Capabilities and Science Drivers for the X-ray Surveyor mission concept

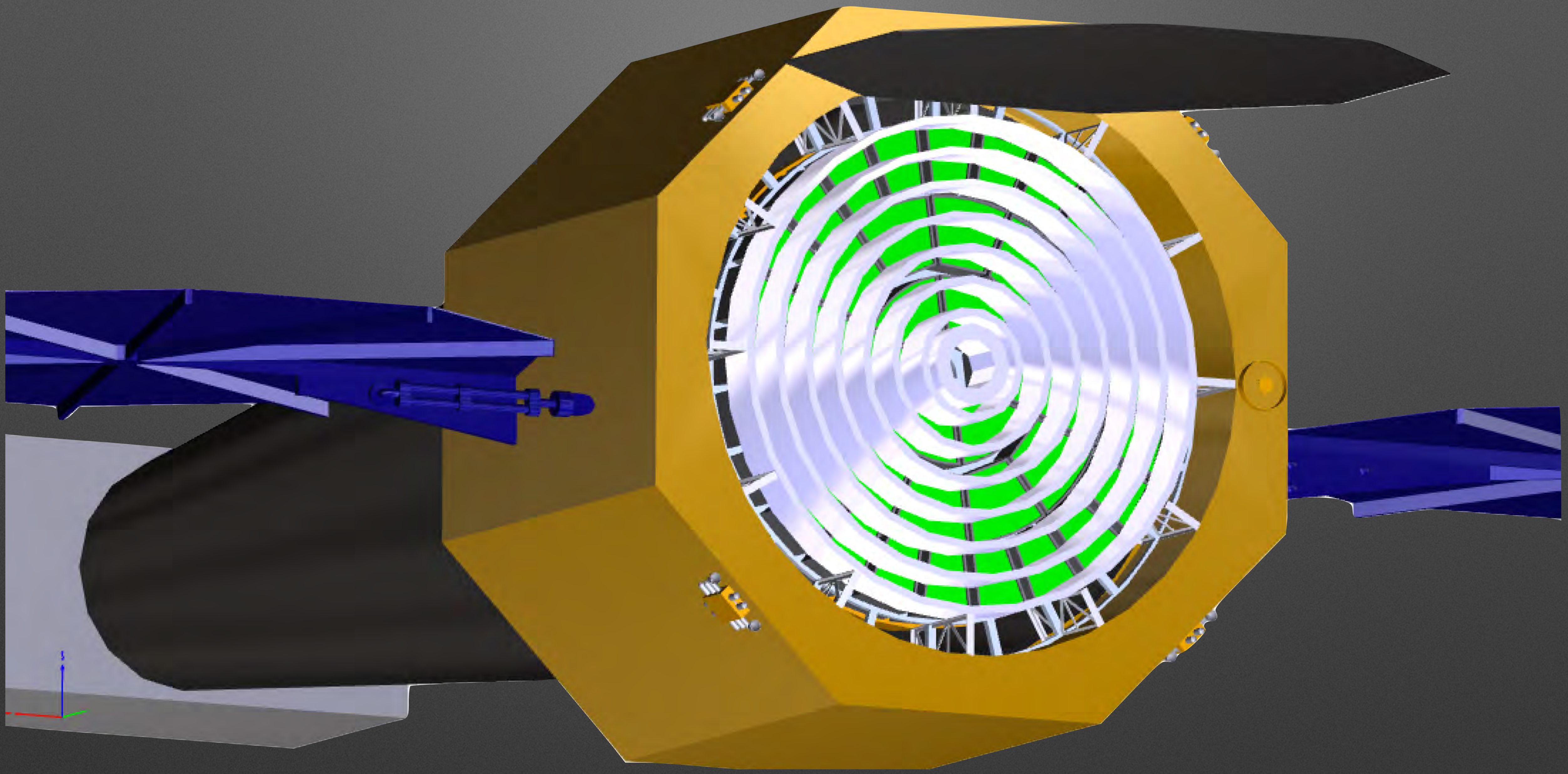
A. Vikhlinin
on behalf of the X-ray Surveyor community

X-ray Surveyor Science Workshop: October 6–8 2015, National Museum of the American Indian in Washington, DC

SOC: J. Gaskin, M. Weisskopf (MSFC), H. Tananbaum, A. Vikhlinin, G. Fabbiano, C. Jones (SAO), E. Feigelson, W. N. Brandt, L. Townsley, D. Burrows (PSU), P. Natarajan (Yale), M. Markevitch (GSFC), A. Kravtsov (Chicago), S. Allen, R. Romani (Stanford), S. Heinz (Wisconsin), C. Kouveliotou (GWU), F. Ozel (Ariz.), R. Mushotzky (UMD), M. Nowak (MIT), R. Osten (STSCI)

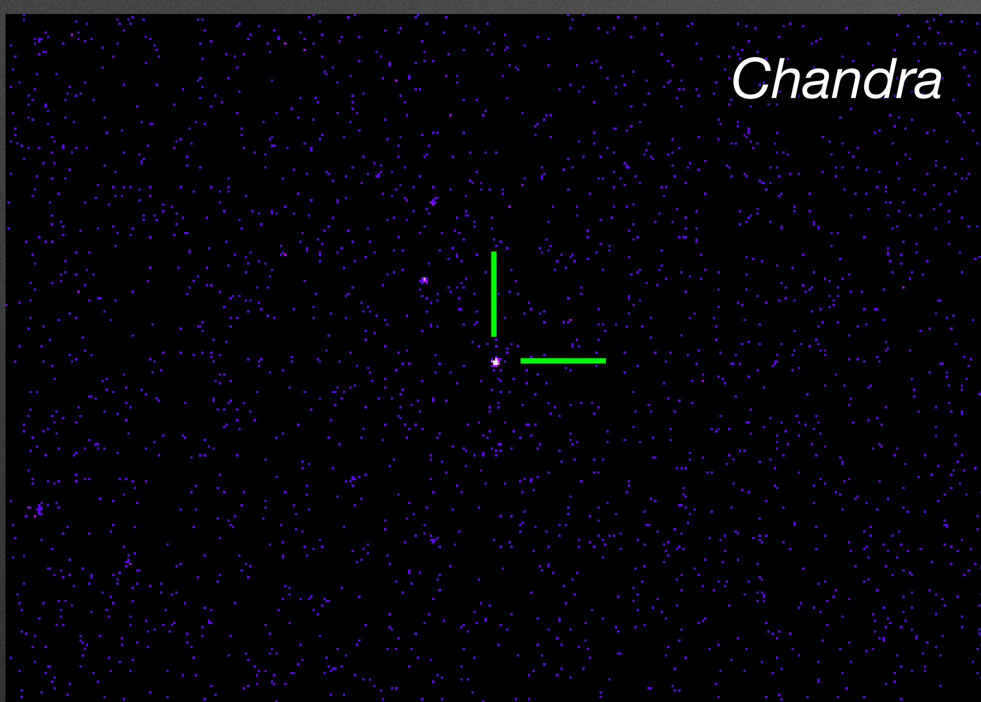
Martin Weisskopf will describe a possible mission configuration and its study at MSFC ACO (next talk)

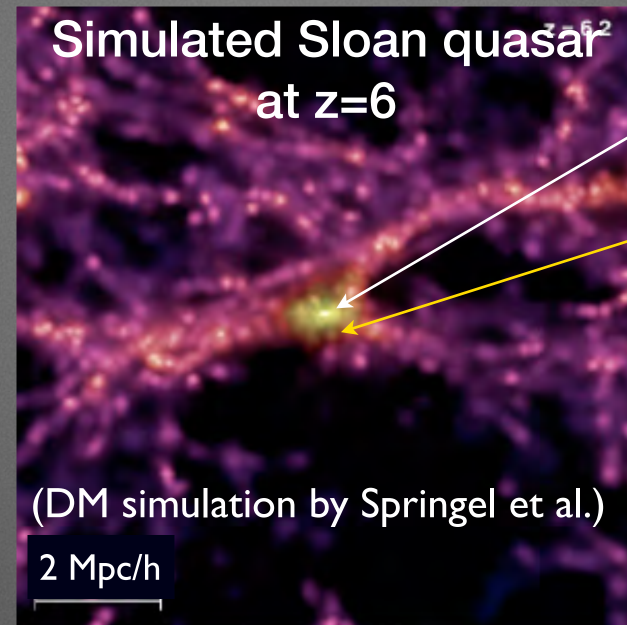
Leap in sensitivity: High throughput with sub-arcsec resolution

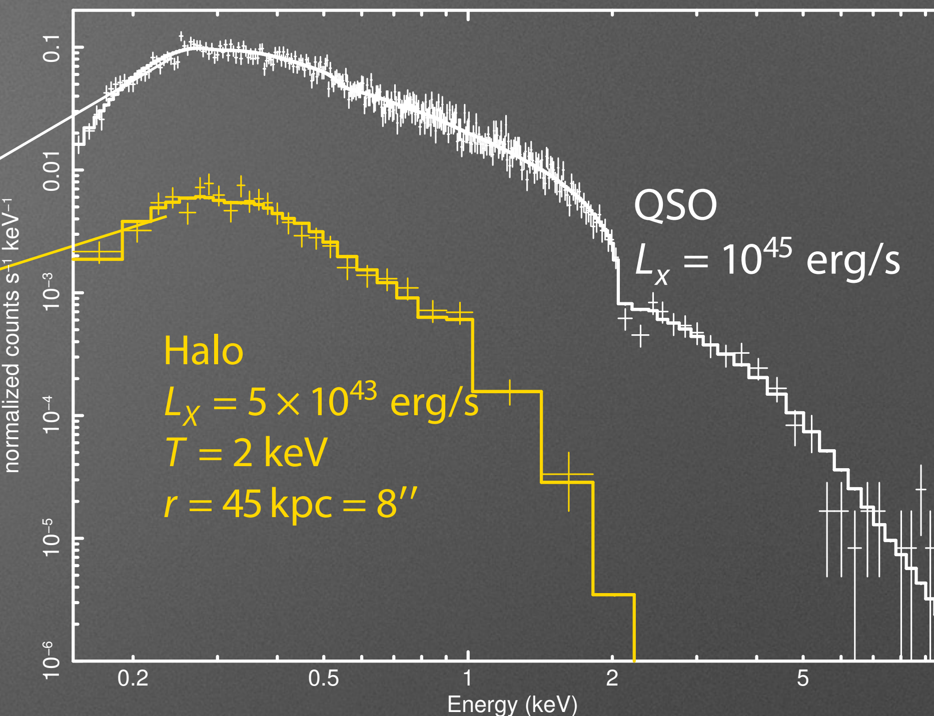


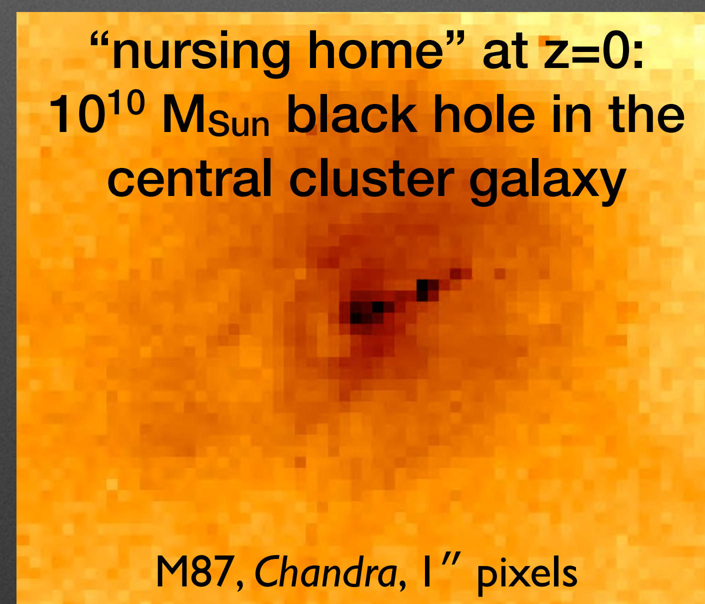
- ×50 more effective area than *Chandra.* 4 Msec *Chandra* Deep Field done in 80 ksec. Threshold for blind detections in a 4Msec survey is ~ 3×10^{-19} erg/s/cm^2 (0.5–2 keV band)
- ×16 larger solid angle for sub-arcsec imaging — out to 10 arcmin radius
- **×800 higher survey speed at the *Chandra* Deep Field limit**

Black holes: from birth to today's monsters









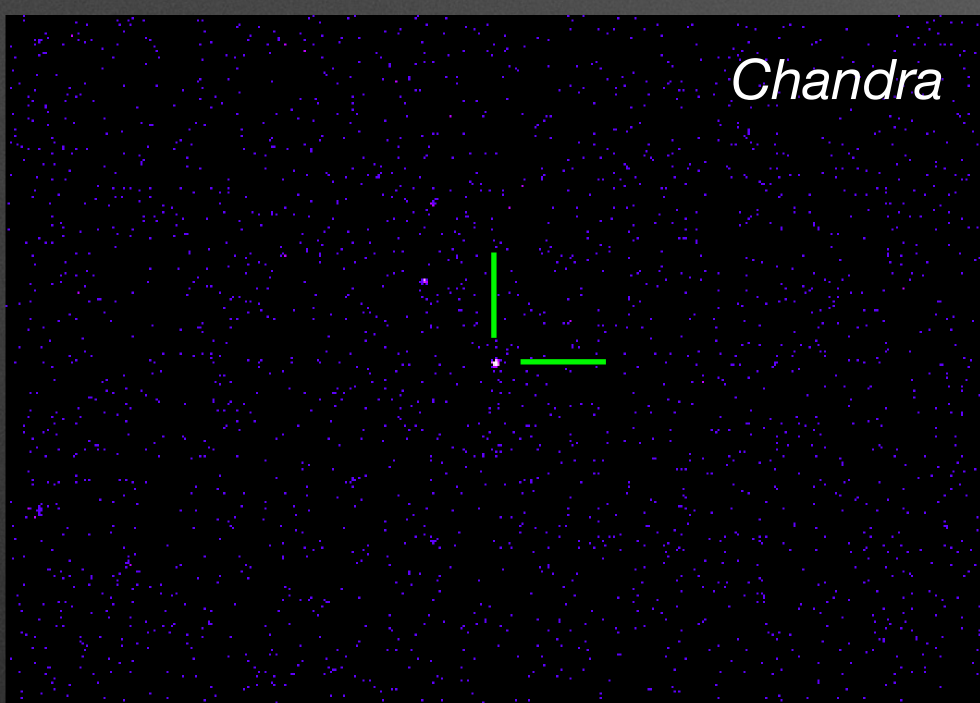
Also:

- Electromagnetic signatures of black hole mergers
- Using X-ray binary population as tracers of star formation, their role in cosmic reionization
- Jets

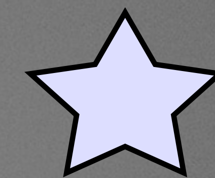
What is their origin?

How do they co-evolve with galaxies and affect environment?

Black holes: what is the nature of their seeds?

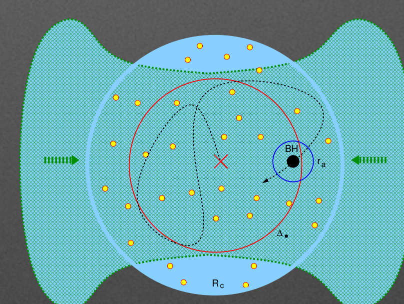


What is their origin?

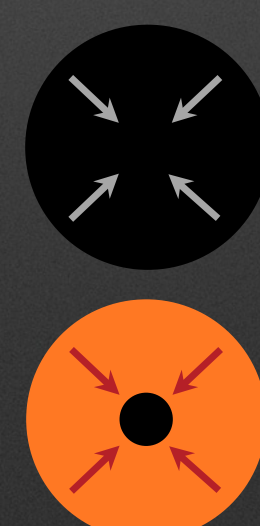


Light seeds: PopIII star remnants, $M_{BH} \sim 10^2 M_{Sun}$

Collapse of nuclear star cluster, $M_{BH} \sim 10^3 M_{Sun}$



Sustained super-Eddington growth to $M_{BH} \sim 10^4 M_{Sun}$ or more



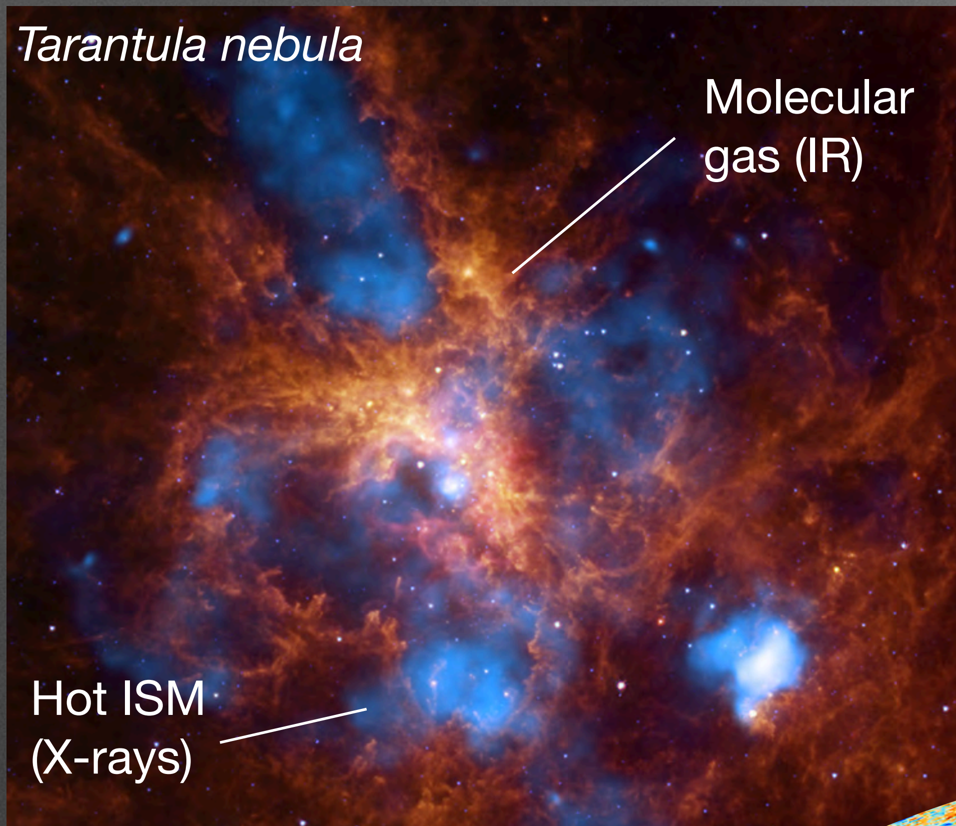
Massive seeds: Direct collapse of supermassive star or a quasi-star object, $M_{BH} \sim 10^5 M_{Sun}$

Nature of black hole seeds — First accretion light in the Universe

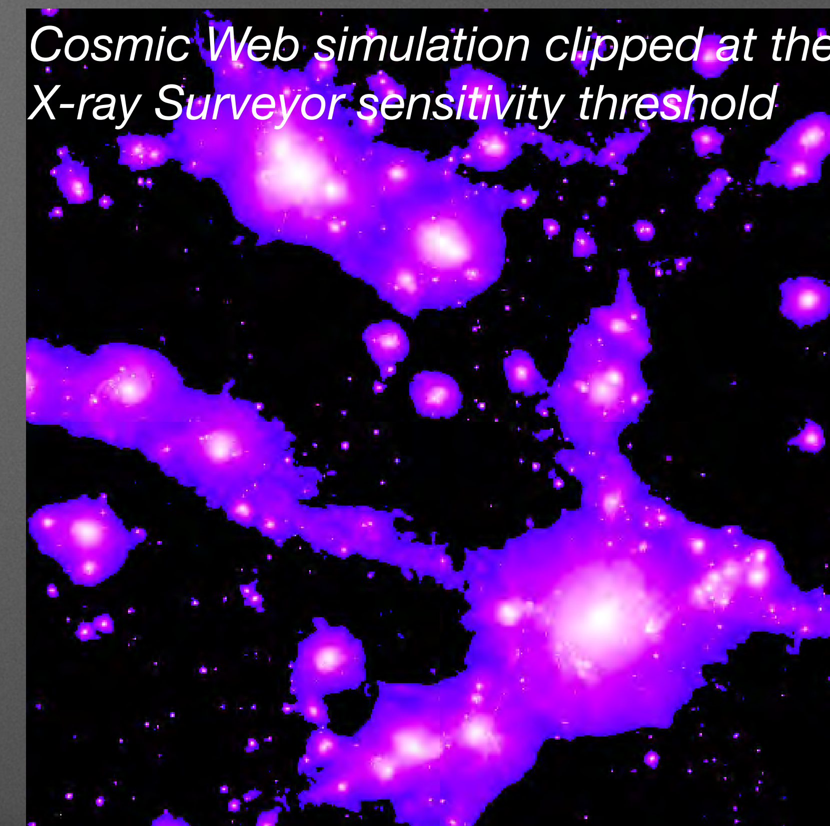
Simulated 2x2 arcmin deep fields observed with JWST, X-ray Surveyor, and ATHENA

- 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).
- Each X-ray Surveyor source will be associated with a unique JWST-detected galaxy. Limiting sensitivity, ~1×10^{-19} erg/s/cm^2, corresponds to L_X ~ 1×10^{41} erg/s or M_{BH} ~ 10,000 M_{Sun} at $z=10$ — well within the plausible seed mass range.
- X-ray confusion limit for ATHENA is 2.5×10^{-17} erg/s/cm^2 (5× 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 O&IR id's further increases the limit (M_{BH}~10^7 M_{Sun} at z=8 is quoted by ATHENA team).

Cycles of baryons in and out of galaxies



Generation of hot ISM in young star-forming regions. How does hot ISM push molecular gas away and quench star formation?



Structure of the Cosmic Web through observations of hot IGM *in emission*

How did the “universe of galaxies” emerge from initial conditions?

Galaxy formation: the nature of feedback

T~100,000 K   T<10,000 K   T>1,000,000 K

Simulated 500 kpc box around a Milky Way type galaxy.

~ 40% of baryons are converted to stars, ~ 60% ejected outside

- ~ 30% are observable in UV absorption
- ~ 30% are heated to X-ray temperatures — unique signature of energy feedback

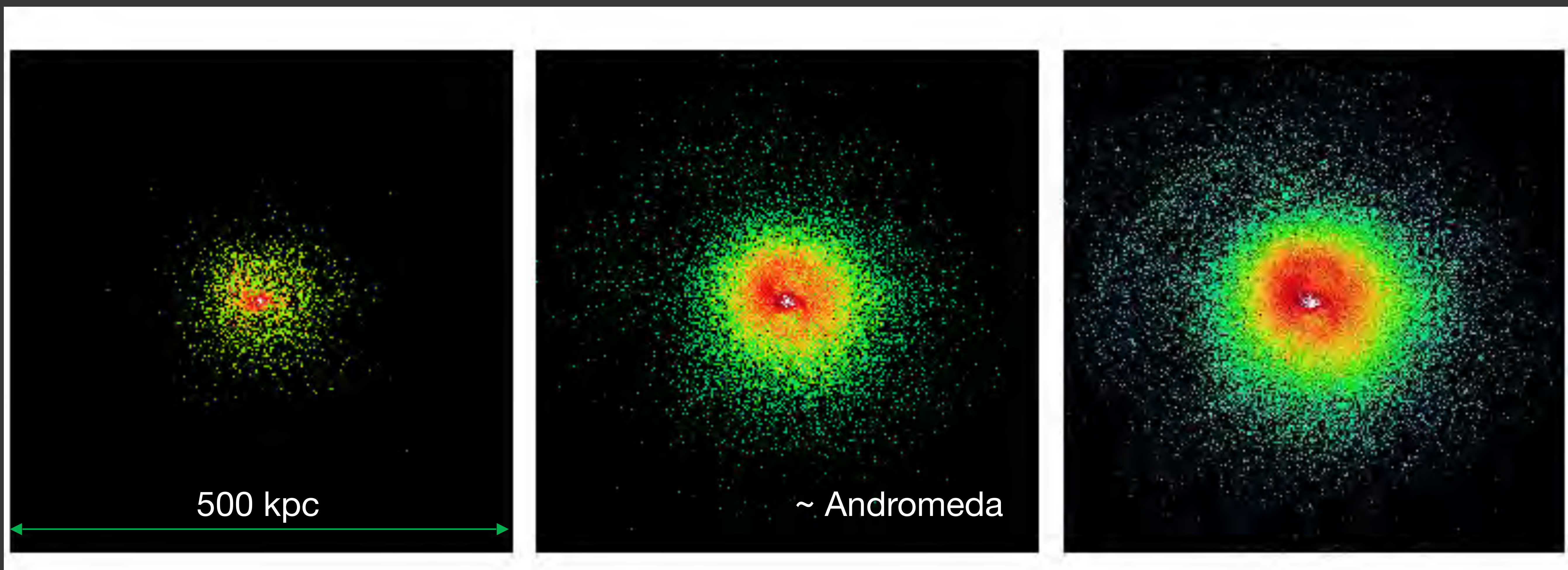
Required observations: detect and characterize hot halos around Milky Way-size galaxies to z~1.

Required capability: ~ 100× sensitivity & angular resolution to separate diffuse emission from bright central sources

Galaxy formation: the nature of feedback

X-ray Surveyor, 100 ksec observations at z=0.02

M_{fid}~10^{12} Msun | 3xM_{fid} | 5xM_{fid}

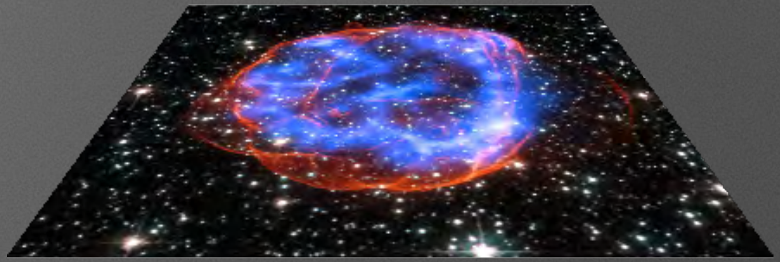


Required observations: detect and characterize hot halos around Milky Way-size galaxies to *z*~1.

Required capability: ~ 100× sensitivity & angular resolution to separate diffuse emission from bright central sources

What physics is behind the structure of astronomical objects?

Plasma physics, gas dynamics, relativistic flows in astronomical objects:



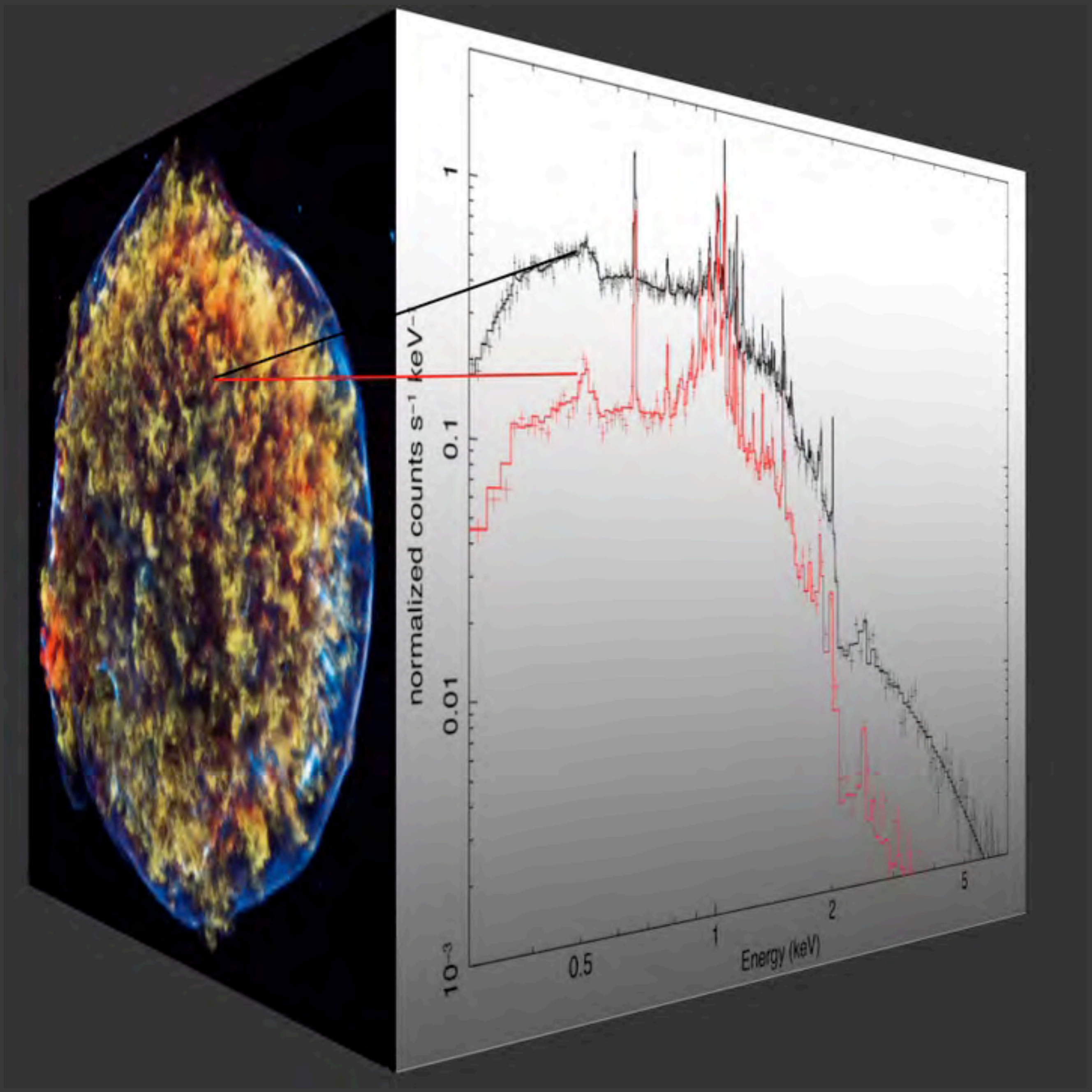
- Supernova remnants
- Particle acceleration in pulsar wind nebulae

- Jet-IGM interactions
- Hot-cold gas interfaces in galaxy clusters and Galactic ISM

- Plasma flows in the Solar system, stellar winds & ISM via charge exchange emission
- Off-setting radiative cooling in clusters, groups & galaxies
- …

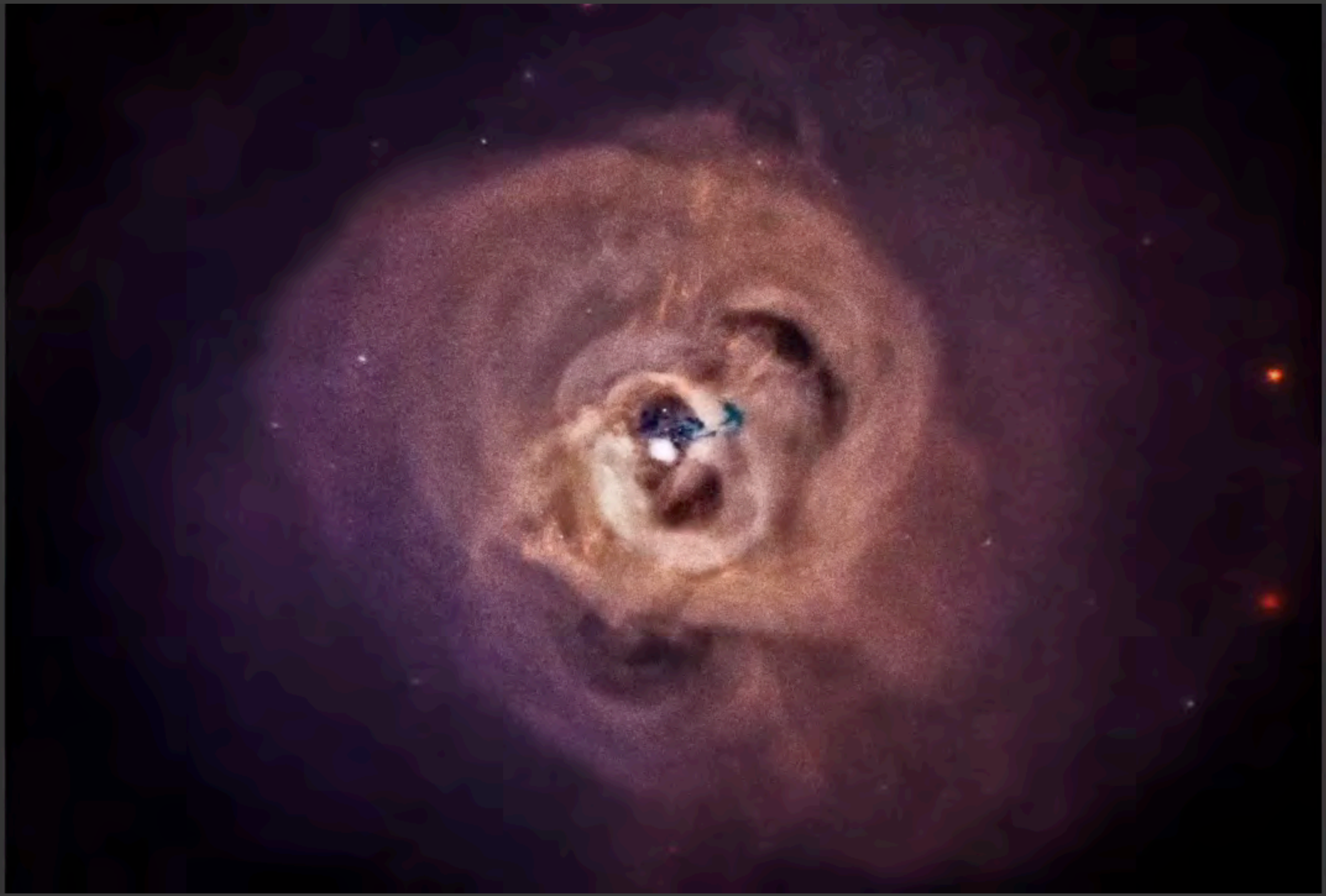
Required capability: high-resolution spectroscopy ***and*** resolving relevant physical scales

New capability: Add 3rd dimension to the data



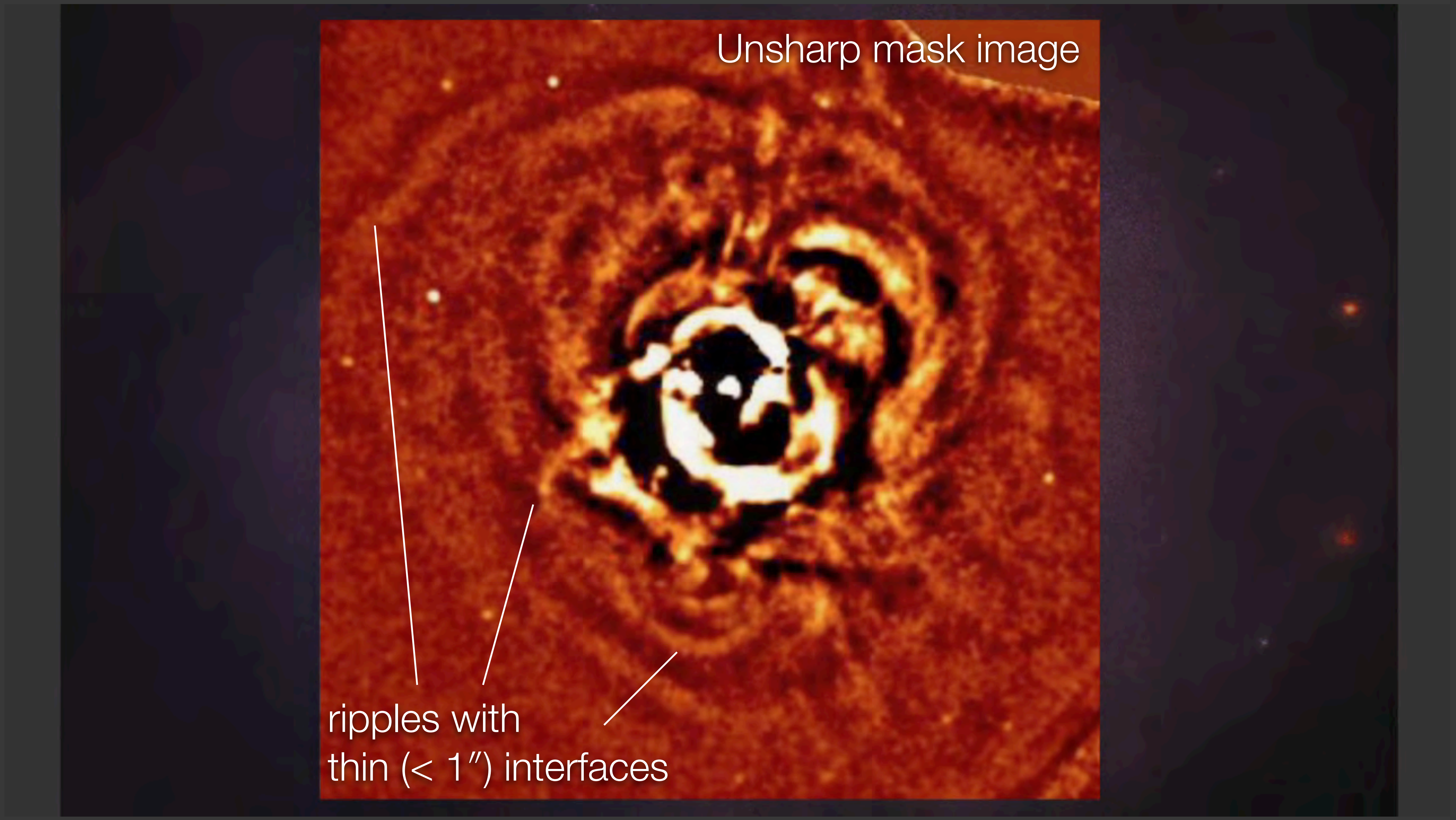
X-ray microcalorimeter will provide high-resolution, high throughput spectroscopy with 1 arcsec pixels — detailed kinematics, chemistry & ionisation state of hot plasmas

Plasma physics in astronomical objects



Chandra image of Perseus cluster: energy output from supermassive black hole balances radiative cooling.

Plasma physics in astronomical objects

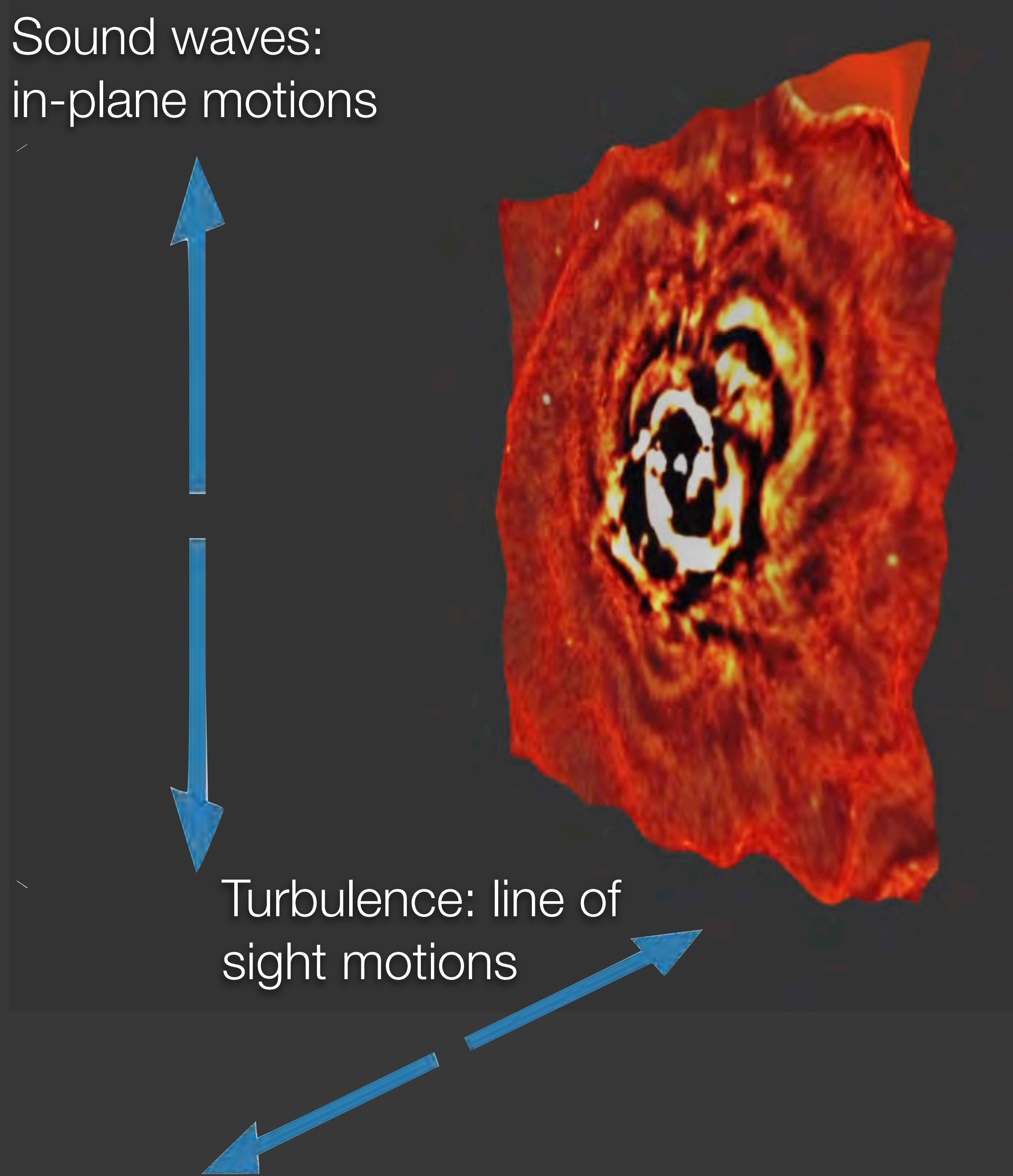


Chandra image of Perseus cluster: energy output from supermassive black hole balances radiative cooling.

Sound waves in viscous plasma (Fabian et al. 2003)?

Turbulence in stratified atmosphere (Zhuravleva, …, Fabian, … et al. 2015)?

Plasma physics in astronomical objects

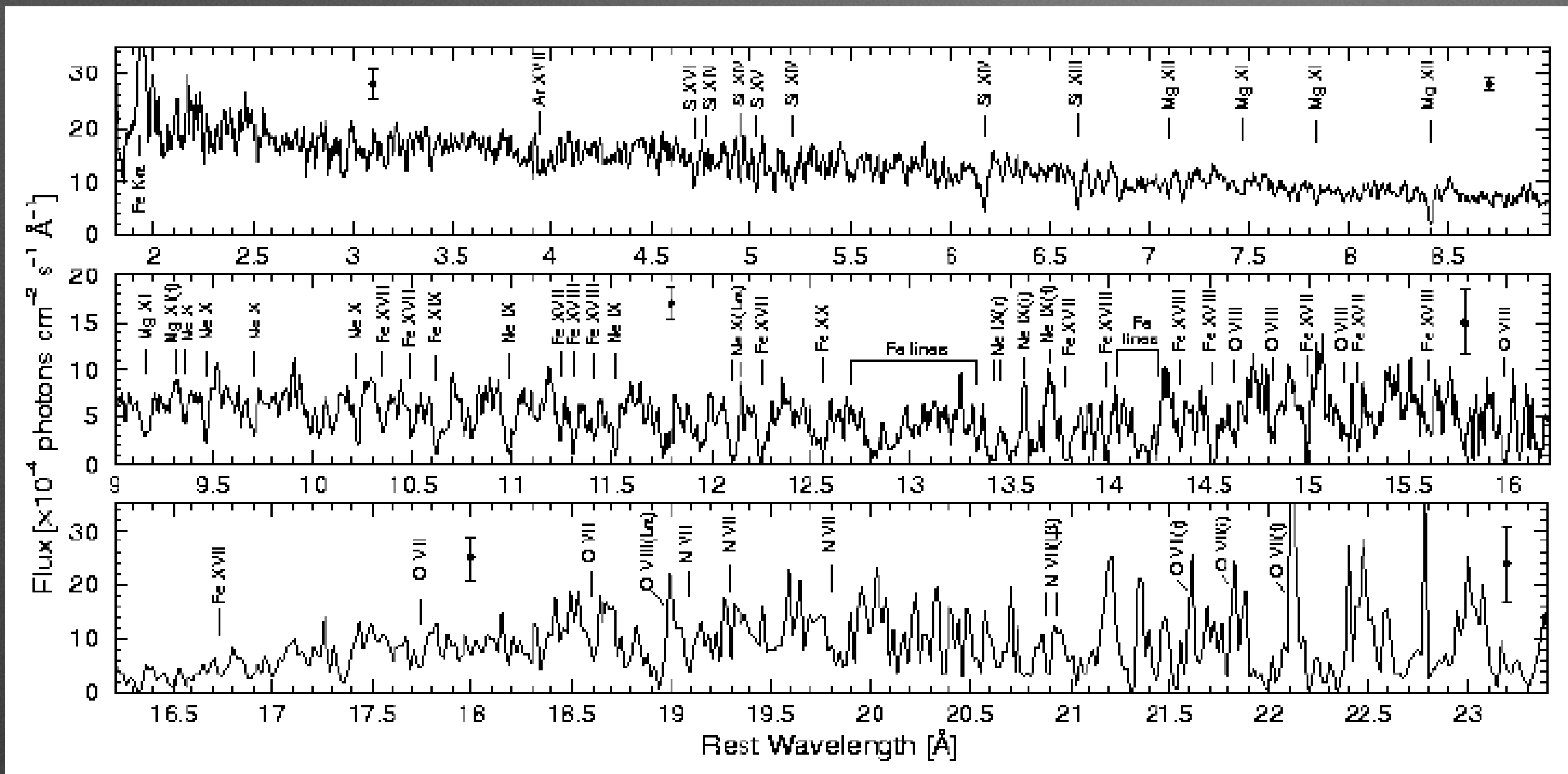


Bulk motions with v=30 km/s can be measured with microcalorimeter (compare with c_s~1000 km/s).

<u>X-ray Surveyor</u>: detailed 3D tomography.

<u>ATHENA</u>: overall Doppler line widths.

Capability leap: high throughput X-ray gratings spectroscopy



Chandra HETG spectrum of NGC 3783. Note the wealth of emission and absorption lines with λ>~9Å (*E*<~1.3 keV)

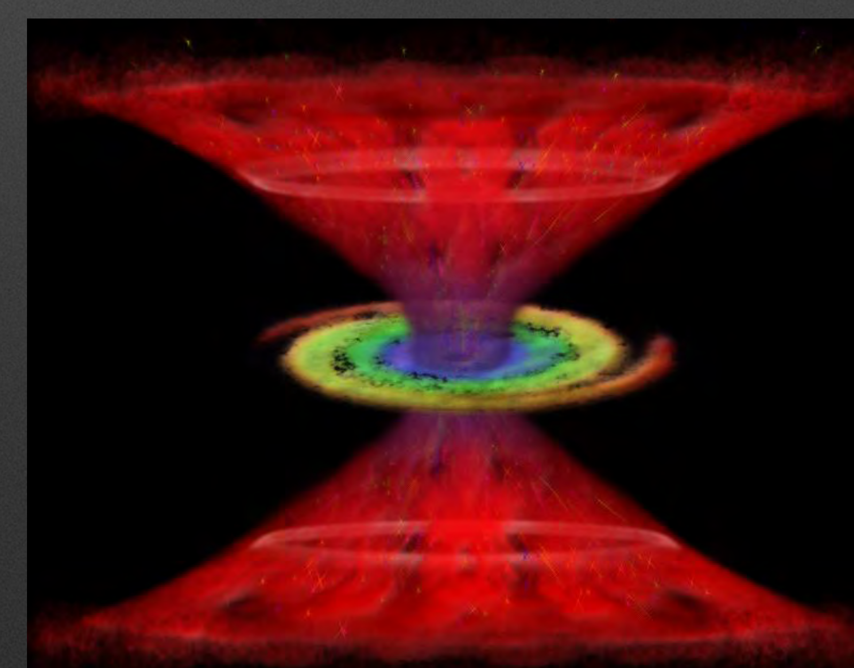
X-ray Surveyor gratings will provide R≈5000 and 4000 cm^2 effective area, adding 250× in throughput and 5× in resolving power compared to Chandra at E=0.6 keV (50× throughput and 20× resolving power compared to XMM Newton)

Physics of the "New Worlds", e.g.:

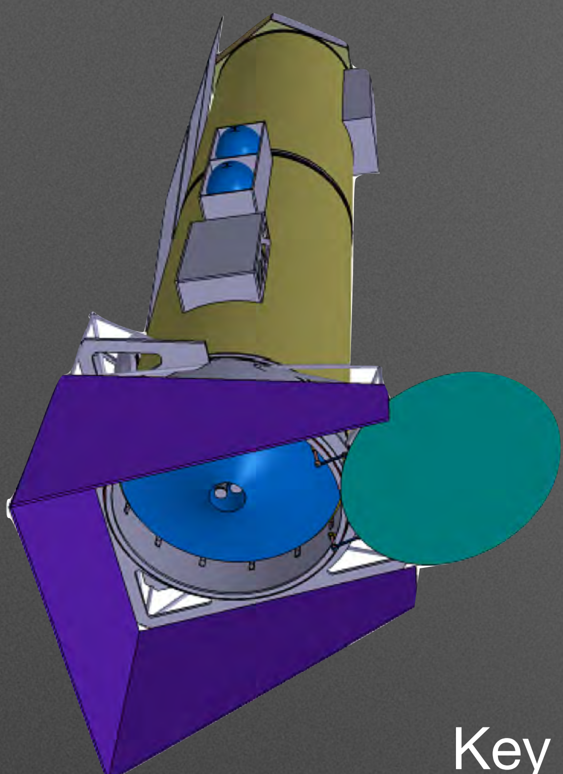
- Star-planet interactions & X-ray absorption in atmospheres of "hot Jupiters"
- Stellar coronae, dynamos in sub-stellar regime
- Stellar winds

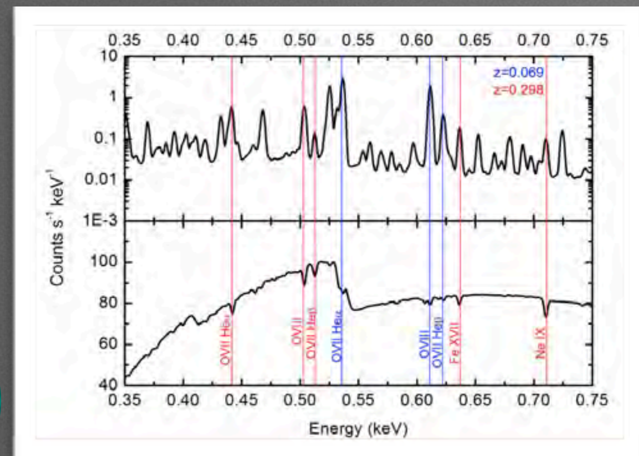
Inner workings of the black hole central engine, e.g.

- spectroscopy of outflows
- tidal disruption events



Athena

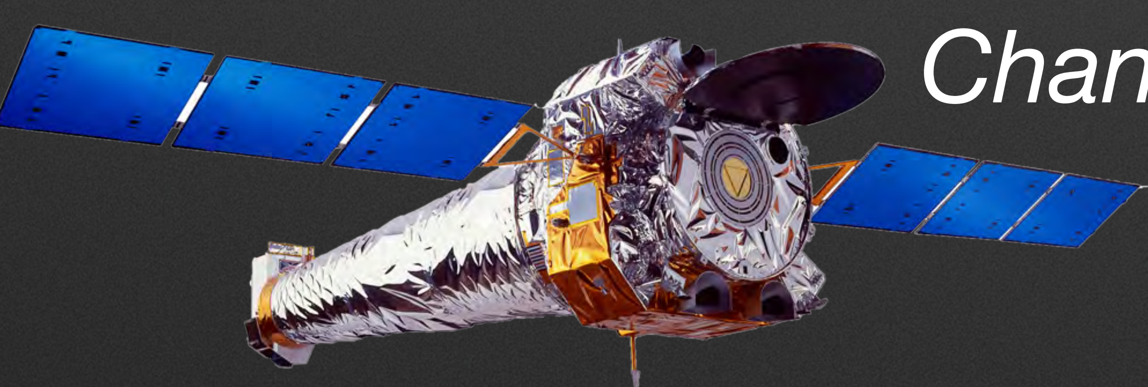




Key Goals:

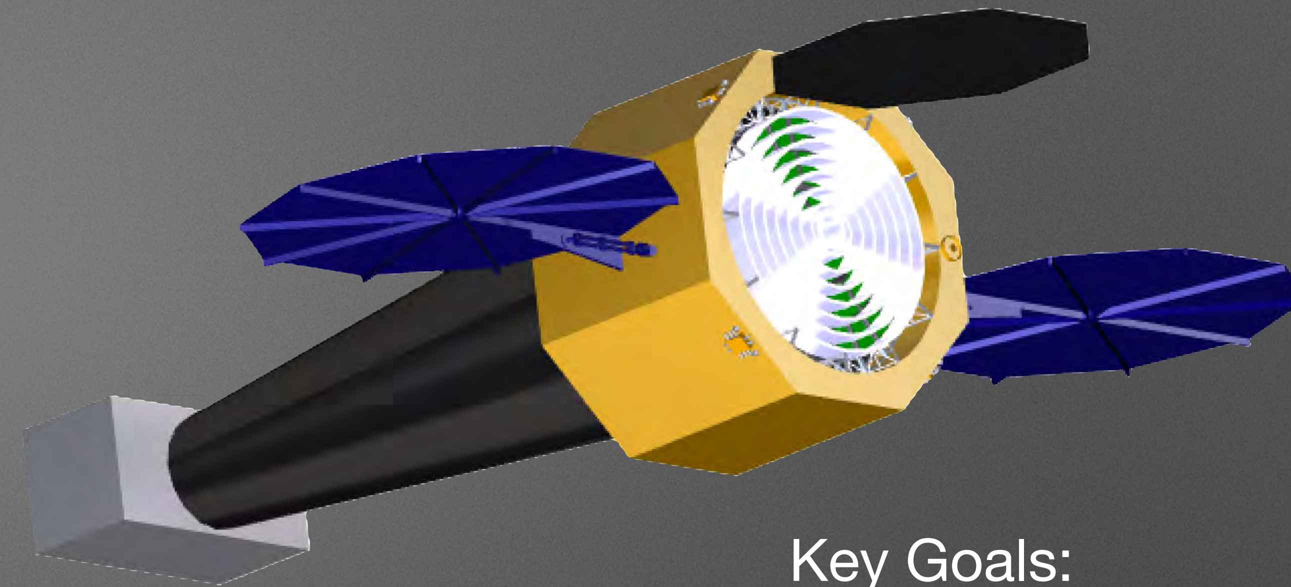
- Microcalorimeter spectroscopy (*R*≈1000)
- Wide, medium-sensitivity surveys

✓ Area is built up at the expense of coarser angular resolution (10× worse) & sensitivity (5× worse than *Chandra*)



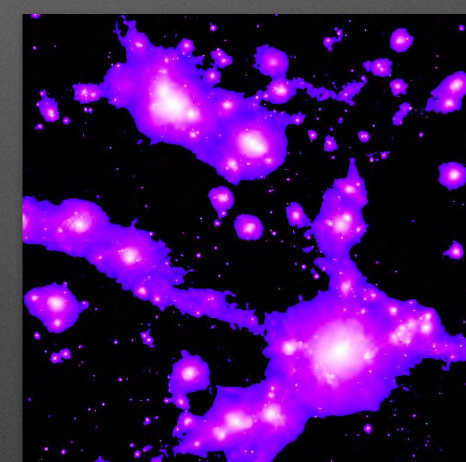
Chandra

X-ray Surveyor



Key Goals:

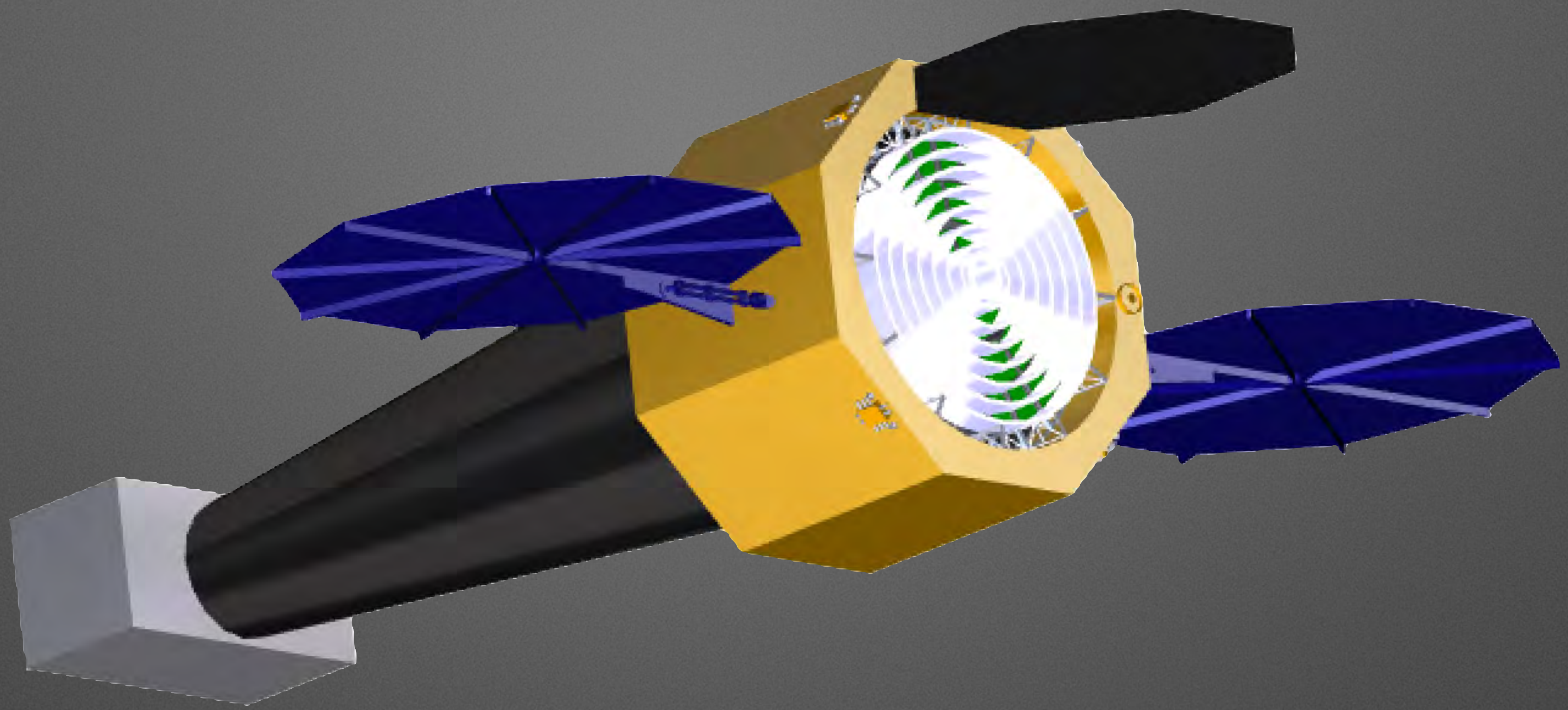
- Sensitivity (50× better than *Chandra*)
- *R*≈1000 spectroscopy on 1″ scales, adding 3rd dimension to the data
- *R*≈5000 spectroscopy for point sources



✓ Area is built up while preserving *Chandra* angular resolution (0.5″)

✓ 16× field of view with sub-arcsec imaging

X-ray Surveyor



- ***Leaps in Capability:*** large area with high angular resolution for 1–2 orders of magnitude gains in sensitivity, field of view with subarcsec imaging, high resolution spectroscopy for point-like and extended sources.

- ***Scientifically compelling:*** frontier science from Solar system to first accretion light in Universe; revolution in understanding physics of astronomical systems.

- ***Feasible:*** *Chandra*-like mission with regards to cost and complexity, with the new technology for optics and instruments already at TRL3 and proceeding to TRL6 before Phase B

Unique opportunity to explore new discovery space and expand our understanding of how the Universe works and how it came to look the way we see it