Tailoring RHA requirements and new guidelines

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Radiation Hardness Assurance and Components Analysis Section

Acknowledgements (ESA):
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12/06/2024

Outline

Part 1 Mission Classification

- Missions
- Criteria for classification
- ECSS
- Tailoring of Requirements

Part 2 RHA requirements tailoring

- Overview
- Examples

Part 3 Other guidelines and Info

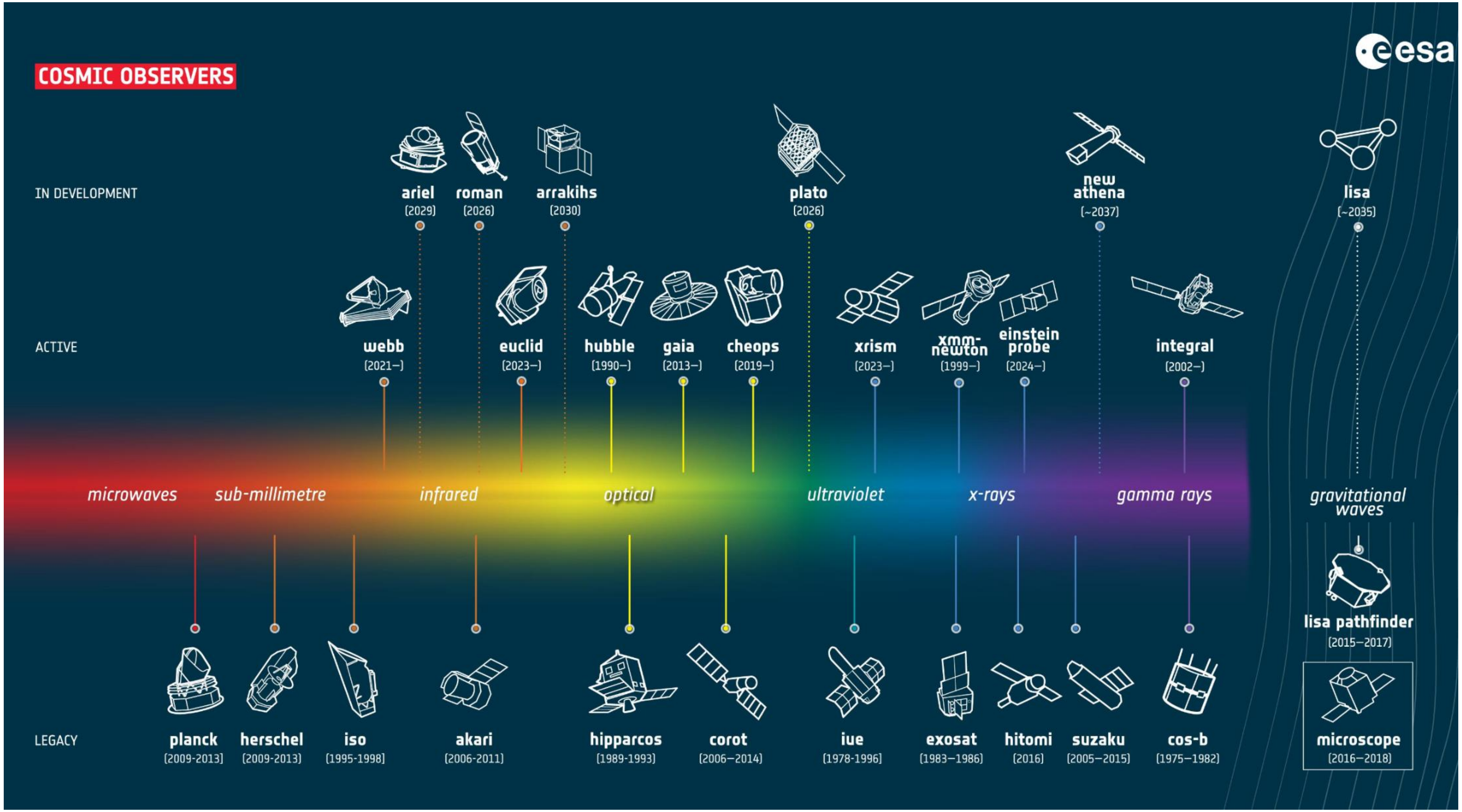
Mission classification

Part 1

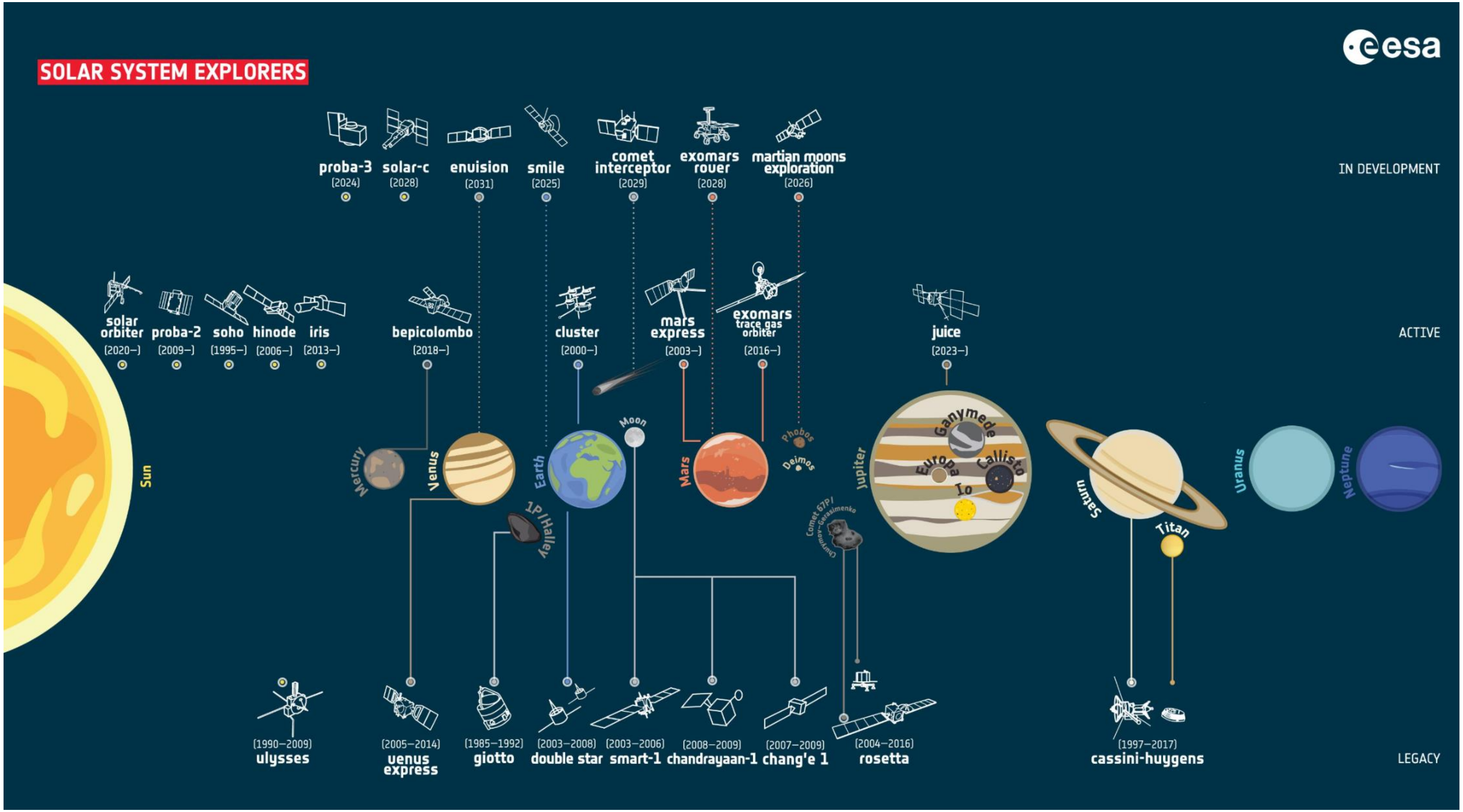
Missions
Science – ESA science fleet of Cosmic Observers

A fleet of astronomy missions observing the Universe across the electromagnetic spectrum – from microwaves to gamma rays.

These missions enable astronomers to tackle big questions such as the origin and evolution of our Universe, from its early beginnings to the stars and galaxies we observe today, and to investigate the fundamental laws that govern the cosmos.



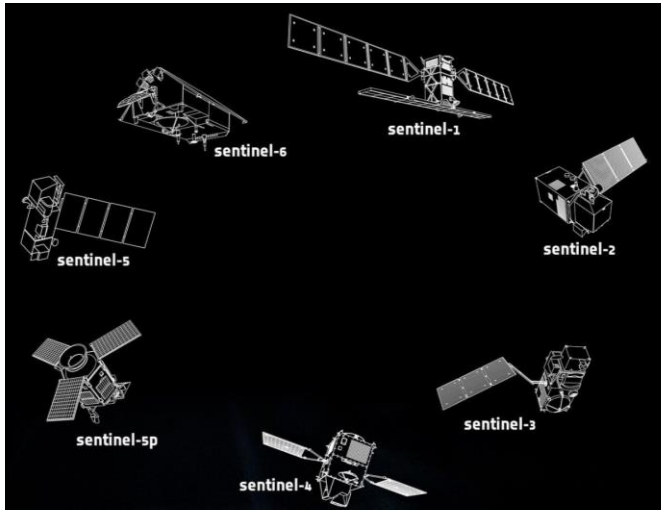
Missions
Science – ESA fleet of Solar System Explorers



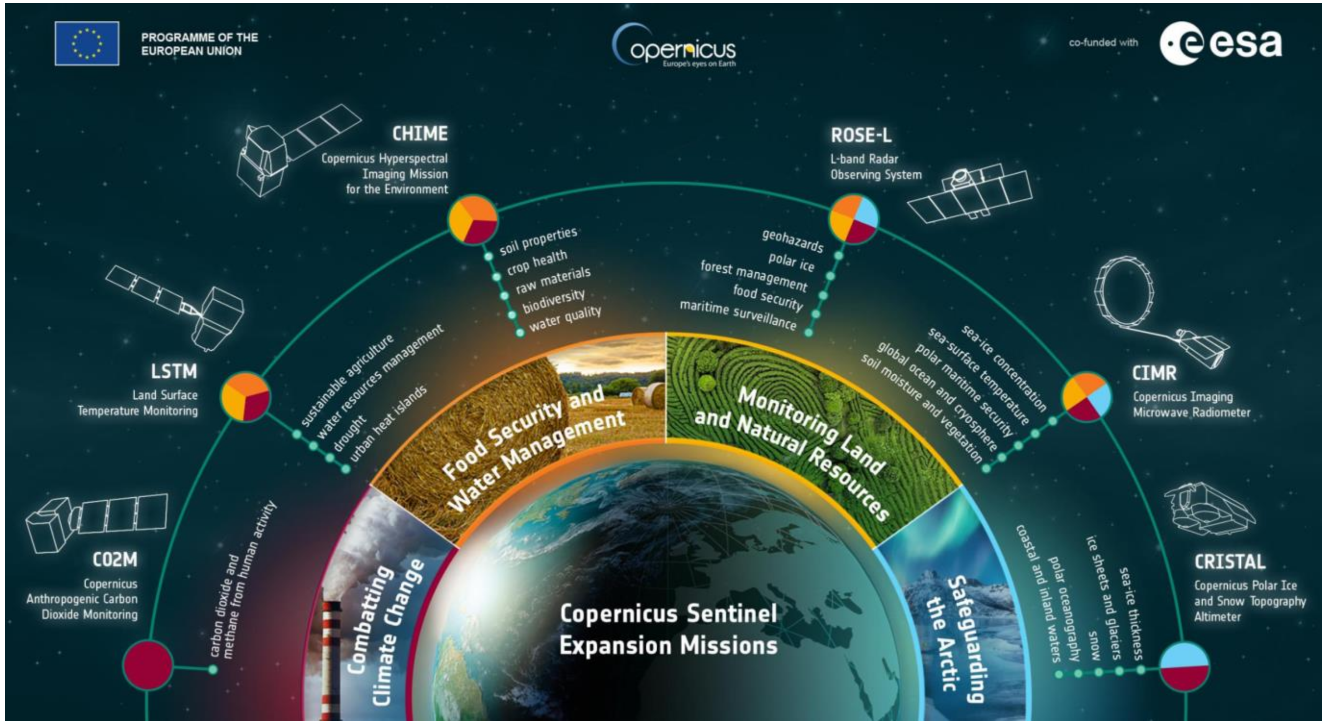
ESA's science missions have been exploring our planetary neighbourhood to tackle the big questions that help to put Earth in context, to understand a planet's interaction with its host star, and to search for habitable worlds

Missions
Earth Observation – Copernicus

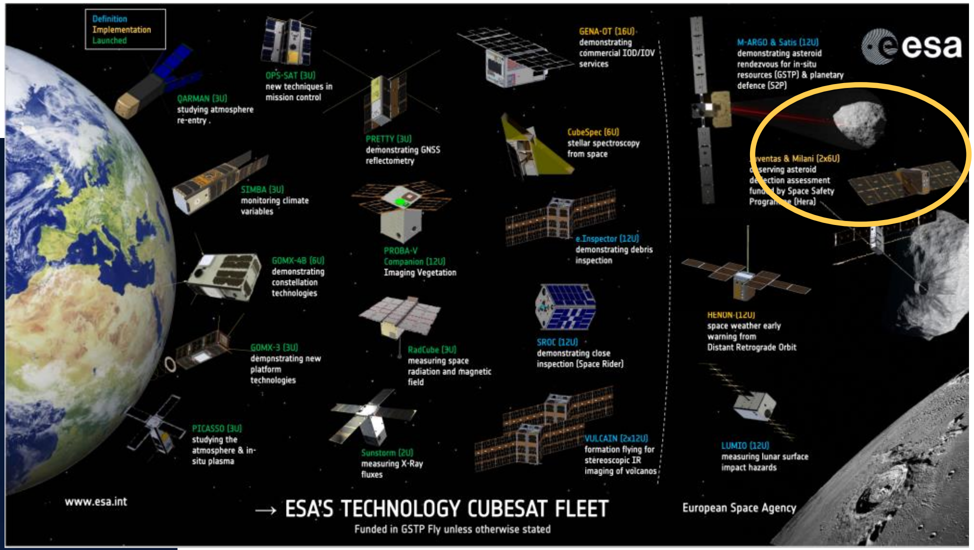
Copernicus is the Earth observation component of the European Union’s Space programme. It provides accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security.



sentinel-1
radar to provide all-weather, day-and-night imagery to monitor oceans, ice and land, and to aid emergency response.
sentinel-2
high-resolution multispectral imager to monitor land and vegetation cover.
sentinel-3
instrument package including a radar altimeter, an imaging radiometer and an imaging spectrometer to monitor oceans and land.
sentinel-4
spectrometer carried on the Meteosat Third Generation Sounder satellites. It is dedicated to monitoring air quality over Europe.
sentinel-5p
carries a spectrometer, primarily to monitor global atmospheric pollution.
sentinel-5
spectrometer carried on the MetOp Second Generation satellites. It is dedicated to monitoring global air quality.
sentinel-6
radar altimeter to measure global sea-surface height for operational oceanography and for climate studies.



Overview - Today and Tomorrow's ESA Missions



2024 Q1 – ESA Impact

Earthcare

Carrying four different instruments,
dedicated to delivering a wealth of new information on exactly how clouds and aerosols affect Earth’s climate – Launched on 24 May 2024

Arctic Weather Satellite

This satellite has been designed to show how it can improve weather forecasts in the Arctic – a region that currently lacks data for accurate short-term forecasts.
Launch planned June 2024

Milani Cubesat

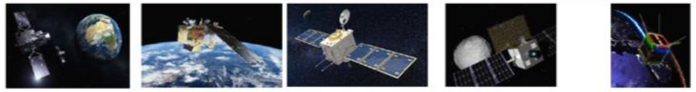
Milani Cubesat
for ESA's Hera asteroid mission
(2 cubesats,12instruments)
will perform close-up mineral prospecting of the Dimorphos asteroid and survey its surrounding dust.
Launch planned October 2024

https://www.esa.int/About_Us/ESA_Publications/ESA_Impact

ESA Approach to Mission Classes

Initial classification with 5 Classes (1-5)

Class Type	1	2	3	4	5
Criticality to Agency strategy	Extremely High	High	Medium	Low	Educational Purpose
Mission Objectives	Extremely High Priority	High Priority	Medium Priority	Low Priority	Educational Purpose
Cost	> 700 M€	200-700 M€	50-200 M€	1-50 M€	< 1 M€
Mission Lifetime	> 10 years	5-10 years	2-5 years	2years-3 months	< 3 months
Mission Complexity	High	High to Medium	Medium	Medium to Low	Low
	Critical Safety issue	Performance should be met	Finding best compromise between risk and cost	Mission is designed according to a hard cost limit	
Examples	ERO **JUICE** **MTG** Argonaut	Proba III FLEX VIGIL ARIEL **SENTINEL-2**	FORUM **CHEOPS** COMET I HARMONY	AWS SCOUTS PROBE B2 (on COMET I) M-ARGO	ESA Edu. FYS



4 different sets of requirements
Pre-tailored from ECSS-Q-ST-60-15

Class V
- < 3 M
- No TID test
- NO SEE test **except for MOSFET VDS > 200V**
- **Proton Test recommended (component or board level)**

Class IV
- 3M-2y
- No TID test if TIDL<5Krad
- **SEE** HI test **recommended**
- **Proton** test **required**

Class III
- 2y -5 y
- No TID if TIDL<5Krad
- HI at part and board level
- Proton at part and board level

Class I & II
- > 5 y
- ECSS-Q-ST-60-15 + ESSB-Q-008
- TID
- SEE

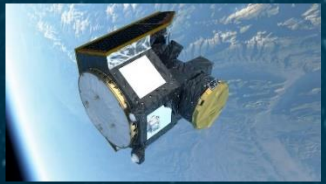
- ESA mission classification encompasses one-off missions (man, non-manned missions), recurring operational spacecraft, IOD/IOV and cubesats. Satellite mega-constellations and launchers are not addressed
- A specific mission class can contain units/payloads with different classes. Namely, mission class is originally defined at project/mission level, but it's possible to conceive different classes for different mission elements on-board the same S/C. Potential differentiation between critical and non-critical equipment to be addressed by the project
- For ECSS Q-Branch, ECSS is fully applicable to Class I (and most of Class II except for EEE components and EEE RHA)
- More flexibility is given to industry as a function of class of the mission (highest flexibility and associated risk for class V), but also more reliance of ESA on contractor's internal processes, more simplification of the documentation and required reporting, at the cost of the less visibility given to ESA and more delegation of responsibility and of risk is given to industry
- Security and safety (comprising space debris requirements/policy) are not subject to tailoring

ESA Mission Classification

2024Q1 - status

	Alpha	Beta	Gamma	Delta
Criticality	High	Medium	Low	Educational
Objectives	High	Medium Priority	Low Priority	Educational
Cost	> 200M€	50 - 200 M€	1 - 50 M€	< 1 M€
Lifetime	> 5 years	2 - 5 years	3 months - 2 years	< 3 months
Complexity	High	Medium	Low - Medium	Low

JUICE,
MTG

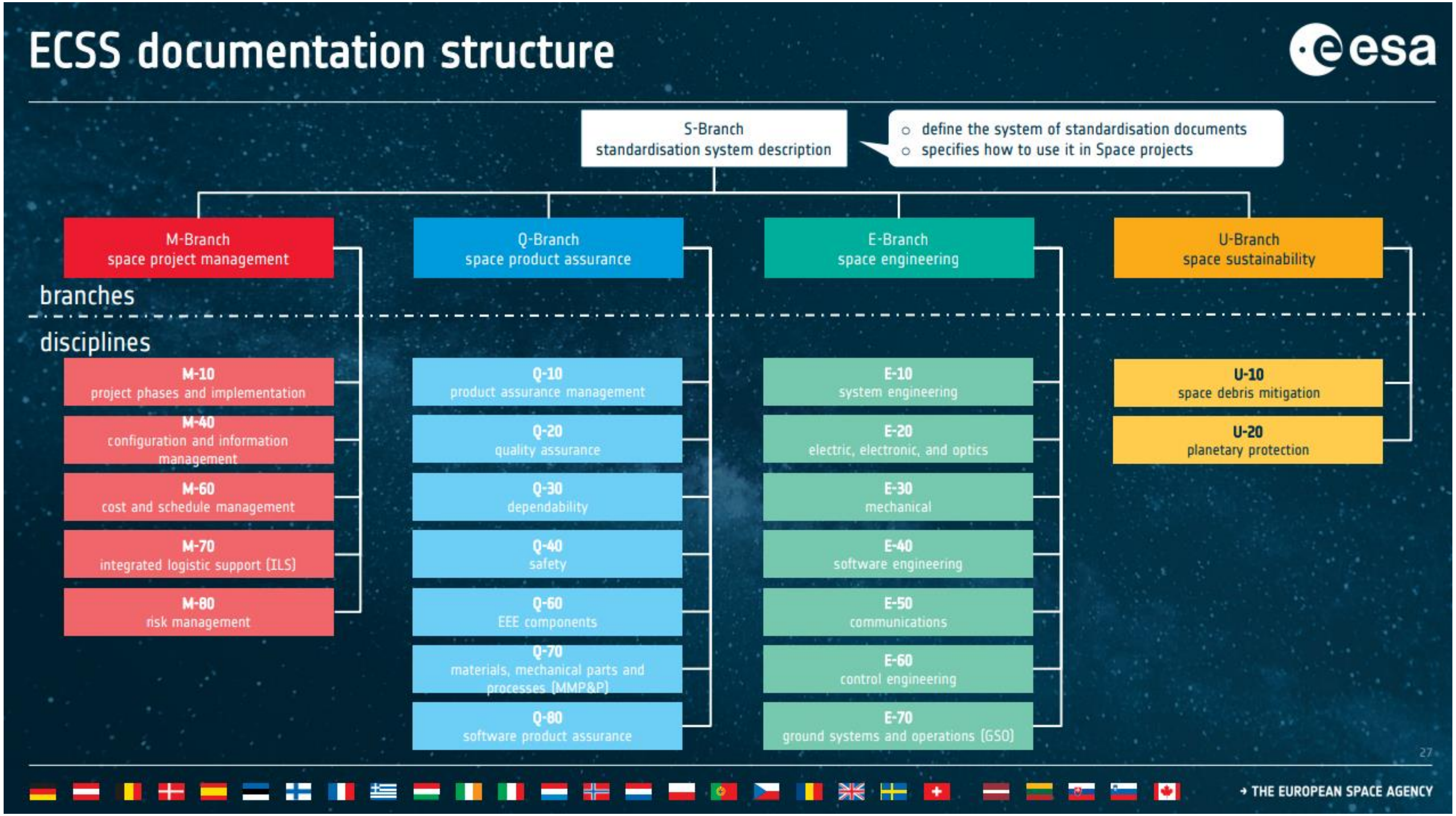


CHEOPS,
Comet-I

AWS
GOMX-5
M-ARGO

ESA
Education
FYS

ECSS standards



Mission lifetime cycle

Mission lifetime cycle	
Phase 0	Mission analysis and identification
Phase A	Feasibility
Phase B	Preliminary Definition
Phase C	Detailed Definition
Phase D	Qualification and Production
Phase E	Utilisation
Phase F	Disposal

Pre Phase A, Phase A — Analysis and Feasibility

- Draft environment definition
- Draft hardness assurance requirements (top level)
- Preliminary studies

Phase B – PDRs — Preliminary Definition

- Final environment definition
- Electronic design approach
- Preliminary spacecraft layout for shielding analysis
- Preliminary shielding analysis & hardness assurance requirements update

Phase C –CDRs — Detailed Definition

- Radiation test results
- Final shielding analysis & final hardness assurance requirement
- Circuit design analysis results

Phase D — Qualification and Production

- Radiation Lot Acceptance Tests (RLAT)

Phase E — Utilisation

- Failure analysis

Radiation Hardness - ECSS ESCC Standards

Radiation Environment Analysis ECSS:

- ECSS-E-ST-10-04C – Space Environment
- ECSS-E-ST-10-12C – Methods for calculating radiation received, it's effects & design margins
- ECSS-E-HB-10-12A – Handbook for the above
- ECSS-E-ST-20-06C – Spacecraft Charging

Radiation Hardness Assurance EEE Components ECSS:

- ECSS-Q-ST-60-15C – RHA for EEE components
- ECSS-Q-HB-60-02A – Techniques for radiation effects mitigation in ASICS and FPGAs handbook

Component Radiation Testing Specifications ESCC:

- ESCC 22900 – Total Dose Irradiation Test Method
- ESCC 25100 – Single Event Effects Test Method and Guidelines
- ESCC 22500– Guidelines for Displacement Damage Irradiation Testing

Pre Phase A, Phase A

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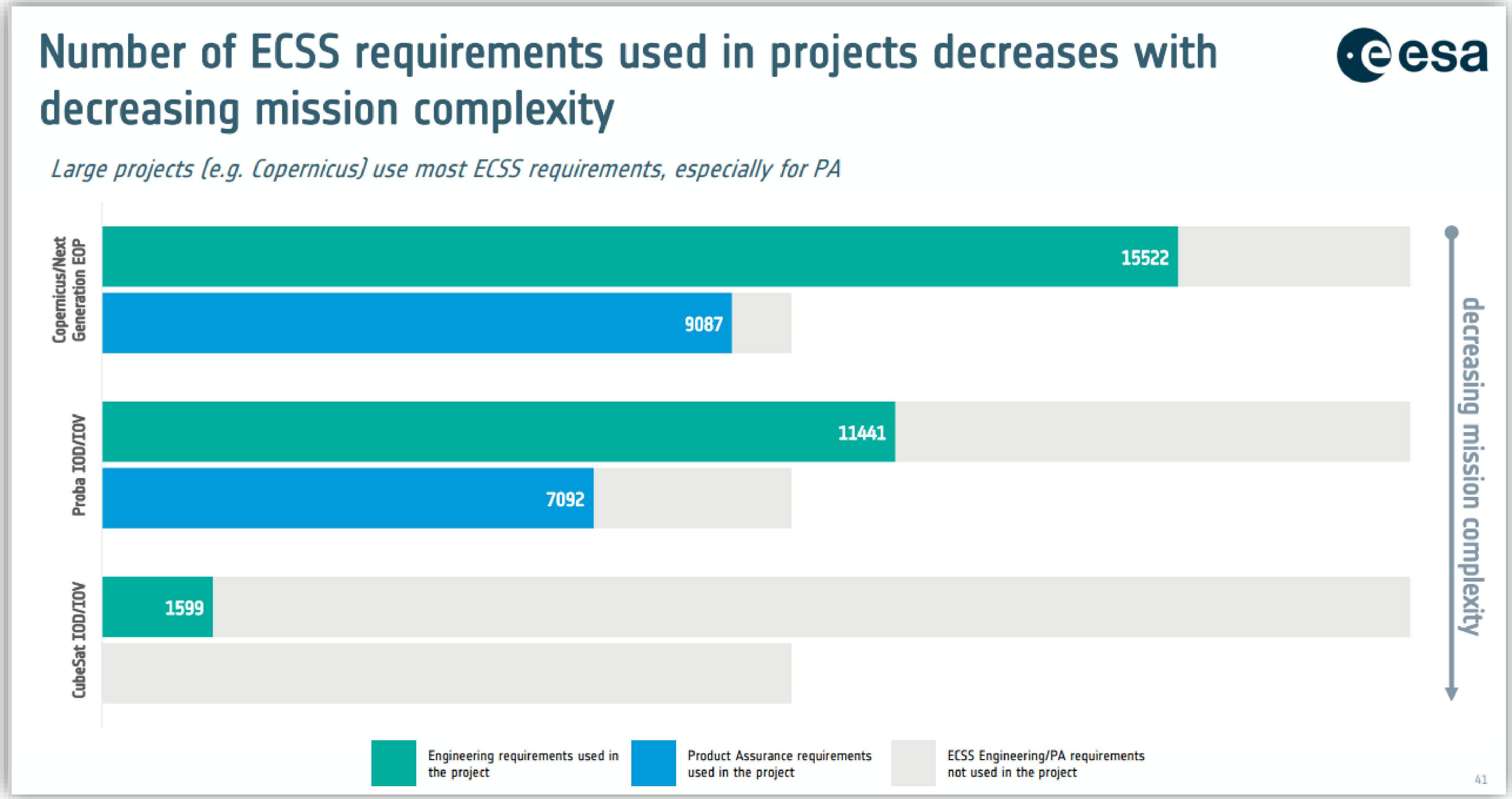
Phase D

- Radiation Lot Acceptance Tests (RLAT)

Phase E

- Failure analysis

Application of ECSS standards in space projects



[ECSS training material downloads](#)

Introduction to the ECSS standardisation system (A.Mancas)

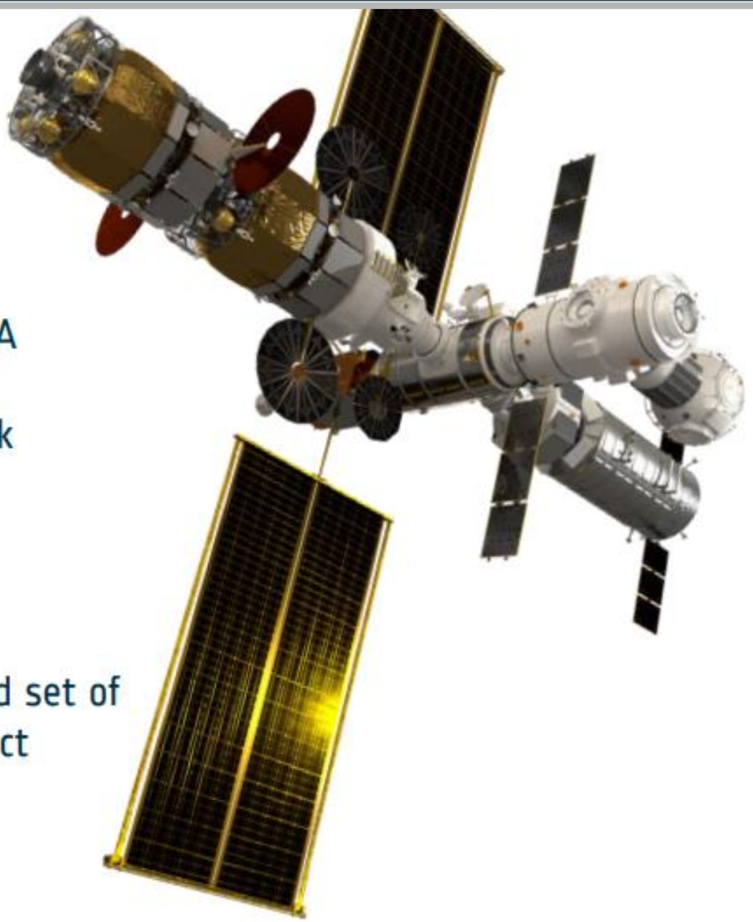
ECSS evolution

ECSS 4.0 and simplification

- stakeholders to identify core & non-core requirements to address the commercialisation needs and the New Space market
- approach to be complemented by the ESA mission classification to tailor the requirements according to the project risk profile

ECSS Master Database

- simplifies the application of a pre-defined set of requirements for a specific mission/project
- improves usability of ECSS standards
- adapts faster to new requirements



Mission classification

- framework to define the appropriate requirements tailored to the profile of the mission
- new structured framework for ESA & MS to manage programmatic risks
- systematic approach for optimising resources in accordance with mission objectives
- framework to develop novel project implementation strategies
- basis for the introduction of novel elements (eg COTS) aiming at reducing development time and cost

→ standardization will support a more dynamic space market in Europe

51

ECSS training material
Introduction to the ECSS standardisation system (A.Mancas)

Pre–tailoring and tailoring ongoing

Pre-tailoring	Tailoring
a **pre-cooked list of standards**, and a **pre-cooked list of requirements** in every standard subject to pre-tailoring **(published at the time of producing the standard*)**	done specifically by every project **by the project itself**

**pre-tailoring matrices are present is standards published after 2015 and subject to pre-tailoring*

- Tailoring of the whole set of requirements for a specific application has demonstrated to be a non-trivial very heavy task.
- It is however acknowledged that a number of requirements may not be meaningful for specific type of project or for specific phases of a project.
- It was therefore considered of ECSS interest to identify possible *types of products* and establish the associated applicability of standards/requirements. This view is shared by all ECSS Space Agencies, and considered of crucial importance by Eurospace.
- The impact of pre-tailoring is that **it will reduce dramatically the *Baseline for tailoring*** (input to steps 3 and 4 in the general tailoring process).
  It will NOT eliminate the need of the final tailoring by the customer.

ECSS training material
Introduction to the ECSS standardisation system (A.Mancas)

45

Example of Pre-tailoring

Input for Step 4 – tailoring of the set of requirements (**per standard**)

Table in each standard needing **explicit** pre-tailoring (category E) – **example** from **ECSS-E-ST-10C Rev. 1**

Table 7-2: Pre-tailoring matrix per "Space product types"

ECSS req. #	Space system	Space segment element and sub-system	Space segment equipment	Launch segment element and sub-system	Launch segment equipment	Ground segment element and sub-system	Ground segment equipment	Ground support equipment	Software	Comments
5.1a	X	X[1]	//[2]	//[2]	-	-	-	-	-	[1] applicable at element level: for subsystem level - see [2] [2] applicability should be defined/tailored at each level for next lower level, depending on product heritage, engineering complexity and industrialization context.
5.1c	X	X[1]	-	//[2]	-	-	-	-	-	[1] applicable at element level: for subsystem level - see [2] [2] applicability should be defined/tailored at each level for next lower level, depending on product heritage, engineering complexity and industrialization context.
5.1d	X	X[1]	//[2]	//[2]	-	-	-	-	-	[1] applicable at element level: for subsystem level - see [2] [2] applicability should be defined/tailored at each level for next lower level, depending on product heritage, engineering complexity and industrialization context.
5.2.1a	X	X	X	X	-	-	-	-	-	

ECSS training material
Introduction to the ECSS standardisation system (A.Mancas)

RHA requirements pre-Tailoring

Part 2

ESA Mission Classification – RHA classes (simplified)

For information, not to be used as a normative reference!

	Class Alpha	Class Beta	Class Gamma	Class Delta
Traceability	High	High but low acceptable	Low OK	Low OK
Total Ionizing Dose	As ECSS	As ECSS & board level possible	If TIDL > 5 krad (DDC) & board level ok	Not required
Total Non-Ionizing Dose	As ECSS	As ECSS & board level possible but only focused beam	If opto critical (if proton env.) & board ok but only focused beam	
RDM_{min} (TID/TNID)	As ECSS/ESSB	2 if low traceability or board test 1 if high traceability	2 if low traceability or board test 1 if high traceability	
Radiation Verification Testing	As ECSS/ESSB	TID: As ECSS except. Bipolar ICs TNID: Opto or if RDM < 2*RDMmin	No RVT required	
Single-Event Effects from Heavy Ions	As ECSS & component level only	All & board level possible	Critical parts & board level ok	Only for power MOSFET (part >200V or embedded) & OC protection parts, board level ok
SEE from Protons	As ECSS & component level only	All & board level possible	All & board level ok	All <u>critical boards</u> or when no SEE mitigation
DSEE LET threshold	As ECSS (60 $MeV.cm^2/mg$)	< 38 $MeV.cm^2/mg$	< 38 $MeV.cm^2/mg$	< 38 $MeV.cm^2/mg$
SEE Mitigation	As ECSS	As ECSS, NDSEL accepted if demonstrated by test	No proton DSEE, derating, NDSEE mitigation/no prop. & SET assessment	Same as Class IV but SET assessment is not required
Rad. Review/Analysis	Yes: As ECSS	Yes: Almost as ECSS	Yes: based on test data & mitigations & criticality analysis & SET analysis & rates	Yes: based on test data & mitigation & criticality analysis
Summary	ECSS	Traceability can be relaxed, board level testing possible with LETth=38 $MeV.cm^2/mg$	Low traceability OK, TID > 5 krad, board level testing OK, SEE HI if critical, proton for the rest, no RVT	Like Class IV & testing reduced to DSEE or when no mitigation impacting overall mission, *mostly risk-avoidance* & proton

For information, not to be used as a normative reference!

ESA Mission Classification – RHA classes (simplified)

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	Class Alpha	Class Beta	Class Gamma	Class Delta
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Summary	ECSS	Traceability can be relaxed, board level testing possible with LETth=38 MeV.cm²/mg	Low traceability OK, TID > 5 krad, board level testing OK, SEE HI if critical, proton for the rest, no RVT	Like Class IV & testing reduced to DSEE or when no mitigation impacting overall mission, *mostly risk-avoidance* & proton

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From EDHPC 2023 EDHPC 2023 – 2 October 2023 – V. Gupta

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Radiation Verification Testing	As ECSS/ESSB	TID: As ECSS except. Bipolar ICs TNID: Opto or if RDM < 2*RDMmin	No RVT required	

For information, not to be used as a normative reference!

From EDHPC 2023 EDHPC 2023 – 2 October 2023 – V. Gupta

ESA Mission Classification – RHA classes (simplified)

For information, not to be used as a normative reference!

	Class Alpha	Class Beta	Class Gamma	Class Delta
Single-Event Effects from Heavy Ions	As ECSS & component level only	All & board level possible	Critical parts & board level ok	Only for power MOSFET (part >200V or embedded) & OC protection parts, board level ok
SEE from Protons	As ECSS & component level only	All & board level possible	All & board level ok	All **critical boards** or when no SEE mitigation
DSEE LET threshold	As ECSS (60 MeV.cm²/mg)	< 38 MeV.cm²/mg	< 38 MeV.cm²/mg	< 38 MeV.cm²/mg
SEE Mitigation	As ECSS	As ECSS, NDSEL accepted if demonstrated by test	No proton DSEE, derating, NDSEE mitigation/no prop. & SET assessment	Same as Class IV but SET assessment is not required

ESA Mission Classification – RHA tailoring

Additional clarifications:

- The proposed tailoring is the set of **minimum requirements**
- **Board level testing** for Class III & IV - number of boards may required a careful trade-off:
  - Class III: e.g. 3 (ON) + 2 (OFF – if applicable) boards are required (TID) & 3 (TNID), 2+1 (for SEE incl. spare)
  - Class IV: e.g. 1 (ON) + 1 (OFF – if applicable) boards are required (TID) & 1 (TNID), 2+1 (for SEE incl. spare)
  - Test data shall be provided at CDR ➔ will boards be ready? What if part fails on the board?
  - In general for TNID: board level OK but focused on part
- Definition of **critical** for Class IV & V:
  - Critical parts in terms of radiation risk
  - But also in terms of "mission impact": specific from one project/design to another, **defined by the project team**!
  - This also includes protection devices (e.g. overcurrent protection)
  - For NDSEE (non-destructive SEE), even if not critical, demonstration to be done to ensure "no failure propagation".
- **RVT for Class IV**: RVT is not based on diffusion lot but on "procurement batch"
- "Low traceability": (= procurement batch) means that multiple samples of a same part reference is procured from the same manufacturer either directly or via a reliable distributor and at the same time.
- **Class V approach**:
  - Though educational mainly – approach shall not be to « close-eyes »
  - Encourage a good design & adequate parts selection & adequate mitigation – otherwise testing required!
  - Concept of safety barrier is highlighted (as also mentioned in the ESA COTS Guidelines)
- **Class IV limit of 5 krad**:
  - Only if Dose Depth Curve (DDC) is used, otherwise (Ray Tracing or 3D MC) 2.5 krad shall be used
- All classes required to provide a **radiation analysis** (level of details adapted) but WCA analysis only for Class I to IV

Viyas Gupta

Standards and guidelines

Part 3

ECSS and ESCC

Radiation Environment Analysis ECSS:

- ECSS-E-ST-10-04C – Space Environment
- ECSS-E-ST-10-12C – Methods for calculating radiation received, it's effects & design margins
- ECSS-E-ST-20-06C – Spacecraft Charging
- ECSS-E-HB-10-12A – Handbook for the above

Radiation Hardness Assurance EEE Components ECSS:

- ECSS-Q-ST-60-15C – RHA for EEE components
- ECSS-Q-HB-60-02A – Techniques for radiation effects mitigation in ASICS and FPGAs handbook

Component Radiation Testing Specifications ESCC:

- ESCC 22900 – Total Dose Irradiation Test Method
- ESCC 25100 – Single Event Effects Test Method and Guidelines
- ESCC 22500– Guidelines for Displacement Damage Irradiation Testing

ECSS document types

standards	→ normative documents → for direct use in invitations to tender and business agreements → content limited to verifiable requirements – state what to do, not how to do it
handbooks	→ non-normative documents → provide guidelines and/or a collection of data
technical memoranda	→ non-normative documents → provide useful information to the space community → content not yet mature for a standard or handbook

ESCC specifications

The ESCC system for the specification, qualification and procurement of EEE parts for use in Space programmes.

The ESCC Specification System comprises Basic, Generic and Detail specifications:

•The **Basic Specifications** provide test methods, qualification methodology and general requirements applicable to all ESCC components.

•The **Generic Specifications** provide the requirements for screening, perodic or lot acceptance testing and qualification testing for individual families of components.

•The **Detail Specifications** provide the performance requirements for individual or ranges of particular components.

Recent developments in RHA standardization

- Ongoing update of the **ECSS-Q-ST-60-15C** (current standard from 2012)
- ESA application note **ESSB-AS-Q-008** in the process of being published, update will include a template for the Radiation Analysis
- Release of the **ESA COTS Guidelines** ongoing (on request)
- Release of the **ESA CubeSat design guidelines** ongoing (on request)

ESA CubeSat design guidelines - intro

The purpose of this document is to act as a **single Reference Document (RD) to be used by external entities developing CubeSat systems for In-Orbit Demonstration (IOD)** missions under European Space Agency (ESA) contract which are typically funded by the Fly element of the General Support Technology Programme (GSTP).

The document is intended to provide ***guidance and recommendations*** for how the engineering work should be carried out, particularly in order to help external entities in reducing/eliminating known technical problems/issues/risks from occurring/recurring during the IOD CubeSat project lifecycle, and to outline how they can meet ESA's expectations as customer/technical manager of the project.

The document is not meant as a replacement for nor as a repetition of the tailored European Cooperation for Space Standardization (ECSS) standards for IOD CubeSats [AD1], which are firm requirements applicable to the contract, but as a complementary document addressing *the engineering best practices* specifically for CubeSat projects due to their different characteristics compared to larger conventional ESA missions.

[AD1] - Tailored ECSS Engineering Standards for IOD CubeSat Projects, ref. TEC-SY/128/2013/SPD/RW, issue 1, revision 3, 24 November 2016.

Standards and Guidelines References list

ECSS Standards and Handbooks (ECSS.nl):

- RHA – EEE Components: ECSS-Q-ST-60-15C
- Space environment: ECSS-E-ST-10-04C
- Calculation of radiation, effects, and margin ST: ECSS-E-ST-10-12C
- Calculation of radiation, effects, and margin HB: ECSS-Q-HB-10-12A
- Engineering techniques for radiation effects mitigation in ASICs and FPGAs handbook ECSS-E-HB-20-40A

ESCC Radiation Test Methods and Guidelines (ESCIES.org) :

- SEE Test Method and Guidelines: ESCC 25100
- TID Steady-state Irradiation Test Method: ESCC 22900
- Guidelines for Displacement Damage Irradiation Testing: ESCC 22500

ESA is working on COTS Guidelines for the use of COTS in space missions:

- Guidelines for the utilization of COTS components and modules (in preparation)
- Engineering guidelines for ESA IOD Cubesat projects (in preparation)

Conferences & papers:

- RADECS & NSREC conference papers available on the IEEE website
- TNS journal papers also available on the IEEE website.

List from - Chapter 15. RADIATION HARDNESS ASSURANCE – Author V.Gupta
ENGINEERING GUIDELINES FOR ESA IOD CUBESAT PROJECTS

Other

Test Methodologies

(IES/ESA) Guidelines Single-Event Effects Testing with a Laser Beam

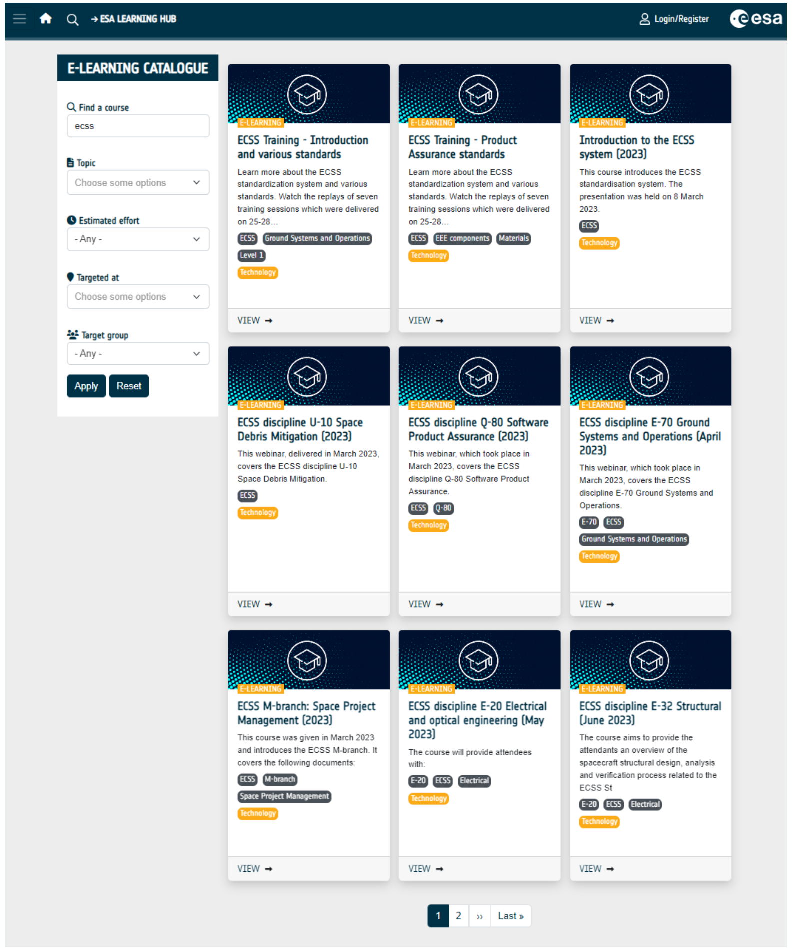
Other material from NASA:

- NASA/TM−20210018053 - Avionics RHA Guidelines: NASA/TM-20210018053
- JPL Pub 19-9 ; Guideline for the Selection of COTS Electronic Parts in Radiation Environments
- JPL Pub 18-2 ; Guideline for Single-Event Effect (SEE) Testing of System on a Chip (SOC) Devices
- JPL Pub 17-7 ; Book of Knowledge Guideline for SEE Testing of COTS Electronics Using Proton Board-Level Testing
- JPL Pub 08-13 ; Guideline for Ground Radiation Testing of Microprocessors in the Space Radiation Environment

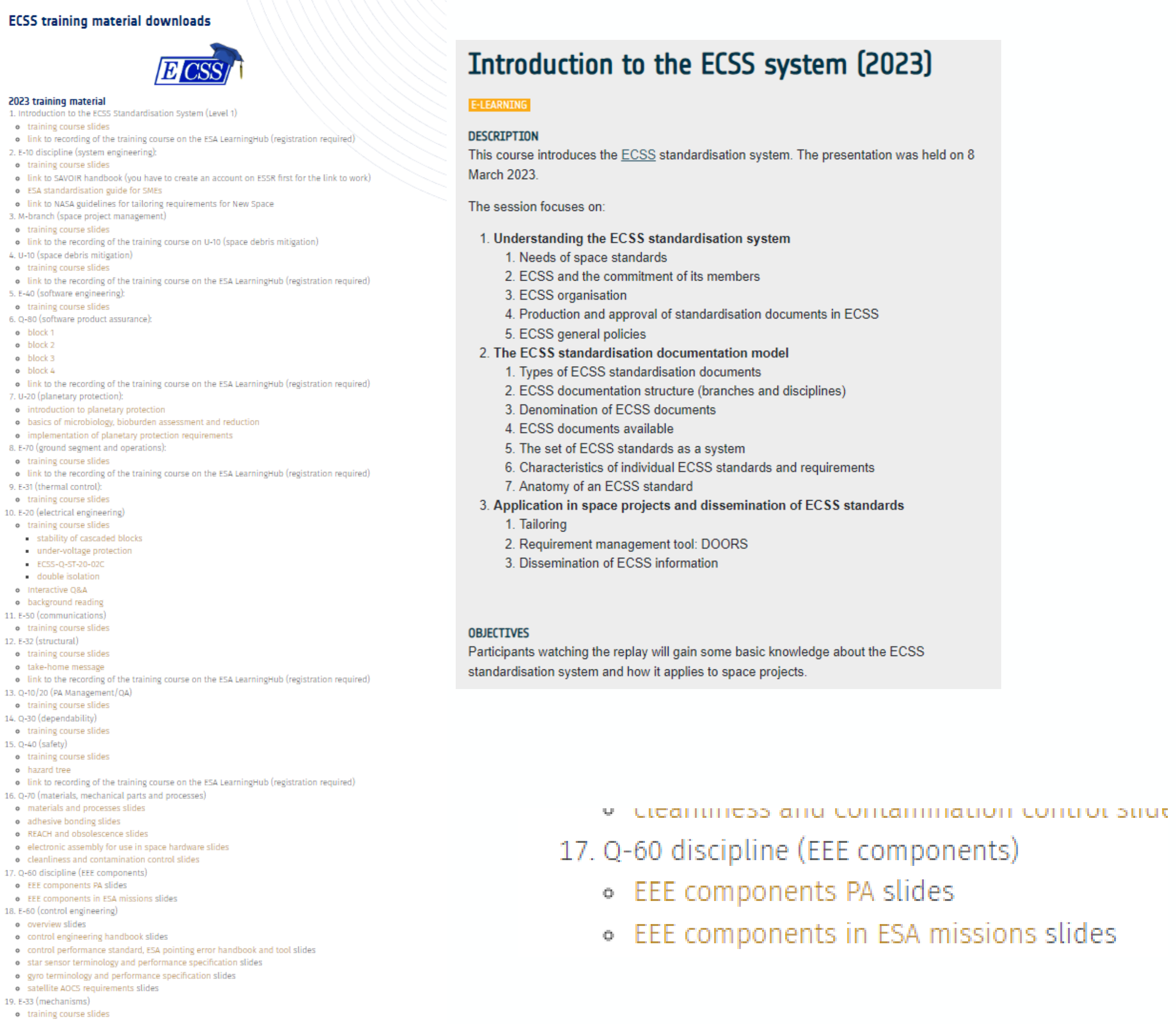
List from - Chapter 15. RADIATION HARDNESS ASSURANCE – Author V.Gupta)
ENGINEERING GUIDELINES FOR ESA IOD CUBESAT PROJECTS

ESA Learning Hub

https://learninghub.esa.int/



https://ecss.nl/ecss-training/



Conferences etc.

7-8 May 2024	RADHARD Symposium
27-31 May 2024	ESA - Interested in CubeSats? Apply for the CubeSat Hands-On Training Week 2024
22-26 July 2024	NSREC – IEEE Nuclear & Space Radiation Effects Conference
5-30 August 2024	ESA - Everything you need to know about the CubeSat Summer School 2024
18–19 September 2024	ESA - Industry Space Days (esa.int)
11 Sept 2024	ESA - RADLAS 2024 : 6th Workshop on Laser Testing of Radiation Effects on Components and Systems
16-20 September 2024	RADECS 2024
--- Biannual events	
October 2022	ACCEDE Workshop on COTS Components for Space Applications (doeeet.com)
Dec 2023	SERESSA - International School on the Effects of Radiation on Embedded Systems for Space

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RADNEXT (workshops, Webinars)

Laboratories (esa.int)

Open Space Innovation Platform - OSIP - Channel: Visiting researchers – access to ESA labs and expertise for your research projects (esa.int)

Thank you for your attention

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