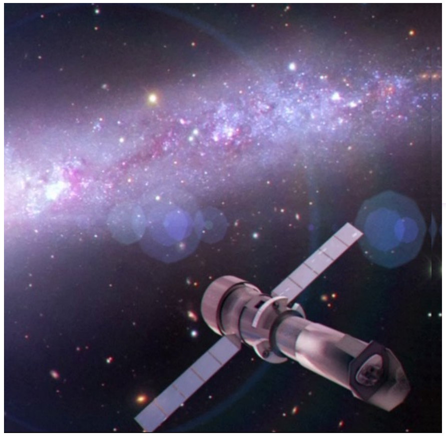
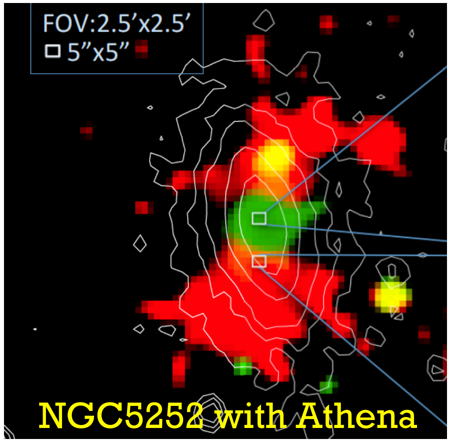
Athena: ESA's X-ray observatory to study the Hot and Energetic Universe





Matteo Guainazzi

ESA/SCI-S, ESTEC, Noordwijk

EWASS 2017, 26 June 2017

Contents

- The Athena science theme: Hot and Energetic Universe
- Athena mission profile and performance
- Core scientific objectives
- Outlook

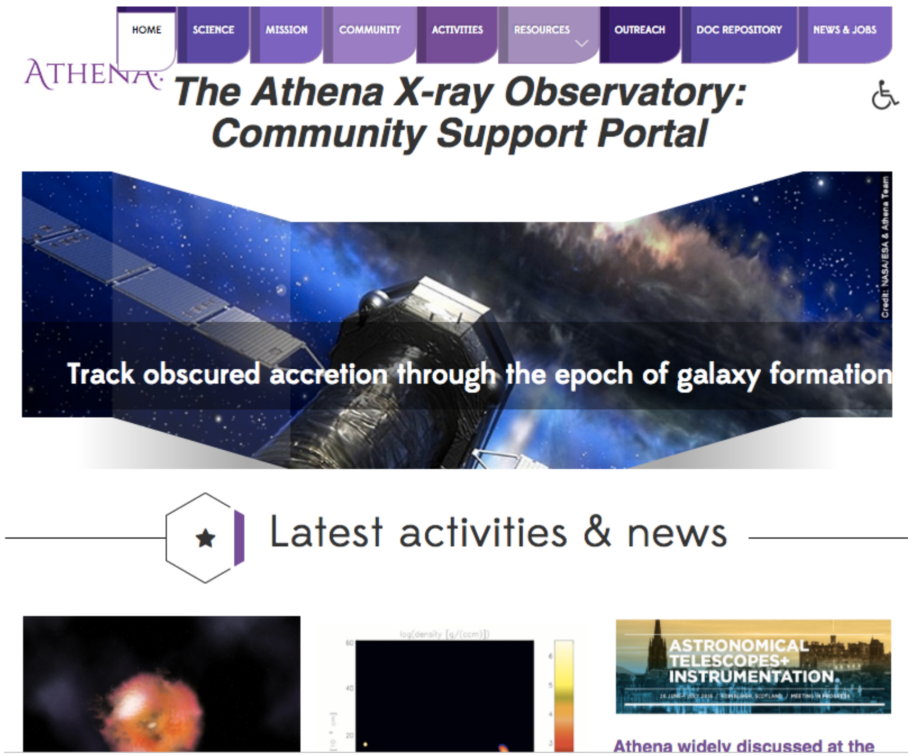
Thanks to the ASST (*Athena Science Study Team*):

K. Nandra. D. Barret, A. Decourchelle, J.W. den Herder, A.C. Fabian, H. Matsumoto, L. Piro, R. Smith, R. Willingale [and former members X.Barcons and D.Lumb]

Advanced Telescope for High-Energy Astrophysics

- Second Large (L2) 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:
  - ToO capability to study transient sources
  - Observatory science across all corners of Astrophysics

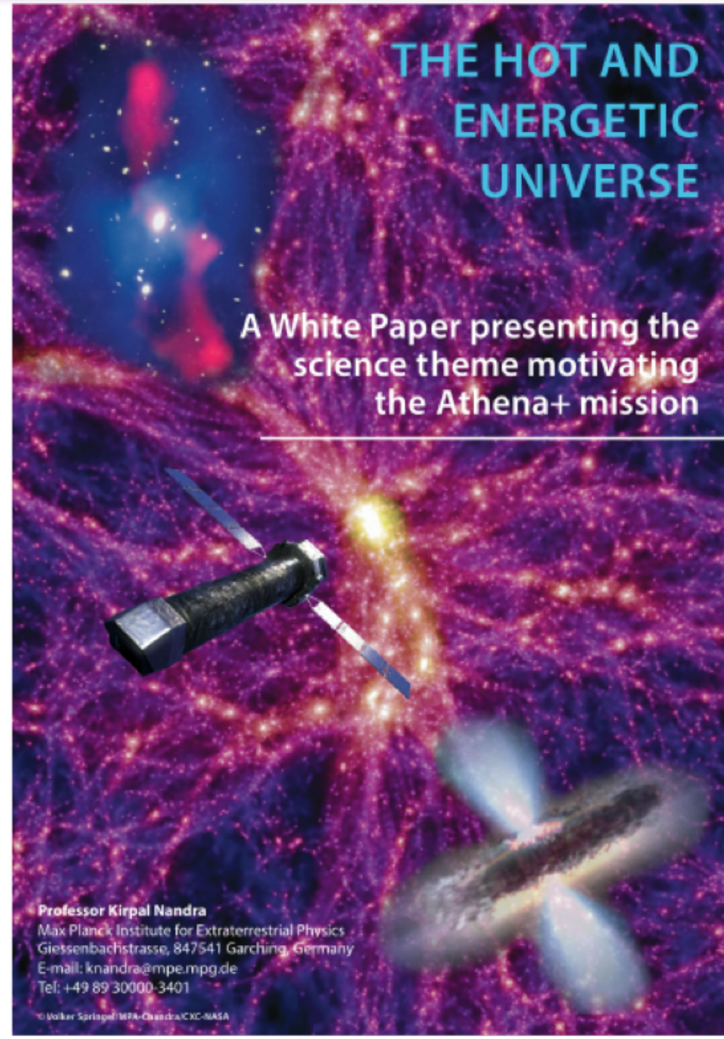
More info at: http://www.the-athena-x-ray-observatory.eu



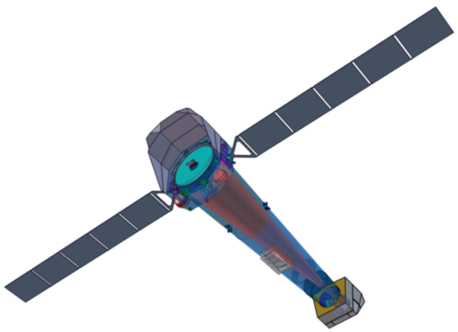
800+ scientists in the Athena community

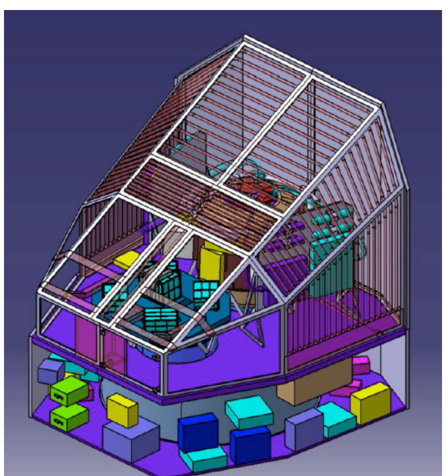
The Hot and Energetic Universe

- 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 times the binding energy of a galaxy
  - 15% of the energy output in the Universe is in X-rays



Mission profile (approved)

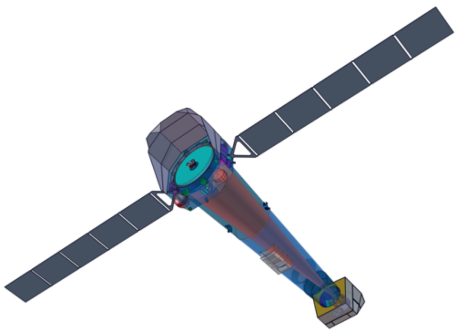




SIM (a.k.a. FPM) concept, ESA CDF

- Single telescope, Silicon Pore Optics (SPO) technology, 12 m focal length, 2 m^2 area (goal) @1 keV, 0.25 m^2 @6 keV
- WFI (Active Pixel Sensor Si detector): wide-field (40'x40') spectral-imaging, CCD-like energy resolution (120-150 eV @6 keV)
- X-IFU (cryogenic imaging spectrometer): 2.5 eV energy resolution, 5'x5' field-of-view, ~5" pixel size
- Defocusing capability increases count rate dynamical range
- 4 hours response with a 50% efficiency to observe a ToO in a random position in the sky
- Metrology system to achieve a final astrometric error ≤1" (3σ)
- Launch 2028, Ariane 6.4, L2 halo orbit (TBC)
- Nominal life-time 5 years + extensions

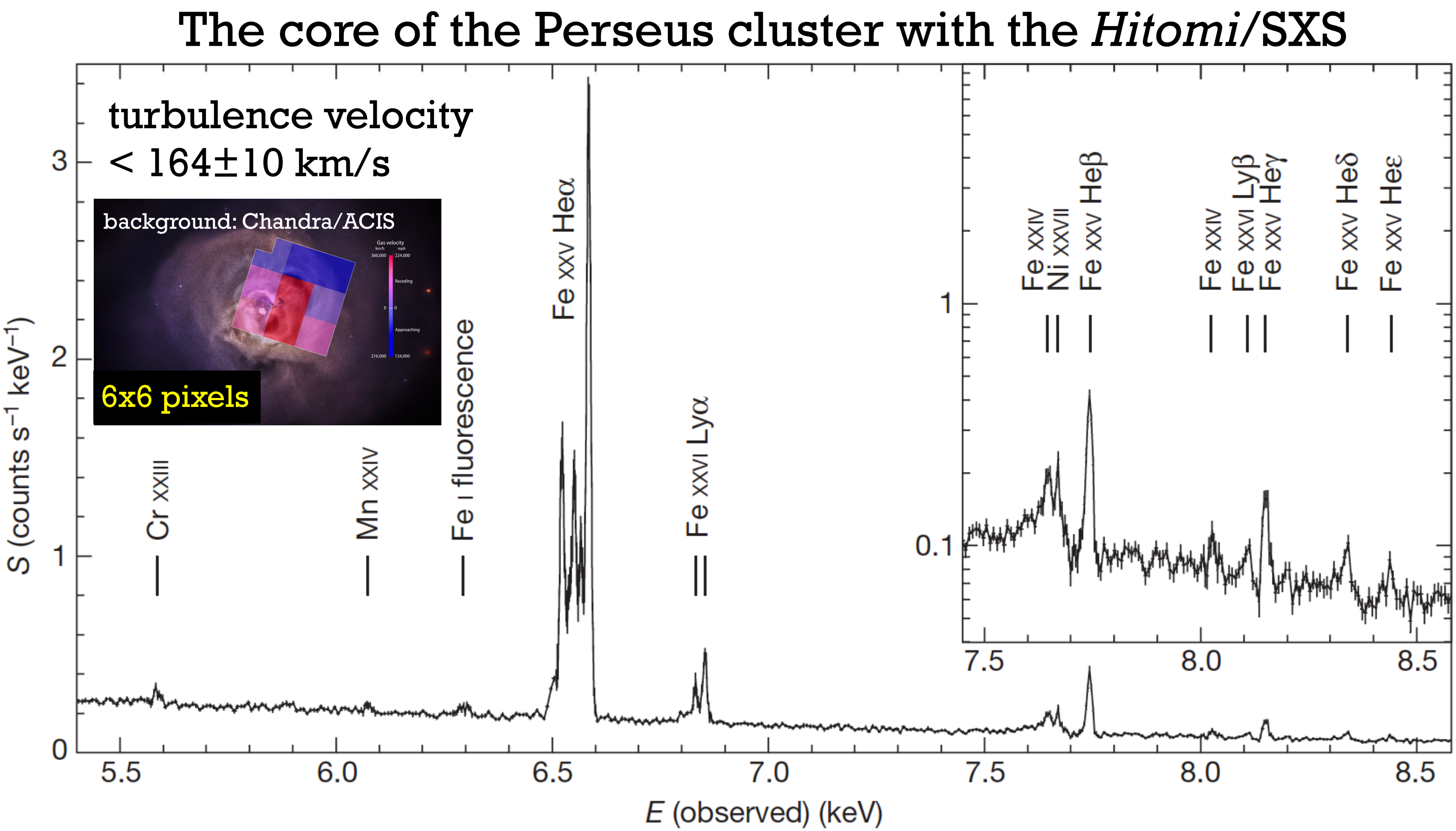
Mission profile (current Phase A)



- Single telescope, Silicon Pore Optics (SPO) technology, 12 m focal length, 1.4-2 m^2 area@1 keV, 0.25 m^2 @6 keV
- WFI (Active Pixel Sensor Si detector): wide-field (40'x40') spectral-imaging, CCD-like energy resolution (120-150 eV @6 keV)
- X-IFU (cryogenic imaging spectrometer): 2.5 eV energy resolution, 5'x5' field-of-view, ~5" pixel size
- Defocusing capability increases count rate dynamical range
- ≥4 hours response with a ≤50% efficiency to observe a ToO in a random position in the sky
- Metrology system to achieve a final astrometric error ≤1" (3σ)
- Launch 2028, Ariane 6.4, L2 halo orbit (TBC)
- Nominal life-time 4 years + extensions

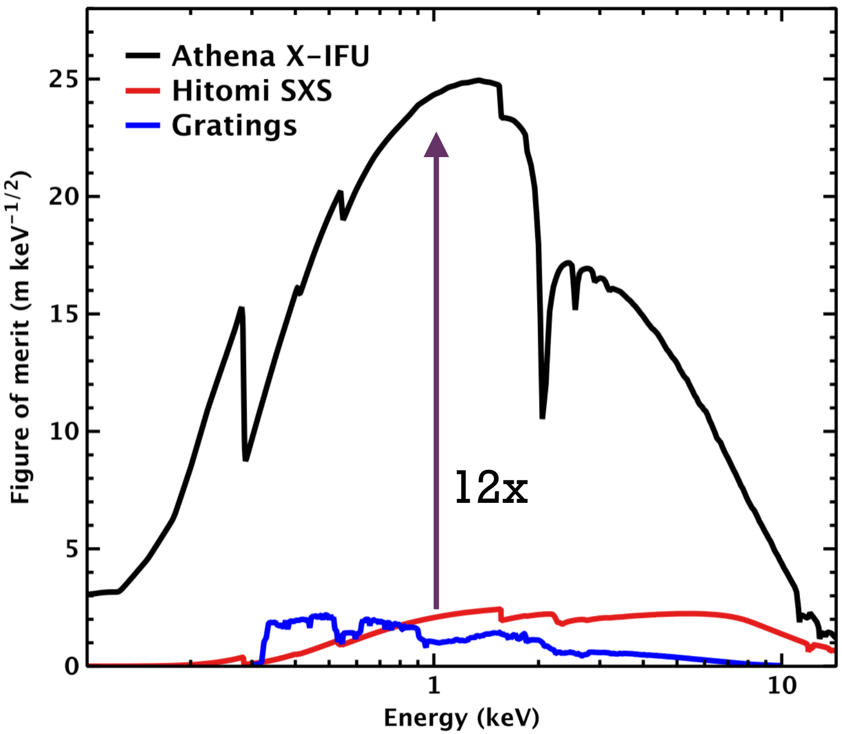
SIM (a.k.a. FPM) concept, ESA CDF

The best X-ray spectrum ever seen by human eyes

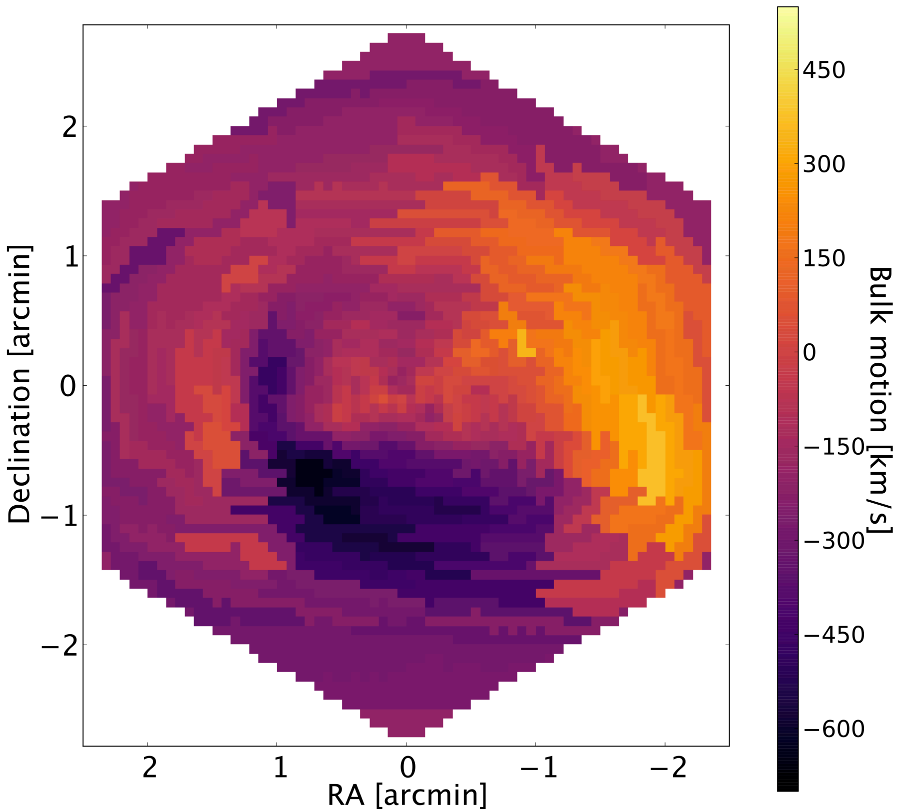


A revolutionary mix of science performance - I

Effective area per energy resolution element

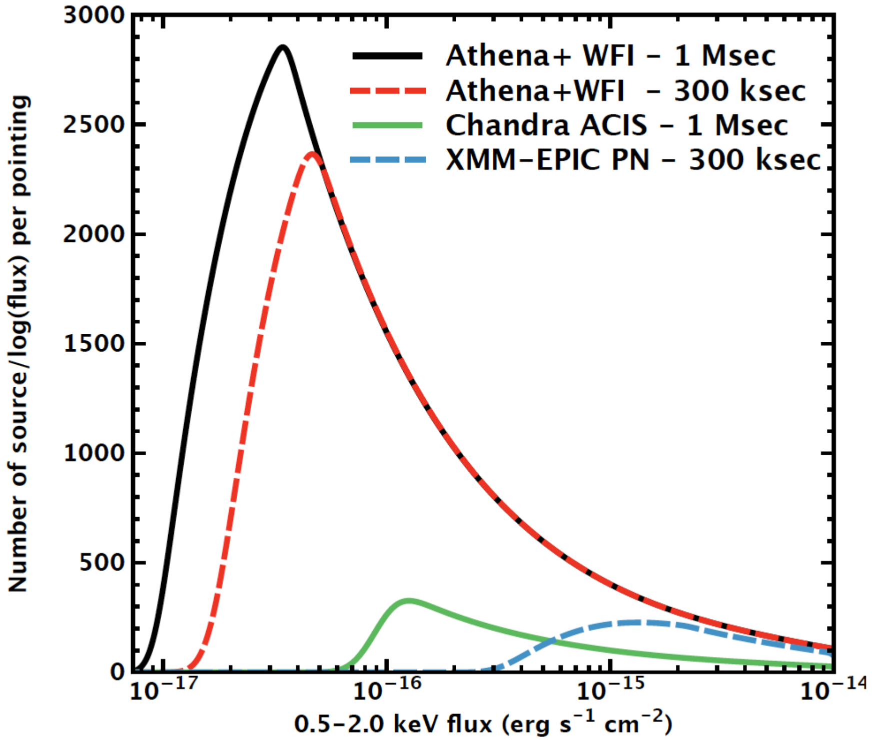


Simulated velocity map at a 5" pixel resolution

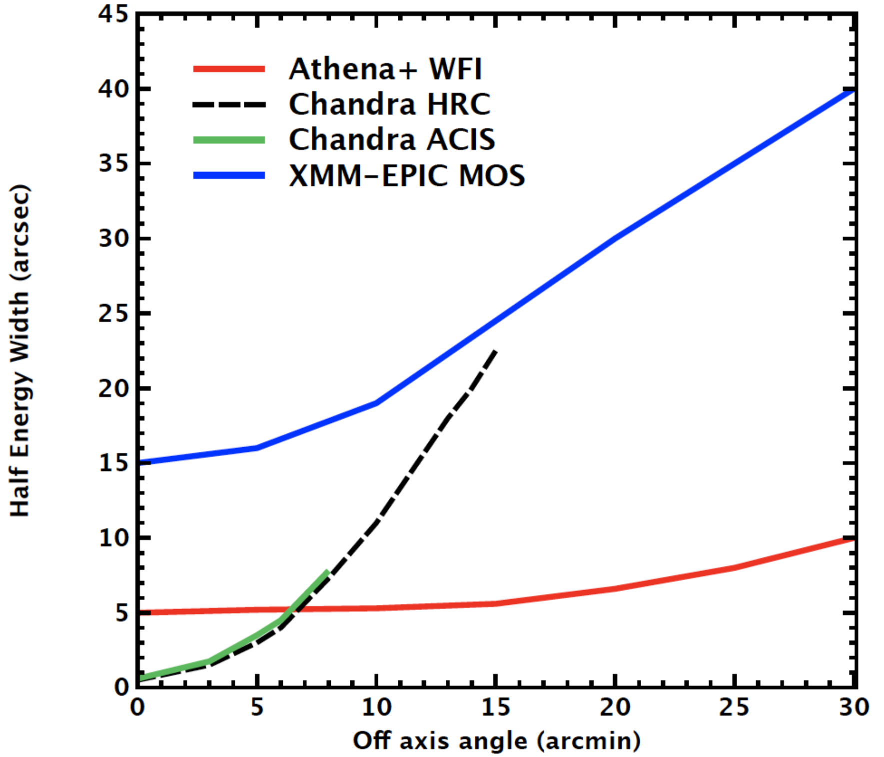


A revolutionary mix of science performance - II

Number of sources per log(flux)



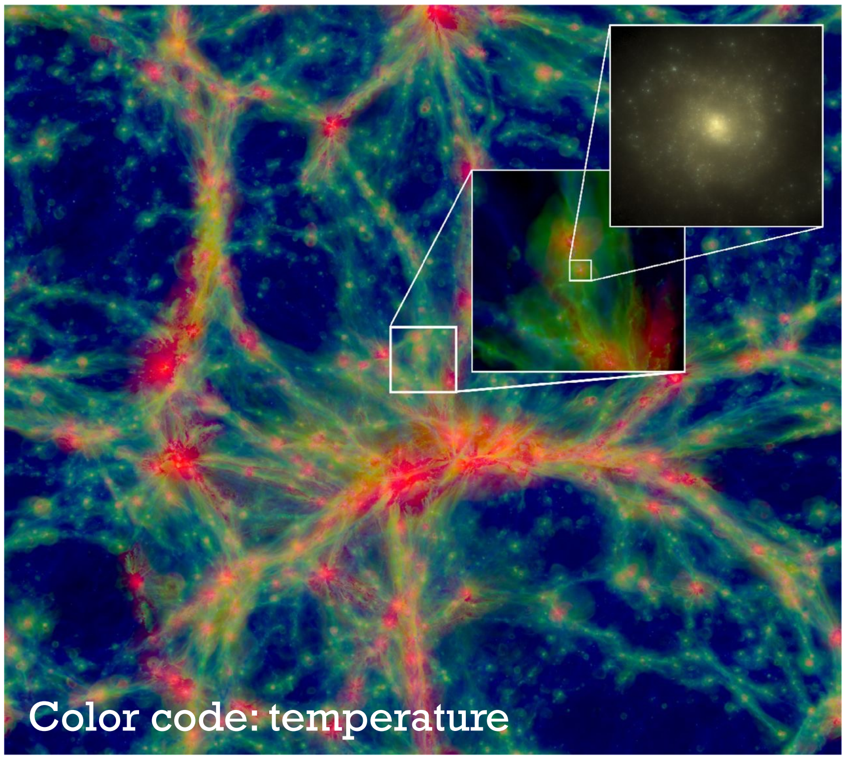
Gentle degradation of the off-axis HEW



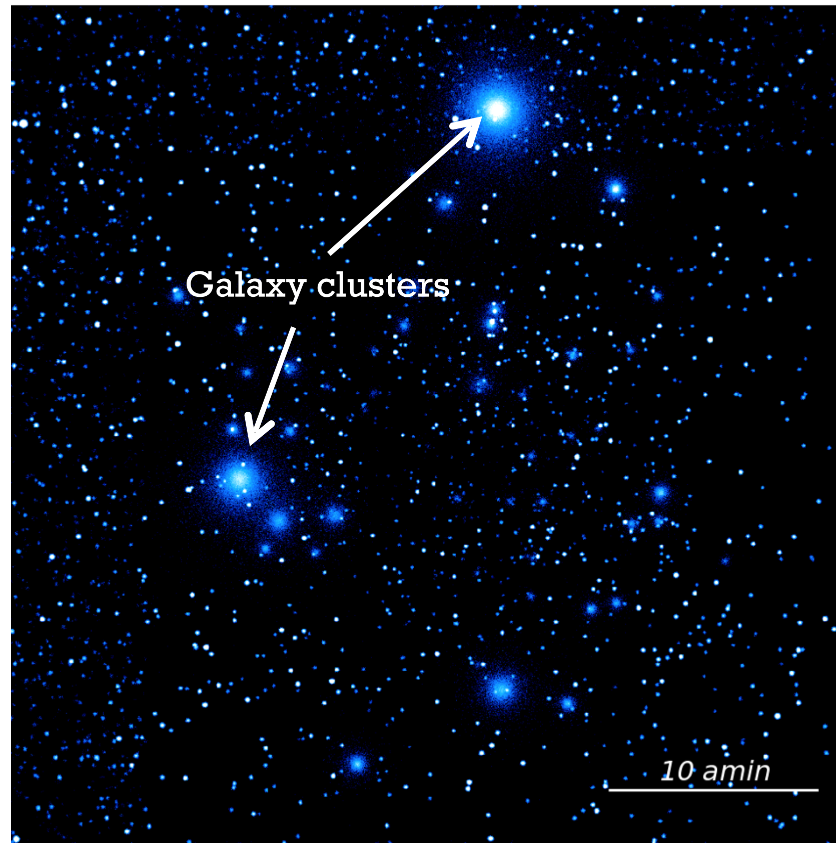
Schaye et al., 2015, MNRAS, 446, 521

The Hot Universe – baryonic assembly

Simulation of the cosmic web (EAGLE)



Athena/WFI 1Ms simulation - MPE & WFI team

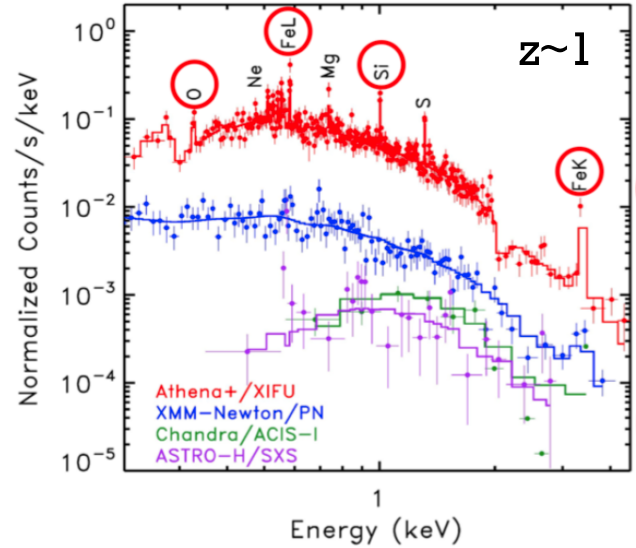


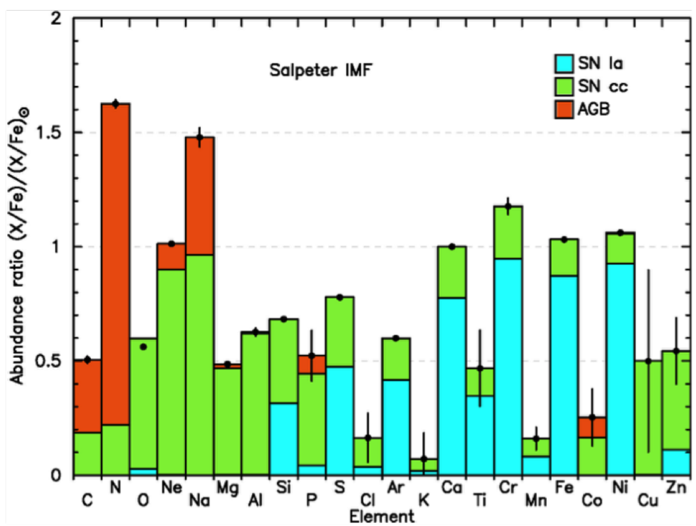
Courtesy: J. de Plaa (SRON)

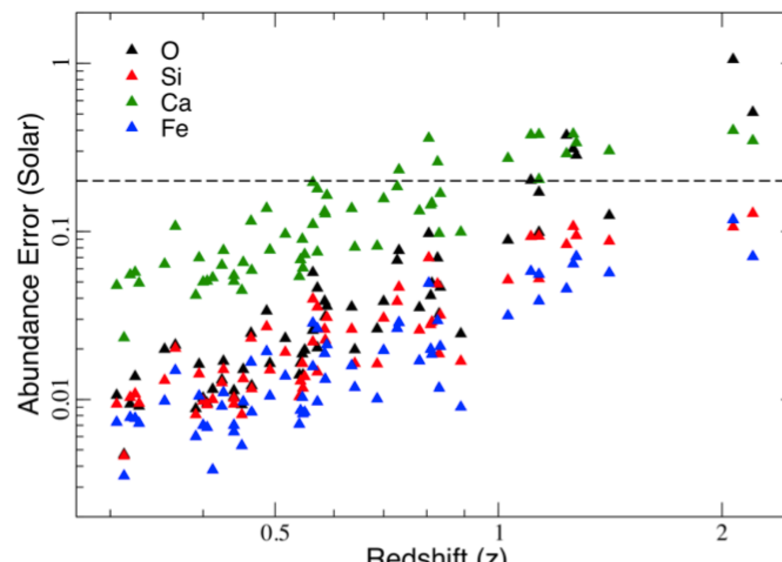
Pointcouteau, Reiprich et al., 2013, arXiv:1306.2319

Chemical evolution of the inter-cluster gas

- 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
- Probing clusters *and* groups up to z~2

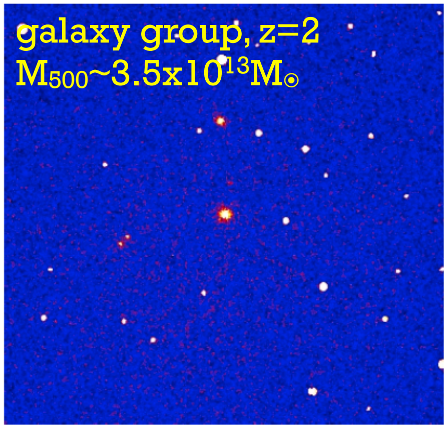




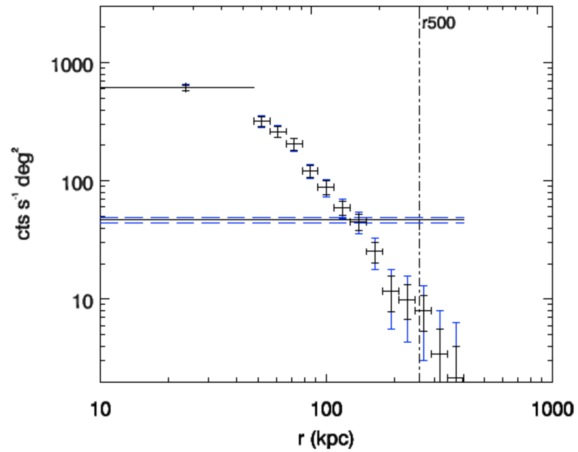


Ettori, Pratt et al. 2013 arXiv1306.2322
Pointecouteau, Reiprich et al. 2013, arXiv: 1306.2319

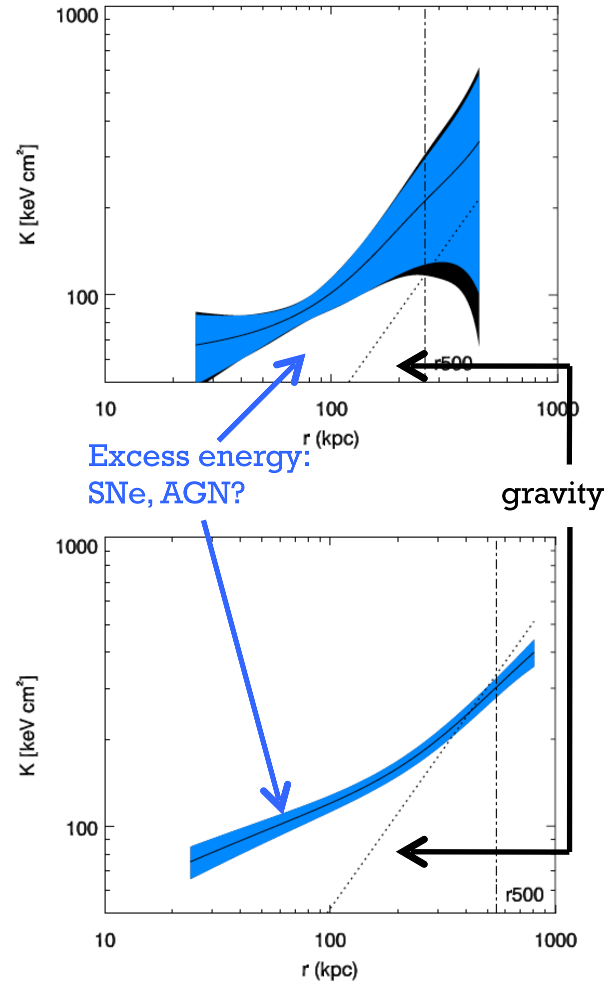
Evolution of hot inter-cluster gas

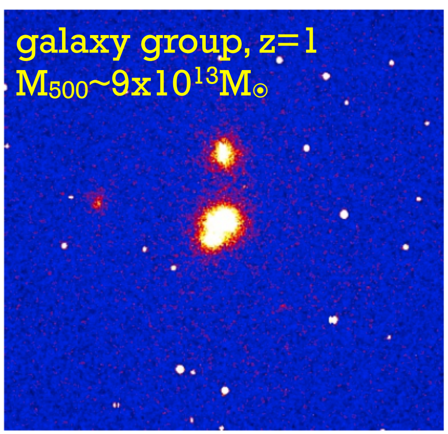


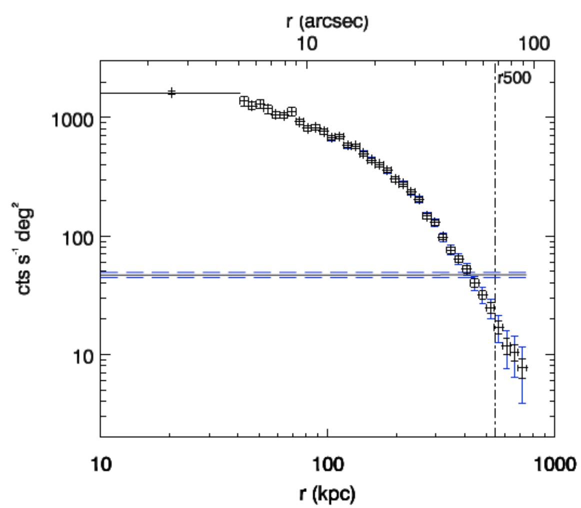
Surface brightness



Entropy profile

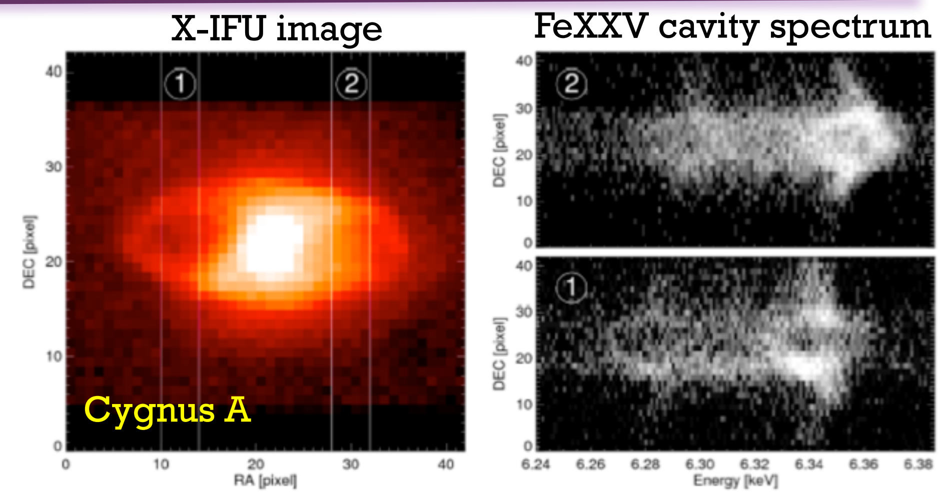


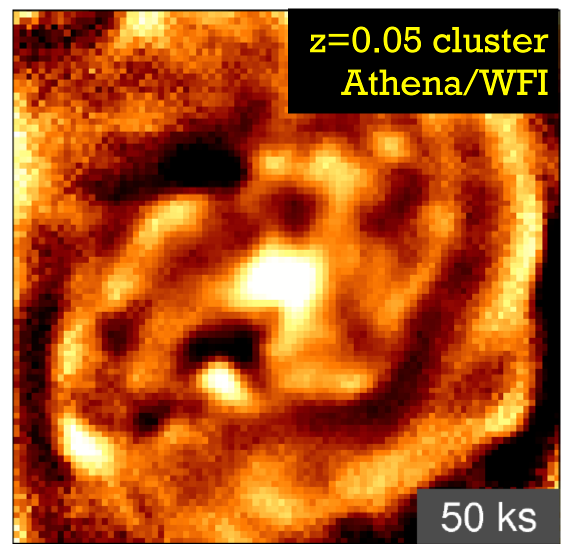




AGN feedback on cluster scales

- 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



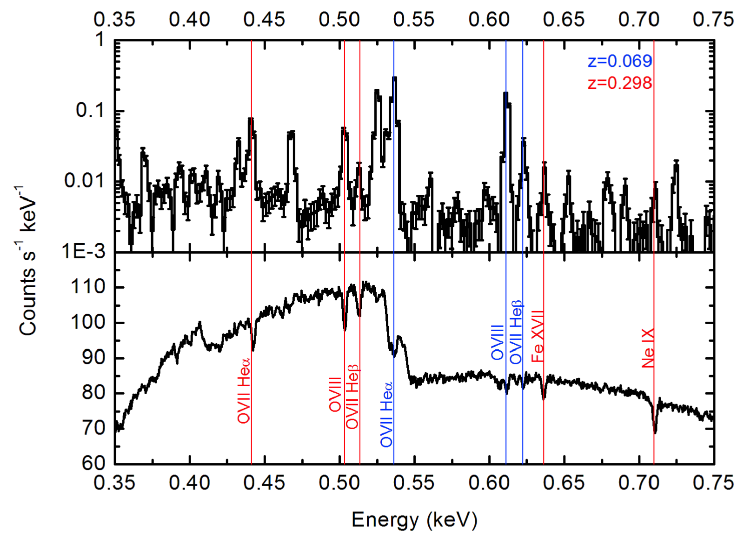


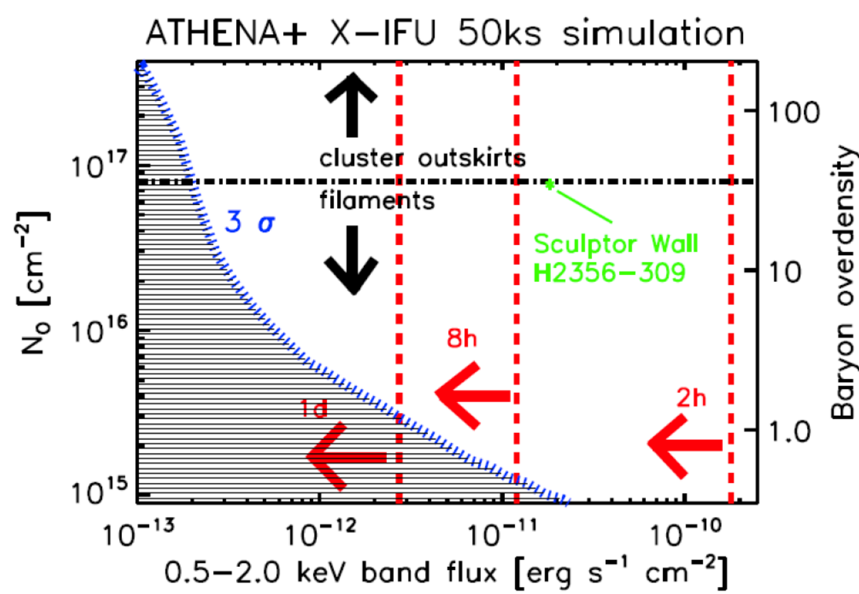
Kaastra et al., 2013, arXiv:; Courtesy: F. Nicastro (OaR)

Missing baryons: the WHIM*

*Warm-Hot Intergalactic Medium

- 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**
  - In emission:
    - Tenuous and extended
    - Key to understand CGM and feedback

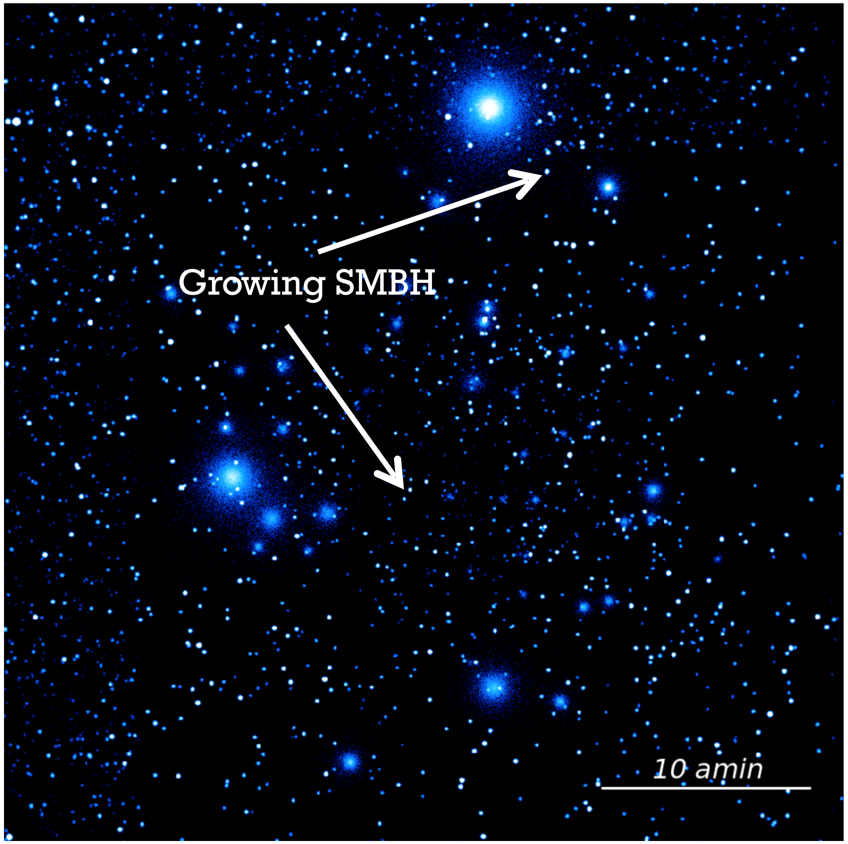




The Energetic Universe – Black Holes

Artistic representation of a super-massive accreting black hole

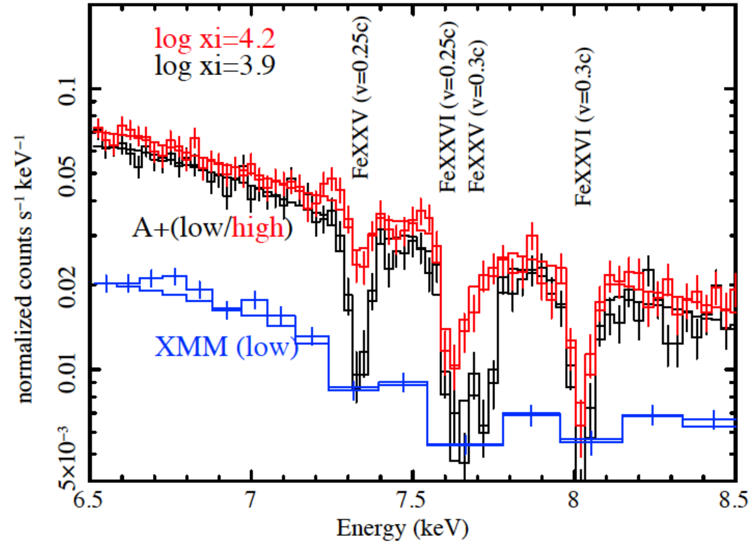
Athena/WFI 1Ms simulation
MPE & WFI team



AGN disk wind feedback with Athena

- Possible evidence for "AGN feedback" regulating the star formation history and ISM chemical enrichment
- AGN outflows with $L_{mech} \gtrsim 1\% L_{bol}$ may be the "feedback messenger"
- Relativistic ($v \gtrsim 0.1c$) disk outflows discovered at X-ray CCD-resolution However:
  - no plasma diagnostic possible
  - no estimate of mass and kinetic energy outflow possible
- High-resolution at the Fe band (6-7 keV) is the key
- Athena will make this possible, up to z~4

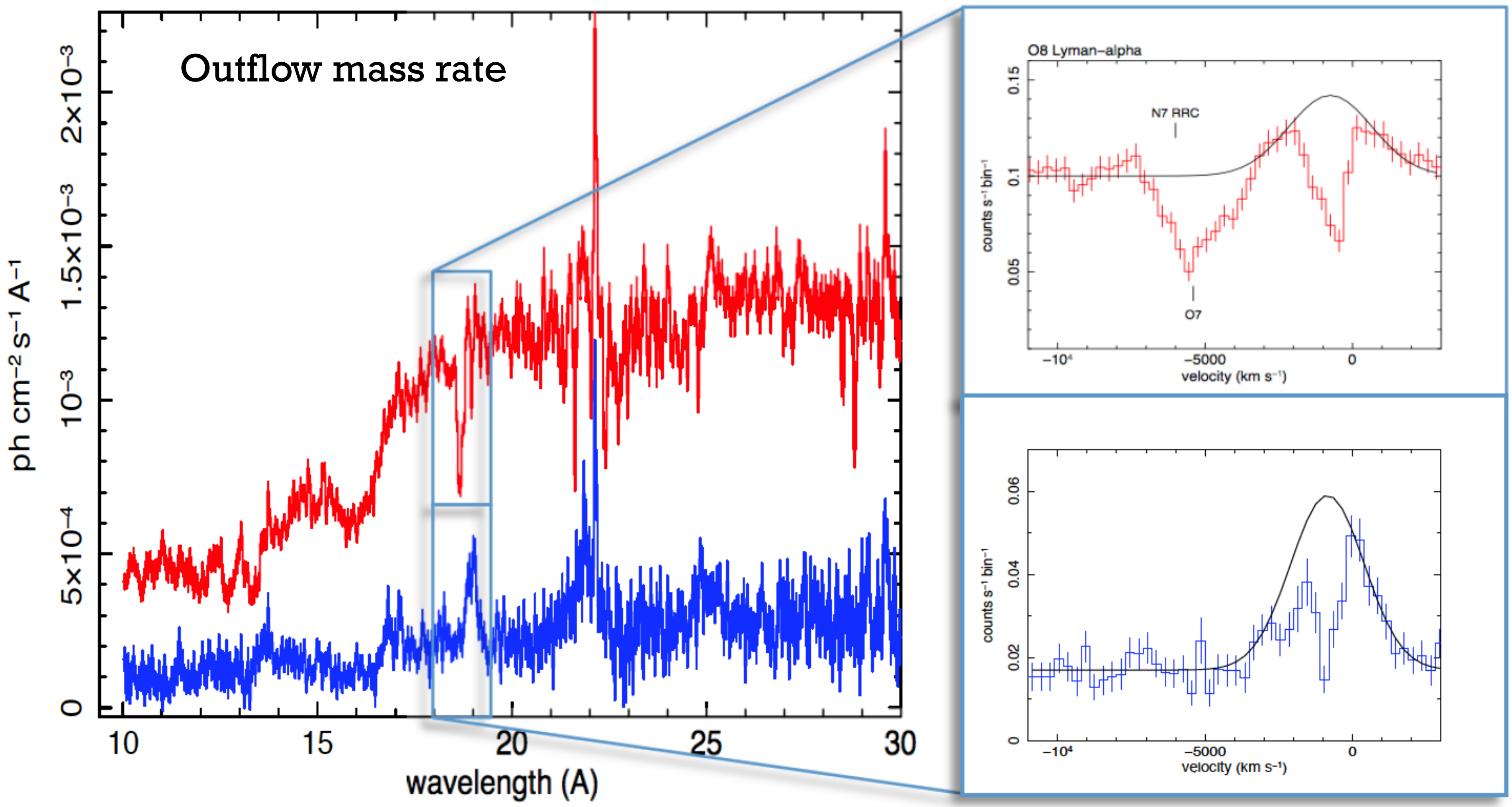
XMM-Newton/EPIC data versus Athena simulation of PDS456 (nearby quasar)



Cappi et al., 2013, arXiv:1306.2330

Determine outflow physics on dynamical timescales

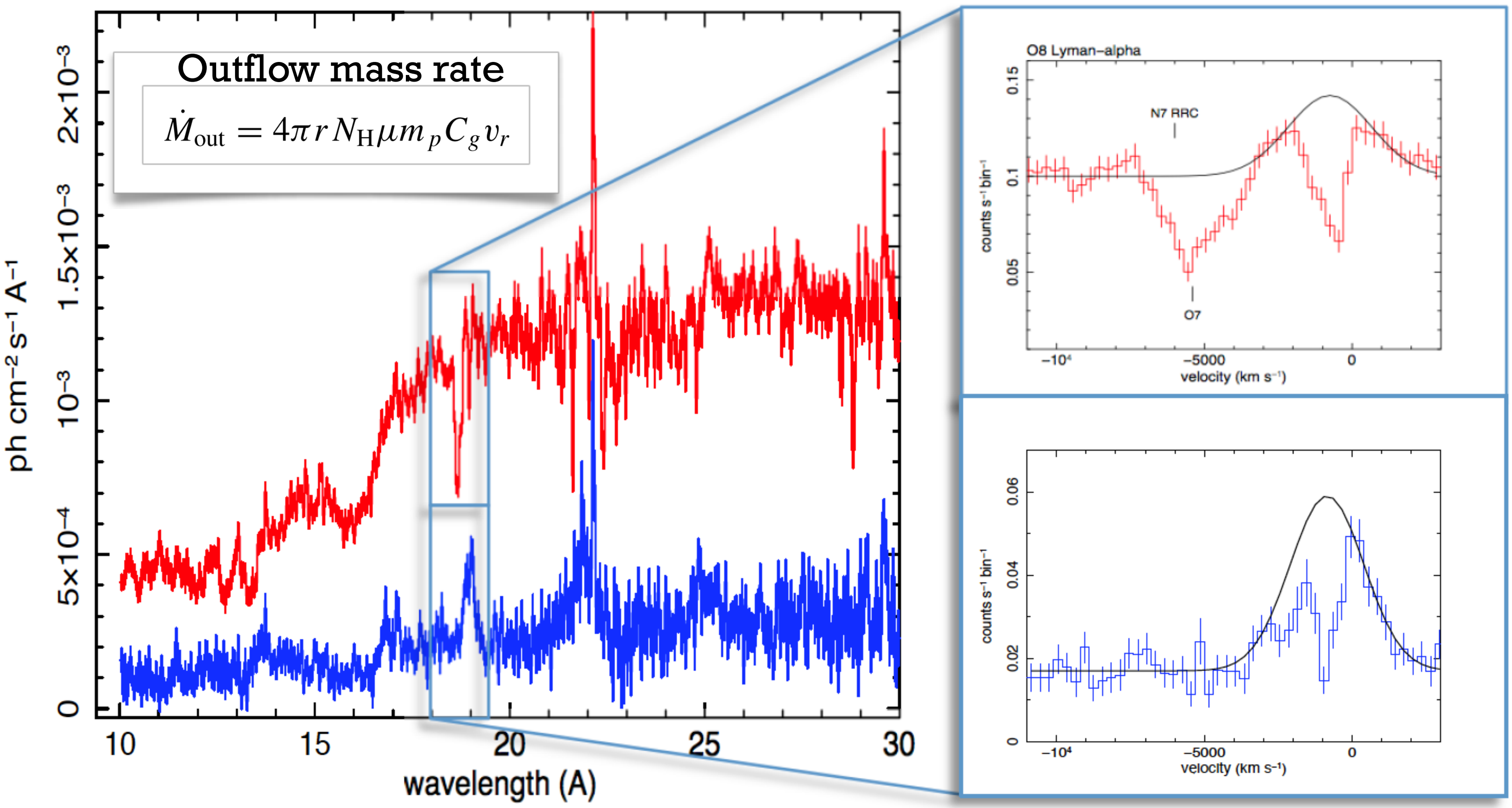
~15 minutes of an Athena observation of a disk wind (NGC4051)



Cappi et al., 2013, arXiv:1306.2330

Determine outflow physics on dynamical timescales

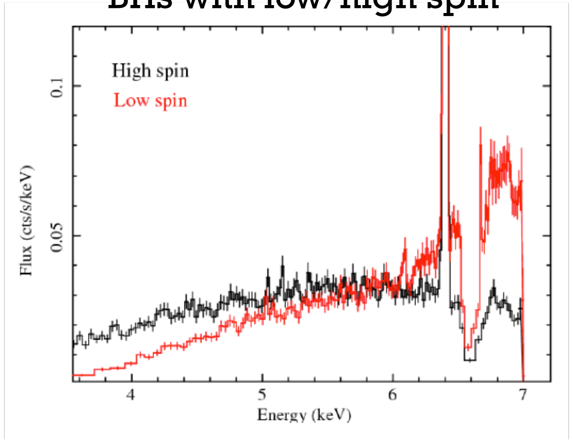
~15 minutes of an Athena observation of a disk wind (NGC4051)

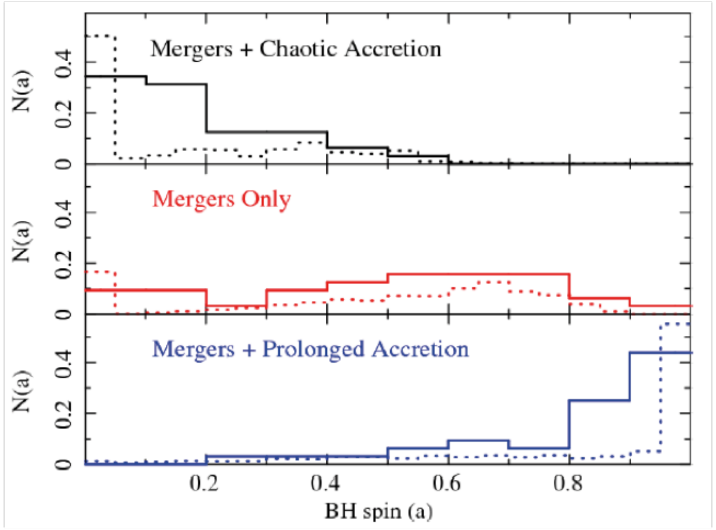


SMBH growth: accretion vs mergers

- 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
- Doable with current missions on ~10 AGN, *but*:
  - Uncertain removal of narrow features
  - Biases: Highly spinning SMBH are radiatively more efficient and therefore are overrepresented in flux-limited samples
- Athena can obtain BH spins for *fainter AGN* (several tens) and *correct for this effect*

Athena simulations of accreting BHs with low/high spin

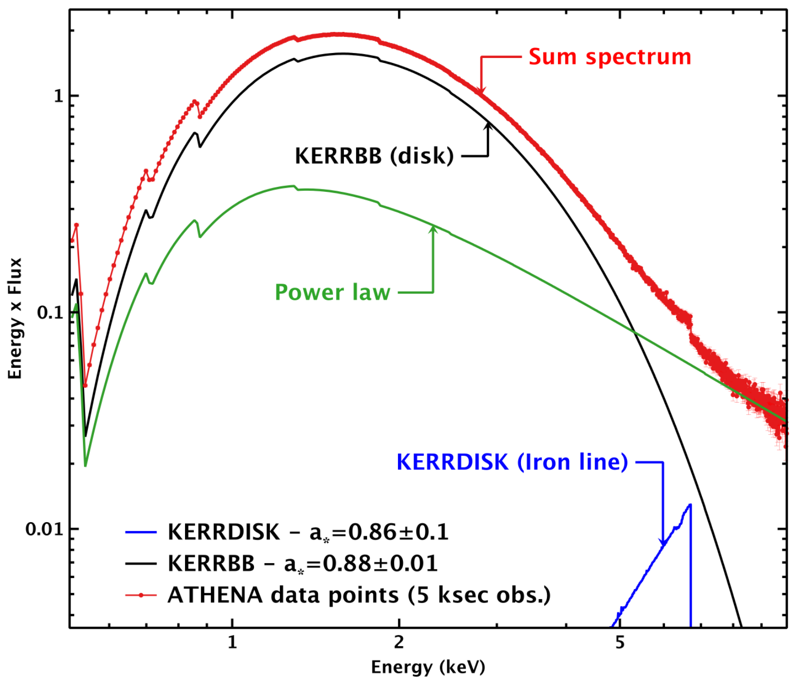




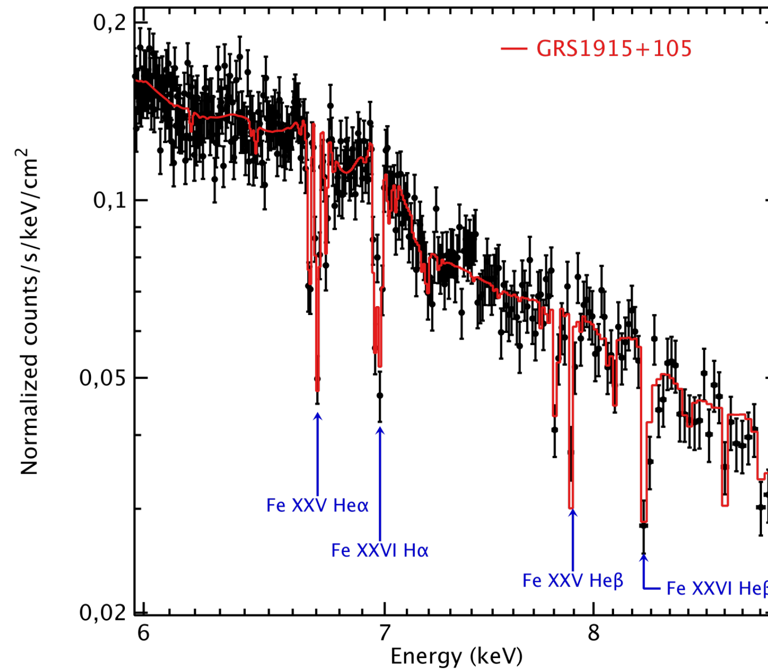
Courtesy J.M. Miller; Barret et al. 2016, SPIE2016

BH accretion physics at all scales

Typical X-ray spectrum of a stellar mass black hole in a binary



Athena simulation of an outflow in a stellar mass black hole binary

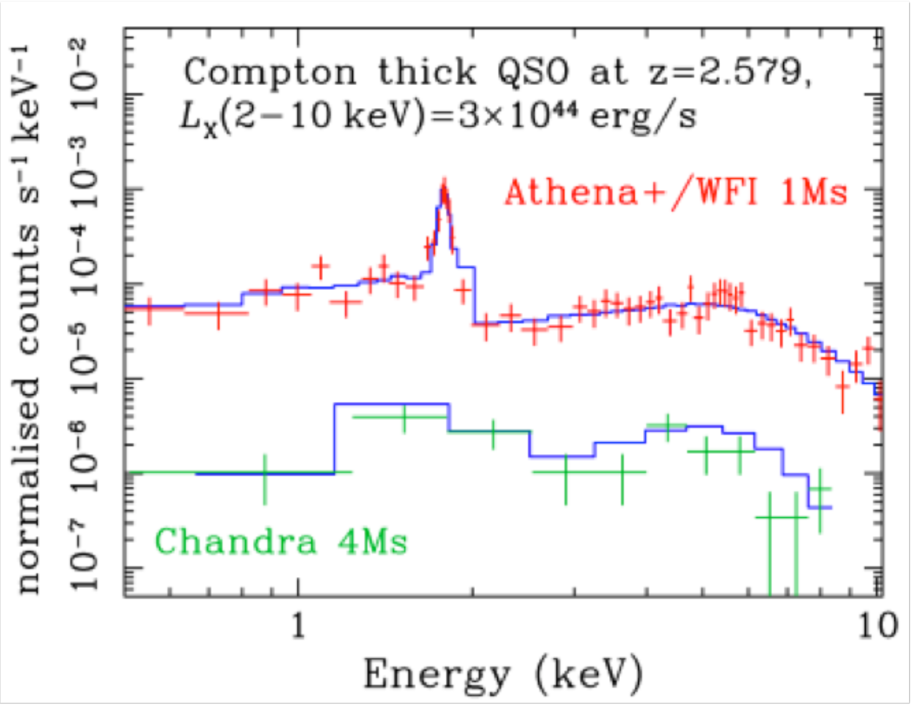


[… for why we expect similar physics: Svoboda, Guainazzi, Merloni, 2017, A&A, in press (arXiv:1704.07268)]

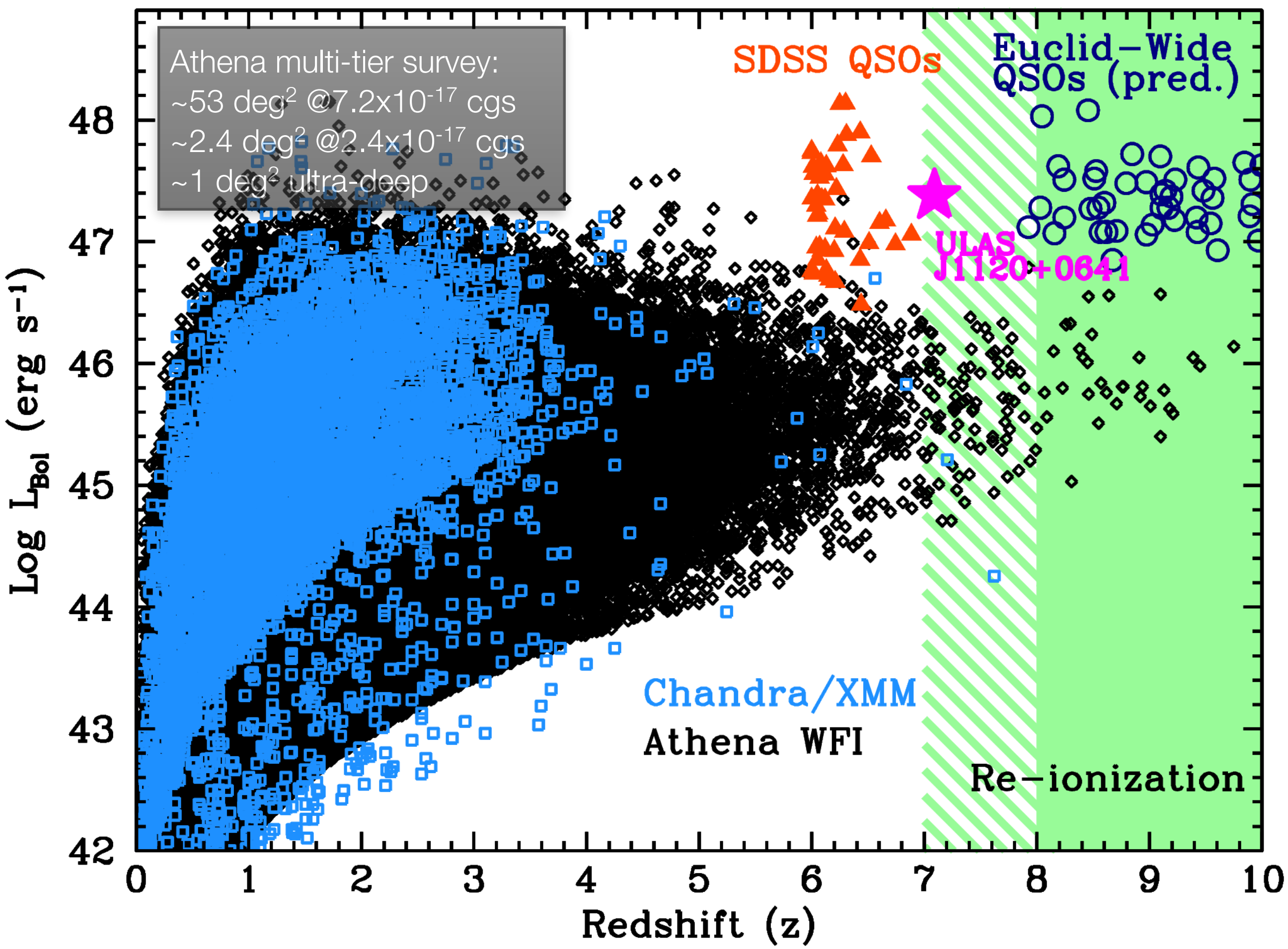
Obscured AGN census @ z~1-3

#AthenaNuggets Carrera

- 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) superposed to a hard continuum spectrum
  - 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.



The history of SMBH growth



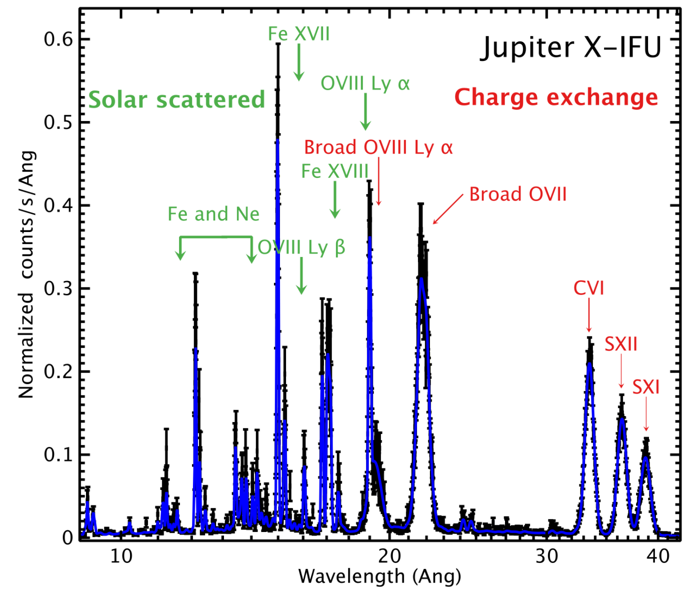
Only extreme AGN expected in opt/IR surveys

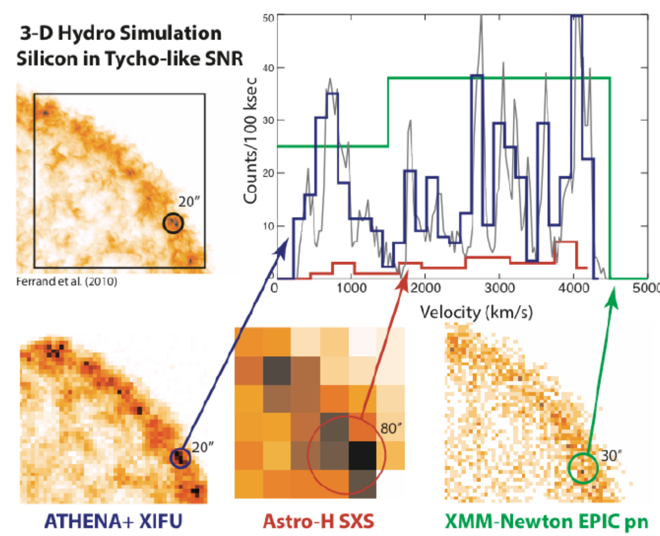
X-rays needed to signpost average AGN

~4-600,000 AGN
~160-400 @8>z>6
[~30 @z>8]
60 Compton-thick AGN (1<z<4) over 6 deg^2

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
- Interstellar medium
- Dark Matter candidates





Outlook

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

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, together with ALMA, E-ELT, SKA, CTA, etc.

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, together with ALMA, E-ELT, SKA, CTA, etc.
- Vibrant community supporting it

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, together with ALMA, E-ELT, SKA, CTA, etc.
- Vibrant community supporting it
- Good progress with Phase A.
  - Key milestone in 2020: Mission adoption by ESA for a launch in 2028.

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, together with ALMA, E-ELT, SKA, CTA, etc.
- Vibrant community supporting it
- Good progress with Phase A.
  - Key milestone in 2020: Mission adoption by ESA for a launch 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