The Wide Field Imager for Athena

Arne Rau (MPE, WFI Project Scientist)

Spanish X-ray Astronomy 2017, Granada, Oct 23–25

CONSORTIUM

AT CH DE DK FR GB GR IT PL PT US

WFI ATHENA

ecap ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

UNIVERSITÀ DEGLI STUDI DI PALERMO

The Open University

cea — DE LA RECHERCHE À L'INDUSTRIE

DTU Technical University of Denmark

THE PENNSYLVANIA STATE UNIVERSITY 1855

MPE Max-Planck-Institut für extraterrestrische Physik

UNIVERSITÉ DE GENÈVE

Smithsonian

Observatoire astronomique de Strasbourg

ia instituto de astrofísica e ciências do espaço

NATIONAL OBSERVATORY ATHENS

CBK PAN

universität wien

IWF

SLAC NATIONAL ACCELERATOR LABORATORY

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

University of Leicester

MIT Massachusetts Institute of Technology

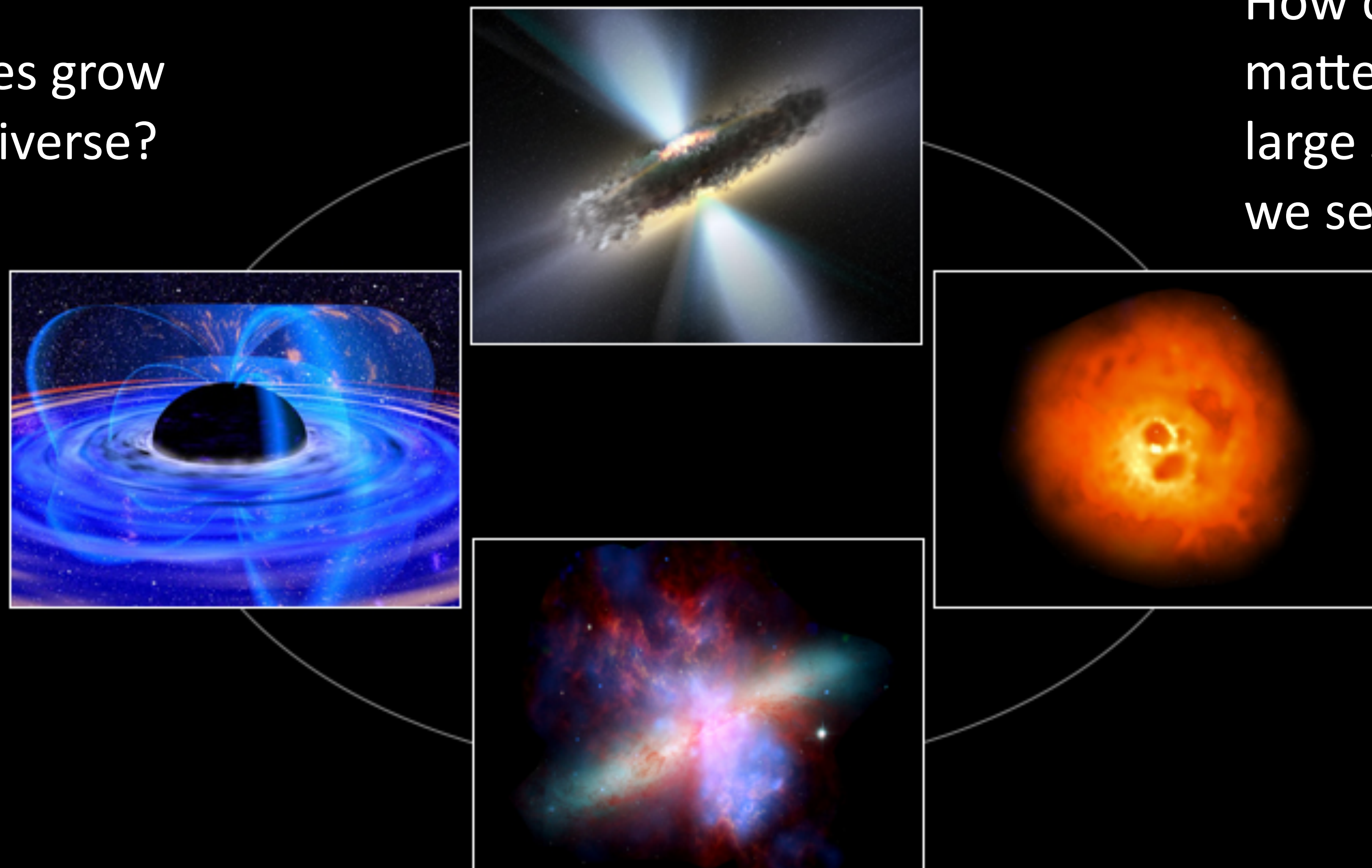
- Science Drivers
- Key Science Requirements
- Instrument & Development Status
- Performance expectations

WFI Science Drivers

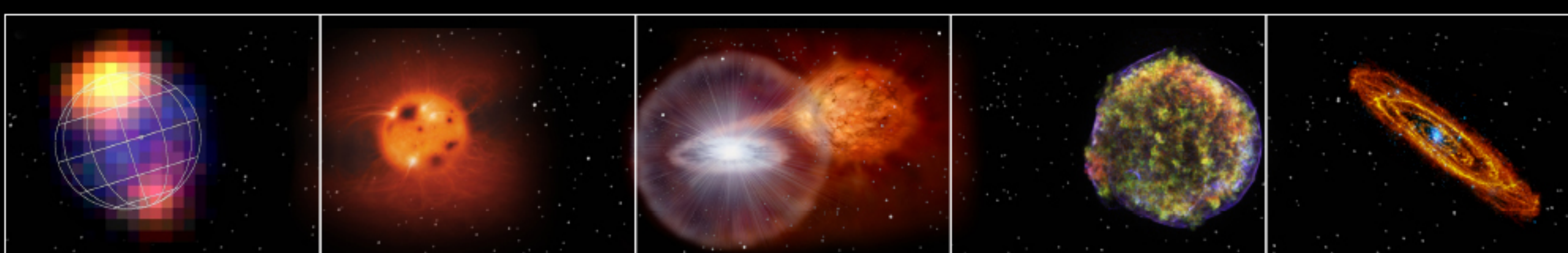
The Hot and Energetic Universe

How do black holes grow and shape the Universe?

How does ordinary matter assemble into the large scale structures that we see today?



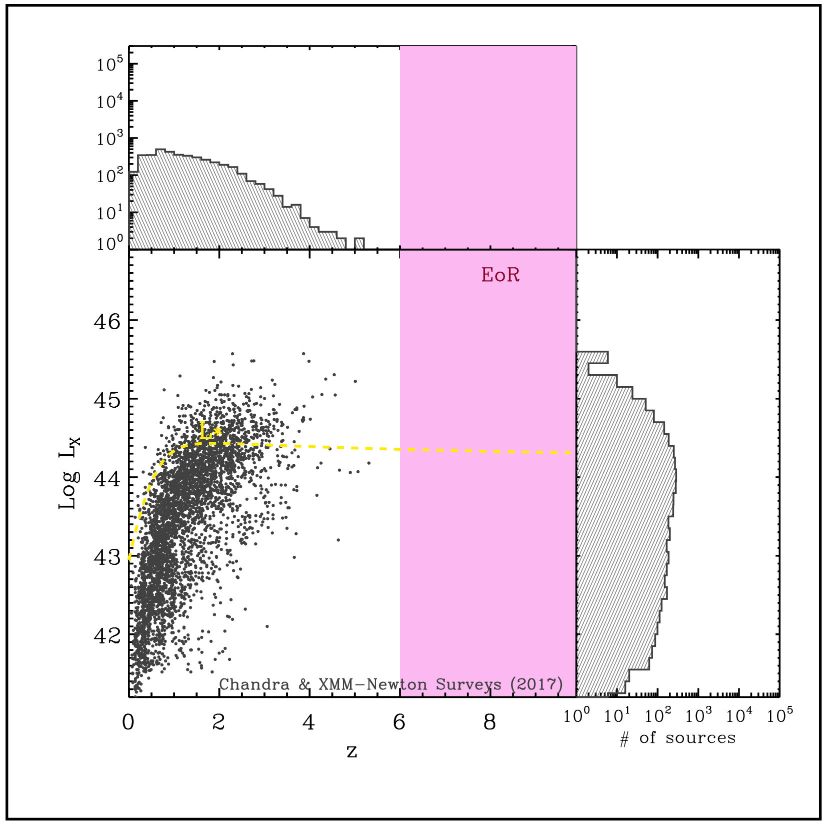
Nandra et al. 2013, arXiv 1306.2307

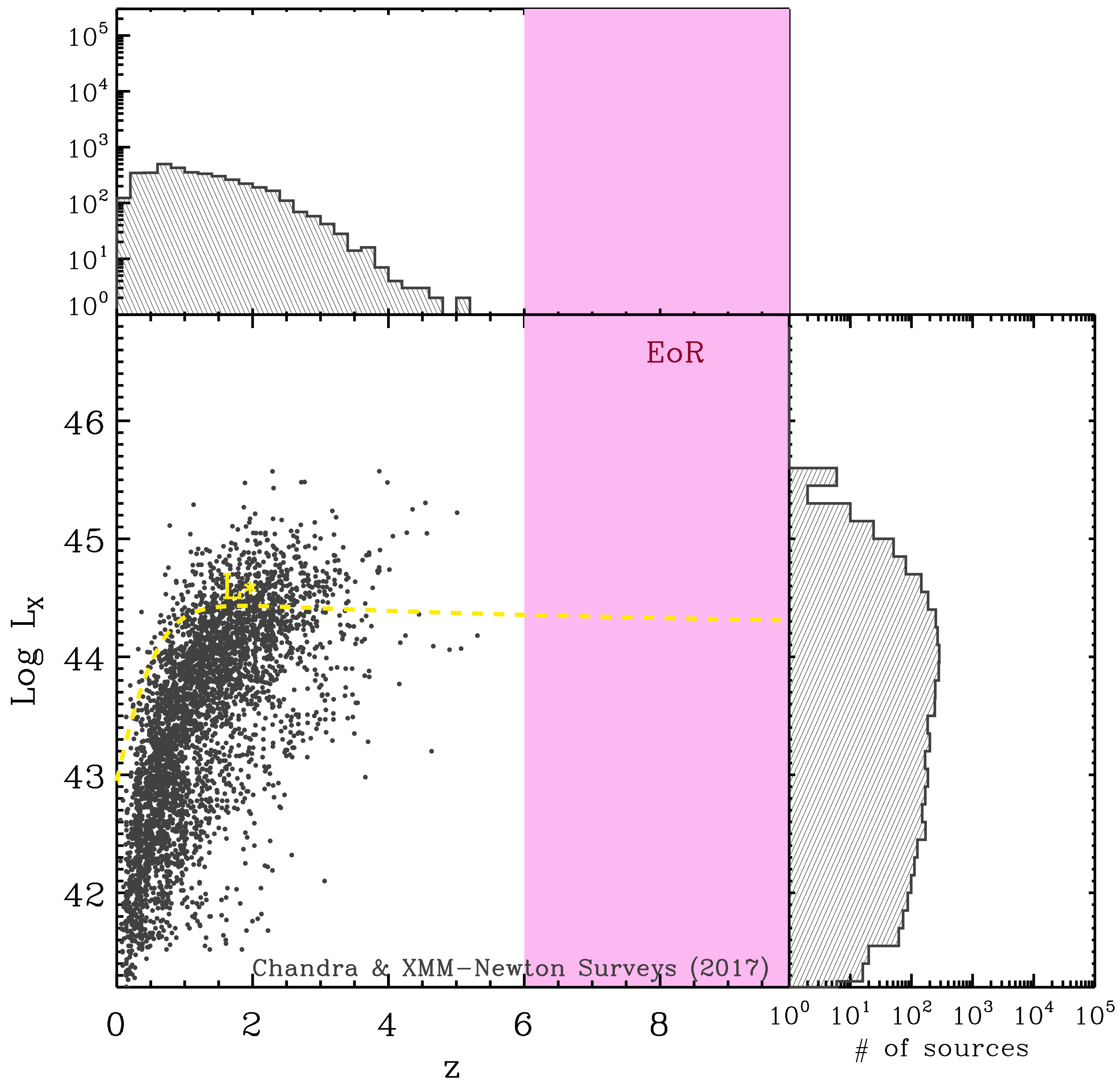


•Formation and Early Growth of Black Holes

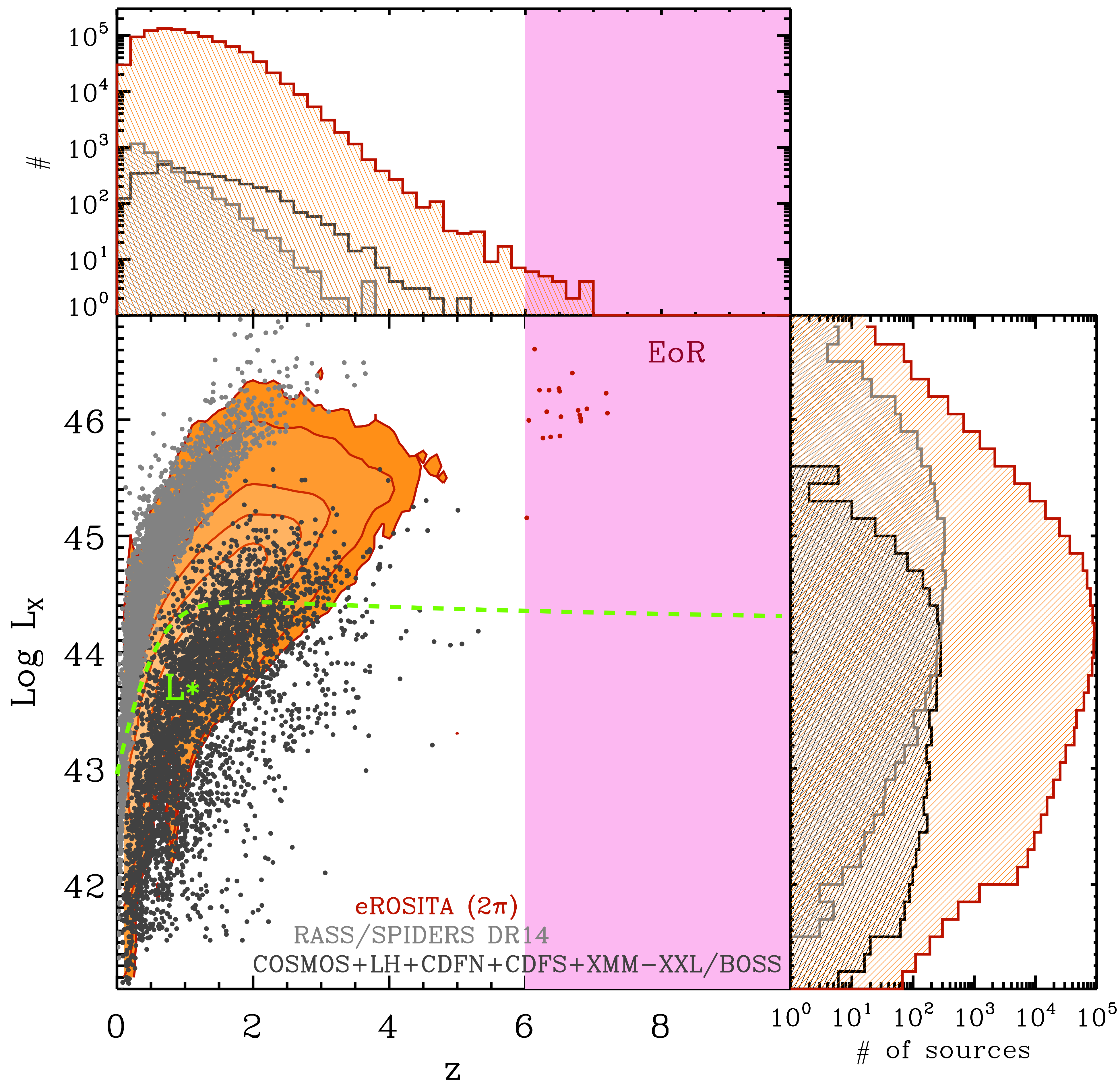
–high-z population and seeds of SMBH

- Accretion through cosmic time
  - complete census of AGN at the peak of activity of the universe
- Accretion Physics
  - spins of compact objects
  - reverberation mapping of X-ray binaries
- Formation and Evolution of Groups and Clusters of Galaxies
  - finding early groups
  - non-gravitational heating processes (entropy profiles)
- AGN feedback in clusters
  - AGN ripples





(Courtesy: A. Merloni)



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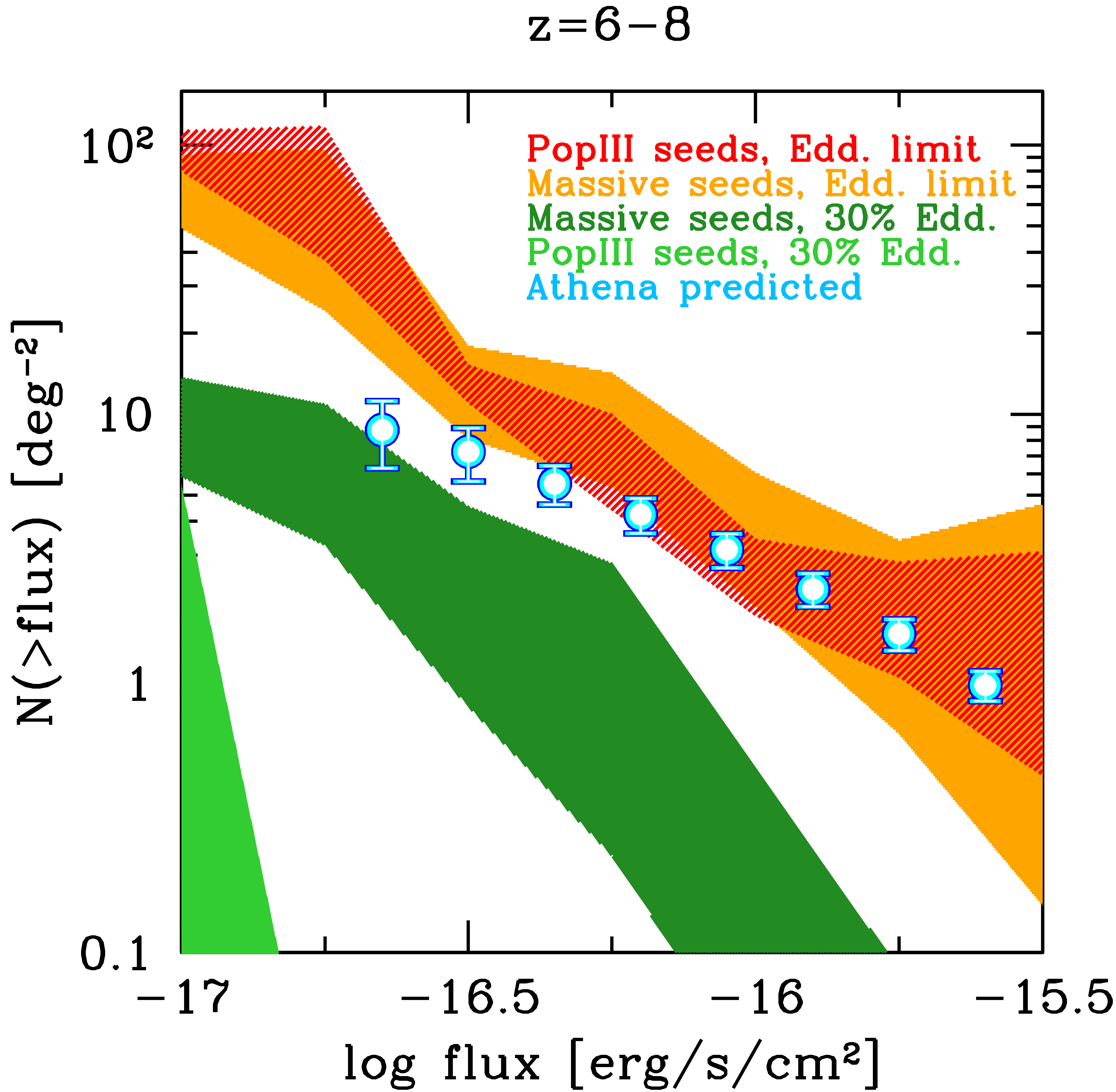

(Aird, Comastri et al. 2013)

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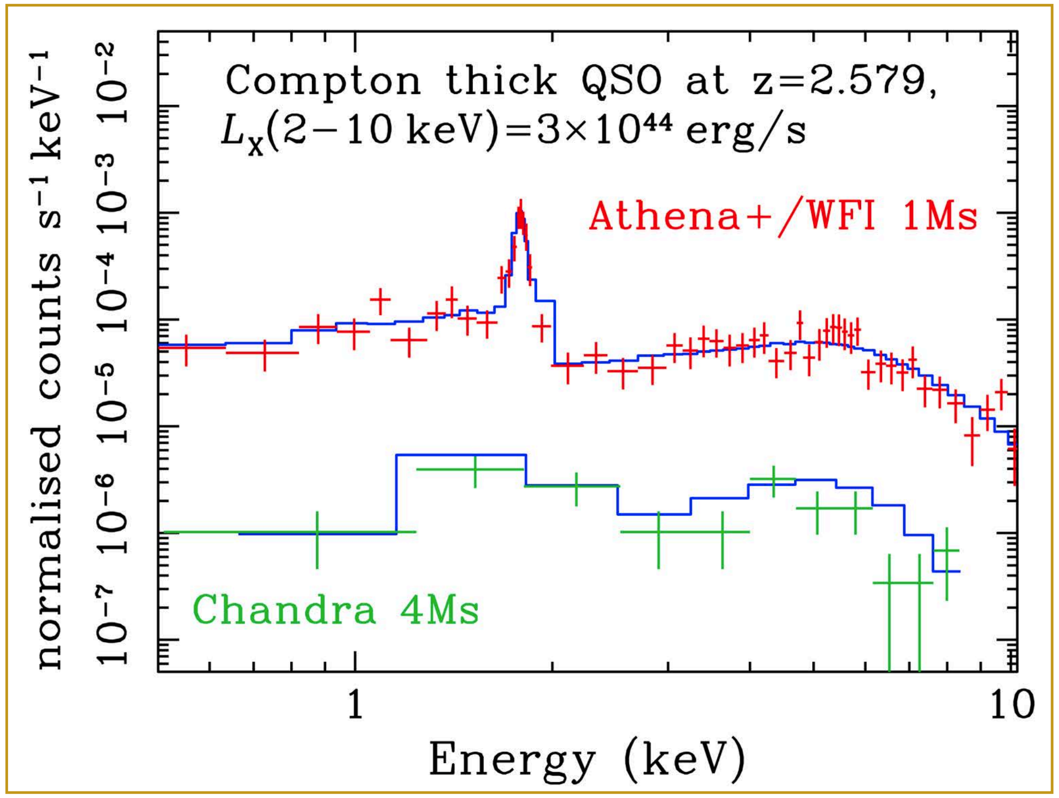

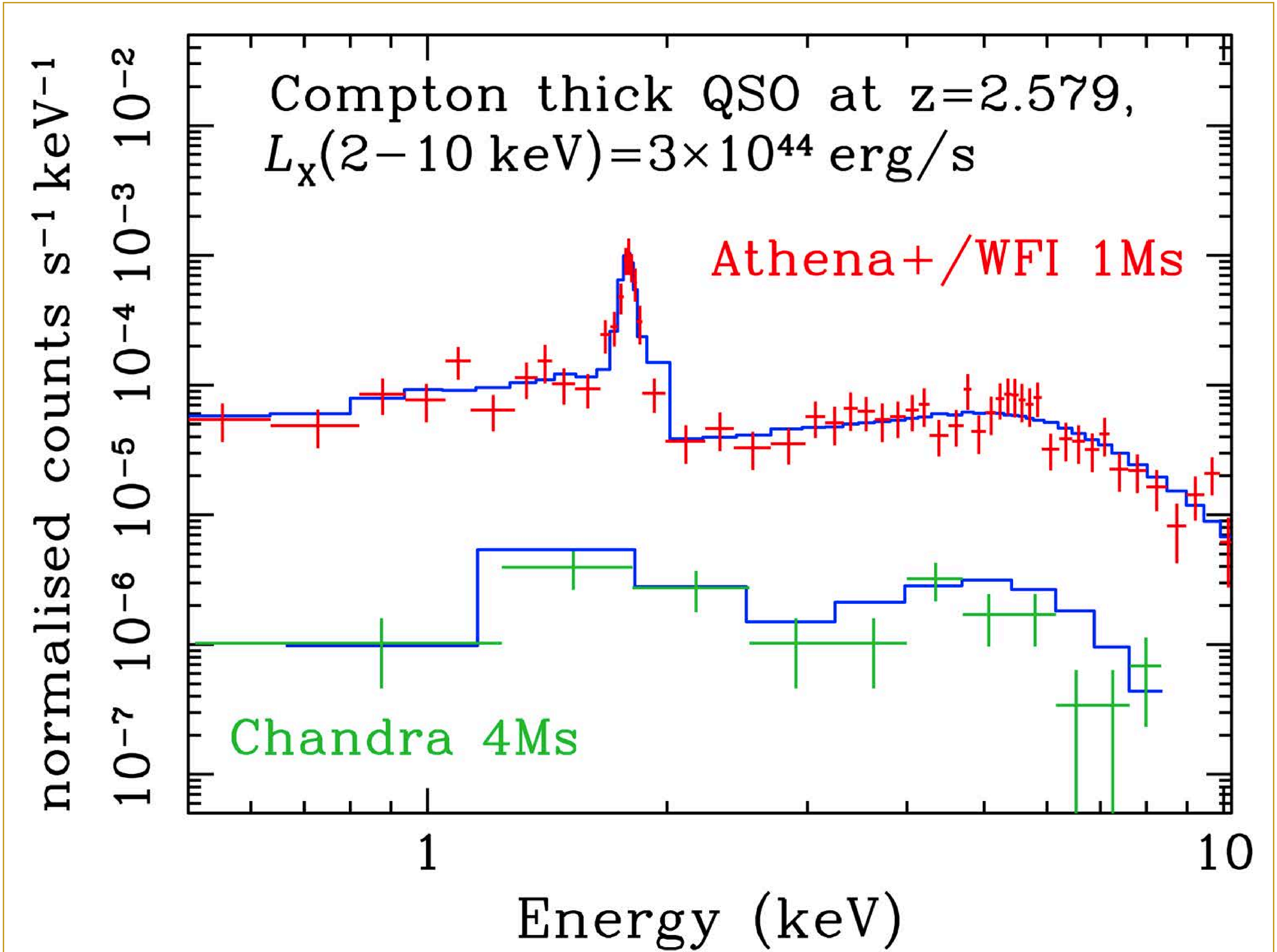

(Georgakis, Carrera et al. 2013)

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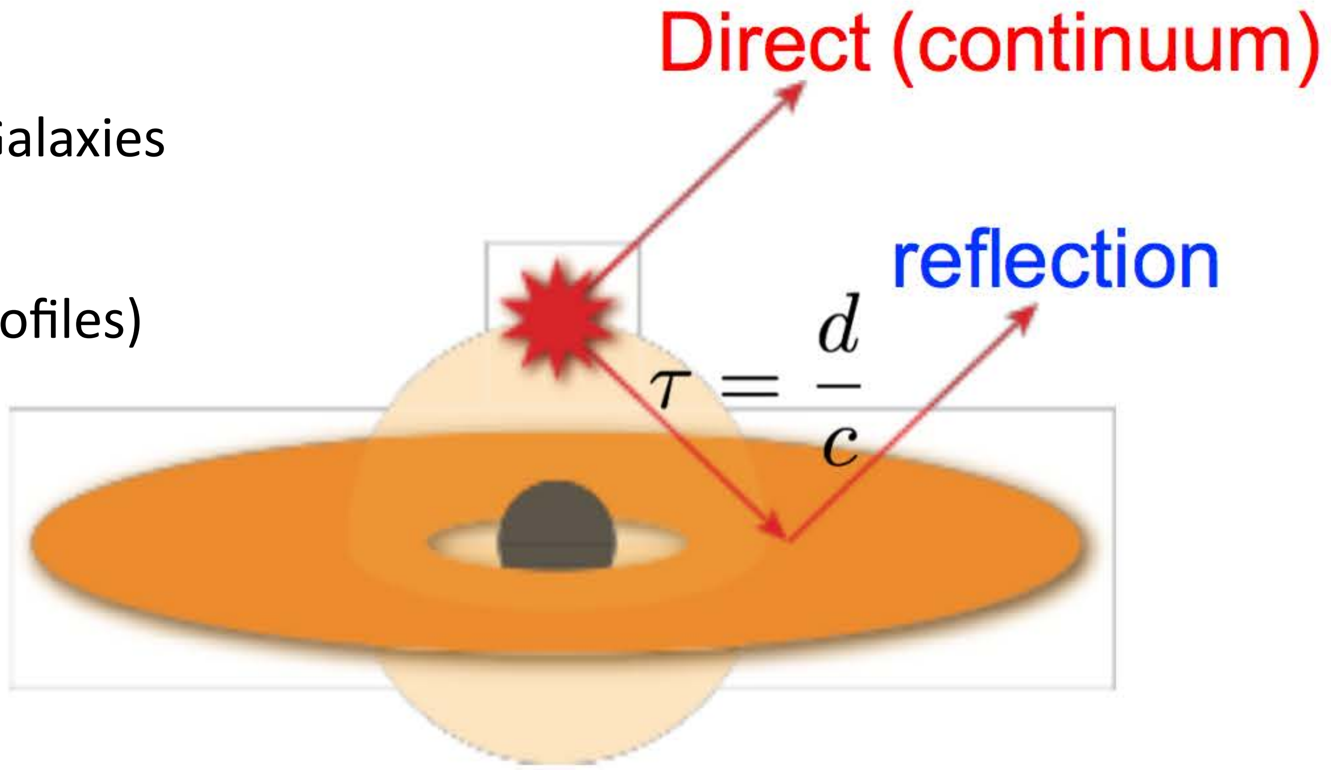
- **Accretion Physics**
  - **spins of compact objects**
  - **reverberation mapping of X-ray binaries**



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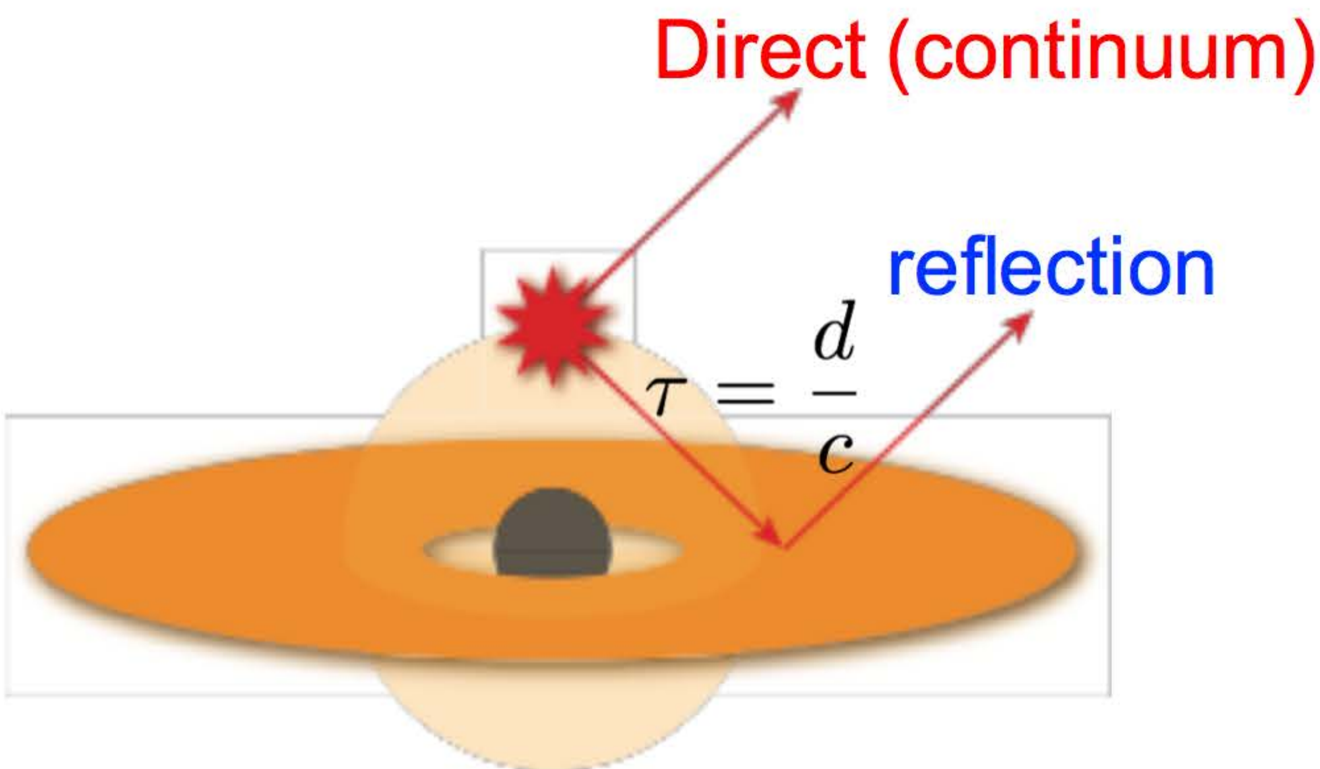
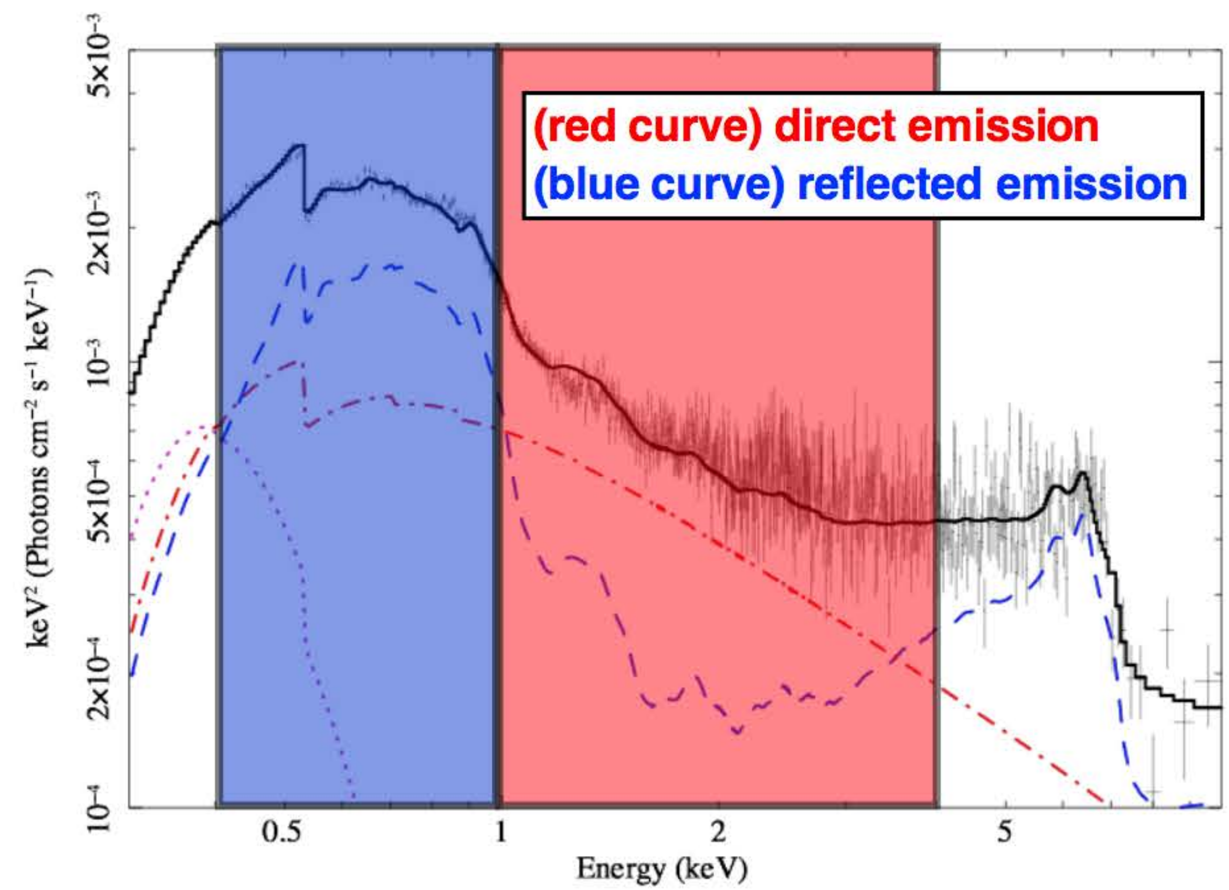
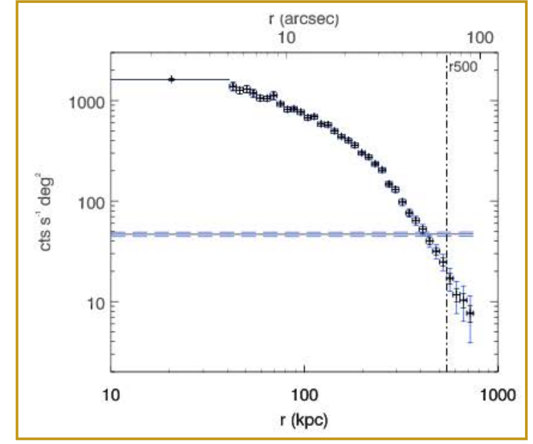
Reverberation Mapping of Galactic X-ray Binaries

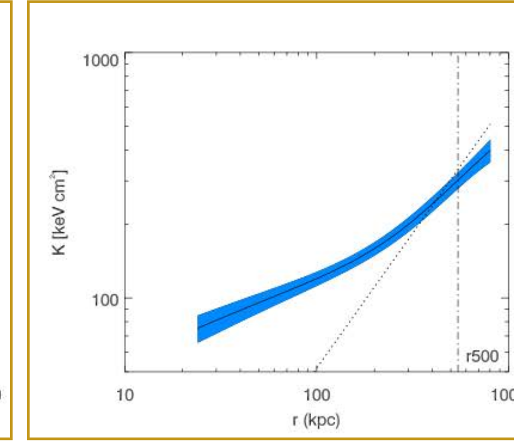




Different light paths → lags between variability in direct emission- and reflection-dominated bands.

(Courtesy: S. Allen)





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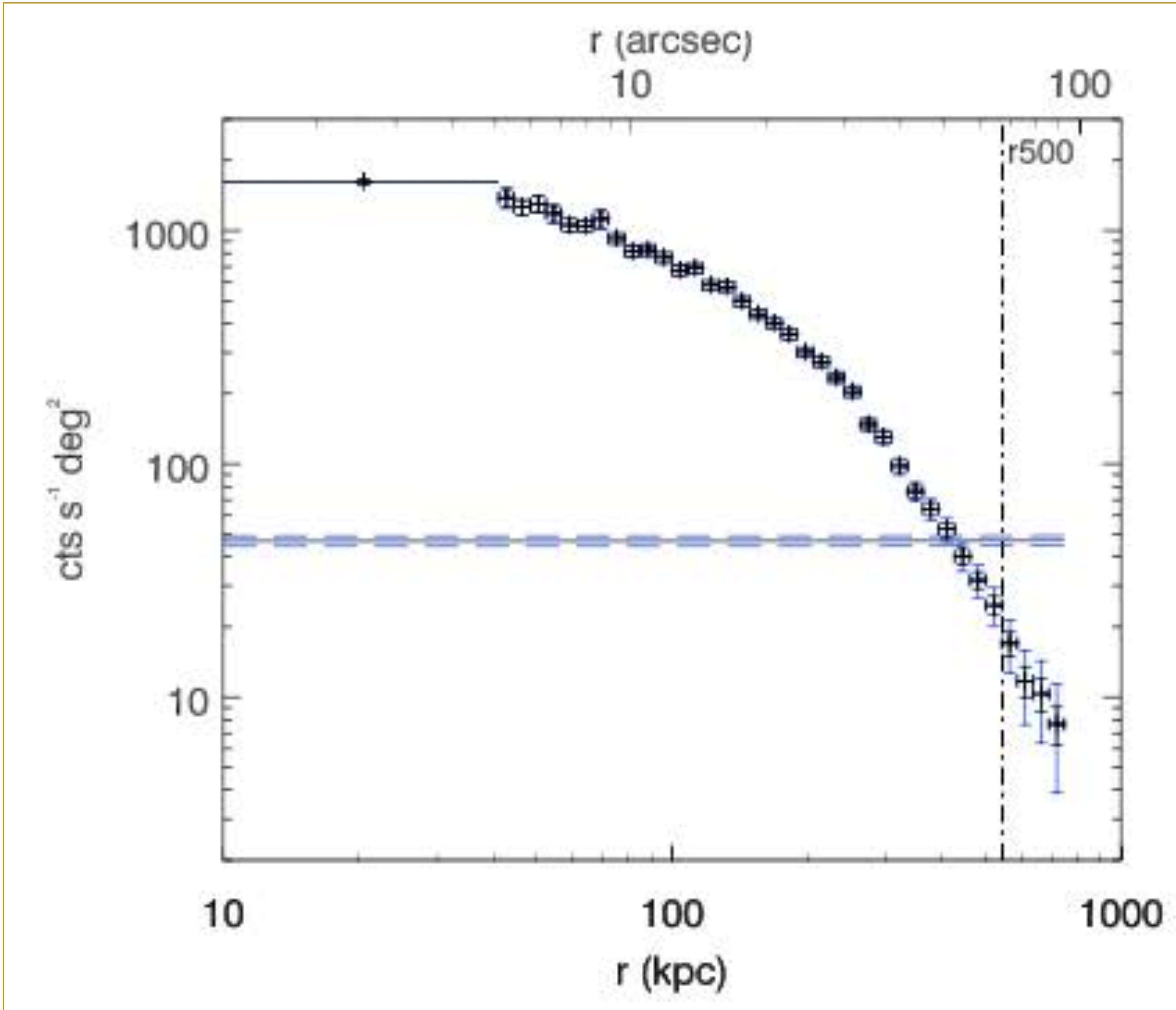
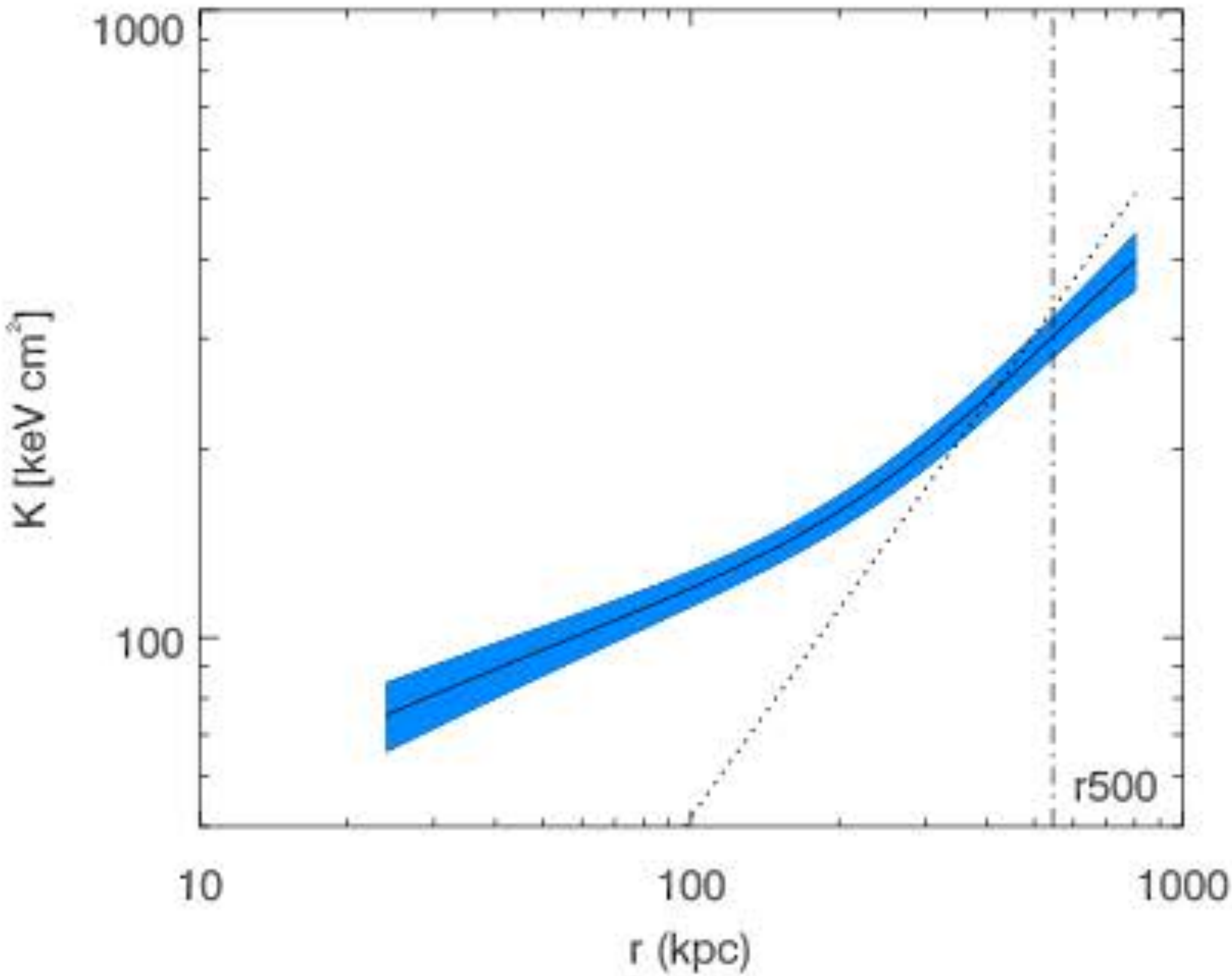


(Pointecouteau, Reiprich et al. 2013)



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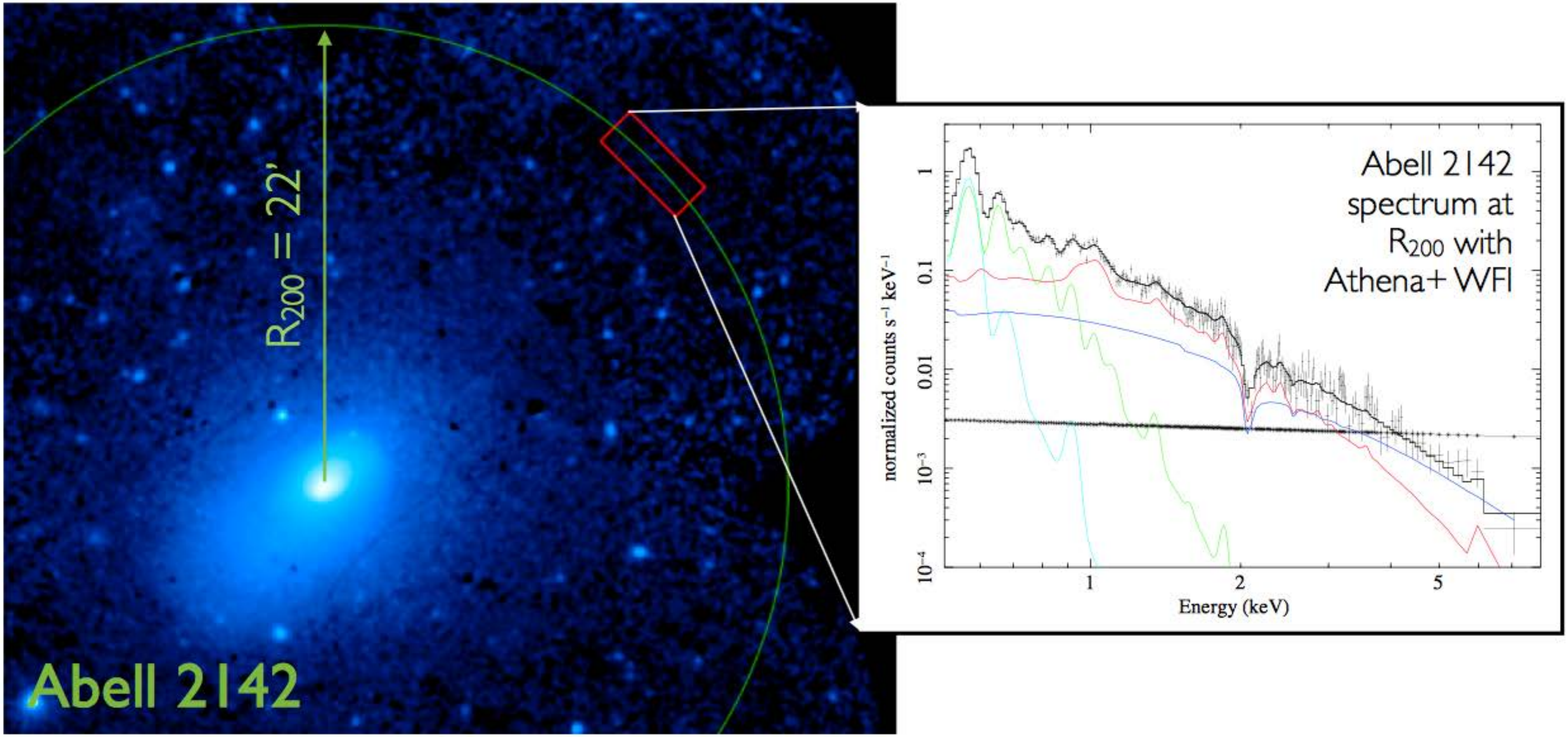
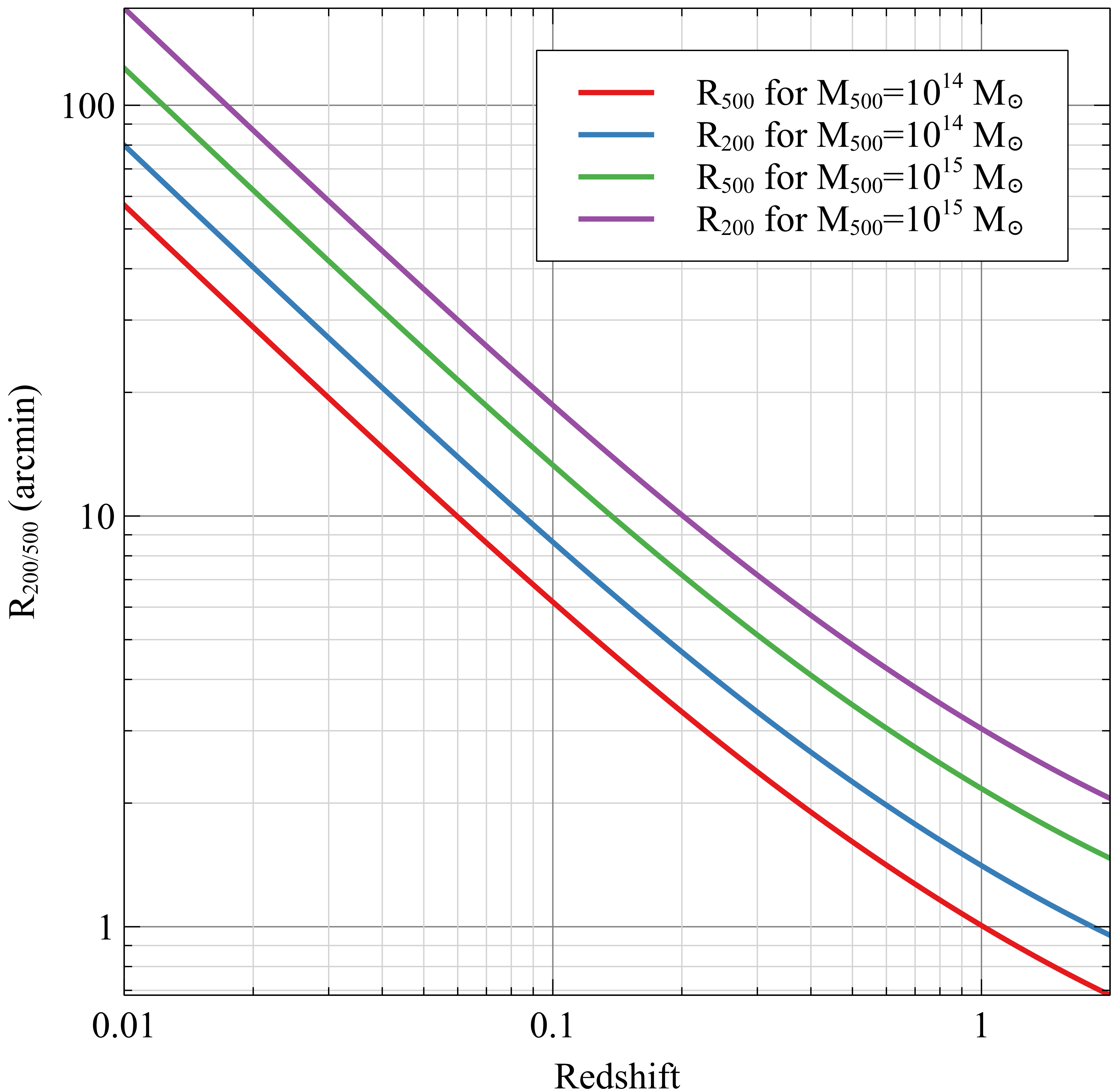


(Ettori, Pratt et al. 2013)

RADIUS OF GALAXY CLUSTERS VS REDSHIFT



(Courtesy: J. Sanders)

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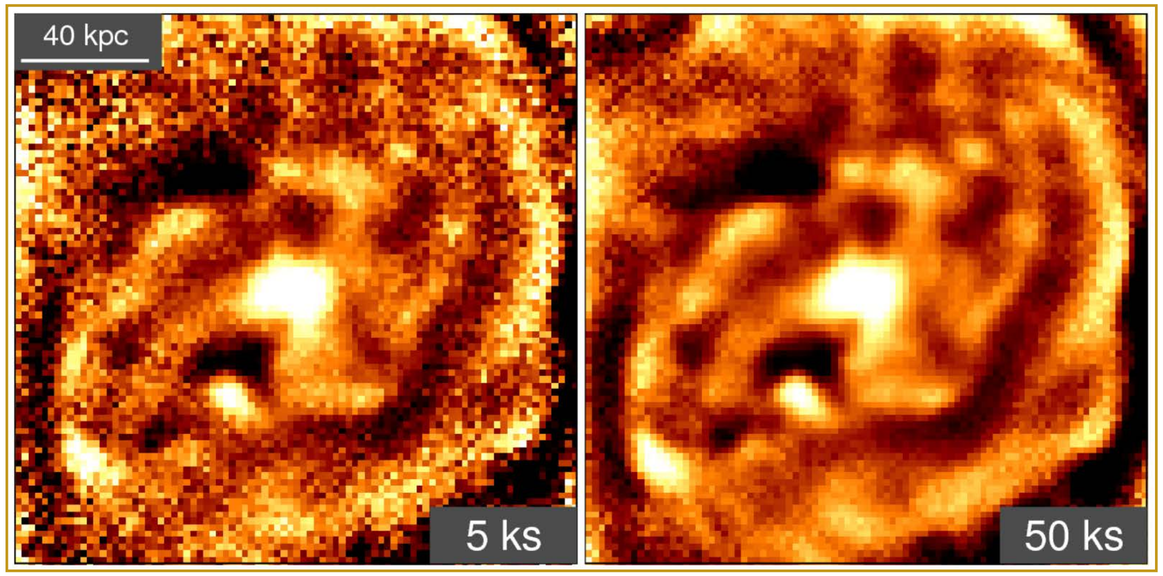
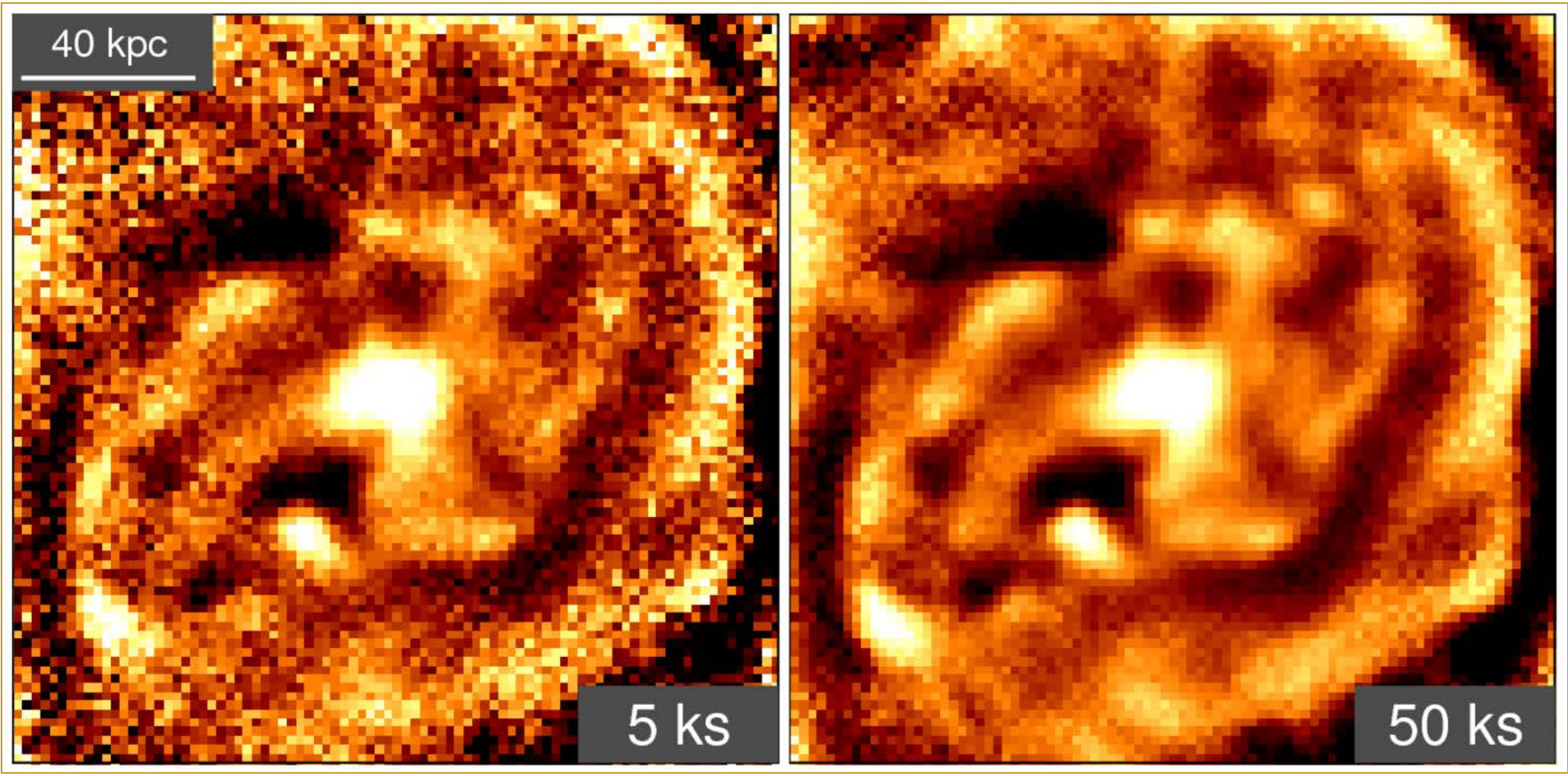




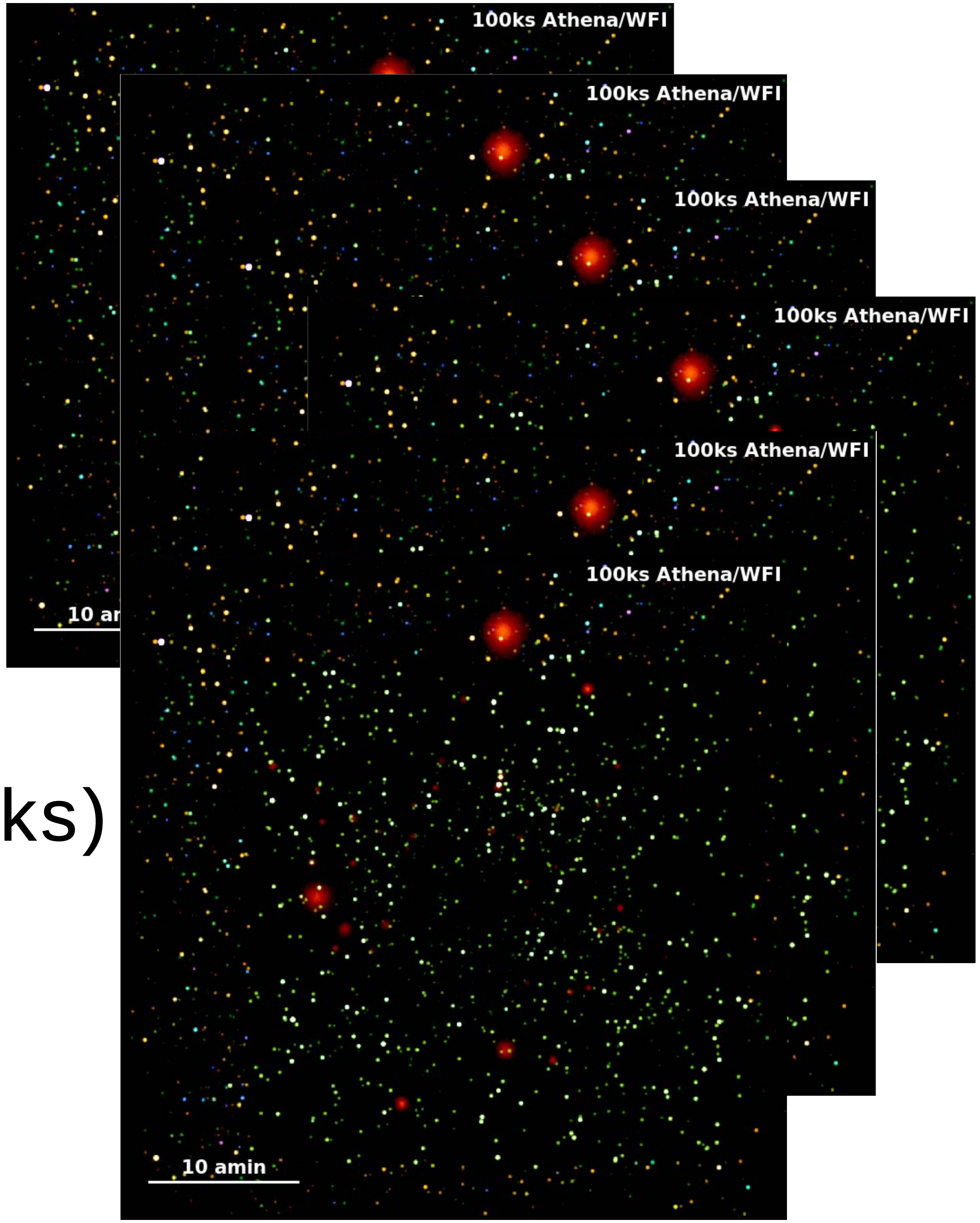
(Croston, Sanders et al. 2013)

MULTI-TIERED SURVEY

required for:
high-z AGN,
Compton Thick AGNs,
Ultra-fast outflows,
early groups

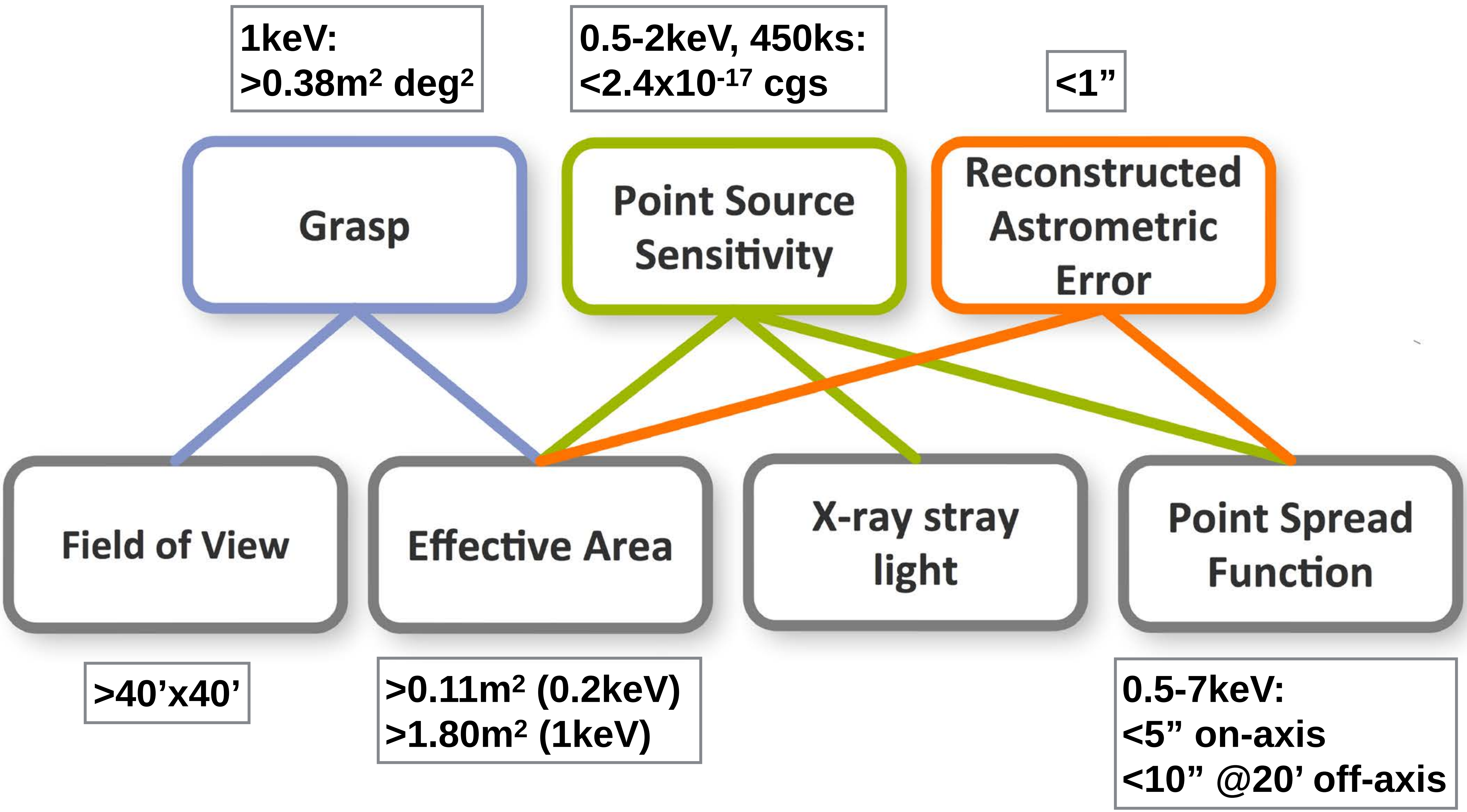
Composed of:
shallow (e.g., ~100x60ks)
medium (10x600ks, 3x700ks)
deep (4x1Ms)

~50 deg^2 of ‘famous’ fields

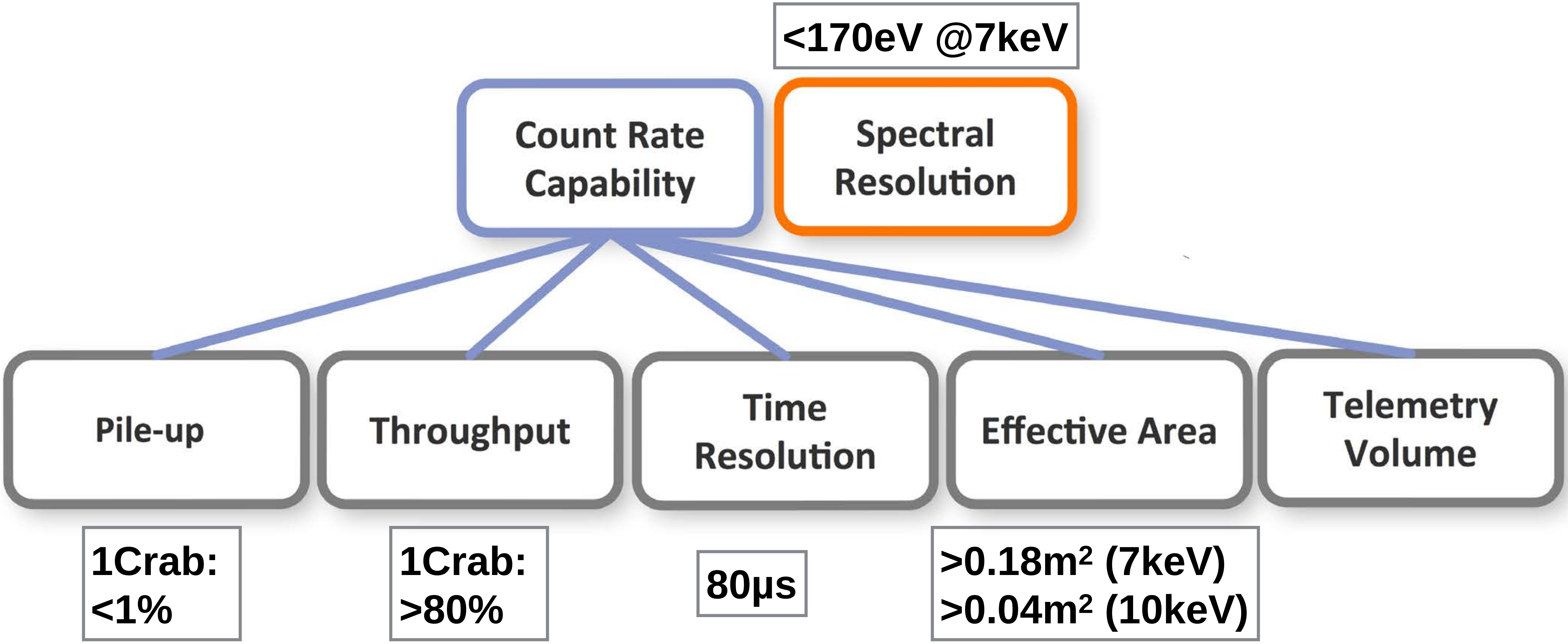


Key Science Requirements

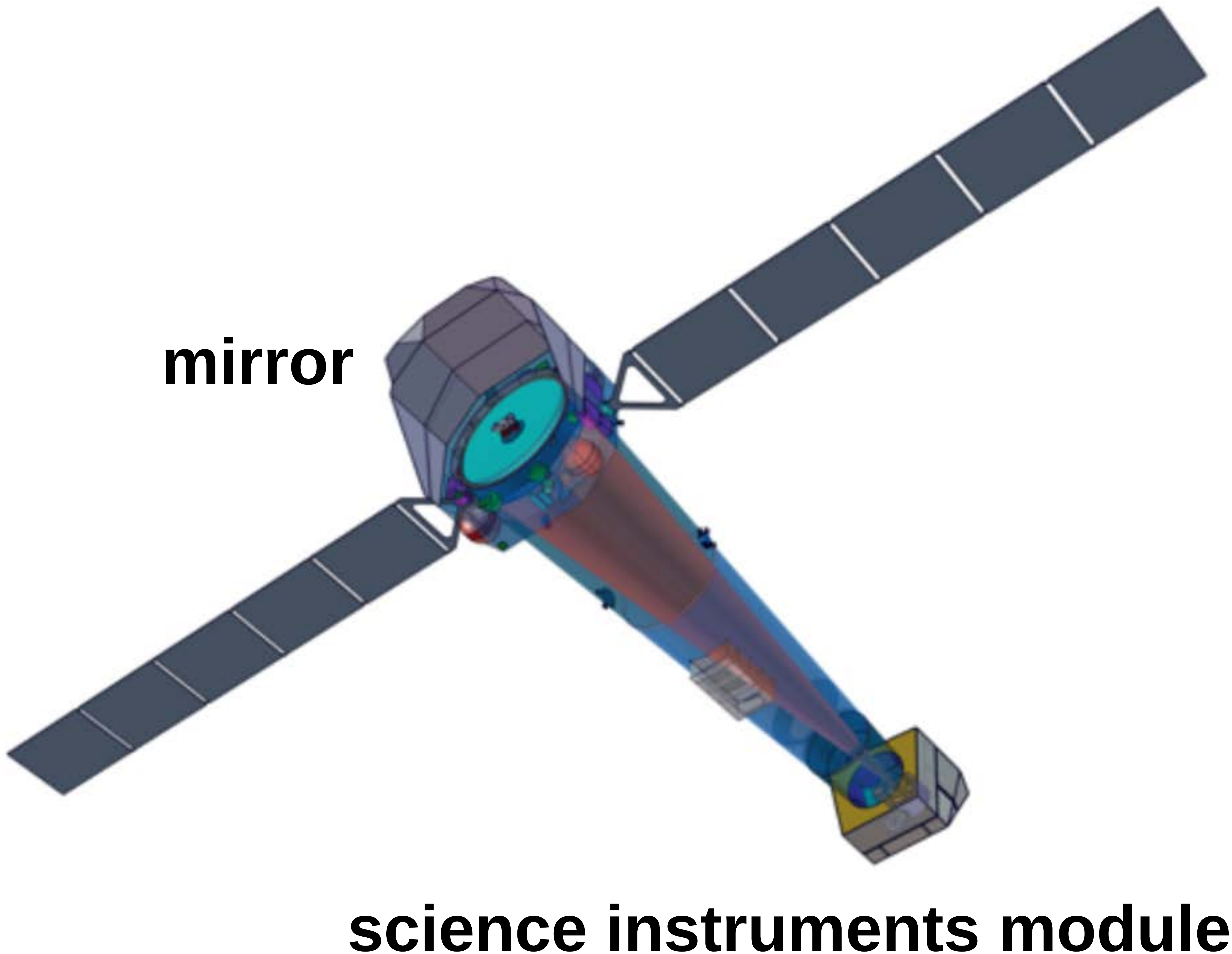
Key science requirements for high-z AGN:



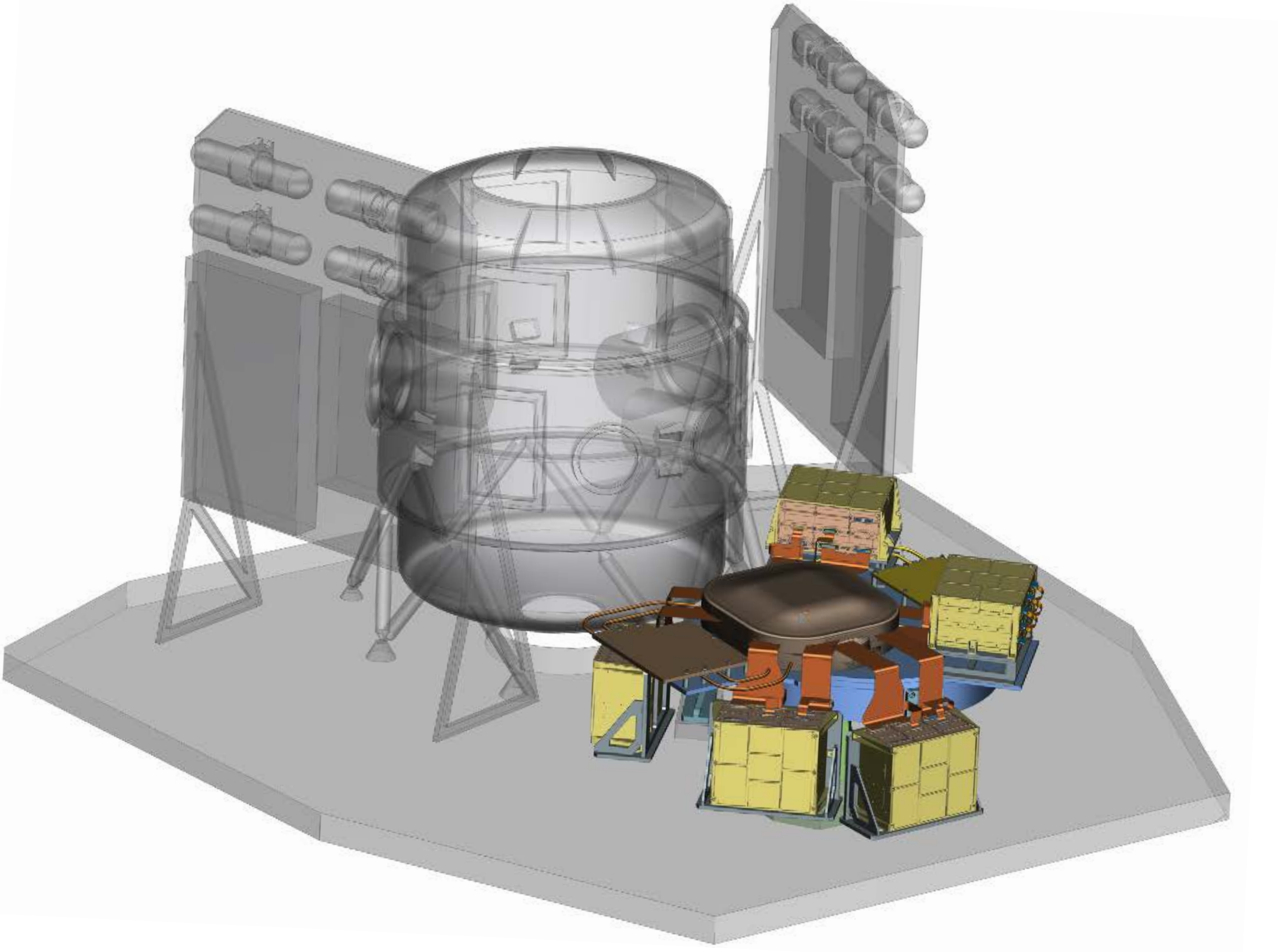
Key science requirements for GBH spin:

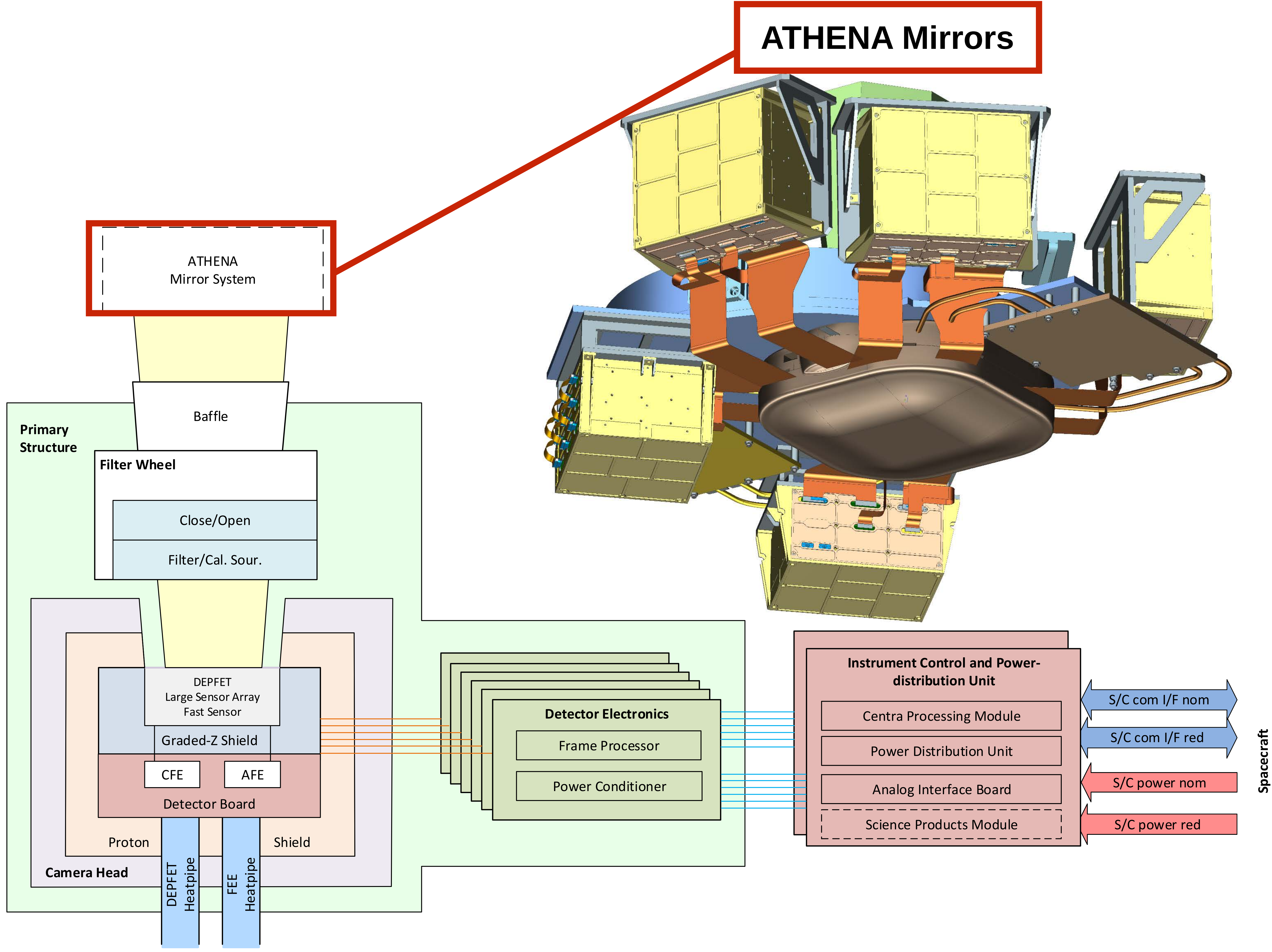


Instrument & Development Status



(Credit: ESA CDF)





ATHENA Mirrors
ATHENA
Mirror System
Baffle
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Close/Open
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DEPFET
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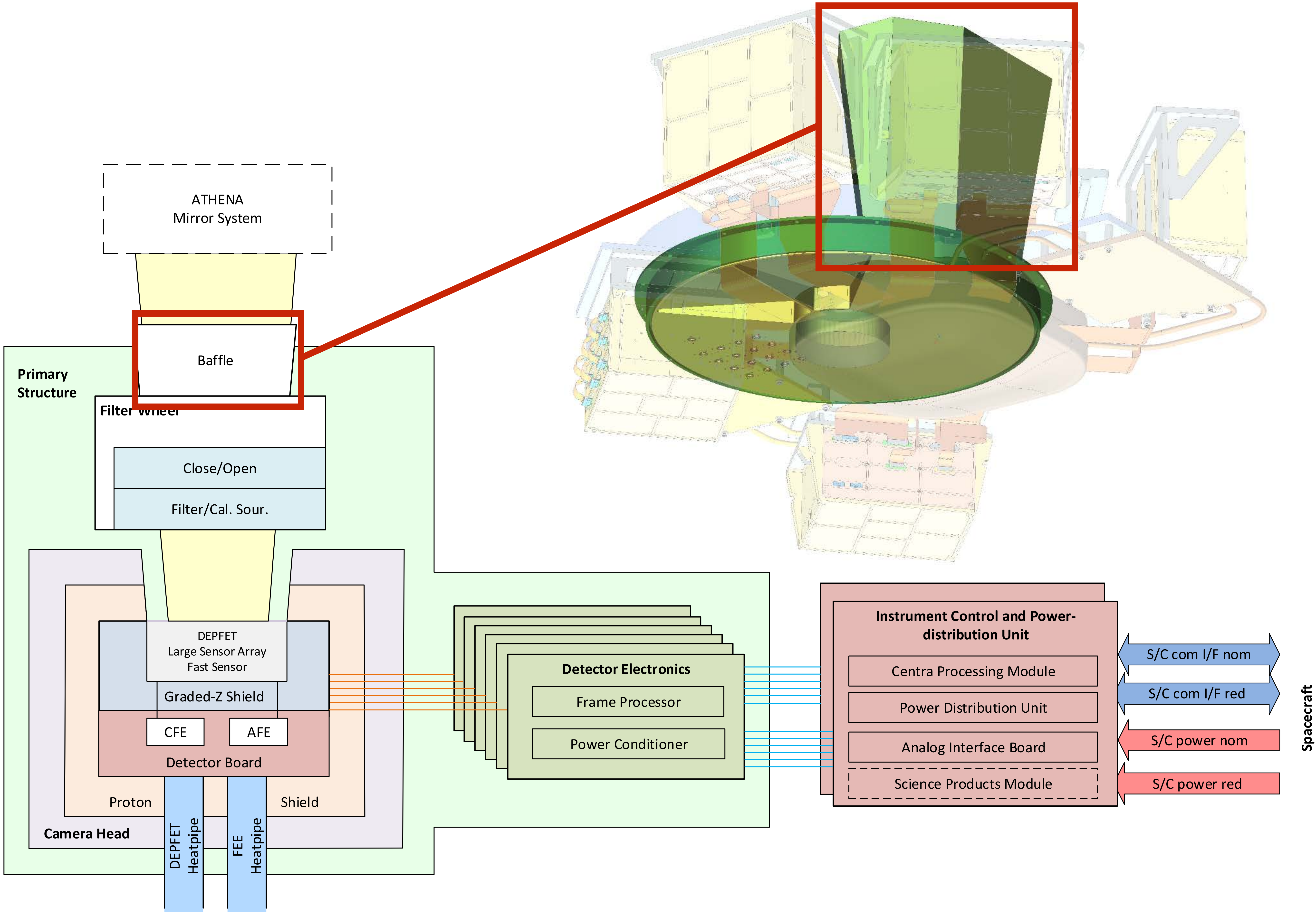
Spacecraft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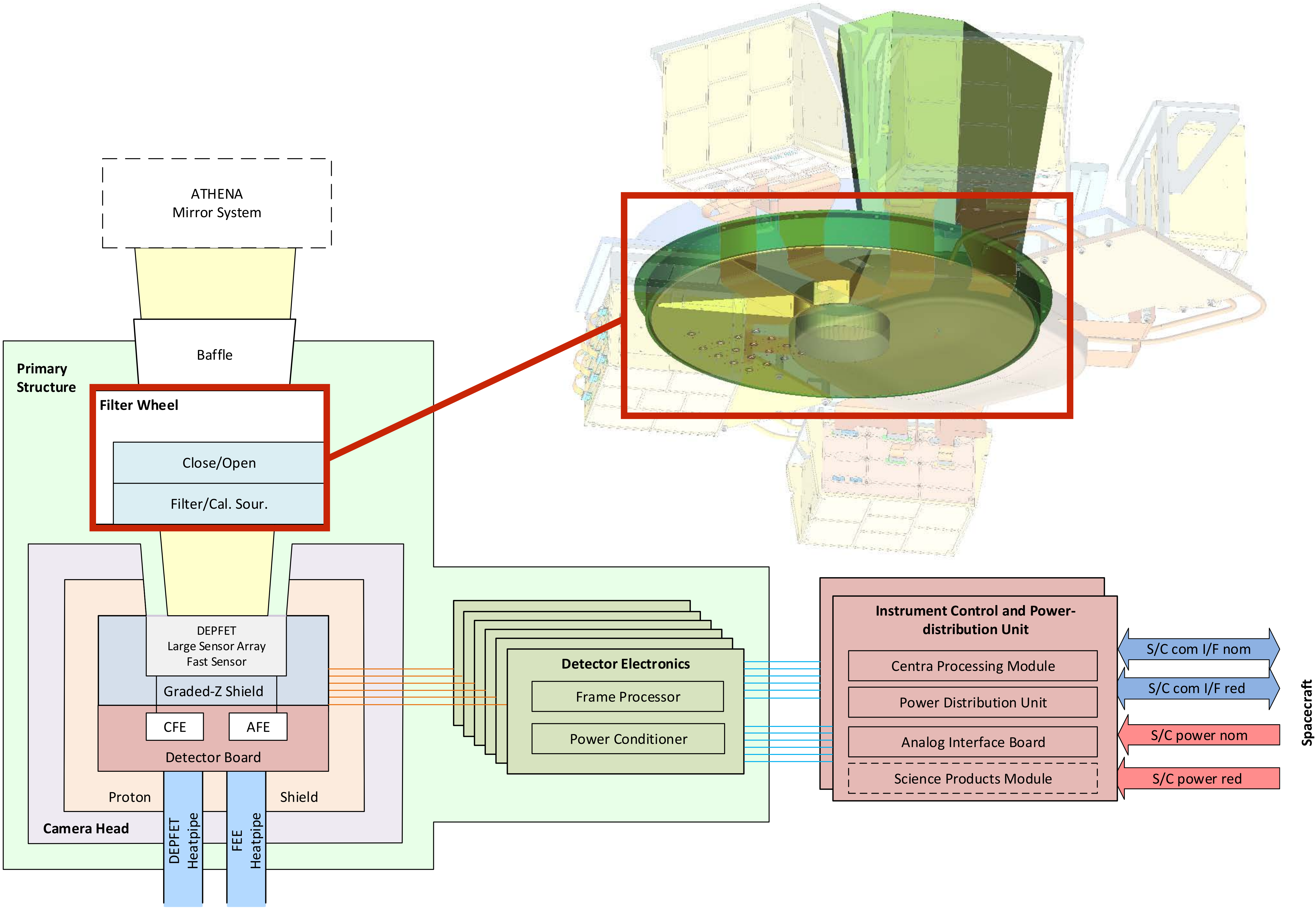
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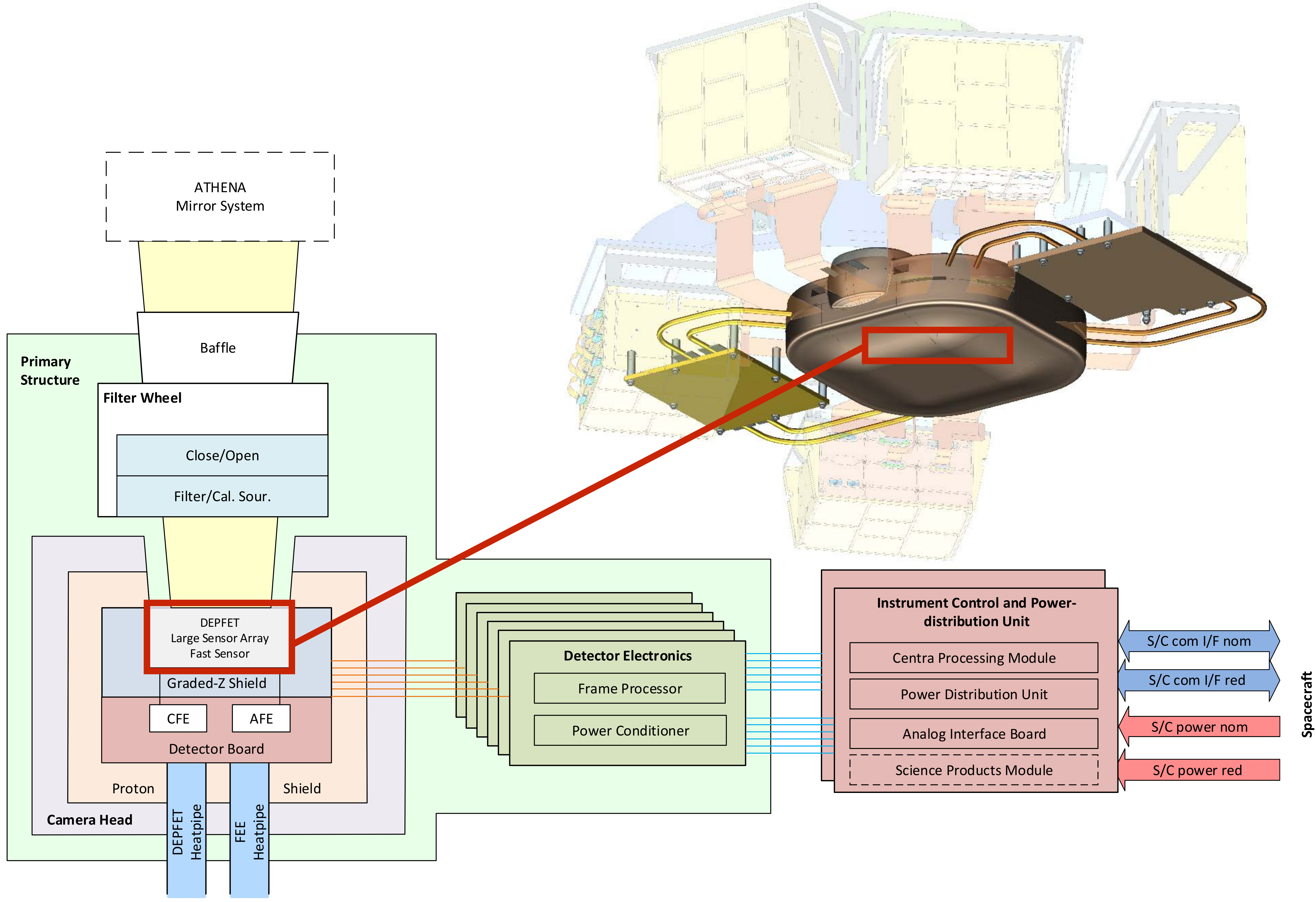
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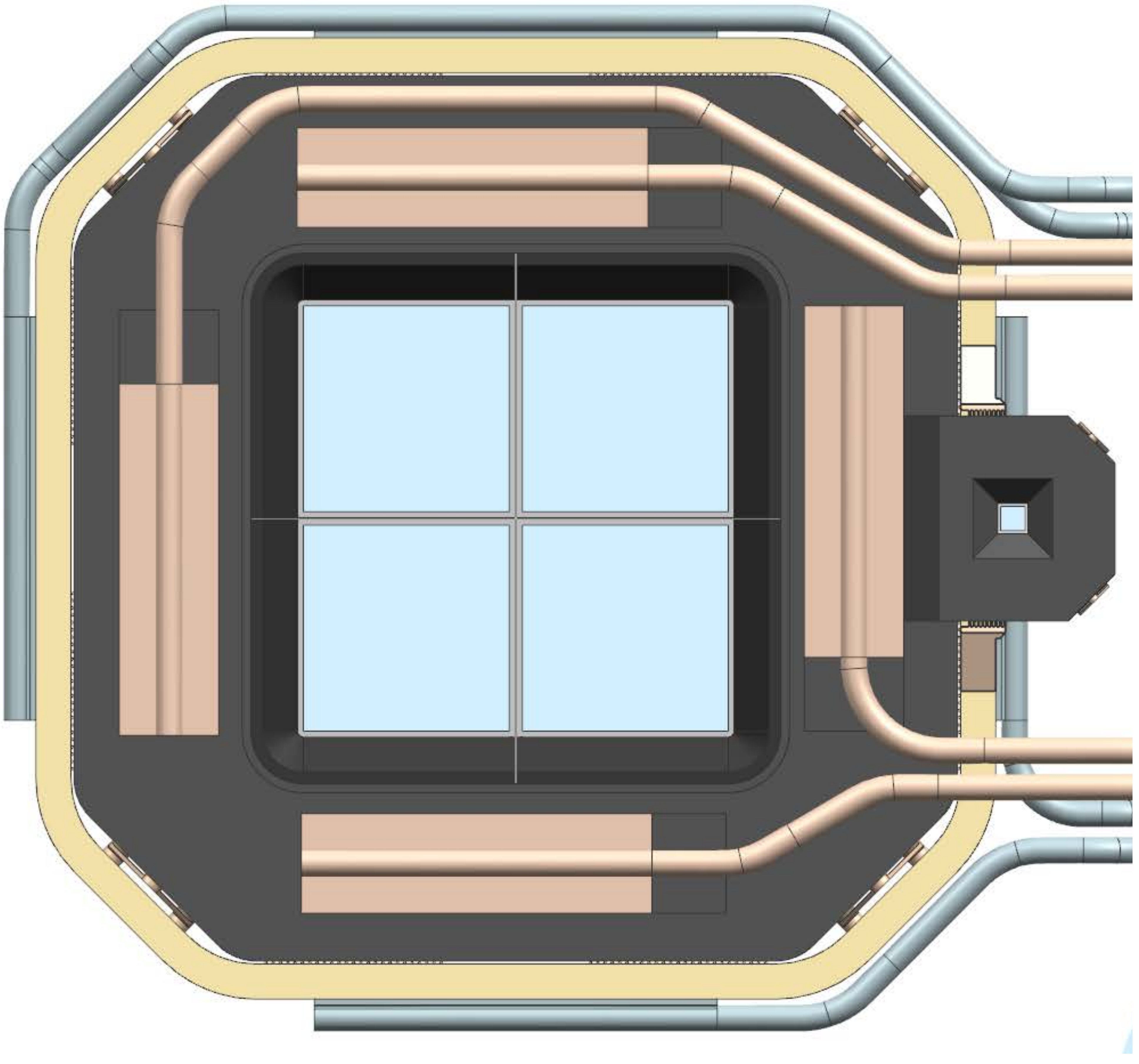


Large Detector Array

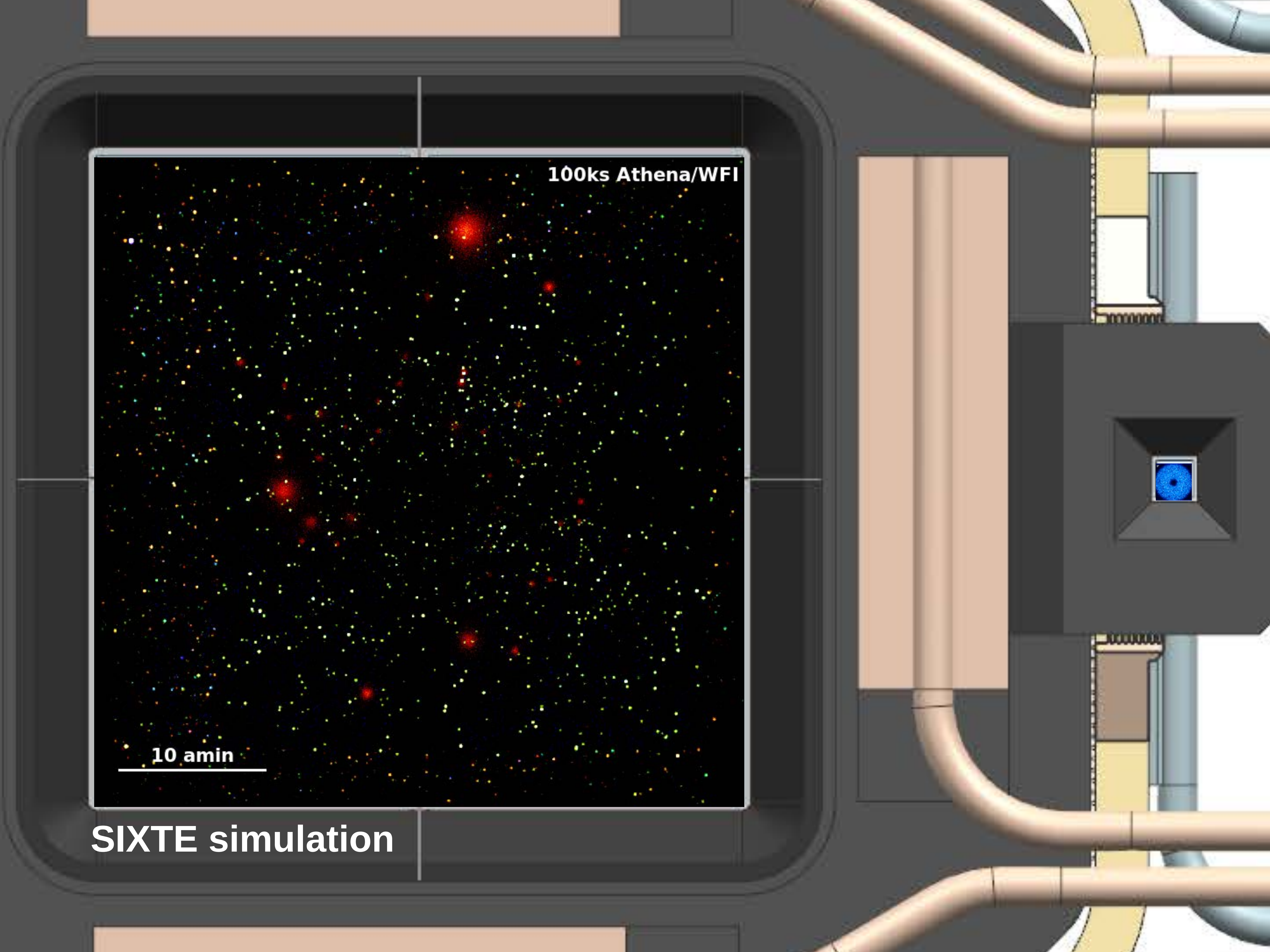
- 40'x40
- 4x512x512 pxl
- <5ms/frame
  <10µs/row

Fast Detector

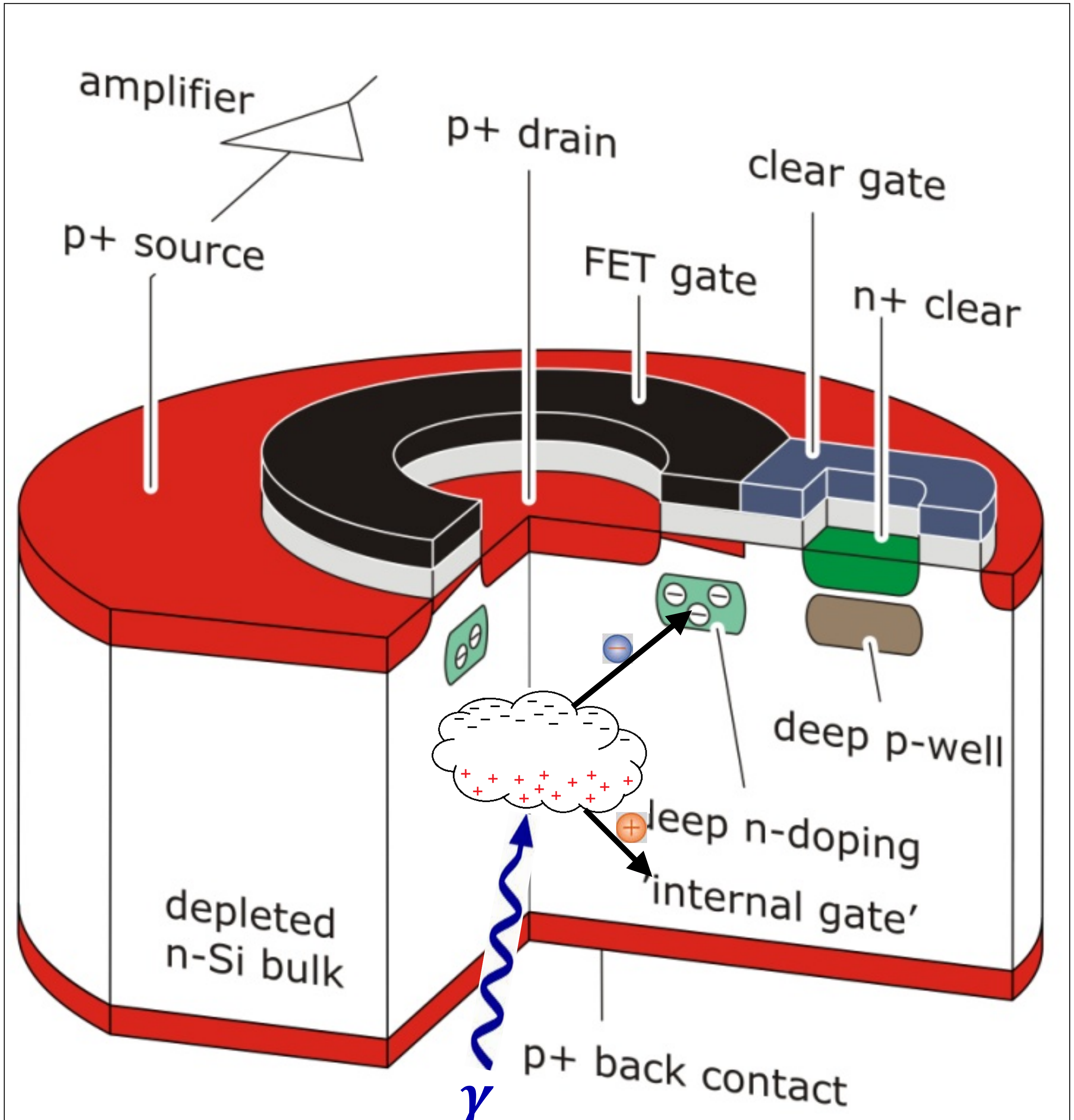
- defocused
- 64x64(/2) pxl
- <80µs/frame
  <2.5µs/row

Both

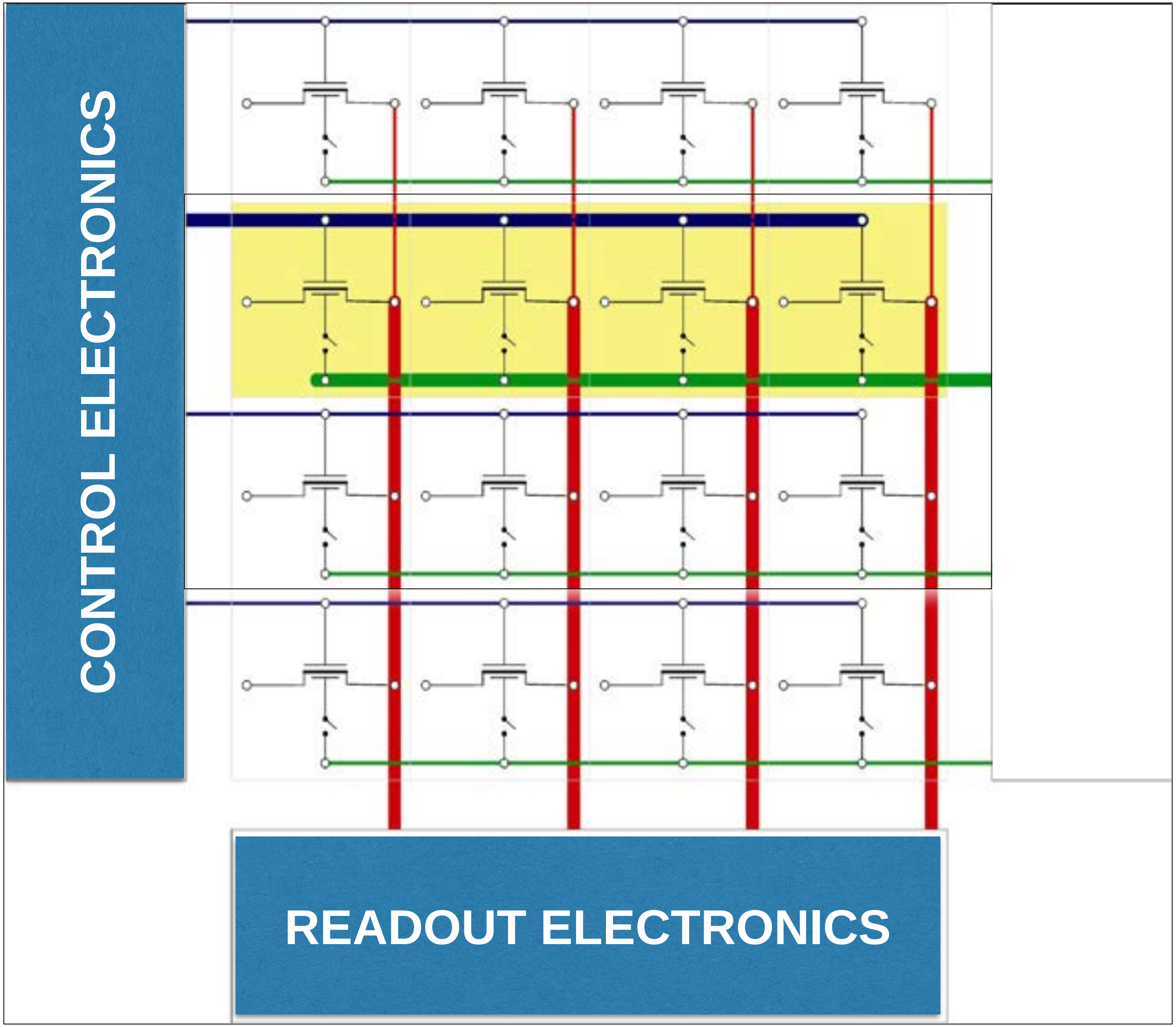
- 130µmx130µm
- DEPFET technology


100ks Athena/WFI
10 amin
SIXTE simulation

The WFI uses matrices of DEPFET active pixel sensors.



All pixels in one active row are read out simultaneously.



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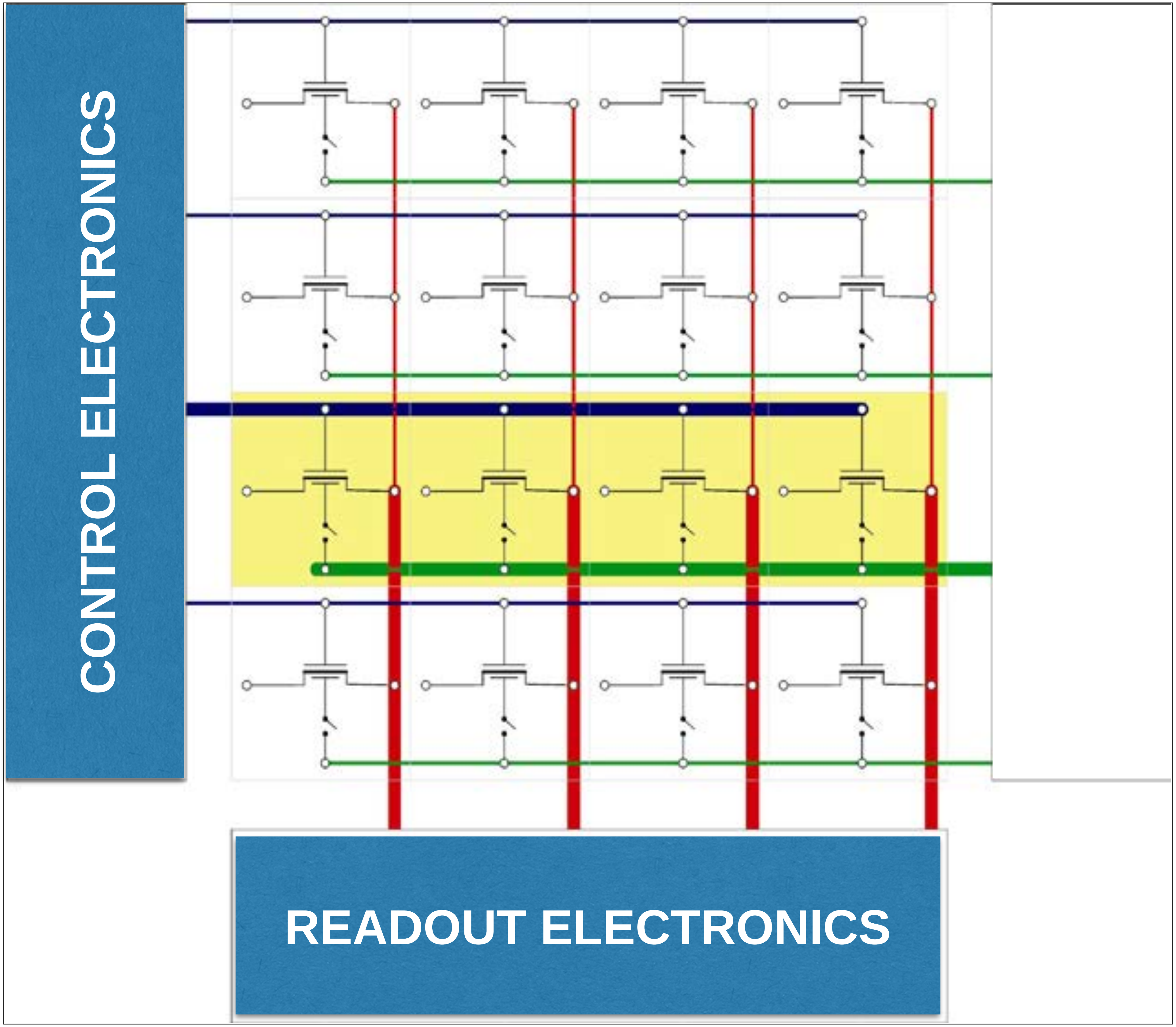

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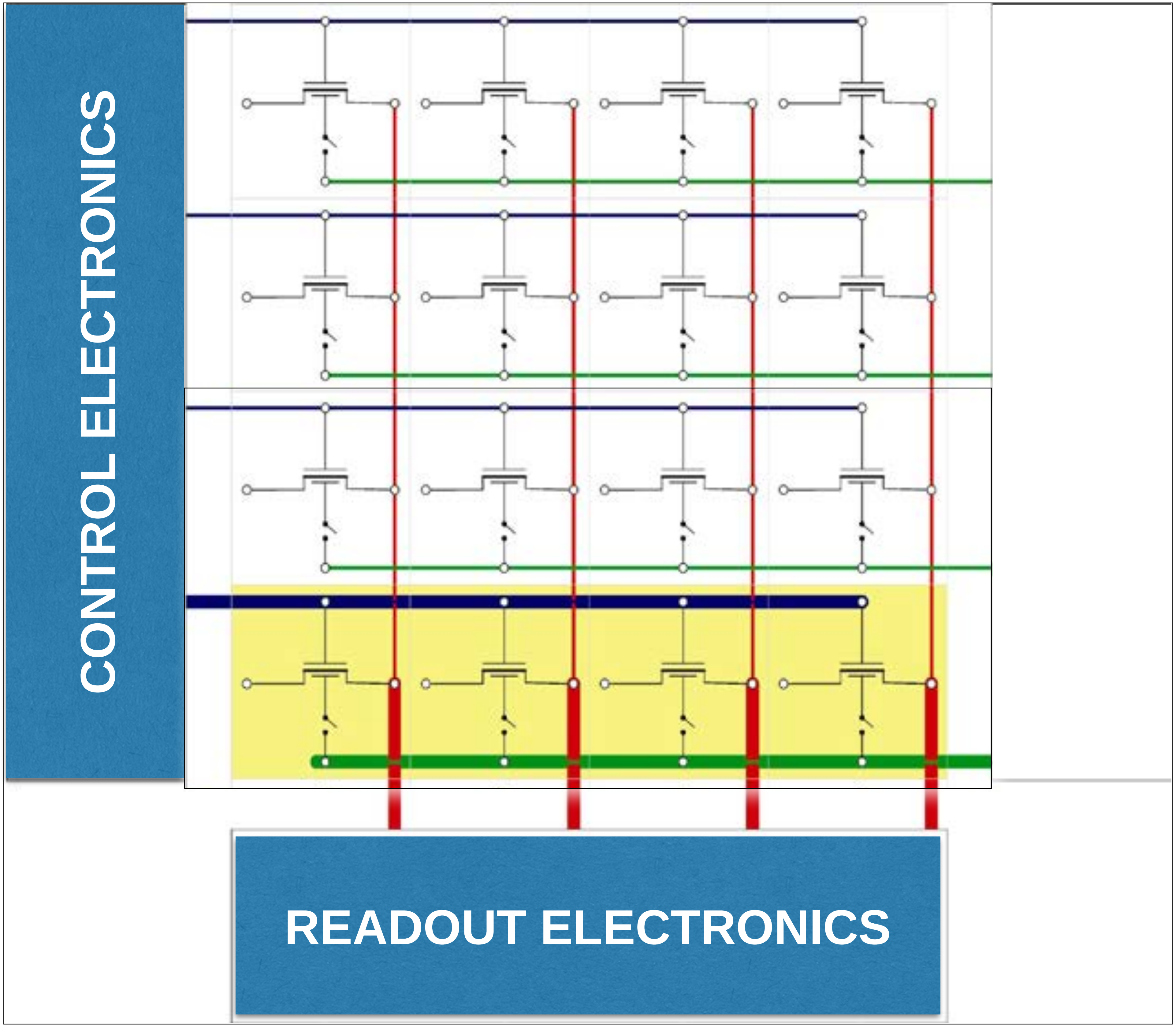
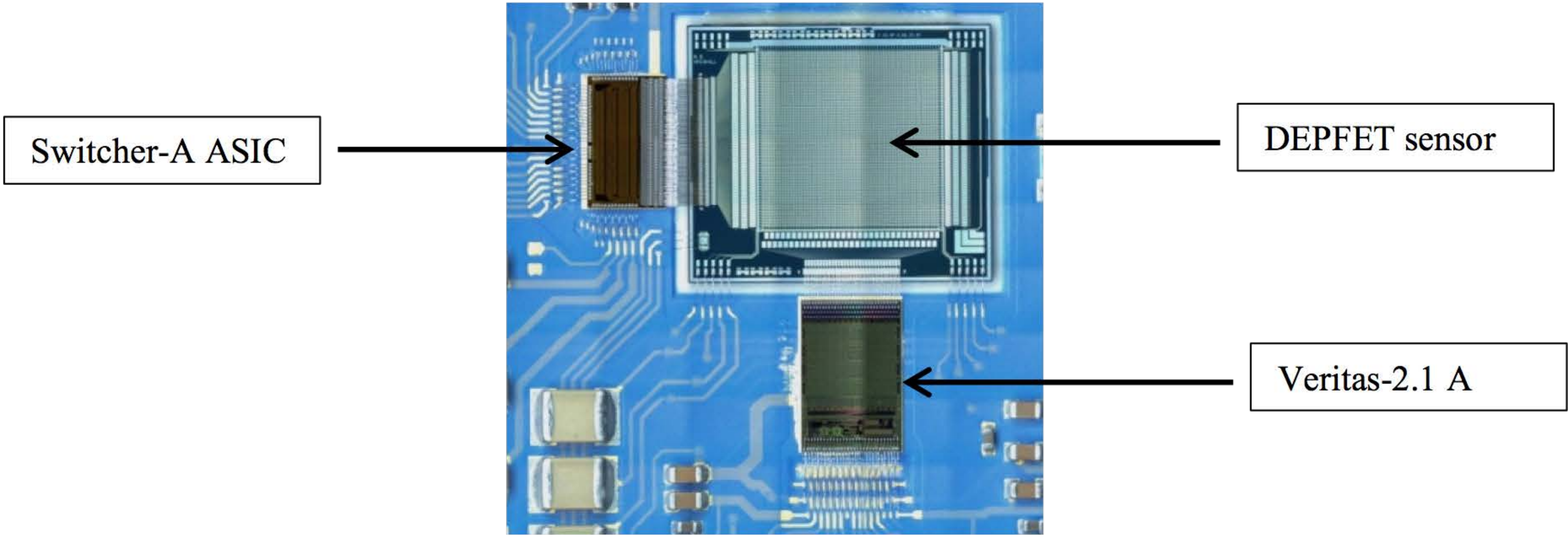


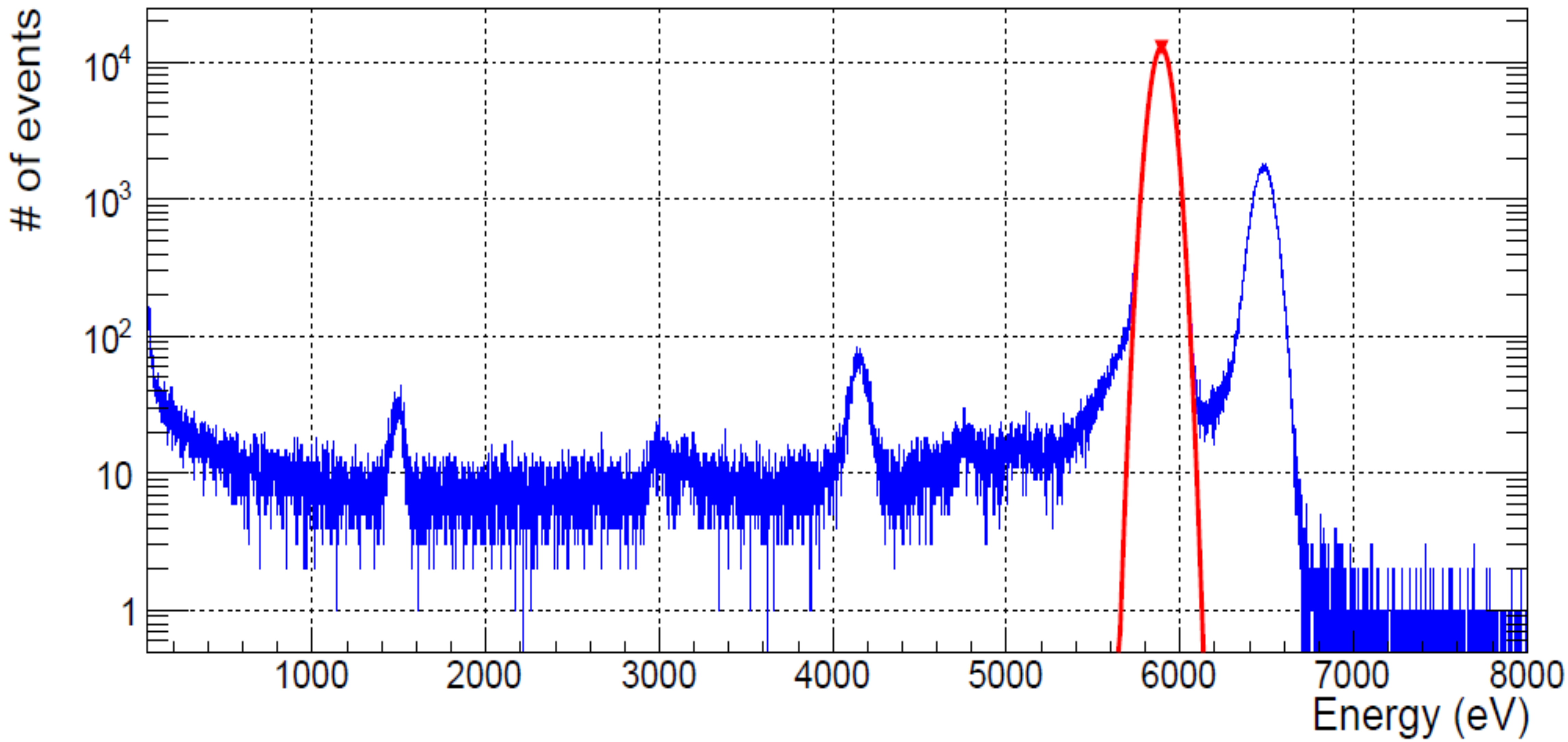
DETECTOR DEVELOPMENT

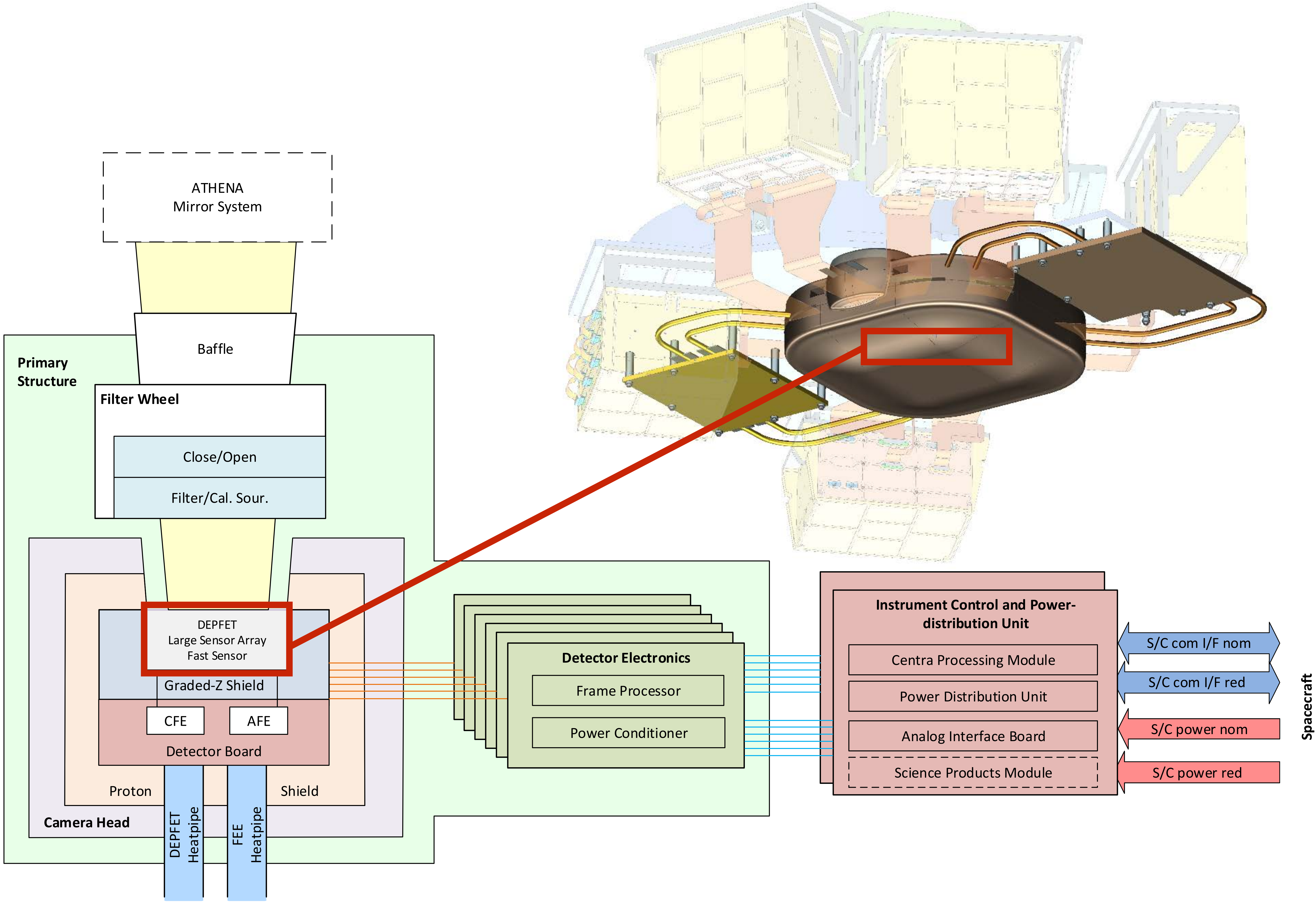
- Variety of prototype WFI DEPFET sensors produced at MPG HLL
  → tested at MPE
- Aim: determine best **technology option** + best **transistor design**
  by systematic measurements using **64x64** pixel matrices



64x64 pxl (FD):
- σ ≈ **2.0 - 2.5 el.** rms + FWHM(5.9keV)≈**130eV** for **2.5 µs/row** (= FD req.)

256x256 pxl (1/2 LD):
- σ ≈ **2.5 el.** rms + FWHM(5.9keV)≈**134eV** for **8.7 µs/row**

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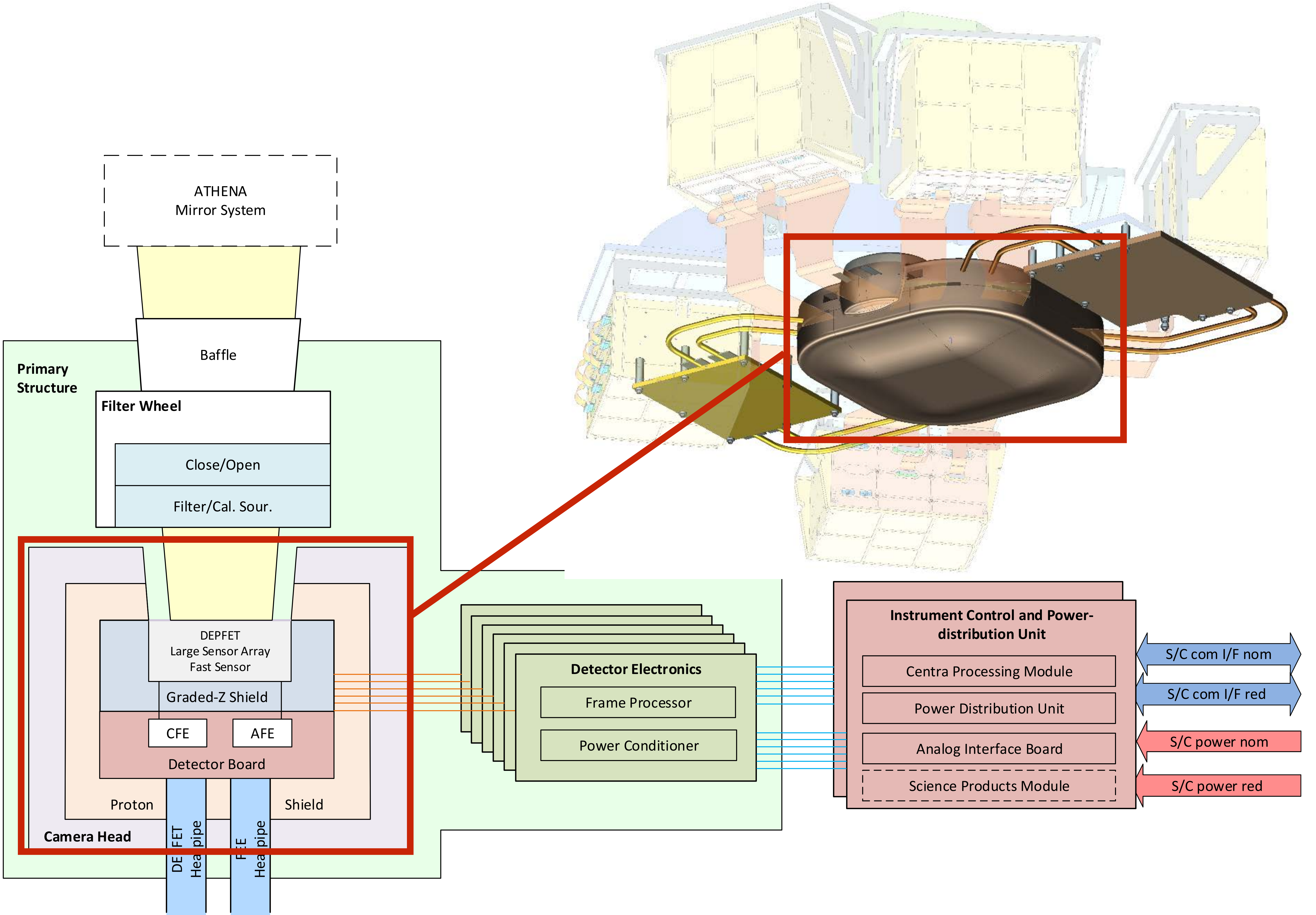
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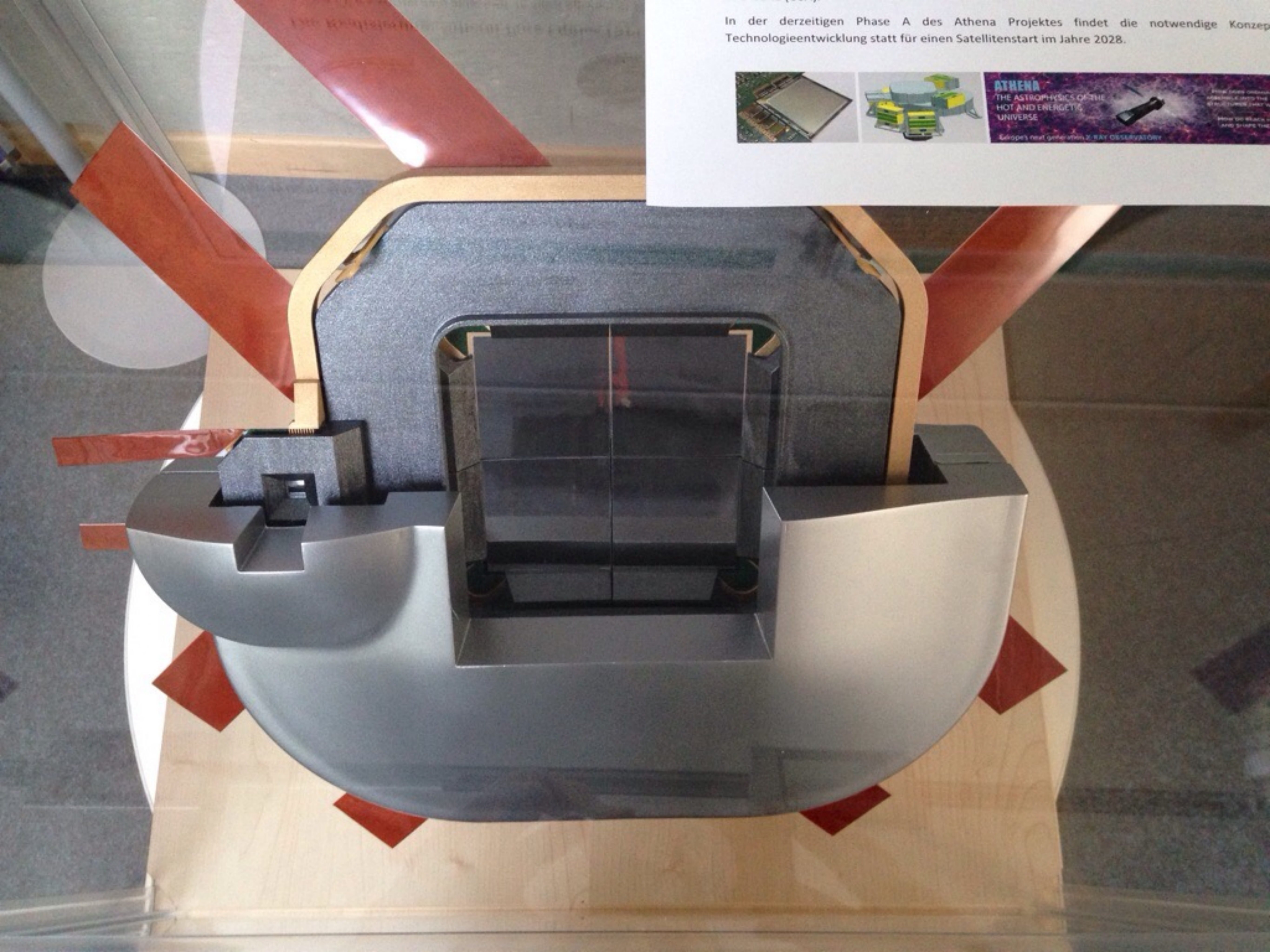
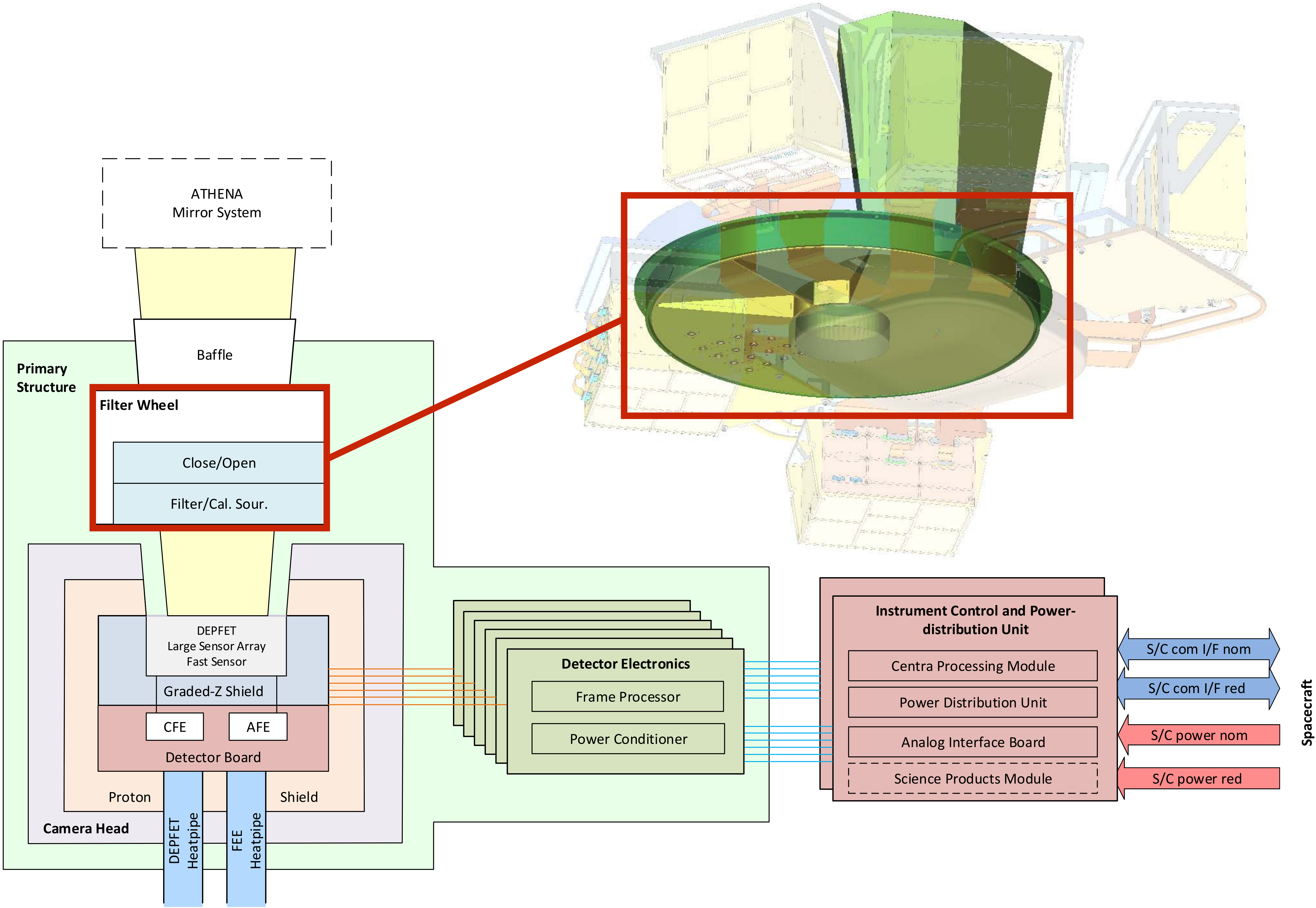

In der derzeitigen Phase A des Athena Projektes findet die notwendige Konzep
Technologieentwicklung statt für einen Satellitenstart im Jahre 2028.
ATHENA
HOT AND ENERGETIC
UNIVERSE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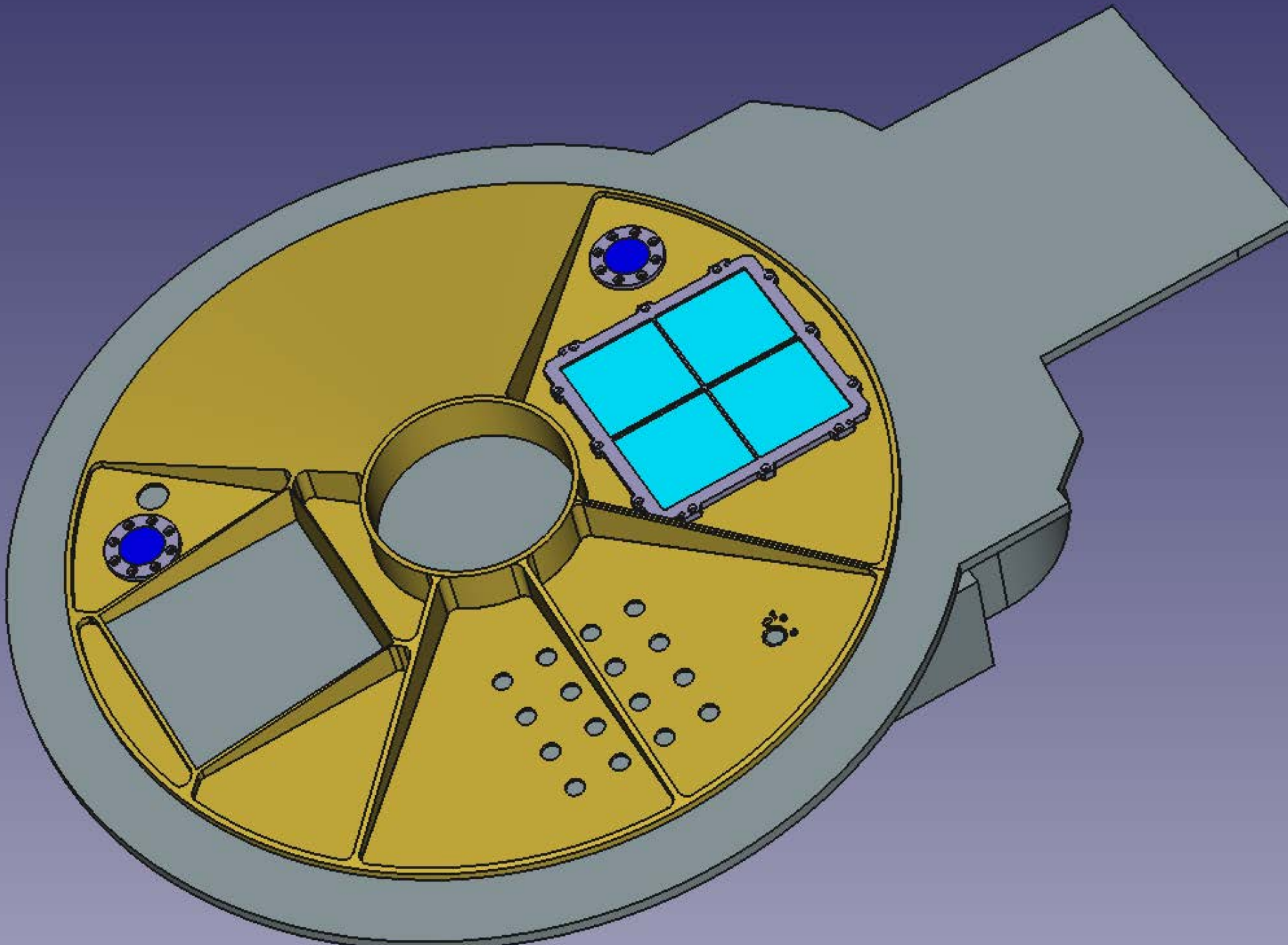
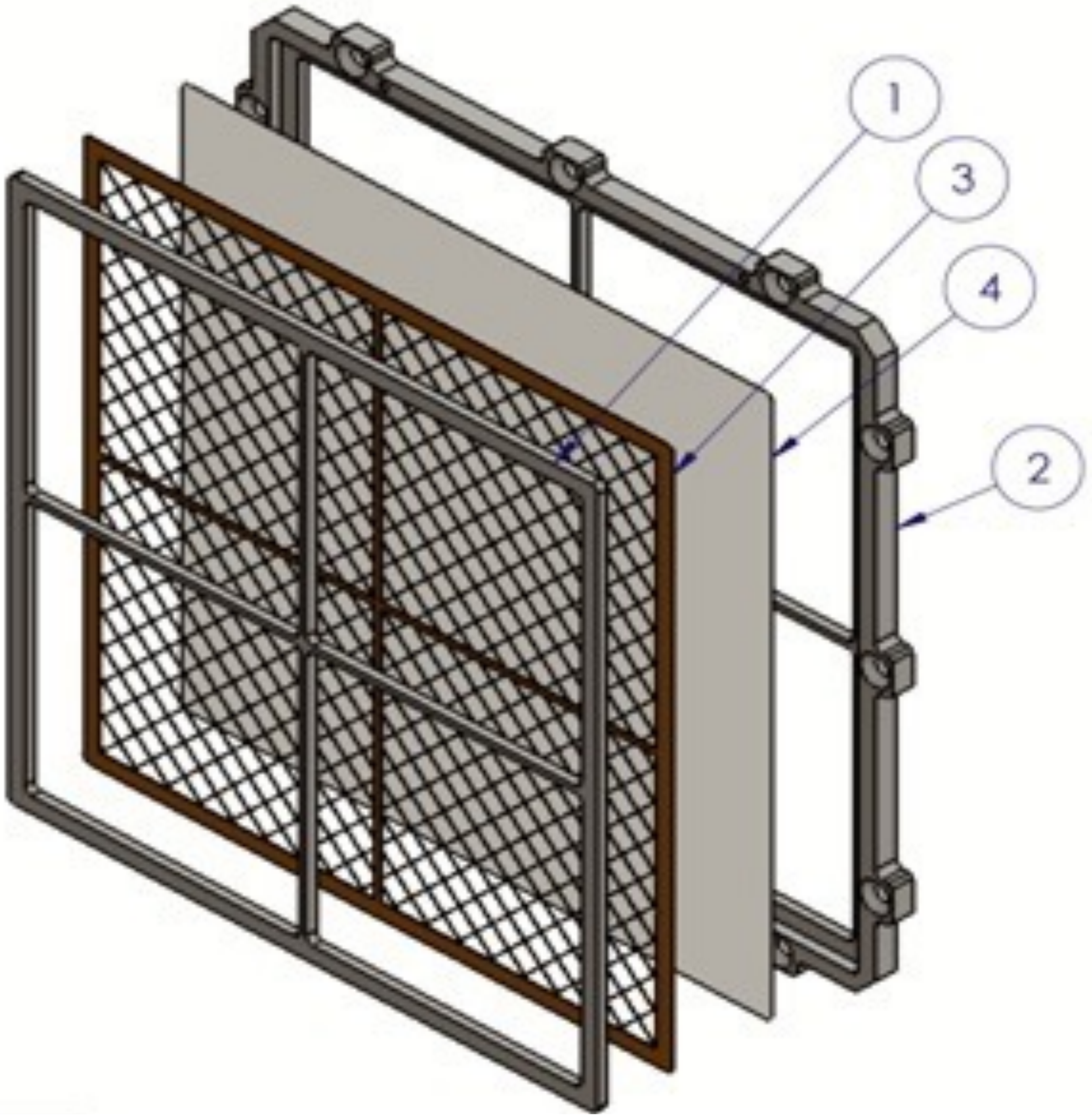


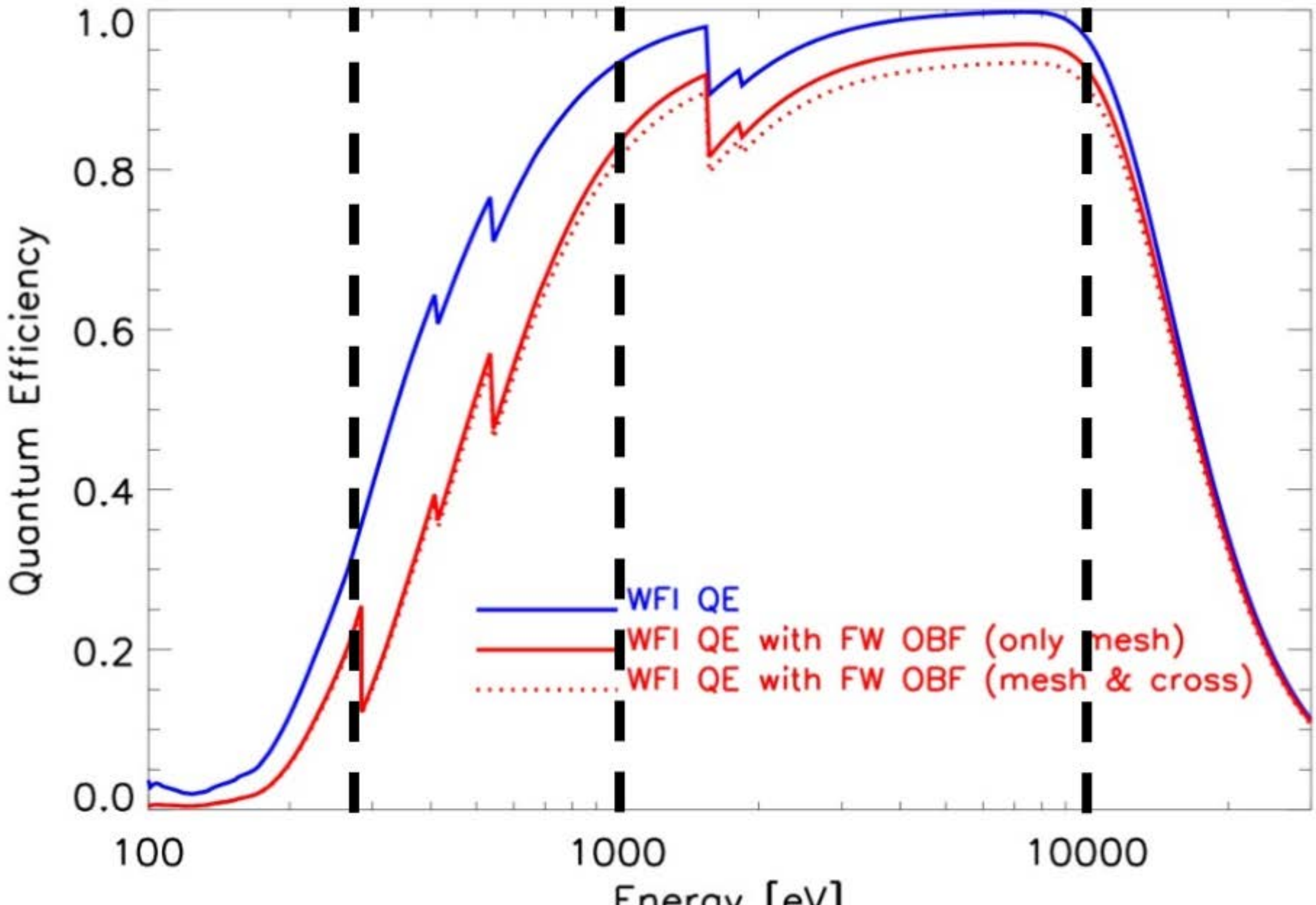
1 - ON-CHIP: 90nm Al+30nm Si_3N_4+20nm SiO_2

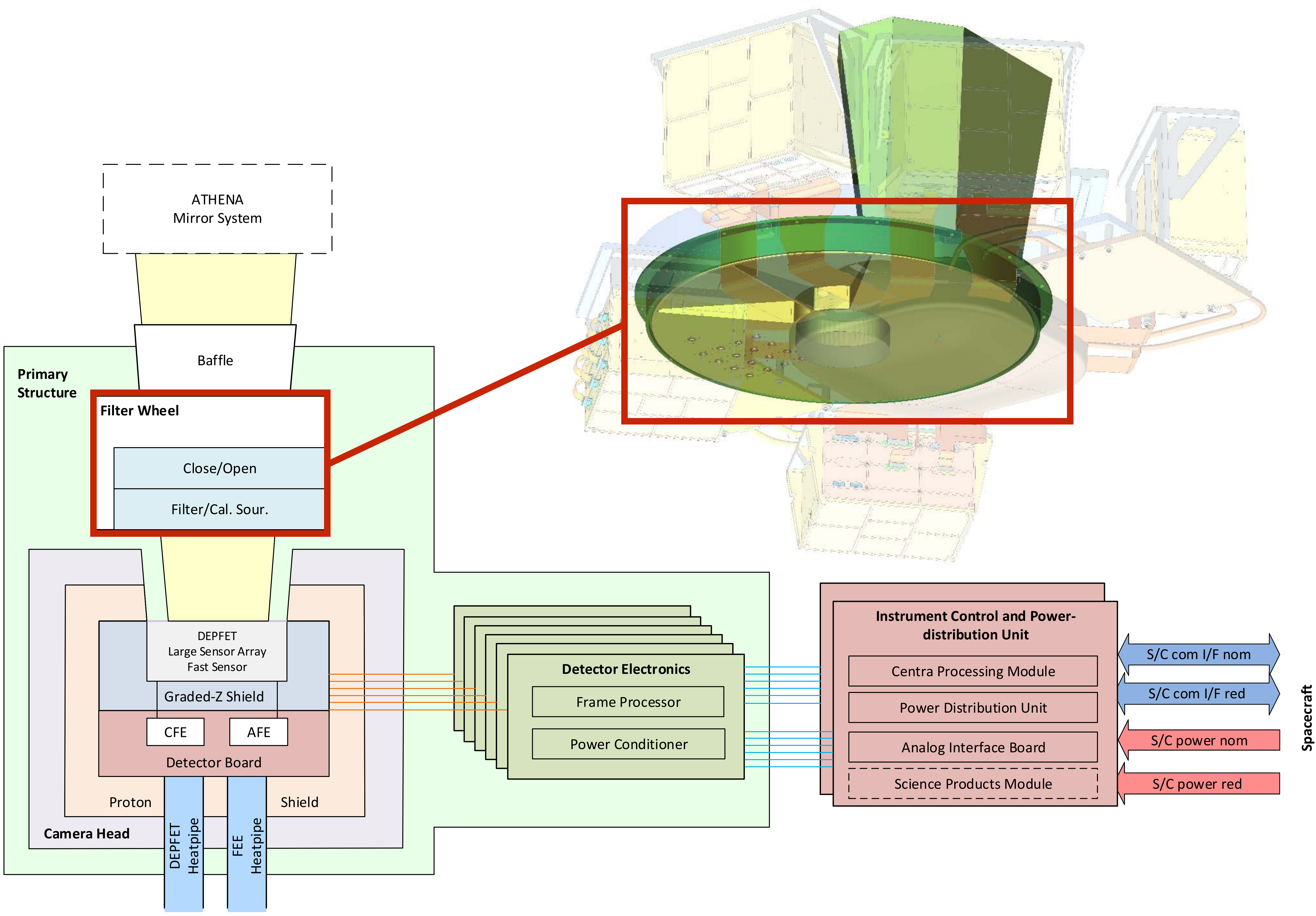
2 - FW: 30nm Al on 150nm polyimide

- 170x170mm^2
- FW without vacuum enclosure
- Critical: acoustic noise loads during launch
- mesh + cross-shaped stiffening



0.277 keV	1 keV	10 keV
QE = 23 %	QE= 83 %	QE = 92 %





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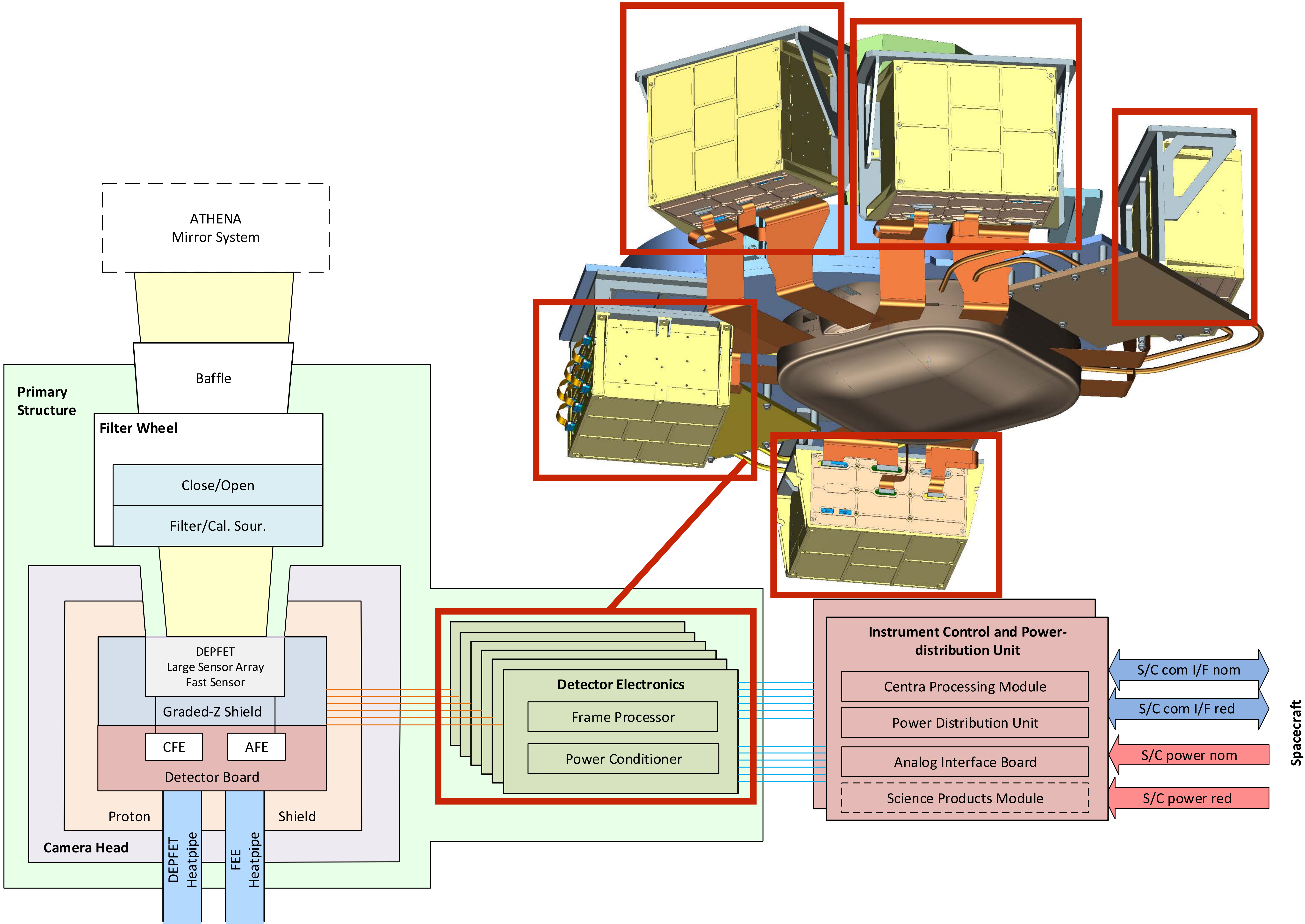

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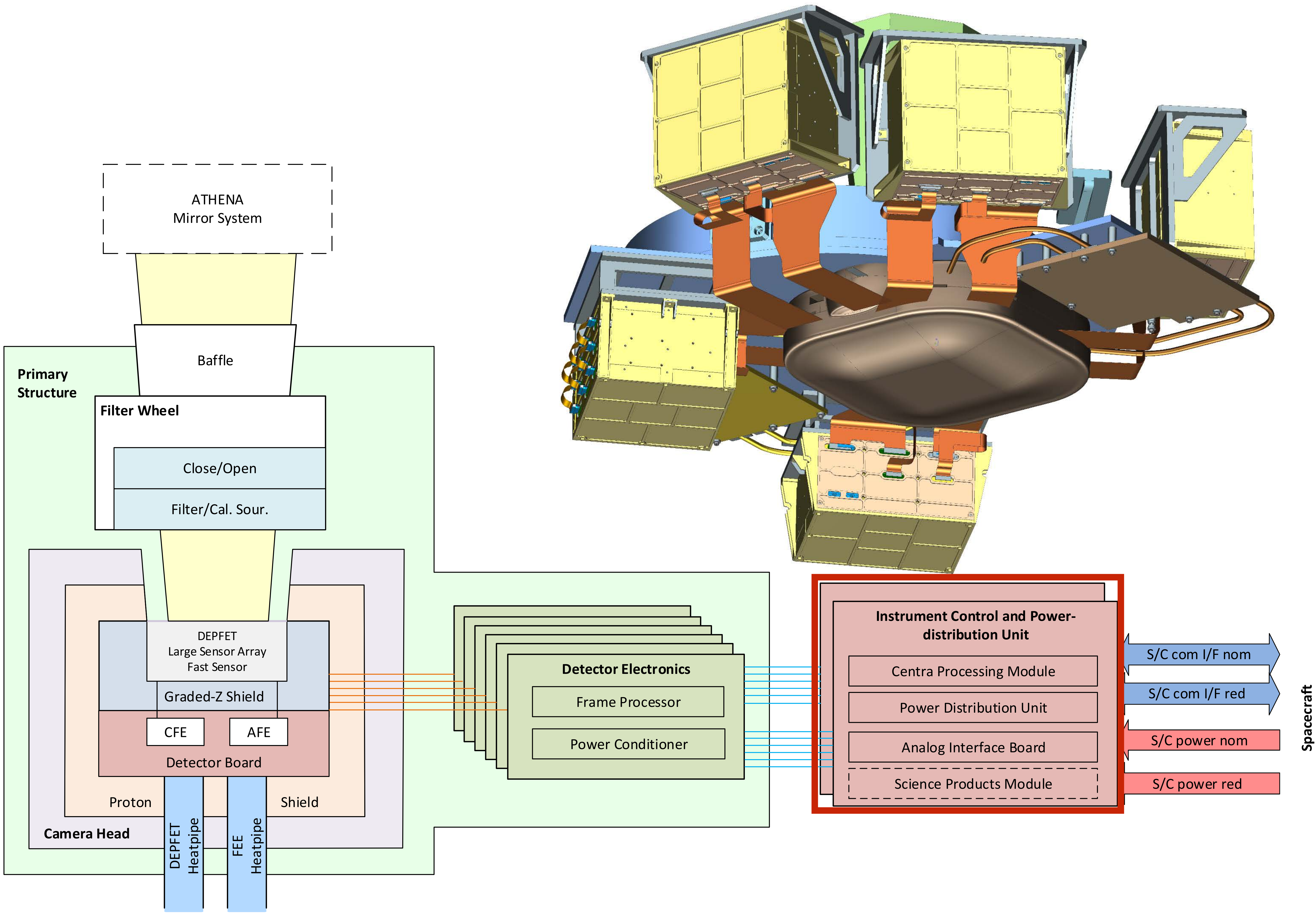
FEE
Heatpipe
Detector Electronics
Frame Processor
Power Conditioner
Instrument Control and Power-
distribution Unit
Centra Processing Module
Power Distribution Unit
Analog Interface Board
Science Products Module
S/C com I/F nom
S/C com I/F red
S/C power nom
S/C power red
Spacecraft

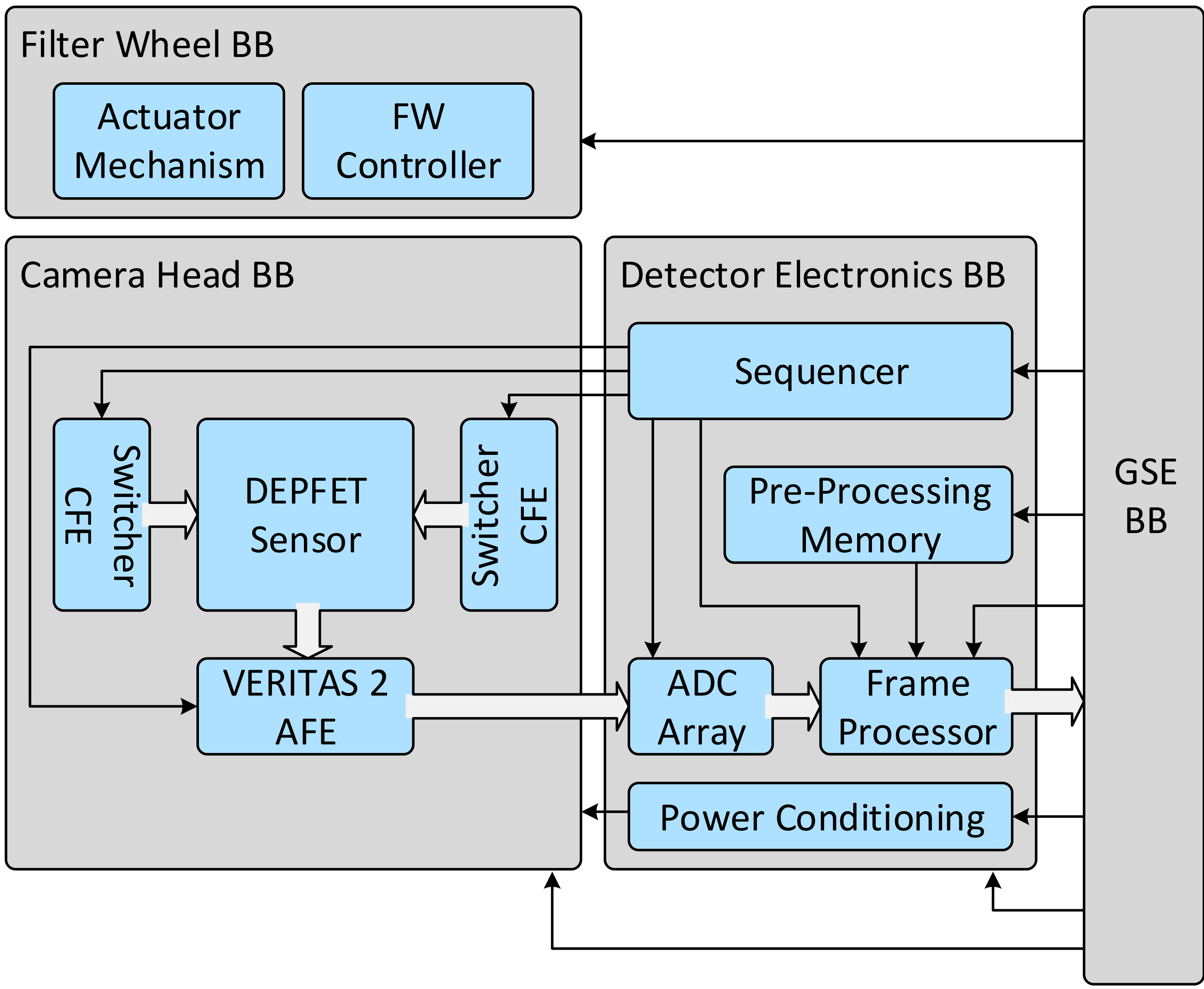

ATHENA
Mirror System
Baffle
Primary
Structure
Filter Wheel
Close/Open
Filter/Cal. Sour.
DEPFET
Large Sensor Array
Fast Sensor
Graded-Z Shield
CFE
AFE
Detector Board
Proton
Shield
Camera Head
DEPFET
Heatpipe
FEE
Heatpipe
Detector Electronics
Frame Processor
Power Conditioner
Instrument Control and Power-distribution Unit
Centra Processing Module
Power Distribution Unit
Analog Interface Board
Science Products Module
S/C com I/F nom
S/C com I/F red
S/C power nom
S/C power red
Spacecraft

2015-2018 WFI Technology Development Activity

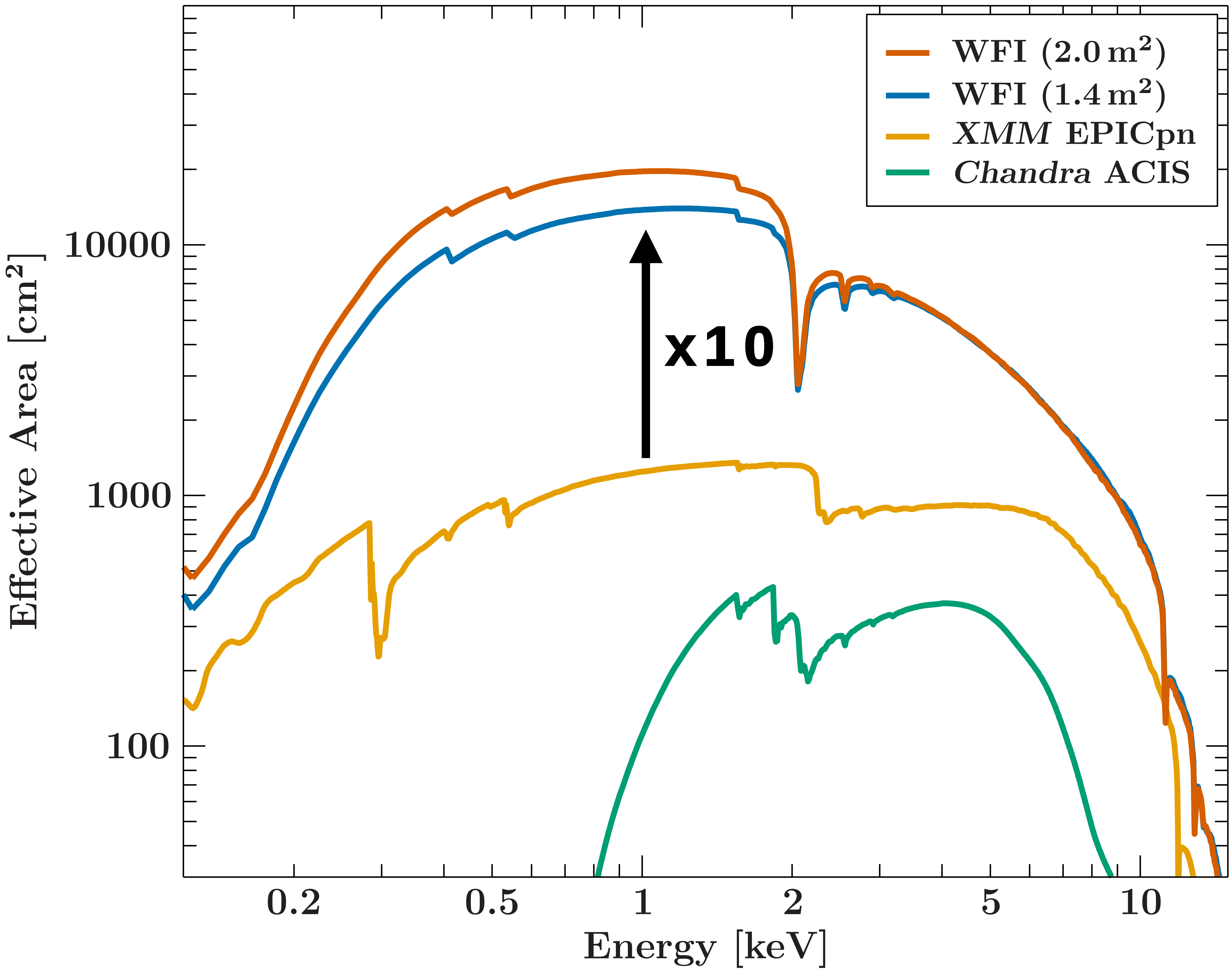
Filter-Wheel:
optical blocking filter.
Critical: ac. noise during launch

Detector:
DEPFET sensors + FEE ASICs.
Critical: Performance verification

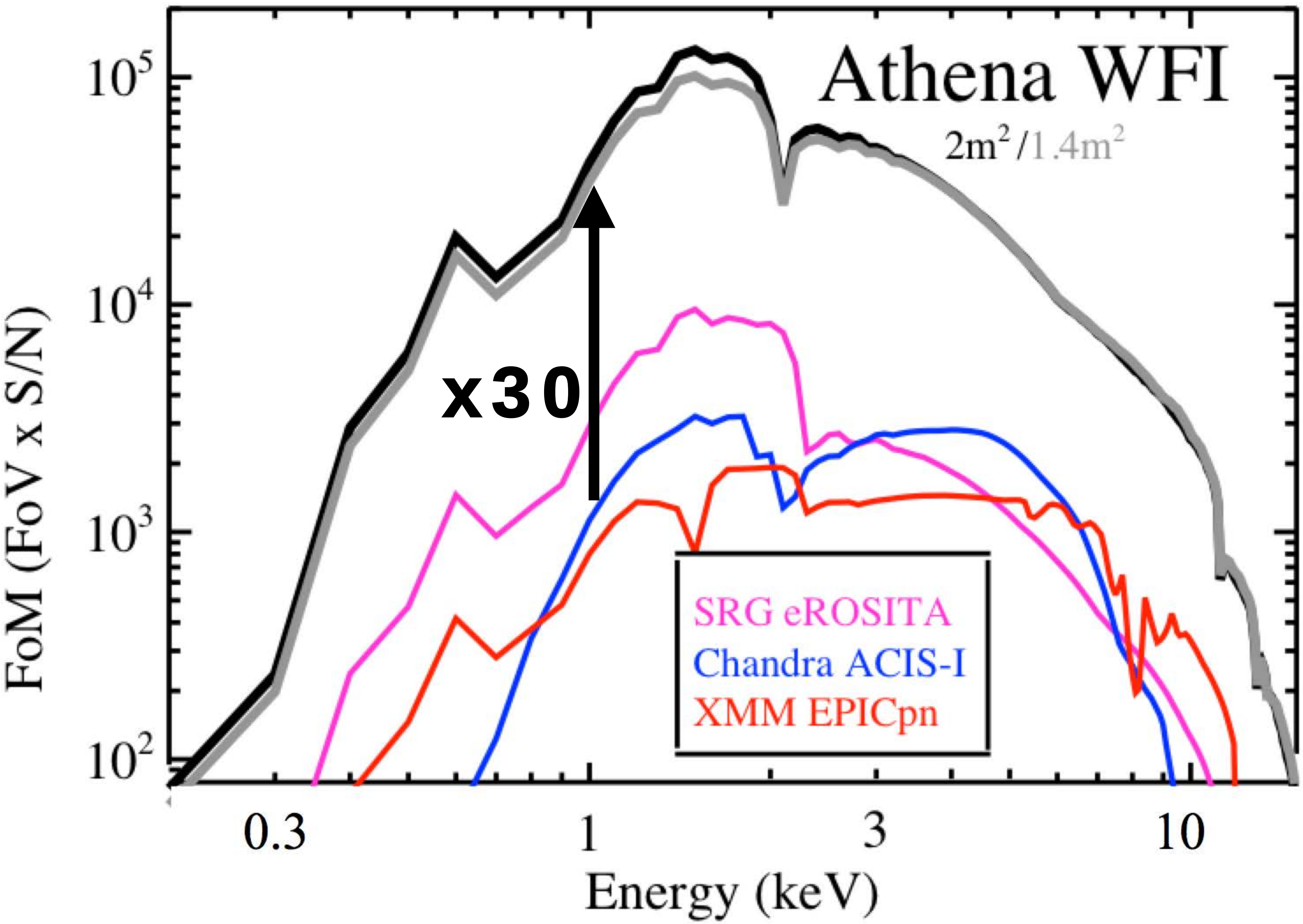
Detector Electronics:
power conditioning +
pre-processing.
Critical: real-time pre-processing
(52Gpx/s per LDA-DE)



Performance Expectations



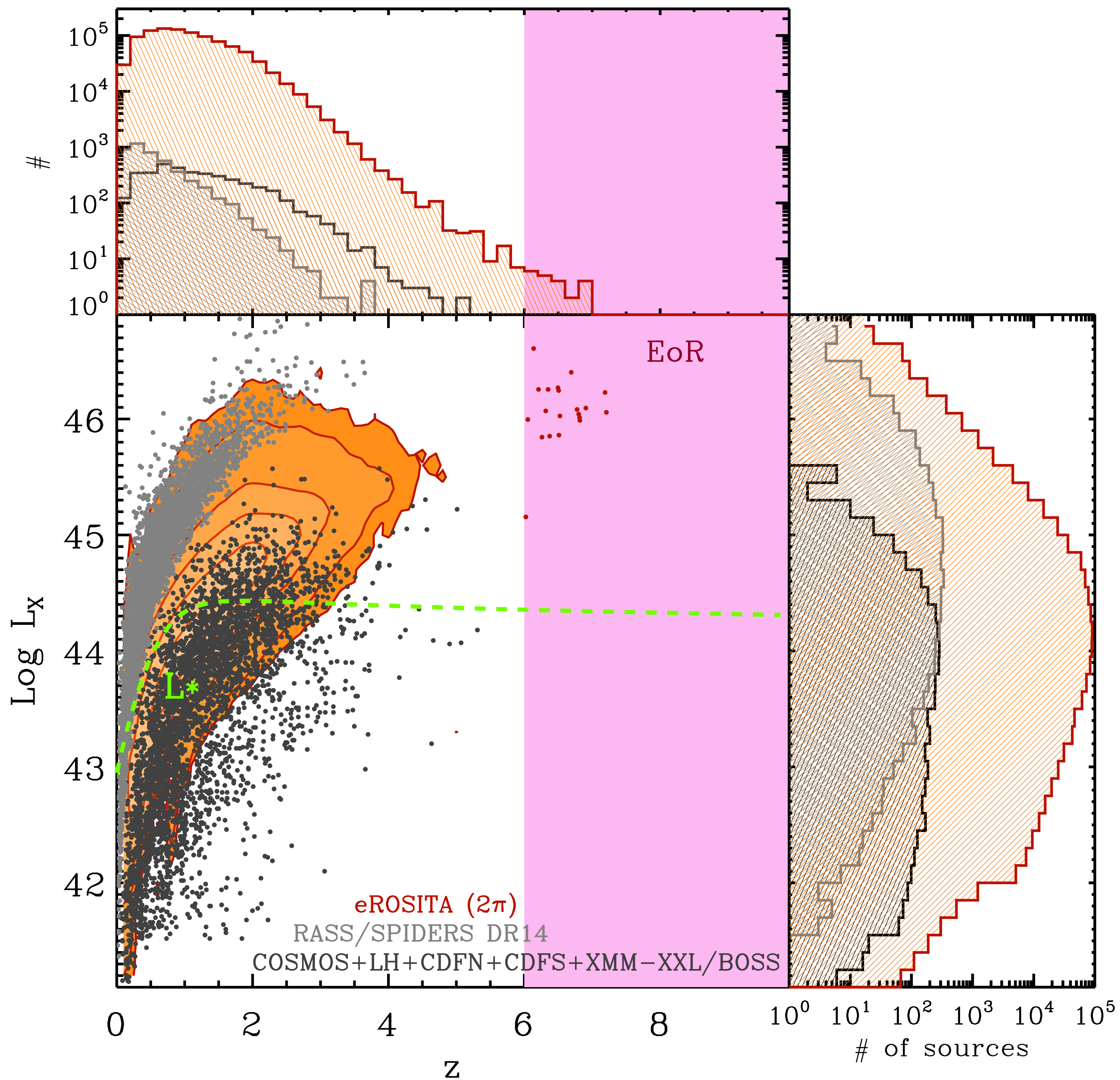
(Courtesy: Th. Dauser)



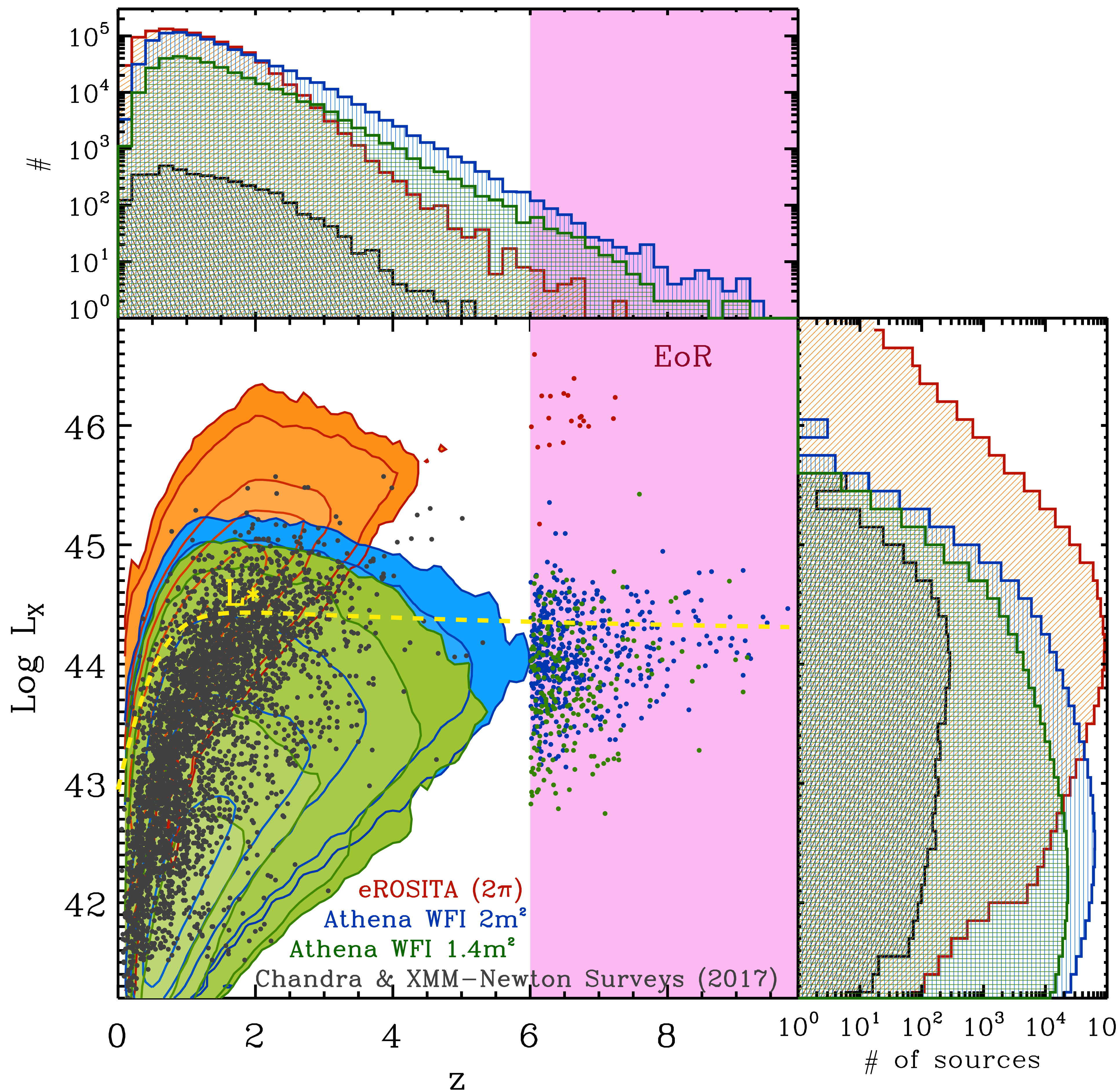
$$FoM = \int \frac{S}{N} dFOV \propto \int_0^{\theta max} \frac{A(\theta, E)}{R(\theta, E) * \sqrt{Bgal(E) * A(\theta, E) + Bdet(E) * f^2}}$$

$A(\theta, E)$ = effective area
$R(\theta, E)$ = PSF HEW
$Bdet(E)$ = detector background
$Bgal(E)$ = CXB
f = focal length

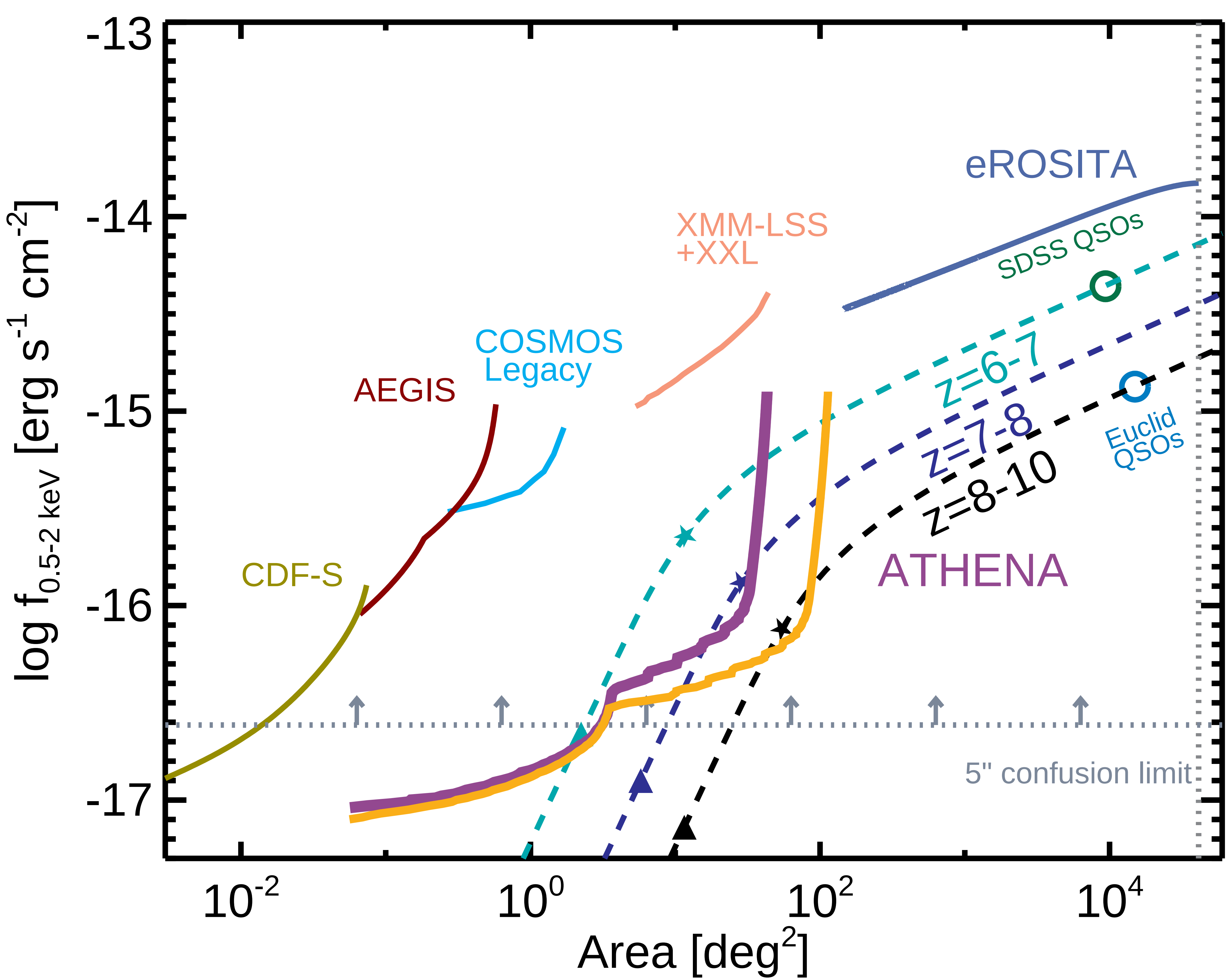
(Courtesy:D. Wik, A. Hornschemeier)



(Courtesy: A. Merloni)

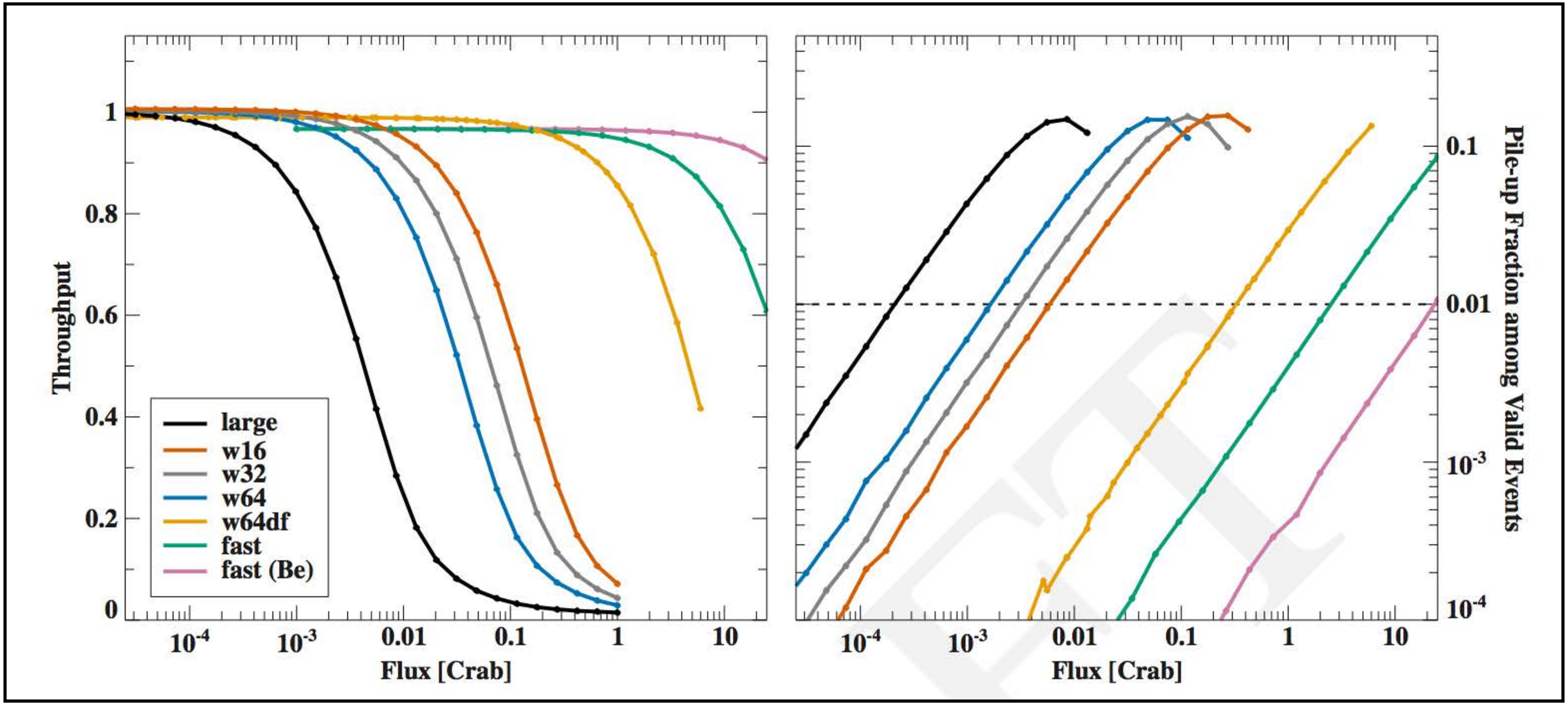


(Courtesy: A. Merloni)



(Courtesy: J. Aird)

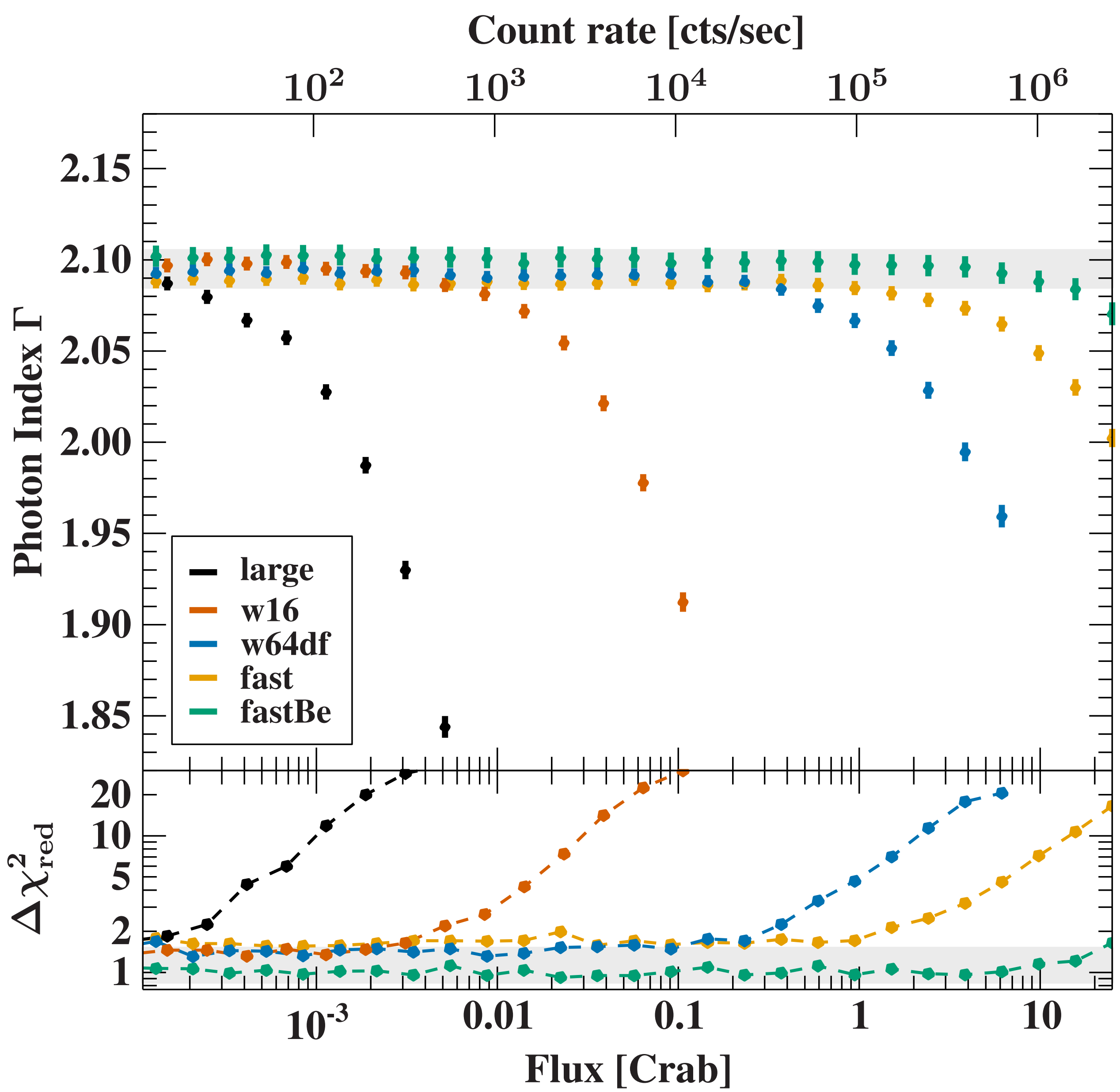
Bright Sources with the WFI Fast Detector

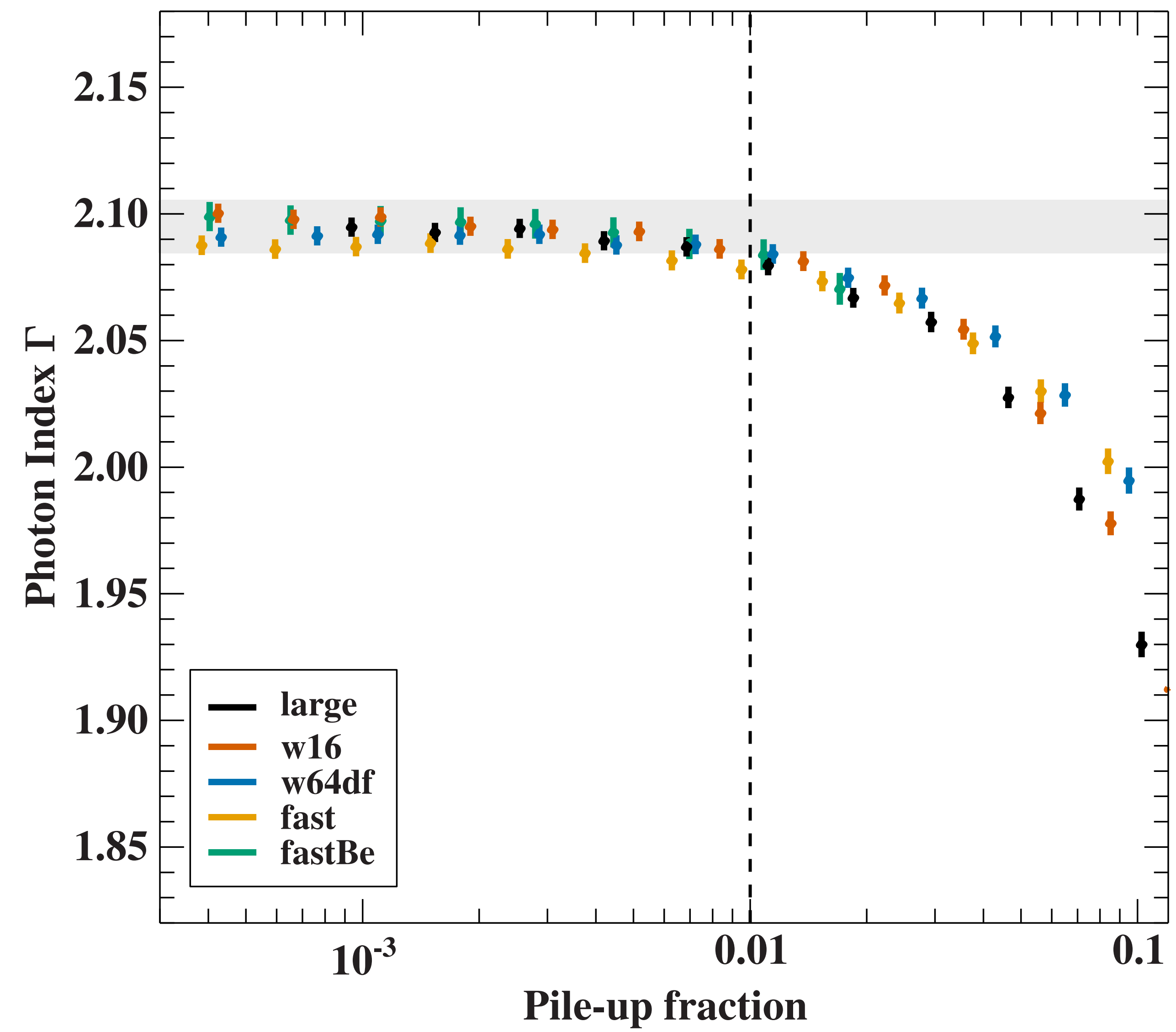


(Courtesy: Th. Dauser)

Bright Sources with the WFI Fast Detector

how does pile-up distort the power law ($E^{-\Gamma}$) observed spectrum?



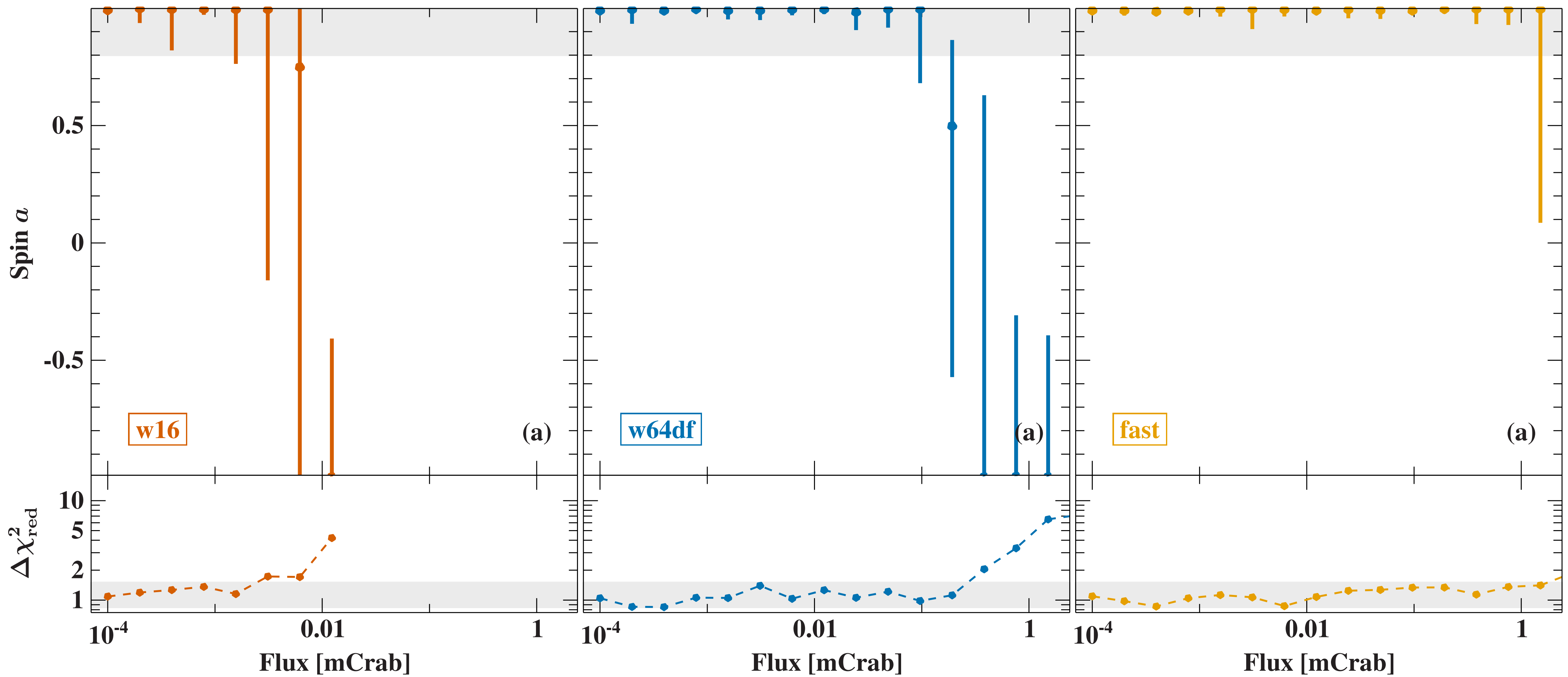


→ **spectral distortion above 1% pile-up fraction**

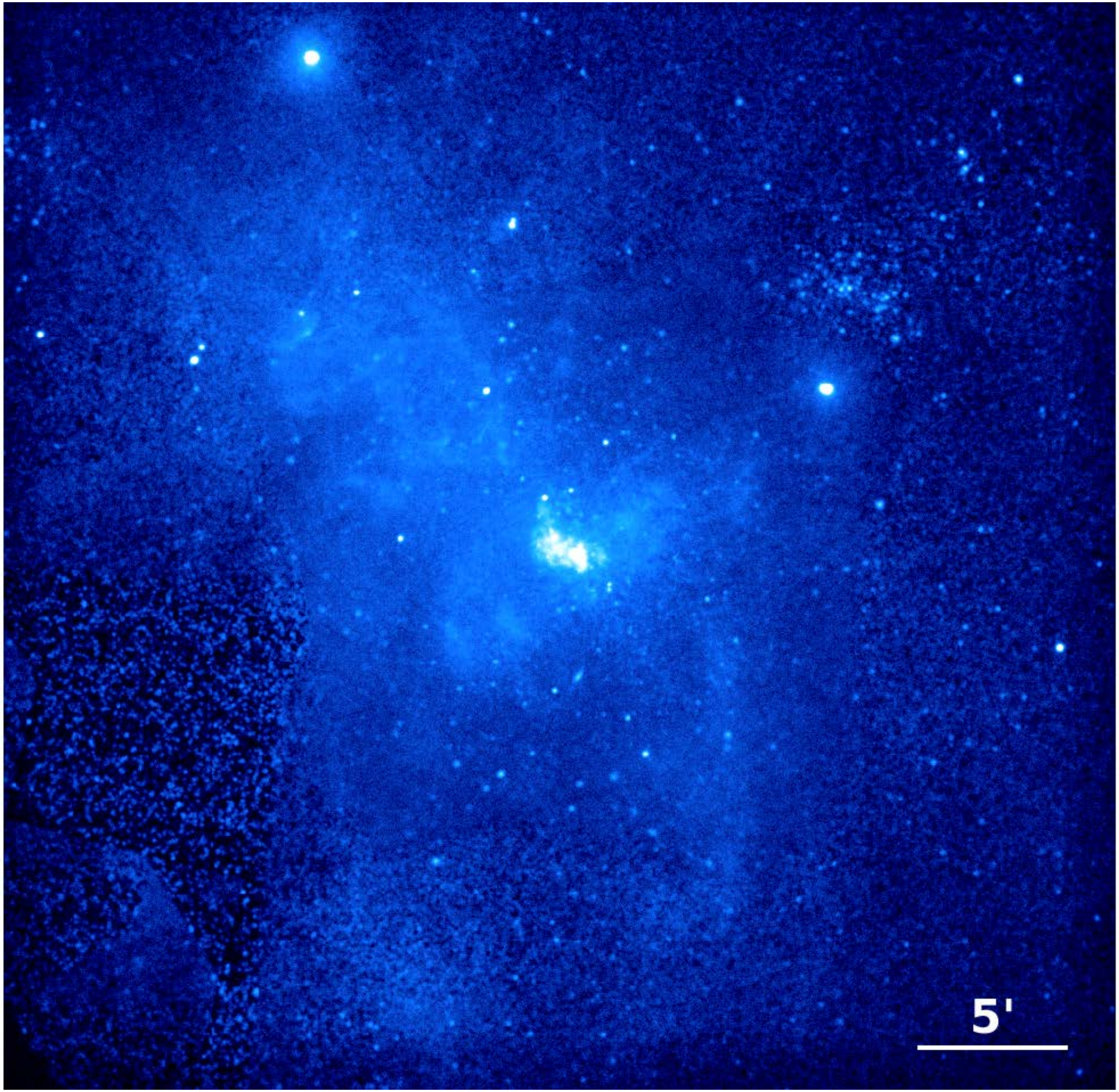
from **Thomas Dauser** , Remeis Observatory & ECAP

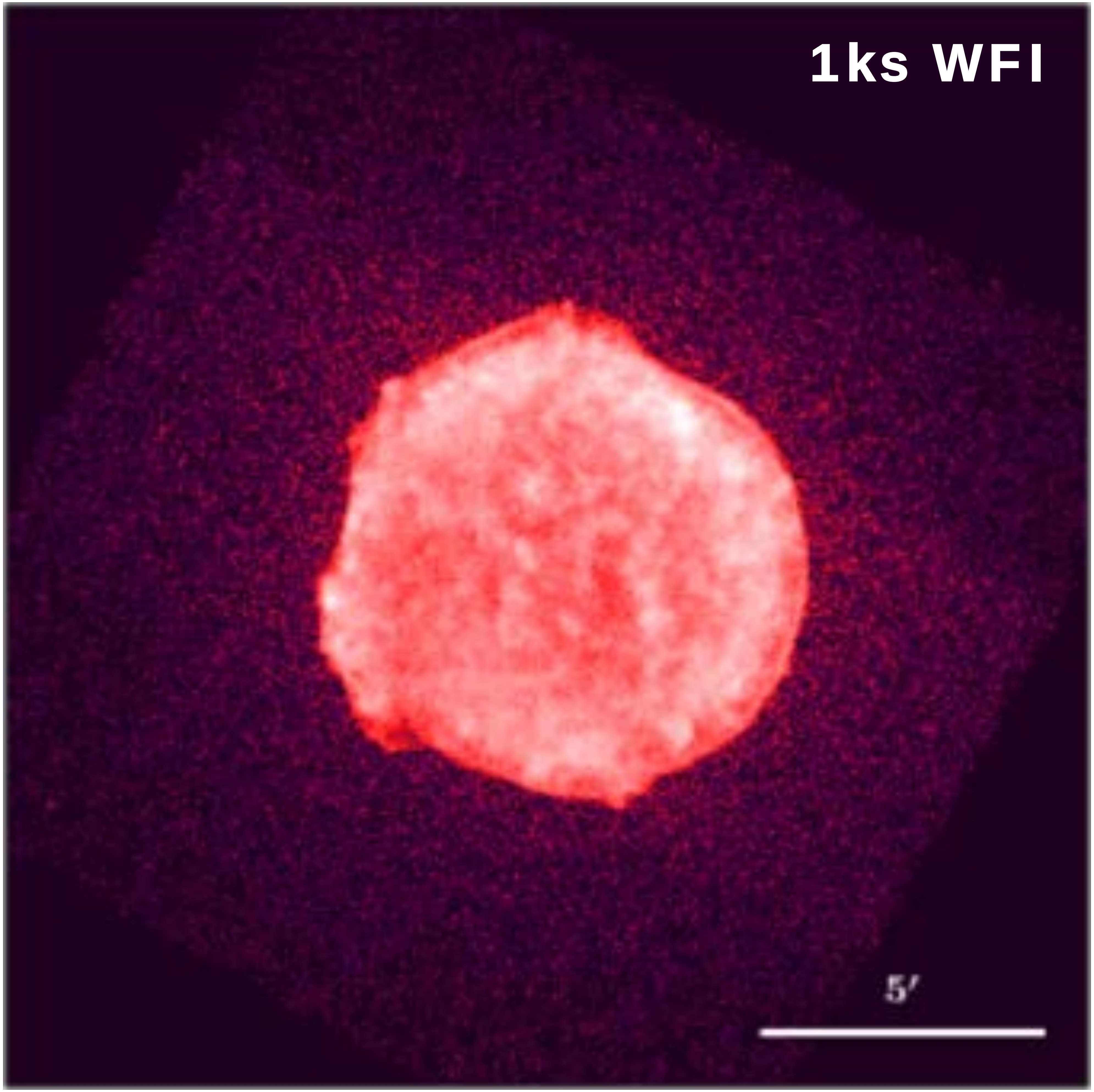
Bright Sources with the WFI Fast Detector

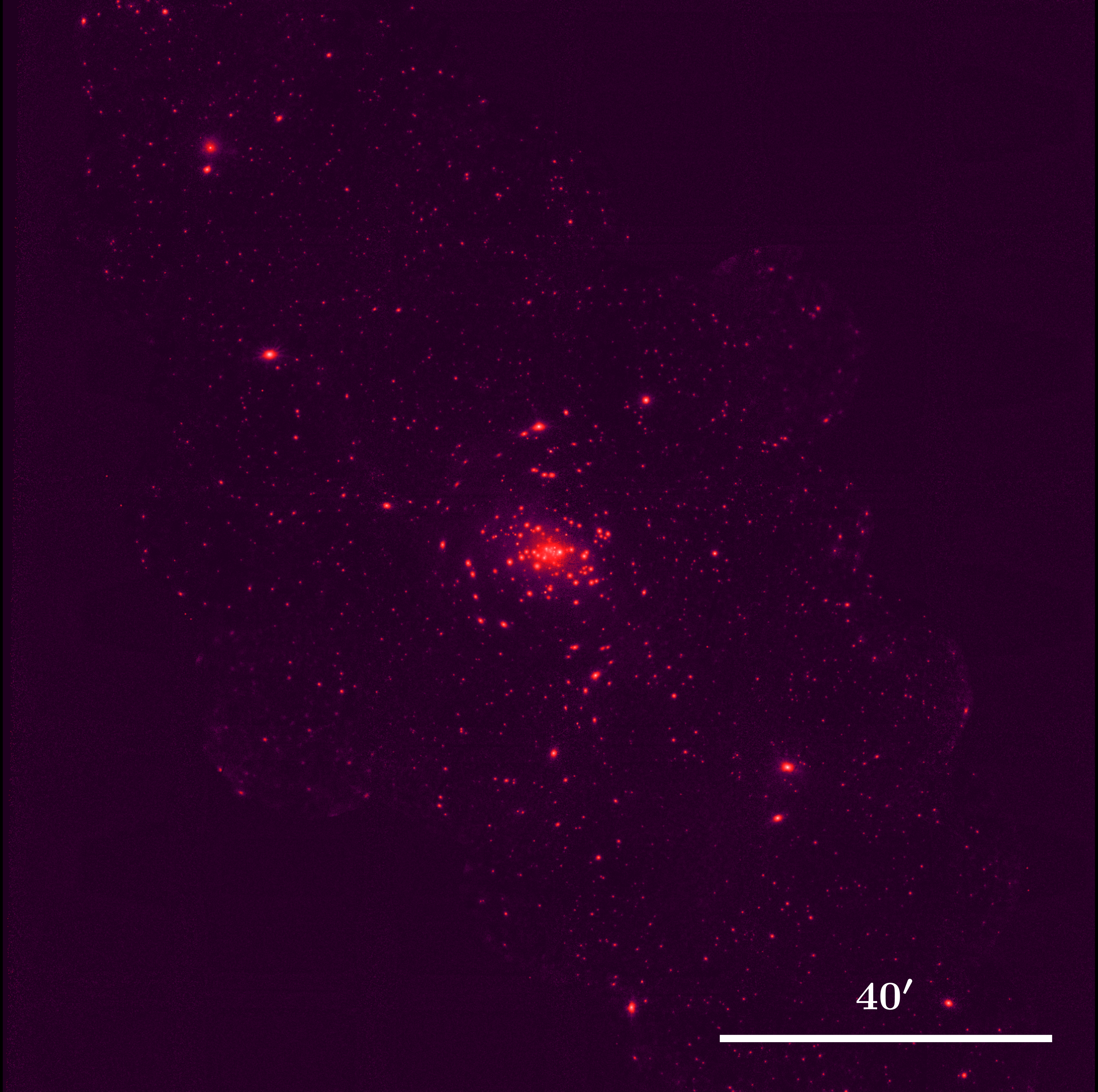
Example of a science observation: black hole **spin** measurements



→ reliable estimate of **spin parameter** up to 1 Crab


5'


1ks WFI
5′


40′

Availability and Documentation

Download and **Support**:

- Source code: `http://www.sternwarte.uni-erlangen.de/research/sixte/`
  (Works on Linux and Mac, git and release versions.)
- Support at `sixte-support@lists.fau.de`.

Documentation on WWW-pages

- SIXTE manual: 66 pages – background of simulations, tutorials
- slides from SIXTE talks and 1st SIXTE workshop

Parameter	**Value**
Energy Range	0.2-15 keV
Field of View	40’ x 40’
Angular Resolution **Pixel Size**	PSF=5`` (on-axis) 130 x 130 $\mu m^2$ (2.2``)
Large DEPFET detector	1024 x 1024 pixel (4 quadrants) ≈ 14cmx14cm
Fast DEPFET detector	64 x 64 pixel (split full frame mode - 2 halves readout)
Operating mode	Rolling shutter
Operating time	Nonstop possible
Quantum efficiency (on-chip + ext. filter)	20% @ 277 eV 80% @ 1 keV 90% @ 10 keV
Energy Resolution	FWHM(1 keV) ≤ 80 eV (end of life) FWHM(7 keV) ≤ 170 eV (end of life)
Time Resolution full frame Fast detector Large detector	 80 µs <5 ms
Count Rate Capability	Fast DEPFET (defocused) 1 Crab: >80% throughput, <1% pile-up
Particle Background (L2 orbit)	$< 5 \times 10^{-3}$ cts cm^{-2} s^{-1} keV^{-1}

http://www.mpe.mpg.de/ATHENA-WFI/