CdTe Focal Plane Detector for Hard X-ray Focusing Optics

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Presenting on behalf of the RAL/NASA HEXITEC Team

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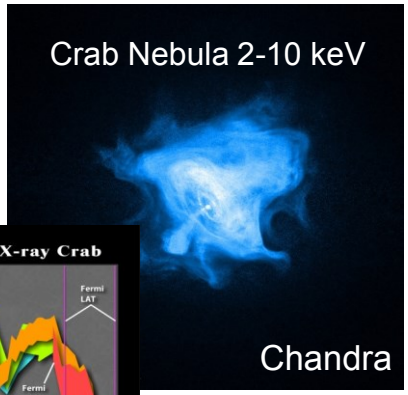
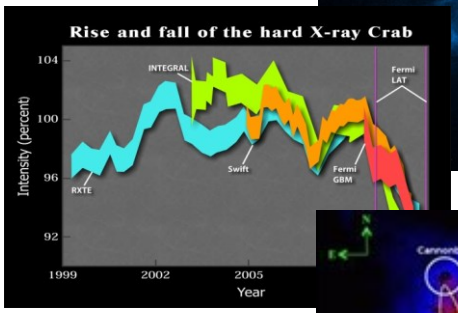
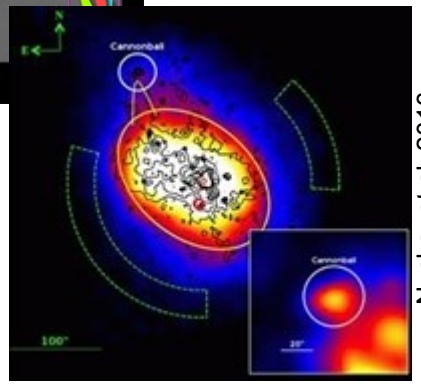
Probing the High-Energy Universe: Astrophysics

- Resolving extended sources on fine spatial scales

  -Pulsar Wind Nebula
  -Supernova Remnants –mapping ^{44}Ti
  -Extragalactic Jets



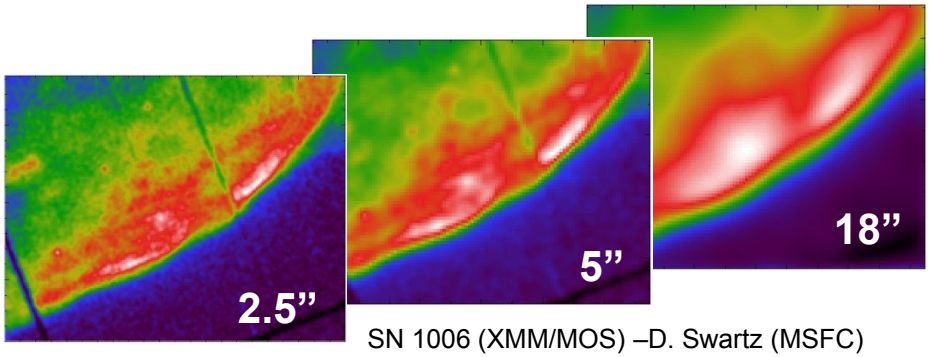




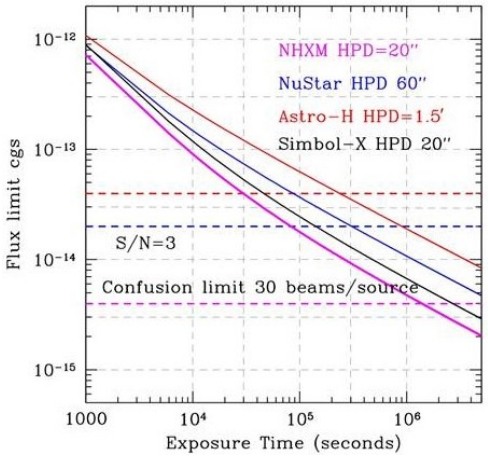
Nynka, et al. 2013

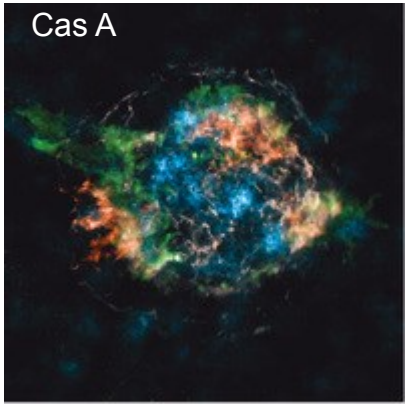
- Mitigating source confusion in crowded fields
  -Mapping the Galactic Center
  star formation, SMBH, accreting white dwarfs, low mass x-ray binaries, millisecond pulsars

- Resolving the Cosmic X-ray background



SN 1006 (XMM/MOS) –D. Swartz (MSFC)

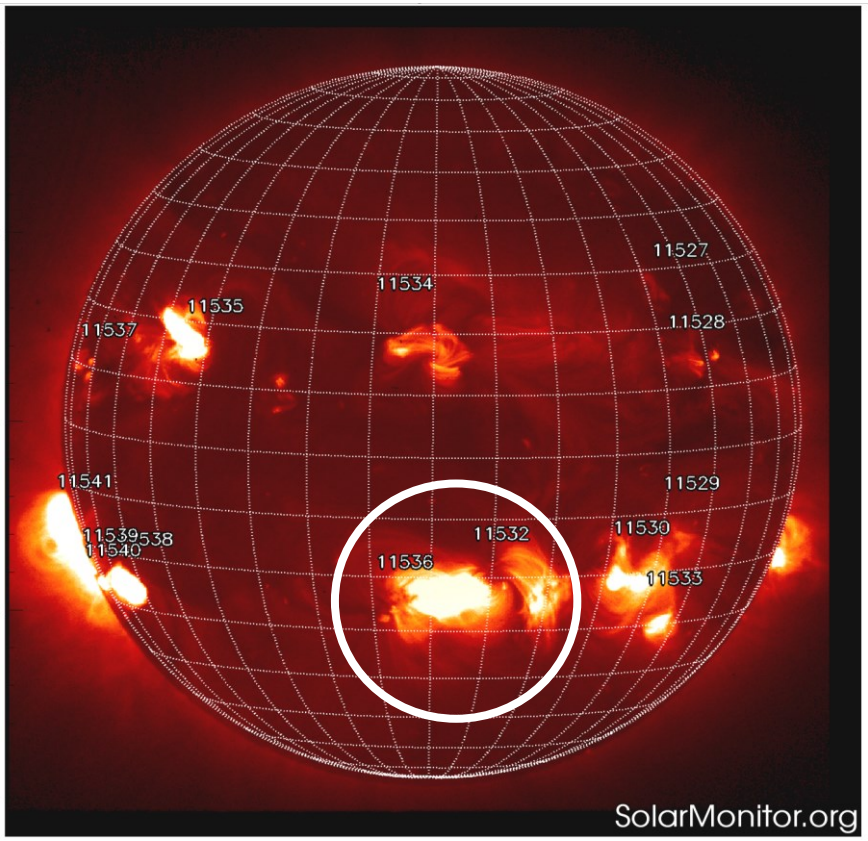




Grefenstette, et al. 2014

Probing the High-Energy Universe: Solar Physics

- Flares occur in active regions (areas of strong magnetic fields).
- Energy release does not only occur in active regions.
- Smaller magnetic fields exist in the quiet Sun and the signature of energy release (the high average temperature of the corona) is everywhere.
- HEROES will also improve upon past searches for the HXR signature of energetic electrons in the non-flaring corona.



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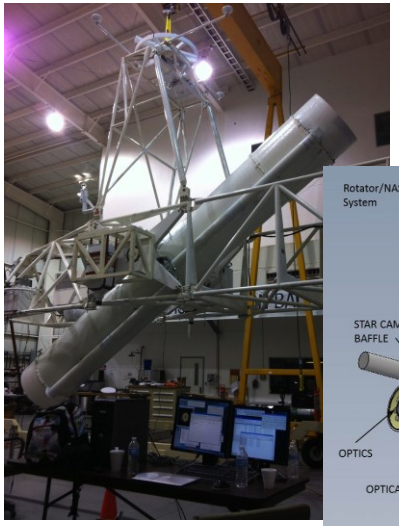
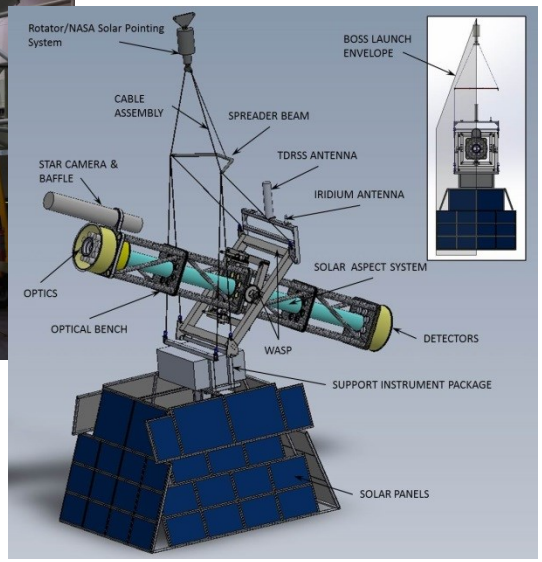
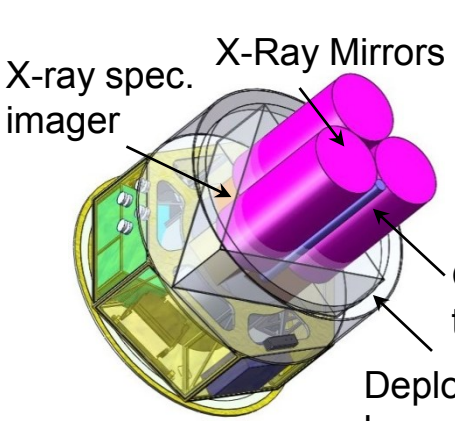
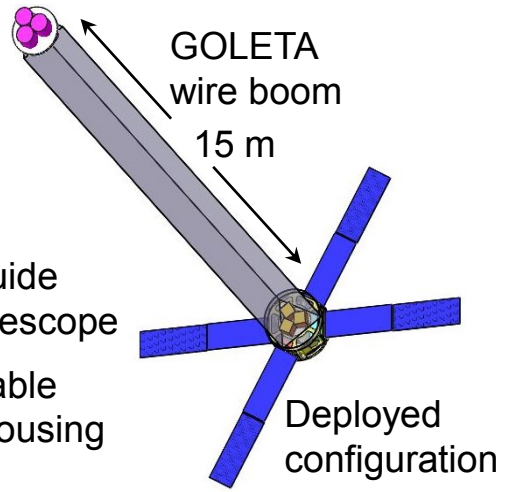
Future Missions
Astrophysics & Solar

Suborbital	Orbital
HEROES (Gaskin-Christe/MSFC/GSFC) SuperHERO(Gaskin-Christe/MSFC/GSFC)	SuperHERO (Gaskin-MSFC/MIDEX/Probe) BEST (Krawczynski-WU St.L/Probe) HEX-P (Harrison-CalTech/Probe) FOXSI (Christe-GSFC/SMEX)









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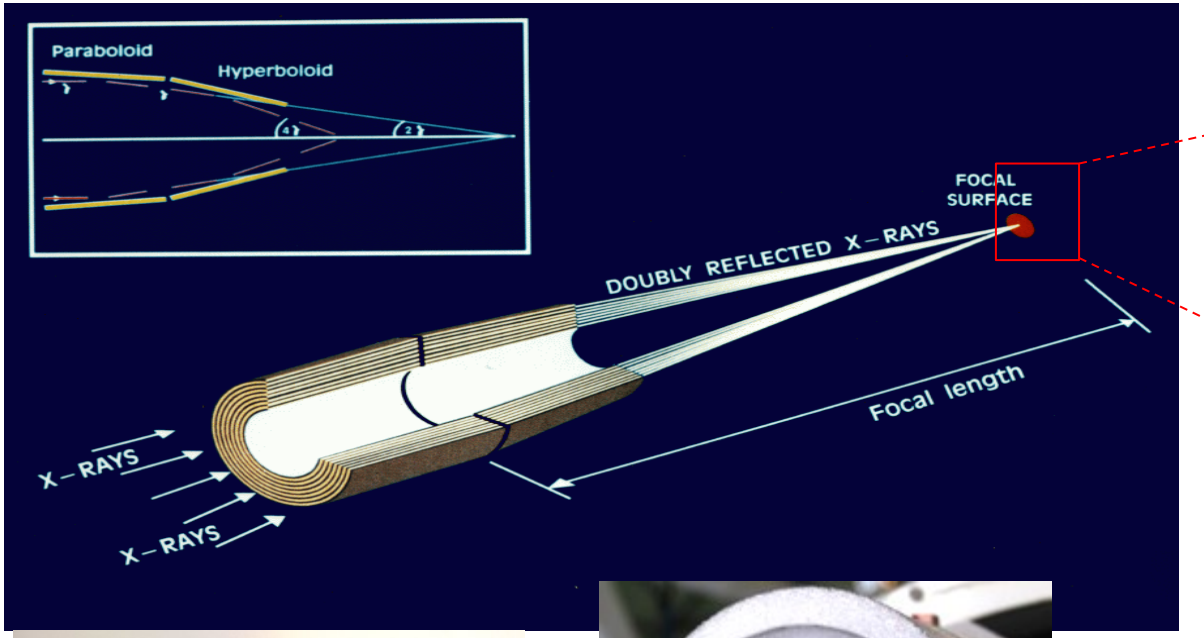
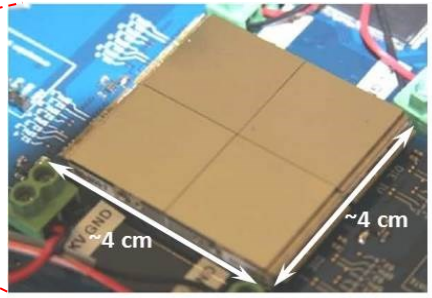
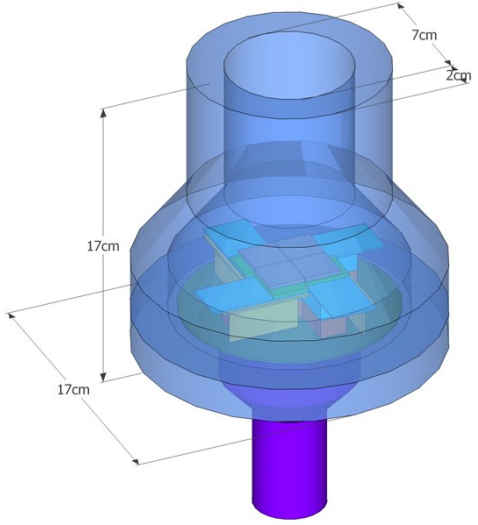
HXR Telescopes

Grazing Incidence Optics – Full Shell	HXR Detectors





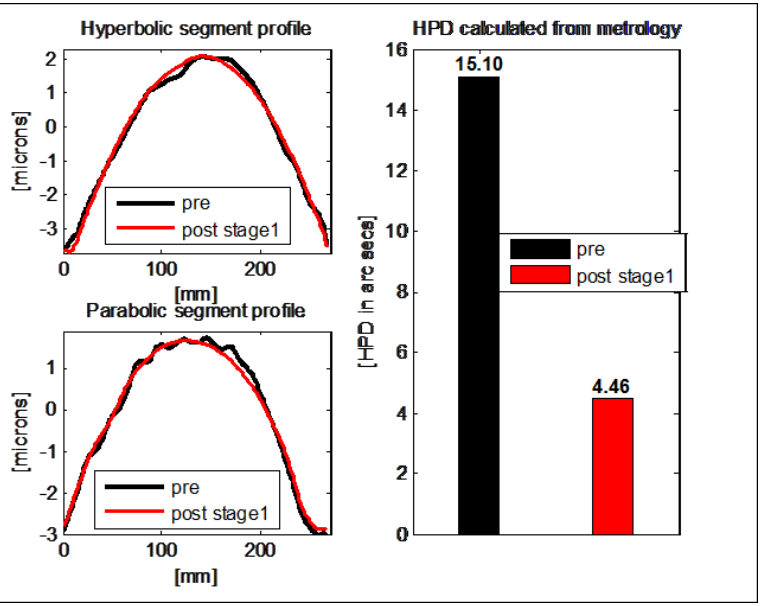


Detector Requirements

Optics Performance - Examples

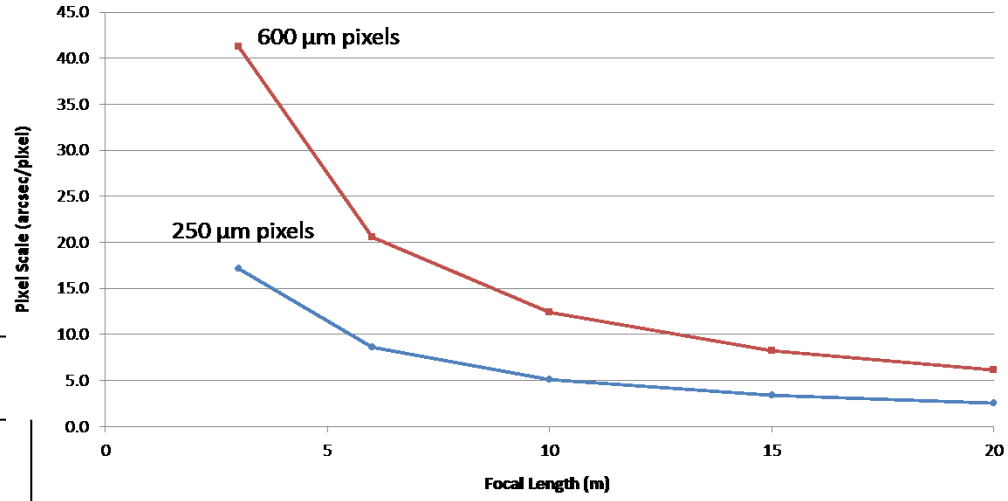
- SuperHERO-suborbital (20 arcsecs)
- SuperHERO-orbital (5 arcsecs)

Differential Deposition



SEE Session 12: Differential Deposition

Pixel Size Vs. Focal Length



Detector Performance

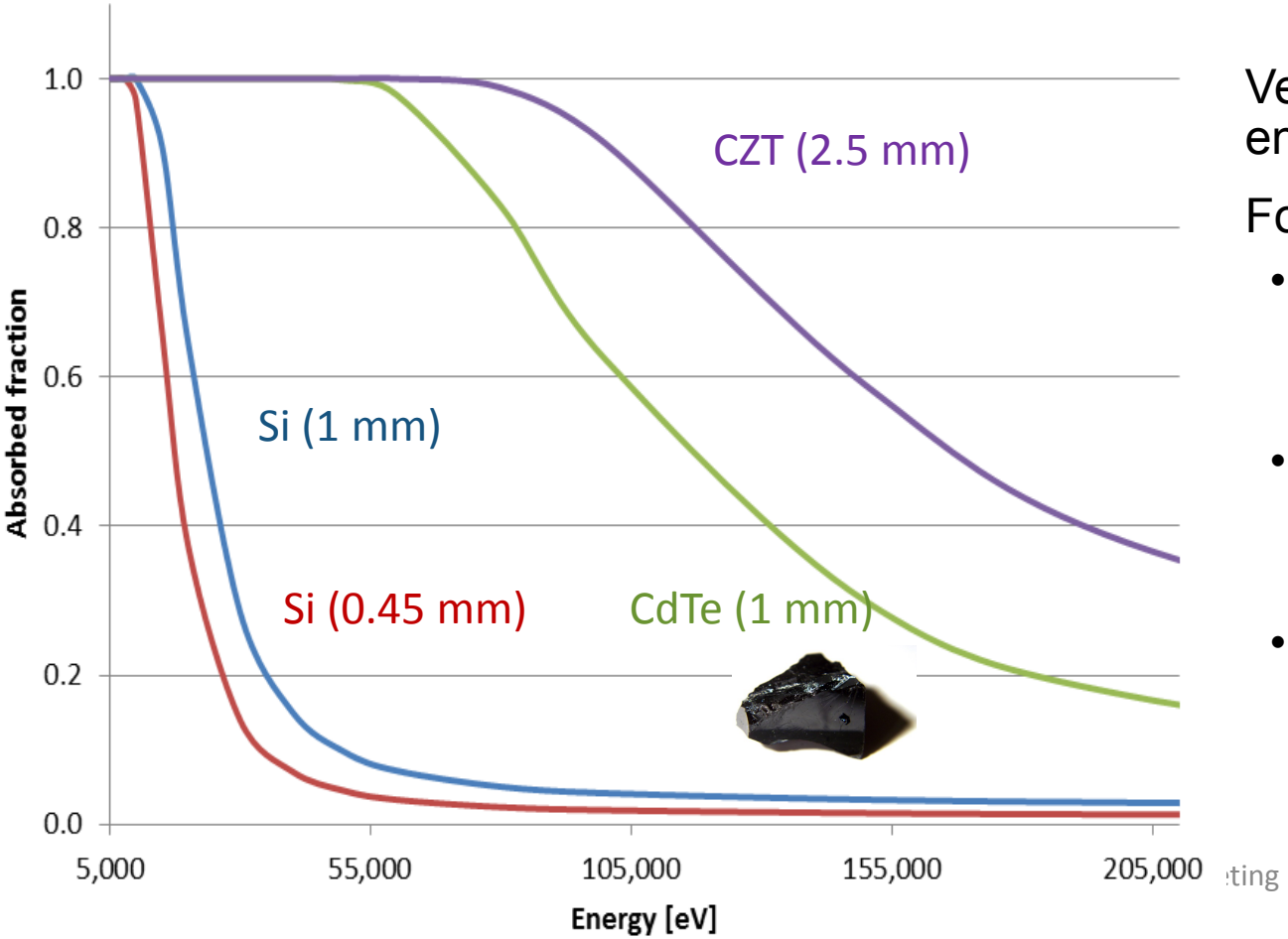
- Good QE in hard x-ray band (CdTe/CZT)
- Good Energy Resolution
- High Count Rates (calibration & Solar)
- Low Background
- Low Power
- High Radiation Tolerance
- Large Format/Arrays

HEXITEC

HIGH ENERGY X-RAY IMAGING TECHNOLOGY

- High Energy X-ray Imaging Technology Consortium formed in 2006 and funded by the Engineering and Physics Sciences Research Council, UK
- HEXITEC ASIC developed by Science and Technology Facilities Council at Rutherford Appleton Laboratory
- Targeted application are materials science, medical imaging, illicit material detection.
- NASA GSFC & MSFC have been collaborating with RAL to develop these detectors for astrophysical and solar observations.

Quantum Efficiency



Very good efficiency at high energies.

For comparison

- 1 mm Si
  50% efficient@22 keV
- 1 mm CdTe
  50% efficient@100 keV
- 2.5 mm CZT
  50% efficient@160 keV

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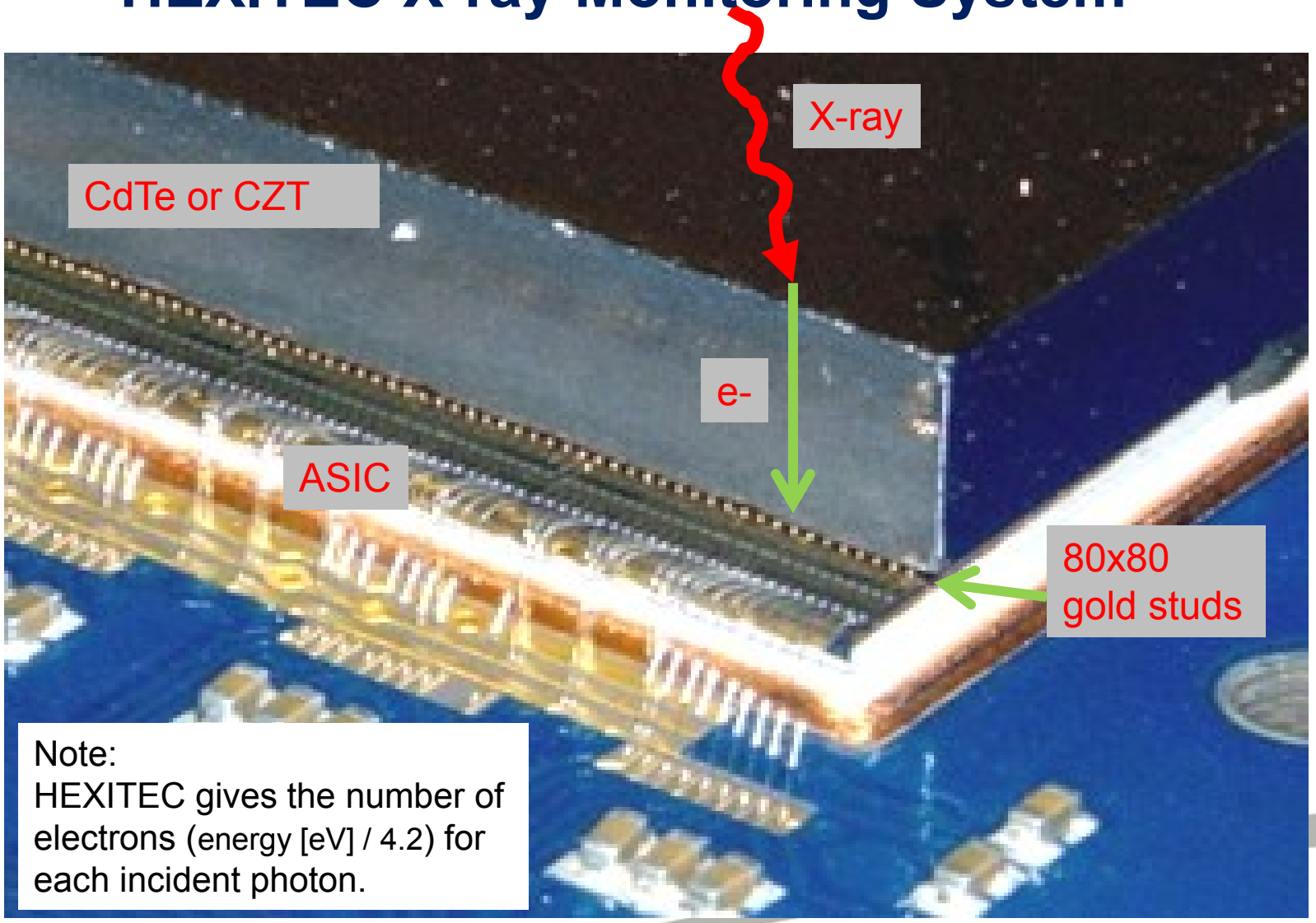
HEXITEC X-ray Monitoring System



Note:
HEXITEC gives the number of electrons (energy [eV] / 4.2) for each incident photon.

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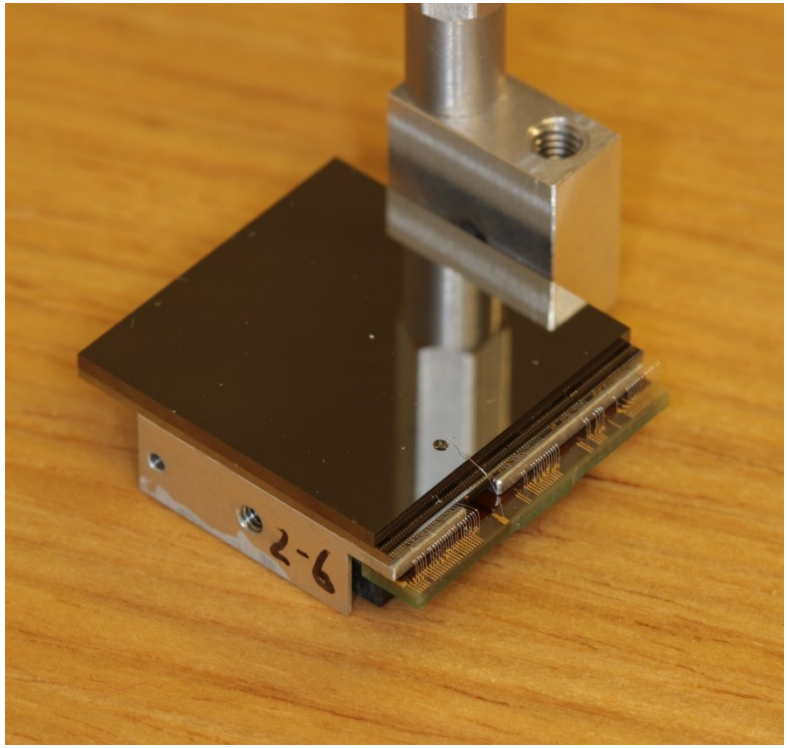
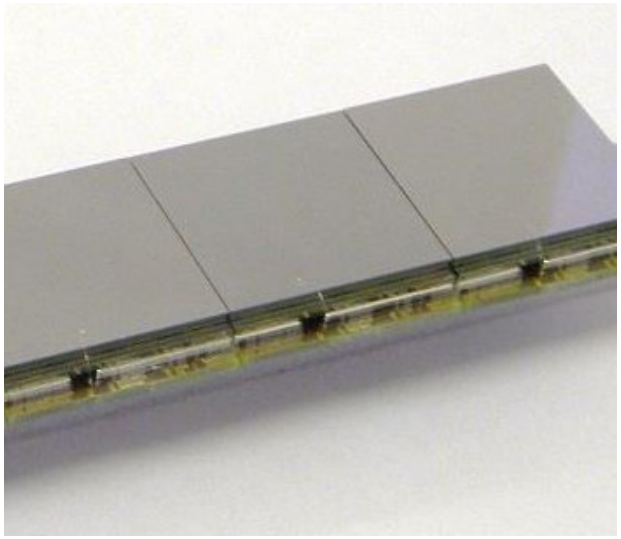
Single Module HEXITEC System



CdTe on HEXITEC ASIC mounted on alignment and cooling block.



Multiple modules mounted on an alignment plate.

Detector modules are aligned and mounted with a minimal gap size of 170 μm!

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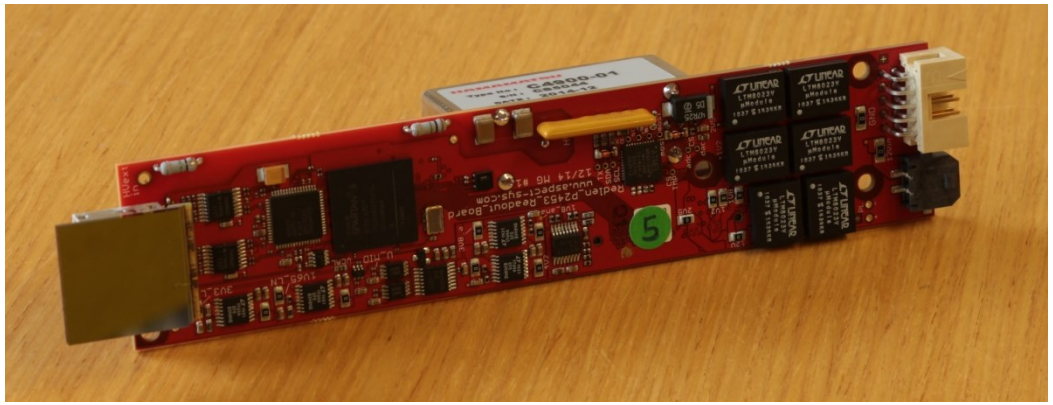
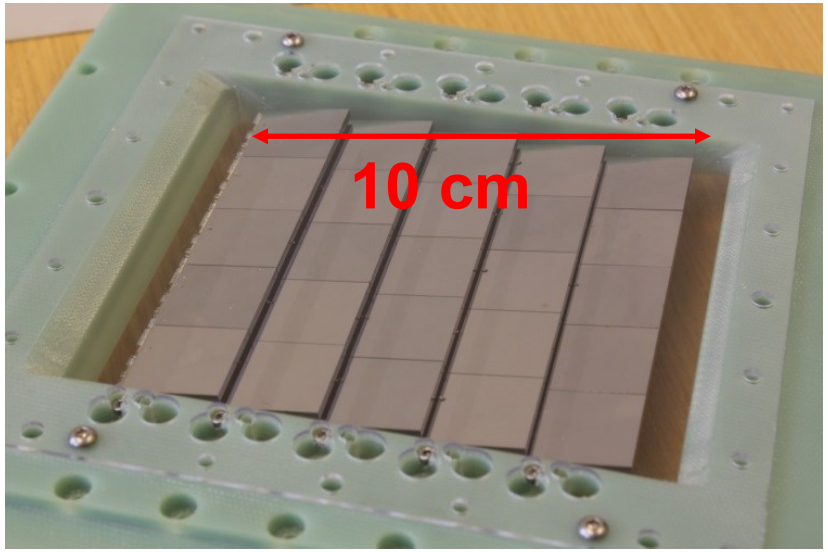
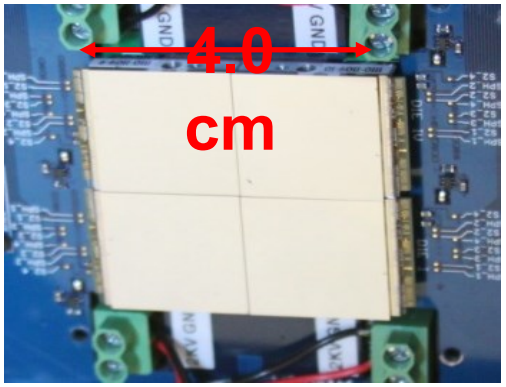
Pixellated Spectroscopic X-ray Systems Based on CdTe Modules (HEXITEC)







NASA

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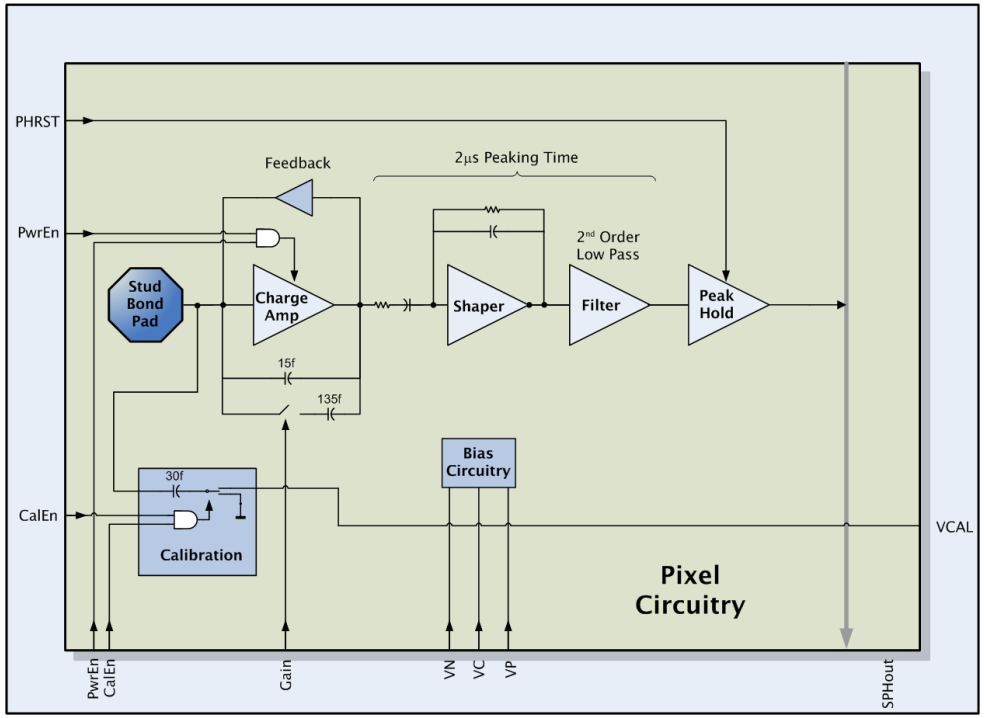
HEXITEC ASIC

- 2 µs shaper > peak hold
- 250 µm pixels
- electron readout
- 50 electrons rms
- VCAL input
- Bias voltage of -300 v to -500 v



No threshold-discriminator or counter is used, instead the energy of every incident photon is recorded.

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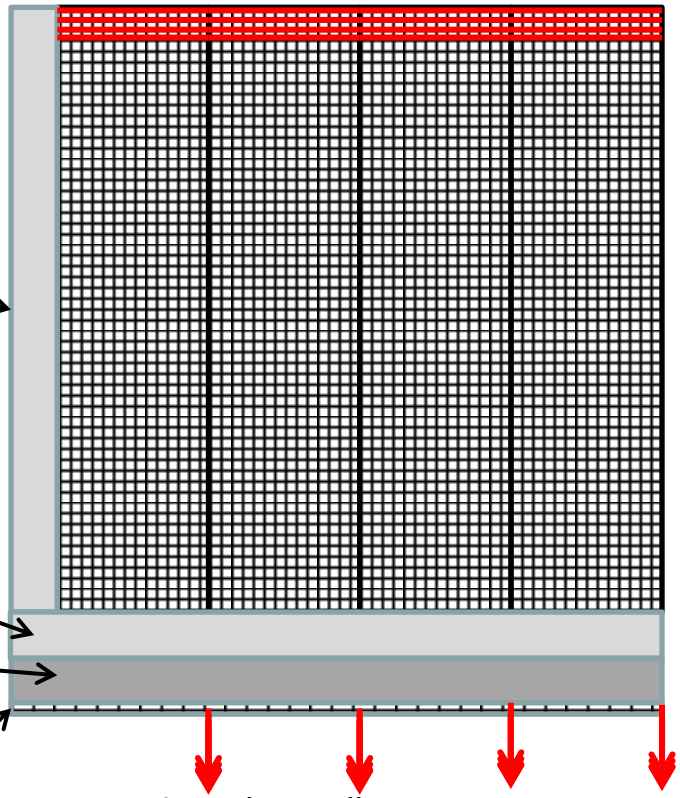
HEXITEC ASIC Readout

Column Registers:
- Read Enable – Readout Pixel
- Power Enable – Full or Reduced Power to Pixel
- Cal Enable – Input Test Pulse to Pixel

Row Registers:
Same as column register – need row and column selected to be true.

Power Distribution and Protection Circuitry

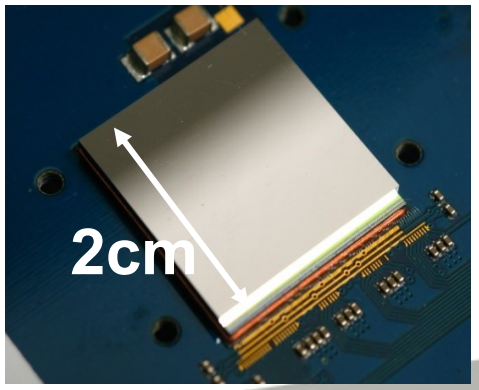
I/O Wire Bond Pads



4x20 Quadrants Read Simultaneously
One frame is =80 rows.
Readout =10,000 frames/second

Operation

- Set-Up Registers
- Run clocks to select rows and clock out PH voltage along columns
- Continuous stream of PH voltages – get all data from all pixels.



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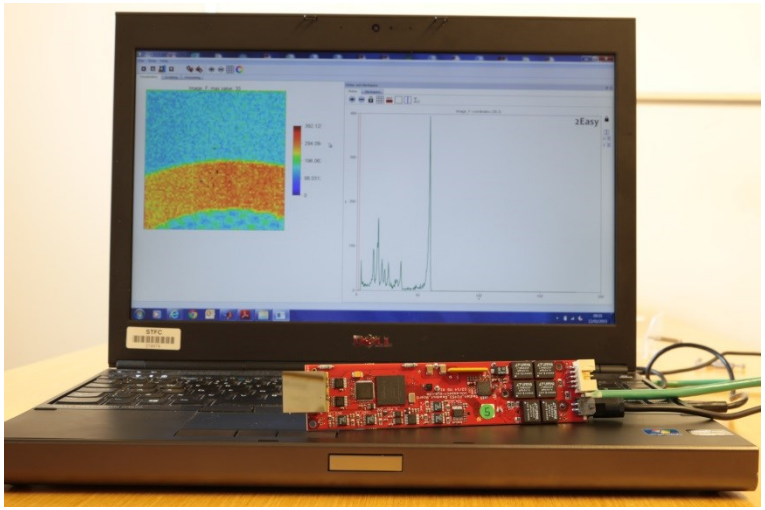
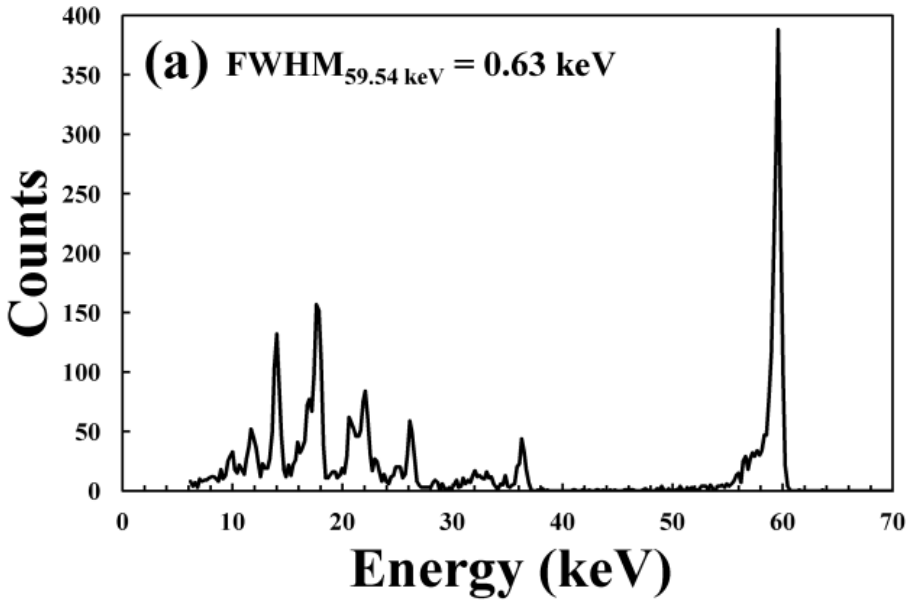
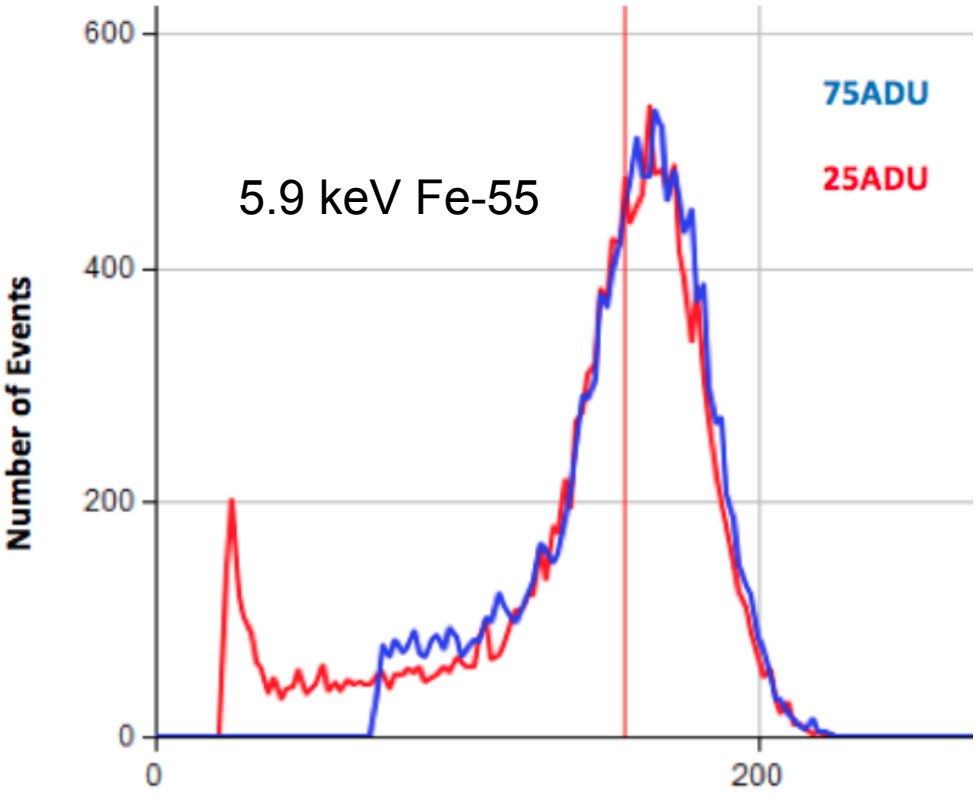
Single Module HEXITEC System

- 80x80 pixels (total 20mm*20mm)
- Energy Range: 4-200 keV
- Max Rate: <10M photons s^{-1}
- 1mm thick CdTe
- $FWHM_{@60keV}$ = 0.8 keV
- $FWHM_{@159keV}$ = 1.2 keV
- (second range 12-600keV)
- Gig Ethernet to laptop system





Performance @ Room Temperature



A spectrum of the 5.9 keV line of Fe-55 for two different settings of the low energy cutoff as measured in channels (25 ADU and 75 ADU) showing a low energy threshold well below 6 keV. The 5.9 keV line was found to be clearly distinguishable from the noise

Better performance expected with cooling to -10 to -30 C

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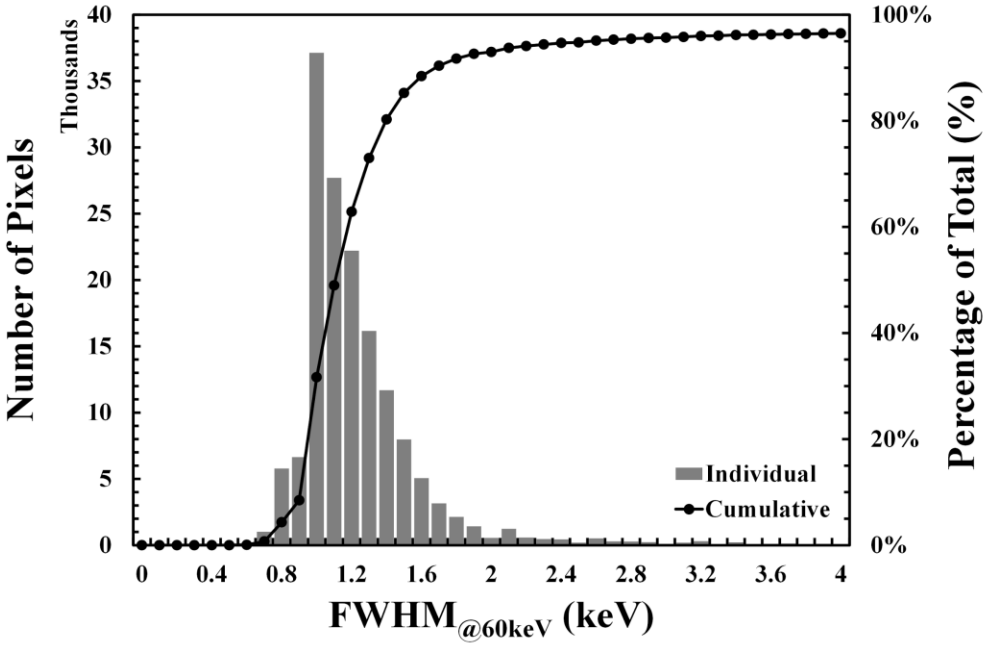
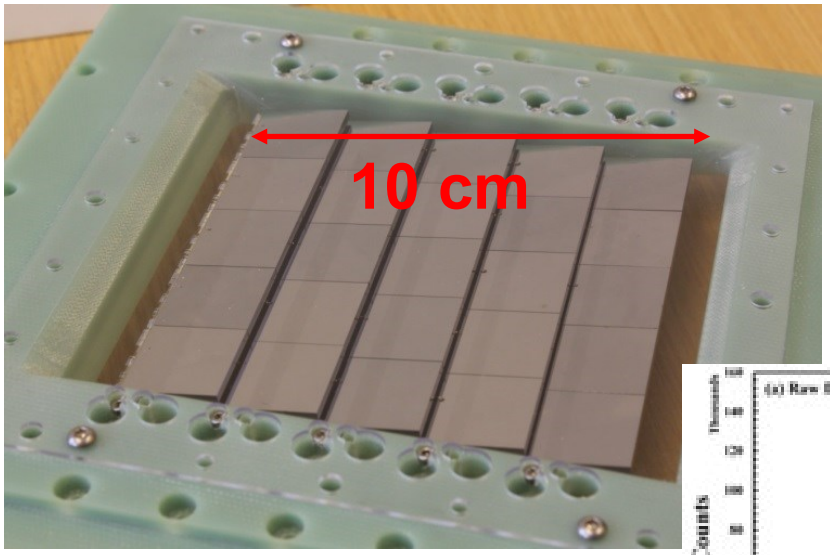
HEXITEC Performance

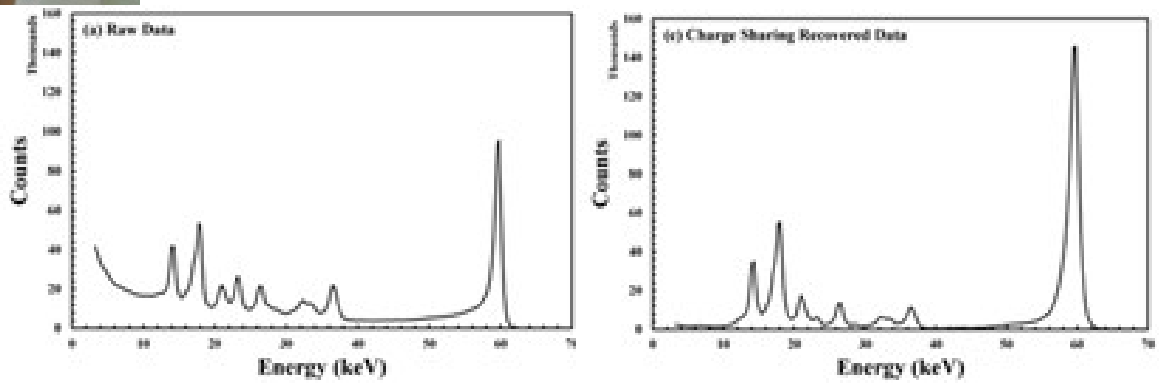
FWHM values (60 keV photopeak) for **160,000 pixels** in the 10 cm x 10 cm CdTe detector system. Only 3% were found to be non-spectroscopic.





-300 V bias, 20°C

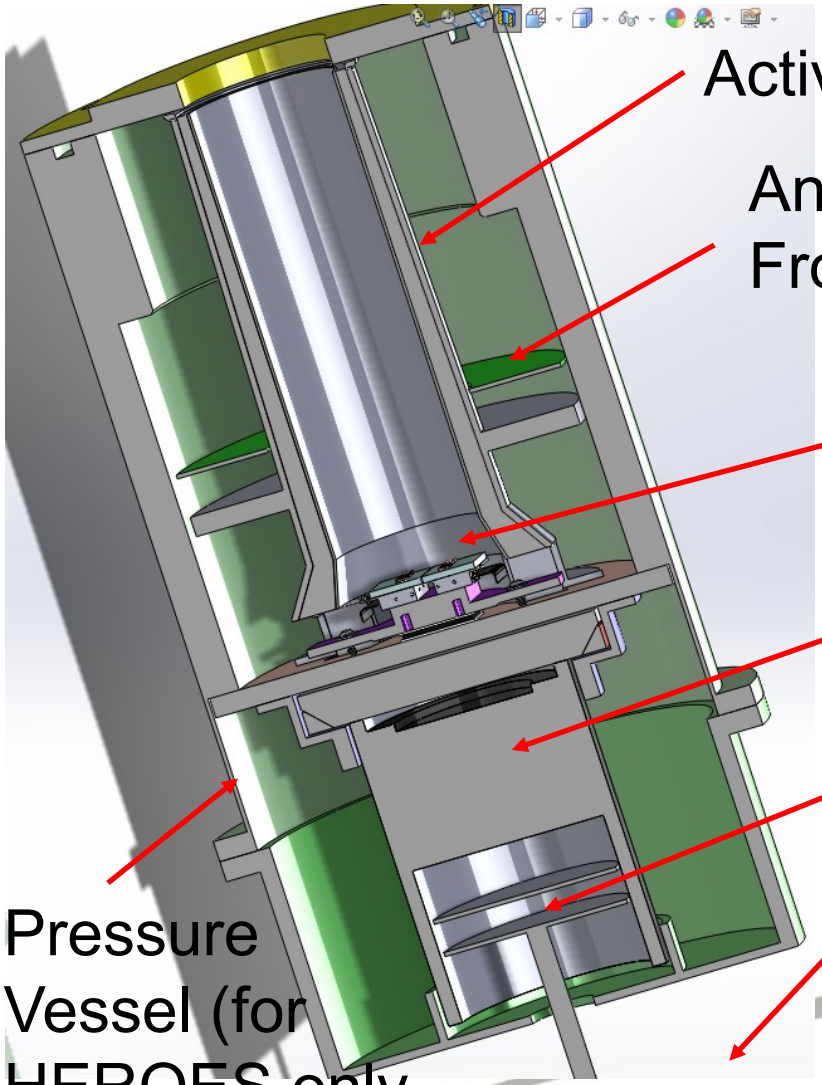
Charge Sharing

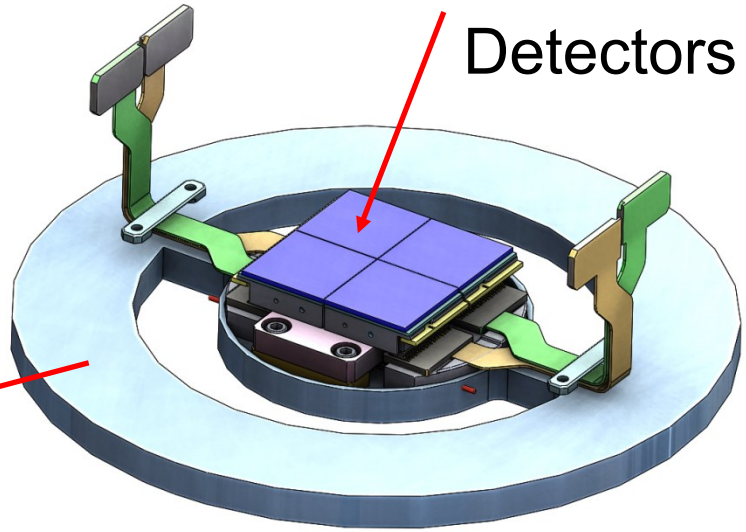


NASA APRA Development

- Funded by NASA APRA (2014)
- Collaboration between NASA GSFC, MSFC, and RAL
- Design is targeting HEROES reflight or SuperHERO and SMEX (FOXSI) or MIDEX (SuperHERO).
- Must use space-flight compliant parts.

Mechanical Design





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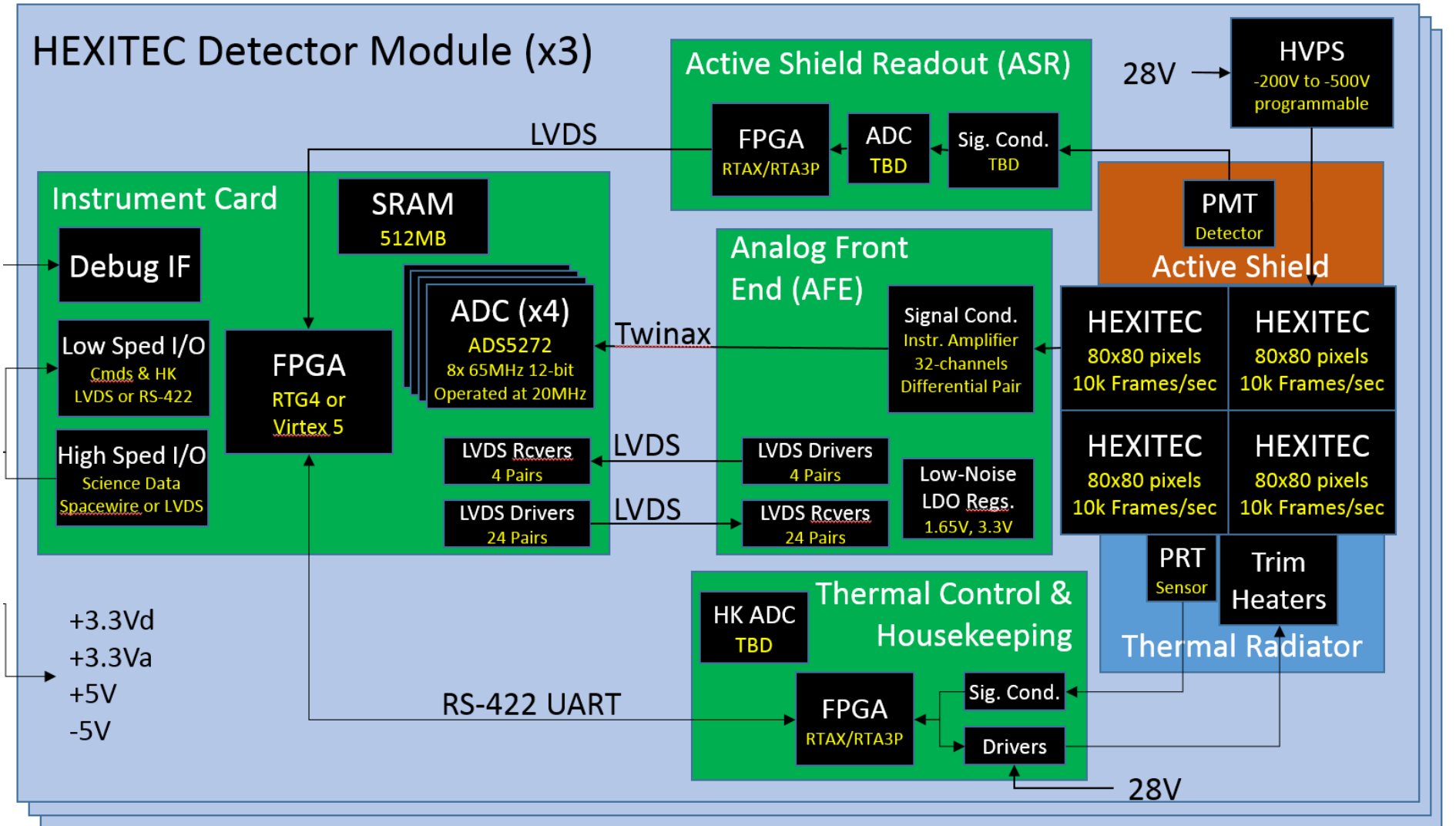
Electrical Design

6400pixels @ (2 x 10) bits/pixel clocked at 10 KHz = ~1.3 Gbps(!!!)

Block diagram of a single detector module

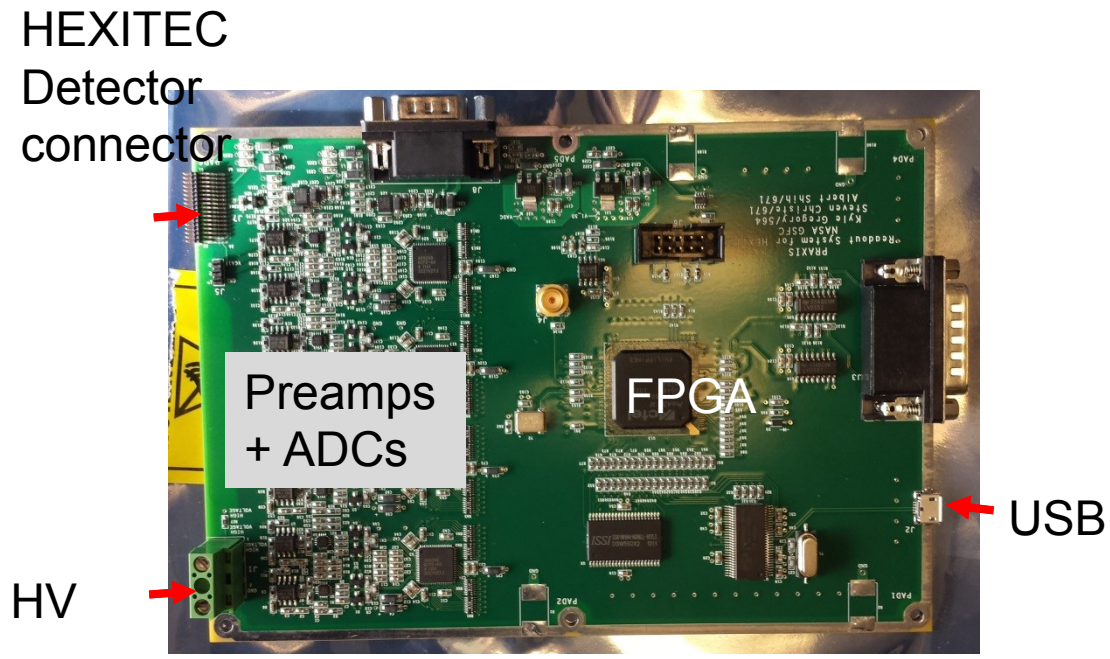


Power Breakdown

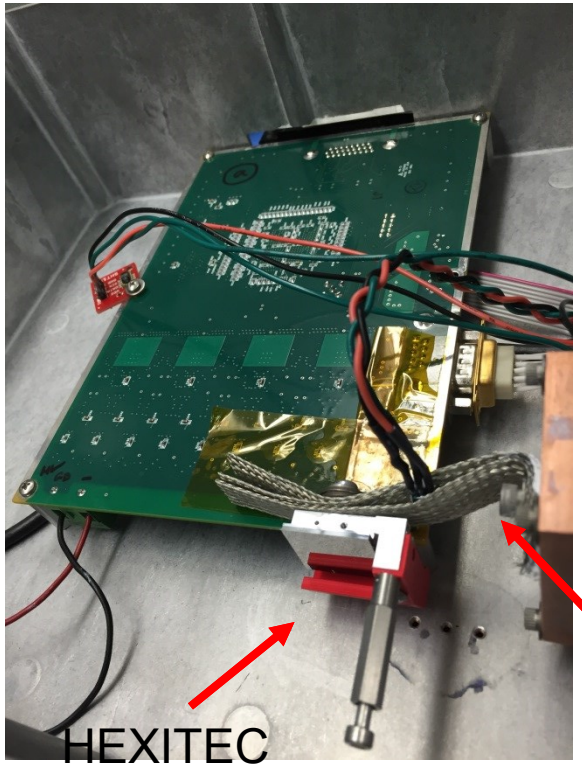
	Power (W)
HEXITEC ASIC (4x)	5.6
Analog Front-End	11
ADCs	4
FPGA	12
Power Supply	10
Total	**~40**

* Power requirements are appropriate with SMEX mission
* Thermal design is on-going.

Laboratory Testing



Test Read-out board (PRAXIS)
A prototype laboratory version of the readout electronics has already been designed and built, and serves the role of the instrument card and two AFE cards in a single board



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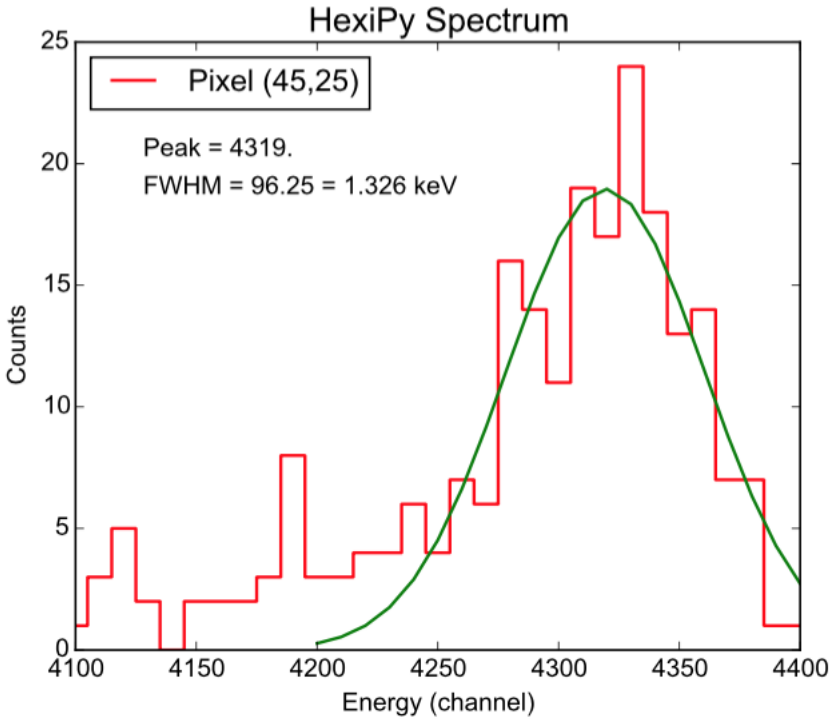
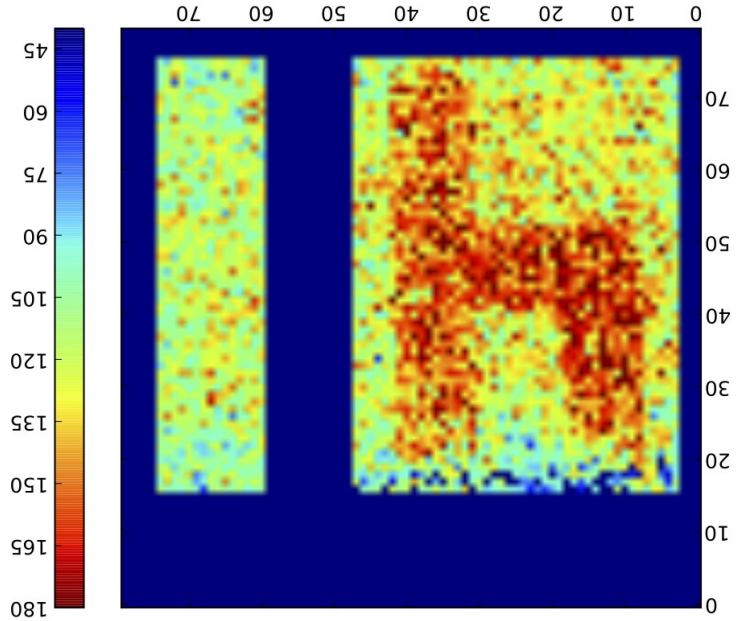
Preliminary Results

- Vibration Test on HEXITEC passed
- Lab version of read-out electronics being tested.
- Resolution measurements consistent with RAL results.





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Summary

- RAL has developed 3-side abuttable CdTe detector, 80x80 pixel arrays with 250 μm-pitch pixels (over 10 years of development).

- These detectors have comparable energy resolution to the NuSTAR detectors and have been successfully operated in the lab-environment in single and arrayed-module configurations.

- GSFC, working with RAL and MSFC is readying these detectors for flight for suborbital and orbital platforms (NASA APRA Grant). Progress on readout electronics and preliminary environmental testing is being made (PRAXIS).

- Refinement of GSFC readout electronics and interface in progress.

- MSFC to calibrate final detector assemblies.


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Acknowledgements

- *Pixellated Cd(Zn)Te high-energy X-ray instrument.* P. Seller et al. Journal of Instrumentation **6** (2011) [IF 1.869]
- *Multiple Module Pixellated CdTe Spectroscopic X-Ray Detector,* M. Wilson et al., IEEE Trans. Nucl. Sci., 2013 doi:10.1109/TNS.2013.2240694

halo
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UNIVERSITY OF SURREY
Royal Surrey County Hospital NHS Foundation Trust
NHS NUCLEAR MEDICINE
EPSRC Pioneering research and skills
Home Office
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OxfordMaterials
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More techniques and applications

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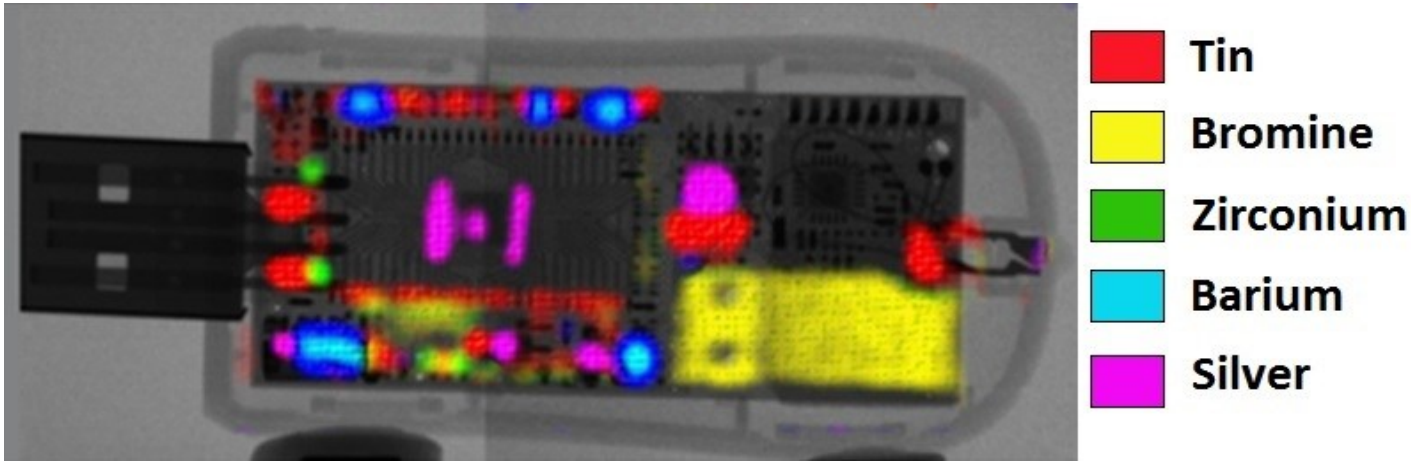
The University of Manchester

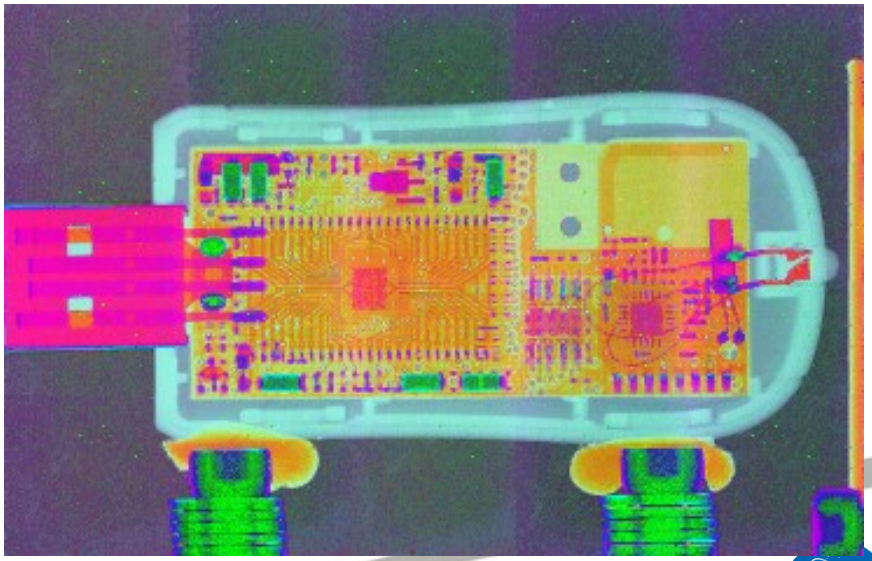
XRF and Transmission

Jacques et al – Analyst (2012)

XRF



Transmission



(Not element specific in this image)

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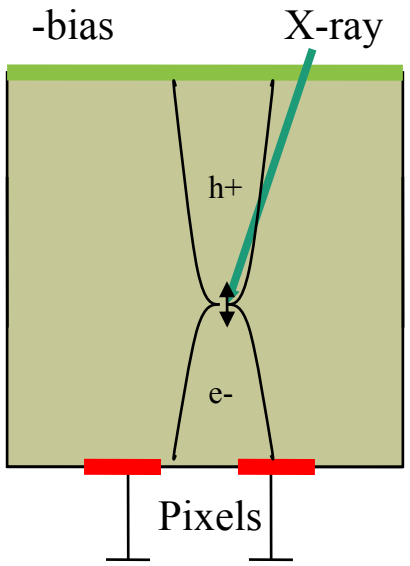
Cadmium Telluride (CdTe)



- Black-looking crystal. Hard and very brittle.
- Large crystals with small pixels more easily available than CZT.
- Band-gap = 1.5 eV, for comparison Si (1.15 eV)
- Radiation conversion factor
  4.4 eV per electron hole pair (w)
  therefore 40 keV photons creates 10^5 carriers
- Fano Factor (F)

$$FWHM[eV] = 2.35 * w * \sqrt{n}\sqrt{F}$$

- Fano-limited energy resolution at 40 keV is 330 eV.