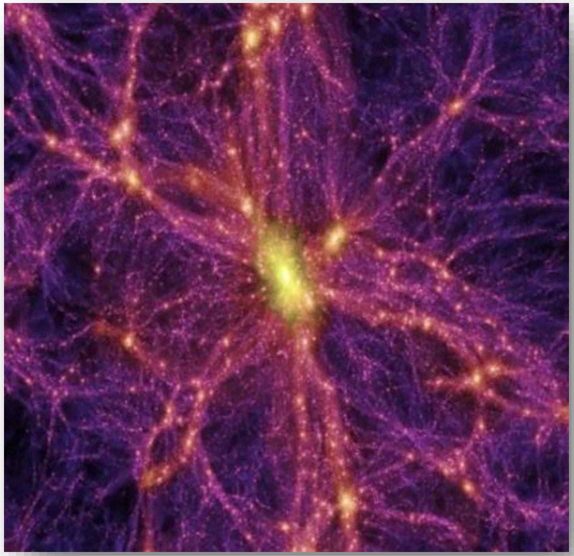
Scientific complexity

Multiple distributed actors

Organizational complexity

Requirement complexity

Euclid Mission Objectives

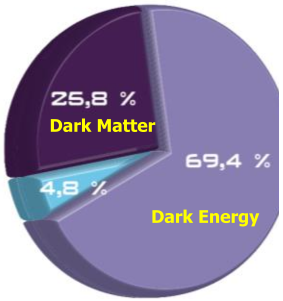


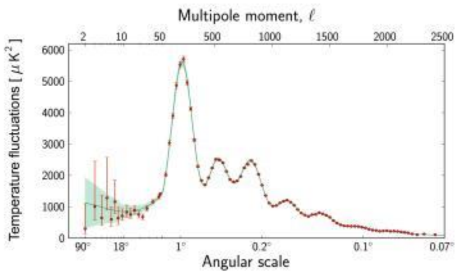
The Euclid Mission will measure the universe expansion history and growth of large-scale structure with a precision that will allow to distinguish time-evolving dark energy models from a cosmological constant, and to test the theory of gravity on cosmological scales. In addition it will constrain the initial conditions in the very early Universe, by determining the statistical distribution of the primordial density fluctuations with high precision, on scales that cannot be probed using observations of the cosmic microwave background (CMB).

The mission will address the following four key cosmological questions:

- ***Dynamical Dark Energy**: Is the dark energy simply a cosmological constant, or is it a field that evolves dynamically with the expansion of the Universe?*
- ***Modification of Gravity**: Alternatively, is the apparent acceleration instead a manifestation of a breakdown of General Relativity on the largest scales, or a failure of the cosmological assumptions of homogeneity and isotropy?*
- ***Dark Matter**: What is dark matter? What is the absolute neutrino mass scale and what is the number of relativistic species in the Universe?*
- ***Initial Conditions**: What is the power spectrum of primordial density fluctuations, which seeded large-scale structure, and are they described by a Gaussian probability distribution?*

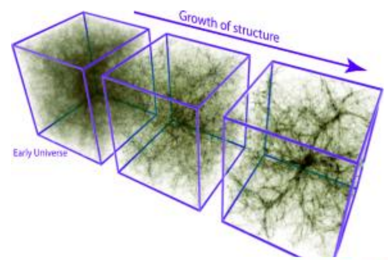
Requirement complexity





The Planck collaboration.

Ade et al 2013

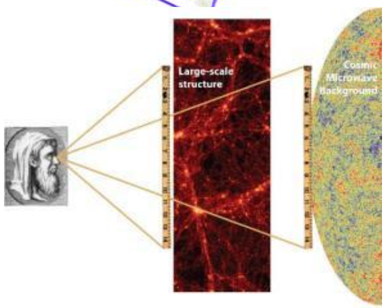


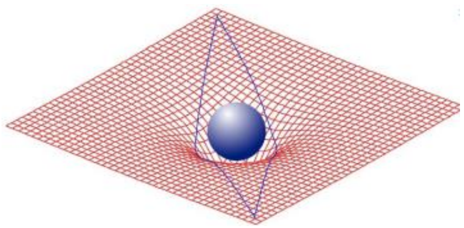
WHAT?
Cosmology beyond the Planck mission:

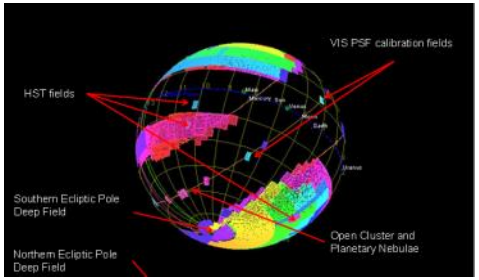
- Dark Matter distribution
- Dark Energy nature

HOW?

- Probed through:
  - BAO
  - Weak Gravitational Lensing





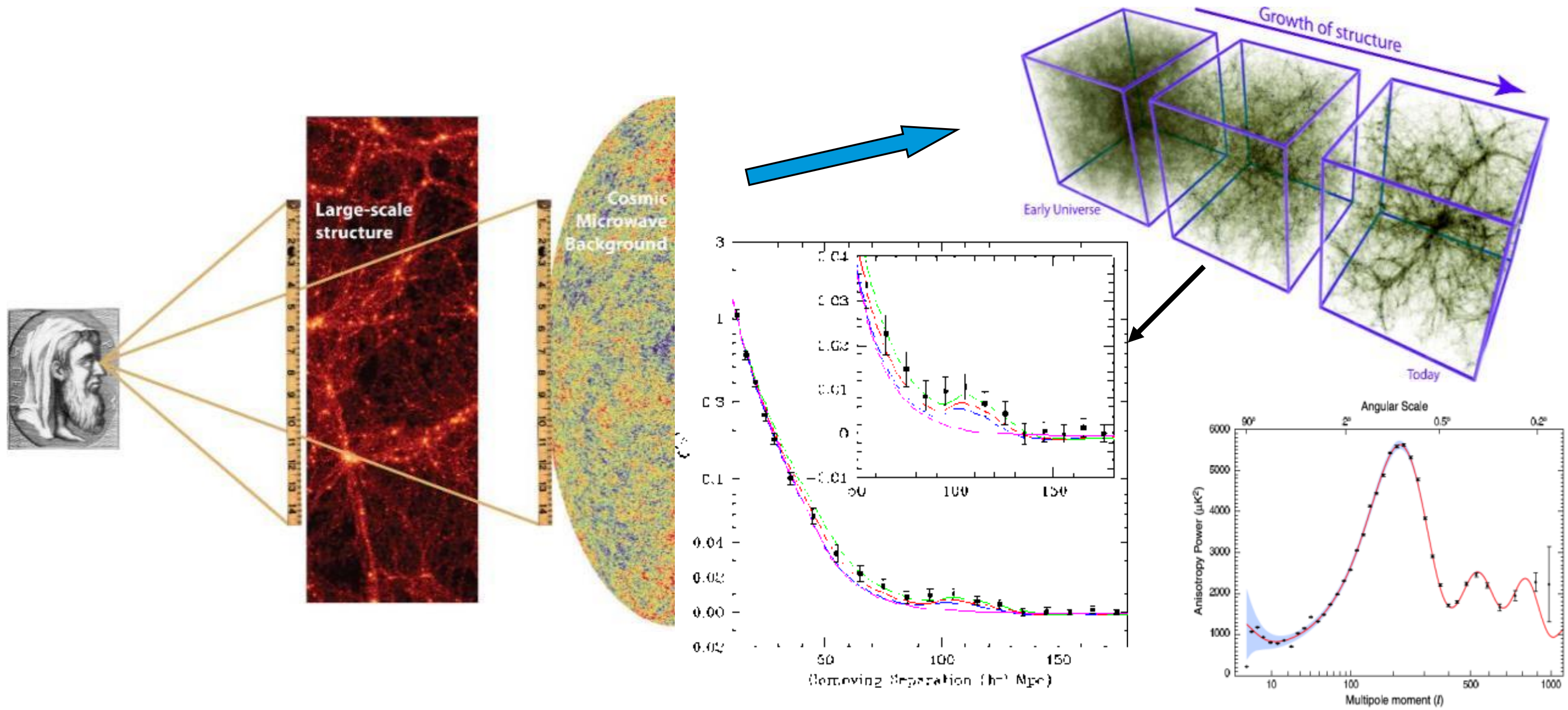


The Mission:

- Large Sky Survey:
  - 15,000 deg2
  - Visible imaging
  - Near-Infrared Photometry
  - Near-Infrared Spectroscopy

Requirement complexity

Baryonic Acoustic Oscillations



Z=1100 from WMAP

BAO reveals the geometry of the luminous matter:

Measure redshifts of galaxies over a large volume

Obtain the power spectrum for a given redshift bin

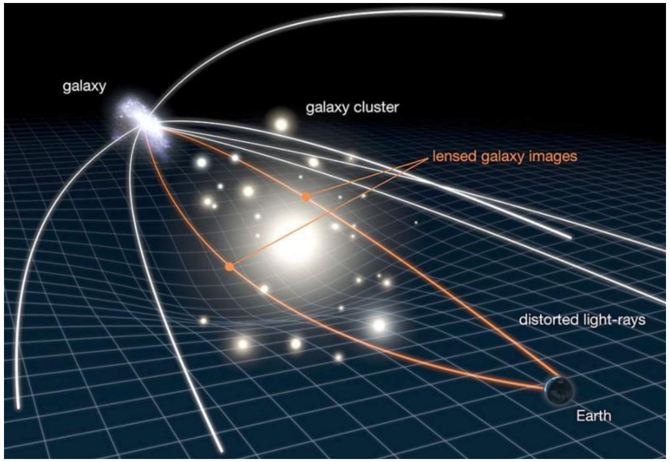
Determine the "wiggles" – the acoustic peaks

The peaks correspond to a typical scale length

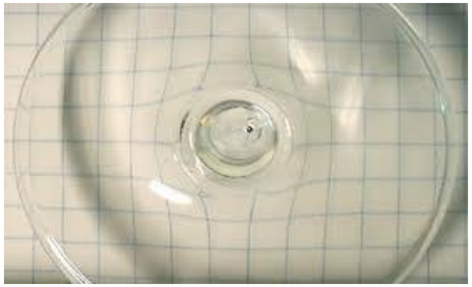
Requirement complexity

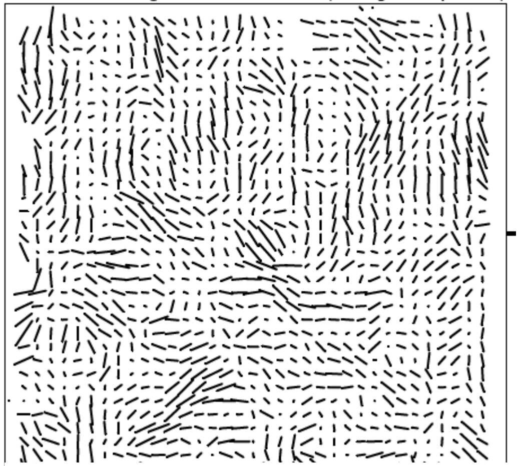
Weak Lensing

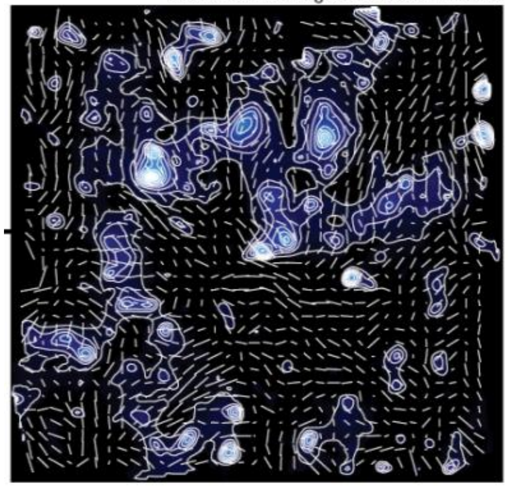
The weak lensing distortion is simply a (very small) change in ellipticity and position angle of a galaxy

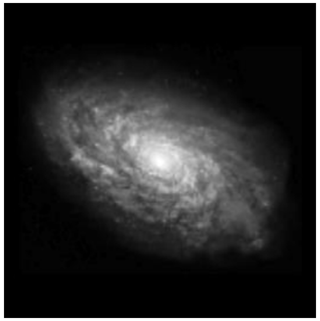


Shear Field





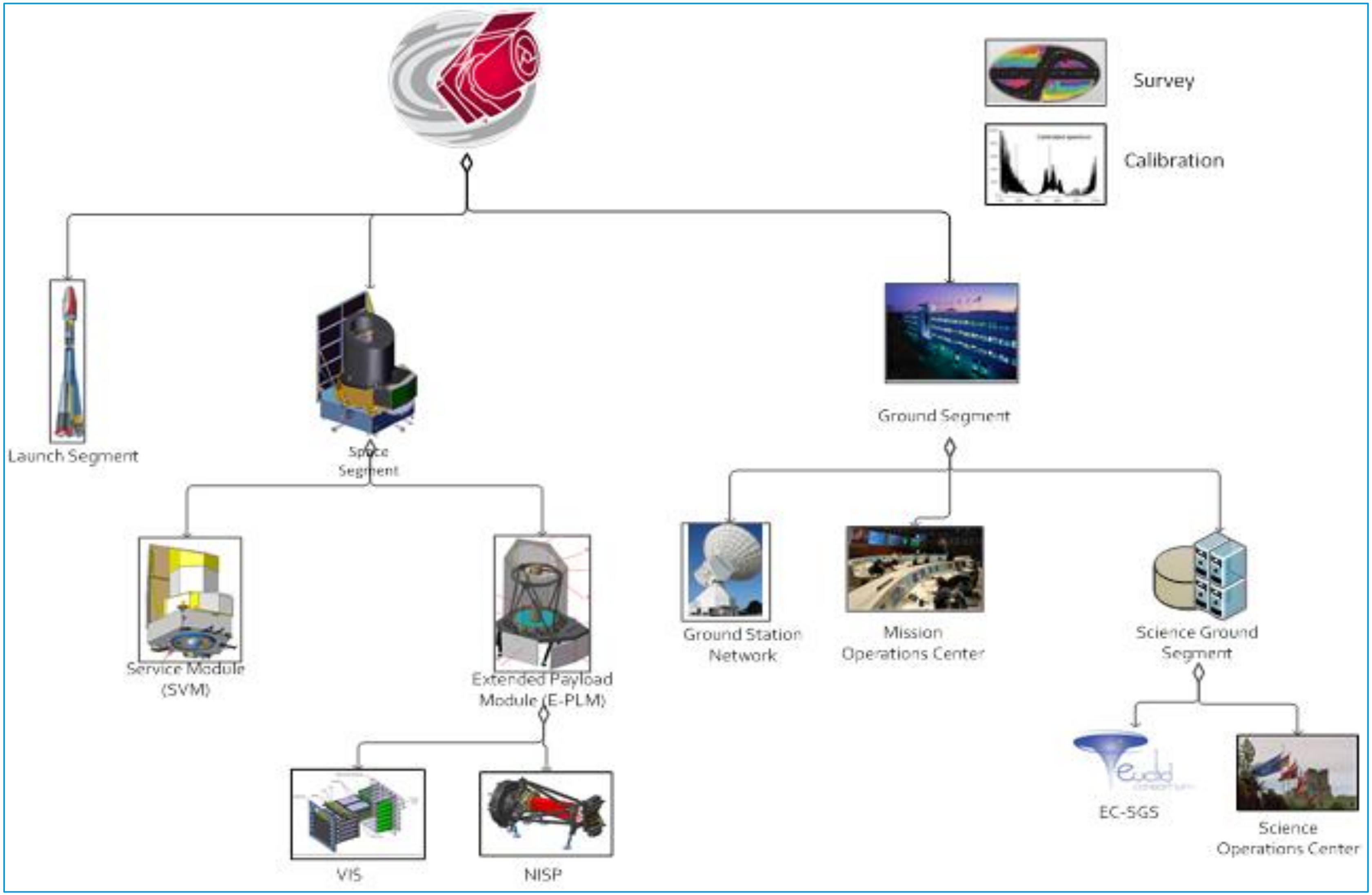




Matter distribution

Gravitational Lensing by Matter

Architectural complexity



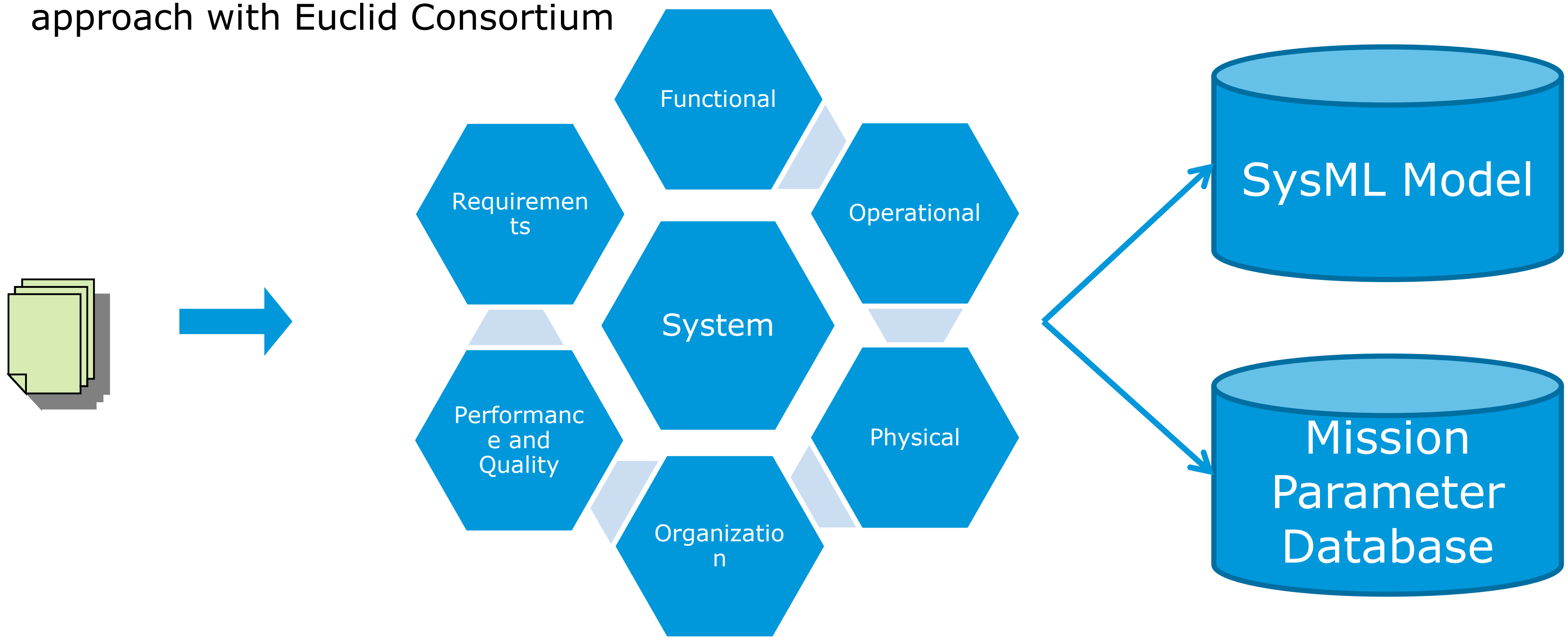
Organizational Complexity

MBSE to tackle the problem

- **Model Based System Engineering (MBSE) approach for Euclid**

  - Complex system and requirement interaction
  - Several actors in the system: ESA, Industry, NASA, large/distributed Euclid Consortium
  - Need to manage information exchange and control efficiently and coherently

  - Decided to implement a Model Based System Engineering (MBSE) collaborative approach with Euclid Consortium



MBSE Components

Methodology

- Language / Semantics: SysML, Euclid ontology
- Processes and guidelines

Tools and infrastructure

- Enterprise Architect ®, MySQL DB, WebServer
- Mission Parameter Database, DB Viewer, Integration

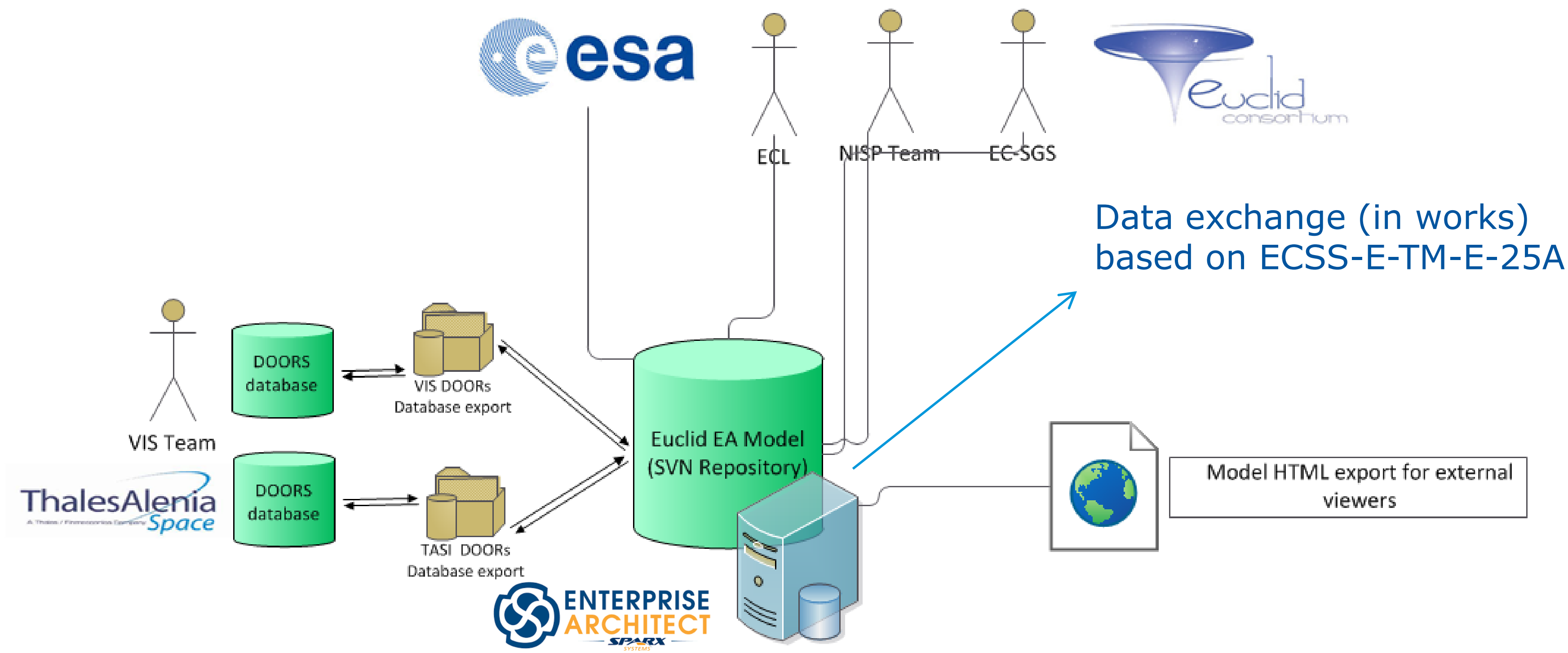
Modelling Scope / Patterns

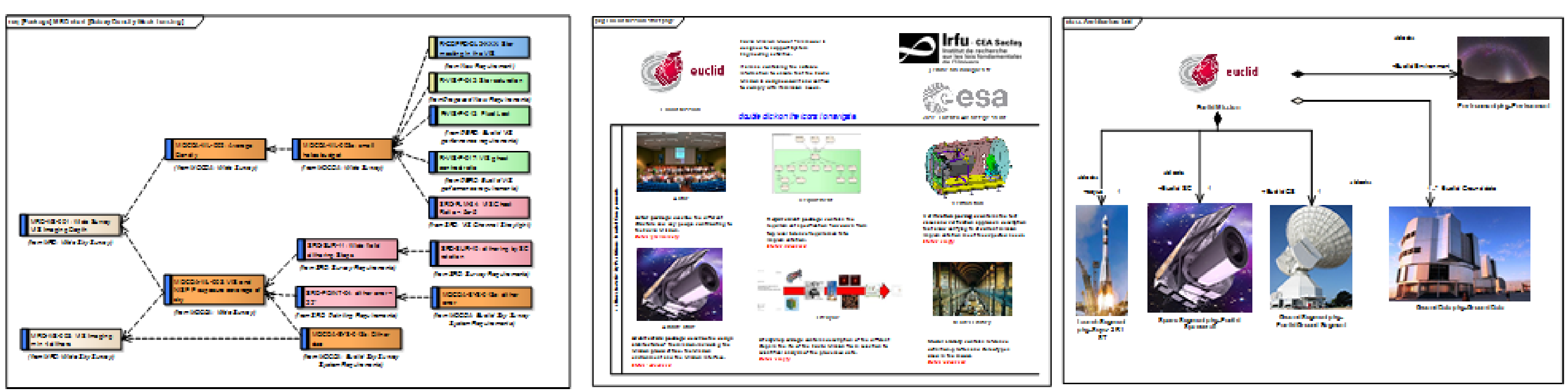
- What to model and too which level.
- Information to include in model.

Views / Usability

- ‘Hybrid’ approach: Model vs document
- Dedicated created for different stakeholders

Euclid System Model deployment and collaboration





Euclid Mission Parameters Database

Consistent assumptions for all analysis, studies and software development: Mission Database (MDB):

- Contains performance parameters for all mission elements and inputs.
- Maintained by European Consortium. Viewers implemented by ESAC.
- Change controlled by CCB with Mission System Engineering Working Group members participation.

Euclid System Model Organization / Views

pkg Euclid Mission start page

Euclid Mission Model: This model is designed to support System Engineering activities.

It aims a containing the suitable information to ensure that the Euclid Mission is designed, built and verified to comply with its mission needs.

Euclid Mission

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers
jerome.amiaux@cea.fr

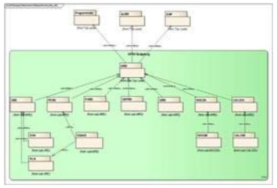
Jose.Lorenzo.Alvarez@esa.int

double click on the icons to navigate.

«allocateActivityPartition» Model Components

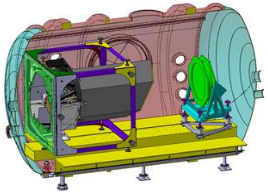
Actor

Actor package describe the different structure and key people contributing to the Euclid Mission.
Status: preliminary



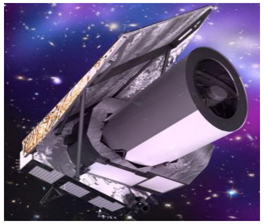
Requirement

Requirement package contains the requirement specification flow down from top level Science Requirements to implementation.
Status: Advanced



Verification

Verification package contains the test cases and verification approach description that allow verifying that current mission implementation meet the expected needs.
Status: empty



Architecture

Architecture package describe the design architecture of the mission, including the Mission product tree, the Mission environment and the Mission interface.
Status: advanced

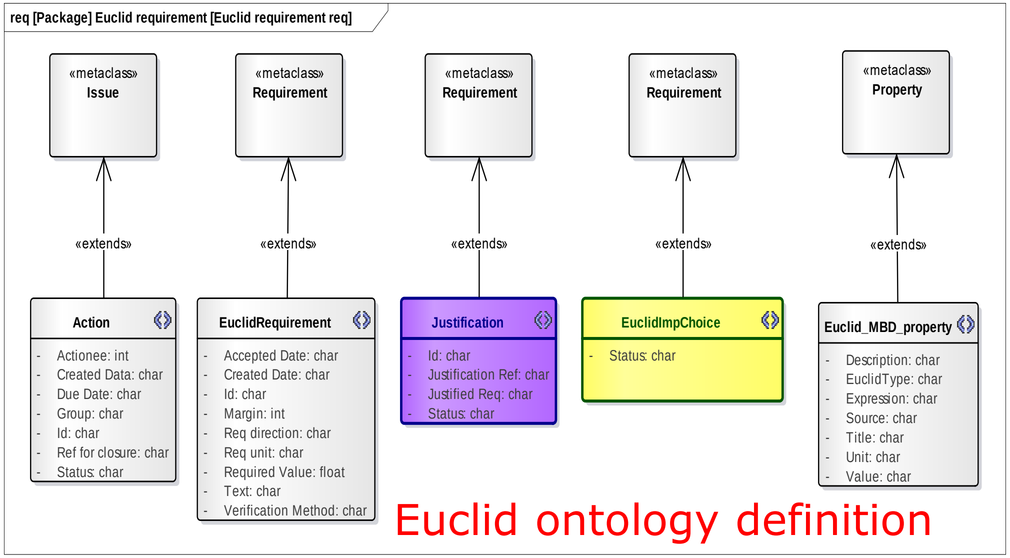
Lifecycle

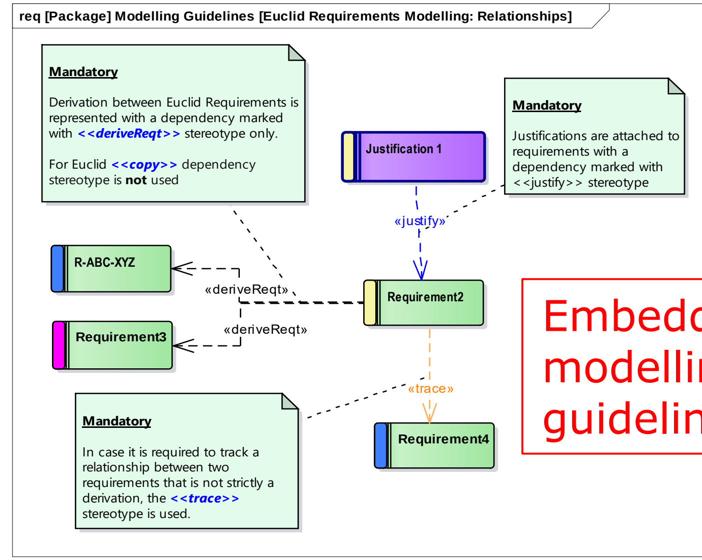
Lifecycle package contains description of the different steps in the life of the Euclid Mission from selection to scientifical analysis of the processed data.
Status: empty

Model Library

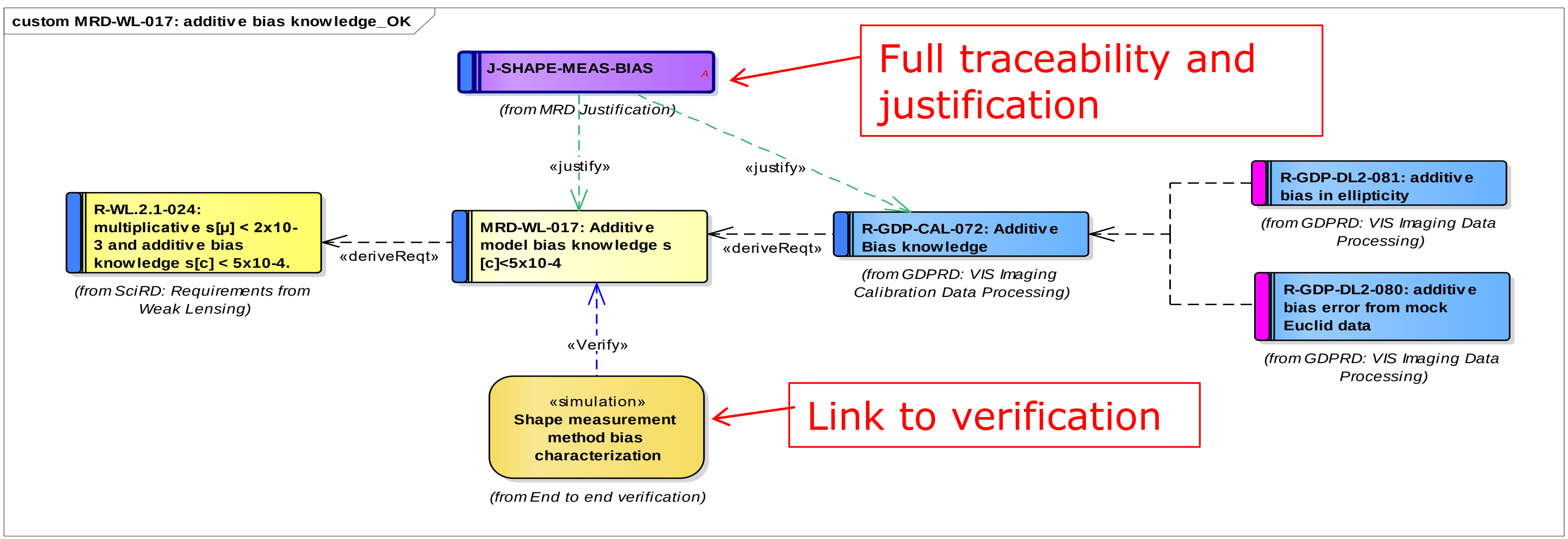
Model Library contains reference definition, profiles and stereotypes used in the model.
Status: advanced

Requirements modelling



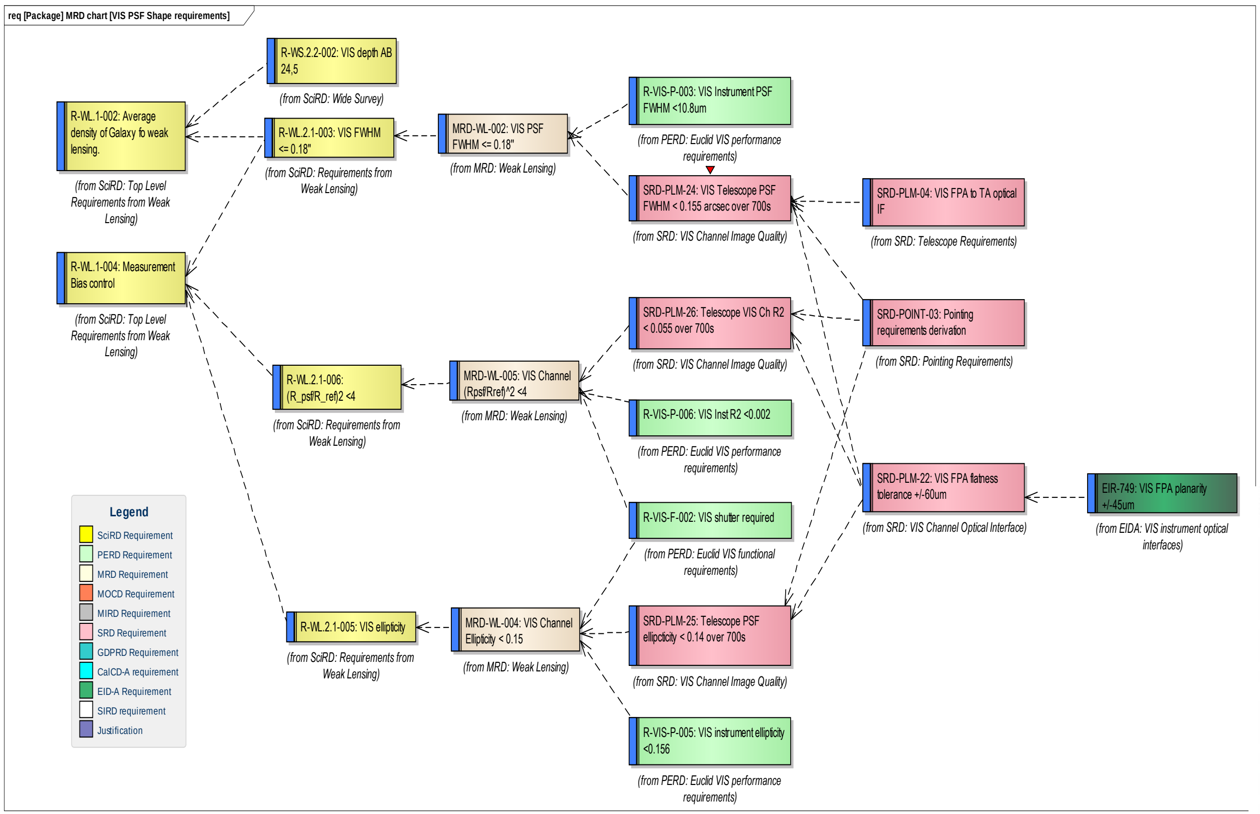


Embedded modelling guidelines



Requirements modelling

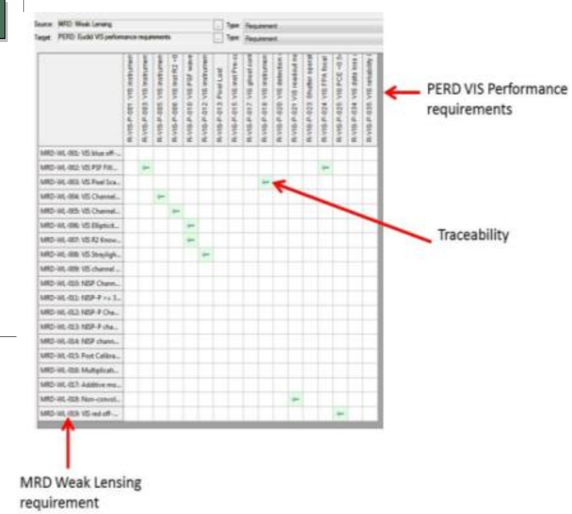
Maintenance and traceability



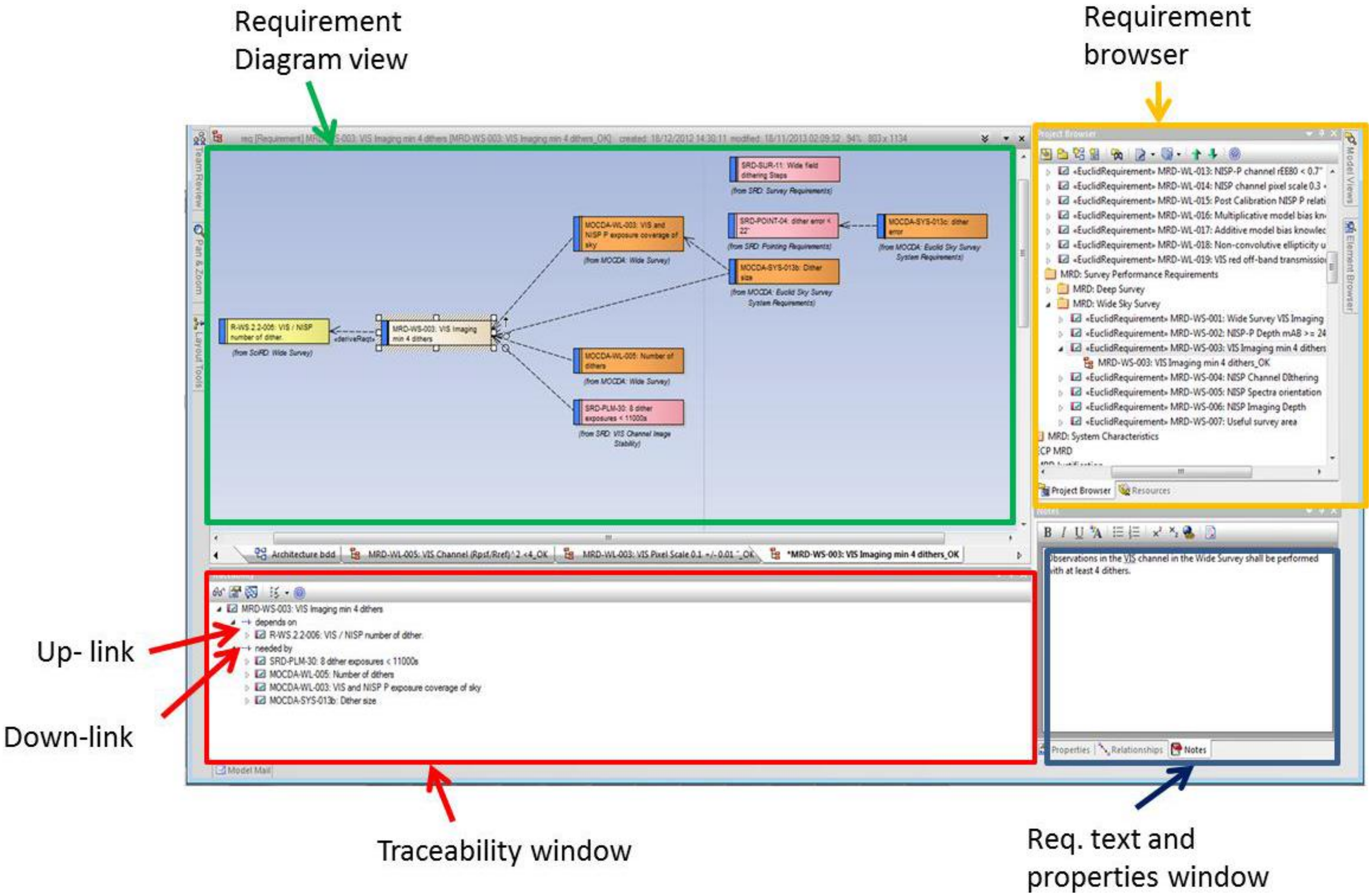
> From Euclid Mission Model: Example of requirements traceability and documentation.

Generation of "Traditional" views provided in reviews:

- Reqs documents
- Traceability matrix
- Verification matrix
- …



Requirements modelling



Requirements modelling

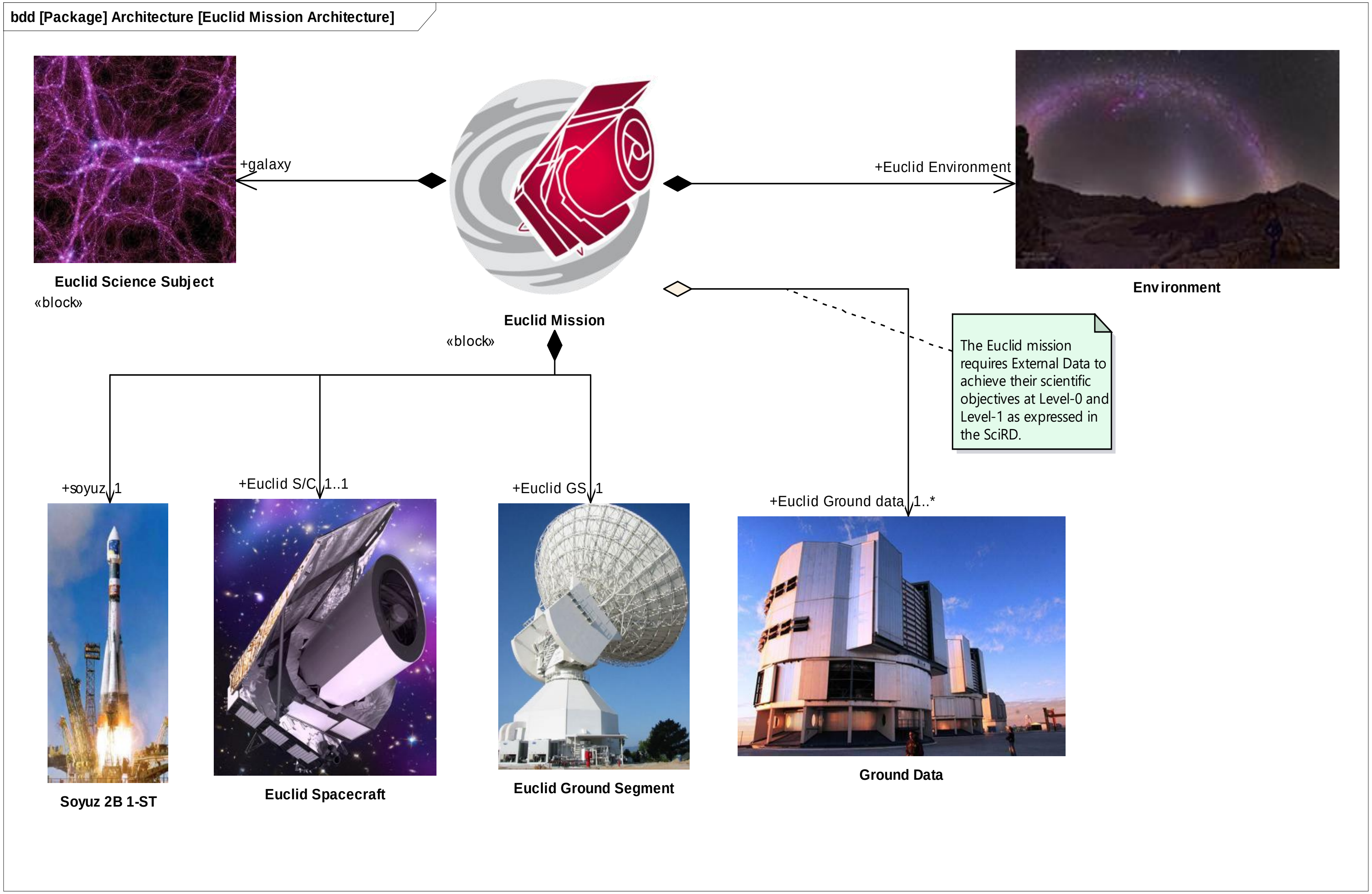
- **Benefits**:

  Start from Ops Concept at Phase A/B1 and systematic analysis of requirements and relationships:

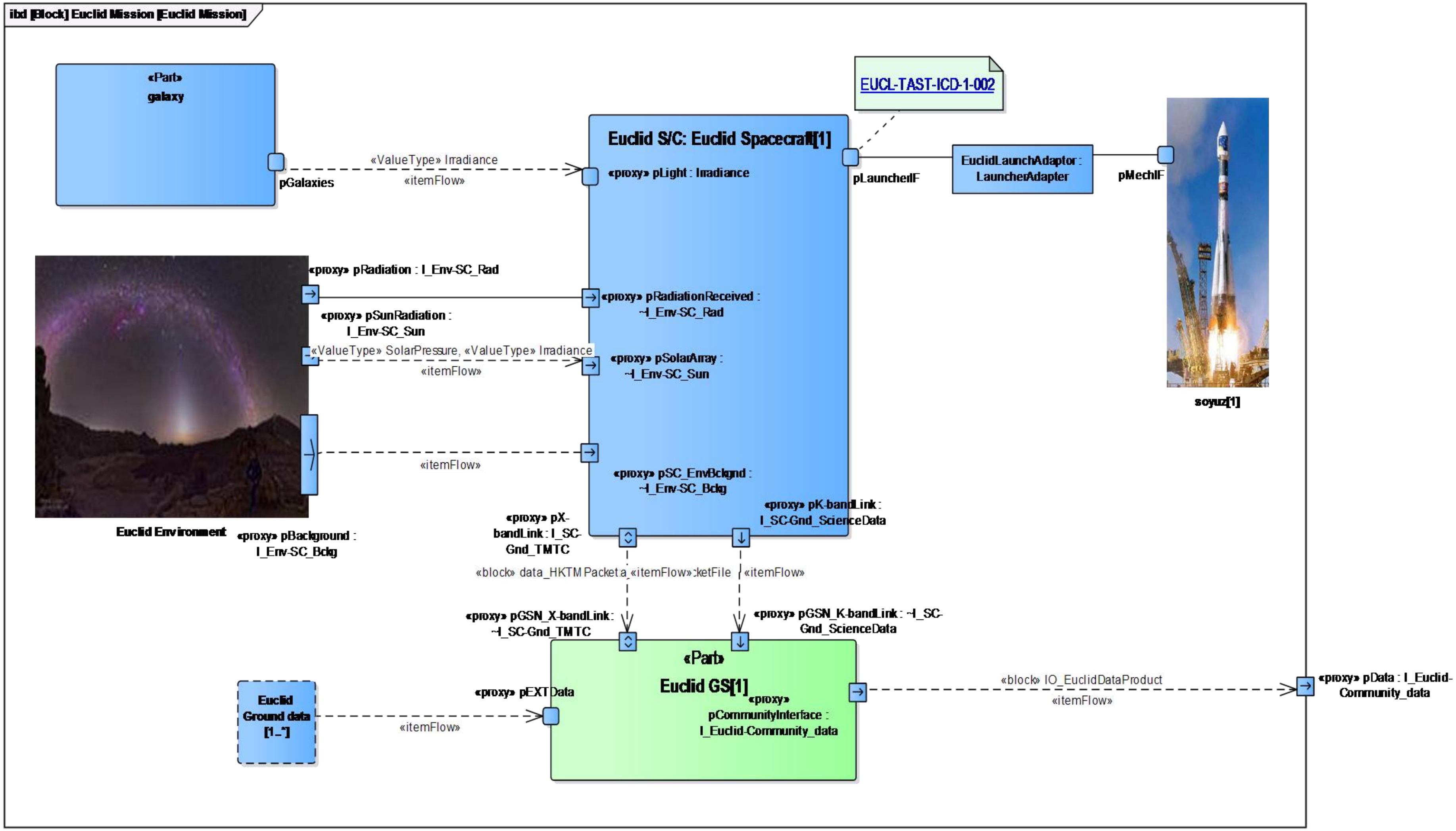
  - Top level requirements reduced to 40 (from over 200…).
  - Clearly differentiated needs from <u>assumed</u> architectural choices.
  - Knowledge Management: Systematic documentation for justification for all requirements – central project knowledge
  - Change Assessment: Quick and complete assessment of impact of changes to all levels. Change control processes driven by the model: annotated issues, request for changes, etc.
  - Mission Requirements Review very successful.

- **Lessons learned / Open Work**:
  - Seamless with classic requirements management (DOORS): Easy import, difficult to maintain linkage. Tool issue.
  - Need to establish **baselines** at regular time intervals for contractual reasons.

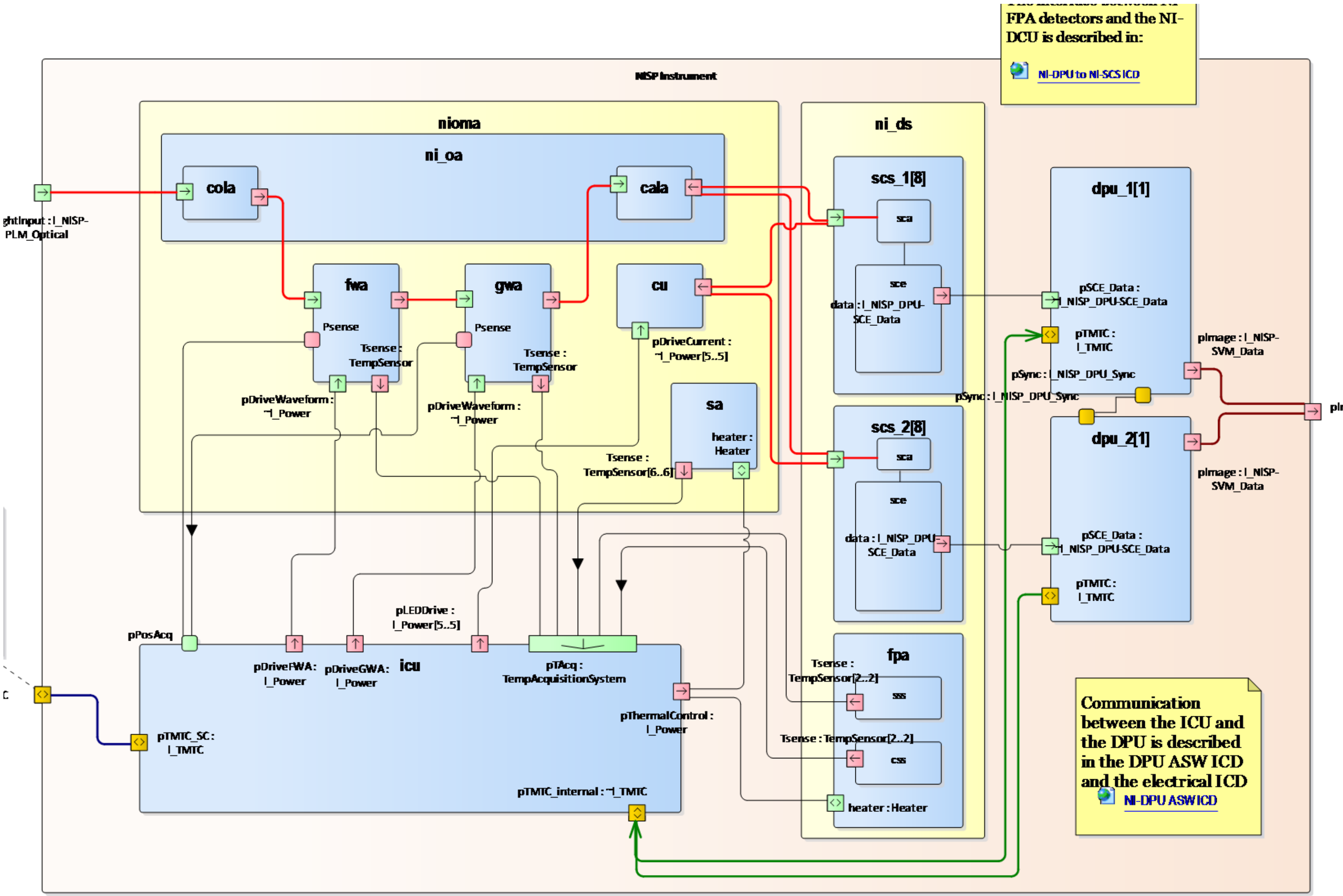
Architecture modelling



Architecture modelling



Architecture modelling

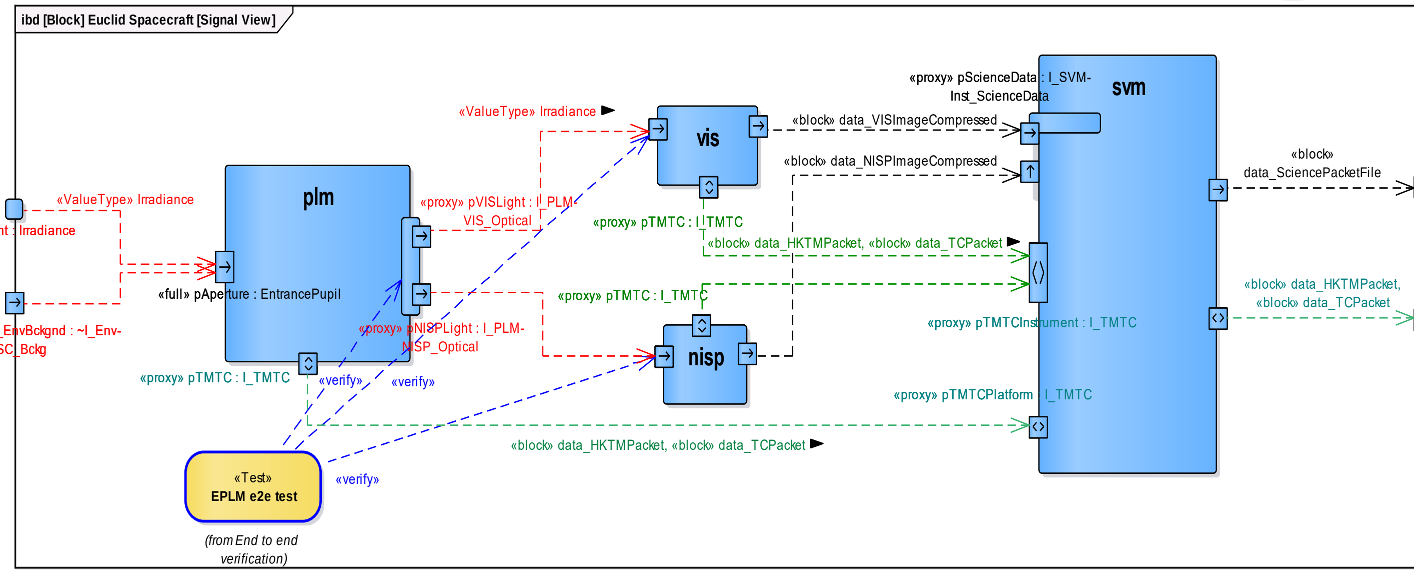


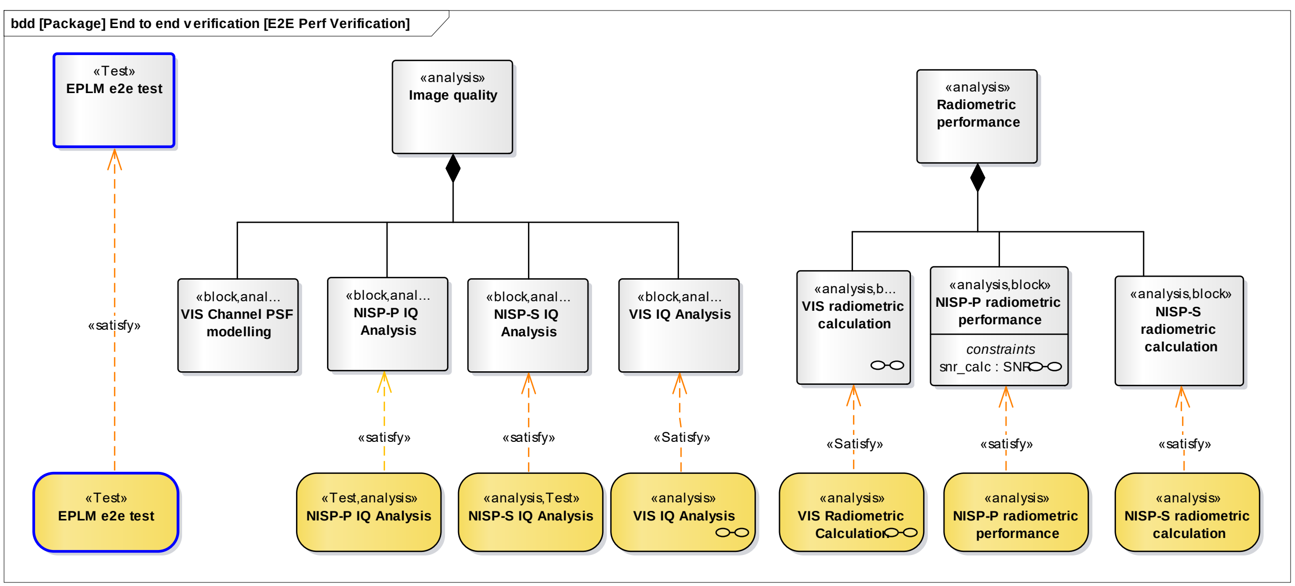
Architecture modelling

- **Benefits**:
  - Systematic identification/definition of all interfaces.
  - Coherent view of functions and allocation.
  - Definition of clear blocks for reusability.
  - Allows completeness in assessment of non nominal conditions and failures.

- **Lessons learned / Open Work**:
  - Level of modelling: When to stop?
  - Maintenance of history of changes and evolution for easy access, tracing of decisions for change.
  - Modelling of variants: how to model trade-offs? -> Currently employing cloned branches of the model
  - Interfaces modelling in SysML: Use of Ports and Association blocks still cumbersome. Association of requirements and behaviour to interfaces not immediate.

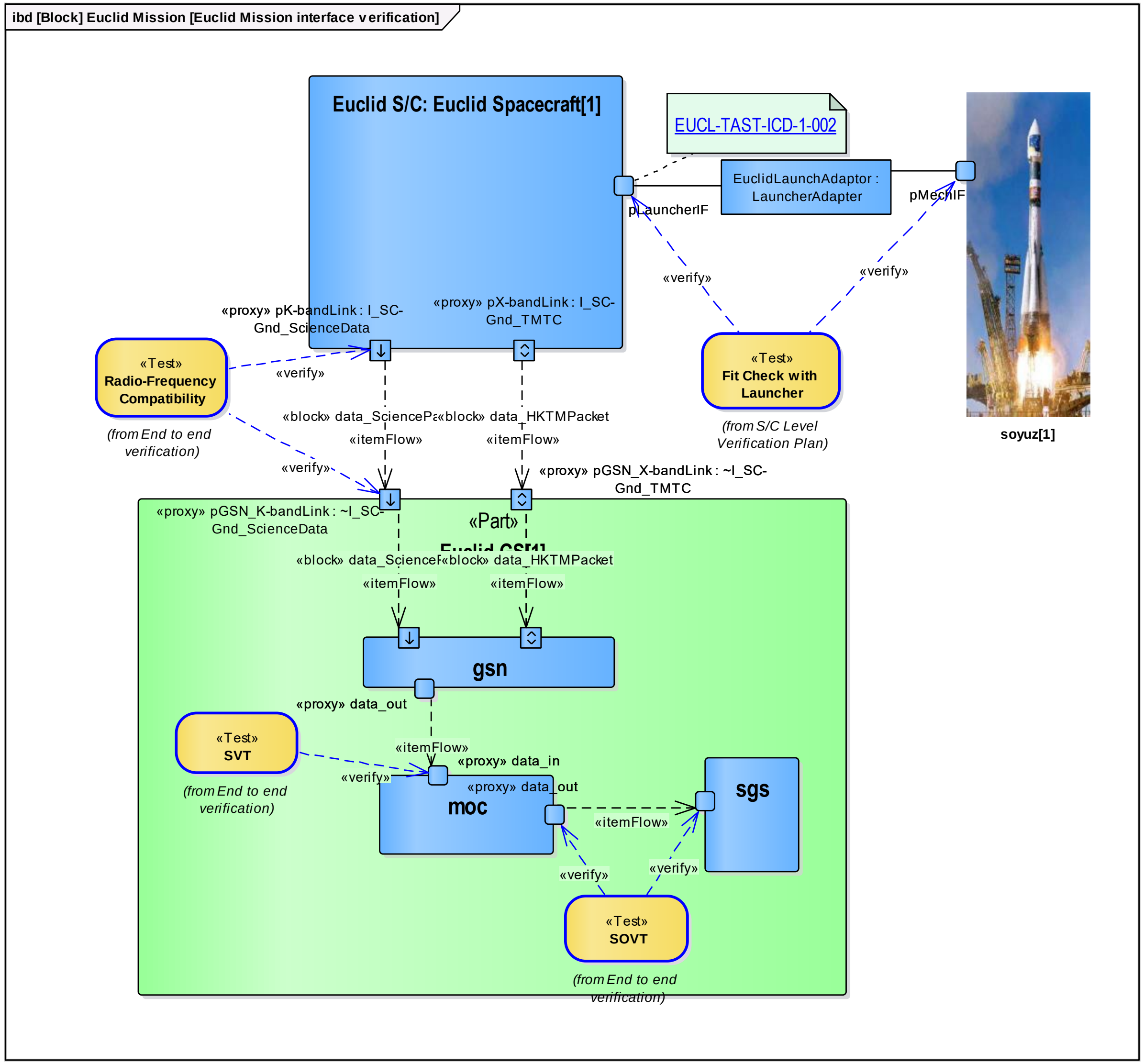
From Architecture to Verification modelling





Hierarchy of verification activities to group into “traditional” verification plans.

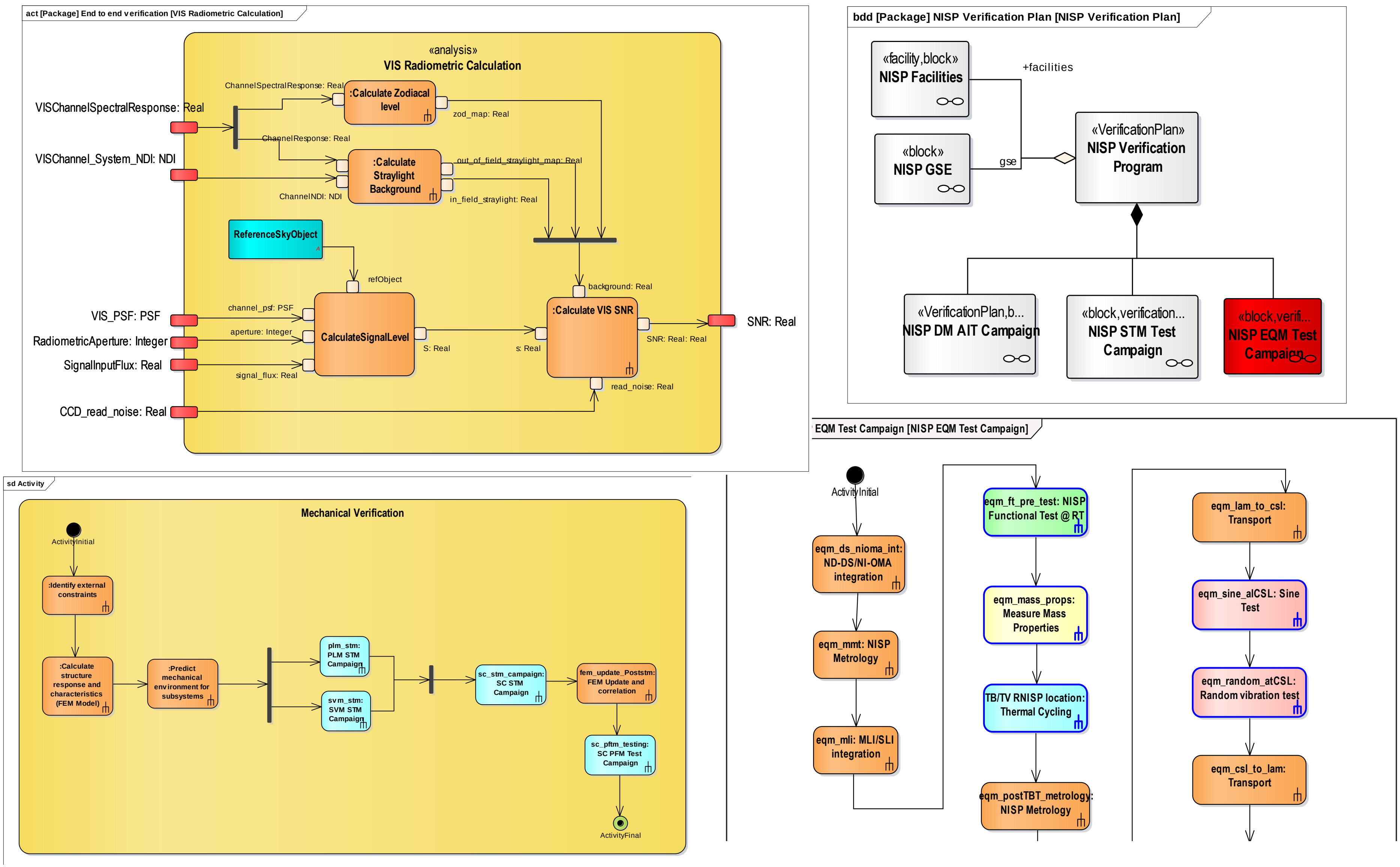
Verification modelling



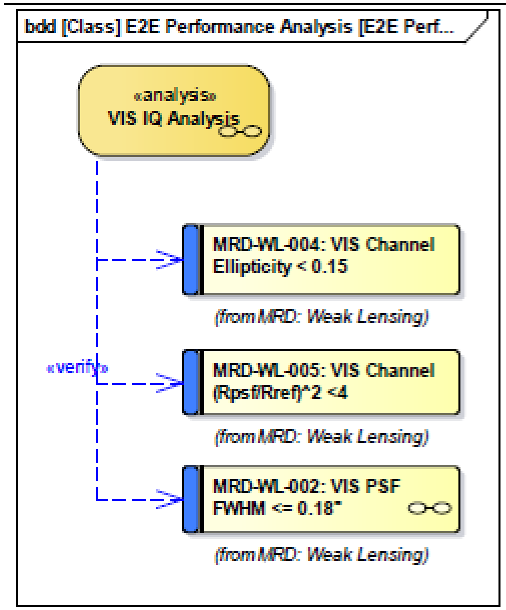
Systematic assignment of verification to interfaces.

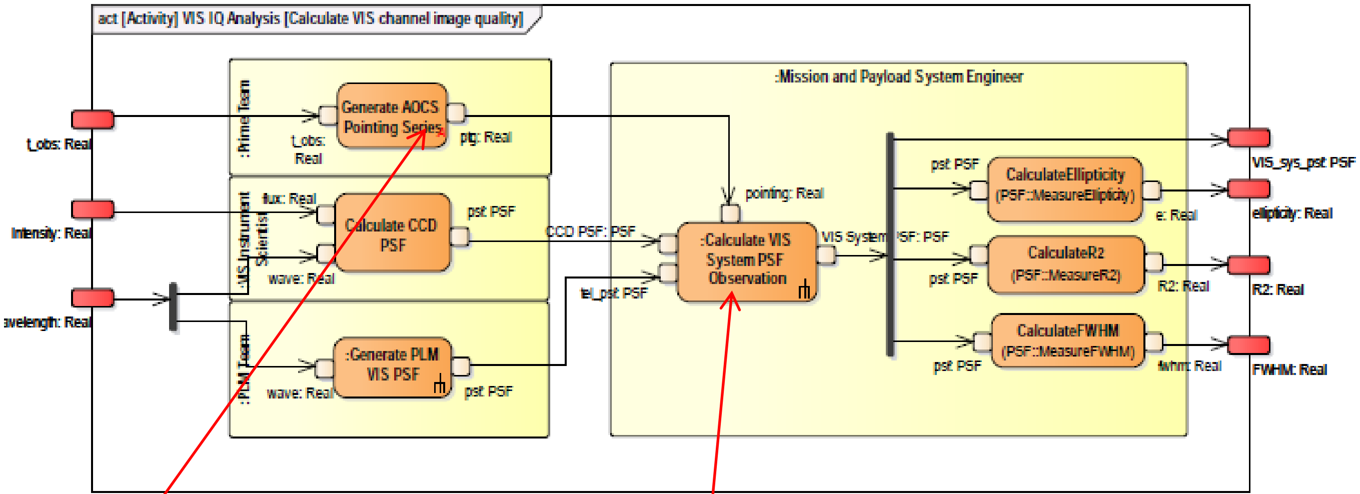
Automated search allows to quickly identify gaps, progress in verification.

Verification modelling



Verification modelling

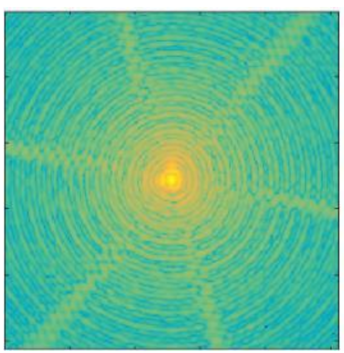




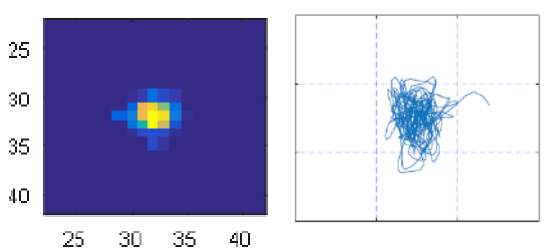
$$PSF_{system}(\theta_X,\theta_Y,\lambda,I) = PSF_{telescope}(\theta_X,\theta_Y,\lambda) * PSF_{instr}(\theta_X,\theta_Y,\lambda) * PSF_{aocs}(\theta_X,\theta_Y) * PSF_{detector}(\lambda,I)$$

$$FWHM_y(\text{l},I) = \frac{a_{Int1y} + b_{Int1y} \times Int}{a_{Int1y} + b_{Int1y} \times Int_0} \times a_{lambda1y} \times \text{l}^{b_{lambda1y}}$$

$$FWHM_y(\text{l},I) = \frac{a_{Int1y} + b_{Int1y} \times Int}{a_{Int1y} + b_{Int1y} \times Int_0} \times a_{lambda1y} \times \text{l}^{b_{lambda1y}}$$



Telescope PSF (9 field points, 4µm sampling)

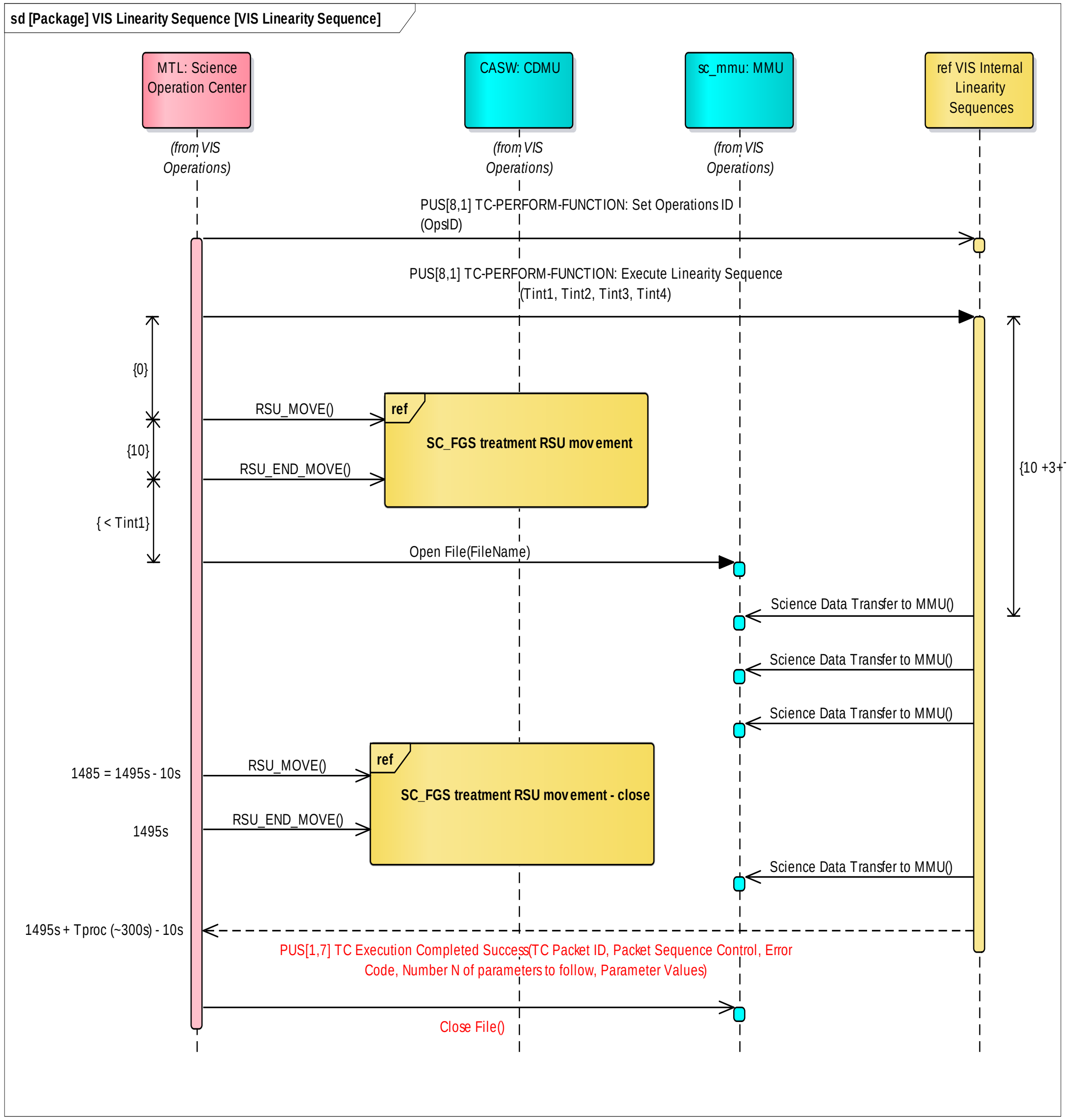


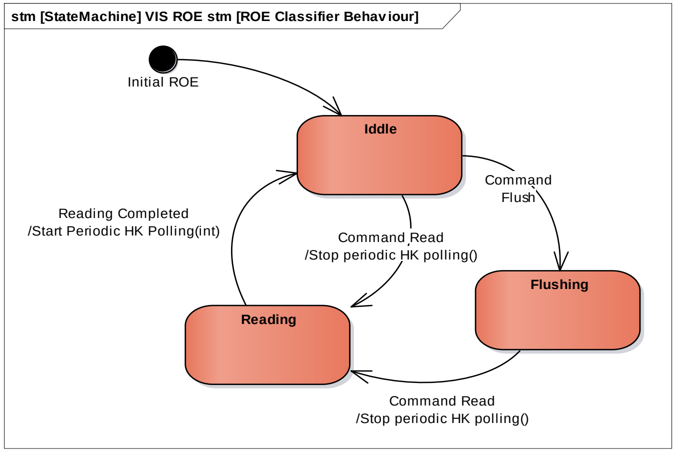
AOCS PSF

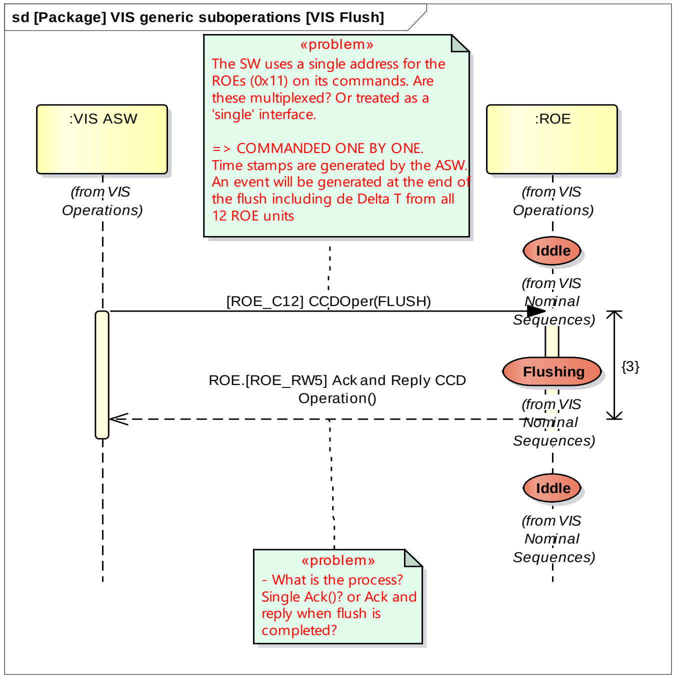
Mission verification tasks are linked to expressions or requirements that are implemented in code. **No automation, just representation in SysML Model**.

Inputs, products and processing functions maintained in **Mission Parameters Database**

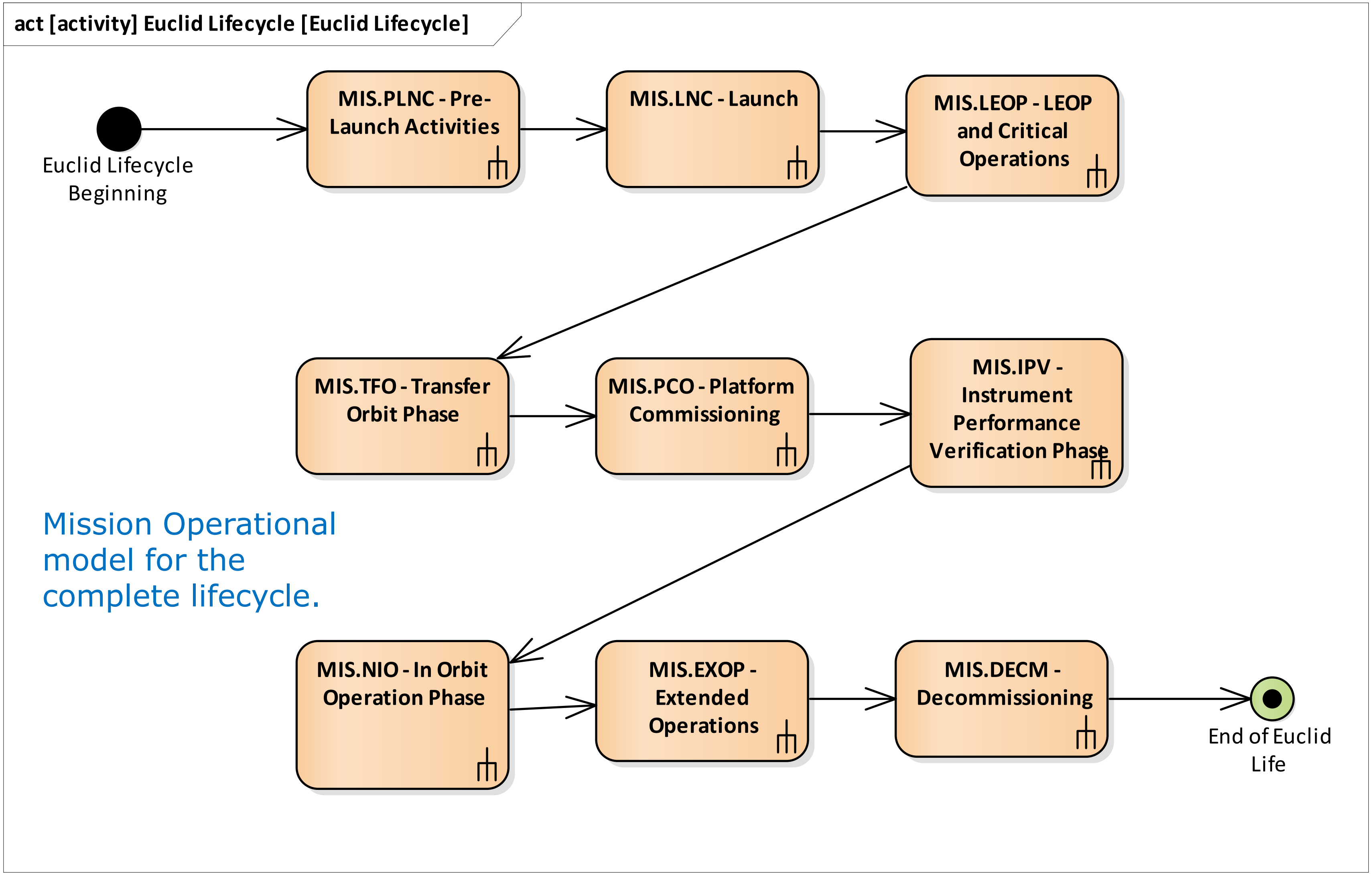
Behaviour modelling





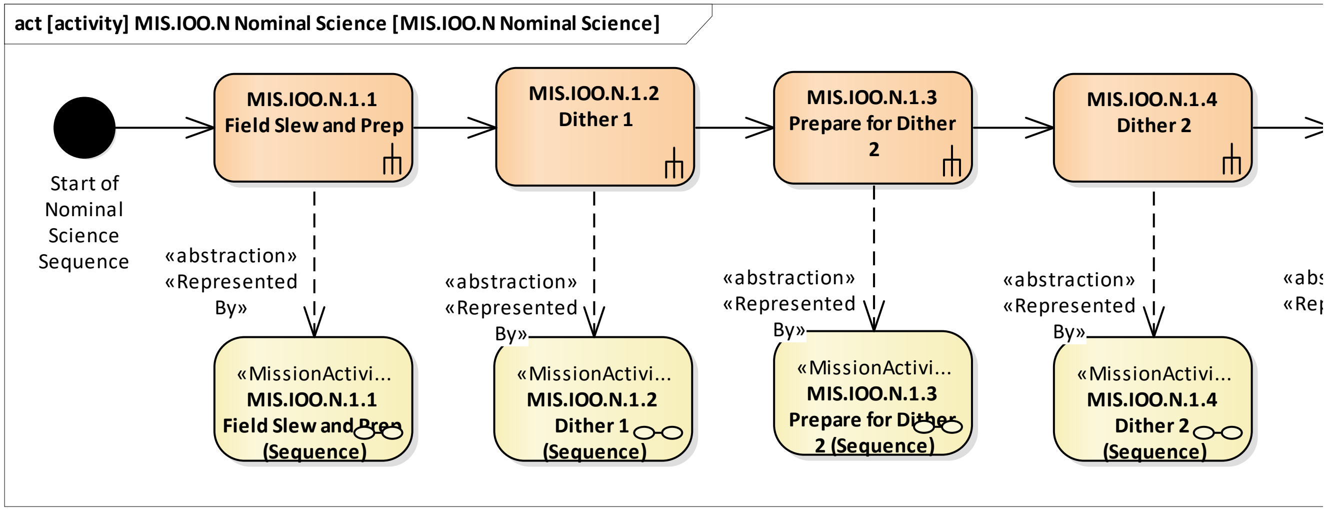


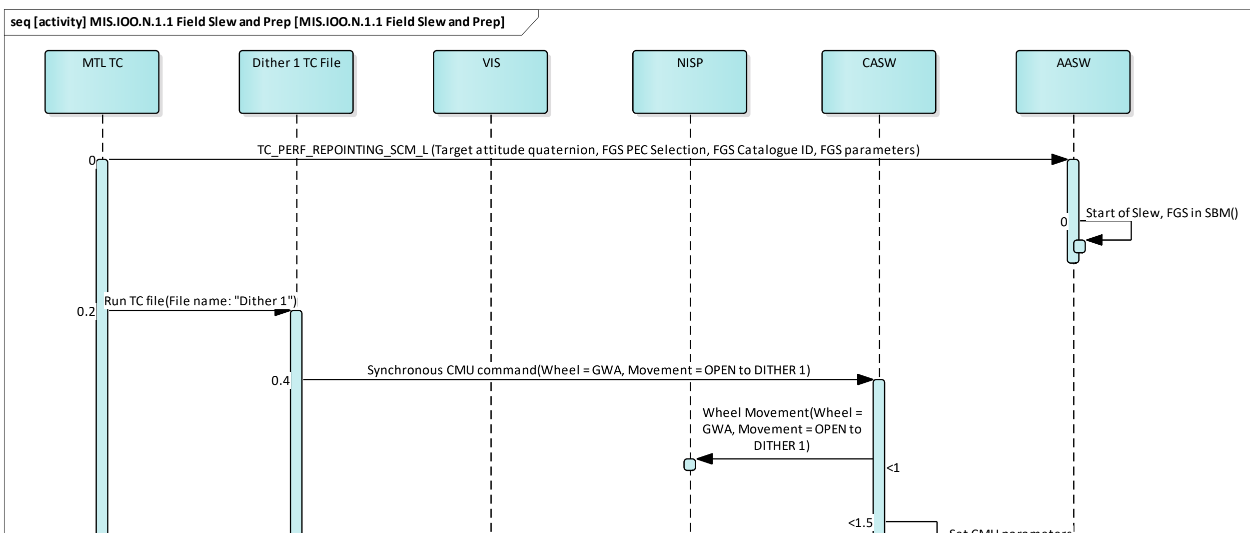
Operations Modelling



Mission Operational model for the complete lifecycle.

Operations Modelling





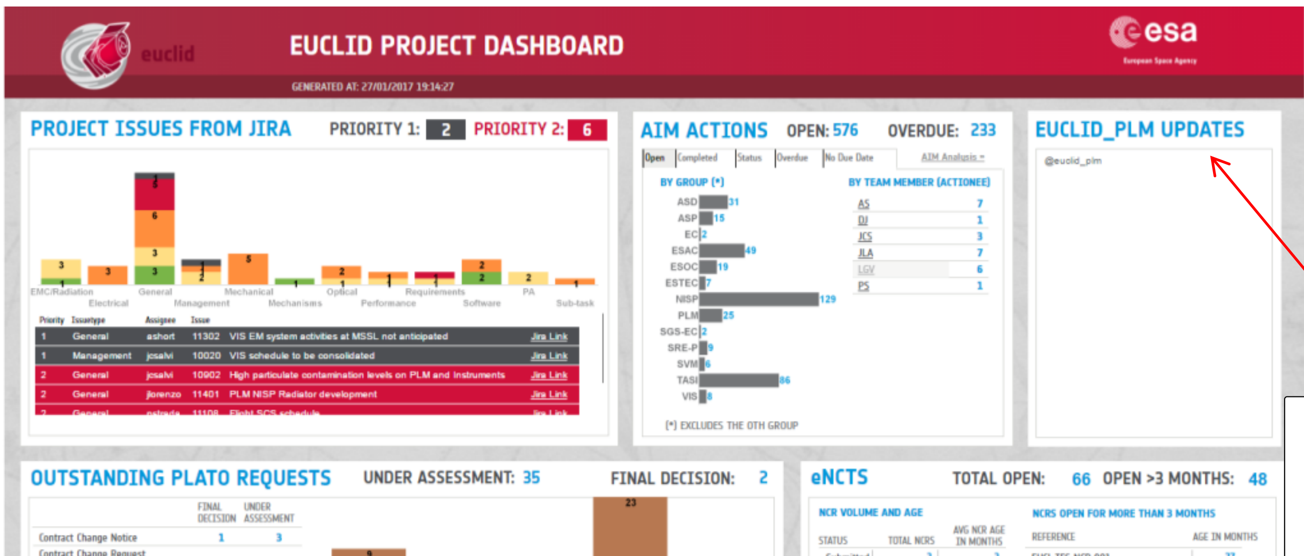
Verification and behaviour modelling

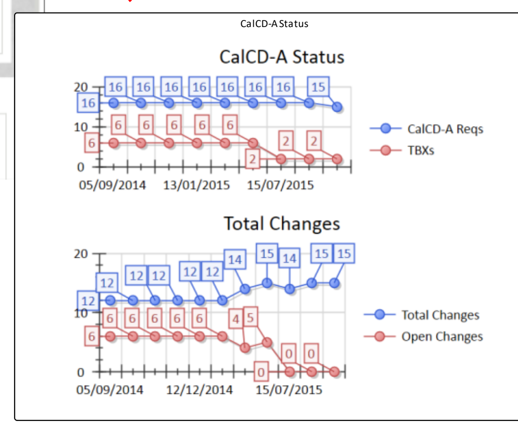
- **Benefits**:
  - Completeness of verification by full coverage check of requirements (incl. functions) and interfaces.
  - Identification of common/repeated tasks: better use of synergies between analysis and tests, reducing duplication and optimizing flow.
  - Key for communication between different players to develop verification plans:
    - Commonly agreed analysis flows, sequences, etc instead of documents.

- **Lessons learned / Open Work**:
  - Integration of model with operations and science operations groups models: currently separate activities
  - Link with verification results: currently we link to test, analysis reports. Appropriate for the use in Euclid. For future missions it should be incorporated in System Knowledge Database.

Views / Communication

- SysML model is in essence a DB with object and connections between them.
  - Knowledge of the semantics allows custom searches and visualizations (both in tool or with external data display applications)
  - Integration into generic project Dashboards:

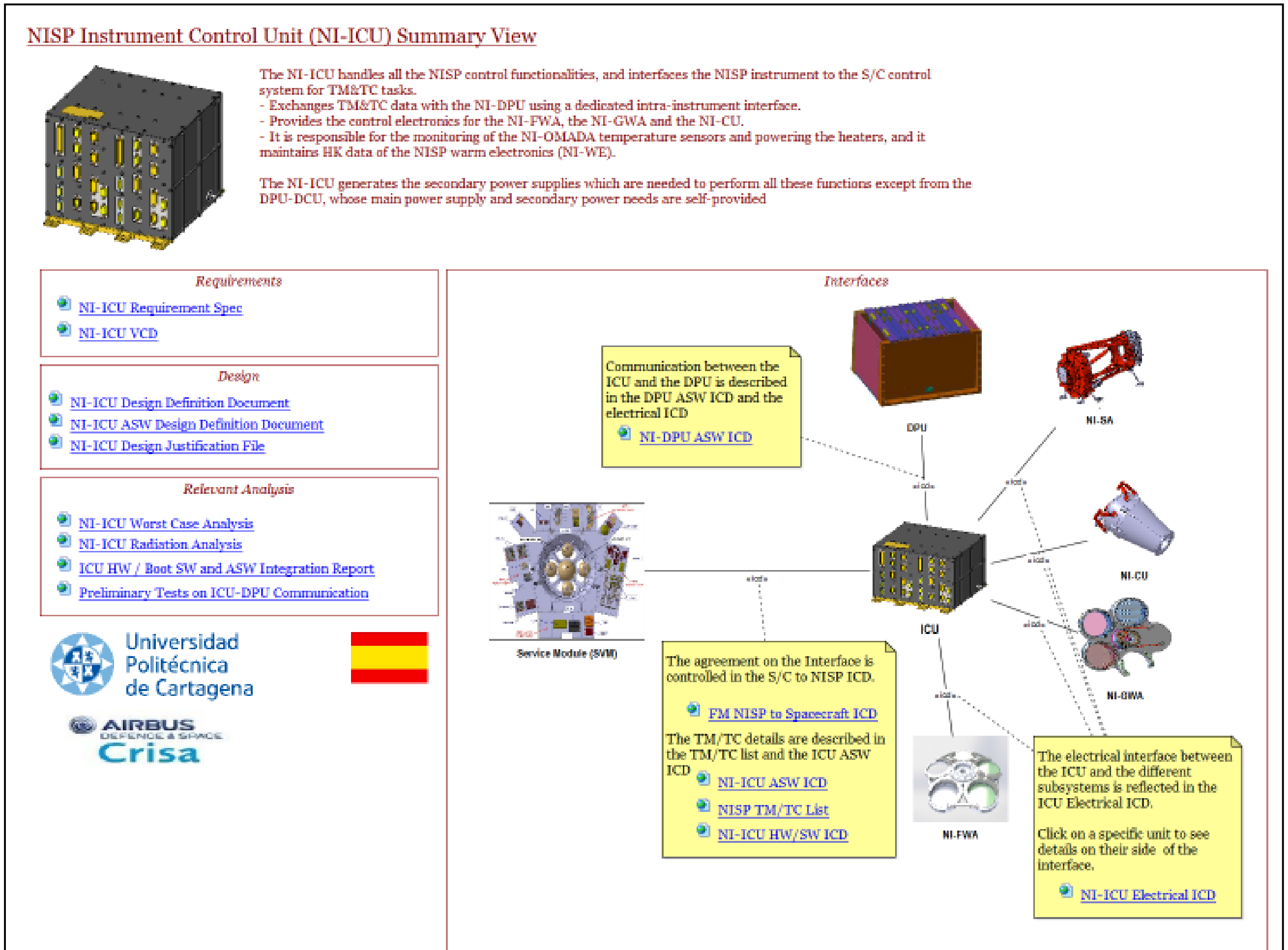




Currently working on integration of model metrics into system Management Dashboard

Views / Communication

Dedicated views created for reviews in HTML, integrating model and the traditional document based ESA review process



Main Lessons learned

- *Use modeling as Systems Thinking “lighthouse”*
- *Define and document a clear modeling approach*
- *Start early: Phase A/B1*
- *Identify to what level is necessary to model*
- *Facilitate Sharing and usage: Observers don’t want to know you have a ‘model’*

Thanks!