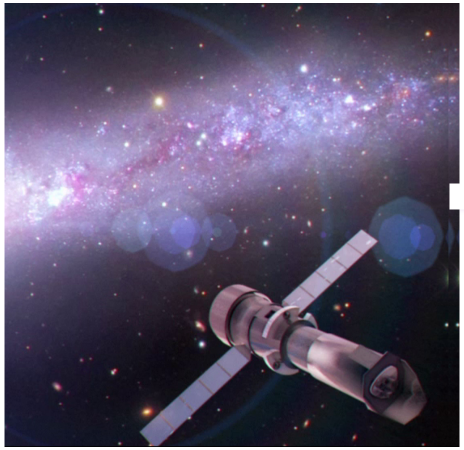
ATHENA



Athena: ESA's X-ray observatory to study the Hot and Energetic Universe in the late 2020s

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- Many thanks to:
  - The Athena Science Study Team: D. Lumb, K. Nandra. D. Barret, J.W. den Herder, A. Decourchelle, A.C. Fabian, H. Matsumoto, L. Piro, R. Smith, R. Willingale
  - The X-IFU team, in particular D. Barret, J.W. den Herder, L. Piro, Th. Lam-Trong, E. Pointecouteau.
  - The Spanish Athena people: J.M. Mas-Hesse, M.T. Ceballos, F.J. Carrera, J.M. Torrejón, J.J. Rodes, G. Miniutti, S. Martínez, P. Monterde

Advanced Telescope for High-Energy Astrophysics

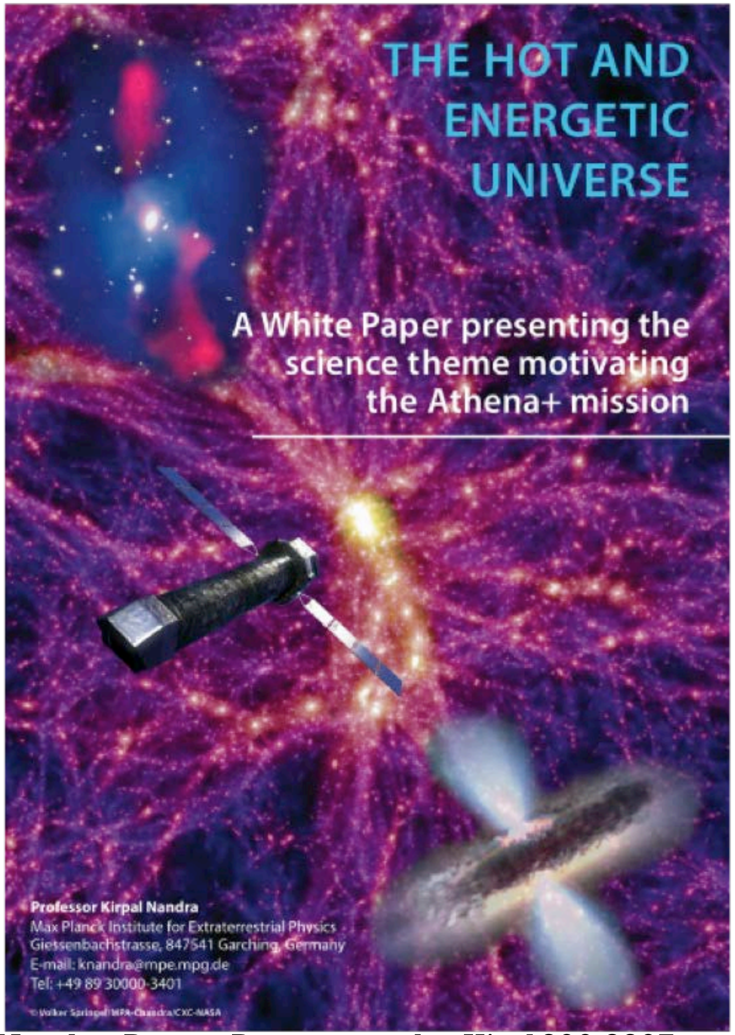
- Second Large (L) mission of ESA Cosmic Vision 2015-2035
- Science theme: The Hot and Energetic Universe
  - How does ordinary matter assemble in the large-scale structures?
  - How do black holes grow and shape galaxies?
- In addition:
  - Fast ToO capability to study transient sources
  - Observatory science across all corners of Astrophysics

Athena S/C CDF design (ESA)

The Hot and Energetic Universe

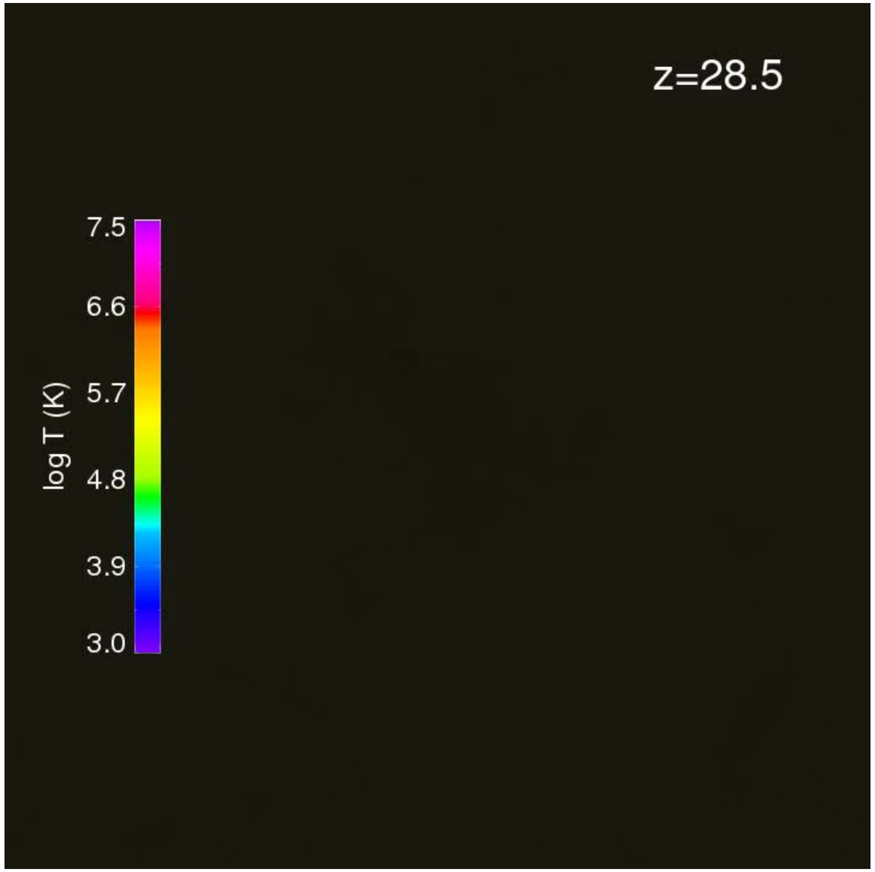
- The Hot Universe: How does the ordinary matter assemble into the large-scale structures that we see today?
  - >50% of the baryons today are in a hot (>10^6 K) phase
  - there are as many hot (> 10^7 K) baryons in clusters as in stars over the entire Universe

- 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

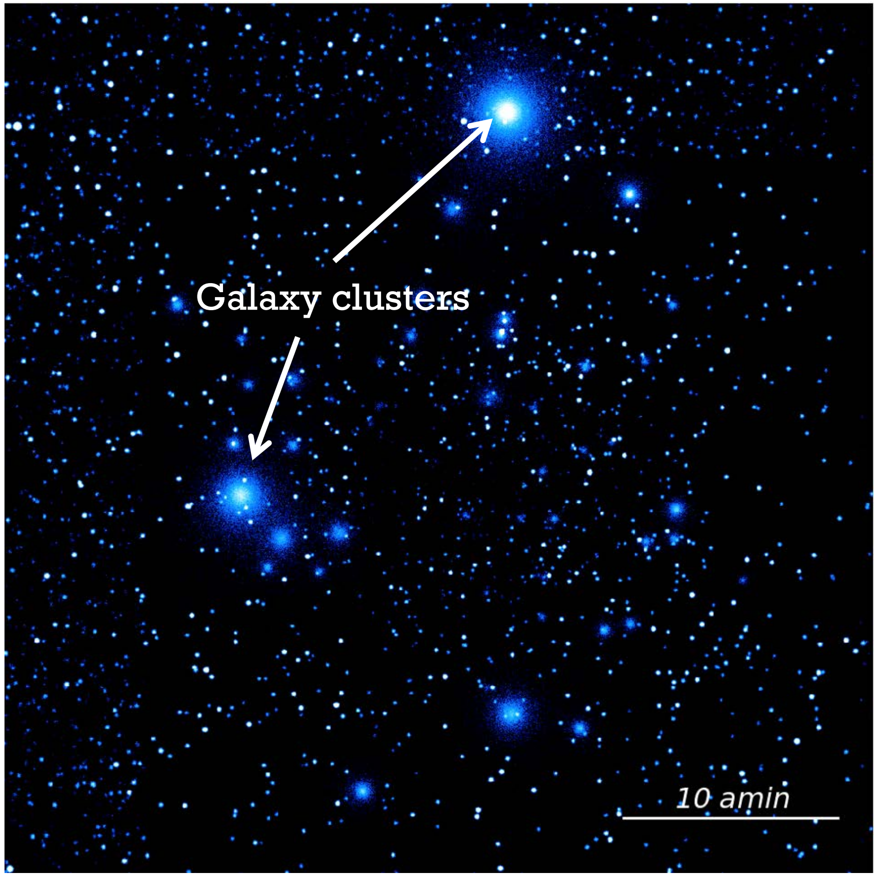


Nandra, Barret, Barcons et al arXiv:1306.2307

The Hot Universe – baryonic assembly



Oppenheimer et al 2009

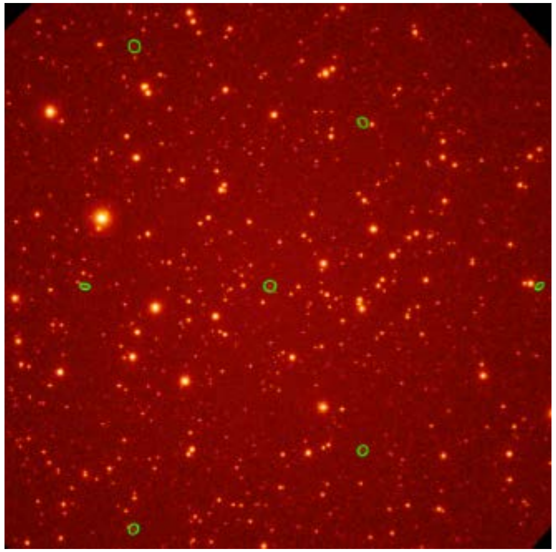


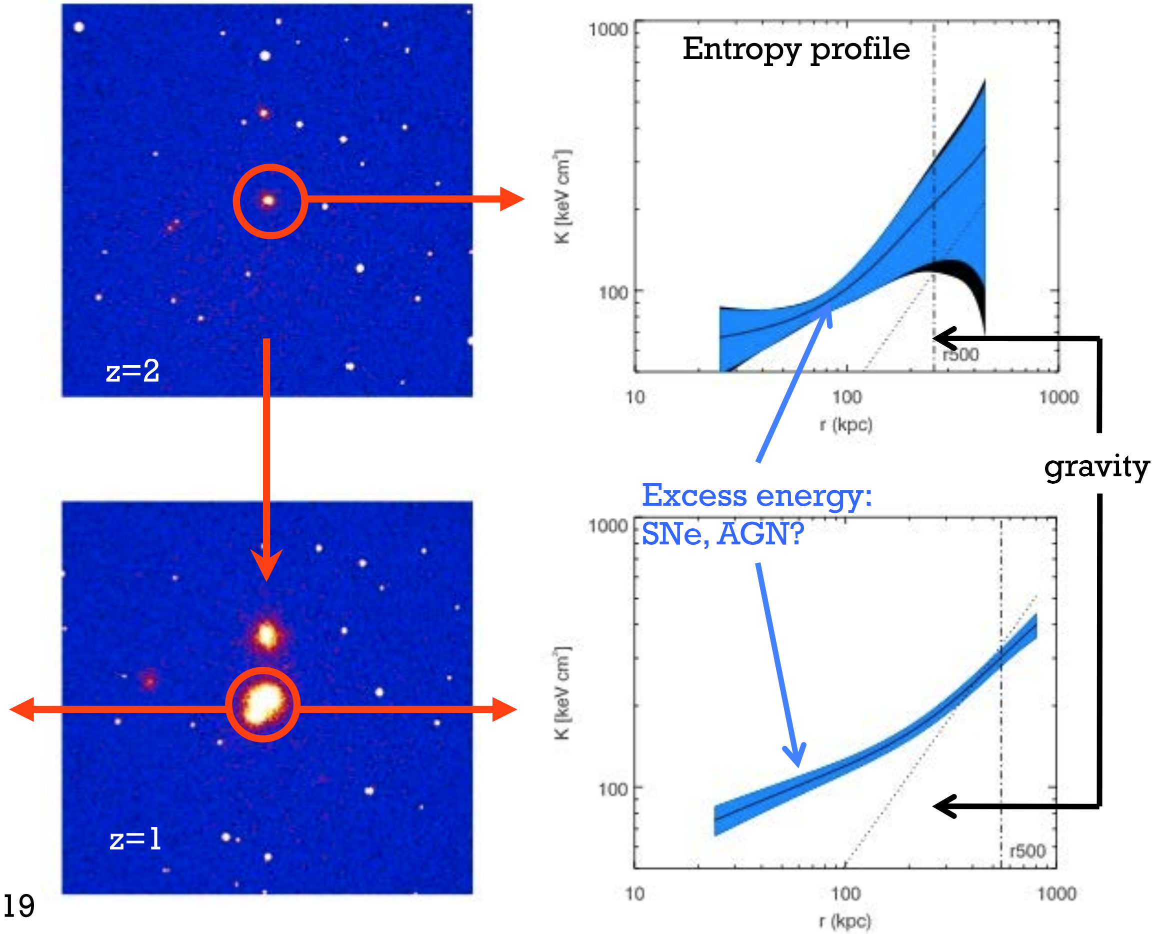
Athena/WFI 1Ms simulation
MPE & WFI team

Evolution of hot cluster gas

Energy deposition history

Search for the first groups
of galaxies at z>2

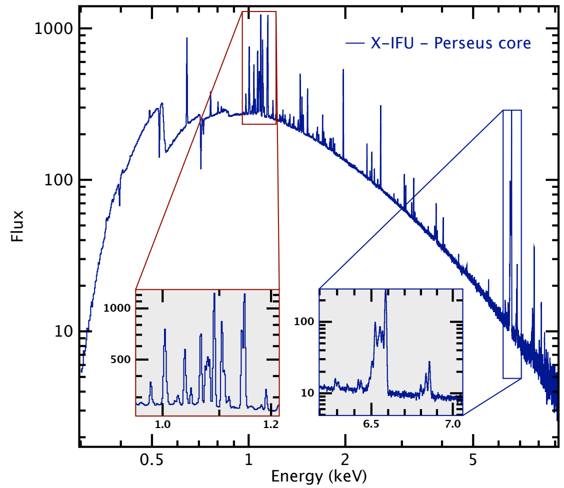


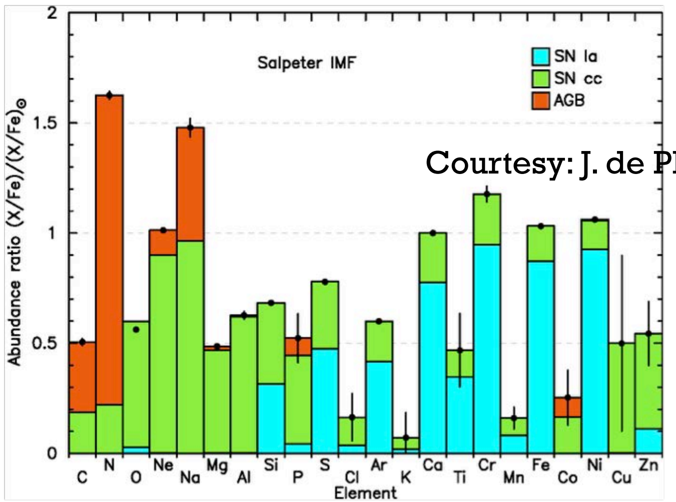


Ettori, Pratt et al. 2013 arXiv1306.2322
Pointecouteau, Reiprich et al 2013, arXiv: 1306.2319

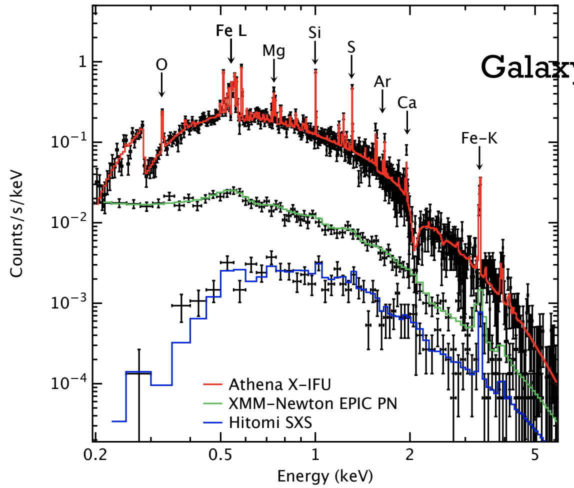
Chemical evolution

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





Courtesy: J. de Plaa 2016

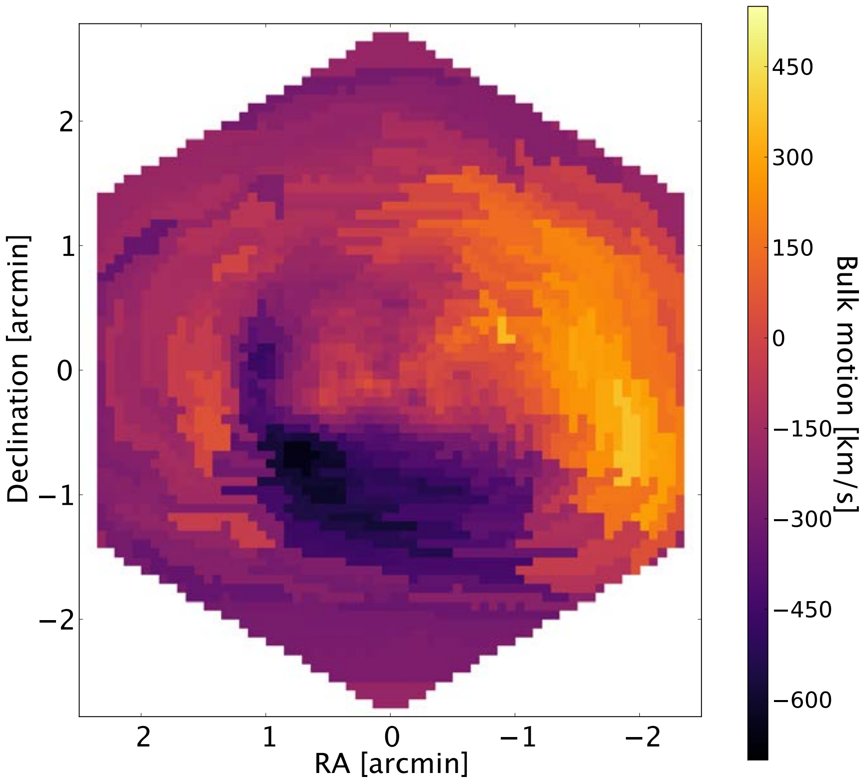


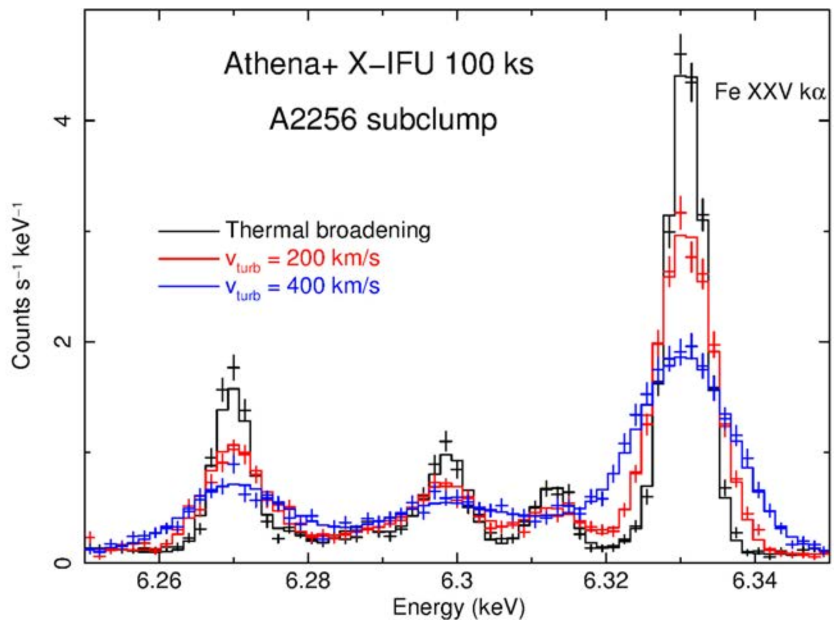
Galaxy group @z=1

Barret et al 2016, SPIE

Bulk motions & turbulence

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





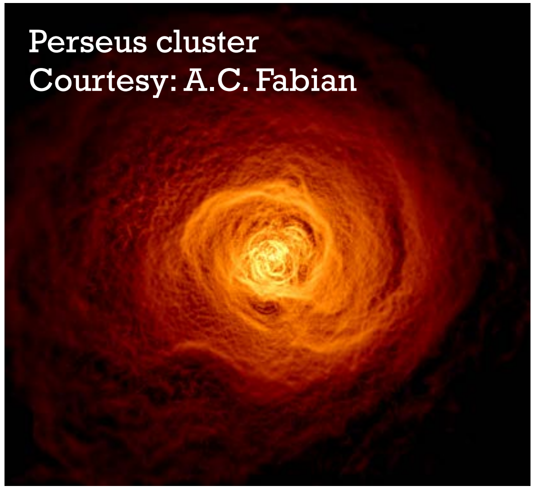
Courtesy: E. Pointecouteau, P. Peille, G.W. Pratt, E. Rasia, V. Biffi, S. Borgani, K. Dolag

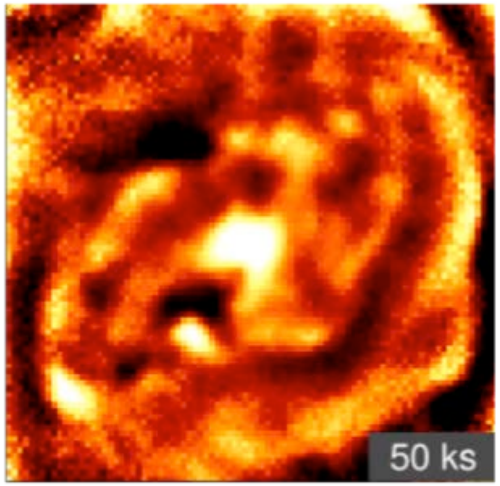
Ettori, Pratt et al. 2013 arXiv1306.2322
Pointecouteau, Reiprich et al 2013, arXiv: 1306.2319

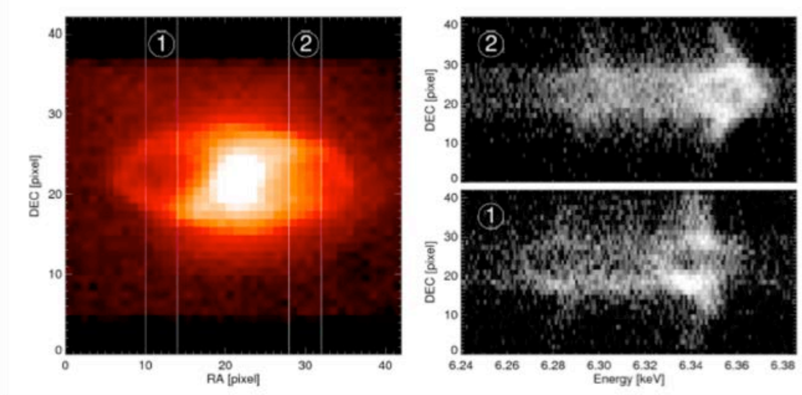
CSIC
Instituto de Física de Cantabria
UC UNIVERSIDAD DE CANTABRIA

AGN feedback on cluster scales

- Dissipation 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





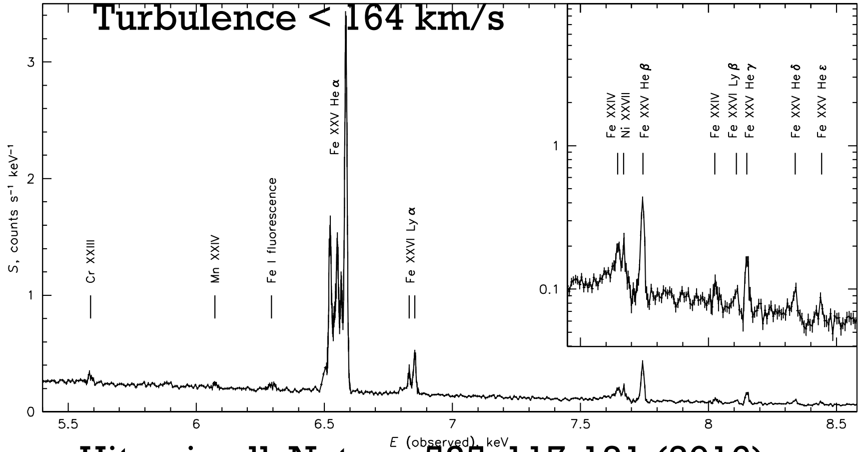
Croston, Sanders et al., 2013 arXiv1306.2323
Simulations by S. Heinz

Hitomi (Feb-Mar 2016)

- The JAXA Hitomi satellite was launched in February 2016, with an X-ray calorimeter on board (resolution~5 eV)
  - Unfortunately, the S/C was lost in March 2016
  - But it had taken 275 ks of data of the Perseus cluster, above 2 keV.
  - DATA ARE AMAZING!

Perseus cluster core

Turbulence < 164 km/s



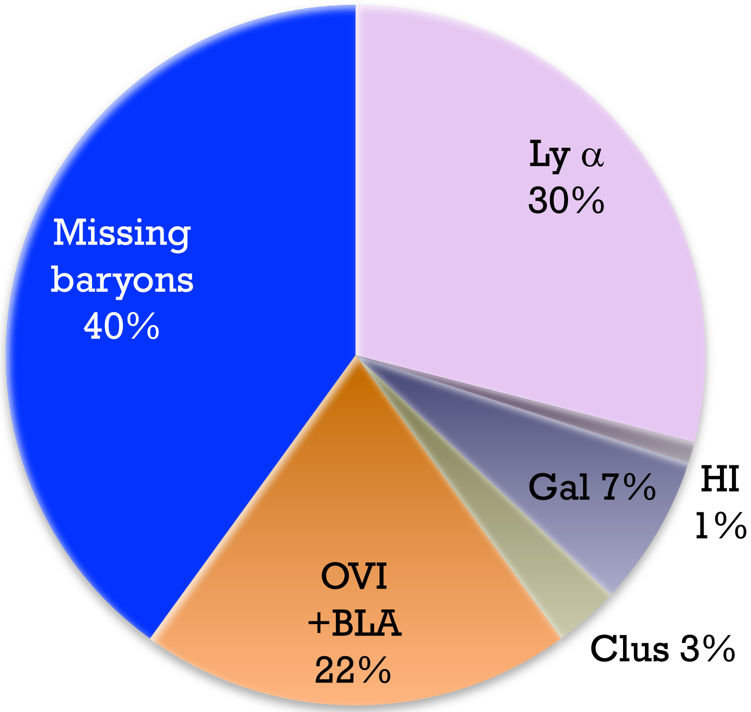
Hitomi coll, Nature, 535, 117-121 (2016)

Courtesy: A.C. Fabian

Missing baryons: the WHIM

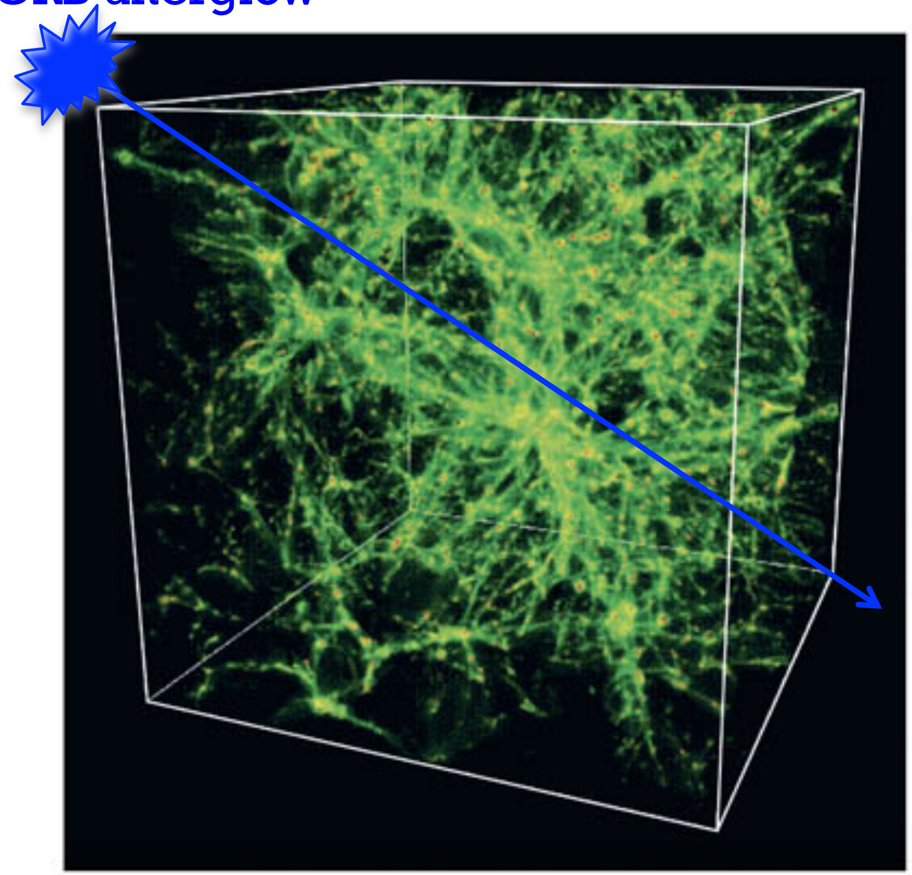
- Cosmological hydro simulations show ~50% of baryons at **$T\sim10^5$-10^7** K in the IGM.
  - Unvirialised and filamentary distribution

- How can they be detected?
  - In absorption:
    - Against a **bright background source (AGN or GRB afterglow)**
    - Detection only along specific lines of sight
  - In emission:
    - Tenuous and extended
    - Need to fight the background
    - Large sky area coverage

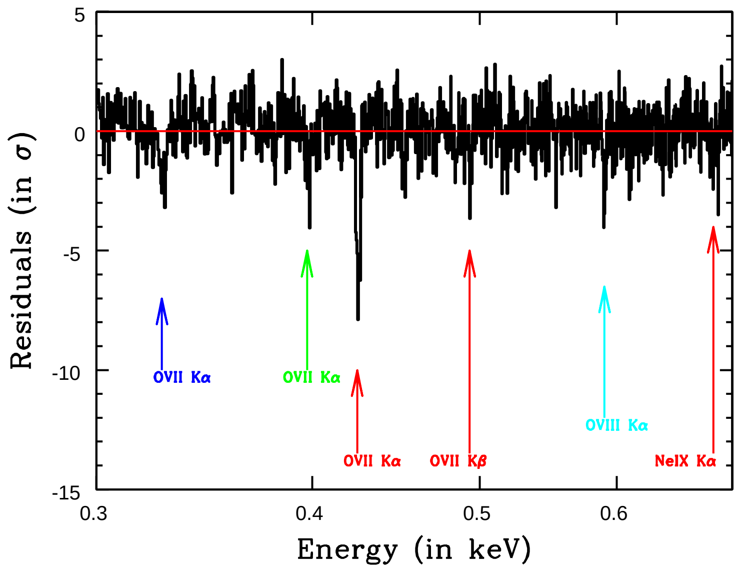


Characterising the missing baryons

BL Lac or
GRB afterglow

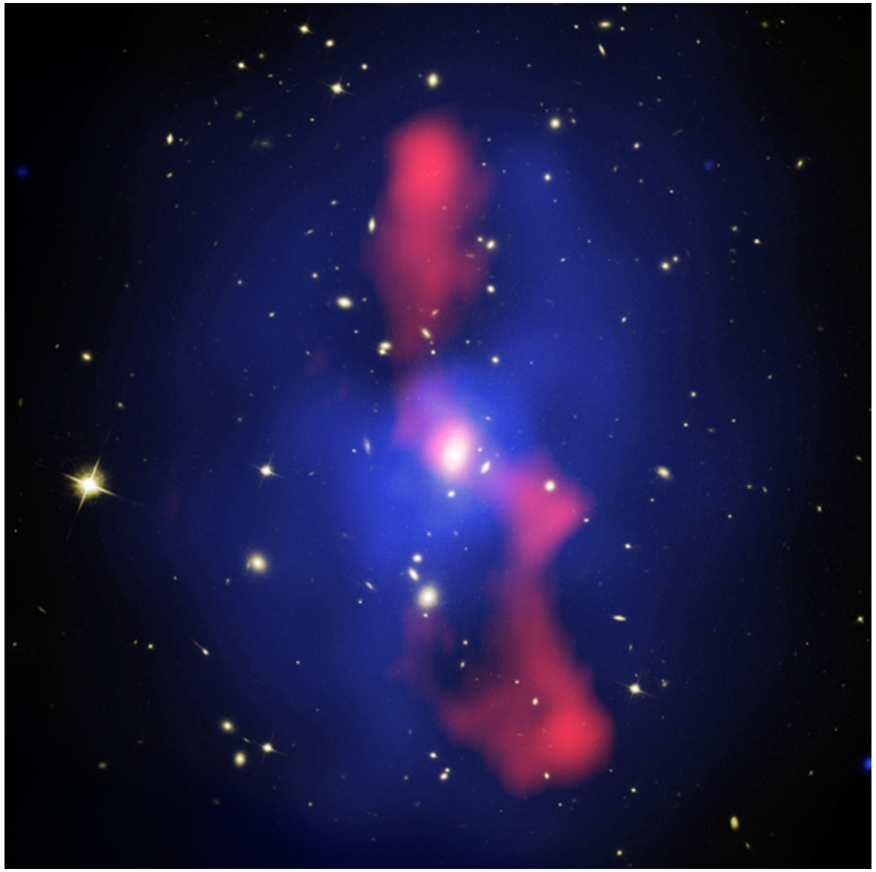


Cen & Ostriker 2006

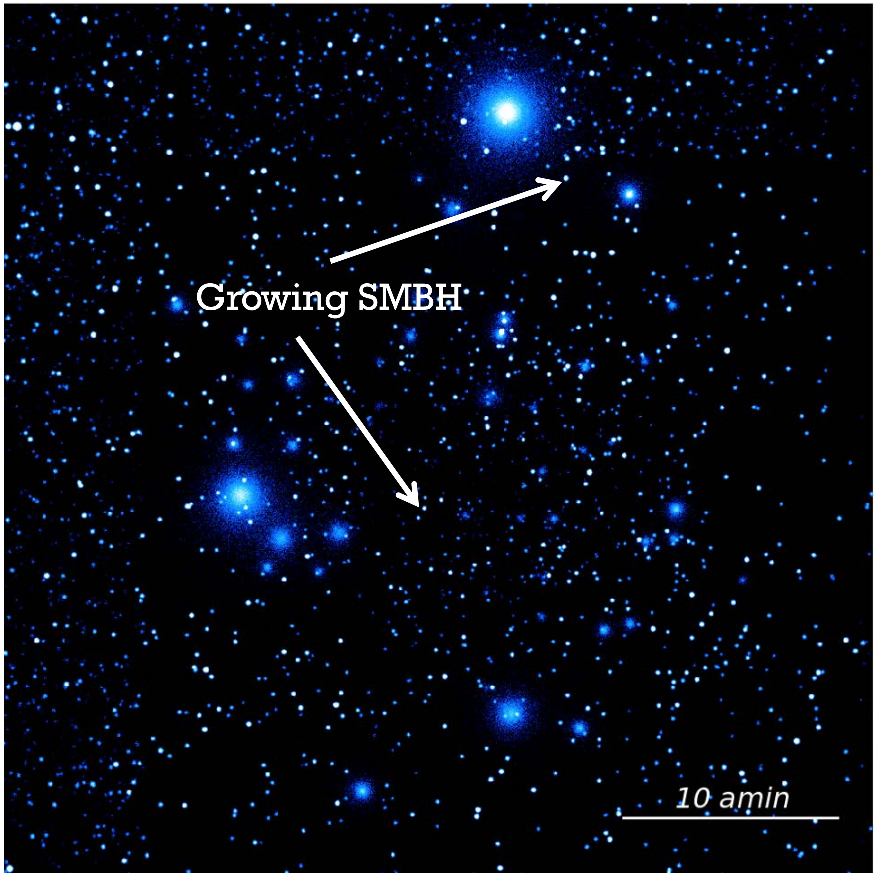


Barret et al 2016, SPIE
Courtesy: F. Nicastro

The Energetic Universe – Black Holes



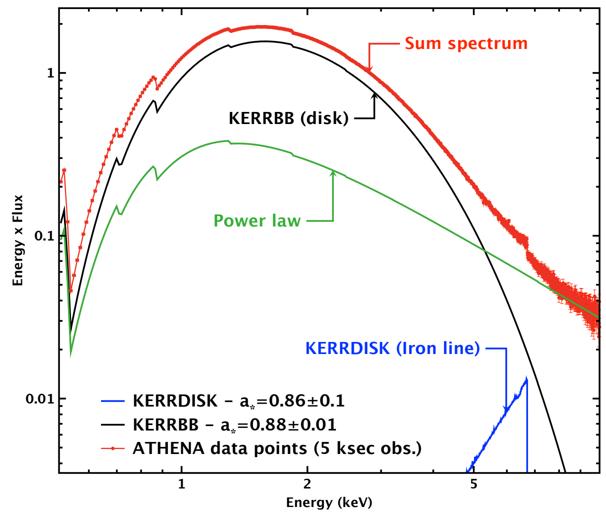
MS0735.6+7421 McNamara et al 2005

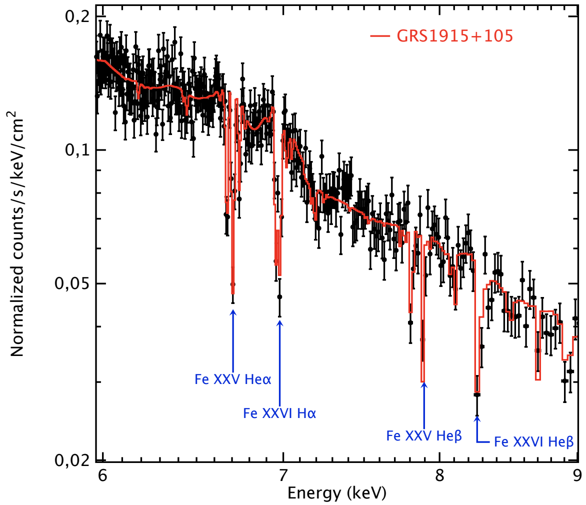


Athena/WFI 1Ms simulation
MPE & WFI team

BH accretion physics

- Measure BH spins
  - Constraints on SN origin
  - Relation to jets



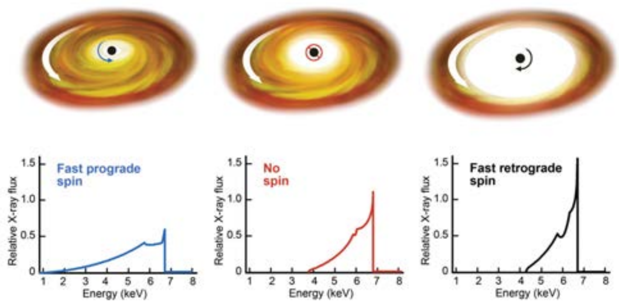


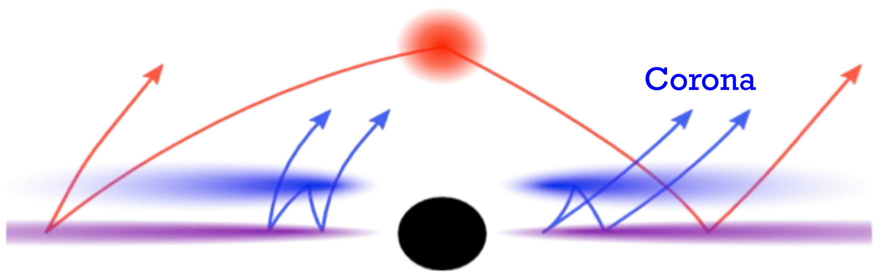
- Accretion geometry
  - Disc truncation from lag spectra
  - Winds as diagnostics of the accretion flow

Courtesy J.M. Miller
Barret et al 2016 SPIE2016

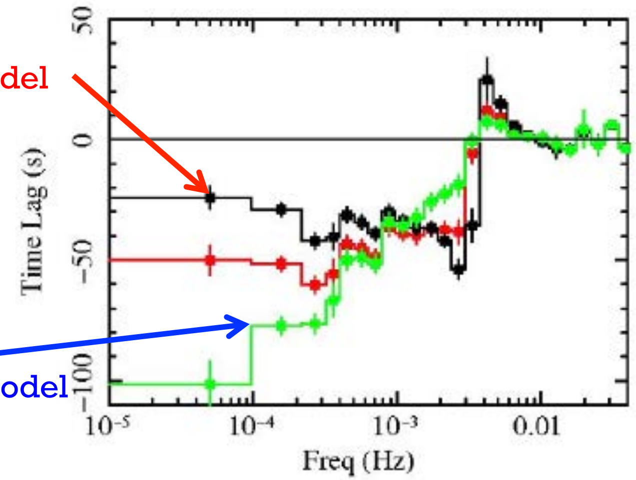
Supermassive Black Hole physics

- Measure SMBH spins through Fe line spectroscopy





- Accretion geometry and jet/disk relation through reverberation mapping

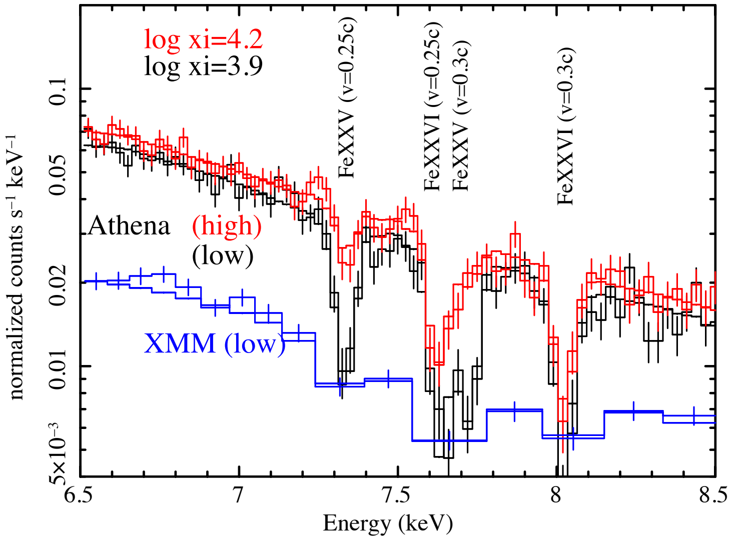


Dovciak, Matt et al 2013, arxiv:1306.2331

AGN winds and outflows

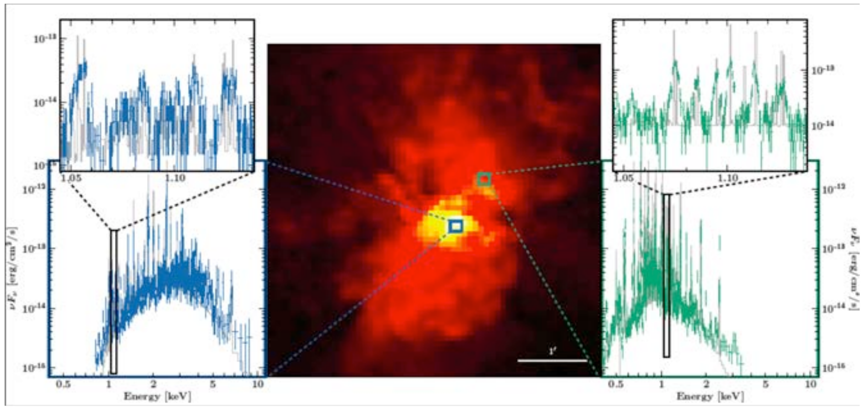
Feedback effective if
$L_{mech} > 1\% \ L_{bol}$

Mechanical energy released in ultra-fast outflows ~v^3



Cappi, Done et al 2013, arxiv:1306.2330

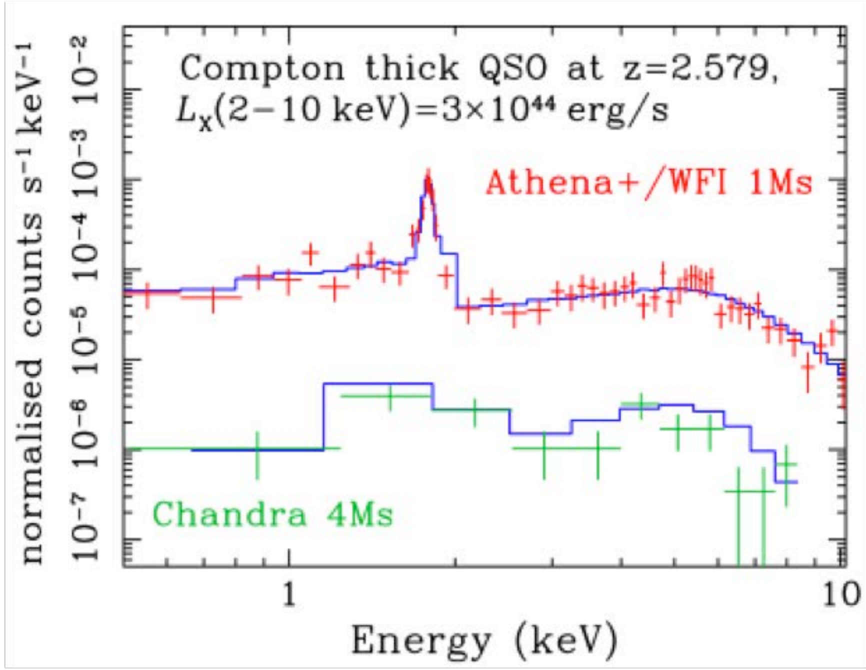
Gas, metals and mechanical energy ejected in the circum-galactic medium by AGN and Starbursts



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

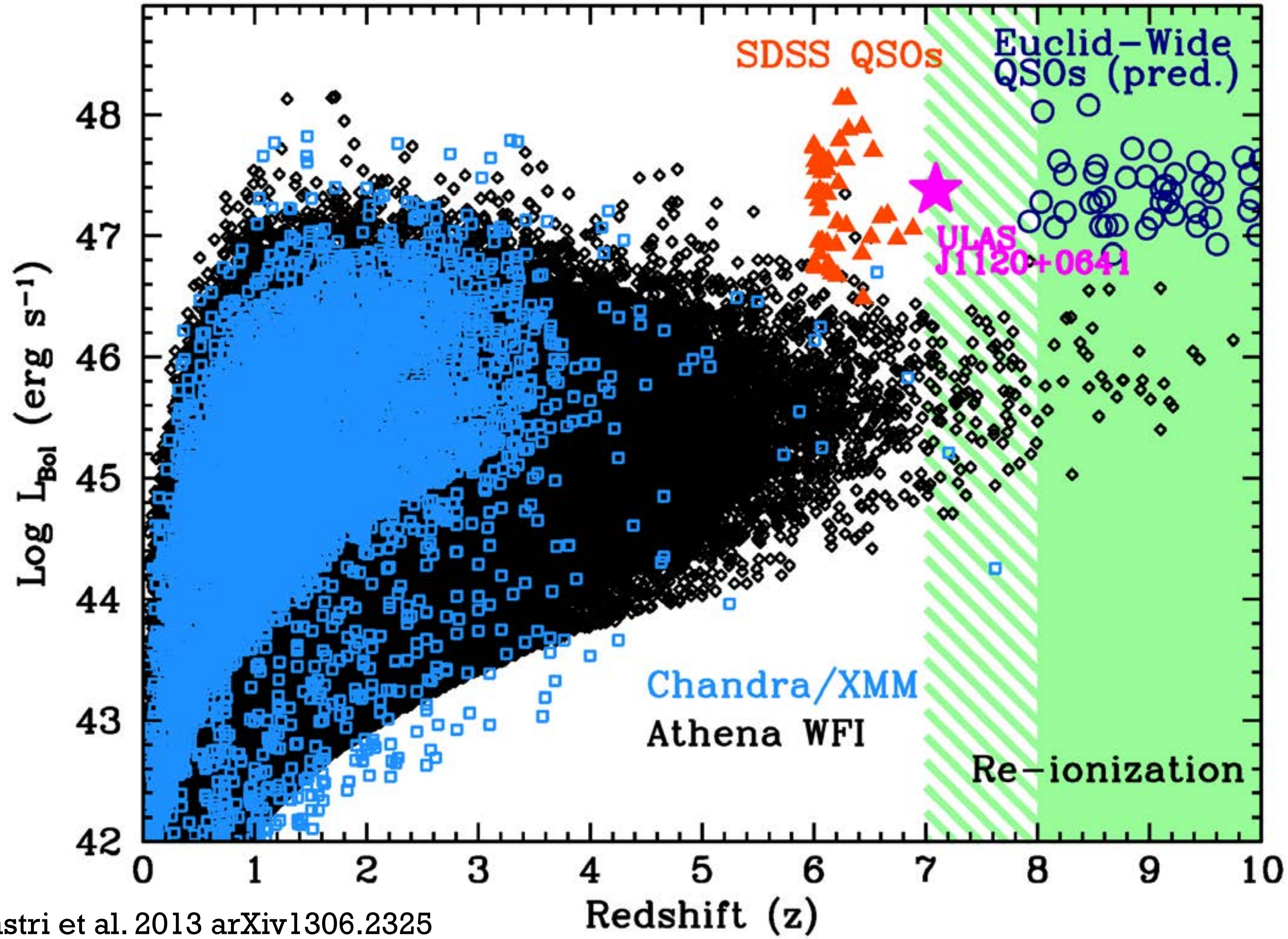
Obscured AGN census @ z~1-3

- 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 signal of Compton-Thick AGN is the Fe emission line, EW ~0.5-1 keV.
  - Athena/WFI observations can uncover CT L* AGN @ z<3
    - MIR observations can reliably uncover heavily obscured AGN, but only when the AGN is very powerful.



Georgakakis, Carrera et al., 2013 arXiv1306.2328

The history of SMBH growth

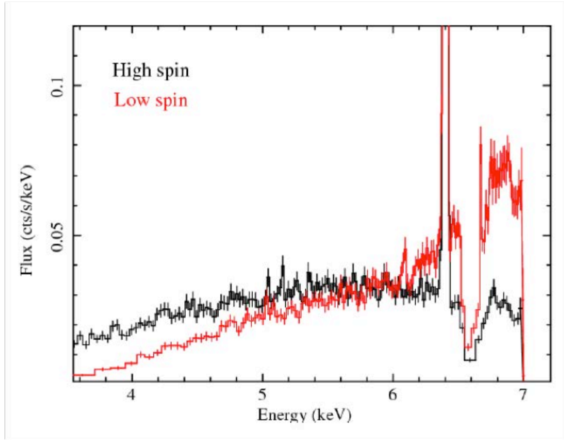


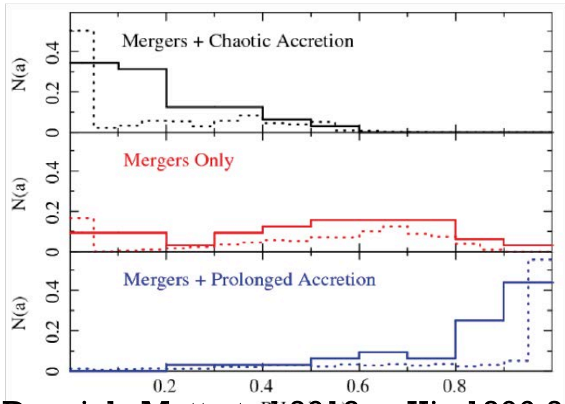
Comastri
Lanzuisi
Aird (2016)

Aird, Comastri et al. 2013 arXiv1306.2325

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
  - Partly doable with XMM-Newton, but for removal narrow features
- Biases: Highly spinning SMBH are radiatively more efficient and therefore are overrepresented in flux-limited samples (Vasudevan et 2016)
  - Athena can obtain spins for fainter sources and correct for this effect

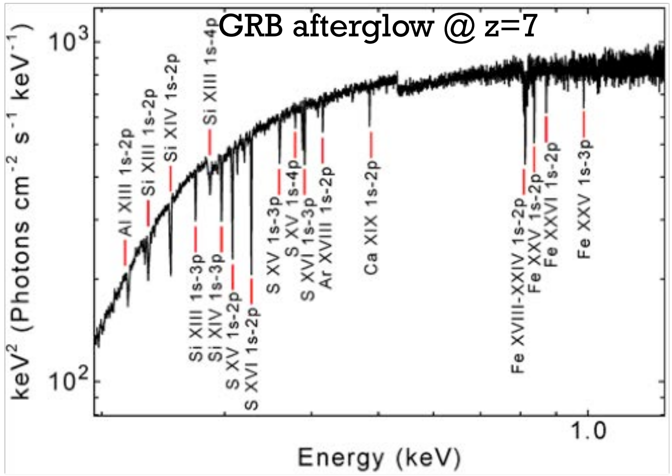


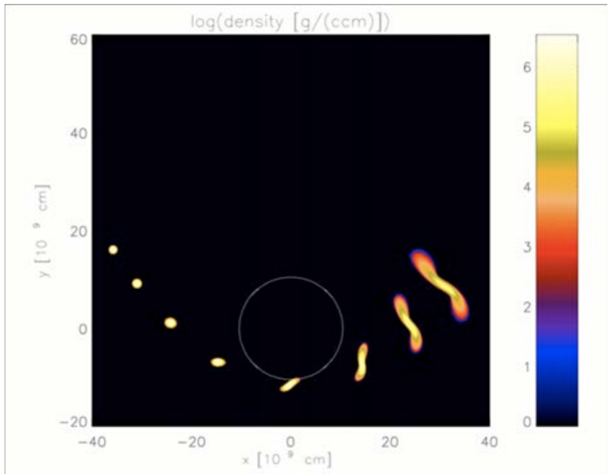


Dovciak, Matt et al 2013: arXiv 1306.2331
simulations by G. Miniutti

Luminous extragalactic transients

- Athena will offer a quick Target of Opportunity facility, whereby a triggered observation could start in 4 hours ~40% of the cases.
- 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

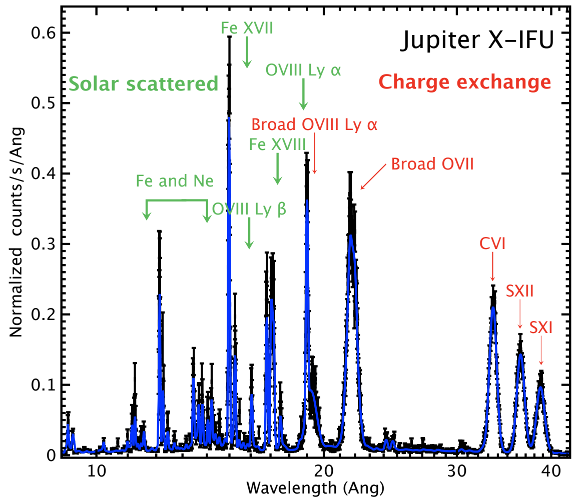


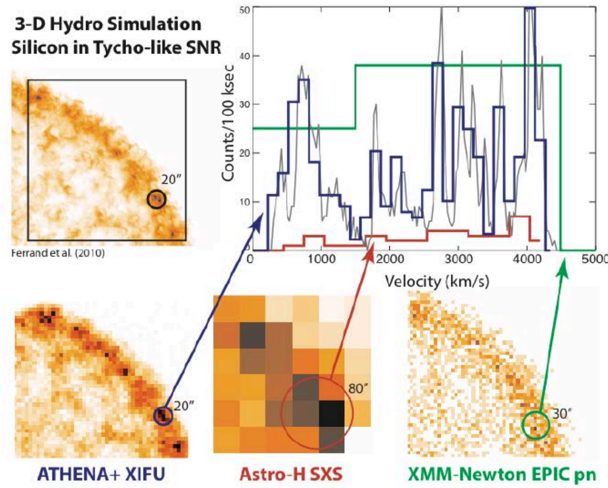


Jonker, O'Brien et al 2013: arXiv 1306.2336
Rosswog, Ramirez-Ruiz & Rix (2009)
Courtesy: P.T. O'Brien and P. Jonker

Observatory Science – all corners of astrophysics

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



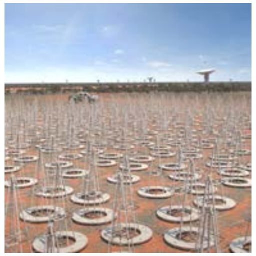


Athena Synergies with other facilities

- ESO-Athena Synergy exercise underway since March 2016
  - Led by ESO-Athena Synergy Team: P. Padovani (chair), E. Hatziminaglou, M. Díaz-Trigo, S. Viti, S. Ettori, M. Salvato, F. Combes, P. Jonker
  - Leading to 2 Synergy White Papers ~March 2017: opt/NIR and sub/mm
  - Synergy topics span a broad range of astrophysics
- SKA-Athena Synergy exercise starting now
  - Led by SKA-Athena Synergy team: R. Cassano (chair), R. Fender, C. Ferrari, A. Merloni.
  - Synergy White Paper due by ~fall 2017
  - AGN, clusters & transients

Athena in the framework of the late 2020s

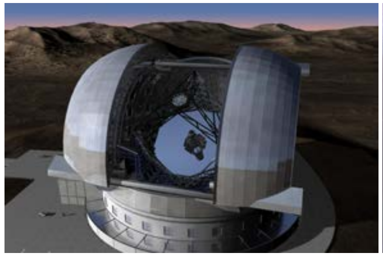
SKA



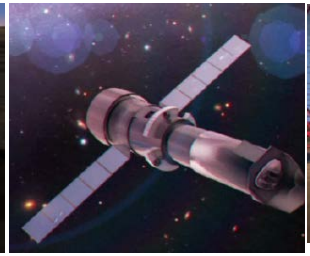
ALMA

JWST

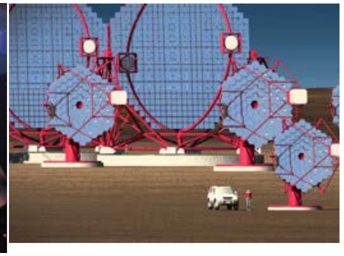
E-ELT

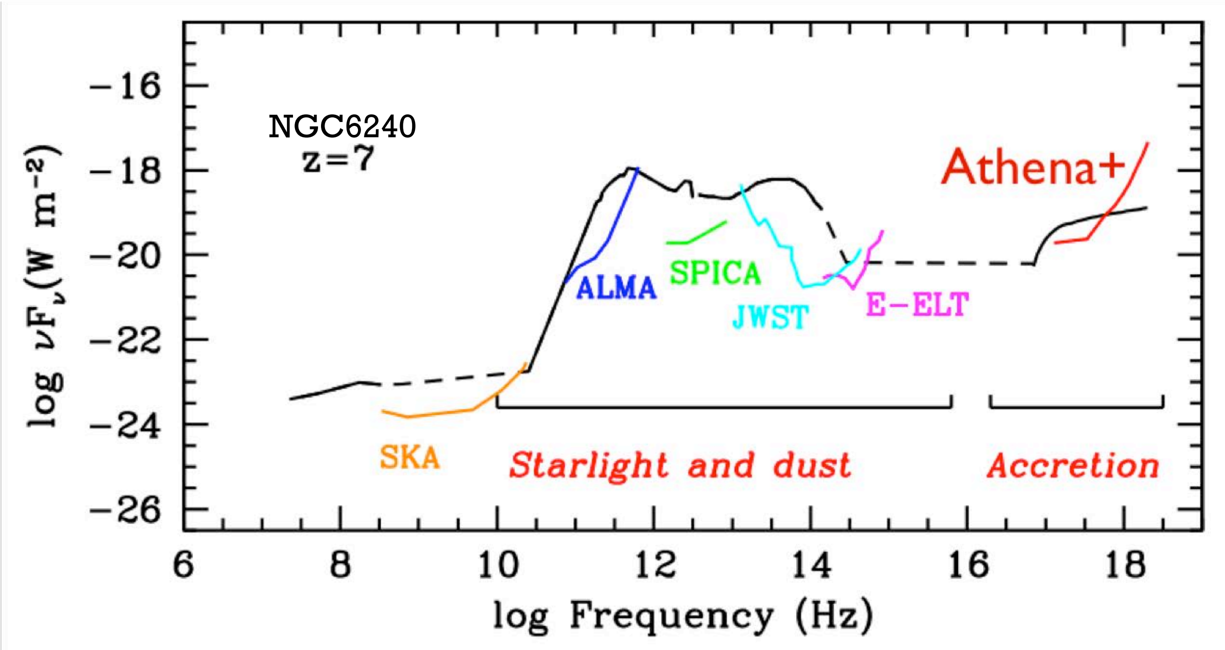


Athena



CTA





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' diameter	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

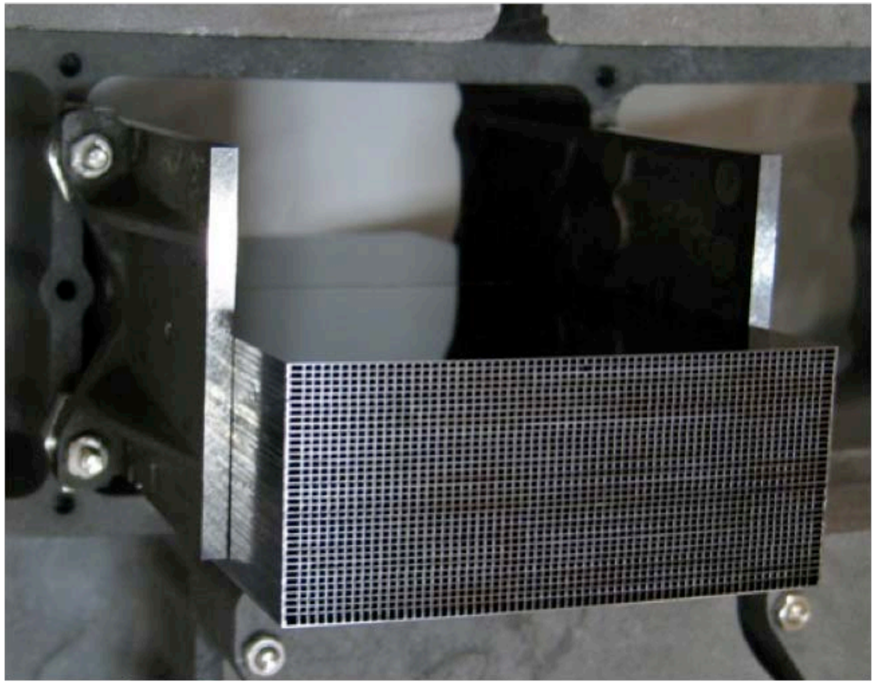
Athena mission concept

- 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 2028, Ariane 64
- L2 halo orbit (TBC)
- Lifetime > 5 yr

Athena concept, ESA CDF

The Athena telescope

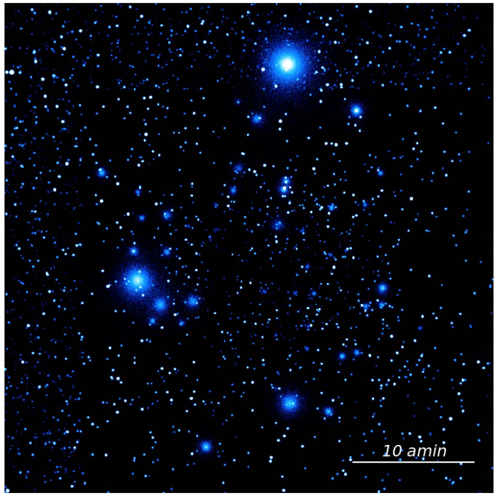
- Light-weight Si-pore optics:
  - 5” HEW on-axis
  - Graceful degradation off-axis, <10” @ 15’
  - 2 m^2 effective area @ 1 keV, with 3.9 m aperture diameter
  - Limited vignetting at 1 keV
- Athena optics development:
  - Grazing incidence optics, Wolter-I type (paraboloid-hyperboloid), largely with conical approximation
  - Vigorous development programme at ESA and industry.

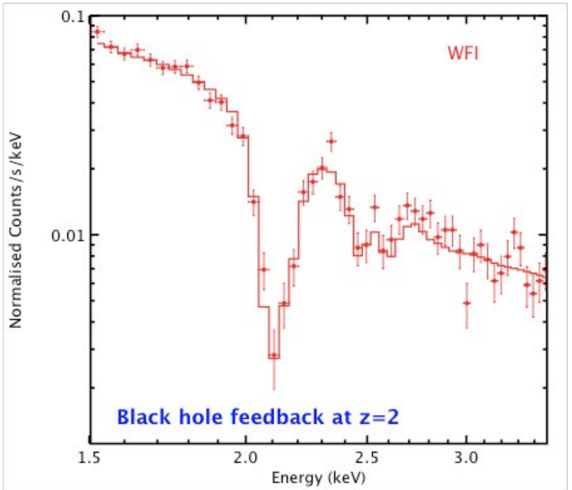


Willingale et al 2013, arXiV: 1308.6785

Wide Field Imager (WFI)

- 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’
  - Separate chip for fast readout of brightest sources
  - Readout speed up to ~30 MHz
- Consortium led by MPE, with other European partners and NASA
- Optimized for sensitive and wide imaging and intermediate resolution spectroscopy, up to very bright sources





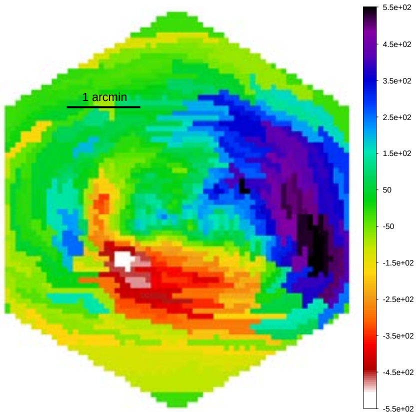
Rau et al 2013, arXiV: 1308.6785

X-ray Integral Field Unit (X-IFU)

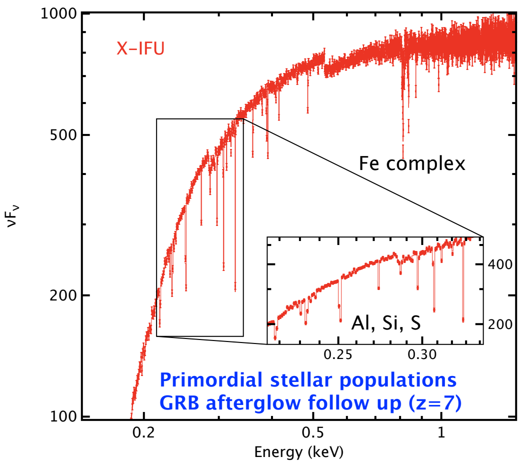
- Cryogenic imaging spectrometer, based on Transition Edge Sensors, operated at 50 mK featuring an active cryogenic background rejection subsystem

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

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

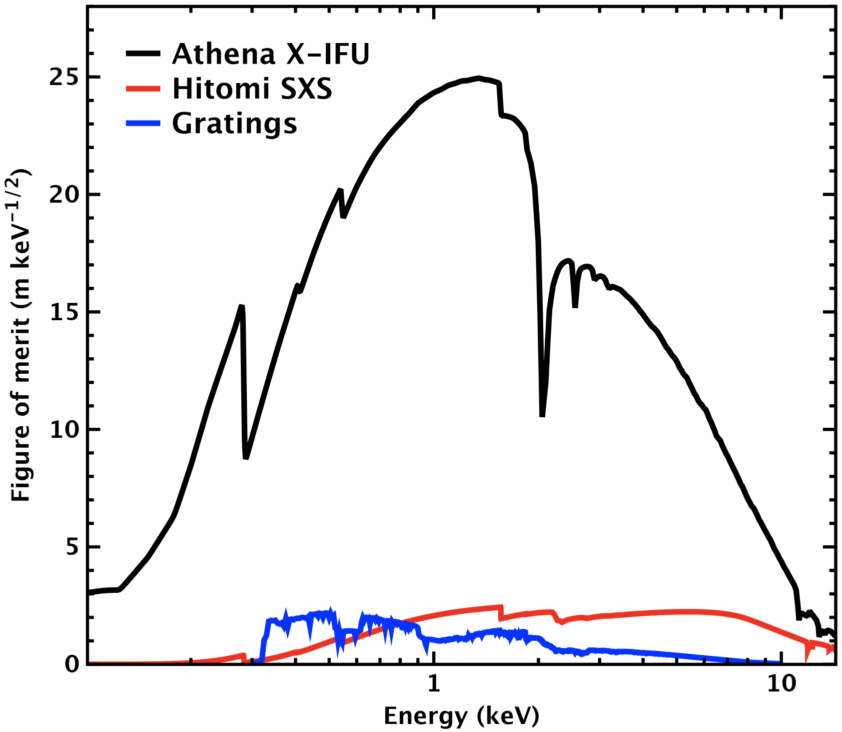


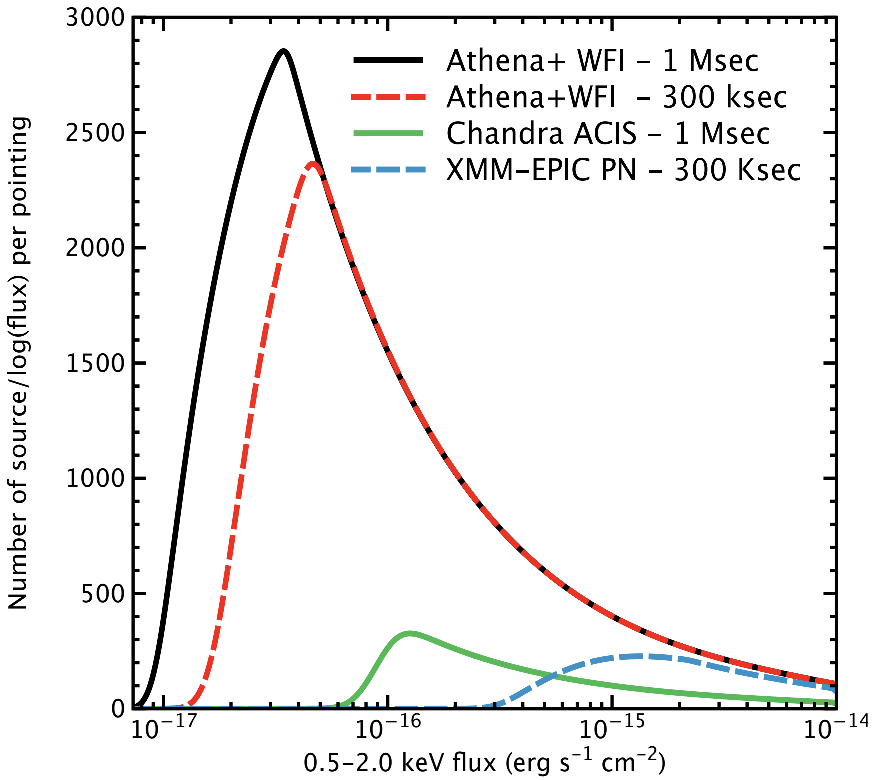
E. Pointecouteau, P. Peille, G.W. Pratt, E. Rasia, V.Biffi, S. Borgani, K. Dolag, J. Wilms



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

Athena: a revolutionary observatory





Athena Community Organisation

ESA Athena Science Study Team (ASST)

D. Lumb (Chair), K. Nandra (Lead & WFI), X. Barcons, D. Barret (X-IFU), A. Decourchelle, J. W. den Herder, A. 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** — X. Barcons, L. Brenneman, M. Cappi
  - **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

CSIC Consejo Superior de Investigaciones Científicas — Instituto de Física de Cantabria — UC Universidad de Cantabria

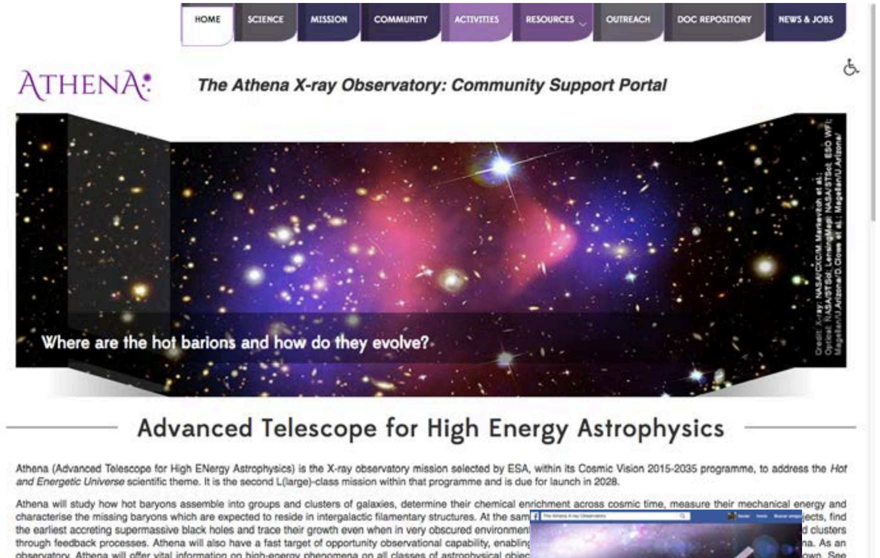
See poster IS8 by Silvia Martínez-Núñez

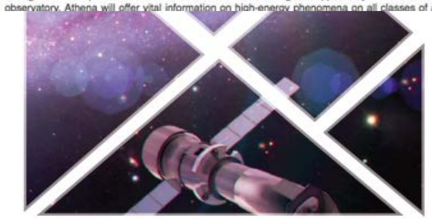
The Athena Community Office

- Athena is currently supported by more than 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
  - Maintain the Athena Community informed
  - Develop communication and outreach activities around Athena

- Follow us on:
  - www.the-athena-x-ray-observatory.eu
  - Twitter @athena2028
  - FB: The Athena X-ray observatory





Athena Project development: Current status

- Phase A on-going, Jun 2015 to end 2017 (PRR)
  - System-level tradeoffs, spacecraft conceptual design
  - Development of the 2 instrument concepts by the consortia
  - Technology development activities (optics, cryo-coolers etc)
  - Contribution from external partners (NASA & JAXA)
- Mission Consolidation Review (MCR) Apr/May 2016 - > ΔPhaseA1
  - Mission concepts are sound
  - Instrument switching mechanism is through a Movable Mirror Assembly
  - Instrument resources challenging: all being addressed or already fixed.
  - Mass lift capacity of Ariane 64 fixed to 7 Tons
  - Consolidation of the Cost at Completion underway
  - **Mission concept to be carried over is that of the proposed mission, with 2 m^2 effective area at 1 keV**

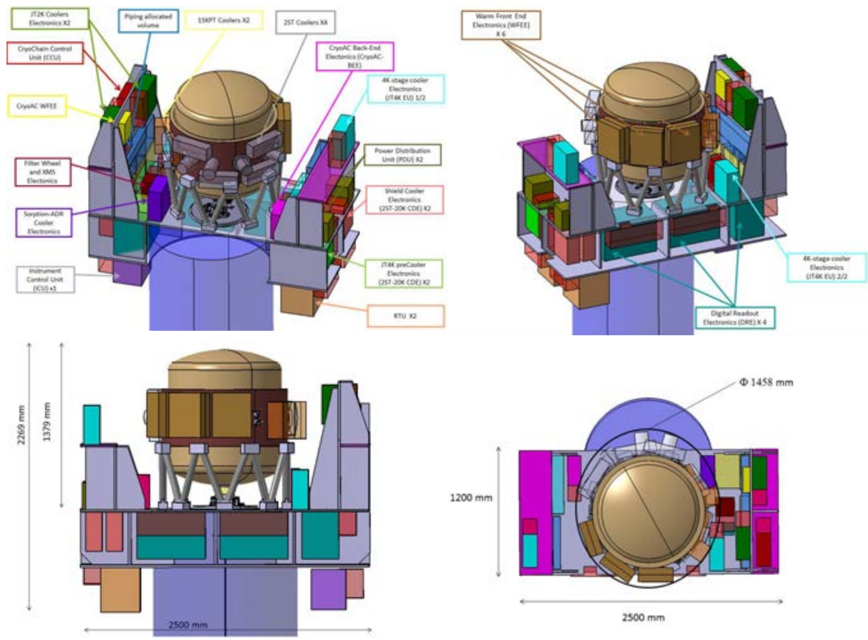
Spanish participation in Athena

- At mission level
  - X. Barcons serves in ESA's Athena Science Study Team
  - Total 48 researchers from institutions in Spain serve in the Athena Community Working Groups and Topical Panels
    - 1 Working Group co-chair and 2 Topical Panels co-chairs (F.J. Carrera & G. Miniutti)
  - Athena Community Office led by IFCA
- At instrument level, all participation focused in the X-IFU

The Athena X-ray Integral Field Unit

- Cryogenic imaging spectrometer:
  - based on Transition Edge Sensor
  - operated at 50 mK
  - multi-stage cooling chain
  - active cryogenic background rejection subsystem
- Consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other partners in Belgium, Finland, Germany, Poland, Spain Switzerland and international partners (NASA and JAXA)
- Optimised for:
  - Spatially resolved X-ray spectroscopy
  - High-resolution spectroscopy

X-IFU preliminary mechanical design



Barret, den Herder, Piro et al 2013 arXiv: 1308.6784
Barret et al 2016, SPIE

X-IFU top level requirements

ATHENA X-ray Integral Field Unit

Parameter	Value
Energy range	0.3 (0.2)-12 keV
Energy resolution at E < 7keV	2.5 (1.5) eV
Energy resolution at E > 7keV	E/ΔE=2800
Field of View	5 arcmin (diameter)
Detector Quantum Efficiency at 1 keV	> 75%
Detector Quantum Efficiency at 6 keV	> 83%
Gain error (rms)	0.4 eV
Count rate capability – faint source	1 mCrab (>80% high-resolution events)
Count rate capability – bright source	1 Crab (>30% low-resolution events)
Time resolution	10 μs
Non X-ray background	< 5 10^{-3} counts/s/cm^2/keV (3 10^{-4} counts/s/cm^2/keV)

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IFCA Instituto de Física de Cantabria
UC Universidad de Cantabria

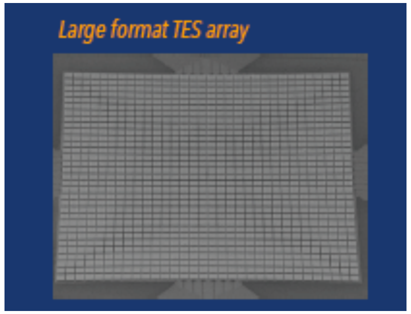
X-IFU technical in a nutshell

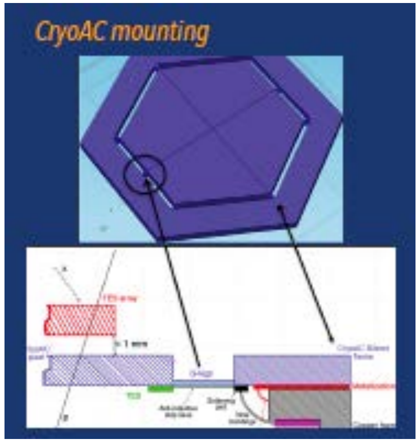
- The X-IFU is based on:
  - Transition Edge Sensors (TES) developed by NASA/GSFC
  - Readout using a Frequency Domain Multiplexing (FDM) technique developed under the leadership of SRON (NL)
  - Active shielding by a TES-based cryogenic anti-coincidence developed under the lead of IAPS
  - Active cooling by a multi-stage cryogenic chain involving European and Japanese mechanical coolers

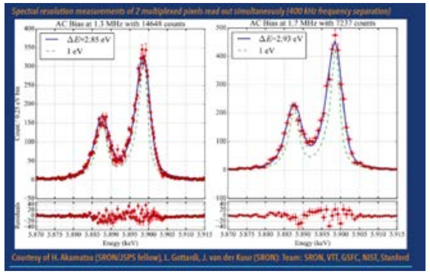
- The X-IFU will be developed by an international consortium under the management of CNES
  - PI: Didier Barret (IRAP). Co-PIs: Jan-Willem den Herder (SRON, NL), Luigi Piro (INAF/IAPS, IT)
  - ESA Member States contributions from Belgium, Finland, France, Germany, Italy, The Netherlands, Poland, Spain and Switzerland
  - Contributions from international partners from US (NASA) and Japan (JAXA)

The X-IFU technological challenges

- Building a large format TES sensor array
- Developing a cooling chain based on mechanical coolers, while minimising perturbations
- Developing a TES-based cryogenic anti-coincidence detector
- Developing an innovative FDM based readout electronics
- Performing on-board event reconstruction
- Optimising the design and defining the calibration strategy with the support of an end-to-end simulator
- Making the X-IFU affordable with the resources available to a complex instrument of an ESA L-class mission







See poster IS4 by M.T. Ceballos

X-IFU Spanish participation

- M. Mas Hesse represents Spain in the X-IFU Consortium Board
- The Detector Cooling System cryostat (dewar).
  - In development by INTA and CAB (Phase A)
  - Demonstration Model being developed, partly funded by an ESA CTP led by CNES. DM delivery to ESA in 2019.
  - Lead: A. Balado (National X-IFU PM). Other participants: J. Azcue, M.A. Alcacera,, A. Gómez, L. González, M. Mas-Hesse, M. Pajas, J. Martín-Pintado, J.A. Viceira y P. Zuluaga-Ramírez
- The Event Processor (EP) algorithms (see Poster IS4 by M.T. Ceballos)
  - In development by IFCA.
  - Part of the DRE (Digital Readout Electronics – led by IRAP) Phase A activities, under the WP on the EP, led by CEA/Irfu
  - Lead: M.T. Ceballos. Other participants: B. Cobo
- Science support
  - X. Barcons (chair) and J.M. Torrejón serve in the X-IFU Science Team
  - As X-IFU Science Team chair X. Barcons is of the X-IFU Management
- X-IFU Instrument Science Centre (operations)
  - IFCA and UA have offered participating in science ground segment activities

Other X-IFU activities in Spain

- R&D in cryogenic detectors based on Mo/Au TES
  - Includes design and fabrication of sensors, absorbers and pixel characterisation
  - Partially funded by an ESA CTP and the AHEAD EU project
  - Lead: L. Fàbrega (ICMAB). Other participants: A. Camón (ICMA), N. Casañ-Pastor (ICMAB), R.M. Jáudenes (ICMAB/ICAM), J. Moral (ICMAB), C. Pobes (ICMA), J. Sesé (INA), P. Strichovanec (INA)
- Promoting high-resolution X-ray spectroscopy in Spain
  - Partially funded by AHEAD EU project through WP2 General Networking and Support to the Community.
  - Lead: J.M. Torrejón (UA). Other participants: all others

Outlook

- Athena will be very powerful X-ray observatory, with key capacities to understand AGN
- It is an essential part of the observational landscape in the late 2020s, together with ALMA, E-ELT, SKA, CTA, etc.
- Good progress with Phase A, issues identified and being addressed
- Spain has a health participation in Athena and the X-IFU
- Need to prepare for its scientific exploitation in 2028+
  - 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