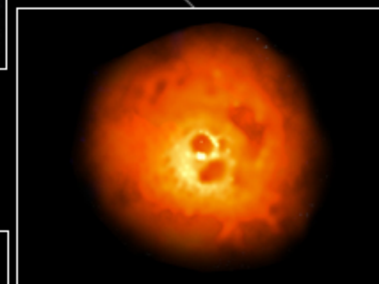
ATHENA

How do black holes grow and influence the Universe?

How does ordinary matter assemble into the large scale structures we see today?

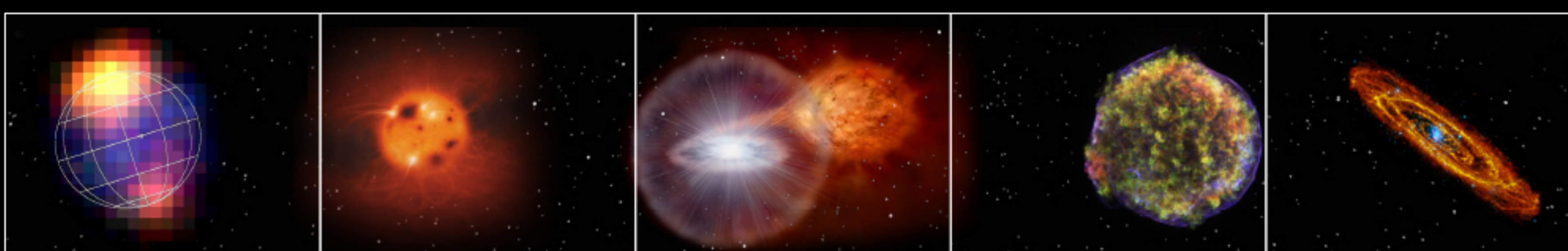


The US Role in Athena

Rob Petre (NASA / GSFC)

US Athena Study Scientist

The Hot and Energetic Universe



Background - Athena history (from P. Hertz presentation)

- 2012: ESA does not select IXO for the L1 opportunity as the first large mission in the Cosmic Vision Programme.
- 2012: Community Study Team examines options for an X-ray observatory under $1B
  - CST identifies three possible X-ray Probe architectures that each deliver a fraction of IXO's science
  - -http://pcos.gsfc.nasa.gov/studies/x-ray-probe-2013-2014.php
- 2013: NASA announces intent to partner on ESA large X-ray mission
- 2014: ESA selects Athena mission for the L2 opportunity as the 2nd large mission in the Cosmic Vision Programme, launching in 2028.
  - US representation on Athena Science Team and community-based Athena Science Working Groups
  - Formulation of the mission by ESA is underway, and a strawman design mission was completed in 2014. ESA plans an instrument AO in CY2016.
  - NASA appointed a US scientist to the Athena Science Study Team and US scientists to the Athena Science Working Groups.
- 2014: NASA issued RFI to assess interest by U.S. organizations in providing hardware for the Athena mission

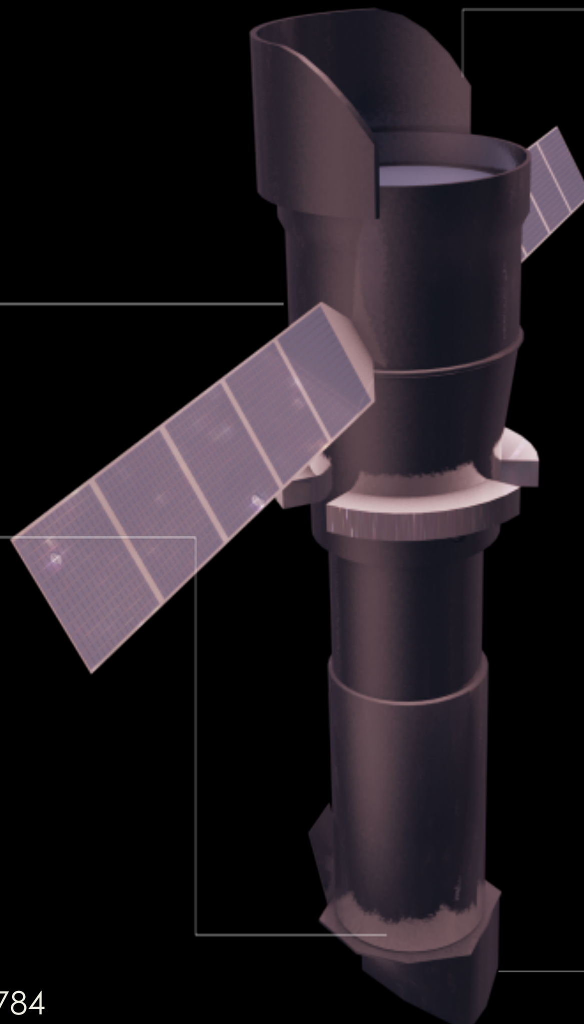
Background - Athena status within NASA (from P. Hertz presentation)

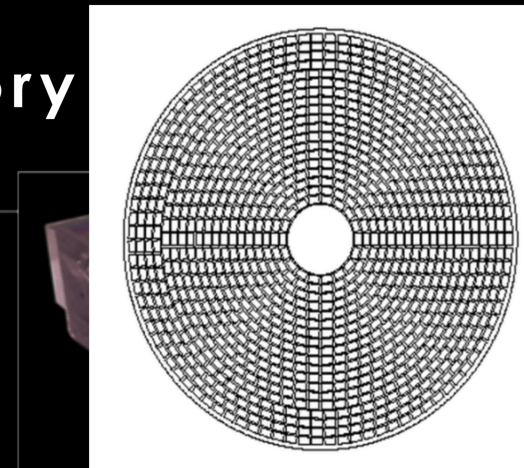
- 2015: NASA is pursuing a partnership with ESA to provide up to \$100-150M in components of the two instruments and/or the observatory.
  - NASA will provide the sensor array for the X-ray Integral Field Unit (microcalorimeter).
  - NASA is considering a proposal for contributions to the Wide Field Instrument (imager).
  - NASA is considering providing use of test facilities, specifically the X-ray and Calibration Facility (XRCF) at MSFC.
  - NASA also plans for funding US members of the Athena science team, a US science data center, and US general observers during operation.
- NASA is budgeting for participation in the Athena mission, but such budgets come at an “opportunity cost” from other Astrophysics budget lines within a constrained budget.
- Based on report of the Midterm Committee, NASA will prioritize investments toward a role in Athena against other competing priorities

ATHENA

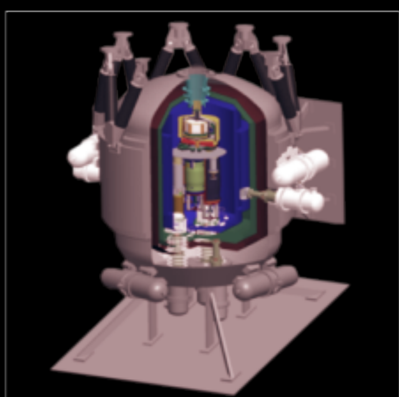
The Athena Observatory

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

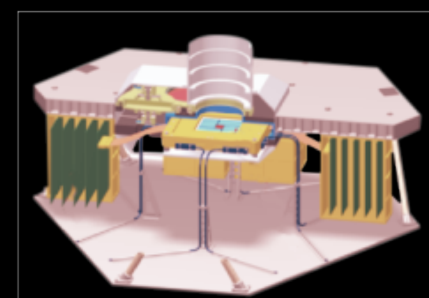




Silicon Pore Optics:
2 m^2 at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



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



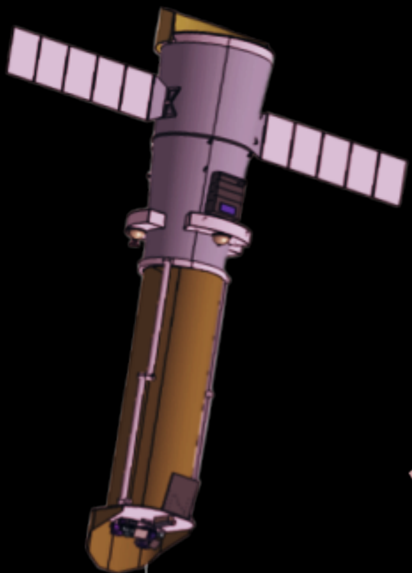
Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

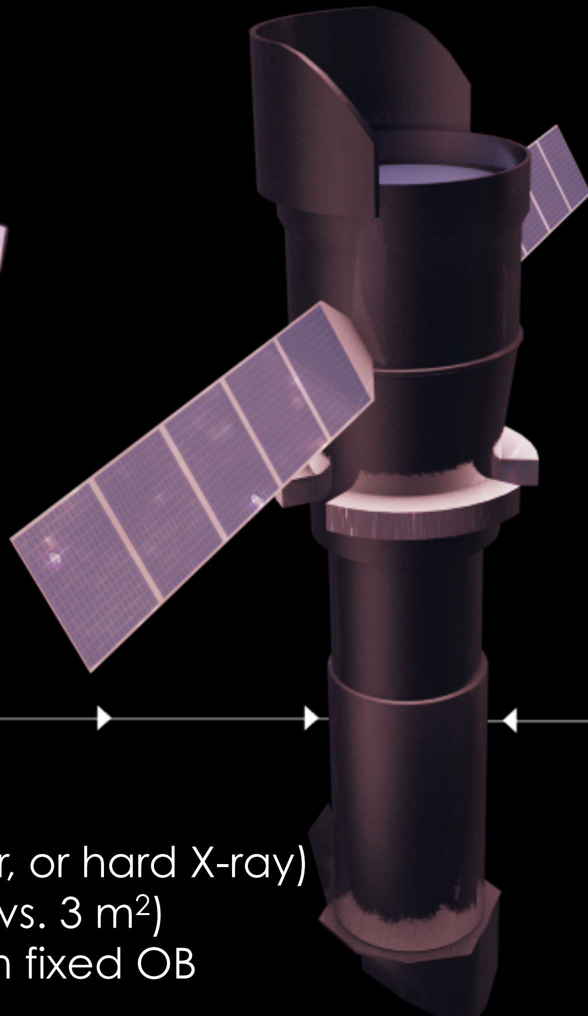
Barret et al., 2013 arXiv:1308.6784

Rau et al. 2013 arXiv1307.1709

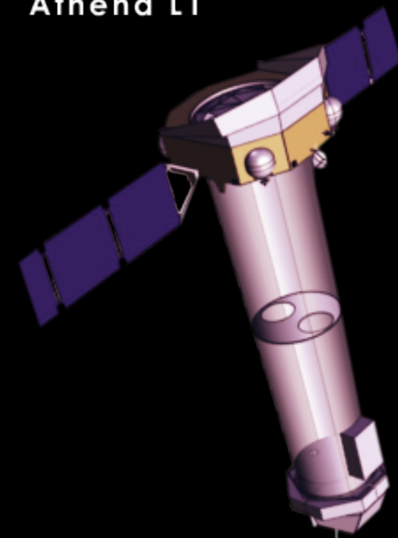
Technical Maturity

IXO (Ariane 5)





Athena L1



Simplified from IXO:
5 to 2 instruments
(no grating, polarimeter, or hard X-ray)
Smaller mirror (1.4-2 m^2 vs. 3 m^2)
20 m extendible to 12 m fixed OB

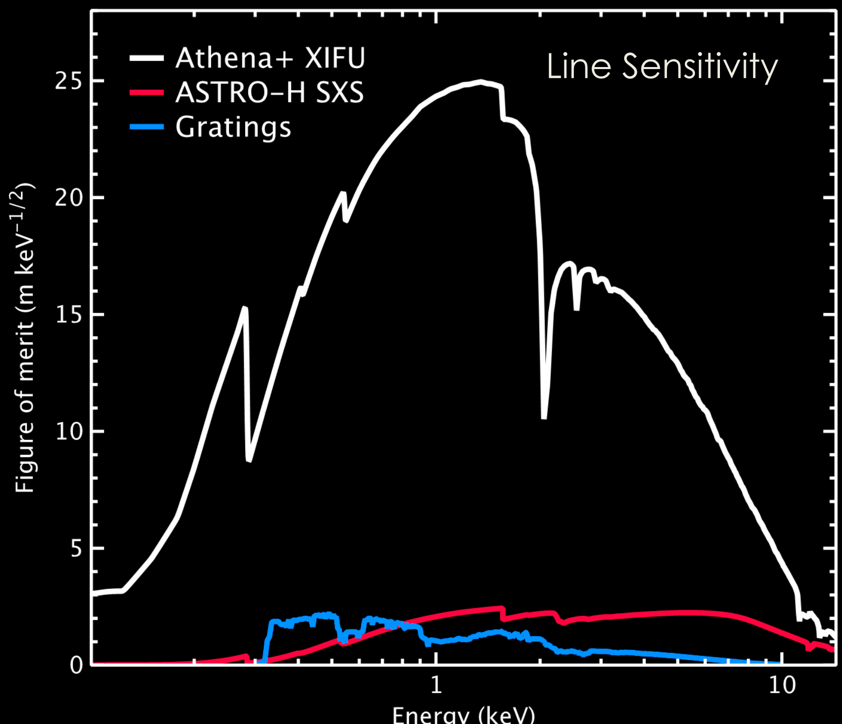
Enhanced over Athena L1:
Angular resolution now 5"
Fields of view increase x 4
Effective area increase x 4
(per instrument)

Differences reflect difference in science emphasis between IXO and Athena

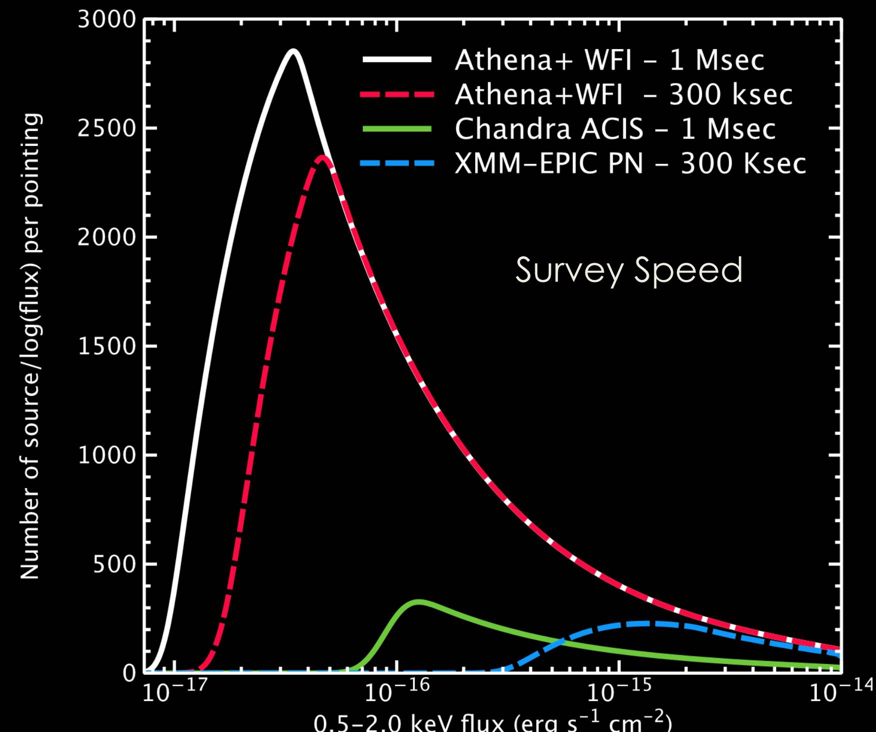
ATHENA

The first Deep Universe X-ray 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

How do Athena objectives compare with IXO's? From the NWNH science objectives:

- *From the cosmic dawn science plan:*
  - Use GSMT and **IXO** to monitor the exchange of gas between the galaxies and the surrounding intergalactic medium
  - Study the rate of formation and growth of black holes in the nuclei of young galaxies using **IXO** and WFIRST

- *From the Physics of the Universe Science Plan:*
  - Find and study distant clusters of galaxies to measure the rate of growth of structure in the universe using **IXO** and microwave background observations
  - Observe X-rays from gas orbiting close to the event horizon of black holes using **IXO**…

- *From the New Worlds Science Plan:*
  - Assess habitability by using **IXO** to characterize the frequency and intensity of flares on host stars

How do Athena objectives compare with IXO's? From the NWNH science objectives:

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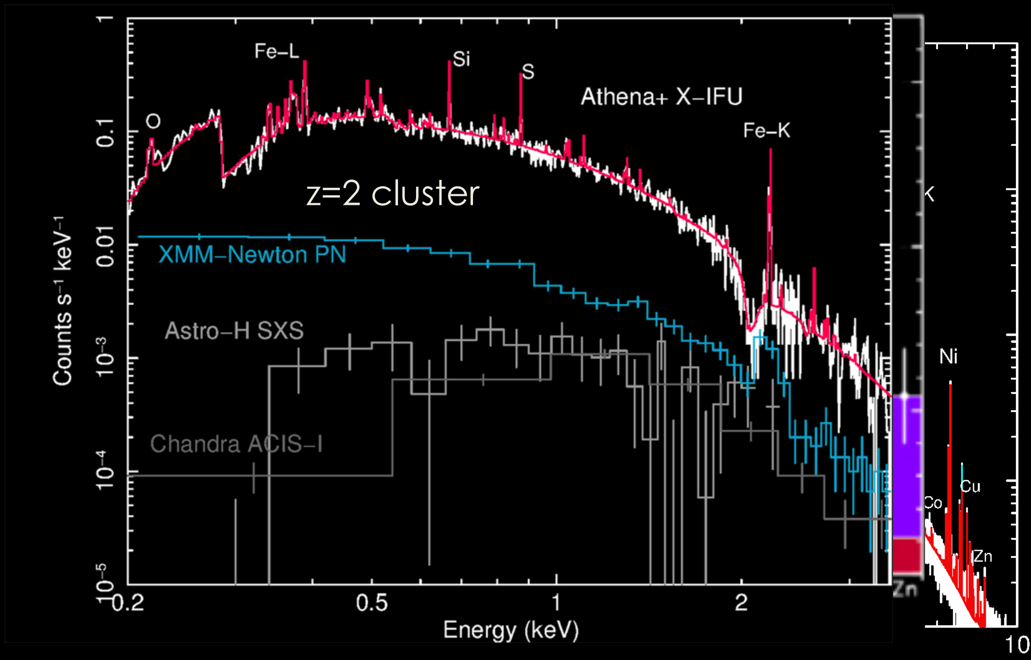
The chemical evolution of hot baryons

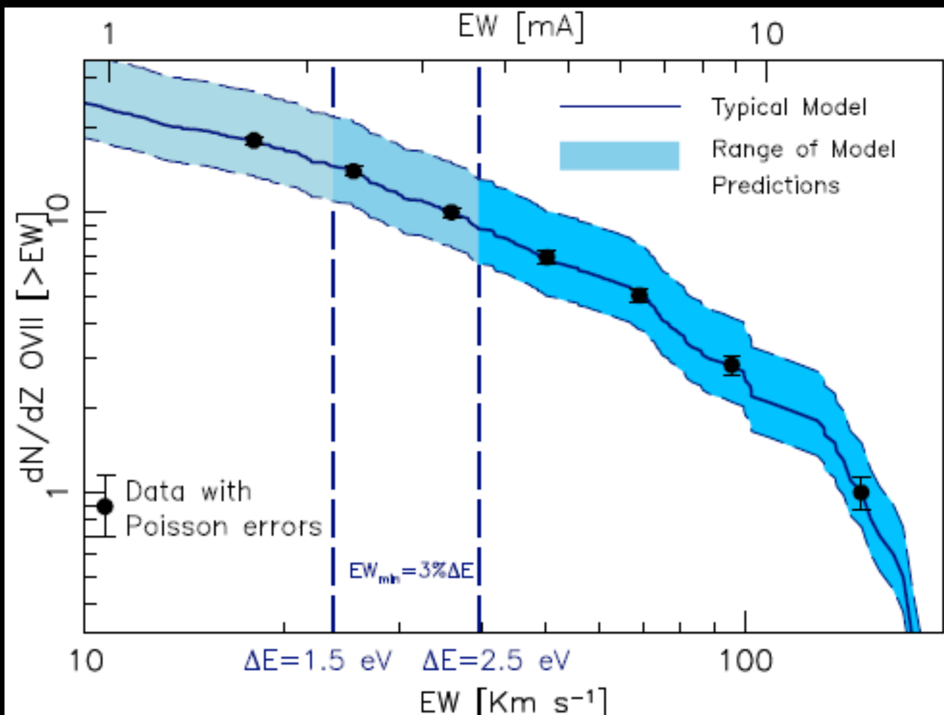
- When and how were the largest baryon reservoirs in galaxy clusters chemically enriched?



Ettori, Pratt, et al., 2013 arXiv1306.2322

Use GSMT and **IXO** to monitor the exchange of gas between the galaxies and the surrounding intergalactic medium

Searching for the Warm-Hot Intergalactic Medium



- Athena requirement will detect EW~3.5mÅ filaments, limited by systematics; with goal resolution, will achieve close to 2mÅ.
- IXO requirement was to be able to detect EW=2mÅ in 200 ksec, limited by source flux and thus able to detect almost twice as many filaments.

(*Figure from Athena White Paper "The missing baryons and the Warm-Hot Intergalactic Medium" (Kaastra, Finoguenov et al., 2013, ArXiv, 1306.2324*)

Use GSMT and **IXO** to monitor the exchange of gas between the galaxies and the surrounding intergalactic medium

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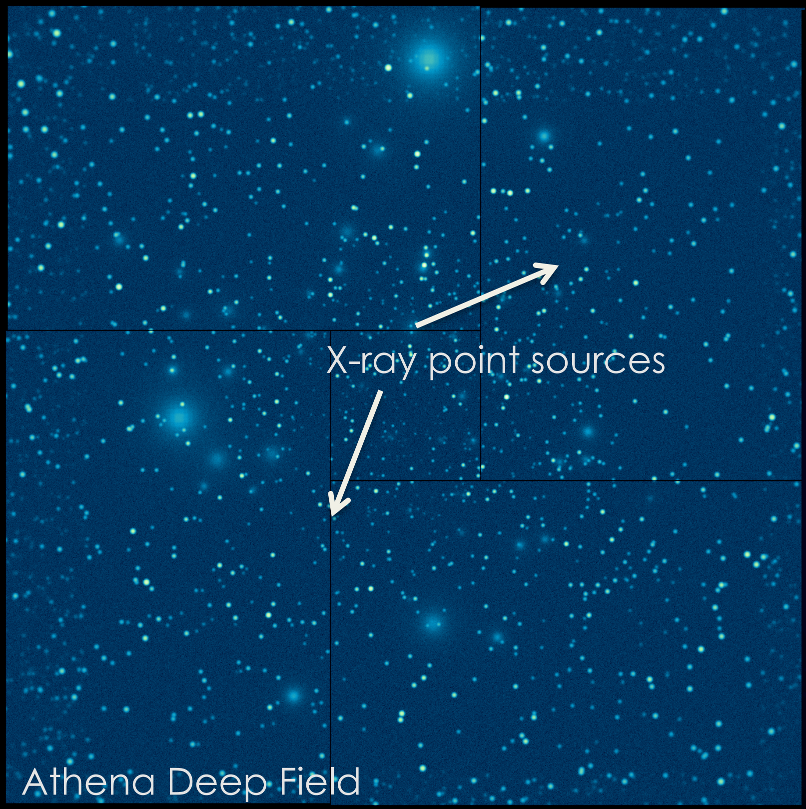
  - **Study the rate of formation and growth of black holes in the nuclei of young galaxies using IXO and WFIRST**

ATHENA

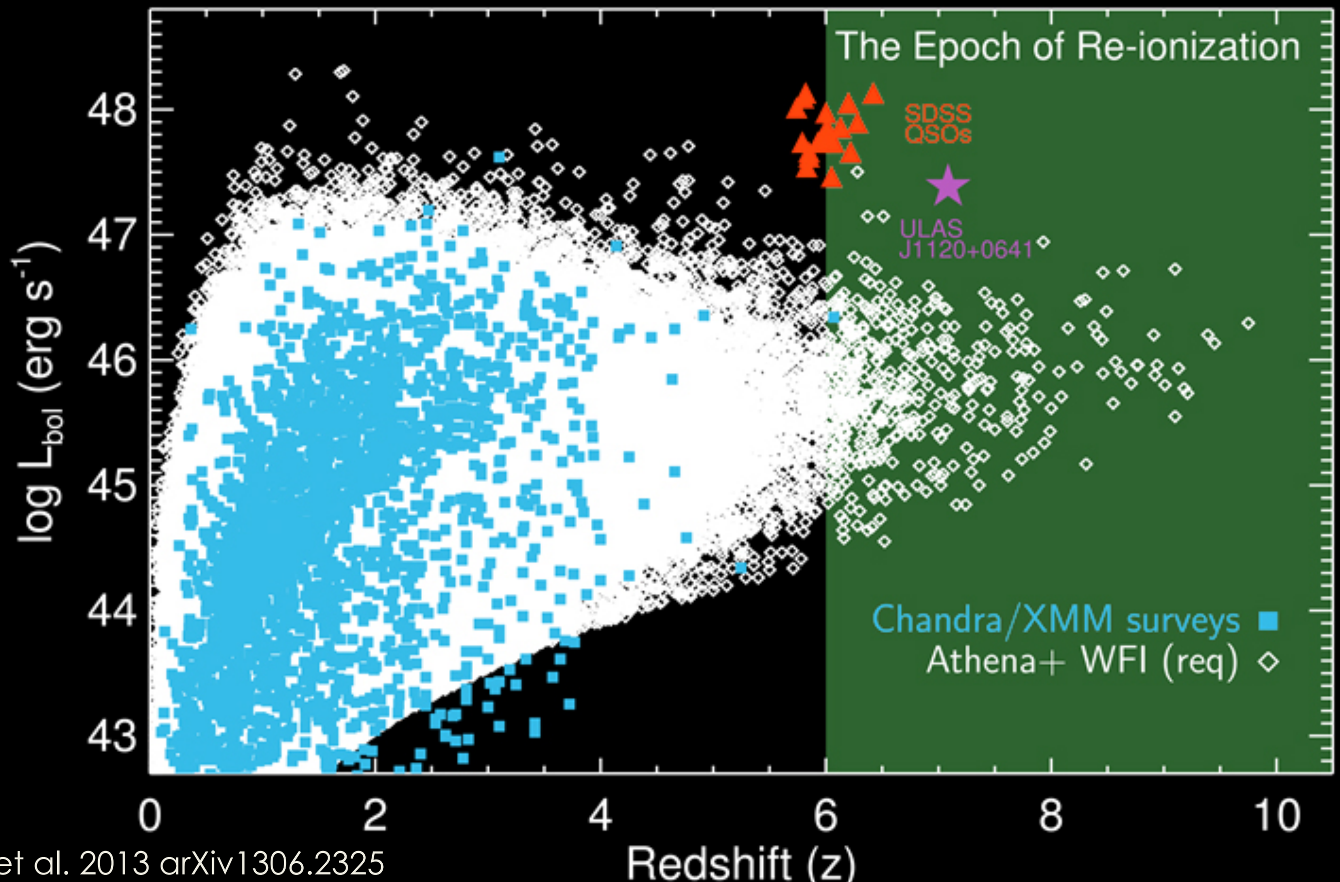
Black hole growth in the early universe



Study the rate of formation and growth of black holes in the nuclei of young galaxies using **IXO** and WFIRST

Black hole growth in the early Universe

- What was the growth history of black holes in the epoch of reionization?



Aird, Comastri et al. 2013 arXiv1306.2325

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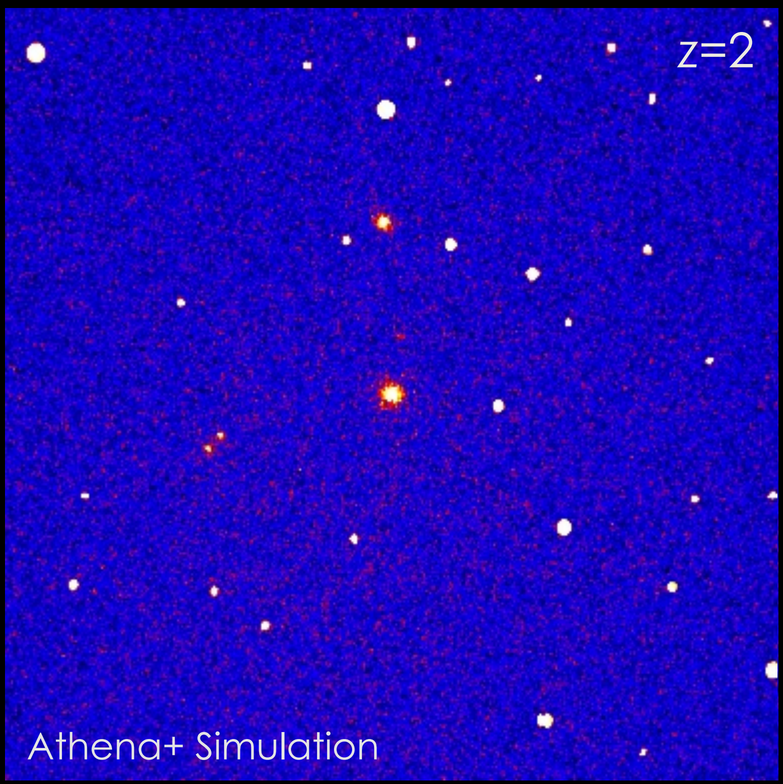
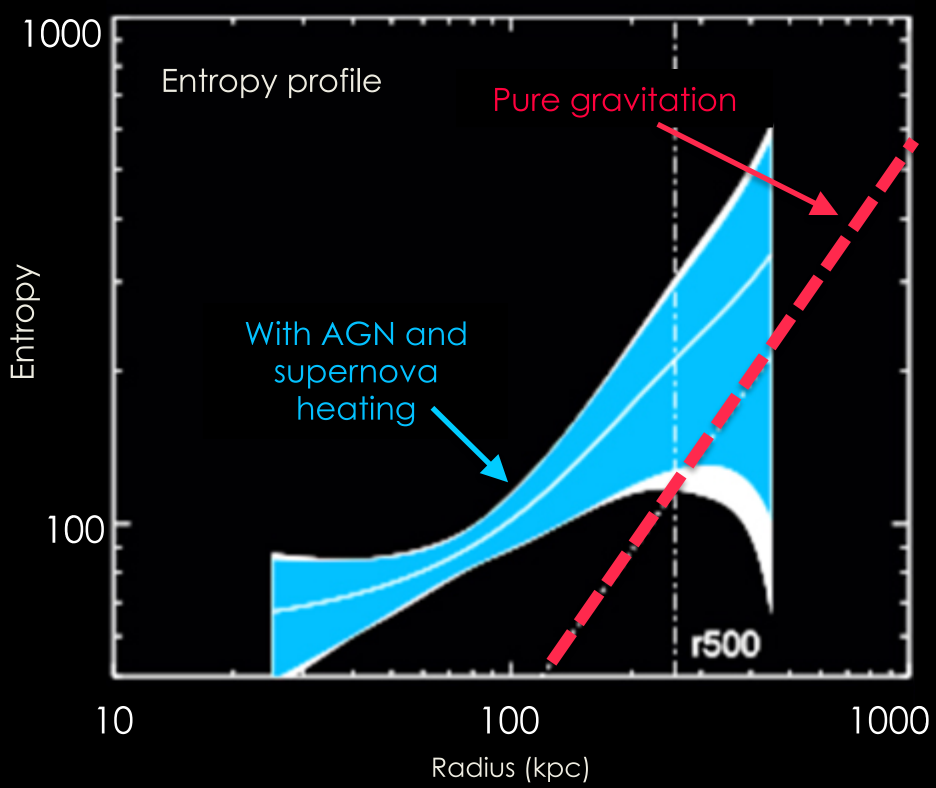
- ***From the Physics of the Universe Science Plan:***
  - **Find and study distant clusters of galaxies to measure the rate of growth of structure in the universe using IXO and microwave background observations**

The formation and evolution of clusters and groups of galaxies

- How and when was the energy contained in the hot intra-cluster medium generated?



Pointecouteau, Reiprich et al., 2013 arXiv1306.2319



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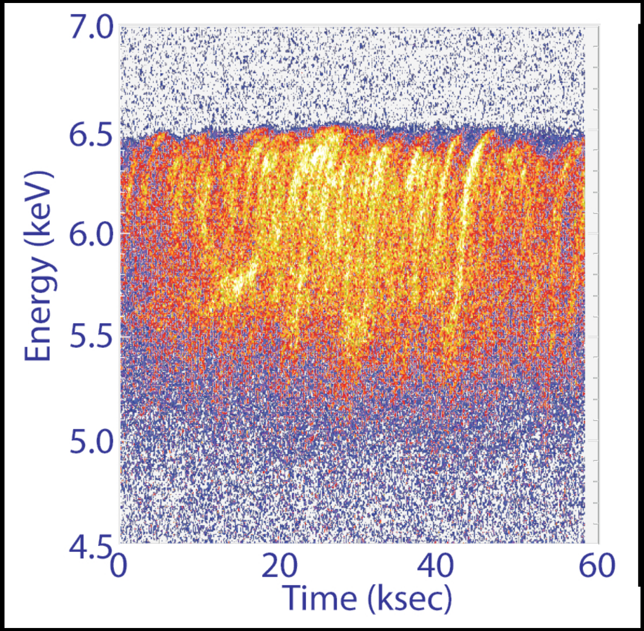
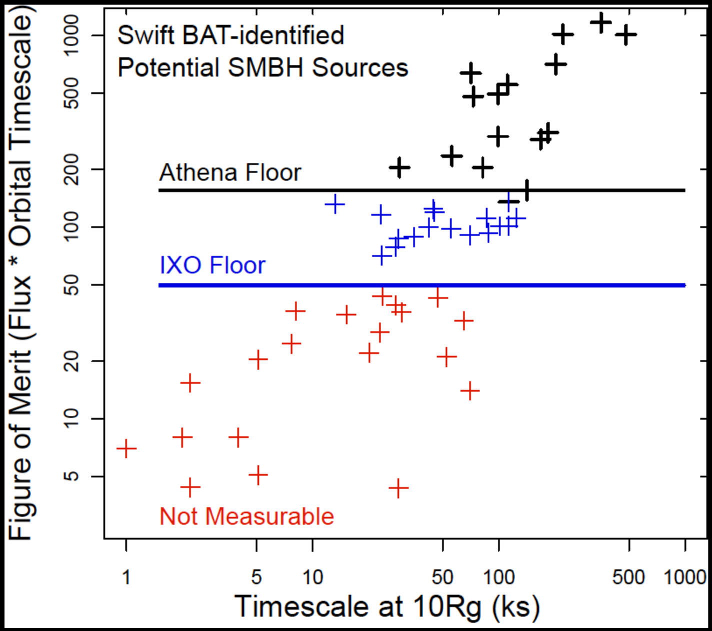
  - **Observe X-rays from gas orbiting close to the event horizon of black holes using IXO…**

Probing GR using high resolution X-ray spectroscopy

- IXO was to probe GR by tracking the temporal/spectral behavior of Fe blobs as they orbit close to the black hole for about 30 AGN
  - Athena's smaller area at 6 keV (~1/3 of IXO) means this can be done for fewer objects
- Athena will measure the spin of ~100 supermassive black holes
  - Athena lacks band pass above 15 keV that allows accurate reflection hump characterization

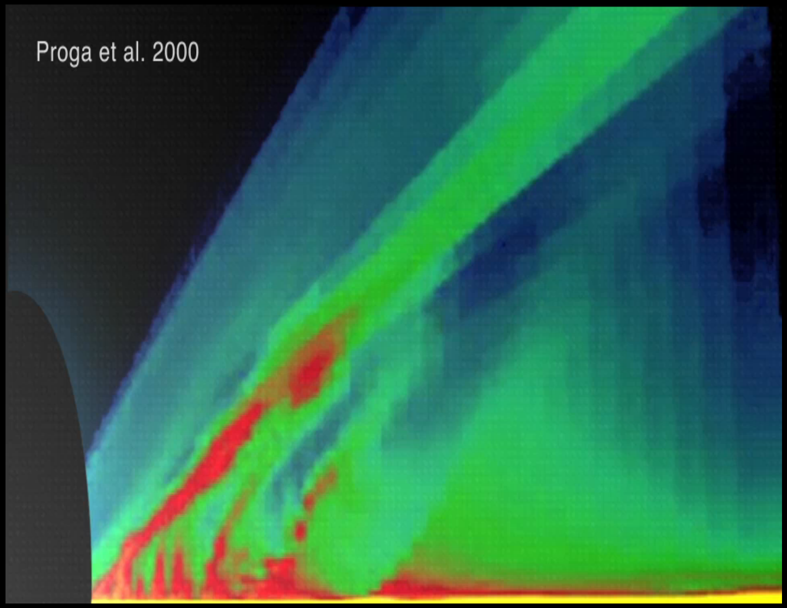


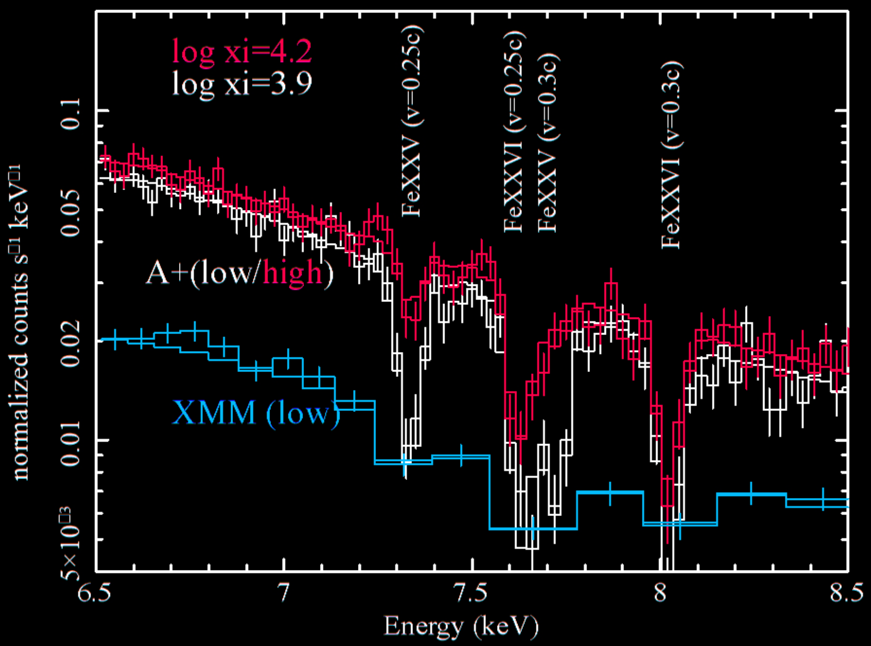


Observe X-rays from gas orbiting close to the event horizon of black holes using **IXO**…

The origin of black hole winds

- Athena does address the current topical questions:
  - How do black holes launch winds and outflows?
  - How much energy do they carry out to larger scales?





Cappi, Done et al., 2013 arXiv1306.2330
Dovciak, Matt et al., 2013 arXiv1306.2331

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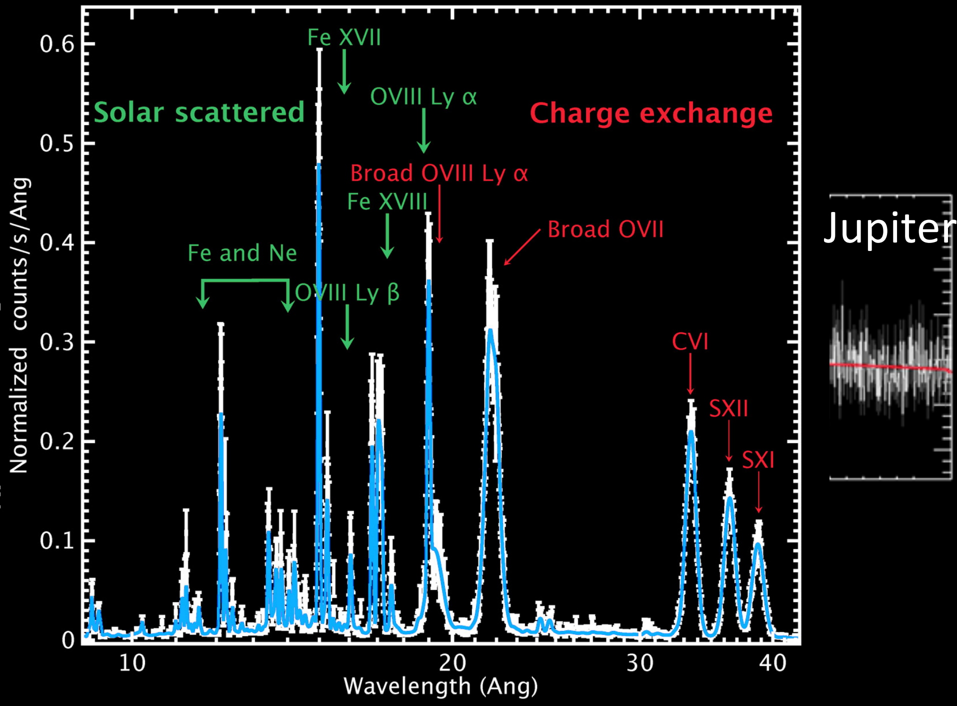
- ***From the New Worlds Science Plan:***
  - **Assess habitability by using IXO to characterize the frequency and intensity of flares on host stars**

Athena: observatory science

- Planets
  - (interaction of solar wind with planet environment and com
- Exoplanets
- Stellar physics
- Supernovae
  - (explosion mechanism, heavy element production)
- Stellar endpoints
  - (physics of outflows and winds in X-ray binaries)
- Sgr A*
- Interstellar dust and medium



Branduardi-Raymont, Sciortino, et al., 2013 arXiv 1306.2332; Sciortino, Rauw et al., 2013 arXiv1306.2333; Motch, Wilms, et al., 2013 arXiv1306.2334; Decourchelle, Costantini et al., 2013 arXiv1306.2335

Assess habitability by using **IXO** to characterize the frequency and intensity of flares on host stars

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- *From the New Worlds Science Plan:*
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Athena Cost Estimate

- Total ESA cost is capped at €1B
  - Includes spacecraft, launch vehicle, reserves, and operations
  - Initial ESA cost estimate requires a reduction of mirror area at 1 keV from 2 m^2 to 1.4 m^2 to remain under the cap
  - Industry studies underway will provide configurations and estimates for both mirror sizes
- Member state consortia provide the focal plane instruments
  - Total cost estimated to be €300M-€400M
- Non-ESA contributions are typically up to ~20 percent of the mission cost
  - Nominal ceiling of ~€220M

Athena mission timeline

- **Phase A: 2015-2017**
  - Phase A1 industry study kickoffs (parallel contracts) – August 2015
  - Mission Concept Review (MCR) data package (2 configurations) - March 2016
  - MCR completed - May 2016
    - **Agreements for non-ESA contributions in place**
  - Mission baseline selection - June 2016
  - Phase A2 kickoff - June 2016
  - AO for science instruments - July 2016
  - Selection of instrument consortia - November 2016
  - Preliminary Requirements Review (PRR) data package - November 2017
  - PRR completed (end phase A) - December 2017
- **Phase B1: 2018-2019**
  - Technology developments (mirror, detectors) at TRL > 5-6 - 2019
  - System Requirements Review - End 2019
  - Mission adoption by the ESA Science Program Committee - Feb 2020
- **Phase B2/C/D kickoff - Nov 2020**
- **Launch - 2028**

Identifying potential NASA contributions

- In December 2013, immediately after ESA selection of the "Hot and Energetic Universe" theme for L2, NASA and the US X-ray astronomy community engaged in a process to identify potential NASA contributions to Athena
- The X-ray SIG produced a white paper drawn from a broad range of community inputs to identify a number of potential contributions
- The PCOS program office assessed the suggestions white paper for cost, risk and science value and presented the result to NASA HQ.
- NASA placed a premium on potential contribution that would enhance the mission science return
- Based on the input, NASA selected a short list of potential contributions that it has subsequently pursued

Potential NASA contributions and rationale

- A contribution to the X-IFU (sensor and front end assembly)
  - Unique microcalorimeter capabilities and experience within the US
- A contribution to the mirror (rings of inner modules)
  - Complementary technology development of slumped glass optics that is at least on par with the silicon pore optics, and has already solved problems facing the silicon pore optics at small radii
- A contribution to the WFI (event recognition hardware and software)
  - Extensive expertise in the US with event recognition and processing in solid state X-ray imagers
- Participation in the Athena Science Ground System
  - Anticipated to be a mirror site of the ESA Athena data center
- Use of US calibration & test facilities
  - Facilities like XRCF are unique

Status of potential NASA contributions

- NASA has a representative on the Athena Science Study Team
- Participation in the X-IFU has been agreed
  - NASA will provide sensor array, calorimeter systems expertise through a GSFC/Stanford/NIST collaboration
- Discussion underway about a possible contribution to the WFI
- ESA is currently not interested in a contribution to the mirror
  - This could change, depending on mirror technology development progress
- NASA contribution to calibration being studied (e.g., XRCF)
- Science ground system concept still under formulation
  - NASA envisions having an XMM-like mirror site, so there is no need to start development until much closer to launch
  - There is a possibility of an expanded NASA role

Opportunities for US astrophysics community participation in Athena

- The US ASST representative was selected by NASA through an open solicitation
  - Over 20 applications were received
- NASA will negotiate for representation on the SWG that replaces the ASST after adoption
- NASA held a solicitation to select US representatives on the ASST science panels
  - Panels help formulate and develop mission science objectives and study science implementation questions (e.g., calibration, background)
  - 24 of ~80 applicants selected: receive funding support for science panel meetings
  - Remainder were invited to join panels, but must provide own travel funding
  - Panel membership remains open to all (currently inviting applications for new members)
  - Panel members receive no data rights
- Potential instrument participation was identified through a NASA RFI
  - One viable response was received for each instrument
- Anticipate a NASA call for a small number of US scientists to be science co-I's on instrument(s)
  - Call would probably come close to mission adoption (2020)

Access to Athena data by US astrophysics community

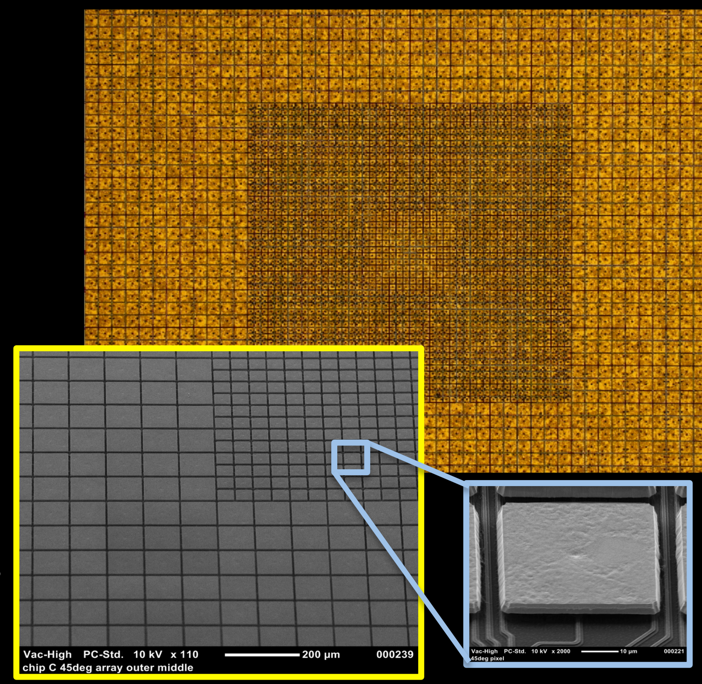
- Instrument team scientists will have access to GTO data
  - US scientist share of GTO data depends on fractional instrument cost borne by NASA
  - ESA Athena Science Management Plan (in development) will define GTO time fraction
- If NASA contributes to the observatory, it is possible that a separate share of GTO time could be made available to NASA
- US scientists will have open opportunity to propose for GO data
  - Expect a similar arrangement to XMM-Newton: no formal quota, but US GO's typically are awarded a minimum of 30 percent of the observing time

Questions from committee

- 1.) Please describe the status of Athena and NASA support in the context of the recommendations of NWNH.
- Athena Status
  - Athena has been selected as the L2 mission for launch in 2028
  - Currently in ESA Phase A1
  - Science requirements and flowdown to instrument and mission requirements under development
  - Two industry mission studies have been started (Airbus and Thales Alenia)
  - Instrument proto-teams have been formed
  - Mission concept review will take place in Spring 2016
- NASA support
  - NWNH recommended $200M over the decade for IXO technology development ($4M in first few years, $20-30M later)
  - Total NASA funding for Athena-related technology development though the SAT program for 2012-2015 has been $12.5M

Questions from committee -2

- 2.) We understand that NASA has budgeted $100M - $150M for a hardware contribution to Athena, plus a U.S. GO program and a U.S. data center. How does the level of U.S. participation affect the design/performance of Athena and access to Athena data by U.S. scientists?
  - Instrument design/performance:
    - X-IFU: The sensor arrays available from the US provides for a composite focal plane design. They might also make possible a larger field of view.
    - WFI: The proposed US contribution would allow for sophisticated onboard event processing to identify flaring sources and anomalous background intervals.
  - Access to data (explained in previous slides)
    - GTO data become available to instrument teams.
    - NASA participation would likely result in US scientists being awarded observation time meeting or exceeding some agreed minimum (XMM model).



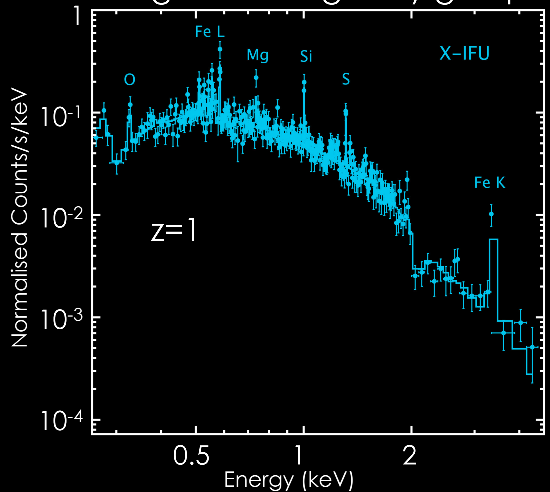
Summary

- ESA has selected Athena as its L2 cosmic visions mission for a 2028 launch
- Athena will fulfill most of the IXO science objectives
- The total ESA mission cost is capped at ~1 B€
    - Member states provide instruments and Science Ground Segment
- NASA has set aside up to $150M for hardware contributions (also ~$30M JAXA contribution)
    - Data center contribution is separate
    - Acceptable hardware contributions must be viewed by NASA as "mission enhancing"
- Potential contributions have been identified; only X-IFU has been agreed
- ESA wants agreement about external contributions by mid-2016
- Numerous opportunities exist for participation in Athena for US scientists

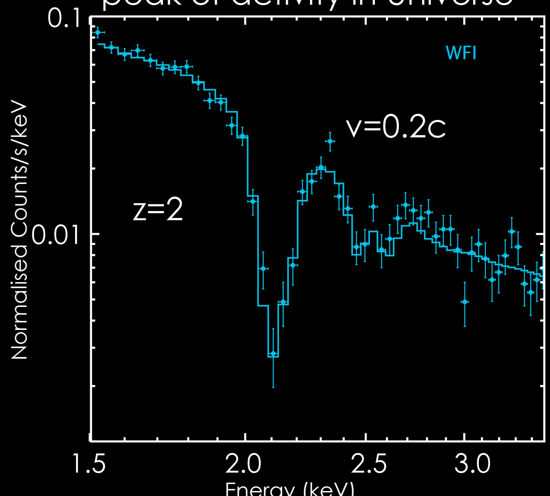
ATHENA

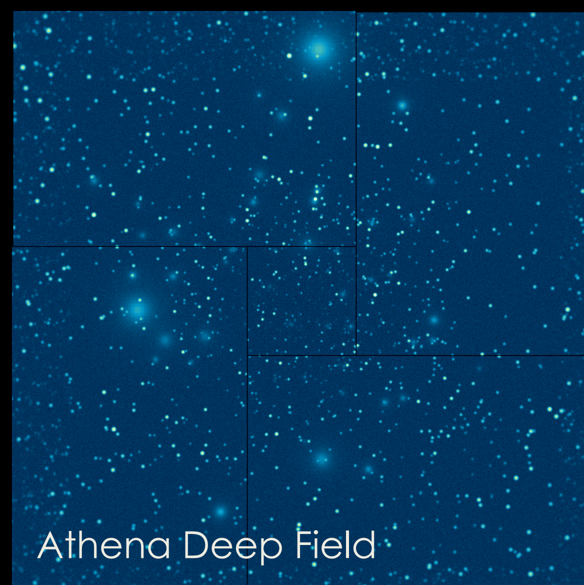
Athena
The first Deep Universe X-ray Observatory

High redshift galaxy group



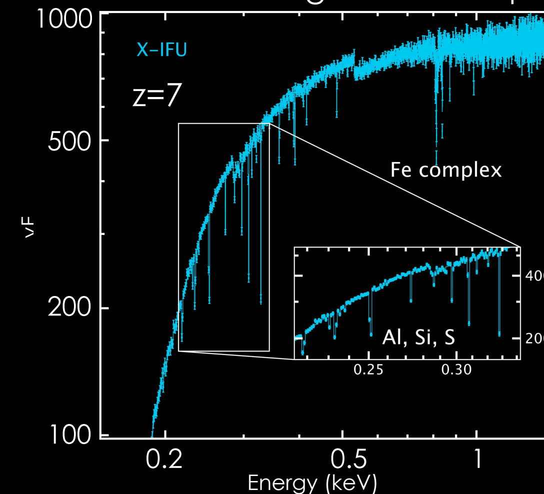
Black hole feedback at
peak of activity in Universe



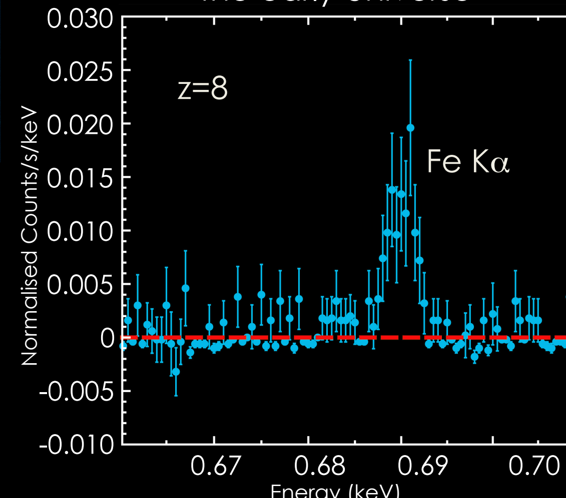


Nandra, Barret, Barcons, Fabian,
den Herder, Piro, Watson et al.
2013 arXiv 1306.2307

Primordial stellar populations
via GRB afterglow follow up



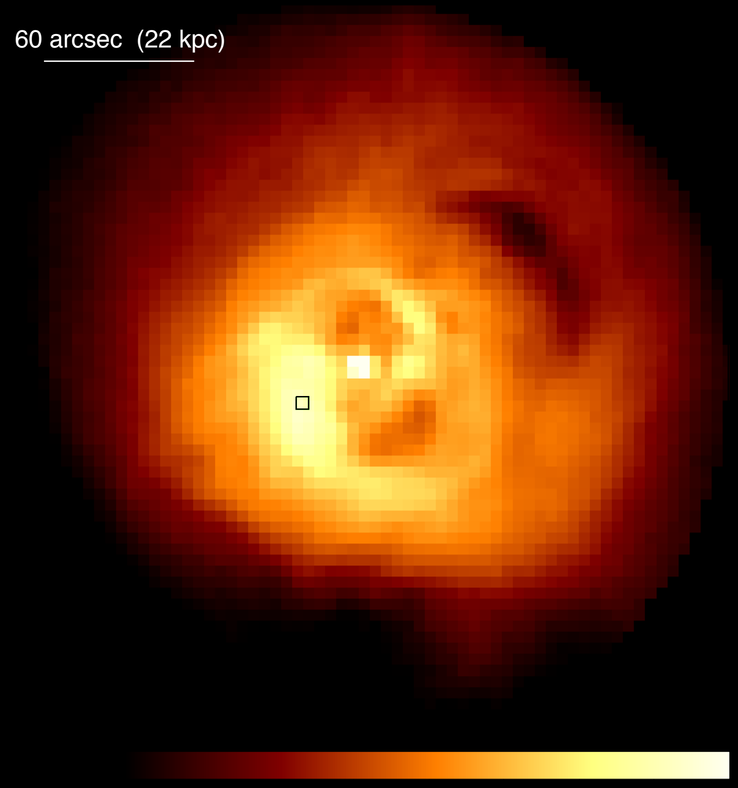
Obscured black hole in
the early Universe

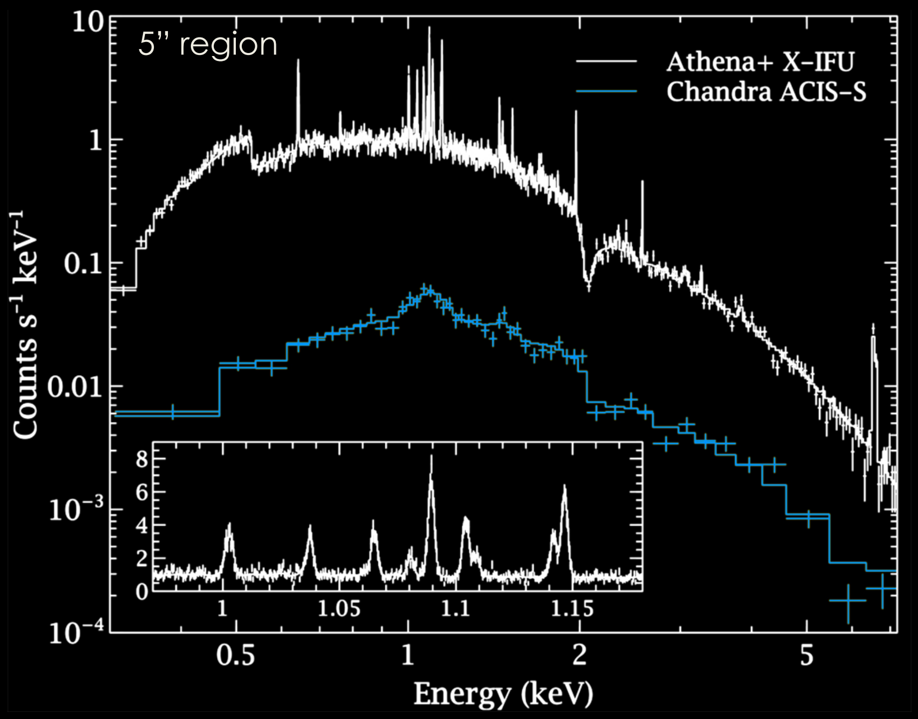


Backup slides

Cosmic feedback: the impact on galaxy cluster scales

- How do jets from Active Galactic Nuclei dissipate their mechanical energy in the hot intracluster medium, and how does this regulate gas cooling and black hole fuelling?





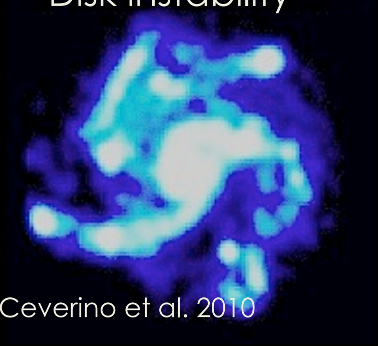
Croston, Sanders et al., 2013 arXiv1306.2323

Use GSMT and **IXO** to monitor the exchange of gas between the galaxies and the surrounding intergalactic medium

Cosmic feedback: black hole and galaxy co-evolution

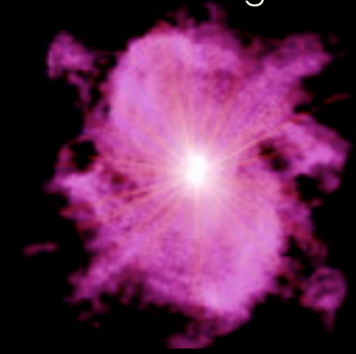
- How much black hole accretion occurs in the most obscured environments? How does this relate to the evolution of the host galaxy?

Disk instability

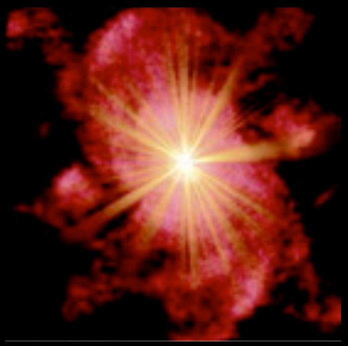


Ceverino et al. 2010

Obscured BH growth

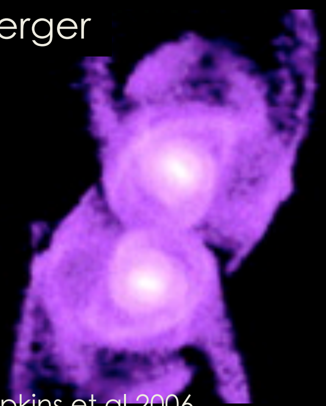


Feedback phase

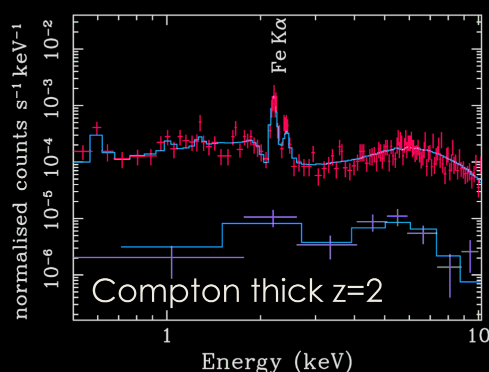


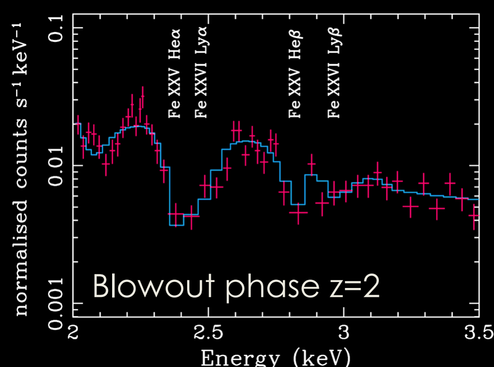
Quiescent remnant

Merger



Hopkins et al.2006





Georgakakis, Carrera et al., 2013 arXiv1306.2328

Study the rate of formation and growth of black holes in the nuclei of young galaxies using **IXO** and WFIRST

Athena+ science in context

Athena+ is a crucial part of the suite of large observatories needed to reach the science objectives of astronomy in the coming decades

X-ray SIG input on Potential US contributions

- X-IFU
  - Option 1: Entire instrument, including dewar, cryocooler and front end electronics
  - Option 2: Insert (focal plane assembly (FPA) , cold electronics, ADRs), front end and ADR control electronics, aperture assembly with blocking filters & readout electronics (Astro-H model)
  - Option 3: FPA or FPA components, cold electronics, aperture assembly or components

- X-ray Mirror
  - Option 1: Part of the mirror (inner modules or outer modules). ESA could provide mandrels
  - Option 2: Glass segments. ESA performs integration. ESA could provide mandrels.

- Grating Spectrometer
  - Option 1: Entire instrument (grating unit and focal plane camera)
  - Option 2: Grating array; member state supplies focal plane camera

- Hard X-ray Telescope
  - Option 1: A complete, stand-alone system as an "outrigger" with optics, structures, and detectors
  - Option 2: Optics and detectors for centrally-mounted system, ESA integrates

X-ray SIG input on Potential US contributions

- Wide Field Imager
  Contributions to event processing electronics and software
- Ground Calibration
  Optics and/or end-to-end calibration at the XRCF
- Moveable Instrument Platform
- Blocking Filters
  Provide for the Calorimeter and/or the WFI
- In-flight Calibration Sources
  Modulated X-ray sources for the Calorimeter and/or the WFI
- Telescope Alignment Monitor/Fiducial Light System
- Science Analysis Software
  Provide the analysis codes linked to atomic physics data - necessary to interpret the high resolution X-ray data (note that this would have significant leverage if it could be combined with a similar effort for Astro-H)
- X-ray Polarimeter Instrument

Potential NASA contributions – ESA view

- Two separate, independent assessments were made in Europe of possible NASA contributions: Science Study Team (ASST) and Project Team
- The SST list was based on the X-ray SIG list
  - Optics core portion (support structure and thermal control)
  - Instrument switching mechanism (Chandra heritage noted)
  - Support to calibration activities (XRCF)
- The ESA Athena team assessment of potential NASA (and JAXA) contributions is summarized in an official ESA document "ATHENA – Possibilities for International Collaboration"
  - Mirror components (hexapod mechanism, structure, modules, thermal control system, singly or in combination)
    - NASA delivery of mirror structure and interior segments called "most promising" option
  - Star tracker assembly
  - Optical metrology system
  - Focal plane module
  - Science Ground Segment support