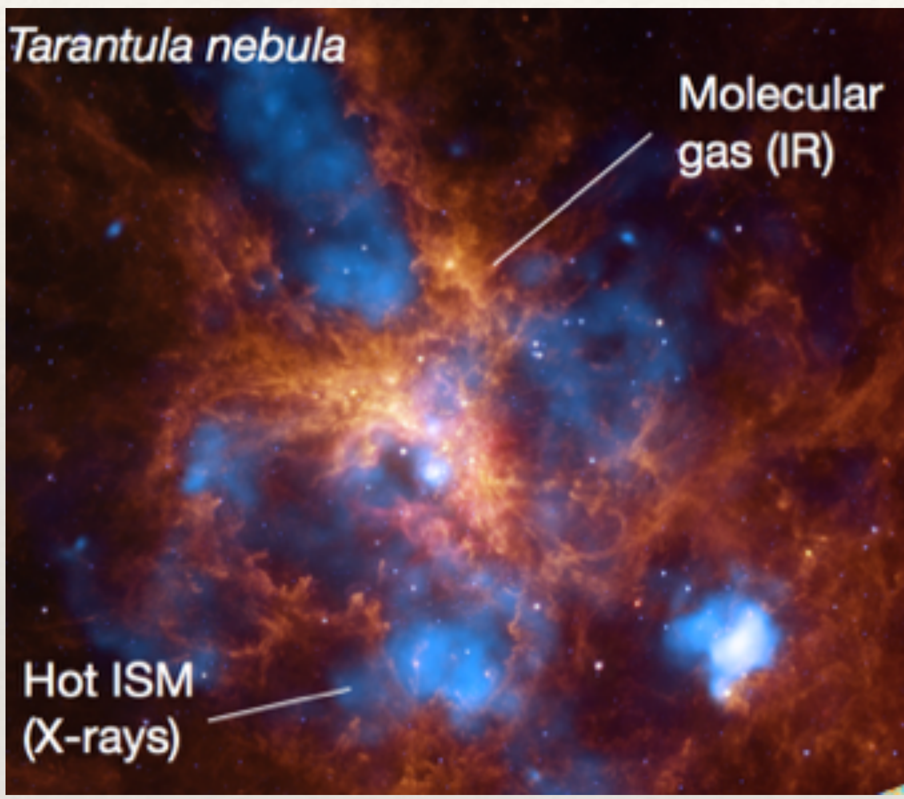
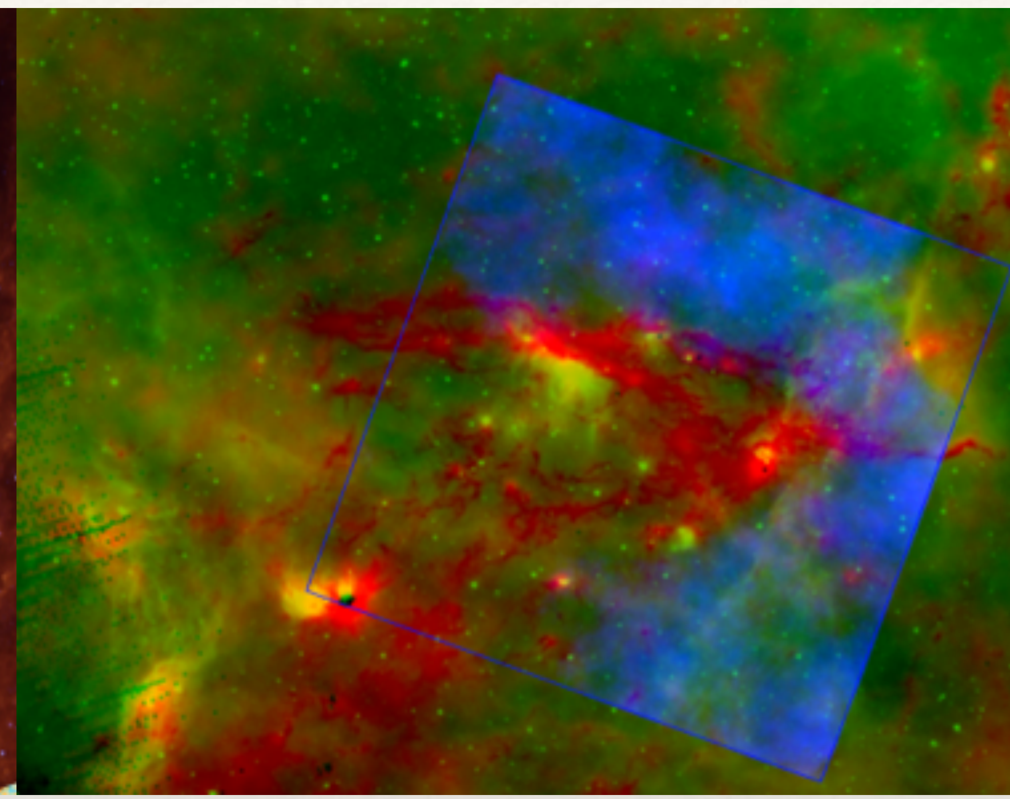
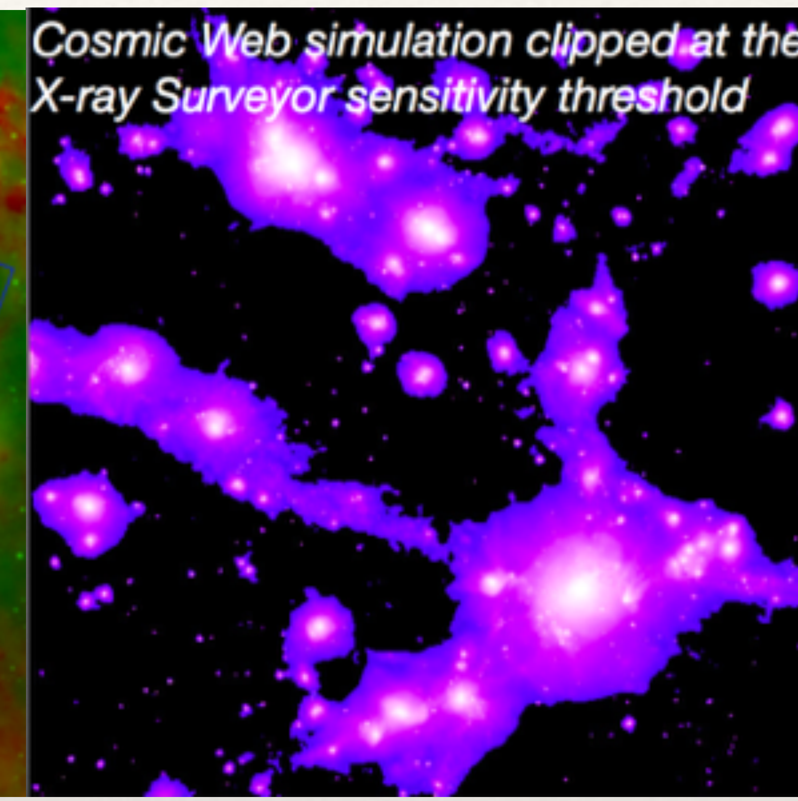
From Chandra to the X-ray Surveyor
Legacies and New Frontiers







Feryal Ozel (Arizona)
on behalf of the Science and Technology Definition Team

Chandra Science for the Next Decade
August 17, 2016

Towards the 2020 Decadal Survey

Large Mission Concept Studies

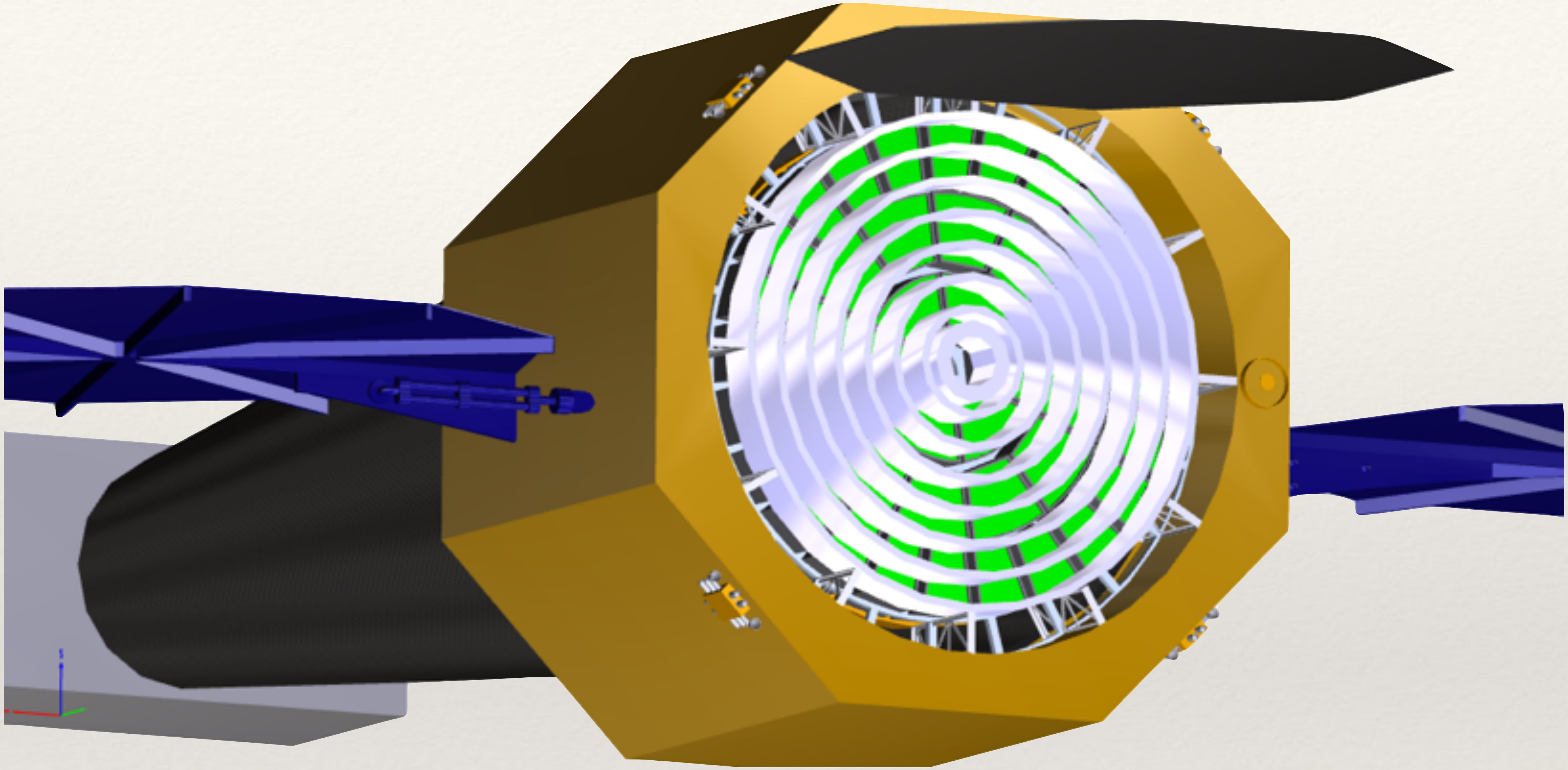
NASA will initiate mission concept studies of the following four large mission concepts:

- **FAR IR Surveyor** – The Astrophysics Visionary Roadmap identifies a Far IR Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.
- **Habitable-Exoplanet Imaging Mission** – The 2010 Decadal Survey recommends that a habitable-exoplanet imaging mission be studied in time for consideration by the 2020 Decadal Survey.
- **Large UV/Optical/IR Surveyor** –The Astrophysics Visionary Roadmap identifies a Large UV/Optical/IR Surveyor as contributing through improvements in sensitivity, spectroscopy, high contrast imaging, astrometry, angular resolution and/or wavelength coverage. The 2010 Decadal Survey recommends that NASA prepare for a UV mission to be considered by the 2020 Decadal Survey.
- **X-ray Surveyor** – The Astrophysics Visionary Roadmap identifies an X-ray Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.

Some Science Drivers

- Emergence of Black Holes in the Early Universe and Co-evolution with galaxies (see K. Shawinski, A. Comastri's, A. Fialkov, N. Cappelutti's talks)
- Cycles of Baryons in and out of Galaxies (see S. Mathur, P. Fabbiano, J. Burchett's talks)
- Feedback from Stars, Supernovae, and Black Holes, in all settings (see P. Maksym, S. Randall, J. Toala's talks)
- Physics of Accretion and Compact Objects (see numerous talks on Thursday)
- X-ray counterparts of GW events and multi-wavelength phenomena

Strawman Mission Concept



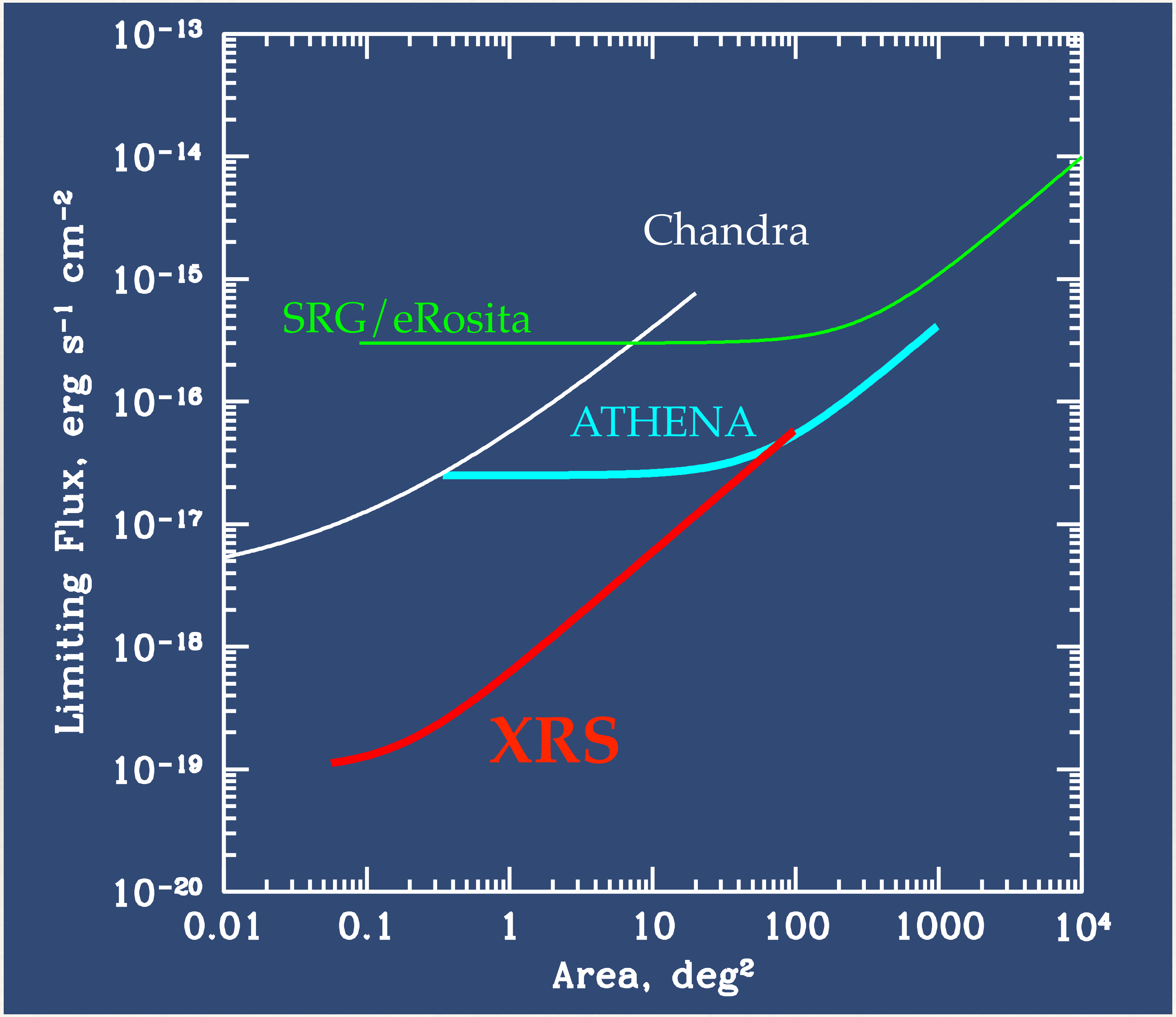
Leap in sensitivity: High throughput, sub-arcsec resolution

×50 more effective area than Chandra

Threshold for blind detections in a 4Msec survey is ~ 3×10^{-19} erg s^{-1} cm^{-2} (0.5–2 keV band)

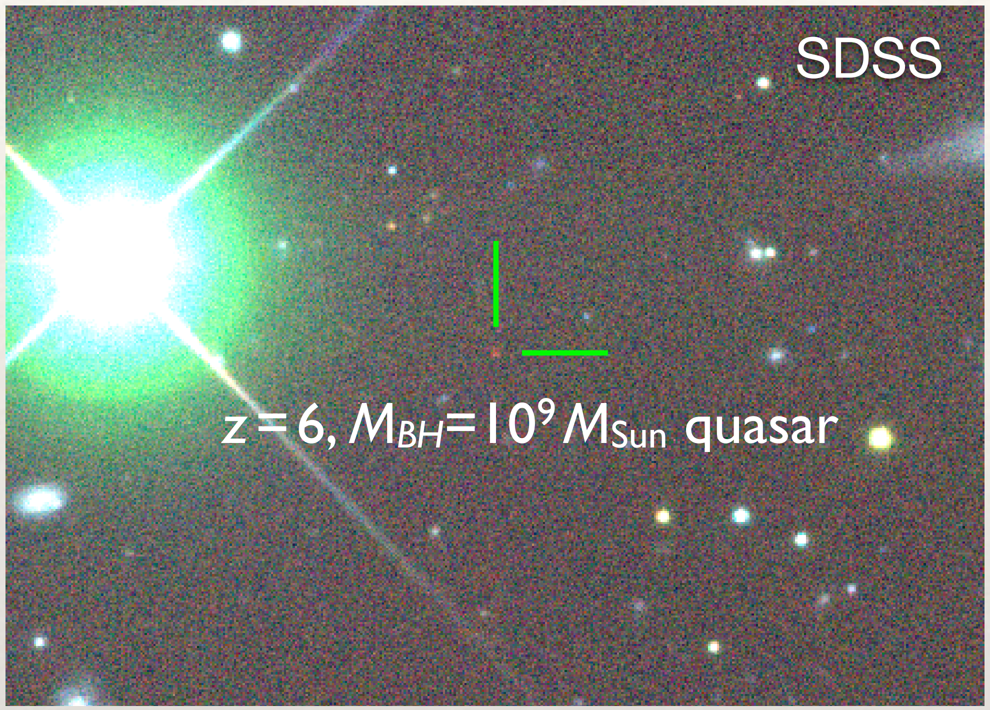
×16 larger solid angle for sub-arcsec imaging — out to 10 arcmin radius

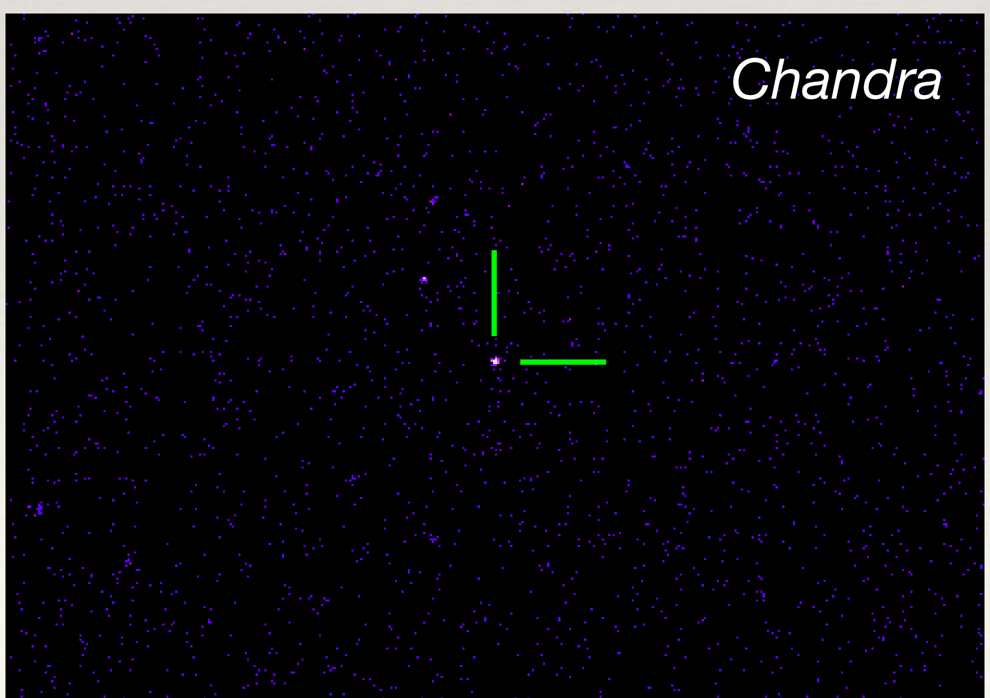
Survey capabilities for a 15 Msec program

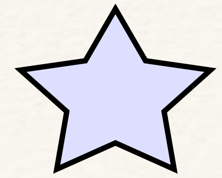


×800 higher survey speed at the Chandra Deep Field limit

Nature of Black Hole Seeds

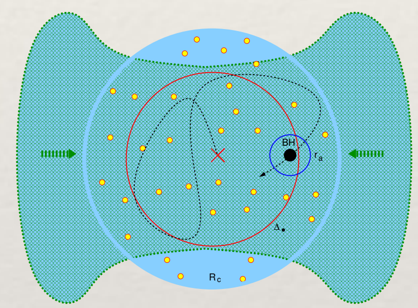




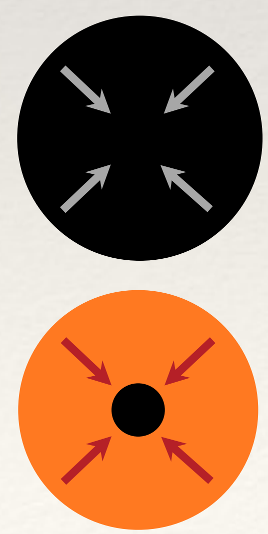


Light seeds: PopIII star remnants, M_{BH}~10^2 M_{Sun}

Collapse of nuclear star cluster, M_{BH}~10^3 M_{Sun}



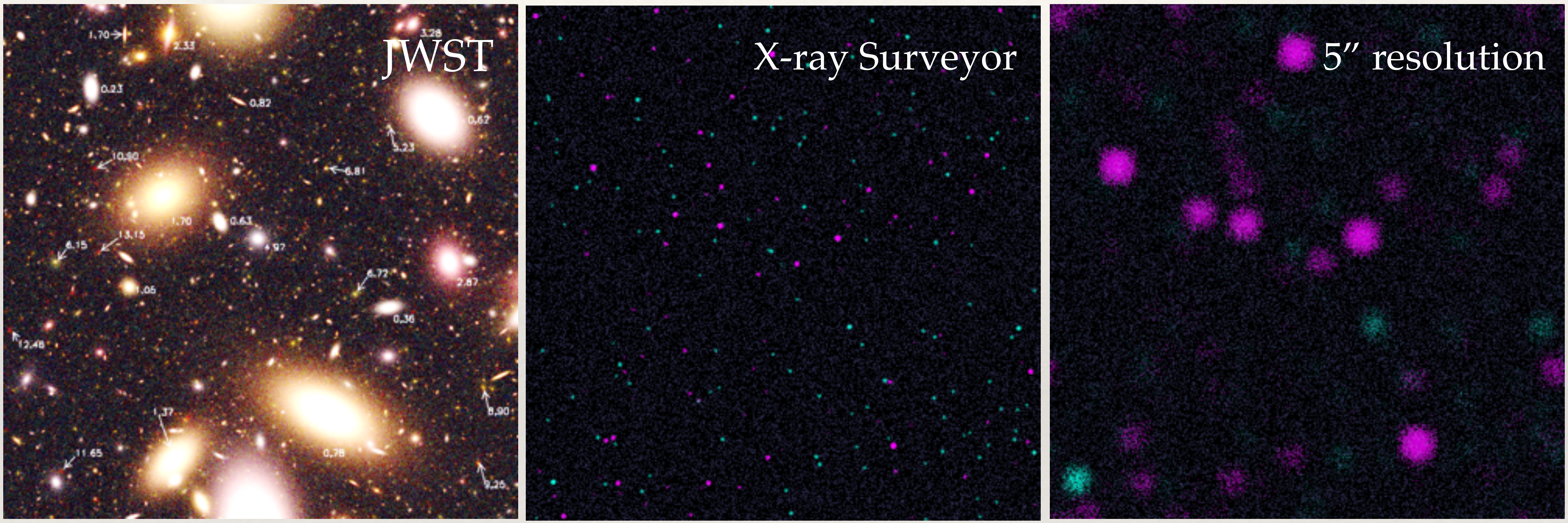
Super-Eddington growth to M_{BH}~10^4 M_{Sun} or more



Massive seeds: Direct collapse of supermassive star M_{BH}~10^5 M_{Sun}

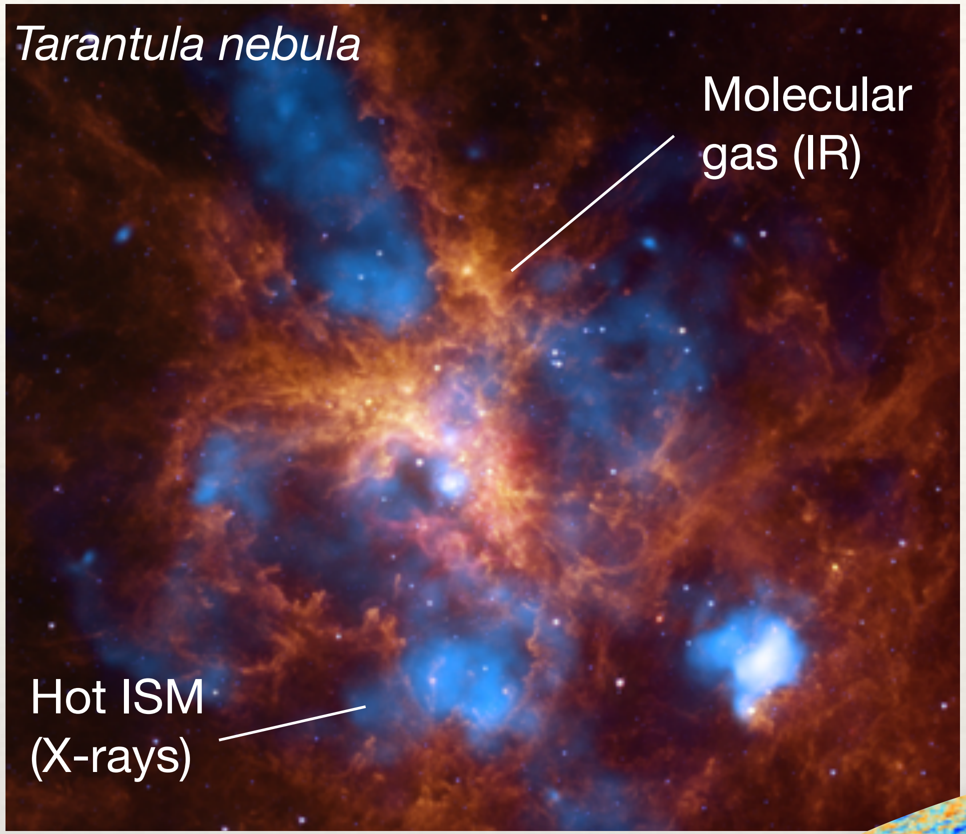
First Accretion Light

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



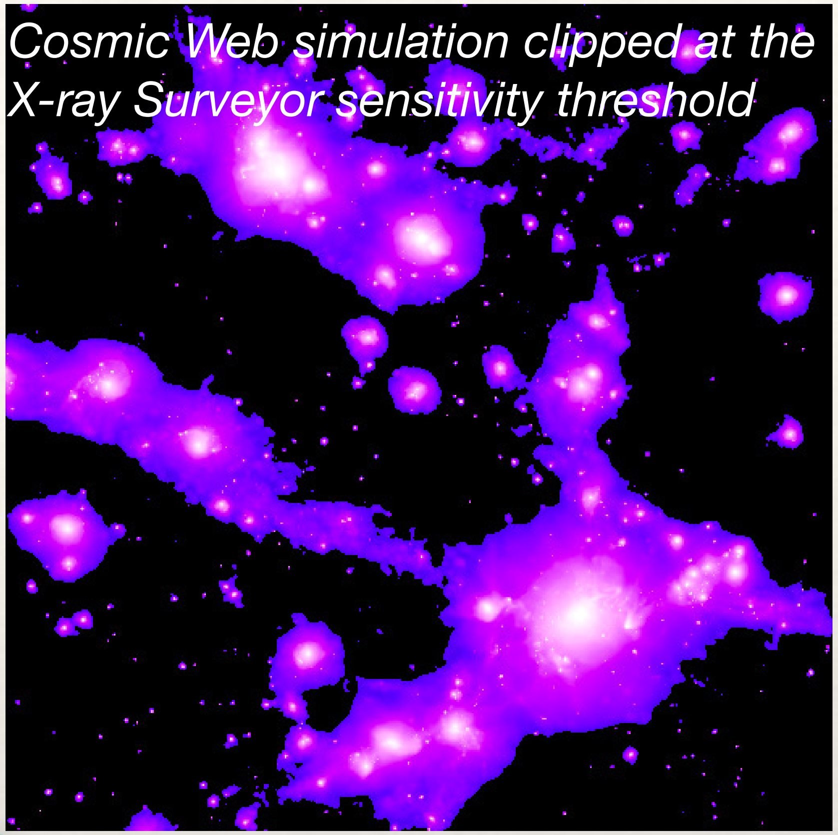
X-ray Surveyor is the perfect and necessary complement to JWST

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?

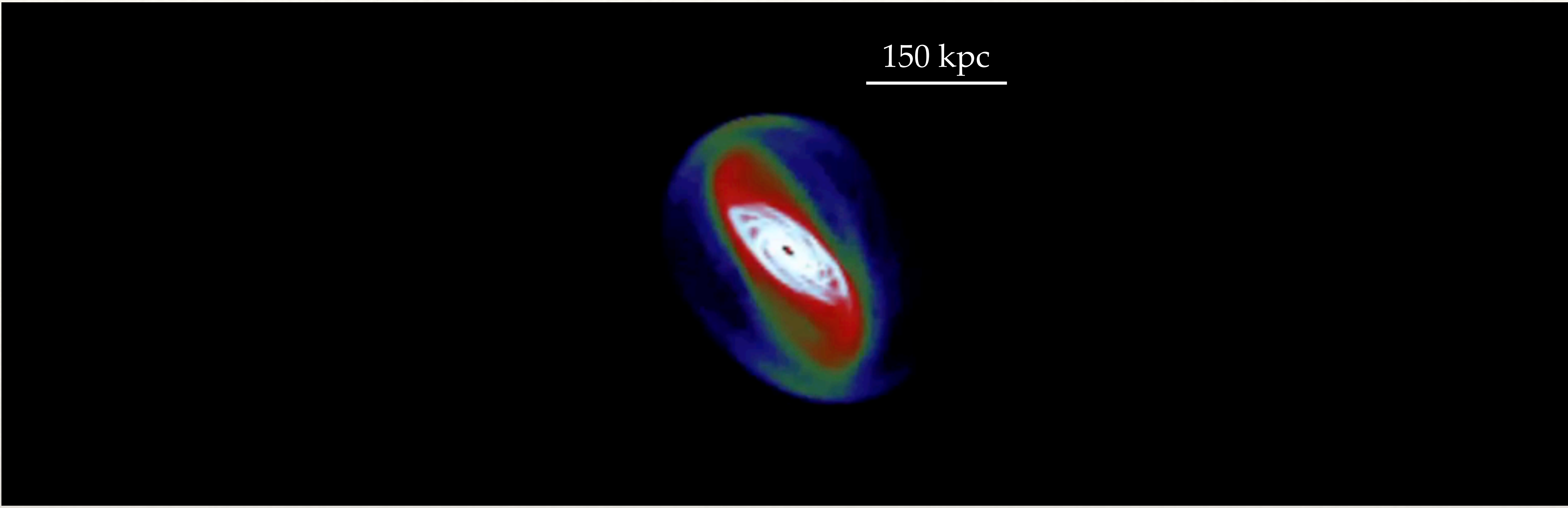
Reachable surface brightness levels are ~ 1/30 of Chandra



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

How did the "universe of galaxies" emerge from initial conditions?

Feedback in Galaxy Formation



Simulated 500 kpc box around a Milky Way type galaxy (credit:Agertz & Kravtsov)

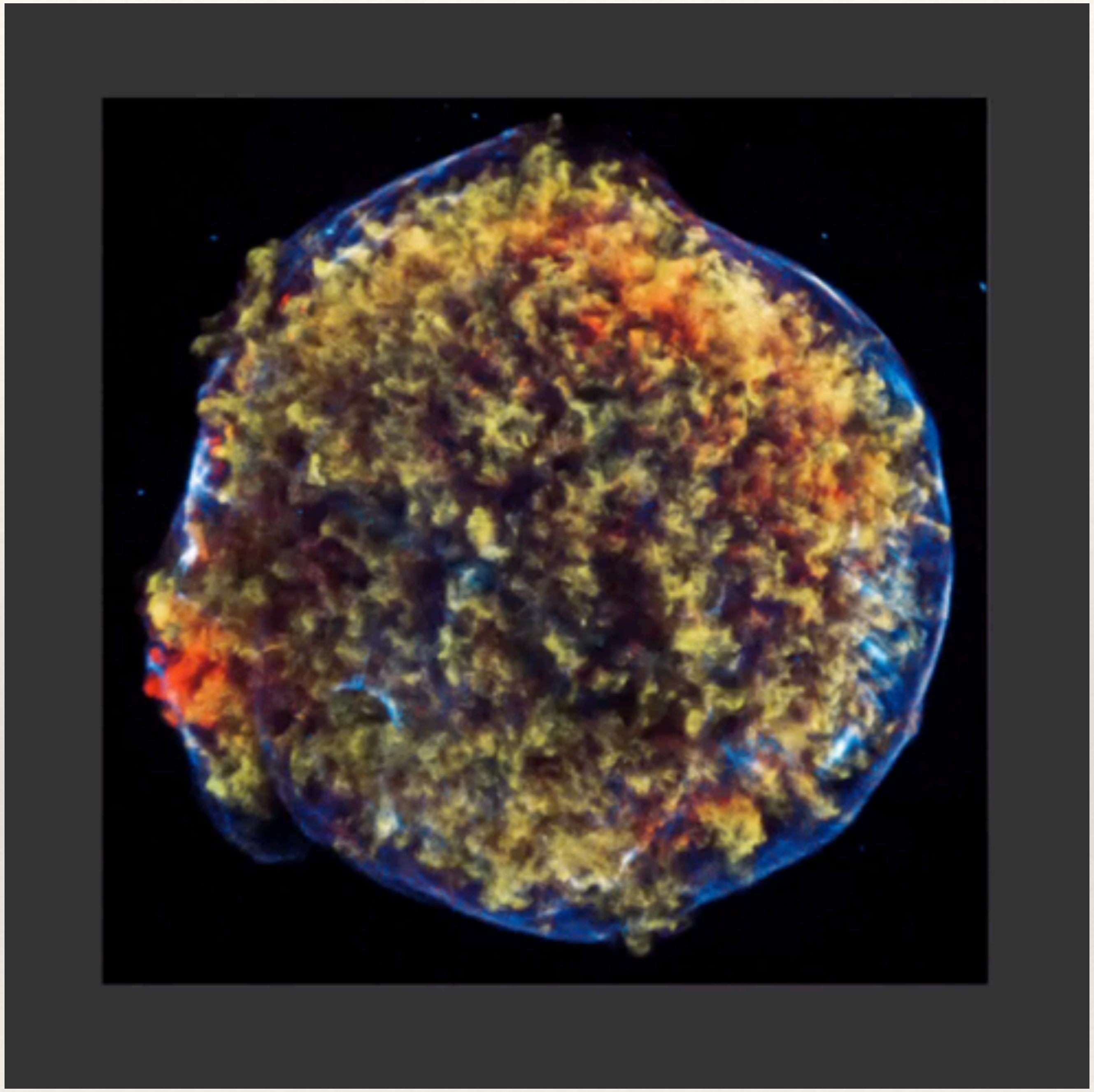
~ 30% are observable in UV absorption

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

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

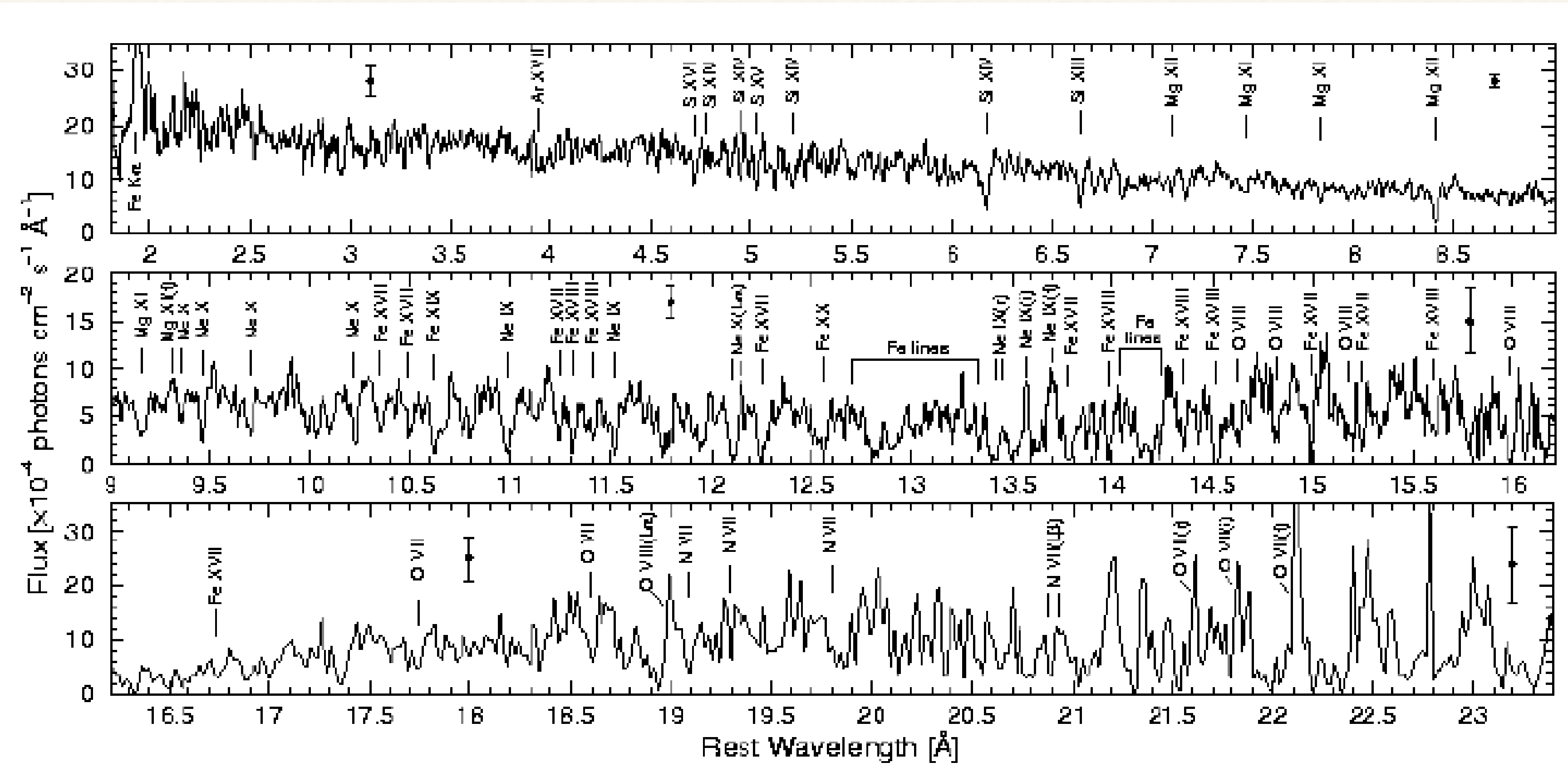
Required capability: ~ 100× sensitivity & angular resolution to separate diffuse emission from bright central sources

New capability: Add 3rd dimension to the data



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

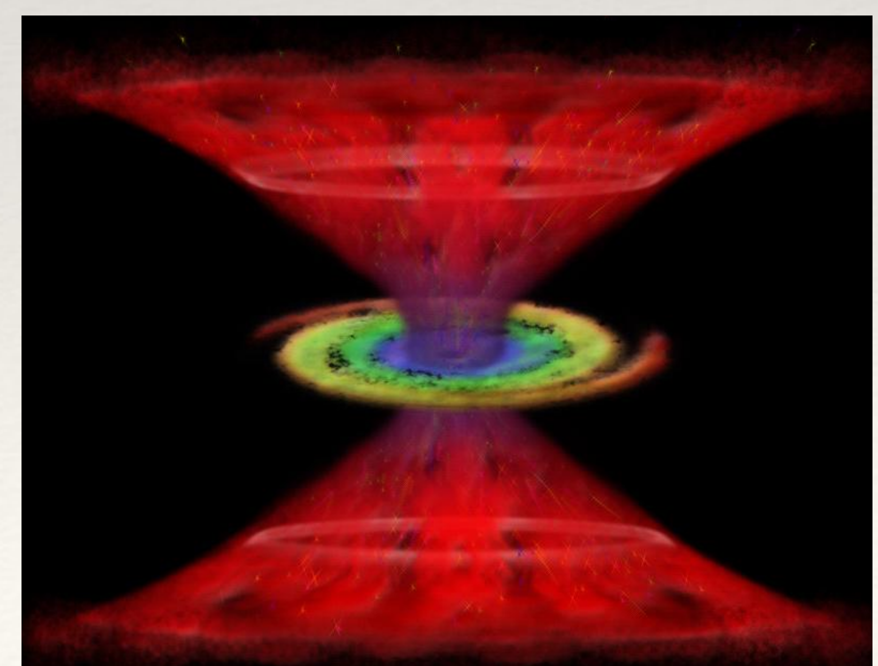
High throughput X-ray gratings spectroscopy



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



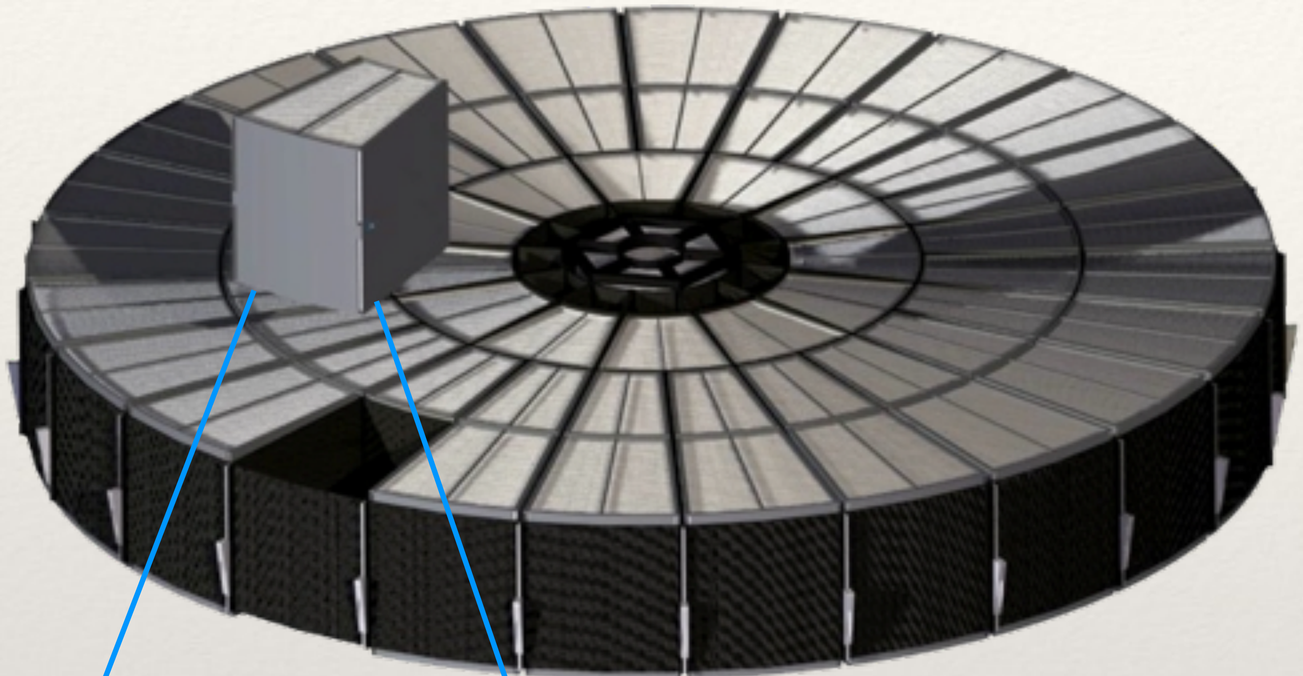
Challenges and Requests

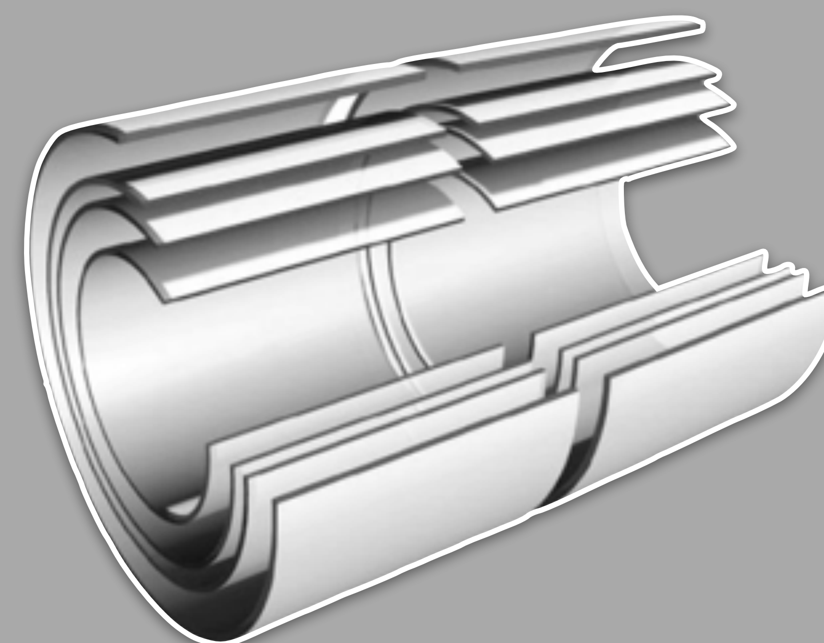
- **Lightweight high angular resolution mirrors**
- Overcoming the *perception* that X-ray Surveyor benefits a small community

Next Generation X-ray Mirrors

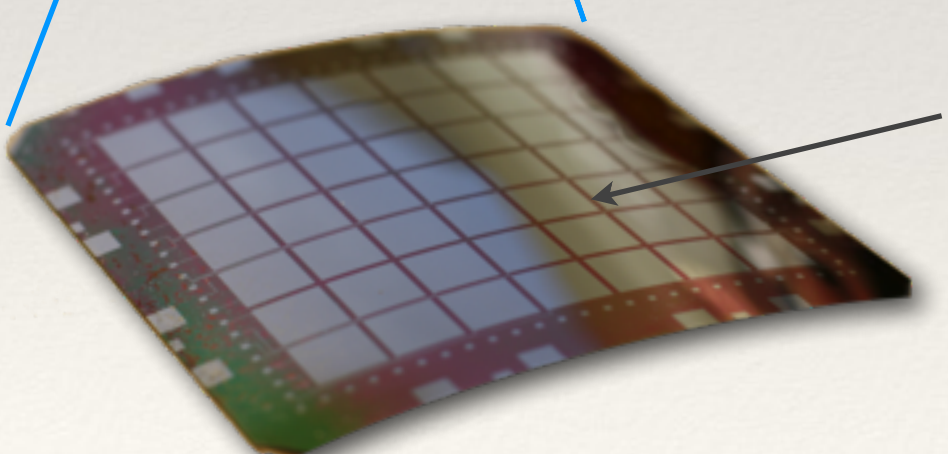
GOAL:

1200 kg for 2.3m^2 of collecting area





Chandra mirror shells are 2.5cm thick.
1,500 kg for 0.08m^2 of collecting area



Innovative technologies for mirror segments (MSFC, SAO, GSFC, MIT, etc.), including a possibility of in-flight adjustments with piezo cells + integrated electronics + strain gauges for in-flight feedback and control

Challenges and Requests

- Lightweight high angular resolution mirrors
- **Overcoming the *perception* that X-ray Surveyor benefits a small community**
  - Help with science working groups
  - Collaborate with and present to colleagues outside of "X-ray community"
  - Contribute to the efforts to better showcase our incredible results

STDT Members


Alexey Vikhlinin, SAO (Chair)


Feryal Özel, Arizona (Chair)


Steve Allen, Stanford


Megan Donahue, MSU


Laura Lopez, Ohio State


Mike Pivovaroff, LLNL


Eliot Quataert, Berkeley


Mark Bautz, MIT

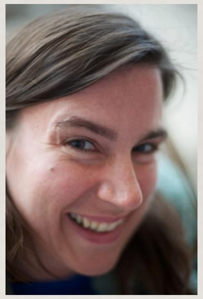

Ryan Hickox, Dartmouth


Piero Madau, UCSC


Dave Pooley, Trinity


Niel Brandt, Penn State


Tesla Jeltema, UCSC

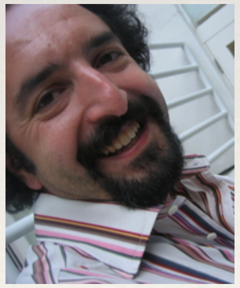

Rachel Osten, STScI


Joel Bregman, Michigan

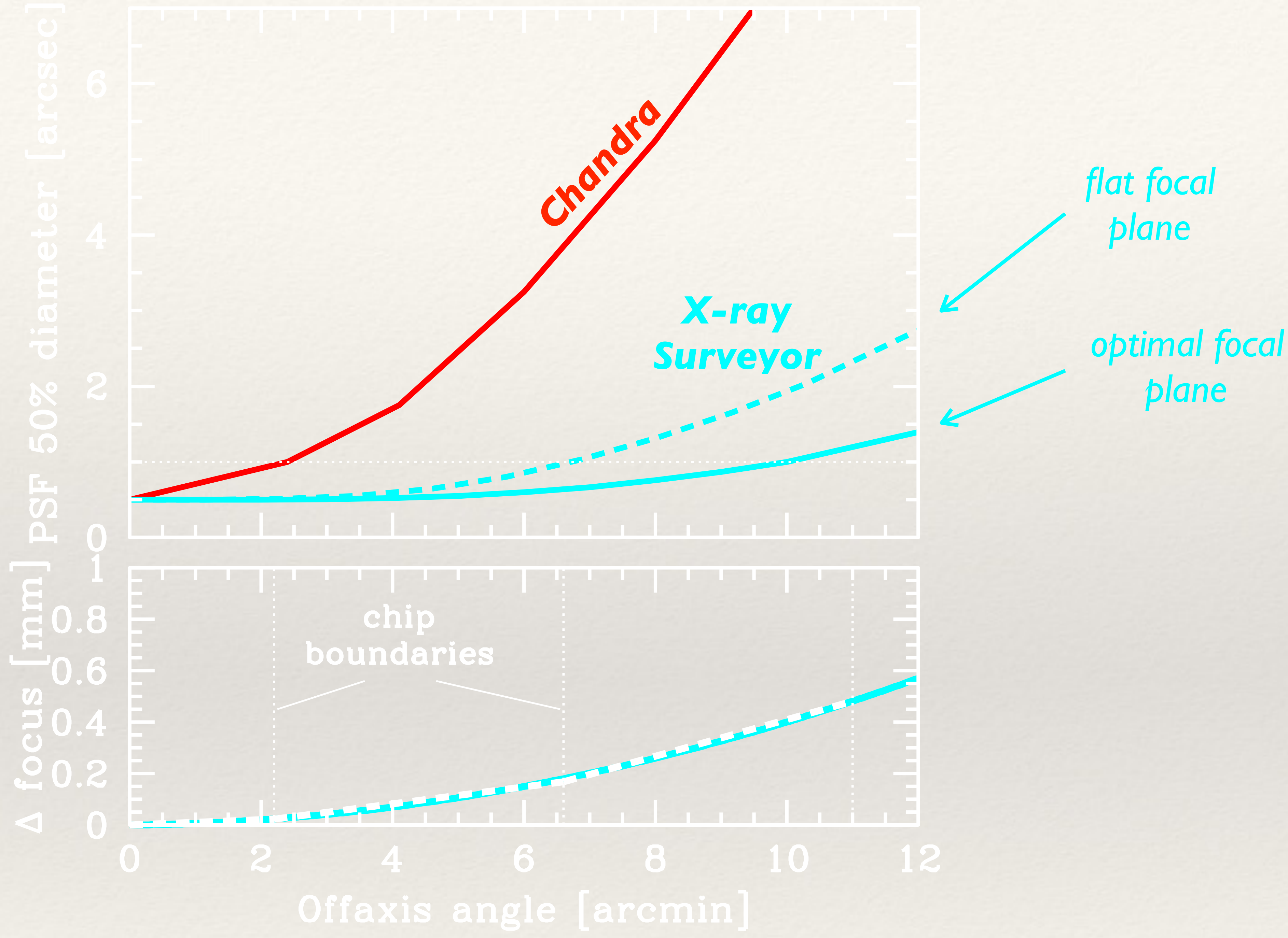

Juna Kollmeier, OCIW


Frits Paerels, Columbia


Andy Ptak, GSFC


Daniel Stern, JPL

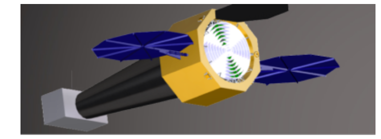
X-ray Surveyor Optical Design



- Sub-arcsec image performance in the soft X-ray band out to 10 arcmin radius
- ×16 larger solid angle for sub-arcsec imaging compared with *Chandra*

Spectroscopy of Black Hole Outflows

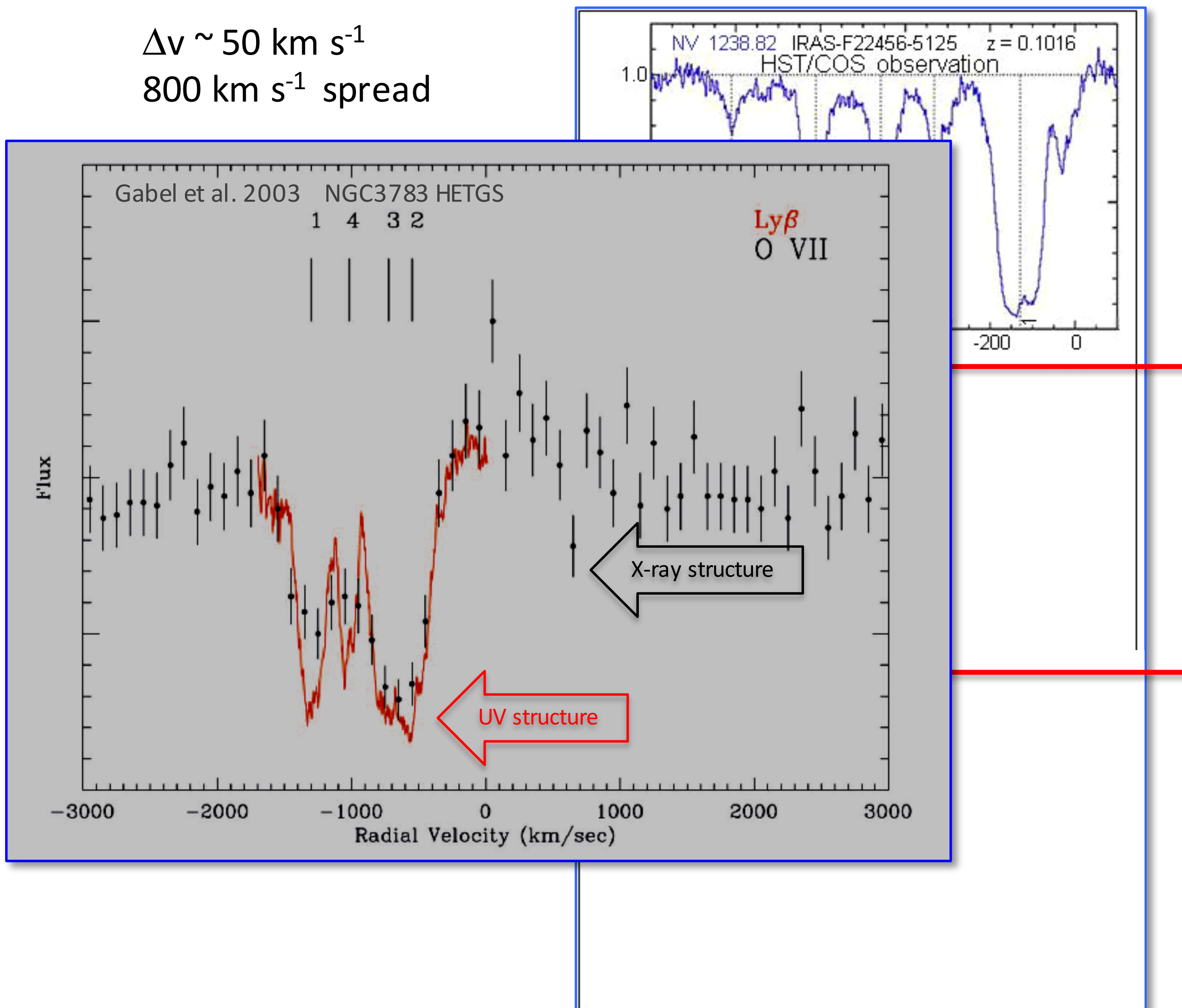
Warm Absorber outflows (WAs)



Even supersonic flows have narrow velocity structures

$\Delta v \sim 50$ km s^{-1}
800 km s^{-1} spread

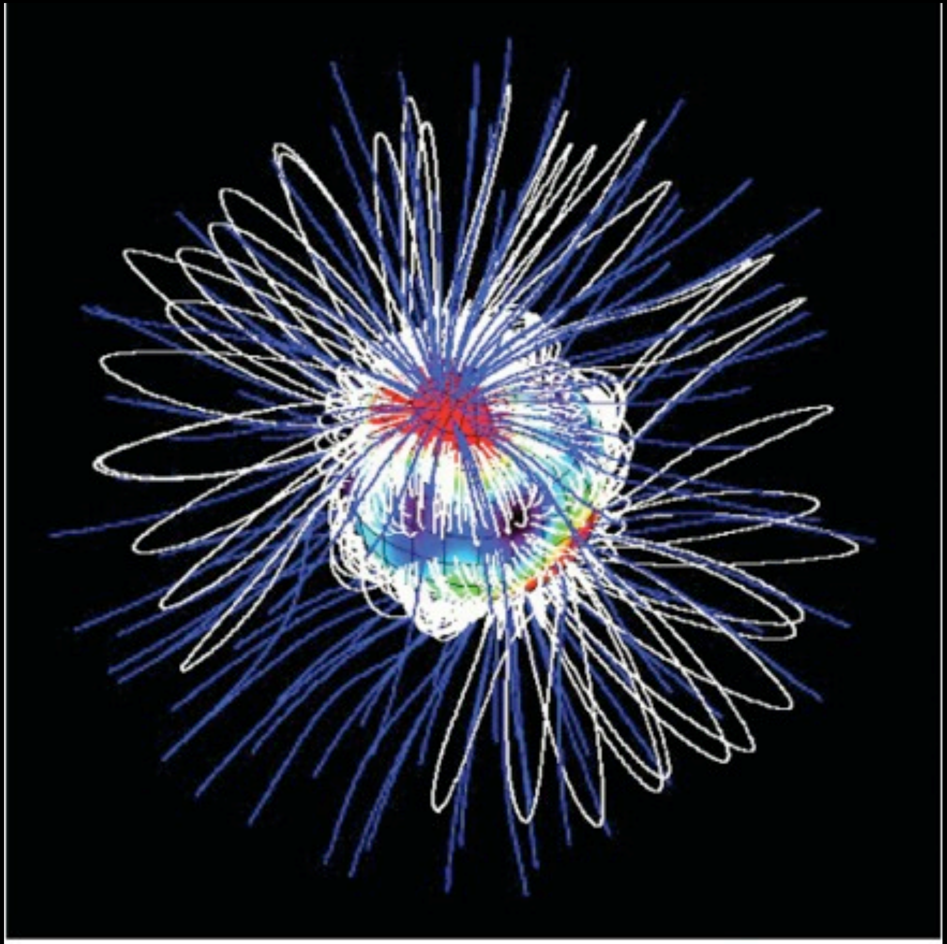
Multiple mass ejection episodes?



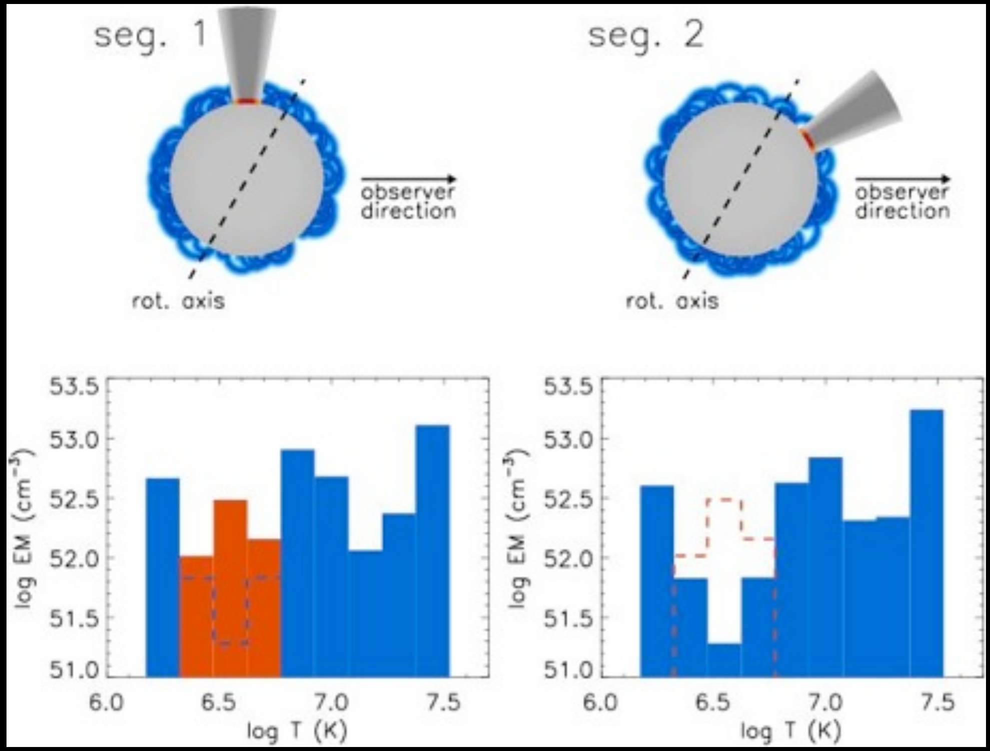
adapted from Arav, WHIMEX simulation

Stellar Dynamo studies

Connecting photospheric structures to coronal structures



Donati J.-F, Landstreet JD. 2009.
Annu. Rev. Astron. Astrophys. 47:333–70

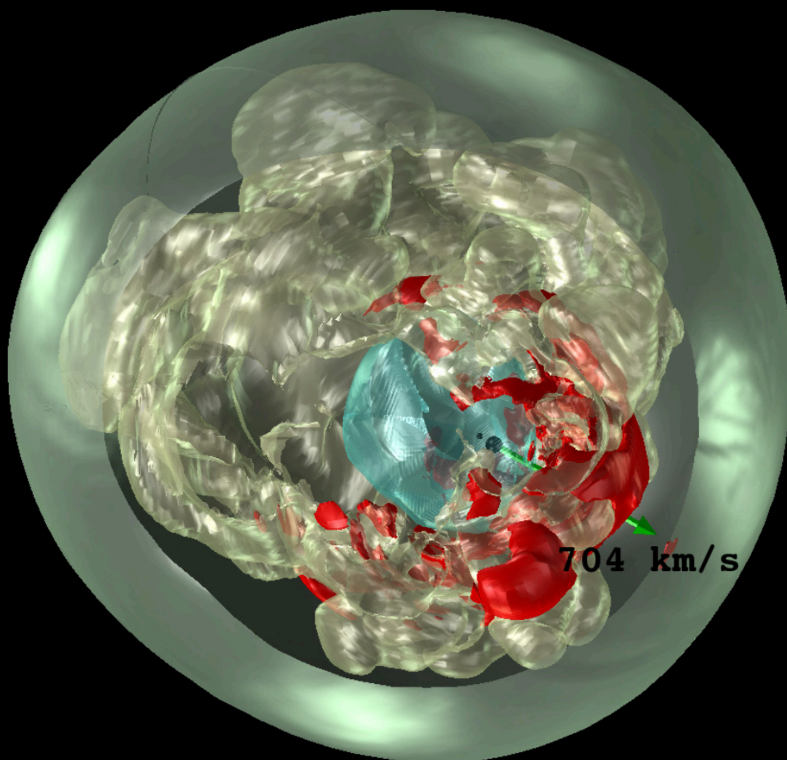


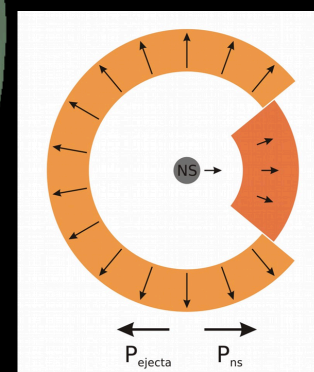
cTTS V2129 Oph
Argiroffi et al. (2011)
blue=coronal emission
orange=accretion

R. Osten

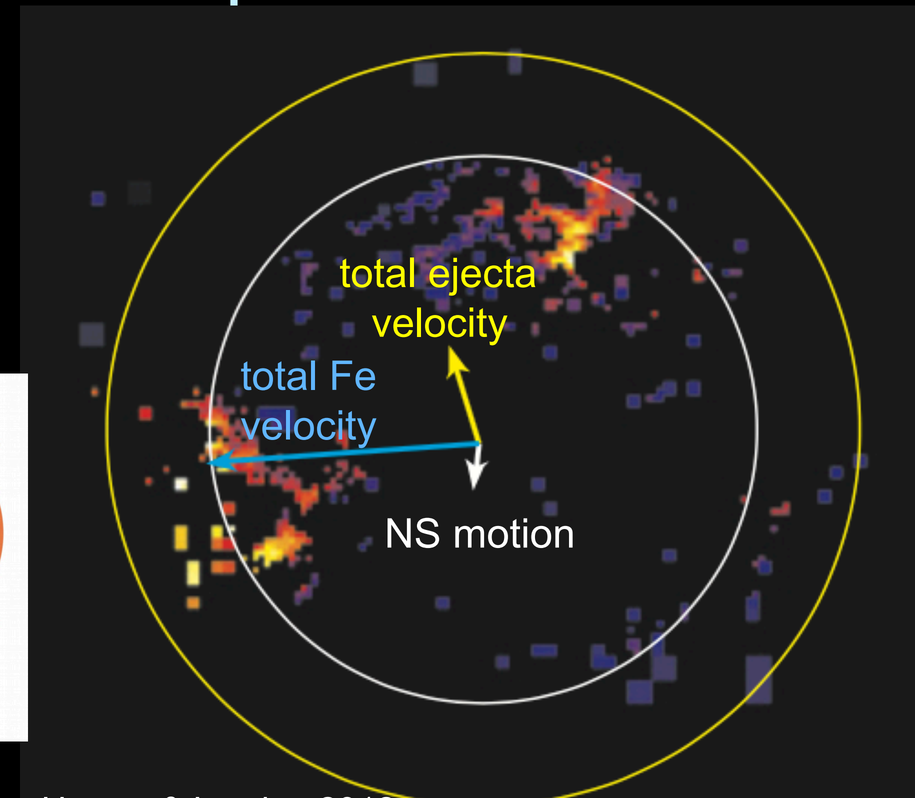
Supernova remnants in high definition

Asymmetries in SN Explosions





Wongwathanarat et al. 2013



Hwang & Laming 2012

- NS velocities may result from a "tugboat" effect from slower-moving ejecta residing near NS
  - Bulk of the ejecta motion is in opposite direction
  - Prediction is thus that NS proper motion will be anti-aligned with net ejecta momentum
- Cas A ejecta dynamics and apparent NS motion seem to support this based on low-res spectra and gratings spectra of some bright knots
- Deeper searches for NSs within SNRs are needed to investigate connection between proper motions and ejecta asymmetries
  - Requires larger area at soft energies, good angular resolution

~~Constraining~~ Solving galaxy formation with observations of gaseous halos

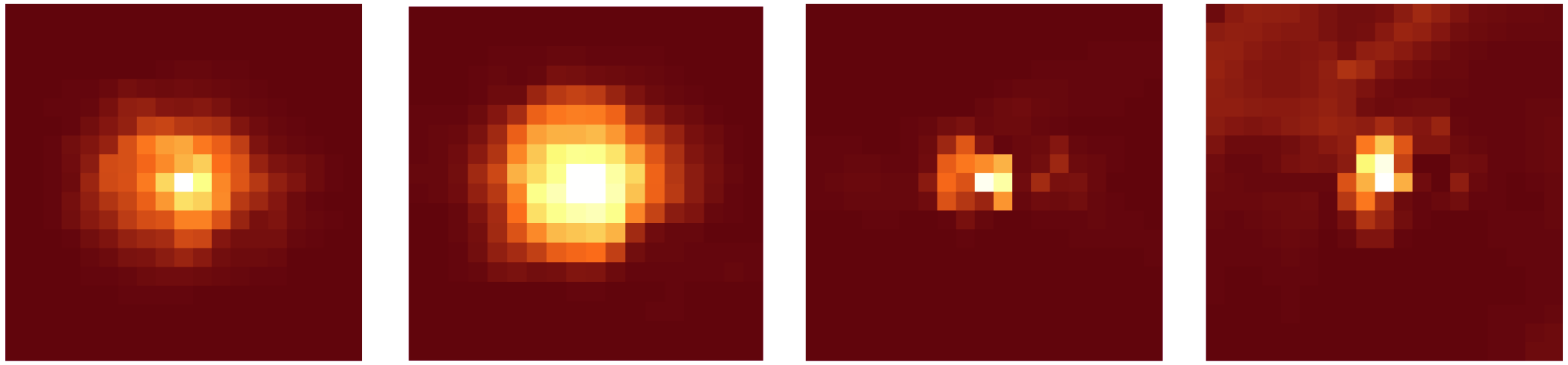
X-ray emissivity maps of gaseous halos of simulations
With different star formation parameters and feedback strength

Gaseous halos are taken at z=1.5 (similar differences expected at lower z)

Scales and color maps matched. Brightness corresponds to observed X-surveyor counts in the 0.2-1 keV band (observer frame). Pixel is 0.5 arcsec (~X-surveyor angular resolution = 4.1kpc physical)

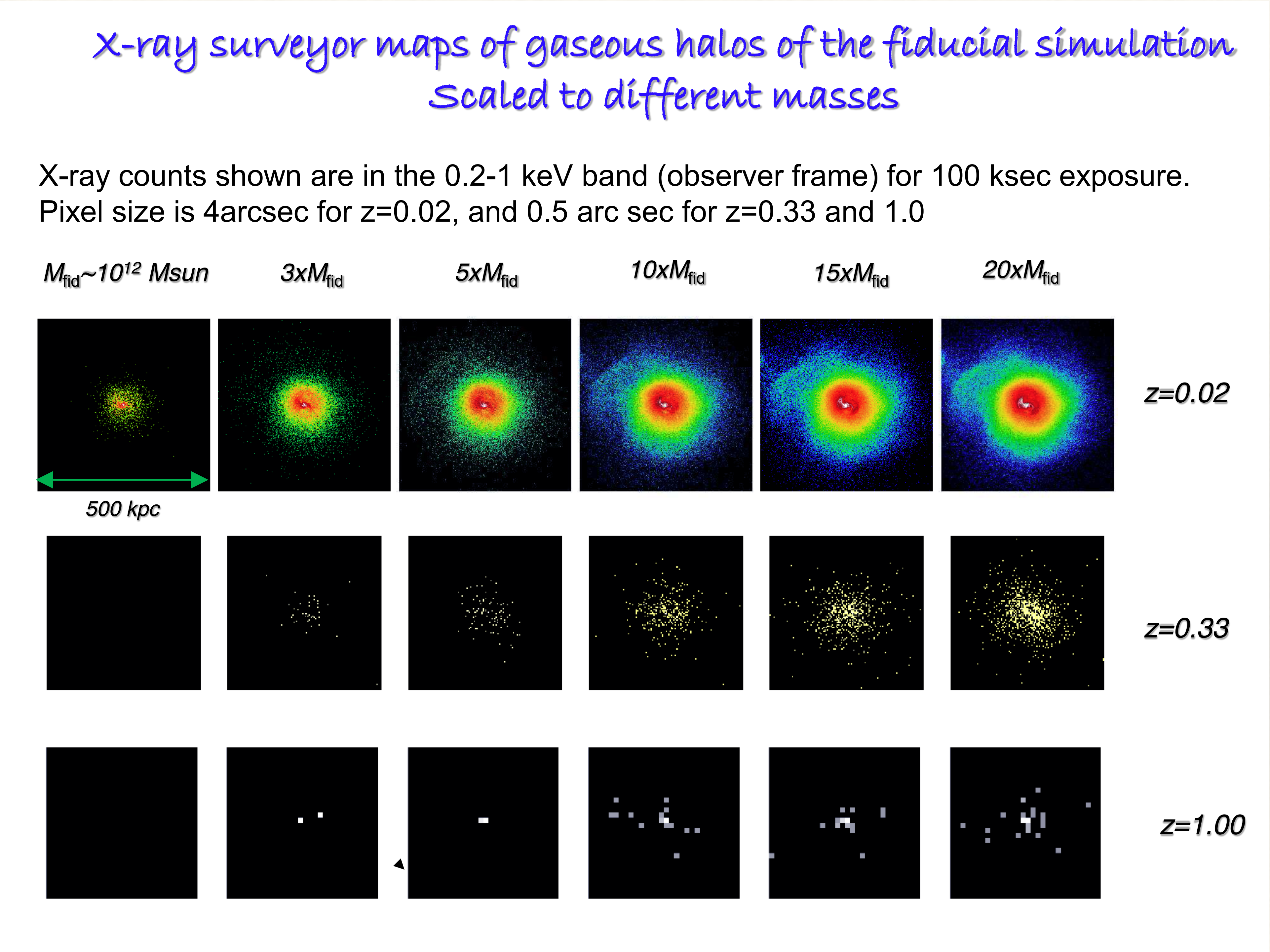
moderate feedback + high sf efficiency (strong outflows)	*moderate feedback + low sf efficiency (weak outflows)*	*strong feedback + low sf efficiency (strong outflows)*	*moderate feedback + high sf efficiency + cosmic rays (strong outflows)*

ratio of counts in these models is 0.15 : 0.91 : 0.09 : 0.83



A. Kravtsov

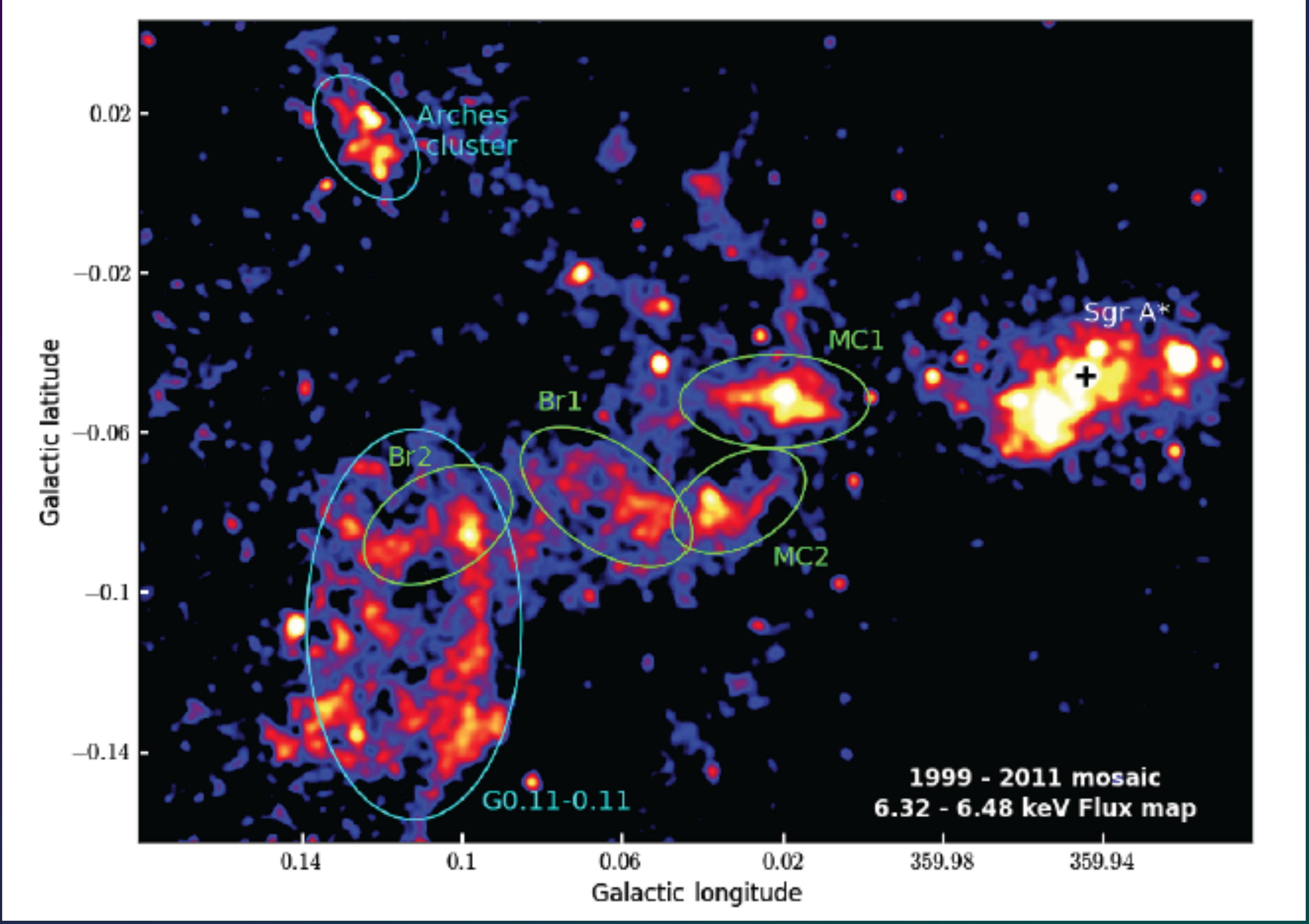
~~Constraining~~ Solving galaxy formation with observations of gaseous halos



A. Kravtsov

Galactic Center

Fluorescent 6.4-keV iron line emission



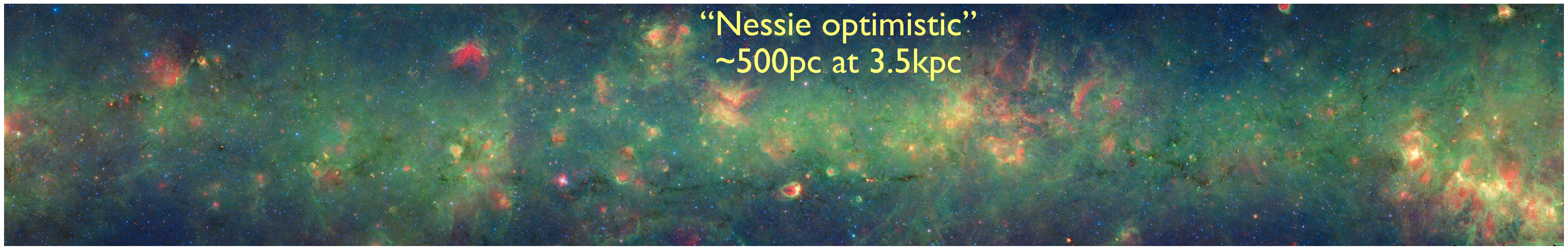
Clavel et al. 2012

M. Morris

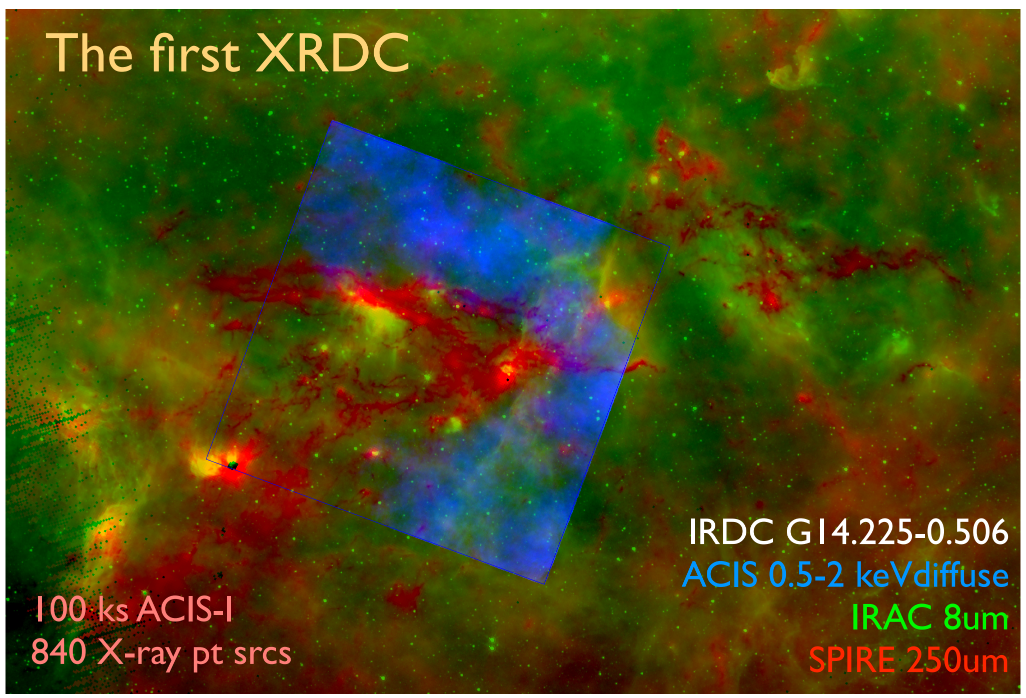
Star formation and feedback in Milky Way

X-raying the Bones of the Milky Way

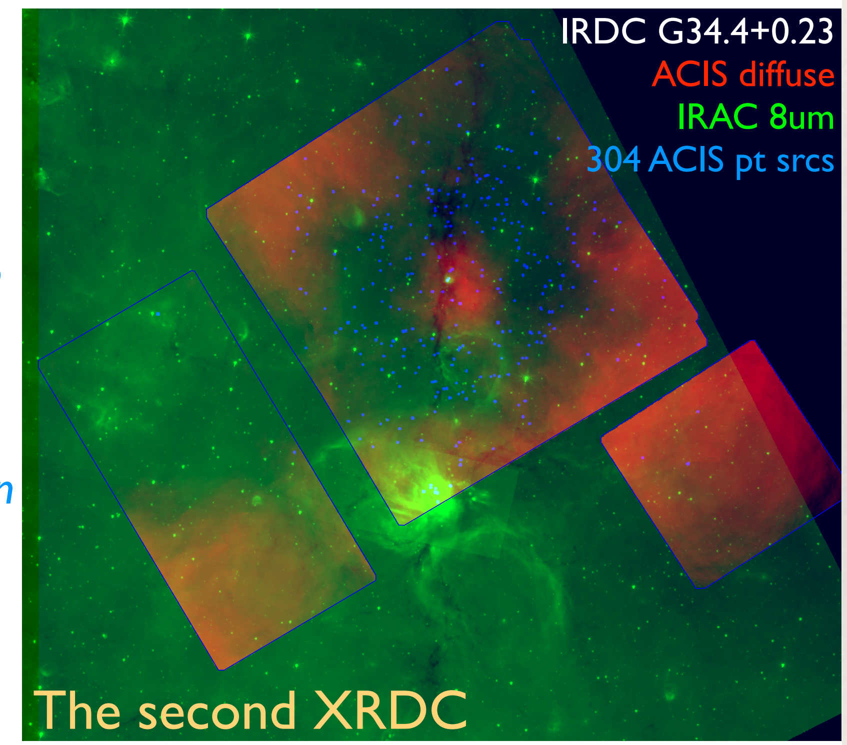
Goodman14: major Infrared Dark Cloud (IRDC) filaments form structures that extend for hundreds of parsecs and form the "spines" of the spiral arms.



Chandra is characterizing the history and extent of star formation in just a couple of individual small IRDCs.



Povich15:
Rapid Circumstellar Disk Evolution and a High Rate of Distributed Star Formation in the IRDC M17 SWex



XRS's sensitivity, large FoV, and compact PSF over wide fields are needed to map these huge structures, building an unprecedented picture of the major skeletons supporting star formation in the Galactic Plane.

L. Townsley

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.

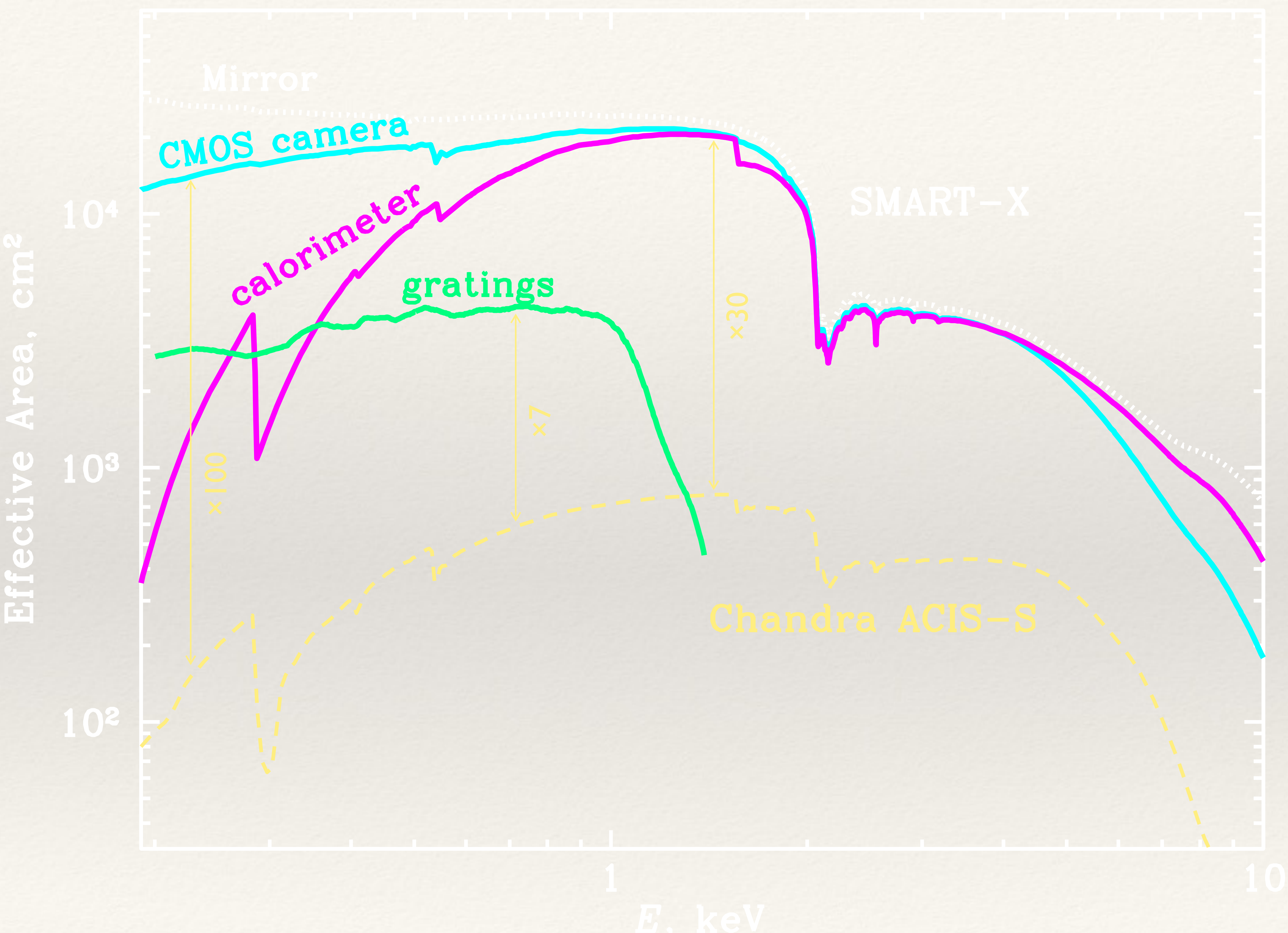
- ***Feasible:*** *Chandra*-like mission with regards to cost and complexity, with the new technology for optics and instruments already at TRL3 and proceeding to TRL6 before Phase B

Unique opportunity to explore new discovery space and expand our understanding of how the Universe works and

Lorem Ipsum Dolor

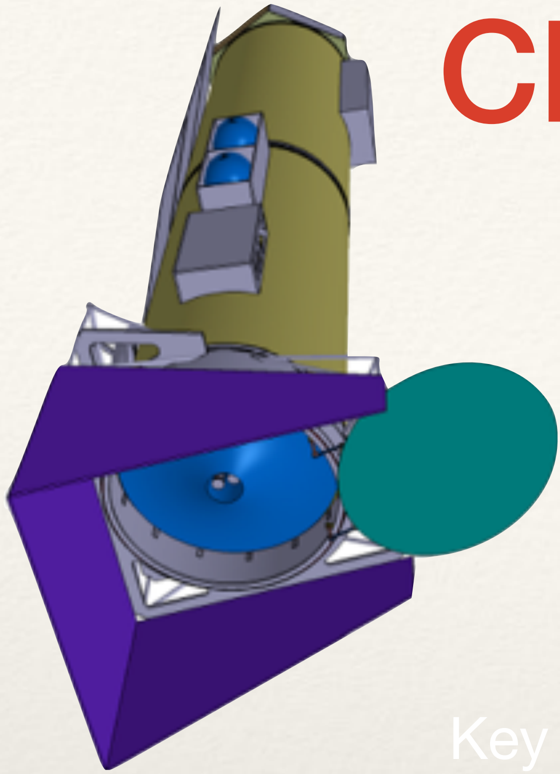
BACKUP SLIDES

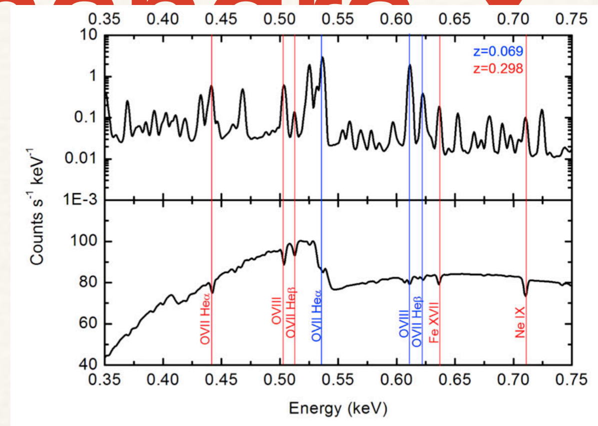
Effective Areas



Chandra X-ray Observatory

Athena



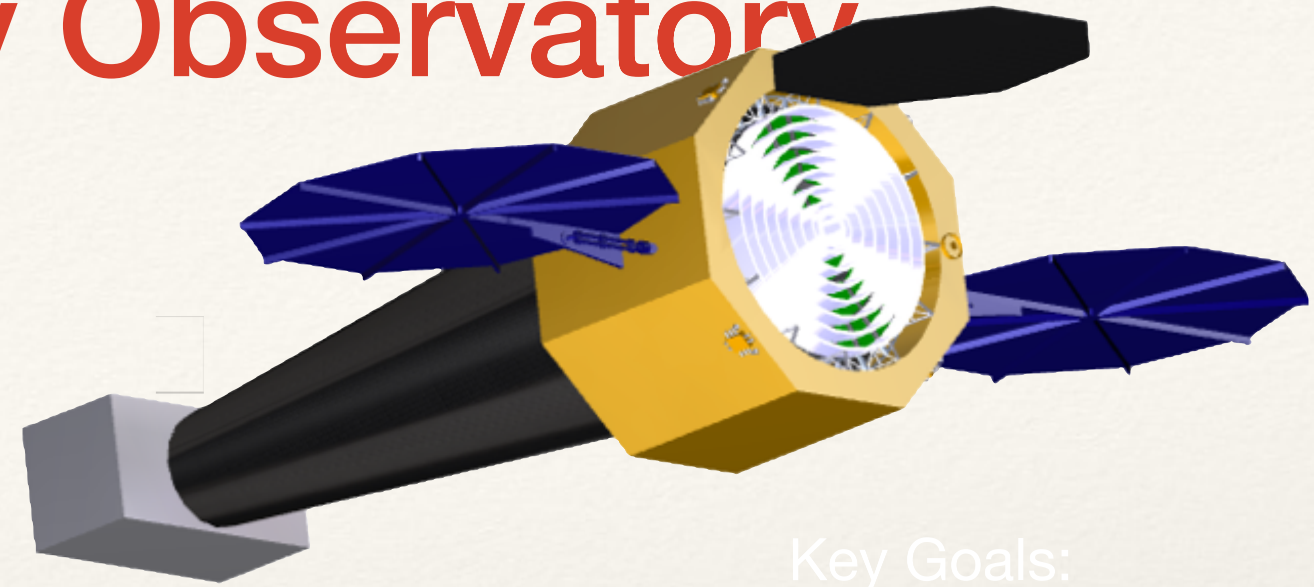


Key Goals:

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

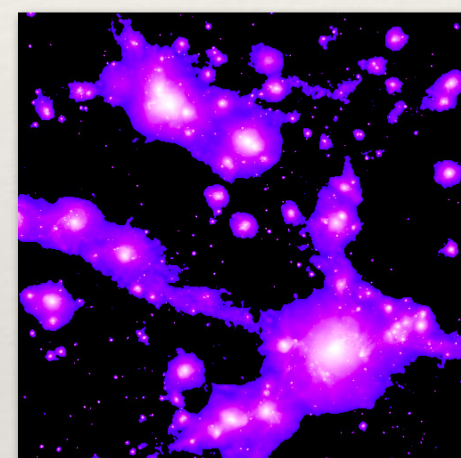
✓ Area is built up at the expense of coarser angular resolution (10× worse) & sensitivity (5× worse than *Chandra*)

X-ray Surveyor



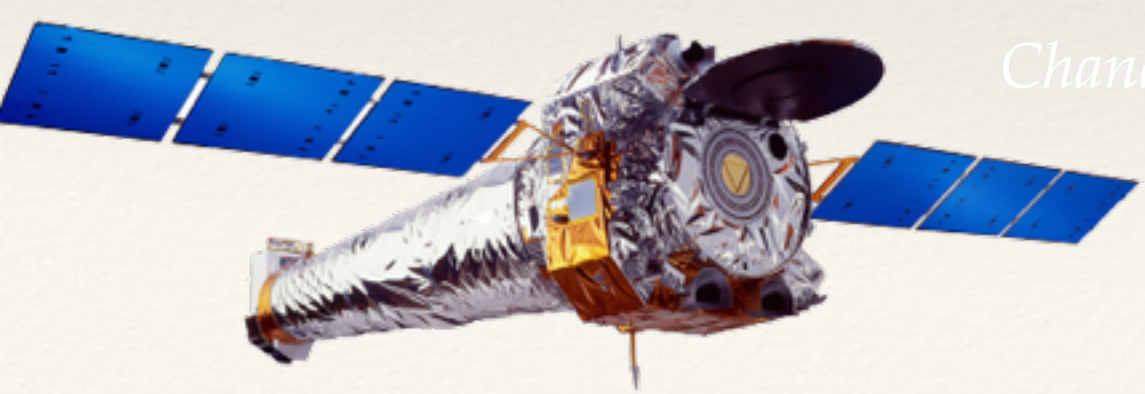
Key Goals:

- 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

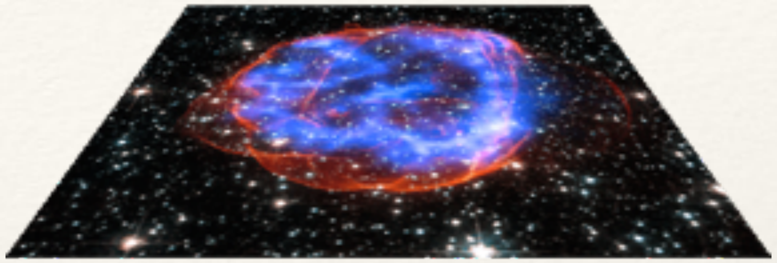


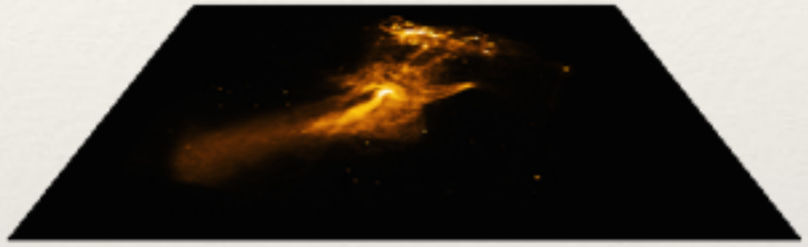
Chandra

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
- …

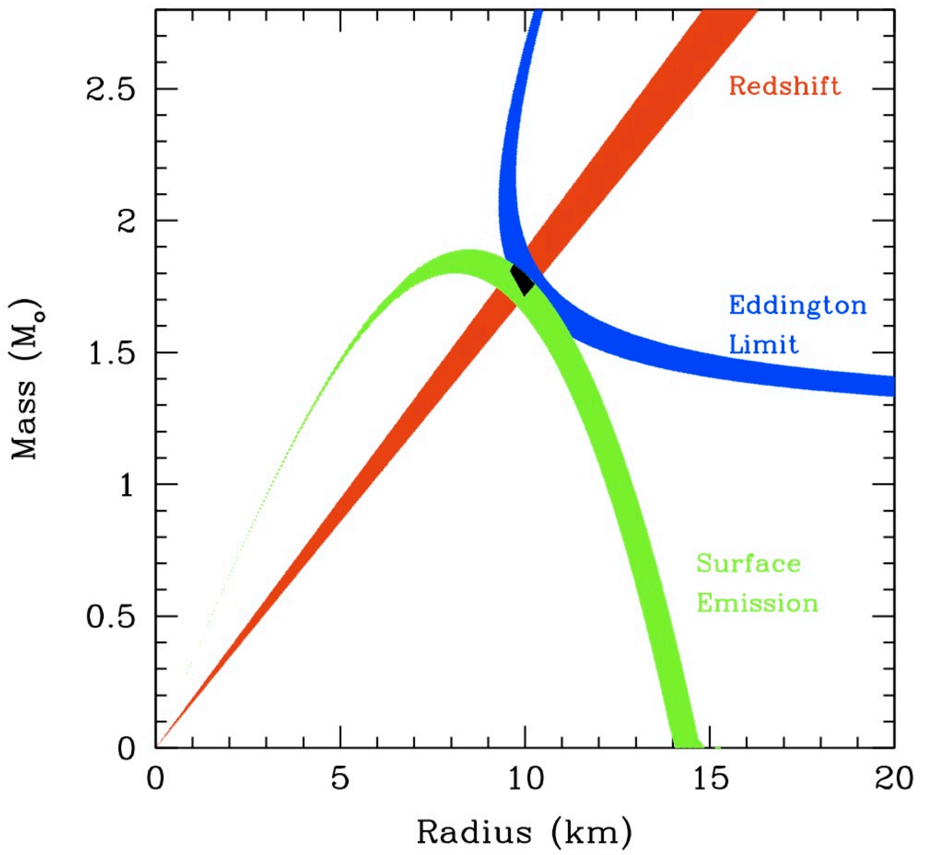




Required capability: high-resolution spectroscopy ***and*** resolving relevant physical scales

Neutron Star Matter

Measurement of Radii



F. Özel