SPI Germanium detectors
More than 20 years in space

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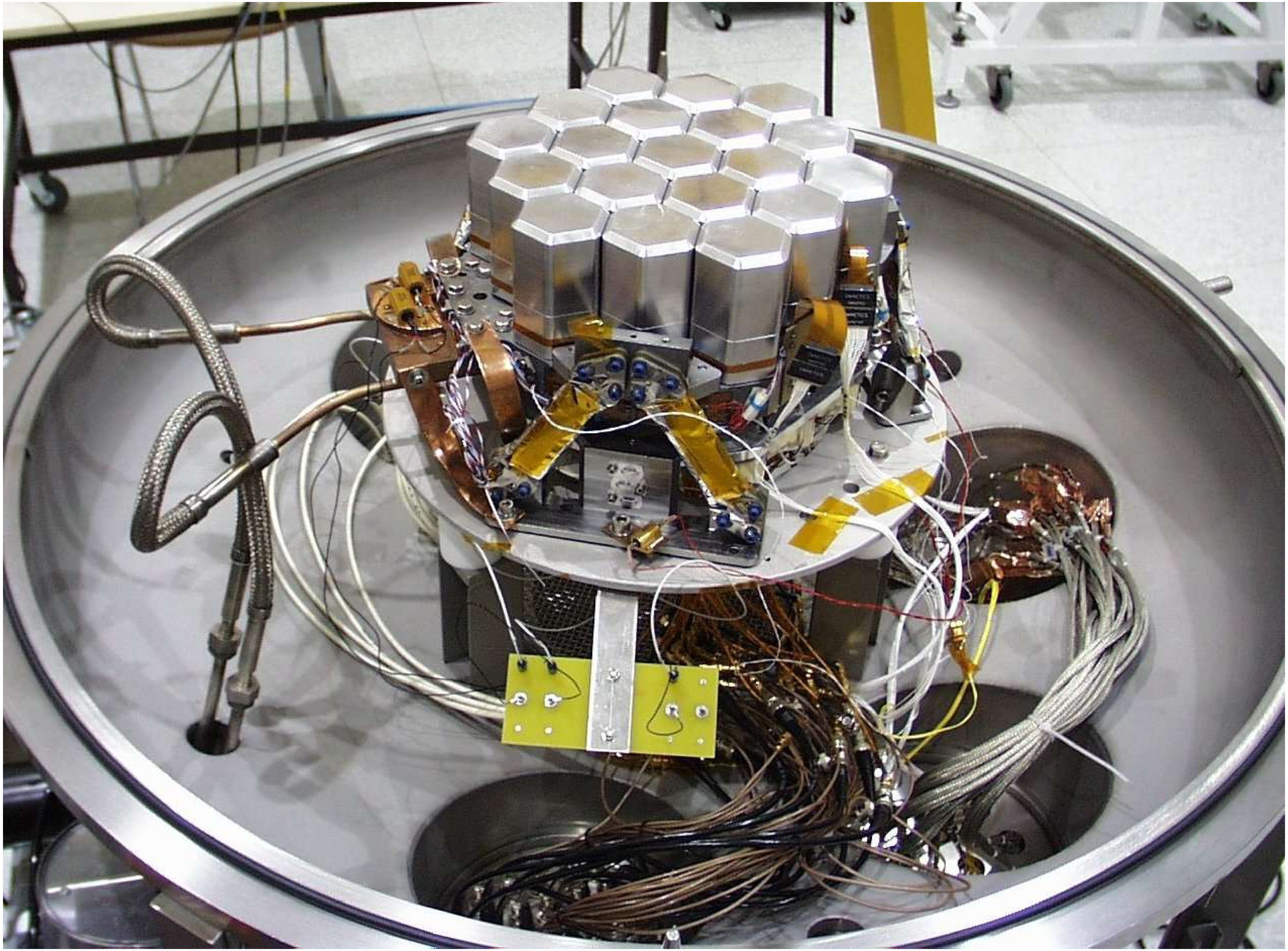
The SPI (Spectromètre Pour INTEGRAL) instrument has been launched in October 2002 aboard the *INTEGRAL* mission. Operating between 20 keV and 8 MeV, it observes the high-energy sky with a modest imaging capability (spatial resolution of ∼2.2◦) over a 30◦ × 30◦ field of view, thanks to a coded mask located 1.7m above the detector plane. Its main scientific objectives, as a spectrometer, are the nucleosynthesis signatures and the electron-positron annihilation line emission, but its performance is also ideal to investigate the emission of all high-energy sources, mainly galactic compact objects, whether transient or permanent.

We report on the performance evolution of the SPI detection plane during 20 years of irradiation in space.



SPI camera assembly prepared for tests in vacuum chamber

SPI camera

19 high-purity Germanium detectors.

Each crystal is hexagonal, 6cm face to face by 7 cm height.

Each GeD is a n-type coaxial, the inner contact is lithium implanted, the outer contact is boron implanted.

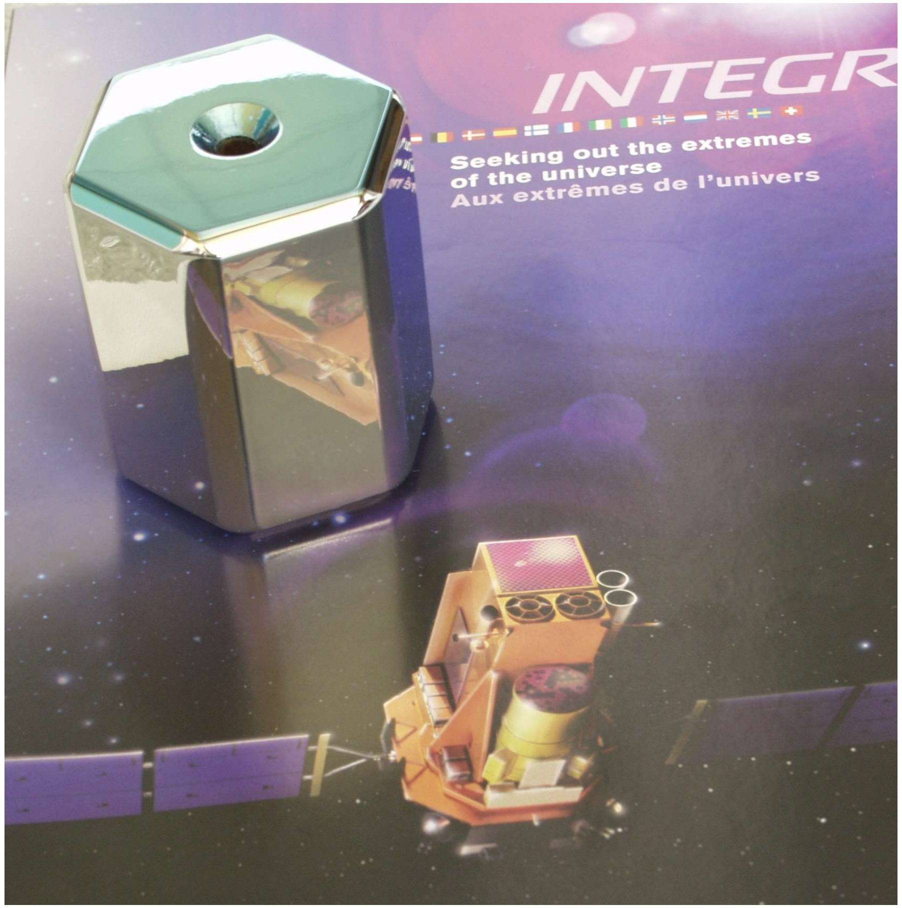
Each crystal is in an Al housing. All detectors have been vented after a specific qualification process.

Nominal HV was 4kV, reduced to 2.5 kV after 4 years in space.

The temperature of the GeD was 90K after launch (October 2002), has been decreased to 85K after 6 months and then to 80K since October 2006.

Total geometrical area is ~500 cm2.
Energy range is 20keV - 8MeV

Four GeD's/electronics failed during the first years of operation.



IRRADIATION OF GeD

- The quality (completeness) of the charge collection relies on the perfection of its crystalline lattice.
- Irradiation by heavy particles induces defects in the crystal that act as trapping sites.
- Charge collection is no longer perfect, thus the energy resolution of the detectors degrades.
- In space, the Ge detectors are irradiated by cosmic rays and solar protons which lead to secondary protons.
- This irradiation produces measurable effects in a few days and significant effects in a few months (Mahoney et al., 1981; Roques et al., 2003).

RADIATION DAMAGE ON GeD

- Holes are the most sensitive charge carriers to trapping. Thus, less trapping occurs in an n-type coax detector as the average path of holes is smaller than in p-type detectors.
- A number of irradiation tests in accelerators helped to quantify the radiation damage. Some of them include studies of annealing recovery.

See for instance: Mahoney et al., 1981 ; Borrel et al., 1999, Leleux et al, 2003; Peplowski et al., 2019 and references therein.

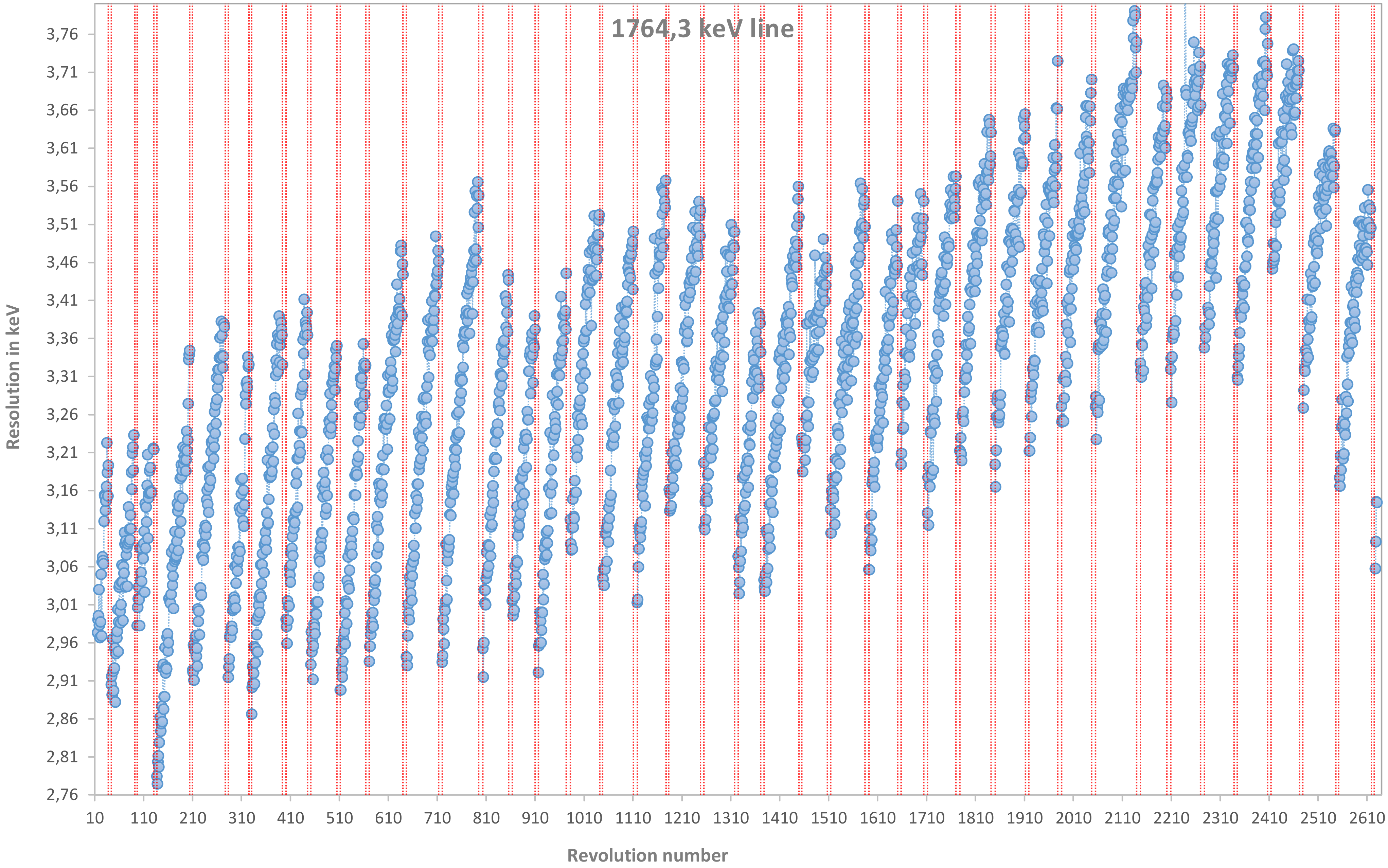
- They show, for example, that

- 1.5 GeV protons induce significant damage above a dose of 3x10^7 protons/cm2.

- 6-70 MeV neutrons produce damage above 10^8 neutrons/cm2.

- For a given dose, the detector energy resolution degrades as the operating GeD temperature increases: this is simply related to the charge-carriers velocity dependence with the temperature.

- There is a great interest in keeping the GeD temperature as low as possible.



Energy resolution of the SPI camera at 1764.3 keV from 2002 October to 2023 February. Each point represents the mean value for a 3 day orbit. The vertical bar pairs correspond to annealing periods.

ANNEALING of GeD

- The radiation damage can be repaired by heating the detector above ~373K.
- This annealing process restores the quality of the crystalline lattice and suppresses traprping sites.
- From the conception phase, SPI has been designed to withstand recurrent annealings.
- SPI has shown that a temperature of ~373K during 200hr allow to restore the original energy resolution of detectors.
- To date, SPI experienced 40 annealings that demonstrates that germanium can be operated with good performance for 20 years in space.
- The annealing duration has been progressively increased to 200hr which ensures a correct recovery after 6 months of irradiation.
- To reduce the degradation speed of the GeD (due to irradiation), their operating temperature has been decreased from 90K to 80K.
- The energy resolution evolution of the 1764keV line for 20 years shows that the energy resolution is kept under control.
- One can note a dependence with the solar cycle of 11 years due to the modulation of the cosmic ray intensity with the sun activity.

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- More details on Germanium detectors:

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