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Exploring the hot and energetic Universe with ESA's Athena mission

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ATHENA+

Instituto de Física de Cantabria (CSIC-UC)

Santander

Joint research institute CSIC- U Cantabria

Basic research & instrument development

100 people

Research lines:

•Cosmology

•Galaxies and AGN

•Particle Physics

•Complex Systems

•Meteorology & Climate change

•Computing & e-Science

IFCA – Galaxies and AGN

Permanent staff:

A Alonso-Herrero, X. Barcons, F.J. Carrera, M.T. Ceballos, A. Fernández-Soto, J.I. González-Serrano

Postdocs: A. Hernán, S. Mateos, A. Ruiz

Engineers: B. Cobo

PhD Students: A. Kahn-Ali. I. Ordovás, J. García

Galaxy & AGN co-evolution

AGN structure, torus, evolution

Radiogalaxies

X-ray/optical/IR extragalactic surveys

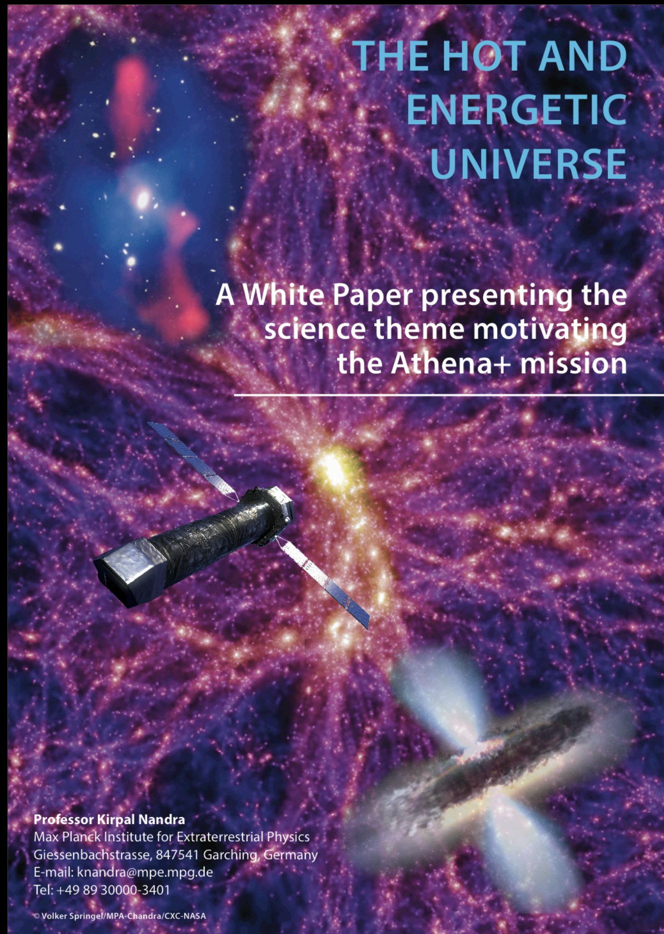
SW for X-ray & optical instruments

Projects/missions:

- XMM-Newton
- GTC/Osiris
- JWST/MIRI
- XEUS/IXO/Athena & X-IFU

The Hot and Energetic Universe

- **The Hot Universe:** How does the ordinary matter assemble into the large-scale structures that we see today?
  - >50% of the baryons today are in a hot (>10^6 K) phase
  - there are as many hot (> 10^7 K) baryons in clusters as in stars over the entire Universe
- **The Energetic Universe:** How do black holes grow and influence the Universe?
  - Building a SMBH releases 30 × the binding energy of a galaxy
  - 15% of the energy output in the Universe is in X-rays



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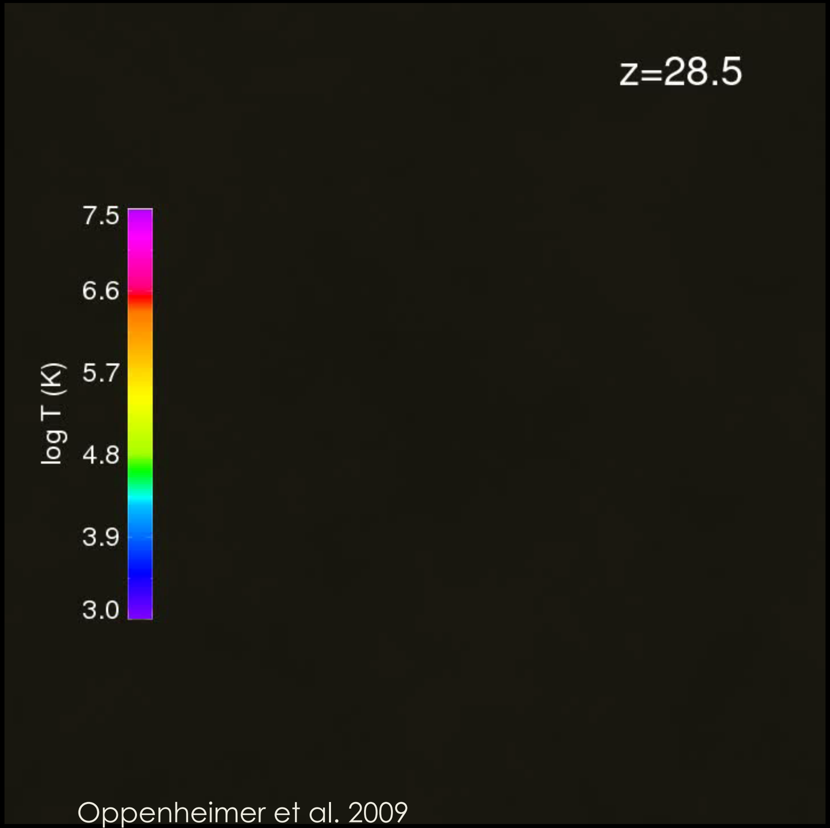
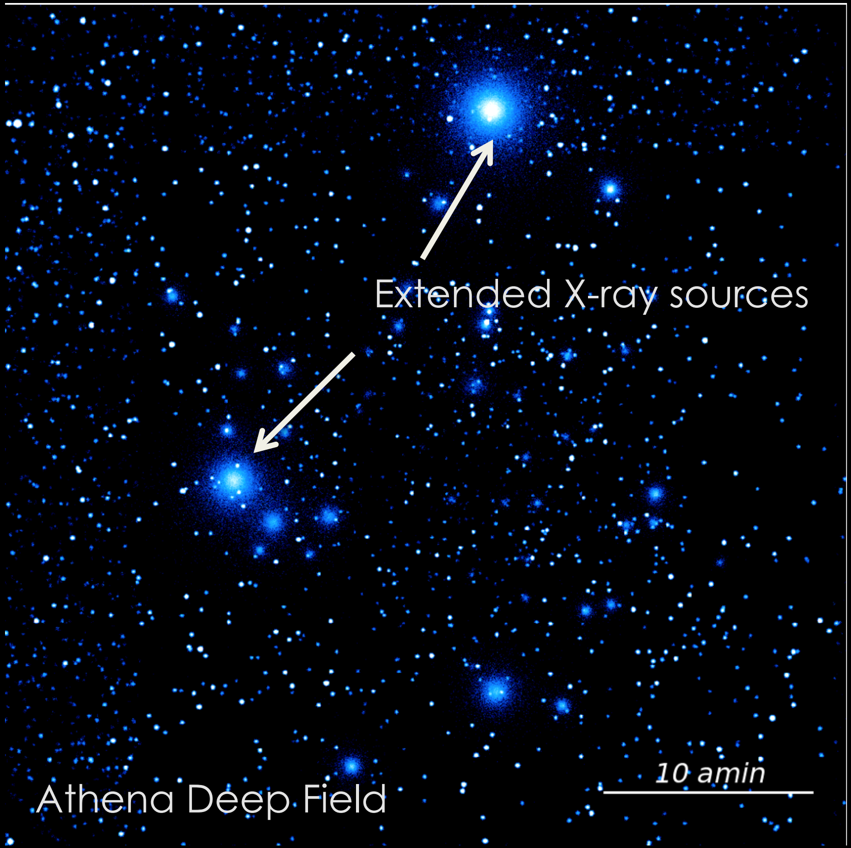
How does ordinary matter assemble into the large scale structures we see today?

See G.W. Pratt's presentation on intracluster medium





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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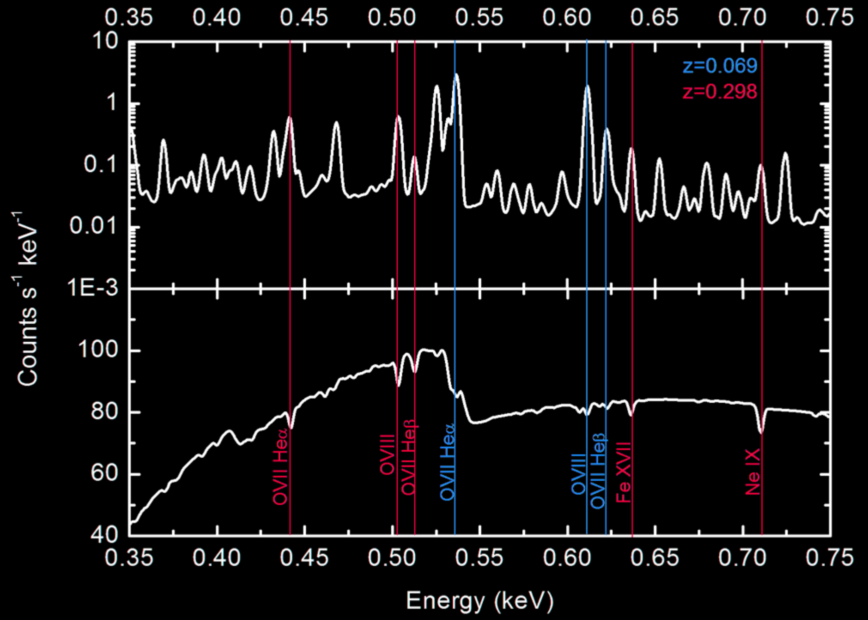
The Warm-Hot intergalactic medium (WHIM)

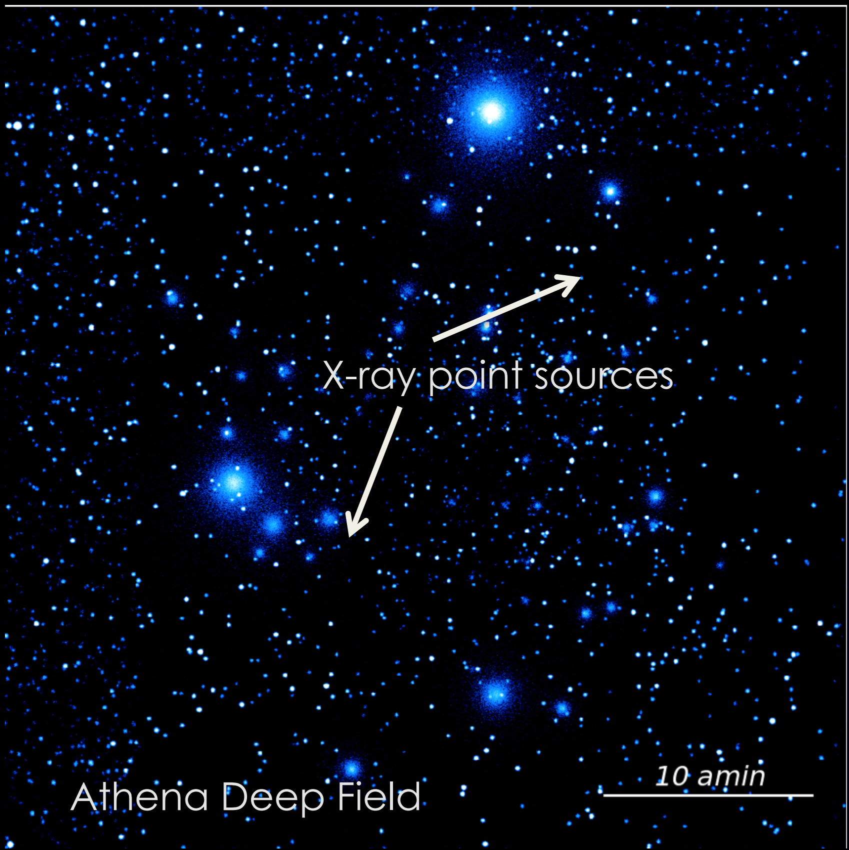
Where are the missing baryons in the local Universe? What is the underlying mechanism determining the distribution of the hot phase of the cosmic web?



Kaastra, Finoguenov et al., 2013 arXiv1306.2324

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

How do black holes grow and shape the Universe?



See next talk by Silvia Mateos

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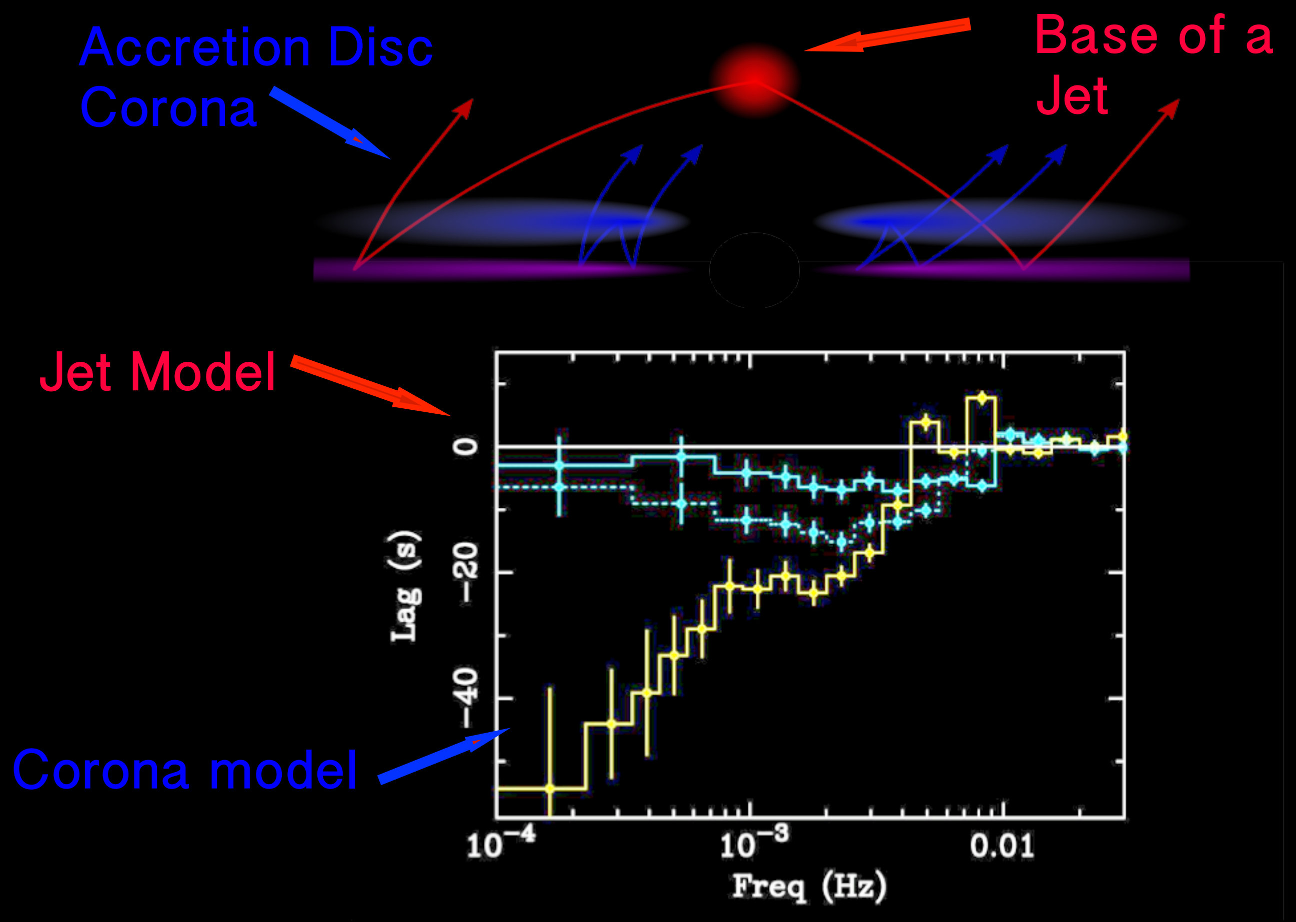
Mapping black holes near the event horizon

How does matter flow onto black holes?



How do black holes grow and shape the Universe?

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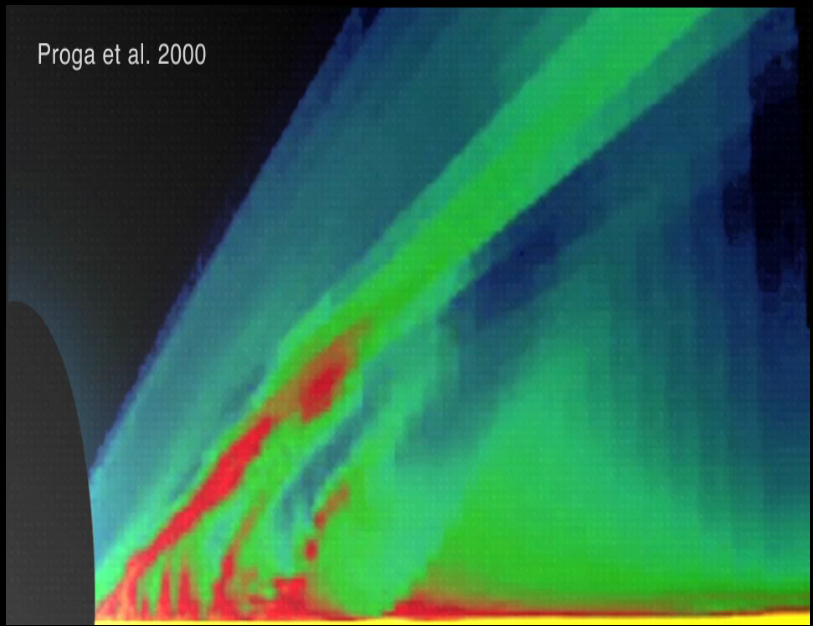
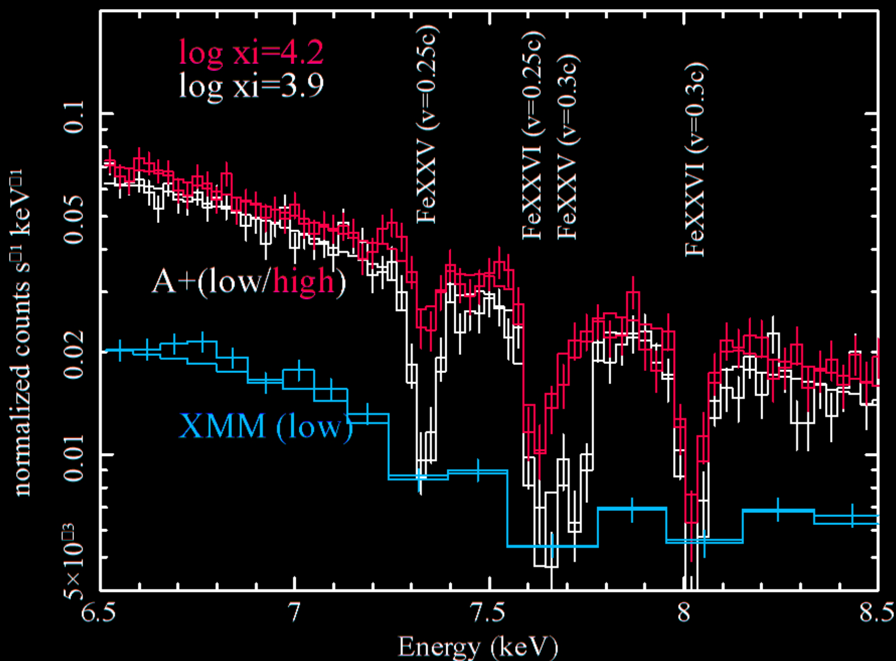
Cosmic feedback: the origin of black hole winds

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

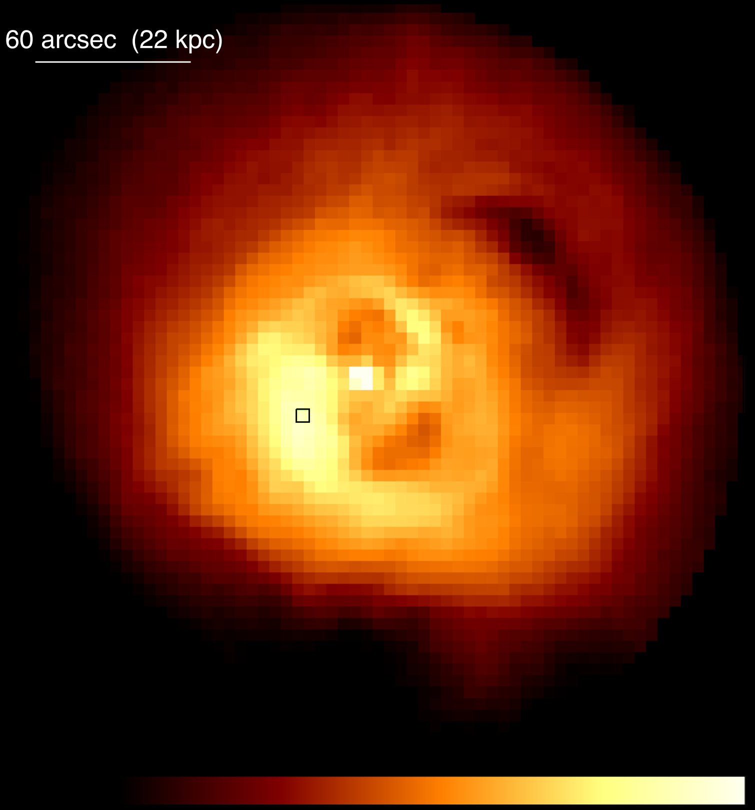


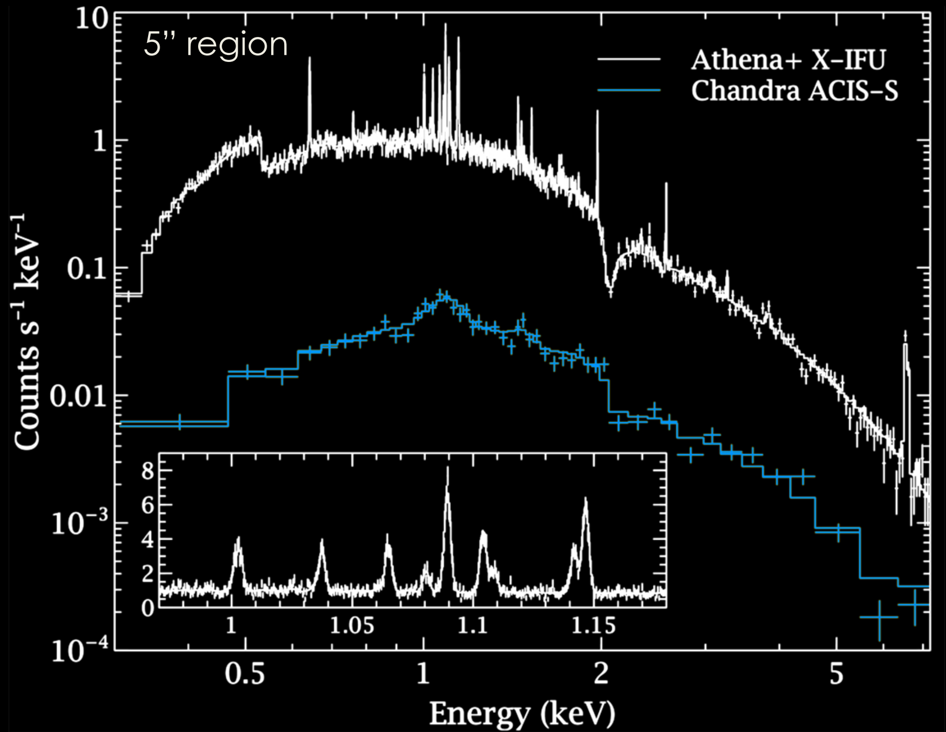


Cappi, Done et al., 2013 arXiv1306.2330
Dovciak, Matt et al., 2013 arXiv1306.2331

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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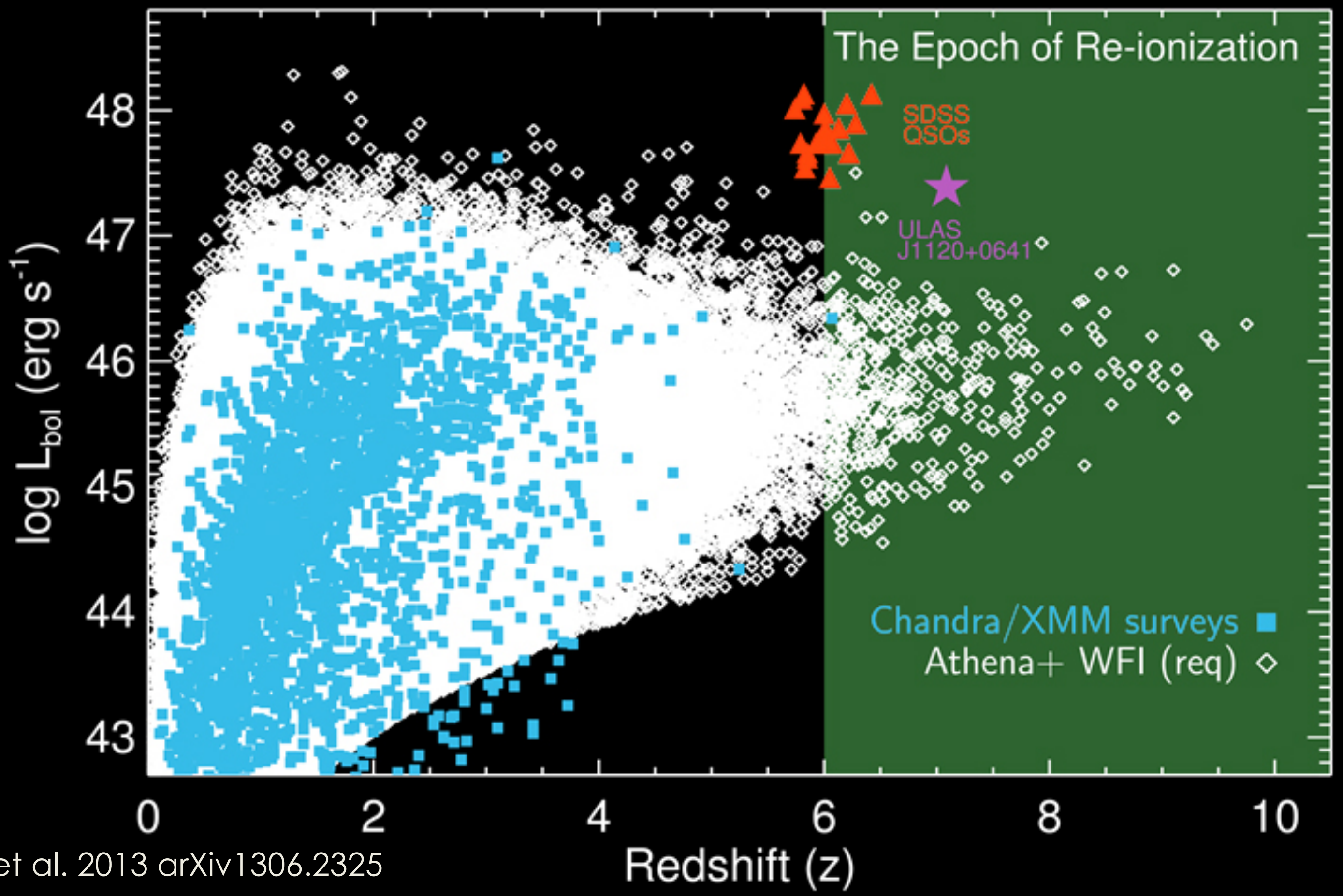
Black hole growth in the early Universe

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



Aird, Comastri et al. 2013 arXiv1306.2325

Cosmic feedback: black hole and galaxy co-evolution

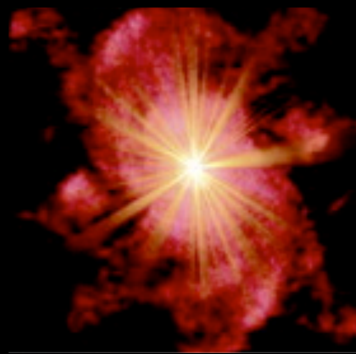
How much black hole accretion occurs in the most obscured environments?
How does this relate to the evolution of the host galaxy?

Disk instability

Ceverino et al. 2010

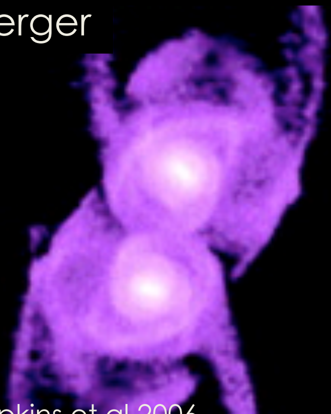
Obscured BH growth

Feedback phase

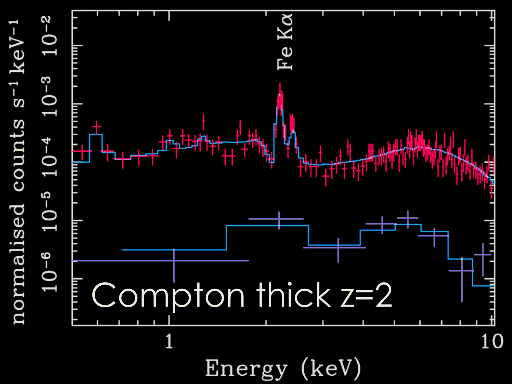


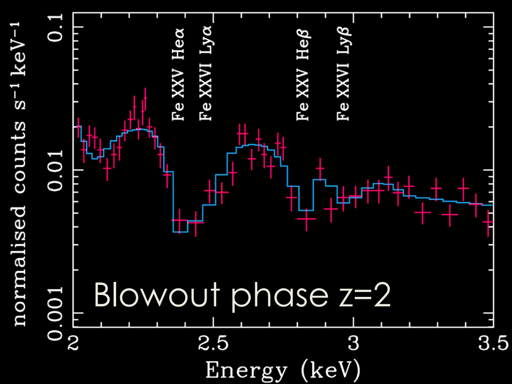
Quiescent remnant

Merger



Hopkins et al.2006

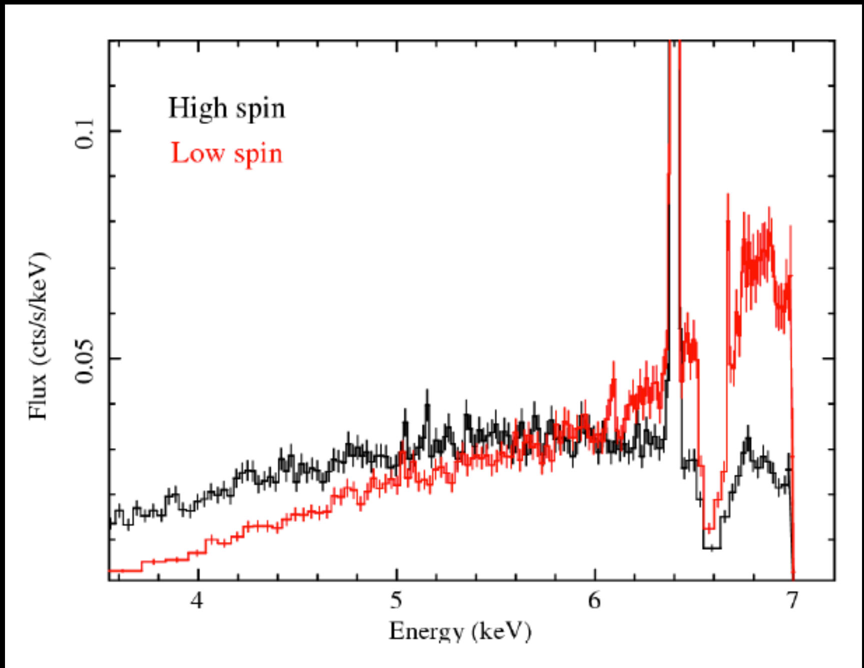


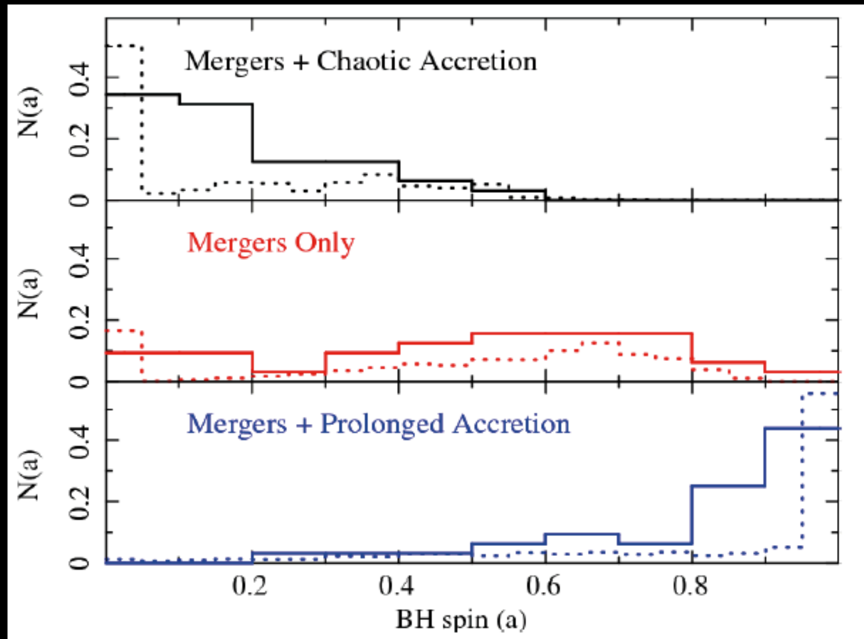


Georgakakis, Carrera et al., 2013 arXiv1306.2328

SMBH growth: mergers or accretion?

Mergers and chaotic accretion spin down SMBB, while smooth accretion spins them up





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Fast reaction to transient sources: GRBs and other

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The Athena Science Requirements

Parameter	value	enables (driving science goals)
Effective area at 1 keV	2 m^2	Early groups, cluster entropy and metal evolution, WHIM, high redshift AGN, census AGN, first generation of stars
Effective area at 6 keV	0.25 m^2	Cluster energetics (gas bulk motions and turbulence), AGN winds & outflows, SMBH & GBH spins
PSF HEW (< 8 keV)	5'' on axis, 10'' off axis	High z AGN, census of AGN, early groups, AGN feedback on cluster scales
X-IFU spectral resolution	2.5 eV	WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4
X-IFU FoV	5' radius	Metal production & dispersal, cluster energetics, WHIM
X-IFU background	< 5 10^{-3} counts/s/cm^2/keV (75%)	Cluster energetics & AGN feedback on cluster scales, metal production & dispersal
WFI spectral resolution	150 eV	GBH spin, reverberation mapping
WFI FoV	40' x 40'	High-z AGN, census AGN, early groups, cluster entropy evolution, jet-induced cluster ripples
WFI count rate	80% at 1 Crab	GBH spin, reverberation mapping, accretion physics
WFI background	< 5 10^{-3} counts/s/cm^2/keV (75%)	Cluster entropy, cluster feedback, census AGN at z~1-4
Recons. astrometric error	1'' (3s)	High z AGNs
GRB trigger efficiency	40%	WHIM
ToO reaction time	< 4 hours	WHIM, first generation of stars

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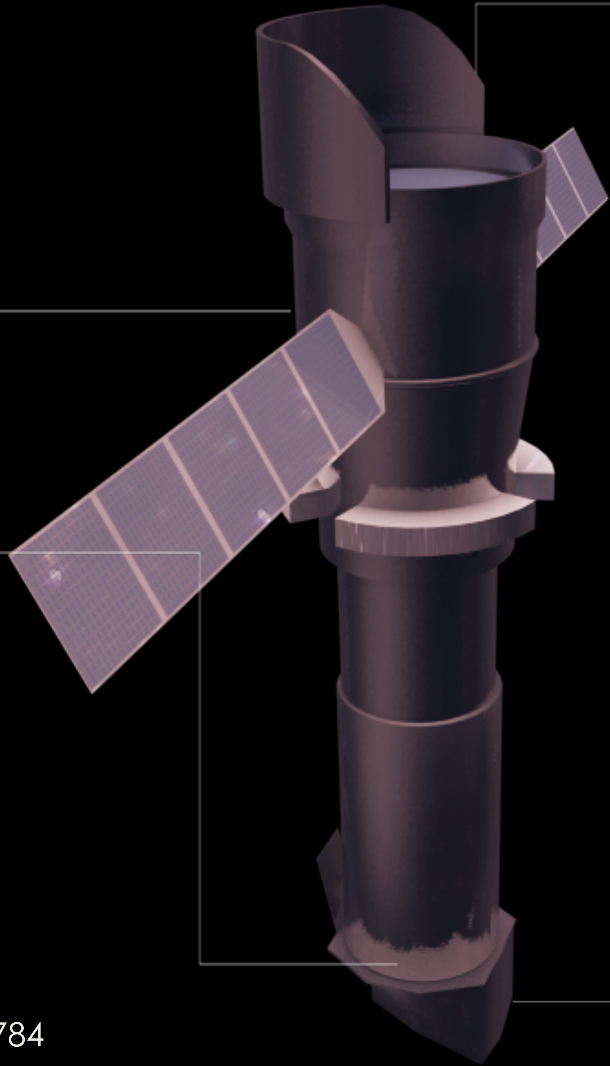
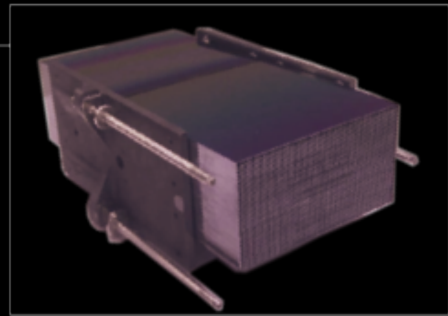
The Athena Observatory

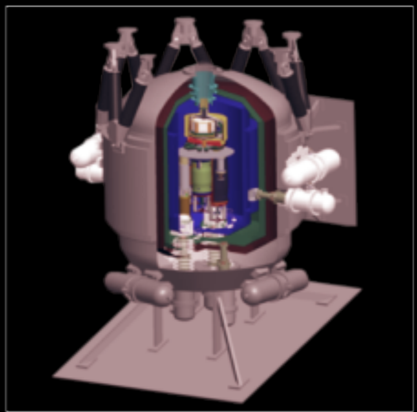
Willingale et al, 2013
arXiv1308.6785

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



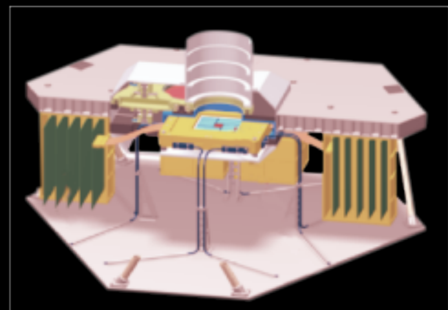


Silicon Pore Optics:
$2\ m^2$ at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: $3\ 10^{-17}$ erg $cm^{-2}\ s^{-1}$



X-ray Integral Field Unit (X-IFU):
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk

Barret et al., 2013 arXiv:1308.6784



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

Rau et al. 2013 arXiv1307.1709

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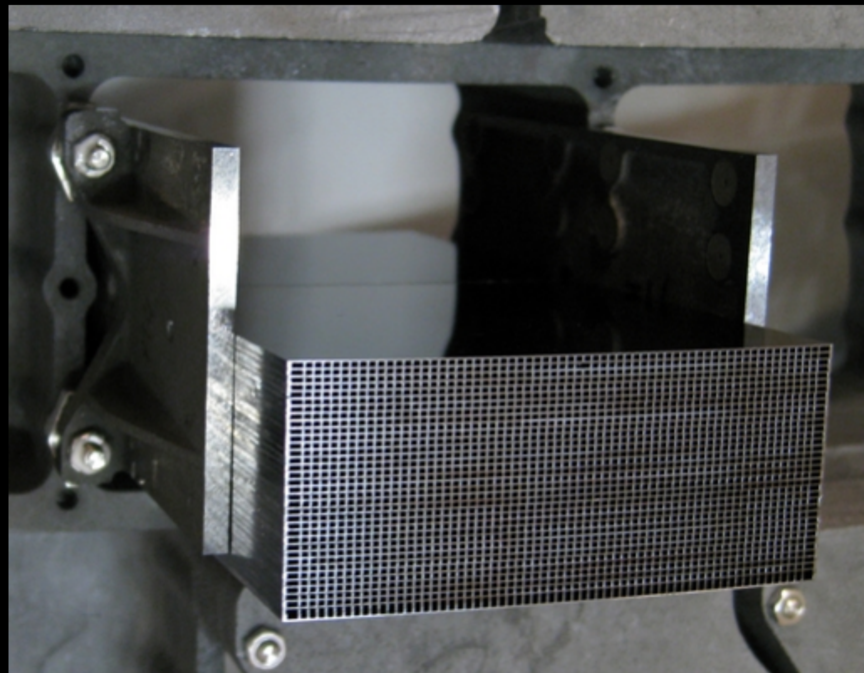
The Athena optics

Development of light-weight optics for X-ray astronomy

Grazing incidence optics, Wolter-I type (paraboloid-hyperboloid), largely with conical approximation

Substrate for reflecting surface is based on “commercial” Si wafers, but with small pores and short reflecting layers

Vigorous development programme at ESA and industry. Demonstration modules produced (TRL~4)



Willingale et al 2013 arXiv1308.6785

The Athena Wide Field Imager (WFI)

The most sensitive images of the X-ray Universe

PI: K. Nandra (MPE)

Based on Si detectors, using Active Pixel Sensors based on DEPFETs.

Key performances;:

•120-150 eV spectral resolution,

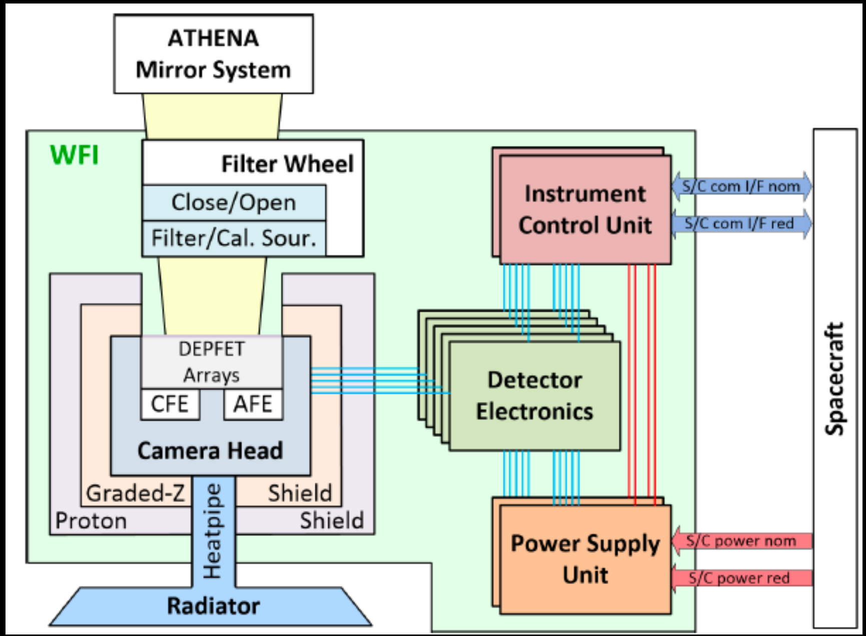
•3" pixel size (PSF oversample)

•Field of view: 40'x40'

•Readout speed up to ~30 MHz

European consortium led by MPE

Optimized for sensitive and wide imaging and intermediate resolution spectroscopy, up to very bright sources



Rau et al 2013, **arXiv1308.6785**

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The Athena X-ray Integral Field Unit (X-IFU)

the 3D view of the Hot and Energetic Universe

PI: D. Barret (CNRS/IRAP). co-Pis: J.W. den Herder (SRON), L. Piro (INAF).

Science Team Chair: X. Barcons

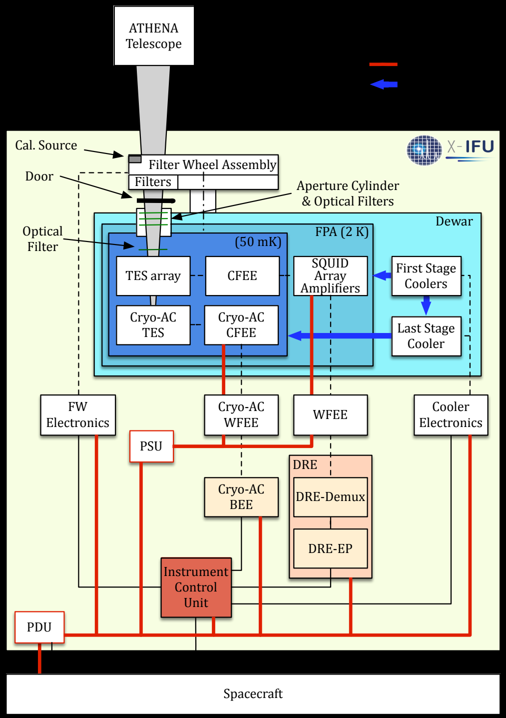
Cryogenic imaging spectrometer, based on Transition Edge Sensors, operated at 50 mK featuring an active cryogenic background rejection subsystem

European consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other partners

Spectral resolution 2.5 eV, FoV 5' diameter

Will be able to:

- Measure cluster gas bulk velocities and turbulence down to 20 km/s
- Detect weak unresolved lines from WHIM filaments (3mÅ), GRB afterglows, etc.
- Use emission lines (eg OVII triplet) to perform plasma diagnostics in a variety of astrophysical environments



Barret et al 2013

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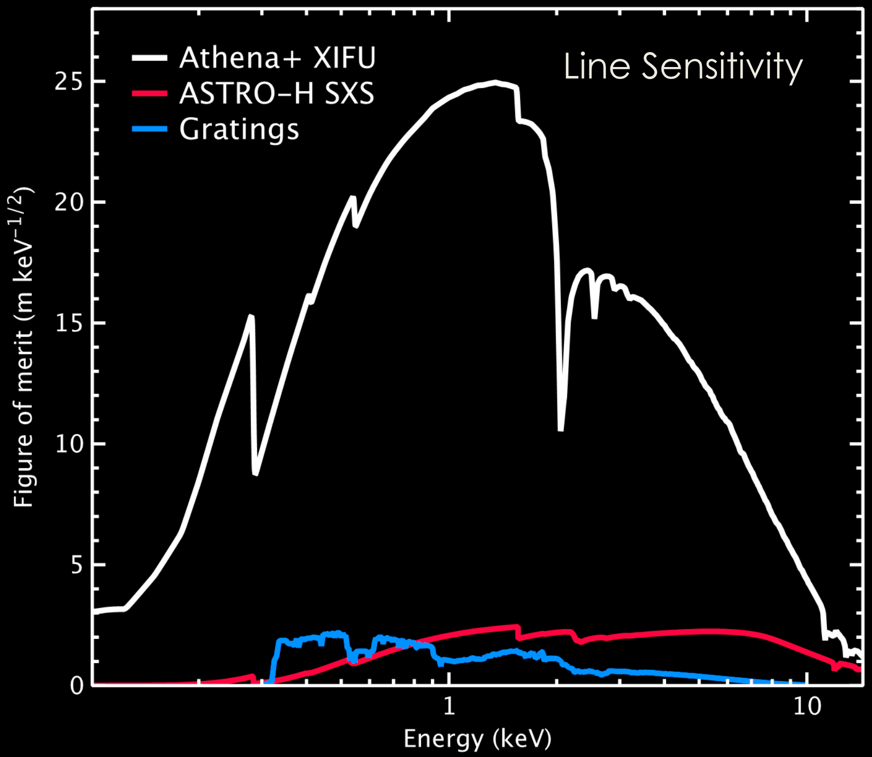
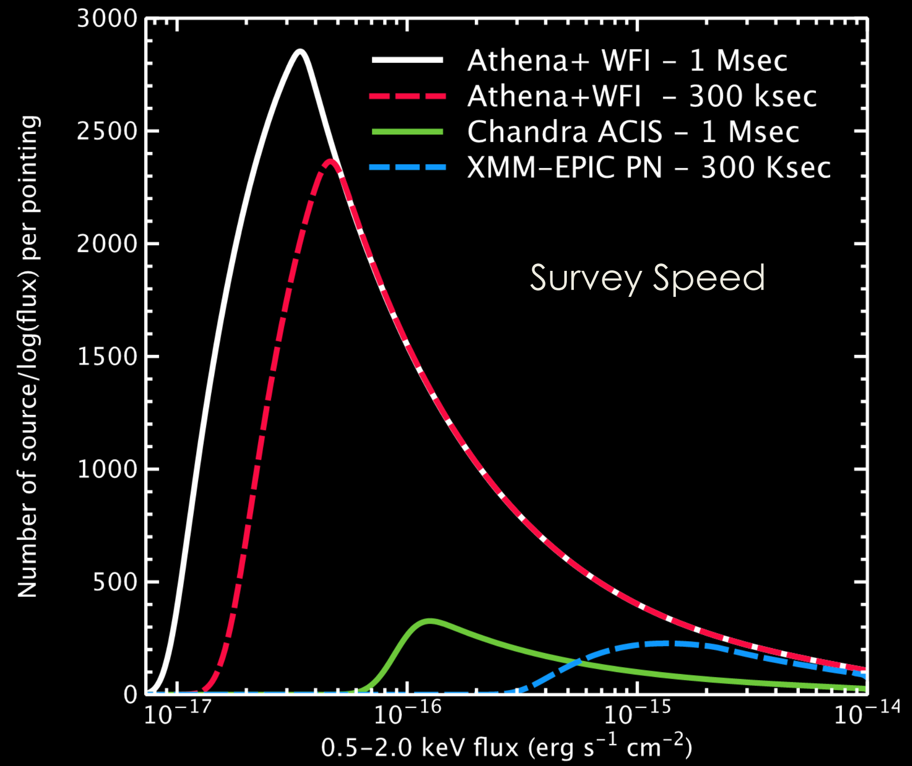
A Deep Universe X-ray Observatory

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

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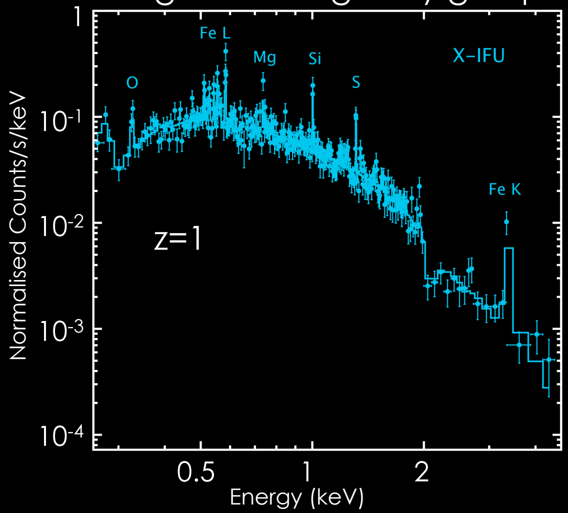
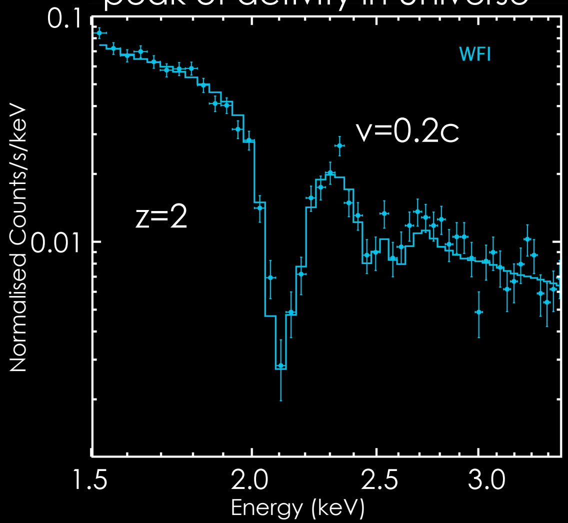
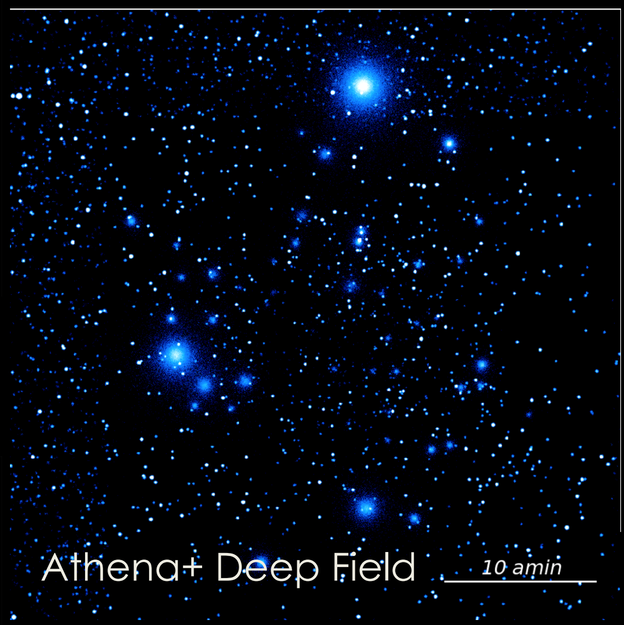
Athena:
Exploring the Hot and Energetic Universe

High redshift galaxy group



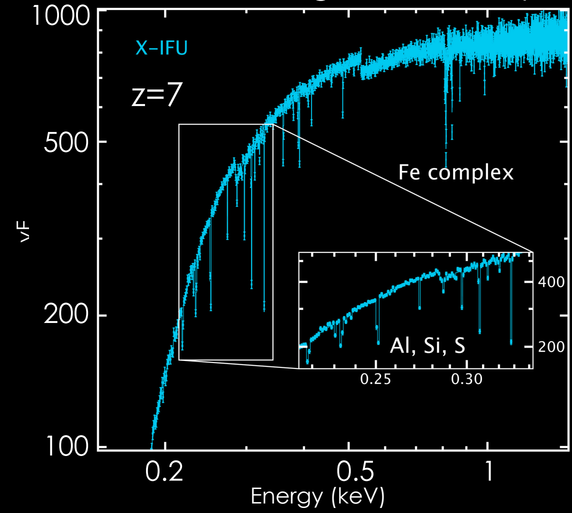
Black hole feedback at
peak of activity in Universe



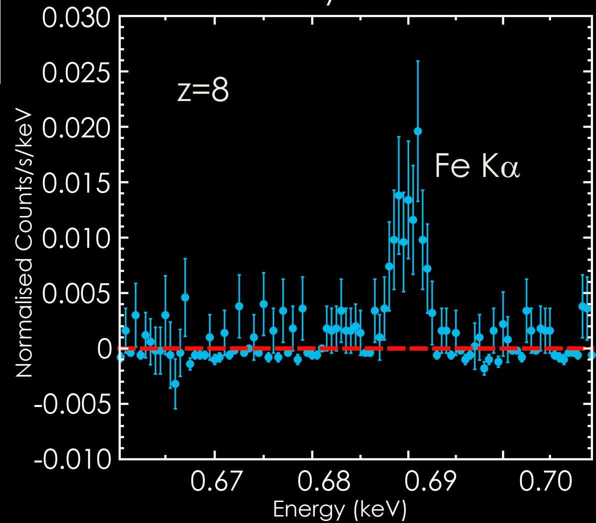


Nandra, Barret, Barcons, Fabian,
den Herder, Piro, Watson et al.
2013 arXiv 1306.2307

Primordial stellar populations
via GRB afterglow follow up



Obscured black hole in
the early Universe



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Athena mission: Where do we stand?

•ESA SPC selected the Hot and Energetic Universe as the theme for L2 in Nov 2013

•ESA SPC selected the Athena mission in June 2014:

Design to cost 1 Bn€ + affordable payload + international partners (20%)

•An Athena Science Study Team was appointed by ESA in July 2014: Lumb (Chair), Nandra (Lead & WFI), Barcons, Barret (X-IFU), Decourchelle, den Herder, Fabian, Matsumoto (JAXA), Piro, Smith (NASA), Willingale.

•Phase 0 executed from August to December 2014, including CDF study

CDF study showed Athena to be feasible

Programmatically would need significant international contribution

A mission with an X-ray telescope fitting within a standard A5 adaptor would fit well within programmatic cost boundaries (but ~30% reduction in eff area)

•Phase A (ITT in preparation)

KO in July 2015

Phase A1 (~1 year) will study in full 2 missions: as proposed and CDF

Mission baseline selection (MCR) in May 2016

Phase A2 will consolidate concept

•SRR (end of Phase B1) by Q3 2019

•Mission adoption by ESA SPC expected by Feb 2020

•Launch in 2028

Athena in context in the ~2030 European landscape

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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The last one

Athena is a major European enterprise: a large X-ray observatory in the late 2020s.

Main science driver is to understand how massive black holes shape the Universe, from their immediate environment to galaxies and clusters.

But its transformational capabilities will reach all corners of Astronomy, from Solar System to Cosmology.

Both CSIC and CNRS have a very active role in Athena. Opportunities for further collaboration do indeed exist.

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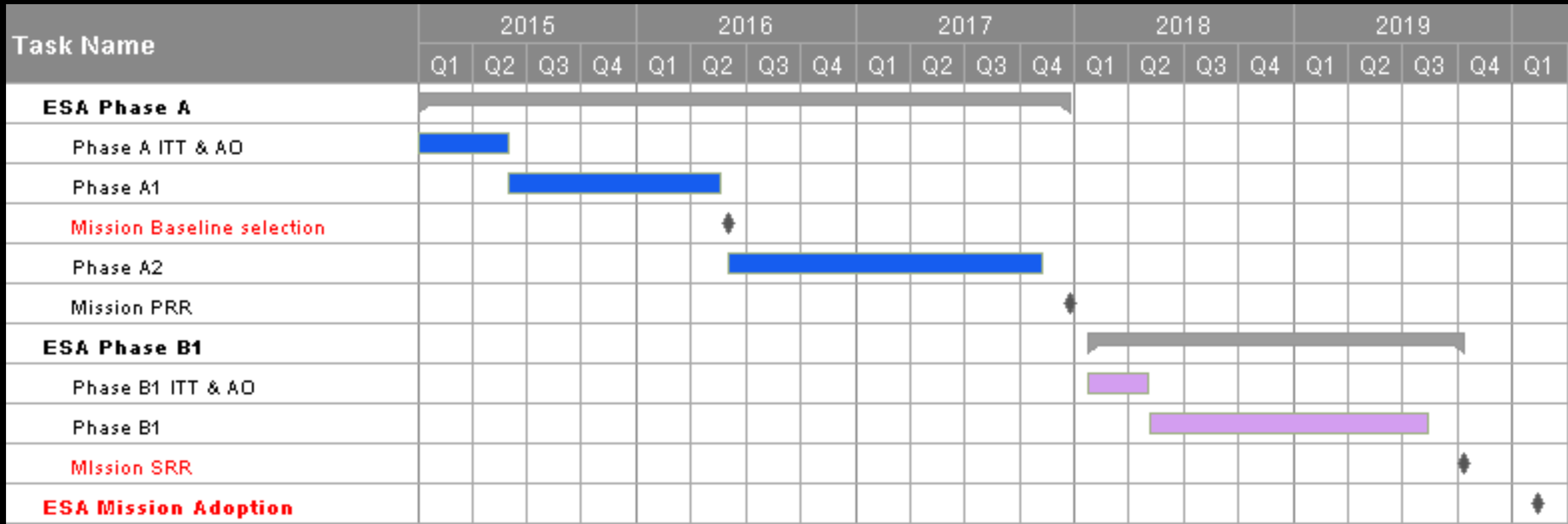
Athena mission schedule



- AO for science instruments: July 2016; Selection: Nov 2016
- Phase A: 2015-2017
- Phase B1: 2017-2019
- SPC adoption: Feb 2020
- Phase B2/C/D Kick-Off: Nov 2020
- Launch 2028

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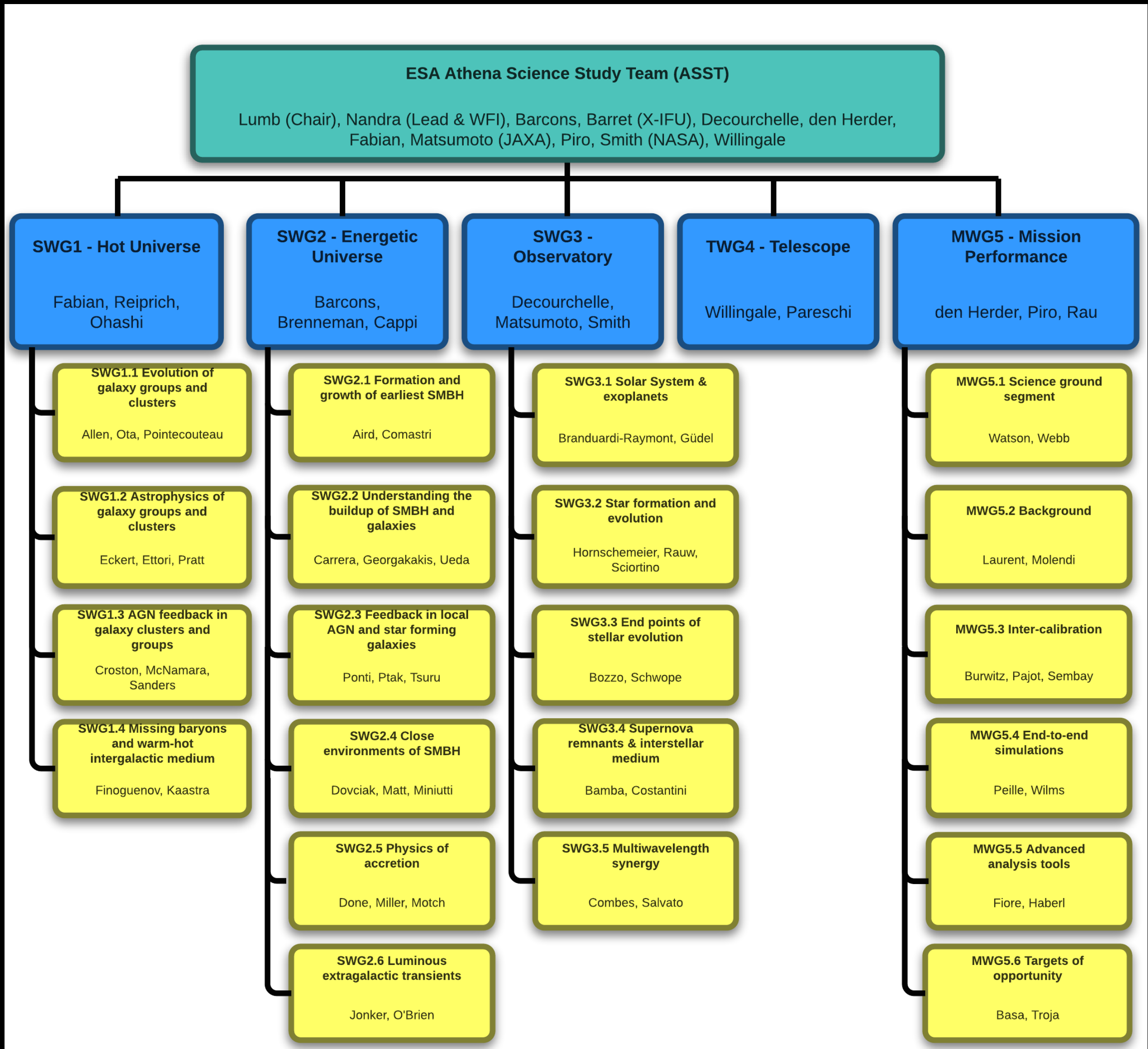
Athena community organisation



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Athena science conference
ESAC (Spain), 8-10 Sep 2015

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esa — Research Science Portal — European Space Agency

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Exploring the Hot and Energetic Universe: The first scientific conference dedicated to the Athena X-ray observatory

8-10 September 2015

ESA/ESAC

Madrid, Spain

Home | Organising Committee | Programme | Venue | Accommodation | Contact

Conference Venue

The conference will be held at the **European Space Astronomy Centre (ESAC)** located at Villafranca del Castillo, Madrid, Spain.

In order to get to ESAC, we recommend using the shuttle bus from the pre-booked hotel (see Accommodation). For independent travel by public transport, taxi, or car from Madrid airport or from the city centre to ESAC, see our descriptions How to get to ESAC or Visit ESAC.

Madrid

Acknowledgements

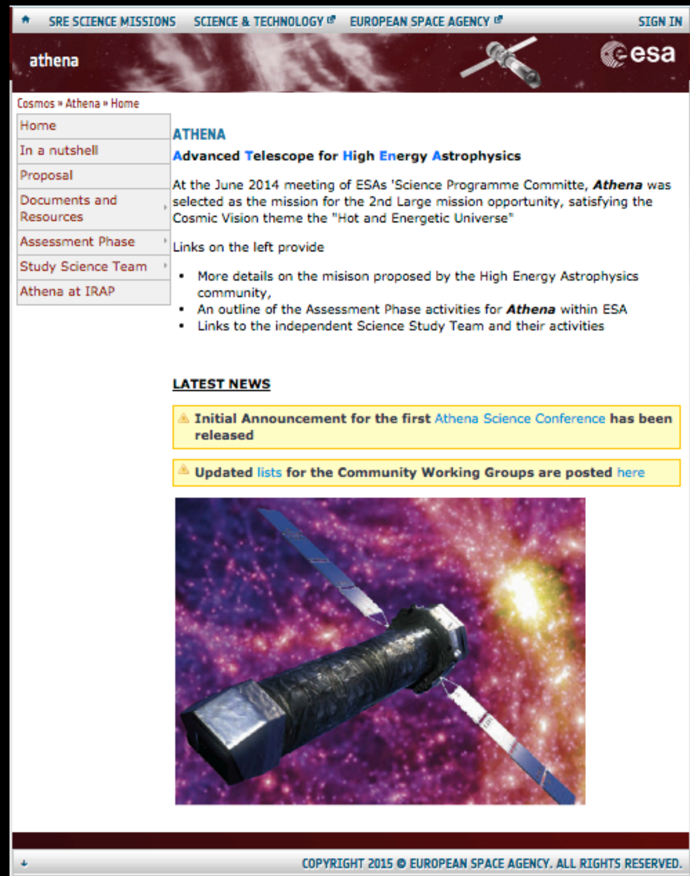
Athena Science Study Team:
D. Lumb (ESA), K. Nandra (DE), D. Barret (FR), X. Barcons (ES), A. Decourchelle (FR), J.-W. den Herder (NL), A.C. Fabian (UK), H. Matsumoto (JP), L. Piro (IT), R. Smith (USA), R. Willingale (UK)

Athena Working Groups & Topical Panels
(~50 chairs and ~600 members)

More information:

http://the-athena-x-ray-observatory.eu/

http://www.cosmos.esa.int/web/athena



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Backup slides

References

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The Hot and Energetic Universe: The evolution of galaxy groups and clusters, Pointecouteau, Reiprich, Adami, et al., 2013arXiv1306.2319P

The Hot and Energetic Universe: The astrophysics of galaxy groups and clusters, Ettori, Pratt, de Plaa, et al., 2013arXiv1306.2322

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The Hot and Energetic Universe: The missing baryons and the warm-hot intergalactic medium, Kaastra, Finoguenov, Nicastro, et al., 2013arXiv1306.2324

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The Hot and Energetic Universe: Understanding the build-up of supermassive black holes and galaxies at the heyday of the Universe, Georgakakis, Carrera, Lanzuisi, et al., 2013arXiv1306.2328

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The Hot and Energetic Universe: Luminous extragalactic transients, Jonker, O'Brien, Amati, et al., 2013arXiv1306.2336J

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Thank you!

www.the-athena-x-ray-observatory.eu

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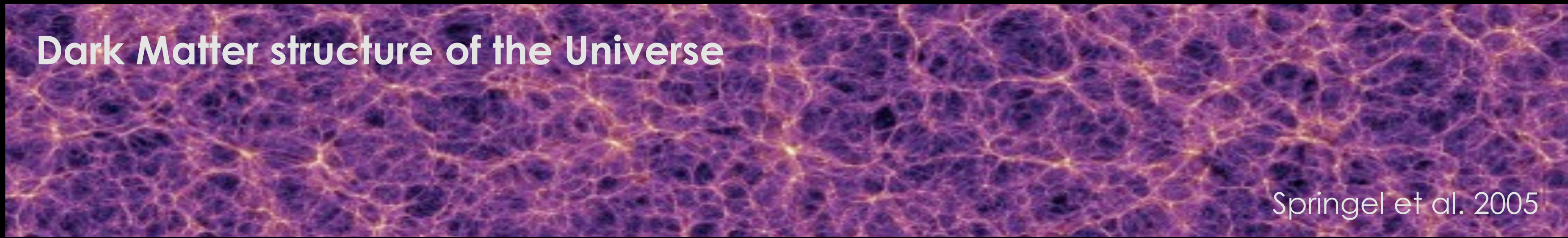
The Hot and Energetic Universe



Finding the earliest galaxy groups

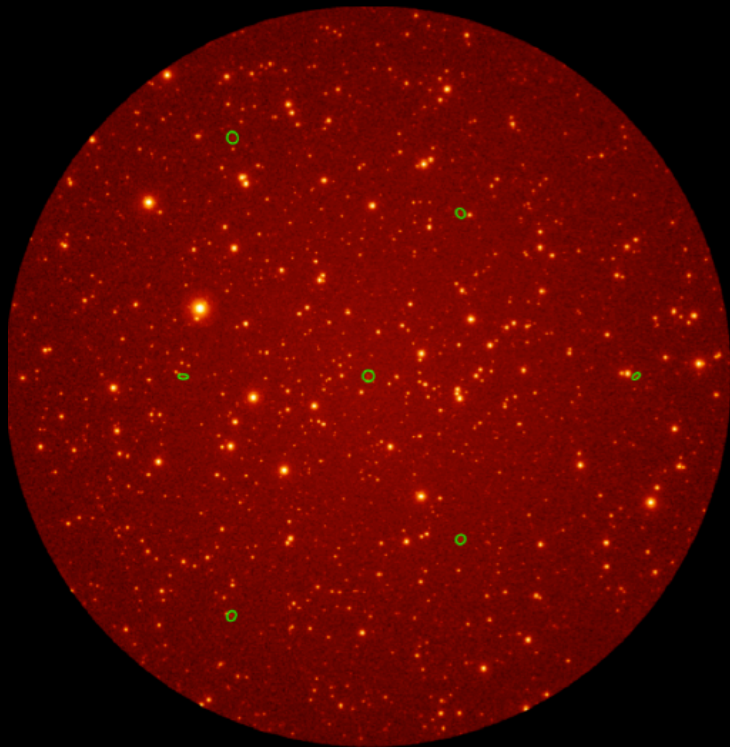
Testing astrophysical cosmology at the largest scales

As a way to constrain models of large-scale structure formation, find the first building blocks of the dark matter structure filled with hot gas.

Athena will be able to detect ~50 groups with mass $M_{500} > 5 \times 10^{13}\ M_{sun}$ at z>2 in 5 years of operation.

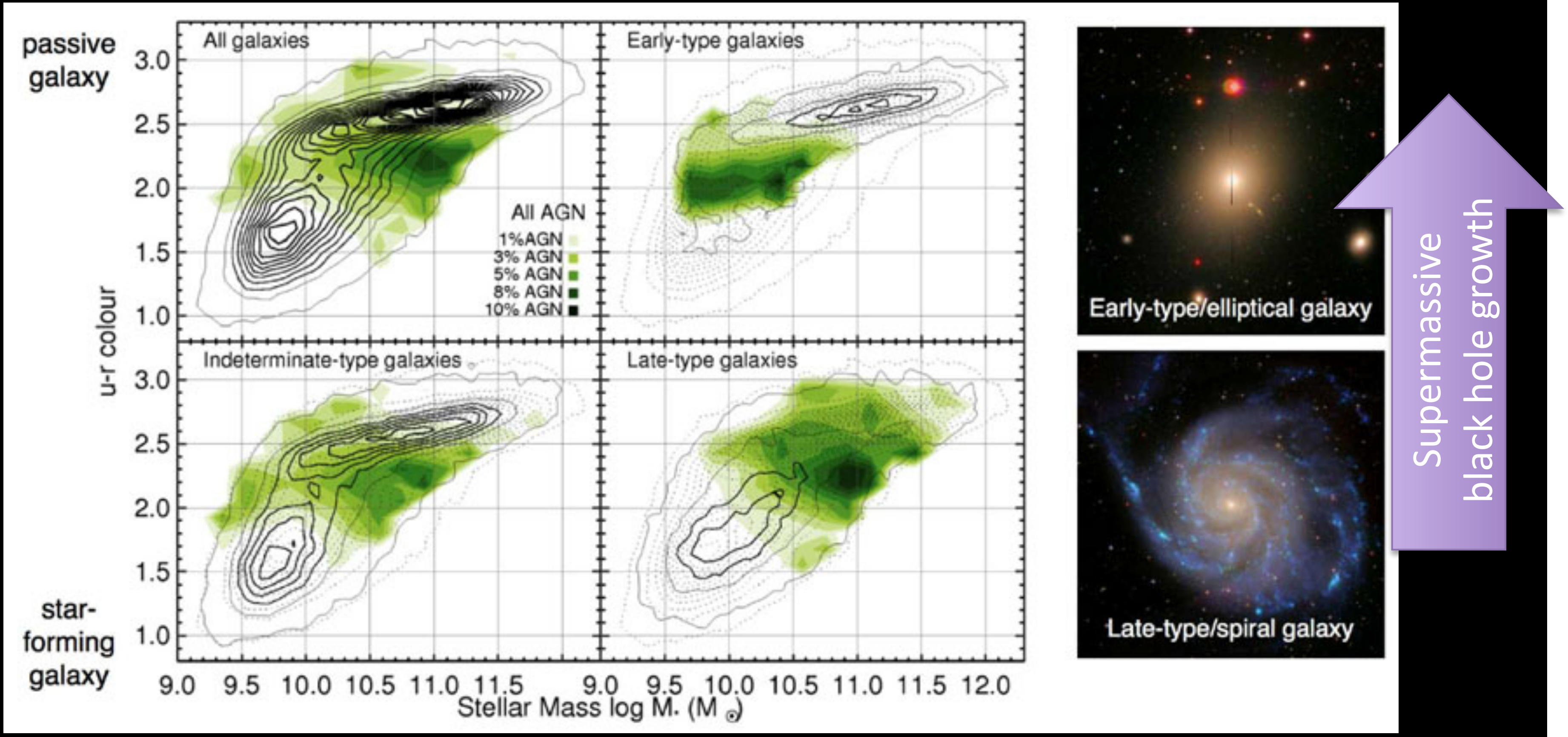
And measure T of ~50% of them

And at least 5 such groups at z>2.5



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

Galaxy downsizing
Why do massive galaxies stop forming stars?



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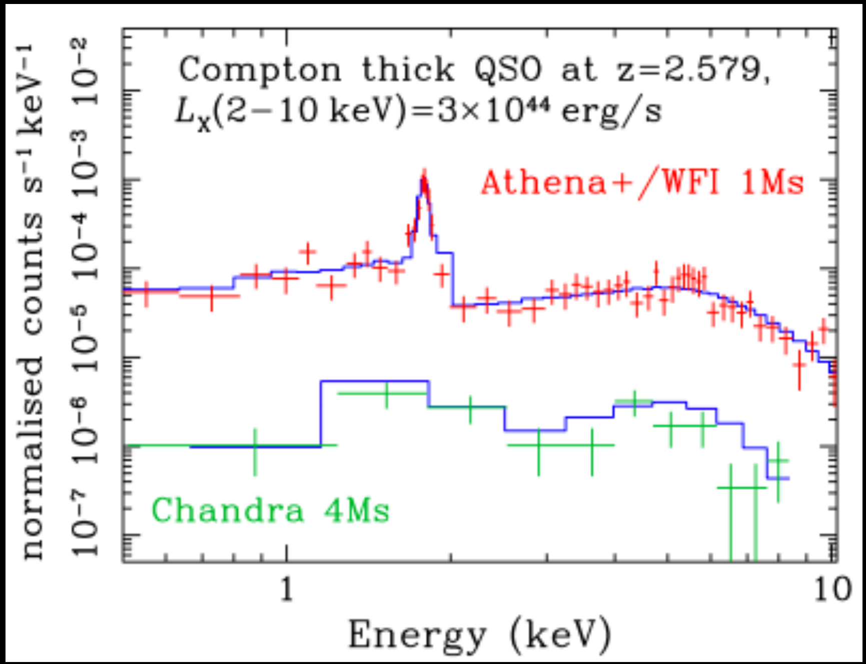
Obscured growth of SMBH through cosmic time

What is the relation between obscured growth of SMBH through cosmic history and how does it relate to galaxy formation?

Most of the star formation and SMBH growth occur at z~1-4. What is the relation between the two processes?

SMBH is expected to occur mostly in heavily obscured (even Compton-Thick) environments, totally inconspicuous to most wavelengths.

Only sensitive X-ray observations can provide an unbiased census of obscured accretion and link it to star formation, as evidenced at longer wavelengths.



ATHENA

The Athena X-ray Integral Field Unit (X-IFU)

the 3D view of the Hot and Energetic Universe

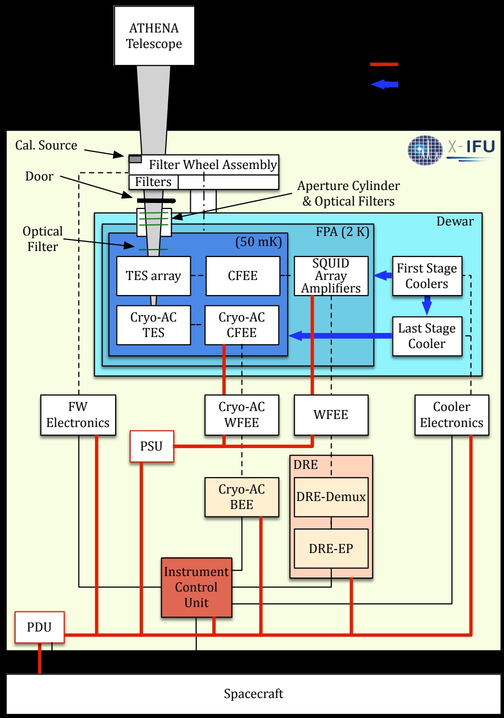
Cryogenic imaging spectrometer, based on Transition Edge Sensors, operated at 50 mK through a multi-stage cooling chain and featuring an active cryogenic background rejection subsystem

European consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other partners

Spectral resolution 2.5 eV, FoV 5' diameter

Will be able to:

- Measure cluster gas bulk velocities and turbulence down to 20 km/s
- Detect weak unresolved lines from WHIM filaments (3mÅ), GRB afterglows, etc.
- Use emission lines (eg OVII triplet) to perform plasma diagnostics in a variety of astrophysical environments



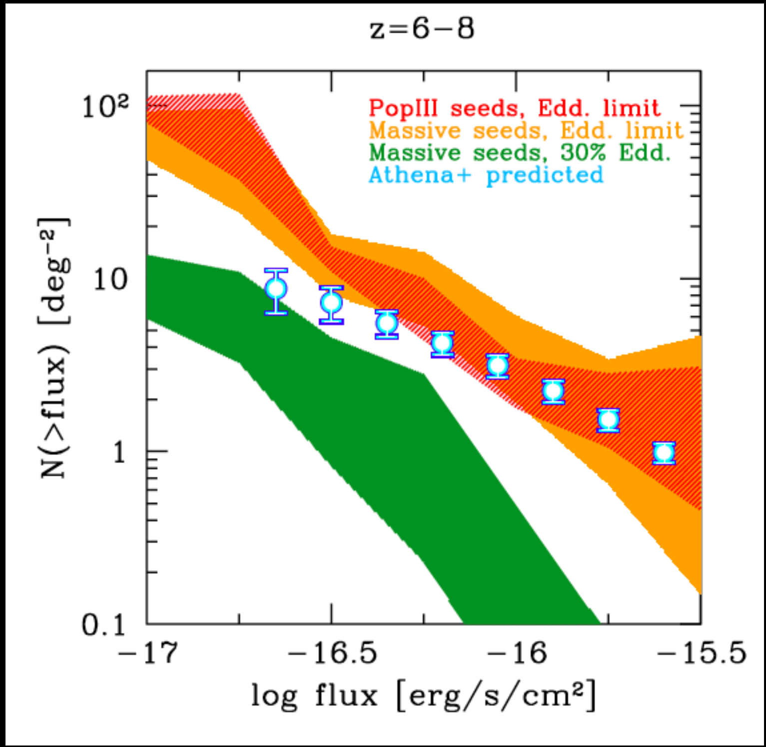
Barret et al 2013, **arXiv1308.6784**

Early Super-Massive Black Holes

What were the seeds of the early SMBH? How did they grow in the early stages after cosmic re-ionisation?

Determine the nature of the seeds of high redshift (z>6) SMBH, which processes dominated their early growth, and the influence of accreting SMBH on the formation of galaxies in the early Universe.

Trace the first generation of stars to understand cosmic re-ionization, the formation of the first seed black holes, and the dissemination of the first metals in the Universe.



Athena Payload: Where do we stand?

- X-ray telescope to be procured by ESA
  - Using Si-based High-Performance Optics developed in Europe
  - NASA/GSFC expressed interest (slumped glass)
- WFI proto-consortium formed, led by K. Nandra - MPE (D) with support from DLR
  - Participation of several ESA MS institutions
- X-IFU proto-consortium formed, led by D. Barret – IRAP (F) with support from CNES.
  - J.W. den Herder (SRON – FPA assembly) and L. Piro (INAF - CryoAC) co-PIs
  - Participation of several ESA MS institutions
  - Contribution from JAXA being firmed up (including shield coolers)
  - Contribution from NASA being defined (including front-end TES sensor array)

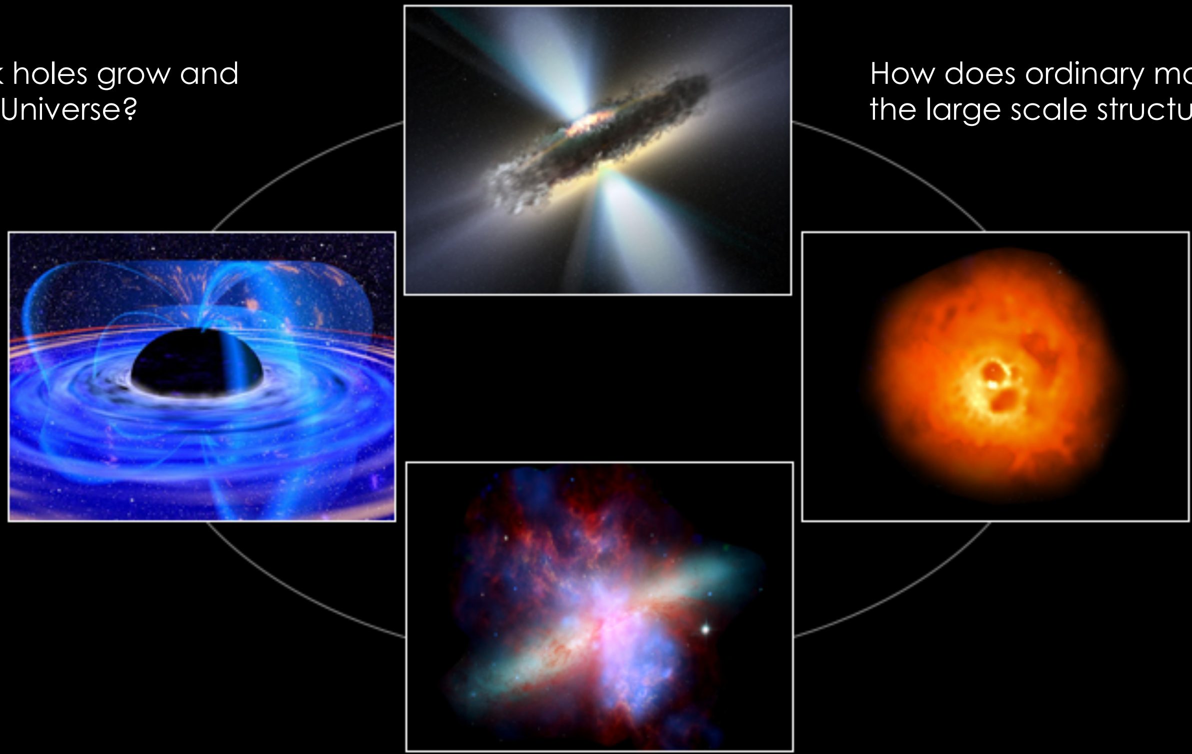
ATHENA

ADDITIONAL SLIDES

ATHENA

How do black holes grow and influence the Universe?

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



The Hot and Energetic Universe

ATHENA

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

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

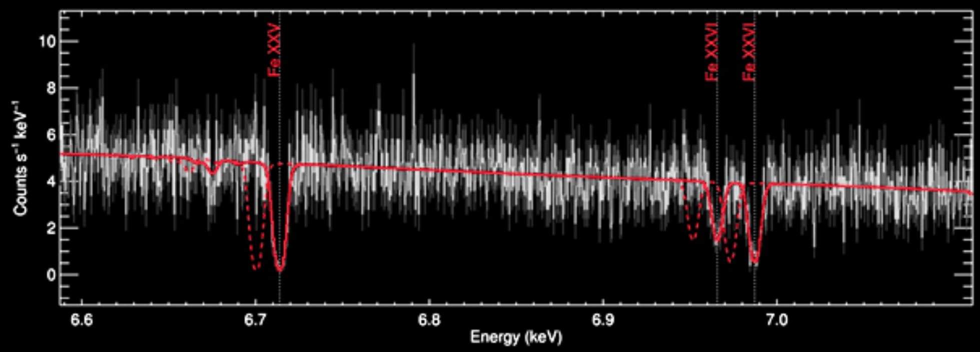
(physics of outflows and winds in X-ray binaries)

Sgr A*

Interstellar dust and medium

High-energy transients

Outflow in X-ray binary, 10ks



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

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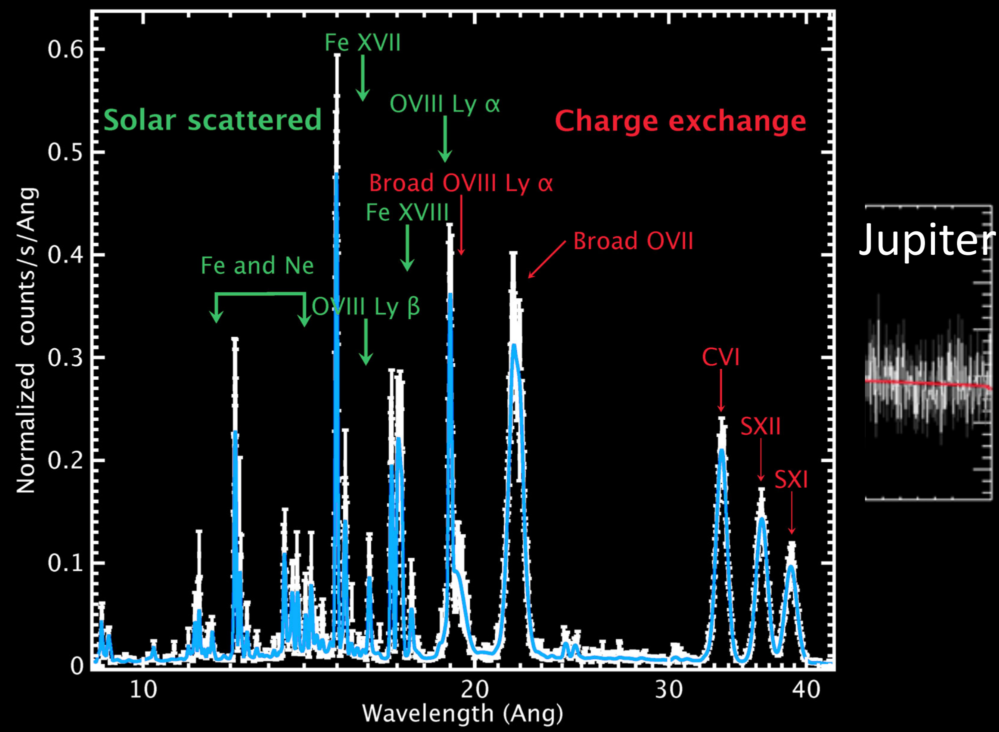
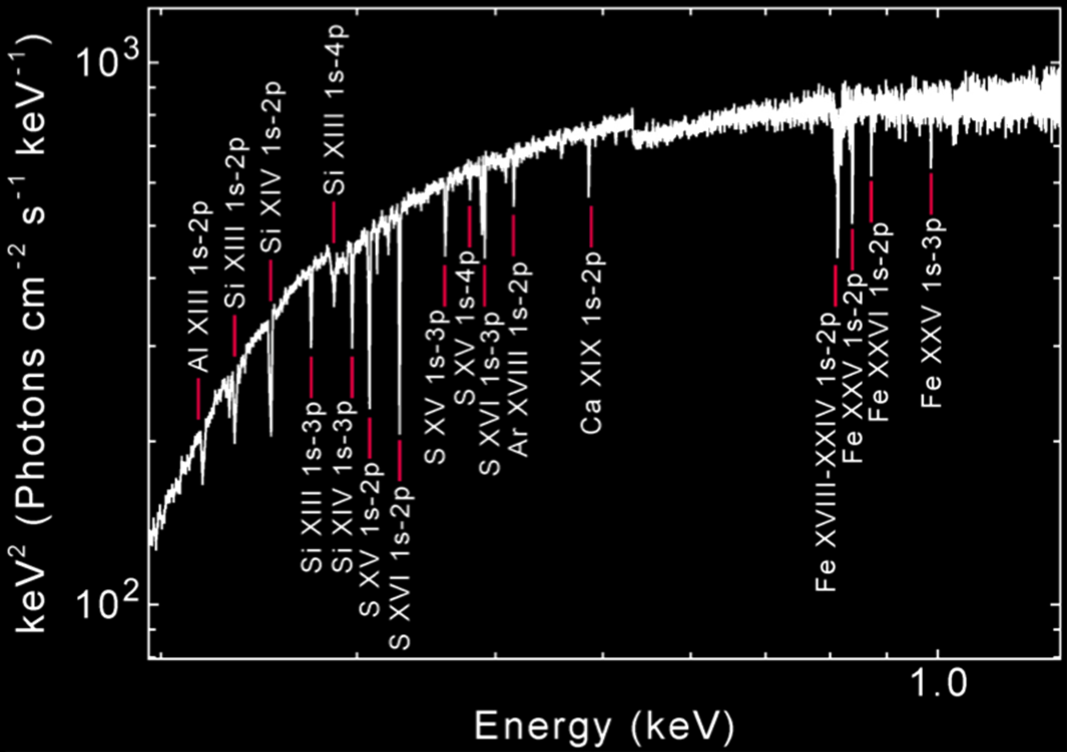


Branduardi-Raymont, Sciortino, et al., 2013 arXiv 1306.2332; Sciortino, Rauw et al., 2013 arXiv1306.2333; Motch, Wilms, et al., 2013 arXiv1306.2334; Decourchelle, Costantini et al., 2013 arXiv1306.2335

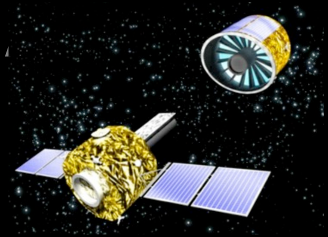
The first stars and black holes

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

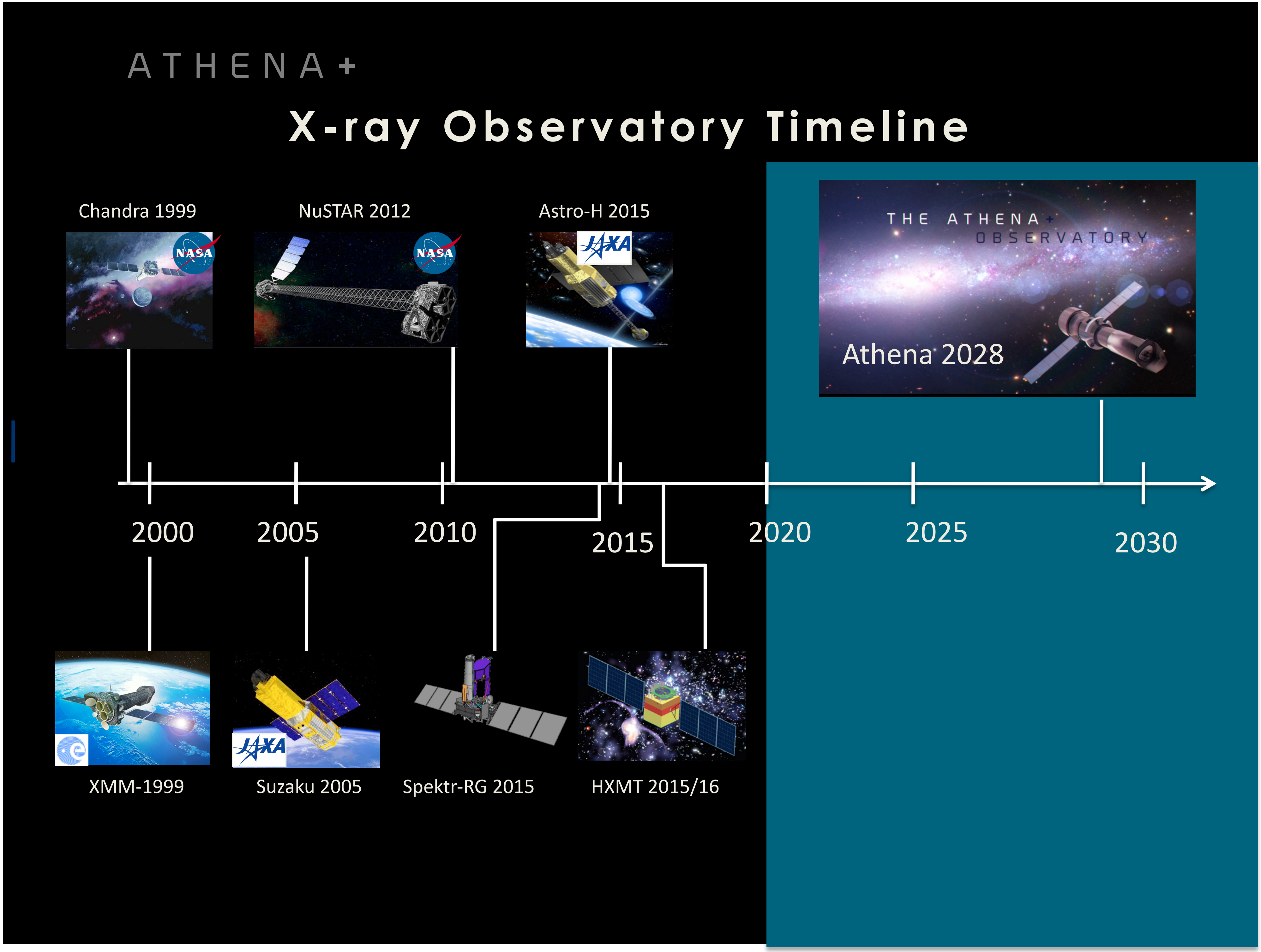


Athena: the History

- 1996 XEUS, European concept for a large X-ray observatory, starts a long route in and out of ESA (often in cooperation with Japan)
- 1990s US develops Constellation-X concept for proposal to NASA (second highest priority in Decadal Survey 2000)
- 2007 XEUS Accepted for Study into the ESA Cosmic Vision programme (along with LISA and Tandem/Laplace)
- 2008 XEUS and Con-X merge into the International X-ray Observatory (IXO), an ESA/NASA/JAXA mission proposal
- Late 2010: US decadal 2010 sets IXO into picture (WFIRST, Explorers, LISA, IXO), but NASA funding issues kill IXO
- March 2011 ESA reformulates approach to Large Missions: they should be European only
- March through December 2011: Athena concept developed for L1 mission
- April 2012 ESA Selects JUICE for L1, launch due in 2022

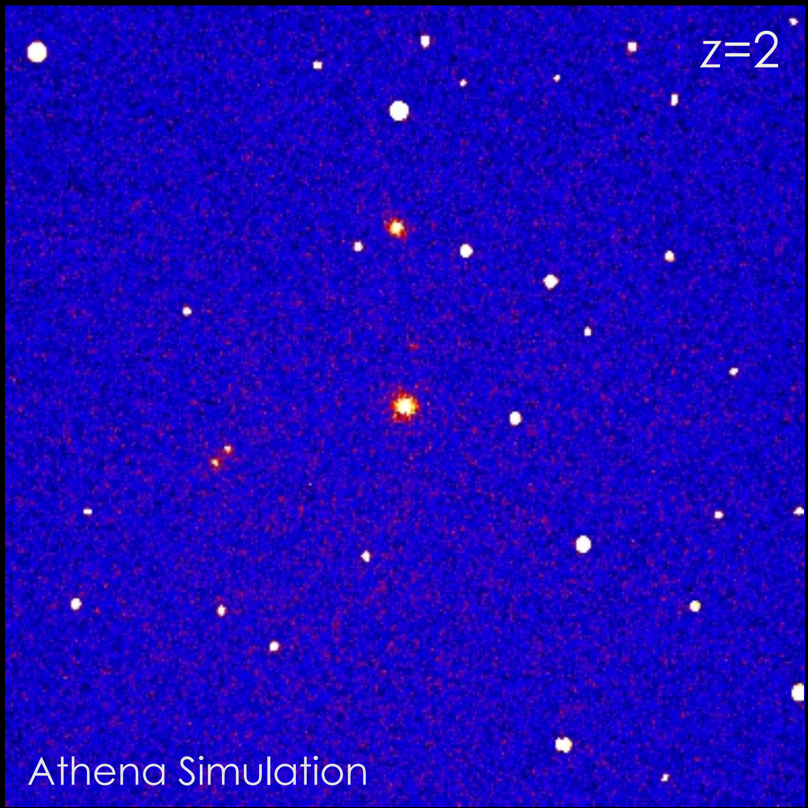
Athena: the way forward

- 2013 ESA reformulates the way in which its Cosmic Vision L-class missions will be decided (Themes first, Missions later)
- Oct 2013: Senior Survey Committee and SPC recommend "The Hot and Energetic Universe" theme for L2 mission in 2028
- Jan 2014: Call for L2 mission proposals
- Apr 2014: Athena Mission Proposal Submitted (only proposal)
- **Late June 2014: L2 mission selection by ESA expected**
- 2014-2018: Technology development phase
- Early 2015: Instrument AO
- 2018-19 Adoption of Mission
- 2028 LAUNCH!

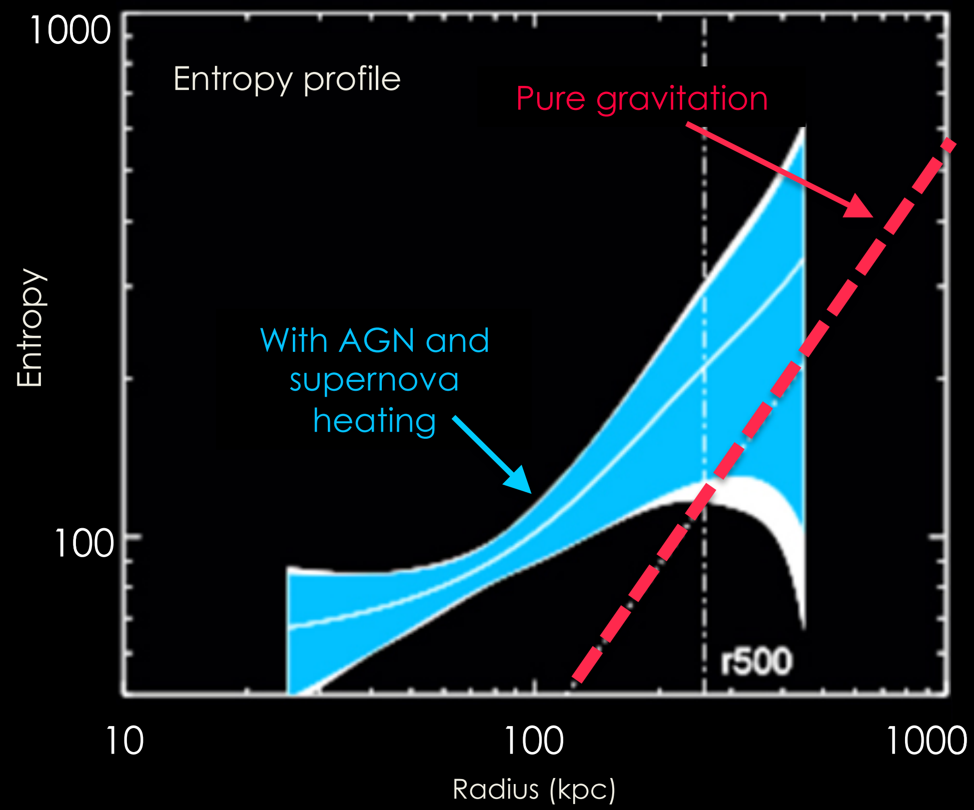

ATHENA+
X-ray Observatory Timeline
Chandra 1999
NuSTAR 2012
Astro-H 2015
THE ATHENA+ OBSERVATORY
Athena 2028
2000
2005
2010
2015
2020
2025
2030
XMM-1999
Suzaku 2005
Spektr-RG 2015
HXMT 2015/16

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?

The formation and evolution of clusters and groups of galaxies

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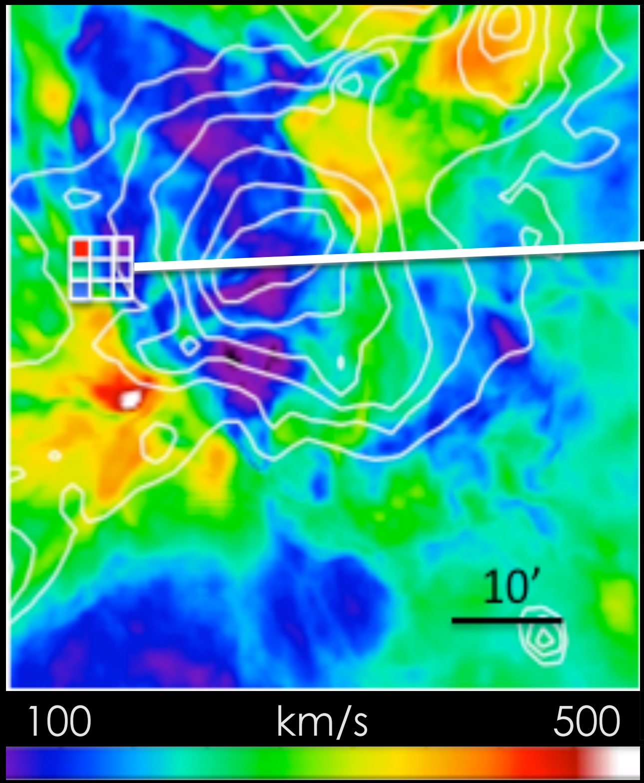
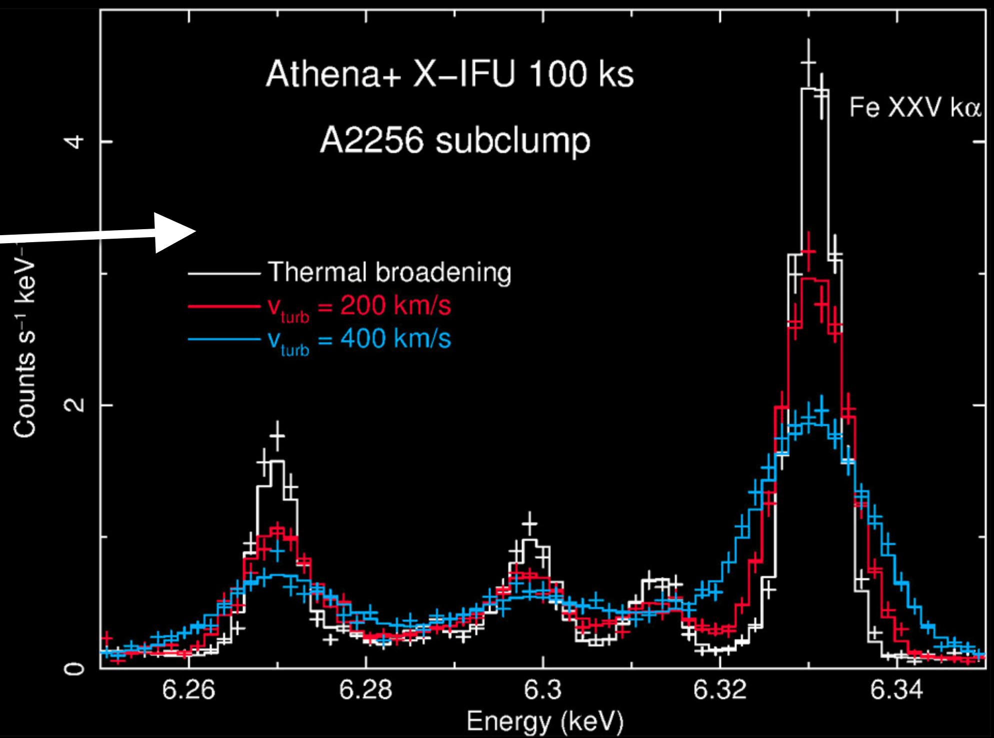
Simulated Velocity map



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

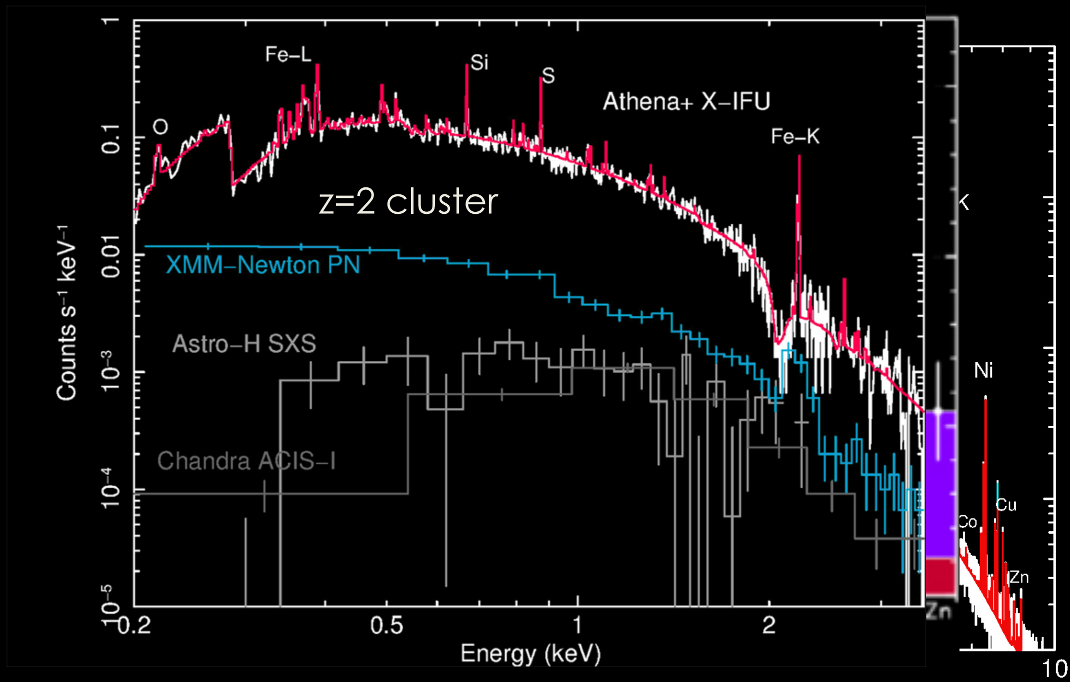


How does ordinary matter assemble into the large-scale structures that we see today?

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

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