Enabling Technologies for Active Pixel Sensors and Rapid Readout Electronics

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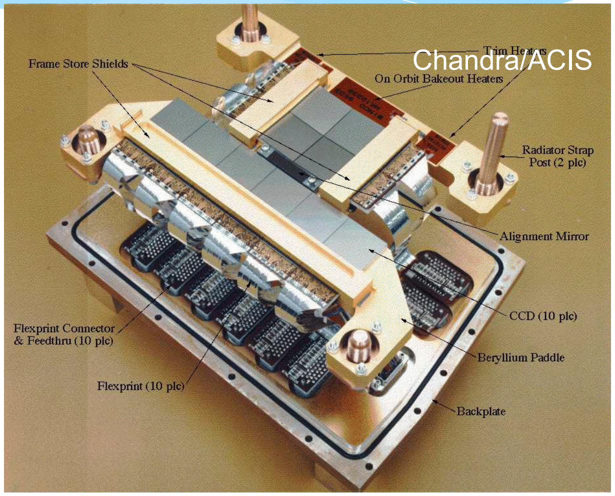
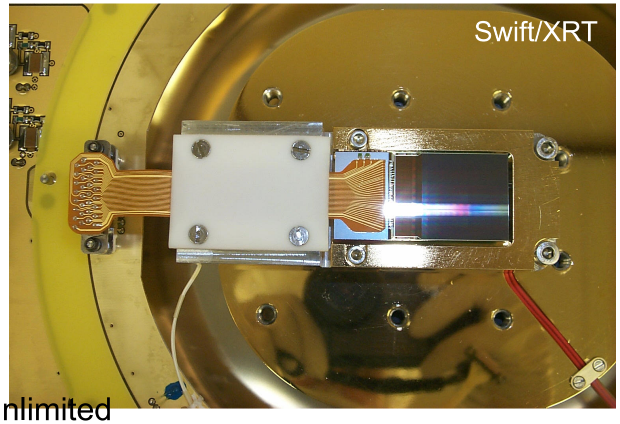
Wide Field Si sensors

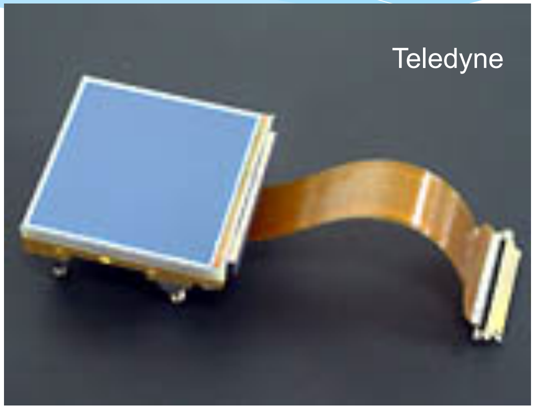
* Wide fields of view will require Si arrays for foreseeable future
* CCDS:
  * Mature technology
  * Large formats
  * Good QE
  * Fano-limited energy resolution
  * Radiation damage
  * Poor time resolution
  * Pileup

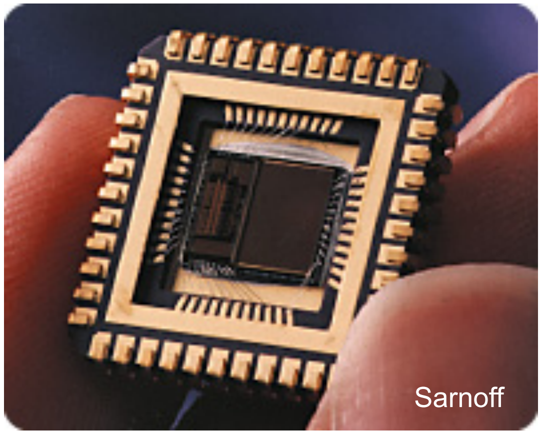




Wide Field Si sensors

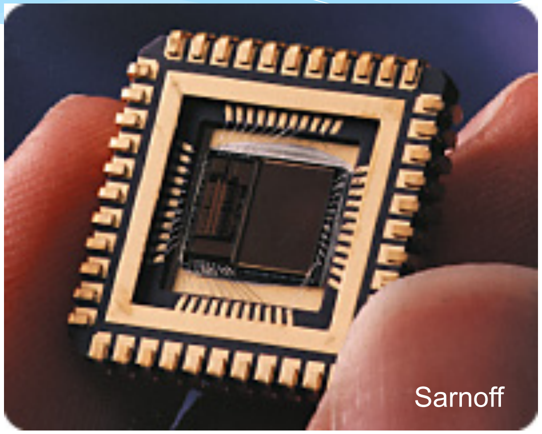
* Active Pixel Sensors:
  * New technology (for X-rays)
    * Up to 4K x 4K pixels
    * Pixel sizes from 10 – 100 µm
  * Large formats
  * Good QE
  * Fano-limited energy resolution (for some designs)
  * Radiation-hard (vs CCDs)
  * Fast readout, minimal pileup
    * Allows thin OBF => good low energy QE
  * Random access
  * Low power

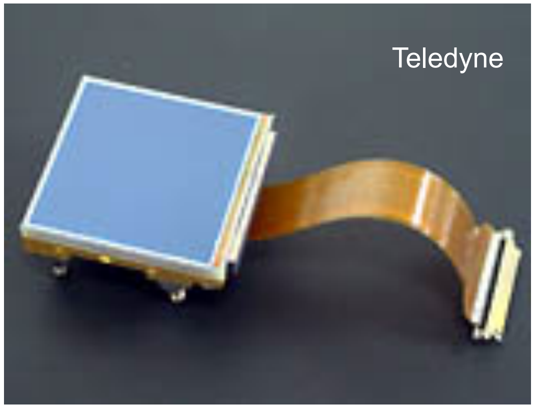




Active Pixel Sensor Architectures

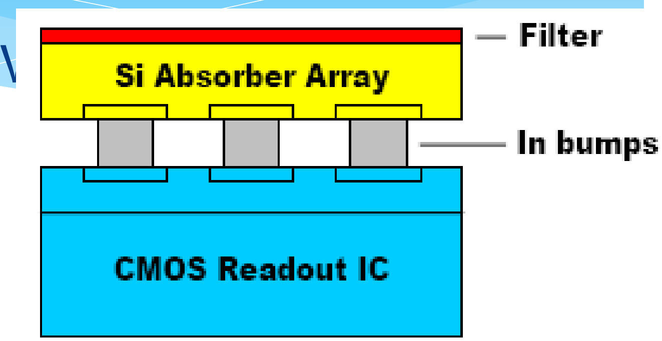
- Monolithic
  - Single Si wafer used for photon detection and readout circuitry
  - Sarnoff and MPE
  - Good energy resolution
- Hybrid
  - Multiple layers optimized for photon detection, readout, etc.
  - MIT/LL and Teledyne

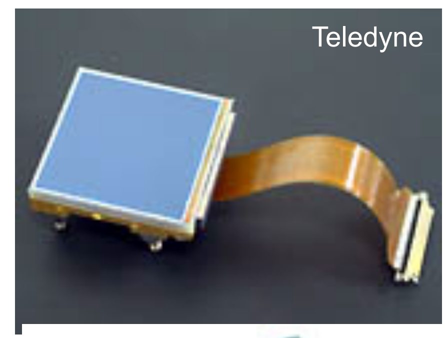


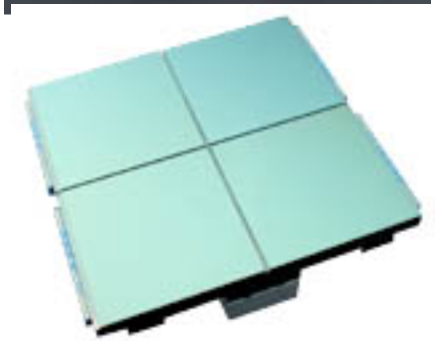


PSU/Teledyne (HyViSI HxRG)

* Based on heritage from NIR detectors, JV HST, OCO, etc.
* High TRL, up to 4Kx4K 10 μm pixels, abuttable, windowed readout, high speed
* Excellent QE ("back-illuminated", >100 μm thick)
* Read noise is high ($8\ e^-$) – we are working with Teledyne on new amp designs to achieve Fano-limited energy resolution
* HxRG Cross-talk is high – we are working with Teledyne on new amp designs to reduce cross-talk to < 1% (initial results successful)
* Progress limited completely by available funding







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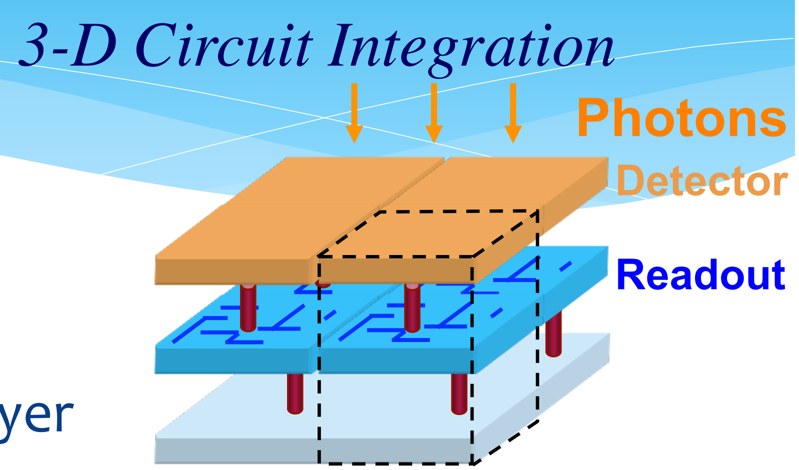
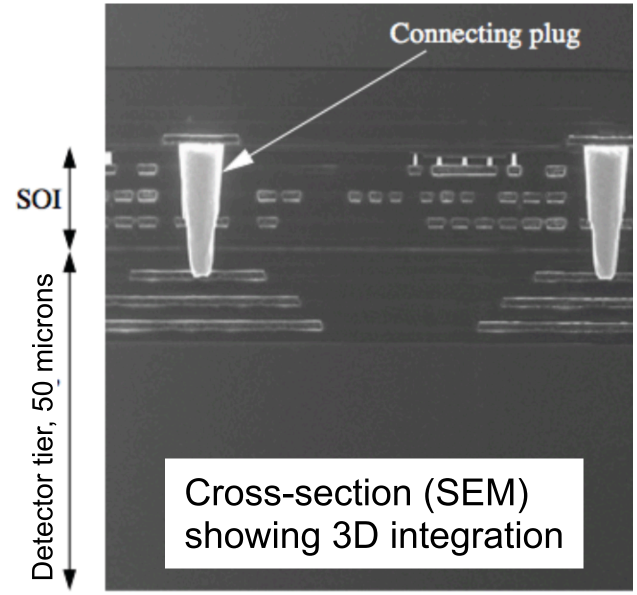
MIT/LL (hybrid 3-D integration)

- Multilayer concept
- 100% fill factor
- Scalable to large focal planes
- Optimize material and fabrication by layer
- Potential for pixel-level intelligence
- Detector layer is high-resistivity, 50 μm thick
- 256x256, 8 μm pixels, in-pixel CDS readout
- "Back-illuminated"
- < 13 e^- read noise, < 190 eV FWHM @ 5.9 keV
- Progress limited by available funding





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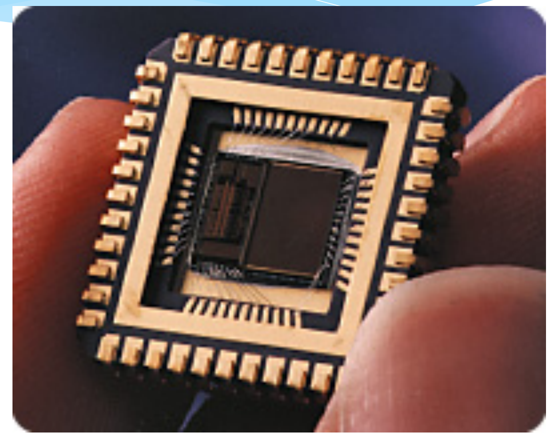
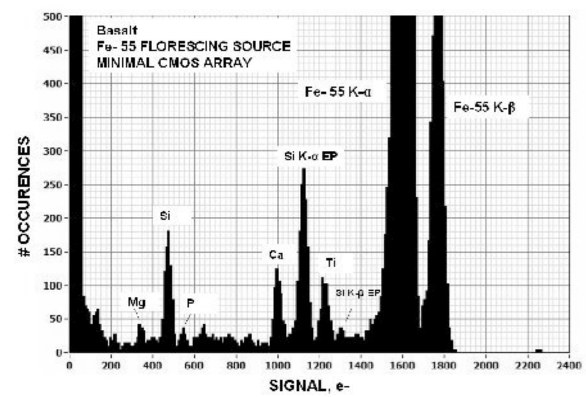
JHU/Sarnoff (monolithic)

- Single layer of Silicon
- Back-illuminated
- Fano-limited ($<2e^-$ read noise)
- Small depletion depth (~10 µm)
- 8 µm pixels (for 3T devices)
- 1K x 1K
- Progress limited by available funding





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APS Development

Parameter	Development Target (SMART-X targets)	Sensor Family		
		JHU/Sarnoff	PSU/Teledyne	MIT/Lincoln
Pixel-level performance:				
Pixel Size	< 15 μm	3	3	3
Read Noise	< 4 e⁻ rms	3	1	2
Pixel Rate	1 Mpix/s	3	3	2
QE (@ 10 keV)	10% (>145 μm depletion)	1	3	2
QE (@ 0.1 keV)	10% (passivated surface)	1	2	2
Charge Collection	< 5% resolution loss	2	2	2
In-pixel CDS	Subtract pixel baseline	3	1	3
Chip-level performance & architecture:				
Chip format	1-4 Megapixels	3	3	1
Pixel uniformity	<5% response variation	2	3	1
Power consumption	<50mW/cm^2	2	3	1
On-chip digitization	12 bits/pixel	1	0	1
Window rate	< 1 ms for 10x10 window	2	3	0
Flight qual.	Space qualification	0	1	0
Focal plane scaling & processing:				
Two-side tiling	< 300 μm seam loss	1	3	1
Processor integration	On-chip event identification	0	0	0
Focal plane qual.	Tolerate space environmnt	0	1	0
Code:	0 = no progress to date	1=some work completed	2=may be met in 1-2 years	3=already demonstrated

APS Funding Needs

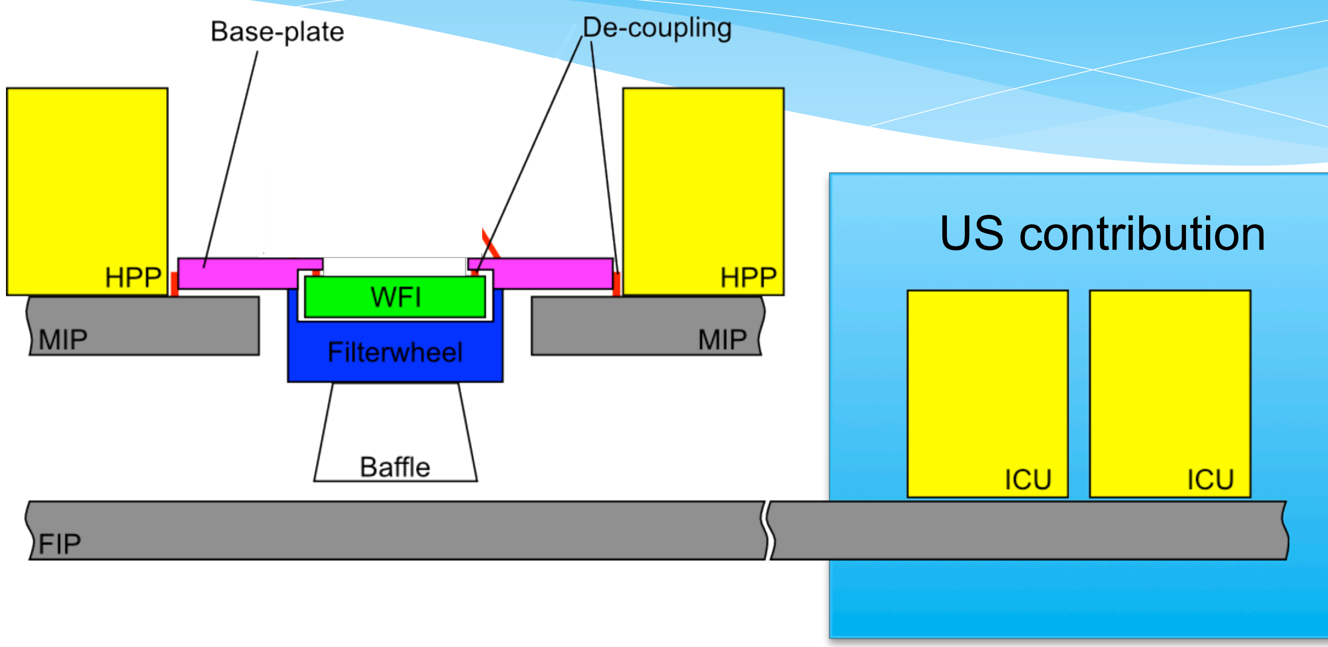
* Note that the success of the ACIS CCDs was built on >10 years of dedicated CCD development efforts
* All three technologies need further development until it becomes clear that at least one can meet all requirements
* Development currently limited by funding stream
  * PSU could progress at least 3 times faster by doubling current funding level
* FY20 completion implies (based on Bautz et al. Astro 2010 white paper):

FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total
$3M	$3M	$3M	$3M	$3M	$3M	$2.5M	$2M	$1.5M	$24M

Rapid readout electronics

* APS sensors require enabling technological developments in readout electronics:
  * CCDs perform data transfer and event recognition at speeds of order 100 kilopixels/s
  * APS sensors will produce data at rates of at least 100 Megapixels/s
  * Cannot perform event recognition in software at these high rates
* Example:
  * ATHENA WFI: PSU, MIT and JHU are part of instrument consortium, responsible for digital electronics
  * WFI has highest data rate requirements, so serves as benchmark

WFI schematic design

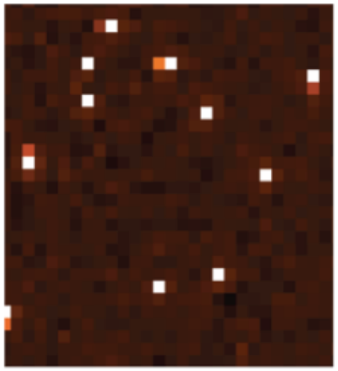


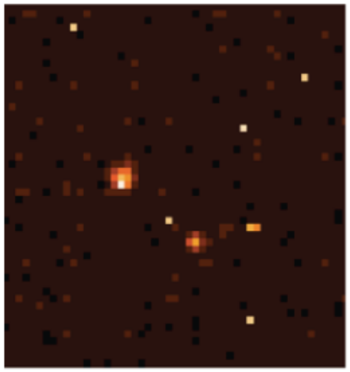
US contribution: high-speed digital electronics

- Provides clean interface between US and European responsibilities
- Capability needed for future US missions (e.g., SMART-X, AEGIS, Gen-X)
- Data rate is 0.8 Gbytes/s (×2)

Rapid Readouts

1. High Speed Data Transfer:
   * Fiber optic cable needed for such high bit rates (DrakaElite)
   * High-speed transceivers: FireFiber (Space Photonics)
   * Need to build and test to achieve TRL 5-6
2. Event Recognition:
   * Must discard empty pixels, find and sum events
   * Need to develop algorithms optimized for APS
   * Need to implement those algorithms in FPGAs to achieve required processing speeds
3. Event Processing:
   * Need to optimize on-board post-processing of events to achieve best APS performance





Processing Funding Needs

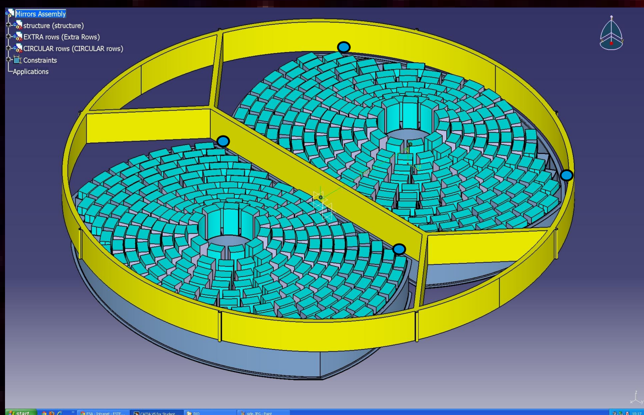
* Development Plan:
  * Year 1: Test optical fiber/transceiver; develop FPGA design; develop APS software simulator
  * Year 2: Build prototype FPGA board, test/iterate, produce engineering model; optimize event processing algorithms based on APS simulator and lab data
  * Year 3: Test FPGA board with APS cameras at PSU, MIT, JHU
  * Year 5: Continue testing program, using latest APS generation

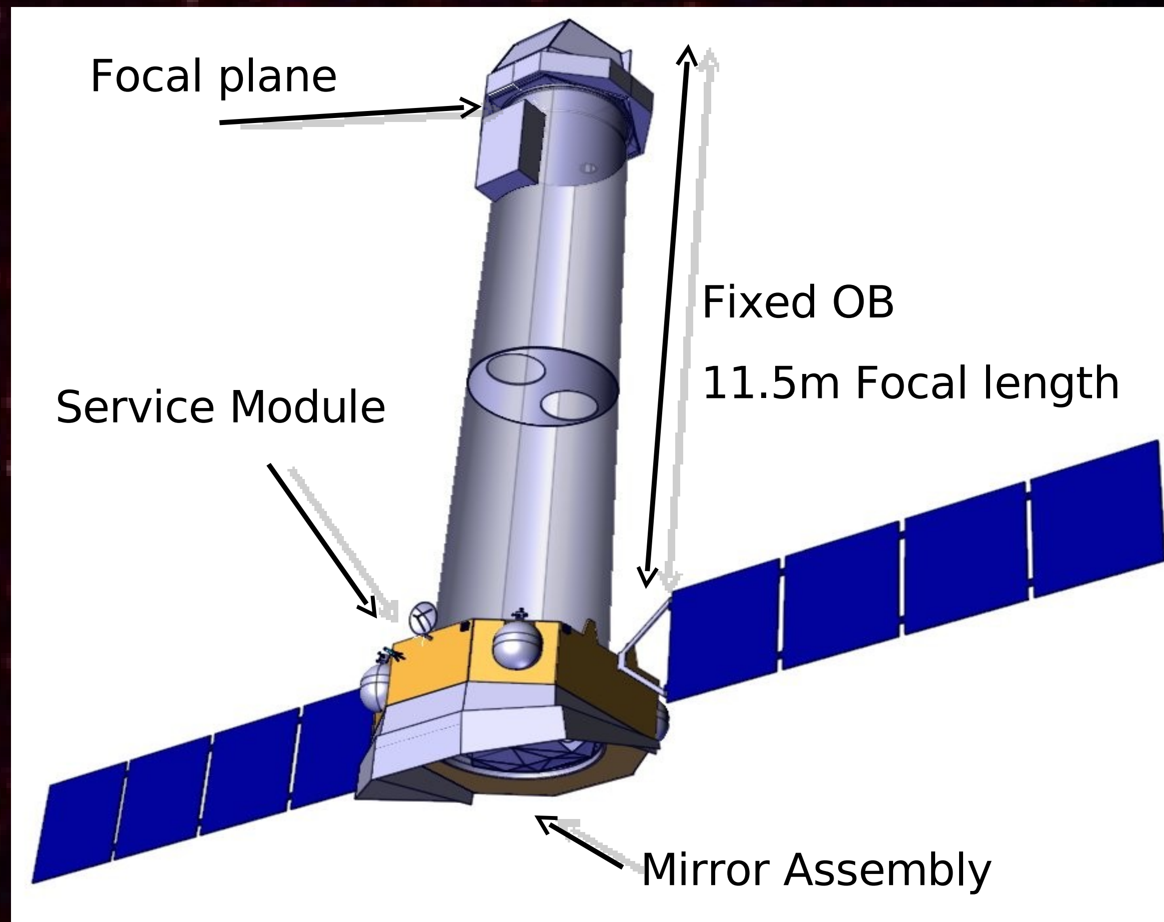
FY12	FY13	FY14	FY15	Total
$0.5M	$0.8M	$1.1M	$0.7M	$3.1M

Summary

* We expect APS sensors to be vital additions to future X-ray astronomy missions, but they need further development to reach their potential and achieve TRL5-6 by 2020. Current funding levels are insufficient to attain this goal. Total funding of about $24M is needed over the next 8 years.
* A more modest effort is required to develop the rapid readout electronics and processing algorithms needed to support these detectors in proposed future missions.

Athena Implementation

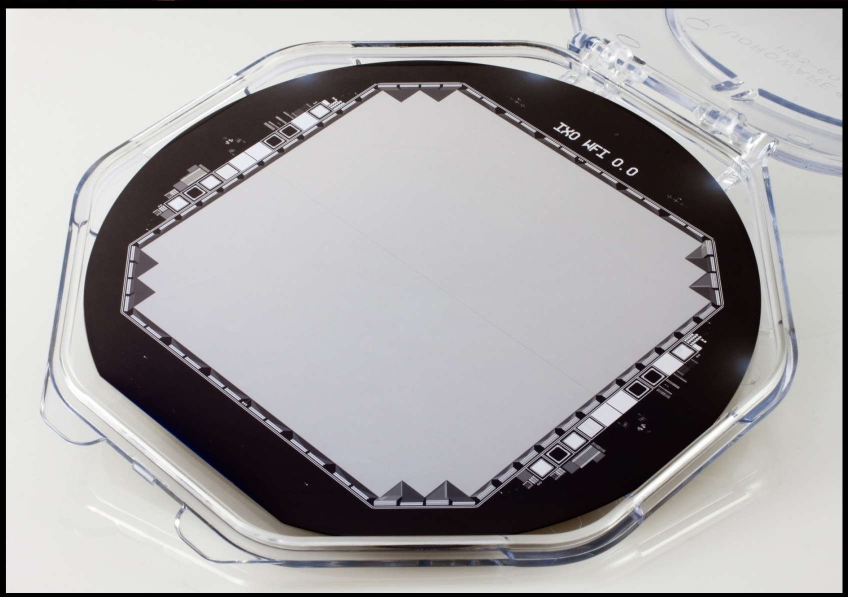




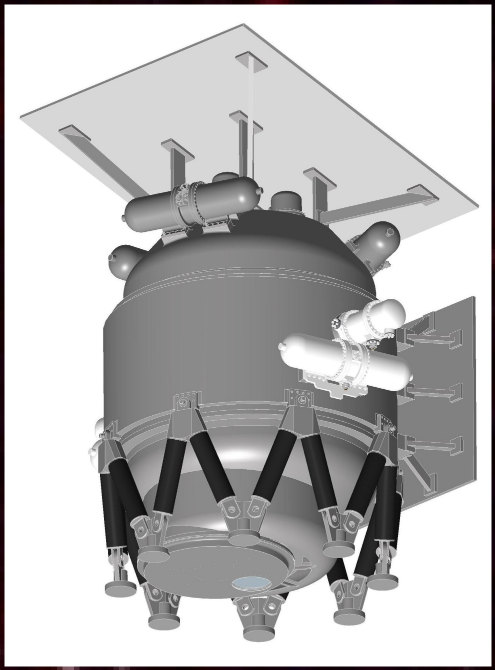
ESA Silicon Pore Optics
“OWL” design
5-10” resolution

Ariane V launch to L2
5yr nominal mission

Athena Instruments



Wide Field Imager (WFI)



Microcalorimeter (XMS)

JAXA, NASA contributions