Energetic Particle Spectrometers for Application within the Distributed Space Weather Sensor System (D3S):

The Energetic Particle Telescope (EPT), its Proposed Miniaturization and the 3D Energetic Electron Spectrometer (3DEES)

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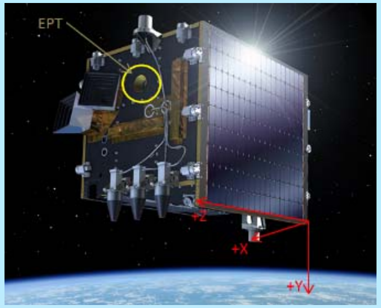
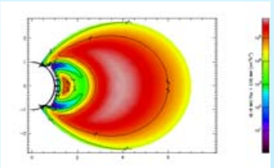


Science-class spectrometers / space radiation monitors / dosimeters are useful tools embarked on spacecraft to collect data for various purposes:

Spacecraft operations:

- Spacecraft anomaly diagnosis: anomalous-event analysis
- Radiation survey during Electric Propulsion Raising



Validation/improvement/development of radiation environment models:

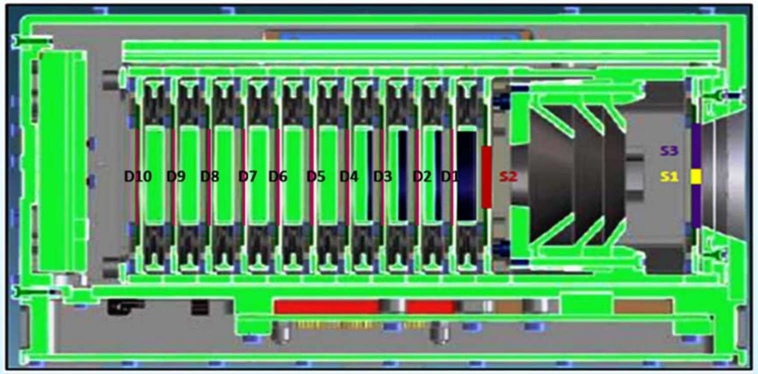
- Spacecraft engineering: allow optimal design and avoid overdesign against radiation
- Space-environment studies

Space weather services:

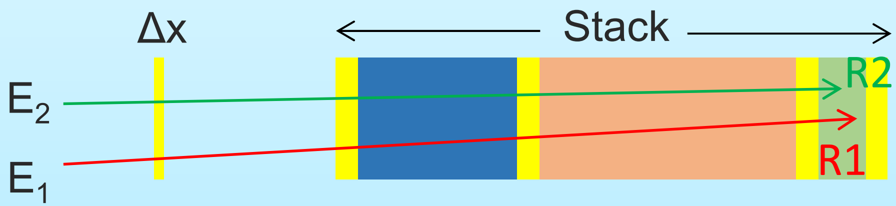
- ESA SSA Space Weather Network: collect as much measurement data as necessary to provide timely and accurate space weather information, nowcasts and forecasts
  - Ground-based instruments
  - Hosted payload instruments and potential SmallSat missions ➔SSA 'Distributed SWE Sensor System' (D3S).

❑ The concept:

M. Cyamukungu, G. Grégoire, *SPIE – Proceedings*, Vol. 8148, p. 814803-1-11 (2011)



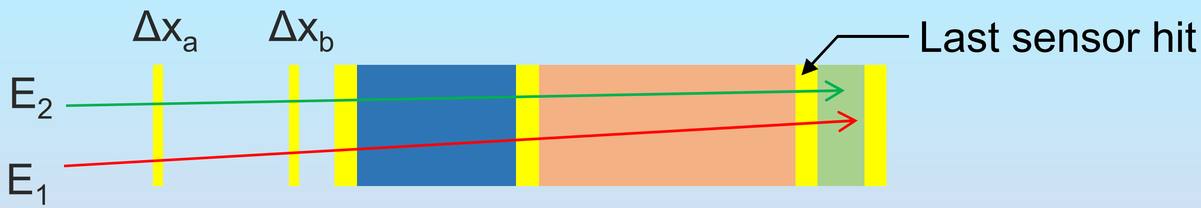
Detecting electrons, protons and He without inter-species contamination



$$\begin{cases} \Delta E_2 - \Delta E_1 = \Delta x (S_2 - S_1) \\ R_1 = R_2 \end{cases}$$

Two particles belonging to different species (1 and 2), having the same «range» can be readily identified if their stopping powers (S_1, S_2) in Δx are different.

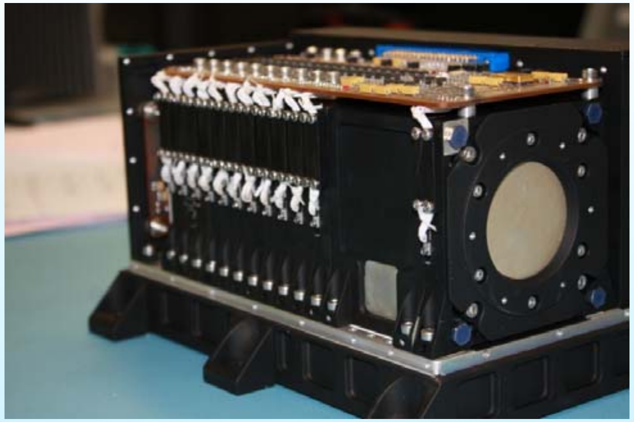
Achieve error-free particle discrimination through «coincident identification» where the result from the «Δx_a-Stack assembly» is cross-validated by that from the «Δx_b-Stack assembly».



❑ The instrument:

Proba-V with EPT onboard was launched on 7 May 2013 into a sun-synchronous polar orbit at ~820 km altitude

The EPT is oriented WEST when in daylight and oriented EAST when in eclipse



- ❖ Performs inflight particle discrimination
- ❖ straightforward count to flux conversion **with no assumption on spectral shape**

TABLE I
ENERGY LIMITS (IN MEV) OF THE VIRTUAL CHANNELS (VC) FOR EACH PARTICLE TYPE

VC	Electrons	Protons	He-ions
1	0.5-0.6	9.5-13	38-51
2	0.6-0.7	13-29	51-116
3	0.7-0.8	29-61	116-245
4	0.8-1.0	61-92	245-365
5	1.0-2.0	92-126	365-500
6	2.0-8.0	126-155	500-615
7	8.0-20	155-182	615-720
8		182-205	720-815
9		205-227	815-900
10		227-248	900-980
11		>248	>980

M. Cyamukungu et al., *IEEE TNS*, vol. 61, no. 6, pp. 3667-3681, December 2014

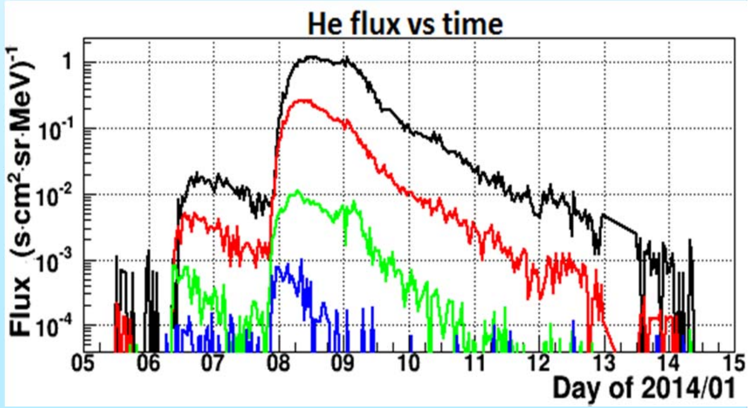
❑ The achievements:

❖ Proton angular distribution in the SAA

- Rotation of the satellite in a given position bin: determination of the anisotropy factor
- Observation of the East-West asymmetry

❖ Solar Energetic Particle (SEP) event analysis

- Analysis of the January 2014 event as a function of time and location
- Composition (H, He) and spectral analysis



❖ Radiation belt dynamics characterization

- Decay time analysis of electron fluxes after geomagnetic storm inducing flux enhancement
- Analysis of the effects of big storms on the radiation belts
- Analysis of inner belt dynamics outside and inside the context of big storms

The Proposed Miniaturization mEPT

- **Requirements for a radiation spectrometer / monitor that can be easily embarked on / in any spacecraft.**

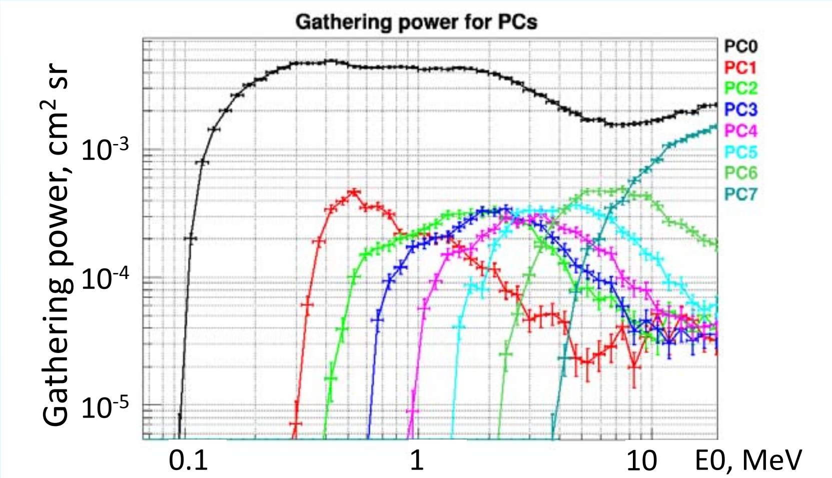
Users' requirements	Physical / Electrical	EPT specifications
Compact	<200 cm^3 (e.g. hybrid in package)	4300 cm^3
Low mass	~200 g	4.6 kg
Low power consumption	~ 1 W	5.6 W
Sensor supply voltage	< 40 V (TBD)	max 60 V
Reduced telemetry	< 2.5 kbit per integration time	4 kbit per integ. time
Interface	Number of pins < 16	9 & 15 pin connectors

❑ Requirements for a radiation detector to act as spectrometer and dosimeter on GTO, GEO, MEO orbit

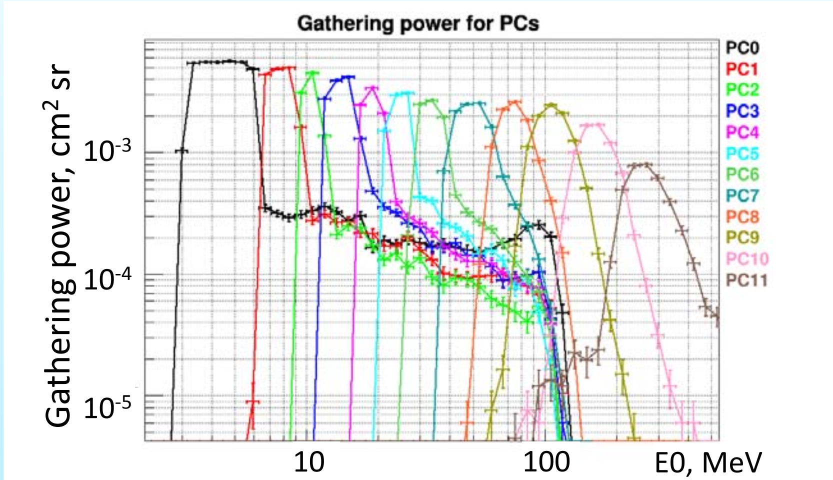
+ Requirements	Functional
Particle rate	Fluxes of up to 10^8 #/cm^2/s (target GTO, GEO, MEO) i.e max <10^5 #/s on most exposed sensor
Particle Species Identification	The capability to classify in-flight the detected events with respect to particle species (electrons, protons, ions) High purity channels with no noise counts.
Spectrometric function	Extraction of the **incident particle spectra** • electrons: 100 keV – 7 MeV • protons 4-400 MeV and • ions < 100 MeV/n with a minimum of 8 quasi-logarithmic energy bins per particle type.
Dosimeter function	Total dose in the front sensor(s) shall be recorded along with information on the **contributing particle** and **energy channel**

❑ **Detection efficiencies** of the channels in mEPT based on the extended EPT concept.

Electrons:



Protons:

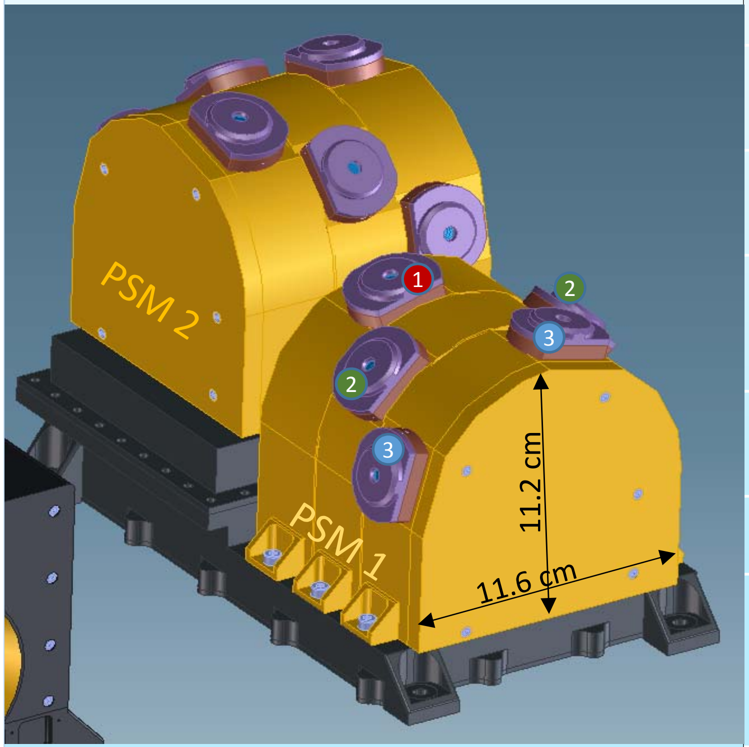


		Incident threshold E (MeV)	
Phys. Channel	Last sensor hit	Electrons	Protons
PC0	S1	0.1	2.8
PC1	S2	0.3	6.3
PC2	D1	0.43	8.9
PC3	D2	0.65	11.2
PC4	D3	0.95	16
PC5	D4	1.3	20
PC6	D5	2.3	28
PC7	D6	3.8	39
PC8	D6	---	56
PC9	D6	---	89
PC10	D6	---	141
PC11	D6	----	223

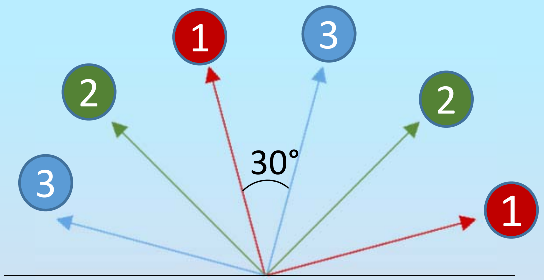
➔ Straightforward count to flux conversion

2 % contamination from 2-4 MeV protons

3DEES
ENERGETIC ELECTRON SPECTROMETER

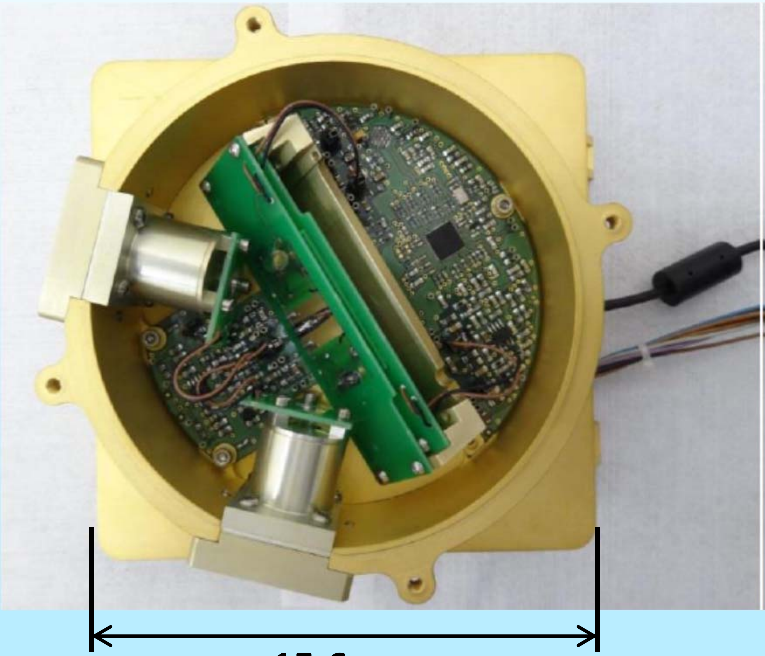


Particle identification		**Mechanical and electrical features per PSM**	
Electrons	100 keV - 10 MeV (16 to 32 channels)	Electrical interface	CAN bus or RS422
Protons	4 MeV - 50 MeV	Aperture diameter	5 mm
Electron energy resol.	20% at 1 MeV (adjustable)	FOV	15° per looking dir
Directions	12 angles with 15° FOV	Geometrical Factor	~2 10^{-4} cm^2 sr
Timing features		Mass	< 2 kg
Resolution	1 (nominal) to 300 s, Adjustable	Overall dimensions	12.0 x 13.6 x 12.7 cm^3
Peak flux	10^9 cm^{-2} s^{-1}	Power	~ 5 W



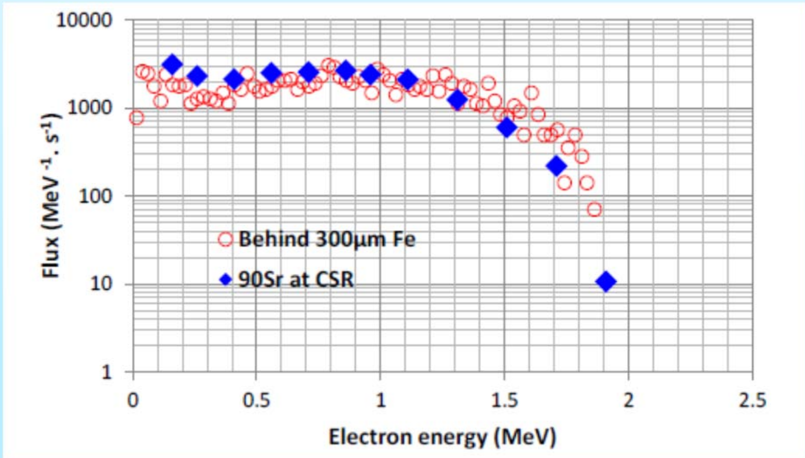
1 PSM (Panoramic Sensor Module) is composed of 3 OSM (Octagonal Sensor Module)

Prototyping: 1 OSM: 2 directions

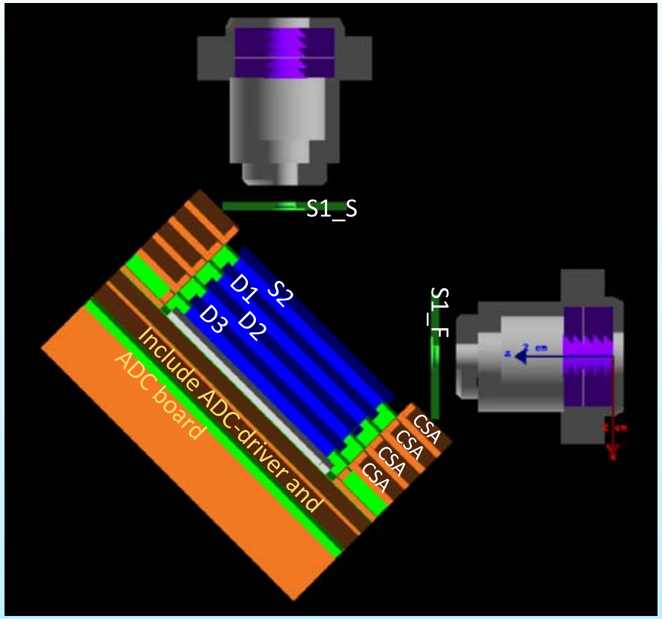


Definition of the physical channels also allow straightforward reconstruction of the incident spectra. Application to 90Sr spectra:

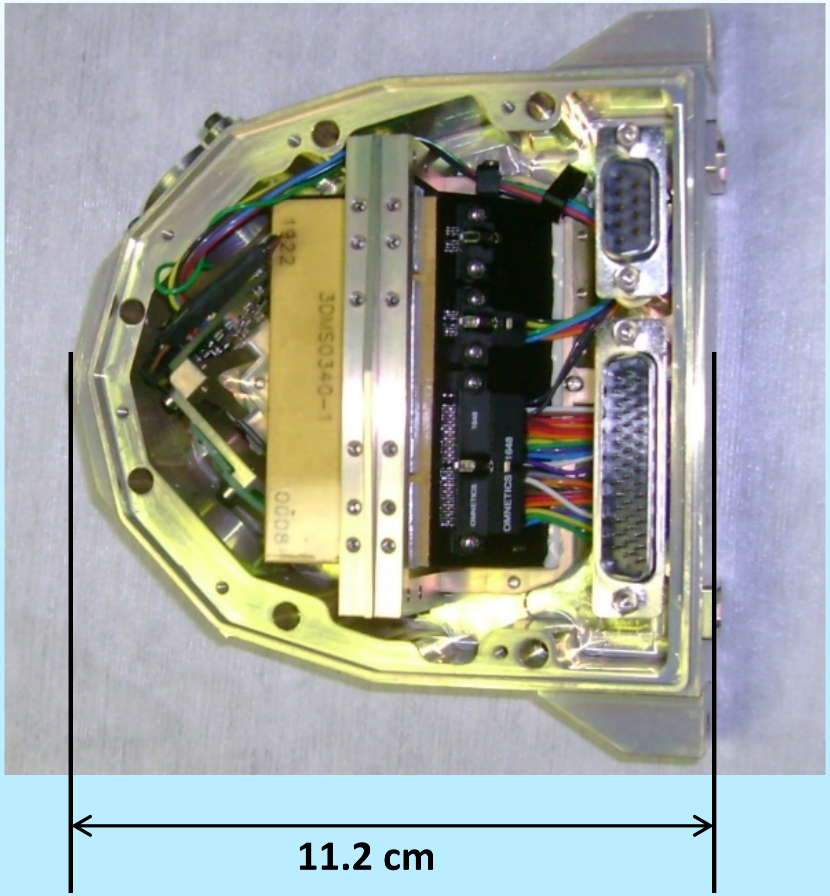
Measured spectrum (blue) compared to simulated 90Sr spectrum



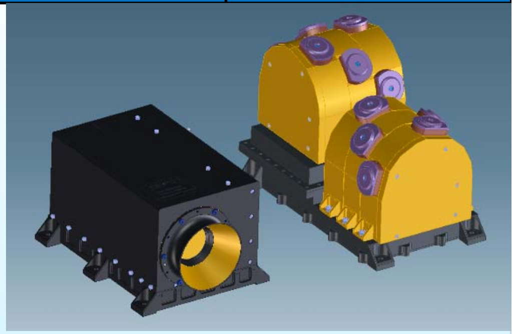
Rather voluminous ➔ miniaturization through stacking of the thick sensors (1.5 mm) and all FEE + moulding, for mechanical robustness



Phase C1:
First moulded sensor stack in a test box representing a real OSM box



- D1-D2-D3 perfect signal output, but noise in S2 is outside the specifications
- CCN planned
- Targeted mission is Proba-3



❑ **Summary:**

Three science class spectrometers has been presented

➢ The EPT has been delivering valuable data for over 6 years. They are included in the ESA - Space Situational Awareness Space Weather Services.

➢ It is possible to use the **EPT concept within a miniaturised instrument** ➔ Enabling technologies exist.

The mEPT has inherited the good particle discrimination capabilities of the EPT ➔ straightforward count to flux conversion **with no assumption on spectral shape.**
It is very suitable for accommodation on small satellites.

➢ The 3DEES is actually still under development. It will give a detailed image including directionality of the electron flux spectra in space.

Thank You

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