Future Exploration Radiation Facility Definition Team (FDT)

Outcomes and Recommendations

02/09/2026

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EUROPEAN SPACE AGENCY

Presentation Outline

- 1. FDT Overview
- 2. Goals, Objectives and Assumptions
- 3. Measurement Requirements
- 4. Heritage/Concepts meeting Requirements
- 5. Development Recommendations
- 6. Conclusion Timeline



FDT Overview

FDT Aims

1. Define requirements for radiation instruments for exploration missions
   - Focus on Exploration destinations
2. Identify measurement techniques to meet those requirements
3. Make recommendations for ESA developments of future instrumentation

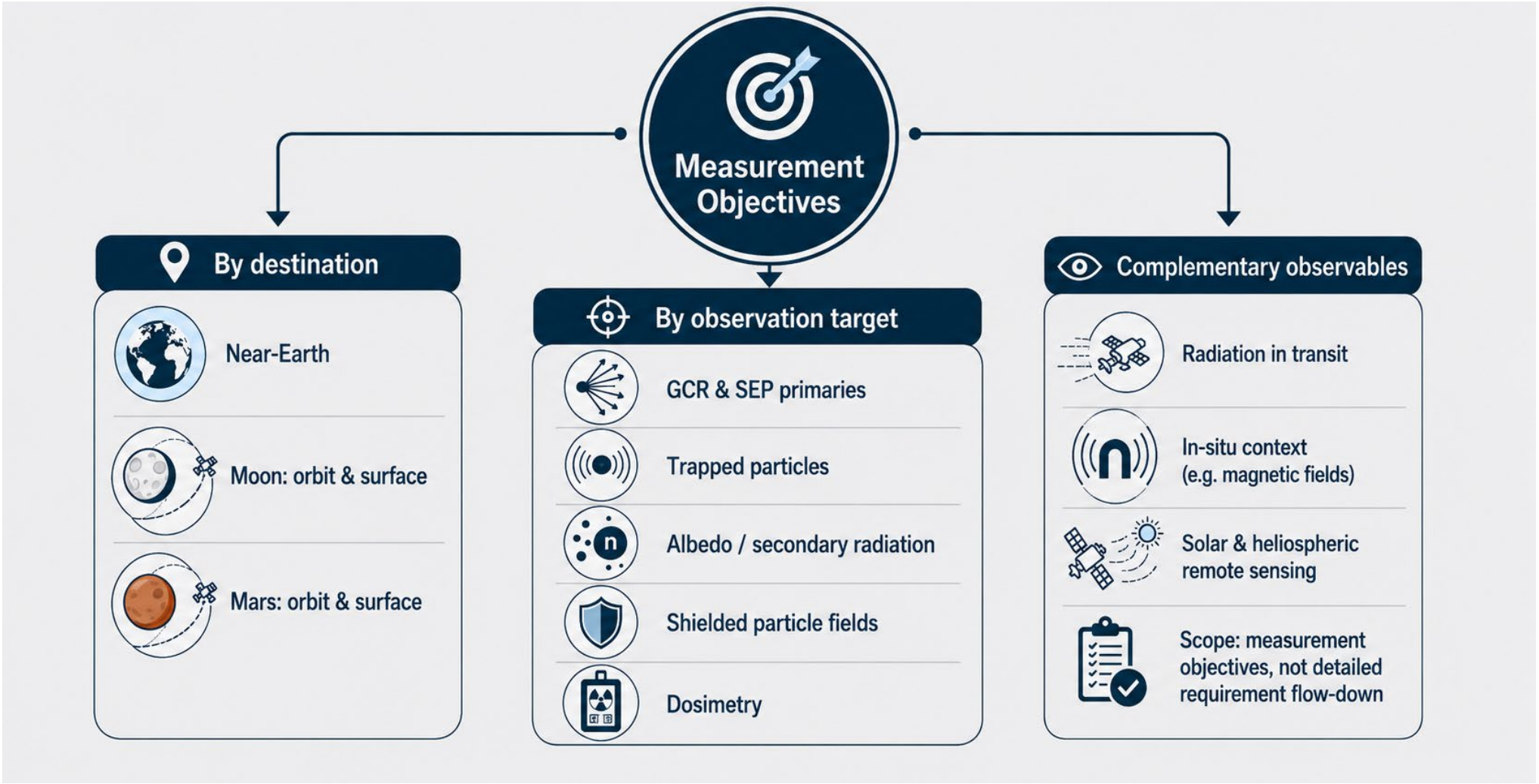
FDT Duration

- 12 months:

1st December 2025 – 30th November 2026

Name	Role	Company/Institution	Country	
			Inst.	Nat.
Piers Jiggens	Chair	ESA (HRE-S)	-	UK
Giovanni Santin	Member	ESA (TEC-EPS)	-	IT
Martin Losekamm	Member	ESA (HRE-LS)	-	DE
Laura Rodriguez Garcia	Member	ESA (SCI-EC)	-	ES
Robert F. Wimmer-Schweingruber	Member	Christian Albrecht University of Kiel	DE	CH/CA
Bernd Heber	Member	Christian Albrecht University of Kiel	DE	DE
Thomas Berger	Member	German Aerospace Center (DLR)	DE	AT
Ramsey Al Jebali	Member	IDEAS(, CENSSS)	NO	SE
Luis Teodoro	Member	CENSSS	NO	PT
Osku Raukunen	Member	Aboa Space Research Oy (ASRO)	FI	FI
Marco Pinto	Member	Laboratory of Instrumentation and Experimental Particle Physics (LIP)	PT	PT
Carlotta Achille	Member	Fondazione E. Amaldi	IT	IT

Objective Identification

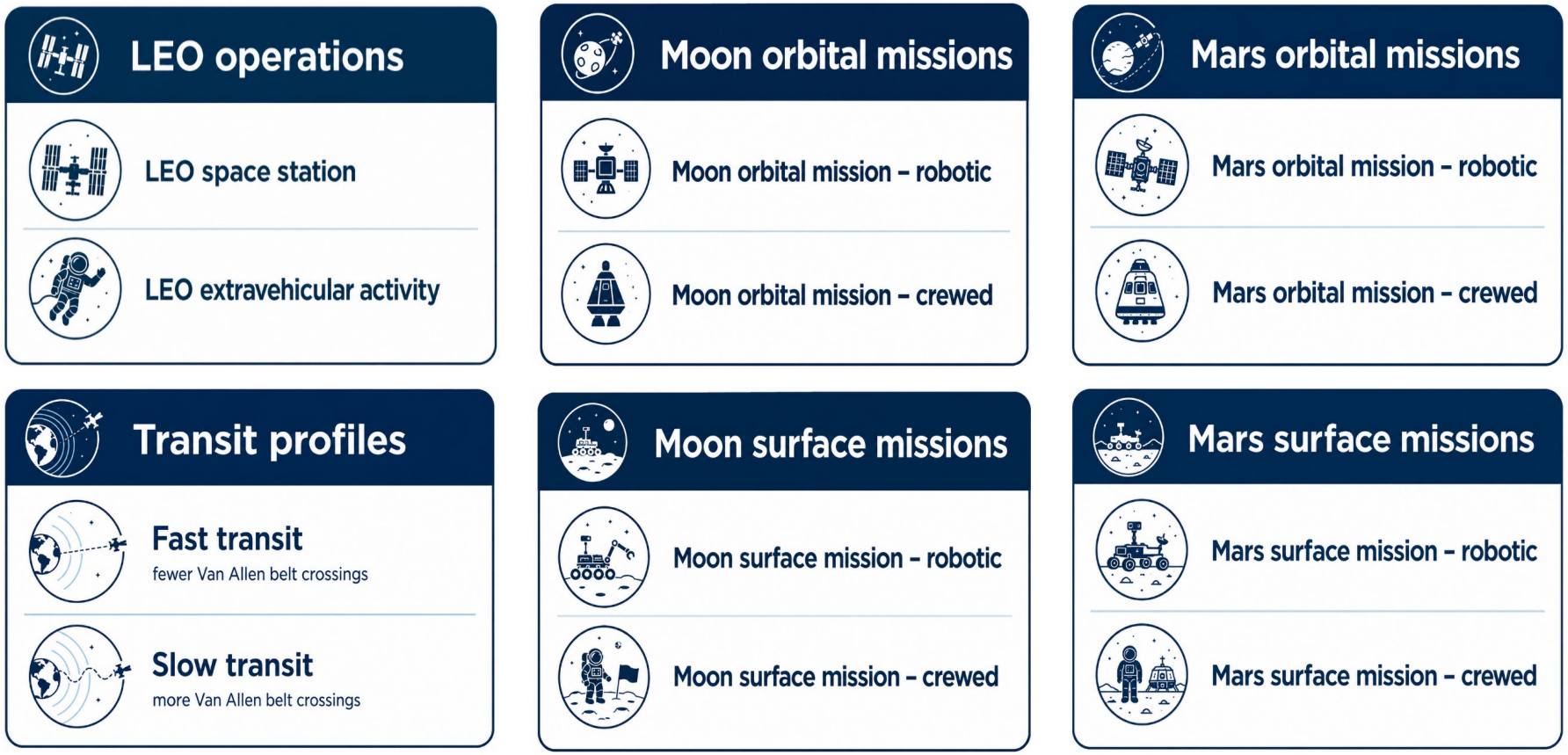


Goals, Objectives and Assumptions

Goal ID	Goal Description	Objective ID	Measurement Objective (Observable)
ESRad-L0-01	Characterise the primary particle radiation environment and its composition at exploration destinations	**ESRad-L1-01**	Galactic cosmic ray flux spectra
		ESRad-L1-02	Solar energetic particle flux spectra
		ESRad-L1-03	Geomagnetic shielding in low-Earth orbit (LEO)
ESRad-L0-02	Forecast the primary particle radiation environment and its composition at exploration destinations	**ESRad-L1-04**	Trapped charged-particle environment in LEO
		ESRad-L1-05	Solar energetic particle precursors
		ESRad-L1-06	Natural secondary charged-particle surface environment
ESRad-L0-03	Characterise the induced radiation environment resulting from interactions of particles with planetary systems (Earth, Moon, and Mars)	**ESRad-L1-07**	Natural secondary charged-particle orbit environment
		ESRad-L1-08	Natural secondary neutral-particle surface environment
		ESRad-L1-09	Natural secondary neutral-particle orbit environment
ESRad-L0-04	Characterise the internal radiation environment resulting from interactions of particles with spacecraft, structures, and habitats	**ESRad-L1-10**	Internal charged-particle environment
		ESRad-L1-11	Internal neutral-particle environment
		ESRad-L1-12	Absorbed crew dose
ESRad-L0-05	Assess the radiobiological risk for humans across exploration destinations	**ESRad-L1-13**	Absorbed reference dose (area dosimetry)
		ESRad-L1-14	Radiobiological crew dose
		ESRad-L1-15	Radiobiological reference dose

Goals, Objectives and Assumptions

- Opportunities to make radiation measurements are limited to the following exploration mission scenarios:



- Critical observations at non-exploration destinations will be covered elsewhere (e.g. space weather)
- Spacecraft design (e.g. attitude control will not be optimised to prioritise radiation measurements
- Resources should be sufficient for science-class measurements
  - Although lower-resource options are worth retaining
  - Sufficient development time for new concepts
  - Mature options for ad-hoc opportunities

Measurement Requirements

Categories (no. high level – no. low level)

- Galactic cosmic rays (3 – 9)
- Solar energetic particles (4 – 12)
- Radiation belts (2 – 7)
- Dosimetry (2 – 8)
- Internal environment (5 – 8)
- Natural secondaries (3 – 6)
- Lunar secondaries (no additional requirements)
- Martian secondaries (4 – 6)
- Near-Earth secondaries (3 – 3)

➢ **Total (26 – 59)**

- Complementary Quantities (11)

Prioritisation

Exploration-focussed (+ to +++)

Radiation protection (RP)

Radiation storm forecasting (RS)

Resource prospecting (RE)

Spacecraft effects (SE)

Exploration Enabled (+ to ++)

Heliophysics (HP)

Background reference (BR)

Simulation benchmarking (SB)

Other (OT)

Prioritisation

	RP	RS	RE	SE
Cat 1	++			++

	HE	BR	SB	OT
Cat 2			++	

Overall Priority: Medium

Prioritisation

	RP	RS	RE	SE
Cat 1	+++			++

	HE	BR	SB	OT
Cat 2		++		

Overall Priority: High

Measurement Requirement Examples

► Galactic Cosmic Rays

Requirement ID	Requirement Name	Parent Objective
ESRad-L2-GCR-200	GCR helium	ESRad-L1-01

► Sub-ID: **ESRad-L2-GCR-201**
Physical Quantity: Differential flux from 10 MeV/n to 160 MeV/n
Temporal Resolution: 10 minutes
Species: Helium ions
Latency: 1 day
Location: Orbit (Moon, Mars), surface (Moon)
Physical Resolution: -

Prioritisation

	RP	RS	RE	SE
Cat 1	+			+

	HE	BR	SB	OT
Cat 2				

Overall Priority: Low

Rationale
GCR helium ions with energies between 10 MeV/n and 160 MeV/n can penetrate light shielding (i.e., spacesuits) but cannot penetrate the walls of a spacecraft optimized for GCR exposure (shielding of around 25 g cm^{-2} aluminum equivalent). They are therefore only relevant to EVA scenarios and (components of) spacecraft behind light or no shielding. Measurements have a low priority because the particle flux is low and integrated doses are therefore dominated by SEP.

► Sub-ID: **ESRad-L2-GCR-202**
Physical Quantity: Differential flux from 160 MeV/n to 500 MeV/n
Temporal Resolution: 10 minutes
Species: Helium ions
Latency: 1 day
Location: Orbit (Moon, Mars), surface (Moon)
Physical Resolution: -

Prioritisation

	RP	RS	RE	SE
Cat 1	+++			++

	HE	BR	SB	OT
Cat 2		++		

Overall Priority: High

Rationale
GCR helium ions with energies between 160 MeV/n and 500 MeV/n penetrate the shielding of spacecraft optimized for GCR exposure. They contribute substantially to the total dose received by crew members (directly or via the production of secondaries), as well as by internal and external spacecraft components. Helium ions at these energies are also a major source of albedo particles; time-resolved knowledge of their flux is therefore a crucial reference for measurements of albedo populations (assessment of variability, background subtraction).

► Internal Environment

Requirement ID	Requirement Name	Parent Objective
ESRad-L2-INT-400	Internal electrons	ESRad-L1-10

► Sub-ID: **ESRad-L2-INT-401**
Physical Quantity: Differential flux from 20 keV to 100 keV
Temporal Resolution: 5 minutes
Species: Electrons
Latency: 1 hour (local) 1 day (Earth)
Location: Inside spacecraft or habitat
Physical Resolution: -

Prioritisation

	RP	RS	RE	SE
Cat 1	+			

	HE	BR	SB	OT
Cat 2				

Overall Priority: Low

Rationale
Inside a spacecraft or habitat, where astronauts are expected to wear regular clothes that provide little shielding, electrons with energies between 10 keV and 100 keV contribute to the skin dose. The requirement has low priority because the contribution to the total dose is small.

► Sub-ID: **ESRad-L2-INT-402**
Physical Quantity: Differential flux from 100 keV to 10 MeV; Integral flux above 10 MeV
Temporal Resolution: 5 minutes
Species: Electrons
Latency: 1 hour (local) 1 day (Earth)
Location: Inside spacecraft or habitat
Physical Resolution: -

Prioritisation

	RP	RS	RE	SE
Cat 1	++			+

	HE	BR	SB	OT
Cat 2			++	

Overall Priority: Medium

Rationale
Inside a spacecraft or habitat, secondary electrons with energies between 100 keV and 10 MeV can contribute to the absorbed dose. Their flux spectrum depends on the shielding thickness and the external environment. Precise knowledge of the spectrum also enables benchmarking of radiation-transport simulations (given knowledge of the external environment). The requirement has medium priority because the contribution to the total dose is not dominant.

Measurement Requirement Examples

► Martian Secondaries

Requirement ID	Requirement Name	Parent Objective
ESRad-L2-MAS-200	Surviving and atmospheric protons	ESRad-L1-06

► **ESRad-L2-MAS-201**

Sub-ID	Physical Quantity	Prioritisation			
ESRad-L2-MAS-201	Differential flux from 10 MeV to 500 MeV		RP	RS	RE	SE
Temporal Resolution	Species	Cat 1	+++			
5 minutes	Protons		HE	BR	SB	OT
Latency	Location	Cat 2			++	
1 hour (local) 1 day (Earth)	Surface	Overall Priority: High				
Physical Resolution						
-						
Rationale						
-						

► **ESRad-L2-MAS-202**

Sub-ID	Physical Quantity	Prioritisation			
ESRad-L2-MAS-202	Differential flux from 500 MeV to 2 GeV; Integral flux above 2 GeV		RP	RS	RE	SE
Temporal Resolution	Species	Cat 1	+			
5 minutes	Protons		HE	BR	SB	OT
Latency	Location	Cat 2			+	
1 hour (local) 1 day (Earth)	Surface	Overall Priority: Low				
Physical Resolution						
-						
Rationale						
-						

Complementary Quantities Examples

► **ESRad-L2-CO-001** — Interplanetary Magnetic Field — Parent Objective: ESRad-L1-02

Rationale

The interplanetary magnetic field (ESRad-L2-CO-001) is closely linked to ESRad-L1-02 (SEP flux spectra). Reconstructing the pitch angle distribution of SEP requires knowledge of three perpendicular magnetic field vectors, and the actual magnetic field configuration directly affects how SEP propagate through interplanetary space. A representative example is the MAG on ACE, which provides continuous vector measurements of the interplanetary magnetic field from twin boom-mounted triaxial fluxgate sensors [118].

► **ESRad-L2-CO-010** — Mars Atmosphere Composition — Parent Objective: ESRad-L1-06, -07, -08, -09

Rationale

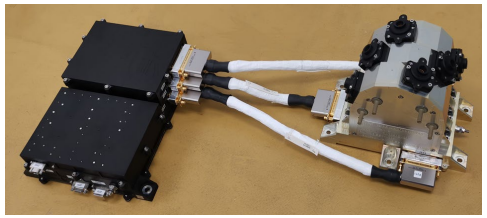
Mars atmosphere composition (ESRad-L2-CO-010) is relevant to four L1 requirements: ESRad-L1-06 (Natural secondary charged-particle environment at the surface), ESRad-L1-07 (Natural secondary charged-particle environment in orbit), ESRad-L1-08 (Natural secondary neutral-particle environment at the surface), and ESRad-L1-09 (Natural secondary neutral-particle environment in orbit). Knowledge of the atmospheric composition is needed to understand the secondary particle interactions that give rise to these environments. The NGIMS on MAVEN, which measures the composition, structure, and variability of the Martian upper atmosphere, is a representative example [132,133].

Heritage/Concepts meeting Requirements

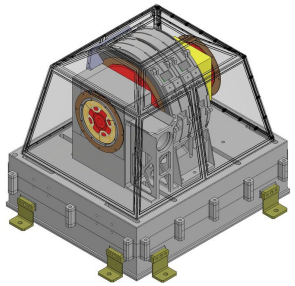
- Instrument Summary presentations were invited from participating investigators from E3P (European Exploration Envelope Programme) member states
- Focus was on coverage of measurement domains:
  - In-orbit primary particle spectrometry
  - Surface particle measurements
  - Internal (habitat) environment measurements
  - Dosimetry
  - Neutron and Gamma ray measurement/spectrometry
- This was the equivalent of survey of capabilities and concepts and heritage instrumentation
  - Wide range of TRL, SWaP, cost, etc.

Charged Particle Spectrometers

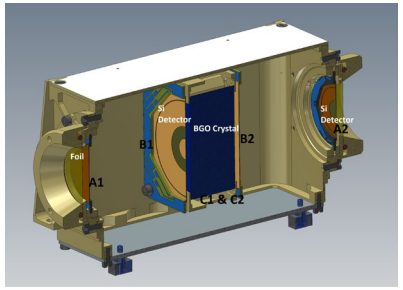
3D Energetic Electron Spectrometer **(3D-EES)**



Athena High-Energy Particle Monitor **(AHEPaM)**



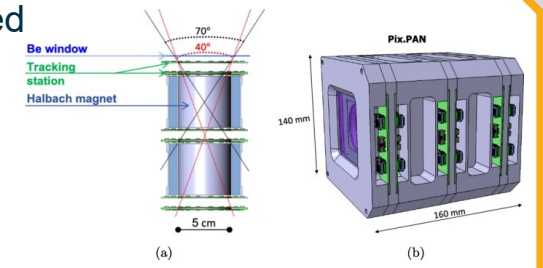
Energetic Particle Detector (EPD) / High-Energy Telescope **(HET)**



Kiel Electron Telescope **(KET)**

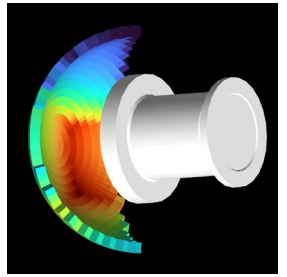


Timepix adapted Penetrating particle ANalyzer **(Pix.PAN)**



Particle Radiation Instrument and Spectrometer for Europe **(PRISE)**

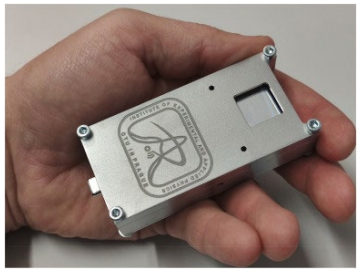
Electron Proton and Helium INstrument **(EPHIN)**



Charged Particle Monitors[1]

[1] Generally lower resource but many with some spectroscopy/directionality capability

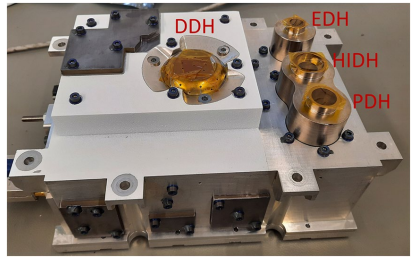
Timepix-based radiation monitor **(HardPix)**



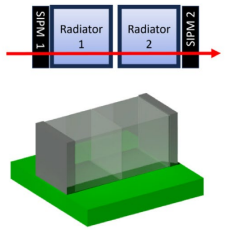
Norwegian Radiation Monitor **(NORM)**

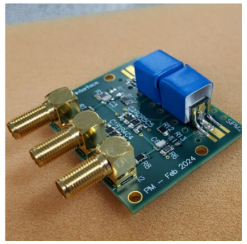


RADiation-hard Electron Monitor **(RADEM)**



High-Energy Proton Instrument **(HEPI)**

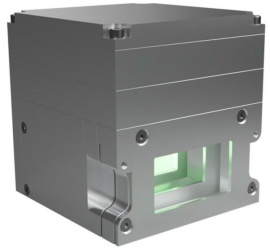




Next-Generation Radiation Monitor **(NGRM)**



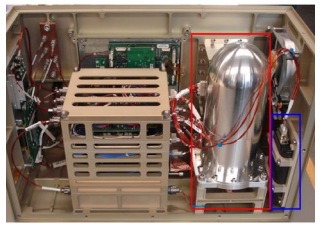
Relativistic Electron and Proton Experiment **(REPE)**



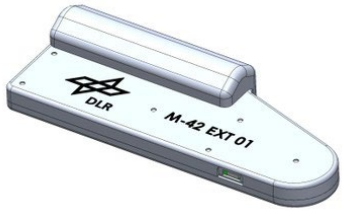
Surface and Internal Detectors & Dosimeters

ESA Active Dosimeter **(EAD)**





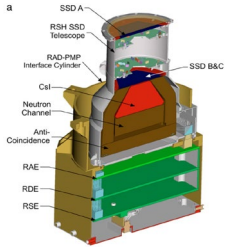
DLR active dosimeters **(M-42)**



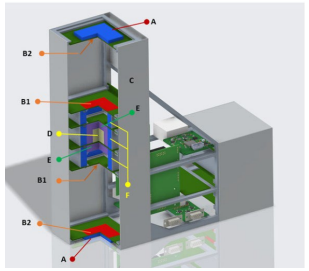
Radiation Assessment Detector **(RAD)** [2]

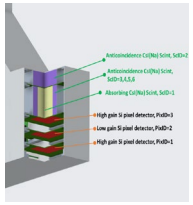
[2] Can also be orbital





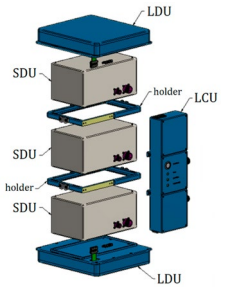
Comprehensive Lunar Radiation monitoring and Dosimetry **(LuRaD)**[2]





[2] Can also be orbital

Light Ions Detector for ALTEA **(LIDAL)**



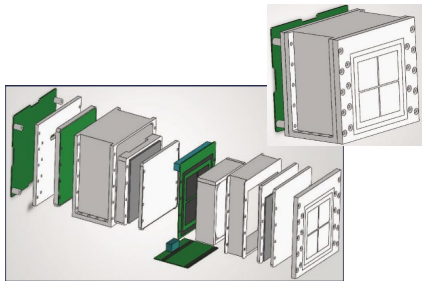
Radiation Mapping Telescope **(RadMap)** [3]



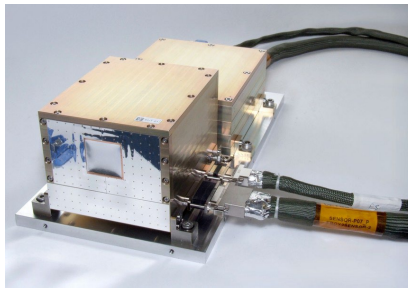
[3] Intended as an internal spectrometer for within habitats to derive radiobiological dose

Neutron & gamma-ray spectrometers

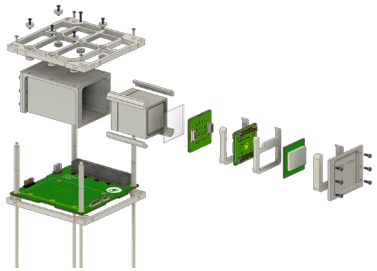
Advanced Spaceborne Telescope for Radiation Analysis in Low Earth Orbit **(ASTRA-LEO)**



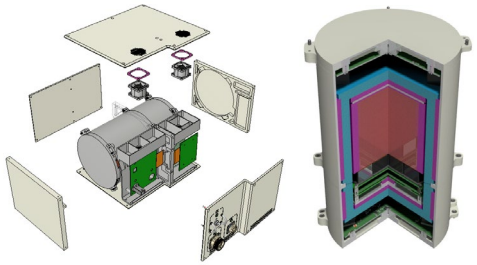
Lunar lander Neutron and Dosimetry instrument **(LND)**



EIRSAT-1's Gamma-ray Module **(GMOD)**



Canadian Active Neutron Spectrometer **(CANS)**



LUVMI-X Neutron Spectrometer **(LUVMI-X/NS)**



Recommendations (Preliminary)

1/ Orbital Environment Spectrometer

(For GCR and SEP measurement and SEP forecasting)

- p+, ions {2 ≤ Z ≤ 26} (selected), e- (separated)
  - 10 MeV/nuc - 2 GeV/nuc (ions); 0.5 – 5 MeV (e-)
- Energy Resolution: < 20% (ions) & < 50% (e-)
- 4-6 viewing directions (one nadir)
- Geom. factor: 10 - 40 cm^2.sr (primary dir.); e- lower

2/ (Mars) Surface Instrument

(For surface fluxes and dose, sim. benchmarking)

- down. p+, ions {2 ≤ Z ≤ 26} (selected, separated), albedo p+
  - 10 – 500 MeV/nuc (less for albedo p+)
- Fast neutron spectra (downward + albedo separate)
  - 10 keV – 100 MeV [multi-method] (3+(*goal*: 5+) bins)
- *Option for tailoring to lunar surface*

3/ Internal Spectrometer

(For accurate internal dose comp., sim. benchmarking)

- p+ & ions {2 ≤ Z ≤ 26} (separated, lower Z of higher priority)
  - 10 MeV/nuc – > ~1 GeV/nuc (note: internal flux spectrum)
- Full 4π coverage with angular resolution 5° x 5° (2° x 2° *goal*)
- Energy res. ~10%; Geom. factor >100 cm^2.sr
- Optional: fast neutron sensitivity & e- and pions
  - 10 keV – 100 MeV (n); 100 keV – 10 MeV (e-); 50 MeV – 1 GeV (pions)

4/ Neutron/Gamma ray Instrument

(For Prospecting and radiobiological dose, Orbit (+ surface)

- Neutrons (may be modular, combining with part of 2/ & 3/)
  - Thermal (count rate), epi-thermal (cnt rate (*goal:* 3 bins)), fast (count rate, differential flux 10 keV – 100 MeV)
- Gamma rays
  - Differential flux (100 keV – 10 MeV); Energy res. ~2-3%
- Surface: Mobility for high-res. scan - Stationary ground truth

What's Missing and Why?

- The development of fast neutrons for dose computations can be an iteration from existing concepts
- Human dosimetry based on absorbed dose and LET are covered by existing concepts
  - Note that Micro-dosimetry may also be of interest down the line
- Complementary Requirements (e.g. solar observations, Mars atmosphere, in-situ magnetometers) will be handled elsewhere (e.g. ESA's Space Safety Office or other groups in HRE)
- Heliophysics (and Exploration enabled science more broadly) will be handled via AO process not developments with ESA-defined requirements

FDT Conclusion Timeline

- FDT is putting together the final report which should be final by end November 2026
- Presentations during this time which yield important critiques may still be incorporated in updates
- FDT report will be released for public comment
  - Check if this is ESA/E3P member states or global (+ Martians)

Agenzia Spaziale Italiana

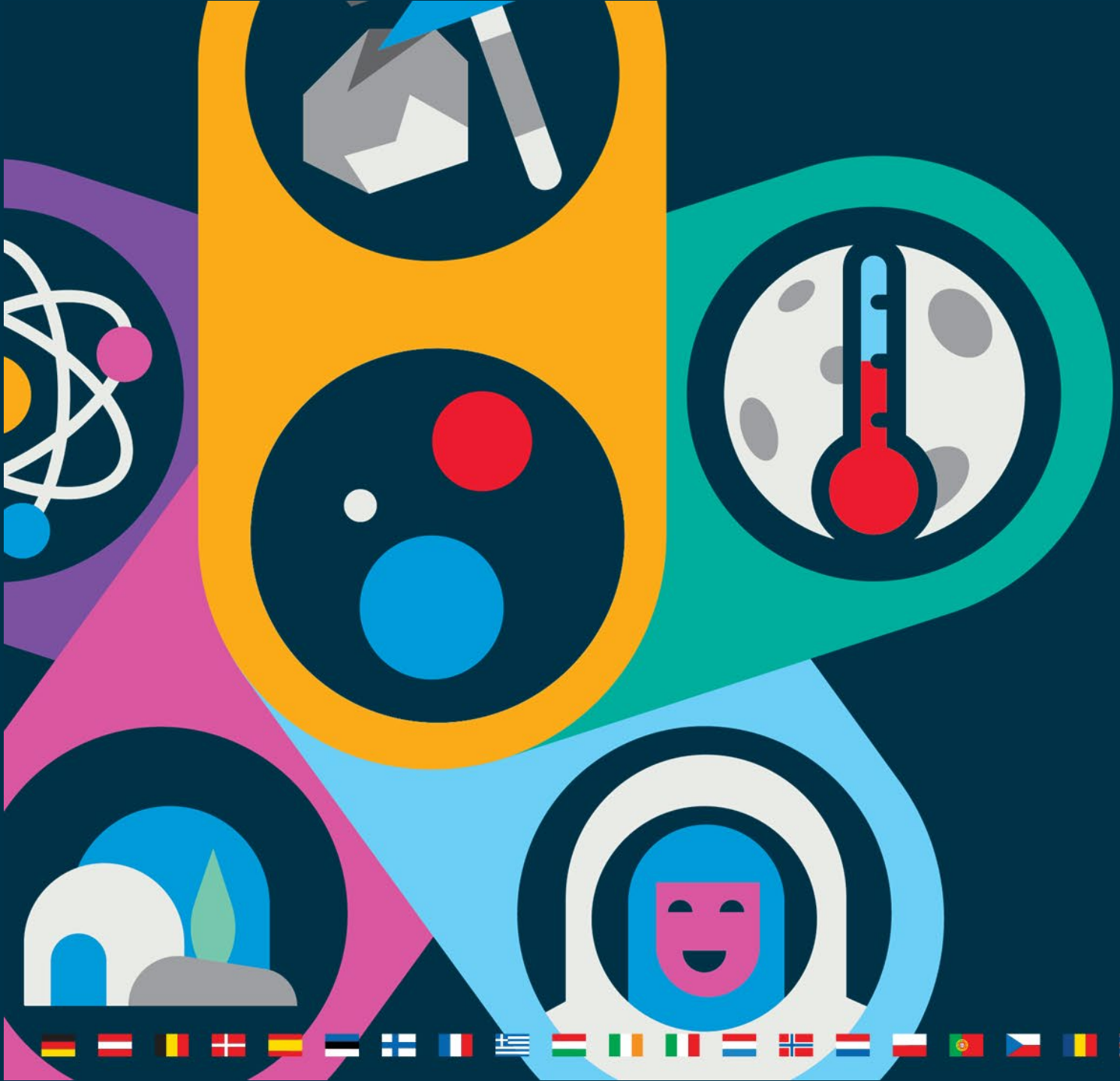
EUROPEAN SPACE AGENCY

Exploration Science Workshop

24-26 November 2026

ASI Agenzia Spaziale Italiana
Rome, Italy

Workshop Webpage



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