The Energetic X-ray Imaging Survey Telescope EXIST

H. Krawczynski (Wash. Univ. St. Louis) for the EXIST team.

Vertex 2007 (Sept. 28, 2007)

- Introduction: Detectors in X-Ray Astronomy.
- The EXIST Mission:
  - Science.
  - Technical Design.
  - Technical Challenges.
- Summary.

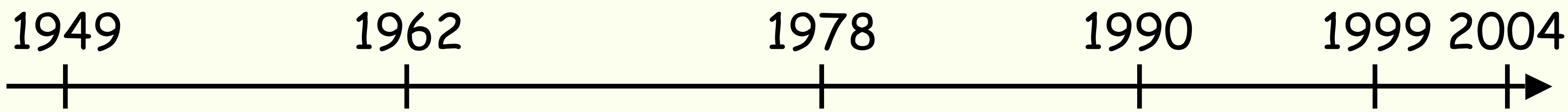
EXIST Concept Study Team

Members (by institution) and Working Group Chairs

Grindlay, Josh (CfA; PI)
Elvis, Martin (CfA)
Fabbiano, Pepi (CfA)
Hong, Jae Sub (CfA)
Kaaret, Phil (CfA)
Loeb, Avi (CfA)
Murray, Steve (CfA)
Wargelin, Brad (CfA)
Harrison, Fiona (Caltech)
Cook, Rick (Caltech)
Fabian, Andy (Cambridge U.)
Barret, Didier (CESR, Fr.)
Bignami, Nanni (CESR, Fr.)
Skinner, Gerry (CESR, Fr.)
Hartmann, Dieter (Clemson U.)
Hailey, Chuck (Columbia U.)
Burger, Arnold (Fisk U.)
Babu, Sachi (GSFC)
Band, David (GSFC)
Barthelmy, Scott (GSFC)
Gehrels, Neil (GSFC)
Mushotzky, Richard (GSFC)
Parsons, Ann (GSFC)
Stahle, Carl (GSFC)
Ticker, Ron (GSFC)
Narita, Tom (Holycross)
Piro, Luigi (Ins. Astro., Italy)
Craig, Bill (LLNL)
Ziock, Klaus (LLNL)
Chakrabarty, Deepto (MIT)
Remillard, Ron (MIT)
Titarchuk, Lev (NRL)
Finger, Mark (NSSTC)
Fishman, Jerry (NSSTC)
Kouveliotou, Chryssa (NSSTC)
Ramsey, Brian (NSSTC)
Fiore, Fabrizio (Rome Obs., Italy)
Blandford, Roger (SLAC/Kavli)
Kahn, Steve (SLAC/Kavli)
Madejski, Greg (SLAC)
Cominsky, Lynn (Sonoma State U.)
Van der Klis, Michiel (U. Am., Neth.)
Boggs, Steve (UC Berkeley)
Jernigan, Garrett (UC Berkeley)
Rothschild, Rick (UC San Diego)
Bildsten, Lars (UC Santa Barbara)
Smith, David (UC Santa Cruz)
Thorsett, Steve (UC Santa Cruz)
Woosley, Stan (UC Santa Cruz)
Ward, Martin (U. Leicester, UK)
Krawczynski, Henric (WU, St. Louis)
Coppi, Paolo (Yale U.)
Conte, Dom (Spectrum Astro)
Purcell, Bill (Ball Aerospace)

Detectors in X-ray Astronomy

Soft X-ray Astronomy (0.1-10 keV)



Detectors in X-ray Astronomy

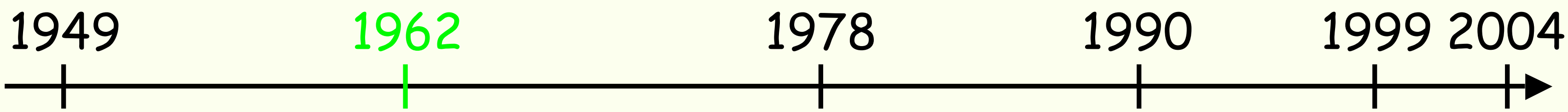
Soft X-ray Astronomy (0.1-10 keV)

1949 — 1962 — 1978 — 1990 — 1999 — 2004

Friedman
et al.
(1949)

Detectors in X-ray Astronomy

Soft X-ray Astronomy (0.1-10 keV)



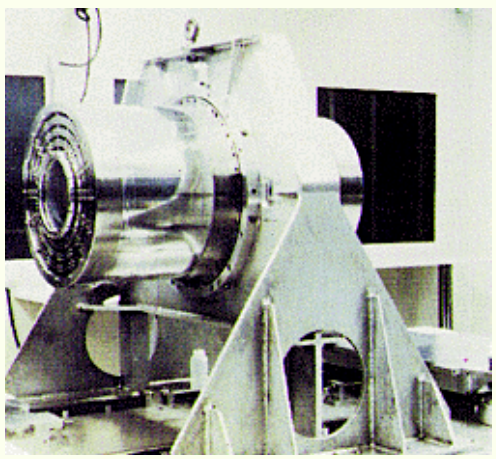
Giacconi et al.

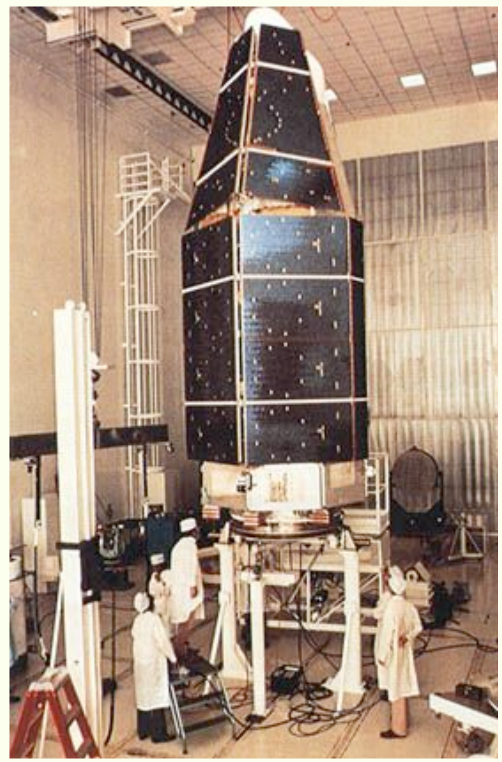
Detectors in X-ray Astronomy

Soft X-ray Astronomy (0.1-10 keV)

1949 — 1962 — 1978 — 1990 — 1999 — 2004

Einstein Observatory:





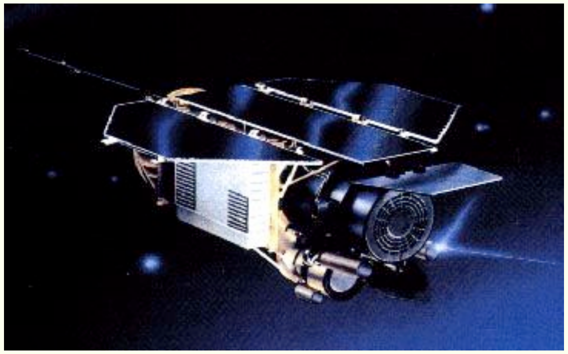
Giacconi et al. (1979)

Detectors in X-ray Astronomy

Soft X-ray Astronomy (0.1-10 keV)

1949 1962 1978 1990 1999 2004

ROSAT:



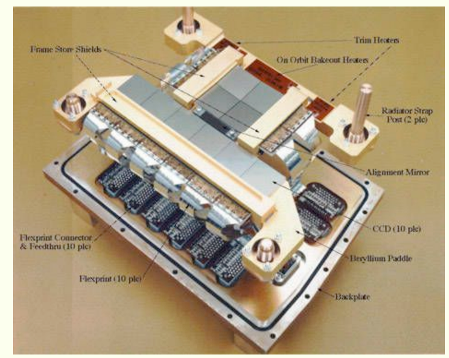
Trümper et al. (1983)

Detectors in X-ray Astronomy

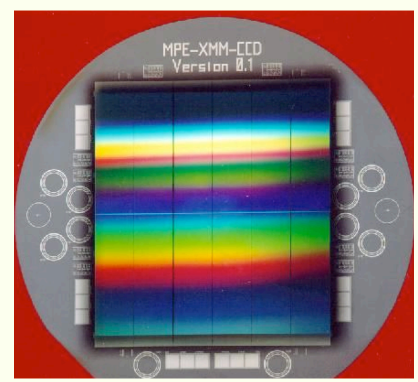
Soft X-ray Astronomy (0.1-10 keV)

1949 — 1962 — 1978 — 1990 — 1999 — 2004

Chandra
ACIS
Garmire et al.
(2003)

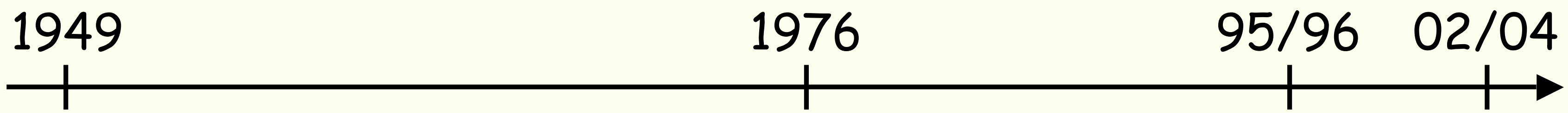


XMM-Newton
PN-Camera
Strüder et al.
(2001)



Hard X-ray Astronomy

Hard X-ray Astronomy (20 keV-200 keV)

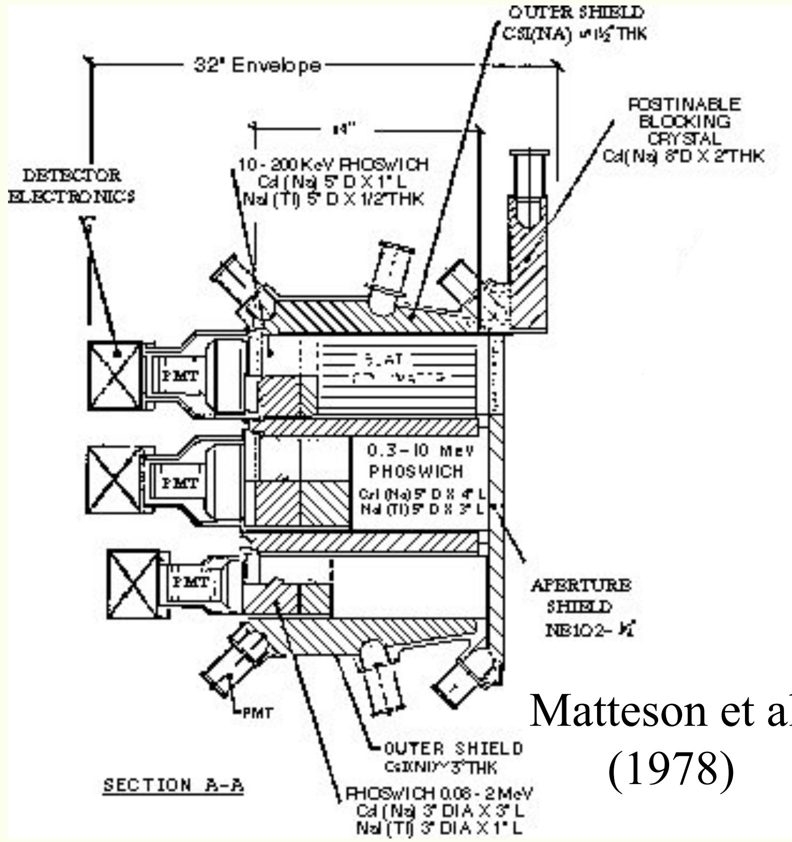


Hard X-ray Astronomy

Hard X-ray Astronomy (20 keV-200 keV)

1949 — 1976 — 95/96 — 02/04

UCSD/MIT
Experiment
on HEAO 1:



Matteson et al.
(1978)

Hard X-ray Astronomy

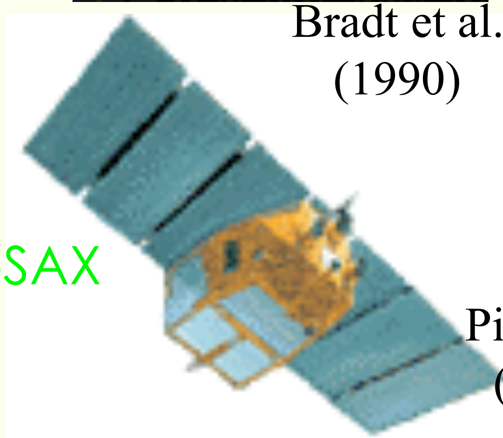
Hard X-ray Astronomy (20 keV-200 keV)

1949 — 1976 — 95/96 — 02/04

RXTE

Bradt et al. (1990)

BeppoSAX



Piro et al. (1995)

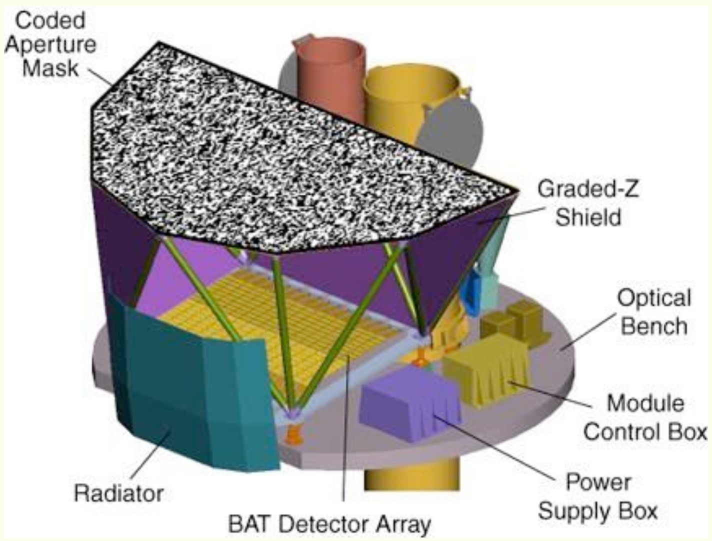
Hard X-ray Astronomy

Hard X-ray Astronomy (20 keV-200 keV)

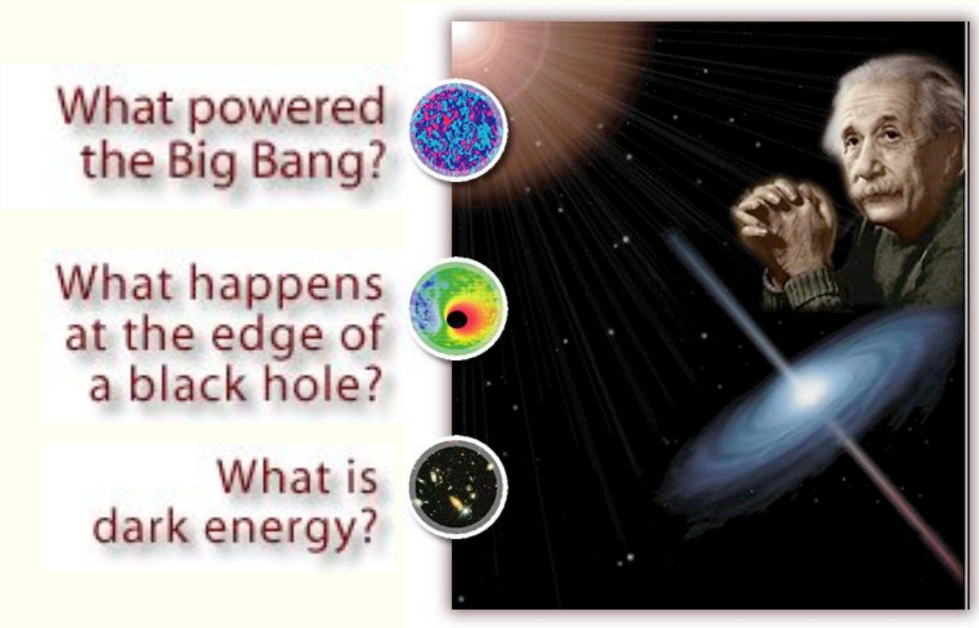
1949 — 1976 — 95/96 — 02/04

IBIS on Integral:
CdTe 2,600 cm^2
Ubertini et al. (2003)

BAT on SWIFT:
CZT 5,200 cm^2
Gehrels et al. (2000)



NASA's Beyond Einstein Program



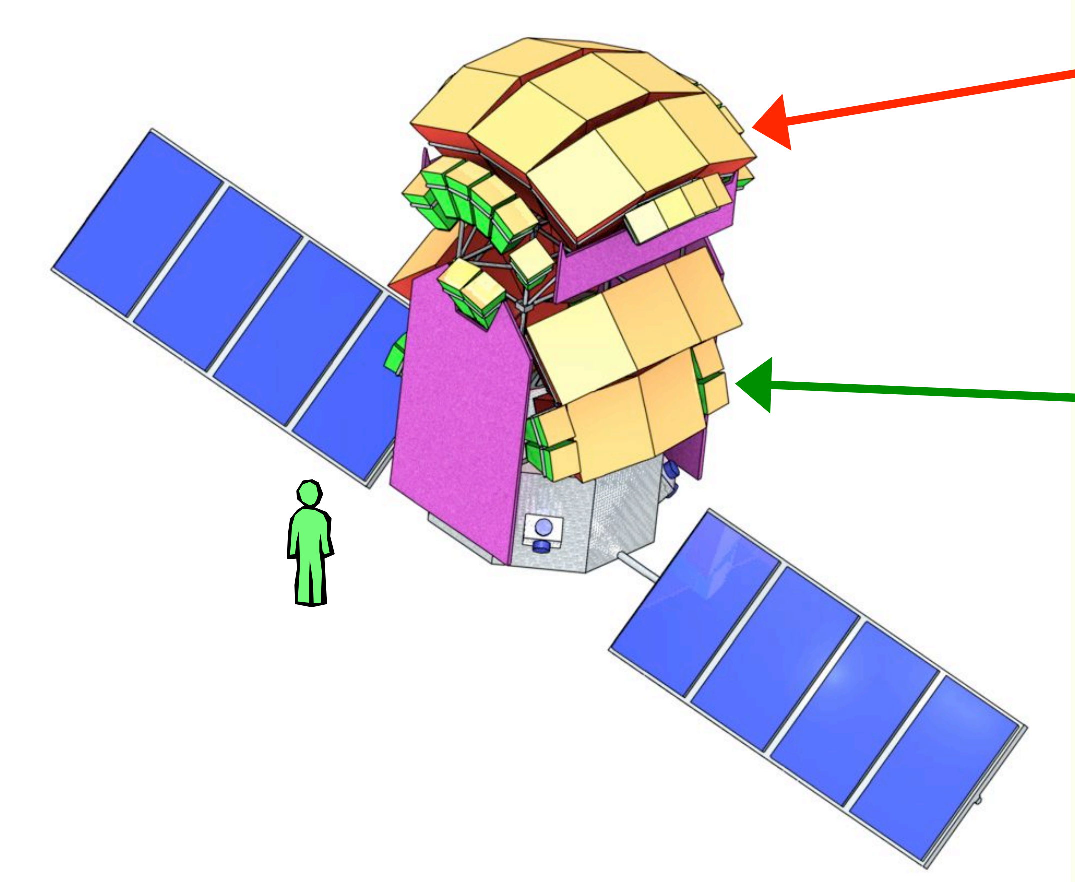
Soft X-rays:

Constellation-X

Hard X-rays:

Black Hole Finder Probe

The EXIST Mission



Energetic X-ray Imaging Survey Telescope

High-Energy Telescopes
HET (10-600 keV)

(19 Coded aperture telescopes, 154˚x65˚ FoV)

Low-Energy Telescopes
LET (3-30 keV)

(32 Coded aperture telescopes, 160˚x64˚ FoV)

EXIST Science: Primary Objectives: Black Hole Science

- Survey <all> Supermassive Black Holes in the z=1…2 range in galaxies to constrain their properties, their role in galaxy evolution, the origin of the Cosmic X-ray background, and the accretion luminosity of the Universe.

- GRBs from $z \geq 7$-10: birth of 1st Black Holes & cosmological probes.

- Supermassive Black Holes masses & spins from timing & spectra.

- Monitor and measure stellar and intermediate Black Holes in the Galaxy and Local Group to Constrain Black Hole Formation and Evolution.

Taking a Black Hole Census

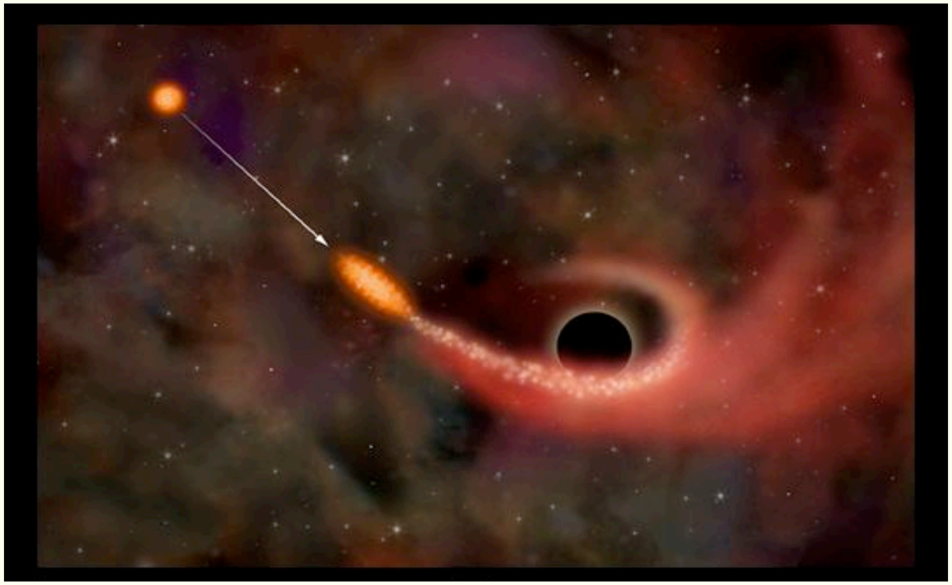
EXIST measures Cen-A <u>every orbit</u>:
characteristic time variability (QPOs) constrain BH mass and spin.

ESO

Dormant SMBHs revealed by Tidal disruption of stars

Tidal disruption of stars spiraling into Dormant SMBHs with mass ~10^7 $M_\odot$:

If 1% of L_{acc} in HX band, ~10^{-5} events/year/Mpc^3 allow **EXIST** to see ~10-30 flares/yr out to ~200Mpc (Grindlay 2004).

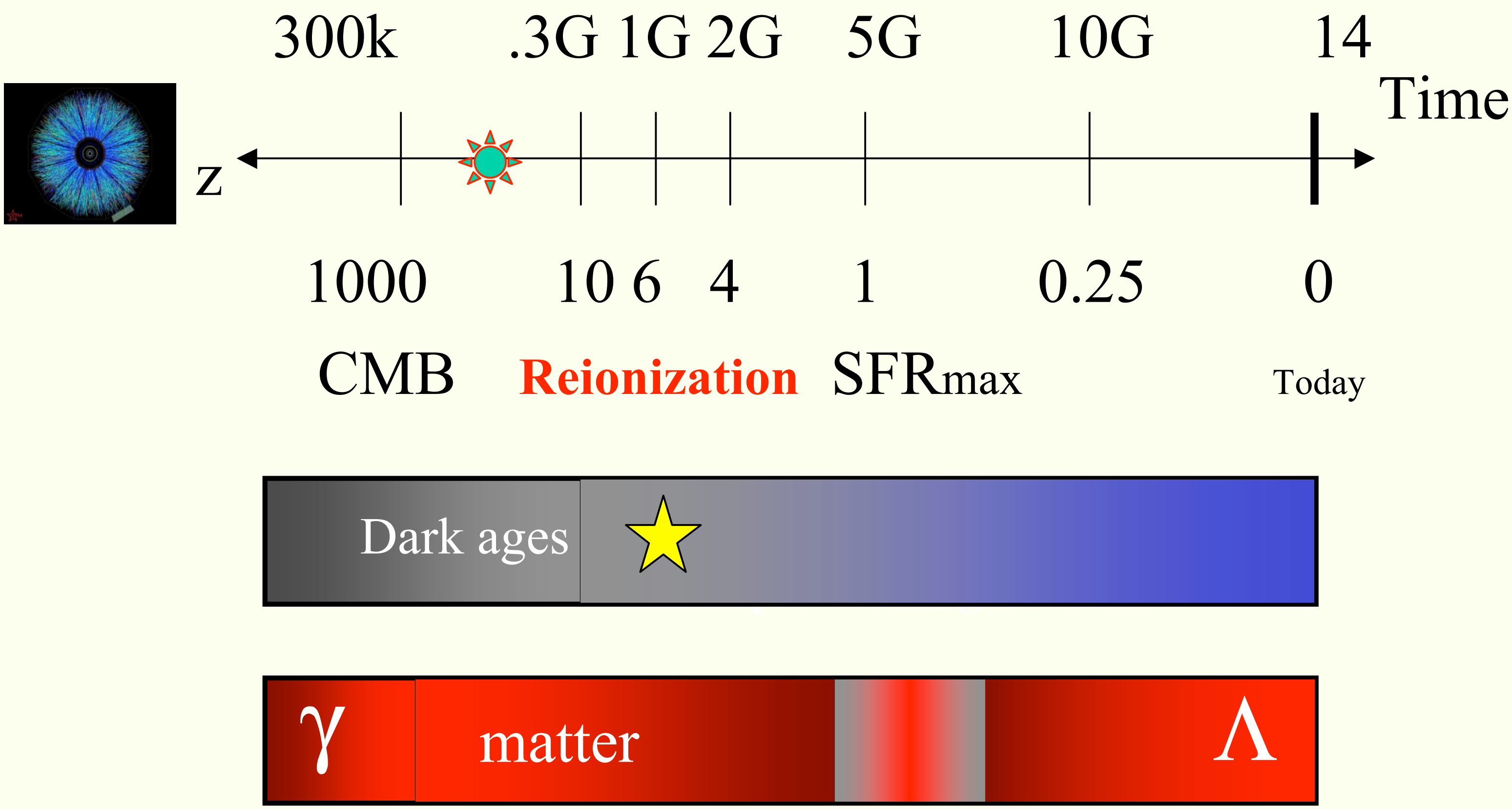


Artists conception of tidal disruption of star in RXJ1242-1119 detected with ROSAT (1991) and confirmed with Chandra (Komossa et al 2004).

Possible soft (~5keV) prompt (~1d) burst detectable out to ~100 Mpc directly with EXIST LET.

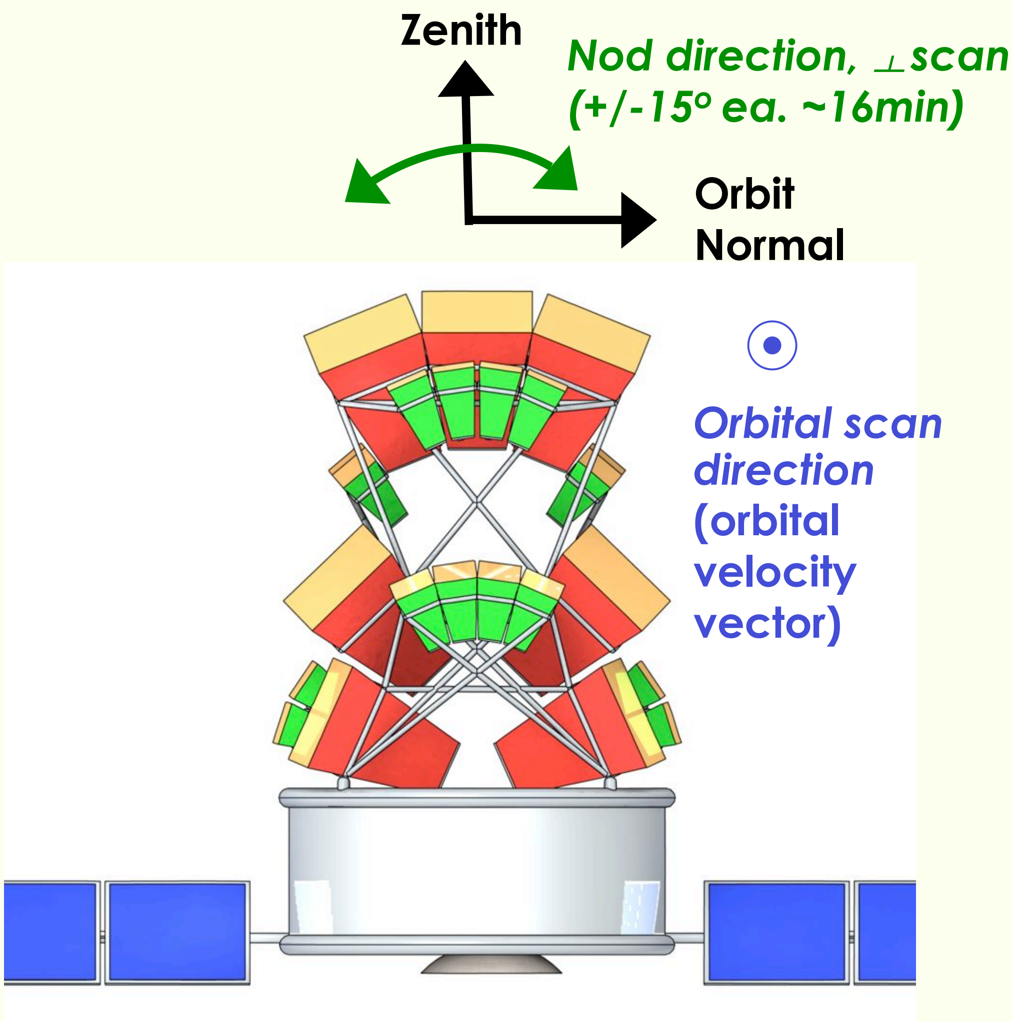
Gamma-Ray Bursts

Observations of 1000's of GRB with high sensitivity to explore high z universe.



Sketch from Hartmann 2007

EXIST Mission Design Parameters

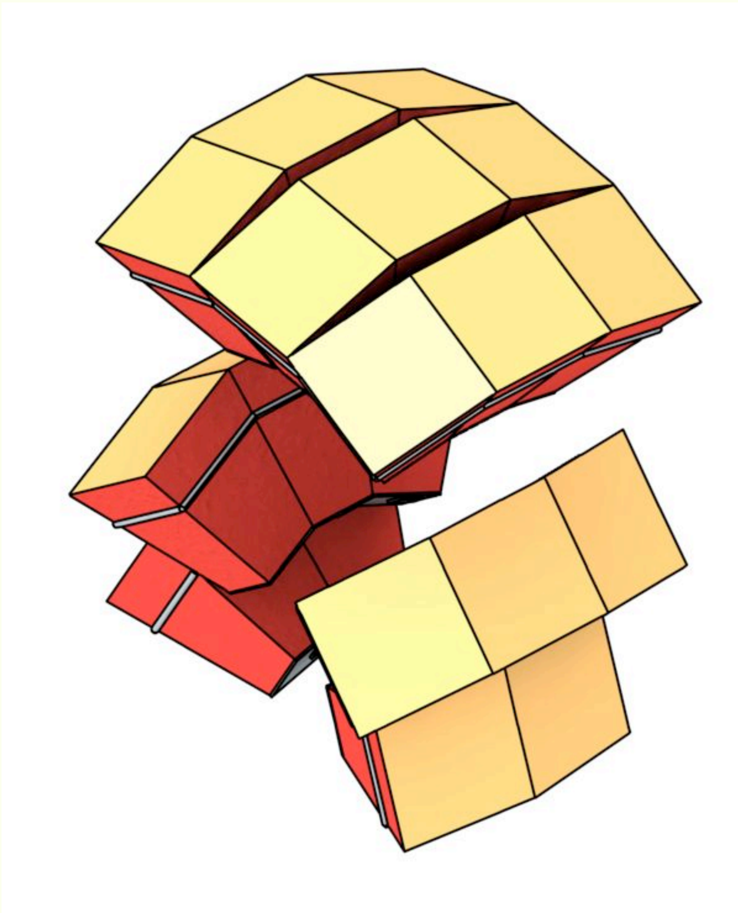


- Zenith pointer - scanning & nodding for ~full-sky coverage each orbit (95min)
- 19 coded aperture HE telescopes ($6m^2$ CZT)
- 32 coded aperture LE telescopes ($1.3m^2$ Si)
- Mass, power, telemetry:
  9500kg, 3kW, 3Mbps
- Mission lifetime: 5 years

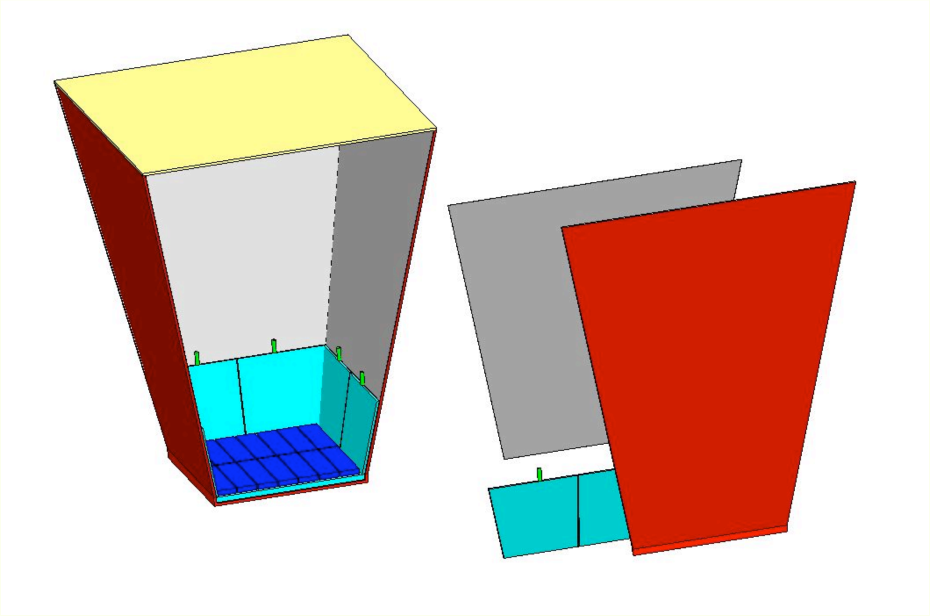
Parameters for *EXIST* configuration

Parameters	EXIST HET	EXIST LET
Energy	10 – 600 keV	4 - 30 keV
Modules	**7+5+7=19**	**6+10+10+6=32**
Mask (W)	5mm thick, 2.5 mm pix	0.05mm thick, 0.2mm pix.
Detector	5mm thick, 1.25mm pix CZT	1mm thick, 160μm strip Si
Det. Area (Mod./Tot.)	56x56 cm^2 / **5.96 m^2**	20x20cm^2 / **1.28 m^2**
F.C. FoV (Mod./Tot.)	21° x21° / **65° x 154°**	16° x16° / **(32°–64°) x 160°**
Ang. Res./5σ Loc.	5.7′/ 1.2′	0.95′/ 11″
Mask-Det. Sep.	1.5 m	0.72 m
Temporal Res.	< 1 ms	< 1 ms
Shields	CsI/passive side, CsI rear shields	Passive
Sensitivity (5σ)	0.05mCrab (<150 keV, ~1yr) 0.5mCrab (>150 keV, ~1yr)	0.05mCrab

The High-Energy Telescopes

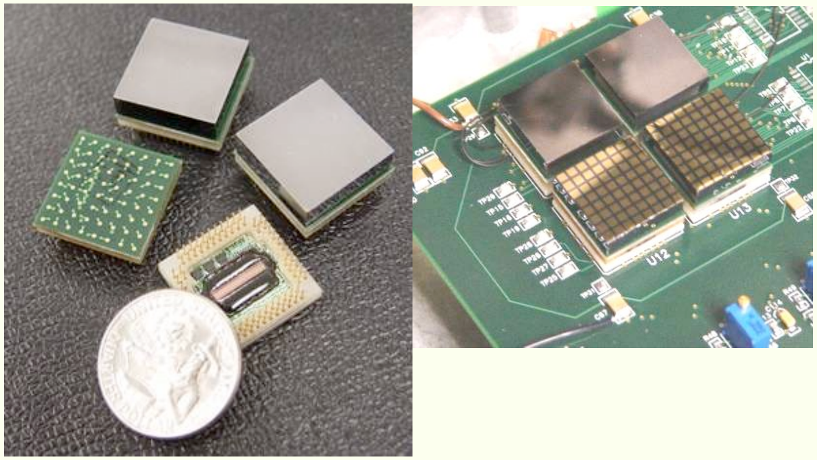


19 Sub-Telescopes



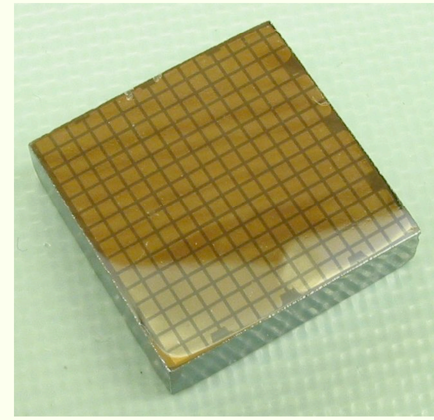
One Sub-Telescope

EXIST Technology: CZT Detectors

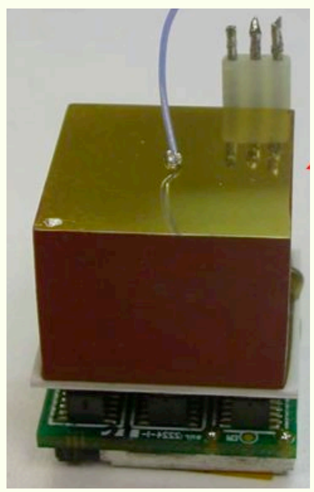


Mounted 64 pixel detectors (0.5x2x2 cm³).

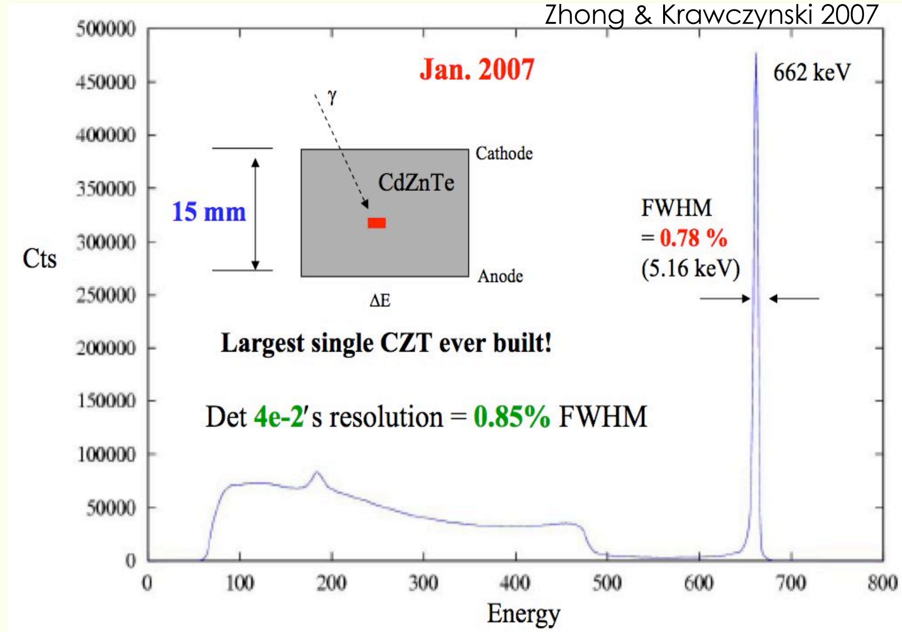
225 pixel detector (0.5x2x2 cm³).



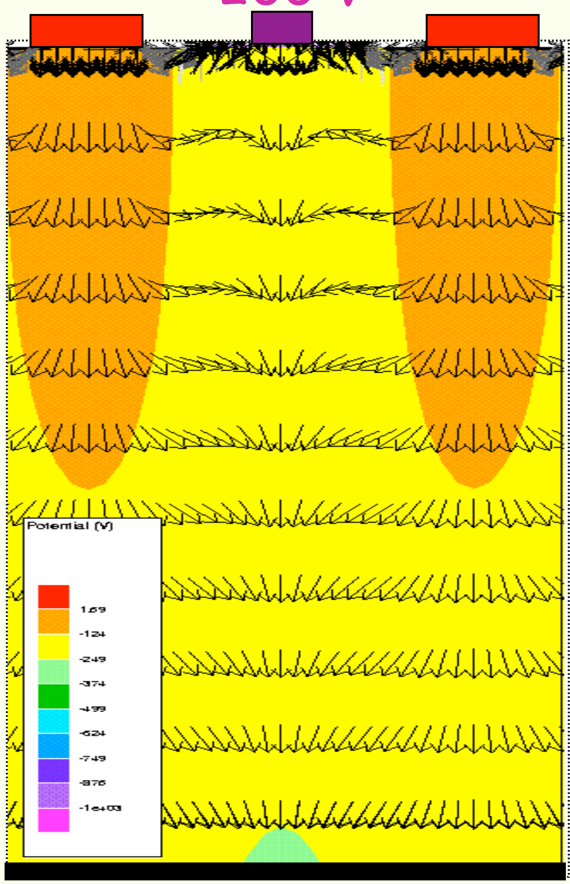
121 pixel detector (1.5x2x2 cm³).



Zhong & Krawczynski 2007

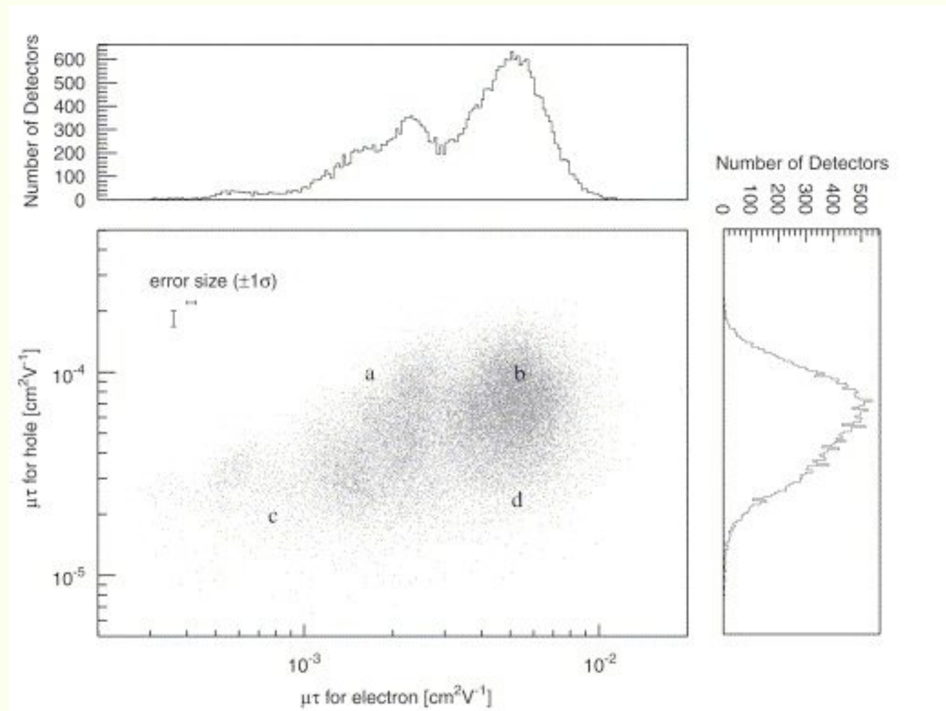


CZT Detectors: Peculiarities



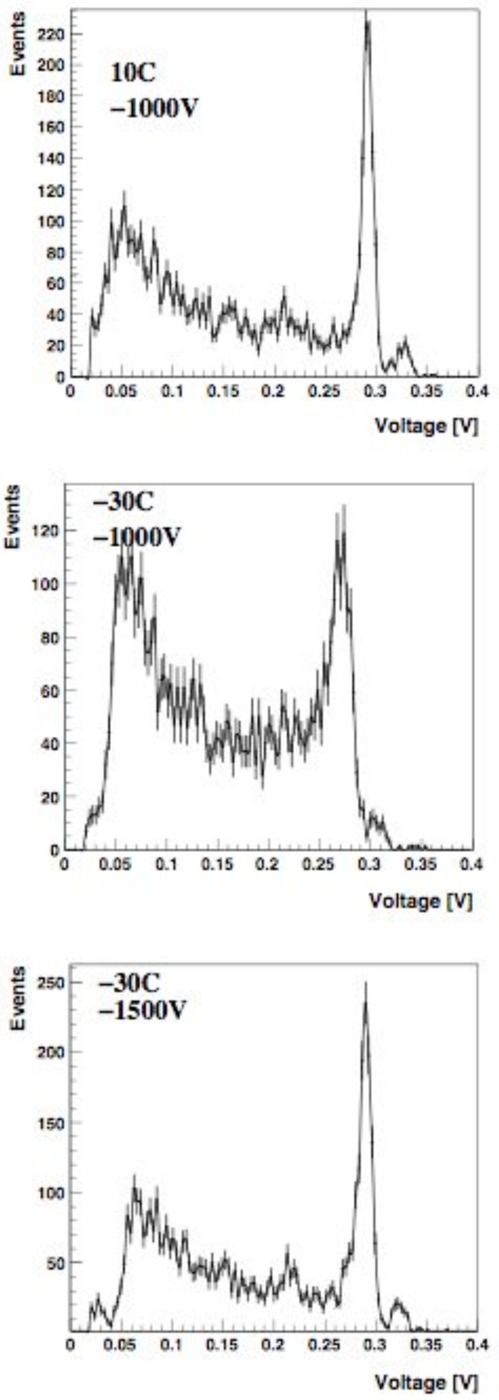
$$\mu_e \tau_e \sim 5 \times 10^{-3} \text{ cm}^2 \text{ V}^{-1}$$

$$\mu_h \tau_h \sim 5 \times 10^{-5} \text{ cm}^2 \text{ V}^{-1}$$



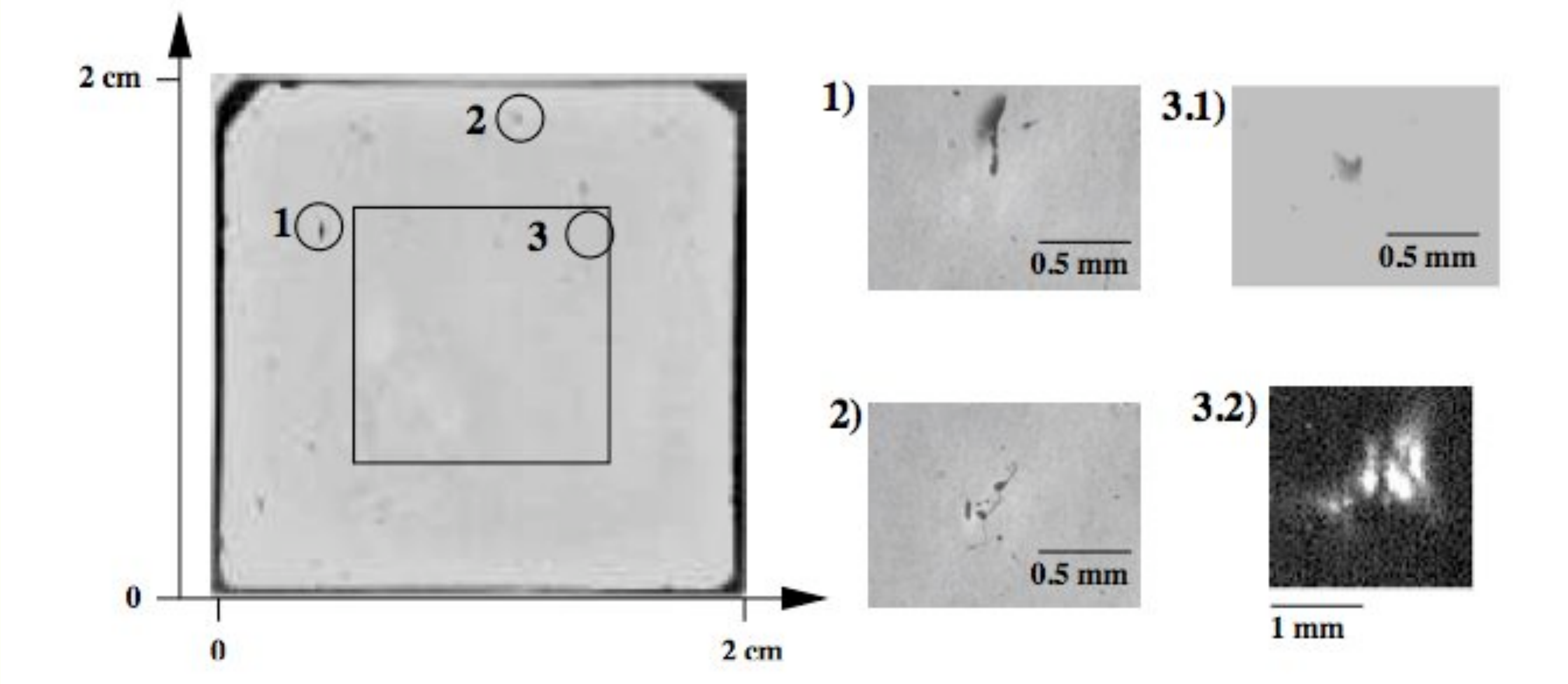
Soto et al. 2005

CZT Detectors: Performance(T)



Jung et al. 2007

CZT Detectors: Quality Control

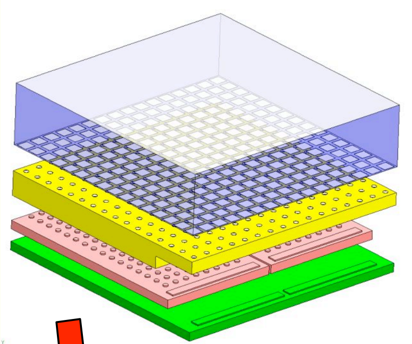


Jung et al. 2007

EXIST Technology: Detector Readout and On-Board Processing

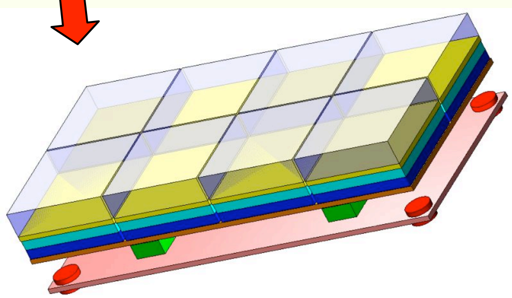
- Large number of detectors:
  - 14,896 detectors (0.5x2x2 cm^3), 3.8 million readout channels.
- ASIC readout:
  - Sparse readout including next-neighbors.
  - Low power: <100μW per channel ASICs.
  - 29,792 ASICs: high yield and and rapid testing required.
  - Several megapixel event-driven CZT array controller.
- On-board processing algorithms
  - Smart algorithms for onboard first-pass processing needed for flare recognition.
  - Processing challenge: backprojection with large number of mask and detector pixels.

EXIST Detector Packaging



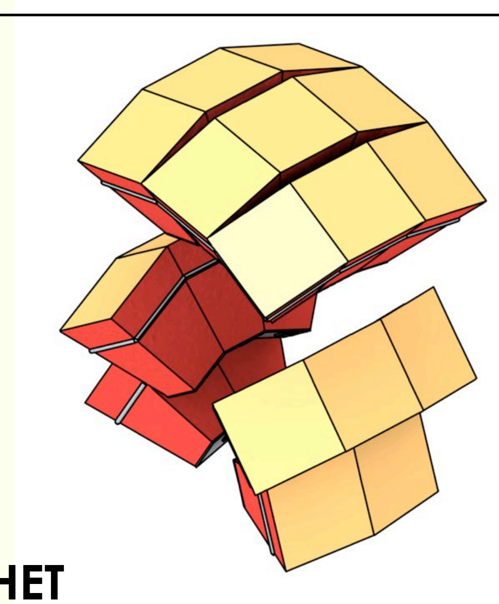
Detector Crystal Unit (DCU)

Crystal **(2x2 cm²)**
(*with Interposer Board?*)
+ 2 x 128 channel ASIC
(*with micro-via tech?*)



Detector Crystal Array (DCA)

2x4 DCUs **(4x8 cm²)**
+ FPGA Board

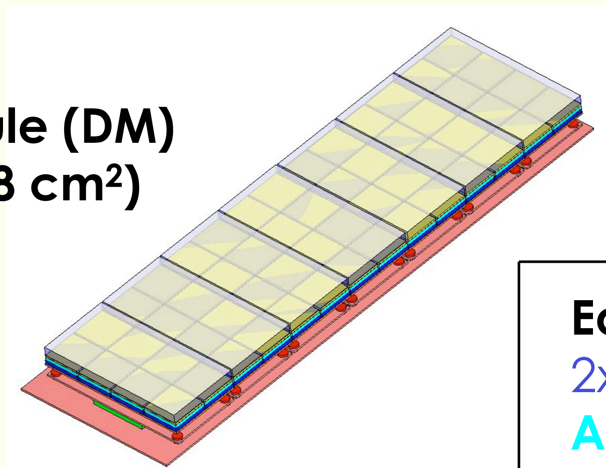


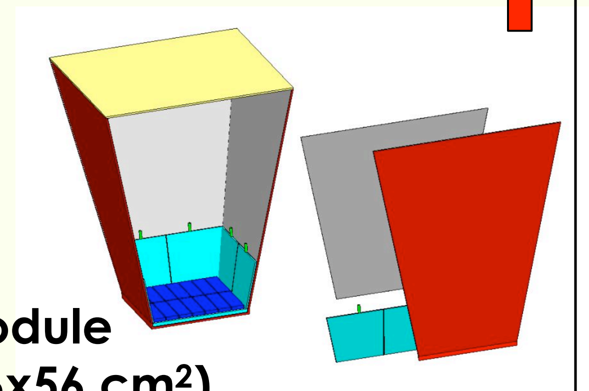
HET

19 Tels **(6.0 m²)**

Detector Module (DM)

1x7 DCAs **(8x28 cm²)**
+ FPGA Board

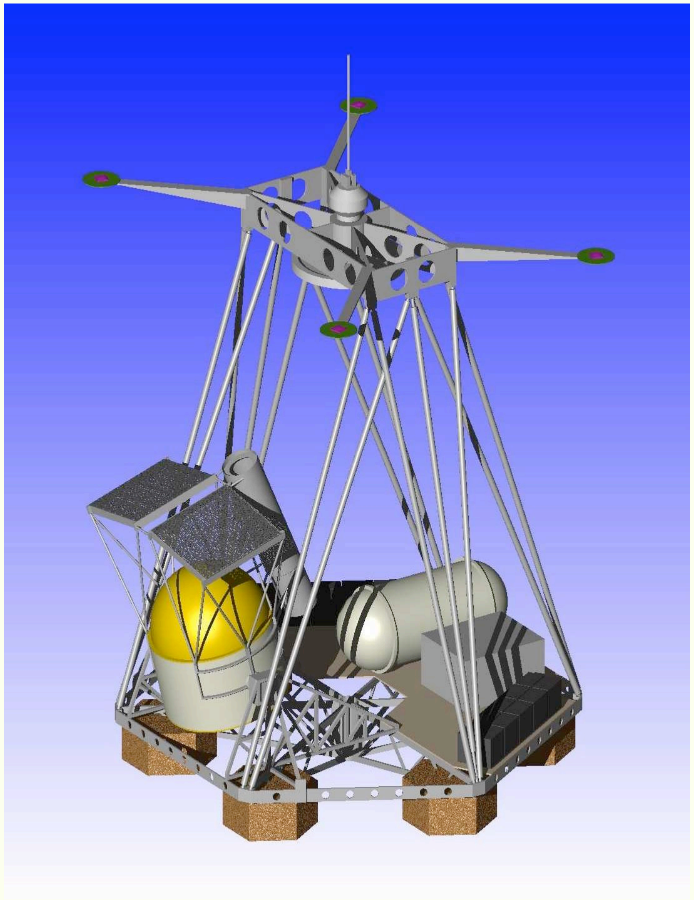




Each Tel Module

2x7 DMs **(56x56 cm²)**
Active & Passive shields

ProtoEXIST: Balloon borne Hard X-ray Survey Telescope

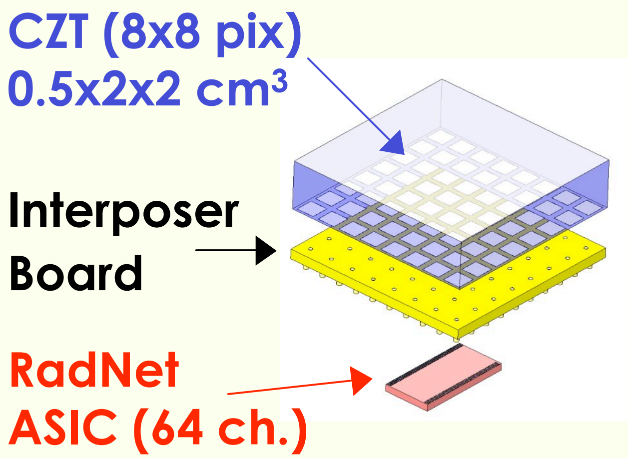


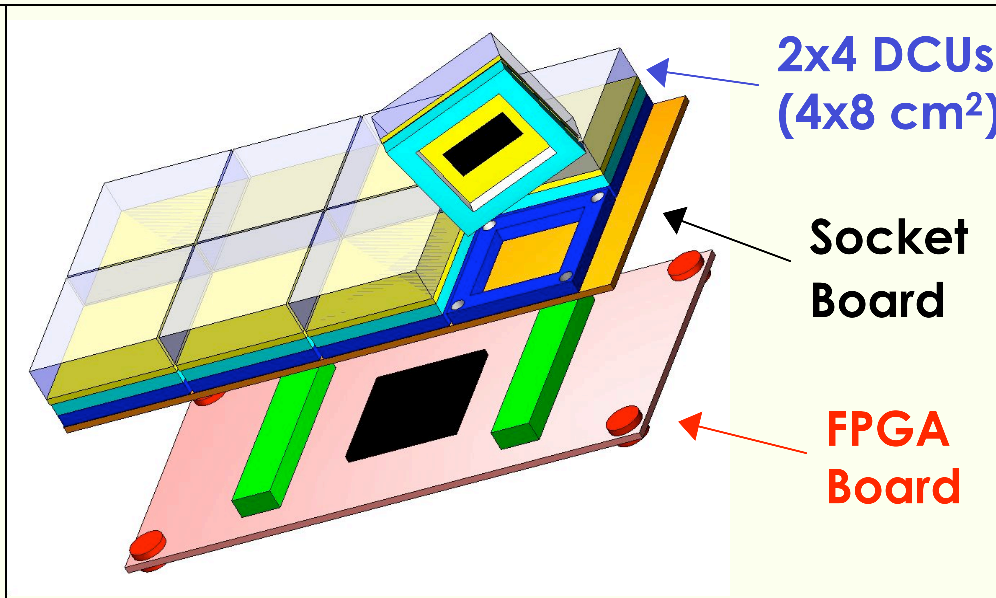
- Pathfinder for Energetic X-ray Imaging Survey Telescope (EXIST) : Black Hole Finder Probe under NASA Beyond Einstein Program)

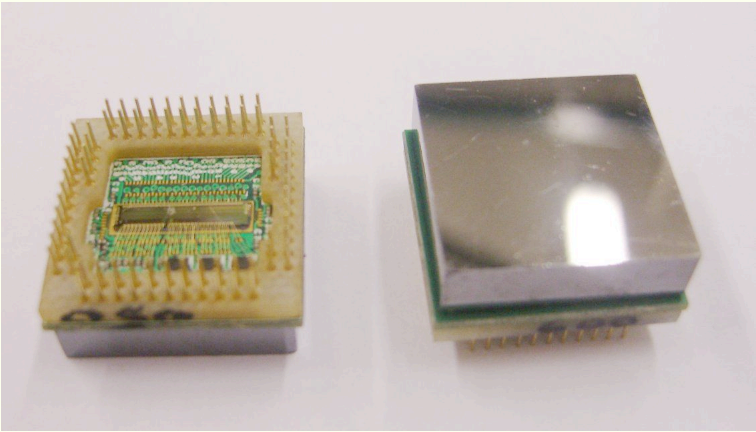
- Building a large area CZT detector with small pixels, covering 10 – 600 keV

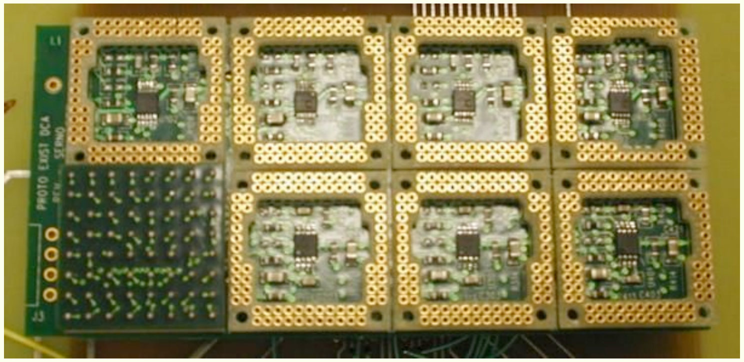
ProtoEXIST1 ~ 1000 cm^2 (2.5 mm pixel)
ProtoEXIST2 ~ > 256 cm^2 (1.25 mm pixel)
EXIST ~ 6 – 8 m^2 (1.25 mm pixel)

ProtoEXIST Detector Packaging





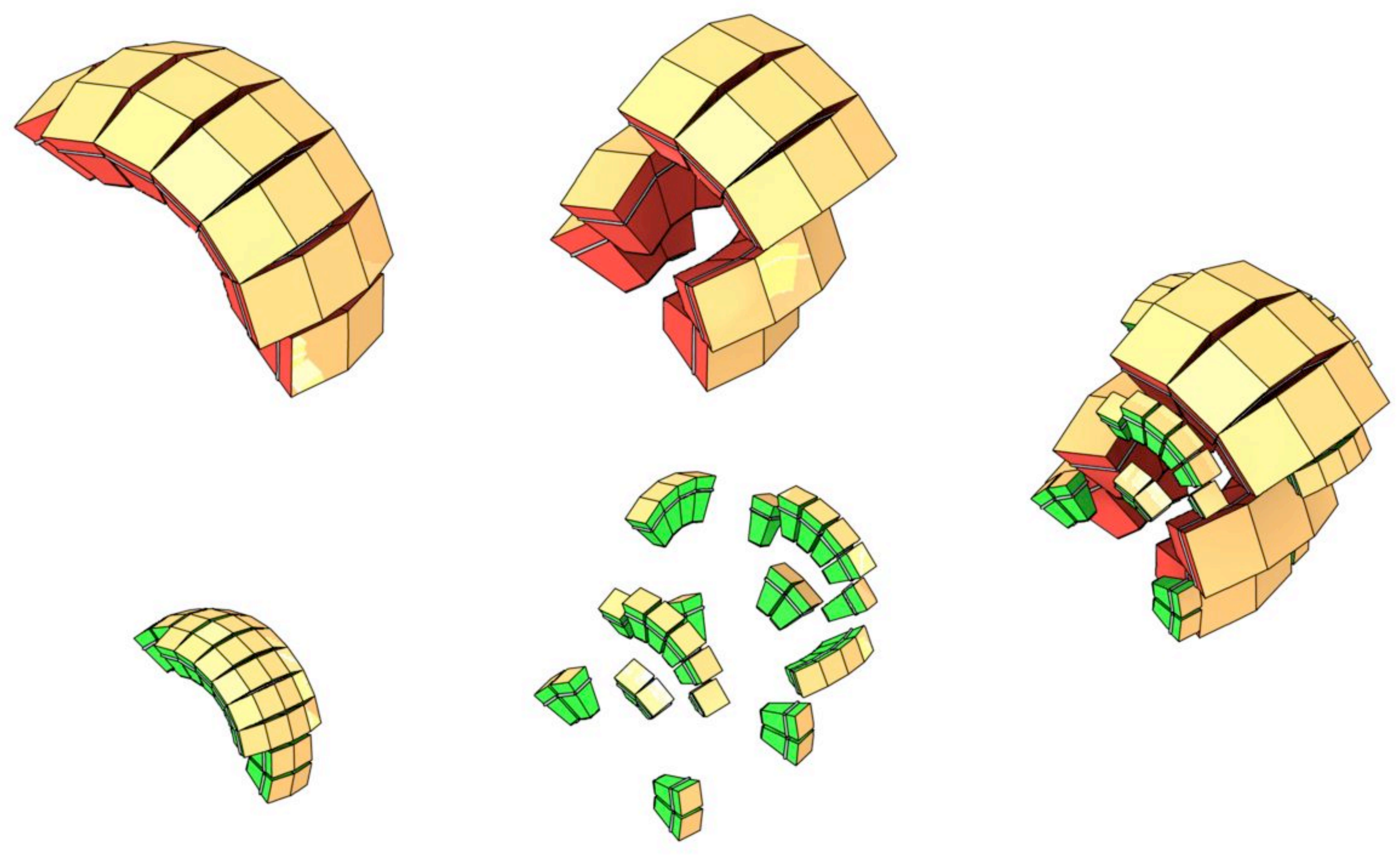


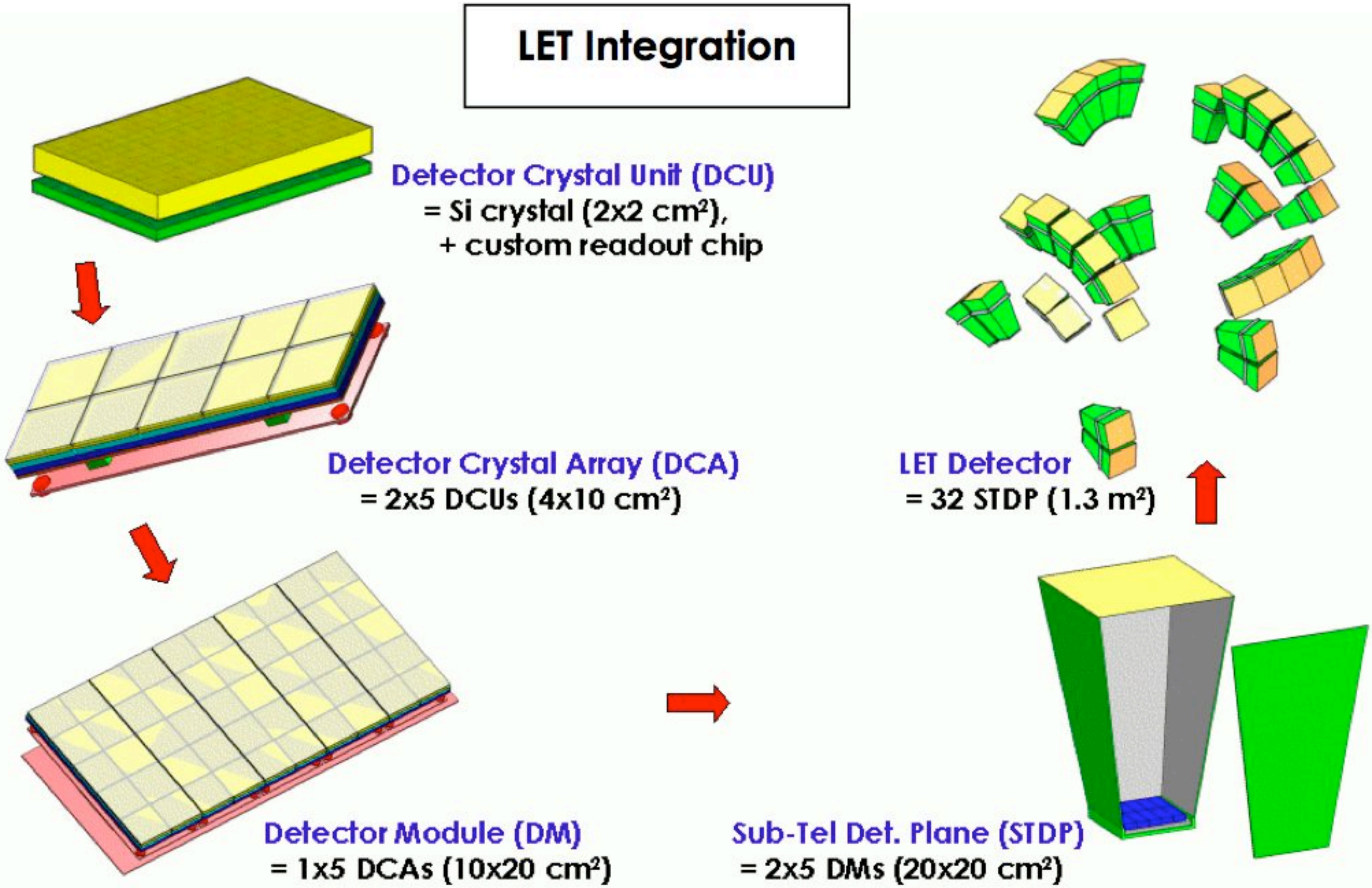


Detector Crystal Unit
(DCU: 4 cm^2)

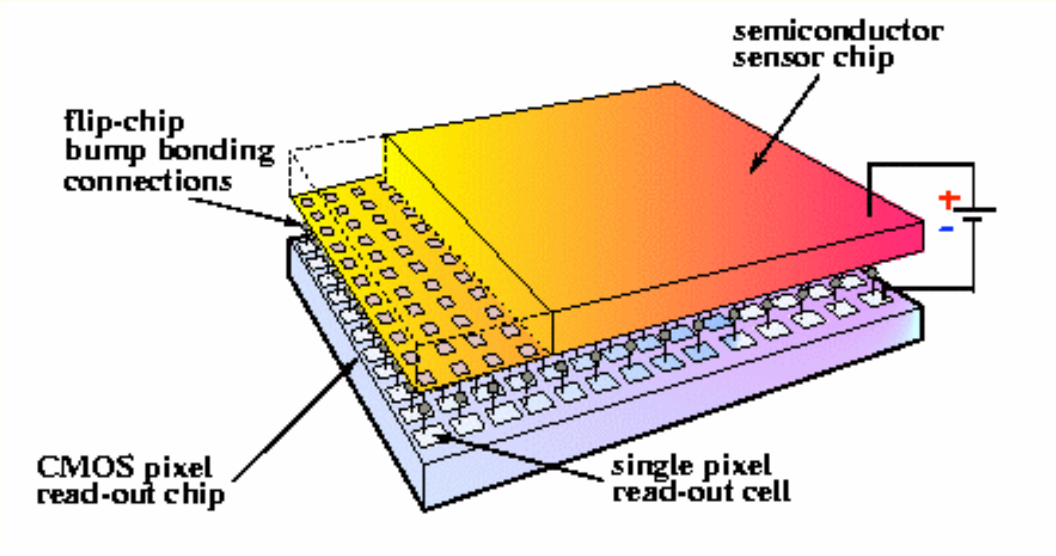
Detector Crystal Array
(DCA: 32 cm^2)

The LET and HET Telescopes




LET Integration
Detector Crystal Unit (DCU)
= Si crystal (2x2 cm²),
+ custom readout chip
Detector Crystal Array (DCA)
= 2x5 DCUs (4x10 cm²)
Detector Module (DM)
= 1x5 DCAs (10x20 cm²)
Sub-Tel Det. Plane (STDP)
= 2x5 DMs (20x20 cm²)
LET Detector
= 32 STDP (1.3 m²)

Hybrid Detectors



- Every pixel has own amplifier (low noise).

- Low power with high time resolution.

- Excellent high energy response via use of thick sensors.

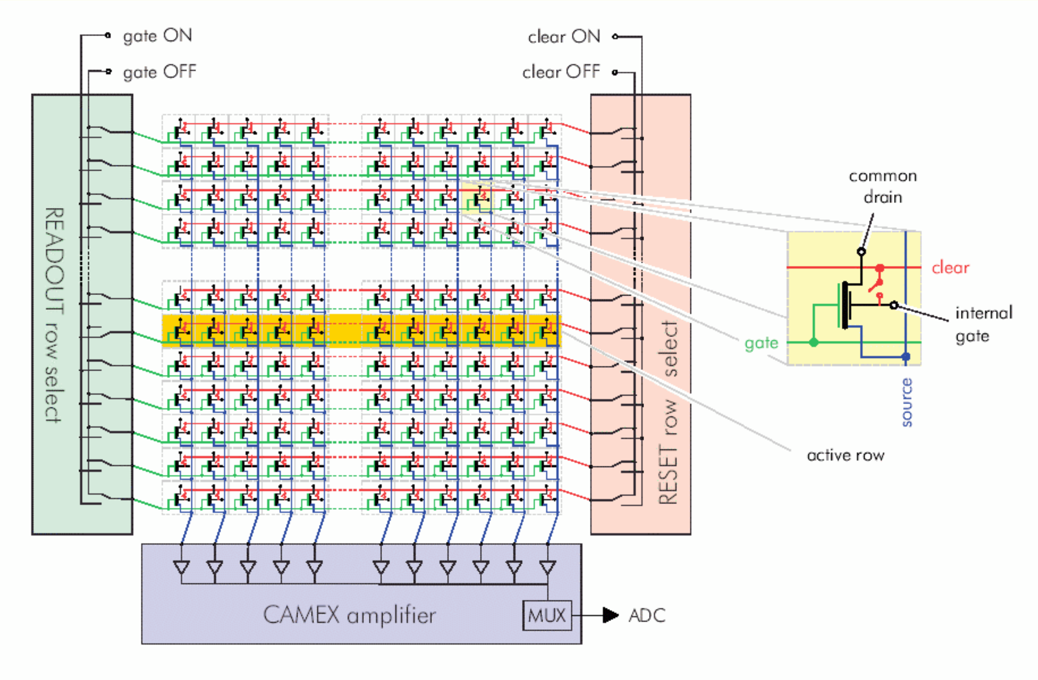
• Hybrid detectors use CMOS readout chips similar to those in IR cameras, but modified for detection of single X-ray photons.

• Transistor level pixel design and simulation has been completed with U. Iowa funding.

• Design meets power and noise goals. Advanced sparse readout scheme enables event time tagging to 100 ms.

• Prototype silicon sensor fabricated (1 mm thick).

DEPFET Detectors



- Every pixel has own FET.

- Low power at low readout rate.

- Excellent energy resolution and low-energy cut-off.

• DEPFET detectors under development at the Max Plank Institute Semiconductor Laboratory (HLL) for XEUS and particle physics experiments.

• First 64x64 pixel prototypes in 2004, now in second generation for improved speed and power (delivery early 2007).

• If second generation performs as expected would need only straight-forward design modifications to meet EXIST requirements

Summary

- EXIST:
  - Will survey the hard X-ray sky every 95min.
  - Uses coded aperture imaging in the 3-600 keV energy range.
- Key technologies:
  - CZT Detectors.
  - Low power ASICs.
  - Packaging of CZT detectors and ASICs.
  - Fast on-board processing of data for the detection of transients.