Development activities of the CdTe/CdZnTe pixel detector for gamma-ray spectrometry with imaging and polarimetry capability in astrophysics

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In the last few years we have been working on feasibility studies of future instruments in the gamma-ray range, from several keV up to a few MeV. The innovative concept of focusing gamma-ray telescopes in this energy range, should allow reaching unprecedented sensitivities and angular resolution, thanks to the decoupling of collecting area and detector volume. High sensitivities are essential to perform detailed studies of cosmic explosions and cosmic accelerators, e.g., Supernovae, Classical Novae, Supernova Remnants (SNRs), Gamma-Ray Bursts (GRBs), Pulsars, Active Galactic Nuclei (AGN). Our research and development activities aim to study a gamma-ray imaging spectrometer in the MeV range based on CdTe detectors, suited for the focal plane of a focusing mission or as a calorimeter for a Compton camera.

DETECTION OF GAMMA-RAYS IN THE MeV ENERGY RANGE (i.e., from a few 100 keV up to a few MeV)

- Coded mask e.g.: SPI instrument of INTEGRAL
- Compton effect: COMPTEL instrument of CGRO

the aperture system and the detector are "coupled"

photon collecting area ↑ detector area ↑ and volume ↑

instrumental background ↑ difficult to increase Signal to Noise (S/N) ratio

- Focusing optics (e.g. Laue lens):

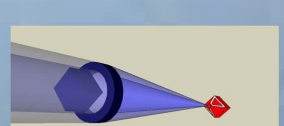
Focus gamma-ray with a Laue lens

photon collecting area ↑ with detector area ↓ and volume ↓

instrumental background ↓ S/N is really improved

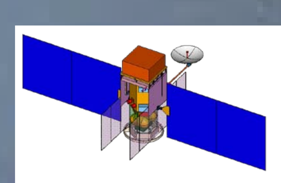
- Compton camera
- Laue focusing lens + Compton camera

Our group has been involved in proposals of different gamma-ray missions:

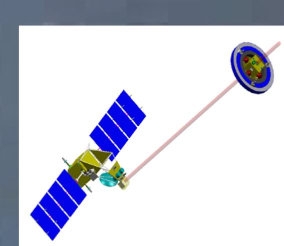


DUAL[2] proposal (2010) Laue focusing lens + Compton camera

GRI[1] proposal (2007) Focal plane detector for a Laue lens telescope with 2 SCs in formation flight



ACT (2005) Compton camera



MAX (2004) Laue focusing lens telescope with 2 SCs in formation flight

and in ground and balloon-borne experiments:

Long Distance Test of CLAIRE

(from CESR)

CLAIRE: First prototype of a Laue lens for gamma- ray astrophysics

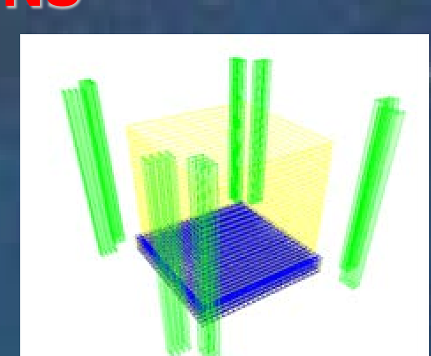
POLARIMETER CAPABILITY

- **Why?** Provide key information about the geometry, magnetic fields, composition, and emission mechanisms in a wide variety of cosmic sources.
- **How?** X-POSIT (X-ray POlarimetric Spectroscopic Imaging Telescope) proposal for a wide field spectroscopic imaging polarimeter for hard X- and soft gamma-ray observations of both transient and persistent cosmic sources/CμSP(CdTe micro-Spectometer Polarimeter)[3] for hard X- and soft gamma-ray astrophysics as a balloon borne payload.
- **Performances?** operate as a scattering polarimeter between 100 and 500 keV; CZT detector with 3D spatial resolution.
- **Task?** measurement of the polarization status of the Crab pulsar, i.e. the polarization level and direction.

DETECTOR MC SIMULATIONS

The main goal of our simulation studies is to determine feasible instrument configurations to achieve the sensitivity requirements of gamma-ray space missions for Nuclear Astrophysics.

We are using the Geant4 Monte Carlo code, and MEGAlib toolkit, to optimize the design of our prototype. Parameters such as the number of layers, thicknesses, and size of the pixel.



Model mass of a Si/CdTe Compton Camera
24 layers Si strip detectors
4 layers CdTe pixel detectors

PERSPECTIVES

In the near future, our institute will be involved in different X- and gamma-ray research activities for nuclear astrophysics where Silicon and CdTe/CdZnTe detectors play an important role in the instrument detection efficiency, sensitivity, energy and spatial resolution.

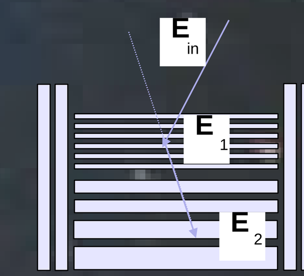
New and further performance tests of CdTe/CdZnTe pixel detector modules as a calorimeter of a Compton camera or as a payload option for a balloon-borne experiment dedicated to hard X- and soft gamma-ray polarimetry or as a detector for the focal plane of a focusing mission will be carried out. Likewise, Monte Carlo simulation studies will support to determine the feasibility of such instrument configurations for a future space mission.

GAMMA-RAY DETECTOR CONCEPT

Challenge: Reaching E ~ 1MeV with high detection efficiency, keeping a good spatial and energetic resolution.

Trade-off detector design:

CdTe thickness	Detection efficiency	Energy resolution
↑	↑	↓
↓	↓	↑



Scheme of the detector prototype

Proposal:

- stack of CdTe pixel detectors with increasing thicknesses
- take advantage of both approaches to find an optimal trade-off between the thickness and the energy resolution
- complex read-out electronics to handle the interactions within thin and thick layers

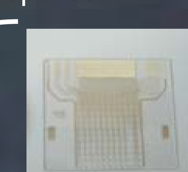
CdTe pixel detector module

Former CdTe pixel detector module prototype[4]:

- CdTe pixel detector: **Pt/CdTe/Pt** with **ohmic contacts** for **electron collection**. Dimensions: **12.15mm x 12.15mm x 2mm.** The anode side was divided into **11x11 pixels** with a **pixel pitch of 1mm** and a **pixel size of 1mm x 1mm**. A **guard ring** with a **width of 0.5mm** surrounds the pixels.
- Read-out ASIC: 128 channel low noise NUCAM ASIC (channel number, interaction amplitude and collection-time estimate, ADC on-chip).
- Glass fan-out board or pitch adapter.

New CdTe pixel detector module prototype:

- CdTe pixel detector: **Al-schottky /CdTe/Pt** for electron collection.
- Read-out ASIC: 128 channel low noise and power VATAGP7.1 ASIC (trigger signal; serial, sparse and sparse with neighbour channels read-out mode).
- Alumina (Al_2O_3) **fan-out** board.



Bump-bonding procedure:

- low melting point solder paste deposited by screen printing
- pick & place machine to place detector onto fan-out board
- reflow step in a controlled atmosphere

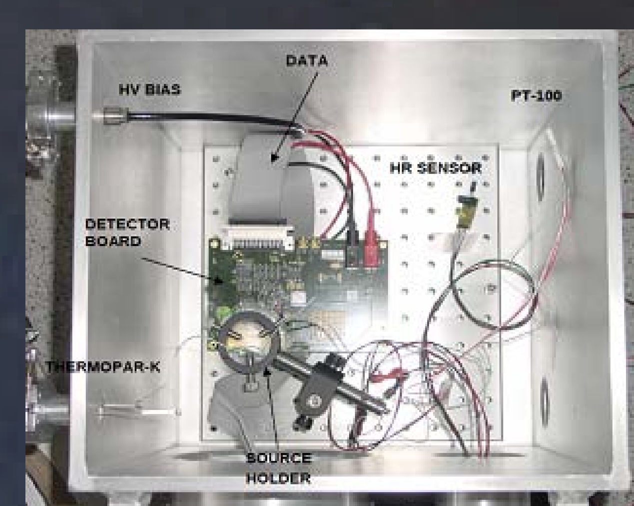
CdTe pixel detector in a stack configuration

Experimental set-up and spectra measurement

The experimental setup consists basically in a vacuum chamber, an oil-sealed rotary vane vacuum pump, a freezer and a controllable high voltage power supply. The vacuum chamber is made of Aluminum and has a volume of 350mm x 300mm x 350mm.

Experimental conditions:

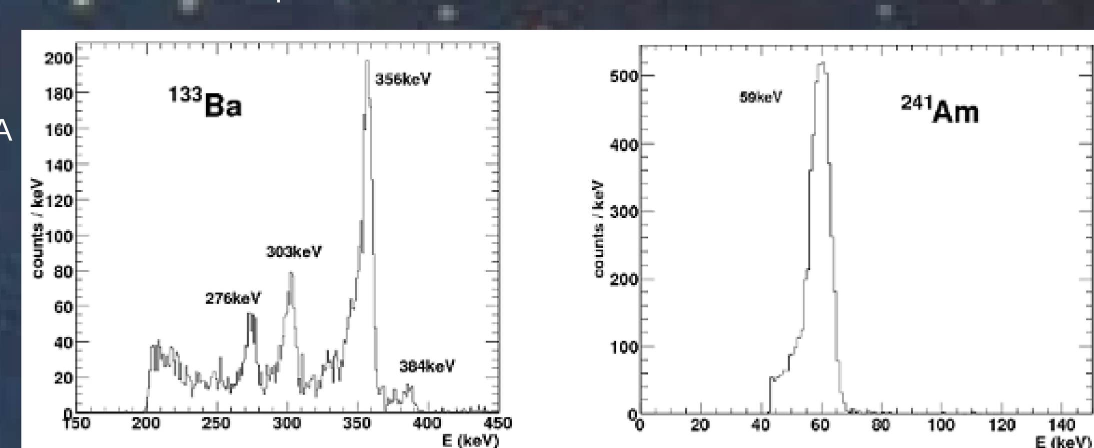
- Detector HV bias: -400V
- Cathode irradiation
- Temperature: -10ºC, Acquisition time: 5 hours
- Radio-isotope: ^{133}Ba@1μCi and ^{241}Am@10μCi
- Distance between detector and radioisotope: 30cm



Experimental set-up inside the vacuum chamber

NUCAM chip settings:

- Leakage current comp.: 2nA
- Threshold: 2.4V/1.8V
- Shaping time: 7.5μs
- ADC amplitude: 350keV
- Collection time clock: 12μs



An energy resolution of 9.2keV (FWHM) at 356keV (133Ba source) and 5.47keV (FWHM) at 59.5keV (241Am source) for one pixel

REFERENCES

[1] Knodlseder, J. et. al., "GRI: focusing on the evolving violent universe", Experimental Astronomy, 23, 121-138 (2009).
[2] Von Ballmoos, P., et al., "The DUAL mission concept", Proc. SPIE 8145, 81450E (2011).
[3] Caroli, E., et al., "A Cadmium telluride micro-Spectometers Hard X ray Polarimeter for a balloon borne payload", 39th COSPAR Scientific Assembly, 14-22 July 2012, Mysore, India.
[4] Alvarez, J-M., Galvez, J-L., et al., "Imaging detector development for nuclear astrophysics using pixelated CdTe", Nucl. Instr. and Meth. In Phy. Res. A 623 (1), 434-436 (2010).

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