Probing the Hot and Energetic Universe: X-rays and Astrophysics

Physics of the Cosmos mini-symposium
X-ray Science Interest Group

Meeting of the American Physical Society
Washington, DC

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The X-ray Universe

Present

Future

XARM (?)

A giant cosmic particle accelerator – a multi-wavelength study of the merging galaxy clusters Abell 3411/3412 (van Weeren+2017, Nature)

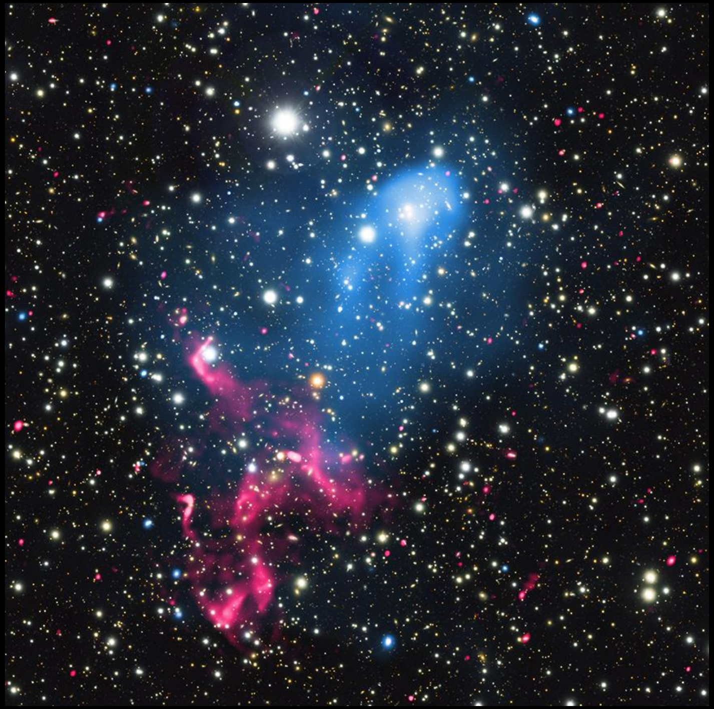
- Cluster radio relics – ultra-relativistic electron plasma in galaxy clusters

- At least two possible origins:
  - Turbulent acceleration from thermal pool
  - Re-acceleration of radio jet plasma

- Key outstanding issue in our understanding of formation of structure.

- Multi-wavelength study of Abell 3411 has resolved this issue

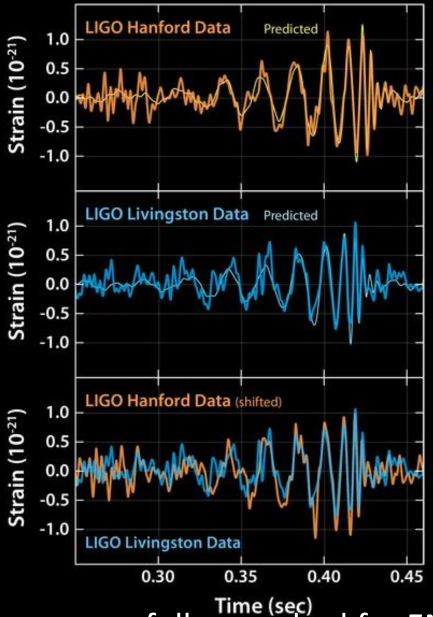
- Merger shocks seen overrunning plasma tail of infalling radio galaxy → relics must originate in re-acceleration of aged radio plasma



Blue – X-ray (Chandra), Red – Radio (GMRT), White – Optical (Subaru)

X-ray Follow-up of Gravitational Wave Sources

- ALIGO detections[*] of BH-BH mergers GW150914 and GW151226 have energized the physics/astrophysics communities!
- Electromagnetic follow-up can provide a wealth of information about compact object mergers:
  - sGRB have short (2 s) burst of high energy emission and longer panchromatic afterglow[†]
  - Combination of GW and EM signals provide mass, distance, inclination, luminosity, redshift, and duration constrain energetics and (potentially) cosmology

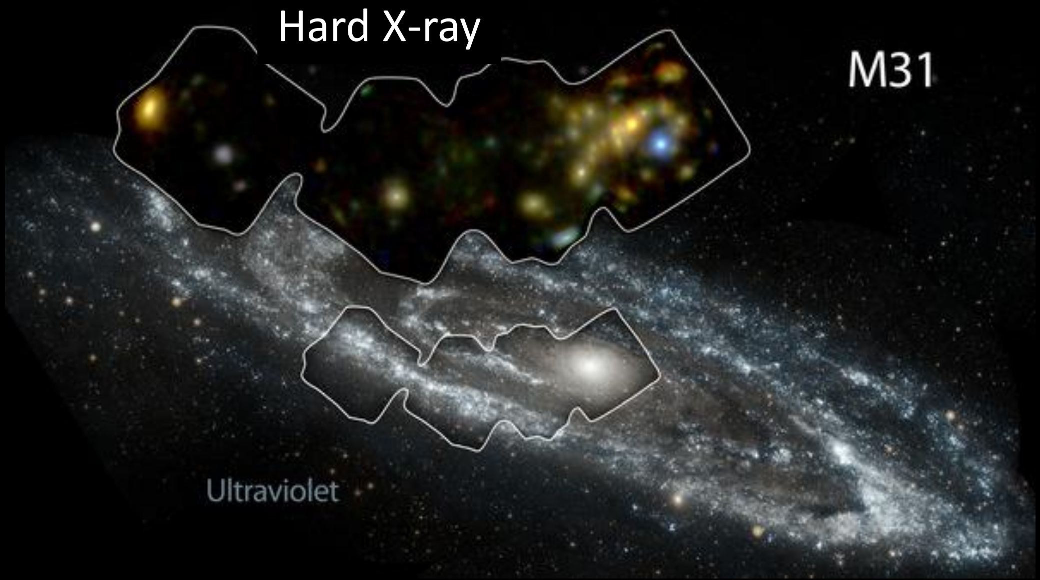


SWIFT unsuccessfully searched for EM counterpart to GW150914 event[‡]
Fermi GBM reported event within 0.4s of GW150914[§]

Future X-ray mission concepts are being developed with optimized follow-up capabilities

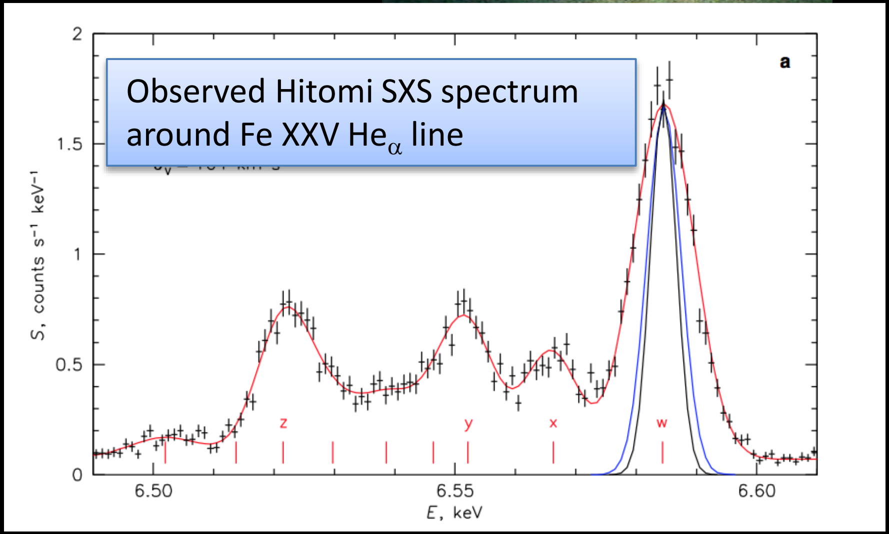
[*]Abbott + (2016); [†]Metzger & Berger (2012);
[‡]Evans+ (2016)l; [§]Connaughton+ (2016)

Nuclear Spectroscopic Telescope Array (NuSTAR)



- NuSTAR mosaic of nearest large spiral galaxy M31 (Wik+2016, Maccarone+2016)
    - Excess of sources in M31 over Milky Way after scaling for stellar mass and star formation rate
    - Two GC X-ray sources believed to be BH primaries are more likely to be neutron stars

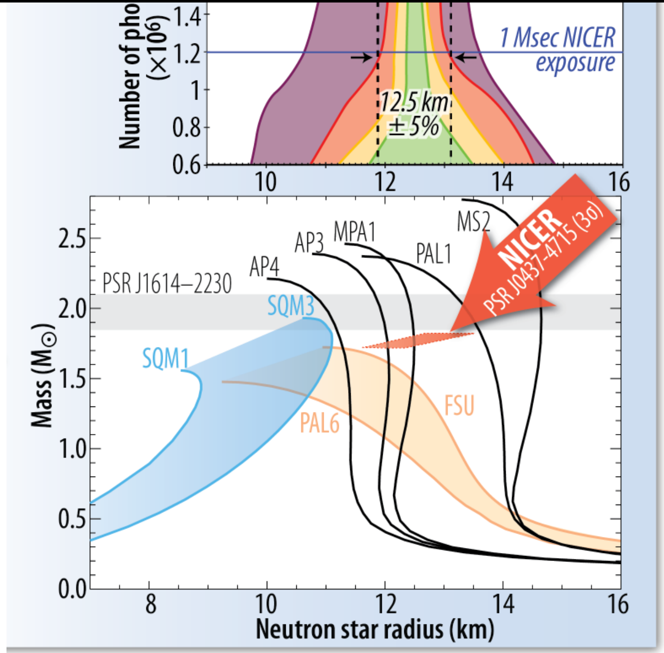
Hitomi Observations of Perseus Cluster



- Nearby massive cool core cluster
- Observed with Hitomi SXS through Be filter (Hitomi Collaboration+2016, Nature)
- Calorimeter resolution ~4.8 eV (CCD resolution 120 eV)
- First direct measuremnt of plasma motions: d 164 ±10 km s^{-1} line width -> turbulent pressure ~4% of thermal pressure
- Need aggressive lab astrophysics program to interpret data from future instruments!

NICER: Neutron Star Interiors from the International Space Station

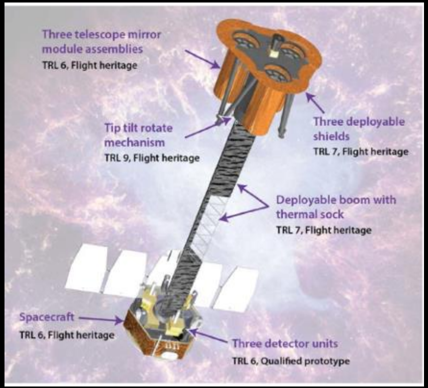
- **NICER will determine precise (5%) radii of msec pulsars from spectrally-resolved X-ray pulse profiles (4 objects)**
- **Radii + (known) masses yield powerful constraints on EOS of ultra-dense matter in neutron star interiors**
- **NICER launch to International Space Station expected in April 2017**



Simulations show the assumed radius is recovered to ±5% with ~10^6 photons

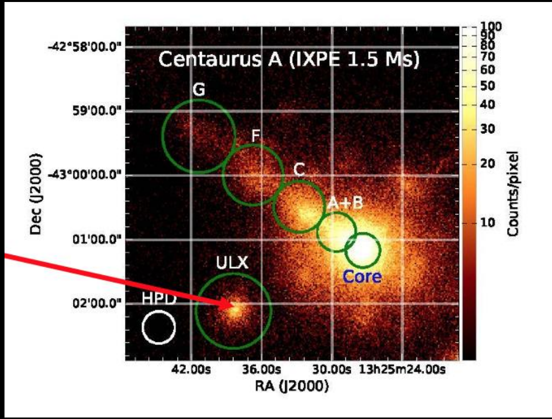
IXPE: Imaging X-ray Polarimetry Experiment

- Small Explorer (SMEX) just funded
- 3 Gas Pixel Detectors behind 3 X-ray telescopes
- 100 times more sensitive than OSO-8
- PI: M. Weisskopf (MSFC)
- 2 year baseline mission



Key Science Objectives

•Measure black hole spin
•Determine geometry and B-field of magnetars
•Outburst history of Sgr A*
•B-field structure of synchrotron-emitting sources
•Geometry and origin of X-ray emission from pulsars (isolated and accreting)



X-ray Astronomy Recovery Mission

- **JAXA has proposed an X-ray Astronomy Recovery Mission (XARM) to recover the science lost with Hitomi**
  - JAXA has invited NASA's participation as a key partner in XARM
  - JAXA target launch : March 2021
- **XARM recommended by NASA Astrophysics Subcommittee, NASA Science Committee, and NASA Advisory Council**
  - NASA developing plan for funding NASA contribution from existing budget with minimal impact to other planned activities
- **NASA and JAXA are developing a notional joint implementation plan for NASA participation in XARM**

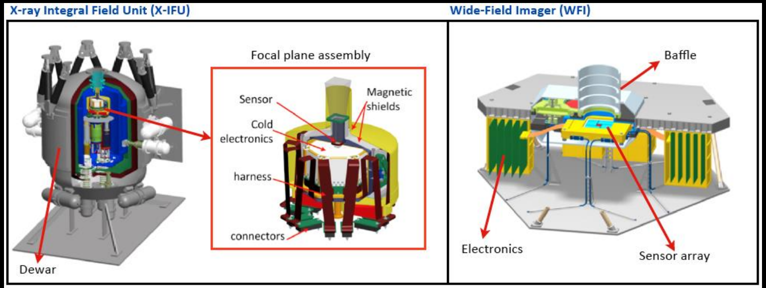
Athena (Astrophysics of the Hot and Energetic Universe)

- ESA L class mission with substantial international contributions
- Primary science themes:
    - How does ordinary matter assemble into the structures that we see today?
    - How do black holes form and grow?
- Launch date: 2028
- http://www.the-athena-x-ray-observatory.eu

Science instruments:

X-ray Integral Field Unit (XIFU) microcalorimeter

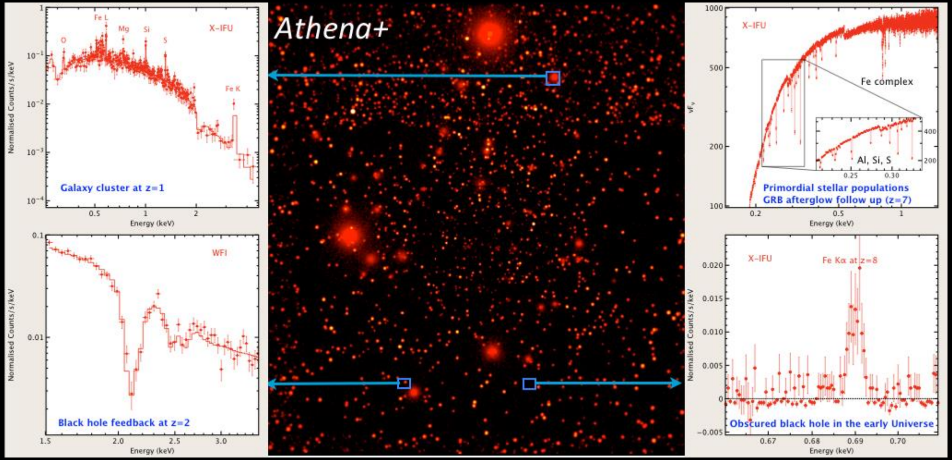
Wide-Field Imager



Key Parameters of Athena Mission

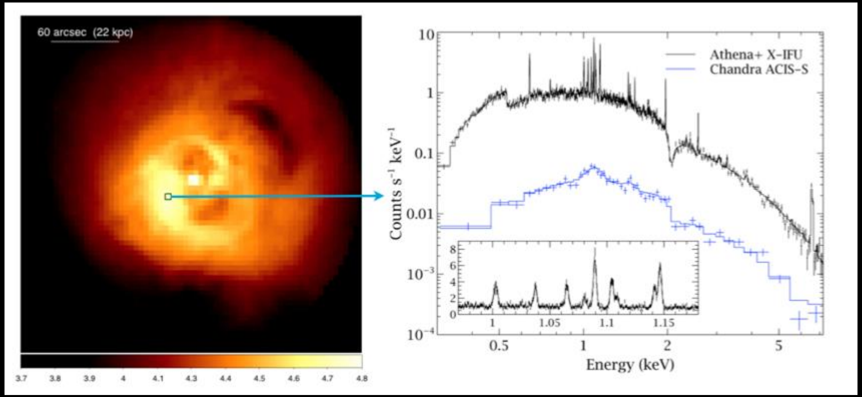
Parameter	Requirements	Enabling technology/comments
Effective Area	$2\ m^2$ @ 1 keV (goal $2.5\ m^2$) $0.25\ m^2$ @ 6 keV (goal $0.3\ m^2$)	Silicon Pore Optics developed by ESA. Single telescope: 3 m outer diameter, 12 m fixed focal length.
Angular Resolution	5” (goal 3”) on-axis 10” at 25’ radius	*Detailed analysis of error budget confirms that a performance of 5” HEW is feasible.*
Energy Range	0.3-12 keV	Grazing incidence optics & detectors.
Instrument Field of View	*Wide-Field Imager:* (WFI): 40’ (goal 50’)	Large area DEPFET Active Pixel Sensors.
	X-ray Integral Field Unit: (X-IFU): 5’ (goal 7’)	Large array of multiplexed Transition Edge Sensors (TES) with 250 micron pixels.
Spectral Resolution	WFI: <150 eV @ 6 keV	Large area DEPFET Active Pixel Sensors.
	X-IFU: 2.5 eV @ 6 keV (goal 1.5 eV @ 1 keV)	*Inner array (10”x10”) optimized for goal resolution at low energy (50 micron pixels).*
Count Rate Capability	> 1 Crab[3] (WFI)	*Central chip for high count rates without pile-up and with micro-second time resolution.*
	10 mCrab, point source (X-IFU) 1 Crab (30% throughput)	*Filters and beam diffuser enable higher count rate capability with reduced spectral resolution.*
TOO Response	4 hours (goal 2 hours) for 50% of time	*Slew times <2 hours feasible; total response time dependent on ground system issues.*

Key Athena Science



Euclid/LSST/will constrain how dark matter structures assemble.

X-ray observations are required to understand the evolution of the baryons (Nandra+2013)

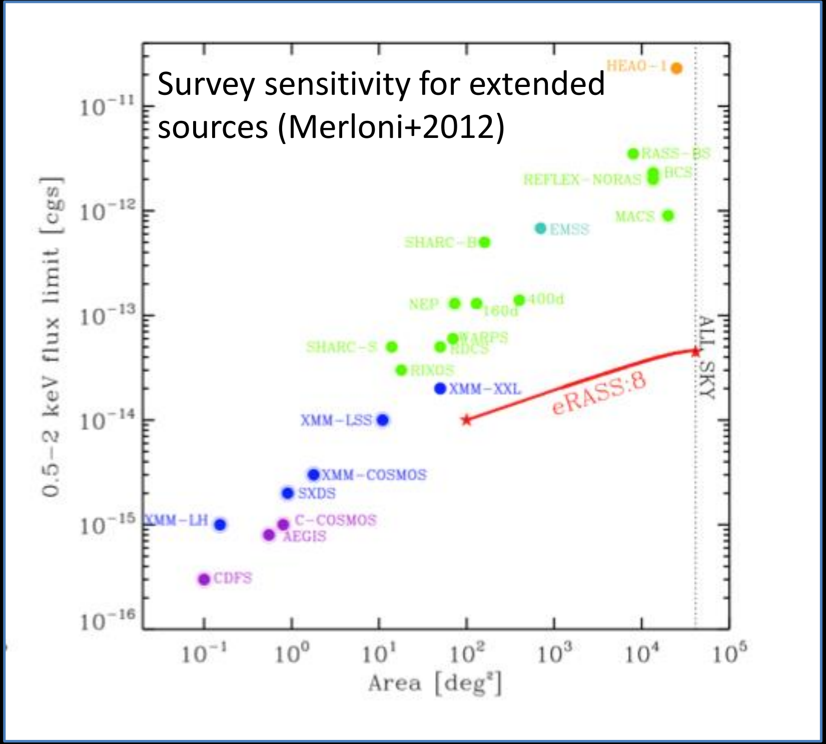


Simulated XIFU spectrum of a small region of the Perseus cluster.

Chandra ACIS-S spectrum (blue) shown for comparison.

extended Roentgen Survey with an Imaging Telescope Array (eRosita)

- X-ray instrument on Russian Spectrum Roengten Gamma (SRG) mission
- First imaging all sky survey up to 10 keV – unprecedented sensitivity
  - Will detect up to 100,000 clusters of galaxies, and map diffuse filaments between clusters
  - Will detect ~3E6 AGN
  - Study in unprecedented detail the Galactic X-ray source populations
- Seven Wolter-1 mirror modules and PN CCD
- Launch scheduled for March 2018



Survey sensitivity for extended sources (Merloni+2012)

Lynx – A Major Leap in Sensitivity

Lynx Mission Concept Study

- One of four large mission concepts selected by NASA HQ to be studied for 2020 NRC Decadal Survey.
- Science and technology team – A. Vikhlinin (SAO) and F. Ozal (Arizona) co-chairs
- STDT will determine science priorities and mission requirements
  - Must deliver “compelling and executable concept”
- Science case assumes that Athena achieves all of its science goals

Lynx Instrument Capabilities

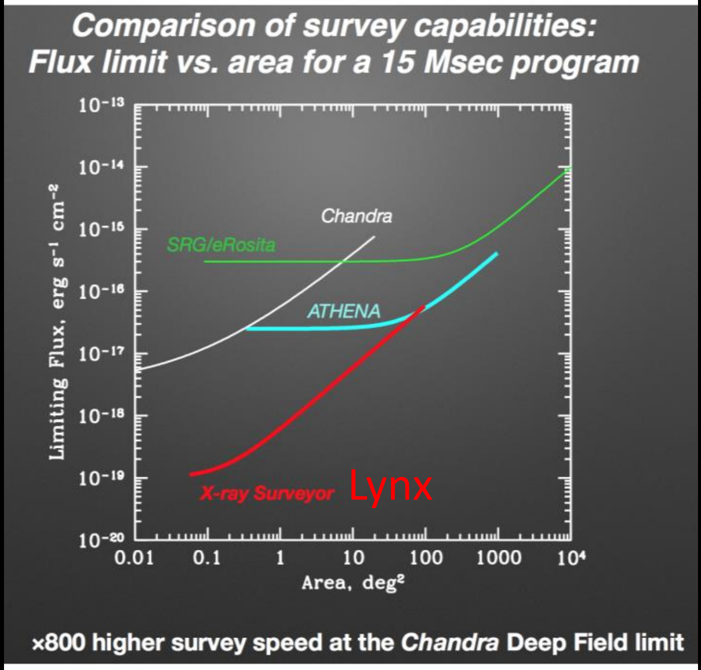
- Microcalorimeter ~ 10^5 pixels; ~ 2 eV resolution
- High Definition X-ray Imager – 22’x22’ FOV
- X-ray gratings – $E/\Delta E$ ~5000+

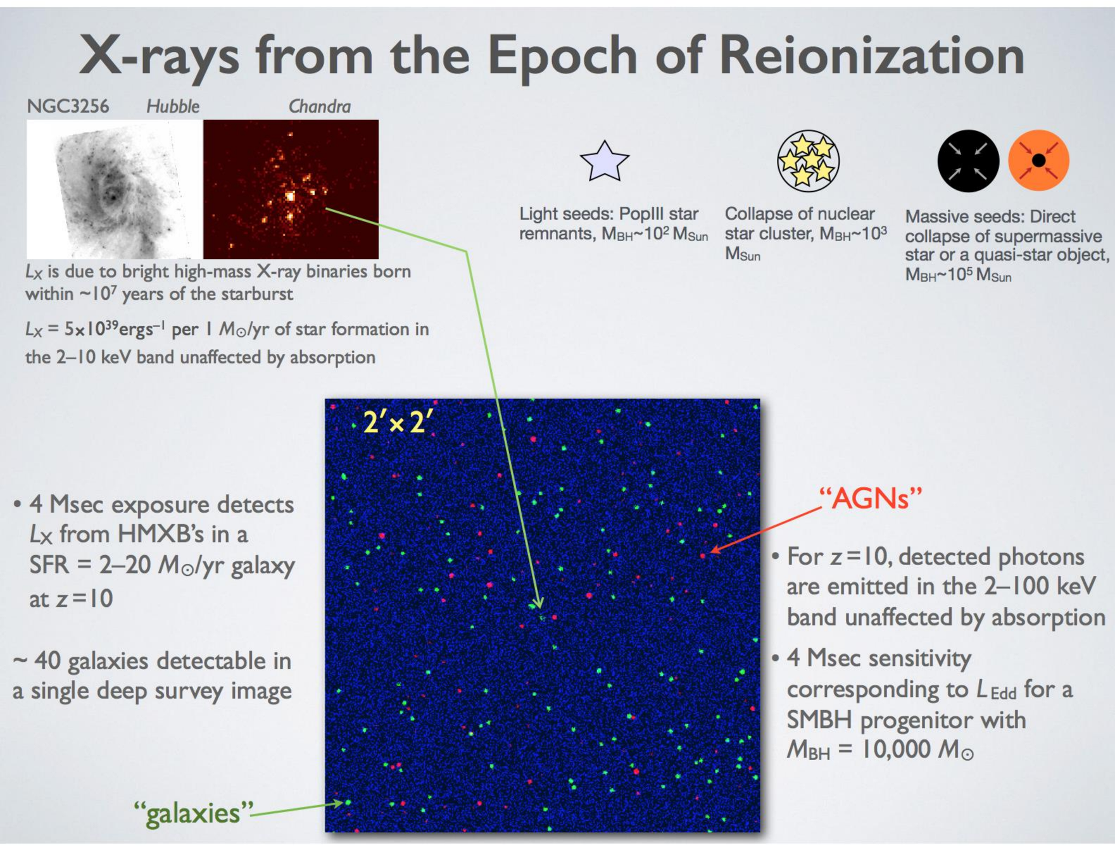
Baseline Lynx Optics Parameters

Diameter	3 m
Focal length	10 m
On axis HP diameter (1 keV)	0.5 arc sec
Design	Wolter-Schwarzshild
FOV diameter (<1 arc sec)	15 arc min
Mirror shells	~300
Mirrors (segmented design)	10,000 to 50,000
Effective area @ 1 keV (mirror only)	~2.5 m^2
Nominal bandwidth	0.1 - 10 keV

Lynx will transform our understanding of black hole formation and growth, and galaxy evolution

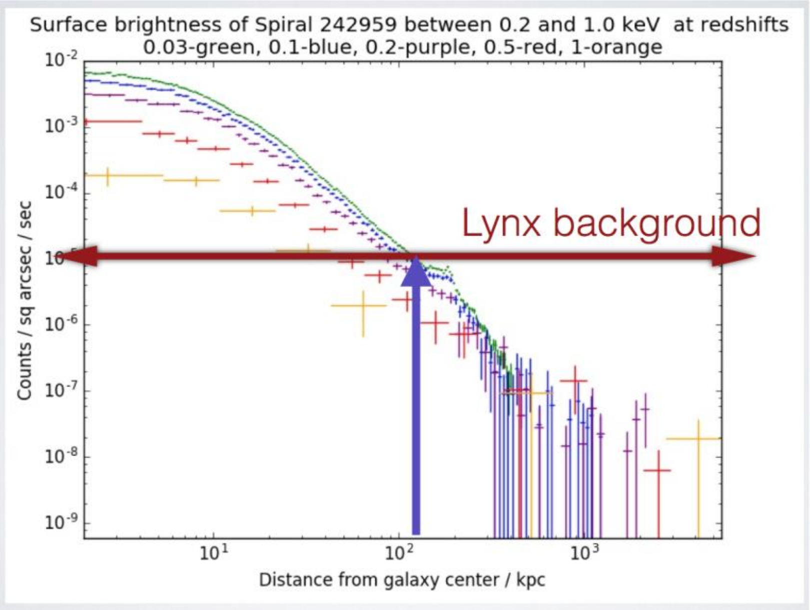
Find z ~10 seeds of first supermassive black holes

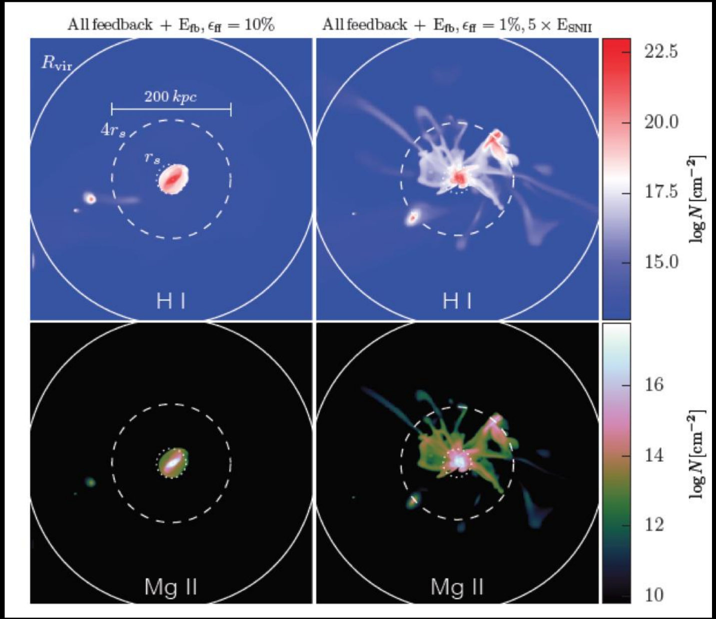




Lynx will transform our understanding of black hole formation and growth, and galaxy evolution

Understand role of hot gas in galaxy halos, where most of a galaxy's baryons are, in galaxy formation & evolution.





Perfect galaxy
Ugly CGM

Perfect CGM
Ugly Galaxy

X-ray Science Interest Group

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  - John Tomsick – jtomsick@ssl.berkeley.edu
- XRSIG website: http://pcos.gsfc.nasa.gov/sigs/xrsig.php
- Recent events:
  - AAS meeting, Grapevine, TX, Jan 3-7 2017
  - HEAD meeting, Naples, FL, Apr 3-7 2016
  - AAS meeting, Kissimmee, FL, Jan 4-8 2016
  - Special HEAD meeting on High Energy Missions, Chicago, IL, Jun 29 – Jul 1, 2015
- Next Face-to-Face Meeting
  - HEAD meeting, Sun Valley, ID, Aug 20-24 2017