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The Science Theme motivating the Athena+ mission

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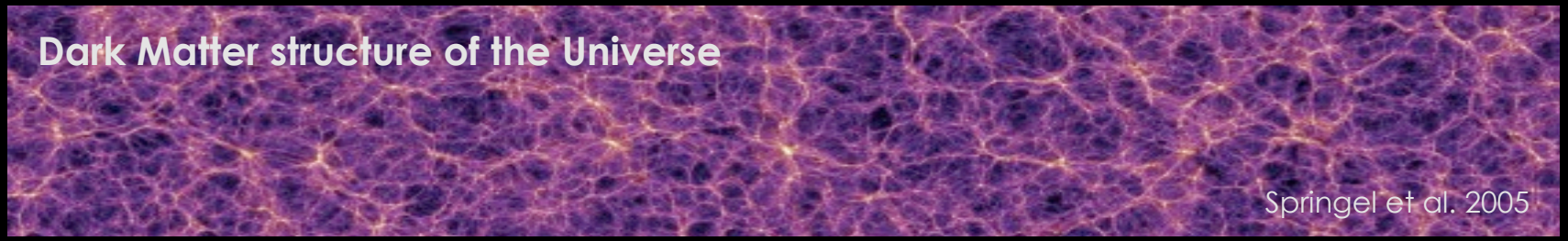
Why does the observable universe look the way it does?



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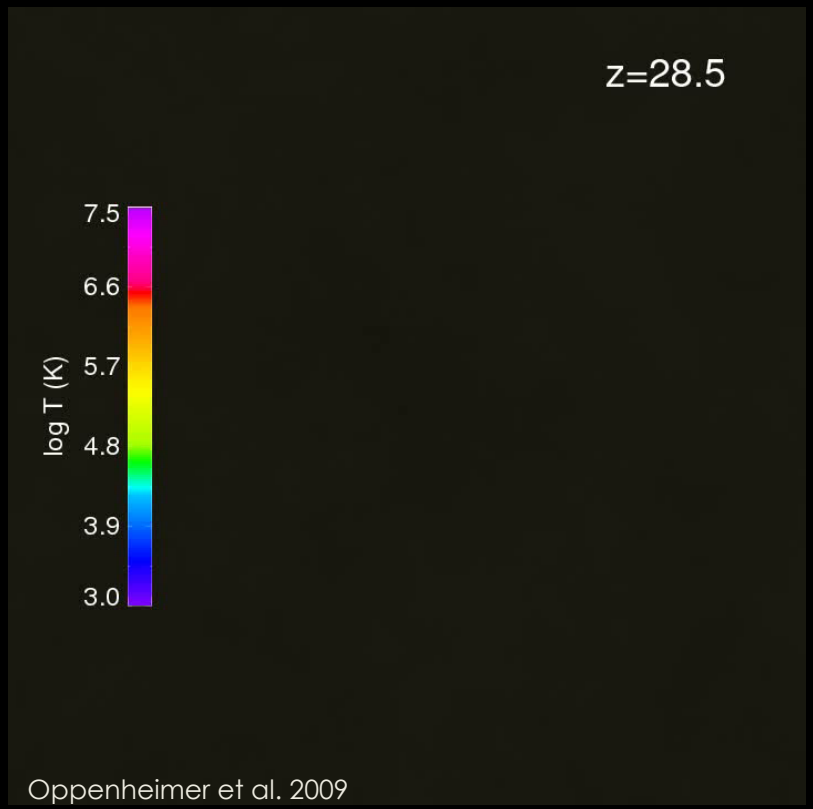
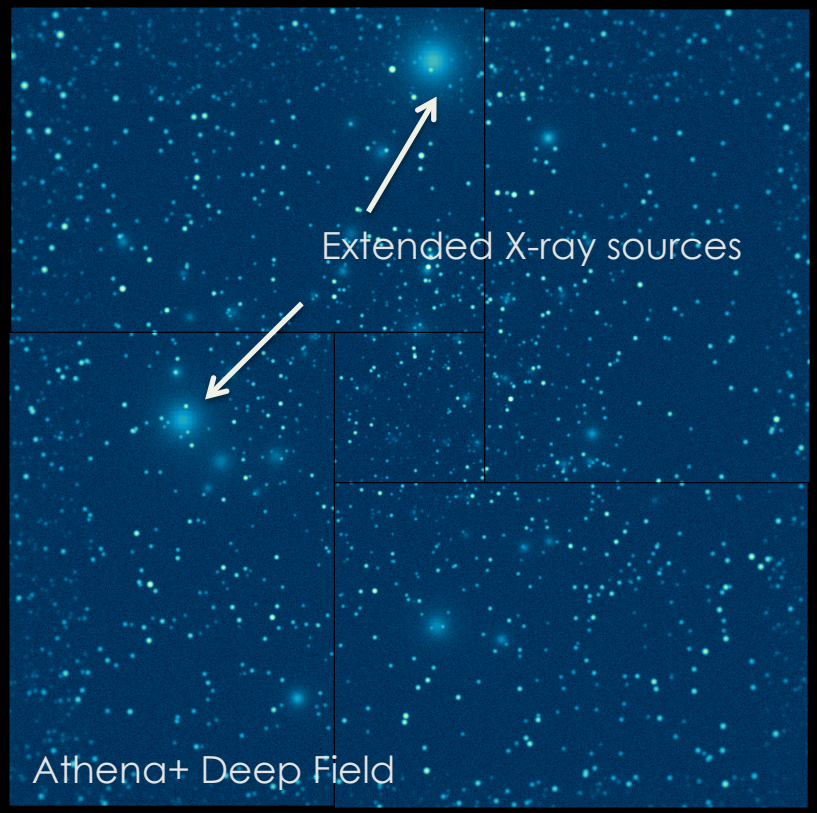
Key questions for observational astrophysics in 2028

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



Oppenheimer et al. 2009



Pointecouteau, Reiprich et al., 2013 arXiv1306.2319

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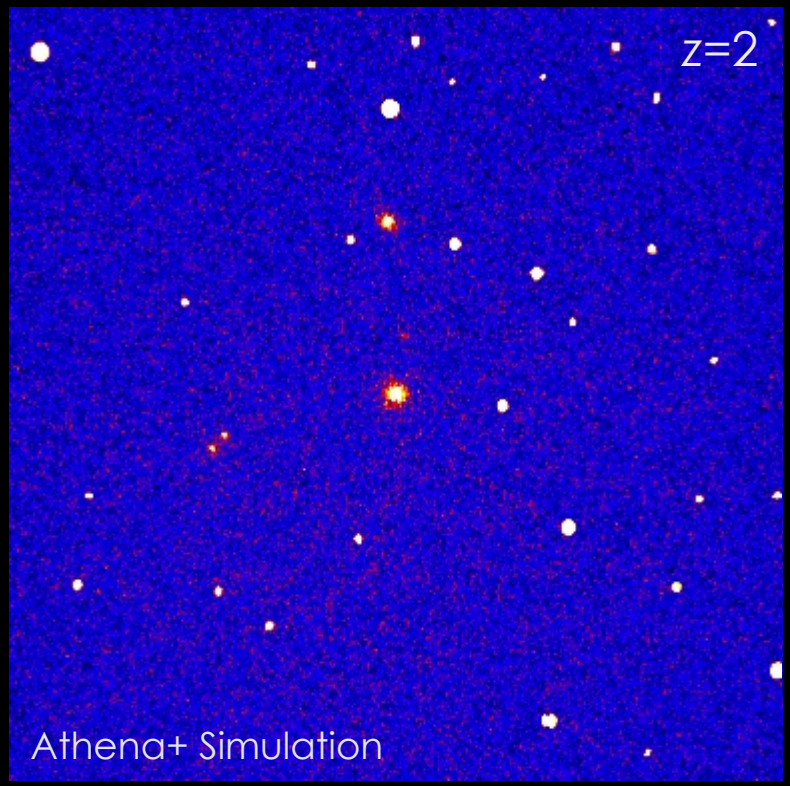
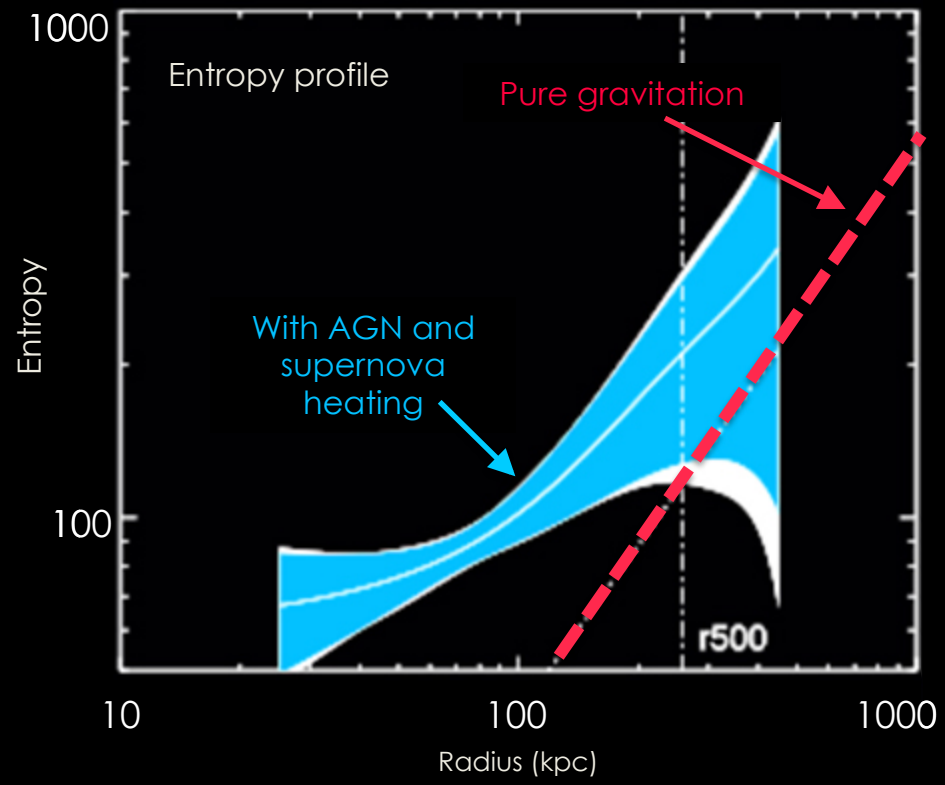
The formation and evolution of clusters and groups of galaxies

How and when was the energy contained in the hot intra-cluster medium generated?



Pointecouteau, Reiprich et al., 2013 arXiv1306.2319



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

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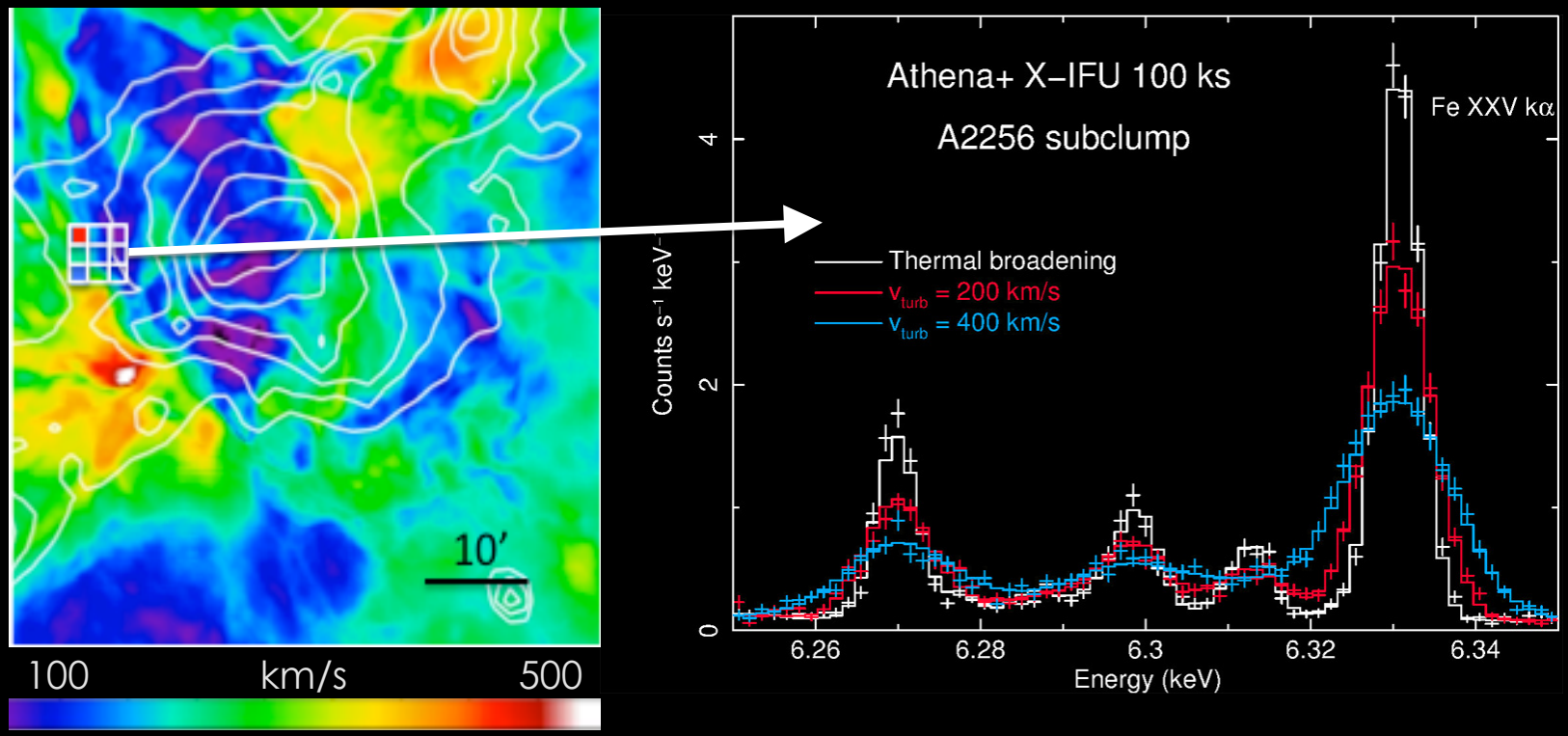
The formation and evolution of clusters and groups of galaxies

How and when was the energy contained in the hot intra-cluster medium generated?

Simulated Velocity map

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



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

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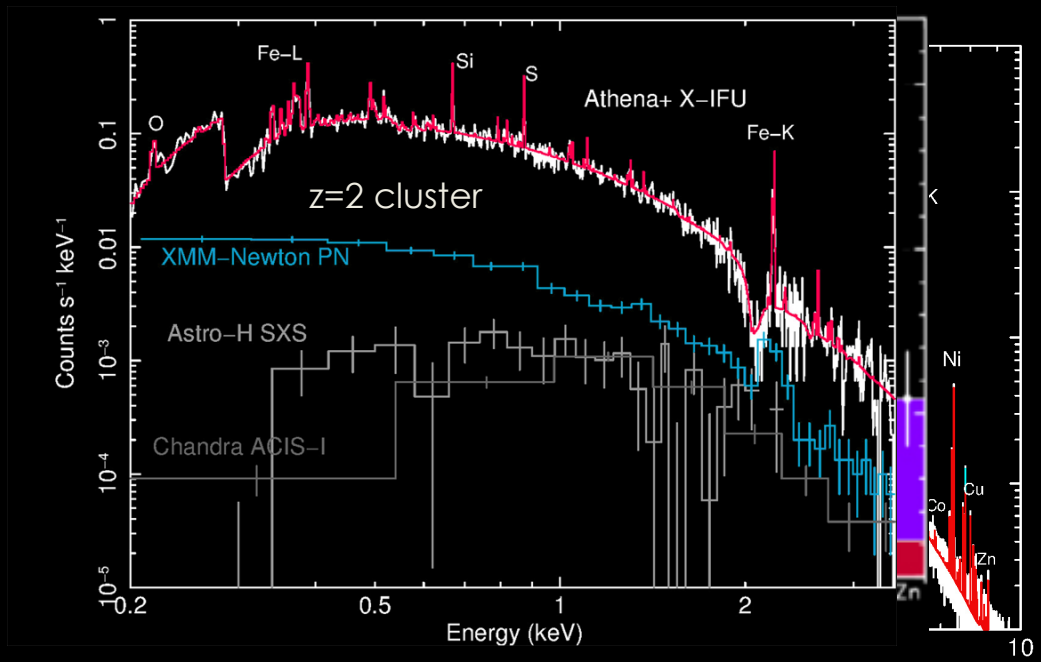
The chemical evolution of hot baryons

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?

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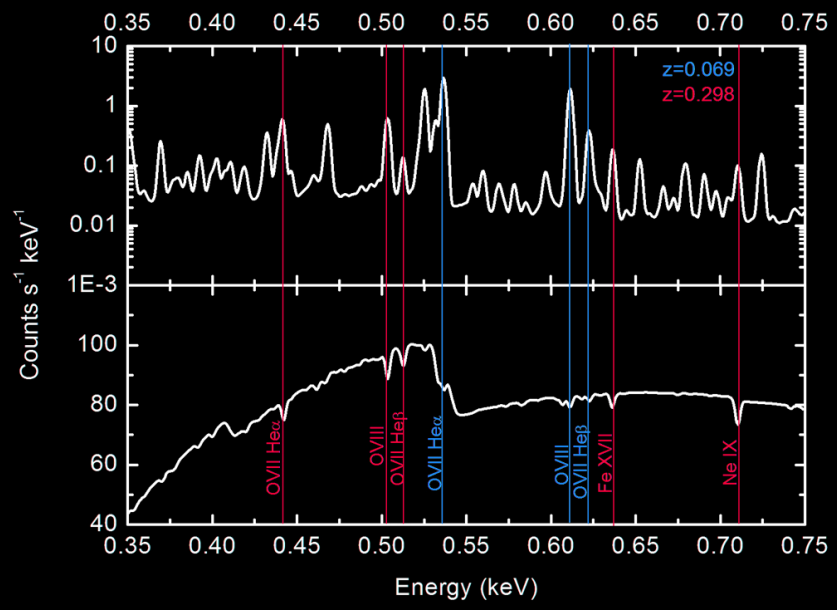
The Warm-Hot intergalactic medium (WHIM)

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?

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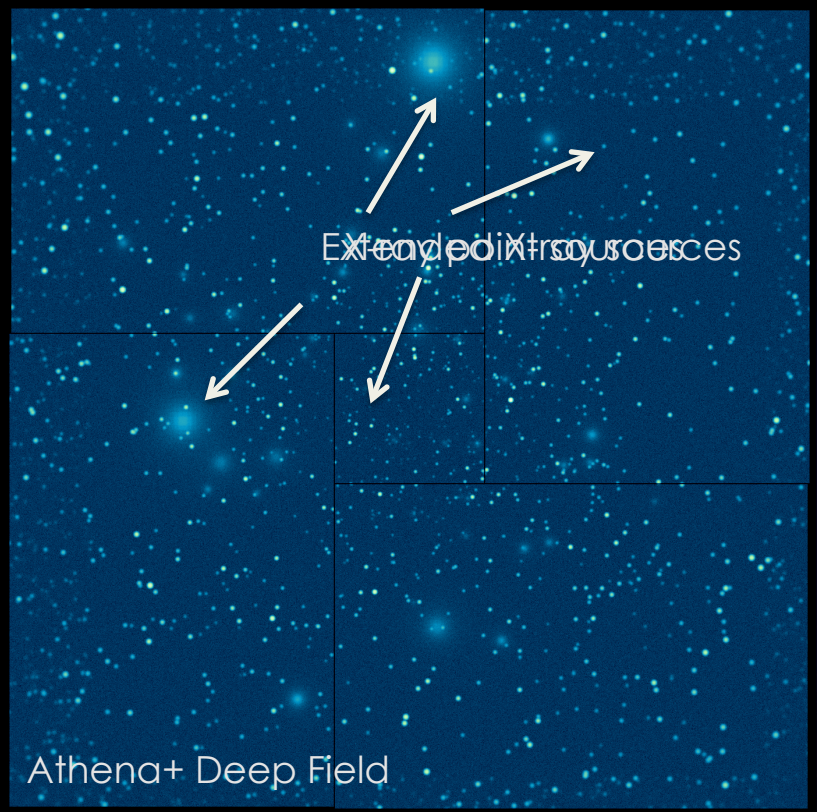
Key questions for observational astrophysics in 2028

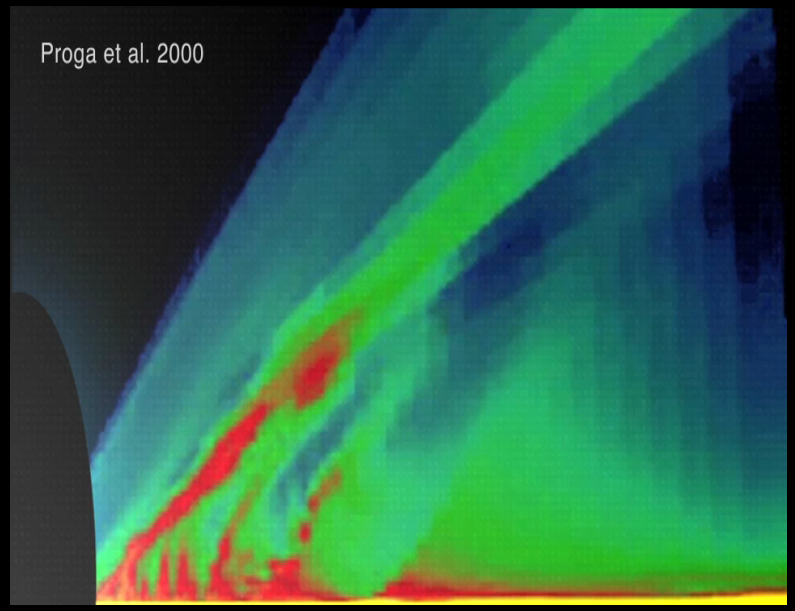
1. How does ordinary matter assemble into the large scale structures we see today?

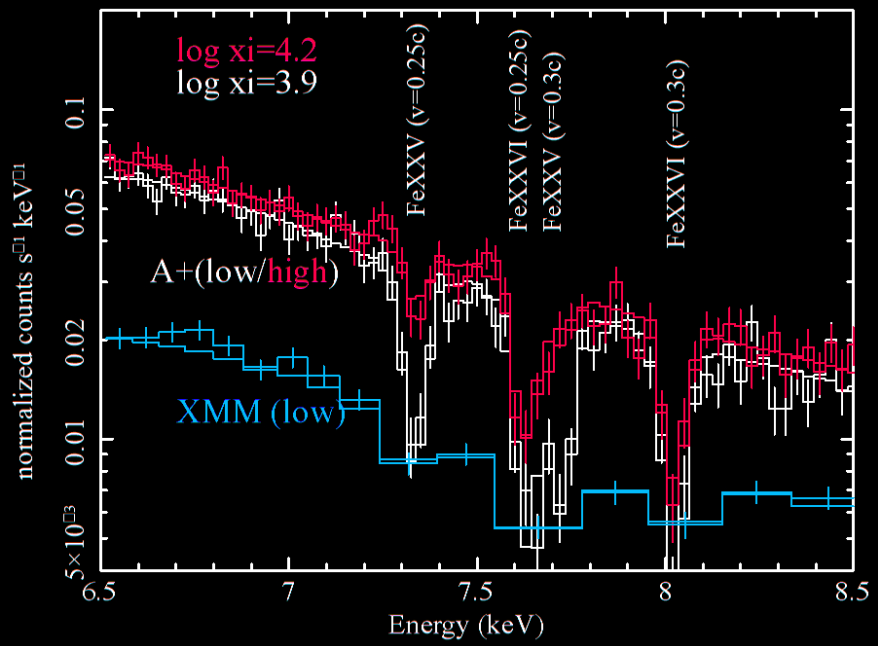
2. How do black holes grow and shape the Universe?



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?

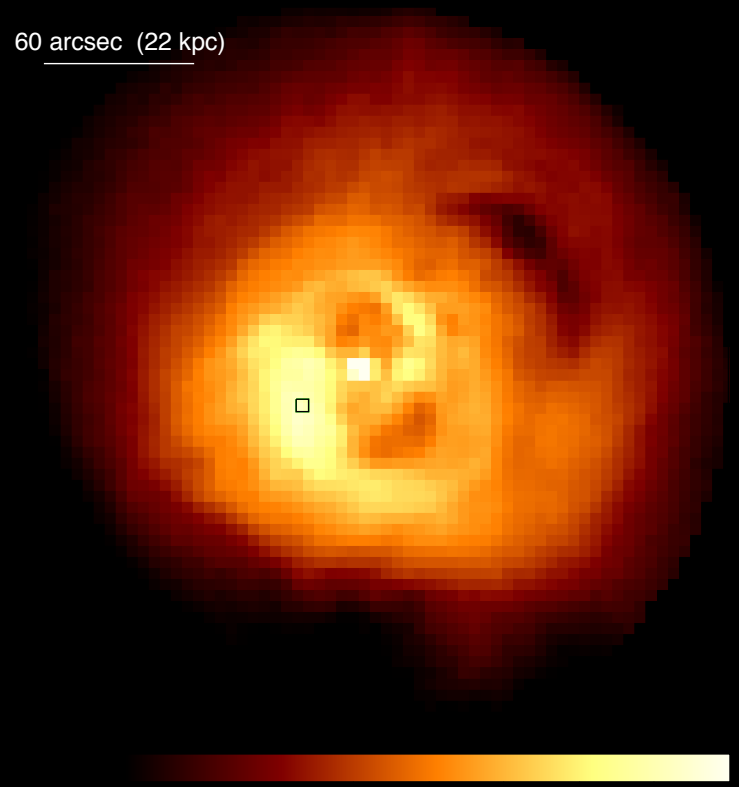


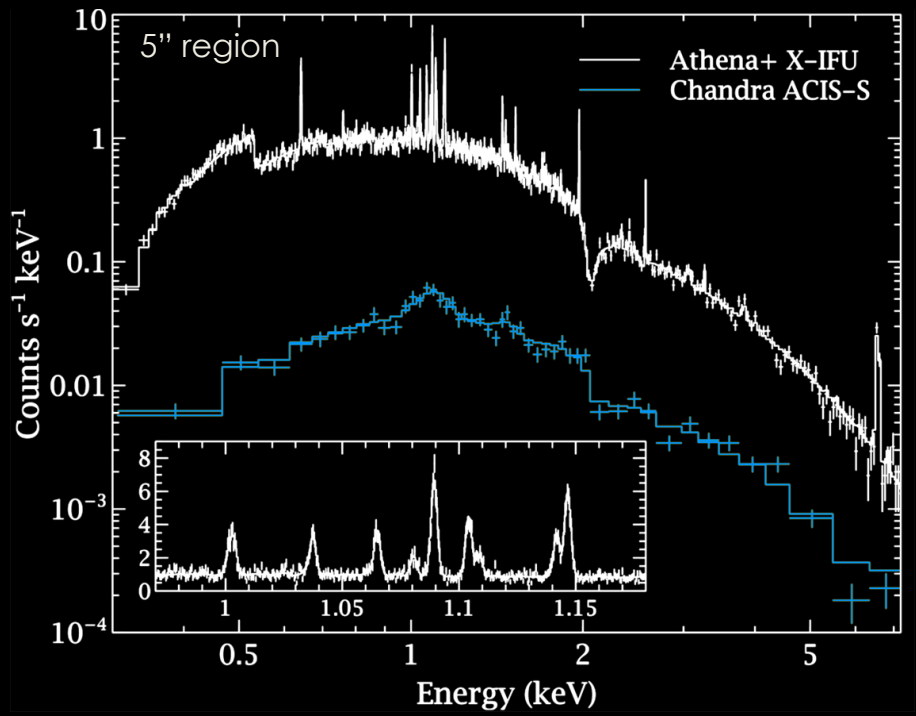


Cappi, Done et al., 2013 arXiv1306.2330
Dovciak, Matt et al., 2013 arXiv1306.2331

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

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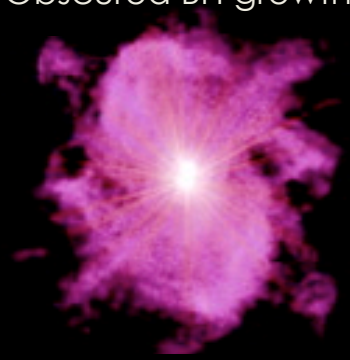
Cosmic feedback: black hole and galaxy co-evolution

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

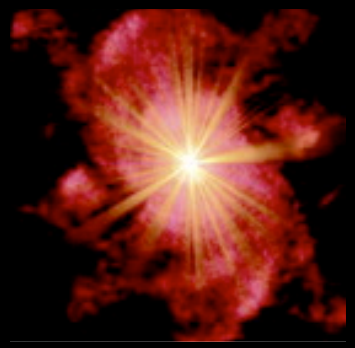
Disk instability

Ceverino et al. 2010

Obscured BH growth

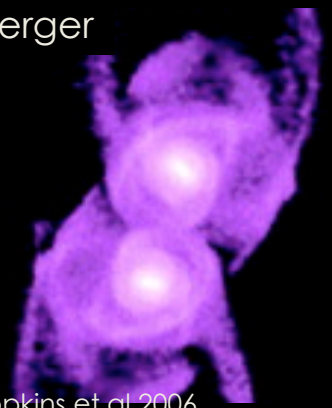


Feedback phase

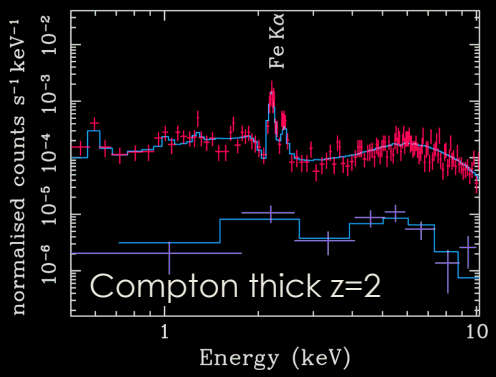


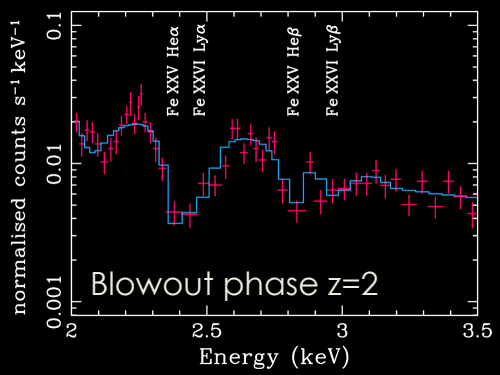
Quiescent remnant

Merger



Hopkins et al.2006





Georgakakis, Carrera et al., 2013 arXiv1306.2328

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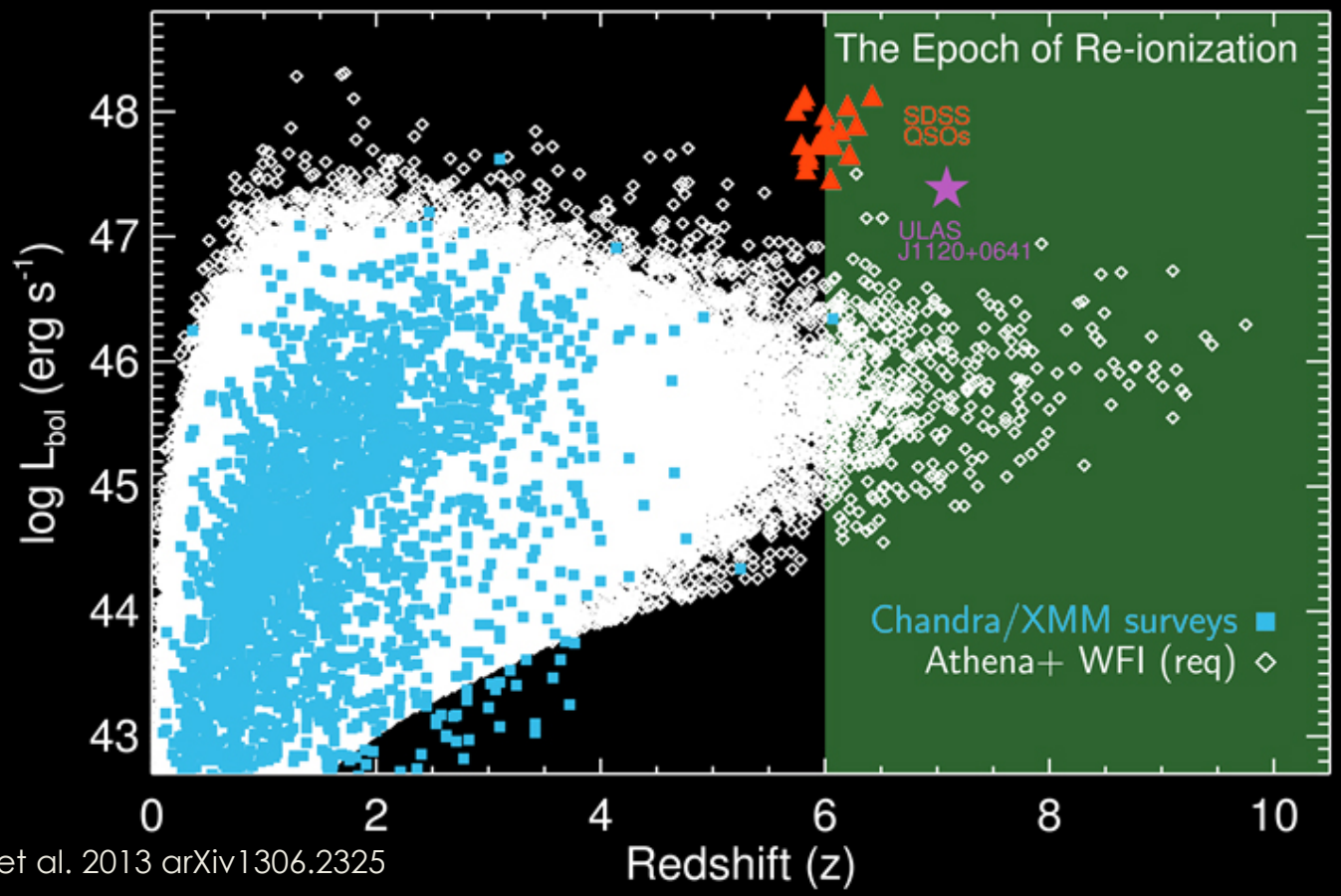
Black hole growth in the early Universe

What was the growth history of black holes in the epoch of reionization?



Aird, Comastri et al. 2013 arXiv1306.2325

How do black holes grow and shape the Universe?

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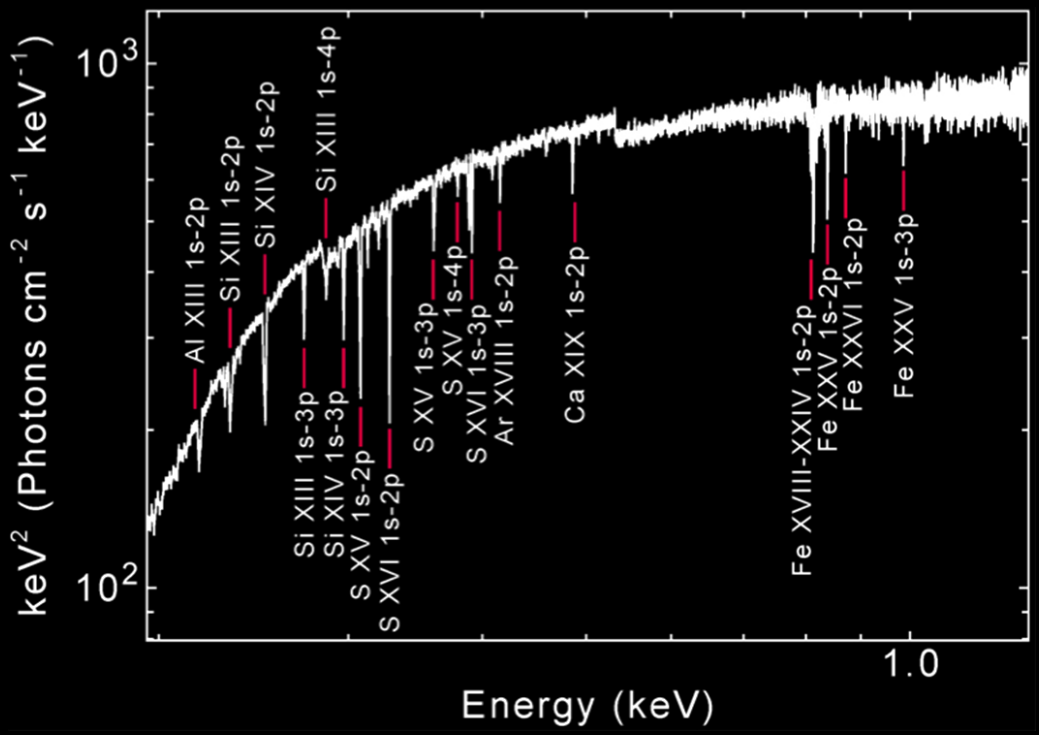
The first stars and black holes

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

Level 1 Science Requirements

- *All results, detections etc. are to be established at the 5 σ level, or equivalent*
- *A minimum of 10 objects per bin is required, when splitting samples as a function of parameters such as redshift or luminosity*
- *A minimum of 25 objects is required when attempting to establish a trend within a sample* against a given parameter (e.g. luminosity, redshift, mass)

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Reference	Requirement (science objective)	Quantification
R-SCIOBJ-111 First groups	Athena shall find the first building blocks of the dark matter structure filled with hot gas by detecting 25 evolved groups of galaxies at z>2 with M_{500}>5 x 10^{13} M_{sun} and determine the gas temperature of a representative sample. At least five groups are expected at z>2.5.	25 galaxy groups with gas temperature at z>2 to investigate L-T relation.
R-SCIOBJ-112 Cluster bulk motions and turbulence	Athena shall measure how gravitational energy is dissipated into bulk motions and gas turbulence in the galaxy cluster population, by achieving a 5 sigma detection of these quantities.	Kinetic energy dissipated from gravitational assembly in 10 regular & 10 irregular galaxy clusters in the nearby Universe.
R-SCIOBJ-121 Cluster entropy profile evolution	Athena shall determine which physical processes dominate the injection of non-gravitational energy into the intra-cluster medium as a function of cosmic epoch by measuring the structural properties (e.g., the entropy profiles) of galaxy groups and clusters. To differentiate between models of feedback and gas accretion, these measurements shall be achieved to the virial radius in local clusters and out to R500 up to z~2, with an uncertainty <25% (at R500 at z=2). Athena shall also measure the evolution of the scaling relations between bulk properties of the hot gas (e.g., the Lx-T relation) out to at least a redshift of 2, to a precision of <25%.	Cosmic history of the injection of entropy in cluster hot gas at 0<z<2. Investigate 10 clusters in each of 4 redshift bins and 3 mass bins (total 120 clusters).

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The Hot Universe
R-SCIOBJ-111 - First groups
R-SCIOBJ-112 - Cluster bulk motions and turbulence
R-SCIOBJ-121 - Cluster entropy profile evolution
R-SCIOBJ-122 - Cluster chemical evolution
R-SCIOBJ-131 - Physics of cluster feedback
R-SCIOBJ-132 - Feedback-induced cluster ripples
R-SCIOBJ-133 - Heating/cooling balance in cluster feedback
R-SCIOBJ-134 - Shock speeds of radio lobes in clusters
R-SCIOBJ-141 - Missing Baryons
R-SCIOBJ-142 - WHIM in emission

The Energetic Universe
R-SCIOBJ-211 - High redshift SMBH
R-SCIOBJ-221 - Complete AGN census
R-SCIOBJ-222 - Census of AGN outflows at z=1-4
R-SCIOBJ-223 - Mechanical energy of AGN outflows at z=1-3
R-SCIOBJ-224 - Ultra-fast outflows at z=1-4
R-SCIOBJ-231 -AGN outflows in local Universe
R-SCIOBJ-232 - Feedback in local AGN and star forming galaxies
R-SCIOBJ-241 -AGN reverberation mapping
R-SCIOBJ-242 - AGN spin census
R-SCIOBJ-251 - GBH and NS spins and winds
R-SCIOBJ-252 - ULXs and SgrA*
R-SCIOBJ-261 - High z GRBs
R-SCIOBJ-262 - TDEs

A Personal Observation

Athena has a 12m Focal Length

The current XRS straw-man design has a similar 10m fl

We should consider variations!

5m : Increased FOV, at the cost of high-energy response. Will make XRS into more of a 'survey' instrument, especially at high-z. Reduced focus on Galactic Fe K science. Would place more constraints on wide-field detector technology.

20m: substantially improved 5-10 keV response, smaller FOV. Focus on Galactic and low-z Fe K band. Fewer requirements on detector

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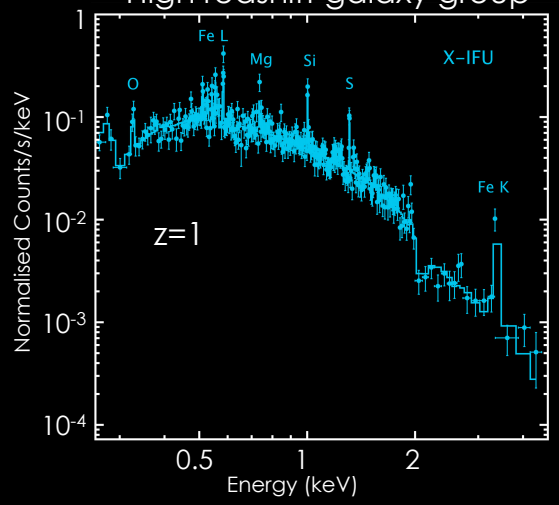
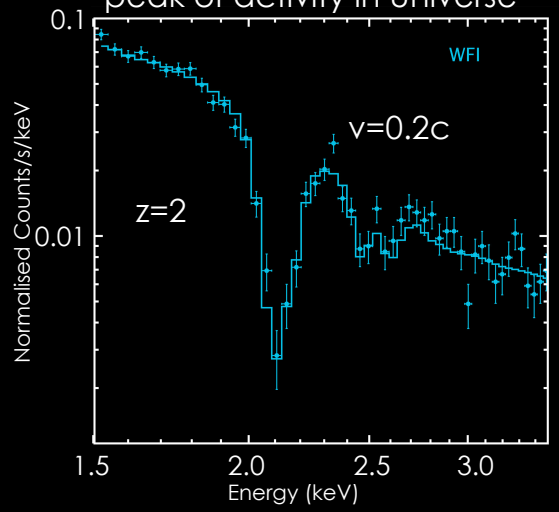
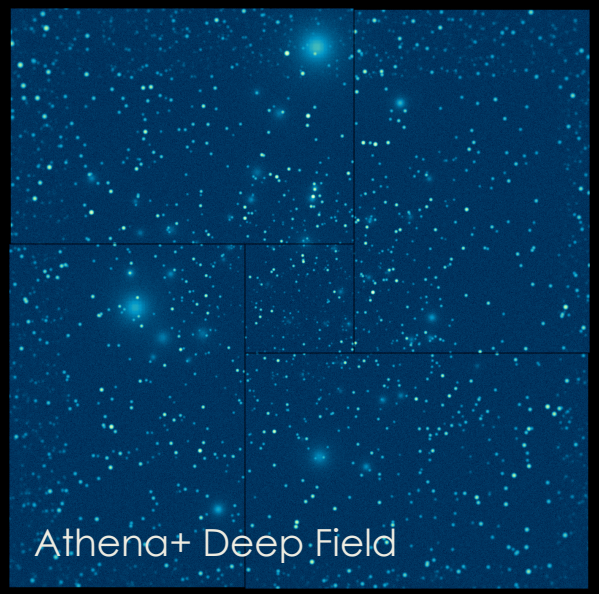
Athena+
The first Deep Universe X-ray Observatory

High redshift galaxy group



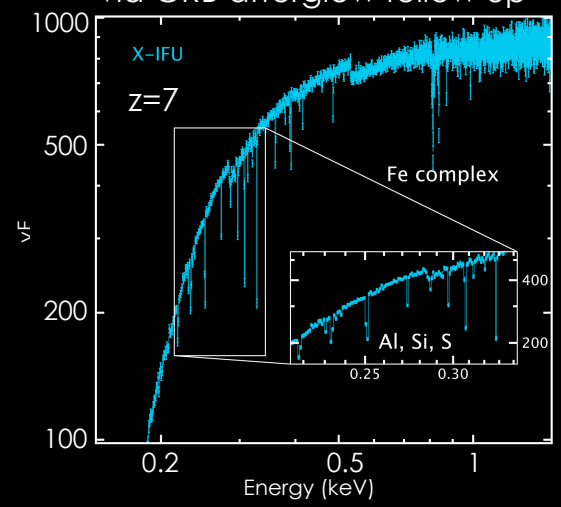
Black hole feedback at peak of activity in Universe



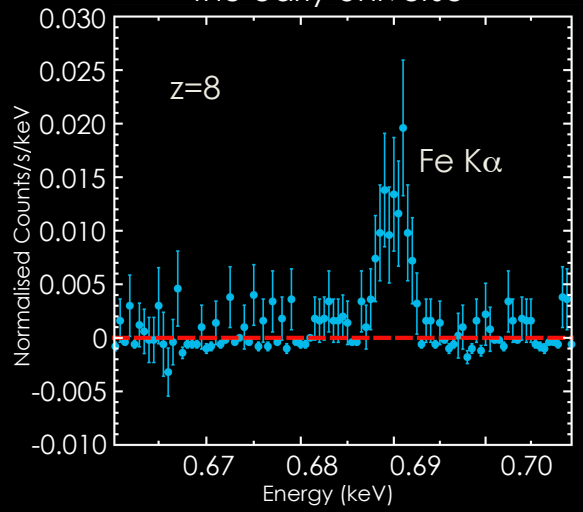


Nandra, Barret, Barcons, Fabian, den Herder, Piro, Watson et al. 2013 arXiv 1306.2307

Primordial stellar populations via GRB afterglow follow up



Obscured black hole in the early Universe



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ADDITIONAL SLIDES

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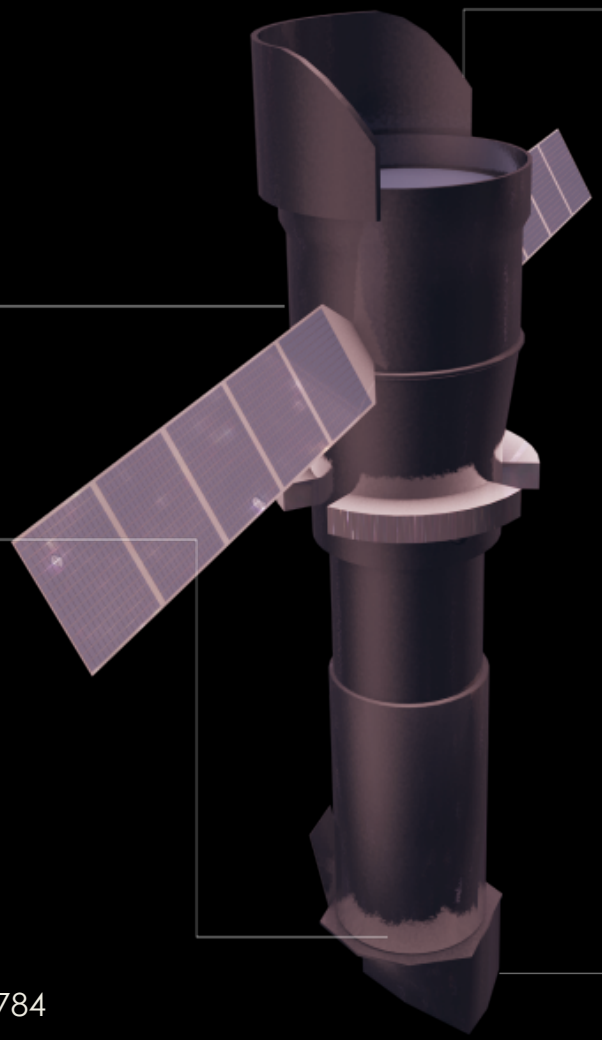
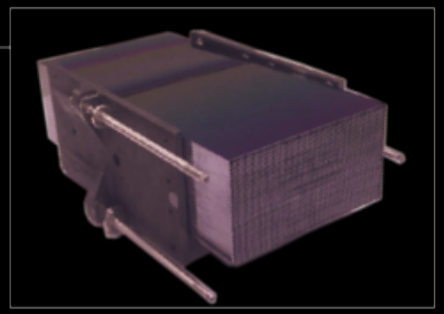
The Athena+ Observatory

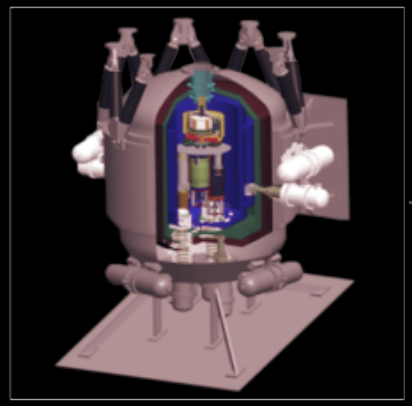
Willingale et al, 2013
arXiv1308.6785

L2 orbit Ariane V
Mass < 5100 kg
Power 2500 W
5 year mission



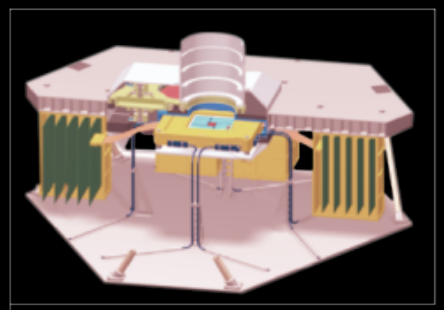


Silicon Pore Optics:
2 m^2 at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



X-ray Integral Field Unit:
ΔE: 2.5 eV
Field of View: 5 arcmin
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

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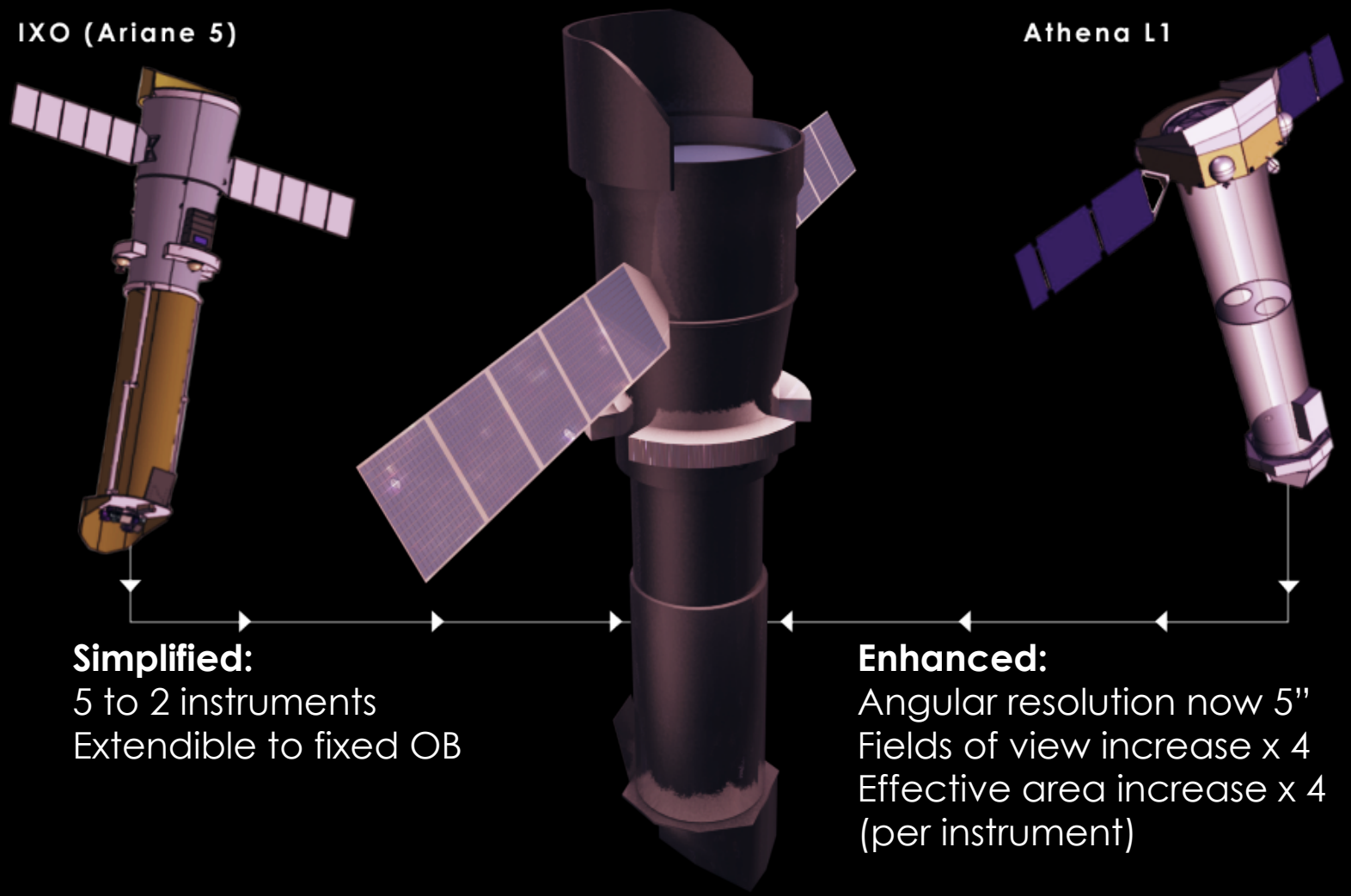
Technical Maturity



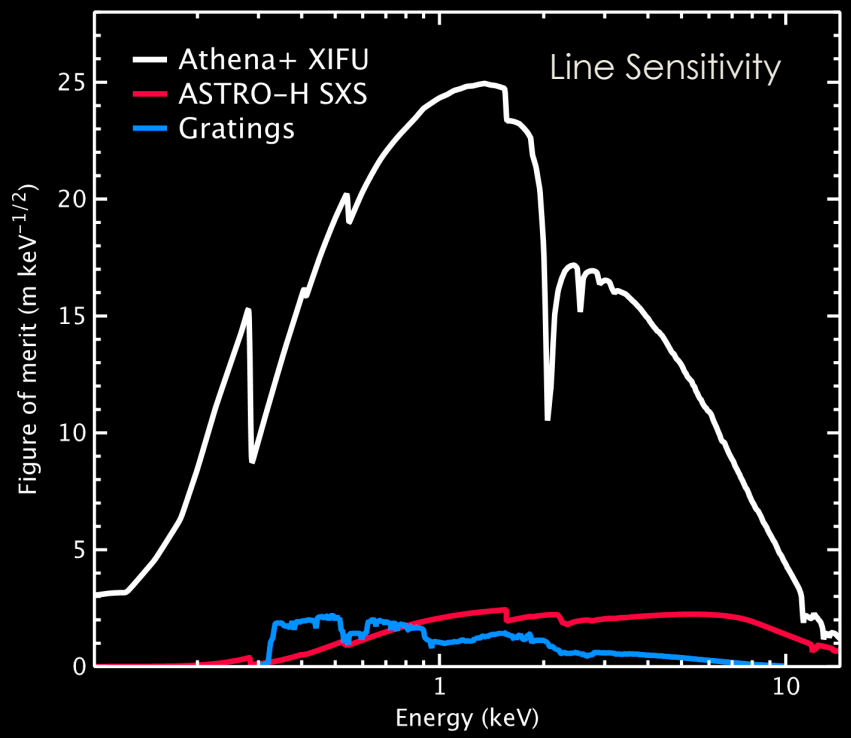
Simplified:
5 to 2 instruments
Extendible to fixed OB

Enhanced:
Angular resolution now 5"
Fields of view increase x 4
Effective area increase x 4
(per instrument)

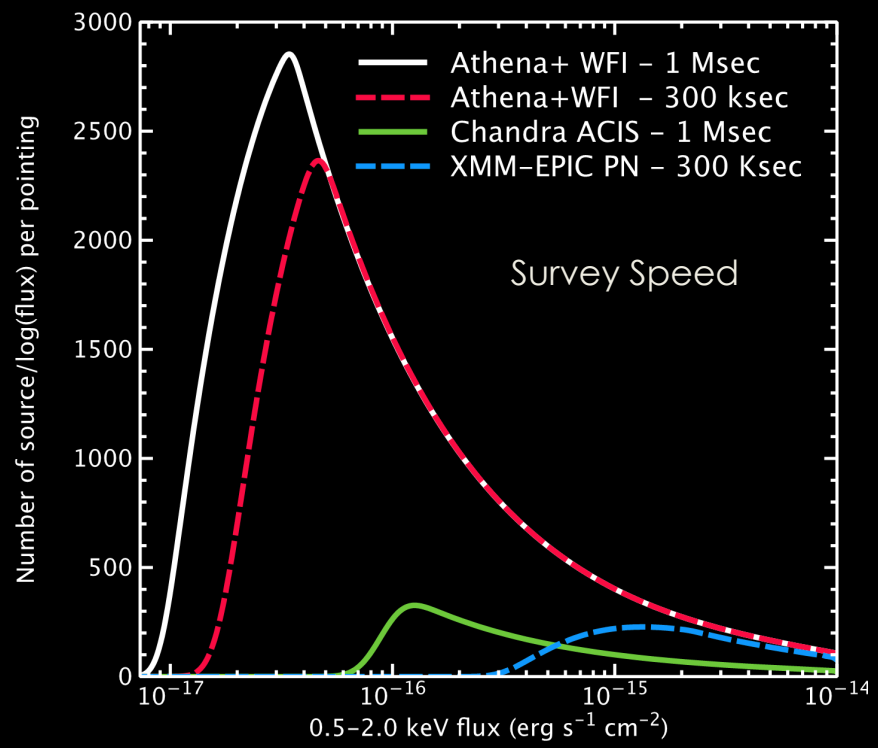
ATHENA+

The first 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

Athena+: a powerful observatory

Planets

(interaction of solar wind with planet environment and comets)

Exoplanets

Stellar physics

Supernovae

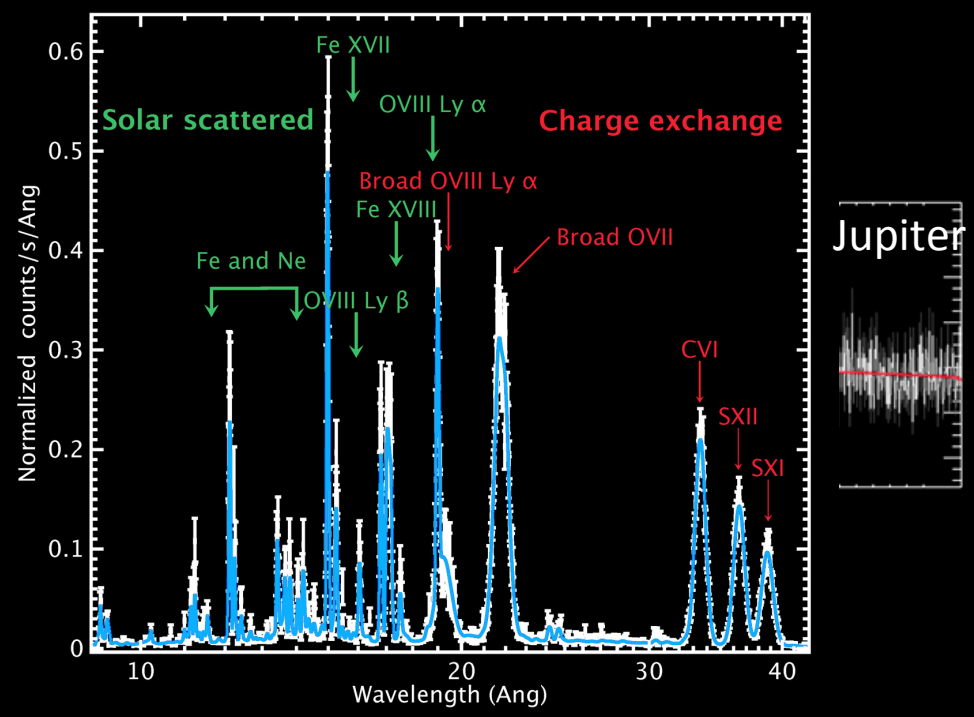
(explosion mechanism, heavy element production)

Stellar endpoints

(physics of outflows and winds in X-ray binaries)

Sgr A*

Interstellar dust and medium



Branduardi-Raymont, Sciortino, et al., 2013 arXiv 1306.2332; Sciortino, Rauw et al., 2013 arXiv1306.2333; Motch, Wilms, et al., 2013 arXiv1306.2334; Decourchelle, Costantini et al., 2013 arXiv1306.2335

Athena+ science in context

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

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Acknowledgements

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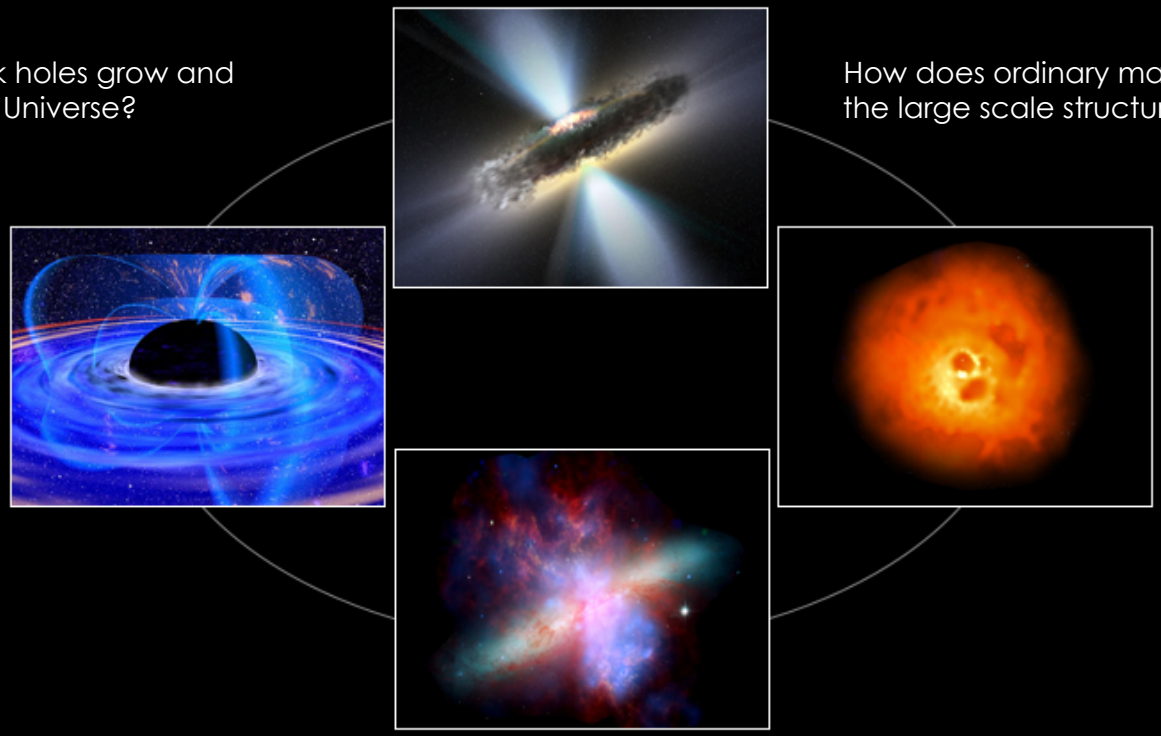

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