Next big steps in X-ray astronomy

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Present-day Universe is the “universe of galaxies”.
How did the “universe of galaxies” emerge from initial conditions?

What physical laws govern this process?
Numerical simulation of formation history for a Milky Way type galaxy. Colors show temperature of the H+He gas. Red corresponds to $T>1000,000K$, blue to $T<10,000K$.

Theoretical framework: Gravitational instabilities drive formation and growth of galaxies. Large fraction of baryons ejected from galaxies due to energy generated within.
Simulated 1.6M light years region around Milky Way type galaxy in different wavebands.

~ 40% of baryons are converted to stars
~ 30% are observable in UV absorption
~ 30% are heated to X-ray temperatures
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4 arcmin image from SDSS survey
(2m optical telescope)

X-ray image
(Chandra)

Black holes with masses > $1000,000,000$ Msun exist at $t=900$ Myr after the Big Bang. Where do they come from?

Need ~ 2 orders of magnitude improvement in capability to observe very early stages of the black hole evolution.
Chandra X-ray Observatory

Structure of Crab nebula

1,000 cm² effective area

Harvard 15-inch Great Refractor ca. 1847

Equation of state of neutron star matter

Dark Energy from observations of galaxy clusters

Path to Chandra successor
Path to *Chandra* successor

- 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

New, smartly built, mirror system. Lower mass, similar angular resolution, same focal length as *Chandra*'s. A factor of 30 more effective area. Sub-arcsec imaging over 15×15′ field.

Next-generation X-ray Mirror
Next-generation X-ray mirror

New mirror is built from densely packed thin segments, mounted into modules.
<900 kg for 2.3m² of collecting area

Performance Gains:
- **×30 more effective area** than *Chandra* combined with big improvements in the low-E detector quantum efficiencies
- **×10 larger solid angle for sub-arcsec imaging** (15′×15′ vs. 4′×4′ for *Chandra*)
- **×500 higher grasp for surveys**

*Chandra* mirror shells are 2.5cm thick.
1,500 kg for 0.08m² of collecting area

Piezo cell + integrated electronics + strain gauges for in-flight feedback and control

Science topics for *Chandra* successor
**First Accretion Light in the Universe**

Simulated 2′×2′, 4 Msec image

X-rays from supermassive black holes at early stages of their growth tree at z=10

**Formation and evolution of galaxy clusters, groups, and massive galaxies throughout cosmic time**

T<10,000 K : Optical & IR light + radio

T>1,000,000 K : X-rays

Gas halos contain >50% of baryons by mass and are X-ray objects (T>10^6 K) for M>10^{12} M_{sun} (~ Milky Way).

Hot gas in first-generation (z=6) galaxy group-sized structures and quasar environments will be detectable and resolvable.

**Uncharted Local Universe**

Hot baryons in the Cosmic Web at z=0 observable in absorption and emission