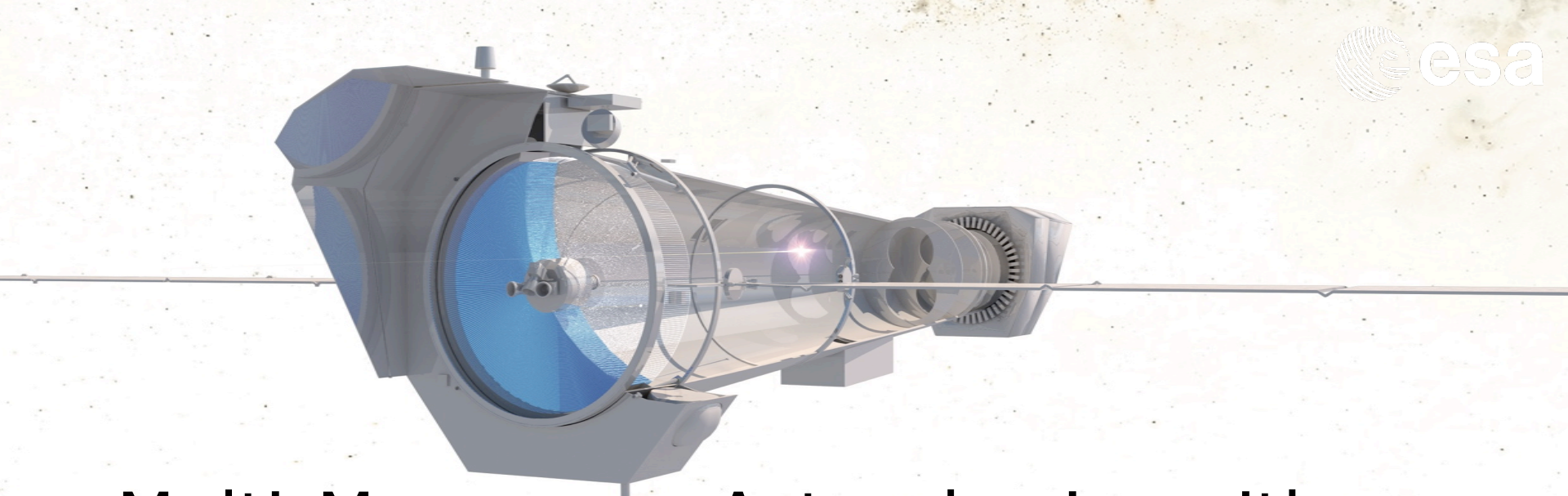


Multi-Messenger Astrophysics with *Athena*

Matthias Ehle (ESA-ESAC/SCI-O) - *Athena* SciOps Study Lead
Matteo Guainazzi (ESA-ESTEC/SCI-S) – *Athena* Study Scientist

Image ©DB/X-IFU

Outline

- *Athena* scientific goals and mission profile
- *Athena* science relevant to multi-messenger
- High-energy counterparts of (Neutron Star)^2 merger events with *Athena*
- High-energy counterparts of (Super-Massive Black Holes)^2 mergers with *Athena*
- Synergies with LISA

Scientific goals of *Athena*

Science theme: **The Hot and Energetic Universe**

- The Hot Universe: How does baryonic matter assemble in large-scale structures? How do they evolve from formation epoch to present day?

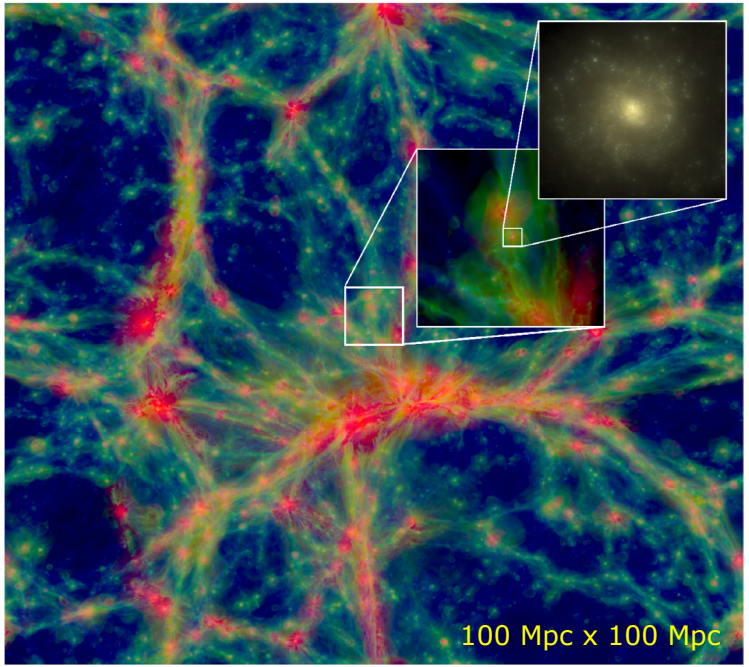
- The Energetic Universe: How do black holes grow & shape galaxies?

- The Observatory & Discovery science:
  - Observatory science across *all corners of astrophysics*
  - Fast response (≤4 hours) capability to study transient sources
  - ~2/3rd of time during nominal operations open to community

The "Hot Universe" with *Athena*

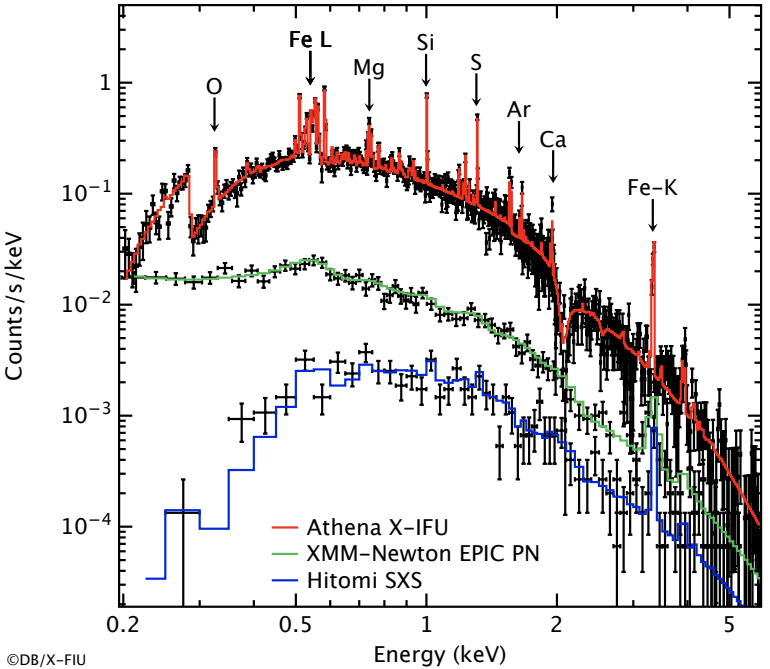
EAGLE cosmological simulation

$T<10^{4.5}$ K $10^{4.5}\leq T\leq 10^{5.5}$ K $T>10^{5.5}$ K



Schaye et al. 2015, MNRAS, 446, 521

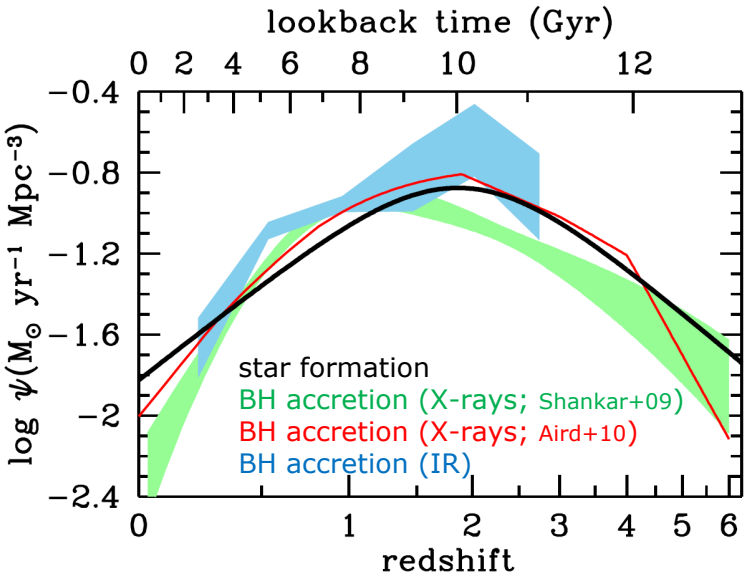
z=1 galaxy cluster (*Athena* vs. XMM/*Hitomi*)



Pointecoteau et al., 2013, arXiv:1306.2319

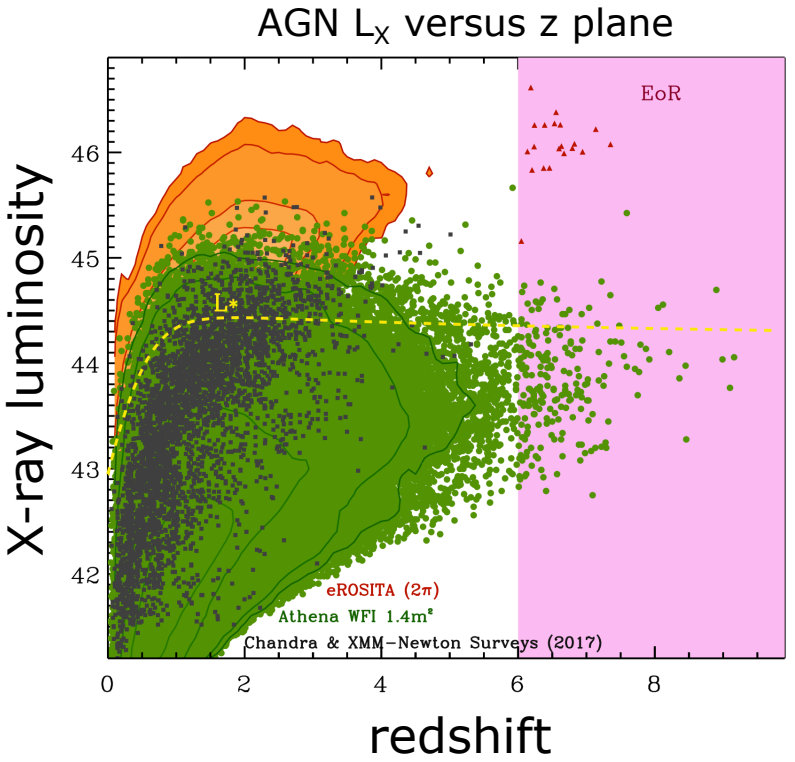
Athena will trace evolution of heavy elements from z~2 to the local Universe

The "Energetic Universe" with *Athena*



The cosmological history of black hole accretion is **uncertain** at z>3, **unknown** at z>6

Madau & Dickinson, ARA&A, 52, 415

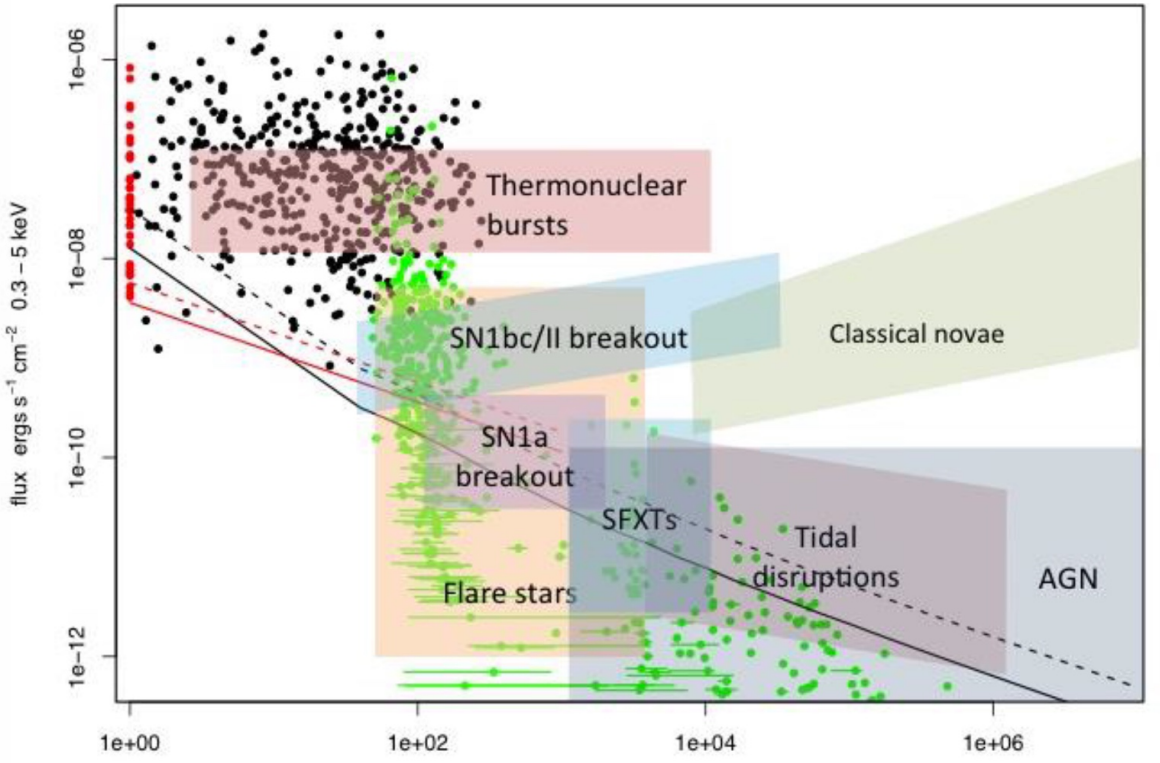


Aird et al., 2013, arXiv:1306.2325. Courtesy A.Rau (MPE)

Mission profile

- **Single telescope**, Silicon Pore Optics (SPO) technology, 12 m focal length, ≥1.4 m^2 area @1 keV, 0.25 m^2 @6 keV
- **WFI** (Active Pixel Sensor Si detector): wide-field (40'x40') spectral-imaging, CCD-like energy resolution (120-150 eV @6 keV)
- **X-IFU** (cryogenic imaging spectrometer): 2.5 eV energy resolution (R>2000 @5 keV), 5' diameter effective field-of-view, ≤5" pixel size
- Count rates capabilities: >1 Crab (WFI)/~1 Crab (X-IFU; 50% throughput)
- **≤4 hours response with ~50% efficiency** to observe a Target of Opportunity (ToO) at a random position in the sky (FoR: 50%, 60% goal)
  - Under study: Autonomous ToO capability
- Launch early 2030s, Ariane 6.4, L2 halo orbit (TBC)

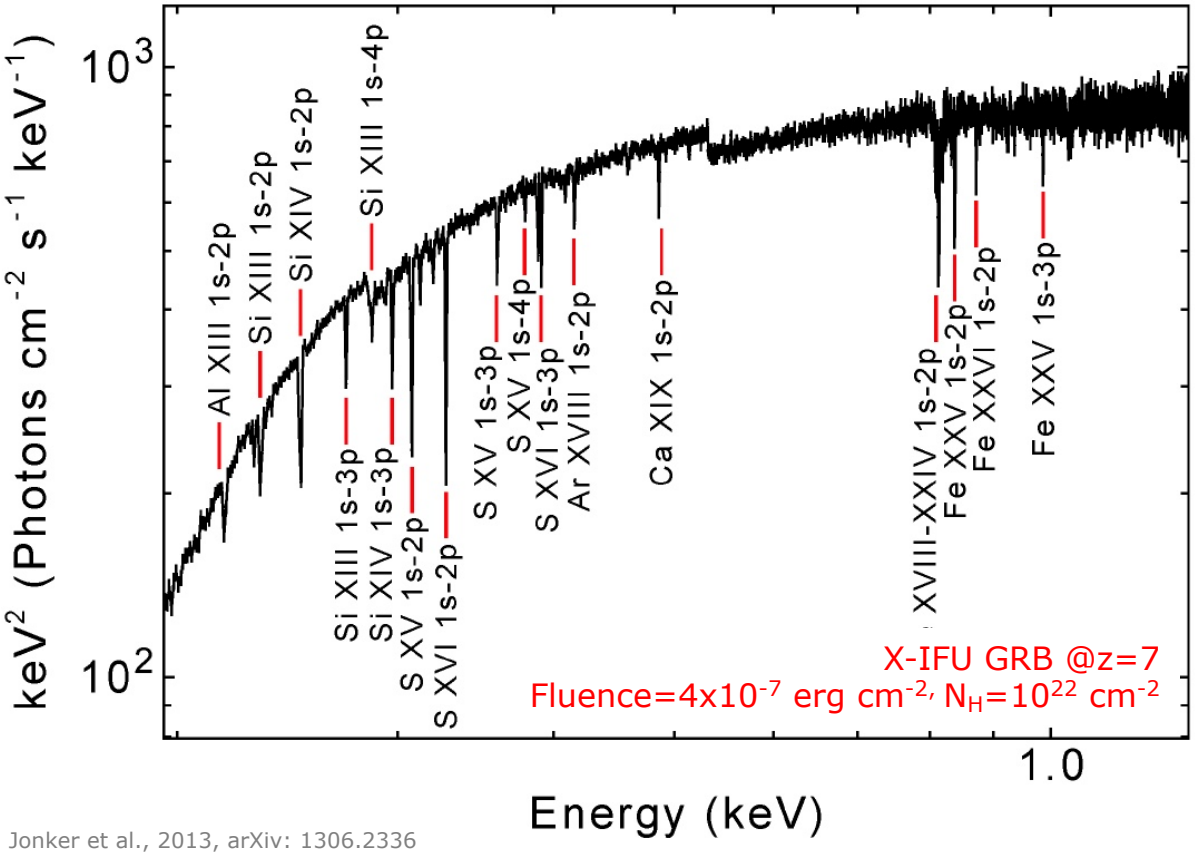
Athena and the transient Universe



- *Athena* White Paper on "Luminous extragalactic transients"
- Three main topics:
  - Gamma-Ray Bursts
  - Tidal Disruption Events
  - Supernovae Shock Breakout
- Other topics covered by the *Athena* science requirements
  - SgrA* (core science)
  - Magnetars
  - Novae
  - Pulsar Wind Nebulae
  - Supernovae

Amati et al., THESEUS M5 Proposal (synergy!)

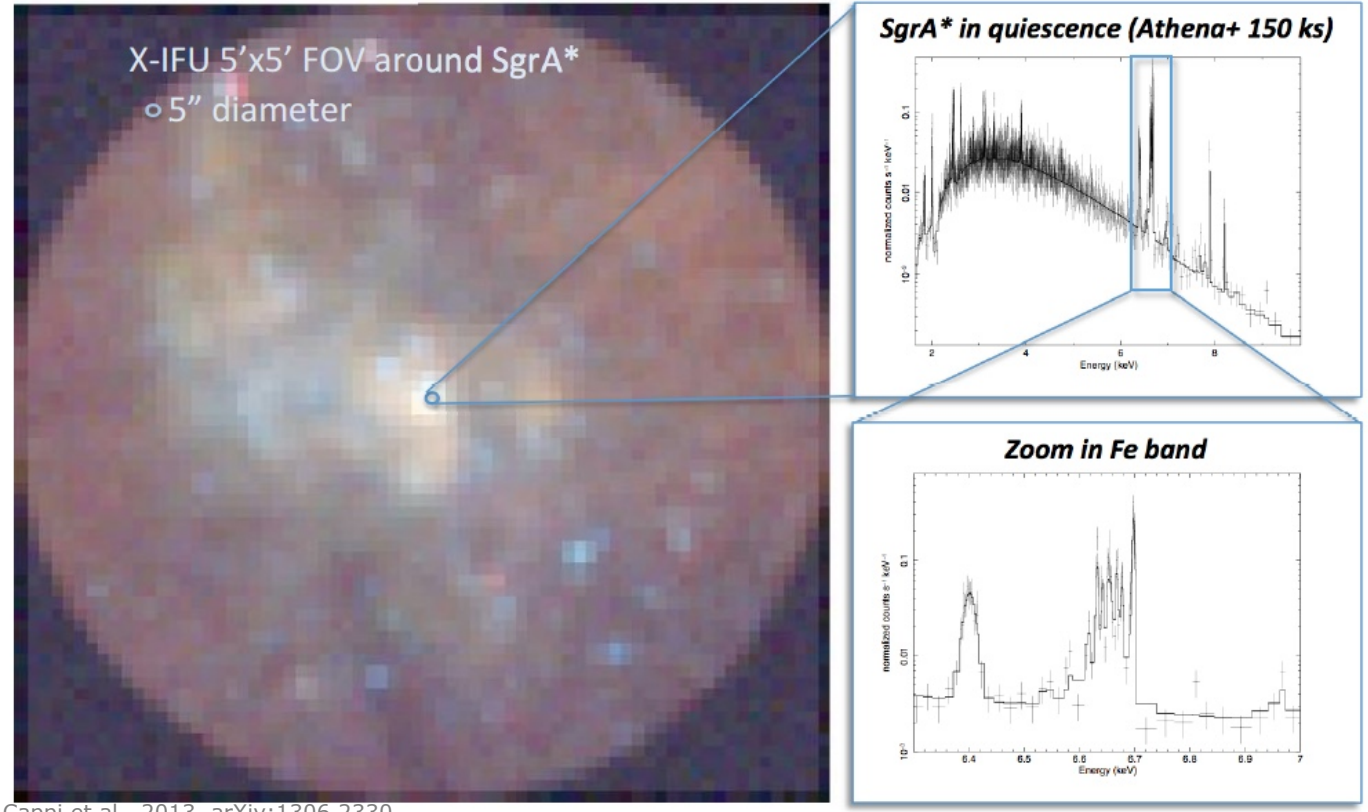
Athena probing the early Universe with GRBs



- X-ray *absorption* spectroscopy of ionized gas from C to Ni
- Metal enrichment in the early Universe
- Primordial stellar population (PopII vs. PopIII)
- *Emission* line spectroscopy of the GRB environment (jet/ ejecta illumination, QPOs in accreting matter)
- Another case involving GRB: WHIM

Jonker et al., 2013, arXiv: 1306.2336

SgrA* (supermassive Milky Way Black Hole)



- Mass ~4x10^{6} $M_{\odot}$
- Accrete ~10^{-6} Eddington
- Daily flares (L_X~100-1000x)
- *Athena* science: nature of quiescent emission (thermal) and flare production and emission
- Bonus: BH activity history via Fe K_{α} reflection nebulae spectroscopy

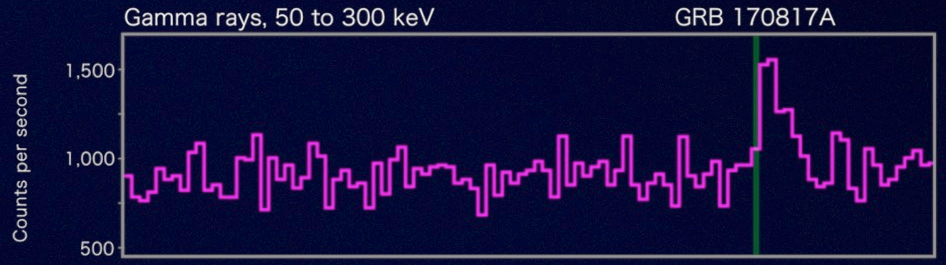
Cappi et al., 2013, arXiv:1306.2330

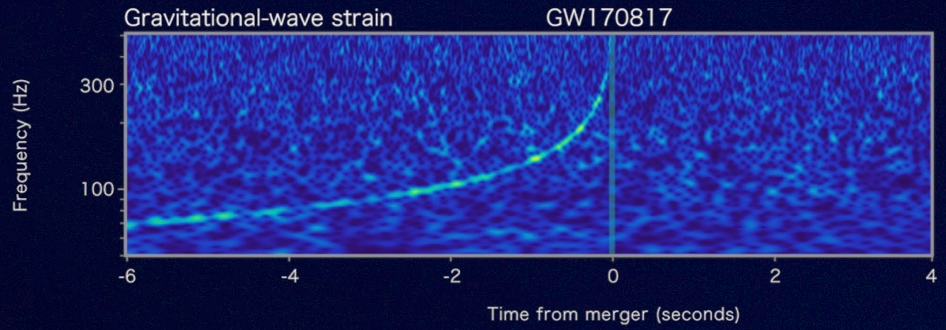
Credit: NASA's Goddard Space Flight Center, Caltech/MIT/LIGO Lab and ESA

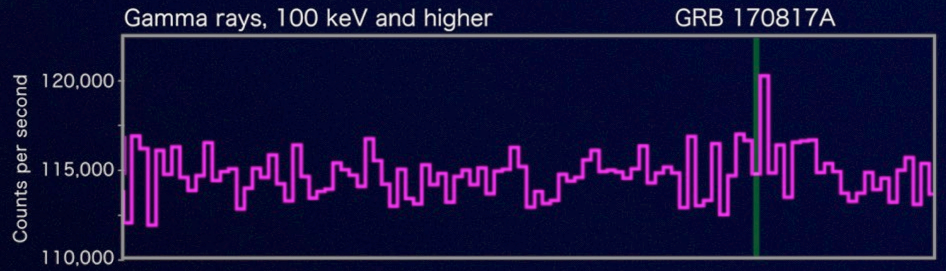
Fermi

LIGO-Virgo

INTEGRAL

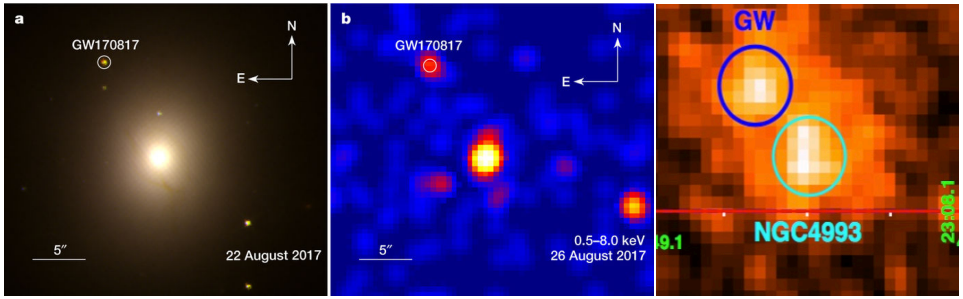






X-ray counterpart of the NS-NS merger

GW170817 EM counterpart



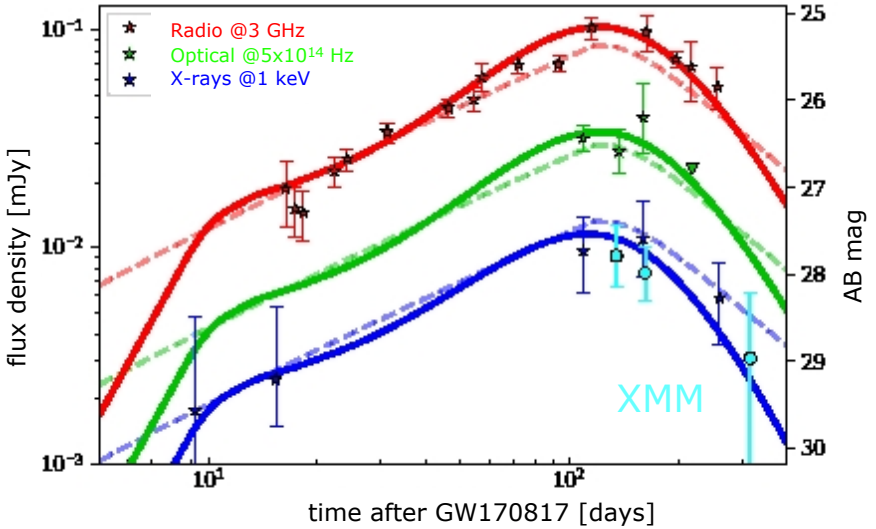
HST Chandra XMM-Newton

Troja, et al., Nature, 2017, 551, 71

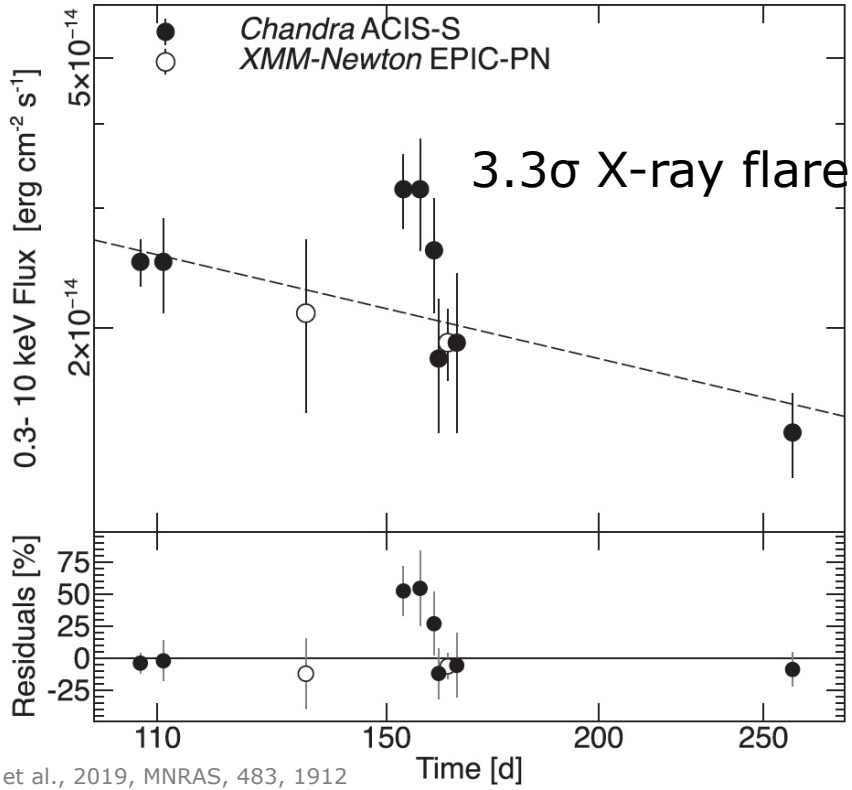
Troja et al., 2018, MNRAS, 478, 18

D'Avanzo, et al., 2018, A&A 613, L

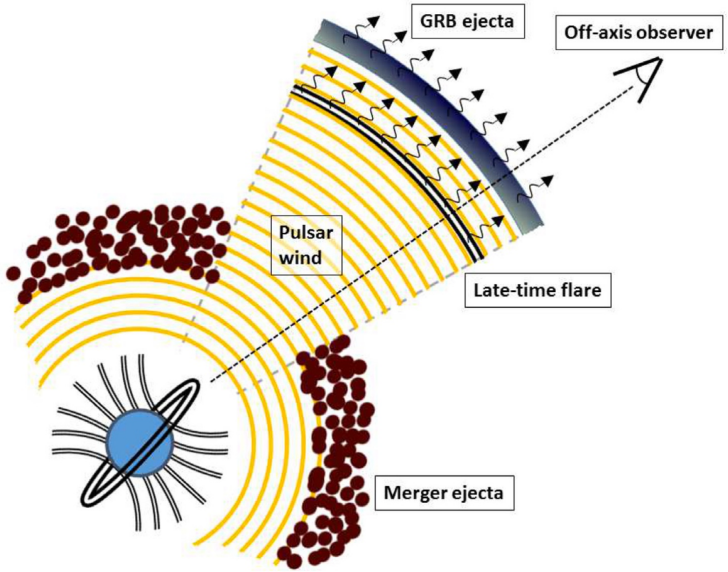
Radio and X-ray light curves



Merger Remnant: Breaking the NS-BH degeneracy



Piro et al., 2019, MNRAS, 483, 1912



Moreover (on year time-scales):

- Long-lasting X-ray plateau
- X-ray kilonova remnants

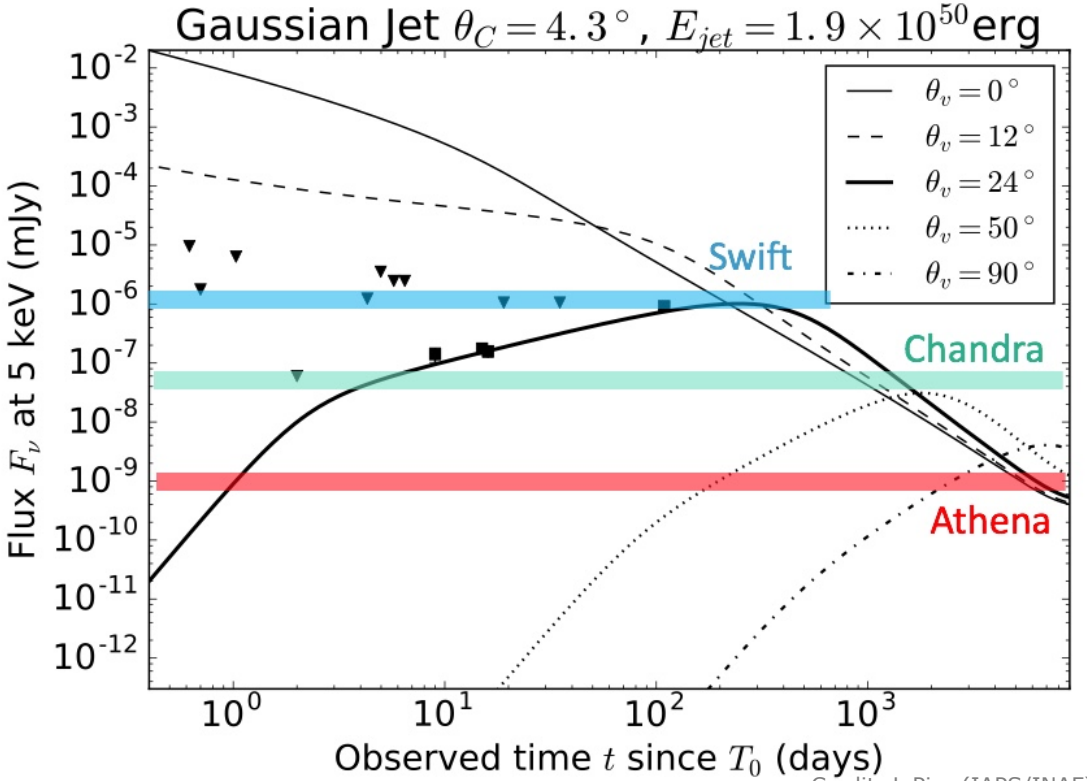
Athena will see them all …

X-rays probe:

- Jet: GRB afterglow (from radio to X-rays)
- Isotropic features:
  - Off-axis (orphan) afterglows
  - Cocoon
- Beaming angle ~1/Γ

Athena needed:

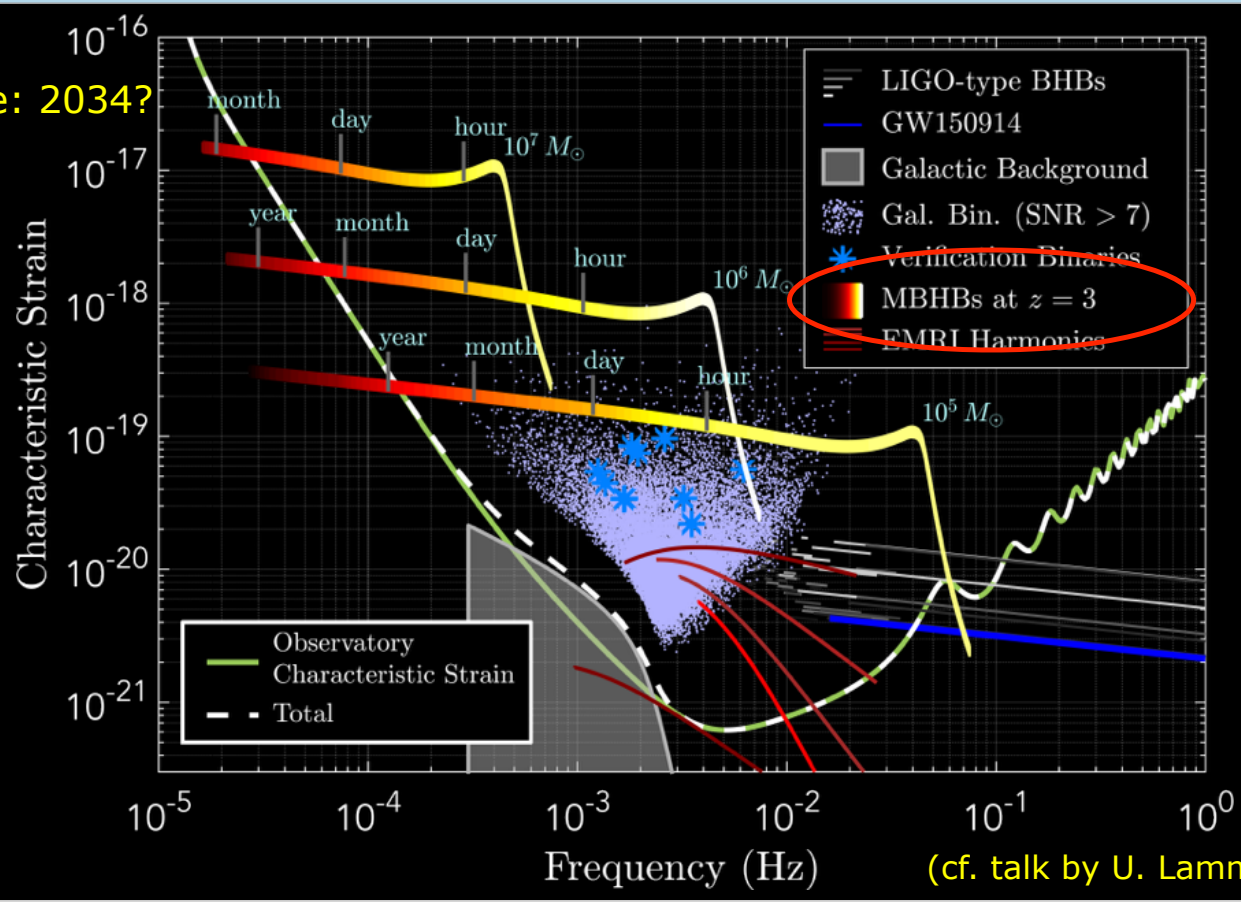
- for any line-of-sight <50°
- to sample most distant counterparts, detected by GW facilities



Credit: L.Piro (IAPS/INAF)

LISA Sensitivity Curve

LISA launch date: 2034?



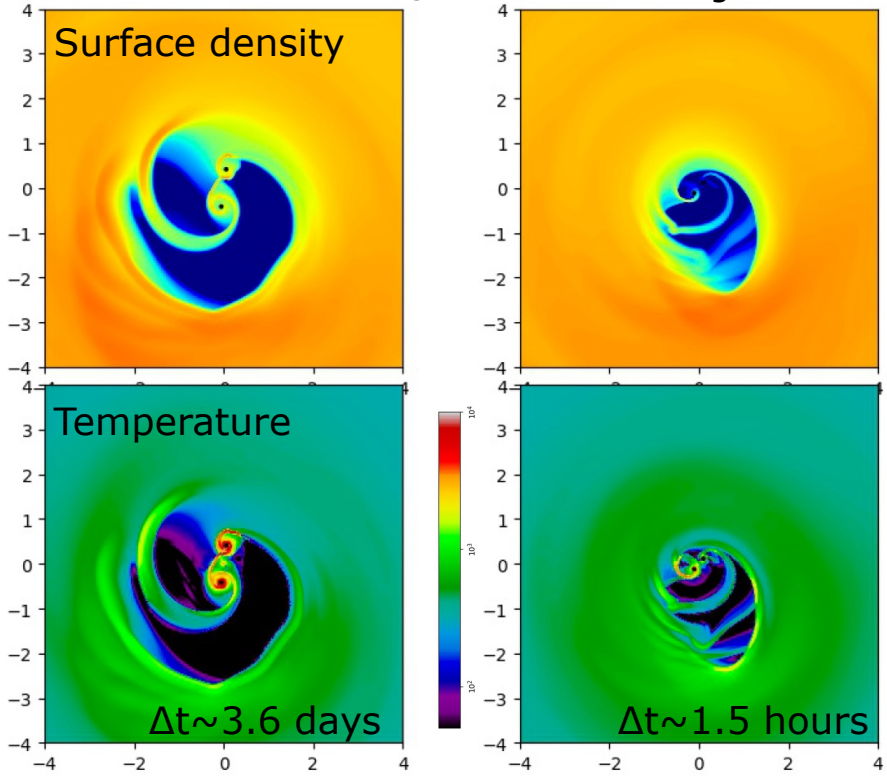
(cf. talk by U. Lammers / P. McNamara)

Why observe SMBH merging with *Athena* & LISA?

- Unique opportunity to probe behaviour of matter in the variable space-time induced by the merging BHs
- Study propagation velocity of photons vs. gravitons by phase-correlating the GW with the X-ray time-modulated signal
- Extend/calibrate cosmic distance scale to $z \leq 2$
    - GWs give luminosity distance, X-rays may provide redshift
- Unique opportunity to probe AGN physics
    - Onset of relativistic jets
    - Formation of AGN corona
    - Lack of predictive, observational-based theory hampered progress so far
- Potentially huge discovery space

X-ray emission from an in-spiraling SMBH merger

$M_{BH}=10^6\ M_\odot$, $d_{start}=60\ r_g$

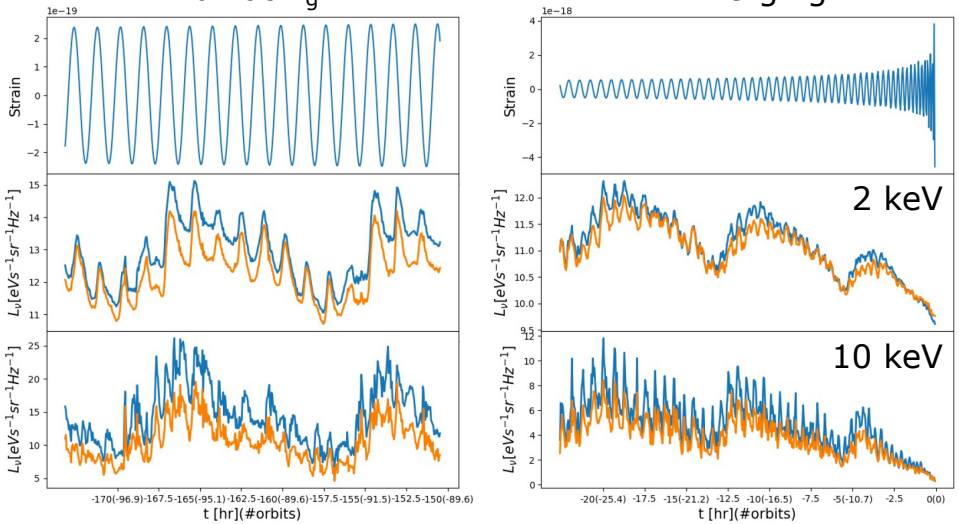


Outer disk: ≤1 keV

Cavity wall: ~2 keV

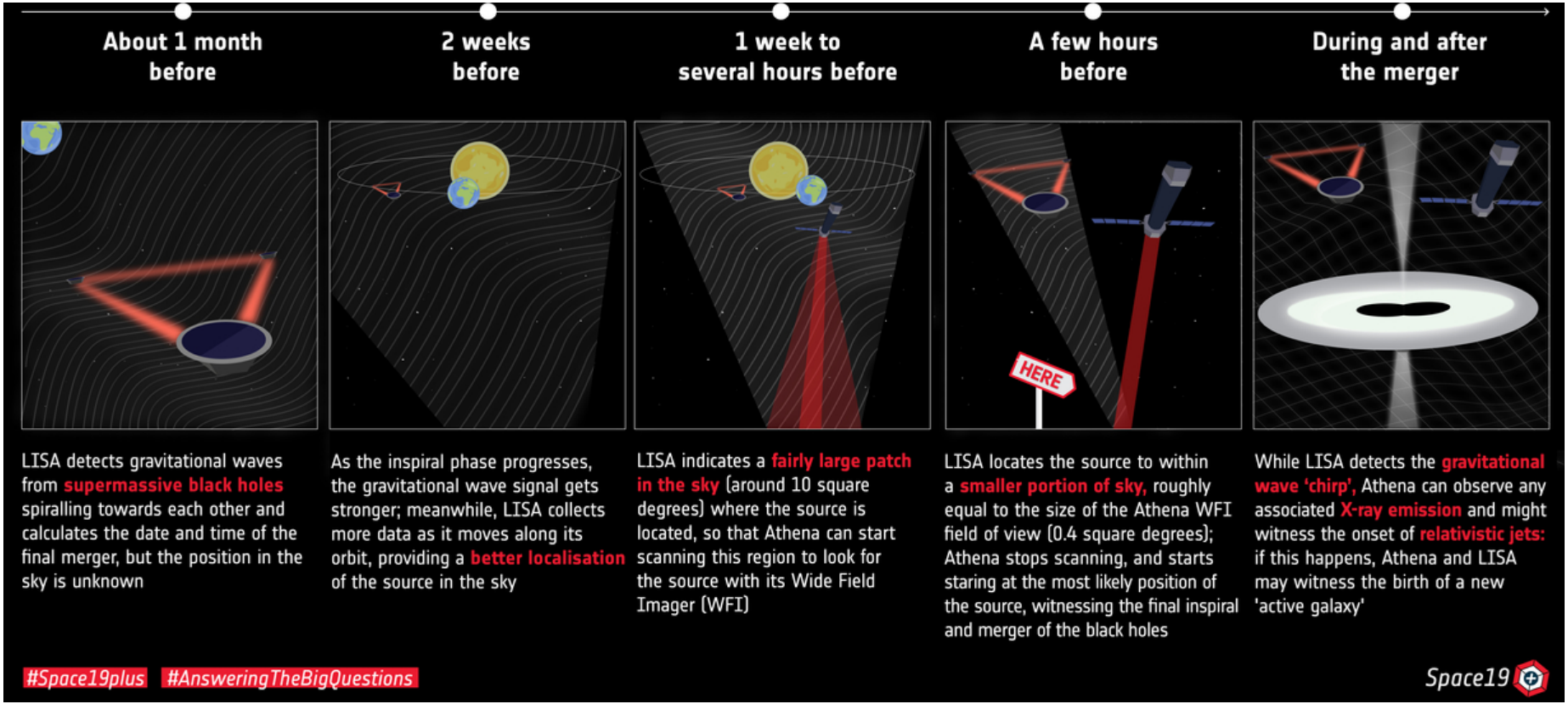
Mini-disks: ≥3 keV

d=60 r_g ~merging



Tang et al., 2018, MNRAS, 476, 2249

Possible *Athena*-LISA synergetic strategy



Conclusions

- *Athena* is designed to address topics of The Hot and Energetic Universe
- However, it is an observatory capable of impacting all fields of astronomy
- Designed to overperform any existing or planned X-ray mission by at least one order of magnitude in several parameter spaces simultaneously
- Rapid ToO response and quick agility are well tuned for future multi-messenger astronomy
- NS-NS merger events:
  - all off-axis jets with inclination <50°
  - most distant counterparts of GW facilities
  - can discriminate the merger remnant nature via weak X-ray flares, or long-lasting X-ray plateaus
- SMBH merger events (synergies with LISA):
  - potentiality of studying behaviour of matter in variable space-time of merging BHs
  - Witness the post-merger onset of AGN activity (corona, jets)
  - **Huge discovery space** – real challenge for theorist to predict what we could see!