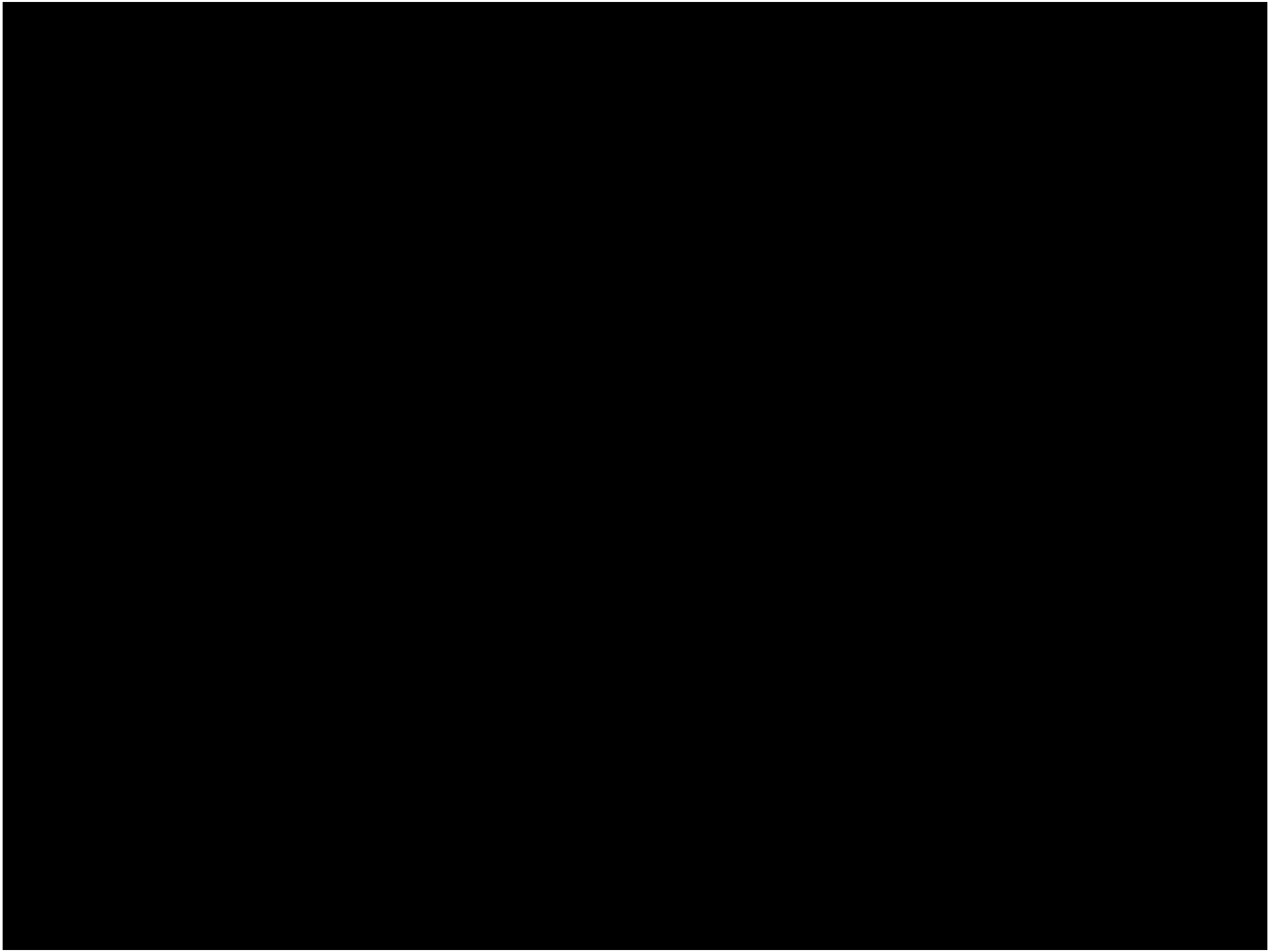
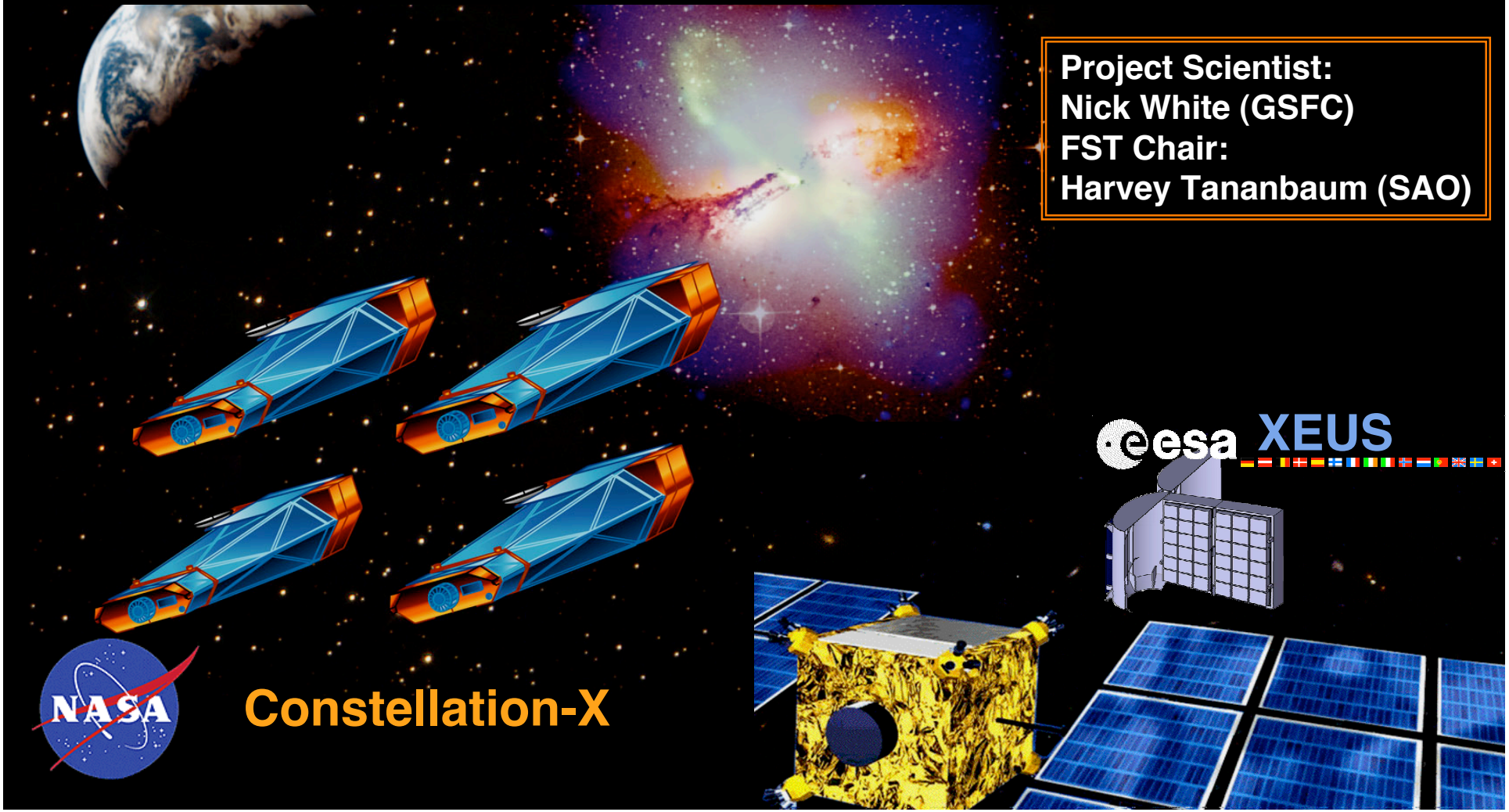


X-ray Observations of the Early Universe

after Chandra, XMM-Newton, and ASTRO-E2

Ann Hornschemeier
Deputy Project Scientist
Constellation-X
NASA GSFC

Project Scientist:
Nick White (GSFC)
FST Chair:
Harvey Tananbaum (SAO)



X-ray Observatories - Outline

- **Current generation:**
  The early Universe at high energy

- **The next generation (2015+):**
  NASA's Constellation-X (+ ESA's XEUS)

- **2025 and beyond…**
  NASA's vision mission (Generation-X)

If that first slide was baffling…

Two ARA&A articles:

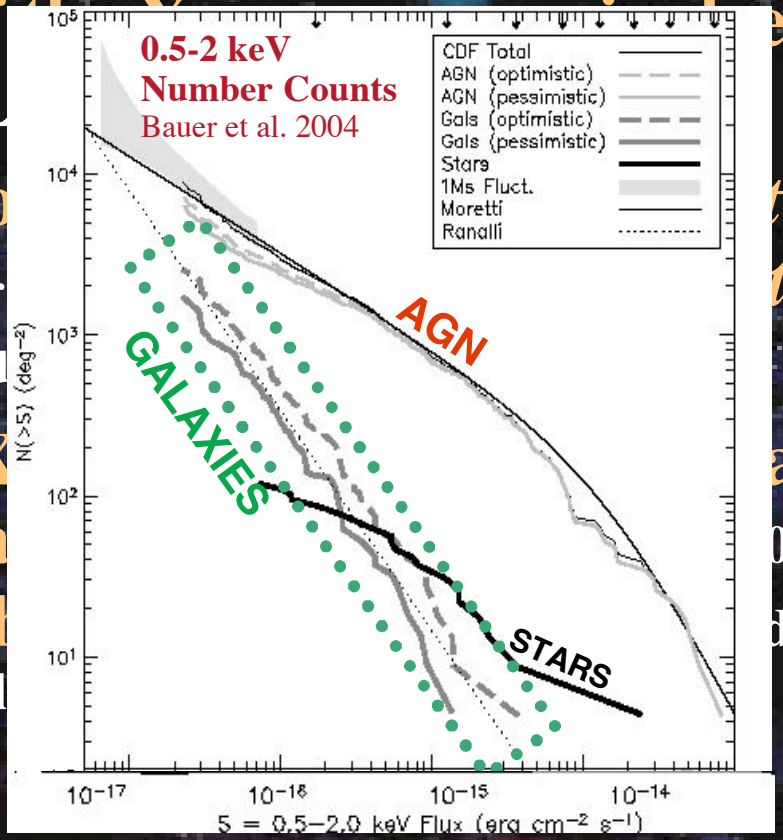
1. Paerels & Kahn (2003) ARA&A
   (High-resolution X-ray spectroscopy)
2. Brandt & Hasinger (2005) ARA&A
   (Deep X-ray Surveys)

A Quick Primer on Extragalactic X-ray Astronomy

- 70-100% of the X-ray sources in deep surveys are AGN ($L_X = 10^{39}$-10^{45} erg s^{-1})
- Highest z confirmed for X-ray *selected* AGN: (z=5.2, Barger et al. 2003) and X-ray *detected* AGN ($z \geq 6.3$, Brandt et al. 2002)
- Studies of X-ray detected normal/starburst galaxies reach $z \approx 1$ (Hornschemeier et al. 2003), and z=3-4 through stacking (e.g., Brandt et al. 2001, Reddy & Steidel 2004, Lehmer et al. 2005)

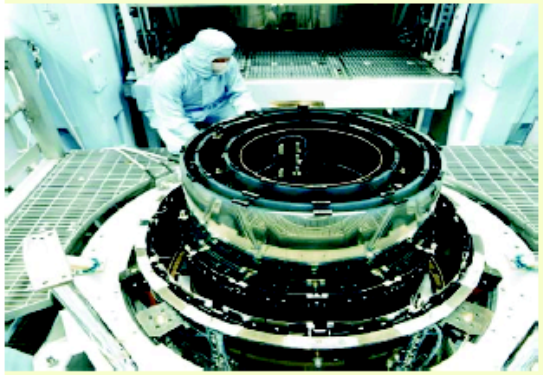
A Quick Primer on Extragalactic X-ray Astronomy

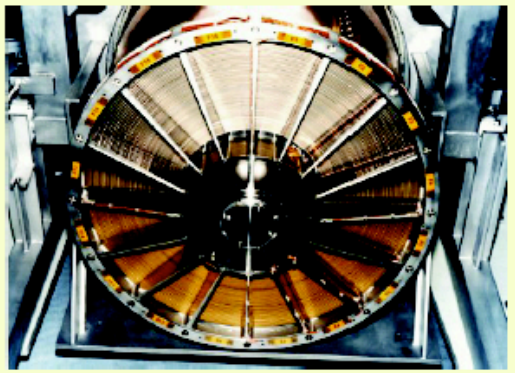
- 70-100% of [illegible] ep surveys are AGN (L[illegible]
- Highest z co[illegible] *ted* AGN: (z=5.2, Barger [illegible] *ted* AGN ($z \geq$ 6.3, Brand[illegible]
- Studies of X[illegible] arburst galaxies rea[illegible] 003), and z=3-4 t[illegible] dt et al. 2001, Reddy & Steidel[illegible]



A Quick Primer on X-ray Optics:

They are extremely heavy.





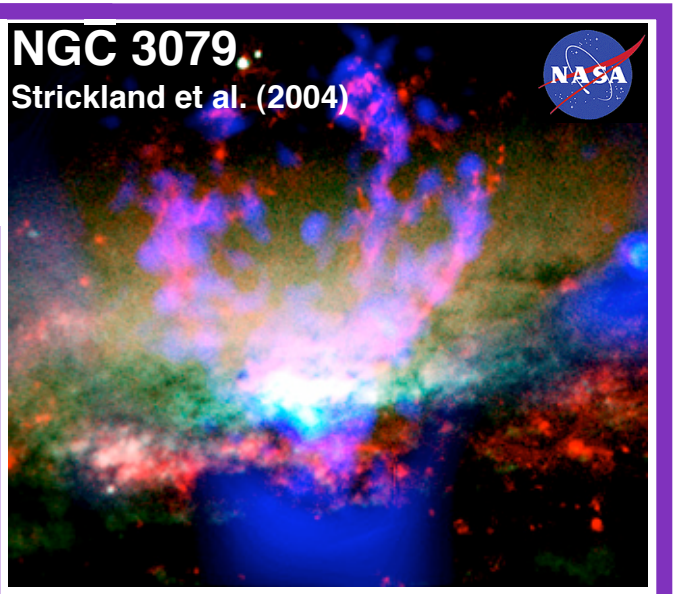
CHANDRA	XMM-NEWTON
0.5”	14”
18500 kg/m^2	2300 kg/m^2
A_{eff} @ 1 keV	A_{eff} @ 1 keV

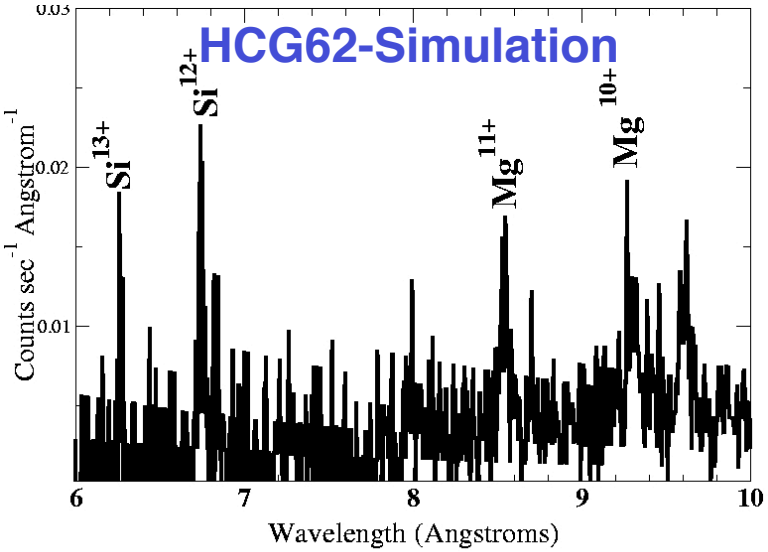
credit: Marcos Bavdaz, ESA-XEUS team

Current X-ray Observatories

Chandra, Launched: 1999

Exquisite Imaging (< 1" PSF)
(0.25-10 keV)



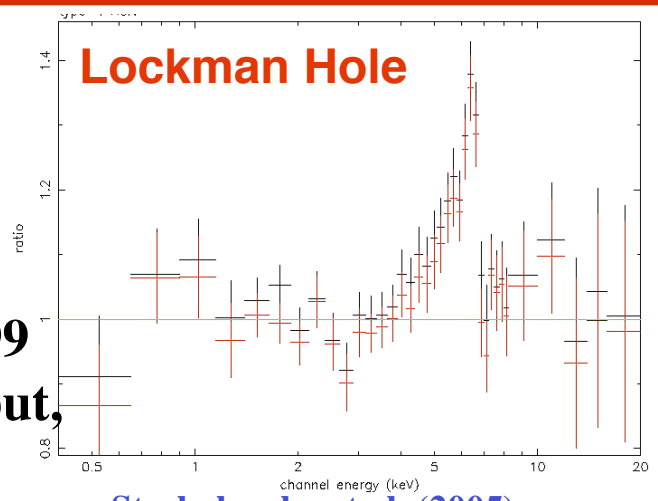


ASTRO-E2

Launch: Summer 2005
R~1000 X-ray spectra
(1-10 keV)

XMM-Newton

Launched: 1999
High throughput,
X-ray spectra
(0.25-12 keV)

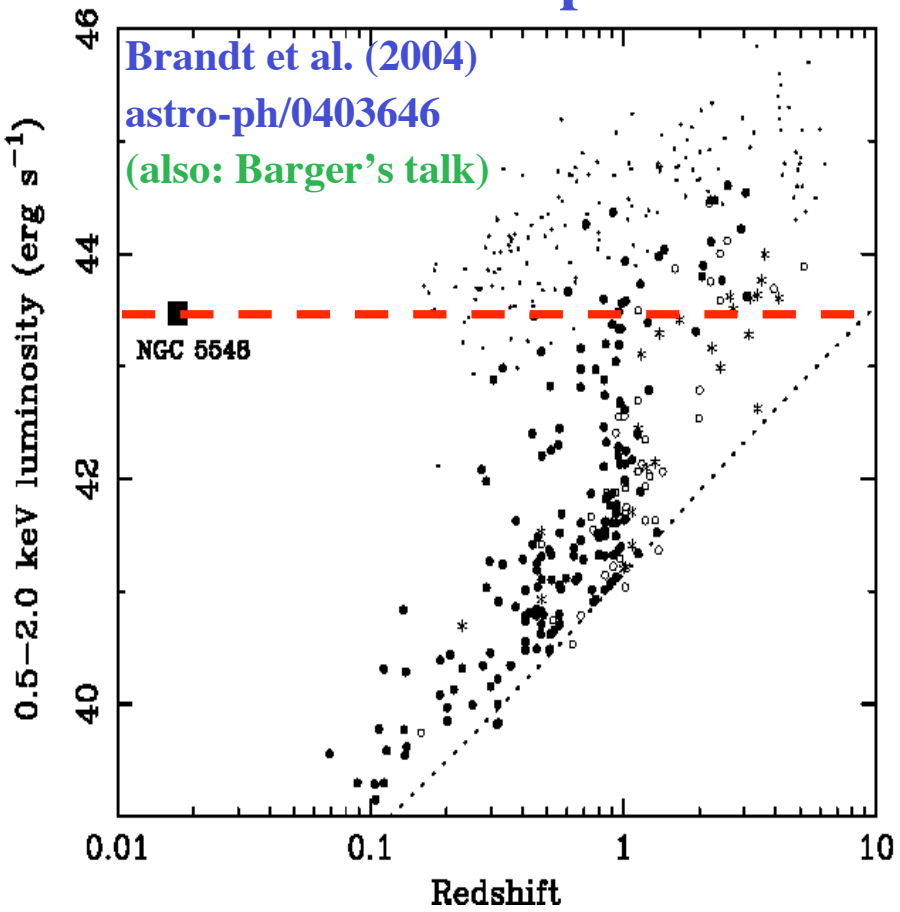


Strebylanska et al. (2005)
astro-ph/0411340

The High Redshift Reach of *Current* X-ray Observatories

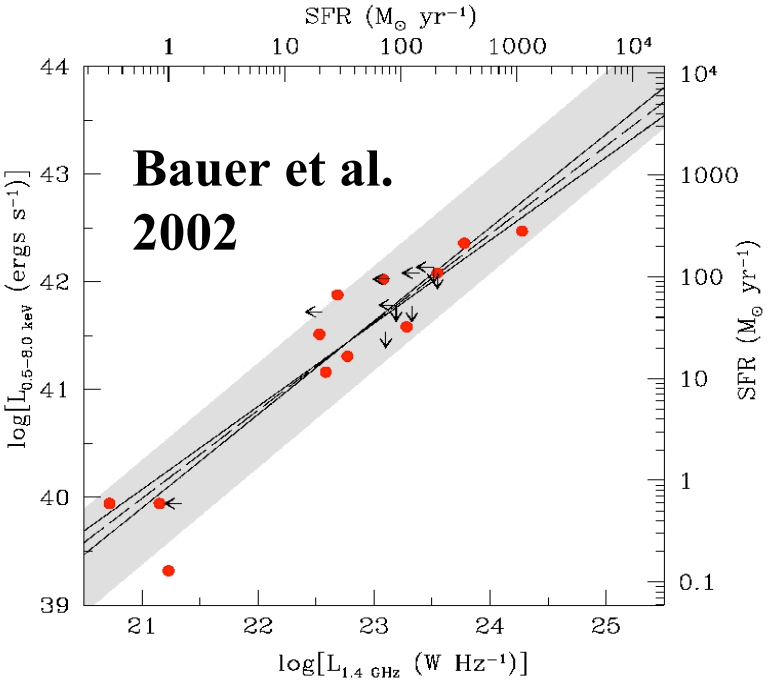
- X-ray surveys efficiently find AGN (sky densities of nearly 6000 deg^{-2})
- Many AGN cannot be optically identified (Barger et al. 2003)
- **Sensitivity to reach AGN at z~10 already achieved**

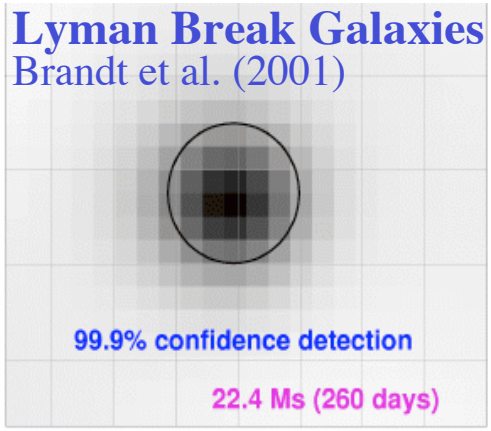
2 Ms Chandra Deep Field-North



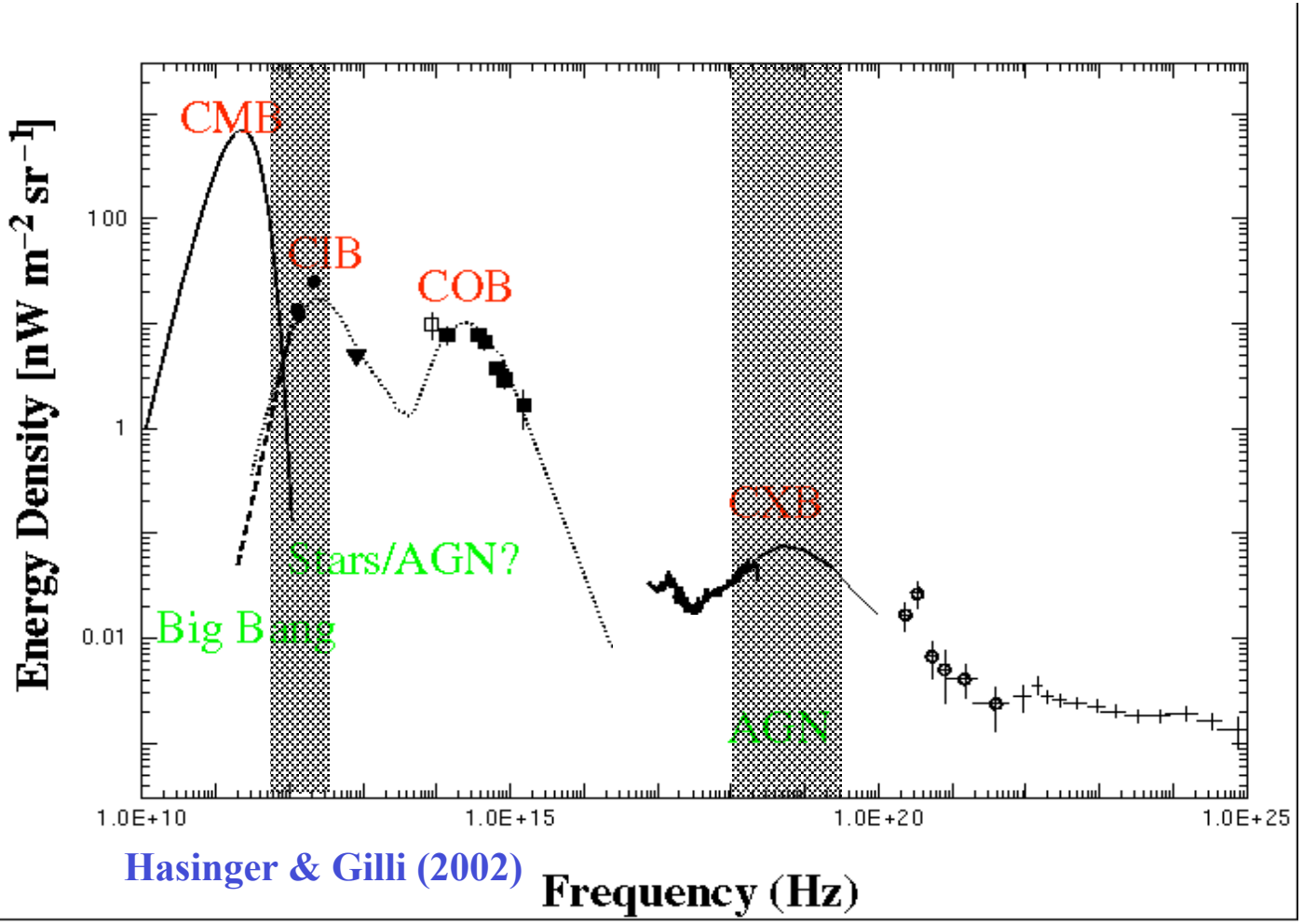
Star Formation at High-z in the X-rays

- Tight L_X-SFR correlation holds up to z=1
  (Bauer et al. 2002,Seibert, Heckman & Meurer 2002, Ranalli et al. 2002, Cohen et al. 2003, Hornschemeier et al. 2005)
- L_X-SFR correlation may extend up to z=3-4 based on stacking analyses
  (Brandt et al. 2001, Nandra et al. 2002, Seibert, Heckman & Meurer 2002, Reddy and Steidel 2003, Lehmer et al. 2005)





Extragalactic Background Radiation (EBR) Studies

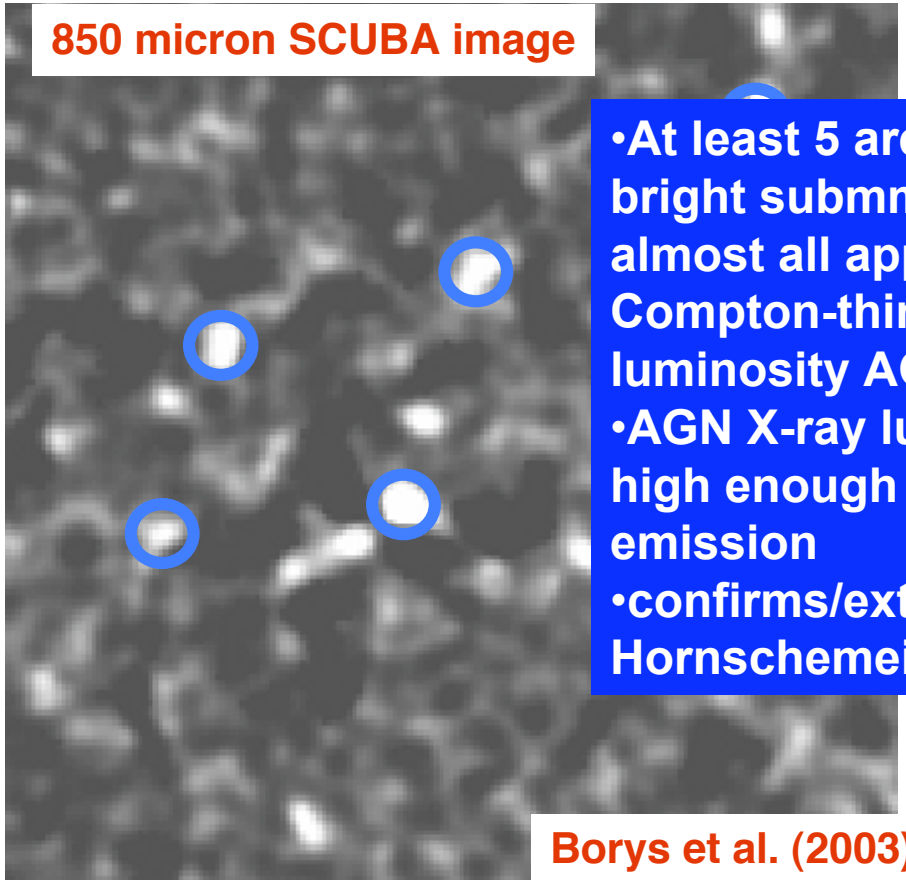


Hasinger & Gilli (2002)

X-ray/Submm Studies: *Coeval SMBH-Spheroid Growth?*

- Tight M_{SMBH} - $M_{Spheroid}$ relationship (e.g., Tremaine et al. 2002) in local galaxies implies causal connection
- If components form together: expect strong SFR and AGN in same galaxies
- **Submm galaxies are sites of some of the highest SFR at high-*z*, but extremely optically faint, difficult to identify (Chapman et al. 2002)**

X-ray/Submm Studies:
Coeval SMBH-Spheroid Growth?



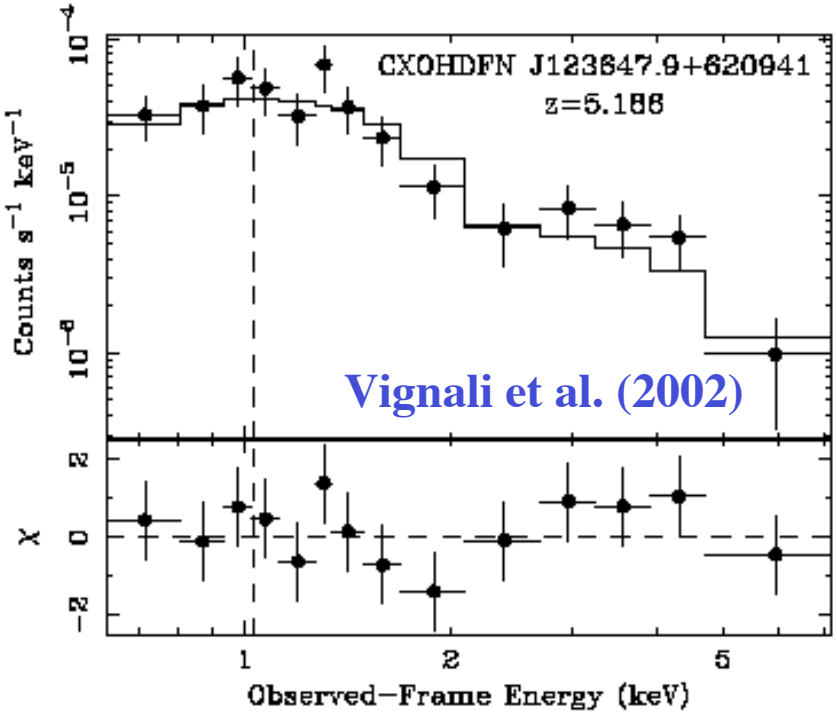
- At least 5 are AGNs (38% of bright submm galaxies) → almost all appear to be Compton-thin moderate-luminosity AGNs
- AGN X-ray luminosity not high enough to power submm emission
- confirms/extends results of Hornschemeier et al. (2000)

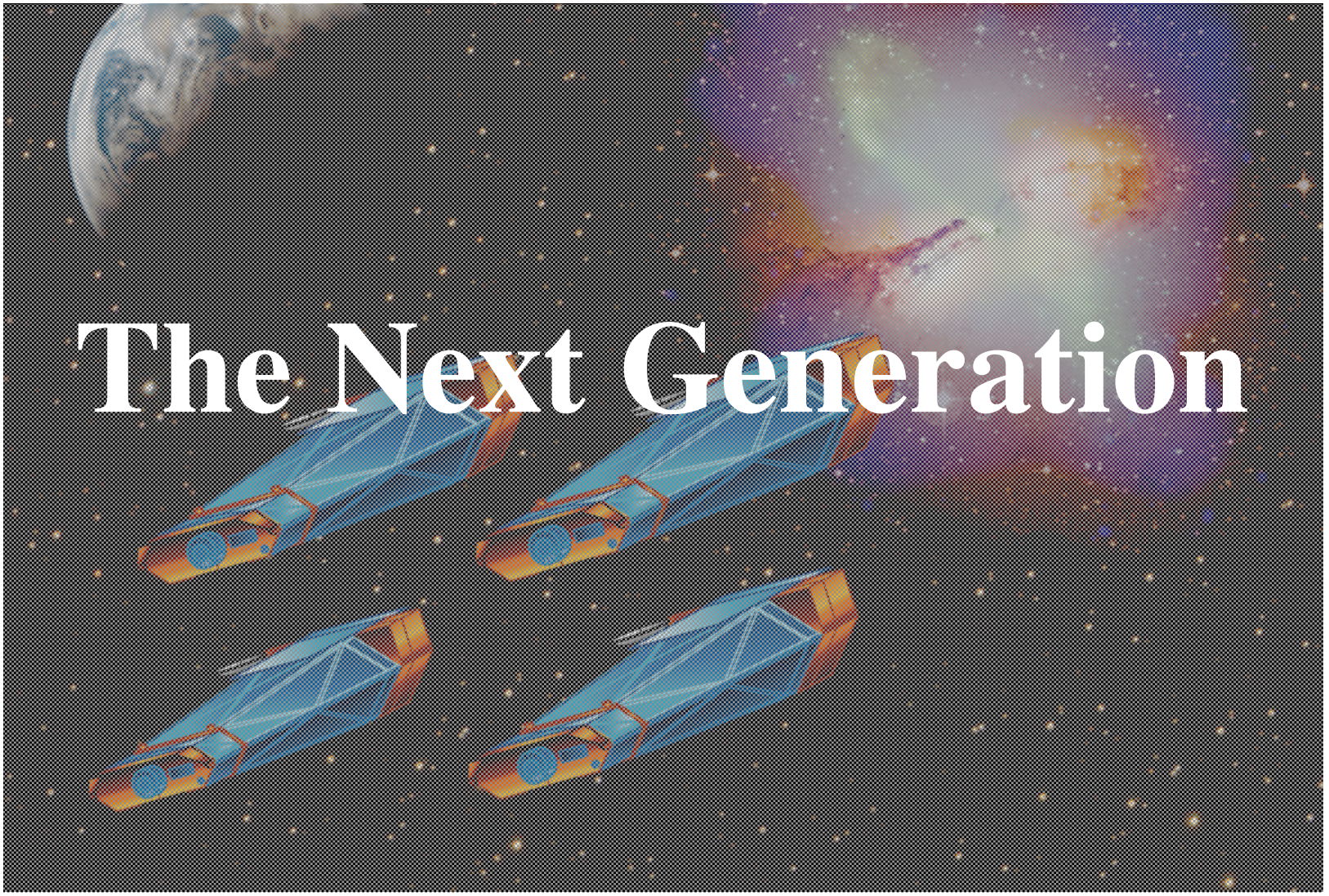
7 (54%) of the sources are X-ray detected In 2 Ms CDF-N (Alexander et al. 2003)

X-ray Properties of AGN at z>4

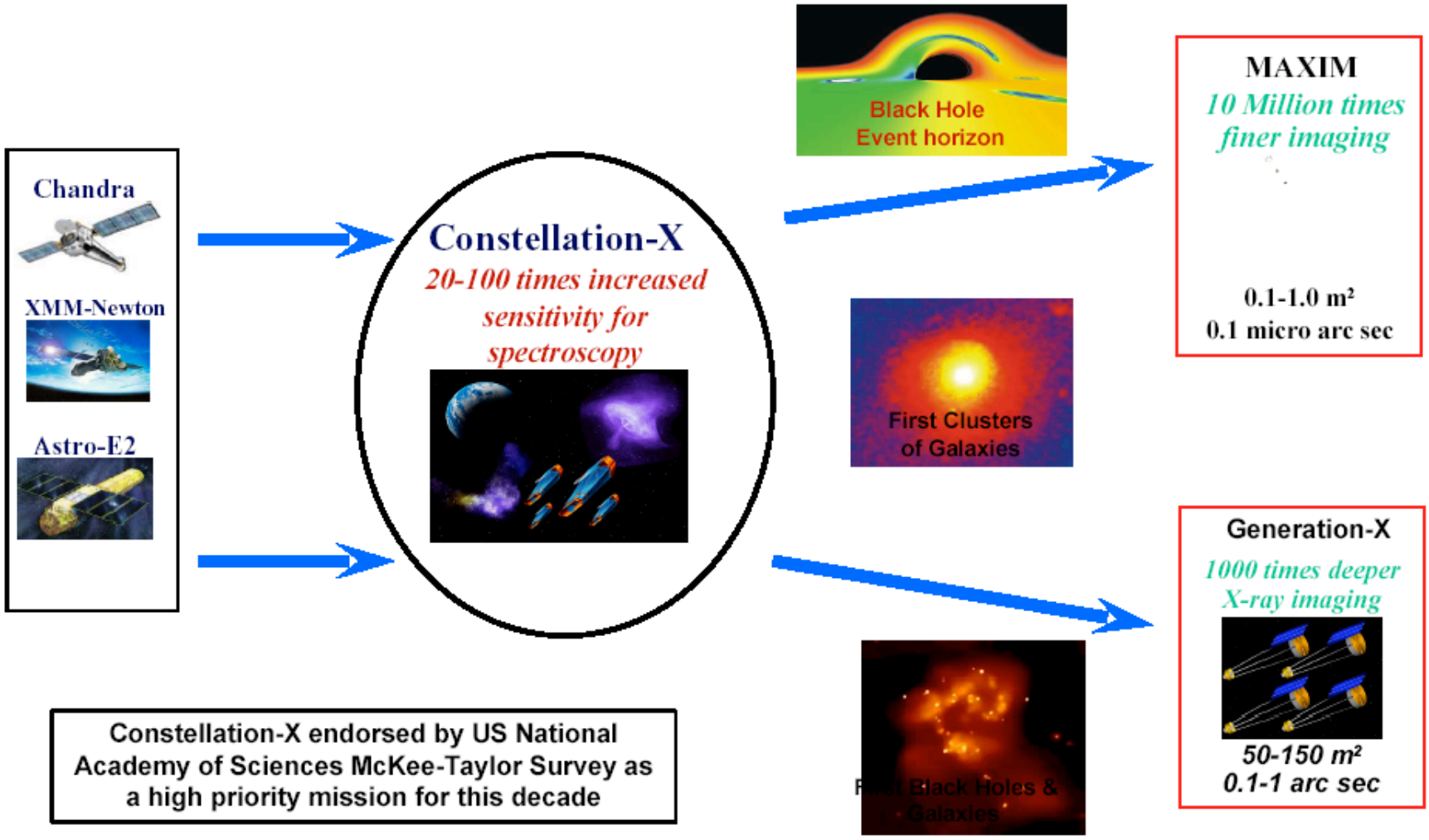
6 photons per day!

- **X-ray emitting properties (e.g. α_{OX} and spectral shape) are same at z>4 as in nearby Universe**
- **SMBH similar to local AGN formed and were actively accreting when the Universe was < 1 Gyr old**

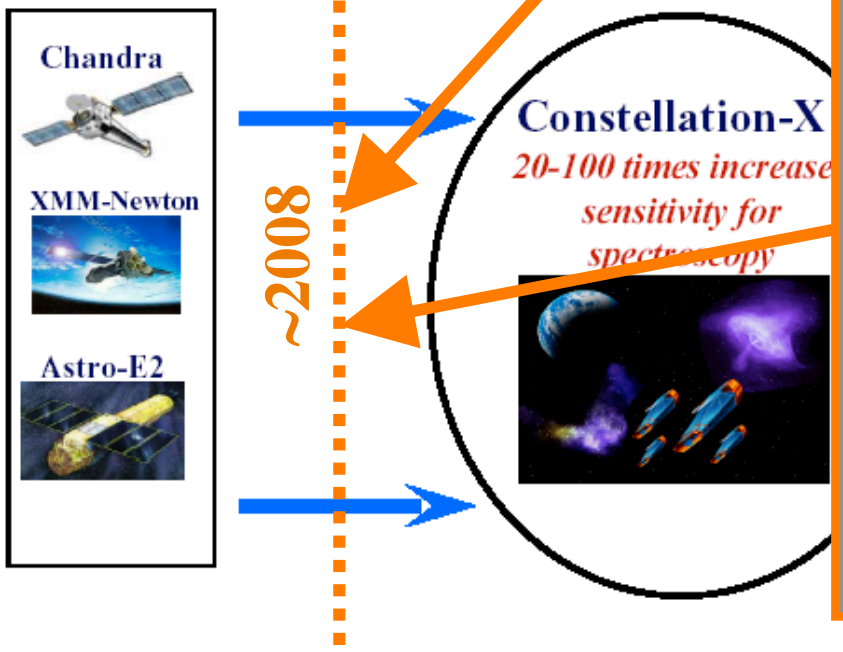



The Next Generation

NASA's X-ray Astronomy Roadmap



NASA's X-ray As



Possible MIDEX missions include

DUO

(wide-field)

&

NUSTAR

(>10 keV, hard X-rays)

+

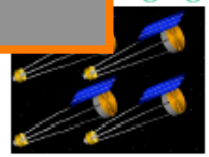
possible JAXA mission

NeXT

(hard X-rays)

XIM
on times
naging
0 m²
arc sec

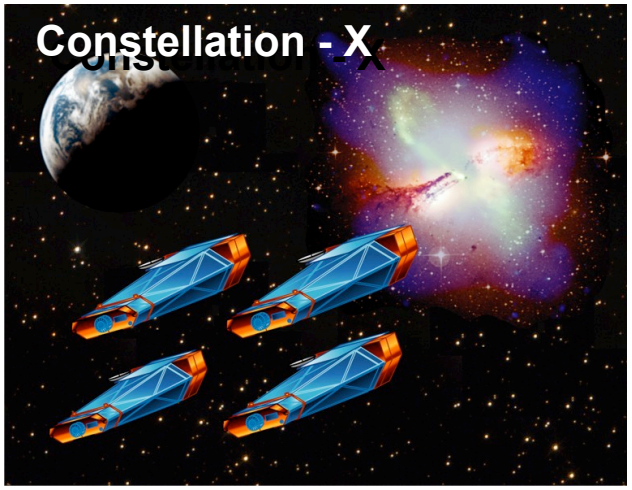
ation-X
s deeper
naging



50-150 m²
0.1-1 arc sec

Constellation-X endorsed by US National Academy of Sciences McKee-Taylor Survey as a high priority mission for this decade

Constellation-X Mission Overview



Use X-ray spectroscopy to observe

- **Strong gravity & inner accretion-disk physics**
- **Dark Matter and Dark Energy**
- **Evolution of Supermassive Black Holes & Galaxies**
- **Production and recycling of the elements**

Mission parameters

– **Telescope area:** 3 m^2 at 1 keV
25-100 times XMM/Chandra for high resolution spectroscopy

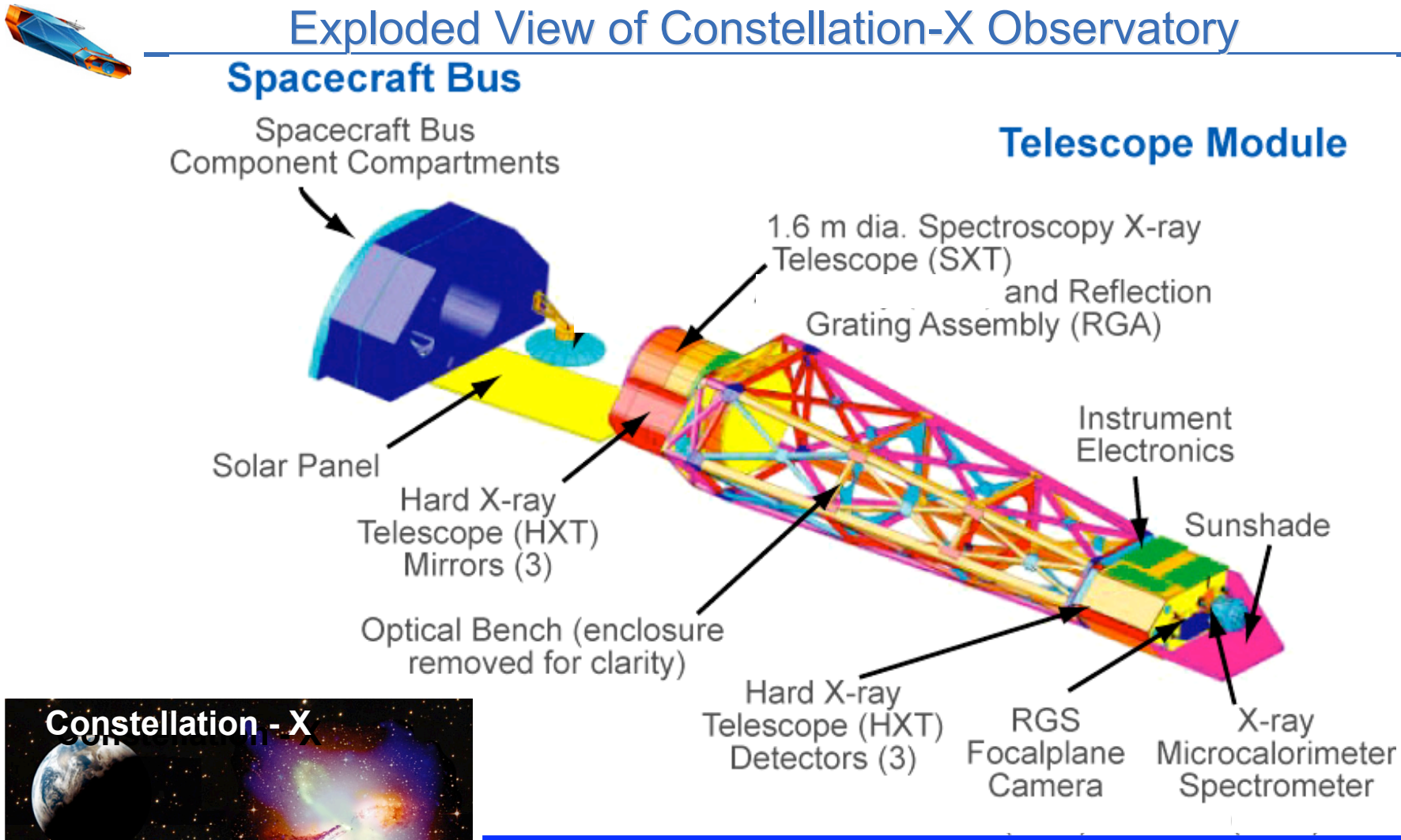
– **Spectral resolving power:** 300-1,500

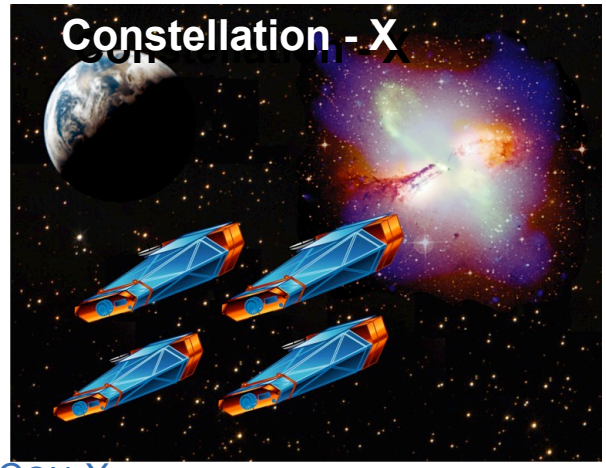
– **Band pass:** 0.25 to 40 keV

An X-ray VLT

Enable high resolution spectroscopy of faint X-ray source populations

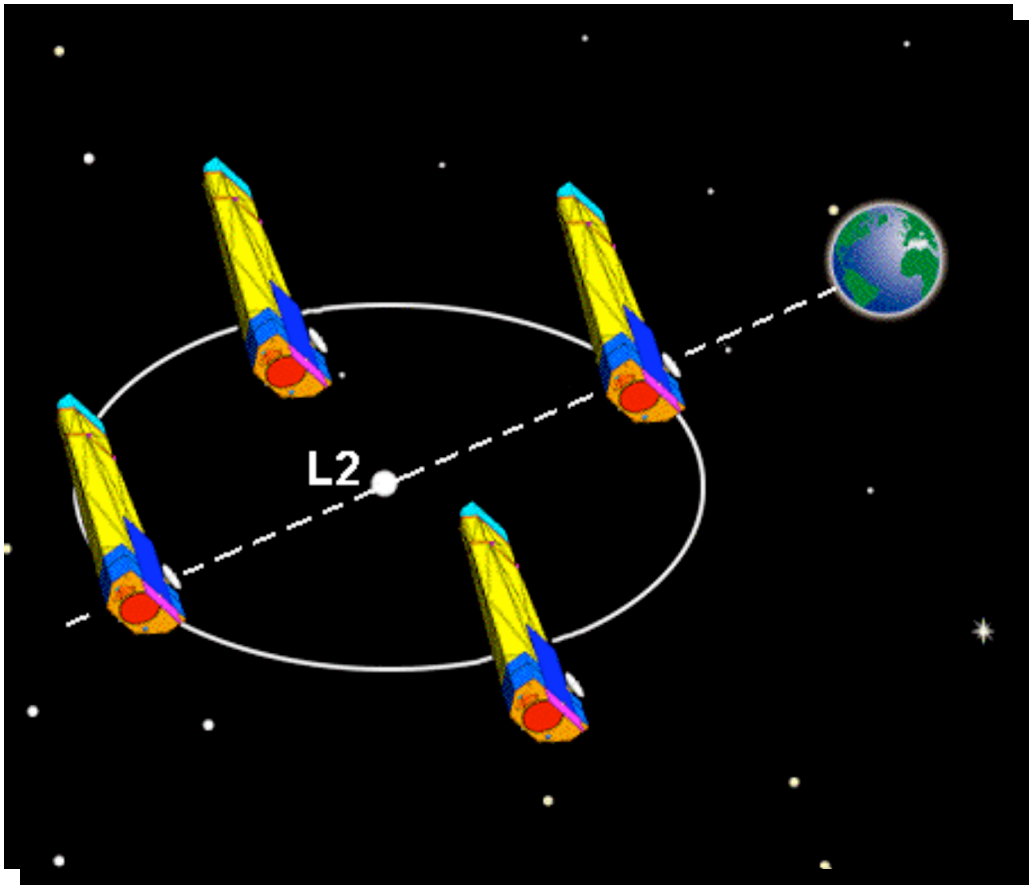
Exploded View of Constellation-X Observatory





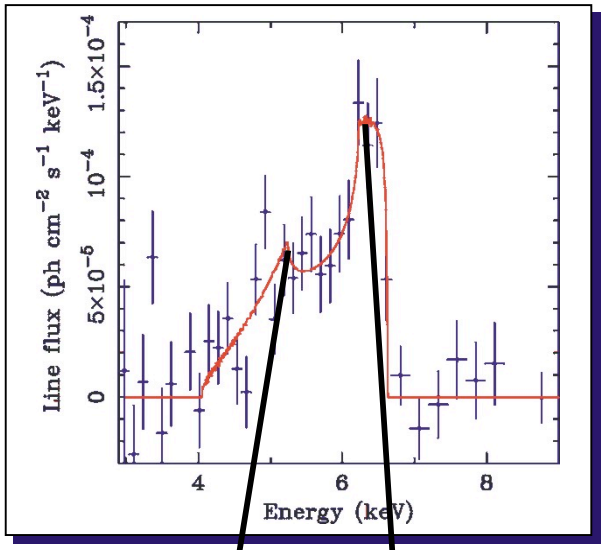
- **Baseline configuration:**
  10 m focal length, 4 spacecraft
- **ESA-merger configuration under study:**
  50 m FL, formation flying

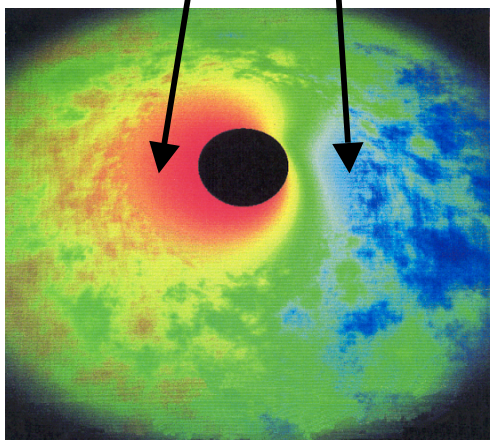
Con-X Orbit: L2



Beyond Einstein:
Probing Strong Gravity with Constellation-X

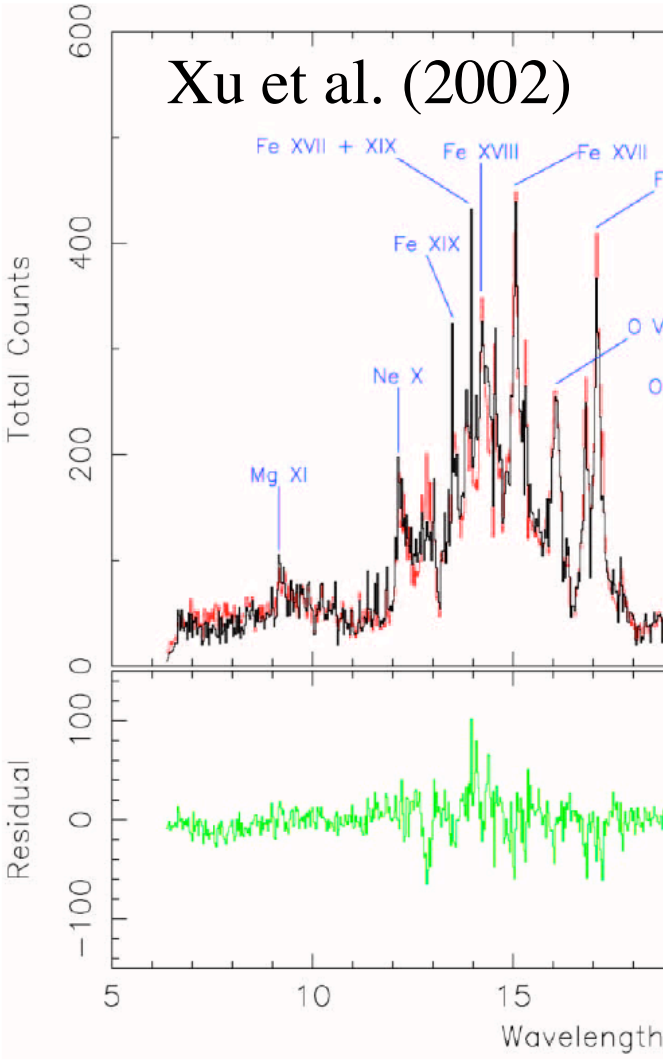
- The Iron fluorescence emission line is created when X-rays scatter and are absorbed in dense matter, close to the event horizon of the black hole.
- Test of General Relativity in the strong field regime





Theoretical 'image' of an accretion disk.

Xu et al. (2002)



absorption lines in spe
background quasars

MEASURED LINE FLUXES FROM THE CENTRAL 2′ OF NGC 4636

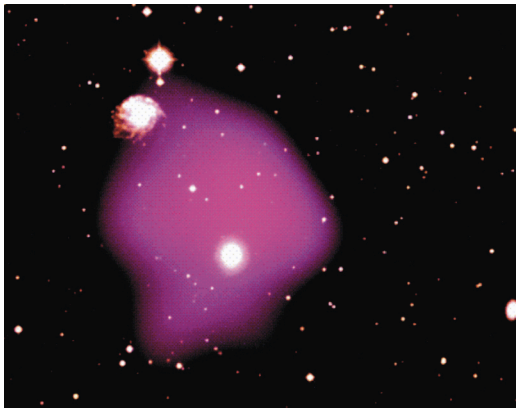
$\lambda_{observed}$ (Å)	λ_0[a] (Å)	Ion	Upper Level Configuration	J_U	Lower Level Configuration	J_L	Flux[b] (10^{-4} photons s^{-1} cm^{-2})
9.2.....	9.169	Mg^{10+}	$1s2p_{3/2}$	0	$1s^2$	0	0.59
	9.228	Mg^{10+}	$1s2p_{3/2}$	1	$1s^2$	0	
	9.231	Mg^{10+}	$1s2p_{3/2}$	2	$1s^2$	0	
	9.314	Mg^{10+}	$1s2p_{1/2}$	1	$1s^2$	0	
12.1.....	12.132	Ne^{9+}	$2p_{3/2}$	3/2	$1s$	1/2	2.24
	12.137	Ne^{9+}	$2p_{1/2}$	1/2	$1s$	1/2	
13.5.....	13.447	Ne^{8+}	$1s2p_{3/2}$	0	$1s^2$	0	2.15
	13.550	Ne^{8+}	$1s2p_{3/2}$	1	$1s^2$	0	
	13.553	Ne^{8+}	$1s2p_{3/2}$	2	$1s^2$	0	
	13.698	Ne^{8+}	$1s2p_{1/2}$	1	$1s^2$	0	
14.2.....	14.208	Fe^{17+}	$2p_{1/2}2p^3_{3/2}3d_{3/2}$	5/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	1.90
	14.208	Fe^{17+}	$2p_{1/2}2p^3_{3/2}3d_{5/2}$	3/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	
14.3.....	14.256	Fe^{17+}	$2p_{1/2}2p^3_{3/2}3d_{3/2}$	1/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	1.45
	14.267	Fe^{19+}	$2s2p^2_{1/2}2p_{3/2}3s$	3/2	$2s2p^2_{1/2}2p^2_{3/2}$	5/2	
14.4.....	14.373	Fe^{17+}	$2p_{1/2}2p^3_{3/2}3d_{3/2}$	5/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	1.85
14.5.....	14.534	Fe^{17+}	$2p^2_{1/2}2p^2_{3/2}3d_{5/2}$	5/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	2.25
	14.571	Fe^{17+}	$2p^2_{1/2}2p^2_{3/2}3d_{5/2}$	3/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	
15.0.....	15.014	Fe^{16+}	$2p_{1/2}2p^4_{3/2}3d_{3/2}$	1	$2p^2_{1/2}2p^4_{3/2}$	0	3.56
15.3.....	15.261	Fe^{16+}	$2p^2_{1/2}2p^3_{3/2}3d_{5/2}$	1	$2p^2_{1/2}2p^4_{3/2}$	0	1.66
16.1.....	16.004	Fe^{17+}	$2p^2_{1/2}2p^2_{3/2}3s$	3/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	1.99
	16.006	O^{7+}	$3p_{3/2}$	3/2	$1s$	1/2	
	16.007	O^{7+}	$3p_{1/2}$	1/2	$1s$	1/2	
	16.071	Fe^{17+}	$2p^2_{1/2}2p^2_{3/2}3s$	5/2	$2p^2_{1/2}2p^3_{3/2}$	3/2	
	16.110	Fe^{18+}	$2s^22p_{1/2}2p^2_{3/2}3p_{1/2}$	2	$2s2p^2_{1/2}2p^3_{3/2}$	2	
16.8.....	16.780	Fe^{16+}	$2p_{1/2}2p^4_{3/2}3s$	1	$2p^2_{1/2}2p^4_{3/2}$	0	2.33
17.0.....	17.051	Fe^{16+}	$2p^2_{1/2}2p^3_{3/2}3s$	1	$2p^2_{1/2}2p^4_{3/2}$	0	5.66
17.1.....	17.096	Fe^{16+}	$2p^2_{1/2}2p^3_{3/2}3s$	2	$2p^2_{1/2}2p^4_{3/2}$	0	
19.0.....	18.967	O^{7+}	$2p_{3/2}$	3/2	$1s$	1/2	1.96
	18.973	O^{7+}	$2p_{1/2}$	1/2	$1s$	1/2	
21.7.....	21.602	O^{6+}	$1s2p_{3/2}$	0	$1s^2$	0	<0.13
21.9.....	21.801	O^{6+}	$1s2p_{3/2}$	1	$1s^2$	0	<0.09
	21.804	O^{6+}	$1s2p_{3/2}$	2	$1s^2$	0	
22.2.....	22.097	O^{6+}	$1s2p_{1/2}$	1	$1s^2$	0	<0.21
24.9.....	24.779	N^{6+}	$2p_{3/2}$	3/2	$1s$	1/2	<0.20
	24.785	N^{6+}	$2p_{1/2}$	1/2	$1s$	1/2	
28.9–29.6...	28.780	N^{5+}	$1s2p_{3/2}$	0	$1s^2$	0	<0.43
	29.082	N^{5+}	$1s2p_{3/2}$	1	$1s^2$	0	
	29.084	N^{5+}	$1s2p_{3/2}$	2	$1s^2$	0	
	29.535	N^{5+}	$1s2p_{1/2}$	1	$1s^2$	0	

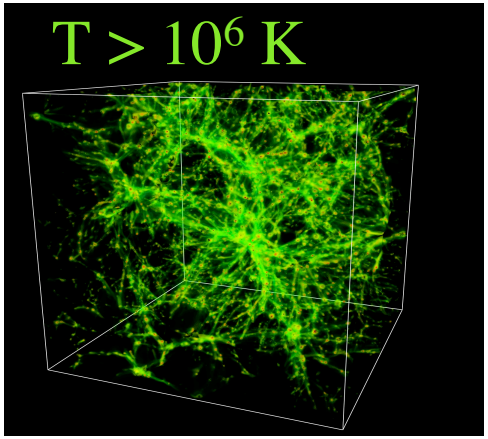
[a] The quantity λ_0 is the wavelength quoted from literature (e.g., Behar et al. 2001; Brown et al. 1998; Drake 1988).
[b] The fluxes shown are the total for the blend of lines at each $\lambda_{observed}$.

Cosmology with Con-X:

tracing dark matter, baryons & metals in groups, clusters and the WHIM

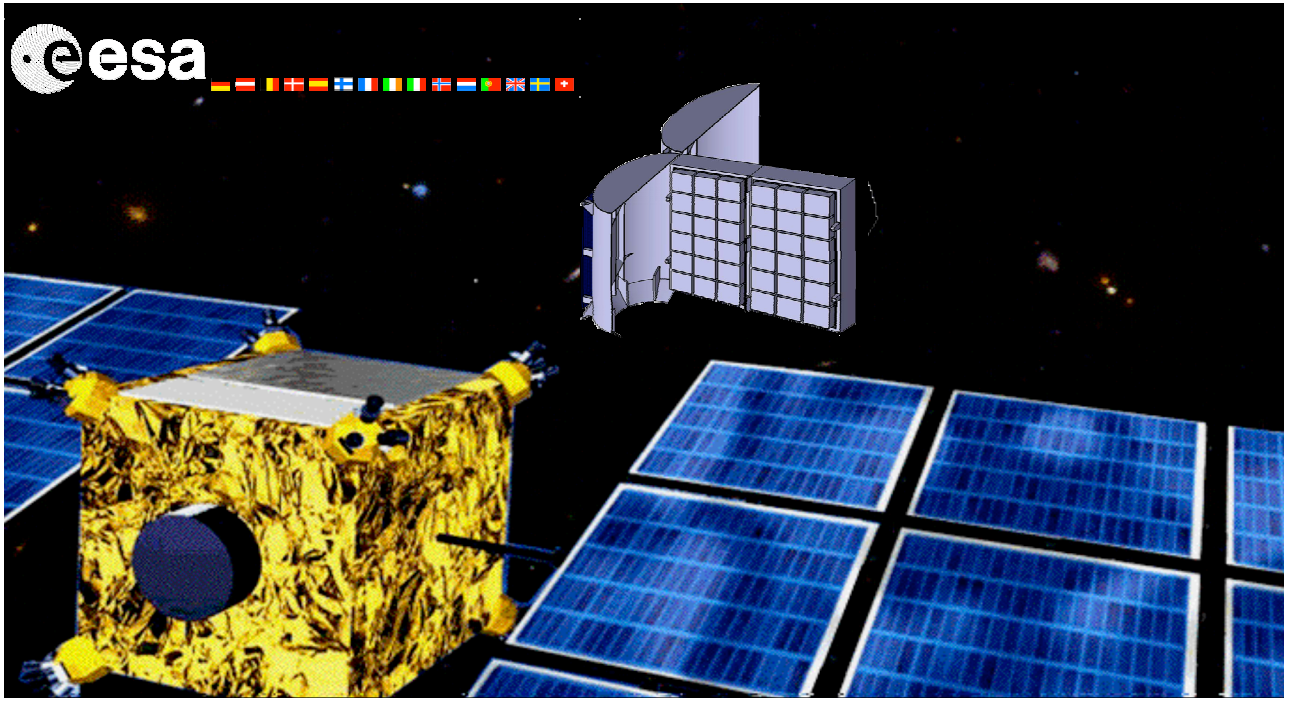
- **Studies of intra-group and intra-cluster medium (where large fraction of all baryons live!) will soon be revolutionized by ASTRO-E2 (non-dispersive high-resolution spectroscopy)**
- Temperature, abundance, and density distribution of the hot IGM will be detected via absorption lines in spectra of background quasars





ESA's Next Generation: XEUS

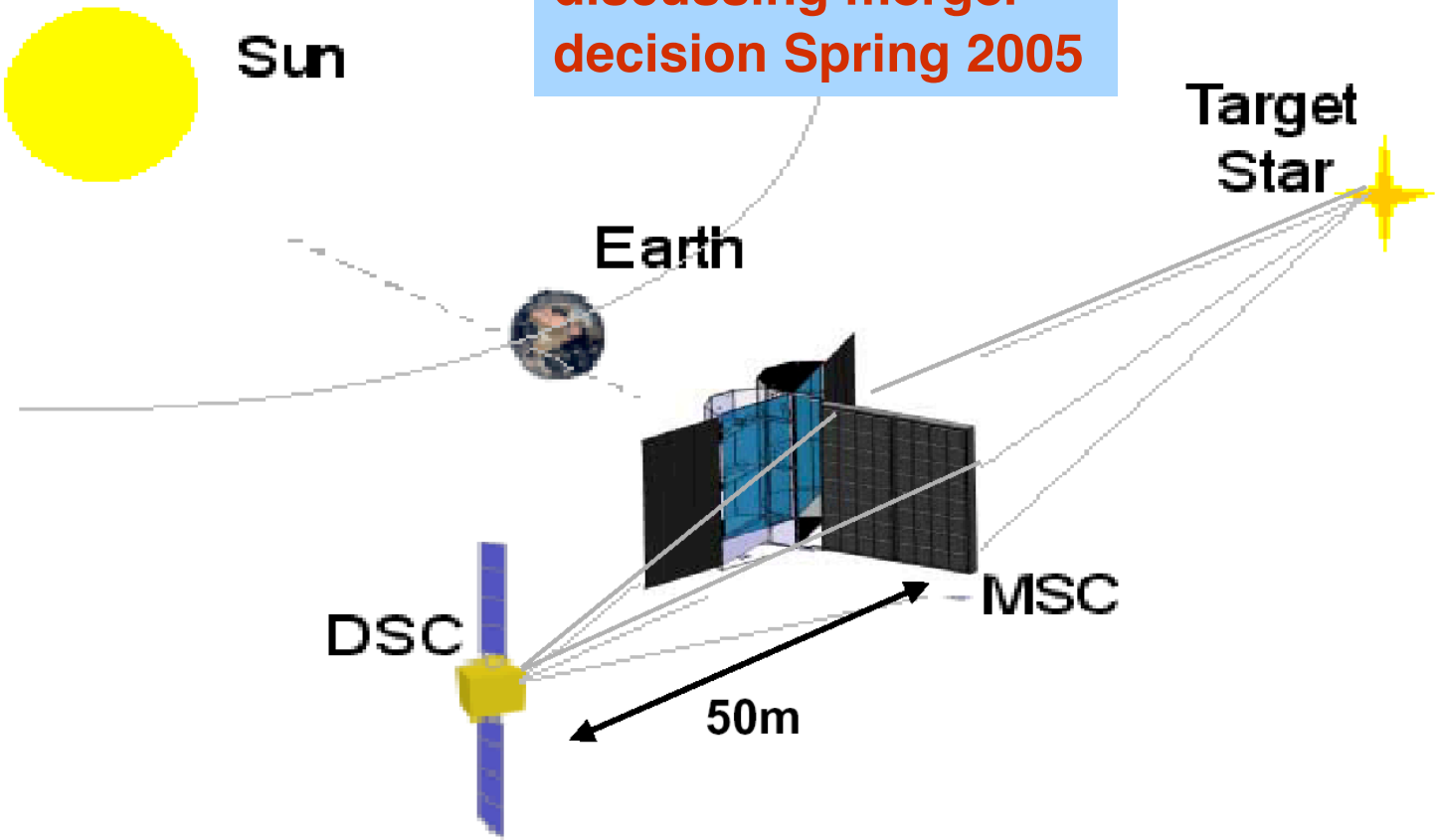
- 10 m^2 telescope effective area at 1 keV (revolutionary pore optics, ≈3× area Con-X)
- Wide Field Imager (WFI), 2"-5" HPD PSF



Thanks to Guenther Hasinger & Arvind Parmar

XEUS Configuration

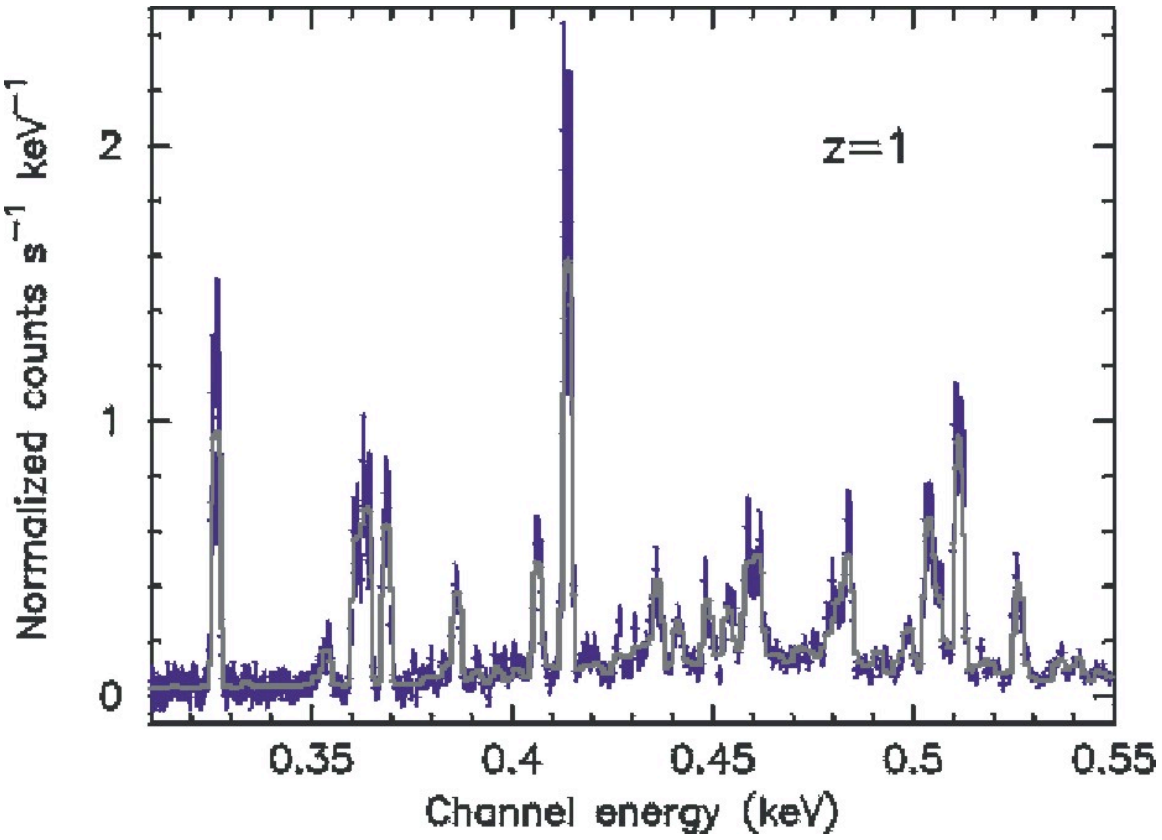
NASA-Con-X Team & ESA-XEUS team discussing merger → decision Spring 2005



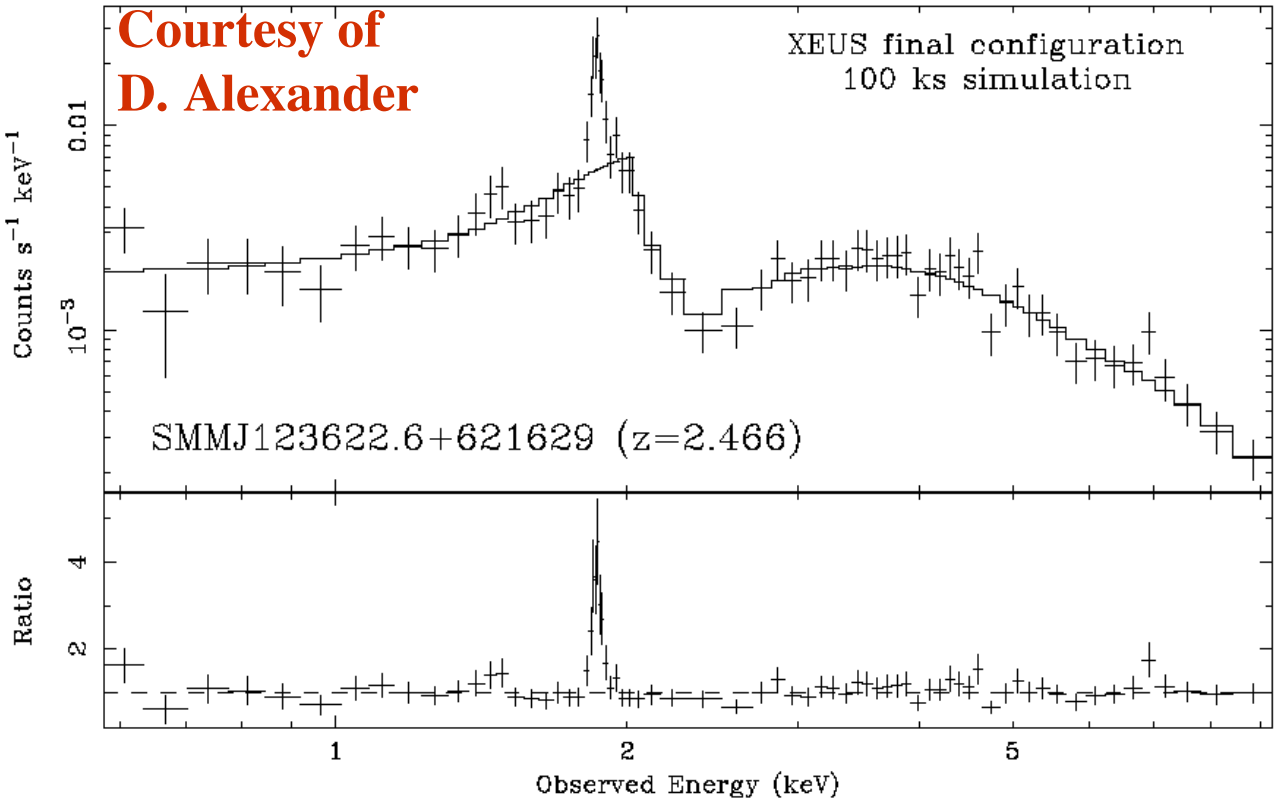
Simulated Constellation-X/ XEUS Spectroscopic Observations of AGN

Constellation-X, 100 ks simulation:
Seyfert Galaxy at z~1

Starburst superwind gives rise to Fe-L emission:
Invisible at optical/UV wavelengths

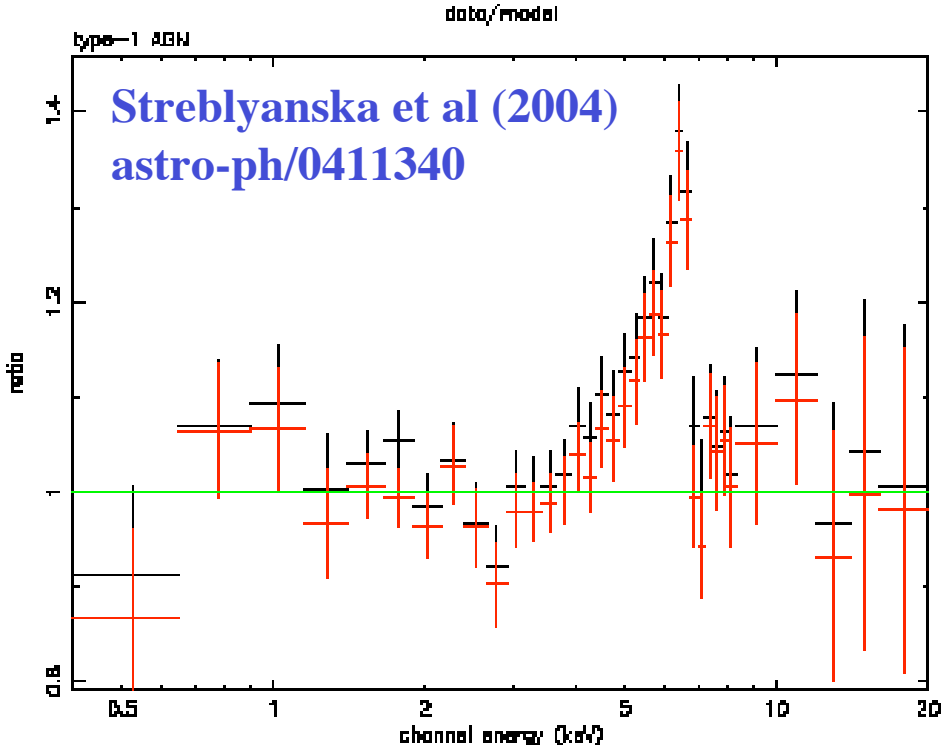


XEUS/Constellation-X Simulation, 1 Ms:
Submm Galaxy at z~2.5



Constellation-X "Simulation"

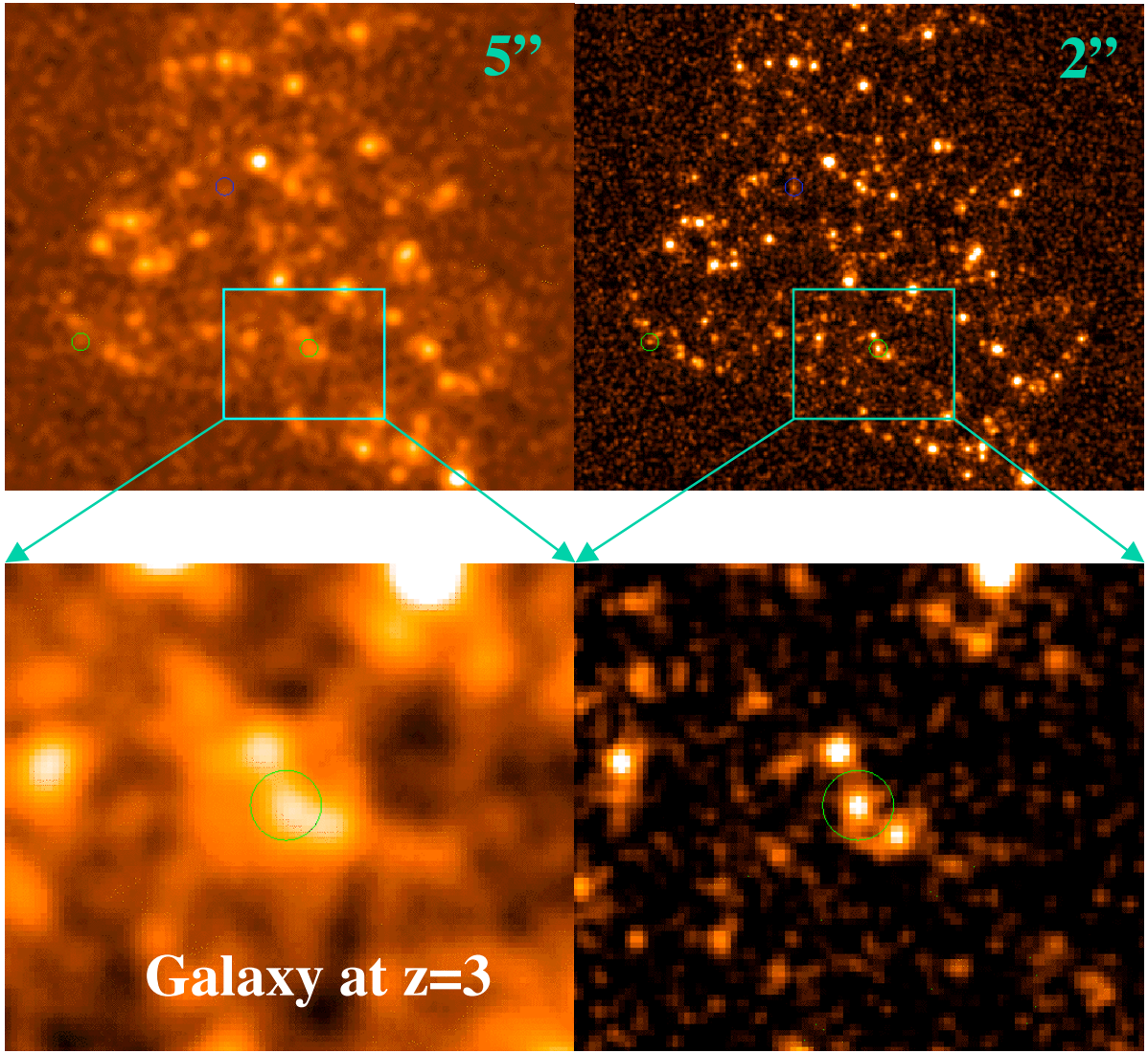
using XMM-Newton Lockman Hole observations



Stacked XMM spectrum of 53 Type 1 AGN

The future of X-ray Astronomy:
Simulated XEUS
IMAGING Observations of Galaxies

Simulations of XEUS HDF 1 million sec observation at different angular resolutions

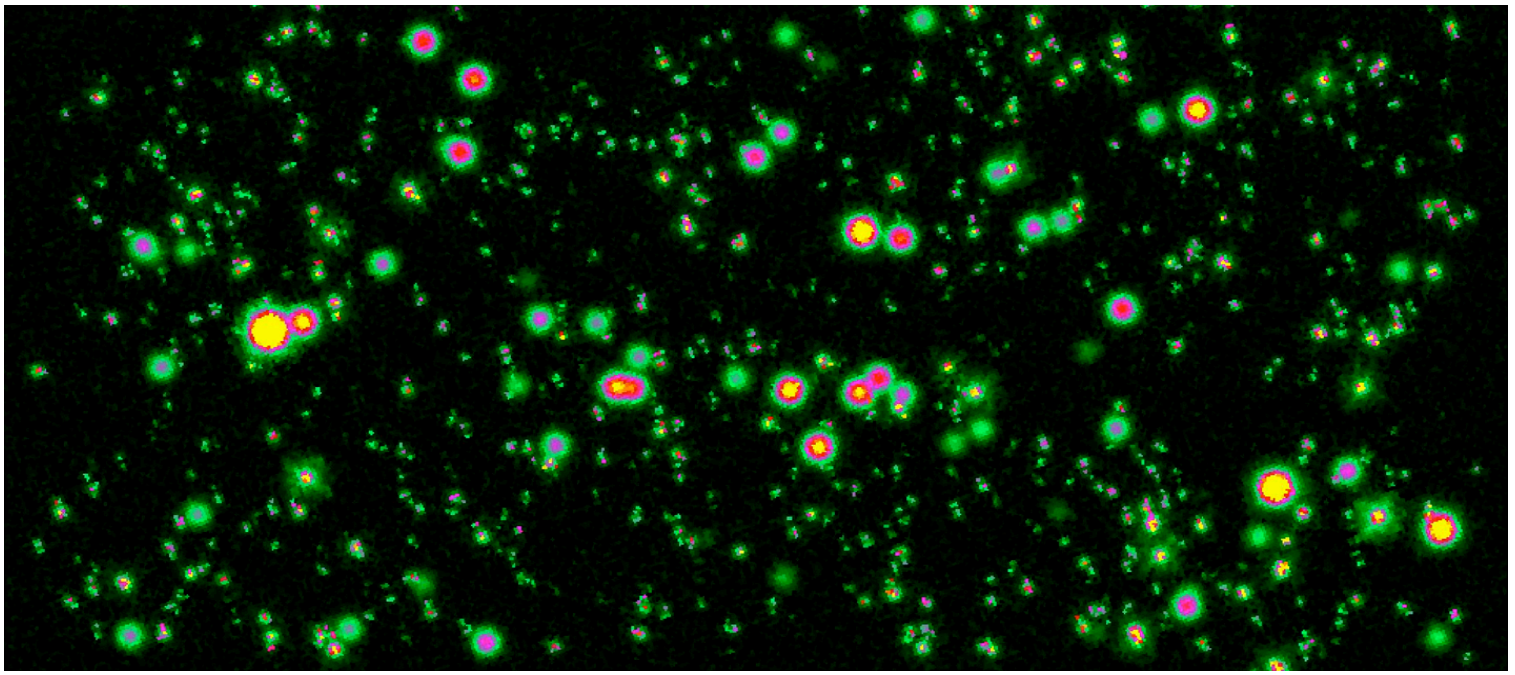


Simulated Generation-X Deep Survey Observations

(thanks to Roger Brissenden, SAO)

Gen-X View of the Hubble Deep Field

100 m^2 effective area and 0.1" PSF



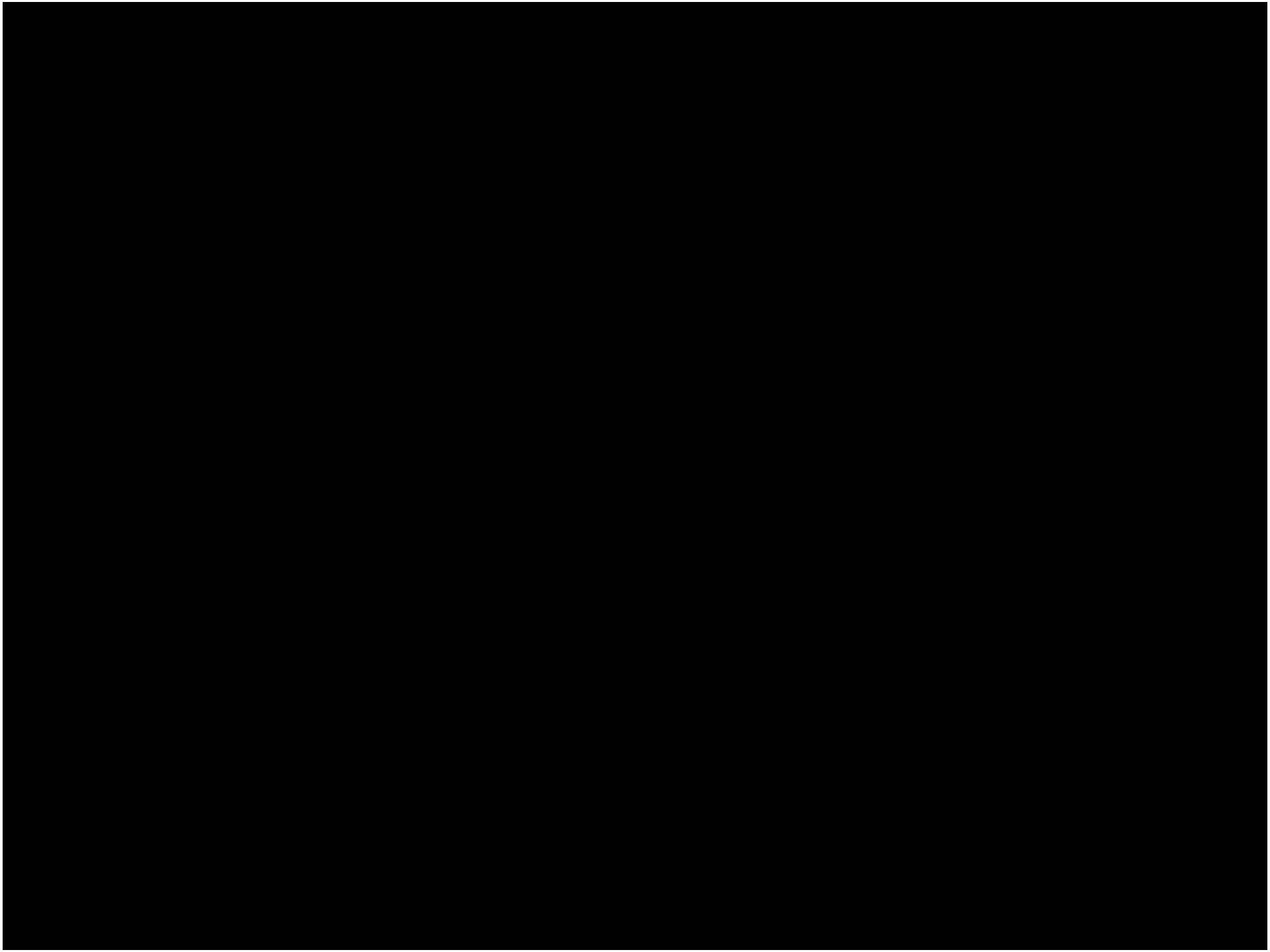
- Simulated 1Ms exposure of the HDF shows most of the 3000 galaxies detected by Hubble

Conclusions
(2nd to last slide)

- High-resolution X-ray spectroscopy will become available for a large number of sources with the launch of Constellation-X
- A merged NASA-ESA mission is under consideration, with particularly high stakes for high-z studies
- The Generation-X mission is planned to detect the first black holes and galaxies at high energy

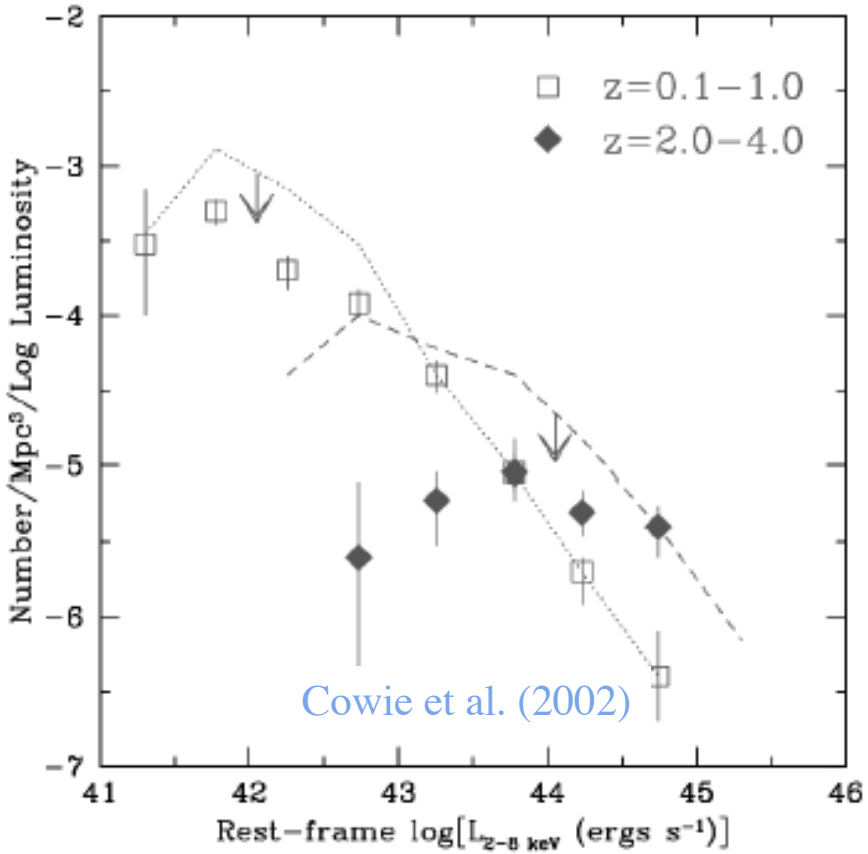
Submit a Constellation-X "Proposal"

- Members of the community are invited to submit "mock proposals" to the Constellation-X project : http://constellation.gsfc.nasa.gov
- Look for "Observation Design Reference Mission"
- **Questions? Email me: annh@milkyway.gsfc.nasa.gov**



"Anti-hierarchal Growth" →

probing lower-luminosity AGN in X-rays



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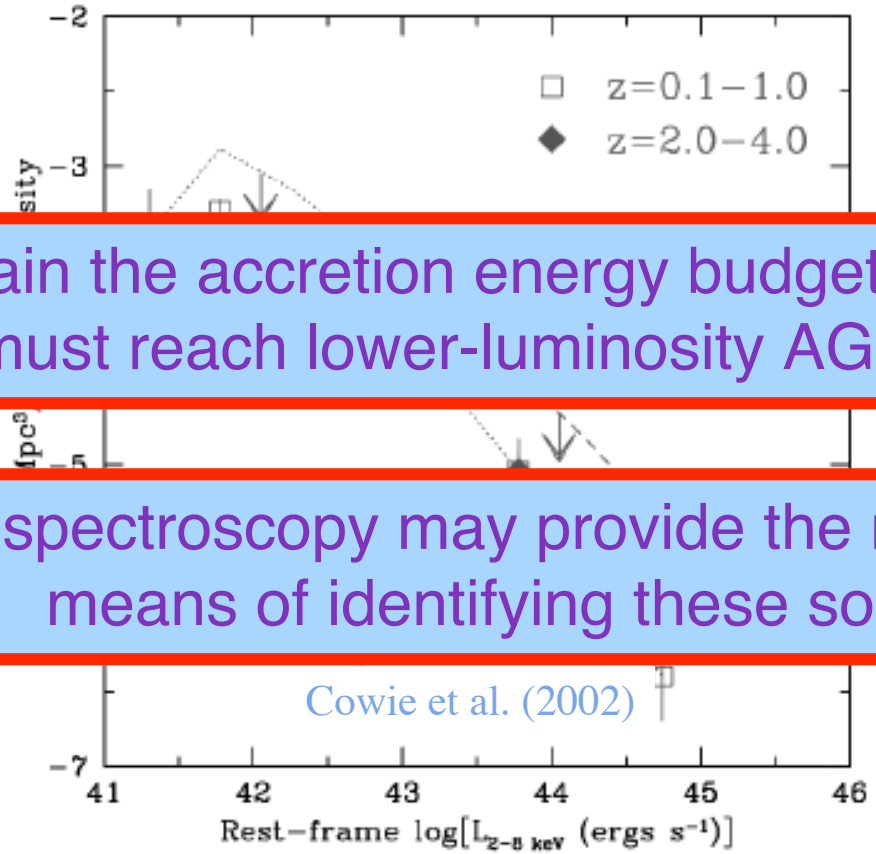

To constrain the accretion energy budget of the Universe, must reach lower-luminosity AGN at z~1

X-ray spectroscopy may provide the most feasible means of identifying these sources

Comparison of Effective Areas:

Past and Future X-ray Missions