Meeting della strumentazione ELT a guida italiana (MORFEO e ANDES)

"ANDES, the high resolution spectrograph for the ELT: System Architecture Design"

14-05-2026 - Napoli

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Top-Level Requirements Driving the ANDES Architecture

High-resolution and stability
- Resolving power **R = 100,000** (–10% / +30%)
- Wavelength calibration precision **< 1 m/s RMS**

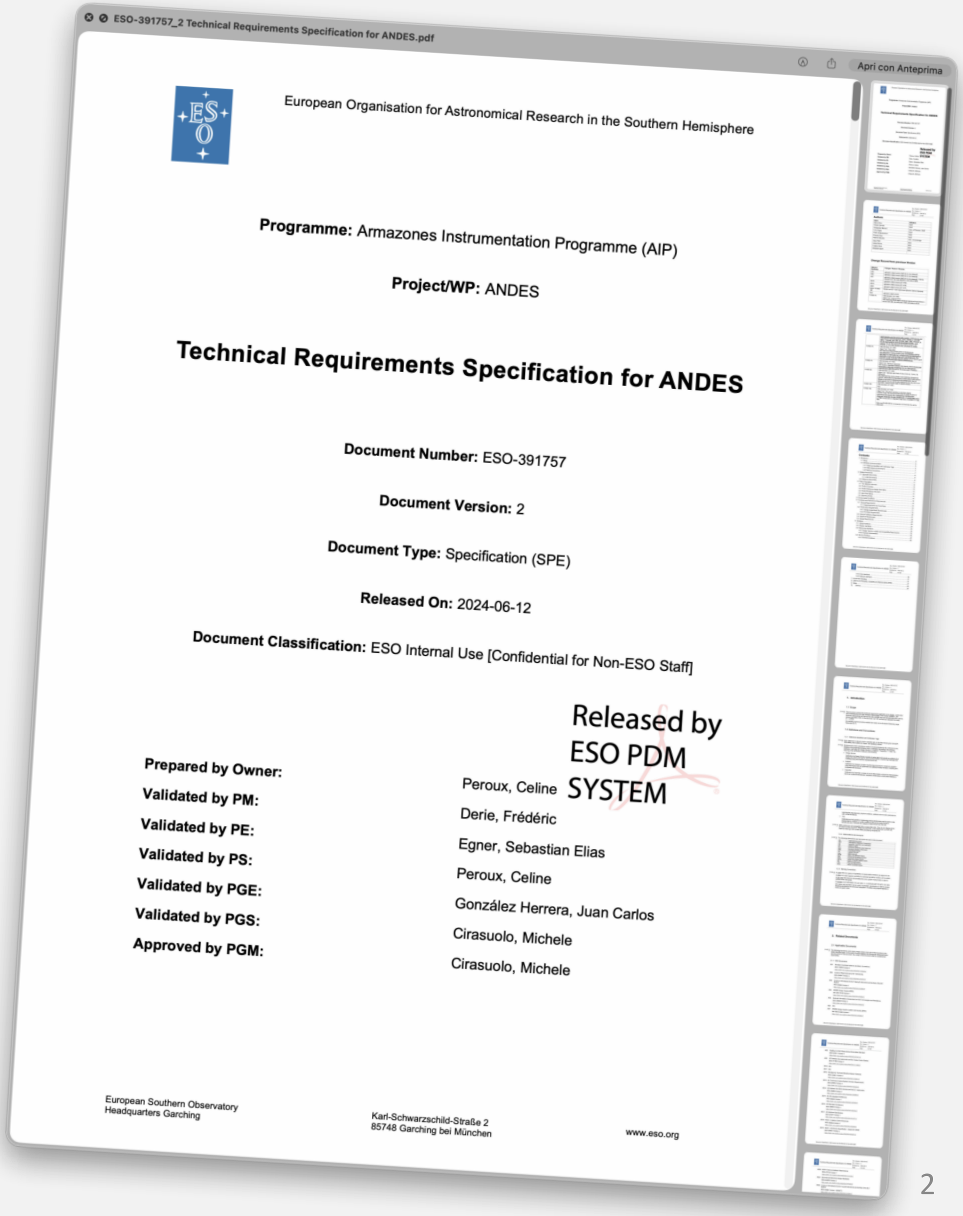
Spectral coverage with TWO observing modes
- Seeing-limited: **350–2400 nm** (simultaneous, single allowed gap)
- IFU mode: **980–1800 nm** (simultaneous)

Simultaneous object and sky capability
- **Two sub-FoVs observed simultaneously**
- Object–sky separation up to **2 arcmin** (goal: 5)
- Minimum separation **15 arcsec** (goal: 10)

Étendue and focal plane constraints
- Full slit FoV **> 1 arcsec²** (goal: 2)
- IFU: **7×7 spaxels**, ≥ **2 spatial scales** FoV ≥ **0.5 arcsec²** at largest scale

Throughput and sensitivity
- Average transmission **> 7%**
- Global minimum **> 4%** above **400 nm**

AO-driven requirements
- SCAO loop closure for guide stars **6 ≤ I_AB ≤ 15**
- **Contrast 10^{-3}**


ESO-391757_2 Technical Requirements Specification for ANDES.pdf

Apri con Anteprima

European Organisation for Astronomical Research in the Southern Hemisphere

Programme: Armazones Instrumentation Programme (AIP)

Project/WP: ANDES

Technical Requirements Specification for ANDES

Document Number: ESO-391757

Document Version: 2

Document Type: Specification (SPE)

Released On: 2024-06-12

Document Classification: ESO Internal Use [Confidential for Non-ESO Staff]

Released by ESO PDM SYSTEM

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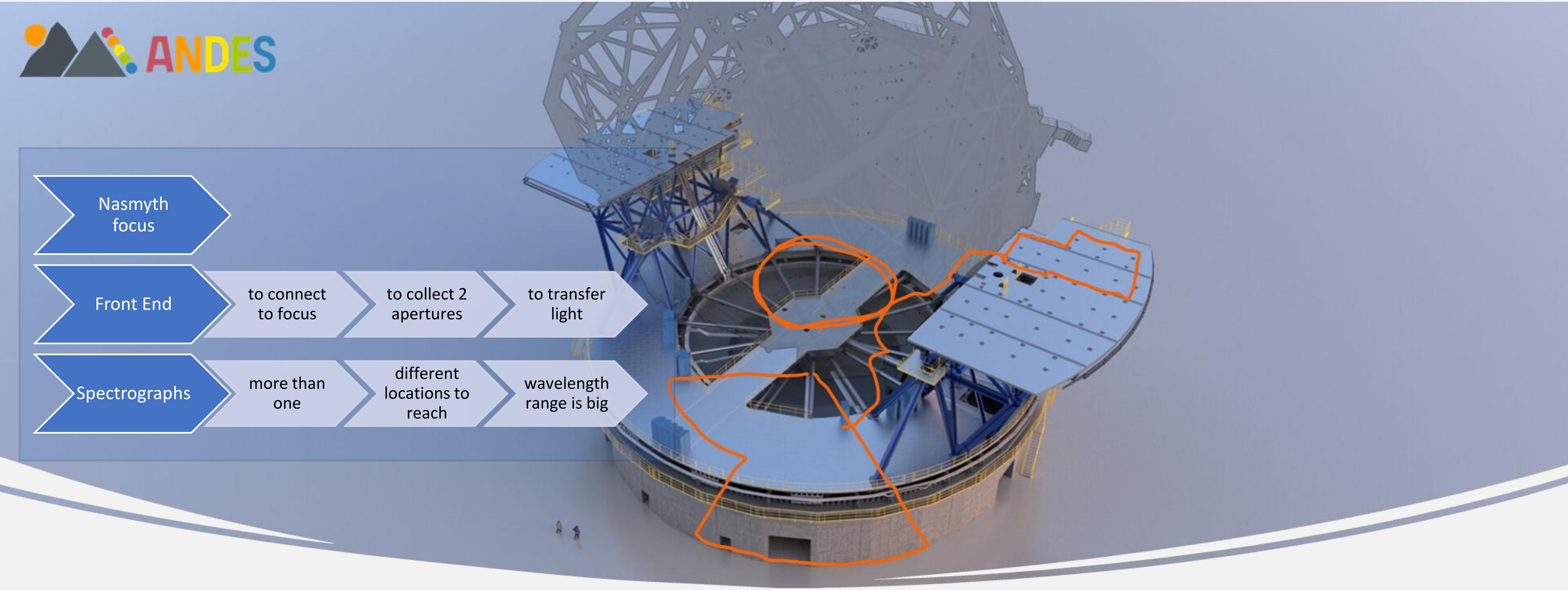
ANDES: deployment – concept in the ELT landscape



ANDES

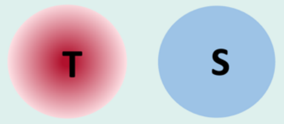
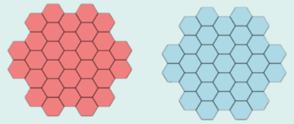
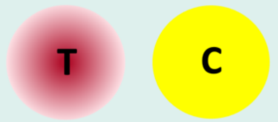
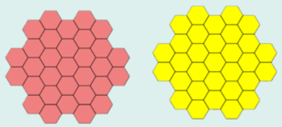
Observing Modes as Key Architectural Driver

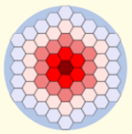
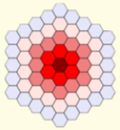
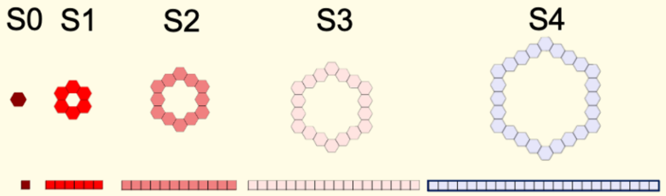
Two baseline observing modes at **R ≈ 100,000**

- **SL-UNI**: seeing-limited, uniform illumination
- **IFU-AO**: integral-field spectroscopy with **SCAO**

Modes implemented via **independent fiber groups**

- **Dedicated slits** inside the spectrographs for each mode
- Mode selection performed at **Front-End level**

observing mode	front-end	fiber link	spectrograph slit
SL-UNI **[U]BV+RIZ+YJH spectrographs** two identical apertures simultaneously illuminated by target and sky (SL-UNI-TS), or target and calibration (SL-UNI-TC) for wavelength reference; beam-switching of the two apertures is possible	input light from the telescope on two, individual large fibers	2 bundles of small fibers uniformly illuminated after scrambler & splicer, to maximize spectral fidelity	2 segments of uniformly illuminated fibers along each spectrograph slit
	 		
	 		

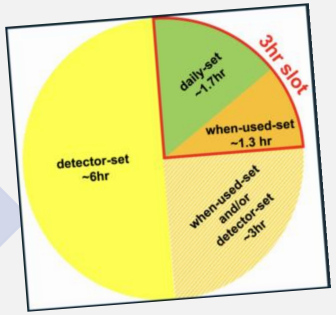
observing mode	front-end	fiber link	spectrograph slit
IFU-AO **YJH spectrograph** IFU of maximum 61 spaxels; 4 spaxel scales of 7, 16, 35, and 100 mas are foreseen **K spectrograph** separate IFU module	input light from the telescope on a microlenses fiber bundle 	fiber bundle after fiber to fiber couplers 	4 segments (S1,S2,S3,S4), one per each hexagonal ring around the central spaxel, and the central spaxel (S0) 

Calibration Strategy and System Implications

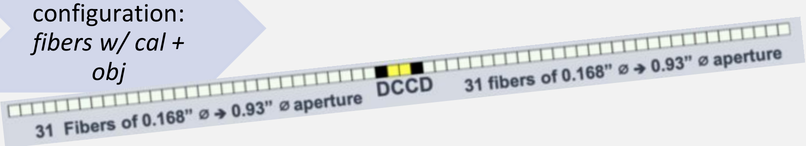
- Calibration strategy driven by **stability and operational efficiency**
- **Mostly off-line (day) calibrations**, acquired when ANDES is not observing
- **on-line calibrations**, simultaneous w/ obs. when required by the science case
- Multiple calibration sources:
  - continuum lamps (flat-fields)
  - **HCL** and **FP** (wavelength calibration)
- Calibration architecture tightly coupled to **FE, FL, and spectrograph design**

System implications

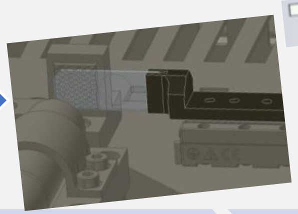
- **day slots for calibration** → complete *daily-set* and *when-used-set*



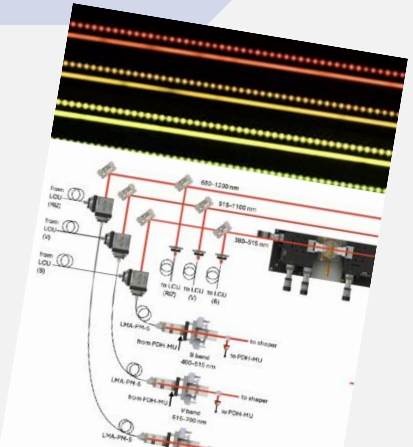
- **Simultaneous reference** → Dedicated fibers → Slit configuration: *fibers w/ cal + obj*



- **masking of individual fibers**



- **Exposure meter** → For optimal baricentric correction → for vis spectrographs
- **Upgrades to be considered** → We have goals in the TRS

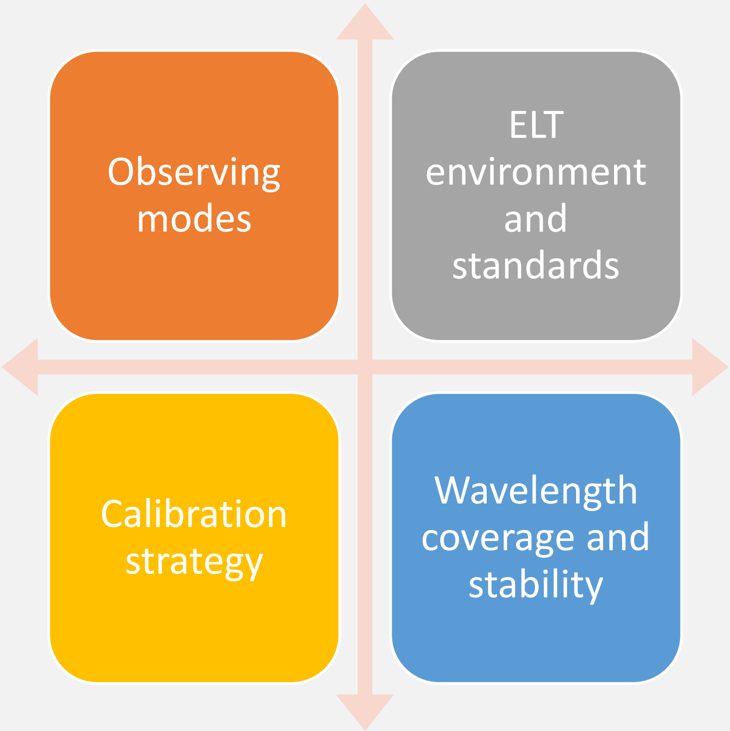


ANDES System Overview

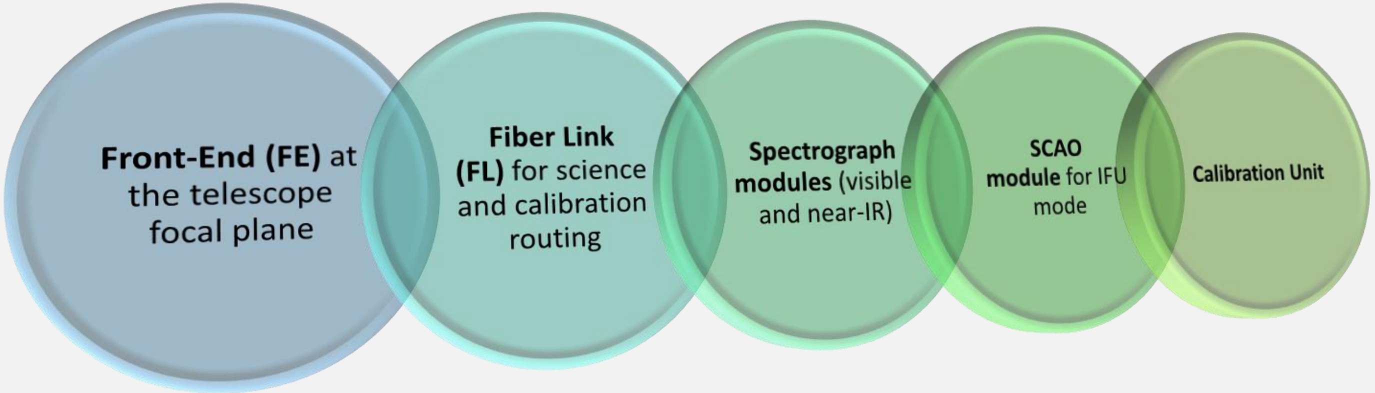
Modular, fibre-fed instrument

Subsystems distributed across **Nasmyth platform** and **Coudé room**

Architecture driven by:



Main subsystem elements:



Model Based Systems Engineering approach

That was the straightforward part; for the remaining specifications and scientific requirements, complexity increases. We have therefore decided to address this through a specific **systems engineering approach**.

Systems engineering
transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological and management methods *(INCOSE definition)*

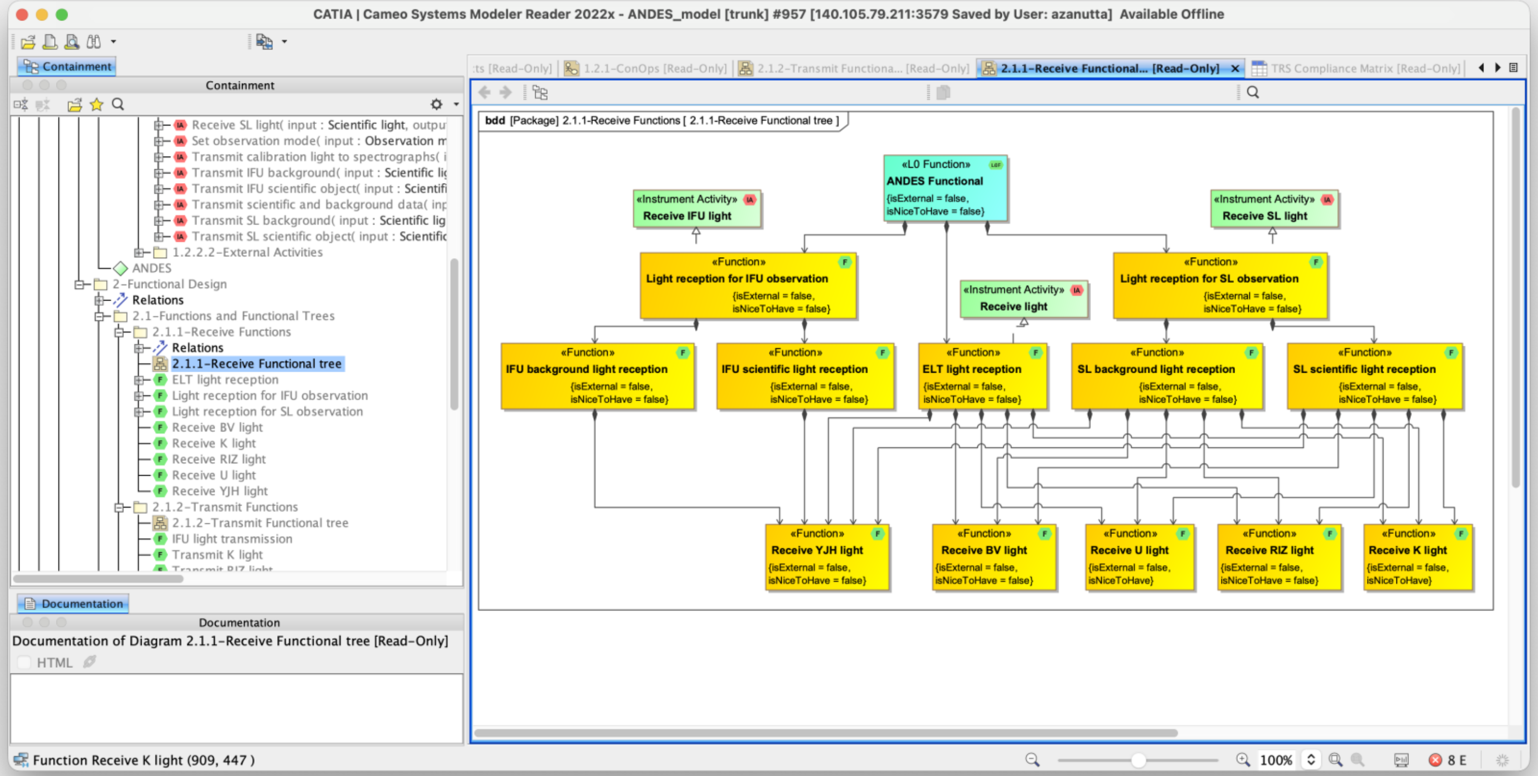
Documents Based Systems Engineering

1. Based on system descriptive documents and support material
2. Classical systems engineering methods
3. Use of various software and tools, depending on the application context

Model Based Systems Engineering (MBSE)

1. Based on a system model created and managed as the single source of truth
2. Use of formal languages like SysML and Arcadia
3. Real-time collaborative work

MODEL and CAMEO tool



formalized application of <u>modelling to support system requirements, design, analysis, verification, and validation activities</u> beginning in the conceptual design phase and continuing throughout development and later life cycle phases (INCOSE SE Vision 2020)

- Univocal system representation
- Complete traceability for all system elements
- Interrelated system representation
- Coherent system representation
- Simple navigation among system information

AstroMBSE

The **AstroMBSE** profile is a specialized implementation of the MBSE methodology developed by INAF and based on ESO standards

Included Features

- **Design methodology**
- **Requirements management**
- **Physical structure management**
- **Interfaces management**
- **Documentation management**
- **Collaborative systems engineering**

Definition of a <u>comprehensive MBSE methodology</u> to drive the development of future astronomical instruments

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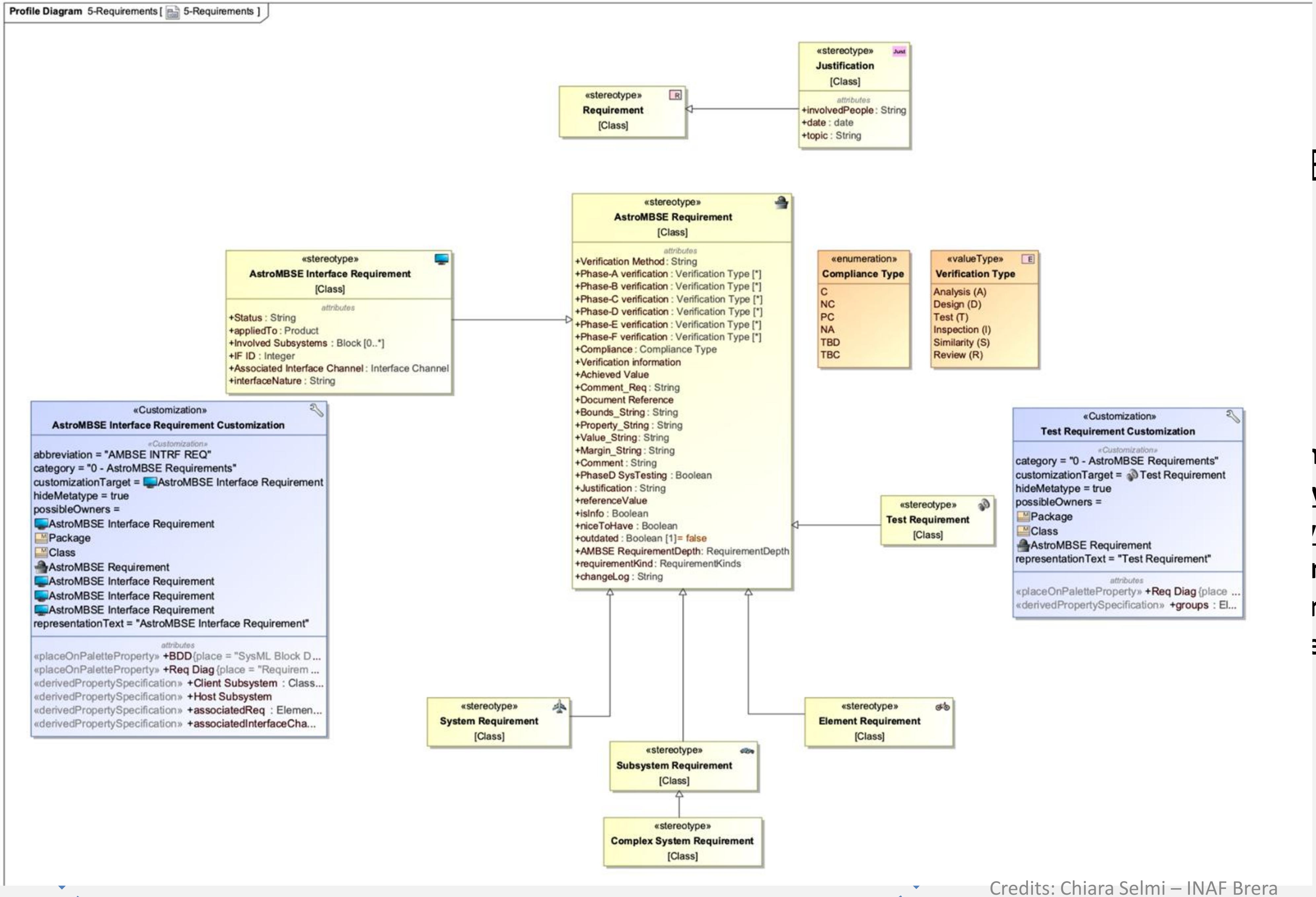

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Credits: Chiara Selmi – INAF Brera

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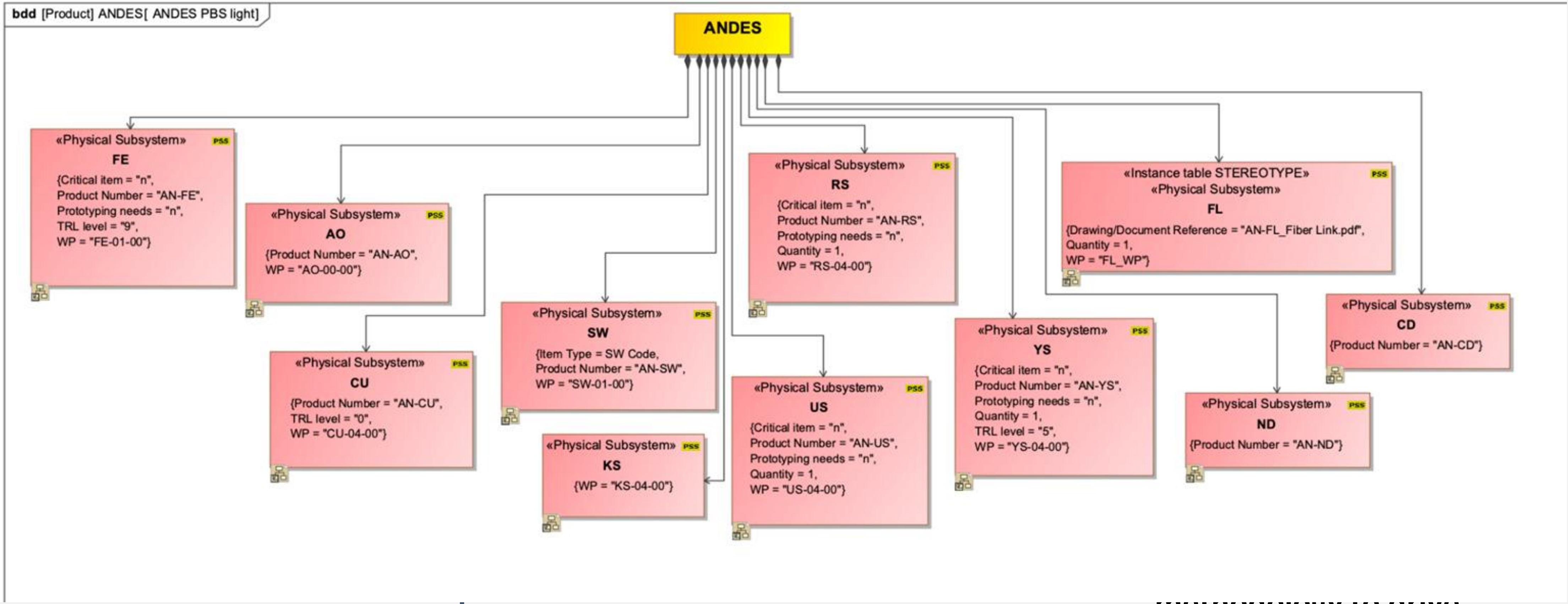

Physical structure management

Interfaces management

Documentation management

Collaborative systems engineering

methodology to drive the development of future astronomical instruments

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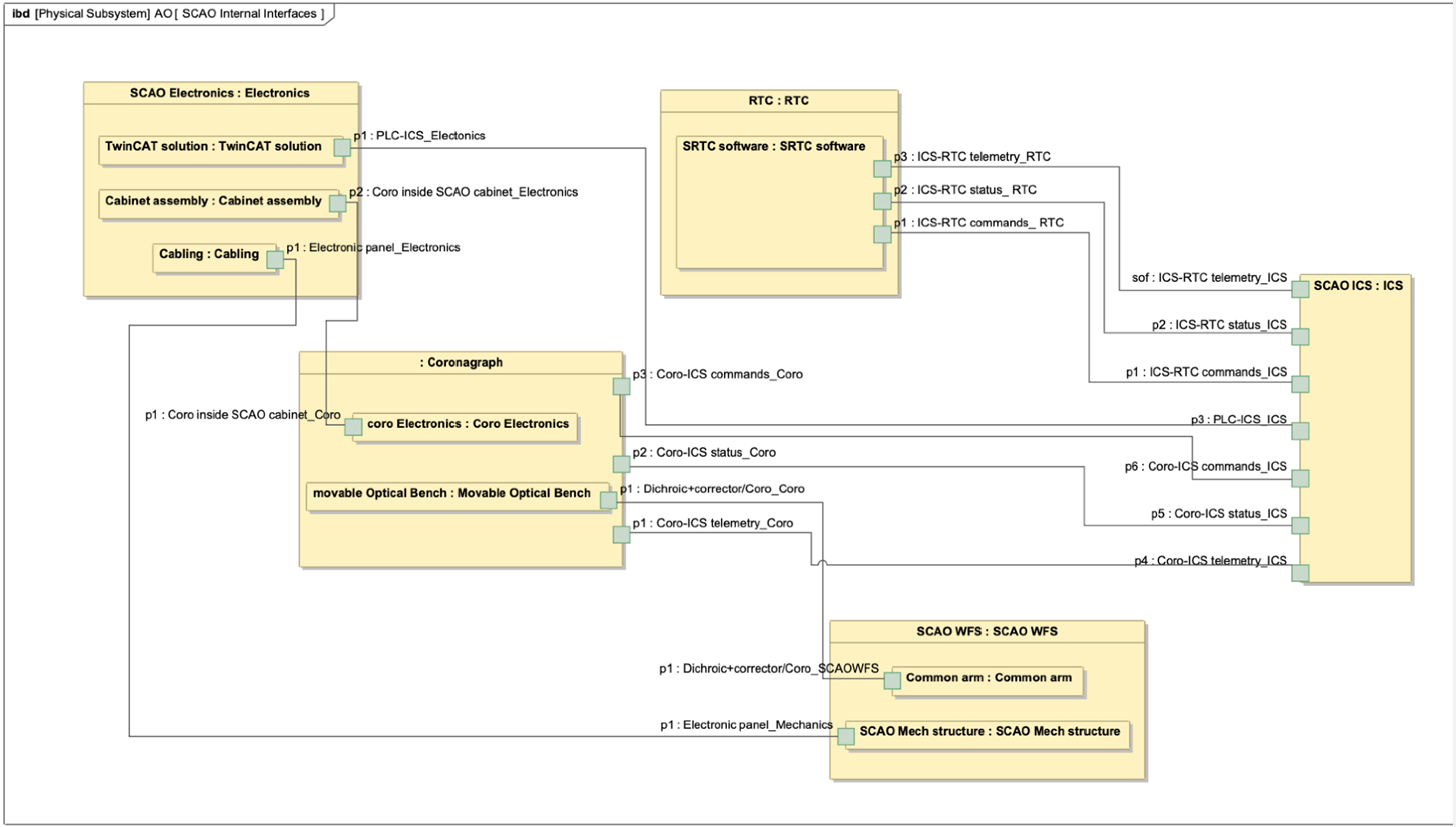

ibd [Physical Subsystem] AO [SCAO Internal Interfaces]
SCAO Electronics : Electronics
TwinCAT solution : TwinCAT solution
p1 : PLC-ICS_Electonics
Cabinet assembly : Cabinet assembly
p2 : Coro inside SCAO cabinet_Electronics
Cabling : Cabling
p1 : Electronic panel_Electronics
RTC : RTC
SRTC software : SRTC software
p3 : ICS-RTC telemetry_RTC
p2 : ICS-RTC status_ RTC
p1 : ICS-RTC commands_ RTC
sof : ICS-RTC telemetry_ICS
SCAO ICS : ICS
p2 : ICS-RTC status_ICS
p1 : ICS-RTC commands_ICS
p3 : PLC-ICS_ICS
p6 : Coro-ICS commands_ICS
p5 : Coro-ICS status_ICS
p4 : Coro-ICS telemetry_ICS
: Coronagraph
p3 : Coro-ICS commands_Coro
p1 : Coro inside SCAO cabinet_Coro
coro Electronics : Coro Electronics
p2 : Coro-ICS status_Coro
movable Optical Bench : Movable Optical Bench
p1 : Dichroic+corrector/Coro_Coro
p1 : Coro-ICS telemetry_Coro
SCAO WFS : SCAO WFS
p1 : Dichroic+corrector/Coro_SCAOWFS
Common arm : Common arm
p1 : Electronic panel_Mechanics
SCAO Mech structure : SCAO Mech structure

AstroMBSE

Criteria

Element Type: document_CIDL ... Scope (optional): FL_CIDL ... Filter:

Excel Import Status: New Updated Obsolete Unchanged

#	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	PSS FL	https://owncloud.ia2.ina	FL Hazard List	LIS		RELEASED	ANDES	INAF	E-AND-FL-LIS-02-00-0C	1
2	PSS FL	https://owncloud.ia2.ina	FL Interface Control Document	ICD		RELEASED	ANDES	INAF	E-AND-FL-ICD-03-00-0	3
3	PSS Fiber Routing	https://owncloud.ia2.ina	FL MAIT FR	PLA		RELEASED	ANDES	INAF	E-AND-FL-PLA-03-00-0	1
4	PSS IFU	https://owncloud.ia2.ina	FL MAIT IFU	PLA		RELEASED	ANDES	INAF	E-AND-FL-PLA-03-00-0	1
5	PSS FL	https://owncloud.ia2.ina	FL Mechanical Thermal Cryo and Vacuum Design and Ana	DER		RELEASED	ANDES	INAF	E-AND-FL-DER-06-00-0	3
6	PSS FL	https://owncloud.ia2.ina	FL Optical Design and Analysis Report	DER		RELEASED	ANDES	INAF	E-AND-FL-DER-04-00-0	3
7	PSS FL	https://owncloud.ia2.ina	FL Product Breakdown Structure	PBS		RELEASED	ANDES	INAF	E-AND-FL-PBS-03-00-0	3
8	PSS FL	https://owncloud.ia2.ina	FL Subsystem Overview	DER		RELEASED	ANDES	INAF	E-AND-FL-DER-03-00-0	3
9	PSS FL	https://owncloud.ia2.ina	FL Risk Register	RRR		DRAFT	ANDES	INAF	E-AND-FL-RRR-01-00-0	1
10	PSS FL	https://owncloud.ia2.ina	FL Compliance Matrix	CMX		RELEASED	ANDES	INAF	E-AND-FL-CMX-03-00-(	3
11	PSS FL	https://owncloud.ia2.ina	FL Control Electronics Design Analysis Report	DER		RELEASED	ANDES	INAF	E-AND-FL-DER-07-00-0	3
12	PSS Fiber Routing	https://owncloud.ia2.ina	Efficiency Budget SL-UNI All Bands	DER		RELEASED	ANDES	INAF	-	1
13	PSS Fiber Routing	https://owncloud.ia2.ina	Efficiency Budget SL-PSF All Bands	DER		RELEASED	ANDES	INAF	-	1
14	PSS Fiber Routing	https://owncloud.ia2.ina	Efficiency Budget SIMCAL All Bands	DER		RELEASED	ANDES	INAF	-	1
15	PSS Fiber Routing	https://owncloud.ia2.ina	Efficiency Budget EXP-M UBV+RIZ	DER		RELEASED	ANDES	INAF	-	1

management

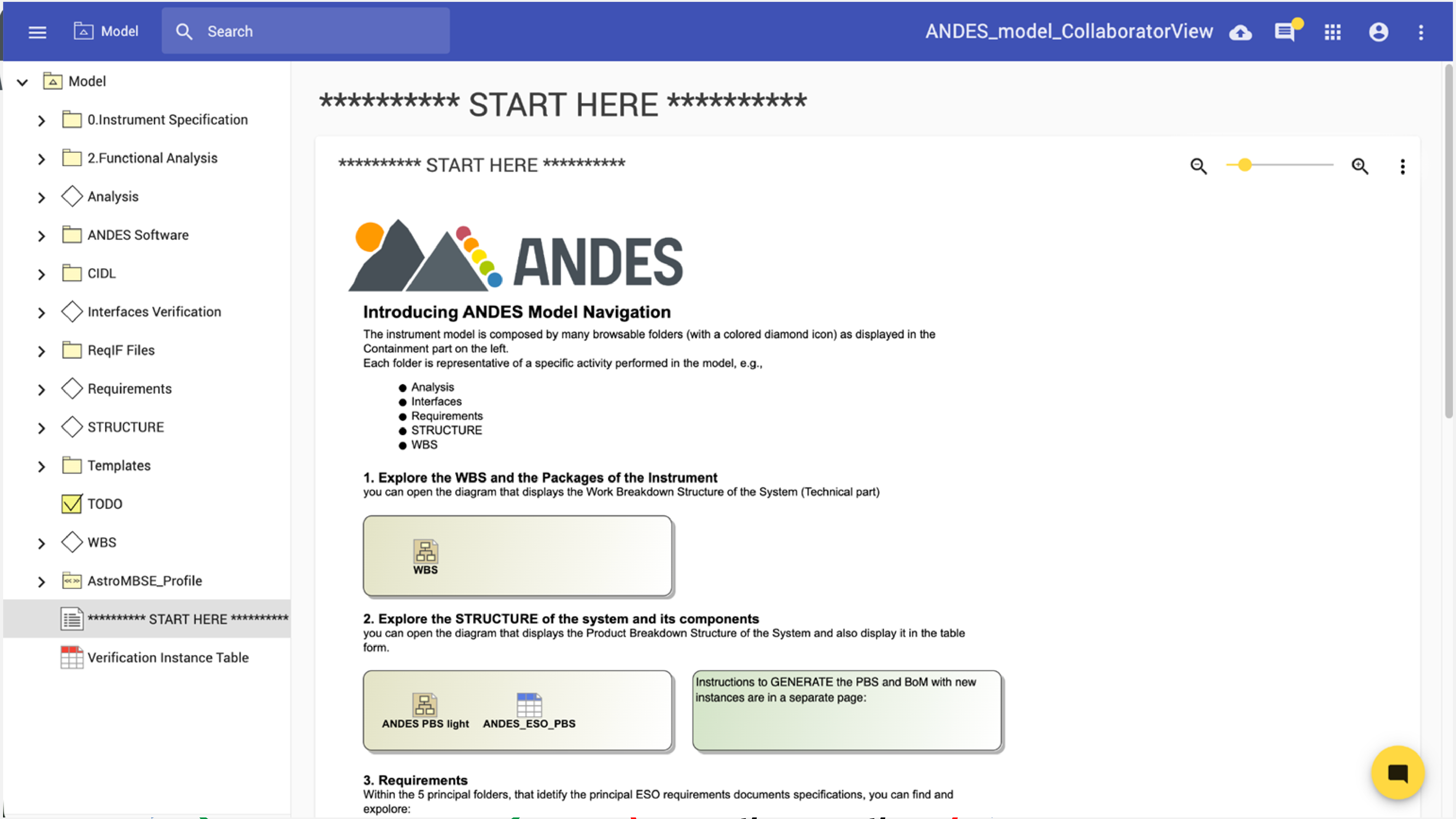
management

instruments

Documentation management

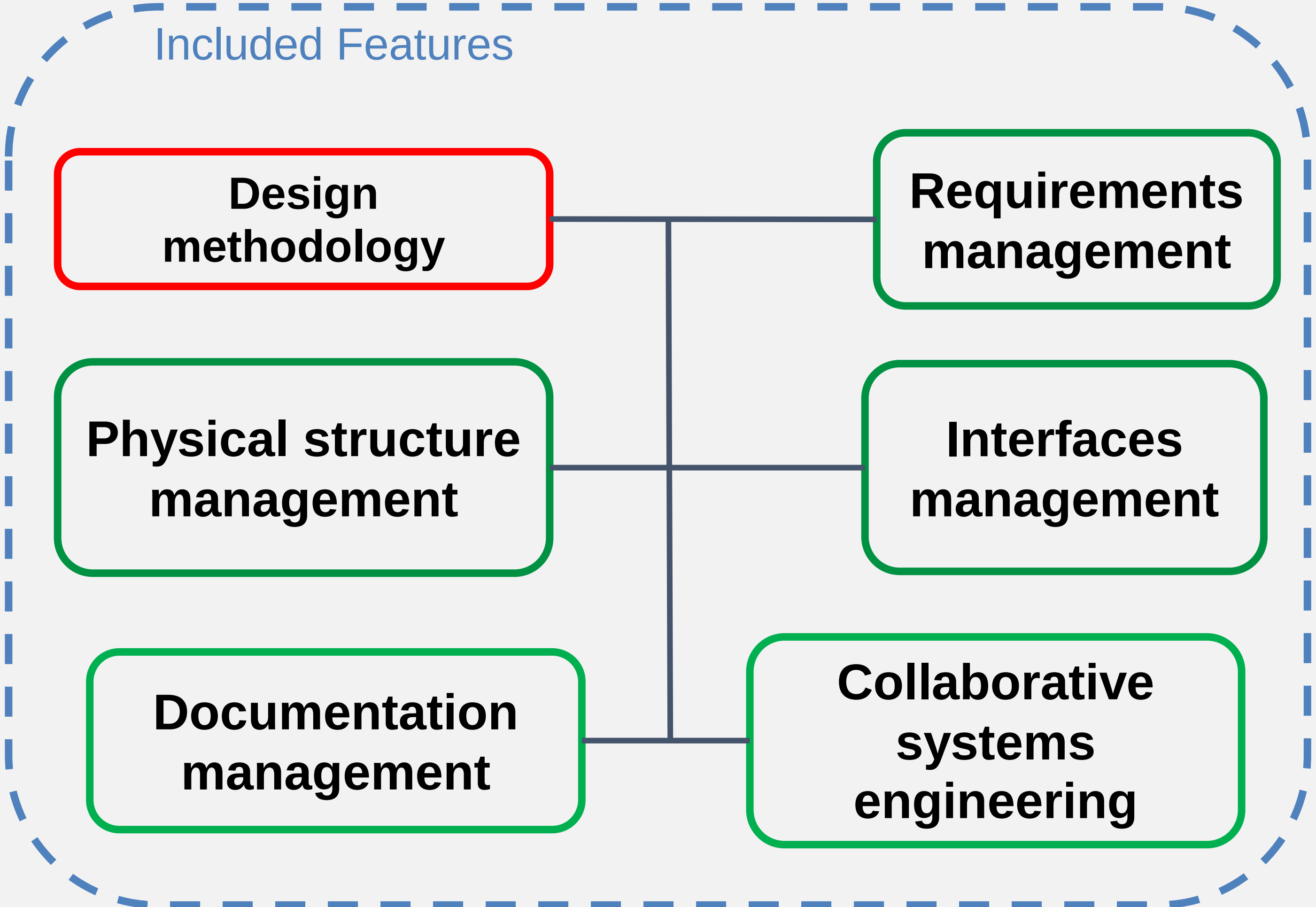
Collaborative systems engineering

Credits: Chiara Selmi – INAF Brera


Model
Search
ANDES_model_CollaboratorView
Model
0.Instrument Specification
2.Functional Analysis
Analysis
ANDES Software
CIDL
Interfaces Verification
ReqIF Files
Requirements
STRUCTURE
Templates
TODO
WBS
AstroMBSE_Profile
********** START HERE **********
Verification Instance Table
********** START HERE **********
********** START HERE **********
ANDES
Introducing ANDES Model Navigation
The instrument model is composed by many browsable folders (with a colored diamond icon) as displayed in the Containment part on the left.
Each folder is representative of a specific activity performed in the model, e.g.,
Analysis
Interfaces
Requirements
STRUCTURE
WBS
1. Explore the WBS and the Packages of the Instrument
you can open the diagram that displays the Work Breakdown Structure of the System (Technical part)
WBS
2. Explore the STRUCTURE of the system and its components
you can open the diagram that displays the Product Breakdown Structure of the System and also display it in the table form.
ANDES PBS light
ANDES_ESO_PBS
Instructions to GENERATE the PBS and BoM with new instances are in a separate page:
3. Requirements
Within the 5 principal folders, that idetify the principal ESO requirements documents specifications, you can find and expolore:

AstroMBSE

The **AstroMBSE** profile is a specialized implementation of the MBSE methodology developed by INAF and based on ESO standards

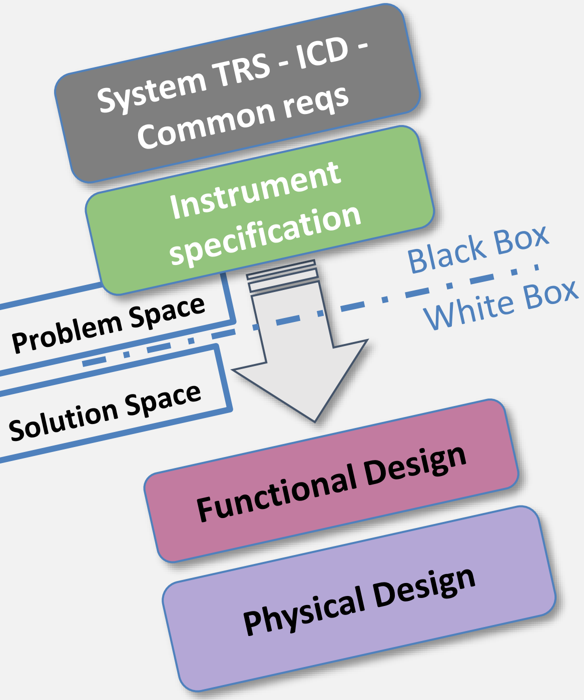


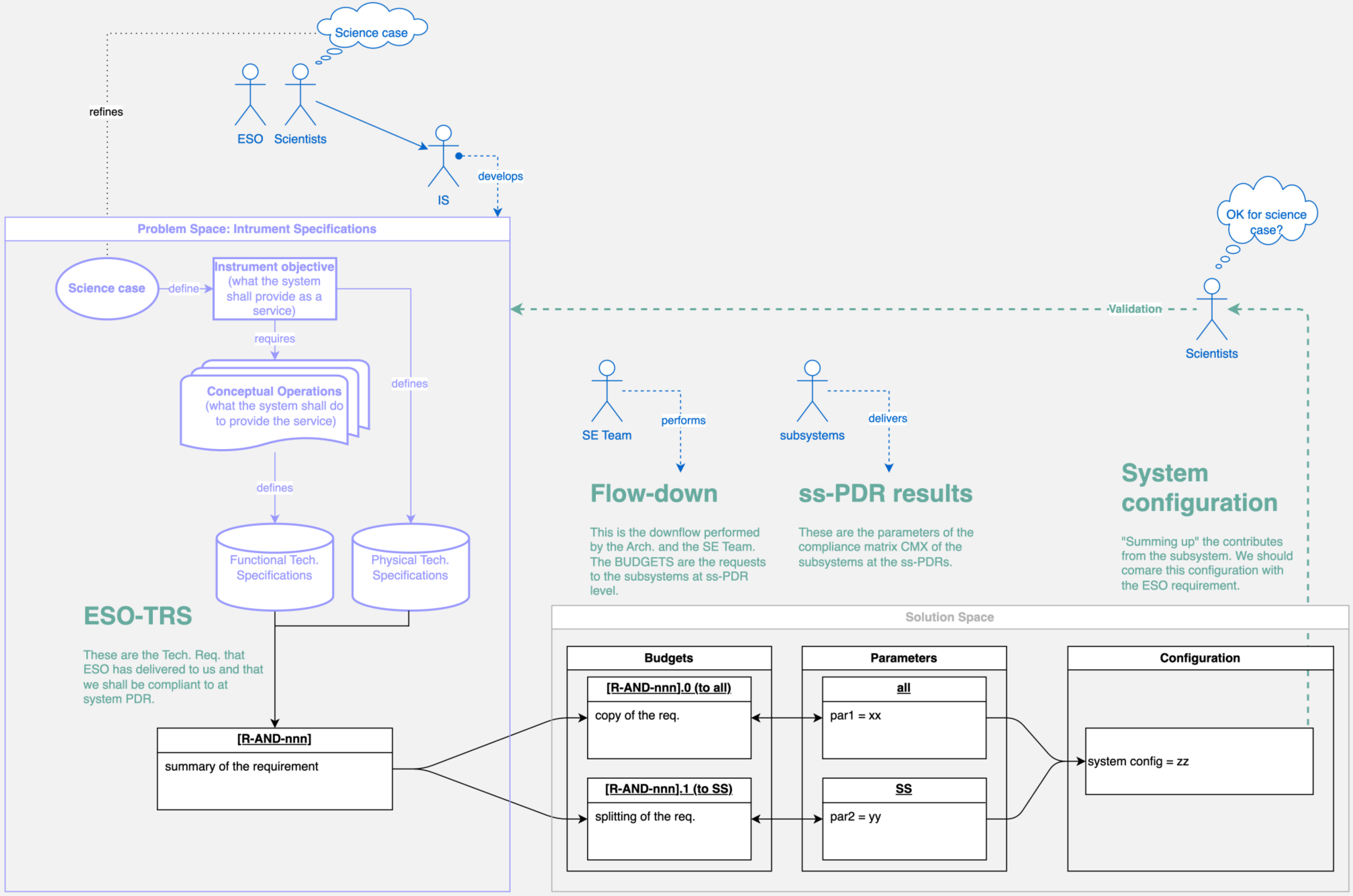
Definition of a <u>comprehensive MBSE methodology</u> to drive the development of future astronomical instruments

Credits: Chiara Selmi – INAF Brera

AstroMBSE - Design methodology

Is structured around two fundamental conceptual domains, the Problem Space and the Solution Space.

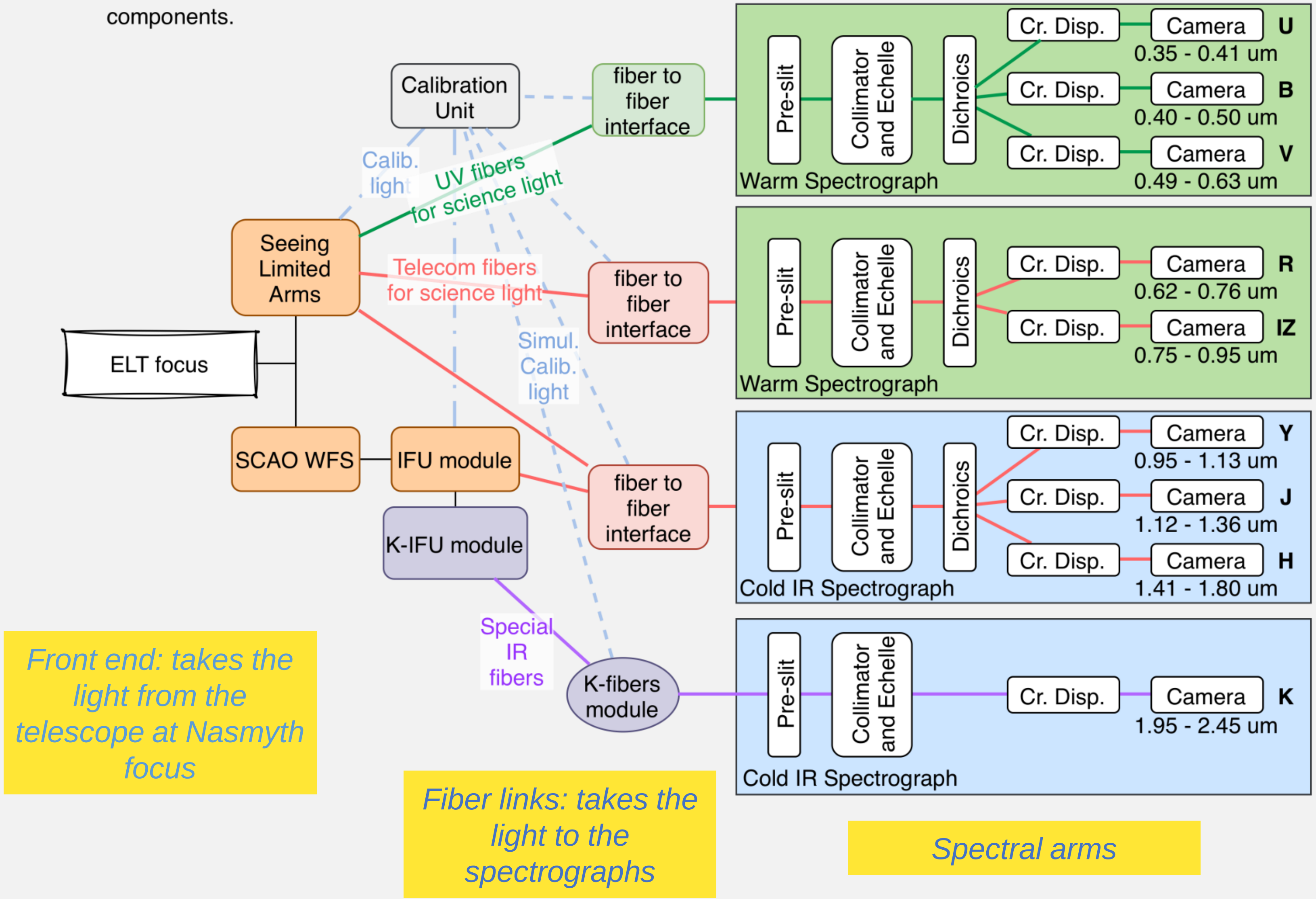




ANDES

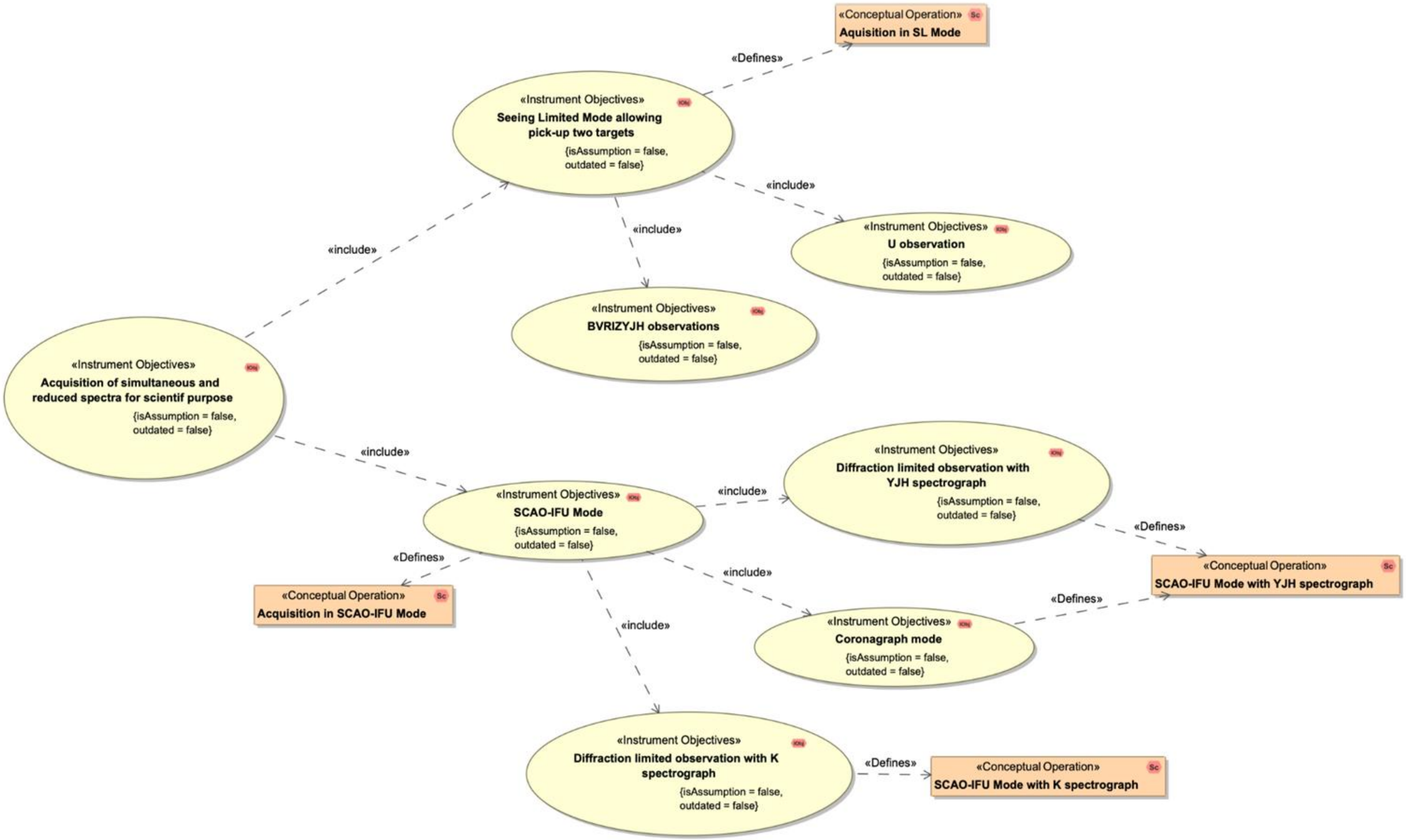
Instrument architecture

Scheme of main instrument components.



- Modular fiber-fed cross dispersed echelle spectrograph
- Simultaneous range (ultra-stable UBV+RIZ+YJH+K) Resolution ~100,000
- interchangeable, observing modes: Seeing limited & SCAO+IFU

Instrument Objectives

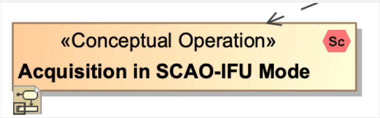


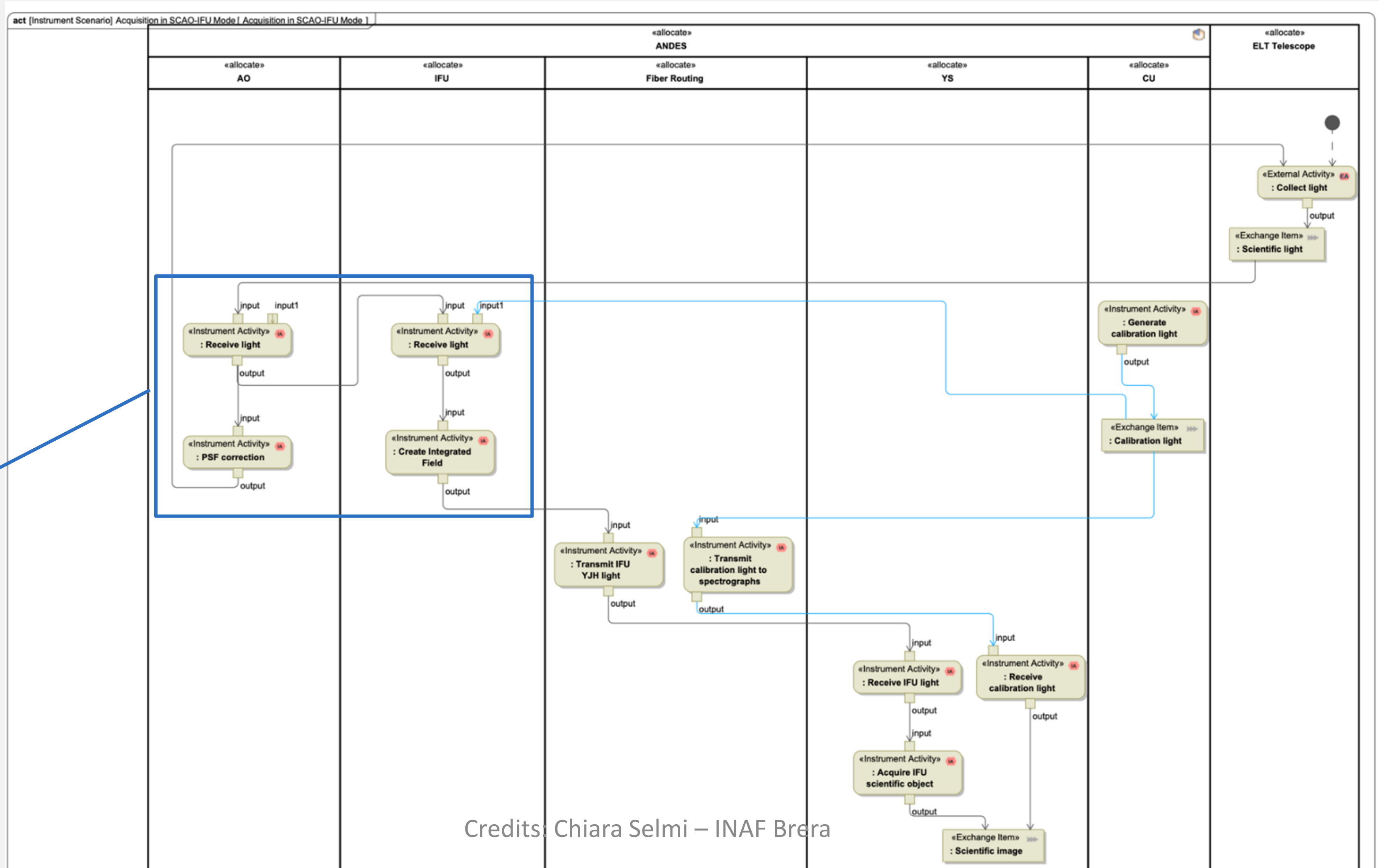
Instrument Activity

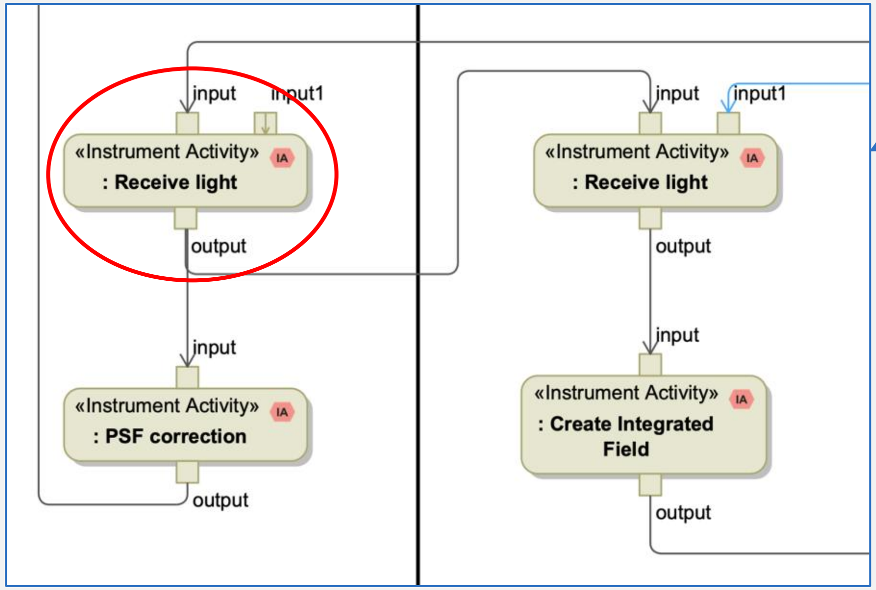
Operationally

Instrument Scenario

Instrument Activity

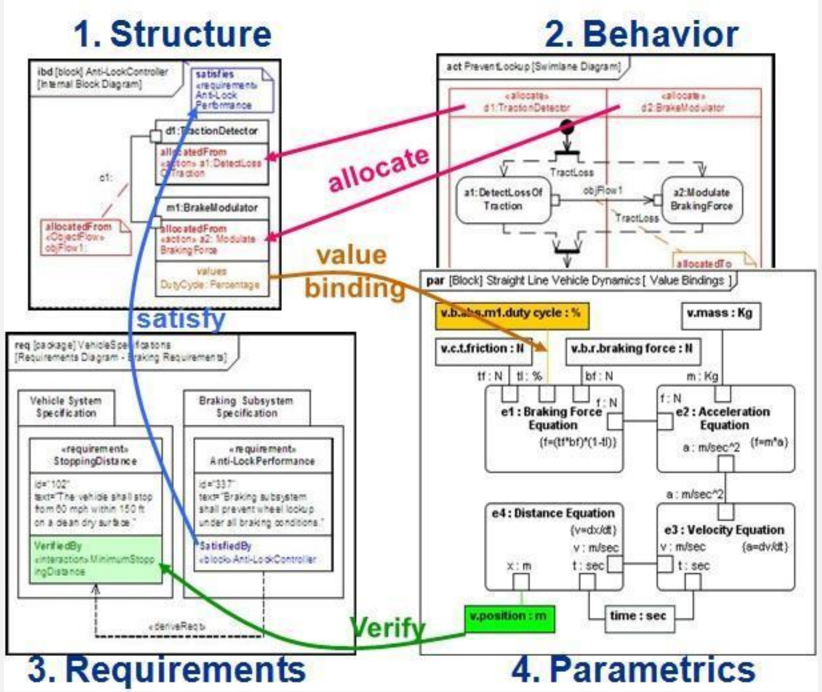






Credits: Chiara Selmi – INAF Brera

The four pillars - connections



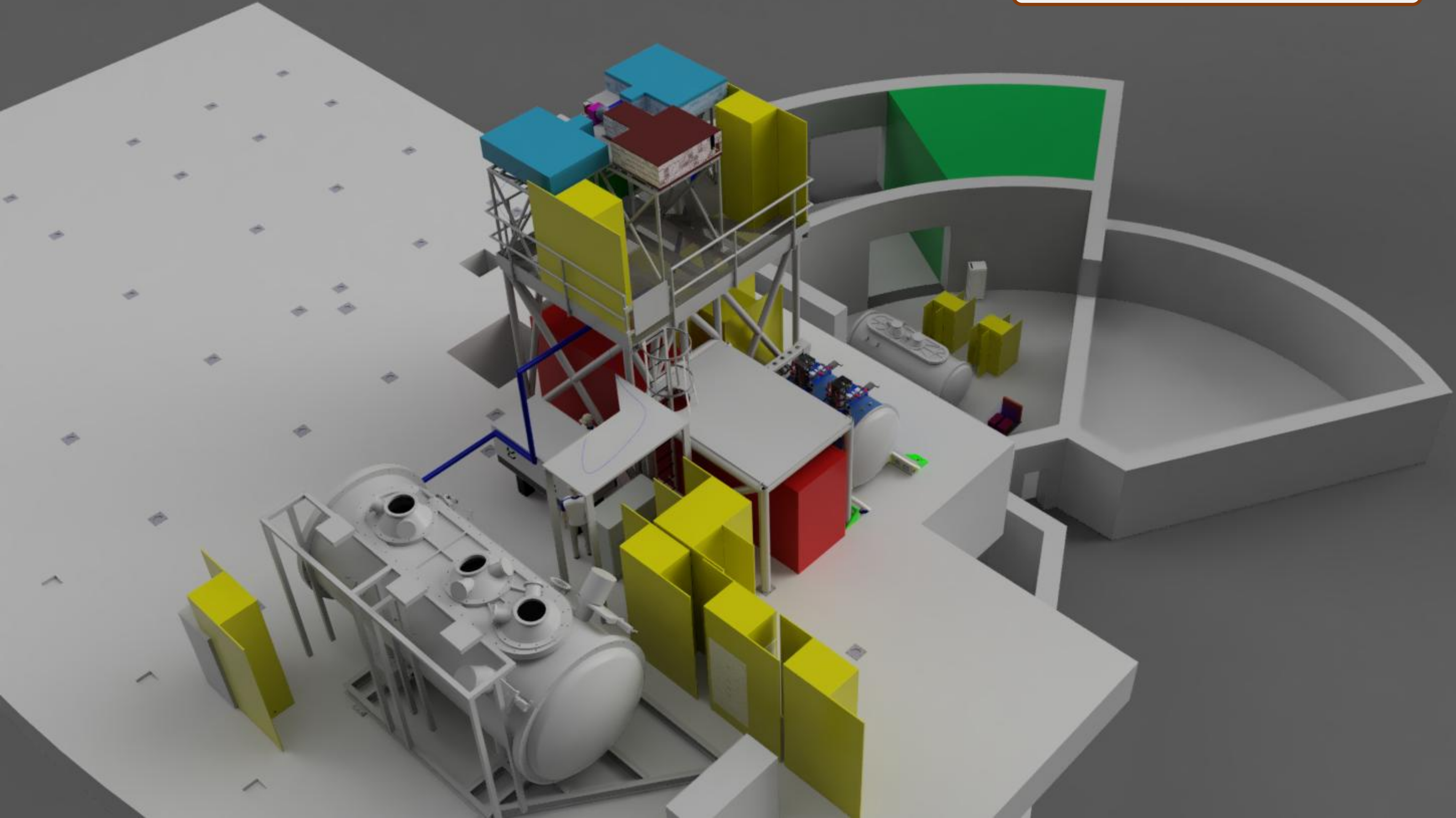
Credits: Dr. Saulius Pavalkis and Gauthier Fanmuy

Project timeline & milestones

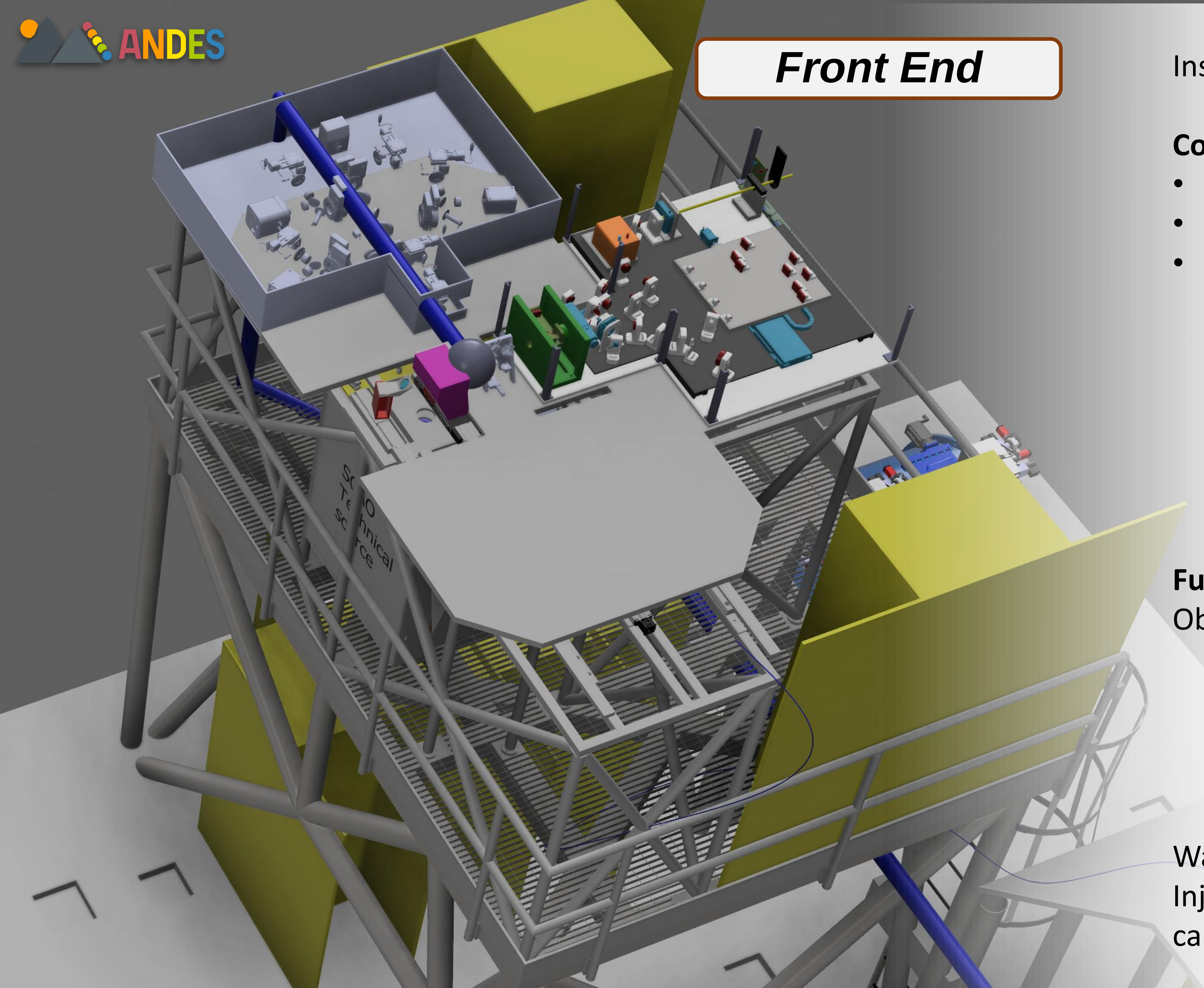
Phase / Milestone	2025	2026	2027	2028	2029	2030 2033	2034	2035
PDR (Preliminary Design Review)	subsys							
Funding & Authorization		internal						
LLI Reviews (Long Lead Items)								
FDR (Final Design Review)				subsys				
PAE (Provisional Acceptance)								
Shipping & Commissioning								

PROPOSED SCHEDULE:
– software PDR: Q2/2026
– system PDR: Q2-Q3/2026
– internal funding review (board): Q3/2026
– ESO official funding review: Q1-Q2/2027
– COU authorization: Q3-Q4/2027
– subsystems LLI reviews: 2027 - 2028
– subsystems FDR: 2028 - 2029
– system FDR Nasmyth (FE,UBV,K,FL,$CU_{UBV\text{-}K}$): Q3/2029
– system FDR Coudé (RIZ + CU_{RIZ}): Q4/2029
– system FDR Coudé (YJH + CU_{YJH}): S2/2030
– PAE: Q4/2034
– shipping / commissioning: mid 2035

Nasmyth & Coudé



Front End



Installed at the ELT Nasmyth focal plane

Consists of:

- Structure
- Cabinets
- Five selectable engaging/moving modules:
    - Two Seeing-Limited arms (identical)
    - One SCAO arm
    - One Coronagraph arm
    - One IFU arm

Functions:

Observing mode selection

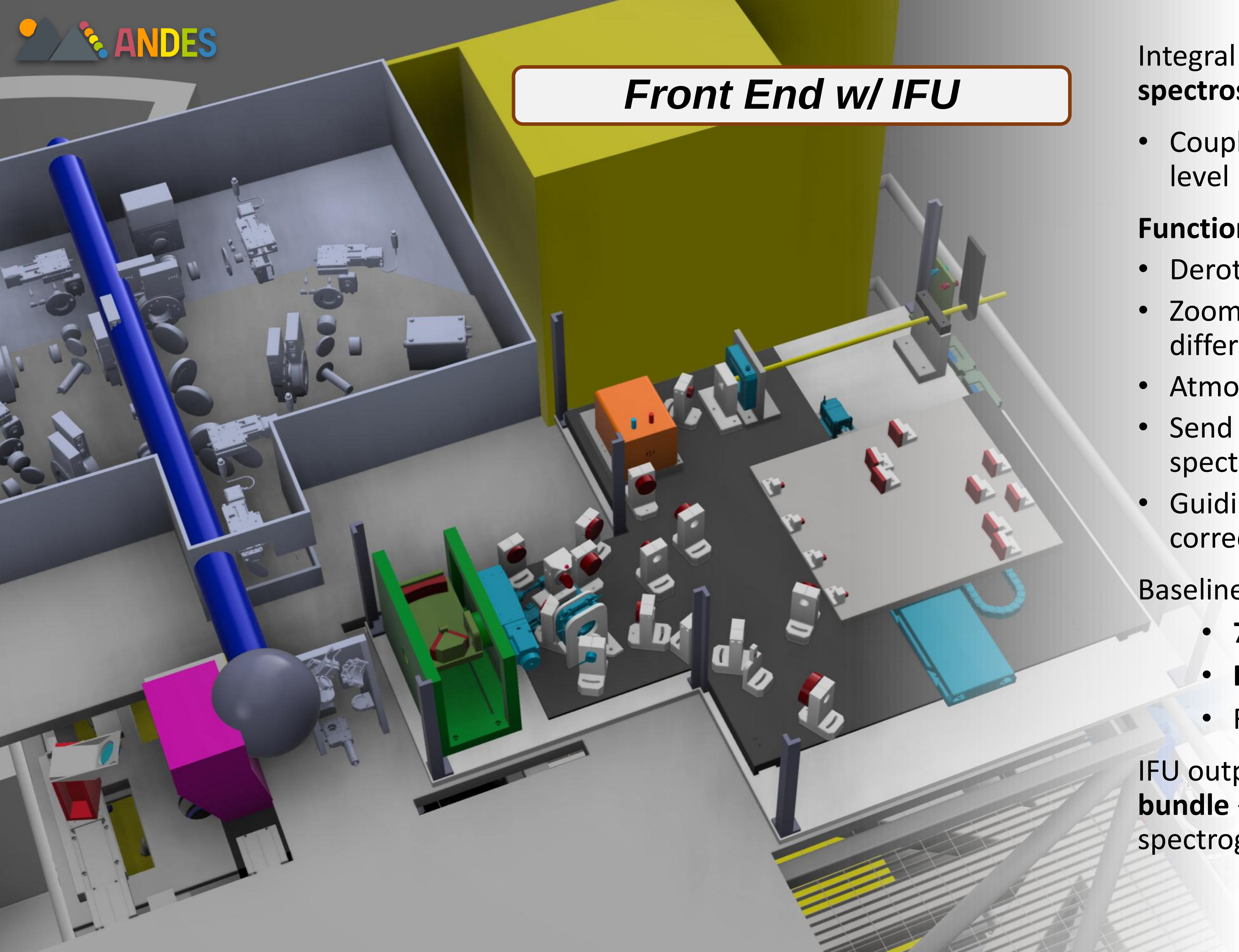
- SL-UNI: object (in axis) + sky (off axis) observation (w/ star avoidance)
- IFU-AO: SCAO and IFU arms engaged

Wavelenght splitting

Injection into science and insertion of calibration fibers

ANDES

Front End w/ IFU



Integral Field Unit for **AO-assisted spectroscopy**

- Coupled to **SCAO module** at Front-End level

Functions:

- Derotation and Stabilization
- Zoom: reimaging the ETL focal plane in different scales for the microlens array
- Atmospheric dispersion correction
- Send the light to YJH and K spectrograph fibers
- Guiding and monitoring, for the correction and field stabilization

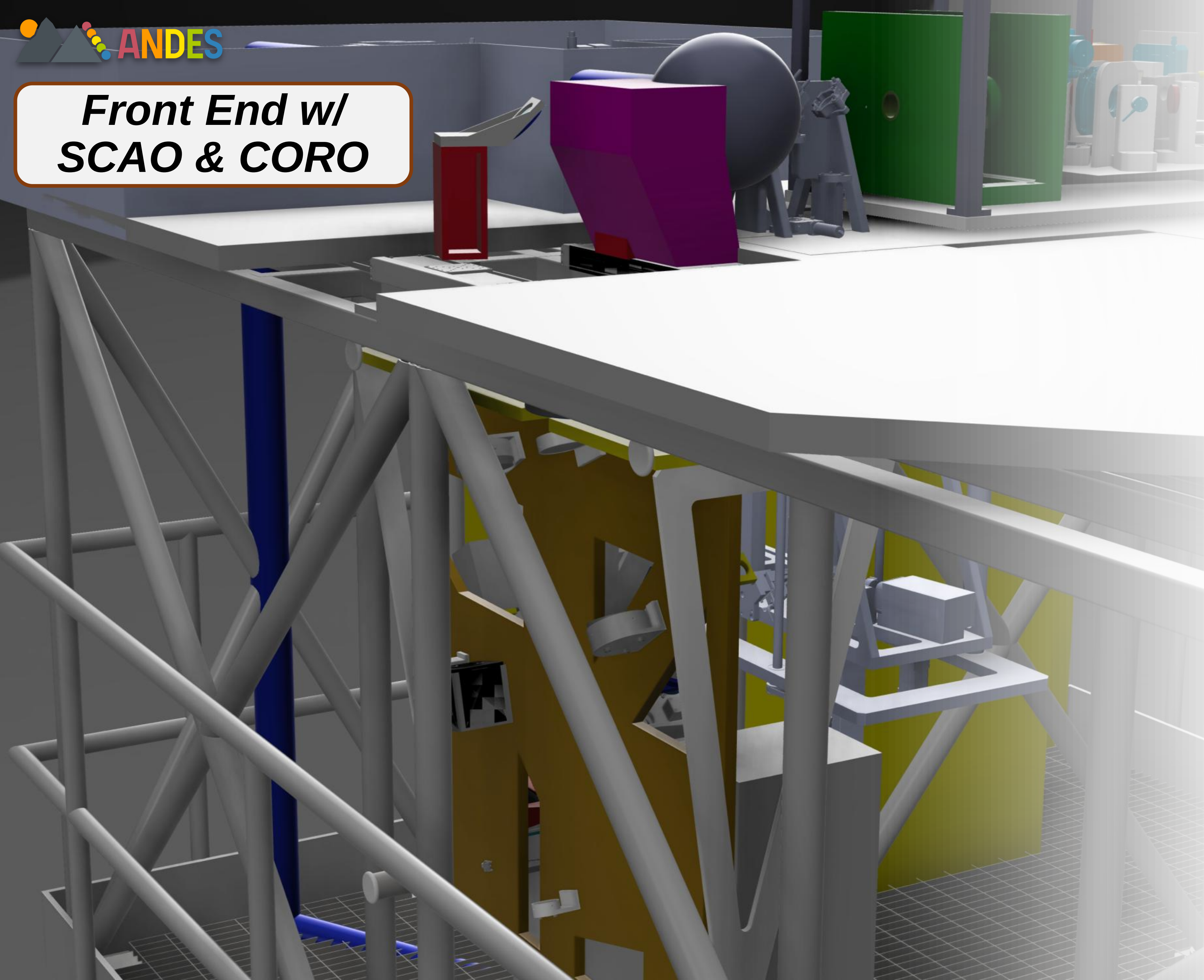
Baseline characteristics:

- **7×7 spaxels**
- **Four selectable spatial scales**
- FoV ≥ **0.5 arcsec²** at largest scale

IFU output reformatted into **fibre bundle** {then feeding the cold spectrographs (YJH and K)}

ANDES

Front End w/ SCAO & CORO



SCAO module functions:

- wavefront sensing and correction
- interface with ELT AO infrastructure
- loop closure on science or off-axis reference

Coronagraph functions:

- stellar light suppression
- improved contrast for close-in companions

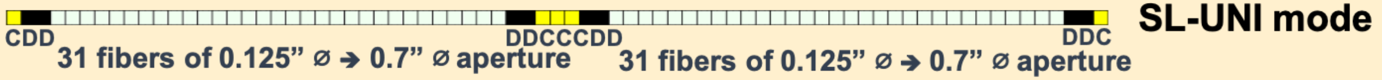
Key subsystem requirements:

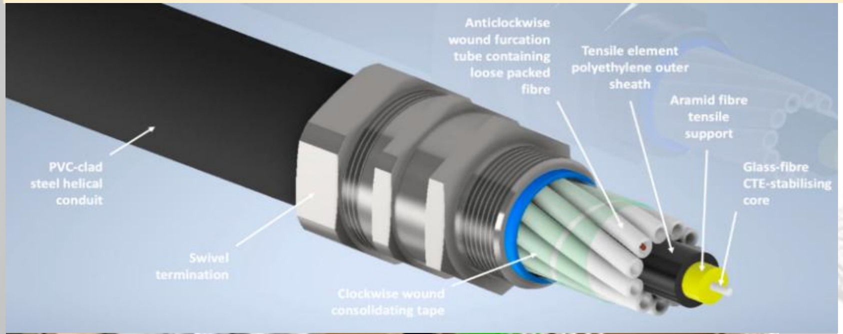
- PSF contrast goal: 10^{-3} at $3\lambda/D$ (25mas) for 1600nm, with I = 8 and median seeing conditions
- SR > 40% in H-band for AO ref I=12 under median seeing conditions
- reference acquisition in radius ≥ 5asec
- operation with reference 6 > I > 15
- IFU diffraction-limited performance in NIR
- Compatibility with IFU spaxel scales and FoV

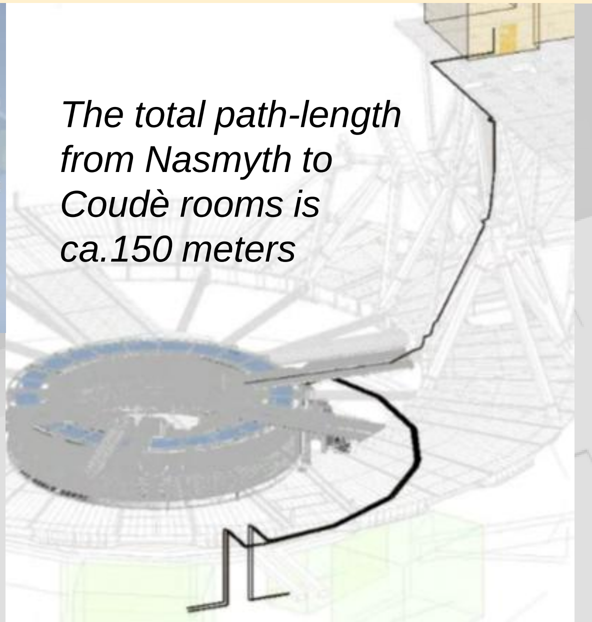
Fiber Link

[U]BV, RIZ spectrographs → 9k x 9k detectors, 0.168" x 11.1" slit

YJH spectrograph → 4k x 4k detector, 0.125" x 9.4" slit







The total path-length from Nasmyth to Coudè rooms is ca.150 meters

Fibre-fed architecture connecting **Front-End to spectrographs**

Independent fibre groups for:

- **Seeing-Limited (SL-UNI)** mode
- **IFU-AO** mode
- **Calibration light**

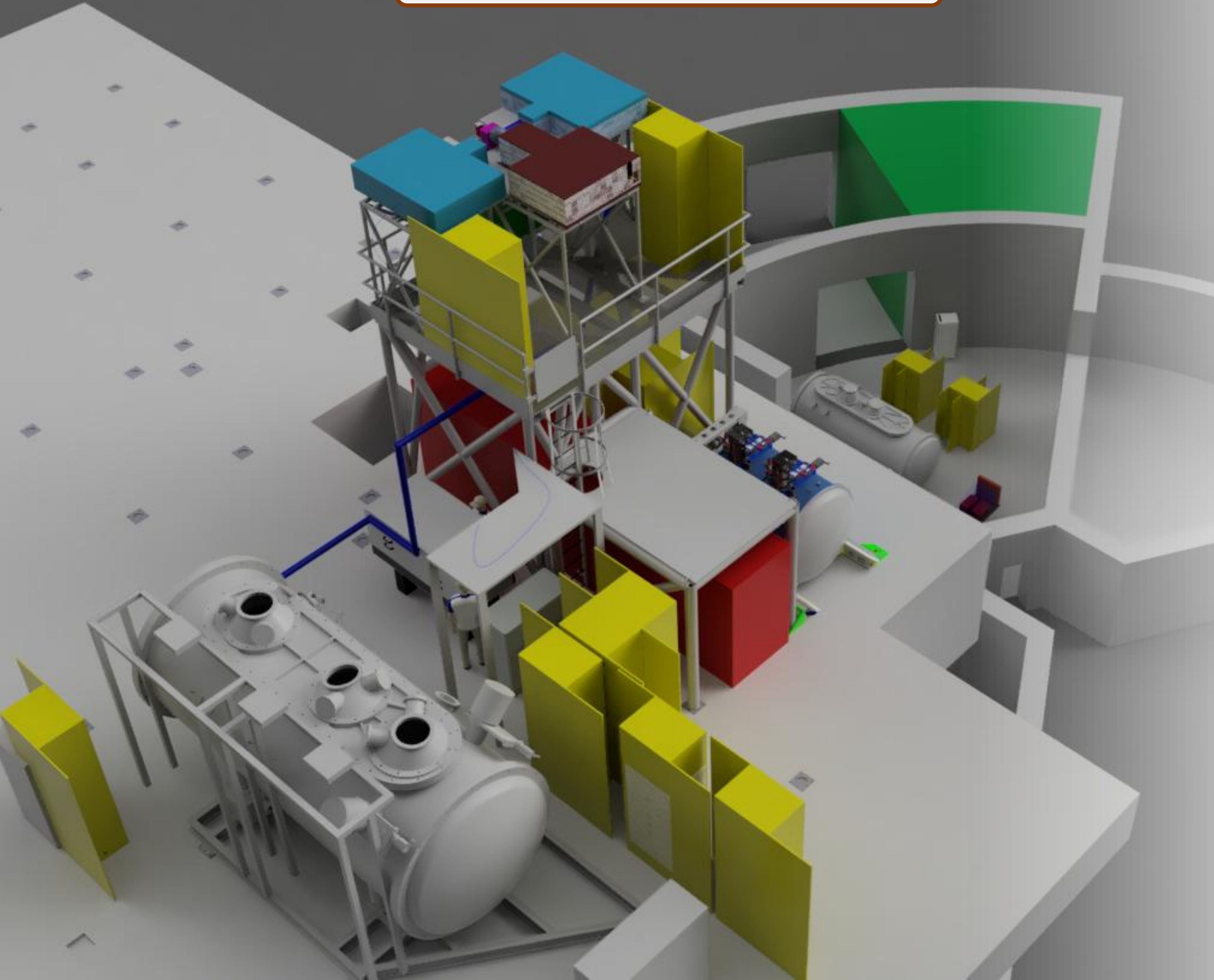
Functions:

- transport of science and calibration light
- Scrambling and uniform (pupil slicing) the light
- Distinguish light of single fiber PSF
- preserve illumination stability

Interfaces:

- Front-End injection w/ CU
- spectrograph slits

UBV spectrograph



Spectral coverage and Resolving power:
350–630 nm , R ≈ 100,000
Installed on the Nasmyth platform (due to low T% of fibers under 450nm)

Main functions:

- dispersion and detection of science and calibration light
- wavelength stability for high-precision spectroscopy
- simultaneous flux monitoring via exposure meter

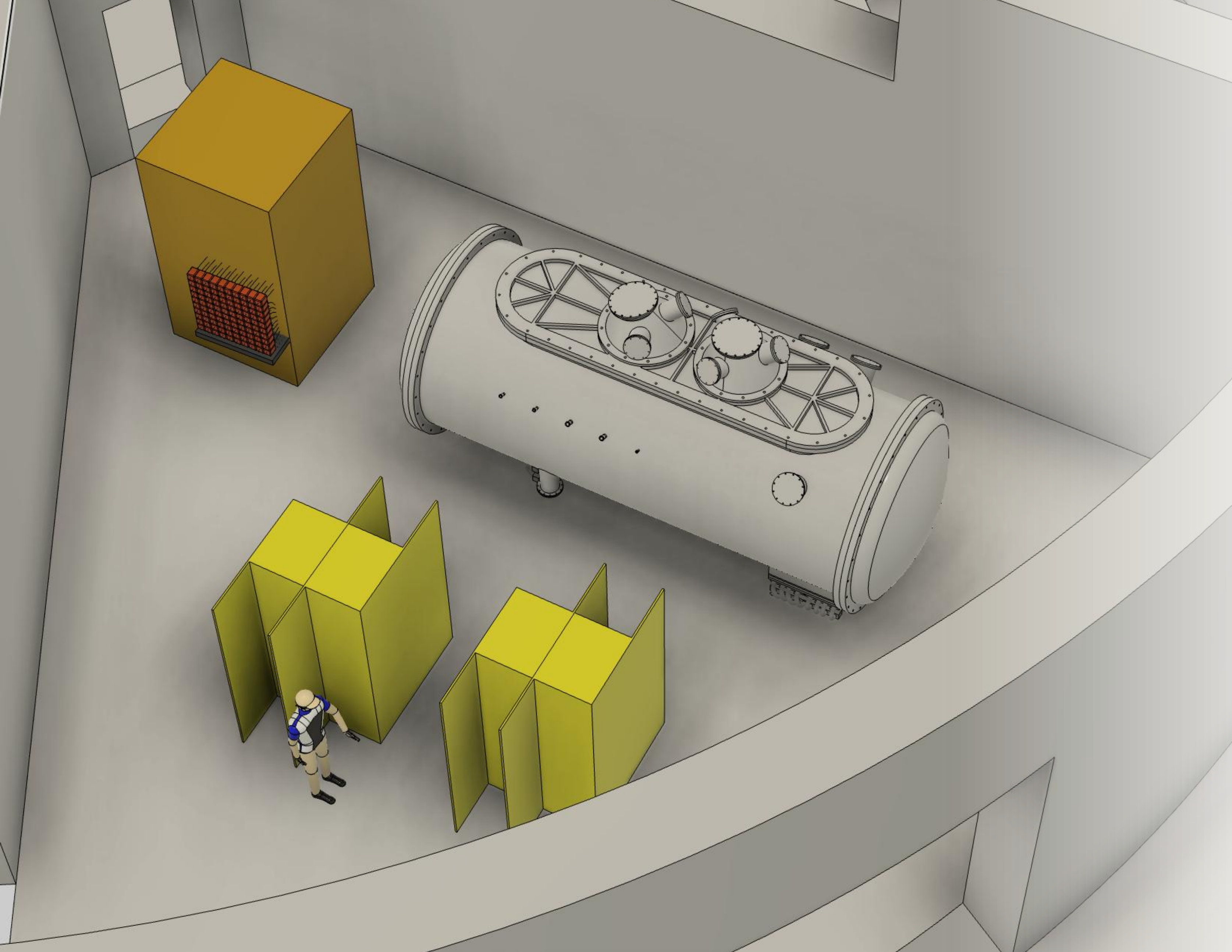
Key technical requirements:

- wavelength stability ≤ 1 m/s
- vacuum operation < 10^{-4} mbar
- thermal stability ≤ 1 mK, 24h
- detectors operated at ~163 K

Optical architecture:

- echelle spectrograph with mosaic R4 and Xdispersers (ESPRESSO like)
- beam size 400 mm
- split into U, B and V arms via dichroics
- 3 CCD 9k x 9k, 10um px

RIZ spectrograph



Spectral coverage and Resolving power:
620–950 nm , R ≈ 100,000
Installed on the Coudé room

Main functions:

- dispersion and detection of science and calibration light
- wavelength stability for high-precision spectroscopy
- simultaneous flux monitoring via exposure meter

Key technical requirements:

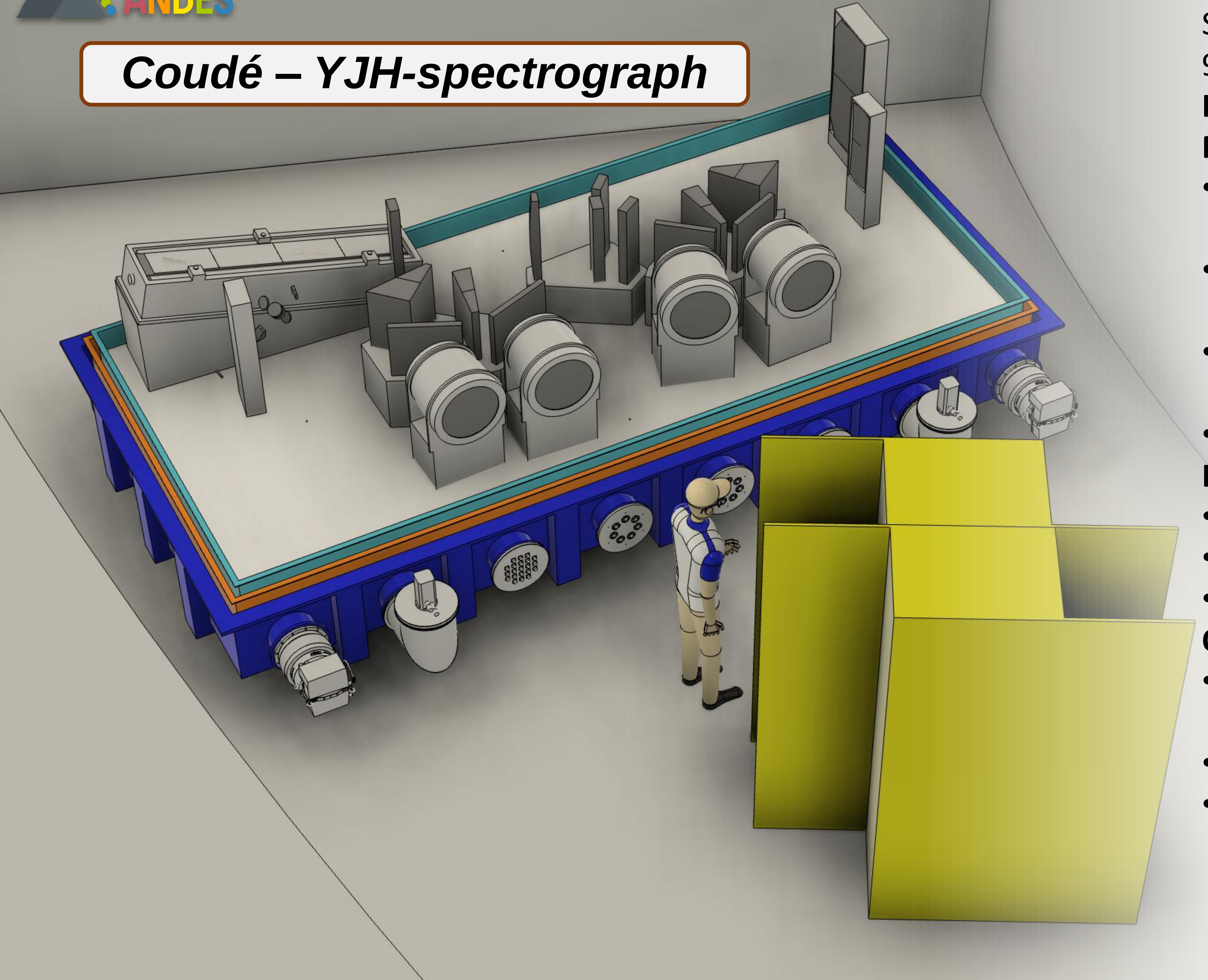
- wavelength stability ≤ 1 m/s
- vacuum operation < 10^{-4} mbar
- thermal stability ≤ 1 mK, 24h
- detectors CCD operated at ~163 K

Optical architecture:

- echelle spectrograph with mosaic R4 and Xdispersers (ESPRESSO like)
- beam size 400 mm
- split into R, IZ arms via dichroics
- 2 CCD 9k x 9k, 10um px

ANDES

Coudé – YJH-spectrograph



Spectral coverage and Resolving power:
950–1800 nm , R ≈ 100,000

Installed on the Coudé room

Main functions:

- dispersion and detection of science and calibration light
- wavelength stability for high-precision spectroscopy
- simultaneous flux monitoring via exposure meter
- Provide slit entrance

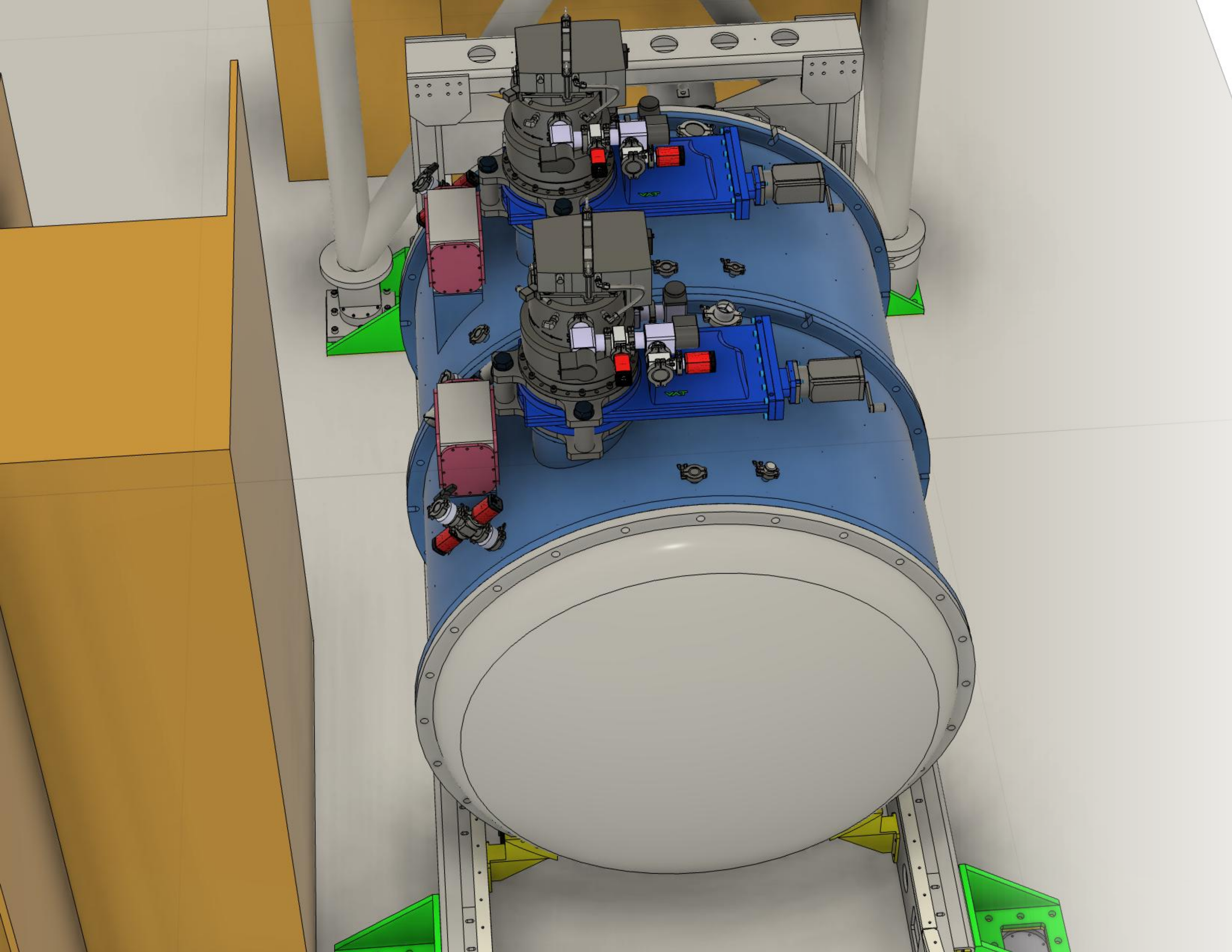
Key technical requirements:

- wavelength stability ≤ 1 m/s
- vacuum operation < 10^{-4} mbar
- thermal stability ≤ 1.5 mK, 24h

Optical architecture:

- echelle spectrograph with mosaic R4 and Xdispersers 16 l/mm
- split into Y, J, H arms via dichroics
- H4RG detectors

K spectrograph



Spectral coverage and Resolving power:
1950–2450 nm , R ≈ 100,000
Installed on the Nasmyth platform
Smaller (ca. 5 tons, 3x2x3m)

Main functions:

- dispersion and detection of science and calibration light
- IFU connection

Key technical requirements:

- Wavelength temp stability 50 m/s
- Spectral sampling ≥2.5 pixel
- Spatial sampling 20µm@F/3.5 (0.031” on sky)
- Detector 4096 x 4096 pixel (H4RG)
- *Slit size and fibers: 20 x 900 micron / 9*
- special infrared fibres of Zirconium ZrF_4 Fluoride Glass
- Transmission ca. 20 – 24 % (w/ detector)

Optical architecture:

- echelle spectrograph
- beam size 80 mm

ANDES

Calibration Unit

Functionality	Baseline	Upgrade: LFC (astrocomb)	Upgrade: IRS (FTS)
Order localisation / spectral flat field	FFS (Halogen lamp)		
Wavelength calibration	HCL + FP	LFC	FP
Drift Tracking	FP		
PSF / LSF	FP (?)	LFC	
Calibrator characterization and monitoring	---	---	HCL, FP (LFC)

Dedicated Calibration Unit (CU) per spectrograph (4 independent CUs)
Fully cabinet-based architecture: ESO-compliant electrical cabinets

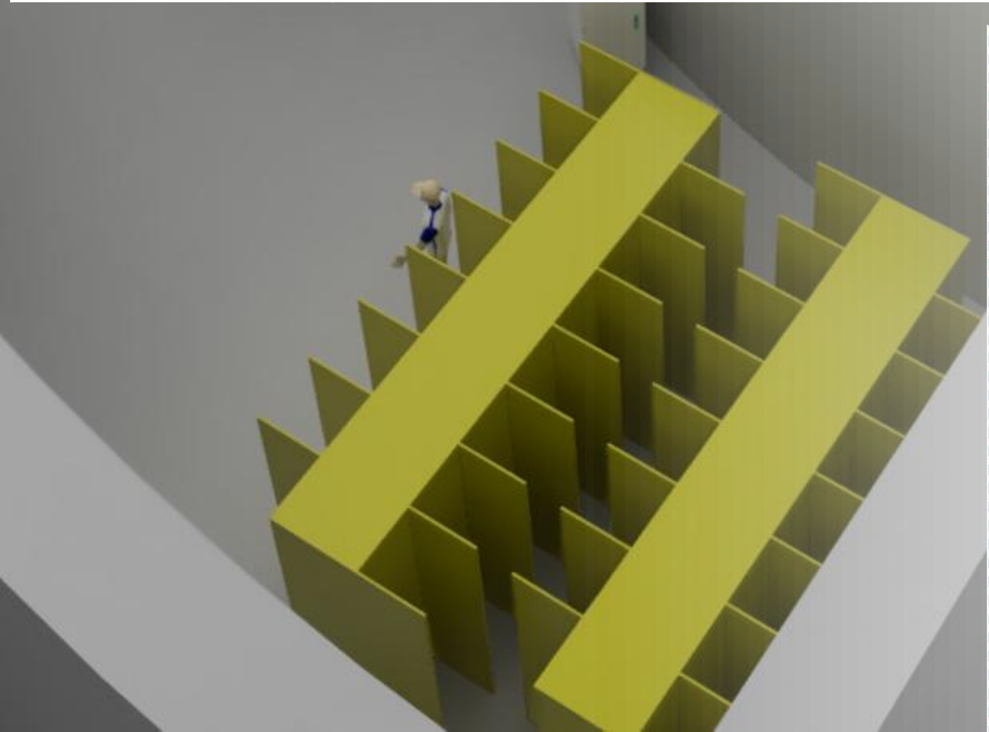
Light Distribution Point (LDP) fully automated and configurable routes calibration light to:

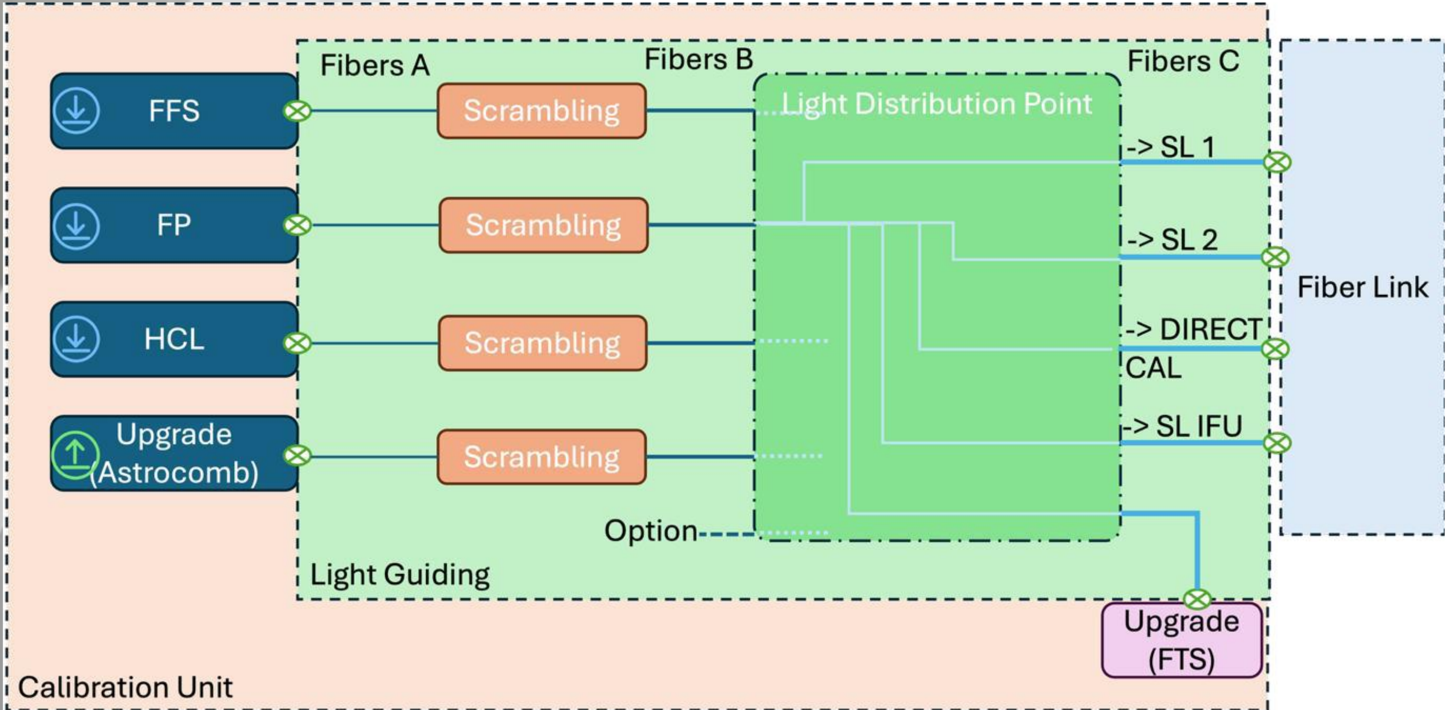
- Front-End (via FL)
- spectrographs (for simultaneous reference)

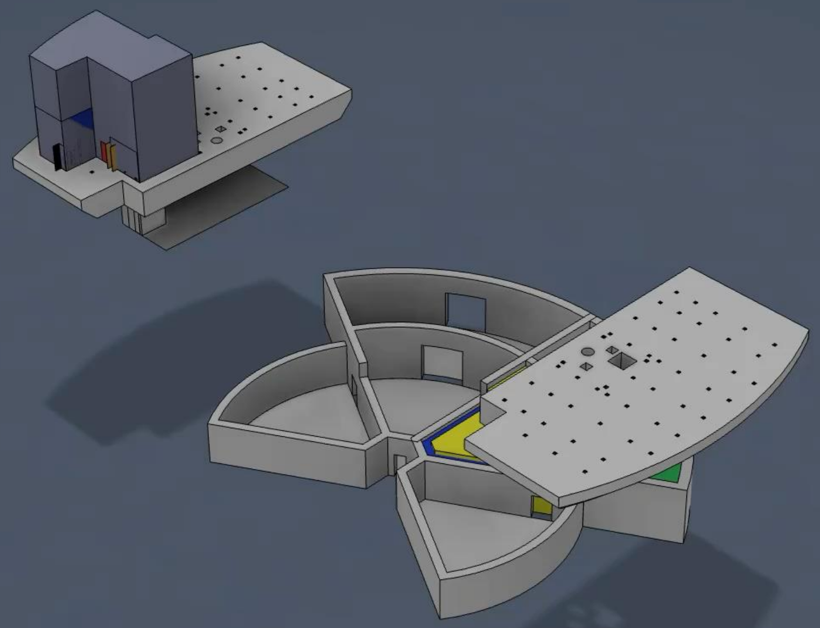
Baseline calibration sources:

- Flat Field Sources (FFS) – Halogen
- Hollow Cathode Lamps (HCL)
- Fabry–Pérot etalon (FP)

Designed for future upgrades







Requirement-driven (SCI & TECH) system architecture
resolving power, stability, wavelength coverage, observing modes

Modular and distributed design
- Front-End (+) at Nasmyth
- fibre-fed spectrographs at Nasmyth and Coudé

Architecture enabling multiple observing regimes
- seeing-limited, IFU-AO
- simultaneous object, sky, and calibration

Calibration and stability at system level
- daily calibration strategy
- Simultaneous direct calibration architecture

Designed for long-term scientific evolution (thanks to ANDES modularity)
- baseline performance fully compliant
- clear path toward ultimate precision goals

ANDES

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Max Planck Institute for Astronomy Heidelberg

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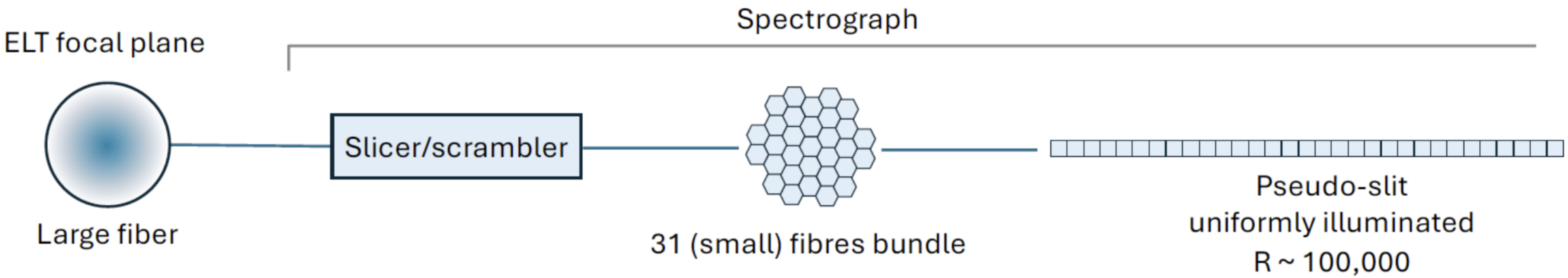
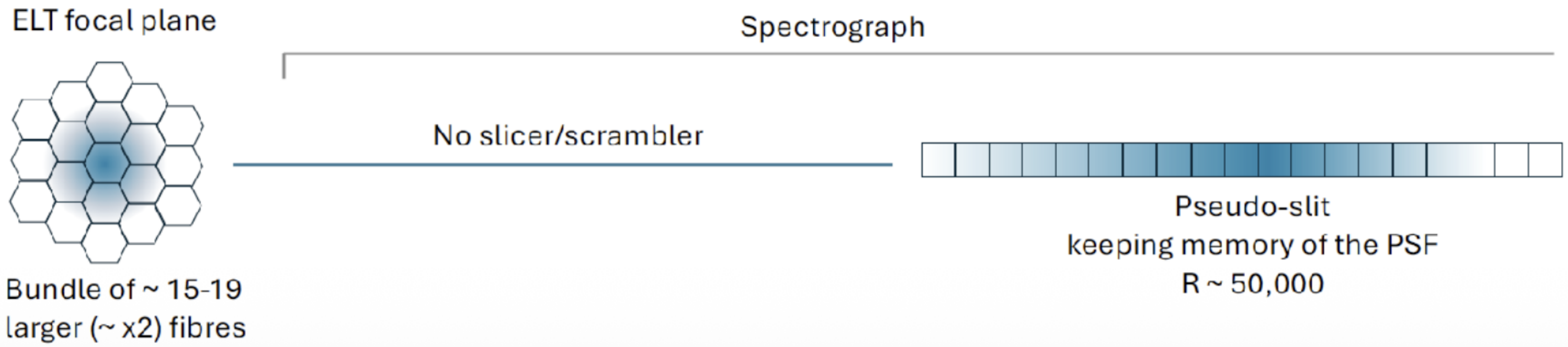
FAINT TARGET MODE



Current SL Observing mode (optimized for exoplanets not for `faint' targets)

- Losses at slicer/scrambler stage
- Spectral resolution higher than typically needed
- Photons spread over entire slit
- **Generally READOUT LIMITED**

combining medium resolution, optimal extraction, high throughput



New Faint Target Mode (lower RON impact)

- optimal extraction of the signal from illuminated fibres allows for a higher on-chip binning
- overall larger aperture ➞ smaller aperture losses
- skipping scrambler and splicer ➞ higher efficiency