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MoonRad Mission and Science Overview

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28th WRMISS, DLR, Cologne, Germany – 2-4 September 2025

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- Technical Approach
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- Preliminary Data Products
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- Outlook

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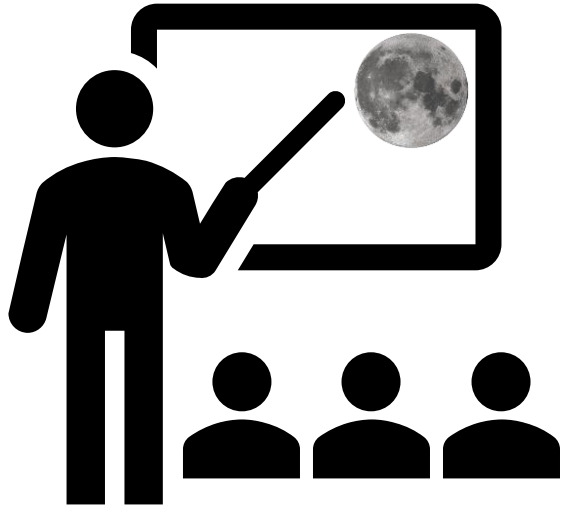
Introduction



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Background

- **REMRED** Space Technologies Ltd. (REM) in collaboration with **HUN-REN** Centre for Energy Research (**EK**) has performed a limited Phase 0 (pre-Phase A) study for a possible **Lunar SmallSat mission concept (MoonRAD) addressing space radiation and space weather research and services** in the Lunar environment
- Making use of
  - ✓ national space weather and space radiation monitoring heritage and know-how
  - ✓ recent national SmallSat capabilities evolution (*REMTECH SmallSat MAIT Centre, HUSAT Satellite Programme)*
- Reflecting to
  - ✓ exploration scientific and possible service needs
  - ✓ European sovereign Lunar exploration needs
  - ✓ national space strategy
  - ✓ ESA strategy

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Mission Statement

- **Lunar Exploration Space Weather Monitoring SmallSat Mission (MoonRad)**
  - ✓ *for Lunar exploration science, service utilisation and technology demonstration purposes*
  - ✓ *for implementation within ESA HRE Directorate executed by a Consortium with Hungarian majority*
  - ✓ *as one of ESA's Lunar exploration small mission (Small Mission for Exploration – SMEX)*
- **1st Hungarian ESA Flagship (SmallSat) Programme**
  - ✓ *lead by a Hungarian SmallSat Integrator Prime*
  - ✓ *with ultimate Hungarian contribution by integrating national space ecosystem into the supply chain*

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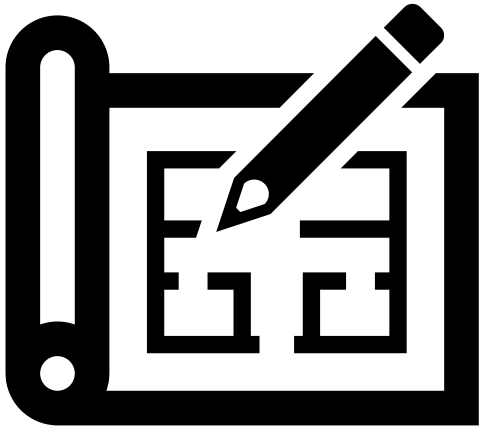
Technical Approach



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Mission Objectives

- **O-1: Monitoring Lunar space radiation and plasma environmental characteristics and dynamic processes to support the reference modelling of Moon radiation environment and effects.**
- **O-2: Demonstration of a future European Lunar space weather near real-time operational service provision.**
- O-3: Secure European market competitiveness in Lunar SmallSat technologies market by considering New Space solutions.

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Mission Design Concept

- ✓ Considers *a first demonstration satellite (**MoonRad-D**) in Lunar orbit* with mission objectives as listed earlier
- ✓ *with a fast-track mission targeting less then 4 years overall duration (Phase A to QAR/DRB)* to be competitive
- ✓ *including Hungarian and European space weather monitoring payloads* with high maturity
- ✓ *possibly followed by a series of further satellites in order to form a MoonRad Constellation (**MoonRad-C**) in Lunar orbit*
  - ✓ To maintain European Lunar space weather monitoring competitiveness by securing monitoring techniques developments and related Lunar demonstration
  - ✓ To expand the Lunar space weather service provision
  - ✓ To maintain European Lunar SmallSat platform technologies competitiveness by securing related key market leader technology developments and related Lunar demonstration
- ✓ *mission ground segment would make use of ESA existing and in-development related infrastructure (e.g. ERFNet use-case)*

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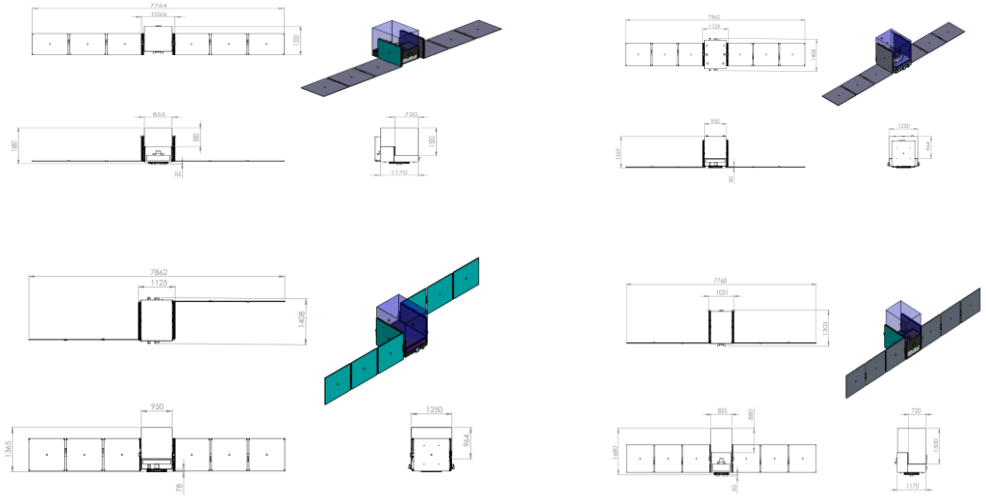
System Design Concept

- ✓Different system concepts and configurations were preliminary analysed
  - ✓Volume envelopes: 1.0 m [W] x 1.0 m [D] x 1.3 m [H]
  - ✓Mass envelopes: 150-200 kg
  - ✓Power envelopes: up to 2 kW



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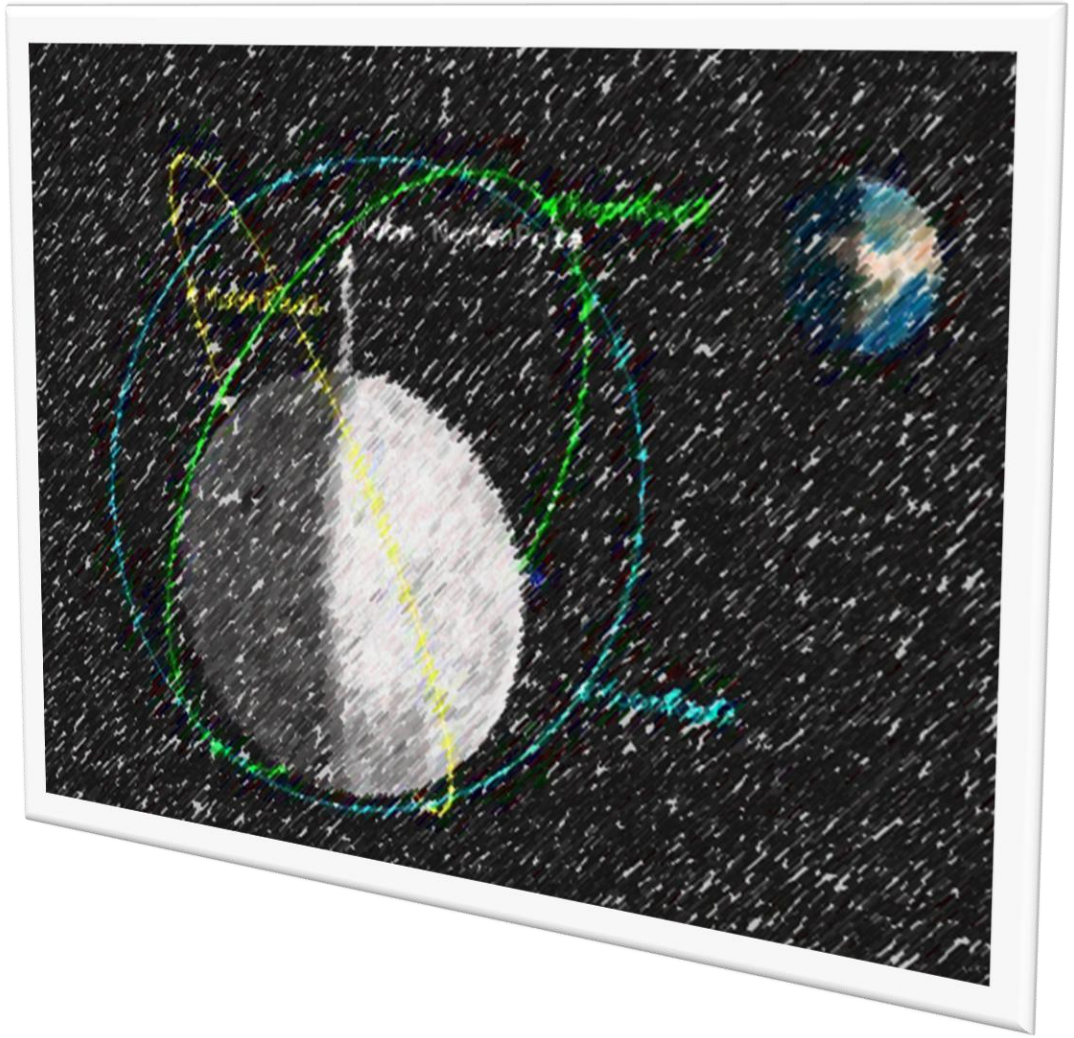
Proposed Orbit

- ✓ Elliptical Lunar Orbit
  - ✓ i ≈ 63°
  - ✓ periselene ≈ 200 km,
  - ✓ aposelene ≈ 2000 km
  - → period T ≈ 3.8 hours
  - → not stable, orbit-maintenance maneuvers are needed



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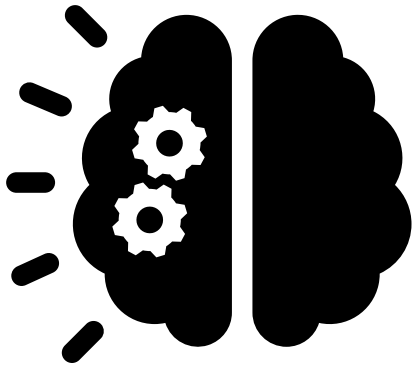

Science Overview

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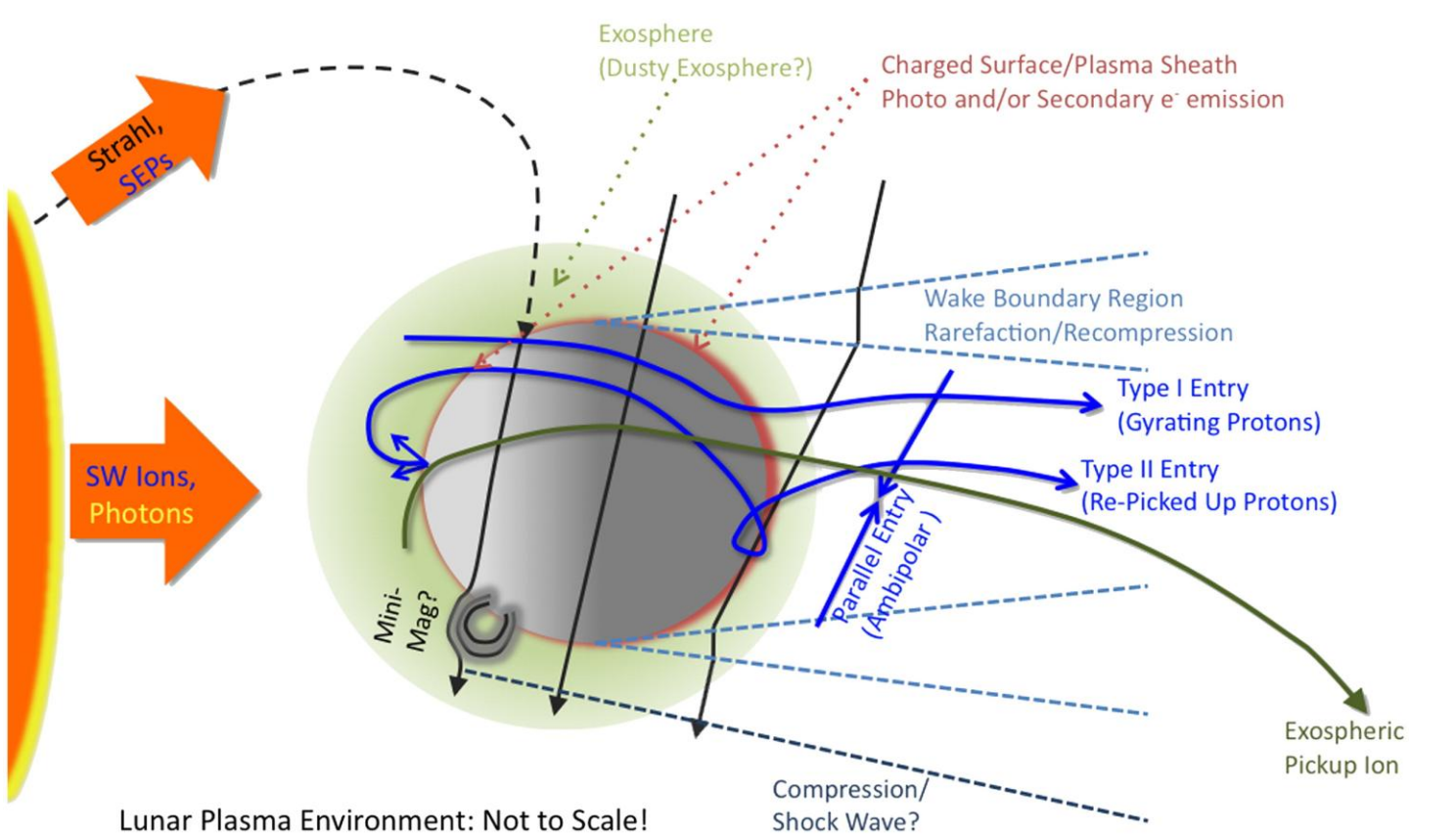
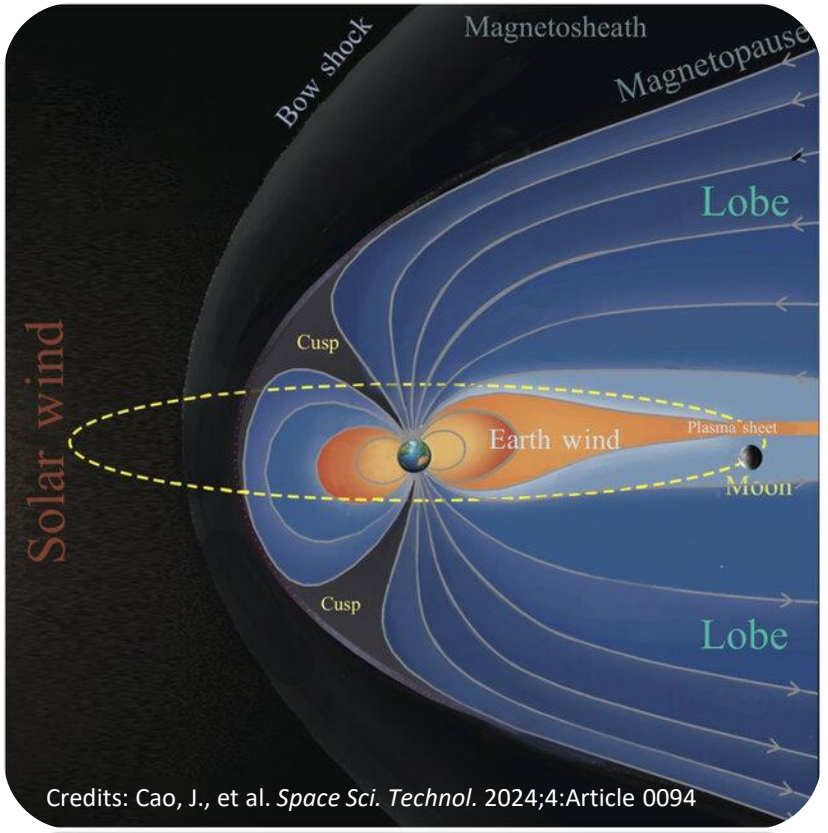
Space Environment and Effects at the Moon



Credits: Halekas, J.S., et al. *Planetary and Space Science*. 2011;59(14), p 1681-1694



Credits: Cao, J., et al. *Space Sci. Technol.* 2024;4:Article 0094

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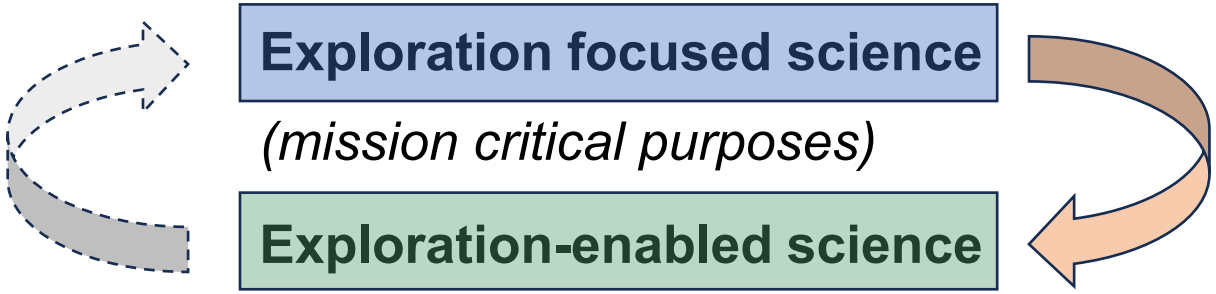
Science Element of Explore2040

- Science as integral part of ESA's exploration programme
- Crucial dual role in achieving Explore 2040 objectives:



- Scientific element described in Explore2040 Implementation building on the foundation of the SciSpacE Strategy

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Exploration Focused Science Themes

A. Local Resources

B. Environment and Effects

C. Crew Health and Performance

D. Habitation

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Exploration Focused Science Themes

A. Local Resources

B. Environment and Effects →

C. Crew Health and Performance ↓

D. Habitation

Determining environmental characteristics and dynamic processes in space, exospheres, atmospheres, and surfaces. **Investigating effects on exploration systems** and monitoring environmental impacts of human activity.

Investigating physiological adaptations, **addressing** behavioural and **radiation-related health risks, and developing countermeasures** and medical capabilities **for long-duration missions.**

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Exploration Focused Science Outputs

- To generate actionable knowledge required for
  - mission design,
  - systems development,
  - operations,
  - Strategic planning.
- Incl. environmental models, risk models, reference datasets, operational tools.
- Developed not only for mission critical purposes but also made available for the wider scientific community → valuable foundation for exploration-enabled science

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Exploration Focused Science Outputs

- The Explore2040 identified the following exploration-focused science data outputs as baseline:
  - Human risk rating report
  - **Radiation Health Risk Model**
  - **Radiation propagation tools and biophysical models**
  - **Countermeasures Compendium**
  - Site/Surface Maps
  - Reference frame
  - **Environment and effects model**
  - Resources model
  - Material properties handbook

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Exploration-Enabled Science Themes

A. Fundamental Physics and Astrophysics

B. Material Sciences

C. Fluids Sciences, Soft Matter, and Biophysics

D. Space and Planetary Environments

E. Biology

- Fundamental Biology
- Space Biotechnology and Agriculture
- Astrobiology

F. Human Physiology

G. Planetary Science

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Exploration-Enabled Science Themes

A. Fundamental Physics and Astrophysics

B. Material Sciences

C. Fluids Sciences, Soft Matter, and Biophysics

D. Space and Planetary Environments →

E. Biology
   - Fundamental Biology
   - Space Biotechnology and Agriculture
   - Astrobiology

F. Human Physiology

G. Planetary Science

Characterising and understanding planetary and deep space environments and expand our understanding of their properties and dynamics. Includes heliophysical, radiation, and solar **observations,** atmospheric phenomena, lighting and interaction with climate and the atmosphere chemistry.

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Preliminary Data Products

Space weather and space dosimetry

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Preliminary Data Products – Space Dosimetry

- PDP-0010: **Absorbed dose (rate) in silicon behind 2 mm Al-eq.**
  - Measurement absorbed dose (rate) in silicon in µGy (µGy h^{-1})
  - 10^{-6} – 10^{0} Gy/h (order of magnitude)
  - 30 s cadence during SPEs
- PDP-0020: **LET spectra in silicon behind 2 mm Al-eq.**
  - Measurement of LET spectra in silicon in $cm^{-2}s^{-1}sr^{-1}(keV/\mu m)^{-1}$ for RHA
  - 0.1-1000 $MeVcm^2/mg$
  - In three orthogonal directions, 60° half angle cone
  - 30 s cadence during SPEs
- PDP-0030: **LET spectra in water behind 2 mm Al-eq.**
  - Measurement of LET spectra in $cm^{-2}s^{-1}sr^{-1}(keV/\mu m)^{-1}$
  - 0.2-120+ keV/µm
  - In three orthogonal directions
  - 30 s cadence during SPEs
- PDP-0040: **Absorbed dose (rate) in water behind 2 mm Al-eq.**
  - Measurement absorbed dose (rate) in water in µGy (µGy h^{-1})
  - $2 \cdot 10^{-6}$ – 2 Gy/h (order of magnitude)
  - 30 s cadence during SPEs
- PDP-0050: **Dose equivalent (rate) in water behind 2 mm Al-eq.**
  - Measurement dose equivalent (rate) in water in µSv (µSv h^{-1})
  - $6 \cdot 10^{-6}$ – 4 Sv/h (order of magnitude)
  - 30 s cadence during SPEs

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Preliminary Data Products – Space Radiation

- PDP-0110: **High Energy >10 MeV Protons** in Interplanetary Medium
  - Measurement of proton flux in $cm^{-2}s^{-1}sr^{-1}MeV^{-1}$ (adaptation of L1-001-M to Lunar orbital environment)
  - 10-500 MeV, min. 5 logarithmically-spaced channels with an integral channel above the upper threshold
  - Dynamic range: 10^8 per channel (dep. on energy), min. 20° half angle cone
- PDP-0120: **High Energy >10 MeV/nuc Ions** in Interplanetary Medium
  - Measurement of ion flux in $cm^{-2}s^{-1}sr^{-1(}MeV/nuc)^{-1}$ (adaptation of L1-002-M to Lunar orbital environment)
  - 10 MeV/n – 5 GeV/nuc, min. 5 logarithmically-spaced channels, Z = 2 – 28 (*92*)
  - Dynamic range: 10^8 per channel (dep. on energy), min. 20° half angle cone
- PDP-0130: **1-to-10 MeV Protons** in Interplanetary Medium
  - Measurement of proton flux in $cm^{-2}s^{-1}sr^{-1}MeV^{-1}$ (adaptation of L1-003-M (L1)) to Lunar orbital environment)
  - 1-10 MeV, min. 3 logarithmically-spaced channels. Note: effects on solar cells
  - Dynamic range: 10^8 per channel (dep. on energy), min. 20° half angle cone
- PDP-0140: **E>30 keV-8 MeV Electrons** Interplanetary Medium
  - Measurement of electron flux in $cm^{-2}s^{-1}sr^{-1k}eV^{-1}$ (adaptation of L1-007-M to Lunar orbital environment)
  - 30 keV-8MeV, min. 8 logarithmically-spaced channels with an integral channel above the upper threshold (for Lunar orbit an upper limit of 4 MeV should be enough)
  - Dynamic range: 10^8 per channel (dep. on energy), min. 30° half angle cone

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Preliminary Data Products – Magnetic Field

- PDP-0210: **Interplanetary and Local Magnetic Field** in orbit
  - Measurement of 3D (solar wind) magnetic field in nT (adaptation of L1-008-M to Lunar orbital environment, IMF+geomagnetic wake+lunar magnetic anomalies(LMAs))
  - 0-200 nT
  - 3 orthogonal measurements

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Preliminary Data Products – Plasma environment

- PDP-0310: **Electron density**
  - Measurement of electron density in m^{-3} (adaptation of IT-002-M to Lunar orbital environment)
  - 10^4-10^8 m^{-3}
- PDP-0320: **Electron temperature**
  - Measurement of electron temperature in eV
  - 10-4000 eV
- PDP-0330: **Ion velocity**
  - Measurement of ion velocity in km s^{-1}
  - 100-1100 km s^{-1}
- PDP-0340: **Ion density**
  - Measurement of ion density in m^{-3}
  - 10^4-10^8 m^{-3}
- PDP-0350: **Ion temperature**
  - Measurement of electron temperature in eV
  - 5-10000 eV

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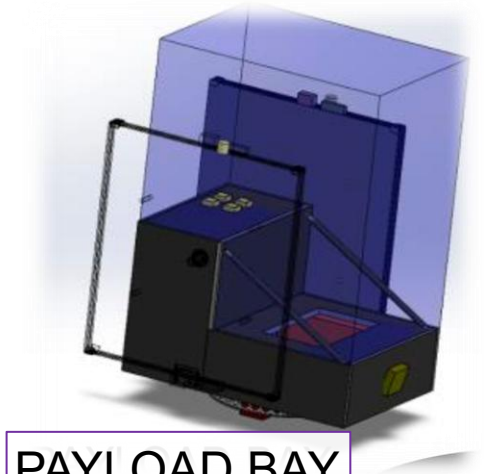
Data Products

- Provisioning to
  - the **S**pace **W**eather **a**nd **S**pace **D**osimetry database system at HUN-REN **EK** (**SWaSDEK**)
  - the **O**pen **D**ata **I**nterface (**ODI**) used by space environment data processing systems at ESA
  - other related infrastructure existing or under development or planning (e.g. **ERFNet, RPSS**, etc.)


PAYLOAD BAY

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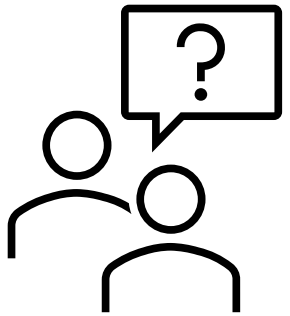

Science Payload Candidates

Possible space weather and space dosimetry instruments

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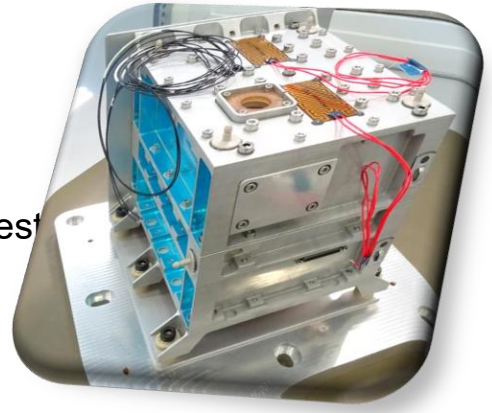
Science Payload Implementation Approach

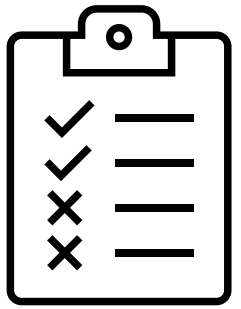
- MoonRad mission system prime: REMRED Ltd.
- Science Payload Suite PI: HUN-REN Centre for Energy Research
  - Science lead, Coordination of science instrument providers (PM, PAM), higher level data product development, Requirements engineering, Integration and Test Scientific Database
  - **RADTEL/TRITEL2** instruments (**modified SDS** payload) provisioning
  - Potentially also building on the generic RadMag development for D3S



- Collaboration potential w.r.t. Science Payload (sub-cos, suppliers)
  - Science Instrument providers (Start TRL: 5 at least, to guarantee compliance with fast track mission goals regarding short mission delivery timeline)
    - Preference given to Hungarian entities with relevant heritage
    - Other ESA member states

Instrument Candidate Selection

- Feasibility Assessment made in the limited Phase 0 (pre-Phase A) Study
  - ✓ **high maturity European instruments to cover the reqs.**, see Preliminary Instrument Candidates on the following slides
- Final selection of the Science Instruments for the MoonRAD Science P/L will be performed according to **ESA Science Team Procedure**



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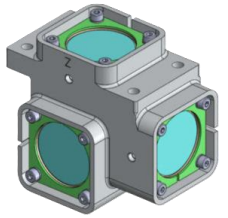
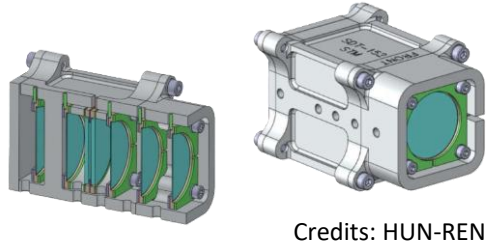
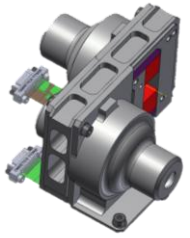
Preliminary Instrument Candidates

- The final selection of science instruments is made by ESA
- Candidates:
  - Absorbed dose and equivalent dose rate: ***TRITEL2*** (3D dosimetry telescope) – **HU**
  - High-energy proton, electron and heavy ion spectra:
    - Space Radiation Telescope ***(RADTEL)*** – **HU**
      - Protons: 3.5 – 400 MeV + integral channels >400 MeV, >600 MeV
      - Electrons: 0.3 – 3.9 MeV + integral channels >4 MeV, >5 MeV
      - Heavy ions: 10 MeV/n – 400 MeV/n
    - Electron and Proton Telescope (***EPT***) – **DE**
      - Protons: 60 keV – 7 MeV
      - Electrons: 20 keV – 400 keV





Credits: HUN-REN EK, REM, ADM



Credits: CAU

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Preliminary Instrument Candidates (cont'd)

- Local magnetic field measurements: fluxgate magnetometer (similar to LMAG on Kaguya)
  - FGM: modified ***MAG*** from Solar Orbiter – **GB**
    or modified ***SOSMAG*** – **DE**
  - ±128 nT

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Outlook

Potential synergies with other space missions

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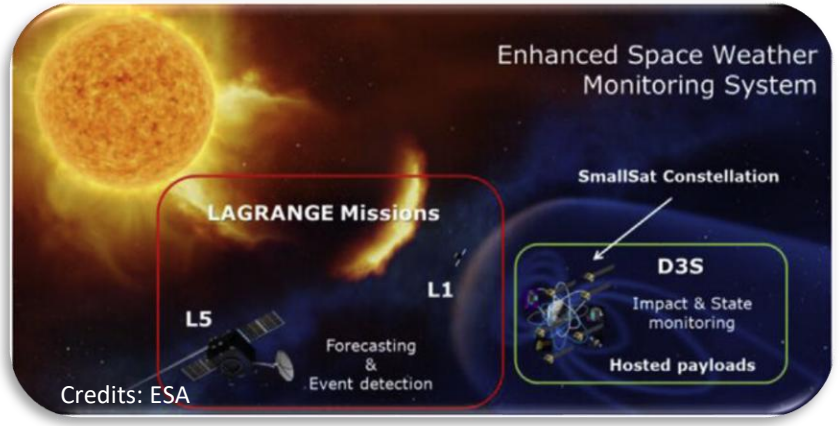
Potential synergies with other space missions

- **Artemis** missions
- Robotic missions
  - on lunar orbit
  - on the lunar surface
- Distributed Space Weather Service System (**D3S**)
  - **Aurora**
  - **Vigil** (L5)
  - Hosted missions



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Thank you for your attention!