The NASA X-ray Probe Missions

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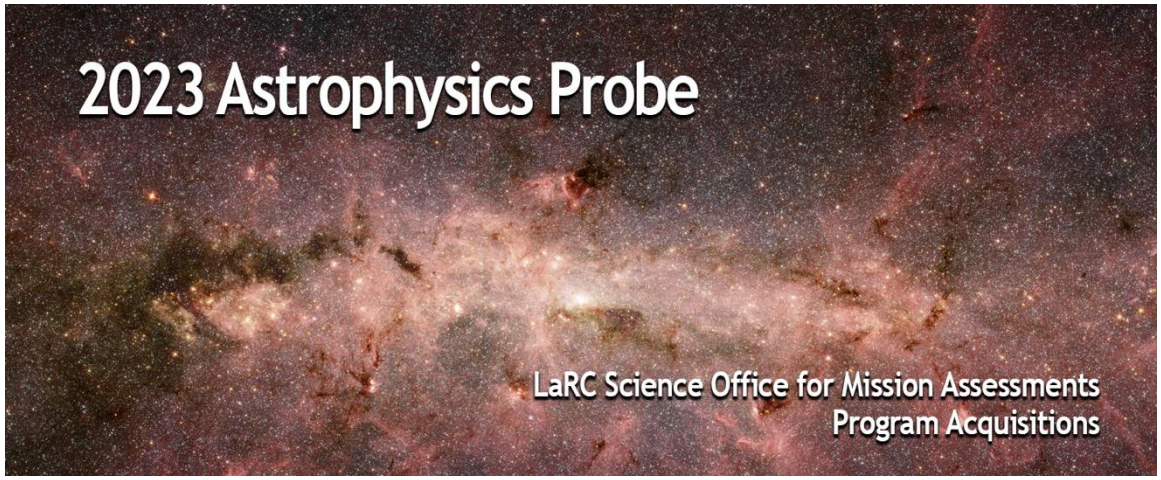
Enrico Bozzo
University of Geneva, Switzerland

The NASA on-going PROBE mission process

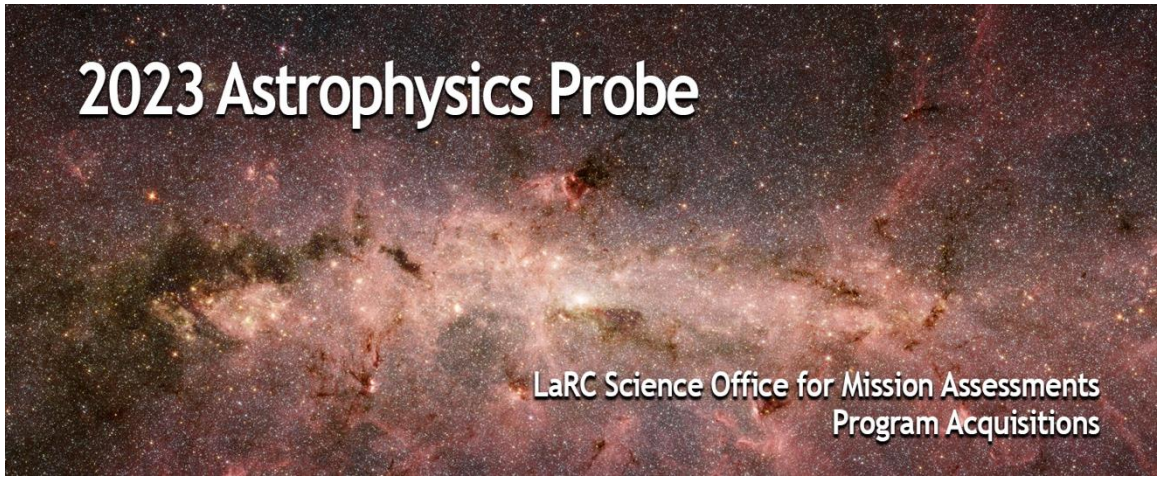


The Astrophysics Probe solicitation responds to a recommendation of the National Academies' *2020 Decadal Survey in Astronomy and Astrophysics*, Pathways to Discovery in Astronomy and Astrophysics for the 2020s, for competed missions in broad areas identified as important to accomplish particular scientific goals.

Astrophysics plans to solicit missions with a PI-managed cost cap substantially larger than for the Medium Explorers. The first solicitation will be for a far-infrared mission, and for an X-ray mission designed to *complement the European Space Agency's Athena mission.*

5 X-ray probe concepts submitted in November 2023
Phase A: selection 14 November 2024 for 12 months (1 X-ray + 1 IR)
1 mission (X-ray or IR) to be launched in >2032

The NASA on-going PROBE mission process

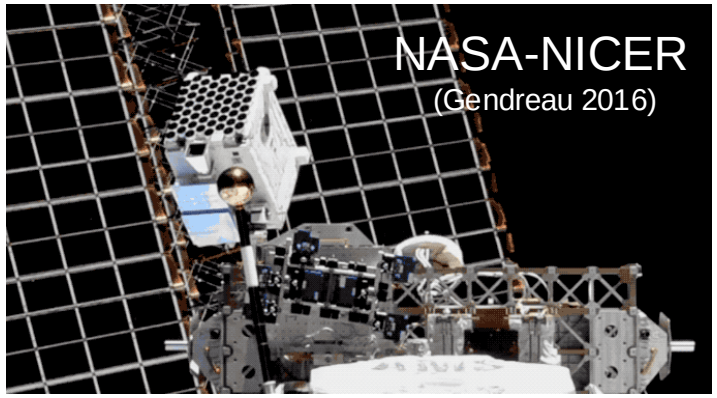


"Astrophysics plans to solicit missions with a PI-managed cost cap substantially larger than for the Medium Explorers. The first solicitation will be for a far-infrared mission, and for an X-ray mission designed to *complement the European Space Agency's Athena mission" (January 11, 2022)*

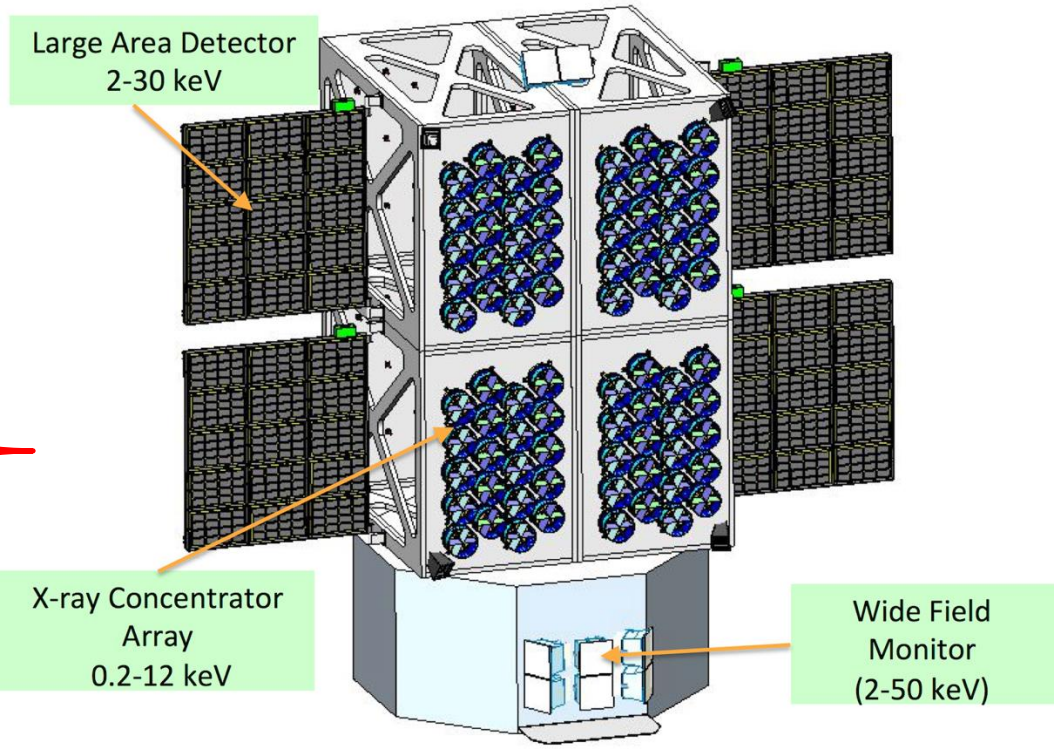
"Change 2: The European Space Agency (ESA) is considering whether the Athena mission will be substantially replanned. It is no longer practical to require proposed X-ray probes to "complement ESA's Athena Observatory." This requirement has therefore been removed" (May 19, 2022)

"On the occasion of the 9th June 2022 SPC workshop Delegations unanimously stated not to support the adoption of the Athena mission in 2023 at the currently estimated CaC ..." (June 26, 2022)

The USA PROBES: STROBE-X

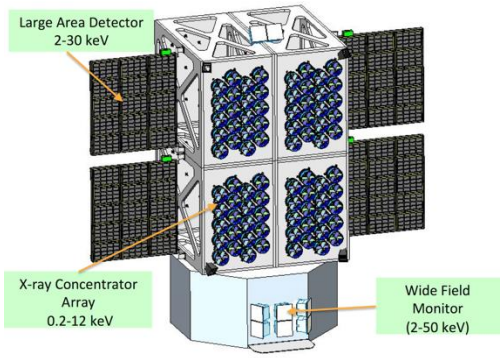


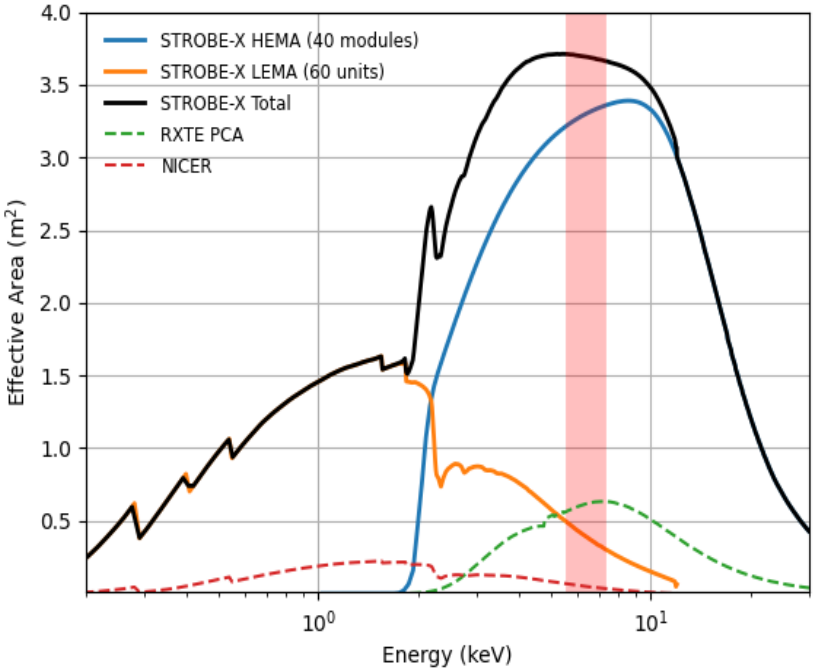
ESA-LOFT
Mission concept
(Feroci 2012)



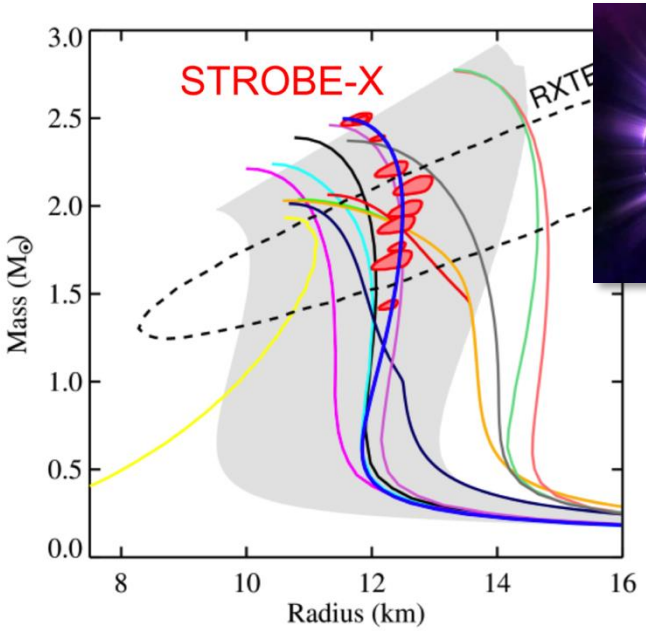
Designed for X-ray timing and spectroscopy in the 0.2-30 keV band, with huge collecting area, high throughput, broad energy coverage, and excellent spectral and temporal resolution
(Ray 2024)

The USA PROBES: STROBE-X

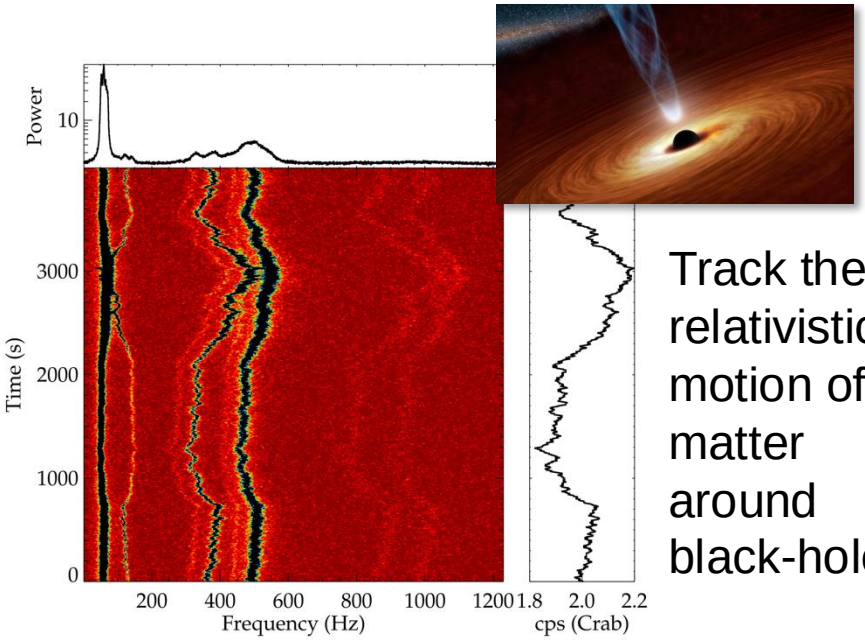




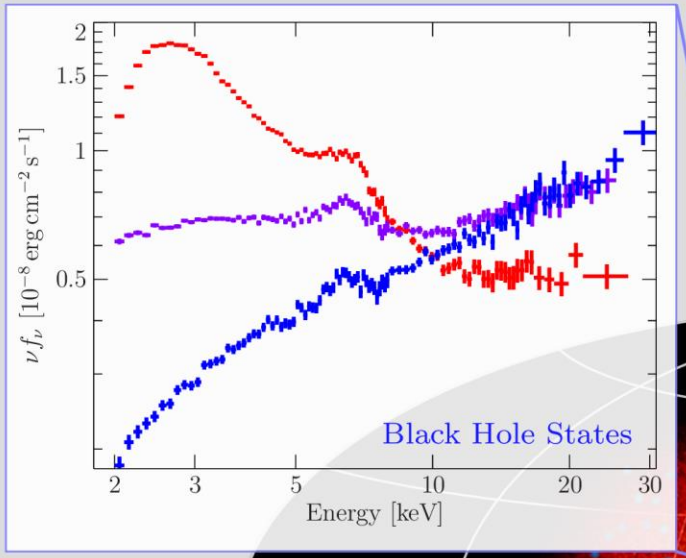
Largest effective area X-ray observatory ever flown

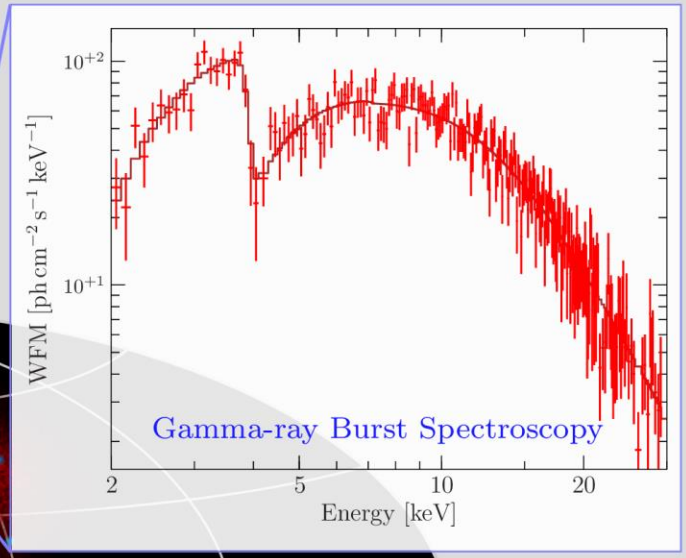


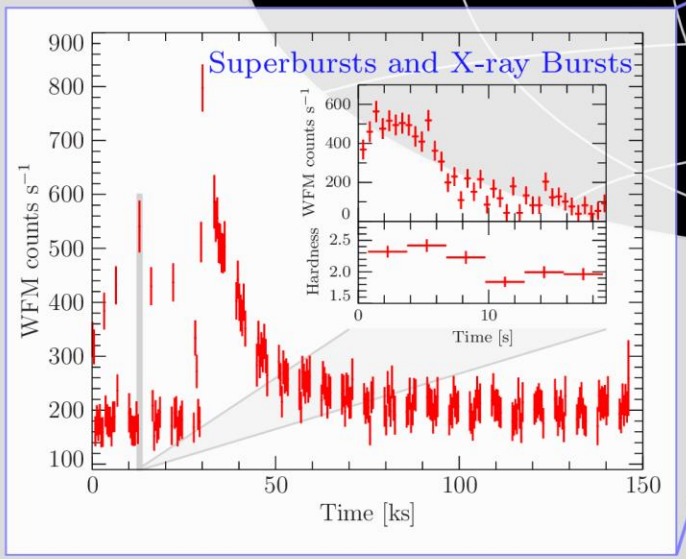
Measure the neutron star equation of state

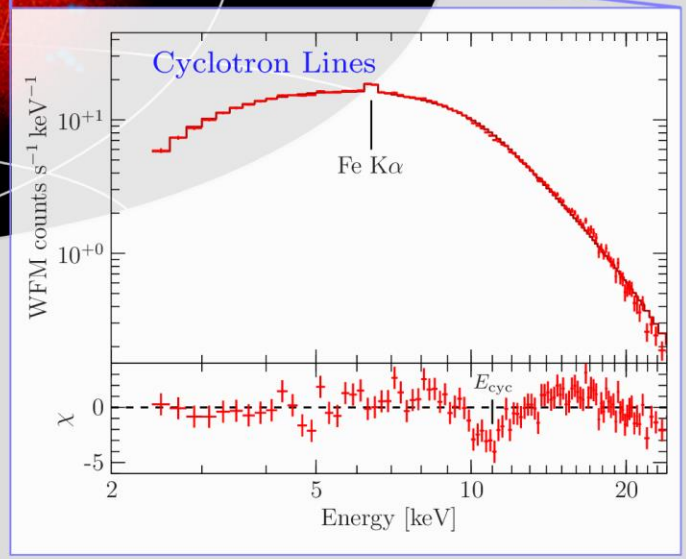


Track the relativistic motion of matter around black-holes

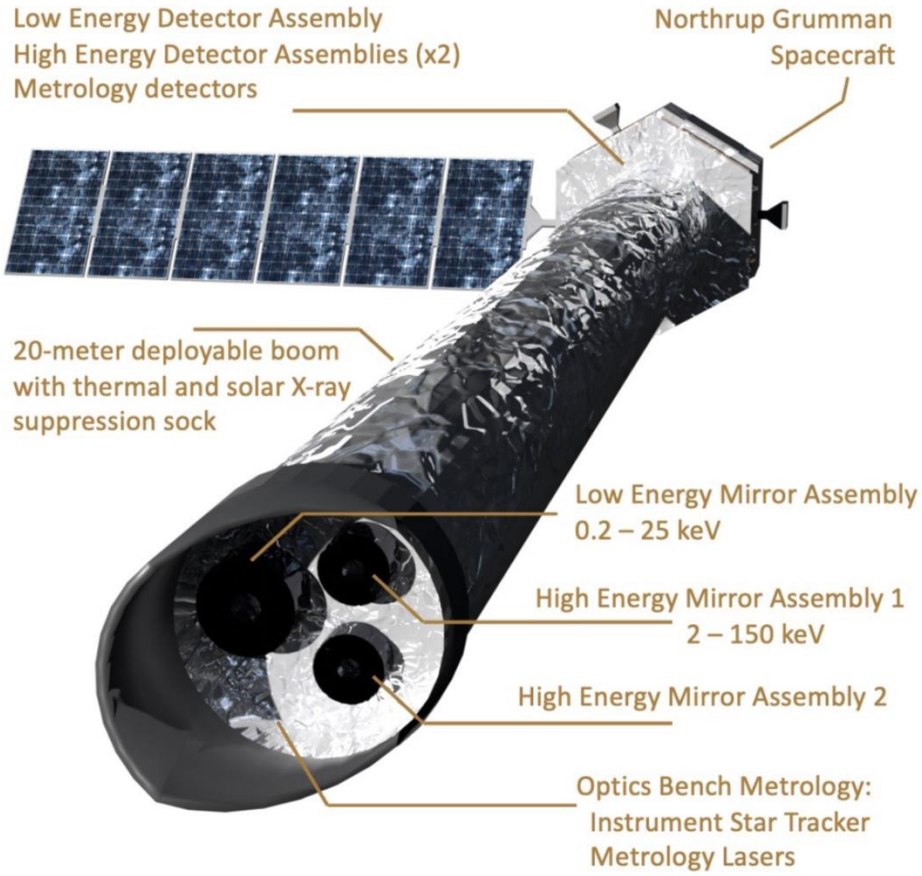

Black Hole States
νf_ν [10^{-8} erg cm^{-2} s^{-1}]
Energy [keV]

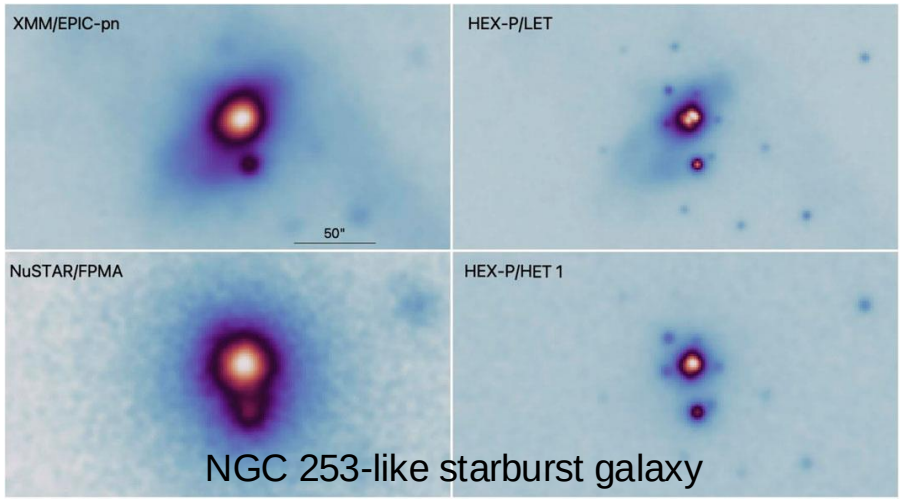

Gamma-ray Burst Spectroscopy
WFM [ph cm^{-2} s^{-1} keV^{-1}]
Energy [keV]

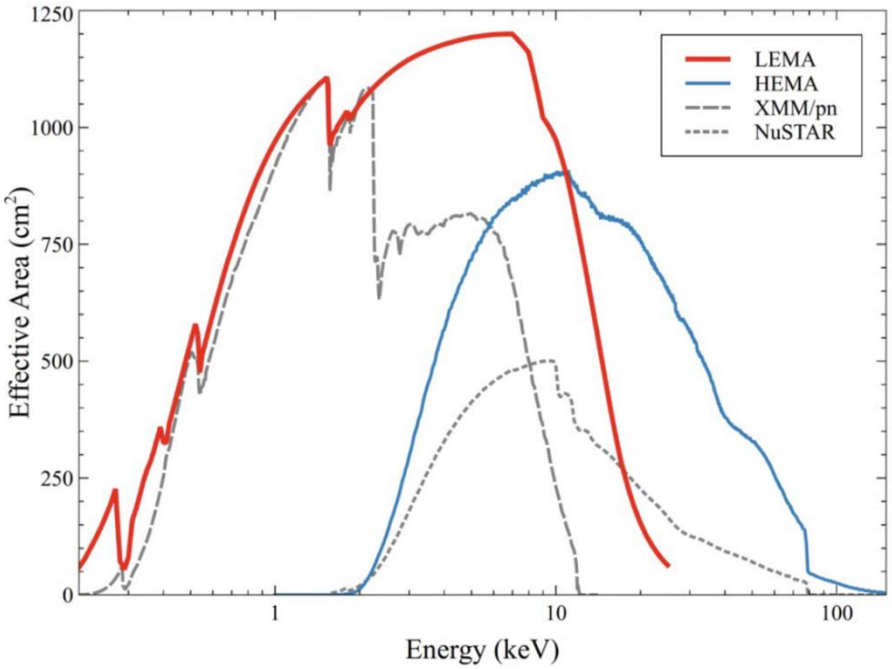

Superbursts and X-ray Bursts
WFM counts s^{-1}
Hardness
Time [s]
Time [ks]


Cyclotron Lines
Fe Kα
E_{cyc}
WFM counts s^{-1} keV^{-1}
χ
Energy [keV]

The USA PROBES: HEX-P



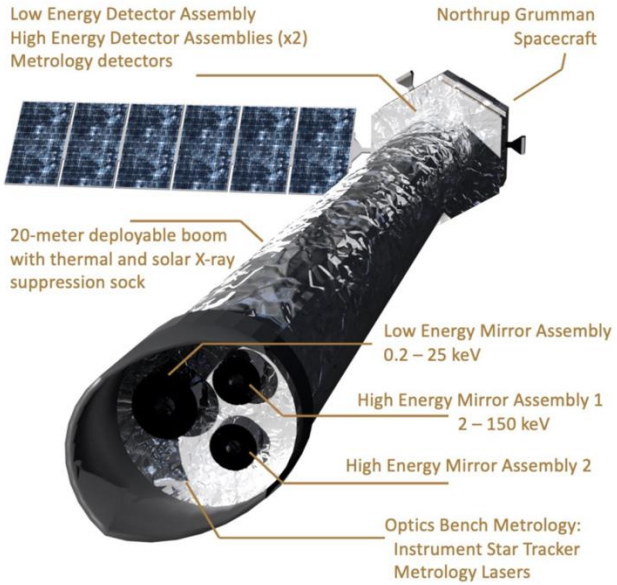




Next generation of broad-band high sensitivity focusing X-ray instruments. Based on the heritage of the powerfulness of the XMM-Newton + NuSTAR

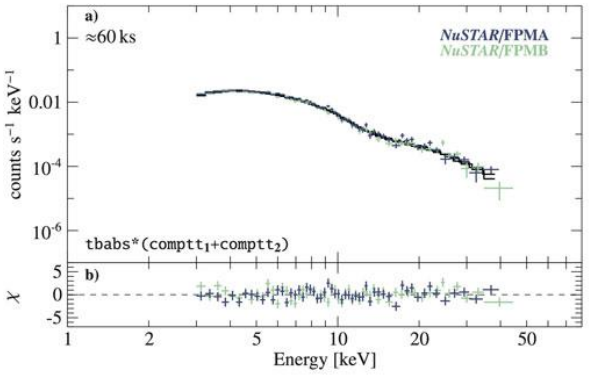
https://www.frontiersin.org/research-topics/59532/high-energy-astrophysics-research-enabled-by-the-probe-class-mission-concept-hex-p/articles

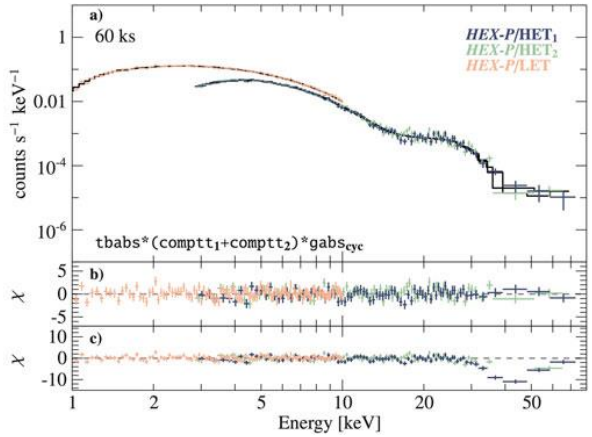
The USA PROBES: HEX-P



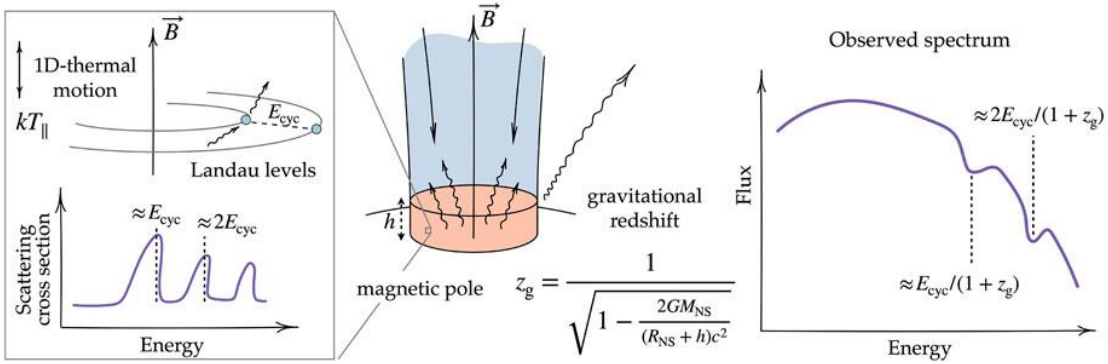
HET		LET	
Band	Sensitivity (erg s^{-1} cm^{-2})	Band	Sensitivity (erg s^{-1} cm^{-2})
2–10 keV	1.1×10^{-15}	0.2–5 keV	3.6×10^{-16}
10–20 keV	1.4×10^{-15}	5.0–10 keV	1.4×10^{-15}
20–40 keV	5.2×10^{-15}	0.5–10 keV	6.0×10^{-16}
40–80 keV	3.9×10^{-14}	10–20 keV	7.5×10^{-15}

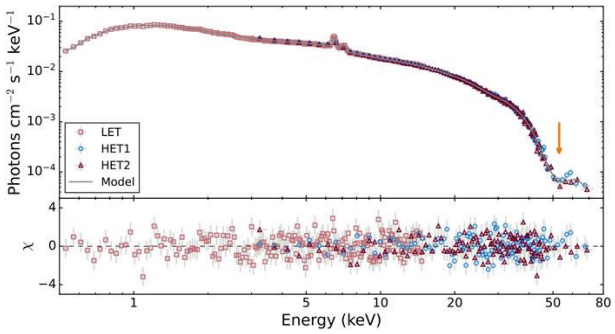
Minimum detectable flux for $\Gamma = 1.9$, $\sigma = 3$, time = 1 Ms





Be X-ray GX 304–1 in quiescence (cyclotron line at 46 keV)



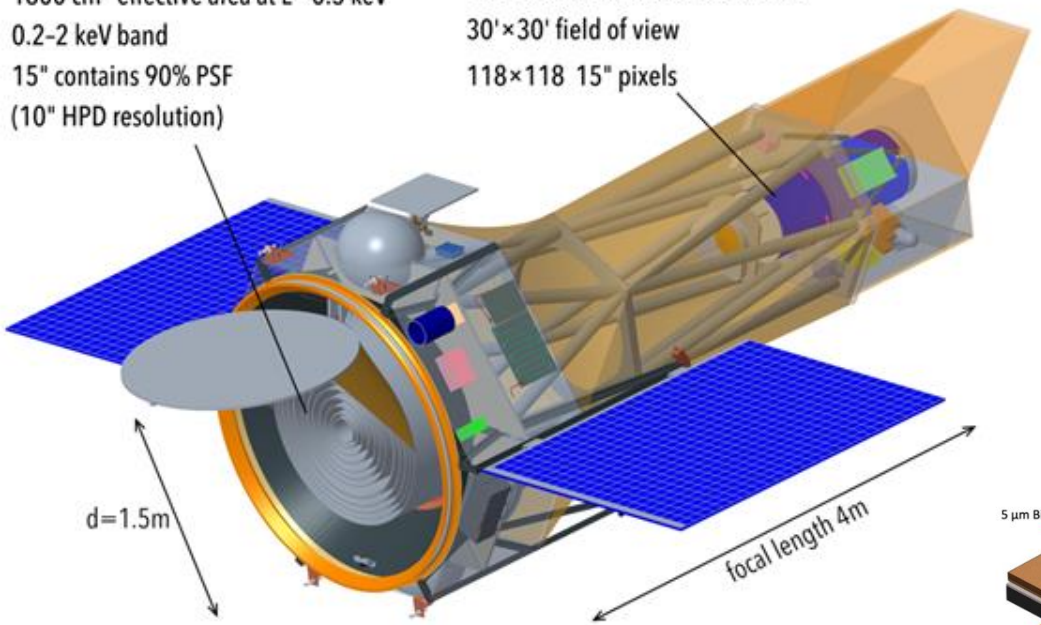


Possible to study cyclotron line variations also as a function of the spin phase (Vela X-1, spin phase 0-0.1)

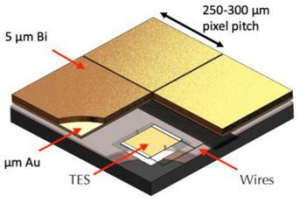
The USA PROBES: LEM

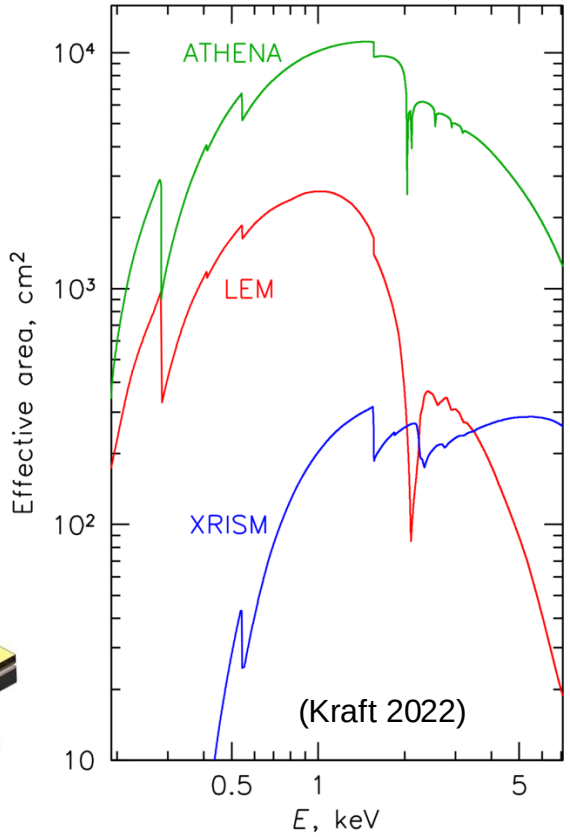
Grazing-incidence X-ray mirror:
1600 cm² effective area at E=0.5 keV
0.2–2 keV band
15" contains 90% PSF
(10" HPD resolution)

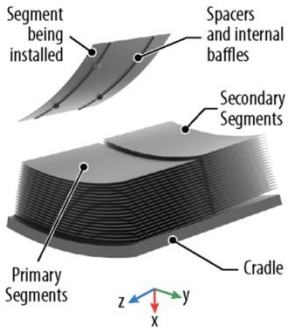
Imaging spectrometer (IFU):
TES microcalorimeter array, cryocooled
2 eV resolution (central area 1 eV)
30'×30' field of view
118×118 15" pixels

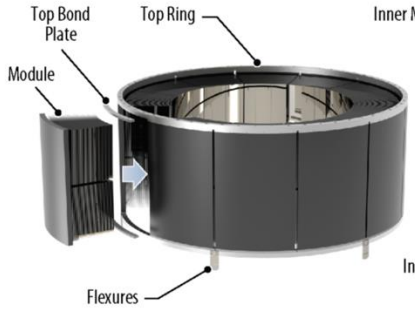


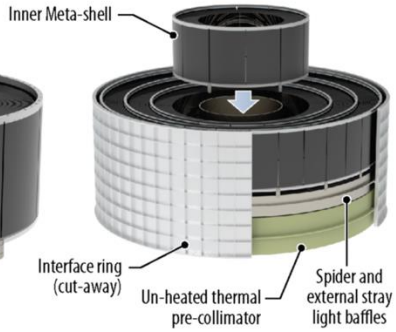
TES sensors







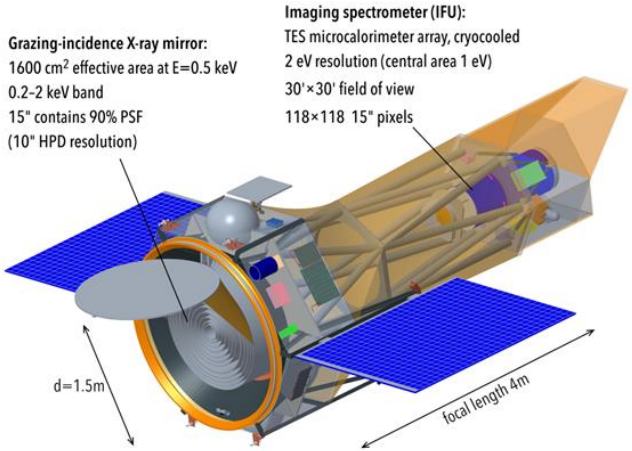


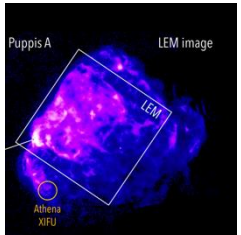


	LEM	XRISM	Athena	Lynx†	HUBS†
Energy band, keV	0.2–2	0.4–12	0.2–12	0.2–7	0.2–2
Effective area, cm²					
0.5 keV	1500	50	6000	14000	500
6 keV	0	300	2000	...	0
Field of view	30'	3'	5'	5'	60'
Grasp* at 0.5 keV	1.3	<0.001	0.12	0.35	1.8
Angular resolution	15"	75"	5"	1"	60"
Spectral resolution	1 eV, 2 eV	7 eV	2.5 eV	3 eV	2 eV
Detector array, pix	118×118**	6×6	50×50**	300×300	60×60

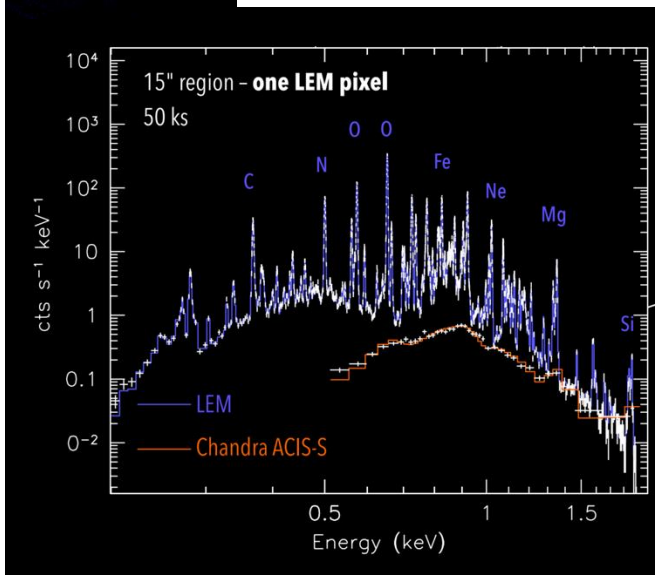
High resolution X-ray spectroscopy (1-2 eV) over a large FoV of 30 arcmin (0.5-2 keV)

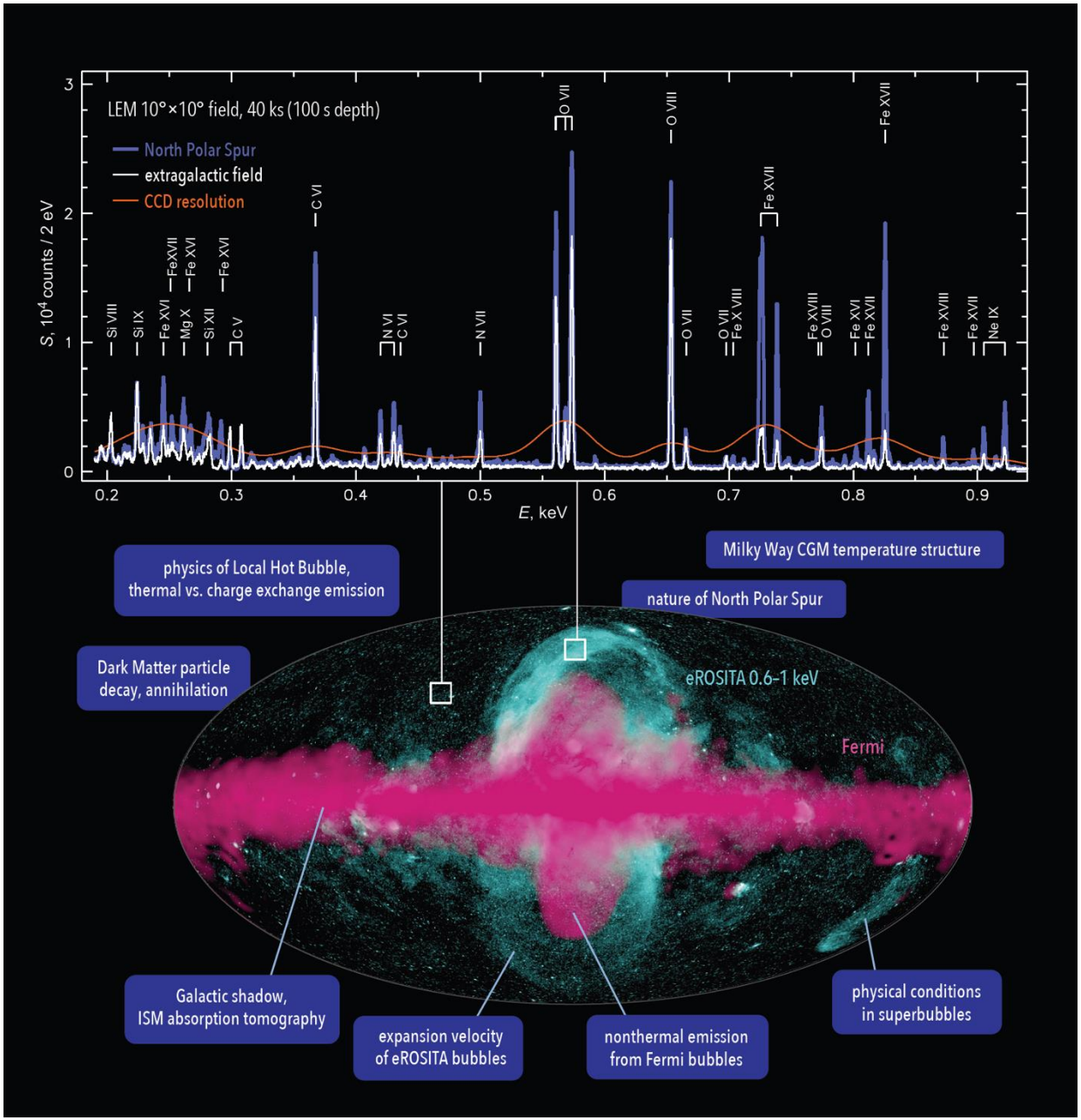
The USA PROBES: LEM



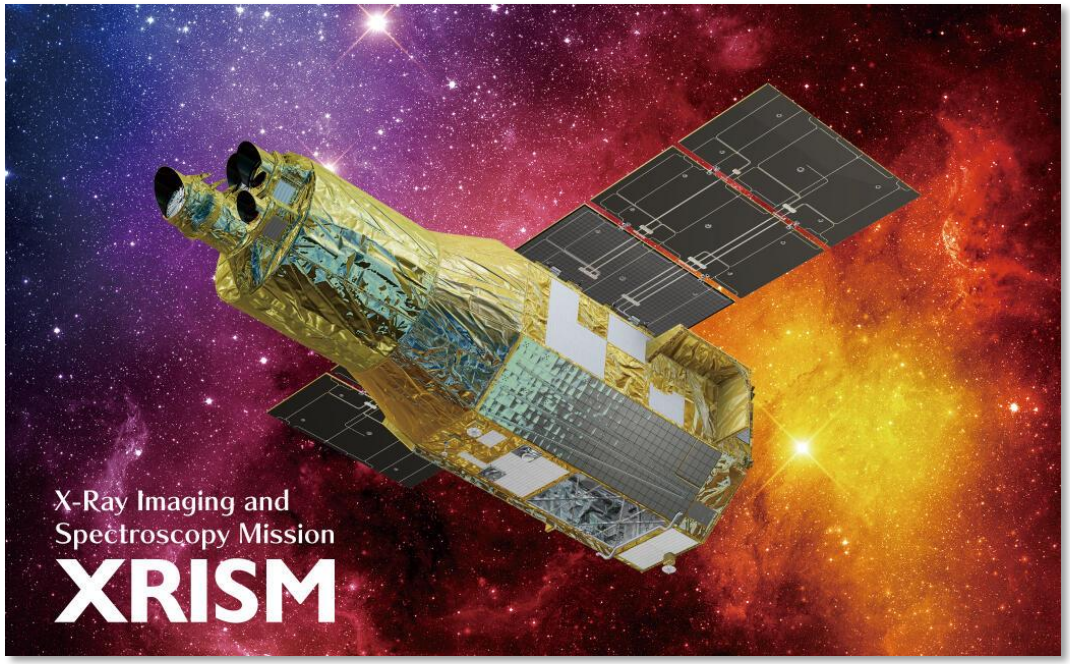


Pointed observations & surveys





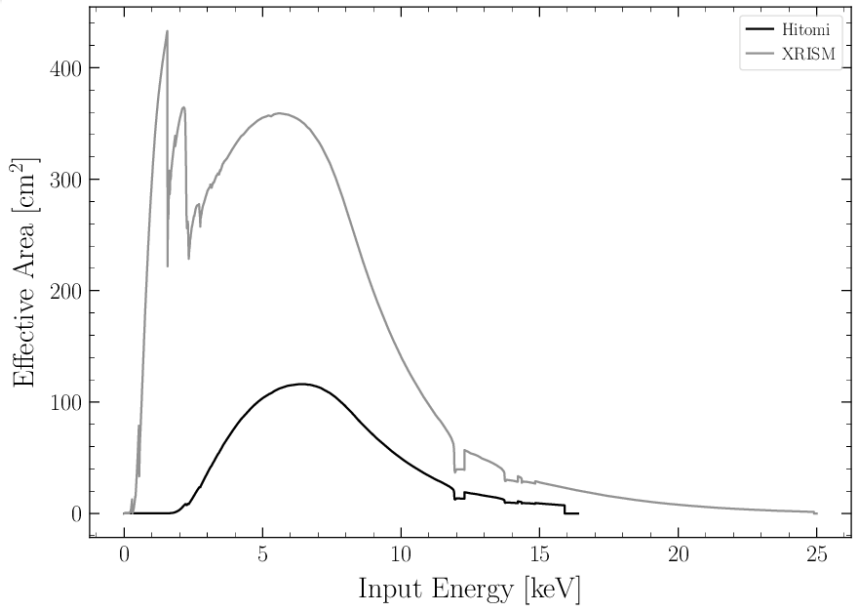
Short parenthesis – XRISM

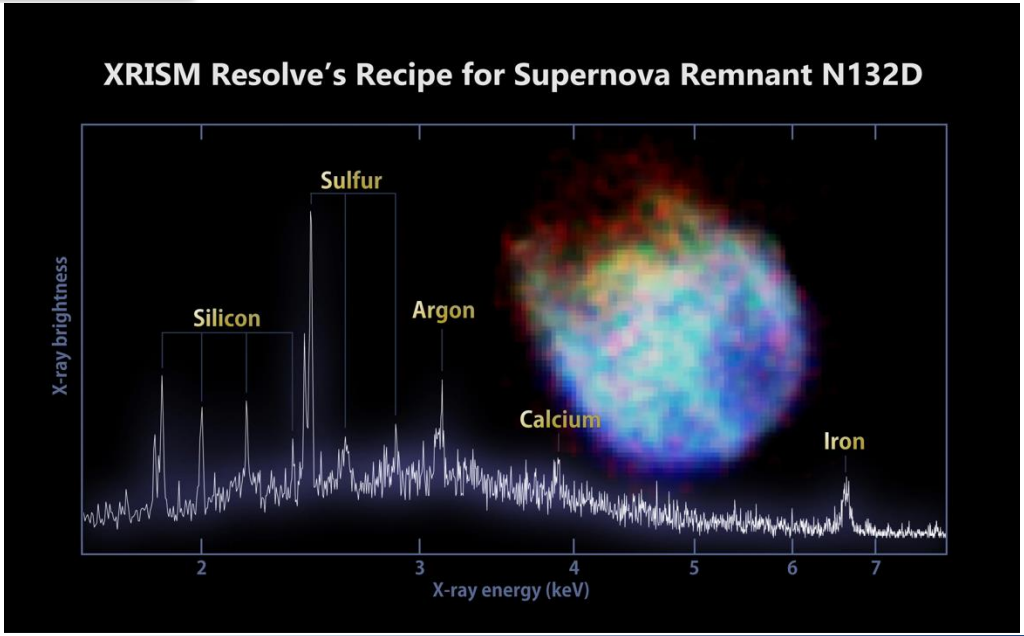


XRISM – JAXA led
Recovery mission for Hitomi
Launched in 2023

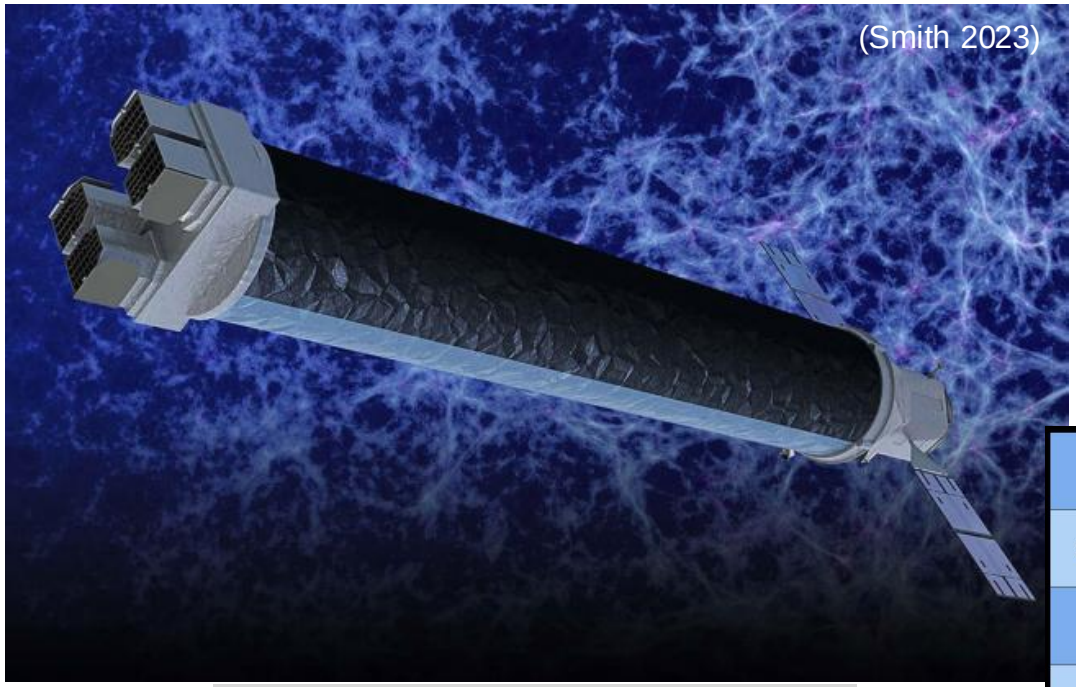
High resolution X-ray spectroscopy
0.2-12 keV

«Gate valve» did not open, so far large loss of effective area & sensitivity reduced to >2 keV.



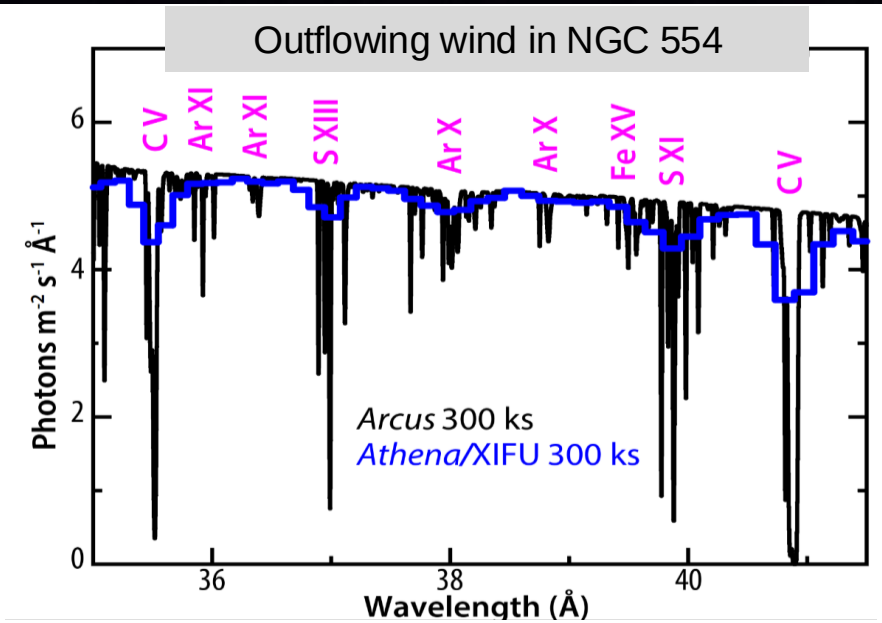


The USA PROBES: ARCUS



High energy resolution (dispersive) observations in both the FUV and X-ray simultaneously

Better sensitivity than previous gratings instruments and larger area than XRISM

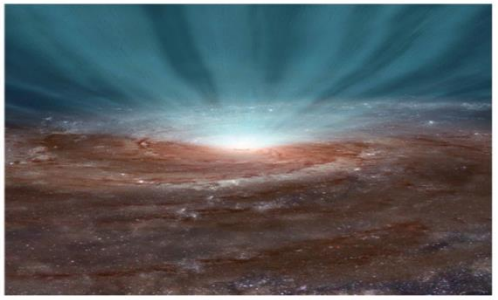


Bandpass	**X-ray:** 10-60 Å **FUV:** 970-1,350 Å
Spectral resolution	**X-ray:** R=3,500 (average over band) **FUV:** R=21,000
Effective Area	**X-ray:** 350 cm² at 19 Å **FUV:** 330 cm² at 1,100 Å
Calibration	**X-ray:** ± 0.4 mÅ (± 5 km/s) **FUV:** ± 0.51 mÅ (± 15 km/s)
X-ray Instrument Technology	Silicon pore optics + critical angle transmission grating + high heritage CCDs
FUV Instrument Technology	Large-format photon-counting detectors + advanced UV mirror coatings
X-ray Background	0.008 cts s^{-1} $Å^{-1}$ at 24 Å
FUV Sensitivity Limit	S/N = 15 in 100 ks with 3e-15 erg/s/cm²/Å
Target of Opportunity Response Time	24 hours
Continuous Observing	100 ks
Launch Date	December 2031

UNIVERSITÉ DE GENÈVE

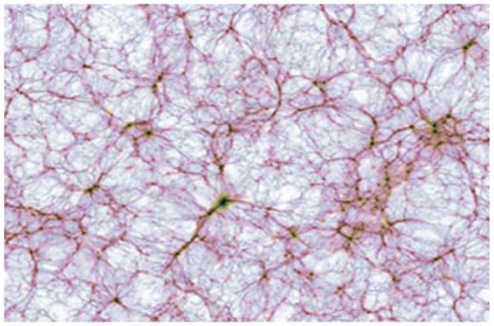
Reveal how black holes impact their surroundings

Measure the mass, energy, and composition of outflowing winds driving feedback from the inner regions of supermassive black holes.



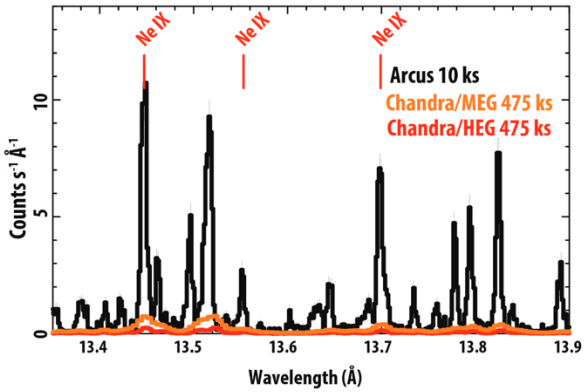
Find the Universe's missing baryons and metals

Measure the spatial and temperature distribution of hot gas at and beyond the virial radii of galaxies and clusters, and the distribution and metal abundance of all phases of gas in our Galaxy's disk.



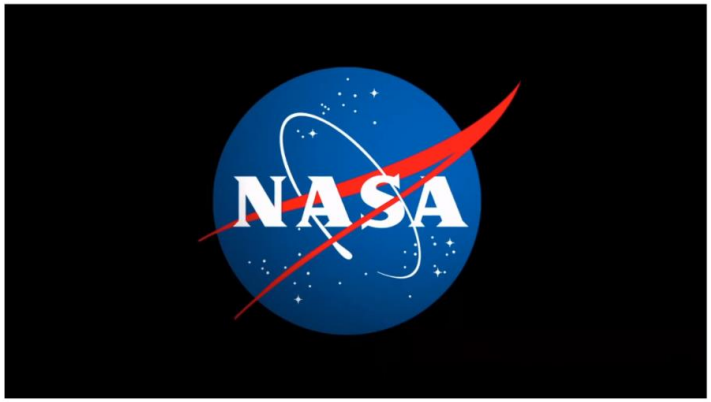
Trace the birth, life, and death of stars and stellar systems

Measure the thermodynamic properties of hot gas in stellar magnetic structures and shocks; measure outer radial density profiles of exoplanet atmospheres.



UNIVERSITÉ DE GENÈVE

NASA Establishes New Class of Astrophysics Missions, Selects Studies



Advanced X-ray Imaging Satellite

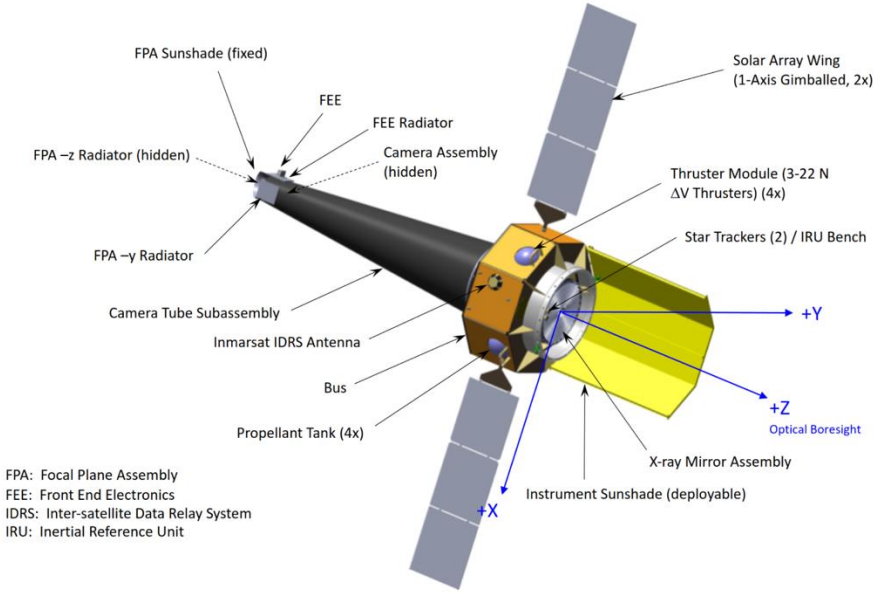
- This mission would be an X-ray imaging observatory with a large, flat field-of-view and high spatial resolution. It would study the seeds of supermassive black holes; investigate the process of stellar feedback, which influences how galaxies evolve; and help determine the power sources of a variety of explosive phenomena in the cosmos. The observatory would build on the successes of previous X-ray observatories, capturing new capabilities for X-ray imaging and imaging spectroscopy.
- Principal investigator: Christopher Reynolds, University of Maryland, College Park
- Project management: NASA's Goddard Space Flight Center in Greenbelt, Maryland

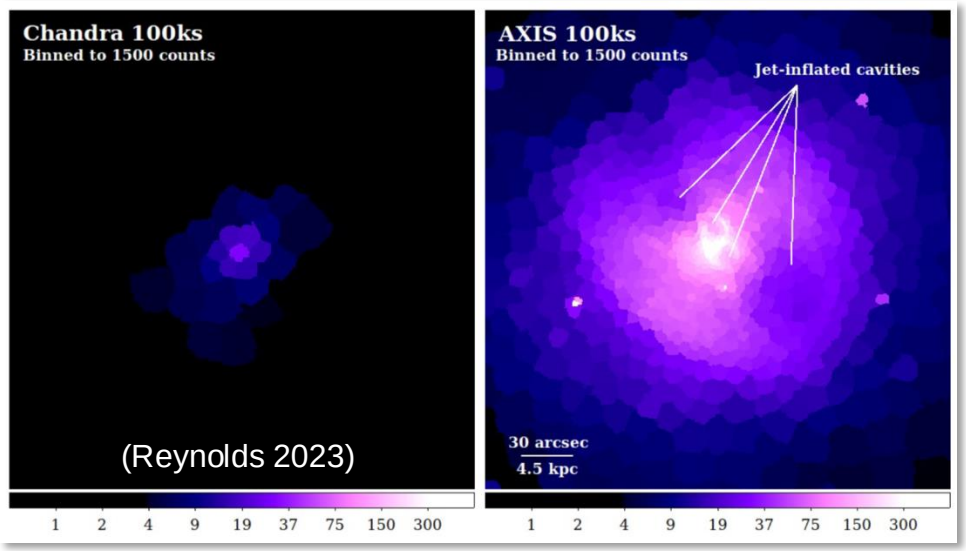
Probe far-Infrared Mission for Astrophysics

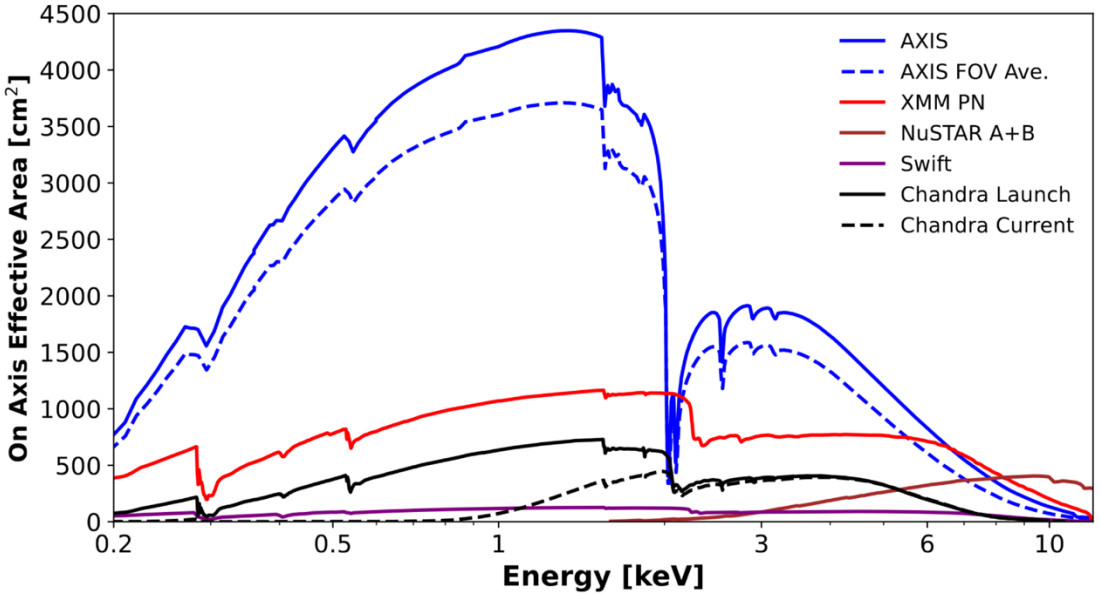
"NASA's Explorers Program brings out some of the most creative ideas for missions that help us reveal the unknown about our universe. Establishing this new line of missions – the largest our Astrophysics program has ever competed – has taken that creativity to new heights," said Nicola Fox, associate administrator, Science Mission Directorate at NASA Headquarters in Washington. "Both of the selected concepts could enable ground-breaking science responsive to the top astrophysics priorities of the decade, develop key technologies for future flagship missions, and offer opportunities for the entire community to use the new observatory, for the benefit of all."

The National Academies of Sciences, Engineering, and Medicine's 2020 Decadal Survey, Pathways to Discovery in Astronomy and Astrophysics for the 2020s, recommended NASA establish this new mission class, with the first mission observing either X-ray or far-infrared wavelengths of light. Mission costs for the new Probe Explorers are capped at $1 billion each, not including the cost of the rocket, launch services, or any contributions.

The USA PROBES: AXIS





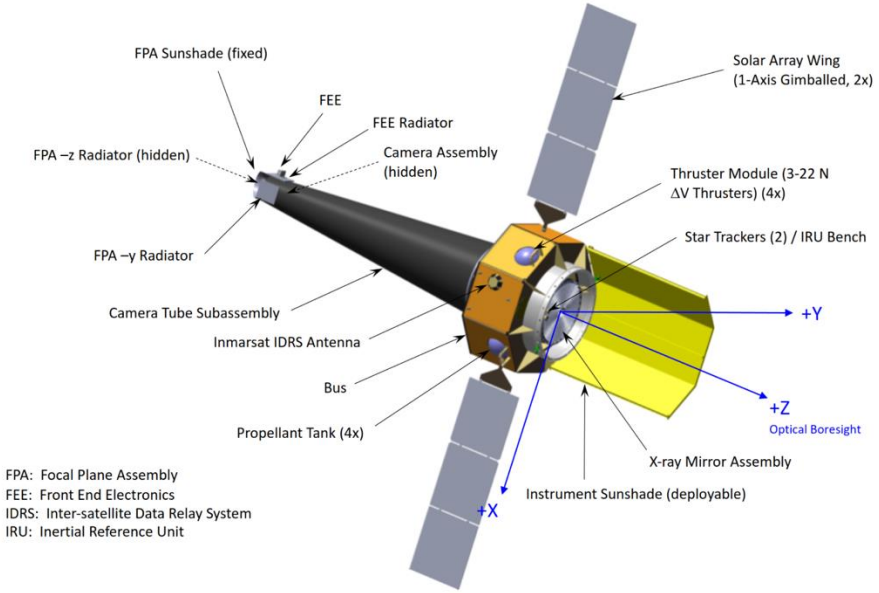


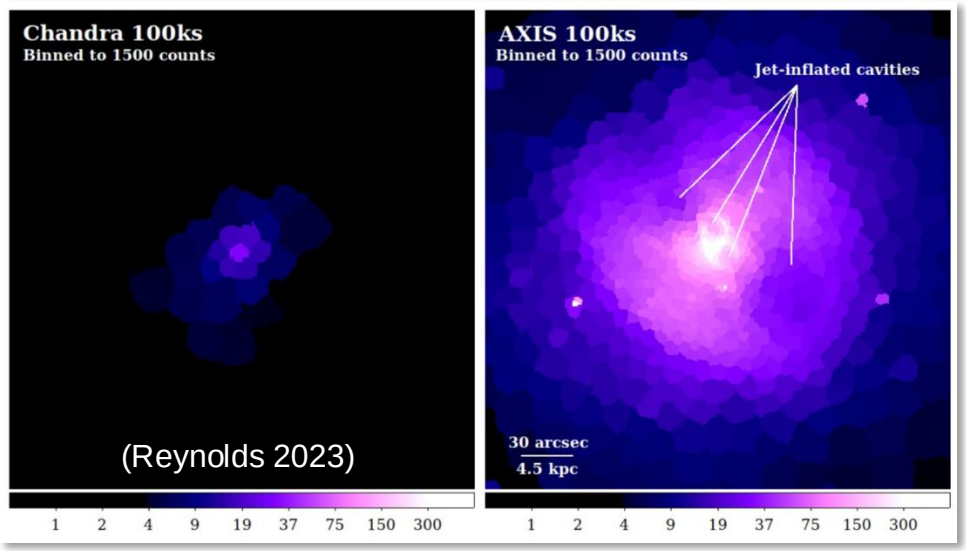
The next high-spatial resolution X-ray observatory (successor of Chandra)

450 arcmin^2 FoV with flat 1 arcsec spatial resolution

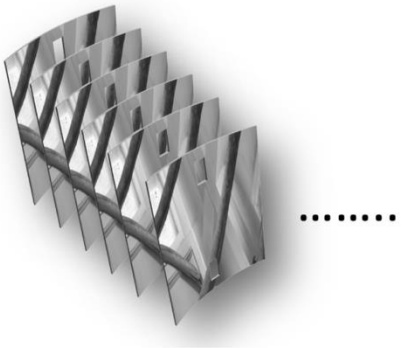
Much larger collective area compared to its predecessors

The USA PROBES: AXIS



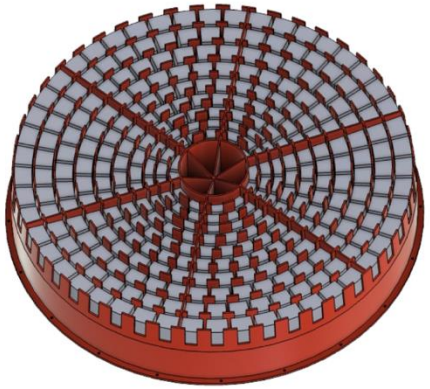


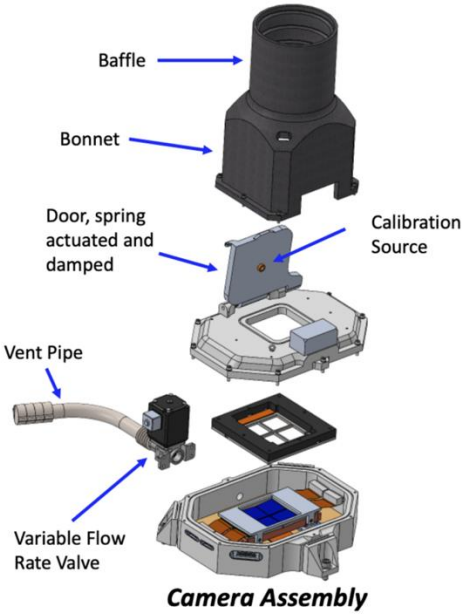
14,000 mirror segments



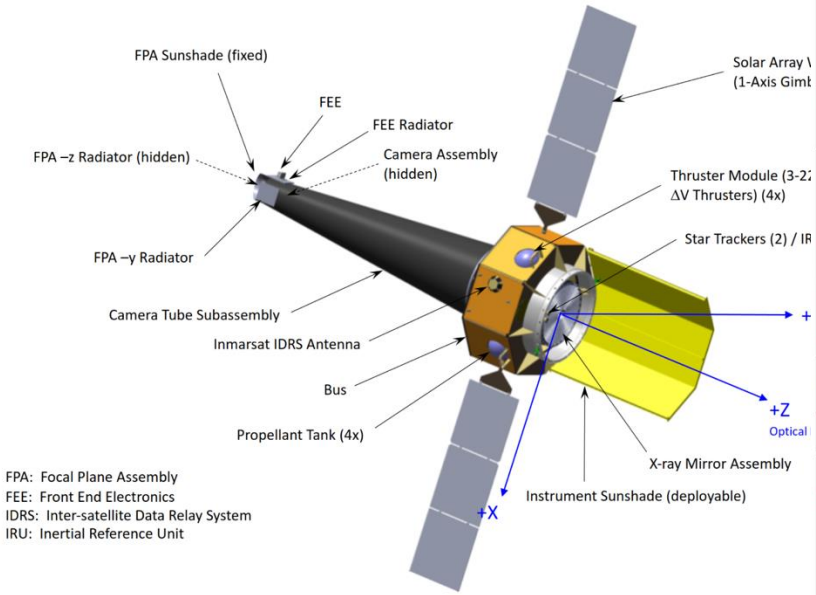
264 mirror models

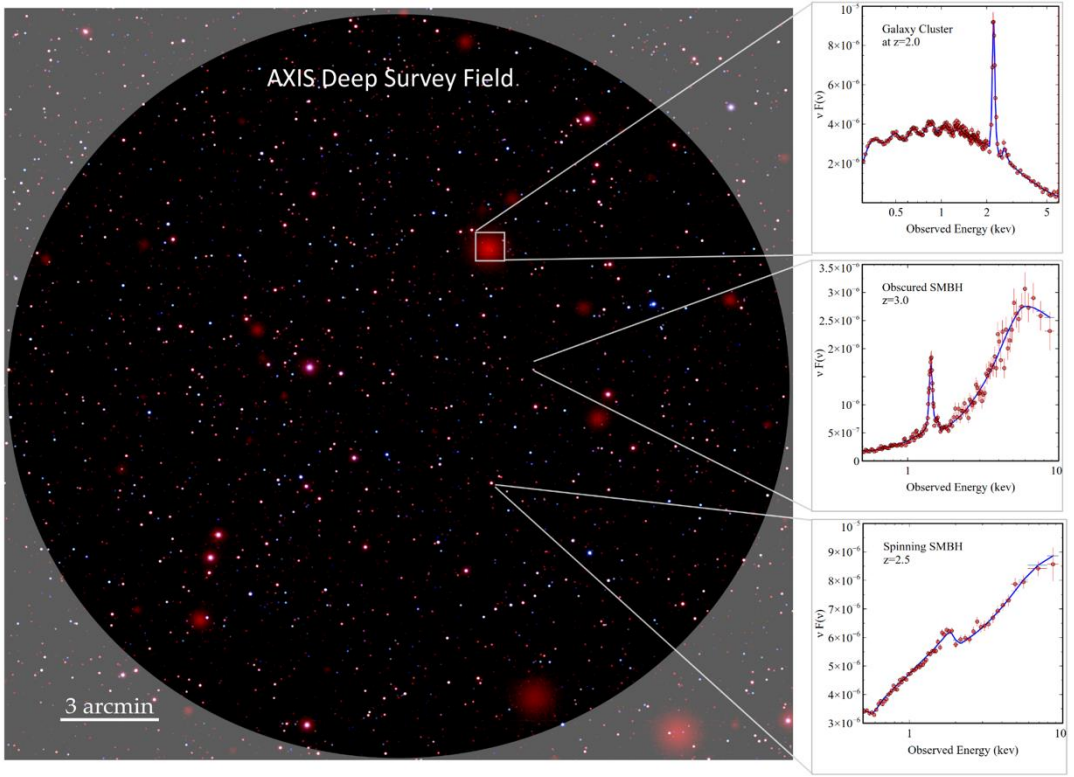
AXIS X-ray Mirror Assembly (XMA)

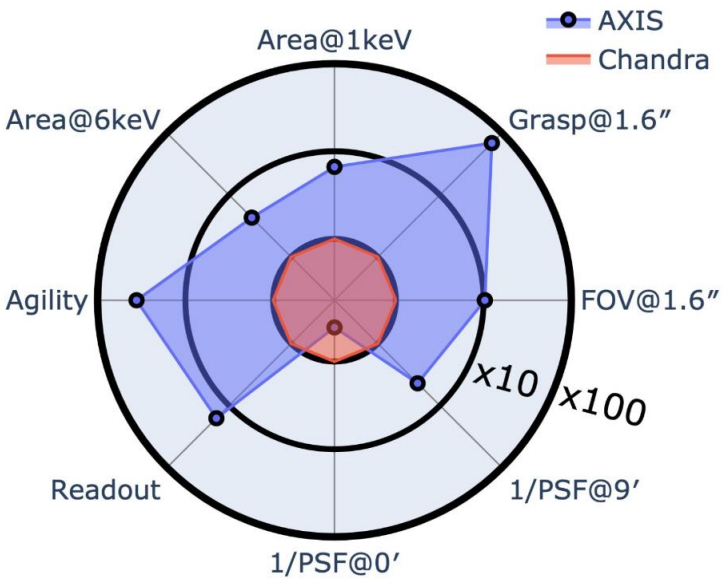




The USA PROBES: AXIS







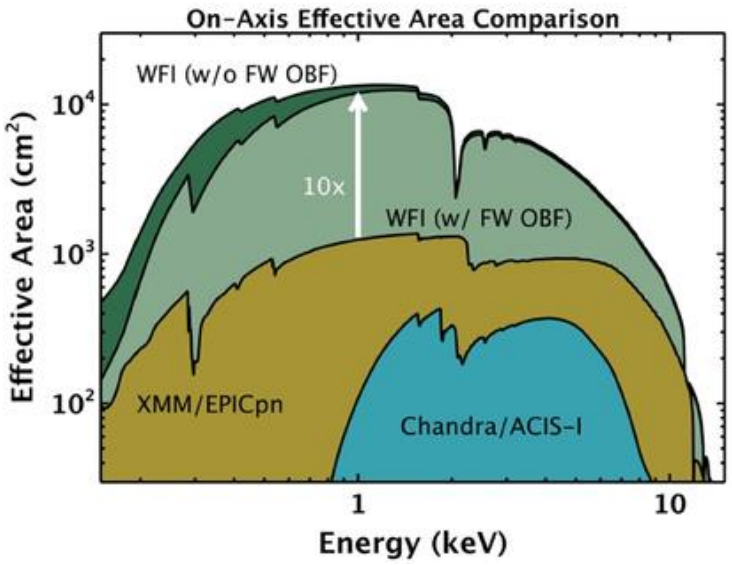
Area	Value	Requirement
Angular Resolution	1 arcsec on-axis 2 arcsec 15′ off-axis	Point source detection, separation, excision
Bandpass	0.2-10 keV	Soft and hard X-ray sensitivity
Effective Area (including detector)	5600 cm² @ 1 keV 1200 cm² @ 6 keV	Faint/low surface brightness source analysis
Energy Resolution	~150 eV @ 6 keV (CCD resolution)	Emission line separation
Readout rate	<50 ms	Variable source analysis
Field of View	24 arcmin (diameter)	Extended source analysis, surveys
Detector Background	4-5x less than Chandra	Sensitivity to low surface brightness
Slew Rate	120 deg / 5 min	Observing efficiency /TOOs

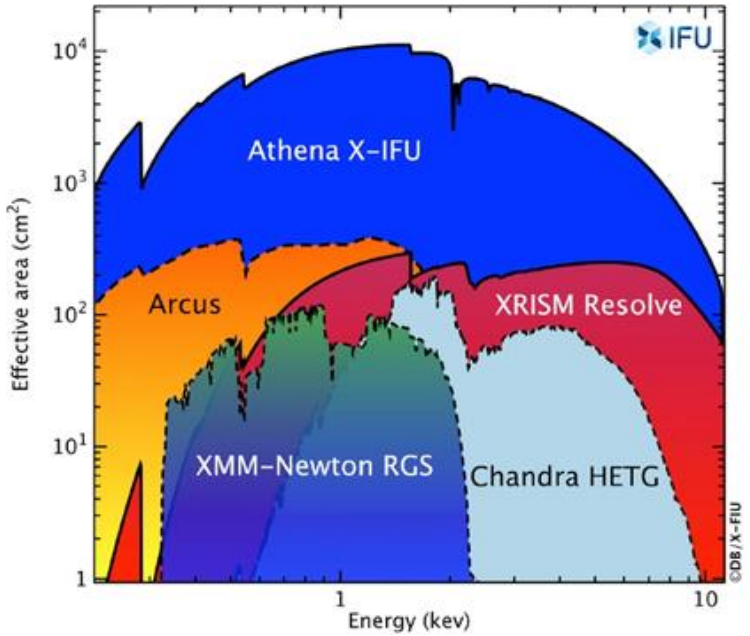
ESA: Athena

(Barret 2023, Rau 2023)

Selected by ESA in 2014: next large observatory for X-ray Astronomy

Phase A study 2014-2019
Phase B1 study 2020-2022
Rescoped, redesigned
Phase A study 2024-2026
Adoption planned Q1 **2027**
Launch 2037



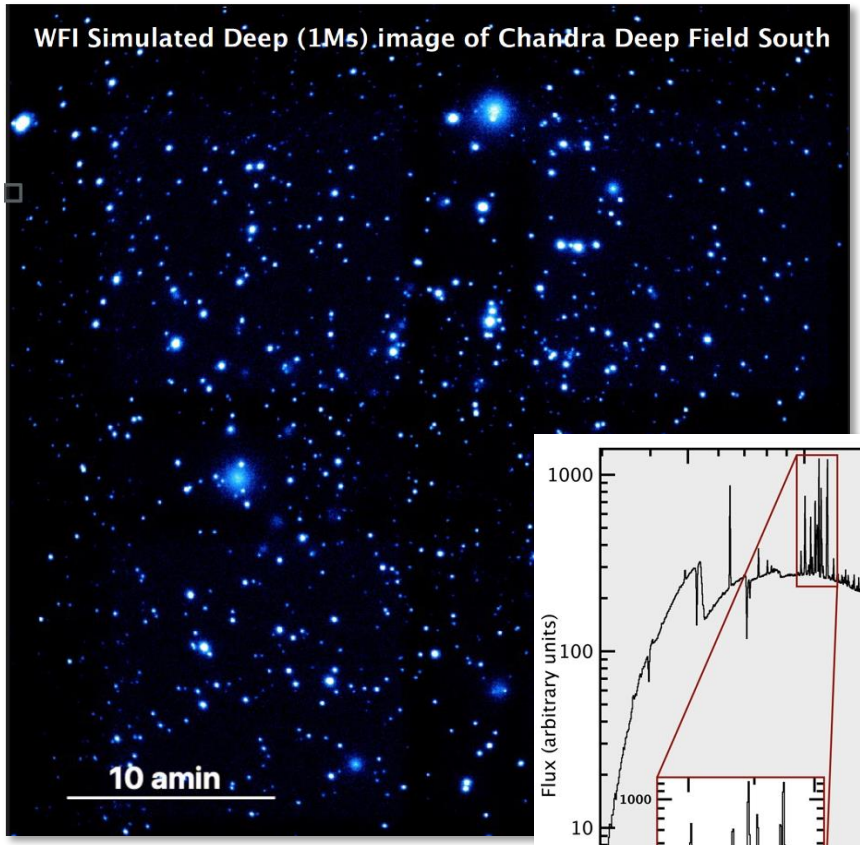


X-IFU: high-resolution spectroscopy

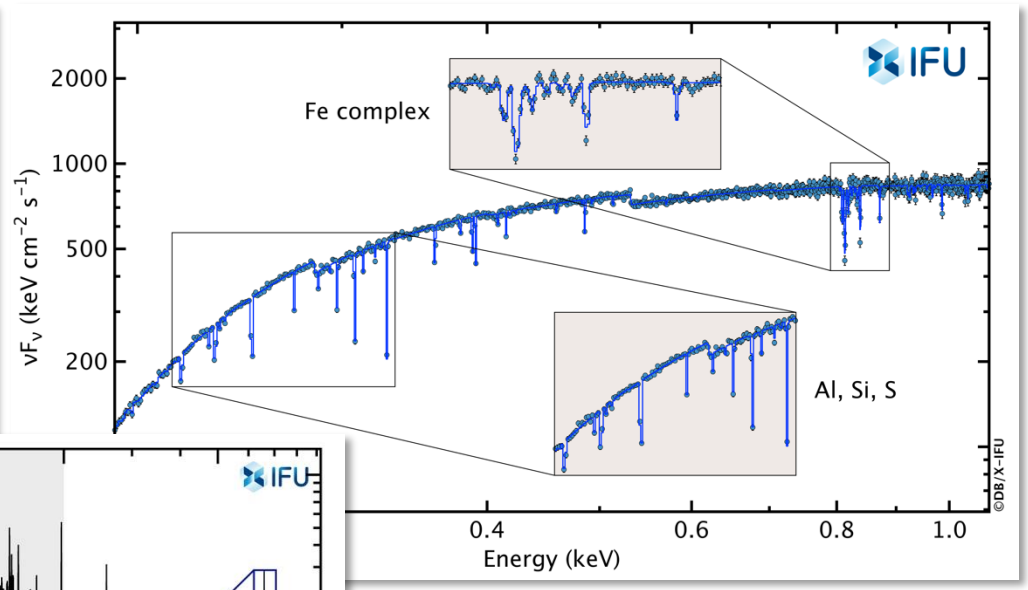
WFI: wide-field deep imaging & spectroscopy

Designed to be a large community observatory

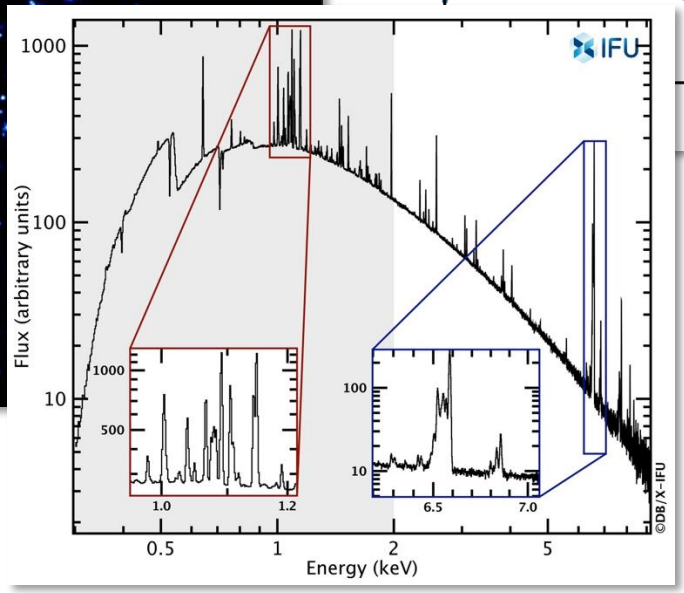
WFI and X-IFU planned to provide the next major leap forward in many topics of high energy Astrophysics



WFI deep field simulation



X-IFU simulations of a GRB spectrum



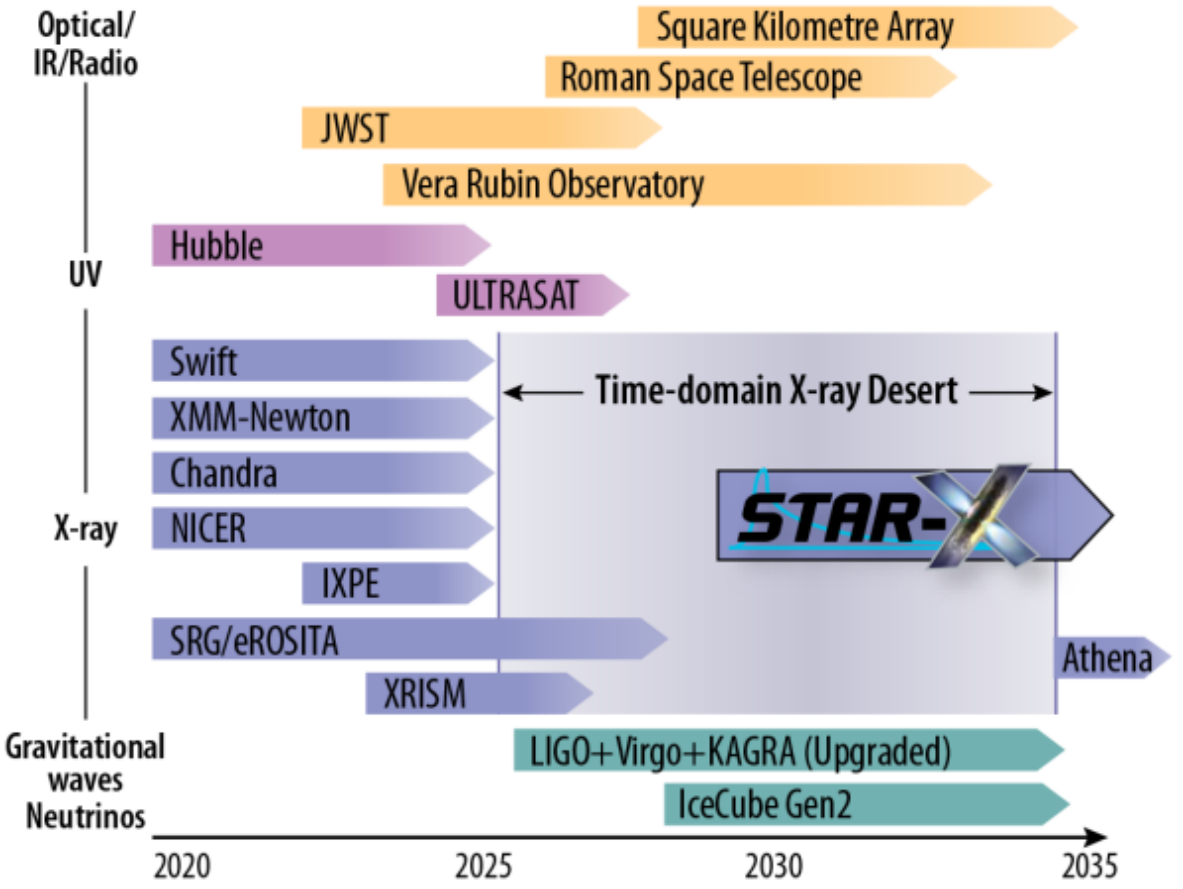
X-IFU simulations of the Perseus Cluster

Good perspectives, no certainties

Artist's impression of the «Time-domain X-ray desert»

Although many developments are on-going and there are promising perspectives to continue a golden-era for high energy Astrophysics, there is yet NO certainty for >2030s

Image (right) from STAR-X team, a mission recently not selected and devoted to time-domain Astronomy in X-rays and UV simultaneously (part of the NASA MIDEX programme)



THANK YOU!

enrico.bozzo@unige.ch