Spid-X

A Gamma camera with spectro-identification and dosimetry embedded functions

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The Caliste Technology and the ALB3DO Laboratory

Since almost 15 years, 3D PLUS and CEA IRFU have been involved in the development of the Caliste technology for space applications. Caliste is a miniature CdTe based imaging spectrometer capable of achieving high energy resolution (better than 1 keV at 60 keV and 5 keV at 662 keV) and high imaging resolution in the gamma range.

The Caliste-O 3D module is the latest development of the Caliste technology[2] which started in 2006. It is made of 8 IDeF-X ASICs[3] moulded with the 3D PLUS technology to form a 3D electronics part, on which a CdTe crystal of 1.4 x 1.4 cm² width and 2 mm thick is mounted.

The Caliste technology has been successfully launched on board the Solar Orbiter satellite, in the STIX instrument[1], proving its high reliability and high performances. Thanks to those good performances, the idea to adapt the technology for nuclear applications has emerged and the Caliste-O, dedicated to this field of application, has been developed.

With this history of mutual developments for advanced detection technology and the will of going further, 3D PLUS and CEA IRFU decided to join their competences in a common laboratory and founded the ALB3DO : Advanced Laboratory for 3D Detection Devices Development.
With the combined expertise of research and industry, ALB3DO creates and promotes disruptive technologies for sensors and systems beyond the state of the art.

1 - S. Krucker et al., "The Spectrometer/Telescope for Imaging X-rays (STIX)", A&A 642, A15 (2020)
2 - O. Limousin et al., "Second generation of portable gamma camera based on Caliste CdTe hybrid Technology", NIMA, 912, 2018, pp. 408-412
3 - O. Gevin et al., "IDeF-X HD: A LYRIDS ASIC for the Readout of CdZnTe Detectors for Space-Borne Applications", JIM, Vol 10, No 02, 2015

Spid-X: the Next Generation of Gamma Camera

A gamma camera, allowing the localization of radioactive sources, is a very useful device in various fields of the nuclear industry: monitoring, D&D or waste management are some examples. However, the information on the source position is not enough and should come with the sources identification and dosimetry information, which are provided by additional devices, such as doserate meter.
With this idea in mind, we are developing the Spid-X Gamma Camera, which embeds the Caliste-O technology and uses state of the art algorithms in order to perform imaging, spectro-identification and dosimetry in real time and simultaneously.

The device is 32,5 x 11 x 18 cm, for a weight under 3 kg

Spid-X Main Properties

- Real Time data acquisition, data processing and data display.
- Two imaging modes, using coded mask aperture and Compton mode, to allow the location of radioactive sources in a wide energy range from 2 keV to 2 MeV.
- The imaging resolution is 1° for radiation under 300 keV and 10° above 300 keV
  Those are state of the art performances for imaging at both low and high energies.
- The spectrometric performances are among the best in the market thanks to the Caliste technology, giving an energy resolution better than 1% at 662 keV.
- Those spectrometric performances are coupled with a patented Deep Learning technology which allow automatic and real time spectro-identification of detected radionuclides.
- The imaging and source detection can be done even if several radioactive sources are involved. In this case, the relative proportion of each sources is given.
- The device is able to perform dose and dose rate measurements, and in the case of multiple sources detection it can give the estimation of the dose due to each individual radionuclide.

The Camera Head

The Caliste-O is mounted on its internal mechanical structure. This structure allows the assembly of the Coded Mask Aperture

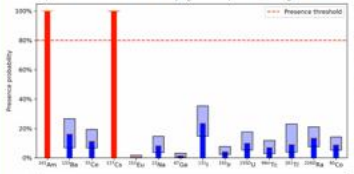
The coded mask is an Optimized Random Aperture (ORA) design. Its size and distance from the Caliste-O detector has been calculated to respond to the specifications of the nuclear industry, and allows gamma imaging for energies up to 300 keV.

Internal arrangement of the parts of the Spid-X device

Spectro-Identification

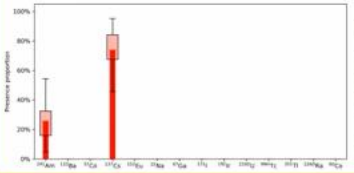
The Caliste technology allows a precise energy reconstruction of detected gamma events in the dynamic range of 2 keV - 2 MeV. Thanks to this high precision, the detected radioactive isotopes can be identified even when they are mixed with others.
This spectro-identification is performed thanks to advanced Convolutional Neural Networks (CNN)* trained on synthetic data, which can determine from a measured spectrum made of a few photons which radioisotopes created the signal, even in the case of multi-sources detection. In this last case, it also provides the information of the relative proportions of the different sources to give as much information as possible to the user.

*Patented, Method and device for identifying atomic species emitting X- or Gamma radiation, WO2020239884A1



The presence probability of various isotope when the camera is placed in front of ^{133}Cs and ^{241}Am sources

This presence is given with error bars to associate the result with confidence level. When the presence probability is greater than 80% with an error bar of less than 2%, the isotope is considered as identified.
^{241}Am and ^{133}Cs have been clearly identified.

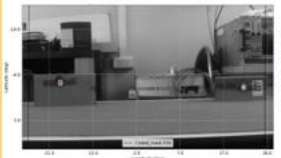


The estimated proportions of the identified radio-nuclides

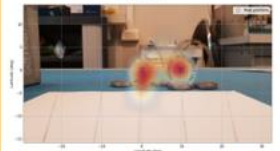
When several radionuclides have been identified, a deep learning algorithm estimates the proportion of each identified radionuclides.
The result is here again given with error bars.
In this case, ^{241}Am and ^{137}Cs have been previously identified, and 25% of the dose is caused by the ^{241}Am, and 75% of the dose caused by the ^{137}Cs.

Imaging

Two imaging methods can be performed, depending on the energy of the detected radio-isotopes : MLEM with coded mask aperture for energies up to 300 keV, and Compton for higher energies



MLEM image reconstruction of two ^{241}Am sources placed 35° apart.
Both sources have an activity of 400 kBq and are placed 1 m away from the camera head, which represents a dose rate of 3.2 nSv/h dose rate at the camera level.
The location precision is better than 1°, obtained in 600 seconds.



Compton image reconstruction of two ^{137}Cs sources placed 10° apart.
Both sources are 1.7 MBq placed 30 cm away from the camera head, which represents a dose rate of 2.8 µSv/h.
The location precision is better than 10°.

Work is currently on going to develop Deep Learning algorithms for image reconstruction in Coded Mask aperture and Compton mode*, in order to improve the spatial resolution and detection efficiency of the Spid-X camera.

* "Deep Learning for Compton image reconstruction with Caliste-resolution imaging spectrometer: An innovative approach to enhance detection sensitivity" by G. Daniel – June, 23rd, 10.5 h, Room Aquarius
* "Automated source reconstructions by means of Coded mask aperture systems and Deep learning algorithm" by G. Daniel – June 25th, 08:40 A.M., Room Vendôme

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History of the ALB3DO Laboratory

Financé par
GOUVERNEMENT
Liberté
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FRANCE RELANCE

ALB3DO
Astro to Industry

The Astrophysics Department of CEA and the French company 3D PLUS have been involved since several years in the development of the Caliste technology, a CdTe based imaging spectrometer capable of achieving high energy resolution

- With this history of mutual developments, 3D PLUS and CEA IRFU decided to join their competences in a common laboratory and founded the **ALB3DO : Advanced Laboratory for 3D Detection Devices Development**
  - With the combined expertise of research and industry, ALB3DO aims to create and promote disruptive technologies for sensors and systems beyond the state of the art

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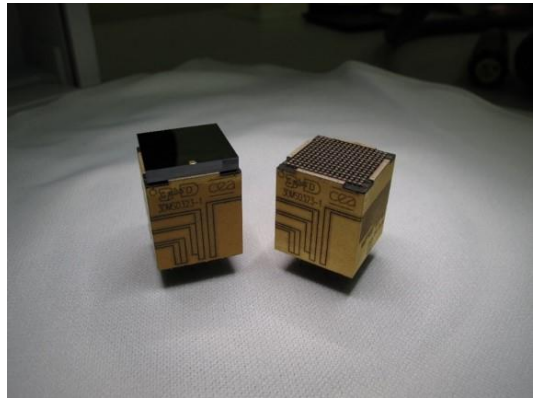

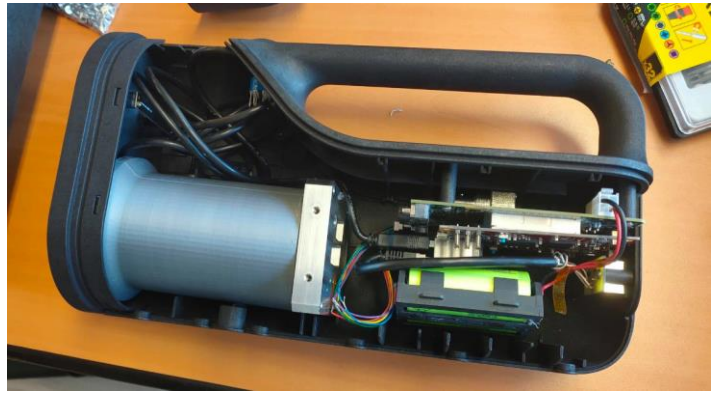

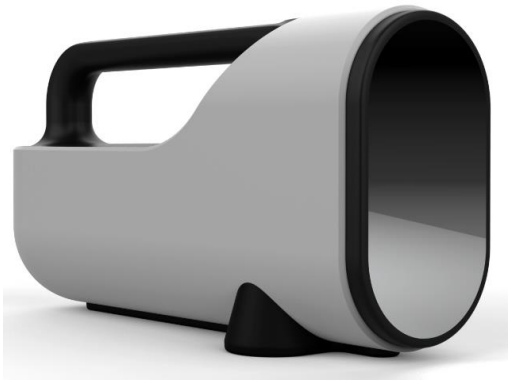

The Spid-X Gamma Camera Properties

- The spectro-identification is performed thanks to advanced Convolutional Neural Networks (CNN) trained on synthetic data, which can determine from a measured spectrum made of a few photons which radioisotopes created the signal
  - In the case of multiple detection, it also provides the information of the relative proportions of the different sources to give as much information as possible to the user
- To this brand new functionality we add two imaging methods :
  - Coded Mask Aperture for energies up to 300 keV with a spatial resolution better than 1°
  - Compton image reconstruction for higher energies with a spatial resolution of 10°
- The device is also able to perform dosimetry and gives the dose rate of each detected radio-isotope
- With all those functions, the Spid-X gamma camera will be able to perform, in real time and during the same acquisition: spectro-identification, imaging and dosimetry
  - giving results within seconds for spectro-identification and minutes for imaging (depending on the activity of the detected radio-isotopes)
  - providing to the user as much information as possible with one portable device of less than 3 kg