34th Annual INCOSE international symposium
hybrid event
Dublin, Ireland
July 2 - 6, 2024

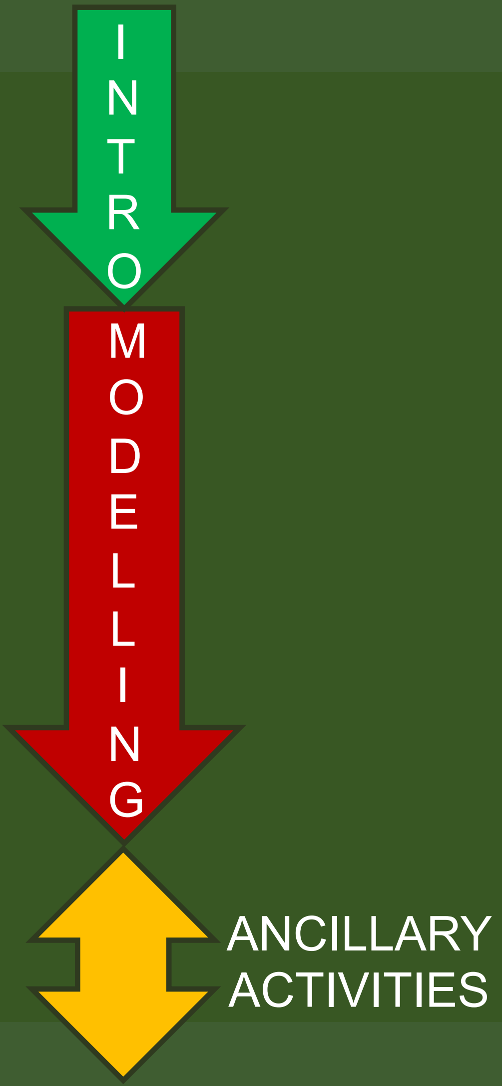
ANDES, the high-resolution spectrograph for the ELT: the adoption of the Model-Based System Engineering approach

Scalera, Marcello Agostino[1,3]; Zanutta, Alessio[1,4]; Riva, Marco[1]; Balestra, Andrea[2]

1 INAF – Astronomical Observatory of Brera
2 INAF – Astronomical Observatory of Padua
3 marcello.scalera@inaf.it
4 alessio.zanutta@inaf.it

Outline

1. The new system engineering approach
2. MBSE applied to ANDES
3. The ANDES spectrograph
4. Requirements Management
5. Life Cycle Management
6. Functional Analysis
7. Physical Analysis
8. Interfaces Management
9. System Documentation Management
10. SysML Personalization
11. Interactive Modelling
12. Conclusions and future development



The new system engineering approach for astronomical projects

CLASSIC METHOD

Document-Based System Engineering

1. Huge and **dispersive documentation**
2. **Poor communication** among disciplines
3. Difficulties in **tracing the development** process
4. Absence of a **global development strategy**
5. Impossible to have a **complete picture of the system** at any development step

TRANSITION

NEW METHOD

Model-Based System Engineering

1. Single location (document) where **all information** about the system is **stored and easily accessible**
2. Development can be easily **checked and evaluated** at any time
3. **Coherent and direct** system development
4. Specialized approaches for astronomy are still under development

MBSE applications 1/2

1. Requirements management

1. Gather **Top Level Requirements** (TLR)
2. Identify **Instrument Objectives**
3. Trace **derivation from TLRs**
4. Allocate **requirements to subsystems**
5. Gather **lower derivation** requirements

2. Life Cycle management

1. Identify the **life phases**
2. Model the **transitions** between life phases
3. Detail life phases with **operative modes and associated activities**

3. Functional Analysis

1. Functional **trees**
2. Activities and **behavioural modelling**
3. Allocate **functions to subsystems**

Associated simulations

1. Requirements verification
2. Duty cycle simulations → Reliability analysis
3. Time duration analysis
4. Computation of allocated power

MBSE applications 2/2

4. Physical Structure Management

1. Import the physical elements **directly from the designers' inputs**
2. Automatically **generate PBS and BoM**

5. Interface Management

1. Integrate **system interfaces**
2. Populate interfaces **according to their nature**
3. Describe the **flows**
4. Automatic **check of the coherency**
5. Setup the **automatic validation method**

Associated simulations

1. Physical **budget computations**
2. Automatic generation of **system related documents**
3. Automatic **verification of the host/client relationship**

6. System Documents Management

1. Active support to **Project Management**
2. Full **traceability and coherency**

ANDES Spectrograph

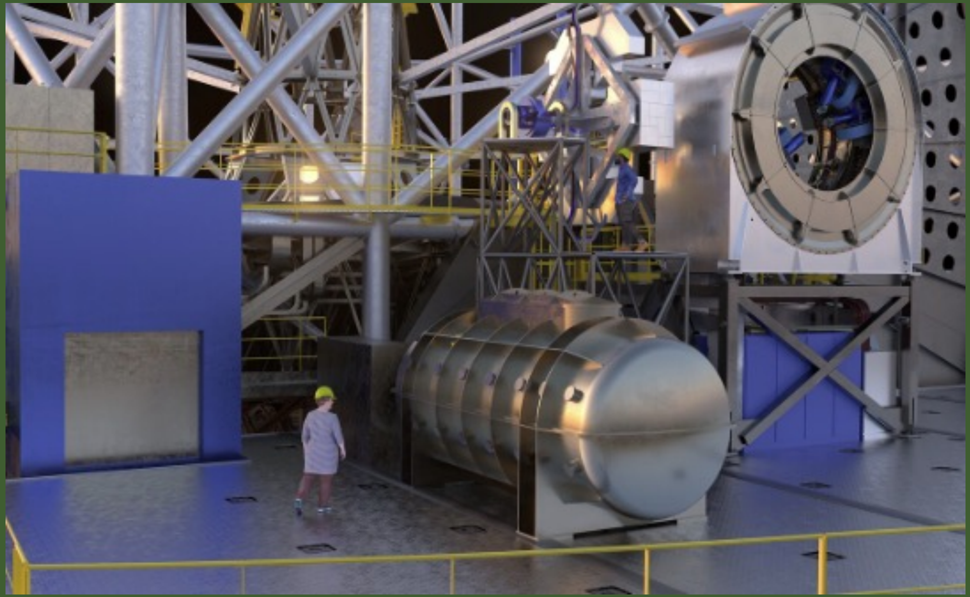
ANDES = ArmazoNes high Dispersion Echelle Spectrograph *

WHAT IS ANDES

1. High spectral resolution instrument R=100000 and very high stability
2. Operates in VIS and NIR spectral range
3. Will operate in the ELT (Extremely Large Telescope)
4. Double operative mode (Seeing Limited or SCAO + IFU)

WHY ANDES

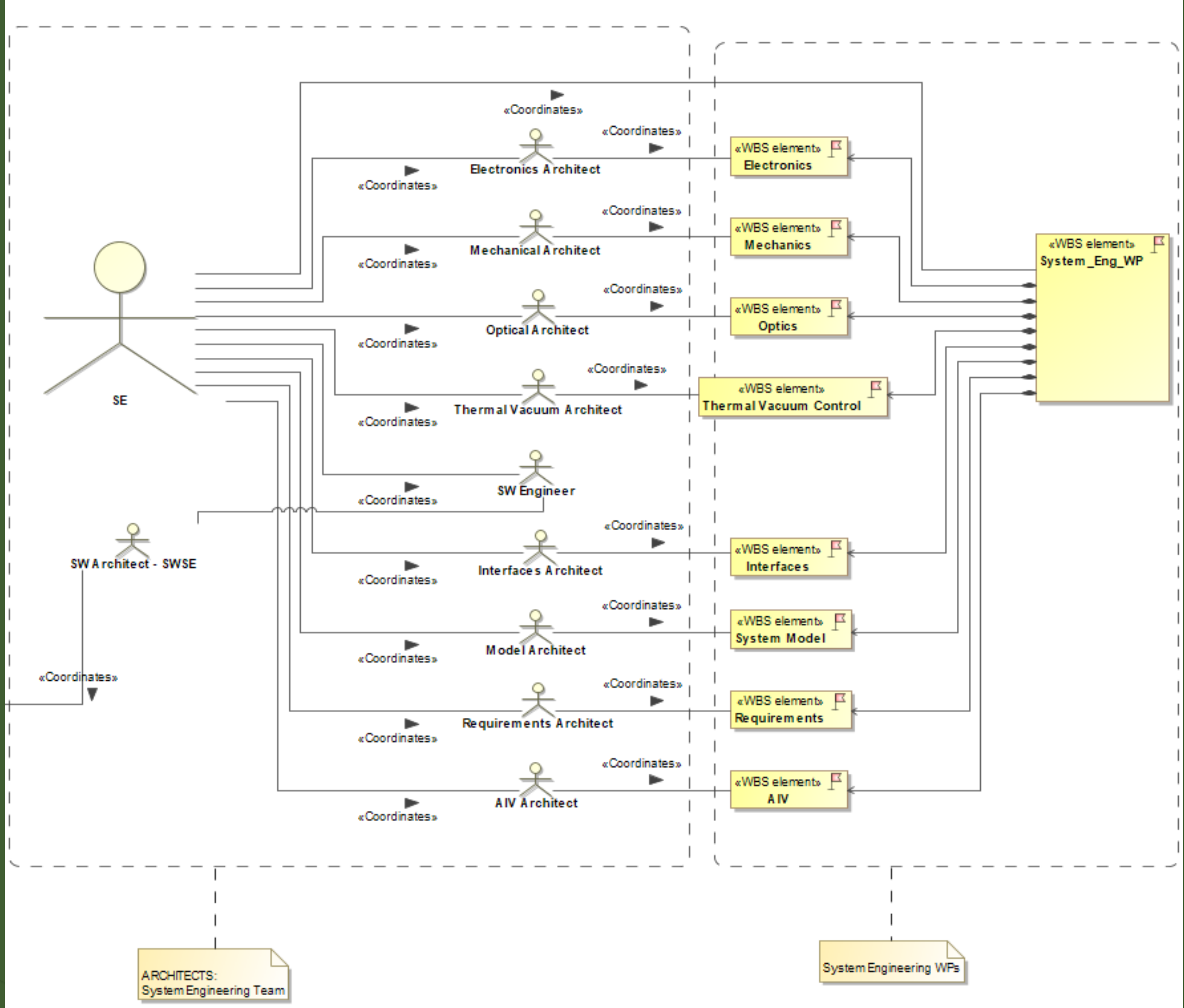
1. Search for scientific proof of extraterrestrial life
2. Characterization of exoplanet atmospheres
3. Testing of universal constants
4. Measurement of the cosmic expansion
5. Study of the primordial universe



*https://elt.eso.org/instrument/ANDES/

Requirements management 1/4

Gather TLR and provide them to architects



Requirements at this early stage are:

- Scientific-oriented requirements
- ESO-specific requirements
- Other standards-related requirements

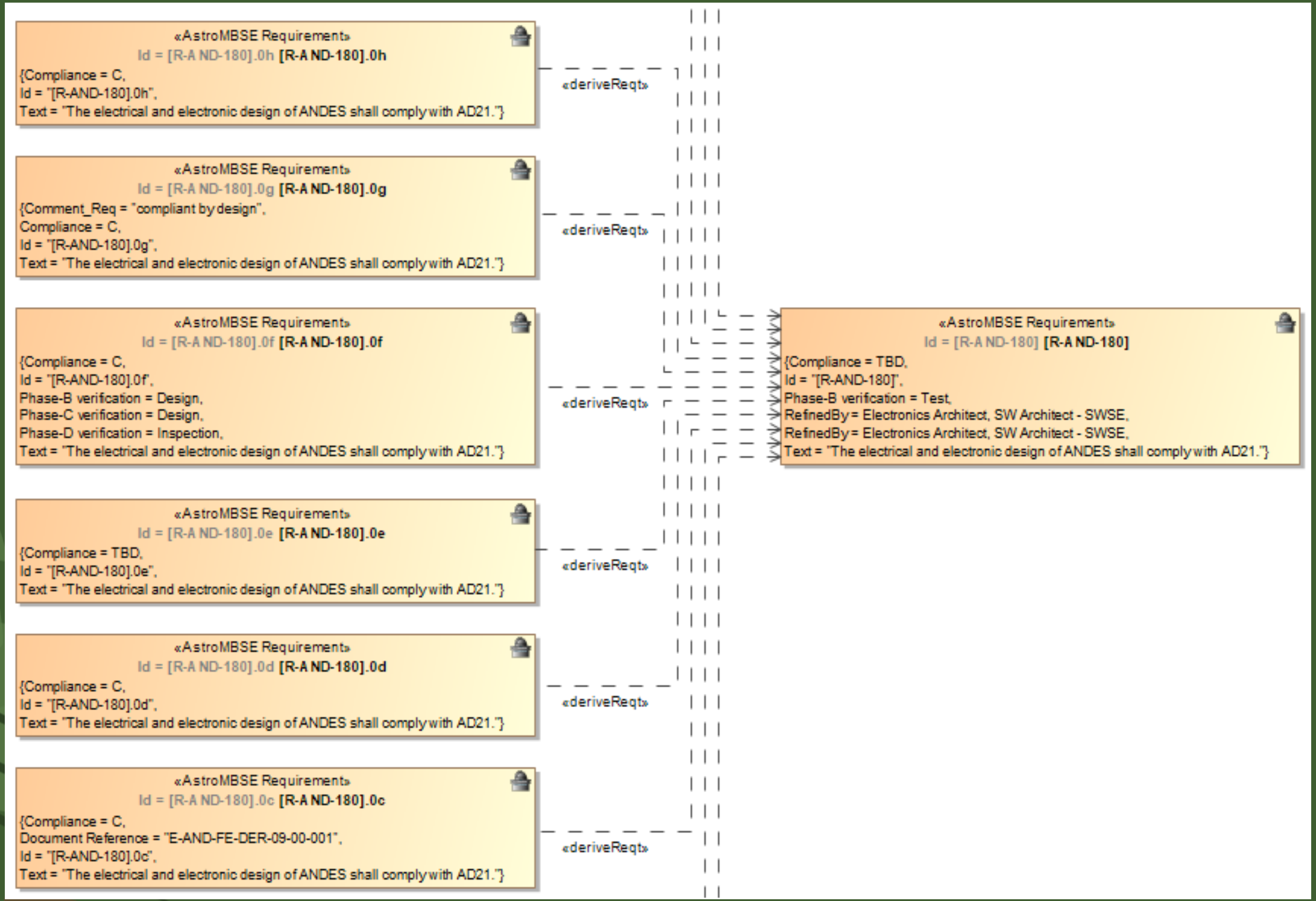
Instrument objectives and basic capabilities can be extrapolated before sending them to architects for refinement

Requirements management 2/4

Gather TLR and provide them to architects

Architects refine requirements associated to their discipline

Requirements produced by architects are also prepared for their delivery to subsystems



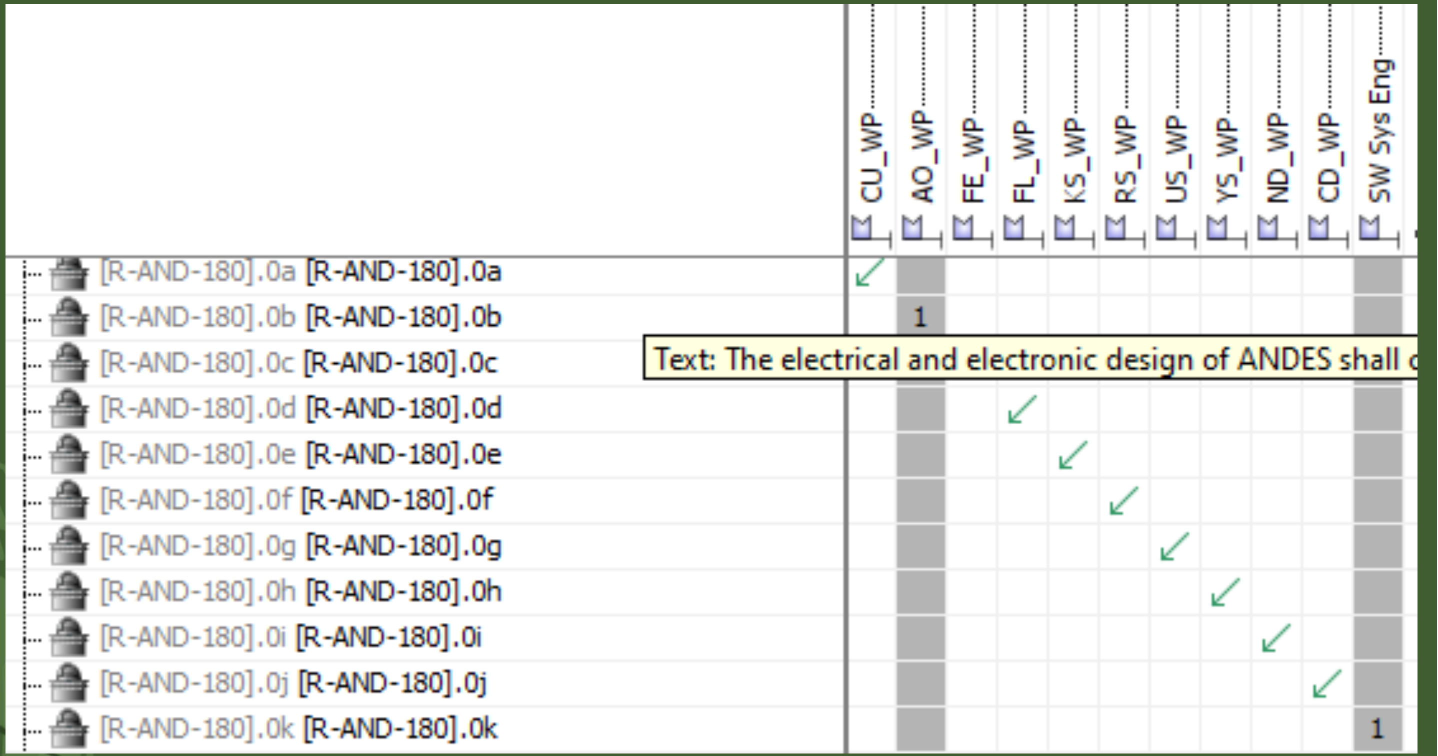
Requirements management 3/4

Gather TLR and provide them to architects

Architects refine requirements associated to their discipline

Requirements are allocated to the subsystems to drive their development

FULL TRACEABILITY



Requirements management 4/4

Numbering scheme

ISSUING RESPONSIBILITY

ARCHITECTS — SS RESP — ELMNT RESP

[R – AND – nn] . xx . SS . m

SYSTEM — SUB SYSTEM — ELEM. — SUB ELEM.

VERIFICATION RESPONSIBILITY

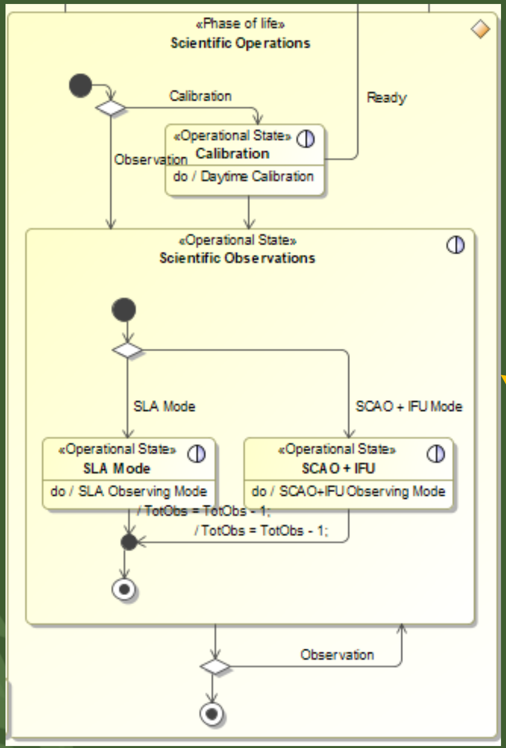
E.G.

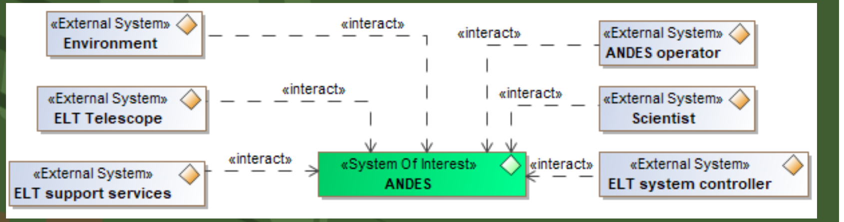
[R–AND–62].1. AO1.3

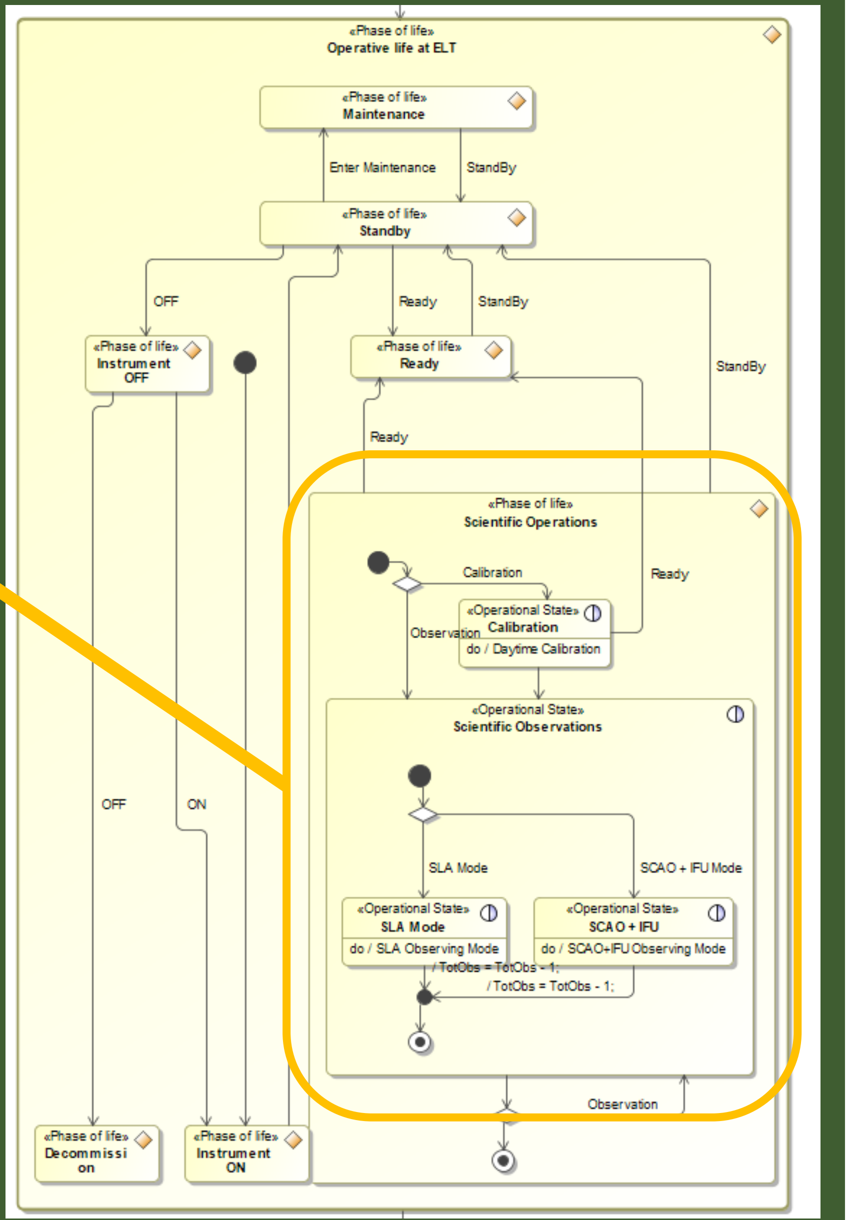
Life Cycle Management 1/2

Represent the phases of the instrument life and the transitions among them

- **Phase of life**: phase in the instrument's lifetime
- **Operational State**: state in which the interactions with the external systems are relatively constant
- **Observing Mode Activity**: behavior triggered when in a state (or while entering/exiting)





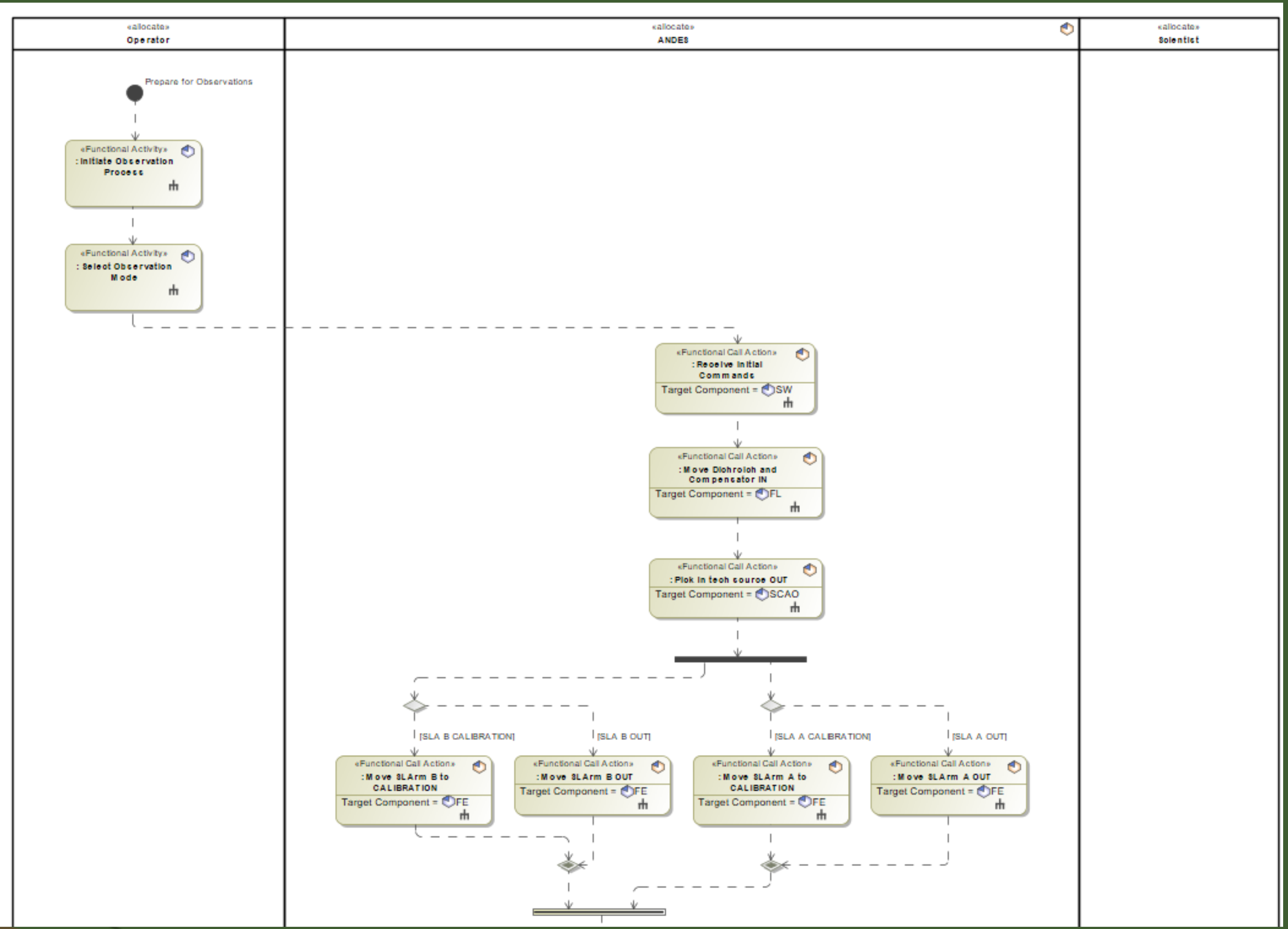


Life Cycle Management 2/2

Represent the phases of the instrument life and the transitions among them

Phases of life or operational state are further refined by Activities

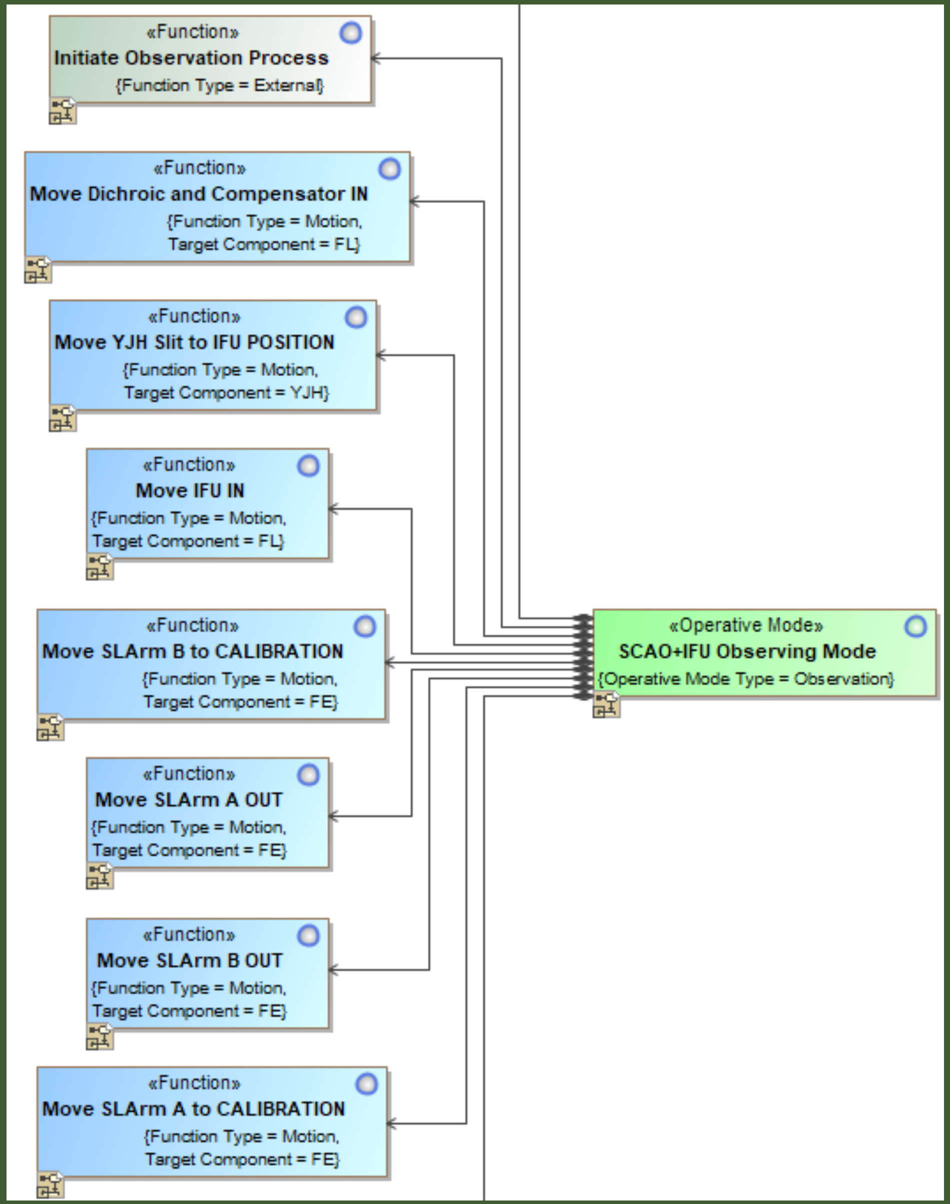
Such activities are used as stepping stones for the system functional analysis



Functional Analysis

Functional trees are created to represent the internal structure of operative modes, made by Functions

- **Function**: intended effect of a product (ECSS-S-ST-00-01C)
- **Function Type:** generic type of the function (Motion, Power ON/OFF, Open/Close, External)
- **Target Component**: system element whose operations are affected by the function



Physical Analysis 1/2

Product tree imported using inputs by designers

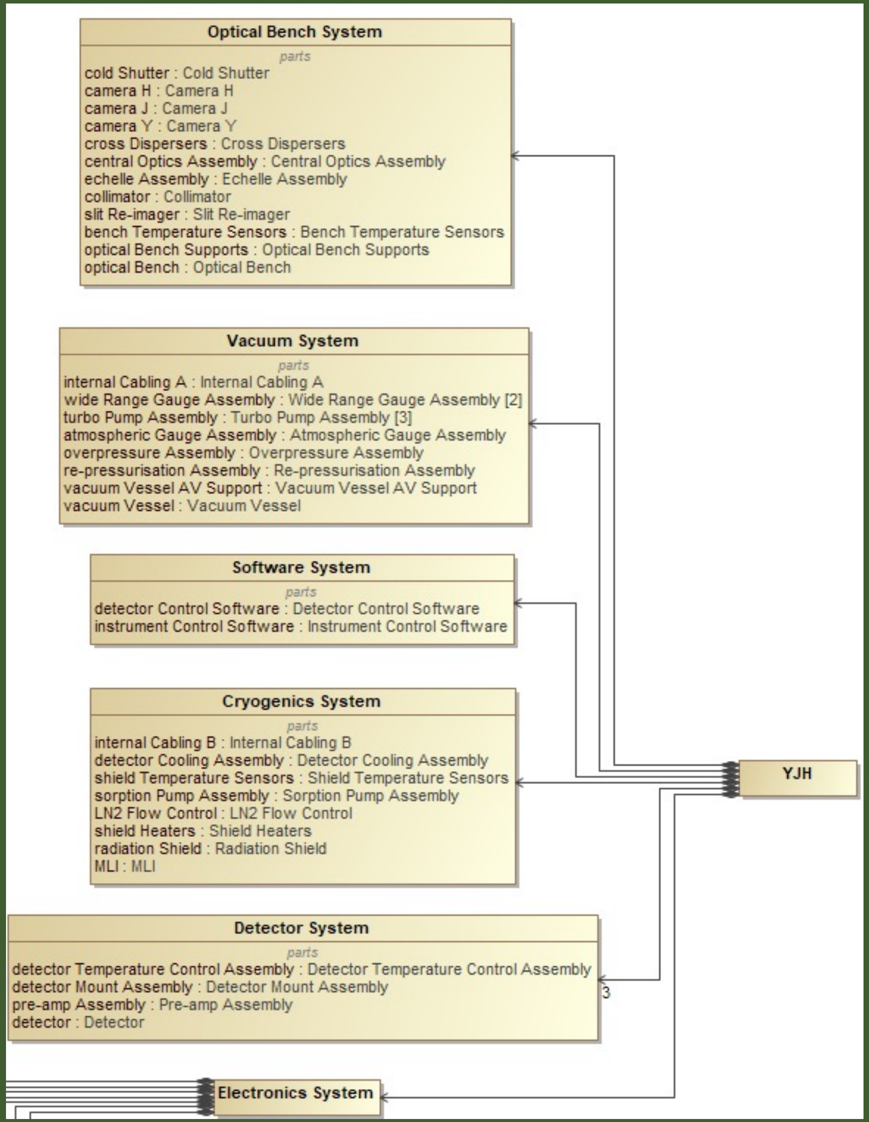
Automatic procedure

Inventor

AN-FE PBS

Num	Name	Part Type	Owner
AN-FE_1	Structure	Structure	FE
AN-FE_1_1	Supporting structure	Supporting structure	Structure
AN-FE_1_2	Arms platform	Arms platform	Structure
AN-FE_1_2_1	SL1 mechanisms	SL1 mechanisms	Arms platform

CAMEO SYSTEMS MODELER™



Physical Analysis 2/2

Automatic generation of PBS and BoM based on imported structure

PBS: all single elements are uniquely reported and identified with a unique code

BoM: identical elements are compacted into a single voice with an associated multiplicity

BoM

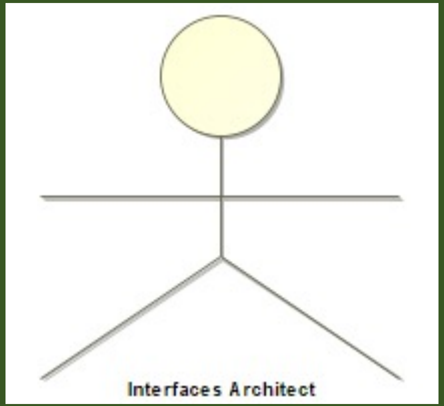
5	⊟ Vacuum System		YJH		YS-07-00	6	n	n
6	Vacuum Vessel		Vacuum System		YS-07-00	6	n	n
7	Vacuum Vessel AV Support		Vacuum System		YS-07-00	6	n	n
8	Re-pressurisation Assembly		Vacuum System		YS-07-00	6	n	n
9	Overpressure Assembly		Vacuum System		YS-07-00	6	n	n
20	Atmospheric Gauge Assembly		Vacuum System		YS-07-00	6	n	n
21	Turbo	3	Vacuum System		YS-07-00	6	n	n
22	Wide Range Gauge Assembly	2	Vacuum System		YS-07-00	6	n	n
23	Internal Cabling A		Vacuum System		YS-07-00	6	n	n

Atmospheric Gauge Assembly

			Assembly						
21	yjh.vacuum System.turbo Pump Assembly[1]	AN-YS_02_6a	AN-YS_02_6 Turbo Pump Assembly	Vacuum System		YS-07-00	6	n	n
22	yjh.vacuum System.turbo Pump Assembly[2]	AN-YS_02_6b	AN-YS_02_6 Turbo Pump Assembly	Vacuum System		YS-07-00	6	n	n
23	yjh.vacuum System.turbo Pump Assembly[3]	AN-YS_02_6c	AN-YS_02_6 Turbo Pump Assembly	Vacuum System		YS-07-00	6	n	n
24	yjh.vacuum System.wide Range Gauge Assembly[	AN-YS_02_7a	AN-YS_02_7 Wide Range Gauge Assembly	Vacuum System		YS-07-00	6	n	n
25	yjh.vacuum System.wide Range Gauge Assembly[	AN-YS_02_7b	AN-YS_02_7 Wide Range Gauge Assembly	Vacuum System		YS-07-00	6	n	n

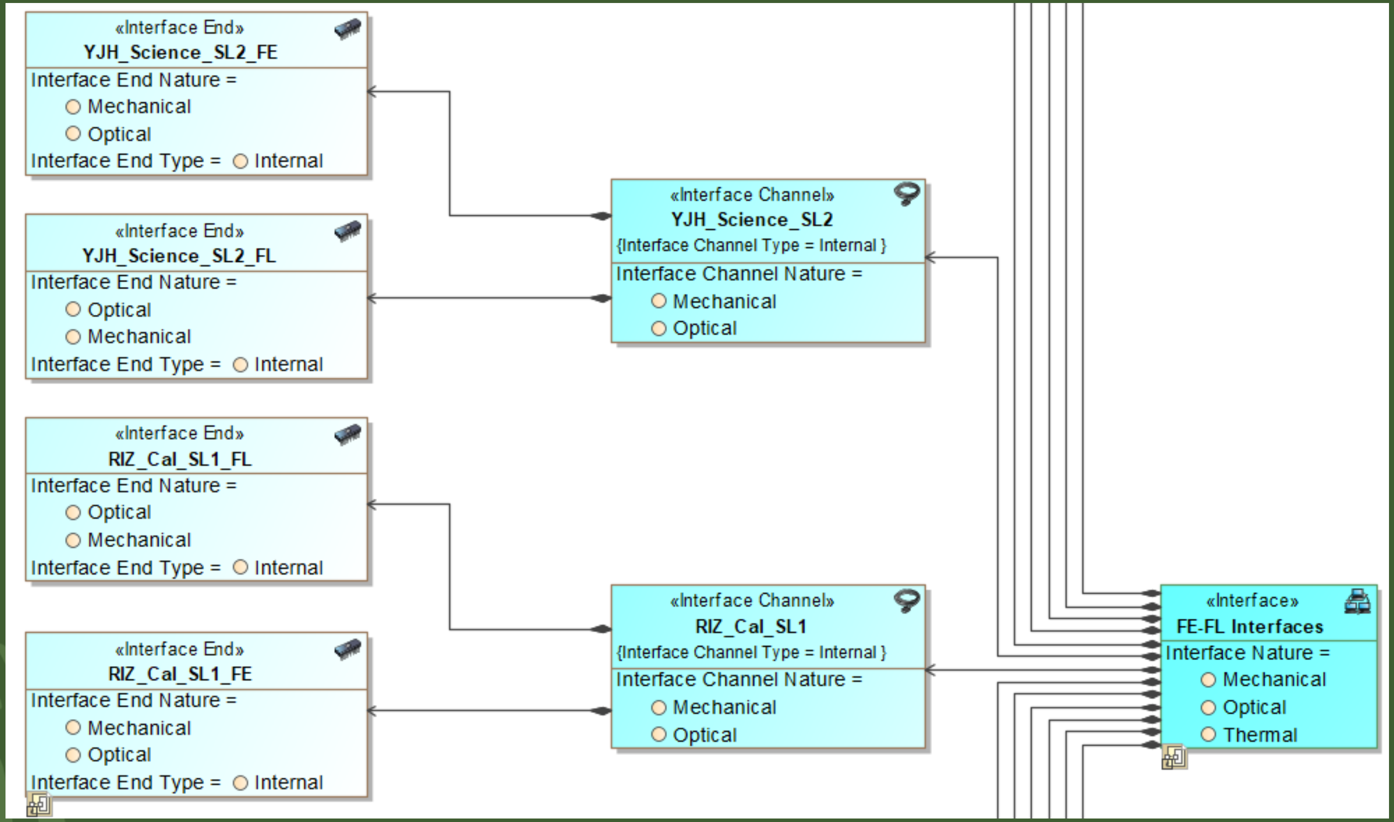
PBS

Interfaces Management 1/5



- Identifies interfaces
- Identifies the natures of these interfaces (optical, mechanical, thermal, fluid, electric)
- Identifies the host and the side ends

Import in model



1. **<u>Interface</u>**: overall representation of the system interface → specification of <<Block>>
2. **<u>Interface Channel</u>**: multiple parts that realize the interface → specification of <<Block>>
3. **<u>Interface end</u>**: side of the interface channel → specification of <<Interface Block>>

Interfaces Management 2/5

CLASSIC METHOD

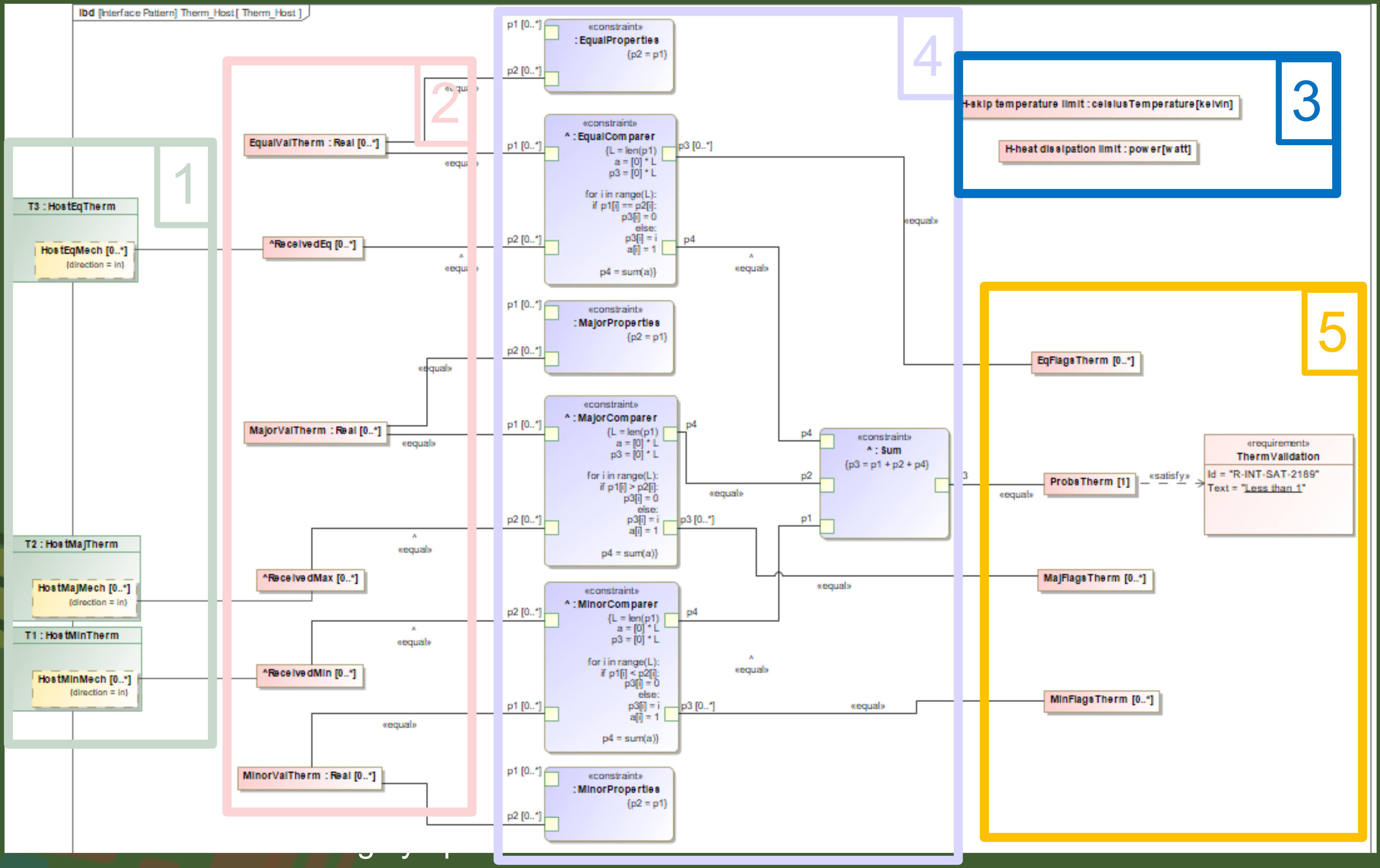
1. Each host-client relationship is manually verified
2. Coherency among connected interfaces is ensured manually
3. Very complex to use as design driver
4. Difficult to keep up to date

AstroMBSE INTERFACES METHOD

1. Automatic verification of all connected interface ends
2. Reliable and repeatable computational method
3. Use of basic SysML elements and capabilities
4. Interfaces are directly embedded in the system and its design
5. Fast and simple setup effort

Interfaces Management 3/5

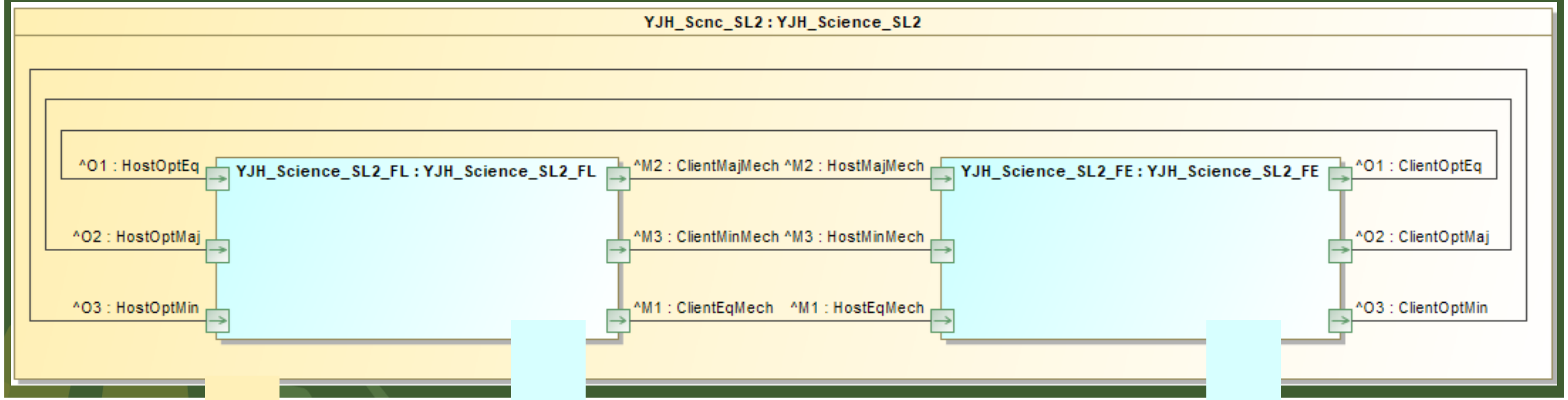
1. Ports that accept/send vectors from/to the complementary interface end
2. Vectors that collect nature dependant values according
3. Nature dependant value properties
4. Comparison computational blocks
5. Validation results generation



Interfaces Management 3/5

- Each interface channel is composed of **two interface ends**
- Each end can be populated with an **arbitrary number of natures**

IBD of an <<Interface>> Class



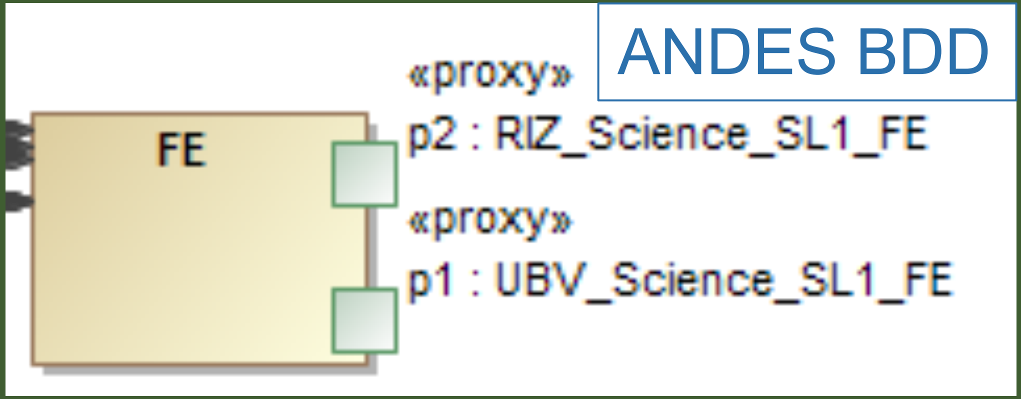
Part typed as an <<Interface Channel>>

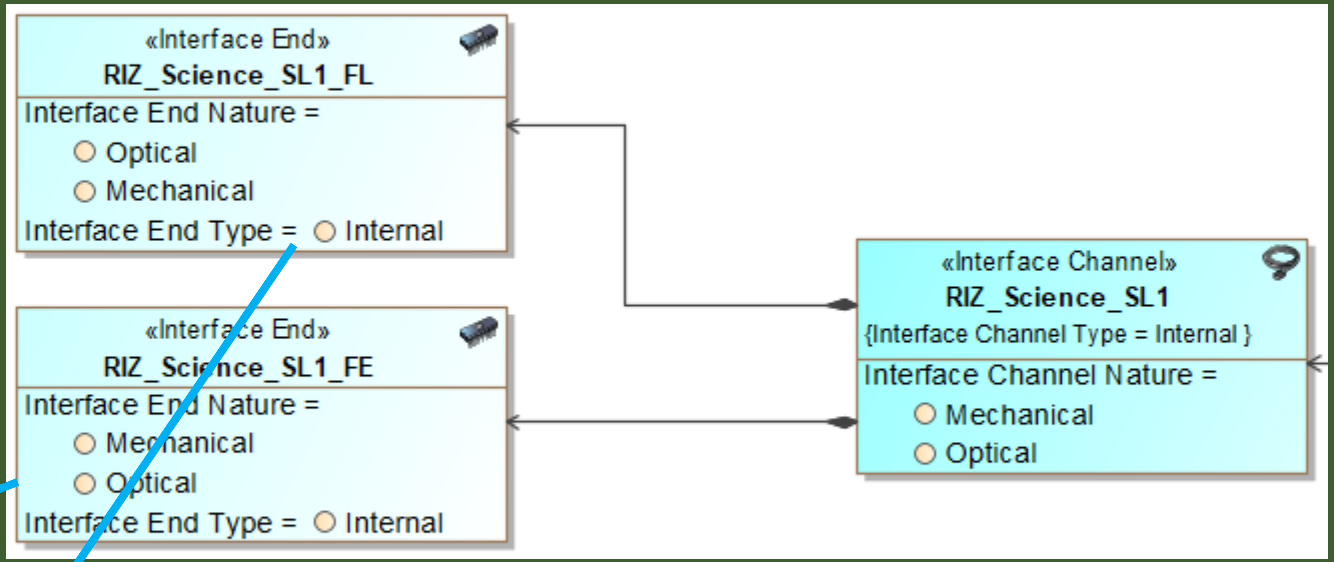
- Container of interfaces' ends

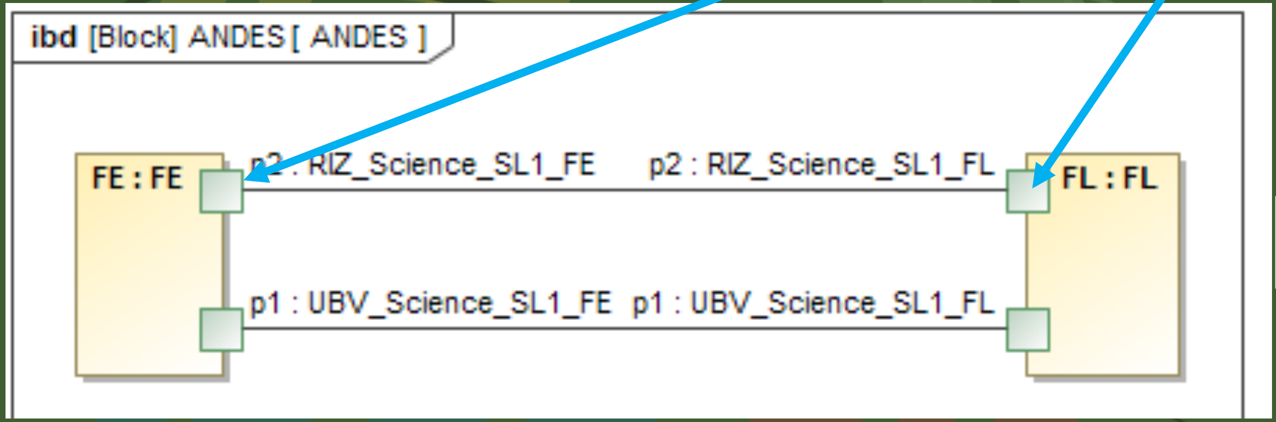
Parts typed as two complementary <<Interface End>>

- Each end is populated according to its nature and as a client or host
- The vectors collecting value properties are flowing through the ports

Interfaces Management 5/5







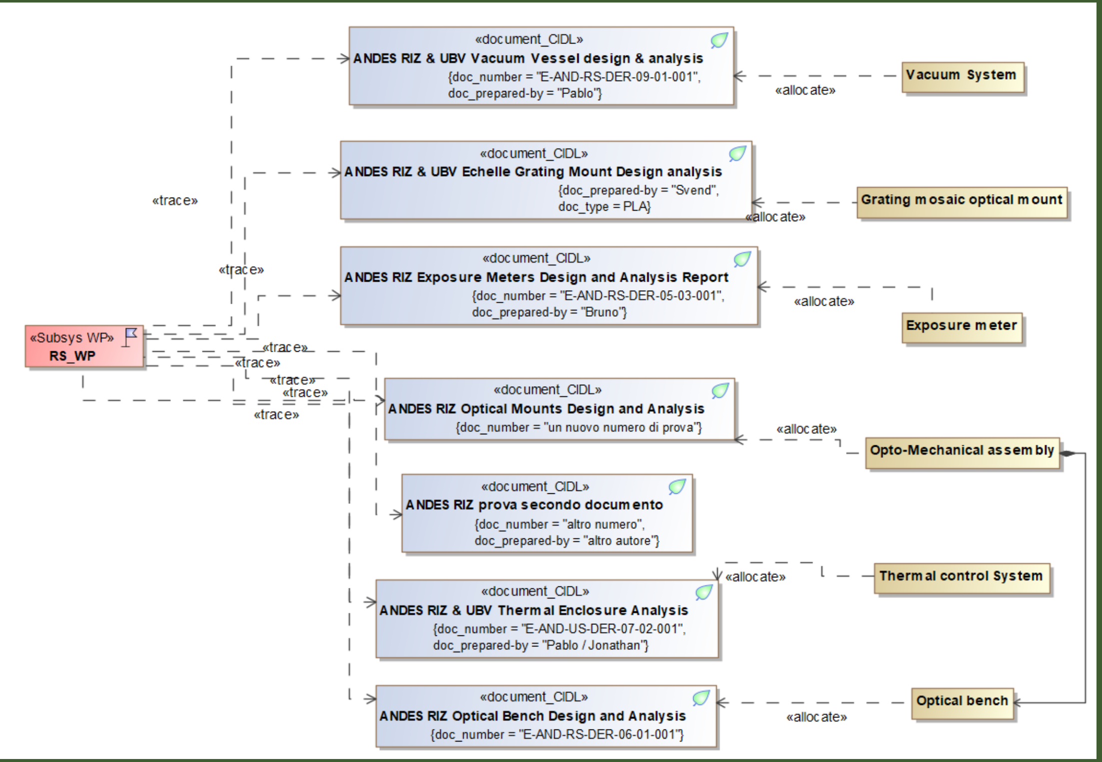
Interfaces Verification Table

Verification Status: Pass Fail ...

#	Name	Unnamed1	ErrorNumb : Real	Equal Flags : Real	Major Flags : Real	Minor Flags : Real
1	us-fl.exposure Meter fibers US	IF-INT_US-FL_2 Exposure	0	0 0 0	0 0 0 0 0 0 0	0 0 0 0
2	us-fl.pseudoslit Matrix US1	IF-INT_US-FL_1 Pseudosli	1	0 0 0	0 0 0 0 0 0 7	0 0 0 0

System Documents Management

- System documents (Design Reports, Test Reports, and more) are stored in the model
- By doing so, the documents are strictly related to the system elements they refer to
- Documents may be associated with any element at any modeling layer

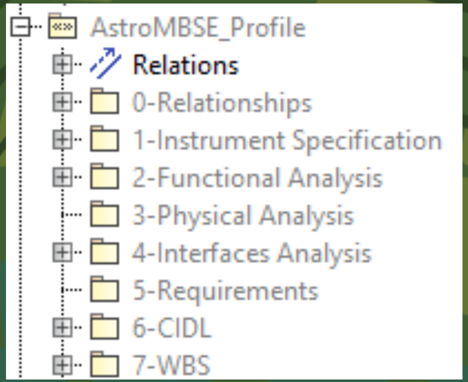


#	Folder - Associated PBS Item	Doc_ Relative- File- Path	Name	Doc_type	Doc_ Subtype	Doc_status	Doc_releasing_org	Doc_prime_contractor	Doc_number	Doc_version	
1	Grating mosaic optical mount		ANDES RIZ & UBV Echelle Grating Mount Design analysis	PLA							S
2	Thermal control System		ANDES RIZ & UBV Thermal Enclosure Analysis						E-AND-US-DER-07-02-001		P
3	Vacuum System		ANDES RIZ & UBV Vacuum Vessel design & analysis						E-AND-RS-DER-09-01-001		P
4	Exposure meter		ANDES RIZ Exposure Meters Design and Analysis Report						E-AND-RS-DER-05-03-001		B
5	Optical bench		ANDES RIZ Optical Bench Design and Analysis						E-AND-RS-DER-06-01-001		
6	Opto-Mechanical assembly		ANDES RIZ Optical Mounts Design and Analysis						un nuovo numero di prova		
7	Grating mosaic optical mount		ANDES RIZ prova secondo documento						altro numero		a

SysML Personalization

AstroMBSE Features

1. PBS and BoM generation
2. Interfaces management
3. Specialization of SysML for astronomical instrumentation
4. Instrument life management
5. Interactions through Collaborator
6. Documentation management



MERGING

RESULT

Formalized AstroMBSE procedure and methodology

Established procedural framework

esa

PROBLEM SPACE
1. Context
2. Objectives

SOLUTION SPACE
1. Functional Analysis
2. Physical Analysis

Interactive Modeling

Classic Method

Designers'/Stakeholders' space

Import changes

Export modified model

System Engineering's space

Active Interaction Method

Designers'/Stakeholders' space

Modifications and comments in views directly in the model

Generate actual views of the model

System Engineering's space

Conclusions and future works

Conclusions

1. MBSE → higher automation of many system engineering processes
2. MBSE → more efficient system engineering effort
3. MBSE → Improved interconnection among the different disciplines
4. MBSE → system development is more coherent and straight to the point

Future Works

1. Make models user-friendly for non-Cameo users
2. Fully formalize the MBSE methodology for astronomical instruments
3. Tailor the methodology to align with strategic partners
4. Move towards the definition of a digital twin for astronomic instruments

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

LAGRANGE

LUPM
LABORATOIRE UNIVERS & PARTICULES MONTPELLIER

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ
Faculty of Physics, Astronomy and Informatics

CENTRO DE ASTROBIOLOGIA
CSIC - INTA

irap
astrophysique & planétologie

HERIOT WATT UNIVERSITY

INSTITUTO DE ASTROFISICA DE CANARIAS
IAC

u b
UNIVERSITÄT BERN

UH
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

cnrs

TLS

UNIVERSITY OF CAMBRIDGE

UKRI
Science and Technology Facilities Council
UK Astronomy Technology Centre

Centro de Astrofísica da Universidade do Porto

IPAG

UPPSALA UNIVERSITET

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN
IN PUBLICA COMMODA
SEIT 1737

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

AIP
Leibniz-Institut für Astrophysik Potsdam

SIGILLUM UNIVERSITATIS HAFNIENSIS

UFRN
UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE

IAA

Stockholm University

AARHUS UNIVERSITY

IAP

UNIVERSITY OF MICHIGAN

ZAH
ZENTRUM FÜR ASTRONOMIE

LMD

DTU

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

ia
instituto de astrofísica e ciências do espaço

FCiências ID
ASSOCIAÇÃO PARA A INVESTIGAÇÃO E DESENVOLVIMENTO DE CIÊNCIAS

LUNDS UNIVERSITET

OBSERVATOIRE DU MONT-MÉGANTIC

INSTITUT DE RECHERCHE SUR LES EXOPLANÈTES
INSTITUTE FOR RESEARCH ON EXOPLANETS
iREx
Université de Montréal

34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

www.incose.org/symp2024
#INCOSEIS