DE LA RECHERCHE À L'INDUSTRIE

CdTe and CdZnTe detectors for Hard X-ray imaging spectroscopy

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www.cea.fr

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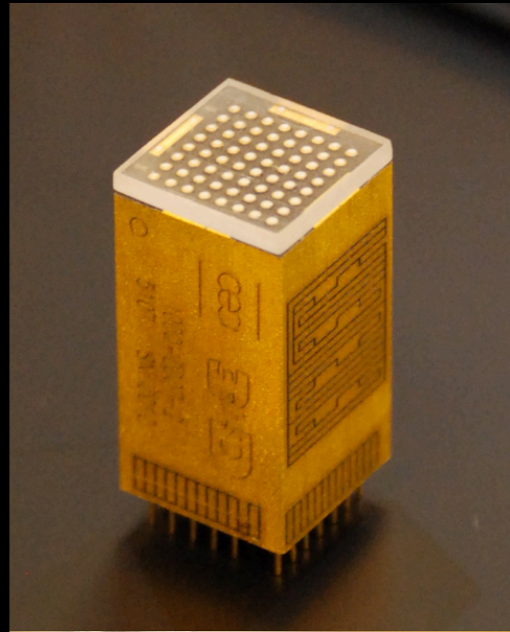
TALK OUTLINE



Intro

State of the art

HXR Imaging spectroscopy constraints

CdTe or CdZnTe?

Fine pitch imaging spectrometers : two recent examples for fair comparisons …

Outro : Take home message

DISCLAIMER

This presentation is not a review of all CdTe and CdZnTe imaging spectrometer technologies worldwide. It shows some advanced developments illustrating different variants in shape, technolgogies, usage and performance of both materials with pixelated patterns, mostly in the field of space science.

A couple of examples are emphasized because they have been using both materials with the exact same electronics, allowing kind of a fair comparison between those two materials when they are used the same way.

The presentation is not intended to review all technologies and inevitably misses some important developments, including in space science.

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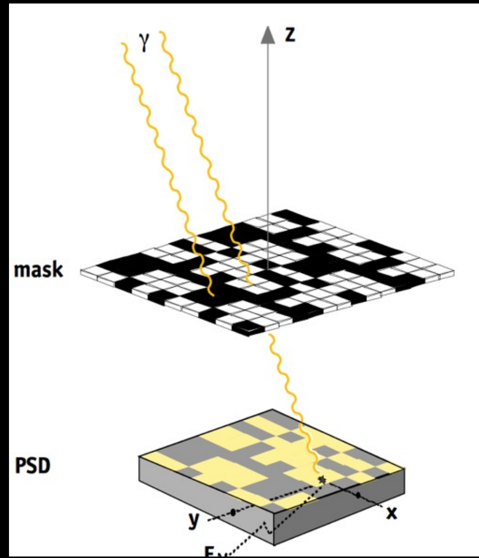
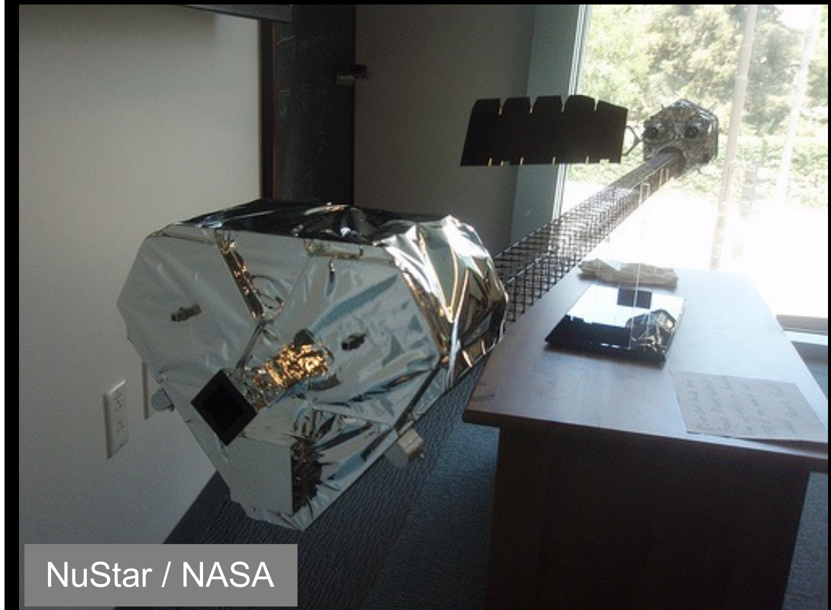
IMAGING SPECTROSCOPY


Integral / ESA

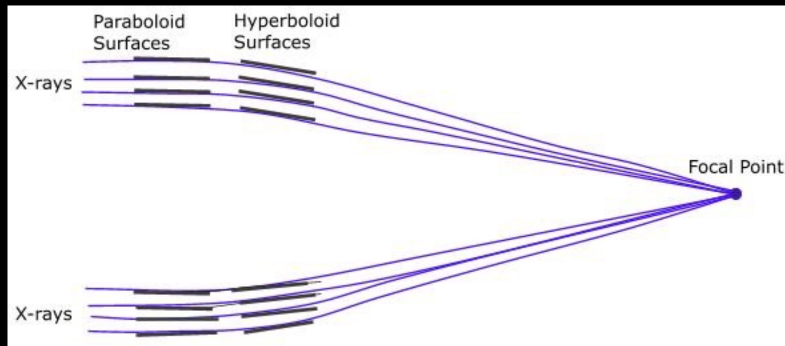
Coded Mask:
- Wide FoV
- Modest Angular resolution
- High Dynamic range in E

Grazing incidence mirrors
- High Angular resolution
- Narrow FoV
- Limited energy range



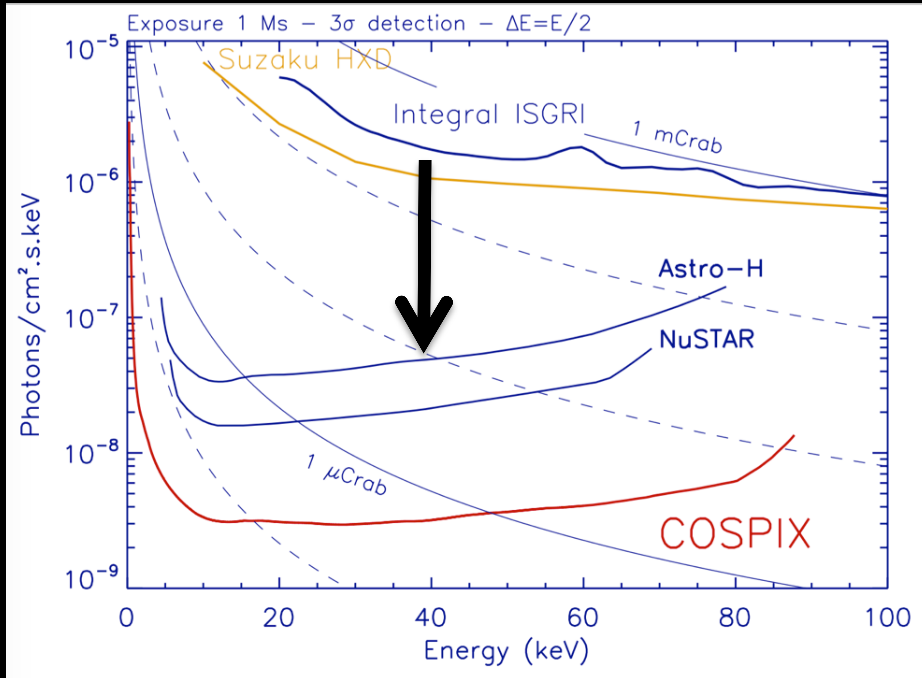

NuStar / NASA


Astro-H / JAXA



TOWARDS A BETTER SENSITIVITY – DIRECT IMAGING

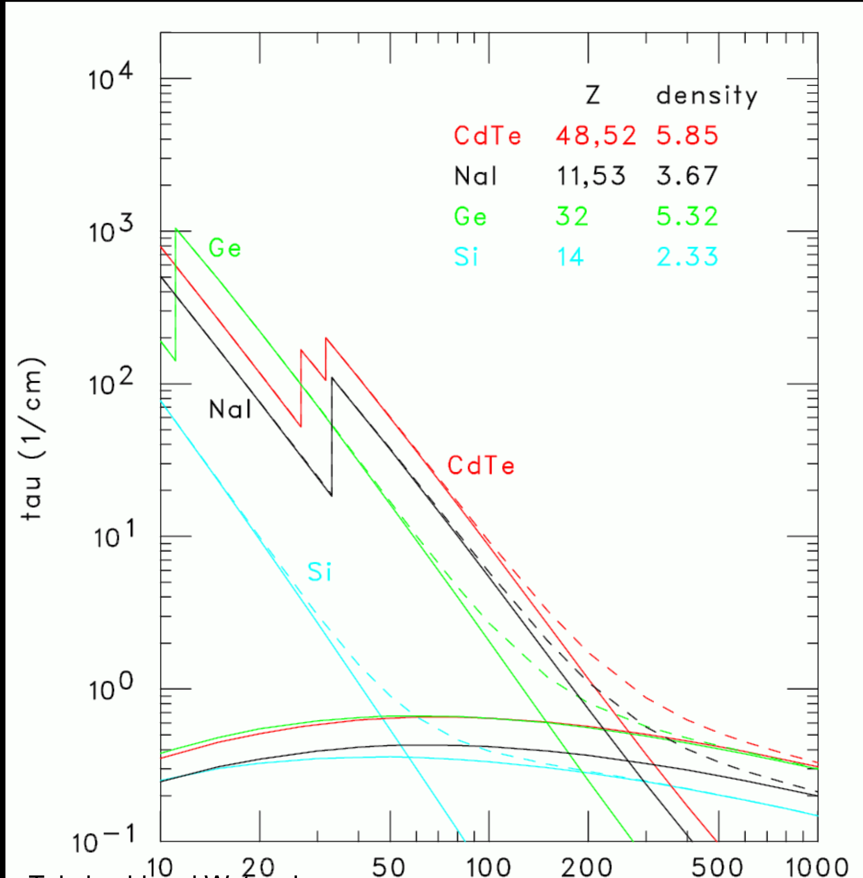
NuStar / NASA



→ *Huge constraints on the detector design*

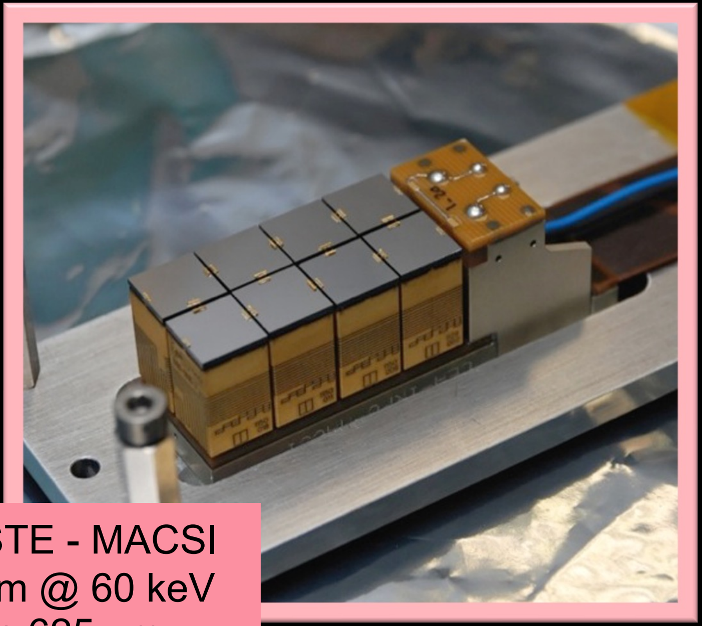
WHY SHOULD WE USE Cd(Zn)Te COMPOUNDS?

- High Z
- High density
- High resistivity
- Moderate cooling
- Compact design
- Flexible pixelization
- Space proven



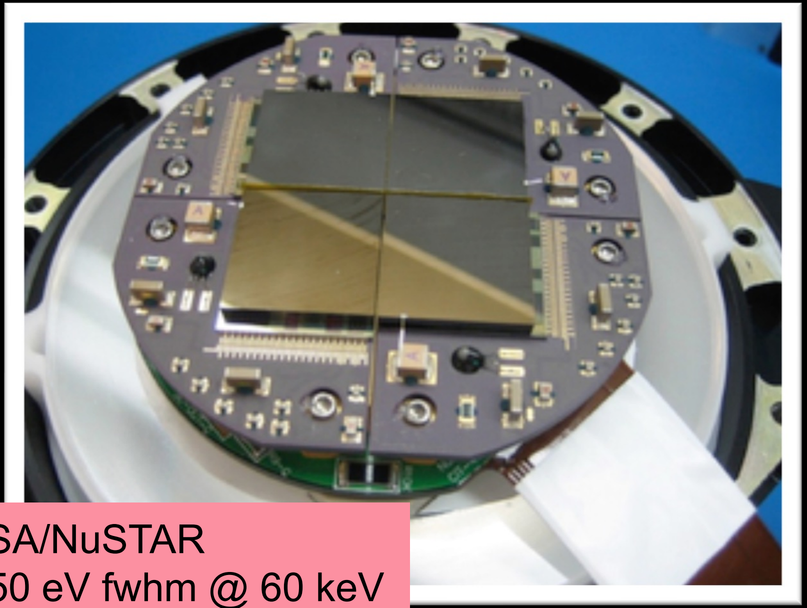
Takahashi and Watanabe 2001

Fine pitch



CEA/CALISTE - MACSI
670 eV fwhm @ 60 keV
32x64 pixels 625 µm

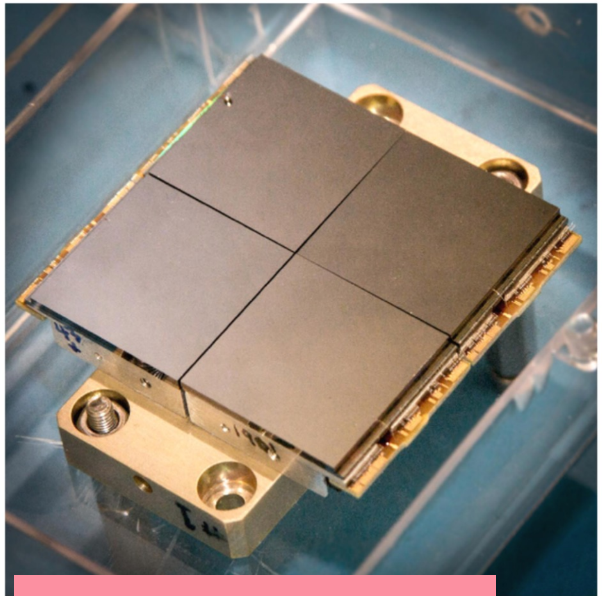
Limousin+14



NASA/NuSTAR
~ 850 eV fwhm @ 60 keV
4x(32x32) pixels 605 µm

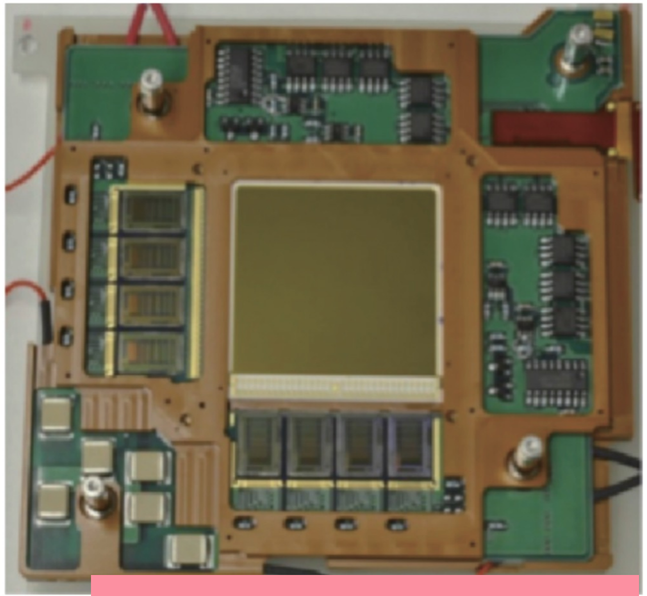
Harisson+13

Very Fine pitch



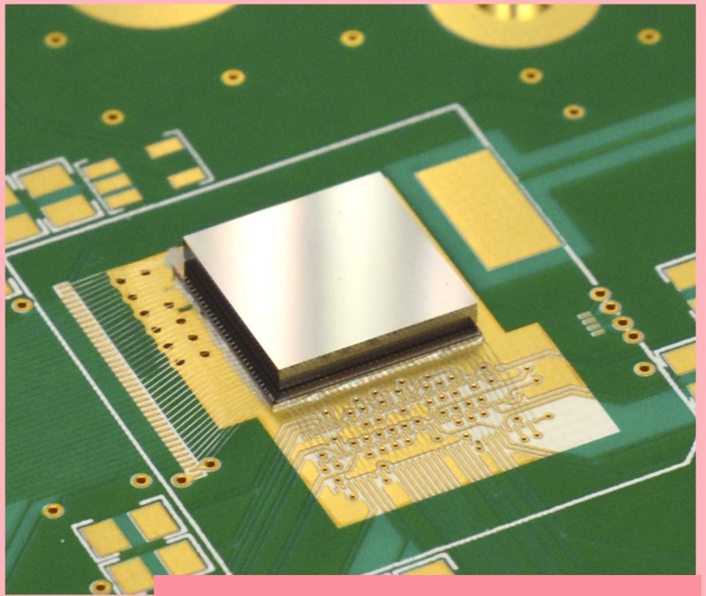
RAL/HEXITEC
~1 keV fwhm @ 60 keV
4x(80x80) pixels 250 µm

Jowitt+21



JAXA/HXI
~2 keV fwhm @ 60 keV
128x128 pixels 250 µm

Hagino+21

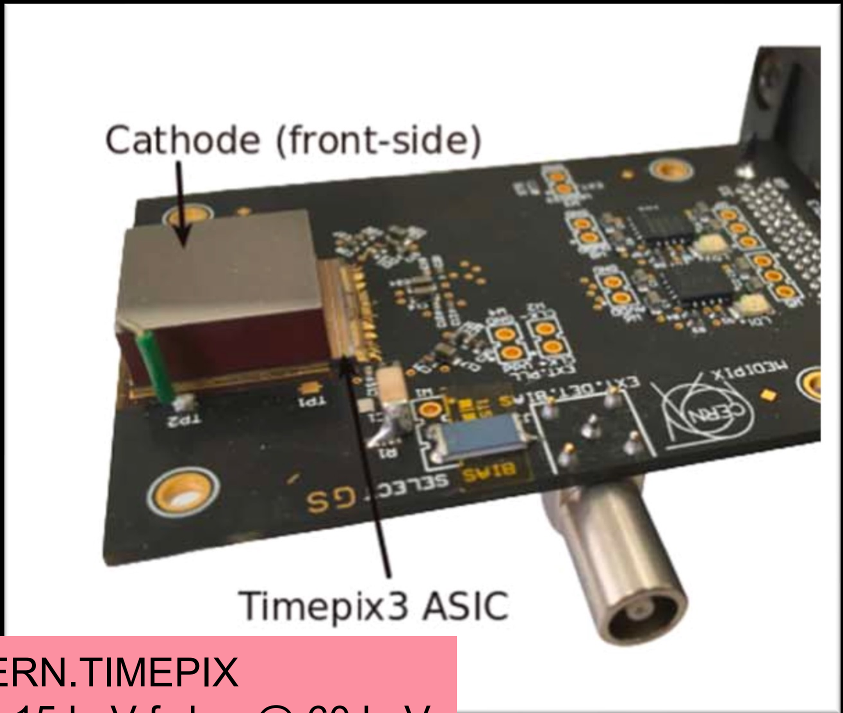


CEA/MC2
~ 0.95 keV fwhm @ 60 keV
32x32 pixels 250 µm

Allaire+23

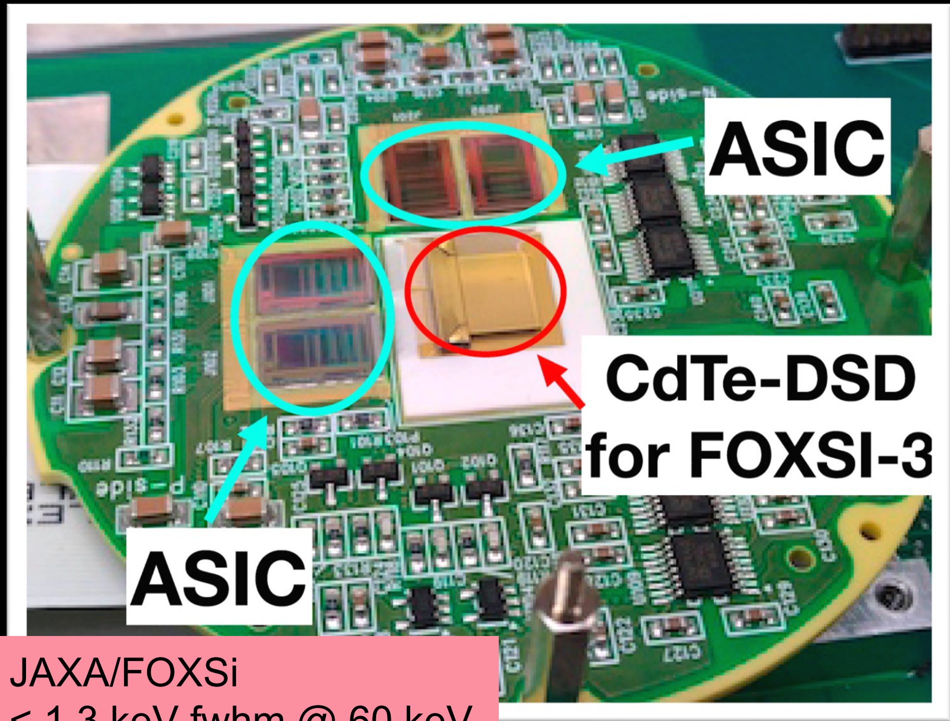
A WORLDWIDE CHALLENGE – FEW RACERS

Ultra Fine pitch



CERN.TIMEPIX
~8-15 keV fwhm @ 60 keV
(26x256) pixels 55µm

Smolyanskiy+24



JAXA/FOXSi
< 1.3 keV fwhm @ 60 keV
128x128 pixels 60 µm

Furukawa+19

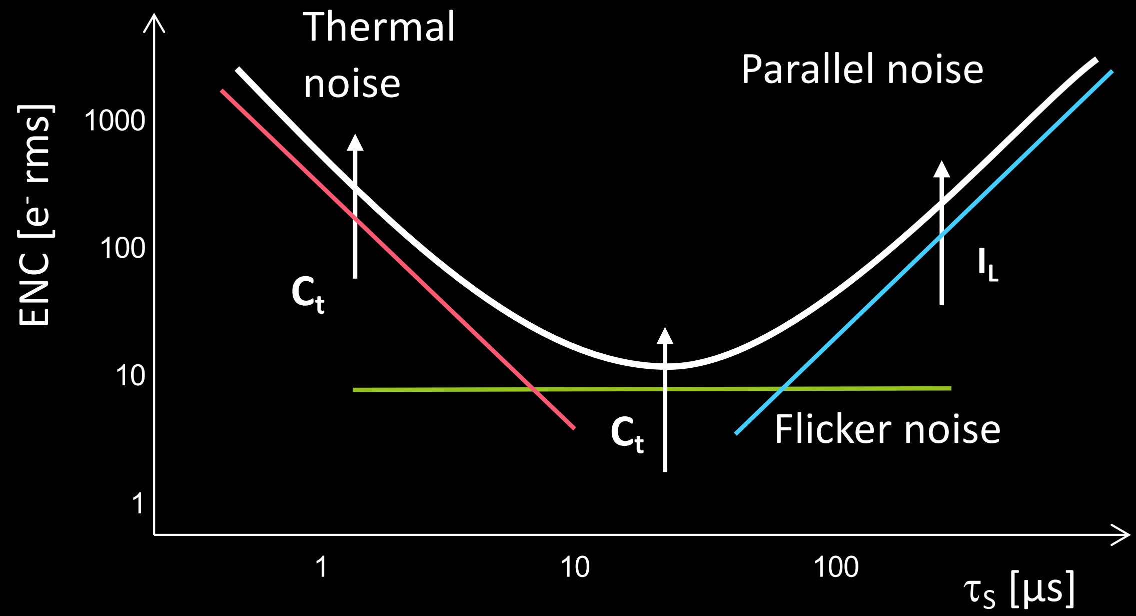
KEY PARAMETERS FOR SPECTROSCOPY

Signal

- **Collect efficiently the charge carriers**
  - + HV
  - + Thin crystals
  - + Corrections and 3D

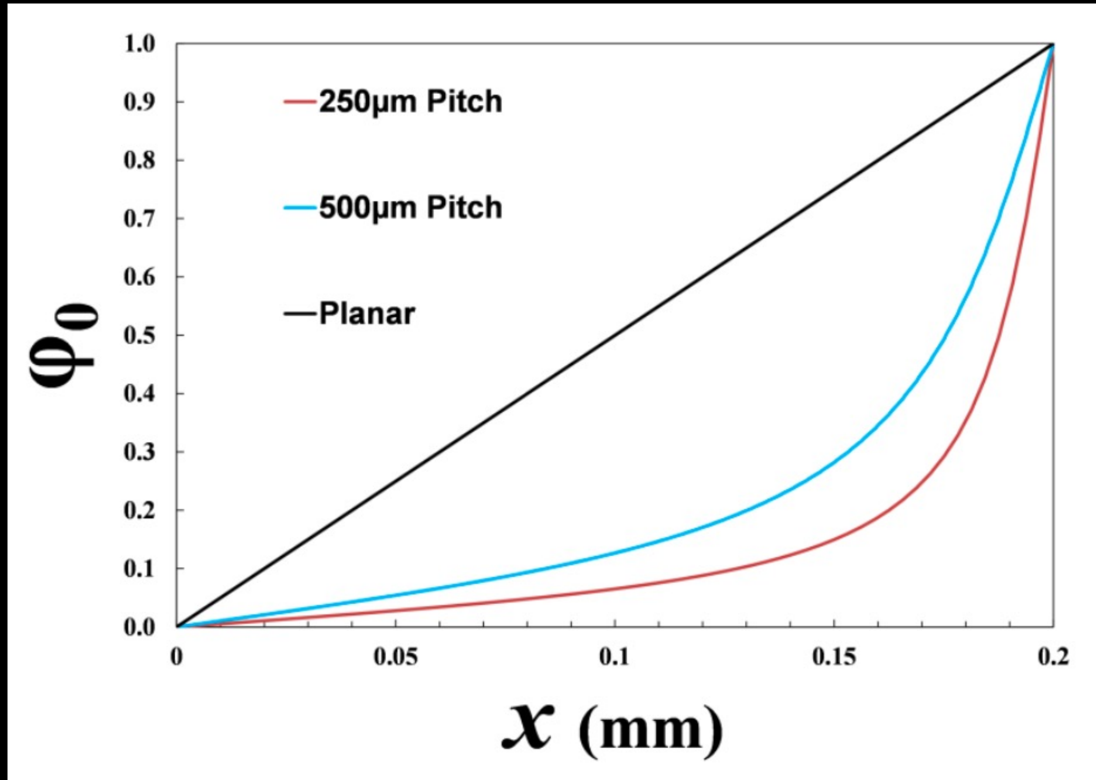
Noise

- In CdTe Fano (0.15) limit is
  - + 147 eV FWHM at 5.9 keV
  - + 226 eV FWHM at 13.9 keV
  - + 467 eV FWHM at 59.54 keV
- Minimize Dark current
- Stray capacitance



$$ENC^2 = C_{\text{tot}}^2 \cdot \left(\frac{\alpha_s}{\tau} + \alpha_f\right) + \alpha_p \cdot I_L \cdot \tau$$

Signal Induction



Thomas et al., 2017

$$CCE = \frac{Q}{q_0} = N \cdot \left[\left(\frac{d}{\mu\tau \cdot V} \right) \cdot \int_0^d \varphi_0(x) \cdot e^{-\frac{d \cdot x}{\mu\tau \cdot V}} \cdot dx + e^{-\frac{d^2}{\mu\tau \cdot V}} \right]$$

Nearly Single carrier detectors

CdTe Vs. CdZnTe ?

CdTe

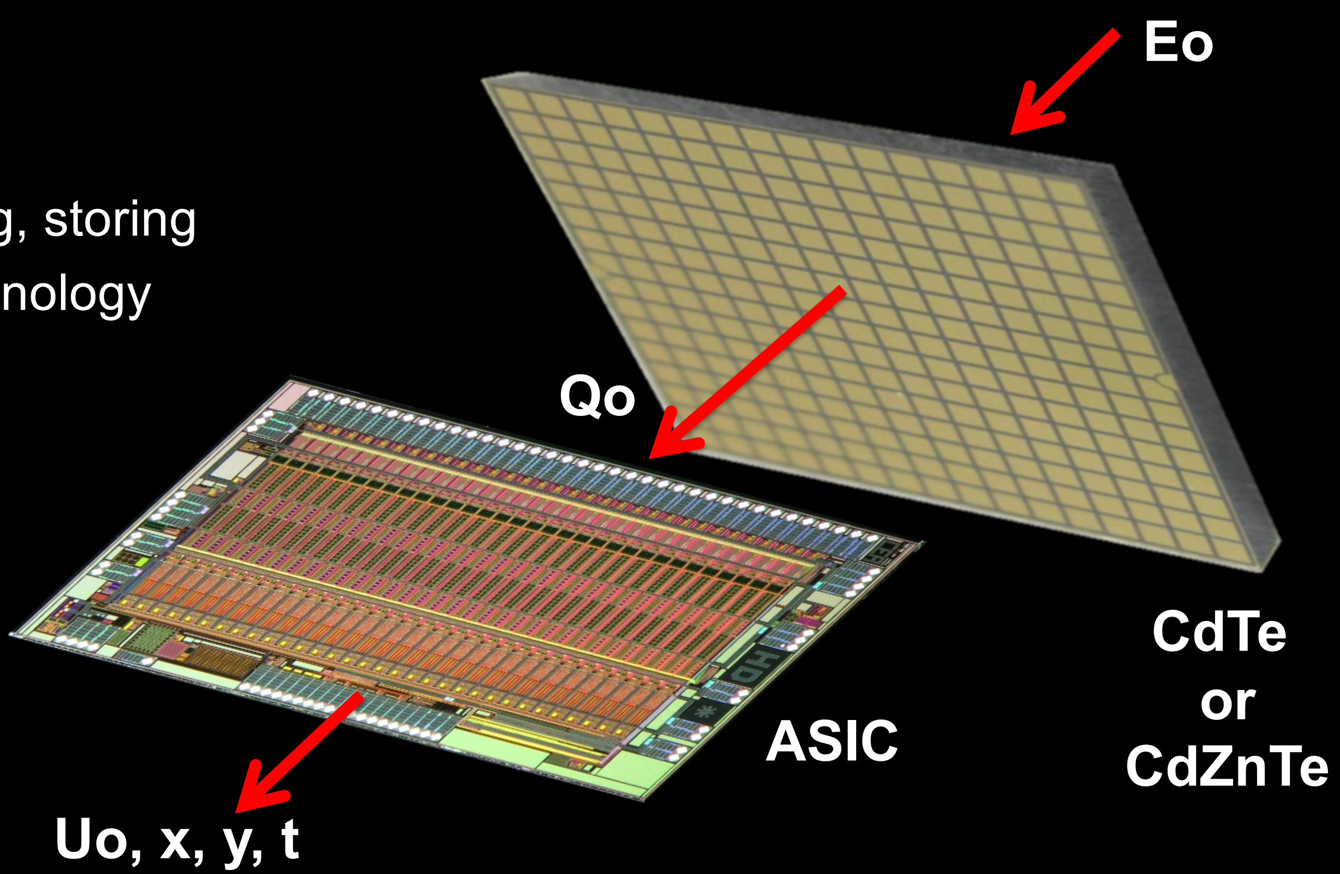
- Band gap 1.44 eV
- Ionization energy ~4.42
- Z = 50
- D = 5.85 g/cm^3
- ~1E9 $\Omega.cm$
- “Easy” to procure in Space grade
- $\mu_e\tau_e$ ~ 3×10^{-3} cm^2V^{-1} (Acrorad)
- $\mu_h\tau_h$ ~ 2×10^{-4} cm^2V^{-1} (Acrorad)

CdZnTe

- Band gap ~1.62 eV
- Ionization energy ~ 4.6 eV
- Z = 50
- D = 5.8 g/cm^3
- 1E10 ~1E11 $\Omega.cm$
- $\mu_e\tau_e$ ~ 13×10^{-4} cm^2V^{-1} (Kromek)
- $\mu_e\tau_e$ ~ 100×10^{-3} cm^2V^{-1} (RedLen)
- $\mu_e\tau_e$ ~ 11×10^{-3} cm^2V^{-1} (RedLen HF)
- $\mu_h\tau_h$ ~ 5~8x10^{-5} cm^2V^{-1}

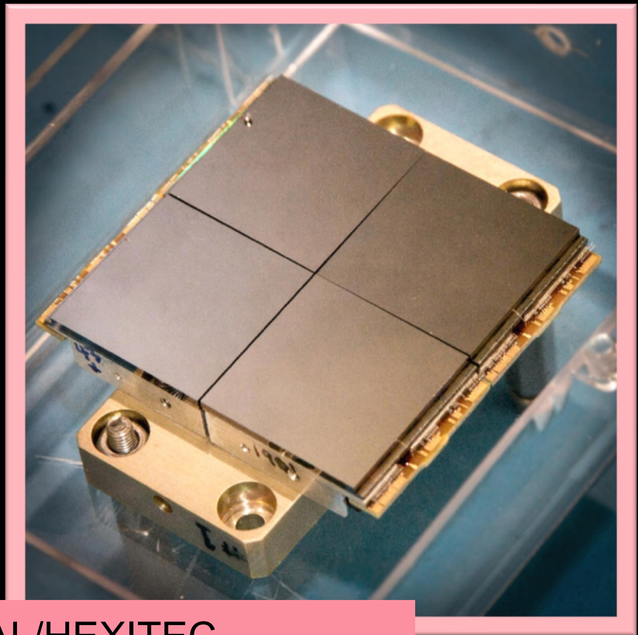
Other consideration for fair comparisons ….

- Geometry
- Handling, cleaning, storing
- Hybridization technology



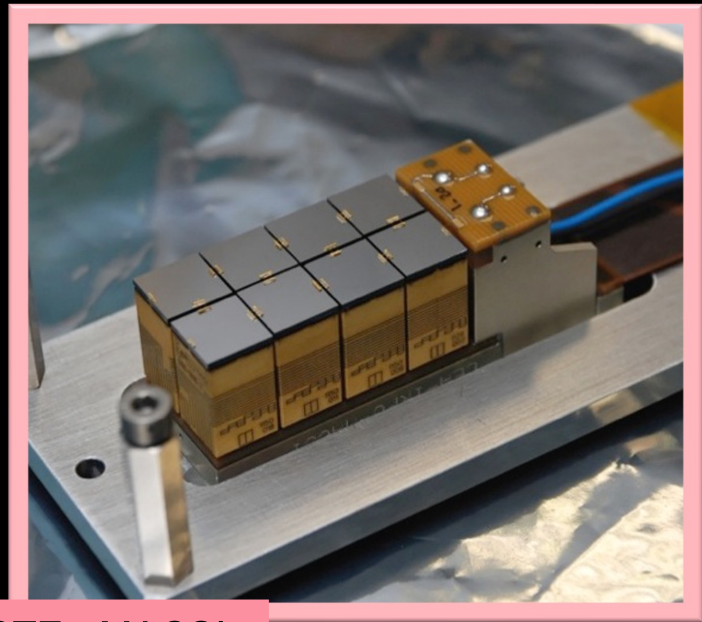
CdTe vs. CdZnTe: the match!

Both technologies evaluated with CdTe and CZT



RAL/HEXITEC
~1 keV fwhm @ 60 keV
4x(80x80) pixels 250 µm

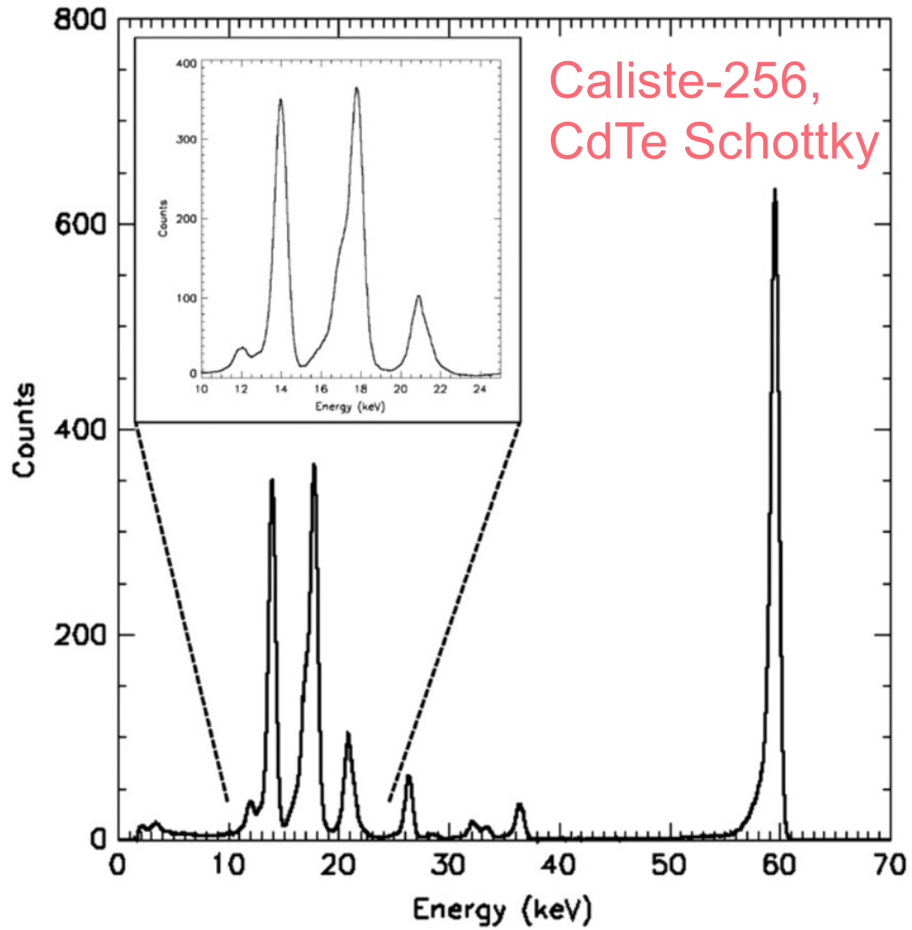
Lowitt+21



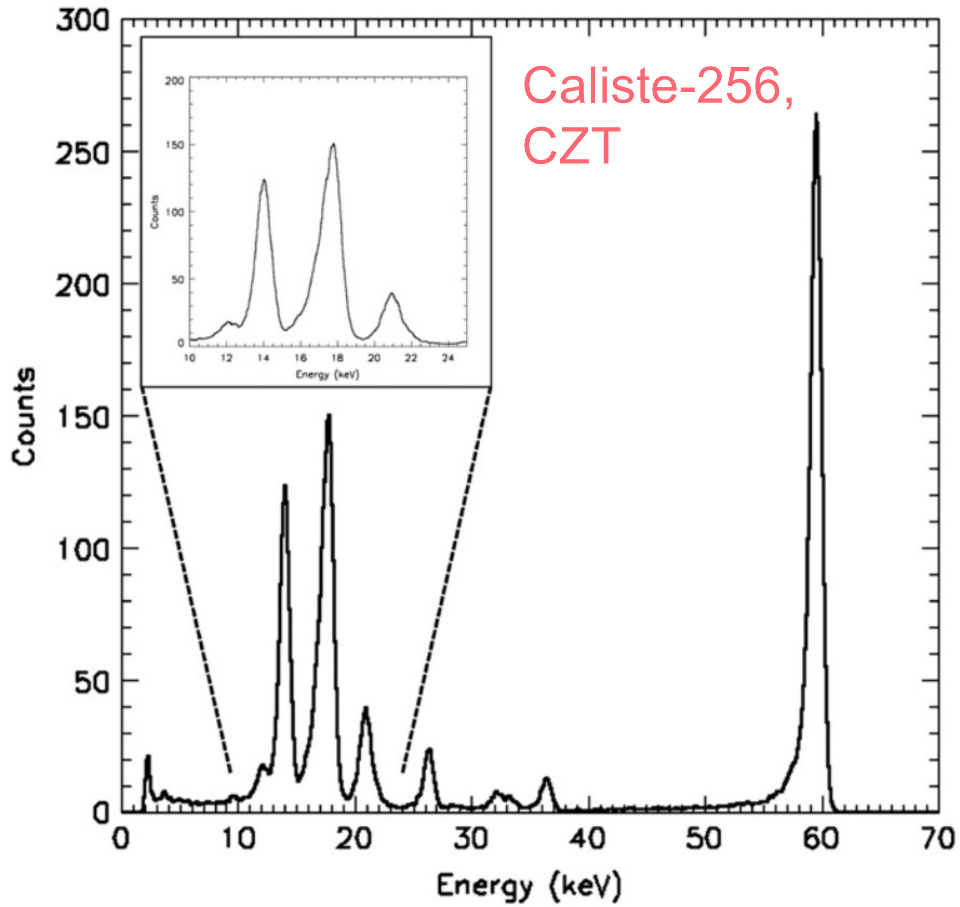
CEA/CALISTE - MACSI
670 eV fwhm @ 60 keV
32x64 pixels 625 µm

Limousin+14

Caliste-256 technology



Am 241 spectrum obtained with Caliste 256 SN5 equipped with a CdTe Schottky diode summing the 256 individually calibrated spectra (0 °C, 300 V, 9.6 µs peaking time). Energy resolution at 59.54 keV is 0.85 keV FWHM. Zoom in the 10–25 keV band emphasizes the energy resolution revealing the structure of the 17.75 keV triplets.

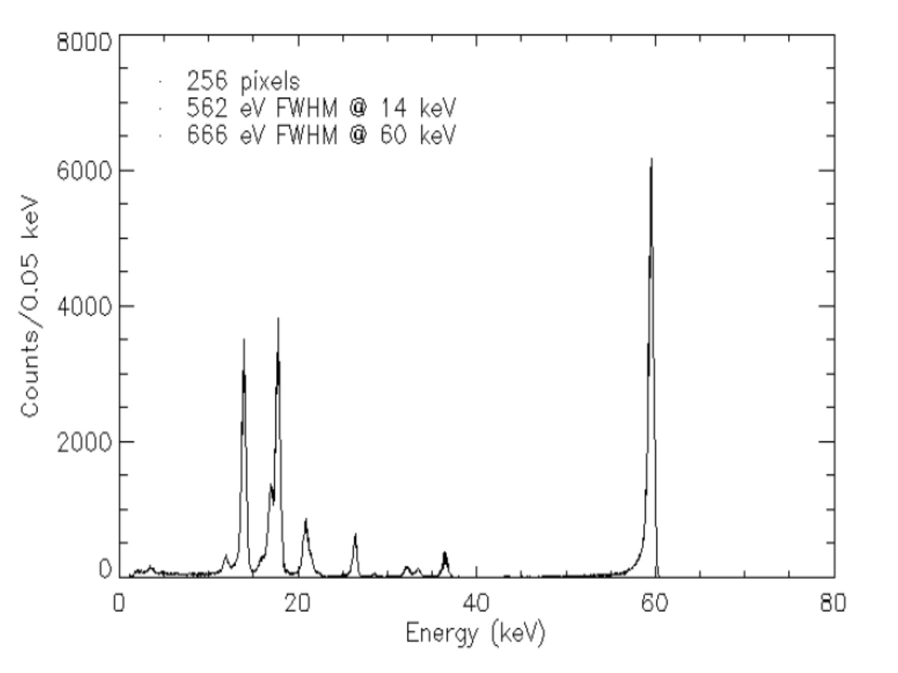


Am 241 spectrum obtained with Caliste 256 SN4 equipped with a CZT detector summing the 256 individually calibrated spectra (– 15 °C, 800 V, 6.0 µs peaking time). Energy resolution at 59.54 keV is 1.09 keV FWHM. Zoom in the 10–25 keV band emphasizes the energy resolution revealing the triangle shape of the 17.75 keV triplets.

Limousin+11

Caliste Technology best spectra with CdTe

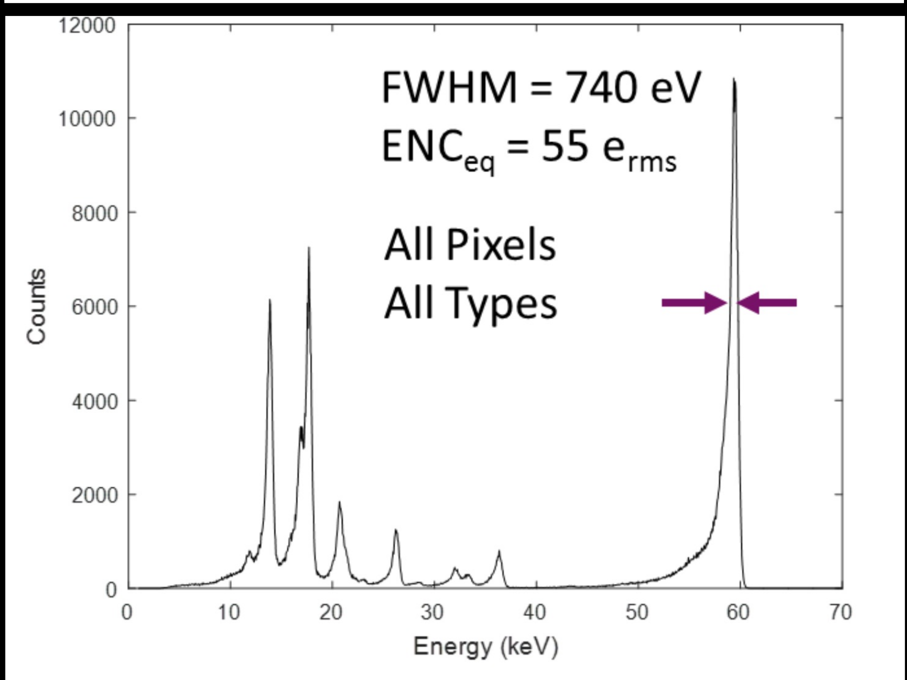
Caliste-HD
All chanels



CdTe Schottky top results

Gevin&Limousin+21

MC2-D2R1
All events

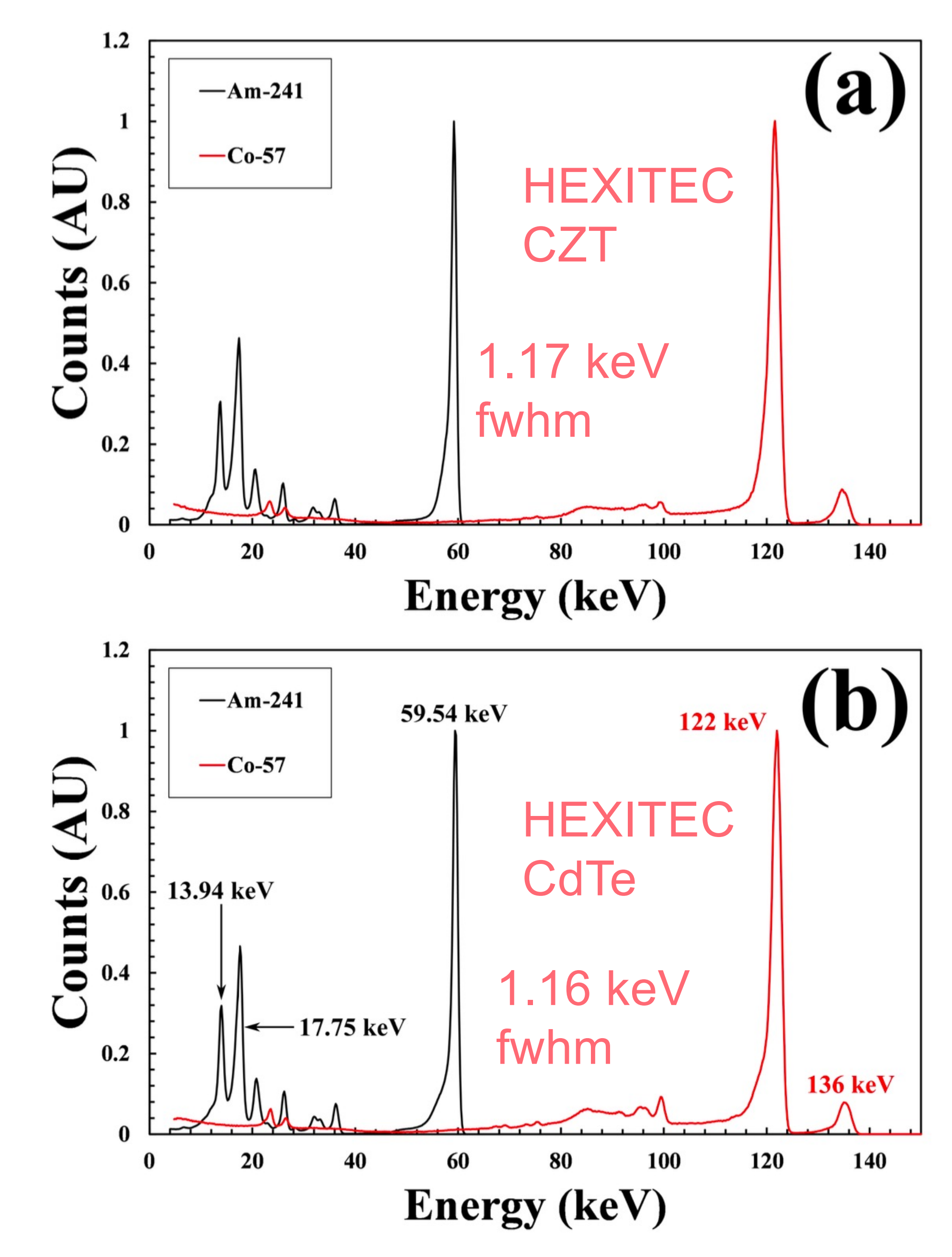


Baudin+18

With support of

KAVLI IPMU

HEXITEC Technology

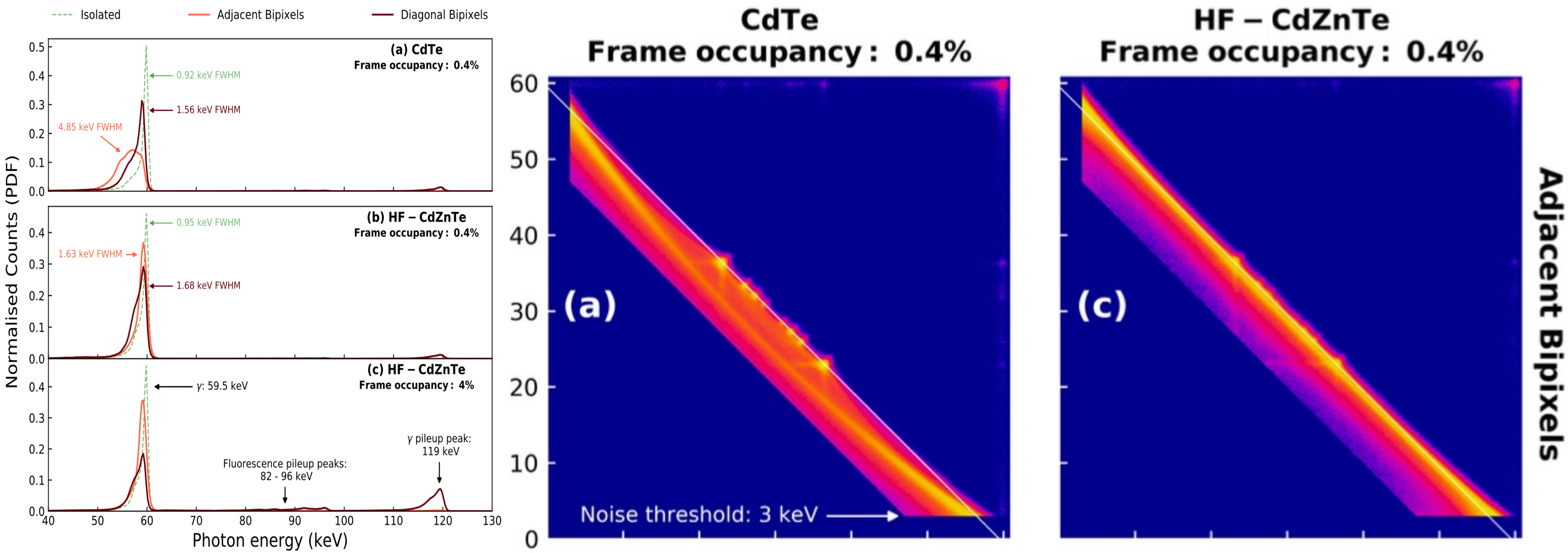


Single events only

Lowitt+21

HEXITEC Technology

Science & Technology Facilities Council | UK Research and Innovation



Multiple events

Koch-Mehrin+21

OUTRO: take home message

- And the winner is …
  CdTe is cheaper than CZT
  CdTe is easy to procure
  CdTe show very good performance at low temperature
  CdTe show very stable performances in space
  CdTe Schottky dark current is unbeatable
  Ideally, CdTe would win with more stability in time …

- Or …
  CZT is more stable in time than CdTe Schottky at low flux
  CZT is good at room temperature
  CZT is ideal when more than 2 mm thick detectors are needed
  CZT HF is looking good in inter pixel gaps

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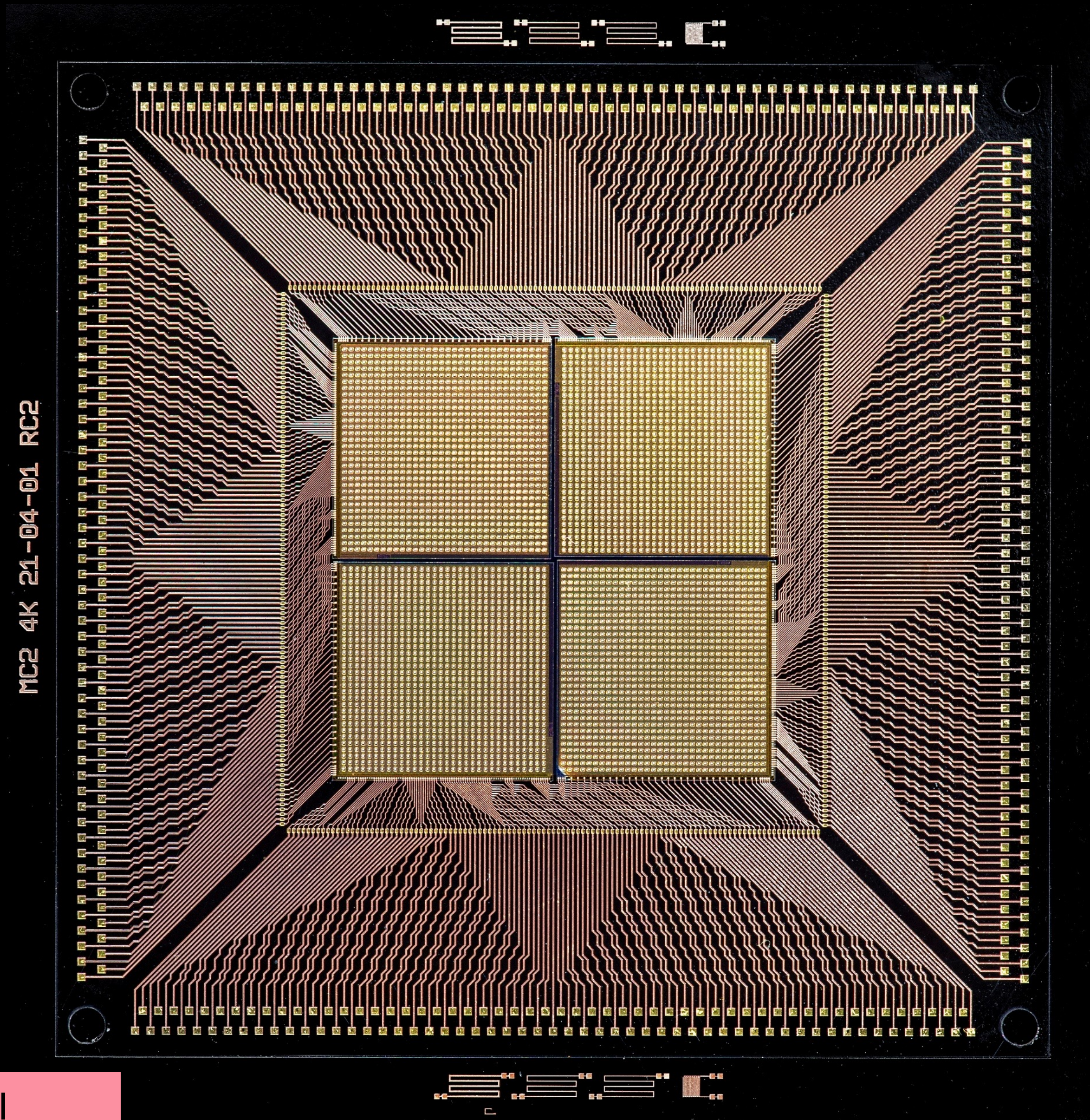
THANKS FOR YOUR ATTENTION !



CEA/MC2 - MACSI
4x(32x32) pixels 250 µm