The high-redshift Universe and the role of galaxies and AGN to cosmic reionization

Lecture 4

• Future X-ray facilities: eROSITA, Athena and beyond (or in between..)

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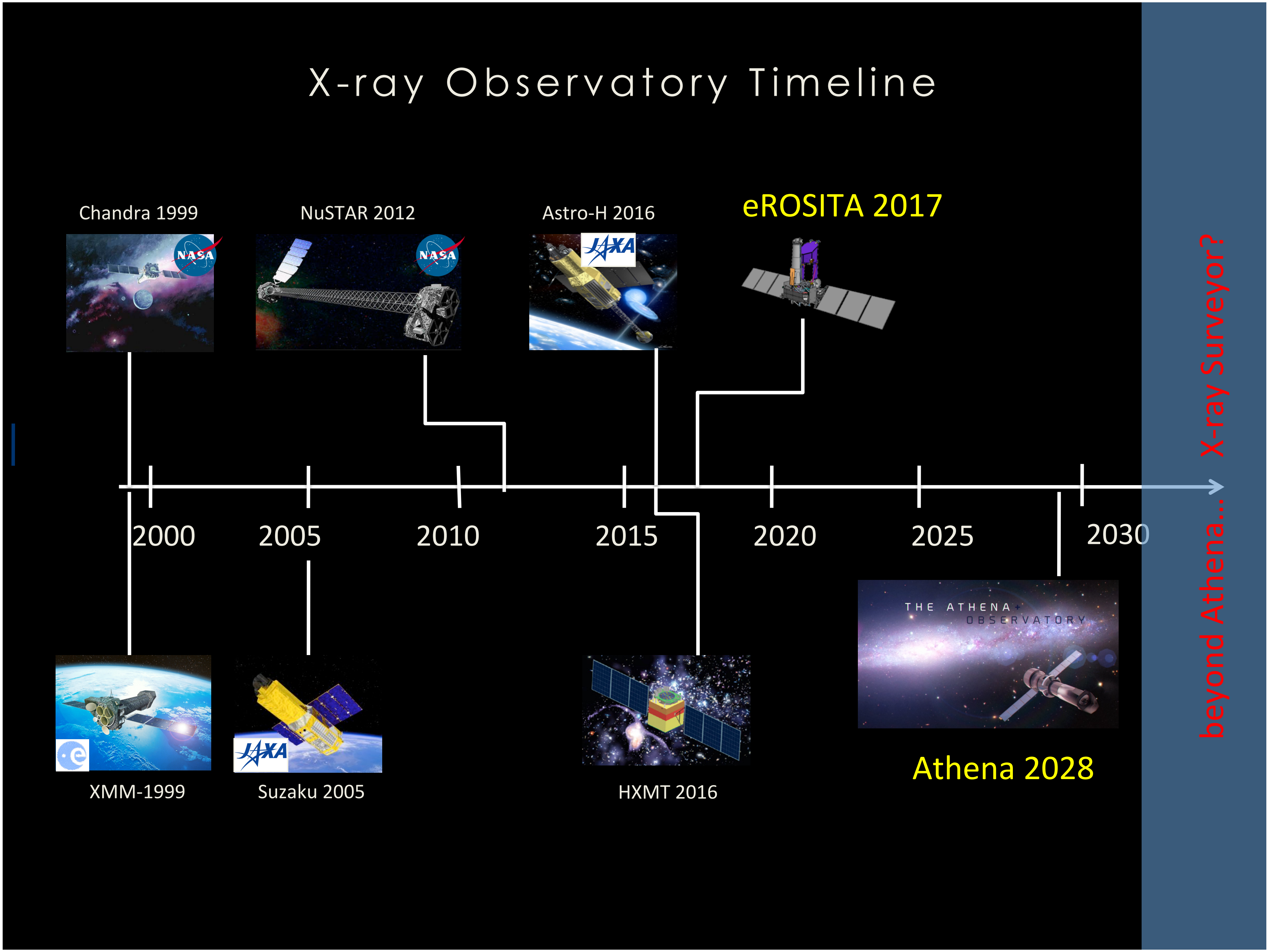
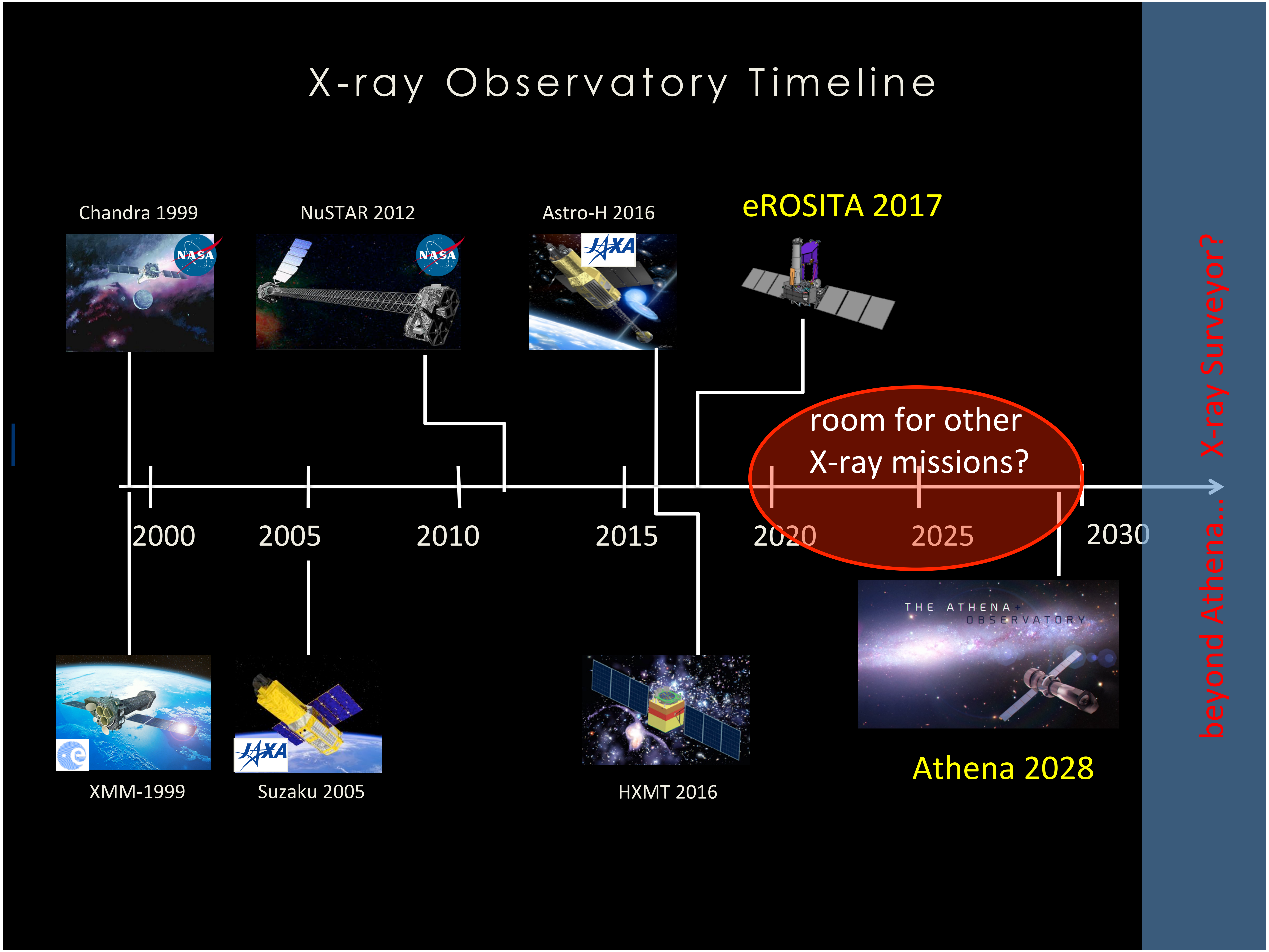
with special thanks to M. Cappi, A. Comastri and M. Brusa


X-ray Observatory Timeline
Chandra 1999
NuSTAR 2012
Astro-H 2016
eROSITA 2017
NASA
NASA
JAXA
2000
2005
2010
2015
2020
2025
2030
THE ATHENA OBSERVATORY
JAXA
XMM-1999
Suzaku 2005
HXMT 2016
Athena 2028
beyond Athena... X-ray Surveyor?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room for other
X-ray missions?
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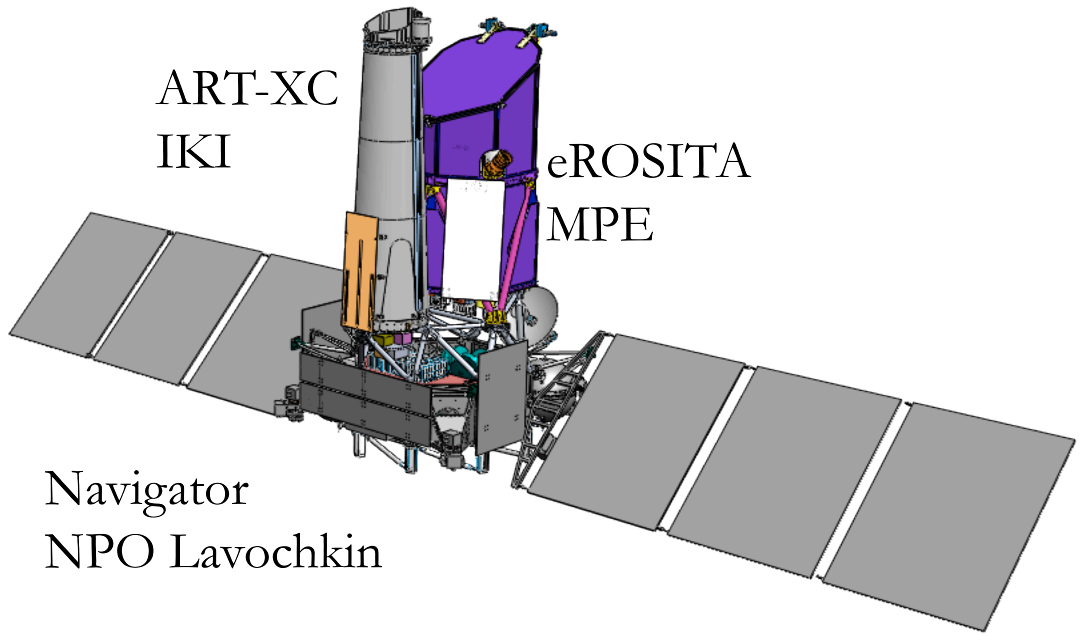
Athena 2028
beyond Athena... X-ray Surveyor?

eROSITA on Spektrum Röntgen Gamma (SRG)

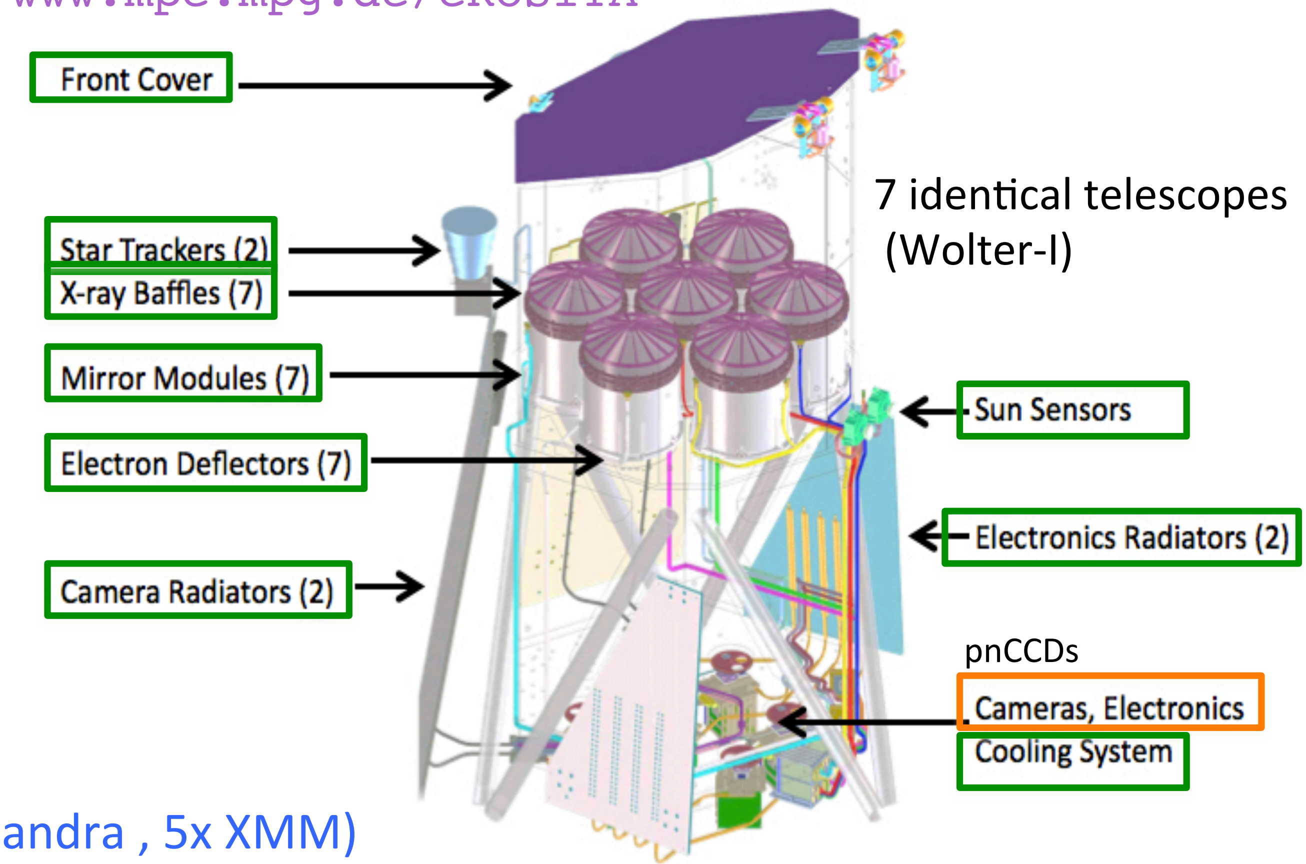
German/Russian collaboration



Launch: Spring 2017 from Baykonour

The eROSITA telescope

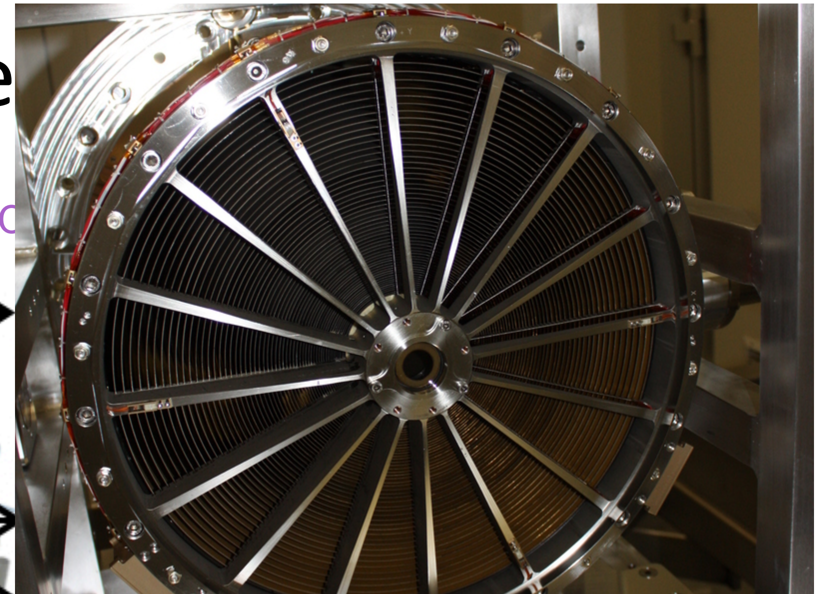
www.mpe.mpg.de/eROSITA

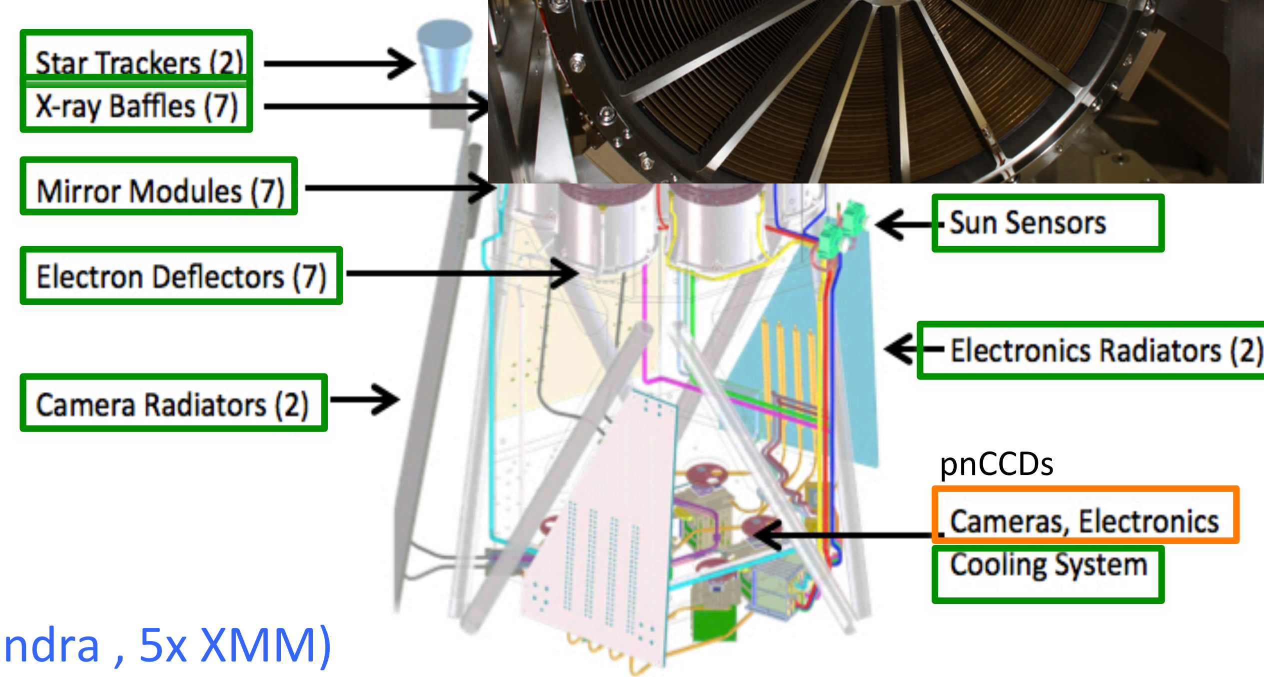


FOV = 0.81 deg^2 (10x Chandra , 5x XMM)
Energy range: 0.3-8 keV,
PSF~15-30” (Chandra ~0.5”, XMM~15”)
Effective Area: ~1400 cm^2 @1keV (~2x Chandra , ~XMM/pn)
Energy res: ΔE~140 eV @6keV (R=ΔE/E=40 as Chandra/XMM CCDs)

The eROSITA te

www.mpe.mpg.de/eRO





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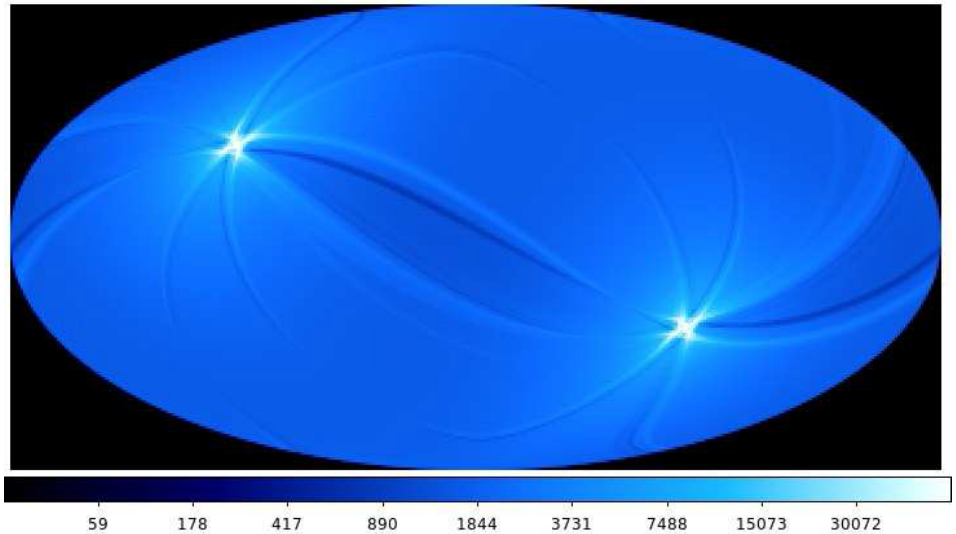
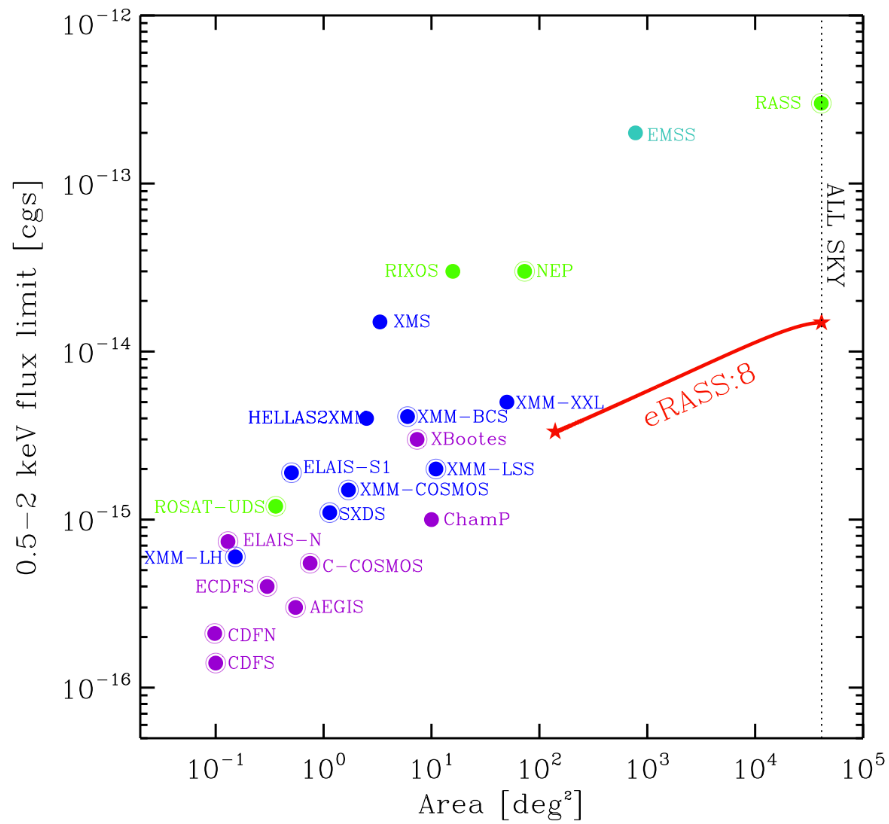
eRASS:8 - the eROSITA all-sky survey

All-sky exposure map





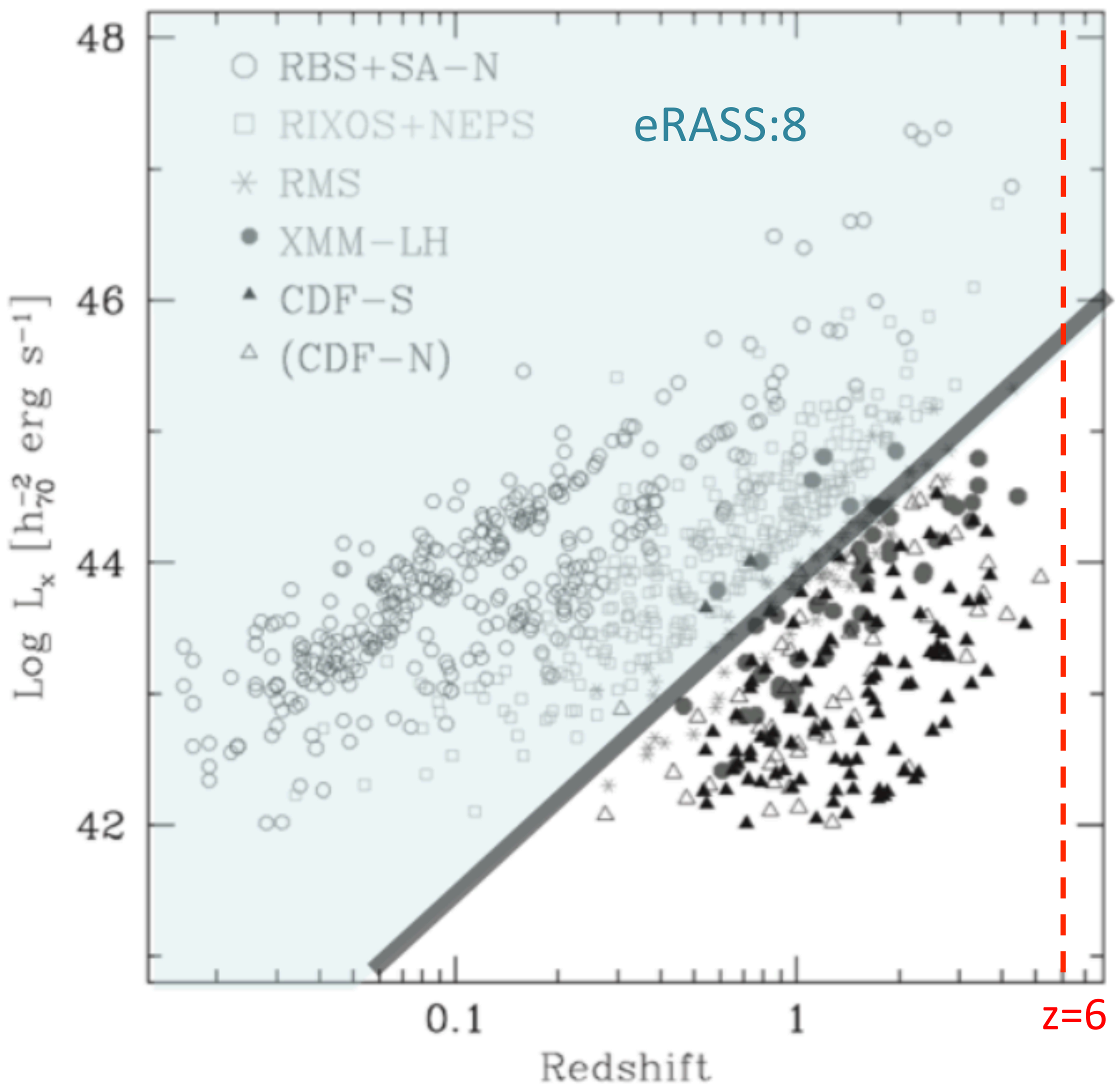
first 4 years: all sky survey

1 pass every 6 months ➔ 8 passes ➔ eRASS:8

subsequent 3.5 years: pointed observation phase

3millions AGN expected in eRASS:8 , how many at high-z ??

High-z AGN in eRASS:8

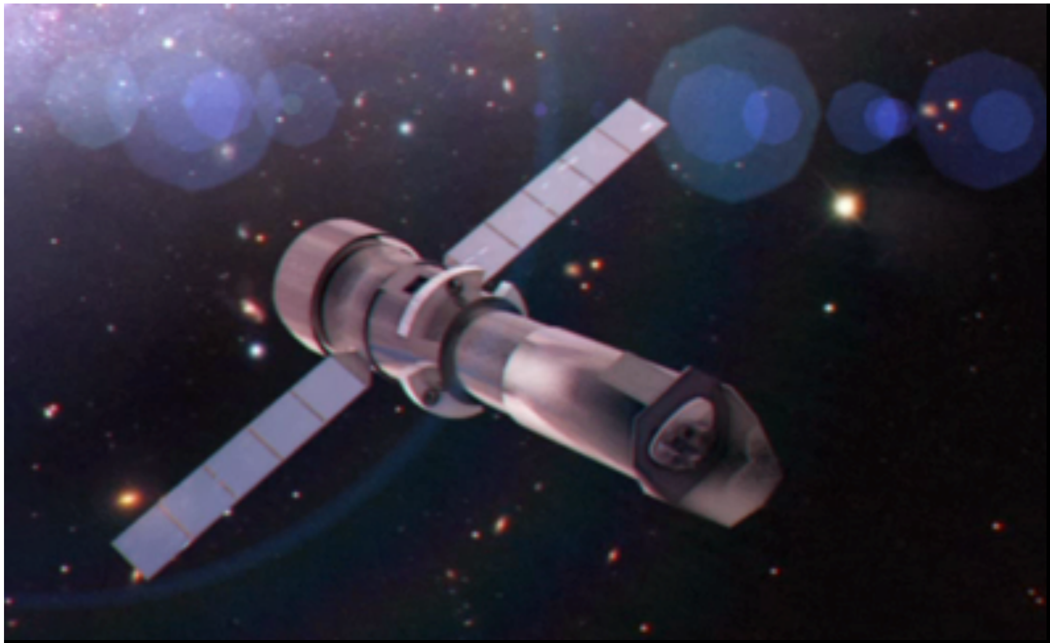


Hasinger et al. 2005, Merloni et al. 2012

$L_x \sim 10^{46}$ erg/s
$L_{bol} \sim 8 \times 10^{13}\ L_{sun}$
➔ SDSS QSOs

logLx	N(z>3)
44-45	3200
45-46	21400
>46	472

progress at z>3 but not at z>6



Athena

The X-ray observatory to study the Hot and Energetic Universe

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

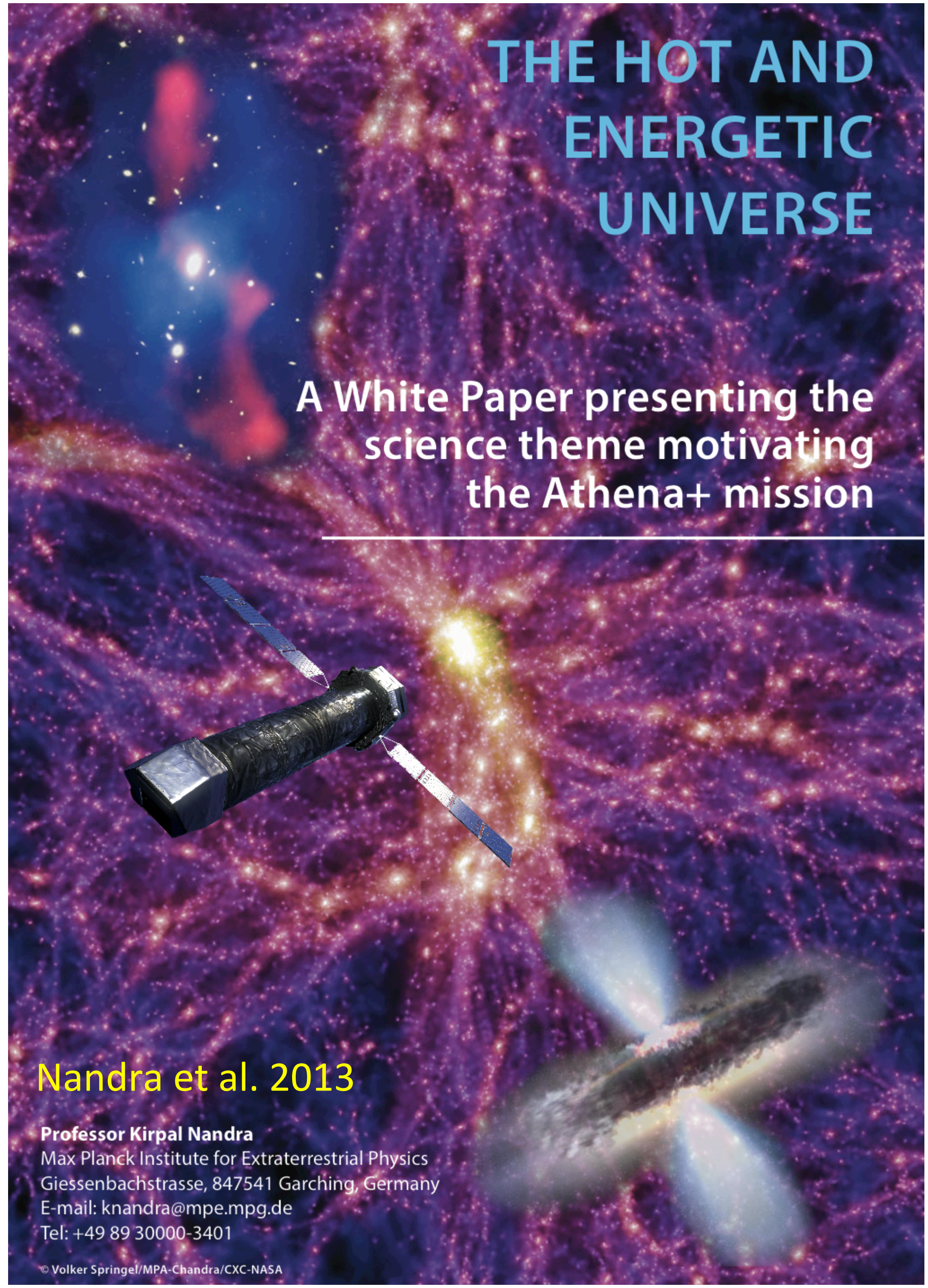
In 2014 Athena was selected by ESA as its second large mission, L2

(L1 is JUICE mission to Jupiter)

Launch foreseen in 2028

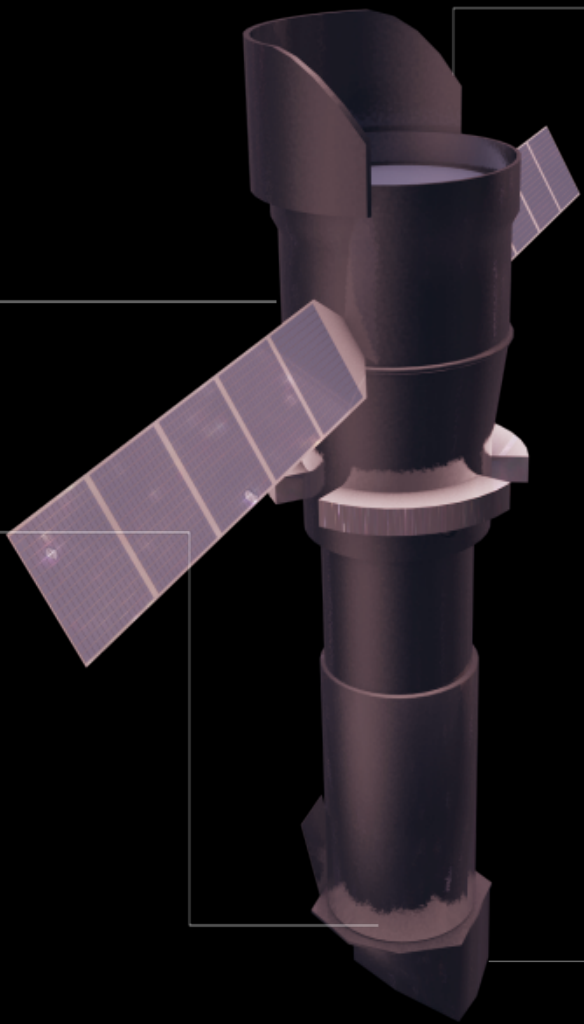
The science themes of Athena

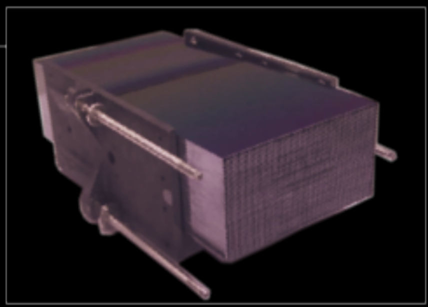
- **The Hot Universe:** How does the ordinary matter assemble into the large-scale structures that we see today?
  - >50% of the baryons today are in a hot (>10^6 K) phase
  - there are as many hot (> 10^7 K) baryons in clusters as in stars over the entire Universe
- **The Energetic Universe:** How do 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



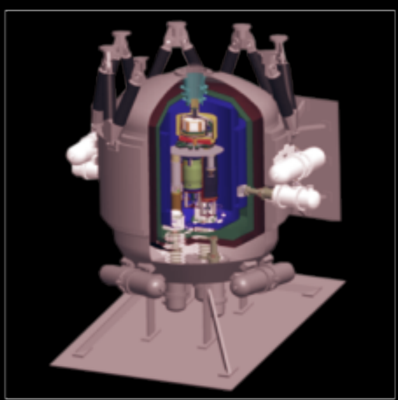
The Athena Observatory

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

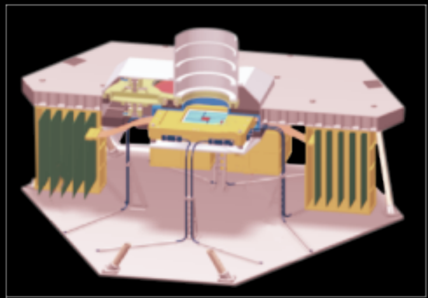




Silicon Pore Optics:
2 m^2 at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}

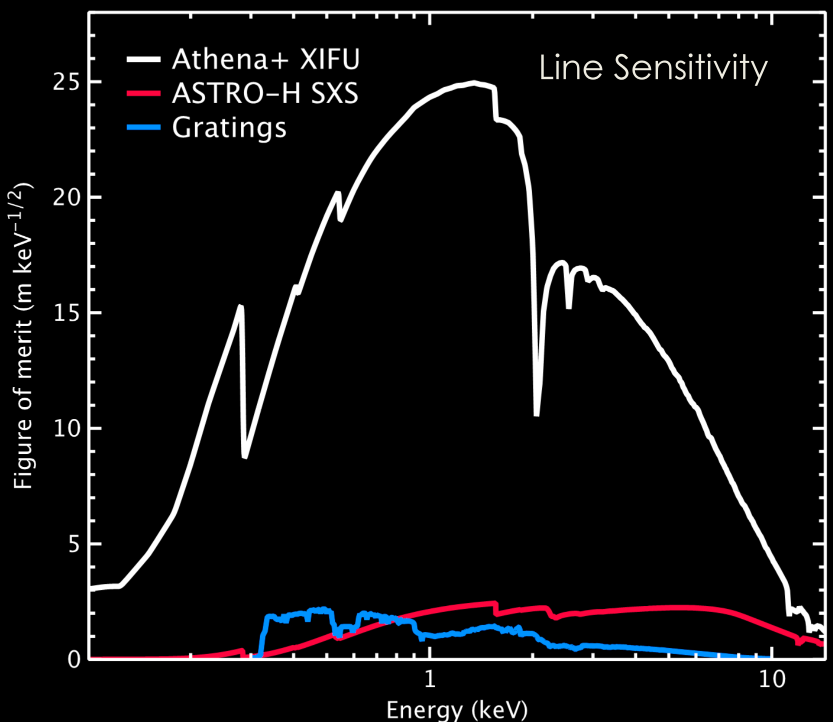


X-ray Integral Field Unit (X-IFU):
ΔE: 2.5 eV (R=2400)
Field of View: 5 arcmin
Operating temp: 50 mk

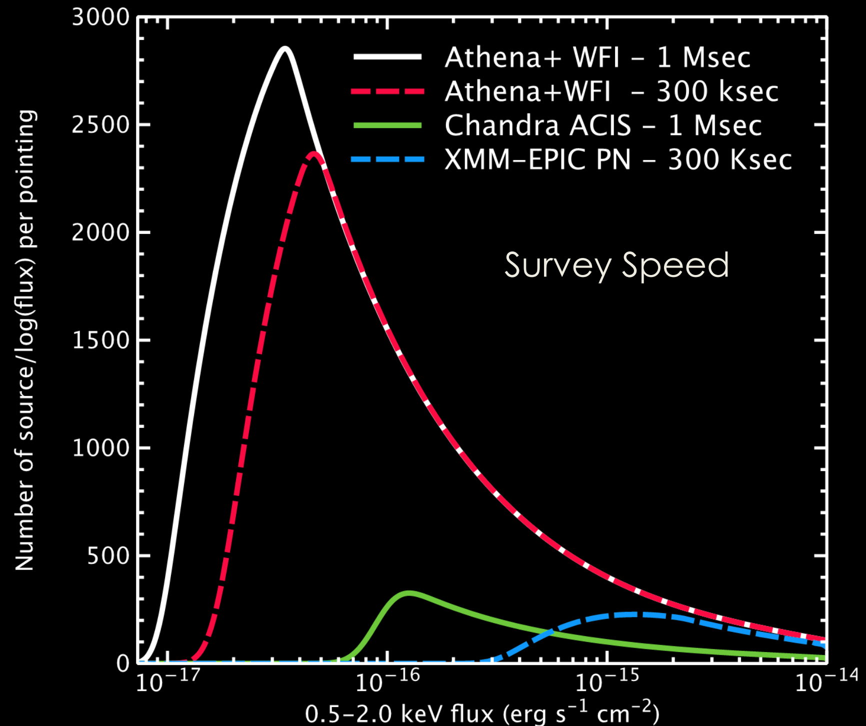


Wide Field Imager (WFI):
ΔE: 125 eV (R=50)
Field of View: 0.4 deg^2
High countrate capability

A Deep Universe X-ray Observatory

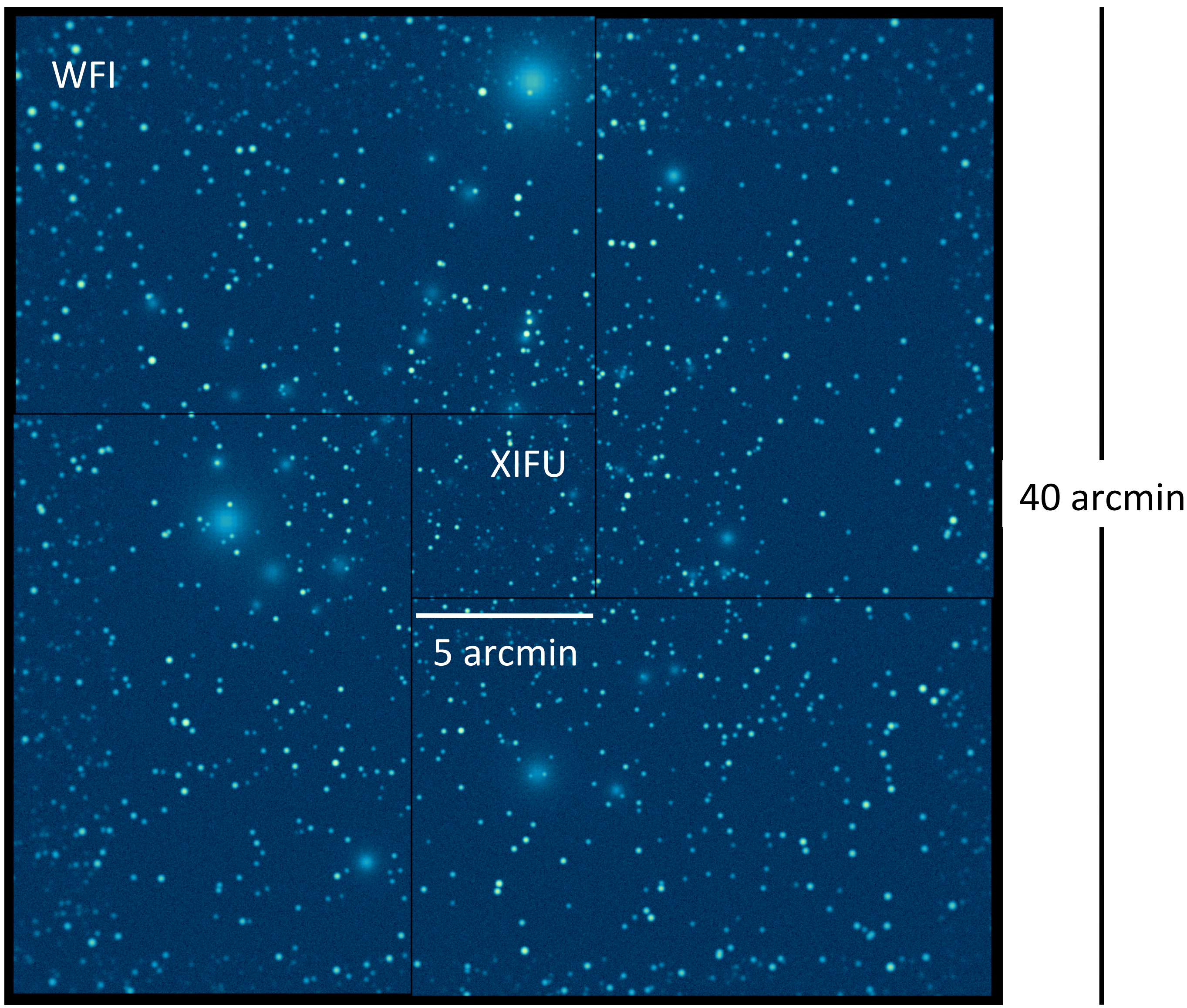


X-ray spectroscopy at the peak of the activity of the Universe

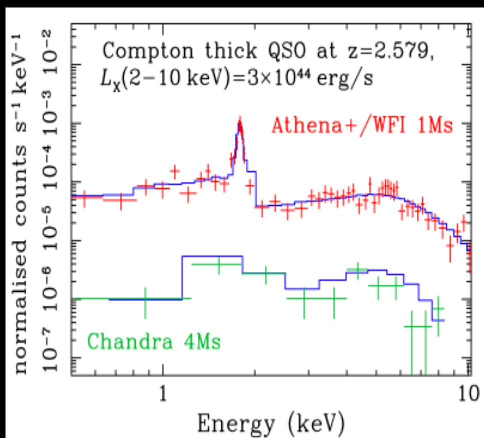


Deep survey capability into the dark ages and epoch of reionization

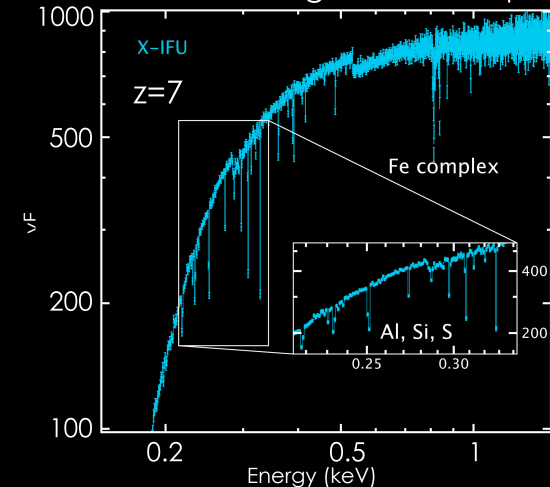
Simulation of an Athena deep field (~1Ms exposure)

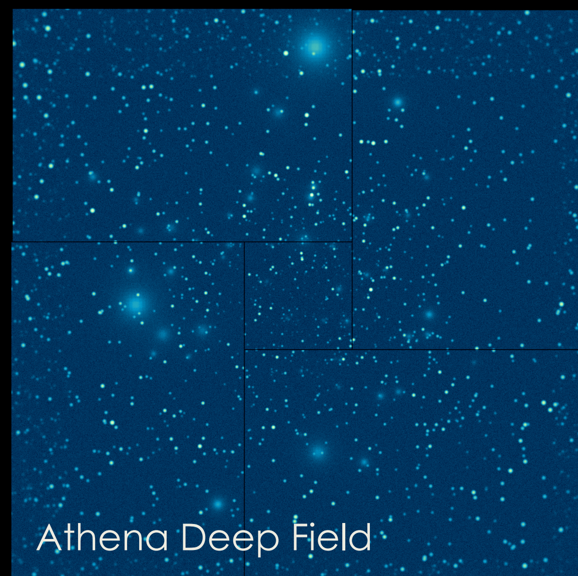


Athena:
Exploring the Hot and Energetic Universe

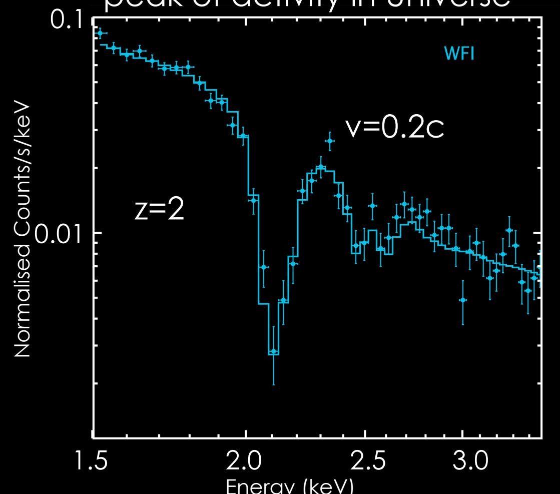


Primordial stellar populations via GRB afterglow follow up



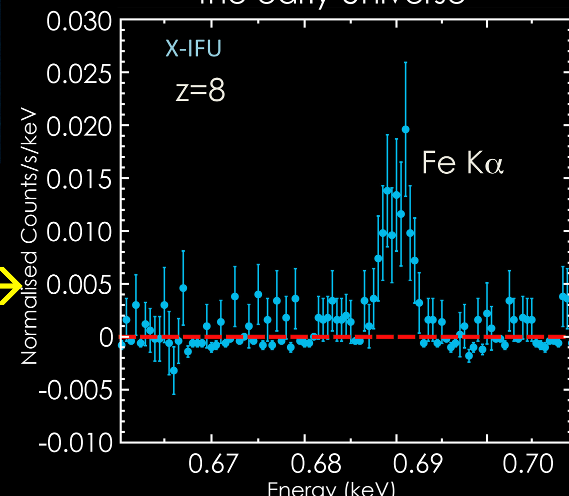


Black hole feedback at peak of activity in Universe



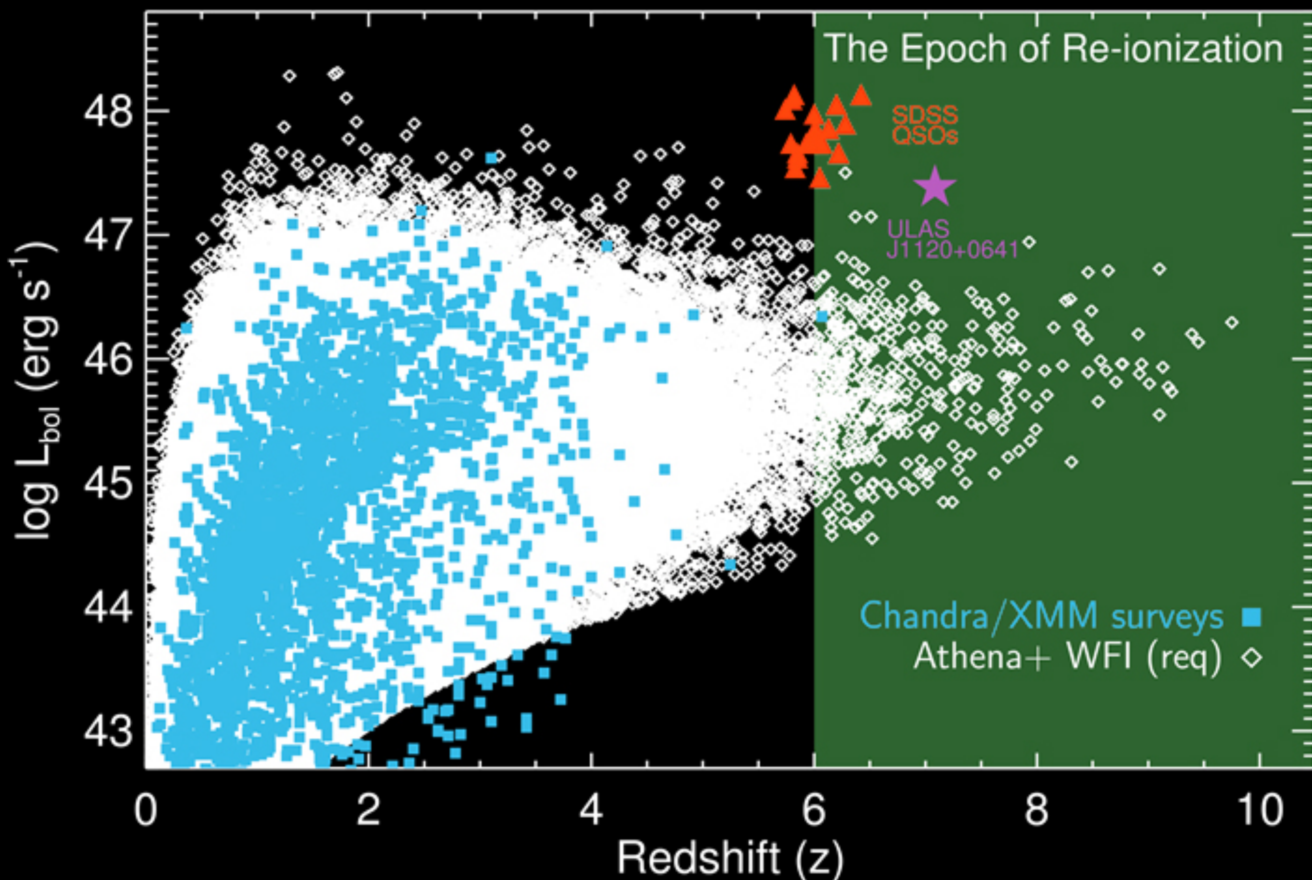
Obscured black hole in the early Universe

but how many?? →



Black hole growth in the early Universe

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

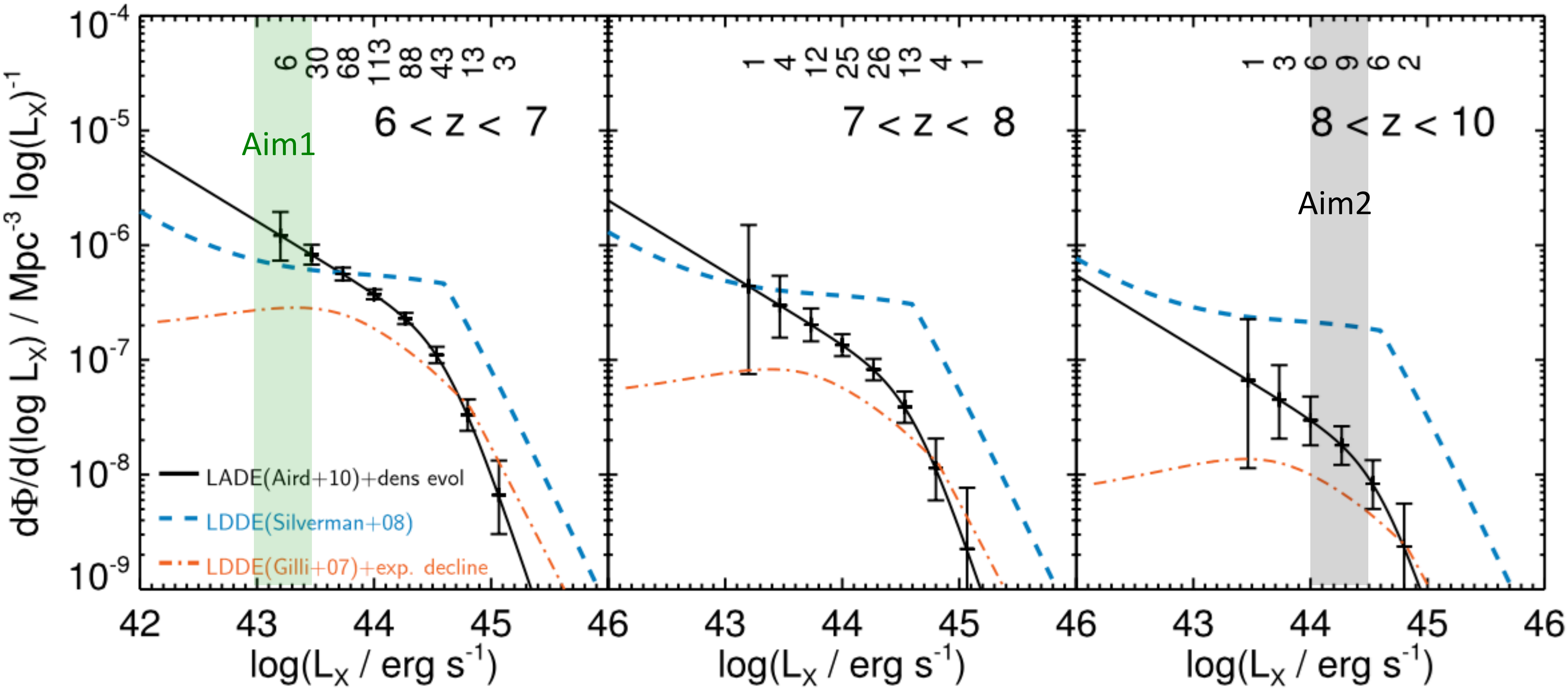


Aird, Comastri et al. 2013 arXiv1306.2325

Athena requirements for high-z AGN

Aim (1): 10 AGN at z=6-7 with log L_X=43-43.5

Aim (2): 10 AGN at z=8-10 with log L_X=44-44.5



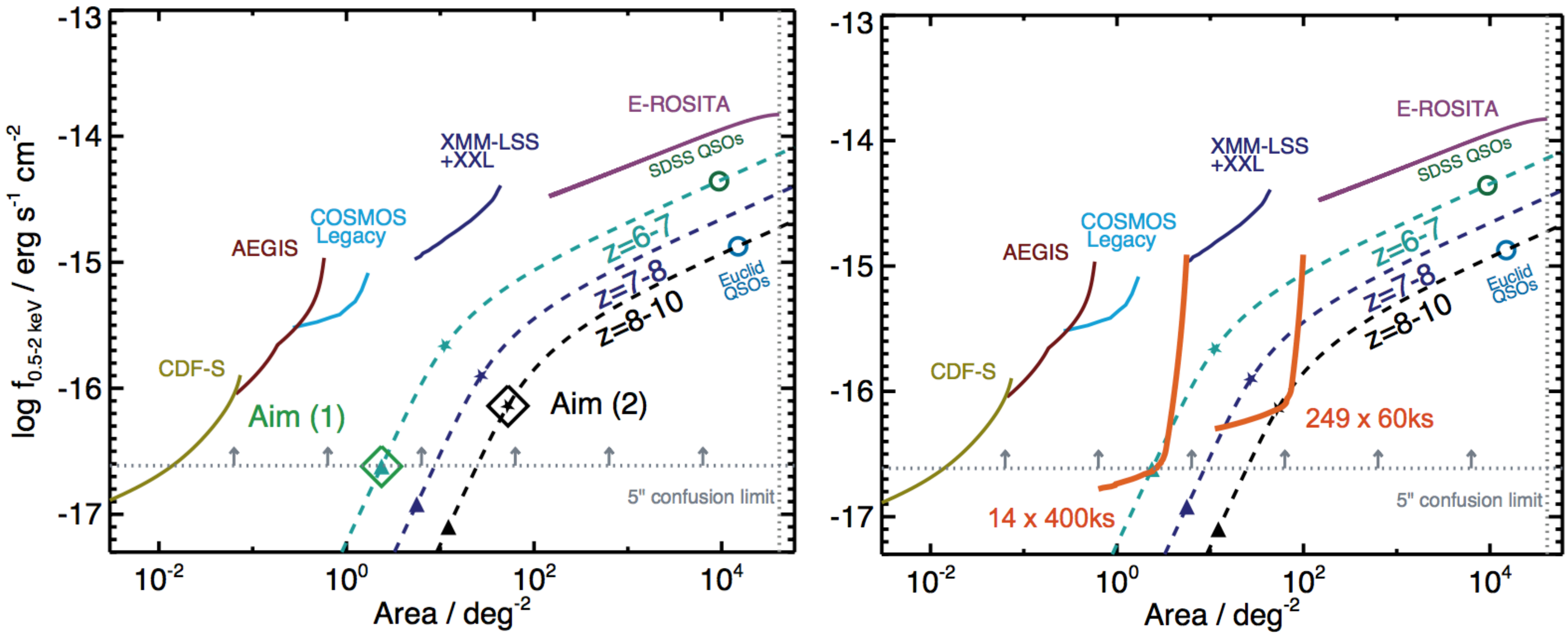
$M_{BH} \sim 10^6 \lambda_{Edd}^{-1} M_{sun}$ @ z=6

$M_{BH} \sim 10^7 \lambda_{Edd}^{-1} M_{sun}$ @ z=8

These requirements translate into two surveys:

2.4 deg^2 down to $2x10^{-17}$ $erg/cm^2/s$ and 52.7 deg^2 down to $7x10^{-17}$ $erg/cm^2/s$

for a total observing time of ~ 1 yr



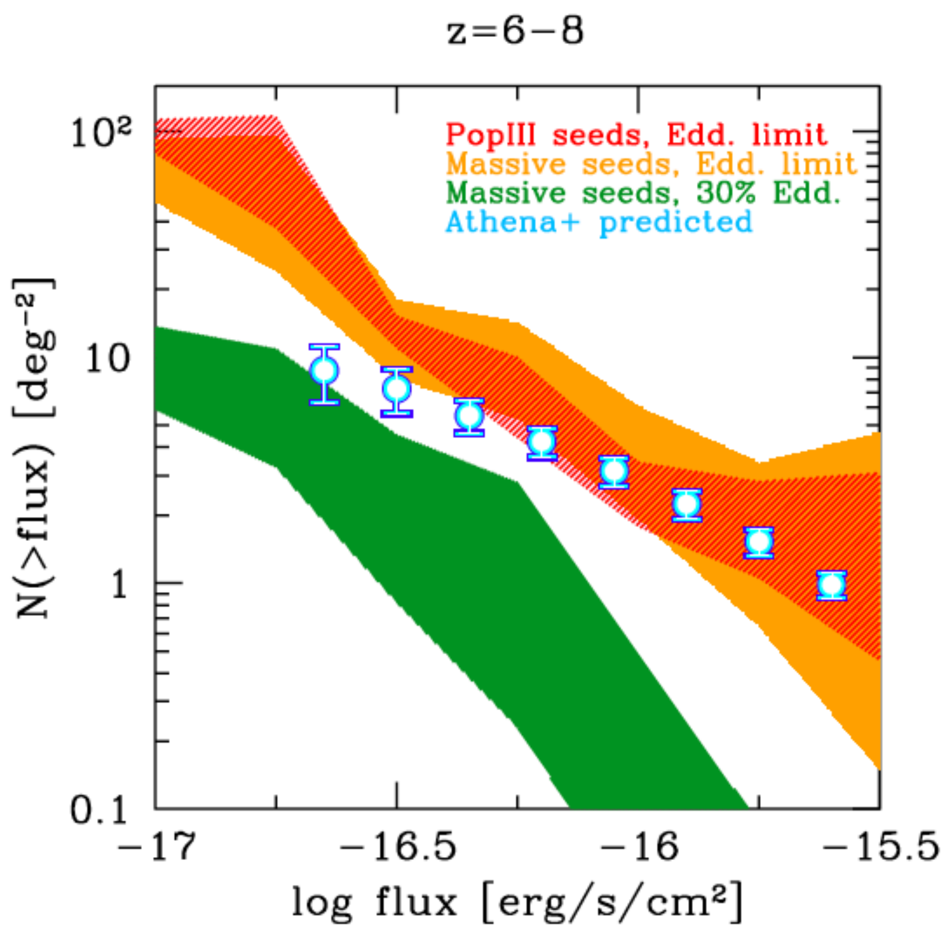
total of >400 AGNs at z>6 in ~ 1yr

Early Super-Massive Black Holes

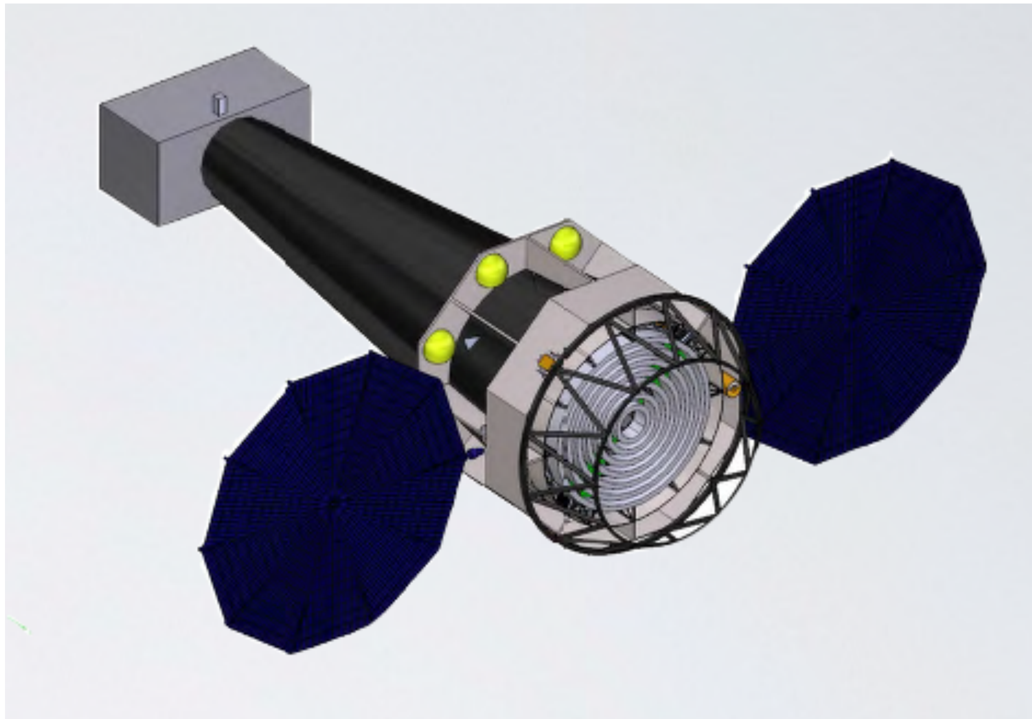
- What were the seeds of the early SMBH? How did they grow in the early stages after cosmic re-ionisation?

Determine the nature of the seeds of high redshift (z>6) SMBH, which processes dominated their early growth, and the influence of accreting SMBH on the formation of galaxies in the early Universe.

Trace the first generation of stars to understand cosmic re-ionization, the formation of the first seed black holes, and the dissemination of the first metals in the Universe.



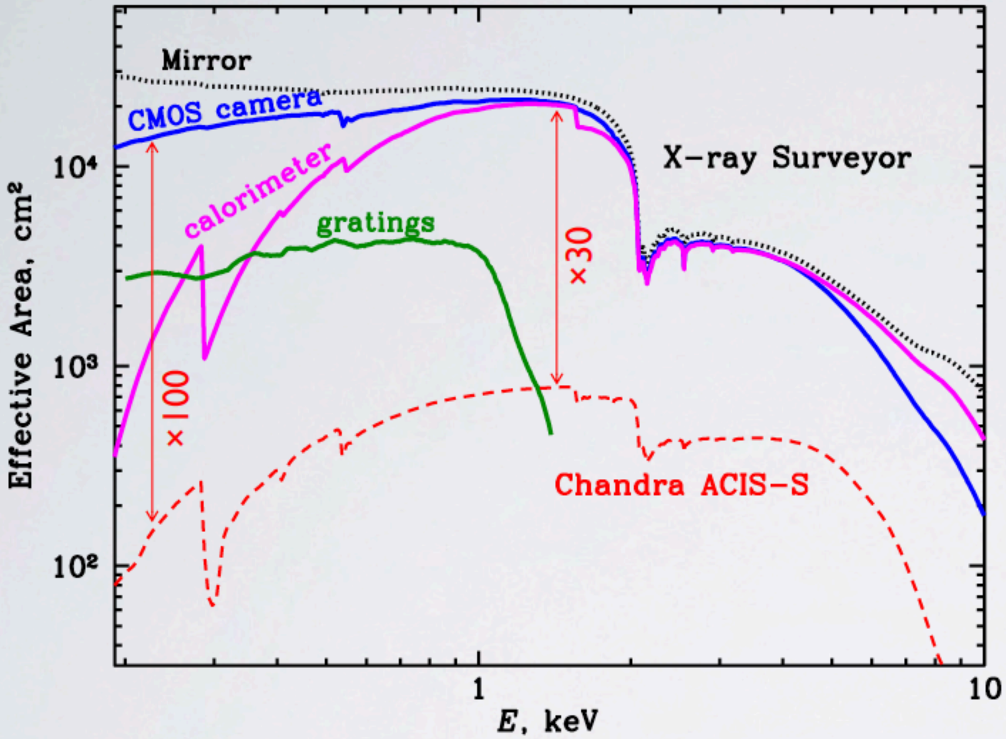
X-ray surveyor

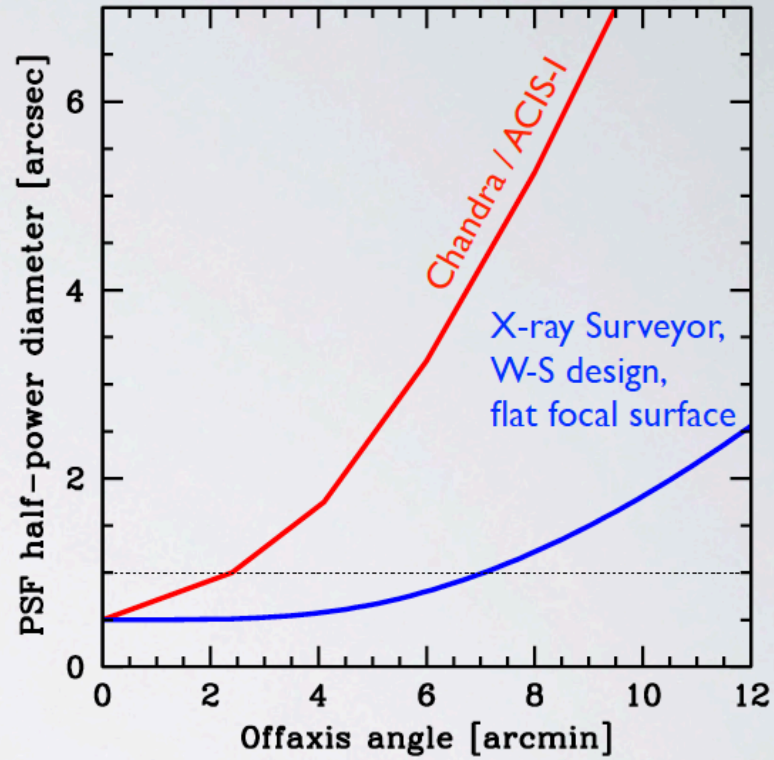


Mission concept study supported by NASA for submission to the Decadal 2020 survey

launch > 2030   (>>2030??)

X-ray Surveyor capabilities: Sensitivity & field of view

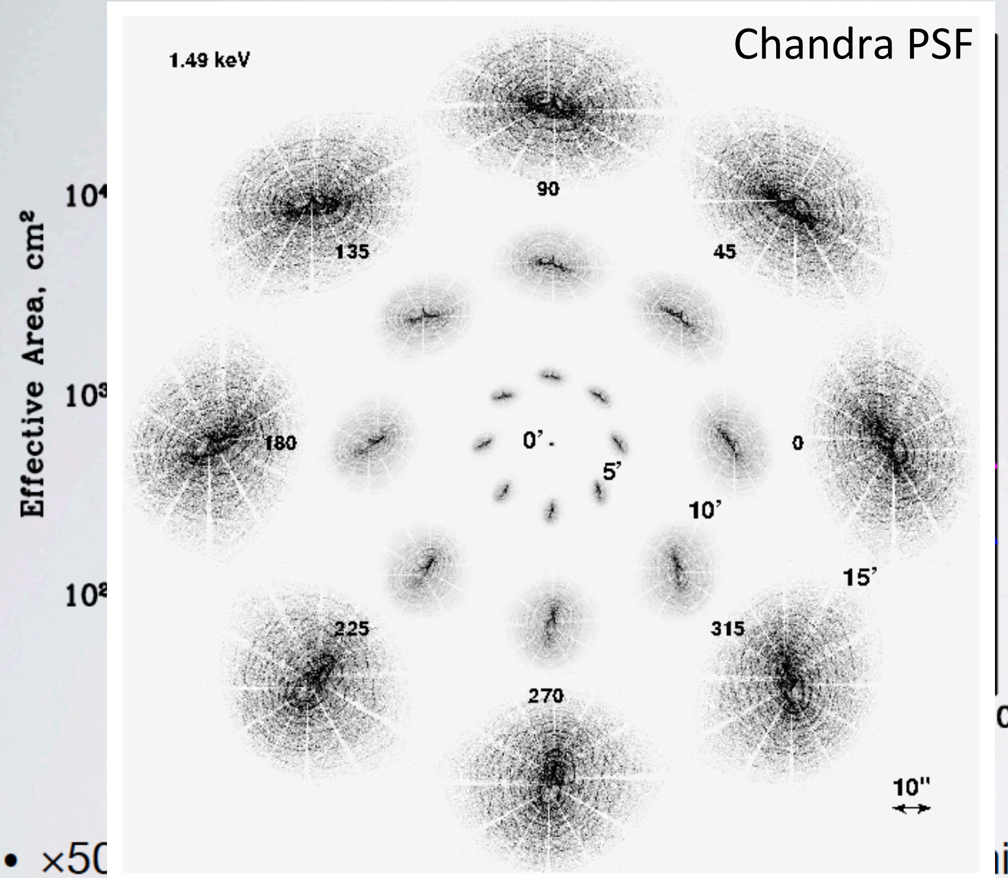


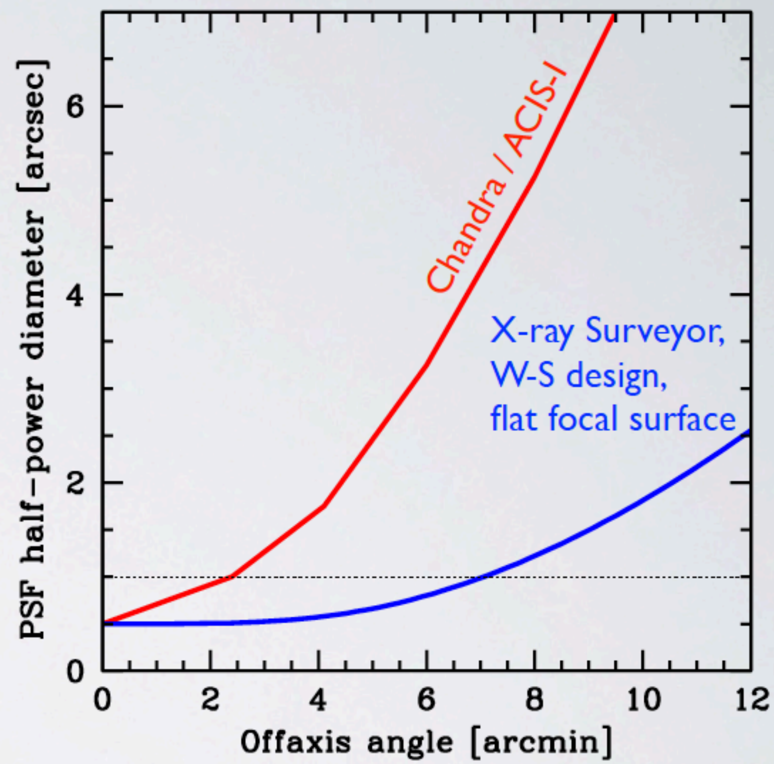


- ×50 more effective area than *Chandra* (due to mirror & QE improvements)
- Neither background nor confusion-limited for PSF better than ~1″ HPD, so sensitivity is proportional to area. 4 Msec *Chandra* Deep Field done in 80 ksec. 4 Msec detection limit is ~ 1×10^{-19} erg/s/cm^2 (0.5–2 keV band)
- ×10 larger solid angle for sub-arcsec imaging with shorter mirrors and Wolter-Schwarzschild optical scheme
- **×500 higher survey speed**

A Vikhlinin

X-ray Surveyor capabilities: Sensitivity & field of view





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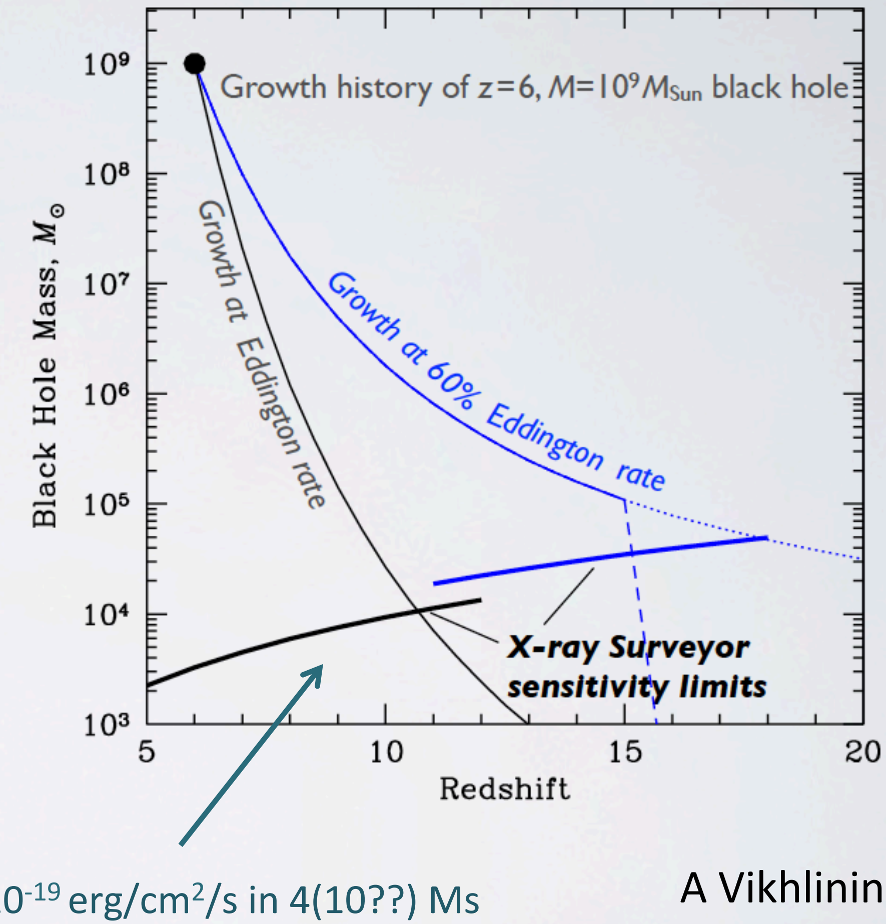
First generations of supermassive black holes

- Age of the Universe at z=6 is barely enough for quasars with $M_{BH}>10^9 M_{Sun}$ to grow via accretion. Likely, quick violent formation of massive seeds, followed by fast accretion.
- Lower-mass black holes, $M_{BH}<10^6\ M_{Sun}$, are best observed in X-rays:
  - Spectral peak ($\lambda_{max} \sim M_{BH}^{1/4}$) shifts towards X-ray band, reducing optical/UV output.
  - Dust obscuration impacts optical/UV. Common IR signatures of obscured AGNs are redshifted out of JWST band at z=10.
  - For small seeds, $L_{opt,AGN}<L_{gal}$
  - X-ray emission is direct probe of accretion, the primary black hole growth channel

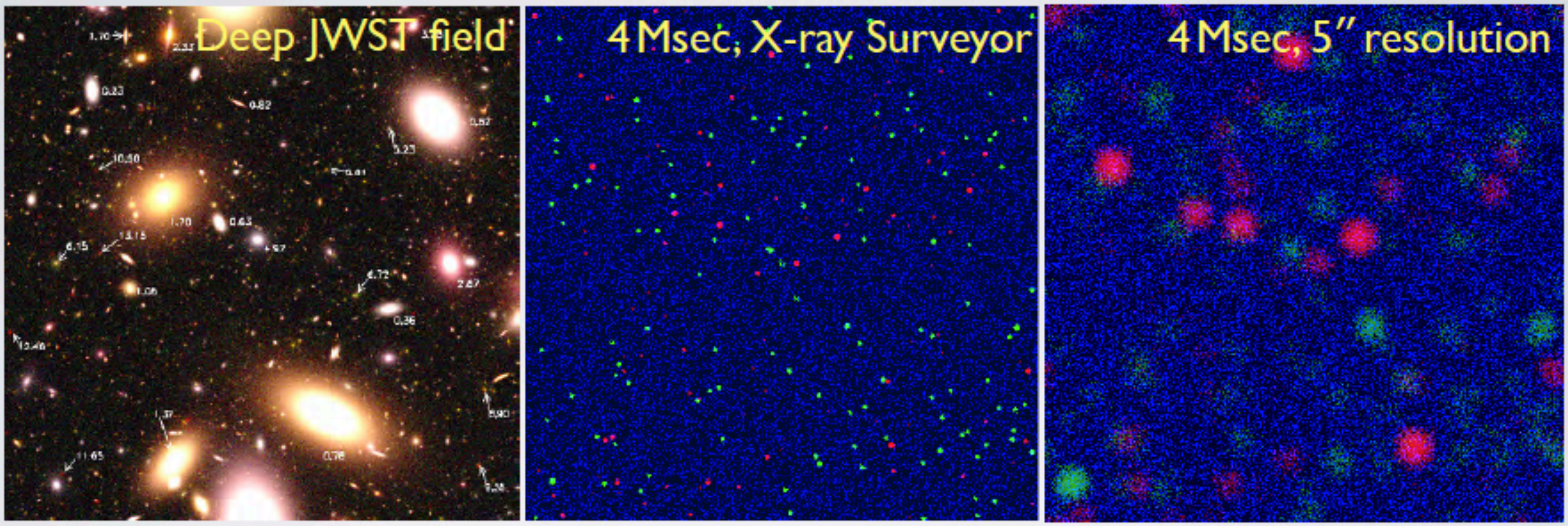


A Vikhlinin

- **X-ray Surveyor will detect *first accretion light in the Universe*: unobscured hard X-rays, *E* > 2 keV in rest frame, from hot accretion disk coronae (~10% of L_{bol}) at *z*=10 from Eddington-accreting black holes with M_{BH} ~ 10,000 M_{Sun}**

Angular resolution requirements for detecting first accretion light

Simulated 2x2 arcmin deep fields observed with JWST, X-ray Surveyor, and ATHENA



- JWST will detect ~2×10^6 gal/deg^2 at its sensitivity limit (Windhorst et al.). This corresponds to 0.03 galaxies per 0.5″ X-ray Surveyor beam (not confused), and 3 galaxies per ATHENA 5″ beam (confused).
- X-ray confusion limit for ATHENA is 2.5×10^{-17} erg/s/cm^2 (5x worse than the current depth of *Chandra* Deep Field). This corresponds to M_{BH} ~ 3×10^6 M_{Sun} at z=10 — above seed mass range. Confusion in OIR id's further increases the limit (M_{BH}~10^7 M_{Sun} at z=8 is quoted by ATHENA team).
- X-ray Surveyor will reach 1×10^{-19} erg/s/cm^2. This corresponds to M_{BH} ~ 10,000 M_{Sun} at z=*10* — well within the plausible seed mass range. *Each X-ray Surveyor source will be associated with a unique JWST-detected galaxy.*

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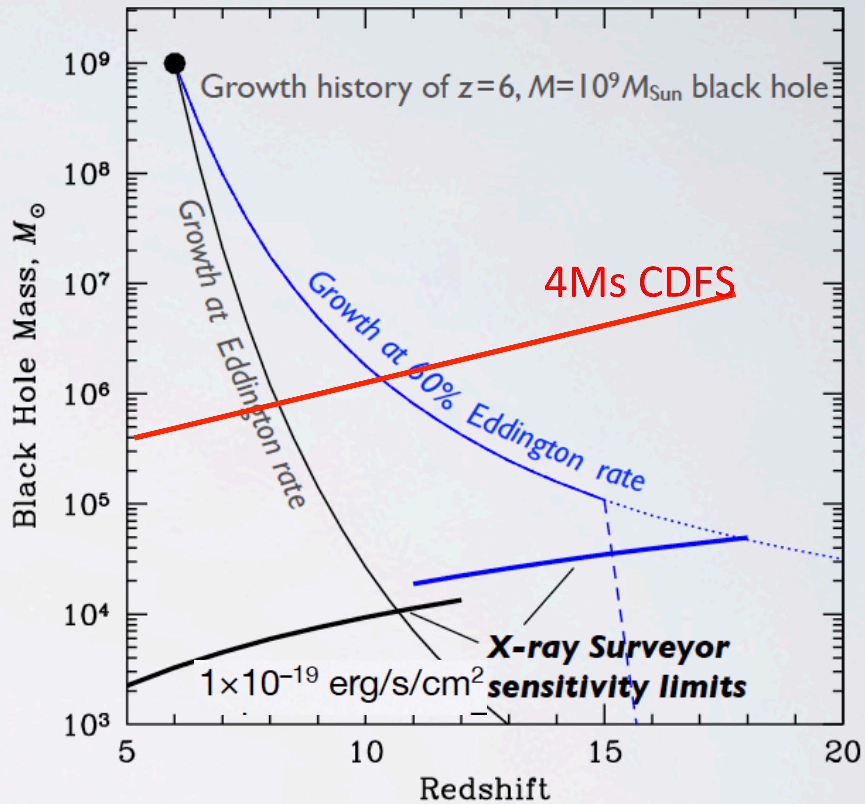

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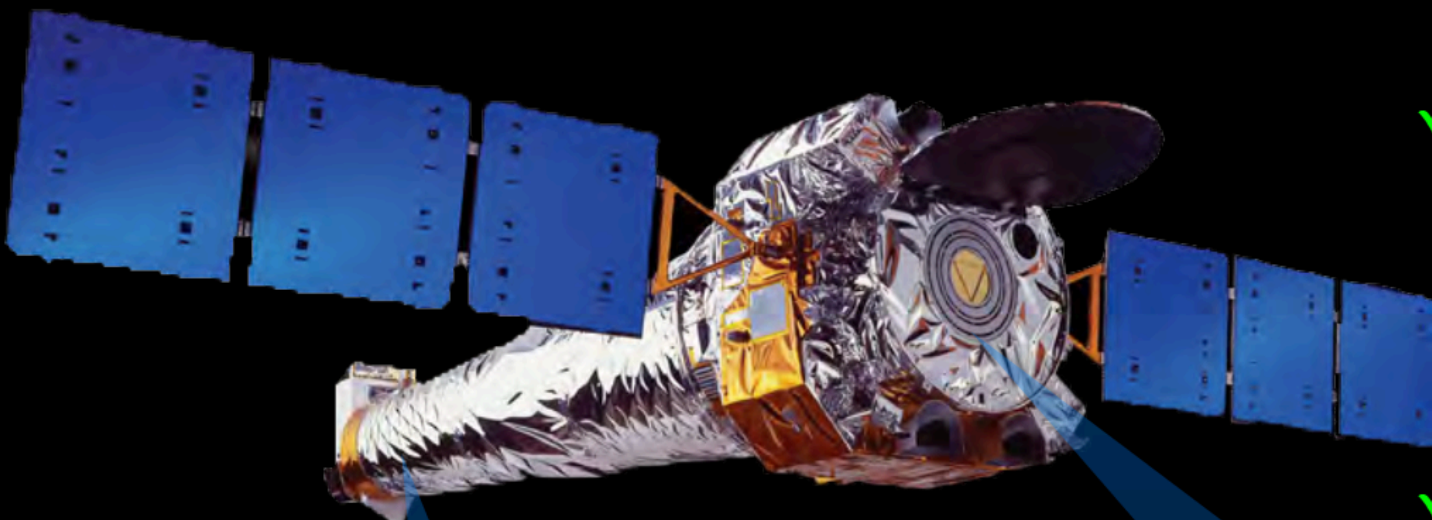
X-ray Surveyor strawman mission concept



- ✓ Technology incorporates *Chandra* heritage and IXO development
- ✓ Most spacecraft requirements similar to those achieved for *Chandra*, with some required extensions (power, data rate) being straightforward
- ✓ *Chandra*-like cost

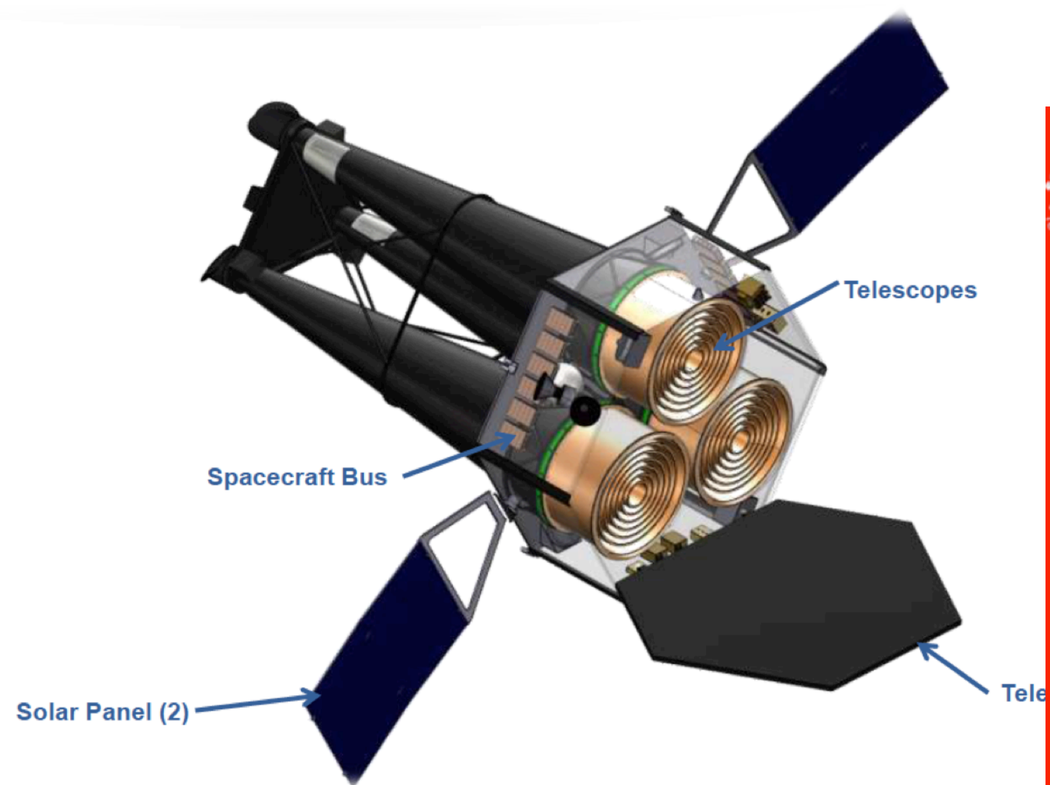
Next-generation science instruments, e.g.:

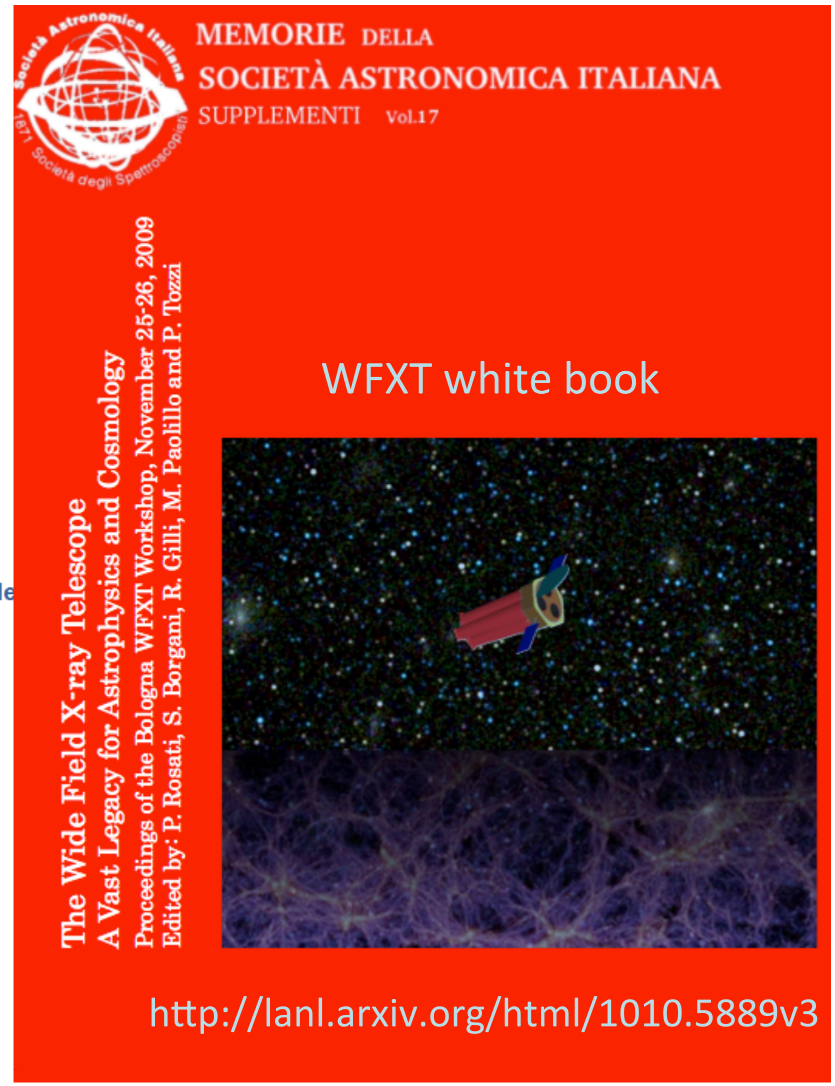
- 5′×5′ microcalorimeter with 1″ pixels and high spectral resolution, 0.2–10 keV
- 22′×22′ CMOS imager with 0.33″ pixels, 0.2–8 keV
- insertable gratings, R = 5000, 0.2–1.2 keV

Next-generation mirrors. Lower mass, same angular resolution, same focal length as *Chandra*'s. **A factor of 30 (50 with QE gains) more effective area. Sub-arcsec imaging over 15×15′ field.**

The Wide Field X-ray Telescope (WFXT)

http://www.wfxt.eu
http://wfxt.pha.jhu.edu





WFXT white book

http://lanl.arxiv.org/html/1010.5889v3

Mission Concept Study

Possible descope of X-ray surveyor or
NASA Explorer mission (smaller option = WFXT/3)

WFXT Key Features

Constant PSF (<= 5" HPD) across 1 degree FOV

Effective area ~ 15 X Chandra at 1 keV (goal 1 m^2)

Bandpass: ~ 0.4-7 keV

Dedicated survey mission, calibrated data products released with no proprietary period

Science goals: discovery and characterization of groups and clusters up z~1-2, evolution of AGN and growth of earliest AGN, star forming galaxies traced up to z>1, halo stars, SNR and compact Galactic objects

Will serve as a target finder for future X-ray missions

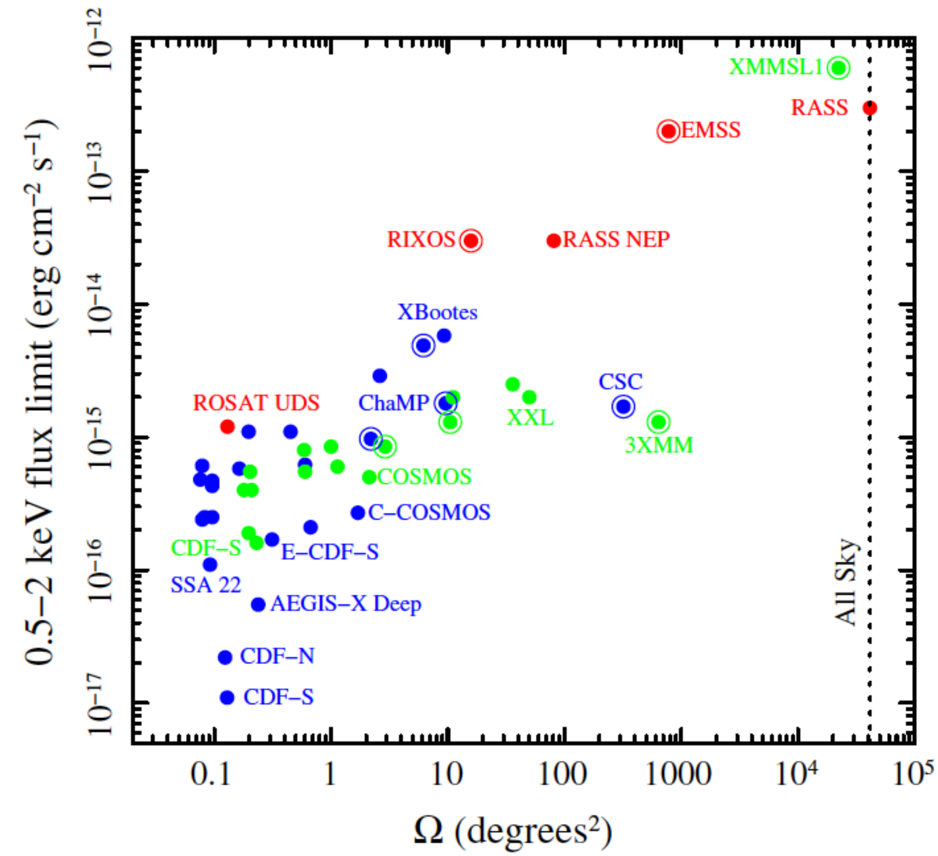
Why WFXT?

The only soft X-ray all-sky survey has been the ROSAT All-Sky Survey (RASS)

Chandra and XMM-Newton are *not* survey instruments

eRosita is slated to launch in 2017 but has ~ 30" avg. PSF

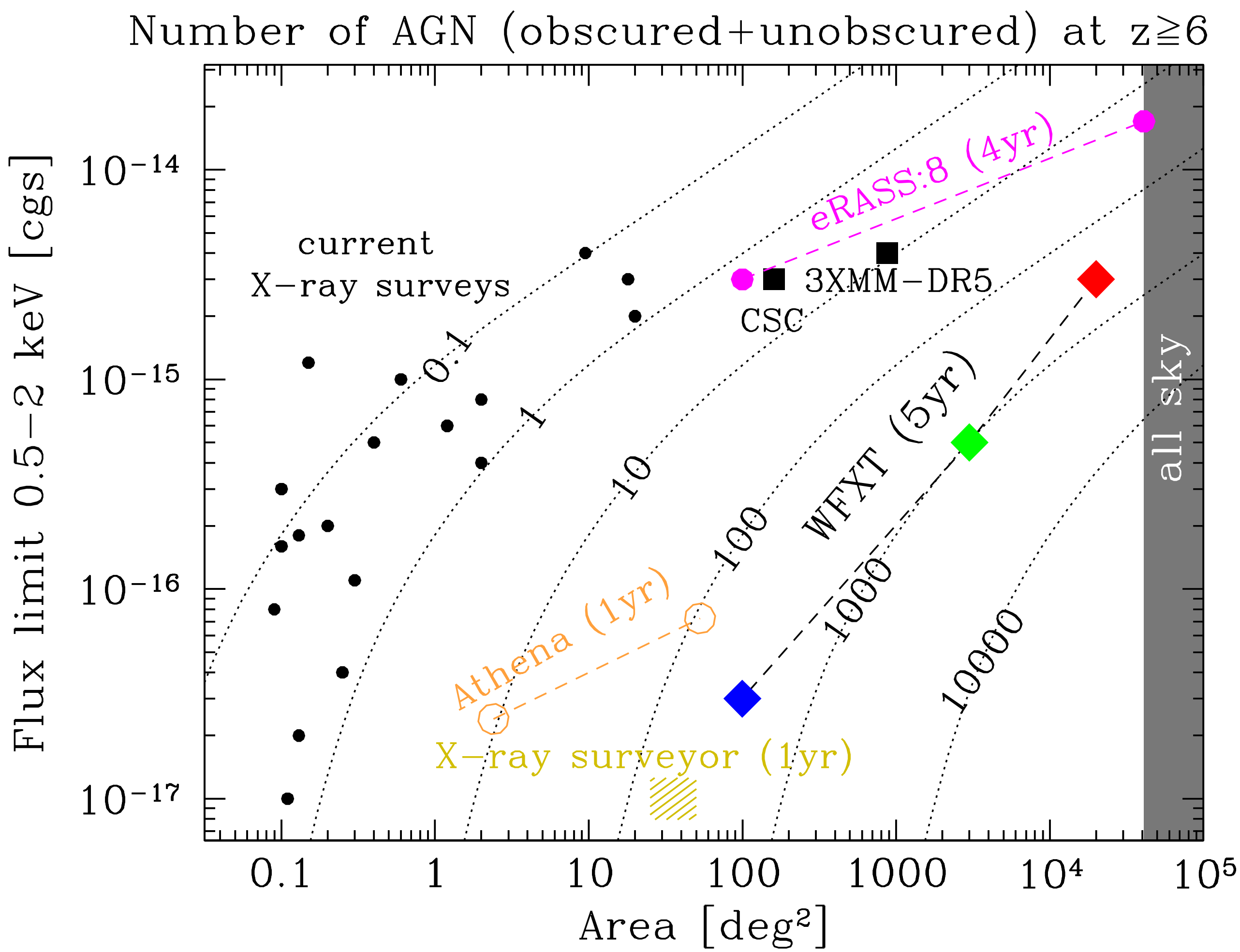
Athena WFI will have 1.4-2 m^2 eff. area but will have a 40' FOV and may only spend ~ 1 year on surveys



Brandt & Alexander (2015)

We need a dedicated survey mission to cover large areas (> 100 sq. deg.) with flux depths matched to LSST and WFIRST: WFXT would be the X-ray SDSS

Wide-and-deep X-ray surveys with WFXT



3 surveys in 5 yrs:

1Ms CDFS x1000
+
Cosmos x1000
+
XBootes x1000

=

~1800 AGN at z>=6

[~900 obscured and ~70 at z>8]

➔obscured/unobscured AGN XLF and clustering at z>6

Match with next-generation multi-band surveys