ATHENA

The Athena science case in context

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- The Hot and Energetic Universe
- Athena in context
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- The Athena science objectives
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  - Observatory science
- Outlook

Thanks to the Athena Science Study Team: D. Lumb, M. Guainazzi, K. Nandra. D. Barret, J.W. den Herder, A. Decourchelle, A.C. Fabian, H. Matsumoto, L. Piro, R. Smith, R. Willingale

Thanks to the ESO-Athena Synergy Team: P. Padovani, M. Díaz-Trigo, M. Salvato, S. Ettori, F. Combes, S. Viti, E. Hatziminaglou, P. Jonker

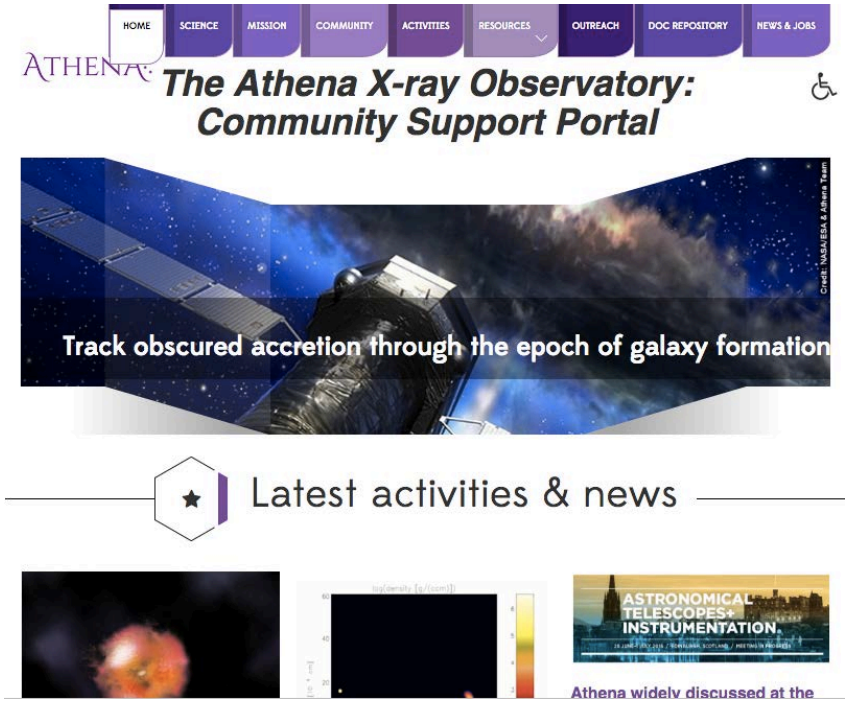
Thanks to the SKA-Athena Synergy Team: R: Cassano, C. Ferrari, R. Fender, A. Merloni

Thanks to the Athena IFCA group: F.J. Carrera, S. Mateos, M.T. Ceballos, S. Martínez-Núñez

AND to the entire Athena Community

Advanced Telescope for High-Energy Astrophysics

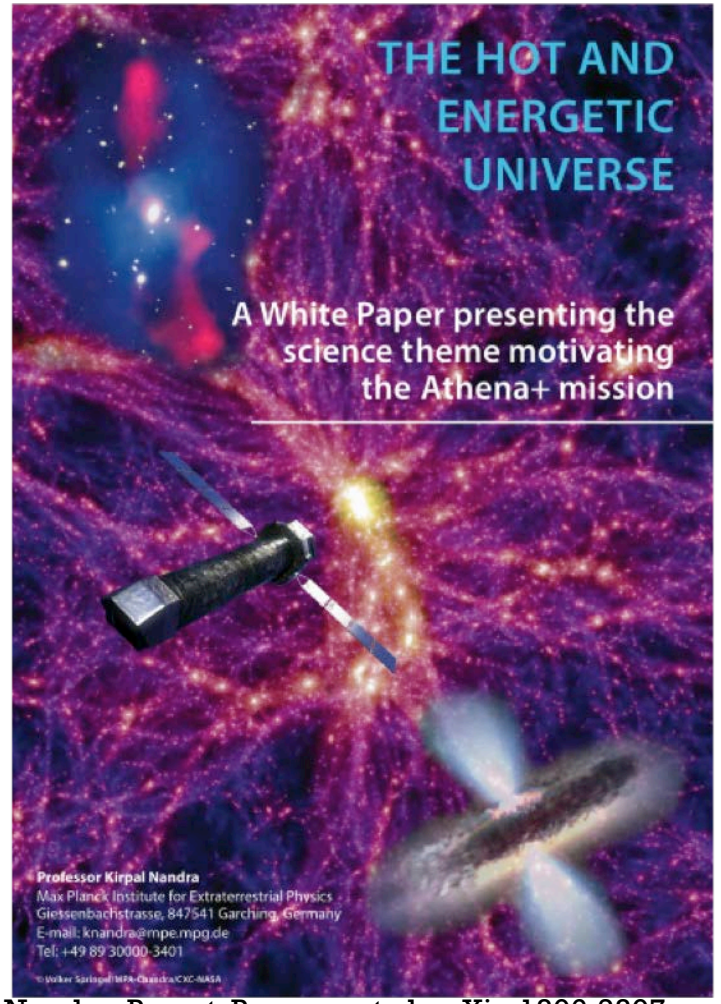
- Second Large (L2) mission of ESA Cosmic Vision 2015-2035
- Science theme: The Hot and Energetic Universe
  - How does ordinary matter assemble in the large-scale structures?
  - How do black holes grow and shape galaxies?
- In addition:
  - Fast ToO capability to study transient sources
  - Observatory science across all corners of Astrophysics



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

The Hot and Energetic Universe

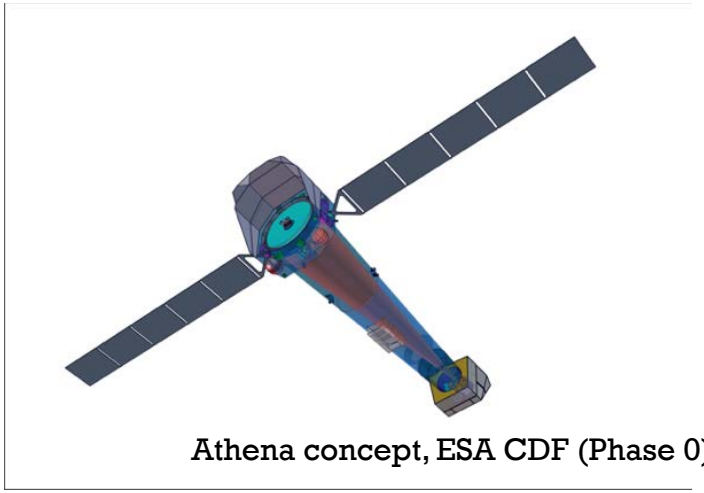
- The Hot Universe: How does the ordinary matter assemble into the large-scale structures that we see today?
  - >50% of the baryons today are in a hot (>10^6 K) phase
  - there are as many hot (> 10^7 K) baryons in clusters as in stars over the entire Universe
- The Energetic Universe: How do black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

Athena mission concept

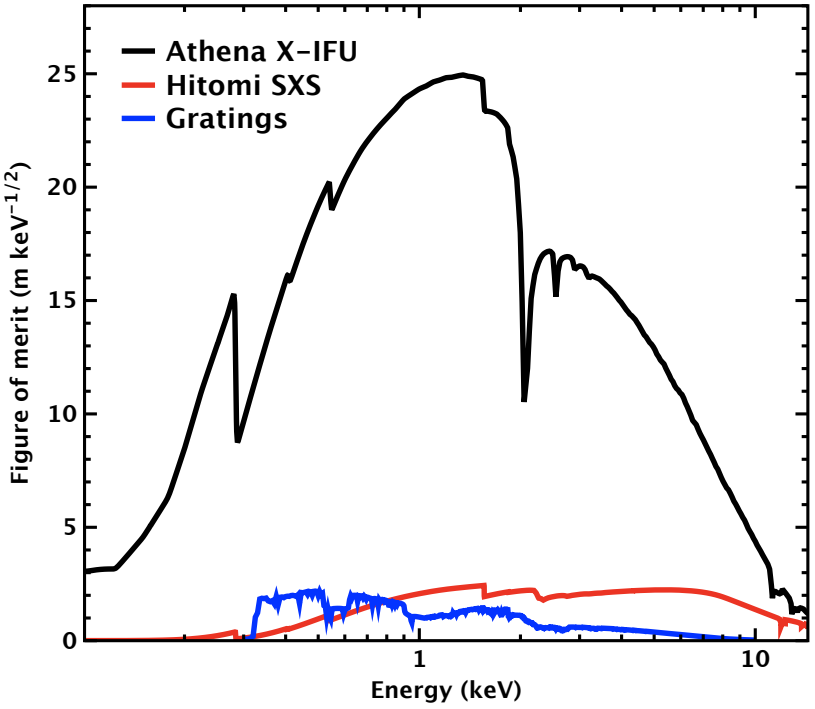
- Single X-ray telescope, using Si pore optics. 12m focal length
  - WFI sensitive imaging & timing
  - X-IFU spatially resolved high-resolution spectroscopy
- Movable mirror assembly to switch between the two instruments
- Launch 2028, Ariane 6-4
- L2 halo orbit (TBC)
- Lifetime > 5 yr

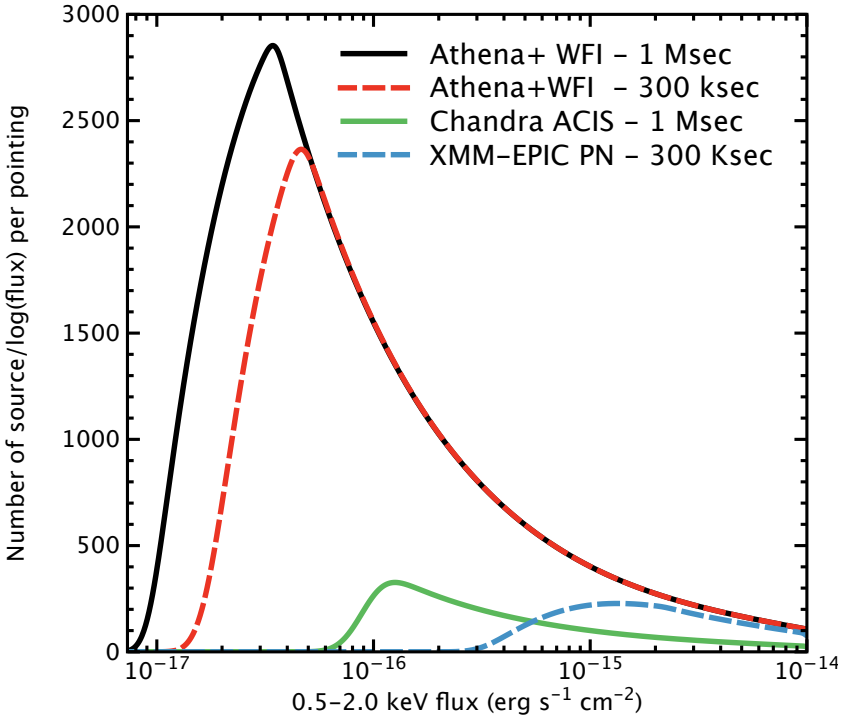


Athena concept, ESA CDF (Phase 0)

- See talks by:
  - **Matteo Guainazzi** (Athena mission concept & status)
  - **Arne Rau** (WFI)
  - **Didier Barret** (X-IFU)

Athena: a transformational observatory

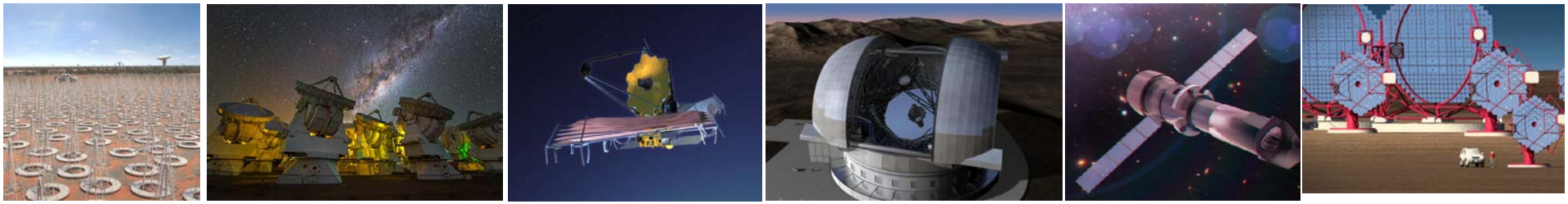


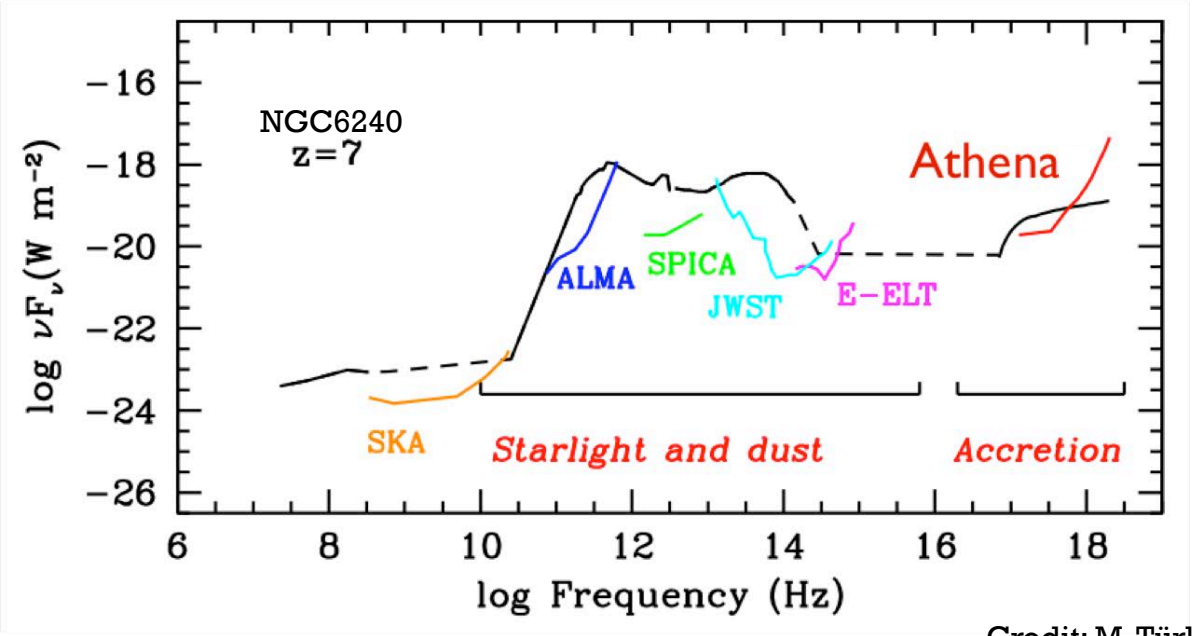


Credit: Athena team

Athena in the framework of the late 2020s

SKA ALMA JWST E-ELT Athena CTA





Credit: M. Türler & Athena team

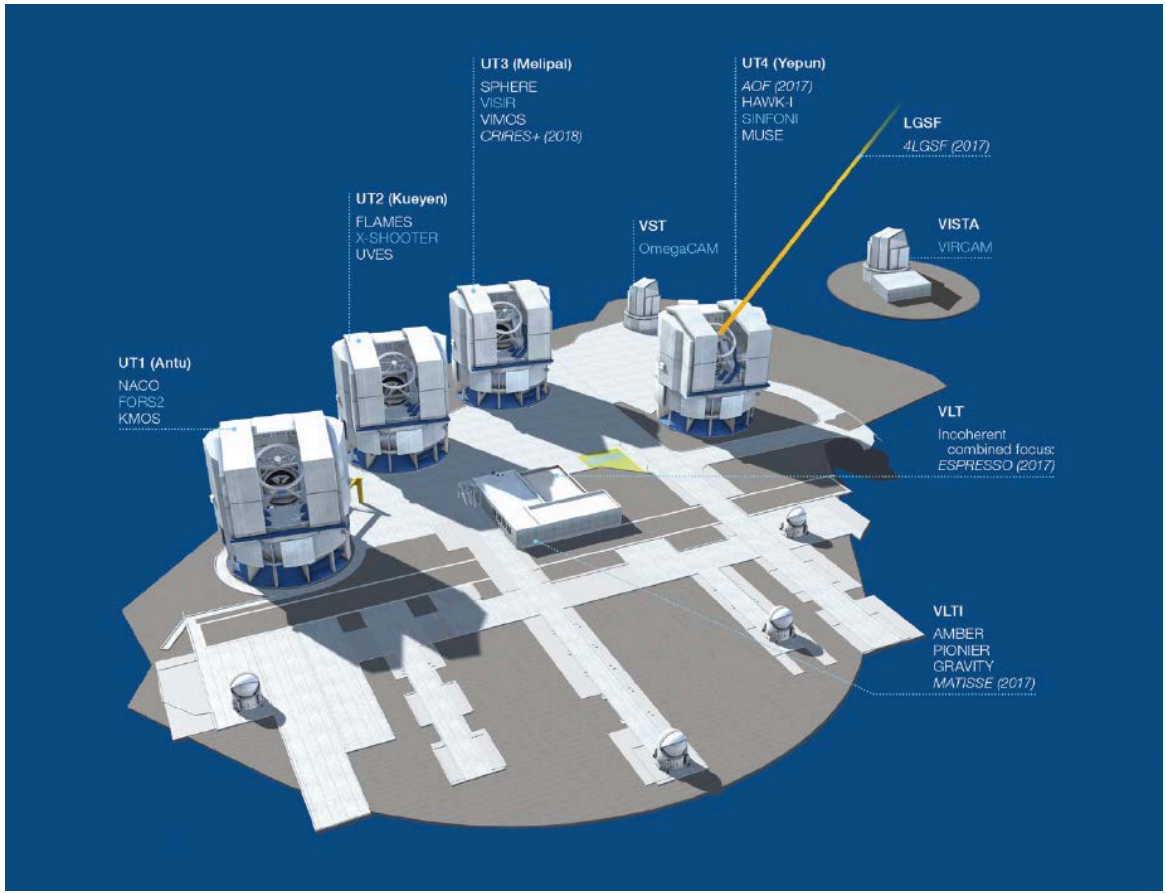
Athena Synergies with other facilities

- Identify scientific synergies between the Athena X-ray Observatory and contemporary observational facilities.
  - Includes “Needs” in both ways and genuine added value science.

- Classification:
  1. **Optical/NIR deep sky observatories (E-ELT, VLT, etc)**
  2. **Sub/mm deep sky observatories (ALMA, single-dish sub/mm etc)**
  3. Large sky monitoring facilities (LSST, Euclid, WFIRST)
  4. **Radio (cm) facilities (SKA and all its precursors)**
  5. Gamma-ray & multi-messenger facilities (CTA, GW, CR, neutrinos)

- **Outcome of exercise**: Produce a series of Synergy White Papers (SWP) identifying and developing such synergies.

ESO Long-Term Programme: VLT/VLTI



- New (2017):
  - 4LGSF
  - ESPRESSO
  - MATISSE
- Next:
  - CRIRES+ (2018)
  - MOONS (2020)
  - ERIS (2020)
  - 4MOST (2021)

T de Zeeuw (2016)
ESO Messenger

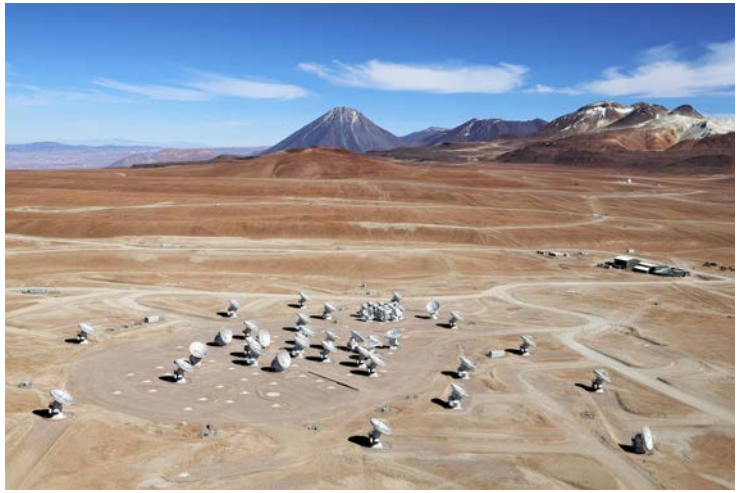
ESO Long-Term Programme: E-ELT

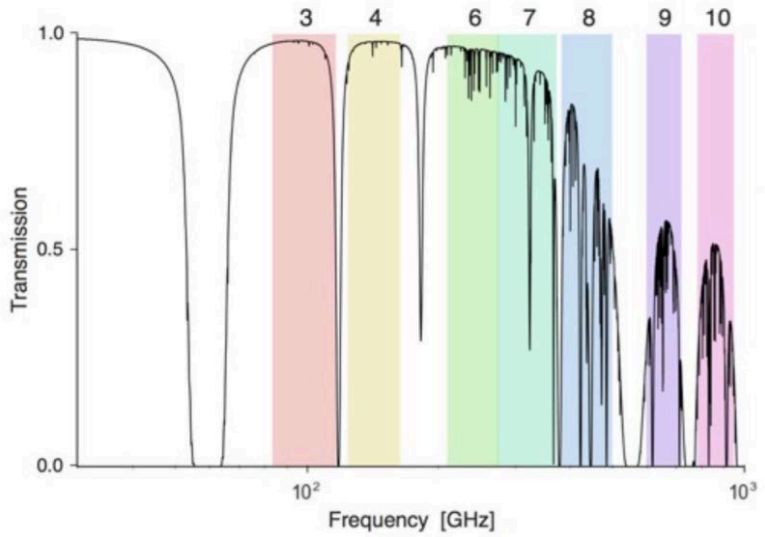
- Largest OIR telecope: 39.3 m aperture
- Construction started in 2014, first light expected in 2024
- Phase 1 authorised:
  - Incomplete M1, no spare sector
  - First generation of instruments:
    - MICADO
    - MAORY (AO module)
    - HARMONI
    - METIS

- Instrument roadmap:
  - MICADO, MAORY, HARMONI, METIS
  - LTAO, HIRES, MOSAIC (Phase A)
  - Instrument 6, XAO PCS

ESO Long-Term Programme: ALMA

- Unique sub/mm interferometer:
  - 66 antennas (54 12m, 12 7m)
  - Baselines up to 16 km
- ALMA is a partnership between ESO, NSF and NINS, serving Europe, North America and East Asia.
  - In cooperation with Chile
- The operations budget contemplates an off-site development line.
  - An ALMA Long-Term Plan being currently discussed





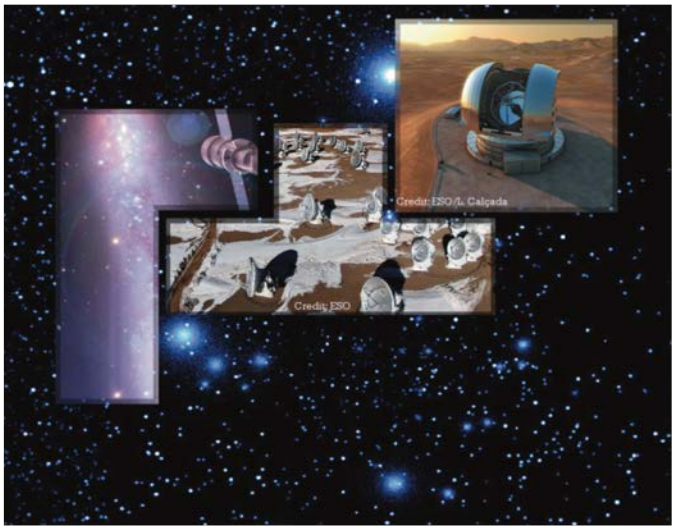
ESO Long-Term Programme: other elements

- La Silla:
  - 3.6m: HARPS + NIRPS
  - 3.5m NTT: EFOSC2, SOFI ⟶ SOXS
- APEX:
  - Extended until 2022
- CTA-S:
  - In progress to locate it in Paranal, to be operated by ESO
- Many ideas for further projects

ESO-Athena Synergies

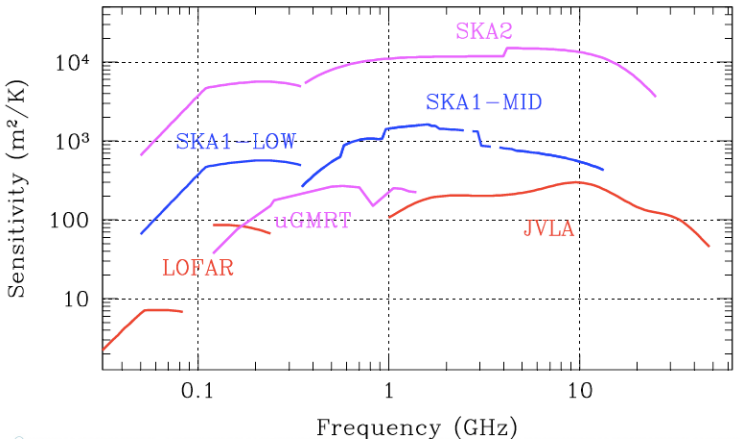
- Explore Athena synergies with
  - Optical/IR (E-ELT, VLT, etc)
  - sub/mm (ALMA etc) facilities
- Kicked-off in March 2016.
- Community consultation via a successful Workshop at ESO 14-16 Sep 2016
- **ESO-Athena Synergy White Paper released** (P. Padovani, F. Combes, M. Diaz-Trigo, S. Ettori, E. Hatziminaglou, P. Jonker, M. Salvato & S. Viti) https://arxiv.org/abs/1705.06064

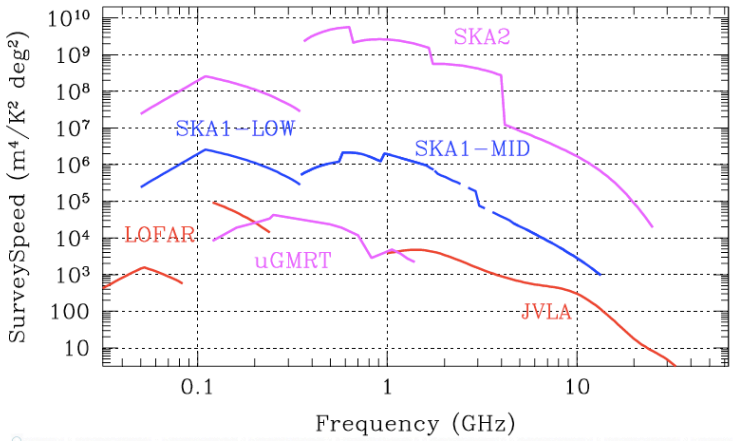
ESO-*Athena* Synergy White Paper



SKA – Square Kilometre Array

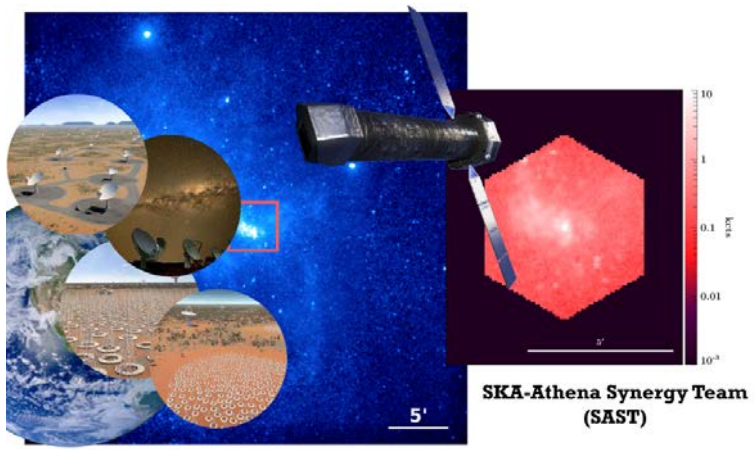
- Global cm-radioastronomy observatory:
  - HQ in Manchester. Observatory sites in Australia and Southafrica
- Currently in Phase B for SKA1
  - Expected start construction of SKA1 early 2019.
- Broad science goals: GR, cradle of life, magnetism, galaxy evolution, cosmic dawn, cosmology etc.



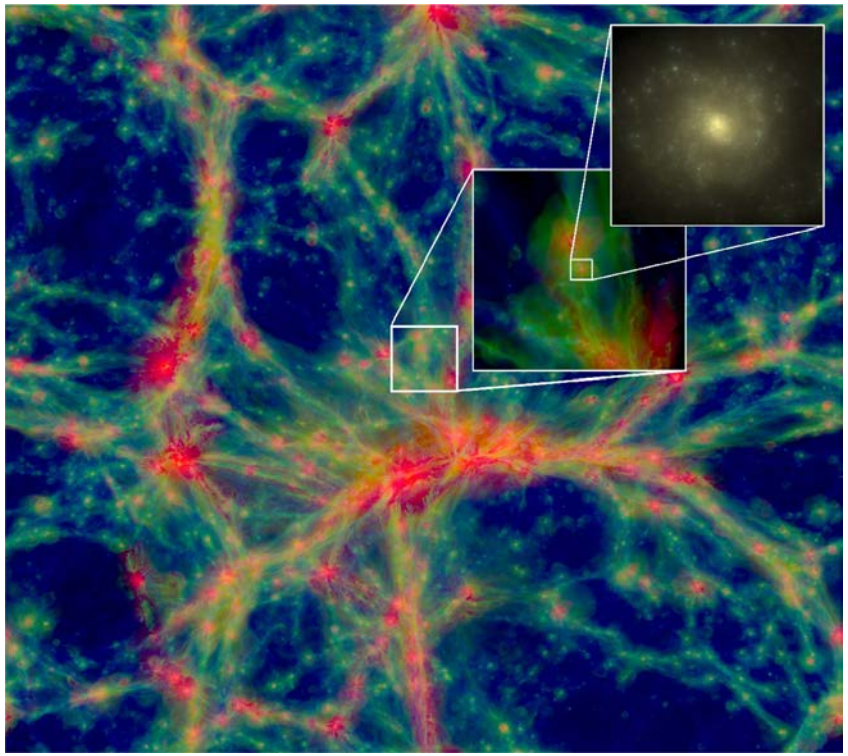


SKA-Athena Synergies

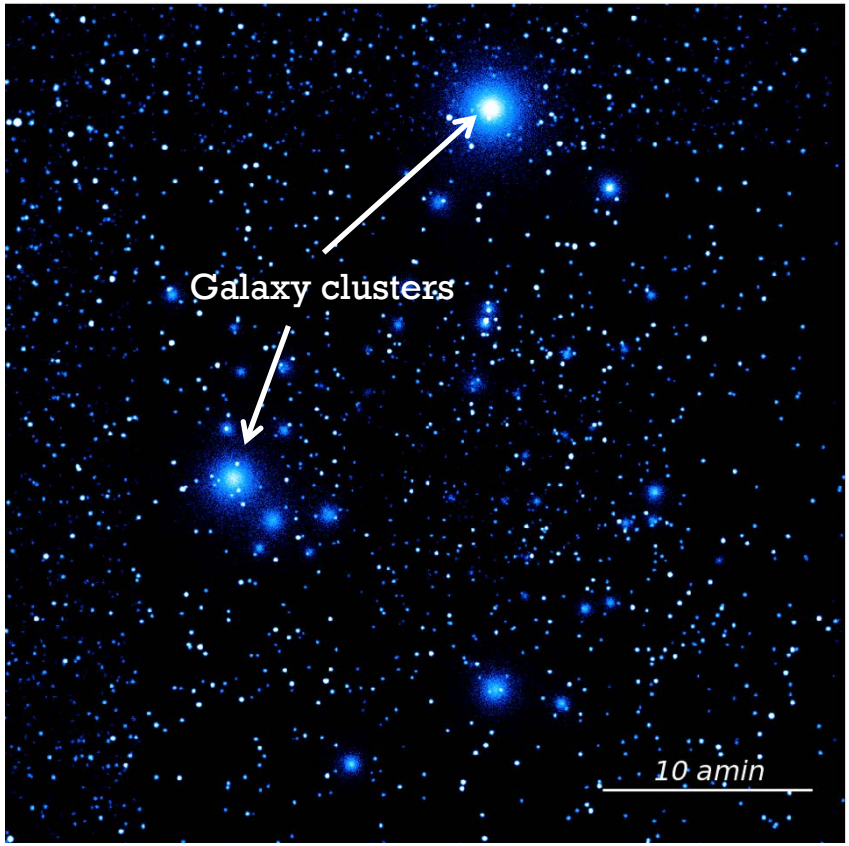
- Explore Athena synergies with SKA and the cm-radio facilities in the late 2020s
- Kicked-off in September 2016
- Community consultation via a successful Workshop at SKA on 24/25 Apr 2017
- SKA-Athena Synergy White Paper in preparation (R. Cassano, Ch. Ferrari, R. Fender, A. Merloni)



The Hot Universe – baryonic assembly



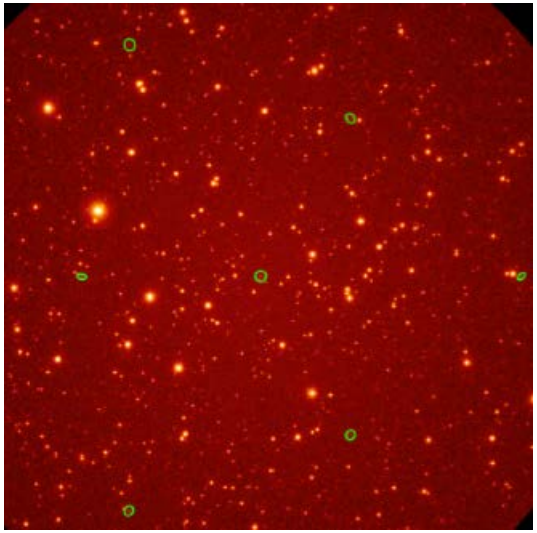
Schaye et al. 2015

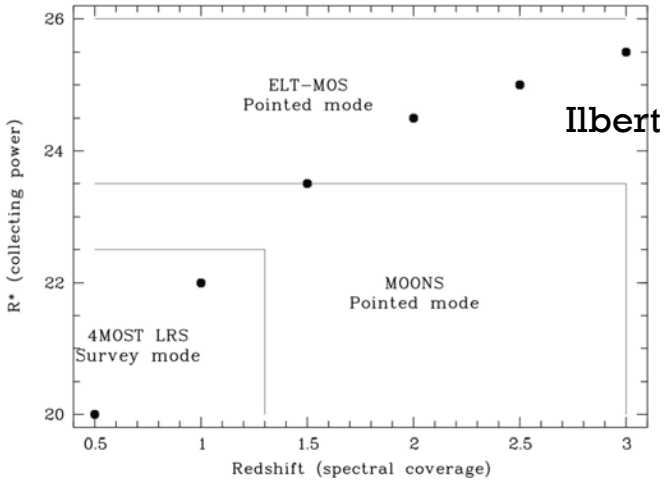


Athena/WFI 1Ms simulation
MPE & WFI team

Early galaxy groups and clusters

- Search for early galaxy groups M > 5 x 10^{13} $M_{\odot}$ at z>2
- Total of ~50 groups in multi-tiered survey lasting for ~1 year





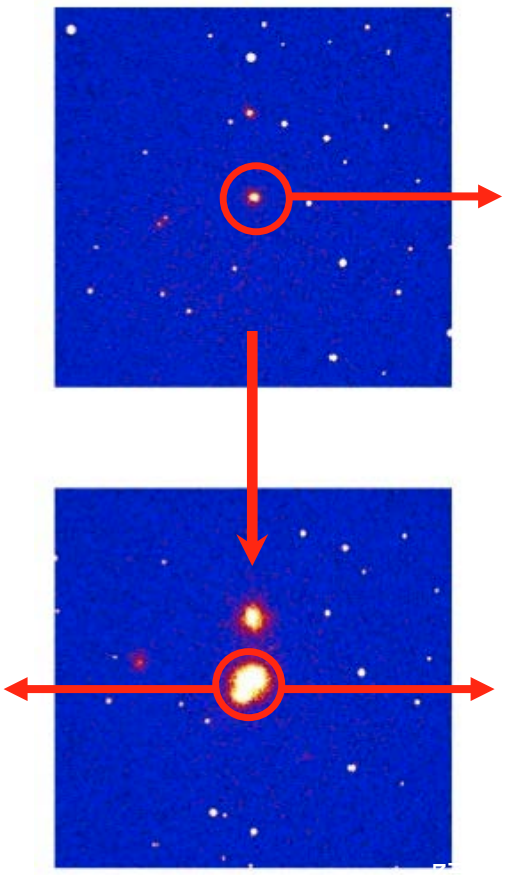
Ilbert et al 2006

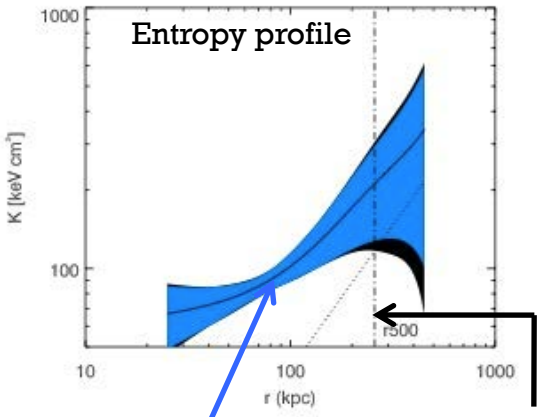
- Redshift, galaxy membership
- Galaxy SEDs, stellar masses, morphology (mergers)
- Galaxy metal enrichment
- SFRs, Diffuse Lyα emission shock tracers

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

Thermal evolution of hot cluster gas

Energy deposition history

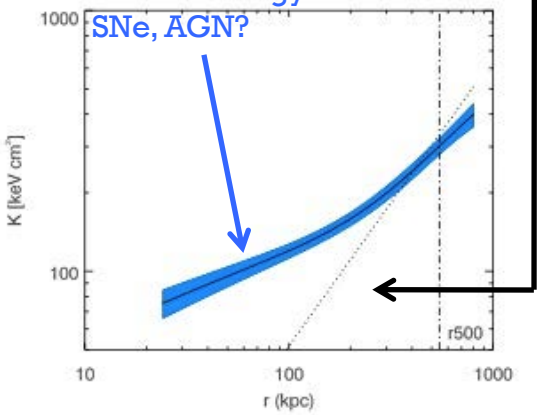




z=2

gravity

Excess energy:
SNe, AGN?



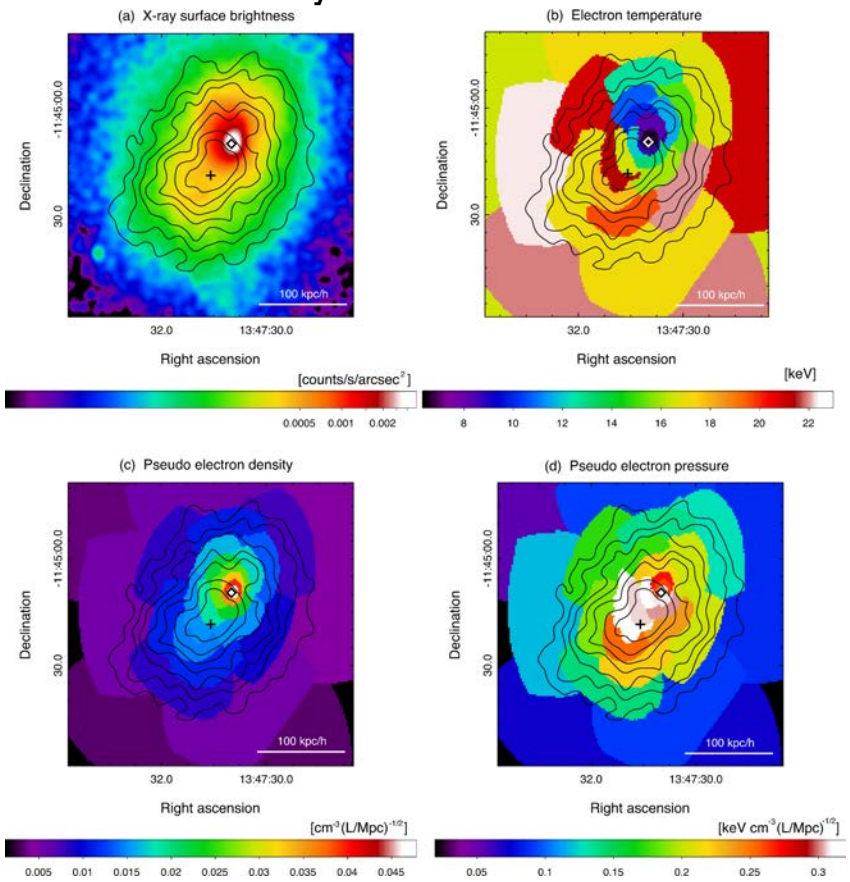
z=1

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

Prospects for SZ cluster observations

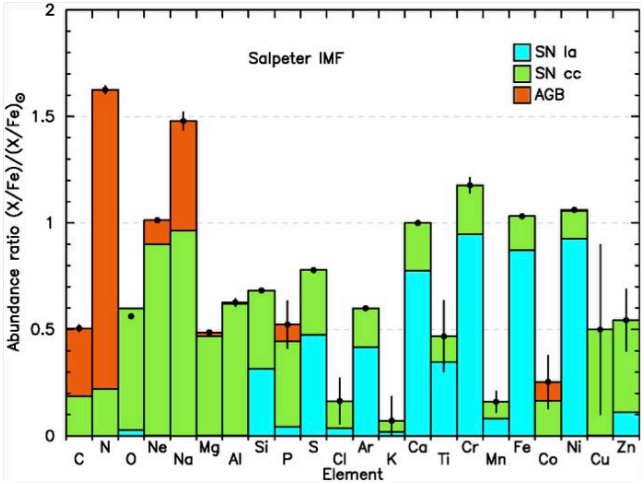
- Sunyaev-Zeldovich observations have moved from detections to multi-band maps in the mm regime.
- Single-dish antennas deliver maps with resolutions 10-20”, while ALMA can go down to 5” (Band 3).
  - This will be perfectly matched by Athena
- In the future ALMA Band 2 observations will keep 5” with MRS > 1’, key for distant cluster mapping
- Large scale SZ structures will be best achieved with large single-dish mm telescopes

RX J1347-1145
Kitayama et al 2016

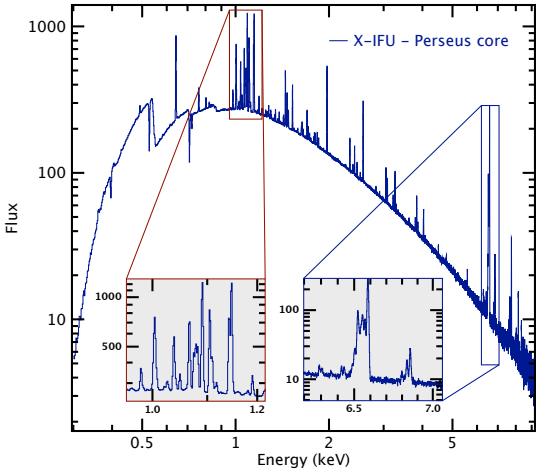


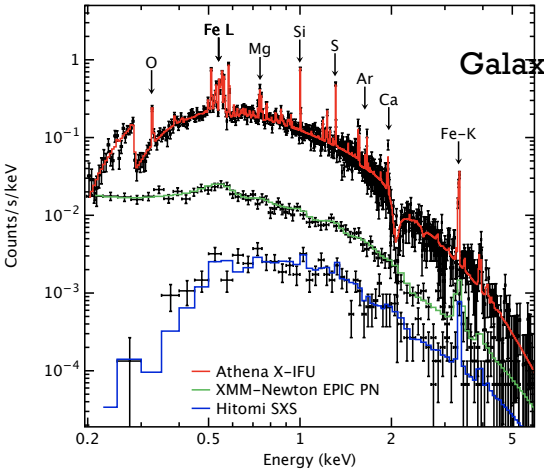
Cluster chemical evolution

- 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



#AthenaNuggets by J. de Plaa



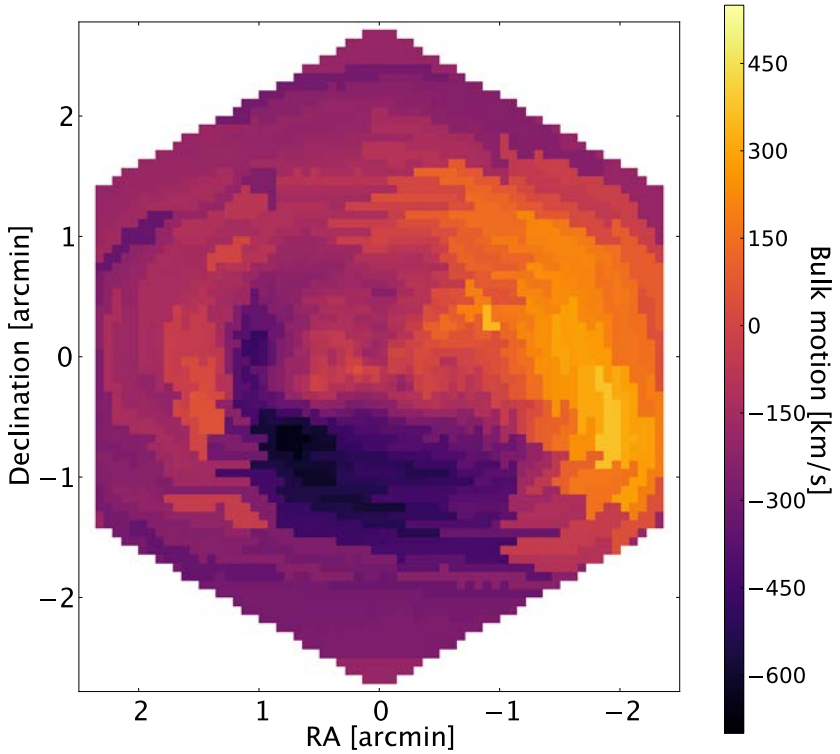


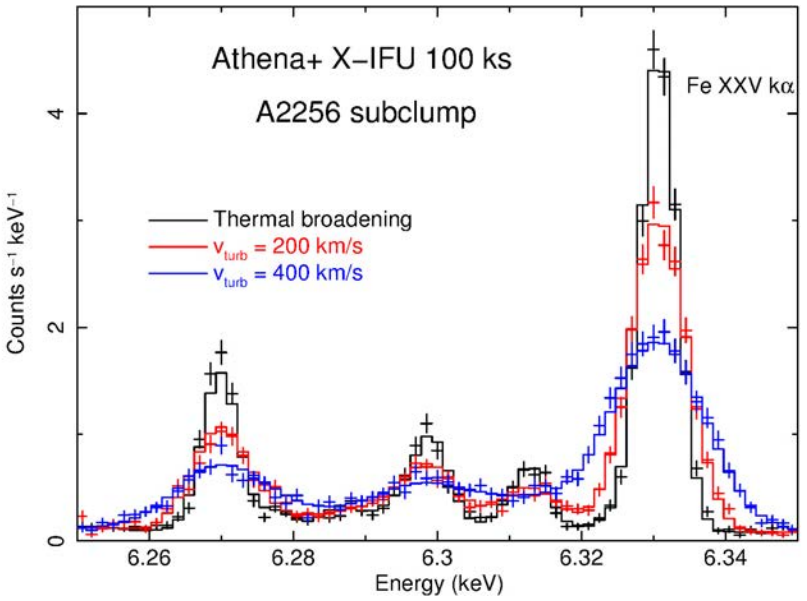
Galaxy group @z=1

Barret et al. 2016, SPIE

Cluster bulk motions & turbulence

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





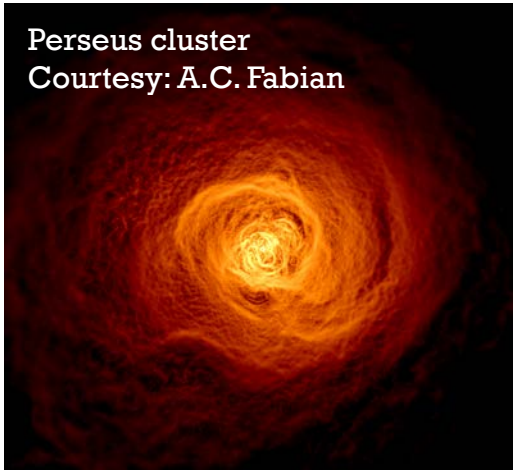
Ettori, Pratt et al. 2013 arXiv1306.2322
Pointecouteau, Reiprich et al. 2013, arXiv: 1306.2319

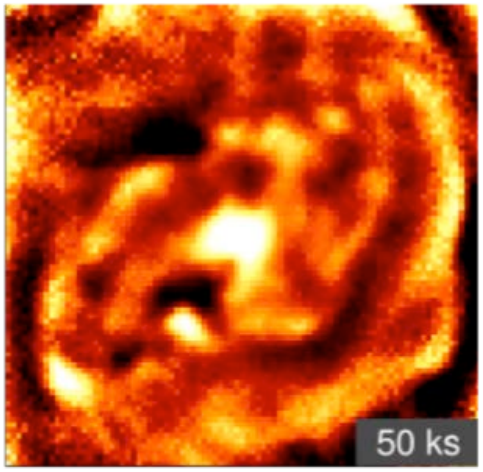
Courtesy: P. Peille, E. Pointecouteau, V. Biffi, E. Rasia, K. Dolag, S. Borgani, J. Wilms

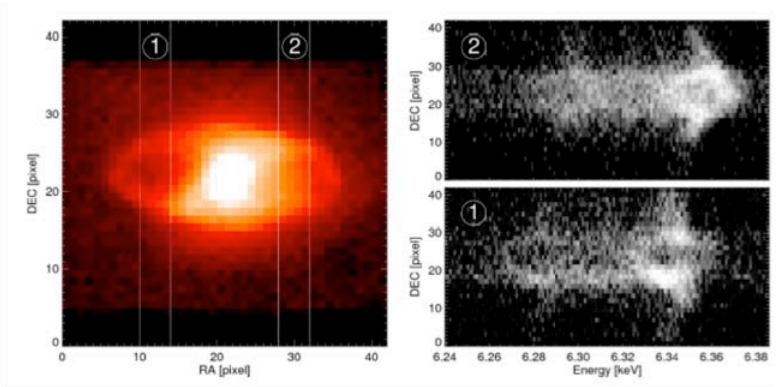
Complementary measurements through 7N (53 GHz) and 57Fe (97 GHz) with ALMA

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



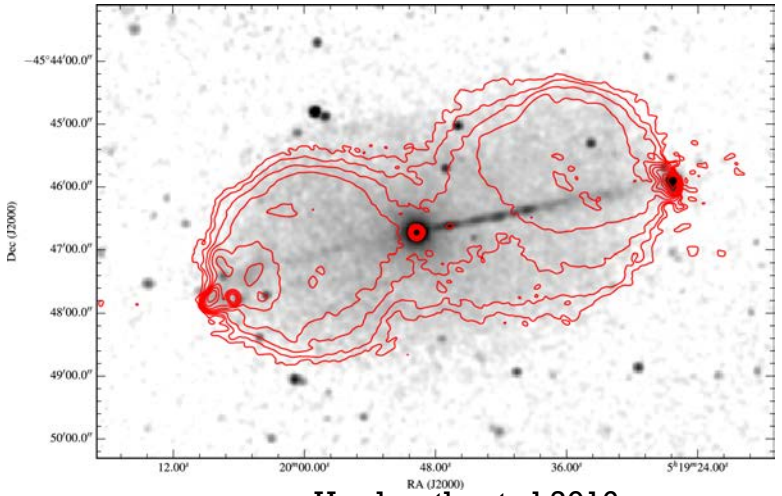




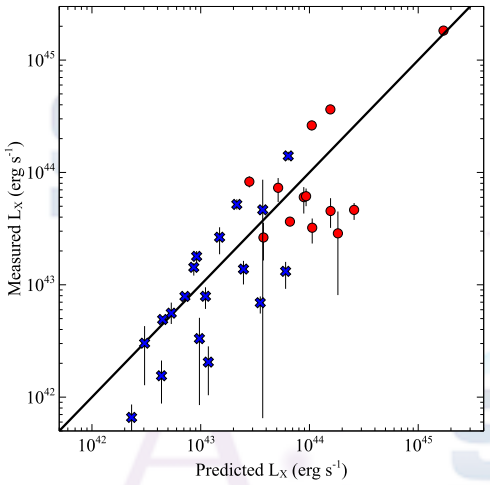
Croston, Sanders et al. 2013 arXiv1306.2323
Simulations by S. Heinz

SKA-Athena synergy: radio lobes clusters

- High-z group X-ray emission contaminated by Inverse Compton from (active or remnant) FRII radiogalaxies. Need sensitive radio observations to excise these.
- Conversely, radio lobe pressure can correctly predict L_X, so use SKA surveys to find groups and clusters.
- Assess the impact of jets in the ICM thermodynamics (entropy injection) at z~2 through sensitive radio observations.



Hardcastle et al 2016

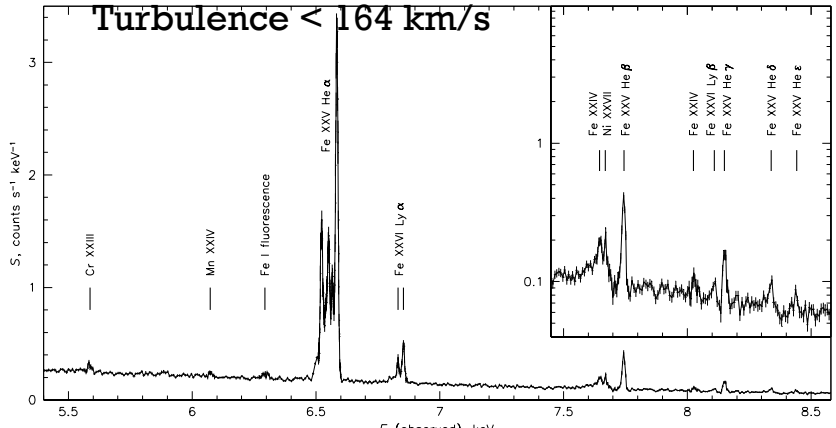


Croston et al 2017

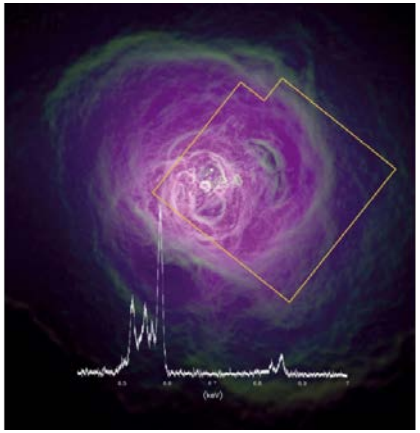
Hitomi (Feb-Mar 2016)

- 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 AMAZING data of the Perseus cluster, above 2 keV.
- JAXA, along with its international partners, is moving ahead with the "Hitomi recovery mission", due for launch in 2021/2

Perseus cluster core
Turbulence < 164 km/s

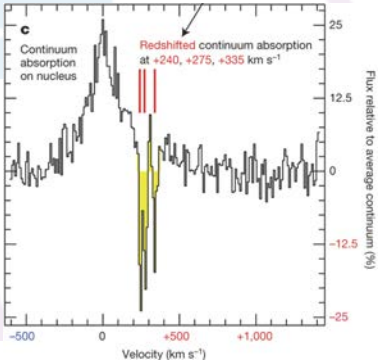


Hitomi coll, Nature, 535, 117-121 (2016)
Courtesy: A.C. Fabian

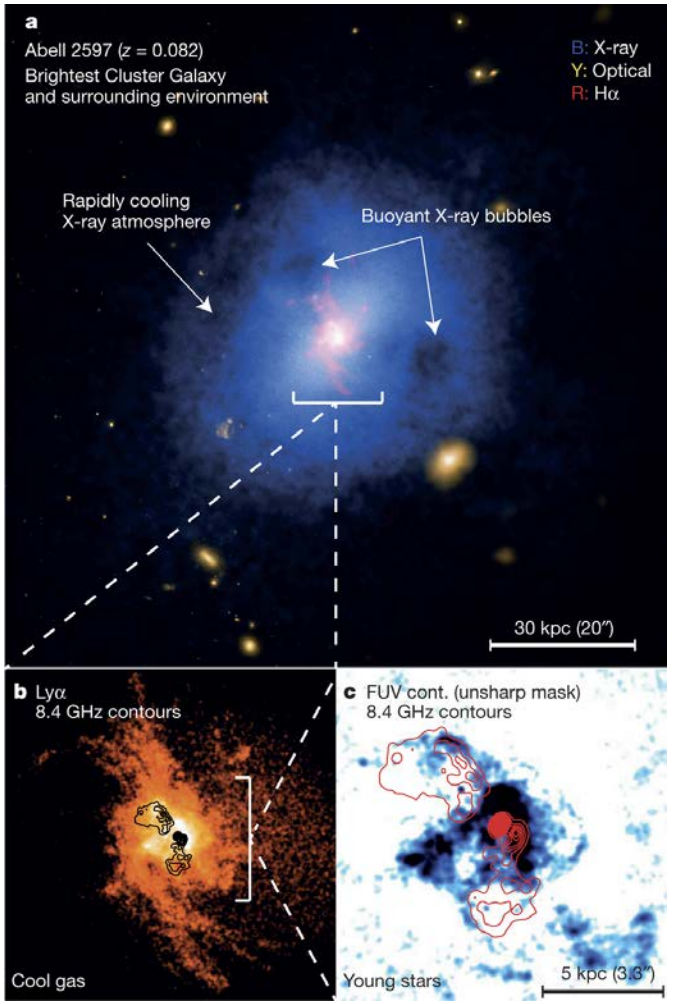


Filaments of warm/cold gas in the ICM

- Dynamics of these filaments can be measured by
  - VLT/X-shooter (warm)
  - ALMA (CO)
  - Athena/X-IFU (surrounding medium)
- Balance between feeding and ouflows
  - ALMA can measure radial velocities of molecular gas clouds

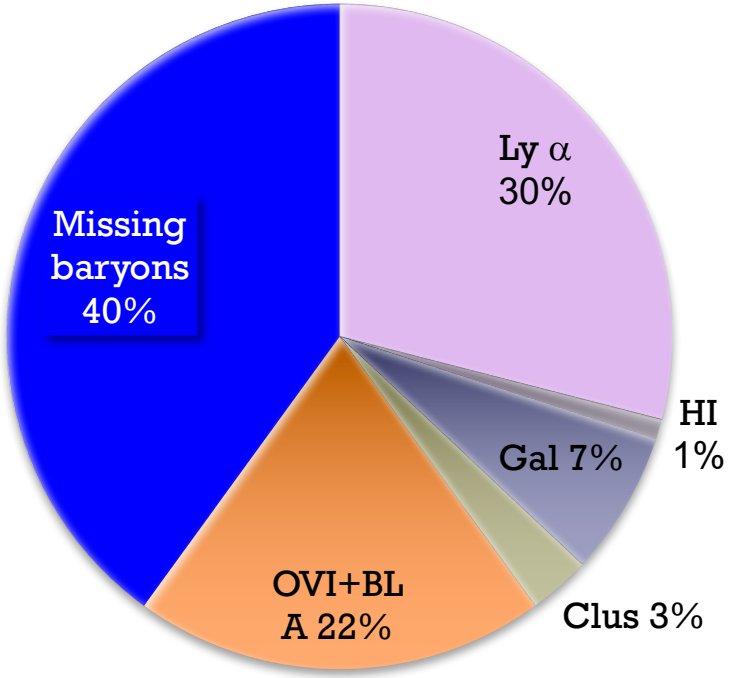


Russell et al 2016
Tremblay et al 2016
Etc.



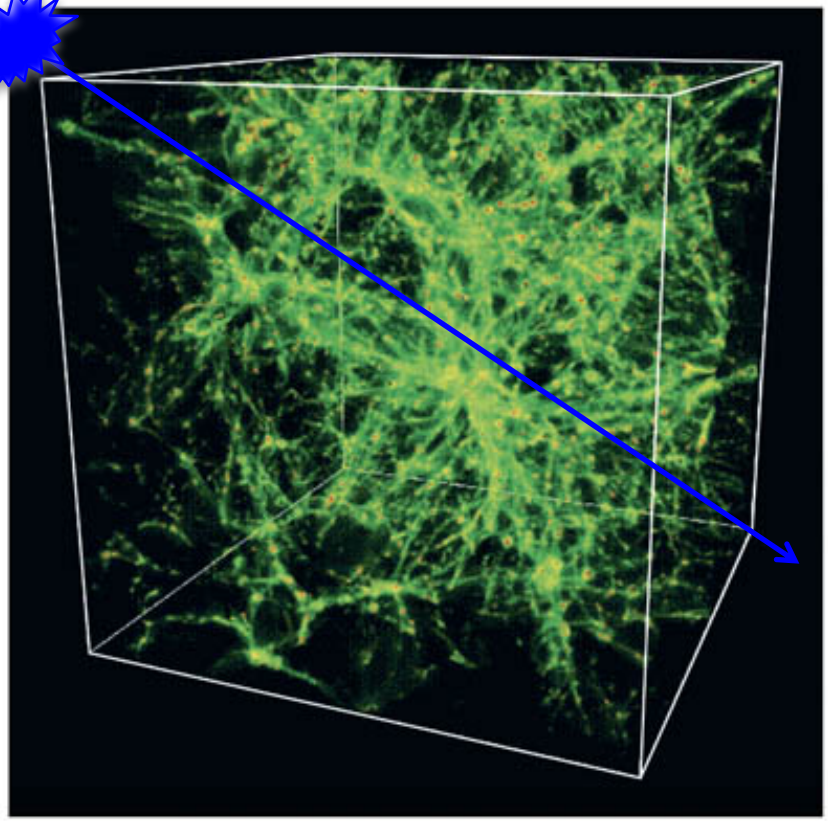
Missing baryons: the WHIM

- Cosmological hydro simulations show ~40% of baryons at **T~10^5-10^7** K in the IGM.
  - Unvirialised, shock heated and filamentary distribution
- Potentially detectable through absorption/emission from ionised species.
- Note that:
  - Mass and metals not necessarily in the same place
  - Circum-galactic medium also contributes to emission/absorption



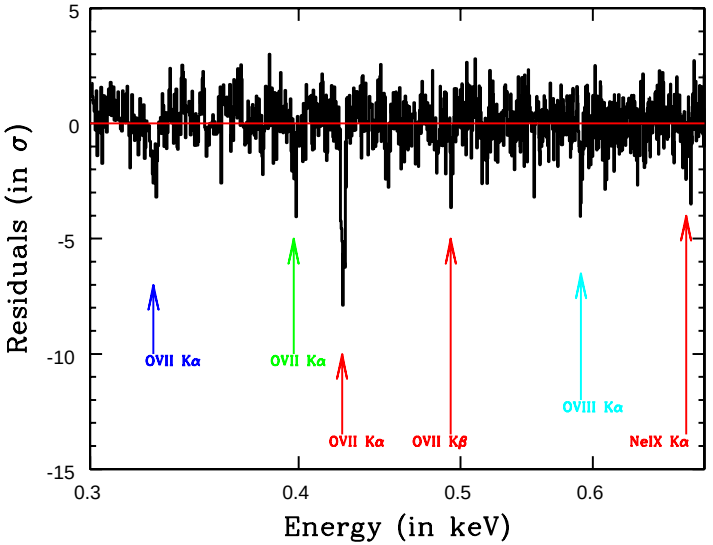
Characterising the WHIM baryons

AGN or
GRB afterglow



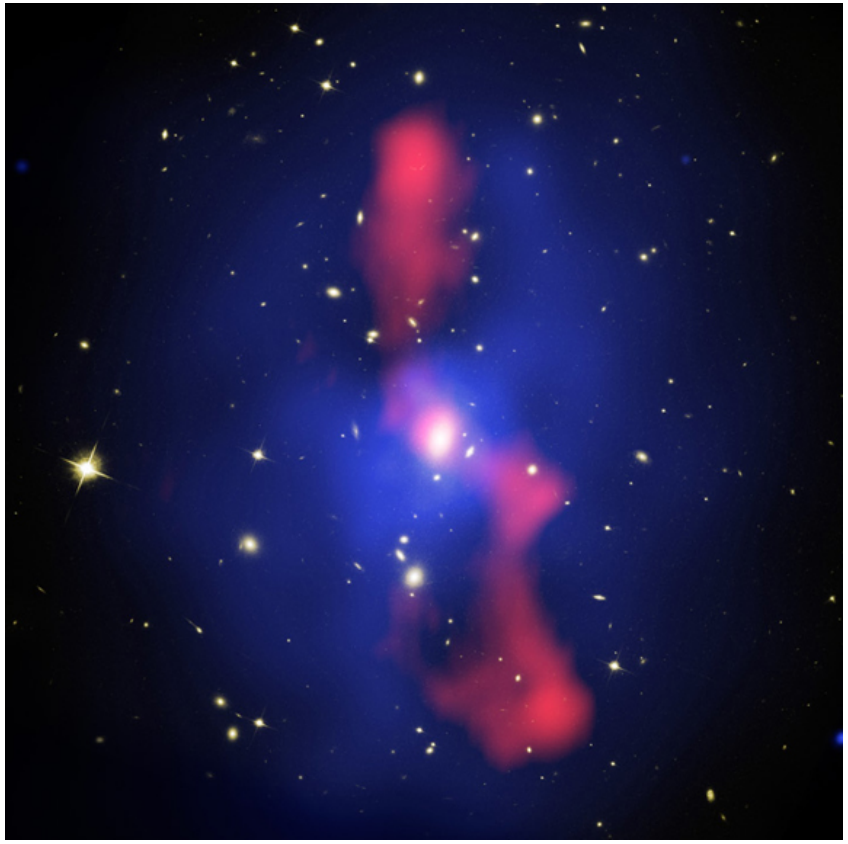
Cen & Ostriker 2006

WHIM filaments against a 10% brightest GRB afterglow

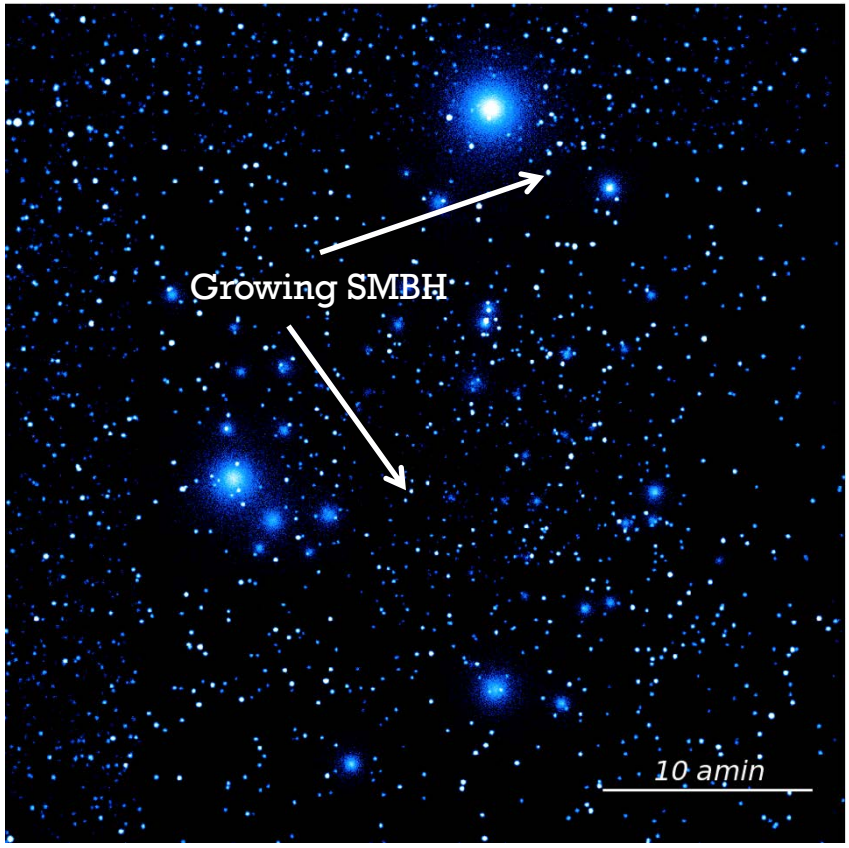


Barret et al. 2016, SPIE
Courtesy: F. Nicastro

The Energetic Universe – Black Holes



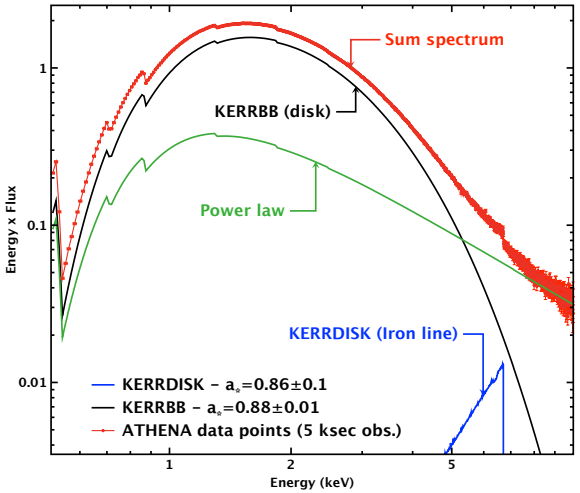
MS0735.6+7421 McNamara et al. 2005

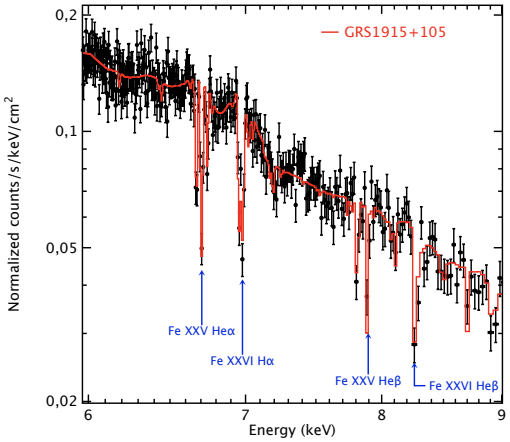


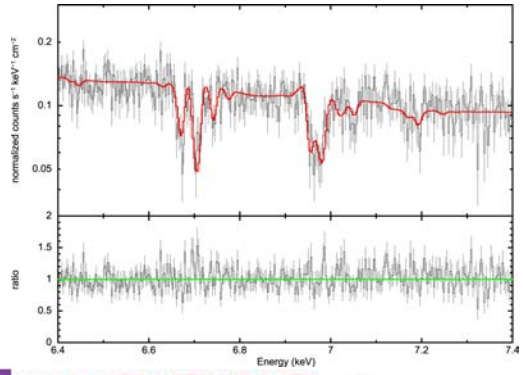
Athena/WFI 1Ms simulation
MPE & WFI team

BHB and NS accretion physics

- Measure BH spins
  - Via continuum fit & Fe line spectroscopy
  - Constraints on SN origin & relation to jets
- Accretion geometry
  - Disc truncation from lag spectra
  - Winds as diagnostics of the accretion flow, exp variable ~100s





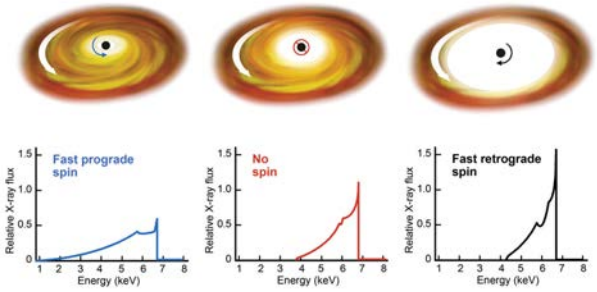


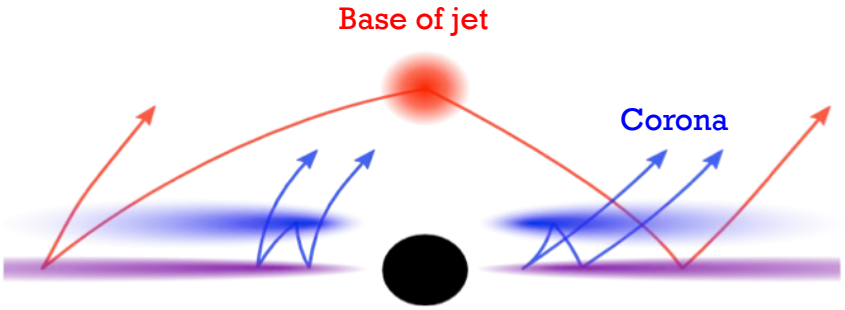
GRS1915
Miller et al 2016

Barret et al. 2016 SPIE2016

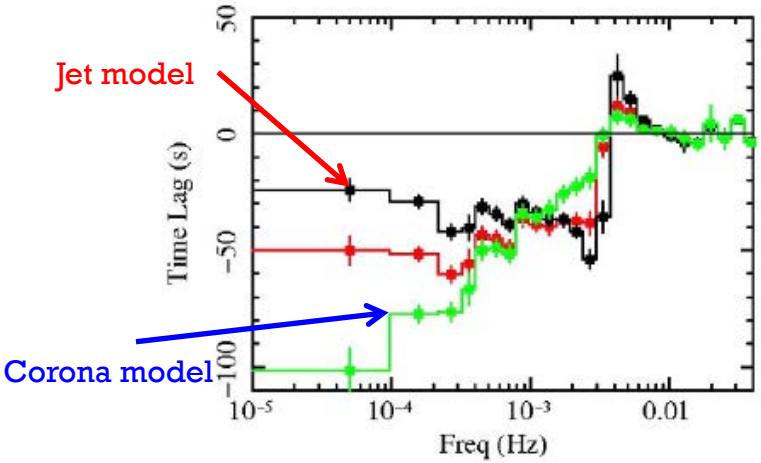
Supermassive Black Hole physics

- Measure SMBH spins through Fe line spectroscopy





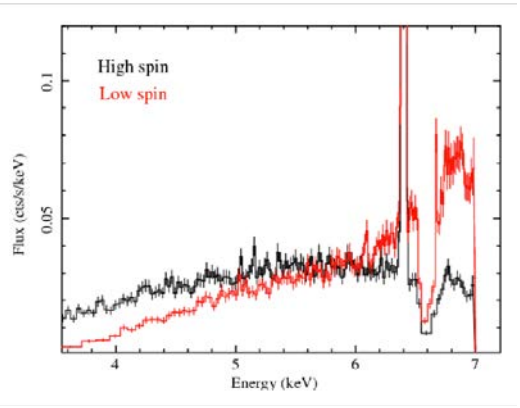
- Accretion geometry and jet/disk relation through reverberation mapping



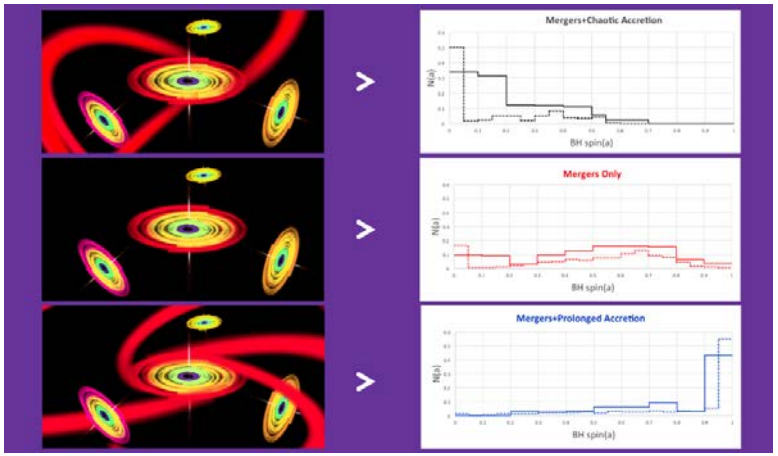
Dovciak, Matt et al. 2013, arxiv:1306.2331

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



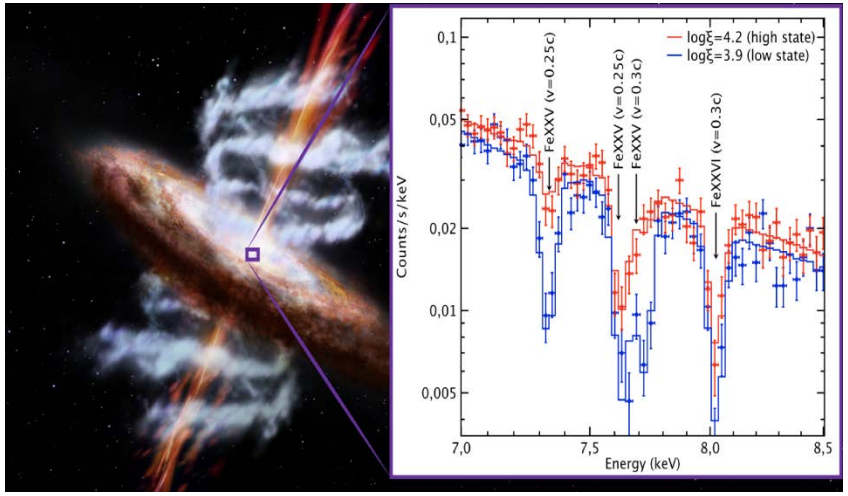
Dovciak, Matt et al. 2013: arXiv 1306.2331



AGN winds and outflows

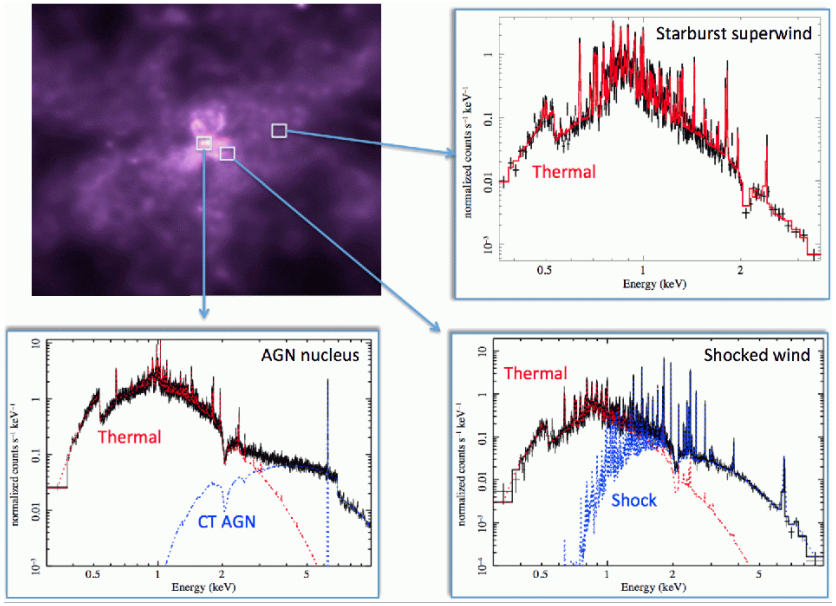
Mechanical feedback effective if $L_{mech} > 1\% L_{bol}$

Mechanical energy released in ultra-fast outflows $\sim v^3$



Cappi, Done et al. 2013, arxiv:1306.2330

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

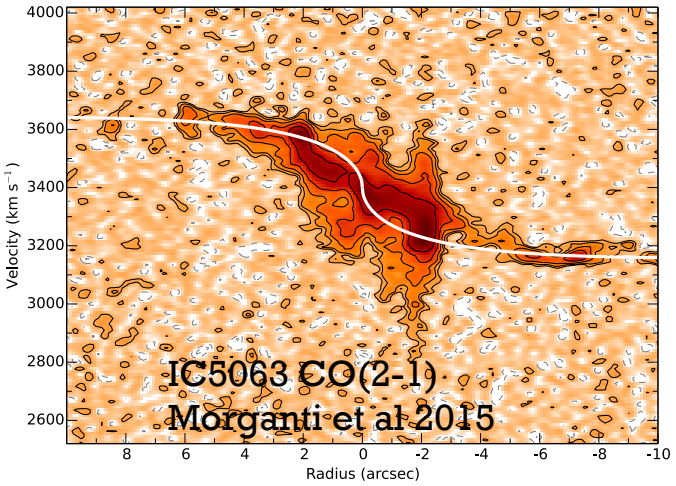


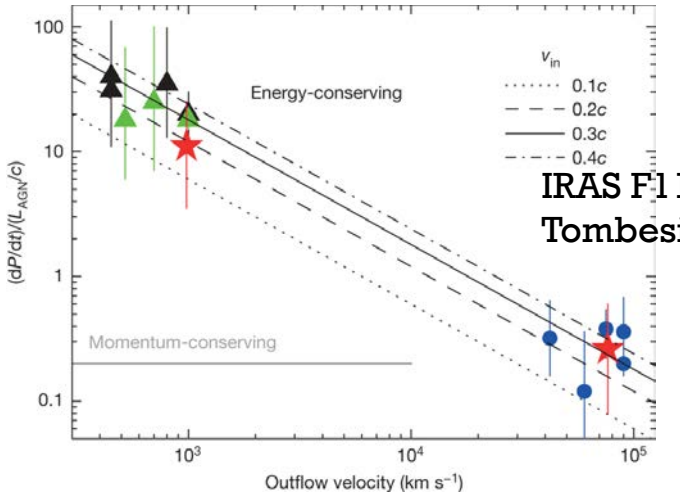
NGC6240, M. Cappi et al. (2013)

#AthenaNuggets by M. Cappi & G. Ponti

AGN molecular outflows and link to UFOs

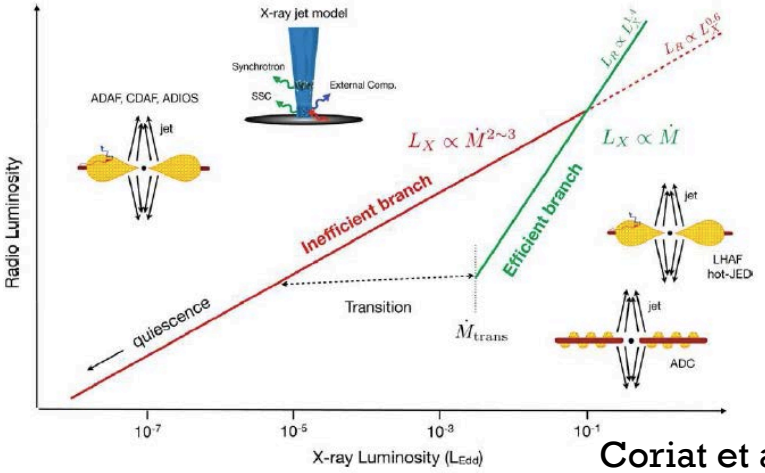
- Molecular outflows are routinely found with IRAM-PdB, ALMA and Herschel, even at significant redshift.
- AGN winds and jets appear to power these molecular outflows in several cases, assuming energy conservation.
- Athena will be able to measure AGN disk wind energetics at z~2, where ALMA is already finding molecular outflows



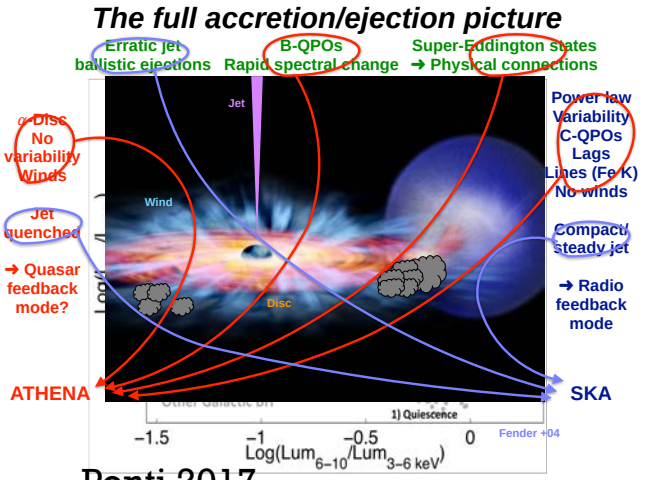


Jets, winds & outflows

- Relationship between accretion (X-rays) and ejection (X-rays for winds/outflows & radio for jets)
- Variability correlation studies (Radio/X-ray): jet-outflow co-existence
- Test jet-spin paradigm
- The origin of radioemission in radio-quiet AGN – needs SKA sensitivity:
  - Synchrotron emission from sub-relativistic jet
  - Free-free from torus corona



Coriat et al 2011



Ponti 2017

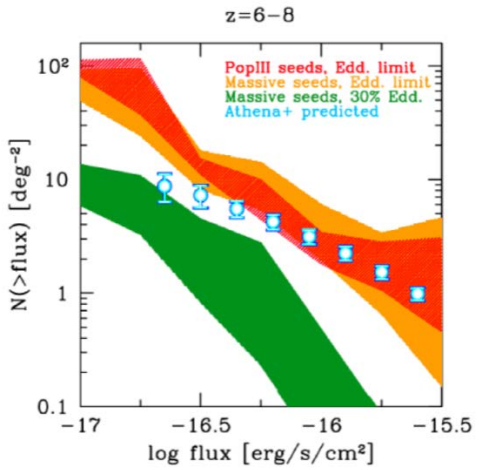
Panessa 2017

SKA-Athena Synergy Workshop

Athena peering into the dark ages

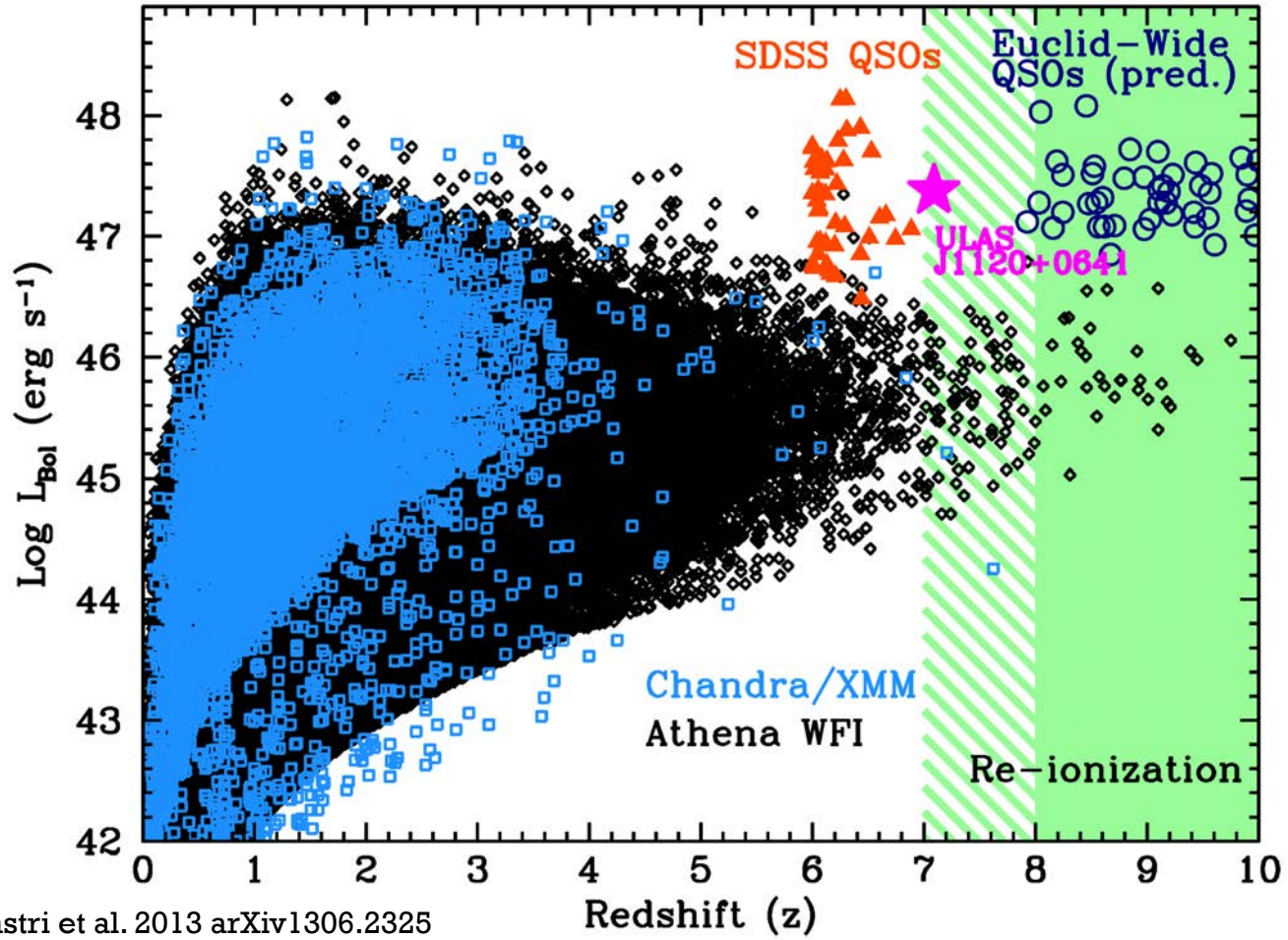
- Athena plans to perform a 1-year multi-tiered survey (~40 deg^2) aiming at:
  - Identifying ~few 100 AGN at z>6
  - Census of the whole AGN population of z~1-3
  - Finding 50 groups at z>2
- It will find 600,000 AGN, down to ~10^{-17} erg cm^{-2} s^{-1}.
- Probe early phases of SMBH growth, and SMBH seed masses

Aird, Comastri et al (2013)



- Obtain counterparts and z (IFU & ALMA)
- ISM masses (ALMA)
- Stellar masses, SMBH masses & SFR (AO NIR/MIR spectroscopy)
- Full survey characterisation: 4MOST, MOONS, ELT-MOS etc

The history of SMBH growth



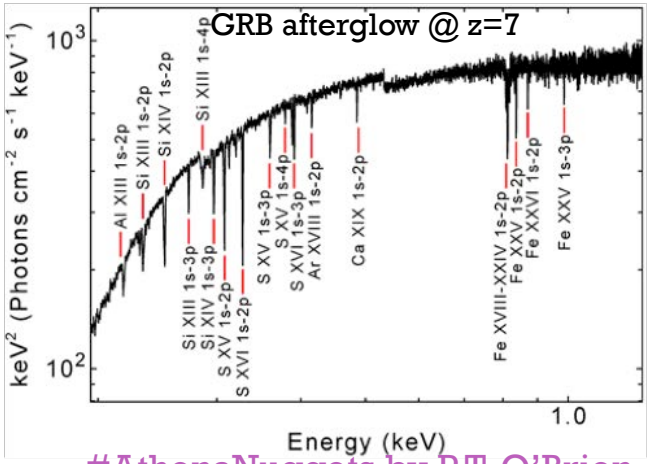
Only extreme AGN expected in opt/IR surveys

X-rays needed to signpost average AGN

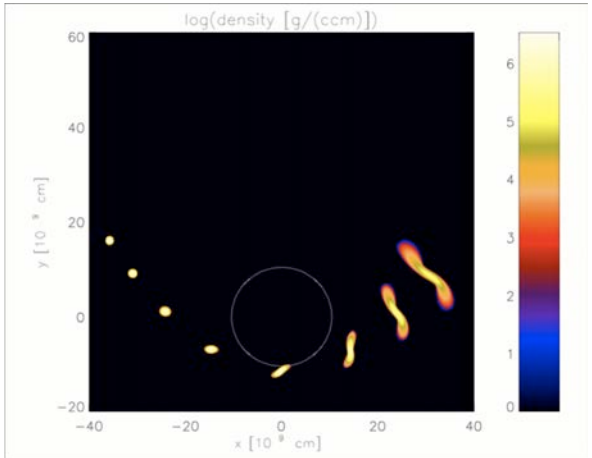
Aird, Comastri et al. 2013 arXiv1306.2325

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.
- Enormous potential for SKA discoveries & study of jetted TDEs (Donnarumma & Rossi)
- Athena will
  - Unveil SMBH through this
  - Reveal the composition of the outflowing material
  - Test for the presence of binary SMBH



#AthenaNuggets by P.T. O'Brien

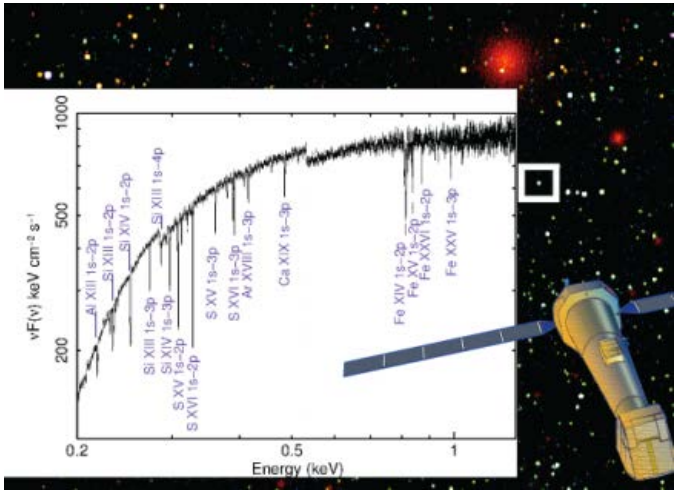


Jonker, O'Brien et al. 2013: arXiv 1306.2336

#AthenaNuggets by P.Jonker

Transient science

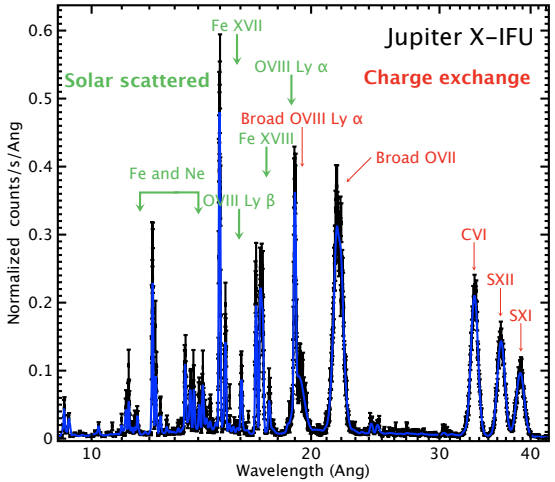
- Obtain (spec or photo) redshifts from the ground, following a GRB alert
  - Requires RRM and OIR photo/spectroscopic facility
- Host galaxy ISM metalicity needs:
  - Athena/X-IFU absorption data for Fe, Si, S, Ca
  - OIR spectroscopy for H, O etc
- Galaxy morphology & spectroscopy at z>7 needs powerful IR imagers and spectrometers (E-ELT)
- OIR polarimetry to provide insight into GRB shock physics



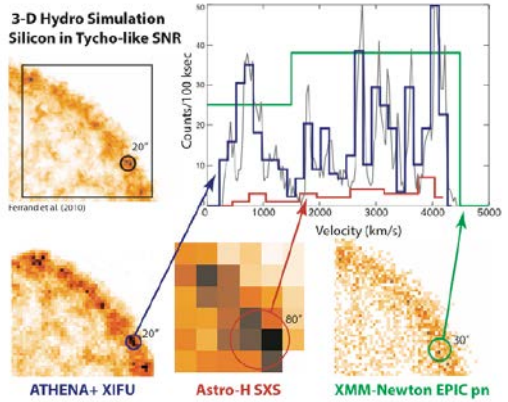
- Athena/WFI will be able to detect ~1000 Tidal Disruption Events every year.
  - Some of them will be detected early enough for a ground-based follow-up.

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



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

ESO-Athena synergies in star formation

- **Indirect detection** of X-ray emission in highly embedded Class 0 TTauri stars, via ALMA detection of N_2H^+ and HCO^+
  - Ionisation important to understand coupling of gas to magnetic fields during infall
- Protoplanetary disk evolution is strongly affected by X-ray **irradiation** (and Cosmic Rays) of the central YSO: chemistry, ionisation, introducing turbulence and disk evaporation.
  - Chemistry measurable by ALMA observations N_2H^+, HCO^+, DCO^+, H_2D^+
  - Simultaneous ALMA and Athena observations determine X-ray/CR balance
- X-ray irradiation by YSOs of surrounding gases, solids and ices drive the chemistry in these zones, where pre-biotic molecules form.
  - Athena and ALMA/IR observations of samples of YSOs will give the details and impact of this process

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, VLT/I, E-ELT, SKA, CTA, etc.
- Vibrant community in scientific and technical support around the world.
  - Opportunities to join the Athena Community every year (next call December 2017)
- **See Matteo Guanazzi's presentation on Phase A status and programmatic aspects**

- 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

#womeninScience

ATHENA FEMALE SCIENTISTS

International Day of Women and Girls in Science, 11 February 2017