Euclid Requirements Engineering supported by SysML

Jose Lorenzo Alvarez
ESTEC
ADCSS - 28/10/2014
**Euclid Mission Overview**

**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
Euclid MBSE Approach

- **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

- Two main elements (to date):
  - Euclid Mission System SysML Model
  - Euclid Mission Parameter Database (in development)
- MBSE framework: selected System Modelling Language (SysML)

Euclid specific SysML extension

**custom Euclid requirement req**

- Action
  - Actionee: int
  - Created Data: char
  - Due Date: char
  - Group: char
  - Id: char
  - Ref for closure: char
  - Status: char

- EuclidRequirement
  - Accepted Date: char
  - Created Date: char
  - Id: char
  - Margin: int
  - Req direction: char
  - Req unit: char
  - Required Value: float
  - Text: char
  - Verification Method: char

- Justification
  - Id: char
  - Justification Ref: char
  - Justified Req: char
  - Status: char

- EuclidImpChoice
  - Status: char

- Euclid_MBD_property
  - Description: char
  - EuclidType: char
  - Expression: char
  - Source: char
  - Title: char
  - Unit: char
  - Value: char
Euclid specific SysML extension

A few of these attributes are added as "char" to make it easier initial data import, but should be implemented with relationships with requirements, use cases, etc.
Euclid MBSE Approach

Mission System Engineering Model:

- **Tool**: *Enterprise Architect by Sparx Systems*

Controls:

- Requirements baseline, traceability, flow-down and maintenance
- In the future: System architecture and interactions, Verification

The Mission level model is developed and maintain by ESA and the European Consortium Mission system teams.
Euclid Mission Model: This model is designed to support System Engineering activities. It aims at containing the suitable information to ensure that the Euclid Mission is designed, built and verified to comply with its mission needs.

**Lifecycle package** contains description of the different steps in the life of the Euclid Mission from selection to scientific analysis of the processed data.
- **Architecture package** describe the design architecture of the mission, including the Mission product tree, the Mission environment and the Mission interface.
- **Actor package** describe the different structure and key people contributing to the Euclid Mission.
- **Requirement package** contains the requirement specification flow down from top level Science Requirements to implementation.
- **Verification package** contains the test cases and verification approach description that allow verifying that current mission implementation meet the expected needs.
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*double click on the icons to navigate.*
Euclid Requirement Engineering

- Requirements definition and traceability
- Interface Consolidation
- Req. Maintenance & Change Control
- Technical Control & tracking
- Mission Verification and validation
Euclid Requirement Engineering

Euclid Mission SysML model (EUCL-EST-OTH-1-003)

Mission Budget and Requirement Justification File (EUCL-EST-TN-1-004)

Mission Requirements Document (MRD)

Mission Operations Concept Part-A (MOCD-A)

Mission Operations Concept Part-B (MOCD-B)

Calibration Concept Document Part-A (CalCD-A)

Calibration Concept Document Part-B (CalCD-B)

Survey Design

System Requirements Document (SRD)

Payload Element Requirements Document (PERD)

Ground Data Processing Requirements Document (GDPRD)

Science Implementation Requirements Document (SIRD)

Mission Implementation Requirements Document (MIRD)

Euclid Consortium

EC-SGS

SVM + PLM

VIS + NISP

EC-SGS

SOC (ESAC)

MOC (ESOC)

European Space Agency
Euclid Requirement Engineering

MRD top-level functional requirements

Functions
- Perform Wide Survey: 15,000 deg²
- Perform Deep Survey: 40 deg²
- Visible imaging
- Near-Infrared Slitless Spectroscopy
- Near-Infrared Photometry
- Provide mission data products in a Euclid Legacy Archive (ELA)

Architecture
- Space Segment
  - Single Telescope
  - VIS Instrument provided by EC
  - NISP Instrument provided by EC
- Ground segment
  - MOC at ESOC
  - SOC at ESAC
  - EC-SGS
  - GSN with X & K-band capability
- Launch Segment
  - Soyuz Launcher

Mission
- Science Lifetime 6 years
- L2 orbit

Agency Constraints
- ECSS Standards
- Decommissioning
- Passivation

ESA UNCLASSIFIED – Releasable to the Public
MRD Main Galaxy Clustering Science requirements

**Galaxy sample selection**
- **Survey size**: 15,000 deg²
- **Average Number of galaxies**: 3500 gal/deg²
- **Galaxy redshift distribution**: Median redshift 0.7 < Z < 2.05

**Spectroscopic red-shift determination**
- **Redshift (z) precision, uncertainty and systematic offset** (see SciRD)
- **Wavelength error**: 85% survey efficiency
- **Flux limit Hα-line**: 3x10⁻¹⁶ erg cm⁻² s⁻¹ @ 1600nm
- **Flux limit other wavelengths**: 3.6x10⁻¹⁶ erg cm⁻² s⁻¹
- **Completeness > 45%**
- **NISP-P spectral range**: 1100-2000nm
- **Redshift catastrophic error fraction**: $f_{cat} < 0.2\%$
  And
  $f_{cat}$ knowledge better than 1%
- **External data under EC responsibility**: 85% survey efficiency
- **NISP-S Imaging of the NISP-P field with sensitivity**: $m_{AB} = 24$ (5σ)
- **Spectral resolution > 250**
- **Z measurement purity > 80%**
- **Subsample with purity > 99%**
### MRD Main Weak-Lensing Science requirements

#### Galaxy Shape Measurement

<table>
<thead>
<tr>
<th>Galaxy sample selection</th>
<th>Survey size</th>
<th>15,000 deg²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85% survey efficiency</td>
<td></td>
</tr>
<tr>
<td>Average Galaxy density</td>
<td>30 deg²</td>
<td></td>
</tr>
<tr>
<td>Median redshift</td>
<td>Z&gt;0.8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VIS PSF Shape</th>
<th>FWHM &lt; 0.18”</th>
</tr>
</thead>
<tbody>
<tr>
<td>εᵢ &lt; 0.15</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VIS PSF knowledge</th>
<th>R²&lt; 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ(R_PSF/R_ref)² &lt; 10⁻³</td>
<td></td>
</tr>
<tr>
<td>σ(εᵢ) &lt; 2x10⁻⁴</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Distortion</th>
<th>Residual &lt; 0.003%</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>CTI effects</th>
<th>σ(ε_NC) &lt; 1.1x10⁻⁴</th>
</tr>
</thead>
</table>

<table>
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<tr>
<th>Shear Model bias</th>
<th>Additive σ[c] &lt; 5x10⁻⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiplicative σ[µ] &lt; 2x10⁻³</td>
</tr>
</tbody>
</table>

#### Photometric red-shift determination

- Photo-z precision and uncertainty:
  \[ \sigma(z)/(1+z) < 0.05 \]
  \[ \sigma(<z>)/(1+z) < 0.002 \]
  \[ f_{cat} < 10\% \]

### Additional Requirements

- **Image quality**
  - Encircled Energy
  - Pixel scale: 0.3”/pix

- **Sensitivity**
  - \( m_{AB} = 24 \) (5σ) in all bands

- **Calibration**
  - Relative Photometric error post-calibration <1.5%

- **Number of photo-z bins**
  - NISP-P wavelength range
  - External g,r,i,z data under EC responsibility

- **Euclid Requirement Engineering**
  - External g,r,i,z data under EC responsibility
Euclid Requirement Engineering

Initially used to track/document main breakdown...

req [Package] R-Level2 [VIS Channel Ellipticity]

R-WL.2.1-005: VIS ellipticity
notes
The ellipticity of the VIS PSF, measured from an image that has been exposed for the nominal integration time, shall be less than 0.15.

(from RD)

SCI-WL.004: VIS Channel Ellipticity
notes
The ellipticity of the VIS PSF, measured from an image that has been exposed for the nominal integration time, shall be less than 0.15.
Note: The ellipticity definition is provided in [ADXX].

(from MRD)

SRD-PLM.XX: Telescope PSF ellipticity
notes
The ellipticity of the telescope PSF at 800 nm shall be as low as possible and lower than 14% at any point of the VIS field of view. (from [RD-03] sect.3.3.2.3)

(from SRD)

PLM-6015: VIS Channel Telescope ellipticity
notes
The ellipticity (e) of the Euclid PLM PSF in the VIS channel at 800nm shall be < 13% (TBC) at any point of the VIS channel Fov.

Note: the requirement value includes contributions from design residuals, integration alignment error, focus error (including flatness tolerance allocated to the VIS instrument detection plane wrt to PLM interface as described PLM-6033), and PLM thermal stability. It does not include the VIS instrument contribution from the detector PSF, nor the spacecraft induced image motion (e.g. AOCS & SVM thermo-elastic effects).

(from PLM RD)

R-VIS-P-005: VIS ellipticity
notes
The ellipticity of the VIS instrument PSF at 800nm (excluding pixelization but including the residual of CTI correction) shall be less than 0.156.

(Budget breakdown:
VIS Ellipticity: 15.6%
SVM + PLM: 14.0%
TOTAL (weighted by FWHM): 14.4%
(4.3% system margin)

(from PERD)

Budget break down:
VIS Ellipticity: 15.6%
SVM + PLM:  14.0%
TOTAL (weighted by FWHM): 14.4%
(4.3% system margin)
Euclid Requirement Engineering

MRD Main Weak-Lensing Science requirements

Galaxy Shape Measurement

- Galaxy sample selection
  - Survey size: 15,000 deg²
  - 85% survey efficiency
  - Average Galaxy density: 30 deg²
  - Median redshift: Z>0.8
- VIS spectral range: 550-900mn

Measurement Bias Control

- VIS PSF Shape
  - FWHM < 0.18"
  - ε_i < 0.15
- VIS PSF knowledge
  - σ(R_{PSF}/R_{ref})^2 < 4
  - σ(ε_i) < 2x10^{-4}
- Distortion
  - Residual < 0.003%
- CTI effects
  - σ(ε_N) < 1.1x10^{-4}
- Shear Model bias
  - Additive σ[c] < 5x10^{-4}
  - Multiplicative σ[μ] < 2x10^{-3}

Photometric red-shift determination

- Photo-z precision and uncertainty
  - σ(z)/(1+z) < 0.05
  - σ(<z>)/(1+z) < 0.002
  - f_{cat} < 10%

Image quality

- Encircled Energy
- Pixel scale: 0.3”/pix

Sensitivity

- m_{AB} = 24 (5σ) in all bands

Calibration

- Relative Photometric error post-calibration < 1.5%

Number of photo-z bins

- 3 Euclid NIR bands

Number of photo-z bins

- External g,r,i,z data under EC responsibility

Legend

- SciRD Requirement
- PERD Requirement
- MRD Requirement
- MOCD Requirement
- MIRD Requirement
- SRD Requirement
- GDPRD Requirement
- CalCD Requirement
- EIDA Requirement
- SIRD Requirement
- Justification

Progressive growth to full req. complexity

Euclid Requirement Engineering
Euclid Model Organization

Double click on the hyperlink to access directly the requirement package.
All top level requirements implemented and traceable in the EA SysML model:

- NISP instrument and SGS requirements created and maintained in EA model
- Industry requirements liked from DOORs database.
- Changes generated and managed in model.
Benefits: Requirement Traceability and control

- Model IS the Mission System Engineering control tool.
- Traceability matrixes generated from model.
- Requirement related KPIs to track the system health and progress.
Benefits: adequate requirement change impact assessment

Assessment of changes impact in the system.
Modified requirement

New requirement
Requirement Document Generation

- Requirement document generation and maintenance from model

- Still some documentation generated “manually”: ESA/Industry paradigm shift to MBSE not mature enough

- SGS, NISP, Calibration Control Document Part-B, Requirement Justification File fully generated from Model

- Model includes configuration control through baselines => Consistency ensured across documents.
Beyond requirement management

pkg Euclid Mission start page

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

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

double click on the icons to navigate.

Euclid Mission

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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

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Status: preliminary

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

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Model Library

double click on the icons to navigate.
- Euclid system architecture modelling progressing as the system gets more defined:
  - PLM, Instruments top level model already in place
  - SGS intensive use of SysML to define their structure and interfaces.
  - Interaction between elements being built (IBD, parametric diagrams).
Architecture modelling

Euclid SysML | Jose Lorenzo Alvarez | ESTEC | 28/10/2014 | Slide 26
Architecture modelling

class VIS instrument bdd

- PLM Structure::VIS Struts
- PLM Structure::VIS Bracket
- VI-FPA
  - VI-FPA::VI-FPA-ES
  - VI-FPA::VI-FPA-ROE
- VI-RSU
  - VI-FPA::VI-FPA::CCD-Flexi
- VI-CU
- PMCU
- CDPU
- 36
- 12
- 12
- 36
SGS Architecture Modelling

Legend

- Mission Level
- SGS Level

class SGS bdd

- Block: Ground Segment pkg::Ground Segment
- Block: SGS Infrastructure
- Block: Euclid Pipeline
- Block: EAS (Euclid Archive System)
- Block: Science Mission Loop

Legend:

- Mission Level
- SGS Level

- Interacts with

Check that acquisitions are consistent with planned observations

- Responsible for:
  - SGS System Lead (from EC Team)
  - SGS Scientist (from EC Team)
  - Euclid Archive Manager (ESAC)
  - SOC Mission Manager (from Actor)
SGS Architecture Modelling

class Euclid Pipeline (overview)
System Internal data flow modelling

```
ibd [Block] Telescope [Telescope ibd]

ibd [Block] Telescope [Telescope ibd] -> m1: Mirror -> m2: Mirror -> fom1: Mirror -> fom2: Mirror

m3: Mirror

dichroic: Dichroic

incident_light : optical_signal
reflected_light : optical_signal
transmitted_light : optical_signal

VIS_Telescope_exit : Telescope VIS interface
NISP_channel_exit : Telescope NISP Interface
```
Use-case definition for SGS

class On-demand Processing Execution Environment

Scientific Community (non EC SWG members)
(from Actor)

EC SWG (from Actor)

EC Operational Euclid Project Scientist
(from Actor)

EC SGS global monitoring and control team
(from Actor)

SDC Prod (from Actor)

Distribute Euclid Data Product to Scientific Community
(from Top-Level Objectives)

Create & Run Processing Plans for On-demand processing

Create & Run Processing Plans for reprocessing campaigns

Arbitrate SDC resources allocation to Processing Plans
(from SGS Monitoring & Control)

not needed? stated in processing parameters?

Manage quality of Euclid data products
(from Top-Level Objectives)

Manage pipeline modules distribution & execution inside EC SGS
(from Top-Level Objectives)
Activity diagrams for pipeline process

**Act Execute On-demand PP**

1. Init
2. Create Processing Plan
3. Select Pipeline Descriptions
4. Attach Sky Areas (optional: Attach SDC)
5. Attach Input Data Queries
6. Divide Sky Area into Sky Patches & generate Processing Orders
7. (optional) Modify Processing Parameters
8. Execute PP (execute PO)
9. PP completed

**Act Execute PO**

1. Receive PO
2. Check consistency of Observation/SkyPatch Local vs. EAS
3. If needed retrieve missing observation data
4. Check availability of external data (related to sky patch) - retrieve if needed
5. Bypass checks?
6. Filter input data (execute query)
7. Transfer input data to cluster storage
8. Retrieve package version from Codeen ("latest stable")
9. Prepare/check cluster infrastructure
10. Execute processing (Pipeline Description traversal by IAL Workflow Manager)
11. Clean infrastructure
12. Check output consistency
13. Complete output data with generic header
14. Store output data into local archive if production
15. Reference output data to EACS
16. PO completed

Each event during PO execution sends log information into EIS.

All input data available locally.

**Act Execute On-the-fly PP**

1. New data available
2. Send L1 data to EAS (PO)
3. Send L1 metadata to EACS
4. Distribute data to 2 SDC per Sky Patch
5. Distribute L1 data from EAS (PO)
6. Get metadata from EACS
7. Get new L1 data from EAS (PO)
8. Register new data location in EAS
9. Receive PO
10. Distribute POs to primary SDC
11. PP completed (primary SDC)
12. Execute PO

Processing activities (PP, PO, Pipeline Descriptions...) are registered in EIS.

Processing activity (PP PO, Pipeline Descriptions, ...) are registered in EIS.

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Focus for coming year(s)

Requirements definition and traceability

Interface Consolidation

Req. Maintenance & Change Control

Technical Control & tracking

Mission Verification and validation
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