Observing Active Galaxies with Chandra and XMM

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## AGN Statistics

Chandra: 980 observations of AGN - 23% of total time  
XMM: ~500 observations of AGN - ~20% of observations  

Papers in refereed journals as of 6/03: Chandra - 85, XMM - 58  

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Seyfert 2

Seyfert 1

NLR 50-100 pc

Fe Kα from Disk/BLR/NLR/Torus

Torus/starburst >~ pc scale

Reflecting gas: $N_H \sim 10^{24} \text{cm}^{-2}$

Scattering gas: tens of pc - kpc

$N_H \sim 10^{21}-10^{22} \text{cm}^{-2}$

Seyfert 2s

Iron Lines

Absorbing gas: ~light-days

NLSY1s

LLAGNs

BL Lacs

Jets/radio galaxies

QSOs
Iron line Diagnostics

Seyfert galaxies are excellent laboratories for studying the accretion flow in AGN

- X-ray reflection from optically thick matter
- Fe Kα fluorescence emission lines
- Fe Kα line has multiple components (from accretion disk, torus, BLR, NLR)
- Lines are variable (Weaver, Gelbord & Yaqoob 2000, ASCA)
- Probe effects of general relativity

MCG-6-30-15 Tanaka et al. 1995
ASCA line profiles - Yaqoob, Weaver 1996
What have we seen with Chandra and XMM?

**Narrow line at 6.4 keV:** Fairall 9 (Sy1), IC 4329A (Sy1), NGC3227 (Sy1), ESO 141-G55 (Sy1), Mrk 6 (Sy1.5), NGC 7469 (Sy1), NGC 5548 (Sy1, FWHM~4,000 km/s), NGC 4151? (Sy1): *EWs range from ~40 to 200 eV. Also Fe K edge is often detected.*

**Broad line:** Mrk 335 (NLSy1), Mrk 766 (NLSy1), Mrk 231 (BAL QSO, FWHM~18,000 km/s), MCG-6-30-15 (Sy1), Q0056-363 (QSO, FWHM~25,000 km/s), Mrk 766 (NLSy1)

**Multiple components with a narrow line at 6.4 keV:** Mkn 509 (Sy1), NGC 3783 (Sy1), MCG-5-23-16 (Sy1.9, broad FWHM~40,000 km/s), IRAS 13349+2438 (NLSy1), Mrk 205 (QSO), NGC 3516 (Sy1), NGC 5506 (Sy 1.9), NGC 3516 (Sy1), Mrk 359 (NLSy1)

**Multiple narrow lines:** NGC 7314 (Sy1), NGC 7213 (Sy1)
Fe K Gallery

IRAS 13349 - NLSy1 (Longinotti et al. 2003)

MCG-5-23-16 - Sy 1.9 (Dewangan et al. 2003)

NGC 7213 - Sy1 (Bianchi et al. 2003)

NGC 3783 - Sy1 (Blustin et al. 2002)

Mrk 335 - NLSy1 (Gondoin et al. 2002)

MCG-6-30-15 - Sy1 (Fabian & Vaughan 2003)

Mrk 766 - NLSy1 (Pounds et al. 2003)

Mrk 359, NLSy1 (O'brien et al. 2001)

NGC 3516 - Sy1 (Turner et al. 2002)

NGC 3516 - Sy1 (Turner et al. 2002)
He-like Fe Lines in XMM Data

Mkn 205  Reeves et al. 2001

Mkn 205  Fe line Contours

PN+MOS

He-Like Fe

Neutral Fe

Mkn 205

X-ray Flux (cm$^{-2}$ s$^{-1}$ keV$^{-1}$)

NGC 5506

Matt et al. 2001

Pounds et al. 2000

Mkn 509

Hlx (keV cm$^{-2}$ s$^{-1}$)

Rest energy (keV)
NGC 7314: Fe XXV & Fe XXVI narrow, rapidly variable, unresolved lines from an accretion disk

- He-like & H-like lines are redshifted, Fe I K line is not.
- Redshift is ~1500 km/s, greater than systemic and statistical uncertainty.
- Is He-like line f, i, or r? HEG cannot resolve.
- Redshift consistent with H-like line if forbidden.
- Ionization balance varies in less than 13,000 s. Lines from close to source.

Chandra HEG low, mean and high-state spectra

Yaqoob et al. 2003
Narrow Line Seyfert 1 galaxies

More rapid X-ray variability and steeper X-ray spectra than broad line Seyfert 1s.

- Soft excesses - continuum components?
- Little absorption - highly ionized gas
- Fe K lines at higher ionization stages
- Rapid and unusual spectral variability
- Generally - ionized reprocessing
- Fe K absorption features?
- Unusual spectral shapes (high and low states)

Black holes with high accretion rates -> ionized disk plus circumnuclear gas
**Ton S180**  

Strong, broad and smooth soft excess. Continuum reprocessing of X-rays from ionized disk or a blend of lines from ionized disk. $M_{BH} \approx 4 \times 10^7$

Fe $K\alpha$ near 7 keV. Fe XXV-XXVI. Broad, sigma = 0.5 keV with XMM, ionized reflection from an ionized disk w/ an inclination of ~65 degrees.

Featureless soft excess requires a highly ionized disk while Fe K region requires moderate ionization (no ionized Fe K edge).

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**Mrk 766**  
Page et al. 2001, A&A

Broad Fe $K\alpha$ line. Soft excess below 0.7 keV. Medium energy component is more variable than the soft excess.
1H 0707 - 49

Sharp feature at ~7 keV. Seen in other NLSY1s. No narrow Fe Kα line. Neutral absorption (partial covering) or ionized disk reflection?


NGC 4051

Low-flux state

Correlated soft and hard x-ray lightcurves - hard X-rays are not pure reflection.

Uttley et al. astro-ph/0306234
Seyfert 1s, Warm Absorbers

<table>
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<th>Soft X-ray features probe: gas kinematics, excitation mechanisms, gas geometry, temperature, density, transport (inflow/outflow), how BH is fueled</th>
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<td>• Ionized X-ray absorption lines, variable absorption</td>
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<td>• narrow lines but some are resolved, blueshifted</td>
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<td>• UV counterparts in many cases</td>
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<td>• weak emission lines</td>
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<td>• mixture of partially ionized and neutral absorbing gas</td>
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Conclude:

Multiphase warm absorber is an expanding shell of gas with outflow velocities of ~500 km/s and \( N_H \approx \text{few } 10^{21} - 10^{22} \text{ cm}^{-2} \). Radius is greater than a few light days.

Some difficulty connecting x-ray / UV absorbers. NGC 7469: highest ionization phase of x-ray absorber is identified with low-velocity phase of the UV absorber.

Low mass loss compared to the accretion rate. Outflow rates are \(~10^{-5}-10^{-4} \text{ solar masses per year.}\)
Soft X-ray Spectra:

MCG-6-30-15; Chandra, Lee et al. 2001

Markarian 509; Chandra; Yaqoob et al. 2003

NGC 5548; Chandra Kaastra et al. 2000, A&A

IRAS 13349; XMM Boller et al. 2003, MNRAS
NGC 4593


Velocity profiles

Chandra MEG photon spectrum

He-like Ne and O triplets
NGC 4151 - Extended X-rays


Optical

X-ray

Chandra HEG & MEG spectra.

70% of soft X-ray emission is resolved.

800 pc

Chandra contours overlaid on HST [O III] 5007 image.

Spectrum dominated by narrow lines from a spatially resolved (1.6 kpc), highly ionized nebula.

X-ray lines have similar velocities, widths, and spatial extent to the optical lines.

The X-ray NLR is composite, consisting of photoionized (T = 3 \times 10^4 K) and collisionally ionized (T = 10^7 K) components.
Seyfert 2 Galaxies

Absorption: low ionization absorption through edge of torus or circumnuclear starburst, up to a fully blocked nucleus ($N_H \sim 10^{24} \text{ cm}^{-2}$)

Extended x-ray emission - photoionization - consistent with size of scattering mirror and optical NLR. Size tens of pc to kpc. $N_H \sim 10^{21}$-$10^{22} \text{ cm}^{-2}$

AGN-driven outflows hundreds of pc across. Clouds may be shock-heated by the nuclear outflow. Velocities are hundreds of km/s

Fe K lines from torus, scattering zone - some show extended Fe K emission. Fe K line EWs up to several keV

Hard x-ray spectra dominated by reflection for $N_H > 10^{24} \text{ cm}^{-2}$

Properties tend to be consistent with unified model, but starbursts have introduced a new wrinkle!
Chandra image of the galaxy center superposed on VLA 6 cm radio contours.

Chandra contours on optical continuum image. Cross marks the position of the radio source.

X-ray emission extends 5” (550 pc) to the NE and coincides with the NE radio lobe and gas in the NLR.

Spectrum is photoionization and fluorescence.

Hard X-ray emission (+ Fe K) extends 20” (2.2 kpc) NE and SW of the nucleus.
Markarian 3


- Hard X-rays - reflection in a cold medium.
- Spectral properties consistent with a Seyfert 1 galaxy viewed edge on.
NGC 5135 - Cohabitation of an AGN and Starburst
Levenson, Weaver & Heckman 2003

- Both the AGN and starburst contribute significantly to the x-ray emission.
- AGN obscured by $N_H > 10^{24} \text{ cm}^{-2}$, much of it due to the starburst
- Below 10 keV nearly all of the emergent luminosity is due to SF, not the AGN
QSOs - Classic

Broad absorption line quasars - ionized, relativistic broad x-ray lines

Intrinsic absorption - do not always see this in spite of earlier claims

Evolution of spectral shapes - stats still accumulating

Fe K lines - 6.4 keV lines tend to be weak features: PKS 0537-286 has Fe K with EW of ~33 eV; upper limits in some other cases. Also ionized lines (Mrk 205)

Quasar 2s - reflection-dominated x-ray spectra with large EW Fe K lines

Search for absorption from the IGM - mostly upper limits so far
Absorption in the BAL QSO APM 08279

Chartas et al. 2002 - Chandra

Chandra lines at 8.1 and 9.8 keV (rest frame). Bulk velocities of x-ray BALs are ~0.2c and ~0.4c

Hasinger et al. 2002 - XMM

XMM line at ~7.6 keV. Inferred column density of $N_H \sim 10^{23} \text{ cm}^{-2}$
Survey of RQ high-z quasars


Detected 16/17 radio-quiet quasars
Redshifts between 3.70 and 6.28
More x-ray quiet than low-redshift quasars
Spectral index flatter than low-redshift quasars
Derive black hole mass of $\sim 10^{10}$ solar masses
Quasar jets / Radio Galaxies

Knots and hot spots in radio jets - synchrotron, thermal, synchrotron self-Compton (SSC) emission, or IC scatt.

SSC: Cygnus A and 3C 295; IC scattering of CMB photons - 3C 273; synchrotron - M87

Centaurus A - x-ray and radio knots offset from each other - (Kraft et al. 2002)

M87 - synchrotron radiation (Wilson & Yang 2002)

**3c 295** - SSC model preferred (Harris et al. 2000)

**Cygnus A** - radio hot spots detected in x-rays; SSC models (Wilson et al. 2000)

**PKS 1127-145** - 330 kpc (Siemiginowska et al. 2002)

**PKS 0637** - kpc sized jet similar to radio jet (Chartas et al. 2000)

**3C 273** - IC scattering of CMB (Sambruna et al. 2001)

**Pictor A** - morphology of western hot spot similar to radio and optical (Wilson et al. 2001)
Surveys of radio jets / radio galaxies

Sambruna et al. 2002

Worrall et al. 2001

X-ray emission from extragalactic jets is common

Generally, IC of CMB photons

X-ray jets are common in low power radio galaxies
BL Lacs

- Strong x-ray variability
- Smooth, featureless spectra
- Lack of x-ray spectral features?
- High polarization
- Relativistically beamed jet close to the line of sight
- Unified schemes - parent population thought to be FR 1 radio sources
- LBLs and HBLs - single population?
MS 0737+7441
Boller et al. 2001, A&A
Simple power law, $\Gamma = 2.3$

PKS 2155-304

Detect resonant absorption from warm/hot gas in our Galaxy or the local IGM. Unresolved O VII $K\alpha$ and Ne IX $K\alpha$. 

XMM light curves

Strongest variability in the hardest bands


Previous claims for lags may be due to satellite orbital interruptions

Limit to magnetic field strength: $B^{1/3} \gtrsim 2.5 \text{ G}$

CCFs for bands H/S (top) and VH/VS (bottom)

Mrk 421: Sembay et al. 2002
Diffuse x-ray emission consistent with elliptical galaxies

Support models for radio-loud AGN, unifying BL Lacs and FR1 radio galaxies - these are the galaxies associated with the edge-on jet.
ULIRGs and AGN

NGC 6240 (Ptak et al. 2003)

Mrk 273 (Xia et al. 2002)

Mrk 231 (Braito et al. 2003) FeK EW~300 eV

IRAS 19254-7245 (Braito et al. 2003)
Low luminosity AGN are more common than originally thought. It’s easier to find them in x-ray than in optical surveys.


62% of nearby galaxies have compact x-ray nuclear source

Large fraction of LLAGNs are radio loud
**NGC 4303**

Jimenez-Bailon et al. 2003

**Nuclear ULXs?**

**NGC 253**

Super starcluster and LLAGN or ULX at the galaxy core, $L_x \sim 1 \times 10^{39}$ erg/s

Core spectrum

L~$10^{39}$ erg/s photoionizing

ULX or LLAGN

Core spectrum

Weaver et al. 2002
Summary

- Fe K lines of all types. Many possibilities for diagnostics, including accretion disks. Fe K emission from NLR, BLR, torus is common.
- NLSY1s - high accretion rates, ionized disks
- Multiphase warm absorber is an expanding shell of gas with outflow velocities of ~500 km/s and $N_H \sim \text{few } 10^{21}-10^{22} \text{ cm}^{-2}$
- Extended x-ray emission in Seyferts dominated by photoionization
- Relativistic outflows in BAL QSOs
- Still trying to reconcile UV and x-ray absorbers in AGN
- Observations support models unifying BL Lacs and FR1 radio gals.
- Extragalactic x-ray jets are common, multiple mechanisms for x-rays
- Starbursts can obscure central AGN - making Sy 1s into Sy 2s?
- LLAGN are more common than previously thought. “Nuclear ULXs”?
- AGN are significant in at least some ULIRGs