The participation of IA/FCUL in the ATHENA X-ray Mission: WFI science towards the earliest AGNs

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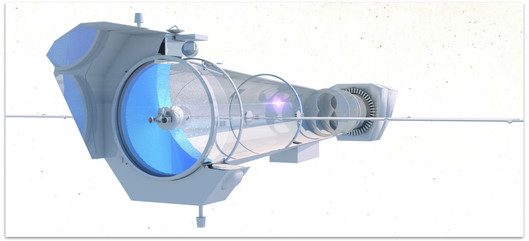
Abstract

ATHENA, the Advanced Telescope for High Energy Astrophysics, is the next-generation X-ray observatory selected as the second large mission (L2) of ESA's Cosmic Vision-programme and scheduled to launch in 2031 (Nandra+13). Athena will address the *"The Hot and Energetic Universe"* science theme with its two main science instruments: the Wide Field Imager (WFI, Meidinger+18) and the X-ray Integral Field Unit (X-IFU). The main scientific cases aimed by the Athena instruments fall mostly behind these two big questions:

- How do baryons assemble and form the large-scale structures in the Universe that we see today?
- And how do black holes grow and influence their surroundings Universe?

With its unparalleled capabilities, *Athena* will be a truly transformational observatory which, operating in conjunction with other future large observatories across the electromagnetic spectrum available like ALMA, ELT, JWST & SKA (among many others), will bring an enormous advance in our knowledge of the energetic universe.

For a quick overview of the science, instrumentation and technology involved in the Athena mission, please consult the *Athena Fact Sheet*.



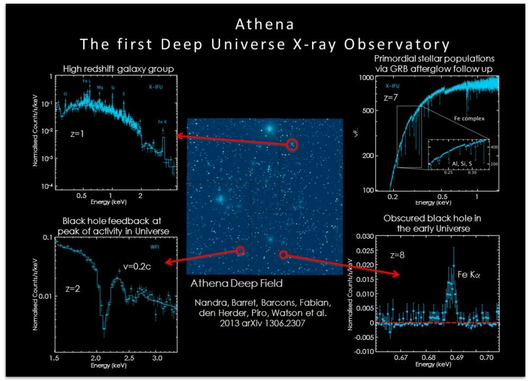


Fig 1) *Top*: Artistic view inside the Athena telescope, with the mirror located up front of the image (Credits: X-IFU Consortium). *Bottom*: Simulation of a *Athena*-WFI image with 600 ks (~7 days) of integration time. Surrounding panels show the spectra from different populations: an *early universe galaxy group*, precursor of today massive clusters of galaxies; detection of the *very first PopIII stars* through GRBs X-ray emission; the influence of SMBH ejecta into the IGM and the *Fe-Kα line* emitted by material closely circling a SMBH.

IA & ATHENA

The birth of the first SMBHs, their evolution, and influence in galaxy formation has been one of the cornerstones of the research carried out by the galaxy evolution group at the IA. Significant effort has been allocated to pinpoint AGN activity up to the highest redshifts as traced by its characteristic emission in the radio and X-rays (see S. Amarantidis and R. Carvajal posters on high-z radio AGNs models and observations for an overview). Therefore, IA participation in ATHENA is a natural step towards these scientific goals. In the following sections we briefly discuss:

- IA involvement in the Wide-Field-imager (WFI) consortium,
- relevance of WFI to the broader search of the earliest black holes, and
- synergies with future observatories (e.g. SKA)

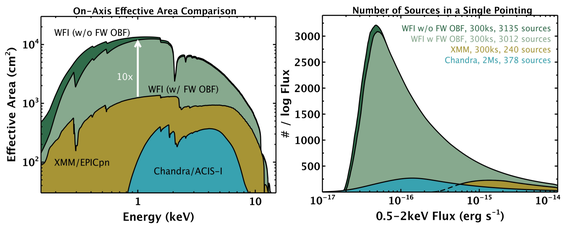


Fig. 2: *Left*) Athena/WFI effective on-axis area compared to Chandra/ACIS-I and XMM-Newton/EPICpn. *Right*) Number of sources per log flux that can be detected in a single pointing with Athena/WFI, XMM-Newton/EPICpn, and Chandra/ACIS-I. Both plots assume an Athena/WFI with an SPO optics with 15 mirror rows. Credits: A.Rau/WFI Team.

Athena improves capabilities over its predecessors (see Fig 2) thanks to:

- larger collecting area (Fig. 2),
- better throughput of the detectors, and
- a homogenous PSF over a 40x40 arcmin Field of View (FoV).

The sensitivities to be reached will increase by at least 10x the number of Active Galactic Nuclei (a.k.a. accreting SMBHs) detected with similar exposure times (Fig. 3), both pushing their characterization to fainter luminosities and into the early stages of BH and galaxy formation.

The involvements of the Institute of Astrophysics and Space Sciences (IA) in *ATHENA* dates back to the very early stages of the Athena proposal and the definition of the scientific and technical requirements of the WFI camera. PT through IA participates in the mission through the:

• WFI Board • WFI Science Team • Athena Science Study Team (ASST)

• WFI Science Working Groups • WFI Science Ground Segment

IA will also deliver hardware components for WFI in collaboration with the PT industry and lead the design one critical system of the telescope.

In fact, very recently (April 2020), the IA and FCUL won a contract with ESA for the development of a high precision optical system to be used for the critical alignment of the spacecraft mirrors (2.5 meters wide) with respect the two instruments onboard. The IA instrumentation team is leading a consortium with the participation of three external partners (2 of them Portuguese): FHP, Evoleo and Thales Alenia Space.

IA & WFI Science

The Epoch of Reionization (EoR; z>6) marks a critical landmark in the history of our Universe. This epoch sees the shine of the first stars, the first galaxies and the first accretion onto SMBHs while it witnesses the initial connection between these components driving their later evolution.

Even nowadays, the EoR is not fully accessible to current instrumentation but, with a set of predefined surveys, *Athena/WFI* promises to provide the required statistics to perform this detailed analysis.

The surveys still need to be precisely defined as they depend on the final specifications of the telescope, its instruments as well as on the unknown nature of the population to be explored. To constrain this population:

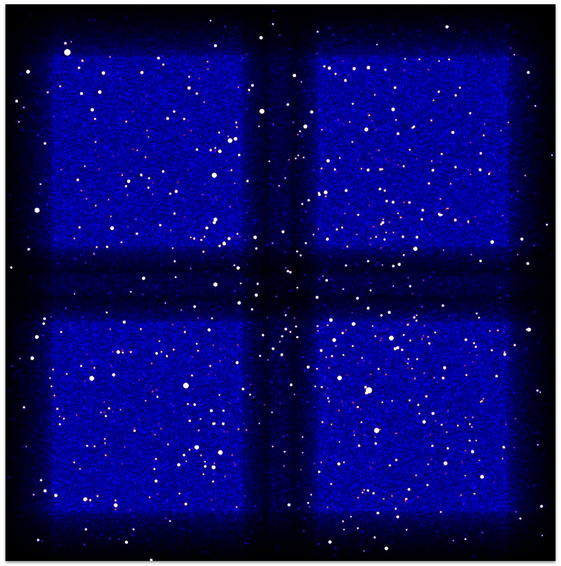


Fig. 3) Simulated image of *Athena*-WFI of a deep field with 600 ks exposure time carried out by the IA-team. The image is the first ever estimate of the number of SMBHs at all redshifts basely purely on the latest cosmological models for galaxy evolution (Amarantidis+19). The detailed analysis of source detected in images like this one can provide the ultimate understanding of the telescope design capabilities and prepare us better for the very exciting science to come.

- IA/FCUL has actively participated in the WFI simulations from source catalogs based on the extrapolation of lower-z luminosity functions and are therefore highly uncertain in the EoR (Lanzuisi+17);
- IA/FCUL is working with our WFI collaborators in a new set of simulations based on the expectations from the cosmological models explored by our group in Amarantidis+19.

The latter approach provides an alternative estimate of sources at the EoR, as well as a physically motivated estimate of the X-ray background.

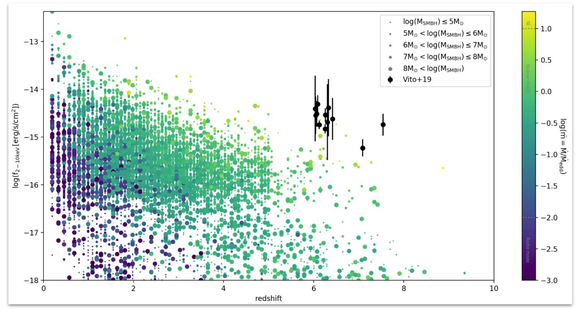


Fig. 4) The hard X-ray rest frame flux as a function of redshift for the input catalog in our simulations (Amarantidis+19) coloured by accretion mode and sized by BH mass. For comparison we show as black points the known X-ray quasars above z>6 (Vito+19).

Two further major contribution of IA to the WFi consortium are:

- Delivery, in collaboration with PT industries, of the multi-layered thermal insulators to be installed around WFI electronics housing. As we enter phade B, the final requirement of space graded material will be defined in the coming months;
- Contribution to the WFI Science Ground Segment by participating in the creation of high-level data products and in the discussions for the suitability for Lisbon to become a data/catalog mirror site.

ATHENA & SKA

The radio and the X-ray still today the most efficient way to trace accretion of matter into BHs. Given the PT involvement in Athena and that:

- In March 2019 Portugal became a founding member of the Square Kilometer Array (SKA), the future most advanced radio interferometer in the world;
- Both Athena and SKA will fully overlap during their operational lives providing a myriad of synergies between the two facilities (the SKA-Athena Synergy White Paper provides the extent and details on a significant number of such synergies);
- Interferometric and X-ray expertise has been building up over the past years at IA/FCUL,

IA and FCUL will continue to push and encourage for interferometric and X-ray based observations & science by PT researchers so that these future facilities provide the maximum benefit to the technological and scientific community in Portugal.

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Acknowledgements

This work is supported by Fundação para a Ciência e a Tecnologia (FCT) through the research grants UIDB/04434/2020, UIDP/04434/2020 and PTDC/FIS-AST/29245/2017. RC acknowledges support from FCT through the Fellowship PD/BD/150455/2019, (PhD::SPACE Doctoral Network PD/00040/2012) and POCH/ FSE (EC).

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