Analysis and Signal Processing

DDays IRFU - 09/07/2019

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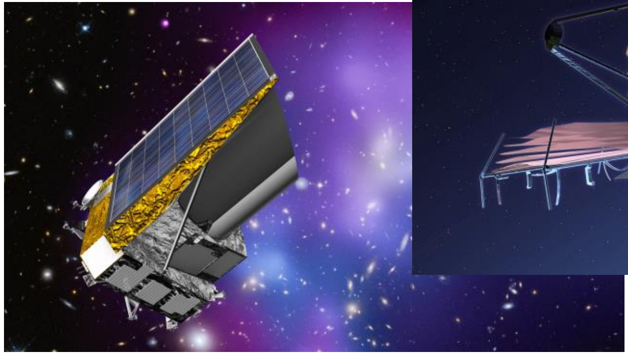
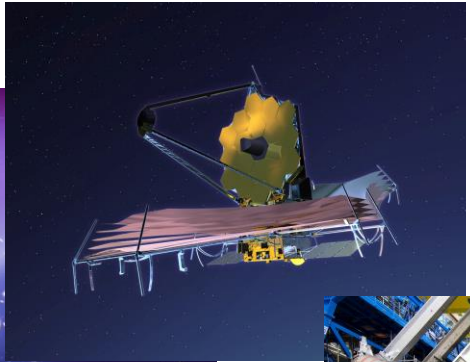
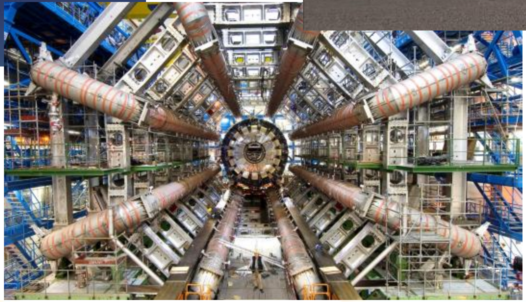
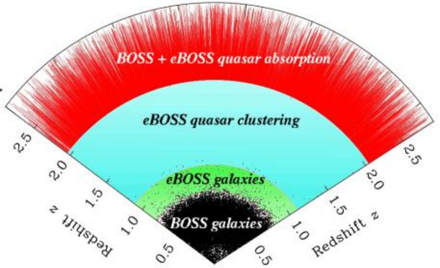
Introduction

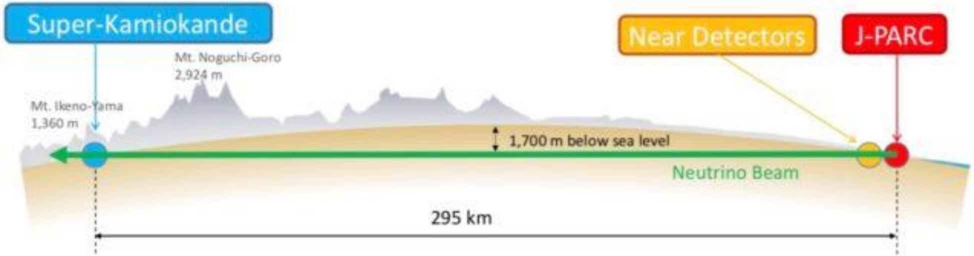
Instruments and observation programs: signal acquisition







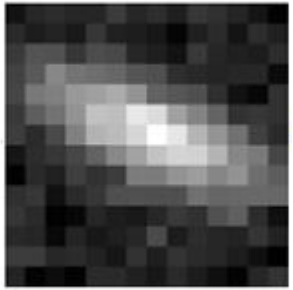




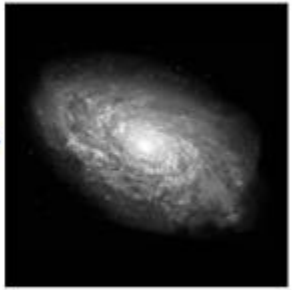
Introduction

Signal forward and inverse process

Bridle et, al. 2008



Detector output
with noise



Intrinsic galaxy
(shape unknown)

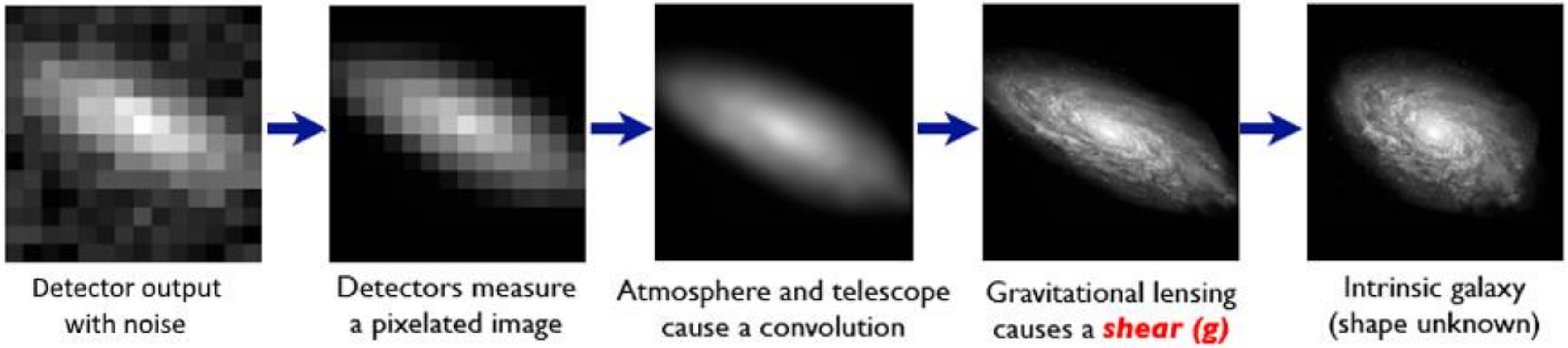
Instrument → Physical process

Analysis and Signal Processing

Introduction

Signal forward and inverse process

Bridle et, al. 2008



Instrument

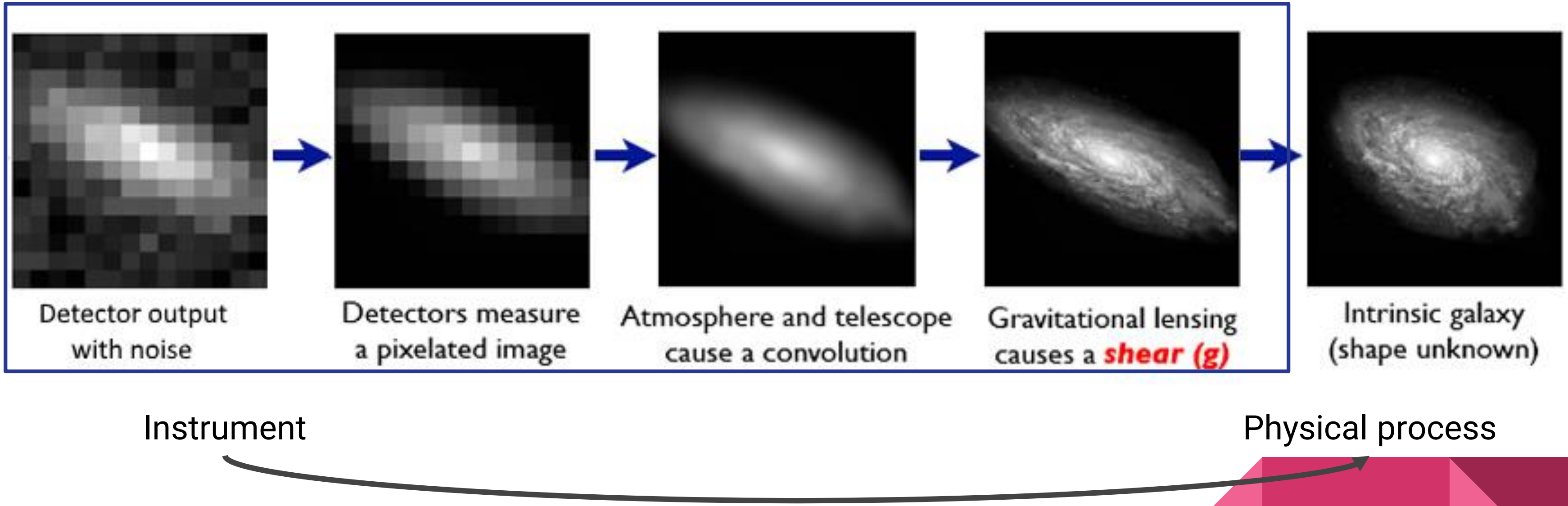
Physical process

Analysis and Signal Processing

Introduction

Signal forward and inverse process

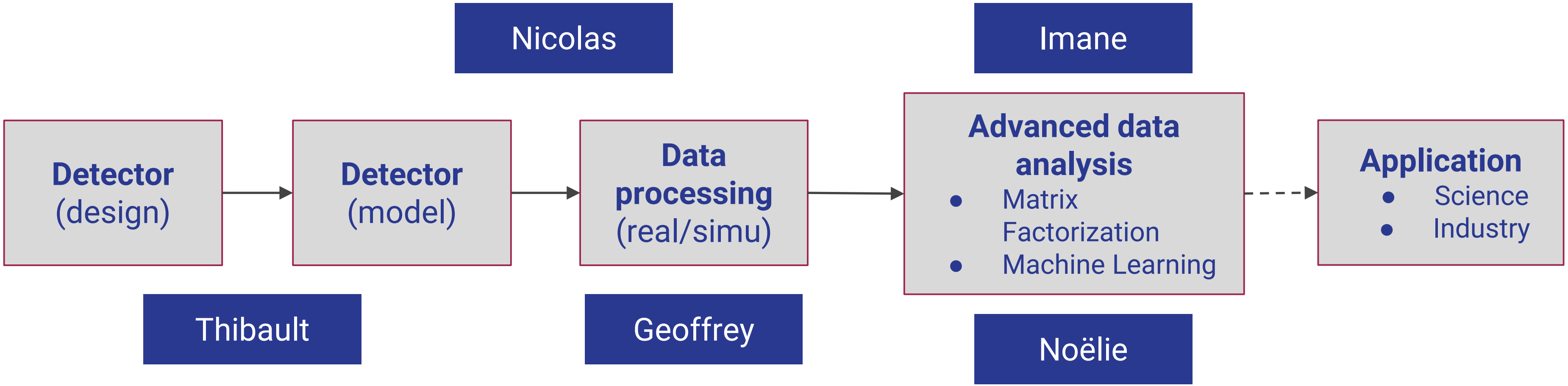
Bridle et, al. 2008



Analysis and Signal Processing

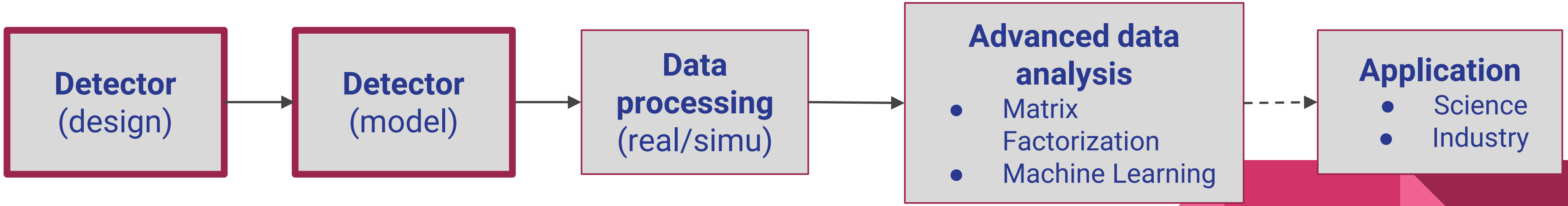
Introduction

From instruments to interpretable data

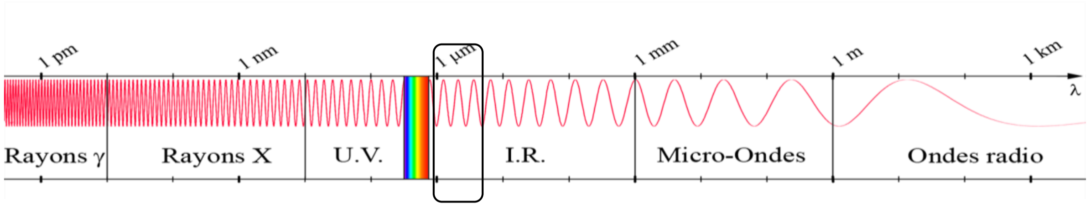


Modelling and experimental characterization of proton irradiation induced luminescence of CdZnTe substrate in HgCdTe detectors

Thibault Pichon (DAp)



ALFA (Astronomical Large Format Array) IR detector



juice	euclid
IR Detectors: Teledyne H1RG	IR Detectors: Teledyne H2RG
Launch Date: 2022	Launch Date: 2022

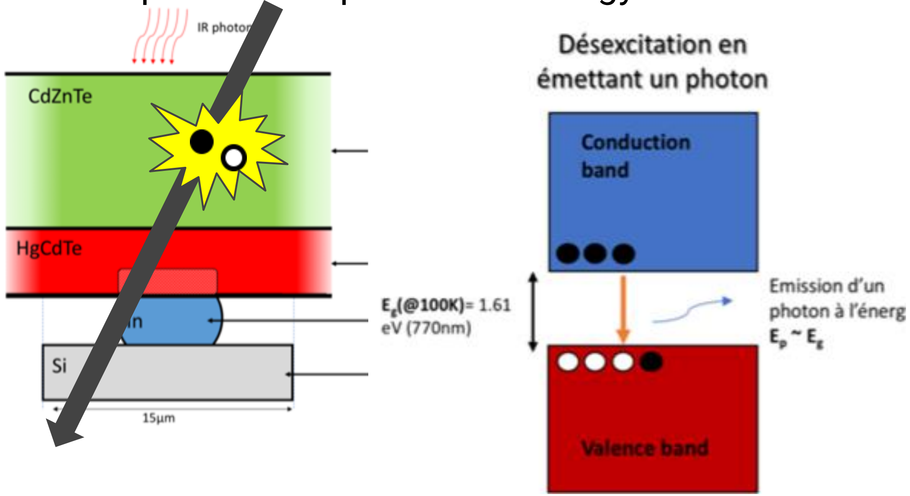
ALFA is an Infrared Detector develop for the future ESA space mission.

ESA Specifications :

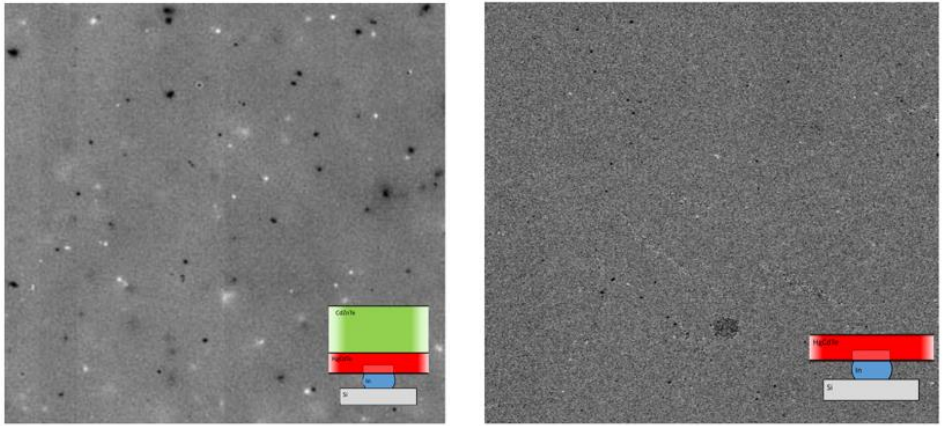
- HgCdTe
- 2048x2048 pixels
- 15µm pixel pitch
- **Spectral Domain 0.8µm - 2.1µm**
- Operating Temperature 100K
- Quantum Efficiency ≥70%
- **Dark Current ≤0.1e-/s/pix**
- Readout Noise ≤ 18 e- rms

ALFA (Astronomical Large Format Array) detector

ALFA pixel = LETI planar technology



Radiation effects on american detectors



Substrate Removal

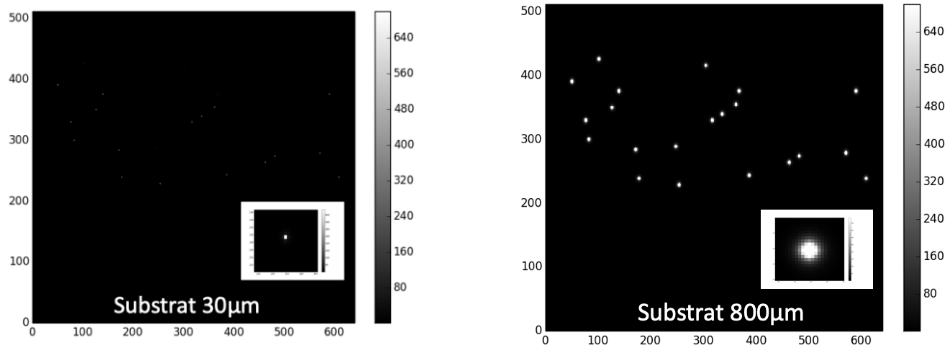
- Degradation of detector performances
- Low yield of substrate removal process

Which substrate thickness can be kept ?

Modelling approach

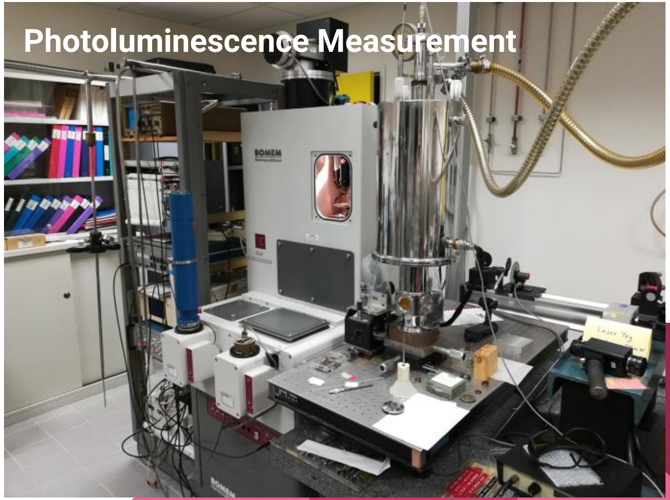
- **Particle penetration is simulated with Monte Carlo simulations.** GEANT4
- **Carriers transport is modelled analytically and with TCAD software.** SILVACO python

Simulated images of a 15µm pixel pitch 512x640 HgCdTe detector



Simulation performed with data found in the litterature 300K

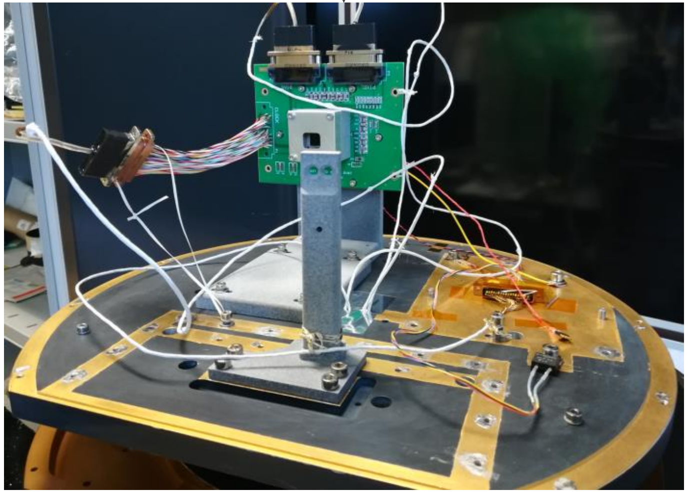
Material properties should be known ⇒ Material characterisation (photoluminescence, cathodoluminescence, ellipsometry, XEOL, …) were performed on representative samples.



Experimental campaigns

Irradiation cryostat

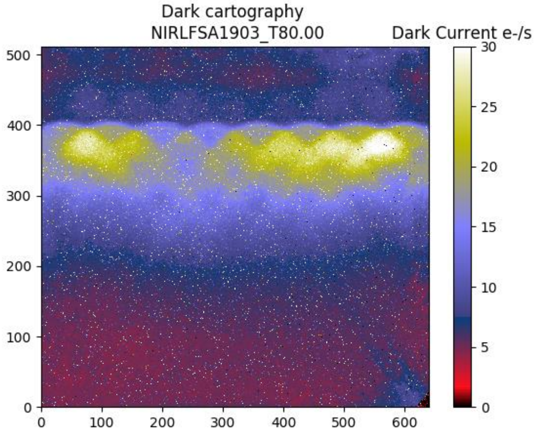
Detector support

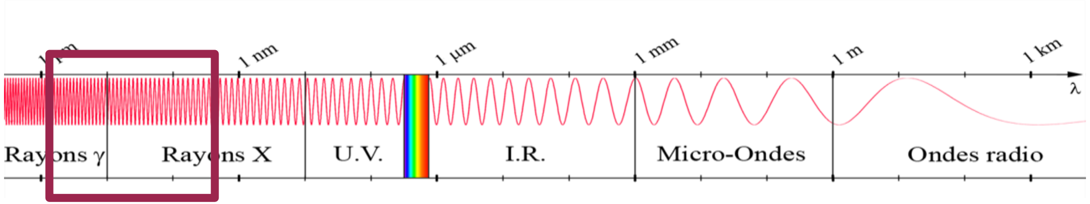


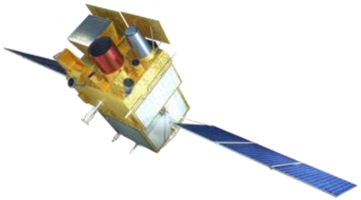
- A cryostat has been refurbished for the irradiation campaign
- Detectors to be irradiated are characterized

Proton Accelerator:
- ALTO accelerator at Orsay

Detectors to be irradiated:
- Similar to ALFA technology
- Smaller format
- Several substrate thicknesses







Data processing for the hard X-ray ECLAIRs telescope onboard SVOM

Nicolas Dagoneau (DAp)

Detector (design) → **Detector** (model) → **Data processing** (real/simu) → **Advanced data analysis**
- Matrix Factorization
- Machine Learning

⇢ **Application**
- Science
- Industry

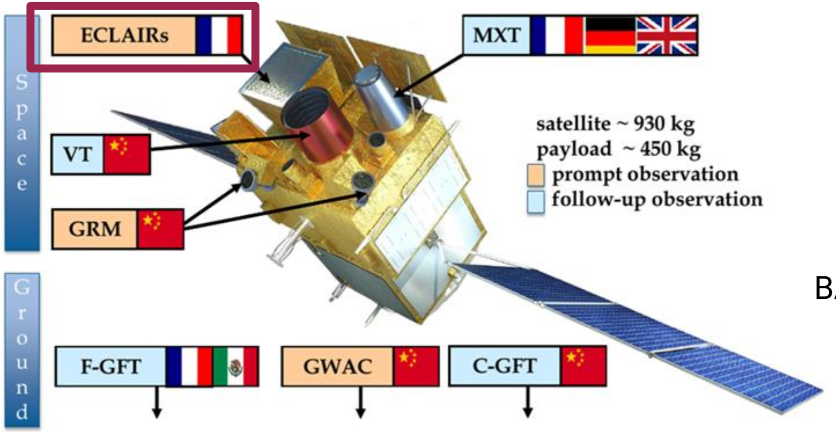
Data processing onboard SVOM/ECLAIRs

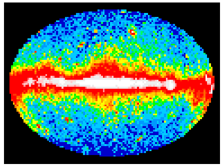
Spaced based multi-band astronomical Variable Object Monitor

French (CNES) – Chinese (CNSA/CAS) collaboration

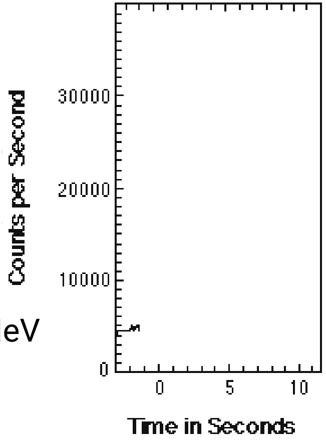
Launch in December 2021 in China (Xichang, Long March rocket)

A multi wave-length mission with space based and ground based instruments





BATSE, 20 keV - 1 MeV

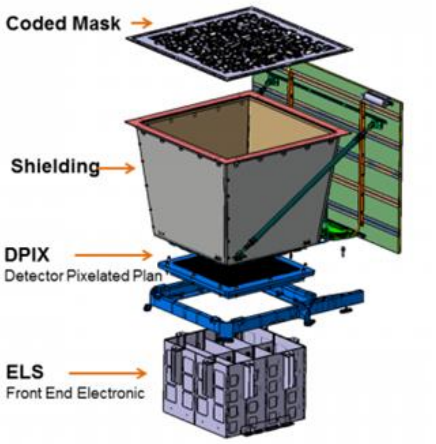


SVOM core program is to detect and observe gamma ray bursts (GRB).

Data processing onboard SVOM/ECLAIRs

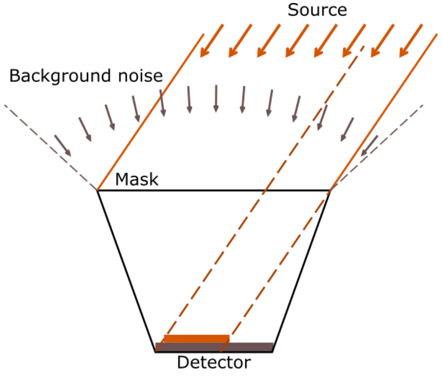
Difficult to focus hard X-rays with mirrors *(need a very long focal length)*

→ ECLAIRs uses coded mask to localise GRB



Energy range: 4-150 keV

Ti-Ta-Ti mask



Field of view: 2 sr

80x80 pixelated CdTe detector

Localization error: < 12 arcmin

2 triggers: count rate monitoring and image

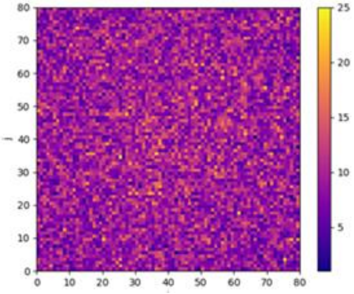
Data processing onboard SVOM/ECLAIRs

Detector signal = Background + known sources contribution + GRB (possibly)

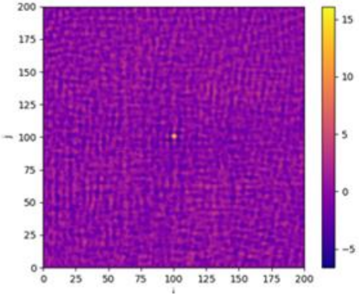
What instrument gives

Scientific product

Noisy projections of the mask



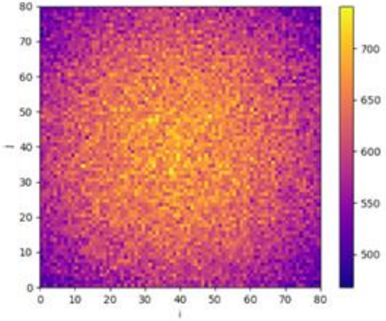
Sky image



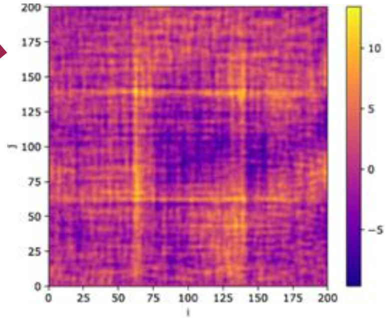
Background cleaning

Deconvolution by the mask

Cleaning 1 - Cosmic X-ray Background (Moretti et, al. 2009)



Deconvolution without cleaning



No cleaning → artifacts that reduce GRB detection efficiency

Cleaning of Cosmic X-ray background (2 methods):

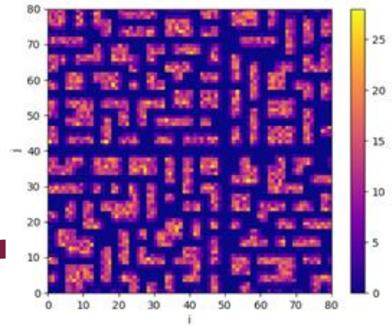
- fit of a quadratic model:

$$a \cdot x^2 + b \cdot y^2 + c \cdot x \cdot y + d \cdot x + e \cdot y + f$$

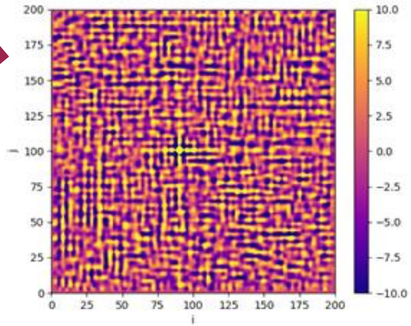
- Wavelets: "à trou algorithms" (Stark et al. 2007) remove large scales in detector images

Wavelets are faster and do not need assumptions on the background shape.

Cleaning 2 - Known X-ray sources



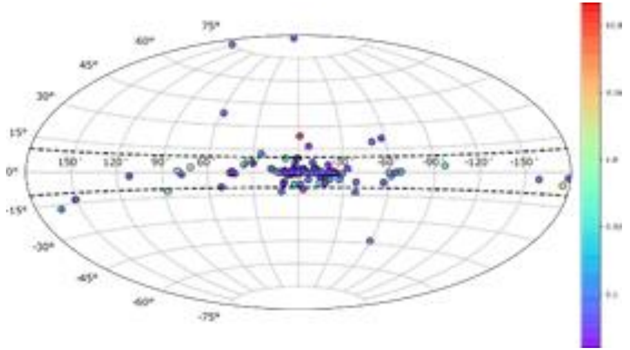
Deconvolution without cleaning

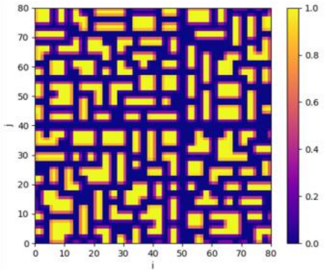


No cleaning → source peak and noise all around that reduce GRB detection efficiency

Cleaning of known sources: fit of the source model (1 param: its flux)

- simultaneously with the Cosmic X-ray Background
- after wavelet cleaning

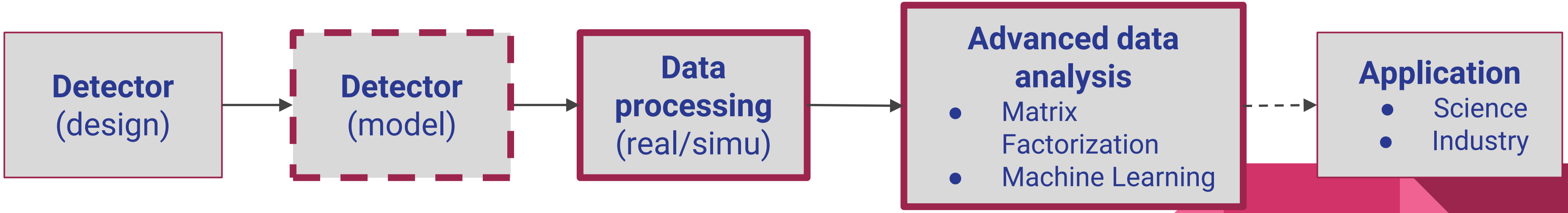




Galactic coordinates

Development and Optimization of a Miniature Compton Camera with coded mask aperture: analysis method of a radiative environment by spectra-identification and 3D localization of gamma ray sources

Geoffrey Daniel (DAp)



Development of a miniature gamma camera

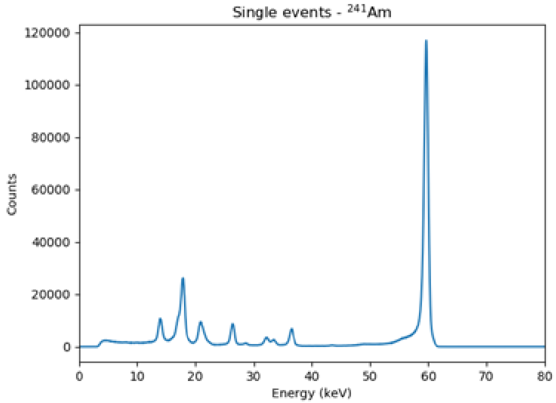
CdTe semi-conductor crystal
Low-noise readout ASICs: IDeF-X HD (DEDIP)

High **energy range**: from 2 keV to 1 MeV

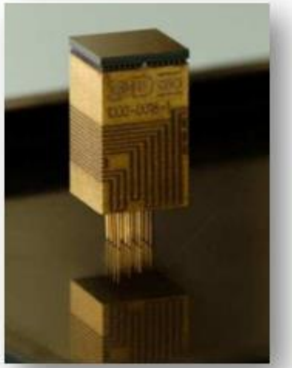
High energy resolution

670 eV FWHM at 60 keV (1,1 %)
4,1 keV FWHM at 662 keV (0,62 %)

→ **Spectrometry**



Caliste-HD (CEA Irfu)



Pixelated detector 16 x 16 pixels

625 µm pixel pitch
1 mm thickness
Surface: 1 cm²

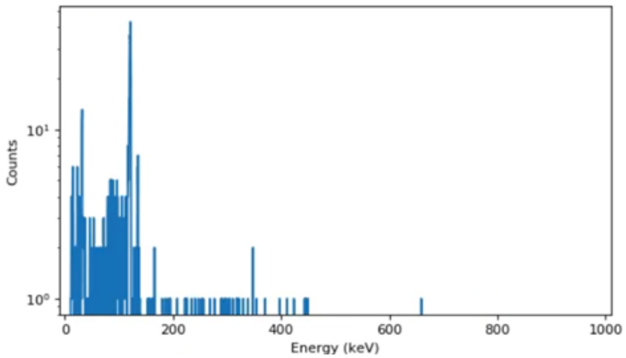
→ **Imaging system**

Nuclear safety application

WIX-HD Camera
Mass: 1 kg

Development of a miniature gamma camera: spectro-identification

Measured spectrum



Which radioelements? → Classification

In which proportions? → Regression

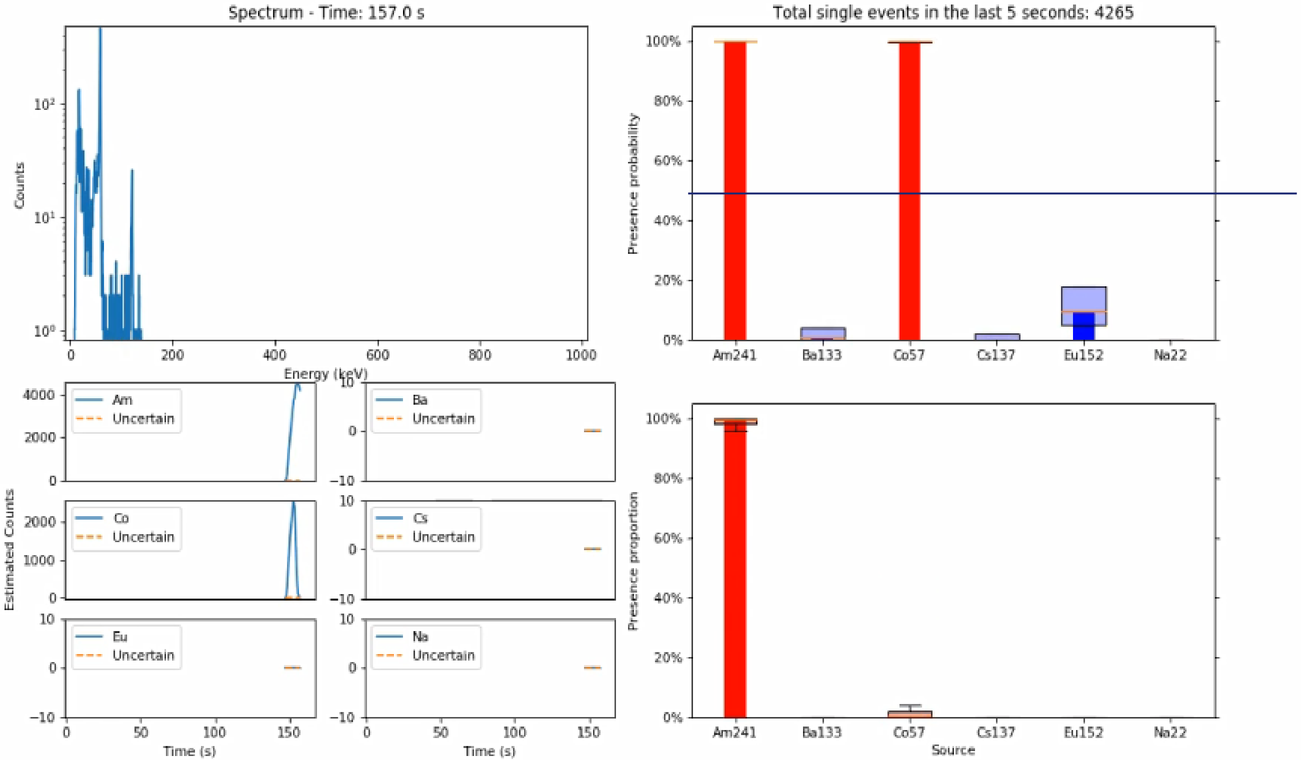
With uncertainties?

Some constraints:
- **Real-time** computation
- Identification for **low-statistics** of photons
- Independent on **operational conditions** (temperature, high-voltage… → impact on calibration)
- Not sensitive to environmental conditions (presence of absorbing materials or diffusing materials)

Our solution: **deep learning**

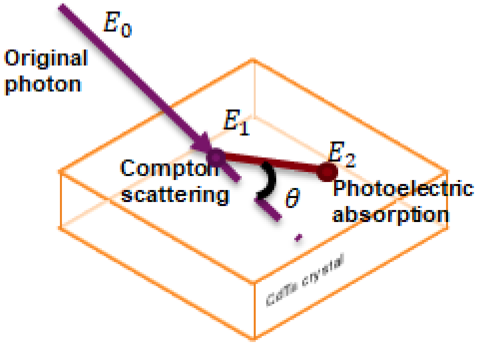
Synthetic data as training set
Real data for testing

Development of a miniature gamma camera: spectro-identification



Decision threshold (50 %)

Development of a miniature gamma camera: localization



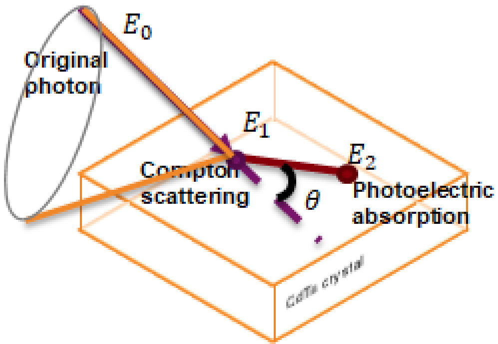
Energy conservation:

$$E_0 = E_1 + E_2$$

Compton kinematics:

$$E_2 = \frac{E_0}{1 + \frac{E_0}{m_e c^2}(1 - \cos(\theta))}$$

Development of a miniature gamma camera: localization



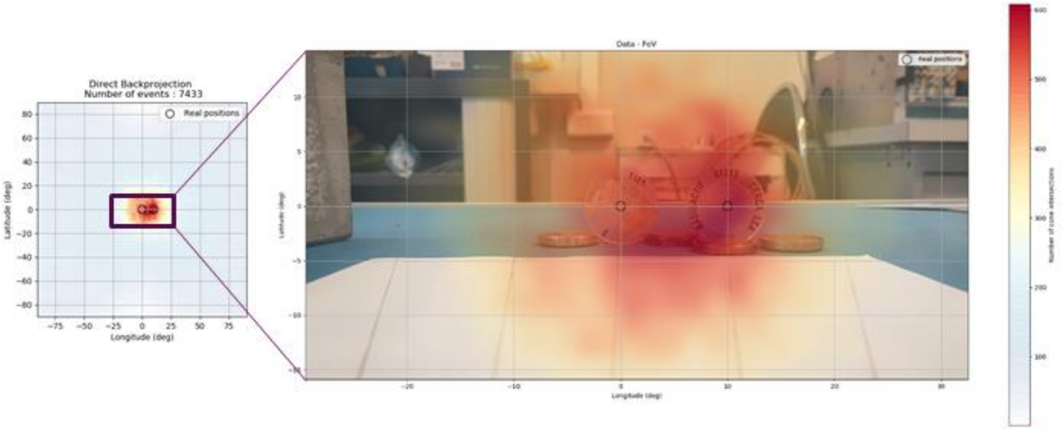
Energy conservation:

$$E_0 = E_1 + E_2$$

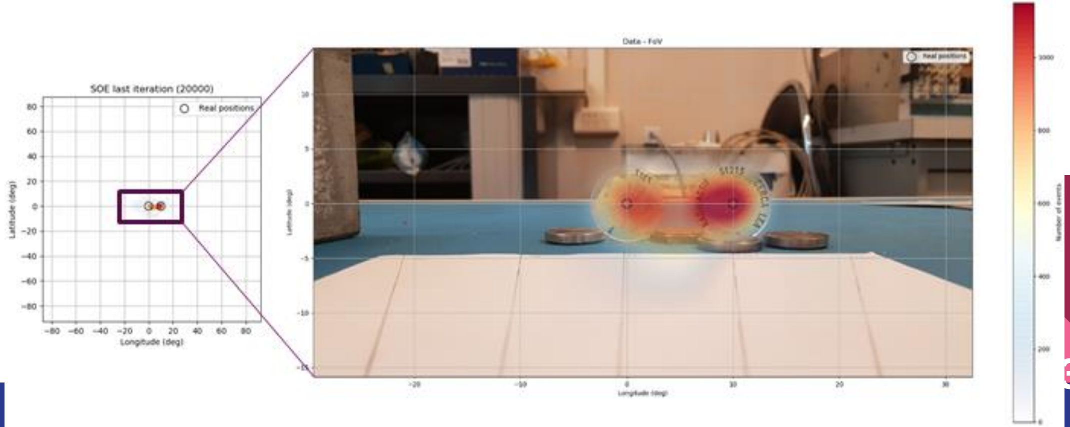
Compton kinematics:

$$E_2 = \frac{E_0}{1 + \frac{E_0}{m_e c^2}(1 - \cos(\theta))}$$

Direct backprojection

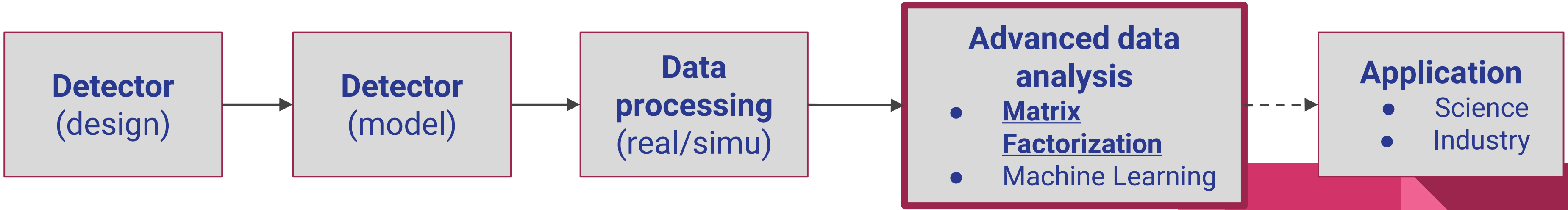


Stochastic Origin Ensemble based on Markov Chain Monte-Carlo

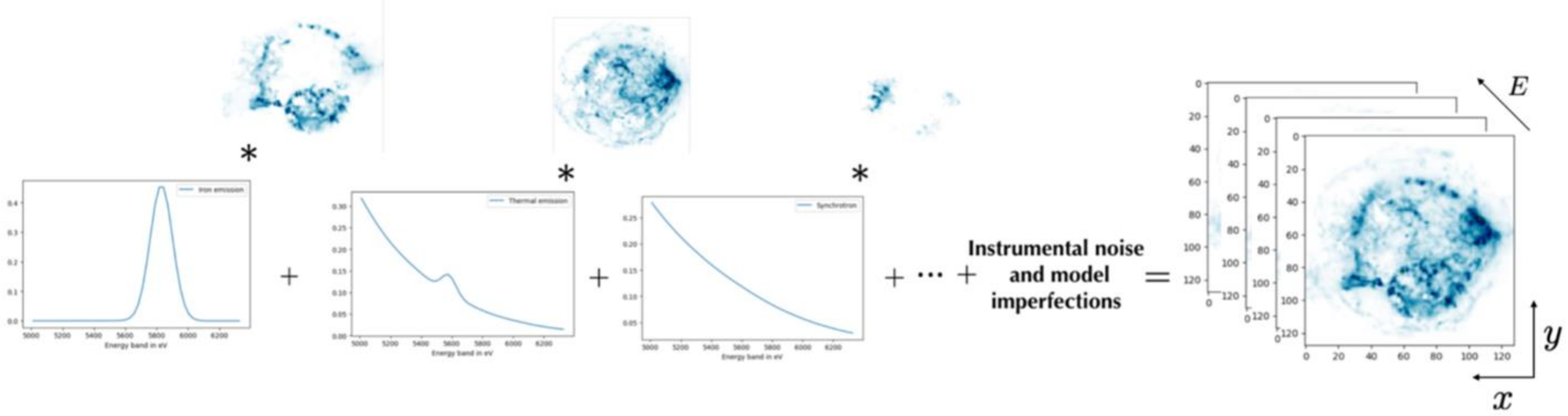


Multivalued data analysis with Blind Source Separation

Imane El hamzaoui (DEDIP)



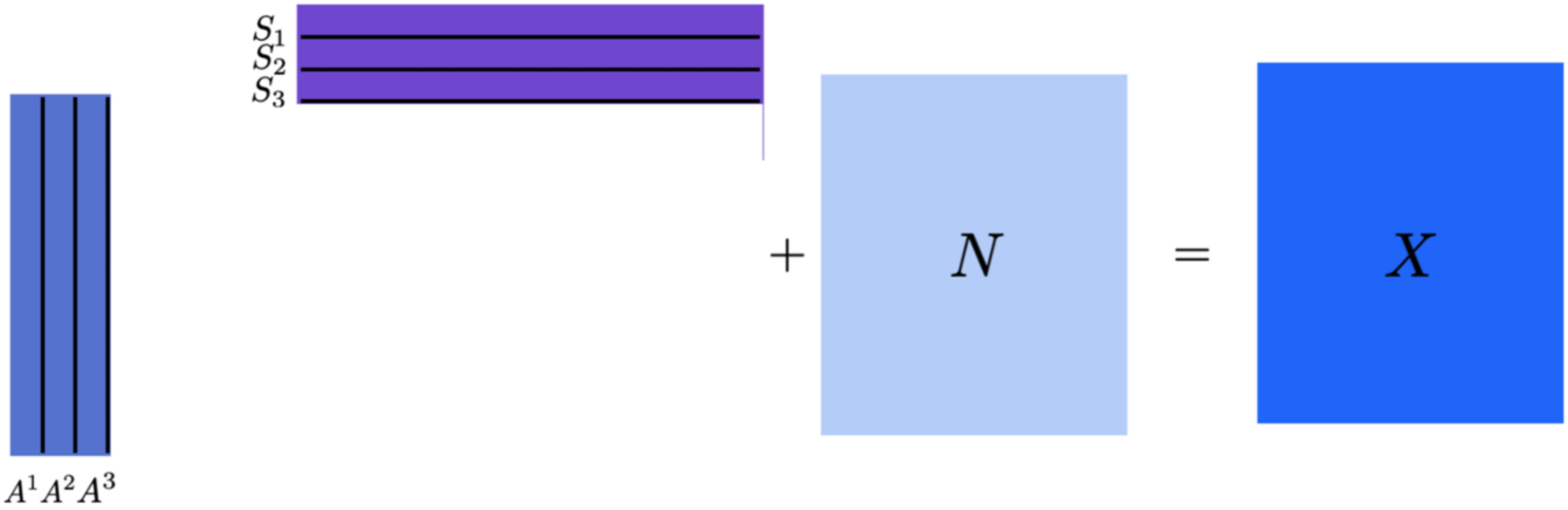
Modelization of the data through Linear Mixture Model



$$\mathbf{A}^1\mathbf{S}_1 + \mathbf{A}^2\mathbf{S}_2 + \mathbf{A}^3\mathbf{S}_3 + \ldots + \mathbf{N} = \mathbf{X}$$

Modelization of the data through Linear Mixture Model

$$\mathbf{A}^1\mathbf{S}_1 + \mathbf{A}^2\mathbf{S}_2 + \mathbf{A}^3\mathbf{S}_3 + \ldots + \mathbf{N} = \mathbf{X}$$

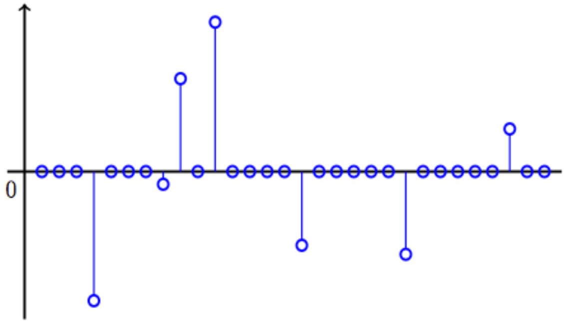


Sparse Blind Source Separation

Blind Source Separation aims at disentangling mixed components to retrieve meaningful information: $\min_{A,S} \underbrace{||X - AS||_F^2}_{\text{Data-fidelity term}}$

$S\Phi^T$

This is an ill-posed problem ⟶ Sparsity constraint



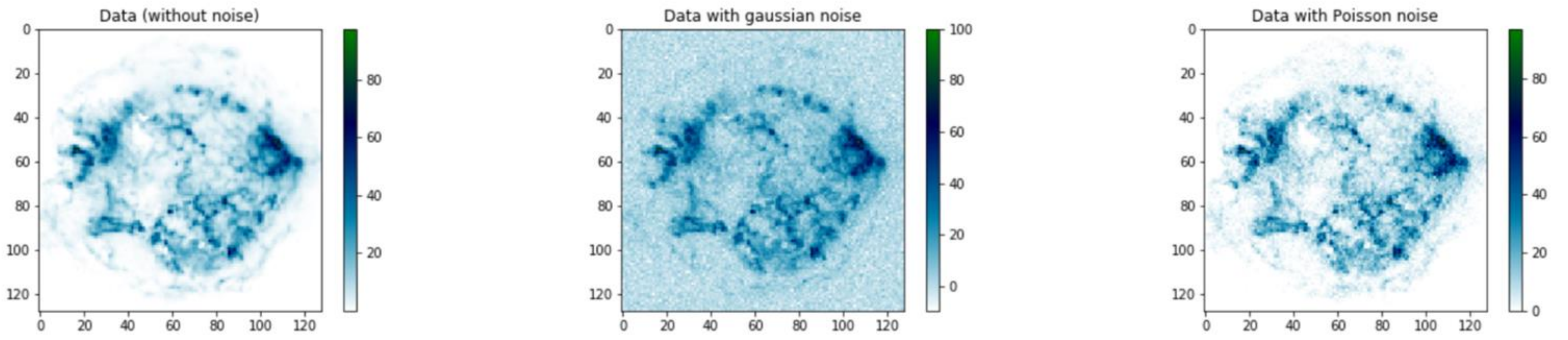
Coefficients of sparse signal

$$\min_{A,S} \underbrace{||X - AS||_F^2}_{\text{Data-fidelity term}} + \underbrace{\lambda ||S\Phi^T||_1}_{\text{Regularization term}}$$

Goal of the PhD: application of the BSS to high-energy imaging

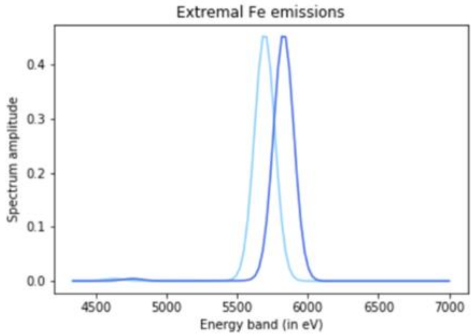
1. Poisson noise: High-Energy photon count is so low that we cannot consider the noise gaussian.

The modelization $\mathbf{X} = \mathbf{AS} + \mathbf{N}$ is no more valid.

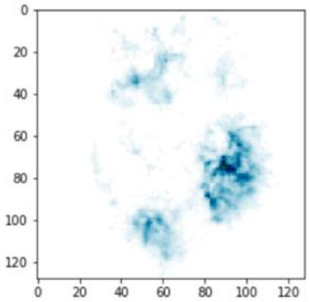


Goal of the PhD: application of the BSS to high-energy imaging

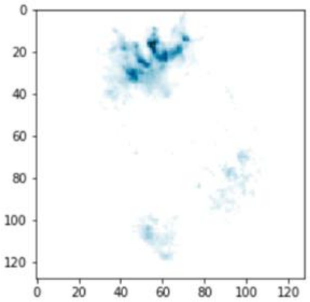
2. Spectral variabilities: spatially variant spectra are ubiquitious to X-ray imaging.



Spectral distribution



Spatial distribution of Fe1



Spatial distribution of Fe2

Necessity of a model that fully accounts spectral variabilities.

Machine learning for CLAS12 data analysis

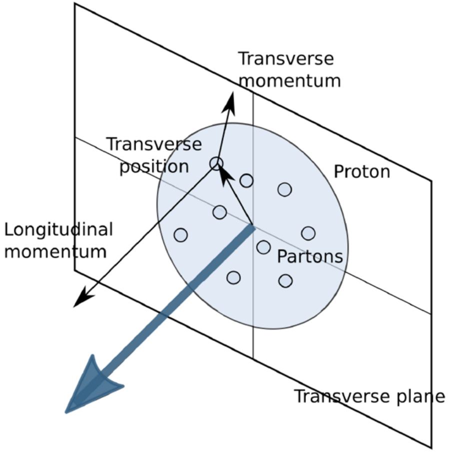
Noëlie Cherrier (DPhN)

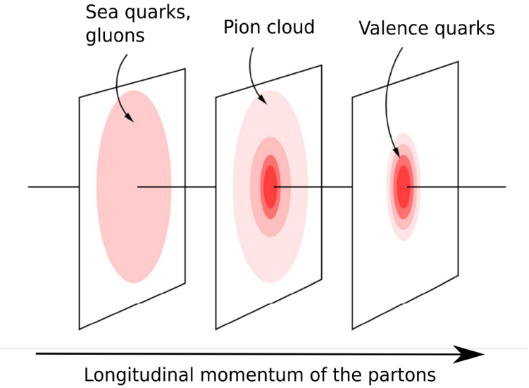
- **Detector** (design) →
- **Detector** (model) →
- **Data processing** (real/simu) →
- **Advanced data analysis**
  - Matrix Factorization
  - **Machine Learning**
- - -→ **Application**
  - Science
  - Industry

Study the proton structure

Scientific interest: understand the structure of the proton

Generalized Parton Distributions (GPDs): quarks longitudinal momentum and transverse position correlations





[Weiss 2009]

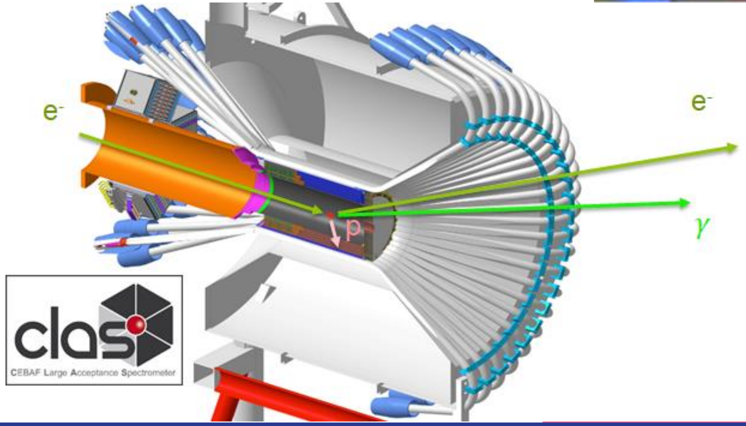
CLAS12 experiment

electron accelerator (10.6 GeV)

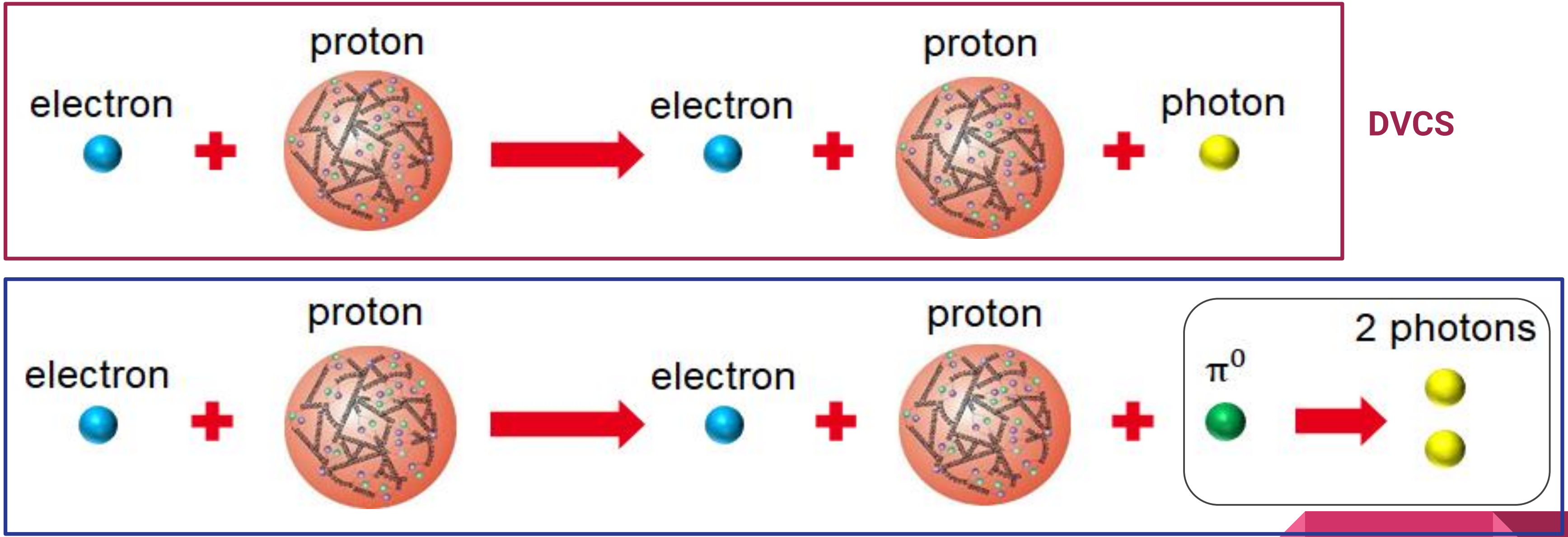
proton target

particle detector

Process of interest to study GPDs: Deeply Virtual Compton Scattering (DVCS)



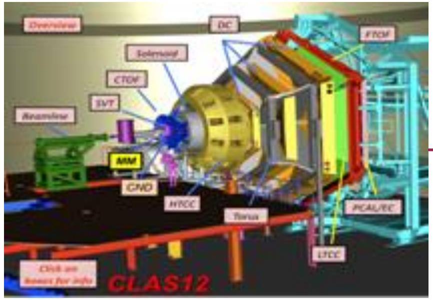
DVCS extraction



DVCS

π^0 - production

Machine learning for DVCS/Pi0 separation



→ **Reconstruction software**
Tracking, pid, ...

→ **for each event**
List of identified particles with their 3-momentum

input for
ML algorithms

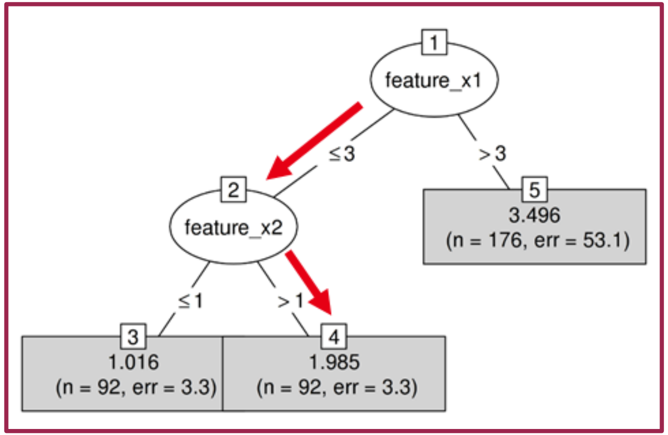
Interpretable ML: training on Monte-Carlo simulations and application on real data

List of reconstructed events →

→ (Smaller) list of DVCS events

Interpretable ML algorithms

✗	Neural networks	y= complex non-linear function of inputs
✓	Decision trees	IF x1>2.7 AND x2<-4.3 THEN y= signal
≈	Boosted decision trees	y= vote among trees



Decision trees

List of rules

If $x_1 > \alpha_1$ and $x_2 < \alpha_2$ then DVCS
If $x_1 < \alpha_3$ and $x_3 > \alpha_4$ then Bkg
...

Feature construction

Constrained Genetic Programming algorithm to build new high-level variables to improve DVCS/Pi0 separation

$p_x^e \quad p_y^e \quad p_z^e \quad \theta^e \quad \phi^e$

$p_x^p \quad p_y^p \quad p_z^p \quad \theta^p \quad \phi^p$

$p_x^{\gamma_1} \quad p_y^{\gamma_1} \quad p_z^{\gamma_1} \quad \theta^{\gamma_1} \quad \phi^{\gamma_1}$

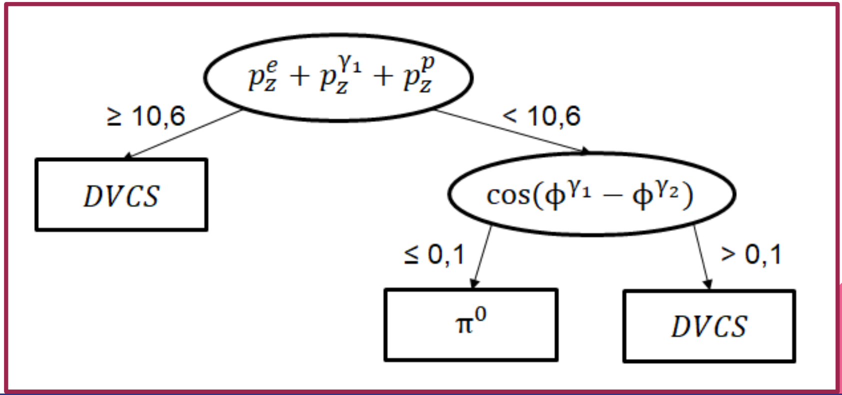
$p_x^{\gamma_2} \quad p_y^{\gamma_2} \quad p_z^{\gamma_2} \quad \theta^{\gamma_2} \quad \phi^{\gamma_2}$

...

$$p_z^e + p_z^{\gamma_1} + p_z^p$$

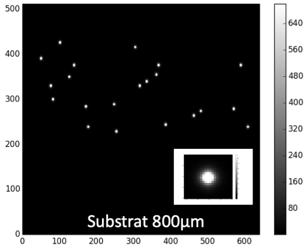
$$(\cos(\phi^{\gamma_1} - \phi^{\gamma_2}) + 9)\cos(\theta^{\gamma_1} - \theta^{\gamma_2})$$

$$\phi^{\gamma_1} - \phi^{\gamma_2}$$

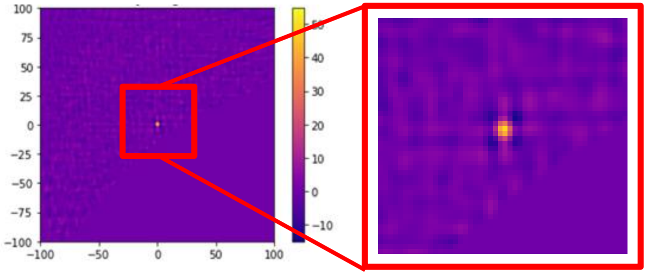


Conclusion

Simulated image of IR detector under irradiation

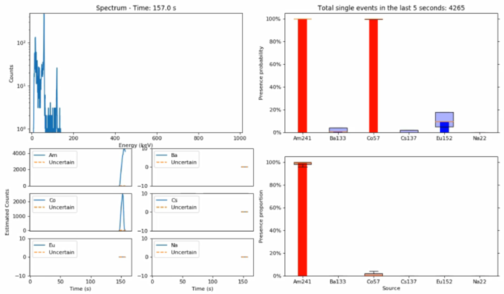


Clean sky image with a well localized GRB



Application

- Science
- Industry



Spectro-identification of radioactive sources