Your future in X-ray astronomy

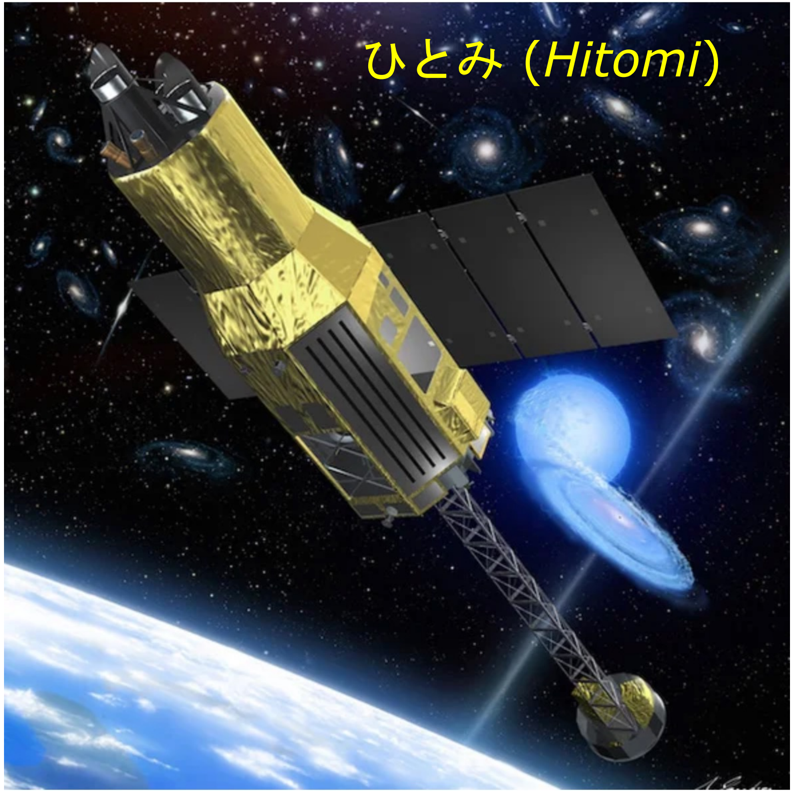
Matteo Guainazzi (ESA/ESTEC)

Big questions

1. What are the physical conditions of the baryons locked in the Universe large-scale structure? How do they evolve from the epoch of their formation?
2. How do accreting super-massive black hole shape the galaxies where they reside, and the large-scale environment surrounding them?
3. How does matter behave under extreme high-gravity conditions?
4. What are the electromagnetic counterparts of Gravitational Wave sources?

Let’s start my story

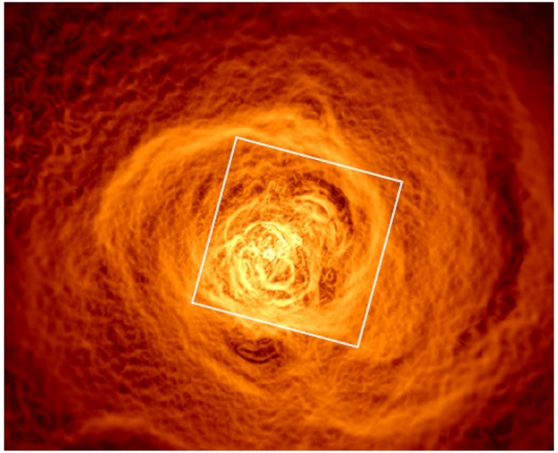
Matteo in 2016
at ISAS (Sagamihara, Japan)

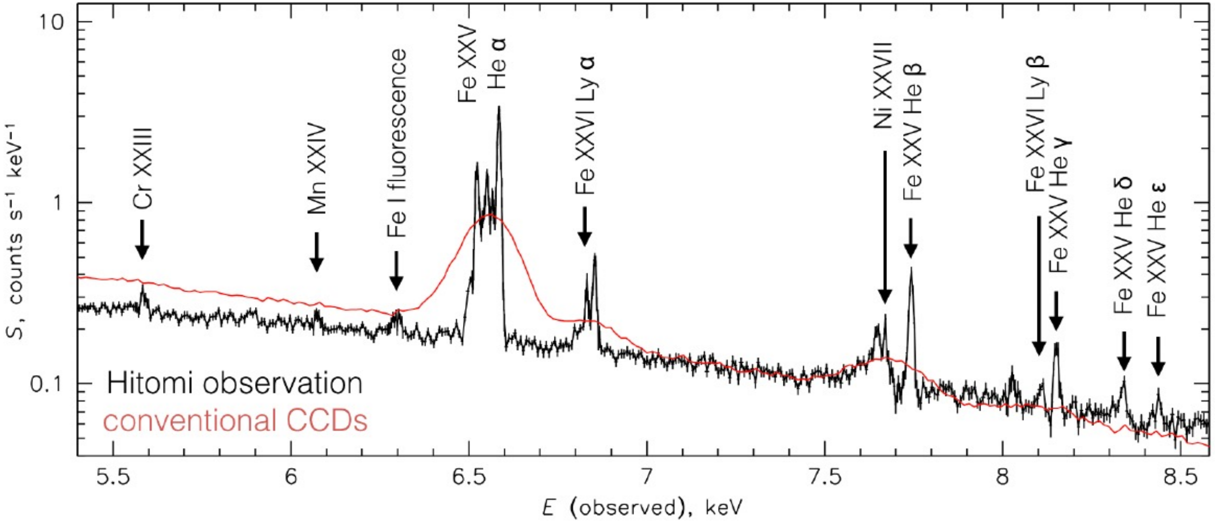


ひとみ (*Hitomi*)

The ひとみ (*Hitomi*) heritage

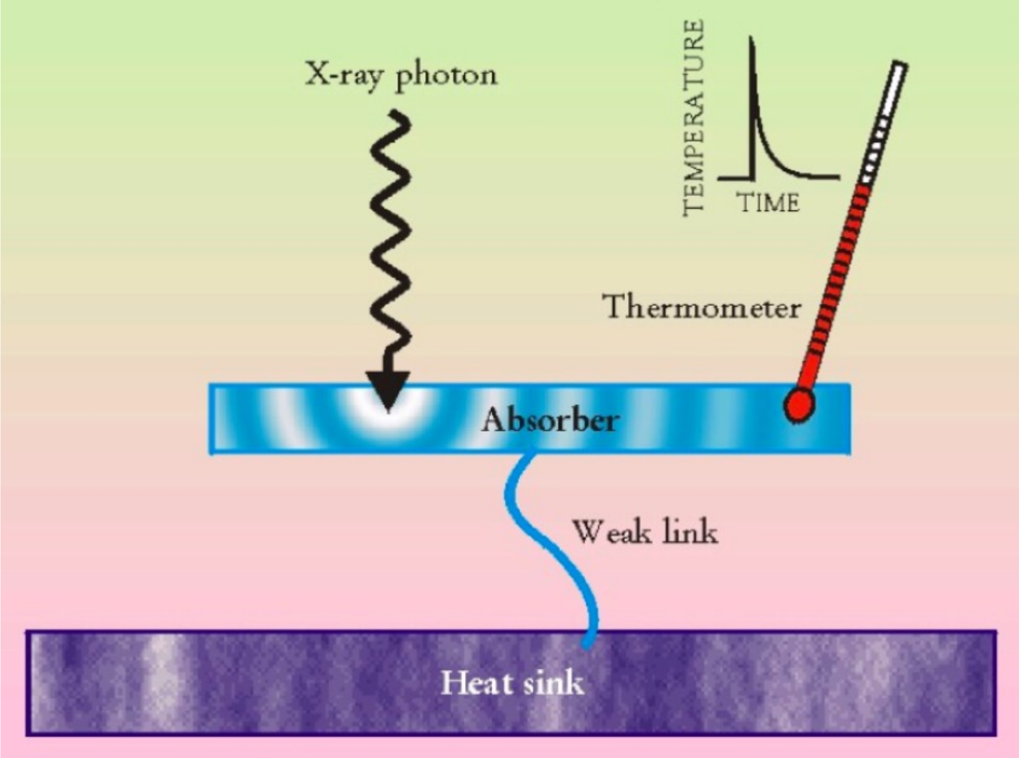
Hitomi/SXS observation of the core of the Perseus Cluster compated to a CCD





Hitomi Collaboration, 2016, Nature, 535, 117

Physics of μcalorimeters



Credit: prof. F. Paerels (Columbia Un.)

- Measure very small changes in temperature in an absorber due to an incoming X-ray photon
- Far better energy resolution at E>2 keV than any X-ray spectrometers conceived so far
- Non-dispersive → enable study of extended and diffuse sources

XRISM (X-Ray Imaging Spectroscopy Mission)

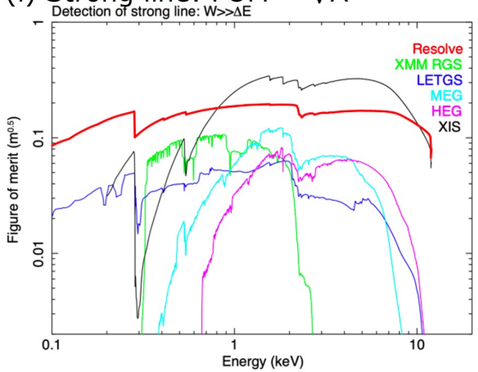
- *Hitomi* was lost after six weeks, leaving an heritage of **~1 science observation**

- JAXA/NASA swiftly agreed on a mission to recover the *"Resolving astrophysical problems by precise high-resolution X-ray spectroscopy"* science theme: **XRISM**
- Payload requirements:
    - Micro-calorimeter **(*Resolve*)**: ≤7 eV energy resolution in the 0.3-12 keV energy range, 3'x3' field-of-view
    - CCD detectors **(*Xtend*)**: Large-field (≥30'x30') , ≤200/250 eV (B/EoL) energy resolution @6 keV
    - Soft X-ray telescope, ~1.7' Half Energy Width

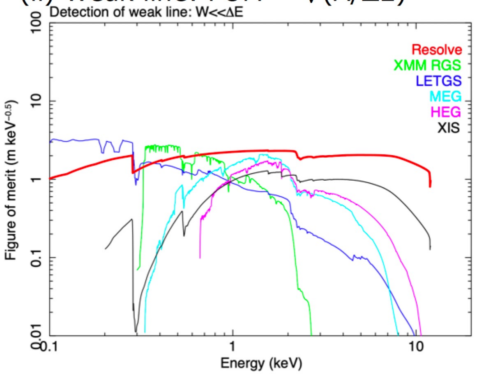
- Launch due ≤end of the Japanese Fiscal Year 2023

Key XRISM spectroscopic performance

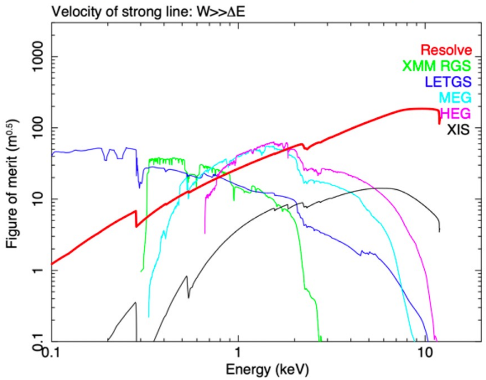
(i) Strong line: FOM ~ $\sqrt{A}$



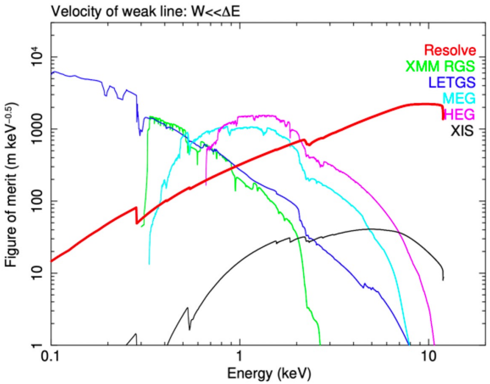
(ii) Weak line: FOM ~ $\sqrt{A/\Delta E}$



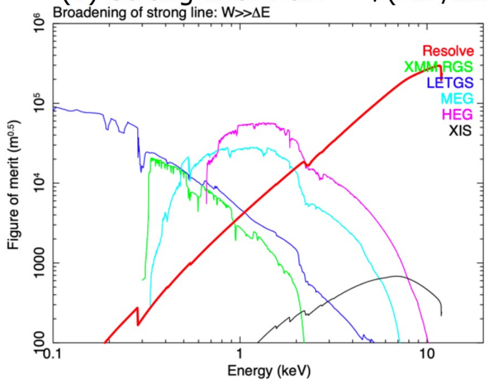
(iii) Strong line: FOM ~ $\sqrt{AE^2/\Delta E^2}$



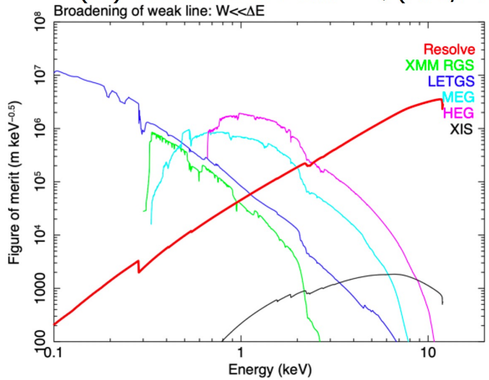
(iv) Weak line: FOM ~ $\sqrt{AE^2/\Delta E^3}$



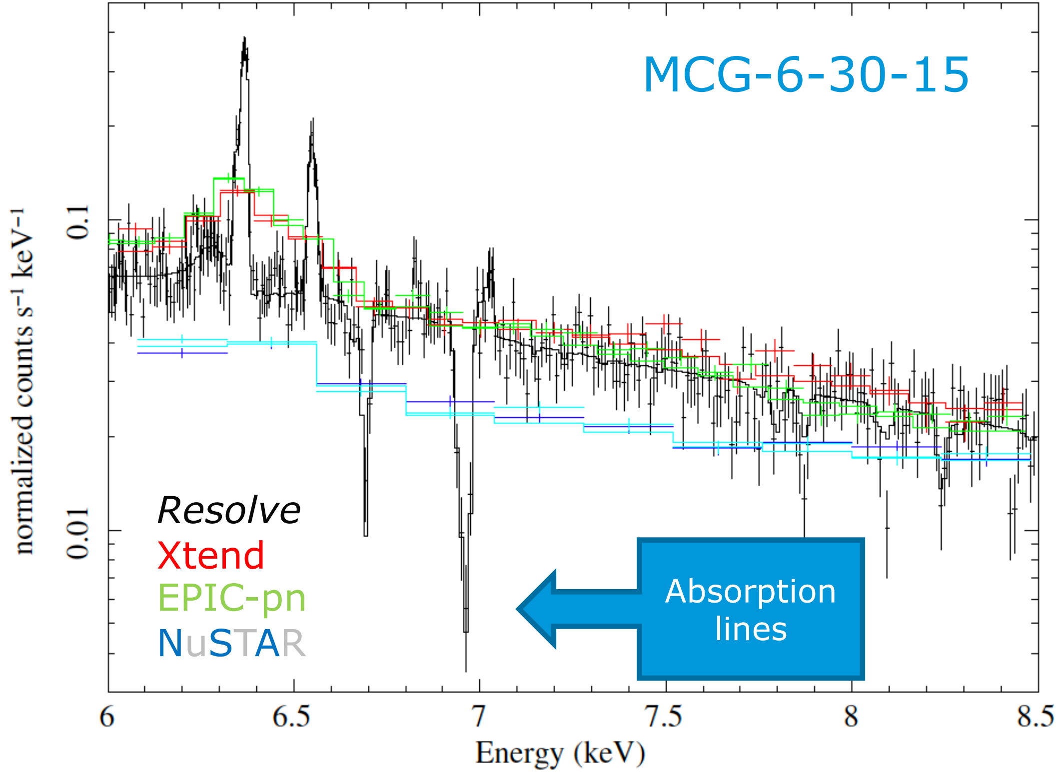
(v) Strong line: FOM ~ $\sqrt{AE^4/\Delta E^4}$



(vi) Weak line: FOM ~ $\sqrt{AE^4/\Delta E^5}$



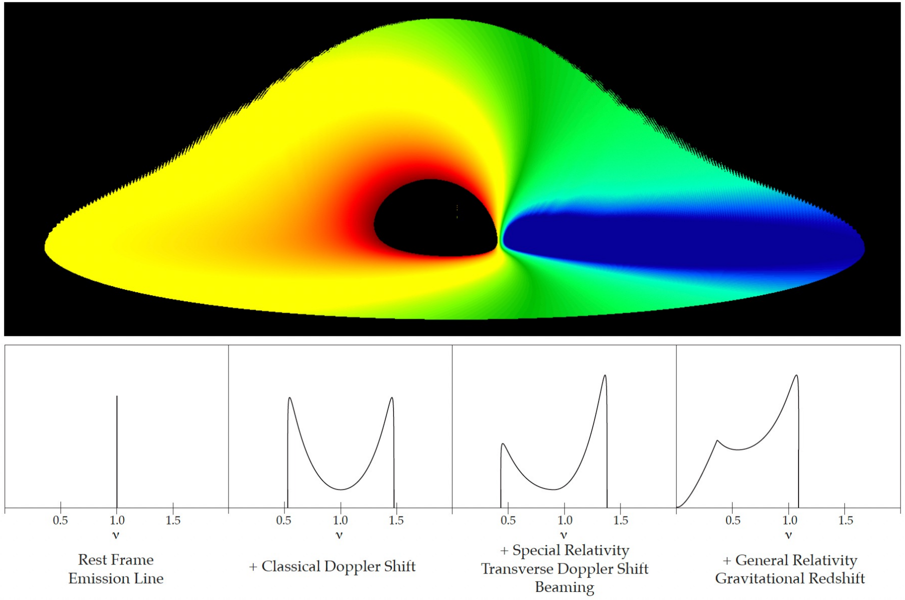
Another example of the μcalorimeter revolution



- Accreting supermassive black hole (Seyfert Galaxy)
- Host strong outflows
- Invisible at CCD resolution
- Only XRISM/SXS will enable plasma diagnostics

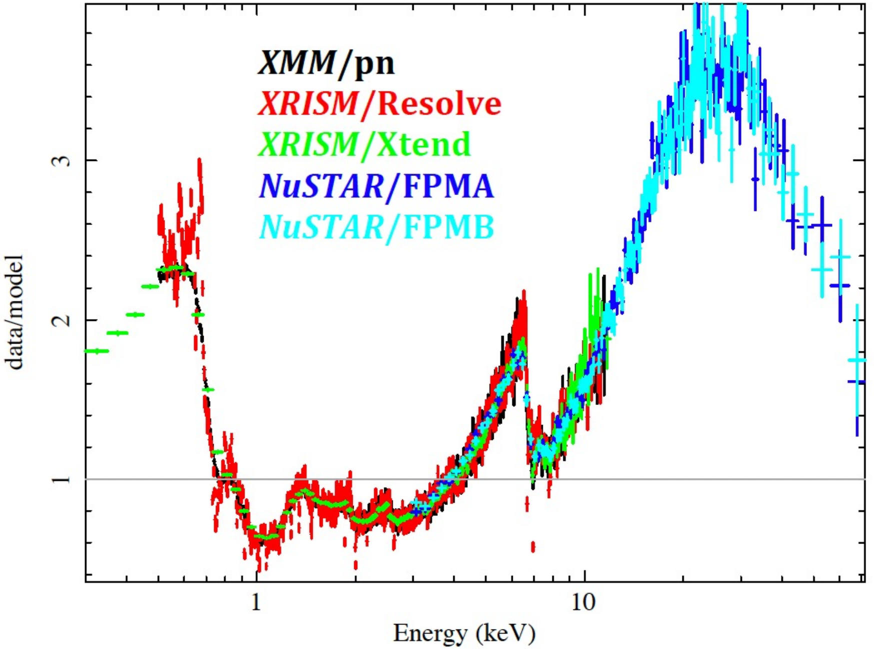
Chasing the black hole spin in AGN

Relativistic reflection and broad emission lines

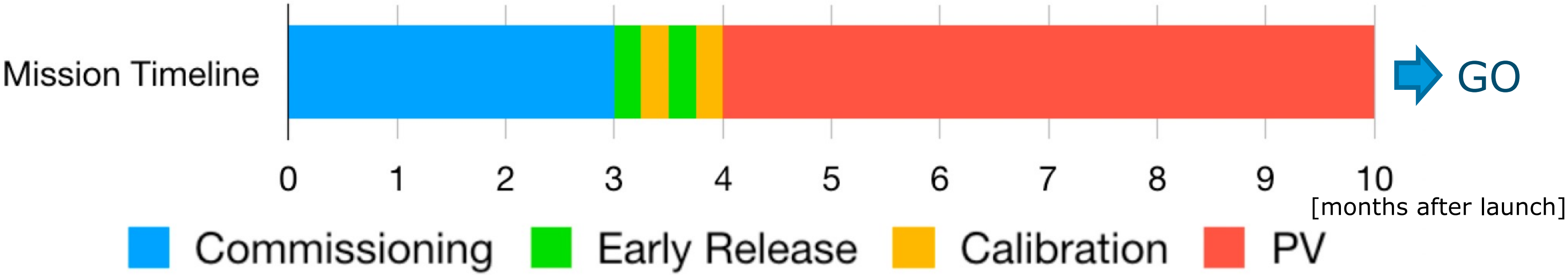


Dan Wilkins Lecture 2

Credit: L. Brenneman (CfA)



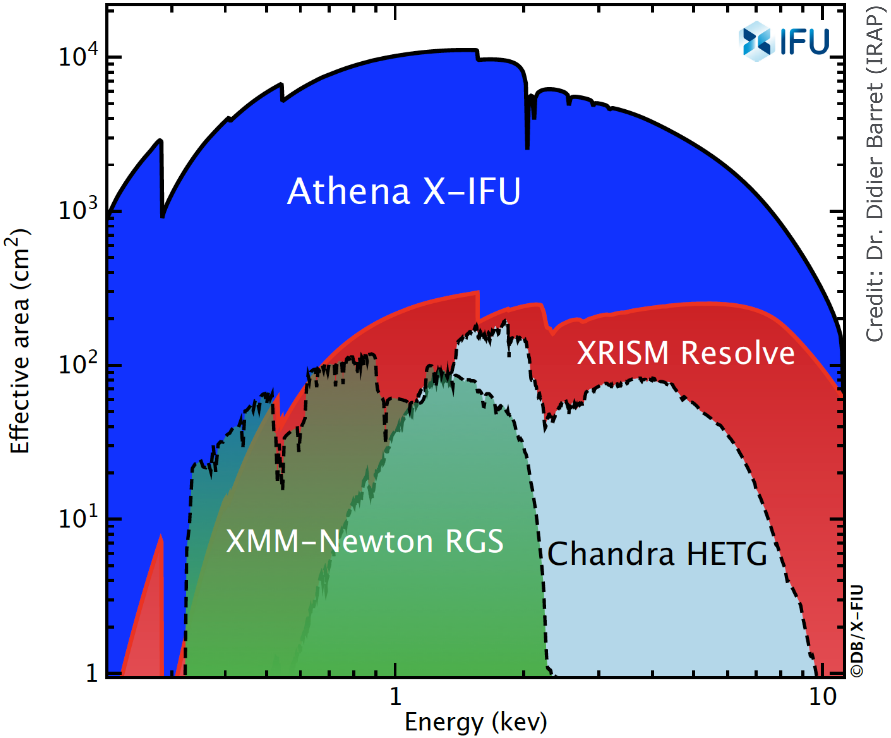
XRISM is an observatory



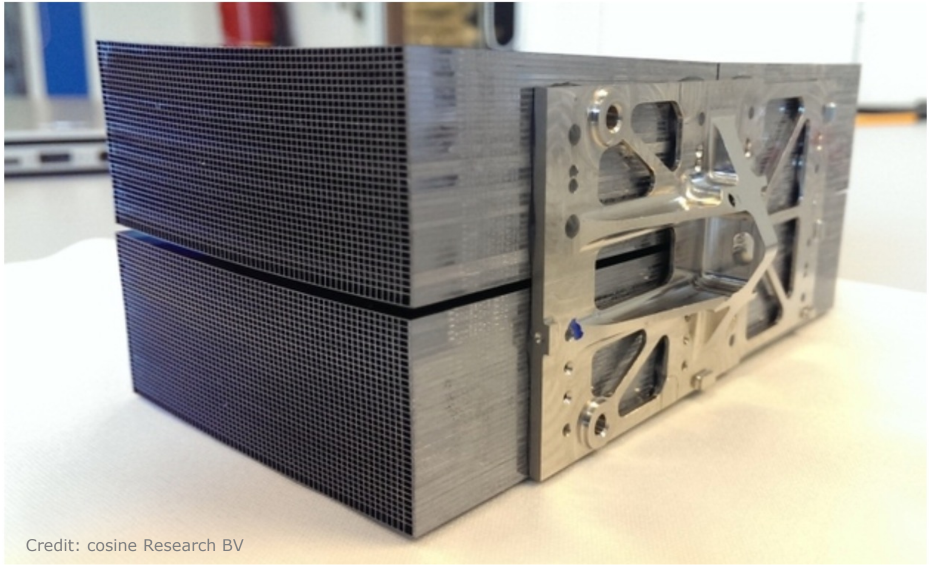
- The time of the Guest Observer (GO) Program is accessible to anyone
- **African/Indian scientists can apply to the 48% of GO "Japanese time"**
  - [European scientists can apply only to the 8% GO "European time"]
- Announcement of Opportunity published ~2 months after launch
- All data become public 1 year after pipeline processing

Athena versus XRISM: area

Total effective area (big X-ray mirror)

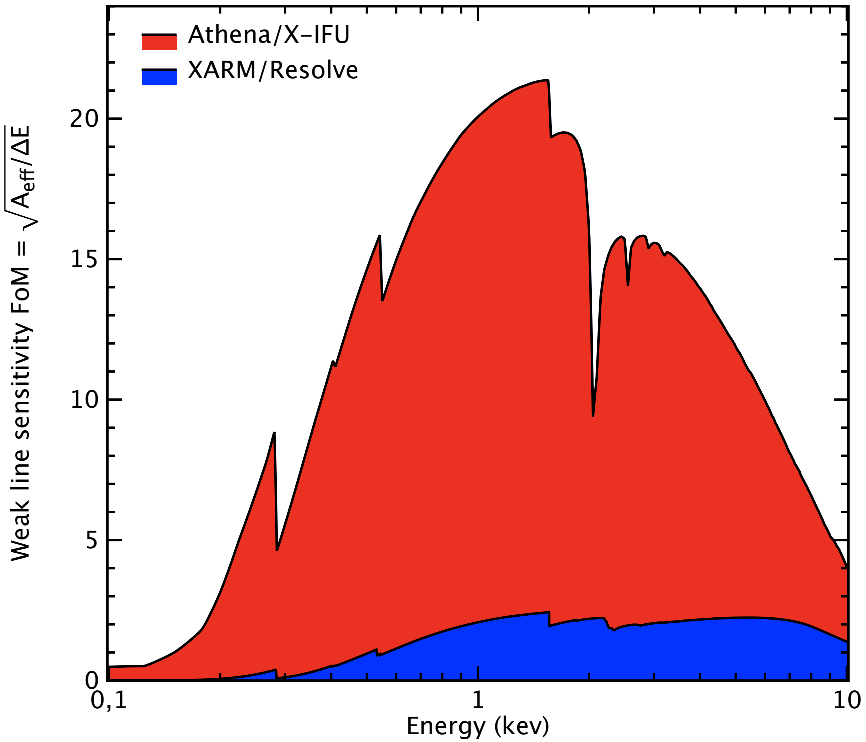


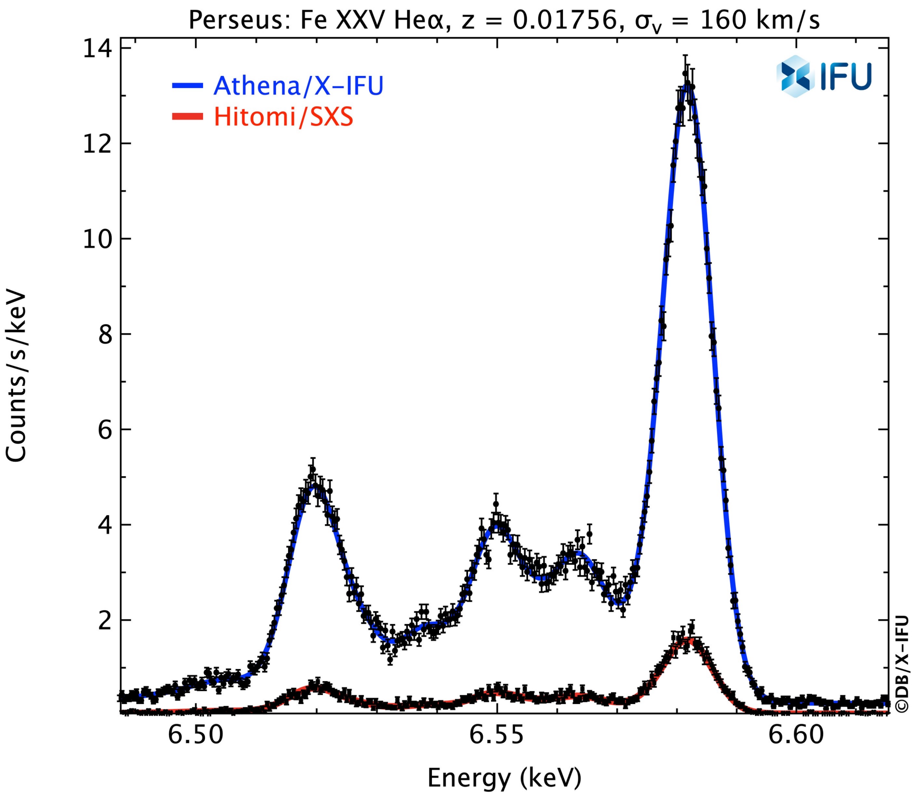
Silicon Pore Optics



Athena will be launched by ESA in the second half of 2030s

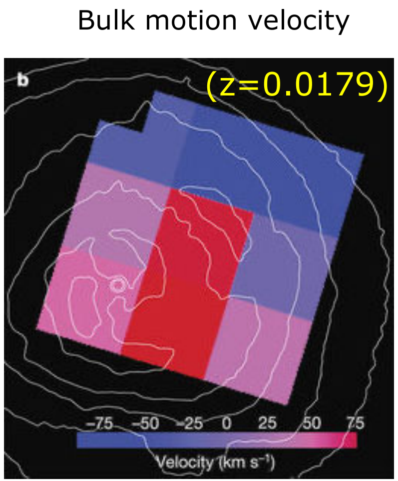
Athena/X-IFU vs. XRISM/SXS in a nutshell



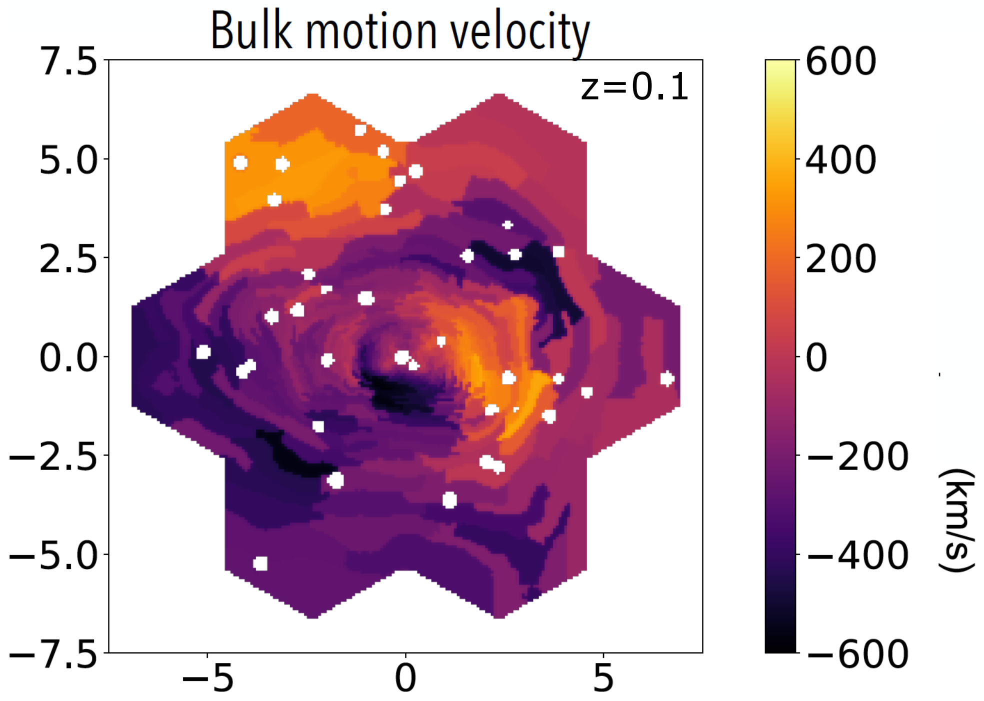


Credit: X-IFU Consortium

Athena vs. XRISM: angular resolution



Hitomi/SXS

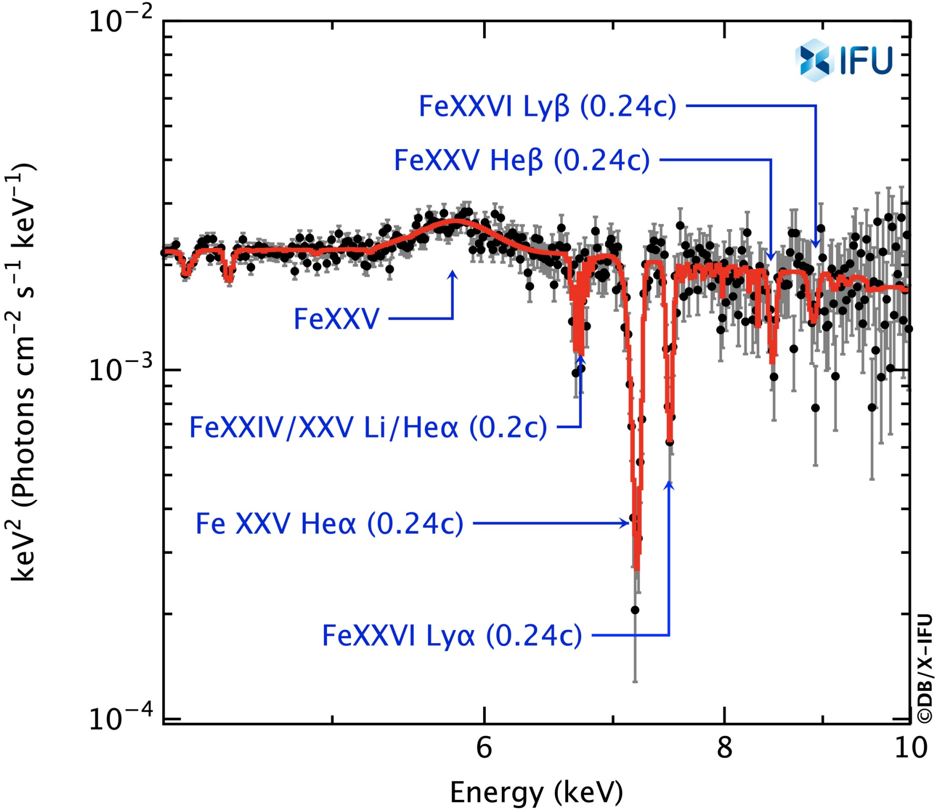


Athena/X-IFU map

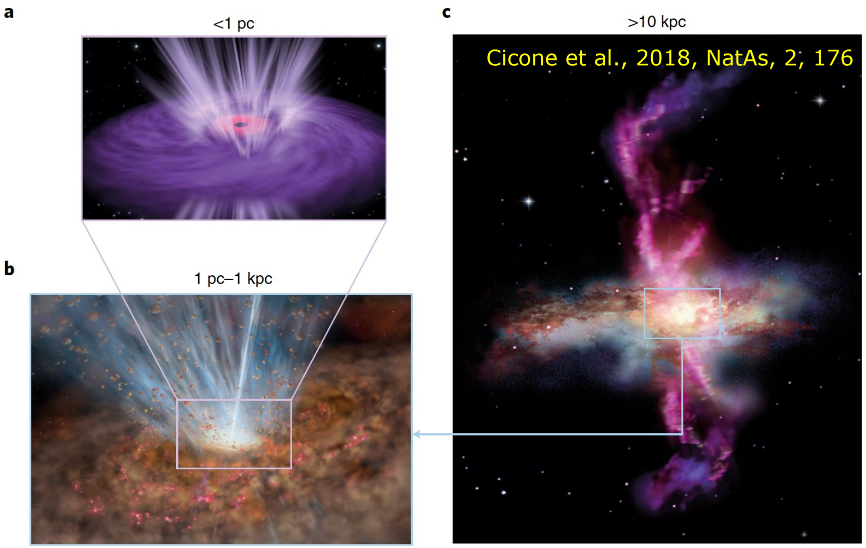
Hitomi collaboration, 2016, Nature, 535, 177

Cucchetti et al., 2019, A&A, 629, 144

Spectroscopy of relativistic AGN outflows

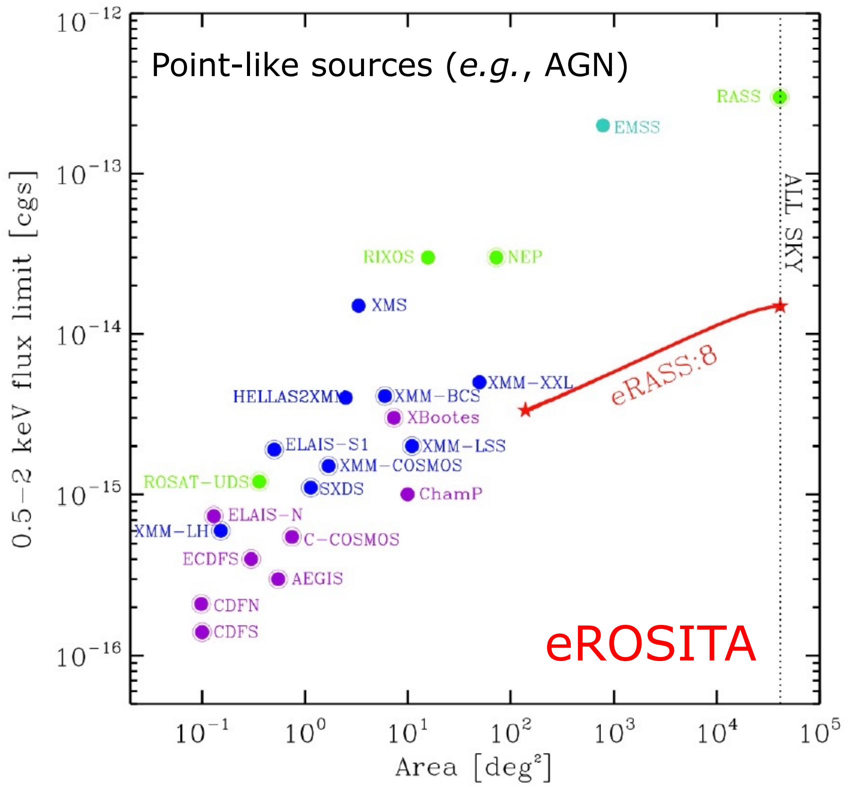


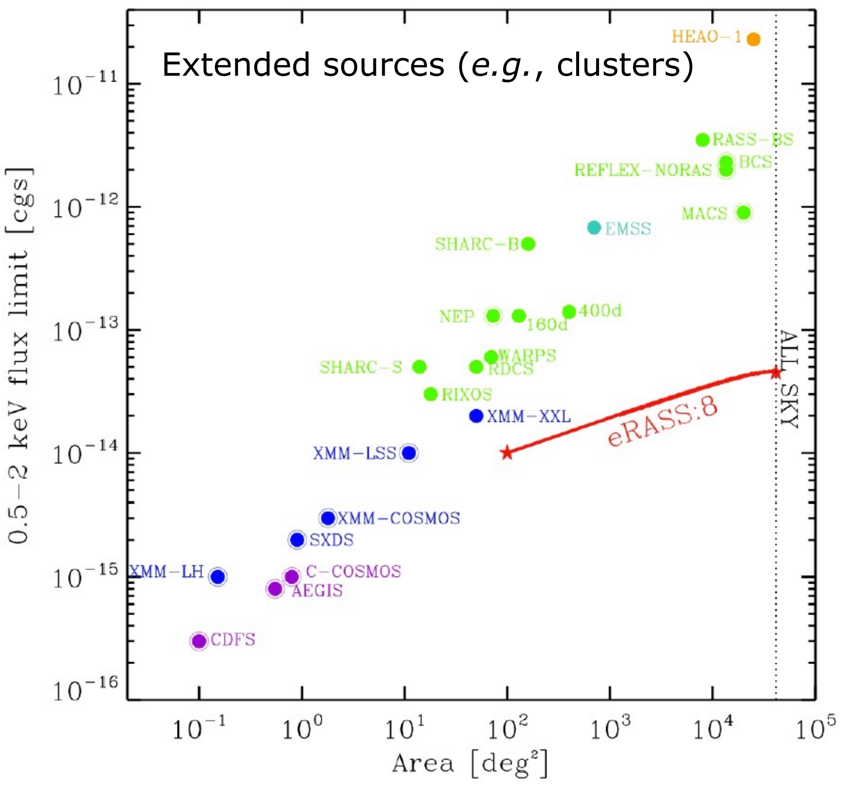
Credit: D. Barret (IRAP)



X-ray spectroscopy probes outflowing ionized gas in the innermost AGN regions (a few 10s gravitational radii, R_G)

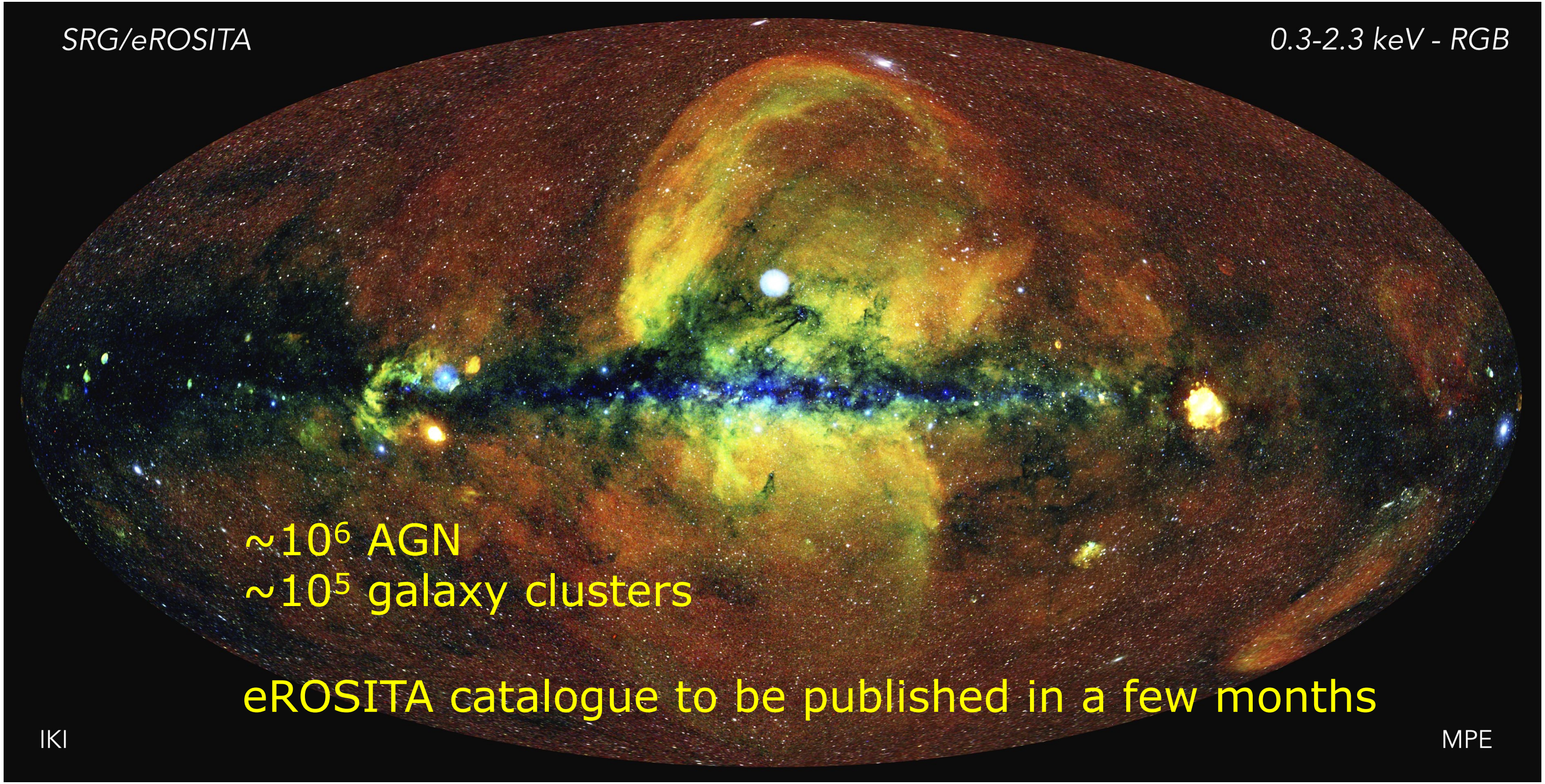
eROSITA and surveys



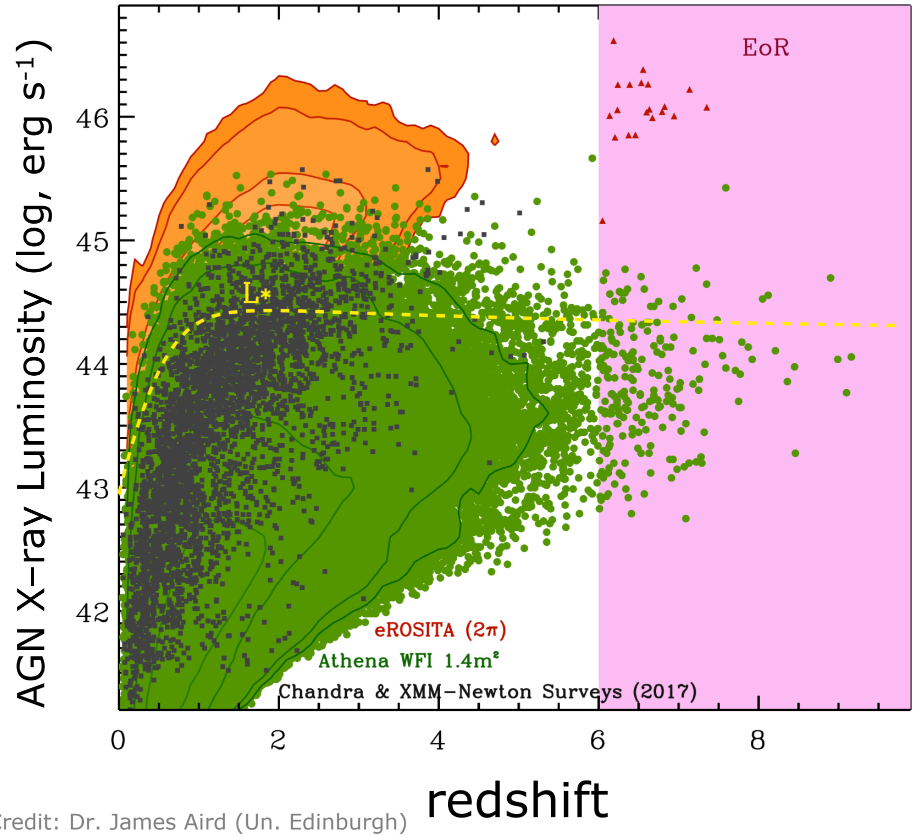


Merloni et al., 2012, eROSITA Science Book

The eROSITA sky



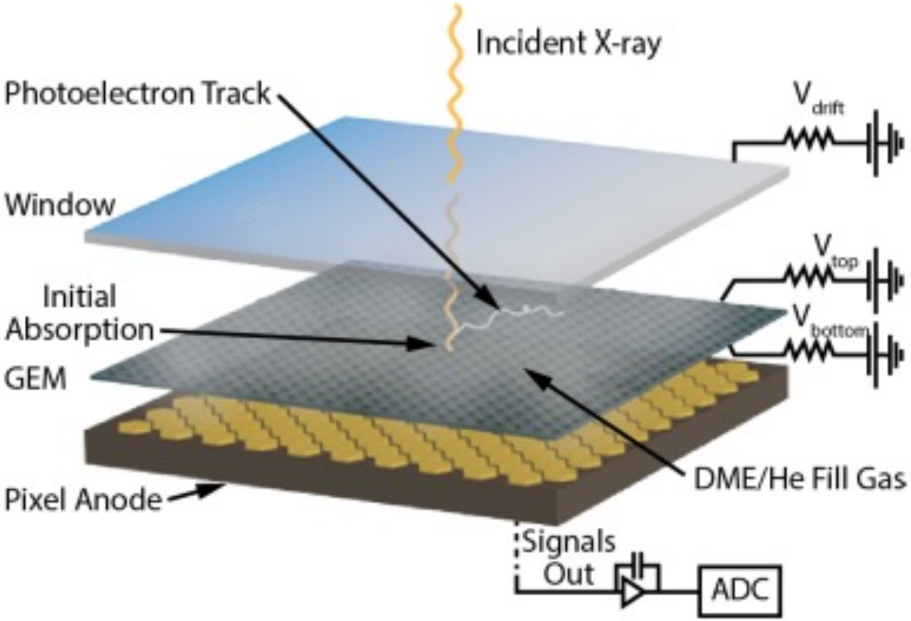
So: why needing *Athena* for AGN?



Credit: Dr. James Aird (Un. Edinburgh)

- *Athena* will deliver new science on accreting super-massive BHs, *e.g.*:
  - How can one build 10^9 M_{Sun} black holes at z~7?
  - Do AGN contribute to ionize the old Universe?
  - How do AGN work at the peak of their activity (z~2-3)?

IXPE

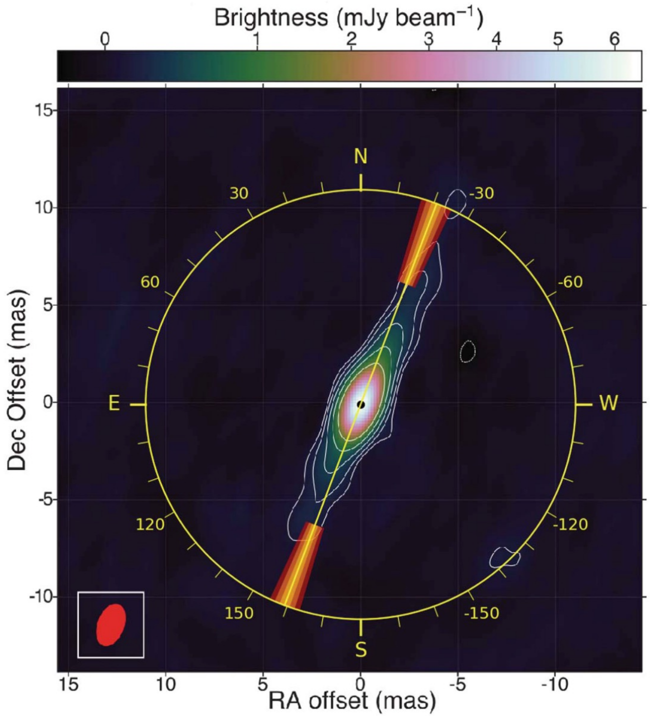


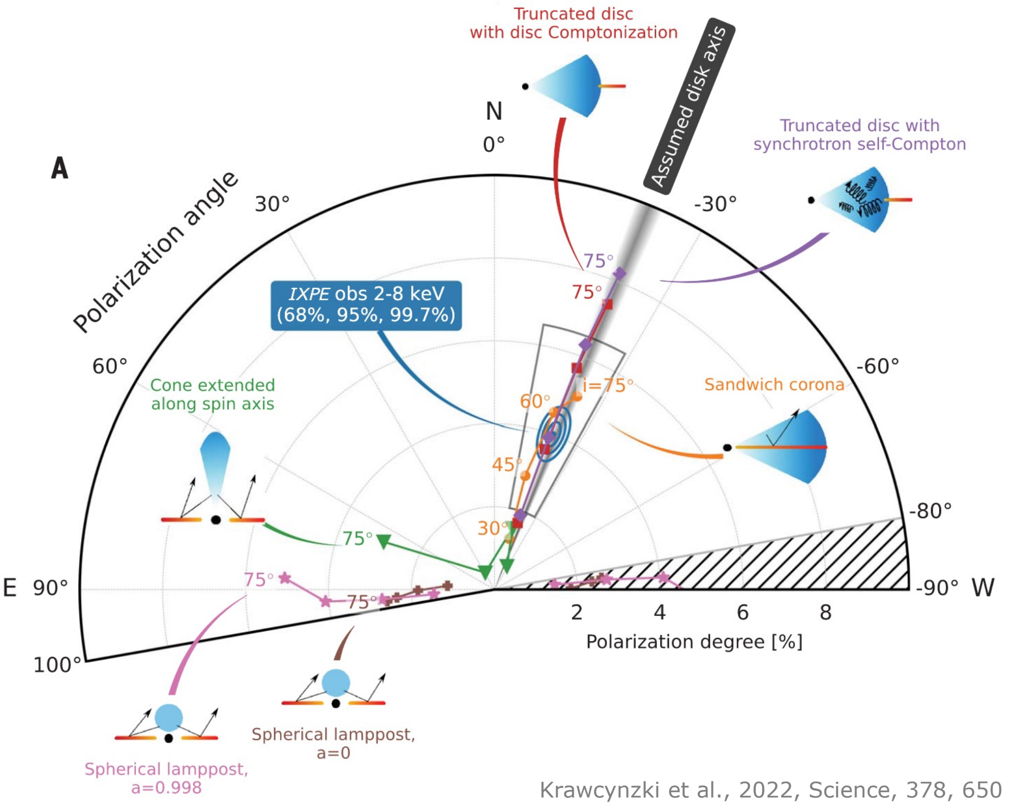
- Launched 9 December 2021
- Exploits polarization-dependence of the photoelectric effect
- 2 – 8 keV

from M. Böttcher Lecture 2

X-ray polarimetry of a XRB: Cyg X-1

Polarization angle along the radio jet

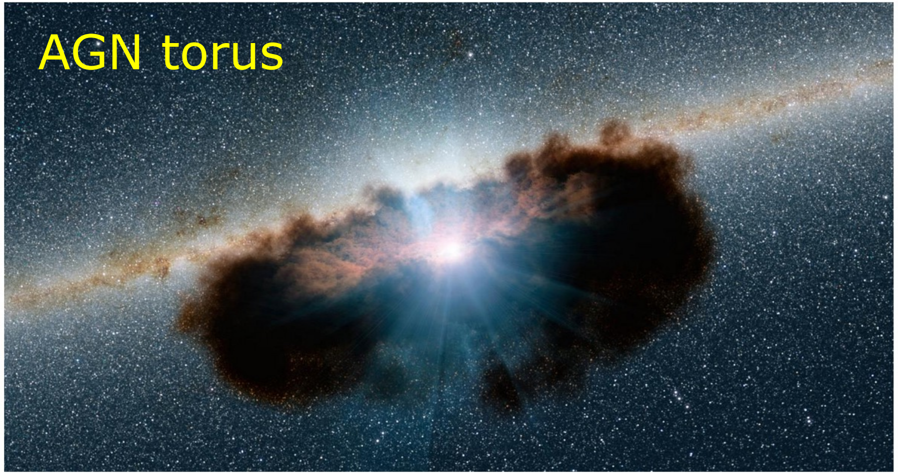


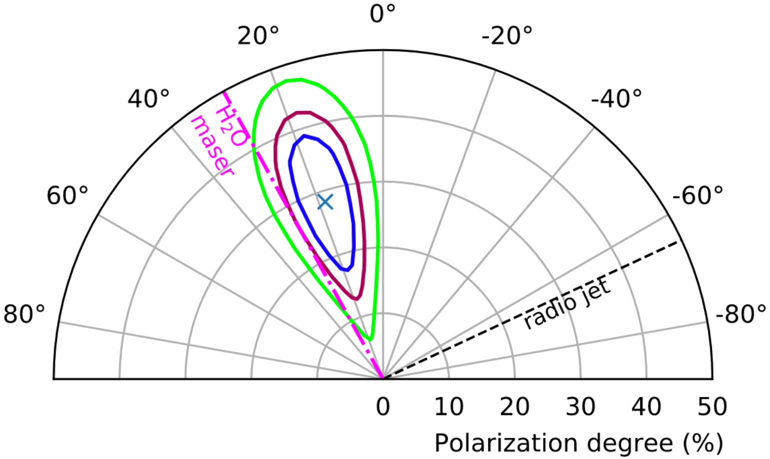


Krawcynzki et al., 2022, Science, 378, 650

X-ray polarimetry of a Seyfert: Circinus

Ursini et al., 2022, MNRAS, 519, 50



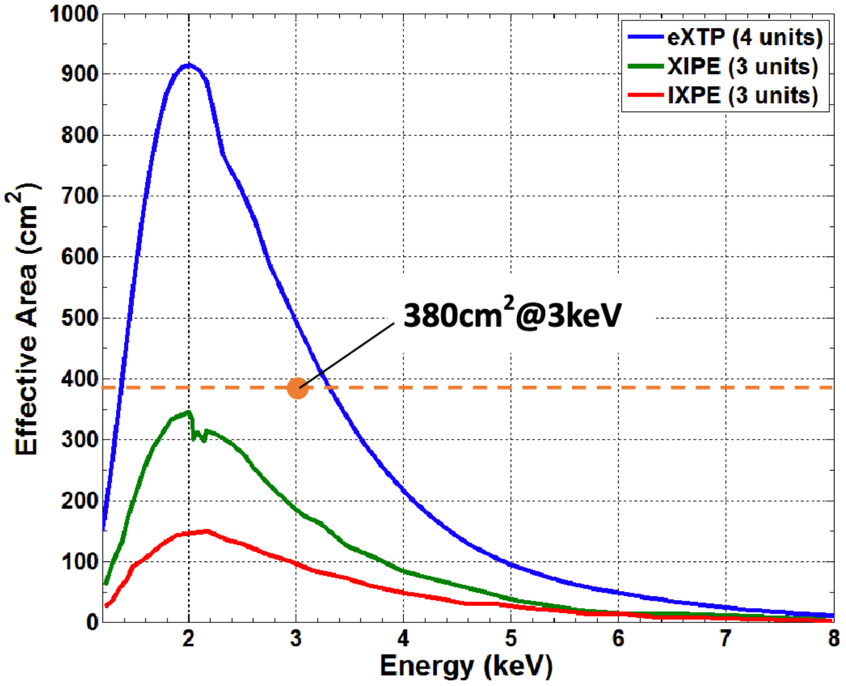


IXPE+*Chandra*: torus opening angle 45-55 degrees

enhanced X-ray Timing Polarimetry (eXTP) mission

- International collaboration of ~20 countries led by CAS/China
- Payload:
  - Spectroscopic Focusing Array (optics+SDD)
  - Large Area Detector (non-imaging SDD)
  - **Polarimetry Focusing Array**
  - Wide Field Monitor
- Expected launch date: ~2027

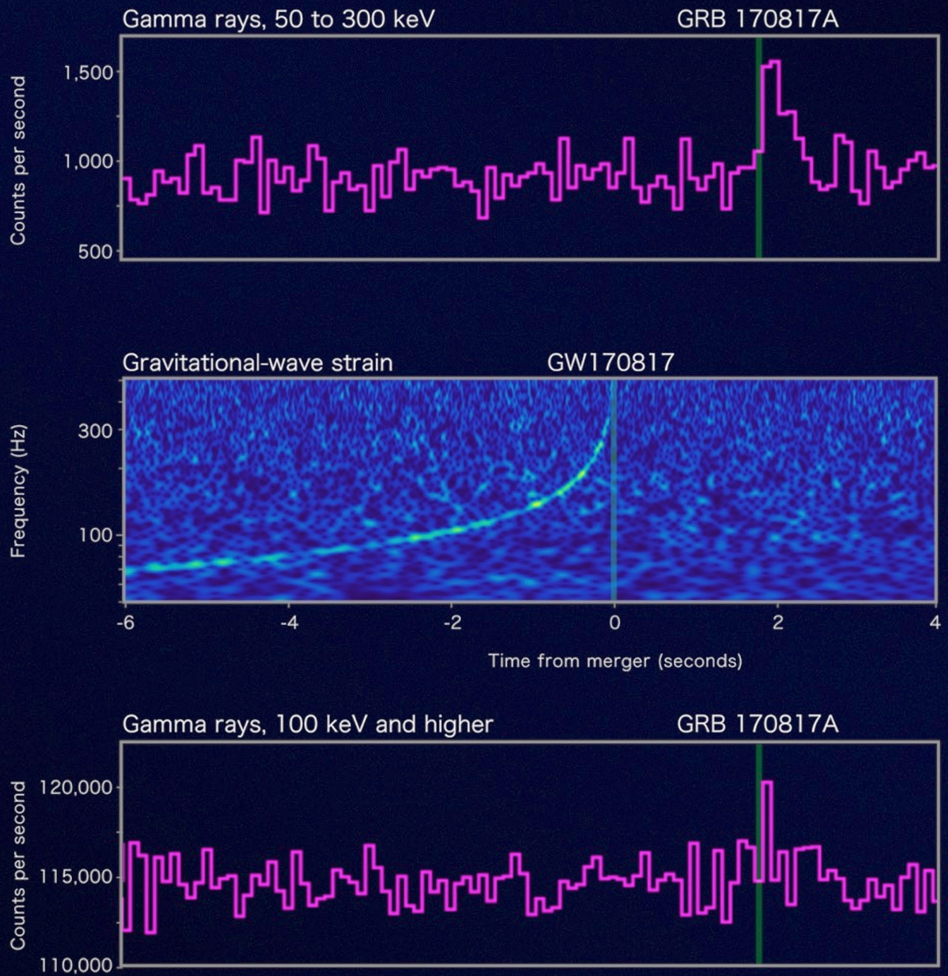
Zhang et al., 2018, arXiv:1812.04020



Fermi

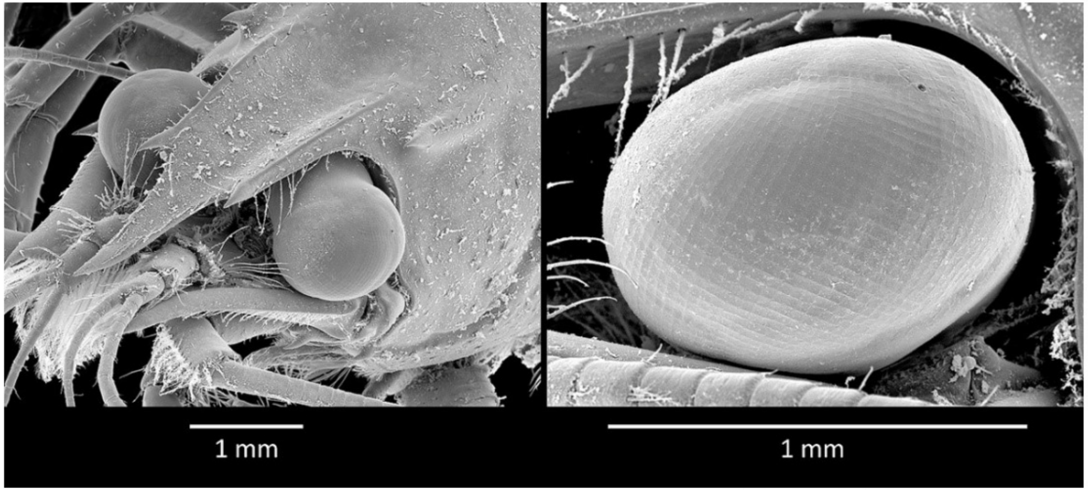
LIGO-Virgo

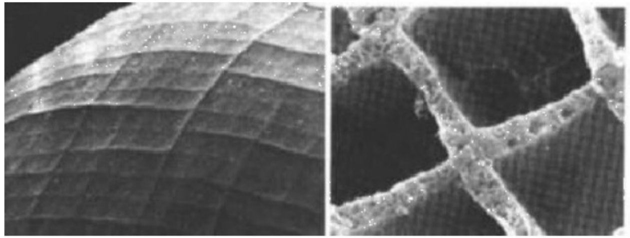
INTEGRAL

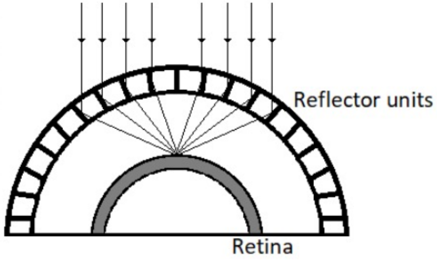


Lobster eye optics

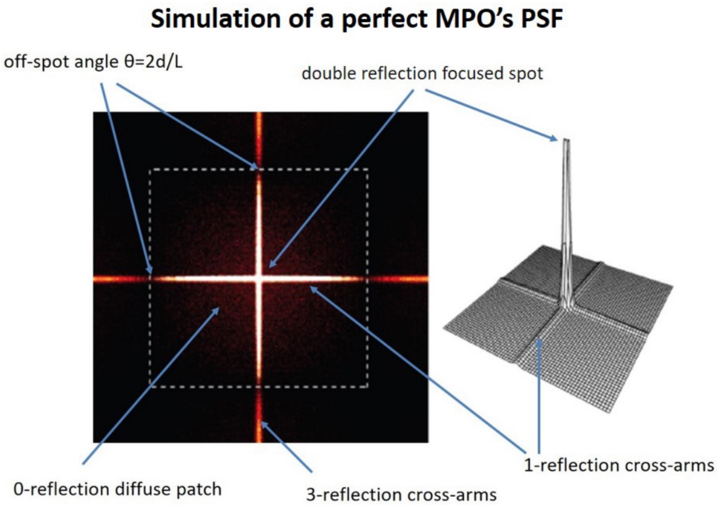
Hudec & Feldman, 2022, Handbook of X-ray and γ-ray Astronomy







Enable large field-of-view high quality imaging

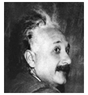


Einstein Probe

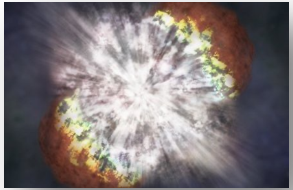
- China/CAS-led mission with participation by ESA and MPE
- Explorer mission for monitoring X-ray sky to discover & characterise high-energy transients and variability in X-ray band
- Launch date: 5-6 Nov 2023
- Low-Earth orbit: ~600 km circular, 35° inclination
- 3-year lifetime (goal: 5 years)

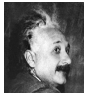
Credit: E. Kuulkers (ESA)

Einstein Probe – Main science goals

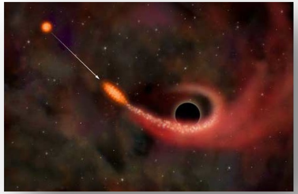


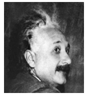
Carry out systematic survey of soft X-ray transients and variability of X-ray sources at unprecedented sensitivity and high cadence



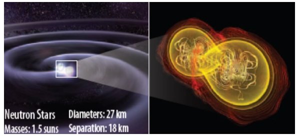


Discover otherwise quiescent black holes at almost all mass scales and other compact objects by capturing their transient flares





Detect and localize the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors



Credit: E. Kuulkers (ESA)

Future NASA X-ray mission?

- MIDEX
    - STAR-X (http://star-x.xraydeep.org/): time-domain survey and rapid response to transient events
- PROBE
    - AXIS (https://axis.astro.umd.edu/): high spatial resolution imaging spectroscopy
    - Arcus (http://www.arcusxray.org/): high-resolution grating spectroscopy
    - HEXP (https://hexp.org/): broadband (0.1-150 keV) spectroscopy
    - LEM (http://lem.cfa.harvard.edu/): large field-of-view μcalorimeter

- Decision ("downselection") in the 2024-25 time-frame → 1±1 to be accepted

Credit: K. Madsen (GSFC)

Your next opportunities

esa

Mid-2023: publication of the eROSITA catalogue

Einstein Probe starts publishing transient alerts

2023

2023

2024

Late-2023: XRISM GO announcement of opportunity

Do not forget to apply for you COSPAR Fellowship!

[see Carlos' presentation]

Summary timeline

XRISM (JAXA/NASA/ESA) GO will (re-)open the window of X-ray non-dispersive spectroscopy

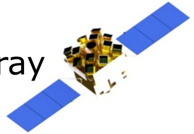
eXTP (RPC/E): unprecedented X-ray polarimetry and timing

New NASA X-ray mission?

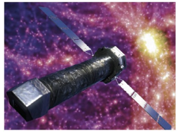
My talk — 2023 — 2024 — 2024-5 — 2027 — ≥2035 — Time (years)

eROSITA (D/RUS) catalogue released

Einstein Probe (RPC/ESA/D) will monitor the X-ray transient Universe with unprecedented sensitivity



Athena (ESA) will address the "Hot and Energetic Universe" themes



Astrosat, Chandra, Insight-XHMT, NICER, NuSTAR, Swift, XMM-Newton are operational

[All dates are "at current conditions and understanding"]