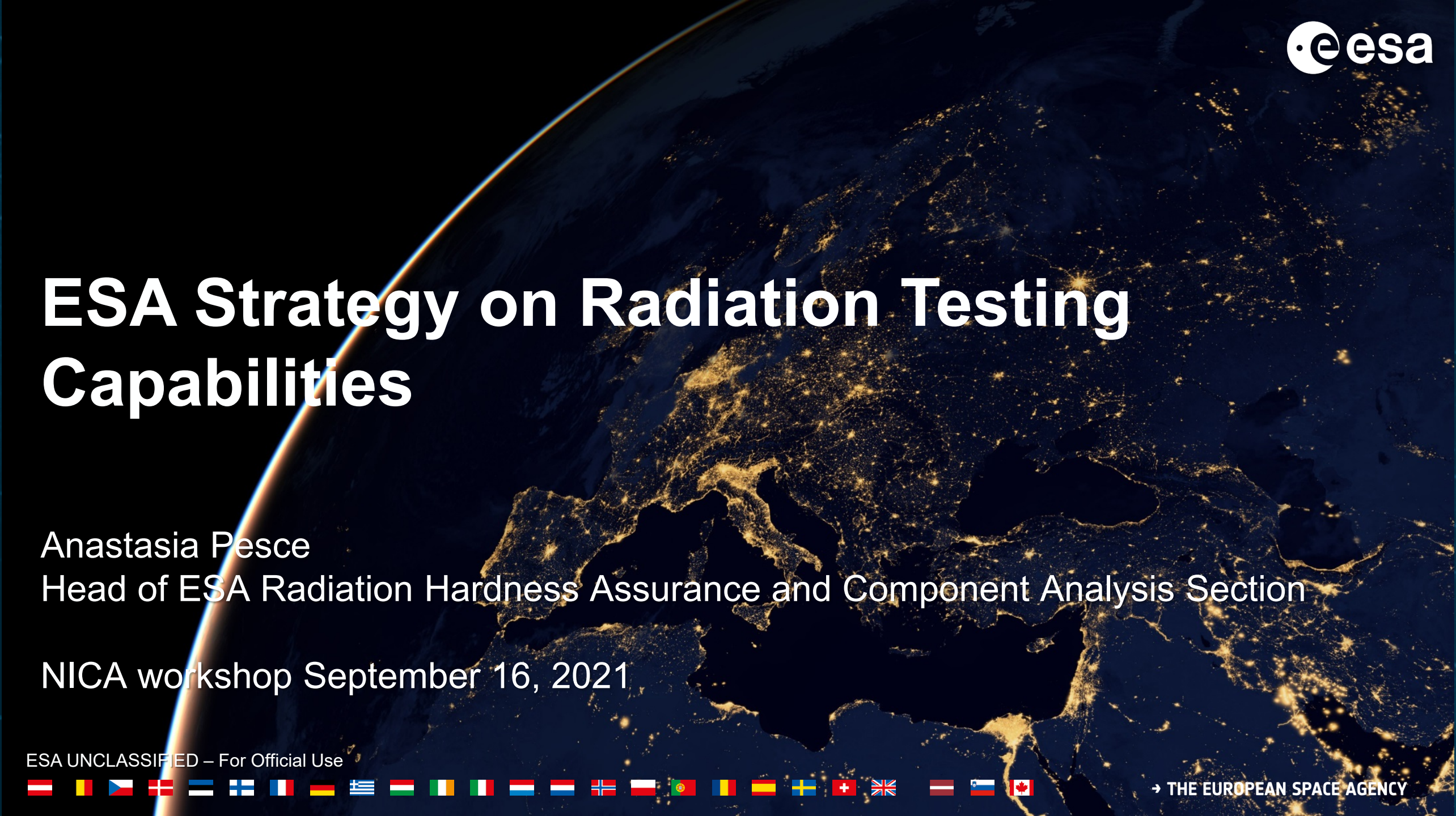


ESA Strategy on Radiation Testing Capabilities

Anastasia Pesce
Head of ESA Radiation Hardness Assurance and Component Analysis Section

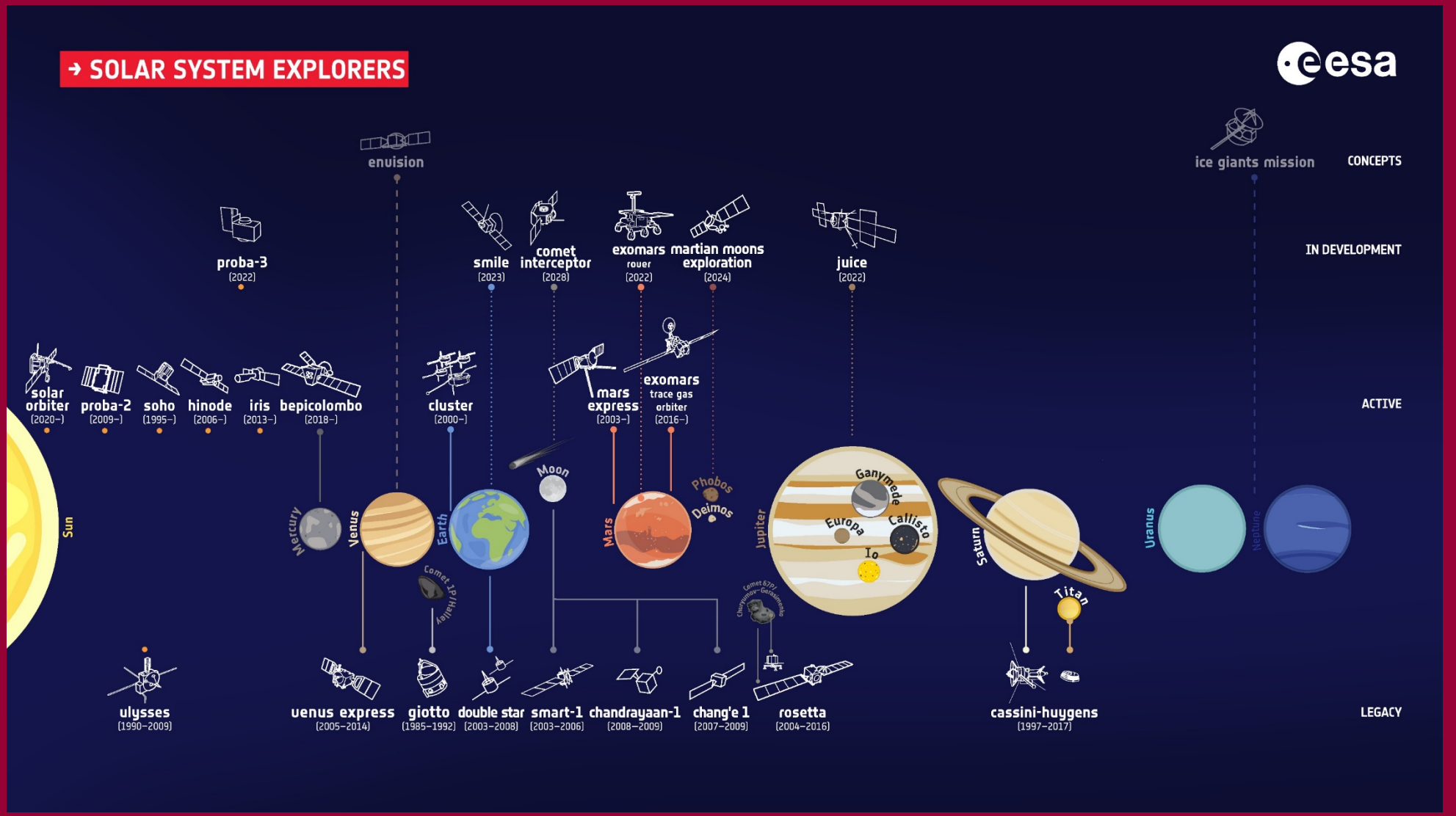
NICA workshop September 16, 2021

We Are ESA

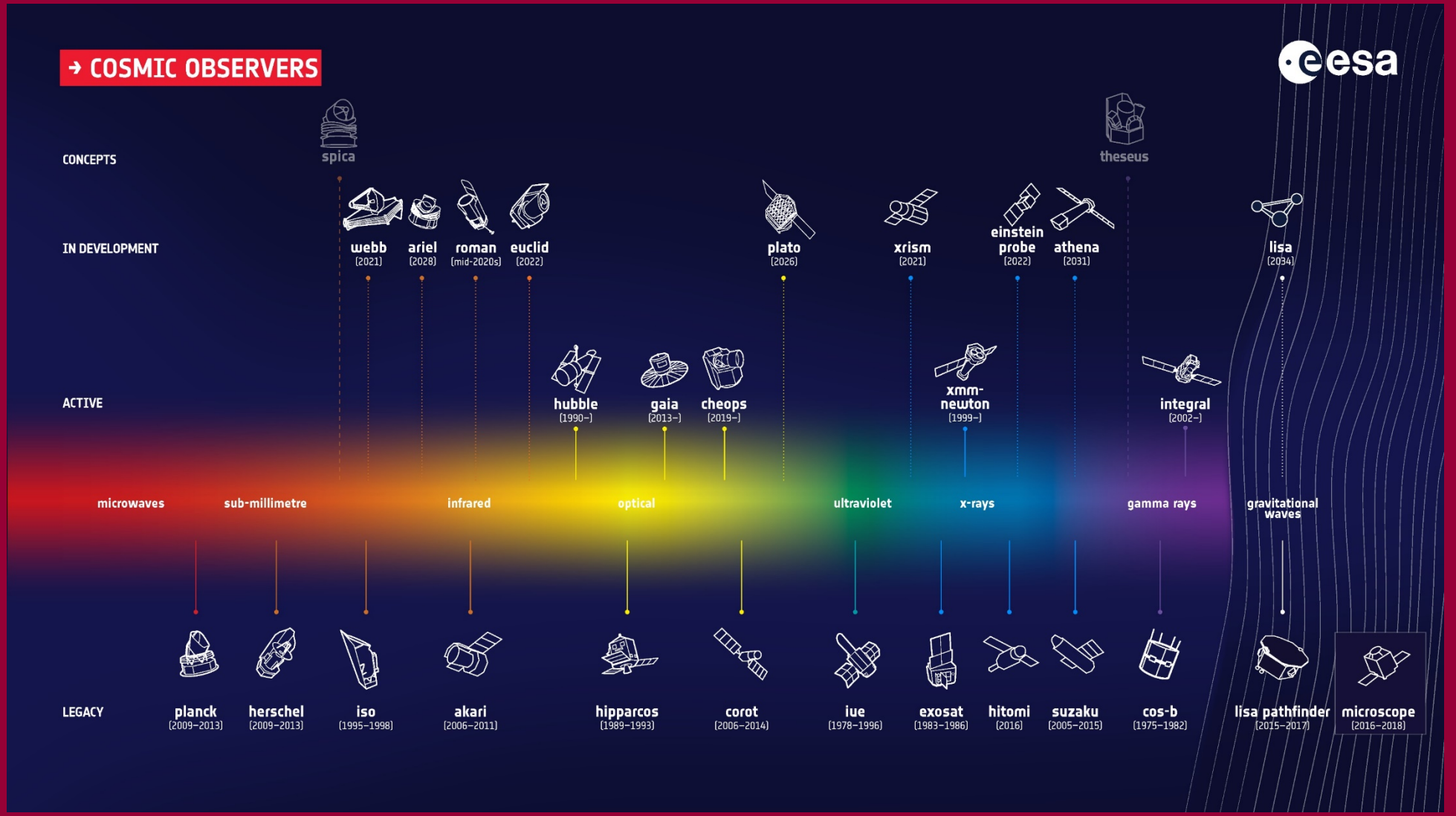
EUROPE'S GATEWAY TO SPACE

WHAT	22 Member States, 5000 employees
WHY	Exploration and use of space for exclusively peaceful purposes
WHERE	HQ in Paris, 7 sites across Europe and a spaceport in French Guiana
HOW MUCH	€6.68 billion = €12 per European per year

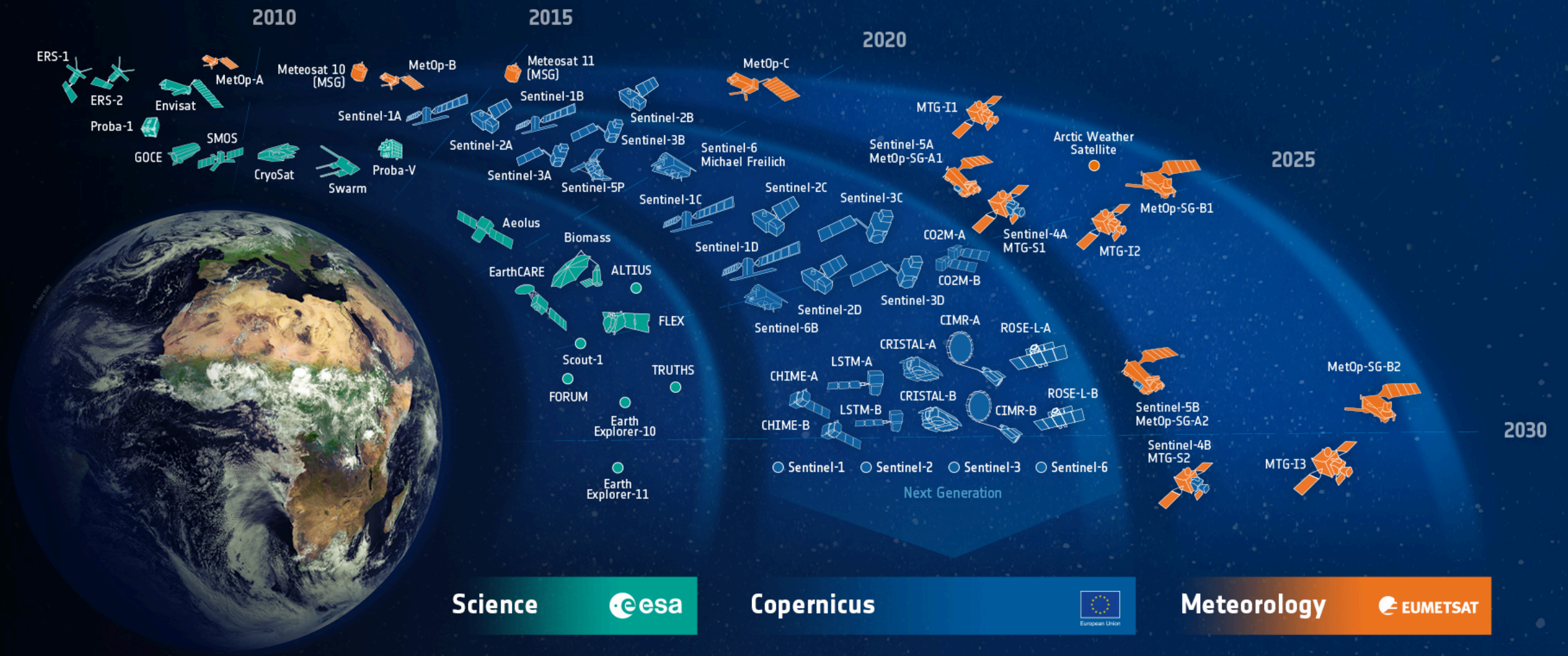
Some of Today and Tomorrow's Science Missions *(1)*



Some of Today and Tomorrow's Science Missions *(2)*

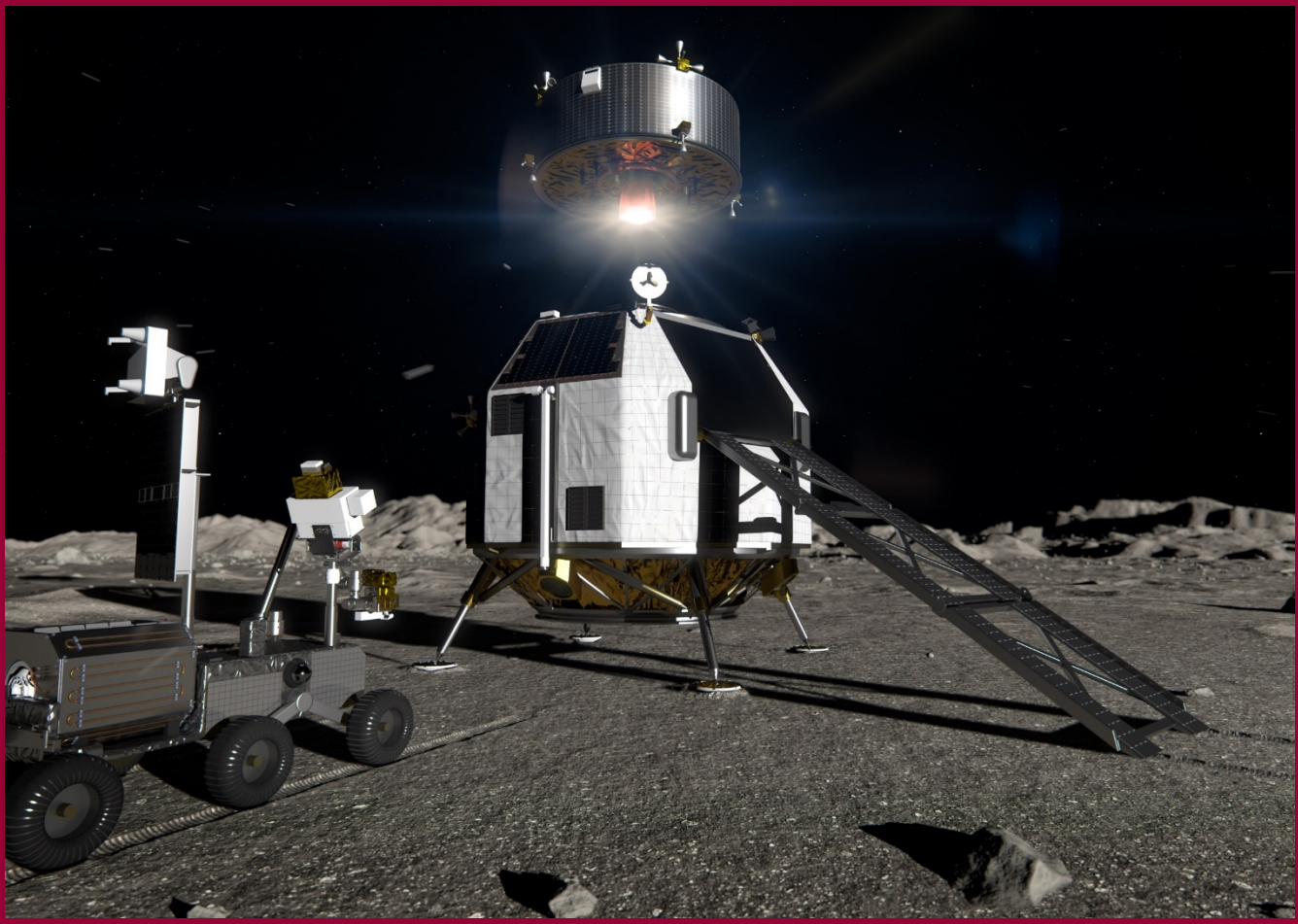


ESA-DEVELOPED EARTH OBSERVATION MISSIONS

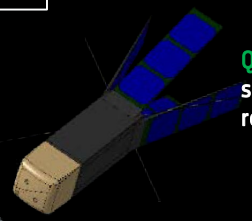


ExPeRT: Exploration, Preparation, Research & Technology

- The ExPeRT programme defines and performs the initial phases of exploration missions to identify critical technologies and contribute to making them reality.
- ExPeRT is committed to establish collaborations with agencies, industries and academia to create exploration opportunities and welcomes the involvement of newcomers and small entities.



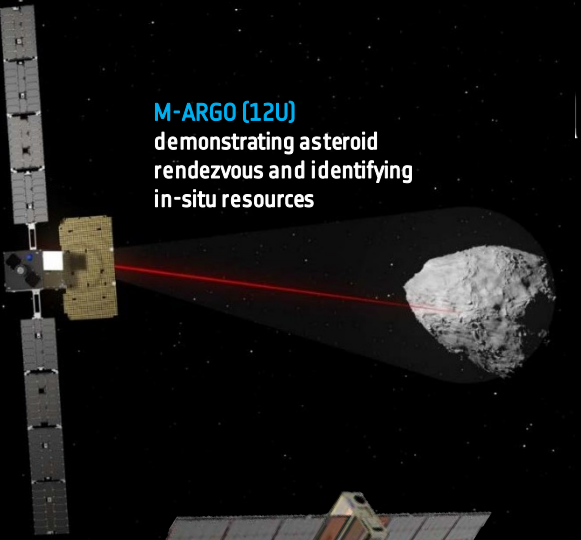
Definition
Implementation
Operation



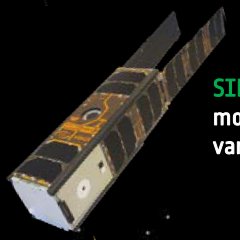
QARMAN (3U)
studying atmosphere re-entry

PRETTY (3U)
demonstrating GNSS reflectometry

GENA-SAT (6U & 12U)
demonstrating commercial IOD/IOV services

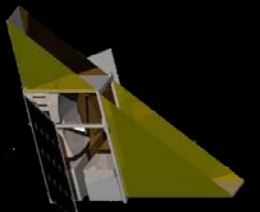


M-ARGO (12U)
demonstrating asteroid rendezvous and identifying in-situ resources

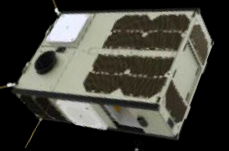


SIMBA (3U)
monitoring climate variables

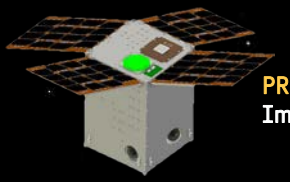
GOMX-5 (12U)
demonstrating next generation constellation technologies



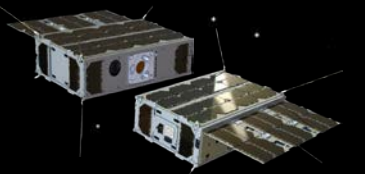
CubeSpec (6U)
stellar spectroscopy from space



GOMX-4B (6U)
demonstrating constellation technologies

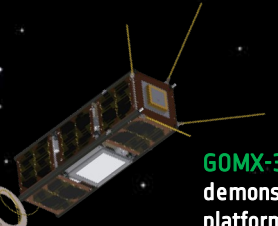


PROBA-V Companion (12U)
Imaging Vegetation

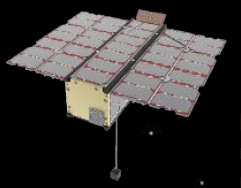


RACE (2x6U)
demonstrating rendezvous and docking

Juventas & Milani (2x6U)
observing asteroid deflection assessment (HERA S2P)

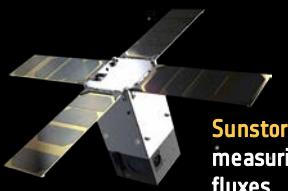


GOMX-3 (3U)
demonstrating new platform technologies



RadCube (3U)
measuring space radiation and magnetic field

PICASSO (3U)
studying the atmosphere



Sunstorm (2U)
measuring X-Ray fluxes

CSC (2x6U)
EC IOD/IOV

LUMIO & VMMO (2x12U)
measuring lunar surface impact hazards & in-situ resources

www.esa.int

→ ESA'S TECHNOLOGY CUBESAT FLEET

Funded in GSTP Fly unless otherwise stated

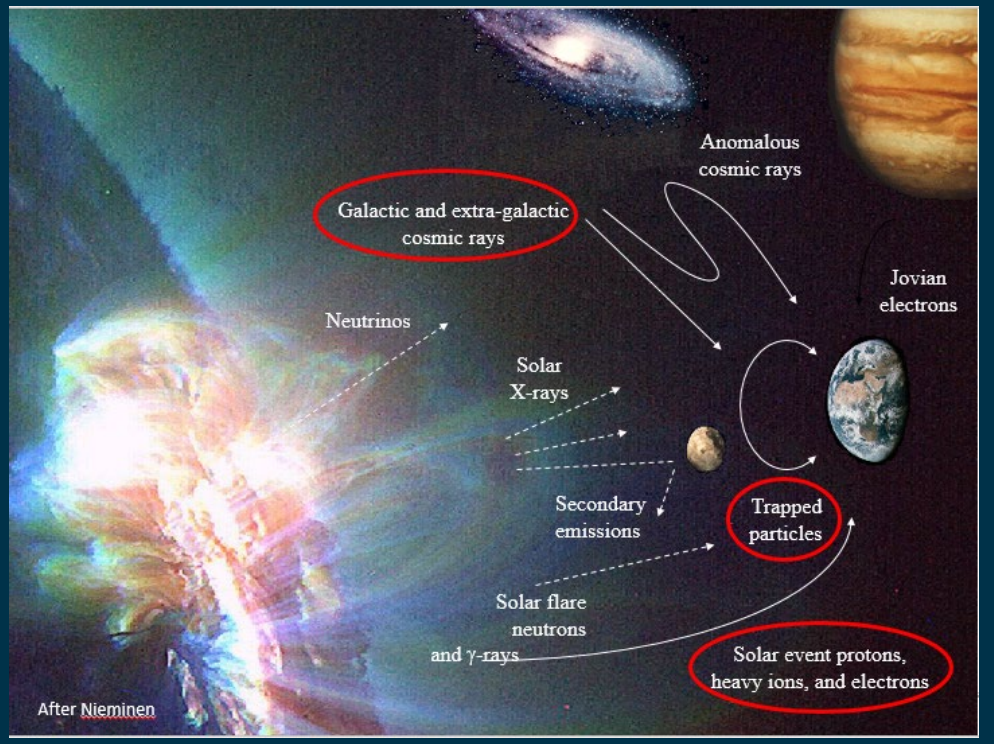
European Space Agency

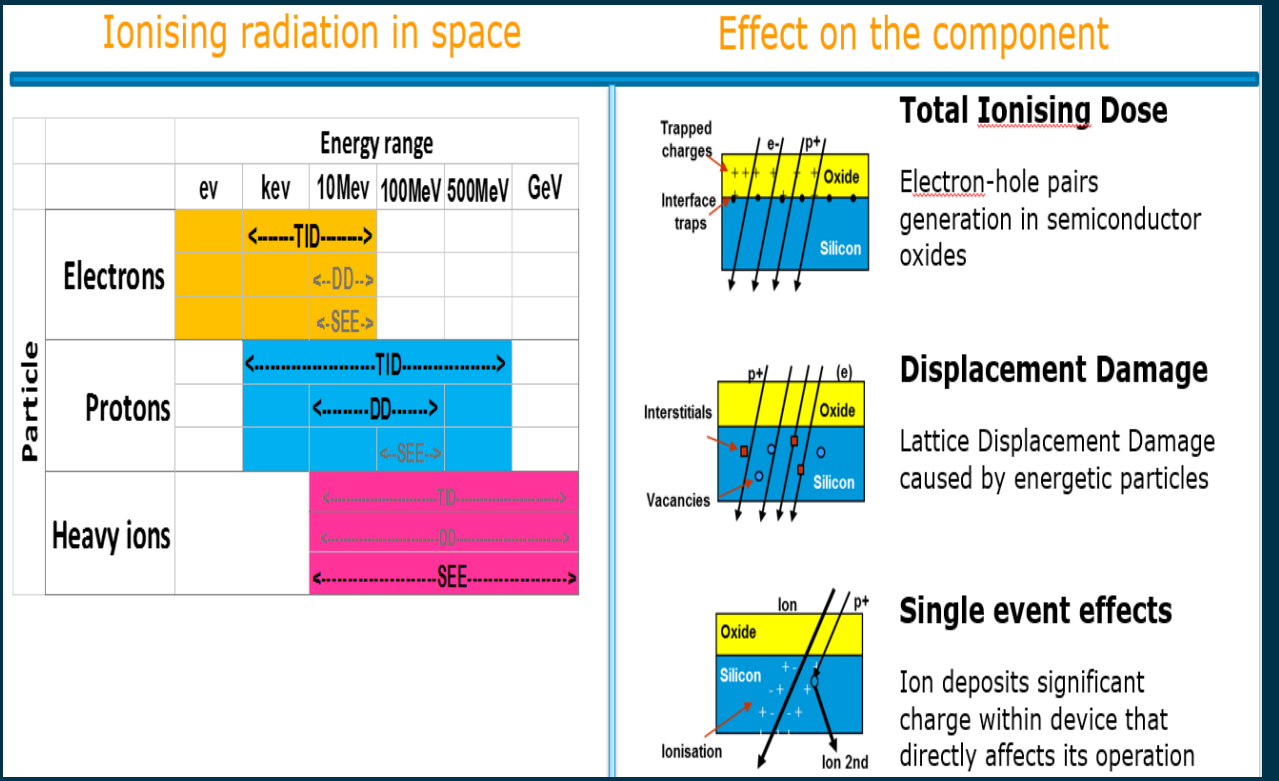
Space Radiation and Effects on Electronics

Radiation belts trapped by planets' magnetospheres, consisting mostly of protons and electrons

Particles originating from the activity of the Sun, which include also heavy ions

Cosmic rays with very high energy





Mission SEE RHA Process (ref ECSS-Q-ST-60-15C)

Mission SEE Radiation environment

- GCR, Solar particle event, Trapped and solar protons fluxes versus LET spectrum

Each EEE parts shall be assessed for sensitivity to SEE

- IC, MMIC, MOSFETs N/P, CCD, Opto

SEE Tests

Sources HI, Proton

- MIL-STD-750 TM1080, ESCC25100, EIA/JESD 57

Table 5-5: Environment to be assessed based on LETth

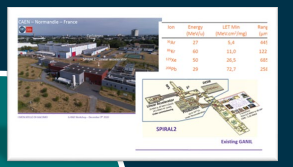
Device LETth (MeVcm²/mg)	Environment to be assessed
LETth < 15	Heavy ions (GCR, solar event ions) Protons (trapped, solar event protons)
LETth= 15-60	Heavy ions (GCR, solar event ions)
LETth>60	No analysis required

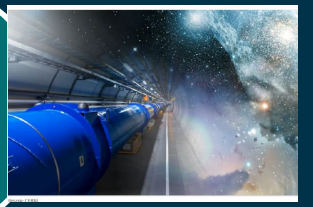
No SEE shall cause damage to a system or a subsystem or induce performance anomalies or outages not compliant with mission specifications

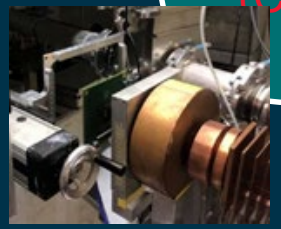
Alternative Sources: Cf-252, Focused Pulsed Laser, Neutron, Alpha sources

Alternative sources shall not be used for SEE qualification.
They can be used to check the test H/W and S/W and to investigate the device relative hardness or specific failure modes as a function of device operations

European Irradiation Facilities for SEE Test







https://irradiation-facilities.web.cern.ch/

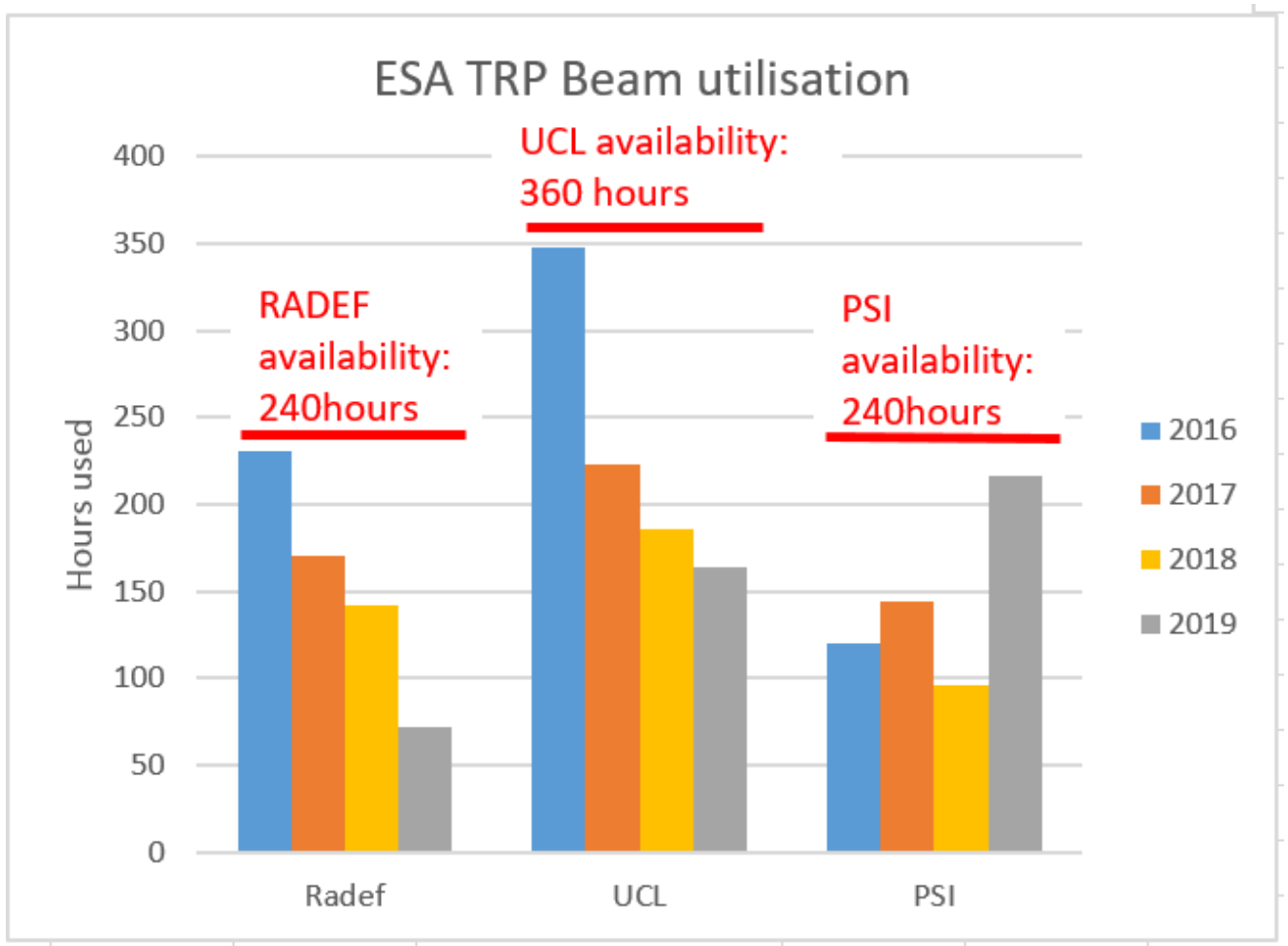
European Irradiation Facilities for SEE Test Beam Energies Availability

Standard Energy	<10 MeV/n
High Energy	10 - 100 MeV/n
Very High Energy	100 MeV/n – 5 GeV/n
Ultra High Energy	5-150 GeV/n

[Ref: The challenges of Testing at European Irradiation Facilities
A. Pesce, A. Costantino
ESCCON2021]

Facilities	Energy (MeV/nucleon)	Available cocktail	Availability per year
UCL HIF (Louvain-la- Neuve, Belgium)	8-10 MeV/n	9 species from C to Xe	About 16 weeks
RADEF (Jyväskylä,Finland)	22 MeV/n , 16.3 MeV/n, 9.3 MeV/n before	O, Fe, Kr 6 ion species, from O to Xe (7 ion species,from N to Xe)	About 12 weeks
KVI CART (Groningen, Netherlands)	30 MeV/n	4 species, from Ne to Xe	1-2 weeks
GANIL G4 (Caen, France)	27 to 60MeV/n	One species per experiment, Ar, Kr, Xe or Pb	1-2 weeks
GSI SIS18 (Darmstadt, Germany)	50 MeV/n to 1-1.5 GeV/n	One species per experiment, can be from proton to U	Less than 1 week Only scientific experiments
CERN CHARM or North Area (Geneva, Switzerland)	6-160 GeV/nucleon	One species per experiment	Less than 1 week

ESA beam time used at ESA supported facilities



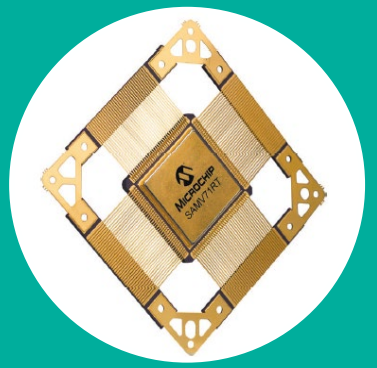
Aim at support facilities developments on **beam quality, dosimetry** and includes an annual fixed amount of hours for irradiations tests for

ESA R&D developments

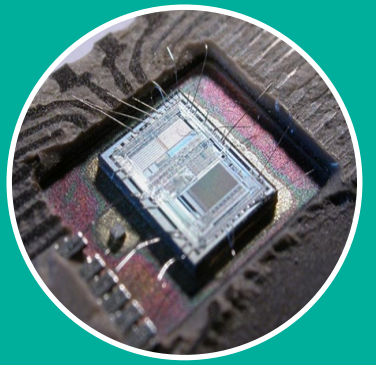
2021_02_24 CMOS image sensor development
2021_02_23 SDRAM memories
2021_02_23 SiC qualification and other mosfet screening
2021_02_18 TIR(detector)
2021_01_21 HERA
2020_10_07 ASIC
2021_01_18 GaN MIM Capacitors
2020_12_11 Small study - intradie SRAM testing
2021_11_24 HERA - cubesat payload only
2020_11_23 SEE laser COTS screening
2020_11_22 FYS
2020_11_02 MEMS pressure modues
2020_10_16 Latchup testing of digital isolator
2020_10_09 GPU

2020_09_28 Phototransistor
2020_09_08 RACOCO
2020_09_07 MPCG
2020_09_06 GPU processors
2020_09_04 RADEM
2020_09_03 3Dnand
2020_09_01 GaN Devices
2020_09_02 SET
2020_09_01 Stuck bits on SDRAM
2020_08_31 Optical Fibers
2020_08_30 Stuck bits on SDRAM
2020_08_10 Proba 3
2020_08_09 NG-LARGE
2020_08_08 NG-ULTRA

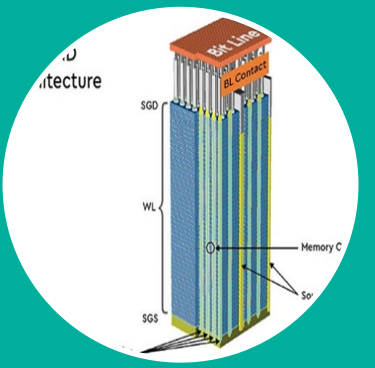
Evolution of the Technology Needs



RAD-HARD parts Developed and Qualified for Space



Rad tolerant Devices

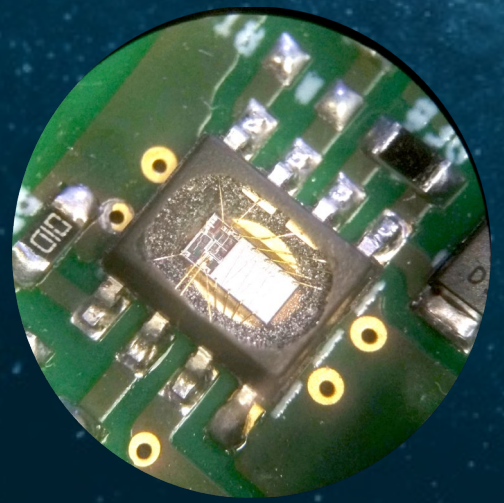


COTS

From RAD-HARD to COTS

Challenges: Limited range of heavy ions at Low Energy

Standard energy ions require sample preparation, delidding/decapping or Die thinning for flip chip to reach the active area with sufficient LET for testing and it may be not technically possible for certain technologies



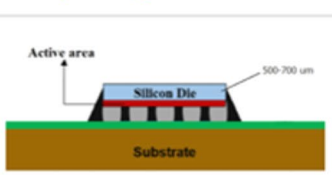
One common particularity of EEE COTS components is the dense packaging

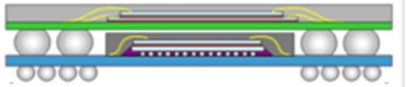
Examples:

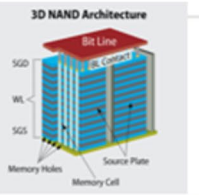
- Multi chip modules
- Flip chip construction
- Hybrids
- Plastic package with Cu bondwires

The exposure of either the dies of such packages is eiter impossible or difficult,
And there is the risk to modify the device response.

need of more enegetic particles to have more range (despite lower LET)



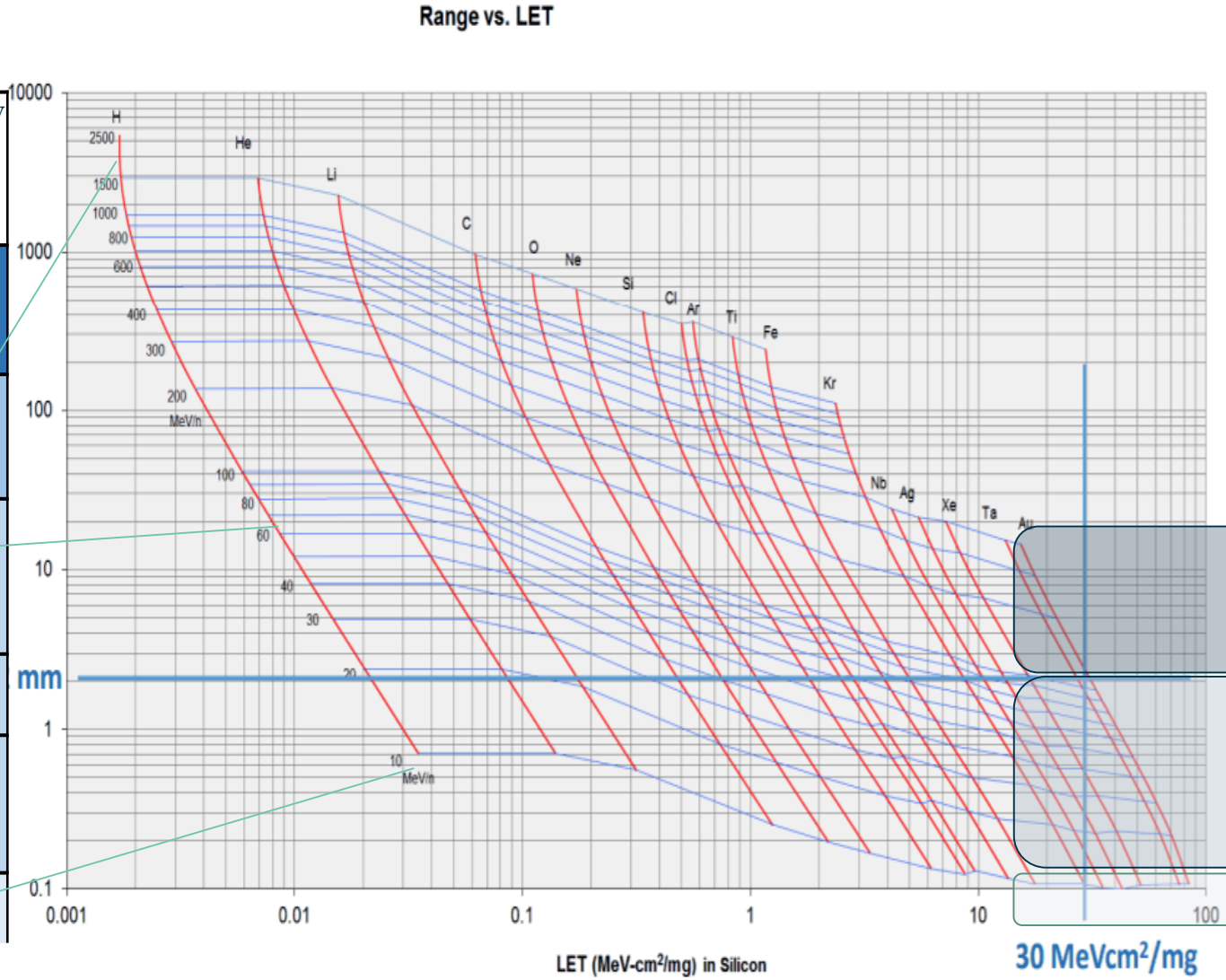




~700um **Flip chip:** Active area facing package Backside irradiation -> die thinning	~2mm **System in package:** Test separately	~500um **Dense structure:** Higher beam penetration range

Linear energy transfer and range

Facilities	Energy (MeV/nucleon)	Range of heavy species (Xe) in silicon
CERN CHARM	6-160 GeV/nucleon	meters
GSI SIS18	50 MeV/n to 1-1.5 GeV/n	2.4 mm to 7.8 cm
GANIL G4	27 to 60MeV/n	50 µm to 685 µm
KVI CART	30 MeV/n	333 µm
RADEF	22 MeV/n , 16.3 MeV/n, 9.3 MeV/n	255 µm 155 µm 92 µm
UCL HIF	8-10 MeV/n	73 µm



Very High energy

High energy

Standard energy

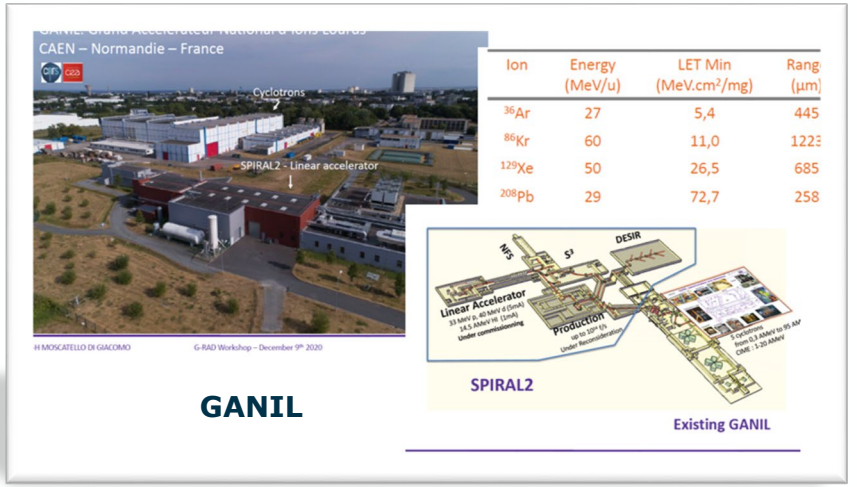
HI High Energy facilities- Challenges

Europe

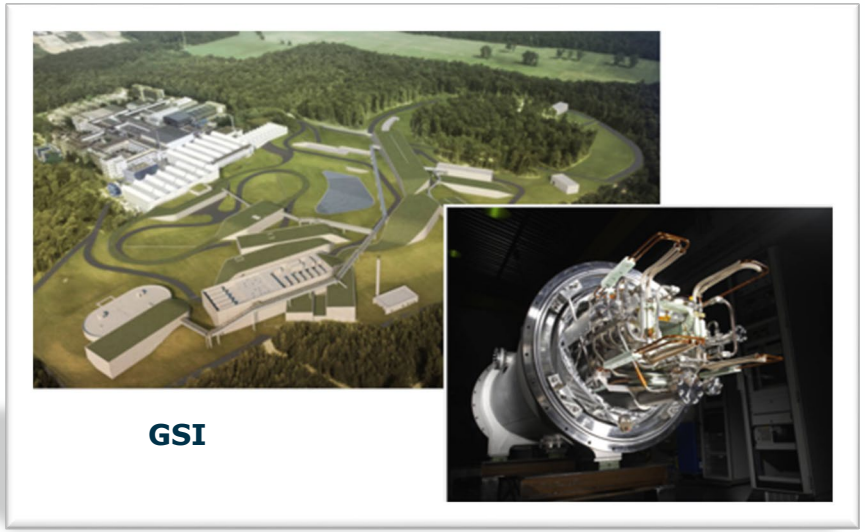
Facilities	Energy (MeV/nucleon)	Availability per year
GANIL G4 (Caen, France)	27 to 60 MeV/n	1-2 weeks
GSI SIS18 (Darmstadt, Germany)	50 MeV/n to 1-1.5 GeV/n	Less than 1 week Only scientific experiments

USA

Facilities	Energy (MeV/nucleon)	Availability per year
TAMU (College Station, TX, USA)	15 MeV/n 25 MeV/n 40 MeV/n	About 20-25 weeks
NSRL (Brookhaven, USA)	1500-217 MeV/n (light to heavy ions)	~20 weeks NASA funded or scientific proposals



After:
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS
Marie-Hélène MOSCATELLO DI GIACOMO for the, G-RAD Workshop 2020



Lack of radiation testing opportunities of High Energy Ion beams

Currently only facilities in USA offer extensive High Energy Ion beams

Requirements of beam quality for testing 1/3

Ref ESCC25100 SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES

https://escies.org/specfamily/view

Requirement	ESCC25100	=> Facility implementation	
LET	the device is commonly considered immune to SEE if tested in normal incidence at a minimum LET of 60MeV.cm2/mg There is an increasing need to perform SEE test at lower and lower LET thresholds. LET disposure between 0.2 MeV/mg/cm² and 1.5 MeV/mg/cm². If possible implement a disposure of 4 LETs within this range Combination of ions, light to heavy species, covering LET at least equal to 38 MeVcm2/mg (Si) up to 60 MeVcm2/mg (Si) at the device sensitive volume, and with range at least of 1 mm (Si).	**LET up to 60MeV.cm2/mg** to consider a device immune to SEE (ECSS-Q-ST-60-15) **LET up to 75MeV.cm2/mg** to consider a device immune to SEE ref NASA/TM-20210018053 **LET 10-60MeV.cm2/mg** necessary to estimate cross section **LET < 2 MeV.cm2/mg** Advances technology nodes show an increase in SEE sensitivity at very low LETs	
Range	a minimum range of 40µm in the target material is recommended. In linear devices and all devices with a relatively thick sensitive volume (>10µm like in bipolar, JFET, etc.), a minimum range of 60µm is recommended. If technology analysis is available the beam energy and range should be such that the Bragg peak is placed beyond the sensitive volume.	Range >60um up to few mm	
Temperature	The **temperature** of the device under test shall be monitored and recorded unless otherwise agreed with the Customer.	Monitored as minimum, control of temperature (eg for SEL)	

Requirements of beam quality for testing 2/3

Ref ESCC25100 SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES

https://escies.org/specfamily/view

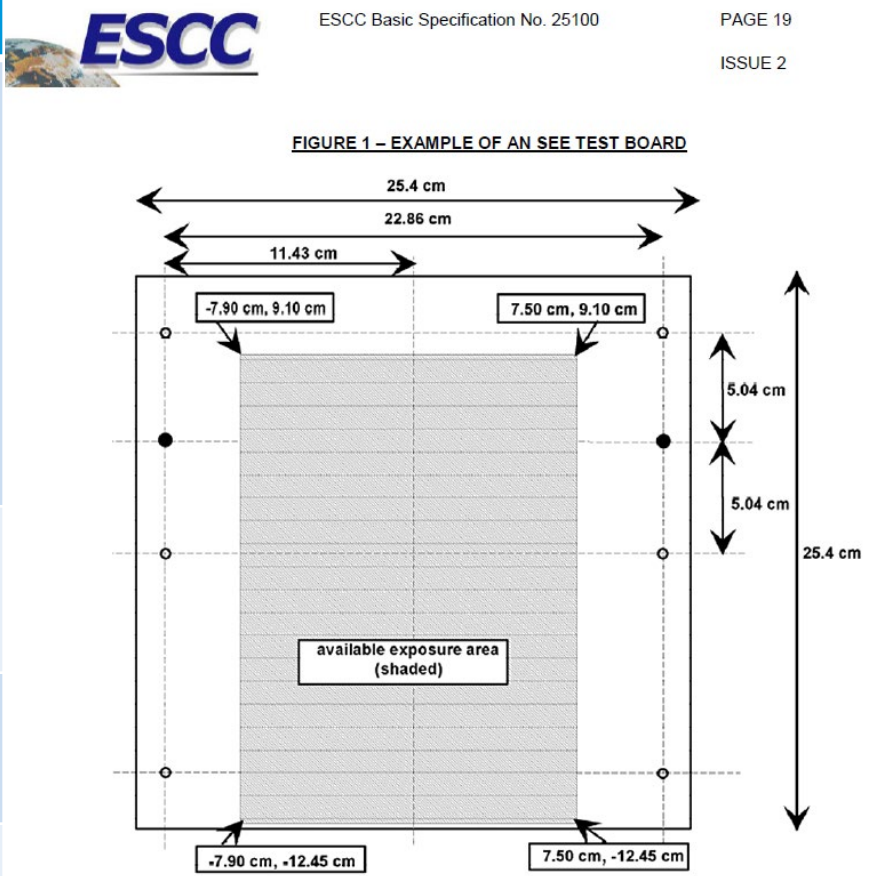
Requirement	ESCC25100	=> Facility implementation
Tilting to explore other LETs values	For LETs not directly available, the device may be tilted to give an increased "effective LET"	Frame that can tilted (remotely)
Flux and energy uniformity	The radiation field shall be uniform to ±10% over the area of the device(s) under test in terms of both fluence and energy	±10% over the area of the device(s) for both energy and flux
Flux min-max	few 10 ions/cm2/s to at least 10E5 ions/cm2/s	Typical fluxes 1E4 – 1E6 ions/cm2/s

Requirements of beam quality for testing 3/3

Ref ESCC25100 SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES

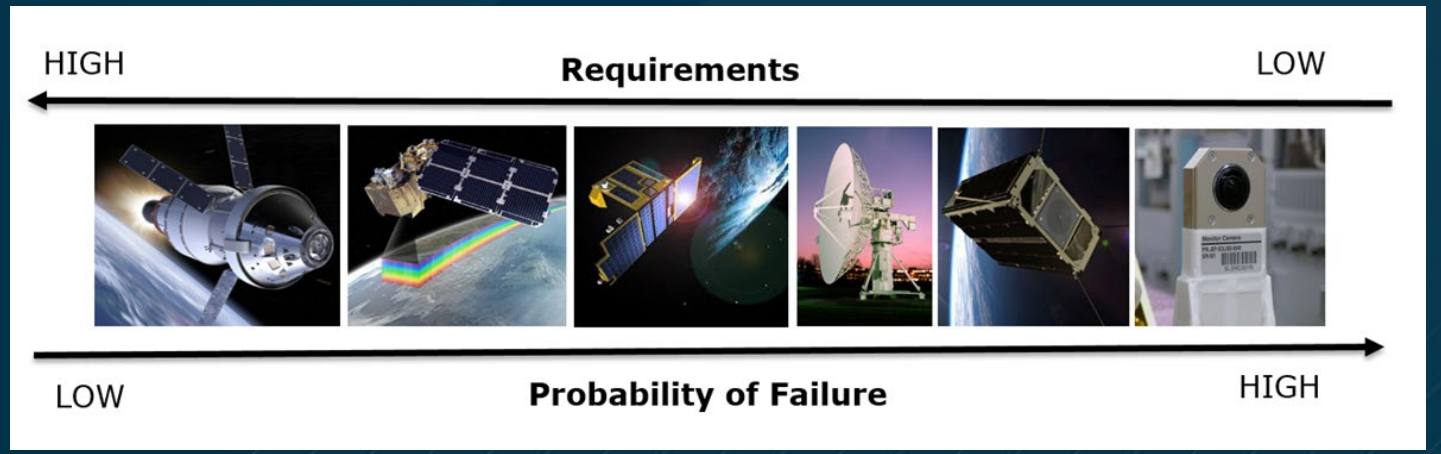
https://escies.org/specfamily/view

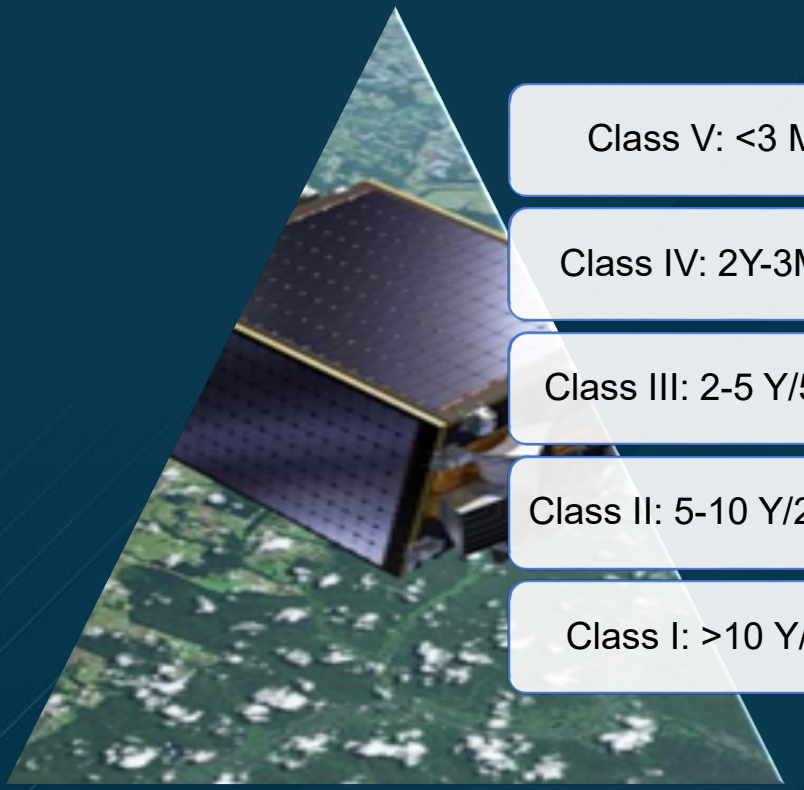
Other general considerations	
Positioning DUTs	Standard frame with design available to customer for preparation (eg see UCL frame on ESCIES.org radiation page) SEE Standard board SEE ref ESCC25100 Remote accurate control of the frame : multiple DUTS mounted on frame to be moved in the beam and testing without accessing/breaking vacuum Laser pointer for accurate positioning Visual feedback (camera) for correct positioning Vacuum Chamber Requirements (ref MIL-STD-750 TM1080)
Timing	Timing 1-2 hours for calibrations to set the cyclotron 15 min to change ions 15 min to access DUTS (vacuum)
Cabling	Feedthroughs flanges and cable distances to be considered. Possibility to have test and monitoring equipment installed close to the beam line and accessible
Space in control room/preparation of experiment	Additional area to prepare the SEE test set up and perform dry run



Evolution of the ESA Mission Requirements

New approach for optimising resources in accordance with mission profiles and objectives
New working methods aiming at reducing development time and cost while balancing risk





Class V: <3 M, <1ME

Class IV: 2Y-3M 50-1ME

Class III: 2-5 Y/50-200 ME

Class II: 5-10 Y/200-700 ME

Class I: >10 Y/>700 ME

Evolution of the RHA Strategy

- **5** Classes, **4 different sets of requirements tailored from ECSS-Q-ST-60-15**
- Class V: Suggested to have a separate standard- Perhaps only PARD

Class V

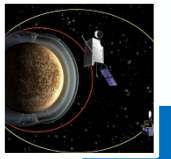
- < 3 M
- No TID test
- **NO SEE test except for MOSFET VDS > 200V**
- Proton Test recommended (component or board level)
- No heavy ion test data are required except for MOSFET > 200V
- Proton Test is recommended (component or board level)

Class IV

- 3M-2y
- No TID test if TIDL<5Krad
- **SEE** HI test **recommended**
- **Proton** test **required**
- 15 MeVcm2/mg < LETth < 38 MeVcm2/mg Heavy ion SEE analysis required
- LET < 15 MeVcm2/mg Heavy ion and proton SEE analysis required

Class III

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

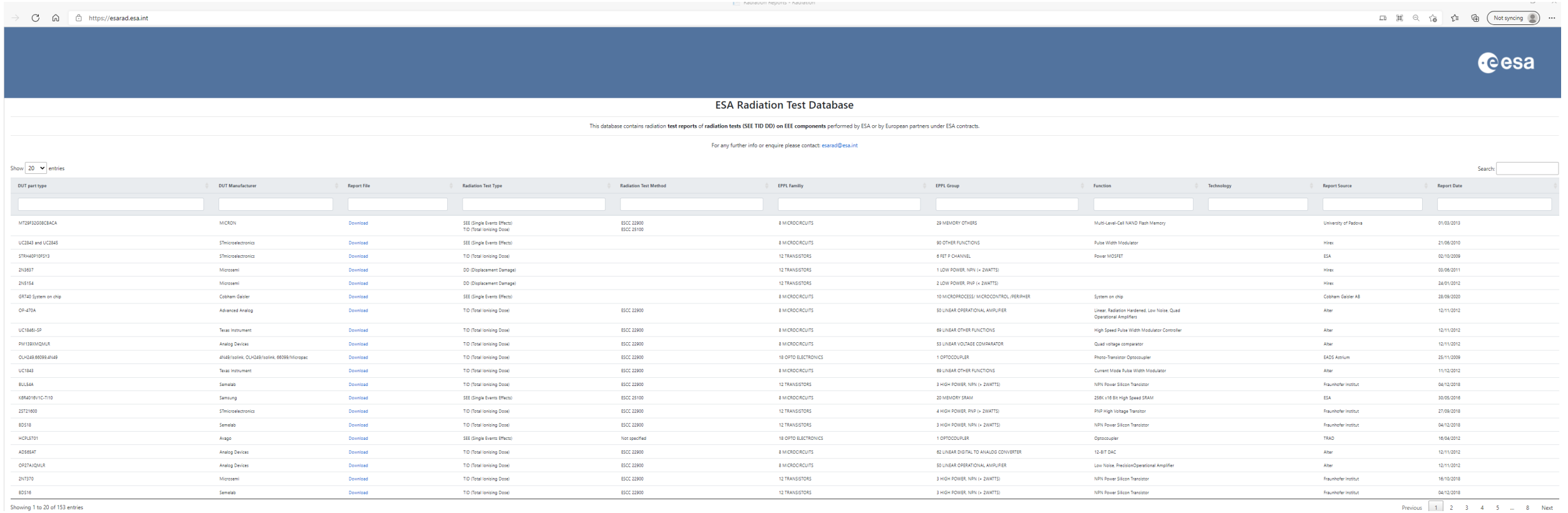


Class I & II

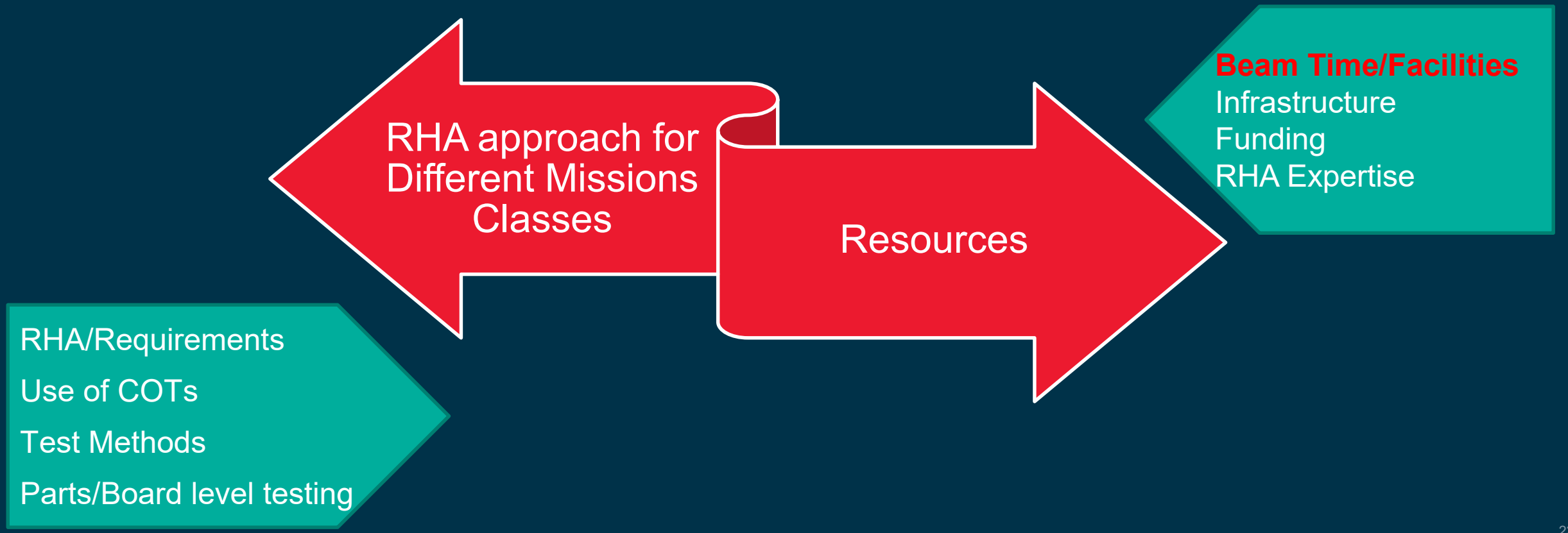
- > 5 y
- ECSS-Q-ST-60-15 + ESSB-Q-008
- TID
- SEE

ESA Website for Radiation Test data- **NEW**

https://esarad.esa.int/

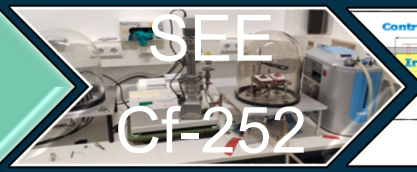


RHA in Space: What's Needed/ What's Next?



ESA Strategy on Radiation Testing Capabilities

ESA In house Capabilities



Electrical Characterization and Environmental Lab
Sample preparation
RHA Engineering Support

European Supported Facilities

UCL

RADEF

PSI

GANIL
GSI
KVI
HPTC
CERN

Support exploitation of Ultra High Energy Beam

NICA?

Radiation Hardness Assurance for All Mission Classes and for all component types

Understand Radiation Effects

Investigate Alternate SEE testing techniques

Exploit new RHA methodologies

ESA Radiation Test Database

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Info on external facilities

https://escies.org/webdocument/showArticle?id=921&groupid=6

e-mail: ERFbooking@esa.int

Info on ESTEC Co60, Cf 252, SEE Laser Testing

e-mail: Co60.Facility.ESTEC@esa.int

THANK YOU

www.esa.int

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