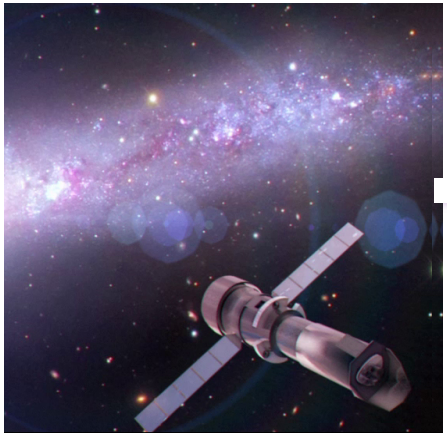
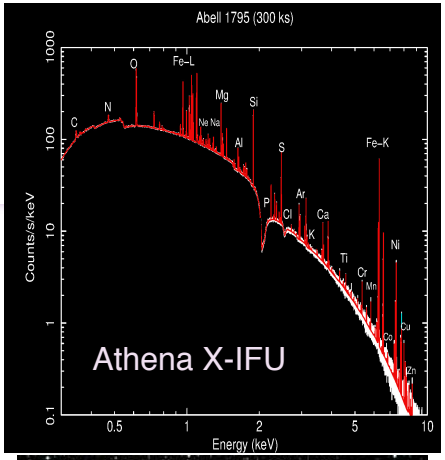
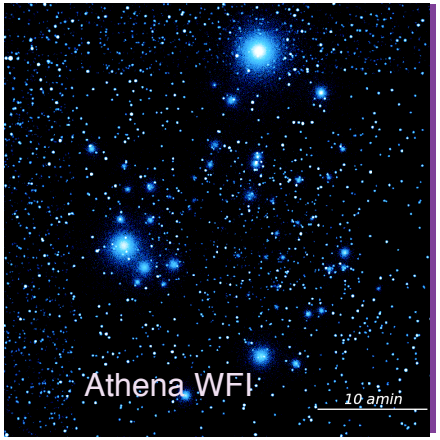
ATHENA

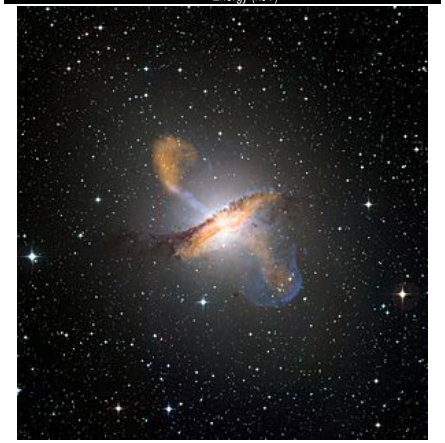
Athena: The ESA Mission to explore the Hot and Energetic Universe

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









X-ray Astronomy 2019
Bologna

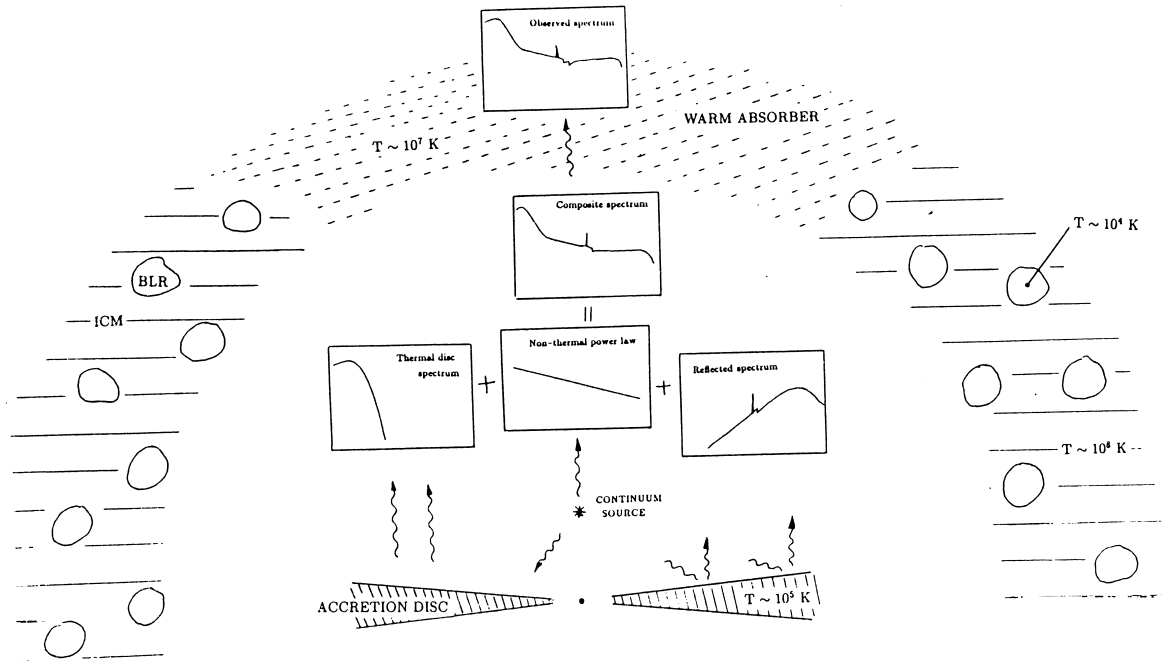
Kirpal Nandra
Max Planck Institute for Extraterrestrial Physics

On behalf of the Athena Science Study Team (ASST)* and Working Groups

**Didier Barret, Anne Decourchelle, Andy Fabian, Jan-Willem den Herder, Hiro Matsumoto, Luigi Piro, Randall Smith, Dick Willingale + Matteo Guainazzi (ESA Chair)*
Additional inputs from M. Bavdaz (ESA), M. Collon (cosine)

X-Ray Astronomy Bologna 1989

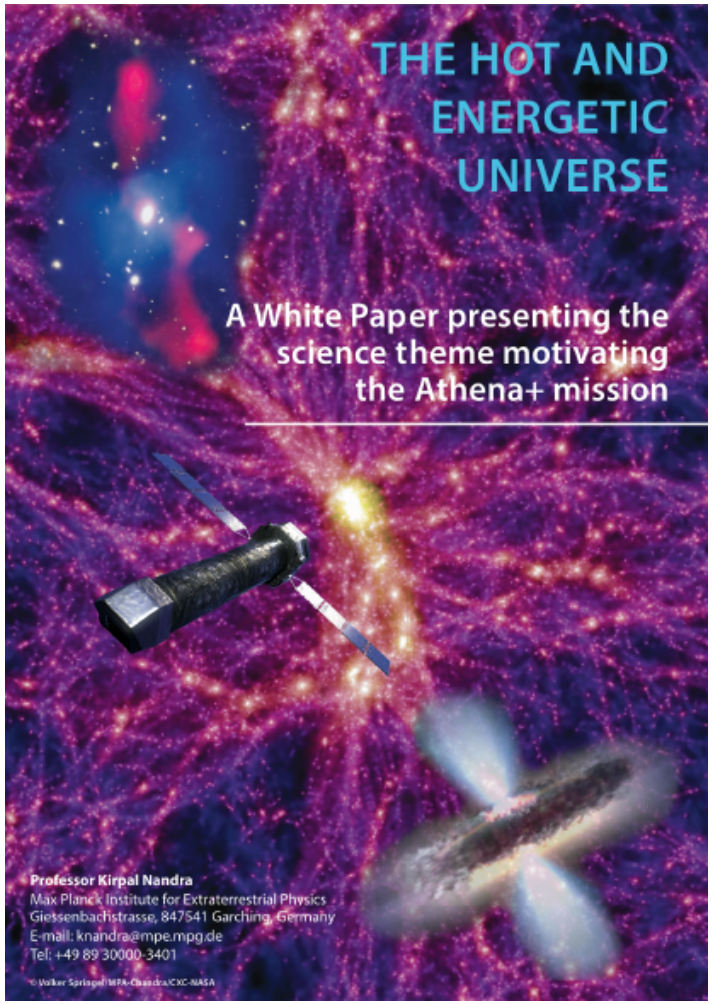
Poster: The X-ray spectrum of MCG-6-30-15



Nandra, K., Pounds, K.A., Stewart, G.C., George, I.M., Fabian, A.C., 23rd ESLAB symposium on two topics in X-ray astronomy, ed. J. Hunt, B. Battrick, ESA SP-296, Vol. 2, p. 1021.

The Hot and Energetic Universe

- Key Questions:
  - How does ordinary matter assemble into the large-scale structures we see today?
  - How do black holes grow and shape the Universe?
- Requires sensitive high resolution X-ray spectroscopy and deep wide field imaging
- Science theme selected by ESA in 2013 based on Senior Survey Committee recommendation
- Athena selected in 2014 as next large mission of ESA's Cosmic Vision program



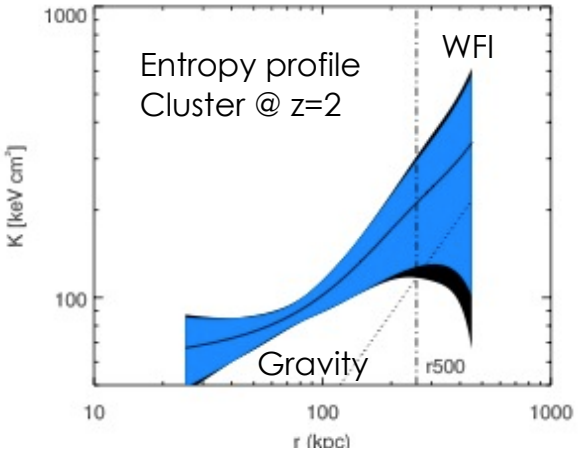
Nandra, Barret, Barcons, Fabian, den Herder, Piro, Watson et al. 2013 arXiv 1306.2307

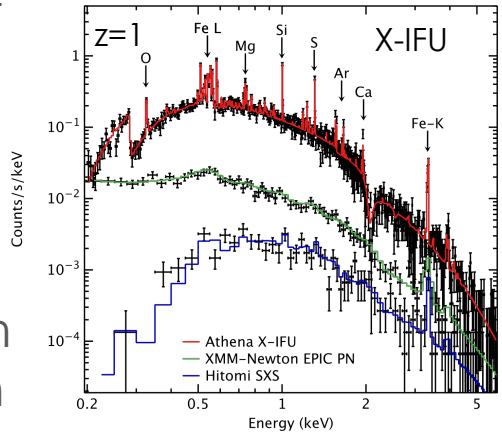
The Hot Universe

- How does ordinary matter assemble into the large-scale structures that we see today?
  - The quest for early galaxy groups @ z>2
  - Thermal history of hot baryons in clusters up to z~2
  - Chemical evolution of cluster gas
  - AGN feedback on cluster scales
  - Missing baryons in the Warm & Hot Intergalactic Medium

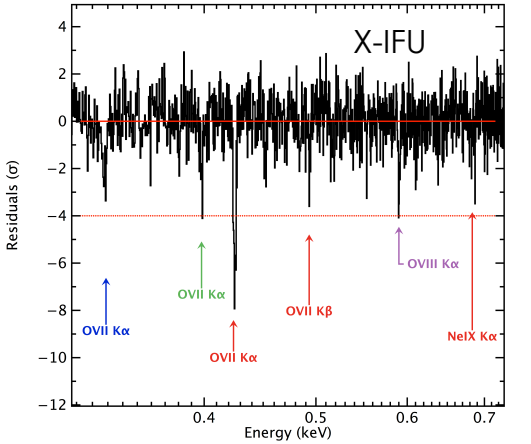
The first groups

Thermal history





Chemical evolution

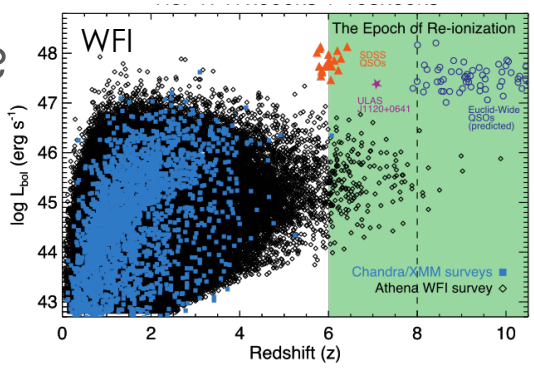


Missing baryons

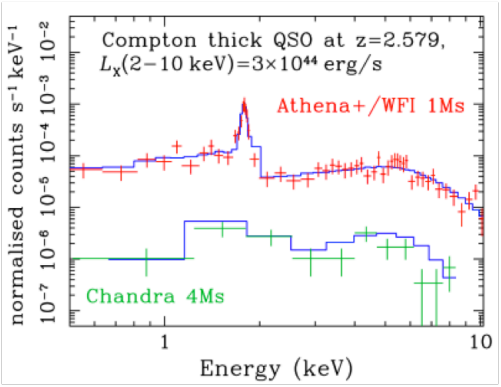
The Energetic Universe

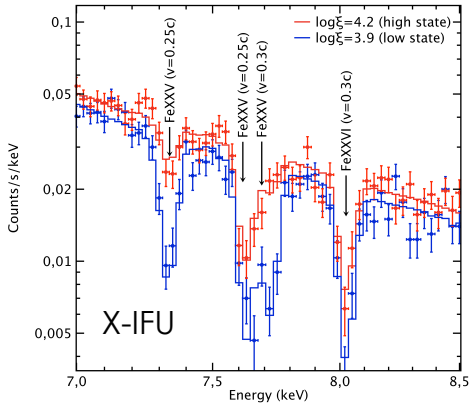
- How do black holes grow and influence the Universe?
  - The early history of SMBH growth at z>6
  - Obscured AGN census z~1-3
  - SMBH outflows z~0-3
  - SMBH growth: accretion vs. mergers
  - BH & SMBH accretion physics
  - Luminous extragalactic transients

Typical AGN z~6-8

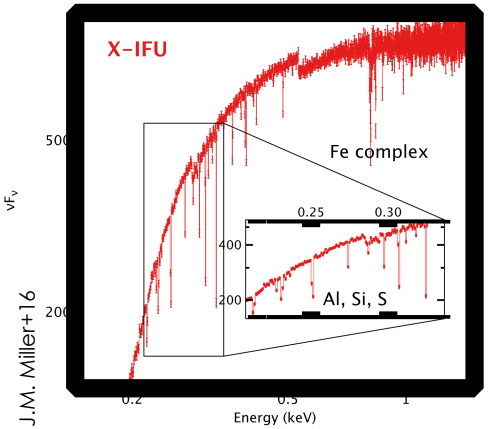


Compton-tick AGN census



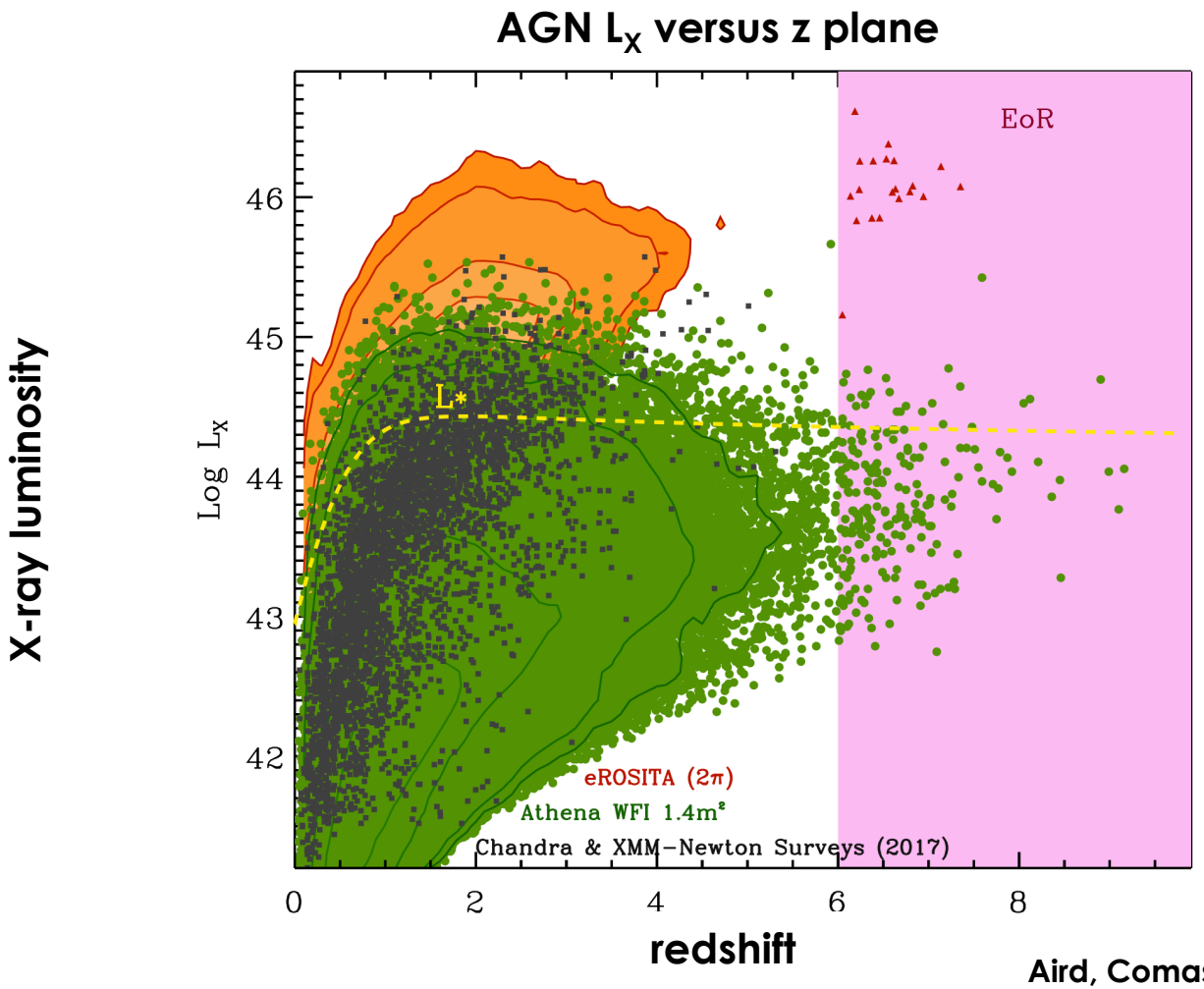


AGN ultra-fast outflows



GRB @z=7

Black Holes in the Early Universe

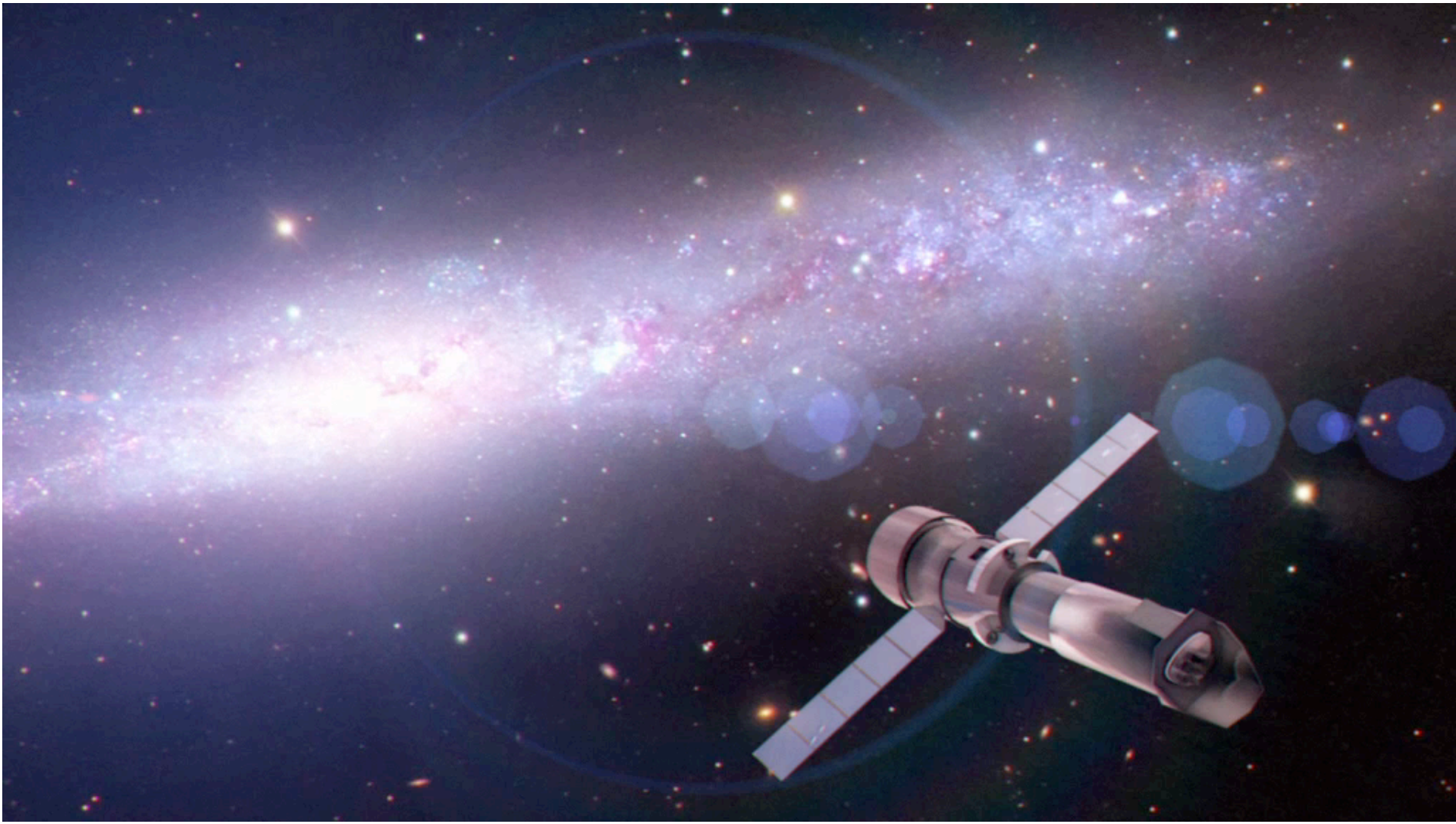


Only most luminous, massive QSOs seen in opt/IR surveys

X-rays needed to signpost typical and obscured AGN

Aird, Comastri et al. 2013 arXiv1306.232
Updated by Andrea Merloni (MPE) (2017)

The first stars and black holes



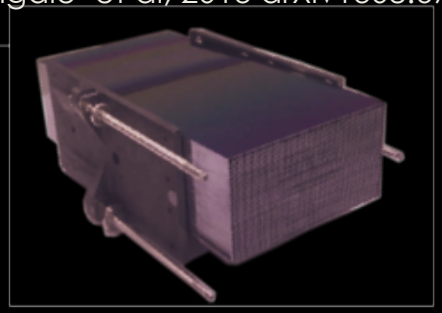
Fast response to transients opens up new window to early Universe

MISSION AS PROPOSED

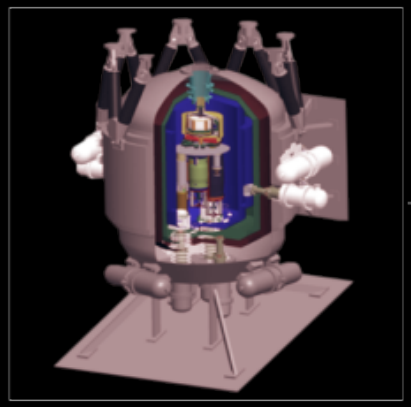
The Athena Observatory

Willingale et al, 2013 arXiv1308.6785

L2 orbit Ariane V
Mass < 5100 kg
Power 2500 W
5 year mission

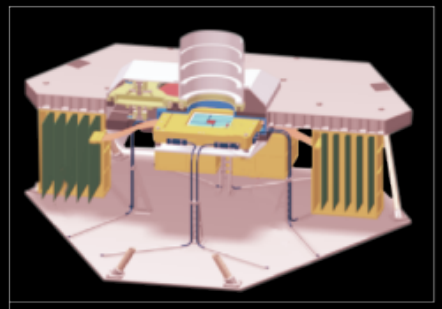


Silicon Pore Optics:
2 m^2 at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



X-ray Integral Field Unit:
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk

Barret et al., 2013 arXiv:1308.6784



Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

Rau et al. 2013 arXiv1307.1709

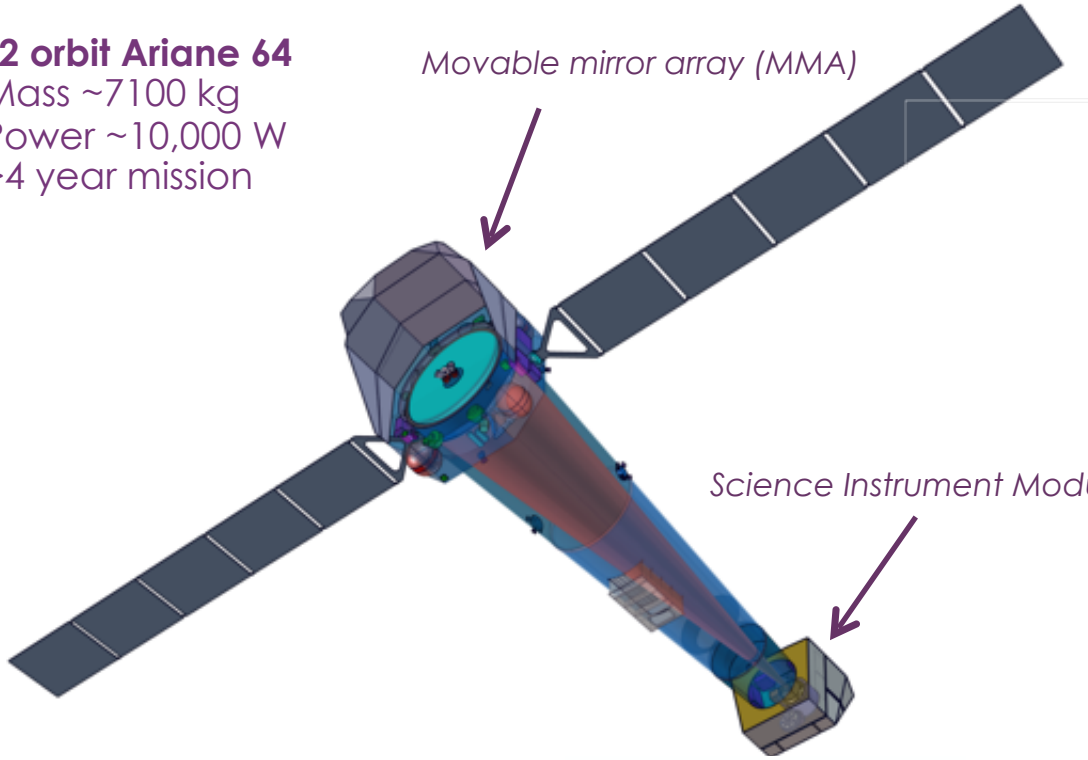
MISSION AT END OF PHASE A

The Athena Observatory

L2 orbit Ariane 64
Mass ~7100 kg
Power ~10,000 W
>4 year mission

Movable mirror array (MMA)

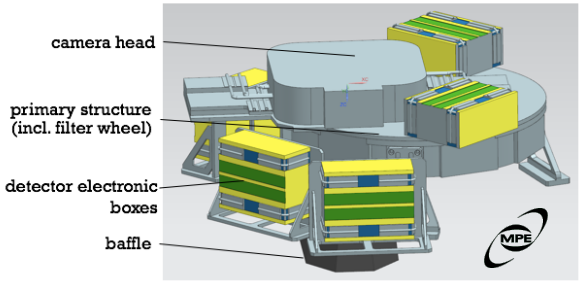
Science Instrument Module (SIM)



CNES project team

Willingale et al, 2013
Bavdaz et al. 2016,2018

Silicon Pore Optics:
1.4 m^2 (goal 2 m^2)@ 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}

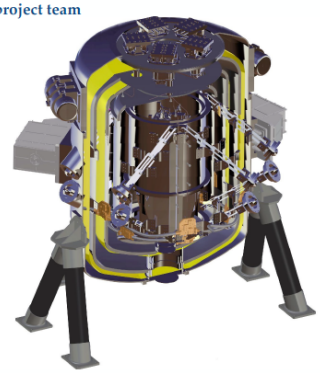


Wide Field Imager:
Si DEPFET-based detector
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

Meidinger et al. 2016, 2018, SPIE

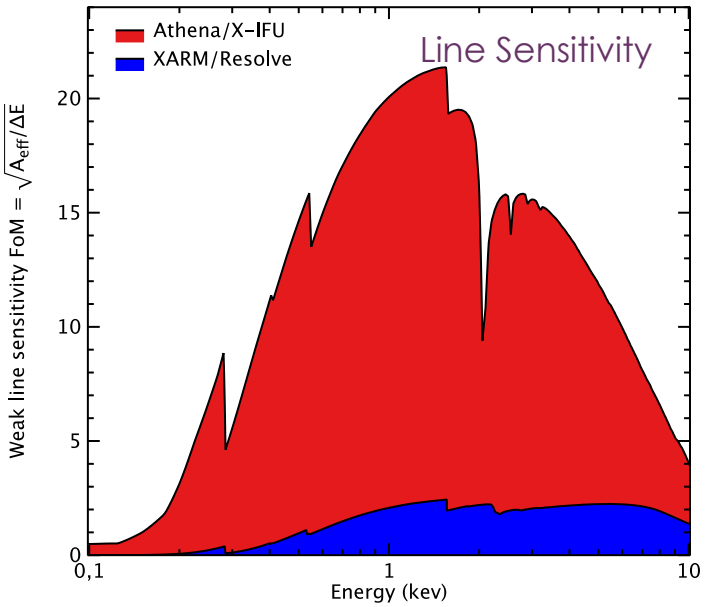
X-ray Integral Field Unit:
TES-based calorimeter
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk

Barret et al., 2016, 2018 SPIE

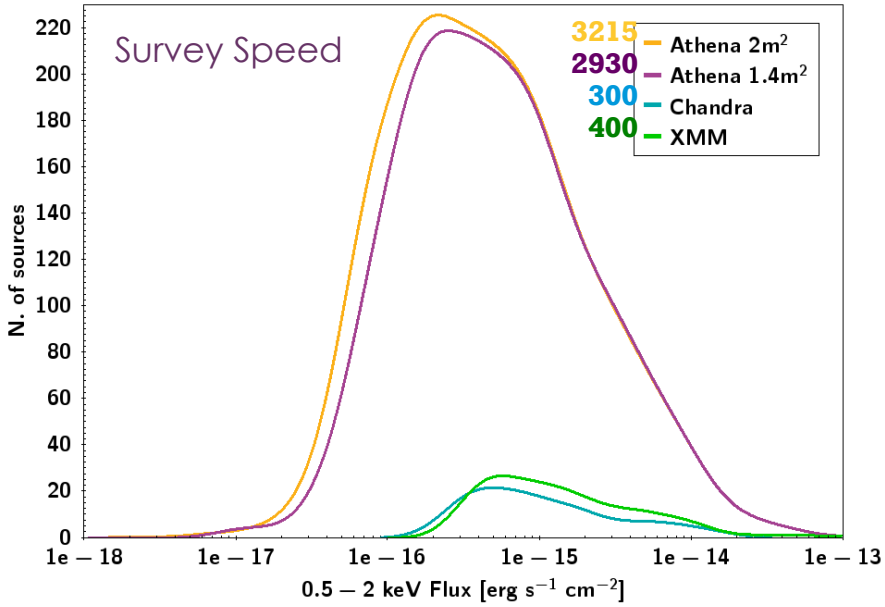


Athena: a revolutionary observatory

Athena has vastly improved capabilities compared to current or planned facilities, and will provide **transformational** science on virtually all areas of astrophysics



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

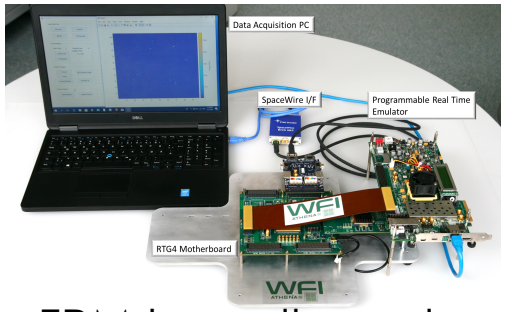


Deep survey capability into the dark ages and epoch of reionization

WFI Status

- **Successful I-PRR** completed Dec 2018. Instrument in Phase B.
- DEPFET Sensor manufacture and performance:
  - Prototype performance demonstrated, flight-like DEPFETs manufactured
- Real-time performance of frame processor
  - Demonstrated via event emulator and lab breadboard
- Flight-worthiness of large, thin-filter assembly (CBK, Palermo)
  - Acoustic noise tests successful!

Flight-like DEPFETs



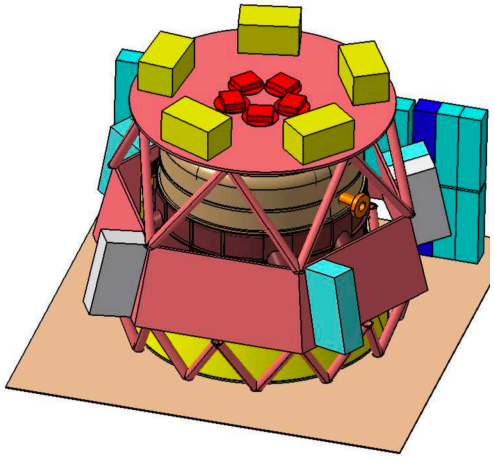
FPM breadboard

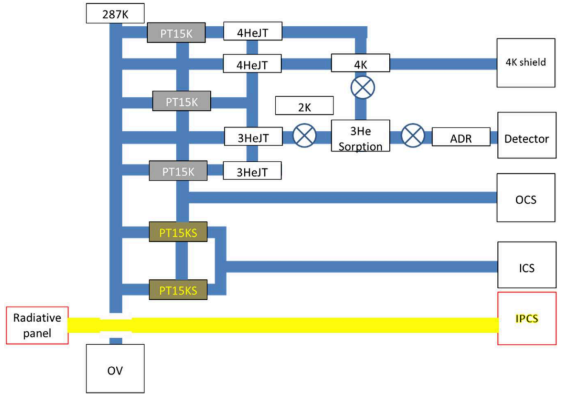
PI: K. Nandra (MPE)

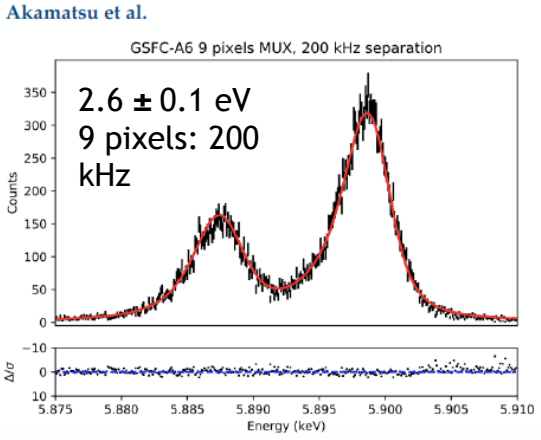
Acoustic Noise tests

X-IFU Status

- **Successful I-PRR** completed April 2019
- Baseline instrument and cryogenic chain shown to be feasible (e.g. mass, power, redundancy)
- Spectral resolution 2.6 eV (9 pixel multiplex) demonstrated
- Further optimizations ongoing



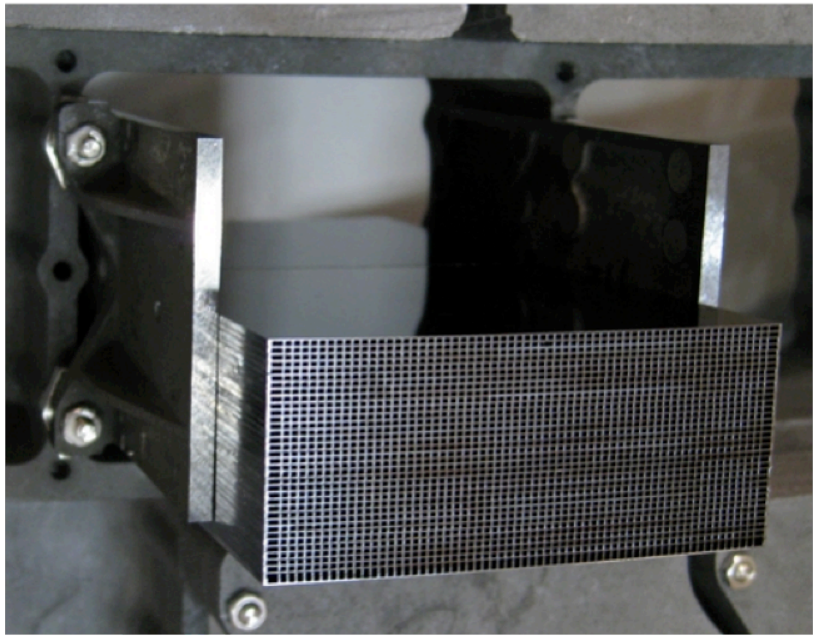




Credit: CNES/X_IFU team PI: D. Barret (IRAP)

Silicon Pore Optics (SPO)

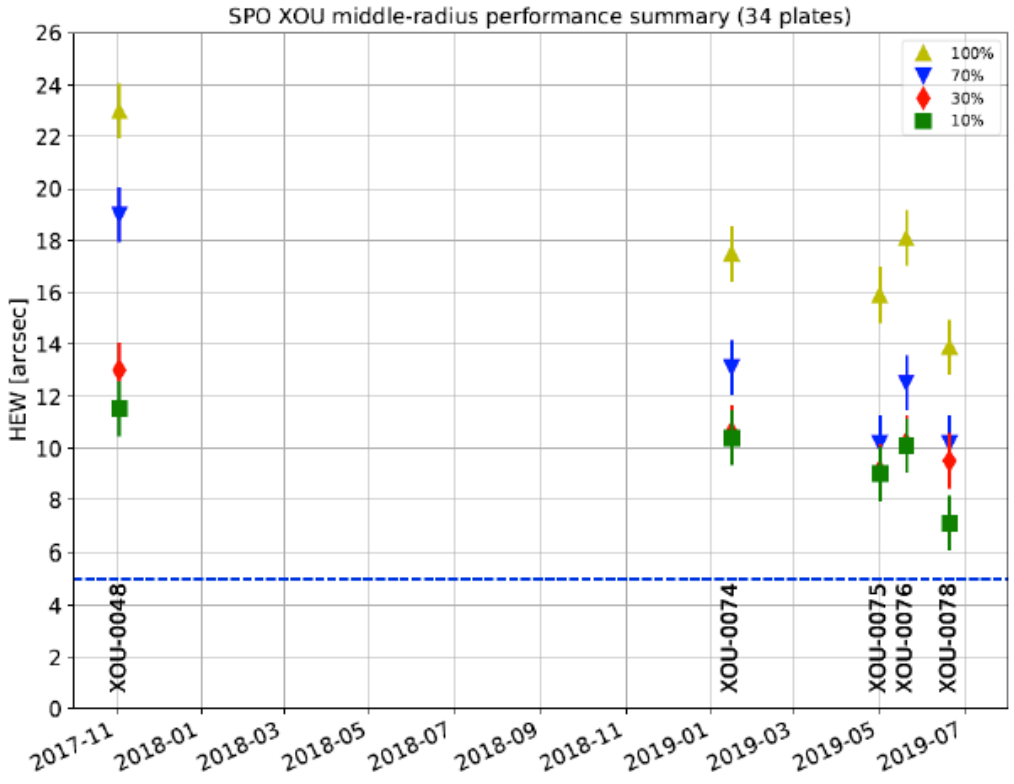
- **Innovative technology using robotic stacking of high-fidelity Si plates**
- **Lightweight, high throughput, good angular resolution**
- **Key optics requirements:**
  - 5" HEW on-axis, <10" @ 15'
  - 1.4 m^2 effective area @ 1 keV
- **Recent (10-plate) HEW measurements:**
  - <12" HEW for 100% of area
  - 8.0" HEW for 70% area
  - 5.0" HEW for 10% of area



Willingale et al 2013, arXiV: 1308.6785
Bavdaz et al. 2018, Proc. SPIE
Collon et al. 2019, Proc. SPIE

SPO Angular Resolution progress

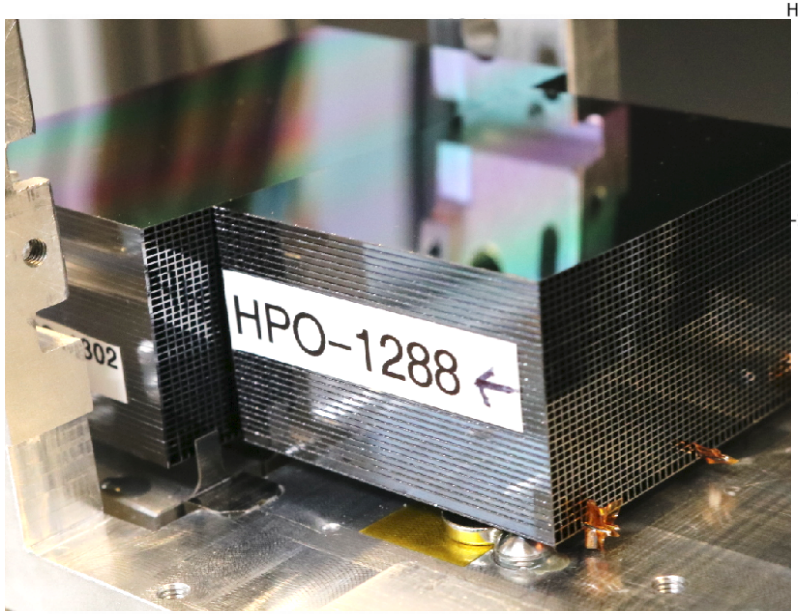
34-plate Performance

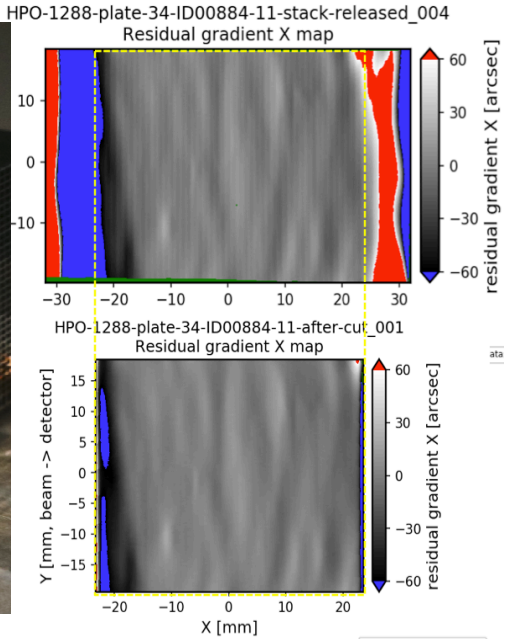


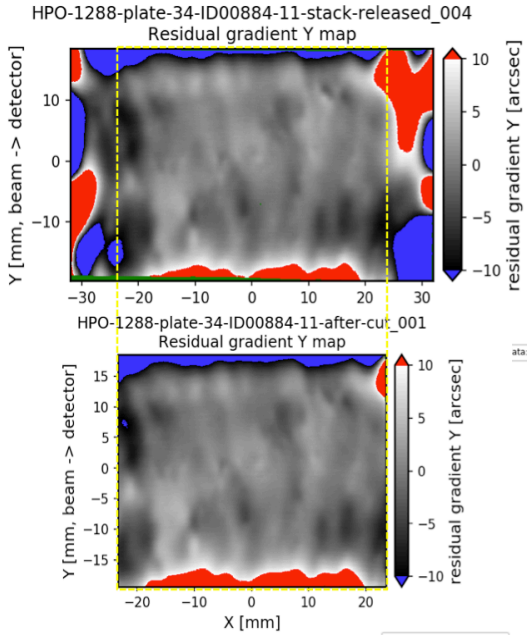
- Restarted process to make 34 plate middle radius XOUs
  - During SPOHO had focused on 10 plate stacks
- 34 plate stacks performance rapidly improving, XOU-0078 best to date
  - XOU-0078 has a number of known defects (wedge bias, curvature)
- Note that bad sides can be removed (see later in this presentation)
  - 70% to become new 100% reference

Number of plates	HEW 100% [1, 32]	HEW 70% [5, 26]	HEW 30% [10, 20]	HEW 10% [12, 14]
34	13.9	10.2	9.5	7.1
20	12.2	9.1	8.7	5.8
10	12.3	9.6	9.5	6.0

SPO Angular Resolution





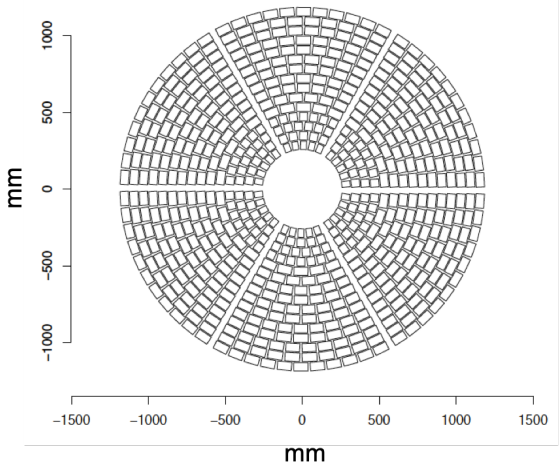


- Much progress understanding issues affecting HEW
- Axial edge effects can be addressed by cutting away areas of poor performance: demonstrated experimentally
- Entrance and exit effects (e.g. anticlastic curvature) being studied intensively

Mirror Design and Effective Area

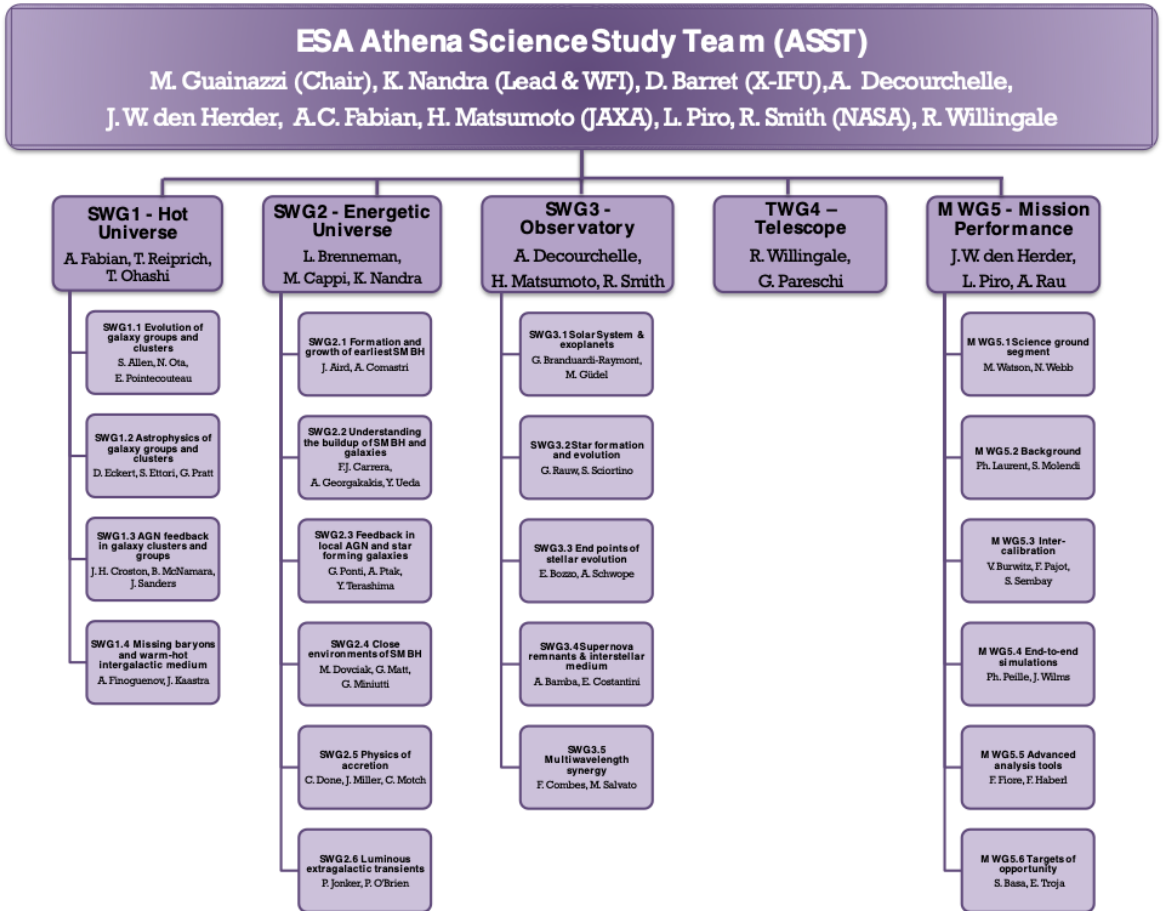
- **Current reference mirror design has 15 SPO rows**
- **Critical Issues for mirror performance**
  - Packing scheme, stack size, inner and outer radii
  - Rib Pitch: 1mm baseline; >2mm greatly improves performance
  - Coatings: optimal B4C difficult, alternatives being investigated
  - Stray Light Baffling: large effect off-axis, mitigation under study

SPO Module Layout



SPO Module Aperture

The Athena Community Structure



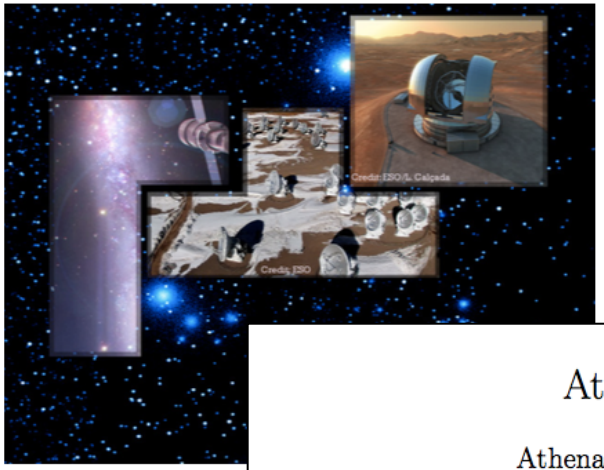
Total ~800 members with roughly annual call

Supported by Athena Community Office@IFCA, Spain (F. Carrera)

Athena Synergy Exercises

ESO-*Athena* Synergy White Paper

Chair: P. Padovani



Chair: R. Cassano

SKA-Athena Synergy White Paper

SKA-Athena Synergy Team

Athena-LISA Synergies

Athena-LISA Synergy Working Group:

Monica Colpi, Andrew C. Fabian, Matteo Guainazzi,
Paul McNamara, Luigi Piro, Nial Tanvir
(with contributions by J.Aird, A.Klein, A.Mangiagli, E.M.Rossi, A.Sesana)

20 February 2019

Next Synergy activities already in progress:

- Multi-messenger and gamma-ray (L. Piro)
- LSST/wide area surveys (M. Watson)

Athena: Summary

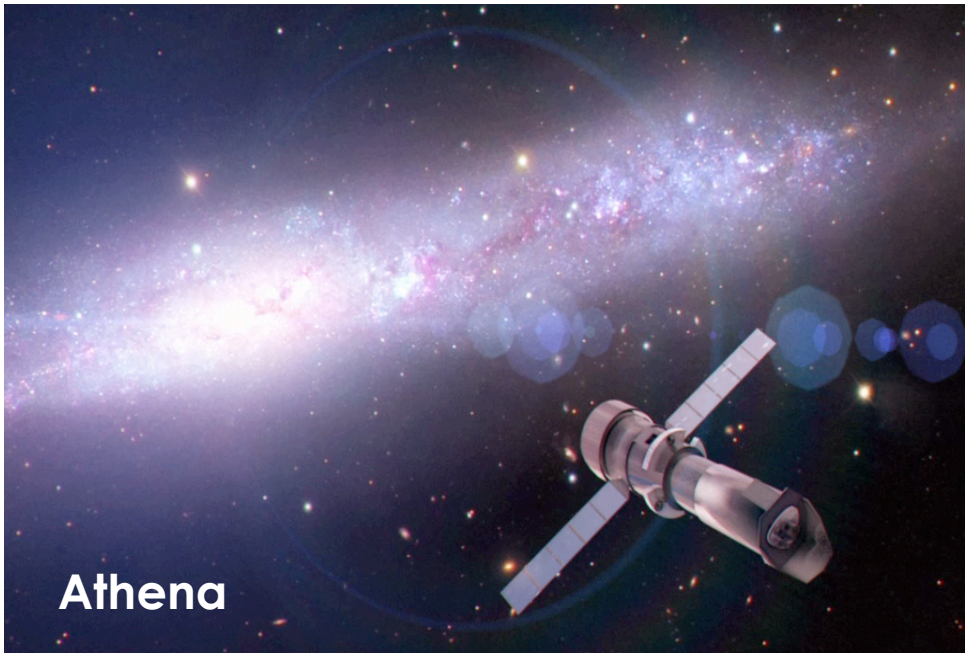
- **Athena** addresses key questions in high energy astrophysics via **high resolution spectroscopy** and **wide-field imaging**
- **Flagship observatory** with capabilities far exceeding current facilities in many respects
- **Schedule and Milestones**
  - *Instrument Consortium Consolidation, teams confirmed Dec 2018*
  - *WFI Instrument I-PRR successfully completed Dec 2018*
  - *X-IFU I-PRR successfully completed in April 2019*
  - **Mission Formulation Review (MFR) just started;** ends Phase A
  - **Mission Adoption Review (MAR)** Nov 2021; ends Phase B1
  - **Launch currently expected ~2031**

X-Ray Astronomy Bologna 1989

State of the art X-ray astronomy

X-Ray Astronomy Bologna 2039

State of the art X-ray astronomy



END