Recent Advances on CdTe/CdZnTe detectors

For High Energy PHOTON

Tad Takahashi
Institute of Space and Astronautical Science (ISAS)
Japan Aerospace eXploration Agency (JAXA)
and
Univ. of Tokyo

Acknowledgement : Z. He(Michigan), P.Luke (LBNL), F. Harrison(Caltech), O. Limousin(CEA), C. Szeles (eV), R. Ohno(ACRORAD), J. Matteson (UCSD)

Outline

- Demand and CdTe/CdZnTe
- Recent Progress on technology
  - Crystal and ASIC
- X-ray Imager
  - Pixel & Strips
- Gamma-ray Detector
  - Coded Mask /PET
  - Compton Camera
- Summary/Future Prospects

Demands

Need Detector Material which can be used as
an alternative to Si (in terms of Efficiency)
an alternative to Ge (in terms of Operating Temperature)

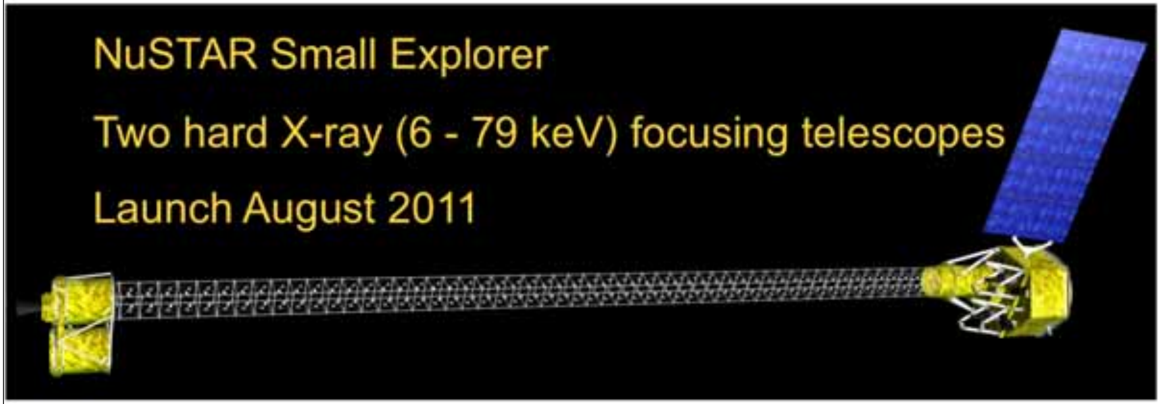
→ Good Energy Resolution similar to Ge (0.2%@662keV)
High Efficiency, above 10 keV upto 1 MeV
Position resolution a few hundred micron
A detector can be operated at room temperature

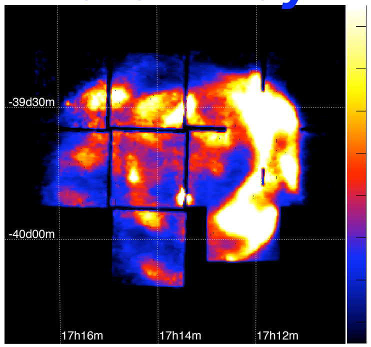
In the field of
Medical Application
Homeland Security
Astronomical Observation

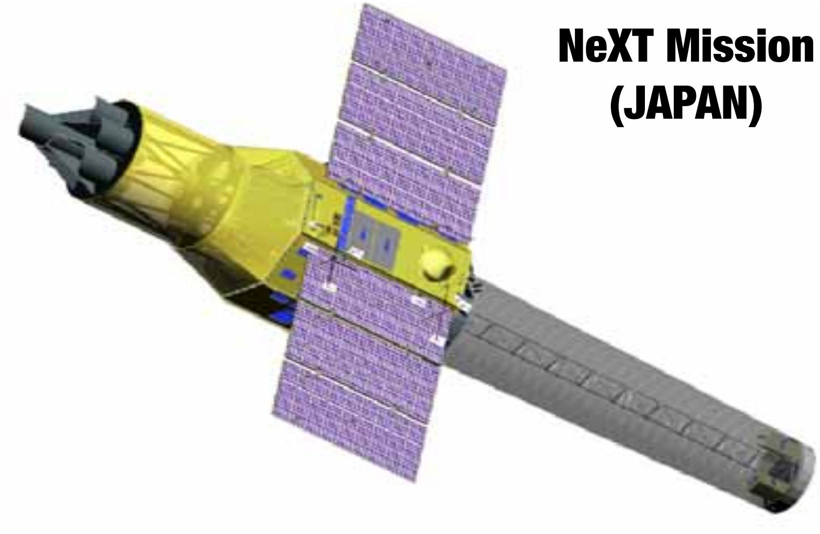
Seems to be very difficult and would need
another 10 to 20 years for the final answer

All next generation telescopes need a Hard-X camera above 10 keV, where Si becomes transparent

To take a photo of SuperNova explosion in hard X-ray

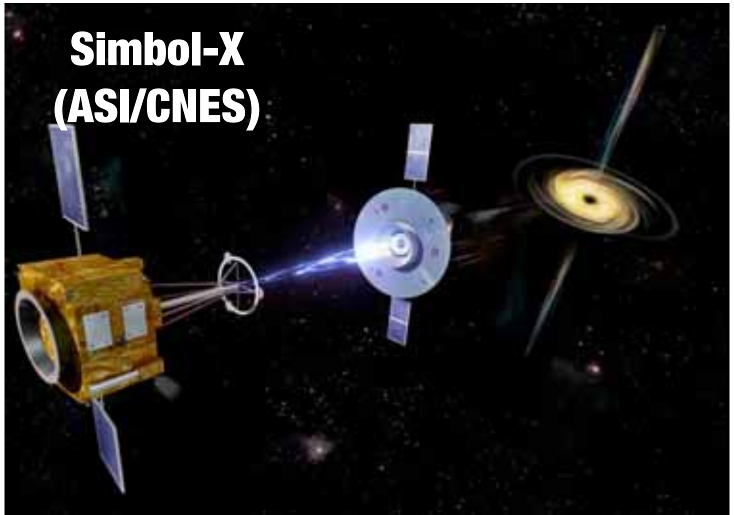






NeXT Mission (JAPAN)

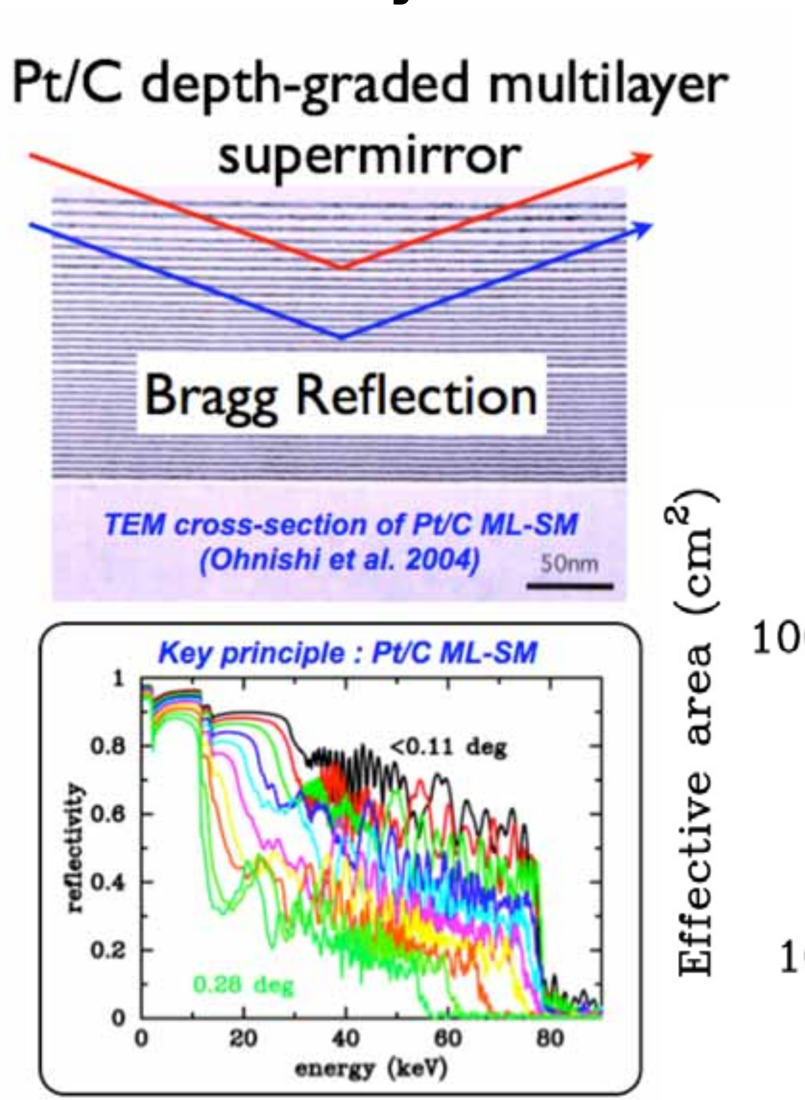
Launch 2013

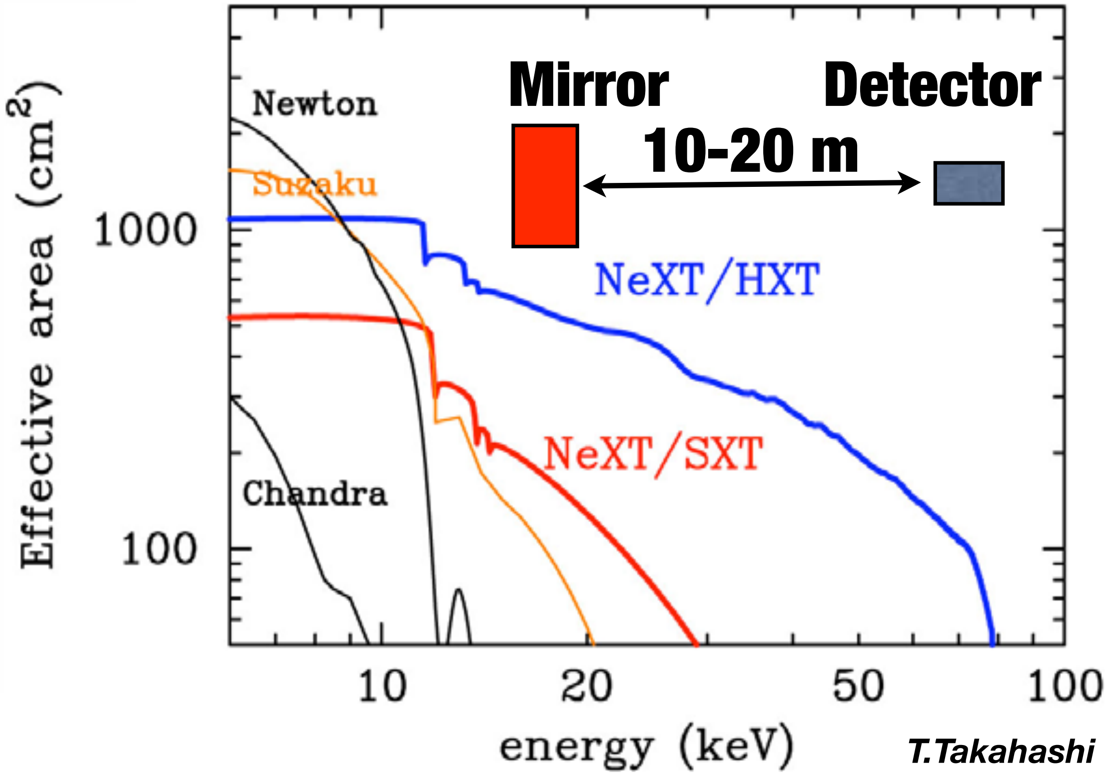


Launch 2014

T.Takahashi

With Newly developed Hard X-ray Mirror





T.Takahashi

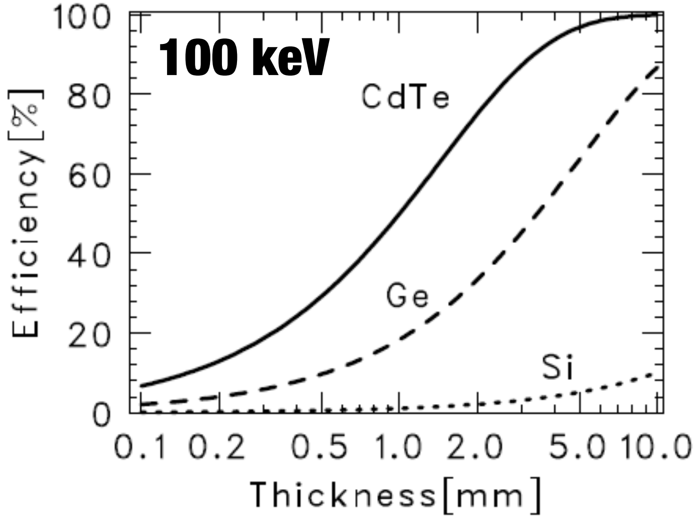
CdTe/CdZnTe seem to be the only candidate
at least, at this moment

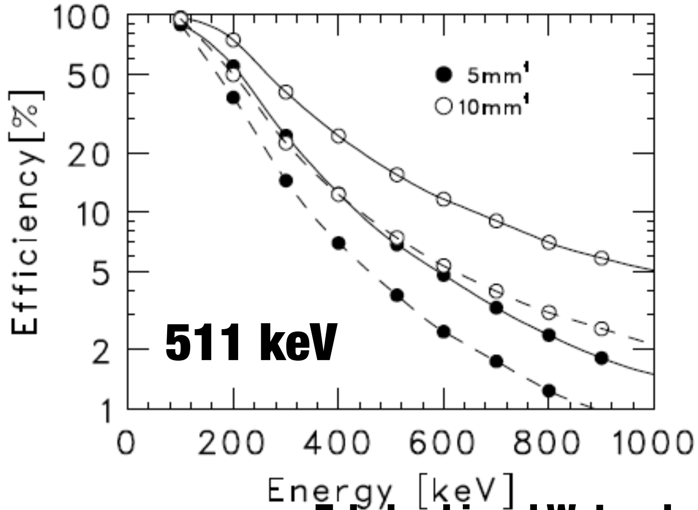
- High Z semiconductor (Z_{Cd} = 48, Z_{Te} = 52), ρ =5.9 g/cm^3

- Room Temperature Operation or Cool Environment

Material	Ge (77K)	HgI_2	CdTe	CdZnTe
Atomic number	32	80, 53	48, 52	48, 30, 52
Band gap (eV)	0.74	2.13	1.50	1.57
Energy per e-h pair (eV)	2.97	4.2	4.4	4.6
Fano factor	0.08	0.19	0.11	0.09
μ_e (cm^2/Vs)	40,000	100	1100	1000
μ_h (cm^2/Vs)	40,000	4	100	10
τ_e (s)	10^{-3}	10^{-5}	10^{-6}	10^{-5}
τ_h (s)	10^{-3}	10^{-5}	10^{-6}	10^{-6}

P. Luke (2006)



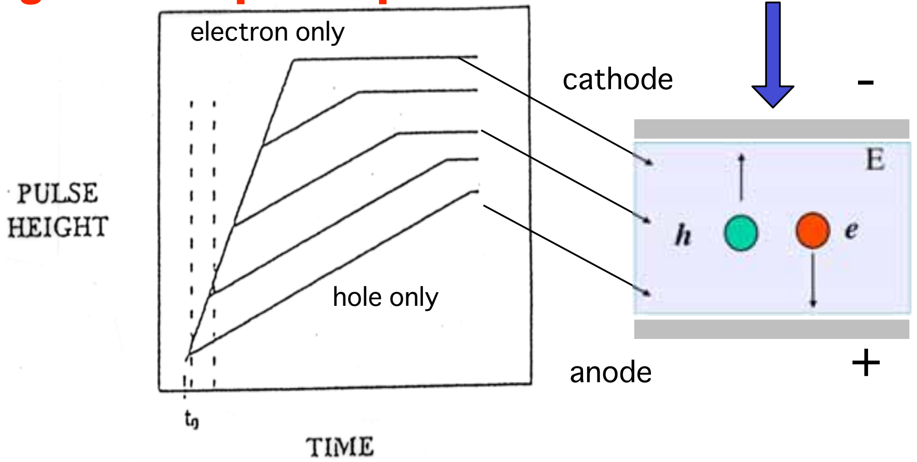


Takahashi and Watanabe (2000)

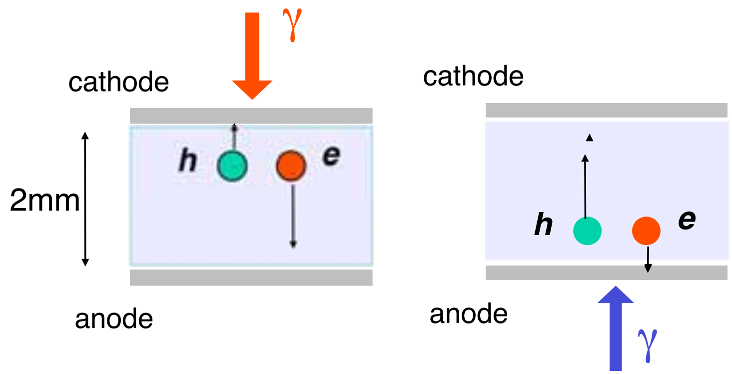
T.Takahashi

Slow mobility/ short lifetime of carriers are a bit problem for CdTe/CdZnTe

Signal is Depth Dependent

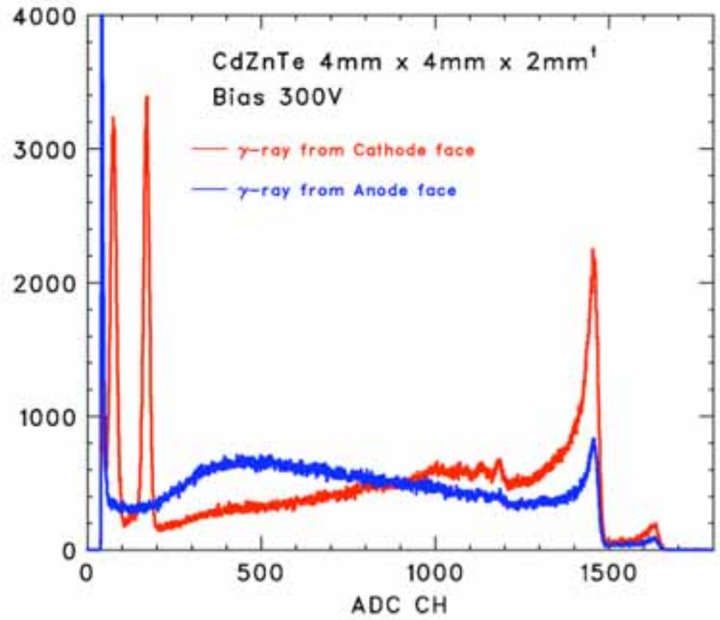


Pulse height depends on the interaction depth



We now know how to handle this Charge Collection Issue (Coplanar Grid/Cross Strip etc.)

For the case of thin detector, and with high bias voltage (400 V/0.5mm), can collect full charge.



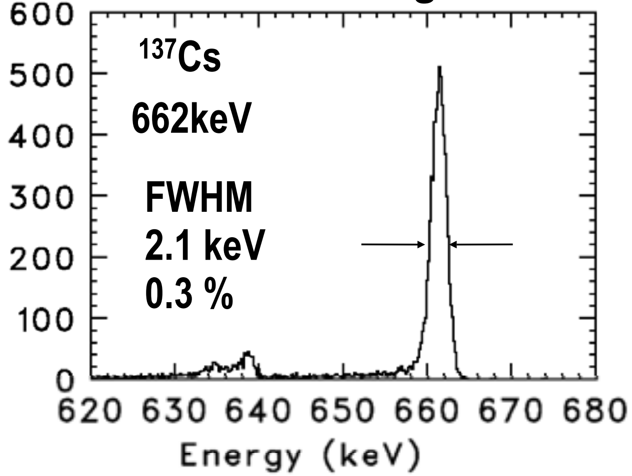
Takahashi and Watanabe (2000)

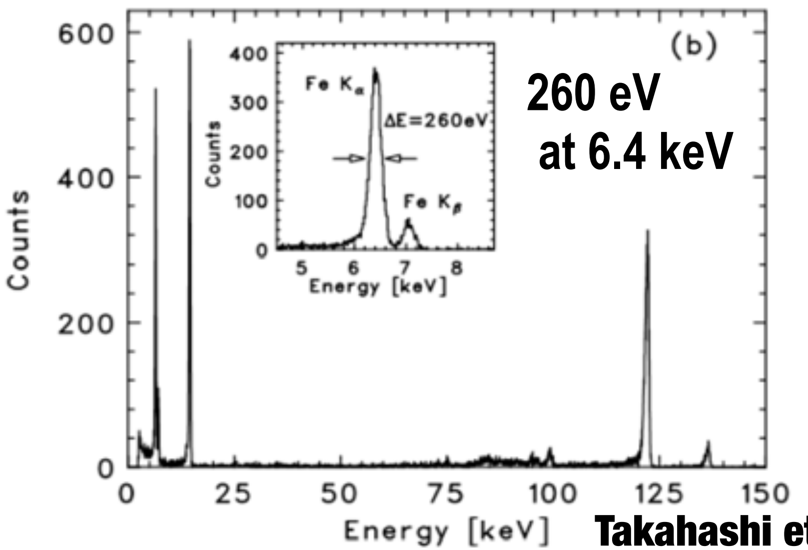
Thick vs Thin approaches, I'll explain later

CdTe/CdZnTe seem to be the only candidate
at least, at this moment

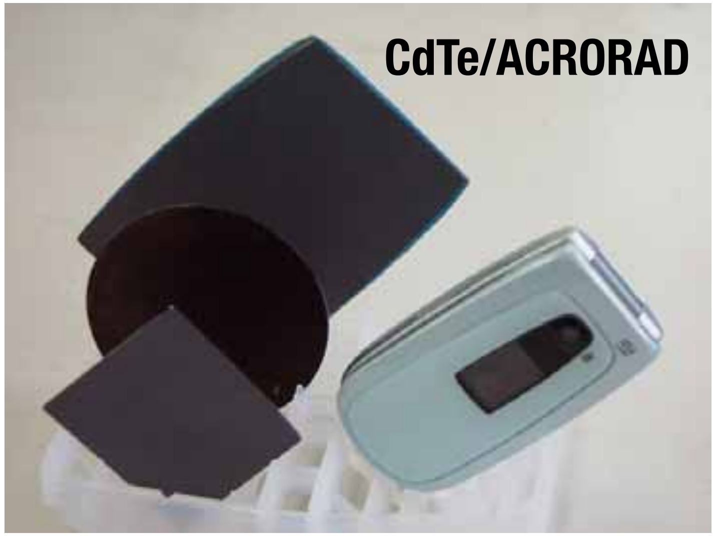
Because, they've already shown good performance

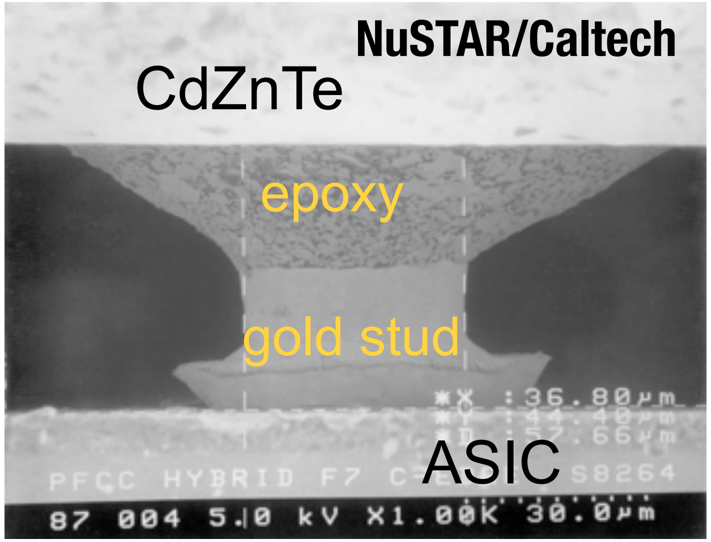
Thin CdTe diode at -20 deg





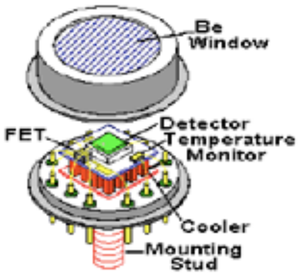
Takahashi et al. 2005





CdTe/CdZnTe Commercial Products

Amptek



AXION

CdTe dental panoramic digital imaging system

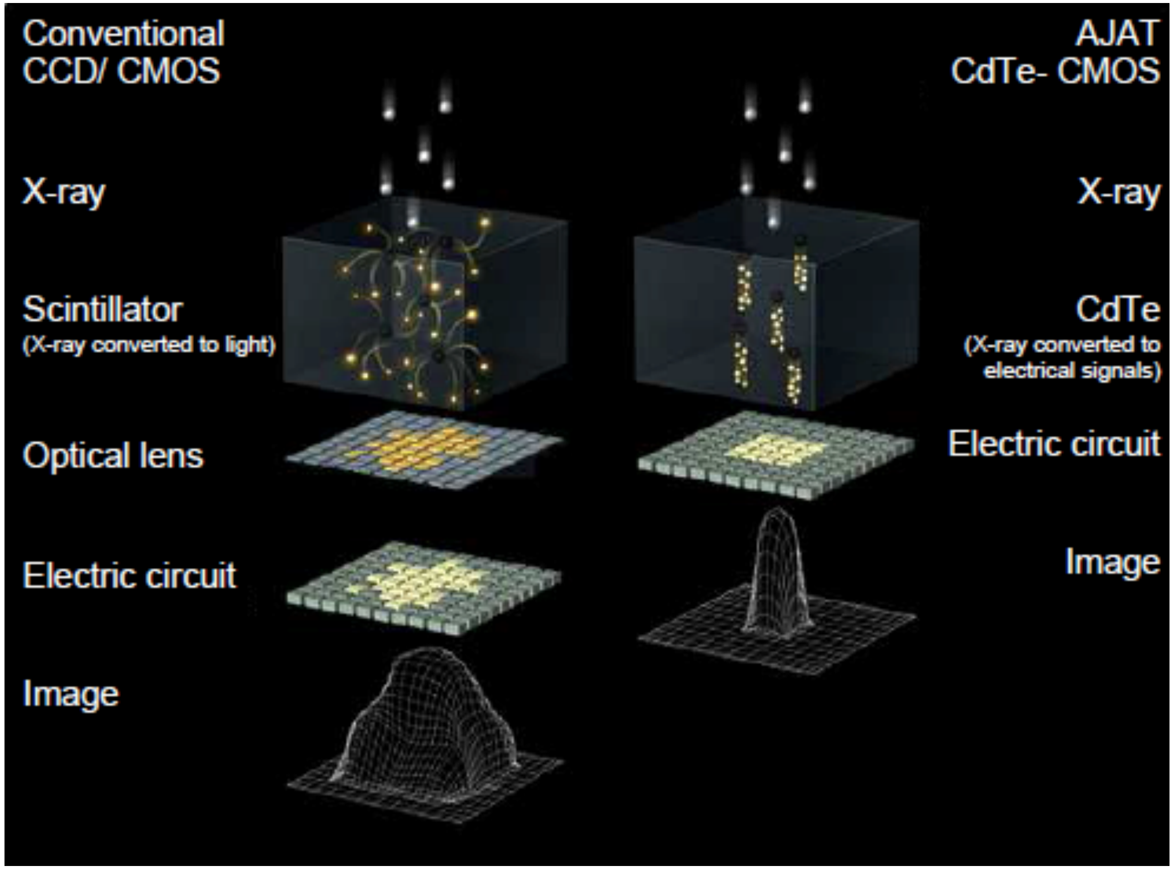
X-ray Spectrometer

aguila (US)

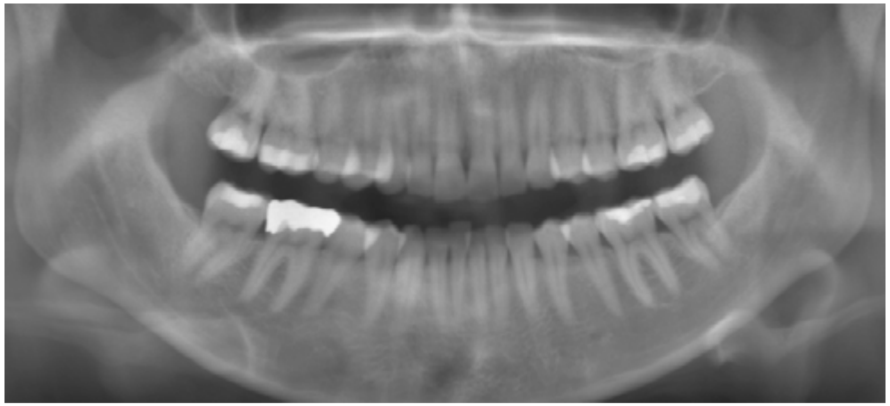
Radiation-Threat-Detector

T.Takahashi

CCD
Scintillator
CMOS



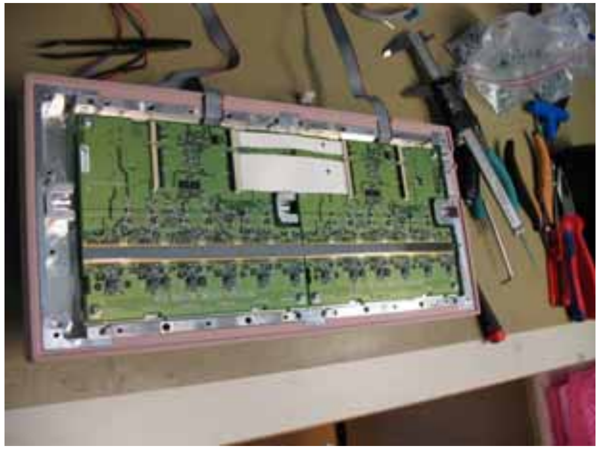
CdTe
CMOS



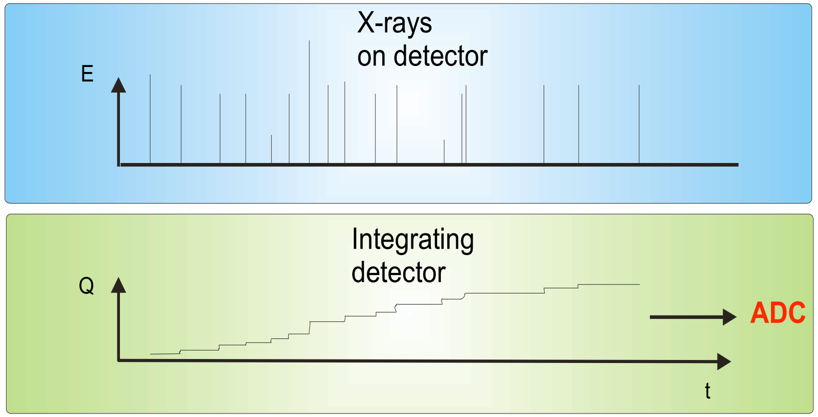
Courtesy of AJAT (Finland)

Commercial Products
Hard X-ray Imager

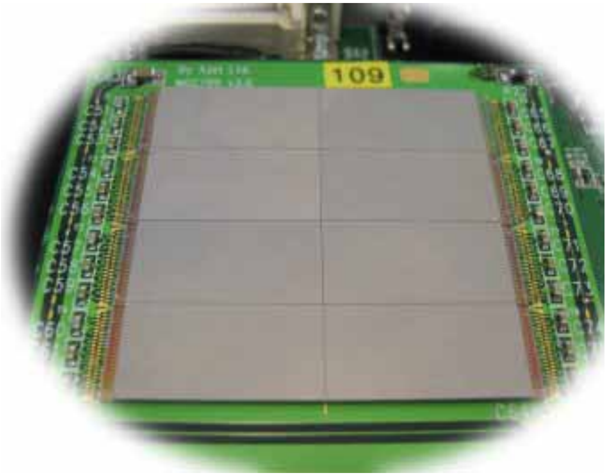
1 dim Imager (30cm)

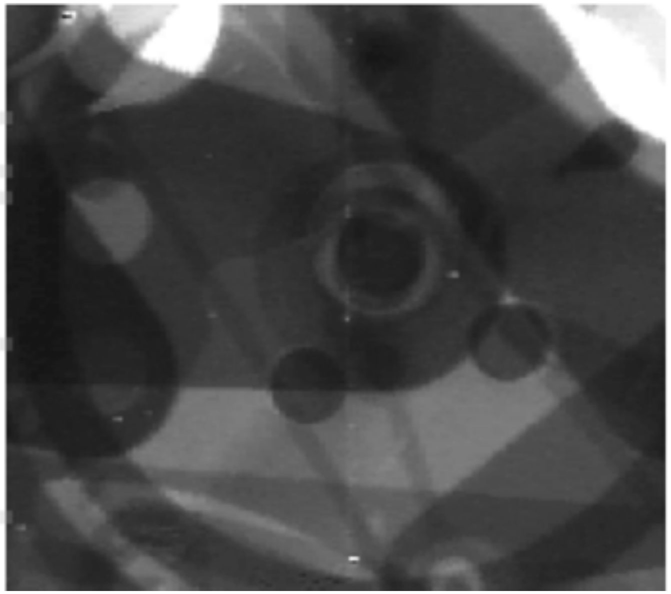


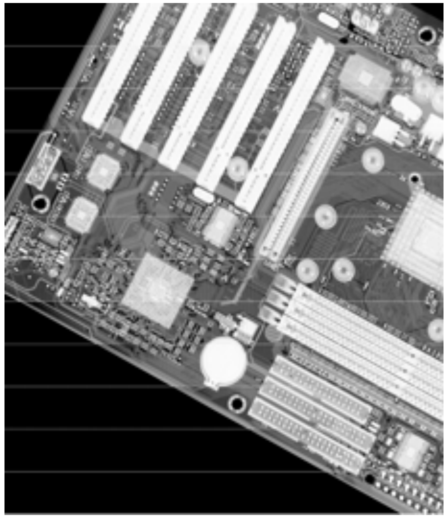
Integrated type



100 micron pitch







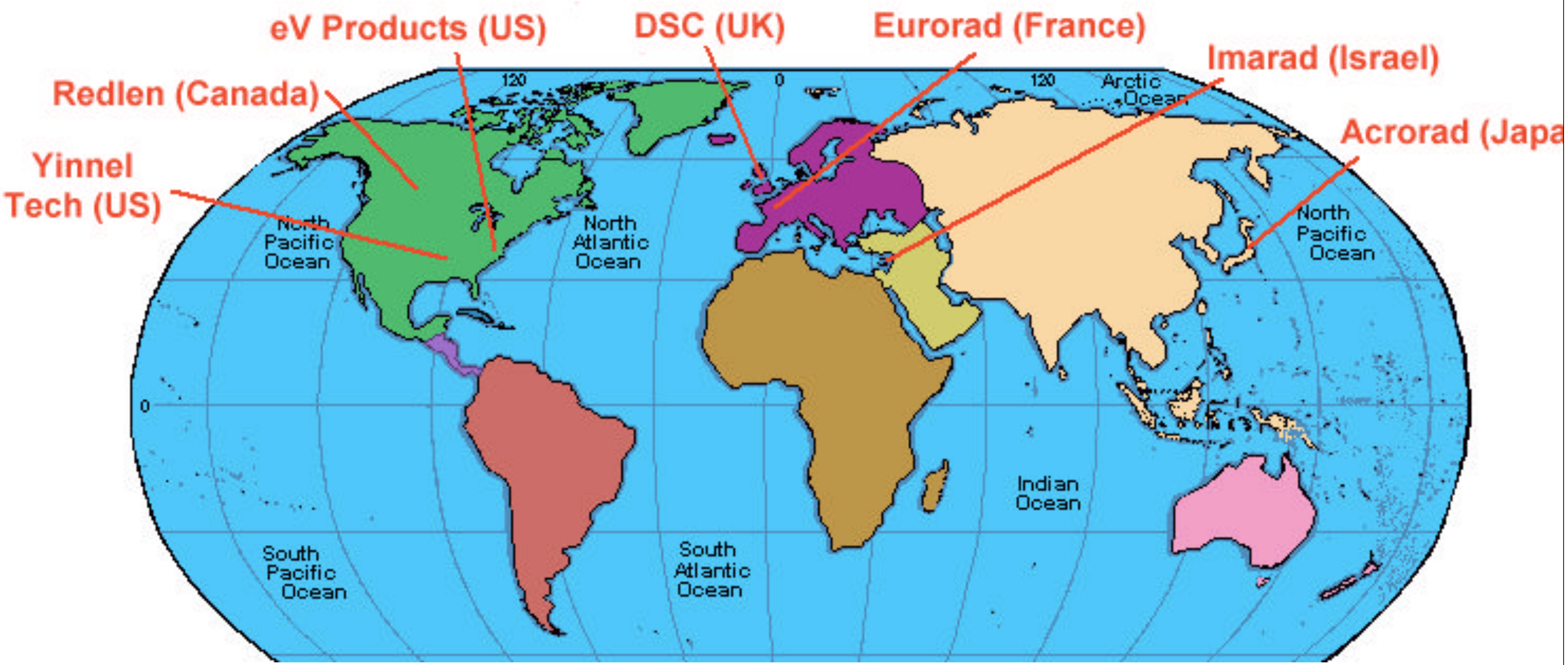
AJAT, Finland

Technologies

Crystal
&
ASIC

Who makes CdTe/CdZnTe Crystal?

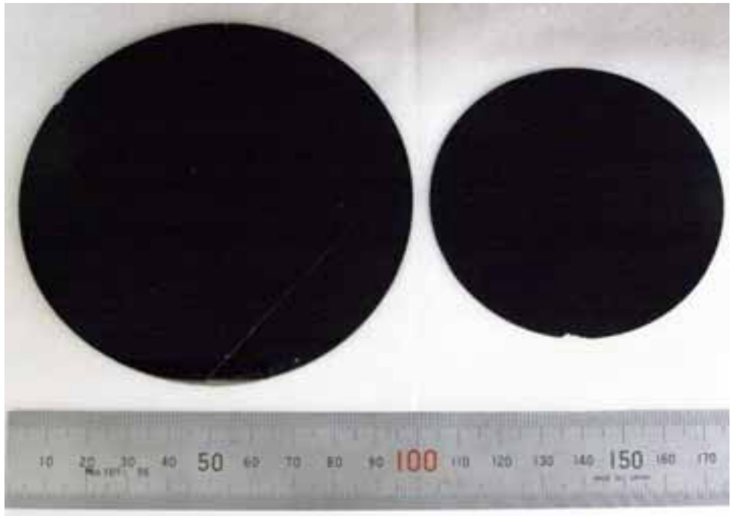
From a review talk by P.J. Sellin (2005)

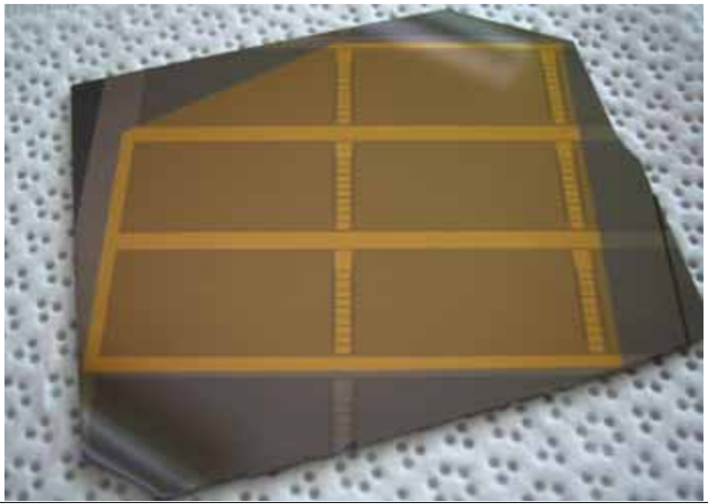


Recent Advances on Technologies

ACRORAD (JAPAN)

Large Single Crystal



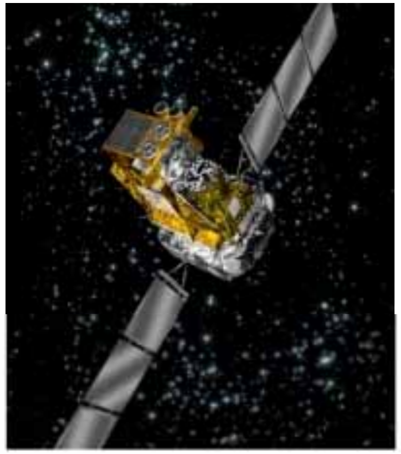


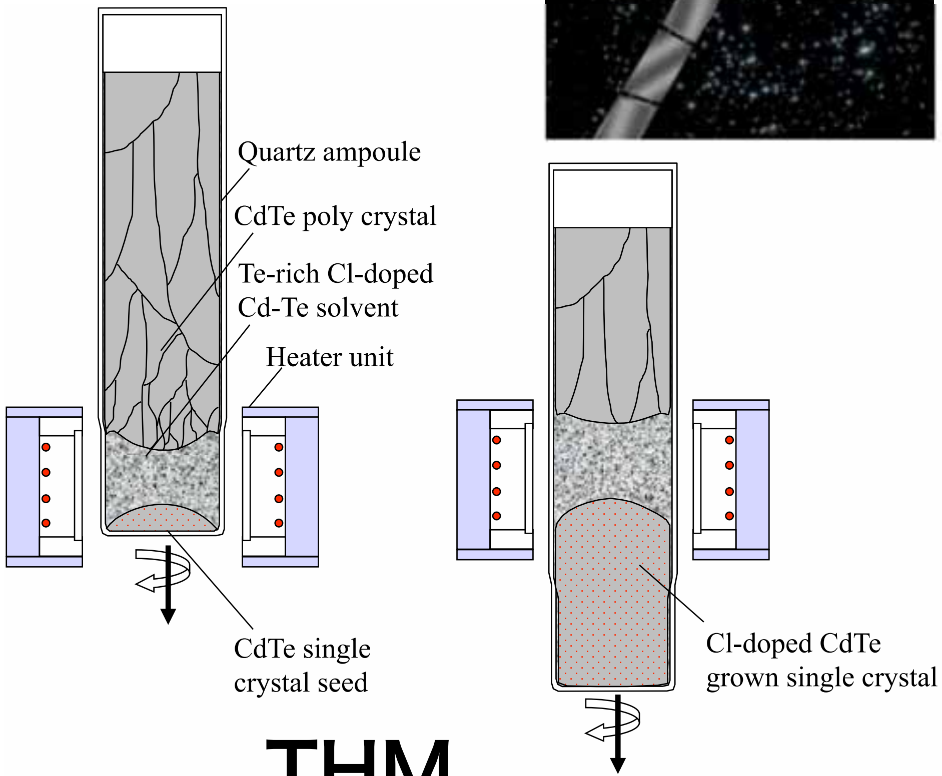
1st Large Scale CdTe Camera in Space (INTEGRAL)

Travel Heater Method (THM)

Careful treatment of post heating

Very uniform wafer



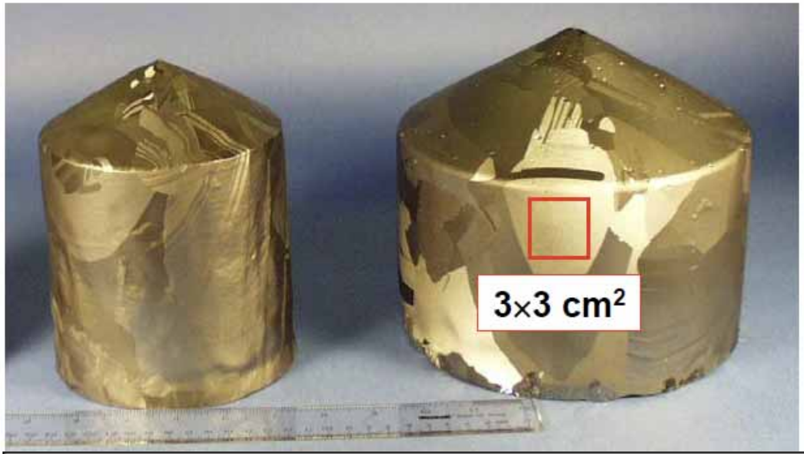


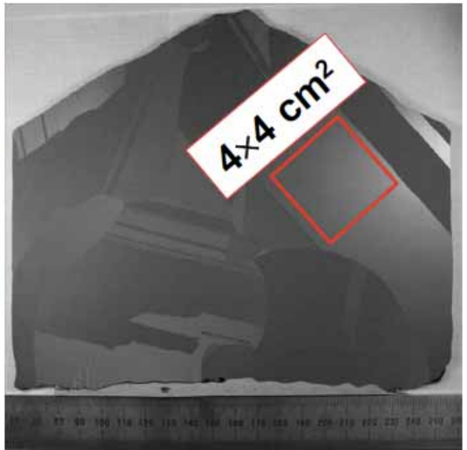
THM

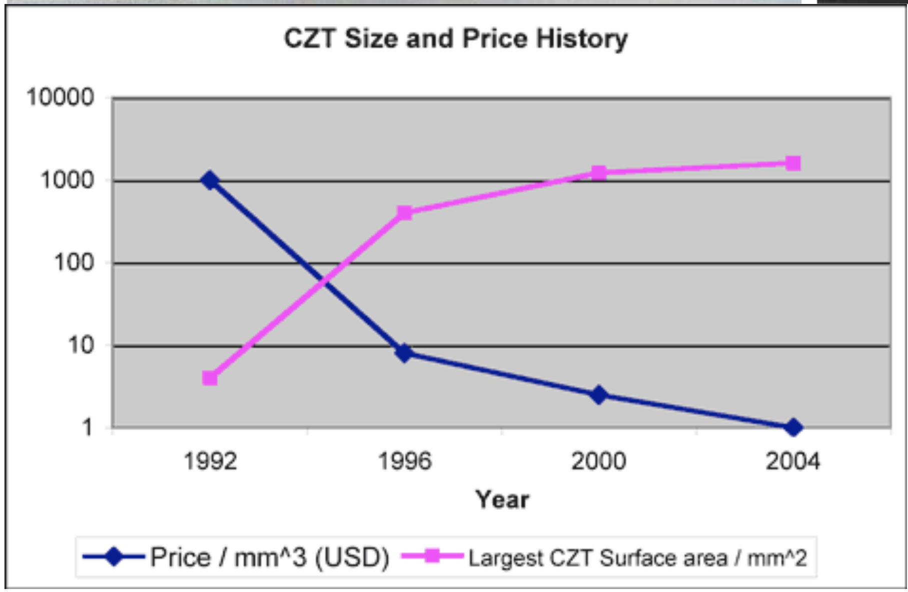
Recent Advances on Technologies

eV Products (High Pressure Bridgman and improved method)

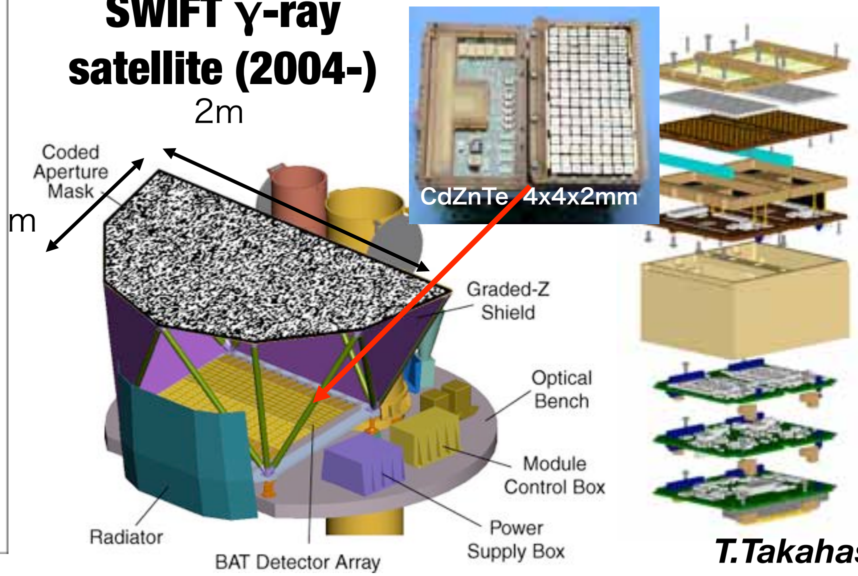
Large Crystal







SWIFT γ-ray satellite (2004-)

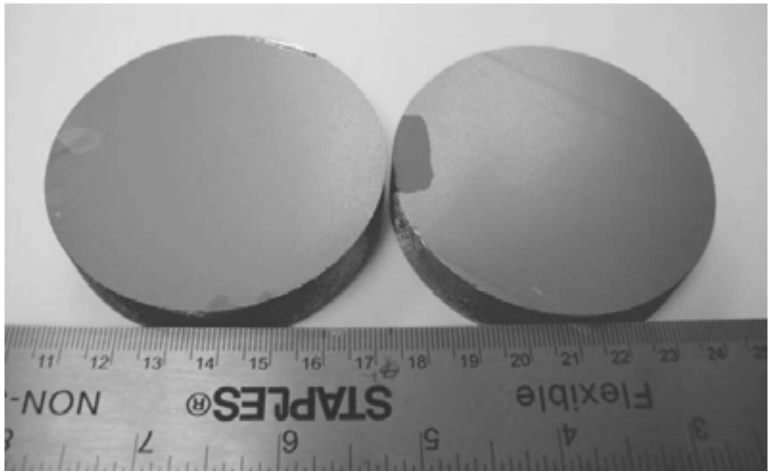


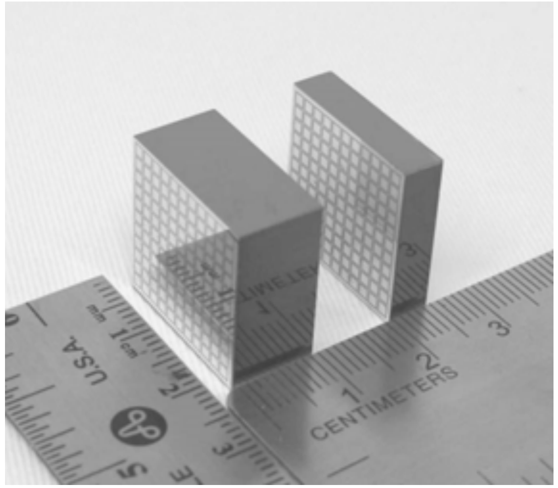
T.Takahashi

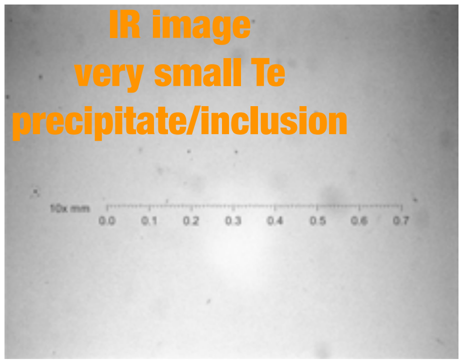
Recent Advances on Technologies

REDLEN

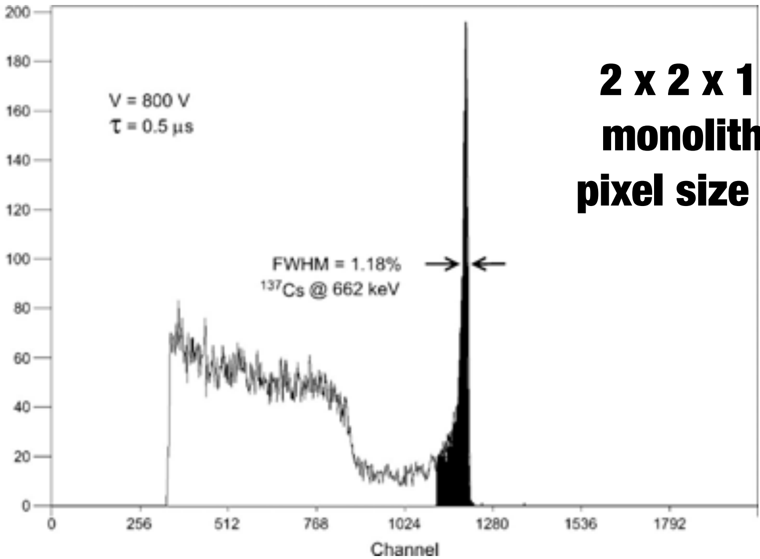
succeeded to make CZT by THM
Large Single Crystal







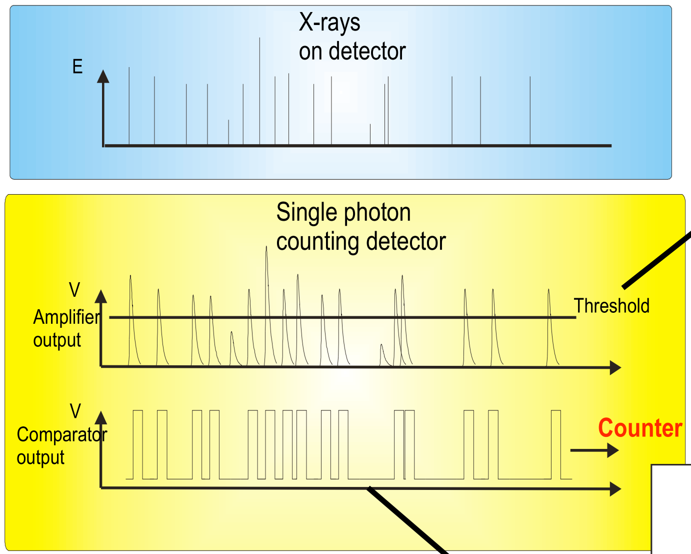
662 keV 1. 18% (7.8 keV, FWHM)
without additional signal correction)

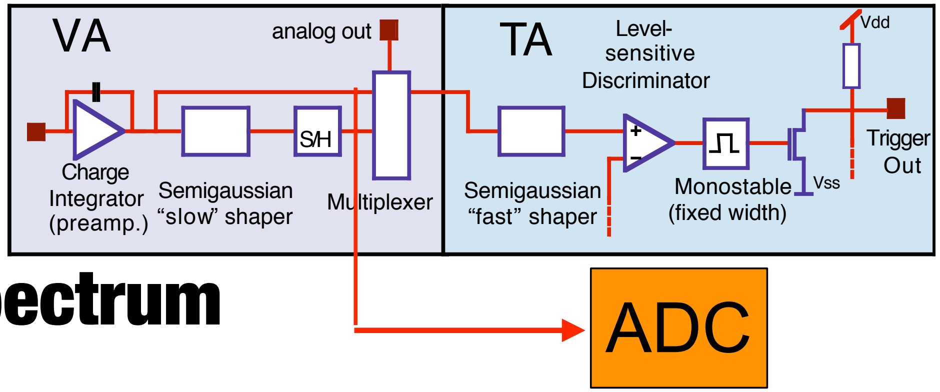


2 x 2 x 1.05 cm^3
monolithic pixel
pixel size 2.46 mm

Chen et al. JAP, 2008

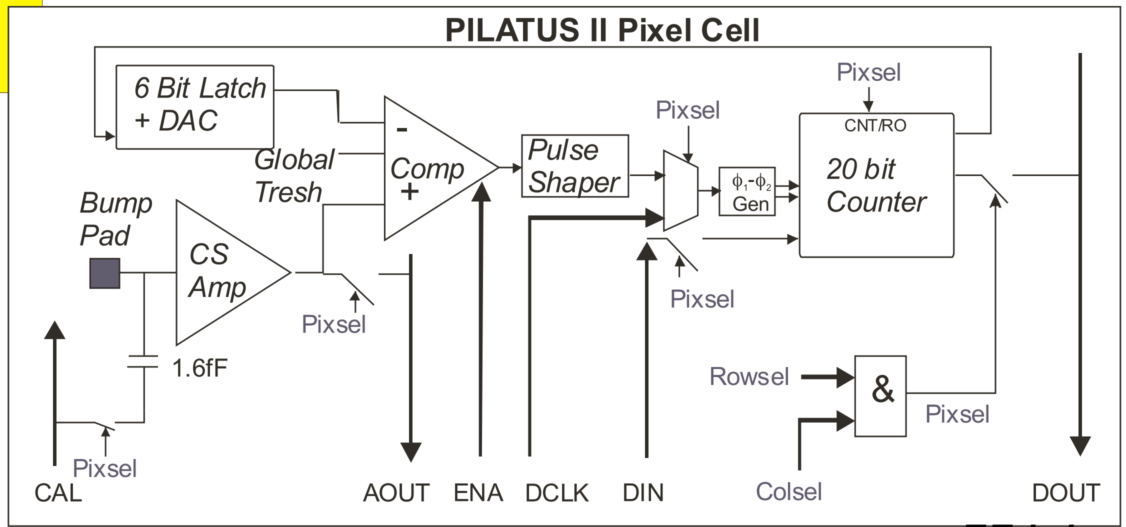
We need ASIC : If you need CdTe/CdZnTe imaging detectors





Spectrum

Need 50 e- at 0pF for both cases



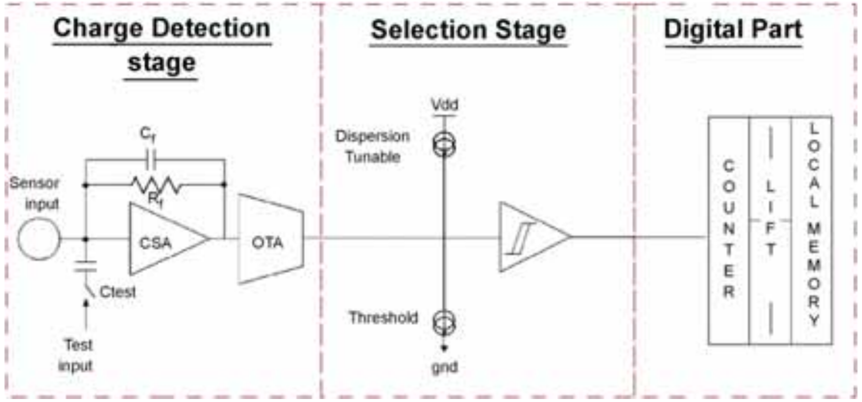
Photon Counting

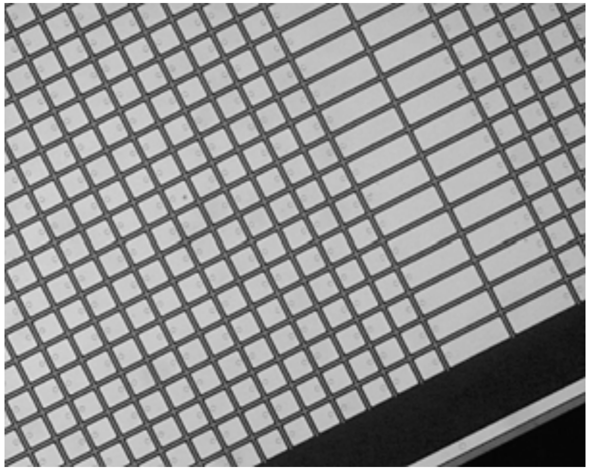
T.Takahashi

Hard X-ray Camera

For photons
above 10 keV
below 100 keV

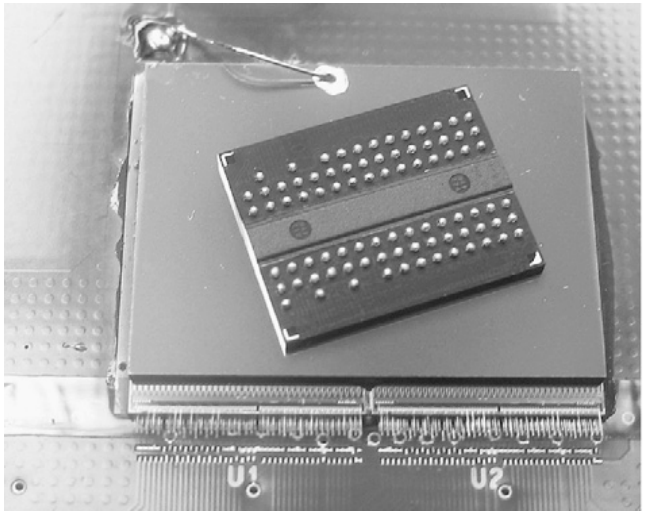
CdTe Photon-counting imager using XPAD chip

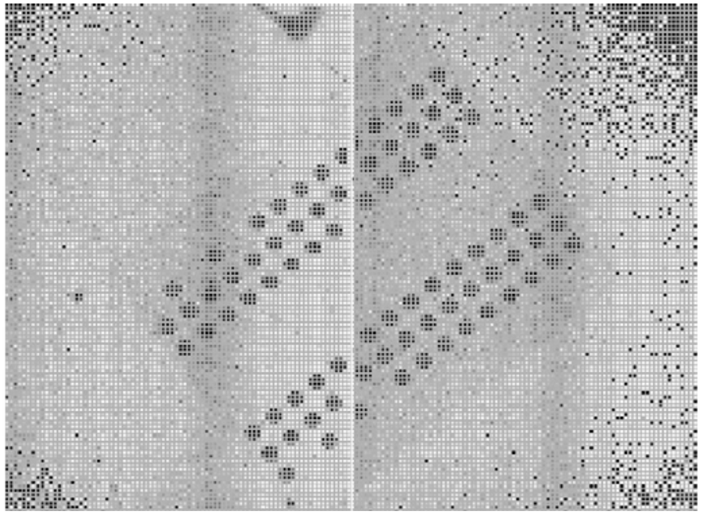




0.7 mm thick CdTe
20 kpixels (130μm x 130μm)

2 ms/frame 10^6 photons/pixel





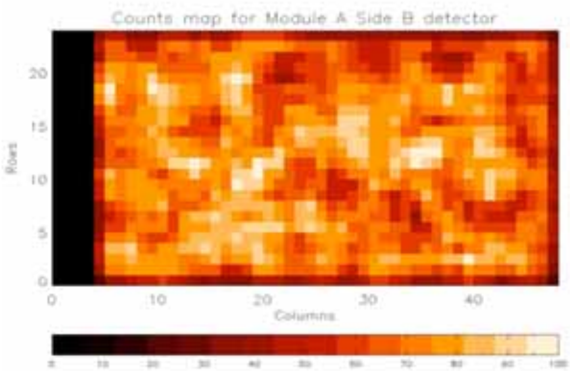
Basalo et al. , NIMA 2008

CdZnTe Imager with Spectroscopic Capability for NuStar Satellite

NDIP08

Prototype (for HEFT)

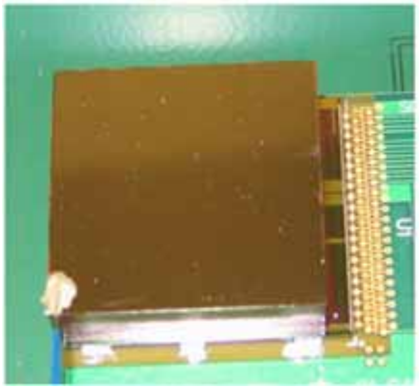
0.5mm pitch, 2mm thick
Two hybrids: 24 x 48

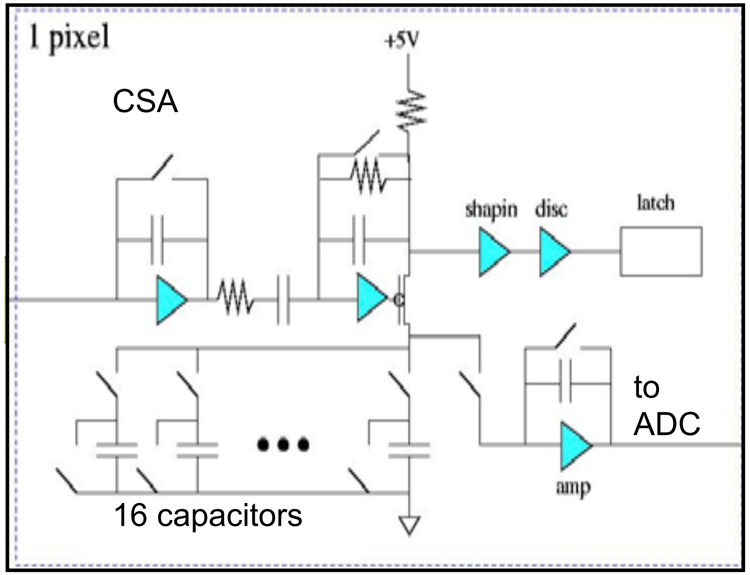


Flat Image

non-uniformity of the image comes from CZT, not from ASIC

32 x 32 array, 0.6 mm pitch
2 mm thick CdZnTe





T.Takahashi

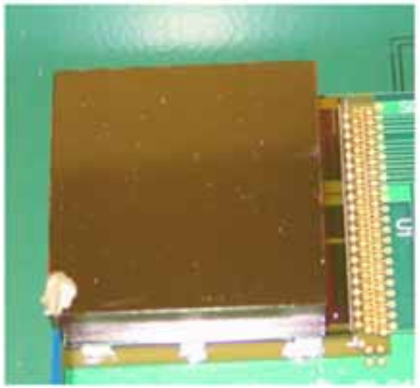
CdZnTe Imager with Spectroscopic Capability for NuStar Satellite

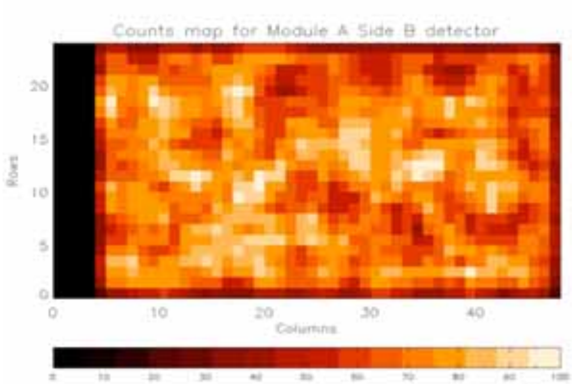
NDIP08

Prototype (for HEFT)

0.5mm pitch, 2mm thick
Two hybrids: 24 x 48

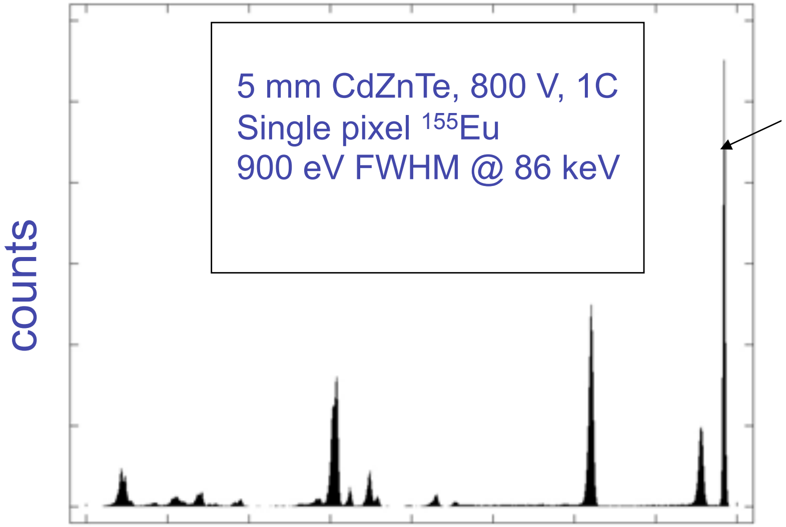
32 x 32 array, 0.6 mm pitch
2 mm thick CdZnTe





Flat Image

non-uniformity of the image comes from CZT, not from ASIC



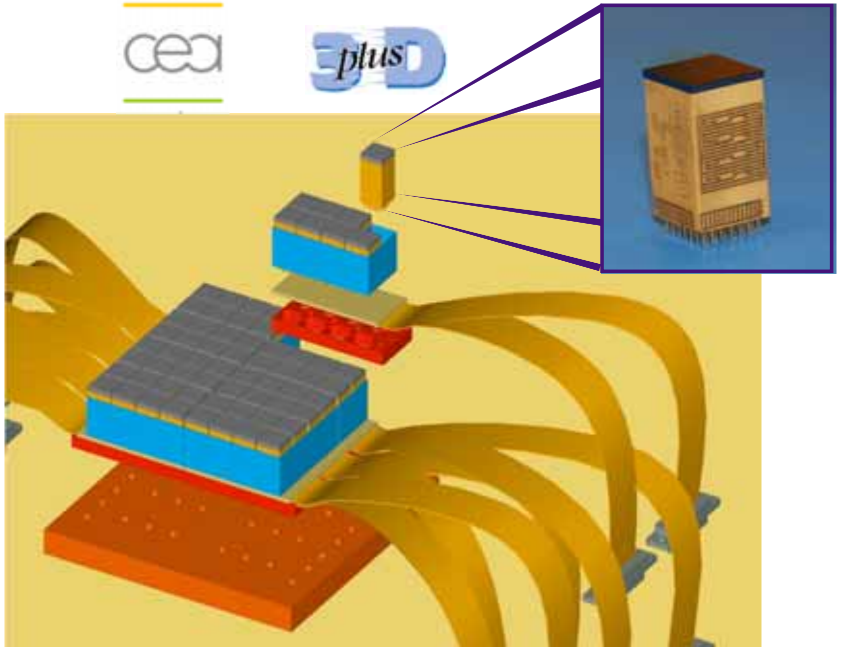
F. Harrison, 2008

T.Takahashi

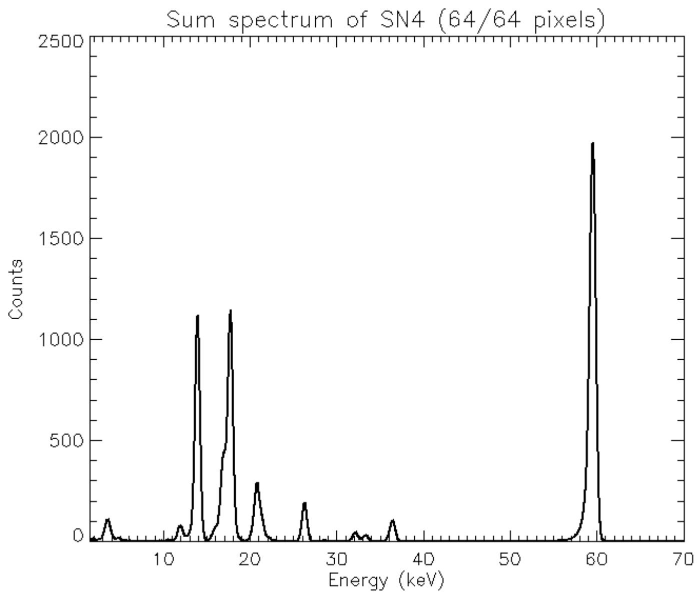
CdTe Imager with Spectroscopic Capability for Simbol-X Satellite

NDIP08

- HED: mosaic of 64 independent CdTe (Al/CdTe/Pt) cameras
- Caliste 64: first prototype of detection unit



^{241}Am spectrum at -10°C, 500V with the single events of the 64 pixels

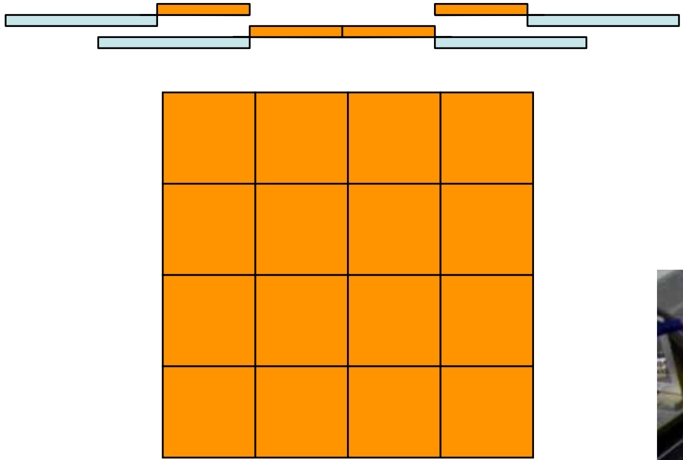


- See A. Meuris' talk in this session

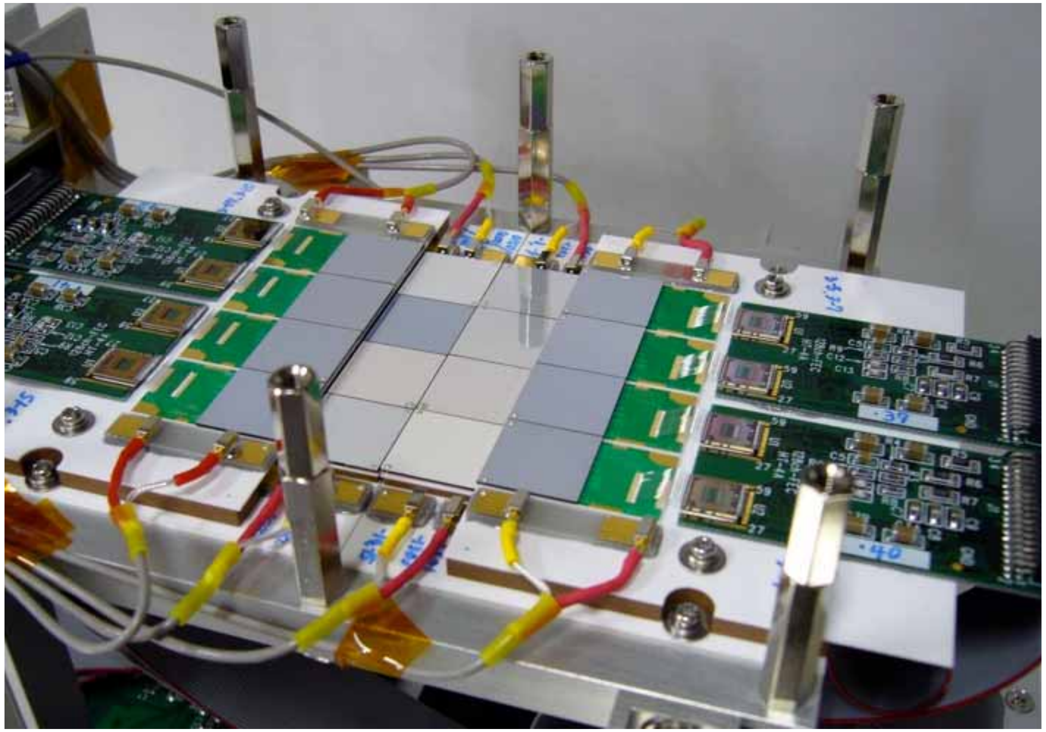
0.66 keV fwhm @ 13.94 keV
0.84 keV fwhm @ 59.54 keV

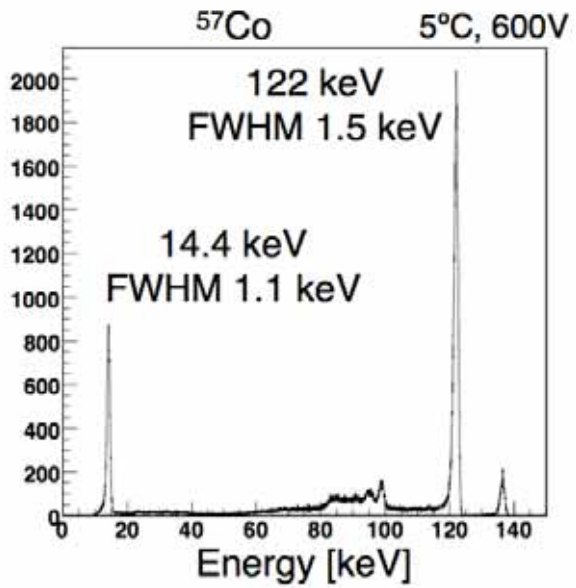
Large Area Hard X-ray Imager

ISAS/JAXA



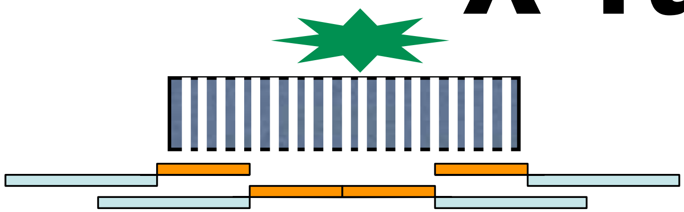
Large Area 1024 pixel CdTe Array
(pixel size 1.4 x 1.4 mm^2)





0.5 mm thick

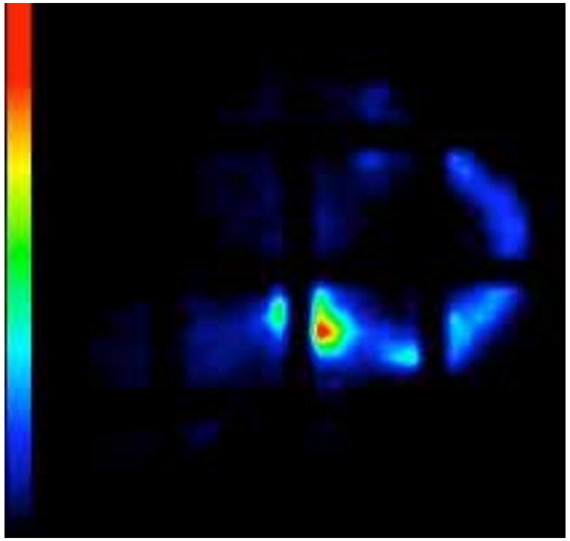
X-ray Imager



A plant(tobacco) in water with ^{99m}Tc and ^{201}Tl

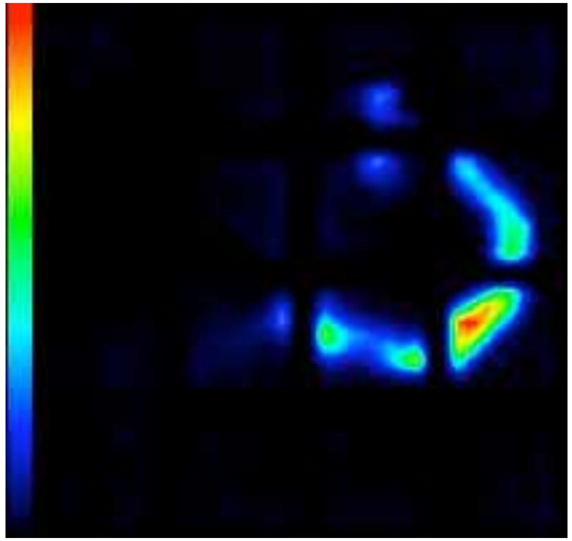
Allow us to study where in the leaf absorb which kind of metal (multi-tracer imaging)

140 keV



^{99m}Tc

69-80 keV



^{201}Tl

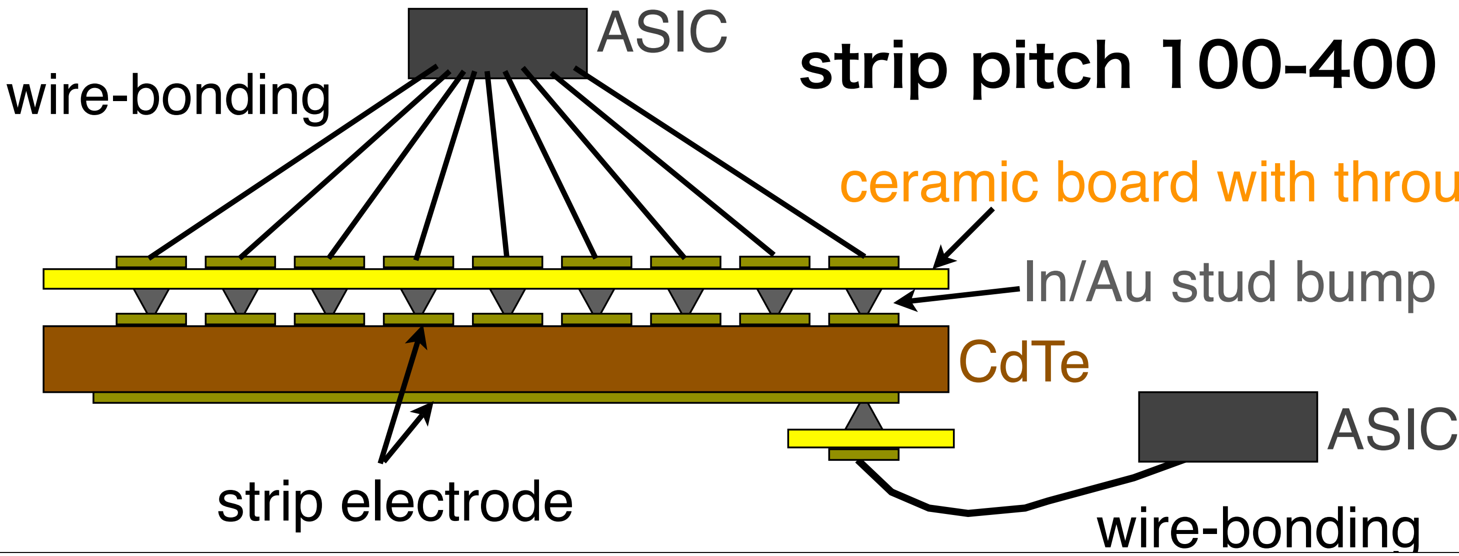
Fine Pitch CdTe Strips

Previously

1) Difficult to make strips on the barrier electrode (In) for CdTe diode.
2) Wire-bond does not work on CdTe.

With new electrode material on CdTe (Al as anode/Pt as cathode) we have succeeded to make fine pitch Double Sided Cross Strip detector

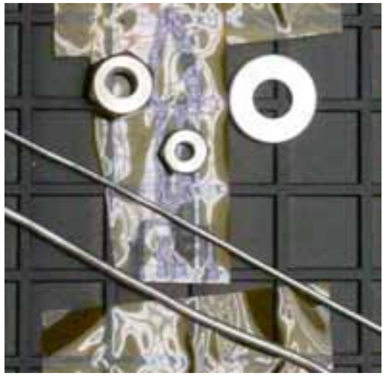
strip pitch 100-400 micron



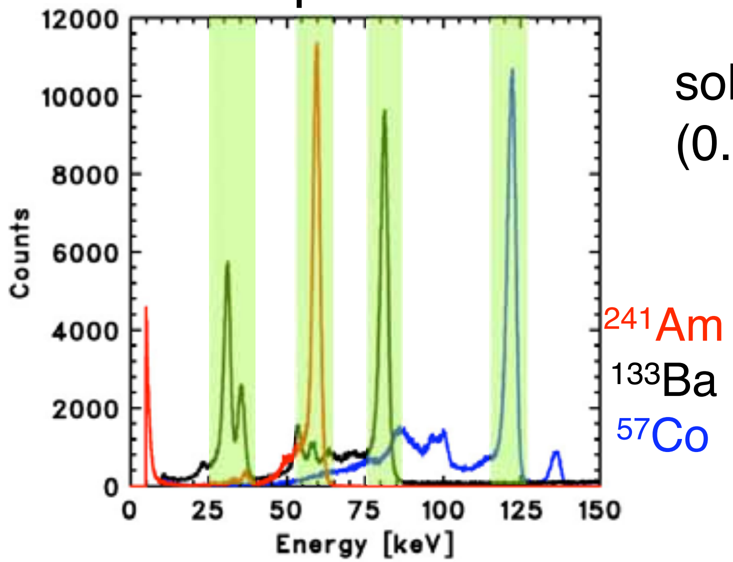
Results(imaging)

NDIP08

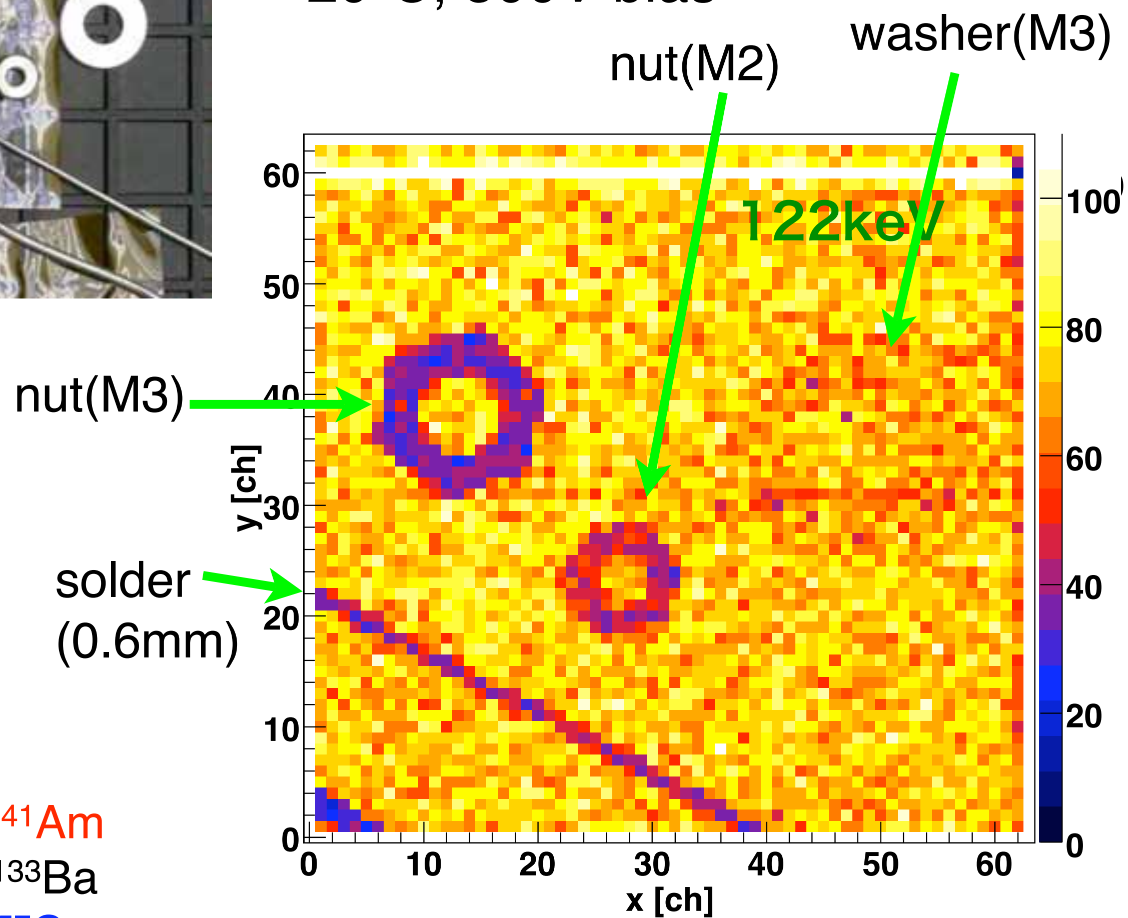
Shadow Image various RIs(^{241}Am, ^{133}Ba, ^{57}Co)



spectra



–20°C, 500V bias



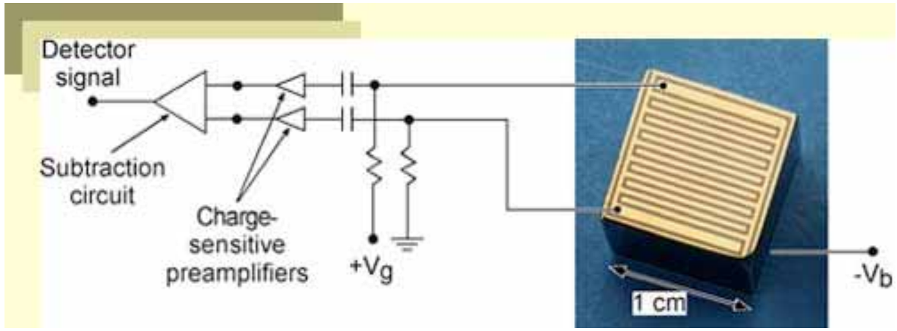
Δx~400μm Imaging Spectroscopy !!

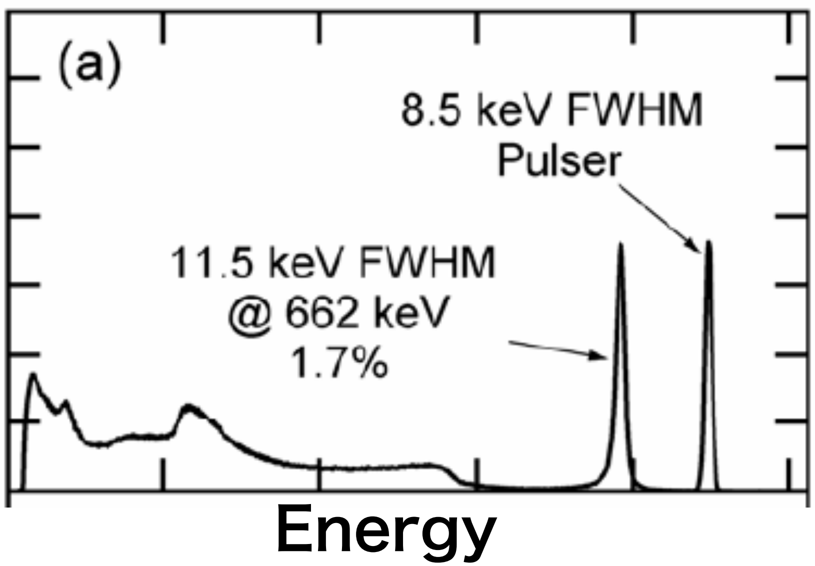
Gamma-ray

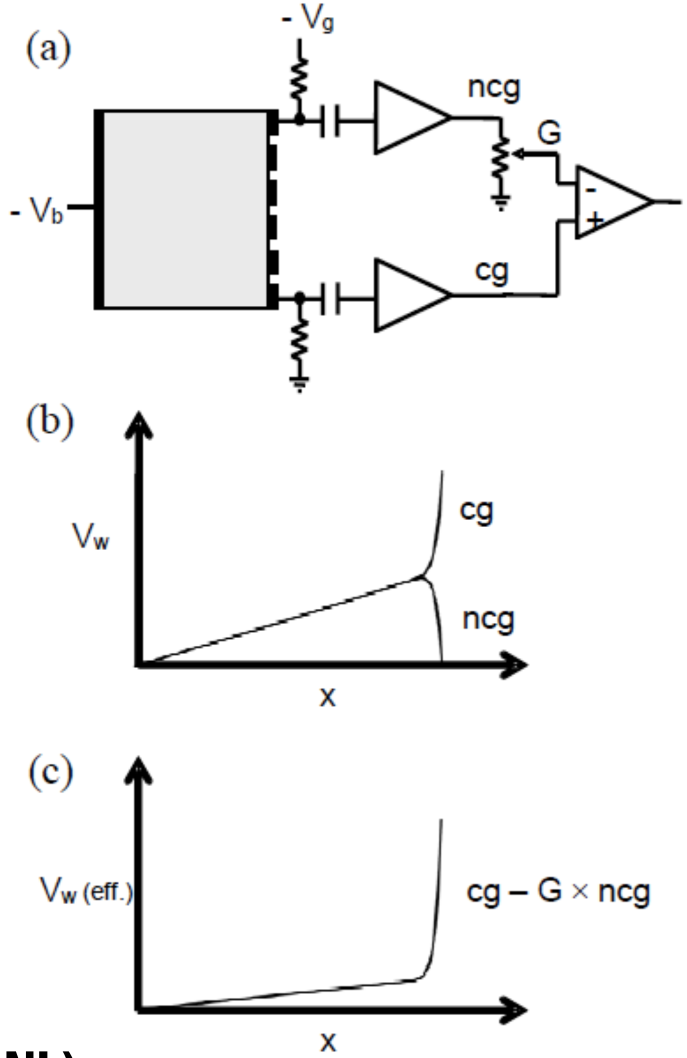
above 100 keV

CdTe & CdZnTe detectors for gamma-ray

Thick Approach







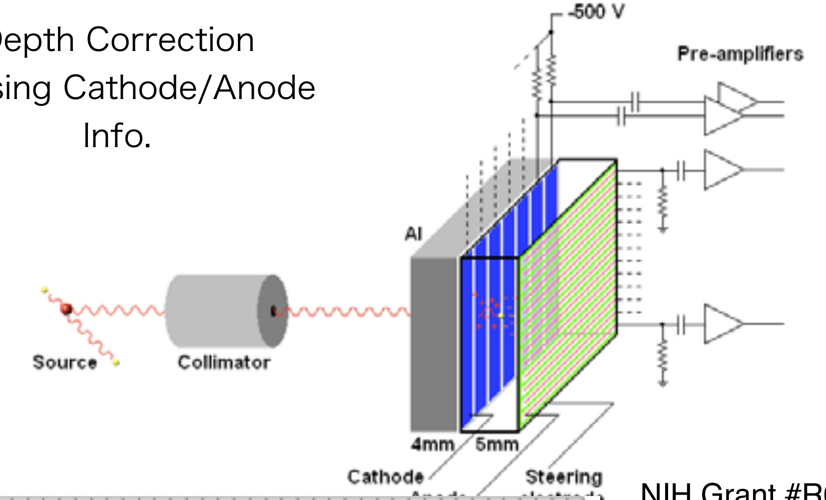
at room temperature

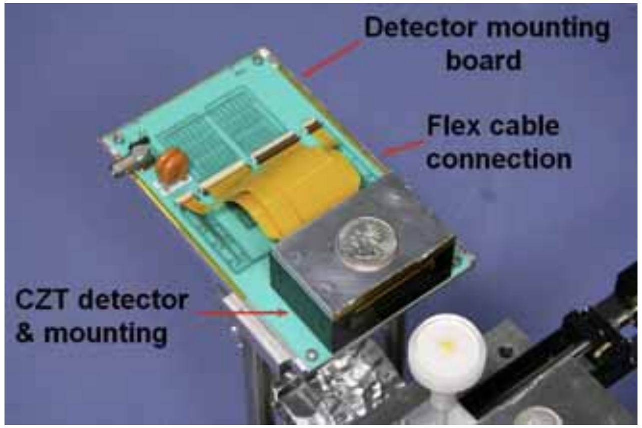
P.Luke (LBNL)

Cross Strip CdZnTe

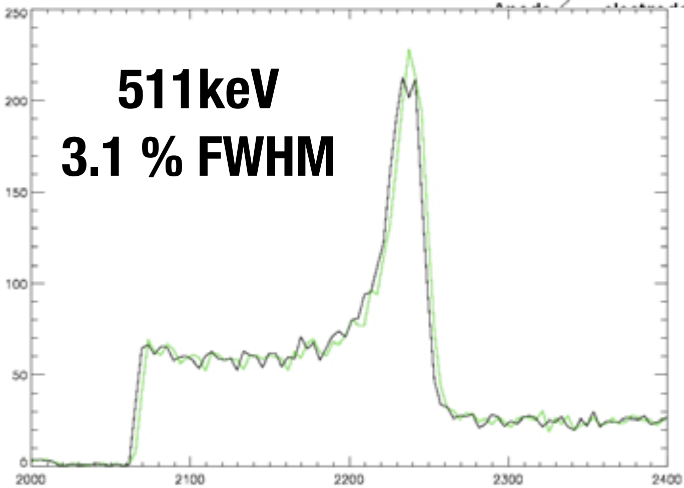
For a Large NIH Program 1 mm spatial resolution, ~2% energy resolution at 511 keV

Depth Correction
by using Cathode/Anode
Info.



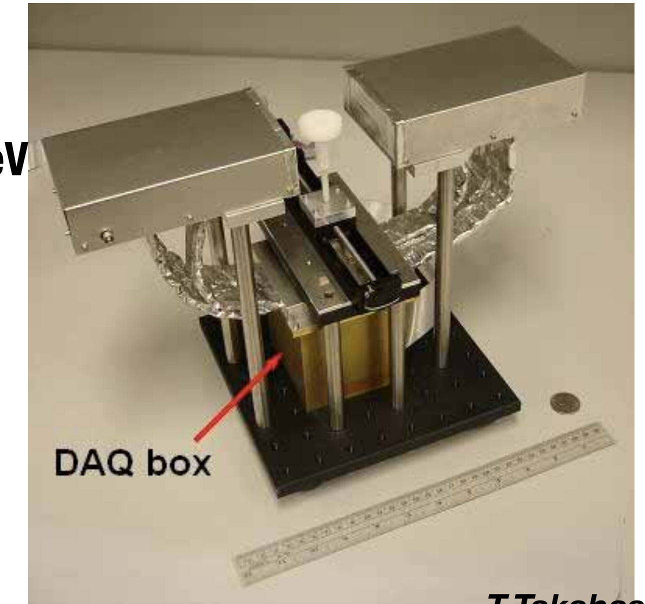


NIH Grant #R01CA120474



Edge on geometry
Eff. of 86 % for 511 keV
by 4cm CZT

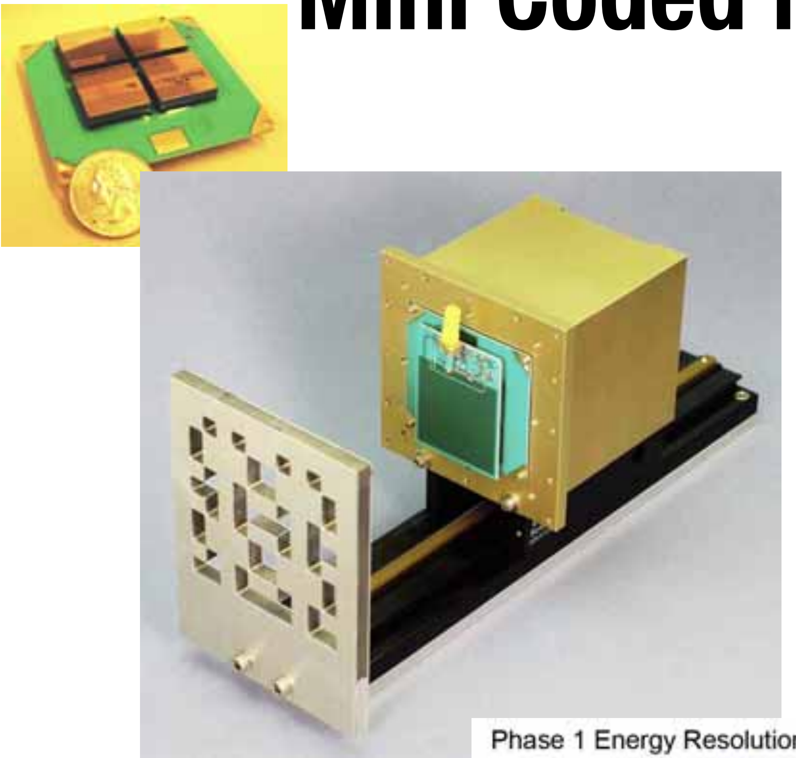
by C. Levin of Stanford,
and J. Matteson et al.
2008



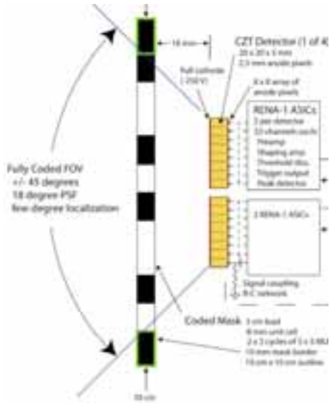
California Breast Cancer Research Program, CBCRP Grant Number 12IB-0092

Gamma-ray Detector

Mini Coded Mask (cross strip CZT)

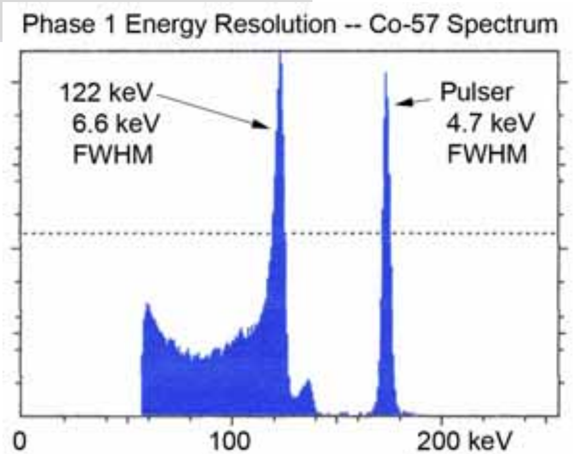


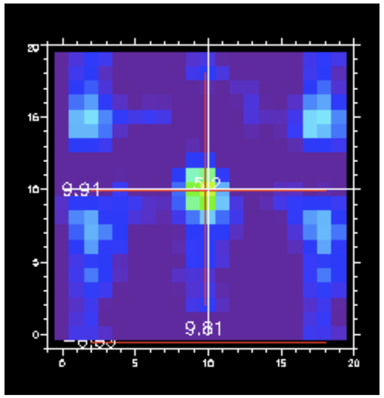
DGAS specs:
- Image a 5 mCi source at >5 m in less than 10 sec, and localize it to <10 degrees
- Energy band of 40 - 250 keV
- Better than 10% energy resolution at 122 keV



Redlen CZT

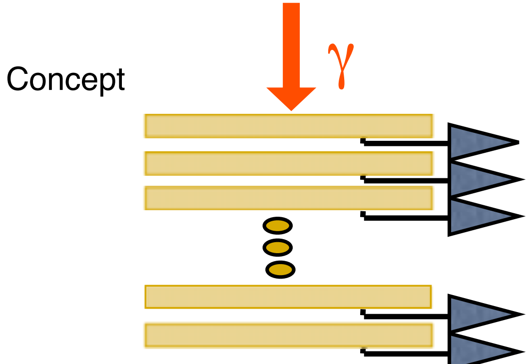
J. Matteson & Aguila Tech., 2008 supported by HSRAPA



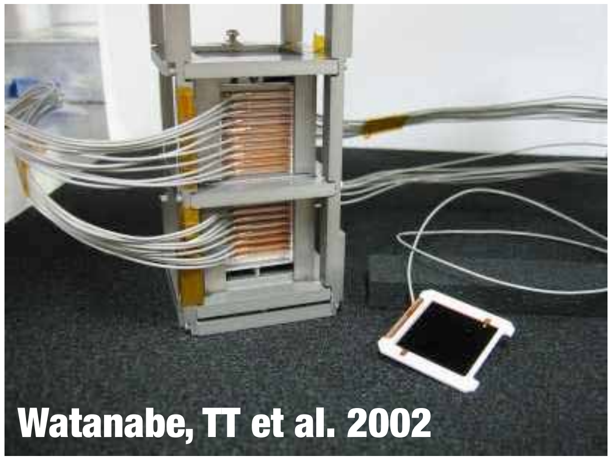


CdTe & CdZnTe detectors for gamma-ray

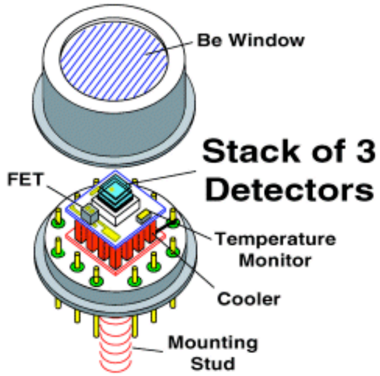
Thin Approach



Full Charge Collection (No Tail)
-> Stack thin CdTe layers
to get high efficiency.



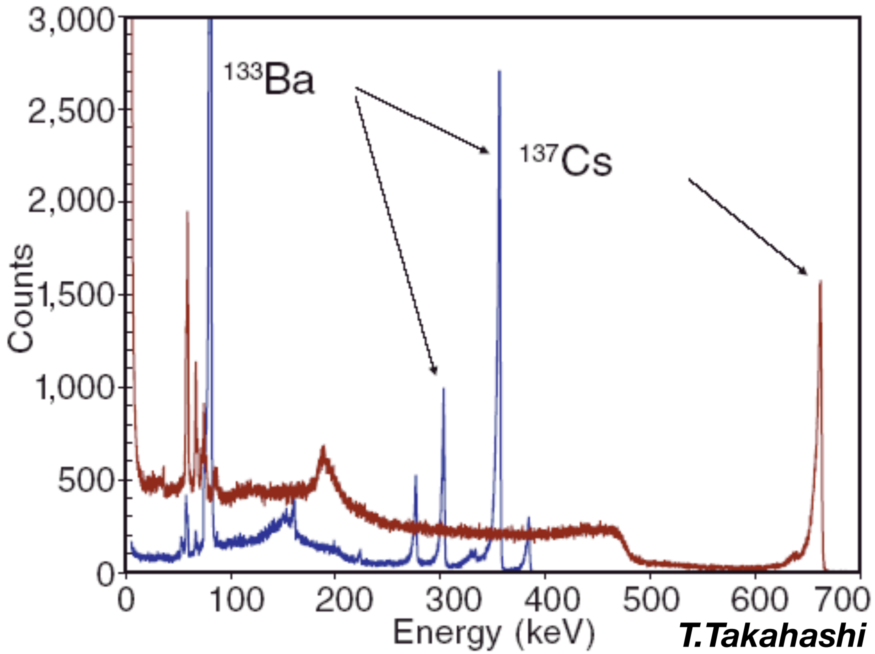
40 layer = 20 mm thick CdTe



Amptek

XR-100T-CdTe-STACK

Area 5 x 5 mm
Thickness 2.25 mm
(three layers)



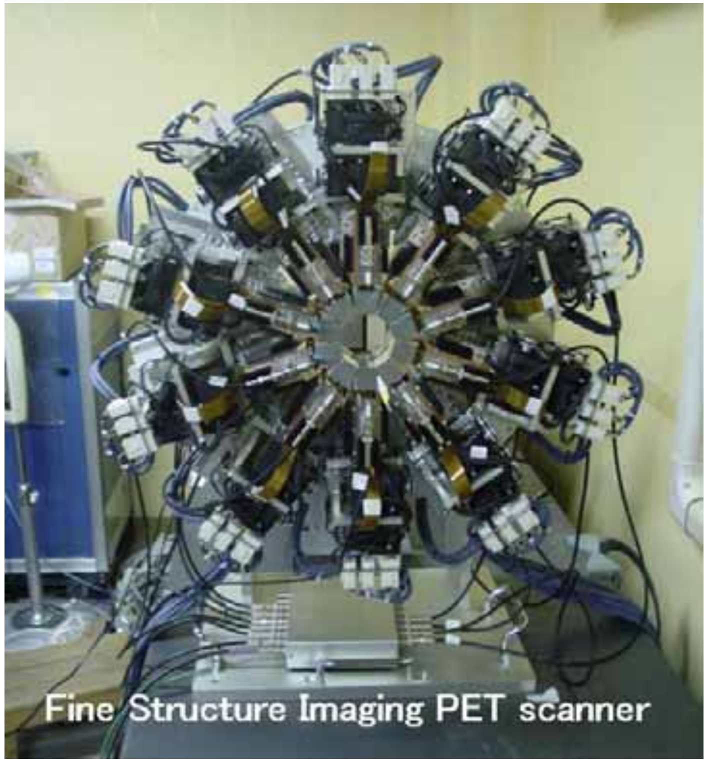
CdTe PET (1st Result)

Achieved Spatial Resolution< 1mm

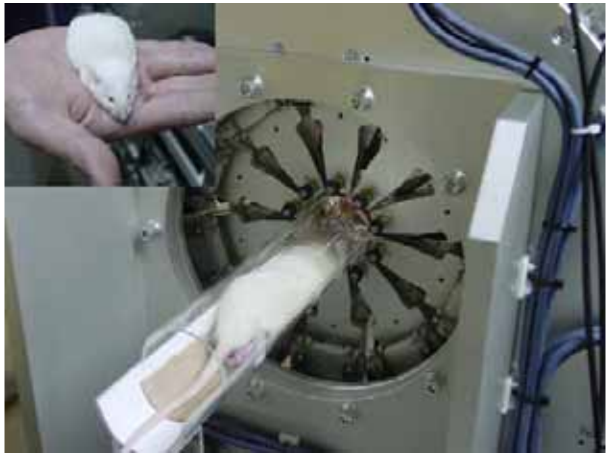
Array of 1mmX1mmX5mm
5120 CdTe BAR

Edge on geometry

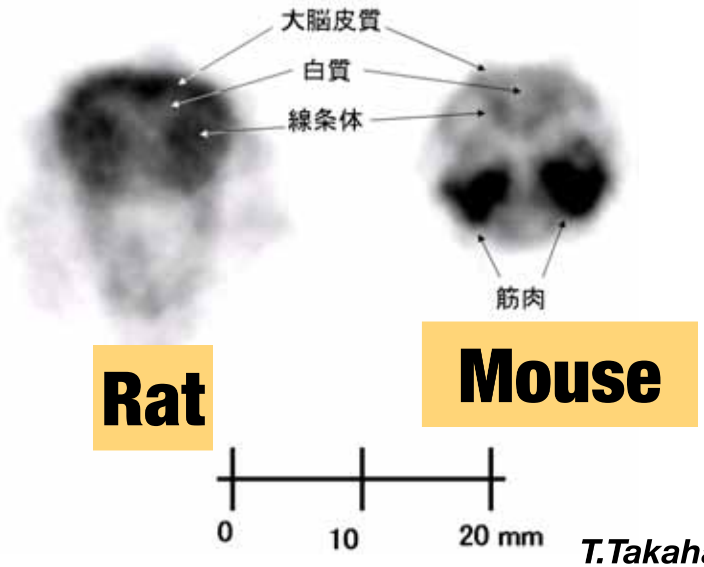
Press Release by K. Ishii, Tohoku Univ., Japan



Tohoku Univ.



Brain



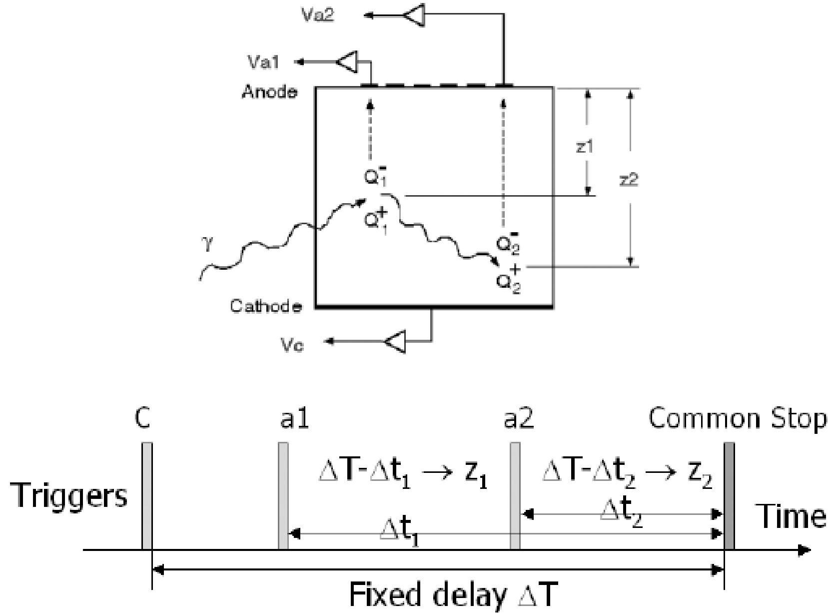
Gamma-ray

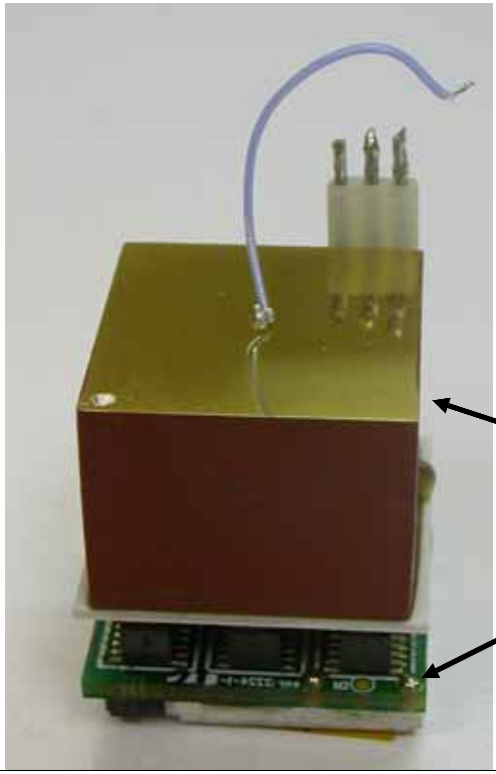
Compton Camera for High Sensitivity Imaging

CdZnTe Compton Camera (Thick)

Z. He et al. Michigan U. (2008)

- Cathode/Anode Ratio (Depth Infc
- Timing Measurement (Drift Time)
  (Multiple Interaction/ Depth Info)

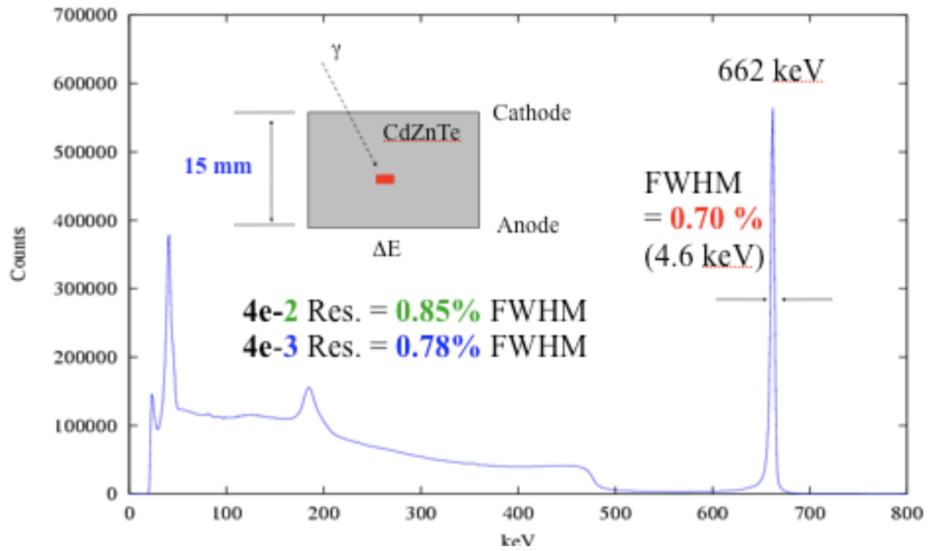




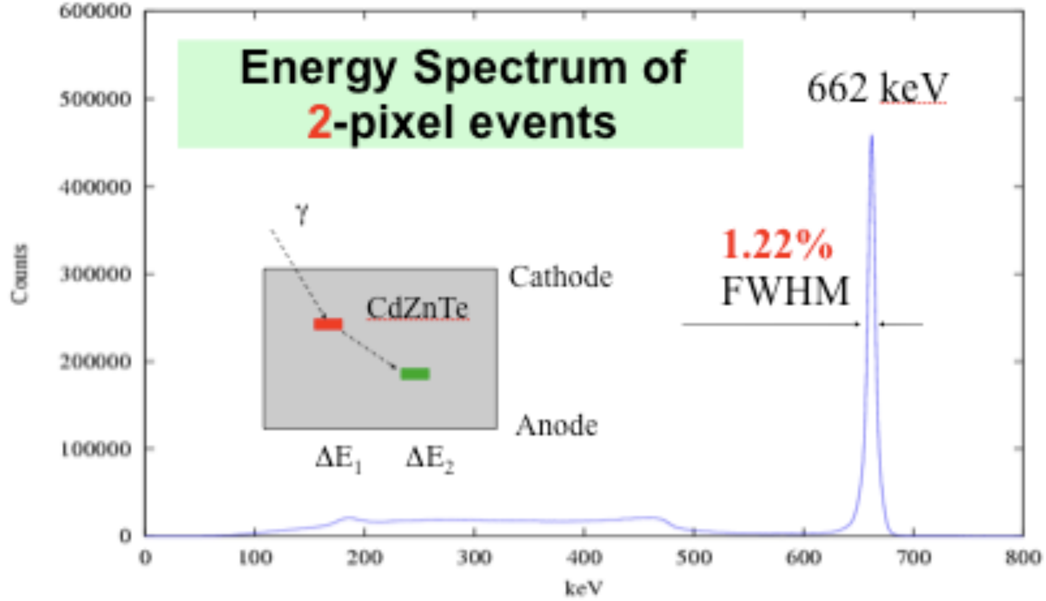
$2\times2\times1.5$ cm^3
= 6 cm^3 CZT(eV Products)

ASIC front-end
(Gamma-Medica-Ideas AS)

Spectrum of 1-Pixel Events from the Entire Detector

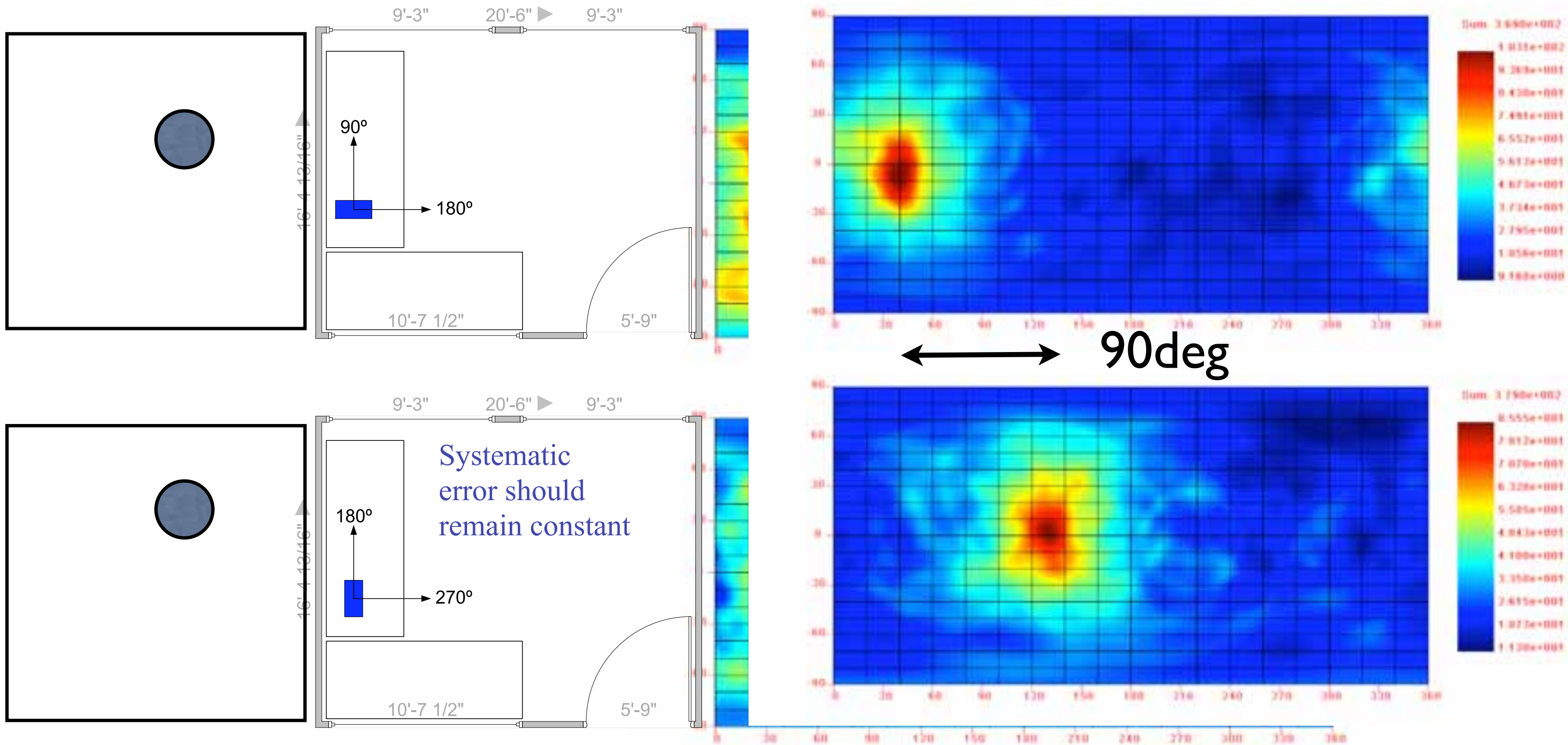


Room-temperature **handheld** **CdZnTe** γ-ray **imaging spectrometers** with energy resolution ~ **1%** FWHM at 662 keV



Demonstration of γ-Ray Imaging using a Single 1.5×1.5×1 cm^3 CZT Detector (FOV=4pi)

Accidentally
Detected a 10 μC ^{137}Cs source next door



angular resolution ~10 degrees at 667 keV

T.Takahashi

Gamma-ray Detector

Si/CdTe Compton Camera (Thin)

Japanese ASTRO-H “fomerly called as **NeXT** (New exploration X-ray Telescope)”Satellite will use it for the sensitive measurement from 100 keV to 600 keV.

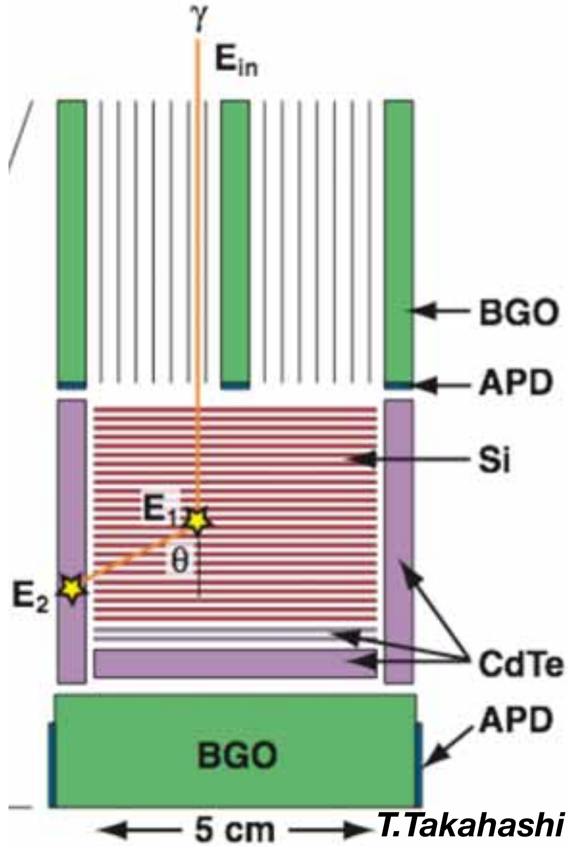
Concept (Takahashi et al. SPIE 2003).

Narrow FOV (field-of-view) Compton camera.

Compton kinematics to suppress backgrounds

Si is ideal device as “Scatterer”,

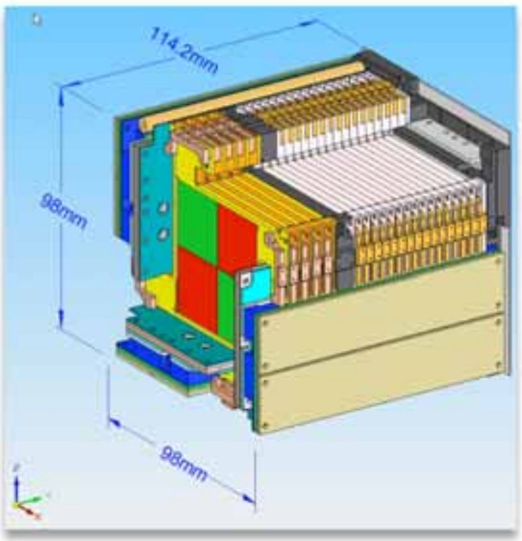
since it is low Z material and momentum of electron around the nuclei is small -> Less affected by Doppler Broadening



1 unit

32 layers of 0.5 mm thick Si Pixel

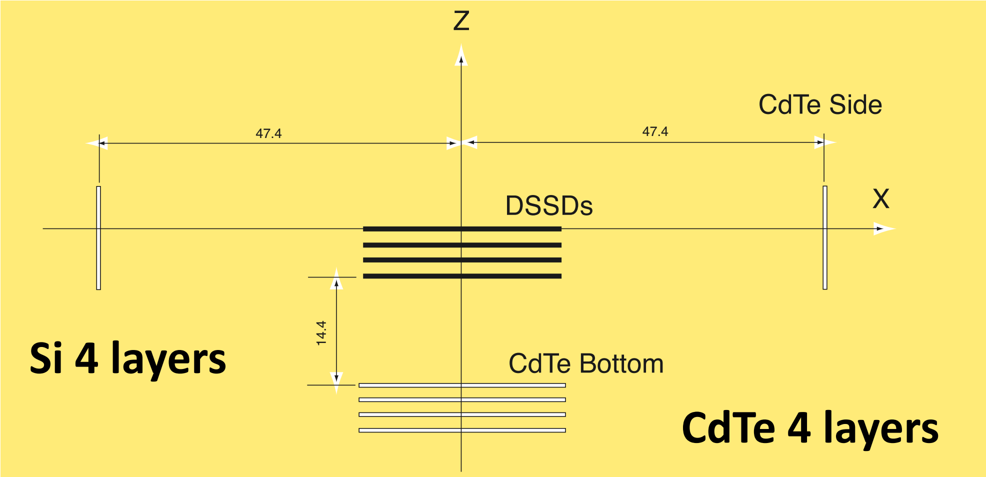
8 layers of 0.75 mm thick CdTe Pixel



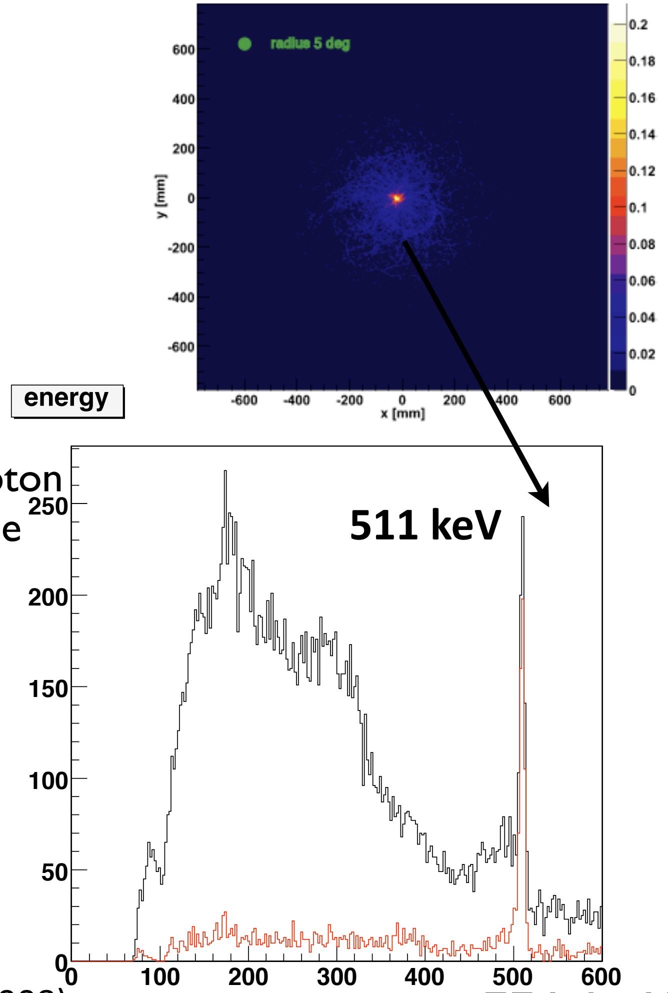
Gamma-ray Detector

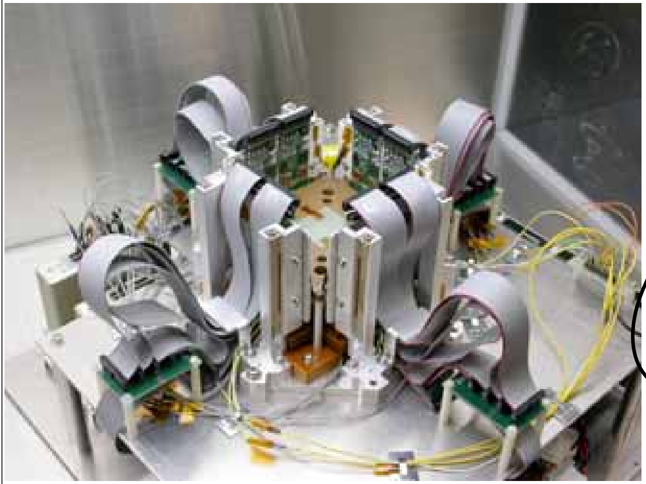
Si/CdTe Compton Camera

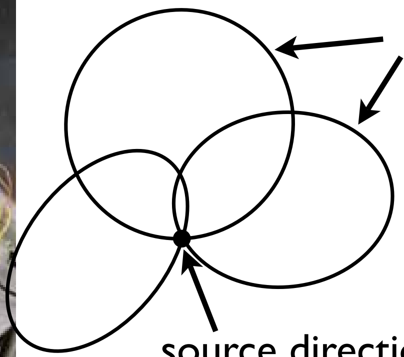
Prototype



511 keV point source (2.5 degrees)
>80 deg FOV







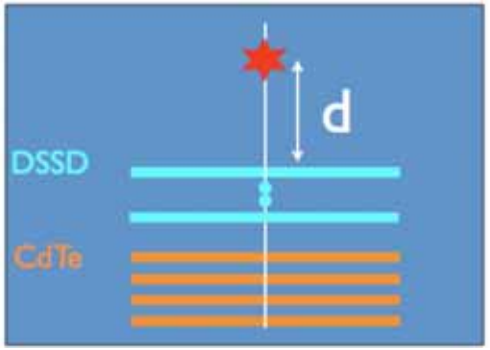
Angular resolution ~3 degrees at 511 keV

(Takeda et al. IEEE NS 2008)

T.Takahashi

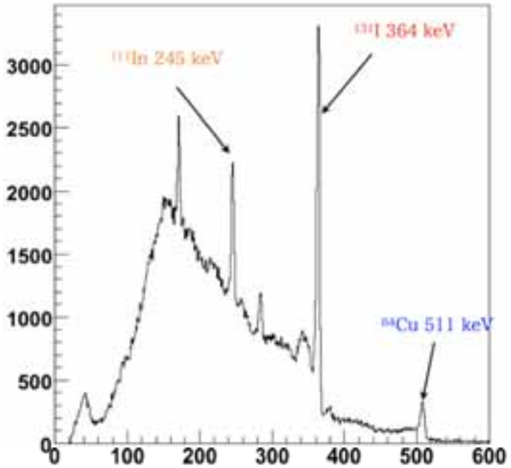
Si/CdTe Compton Camera

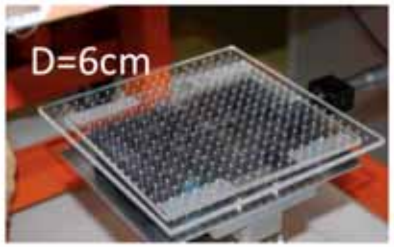
NDIP08

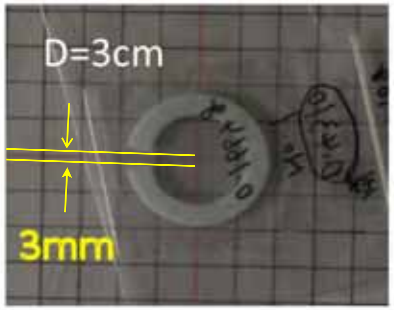


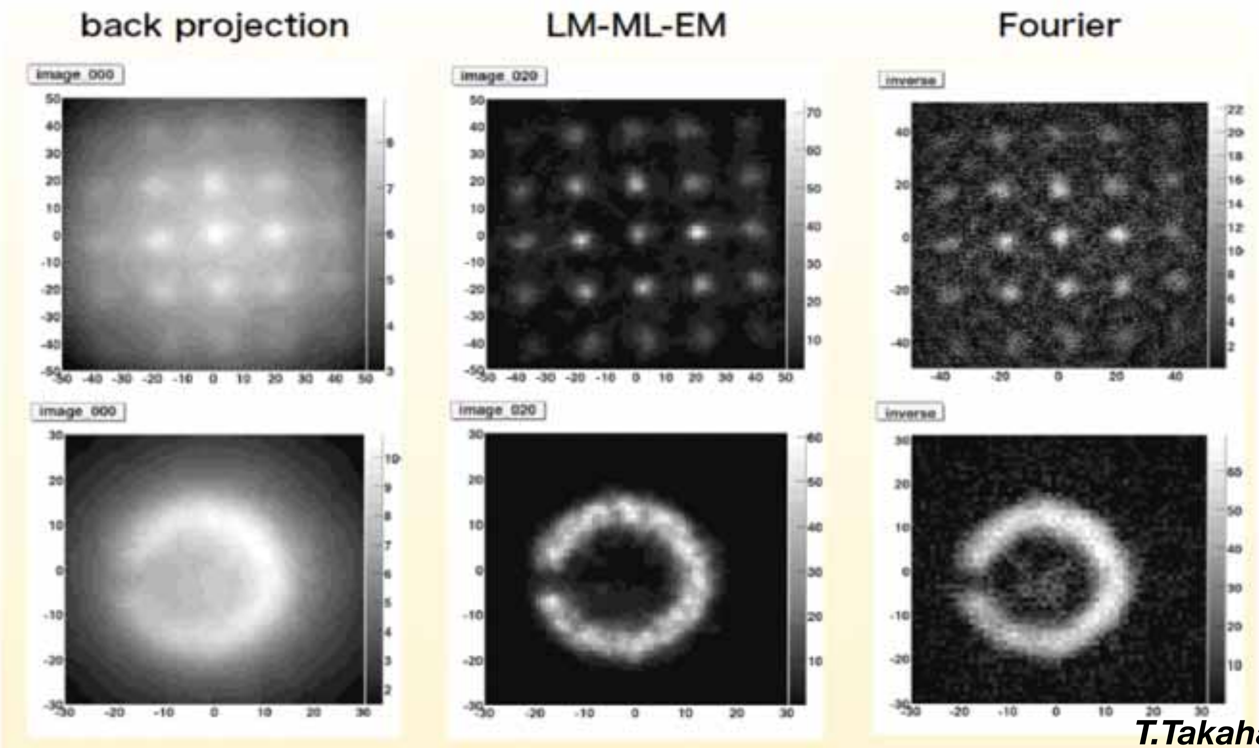
Good performance for both multiple and diffuse sources. Large FOV and good energy resolution

ISAS, 2008









(Takeda et al. IEEE NS 2008)

T.Takahashi

Summary/Future Prospects

1. **CdTe and CdZnTe are now in the phase of real application.**
2. Large and Thin CdTe wafers are widely used for the commercial products of hard X-ray camera
3. Photo Counting Detector (10^9-10^{10} photons/pixel /s)would be the next step.
4. For gamma-ray detection, *Thick* approach and *Thin* approach both work.
5. Homeland Security and Medical Imaging boost the development
6. Space missions are always one step ahead in terms of technological requirements, which is good.