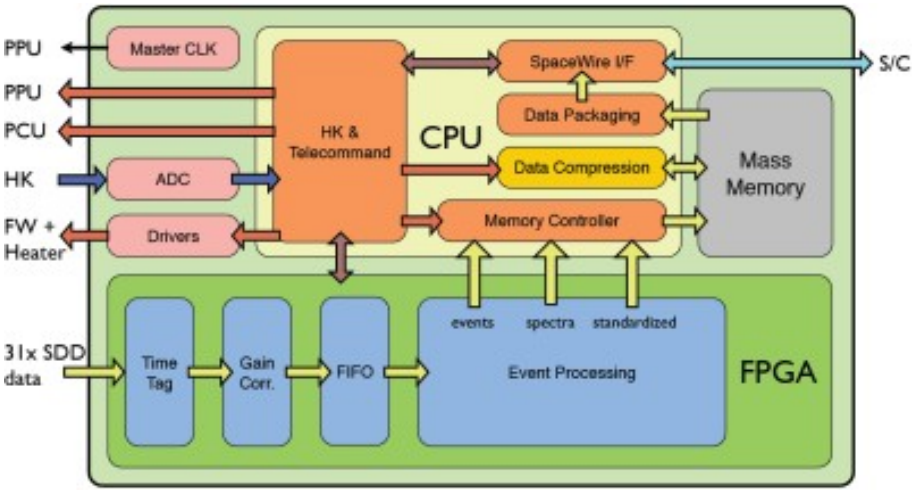
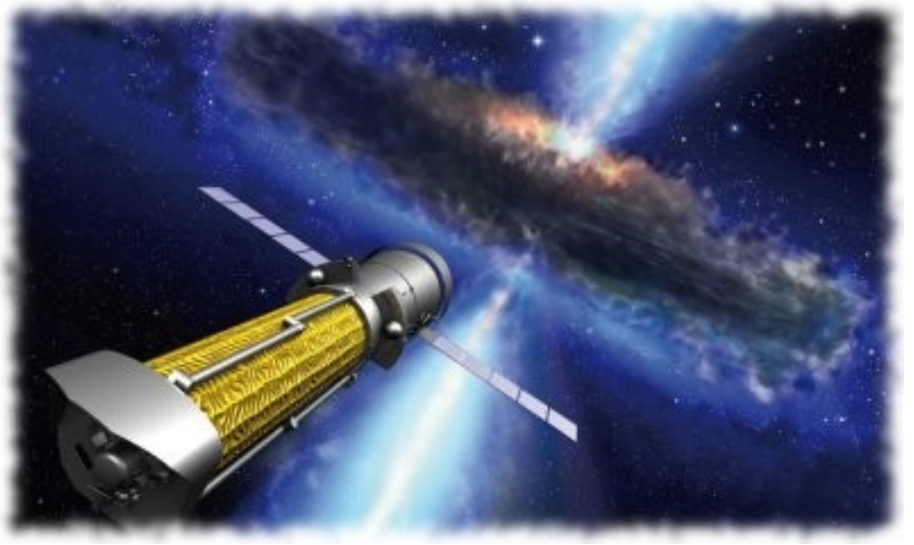
The High Timing Resolution Spectrometer on board the International X-ray Observatory



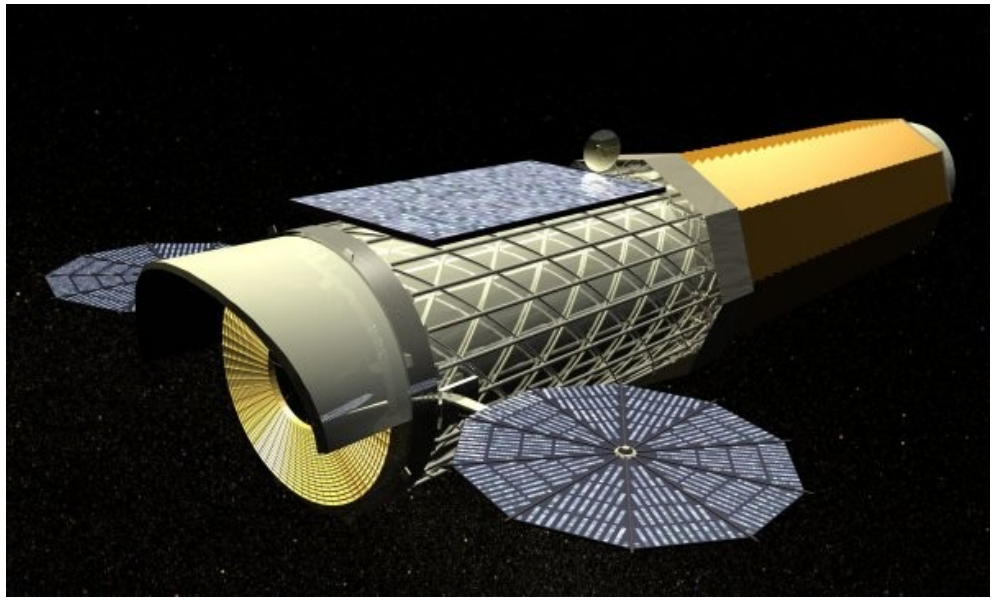


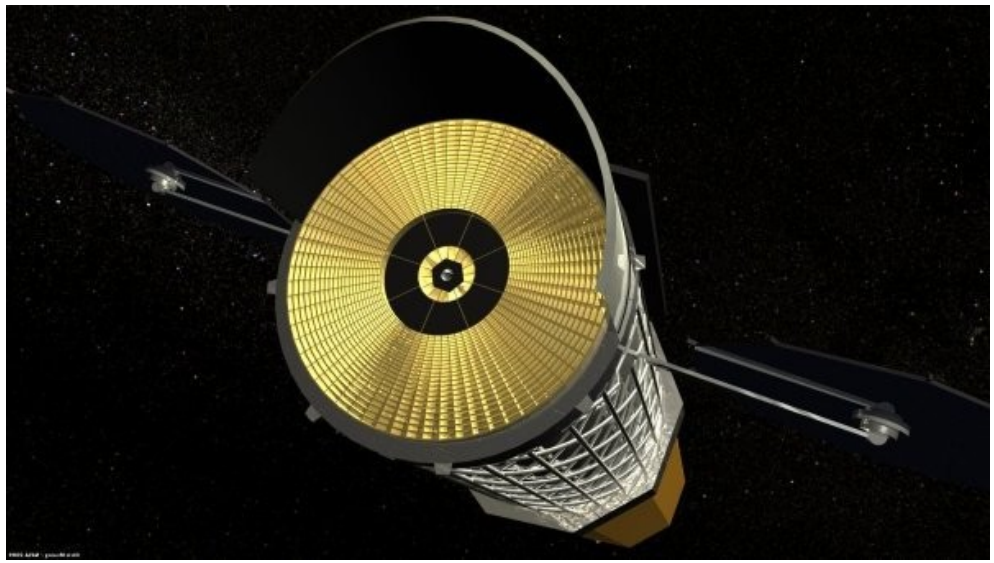
Henning Wende – IAAT (Tübingen)

Schule für Astroteilchenphysik 2010
6.-14. Oktober, Obertrubach-Bärnfels

International X-ray Observatory

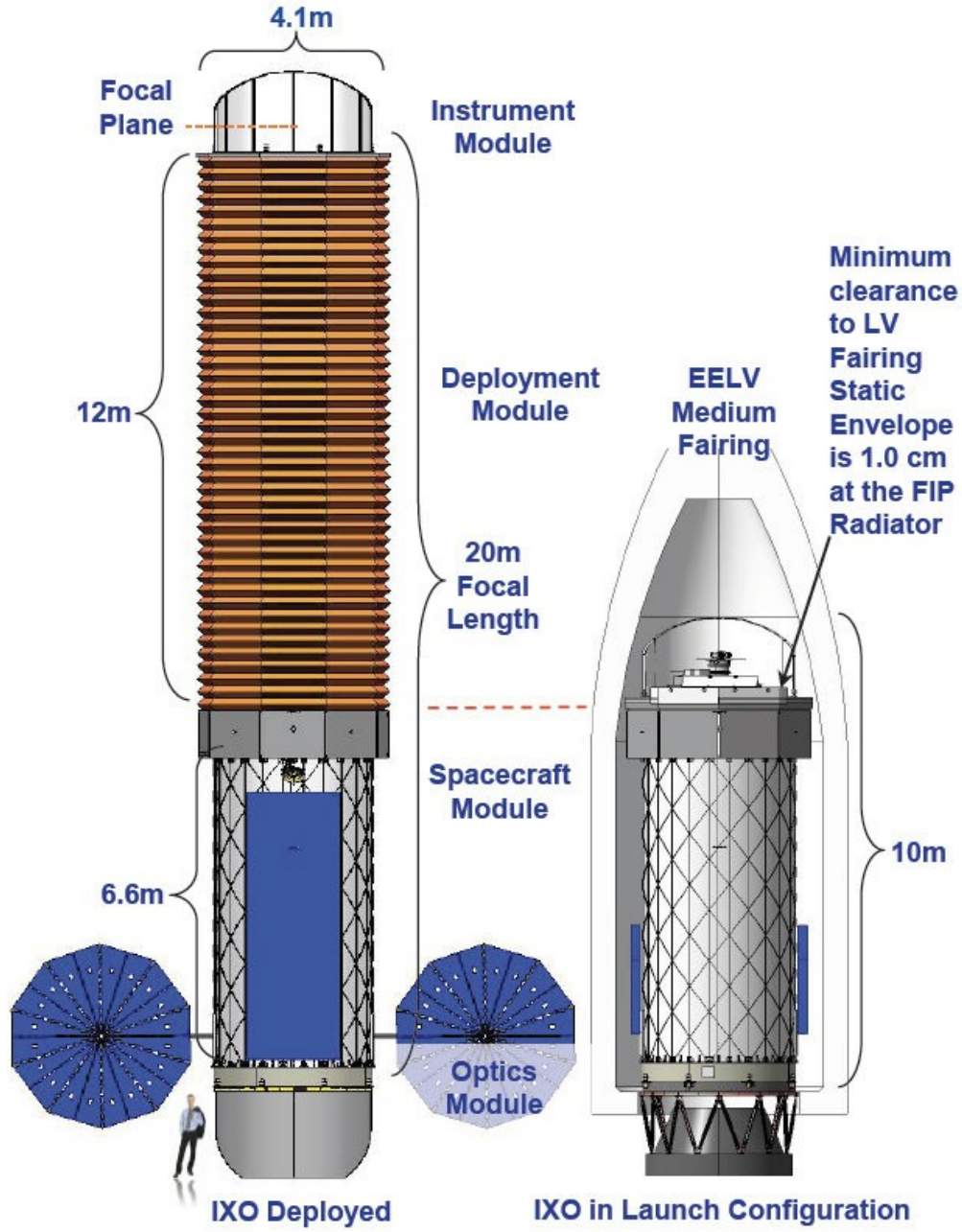
- **NASA-ESA-JAXA Mission**
- **Telescope:**
  - $3\,m^2$ at 1.25 keV
- **Spectral Resolution:**
  - 2.5 eV at 0.3 - 7 keV
  - 150 eV at 0.1 - 15 keV
- **Angular Resolution:**
  - 5 arcsec at 0.3 - 7 keV
  - 30 arcsec at 7 - 40 keV
- **Count Rate:** 10^6 cps **(HTRS)**



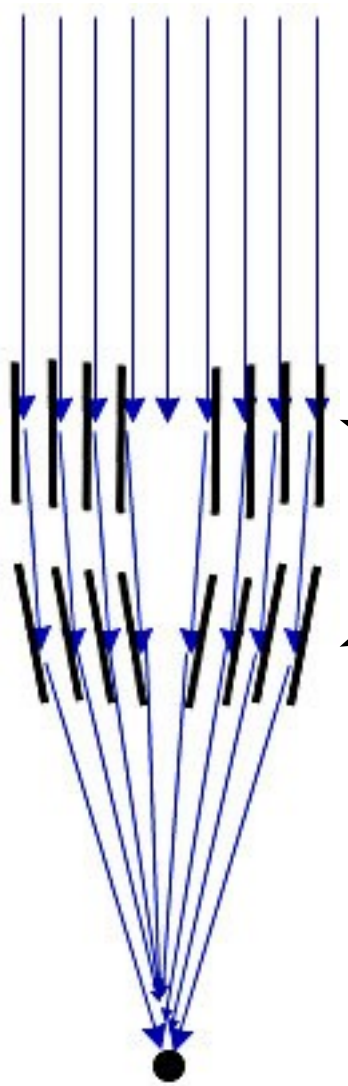


IXO Launch and Mission

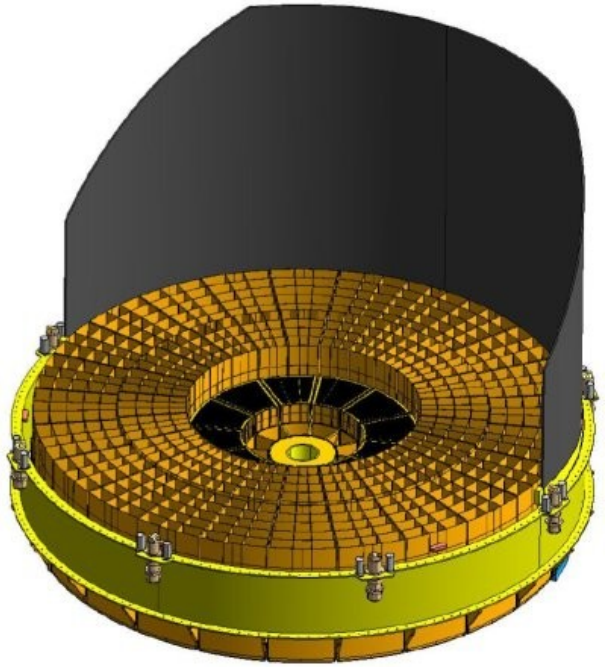
- **Launch in 2021** (+X)
- Ariane 5 ECA / Atlas V 551
- Modular structure for transport and deployment:
  - Instrument Module
  - Deployment Module
  - Spacecraft Module
  - Optics Module
- **Operation in L2 orbit for 5y** (consumables for 10y)

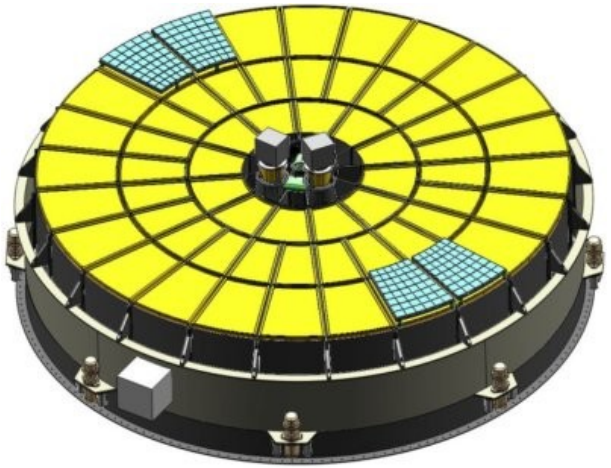


IXO X-ray Optics



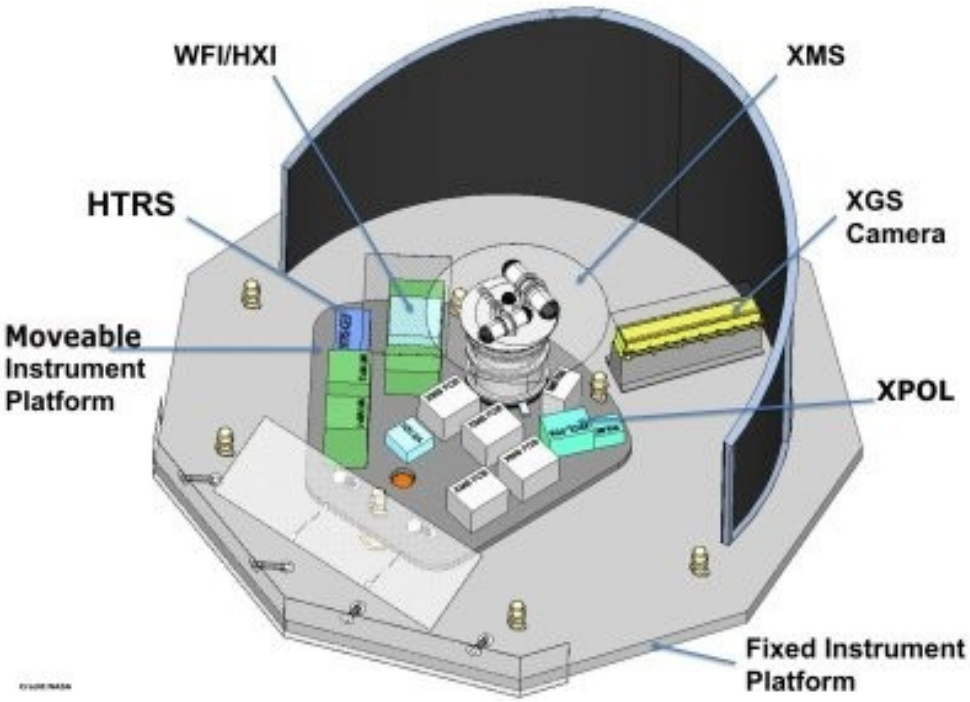
- **index of refraction is ≈1 for x-rays**
- x-ray optics use reflection from a surface
  - 1st parabolic
  - 2nd hyperbolic
- two technologies for reflective elements:
  - **silicon pore optics (ESA)**
  - **segmented glass optics (NASA)**





IXO Instruments

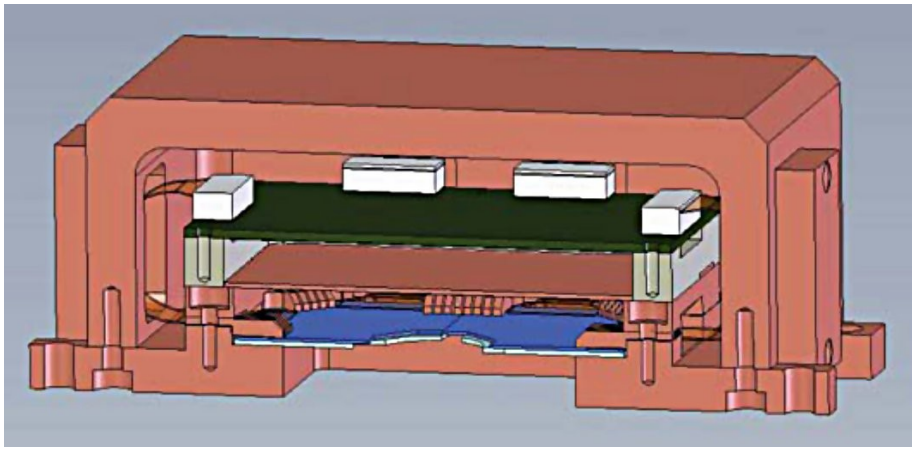
- **Wide Field Imager + Hard X-ray Imager**
- X-ray Microcalorimeter Spectrometer
- X-ray Grating Spectrometer
- X-ray Polarimeter
- **High Timing Resolution Spectrometer**

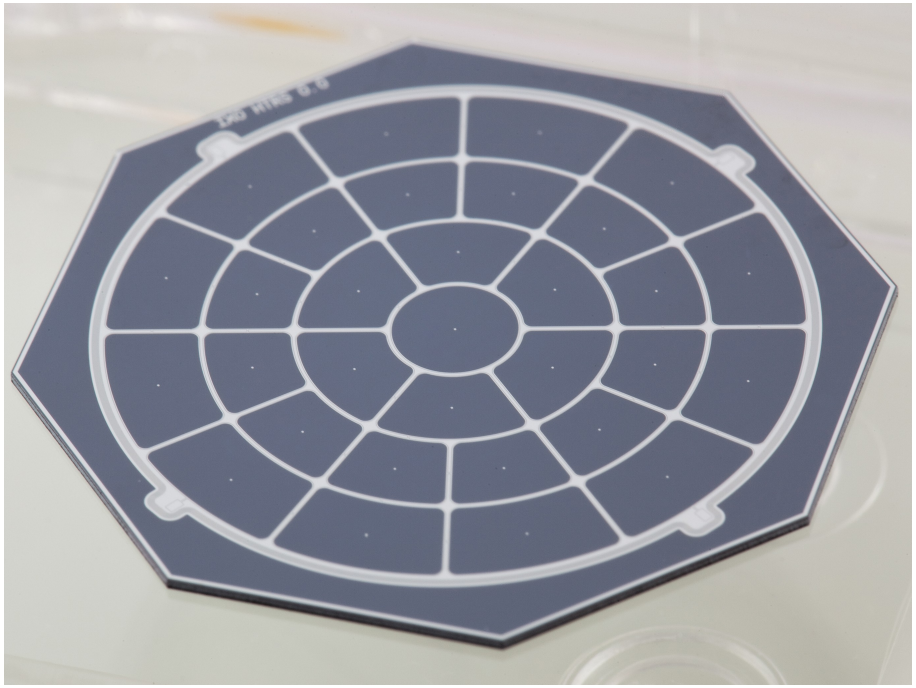


4 instruments on moveable platform
XGS on fixed platform

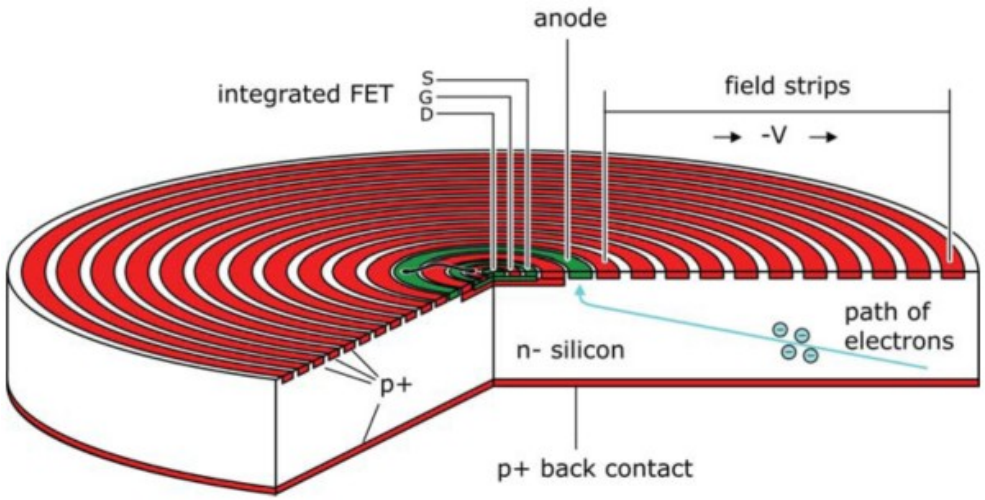
HTRS Instrument

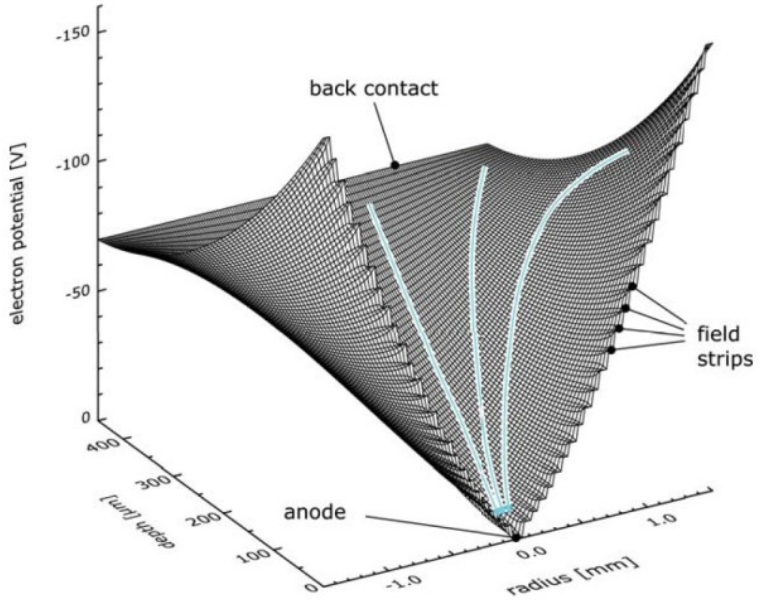
- high precision timing measurements up to **1 million counts / second**
- operating in the band of **0.3 keV – 15 keV**
- spectral resolution of **150 eV FWHM @ 6 keV**
- event loss due to pile-up **< 1 % @ 1 crab**



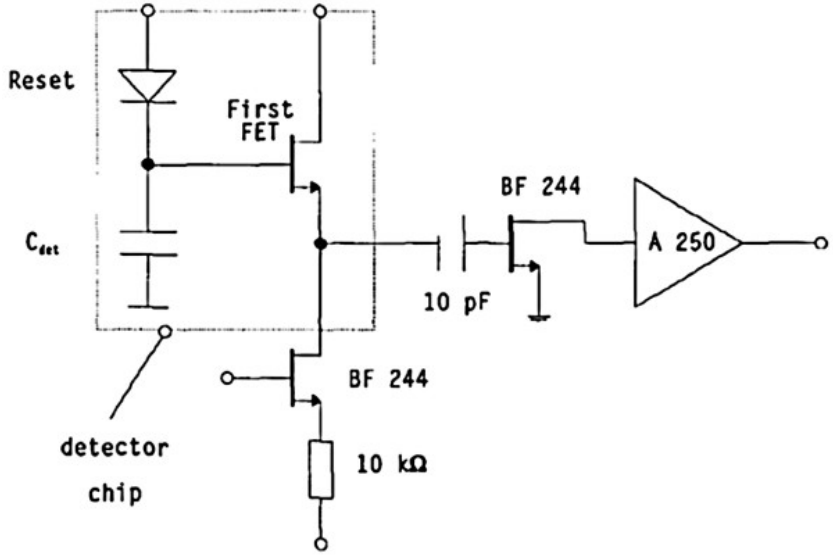


Silicon Drift Diodes

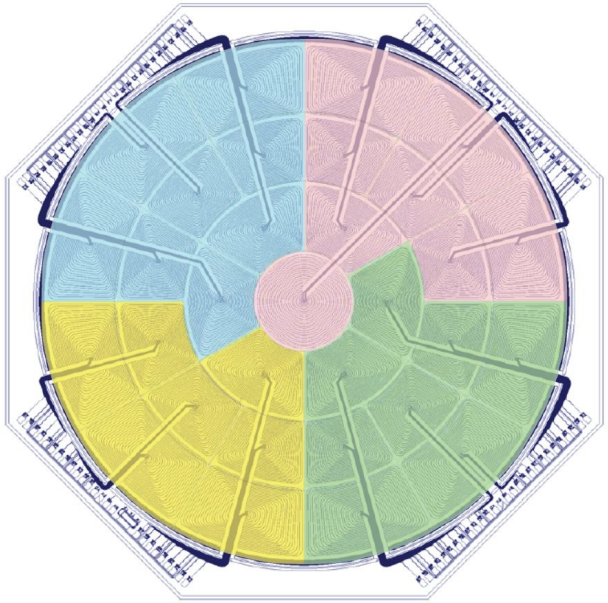




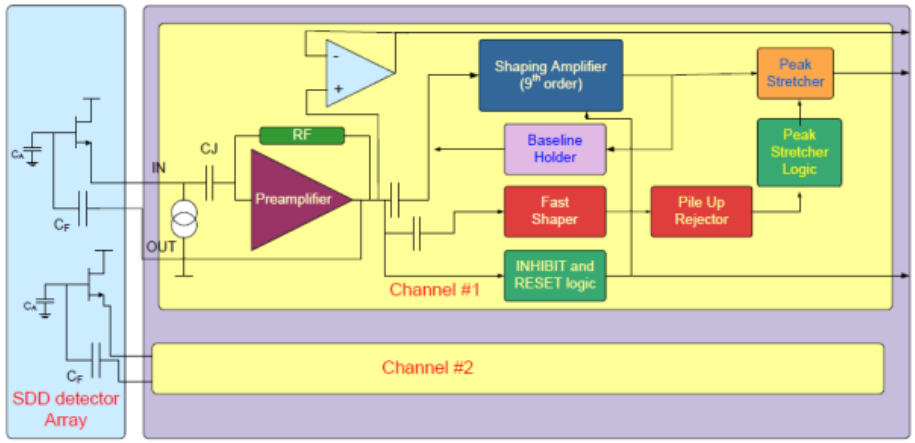
- optimized shape of the potential
  - **short shaping times**
- extremely small anode capacitance
  - **high energy resolution**
  - low leakage current
  - only very moderate cooling needed



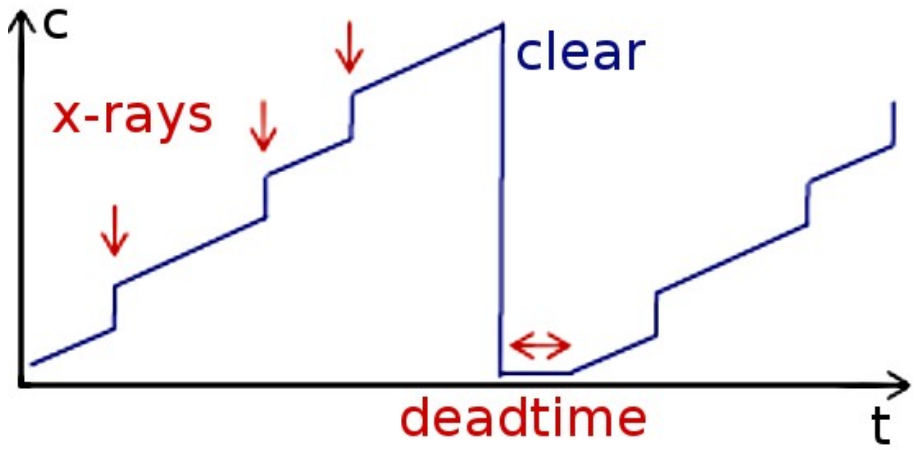
HTRS Detector & Operation



- four quadrants composed of 31 silicon drift diodes
- **single pixel operation and readout** no frames are produced!!!

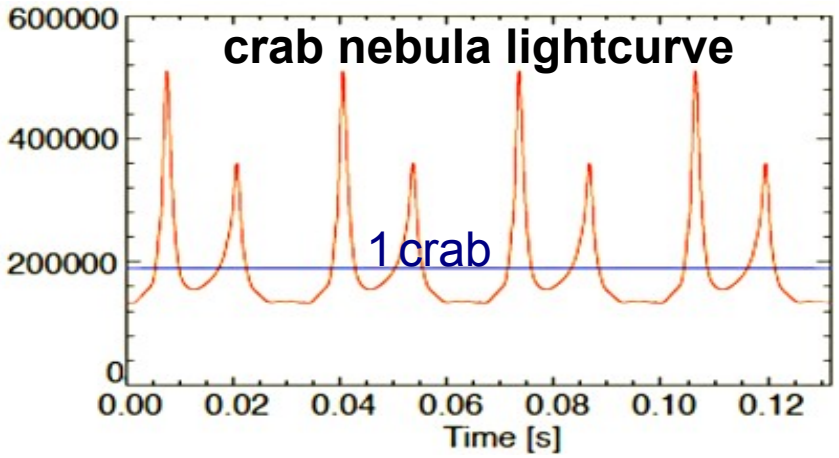


quadrant readout electronics



integration of **signal charges** and **leakage current** in one pixel

Modes and Data Rates



- **single event mode**
  time & energy for each event
- **spectral binning mode**
  - configurable integration time
  - configurable energy res.
- additional **standard modes**

- data rate @ 1 crab:
  16 Mbit/s (depends on mode)
- maximum data rate possible for transfer to ground:
  ~0.75 Mbit/s
- desired compression:
  by factor of ~21
- compression has to be done as fast as possible
- compression must provide checks for data integrity

Compression Algorithm

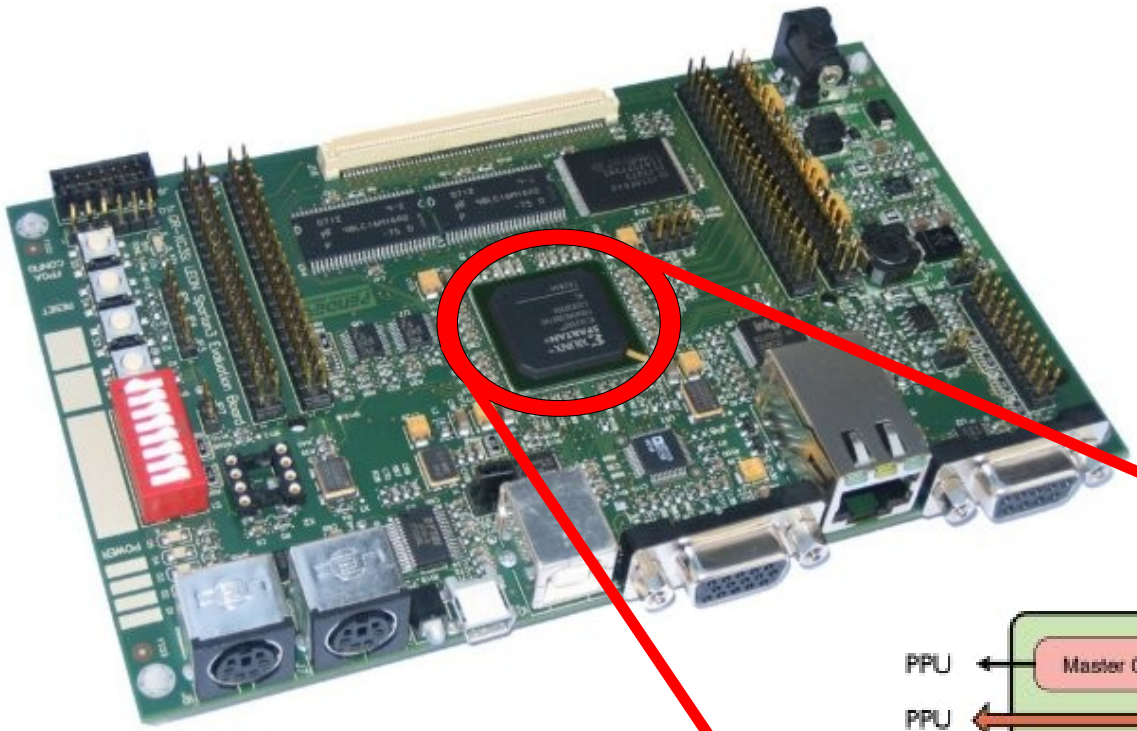
bzip2

- **Burrows-Wheeler transform** transforms symbol strings into groups of similar symbols
- **Huffman encoding** encodes symbols efficiently using a variable-length code table
- **Multithreading** is possible due to block compression
- **32-bit CRC** in each block to ensure data integrity

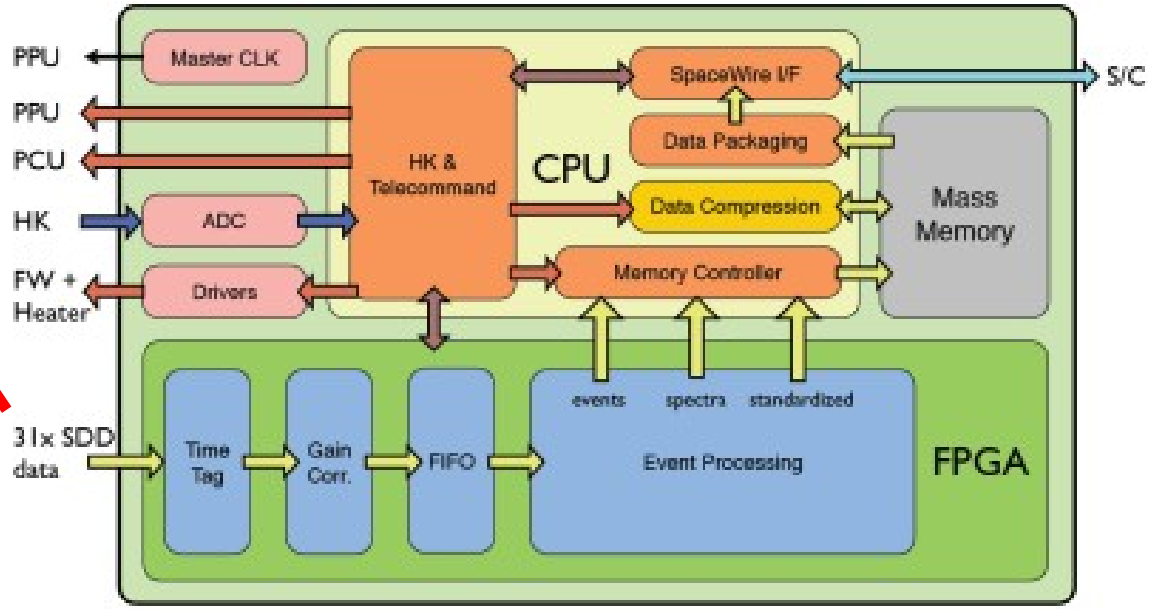
- data rate @ 1 crab: **16 Mbit/s** (depends on mode)
- maximum data rate possible for transfer to ground: **~0.75 Mbit/s**
- desired compression: **by factor of ~21**

compression factor: **>25**

Leon3 on Spartan3 FPGA



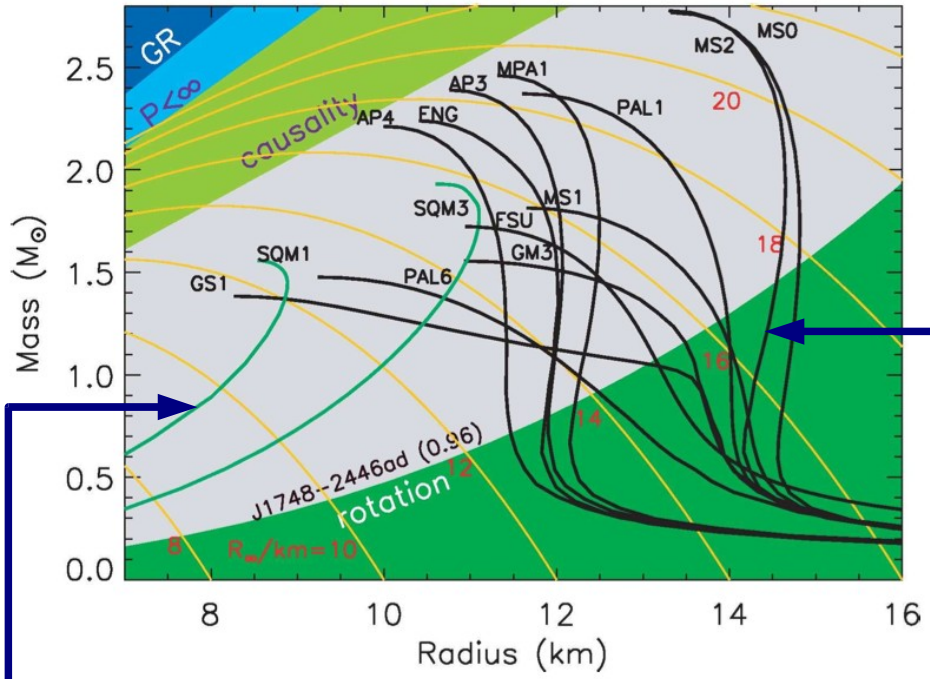
Leon3 is a **VHDL** model of a **32-bit microprocessor** with SPARC V8 architecture that is loaded into a **Field Programmable Gate Array (FPGA)**



CPU inside the DPU for

- detector operation
- observing mode generation
- data compression

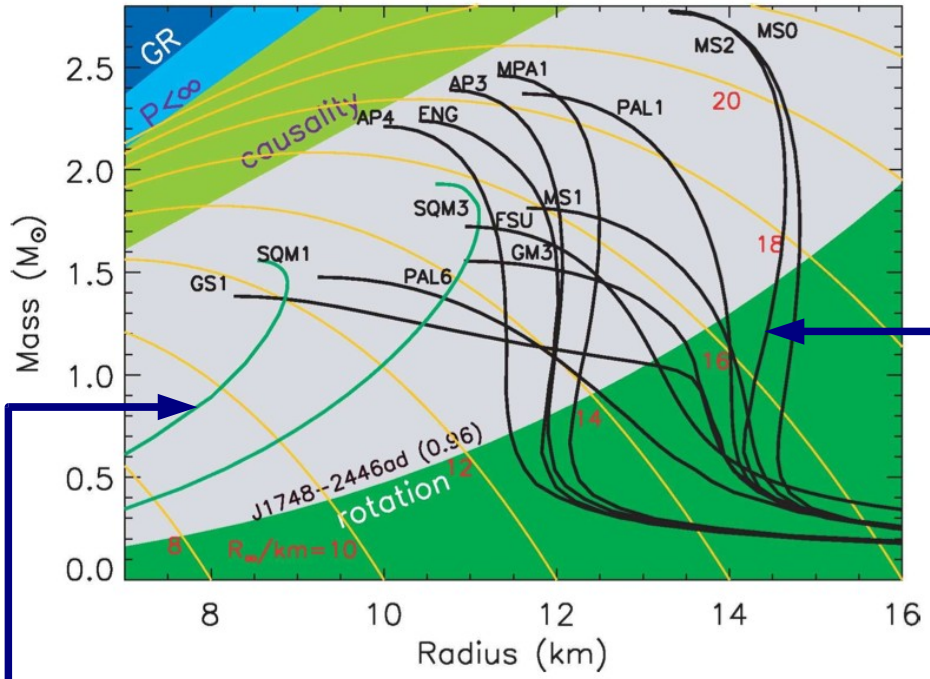
HTRS Science



- equation of state not well known for neutron stars
  - **bound quark states** (baryons and mesons)
  - **strange quark matter**

- **mass-radius relation needed!**
- mass well known from radio observations of binaries **$M \approx 1.4 M_{Sun}$**
- confirmations of **R≈10-15km** from X-ray spectroscopy (Chandra, XMM-Newton)

HTRS Science



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HTRS will provide **time resolved spectroscopy** of X-ray bursts that allows absolute radii measurements with relative precision of 10%


That's all Folks!

IXO Payload Performance

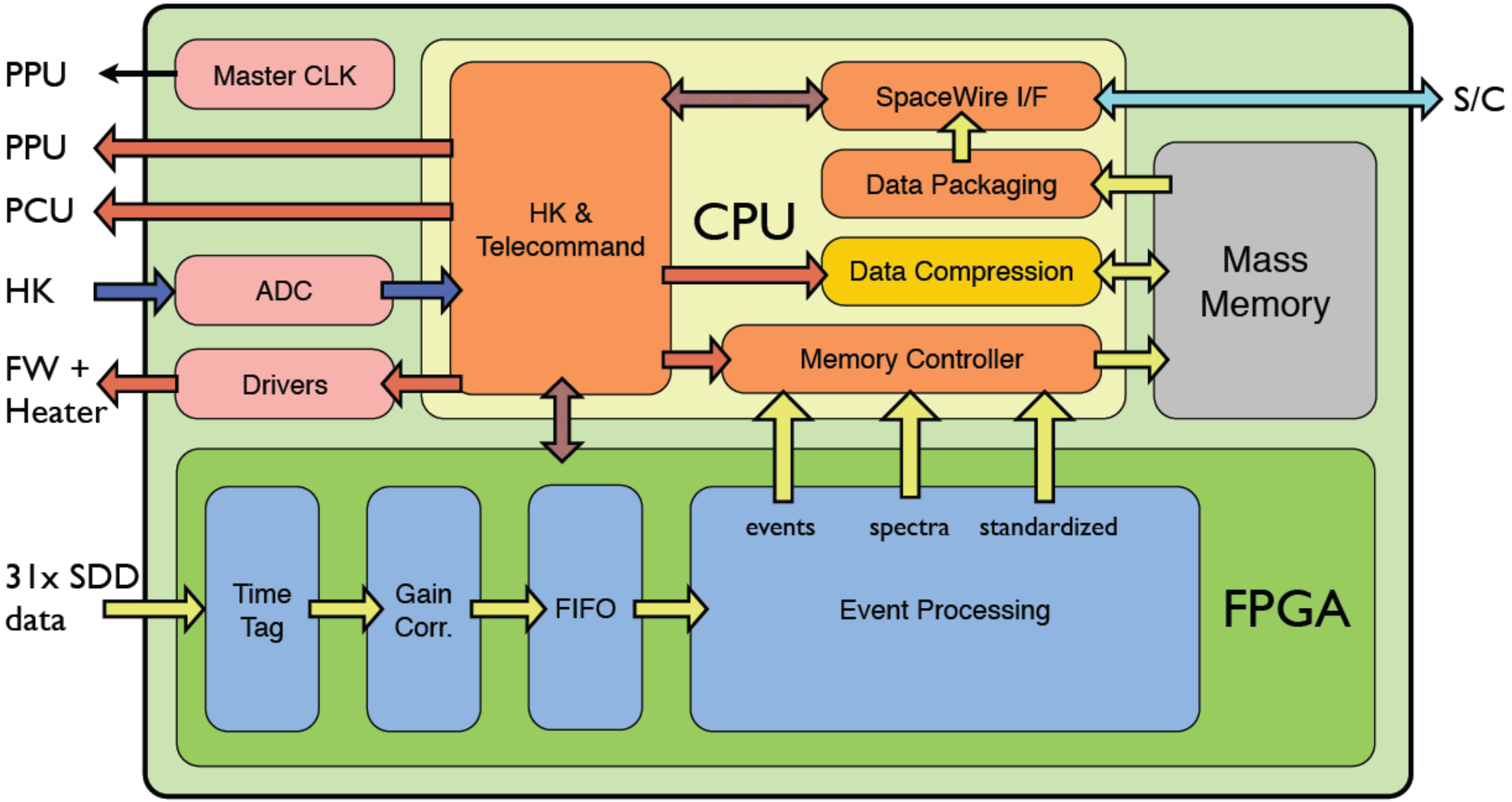
Instrument		Bandpass	PSF (HPD)	FOV	Energy Resolution	Science Driver
		keV	arcsec	arcmin	eV@keV	
XMS	Core	0.3–12	5	2 × 2	2.5@6	Galaxy Clusters
	Outer			5 × 5	10@6	
WFI/ HXI	WFI	0.1–15	5	18 diameter	150@6	SMBH survey
	HXI	10–40	30	8 × 8	1000@30	SMBH Spin
XGS		0.3–1.0	5	N/A	E/ΔE = 3000	Cosmic Web
HTRS		0.3–10	N/A	N/A	150@6	NS EoS
XPOL		2.0–10.0	6	2.5 × 2.5	1200@6	SMBH Spin

Instrument	Mass [kg]	Power [W]
XMS	263	649
WFI/HXI	89	268
XGS	50	77
HTRS	23	109
XPOL	9	46
FMA	1731	1540

Flight Mirror Assembly

Eff. Area	@ Energy
3.00 m^2	1.25 keV
0.65 m^2	6.00 keV
0.15 m^2	30.0 keV

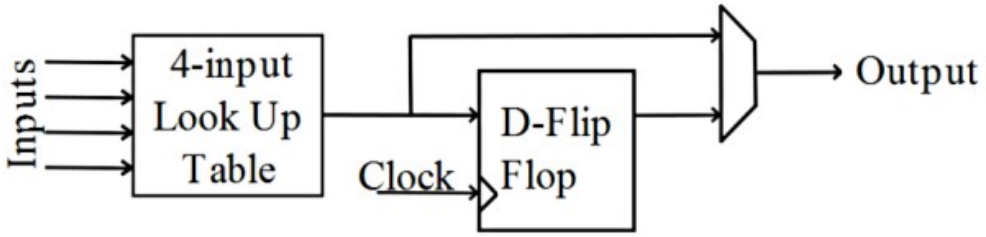
IAAT Hardware Contribution



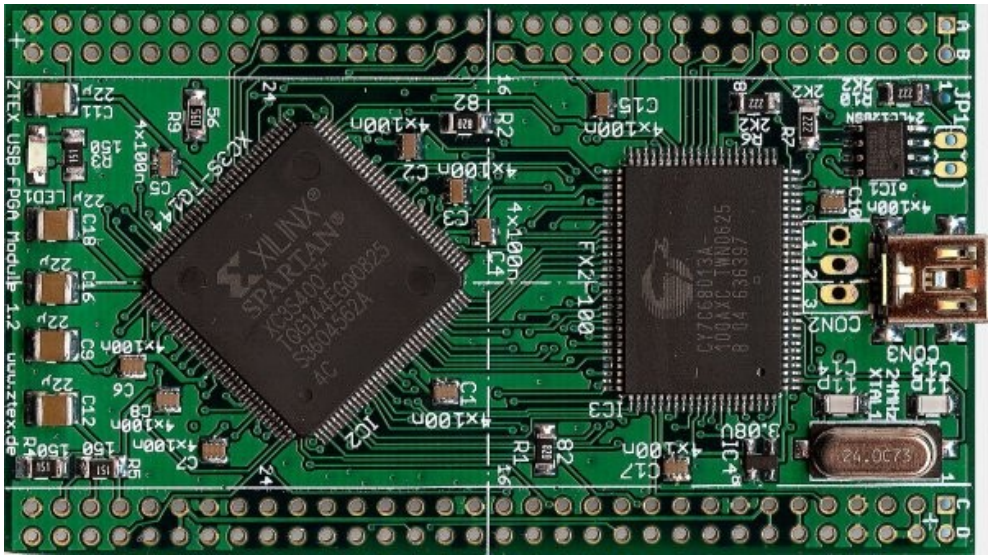
Digital Data Processing Unit

Field Programmable Gate Array

- IC to be programmable 'in the field' – FPGA
- programmed using a certain **H**ardware **D**escription **L**anguage (e.g. VHDL)
- composed of configurable **logic blocks** (logic cells) and **interconnects**
- unlike microcontrollers used for **parallel processing**



simple FPGA logic cell



Spartan3 USB-FPGA-Module

bzip2 Algorithm

- compresses data in blocks of 100 – 900 kB
- **Run-length encoding** to cut short (long) runs of symbols
- **Burrows-Wheeler transform** to transform symbol strings into more easy to compress groups of similar symbols
- **Move-to-front transform** to reduce size of symbols by replacing them by an "recently used symbols"-index
- **Run-length encoding** again (many zeros due to MTF)
- **Huffman encoding** uses a variable-length code table to encode symbols efficiently
- **32-bit CRC** in each block to ensure data integrity