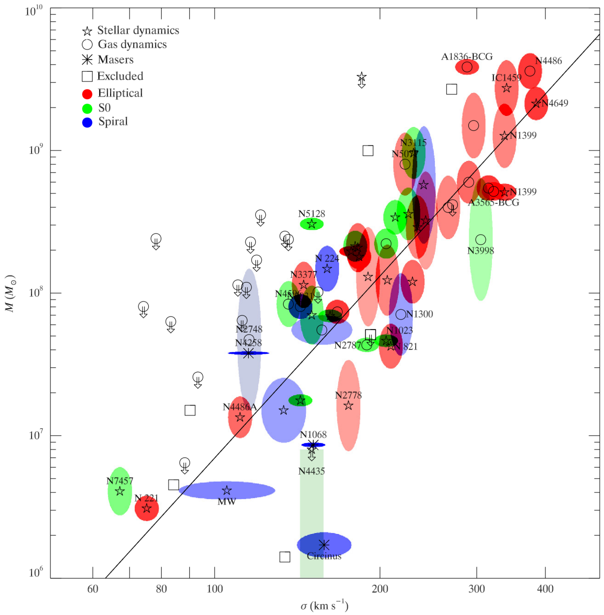
Reflection From the Strong Gravity Regime in a z=0.658 Gravitationally Lensed-Quasar

Mark Reynolds

Dominic Walton, Jon Miller and Rubens Reis

Astronomy

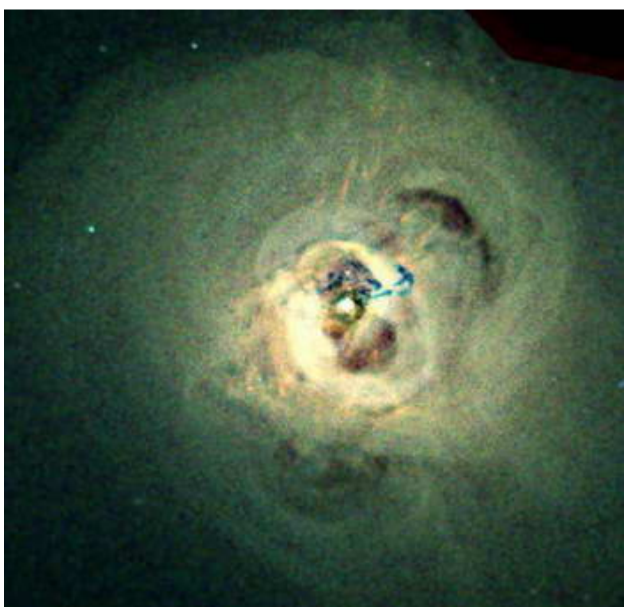
The X-ray Universe 2014 – Trinity College Dublin – 18th June 2014



Why Measure spin?

Central to theory of relativistic jets

Tapping the spin energy? BZ effect?

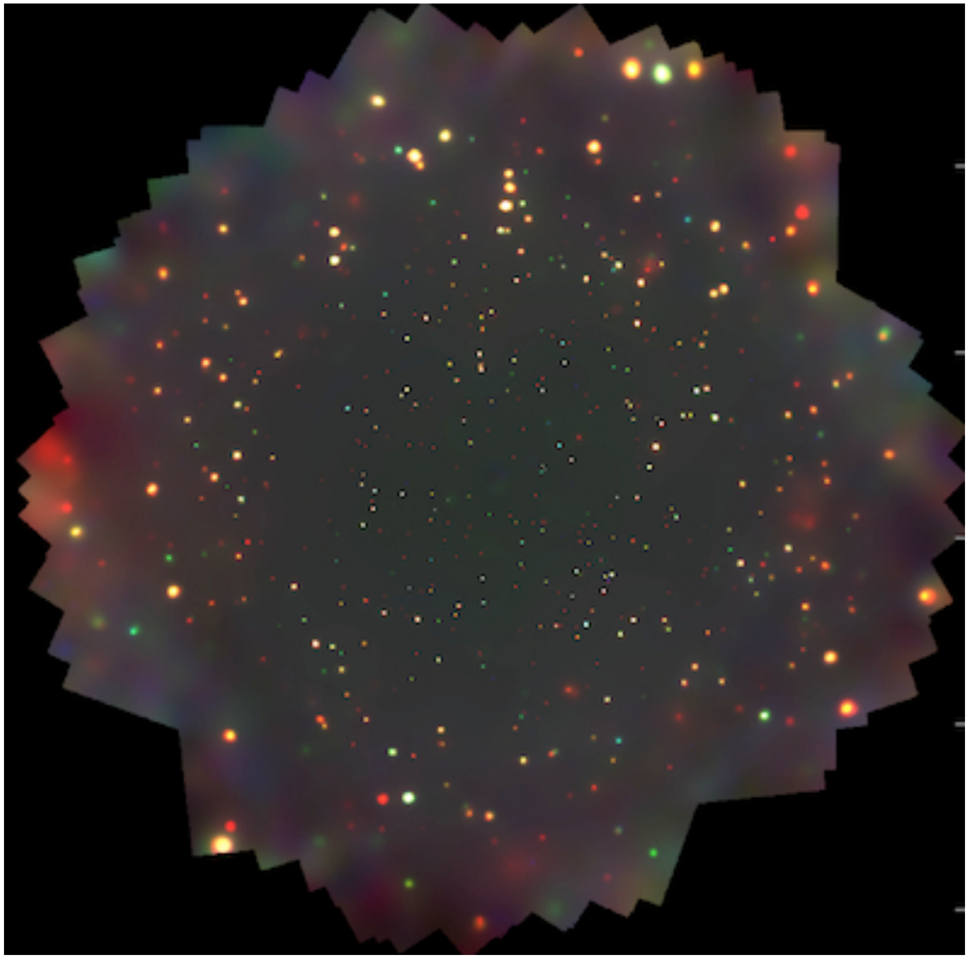


Regulating star formation and galaxy evolution

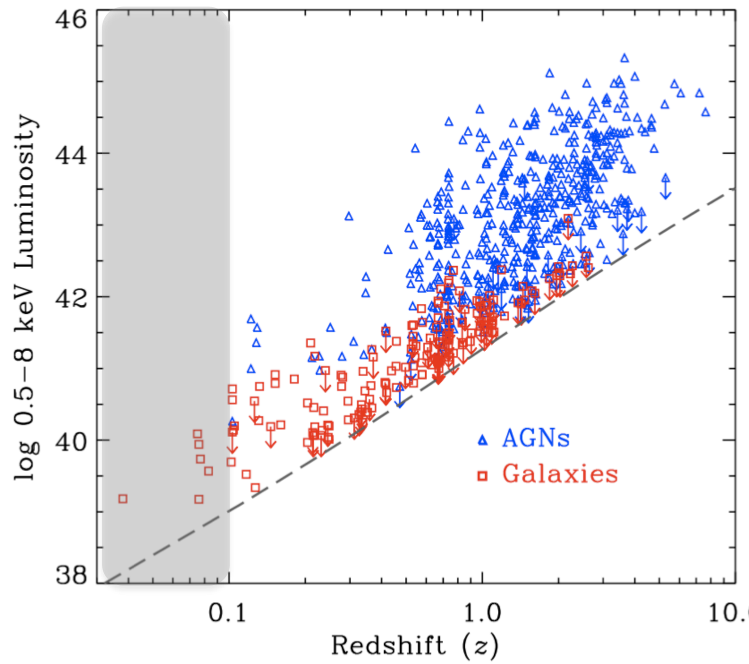
Growth of supermassive BHs through Cosmic time

Directly probe strong gravity, Application to models of GRBs and SNe, Total ionizing flux in the Universe – Gravitational-waves from merging SMBHs etc.

Black Holes are Cosmologically Numerous



4 Ms CDF-S



http://www2.astro.psu.edu/~niel/cdfs/cdfs-chandra.html

Lehmer et al. (2012)

Growth of Supermassive Black Holes

Prolonged, disk-mode,
coherent accretion
(quasar phase)

Constant angular momentum-axis

↓

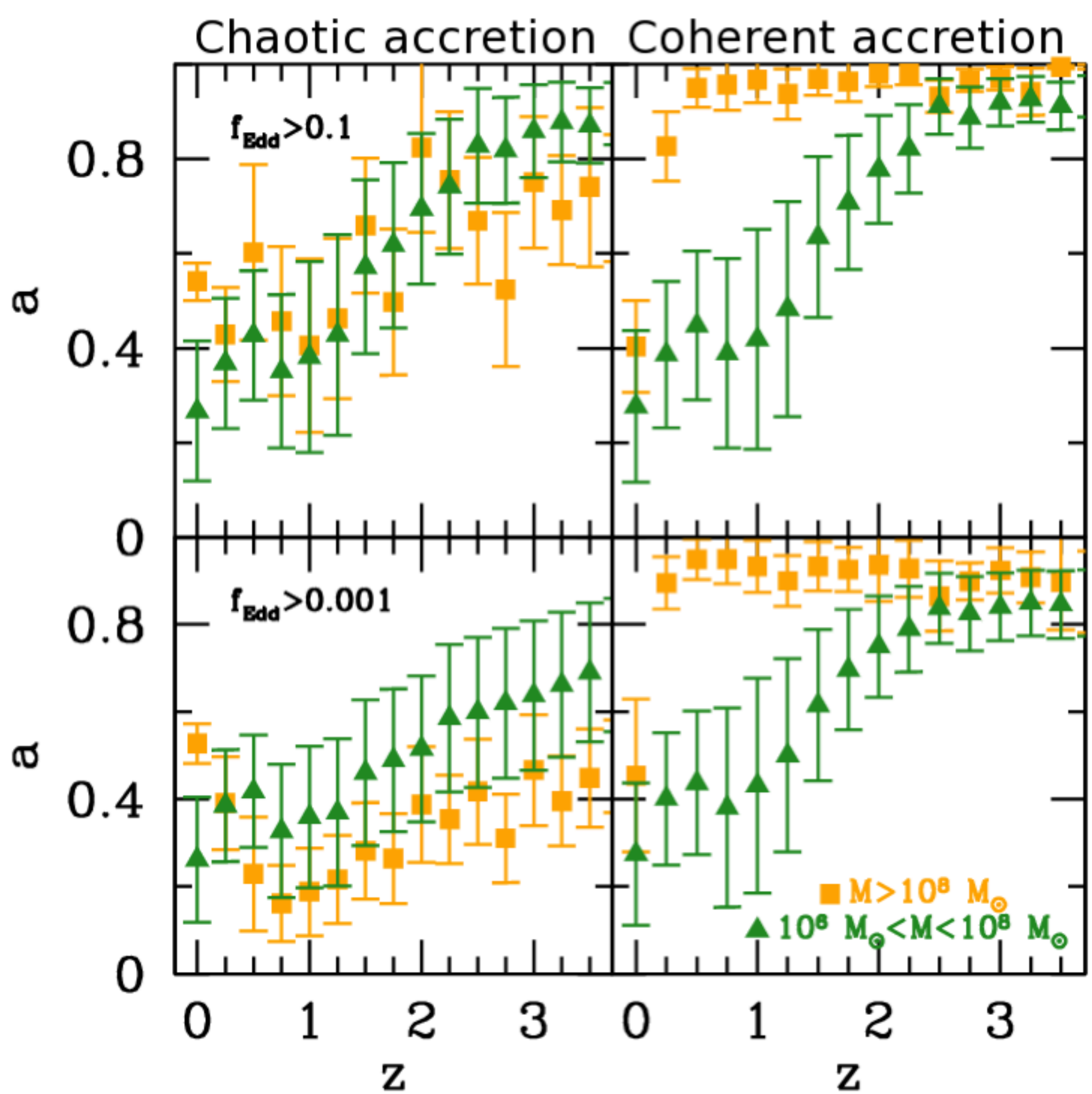
Spin up

Accretion via small, short
uncorrelated episodes

Galaxy mergers or Chaotic
accretion

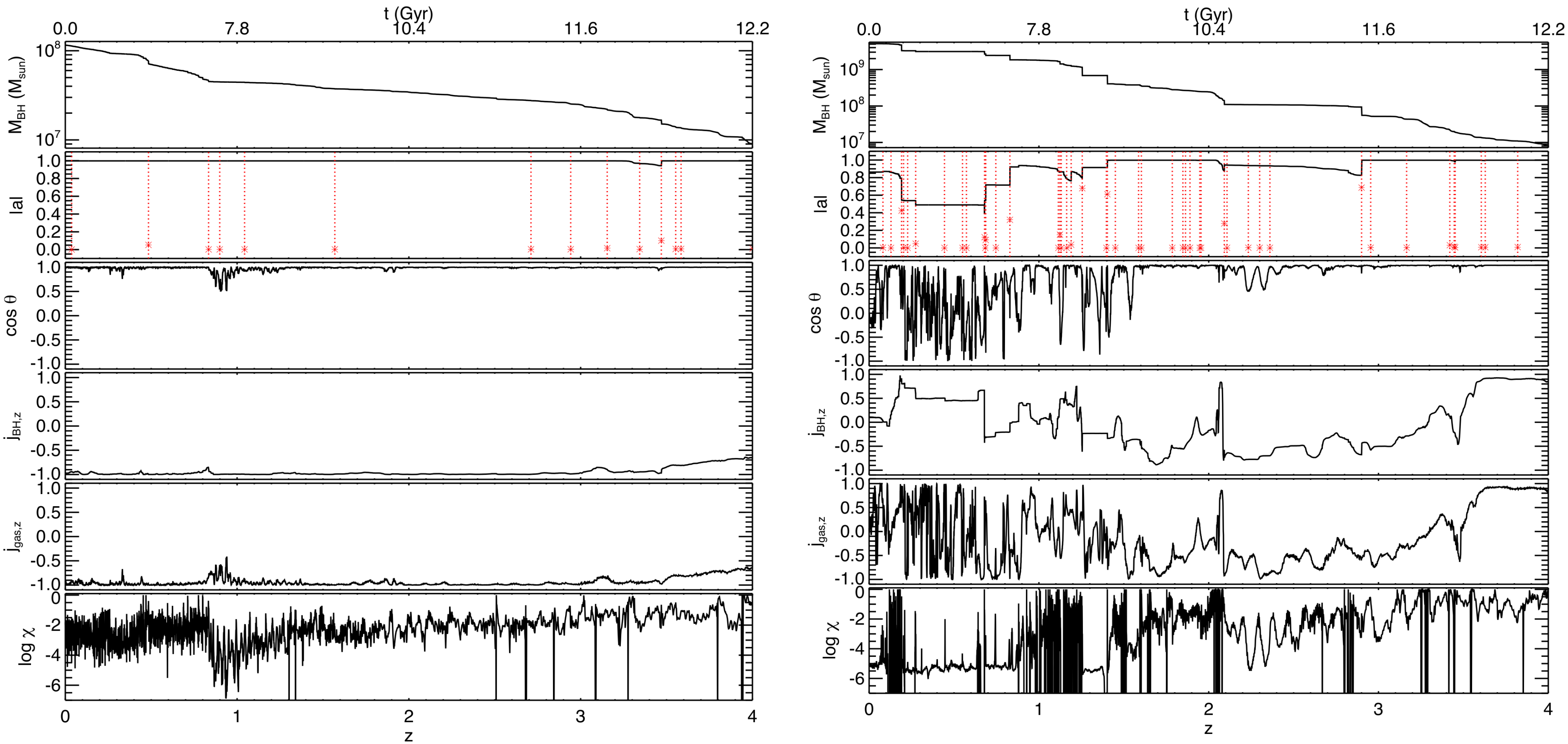
↓

Spin down



Volonteri et al. (2013)

Growth of Supermassive Black Holes



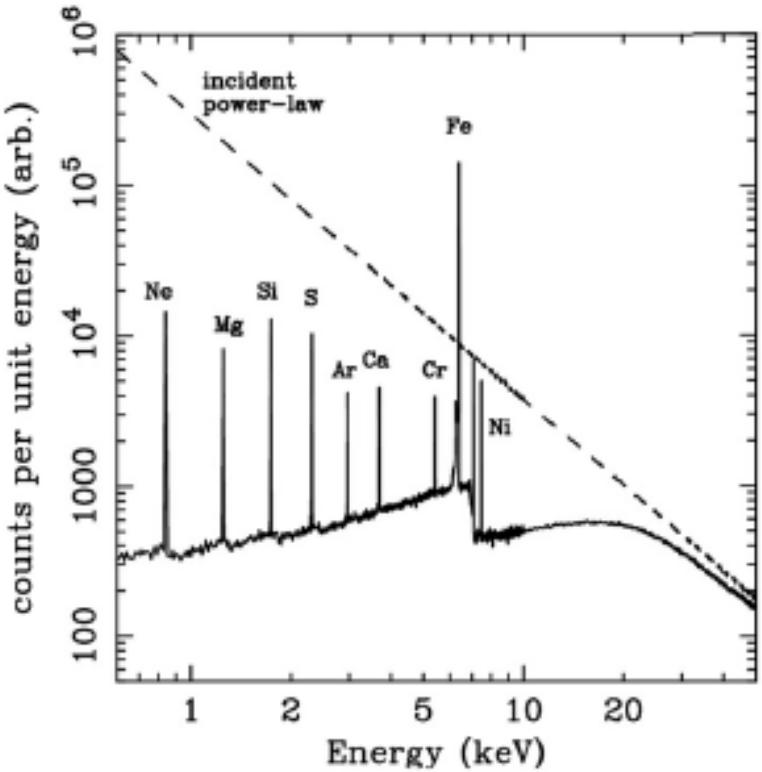
Coherent Accretion
M_{BH} = 1e8 M_{sun}
(~ 6% mergers)

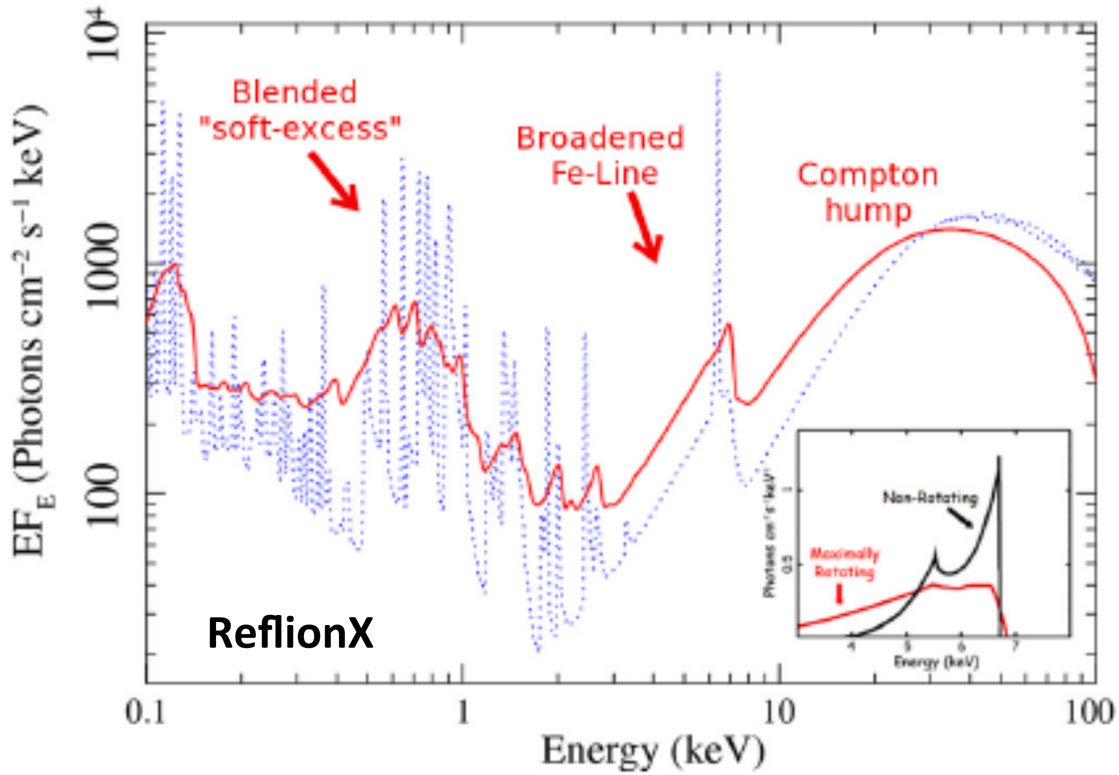
Chaotic Accretion
M_{BH} = 5e9 M_{sun}
(~73% mergers)

Dubois et al. (2014), Sesana et al. (2014)

Measuring BH Spin: The Reflection Paradigm

Test particles in strong gravity regime!



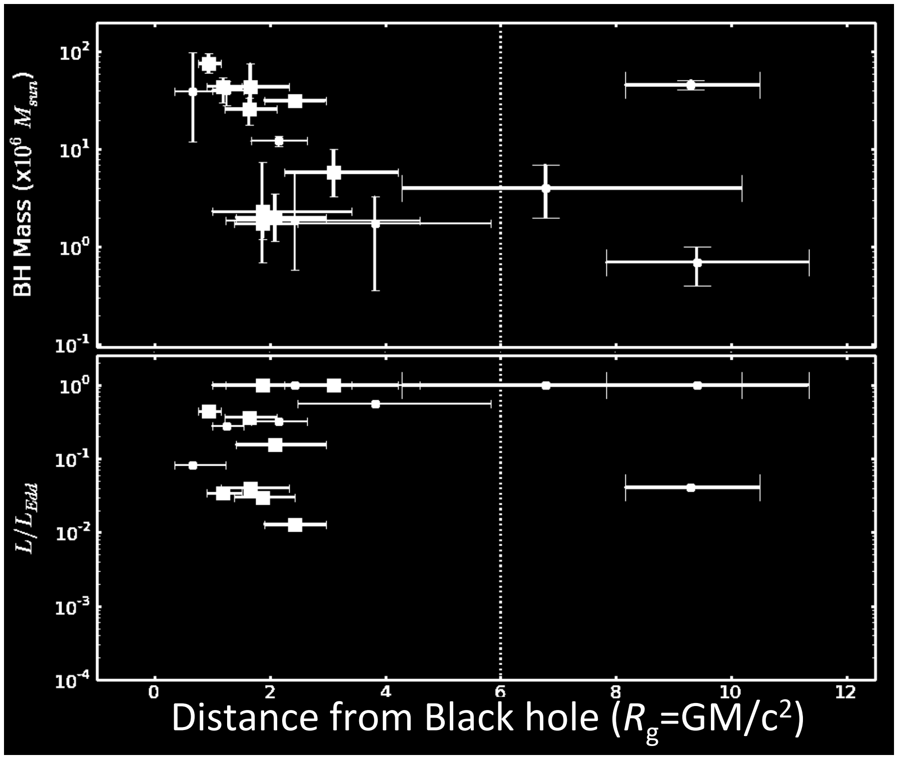


Strong gravity affects all of the reflection component
and is NOT limited to the Fe Kα line profile

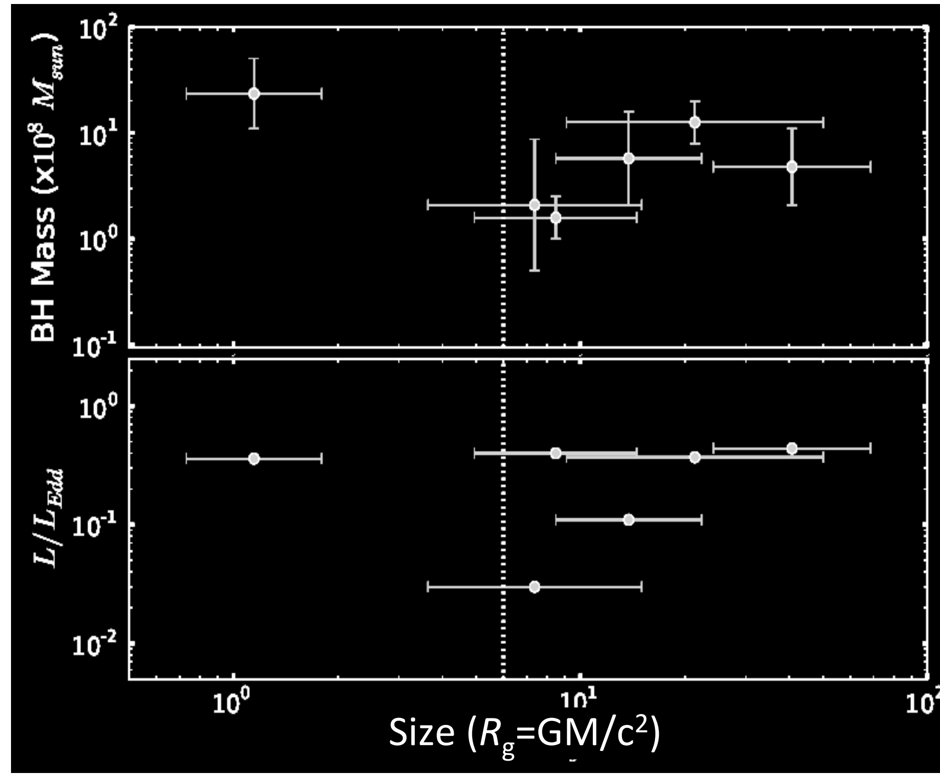
e.g., Ross & Fabian 2005, Dovciak 2011, Wilkins & Fabian 2012, Dauser et al. 2013

Black Hole Coronae

Coronae distance for 17 Seyferts based on reverberation lags



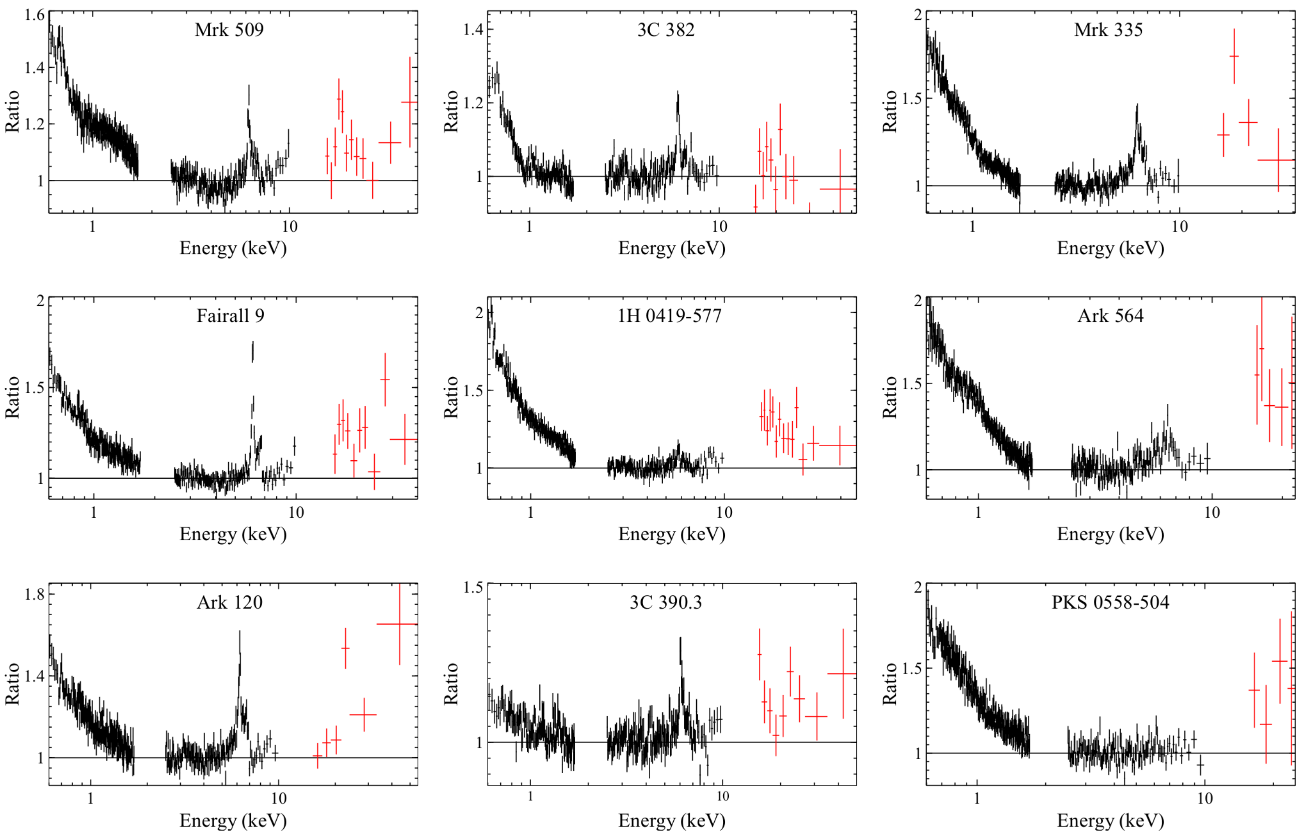
Coronal size for 6 Quasars based on microlensing



This sample suggests that black hole coronae are very compact and located near the black hole.

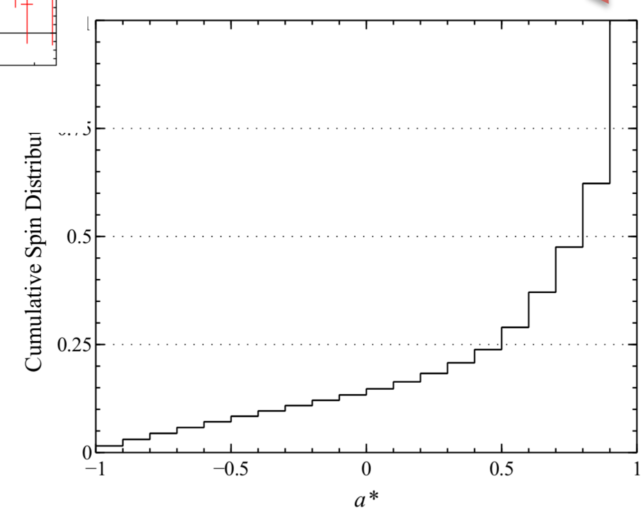
Reis & Miller (2013)

Spin of Local Seyferts



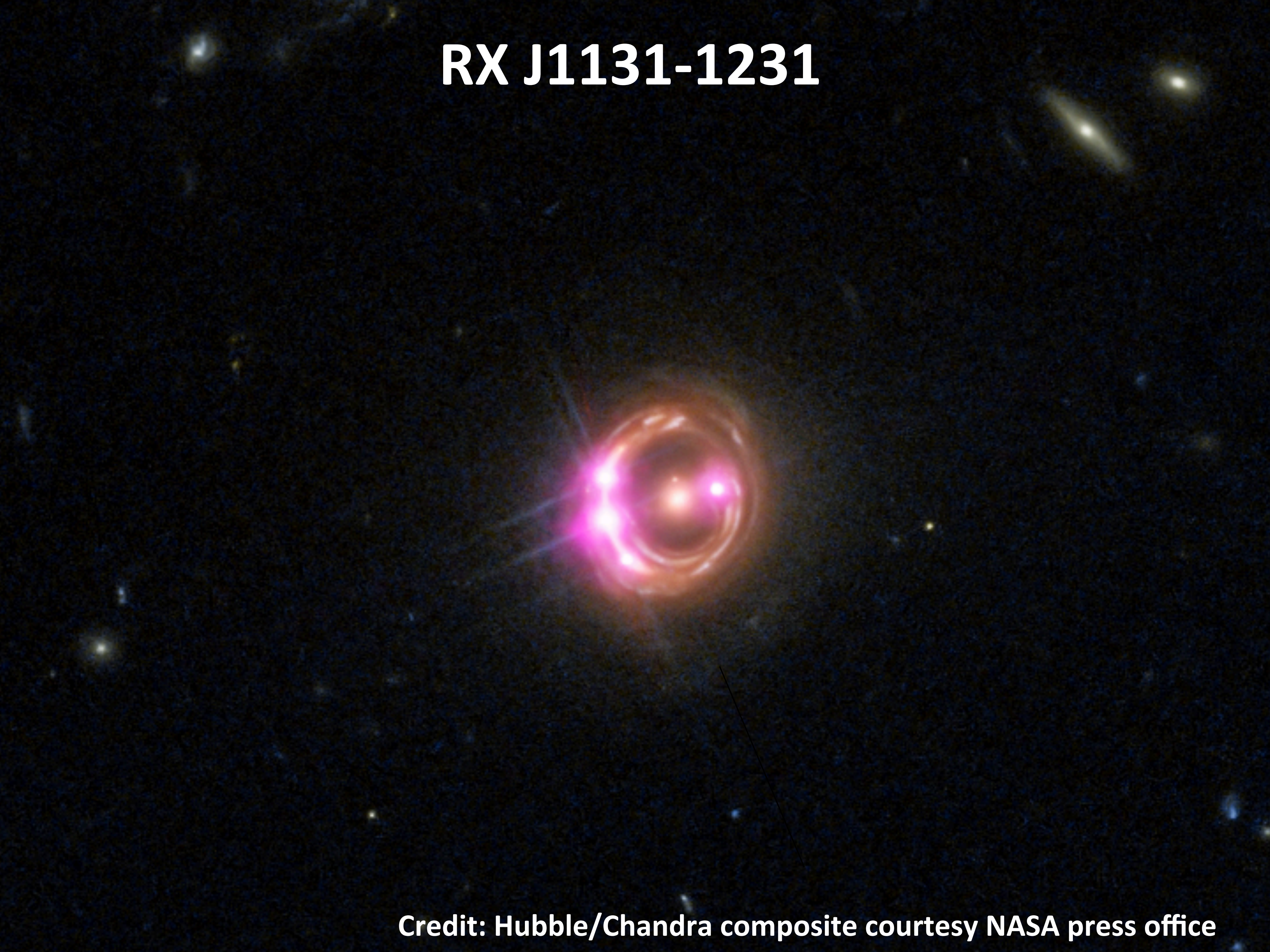
Favoring coherent scenario?

But… selection effects etc.

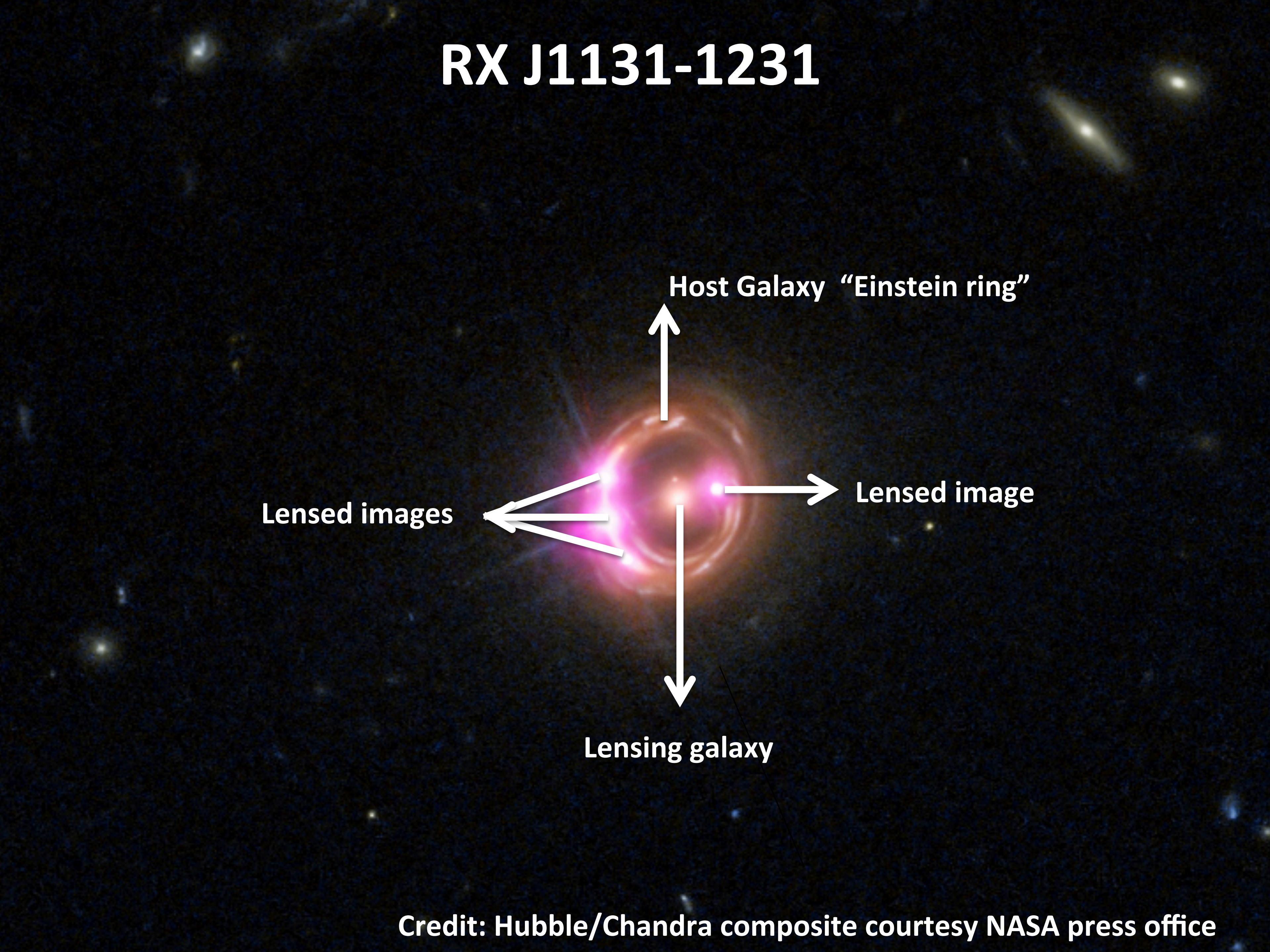


- Local AGN (z < 0.1) with minimal absorption.
- Characteristic reflection features present.

Walton et al. (2012), Reynolds (2013)


RX J1131-1231
Credit: Hubble/Chandra composite courtesy NASA press office

RX J1131-1231



Credit: Hubble/Chandra composite courtesy NASA press office

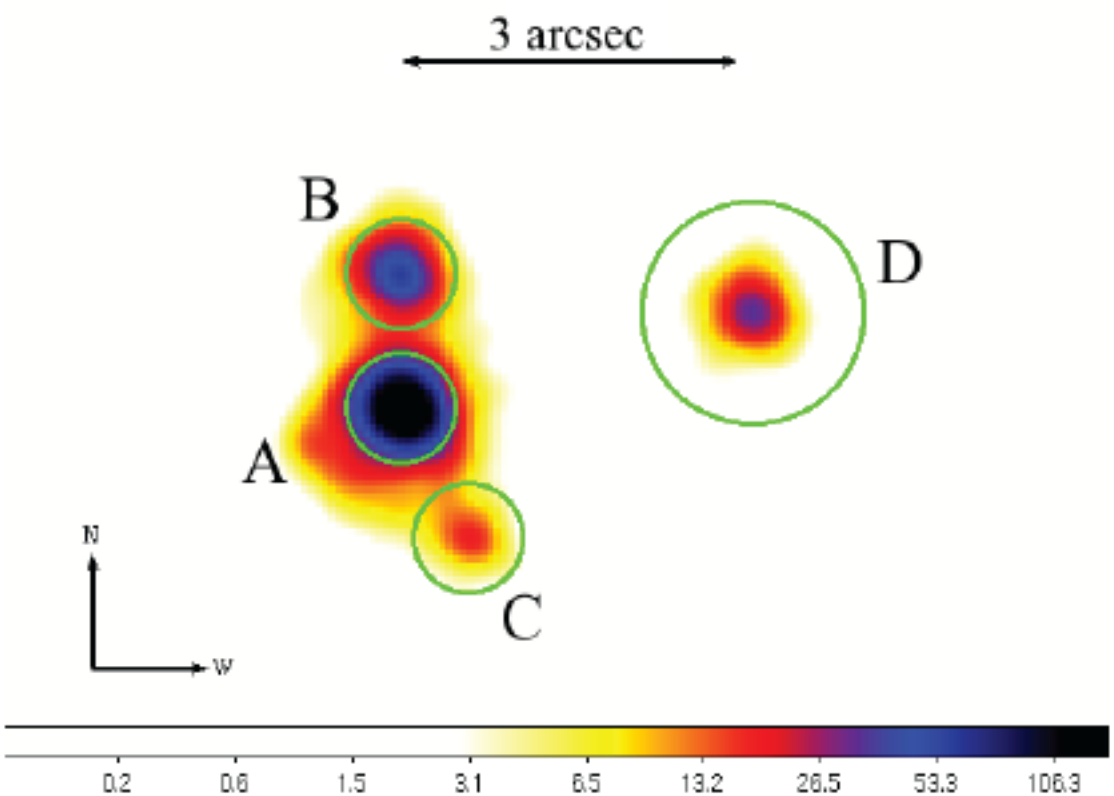
Gravitational lensing: A Natural Telescope

RX J1131-1231

Quasar at z=0.658, lensing galaxy at z=0.295

Mass ~ 2×10^{8} M_{sun} (via MgII line)

Intrinsic (non-magnified) luminosity $\log_{10}$ ~45 erg s^{-1} (magnification factor ~11.6)

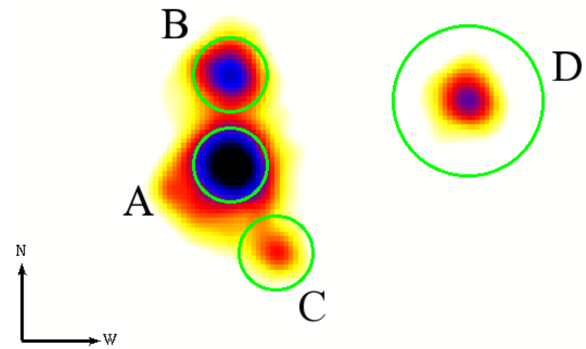


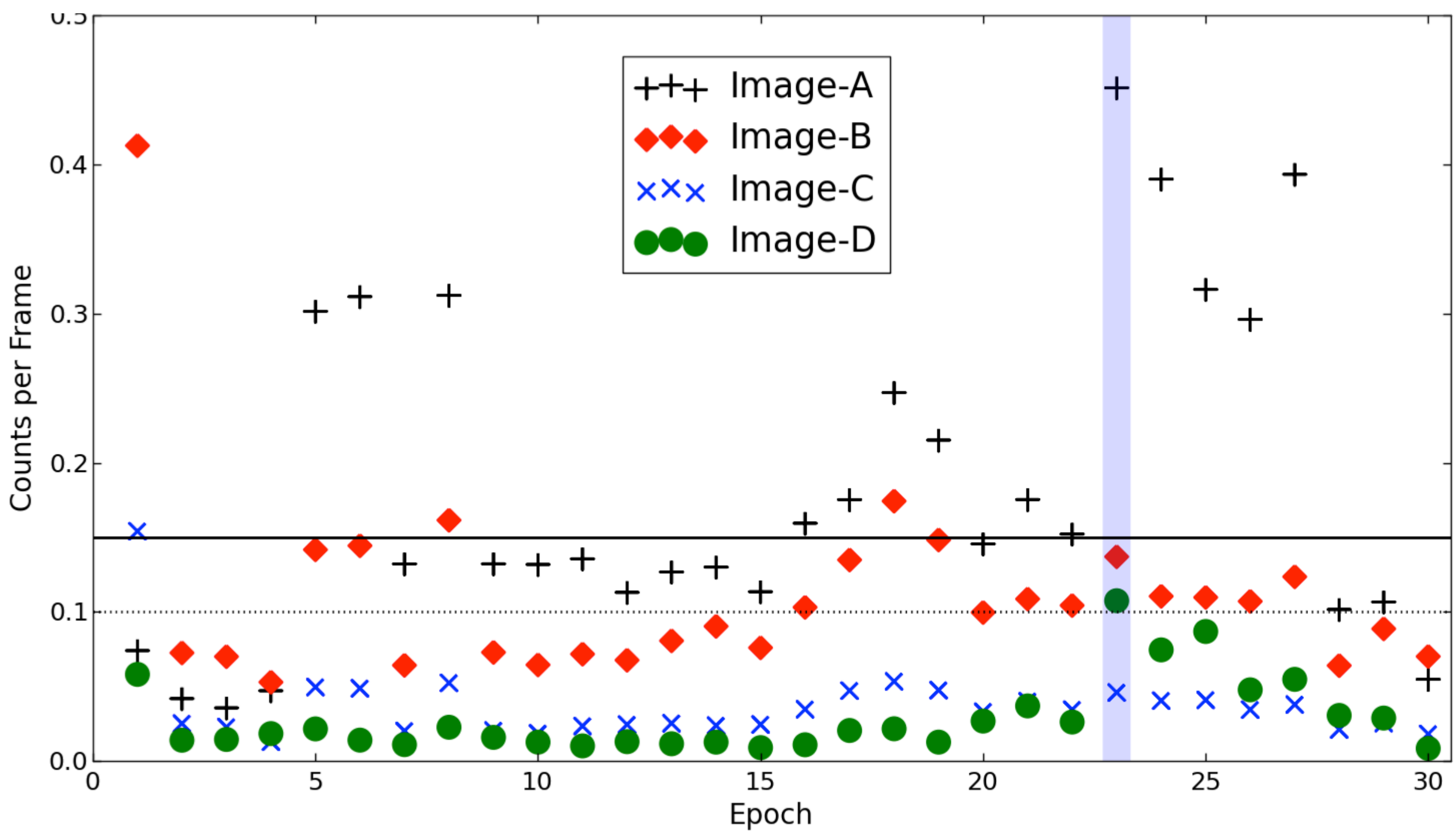
Magnification:

A = 23.7
B = 13.9
C = 13.4
D = 1.58

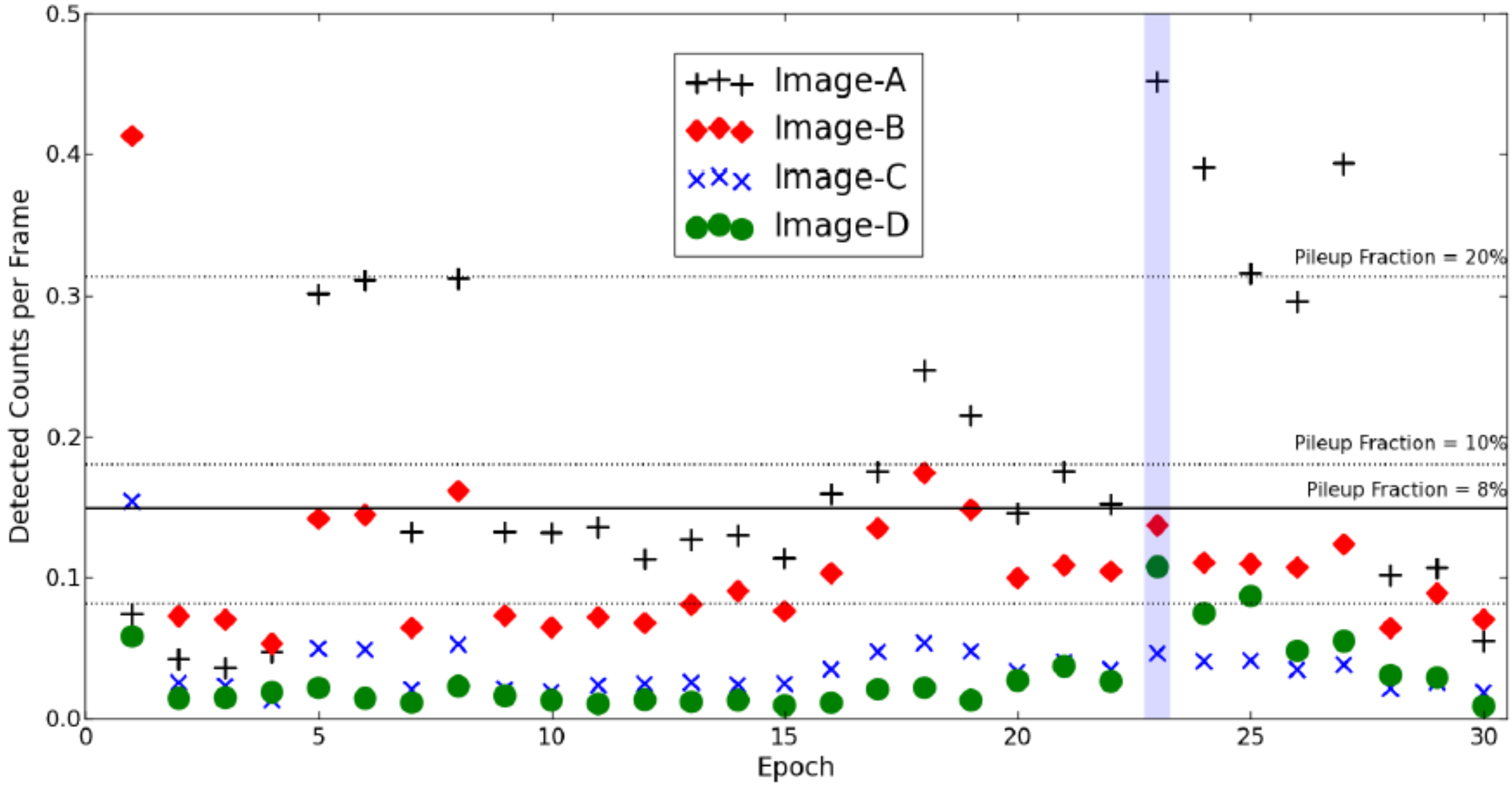
Blackburne et al. 2006

30 Chandra Pointings over 8 Years ~ 350ks





Pileup Estimates and Rejections

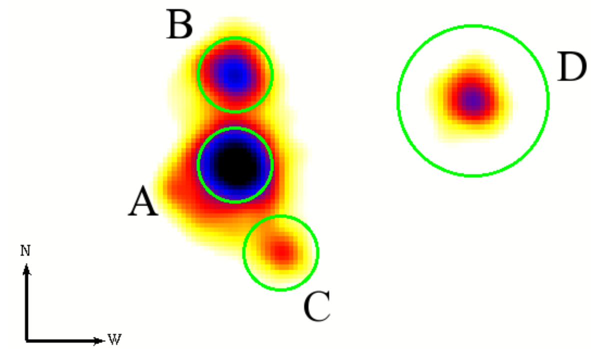


- Detailed MARX simulations
- Read out streak analysis
- Grade ratio comparison

Pile-up is negligible!

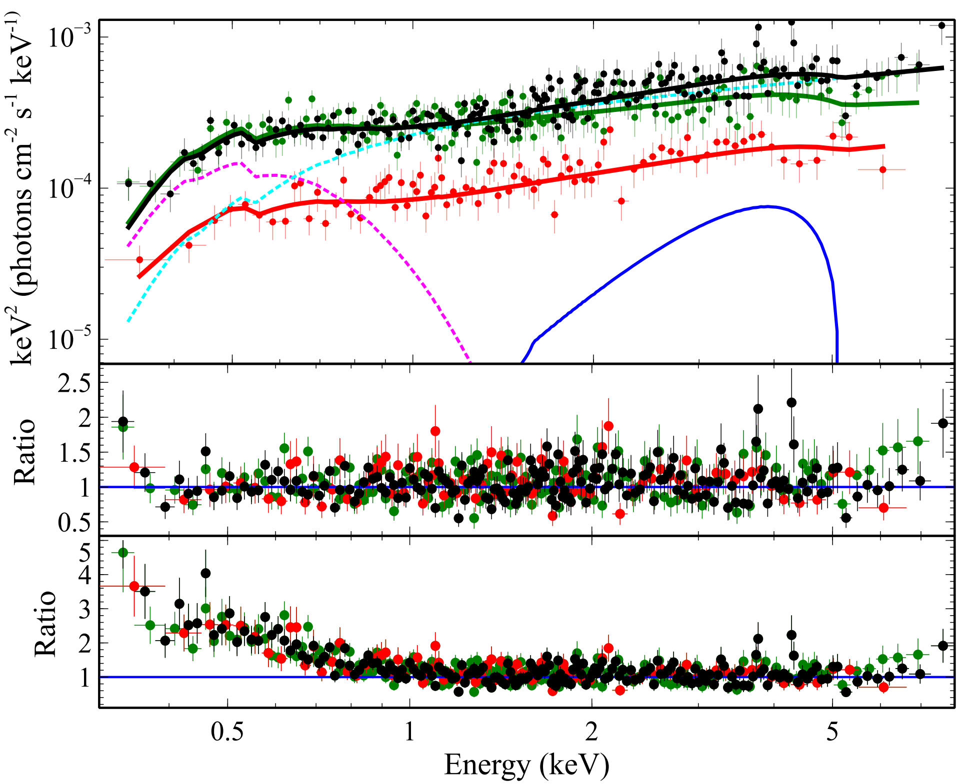
All observations with > 8% pile-up ignored

Representative Epoch:
Comparison of Images B, C & D



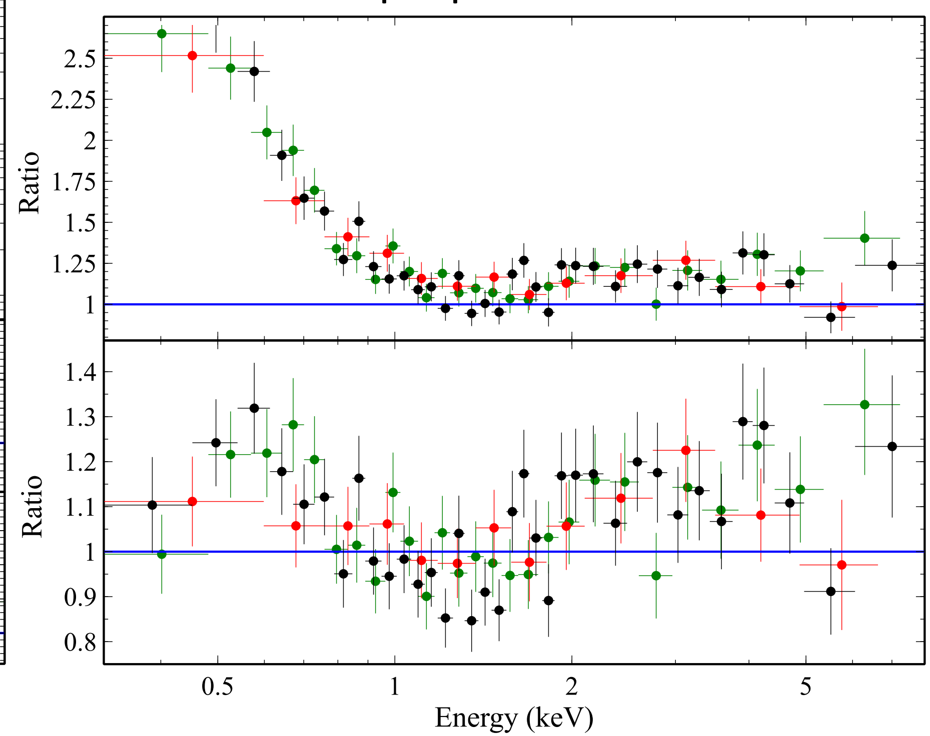
Purely *phenomenological* model

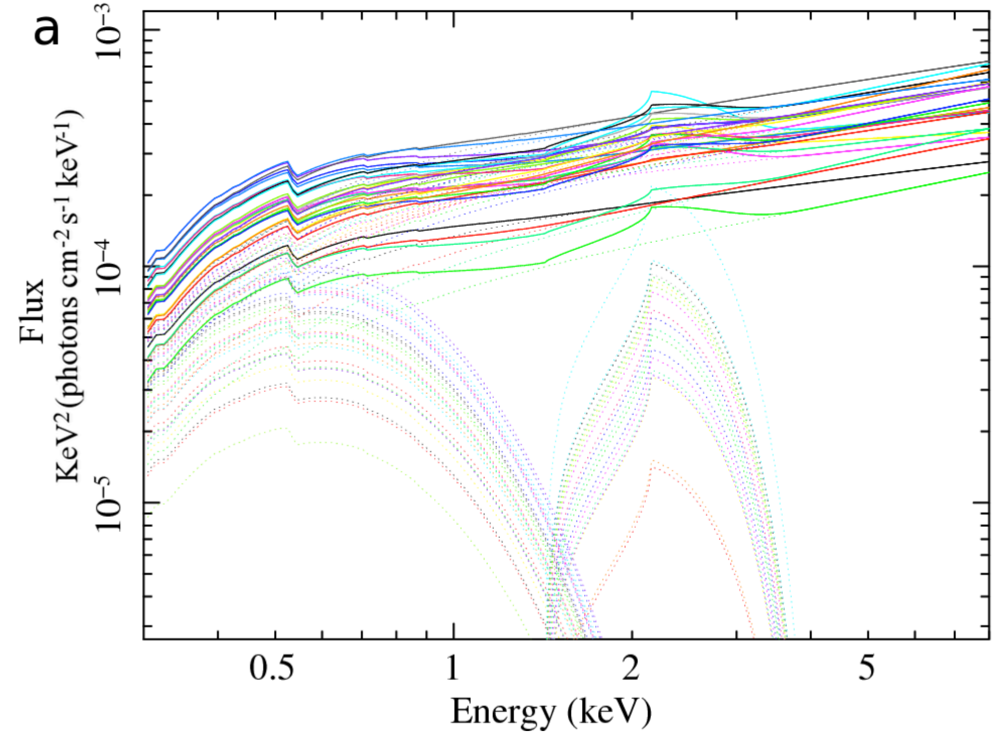
phabs x zphabs x(zpowerlaw + diskbb+ relline)



Top – Diskbb and Relline Norm = 0

Bottom – simple powerlaw fit





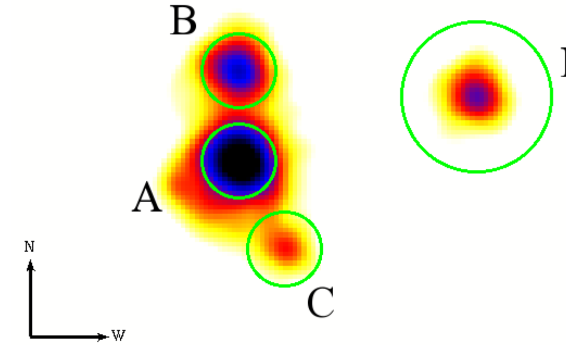
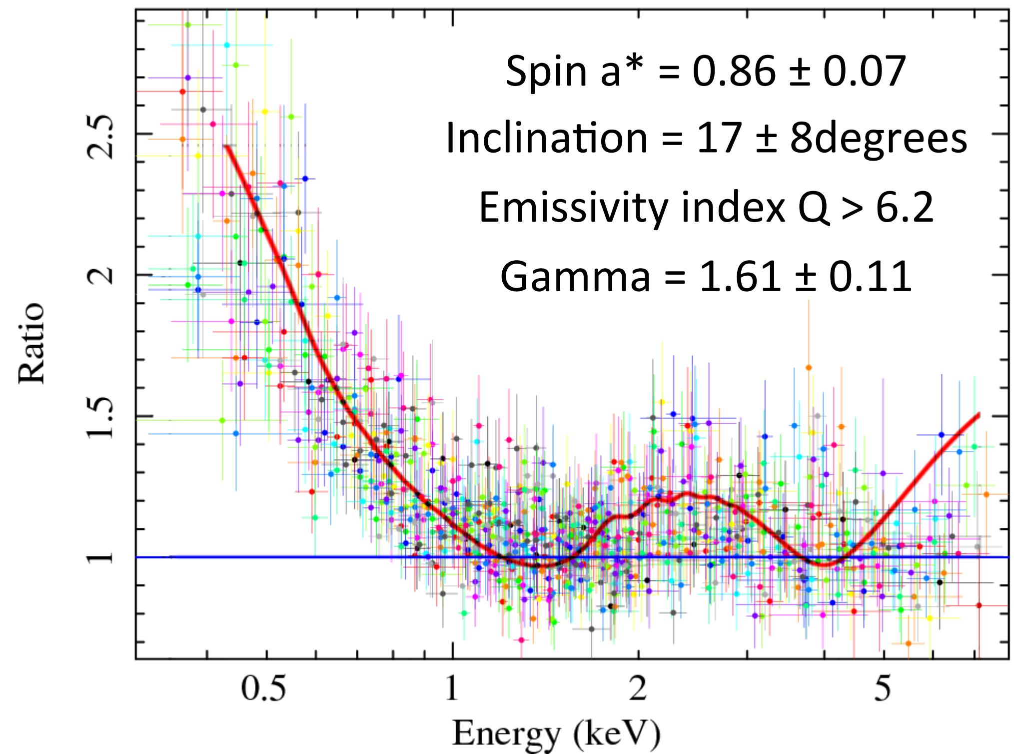
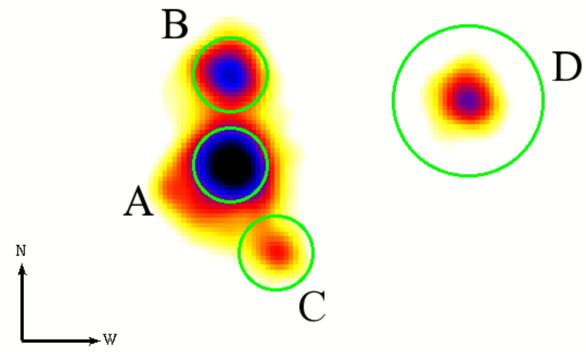


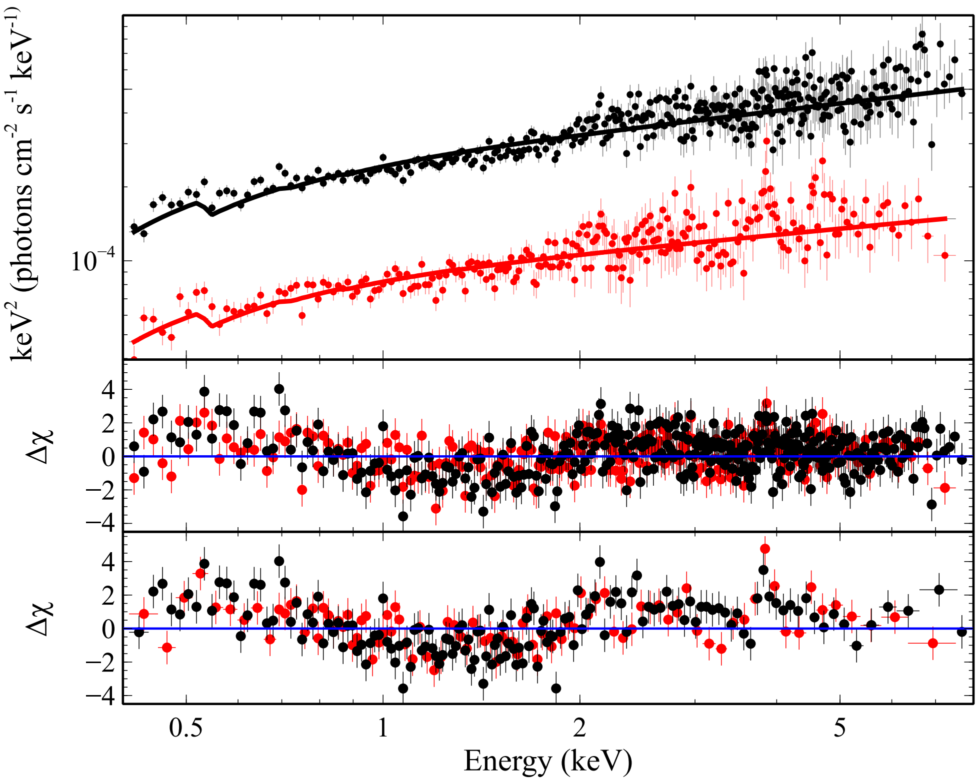
Image B All Epochs

DiskBB temperature, Relline energy, Inclination, spin and $N_{H(z=0)}$ were tied between epochs.

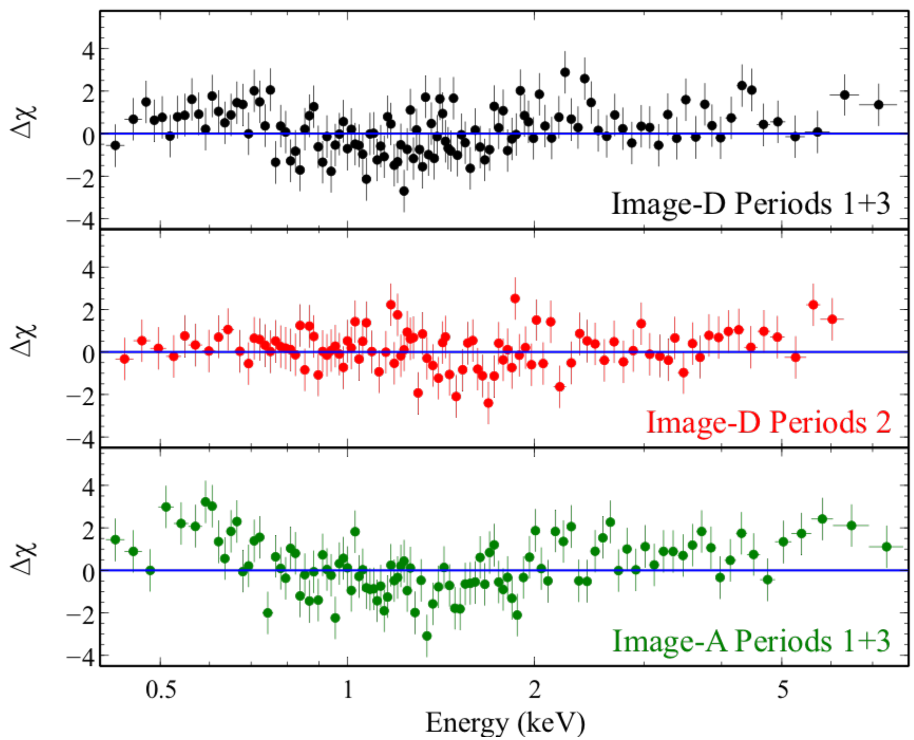


Increase S/N = add 'em up



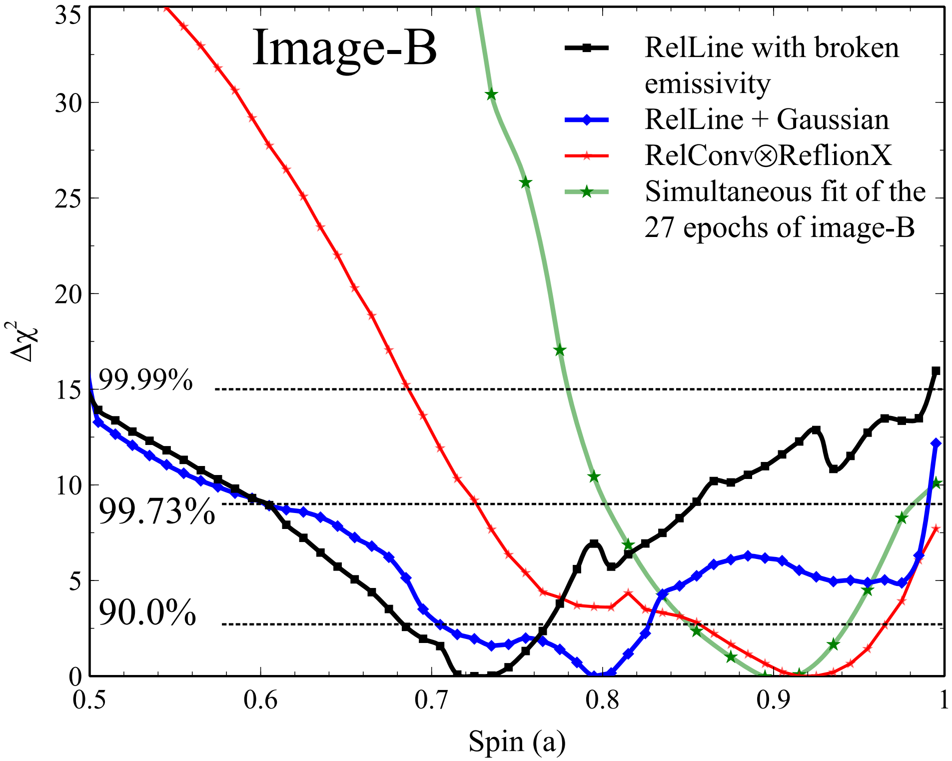


Images B and C



Images A and D

Co-Added Spectra of Individual Images



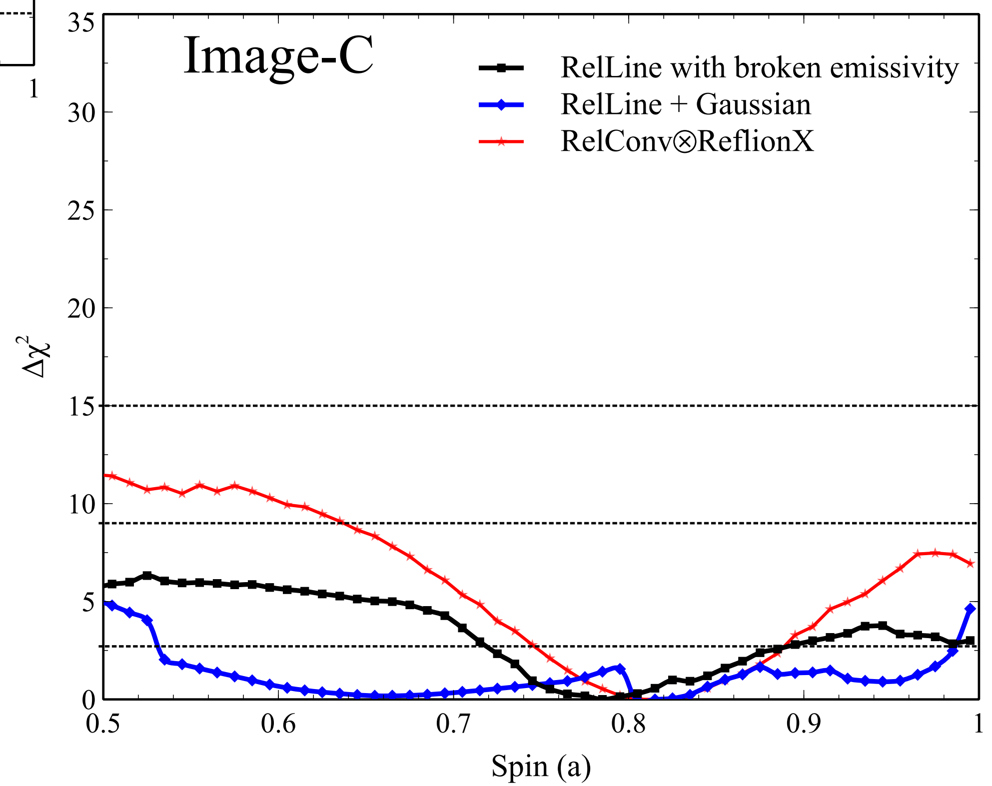
Fit with previous phenomenological model as well as using a self-consistent reflection model for the soft excess, broad line and Compton hump.

Purely *phenomenological* model

zpowerlaw + diskbb+ relline

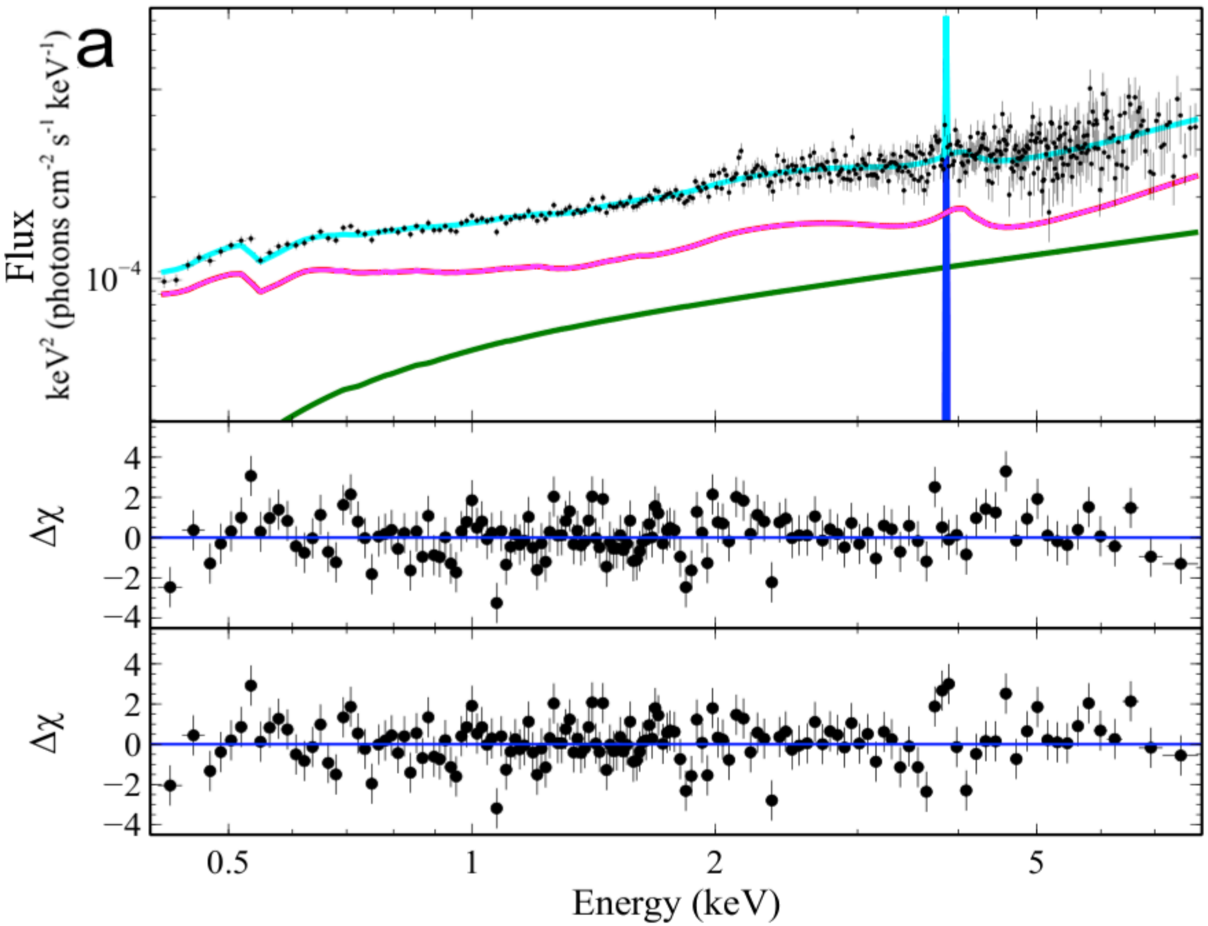
And *physical* model

zpowerlaw + relconv*reflionX



Chandra

$F_{(0.3 – 10.0\ keV)}$ ~ (1.45 +/- 0.06) e-12 erg s^{-1} cm^{-2}



$a^* = 0.9^{+0.07}_{-0.15}$

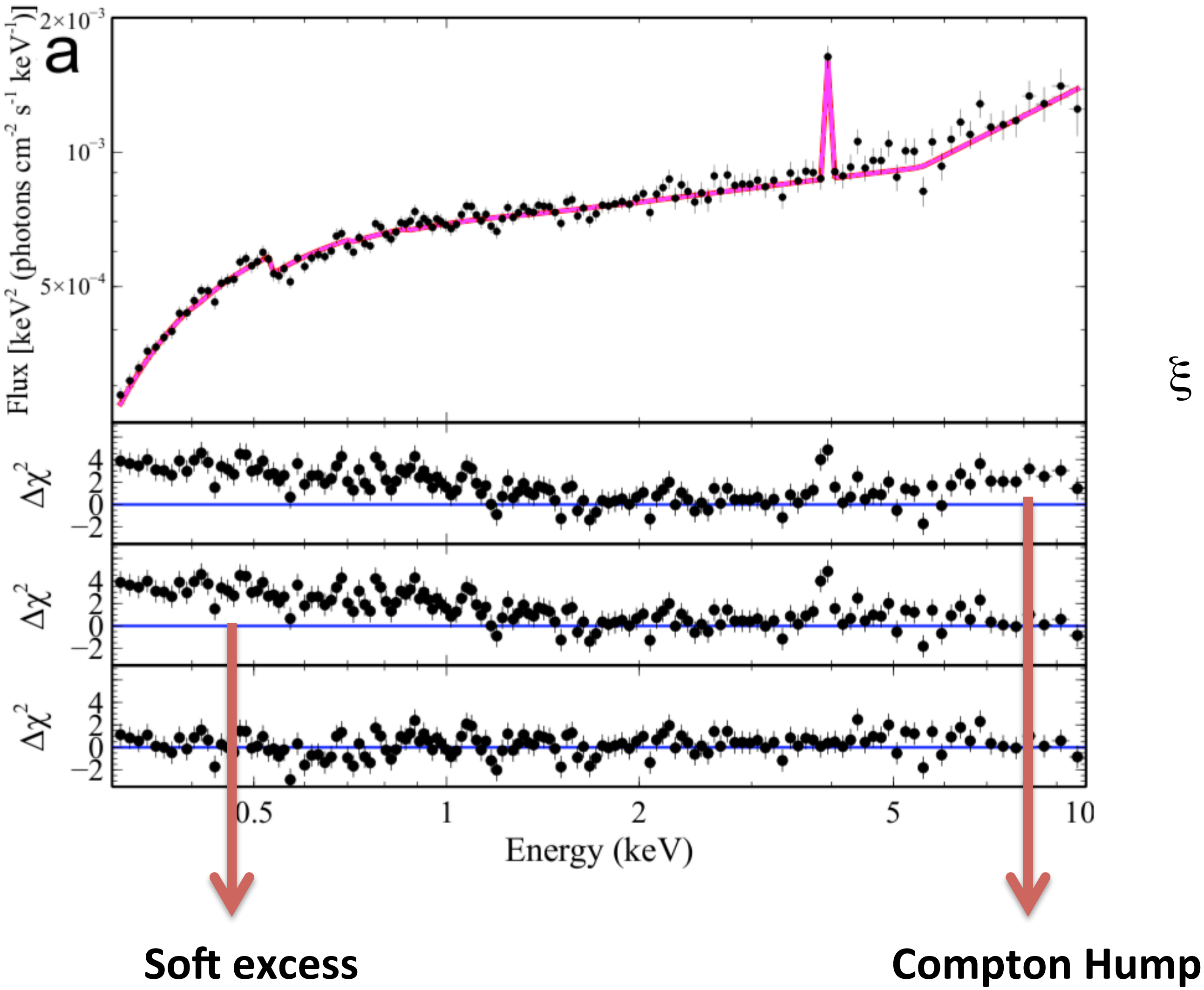
ξ = 725 +/- 200 erg s^{-1} cm^{-2}

Γ = 1.59 +/- 0.08

R_{frac} = 1.7 +/- 1.0
(0.1 – 100 keV)

XMM-Newton

$F_{(0.3 – 10.0\ keV)}$ ~ (5.52 +/- 0.05) e-12 erg s^{-1} cm^{-2}



$a^* = 0.64^{+0.33}_{-0.14}$

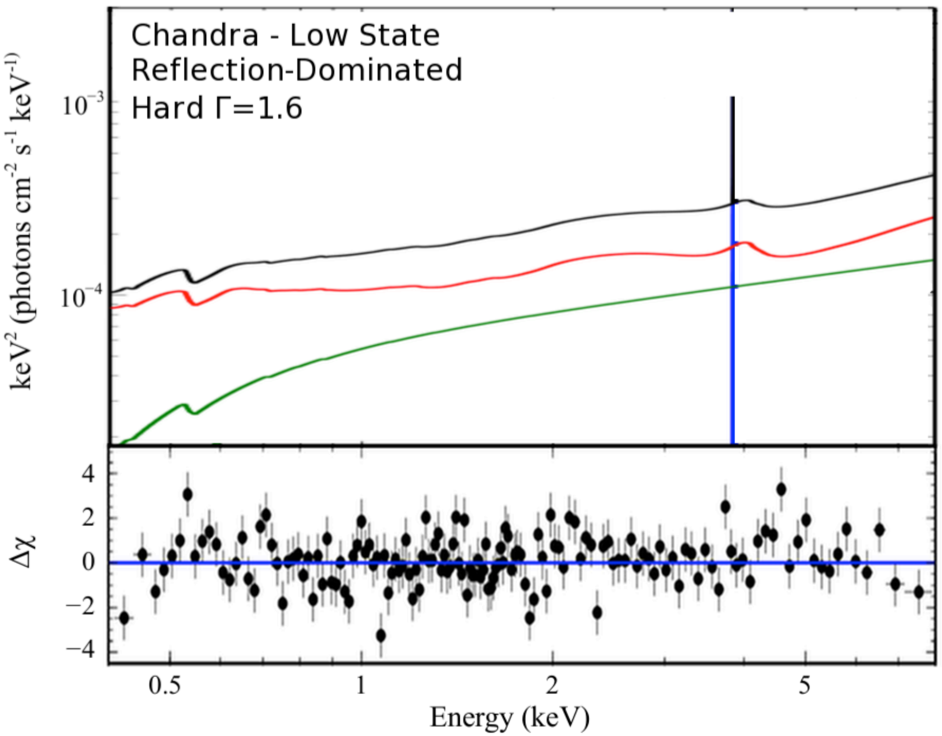
ξ = 90 +/- 20 erg s^{-1} cm^{-2}

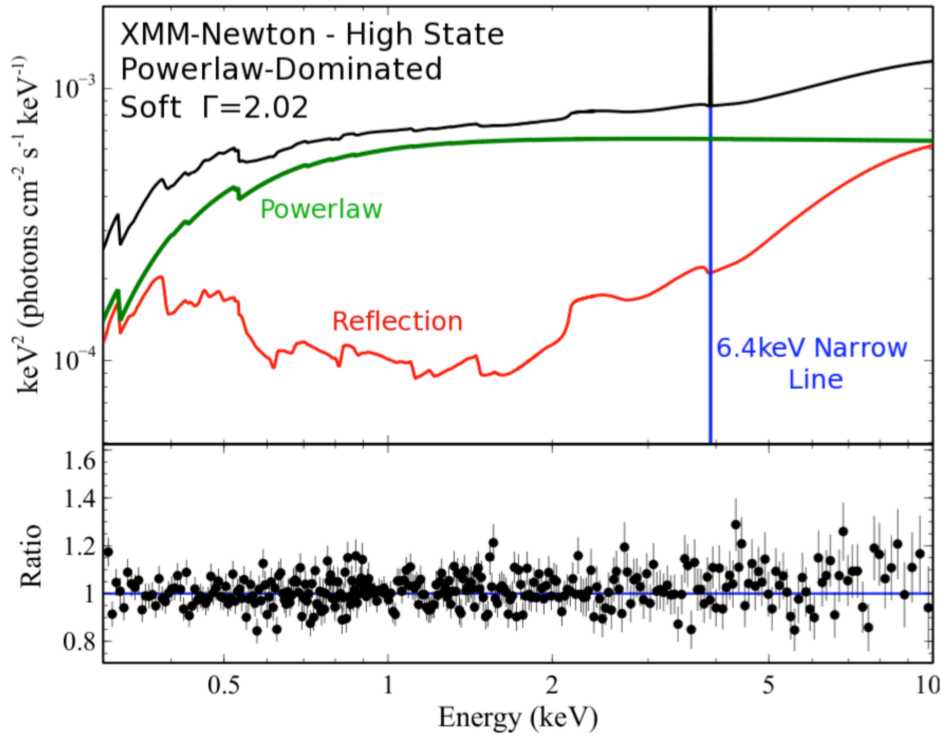
Γ = 2.02 +/- 0.04

R_{frac} = 0.53 +/- 0.13
(0.1 – 100 keV)

Chandra (Γ=1.6) *XMM-Newton* (Γ=2.02)

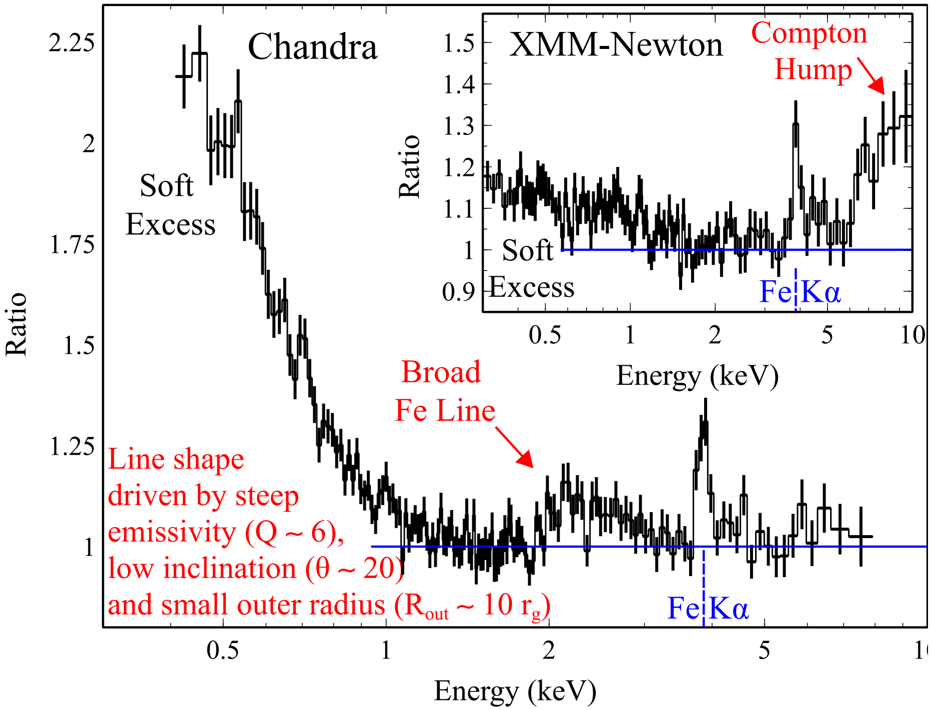
zpowerlaw + relconv*reflionX

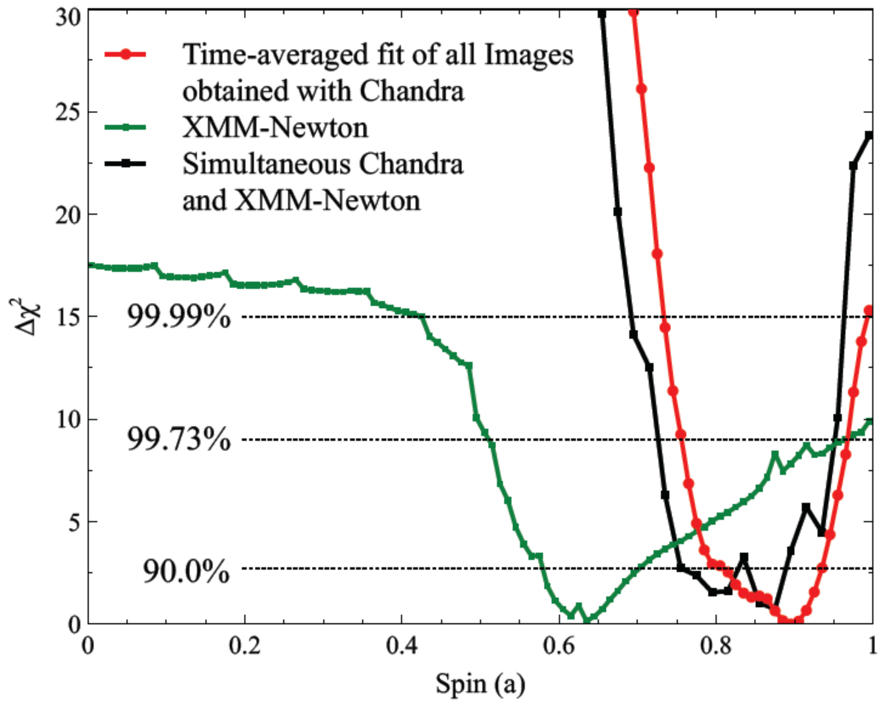




Similar behavior has been reported for a number of local AGN, most famously 1H 0707-495 (Fabian et al. 2009) and MCG-6-30-15 (Vaughan & Fabian 2004) as well as numerous stellar mass black holes (e.g. Reis et al. 2013)

Reflection From the Strong Gravity Regime in a z = 0.658 Gravitationally Lensed-Quasar

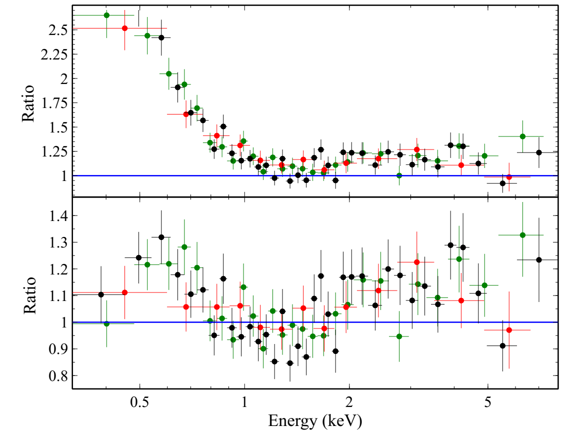




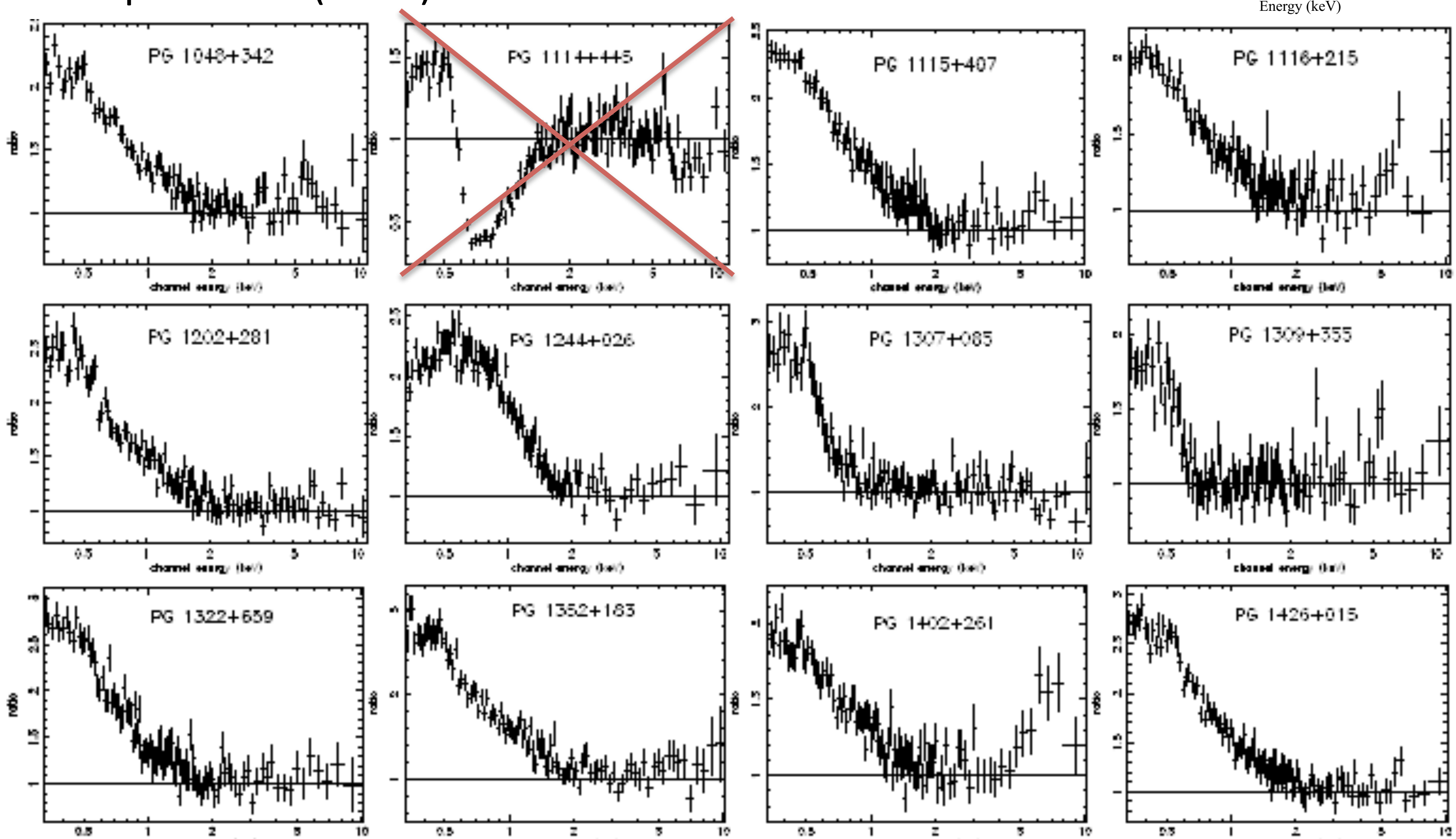
$$a = 0.87^{+0.08}_{-0.15} \ (3\sigma \text{ confidence})$$

Reis et al., *Nature* 2014, 507, 207

PG Quasars Showing Clear Soft Excess

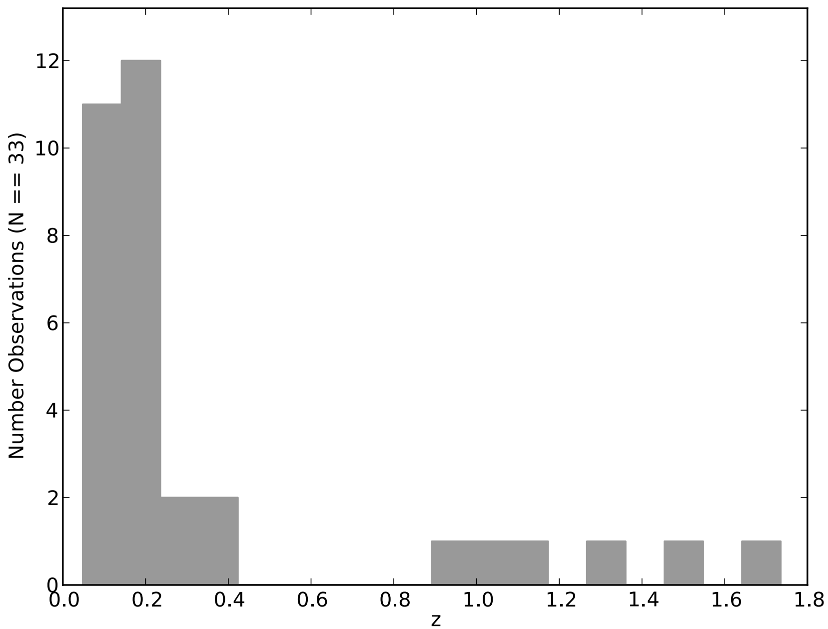


Porquet et al. (2004)

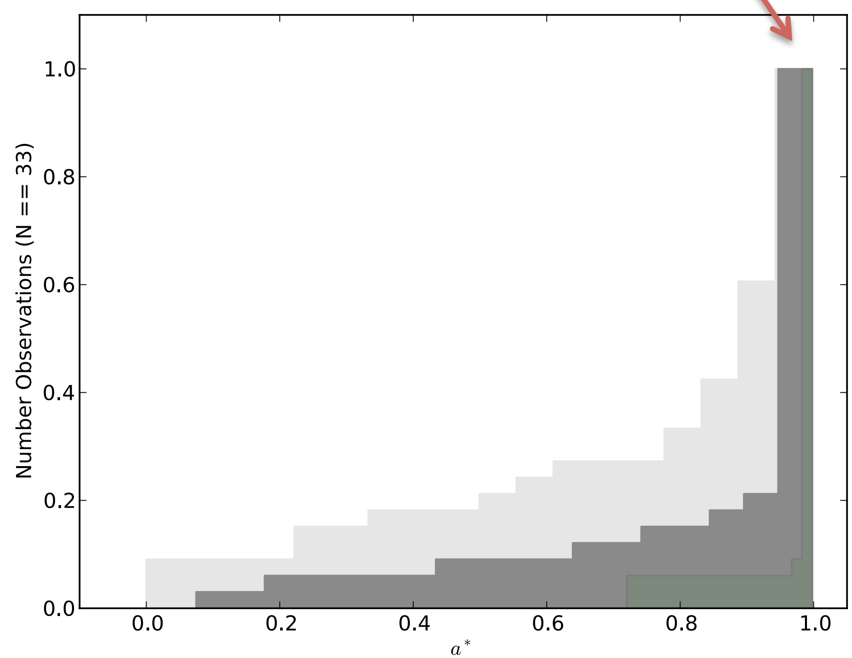


PG Quasars Showing Clear Soft Excess

Favoring coherent scenario?



Redshift Distribution

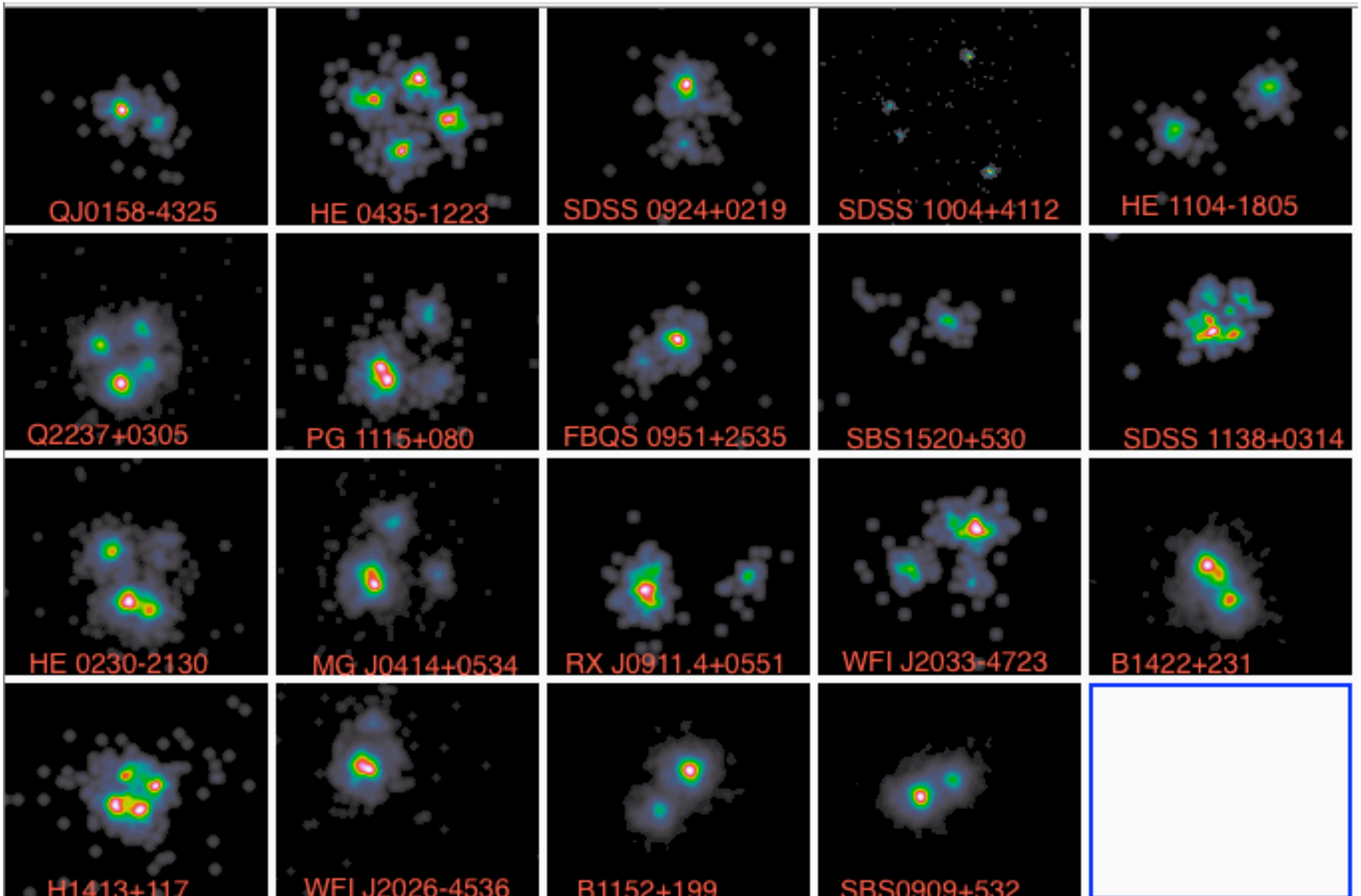


Spin Distribution

Preliminary

Reynolds et al. in prep

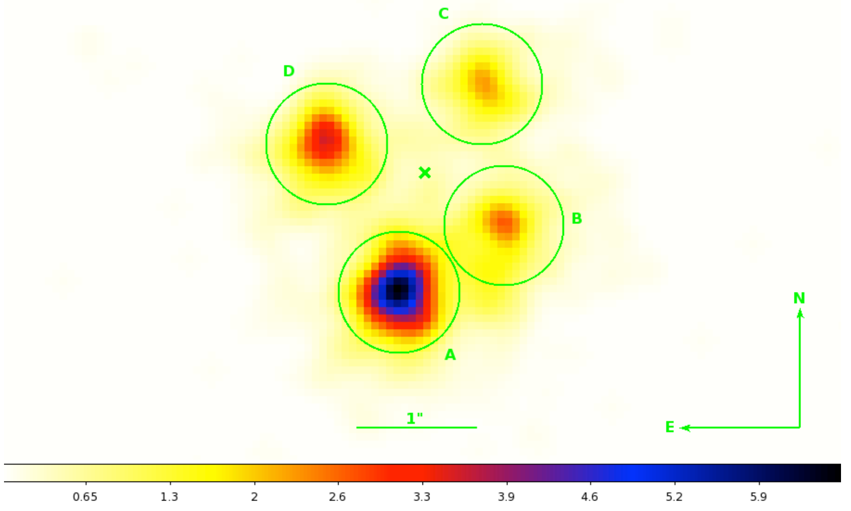
Future Prospects...

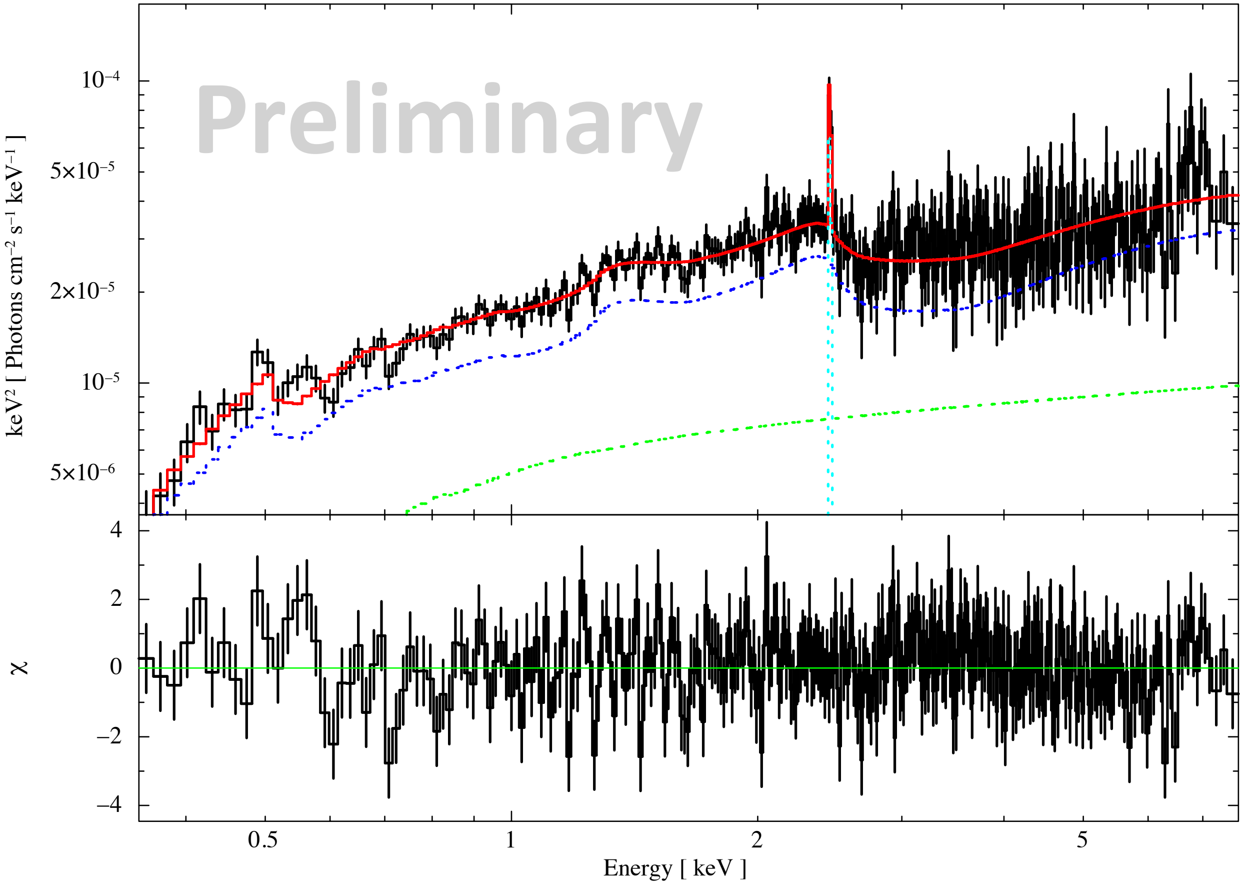


Q2237+0305

The ``Einstein cross'', a quadruply imaged quasar at z = 1.695

E.g., Schmidt et al. 1998, Dai et al. 2004

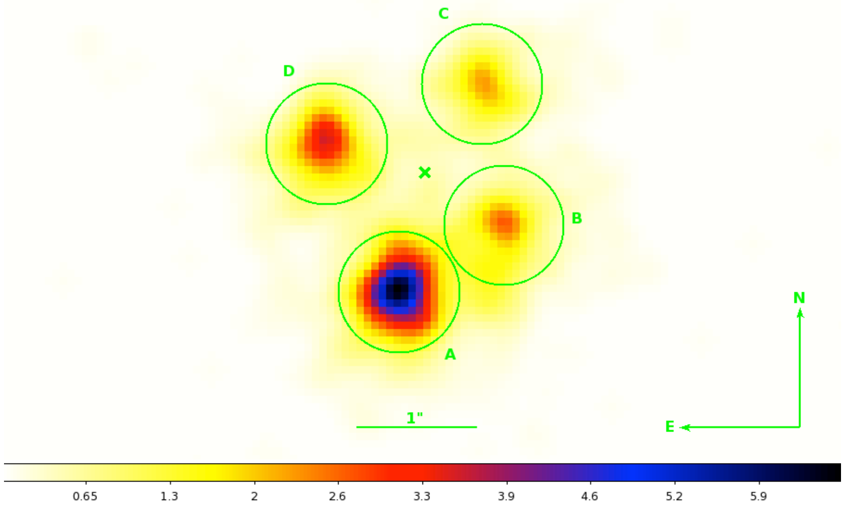




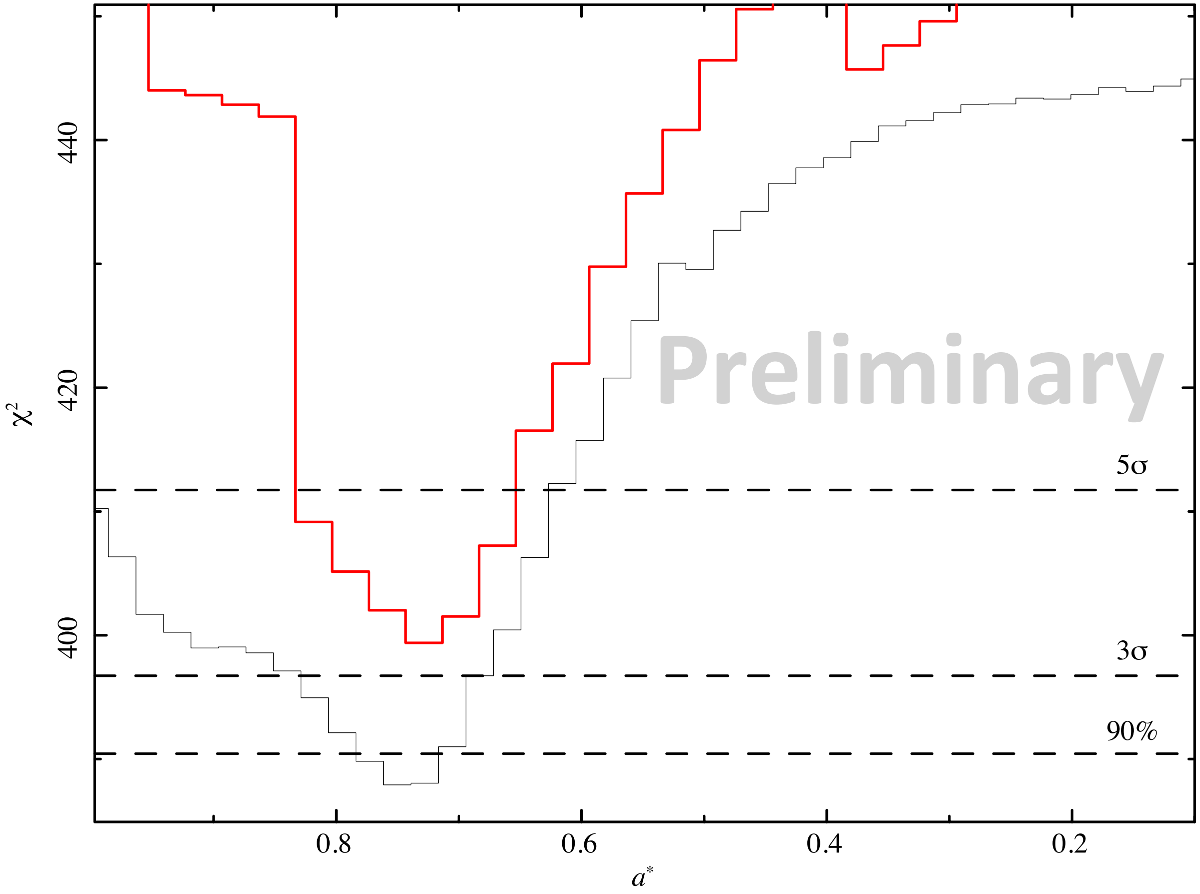
- **Lens at z ~ 0.03**
- **480 ks over 10 yrs with *Chandra***
- **Magnification ~ 10x**
- **Spectrum shows strong ``Reflection'' features**
- **23k counts…**

Q2237+0305

$a^* > 0.6$ **(5σ)**



Reynolds et al. (in prep)



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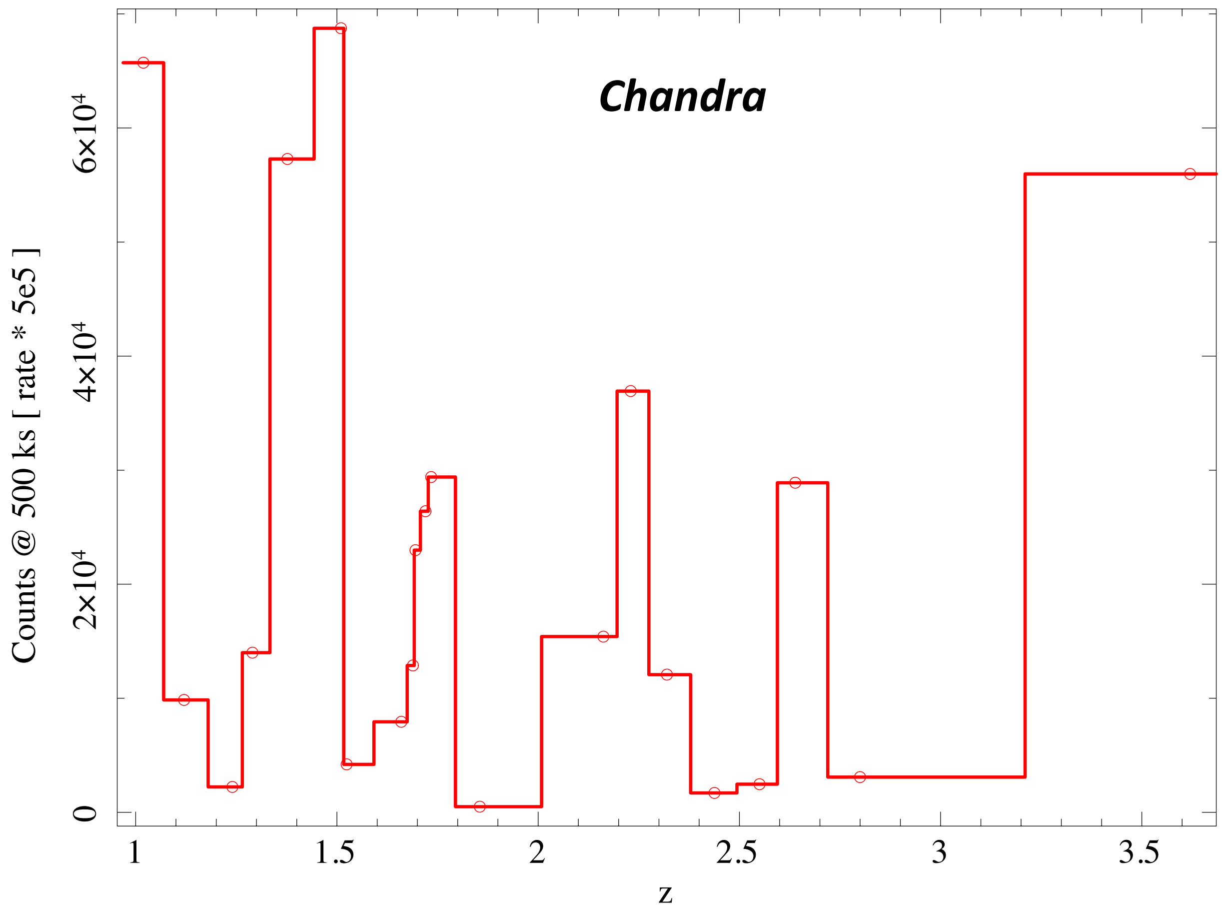
Future → towards Athena+

Expected cumulative counts from the sample of lensed quasars in a 500 ks exposure



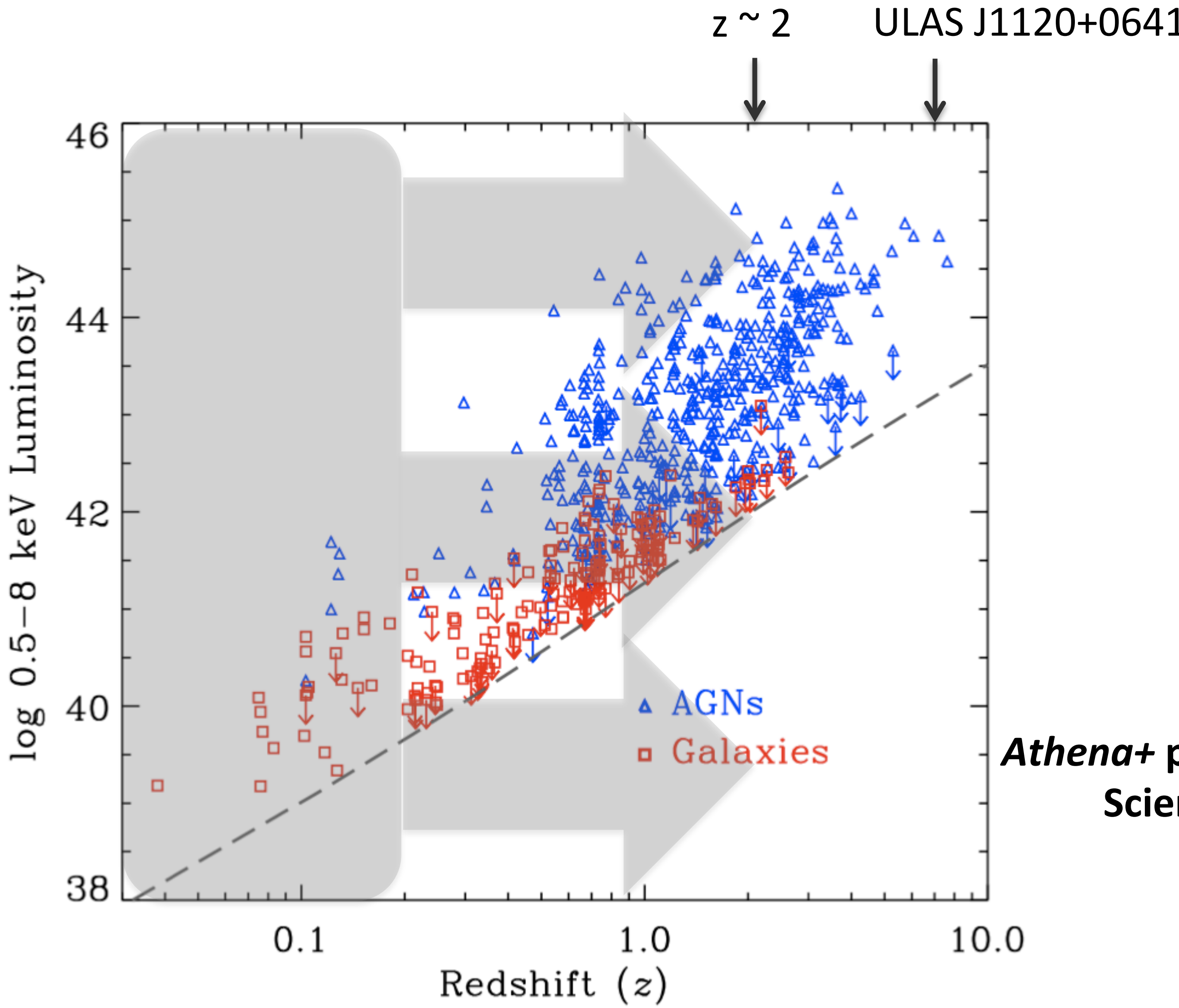
XMM-Newton

Larger → Scale ~ 1.5x

***Athena+* pathfinder Science!**

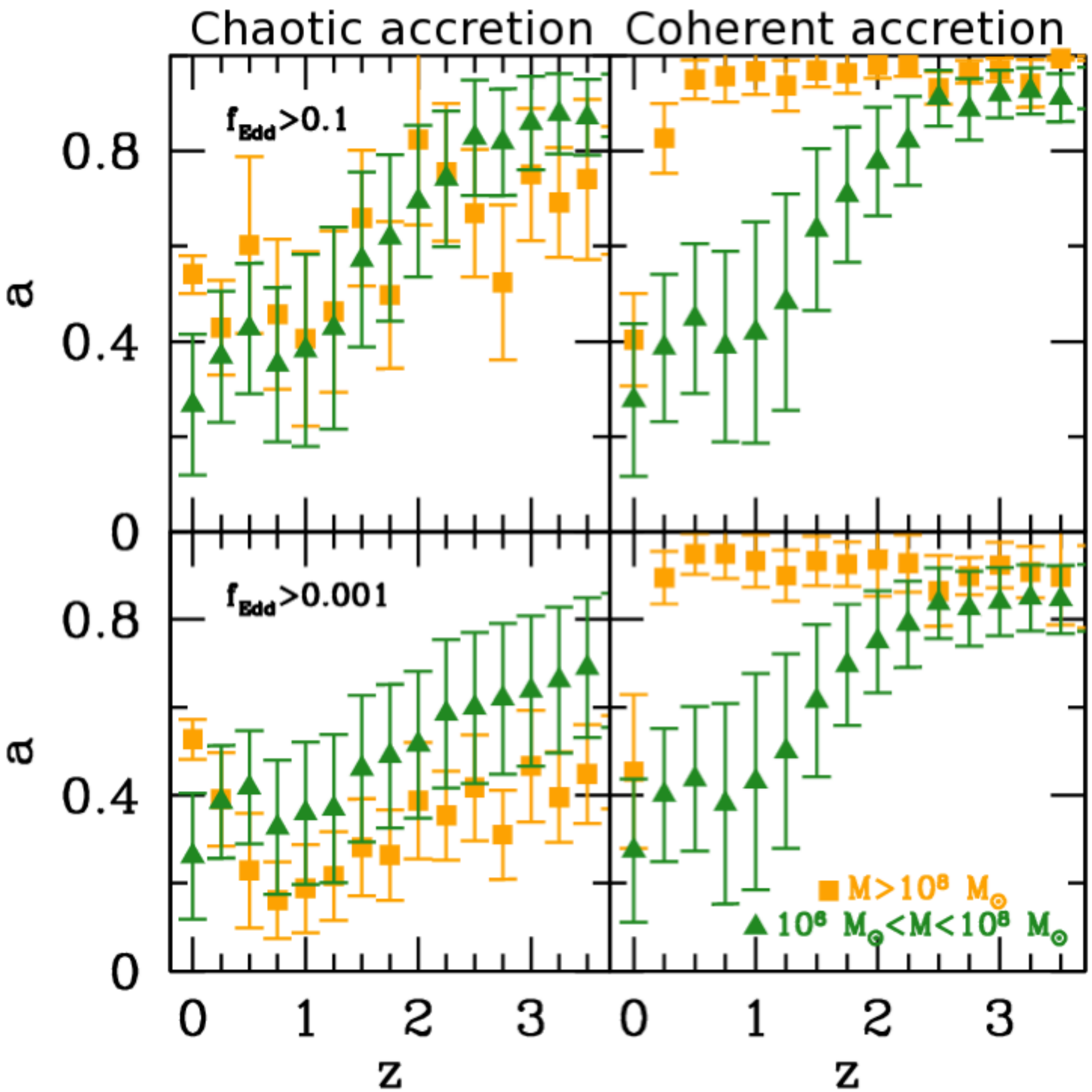
Future → Towards Athena+

2014 → 2020/2030 → 2100?



***Athena+* pathfinder Science!**

Growth of Supermassive Black Holes



z < 0.1
→ local Seyferts

0.1 < z < 0.4
→ PG Quasars

z > 0.5
→ lensed systems

Volonteri et al. (2013)

Summary

- **Gravitational lensing offers a rare opportunity to study the innermost relativistic region in distant quasars.**

- **Ability to study the inner regions around cosmological black holes brings with it the potential to measure their spin:**

  → Directly study the co-evolution of the black hole and its host galaxy

- **Dramatic increase in the flux due to gravitational-lensing allows us to begin assembling a sample of supermassive black hole spins at moderate ($z < 1.5$-2.5) redshift with current X-ray observatories.**

Need deep observations with *XMM-Newton* and *Chandra*!