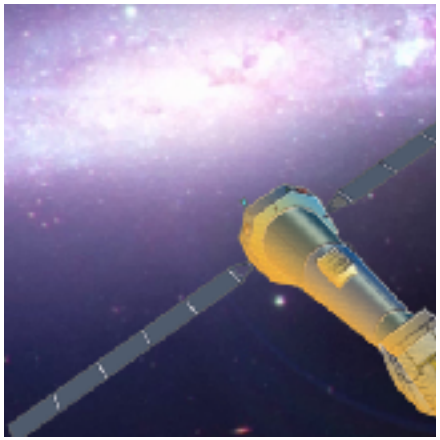
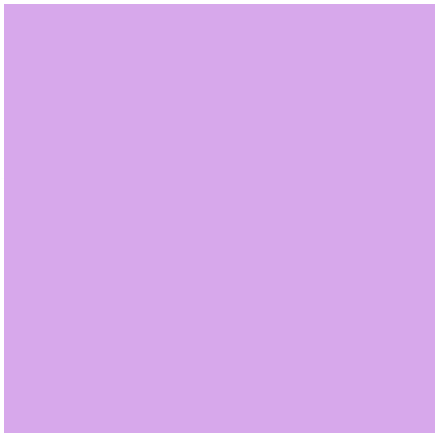
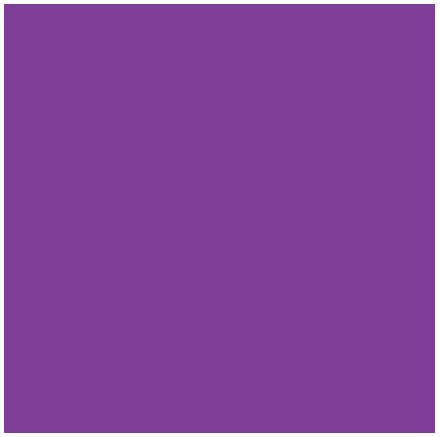
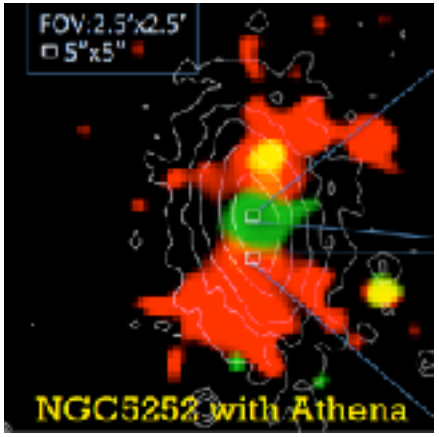
ATHENA

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









Francisco J. Carrera, on behalf of the ASST

Instituto de Física de Cantabria (CSIC-UC), Santander, Spain

SXA17, IAA, Granada, 23 October 2017

Contents

- Athena in a nutshell
- The Athena science theme: Hot and Energetic Universe
- Mission concept & payload
- Project development status
- Athena science
- Synergies
- Community
- 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**)

- WG chairs
- ACO
- Many others…

Advanced Telescope for High-Energy Astrophysics

- Second Large (L2) mission of ESA Cosmic Vision 2015-2025
- 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 (**2/3 AO**)

More info in:
http://www.the-athena-x-ray-observatory.eu

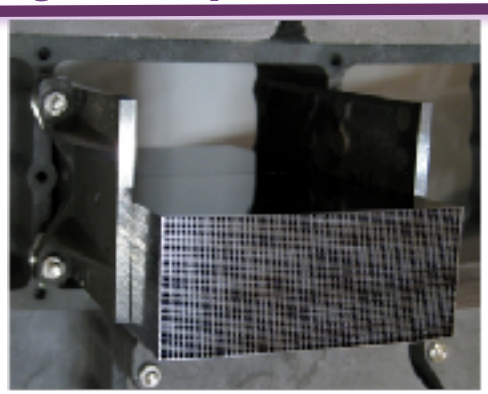
Athena mission concept

- 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 ≤2029, Ariane 6.4
- L2 halo orbit (TBC)
- Lifetime > 4 yr

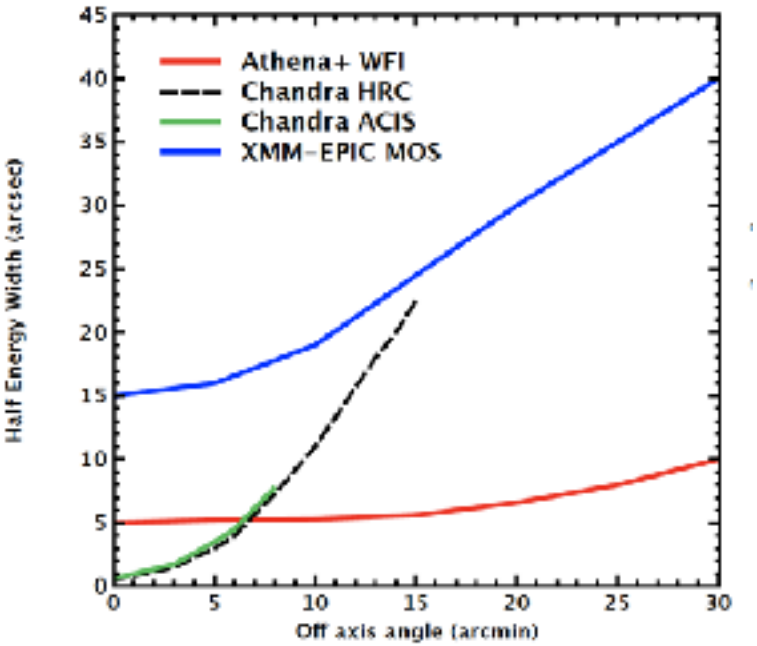
Athena concept, ESA CDF

The Athena X-ray optics

- Athena optics development:
  - Light-weight Si-pore optics
  - Grazing incidence optics, Wolter-I type (paraboloid-hyperboloid), largely with conical approximation
  - Vigorous development programme on-going.
- Performance:
  - 5´´ HEW on-axis
  - Graceful degradation off-axis, <10´´ @ 30´
  - ≥1.4 m^2 effective area @ 1 keV, 0.25 m^2 effective area @ 6 keV
  - Limited vignetting at 1 keV



#AthenaNuggets by Willingale

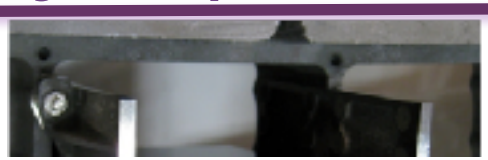


Willingale, Pareschi et al. 2013, arXiV: 1308.6785

Instituto de Física de Cantabria

The Athena X-ray optics

- Athena optics development:
  - Light weight Si pore optics



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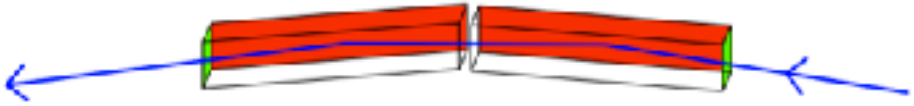

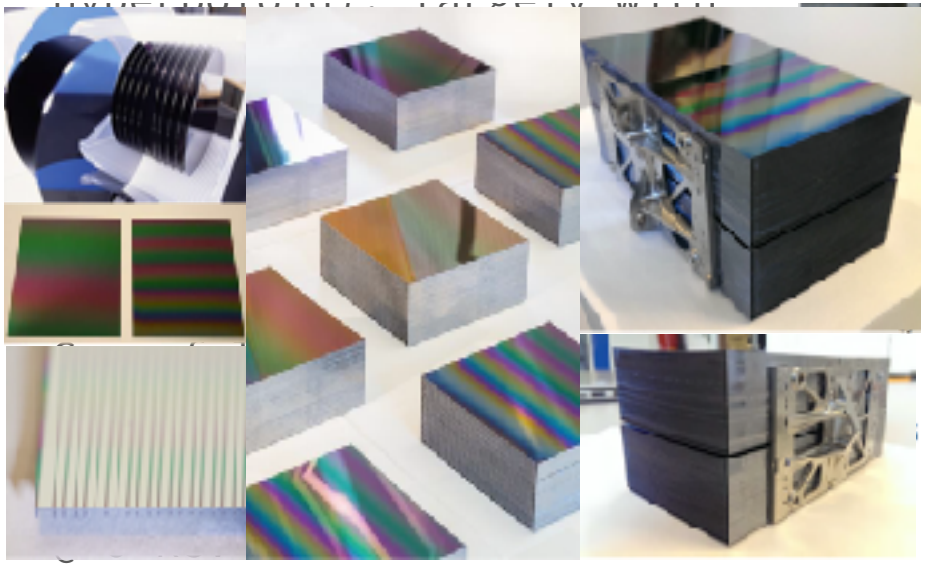

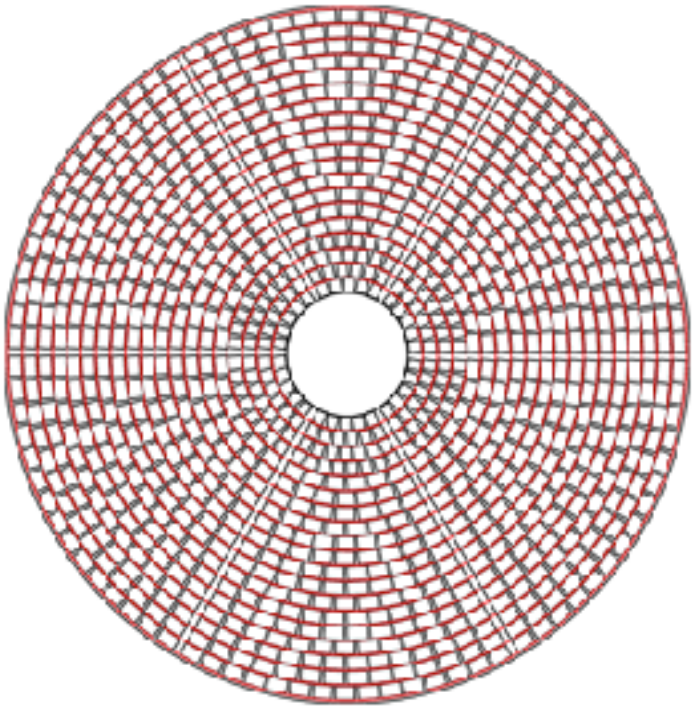

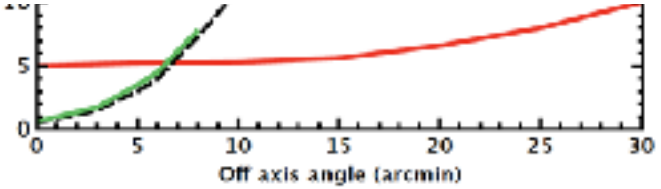

- Limited vignetting at 1 keV

Courtesy D. Willingale (LU) and ACO team

Willingale, Pareschi et al. 2013, arXiV: 1308.6785

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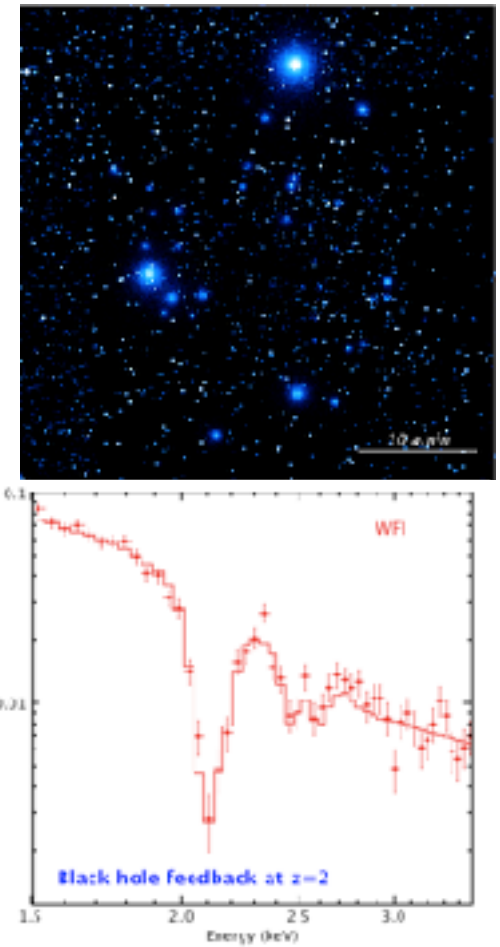
Wide Field Imager (WFI)

- Based on Si detectors, using Active Pixel Sensors based on DEPFETs.
- Key performances:
  - 120-150 eV spectral resolution
  - 2.2´´ 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

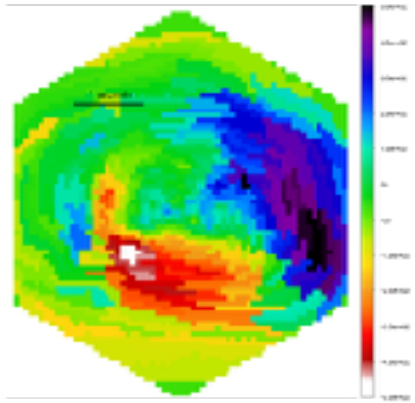
See Arne Rau's talk

#AthenaNuggets by Rau

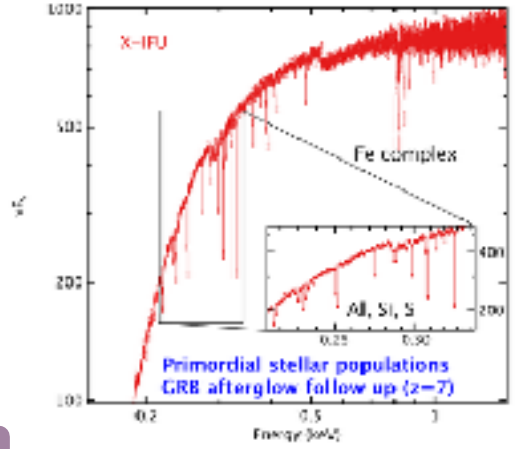
X-ray Integral Field Unit (X-IFU)

- 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´´

#AthenaNuggets by Duband



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



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

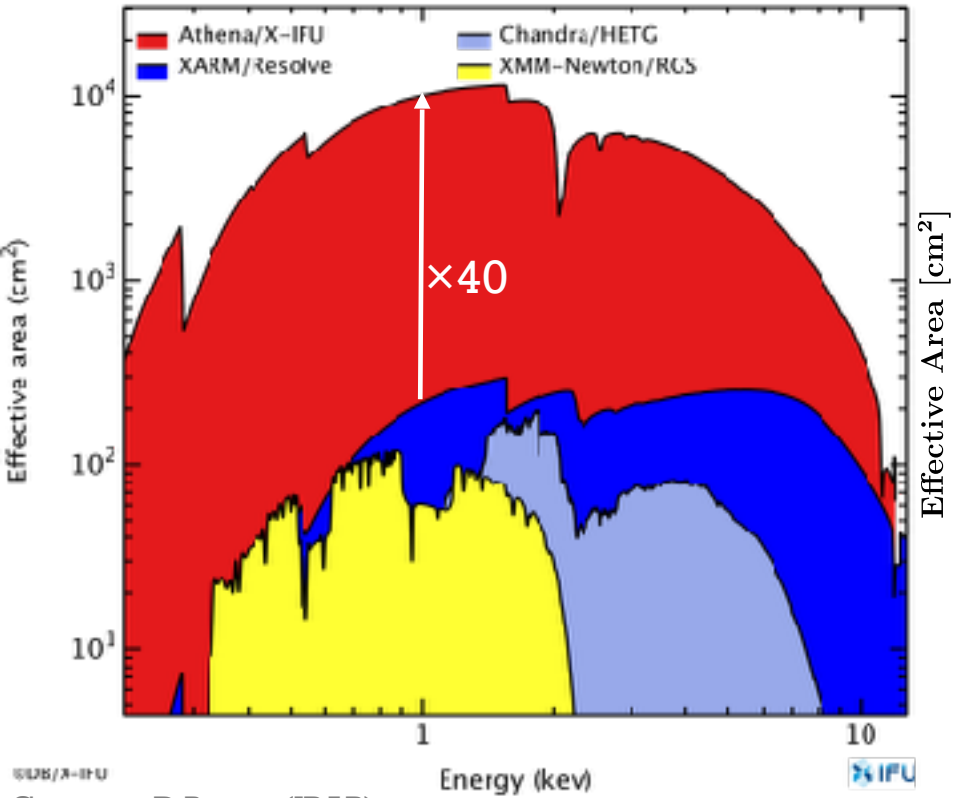
See talks by Didier Barret and Javier Gómez-Elvira

Athena Project development: Current status

- Phase A on-going:
  - Mission concepts are sound
  - Mature mid-Phase A spacecraft design
  - Mass constraint (conservative 7 tons) can be achieved with at most minor reduction in mirror diameter (1 row/20)
  - Instrument thermal and mass budgets to be consolidated
  - Consolidation of the Cost at Completion underway: saving options
    - Some have little or no science impact
    - Reduced ToO capabilities? (**exploring soft solutions**)
    - Reduced mirror to 15 rows (1.4m^2@1keV) **if needed for cost-compliance**

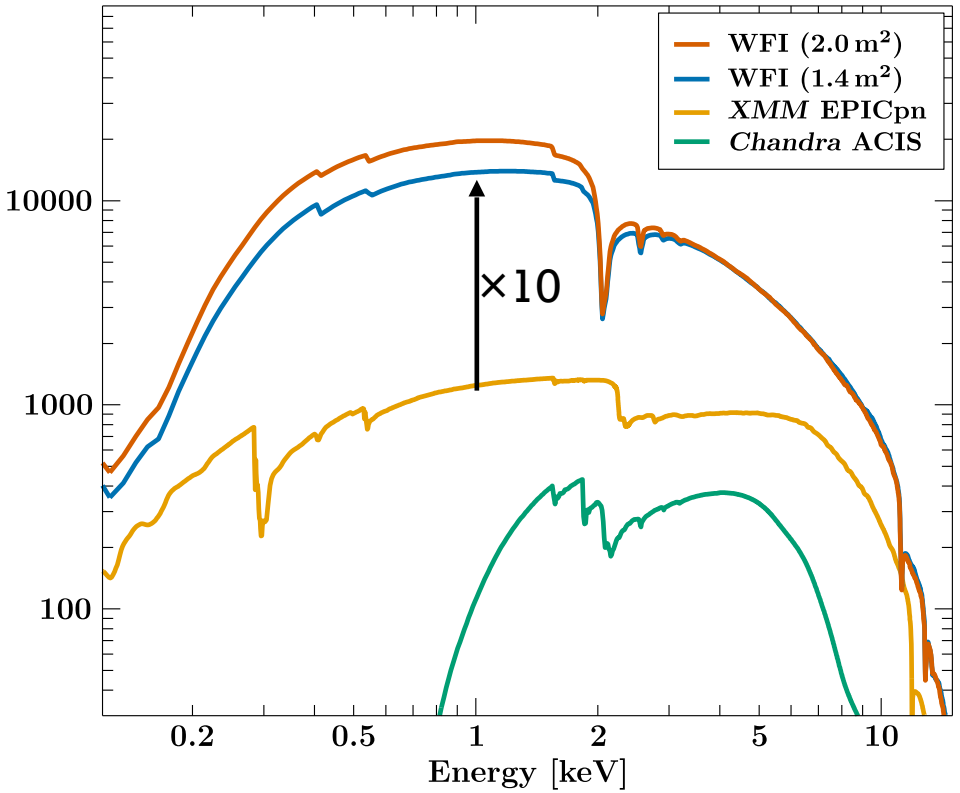
Athena remains a large effective area mission

X-IFU+mirror collecting area



Courtesy D.Barret (IRAP)

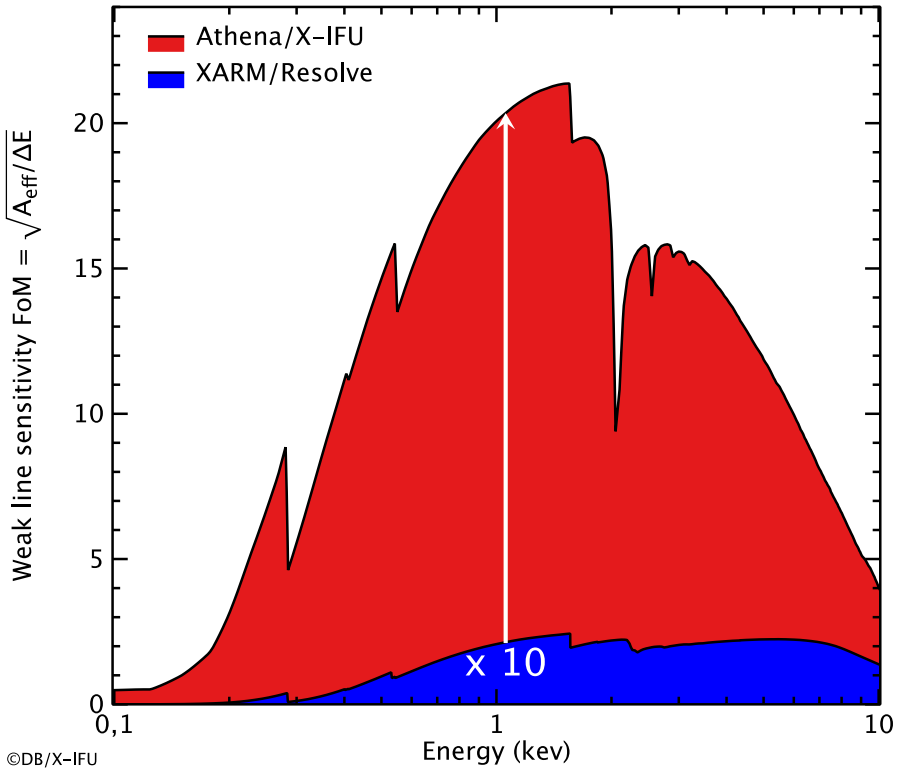
WFI+mirror collecting area



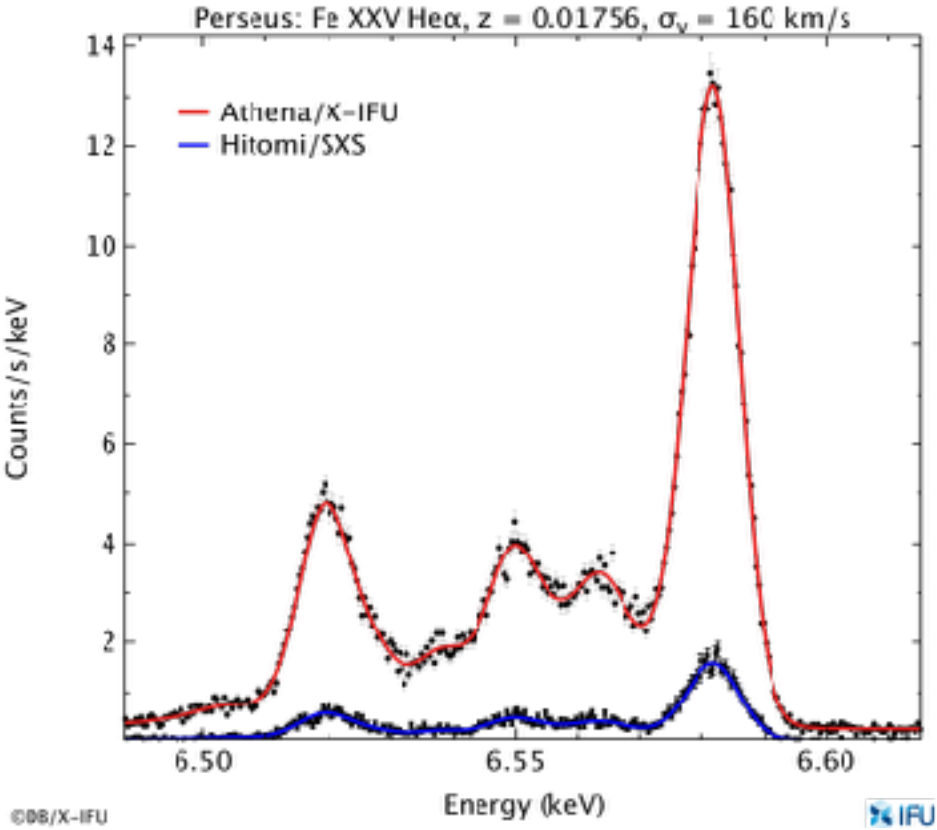
Courtesy A.Rau (MPE)

A giant leap in high-resolution spectroscopy: X-IFU

Weak line sensitivity



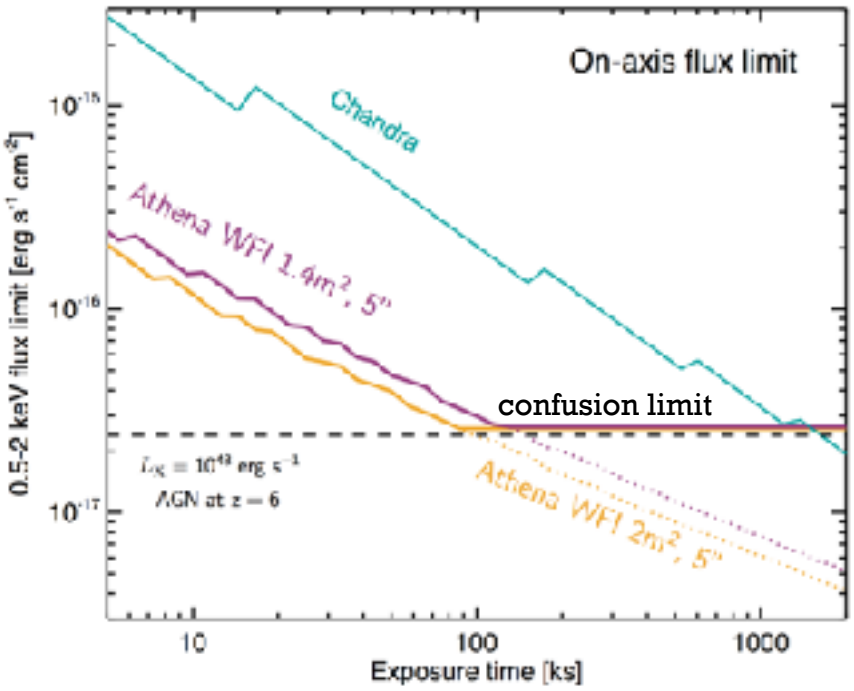
X-IFU vs. the best-quality existing high-resolution spectrum @6 keV

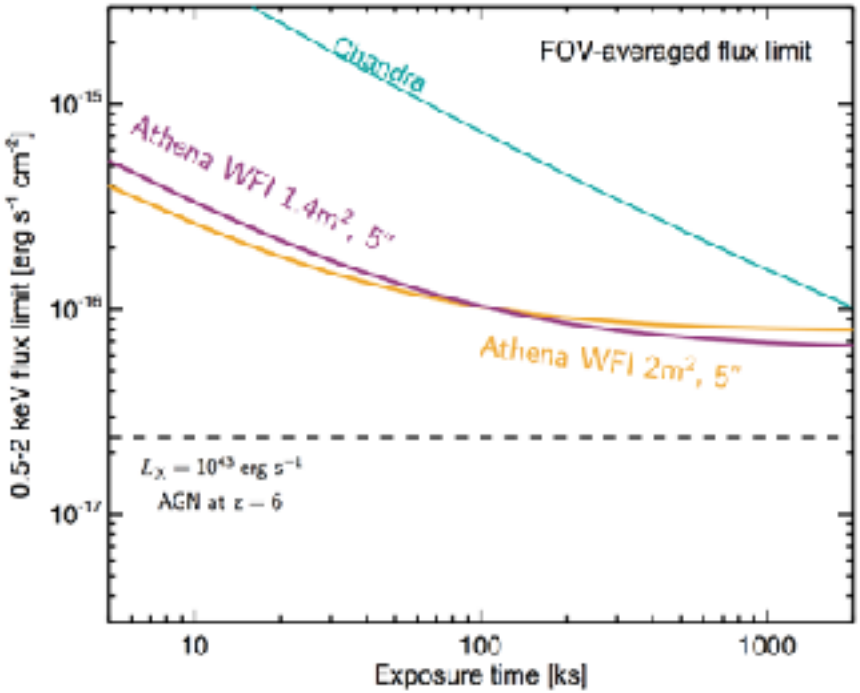


Courtesy D.Barret (IRAP)

See Didier Barret's talk

Athena: a powerful survey machine I WFI



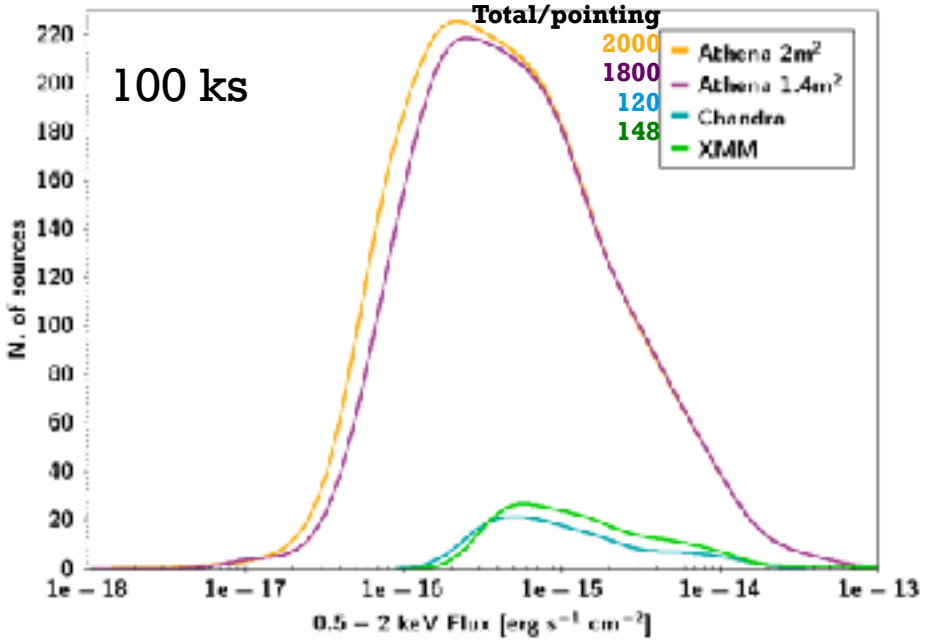


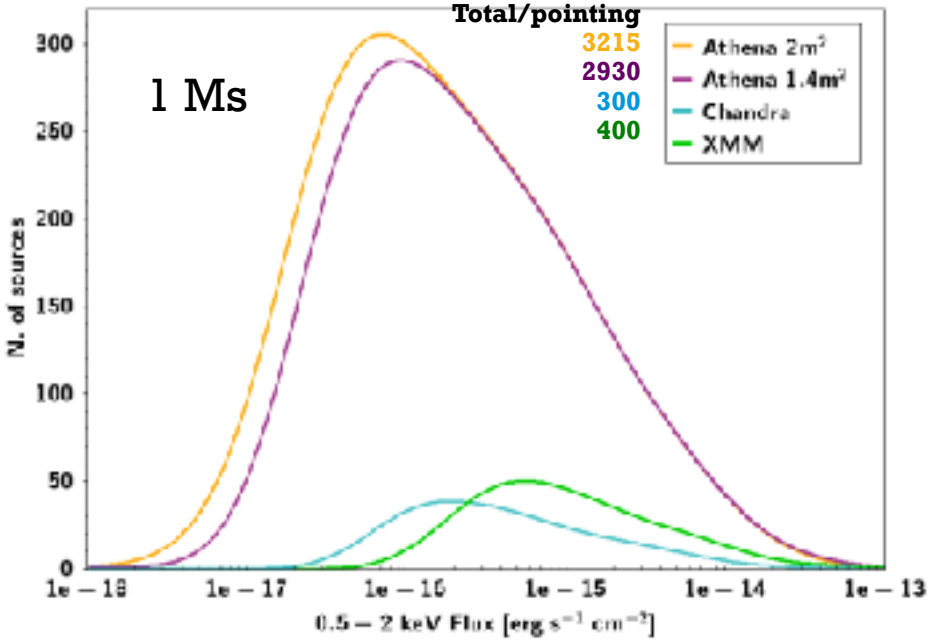
Athena survey over the nominal 4 year mission: 4×1Ms + 3×700ks + 10×600ks + 103×60ks

Courtesy J. Aird (IoA)

Athena: a powerful survey machine II WFI

WFI
Nsou/pointing/log(flux)



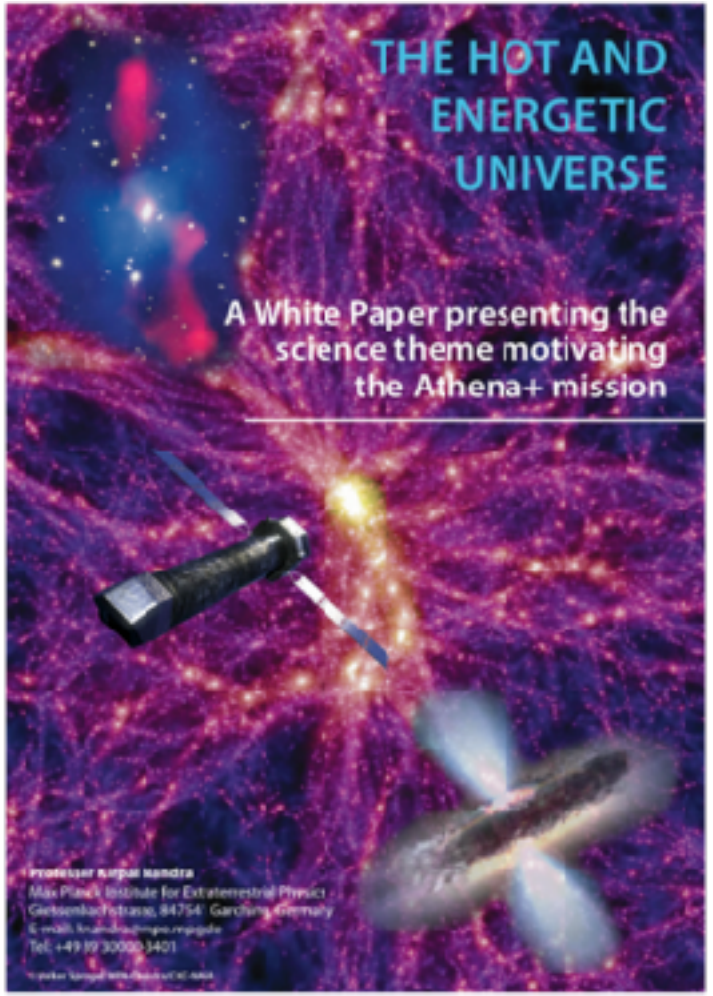


≥400,000 AGN (≥150 @6≤z≤8) - Compton-thick up to z≅3

Courtesy G.Lanzuisi, A.Comastri (OABo);
Aird et al., 2013, ArXIV;1306.2325

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

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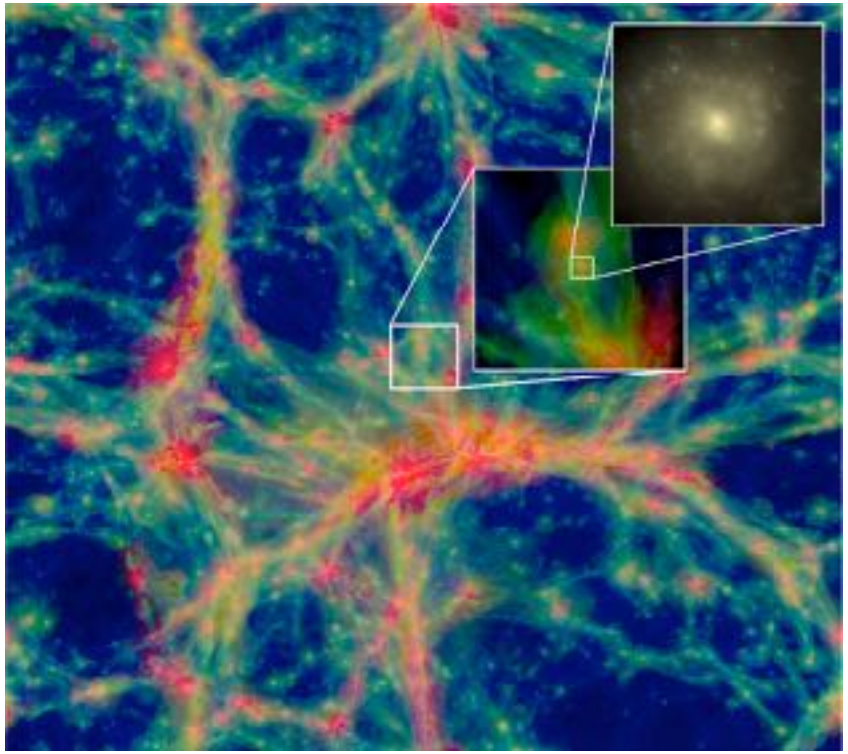
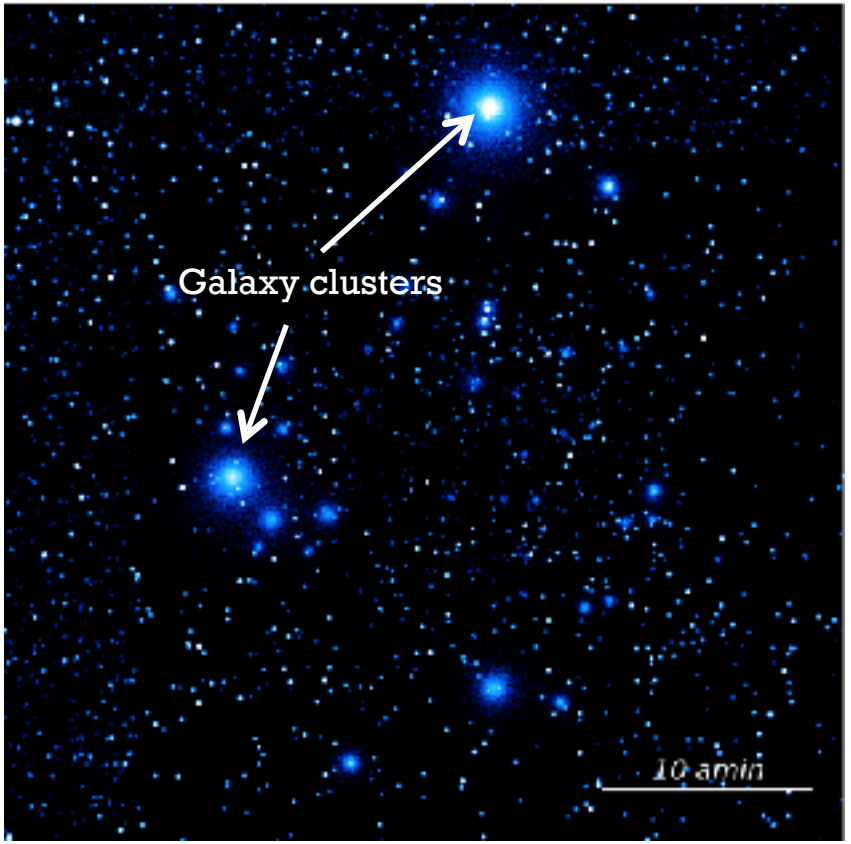
The Hot Universe – baryonic assembly

EAGLE cosmological simulation

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



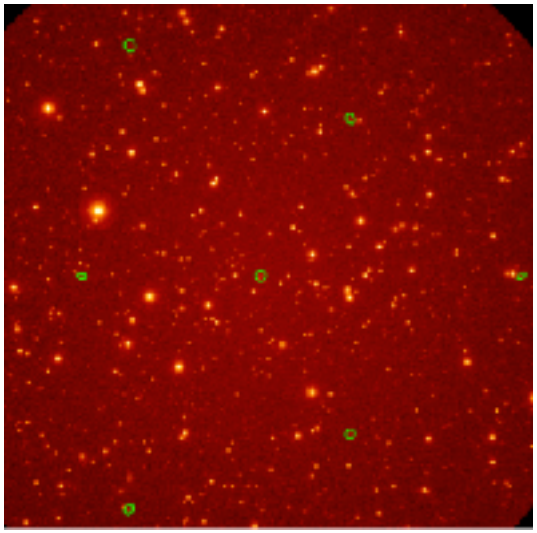
Schaye et al. 2015



Athena/WFI 1Ms simulation
MPE & WFI team

Evolution of hot cluster gas

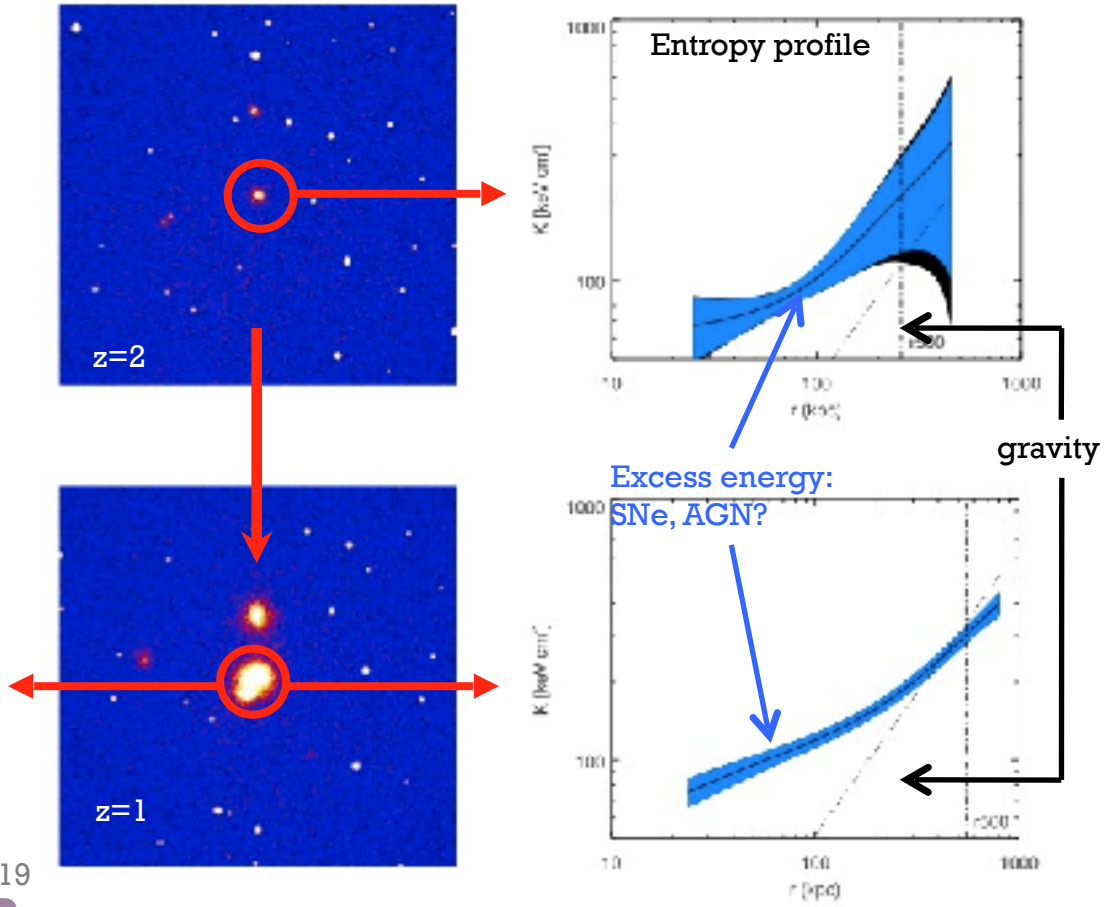
Search for the first groups of galaxies at z>2



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

See Arne Rau's talk

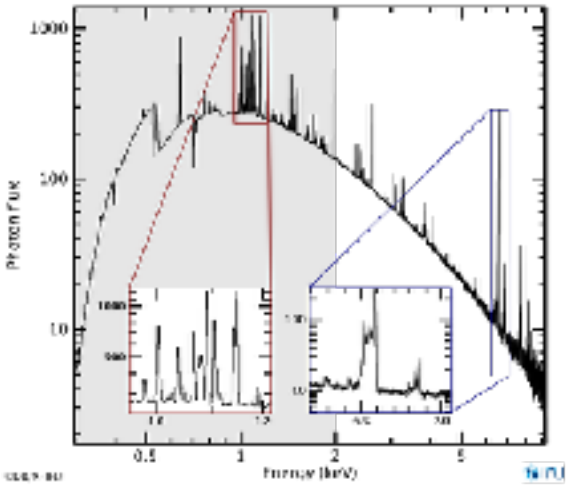
Energy deposition history



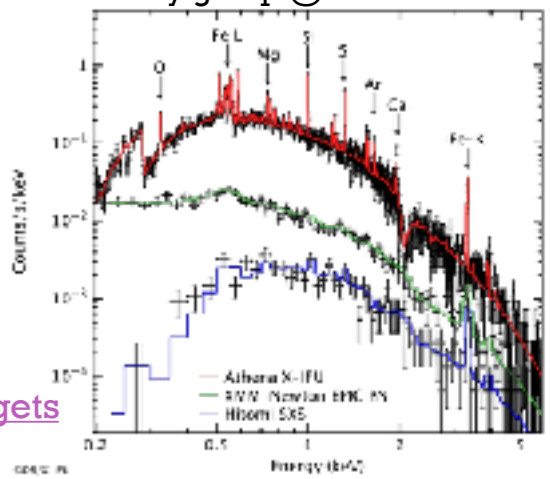
Chemical evolution

- 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

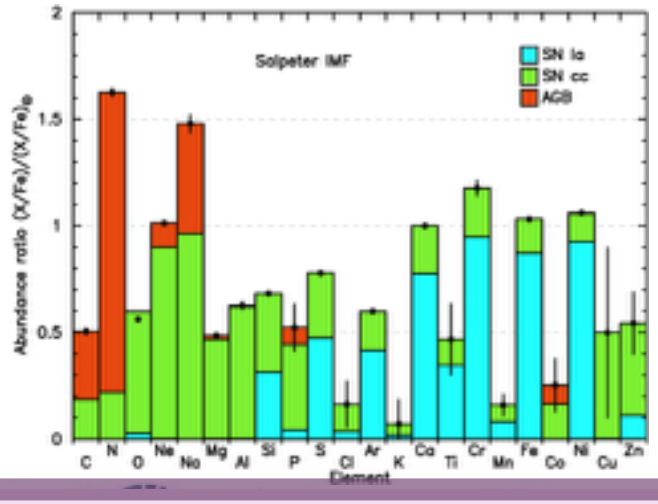
Perseus core 100ks X-IFU



Galaxy group @z=1 50ks X-IFU



Barret et al. 2016, SPIE



Courtesy: J. de Plaa 2016

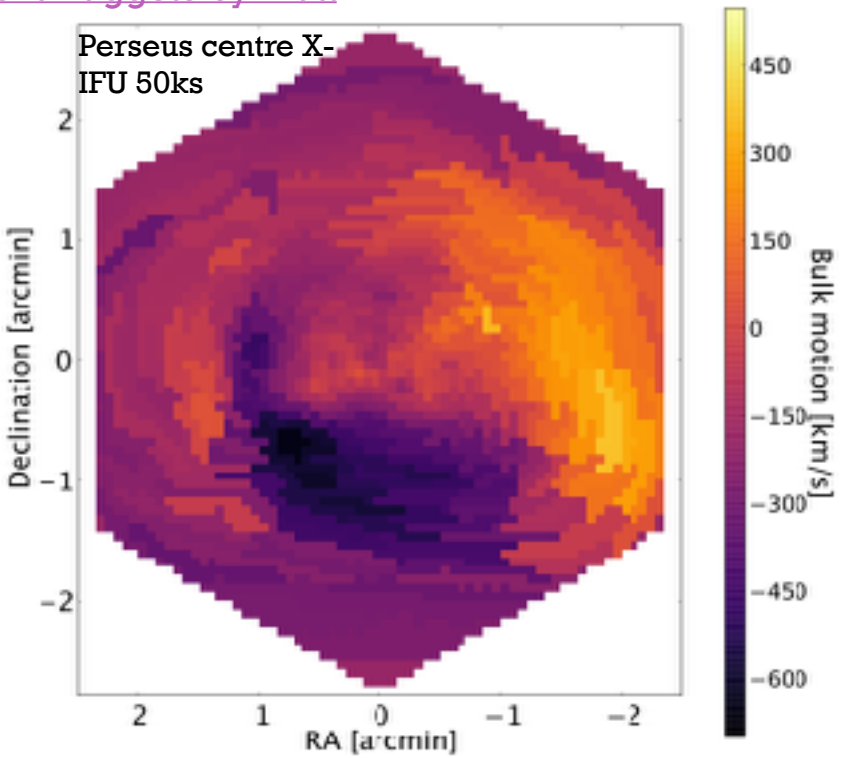
#AthenaNuggets by de Plaa

See Didier Barret's talk

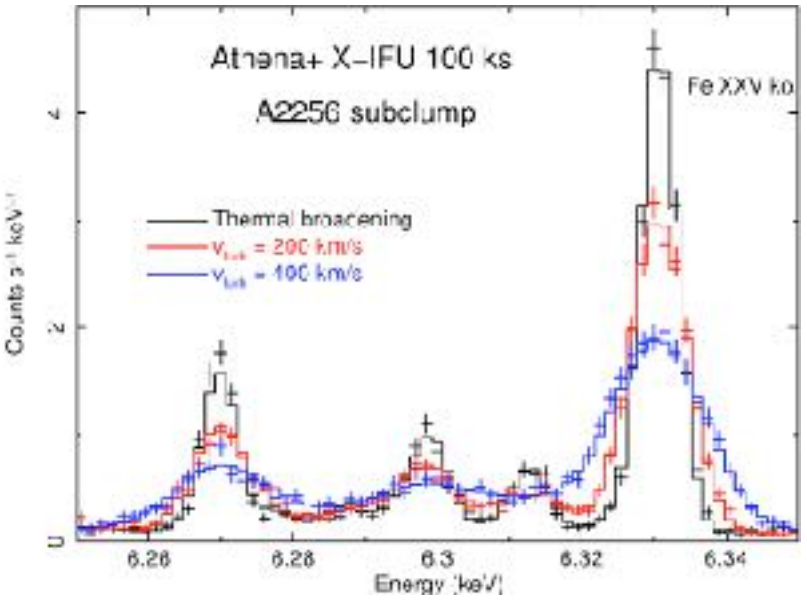
Cluster bulk motions & turbulence

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

#AthenaNuggets by Pratt



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

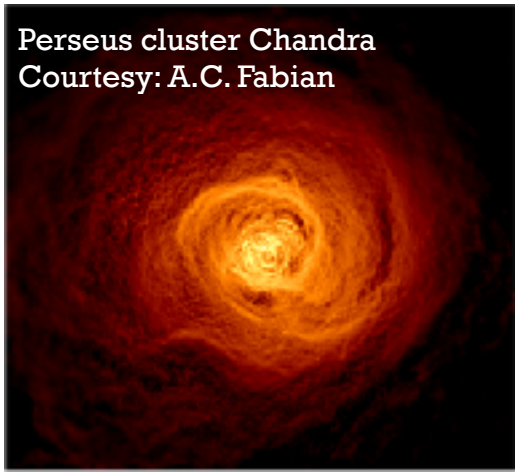


Ettori, Pratt et al. 2013 arXiv1306.2322
Pointecouteau, Reiprich et al. 2013, arXiv: 1306.2319

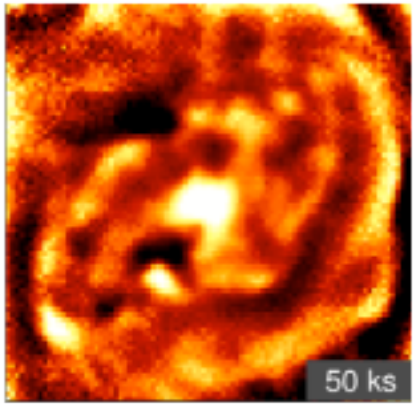
See Didier Barret's talk

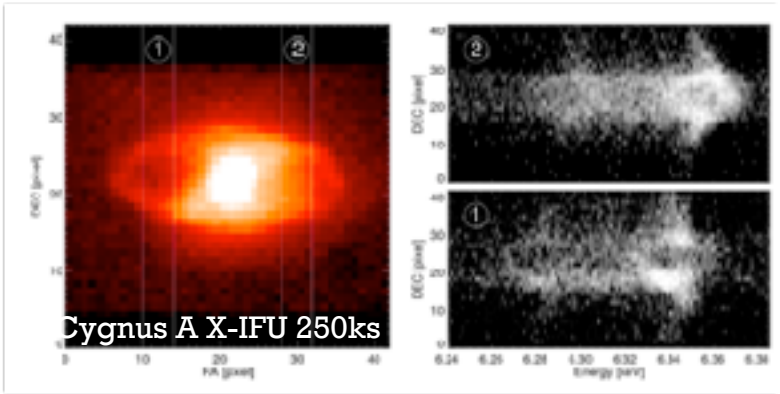
AGN feedback on cluster scales

- 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



Cluster core z=0.05
WFI 50ks





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

See Didier Barret's talk

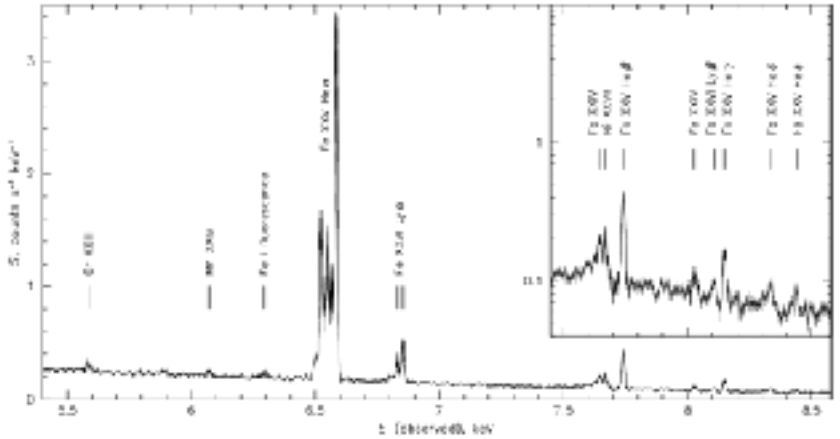
Aperitif: Hitomi(Feb-Mar 2016)

- 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!

#AthenaNuggets by Fabian

See Didier Barret's talk

Perseus cluster core turbulence <164 km/s

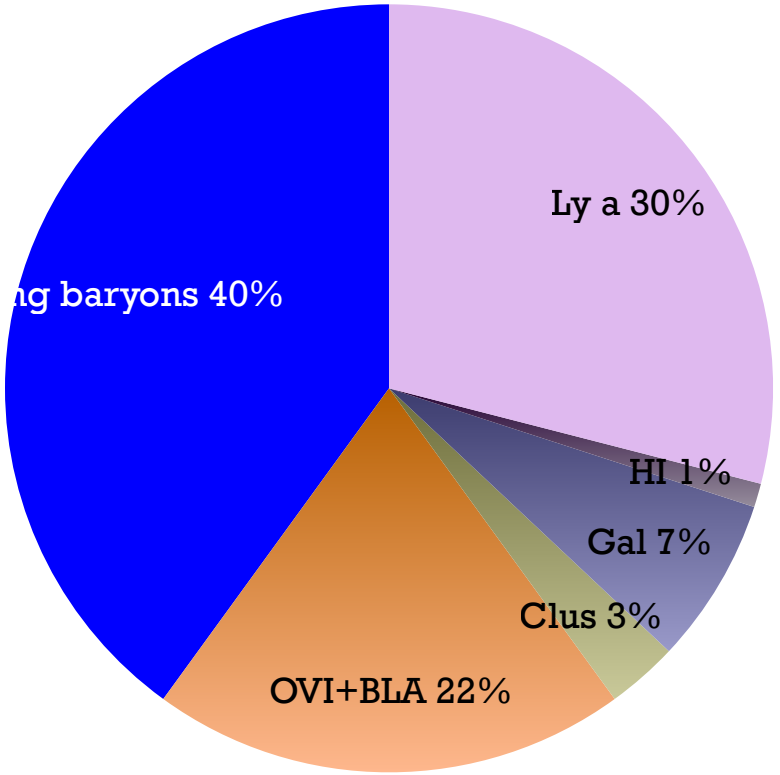


Hitomi coll. Nature, 535, 117-121 (2016)
Courtesy: A.C. Fabian

2017

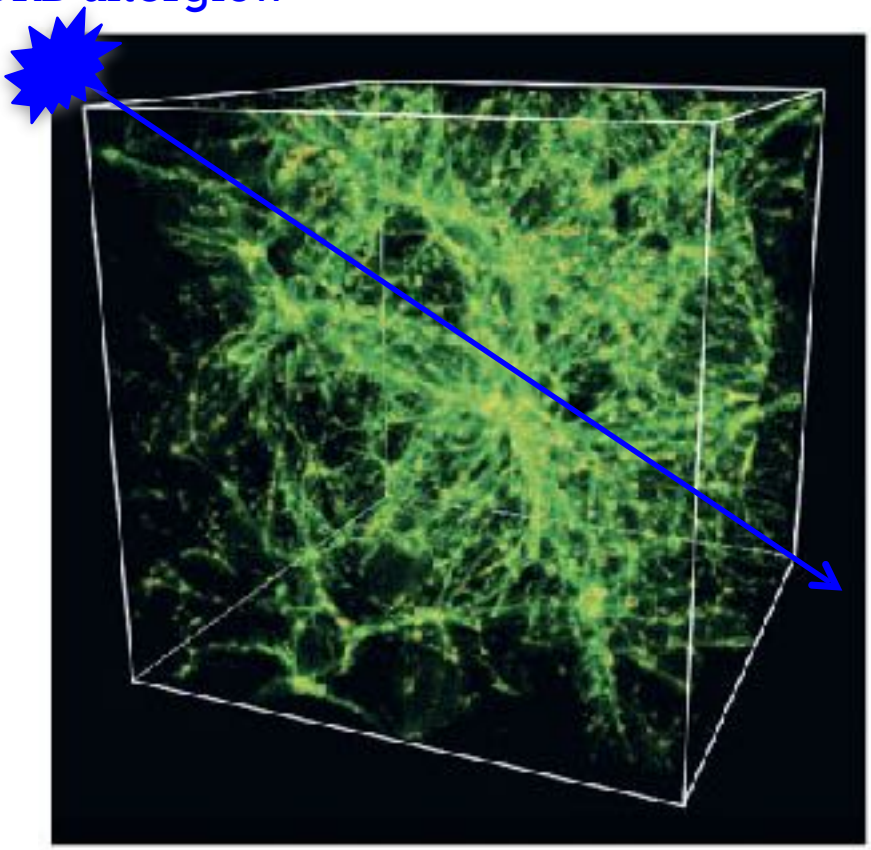
Missing baryons: the WHIM

- Cosmological hydro simulations show ~50% of baryons at **T~10^5–10^7** K in the IGM.
  - 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



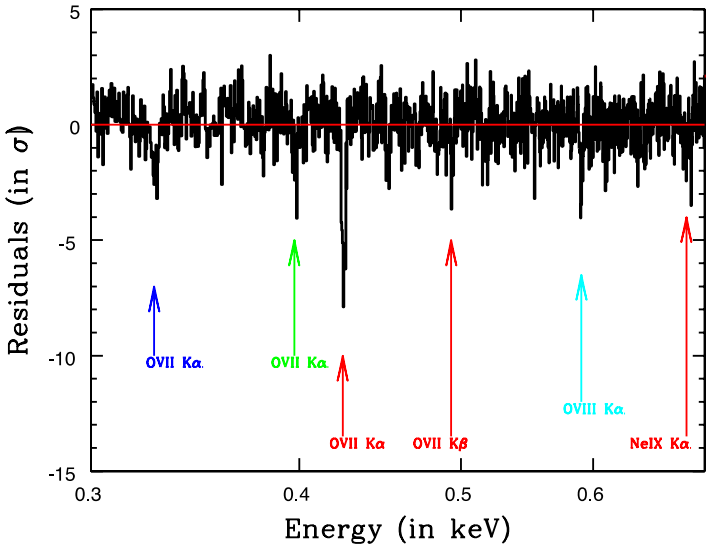
Characterising the WHIM baryons

BL Lac or
GRB afterglow



Cen & Ostriker 2006

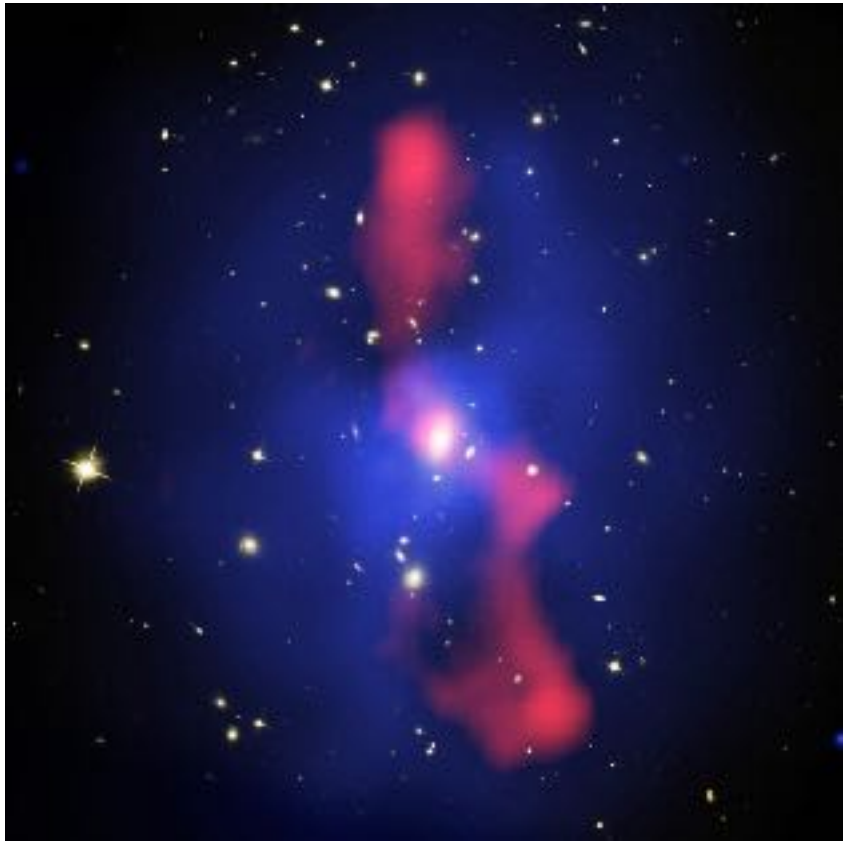
WHIM filaments against a 10% brightest GRB afterglow z>0.8



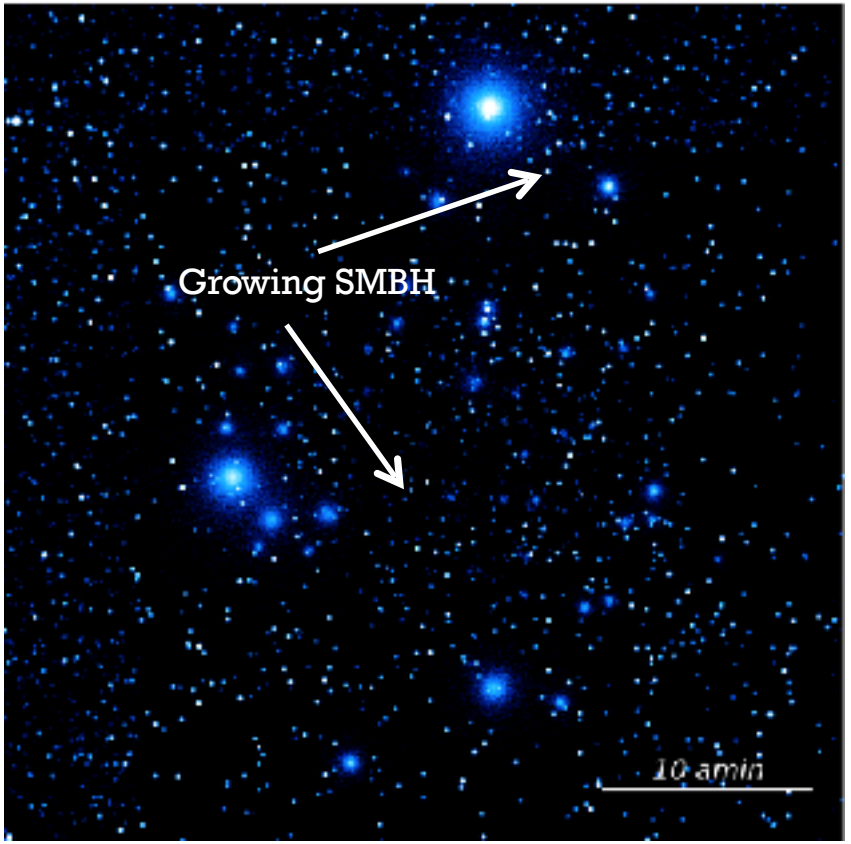
Barret et al. 2016, SPIE
Courtesy: F. Nicastro

See Didier Barret's talk

The Energetic Universe – Black Holes



MS0735.6+7421 McNamara et al. 2005

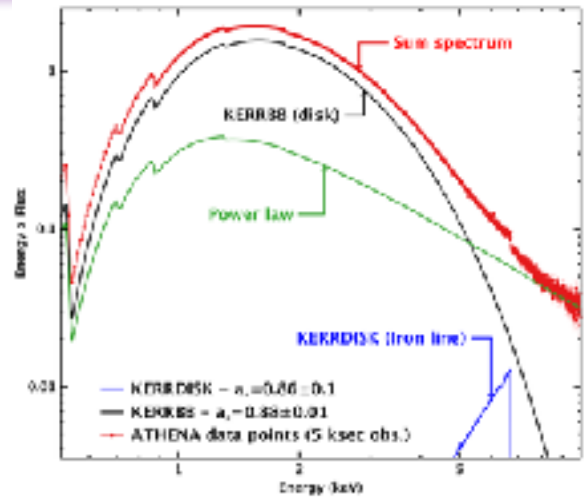


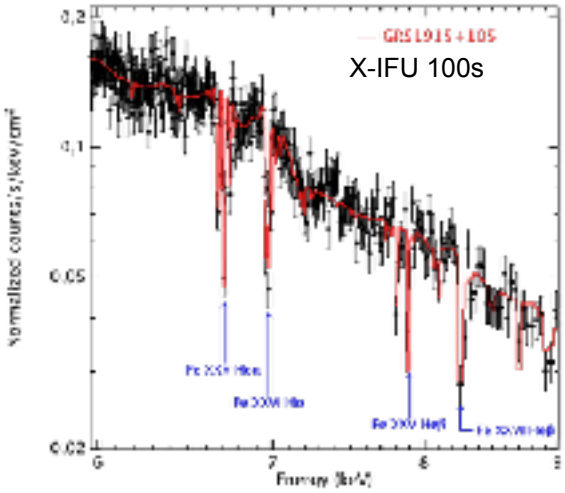
Athena/WFI 1Ms simulation
MPE & WFI team

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

#AthenaNuggets by Diaz-Trigo



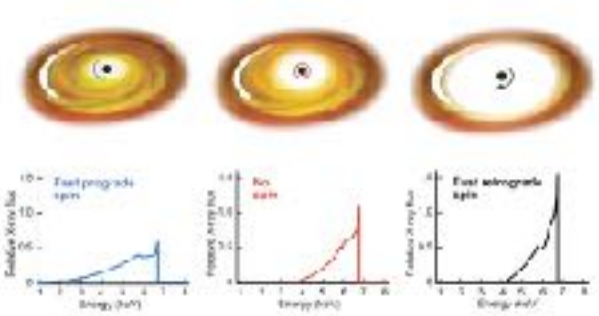


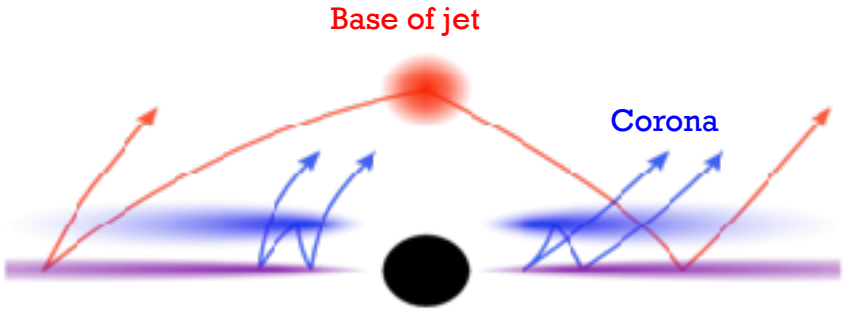
Courtesy J.M. Miller
Barret et al. 2016 SPIE2016

See talks by Giovanni Miniutti and Didier Barret

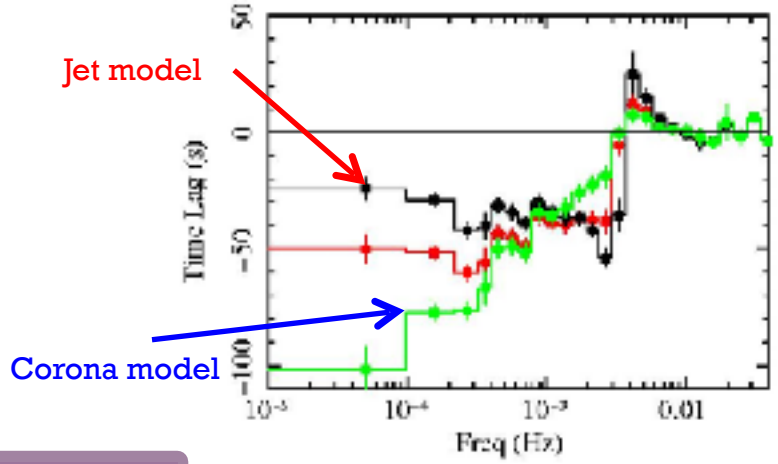
Supermassive Black Hole physics

- Measure SMBH spins through Fe line spectroscopy





- Accretion geometry and jet/disk relation through reverberation mapping



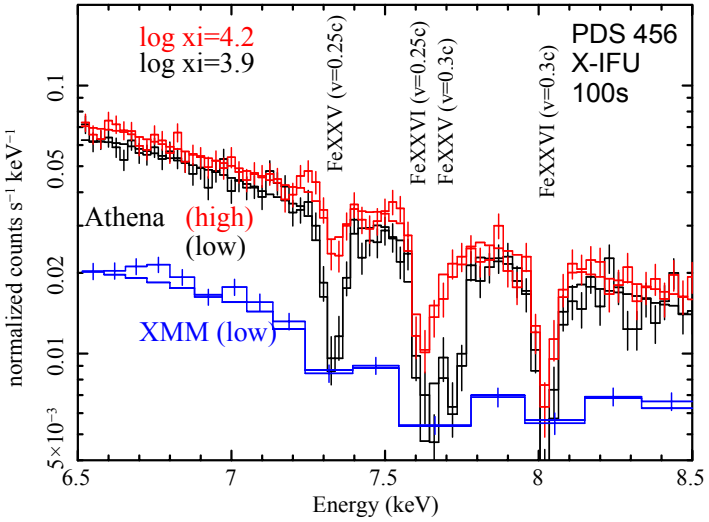
Dovciak, Matt et al. 2013, arxiv:1306.2331

See Giovanni Miniutti's talk

AGN winds and outflows

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

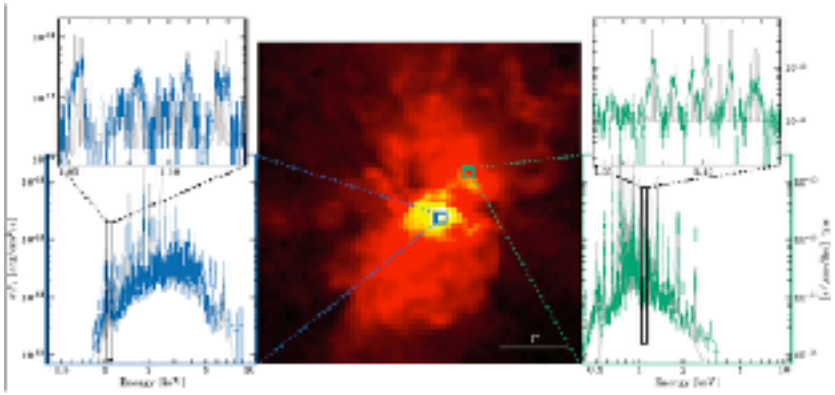
Mechanical energy released in ultra-fast outflows ~v^3



#AthenaNuggets by Cappi

Cappi, Done et al. 2013, arxiv:1306.2330

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



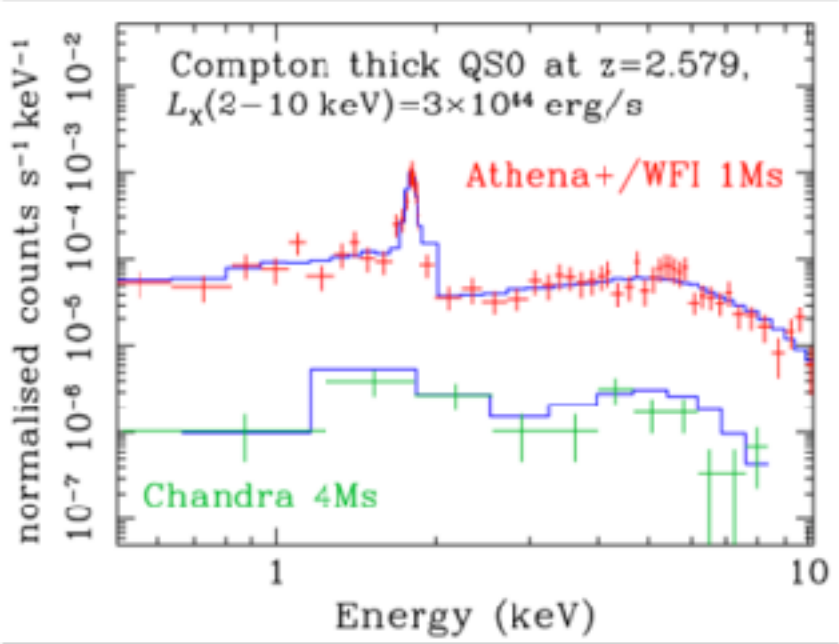
A. Ptak and the Athena simulation team (in progress)

See talks by Giovanni Miniutti and Didier Barret

Obscured AGN census @ z~1-3

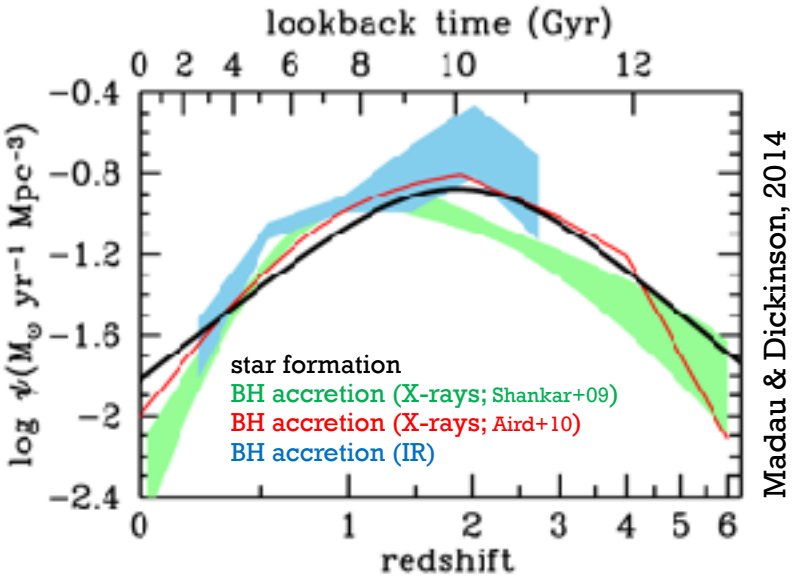
- What is the relation between obscured growth of SMBH through cosmic history and how does it relate to galaxy formation?
  - Most SMBH growth expected in heavily obscured (including Compton-Thick) environment.
  - Best X-ray signal of Compton-Thick AGN is the Fe emission line, EW ~0.5-1 keV.
  - Athena/WFI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

#AthenaNuggets by Carrera



Georgakakis, Carrera et al. 2013 arXiv1306.2328

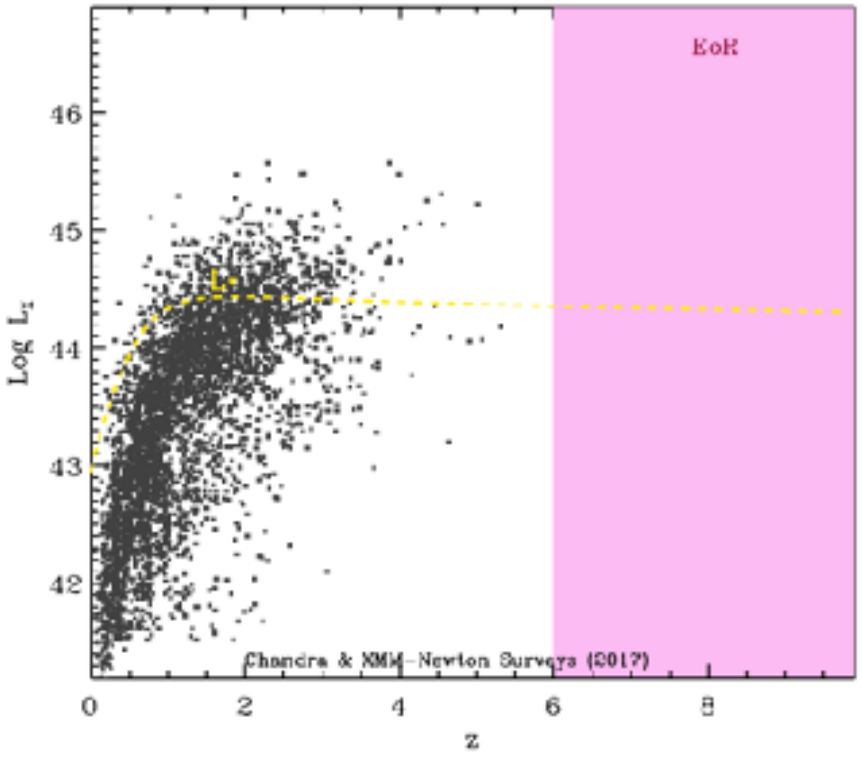
The history of SMBH growth



Madau & Dickinson, 2014

- The cosmological history of black hole accretion is **uncertain** at z>3, **unknown** at z>6

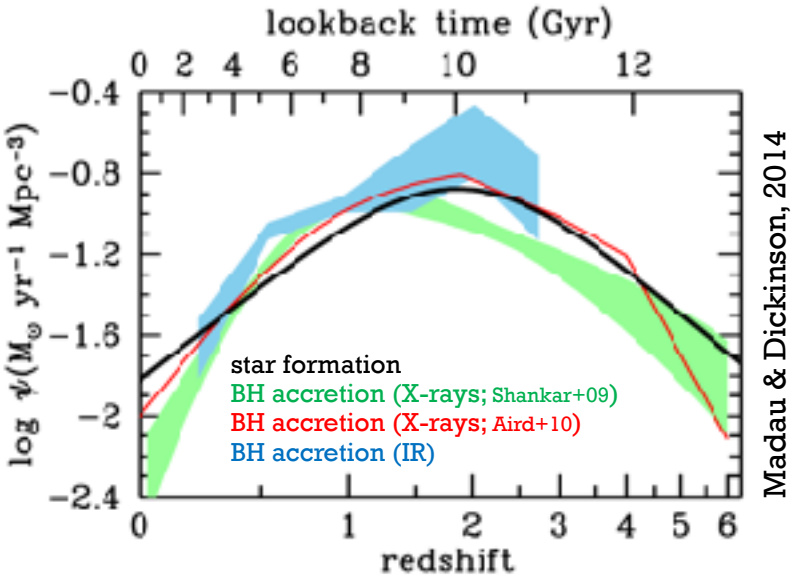
AGN L_X versus z plane



Aird+13, Courtesy of A. Rau (MPE)
Aird, Comastri et al. 2013 arXiv1306.2325

- Only extreme AGN expected in opt/IR surveys
- Athena needed to signpost average AGN

The history of SMBH growth



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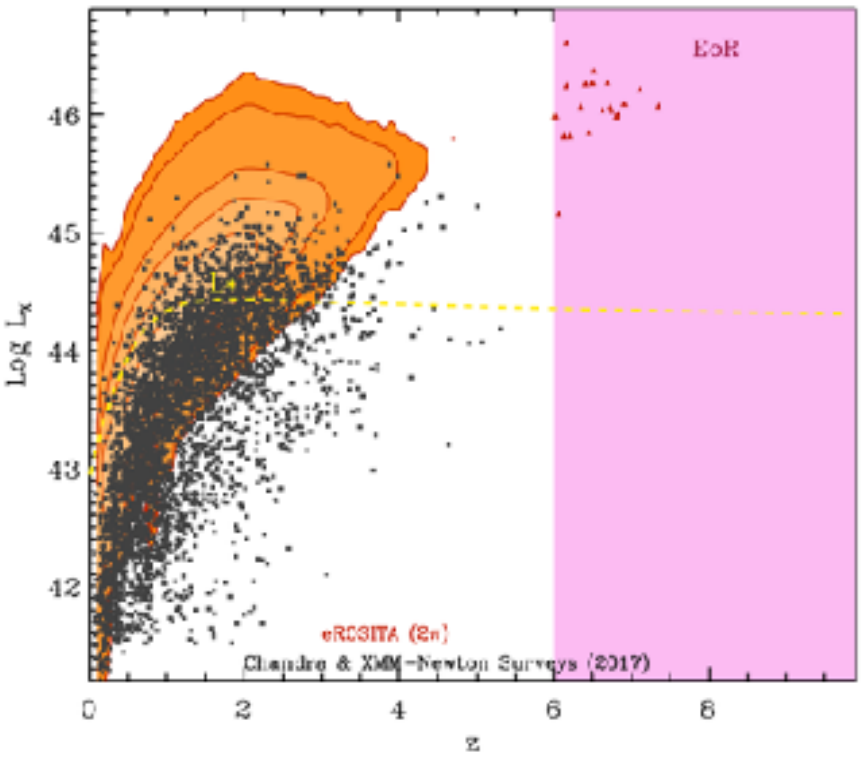

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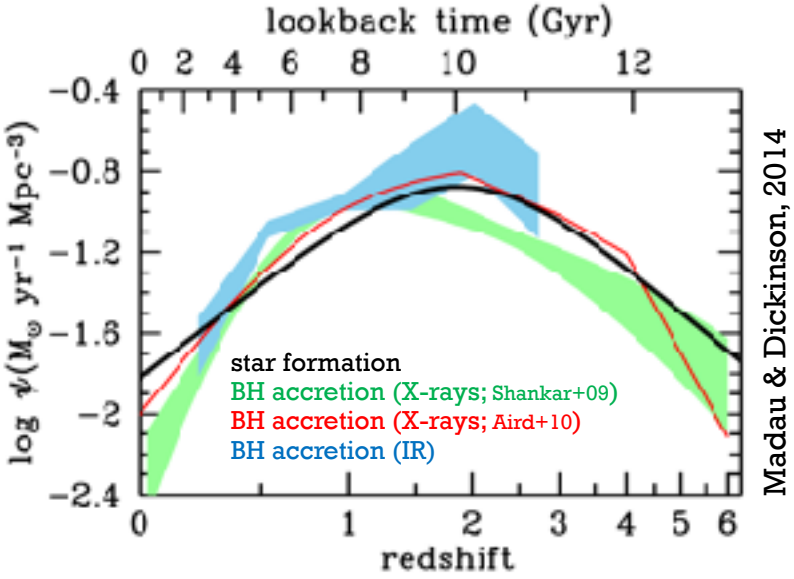

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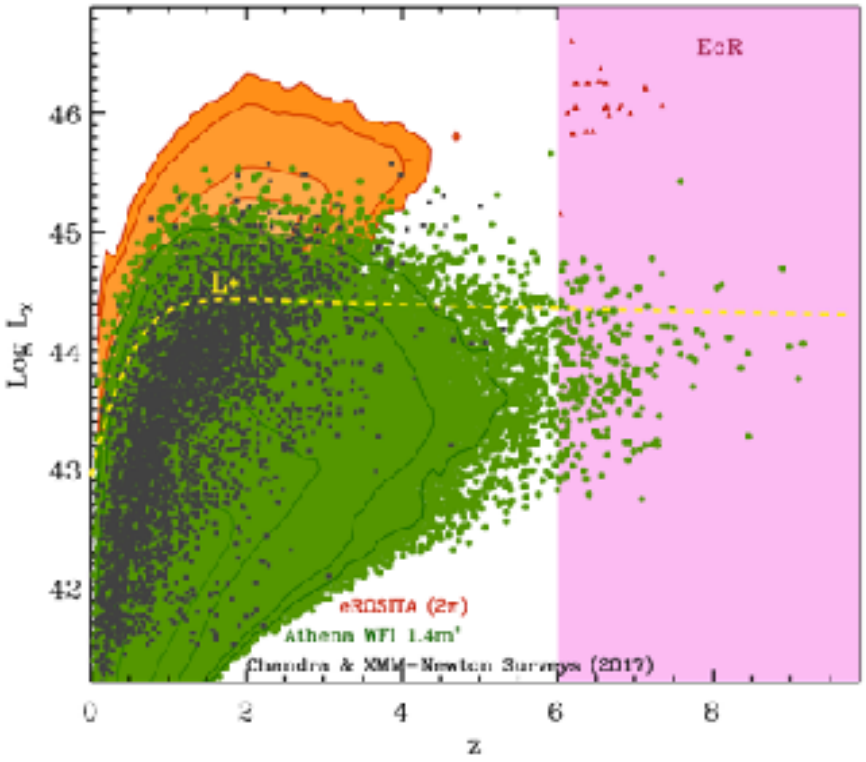

Aird+13, Courtesy of A. Rau (MPE)
Aird, Comastri et al. 2013 arXiv1306.2325

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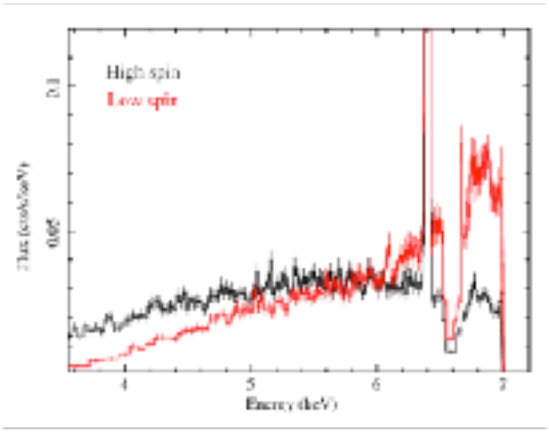
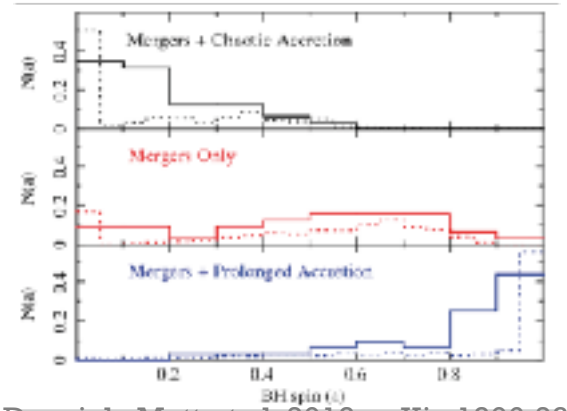
SMBH growth: accretion vs. mergers

- 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 al. 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

#AthenaNuggets by Brenneman & Miniutti

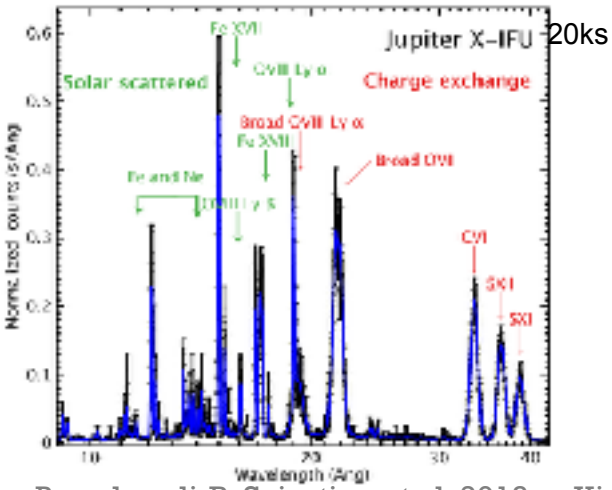
See Giovanni Miniutti's talk

Observatory Science – all corners of astrophysics

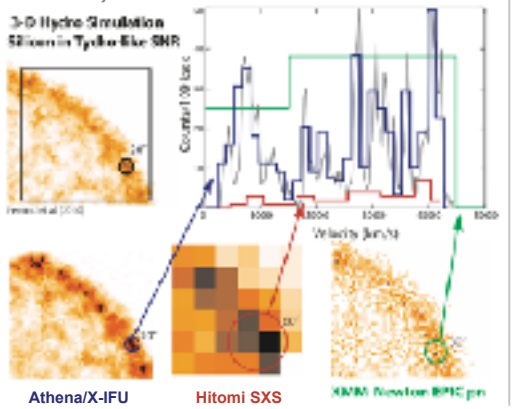
- Planets and solar system bodies
- Exoplanets: magnetic interplay
- Star formation, brown dwarfs
- Massive stars: mass loss
- Supernovae: explosion mechanisms
- Supernova remnants: shock physics
- Stellar endpoints (NS)
- Interstellar medium
- …

#AthenaNuggets by Branduardi-Raymont

#AthenaNuggets by Motch



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

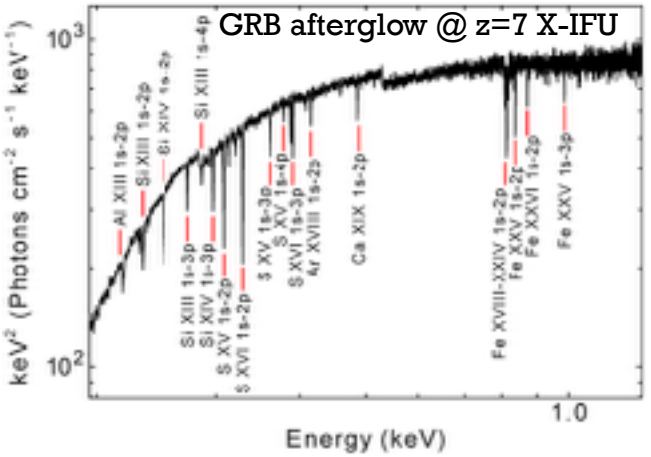


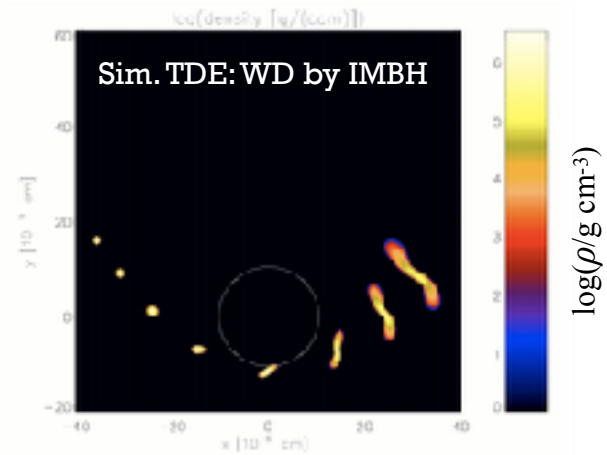
Decourchelle, Costantini et al. 2013: arXiv 1306.2335
Motch, Wilms et al. 2013: arXiv 1306.2334

See talks by Giovanni Miniutti and Didier Barret

Luminous extragalactic transients

- Athena will offer a quick Target of Opportunity facility, whereby a triggered observation could start in 4 hours ~50% 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
  - Reveal the composition of the outflowing material
  - Test for the presence of binary SMBH
- GW…





#AthenaNuggets by O'Brien

#AthenaNuggets by Jonker

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

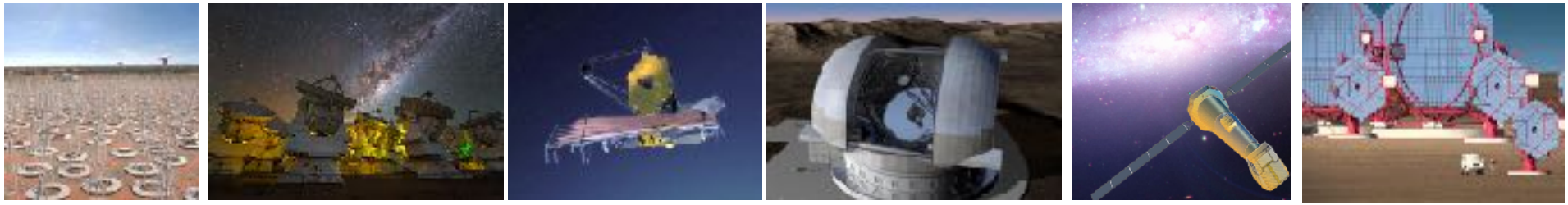
See Didier Barret's talk

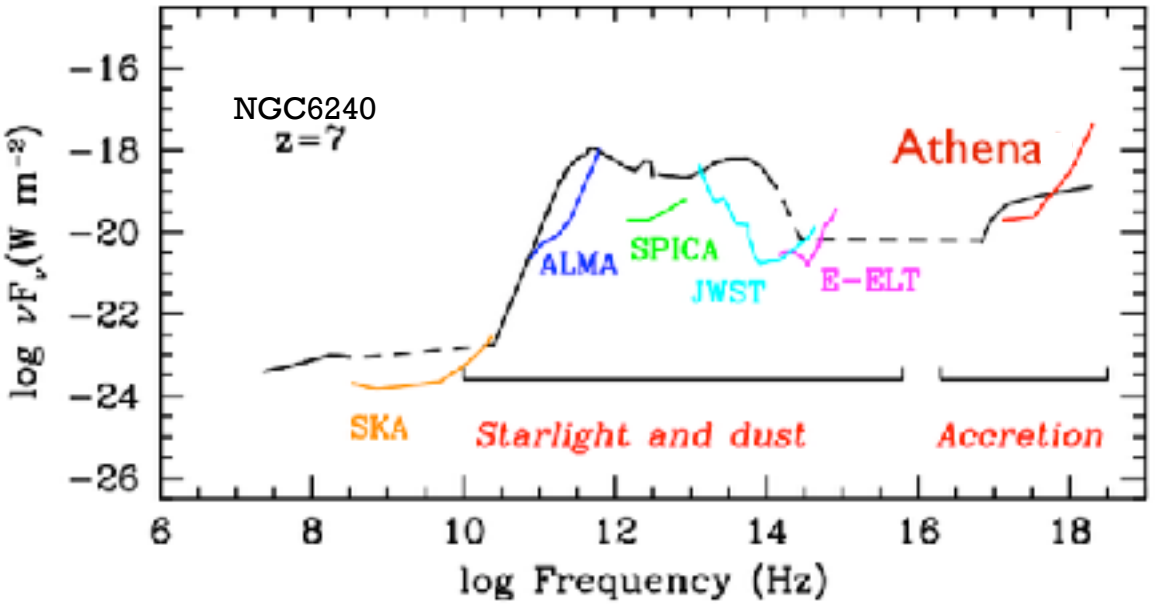
Athena Science Requirements

Parameter	value	enables (driving science goals)
Effective area at 1 keV	≥1.4m^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'' (3σ)	High z AGNs
GRB trigger efficiency	50%	WHIM, GW
ToO reaction time	≤4 hours	WHIM, first generation of stars, GW

Athena in the framework of the late 2020s

SKA ALMA JWST E-ELT Athena CTA





Credit: M. Türler & Athena team

Athena Synergies with other facilities I

- **ESO-Athena Synergy**
  exercise finished
  - Led by ESO-Athena Synergy Team: P. Padovani (chair), E. Hatziminaglou, M. Díaz-Trigo, S. Viti, S. Ettori, M. Salvato, F. Combes, P. Jonker
  - Synergy White Paper **arXiv:1705.06064**
  - Synergy topics span a broad range of astrophysics

- **SKA-Athena Synergy**
  exercise finishing now
  - Led by SKA-Athena Synergy team: R. Cassano (chair), R. Fender, C. Ferrari, A. Merloni.
  - Synergy White Paper due by ~end 2017
  - AGN, clusters & transients

#AthenaNuggets by Diaz-Trigo

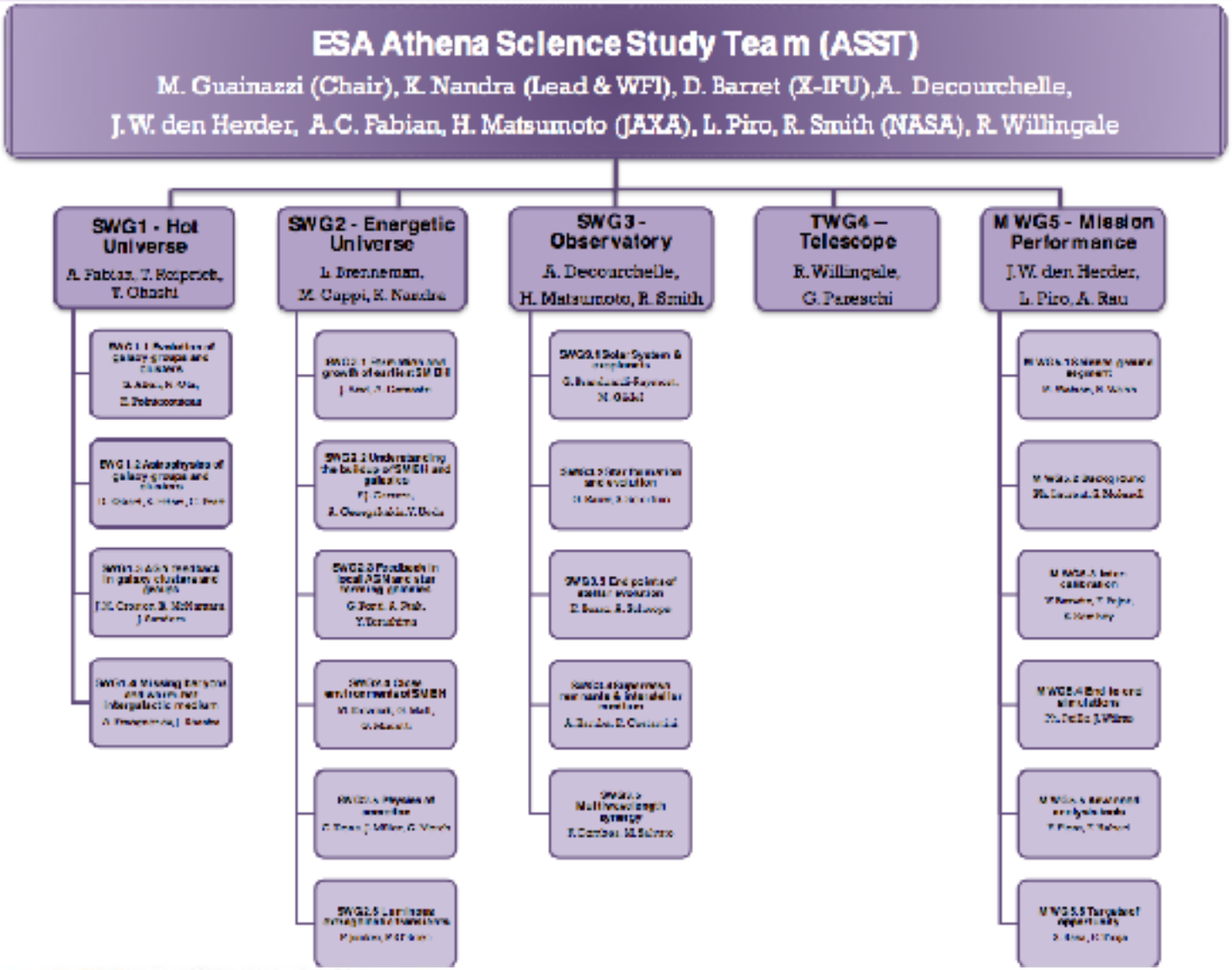
See talks by Iván Agudo and Silvia Martínez

Athena Synergies with other facilities II

- **Gamma-ray and multi-messenger facilities-Athena** synergies
  - CTA, **LIGO/VIRGO**, other future (e.g. SVOM…), neutrinos?, cosmic rays?
  - Led by Luigi Piro (ASST)
  - Complex endeavour
  - To start soon
- **Wide-Field Opt/IR Surveyors-Athena** synergies
  - Euclid, WFIRST, LSST…
  - Led by Paul Nandra (ASST)
  - Complex endeavour
  - To start early next year
- Many others…

See talks by Romano Corradi, Antonio de Ugarte and Juan A. Fdez

Athena Community Organisation



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

See Silvia Martínez's talk

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
  - ≥1 order of magnitude improvement over several performance parameters with respect to any existing or planned X-ray missions
- It will be an essential part of the observational landscape in the late 2020s, together with ALMA, E-ELT, SKA, CTA, etc.
- Vibrant community ≥800 astronomers supporting it
- Technologically challenging, but based upon a robust scientific, technical and commercial heritage
- Good progress with Phase A.
  - Key milestone in 2020: Mission adoption by ESA for a launch in 2028/29.

- **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**

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

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2nd Athena conference
Palermo (Italy)
24-28 Sep 2018