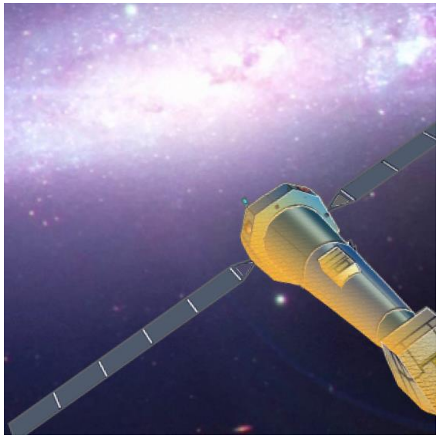
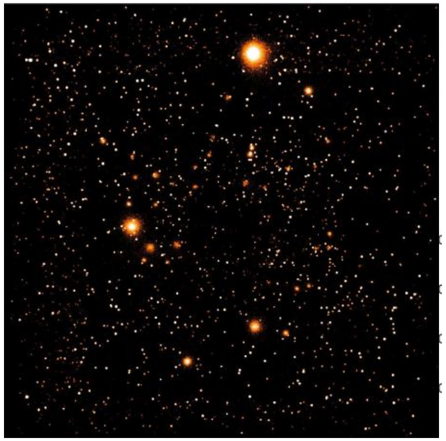
Athena: The Advanced Telescope for High Energy Astrophysics





Giorgio Matt

Università Roma Tre, Italy

IWARA 2018, Ollantaytambo, Sep 10, 2018

Contents

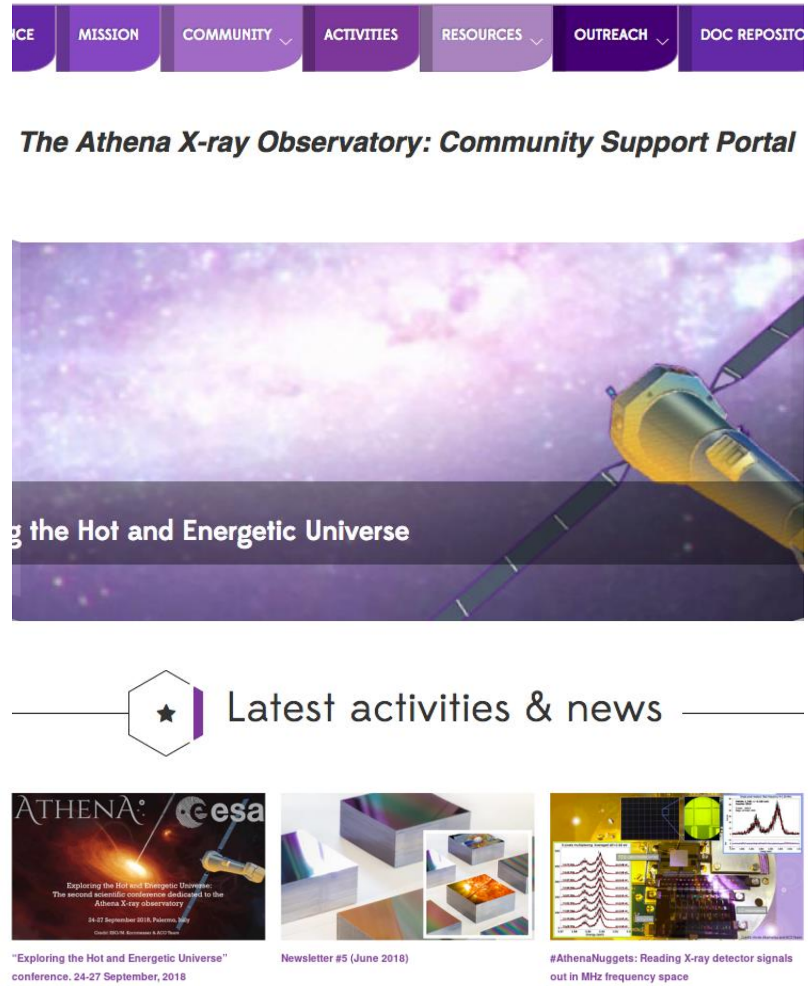
- *Athena* in a nutshell
- The *Athena* science theme: Hot and Energetic Universe
- *Athena* science requirements and performance
- Mission concept & payload
- Project development status
- Outlook

Thanks to:

- The *Athena* Science Study Team: M. Guainazzi, K. Nandra. D. Barret, J.W. den Herder, A. Decourchelle, A.C. Fabian, H. Matsumoto, L. Piro, R. Smith, R. Willingale
- X. Barcons for the initial presentation
- Athena Working Groups and Instrument Teams

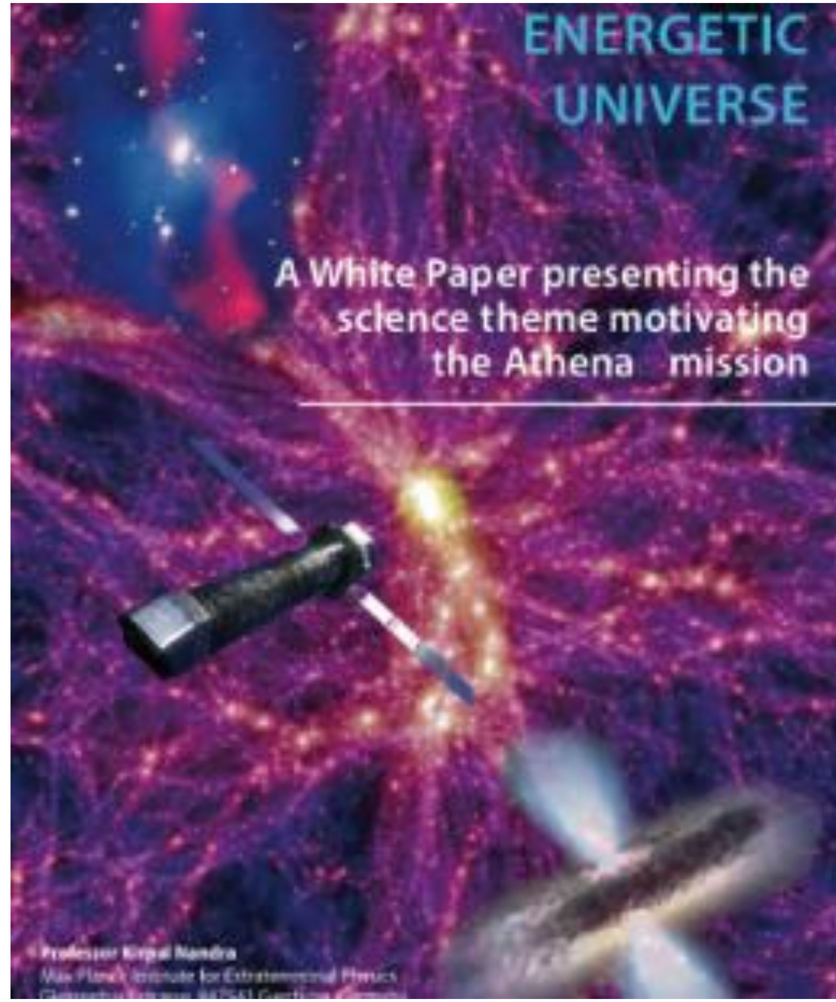
Advanced Telescope for High-Energy Astrophysics

- Second Large (L2) mission of ESA Cosmic Vision
- Science theme: The Hot and Energetic Universe:
  - How does ordinary matter assemble into the large-scale structure we see today?
  - How do black holes grow and shape the Universe?
- Next generation X-ray observatory designed to address science theme
- Broad impact across many areas of astrophysics
- More info at www.the-athena-x-ray-observatory.eu



The Hot and Energetic Universe

- The Hot Universe: How does ordinary matter assemble into the large-scale structures that we see today?
  - >50% of the baryons today are in a warm to hot (>10^6 K) phase
  - Now 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 up to 30 × the binding energy of a galaxy
  - 15% of the energy output in the Universe is in X-rays

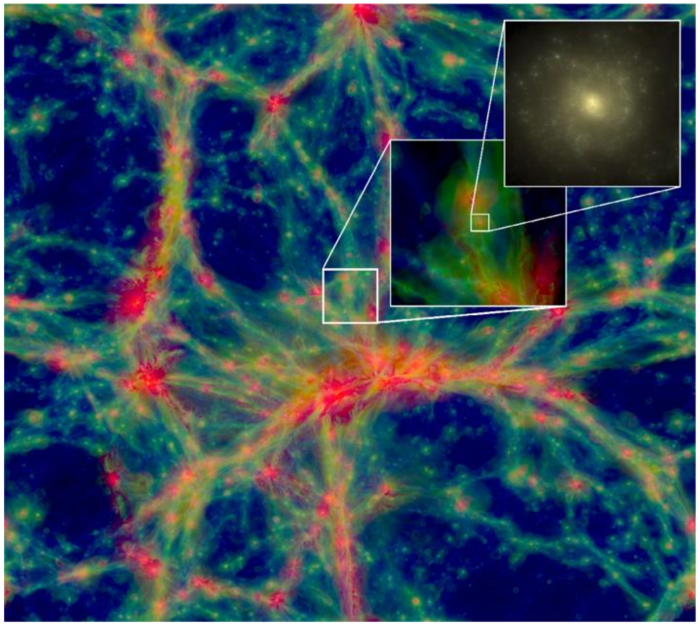


Nandra, Barret, Barcons et al. arXiv:1306.2307

The Hot Universe – baryonic assembly

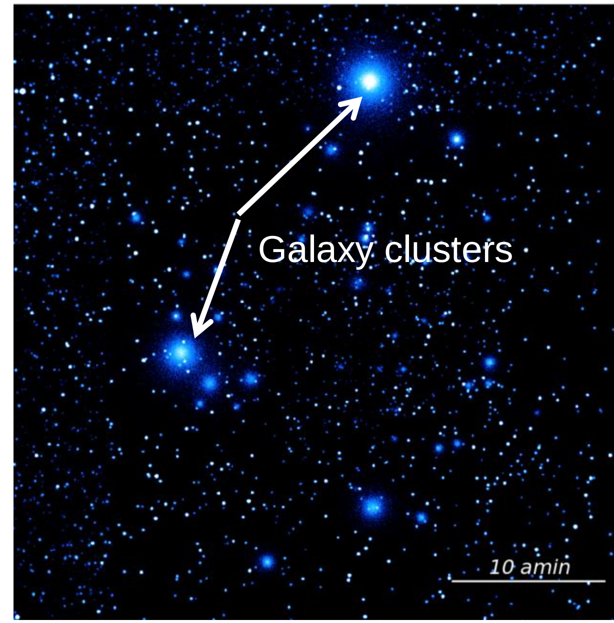
EAGLE cosmological simulation

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



Schaye et al. 2015

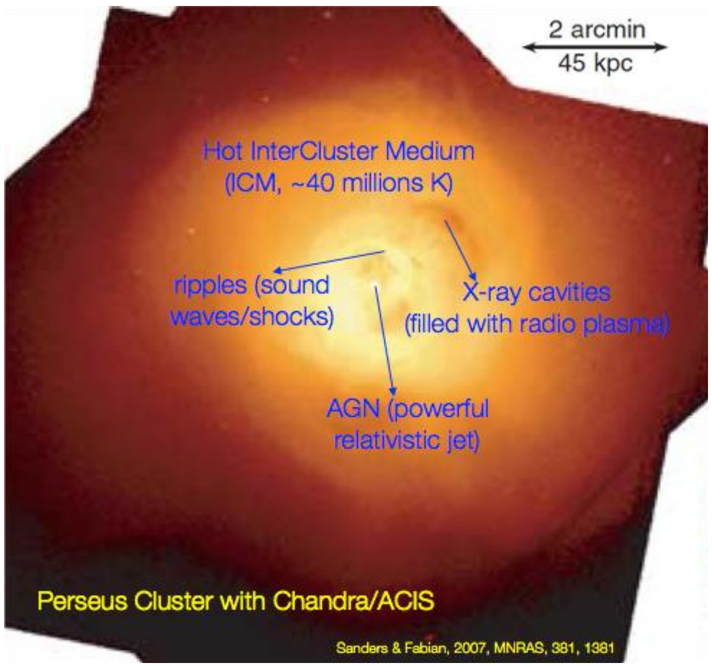
Athena/WFI 1Ms simulation
MPE & WFI team



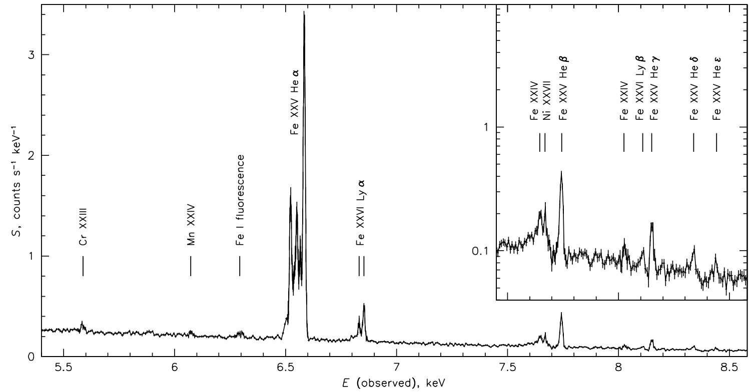
- Evolution of hot cluster gas
- Chemical evolution of intracluster medium
- Cluster bulk motion and turbulence
- AGN feedback on cluster scales
- Missing baryons: the WHIM

Hi-res spectroscopy in action: Hitomi (Feb-Mar 2016)

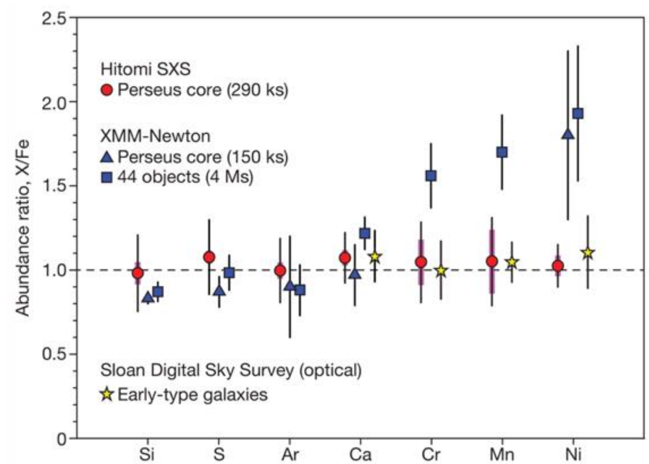
The *Hitomi*/SXS (non-dispersive micro-calorimeter) is the first X-ray instrument resolving emission lines in extended sources and measuring their Doppler broadening and shifts



The quiescent intracluster medium in the core of the Perseus cluster. Hitomi Collaboration, Nature, 2016

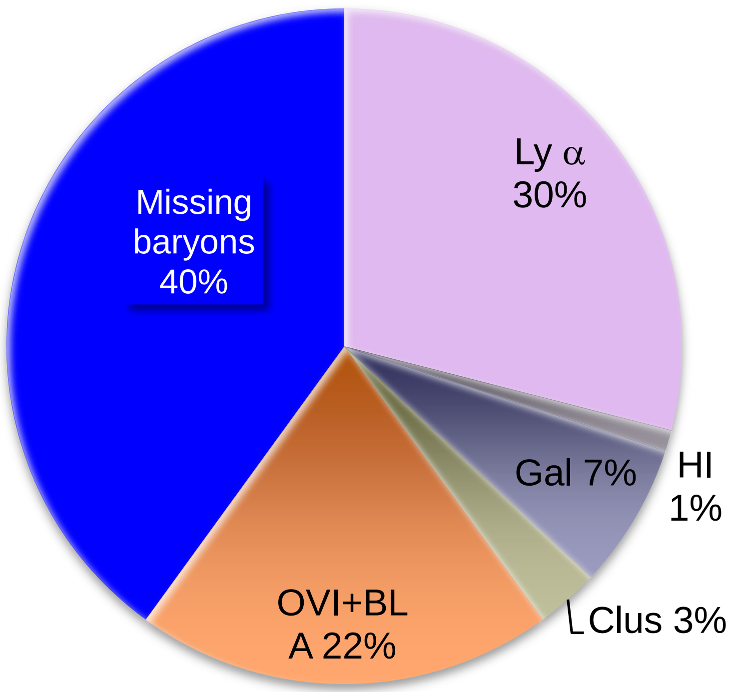


Solar abundance ratios of the iron-peak in the Perseus cluster. Hitomi Collaboration, Nature, 2017



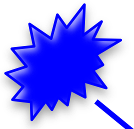
Missing baryons: the WHIM

- Cosmological hydro simulations show ~50% of baryons at **T~10^5-10^7** K in the IGM at low redshift
  - Unvirialised and filamentary distribution
- How can they be detected?
  - In absorption:
    - Against a **bright background sources (AGN or GRB afterglow)**
  - In emission:
    - Tenuous and extended
    - Key to understand CGM and feedback

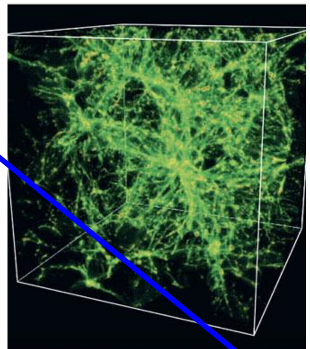


Detecting the WHIM baryons in absorption

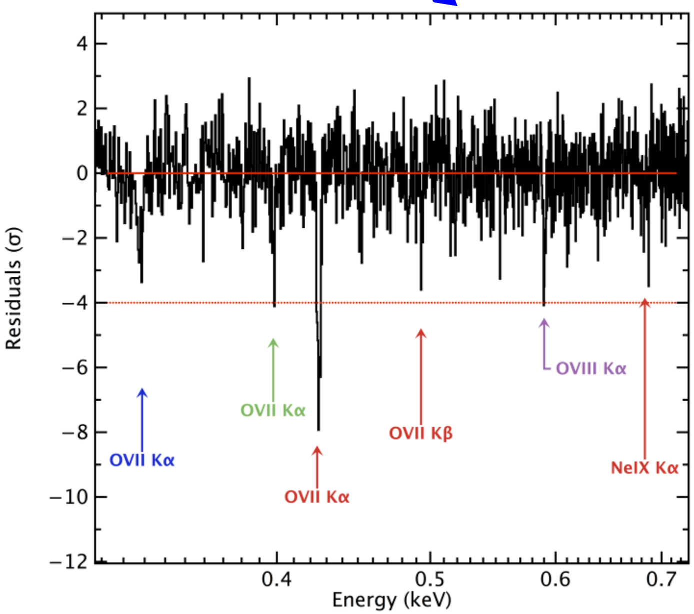
WHIM filaments against brightest GRB afterglows



BL Lac or
GRB afterglow



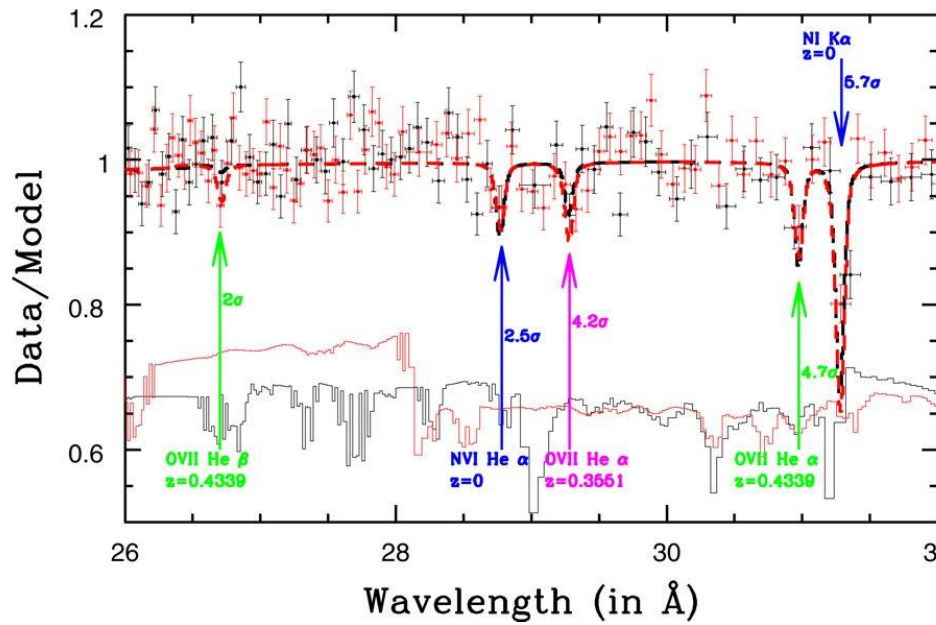
Cen & Ostriker 2006



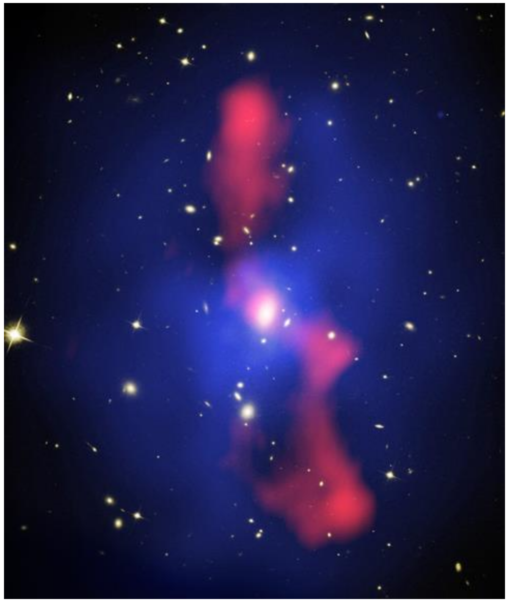
Barret et al. 2016, SPIE
Courtesy: F. Nicastro

XMM-Newton finds missing baryons observing a QSO at z > 0.4 !

Nicastro et al., Nature, 2018

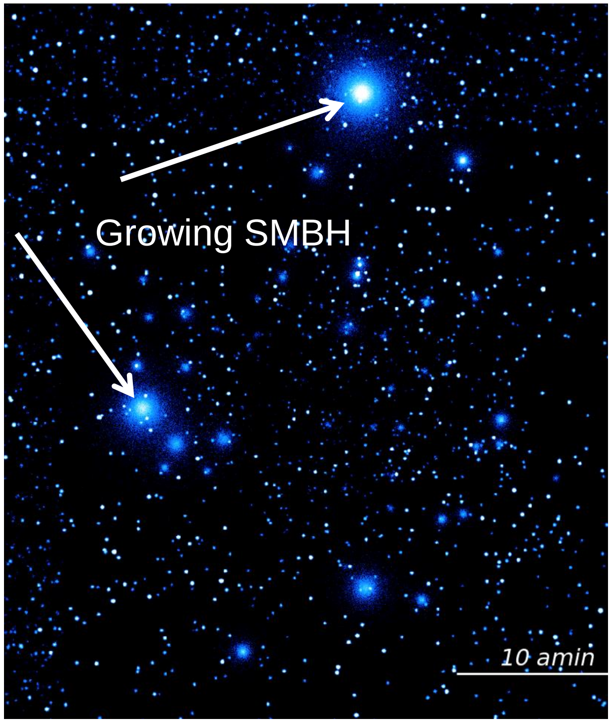


The Energetic Universe – Black Holes



MS0735.6+7421 McNamara et al. 2005

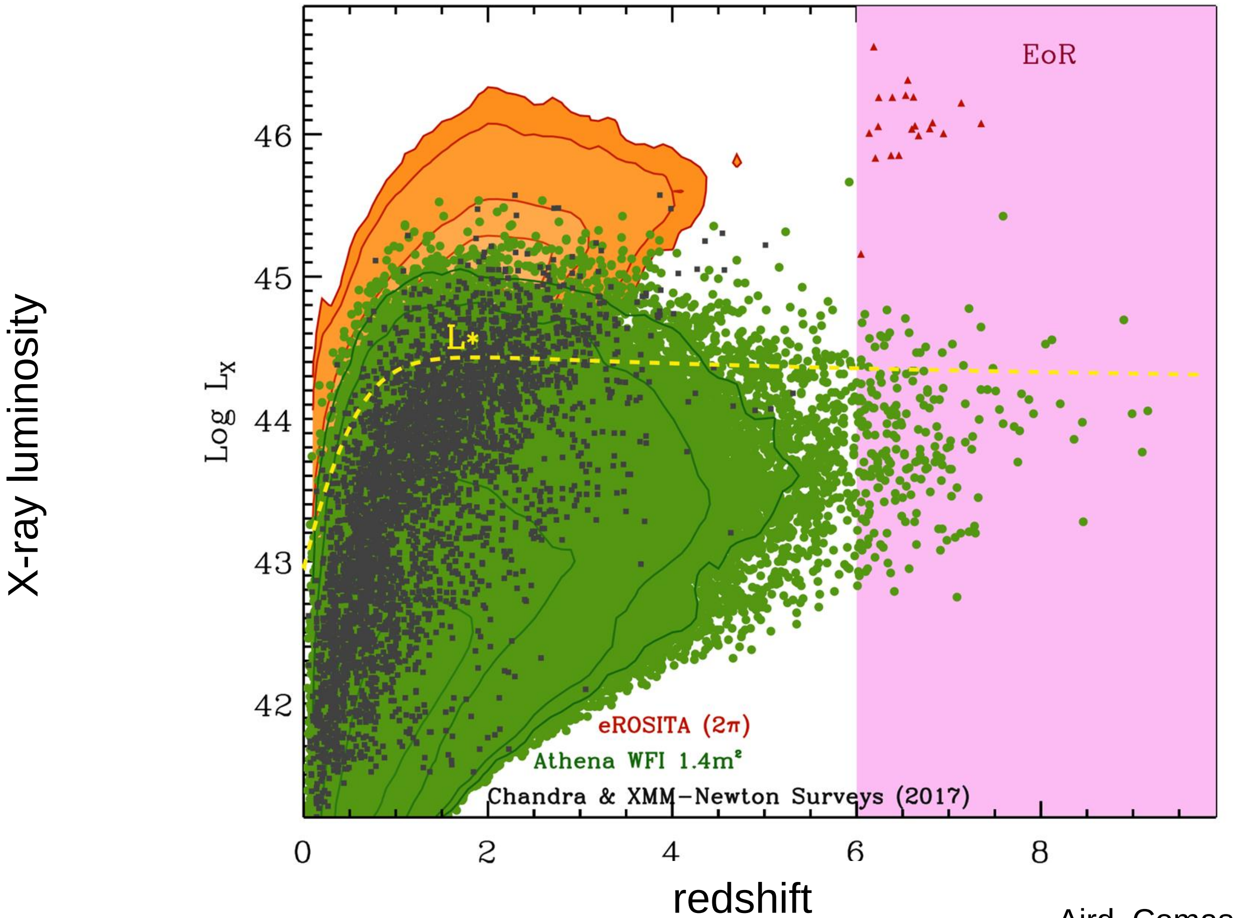
Athena/WFI 1Ms simulation
MPE & WFI team



- Stellar black holes
- Supermassive black holes physics
- AGN winds and outflows
- Obscured AGN: census @z~1-3
- SMBH growth: accretion vs merger

The history of SMBH growth

AGN L_X versus z plane



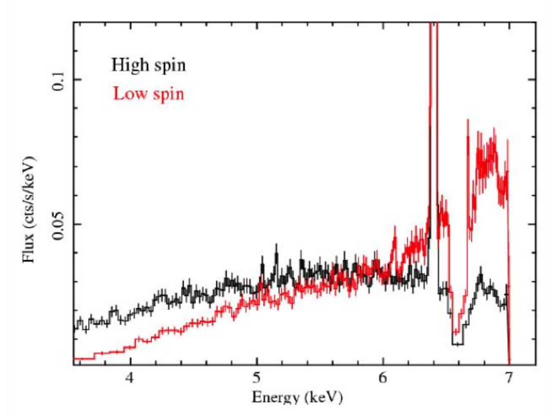
Only most luminous /massive QSOs expected in opt/IR surveys

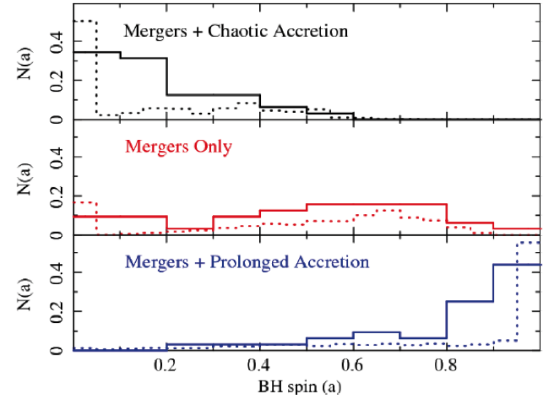
X-rays needed to signpost typical and obscured AGN

Aird, Comastri et al. 2013 arXiv1306.232
Updated by Andrea Merloni (MPE) (2017)

SMBH growth: accretion vs mergers

- SMBH spin distribution is highly sensitive to SMBH growth history
  - Accretion spins up SMBH
  - Mergers & chaotic accretion spin down SMBH
- A SMBH spin survey with *Athena* will reveal dominant SMBH growth mode
  - Partly doable with XMM-*Newton*, but for removal narrow features

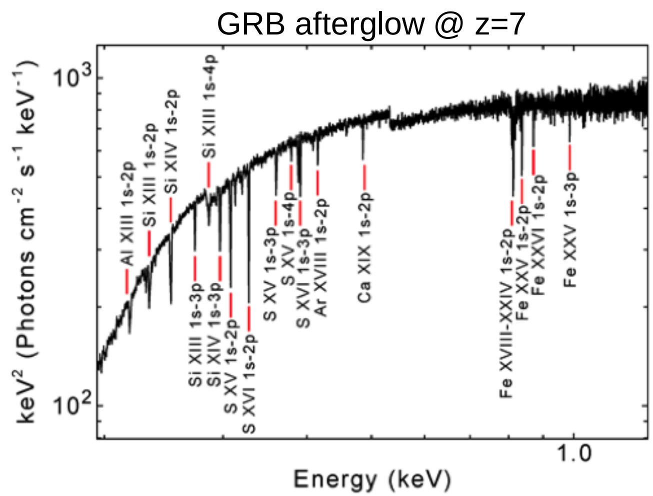


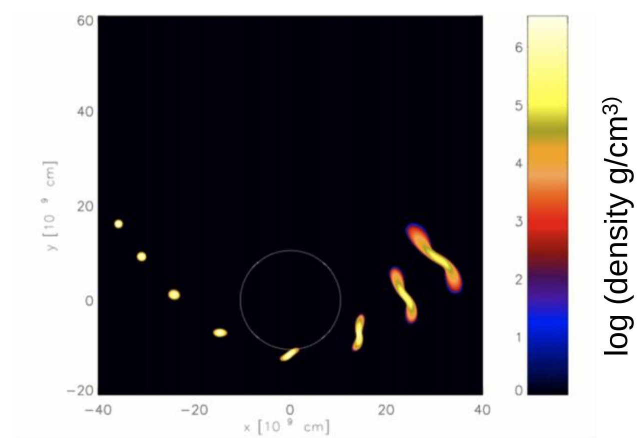


Dovciak, Matt et al. 2013: arXiv 1306.2331
simulations by G. Miniutti

Luminous extragalactic transients

- *Athena* will offer fast Target of Opportunity response, whereby a triggered observation could start in ≤ 4 hours
  - 40% of GRB afterglows anywhere on the sky can be followed-up by X-IFU with at least 50 ks t_{exp}
- High-z GRB afterglows will reveal the ISM composition at z>7-10
- Tidal Disruption Events (TDEs) result from the destruction of a star by a SMBH. *Athena* will
  - Unveil SMBH through this
  - Reveal the composition of the outflowing material
  - Test for the presence of binary SMBH



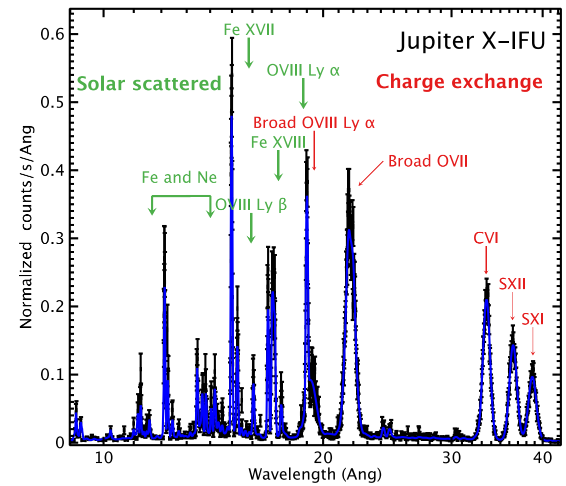


Jonker, O'Brien et al. 2013: arXiv 1306.2336
Rosswog, Ramirez-Ruiz & Rix (2009)
Courtesy: P.T. O'Brien and P. Jonker

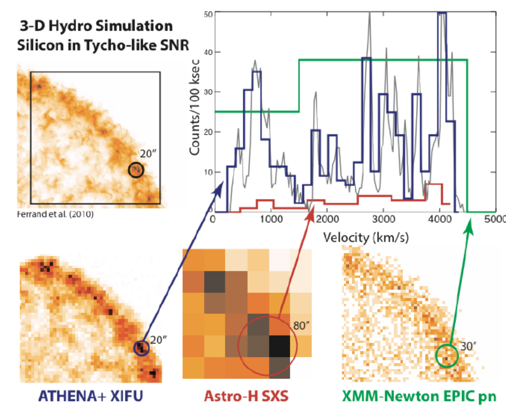
Observatory and discovery science

- Planets and solar system bodies
- Exoplanets: magnetic interplay
- Star formation, brown dwarfs
- Massive stars: mass loss
- Supernovae: explosion mechanisms
- Supernova remnants: shock physics
- Stellar endpoints (NS)
- Interstellar medium
- Dark matter candidates
- …

~ 2/3 (TBC) of the *Athena* nominal operational life will be allocated to the international astronomical community through a competitive peer review process



Branduardi-R, Sciortino et al. 2013: arXiv 1306.2332
Sciortino, Rauw et al. 2013: arXiv 1306.2333

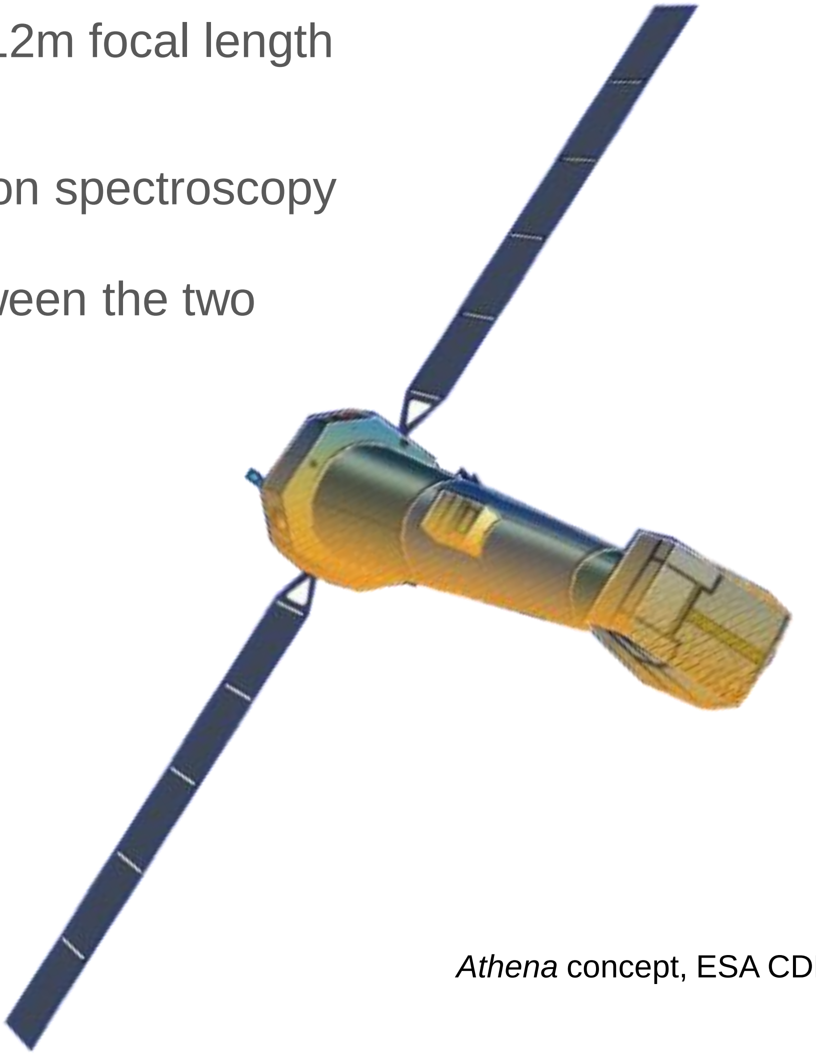


Decourchelle, Costantini et al. 2013: arXiv 1306.2335
Motch, Wilms et al. 2013: arXiv 1306.2334

IWARA 2018, Ollantaytambo, Sep 10, 2018

Athena mission concept

- Single telescope, using Si pore optics. 12m focal length
  - WFI sensitive imaging & timing
  - X-IFU spatially resolved high-resolution spectroscopy
- Movable mirror assembly to switch between the two instruments
- Launch early 2030s, Ariane 6.4
- L2 halo orbit (TBC)
- Lifetime: 4 yr +Possible extensions



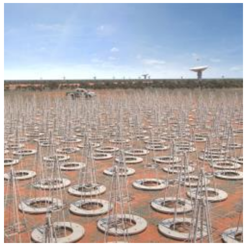
Athena concept, ESA CDF

Athena Science Requirements

Parameter	value	enables (driving science goals)
Effective area at 1 keV	≥1.4 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 (≤ 7 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 0.2-12 keV	WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4
X-IFU FoV	5' effective diameter	Metal production & dispersal, cluster energetics, WHIM
X-IFU background	< 5 10^{-3} counts/s/cm^2/keV 2-10keV	Cluster energetics & AGN feedback on cluster scales, metal production & dispersal
WFI spectral resolution	150 eV <80eV (1keV) & <170eV (7keV)	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	1 Crab > 80%	GBH spin, reverberation mapping, accretion physics
WFI background	< 5 10^{-3} counts/s/cm^2/keV 2-7keV	Cluster entropy, cluster feedback, census AGN at z~1-4
Recons. astrometric error	1'' (3s)	High z AGNs
GRB trigger efficiency	50%	WHIM
ToO reaction time	≤ 4 hours	WHIM, first generation of stars

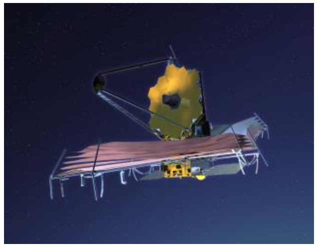
Athena in the framework of the late 2020s

SKA

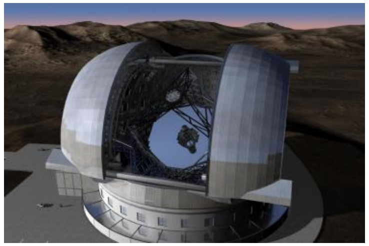


ALMA

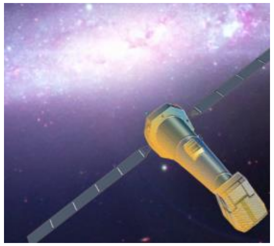
JWST



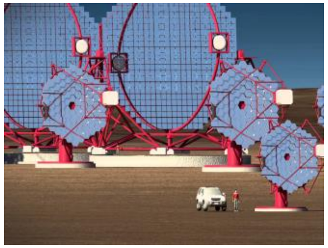
ELT

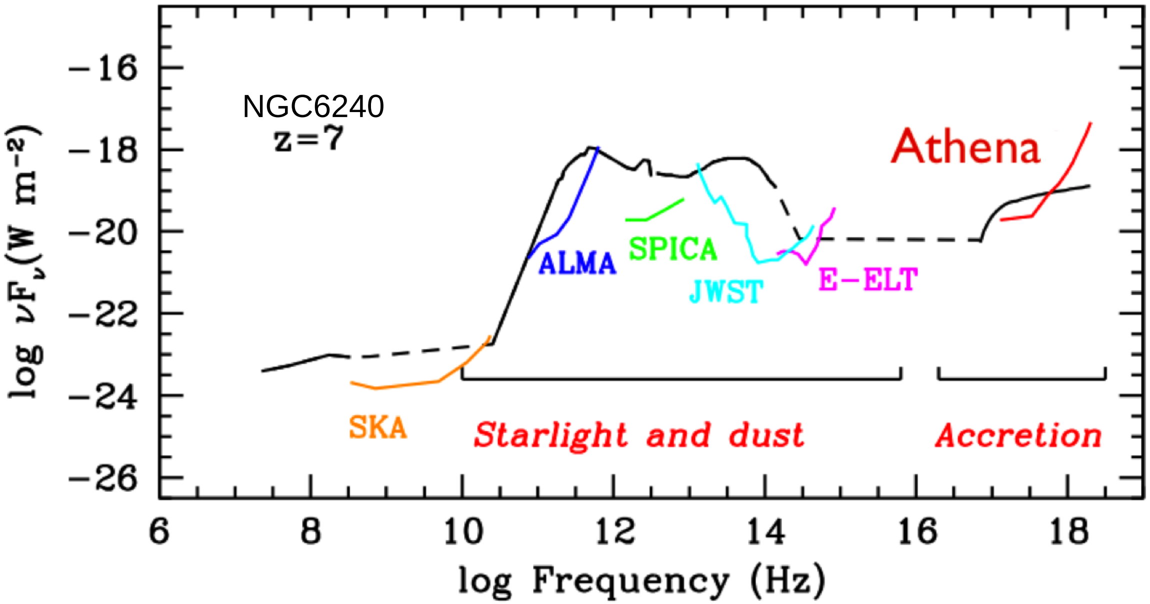


Athena



CTA

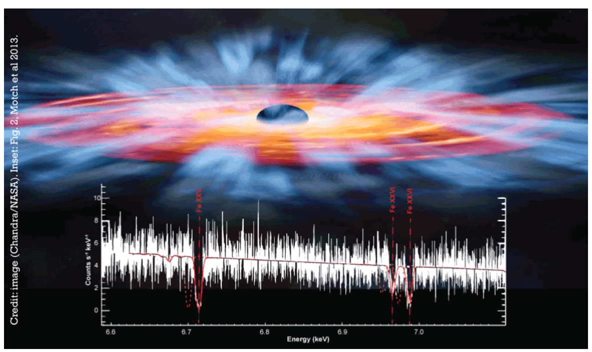




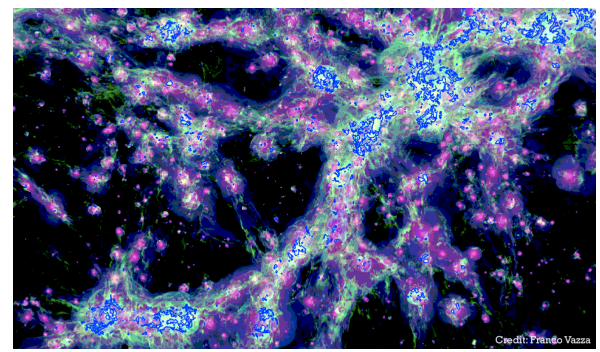
Credit: M. Türler & Athena team

Athena Synergies with other facilities

- ESO-*Athena*
  - Led by: P. Padovani (chair), E. Hatziminaglou, M. Díaz-Trigo, S. Viti, S. Ettori, M. Salvato, F. Combes, P. Jonker
  - arXiv:1705.06064
  - Early groups & clusters, IM physics, missing baryons, SMBH history, AGN feedback, outflows, transient science, star formation & stars



- SKA-*Athena*
  - Led by: R. Cassano (chair), R. Fender, C. Ferrari, A. Merloni.
  - Synergy White Paper published July 2018
  - AGN, clusters & transients



- Future Synergy Exercises planned with large-area and gamma ray/multi-messenger facilities

Outlook

- *Athena* will be a transformational X-ray observatory
  - Designed to address the Hot and Energetic Universe science theme
  - Will impact virtually every corner of astronomy
- It will be an essential part of the observational landscape in the late 2020s-early 2030s together with ALMA, ELT, SKA, CTA, etc.
- Vibrant community supporting it
- Key milestones: Phase A completion end 2019, Mission Adoption end 2021and Launch early 2030s

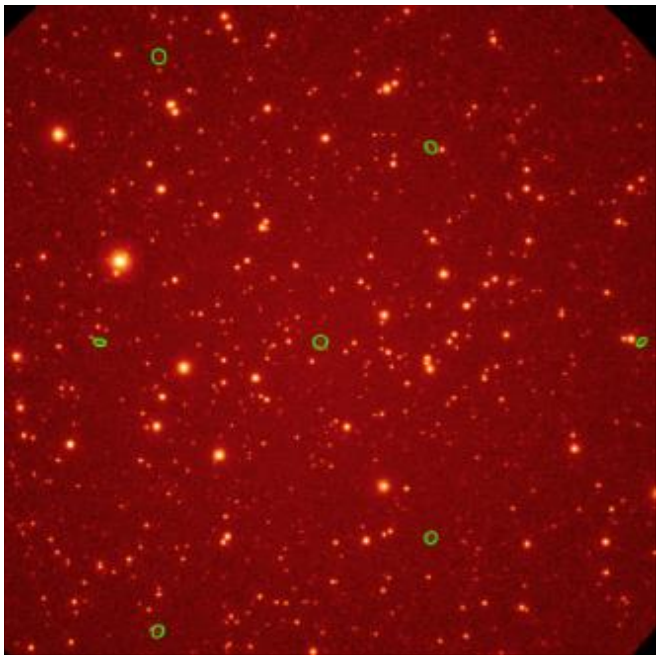
- Follow Athena on
  - Web: www.the-athena-x-ray-observatory.eu
  - Twitter: @athena2028
  - Facebook: The Athena X-ray Observatory
  - Athena Community Office email: aco@ifca.unican.es

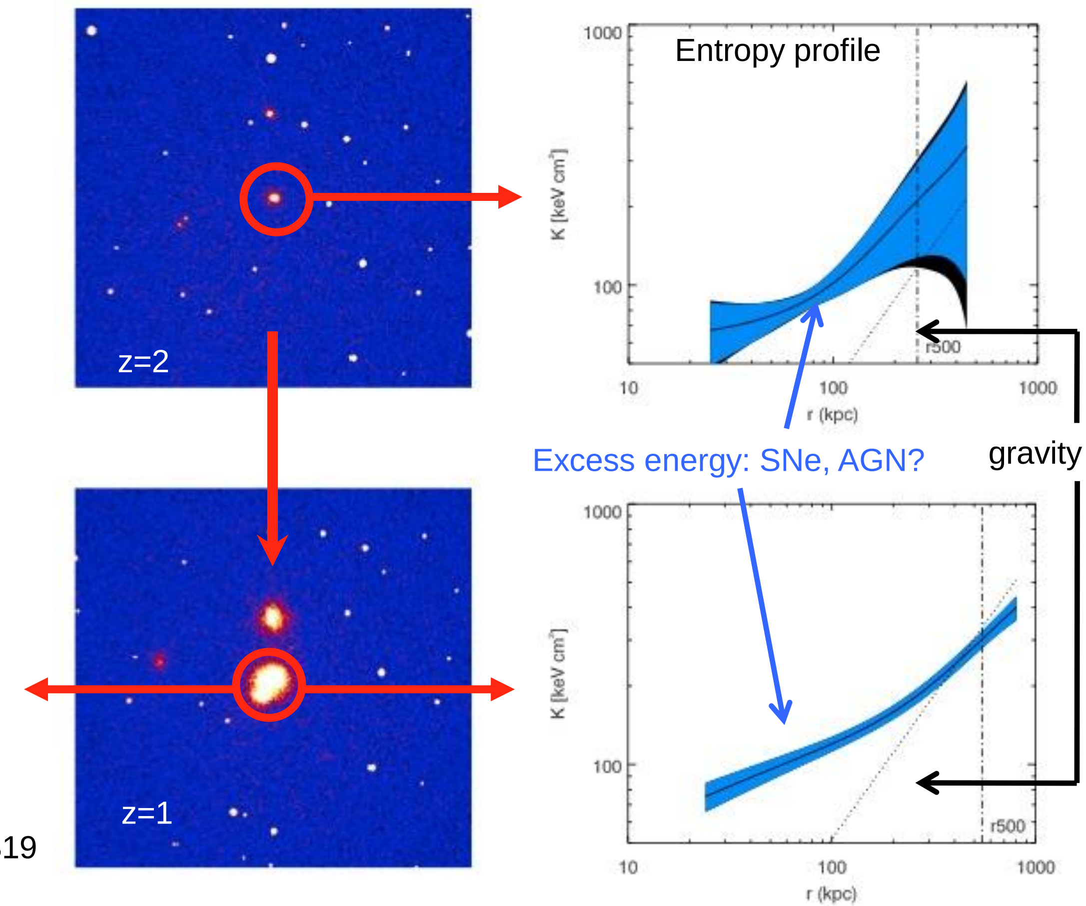
Backup slides

Evolution of hot cluster gas

Search for early groups of galaxies at z>2

Energy deposition history



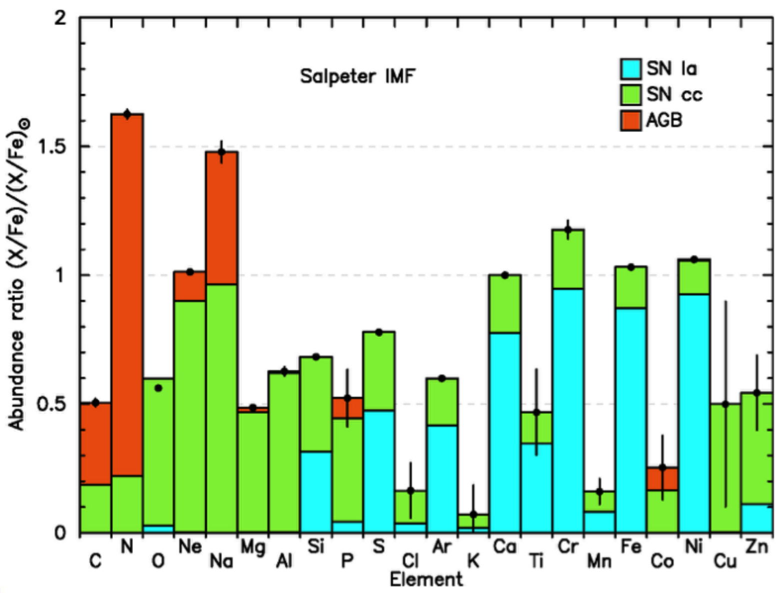


Ettori, Pratt et al. 2013, arXiv1306.2322
Pointecouteau, Reiprich et al. 2013, arXiv: 1306.2319

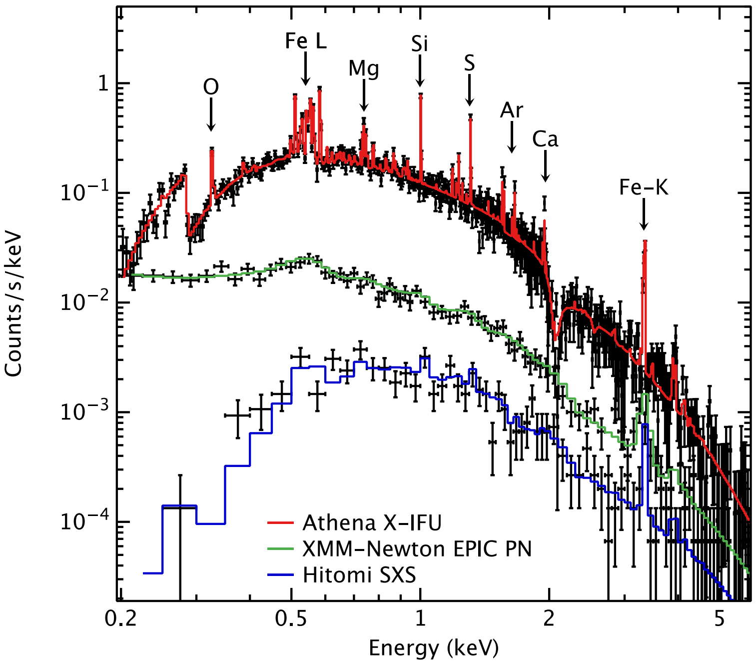
Chemical evolution

- Clusters of galaxies are closed boxes, all gas is virialised in the DM potential well
- Cosmic chemical evolution traced by cluster gas
- Constraints on origin of elements and IMF

Courtesy: J. de Plaa 2016



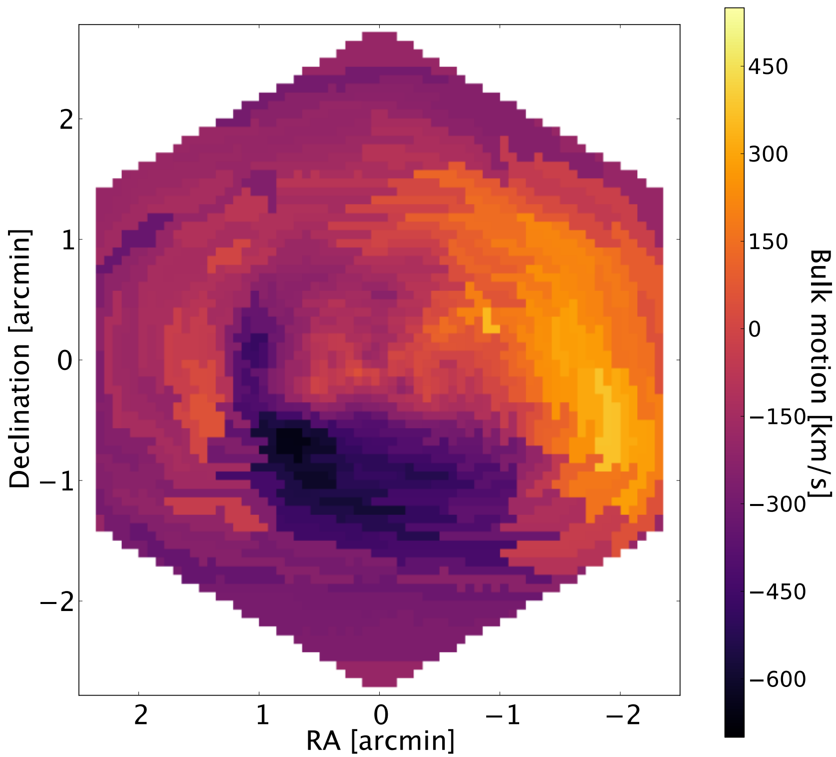
Galaxy group @z=1 50ks
Athena/X-IFU



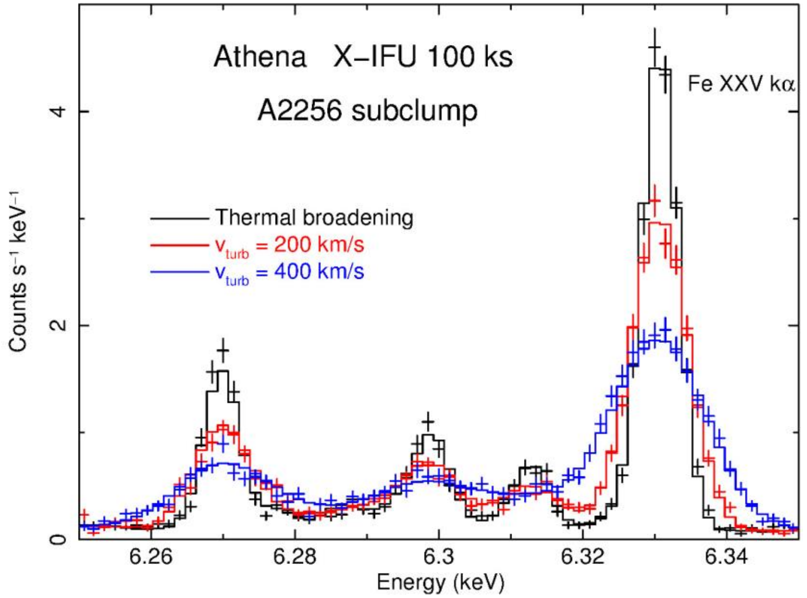
Barret et al. 2016, SPIE

Cluster bulk motions & turbulence

Athena will measure gas bulk motions and turbulence down to 20 km/s



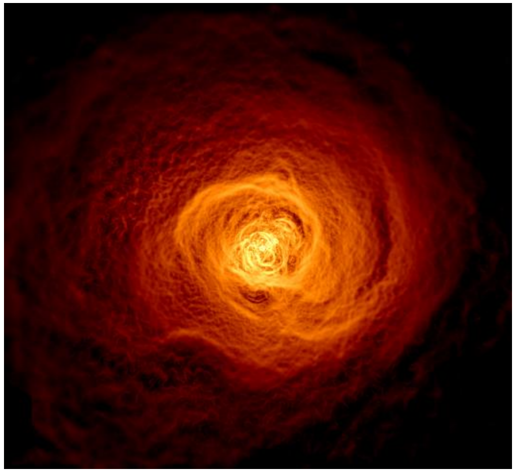
Bulk velocity map. Courtesy: P. Peille, E. Pointecouteau,
V. Biffi, E. Rasia, K. Dolag, S. Borgani, J. Wilms



Ettori, Pratt et al. 2013 arXiv1306.2322
Pointecouteau, Reiprich et al. 2013, arXiv: 1306.2319

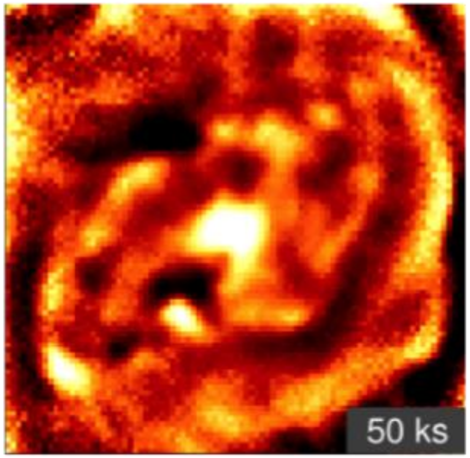
AGN feedback on cluster scales

- Dissipation of AGN energy into ICM
  - Energy stored in hot gas around bubbles via bulk motions and turbulence
  - History of radio cluster feedback via ripples
  - AGN jet fuelling vs. cooling through temperature distribution
  - Shock speeds of expanding radio lobes

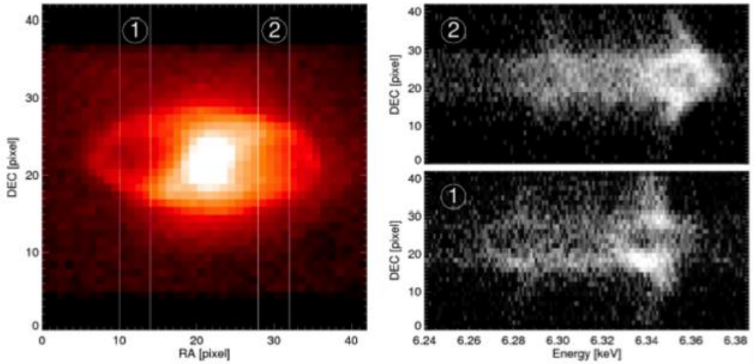


Perseus cluster.
Courtesy: A.C. Fabian

Athena/WFI observation of a cluster core at z=0.05



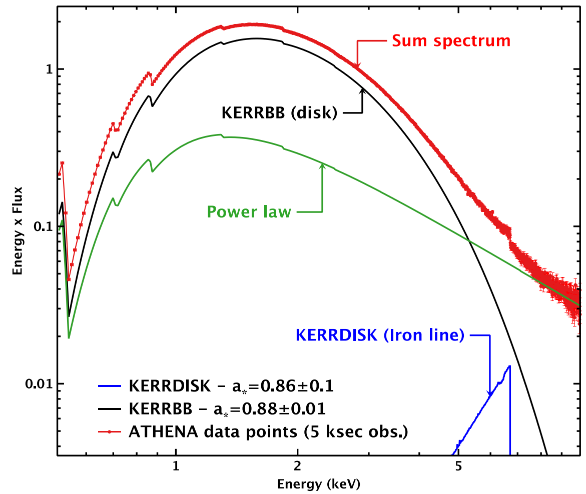
Cygnus A: X-ray image and chosen virtual spectral slits (left) and *Athena*/X-IFU spatially resolved simulated spectra of the 6.7 keV Fe XXV Kα line (right)

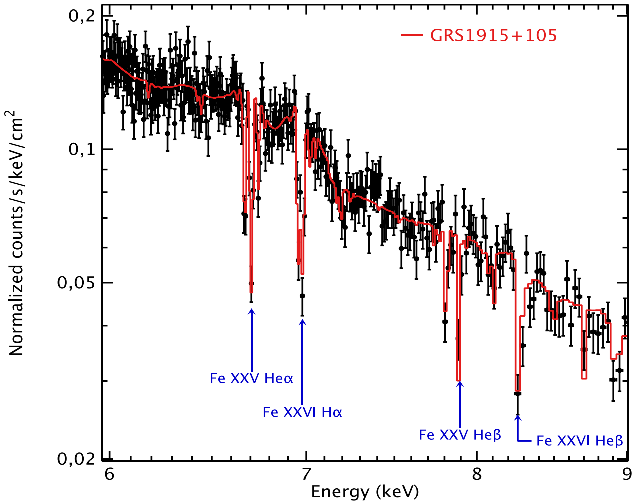


Croston, Sanders et al. 2013 arXiv1306.2323. Simulations by S. Heinz

Stellar black holes

- Measure BH spins
  - Constraints on SN origin
  - Relation to jets
- Accretion geometry
  - Disc truncation from lag spectra
  - Winds as diagnostics of the accretion flow

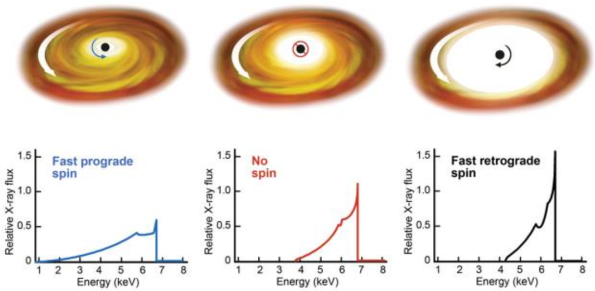




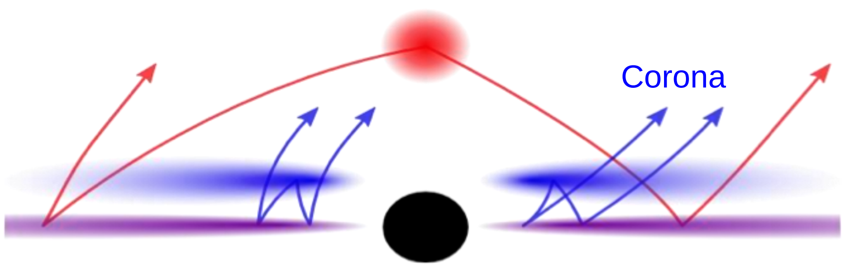
Courtesy J.M. Miller
Barret et al. 2016 SPIE2016

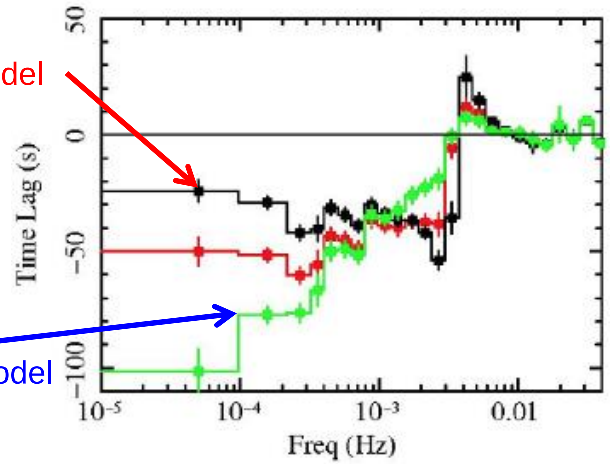
Supermassive Black Hole physics

- Measure SMBH spins through Fe line spectroscopy



- Accretion geometry and jet/disk relation through reverberation mapping





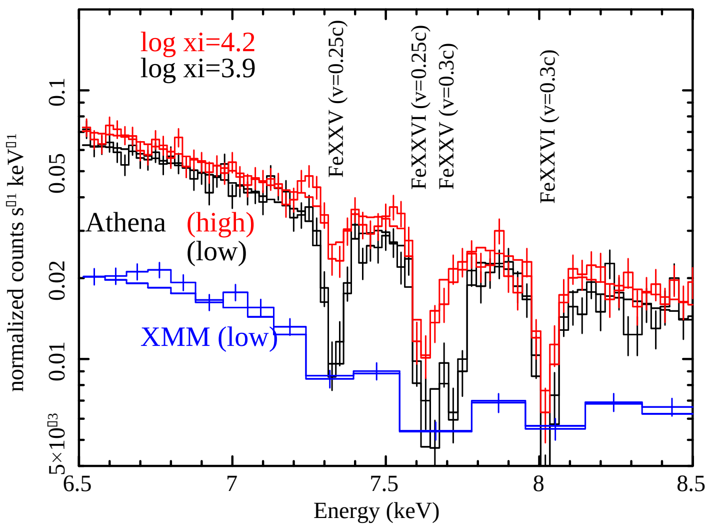
Dovciak, Matt et al. 2013, arxiv:1306.2331

AGN winds and outflows

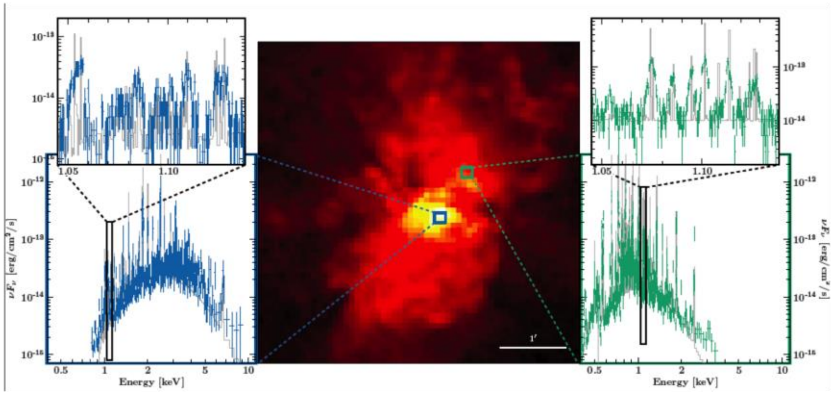
Mechanical feedback effective if $L_{mech} > 1\% \ L_{bol}$

Mechanical energy released in ultra-fast outflows α v3

Gas, metals and mechanical energy ejected into the circum-galactic medium by AGN and Starbursts



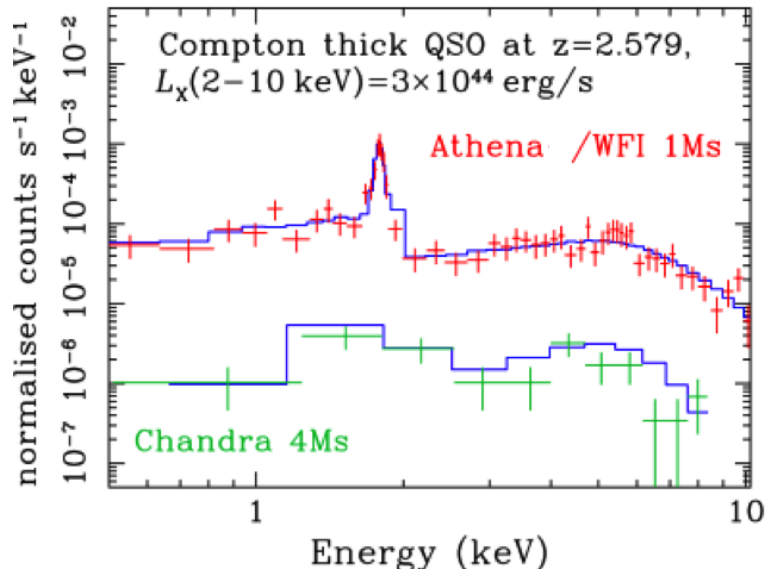
Cappi, Done et al. 2013, arxiv:1306.2330



A. Ptak and the *Athena* simulation team (in progress)

Obscured AGN census @ z~1-3

- What is the relation between obscured growth of SMBH through cosmic history and how does it relate to galaxy formation?
  - Most SMBH growth expected in heavily obscured (including Compton-Thick) environment
  - Best X-ray signature of typical Compton-thick AGN is the Fe emission line, EW ~0.5-1 keV
  - *Athena*/WFI observations can uncover Compton-Thick average AGN at z~3
  - MIR observations can also uncover heavily obscured AGN, but **only** when the AGN is very powerful



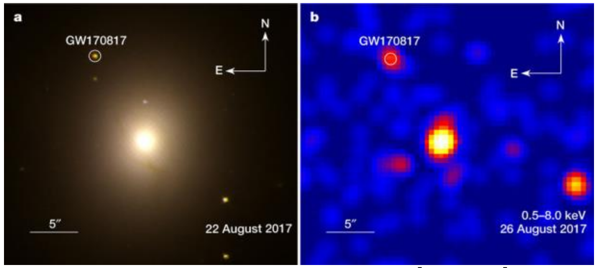
Georgakakis, Carrera et al. 2013 arXiv1306.2328

Chasing the transient Universe with Athena

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

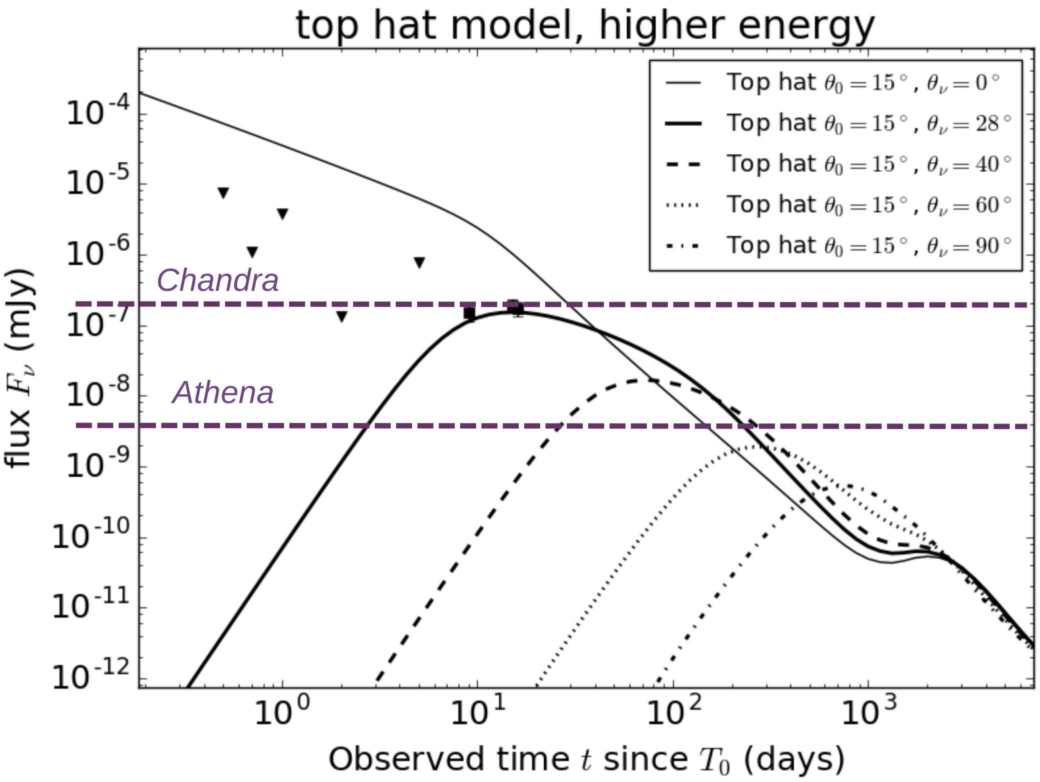
Athena needed for any line-of-sight ≥40º (~70% of potential GRBs)

GW170817 counterpart



Troja, et al., Nature, 2018

HST *Chandra*



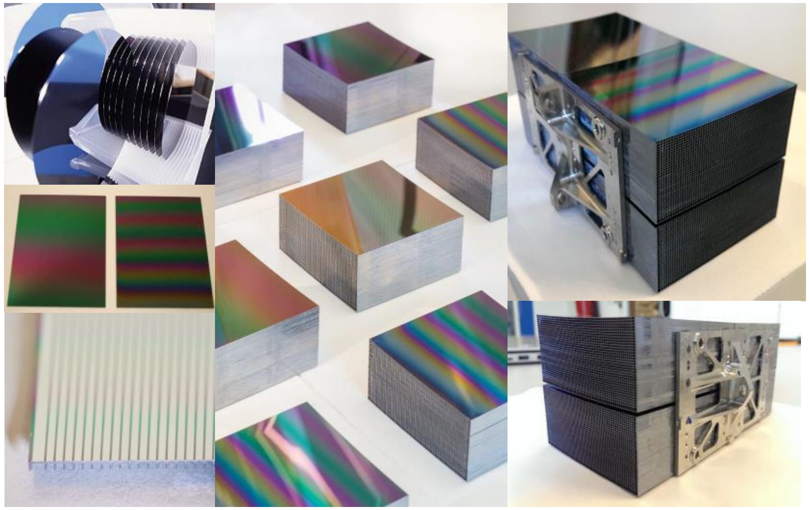
Courtesy L.Piro (IAPS/INAF)

The Athena X-ray optics

- *Athena* optics development:
  - Light-weight Si-pore optics
  - Grazing incidence optics with Wolter-Schwarzschild type I geometry optimised to provide wide flat field imaging
  - Vigorous development programme on-going

- Expected Performance:
  - 5´´ HEW on-axis
  - Graceful degradation off-axis

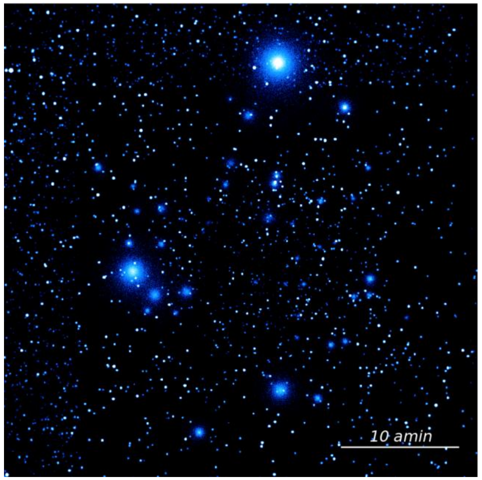
    HEW <10´´ @ 30´
  - ≥1.4 m^2 effective area @ 1 keV
    0.25 m^2 effective area @ 6 keV

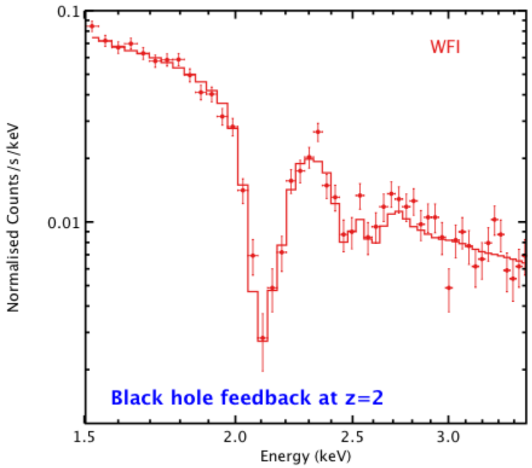


Willingale, Pareschi et al. 2013, arXiV: 1308.6785
Cosine/ESA

Wide Field Imager (WFI)

- Silicon Active Pixel Detector based on DEPFET technology
- Key performances:
  - 50-150 eV spectral resolution @ 6 keV
  - 2.2´´ pixel size (PSF oversample)
  - Field of view: 40´×40´ square
  - Separate chip for fast readout of brightest sources
  - Readout speed up to ~30 MHz
- Consortium led by MPE, with other European partners (DE, AT, DK, FR, IT, PL, UK, CH, P & GR) and NASA
- Optimized for sensitive wide-field imaging and intermediate resolution spectroscopy, up to very bright sources





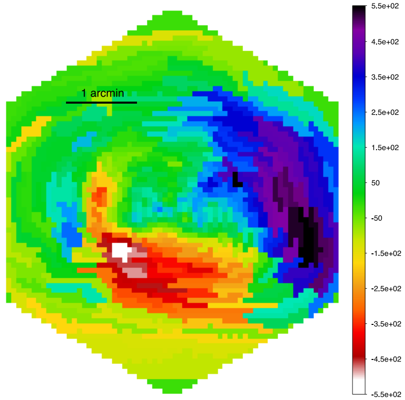
Rau et al. 2013, arXiV: 1308.6785
http://www.mpe.mpg.de/*ATHENA*-WFI/

X-ray Integral Field Unit (X-IFU)

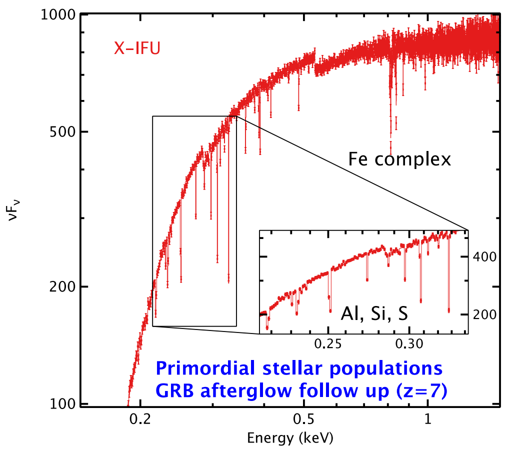
- Cryogenic imaging spectrometer, based on Transition Edge Sensors, operated at 50 mK featuring an active cryogenic background rejection subsystem

- Consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other European partners (BE, FI, GE, PL, ES, CH), NASA and JAXA

- Key performance parameters:
  - 2.5 eV energy resolution <7 keV
  - FoV 5´ diameter
  - Pixel size <5´´

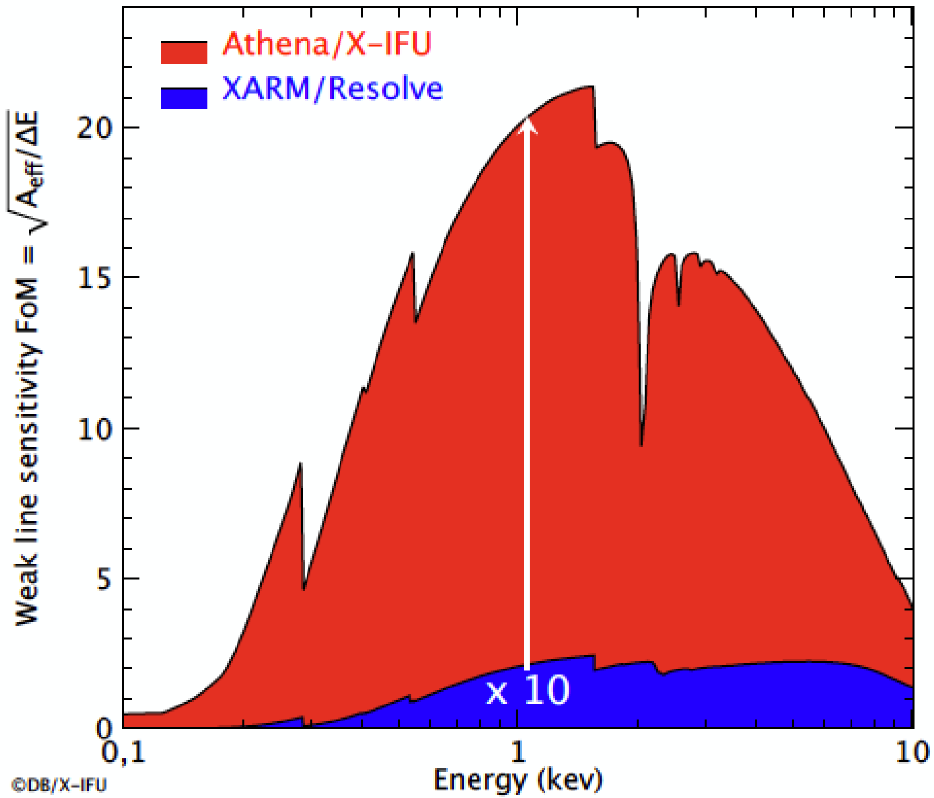


E. Pointecouteau, P. Peille, E. Rasia, V.Biffi, S. Borgani, K. Dolag, J. Wilms

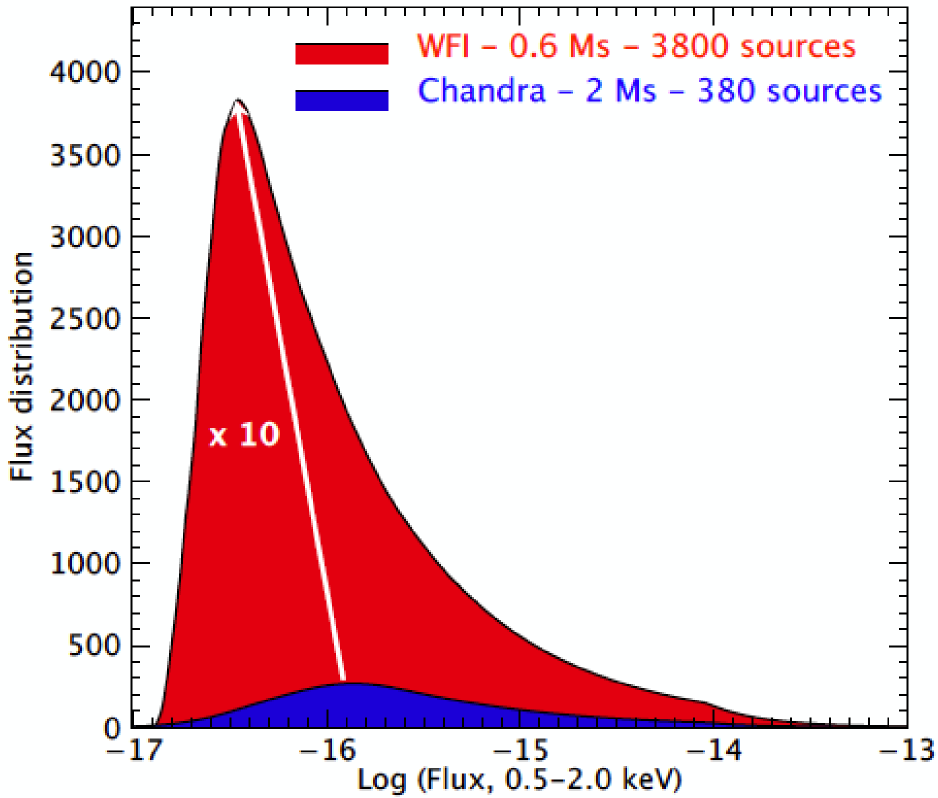


Barret et al. 2013, arXiV: 1308.6784
http://x-ifu.irap.omp.eu/

Athena: a transformational observatory



Weak line sensitivity comparison between X-IFU and XRISM

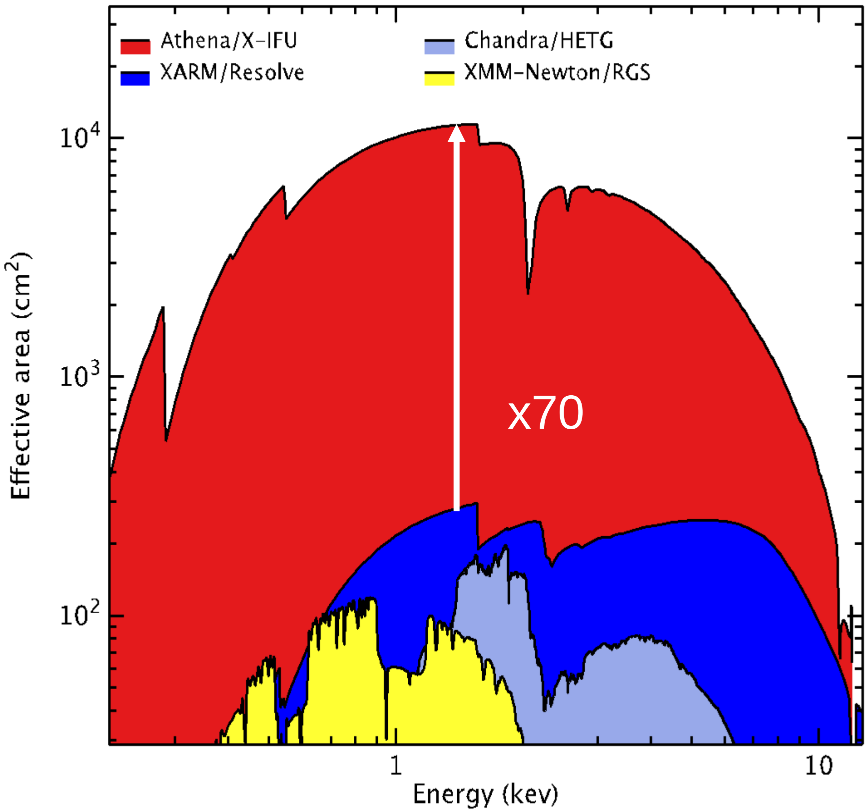


Flux distribution comparison between WFI and Chandra deep pointing

Credits: X-IFU team & J. Aird/A. Rau (WFI team)

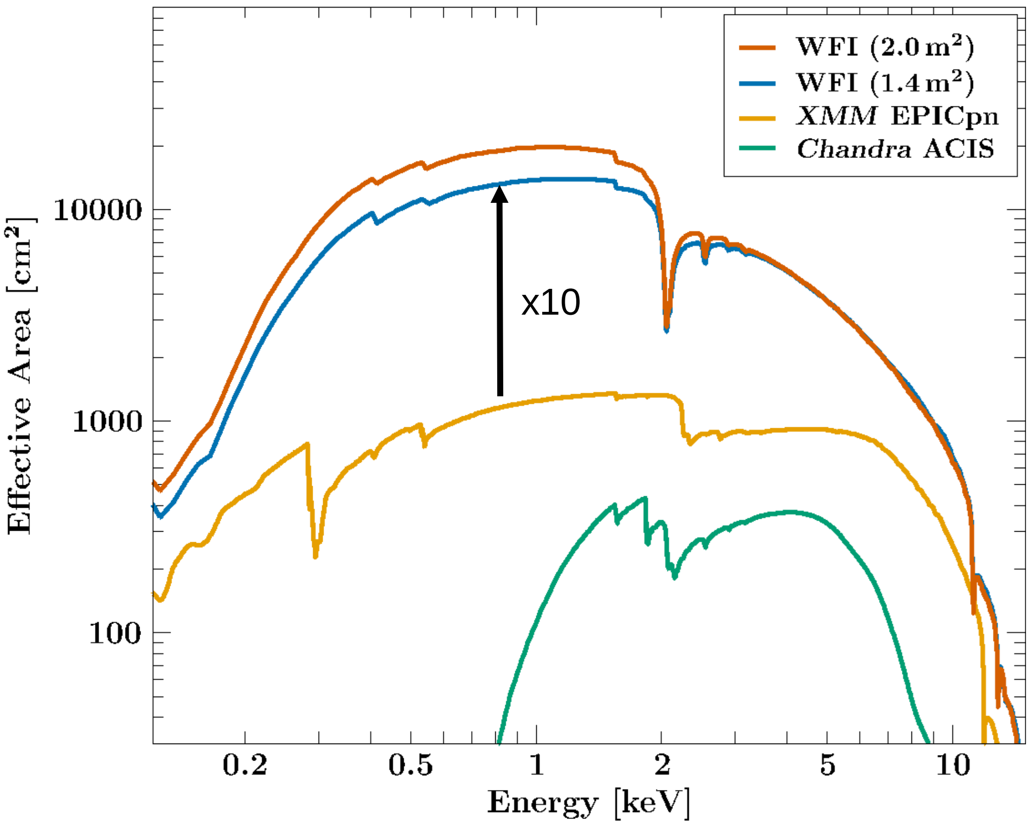
Athena is a large effective area mission

X-IFU+mirror collecting area



Courtesy D. Barret (IRAP)

WFI+mirror collecting area



Courtesy A. Rau (MPE)

Athena Community Organisation

ESA Athena Science Study Team (ASST)

M. Guainazzi (Chair), K. Nandra (Lead & WFI), D. Barret (X-IFU), A. Decourchelle, J.W. den Herder, A.C. Fabian, H. Matsumoto (JAXA), L. Piro, R. Smith (NASA), R. Willingale

SWG1 - Hot Universe
A. Fabian, T. Reiprich, T. Ohashi

- **SWG1.1 Evolution of galaxy groups and clusters** — S. Allen, N. Ota, E. Pointecouteau
- **SWG1.2 Astrophysics of galaxy groups and clusters** — D. Eckert, S. Ettori, G. Pratt
- **SWG1.3 AGN feedback in galaxy clusters and groups** — J.H. Croston, B. McNamara, J. Sanders
- **SWG1.4 Missing baryons and warm-hot intergalactic medium** — A. Finoguenov, J. Kaastra

SWG2 - Energetic Universe
L. Brenneman, M. Cappi, K. Nandra

- **SWG2.1 Formation and growth of earliest SMBH** — J. Aird, A. Comastri
- **SWG2.2 Understanding the buildup of SMBH and galaxies** — F.J. Carrera, A. Georgakakis, Y. Ueda
- **SWG2.3 Feedback in local AGN and star forming galaxies** — G. Ponti, A. Ptak, Y. Terashima
- **SWG2.4 Close environments of SMBH** — M. Dovciak, G. Matt, G. Miniutti
- **SWG2.5 Physics of accretion** — C. Done, J. Miller, C. Motch
- **SWG2.6 Luminous extragalactic transients** — P. Jonker, P. O'Brien

SWG3 - Observatory
A. Decourchelle, H. Matsumoto, R. Smith

- **SWG3.1 Solar System & exoplanets** — G. Branduardi-Raymont, M. Güdel
- **SWG3.2 Star formation and evolution** — A. Hornschemeier, G. Rauw, S. Sciortino
- **SWG3.3 End points of stellar evolution** — E. Bozzo, A. Schwope
- **SWG3.4 Supernova remnants & interstellar medium** — A. Bamba, E. Costantini
- **SWG3.5 Multiwavelength synergy** — F. Combes, M. Salvato

TWG4 – Telescope
R. Willingale, G. Pareschi

MWG5 - Mission Performance
J.W. den Herder, L. Piro, A. Rau

- **MWG5.1 Science ground segment** — M. Watson, N. Webb
- **MWG5.2 Background** — Ph. Laurent, S. Molendi
- **MWG5.3 Inter-calibration** — V. Burwitz, F. Pajot, S. Sembay
- **MWG5.4 End-to-end simulations** — Ph. Peille, J. Wilms
- **MWG5.5 Advanced analysis tools** — F. Fiore, F. Haberl
- **MWG5.6 Targets of opportunity** — S. Basa, E. Troja

The Athena Community Office

- *Athena* is currently supported by about 800 researchers. Their scientific and technical expertise are key for the success of the mission.

- The ASST appointed the *Athena* Community Office to obtain assistance in:
  - Organisational aspects and optimisation of community efforts
  - Keep the *Athena* Community informed
  - Develop communication and outreach activities around *Athena*

- Led by IFCA (CSIC-UC) in Spain, with contributions from IRAP, MPE and UniGe

Athena Project development: Current status

- Phase A ongoing, last milestone Status Review #1 (January 2018):
  - Comprehensively reviewed the Phase A work performed so far at the system level, including technical, cost and schedule aspects
  - Confirmed the good status of the spacecraft design and identified no showstopper to progressing towards adoption

- A modification of the mission baseline was needed to match mass- and cost-constraints:
  - A 15-row mirror baseline (limited science impact, preserving all major science requirements):
  - Reduction of the effective area at 1 keV from $2m^2$ to $1.4m^2$
  - Reduction of the nominal life from 5 years to 4 years

- The first major reviews of the instruments, the Instrument Preliminary Requirements Reviews (I-PRRs) are scheduled for the second half of 2018