

# Probing Active Galactic Nuclei with the Iron Line

by Michael McElwain

Physics 269B: Active Galactic Nuclei – Current Understanding and  
Research

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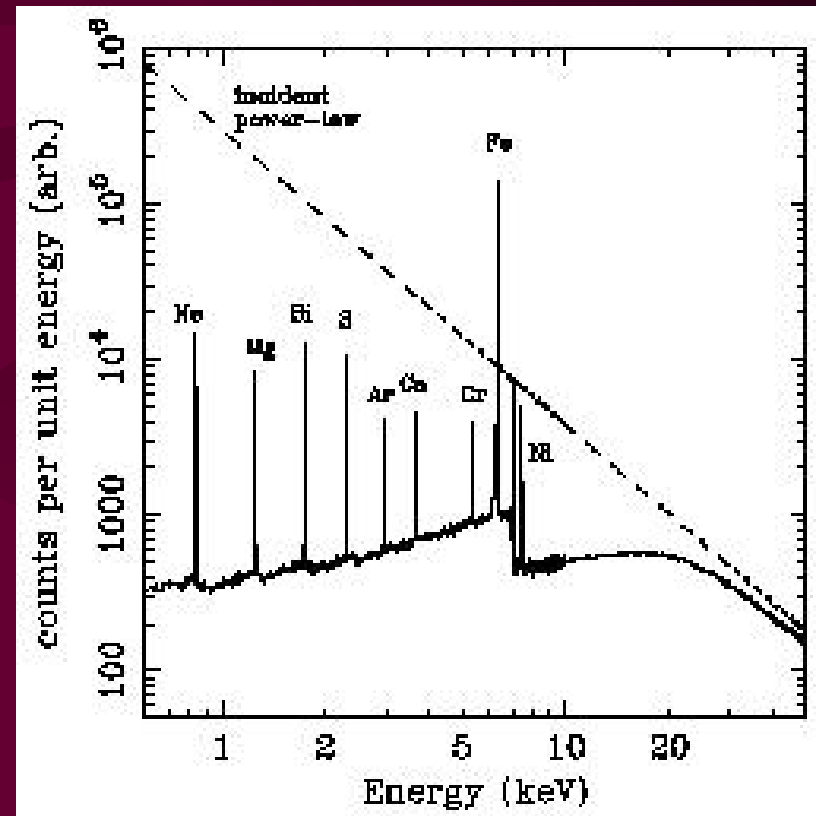
# Overview

- Iron line production in AGN
- Iron line profile
- AGN structure
- Observations
- Variability
- Reverberation mapping
- Conclusion



# X-ray reflection from an illuminated slab

- Fluorescent  $K\alpha$  emission is present in the most abundant metals.
- Fe absorption edge
- A significant amount of energy is Compton scattered to hard X-rays, producing the Compton reflection “hump.”



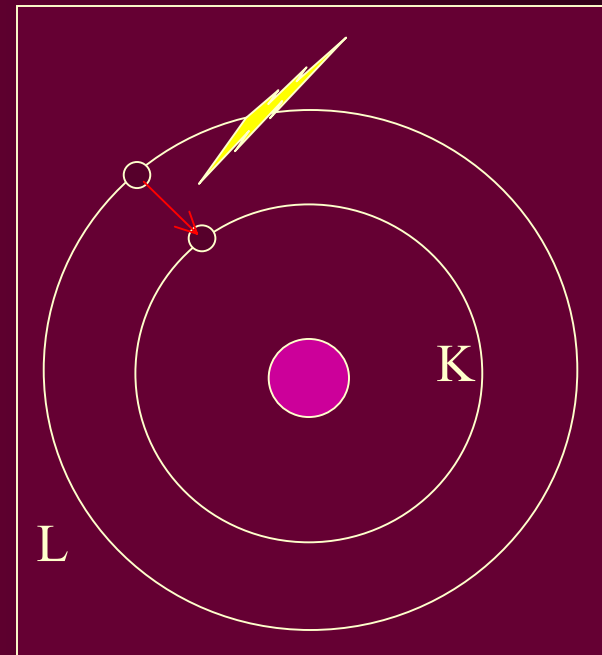
# Iron line production in AGN

## Neutral Iron

- K shell electron absorbs a  $> 7.1$  keV X-ray.
- An electron drops from the L shell to the K shell emitting a 6.4eV photon that leaves the atom (33% probable), or is re-absorbed by an electron in an outer shell and ejected later (66% probable). This reabsorption before ionization is called the Auger effect.

## Highly Ionized Iron

- Less photons will be absorbed by outer shell electrons, therefore reducing the Auger effect. The fluorescent yield is high, meaning that radiation is absorbed at one wavelength and almost immediately re-radiated at a different wavelength.



Schurch, presentation

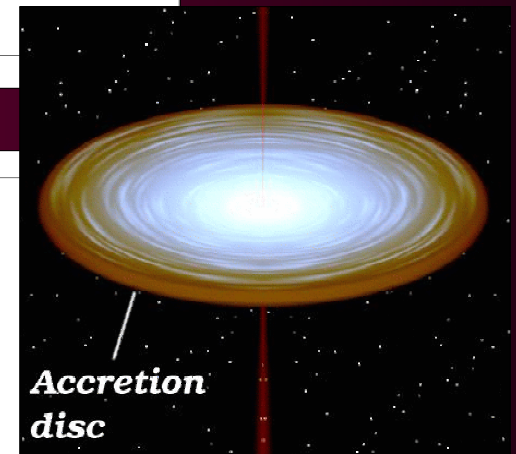
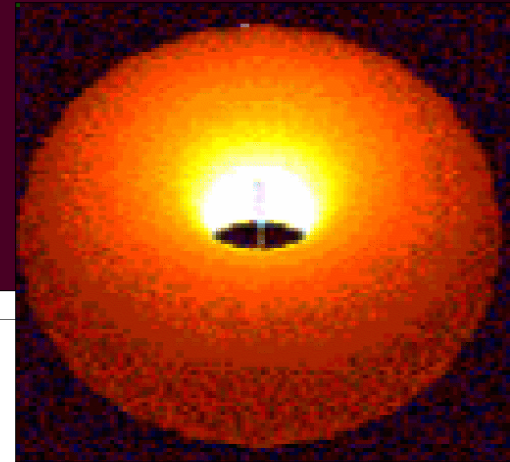
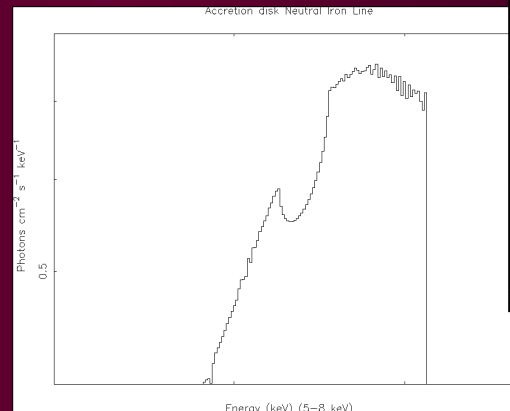
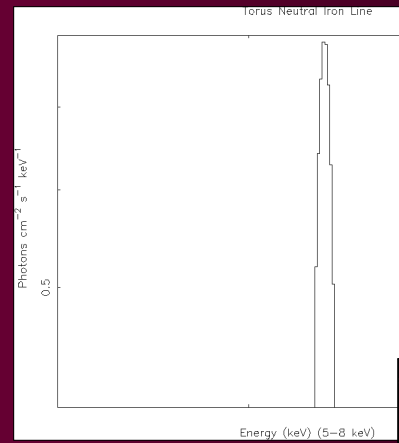
# Iron line details

- The observed equivalent width is usually 50-300 eV.
- Large FWHM velocities, as high as 100,000 km/s in MCG --6-30-15.
- The equivalent width decreases as the inclination increases, due to extra absorption and scattering. This means that Seyfert 1 galaxies have the strongest Fe lines.
- \*\*The strength of the broad iron line depends on:
  1. The accretion disk structure.
  2. The relative abundances of elements in the accretion disk.
  3. The inclination angle of the accretion disk.
  4. The ionization state in the outer layers of the accretion disk.

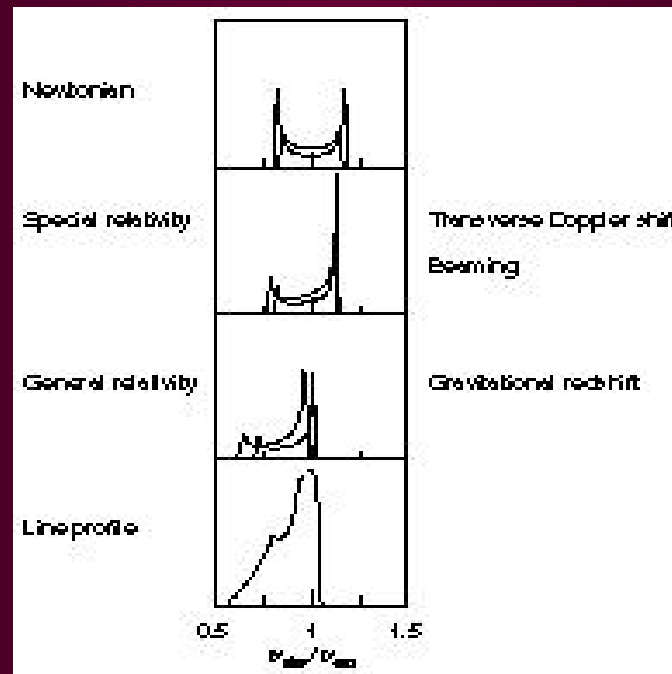
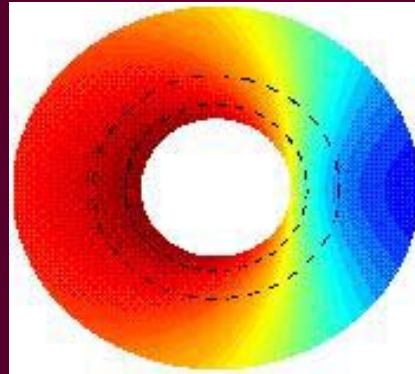
# Iron line profile

- The iron line originates in the inner accretion disk, the standard unification model hypothesized molecular torus, and intermediate regions.
- Lines created in different locations of the surrounding material have different line profiles.

Schurch, presentation



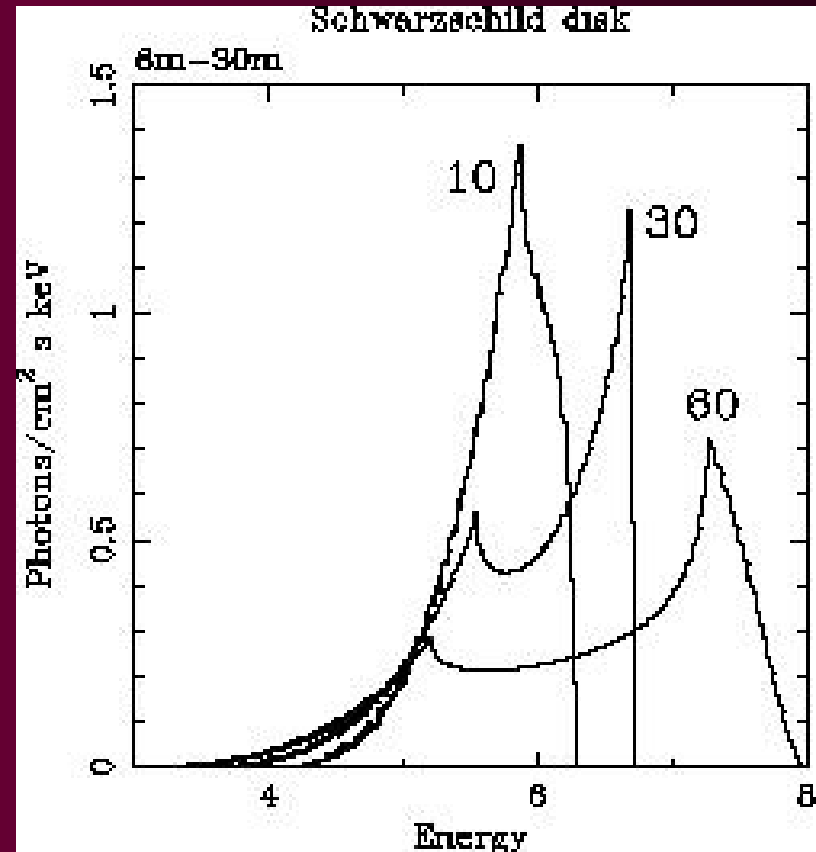
# Iron line profiles from an accretion disk model



Fabian, 2000

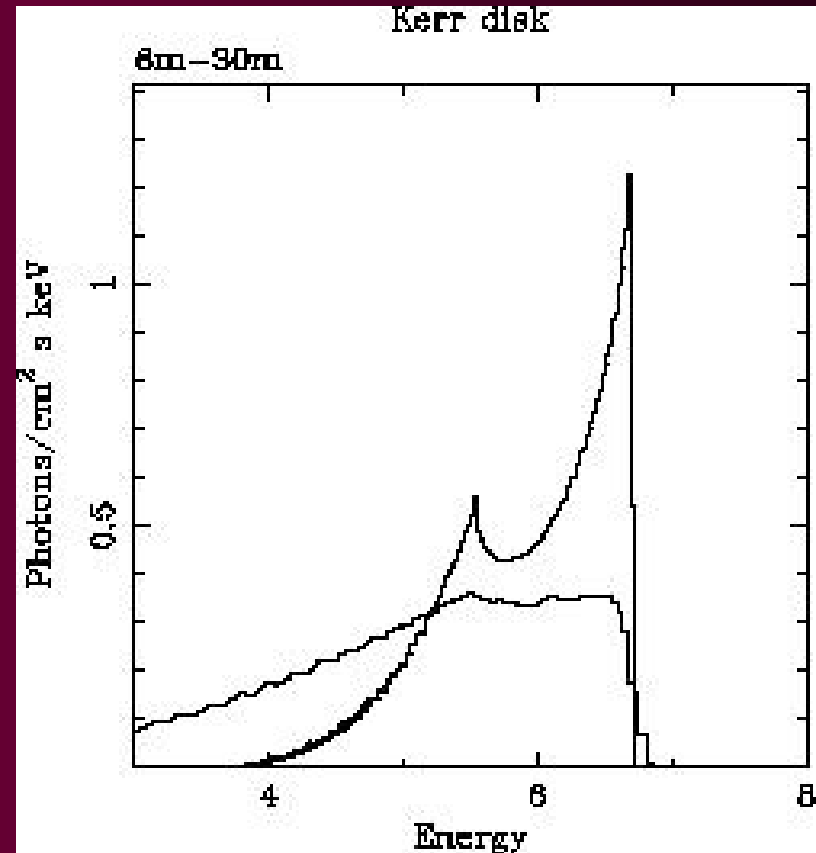
# Schwarzschild disk iron line profile model

- Iron line profiles emitted from the accretion disk surrounding a Schwarzschild black hole. The beaming is a function of inclination, meaning that blue-shifting will increase as the inclination increases. Offsetting this effect will be the additional absorption and scattering by the molecular torus.
- The red-shifted side of the line profile is strongly dependent on the inner radius of marginal stability.



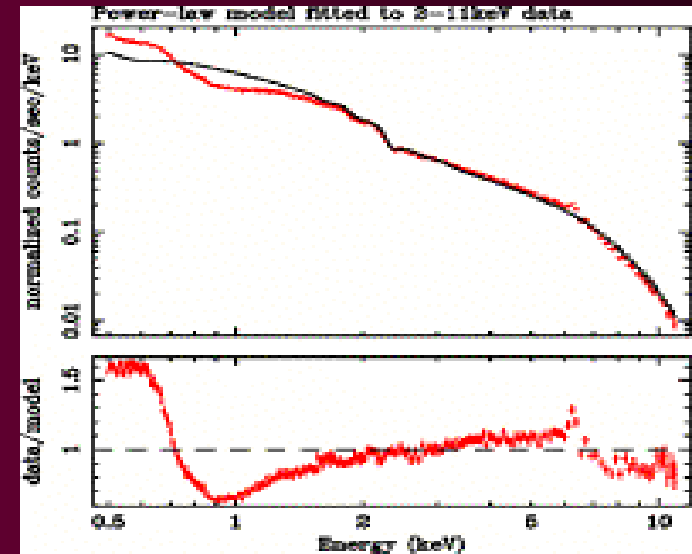
# Kerr disk iron line profile model

- Since the red-shifted side of the line profile is strongly dependent on the inner radius of marginal stability, it should be no surprise that the iron line profile around a Kerr black hole is wider due to additional gravitational red-shifting.



# Technique used to extract the iron line profile

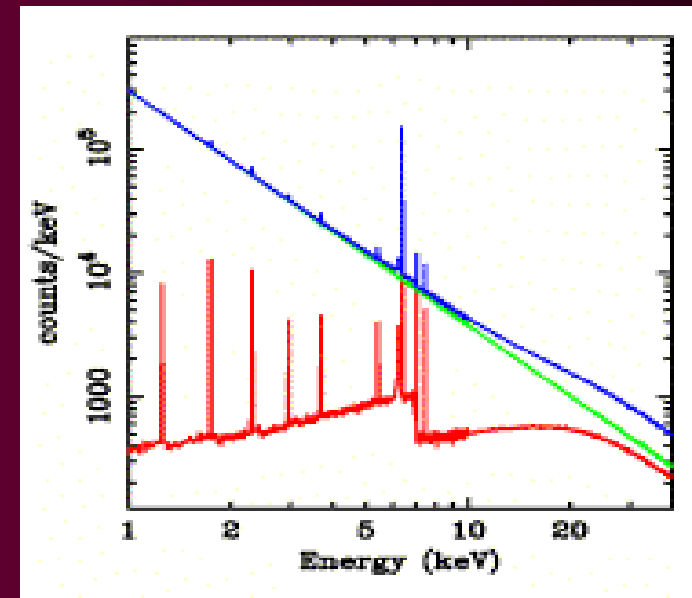
- XMM-Epic observations of MCG 6-30-15, showing the spectral energy distribution in the upper panel. The lower panel shows the residuals after the modeled X-ray continuum is subtracted. Obviously, errors occur when trying to model the X-ray continuum.



Continuum components:

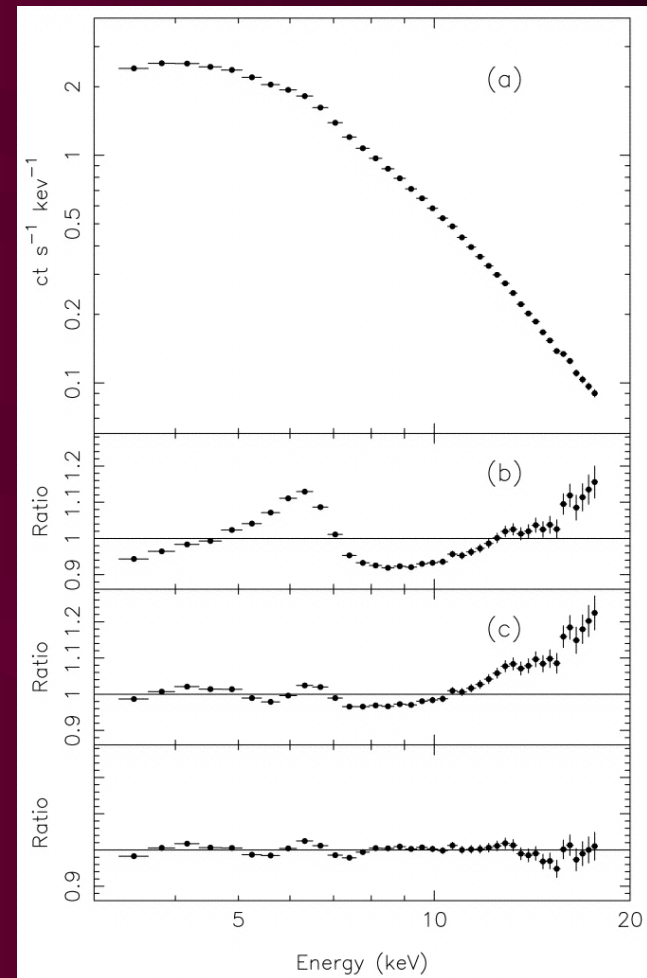
1. X-ray power law
2. Broad emission lines (Fe  $K\alpha$ )
3. Inverse compton reflection
4. Warm absorbers surrounding the AGN
5. Galactic neutral cold absorption

Reynolds, presentation



# Technique used to extract the iron line profile: 2

- RXTE spectrum of MCG - 6-30-15. Panel *a* shows the count spectrum. Panel *b* employs a power-law to model the spectrum. Panel *c* employs a power law and broad Gaussian line. Panel *d* employs a power-law, Gaussian line, and reflection component, which appears to be a pretty good fit.



Vaughan & Edelson, 2000

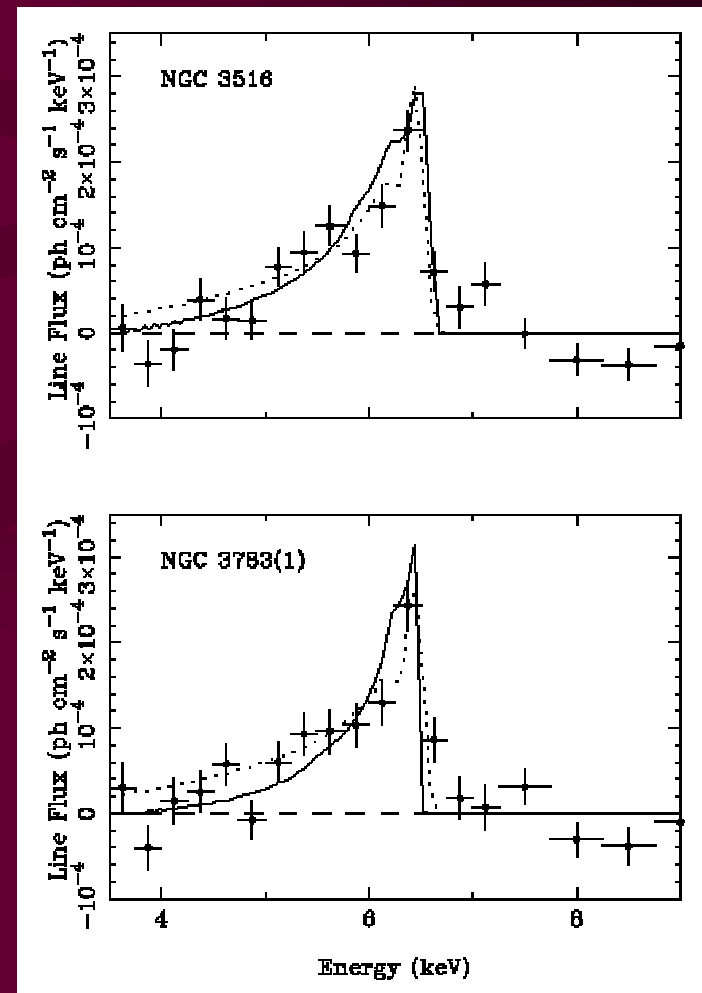
# Sample ASCA spectra

Nandra et al presented a paper of 18 Seyfert 1 galaxy spectra, of which they fit the Fe  $K\alpha$  lines to Schwarzschild and Kerr black holes. They determined a 30o mean inclination for their sample, thus confirming the unification scheme for Seyfert galaxies.

Some AGN with high S/N

- MCG-6-30-15(Tanaka et al. 1995)
  - might be an oddity because it is a rather small black hole that appears to be spinning quickly.
- NGC 3516 (Nandra et al. 1999)
- NGC 4151 (Wang et al. 1999)

Nandra, 1997



# Previous instruments

## Ginga satellite

- Operated from 1987 to 1991.
- Sensitive to energies from 1-500 keV
- First instrument to discover the 6-7 keV iron line around an AGN.



## The Advanced Satellite for Cosmology and Astrophysics (ASCA)

- Operated from 1993 to 2001.
- Sensitive to energies from .04-10 keV
- Provided good resolution to probe the broad iron line around AGNs.



NASA website

# Current instruments

## Rossi X-ray Timing Explorer (RXTE)

- Operated from 1995 to ???.
- Sensitive to energies from 2-250 keV
- Main purpose is to measure X-ray variability, with moderate spectral resolution. Used by Edelson and Markowitz to measure iron line variability.



## Chandra X-ray Observatory

- Operated from 1999 to ???.
- Sensitive to energies from 0.1-10 keV
- High resolution, can separate narrow and broad Fe lines.



## X-Ray Multi Mirror Mission (XMM-Newton)

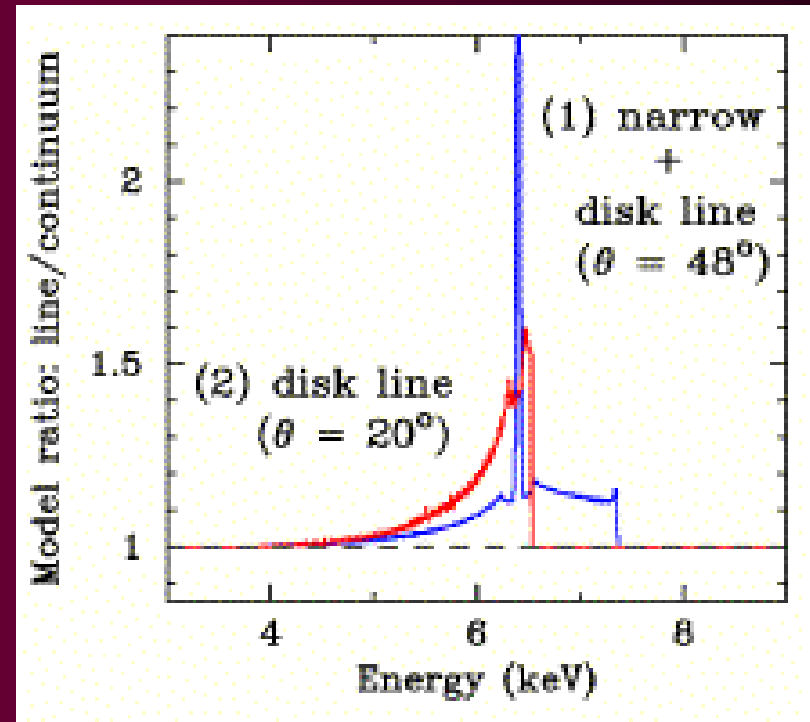
- Operated from 1999 to ???.
- Sensitive to energies from 0.1-15 keV
- Simultaneous X-ray and Optical Images



NASA website

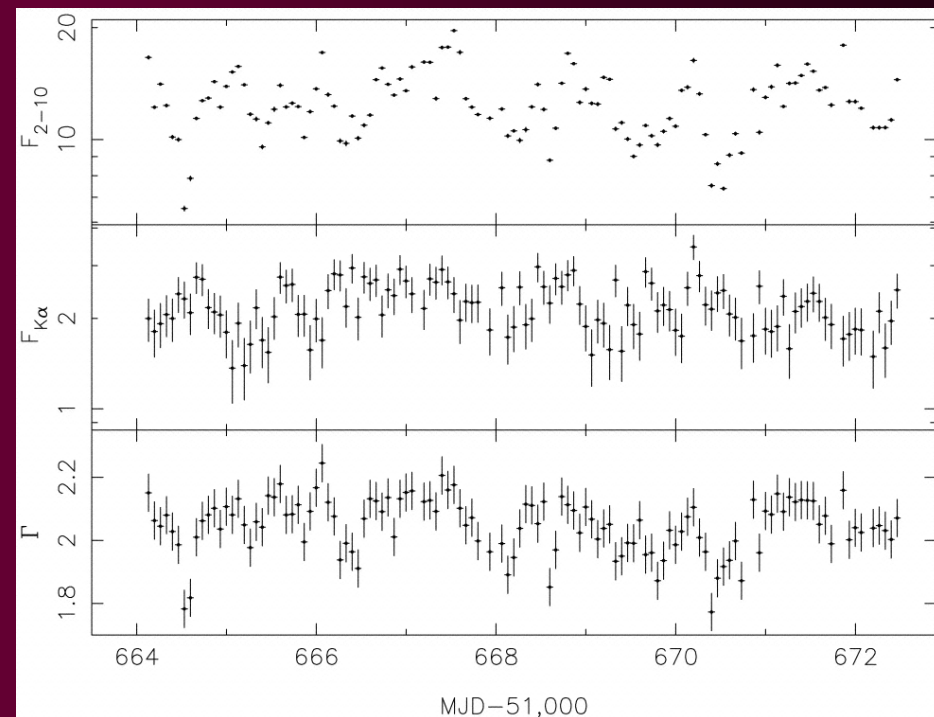
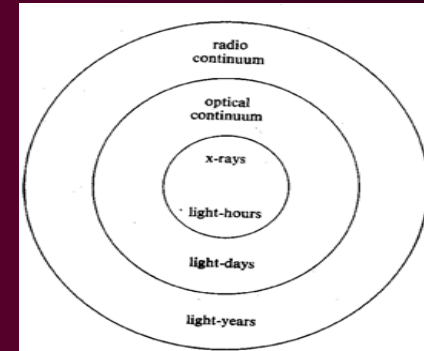
# Identifying the narrow and broad iron lines

- The inclination of the accretion disk will be inaccurately calculated if the narrow line is not subtracted from the broad line.
- Chandra can resolve the two components, providing a contemporary solution to this problem.



# AGN Variability –Seth Hornstein (in progress)

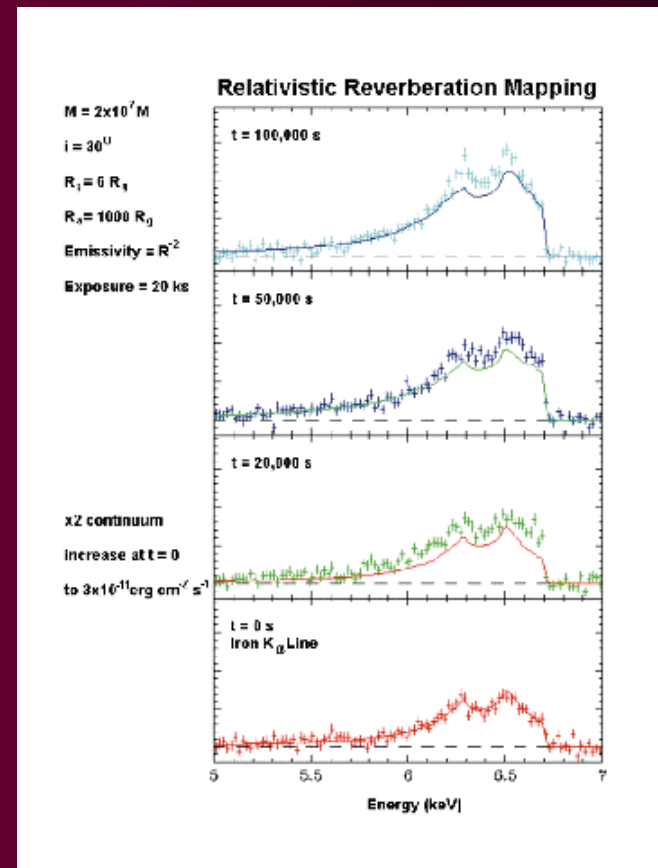
- Using RXTE, Vaughan & Edelson did a recent study of Fe K $\alpha$  variability in MCG –6-30-15, finding that the line flux does vary on short timescales ( $< 1$  day). This confirms that the iron line originates close to the black hole; however, the variation does not correlate with continuum. The continuum flux directly affects the ionization instabilities within the disk, which affect the Fe K $\alpha$  line. This may account for the unexpected lag in variability correlation.
- The problem with RXTE is that the spectral resolution is inadequate to make arguments about the shape of the Fe K $\alpha$  line.



Vaughan & Edelson, 2000

# Reverberation mapping (Erin Hicks, in progress)

- In reverberation, a change in the continuum will be echoed throughout the disk, therefore changing the Fe  $K\alpha$  line profile.
- Constellation X will have the throughput and resolution to map Fe  $K\alpha$  line reverberation. The projected launch date is  $\sim$  2010.



## Iron lines in other sources

- The strength of the iron line decreases as the luminosity increases to even higher luminosities (Quasars), most likely due to the increased ionization of the accretion disk.
- LLAGN are difficult to study because they have a significantly smaller X-ray luminosity.

# Conclusions

- Fe  $K\alpha$  lines probe the innermost regions of AGNs
- Used to investigate the accretion disk structure
  - Tells us about black hole mass
  - Black hole spin
  - Inclination of the accretion disk
  - Ionization state of the accretion disk
  - Elemental abundances within the accretion disk
- Variability and reverberation mapping will be used to further constrain AGN models

# References

**PAPERS // Can give full citations upon request**

**Fabian et al. 2000**

**Nandra et al. 1997**

**Reynolds 2000**

**Tananka et al. 1995**

**Vaughan & Edelson 2001**

**Weaver et al. 2001**

## **TELESCOPES**

GINGA, <http://heasarc.gsfc.nasa.gov/docs/ginga/ginga.html>

ASCA, <http://heasarc.gsfc.nasa.gov/docs/asca/asca.html>

ROSAT, <http://heasarc.gsfc.nasa.gov/docs/rosat/rosat.html>

RXTE, <http://heasarc.gsfc.nasa.gov/docs/xte/rxte.html>

CONSTELLATION-X, <http://constellation.gsfc.nasa.gov/docs/science/summary.html>

## **PRESENTATIONS**

**Aretxaga, 26<sup>th</sup> International School for Young Astronomers Conference**

**Constellation X, Project science update**

**Schurch, Leicester University Journal Club**