Space environment: effect on detectors examples with Integral and Astro-H

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Plan

1. Description of the space environment.
2. Effect of radiation on electronic devices.
3. Calibration project for Astro-H.

The space environment

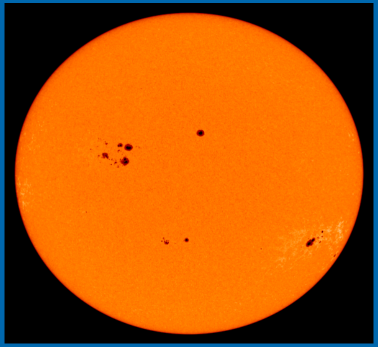
Space constraints

- Launch
  - Chocks, vibrations
- Space environment
  - Thermal Variations
  - Vacuum
  - Radiations
  - Contamination
  - Micrometeorites, space debris

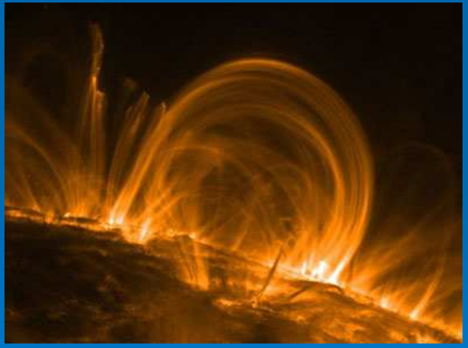
The radiative environment

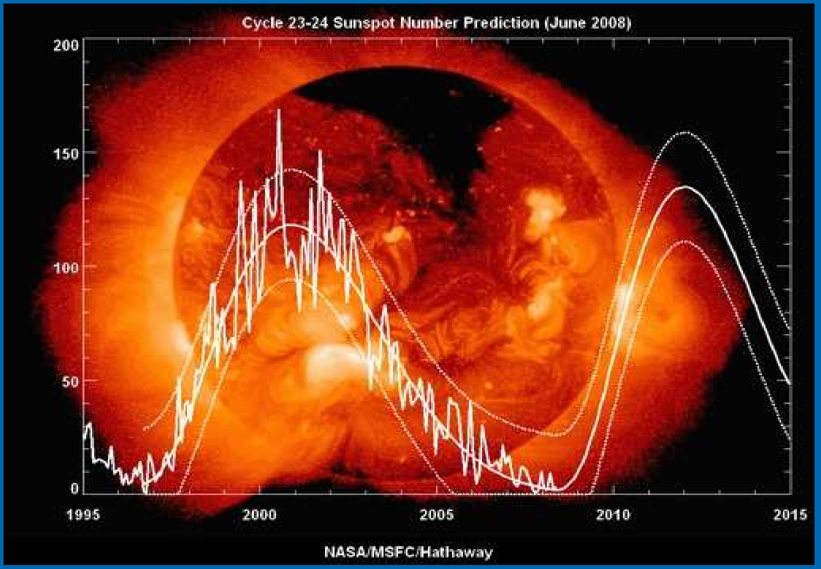
Solar activity

Sunspot
(Galilée, 1610)

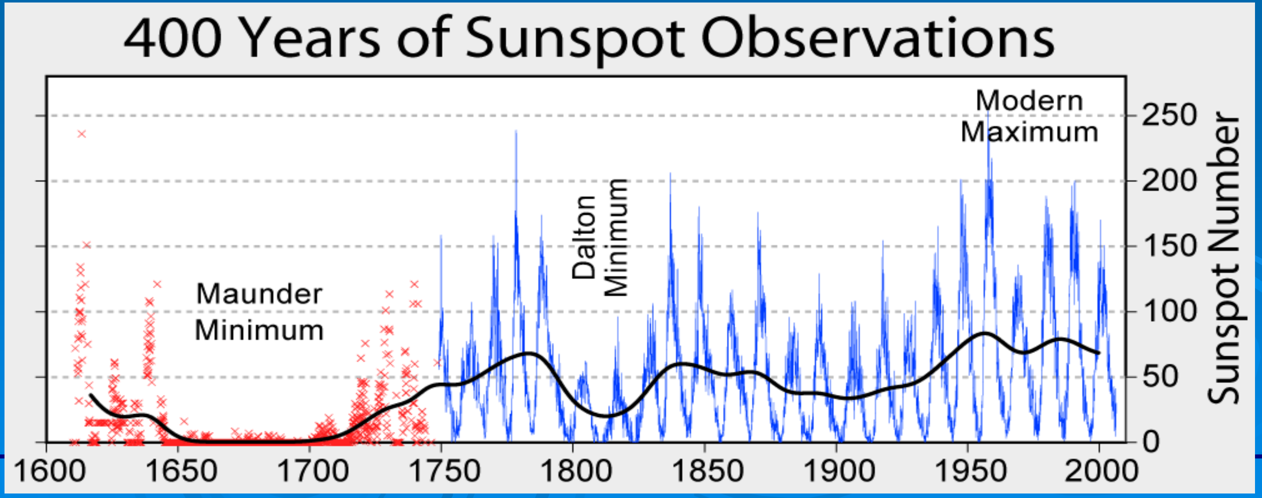


flares



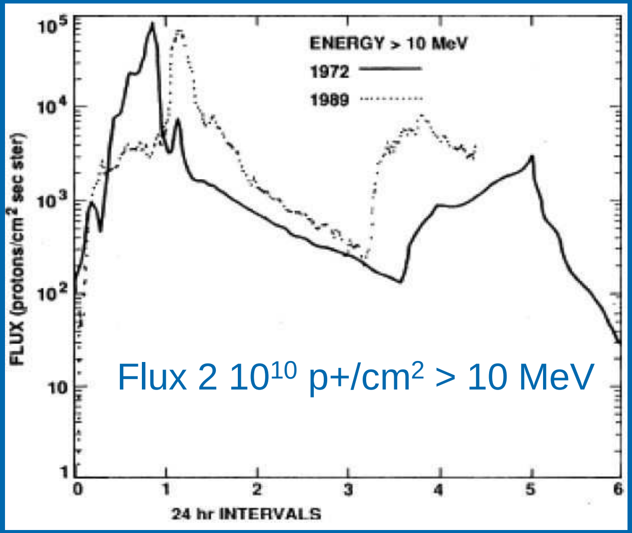


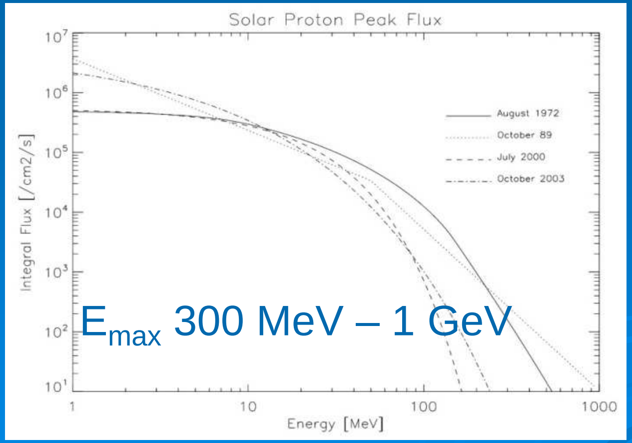
11 ± 2 years cycle
Cycles are not similar !

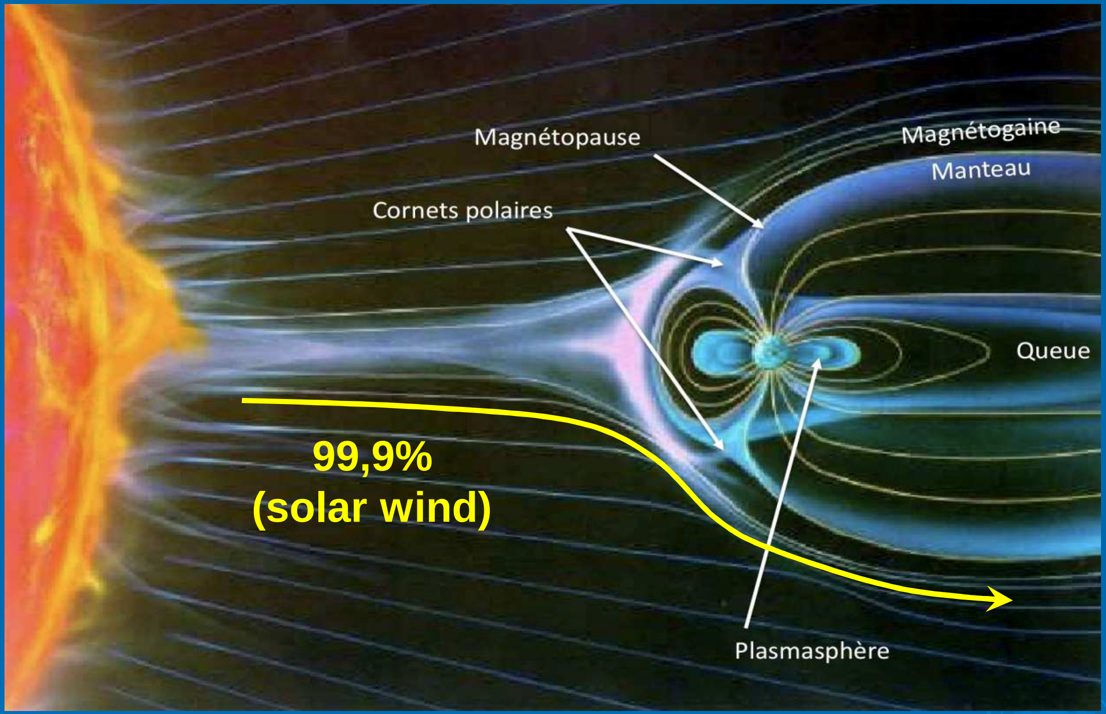


Solar particles

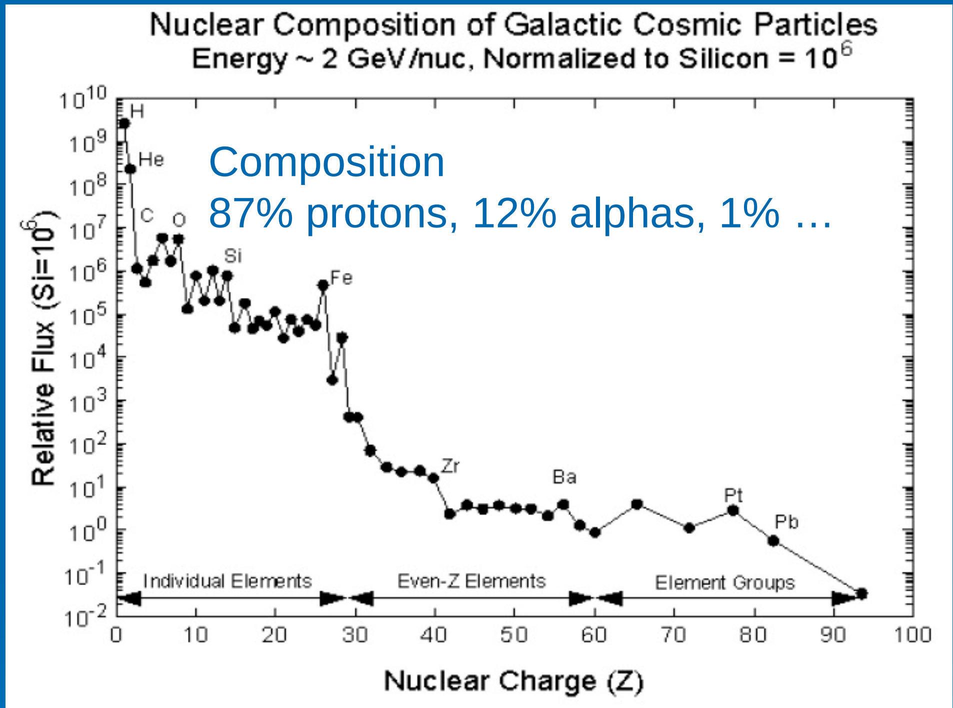
Events occuring on hours to days timescale





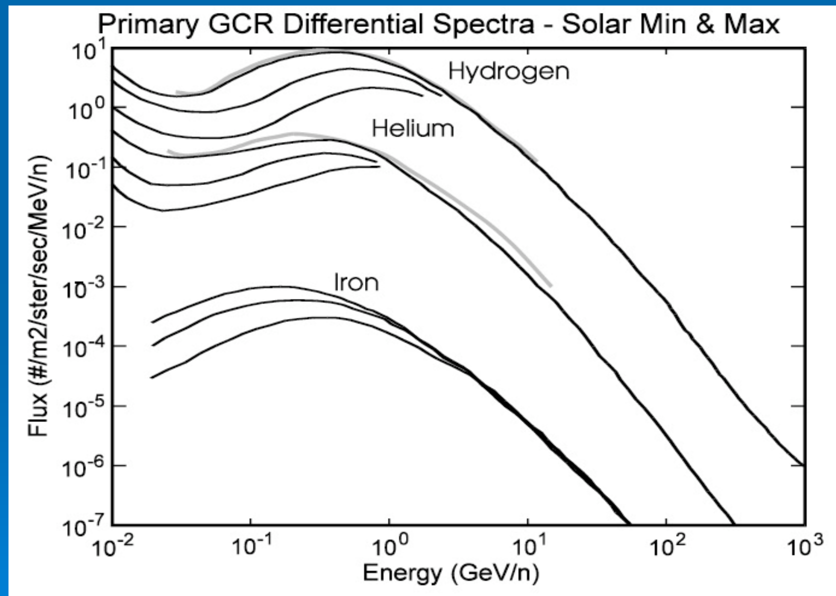


Cosmic Rays

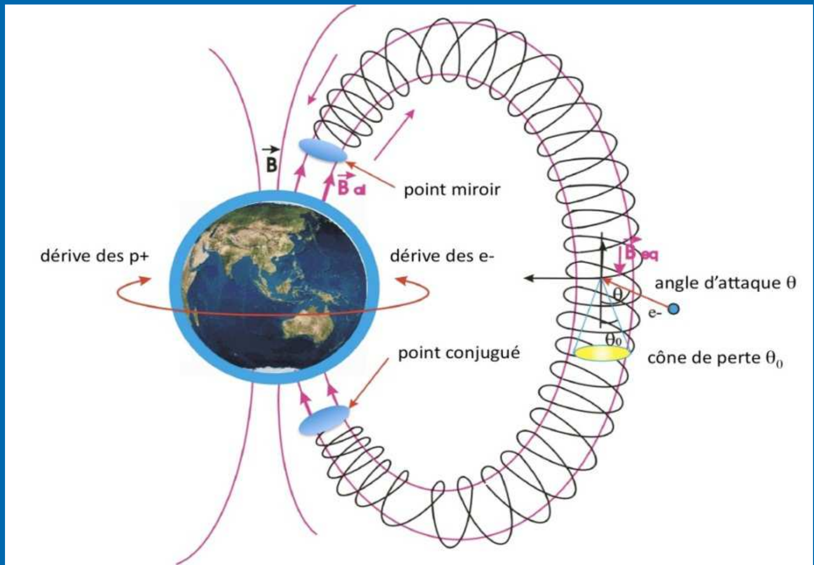


Composition
87% protons, 12% alphas, 1% …

Solar modulation



Trapped particles

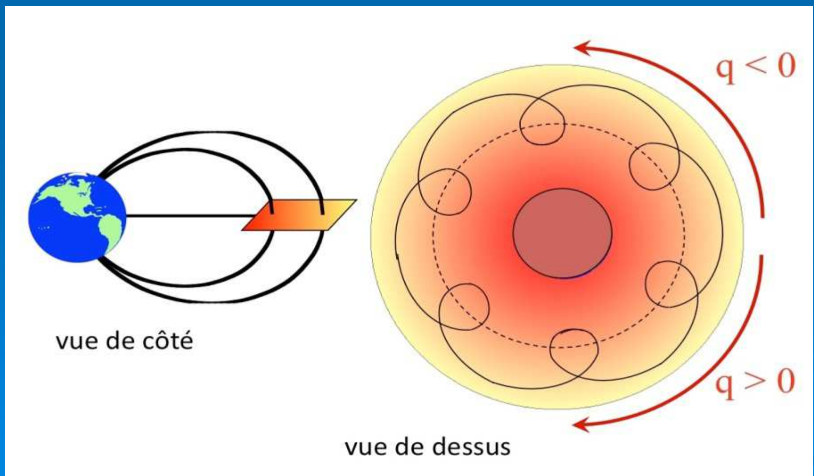


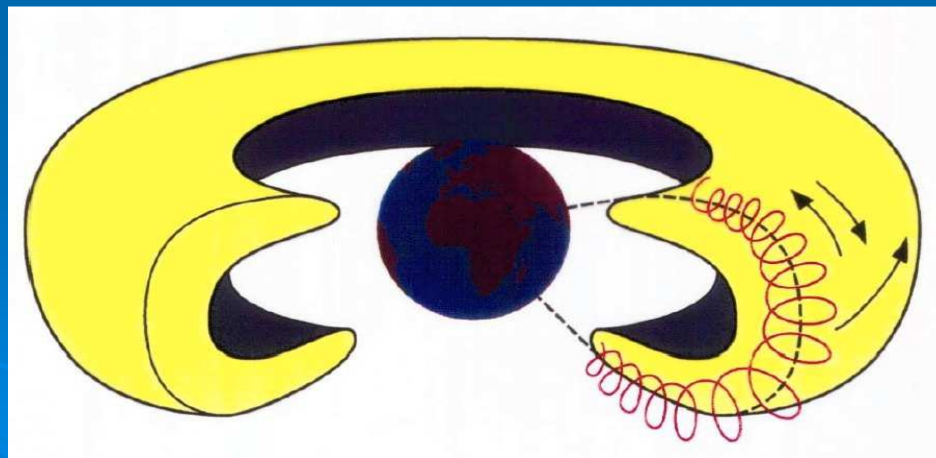
Trapping mechanisms:

• rotation (Lorentz force)

• Magnetic mirror.

• East-West drift, due to magnetic field gradient.





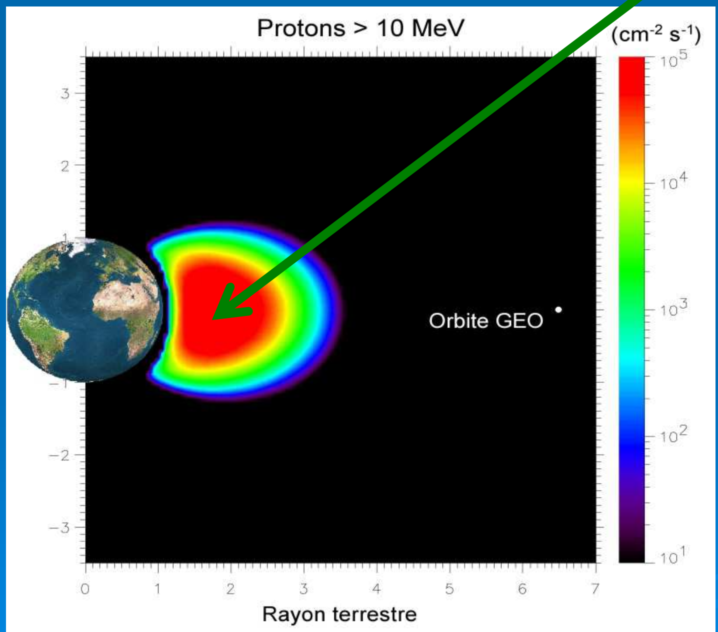
Van Allen belts

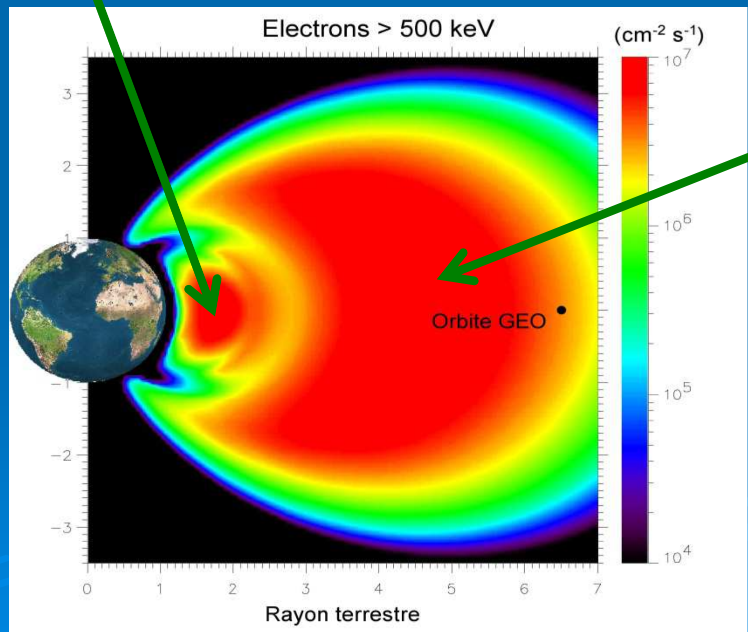
Two belts:

- Internal (stable)
- External (dynamic)

Protons and electrons coming from cosmic and solar particles interaction into the atmosphere

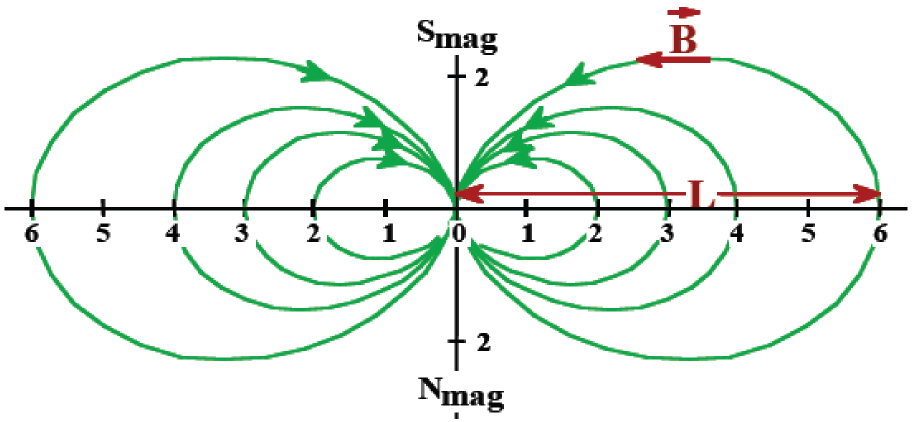
$$n \rightarrow p^{+} + e^{-} + \overline{\nu}_e$$





Solar particles injected from the magnetosphere tail.

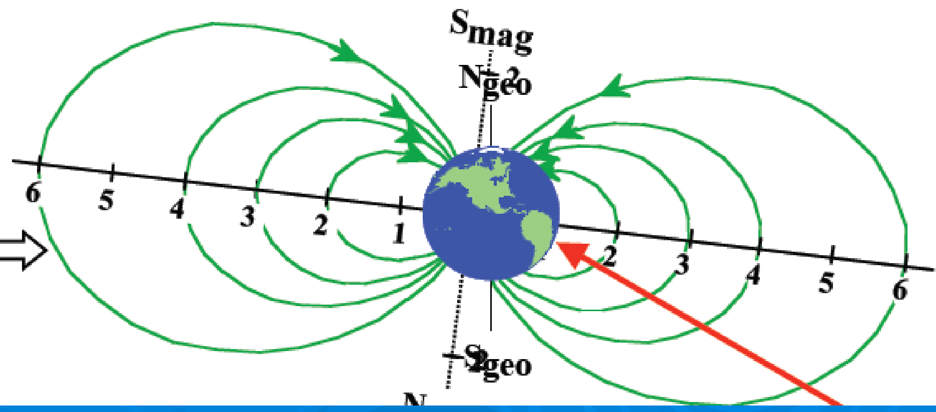
South Atlantic Anomaly (1/2)



Dipole field lines

Earth magnetic field:

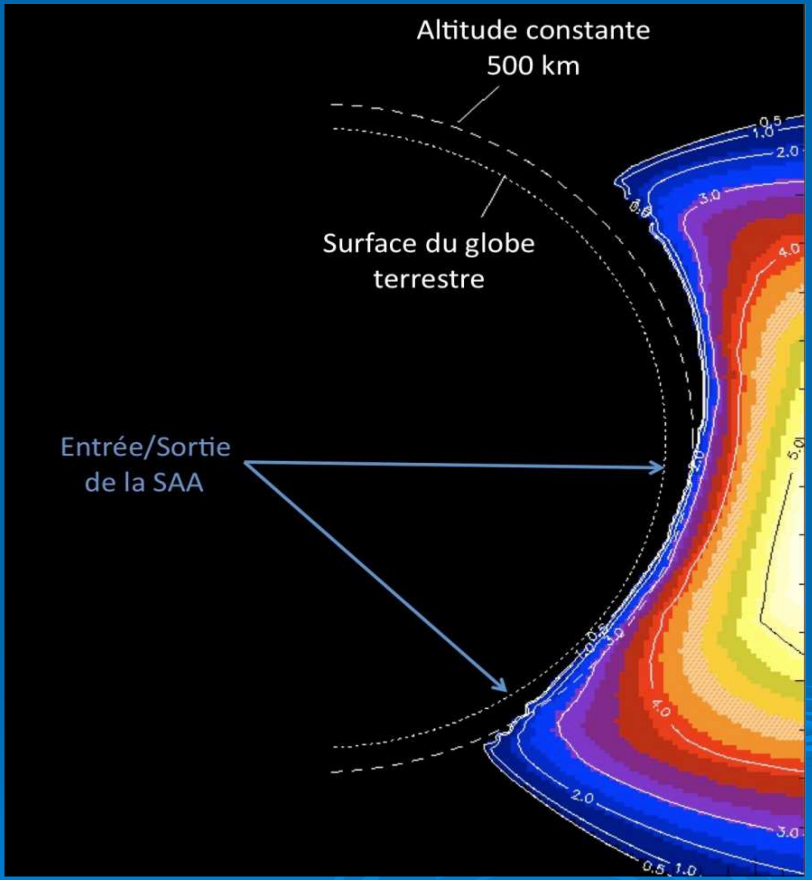
- inclined (~10°)
- Center offset (~500 km)



SAA

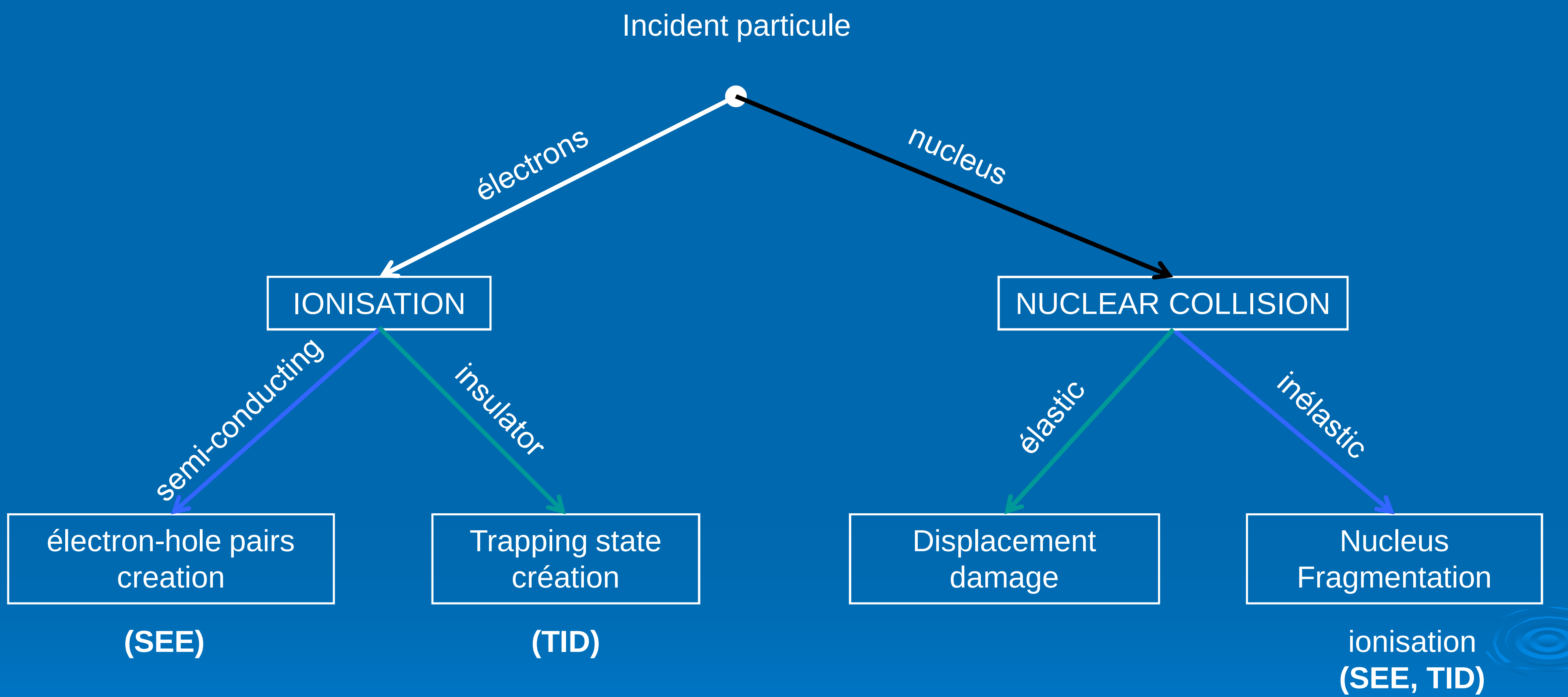
South Atlantic Anomaly (2/2)

- The **South Atlantic Anomaly** (SAA) is an area where the Earth's inner Van Allen radiation belt comes closest to the Earth's.
- This leads to an increased flux of energetic particles in this region.
- The effect is caused by the non-concentricity of the Earth and its magnetic dipole.



Effect of radiations on electronic devices

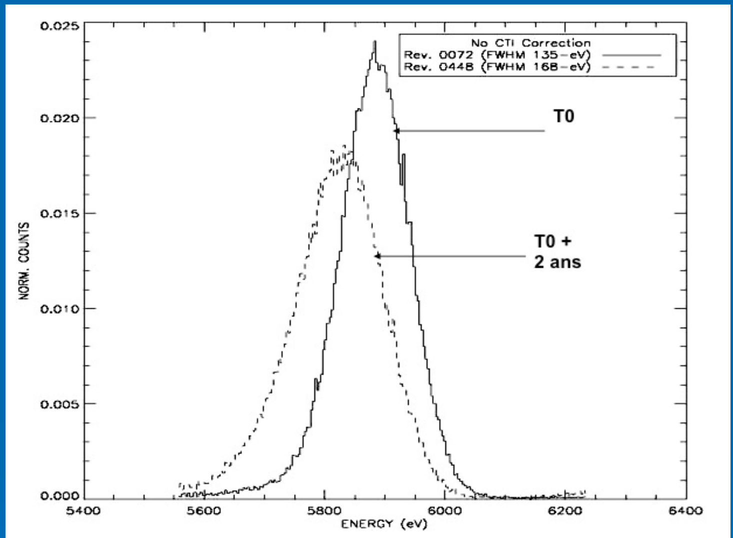
Effects on electronic devices



- TID : "Total Ionising Dose" is a long cumulative effect
- SEE : "Single Event Effect" is a transient single effect

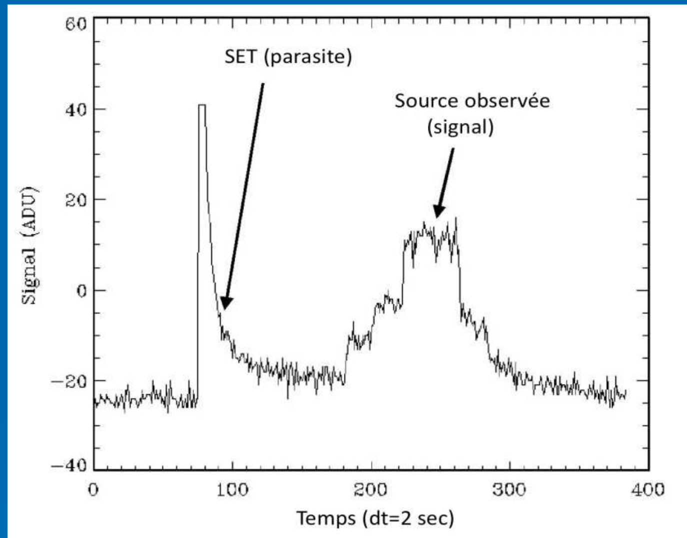
Examples

Dose →



Spectral resolution dégradation (XMM)

SEE →



Transient signal (ISOCAM)

Effect of SEE on electronic devices

- Effect of the ionizing particle depends on the energy deposit in the component (LET):

$$\boldsymbol{LET = \frac{1}{\rho}\frac{dE}{dx}}$$

- ***Latch-up*** (***SEL***) : parasitic current induce by the particle passage which could produce a short-circuit and potentially destroy the component.
- ***Single event upset (SEU)***: bit flip in a register.
- Radhard Technics to immunize the electronics against SEE.

Component tolerance to SEE (1/3)

Measures of the circuit properties

SEL and SEU (*single event latch-up / upset*) cross sections with respect to LET (*linear energy transfer*) :

$$\sigma = \frac{N_{LET}}{N_{inc}}$$

N_{inc} = number of incident ions which will depose a given LET.

M/Q = 3,33

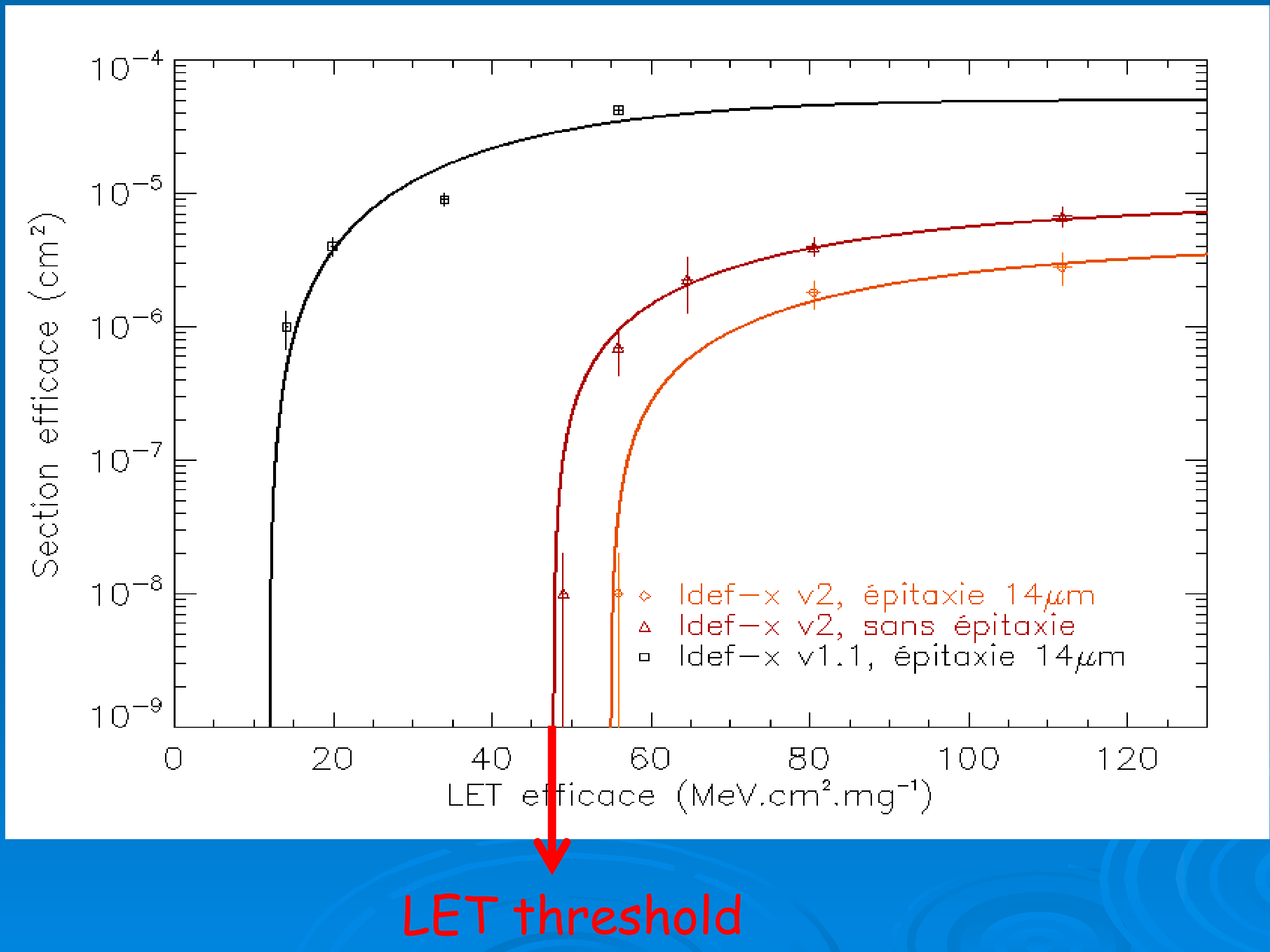
Ion	Energy [MeV]	LET [MeV/mg/cm2]	Range [microns]
$^{13}C^{+4}$	131	1.2	266
$^{22}Ne^{+7}$	235	3.6	199
$^{40}Ar^{+12}$	372	9.95	119
$^{58}Ni^{+18}$	567	21.3	98
$^{83}Kr^{+25}$	756	31.0	92

M/Q = 5

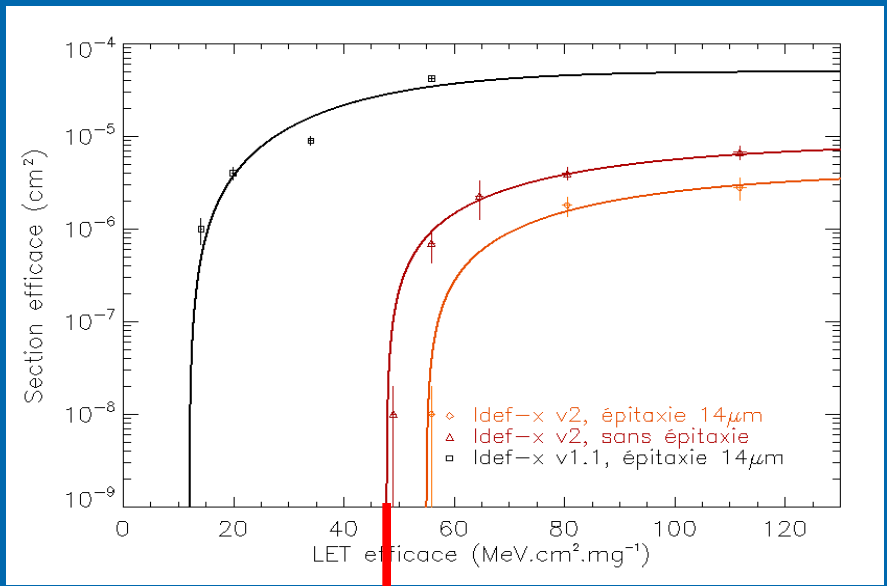
Ion	Energy [MeV]	LET [MeV/mg/cm2]	Range [microns]
$^{15}N^{+3}$	62	3.3	64
$^{20}Ne^{+4}$	78	6.2	45
$^{40}Ar^{+8}$	150	15.9	42
$^{84}Kr^{+17}$	316	40.1	43
$^{132}Xe^{+26}$	459	67.7	43

Component tolerance to SEE (2/3)

Measures of the circuit properties



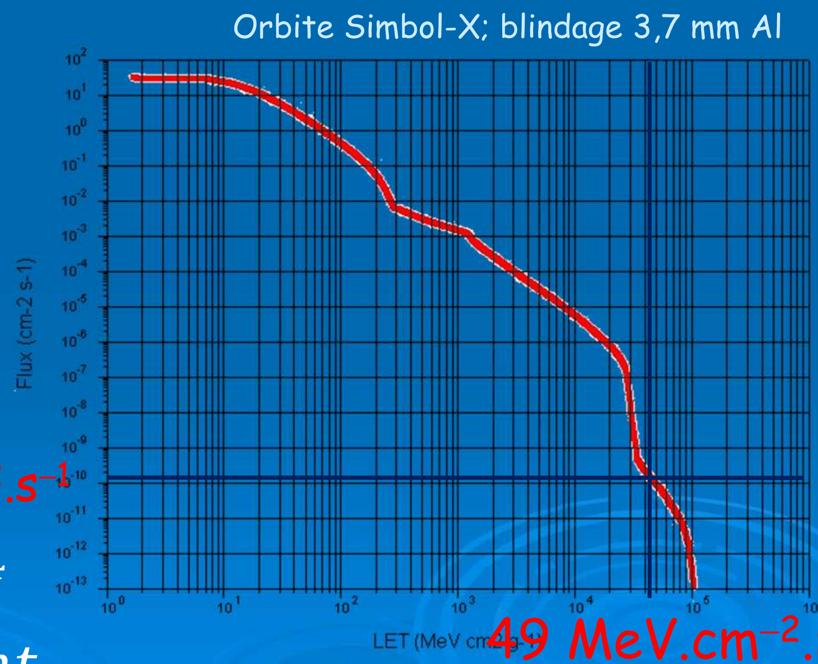
Component tolerance to SEE (3/3)



49 MeV.cm^{-2}.mg^{-1}

Failure probability in orbit

- Convolution of the cross section (cm^2) by the LET spectrum (cm^{-2}.s^{-1}) gives the foreseen SEE rate (s^{-1}) :



10^{-10}.cm^{-2}.s^{-1}

49 MeV.cm^{-2}.mg^{-1}

$$prob_{SEE} = 10^{-10} A_{comp} t_{orb} = 4\ 10^{-4}$$

$$for\ 3\ years\ and\ 2\ x\ 2\ mm\ component$$

Calibration project for Astro-H

Context: ESA contribution to Astro-H

	ESA CONTRIBUTION TO ASTRO-H	**Doc. no. : SRON-ASTH-PL-2010-004** **Issue : 2.2** **Date : 26 September 2010** **Page : 2 of 36**

ESA contribution to the Japanese X-ray mission ASTRO-H

Technical lead:

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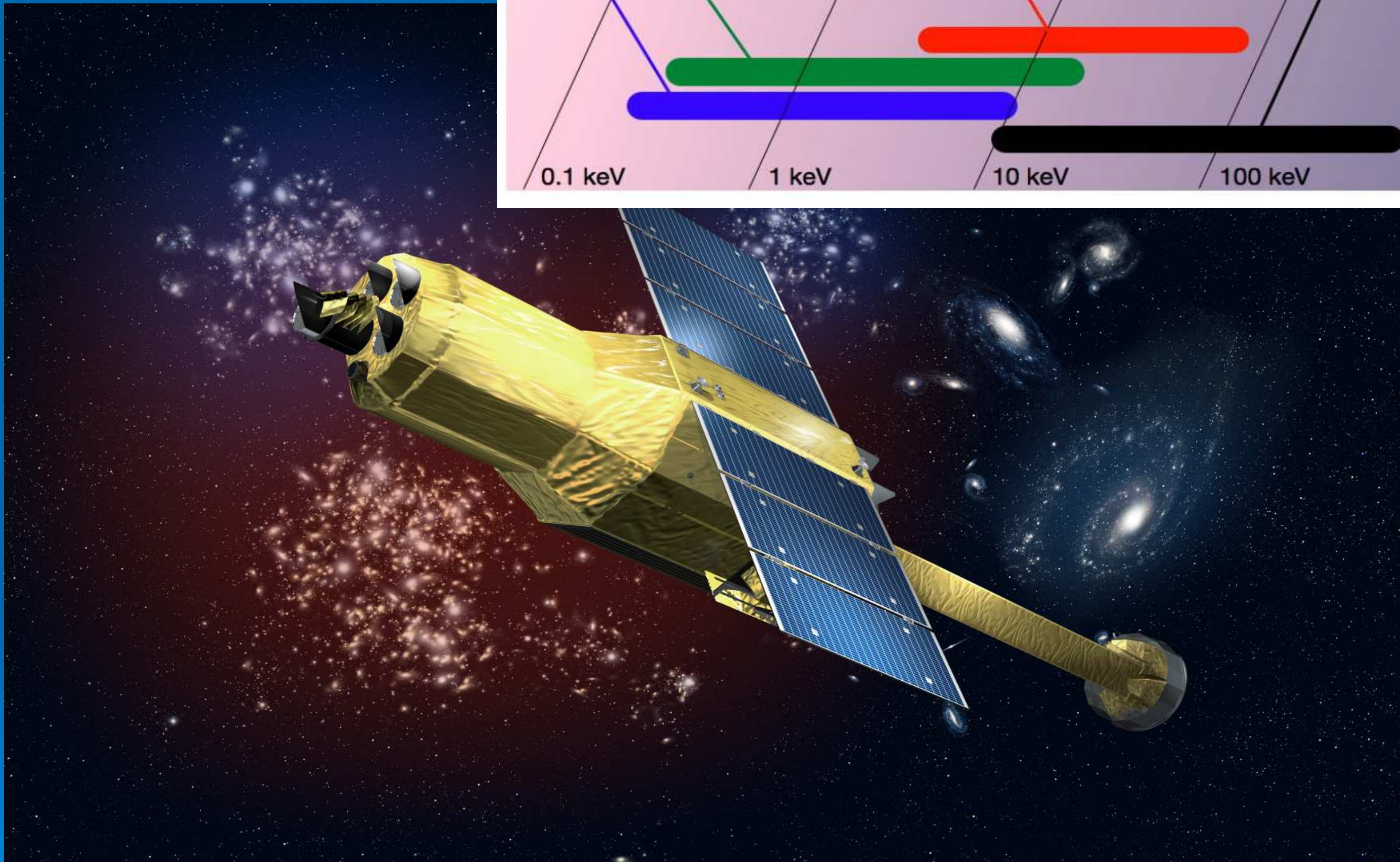
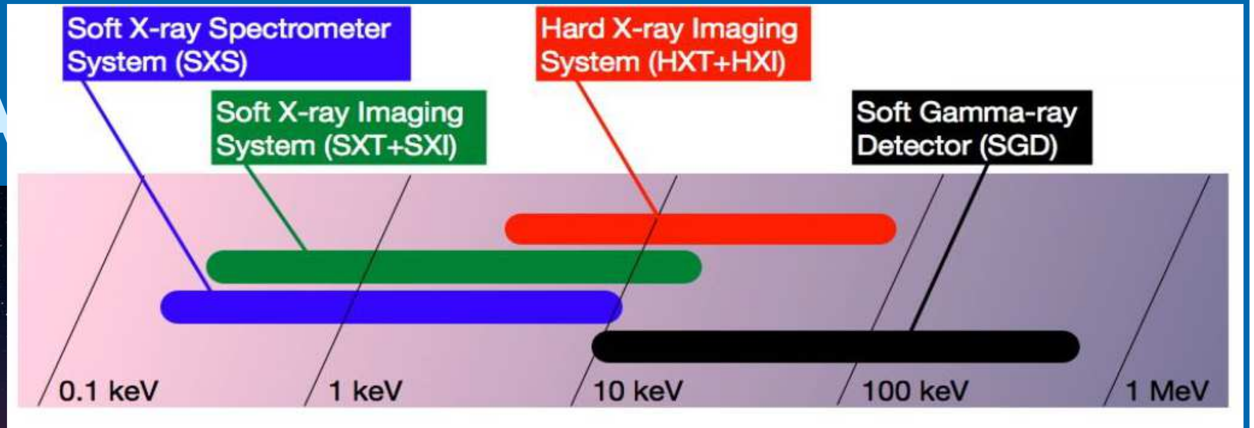
Context

ASTRO-H is the next major X-ray mission with a planned launch date of 2014. Its key scientific objectives include:

- revealing the large scale structure of the Universe and its evolution

A

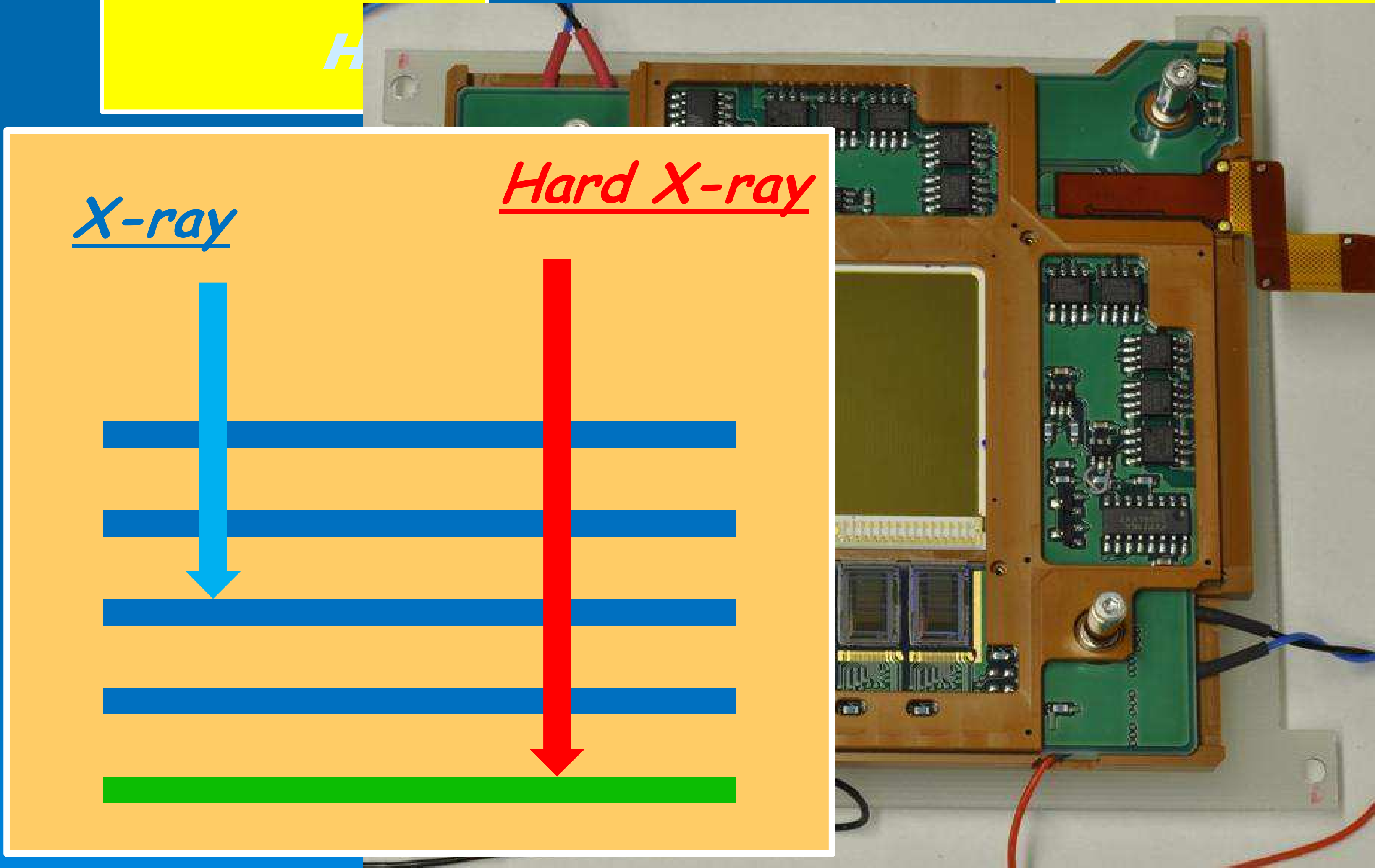


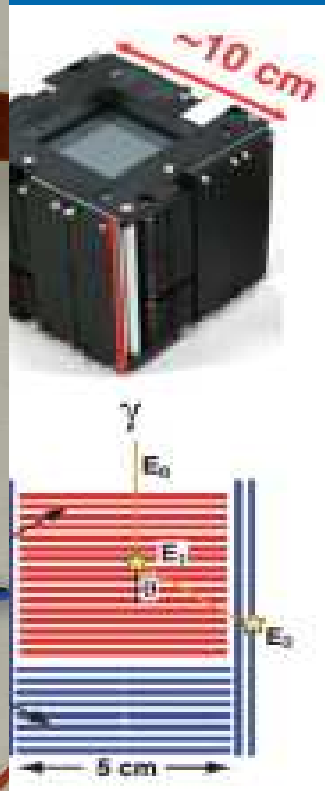


Soft X-ray Spectrometer System (SXS)
Hard X-ray Imaging System (HXT+HXI)
Soft X-ray Imaging System (SXT+SXI)
Soft Gamma-ray Detector (SGD)
0.1 keV
1 keV
10 keV
100 keV
1 MeV

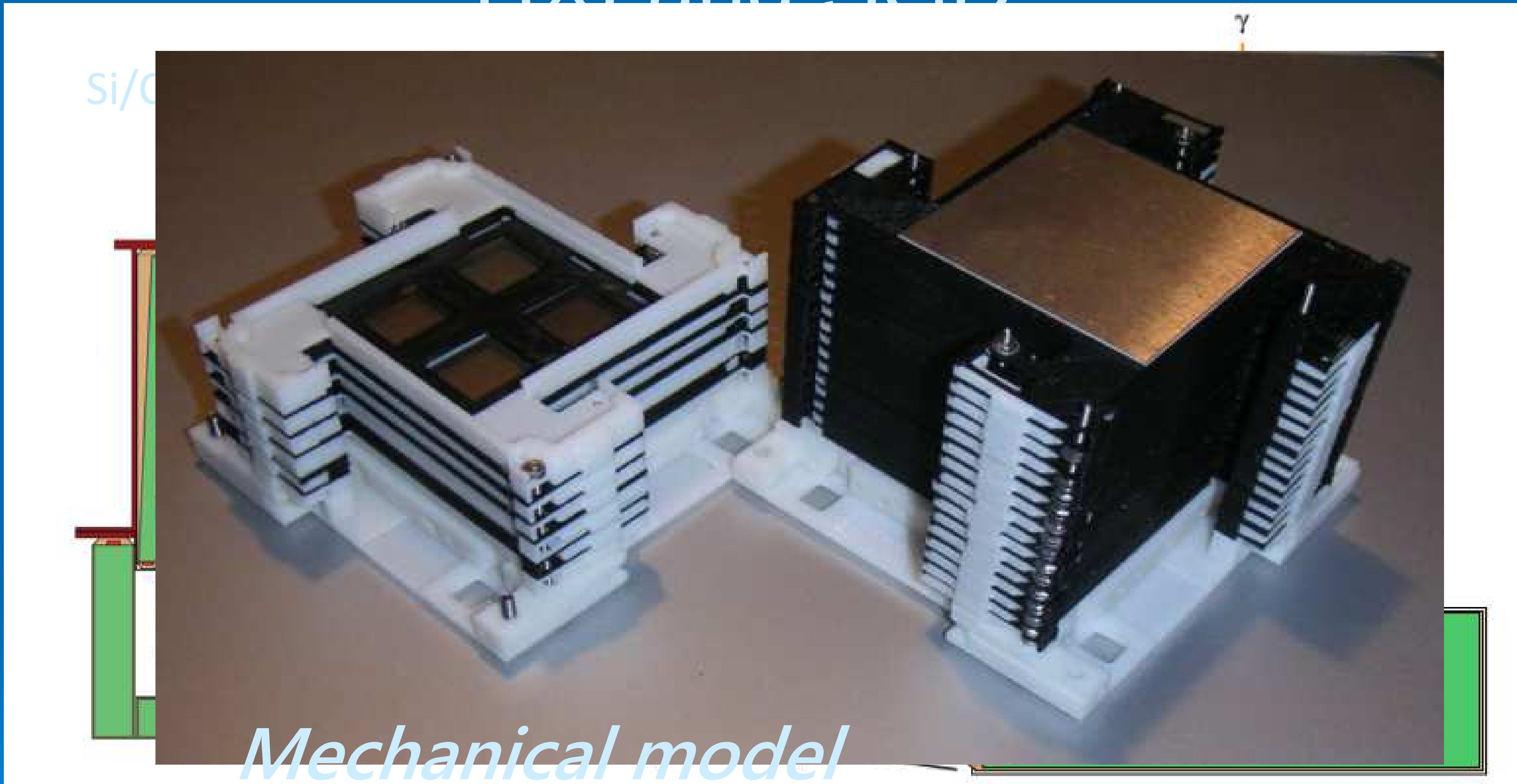
ASTRO-H

HXI and SGD





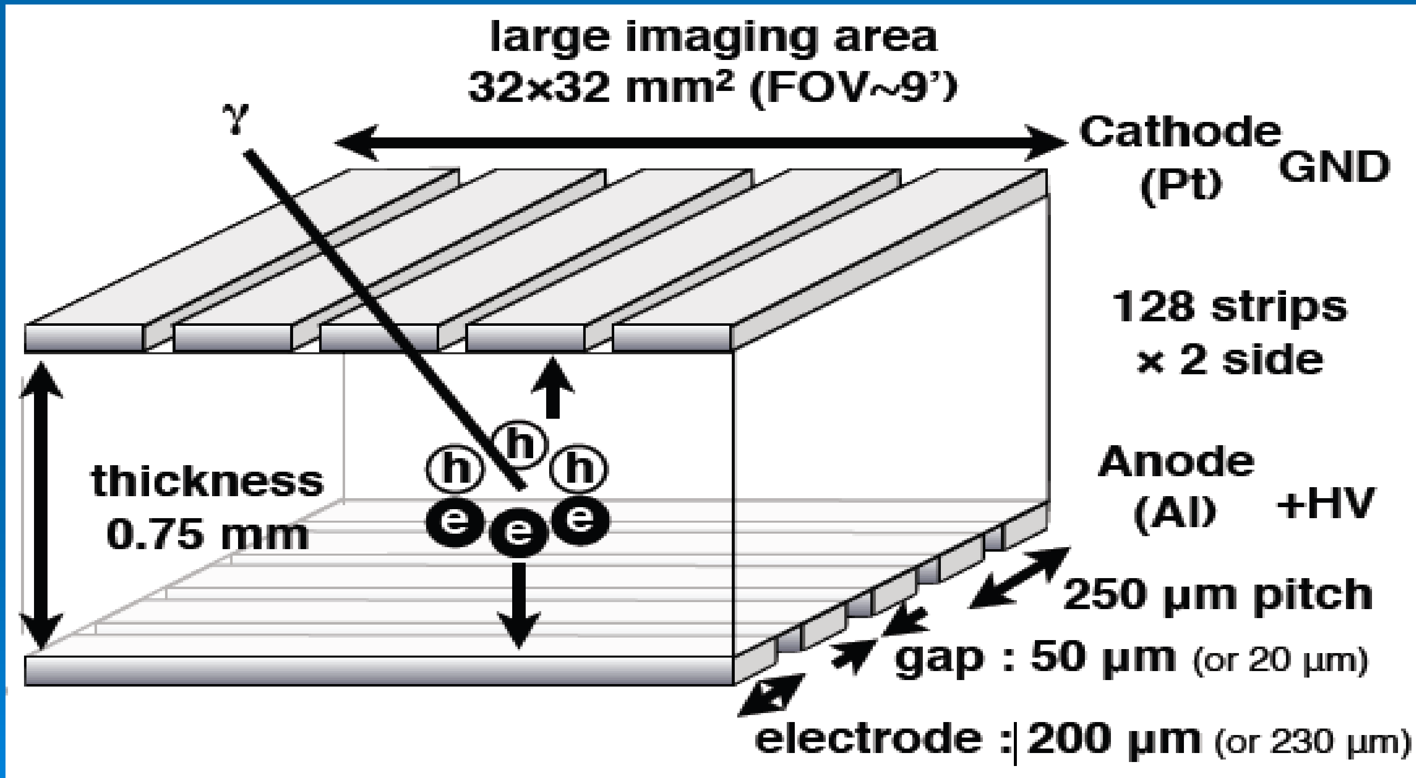
HXI and SGD



Mechanical model of SGD

Detector for HXI

- DS-CdTe : high detection efficiency thanks its atomic number (48-52)

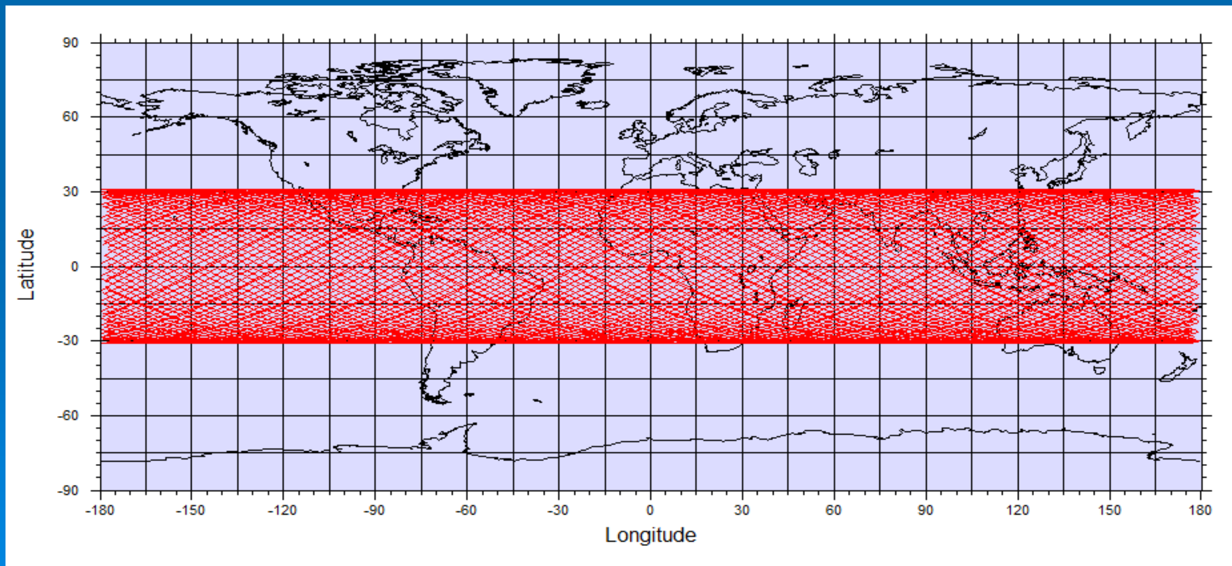


Study of Astro-H SGD ASICs

Astro-H orbit

Low Earth Orbit

- Orbit Altitude: 550 km
- Orbit Inclination: ~31 degrees
- Orbit Period: 96 minutes
- Launch : 2014
- 4 years of operation



Models used to determine the Astro-H space environment

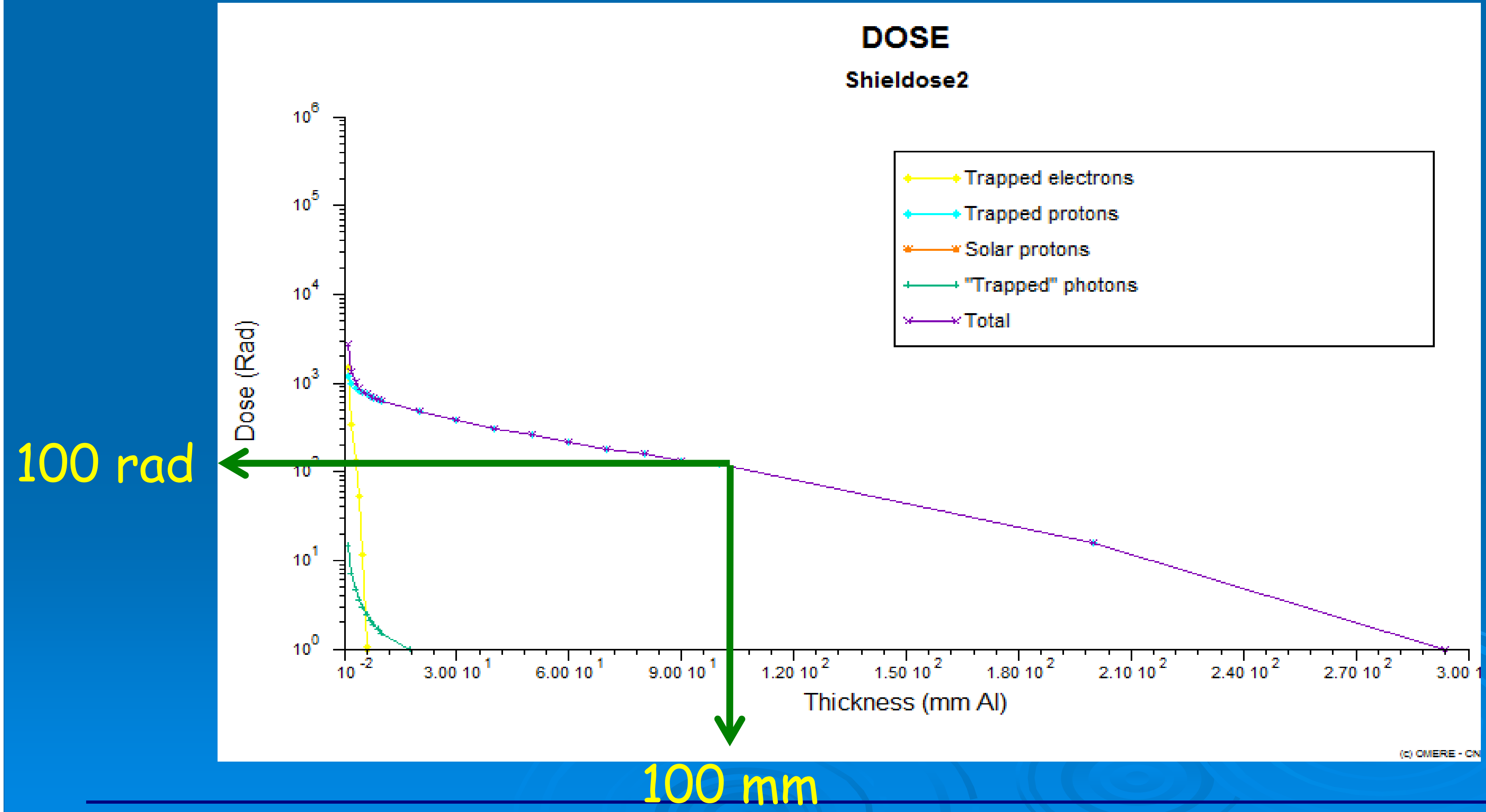
a) Trapped protons model is AP-8 MAX (NASA/NSSDC)

b) Trapped electrons model is AE-8 MIN (NASA/NSSDC)

c) Solar protons model is SOLPRO (NASA/NSSDC)

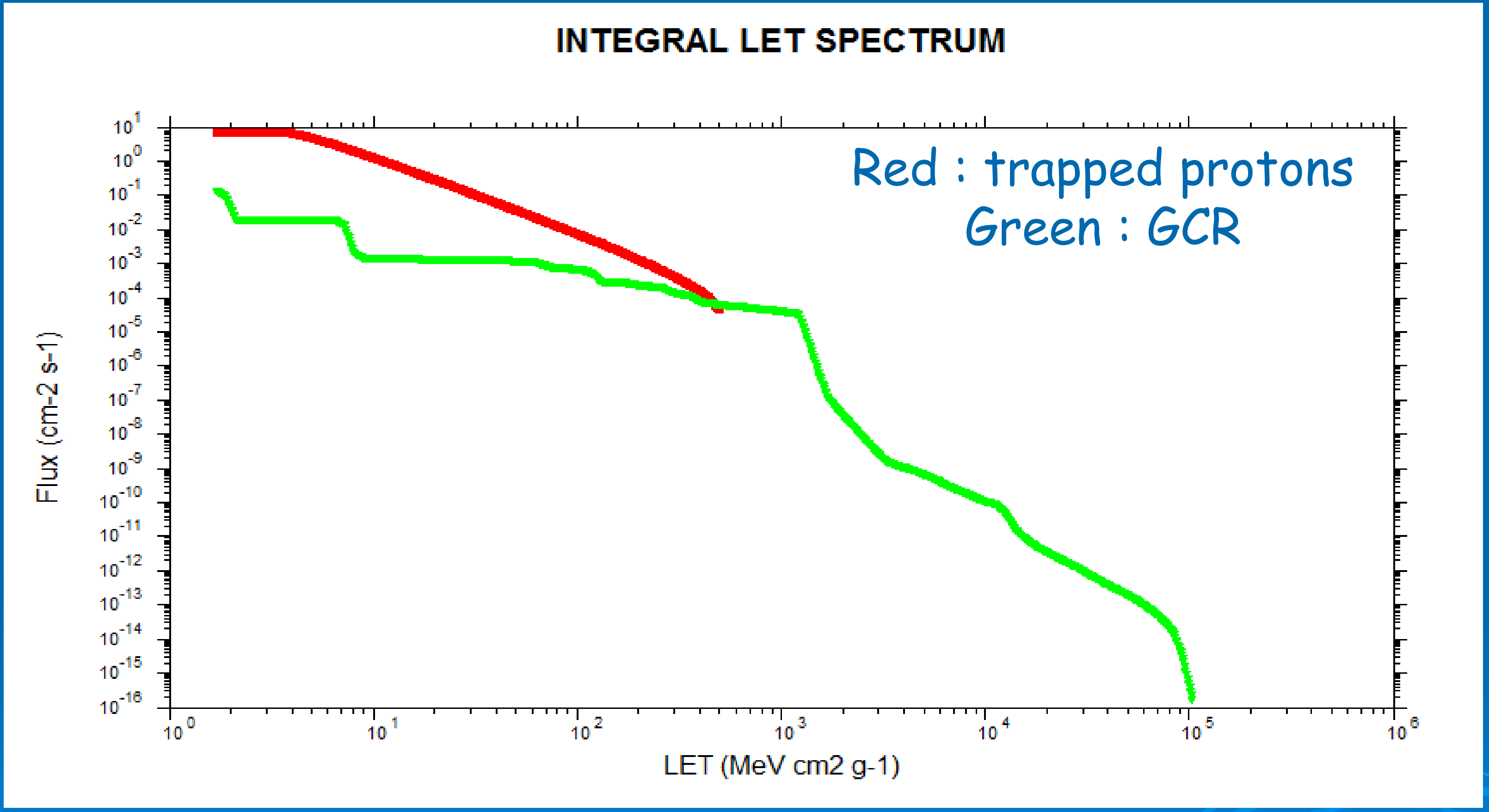
d) Cosmic-ray model is GCR-ISO (ISO 15390)

Dose curve



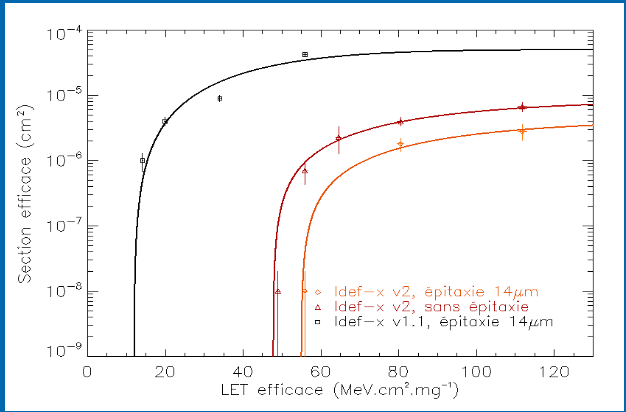
DOSE
Shieldose2
Trapped electrons
Trapped protons
Solar protons
"Trapped" photons
Total
Dose (Rad)
Thickness (mm Al)
100 rad
100 mm

LET spectrum



LET computed with 10 cm Al shielding

Radiation Test (1/2)



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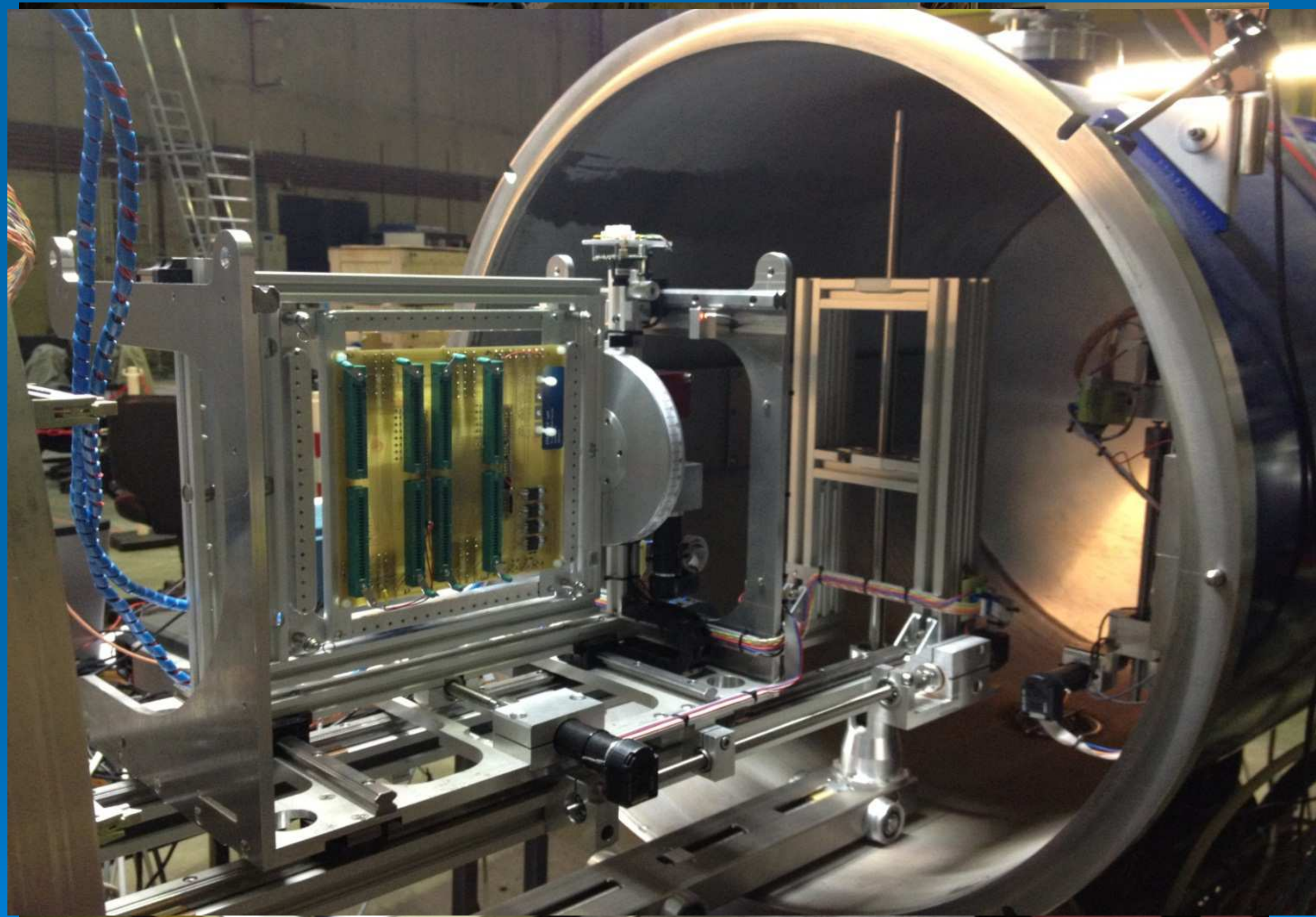
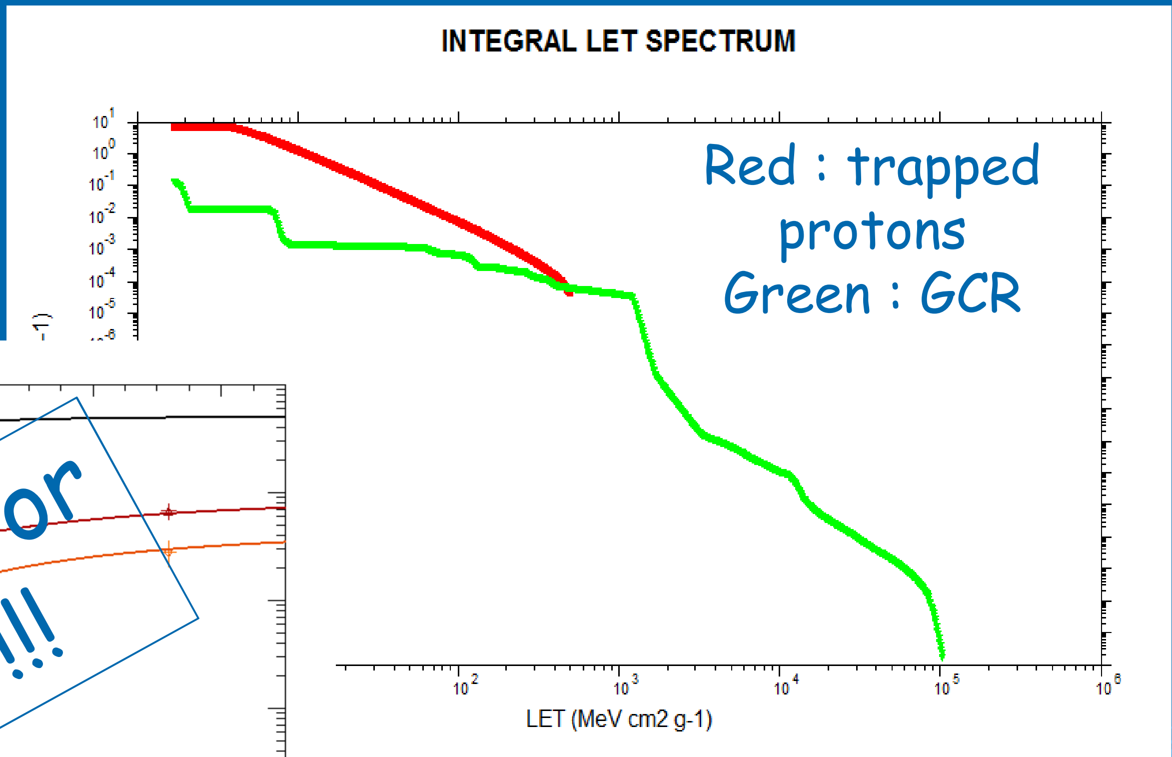
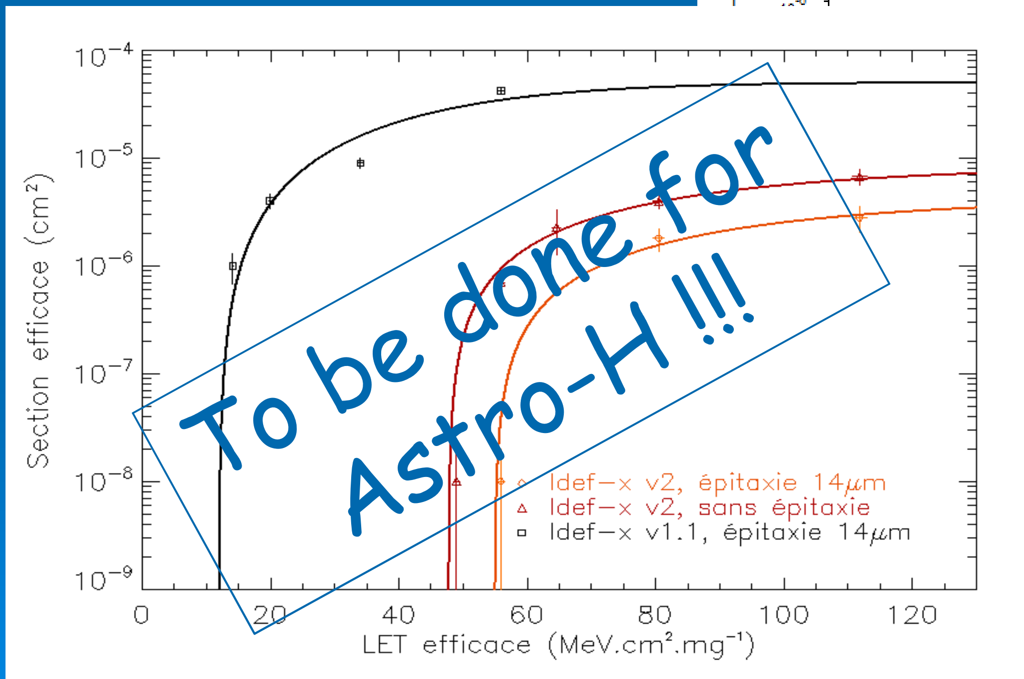


HIF accelerator line at Louvain-la-Neuve (Belgium)

Radiation tests (2/2)

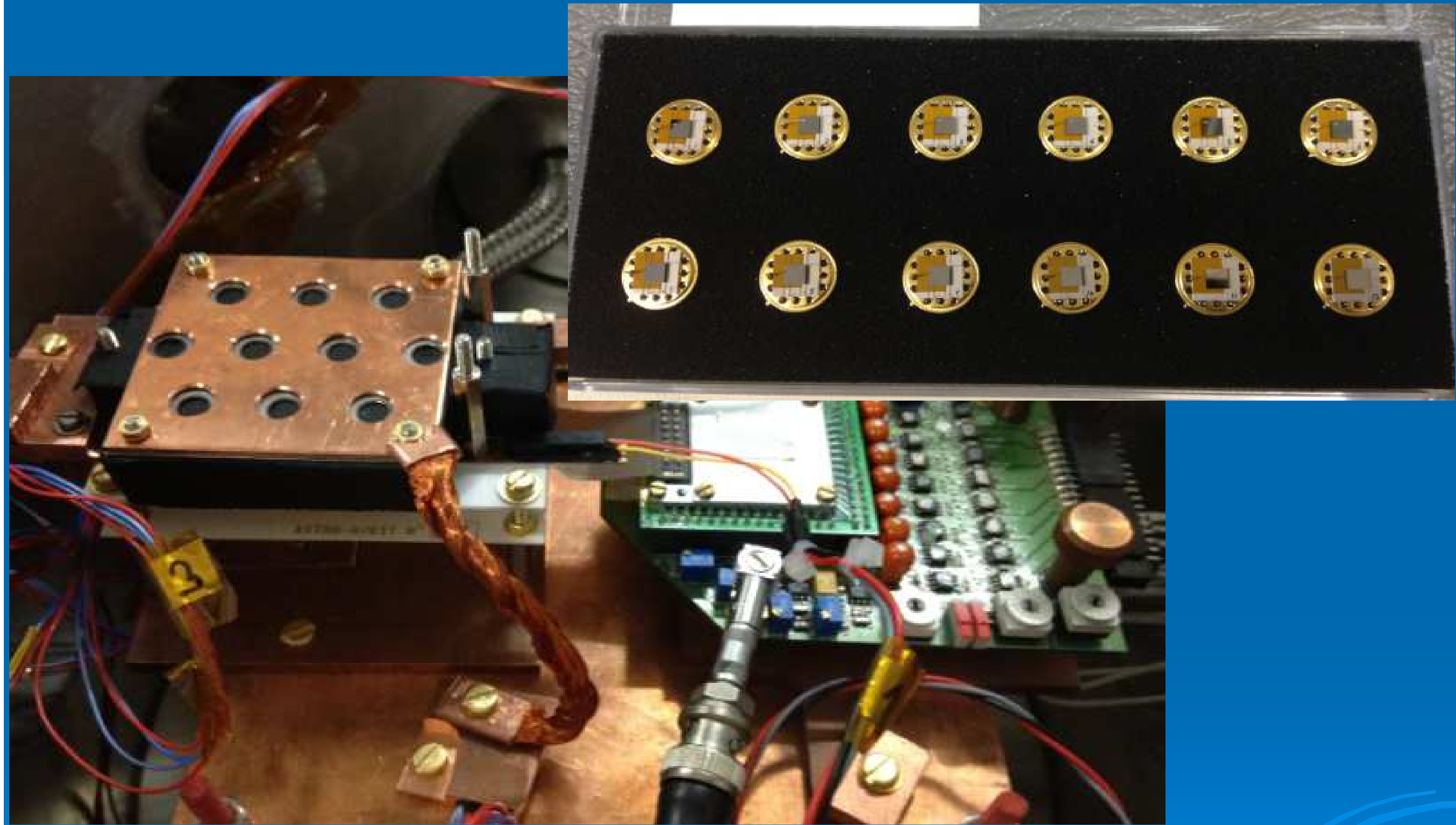




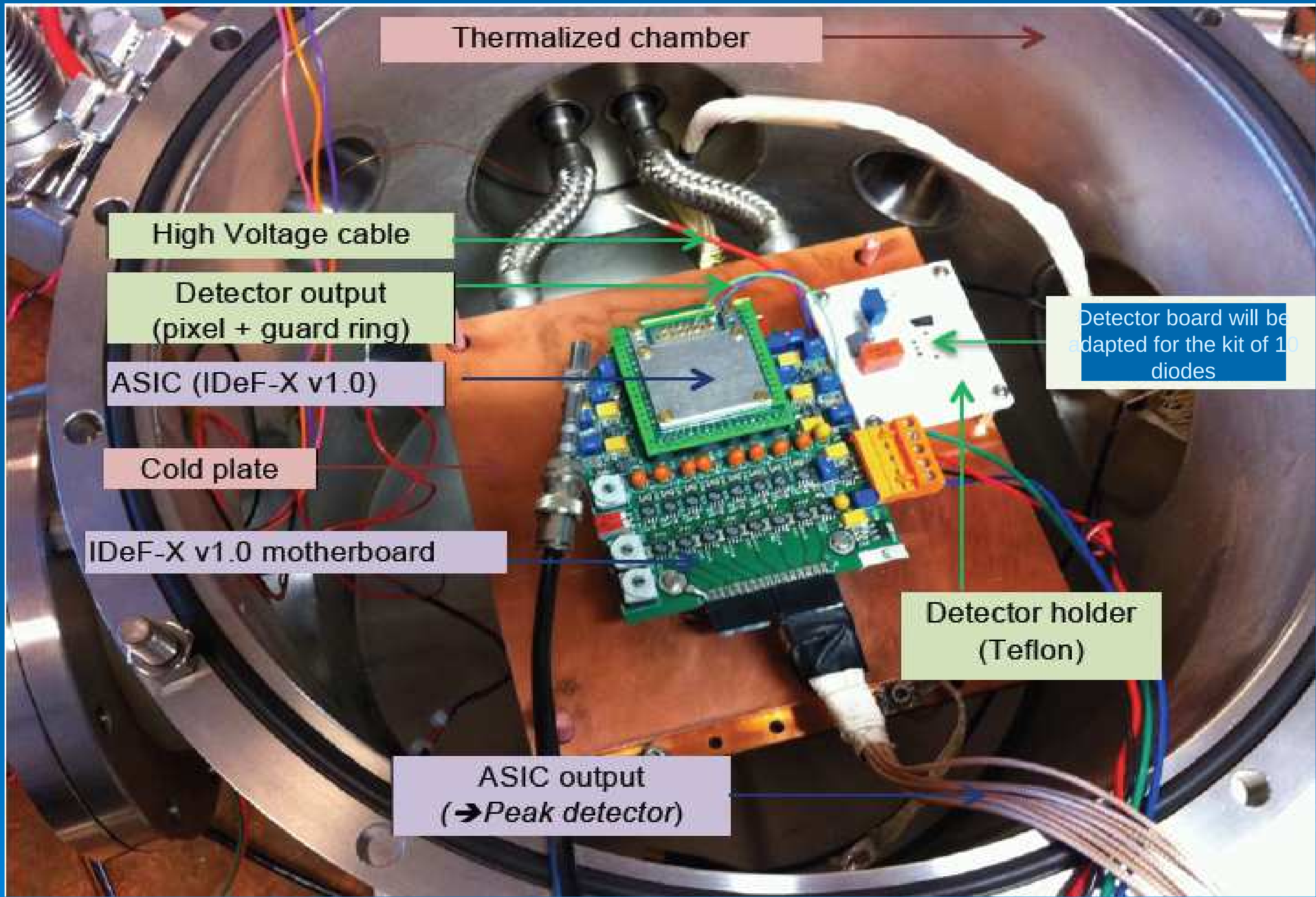
⇒ SEE probability !!

Study of Astro-H HXI and SGD CdTe detectors

Test bench in CEA



test equipment for the diodes



PSI protons accelerator (Switzerland)

Thank you !