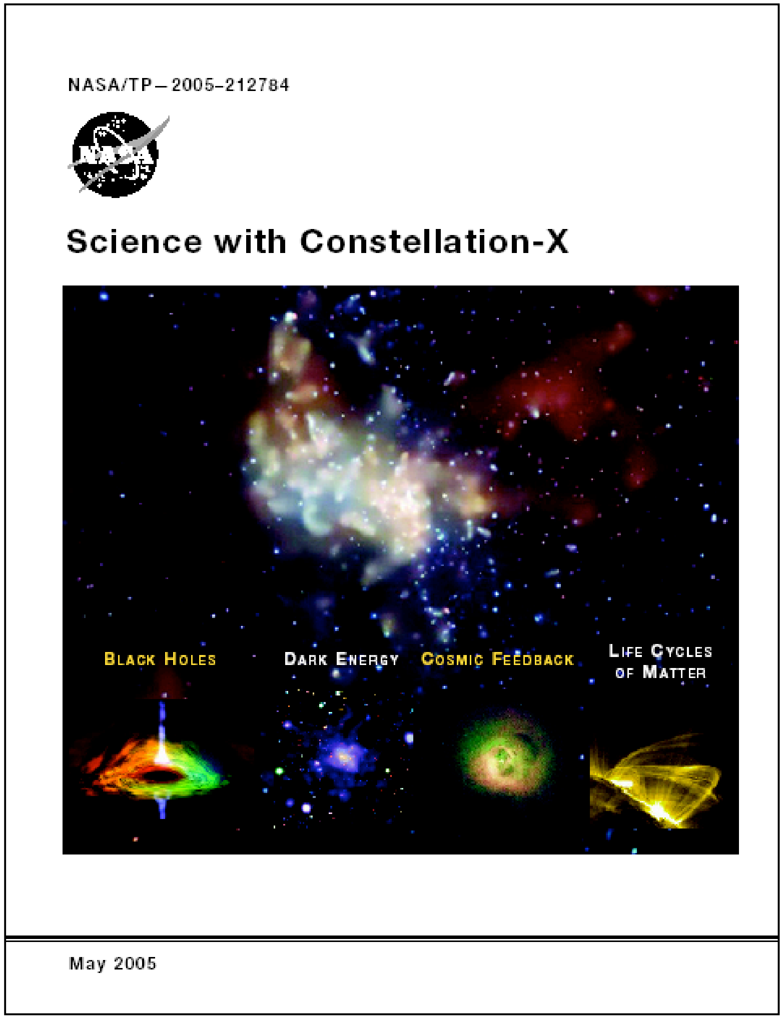
Con-X Science Booklet: Released Summer 2005



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Constellation-X
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Studying Dark Energy, Black Holes and Cosmic Feedback at X-ray Wavelengths:

NASA's Constellation-X Mission

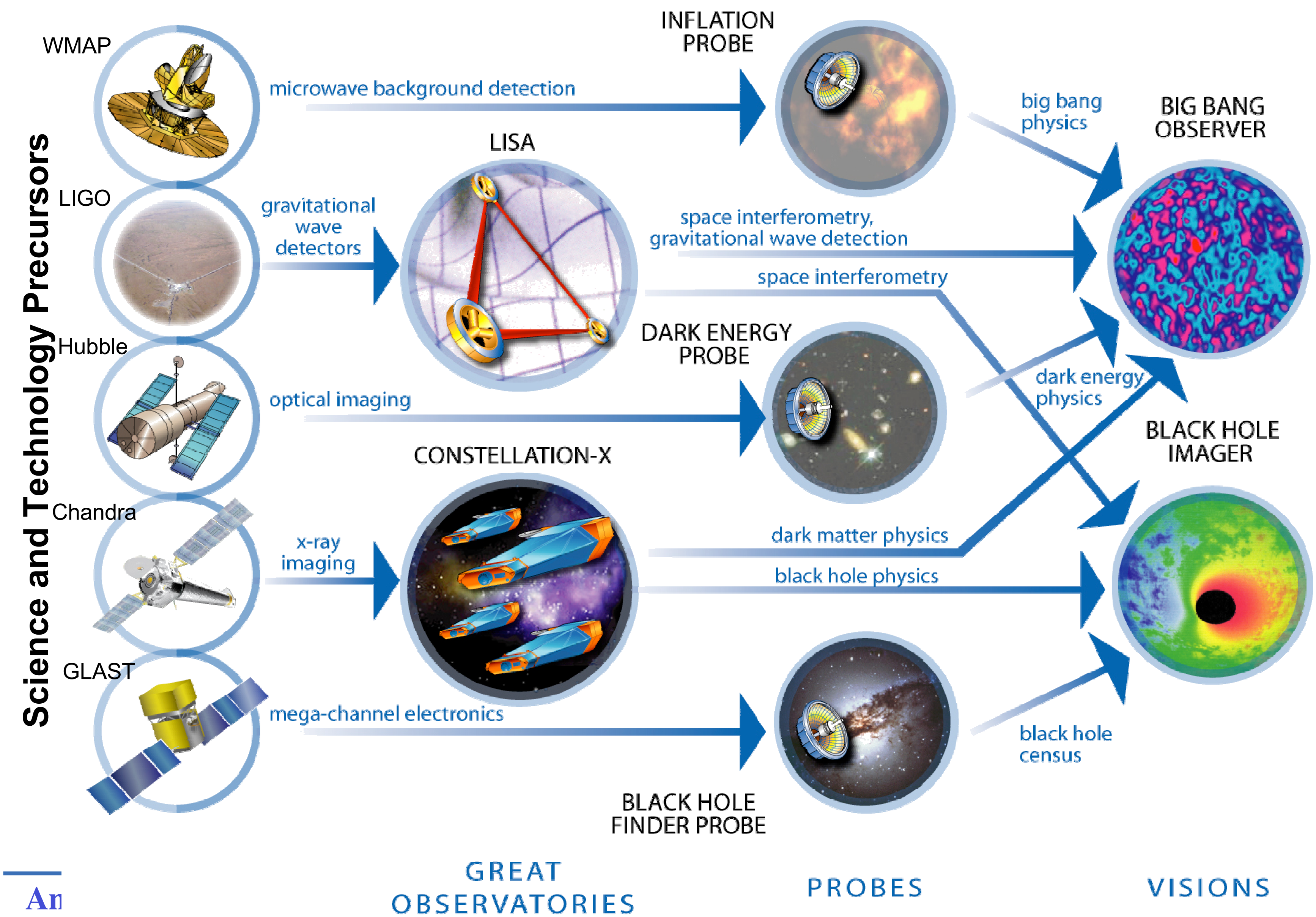
Project Scientist:
Nick White (GSFC)
Facility Science Team Chair:
Harvey Tananbaum (SAO)

http://constellation.gsfc.nasa.gov

Outline

- **Constellation-X Mission**
- **Dark Energy Constraints using Galaxy Clusters**
- **Black Holes & Strong Gravity**
- **Cosmic Feedback in the X-ray Band**

The Beyond Einstein Program



The Constellation-X Mission

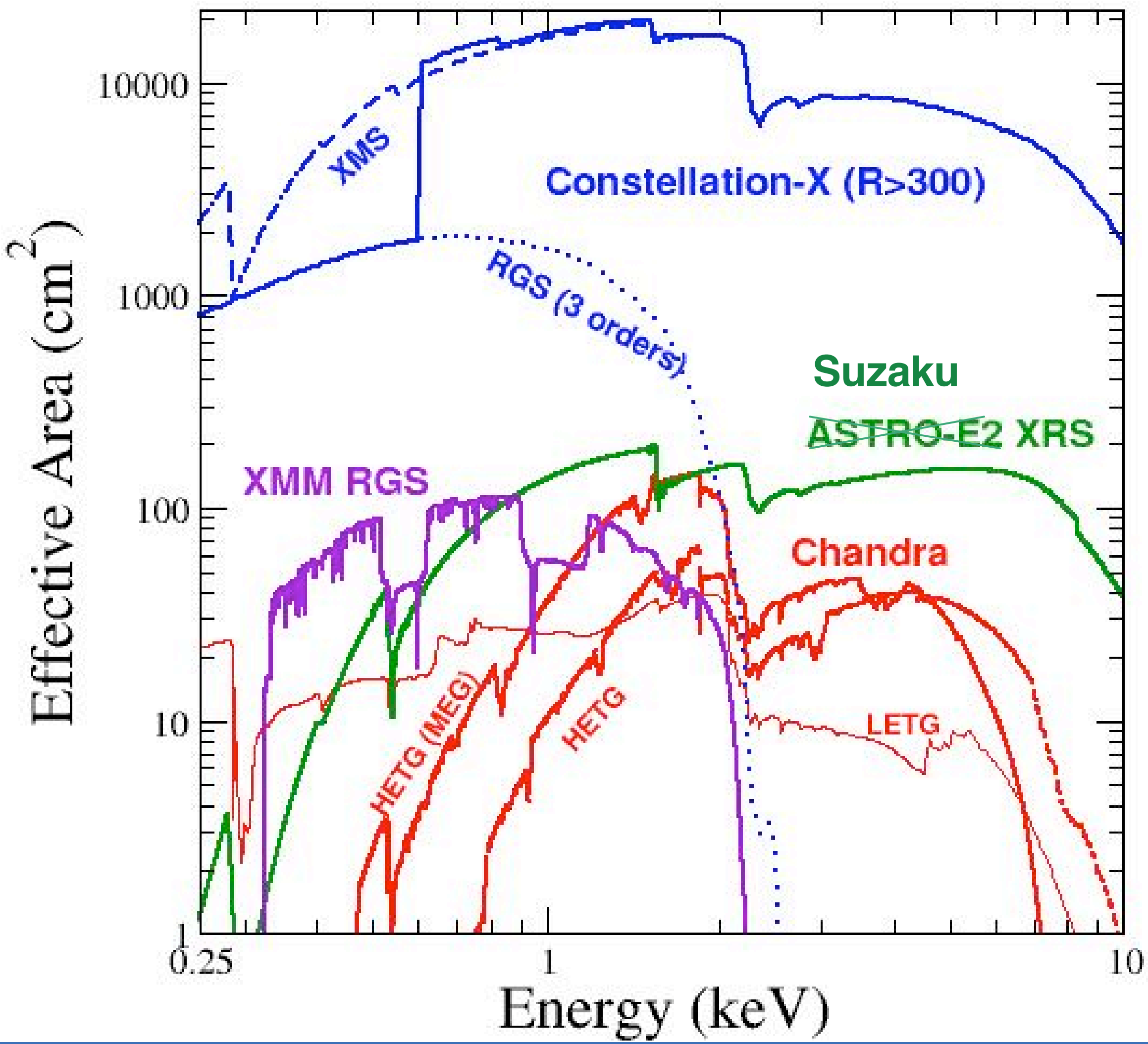
- Black Holes:
- Dark Matter and Dark Energy
- Cosmic Feedback
- Life Cycles of Matter and Energy

Observatory dedicated to high resolution X-ray spectroscopy:

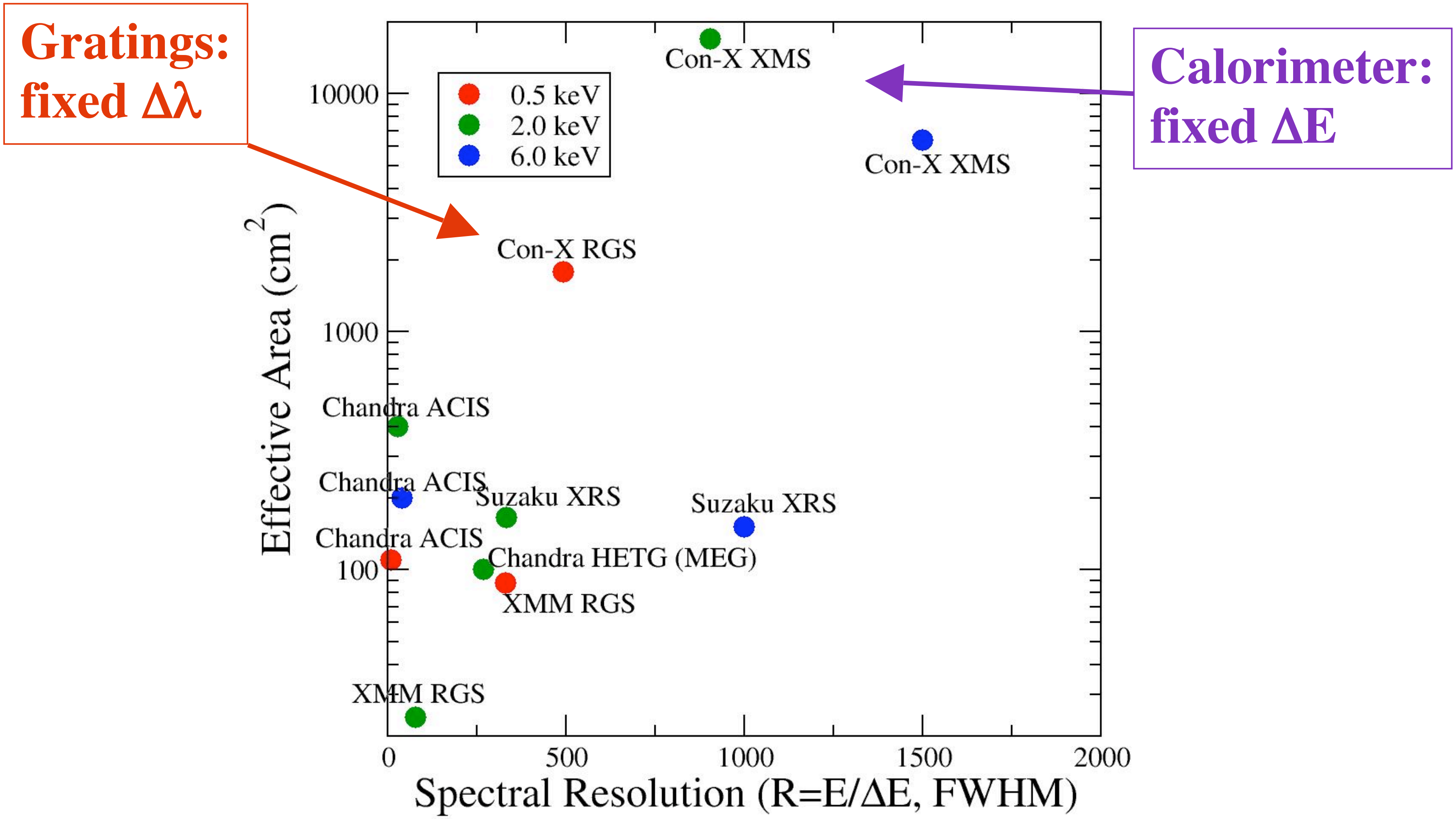
- **25-100 times sensitivity gain over Chandra**
- **Baseline of four space-craft working as a single large telescope**

Constellation-X given strong endorsement by US National Academy of Sciences McKee-Taylor & Turner Committee Reports

X-ray Mission Collecting Areas

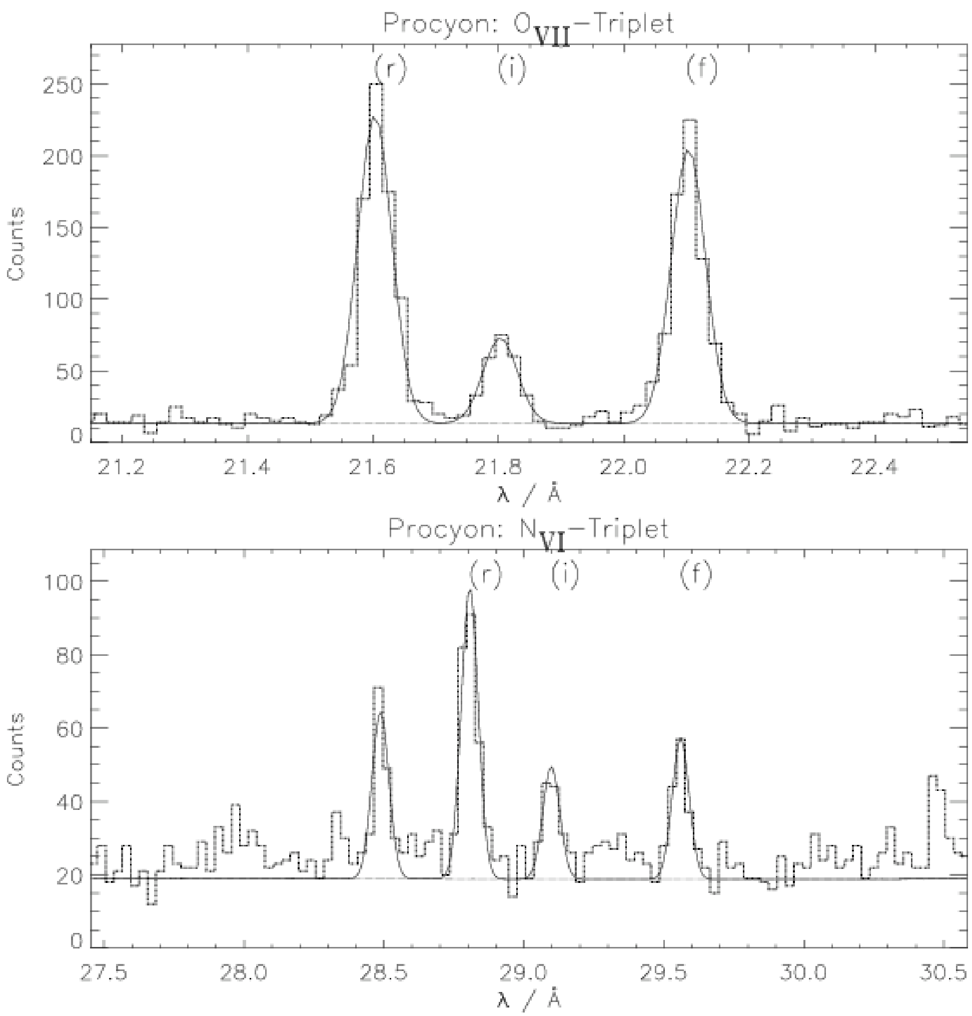


Resolving Power:
Collecting Area vs. Spectral Resolution



High Spectral Resolution in the X-ray Band

Notes on X-ray Spectroscopy

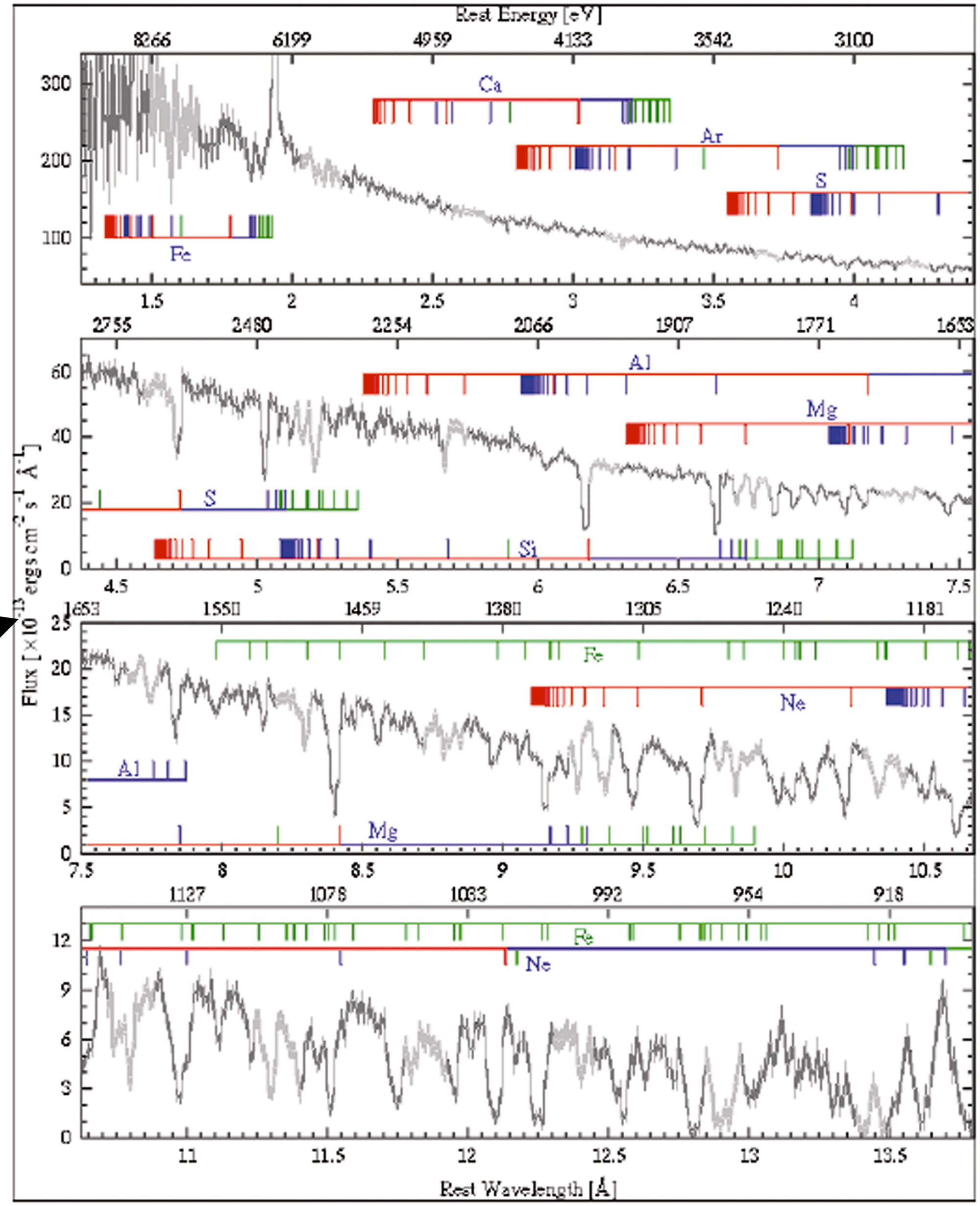


Procyon XMM RGS spectrum (Ness et al. 2001)

- X-ray spectroscopic workhorse: the He-like triplet ➔ density and temperature diagnostics
- This guides our spectral resolution requirements for hot X-ray plasmas:
  - Thermal broadening limits resolution to $R \sim 410\sqrt{M/T}$
  - ***Practical maximum for X-ray plasmas is R~10,000***

Notes on X-ray Spectroscopy

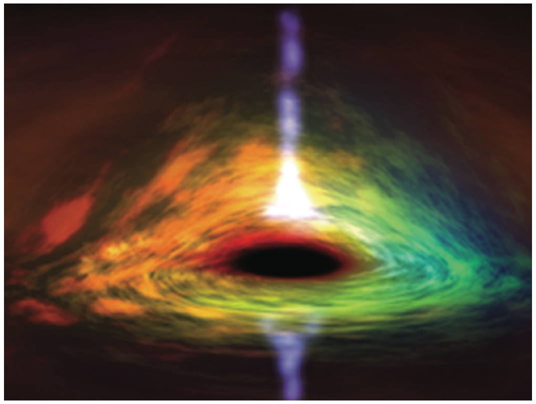
- Absorption spectra of cool plasmas, however, contain complex velocity structures
- **Example: NGC 3783, nearby Seyfert 1 (900 ks Chandra HETG; Kaspi et al. 2002)**
  - **RED: H-like lines**
  - **BLUE: He-like lines**
  - **GREEN: Other ions, e.g., lower ionization-metals Fe XVII and Fe XXIV**
- **Constellation-X, with its large effective area, will collect a spectrum of similar quality in 50-100 ks**



Constellation-X
Science

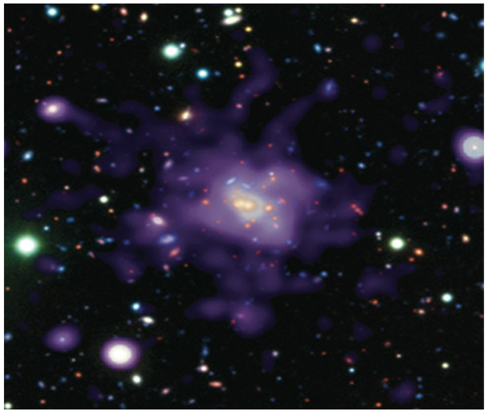
Constellation-X Science

Black Holes



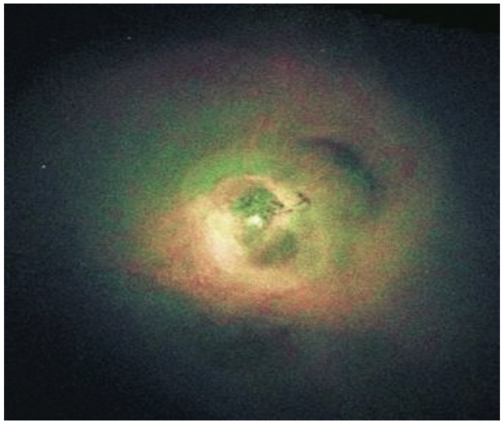
What is the detailed structure of the inner accretion disk?
How prevalent are intermediate-mass black holes?

Dark Energy & Matter



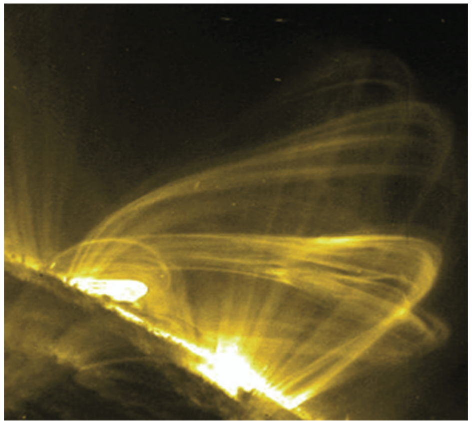
Does dark energy evolve with redshift?

Cosmic Feedback



How have accretion disks in AGN affected galaxy evolution?
How do starburst galaxies enrich the IGM?

Life Cycles of Matter



What is the nature of matter that makes neutron stars?
How do stellar outflows affect planet formation?

Galaxy Clusters:
Constraints on Dark Energy

(thanks to Steve Allen, Stanford)

Cosmology with galaxy clusters

1. Galaxy clusters, like supernovae, have a measured property that can be used for distance-*z* comparisons **(f_{gas} measurements; e.g., Allen et al. 2002, 2004)**
2. Also, number density, spatial clustering and evolution of clusters are all strong functions of dark energy **(Cluster luminosity/mass function measurements; e.g., Majumdar & Mohr 2003)**

Both require large samples (>> hundreds) of large, dynamically relaxed clusters where hydrostatic equilibrium holds (identified in e.g., the ROSAT All Sky Survey)

X-ray Emission from Clusters of Galaxies

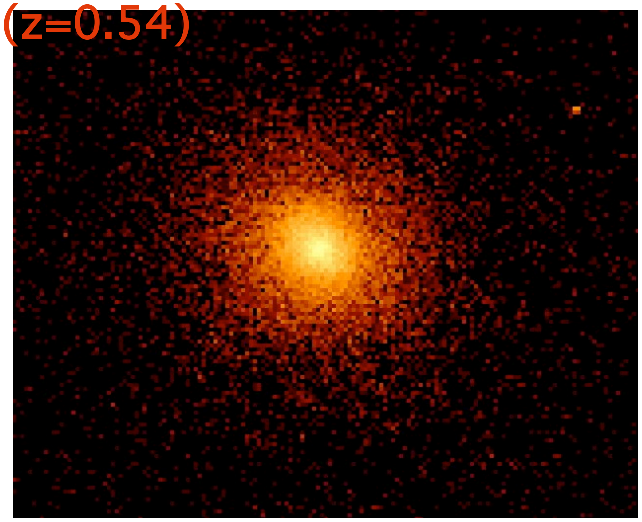
- X-ray emitting gas dominates the overall baryonic mass in clusters ($M_{gas} \sim 6M_{stars}$; e.g., Fukugita, Hogan & Peebles 1998).
- **Observables:**

  1. **X-ray surface brightness profile.**
  2. **Deprojected (spectrally-determined) temperature (*kT*) profile**

+ assumption of hydrostatic equilibrium

_ *M(r)*

Chandra image of MACS1423+24 (z=0.54)



f_{gas} Measurements with Clusters of Galaxies

- Galaxy clusters are so large that their matter content should provide a fair sample of matter content of Universe.

If we define:

$$f_{gas} = \frac{\text{X-ray gas mass}}{\text{total cluster mass}} \qquad f_{gal} = 0.19h^{0.5}\, f_{gas}$$

Then:

$$f_{baryon} = f_{gal} + f_{gas} = f_{gas}(1 + 0.19h^{0.5})$$

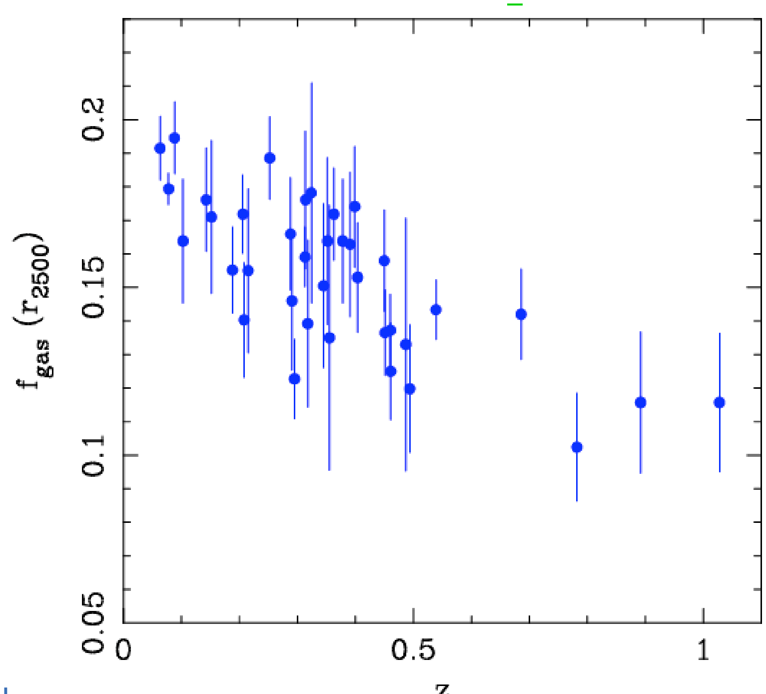
Since clusters provide ~ fair sample of Universe $f_{baryon}=b\Omega_b/\Omega_m$

$$\Omega_m = \frac{b\Omega_b}{f_{baryon}} = \frac{b\Omega_b}{f_{gas}(1+0.19h^{0.5})}$$

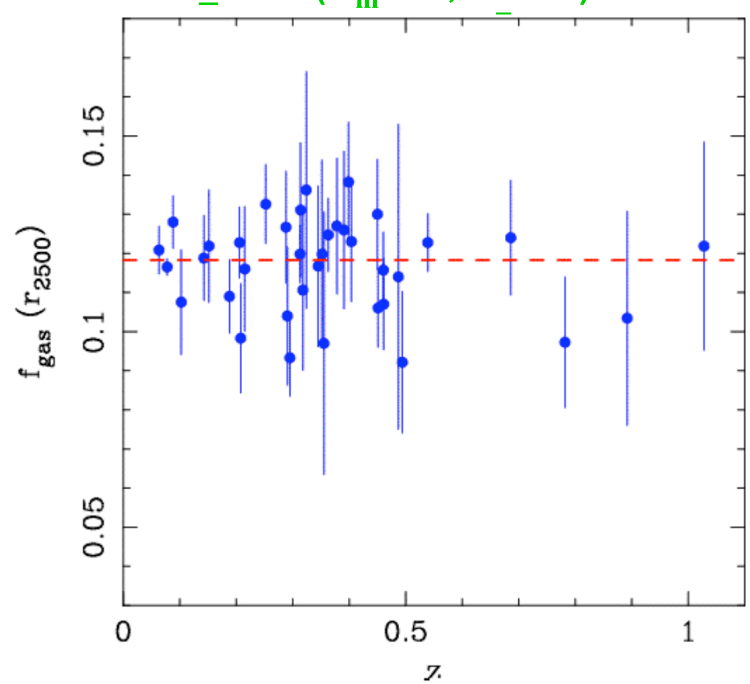
f_{gas} Dependence on Distance
(Allen et al 2005, Rapetti et al. 2005)

- **The measured fgas values depend on the distance to the clusters as $f_{gas} \propto d_A^{\ 1.5}$**
- **Distance dependence arises from geometry and assumption of hydrostatic equilibrium**

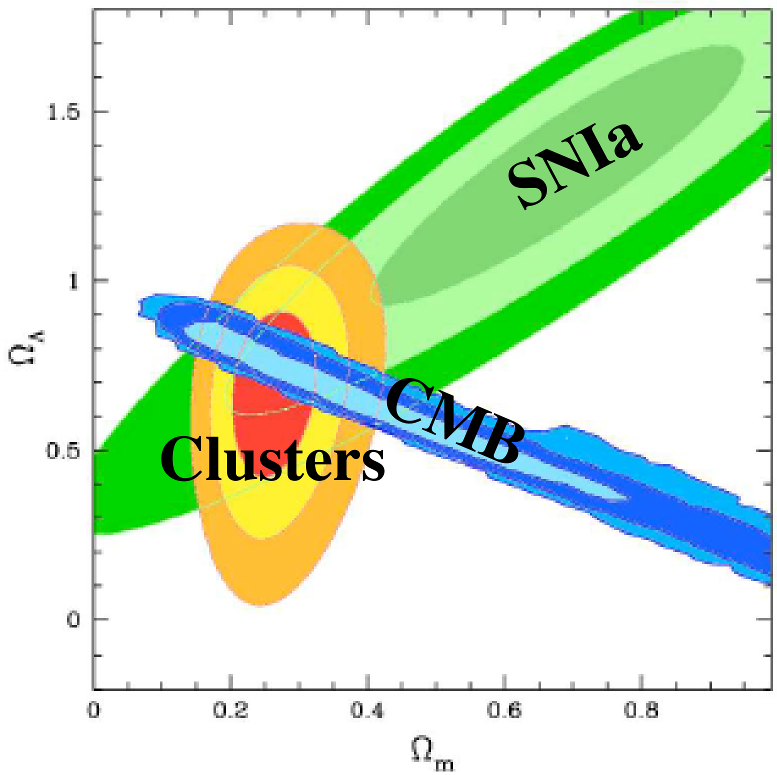
SCDM (Ω_m=1.0, $\Omega\_$=0.0)



_CDM (Ω_m=0.3, $\Omega\_$=0.7)



Cosmological Parameters
(Allen et al. 2005 DETF Paper)



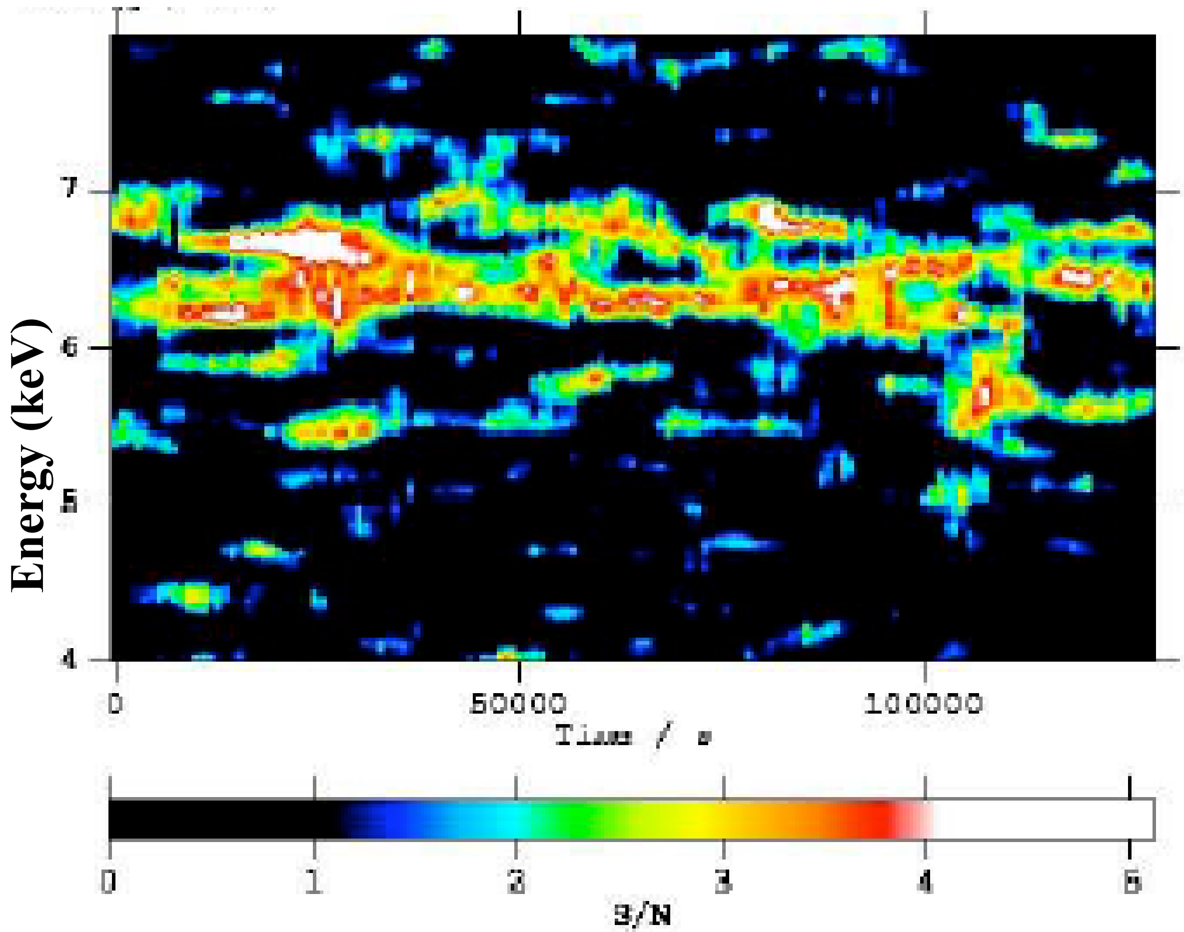
- Con-X's effective area critical to study large sample of clusters
- Expect a large snapshot survey followed by deeper spectroscopic observations of relaxed clusters
- will achieve f_{gas} measurements to better than 5% for individual clusters:
  - **Corresponds to Ω_M=0.300±0.007, Ω_Λ=0.700±0.047**
  - **For flat evolving DE model, w_0 = -1.00±0.15, w' = 0.00±0.27**

Constraints are similar & complementary to SN Ia studies

Black Holes:
Strong Gravity and the Inner Accretion Disk

Fe Kα: Accretion Disk Structure

- Fe K fluorescence fron surface layers of thin, Keplerian accretion dis
- Chandra/XMM ◊ beginning to probe structure on orbital/sub orbital timescales in outskirts of accretion disk
- **Con-X will do the san for ~100-200 nearby AGN**



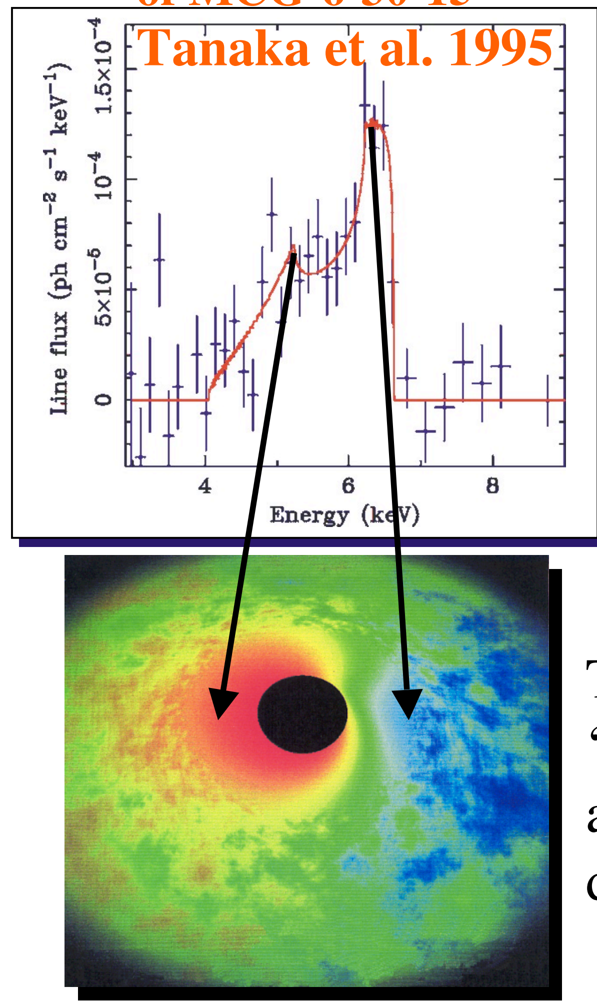
XMM-Newton obs. of Mrk 766

Credit: Turner et al. (2005; astro-ph/0506223)

Beyond Einstein:
Probing Strong Gravity with Constellation-X

- The Iron fluorescence emission line is created when X-rays scatter and are absorbed in dense matter, close to the event horizon of the black hole.
- Test of General Relativity in the strong field regime

ASCA X-ray spectrum of MCG-6-30-15

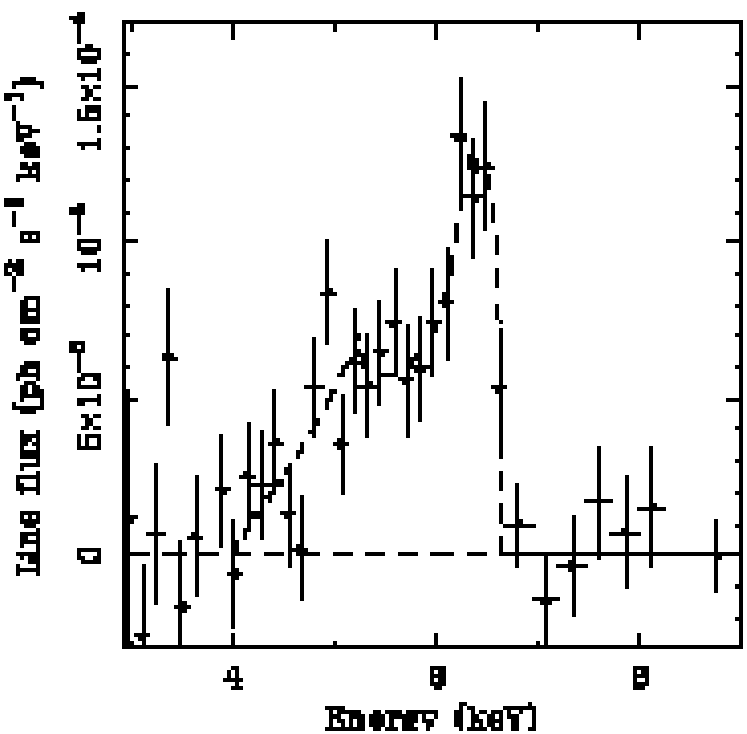


Theoretical 'image' of an accretion disk.

Inner Accretion Disks: MCG-6-30-15

- MCG-6-30-15 (d=37 Mpc)
- $M_{BH} \sim 10^6 - 2\times 10^7\ M_\infty$
- Strong time variability of line profile: emission at <6 gravitational radii
- Relatively common in ASCA studies of Seyferts (14/18 have resolved Fe K lines; Nandra et al. 1997)
- Typically line energy ~6.4 keV and σ=0.43± 0.12 keV

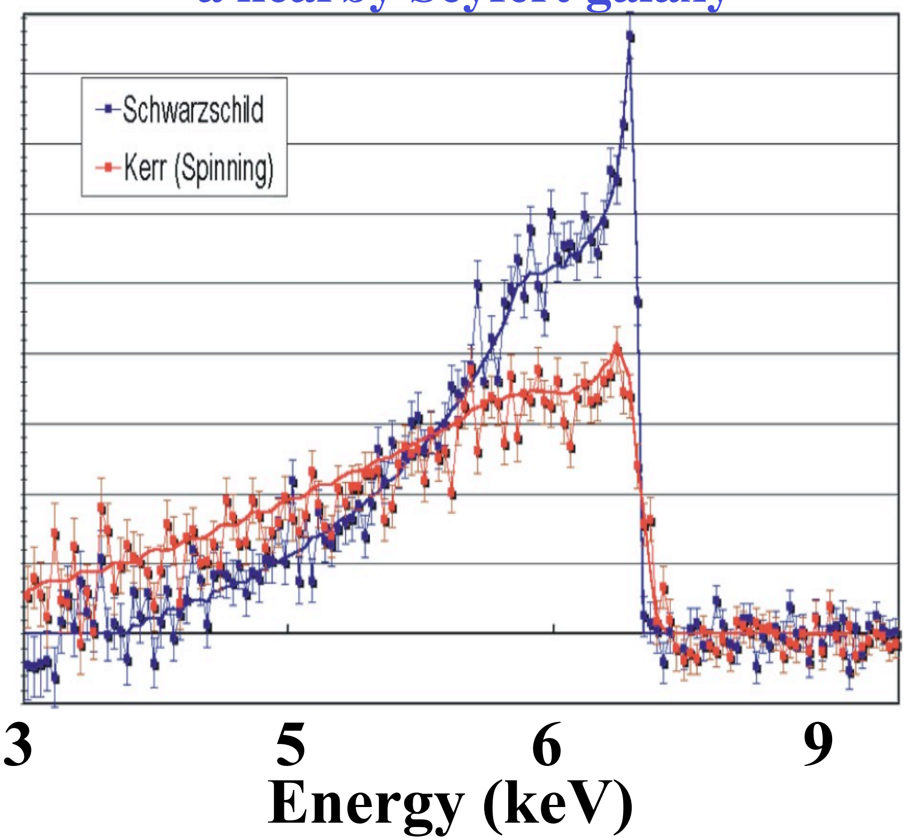
ASCA X-ray spectrum of MCG-6-30-15
Tanaka et al. 1995



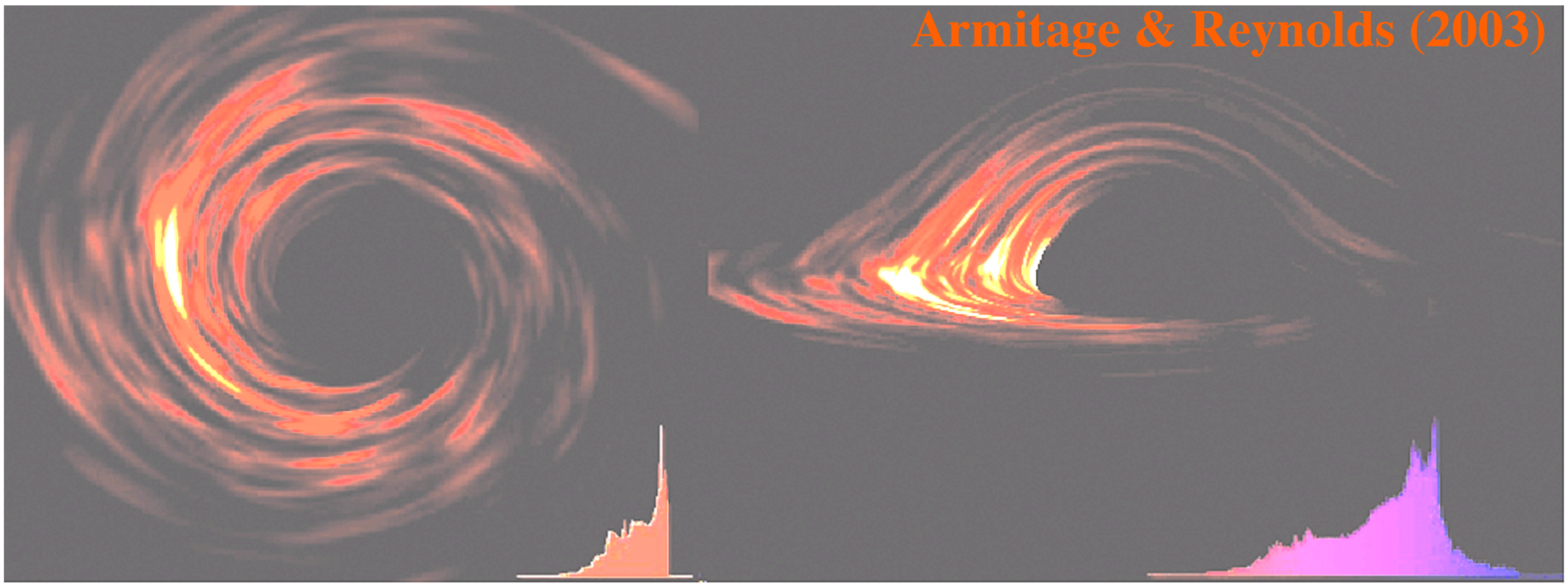
Constellation-X's Role: Reverberation Mapping

- Current limitation: vast range of black hole angular momentum fits same Fe K data (e.g., Dovciak, Karas & Yaqoob 2004)
- Con-X will track X-ray flares across accretion disks via reverberation effects, constraining the nature of space-time around black holes (Young & Reynolds 2000)

Constellation-X simulation of a nearby Seyfert galaxy



Black Holes:
Structure of the Inner Accretion Disk



Tracking material around accretion disks with X-ray spectroscopy allows us to probe the nature of space-time very near the black hole

Cosmic Feedback

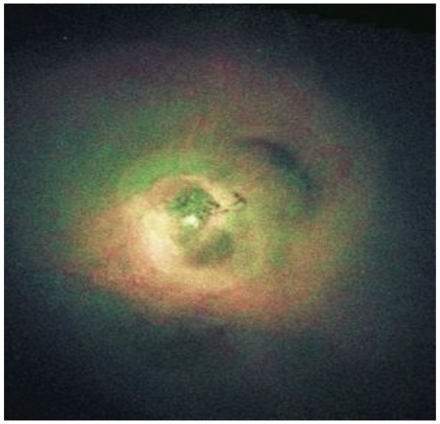
Definition of Feedback

- Definition of feedback:
  - ***Return, via outflows, of mechanical energy, radiation, and chemical elements from star formation and black holes to the interstellar and intergalactic medium***
  - Self-regulation of processes across vast scales (e.g., correlation between stellar bulge mass, velocity dispersion and nuclear black hole mass in galaxies: Magorrian relation)

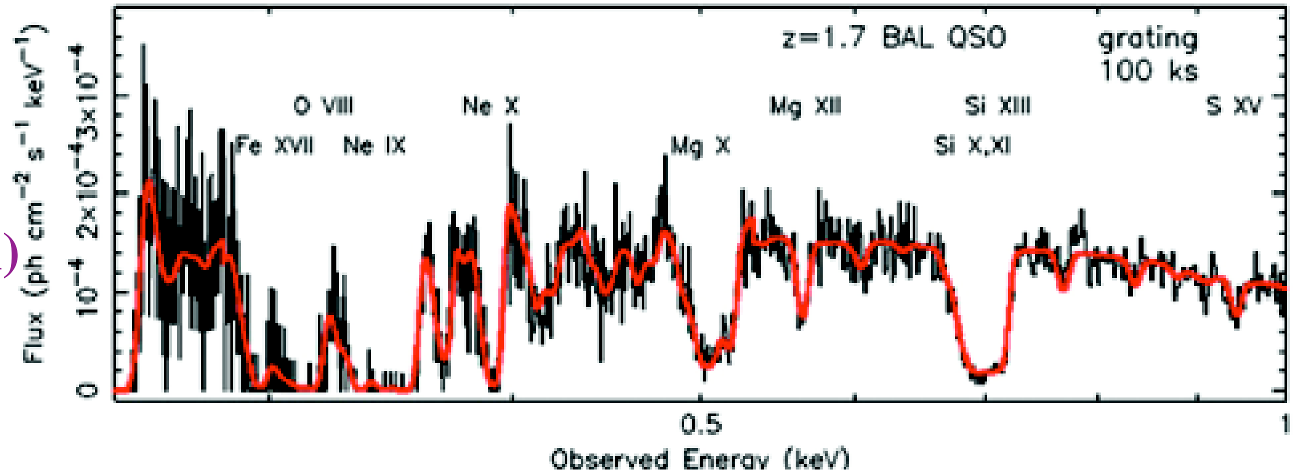
AGN Feedback

- Large scale-structure simulations require AGN feedback to regulate the growth of massive galaxies (e.g., Di Matteo et al. 2005, Croton et al. 2005)
- Non-dispersive X-ray spectroscopy of clusters needed to probe hot plasma (Begelman et al. 2003,2005)
- Powerful AGN outflows in the Universe at z=1-3 ◊ Chandra/XMM have studied highly ionized outflows in *local* AGN (NGC 3783; Kaspi et al. 2002)

Perseus Cluster of Galaxies (Chandra image)



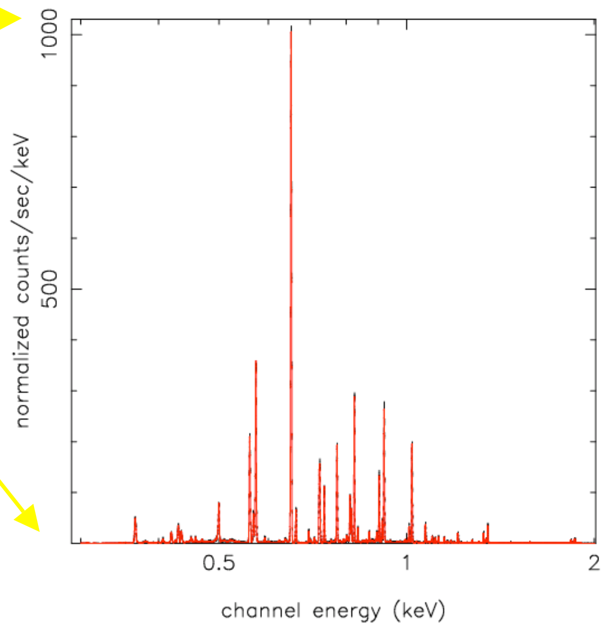
Con-X simulation of BAL QSO (S.Gallagher, UCLA)



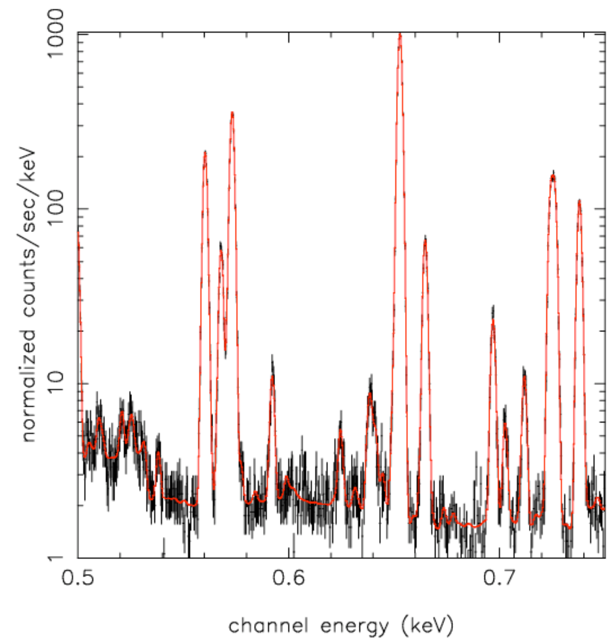
Supernova (Stellar) feedback

Wind plasma diagnostics (D. Strickland, JHU)

M82 Chandra central 5x5 kpc
0.3-1.1 keV,
1.1-2.8 keV
2.8-9.0 keV



Simulated 20 ks Con-X northern halo observation, 0.3-2.0 keV.



O VII and O VIII region. Well resolved triplet, high S/N in continuum.

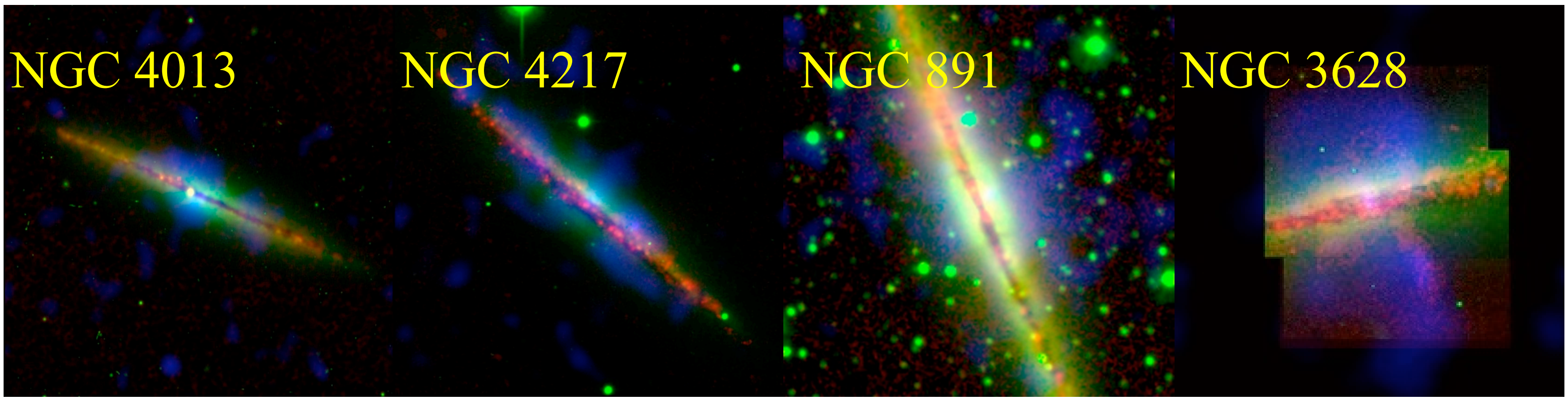
With calorimeter ~2-eV resolution we can determine T, n_e t, [Z/H], v_{HOT} accurately in many extended winds (not just M82).

Hot gas around normal disk galaxies

courtesy of D. Strickland (JHU)

Normal spiral galaxies

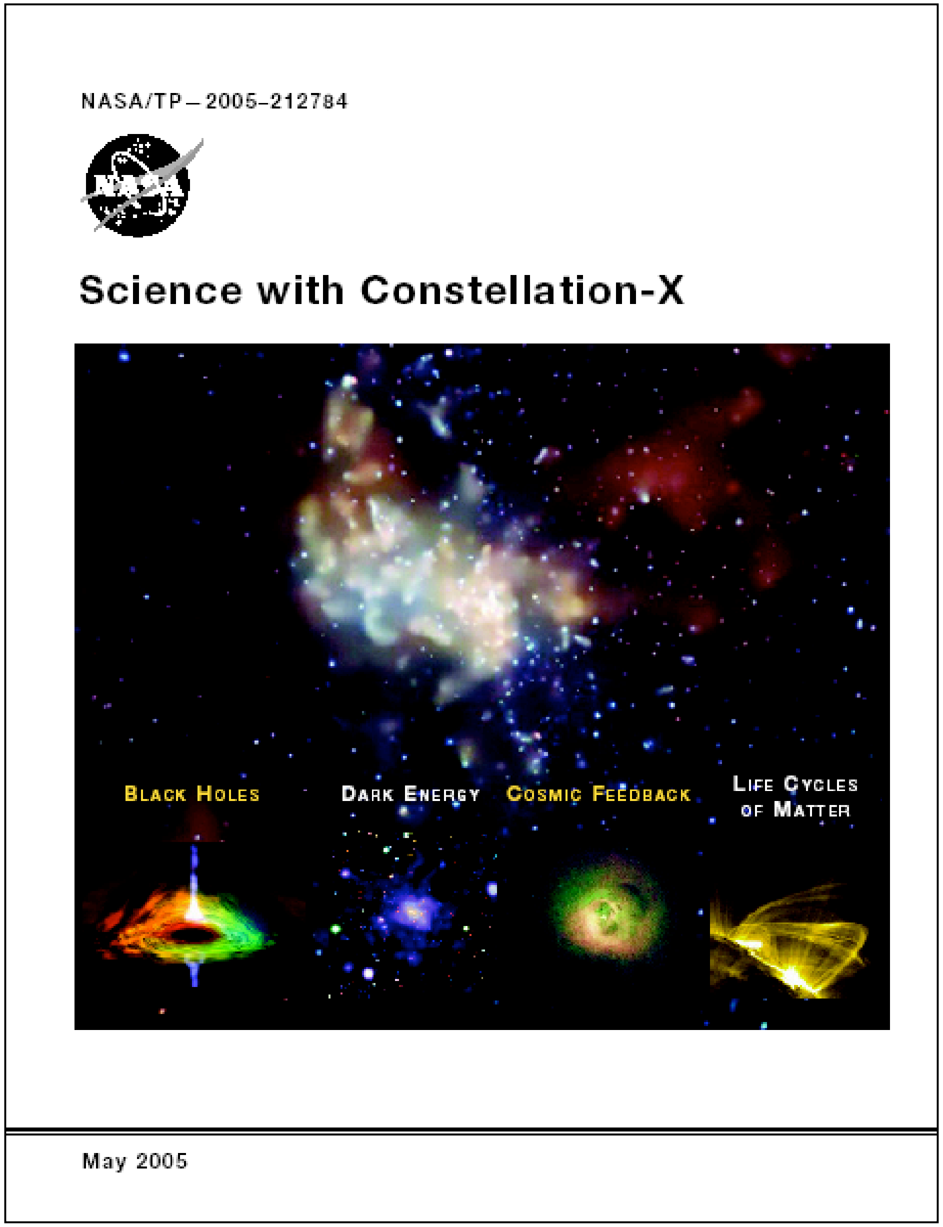
Example starburst galaxy with superwind



Red: H-alpha (WIM), Green: R-band (starlight), Blue: Diffuse soft X-ray (3 million deg gas).
The region covered by each image is 20 x 20 kpc. Intensity scale in square-root.

Interested in more Constellation-X Science?

Available in PDF form at constellation.gsfc.nasa.gov


NASA/TP—2005-212784

Science with Constellation-X

May 2005

THANK YOU

- Please visit http://constellation.gsfc.nasa.gov
- **Questions? Email me: annh@milkyway.gsfc.nasa.gov**

Constellation-X
Facility Science Team

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- **Instrument Product Team Leaders:** HXT: Fiona Harrison (CalTech) Grating/CCD: Kathryn Flanagan (MIT) Calorimeter: Richard Kelley (GSFC) SXT: Rob Petre (GSFC)
- **FST At-Large Members, Science**: Scott Anderson (U. Washington)Keith Arnaud (U. of Maryland) Steven Allen (Stanford) Jill Bechtold (U. of Arizona) Mitchell Begelman (U. of Colorado) Elliot Bloom (SLAC) Joel Bregman (U. of Michigan) Claude Canizares (MIT) Andy Fabian (Institute of Astronomy - UK) Gabriele Ghisellini (Osservatorio Astronomico di Brera-Italy) John Hughes (Rutgers U.) Duane Liedahl (Lawrence Livermore National Lab) Abraham Loeb (Harvard University)Frank Marshall (GSFC) Giorgio Matt (Universit‡ degli Studi Roma Tre-Italy) Bruce Margon (STScI) Richard Mushotzky (GSFC) Robert Rosner (U. Chicago) Chris Reynolds (U. of Maryland) Michael Shull (U. of Colorado)