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CENSSS Centre for Space Sensors and Systems

ideas

ASTRA-LEO: Multi-Particle Detection for CENSSAT-1

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Presented at SPACEMON 2025, Space environments monitoring workshop

11-13 June 2025, ESA/ESTEC

Radiation Detection in Space Applications

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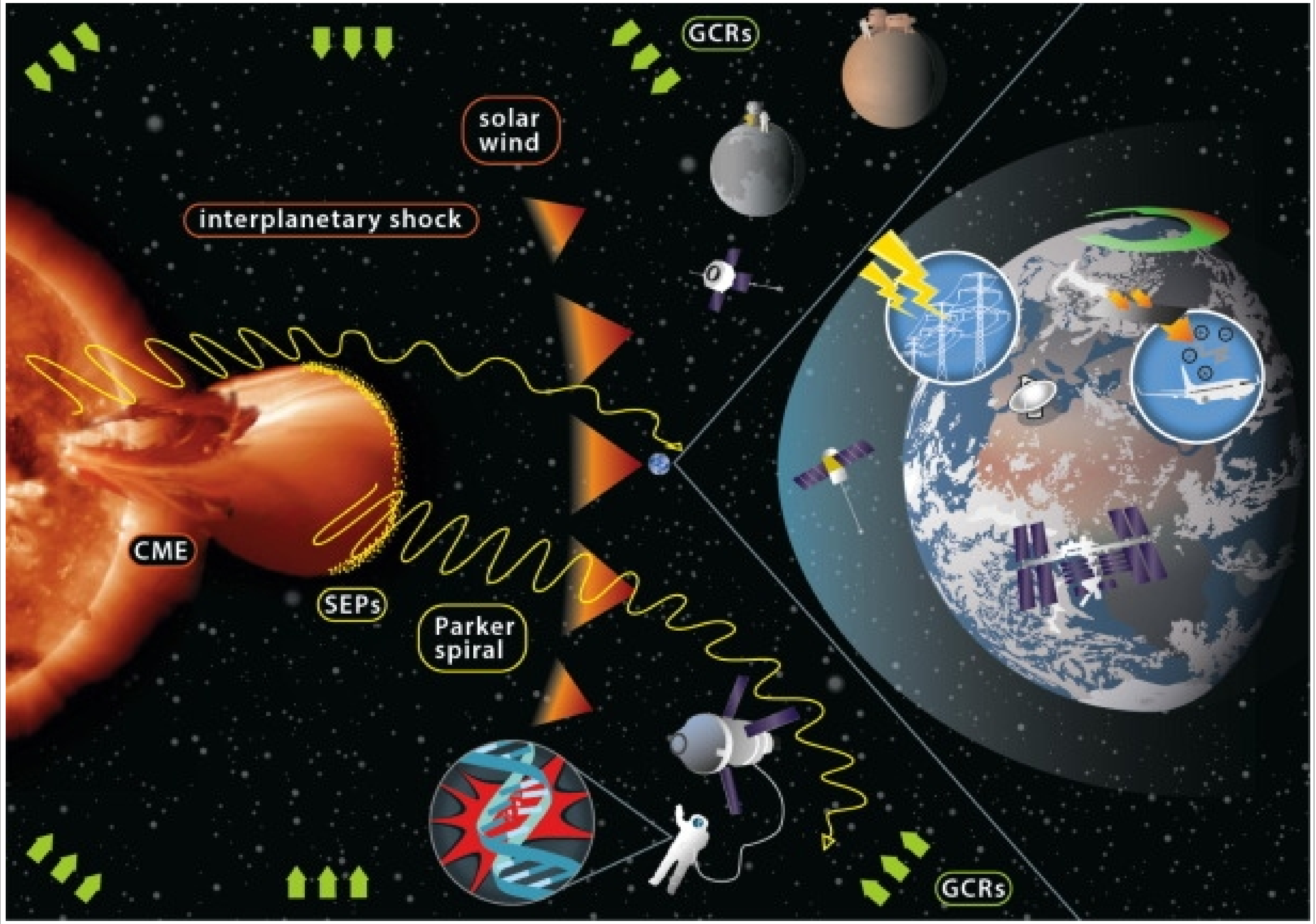
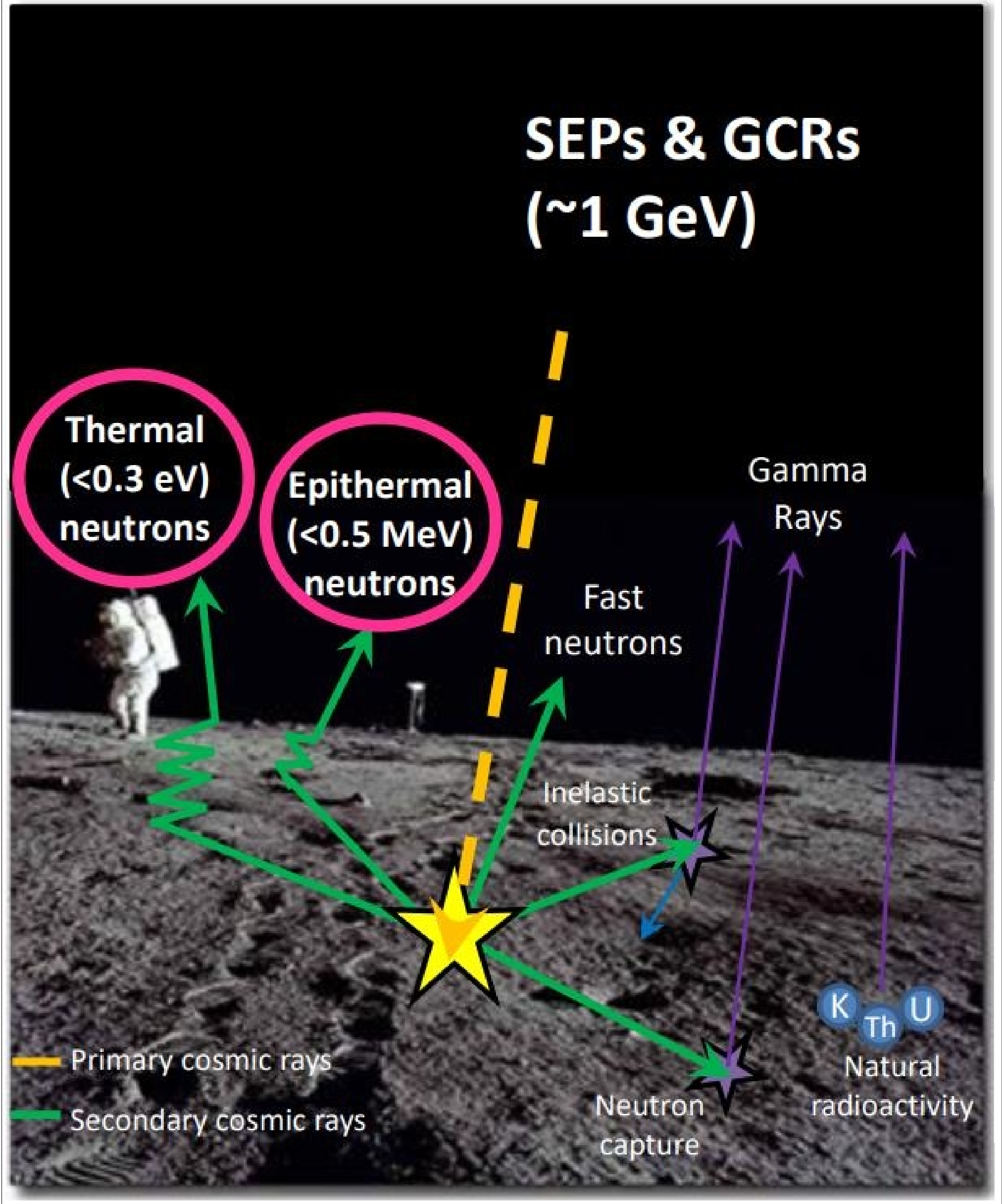


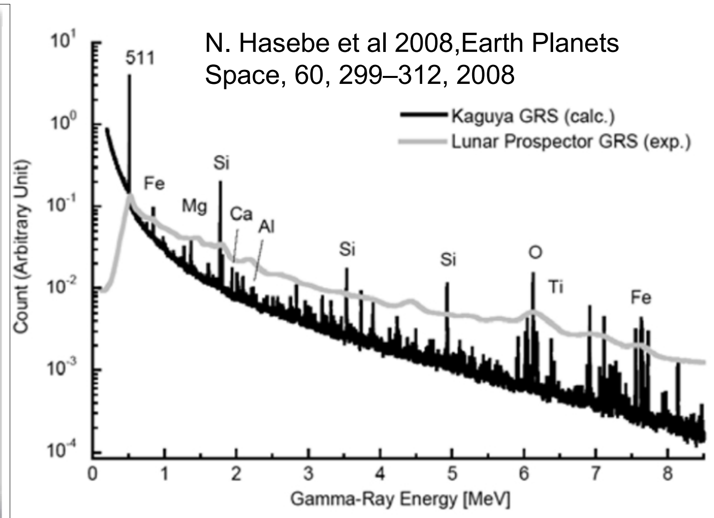
Space weather and its impacts on satellites, communication, and navigation systems, with a focus on radiation effects. **Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs)** are key contributors to increased radiation levels, posing risks to satellite electronics, disrupting communication signals, and degrading navigation accuracy.

J. Guo, B. Wang, K. Whitman et al., Particle radiation environment in the heliosphere: Status, limitations, and recommendations, Advances in Space Research, https://doi.org/10.1016/j.asr.2024.03.070



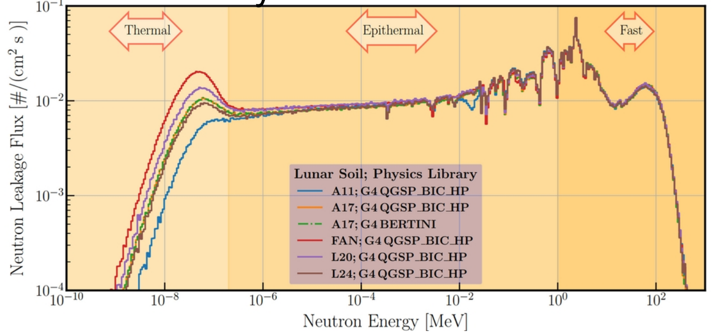
Effects of Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs) interacting with a planetary surface. The collisions generate **gamma-rays** and **fast neutrons**, which provide valuable information for elemental composition analysis and mapping hydrogen/water-rich regions through neutron moderation and gamma-ray spectroscopy.

N. Hasebe et al 2008,Earth Planets Space, 60, 299–312, 2008



Gamma-ray spectroscopy:
Mainly for elemental composition analysis via gamma-ray emission signature

Simulated by Luis F. A. Teodoro



Thermal amd epithermal neutrons:
Mainly for mapping hydrogen-rich materials like water.

From ISRU to LEO: Origin of ASTRA-LEO

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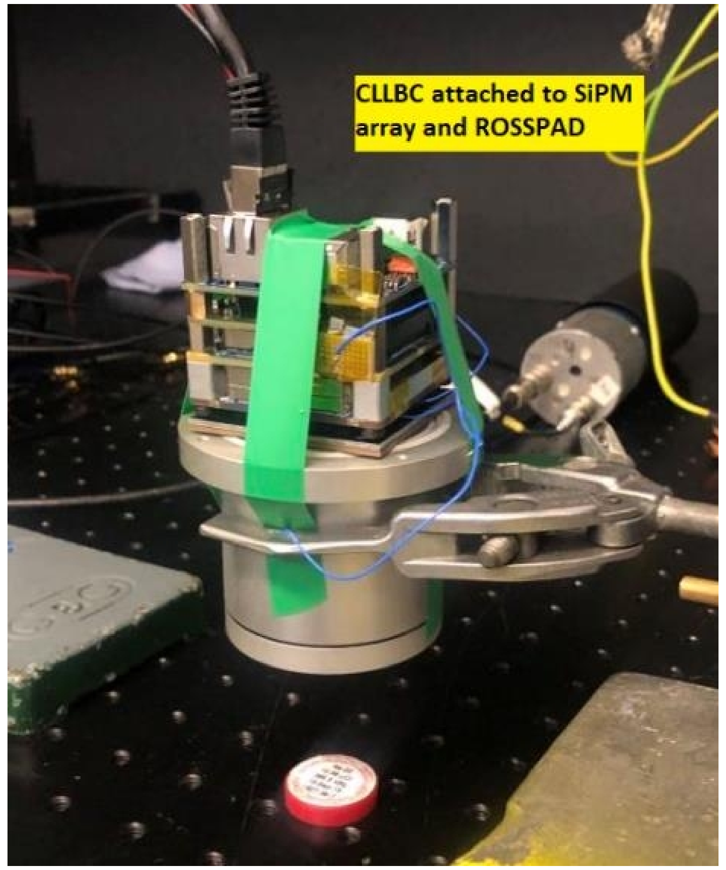
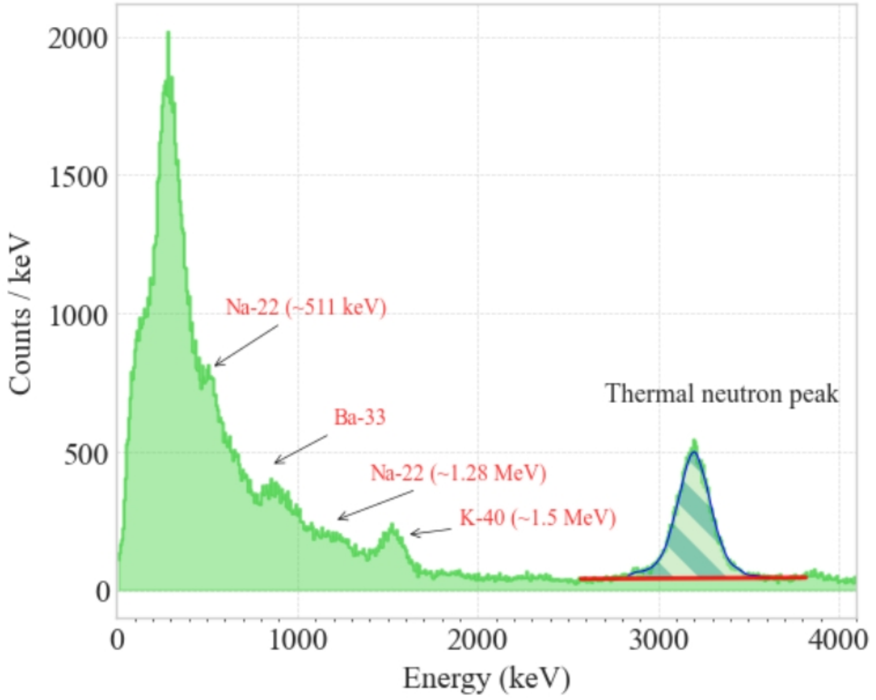
Initial work conducted at CENSSS under Work Package 5 focuses on In Situ Resource Utilization (ISRU).

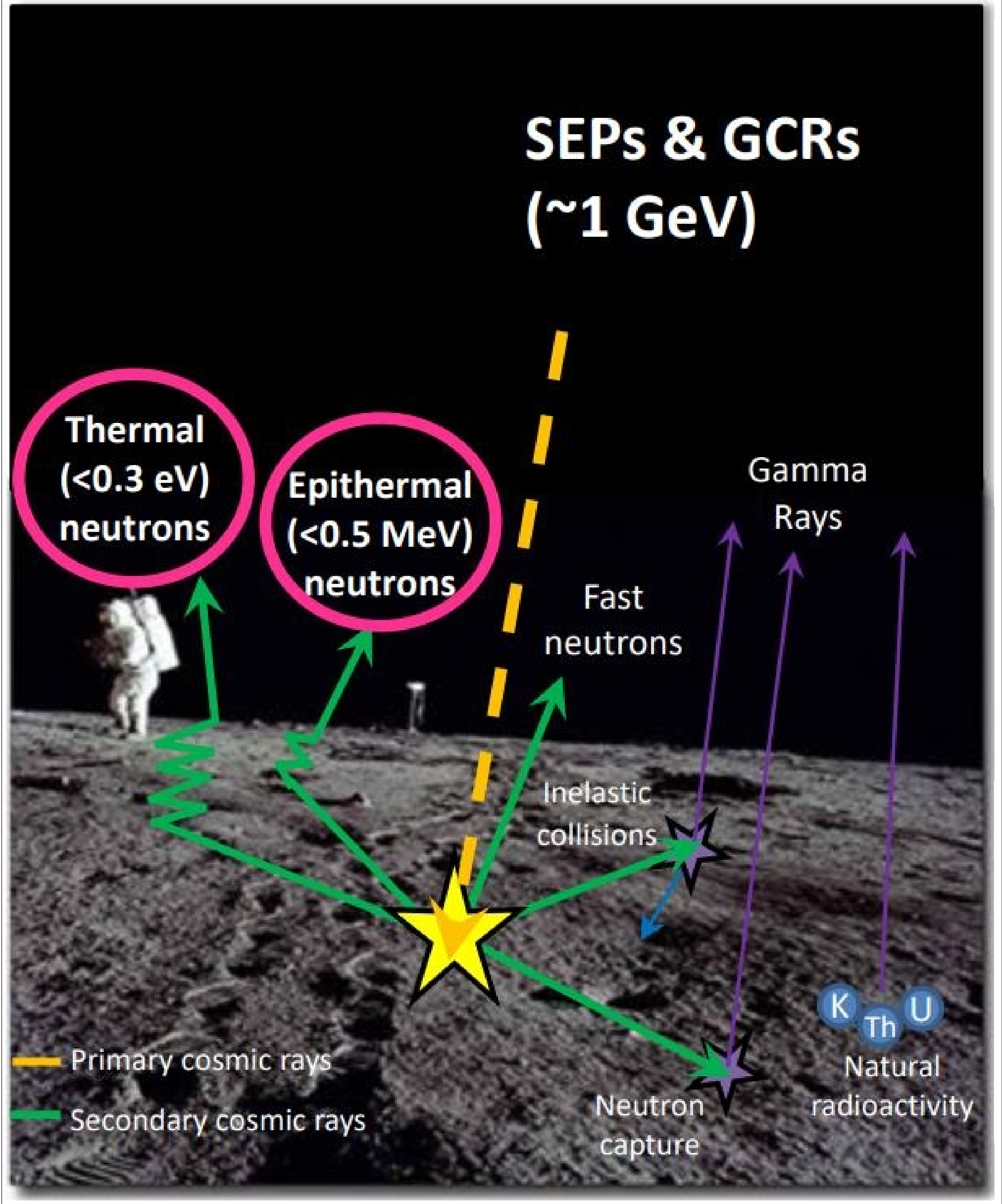
Aim: Develop compact systems for gamma-ray and neutron spectroscopy for space.

Scintillators evaluated for compatibility with IDEAS SIPHRA ASIC (IDE3380) (SiPM-optimised), Laboratory studies, including those conducted at the University of Glasgow, identified CLLBC as a strong candidate





*Deniz Ölçek et al 2024 JINST 19 C01030



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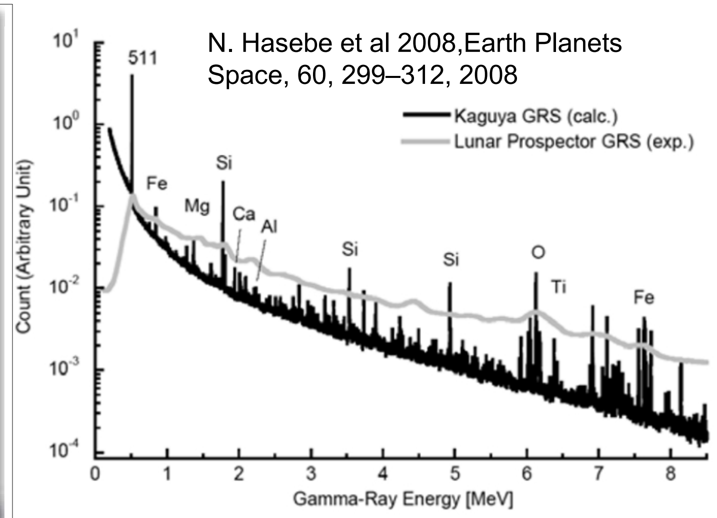
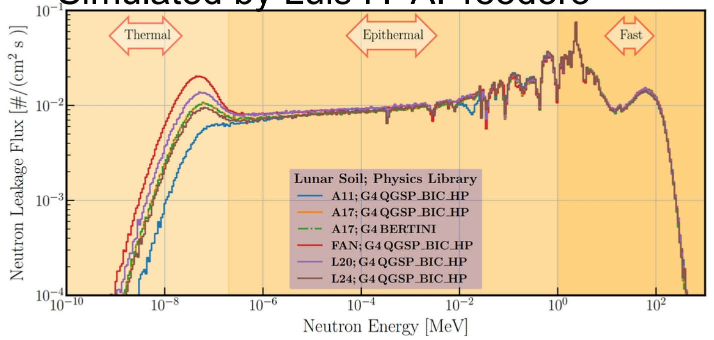


Gamma-ray spectroscopy:
Mainly for elemental composition analysis via gamma-ray emission signature

Simulated by Luis F. A. Teodoro



Thermal amd epithermal neutrons:
Mainly for mapping hydrogen-rich materials like water.

From Concept to TRL3 and Chessboard Design

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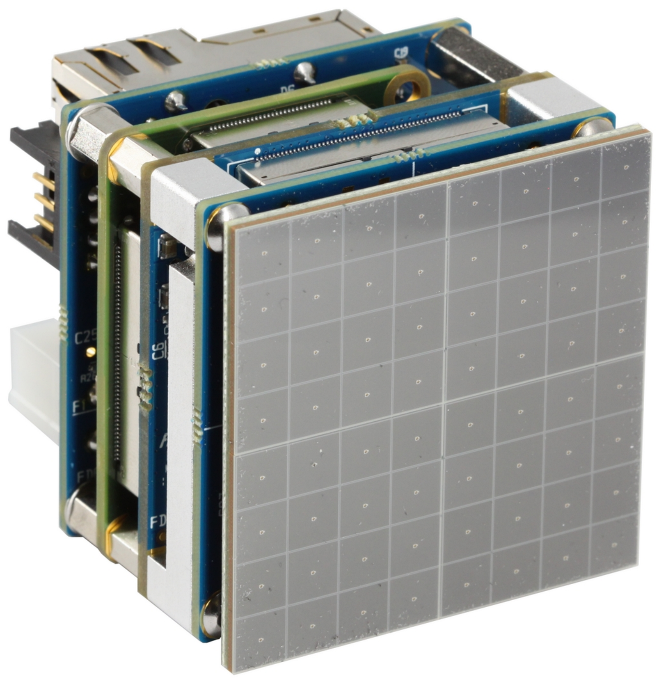
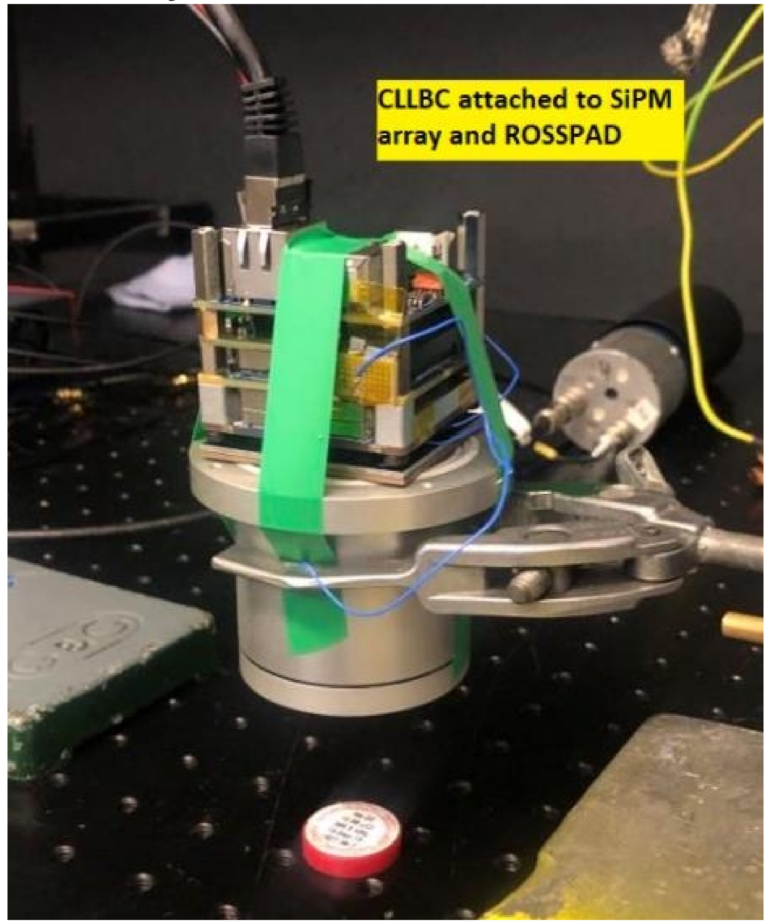
Experimental data was used to tune the modeling of the detector in Geant4, parameters such as Bircks constant, energy resolution, digitisation..ect

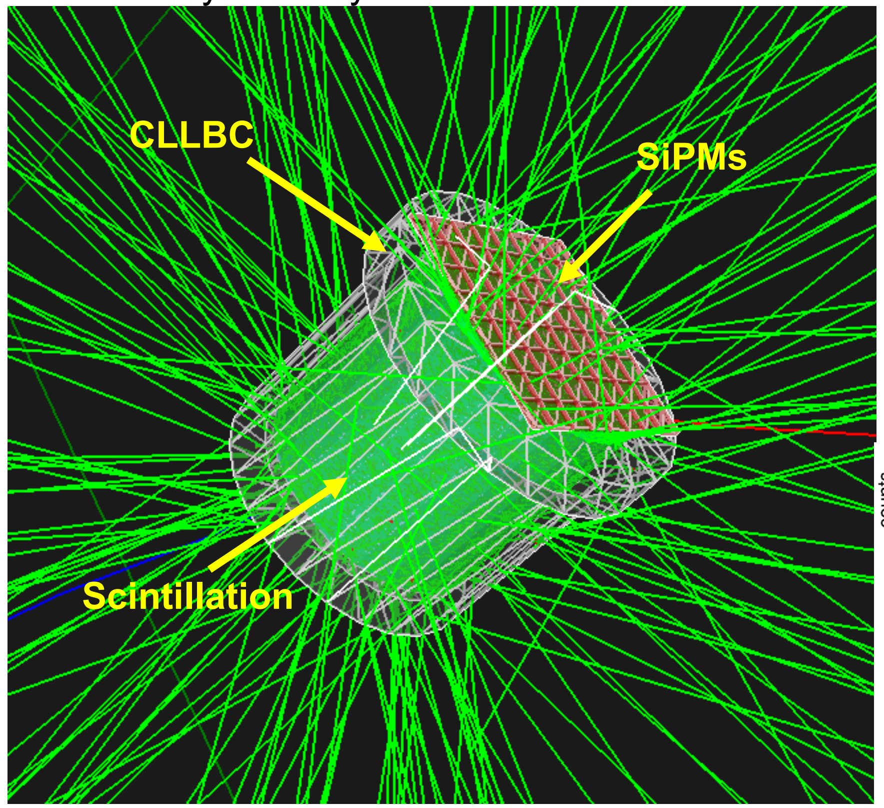


ROSSPAD (https://ideas.no/products/rosspad/) with Hamamatsu SiPM array attached, 4x IDE3380 (https://ideas.no/products/ide3380)

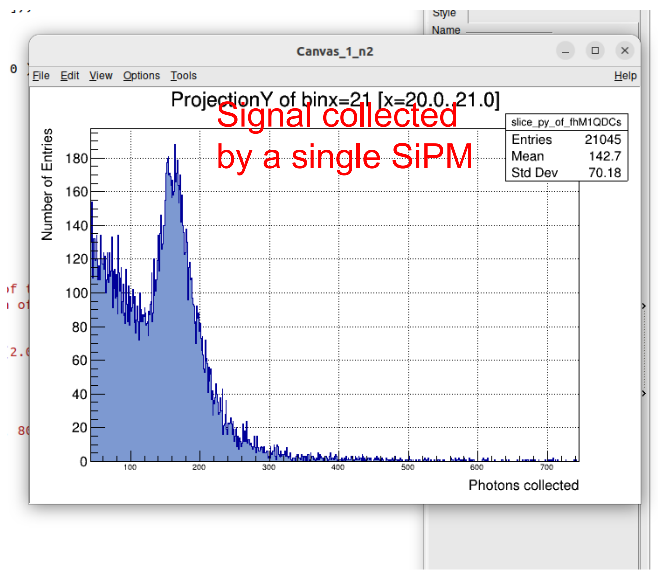
*Deniz Ölçek et al 2024 JINST 19 C01030

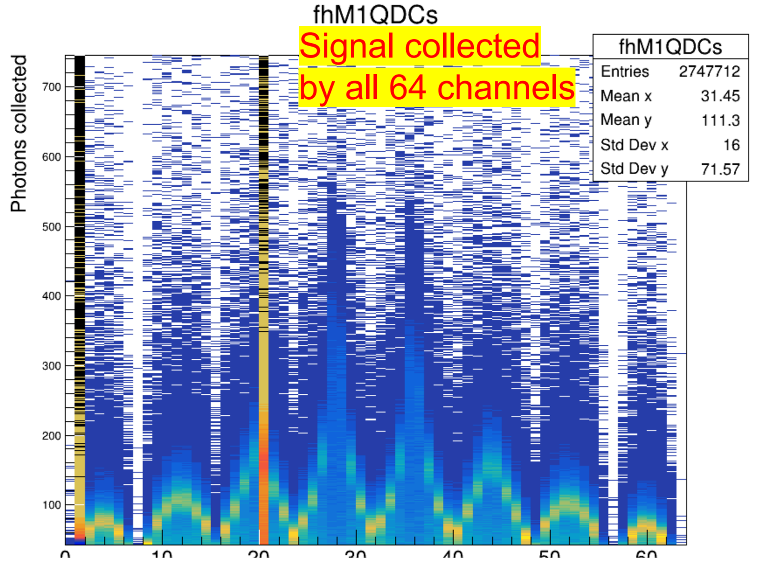


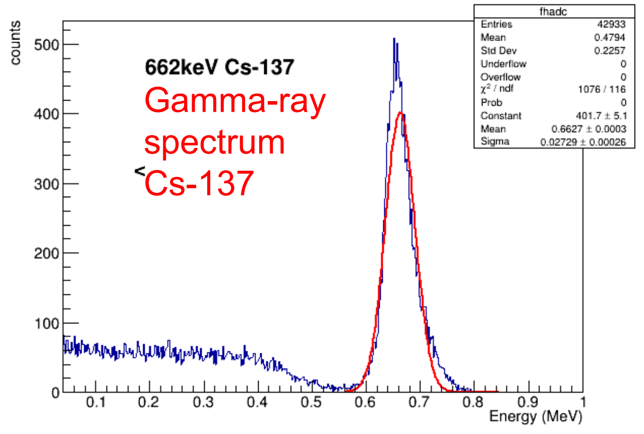
Simulated by Ramsey Al Jebali Nov. 2023

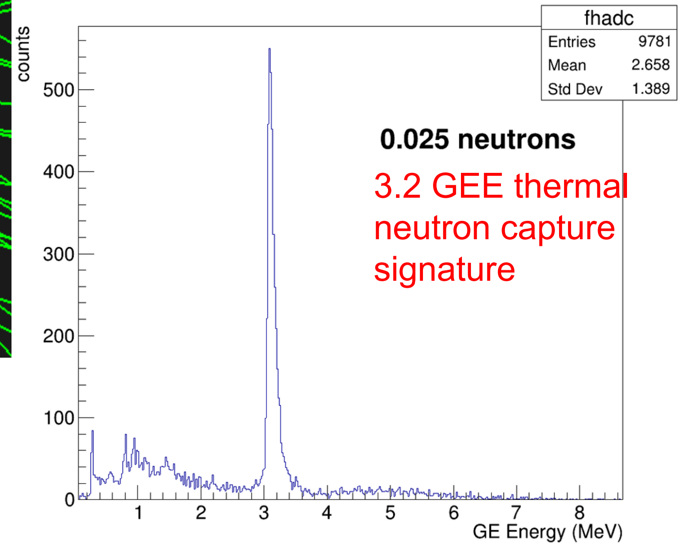


Geant4 simulation of the detector geometry. Scintillation photons are confined within the detector volume.









Geant4 results, Top: Energy spectrum for 0.662MeV Cs-137 source, Buttom: Energy spectrum from thermal neutron capture.

From Concept to TRL3 and Chessboard Design

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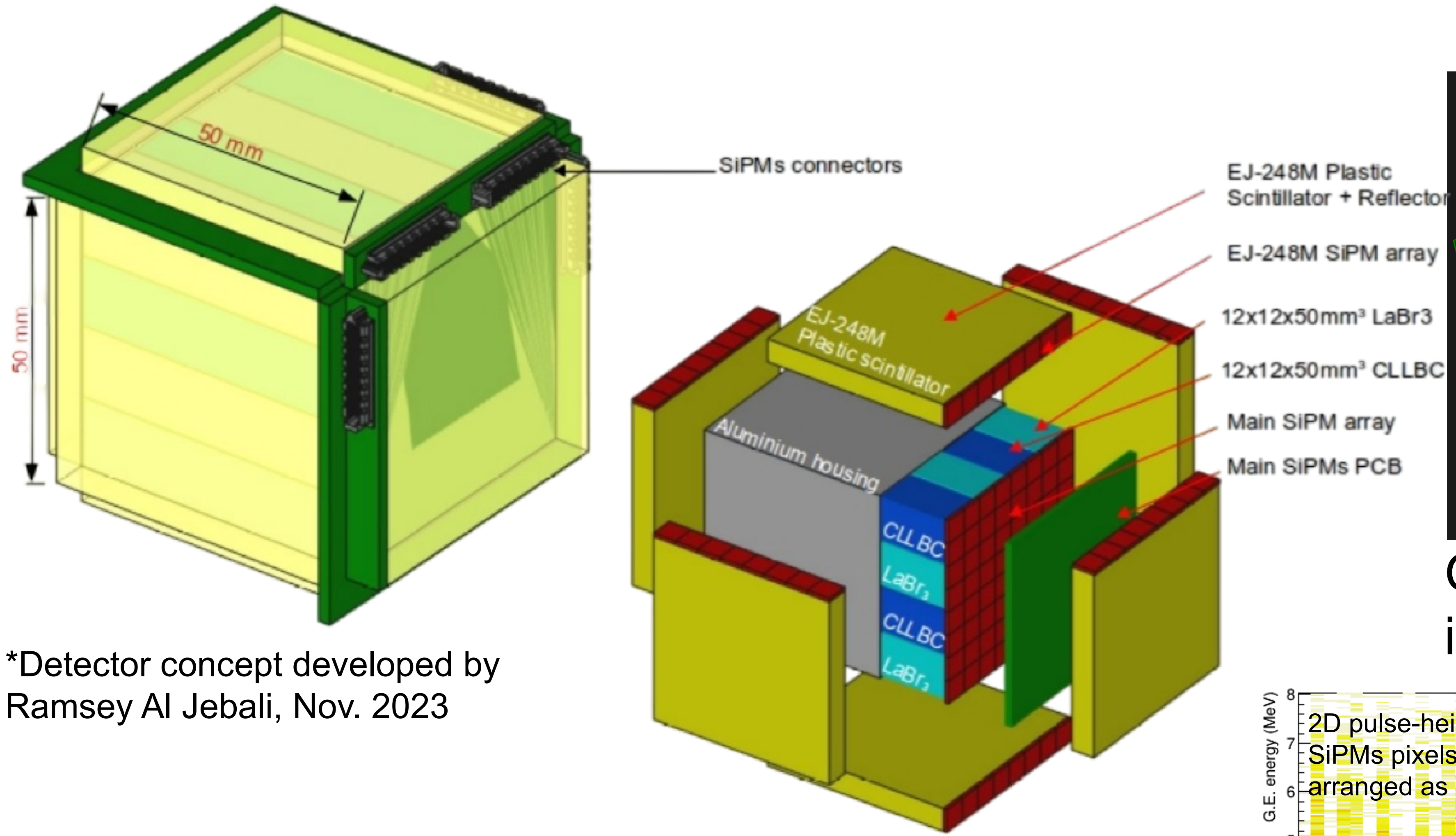
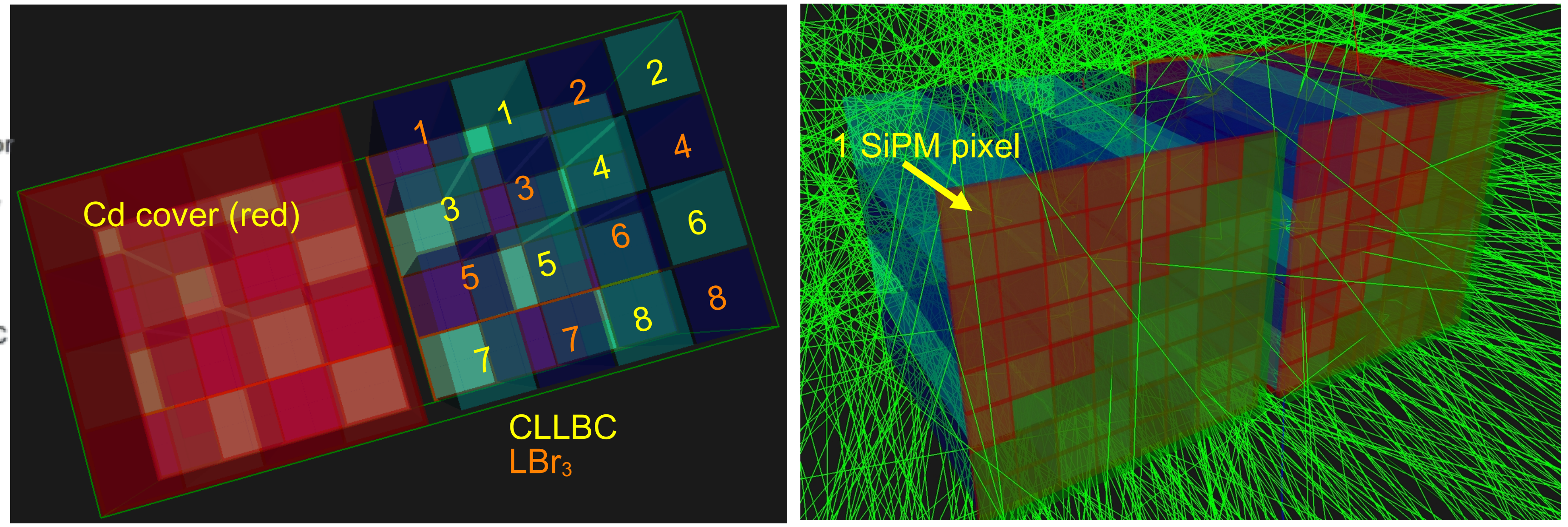
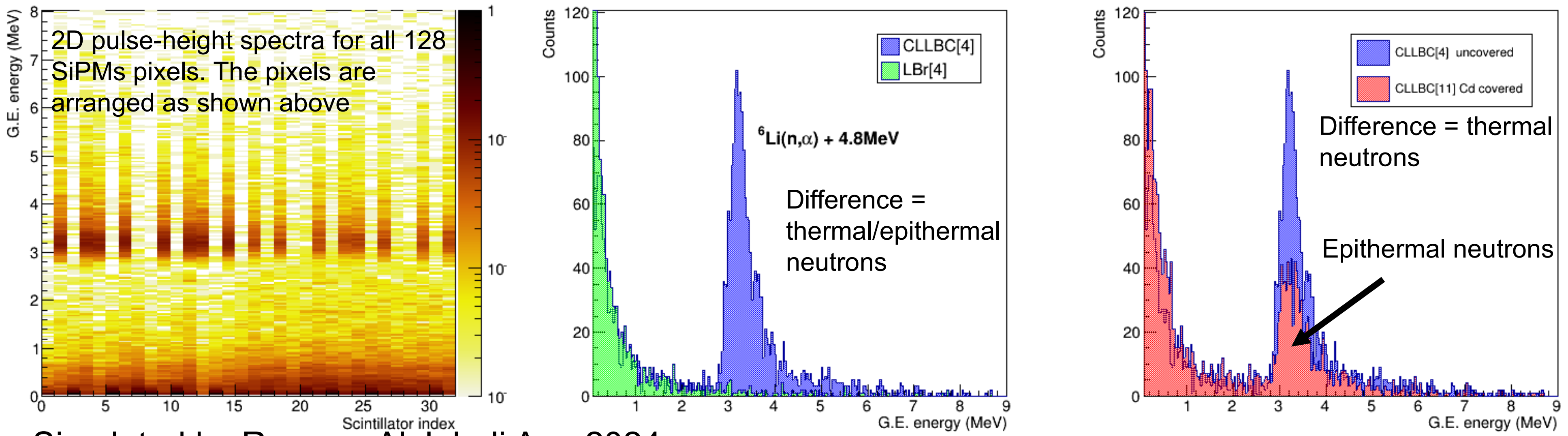


*Detector concept developed by Ramsey Al Jebali, Nov. 2023



Geant4 based simulation of two detector units, one of which is covered in Cd sheet to filter away thermal neutrons.

The detector unit consist of a matrix of $LaBr_3$ and CLLBC scintillators arranged in alternating pattern, surrounded by EJ-248M plastic scintillator tiles. The detector will be optimised for the detection of SEPs, gamma-rays and thermal neutrons.



Simulated by Ramsey Al Jebali Apr. 2024

SIPHRA's lack of PSD capability limitedneutron/gamma discrimination using a single scintillator. We adopted a **hybrid design**: CLLBC (neutron + gamma) interleaved with $LaBr_3$ (gamma-only) – a **checkerboard configuration**.

Selene’s Explorer for Roughness, Regolith, Resources, Neutrons and Elements **(SER3NE)**

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The hybrid detector has been proposed for a lunar orbiter to ESA OSIP, together with UiO Geosciences department, DLR, IAS and TUB.

Small satellite mission performing gamma-ray and neutron spectroscopy, hyper-spectral near-infrared spectroscopy, and laser altimetry, roughness, and albedo observations at unprecedented spectral and ground resolution.

The aim is to characterise the lunar surface to unravel its volatile origin and delivery processes, to uncover the geological processes that shaped the Moon

Payloads: GRNS, Laser Altimetry, S-LIM (Serene-Lunar Infrared Mapper).

Accepted in 2024 for Pre-Phase A – ongoing work.

More about SER3NE and lunar application go to talk by Dr. Anja Kohfeldt et al 10:20 AM, 12 June 2025 https://indico.esa.int/event/555/contributions/10901/

SER3NE

University of Oslo first CubeSat: CENSSAT-1

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In 2024, CENSSS restructured to focus on **CENSSAT-1** – the University of Oslo's first CubeSat.

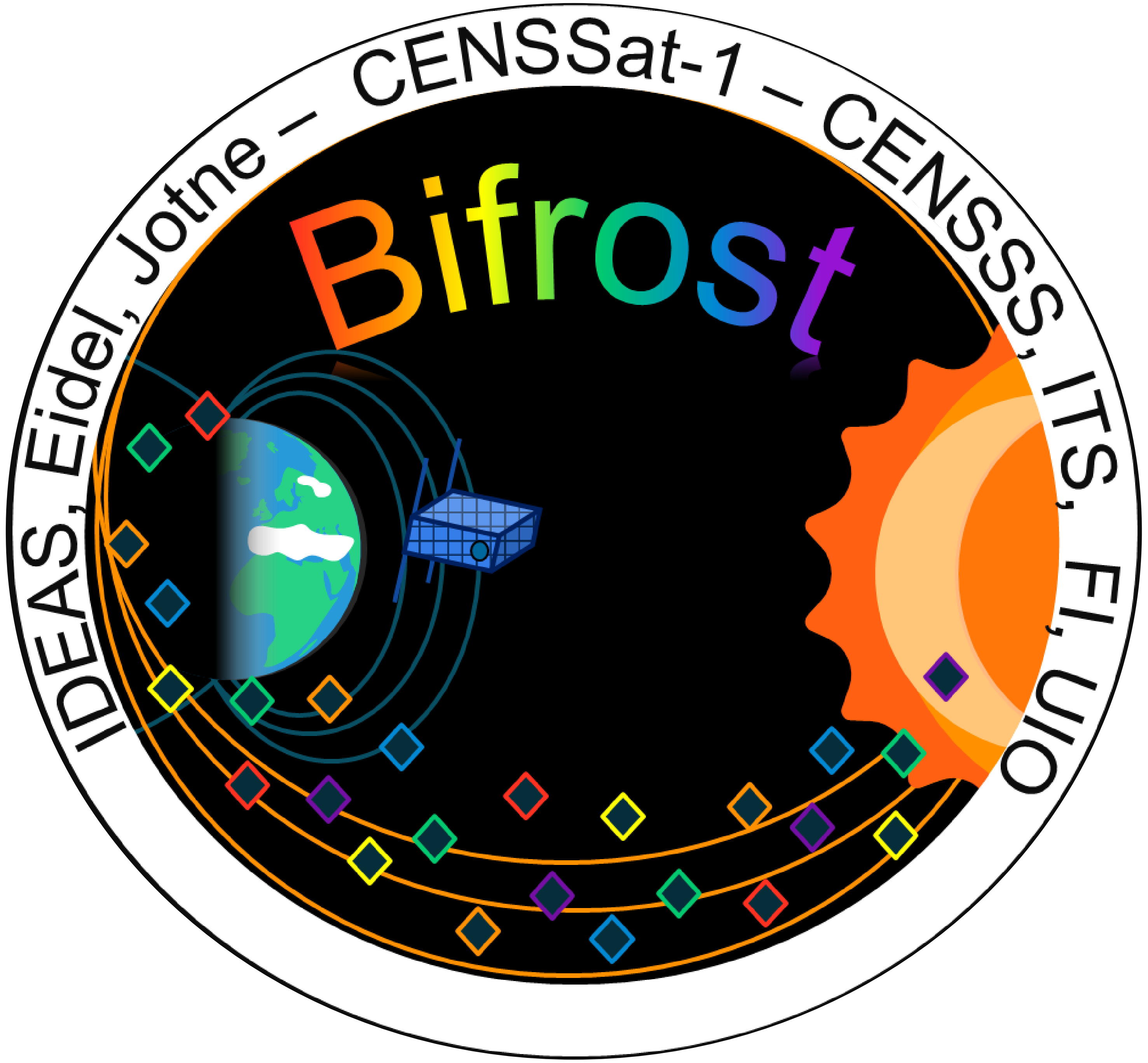
The detector designed to measure gamma-rays, neutrons, and solar energetic particles (SEPs) aboard the CENSSAT-1, a 6U satellite scheduled for launch in late 2027.

Other payloads: Multineedle Langmuir probe (m-NLP), a Multispectral camera and a Space Debris Radar provided by UiT.

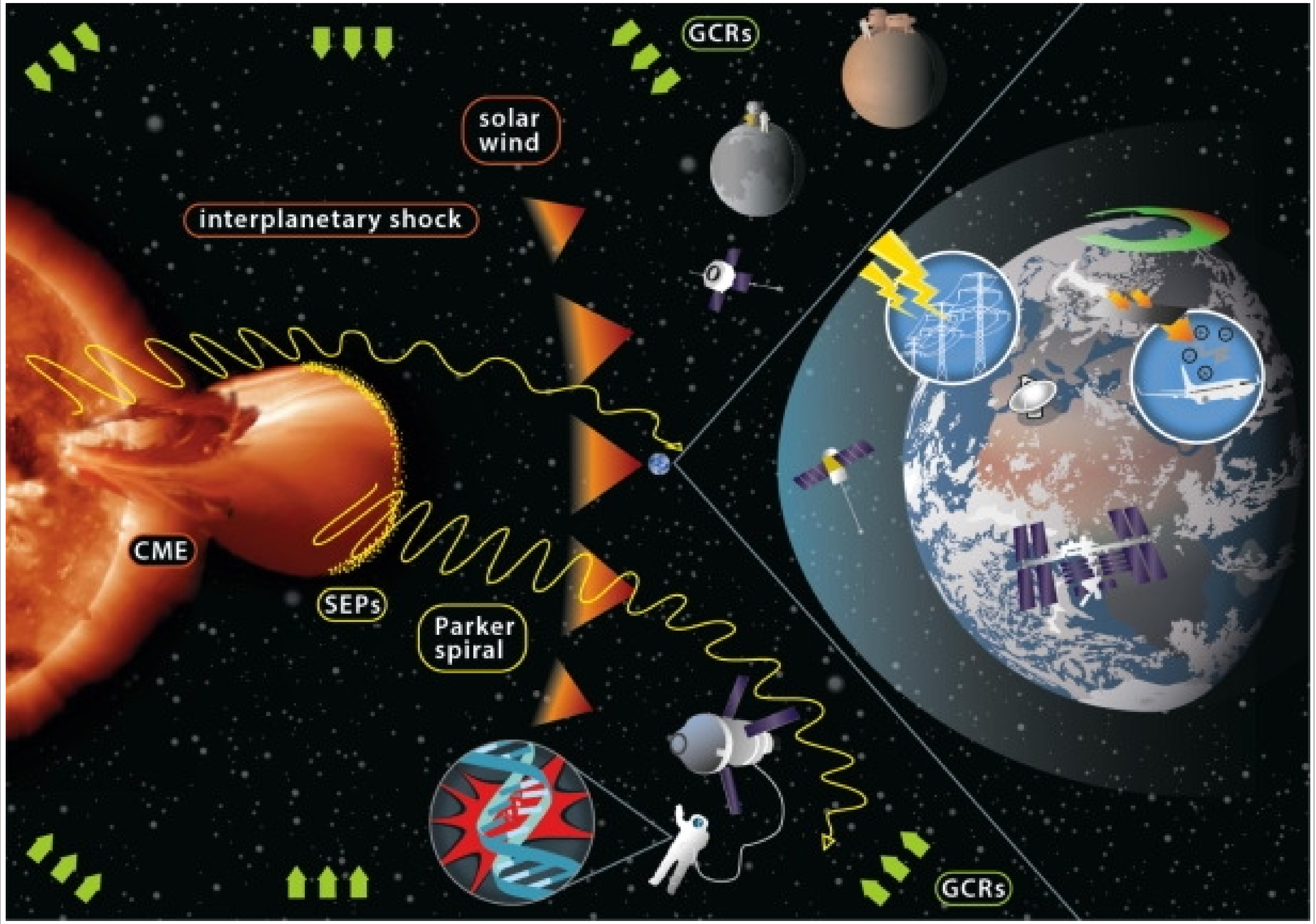
Scientific objectives:

1) Study the relationship between plasma variations, SEPs, and auroral emissions
2) Feasibility Study into the Neutron Lifetime Discrepancy: resolving inconsistencies between laboratory and space measurements
3) Detection of Gamma-ray Bursts (GRBs)

Operation objective: SEP detection and alerting onboard payloads.



Detector Design Adjustments for LEO



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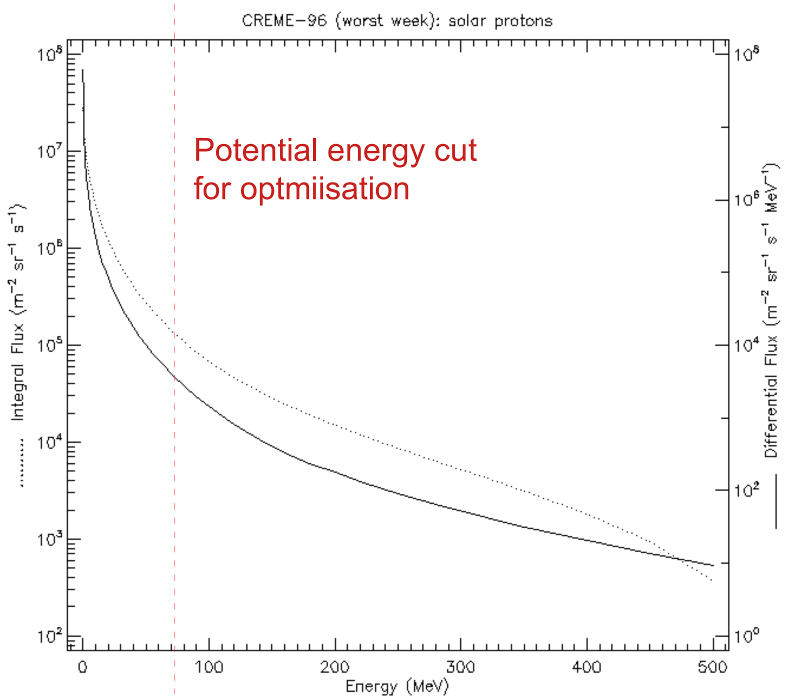
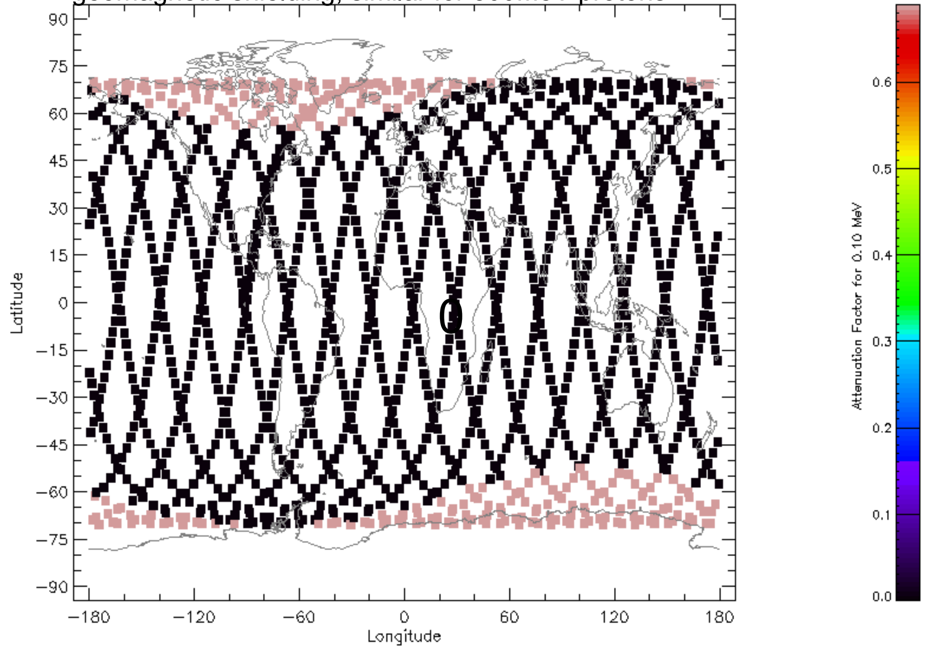
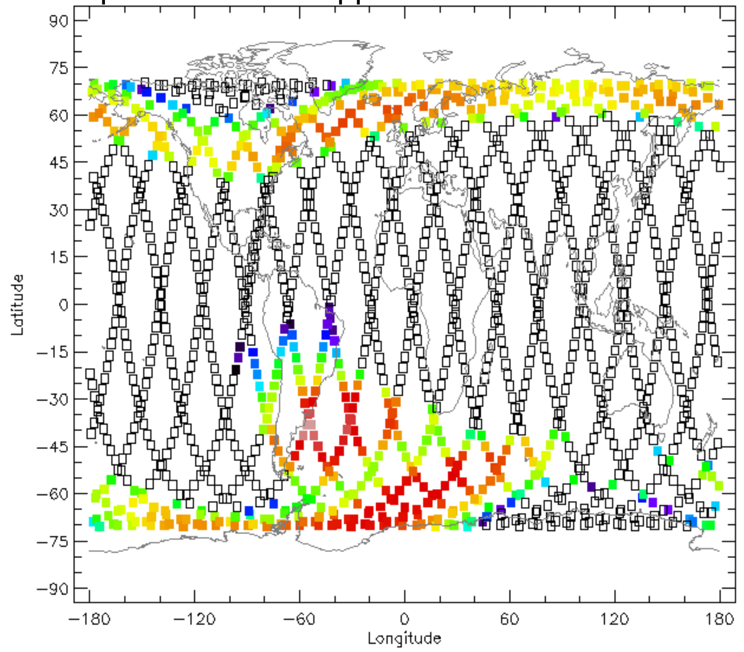


geomagnetic shielding, similar for 500MeV protons



expected flux of trapped electrons



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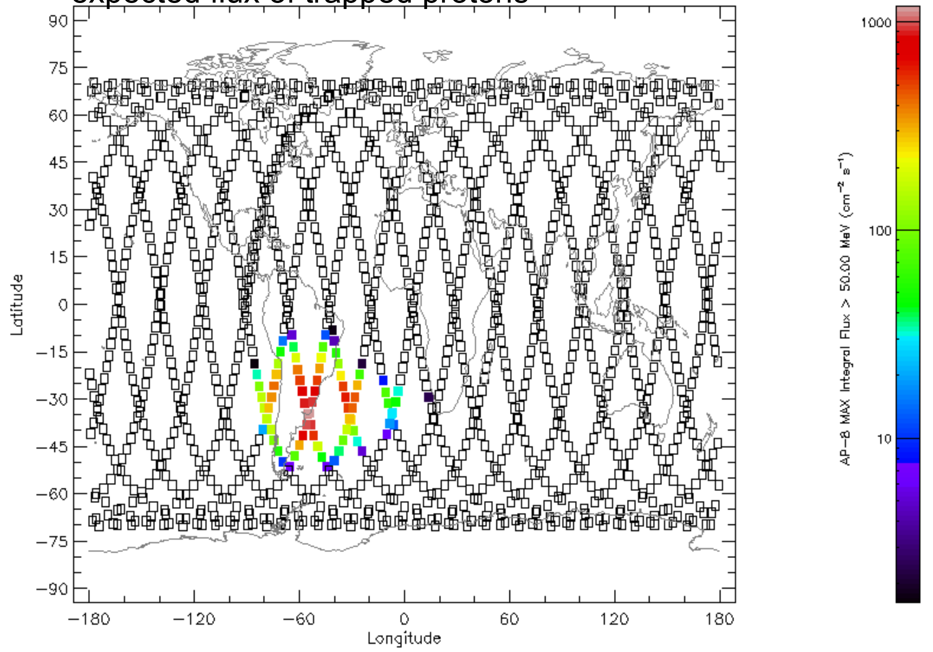

Good understanding of the radiation environment in LEO is essential for the detector design parameters. Tools such as the Space Environment Information System (SPENVIS) are useful for estimating particle fluxes, though various models and tools to ensure accuracy will be reviewed during the mission design phase.

Note the high flux intensity of protons in the SAA.

CENSSAT-1 and Timeline

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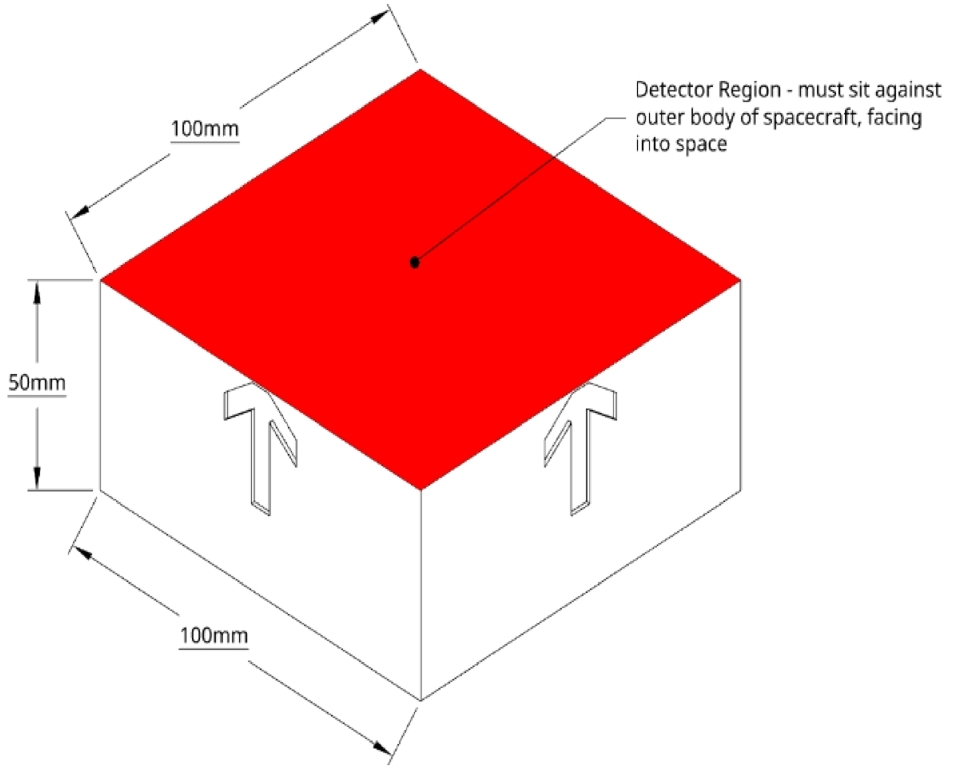
Deployment at ~500km at 95^{o} inclination
Mission lifetime of 1 year
Launch window late 2027/early 2028

Table 2: Mass and data budget for CENSSAT-1. Bracket percentages show the margin for error, which is unique for each instrument and estimated by the instrument teams.

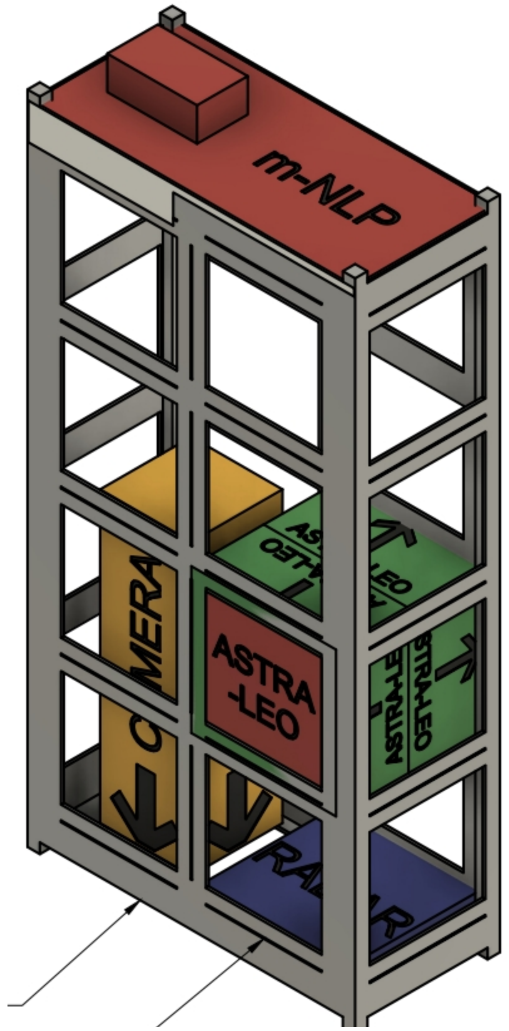
	Mass (kg)	Total Mass (kg)	Data Rate (MB/Orbit)	Total Data Rate (MB/Orbit)
Camera	0.7 (+20%)	0.8	5 (+10%)	5.5
ASTRA-LEO	4 (+20%)	4.8	39.8 (+20%)	47.8
m-NLP	0.5 (+5%)	0.5	50 (+5%)	52.5
Space Debris Radar	0.08 (+20%)	0.1	5 (+5%)	5.3
Total		6.2		111.1

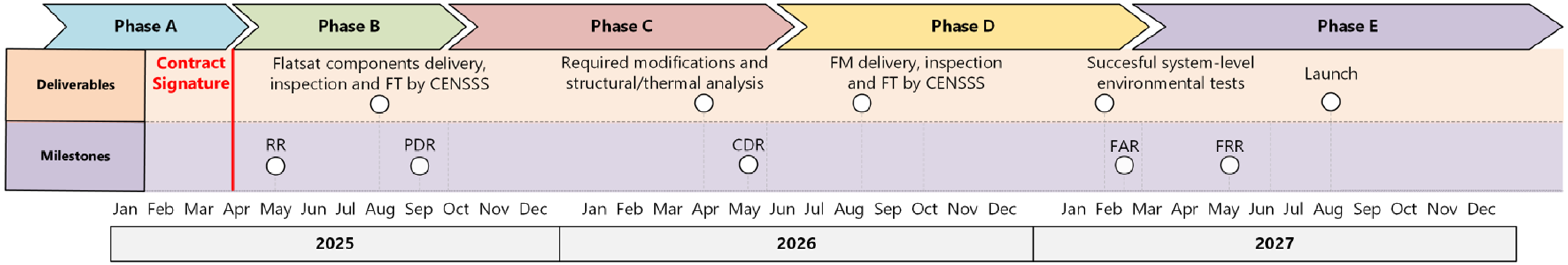
Table 3: Power budget for CENSSAT-1, including expected duty cycles.

	Power (W)	Margin (%)	Duty Cycle	Total Power (W)
Camera	4	20	0.3	1.4
ASTRA-LEO	10	20	0.9	10.8
m-NLP	2	5	0.9	1.9
Space Debris Radar	12.5	5	0.3	3.9
Total				18.0



1U payload, consists of two detector units, one zenith and one nadir facing, taking 10x10x10cm space.





Detector Design Adjustments for LEO

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GRB Detection: GRB photon spectra are non-thermal and typically modelled using the Band function

$$N(E) = A \begin{cases} \left(\frac{E}{100\,\mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right), & E \le (\alpha-\beta)E_0 \\ \left(\frac{(\alpha-\beta)E_0}{100\,\mathrm{keV}}\right)^{\alpha-\beta} \exp(\beta-\alpha)\left(\frac{E}{100\,\mathrm{keV}}\right)^{\beta}, & E > (\alpha-\beta)E_0 \end{cases}$$

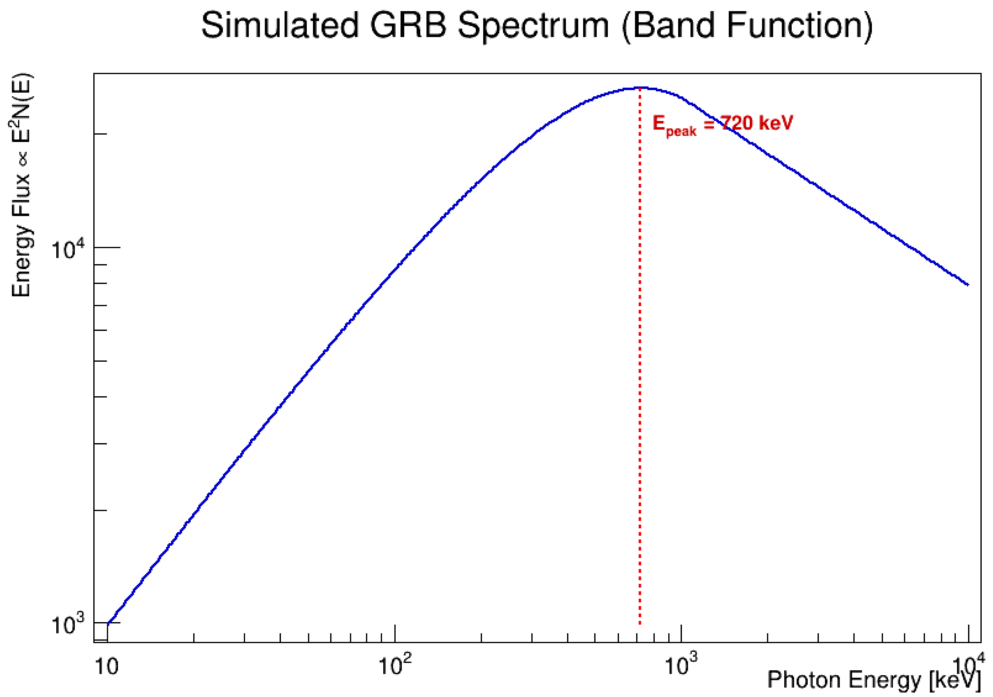
Fitting parameters
– α: Low-energy slope
– β: High-energy slope
– E_0: Characteristic break energy

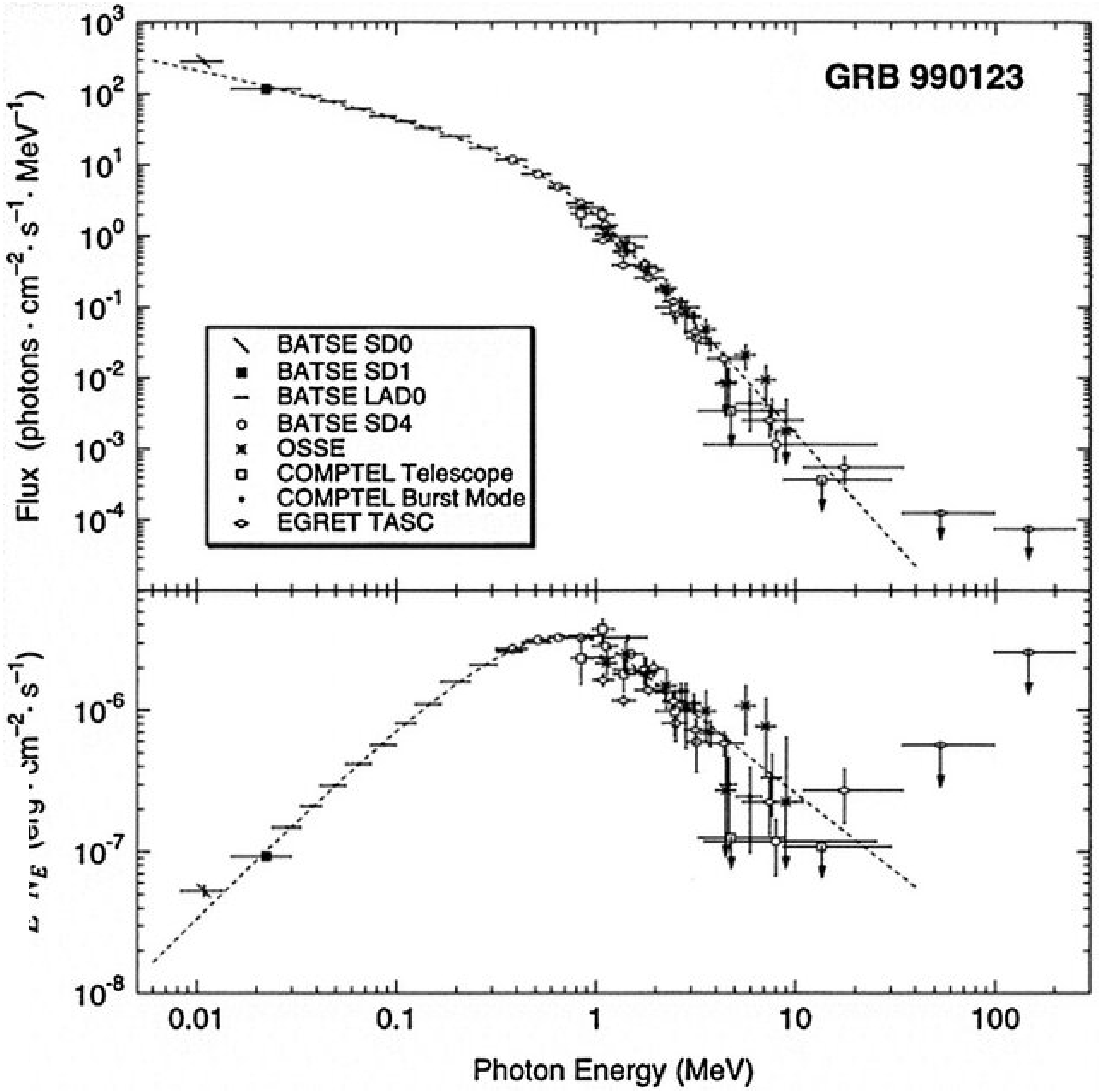
Characterised by low-/high-energy indices (α, β) and break energy (E_0):

- Simulate prompt GRB spectra
- Optimise detector energy response and trigger logic
- Estimating sensitivity to short vs long GRBs

Ep for long GRBs is often ~100–1000 keV

Stopping power:
A 1 cm CLLBC layer causes ≥ 90 % interaction probability for 50 keV – 2 MeV photons, covering the bulk of prompt GRB emission.





The Band function illustrated by spectrum of GRB 990123 with Epeak = 720 keV (Briggs et al. 1999) Taken from Willingale et al DOI 10.1007/s11214-017-0366-4

Detector Design Adjustments for LEO

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Earth-bound neutrons form anisotropic fluxes in LEO:
Upward-going: originate from atmospheric interactions
Downward-going: gravitationally returning neutrons

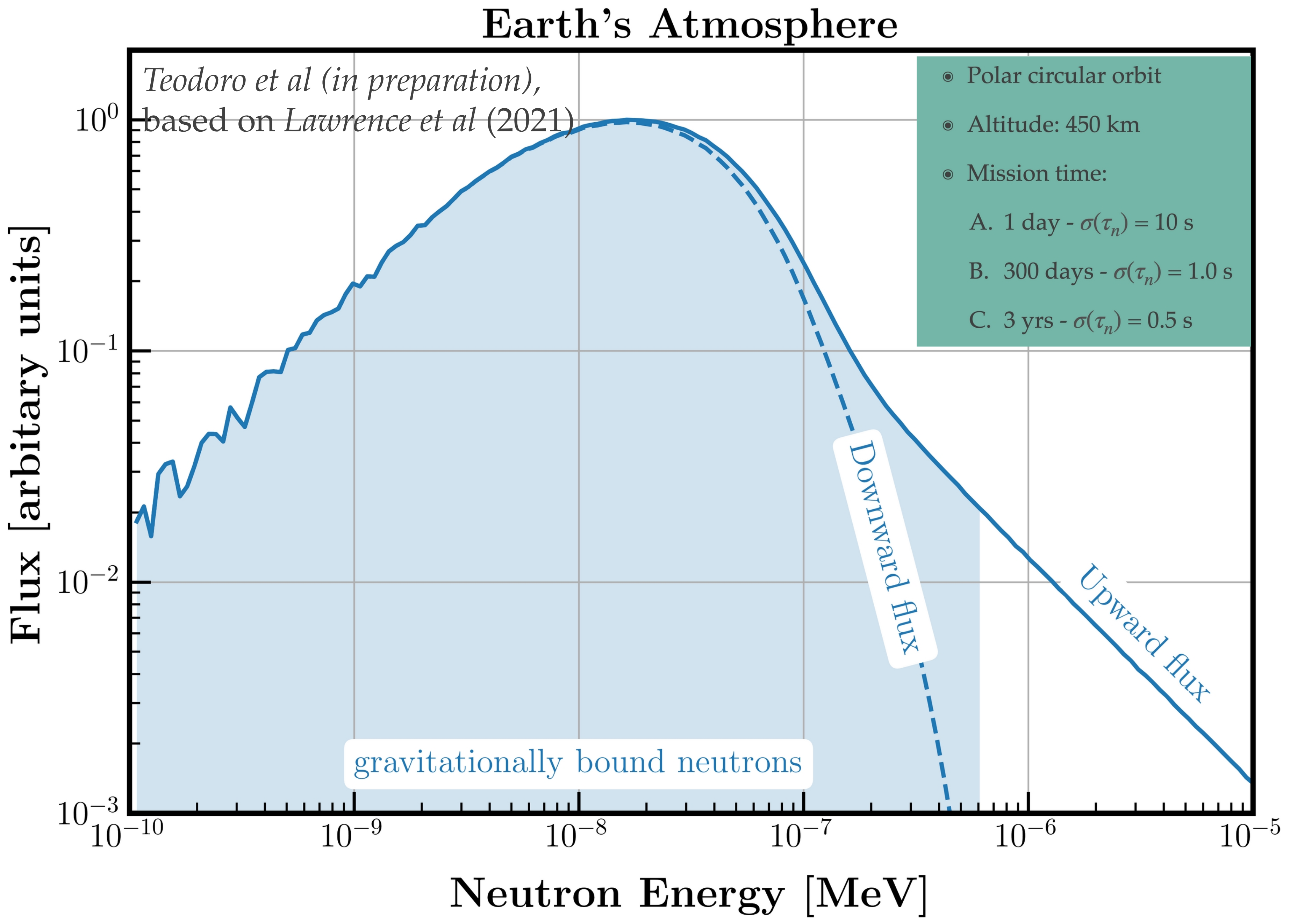
The flux asymmetry is sensitive to neutron decay time:

More decay in transit ⇒ fewer downward neutrons

Requires:
- Angular resolution of neutron fluxes
- Background discrimination and orbit-based modelling

It should be possible to distinguish epithermal from thermal neutrons by analysing the ratio of the Gd/Cd covered part of the detector with the uncovered.

Fast neutrons can also be identified by analysing the energy-deposited signatures in the EJ-248M tiles and the crystal scintillators. This will be investigated at the end of the detector design phase using Geant4 simulations. Combining these scintillators and detection techniques will allow identification of neutrons of different energies, gamma-rays and charged particles enhancing the capability of the ASTRA-LEO detector units.



Designing a Scintillation based Radiation Detector

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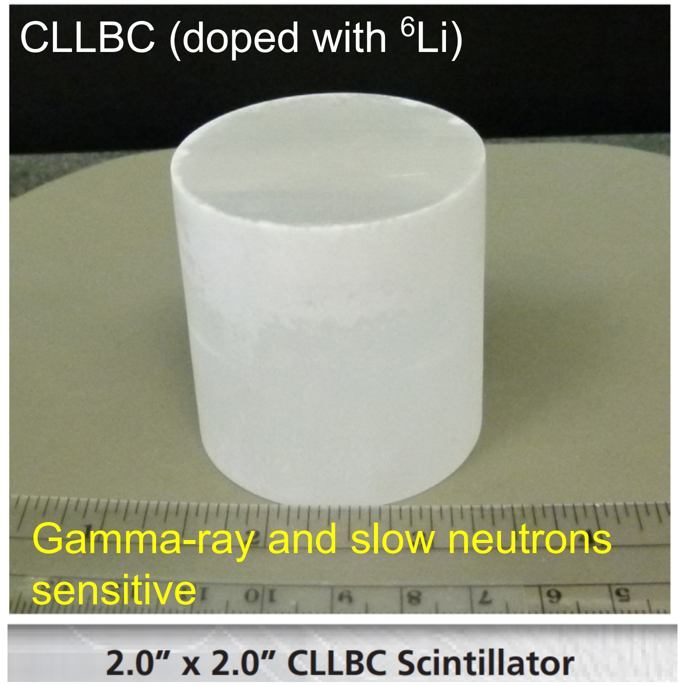
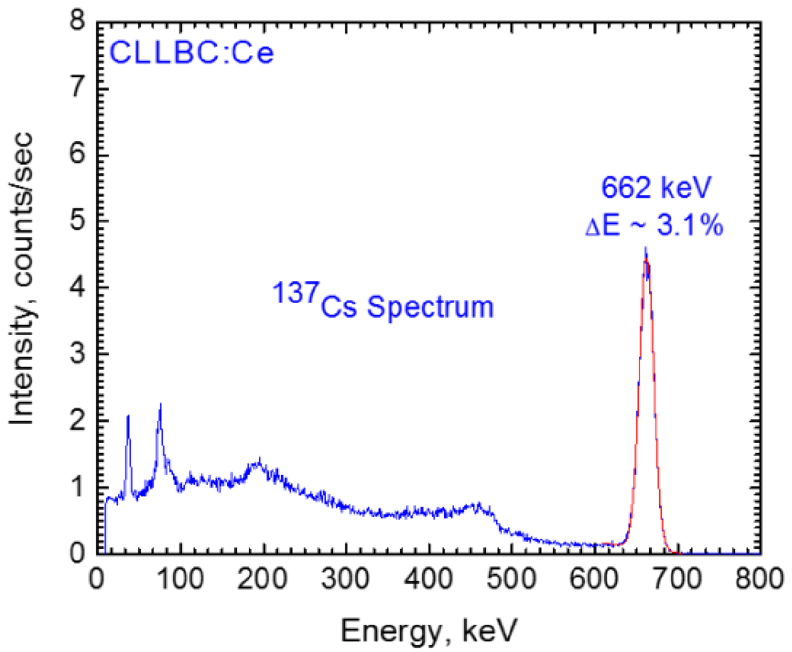
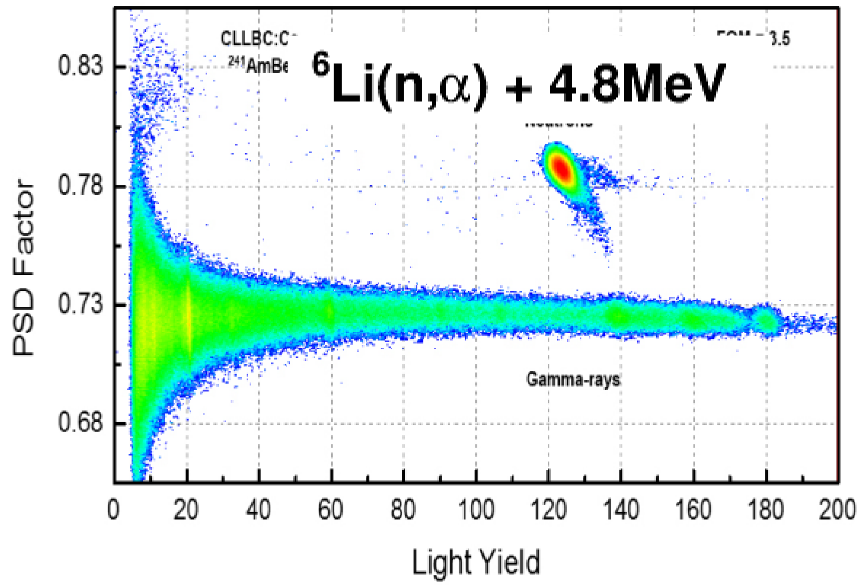
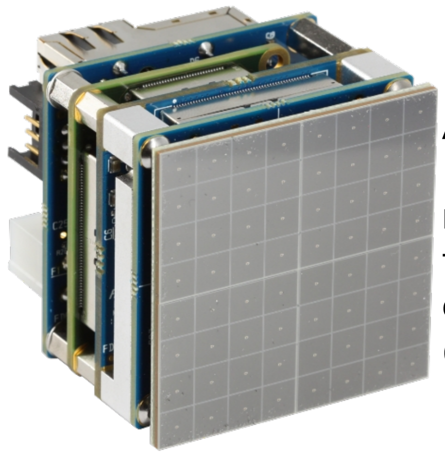
There are many different scintillator materials, each suited for a specific type of radiation and has its own unique properties:

- Gamma-ray spectroscopy mainly via photoelectric/Compton and pair-production (**inorganic scintillators**),
- Fast neutrons mainly via neutron scattering (**organic scintillators**)
- Thermal neutrons mainly via neutron capture in elements with high neutron absorption cross-section.
- Charged particles mainly via energy loss through ionization of the medium atoms (**organic + inorganic scintillators**)



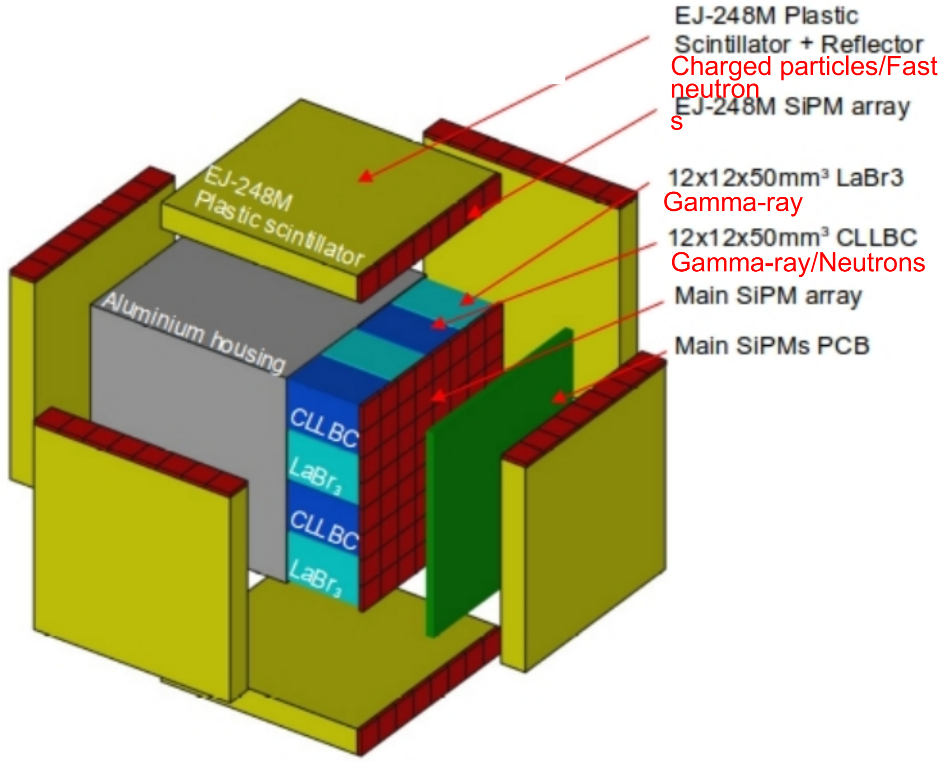






An array of Hamamatsu SiP mounted on top the readout electronics (ROSSPADs)

https://ideas.no/products/rosspad/



Detector Design Adjustments for LEO

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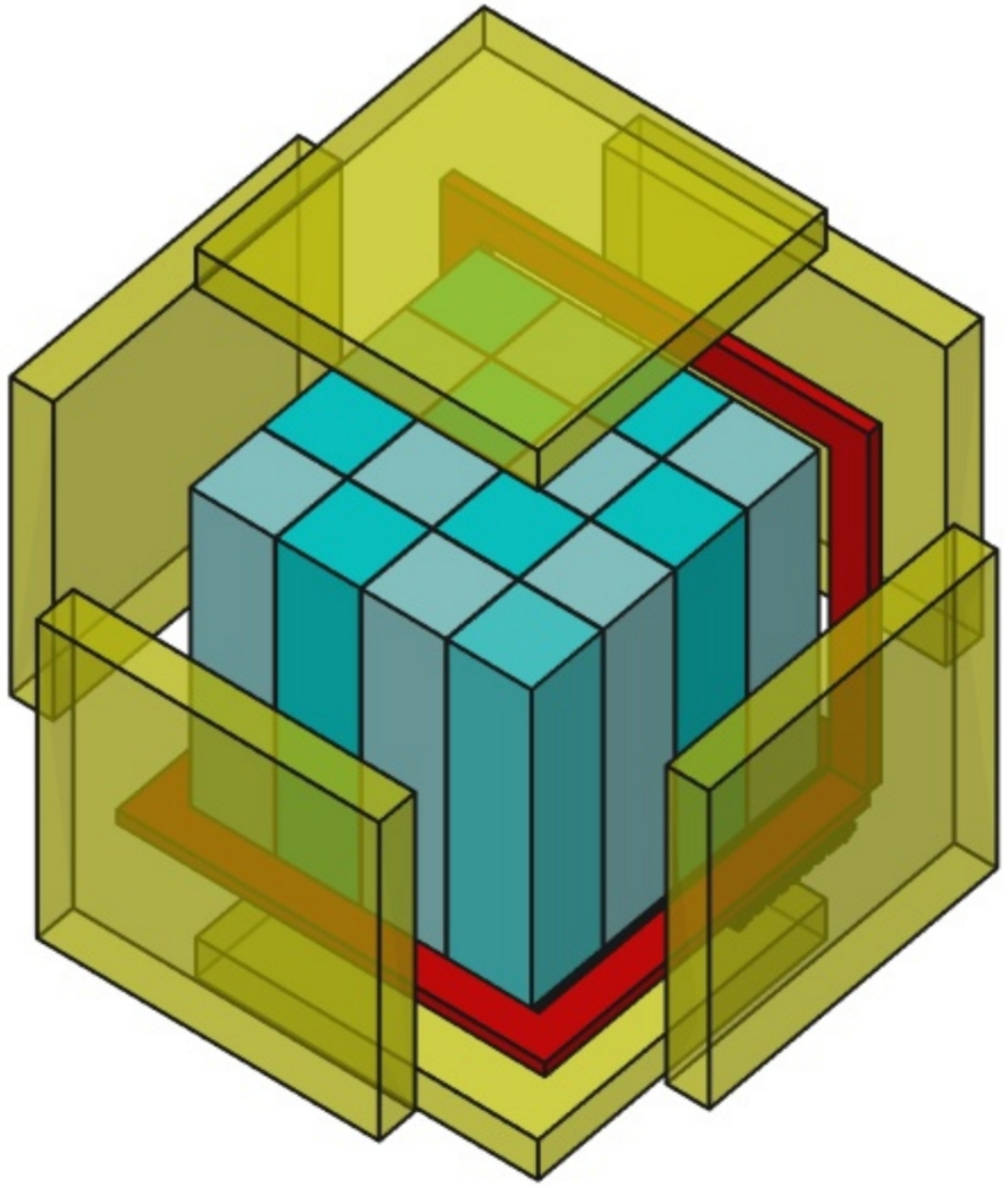
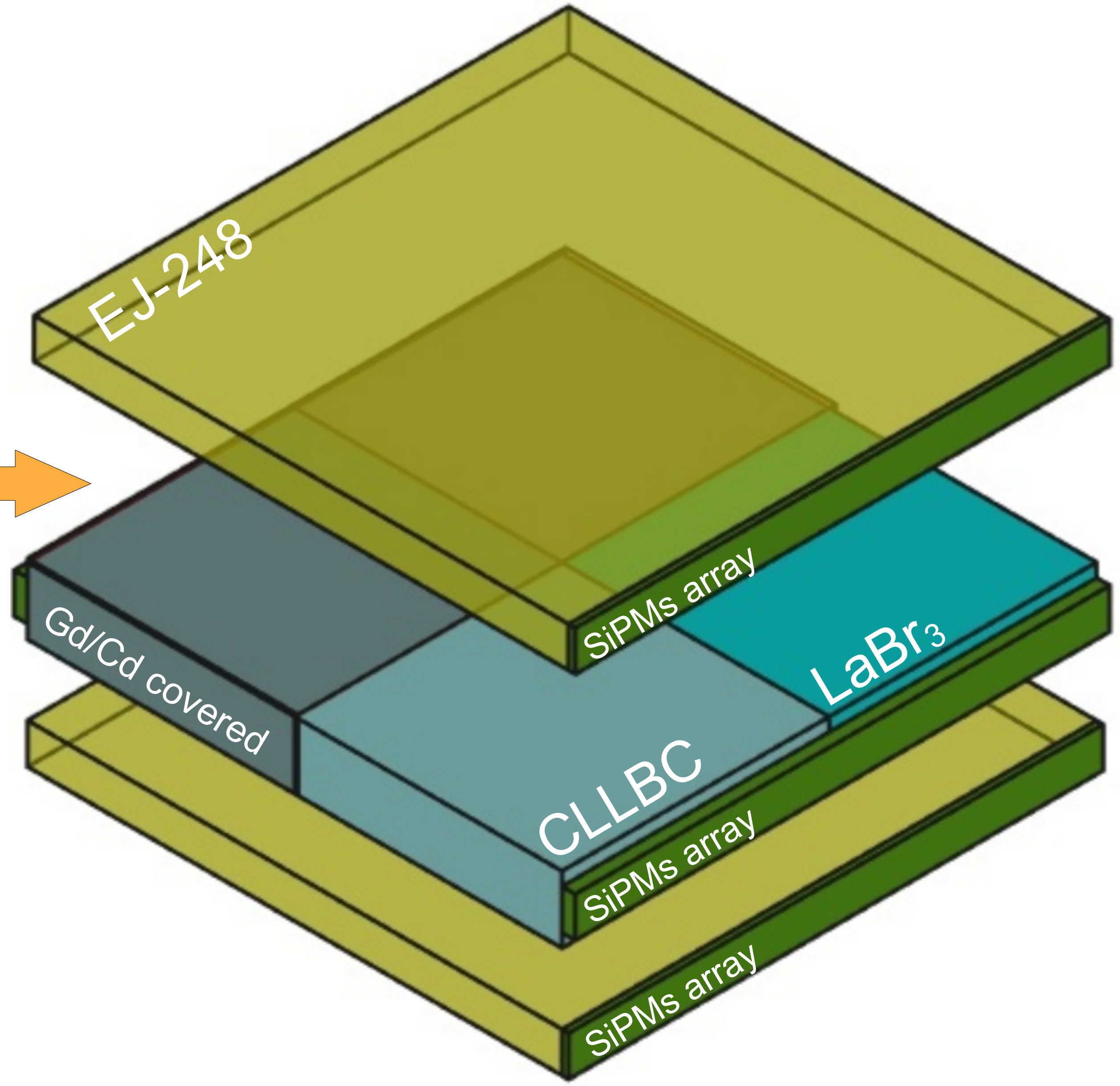
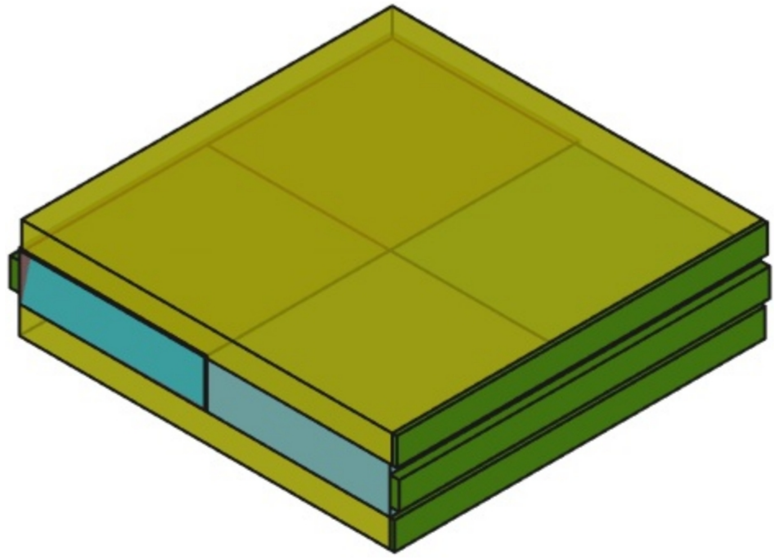
Original concept



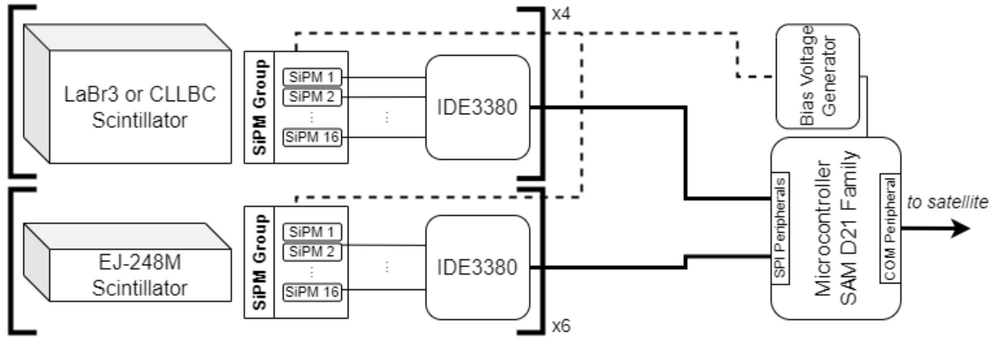
Adapted to CENSSAT-1 (Preliminary)



Compact sensor: 8 × 8 × 1 cm³ crystal ≈ 300 g, fitting within CubeSat-class mass and volume budgets. ~400g



Readout electronics will be based on the Radiation hard IDE3389 and a MC



Work in progress: Measurements at ESS Source-Testing Facility April 2025

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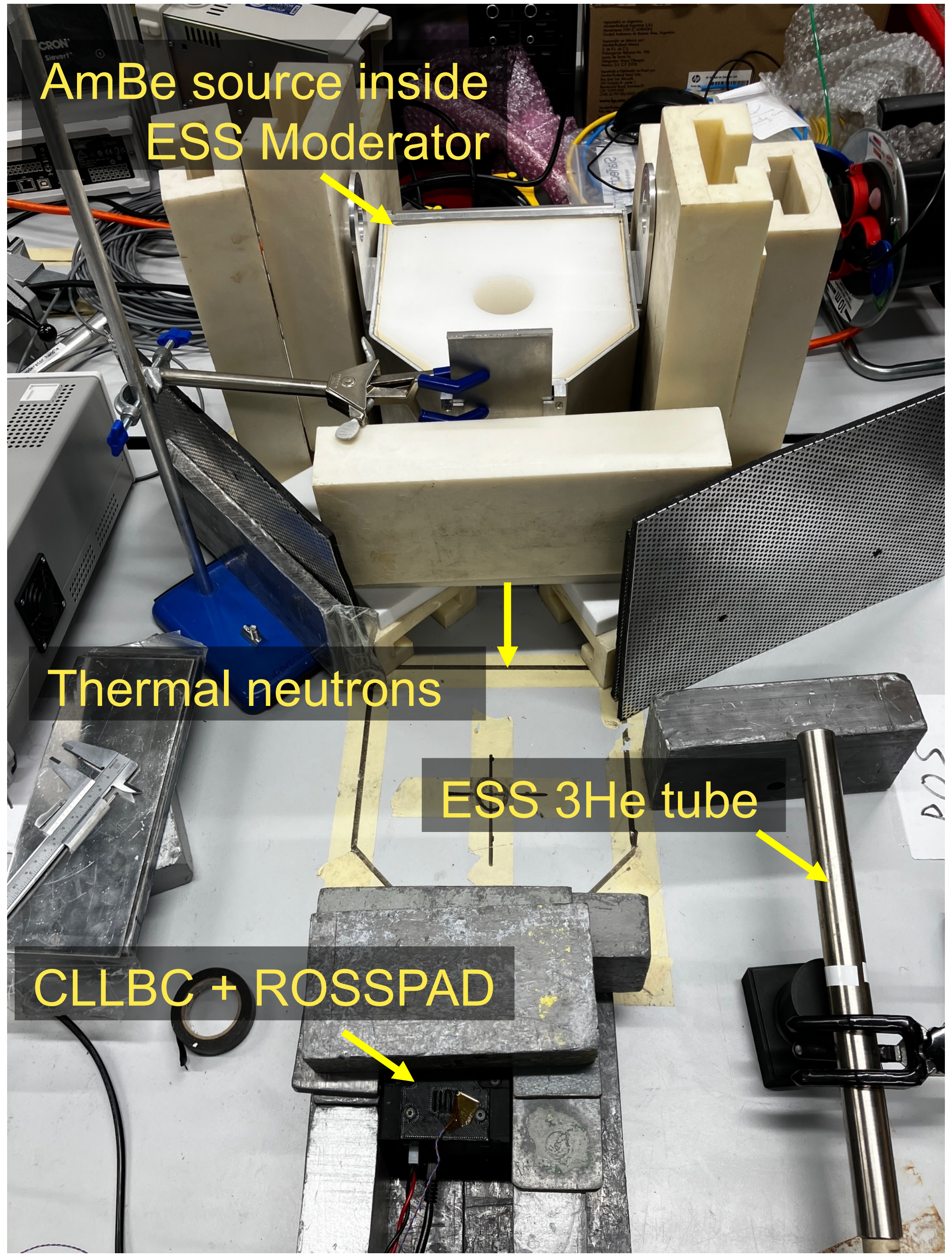
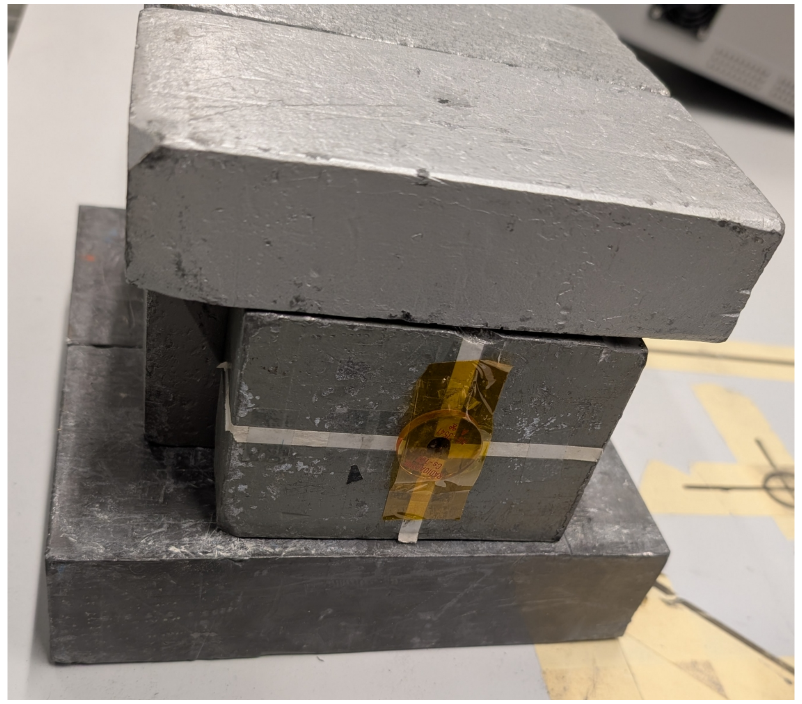
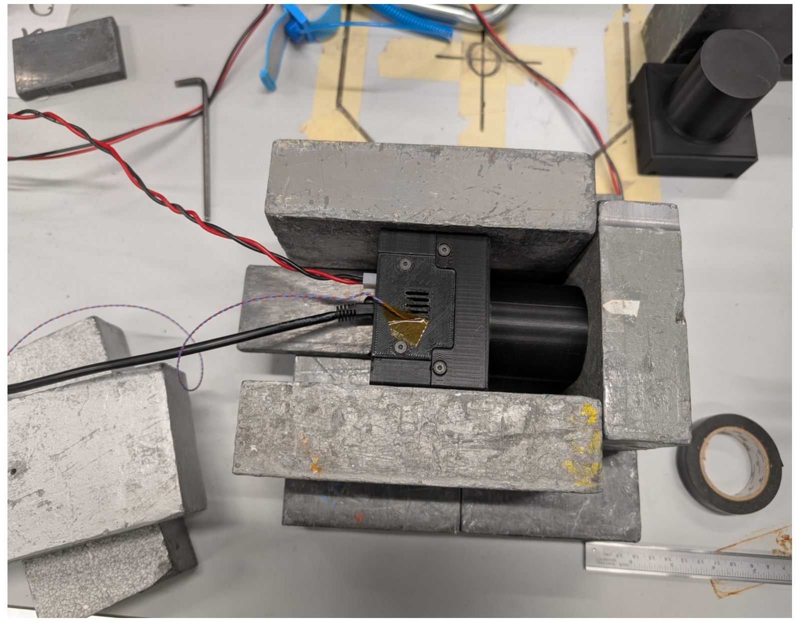
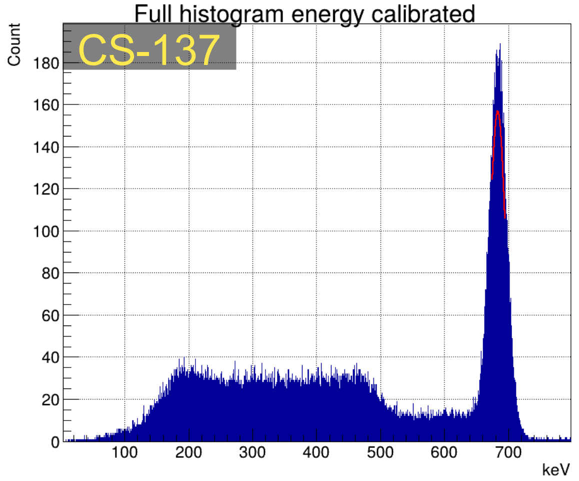
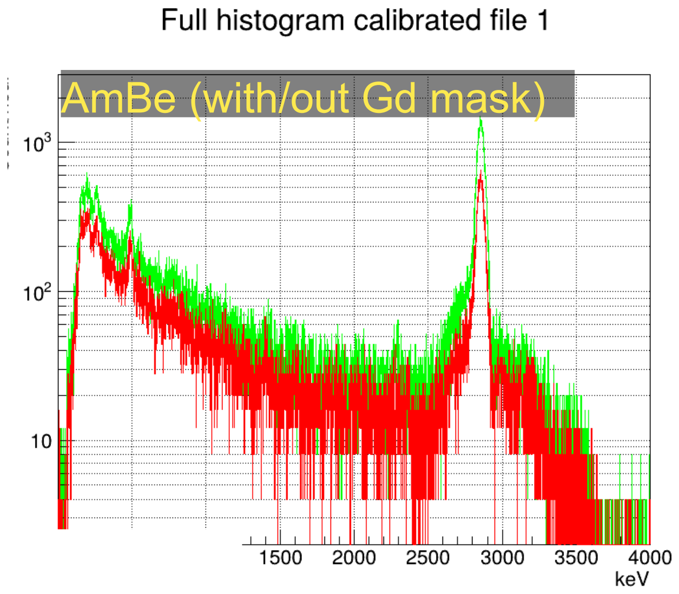






Rebecka Wahlén at ESS Source-Testing Facility in Lund, April 2025





Conclusion

- Space radiation offers a rich and dynamic environment waiting there to be explored.
- Compact hybrid neutron and gamma-ray detector concept at CENSSS selected for ESA OSIP pre-phase A study -> SER3NE mission proposal.
- Optimising the concept for LEO on CENSSSAT-1 using detailed demonstrator modelling.
- Two PhD candidates Rebecka Wahlén and Sam Holdcroft drive ASTRA-LEO and support the development of the SER3NE detector.
- Next-generation space orienated instrument aims to double thermal-neutron efficiency and enable fast-neutron detection:
    - A factor of 2 improvement in thermal neutron sensitivity.
    - Single scintillator material, i.e largely reducing systematics and simplify modelling
    - Enables fast neutron detection together.

The team

Codin Gheorghe

Anja Kohfeldt

Rebecka Wahlén

Svein-Erik Hamran

Anastasios-Faidon Retselis

Elise Wright Knutsen

Luis Filipe Alves Teodoro

Sam Holdcroft