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
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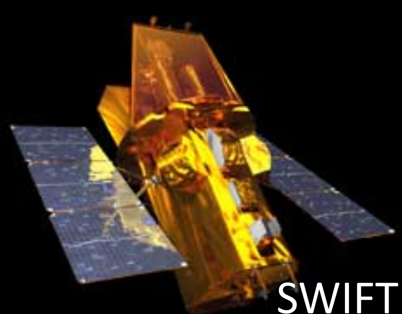
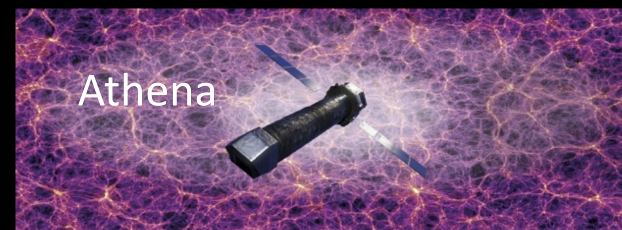
The X-ray Universe

Present

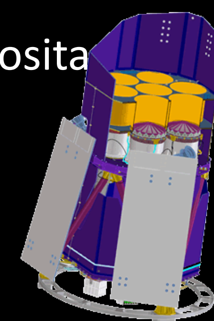


Future



NICER

eRosita

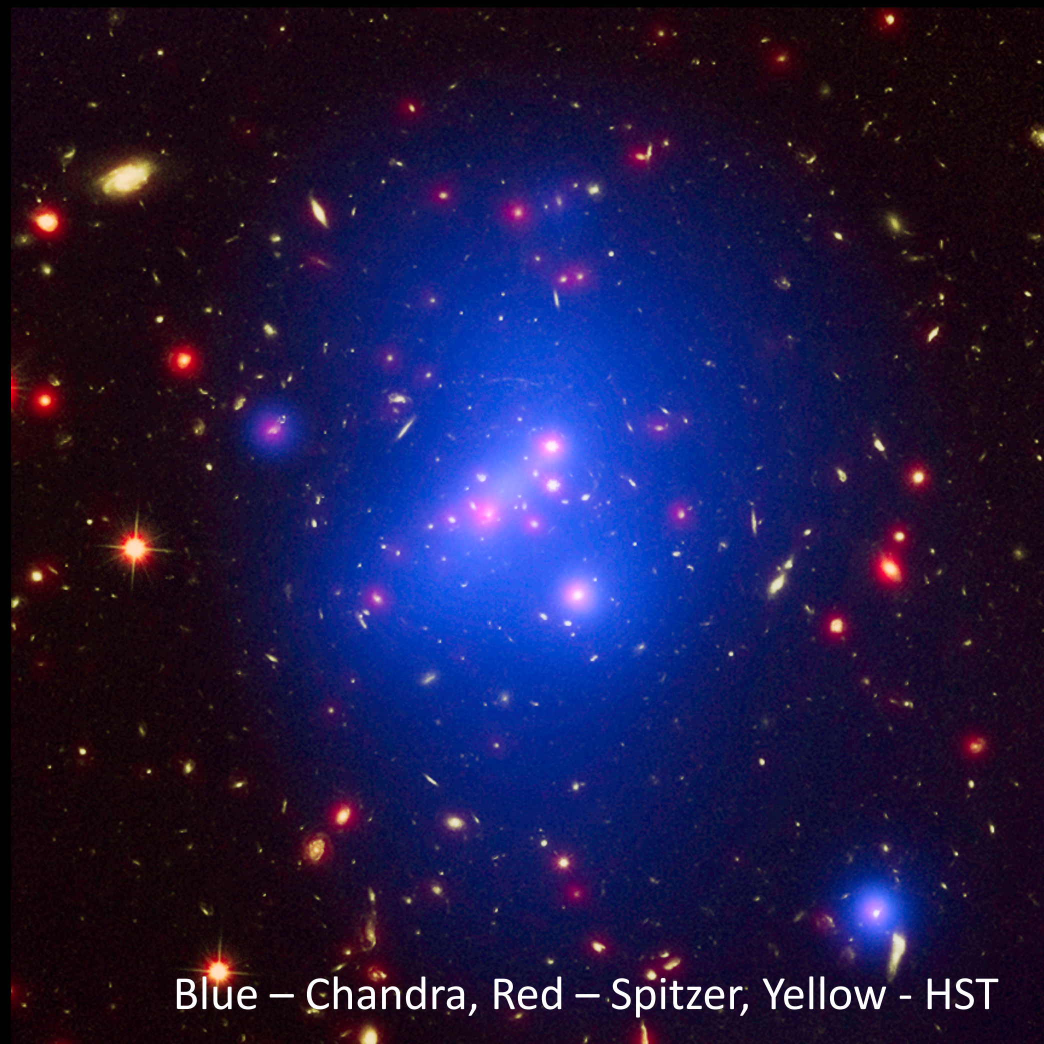


X-ray Surveyor?

Chandra/Spitzer/Hubble observation of z=1.75 cluster of galaxies IDCS J1426.5+3508 (Brodwin+2015,2016)

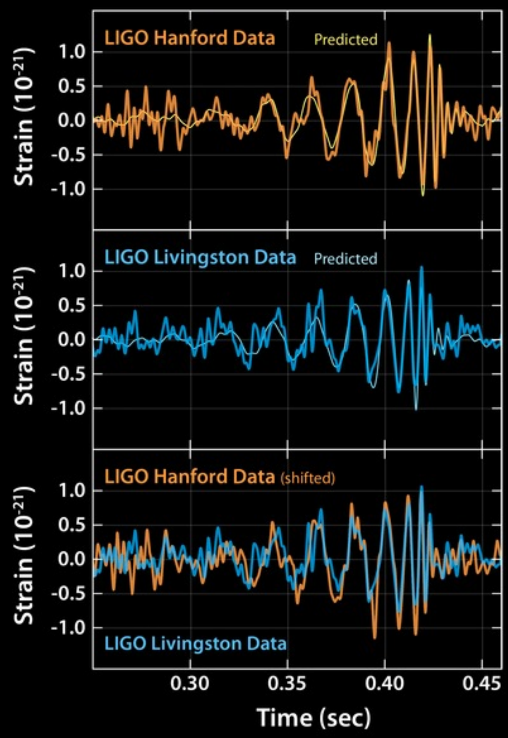
$$M_{R500,Y_X}\, 2.6^{+1.5}_{-0.5} \times 10^{14} M_{\odot}$$

- Highest redshift cluster with X-ray, SZ, and lensing estimates of gravitating mass.
- No detection of heavy metals (Z<0.18 at 2 sigma)
- Dense, low entropy core – one of few cool core clusters known beyond z=1
- Identified as part of IRAC Distant Cluster Survey
- This one object does not put stress on ΛCMD.



X-ray Follow-up to Gravitational Wave Sources

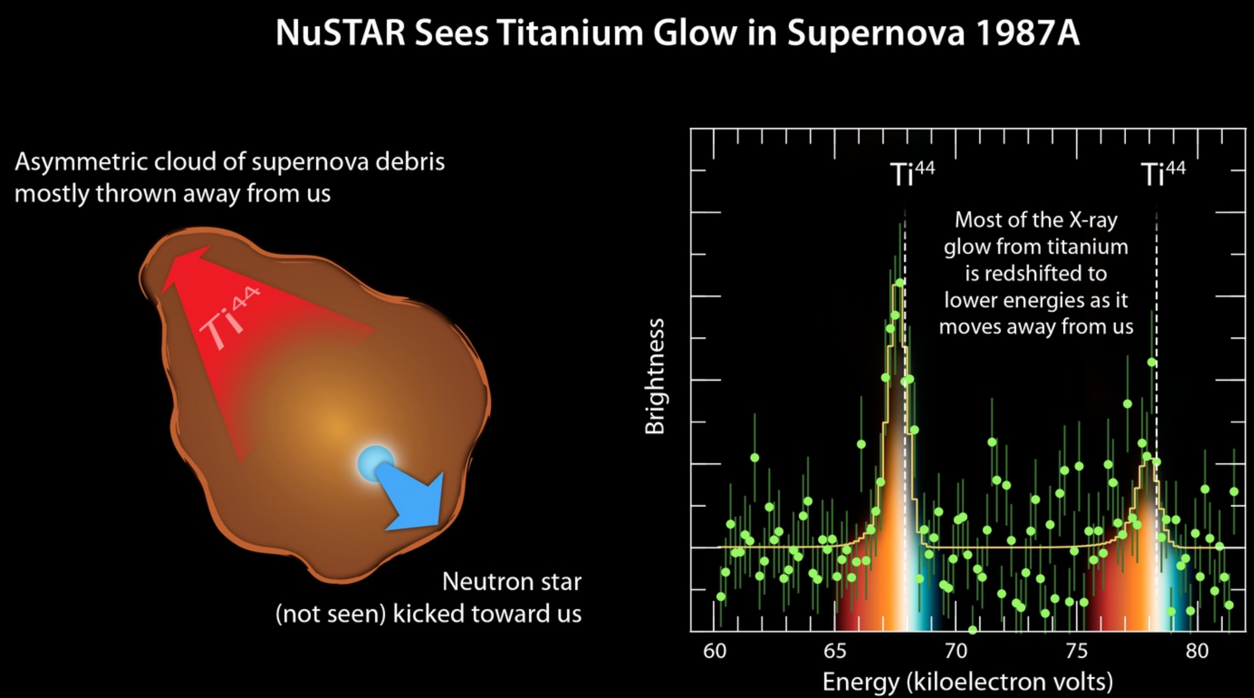
- ALIGO detection (Abbott+2016) of a BH-BH merger has energized the physics/astrophysics communties!
- Electromagnetic follow-up can provide a wealth of information about compact object mergers:
  - sGRB have short (2 s) burst of high energy emission and longer panchromatic afterglow (Metzger and Berger 2012)
  - 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 the GW150914 event (Evans+2016)

Future X-ray mission concepts are likely to be developed to optimize follow-up efficiency

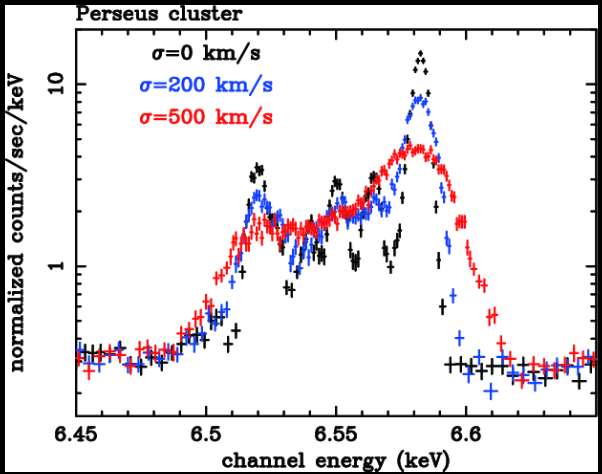
Nuclear Spectroscopic Telescope Array (NuStar)



- Detection of narrow emission lines at 67.87 and 78.32 keV from the decay of ^{44}Ti
- Lines are redshifted by ~700 km s^{-1}
- Direct evidence of asymmetric explosion (Boggs+2015)

Hitomi observation of Perseus Cluster

Chandra image of Perseus cluster (Fabian+2005)



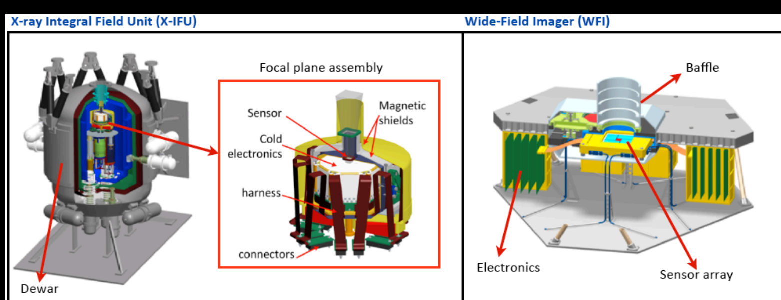
Simulated Hitomi SXS spectrum around Fe XXV K_α line

- Nearby massive cool core cluster
- Observed with Hitomi SXS through Be filter (Fabian+2016, in press)
- Calorimeter resolution ~4.8 eV (CCD resolution 120 eV)
- Can resolve turbulent broadening, bulk motions, etc.

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

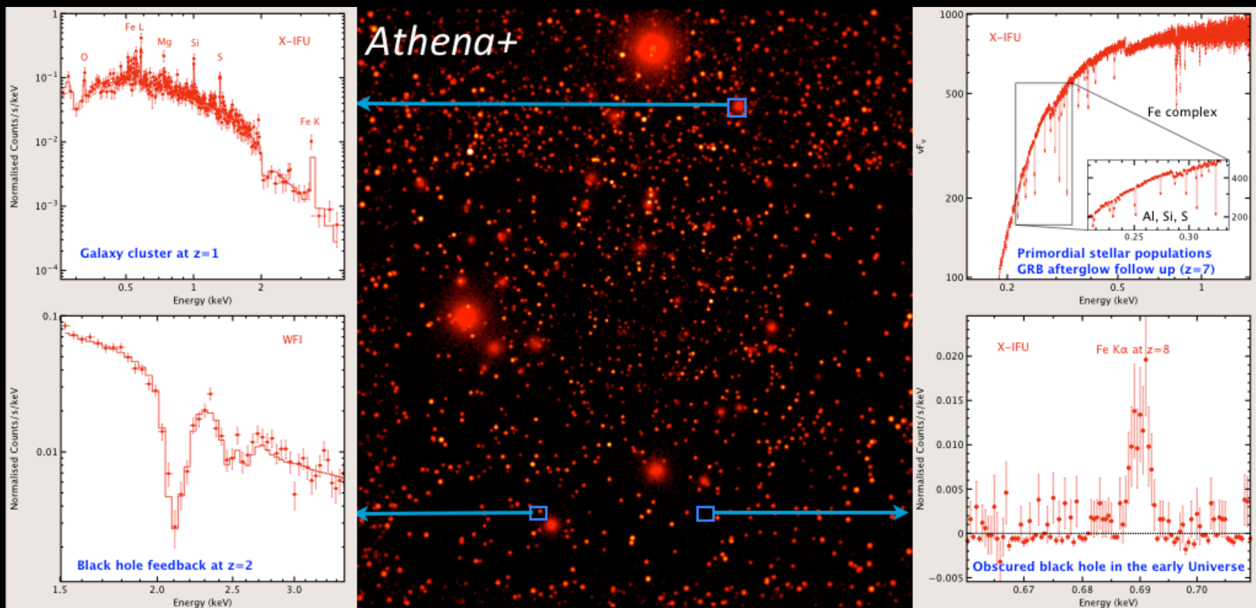
Two science instruments: X-ray Integral Field Unit (XIFU) microcalorimeter and Wide-Field Imager DEPFET sensor array



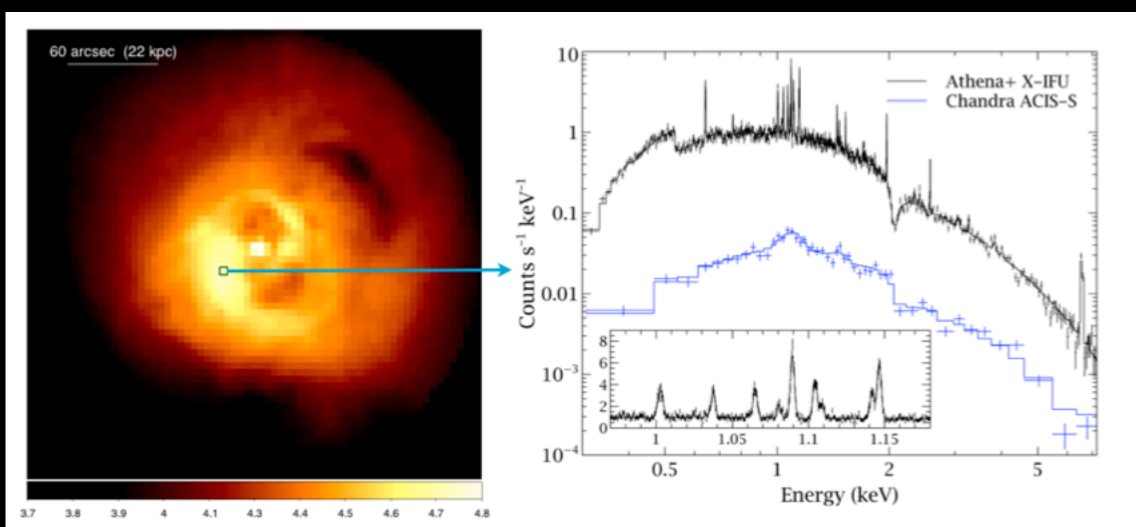
Parameter	Requirements	Enabling technology/comments
Effective Area	2 m^2 @ 1 keV (goal 2.5 m^2) 0.25 m^2 @ 6 keV (goal 0.3 m^2)	Silicon Pore Optics developed by ESA. Single telescope: 3 m outer diameter, 12 m fixed focal length.
Angular Resolution	5" (goal 3") on-axis 10" at 25' radius	*Detailed analysis 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 Parameters of Athena Mission

Athena Science



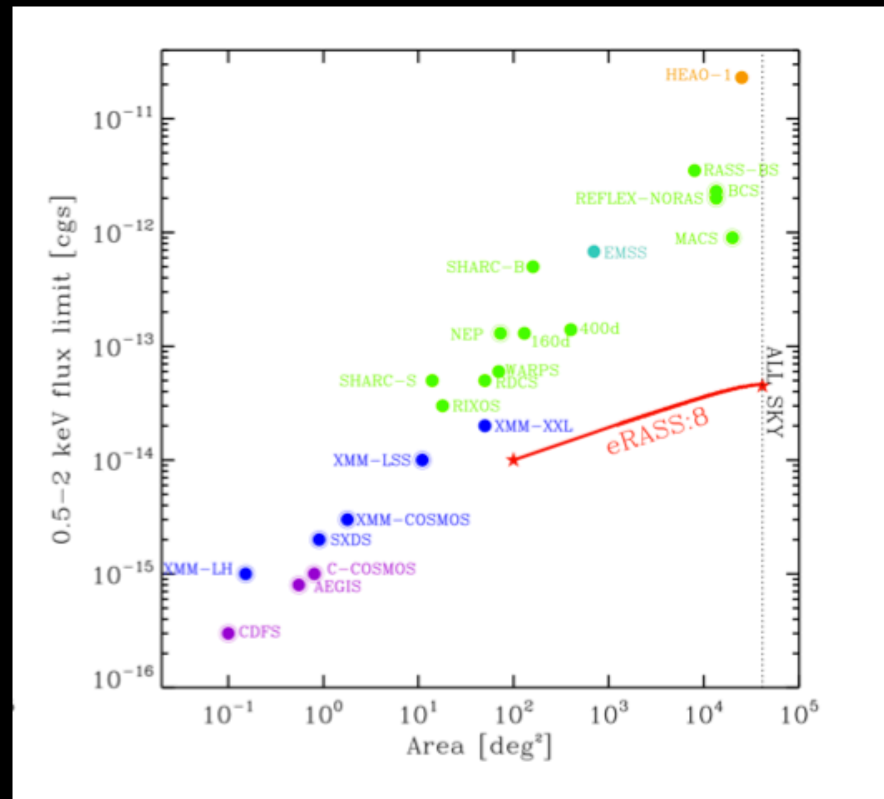
Euclid/LSST/numerical simulations will constrain how dark matter structures assemble. X-ray observations are required to understand the evolution of the baryons (Nandra +2013)



Simulated XIFU spectrum of a small region of the Perseus cluster (Nandra+2013). ACIS-S spectrum (blue histogram) shown for comparison.

extended Roentgen Survey with an Imaging Telescope Array (eRosita)

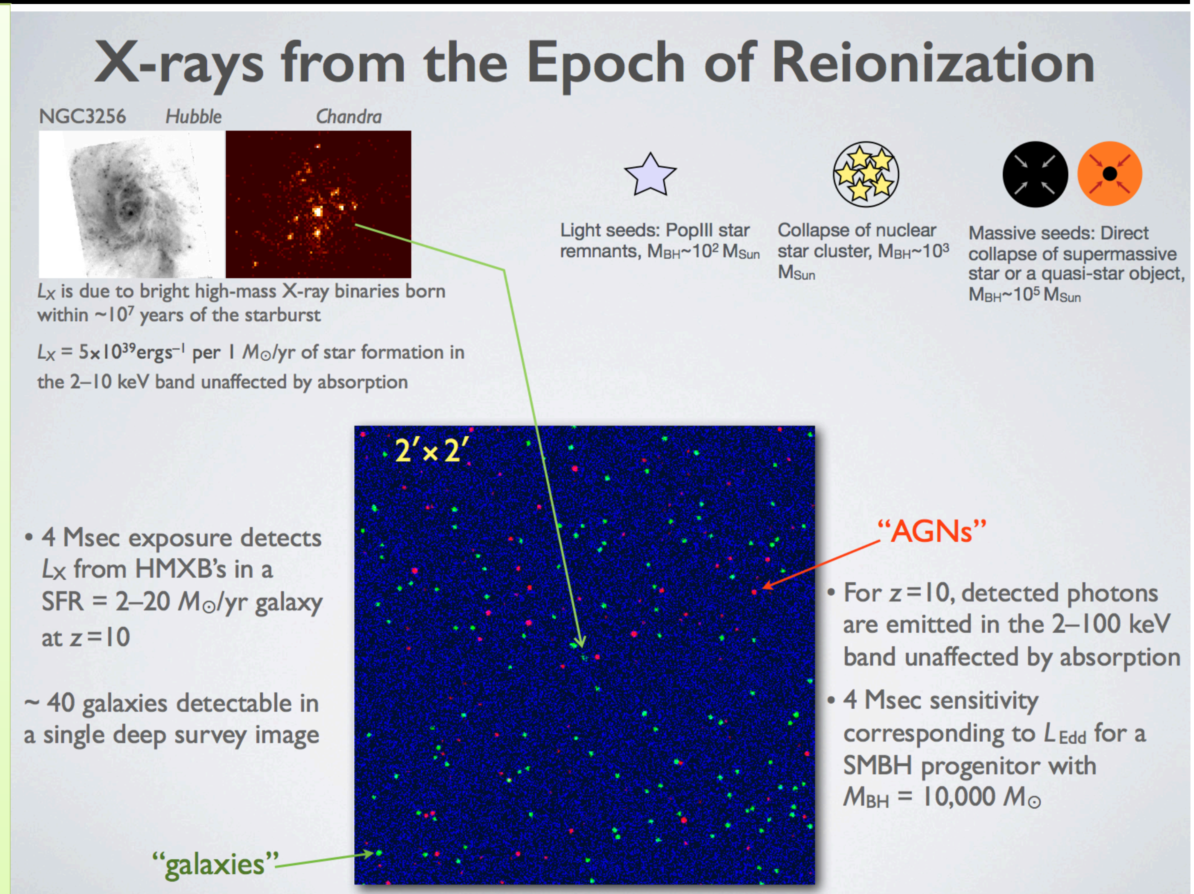
- Primary instrument on Russian Spectrum Roengten Gamma (SRG) mission
- First imaging all sky survey up to 10 keV – unprecedented sensitivity
  - Will detect up to 100,000 clusters of galaxies, and map diffuse filaments between clusters
  - Will detect ~3E6 AGN
  - Study in unprecedented detail the Galactic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



Survey sensitivity for extended sources (Merloni+2012)

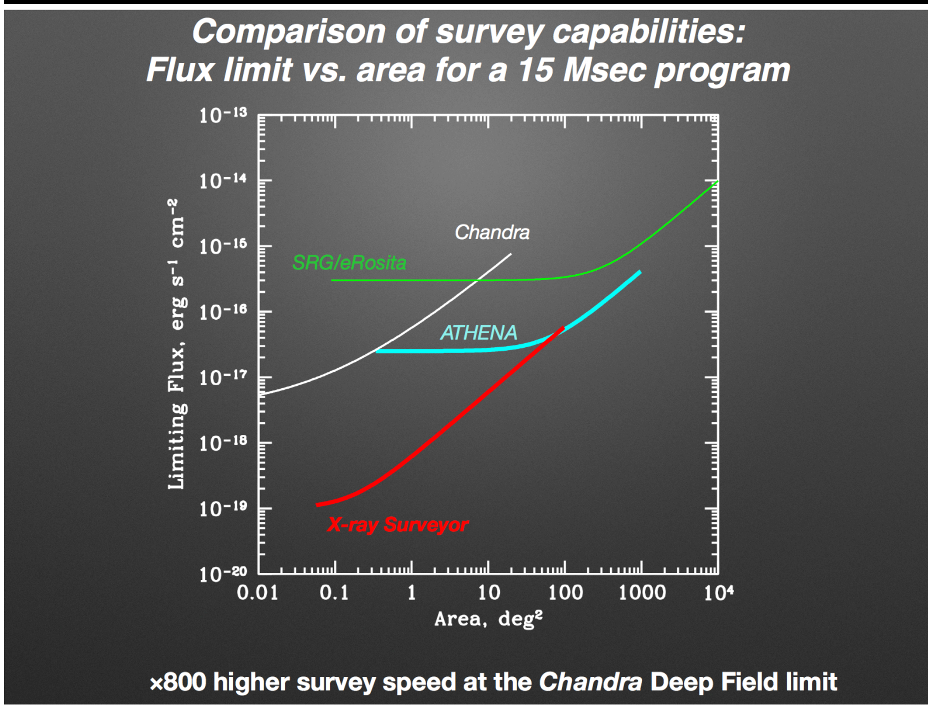
X-ray Surveyor – A Major Leap in Sensitivity

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



Detect black holes of M~10,000 M_{solar} to z=10

Notional X-ray Surveyor Concept

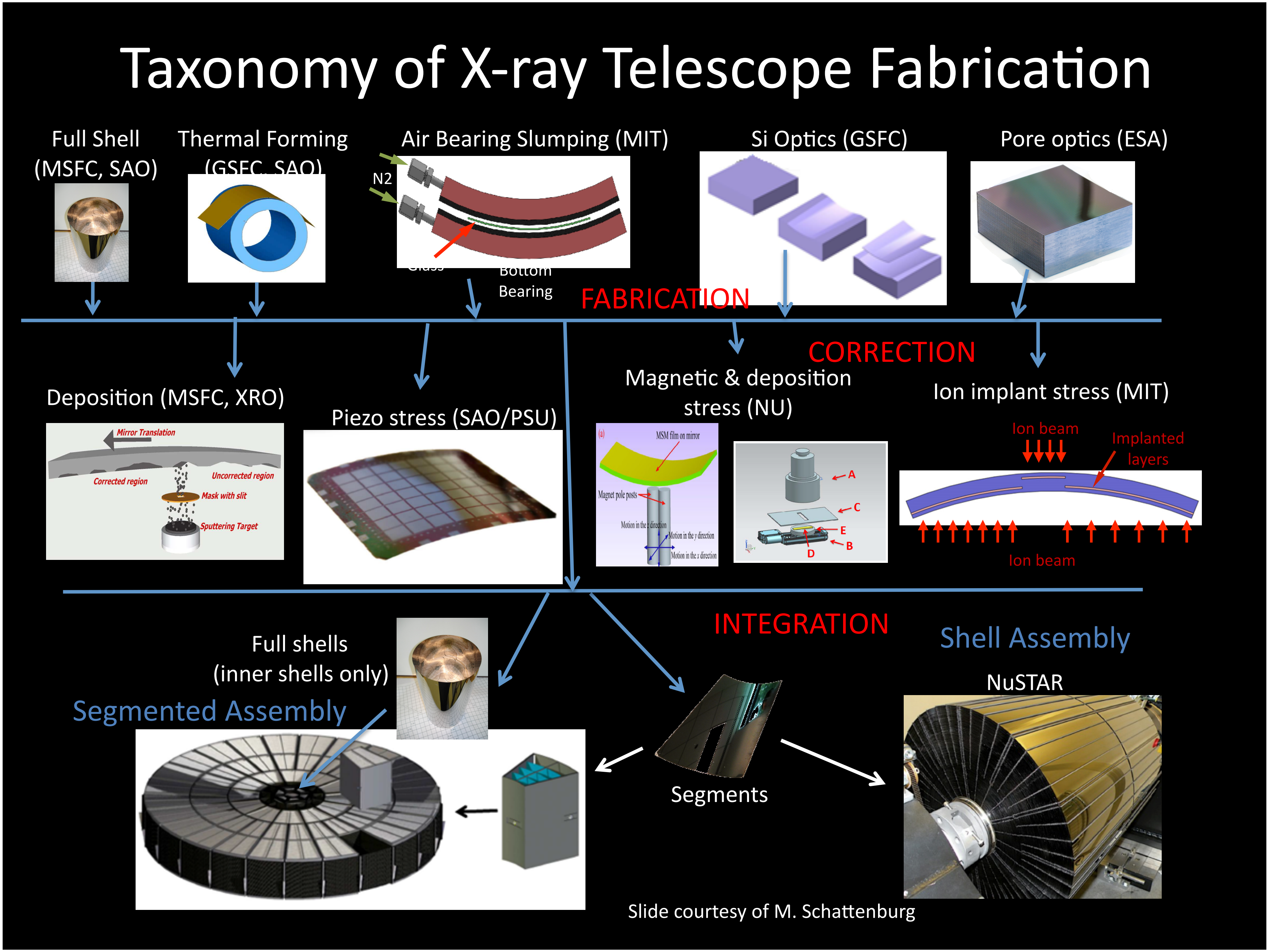


Diameter	3 m
Focal length	10 m
On axis HP diameter (1 keV)	0.5 arc sec
Design	Wolter-Schwarzshild
FOV diameter (<1 arc sec)	15 arc min
Mirror shells	~300
Mirrors (segmented design)	10,000 to 50,000
Effective area @ 1 keV (mirror only)	~2.5 m^2
Nominal bandwidth	0.1 - 10 keV

SAO/MSFC Advanced Concepts Office study for one potential configuration of XRS (Gaskin+2015)

Cost (including LV) < $3B

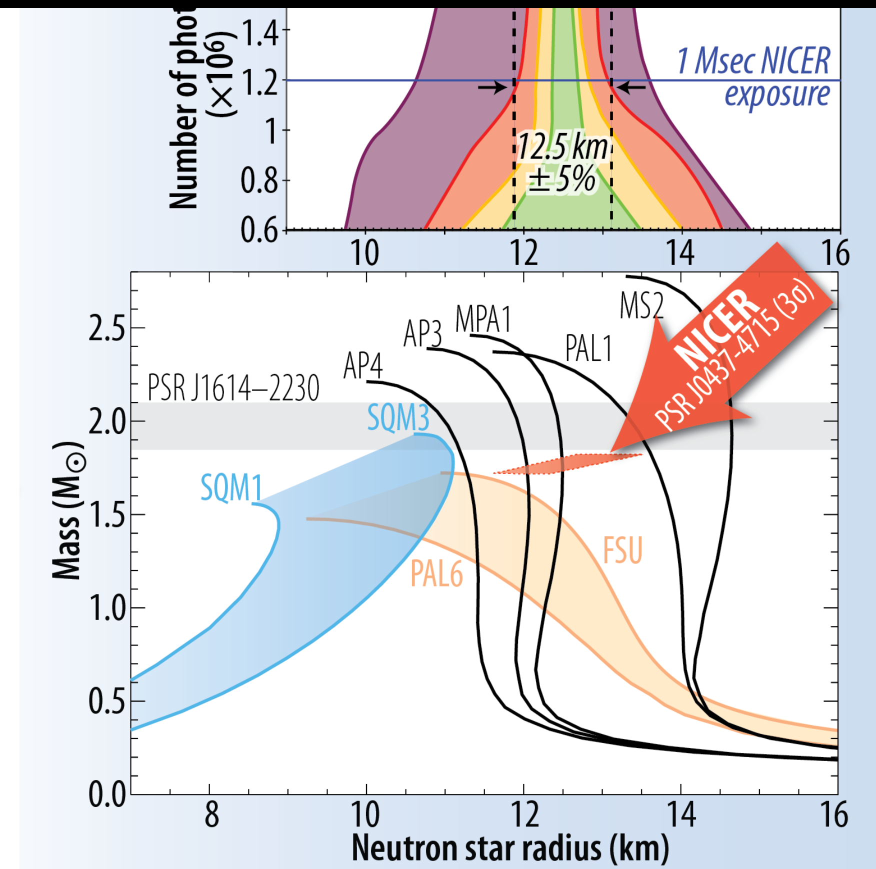
Potential optics requirements for XRS (courtesy of M. Schattenburg)



Taxonomy of X-ray Telescope Fabrication
Full Shell (MSFC, SAO)
Thermal Forming (GSFC, SAO)
Air Bearing Slumping (MIT)
N2
Bottom Bearing
Si Optics (GSFC)
Pore optics (ESA)
FABRICATION
CORRECTION
Deposition (MSFC, XRO)
Mirror Translation
Corrected region
Uncorrected region
Mask with slit
Sputtering Target
Piezo stress (SAO/PSU)
Magnetic & deposition stress (NU)
MSM film on mirror
Magnet pole posts
A
C
E
B
D
Ion implant stress (MIT)
Ion beam
Implanted layers
Ion beam
INTEGRATION
Full shells (inner shells only)
Segmented Assembly
Shell Assembly
NuSTAR
Segments
Slide courtesy of M. Schattenburg

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 January, 2017**



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

X-ray Science Interest Group

- Contact Information
  - Mark Bautz – mwb@space.mit.edu
  - Ralph Kraft – rkraft@cfa.harvard.edu
- XRSIG website: http://pcos.gsfc.nasa.gov/sigs/xrsig.php
- Recent events:
  - 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 Meeting
  - AAS meeting, Grapevine, TX, Jan, 2017