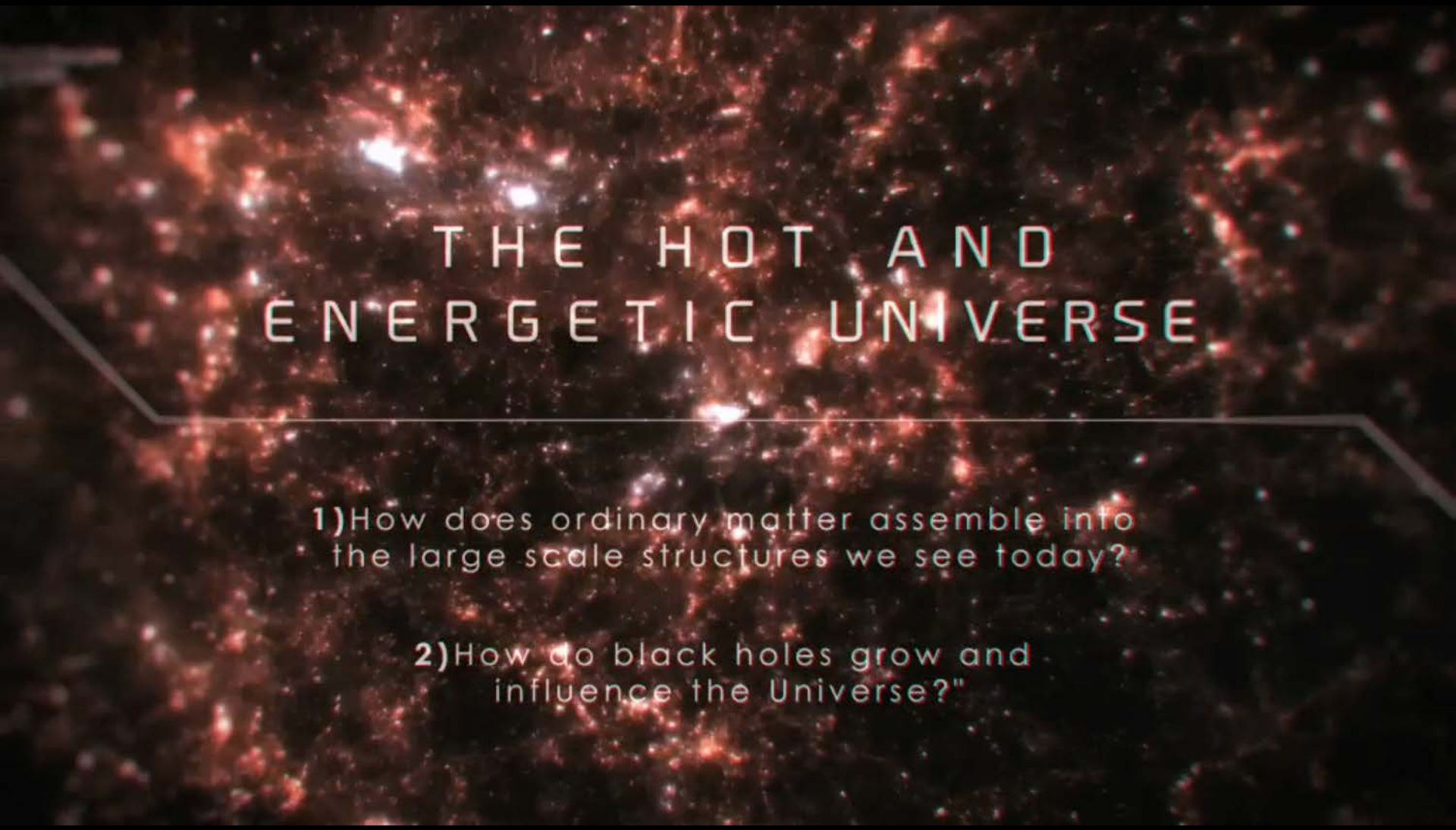
Athena, XRISM, IXPE

LUIGI PIRO
Athena Italian PI
IAPS/INAF



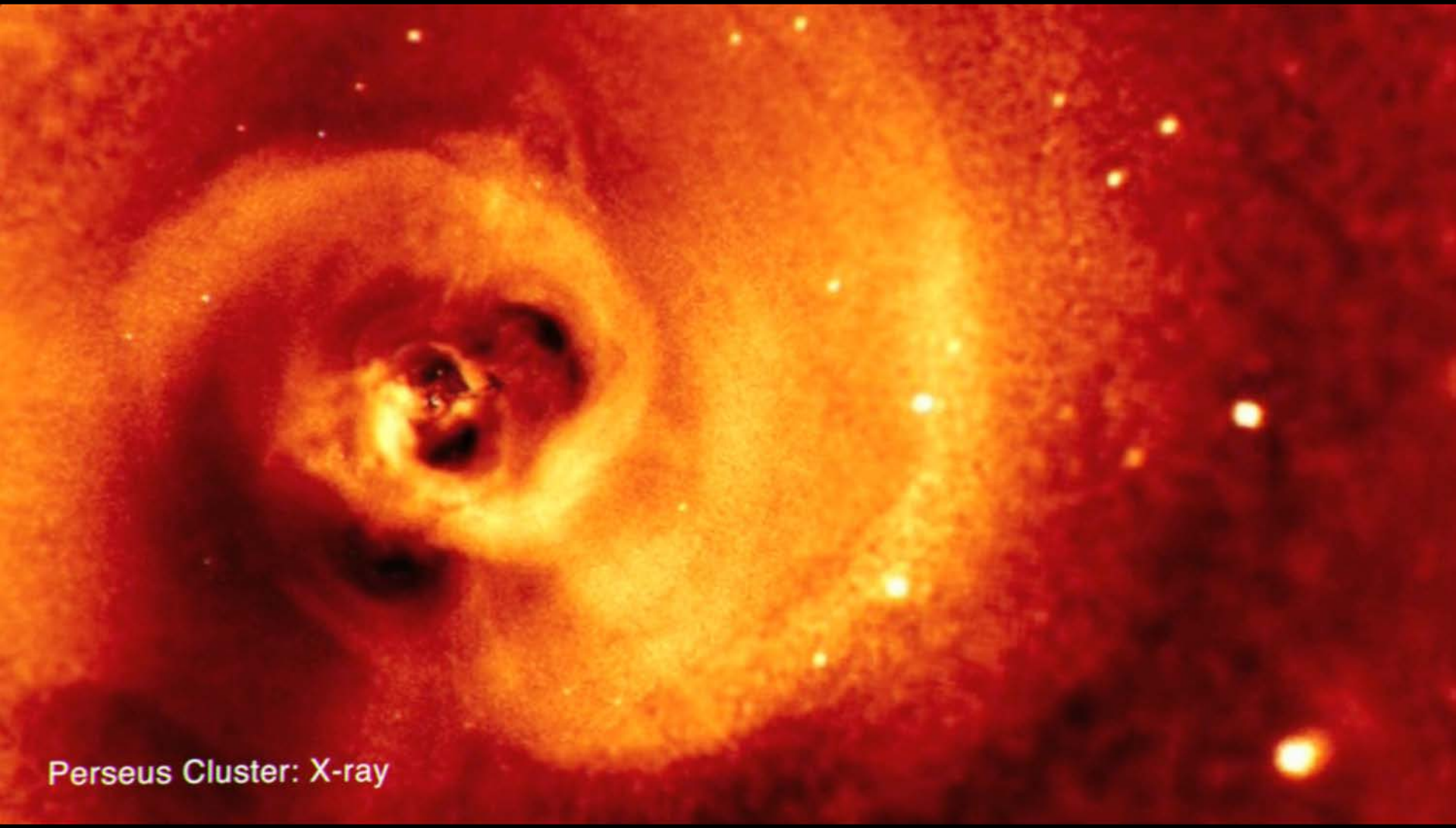
Outline

- Science goals
- Methods of X-ray detection: photon interaction with matter, Imaging techniques, bkg and sensitivity, detector typologies and spectroscopy
- X-ray spectroscopy: cryogenic microcalorimeters & techniques, grating
- ATHENA and its X-ray Integral Field Unit



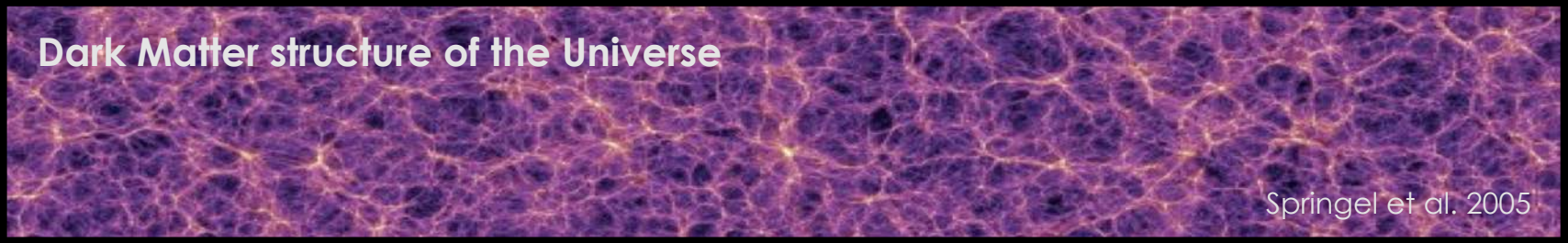
The Science Theme motivating the Athena mission


Perseus Cluster: Optical

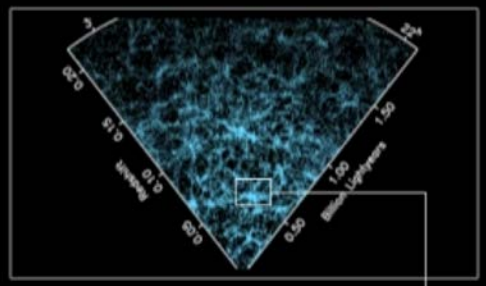

Perseus Cluster: X-ray

ATHENA

Why does the observable universe look the way it does?



THE COLD UNIVERSE

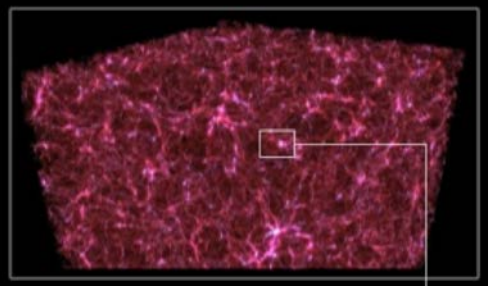


LARGE SCALE GALAXY DISTRIBUTION



STARS AND GALAXIES

THE HOT UNIVERSE

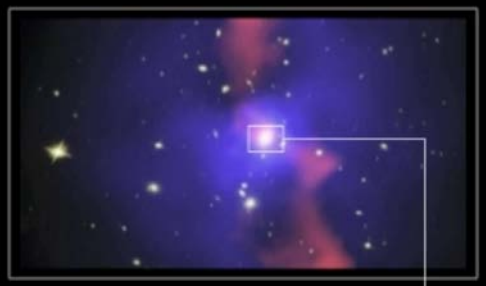


INTERGALACTIC MEDIUM

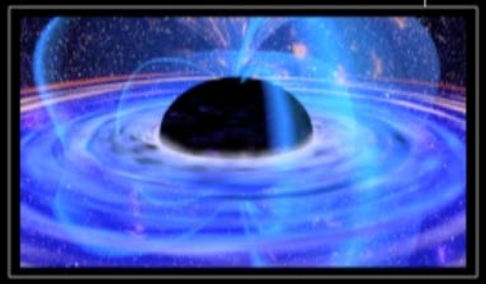


GALAXY CLUSTERS & GROUPS

THE ENERGETIC UNIVERSE



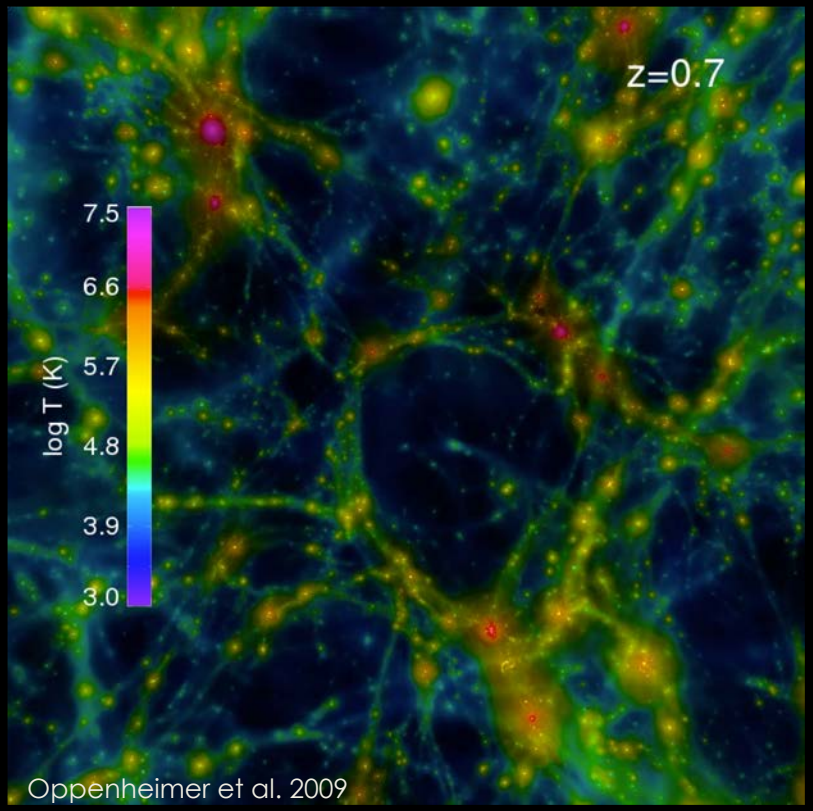
COSMIC FEEDBACK

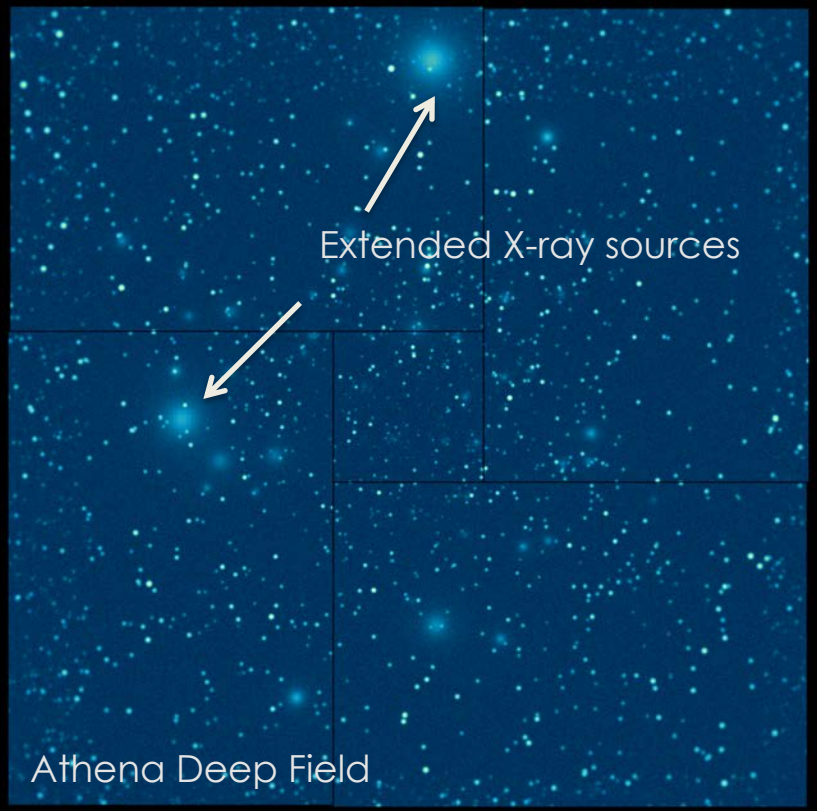


BLACK HOLES

Key questions for observational astrophysics in 203

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



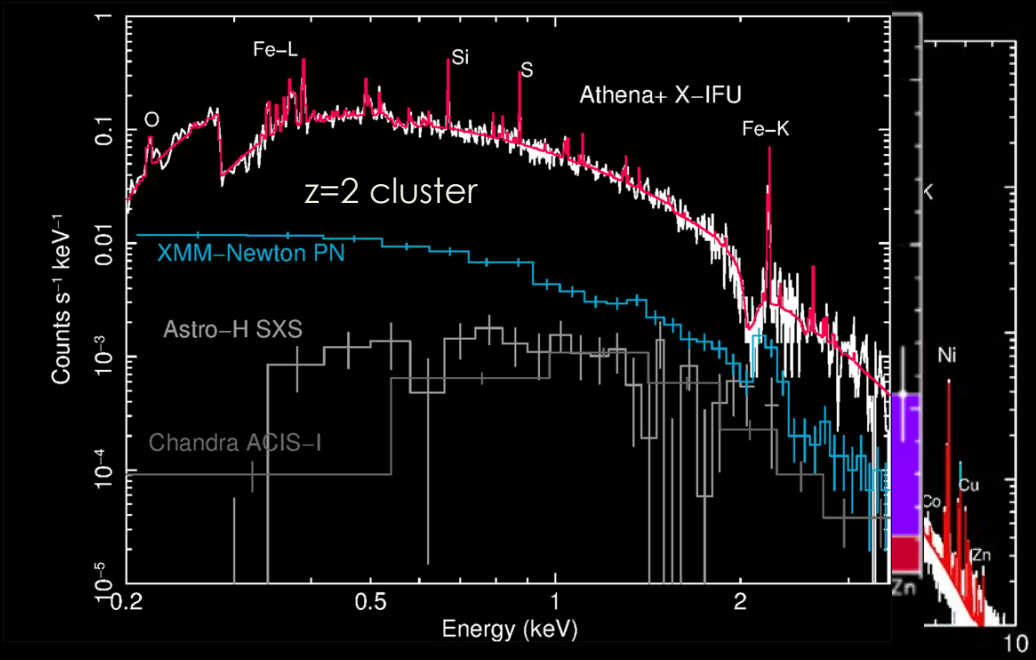


Pointecouteau, Reiprich et al., 2013 arXiv1306.2319

ATHENA

The chemical evolution of hot baryons

When and how were the largest baryon reservoirs in galaxy clusters chemically enriched?



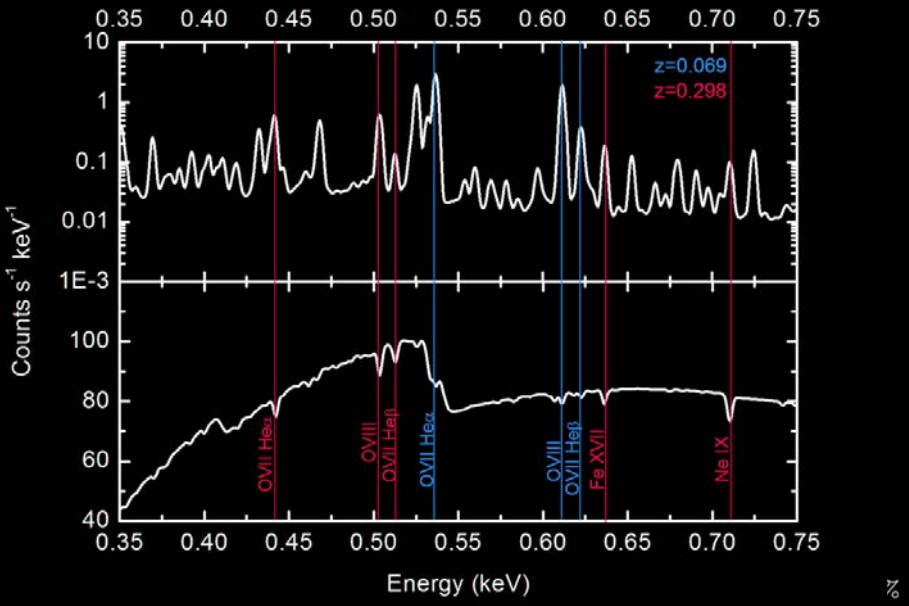
Ettori, Pratt, et al., 2013 arXiv1306.2322

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

ATHENA

The Warm-Hot intergalactic medium (WHIM)

Where are the missing baryons in the local Universe? What is the underlying mechanism determining the distribution of the hot phase of the cosmic web?



Kaastra, Finoguenov et al., 2013 arXiv1306.2324

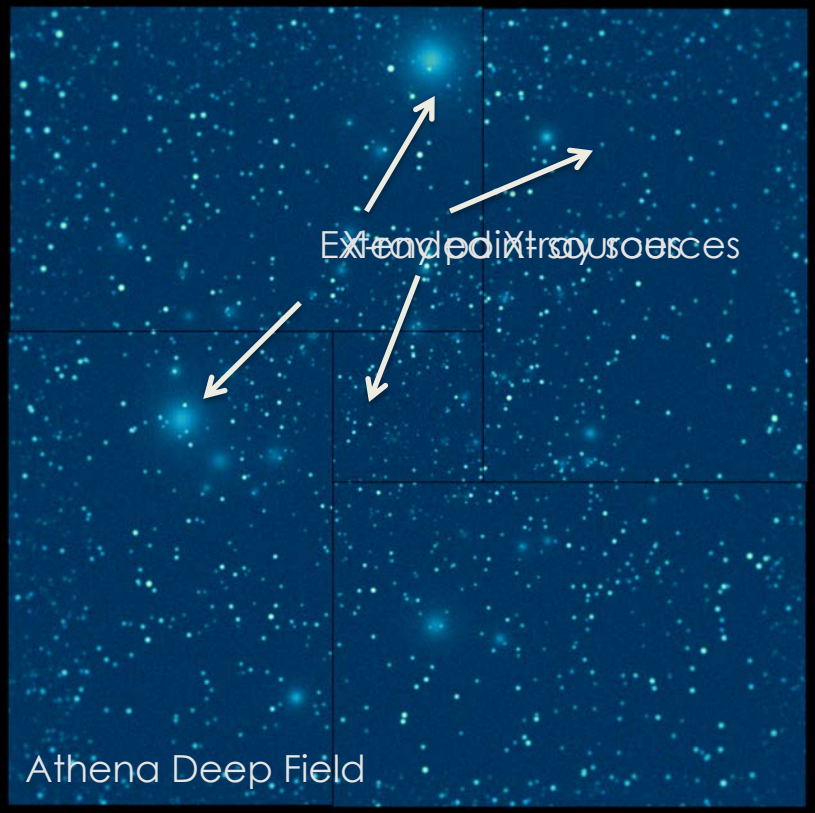
How does ordinary matter assemble into the large-scale structures that we see today?

ATHENA

Key questions for observational astrophysics

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

2. How do black holes grow and shape the Universe?

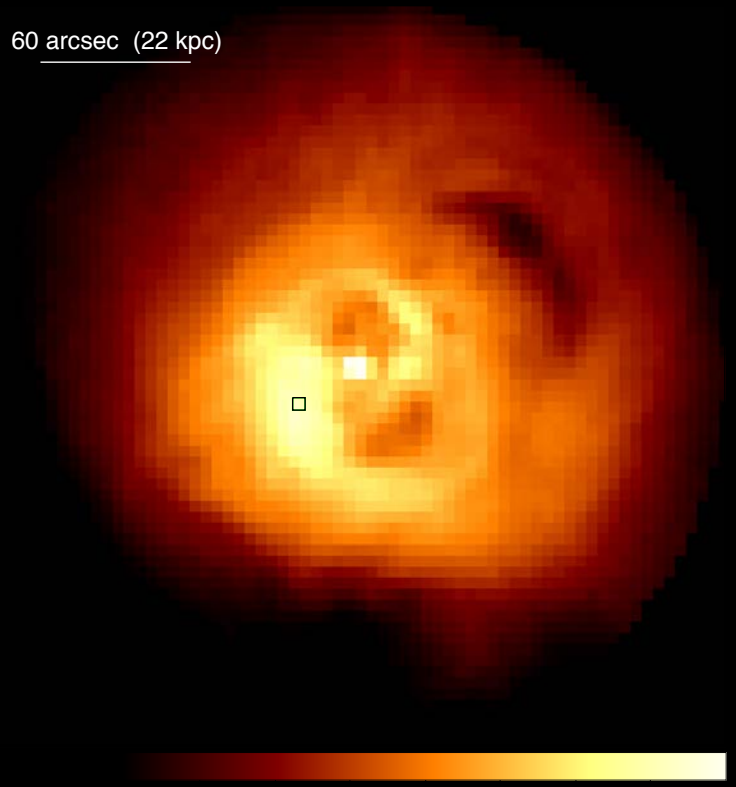


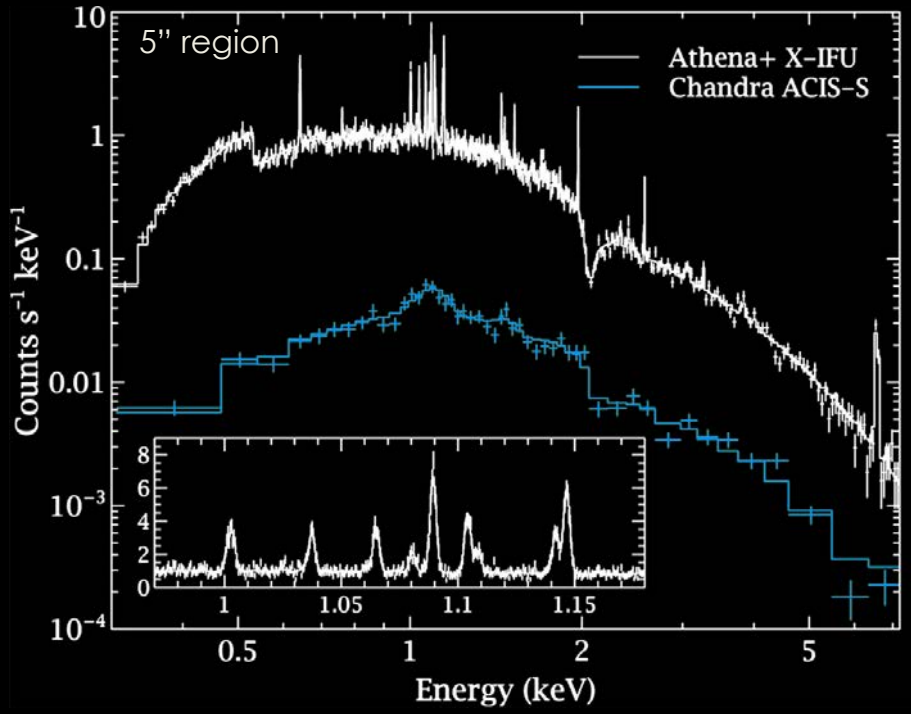


ATHENA

Cosmic feedback: the impact on galaxy cluster scales

How do jets from Active Galactic Nuclei dissipate their mechanical energy in the hot intracluster medium, and how does this regulate gas cooling and black hole fuelling?



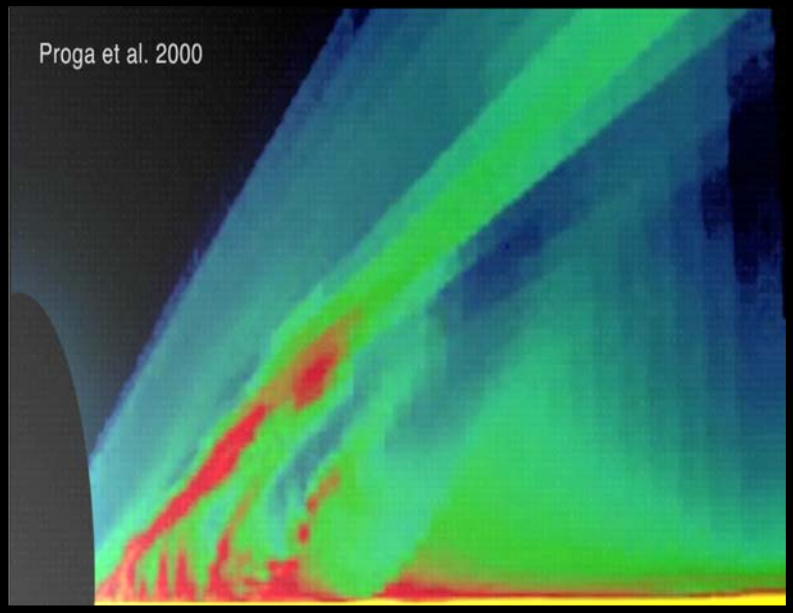


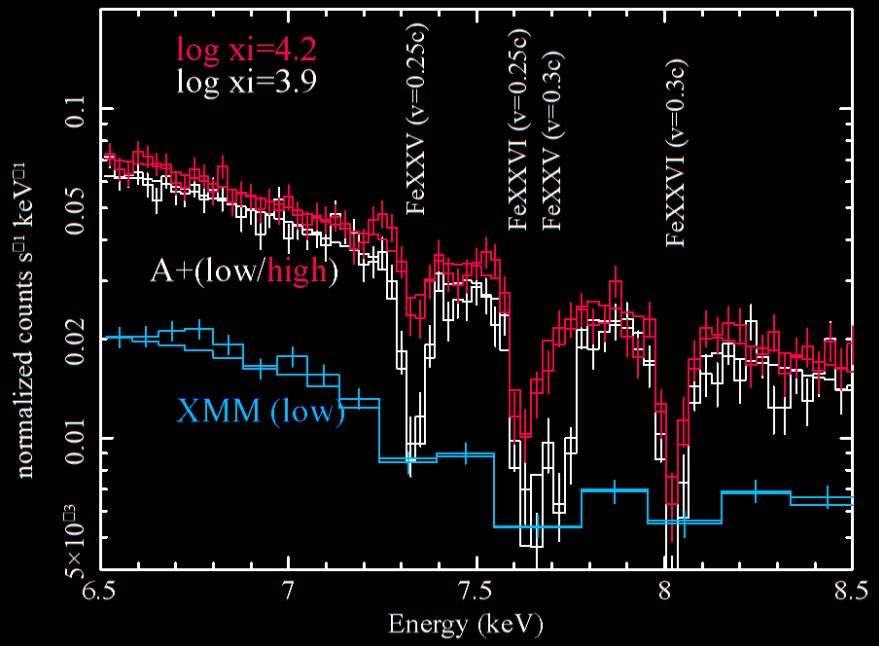
Croston, Sanders et al., 2013 arXiv1306.2323

ATHENA

Cosmic feedback: the origin of black hole winds

How do black holes launch winds and outflows?
How much energy do they carry out to larger scales?





Cappi, Done et al., 2013 arXiv1306.2330
Dovciak, Matt et al., 2013 arXiv1306.2331

How do black holes grow and shape the Universe?

ATHENA

Cosmic feedback: black hole and galaxy co-evolution

How much black hole accretion occurs in the most obscured environments?
How does this relate to the evolution of the host galaxy?

Disk instability

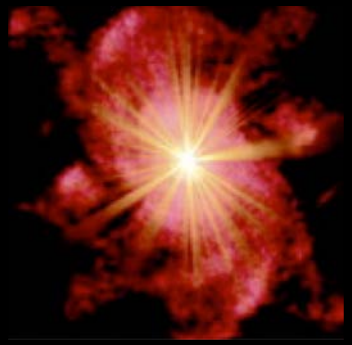


Ceverino et al. 2010

Obscured BH growth



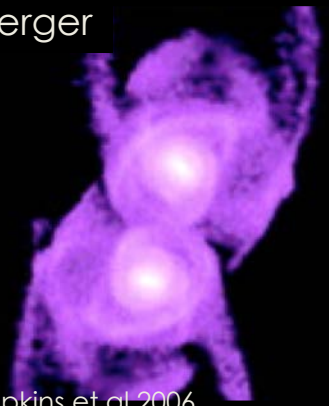
Feedback phase



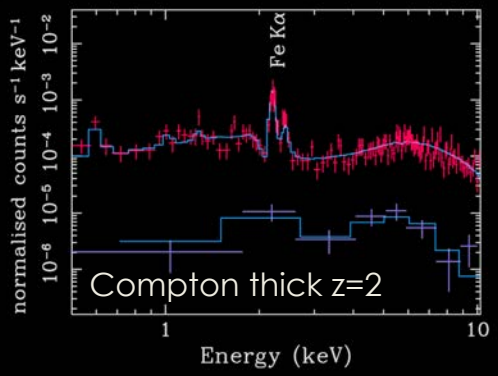
Quiescent remnant

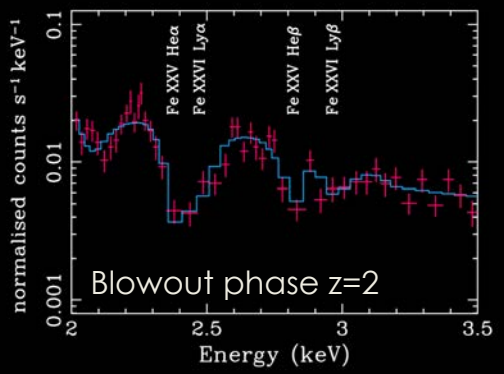


Merger



Hopkins et al.2006

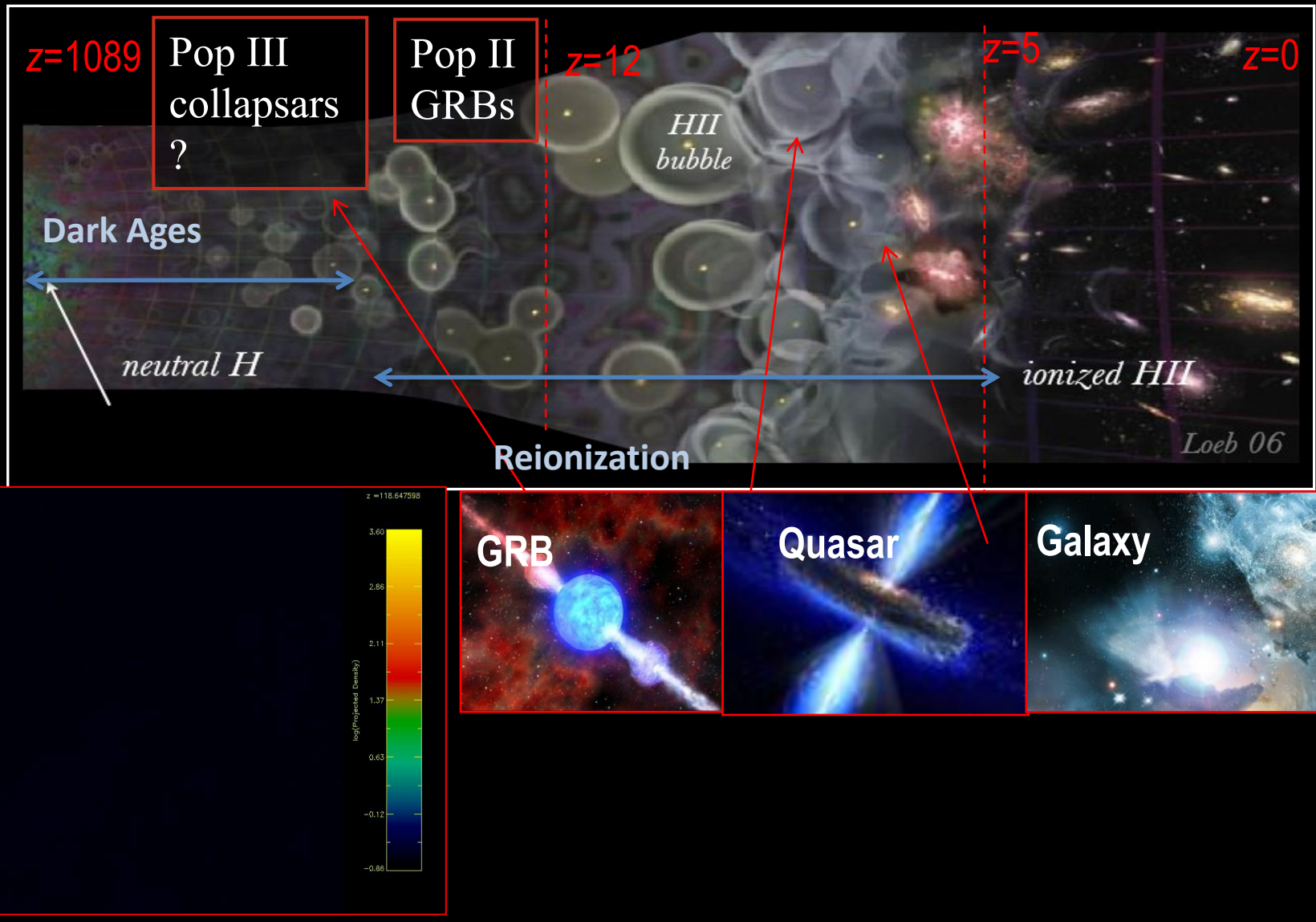




Georgakakis, Carrera et al., 2013 arXiv1306.2328

How do black holes grow and shape the Universe?

The first stars, the first BH, the first metals



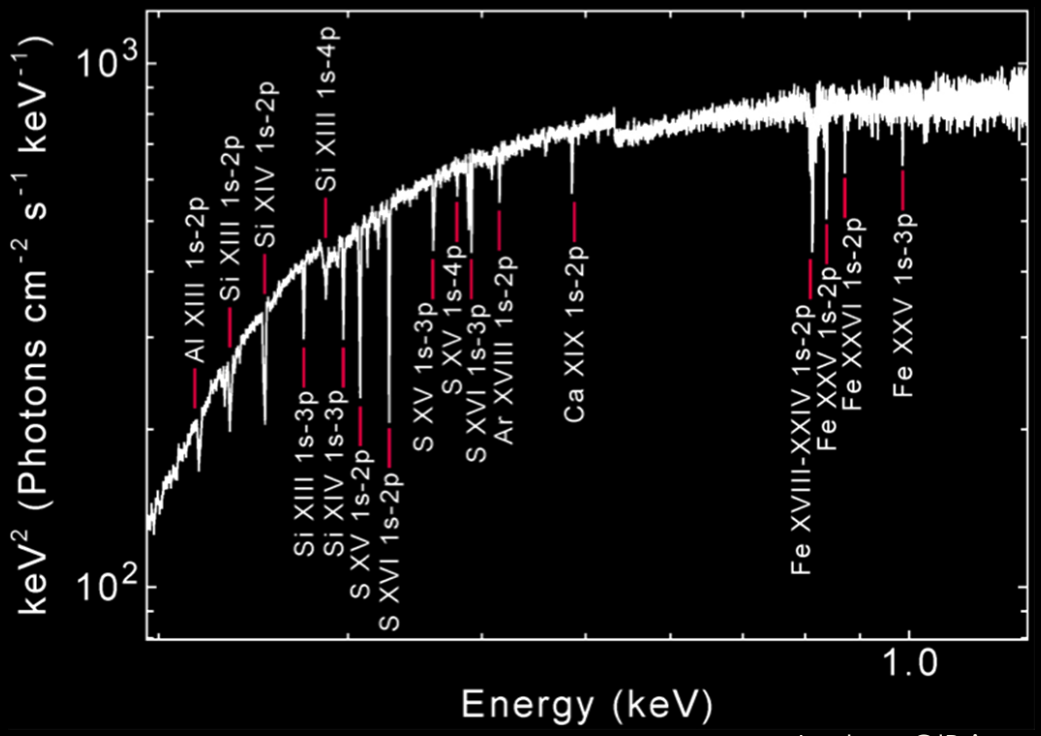
ATHENA



The first stars and black holes

When did the first generation of stars explode to form the first seed black holes and disseminate the first metals in the Universe?

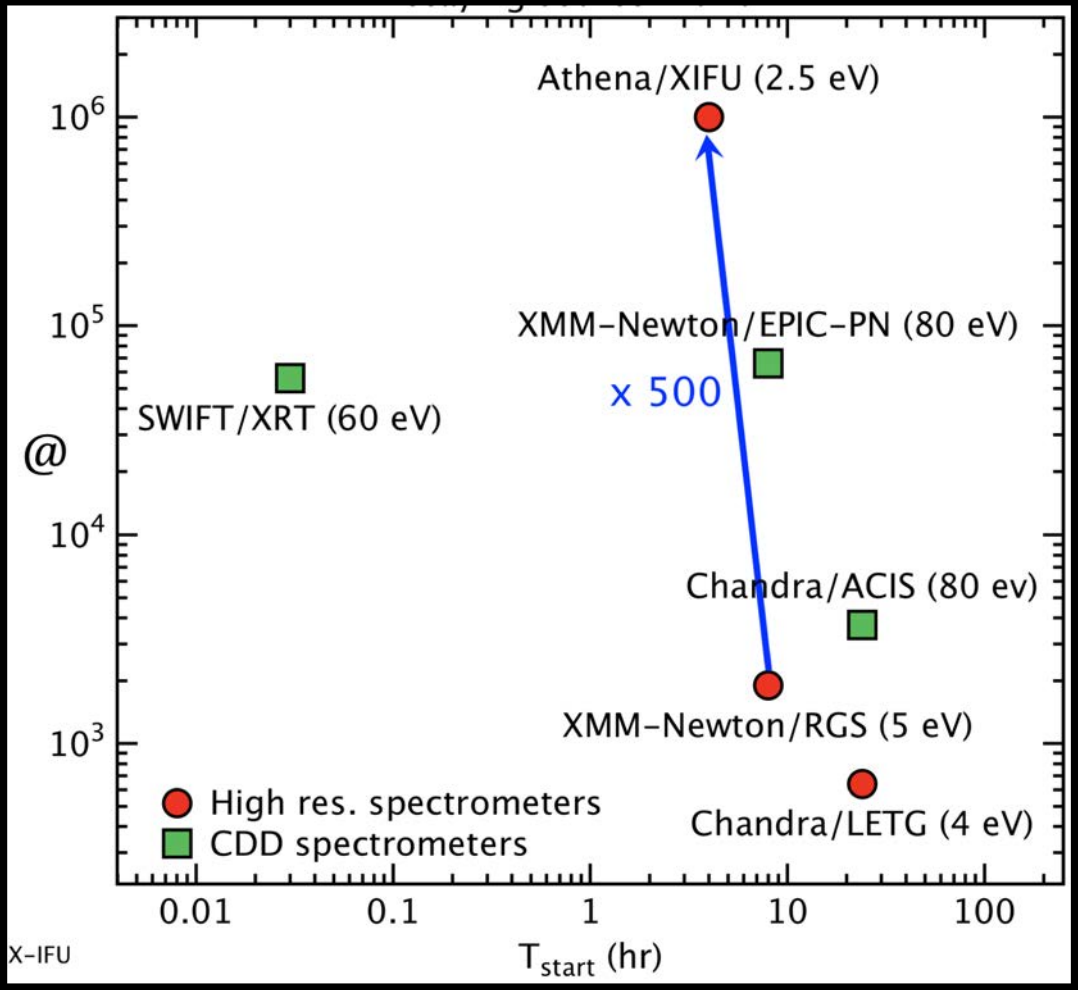
Gamma Ray Burst at z=7



Jonker, O'Brien et al., 2013 arXiv1306.2336

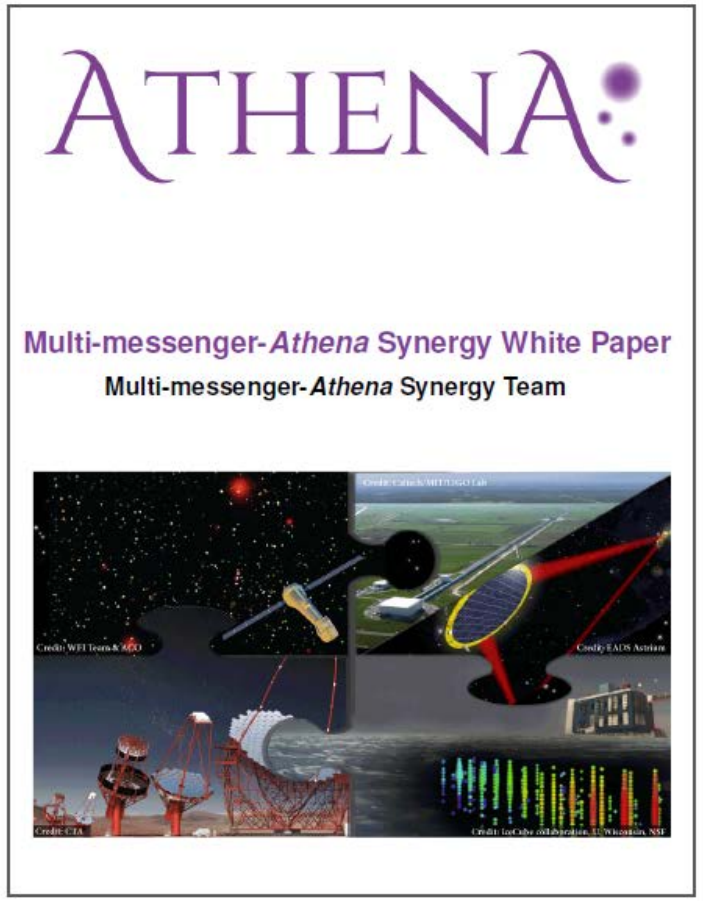
How do black holes grow and shape the Universe?

Athena TOO capability on GRBs



THE ATHENA MULTI-MESSENGER SYNERGY WHITE PAPER

- Scientific synergies between the Athena and Gravitational Waves, neutrinos, high energy and Gamma Ray Burst transient facilities that will be operational contemporary to Athena.
- Outline the operational scenario to successfully implement the synergy science goals
- Each facility (incl Athena): contact person + experts
  - **A& ground based GW, AVirgo/Aligo and future facilties**
  - **A& LISA**
  - A& v's and HE (ICECUBE, KM3Net, CTA)
  - A& Transient Universe experiments a la Theseus
  - Piro et al. 2021



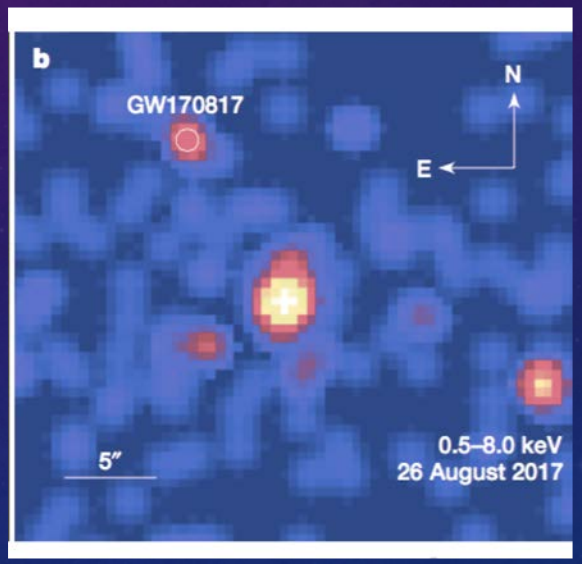
ATHENA AS A MULTIMESSENGER TOOL

- Energetic phenomena explosions, accelerations sites, transients
- Athena assets:
  - 10-100 fewer field sources (per sq degree) compared to lower frequencies
  - Wide field (40 arcmin2) (+mosaic/raster scan)
  - arcsec imaging (location accuracy 1arcsec)
  - sensitivity down to few 10^{-17} erg/cm2/s
  - Integral field spectroscopy with high spectral resolution (R=1000@2.5keV)
  - Fast Too (4hrs) , large FoR(>50%)

ATHENA AND GROUND-BASED GW DETECTORS

- Synergy science themes
  - Jet physics and BH accretion
  - Formation and evolution of black holes,
  - NS EOS,
  - Acceleration processes
  - How did intermediate- and high-Z elements form
- Class of Sources
  - Binary stellar mergers (BNS, BBH, NS-BH)

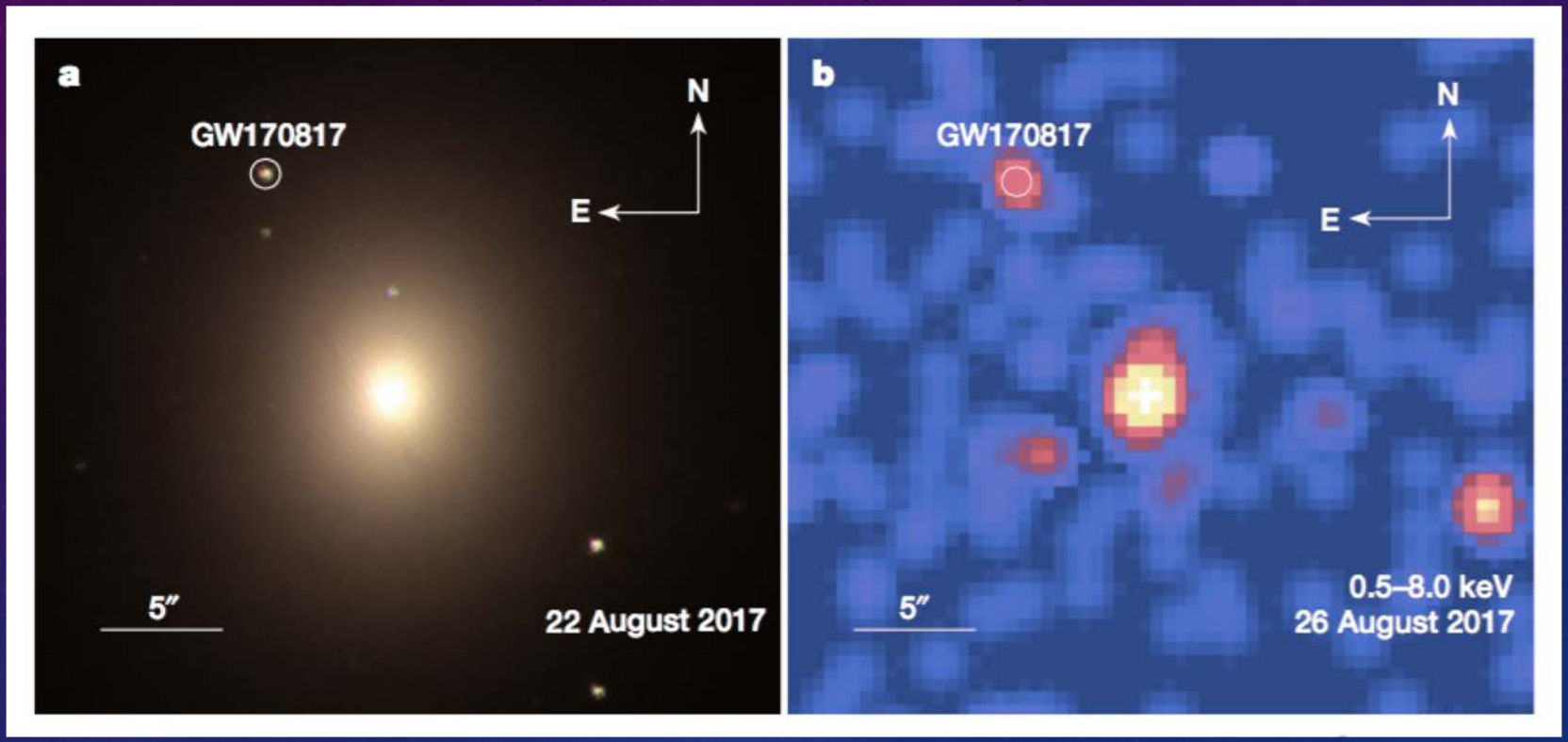
Discovery image of GW170817 with Chandra



Troja, Piro, van Eerten+ Nature, 2017

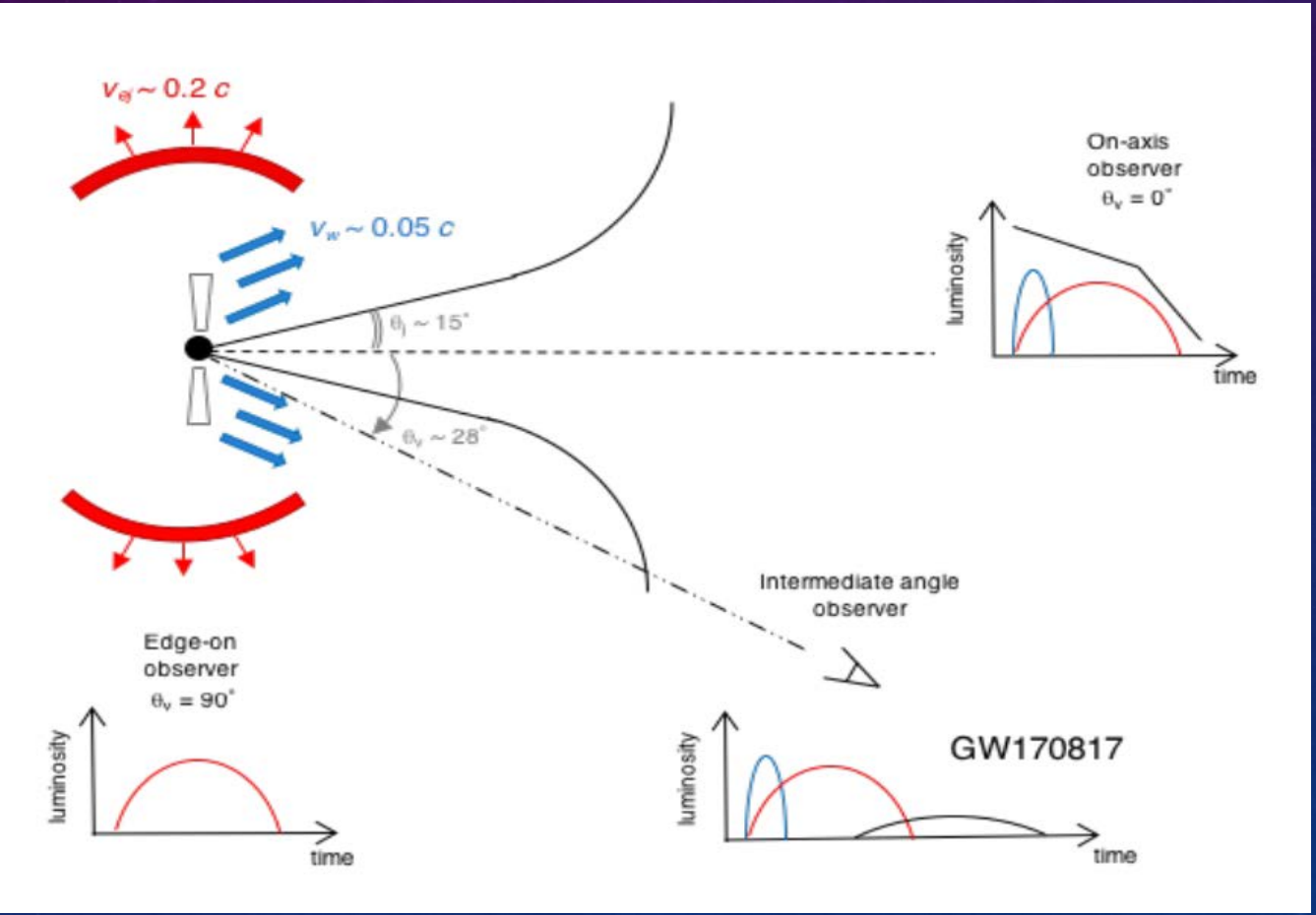
X-RAY AFTERGLOW AND KILO-NOVA FROM GW170817

Discovery image of GW170817 Left HST, right Chandra



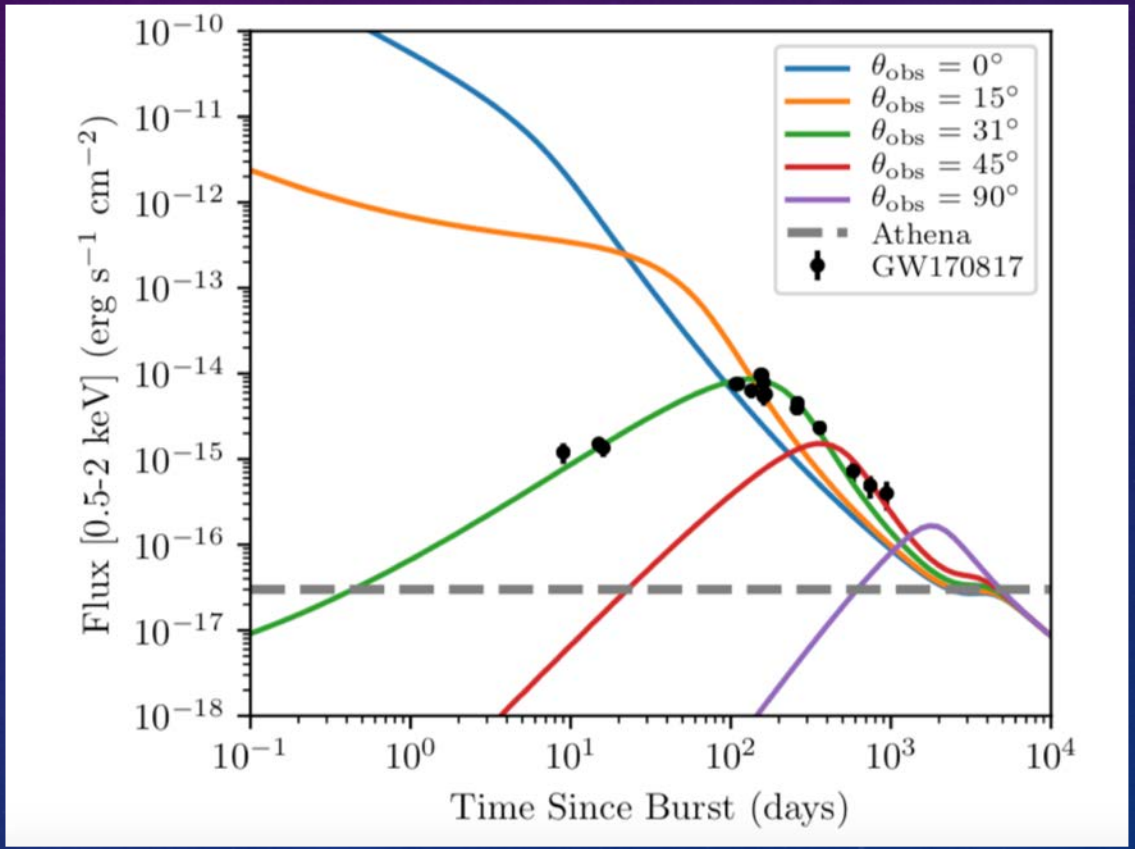
Troja, Piro, van Eerten+ 2017

BROADBAND PICTURE

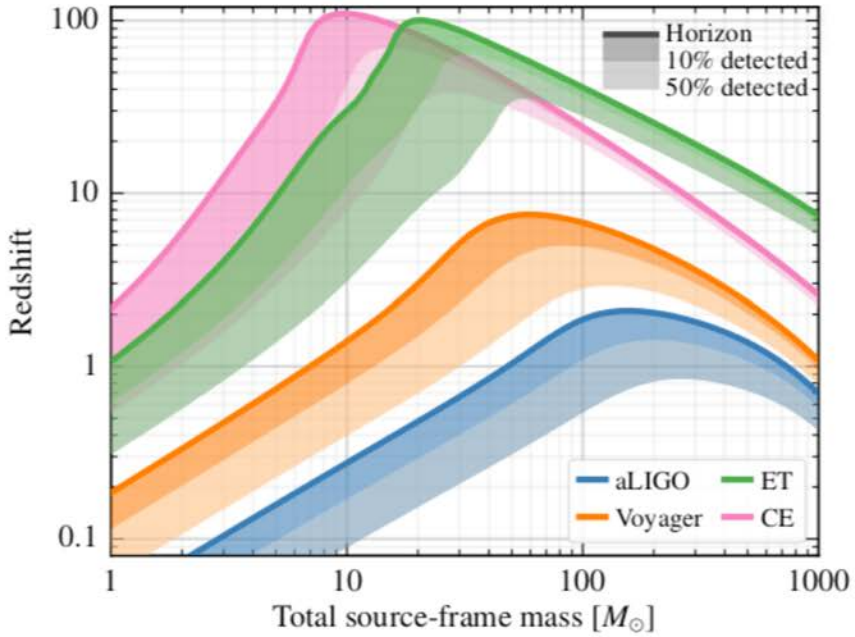


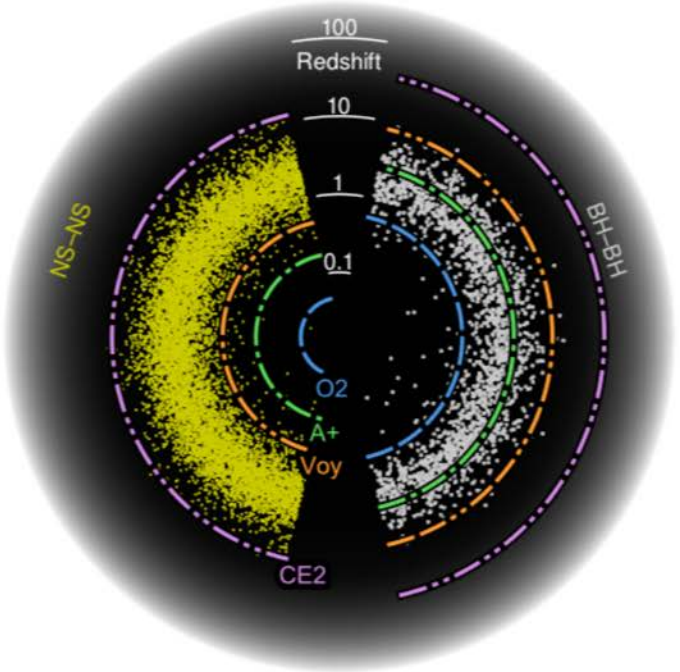
EXTENDING THE EM HORIZON OF GW MERGERS WITH ATHENA

- GW170817-like



THE HORIZON OF GW INTERFEROMETERS



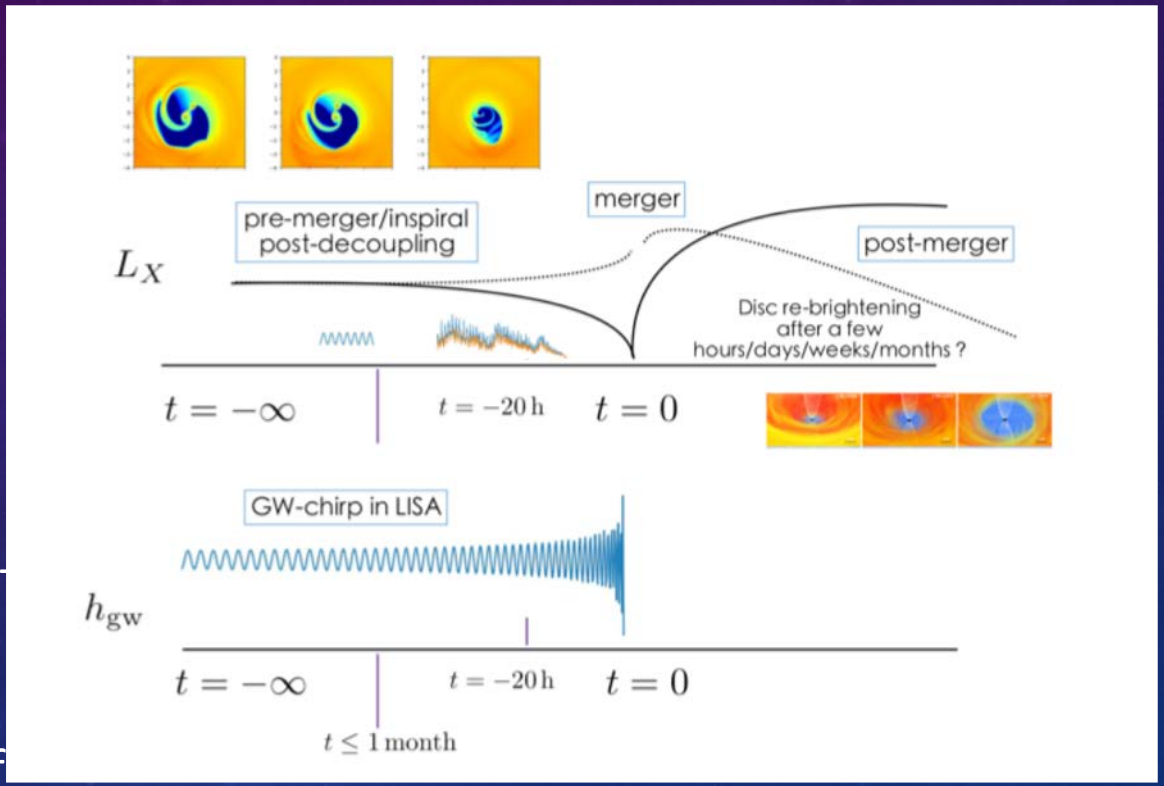


Network	N(detected) [yr^{-1}]	Median loc. [sq.deg]	N(<1 sq.deg.) [yr^{-1}]	N(<10 sq.deg.) [yr^{-1}]	N(<100 sq.deg.) [yr^{-1}]
HLVKI	15	7	0	15	15
3Voyager	800	20	5	170	770
1ET+2Voyager	6,100	21	20	960	6,100
1ET+2CE	320,000	12	4,500	130,000	310,000

TIMELINE OF SMBH BINARIES

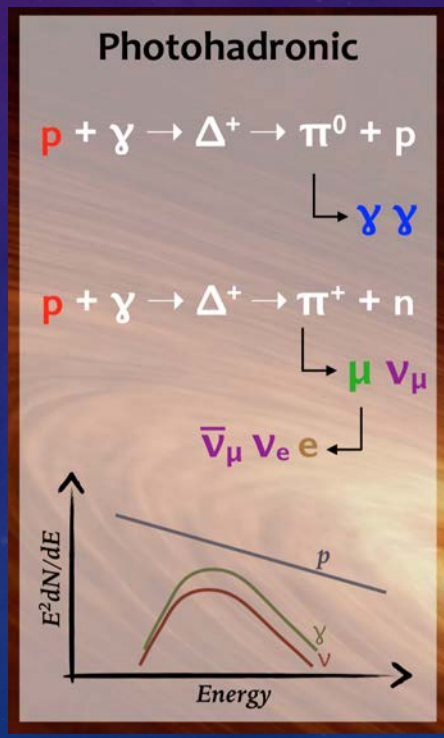
X-ray emission based on theory, widespread range of prediction

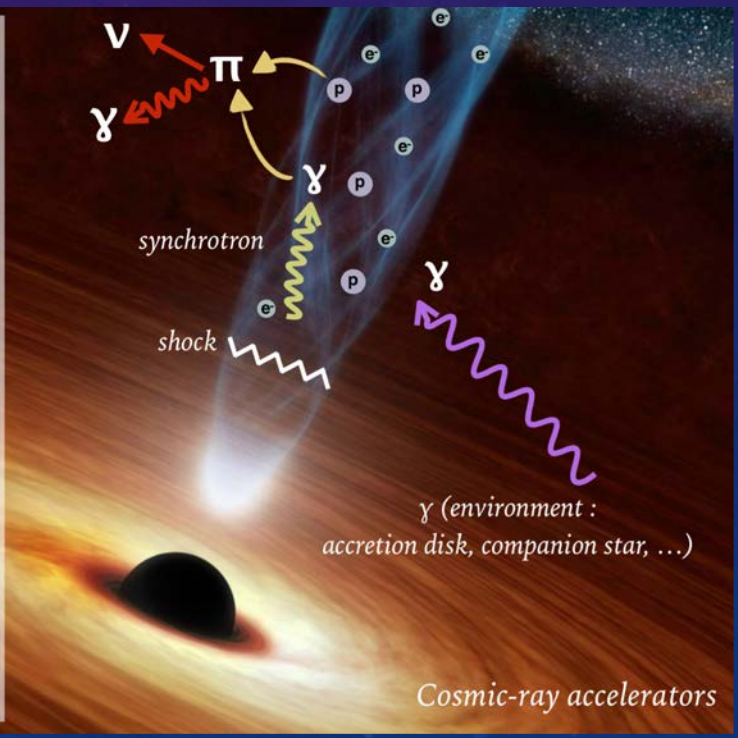
- Premerger: Gas accretion may be present before the merger (modulated): X-ray precursor
- Post-merger: formation of hot corona, launch of jet



ATHENA, CTA AND NEUTRINO SYNERGIES

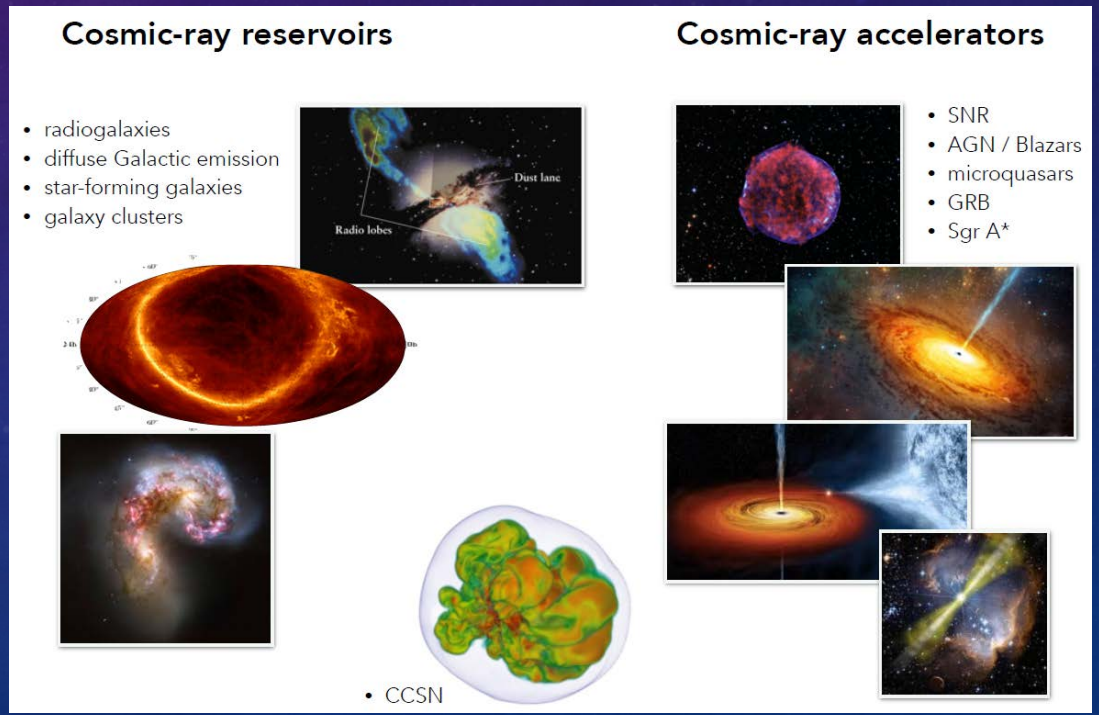
- Overaching theme: Cosmic Accelerators, Cosmic Ray Researvoir
  - Sources of CR's
  - Hadronic vs Leptonic
- Sources:
  - Blazars
  - SNR
  - Sne (v's from CC)
  - Magnetars
  - TDE
  - PWN
  - GRBs
  - Clusters as CR reservoirs





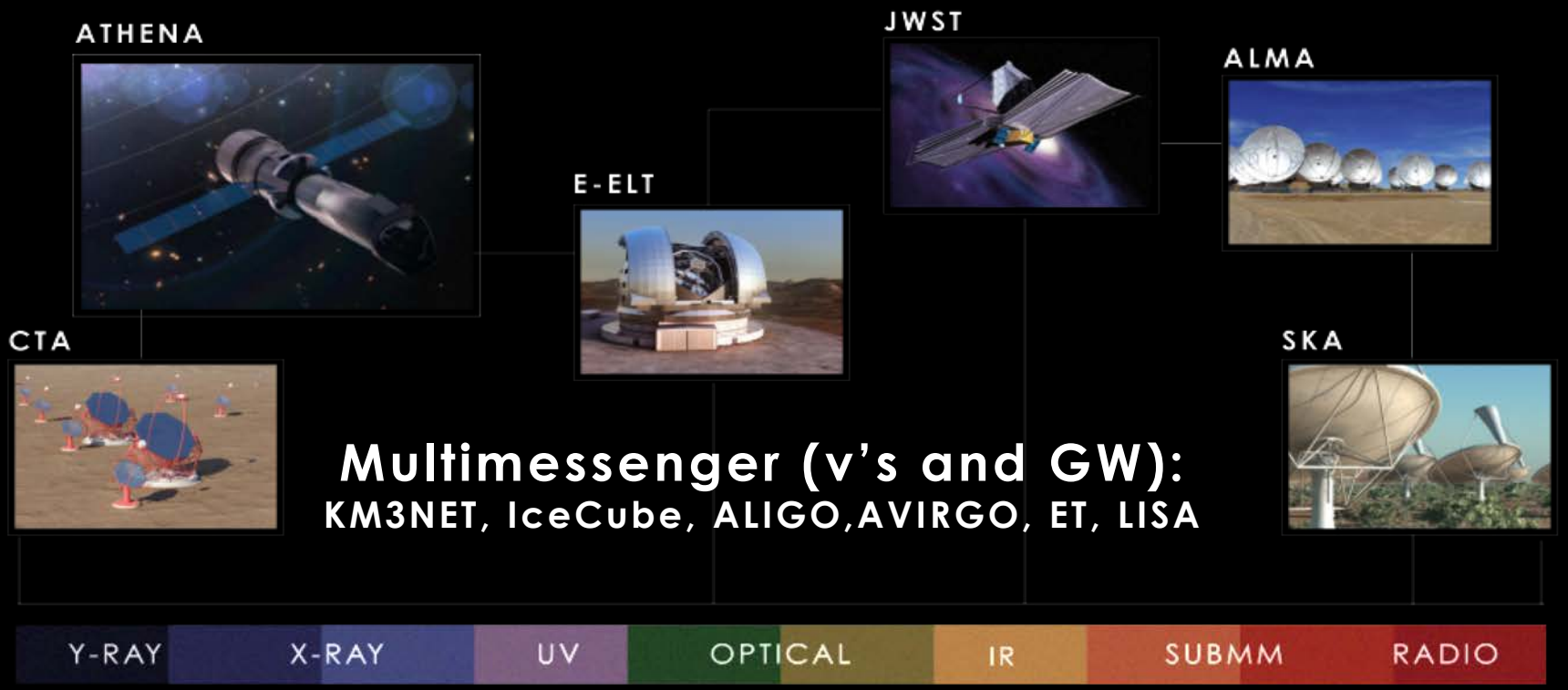
ATHENA, CTA AND NEUTRINO SYNERGIES

- Overaching theme: Cosmic Accelerators, Cosmic Ray Researvoir
  - Sources of CR's
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  - Blazars
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  - Magnetars
  - TDE
  - PWN
  - GRBs
  - Clusters as CR reservoirs



esa

Athena in context of large facilties



Athena is a crucial part of the suite of large observatories needed to reach the science objectives of astronomy in the coming decades

ATHENA

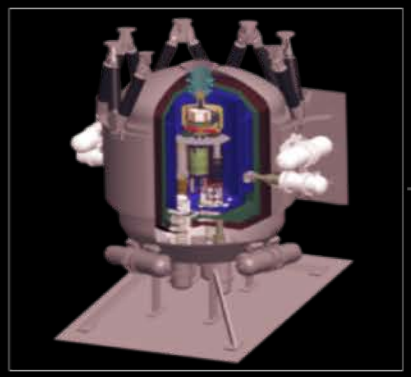
The Athena Observatory

Willingale et al, 2013
arXiv1308.6785

L1 orbit Ariane VI
TOO in 4 hrs
Mass 7 tons
Power 2500 W
4+6 year mission



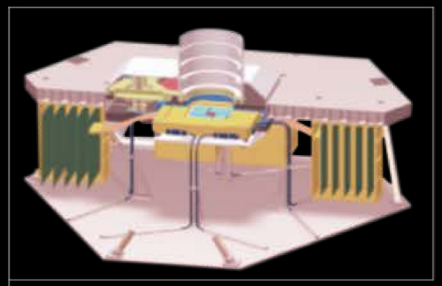
Silicon Pore Optics:
1.4 m^2 at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



X-ray Integral Field Unit:
ΔE: 2.5 eV
Field of View: 5 arcmin
Low background
Operating temp: 50 mk

Barret et al., 2013 arXiv:1308.6784





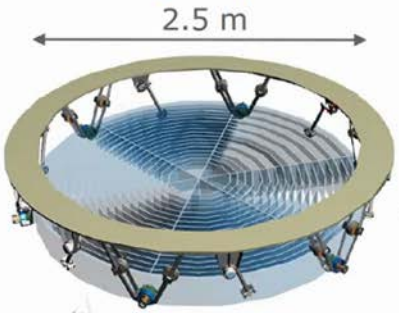
Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

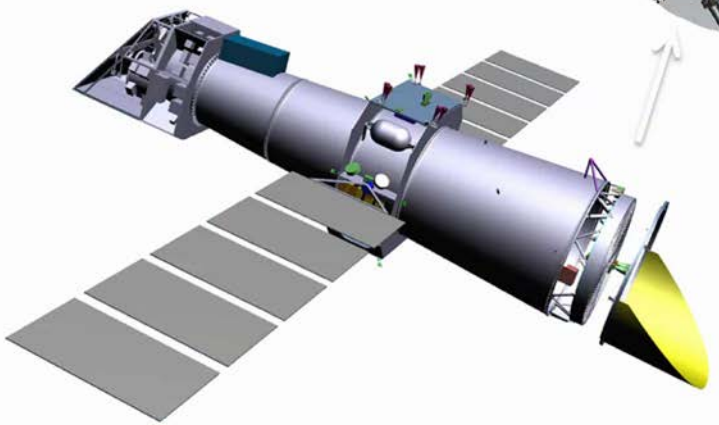
Rau et al. 2013 arXiv1307.1709

Athena Mirrors

Athena requires the largest x-ray optic ever built

- Huge size requires modularisation
- Industrial production mandatory
- Cost and schedule compliance
- Innovative mounting scheme for instrument selection







Athena mirror:

600 mirror modules
~ 100,000 mirror plates
~ 300 m² polished and coated area
(comparable with 20 m ground based telescope)

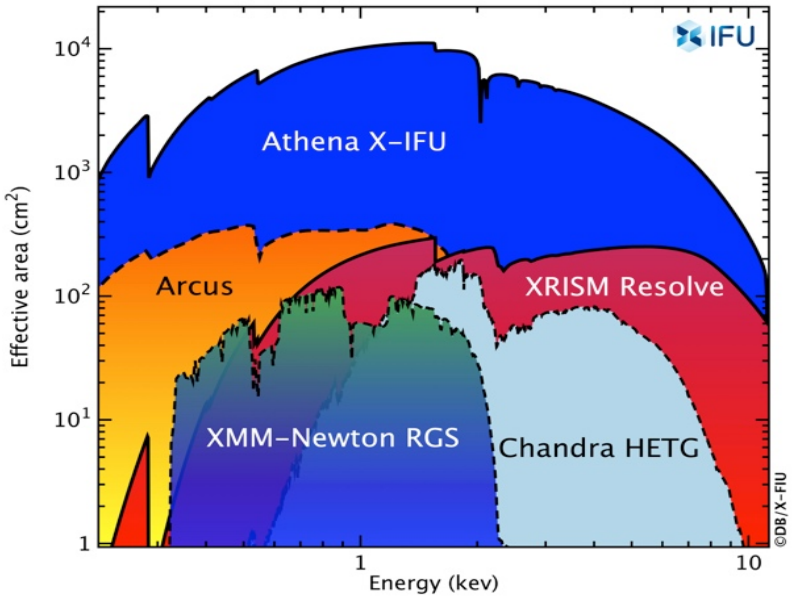
⇒ 2 MM / day production rate required
⇒ (assuming 8h/d, 180 d/y, all MMs in 2 years)

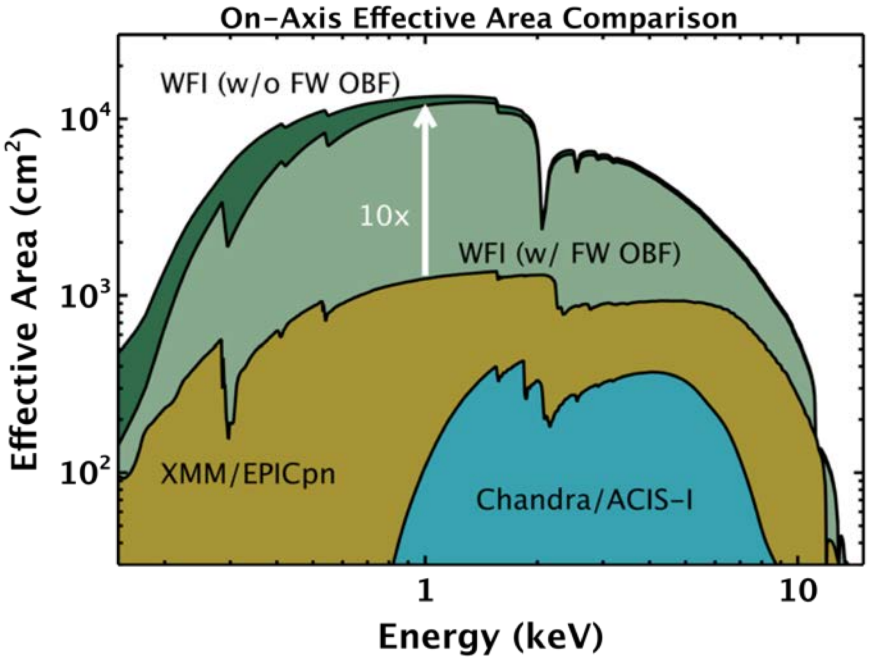
ESA UNCLASSIFIED - For Official Use

Schedule

✓ Hot&Energetic Univ. Theme selected for ESA L2	Nov. 2013
✓ Athena Mission selected	Jun. 2014
✓ Phase A and B1	on going
✓ Implementation Phase	2023
✓ Launch	2033/34
✓ Operations:	4 +6 years

Effective Area

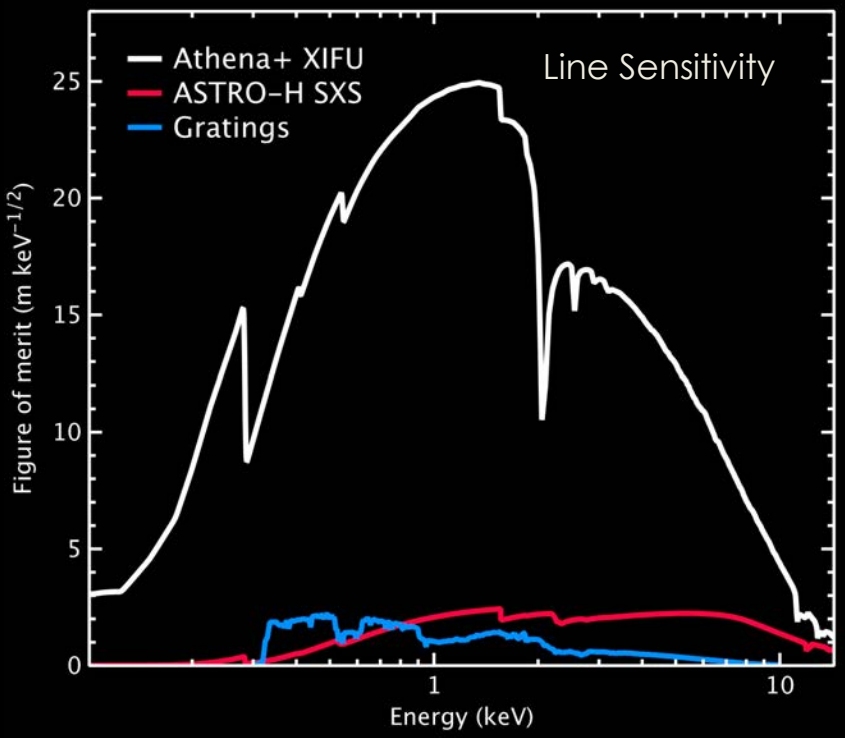




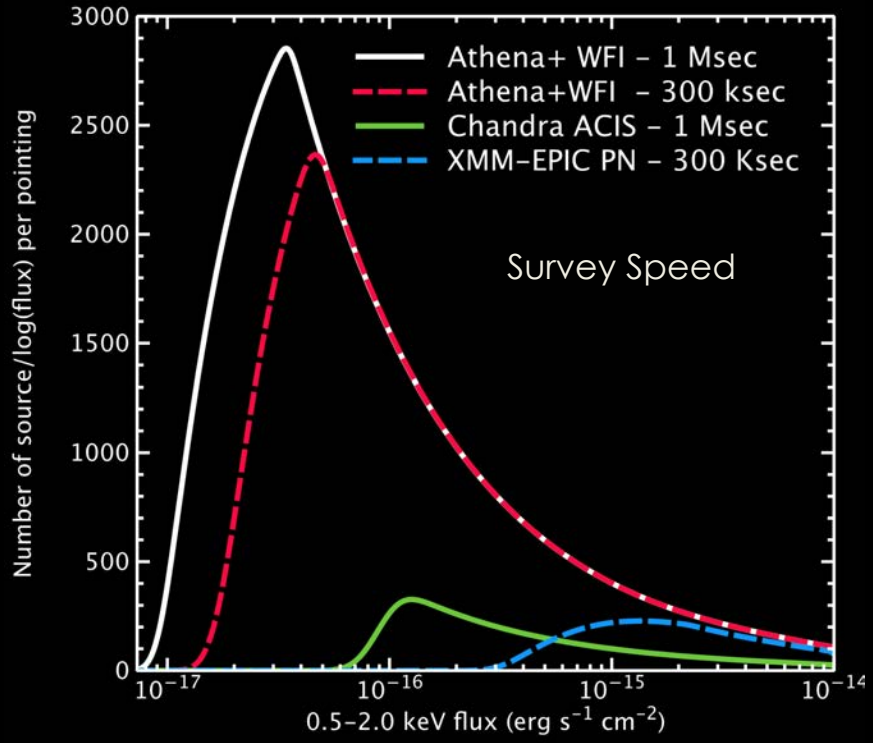
ATHENA

A Deep Universe X-ray Observatory

Athena+ has vastly improved capabilities compared to current or planned facilities, and will provide **transformational** science on virtually all areas of astrophysics



X-ray spectroscopy at the peak of the activity of the Universe



Deep survey capability into the dark ages and epoch of reionization