Athena,
the ESA observatory to study
AGN
in the Hot and Energetic Universe

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AGN Spain 2016, Tenerife, 27 October 2016

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Contents

- Athena in a nutshell
- Mission concept & payload
- Athena science requirements and performance
- The Athena science theme: Hot and Energetic Universe
- Project development status
- Synergies
- Community: ACO
- Spanish participation
- Outlook

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

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:

Latest activities & news

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

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Athena mission concept

- Single telescope, using Si pore optics. 12m focal length
  - WFI sensitive imaging & timing
  - X-IFU spatially resolved high-resolution spectroscopy
- Movable mirror assembly to switch between the two instruments
- Launch 2028, Ariane 64
- L2 halo orbit (TBC)
- Lifetime > 5 yr

Athena concept, ESA CDF

The Athena X-ray optics

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

Willingale, Pareschi et al. 2013, arXiV: 1308.6785

Wide Field Imager (WFI)

- Based on Si detectors, using Active Pixel Sensors based on DEPFETs.
- Key performances;:
  - 120-150 eV spectral resolution,
  - 2.3” 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

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X-ray Integral Field Unit (X-IFU)

- Cryogenic imaging spectrometer, based on Transition Edge Sensors, operated at 50 mK featuring an active cryogenic background rejection subsystem
- Consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other European partners (ES, CH, BE, FI, PL, DE), NASA and JAXA.
- Key performance parameters:
  - 2.5 eV energy resolution <7 keV
  - FoV 5’ diameter
  - Pixel size <5”

E. Pointecouteau, P. Peille, 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/

Athena Science Requirements

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

Athena: a transformational observatory

Credit: Athena team

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

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

Hitomi (Feb-Mar 2016)

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

Perseus cluster core
Turbulence < 164 km/s

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

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The Energetic Universe – Black Holes

MS0735.6+7421 McNamara et al. 2005

Athena/WFI 1Ms simulation
MPE & WFI team

AGN winds and outflows

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

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

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

Cappi, Done et al. 2013, arxiv:1306.2330

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

#ÅthenaNuggets by M. Cappi & G. Ponti

AGN Spain 2016, Tenerife, 27 October 2016

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BH accretion physics

- Measure BH spins
  - Constraints on SN origin
  - Relation to jets
- Accretion geometry
  - Disc truncation from lag spectra
  - Winds as diagnostics of the accretion flow

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

Supermassive Black Hole physics

- Measure SMBH spins through Fe line spectroscopy

- Accretion geometry and jet/disk relation through reverberation mapping

Dovciak, Matt et al. 2013, arxiv:1306.2331

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

Obscured AGN census @ z~1-3: why care?

- Most energy emitted from accretion in the Universe is obscured
- Relationship between build-up of SMBH and growth of host galaxies:
  - through obscured phase z~1-4

- Unclear (but significant) contribution of Compton Thick (CT) objects

Obscured AGN census @ z~1-3: Methodology

- Divide parameter space in bins (hypercubes):
  - z, L_X, N_H...
- Explore different exposure times:
  - Survey geometry(4×1Ms+3×700ks+9x450ks+230×80ks)
  - Dedicated, but shared with hi-z AGN...
- Analysis of (many) spcpic sims to quantify:
  - Texp needed to get a given quality in a given parameter bin
  - Area/Texp needed to get a given number of sources
  - (Impact of de-scoping options)
  - ...

Obscured AGN census @ z~1-3

- Complete census of heavily obscured (dominant?) AGN
- Recovering within 30% L_X and N_H (CT:log(N_H/cm^{-2})=24.5,25.5)
  - using only WFI spectrum and z
  - Synergies with multi-λ
- Brightman&Nandra'11 torus
- Gilli+07 CXB model
- Can do it for L* for z≤3
- Need ≥400ks exposure

$\log N_H$=24.5
L_X(2-10keV)=5×10^{44} cgs z=2

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#ÅthenaNuggets by F.J. Carrera

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The history of SMBH growth

Aird, Comastri et al. 2013 arXiv1306.2325

Only extreme AGN expected in opt/IR surveys

X-rays needed to signpost average AGN

#ÅthenaNuggets by A.Comastri, G.Lanzuisi & J.Aird

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X-ray spectroscopic z

- Using method of Castelló+11, essentially:
  - FT analysis of spectrum/simple model
  - Look for peaks of emission
  - Spectral fit with FT peak energy as input
  - Working to implement wavelet method
- Preliminary tests with simulated CT AGN spectra
  - Estimated fraction in z,L_X bin $\Delta z/z \leq 0.1$
  - Different values of Texp:
    - T_{exp}=60ks: $\gtrsim$50% for $L_X \geq 5\times10^{45}$ erg/s for $z \leq 4$
    - T_{exp}=400ks: $\geq$50% for $L_X \geq 10^{45}$ erg/s for $z \leq 2$
    - T_{exp}=1Ms: $\geq$70% for $L_X > L^*$ for $z \leq 2$

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

- ESO-Athena Synergy exercise underway since March 2016
  - Led by ESO-Athena Synergy Team: P. Padovani (chair), E. Hatziminaglou, M. Díaz-Trigo, S. Viti, S. Ettori, M. Salvato, F. Combes, P. Jonker
  - Leading to 2 Synergy White Papers ~March 2017: opt/NIR and sub/mm
  - Synergy topics span a broad range of astrophysics

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

Athena Community Organisation

ESA Athena Science Study Team (ASST)

D. Lumb (Chair), K. Nandra (Lead & WFI), X. Barcons, D. Barret (X-IFU), A. Decourchelle, J. W. den Herder, A. Fabian, H. Matsumoto (JAXA), L. Piro, R. Smith (NASA), R. Willingale

SWG1 - Hot Universe
A. Fabian, T. Reiprich, T. Ohashi

- **SWG1.1 Evolution of galaxy groups and clusters** — S. Allen, N. Ota, E. Pointecouteau
- **SWG1.2 Astrophysics of galaxy groups and clusters** — D. Eckert, S. Ettori, G. Pratt
- **SWG1.3 AGN feedback in galaxy clusters and groups** — J. H. Croston, B. McNamara, J. Sanders
- **SWG1.4 Missing baryons and warm-hot intergalactic medium** — A. Finoguenov, J. Kaastra

SWG2 - Energetic Universe
X. Barcons, L. Brenneman, M. Cappi

- **SWG2.1 Formation and growth of earliest SMBH** — J. Aird, A. Comastri
- **SWG2.2 Understanding the buildup of SMBH and galaxies** — F.J. Carrera, A. Georgakakis, Y. Ueda
- **SWG2.3 Feedback in local AGN and star forming galaxies** — G. Ponti, A. Ptak, Y. Terashima
- **SWG2.4 Close environments of SMBH** — M. Dovciak, G. Matt, G. Miniutti
- **SWG2.5 Physics of accretion** — C. Done, J. Miller, C. Motch
- **SWG2.6 Luminous extragalactic transients** — P. Jonker, P. O'Brien

SWG3 - Observatory
A.Decourchelle, H. Matsumoto, R. Smith

- **SWG3.1 Solar System & exoplanets** — G. Branduardi-Raymont, M. Güdel
- **SWG3.2 Star formation and evolution** — A . Hornschemeier, G. Rauw, S. Sciortino
- **SWG3.3 End points of stellar evolution** — E. Bozzo, A. Schwope
- **SWG3.4 Supernova remnants & interstellar medium** — A. Bamba, E. Costantini
- **SWG3.5 Multiwavelength synergy** — F. Combes, M. Salvato

TWG4 – Telescope
R. Willingale, G. Pareschi

MWG5 - Mission Performance
J.W. den Herder, L. Piro, A. Rau

- **MWG5.1 Science ground segment** — M. Watson, N. Webb
- **MWG5.2 Background** — Ph. Laurent, S. Molendi
- **MWG5.3 Inter-calibration** — V. Burwitz, F. Pajot, S. Sembay
- **MWG5.4 End-to-end simulations** — Ph. Peille, J. Wilms
- **MWG5.5 Advanced analysis tools** — F. Fiore, F. Haberl
- **MWG5.6 Targets of opportunity** — S. Basa, E. Troja

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

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

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Spanish participation in Athena

- At mission level
  - **X. Barcons** serves in ESA's ASST
  - Total 48 researchers from Spanish institutions serve in the TP:
    - 1 WG co-chair (XB) and 2 TP co-chairs (**FJC** and **G. Miniutti**)
    - **AGN**: 20 in SWG2 (Energetic Universe), 6 in SWG3.5 (synergies) and 6 in MPG5 (mission performance)
    - Athena Community Office led by IFCA
- At instrument level, all participation focussed in X-IFU

ATHENA X-ray Integral Field Unit

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Spanish participation in X-IFU

- **M. Mas Hesse** represents Spain in the X-IFU consortium board
- The Detector Cooling System cryostat (dewar)
  - In development by INTA and CAB (Phase A)
  - Lead: **A. Balado** (national X-IFU PM). Other participants: **J. Azcue, M.A. Alcacera, A. Gómez, L. González, M. Mas-Hesse, M. Pajas, J. Martín-Pintado, J.A. Viceira y P. Zuluaga-Ramírez**
- The Event Processor algorithms:
  - In development by IFCA
  - Lead: **M.T. Ceballos**. Other participants: **B. Cobo**
- Science support:
  - X-IFU Science Team: **X. Barcons** (chair), **J.M. Torrejón**
- X-IFU Instrument Science Centre (operations):
  - IFCA and U. Alicante have offered to participate

Athena Project development: Current status

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

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
  - Well suited to address AGN science in particular
- 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
  - Soon another call to join TP: don't miss 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