Probing Relativistic Astrophysics Around SMBHs : The Suzaku AGN Spin Survey

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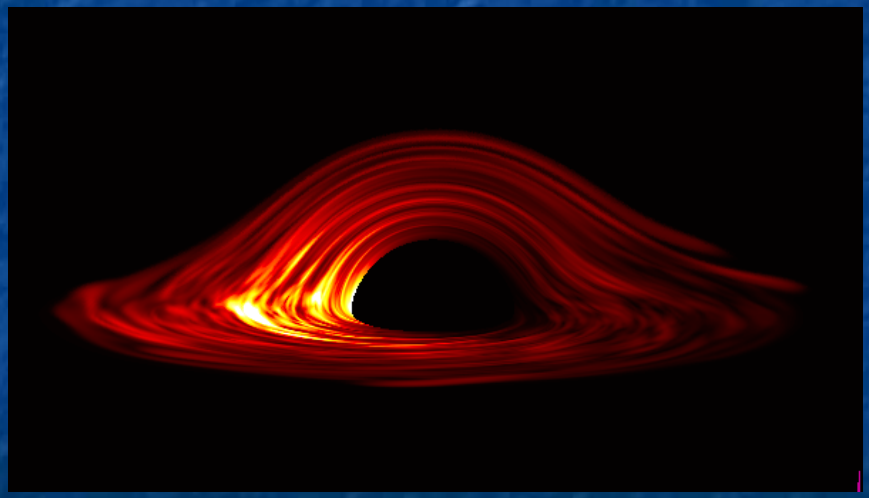
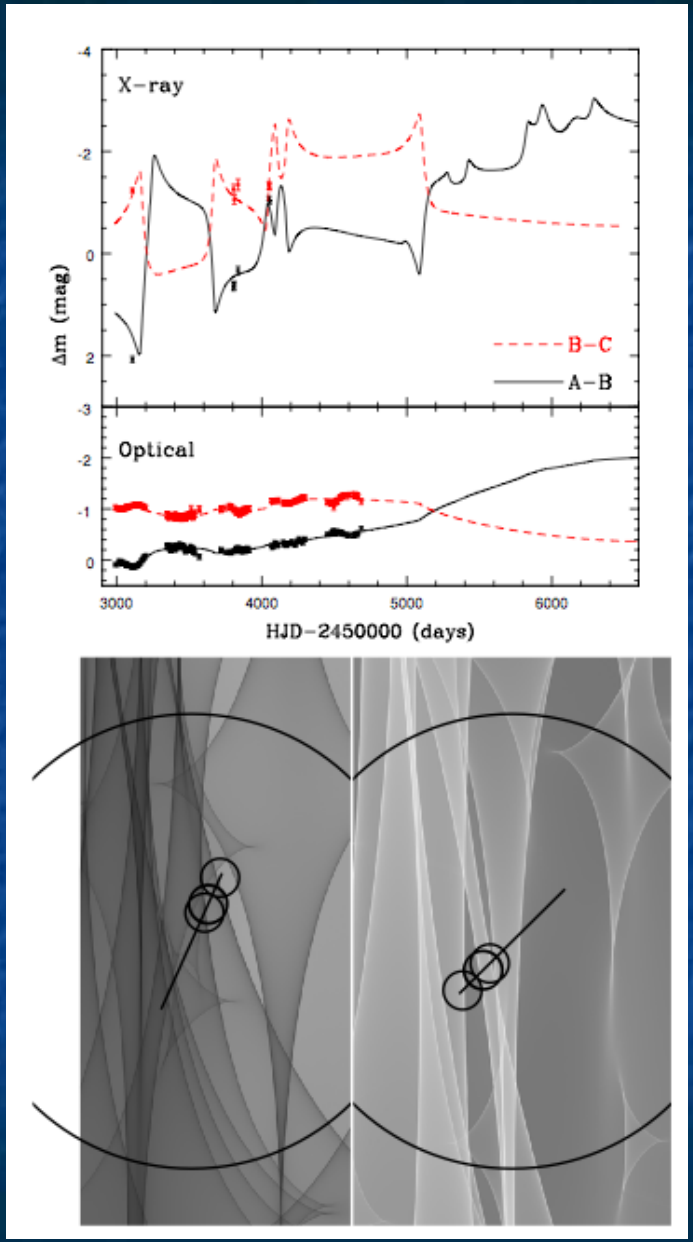


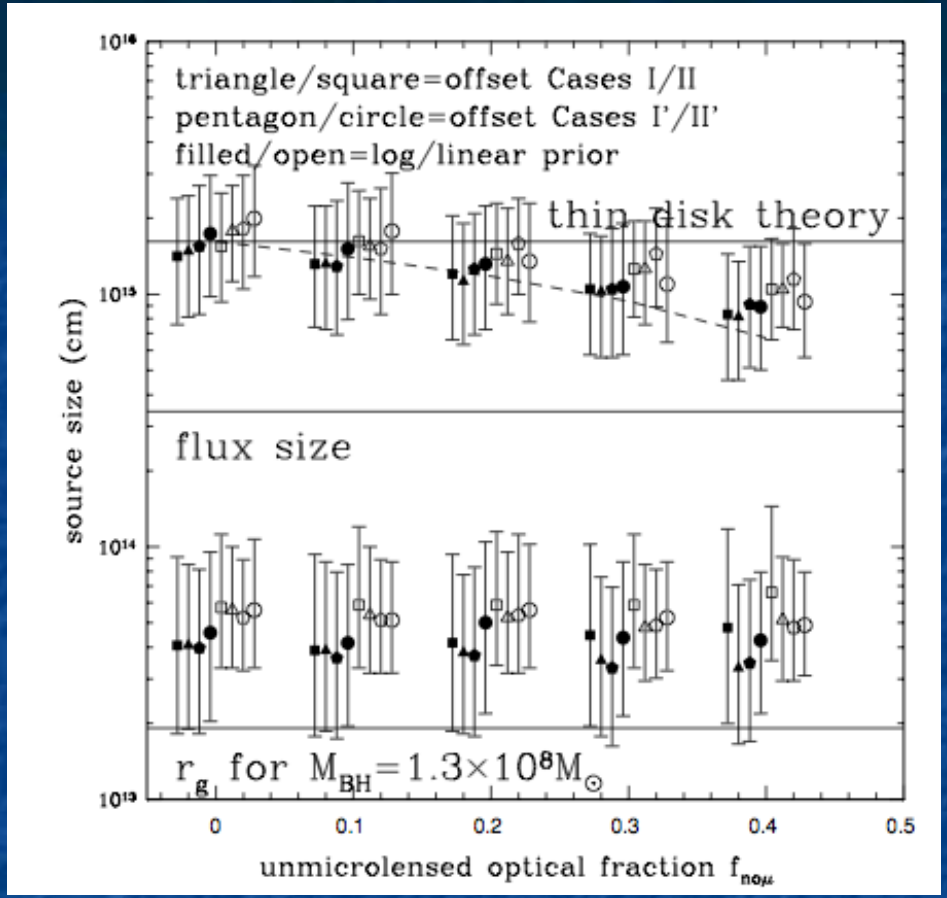
The Key Project Team

- Chris Reynolds (PI)
- Laura Brenneman
- Andrew Fabian
- Kazushi Iwasawa
- Julia Lee
- Anne Lohfink
- Jon Miller
- Richard Mushotzky
- Kirpal Nandra
- Mike Nowak
- Rubens Reis
- Margaret Trippe
- Marta Volonteri

I : Introduction

- **Black hole accretion** paradigm for AGN has very solid foundation in physics, underpinned by plethora of observations and theory
- We know that...
  - Black holes grew in radiative-efficient mode (Soltan, Davis+Laor)
  - Efficient accretion proceeds via a thin accretion disk
  - Most of the gravitational potential energy of accretion flow is released very close to black hole ($\Phi \sim -GM/r$)
  - Significant fraction of energy emitted in "hard X-ray tail"... cannot be the accretion disk proper and, instead, must be corona/jet
  - In type-1 objects, we can see down to the inner disk (X-ray variability, optical/UV spectrum, microlensing)
- **Presence of X-ray reflection/irradiation features from the disk is a completely natural consequence of the basic AGN paradigm**

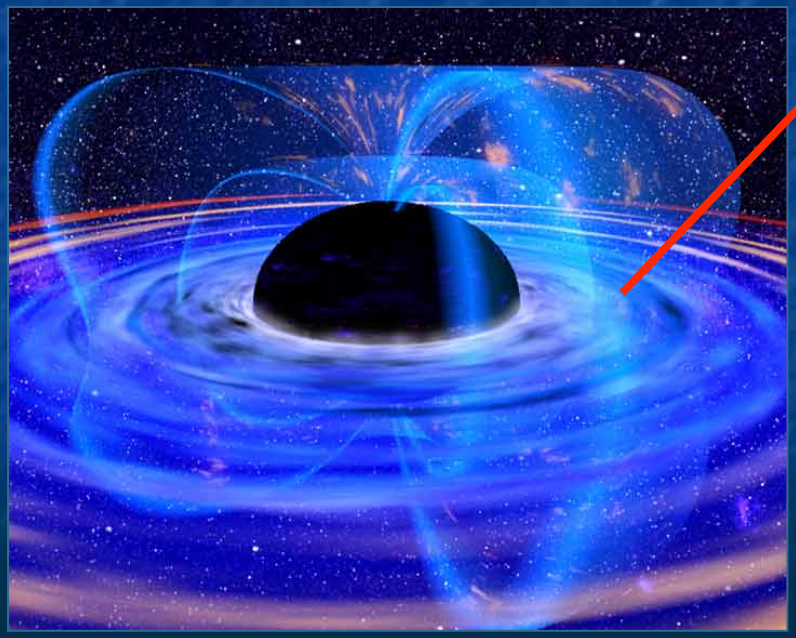


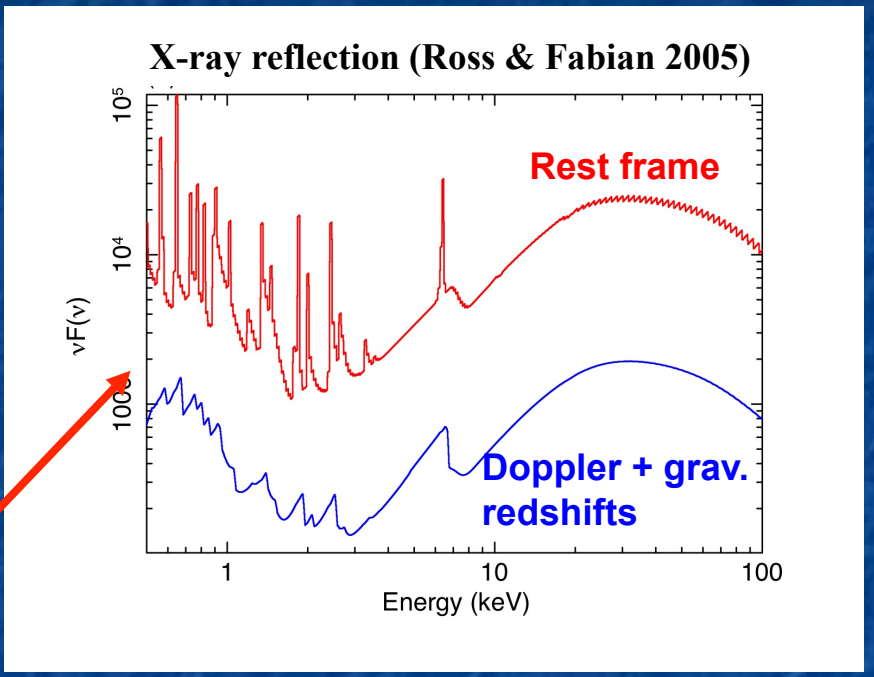


Microlensing in QSO RXJ1131-1231
Dai et al. (2010)

X-ray reflection spectroscopy and black hole spin

Probe the physics of the inner disk and the spin of the black hole using relativistically blurred spectral features (most importantly, broad iron line)

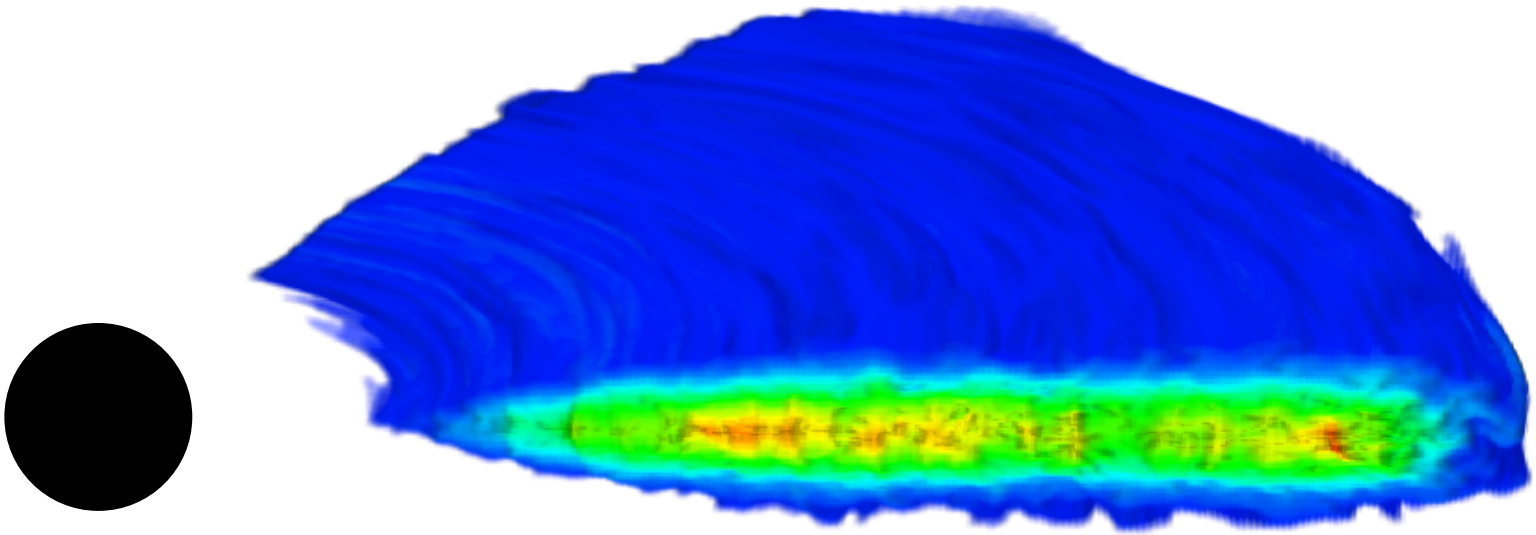




Sensitivity to black hole spin…

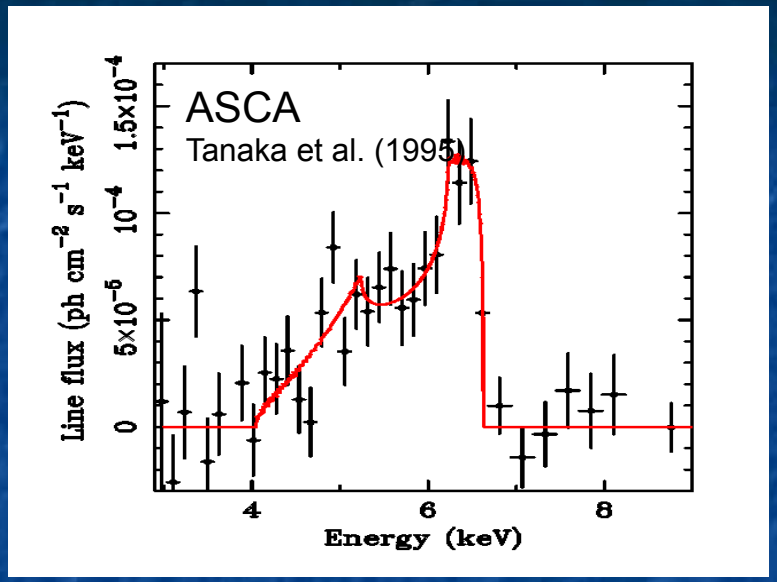
- Radiatively-efficient accretion disk will produce reflection features down to the innermost stable circular orbit (ISCO)
- ISCO decreases with increasing (prograde) spin… thus characteristic gravitational redshift increases

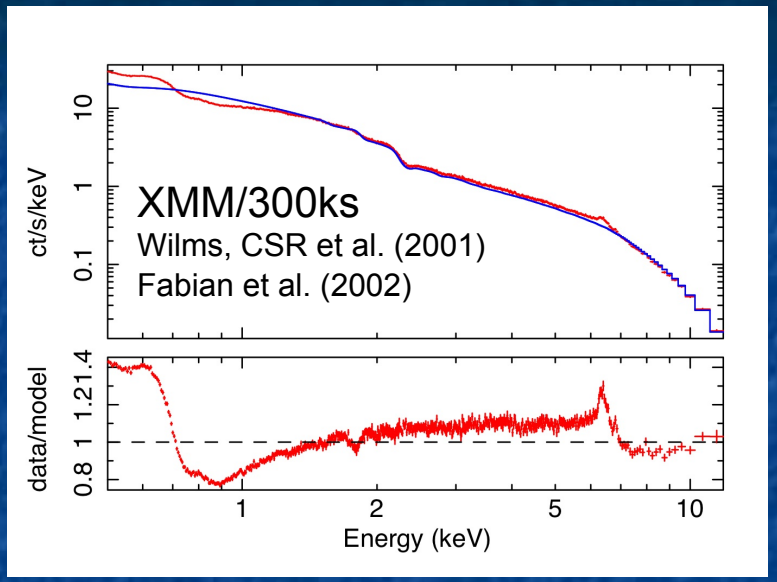
3-D MHD simulation of thin disk (pseudo-Newtonian potential)

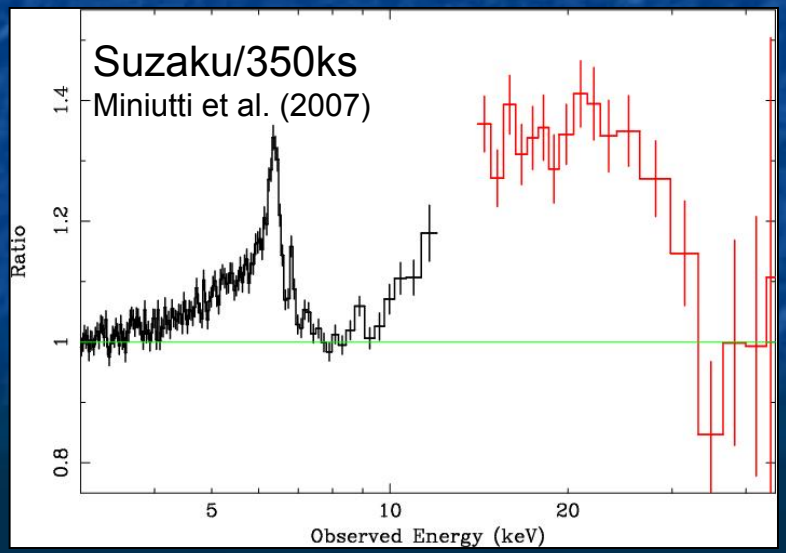


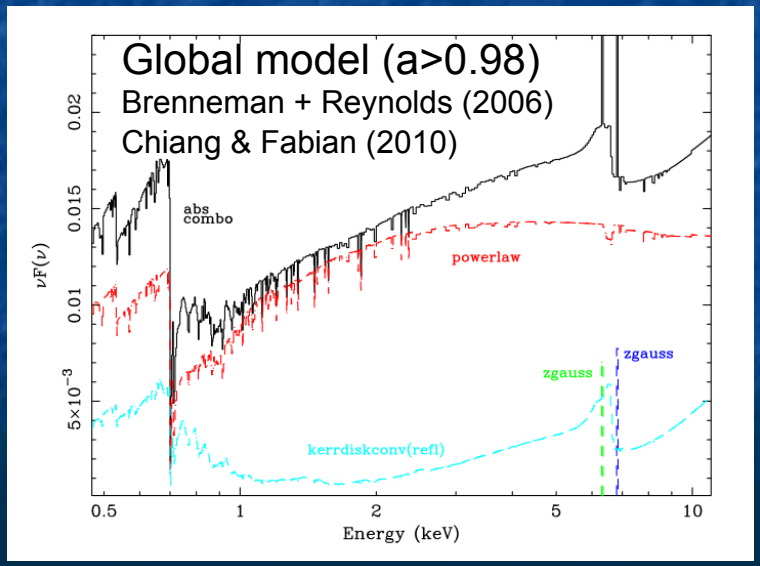
Run MHD3d_2hr
Reynolds & Miller (2008)
Reynolds & Fabian (2008)

The Seyfert galaxy MCG-6-30-15





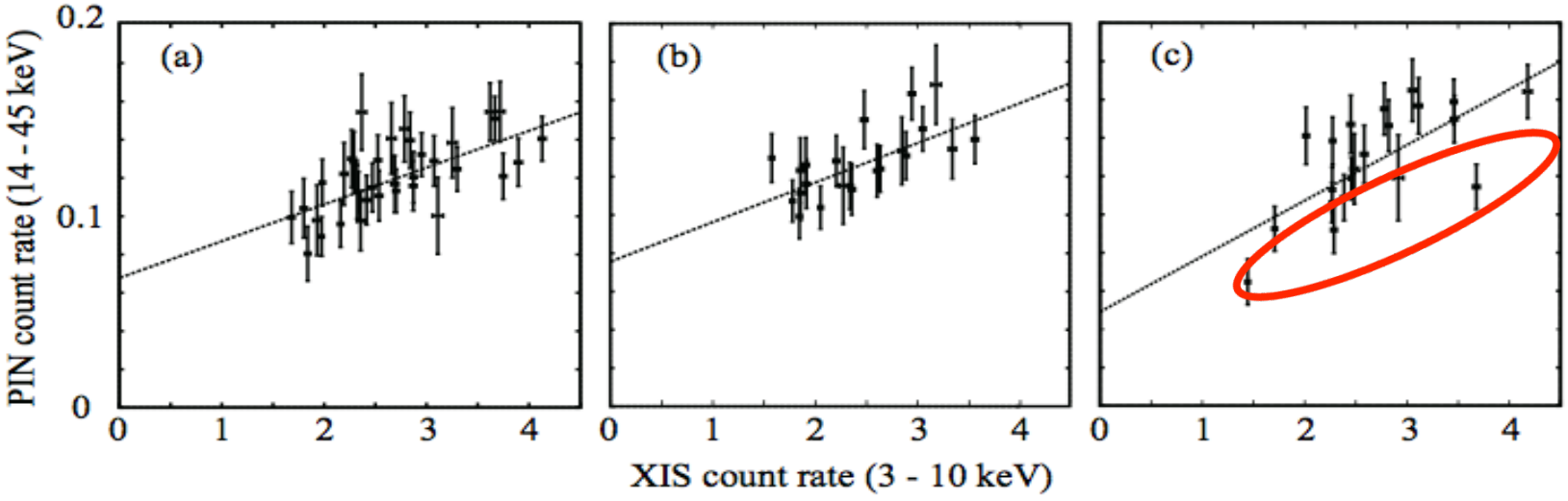


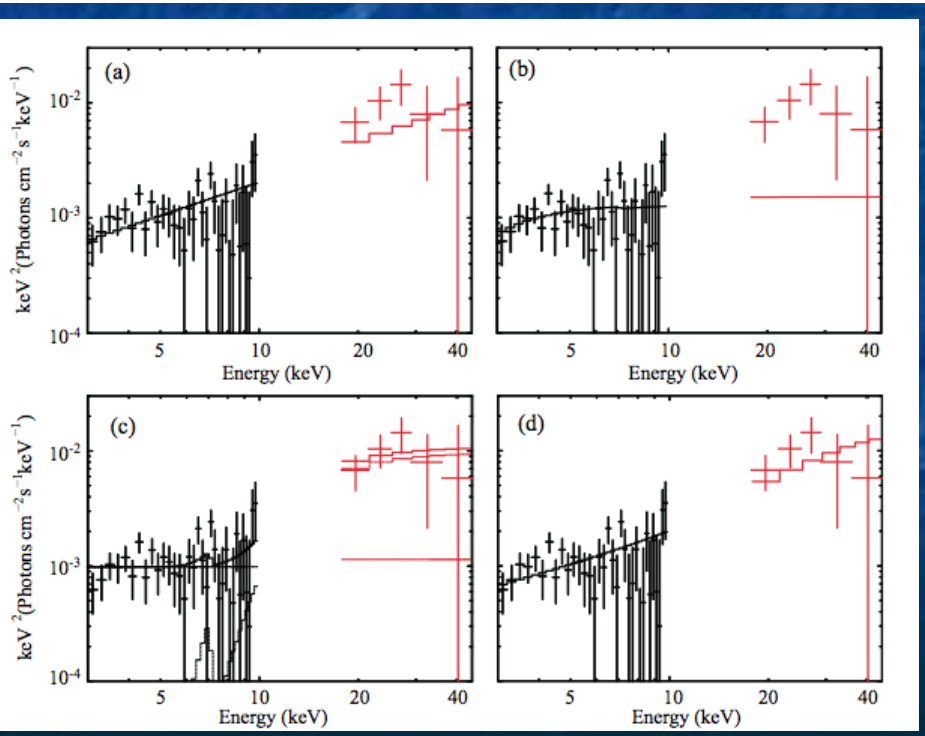


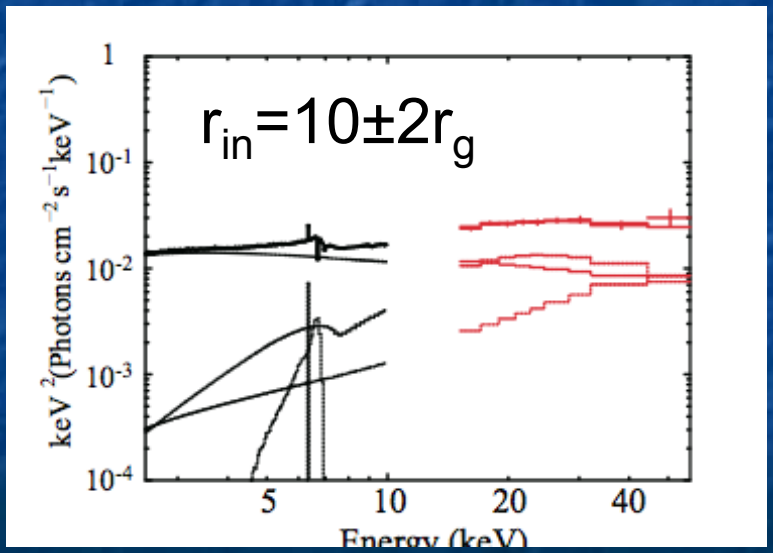
II : Suzaku AGN Spin Survey

- Prior to Suzaku Cycle-4 (2008)…
  - Broad iron lines seen in 30—50% of Seyfert 1 nuclei (Nandra 2007)
  - Spin constraints in only one AGN (MCG-6-30-15; a>0.98)
  - Has been suggested that MCG-6-30-15 had spectral pathologies (multiple partial covering WAs?; Miller et al. 2007, Noda et al. 2011)

- Goal of Suzaku AGN Spin Survey (Cycle 4—6 Key Project)
  - Obtain high S/N spectra of 5 local AGN with known broad iron lines; NGC3783, NGC3516, FairaII 9, 3C120, Mrk841 (1.3Ms total)
  - Measure black hole spins… attempt first look at spin distribution
  - Probe physics of inner accretion disk (ionization, emissivity profile)
  - Legacy datasets for the AGN community (useful for all aspects of AGN physics; absorbers, continuum variability etc.)
  - Currently have three datasets in hand; two more this coming Cycle

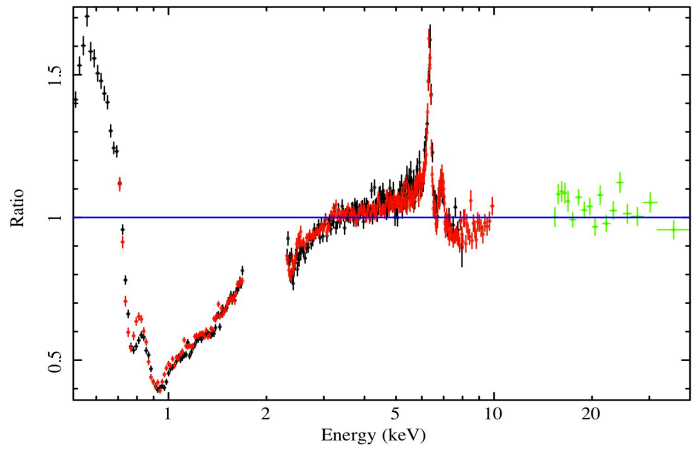




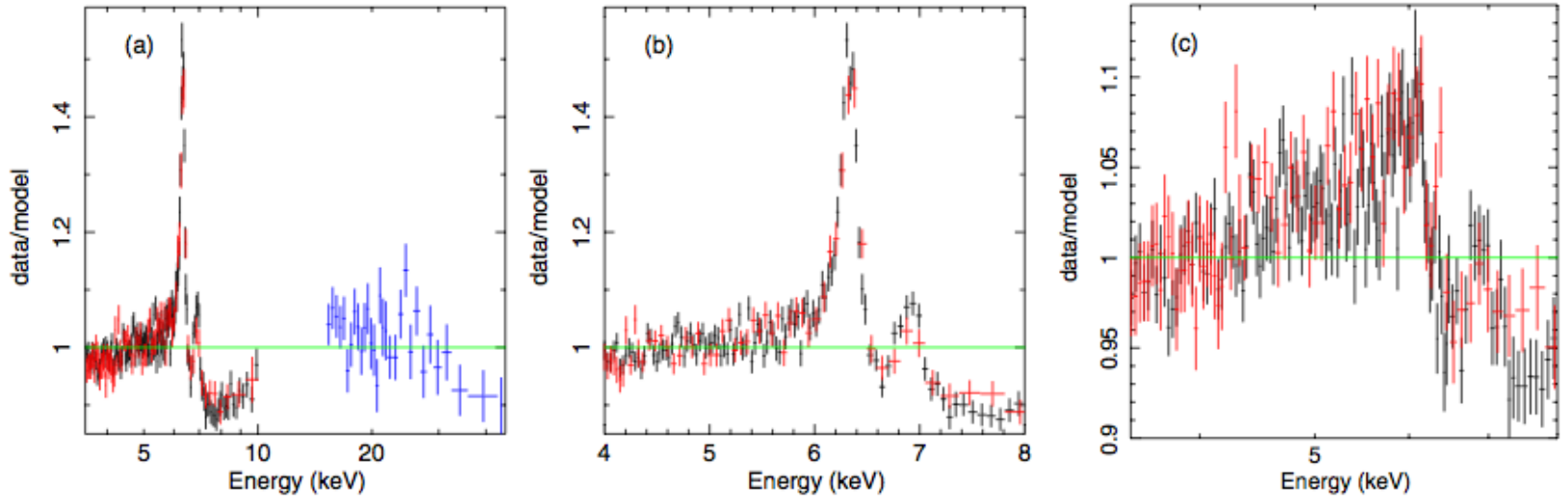


Noda et al. (2011)

Seyfert 1.5 nucleus in NGC3783 (200ks; July 2009)

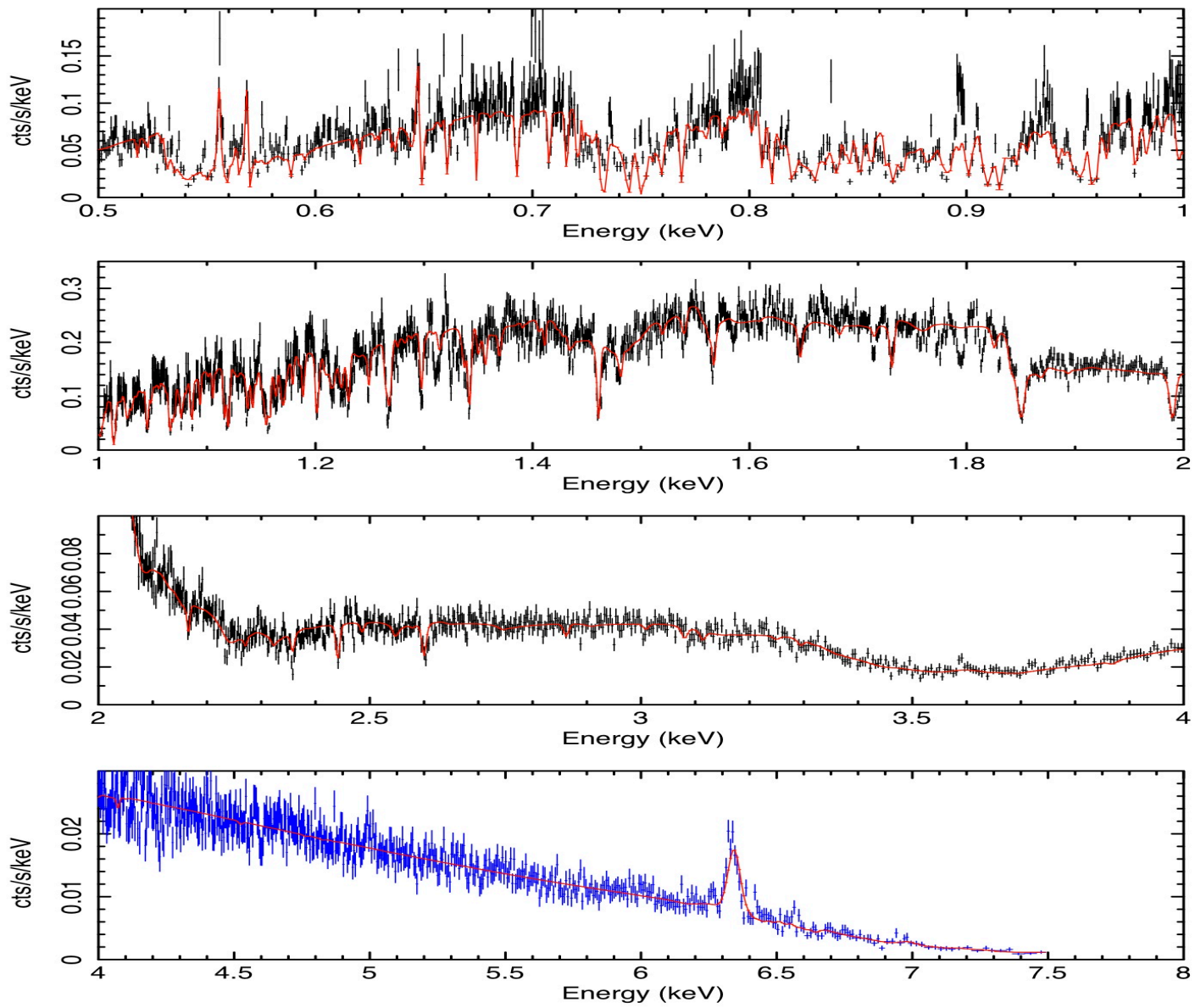


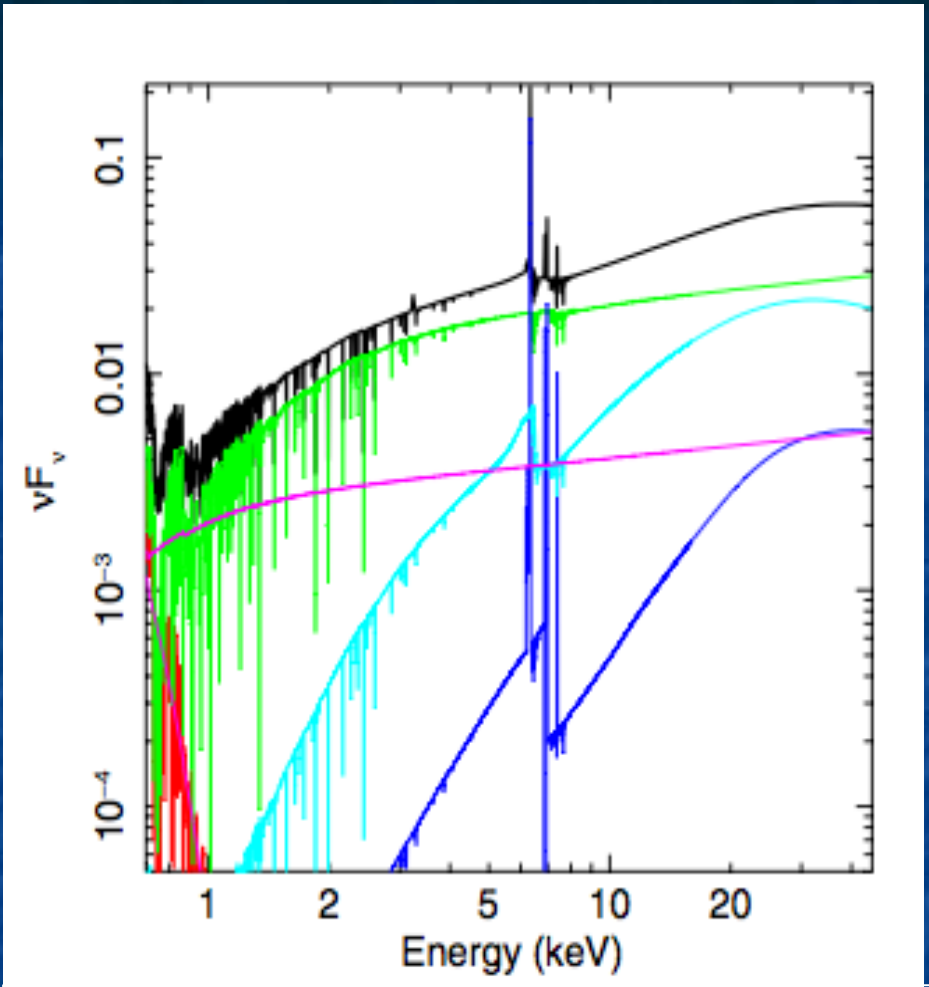
Suzaku XIS+PIN spectrum ratioed against simple power-law. A global model of this spectrum requires multi-zone ionized absorption, reflection from distant matter, and reflection from inner accretion disk



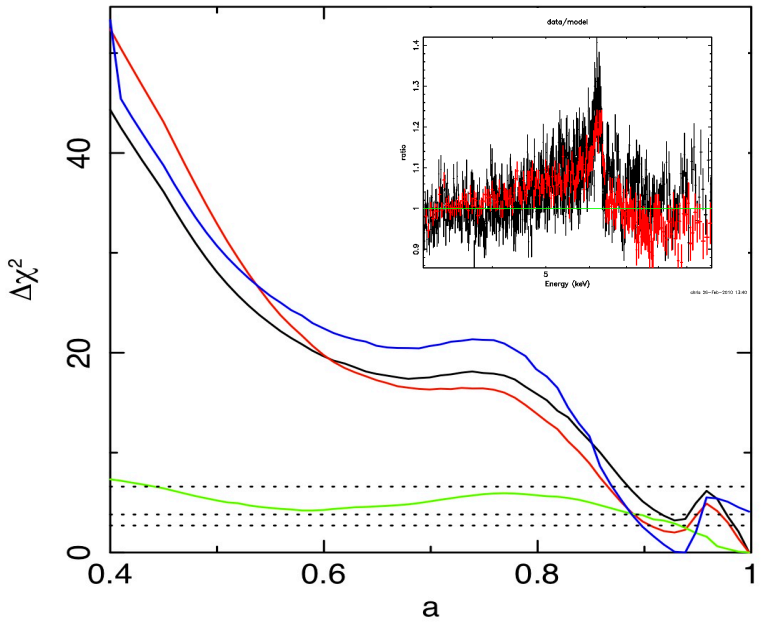
Brenneman, Reynolds, Nowak et al. (2011)
Reis, Fabian, Reynolds et al., ApJ, submitted

900ks Chandra/HETG (e.g. see Krongold et al. 2003, Netzer et al. 2003)





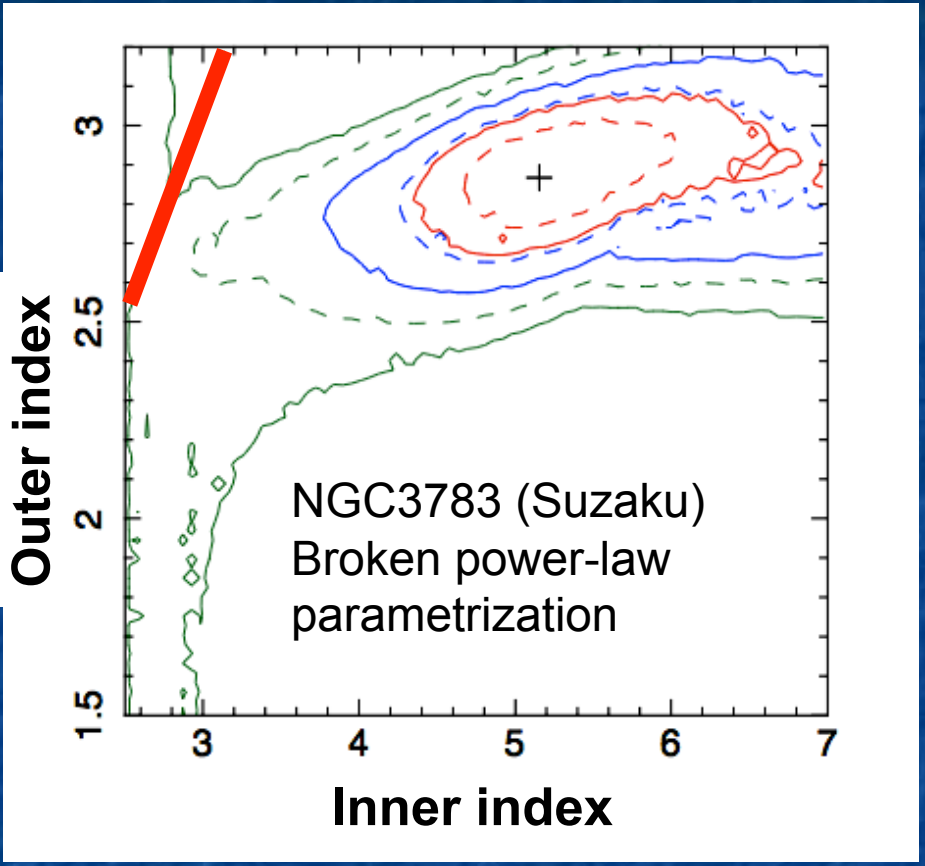
Require high spin (a>0.90 at 90% CL). This includes all uncertainities associated with ionized absorption, irradiation profile of inner disk, iron abundance, and treatment of PIN background.



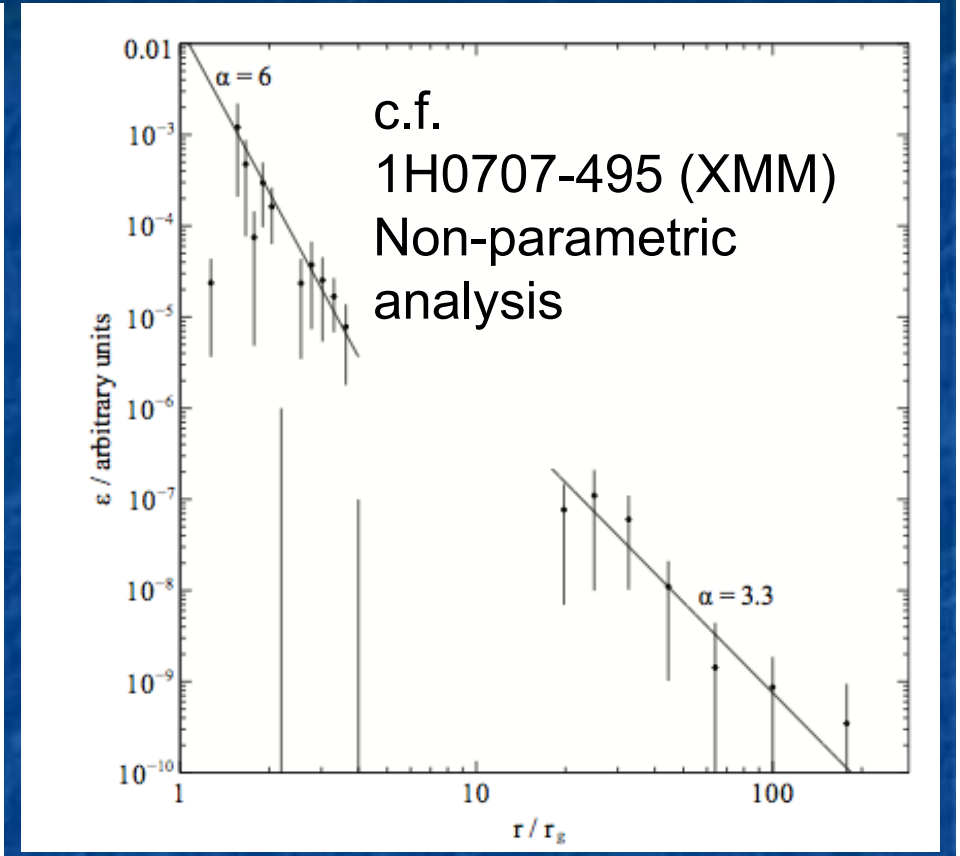
Z_{Fe}=3.7±0.9 (likely why Patrick et al. 2011 get lower spin)

Brenneman, Reynolds, Nowak et al. (2011)
Reis, Fabian, Reynolds et al., ApJ, submitted

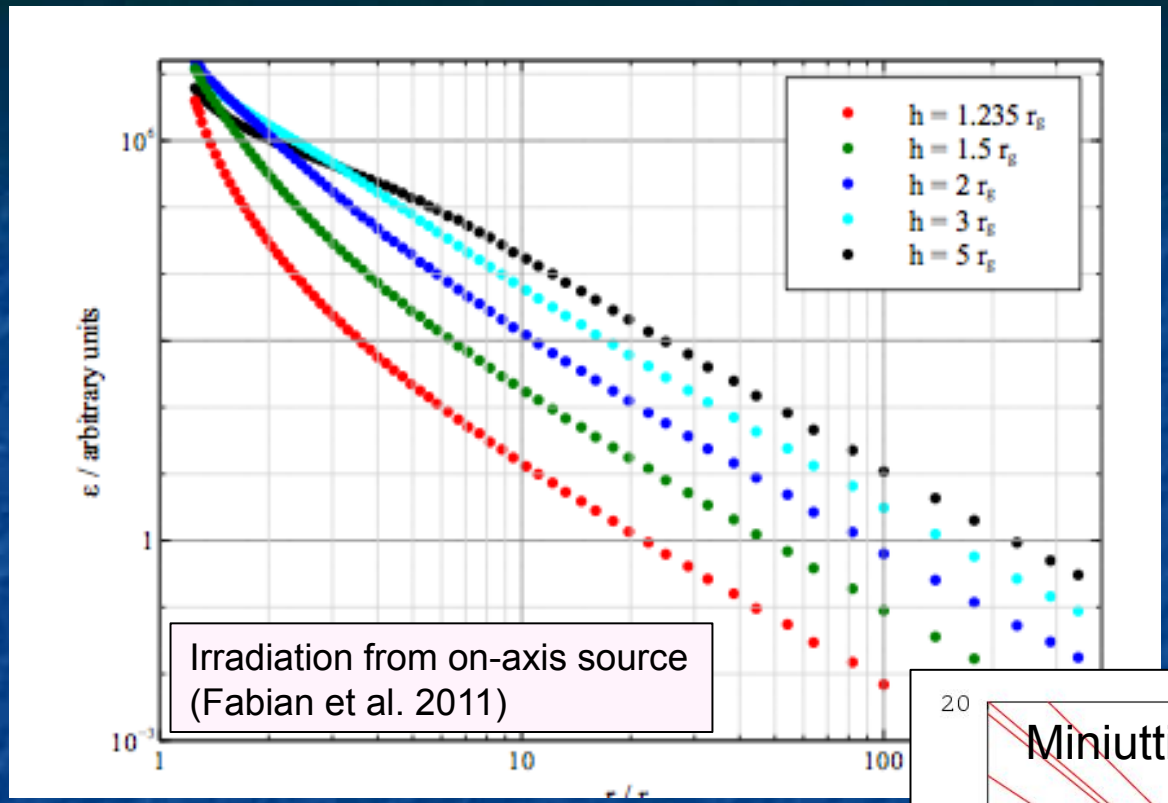
Irradiation profiles

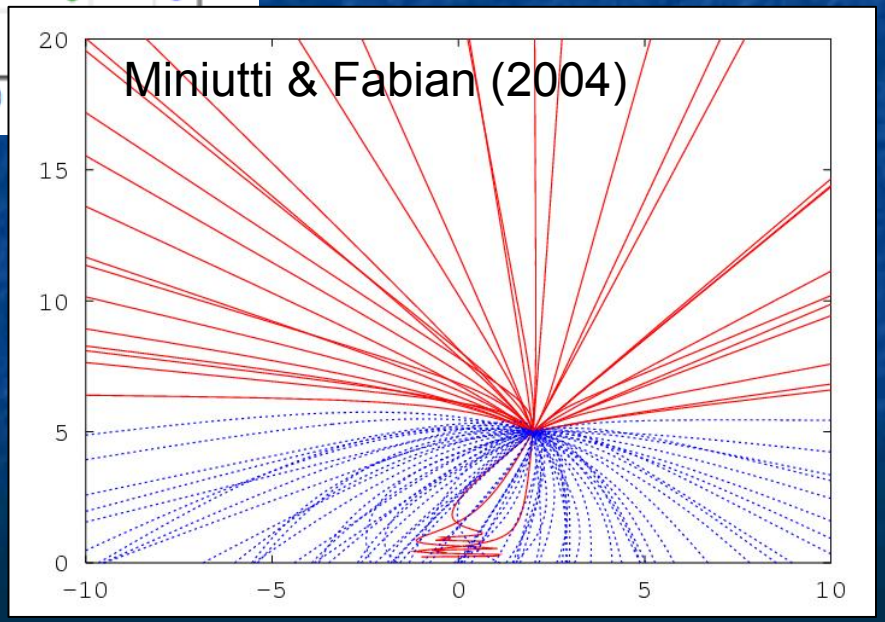


Brenneman, Reynolds, Nowak et al. (2011)



Wilkins & Fabian (2011)

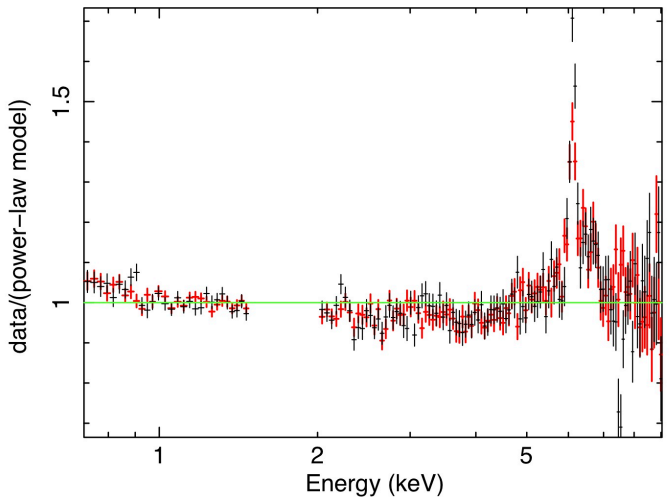




Analysis of spectral variability suggests changes in both luminosity and geometry (position) of X-ray source

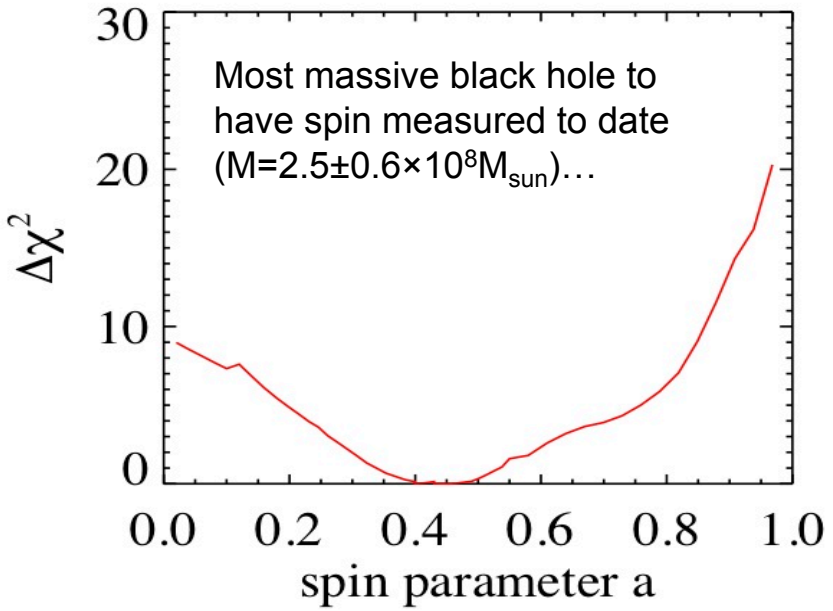
Reis et al. (submitted)

Powerful Seyfert/QSO Fairall 9 (250ks; May 2010)

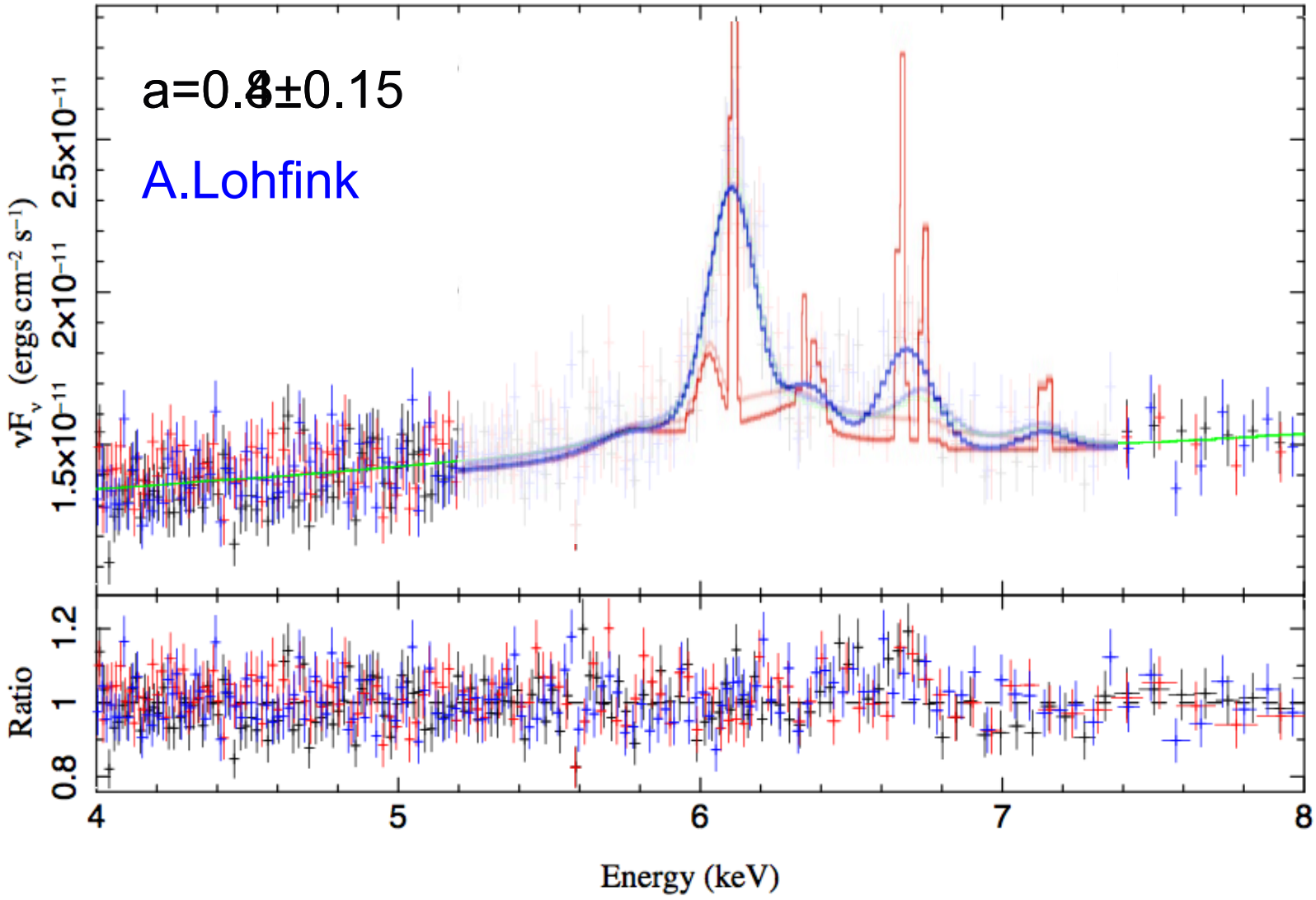


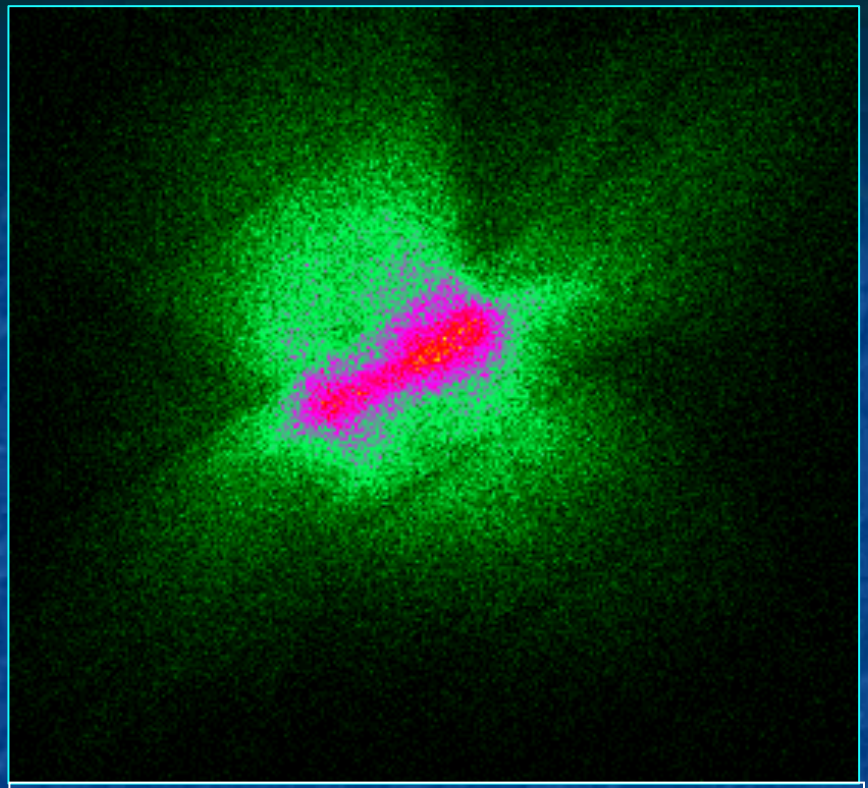
XIS data ratioed against simple power-law. Very "clean" object - no evidence for any intrinsic absorption. Broad iron line is weak but clearly seen to low-energy side of strong narrow iron line.

Joint analysis of deep XMM and Suzaku data find intermediate spin (a=0.26-0.62). This constraint includes uncertainties due to presence of narrow Fe25/Fe26 lines, and presence of the soft excess



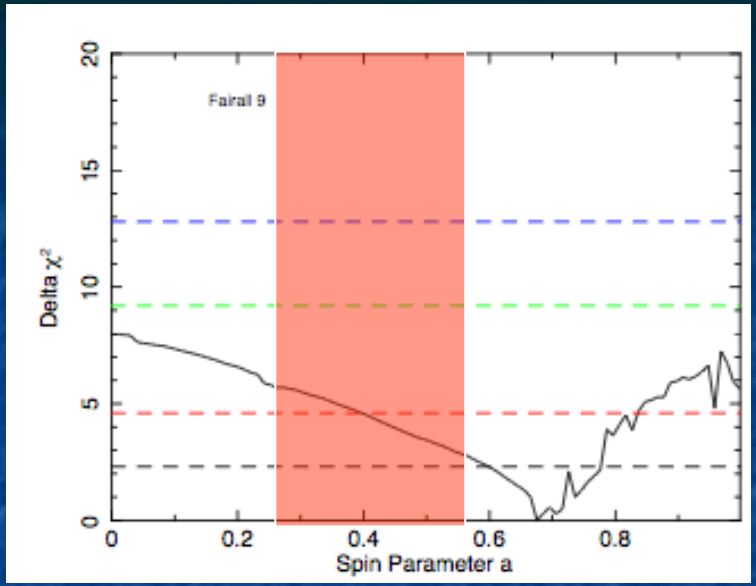
Talk by Anne Lohfink

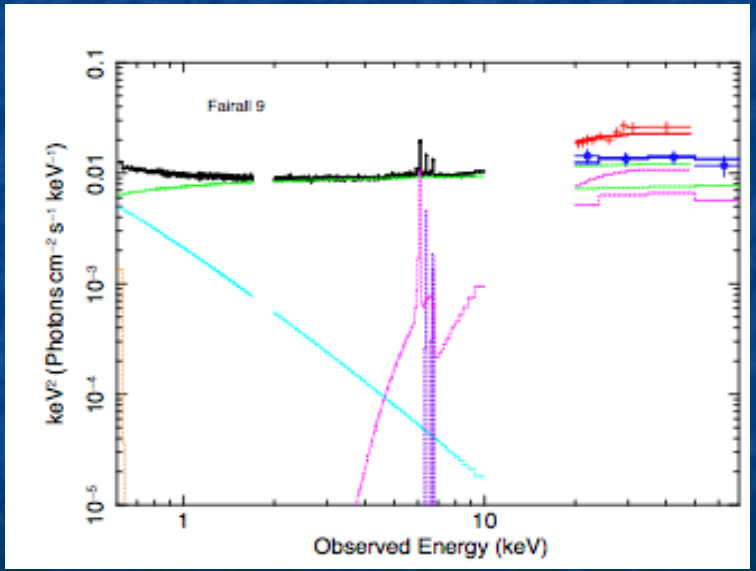

a=0.8±0.15
A.Lohfink
νF_ν (ergs cm^-2 s^-1)
1.5×10^-11
2×10^-11
2.5×10^-11
Ratio
0.8
1
1.2
4
5
6
7
8
Energy (keV)



XIS3 image of Fairall 9 : Spacecraft **wobble** caused a 1 arcmin elongation of this point source. Corrected using tool developed by M.Nowak.

Principal concerns resulting from anomaly is the XIS/PIN cross-normalization.

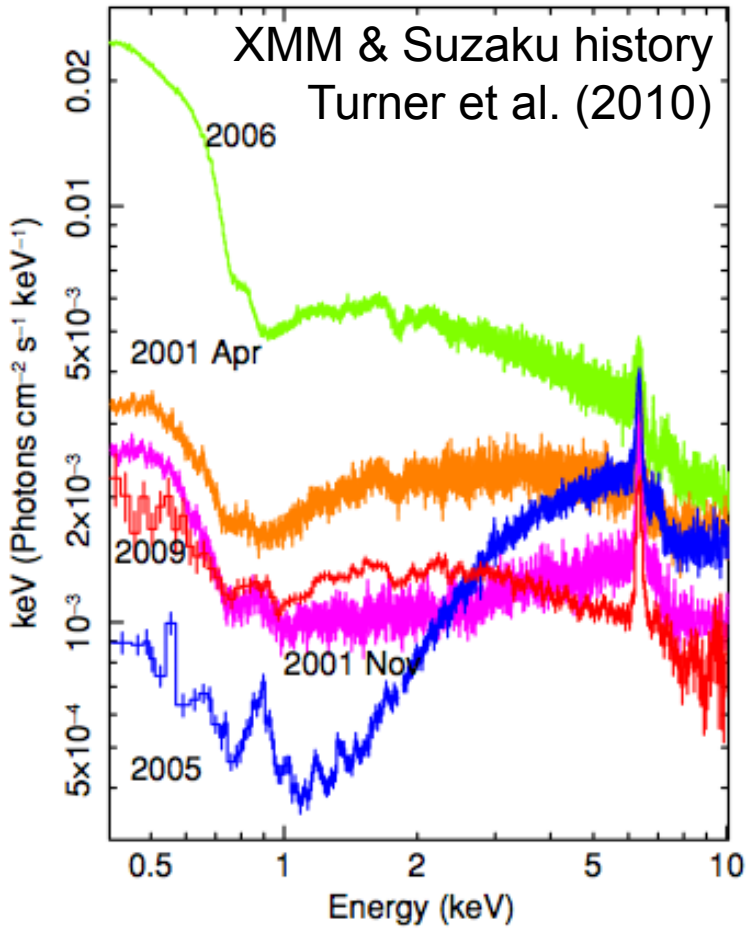


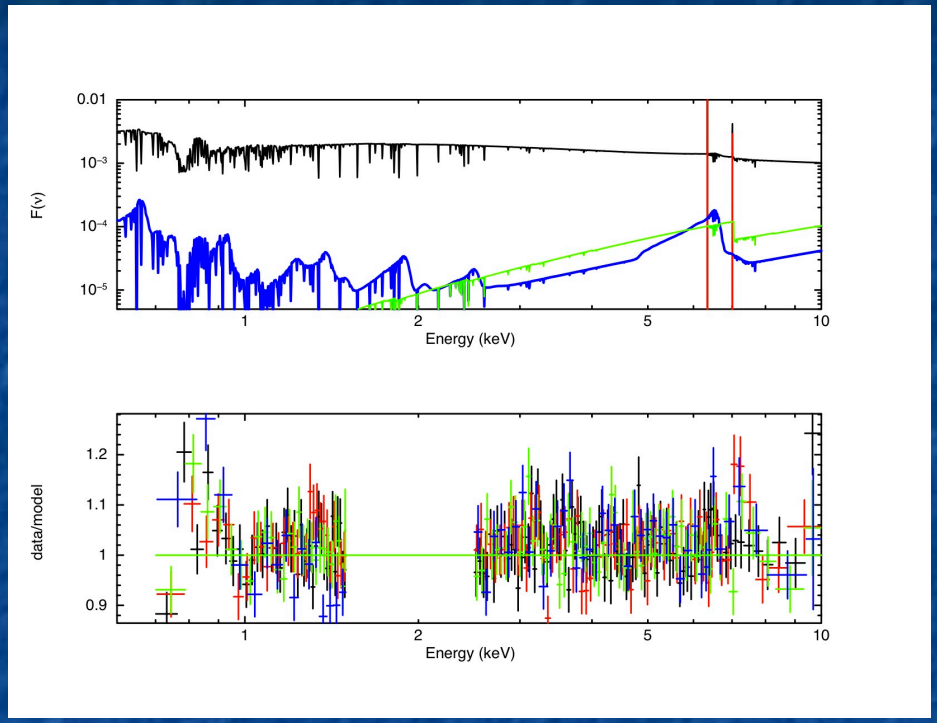


Patrick, Reeves et al. (2011)

See talk by Mitsuda-san

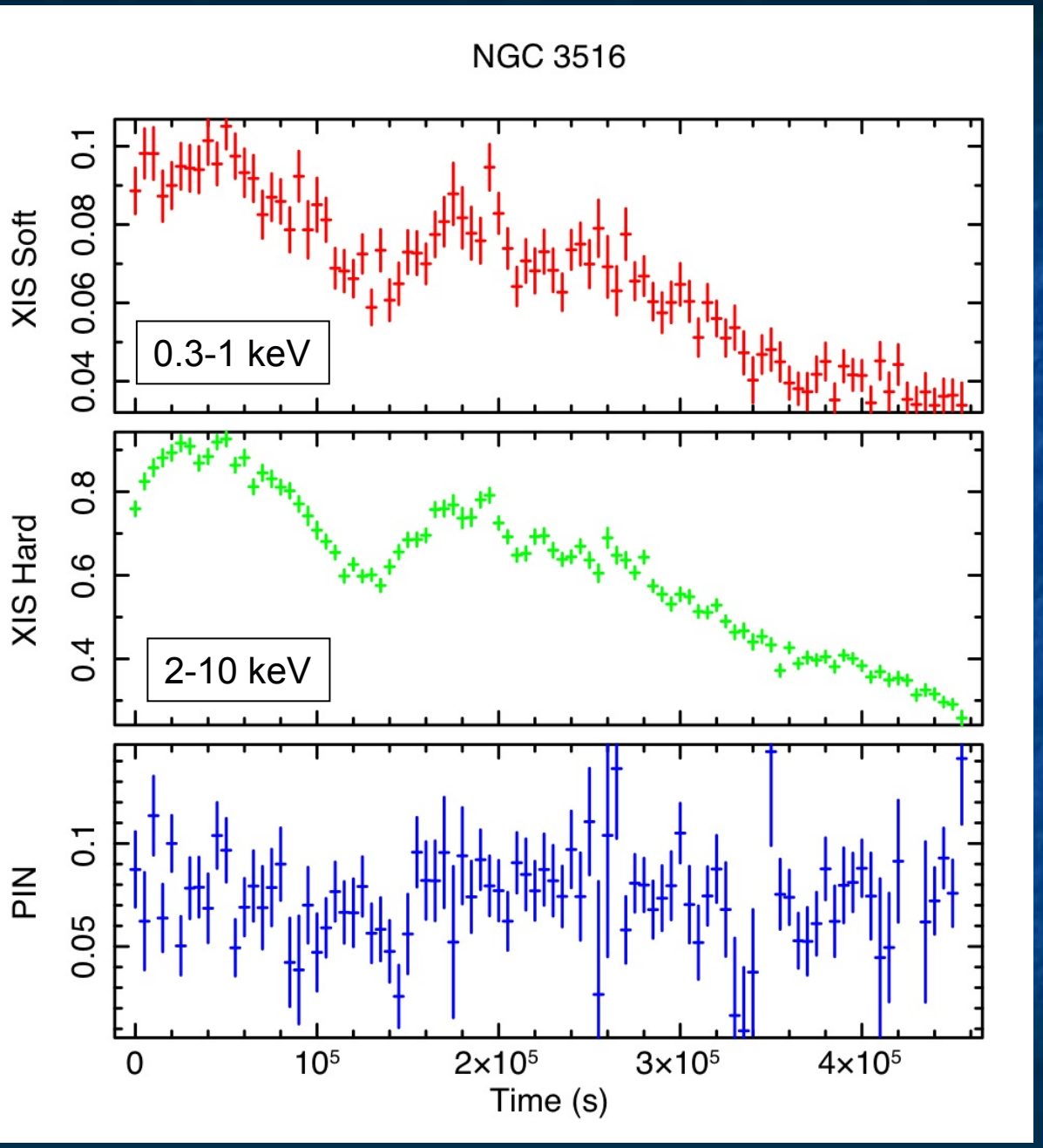
Seyfert 1 nucleus in NGC3516 (250ks; November 2009)

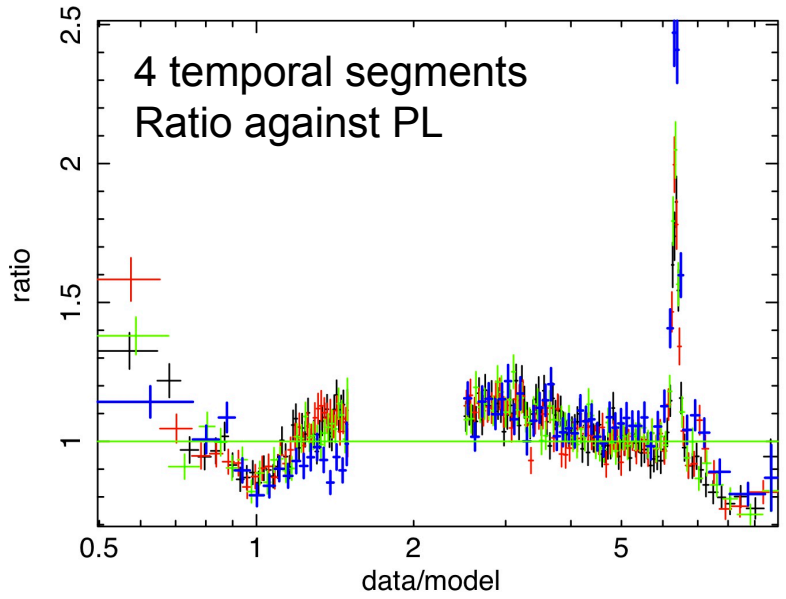




Complex, time-variable absorption

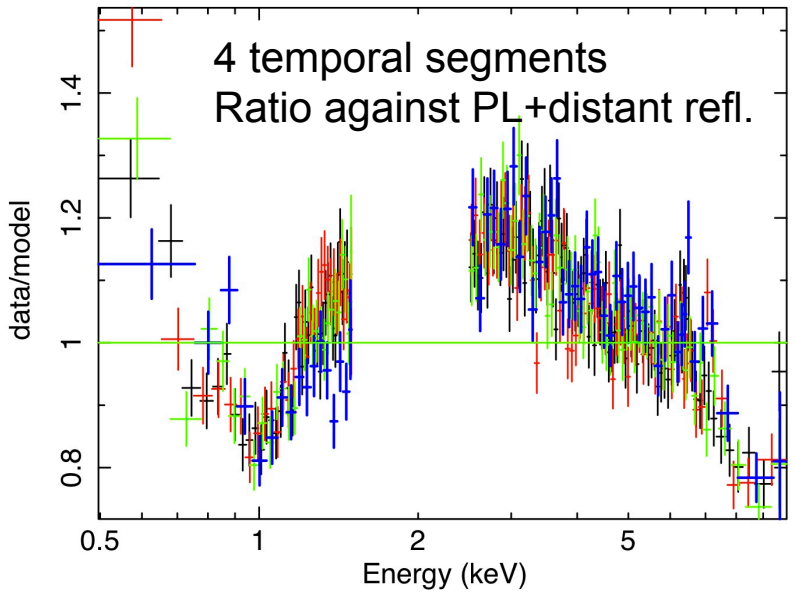
Suzaku data consistent with presence of reflection from inner disk… but poor constraints on properties of disk or spin


NGC 3516
XIS Soft
0.04
0.06
0.08
0.1
0.3-1 keV
XIS Hard
0.4
0.6
0.8
2-10 keV
PIN
0.05
0.1
0
10^5
2×10^5
3×10^5
4×10^5
Time (s)



Short-term 0.5-10keV variability mostly achromatic

Remaining deviations can be modeled as due to (constant) distant reflection

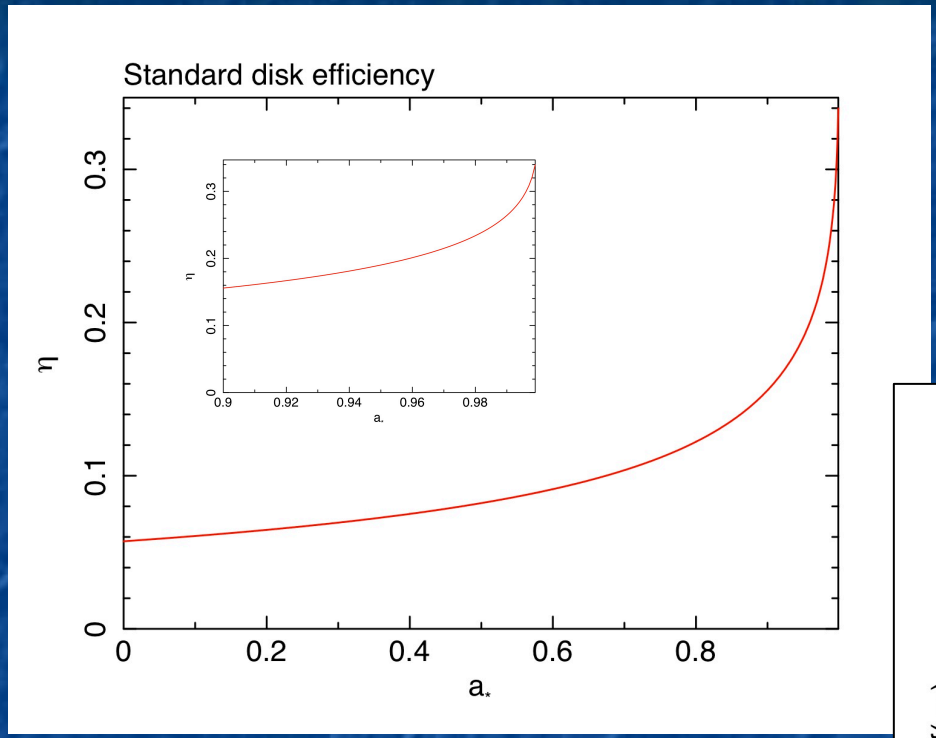


Variability can not be due to changing absorption, unless absorbers are Compton-thick “bricks” (Turner et al. 2011)

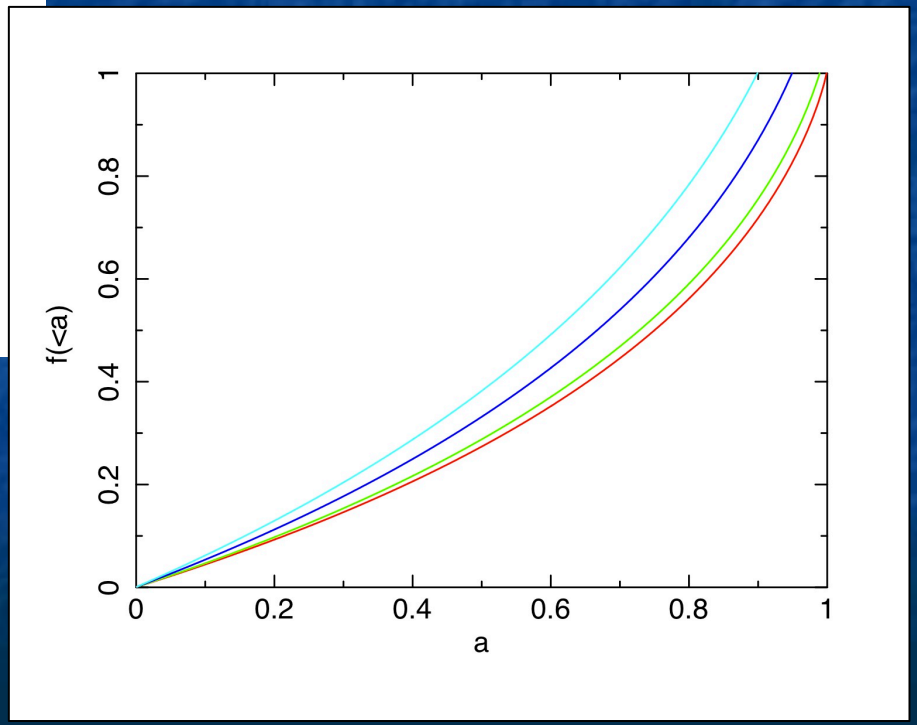
III : Supermassive black hole spin : Current status

MCG-6-30-15	a>0.98	(Brenneman & CSR 2006)
1H0707-495	a>0.97	(Zoghbi et al. 2010)
NGC3783	a>0.90	(KP; Brenneman et al. 2011)
Mrk79	a=0.7±0.1	(Gallo et al. 2011)
Mrk335	a=0.7±0.1	(Patrick et al. 2011)
SWIFTJ2127.4	a=0.6±0.2	(Miniutti et al. 2010)
Fairall 9	a=0.4±0.15	(KP; Lohfink et al., in prep)
Sgr A*	a=0.94	(Moscibrodzka et al. 2010)

Spin bias in AGN surveys



Assuming that accretion rate is determined by environment, high-spin sources will be more luminous due to change in efficiency… **high-spin will be over-represented in flux-limited surveys**

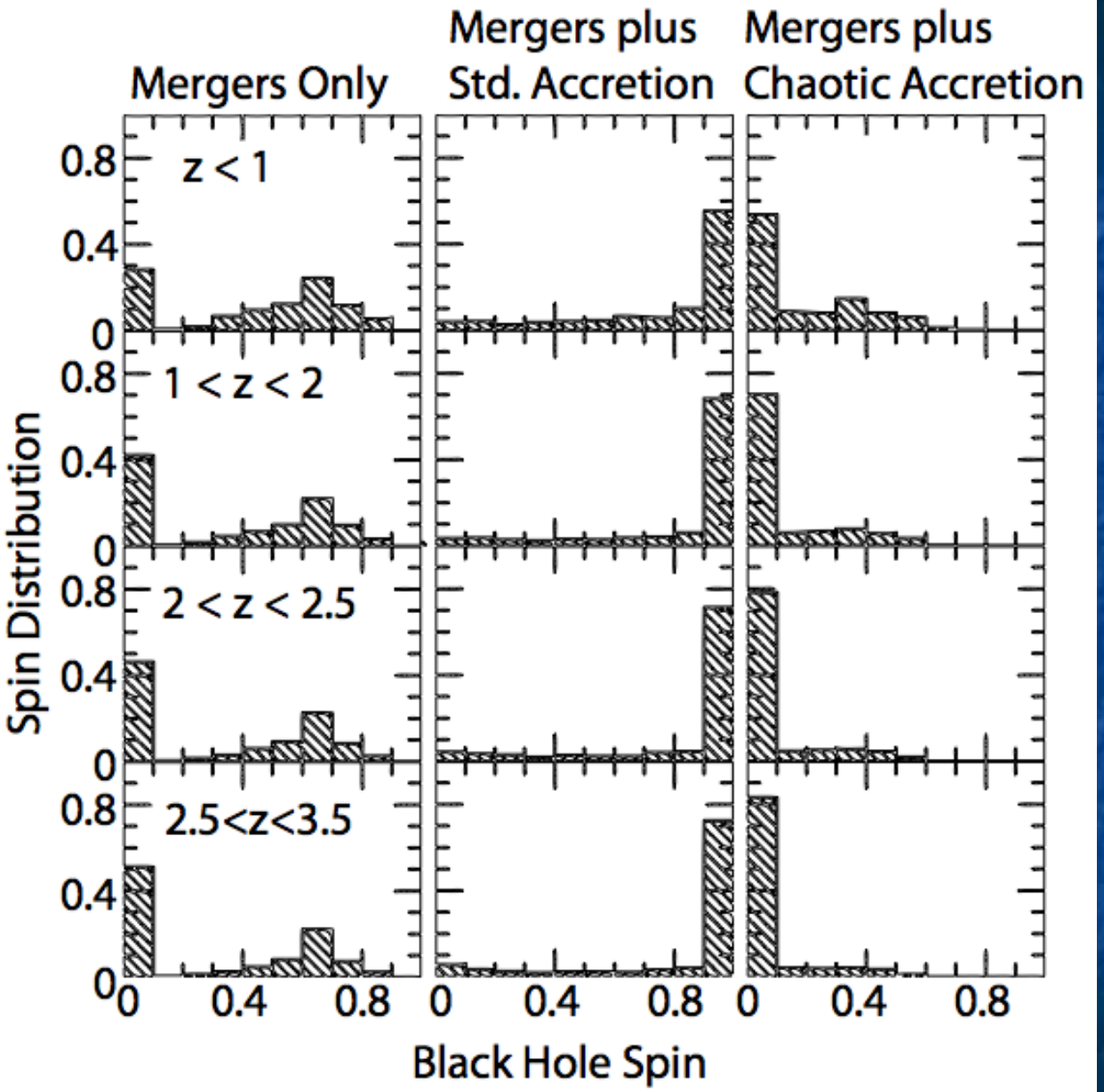


For flat intrinsic spin distribution, flux limited survey will yield…

- 50% sources with a>0.73 (a_{max}=0.99)
- 50% sources with a>0.67 (a_{max}=0.95)

Current results suggest moderately top-heavy spin distribution, $f(<a)\sim a^2$

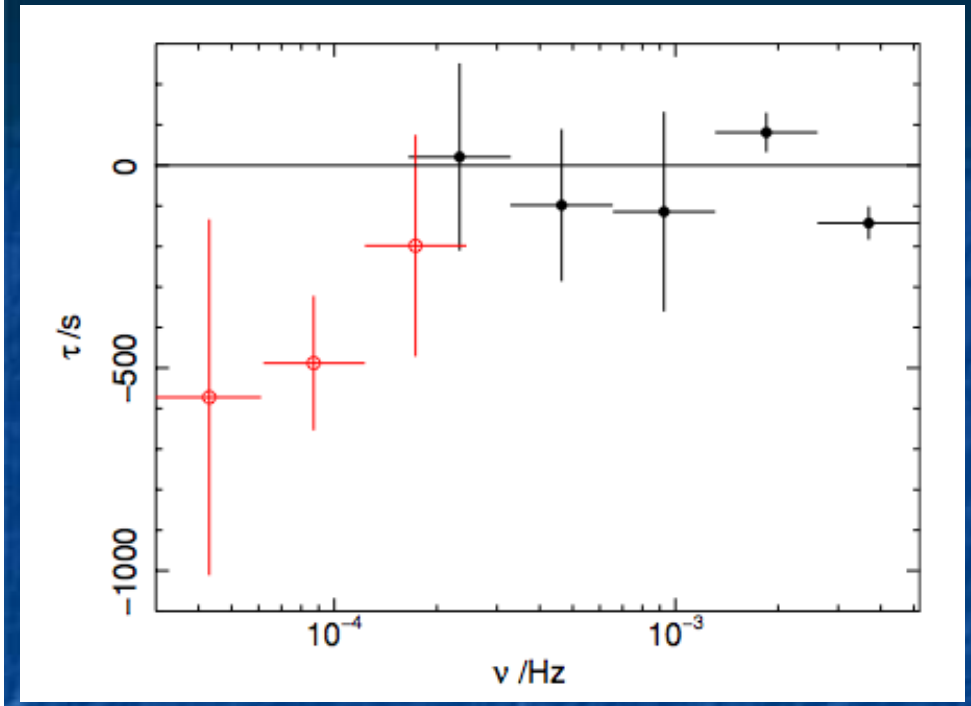
Berti & Volonteri (2008)

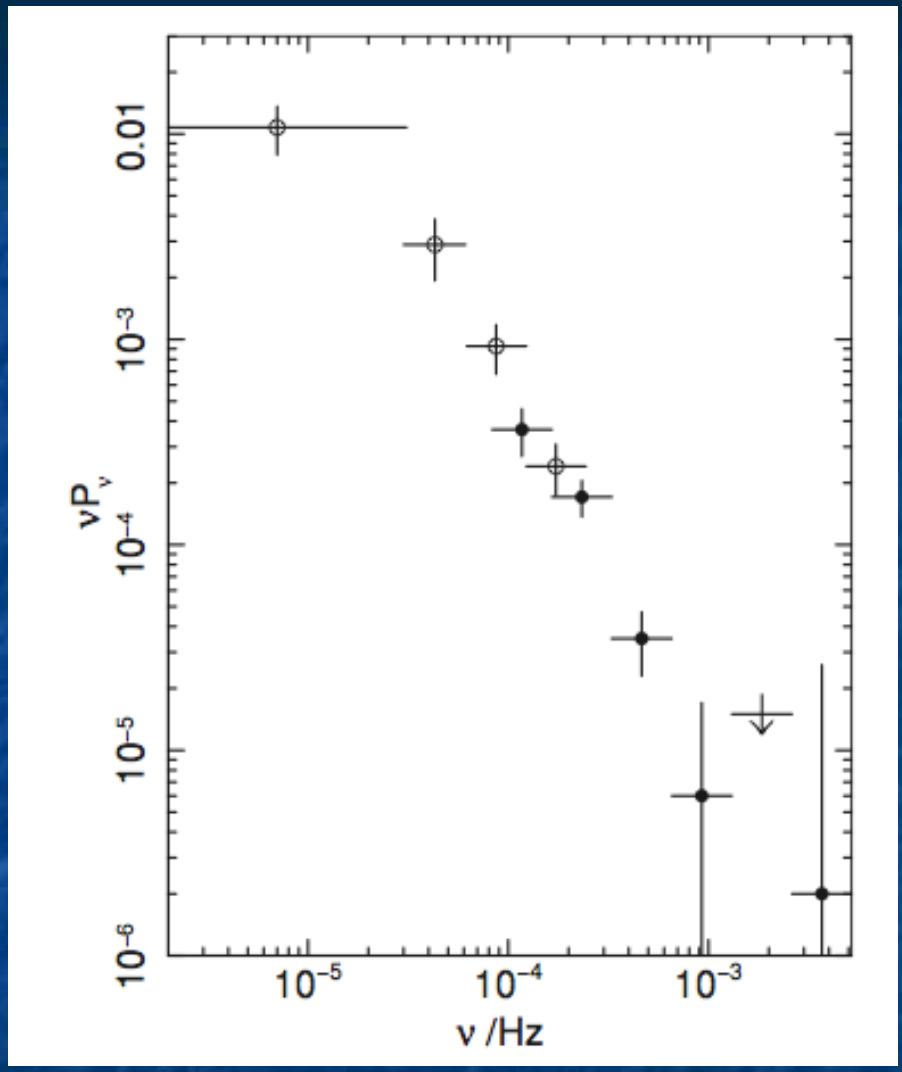


Summary

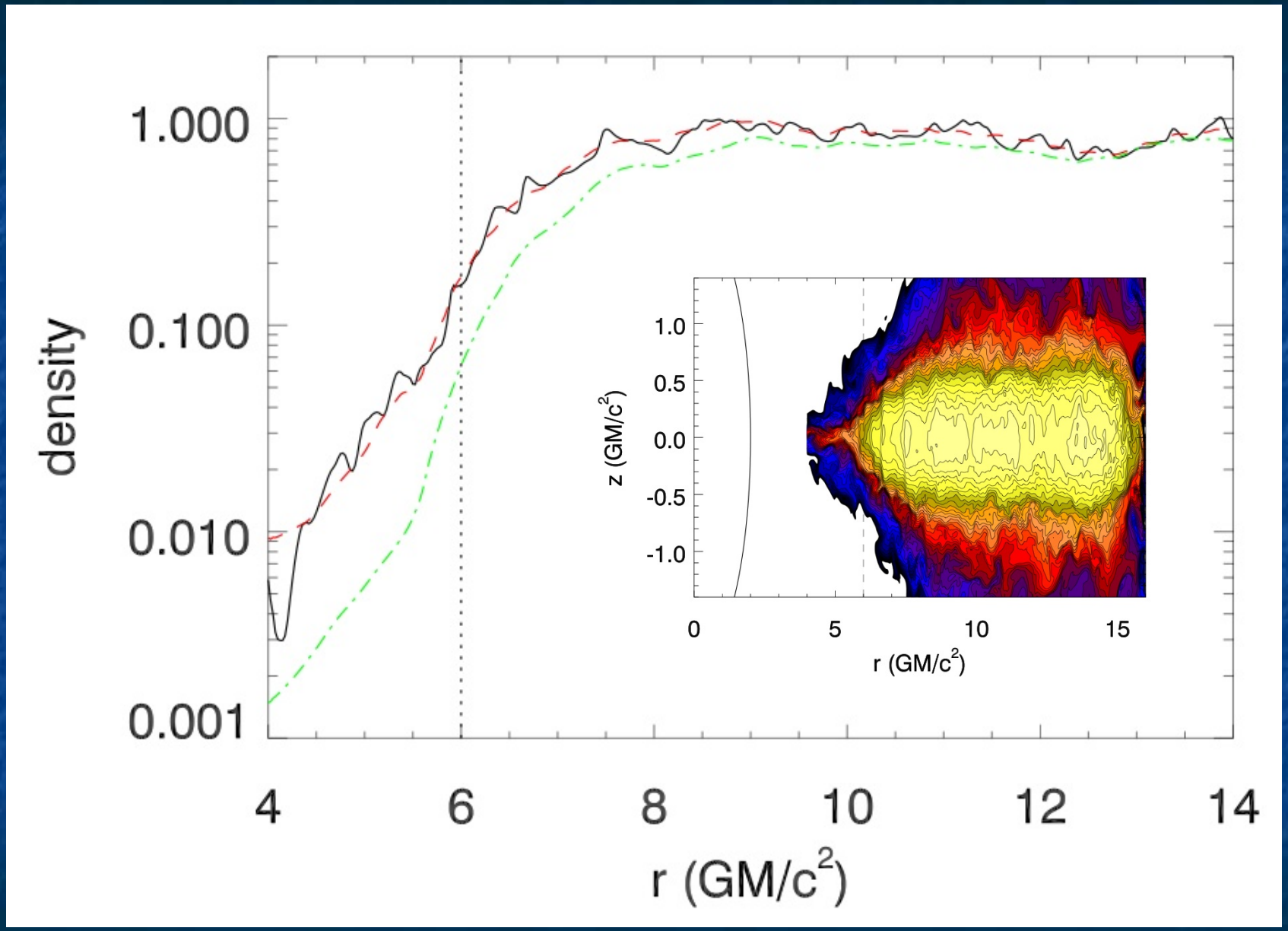
- Growing number of Suzaku and XMM datasets for which AGN spin can be analyzed
  - Spectral models need to respect the physics (blur ALL disk components, photo-absorption MUST be accompanied by line emission…)
  - Must consider systematic errors
- Accretion disk physics…
  - Clearly seeing very steep emissivity profiles… strong light bending or ISCO/MHD effects
  - High iron abundances appear generic
- Early days yet, but data might be starting to argue for top-heavy spin distribution function

Backup slides

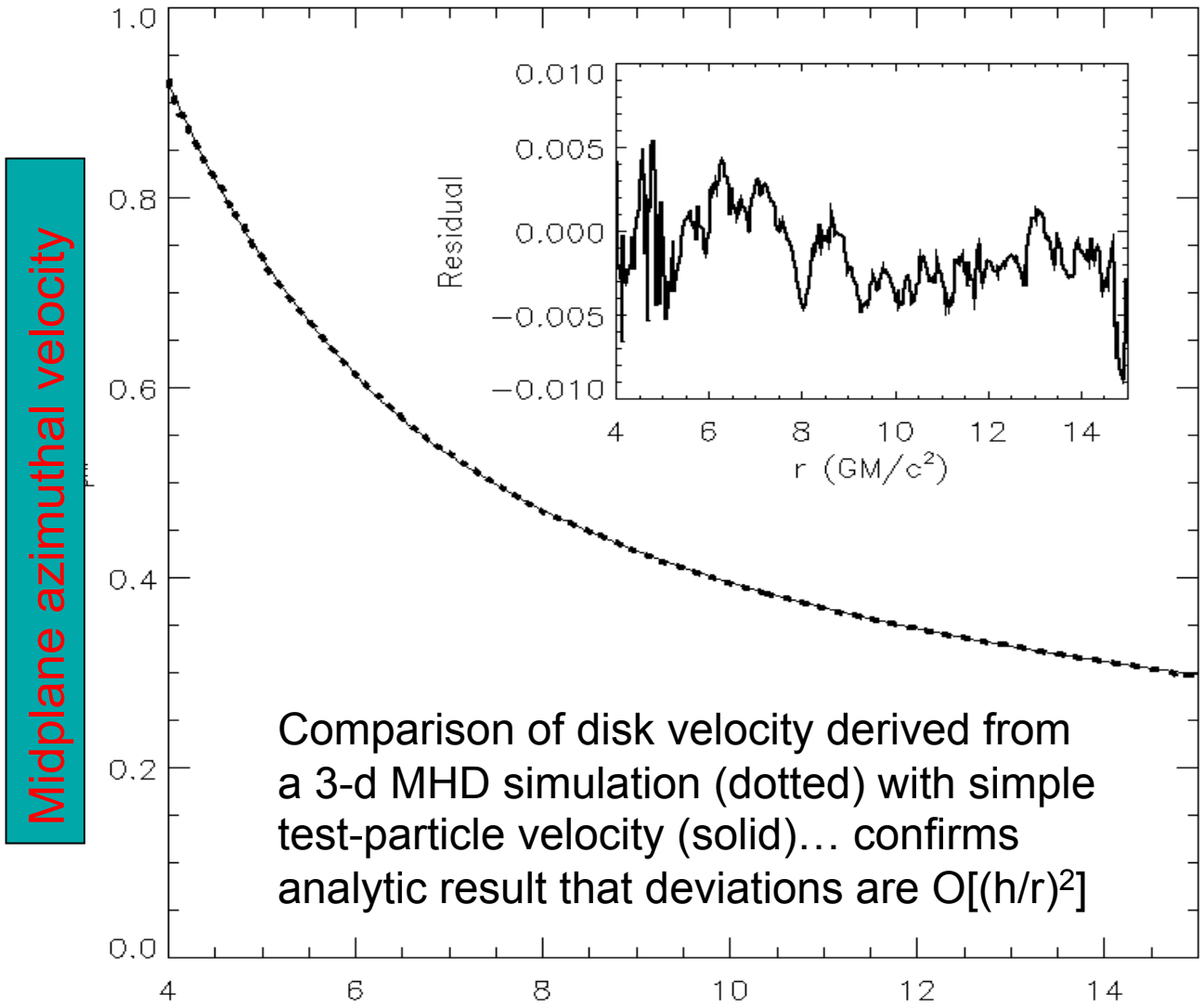




Turner et al. (2011)

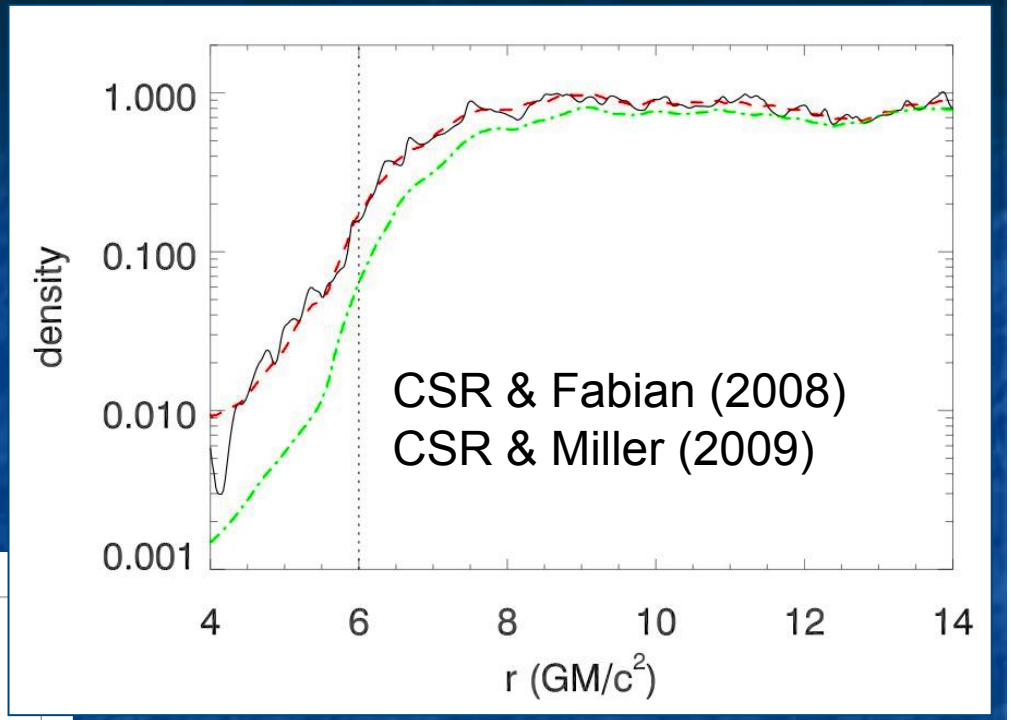


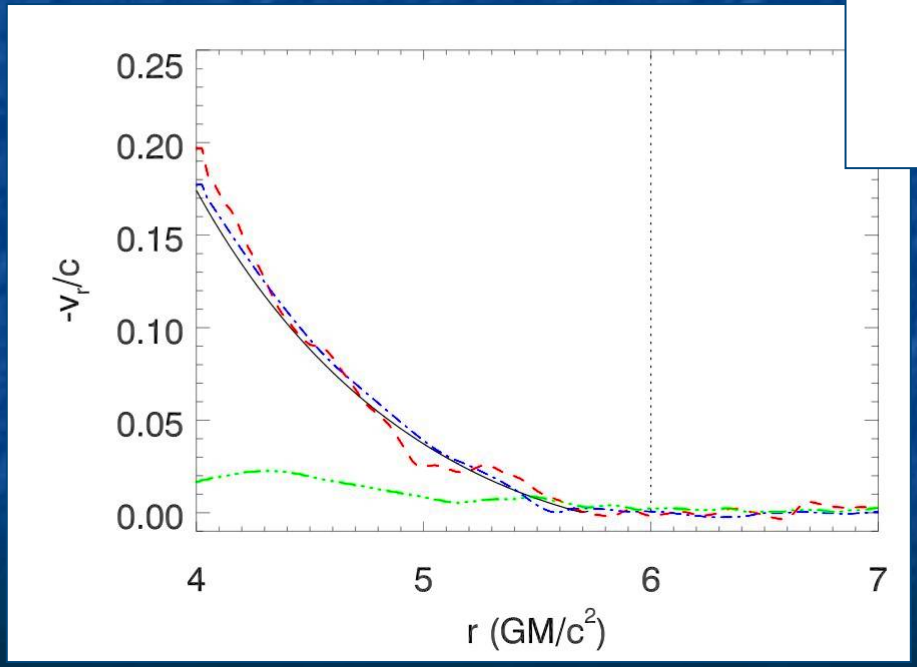
Reynolds & Fabian (2008)



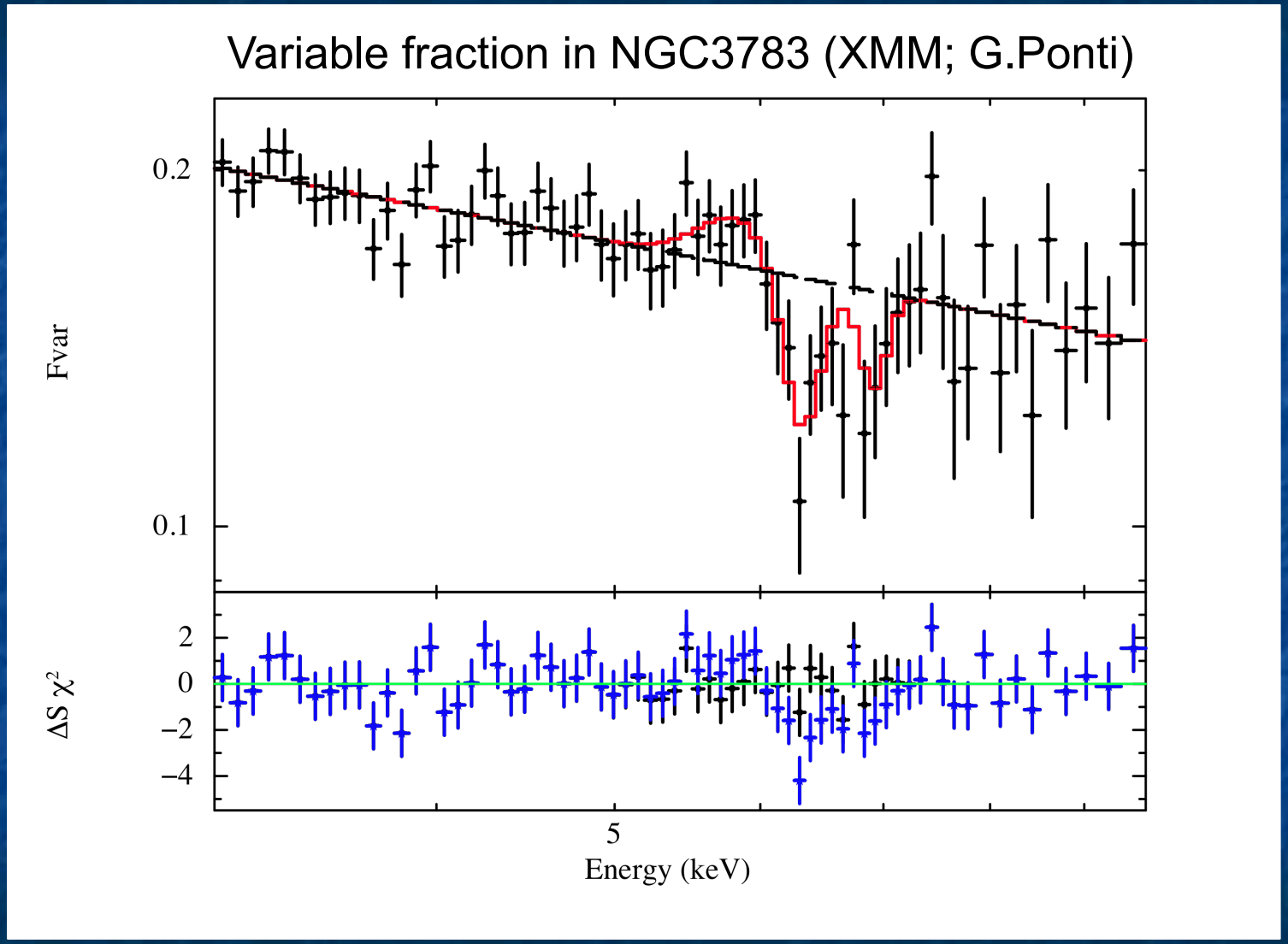
Comparison of disk velocity derived from a 3-d MHD simulation (dotted) with simple test-particle velocity (solid)… confirms analytic result that deviations are $O[(h/r)^2]$

Truncation of iron line at ISCO depends on density – the debate over stress at the ISCO is largely irrelevant to iron line spin measurements!



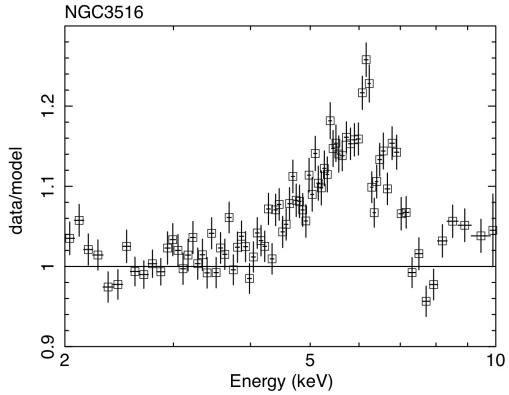


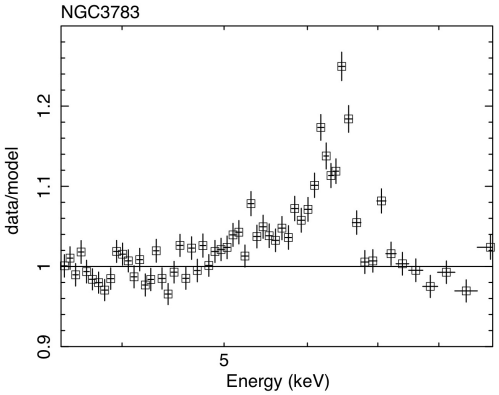
Supporting evidence for our spectral model from XMM…

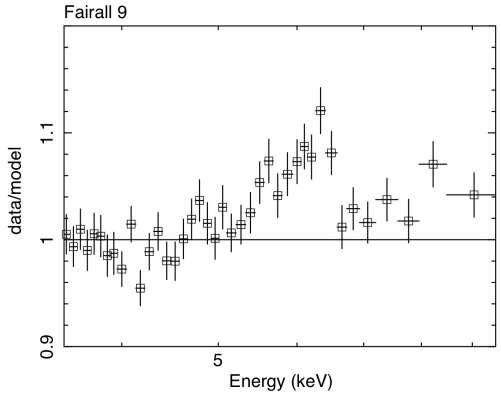


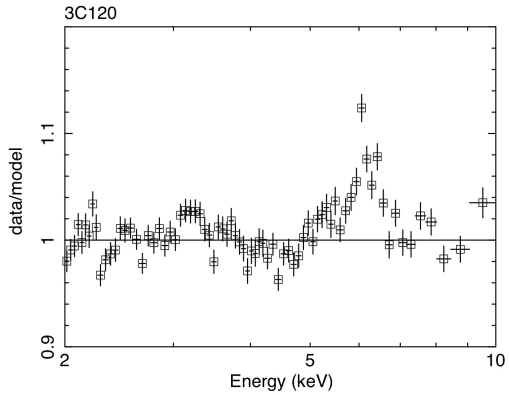
Suzaku Key Project (PI: Reynolds)

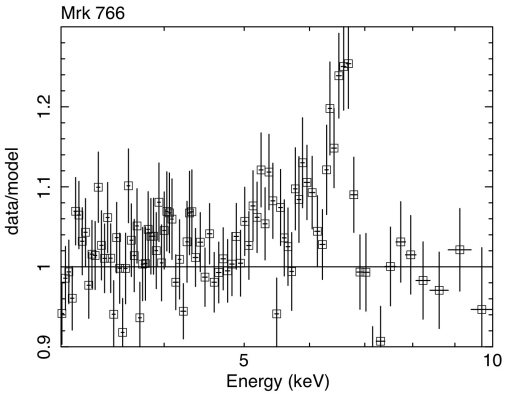
Spin measurements of sample of SMBHs

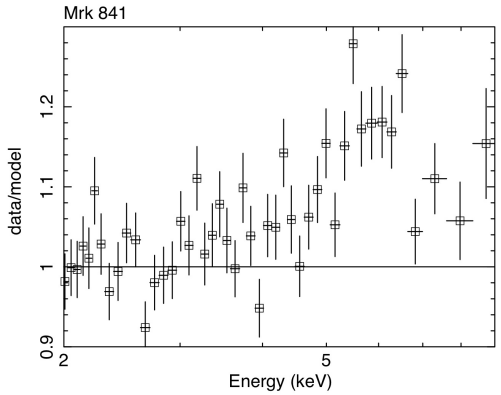








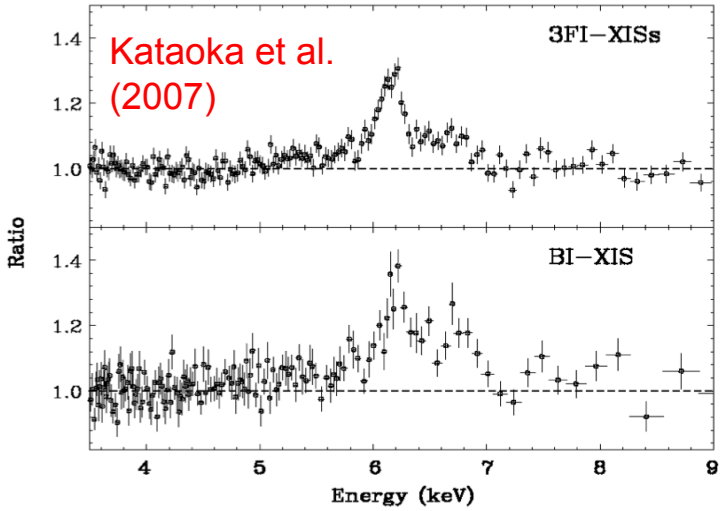


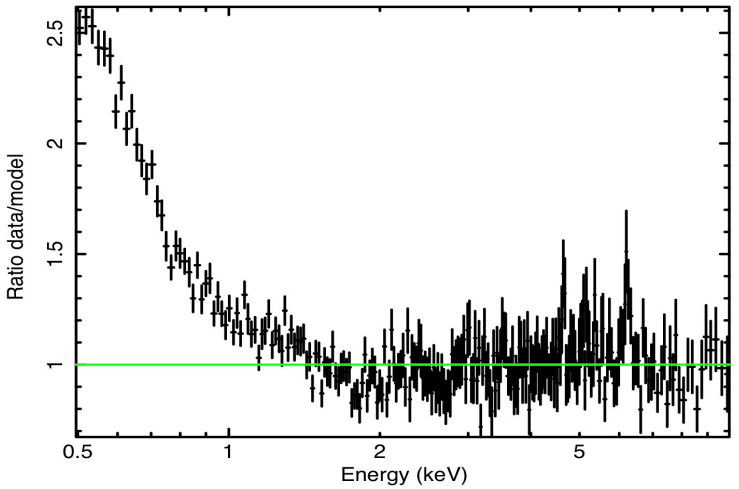


Still to come…

3C120 (300ks; Cycle-6)

- Obtain the best view yet of central engine structure of a radio-loud AGN.
- Probe connection between black hole spin and jet production.
- Coordinated NuSTAR and radio coverage





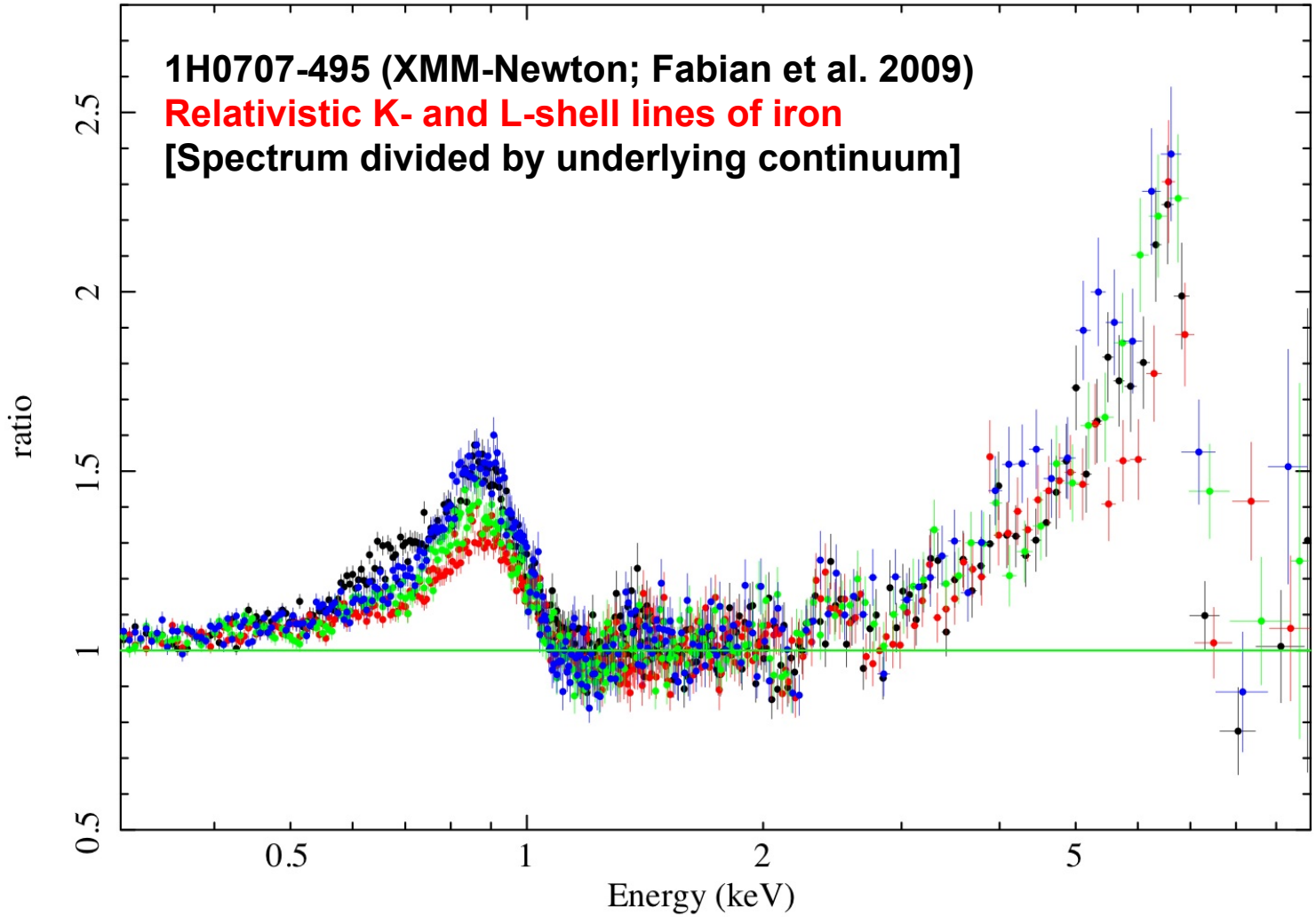
Mrk841 (350ks; Cycle-6)

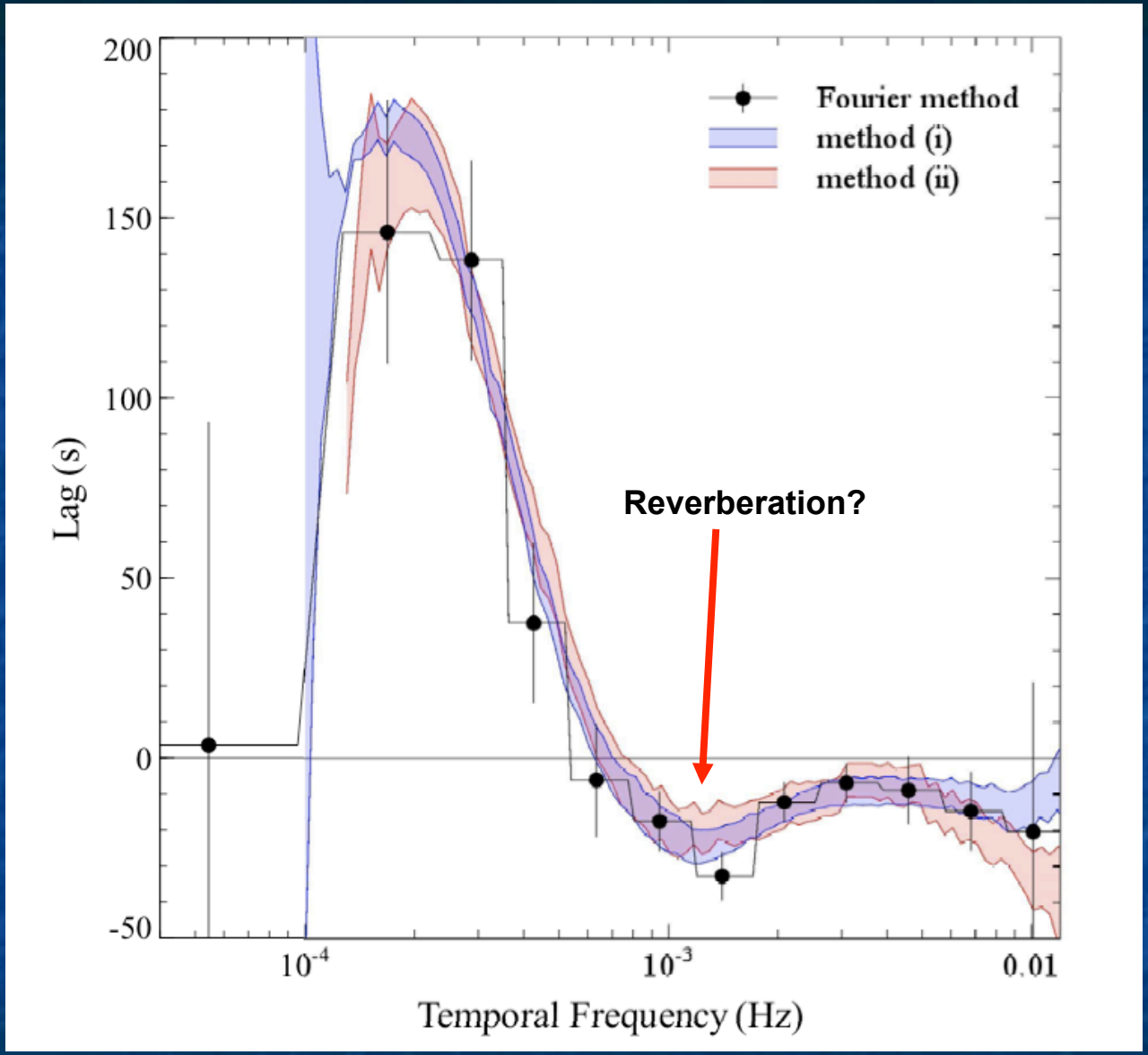
- Probe nature of powerful soft excess AND broad iron line
- Soft excess X-ray reprocessing in inner disk?

Final results/products:

- Combine with re-analysis of deep archival datasets to produce set of "gold-standard" SMBH measurements… then constrain simple forms for SMBH spin distribution
- Most direct view of spin-jet and disk-jet connections
- Detailed guidance for exploiting broad iron line diagnostics with future missions.

1H0707-495 (XMM)





Iron-L line vs continuum in 1H0707; Zoghbi et al. (2009)