Athena:
ESA’s X-ray observatory for the late 2020s

Thanks to ASST (Lumb, Nandra, Barret, Decourchelle, den Herder, Fabian, Matsumoto, Piro, Smith, Willingale) and to the >800 community researchers

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9-11 May 2016
Athena driving science: 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 x the binding energy of a galaxy
  - 15% of the energy output in the Universe is in X-rays
## Athena Science Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
<th>enables (driving science goals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective area at 1 keV</td>
<td>2 m²</td>
<td>Early groups, cluster entropy and metal evolution, WHIM, high redshift AGN, census AGN, first generation of stars</td>
</tr>
<tr>
<td>Effective area at 6 keV</td>
<td>0.25 m²</td>
<td>Cluster energetics (gas bulk motions and turbulence), AGN winds &amp; outflows, SMBH &amp; GBH spins</td>
</tr>
<tr>
<td>PSF HEW (&lt; 8 keV)</td>
<td>5'' on axis, 10'' off axis</td>
<td>High z AGN, census of AGN, early groups, AGN feedback on cluster scales</td>
</tr>
<tr>
<td>X-IFU spectral resolution</td>
<td>2.5 eV</td>
<td>WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4</td>
</tr>
<tr>
<td>X-IFU FoV</td>
<td>5' radius</td>
<td>Metal production &amp; dispersal, cluster energetics, WHIM</td>
</tr>
<tr>
<td>X-IFU background</td>
<td>&lt; 5 $10^{-3}$ counts/s/cm²/keV (75%)</td>
<td>Cluster energetics &amp; AGN feedback on cluster scales, metal production &amp; dispersal</td>
</tr>
<tr>
<td>WFI spectral resolution</td>
<td>150 eV</td>
<td>GBH spin, reverberation mapping</td>
</tr>
<tr>
<td>WFI FoV</td>
<td>40' x 40'</td>
<td>High-z AGN, census AGN, early groups, cluster entropy evolution, jet-induced cluster ripples</td>
</tr>
<tr>
<td>WFI count rate</td>
<td>80% at 1 Crab</td>
<td>GBH spin, reverberation mapping, accretion physics</td>
</tr>
<tr>
<td>WFI background</td>
<td>&lt; 5 $10^{-3}$ counts/s/cm²/keV (75%)</td>
<td>Cluster entropy, cluster feedback, census AGN at z~1-4</td>
</tr>
<tr>
<td>Recons. astrometric error</td>
<td>1'' (3s)</td>
<td>High z AGNs</td>
</tr>
<tr>
<td>GRB trigger efficiency</td>
<td>40%</td>
<td>WHIM</td>
</tr>
<tr>
<td>ToO reaction time</td>
<td>&lt; 4 hours</td>
<td>WHIM, first generation of stars</td>
</tr>
</tbody>
</table>
Athena mission concept

- Single telescope, using Si pore optics. 12m focal length
- WFI sensitive imaging & timing
- X-IFU spatially resolved high-resolution spectroscopy
- Instrument switch mechanism
- Launch 2028, Ariane 6 4 (TBC)
- L2 halo orbit (TBC)
- Lifetime > 5 yr
Athena 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
Athena 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

- European consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other European partners, NASA and JAXA.

- Spectral resolution 2.5 eV, FoV 5' diameter

- Will be able to:
  - Measure cluster gas bulk velocities and turbulence down to 20 km/s
  - Detect weak unresolved lines from WHIM filaments (3mÅ), GRB afterglows, etc.
  - Use emission lines (eg OVII triplet) to perform plasma diagnostics in a variety of astrophysical environments

Barret et al 2013, arXiV: 1308.6784
http://x-ifu.irap.omp.eu/
Athena: A deep Universe X-ray observatory

X-ray spectroscopy at the peak of activity in the Universe

Deep survey capability into the epoch of reionisation
Nandra, Barret, Barcons, Fabian, den Herder, Piro, Watson et al.
2013 arXiv 1306.2307

Athena Deep Field

Galaxy cluster at z=1

Normalized Counts/s/keV

10⁻¹
10⁻²
10⁻³
10⁻⁴

Energy (keV)
0.5
1
1.5
2
2.5
3

Fe complex
Al, Si, S

Primordial stellar populations
GRB afterglow follow up (z=7)

X-IFU
ν
ν
F
ν
100
200
500
1000

Energy (keV)
0.2
0.5
1

200
400

0.25
0.30

Fe Kα
S
O
Si
Mg

X-IFU

Normalised Counts/s/keV

10⁻⁴
10⁻³
10⁻²
10⁻¹

1

Energy (keV)
0.5
1
2
1.5
2.0
2.5
3.0

0.01
0.1

Black hole feedback at z=2

Normalized Counts/s/keV

10⁻⁴
10⁻³
10⁻²
10⁻¹

1

Energy (keV)
1.5
2.0
2.5
3.0

0.01
0.1

0.01
0.02

Obscured black hole in the early Universe

Fe Kα at z=8

Normalized Counts/s/keV

-0.005
0
0.005
0.010
0.015
0.020

Energy (keV)
0.67
0.68
0.69
0.70
XMM-Newton science after next decade with Athena

XMM-Newton science 2016
- Solar System, exo-planets, stars hot/cool
- Compact objects: BH, NS systems, SN/GRB
- Compact objects: SMBH
- Diffuse emission: SNRs
- Diffuse emission: Halos WHIM & DM
- Diffuse emission: large-scale outflows, clusters of galaxies
- Surveys & cosmology

Athena level 0 science
- Determine how and when large-scale hot gas structures formed in the Universe and track their evolution from the formation epoch to the present day.
- Perform a complete census of black hole growth in the Universe, determine the physical processes responsible for that growth and its influence on larger scales, and trace these and other energetic and transient phenomena to the earliest cosmic epochs.
- Provide a unique contribution to astrophysics in the 2030s by exploring high energy phenomena in all astrophysical contexts, including those yet to be discovered.
High-z groups and clusters
classical and thermodynamical evolution
connection to galactic feedback (SF & BH)

→ chemical enrichment
→ energy deposition history

Ettori, Pratt et al. 2013 arXiv:1306.2322
Baryon assembly in cluster potential wells

Bulk motions

Turbulence

Ettori, Pratt et al. 2013 arXiv1306.2322
Peille, Pointecouteau et al, XST-TN-014

XMM-Newton, the next decade

9-11 May 2016
Finding and characterising the WHIM missing baryons

Kaastra, Finoguenov et al. 2013 arXiv1306.2324
The history of SMBH growth

Aird, Comastri et al. 2013 arXiv1306.2325

XMM-Newton, the next decade

9-11 May 2016
Athena in the framework of the late 2020s

- Achieving some of the Athena science objectives needs data from other facilities (optical/NIR, sub/mm, etc)

- In general, scientific synergies can be identified between Athena and other available facilities in the late 2020s:
  - Deep optical/IR
  - Sub/mm
  - Wide-area opt/NIR surveys
  - Radio (cm)
  - Gamma-ray and multi-messenger
ESO-Athena Synergy exercise

- Leading to 2 Synergy White Papers ~March 2017: opt/NIR and sub/mm
- Supported by ESO, ESA, MPE, IFCA and others
- EAST: P. Padovani (chair), E. Hatziminaoglou, M. Díaz-Trigo, S. Viti, S. Ettori, M. Salvato, F. Combes, P. Jonker
- KO March 2016
- Workshop at ESO (by invitation) Sep 2016

XMM-Newton, the next decade

9-11 May 2016
Athena project milestones

- ESA SPC selected the Hot and Energetic Universe as the theme for L2 in Nov 2013
- ESA SPC selected the Athena mission in June 2014:
  - Design to cost 1 Bn€ + affordable payload + international partners (< 20%)
- The Athena Science Study Team was appointed by ESA in July 2014
- Phase 0 executed from August to December 2014, ESA/CDF study
  - CDF study showed Athena to be feasible
  - May need significant international contribution or a 30% reduction in effective area
- Phase A1 (July 2015 – May 2016)
  - Study whether Athena is feasible, and determine mirror size
  - Mission Consolidation Review (MCR) in May 2016
- Phase A2 (Jun 2016- late 2017) Complete assessment study on selected mission concept
  - Ends with PRR Preliminary Requirements Review
- Phase B1 (early 2018 – mid 2019)
  - Systems Requirement Review (SRR) Q3 2019
- Mission adoption by ESA SPC expected by Feb 2020, provided
  - SRR is successful, mission & payload are affordable
- Launch in 2028
Athena: Recent progress

- Consolidation of contributions from international partners: JAXA (X-IFU) and NASA (X-IFU and WFI).

- SRD v1.1 and MOP delivered to ESA
  - Strong involvement from WG/TP chairs and the entire community

- Converging into a Science Management Plan (SMP) draft
  - Science Ground Segment (SGS) organisation baselined to a Herschel-like model

- Needs for data from other facilities drafted
  - Synergy exercise with ESO underway. First contact with SKA successful.

- Community involvement
  - 811 scientists world-wide in Athena Working Groups & Topical panels
  - ASST established the Athena Community Office, led by IFCA, to help organising and liaise with the community.
ESA Athena Science Study Team (ASST)
Lumb (Chair), Nandra (Lead & WFI), Barcons, Barret (X-IFU), Decourchelle, den Herder, Fabian, Matsumoto (JAXA), Piro, Smith (NASA), Willingale

SWG1 - Hot Universe
- SWG1.1 Evolution of galaxy groups and clusters
  - Allen, Ota, Pointecouteau
- SWG1.2 Astrophysics of galaxy groups and clusters
  - Eckert, Etori, Pratt
- SWG1.3 AGN feedback in galaxy clusters and groups
  - Croston, McNamara, Sanders
- SWG1.4 Missing baryons and warm-hot intergalactic medium
  - Finoguenov, Kaasstra

SWG2 - Energetic Universe
- SWG2.1 Formation and growth of earliest SMBH
  - Aird, Comastri
- SWG2.2 Understanding the buildup of SMBH and galaxies
  - Carrera, Georgakakis, Ueda
- SWG2.3 Feedback in local AGN and star forming galaxies
  - Ponti, Ptak, Terashima
- SWG2.4 Close environments of SMBH
  - Dvorkin, Matt, Miniutti
- SWG2.5 Physics of accretion
  - Done, Miller, Motch
- SWG2.6 Luminous extragalactic transients
  - Jonker, O’Brien

SWG3 - Observatory
- SWG3.1 Solar System & exoplanets
  - Branduardi-Raymont, Gudel
- SWG3.2 Star formation and evolution
  - Hornschemeier, Rauw, Scorzato
- SWG3.3 End points of stellar evolution
  - Baozu, Schwope
- SWG3.4 Supernova remnants & interstellar medium
  - Bamba, Costantini
- SWG3.5 Multiwavelength synergy
  - Combes, Salvato

TWG4 – Telescope
- TWG4.1 Science ground segment
  - Watson, Webb
- TWG4.2 Background
  - Laurent, Molendi
- TWG4.3 Inter-calibration
  - Burwitz, Pajot, Sembay
- TWG4.4 End-to-end simulations
  - Peille, Wilms
- TWG4.5 Advanced analysis tools
  - Fiore, Haberl
- TWG4.6 Targets of opportunity
  - Bassa, Troja

MWG5 - Mission Performance
- MWG5.1 Science ground segment
- MWG5.2 Background
- MWG5.3 Inter-calibration
- MWG5.4 End-to-end simulations
- MWG5.5 Advanced analysis tools
- MWG5.6 Targets of opportunity
Outlook

- Athena is the natural follow-on mission to XMM-Newton
  - With truly transformational capabilities with respect to current missions
- Athena undergoing vigorous development, currently in Phase A
- Athena essential part of the late 2020s landscape
- Continued support from the X-ray astronomy community needed.
- Long life to XMM-Newton!!!

www.the-athena-x-ray-observatory.eu
Twitter: @athena2028
Facebook: Athena2028