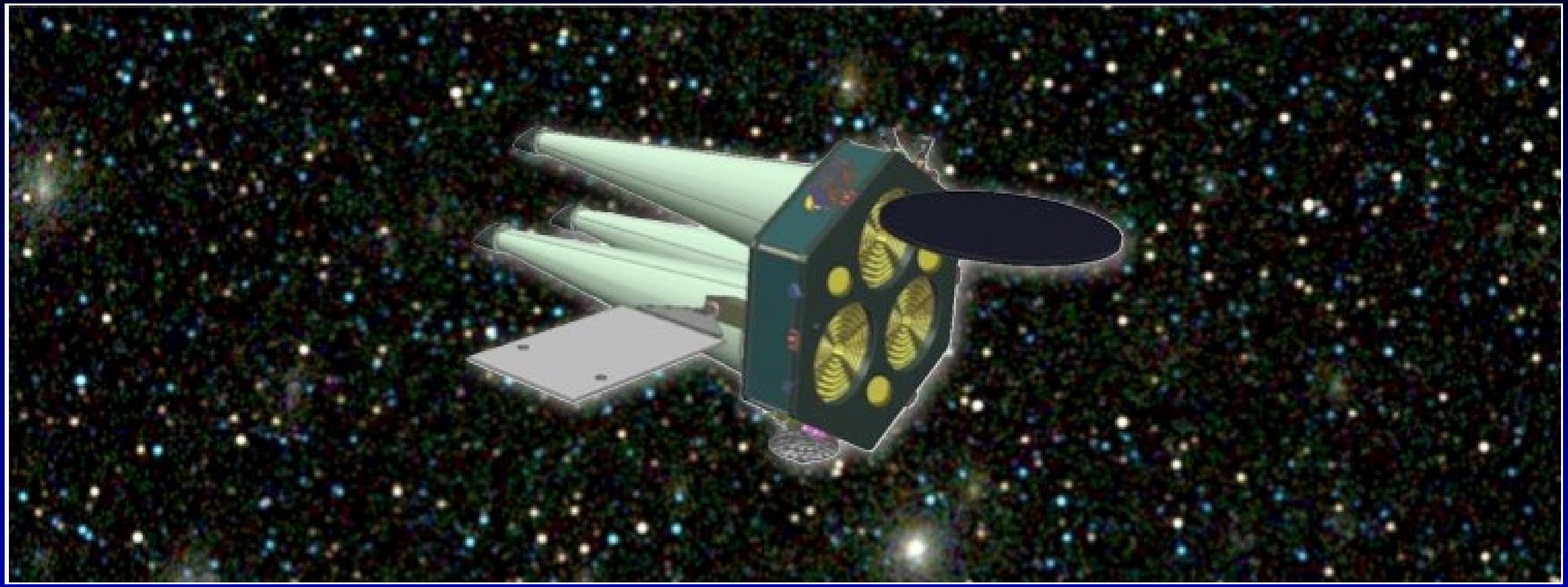


Wide Field X-ray Telescope

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

http://www.wfxt.eu/

Stephen Murray for the WFXT Collaboration
Johns Hopkins University
Dec. 14, 2011

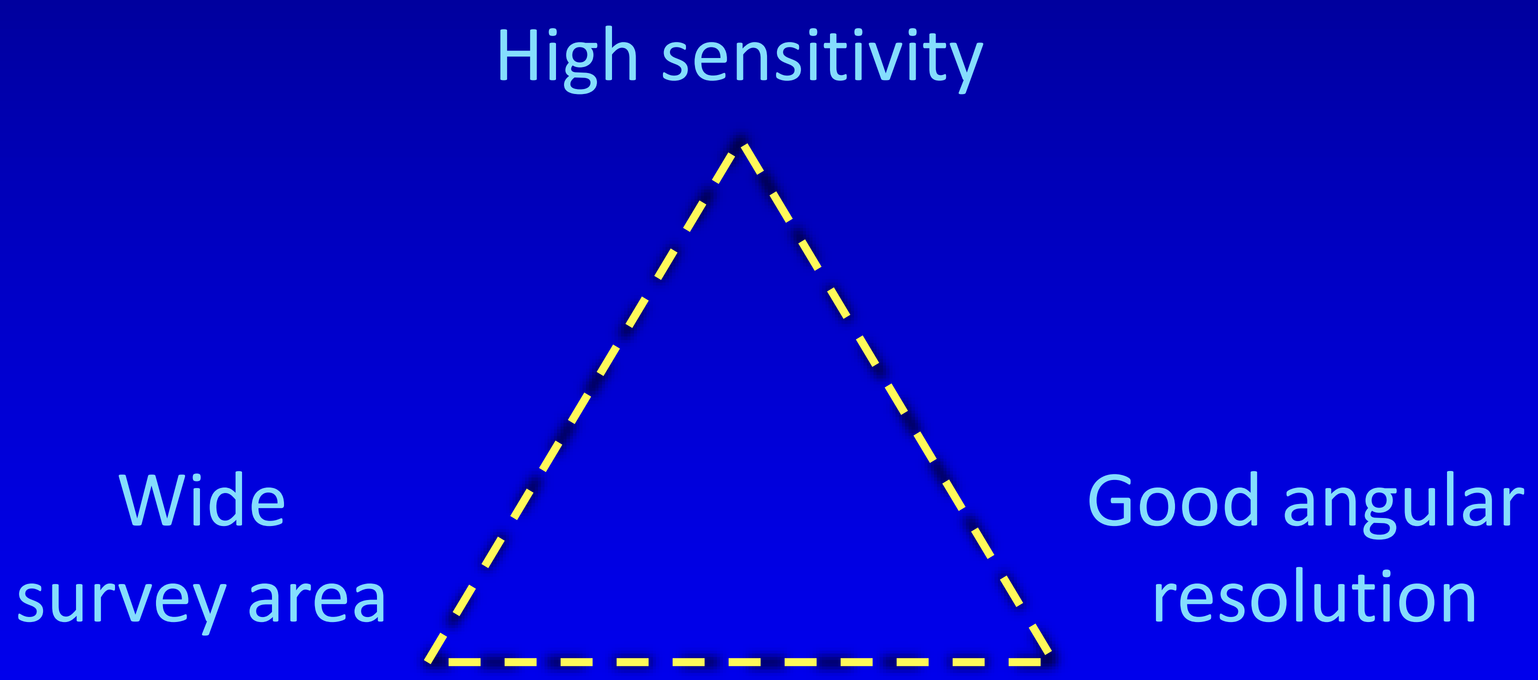
WFXT Collaboration

JHU: Stephen S. Murray (PI), Kip Kuntz, Riccardo Giacconi, Timothy Heckman, Suvi Gezari
APL: Hal Weaver, Carey Lisse, Neil Miller, Cheryl Reed
CfA: Alexey Vikhlinin, William Forman, Christine Jones, Andrew Goulding, Paul Reid, Andreas Zezas, Pepi Fabbiano
MSFC: Martin Weiskopf, Brian Ramsey, Ron Elsner, Steve ODell
GSFC: Andrew Ptak
MIT: Mark Bautz
Dartmouth: Ryan Hickox
PSU: Niel Brandt, Eric Feigleson, Don Schneider
Princeton: Neta Bahcall
Stanford: Steve Allen
MSU: Megan Donahue, Mark Voit

U. Michigan: Gus Evrard
STScI: Kathryn Flanagan, Carol Christian
U. Chicago: Andrey Kravtsov
U. Waterloo: Brian McNamara
ESO: Piero Rosati, Paolo Padovani
MPE: Rashid Sunyaev
U. Trieste: Stefano Borgani
U. Naples: Maurizio Paolillo
INAF-Brera: Giovanni Pareschi, Oberto Citterio, Gianpiero Tagliaferri, Sergio Campana, Ginevra Trinchieri, Marta Civitani, Alberto Moretti
INAF-Bologna: Roberto Gilli
INAF-Trieste: Paolo Tozzi, Joana Santos, Barbara Sartoris
INAF-Capodimonte: Massimo Della Valle, Domitilla de Martino
ASI Science Data Center: Paolo Giommi

The Future of X-ray Surveys

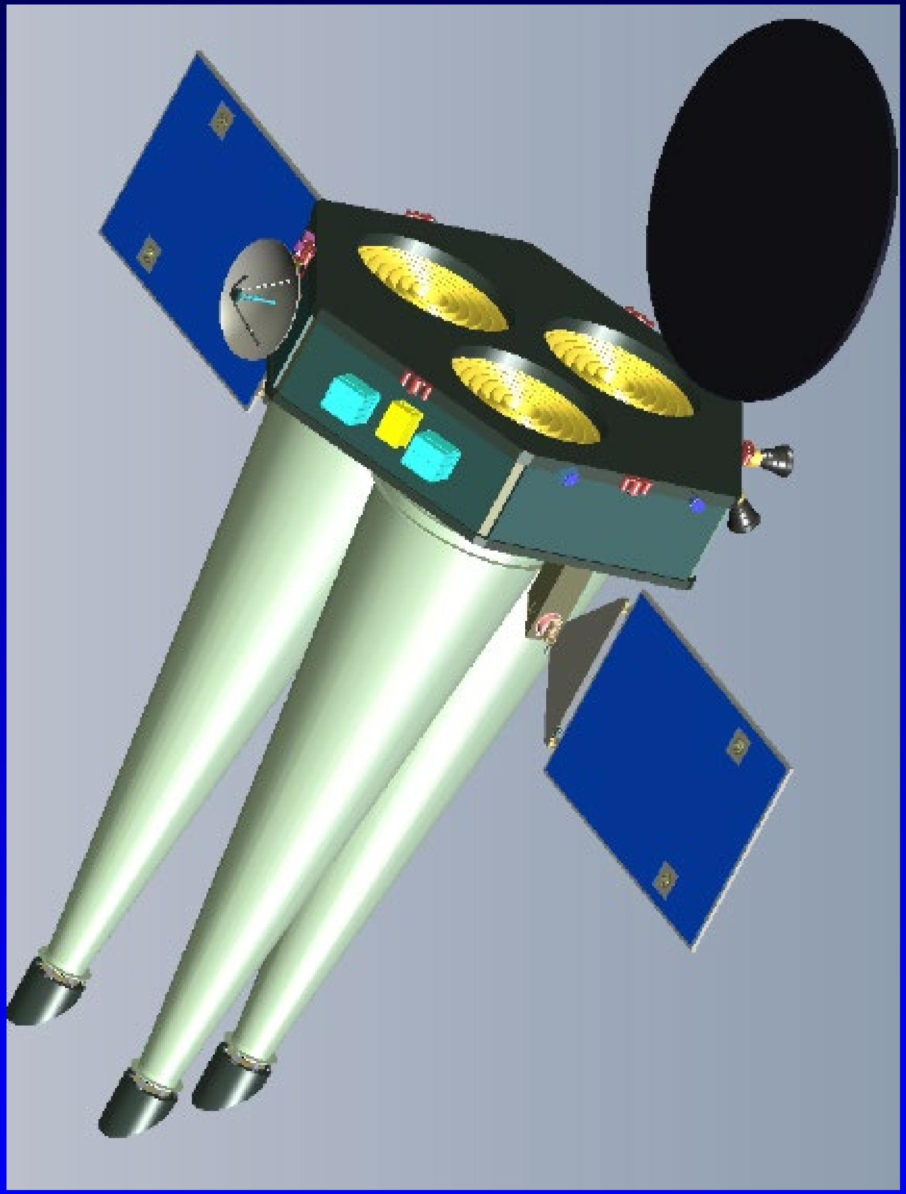
First SMBHs, galaxy/AGN co-evolution, feedback mechanisms, cosmic cycle of baryons, structure formation, precision cosmology - all require:



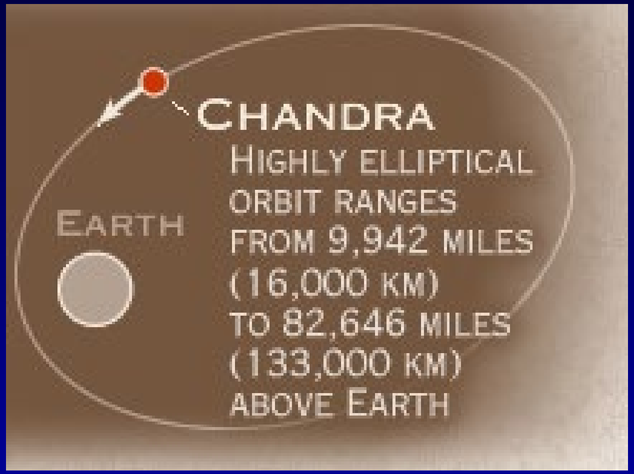
Can be done with a specific X-ray optical design and modest technological development, ready to be done now

Beyond eROSITA - WFXT

- Three co-aligned 5” HEW, 1 degree FoV telescopes, with CCD camera
- ~10x Chandra effective area @ 1 keV



Robust multiple telescope/detector system



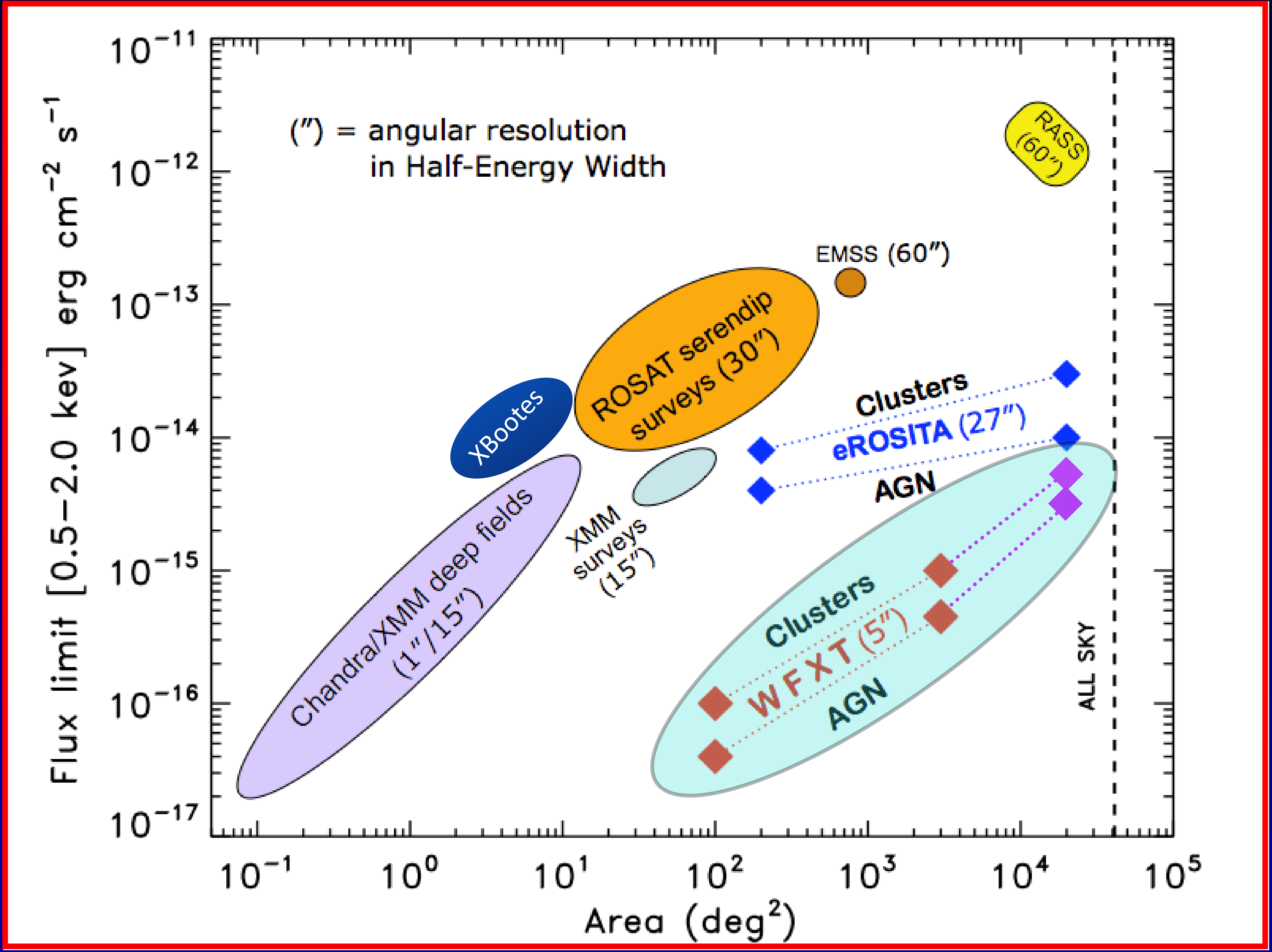
Chandra-like HEO
64 hr period
Large field of regard
Long observations

or

Low Earth Orbit
550 km @ 6^0
Low Background

WFXT

"SDSS" for X-rays
(Wide), Medium and Deep Surveys



Dramatic advance over existing/planned missions in combined solid angle/sensitivity
Proven large discovery space

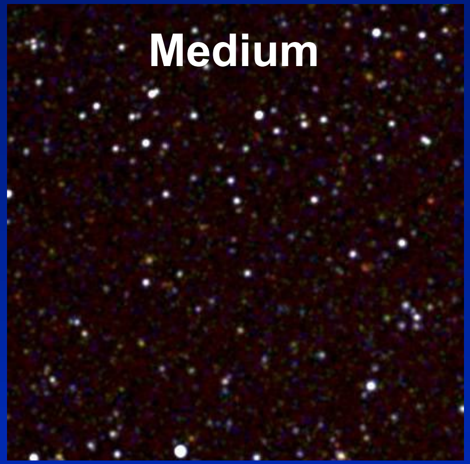
Two (three) surveys
- (Wide 15,000 deg^2)
- Medium 3000 deg^2
- Deep 100 deg^2, 800 times CDFs

GO Program
- 40% Observing time

WFXT Surveys

WFXT Deep Survey = 100 sq deg
~800 times solid angle equivalent of Chandra Deep Fields

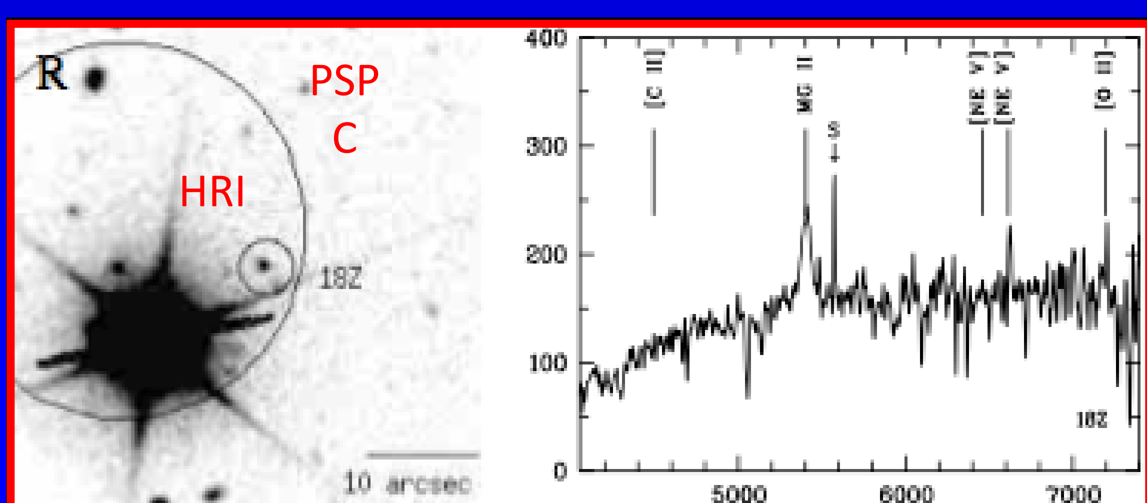
Description of the WFXT Surveys		
Quantity	Survey	
	Deep	Medium
Ω (deg^2)	100	3,000
Exposure	400 ksec	13 ksec
Total Time	1.5 yr	1.5 yr
S_{min}(0.5-2 keV) point-like erg s^{-1} cm^{-2} at 3σ	4.0×10^{-17}	4.5×10^{-16}
Total AGN Detected	$\sim 4.7 \times 10^5$	$\sim 4.4 \times 10^6$
S_{min}(0.5-2 keV) extended erg s^{-1} cm^{-2} at 5σ	1×10^{-16}	1×10^{-15}
Total Clusters/Groups	$\sim 3 \times 10^4$	$\sim 2 \times 10^5$

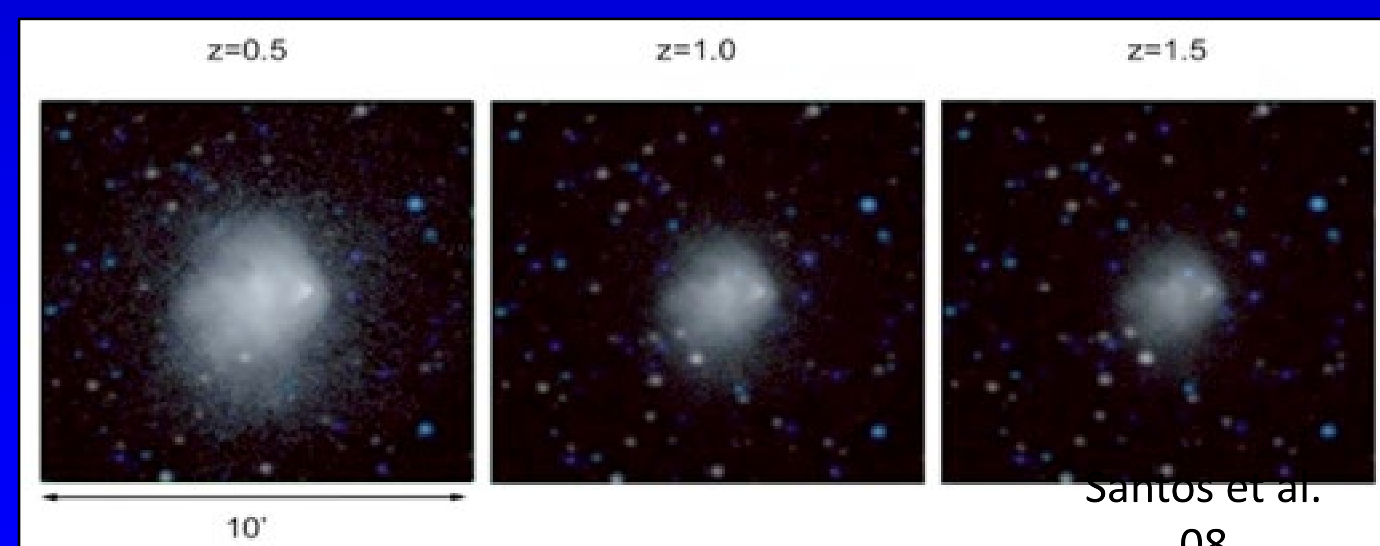


Angular resolution

HEW= 5” goal over the entire FoV

- Improve sensitivity for point and extended sources, AGN/cluster/group discernment at any redshift
- Minimize source confusion, especially confusion free Deep survey
- Efficient identification of optical counterparts, Chandra-like id accuracy (<1” radius error circle, >90% right IDs), essential for $5x10^6$ AGN and 2×10^5 clusters!
- Detect sharp features of the ICM (shocks, cold fronts, cavities)
- Resolve cool cores of z>1 clusters (essential for cosmological applications, reliable mass proxy)



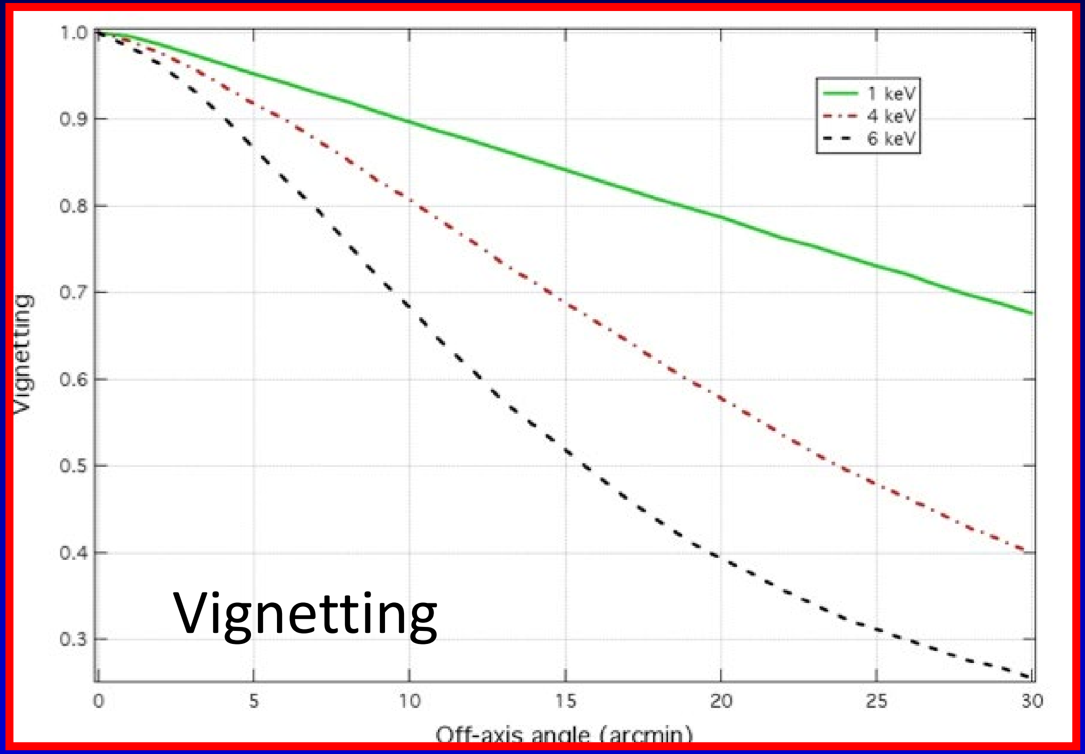


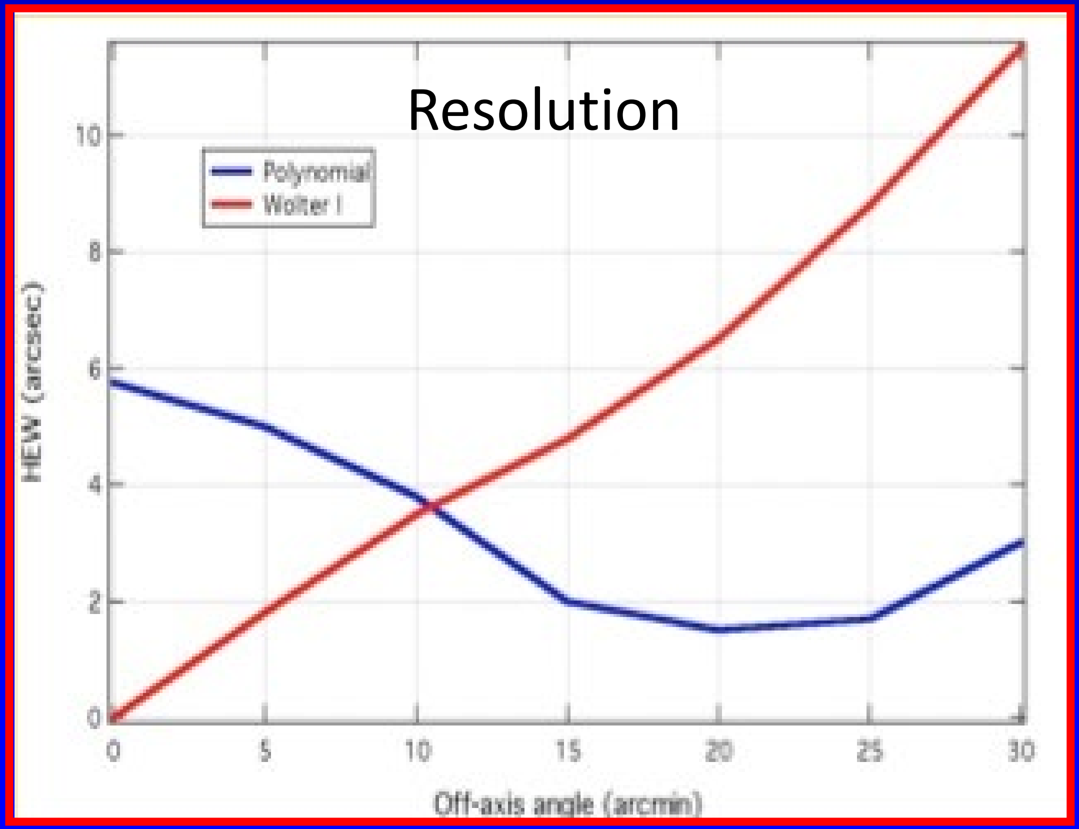
ROSAT Lockman Hole survey (25” vs 5” resolution) (Lehmann et al. 2001)

Approved for public release,distribution unlimited

WFXT Telescope Design

Key to Wide Field Surveys





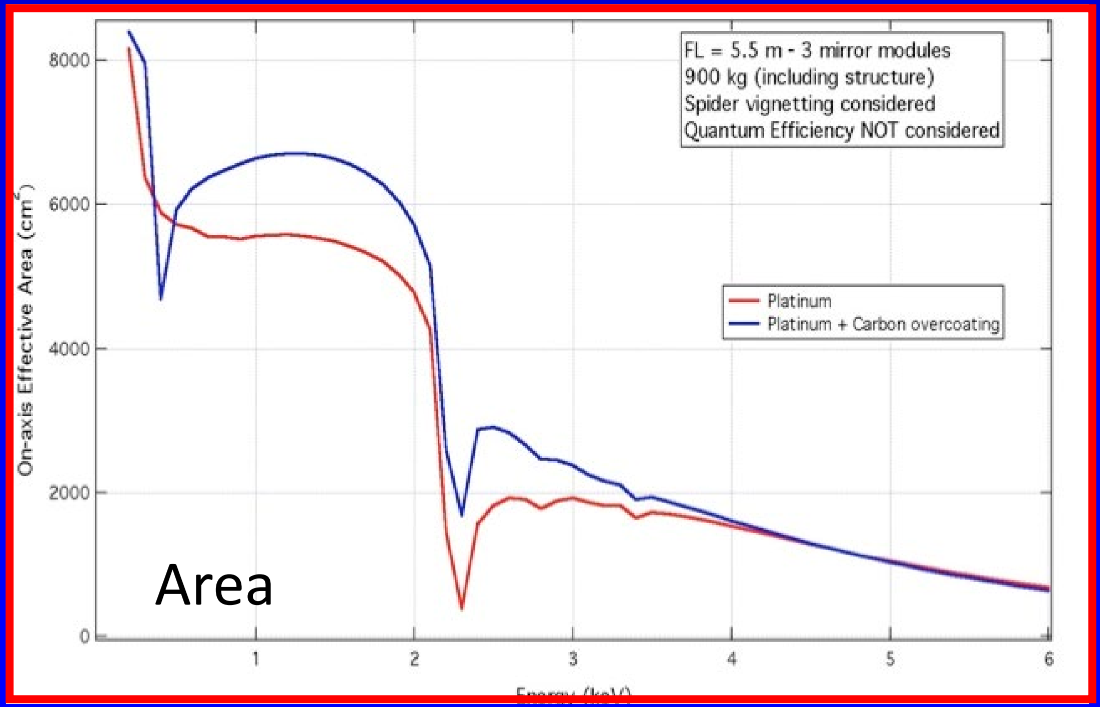
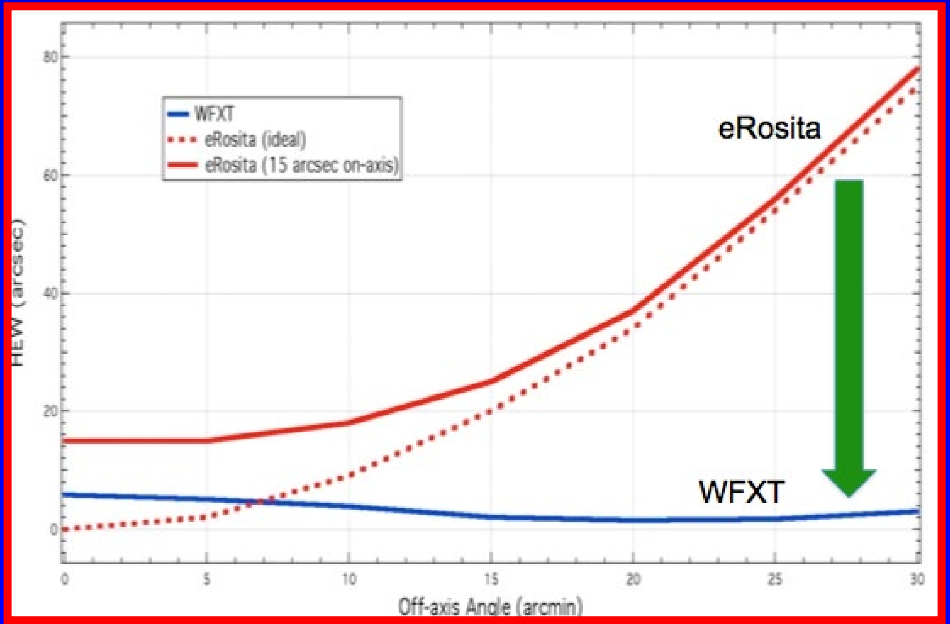


Figure of Merit: Discovery Speed

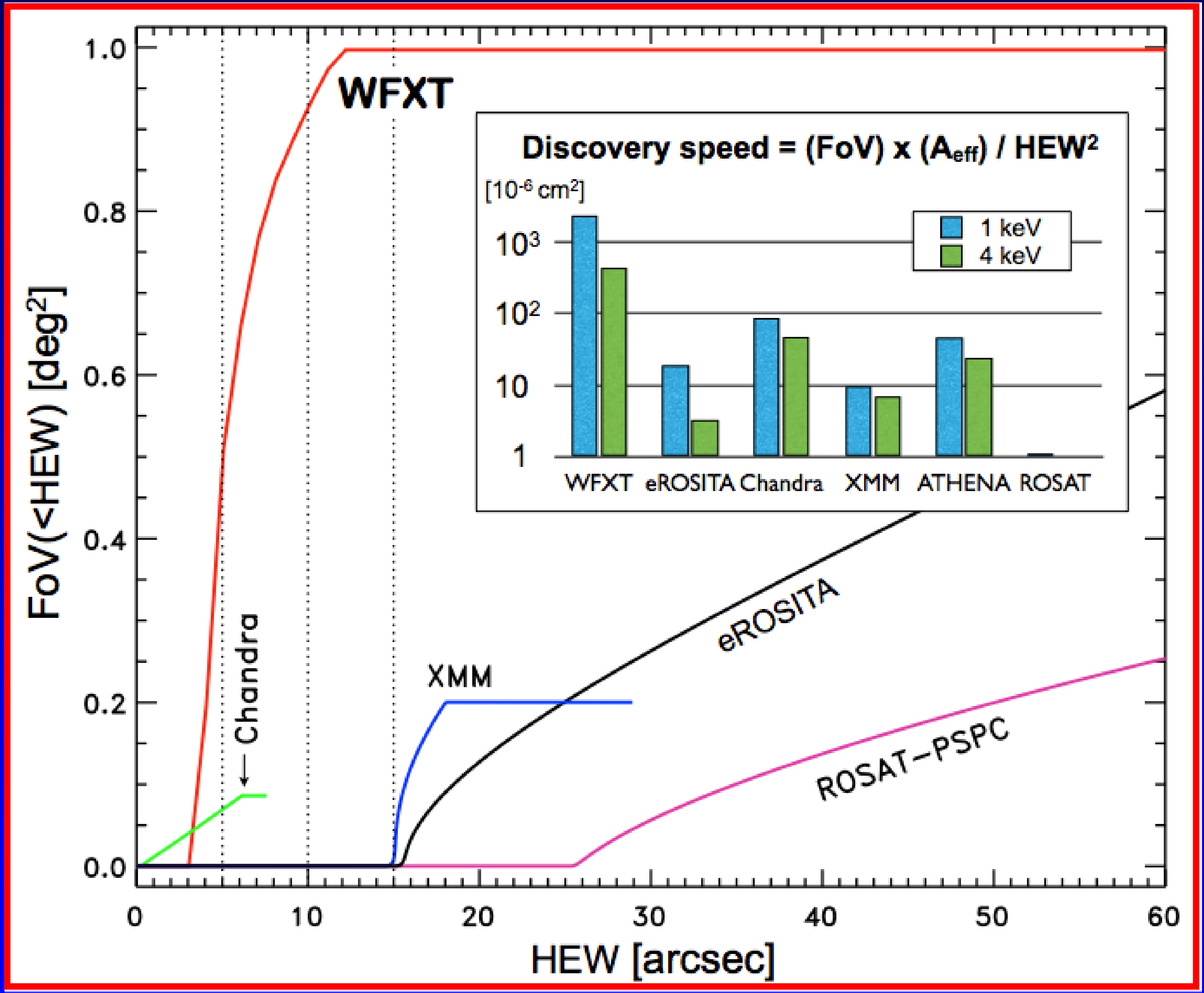
$$M = (FoV) \times (A_{eff})/(HEW)^2 \ cm^2$$

Speed in carrying out large sensitive surveys and identifying distinct sources.

Cumulative field of view available at a given angular resolution (HEW) as a function of HEW for five missions.



Wide field design matters!!!

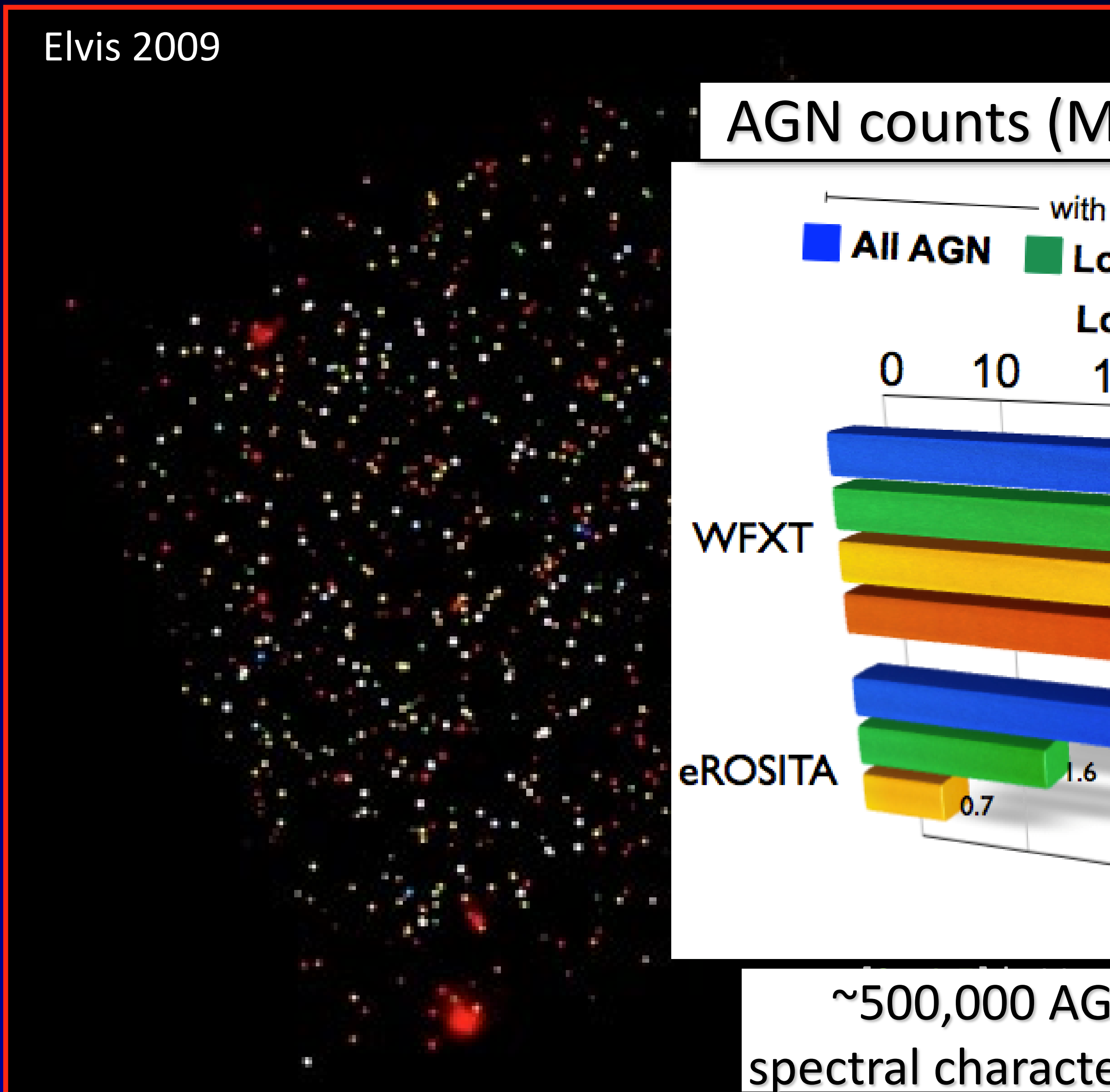


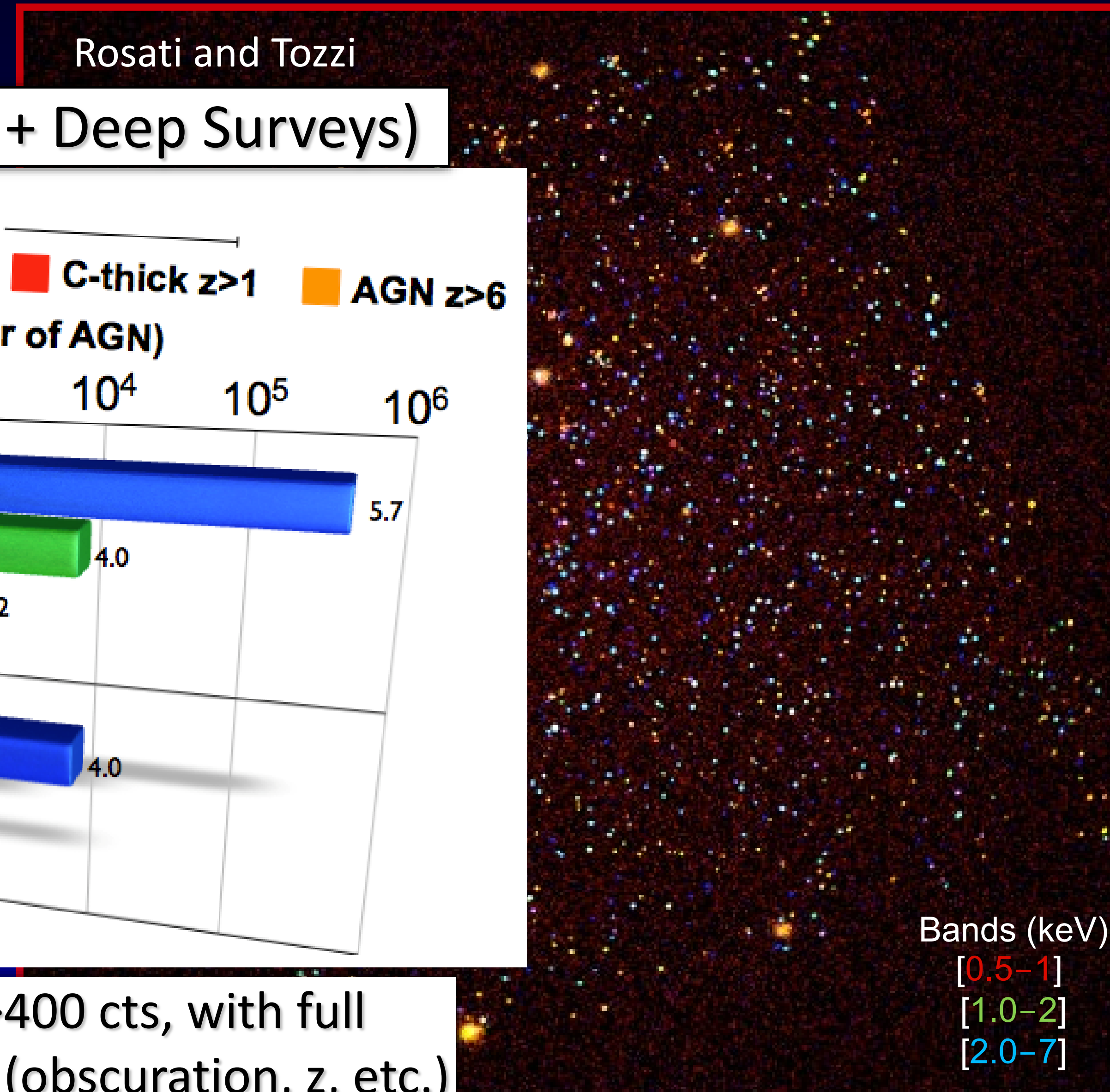
Insert shows the figure of merit for survey discovery speed (Grasp/HEW^2). WFXT is about 100 times better than any past or planned X-ray mission.

Simulation: one medium survey "tile"

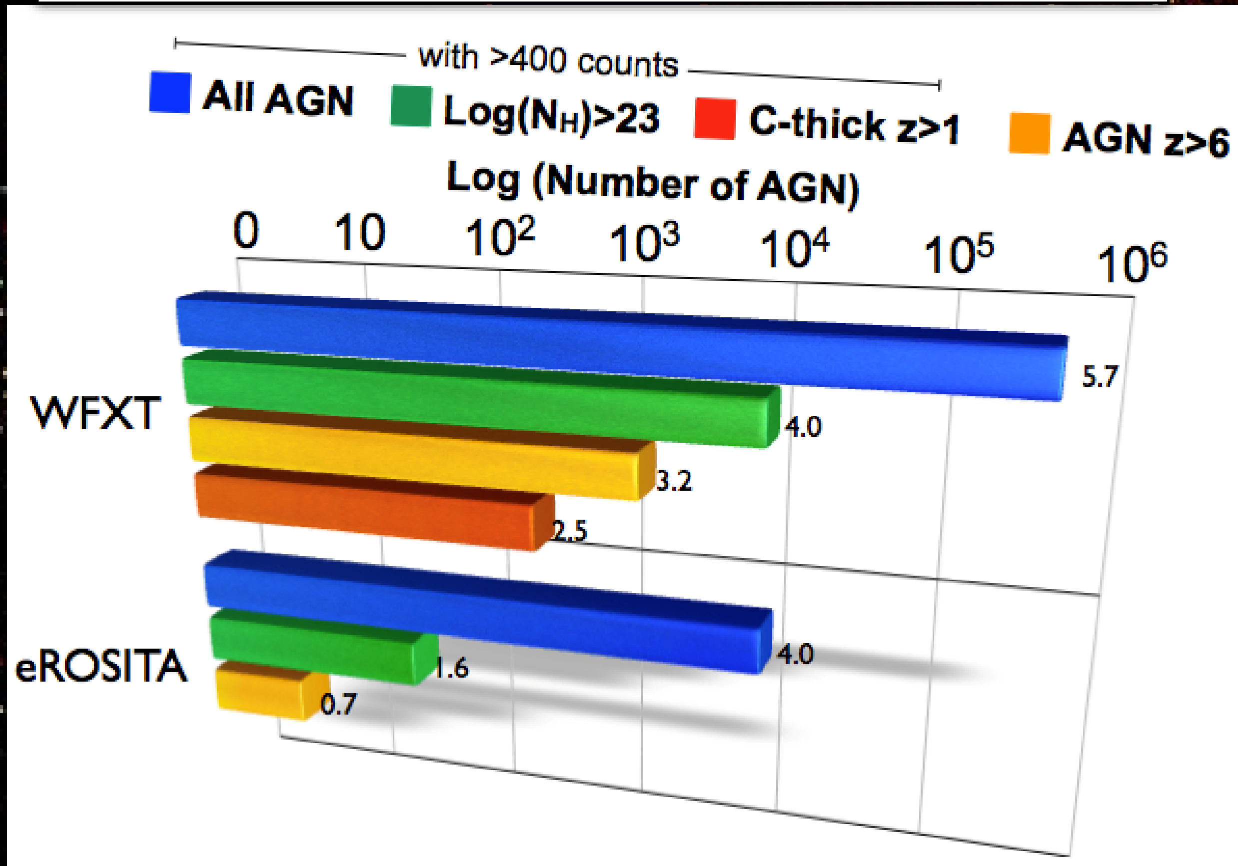
Chandra COSMOS- 1.8 Msec (1 sq deg)

WFXT - 20 Ksec





AGN counts (Medium + Deep Surveys)



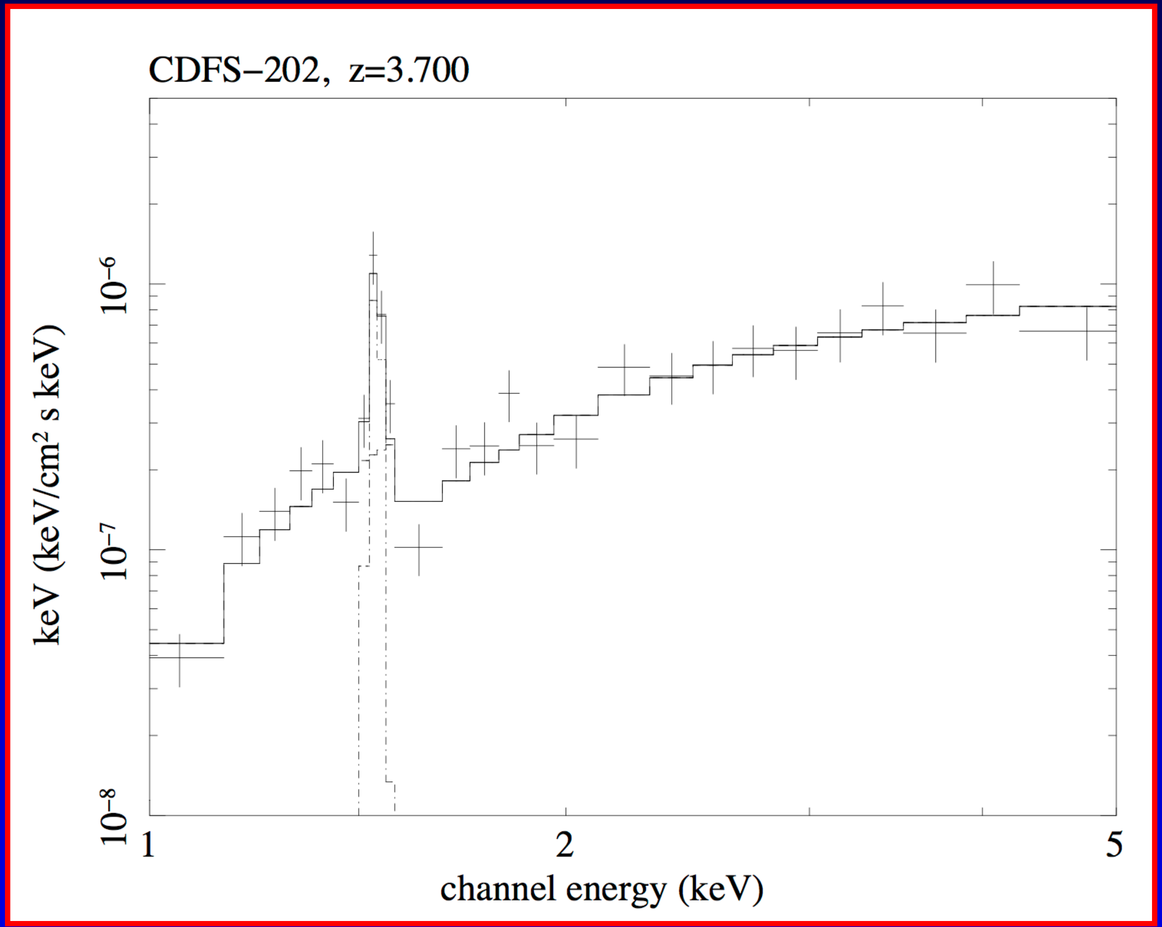
~500,000 AGN with >400 cts, with full spectral characterization (obscuration, z, etc.)

WFXT simulation: Same sources as Chandra
5 arc second HEW, not confusion limited

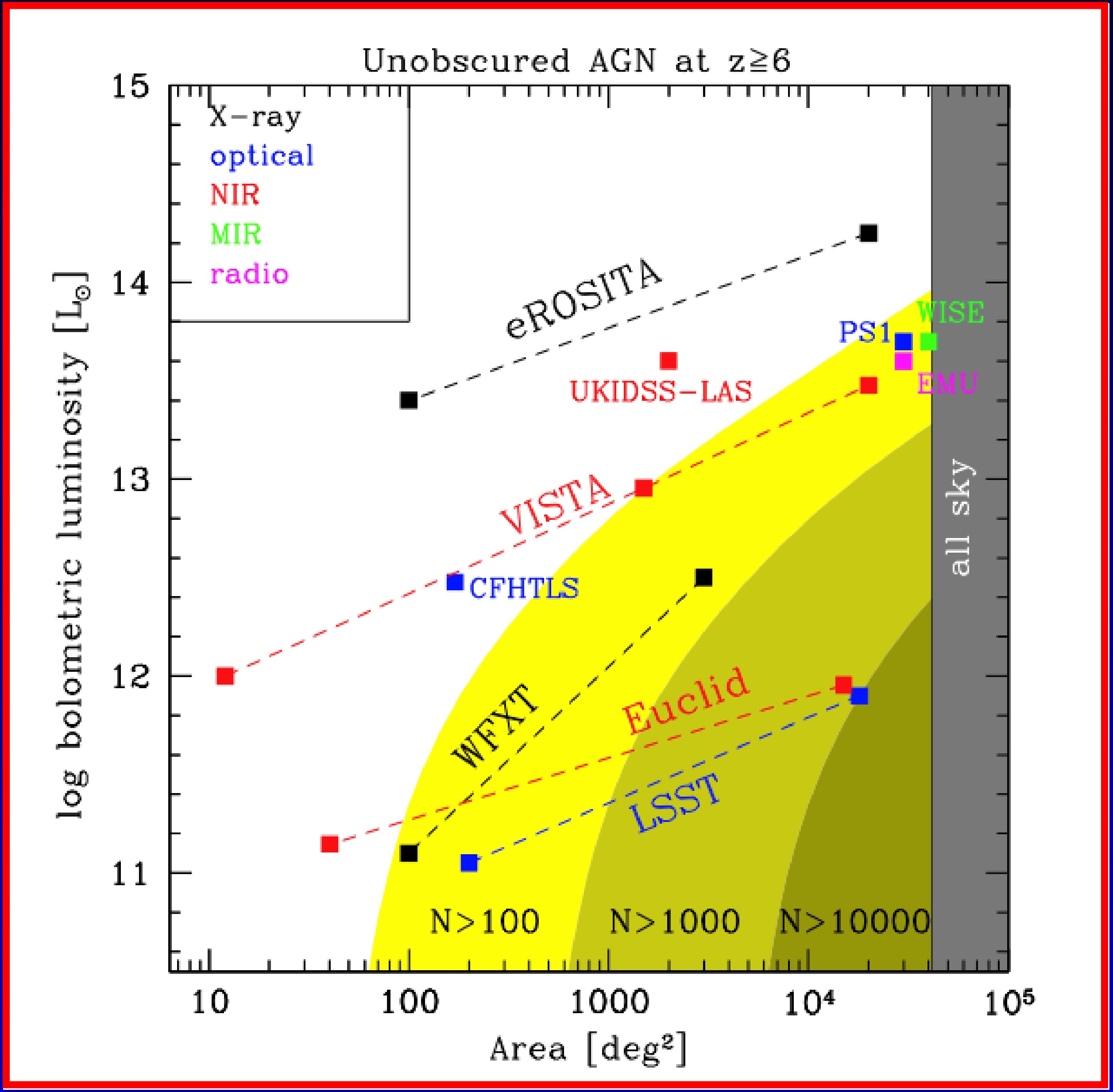
~90 x faster surveys than Chandra

High Redshift QSOs

L(2-10 keV) = 6x10^{44} erg/s



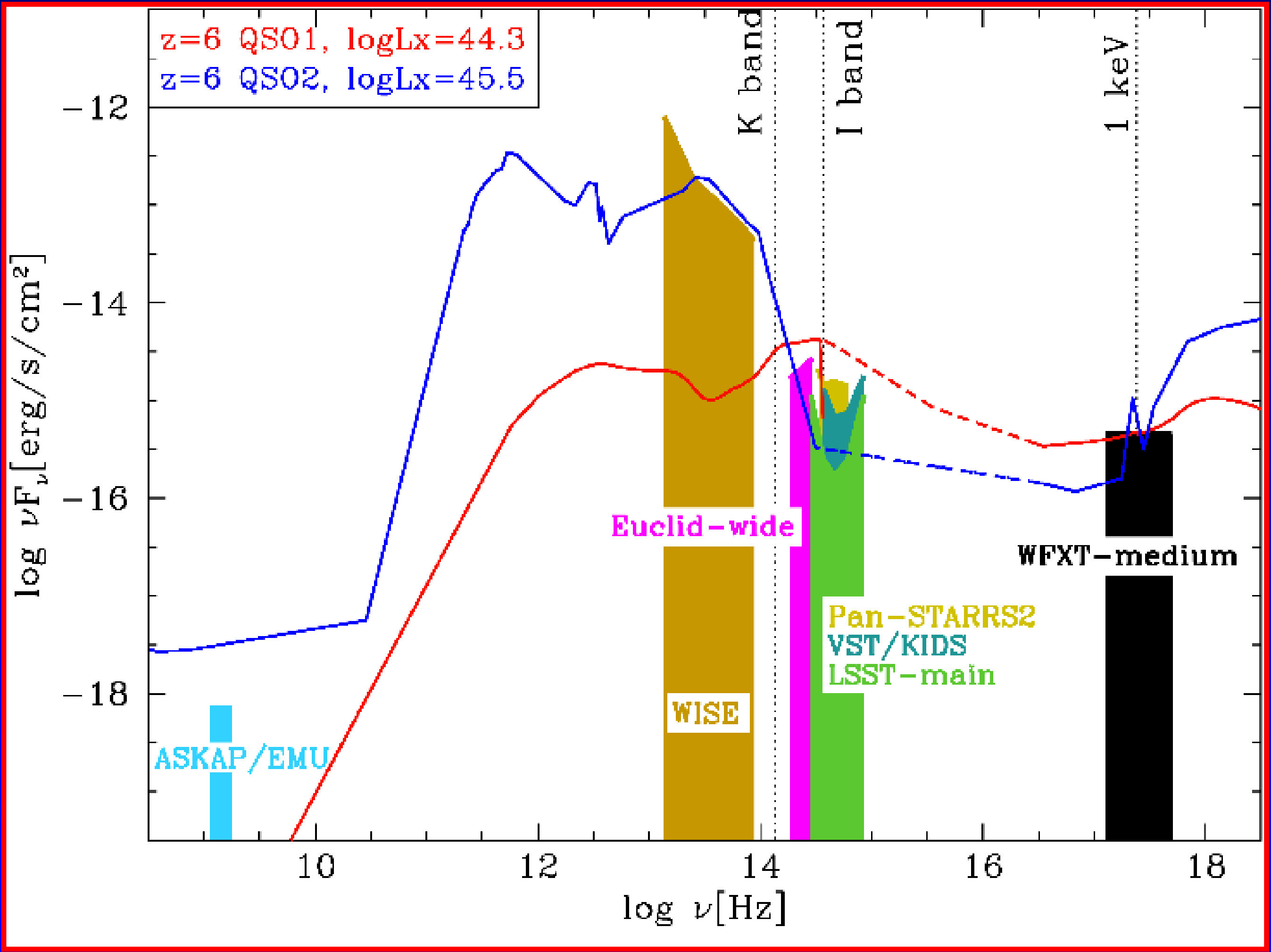
- Simulated 400 ksec spectrum of highly obscured, high redshift AGN
- $N_H = 10^{24}$, $\Gamma = 1.82$, $EW_{line} = 1$ keV.
- 530 counts total
- Strong iron line and allows an accurate redshift determination from the X-ray data alone.



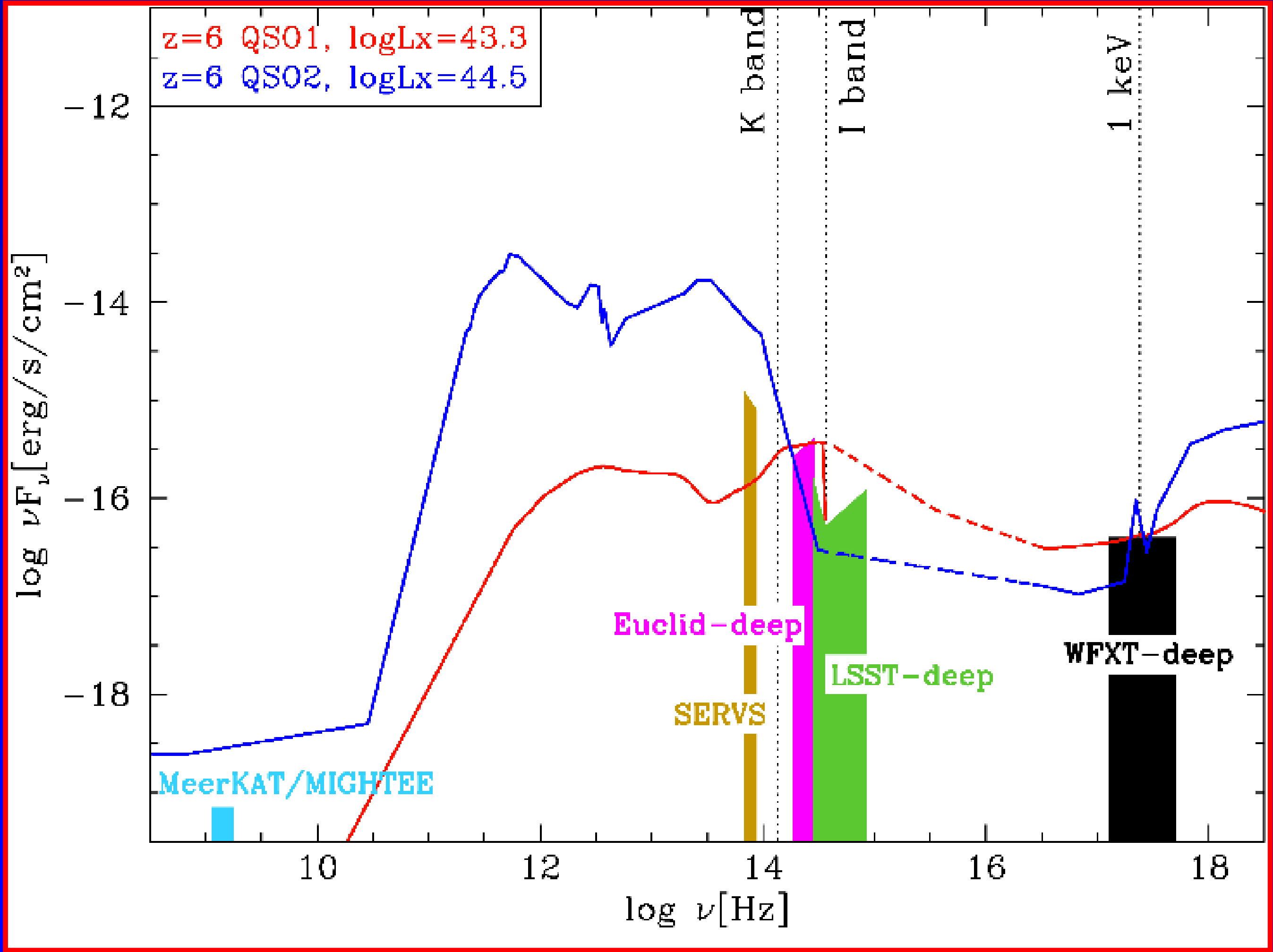
- WFXT detects close to 1000 unobscured z>6 QSO's with more than 400 cts, similar number obscured
- Pessimistic case assumes an exponential decline towards high-z in the space density of AGN at all luminosities.
- Synergistic: Euclid and LSST identify the WFXT sources, WFXT picks out the AGN (especially high-z, obscured)

Synergies with other wide area surveys

WFXT is the only X-ray mission that will match, in area and sensitivity, the next generation of wide-area O/IR and radio surveys



z=6 Medium Survey QSO

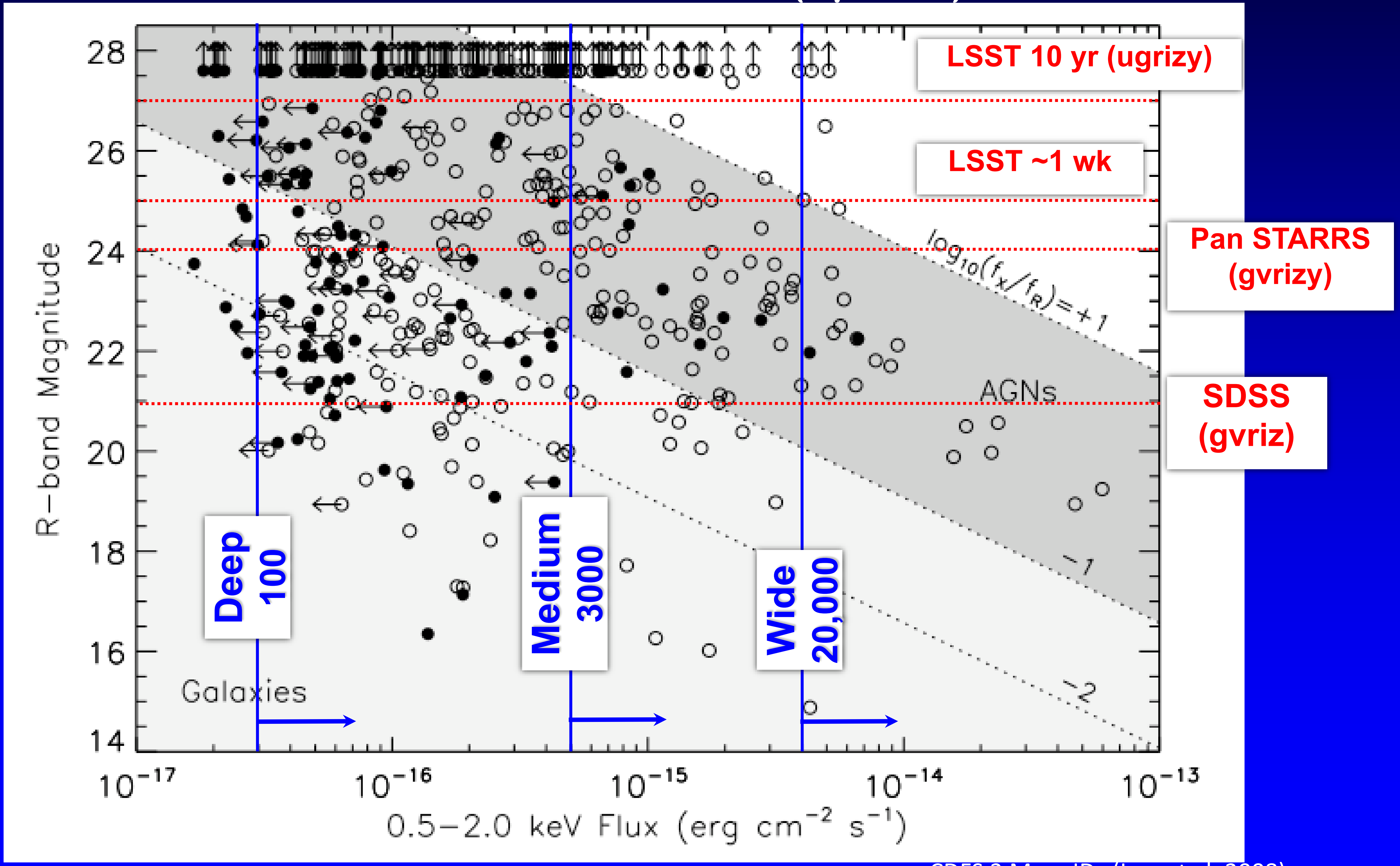


z=6 Deep Survey QSO

Courtesy of R.Gillli

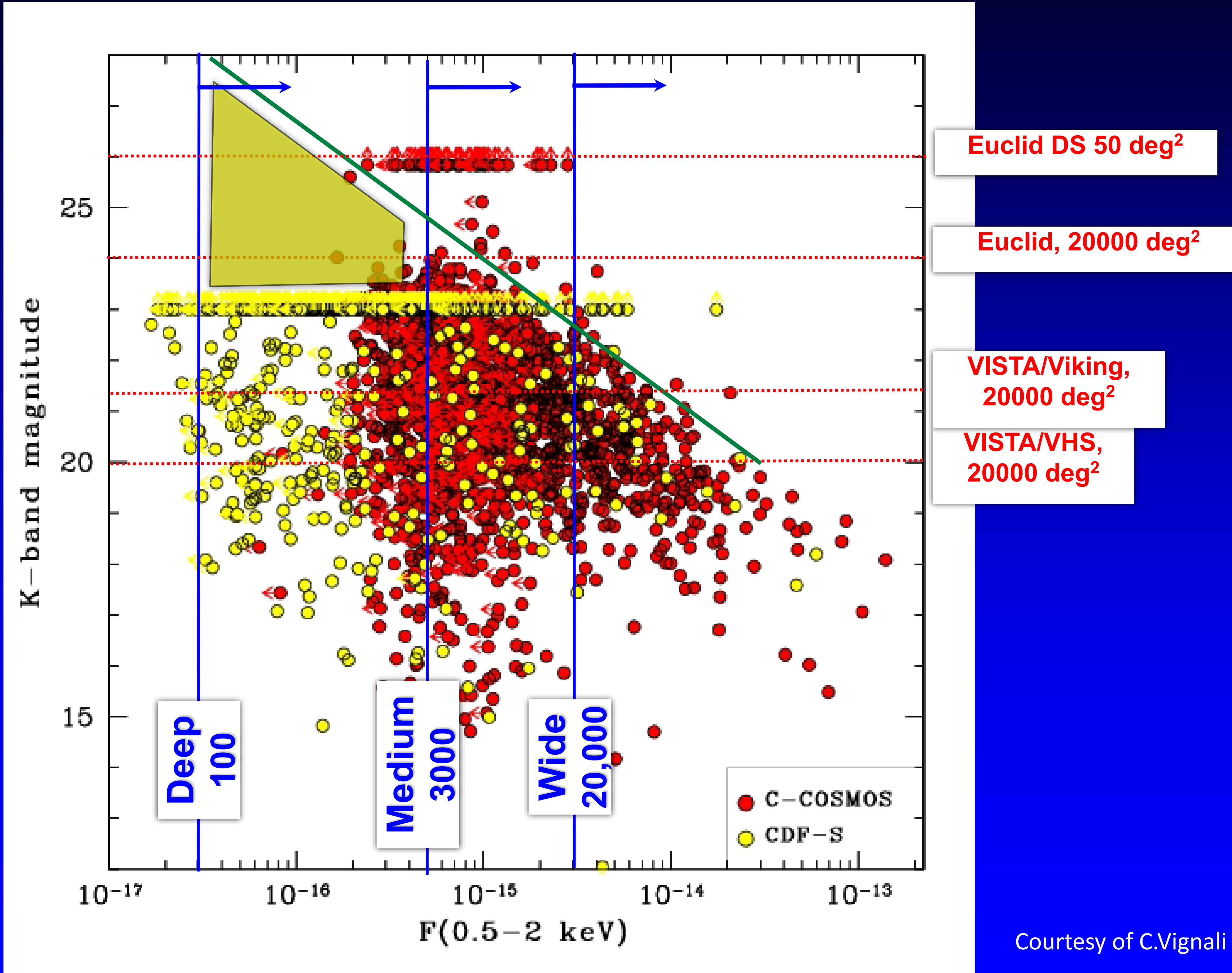
How will we identify 500,000 clusters and 100 million AGN ???

Source identification (optical)



CDFS 2 Msec IDs (Luo et al. 2008)

Source identification (near IR)



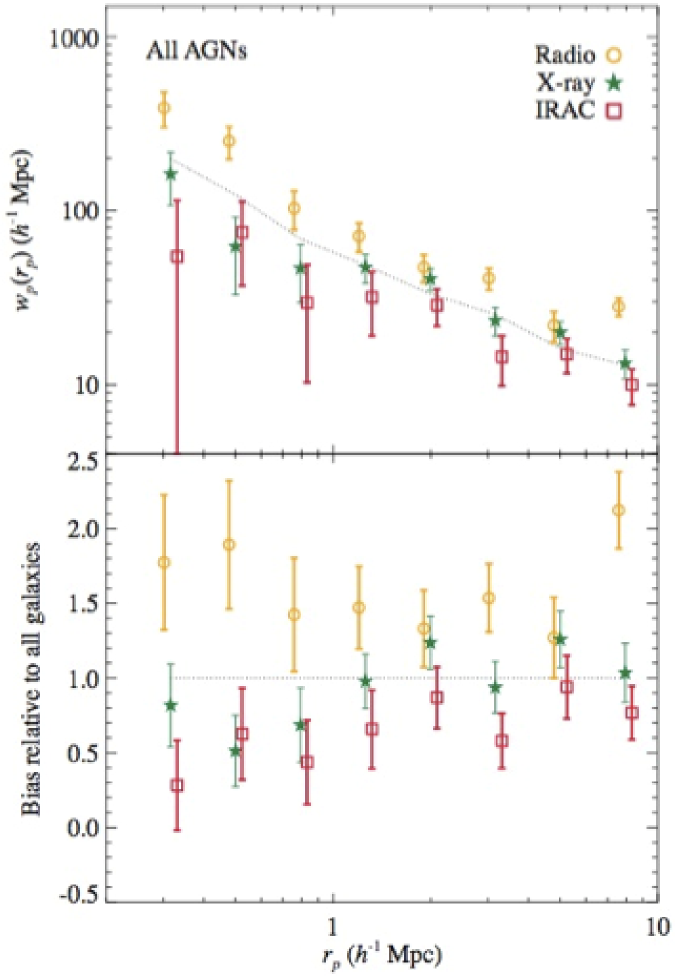
Courtesy of C.Vignali

AGN Clustering

Correlation function <=> halo mass

At z ~ 0.5, relation between M_{halo} and Eddington ratio

(Hickox et al. 2009)



Radio AGN are low-Eddington, strongly clustered (b_{AGN} = 2.0 ± 0.2)

X-ray AGN are moderate Eddington, clustered like normal galaxies (b_{AGN} = 1.4 ± 0.2)

Infrared AGN are high-Eddington, weakly clustered (b_{AGN} = 1.0 ± 0.2)

need much better statistics

==> WFXT

WFXT X-RAY SURVEYS can answer...

1. Do “typical” (ie. X-ray selected) AGN represent just a slow, stochastic decay from the QSO phase?

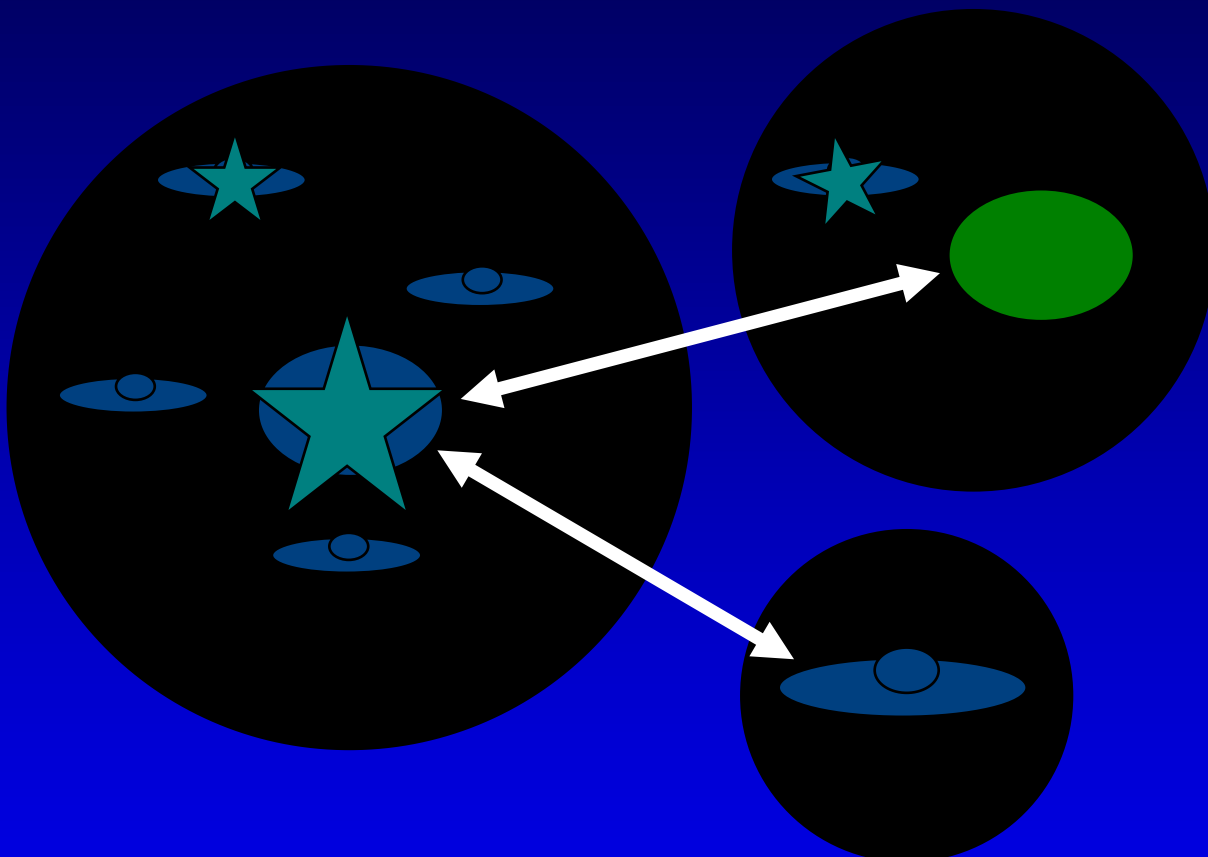
If so, expect some dependence of bias with luminosity, but (possibly) relatively weak merger signal compared to quasars (e.g. Hopkins et al.)

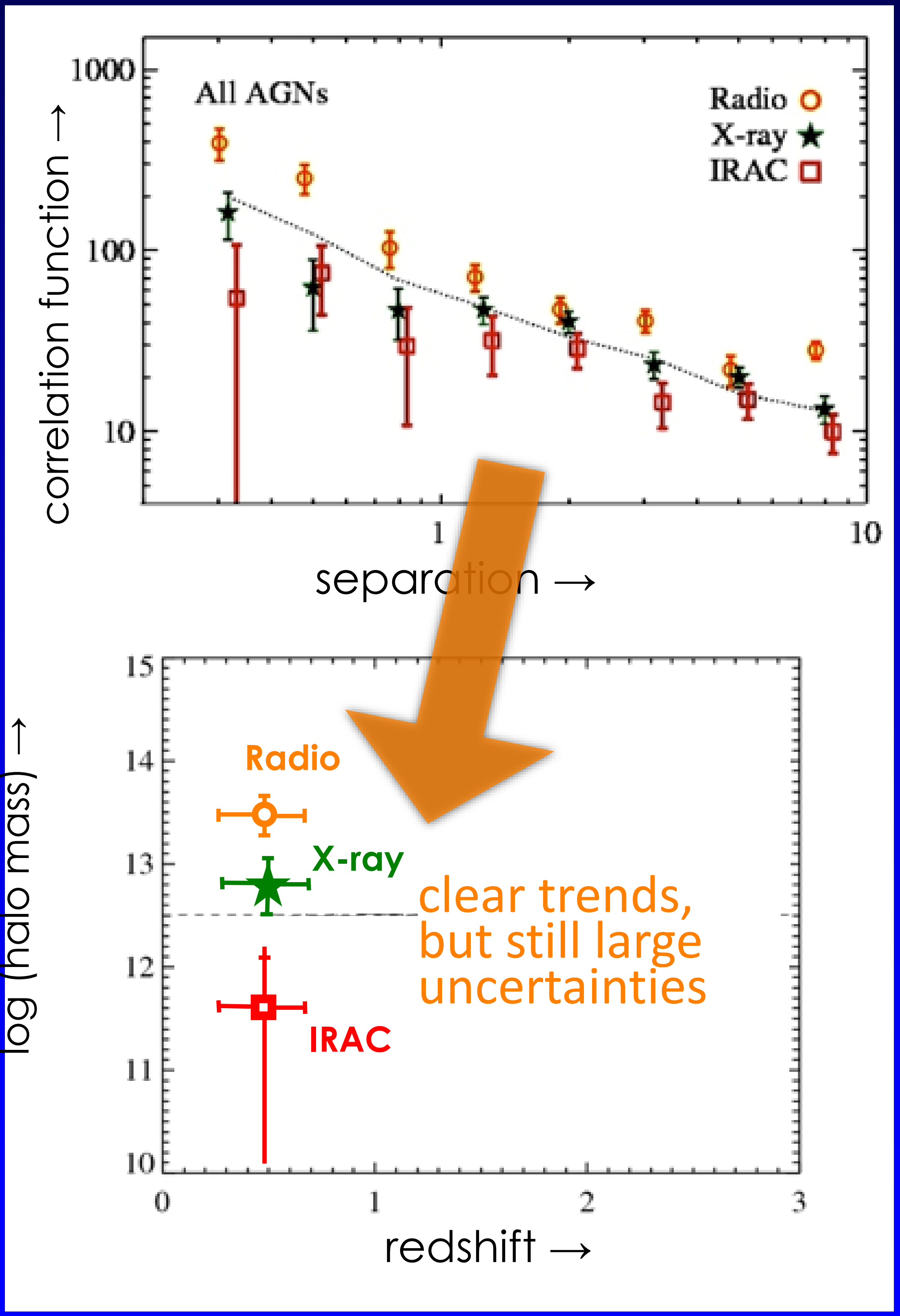
2. OR do X-ray AGN have their own triggers, e.g. secular accretion of cold gas (e.g. disk instabilities), through cooling from halo, minor interactions etc..

If so, might expect weak dependence of bias with luminosity, but might expect small-scale signal if fueled by interactions

AGN Clustering

Correlation function <=> halo mass & interactions

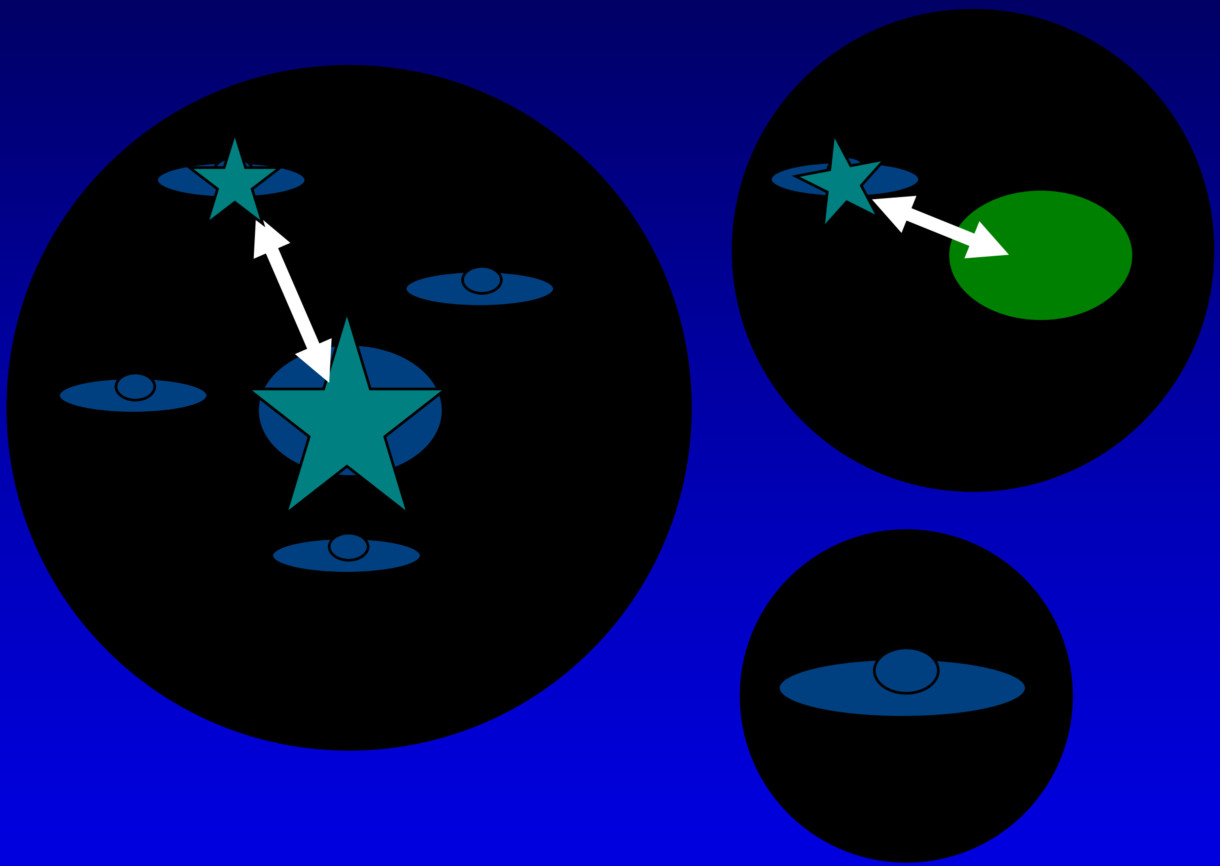


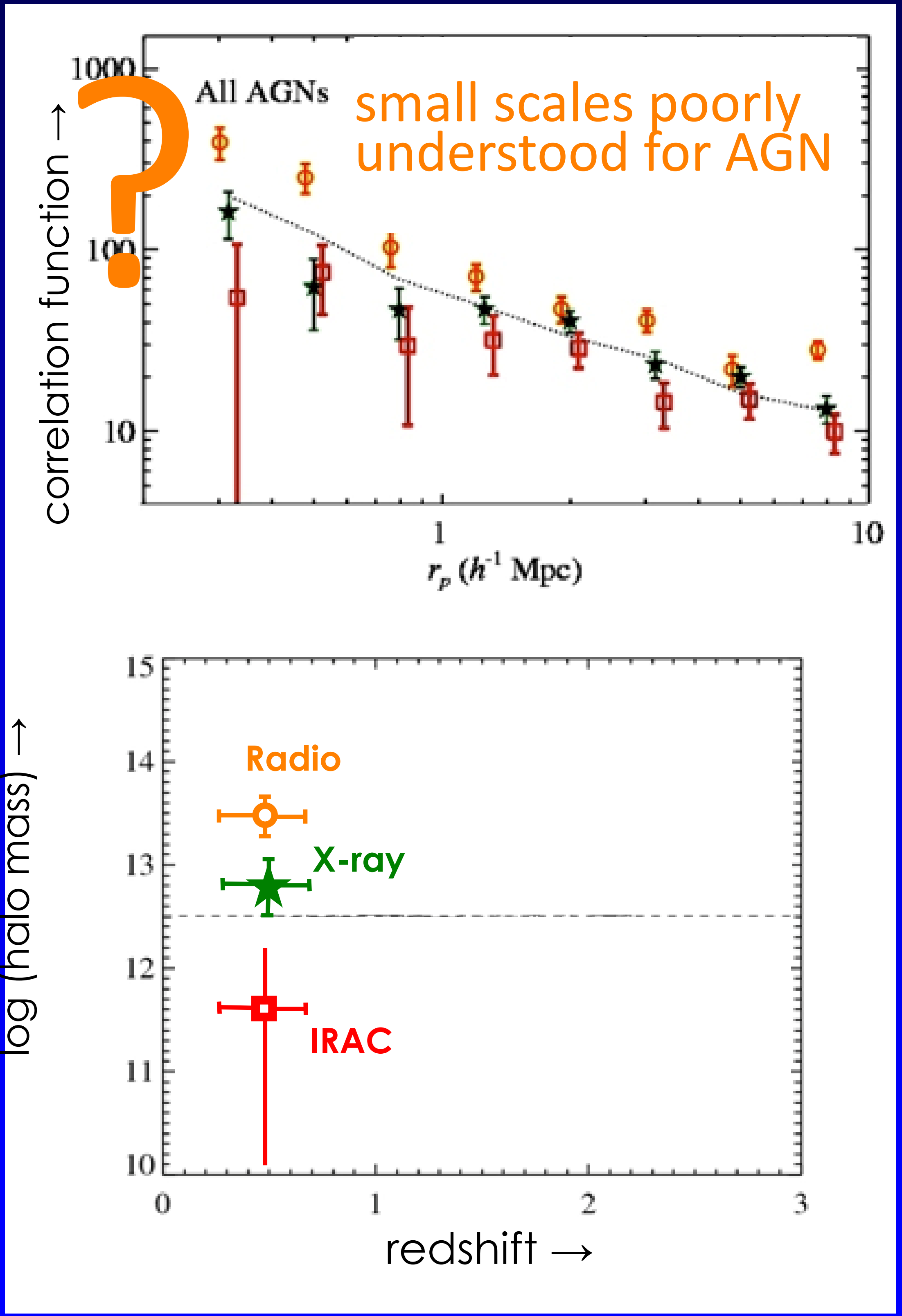


Clustering on large scales tells us HALO MASS:
How is the growth of black holes related to the growth of large-scale structure?

AGN Clustering

Correlation function <=> halo mass & interactions



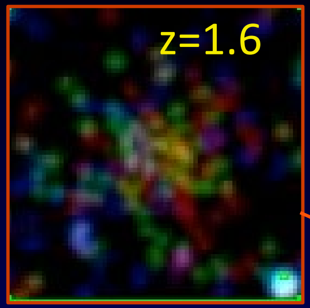


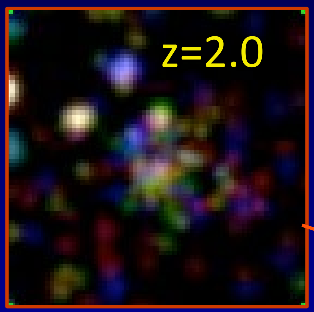
Clustering on small scales tells us MERGERS AND INTERACTIONS

Theoretical make different predictions for AGN clustering but differences can be small

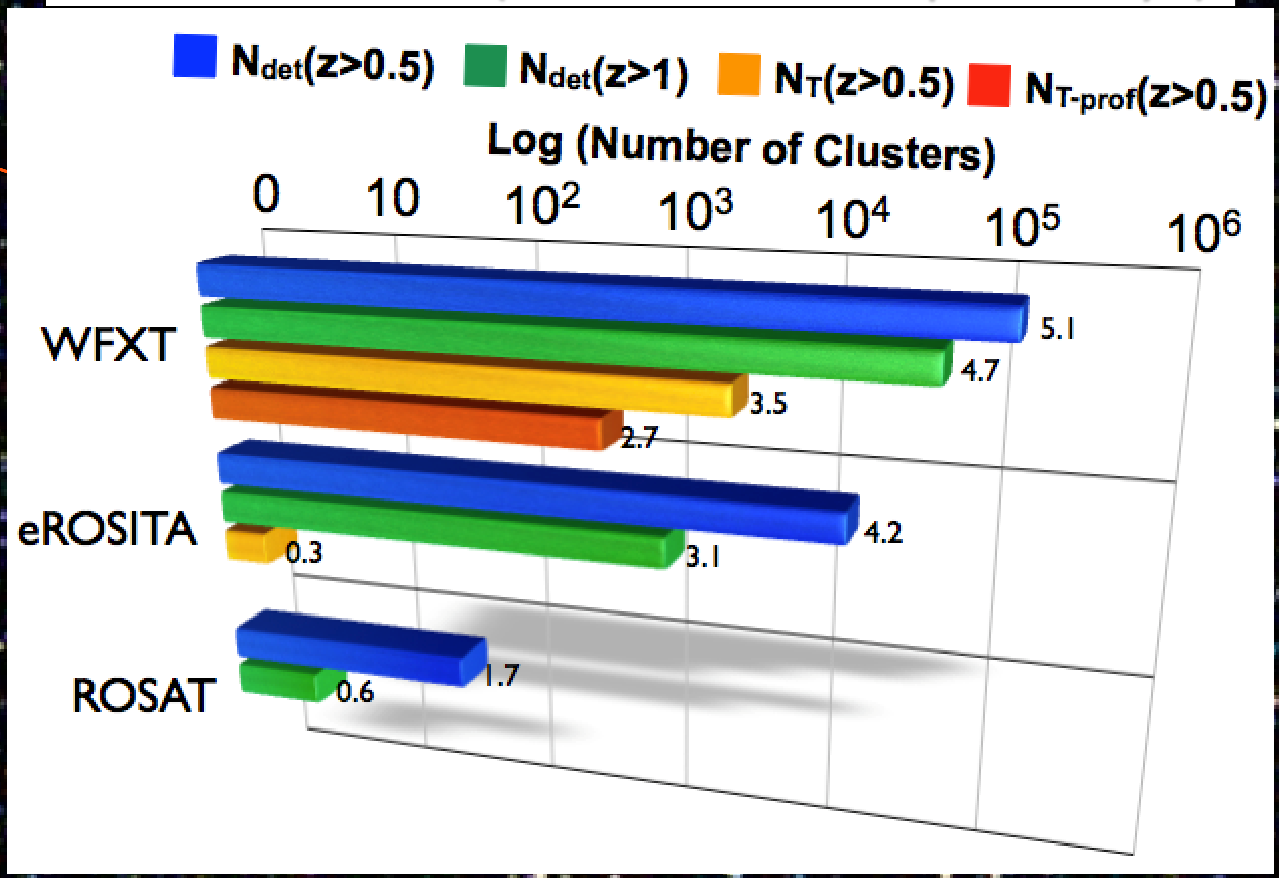
we need much better statistics: WFXT

WFXT simulation: 20 ksec





Cluster counts (Medium + Deep Surveys)

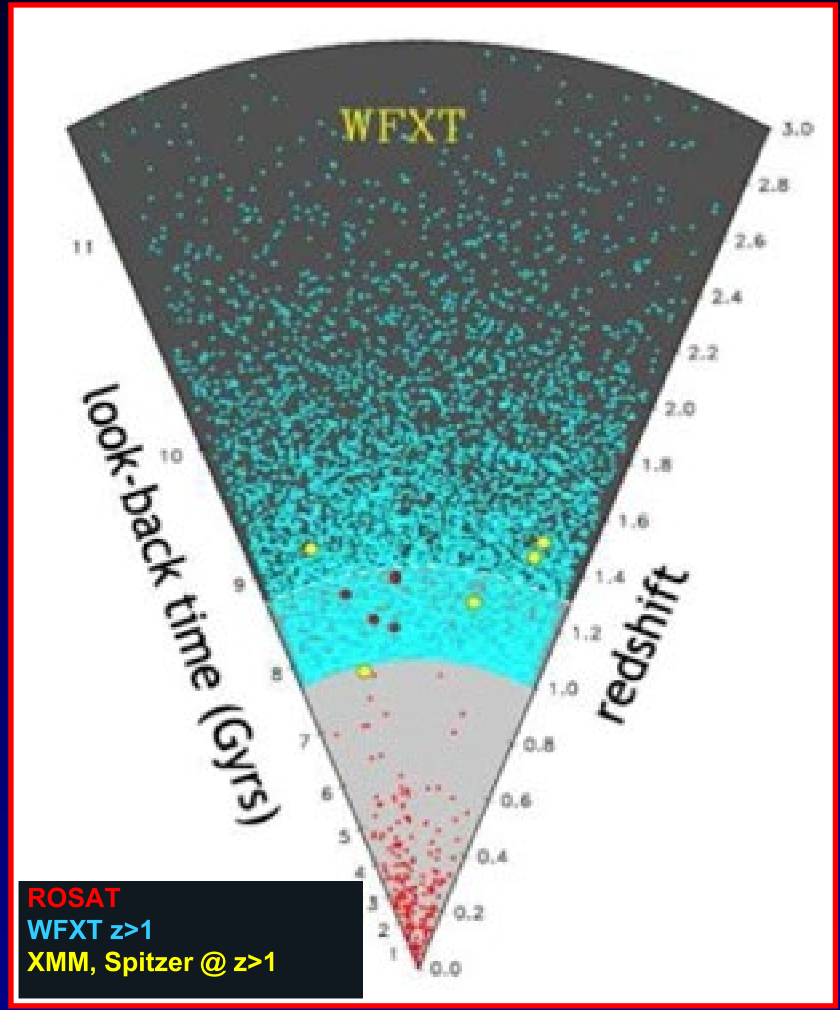


>3,000 clusters at z>0.5, from which z can be be measured from Fe line

Not just a cluster counting machine

Cluster Surveys

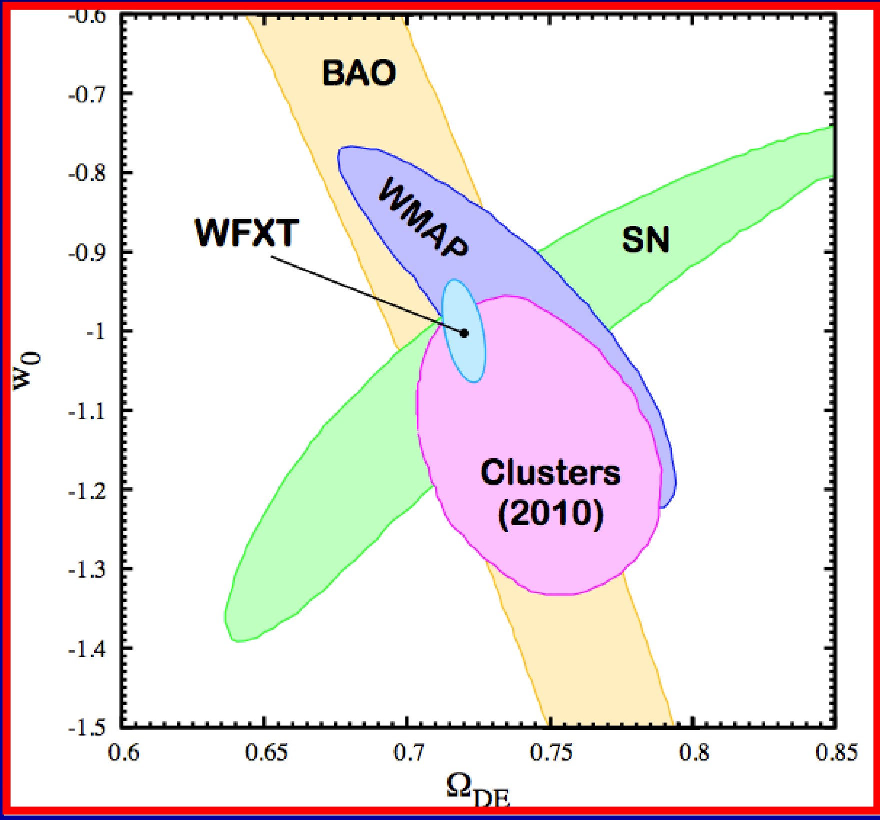
- Characterize ICM properties and measure mass proxies for thousands of clusters at z>1.
- Trace the epoch of entropy injection and metal enrichment of the ICM.
- Study the intense dynamics of proto-cluster assembly at z~2.
- Multi-λ synergies: a vast scientific legacy for decades to come
- Path finder for follow-up studies with ELTs, ALMA, SMART-X,...



Detected clusters:
~200,000 total
z>0.5: ~125,000
z>1: ~50,000

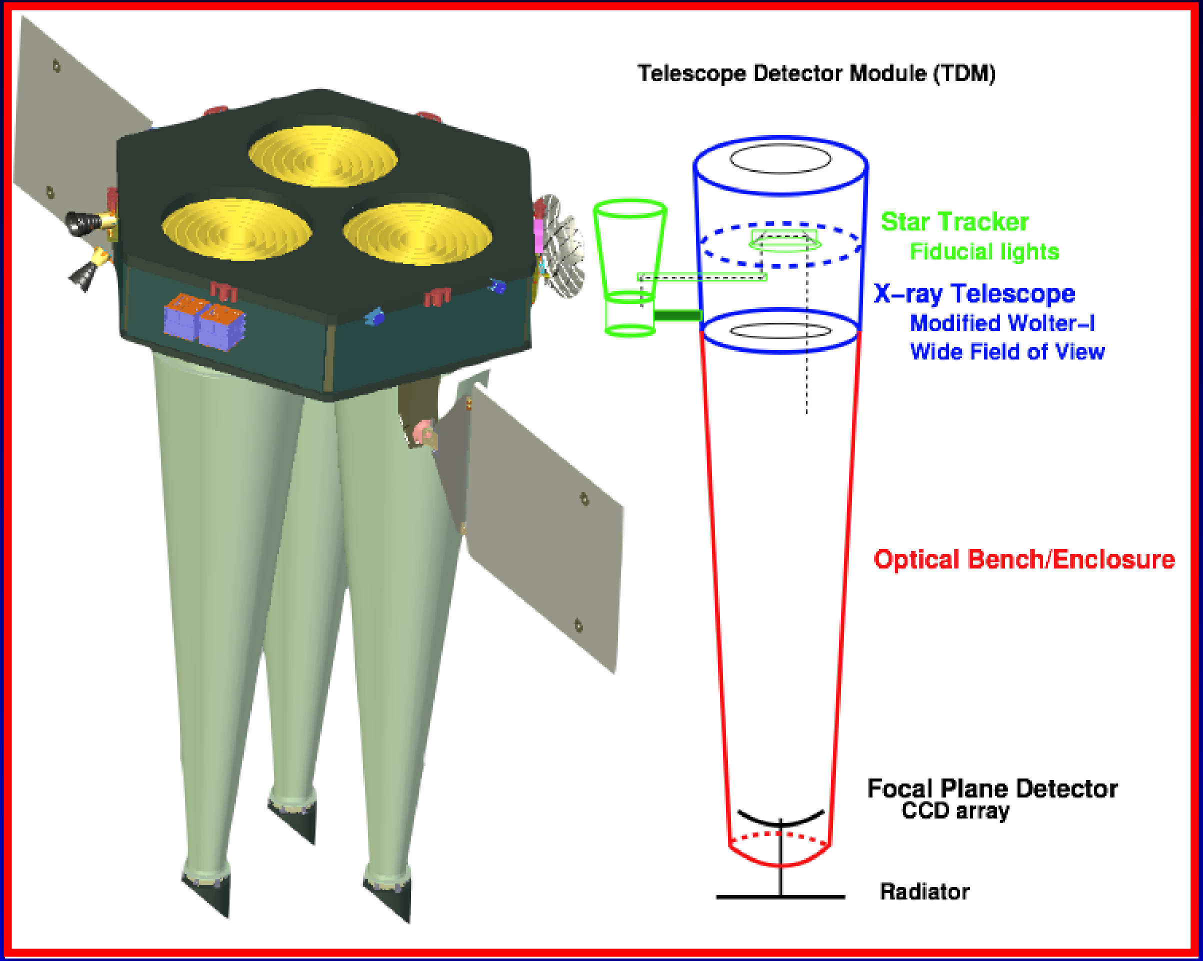
Directly measured z and kT:
>~5000 total
z>1: ~2,000
T profiles and abundances
z>0.5: ~500

- WFXT forecast based evolution of the cluster abundance and the space distribution of 5000 clusters
- **Redshifts and mass proxies are derived from the WFXT alone**
- w_0 and Ω_{DE} are measured with 6% and 1% accuracy (68% c.l.), when a flat Universe is assumed.

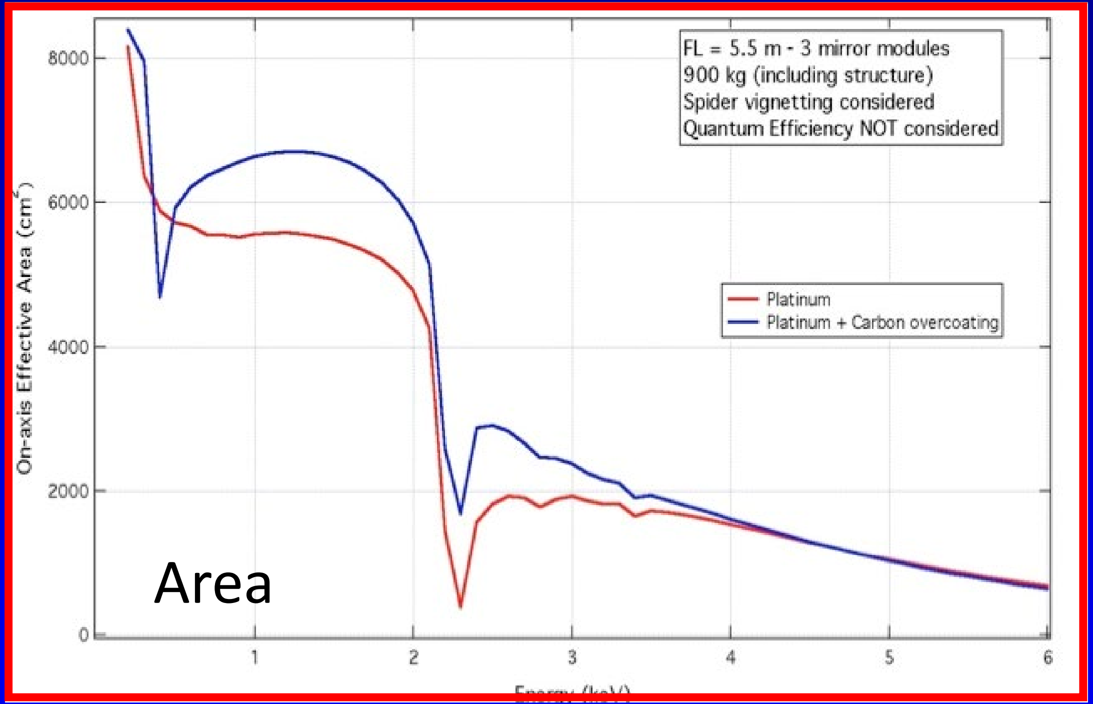


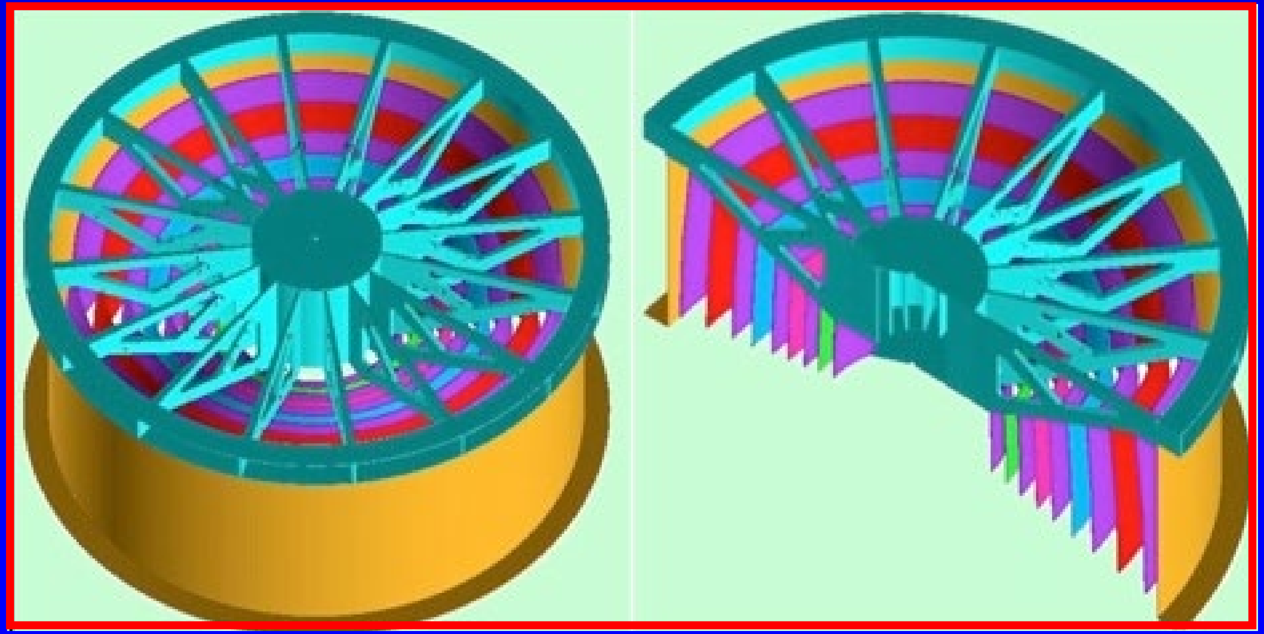
Approved for public release,distribution unlimited

Mission Implementation



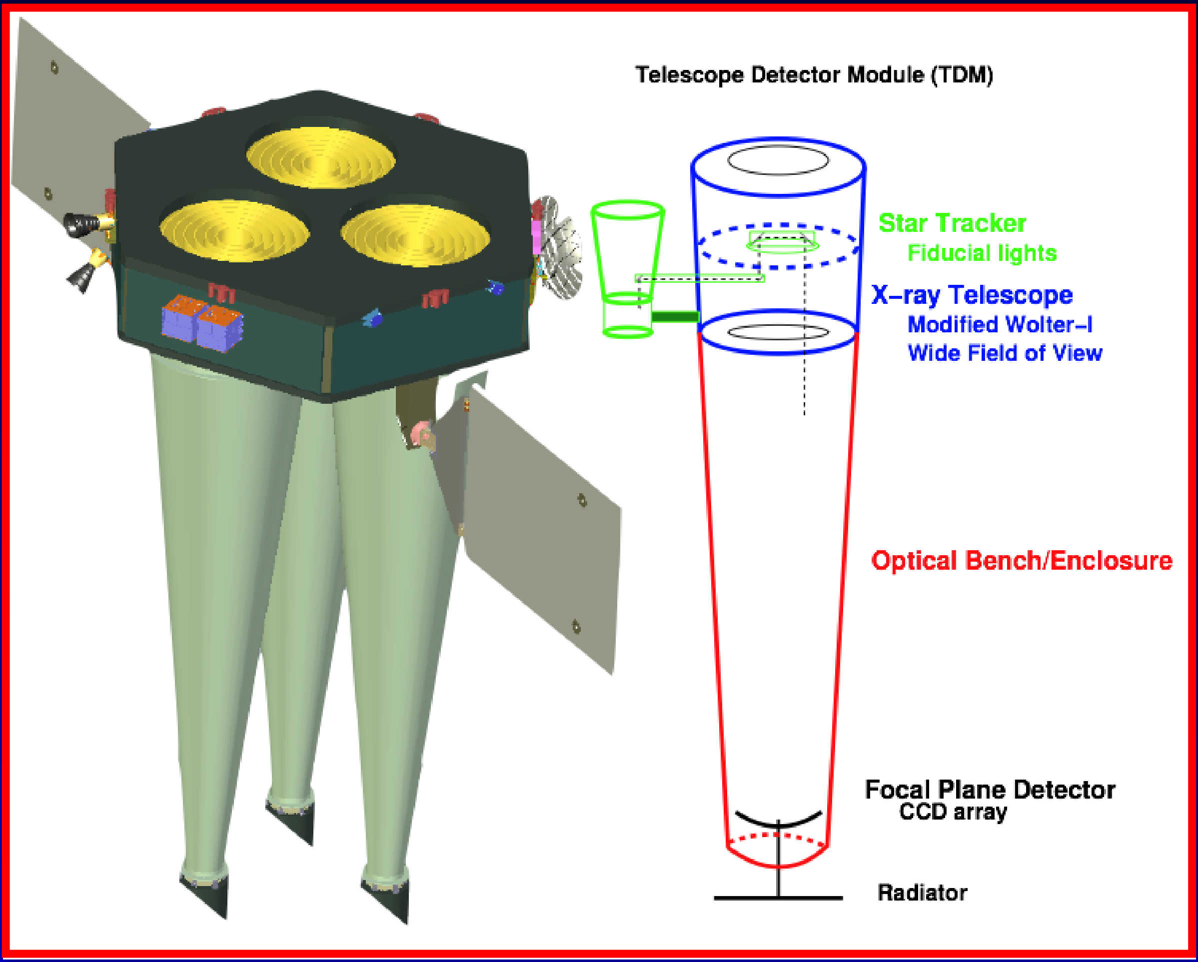
- Three modules approximately co-aligned
- Telescope, detector, aspect system, bench
- Photon-counting, post-facto image reconstruction
- Chandra/Suzaku CCDs available





- 55 fused silica shells/module
- 2-3 mm thick, 0.36-1.10 m diameter
- 0.220-0.408 m long
- 300 kg/module (with structure)

Mission Implementation

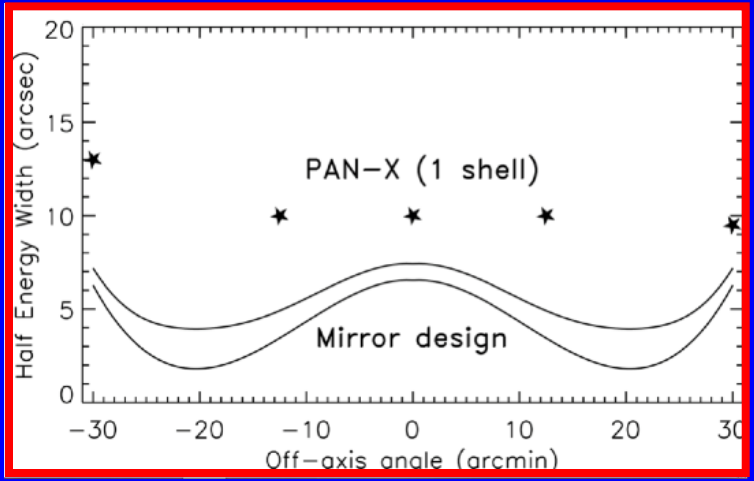


- Three modules approximately co-aligned
- Telescope, detector, aspect system, bench
- Photon-counting, post-facto image reconstruction
- Chandra/Suzaku CCDs available

Table 2: WFXT Mission Performance Requirements

Parameter	Requirement	Goal
Area (1 keV)$^{(*)}$	7,000 cm^2	10,000 cm^2
Area (4 keV)	2,000 cm^2	4,000 cm^2
Field of View	1°x 1 °	1°x 1 °
Angular Resolution (1 keV)	5″ HEW	≤5″ HEW
Pixel Size	∼1″	∼1″
Energy Band	0.2 - 4 keV	0.1 - 6 keV
Energy Resolution	$\frac{E}{\Delta E} > 10$	$\frac{E}{\Delta E} > 20$
Time Resolution	< 3 seconds	< 1 second

$^{(*)}$ The WFXT ∼0.7 m^2 area meets that required in our earlier Astro2010 mission concept, but is ∼2/3 of the goal.

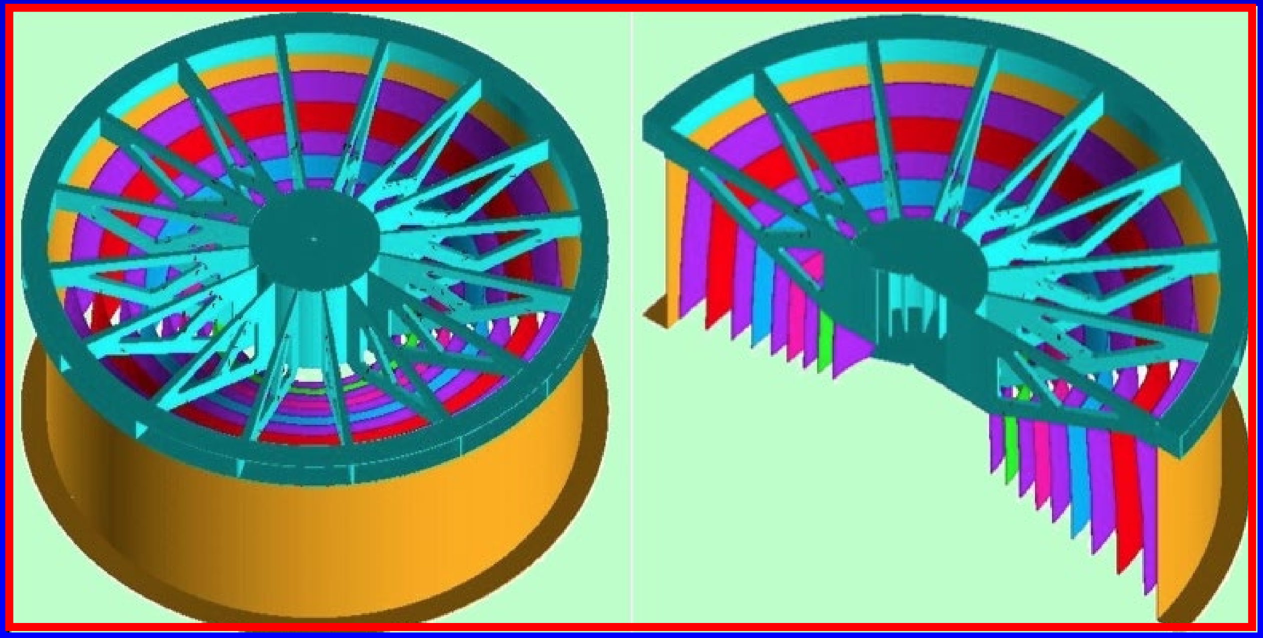


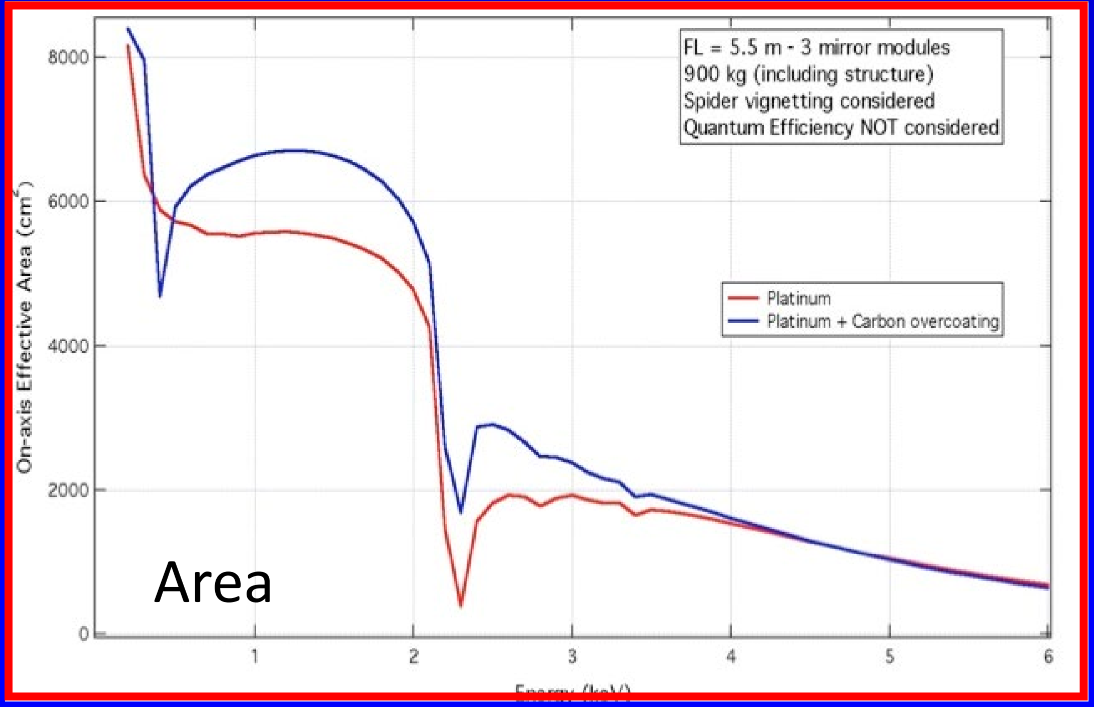
Citterio 1999

- Mirror development well underway: 10" HEW already achieved

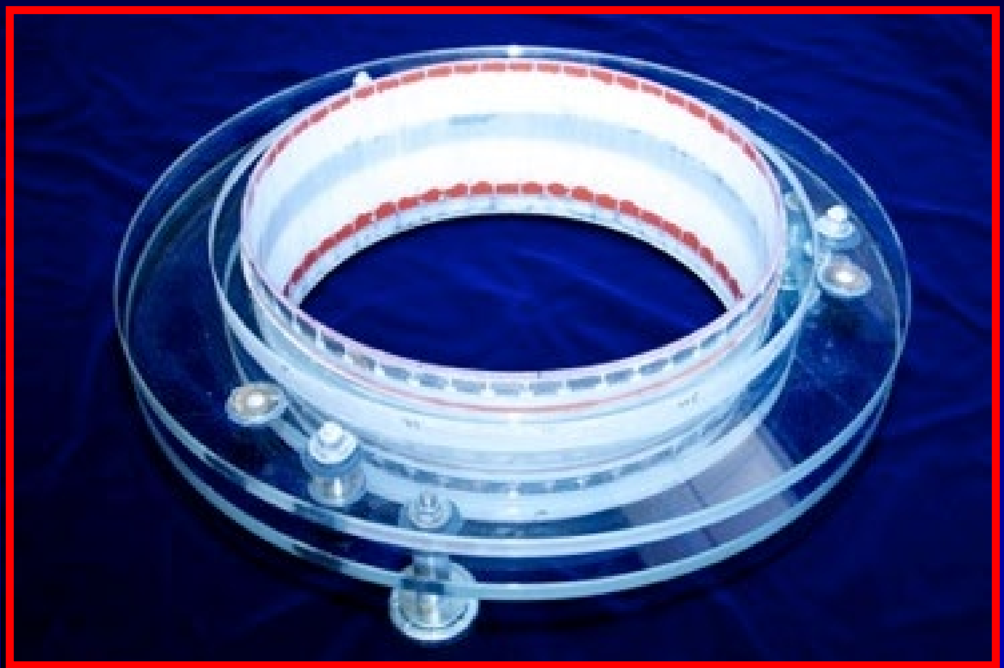
Wide Field Telescope Design

Item	Value	Comment
Number of Shells	55	Nested fused silica
Focal Length	5.5 m	
Diameter	0.36-1.10 m	
Length	0.220 - 0.408 m	inner shells shorter
Thickness	1.7-3.0 mm	inner shells thinner
Mass	300 kg	includes structure
Area	2,250 cm^2	@ 1 keV

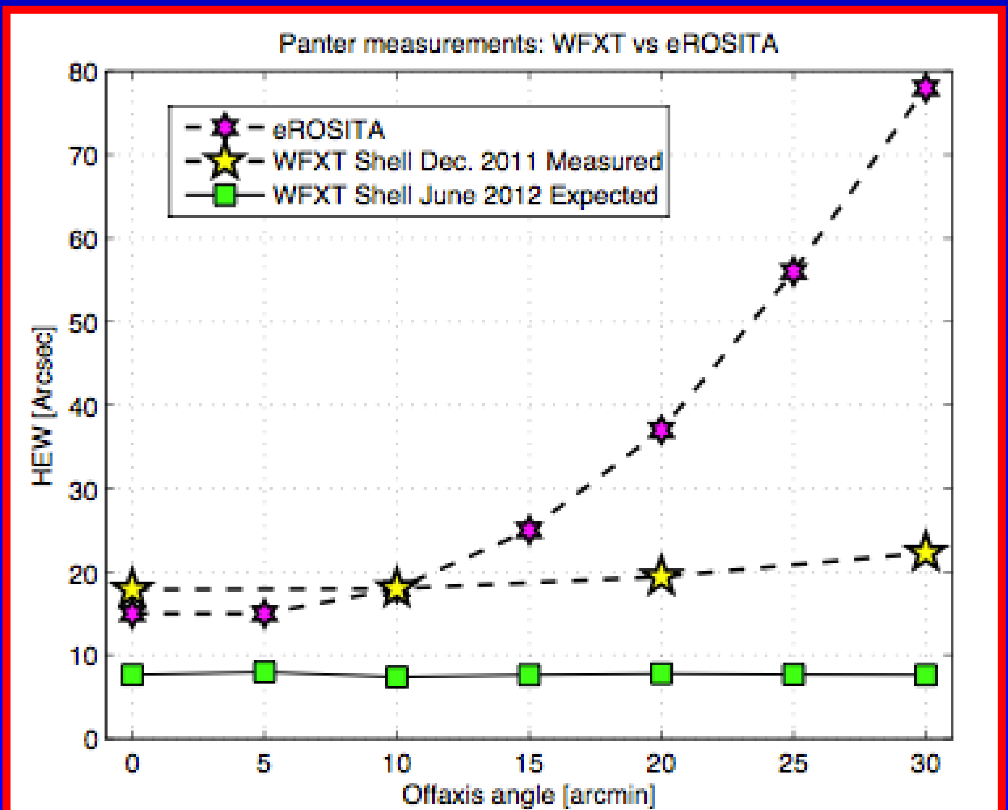




Telescope Process

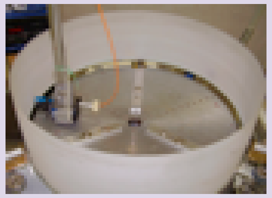
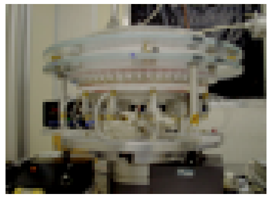
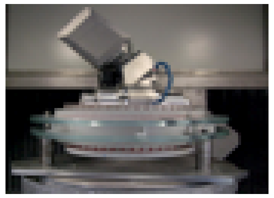
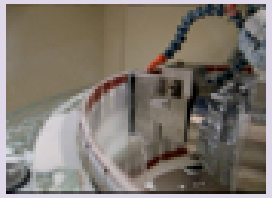


Prototype Shell

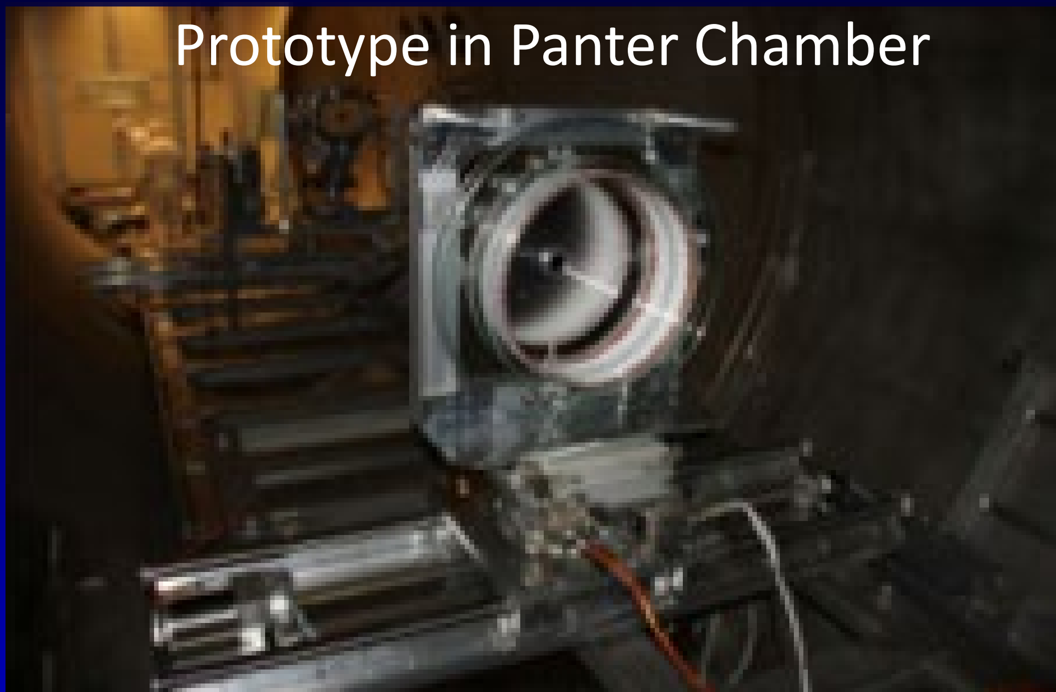


X-ray Test at Panter - Dec 12, 2011

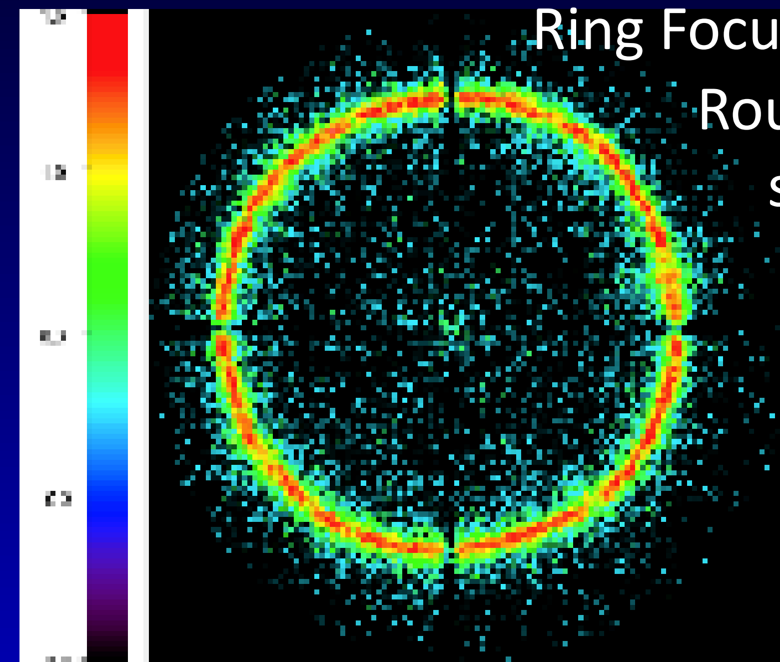
Manufacturing Process

	**Raw grinding.** Starting from a raw Fused Silica glass tube, first grinding operations are performed to obtain a double cone profile at the required thickness of a few millimeters.
	**Out-Of-Roundness Metrology.** The shell is characterized in terms of Out-Of-Roundness errors, supporting it onto an astatic support jig.
	**Temporary stiffening.** The shell is integrated into a special "Shell Support Structure", a suitable jig structure able to allow the metrology, machining and all the necessary operations before the assembling of the shell into the final structure.
	**Fine grinding.** An Out-of-Roundness correction is obtained by means of a fine grinding process. These operations are performed using a high precision lathe and with a proper metrology system mounted on the machine.
	**Polishing.** The polishing process is performed by CNC polishing systems, controlled on 7-axis, that use a patented tool to provide a distributed pressure and variable area head for the polishing of aspheric and complex forms. The tool used for polishing is also called "Bonnet" and it is given by a spinning, inflated, membrane-tool compressed against the surface of the mirror.
	**Superpolishing.** A superpolishing process is performed by means of a pitch tool mounted onto the Zeeko CNC machine, in order to remove the remaining mid-frequencies errors left by the Bonnet polishing and to achieve the required micro-roughness.

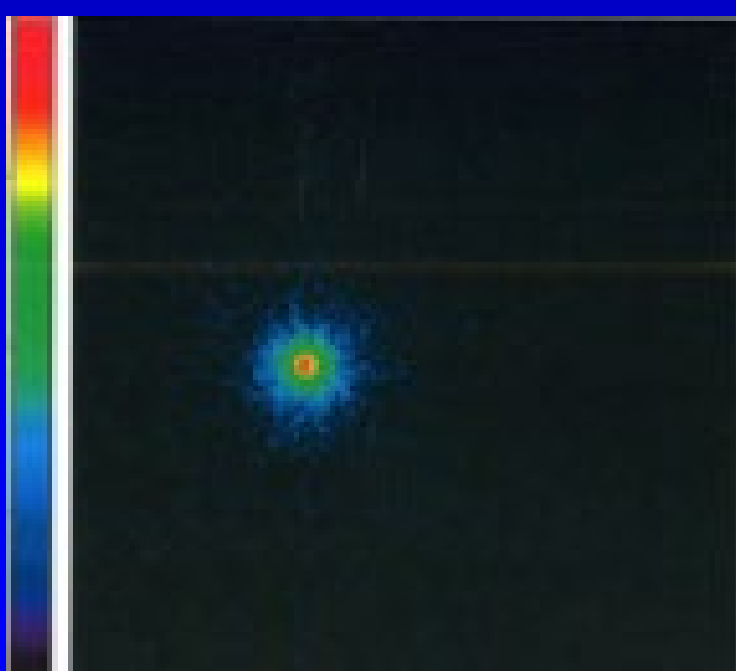
X-ray Testing at MPE Panter



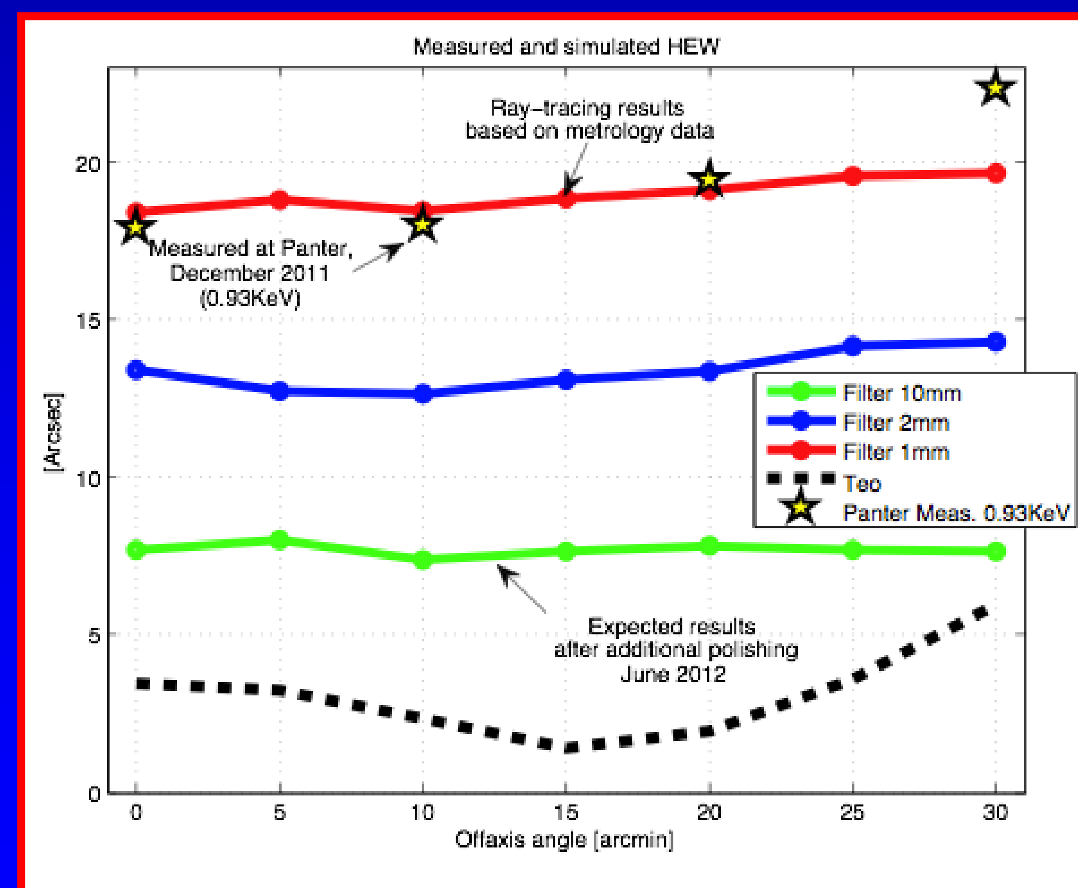
Prototype in Panter Chamber



Ring Focus (200 mm out of focus)
Round shell shows that the support mount works

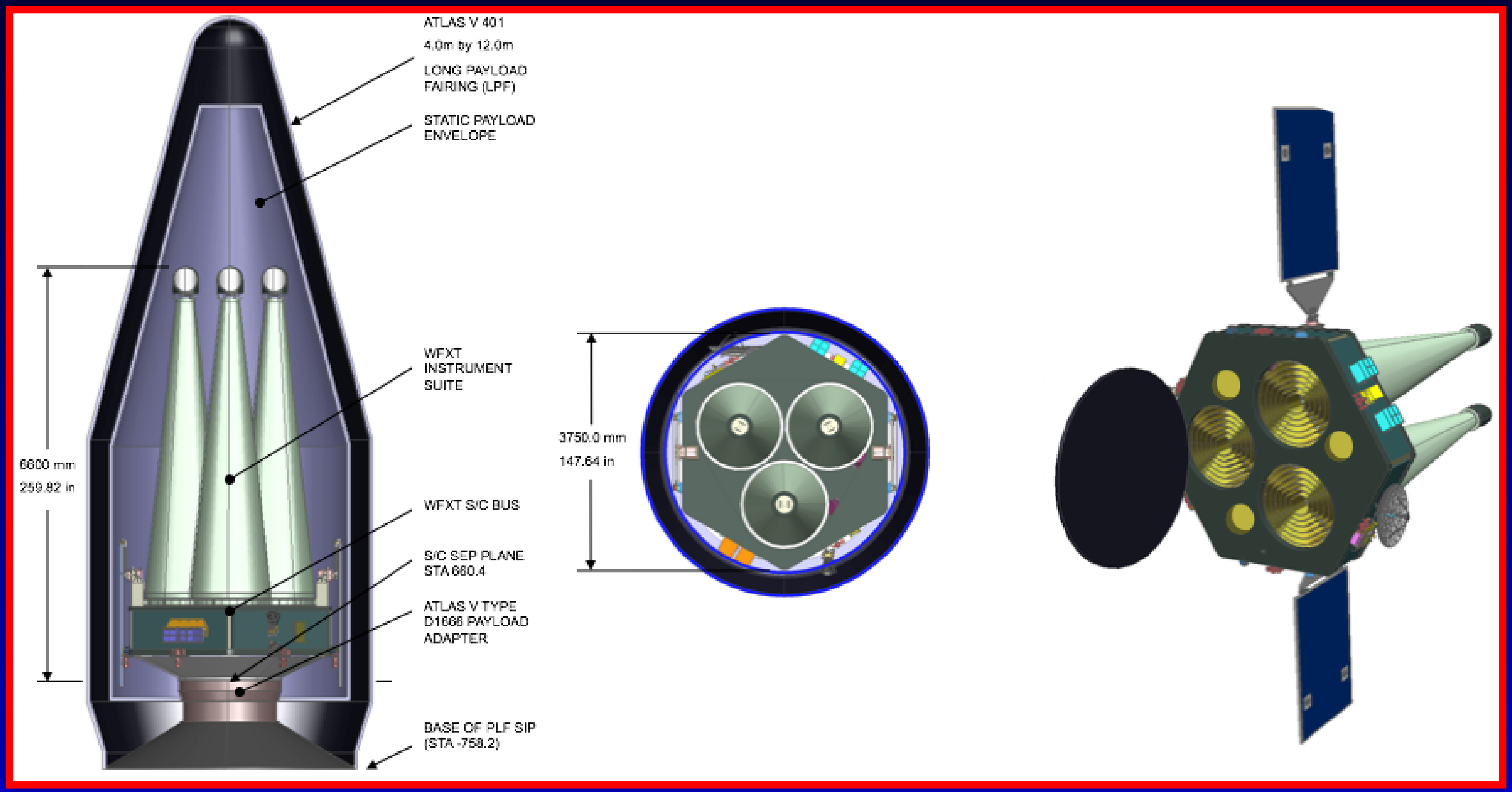


On-axis @ 0.28 keV



Metrology predicts X-ray performance

Spacecraft and Launch



Payload fits within the standard Atlas V fairing and is also compatible with Falcon 9

- System requirements are all well within current capabilities.
- WFXT is an order of magnitude less demanding than Chandra for attitude control and knowledge.
- Margins on mass (~30%) and power (~80%) are large

Item	Mass (kg) includes contingency	Power (W) includes contingency
S/C Bus - dry	1010	453
Science Payload	1638	663
Flight System - dry	2648	1116
Propellant	49	
Flight System - launch	**2697**	**1116**
Capacity	3500	2000
Margin	30%	79%

Mass and Power

Table 4: Mass and Power Budget - Current best estimates (CBE) and contingency (Cont) are listed by subsystem. Margins of 30% for mass and 79% for power are in addition to contingencies of 26% and 22%.

Item/Subsystem	Mass			Power		
	CBE (kg)	Cont. (%)	Total (kg)	CBE (W)	Cont. (%)	Total (W)
Structures & Mechanisms	405	20	486			
Electrical Power & Distribution	118	32	156	29	27	34
Command & Data Handling	60	15	69	105	5	110
Telecom	35	11	39	43	7	46
Thermal Control	30	25	38	71	25	89
Attitude Determination & Control	71	6	75	100	5.0	105
Payload Adaptor	100	20	120			
Propulsion - dry	25	7	27	60	15	69
S/C Bus - dry Total	**844**	**20**	**1010**	**408**	**11**	**453**
Telescope & Structure	900	30	1170	225	30	292
Optical Bench	225	20	270	75	30	97
CCD Camera and Electronics	75	30	98	135	30	176
Star Tracker/Fiducial Lights	60	30	78	75	30	98
Science Payload Total	**1260**	**30**	**1638**	**510**	**30**	**663**
Flight System - dry	**2104**	**26**	**2648**	**918**	**22**	**1116**
Propellant			**49**			
Flight System - launch			**2697**			**1116**
ELV Capacity to Orbit		**Atlas V 431**	**3500**	**EOL Observatory Power**		**2000**
Mass Margin (kg)			**803**	**Power Margin (W)**		**884**
Mass Margin (%)			**30**	**Power Margin (%)**		**79**

WFXT design is mature and includes large contingency.
With an assumed Atlas V launch the margins are quite large
A less expensive, but more capable Falcon 9 would provide even larger margin

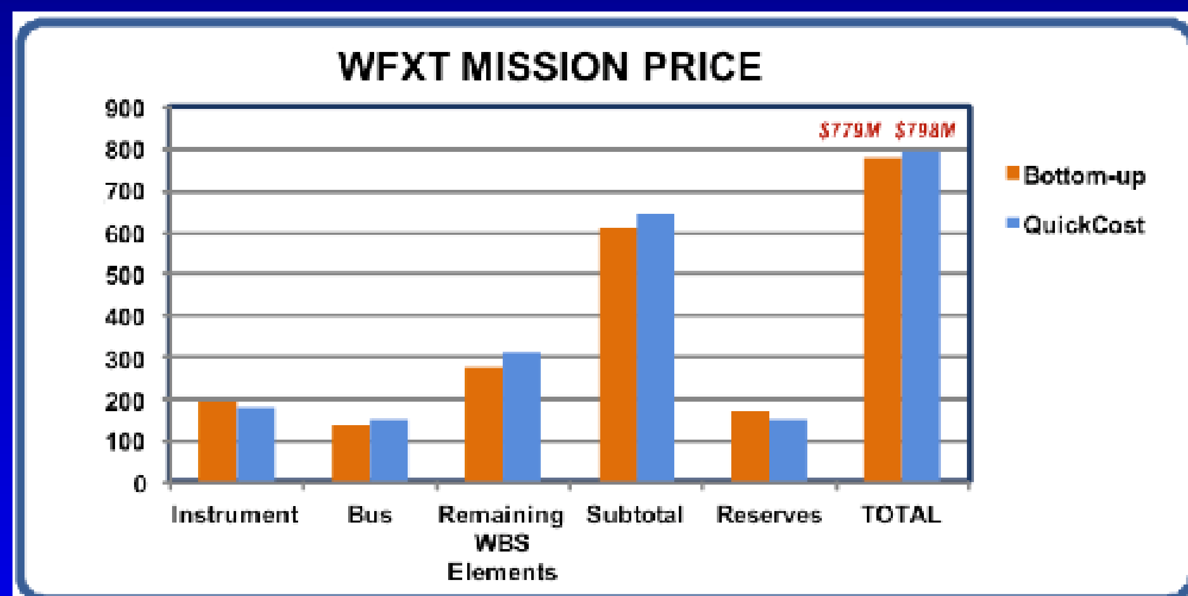
Cost and Schedule

Table 5: Bottoms Up Cost Estimate $779M (FY12 dollars) including GO program and reserves, and exclusive of launch services (estimated range $90–180M)

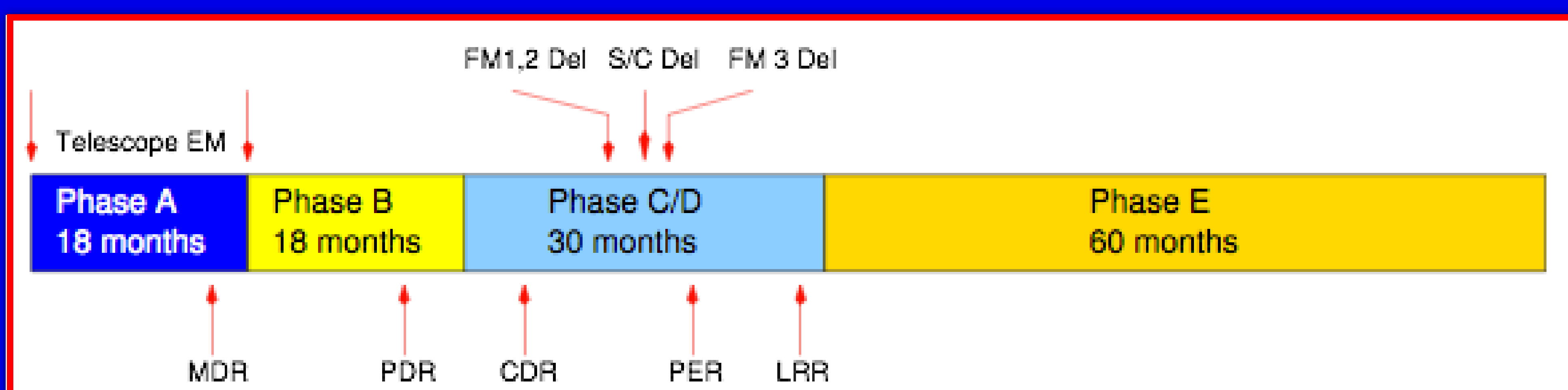
PM/QA MSE	Science Pre-launch	Science Instr	S/C BUS	Ground System	I&T LEOP	EPO	Mission Ops	Reserves†	GO Grants	Total
70	5	195	140	50	55	10	60	169	25	779

† 30% reserves Phase A,B,C/D =$156M, 20% reserves Phase E =$13M (exclusive of GO grants)

Cost validated by a model based independent cost estimate at 70% confidence



Mission schedule:
66 months to launch
60 month operations



WFXT: The Ultimate X-Ray Survey

- WFXT addresses New World New Horizons science objectives
  - What happens close to a black hole (seconds to days) ?
  - Growth and evolution of supermassive black holes (z>6)
  - Formation/evolution of clusters of galaxies and cosmology (z>1.5)
  - Growth of Large Scale Structure and the Cosmic Web
- WFXT is technically ready to start and launch in 5.5 years
  - Large mass and power margins above standard contingencies
  - TRL >= 6, except for telescope currently at TRL=4, development already in place to achieve TRL 6 by the end of Phase A
- WFXT is a moderate class mission
  - Cost < $1B (US FY12) including 30% reserves, launch, operations and a funded GO program
  - Validated by independent cost estimate $779M + launch ($90-180M)

CST Questions

- Can WFXT address “What happens close to a black hole” using Fe-L line measurements?
  - Besides stacking analyses, WFXT will have the power to perform X-ray reverberation mapping for single AGN using the Fe-L line as done by XMM for 1H0707-495 (Fabian et al. 2009, Zoghbi et al. 2011). The XMM measurements just required CCD resolution and photon statistics of a few hundred thousands photons, well within reach of WFXT for bright sources. As an example, a 100ks WFXT observation of 1H0707-495 would produce>1x10^7 counts and excellent mapping of the Fe-L line at ~0.9 keV rest frame.

- For how many AGN in the survey will WFXT be able to directly measure masses and spins from the X-ray spectrum?

  - Detection of Fe-L line in AGN is relatively rare, while Fe-K line at ~6.4 keV appears to be a more common feature. The Fe-K line will fall within the WFXT goal bandpass at z> 0.1. By requiring a photon statistics of $1x10^6$ photons to measure the line profile and line-continuum time delays (as typical of such studies with Chandra and XMM), one would expect to measure both BH spin and mass for a few (~5) AGN in the WFXT deep survey. However, the WFXT surveys will tend to avoid regions with bright sources. Instead, if 10Ms (i.e. about half-year at 0.7 efficiency) are dedicated to observations of bright AGN in the GO phase, this will allow measurement of spin and BH mass for up to ~100 unobscured AGN with more than $1x10^6$ net counts each, (i.e. 100 unobscured AGN with f_{soft} > $4x10^{-12}$ erg/cm2/s observed for 100ks each). Note: the exact number depends on the distribution of BH masses - hence of spectral time lags.

  - As far as variability to sample what happens close to the central BH, lags between different energy bands have been observed by XMM (Fabian et al 2009, Zoghbi et al 2010, 2011, Miller et al. 2010), so WFXT will do better in terms of photon statistics sampling more AGNs (the timescales are hundreds to thousand of seconds). Measurements of lags in the X-ray spectra themselves are limited today to only a few objects (3-5), and WFXT will allow access to tens to hundreds of AGNs with similar statistics, but the precise number depend on the time spent in long observing campaigns on each target (>200 ks each). Looking at variability lags between narrow X-ray bands, in principle, probes the structure of the accretion disk. If detected they may constrain the size and geometry of the "hotspots". However, since WFXT is not efficient in hard X-rays, the improvement space wrt XMM is limited, as the reflected component needs to be a significant part of the spectrum to do such studies (and only for very nearby AGNs, so redshift won't help).

- How will the 1200-9000 z>6 AGN be identified? By WFXT itself from Fe K lines, or in followup surveys? If the space density of z>6 AGN is uncertain by a factor of >20, how can the expected number of AGN be limited to a range of < 10x?
    - The Fe-K line will be used, as we applied a 400 ct threshold for determining the number of AGN. We wrote that we expect "about 1200-9000 objects" at z>6, and later on we wrote that "the space density of such z>6 AGNs is uncertain by at least a factor of 20". This is because the discrepancy between model expectations increases towards low-luminosities/faint-fluxes. When computing the total number of objects expected by WFXT according to different models, we are also (obviously) counting AGN at high-luminosities/high-fluxes, where we know how things go. Therefore, the uncertainty on the total number of objects at z>6 has to include all luminosities/fluxes, and is therefore smaller than the uncertainty on low-luminosity/low-flux AGN.
- How many clusters, at which redshifts, will WFXT be able to measure as mass proxies?
    - We expect to detect ~5000 clusters at z>0,5 for which we can determine from the X-ray data alone the temperature and redshift with enough accuracy to be useful as mass proxies, and for cosmology. of these , about 3000 will be in the 0.5 - 1.0 redshift range, and 2000 will be at z>1.0. This sample is ~50 times the present ROSAT survey cluster sample - for which Chandra and/or XMM follow up was used to get the high quality X-ray data needed.
- Regarding cluster cosmology, what will be the advance of WFXT over eROSITA, especially in regards to the DE measurements (e.g. Figure 5)?
    - See the predictions from eROSITA, but see the presenttions from the eROSITA 2011 Conference:
      H. Boehringer: "Prospects for eROSITA Galaxy Cluster Research"
      A. Pillepich: "The X-ray cluster survey with eROSITA: predictions for cosmology, cluster physics, and primordial non-Gaussianity"