X-ray emission appears to be a universal property of active galaxies.

X-ray emission produced in compact region closest to the black hole – rapid variability on timescales down to minutes.

Produced by accretion disk + magnetized disk corona.
X-ray Spectroscopy of Active Galaxies

Rich spectra - note continuum components and atomic features.

Chandra and XMM-Newton observe mainly in the 0.5-10 keV band.
Chandra X-ray Observatory
Operating since 1999 July

Angular resolution and positions improved by factor ~ 10.
50-250 times sens. of previous missions.

Spectral resolution with gratings improved by factor ~ 30-50.

X-ray Multi-Mirror Mission-Newton
Operating since 1999 December

Photon collecting ability improved by factor ~ 10 for spectroscopy.

Both missions continue to operate well and plausibly can continue for 5-10 more years.
Three Exciting Topics Being Advanced by Chandra and XMM-Newton

• X-ray spectroscopy of active-galaxy accretion disks and winds.

• Ultra-sensitive X-ray surveys of the distant Universe.

• X-ray studies of the first supermassive black holes.

Also some future prospects for X-ray astronomy.
X-ray Spectroscopy of AGN Disks

Calculated X-ray image of relativistic inner disk

See broad + skewed iron K lines.
Show ~ 100,000 km/s velocities, Doppler boosting, gravitational redshift, maybe black-hole spin effects.
Continuum and line rapidly variable.

Quasi-thermal X-ray excess from disk

Fluorescent iron K line from disk irradiation

Ark 564
XMM–Newton EPIC
Vignali et al. (04)

Soft X-ray excess
Power law

Broad iron K line from the active galaxy
MCG–6–30–15
XMM–Newton
Fabian et al. (02)
X-ray Spectroscopy of AGN Winds

Active galaxies not only swallow matter but also eject it in powerful winds (likely radn. driven).

These may be important source of feedback in and around host galaxy.

X-ray grating spectra of winds have revealed 140+ discrete atomic spectral features.

Absorption lines and edges from outflow

Chandra HETGS spectrum of the active galaxy NGC 3783

Kaspi et al. (2002)
X-ray Spectroscopy of AGN Winds

Absorption lines, emission lines, absorption edges, RRCs.

H-like and He-like ions of C, N, O, Ne, Mg, Al, Si, S.

Kinematics
- Outflowing at ~ million mph
- Velocity dispersion – acceleration?

Physical conditions
- Photoionized
- Multiple ionization components
- Few hundred thousand K

Geometry
- Large global & l.o.s covering factors

Time variability fairly mild.
Ultra-Sensitive X-ray Surveys

The Chandra Deep Field-North

Chandra gives up to 50-250 times the sensitivity of pre-Chandra surveys.

Faintest sources have ~ 1 count per 5 days.

About 21 “deep” X-ray surveys ongoing. Large investment of observatory time.

Key questions:

Demography and variety of X-ray sources?

How has supermassive black hole growth proceeded over cosmic history?

How have supermassive black holes and their host galaxies affected each other?

How have the X-ray source populations in non-active galaxies evolved?
Optical Counterparts to X-ray Survey Sources

Dominant source population (70-80%) is active galaxies ("AGN") at z ~ 0.5-5.2.

Many would have been impossible to find without the X-ray information.

Detected AGN sky density is ~ 10 times higher than for optical surveys.

AGN more numerous and varied than previously thought.

Star-forming galaxies also abundant at faintest X-ray fluxes.
Heavily Obscured Active Galaxies in Deep X-ray Surveys

X-rays can penetrate large column densities.

X-ray spectroscopy can measure a huge range of absorption column densities via photoelectric cutoff – a factor of \( \sim 100,000 \).

Absorption bias drops toward higher redshifts.

Majority of active galaxies in deep X-ray surveys are X-ray obscured.

Obscuration appears to be luminosity dependent.

A substantial number (extra \( \sim 30\% \)) of active galaxies are so heavily obscured that are not detected yet.

\( \sim 10^{23} \text{ cm}^{-2} \).
Cosmic Evolution of Moderate-Luminosity, Typical Active Galaxies

Optical evolution of luminous quasars

- Billion solar-mass black holes mostly fed and grew at high redshift (2-4 Gyr after Big Bang).

X-ray evolution of moderate-luminosity AGNs

- Black-hole growth in less-luminous active galaxies persists substantially longer in cosmic time.

Fan et al. (2001) Hasinger et al. (2005)

Black-hole growth in less-luminous active galaxies persists substantially longer in cosmic time.
Active Galaxies at the Highest Redshifts

Recent dramatic increase in the number of known \( z > 4 \) quasars.

Quasars found to \( z \sim 6.3 \) (890 Myr after B.B.).

How were these first supermassive black holes and their host galaxies growing? X-rays.

Fan et al. (2004)
X-rays from the First Supermassive Black Holes

Efficient Chandra X-ray detections of most distant quasars

Now have X-ray detections for ~ 100 quasars at z > 4.

Reliable population studies of their X-ray emission.

Despite the strong number density evolution of quasars, individual quasar emission regions change little.

Combined Chandra spectrum of 46 quasars at z > 4

Indistinguishable from nearby quasar X-ray spectra!

Relative X-ray-to-optical luminosity

Strateva et al. (2005)

Brandt et al. (2002)

Vignali et al. (2005)
Some Future Prospects

**X-ray spectroscopy of disks and winds**

- Clear detections of strong-gravity effects close to black holes
- Assess importance of wind power and feedback

**Ultra-sensitive X-ray surveys**

- Deeper and harder for most heavily obscured active galaxies
- Co-evolution of black holes and their host galaxies

**First supermassive black holes**

- Push to higher redshift and lower luminosity active galaxies
- From first stars or primordial?