



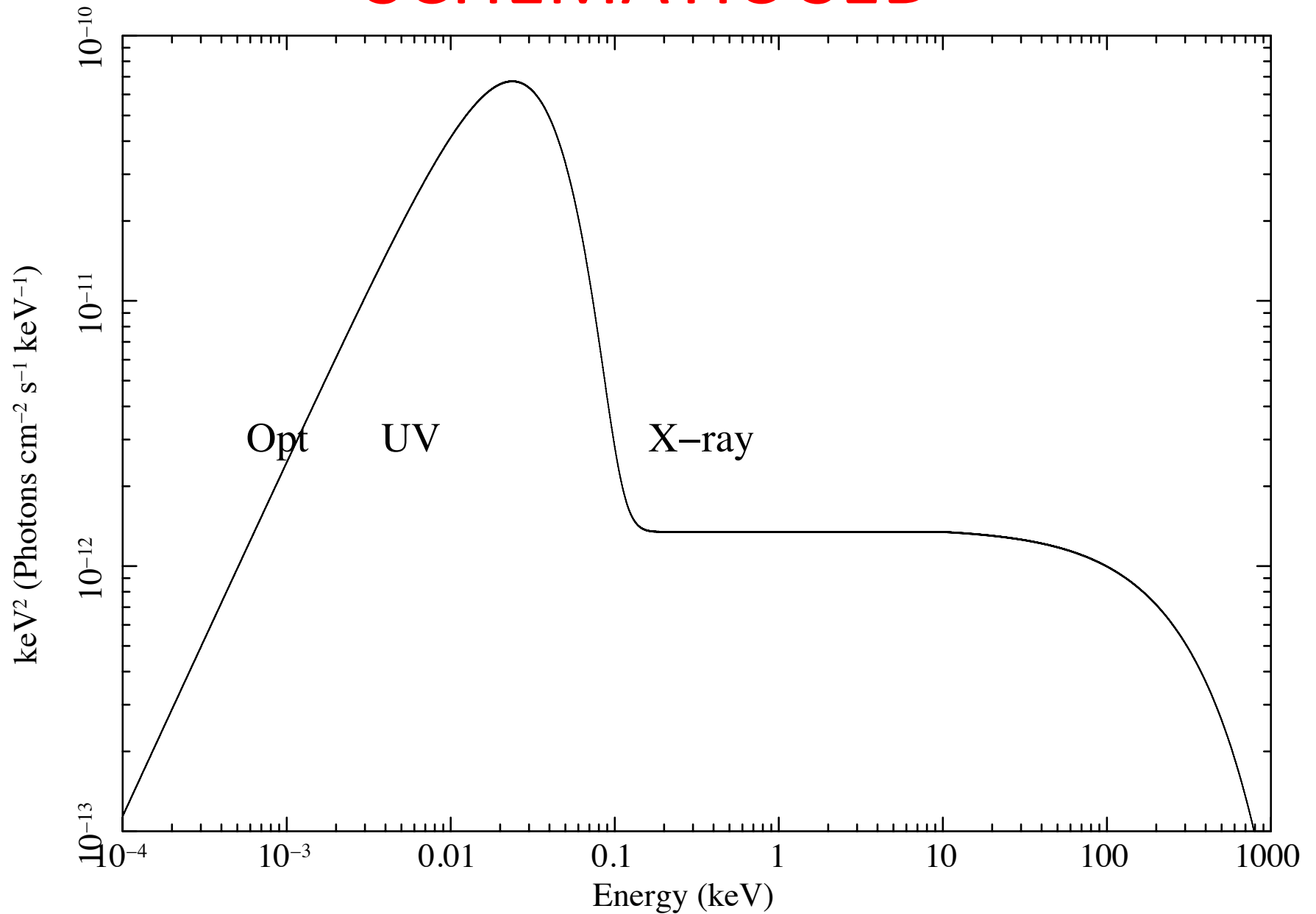
Reflection and Reverberation around Accreting Black Holes

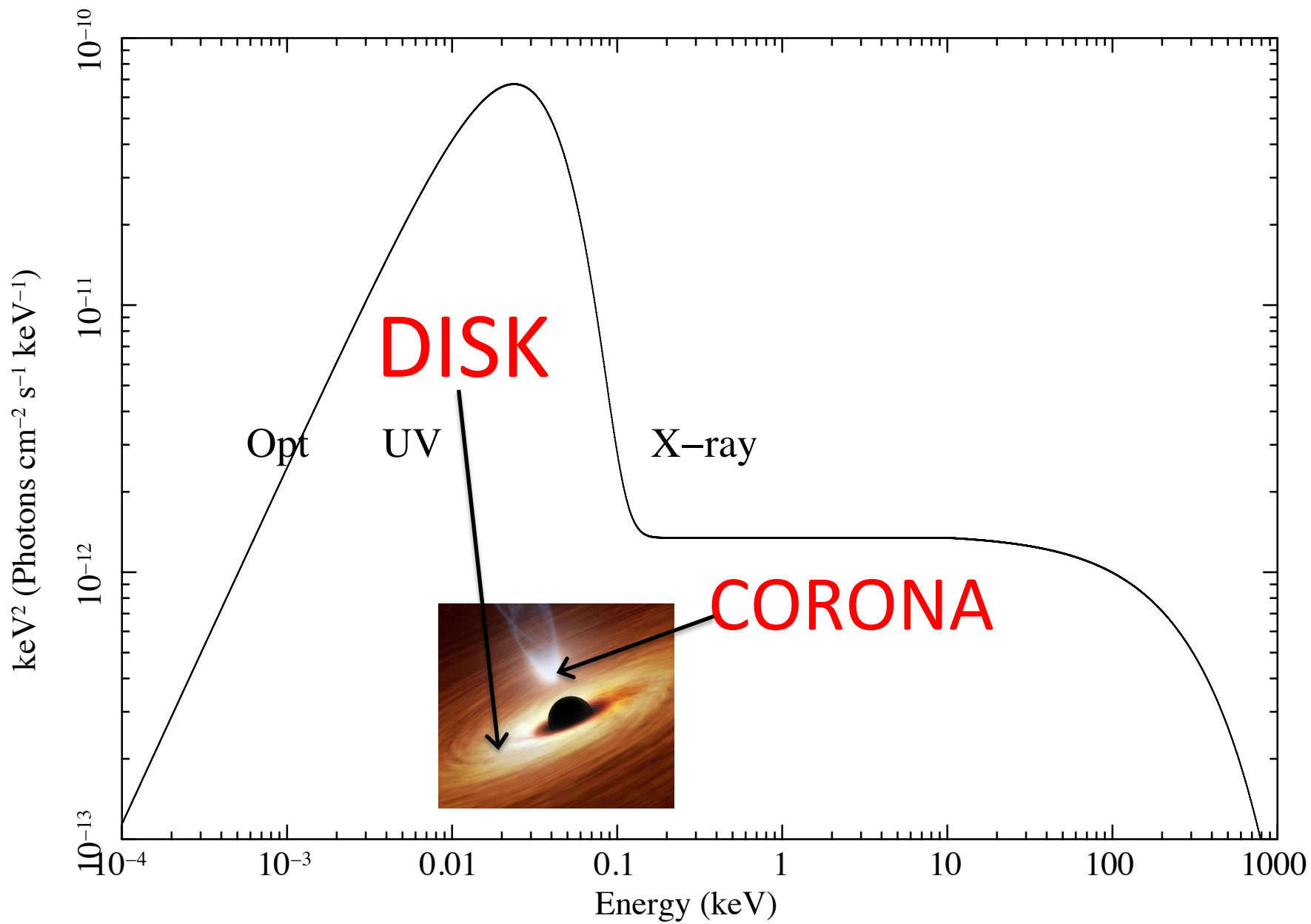
Andy Fabian

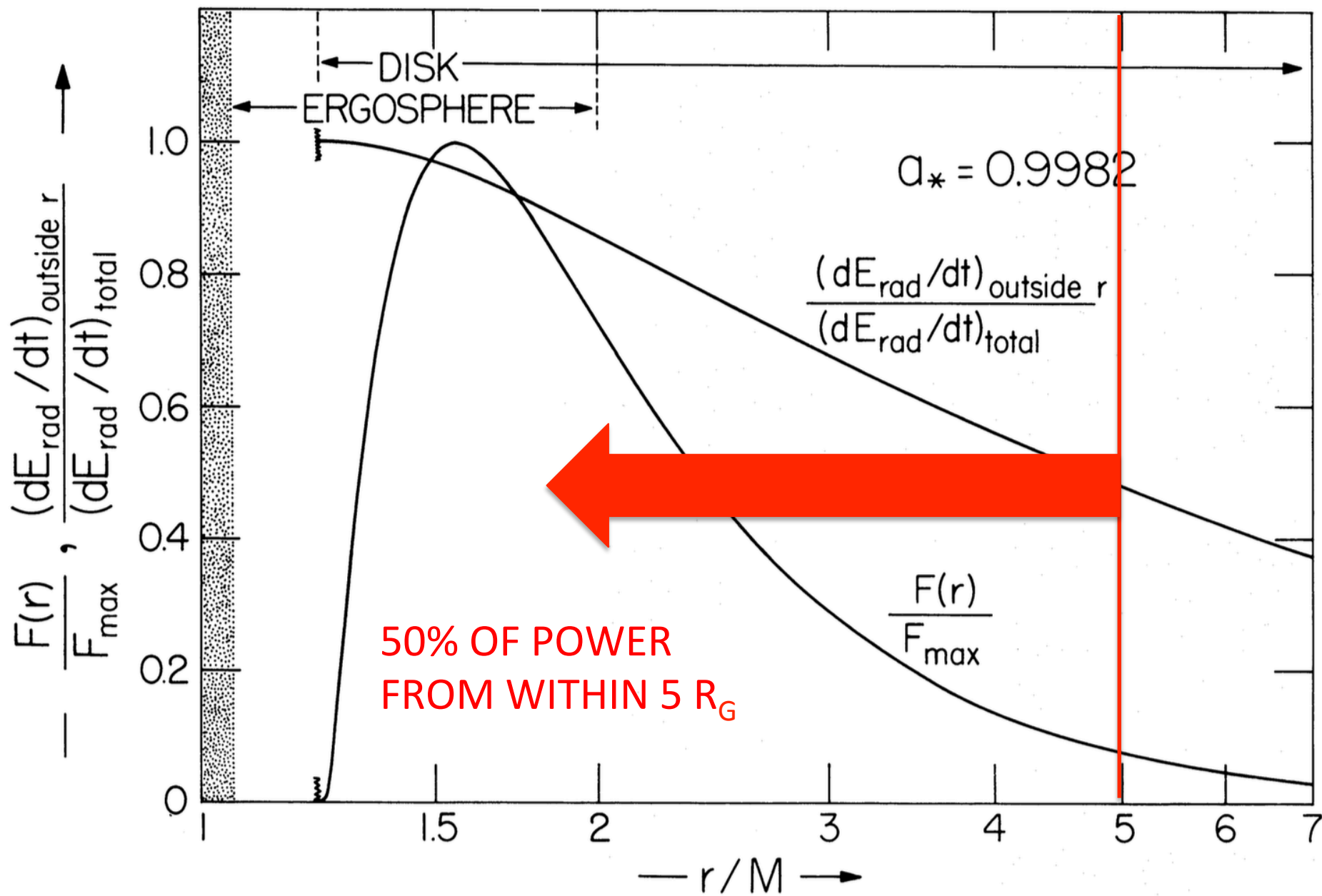
Institute of Astronomy, University of Cambridge



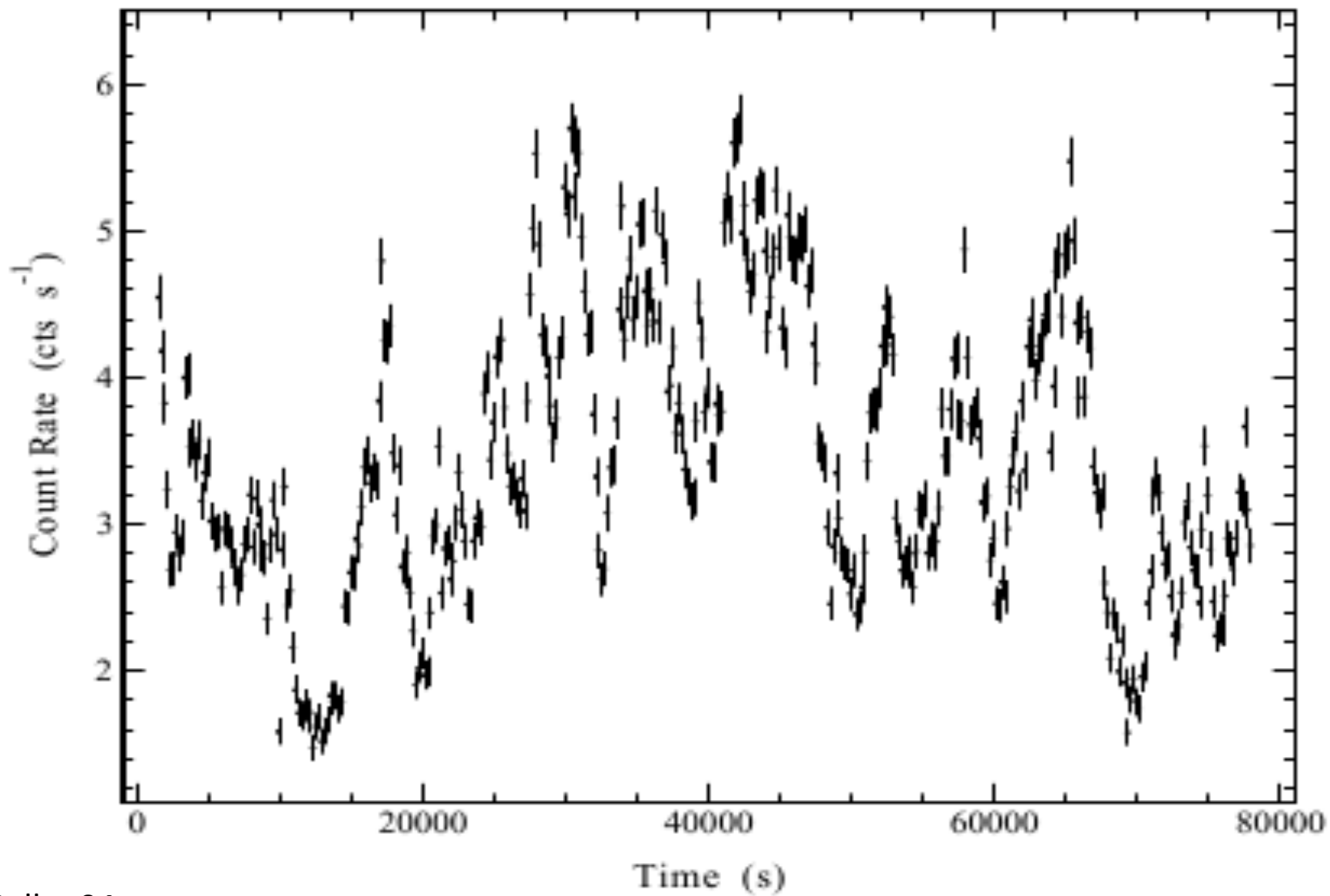
SCHEMATIC SED





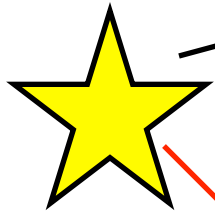


1H0707-495

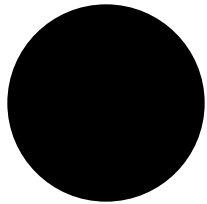


Direct Power-law

To observer

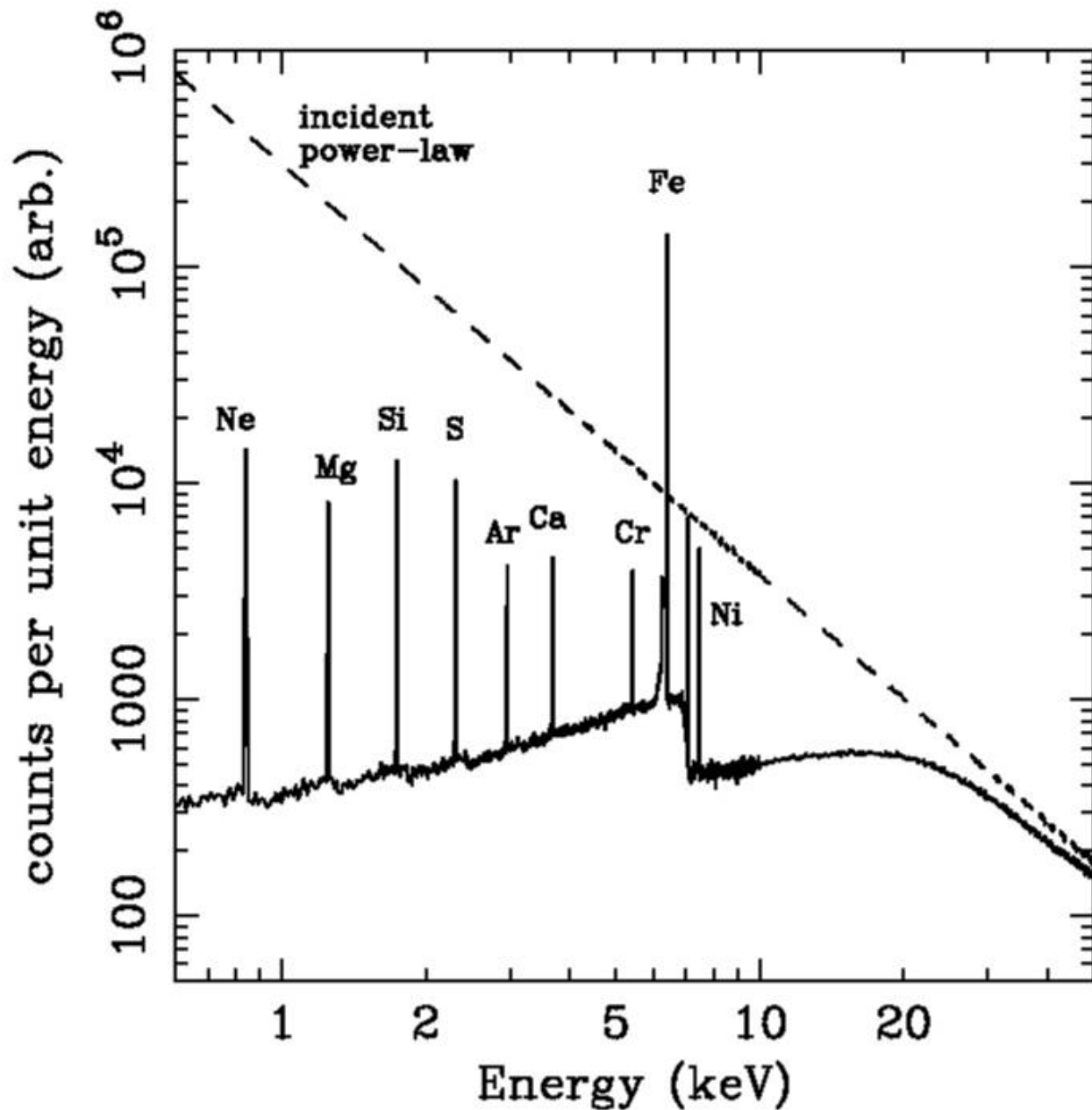


“Reflection” spectrum

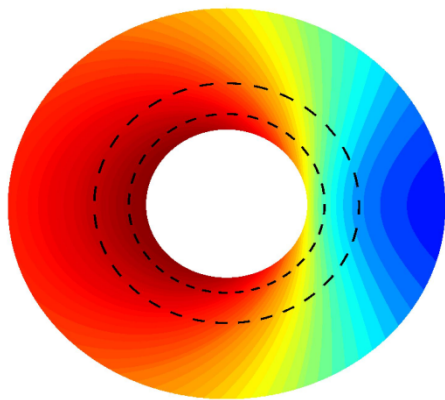


Accretion disc





Reflection
from
cold matter
of cosmic
abundance



Relativistically Broadened Line

Kerr disk

6m–30m

Photons/cm² s keV

1
0.5

Schwarzschild

Kerr

Energy

Fabian+89, Laor 91...

Newtonian

Special relativity

Transverse Doppler shift

Beaming

General relativity

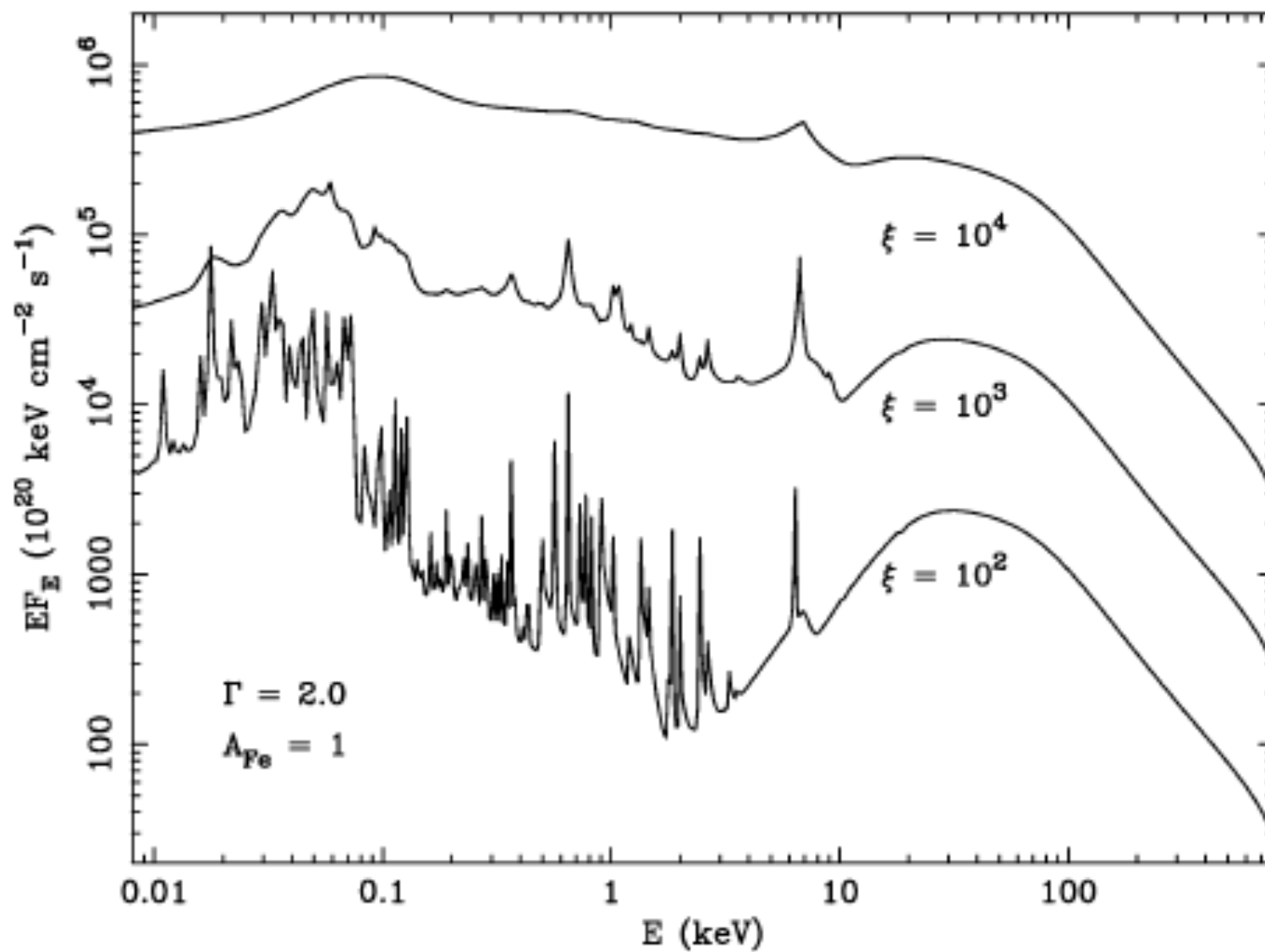
Gravitational redshift

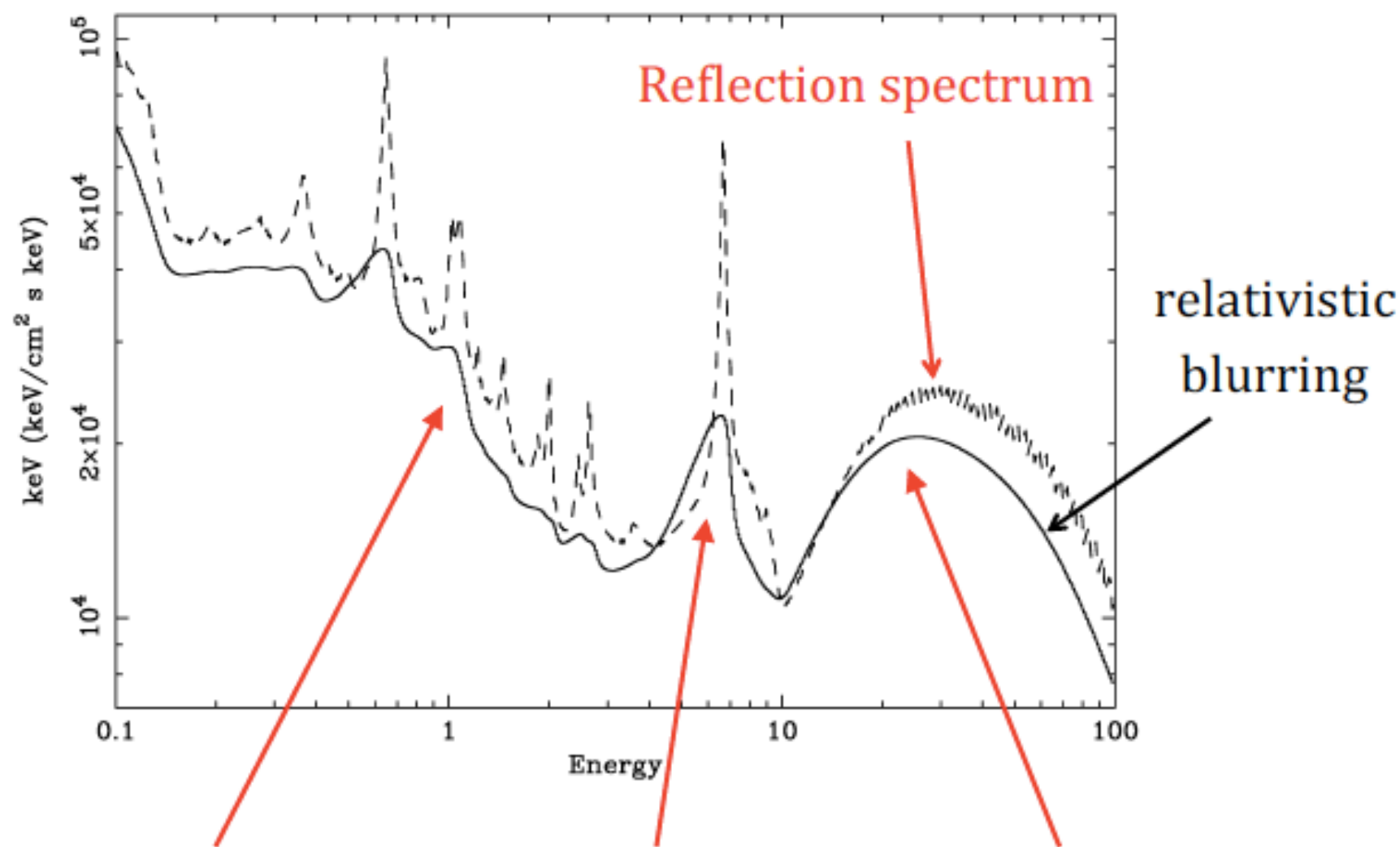
Line profile

0.5 1 1.5

$\nu_{\text{obs}}/\nu_{\text{em}}$

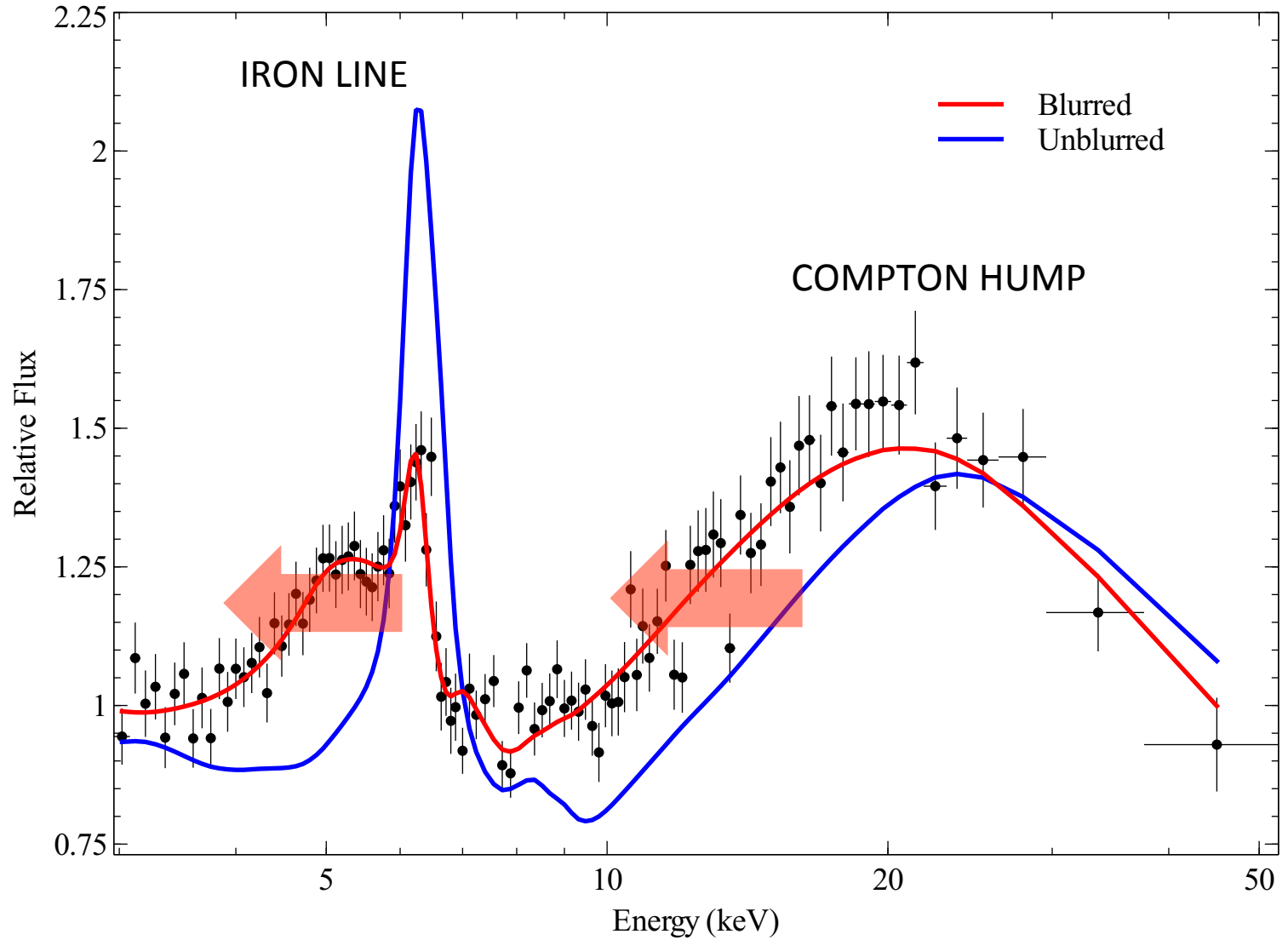
Reflection from ionized gas Ross+Fabian05; Garcia+13

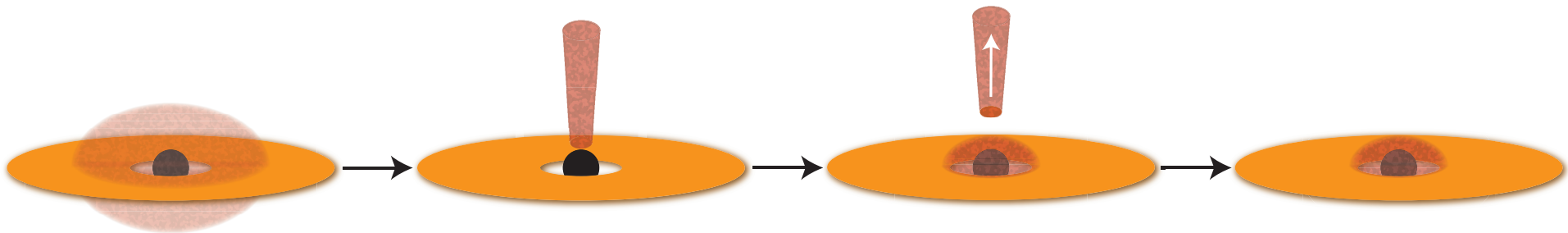




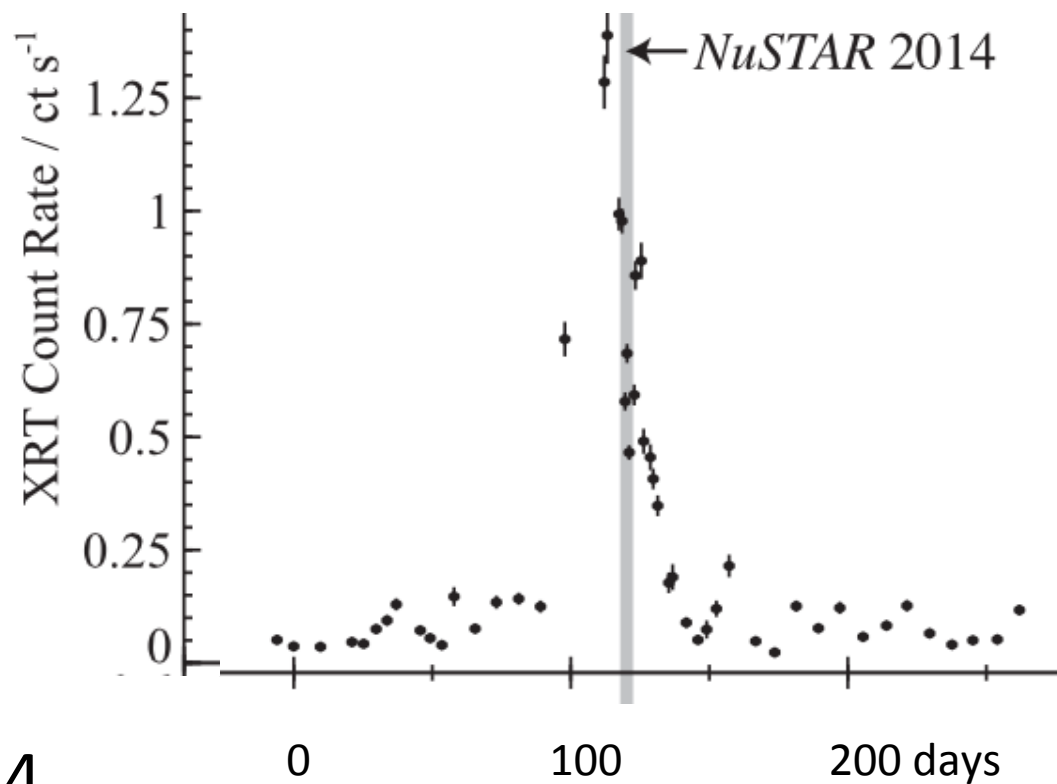
Soft excess - broad iron line - Compton hump

Sometimes most emission from $1-2r_g$

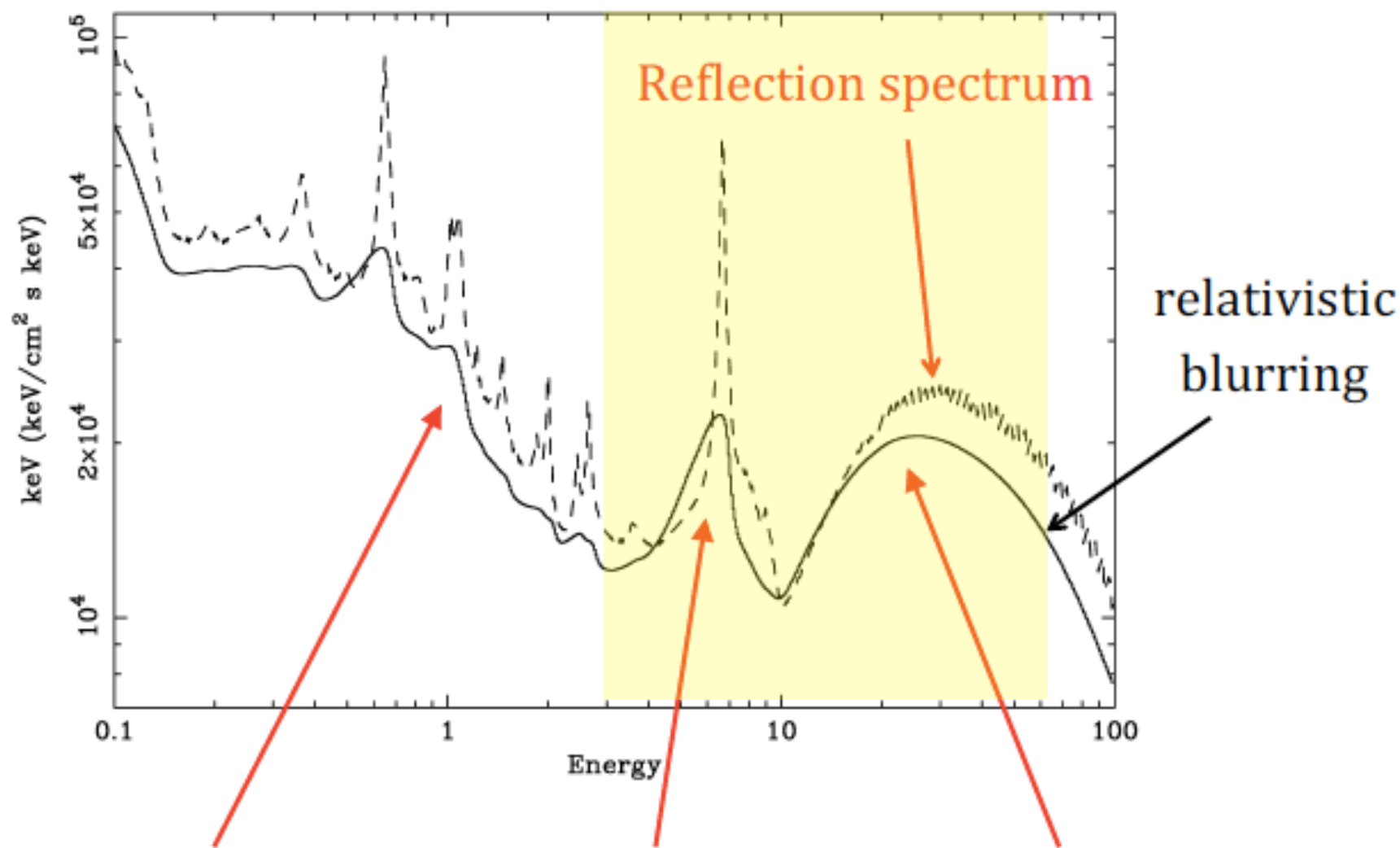




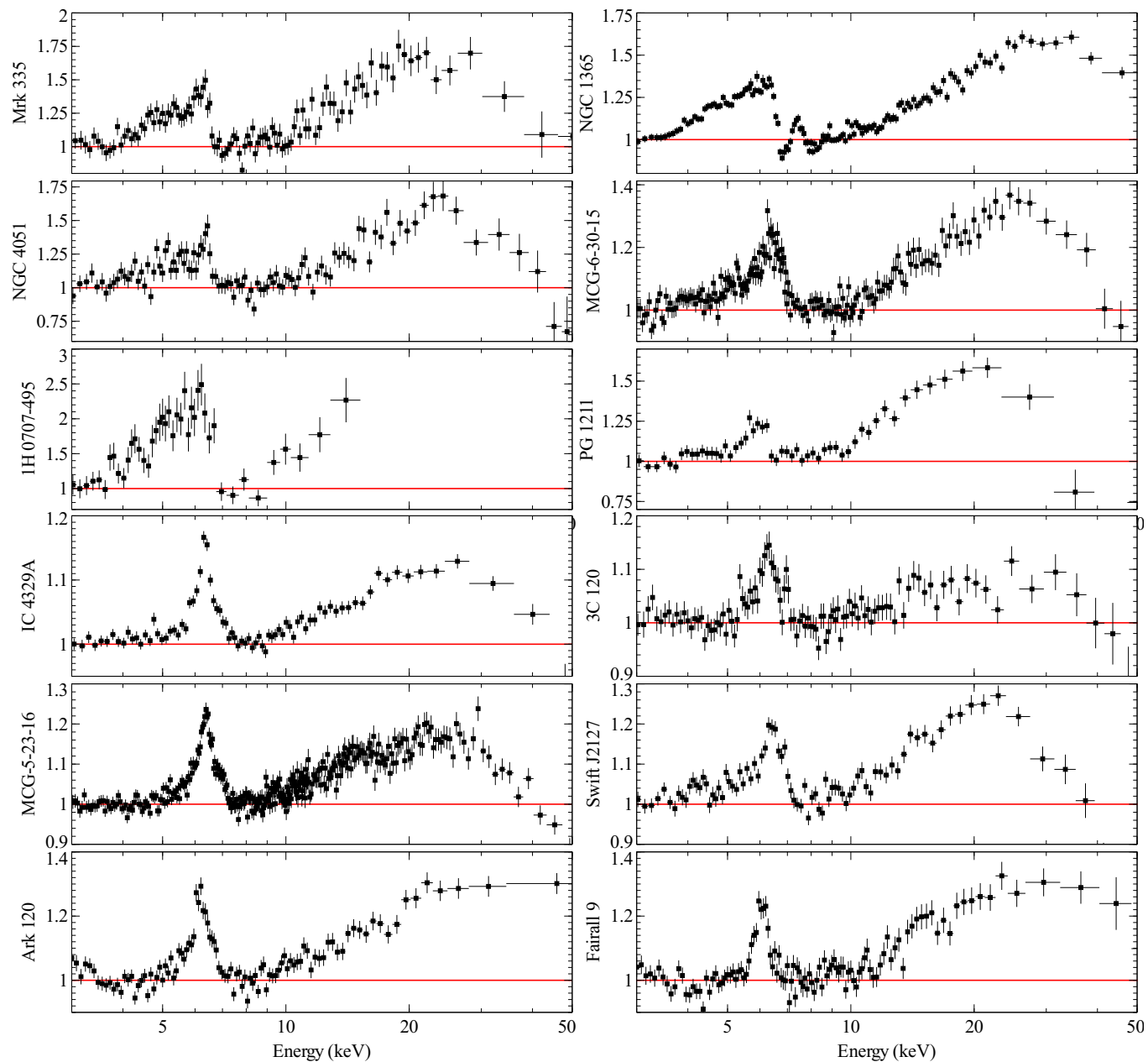
Mkn335



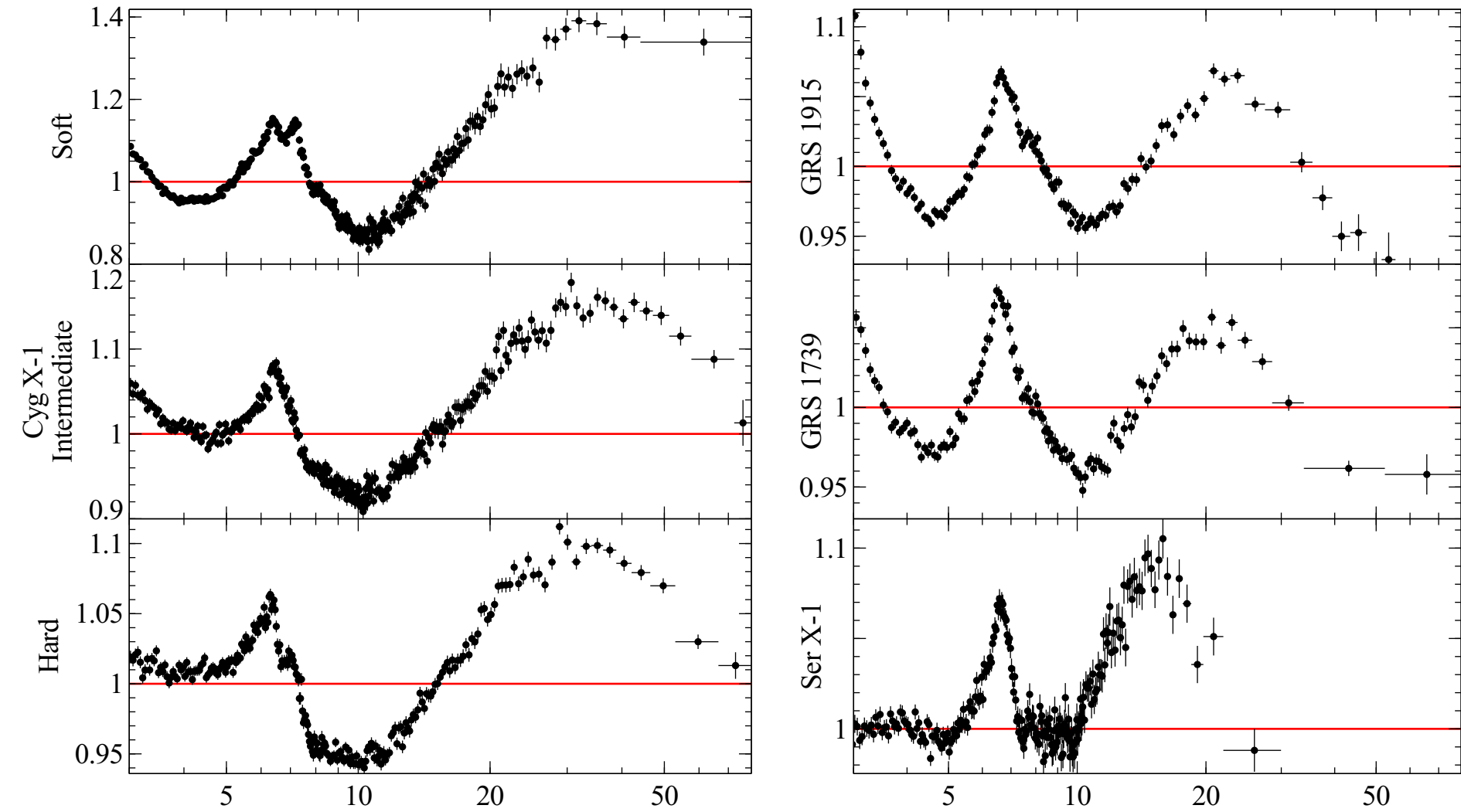
Wilkins+14

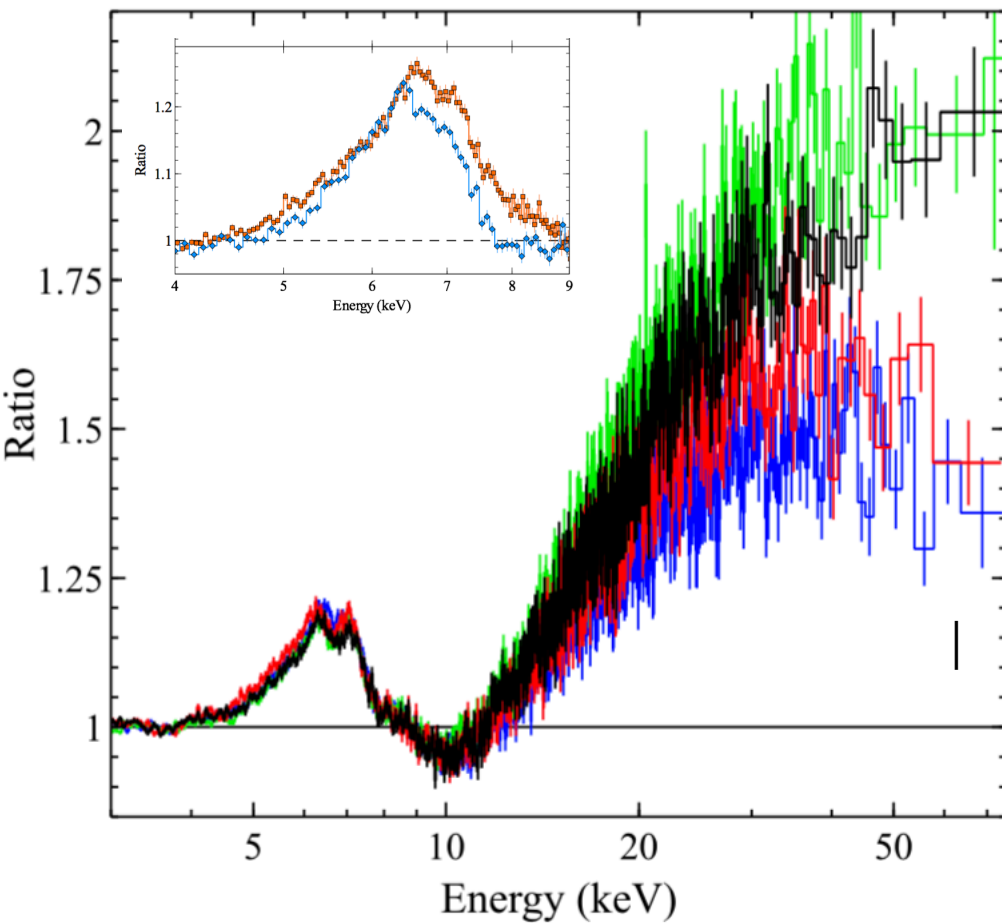


Reflection in AGN with NuSTAR



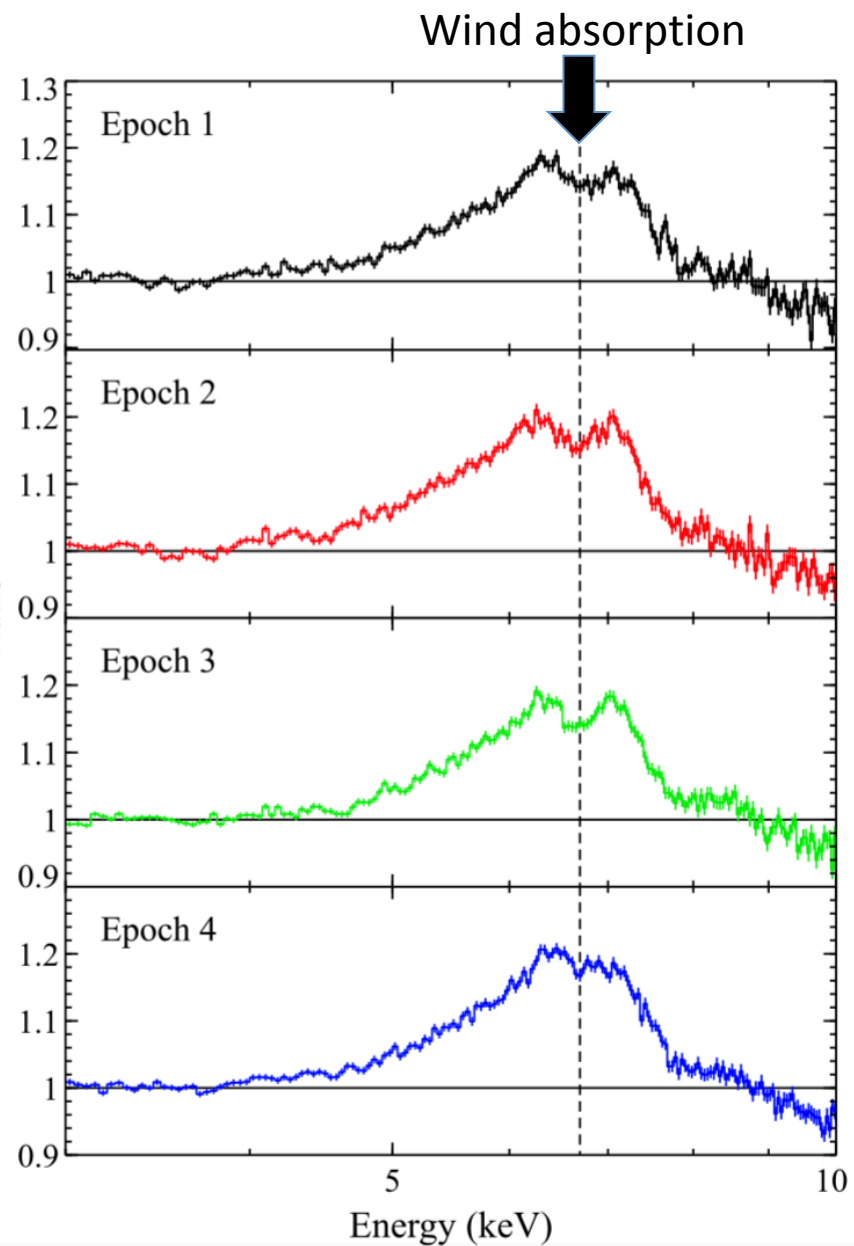
and Galactic sources too



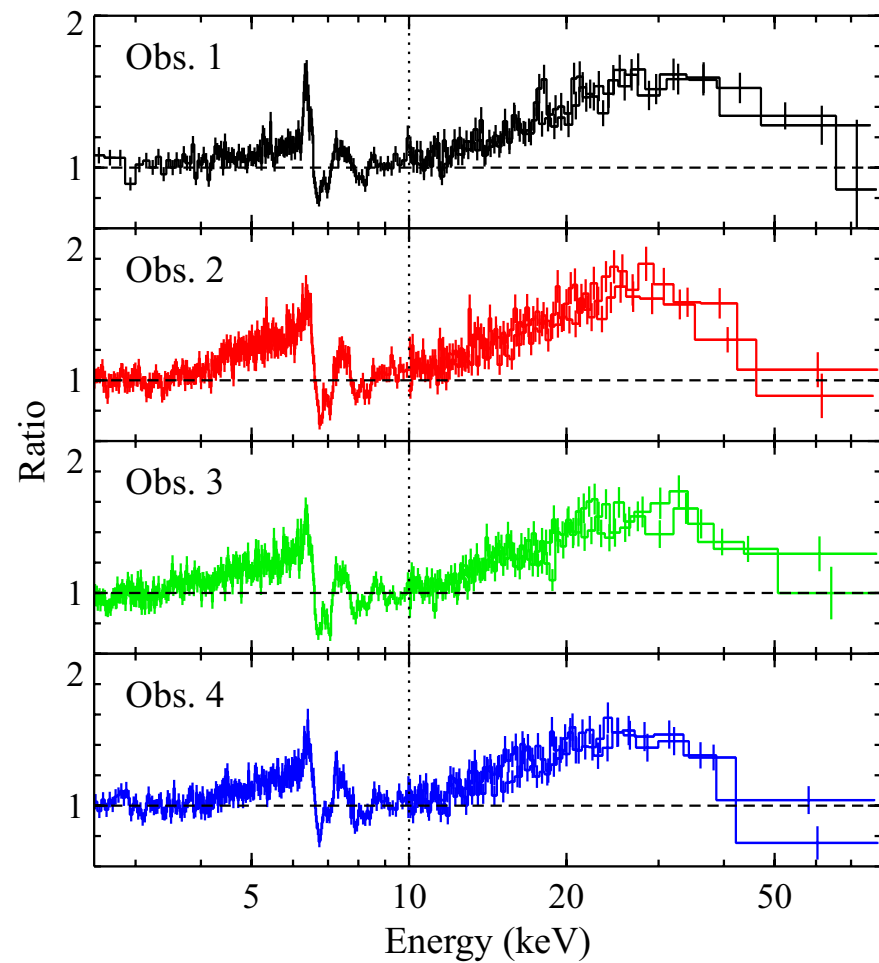
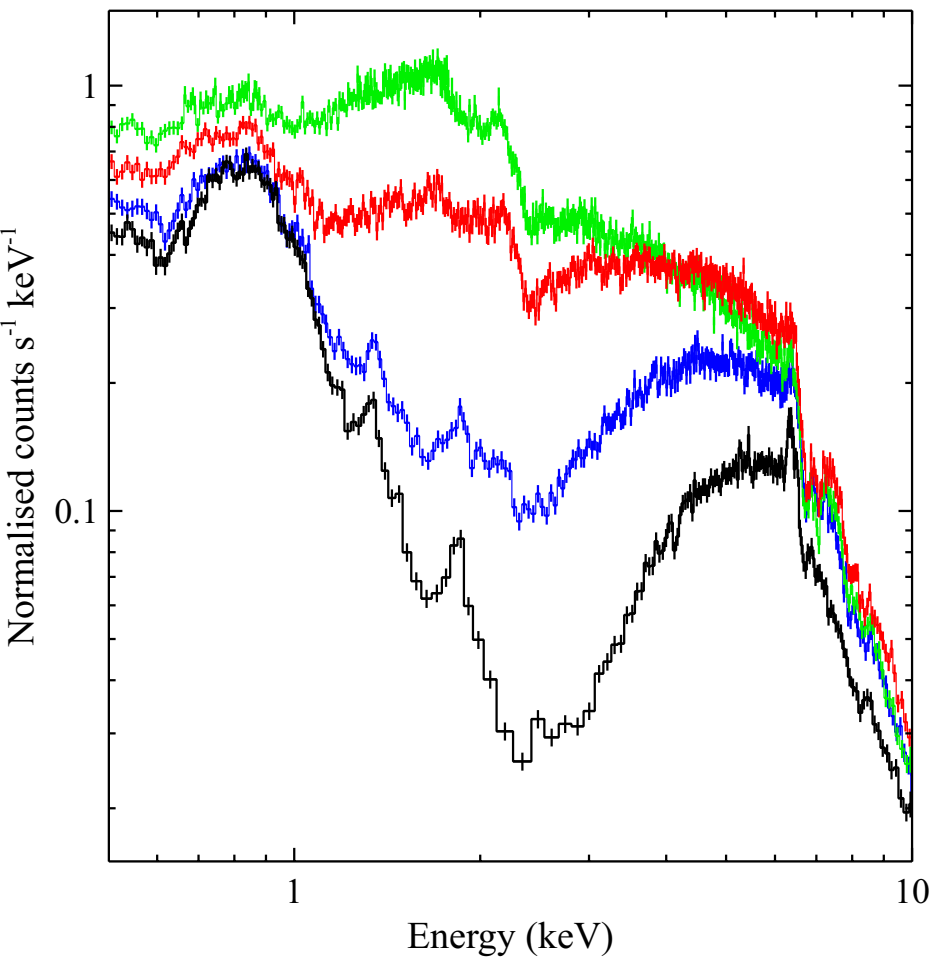


Cygnus X-1 $a > 0.93$

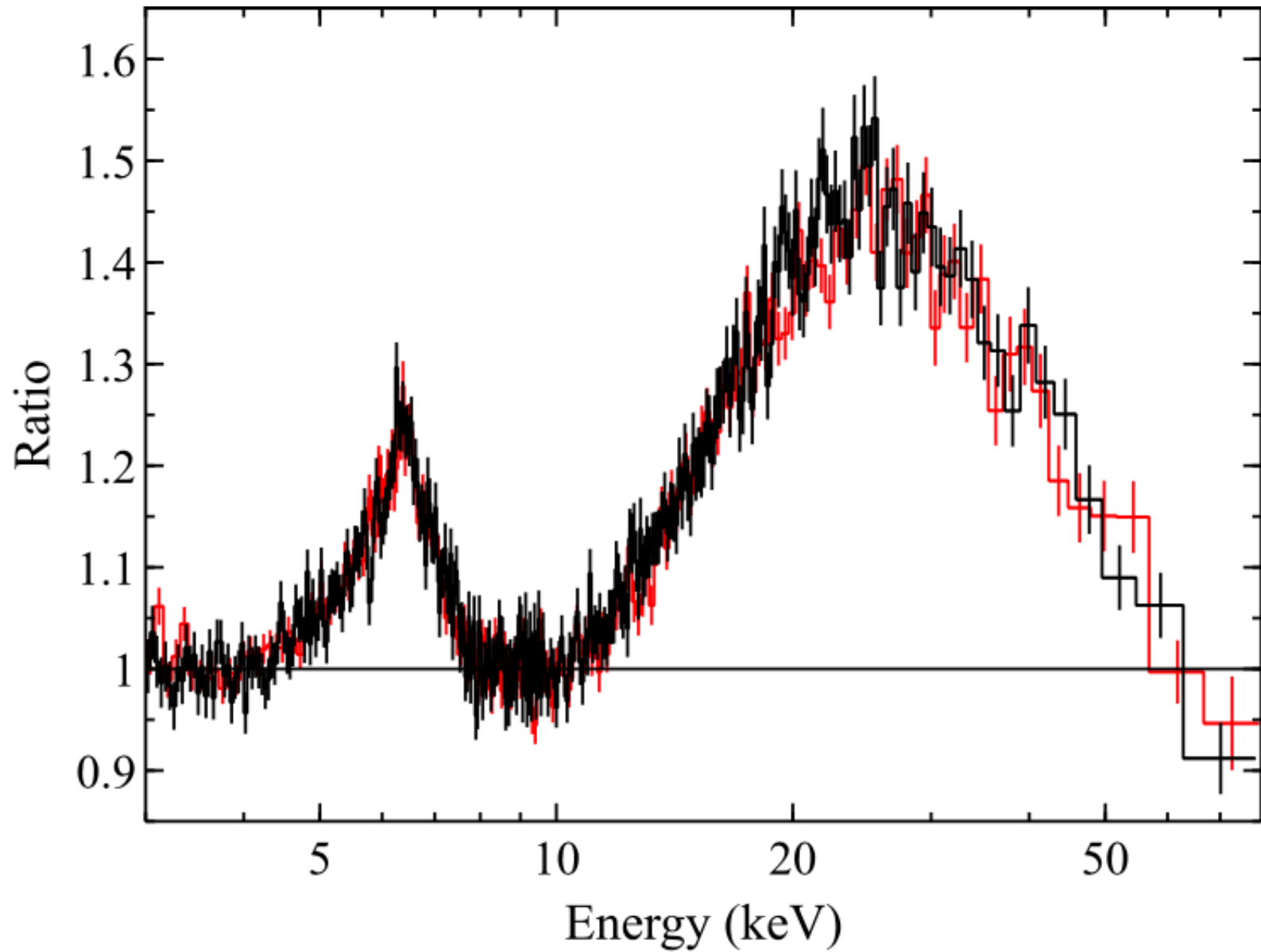
Walton+16, Parker+15

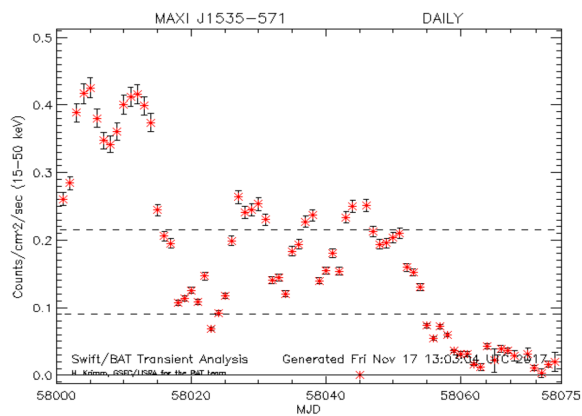
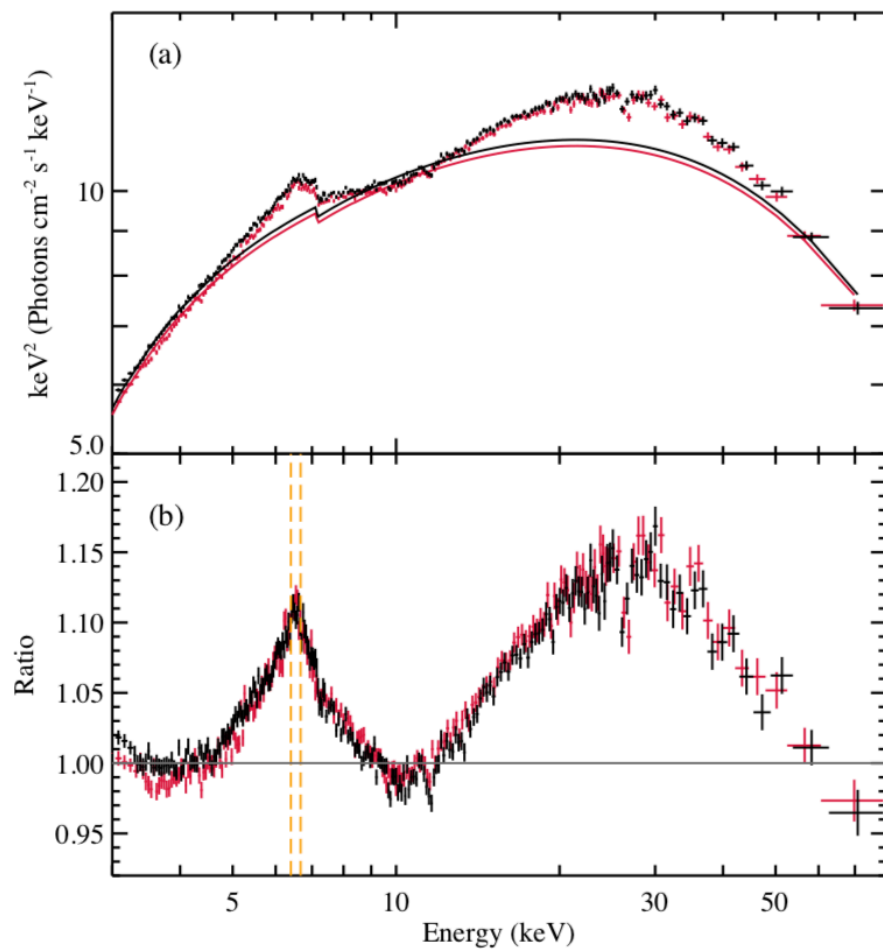
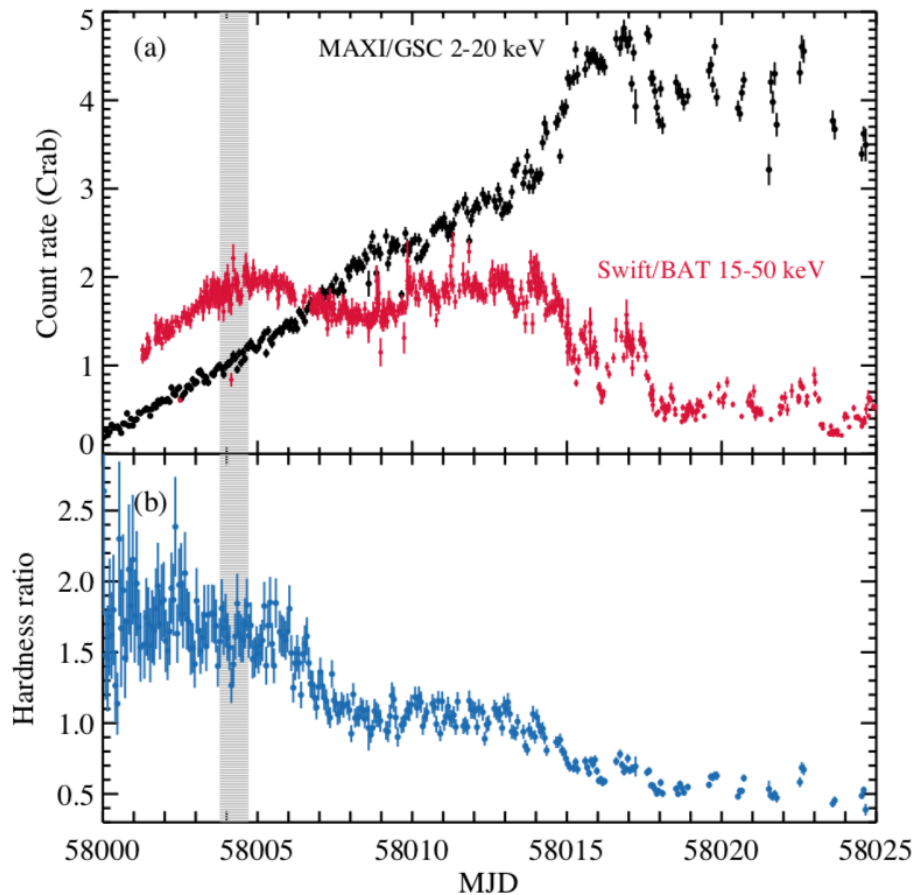


NGC1365 XMM+NuSTAR



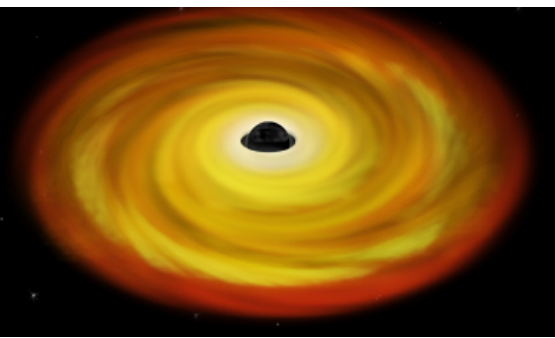
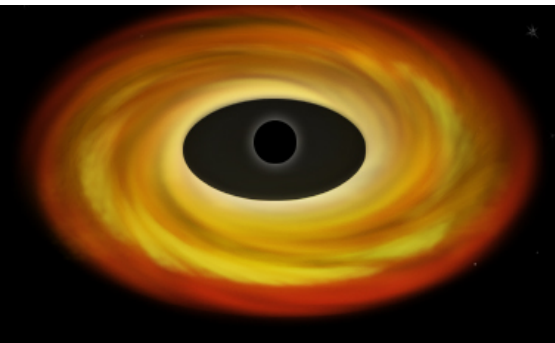
V404 Cyg Flare NuSTAR



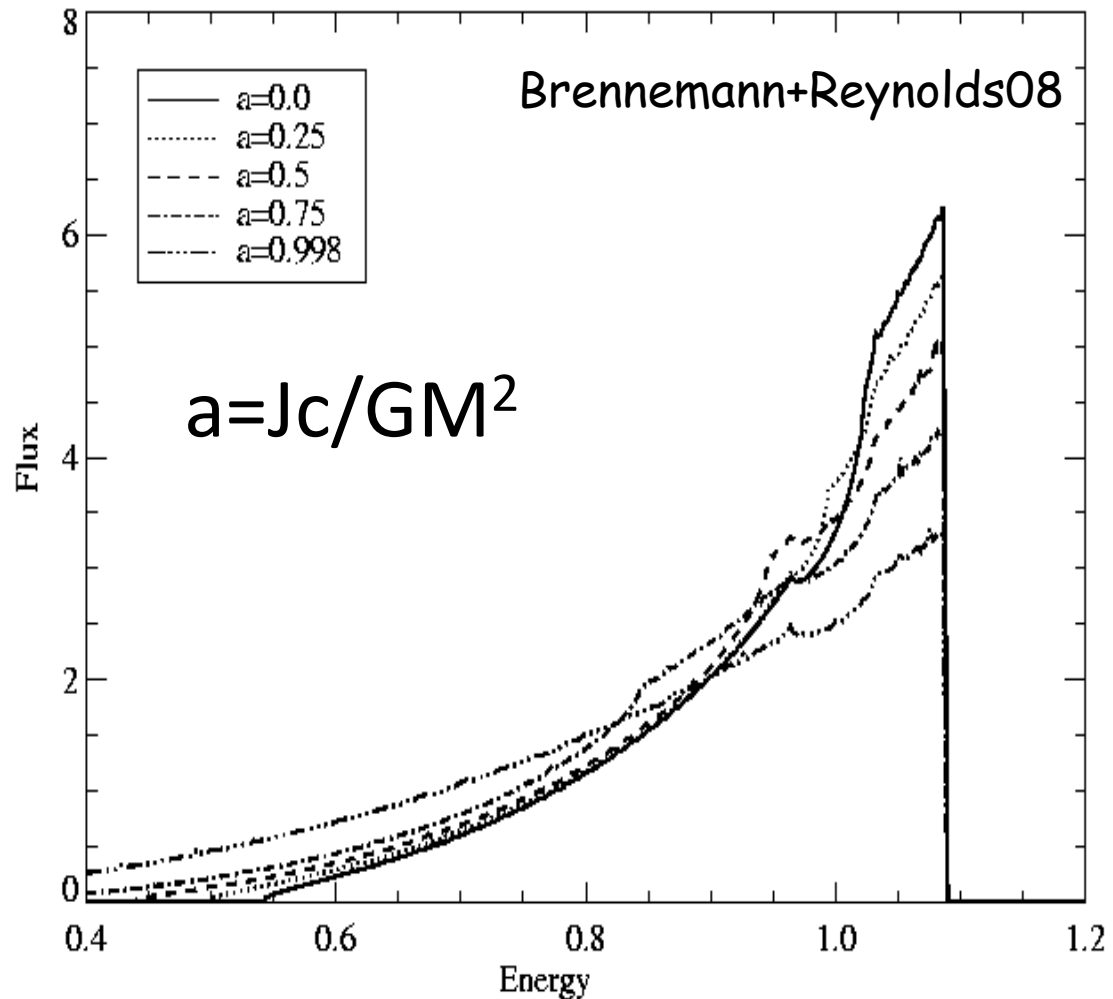


Probing Black Hole Spin

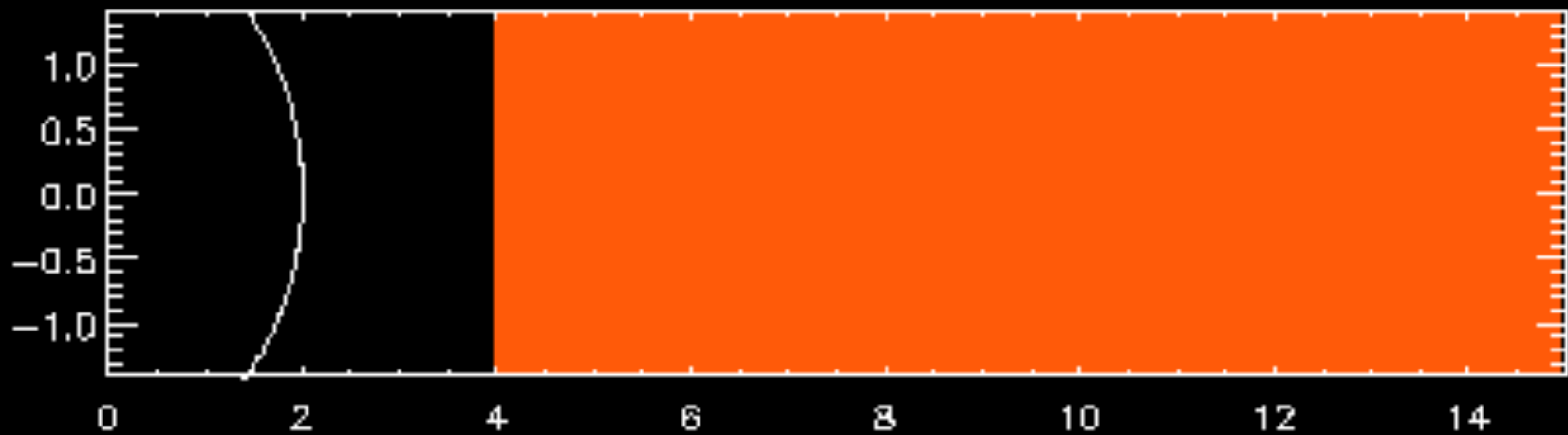
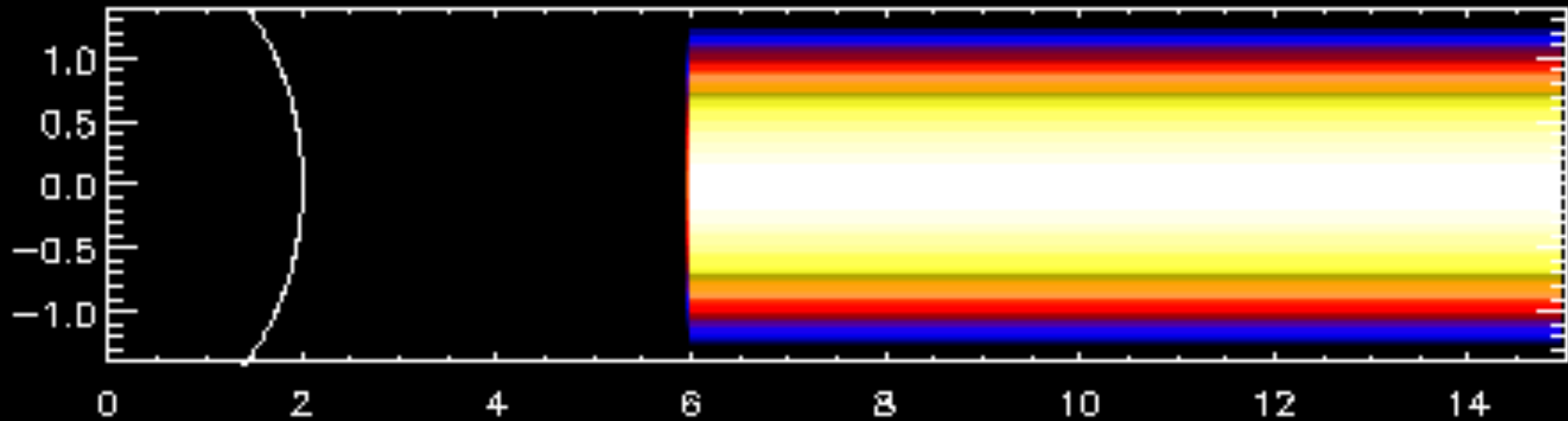
No spin



Max spin

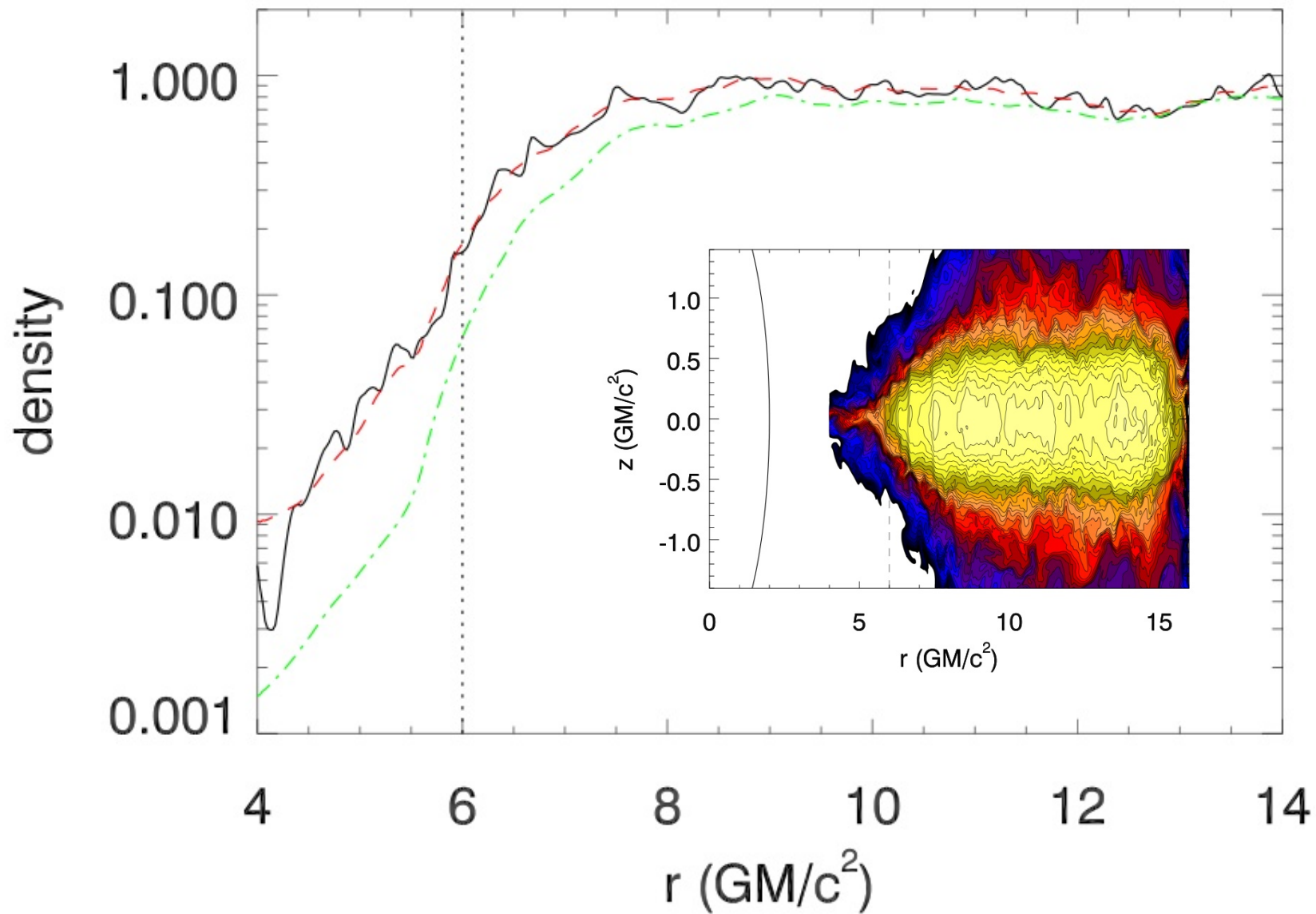


Density

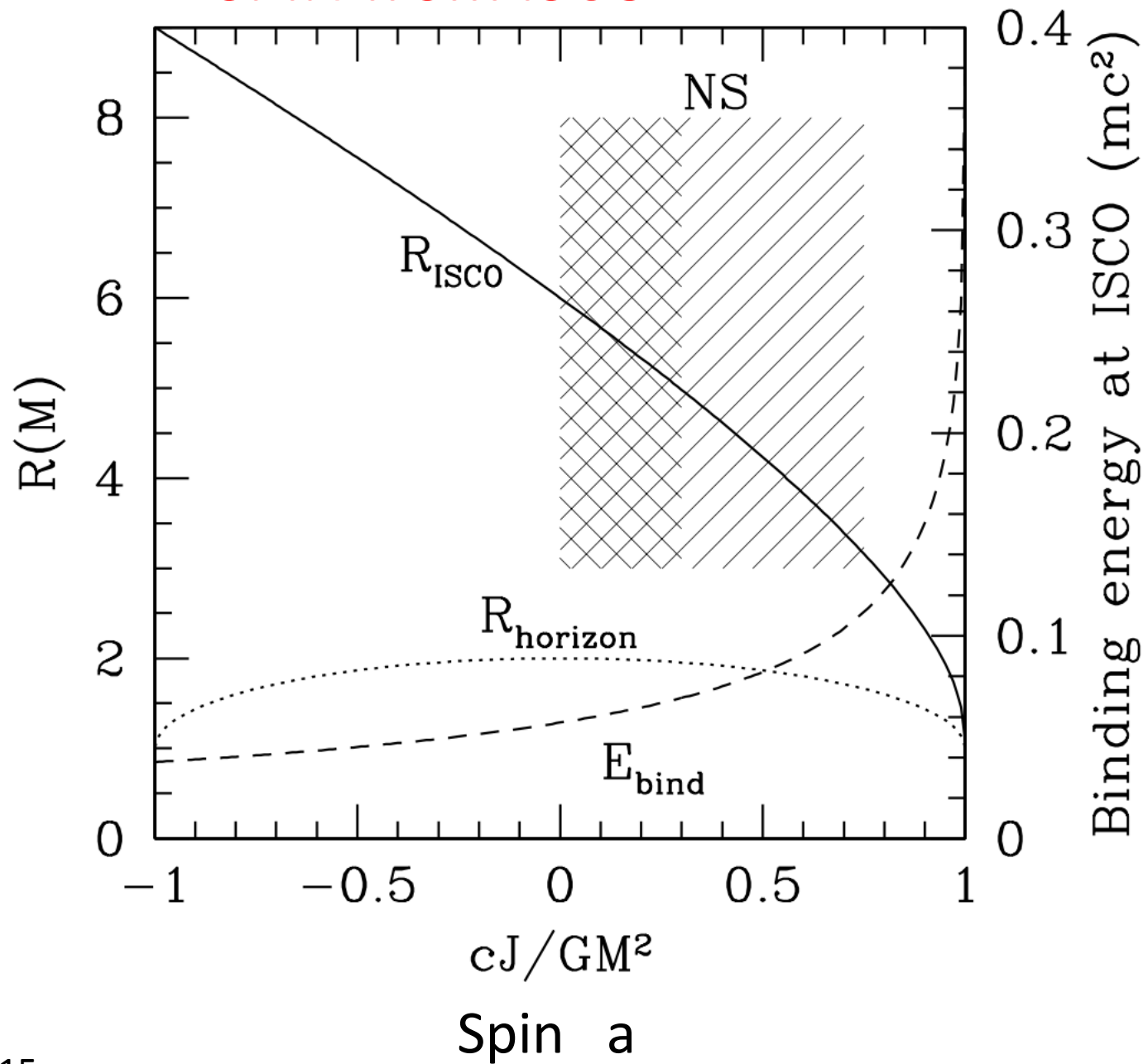


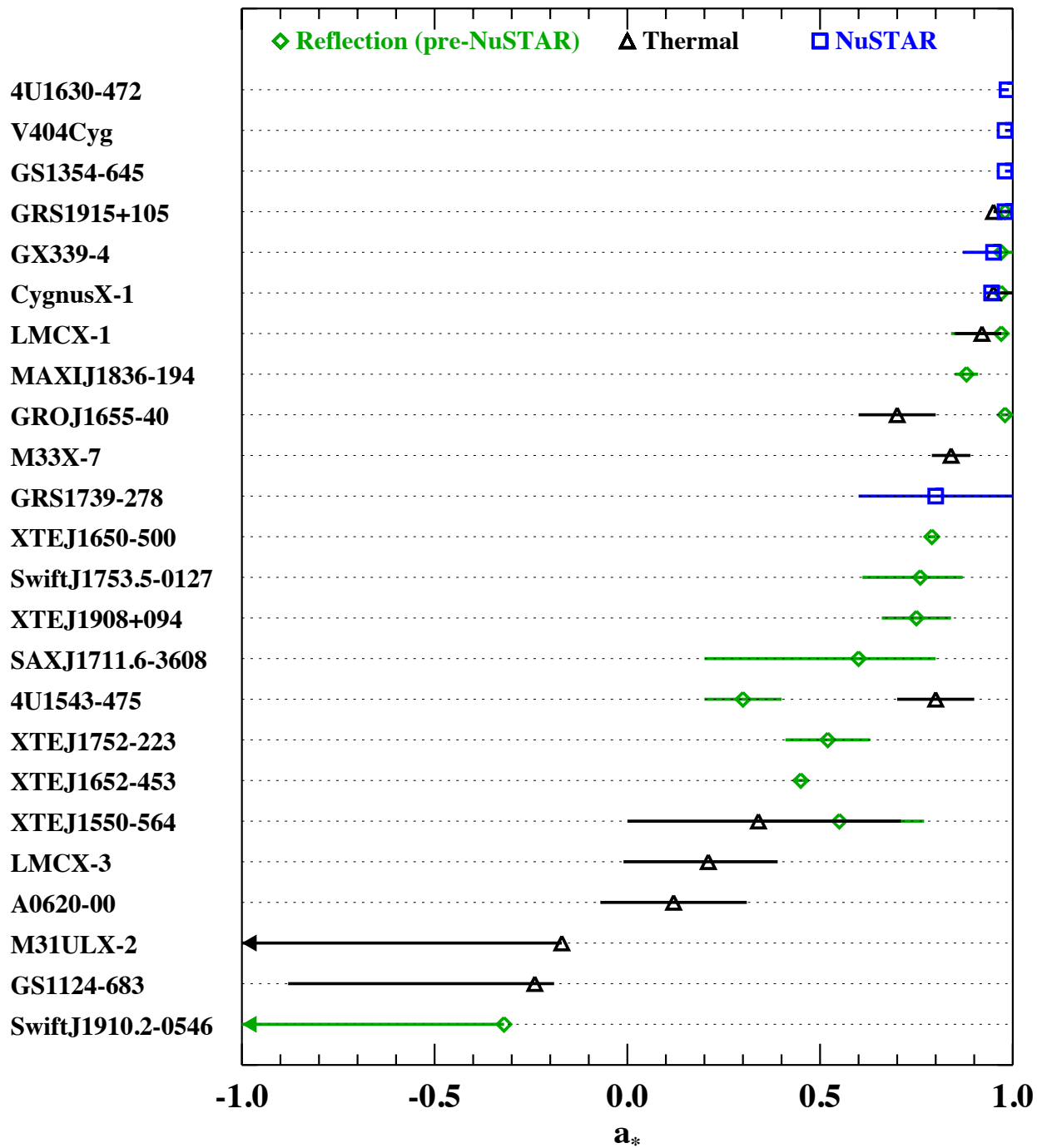
Azimuthal field

Reynolds & Fabian 08

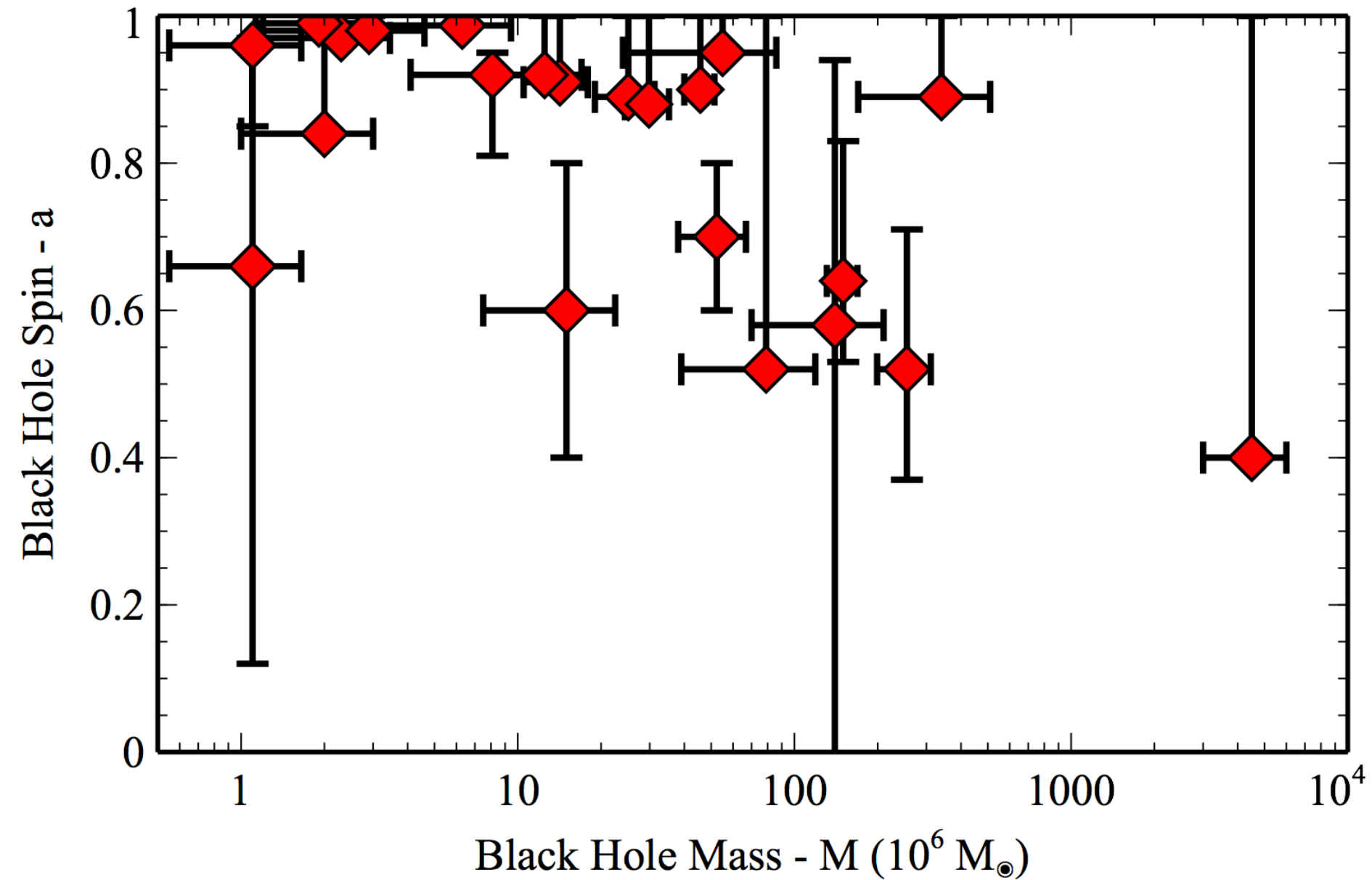


SPIN from ISCO

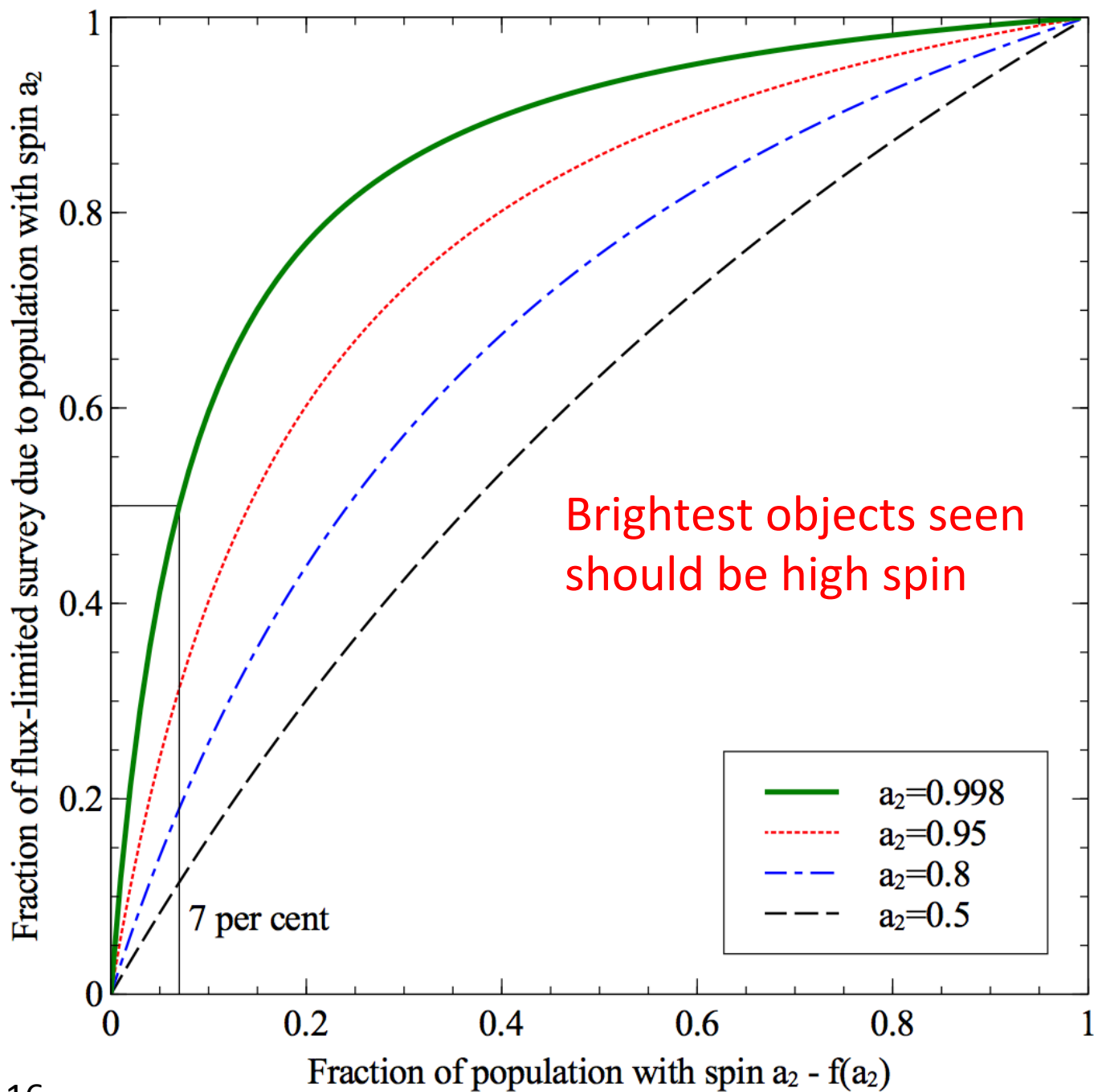


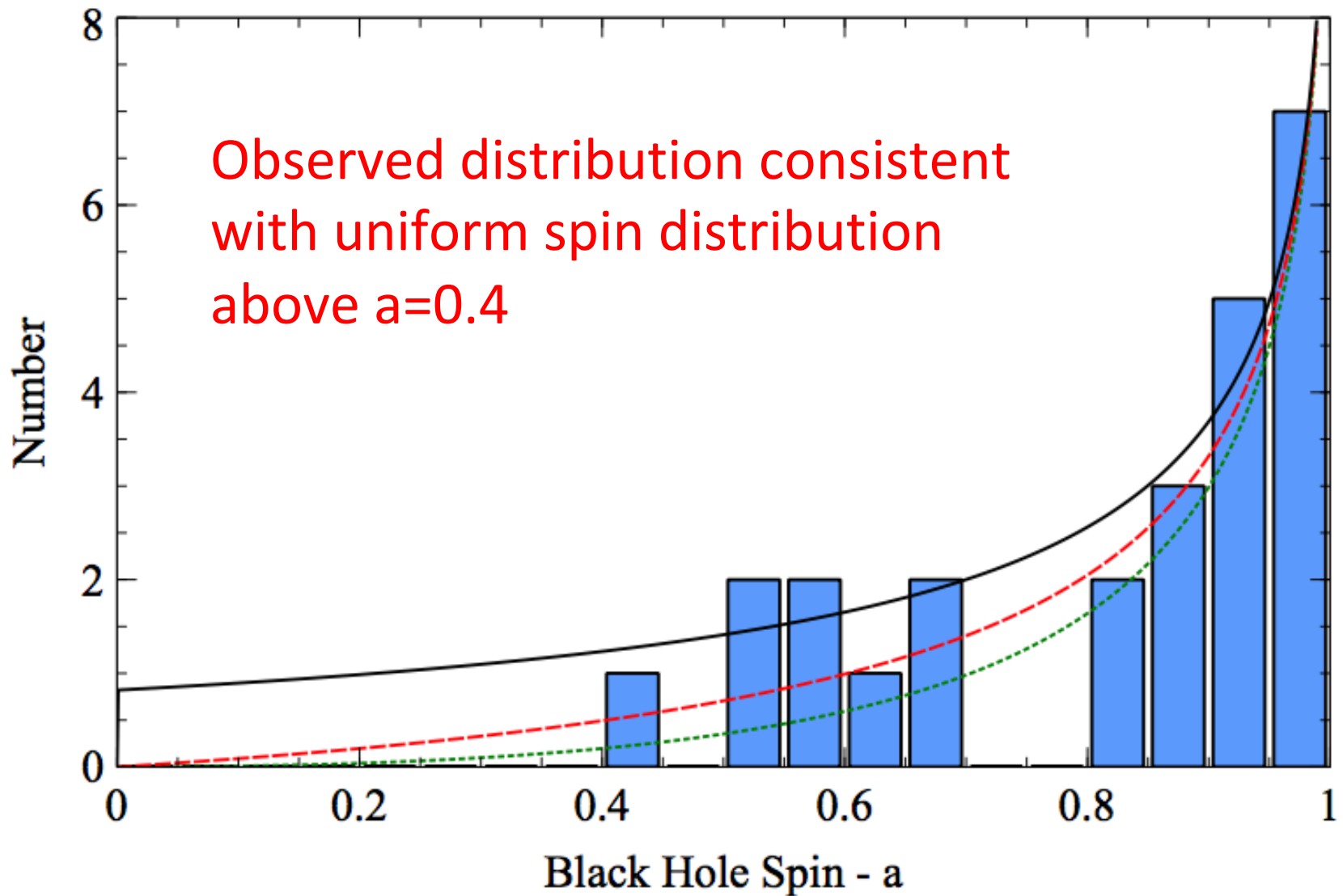


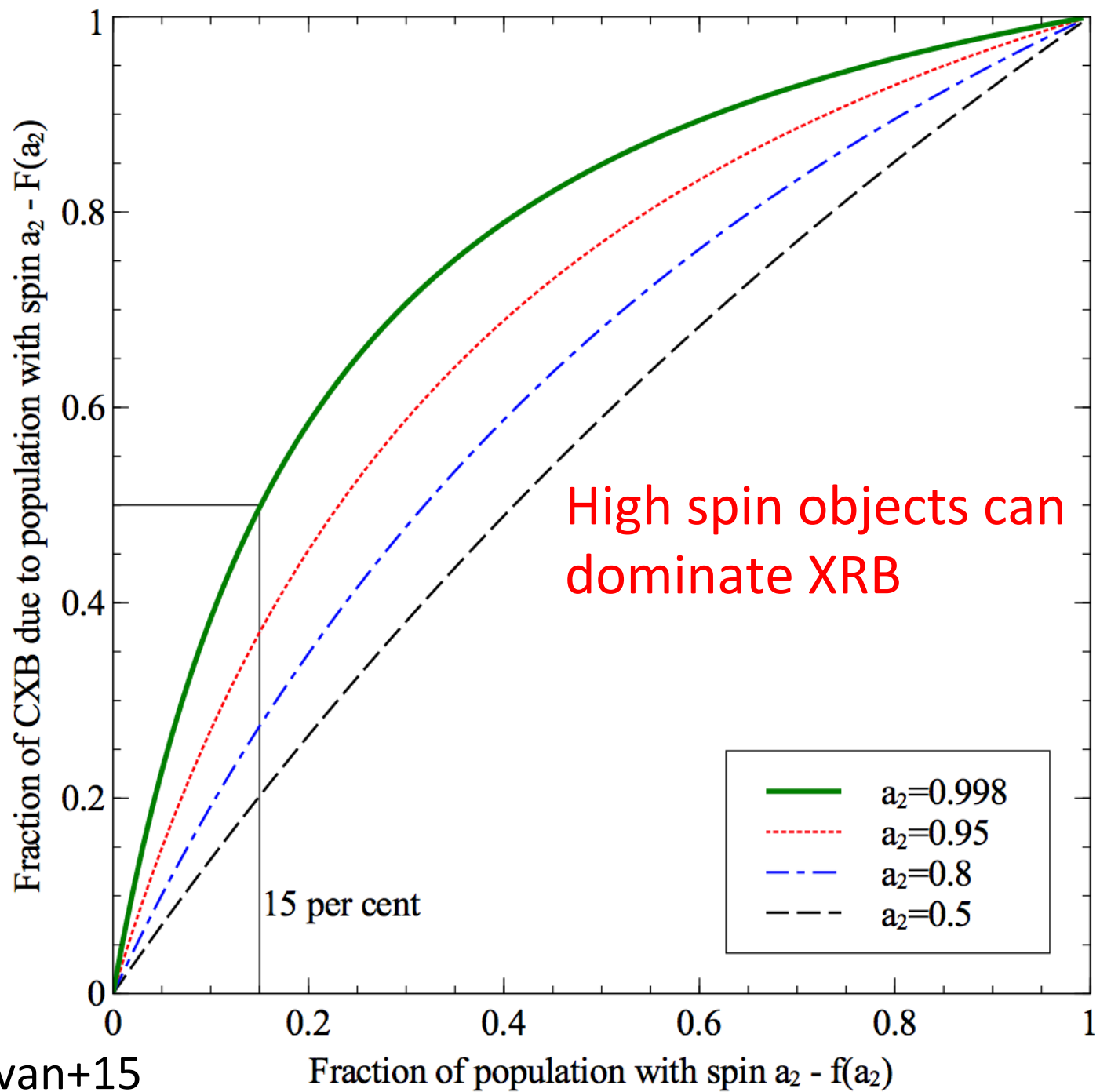
Black Hole Spin from Reflection Spectrum



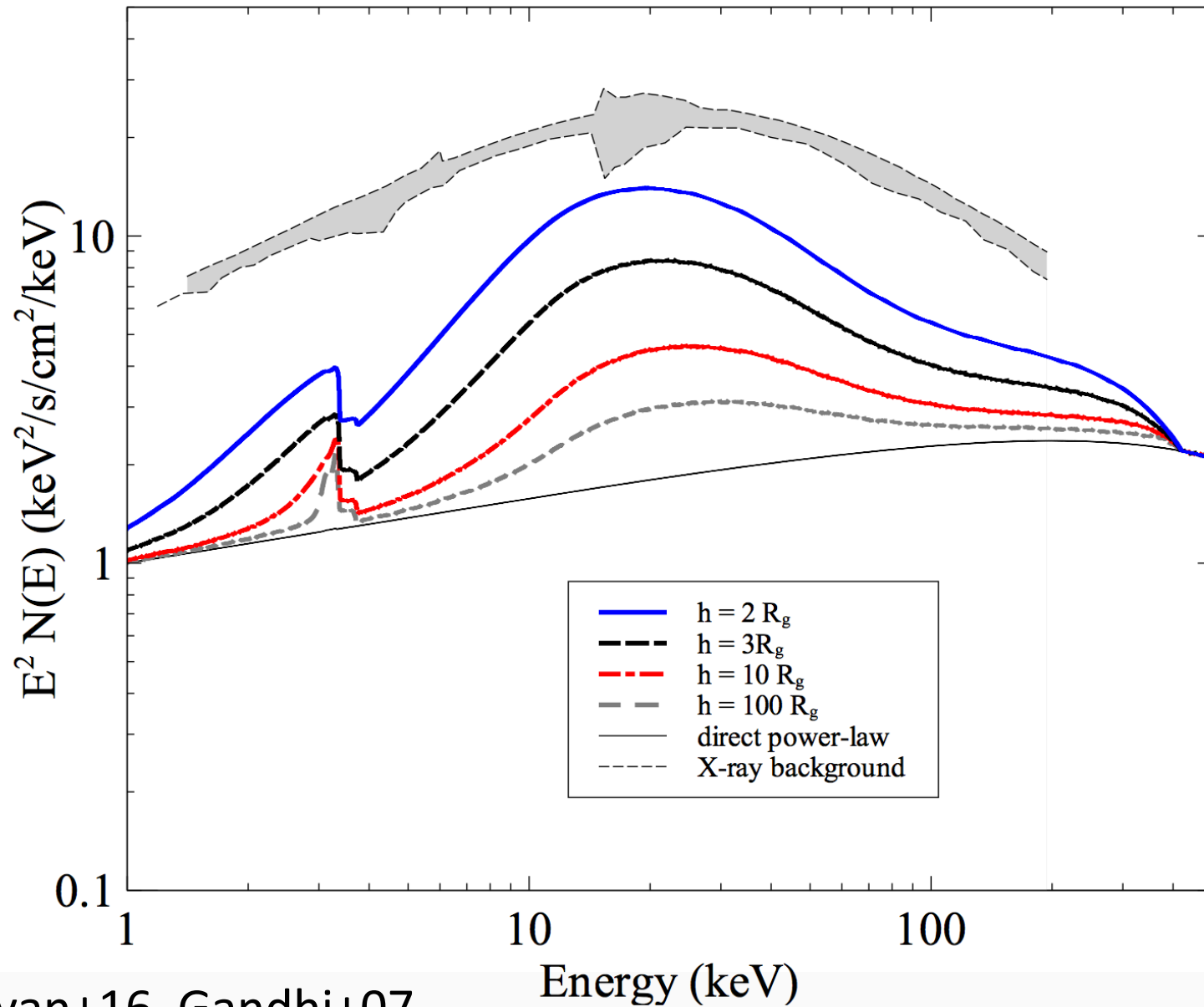
Reynolds14, Vasudevan+16





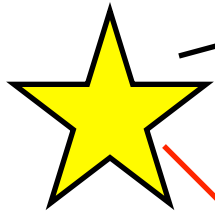


X-ray Background Spectrum



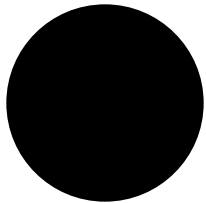
Direct Power-law

To observer



Corona

“Reflection” spectrum



Accretion disc

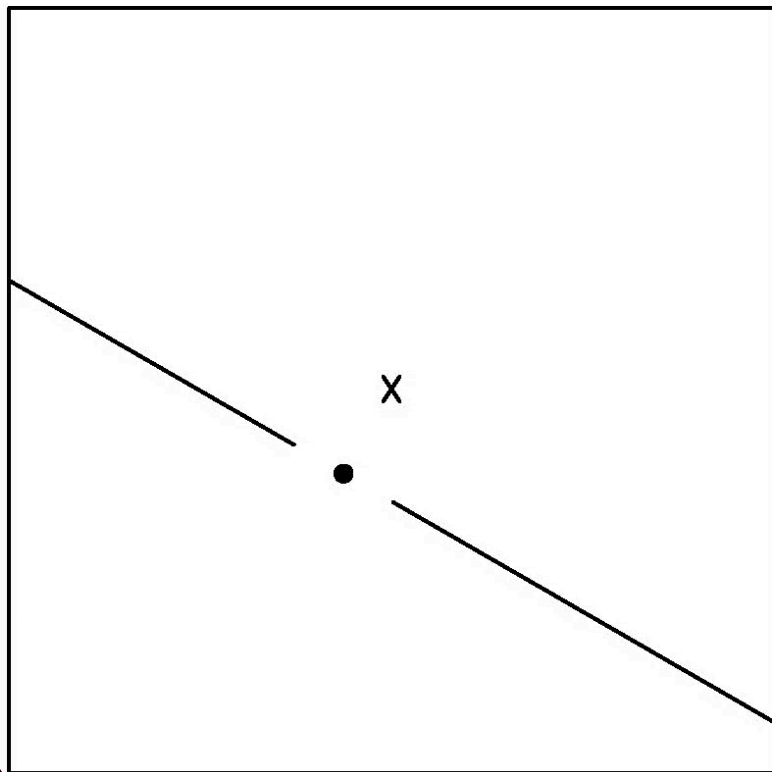


Path difference leads to

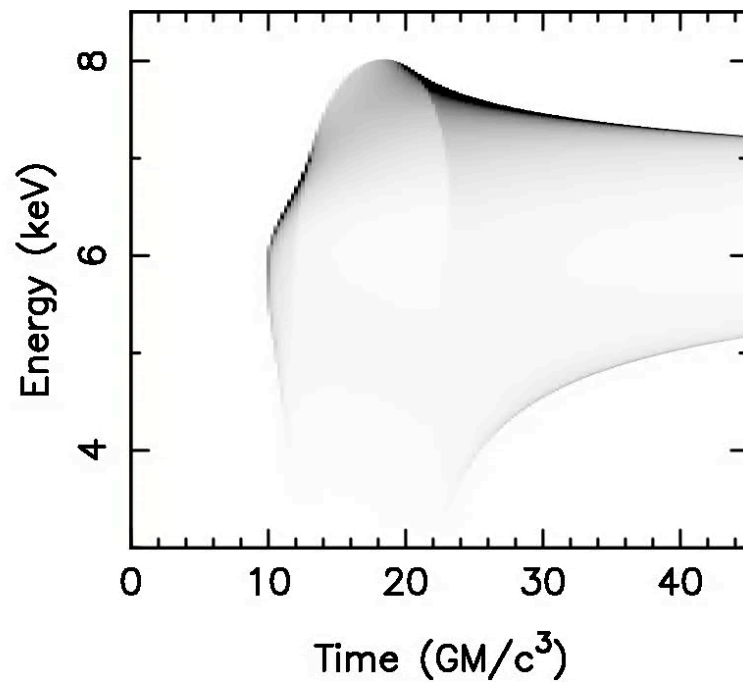
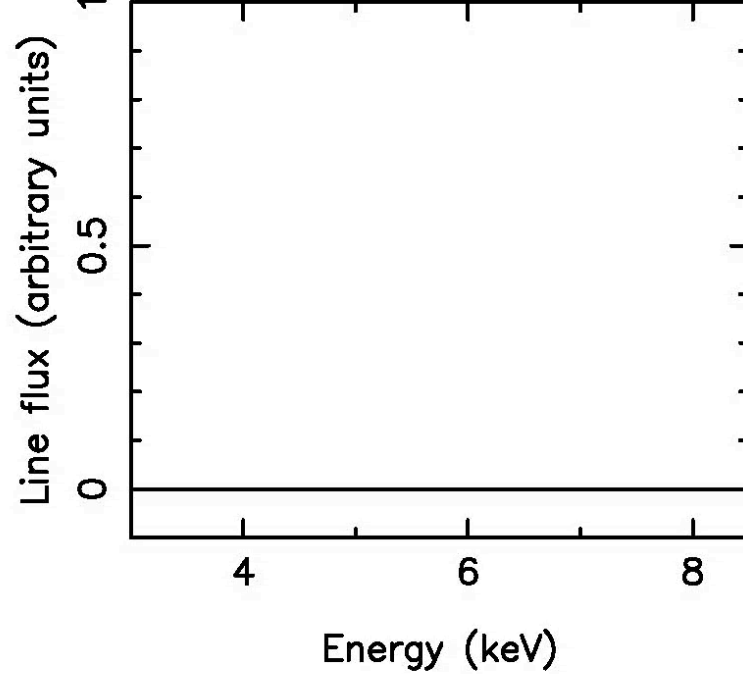
Reverberation

$$h = 10.0 \text{ GM}/c^2, i = 60.0^\circ, \text{ISCO} = 6.0 \text{ GM}/c^2$$

$$\tau = 0.00 \text{ GM}/c^3$$



Cackett13

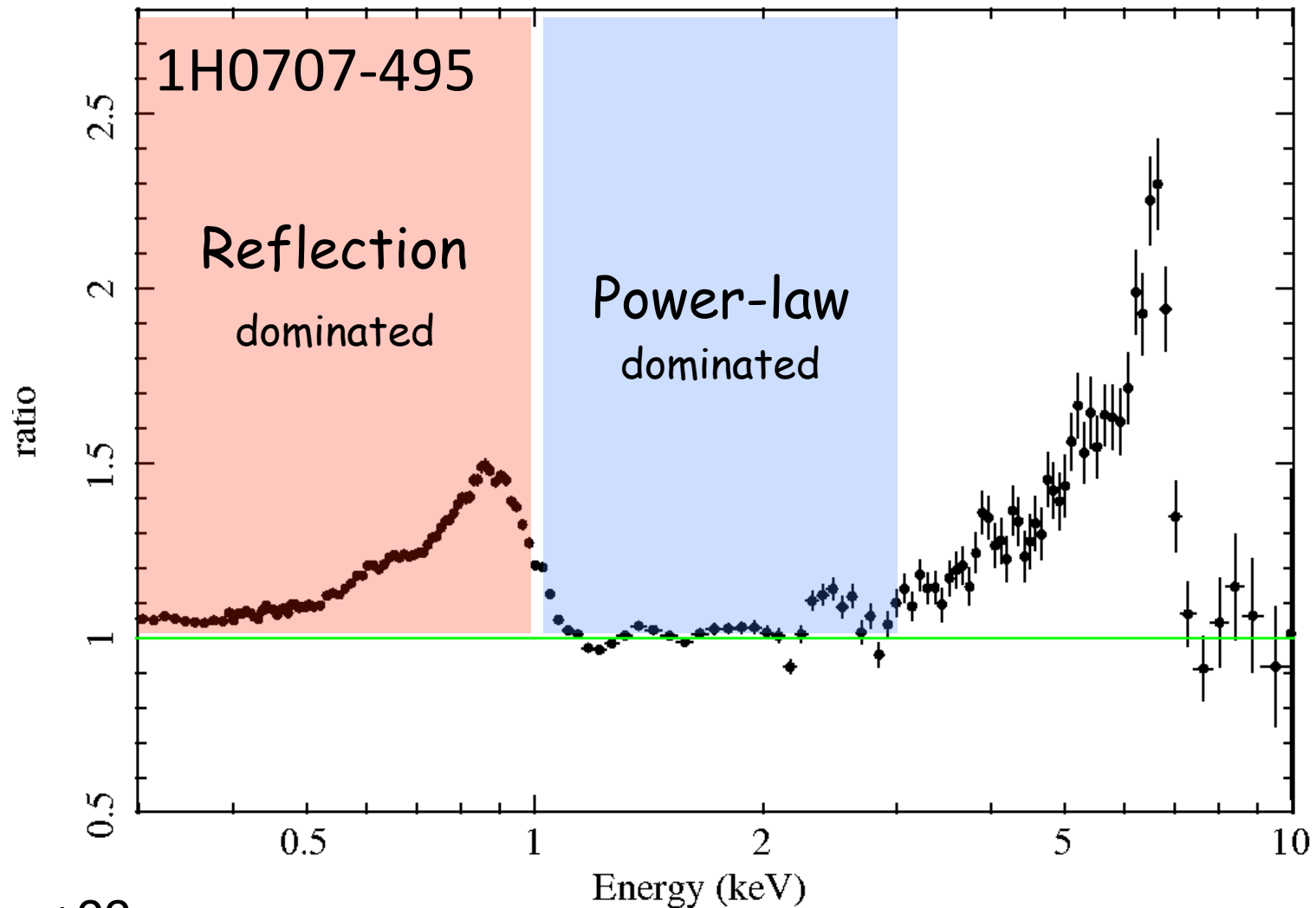


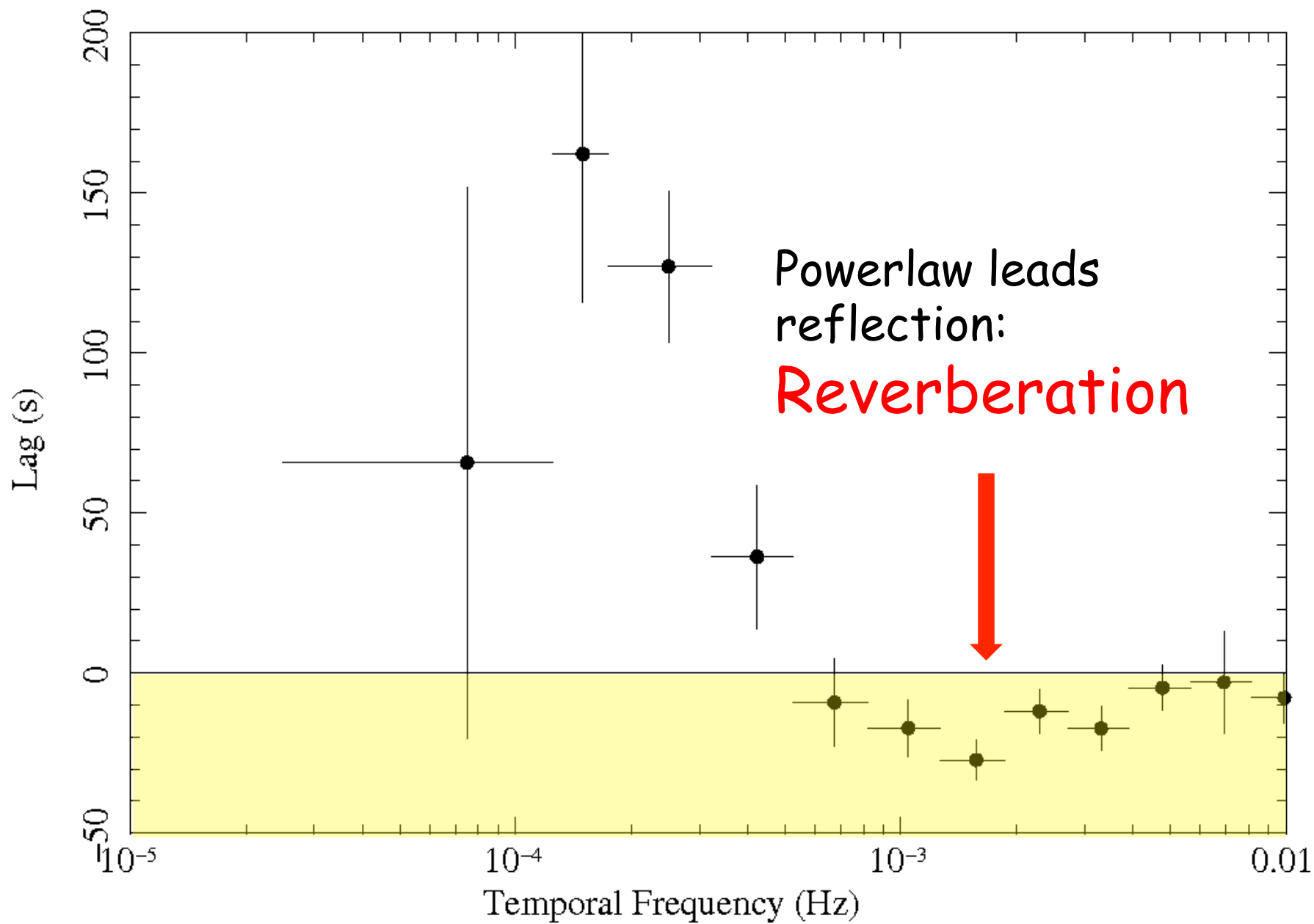
Observations of Reverberation complicated
since see both Direct and Reflection
components together

Separate spectrally
(contributions vary with energy)

Need Spectral Timing

X-ray Reverberation

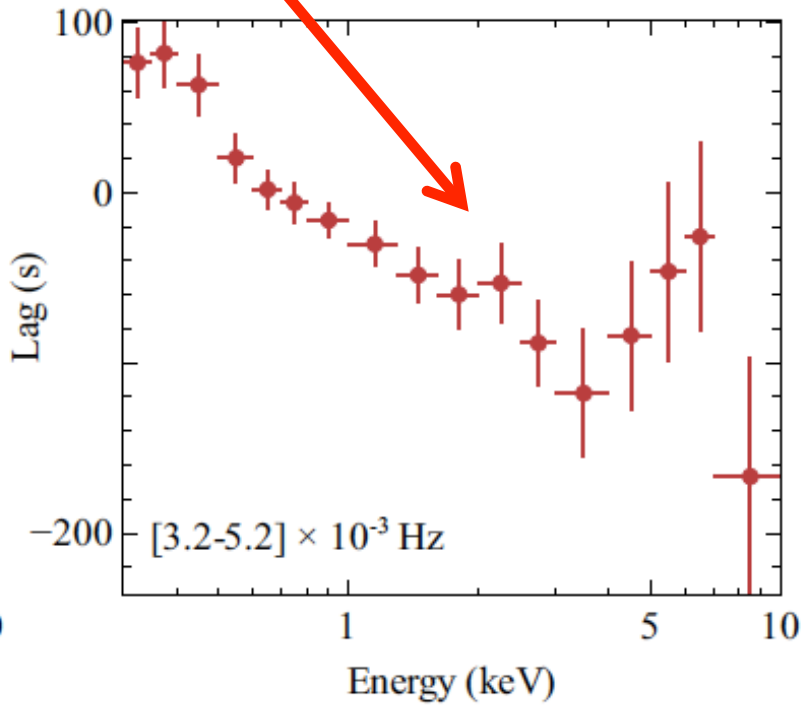
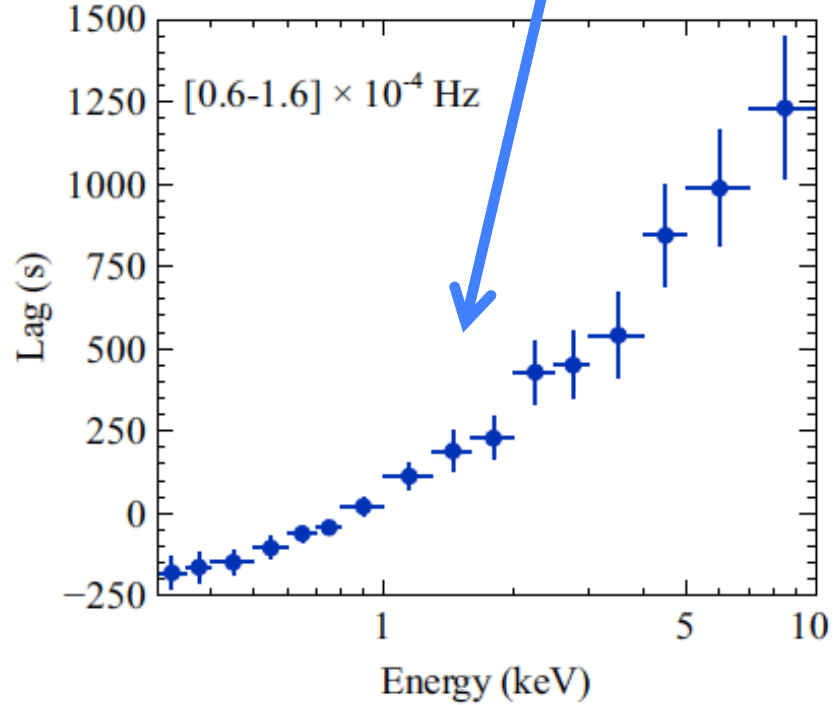
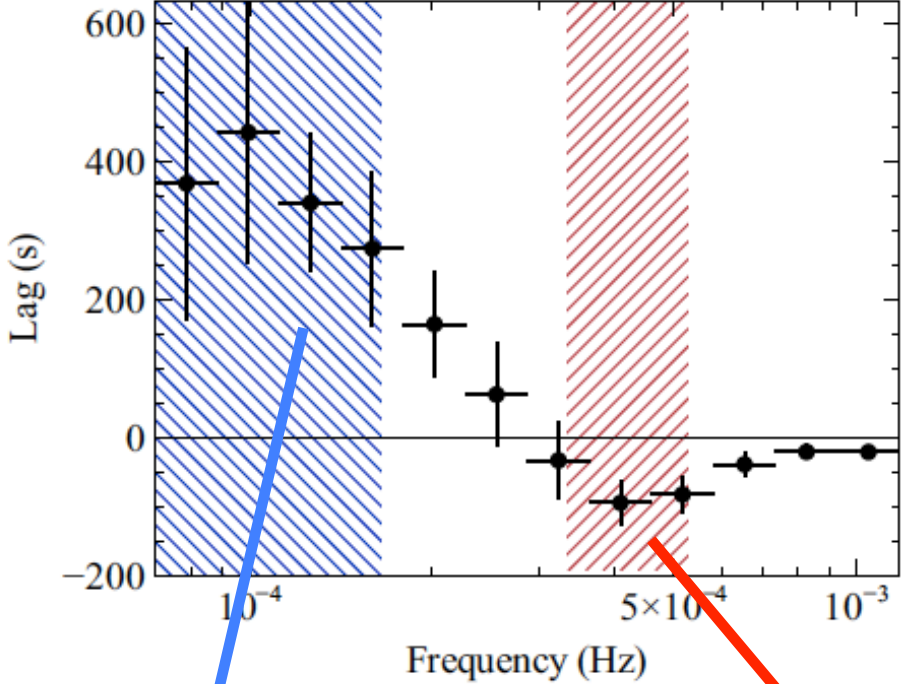


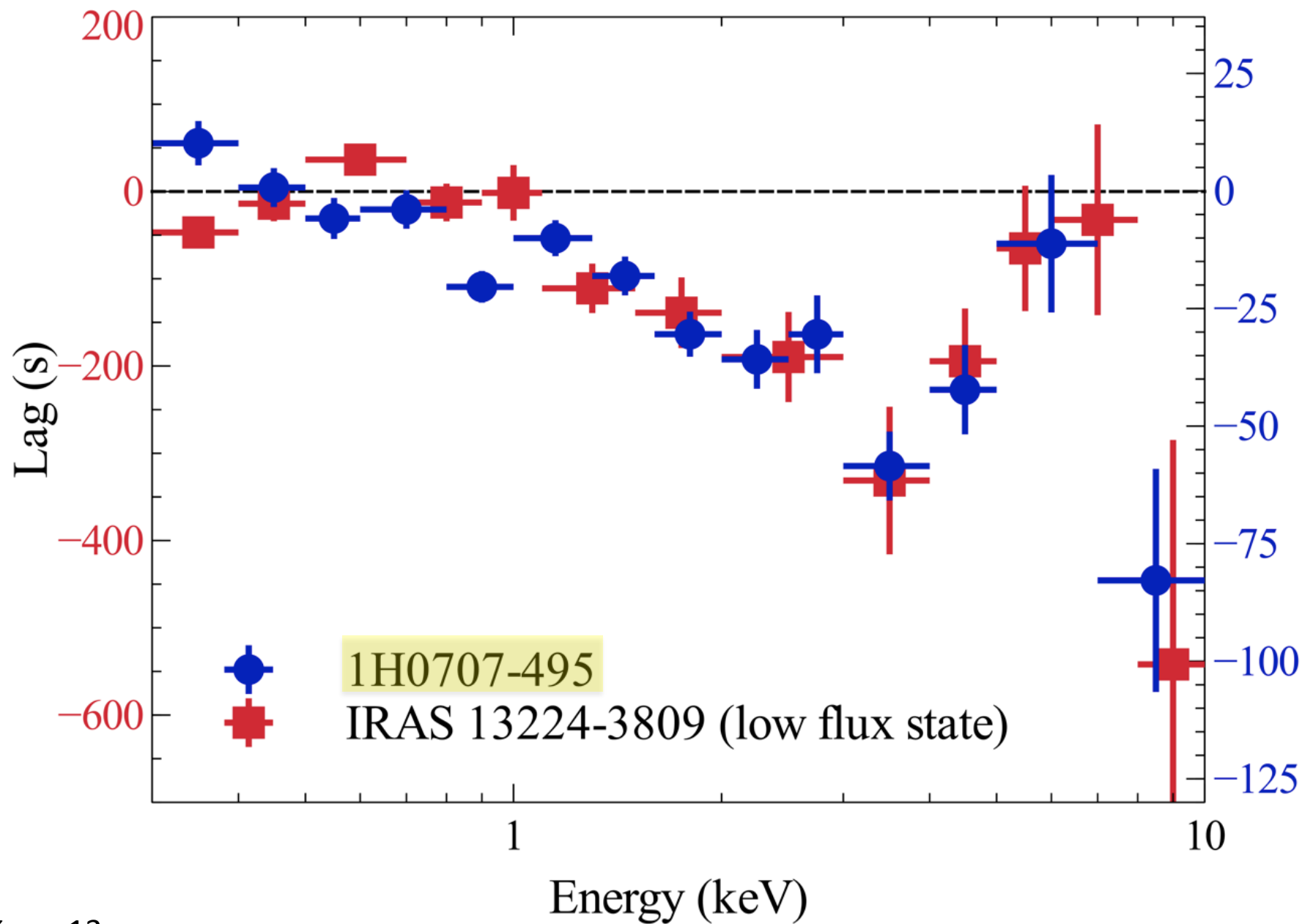


Akn564
Kara+13

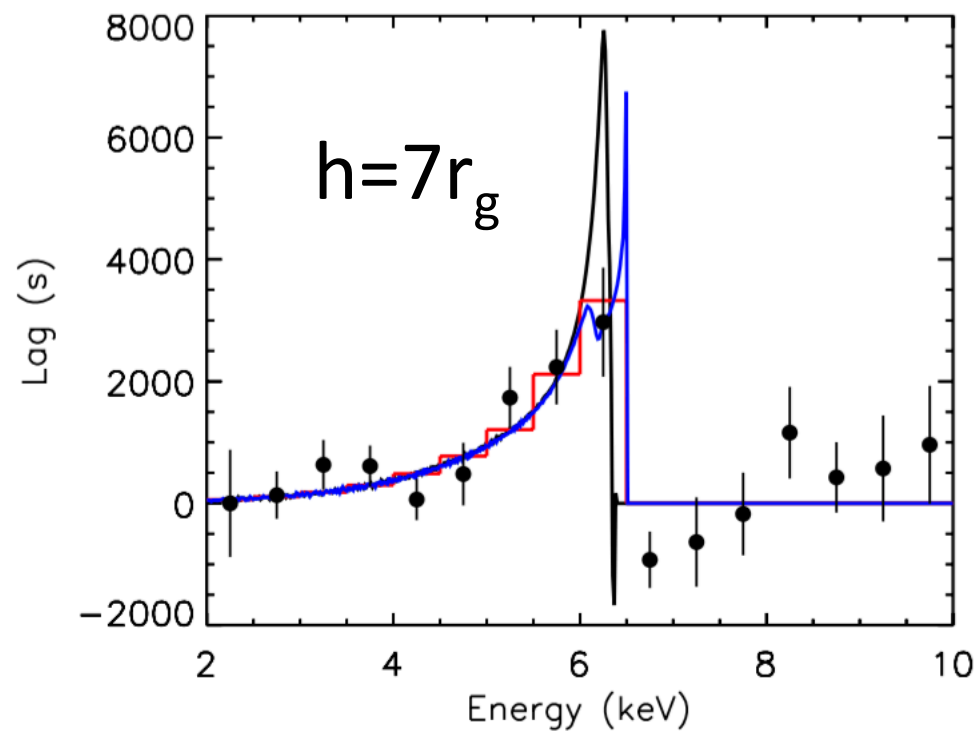
Low frequency lag
featureless so
NOT reverberation

High frequency lag shows iron
So is reverberation

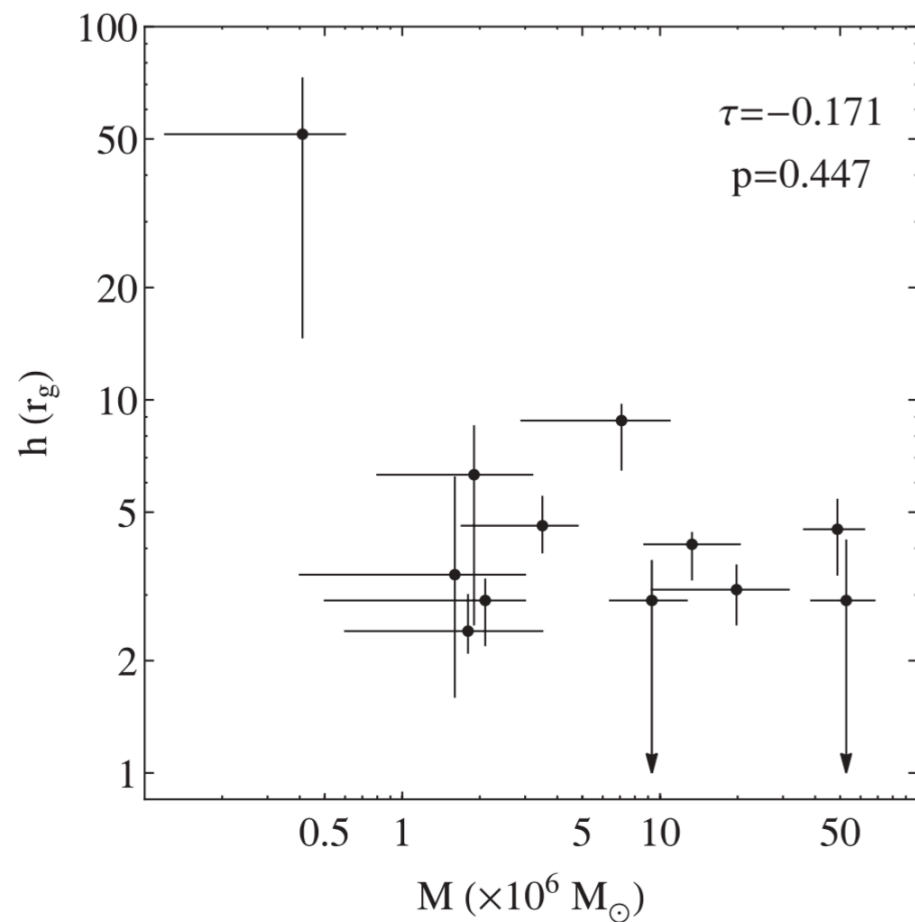




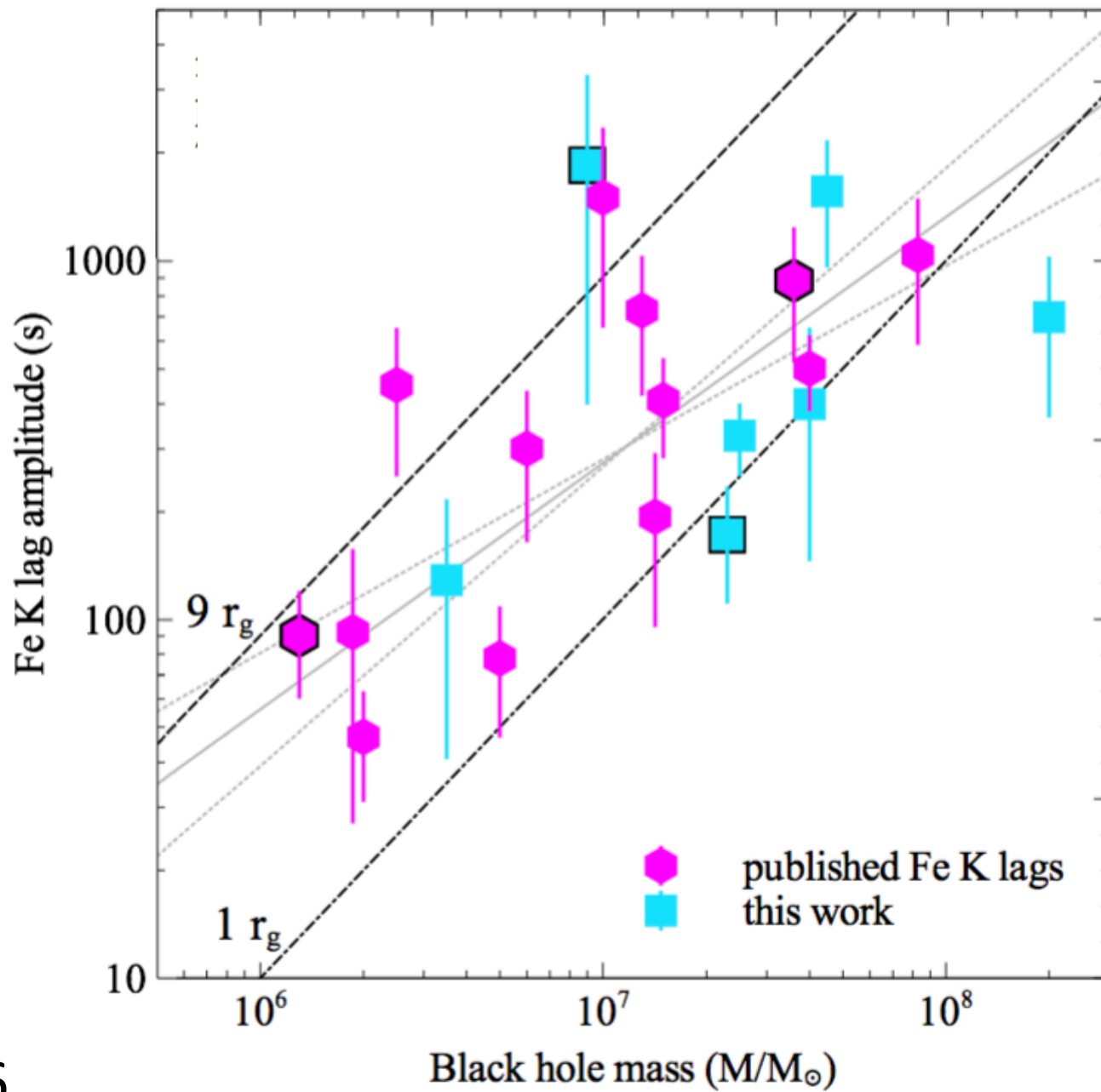
GR Modelling



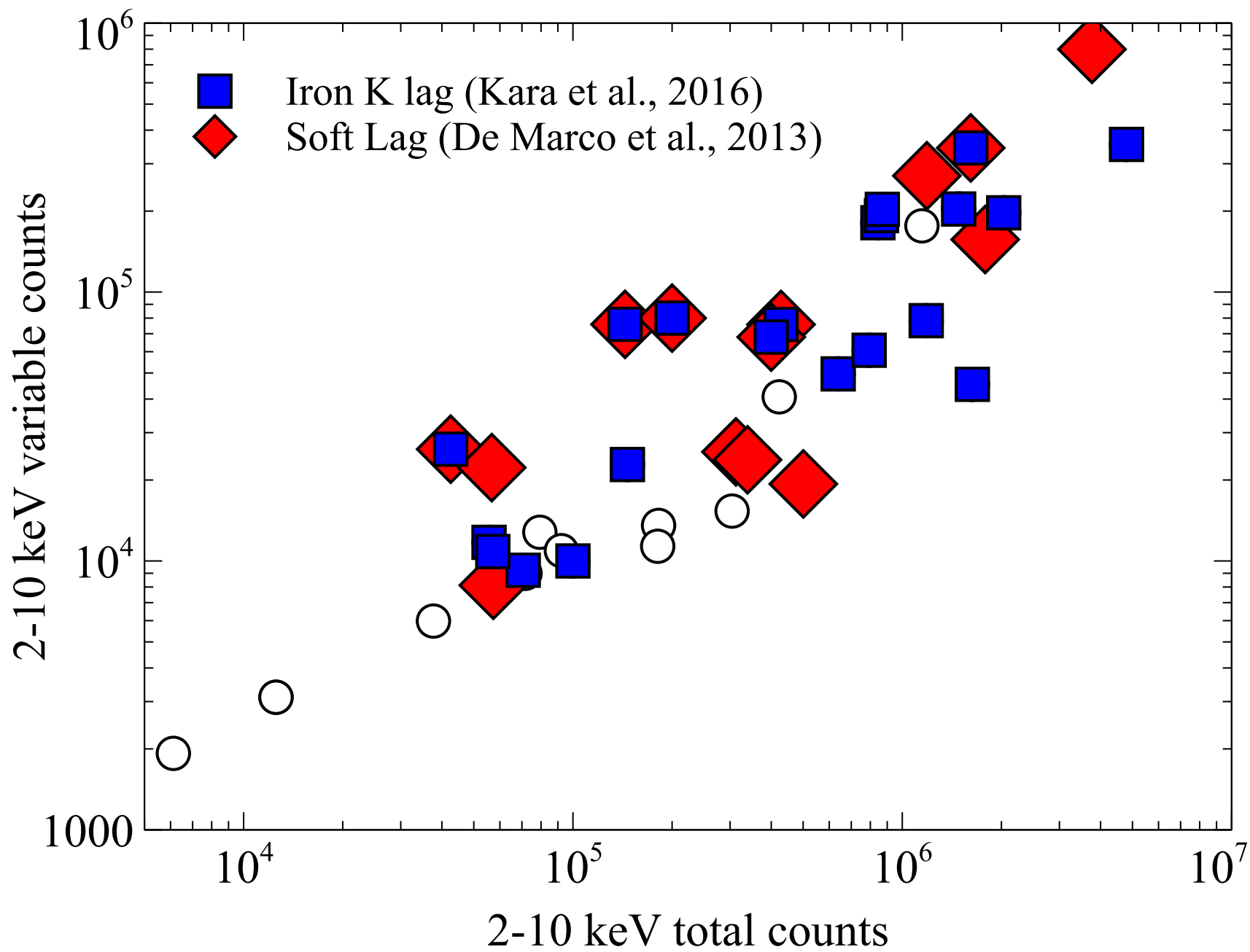
Cackett+14



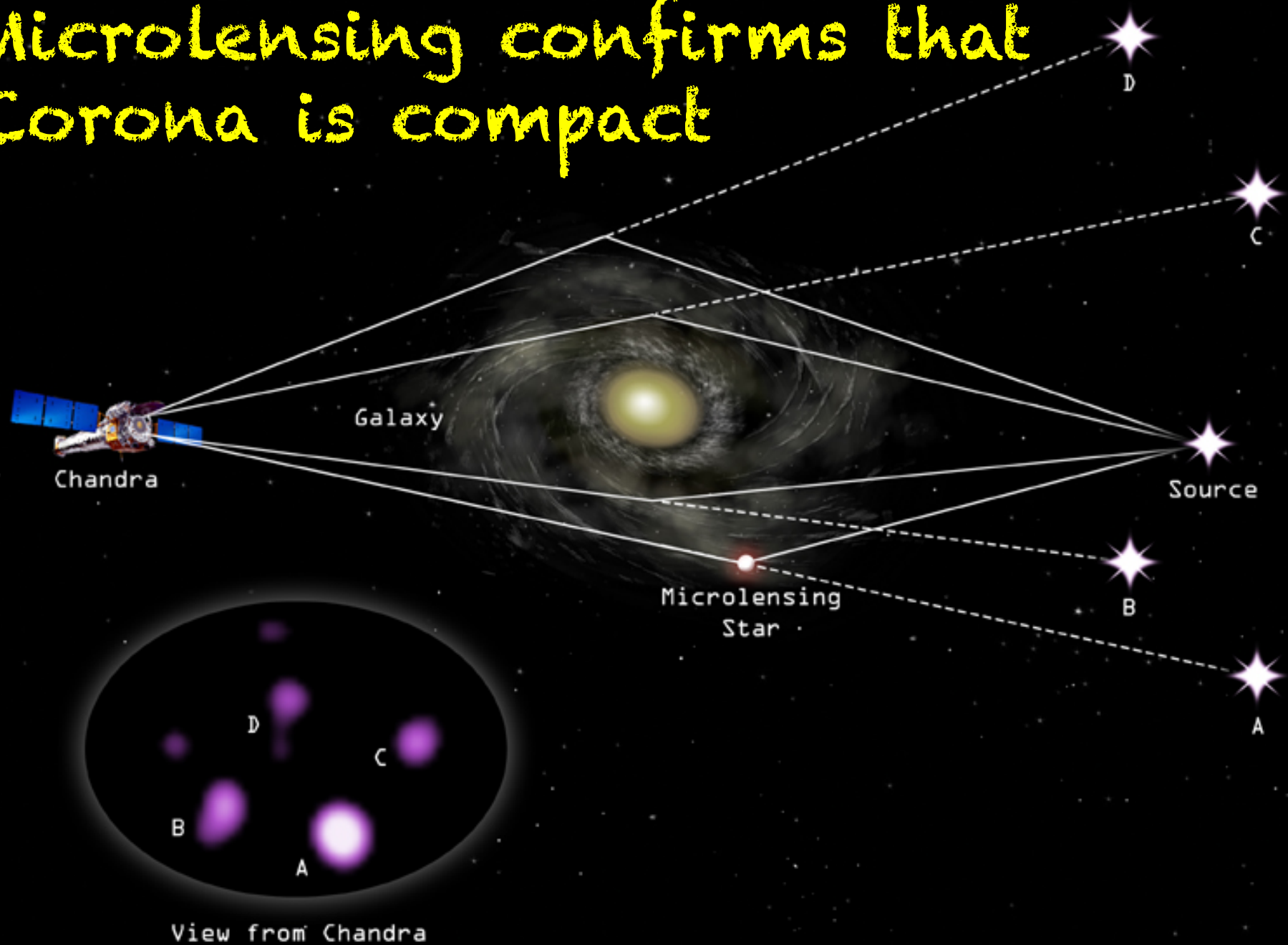
Emmanoulopoulos+14



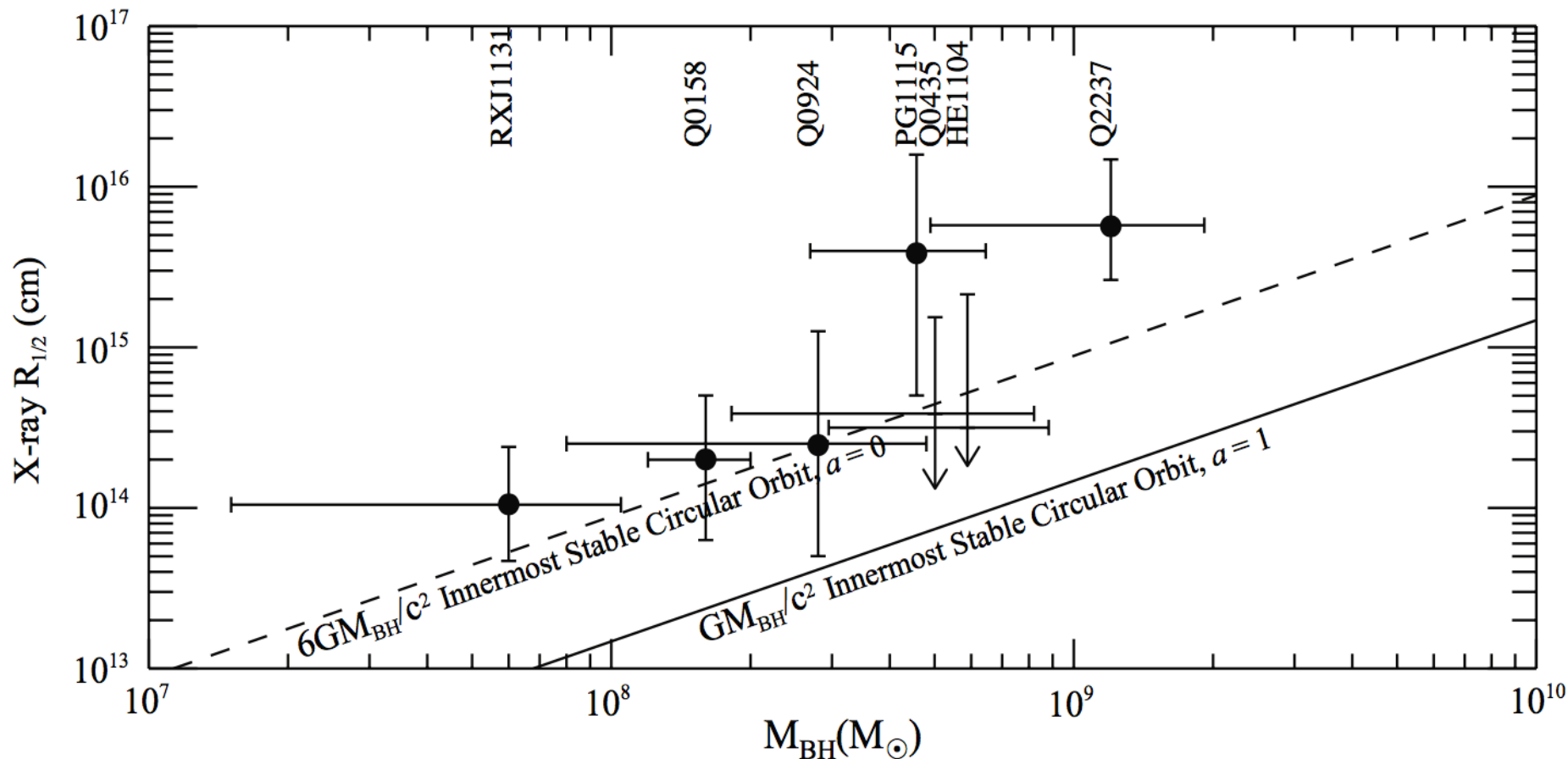
Kara+16



Microlensing confirms that Corona is compact

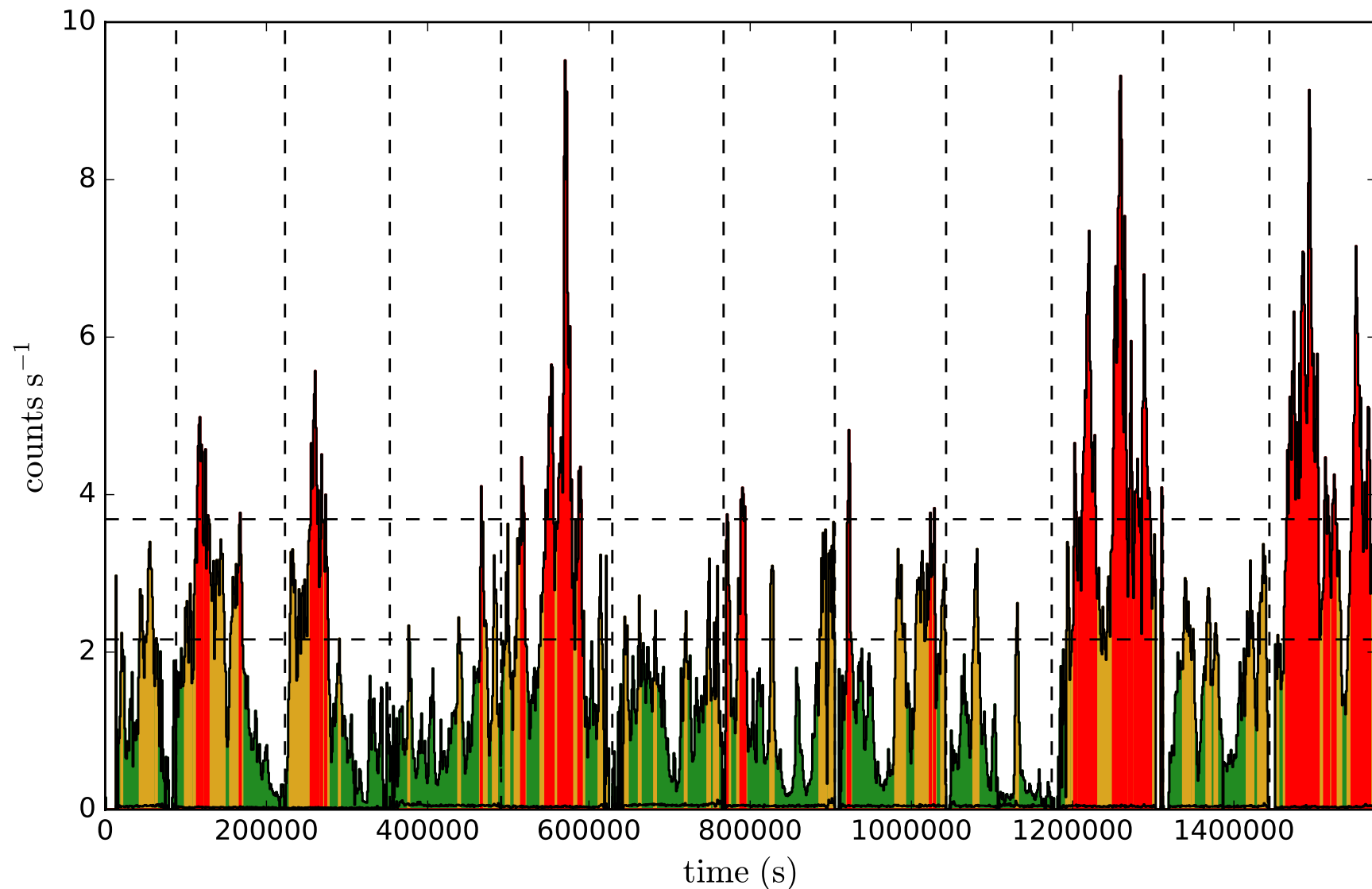


Coronal Size from Microlensing: Coronae are Compact

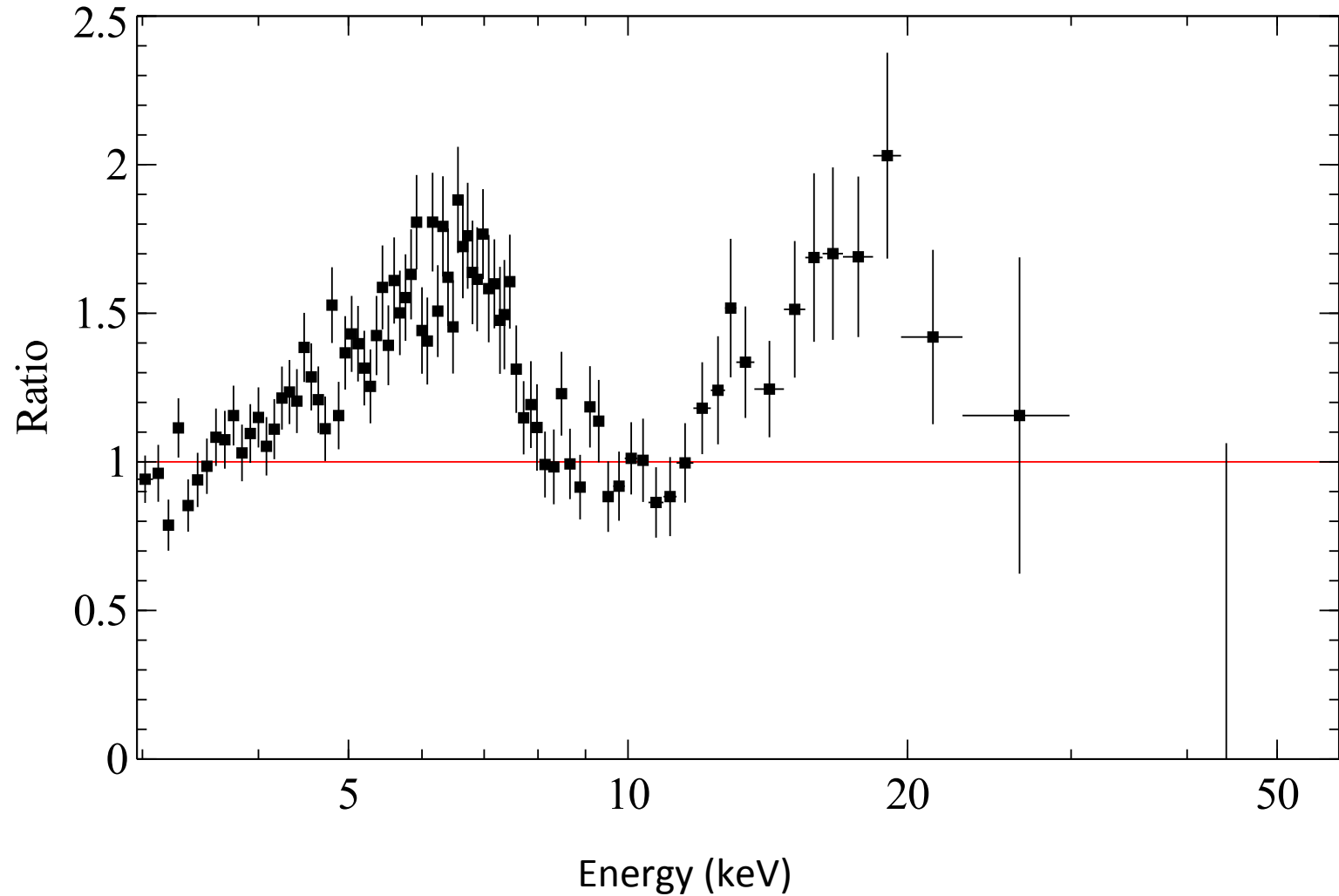


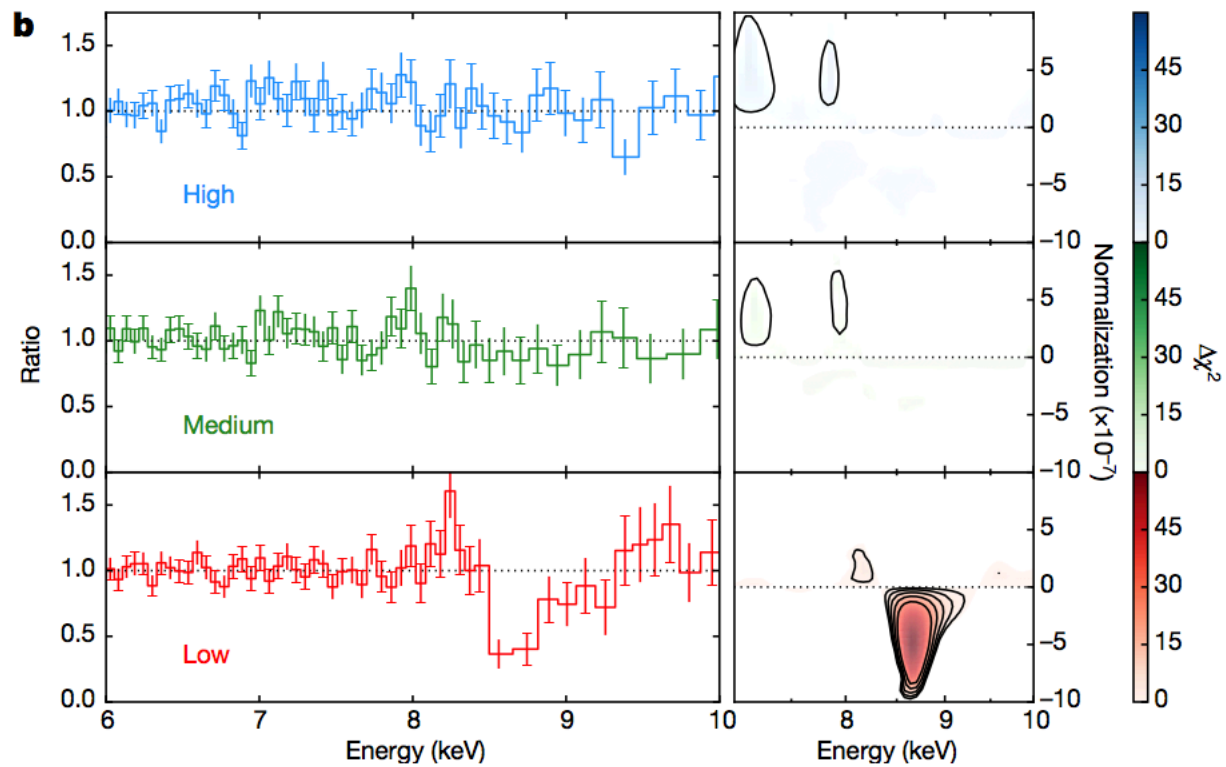
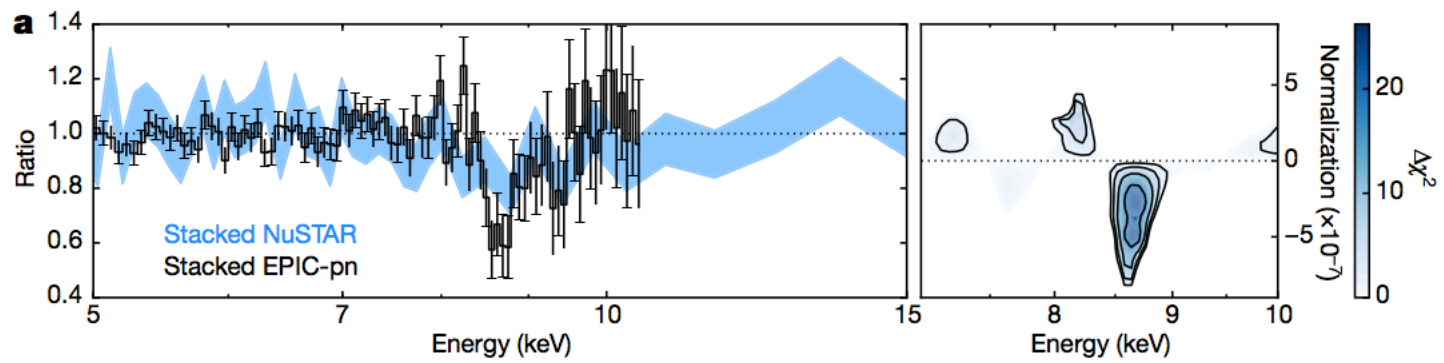
IRAS13224-3809 – MOST VARIABLE AGN IN X-RAYS

XMM + NuSTAR PROGRAMME 1.5Ms

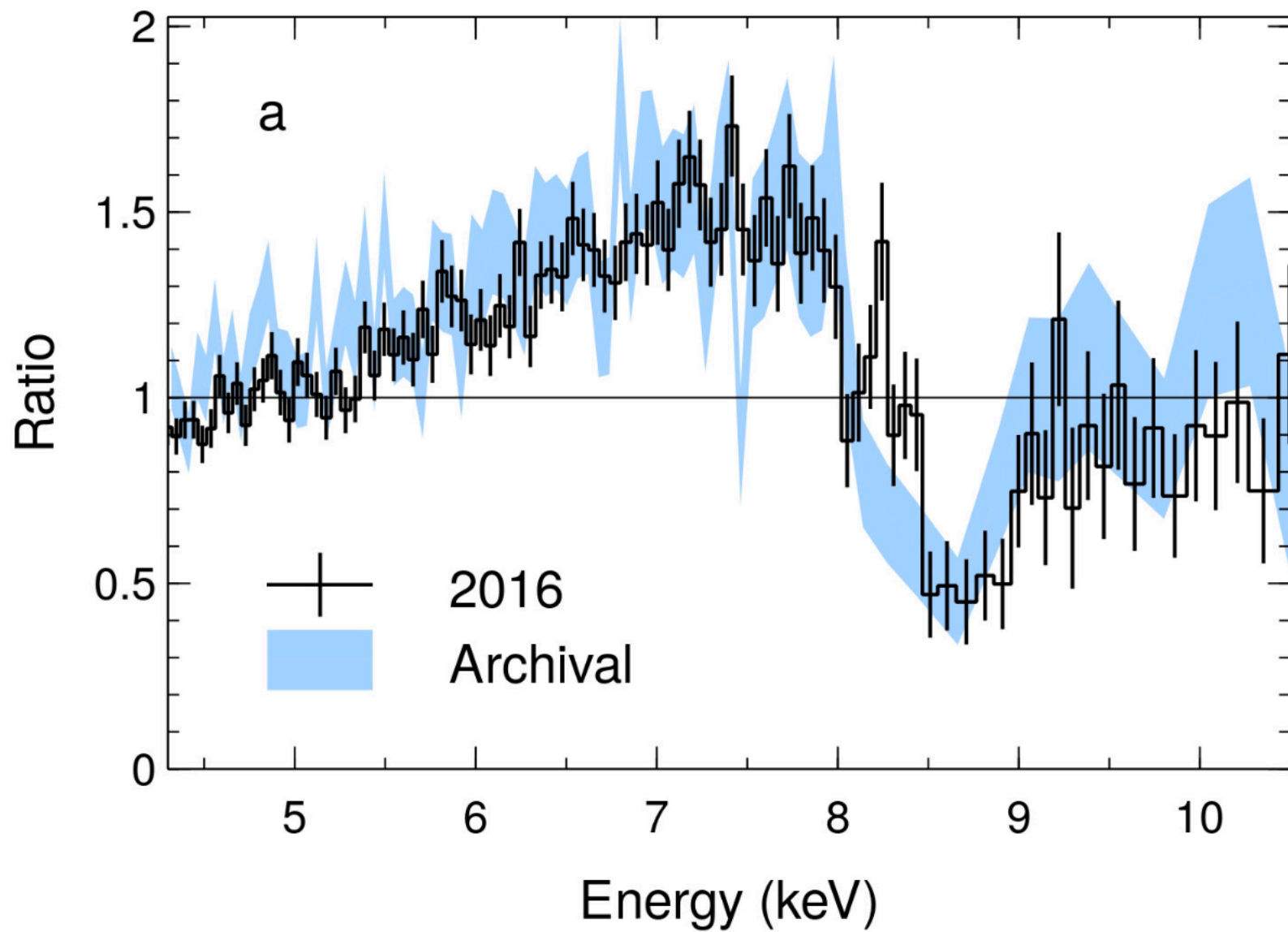


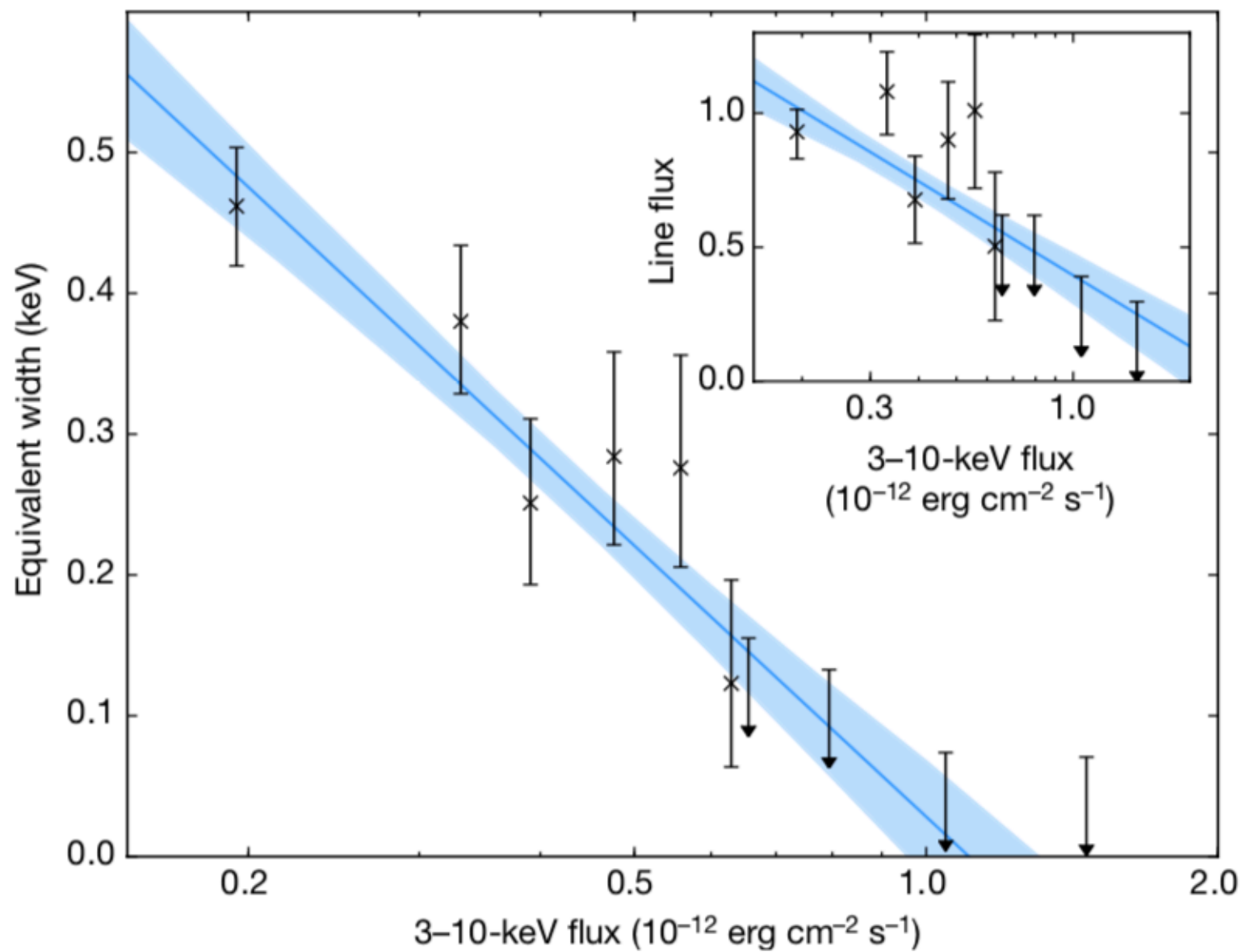
NuSTAR spectrum from 2016

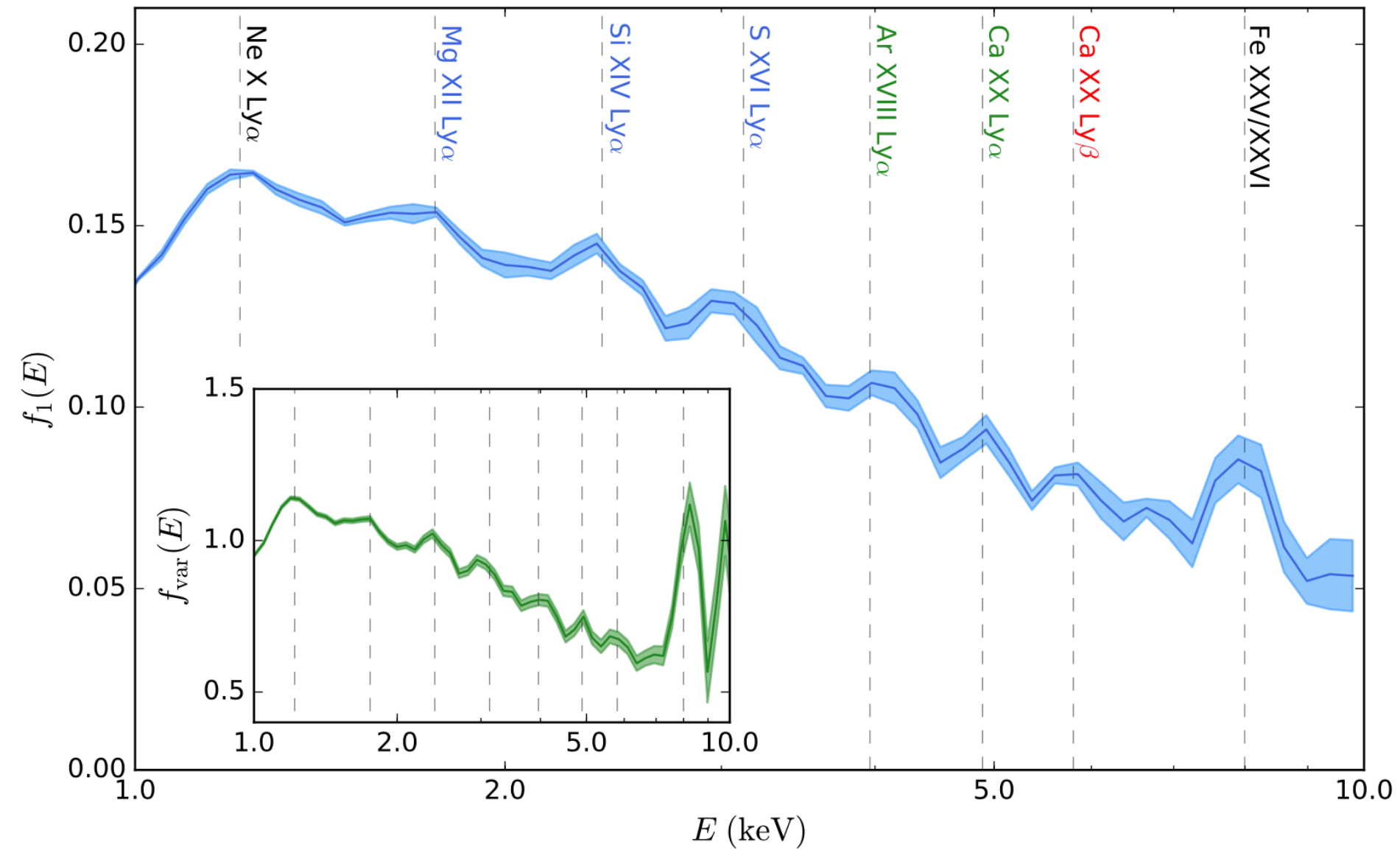




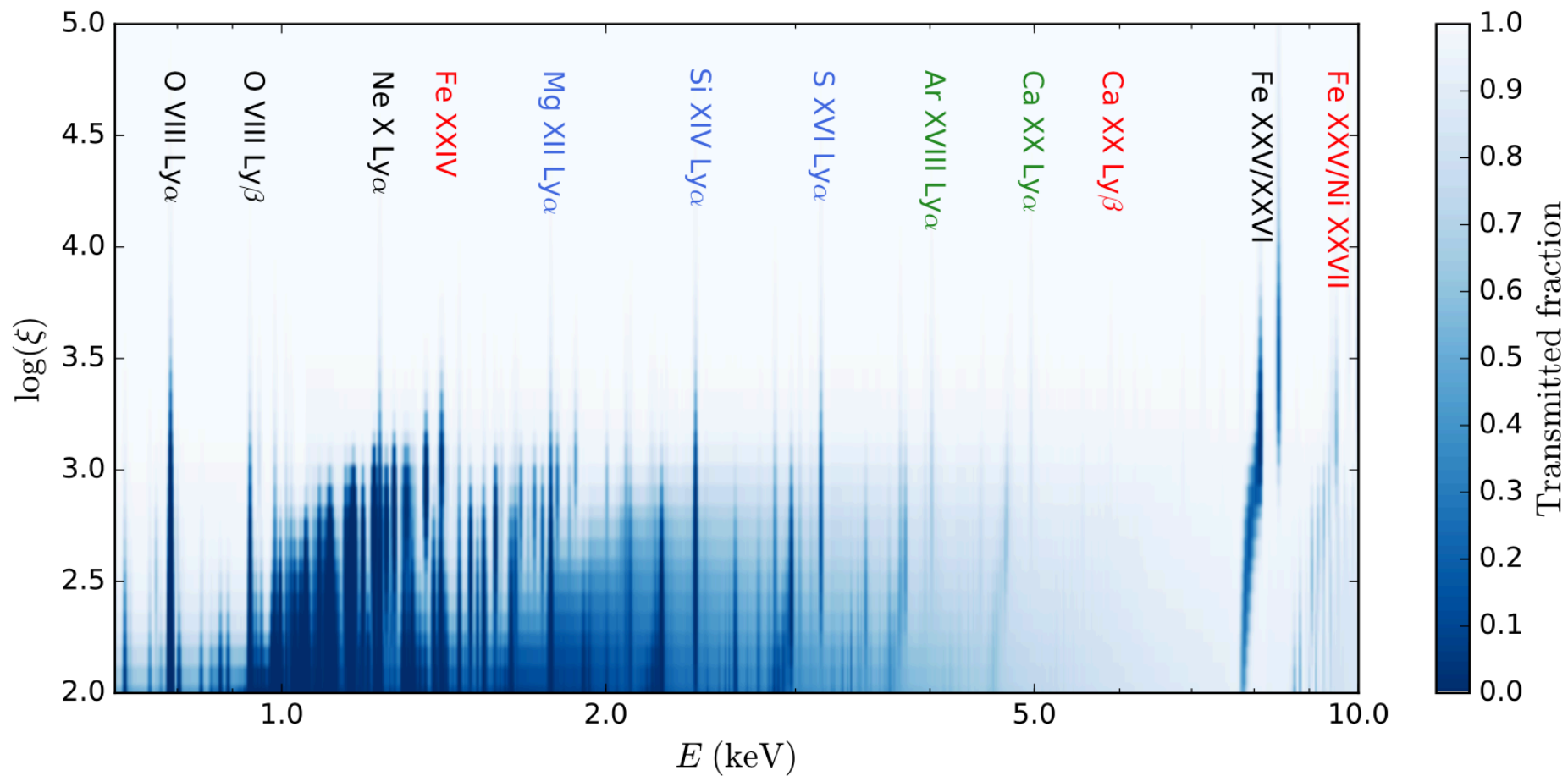
Parker+17a



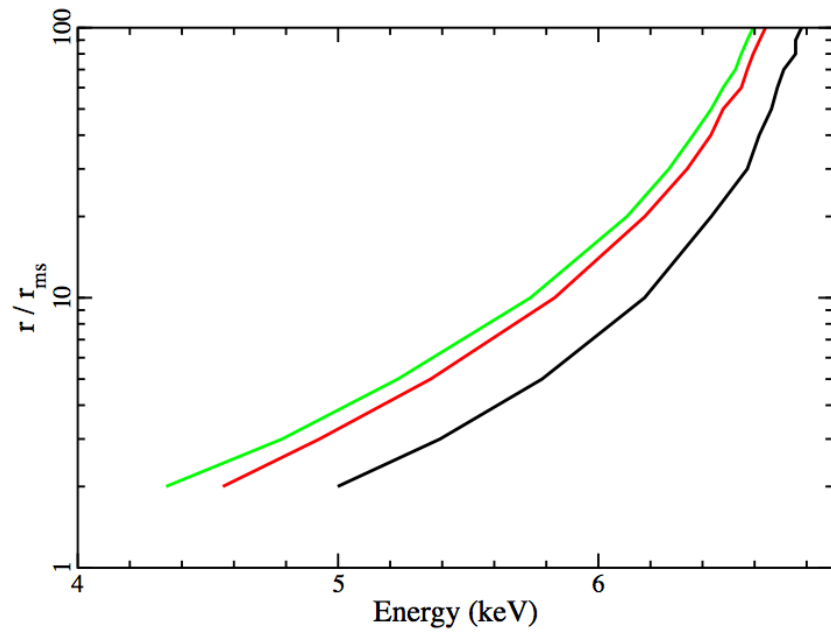




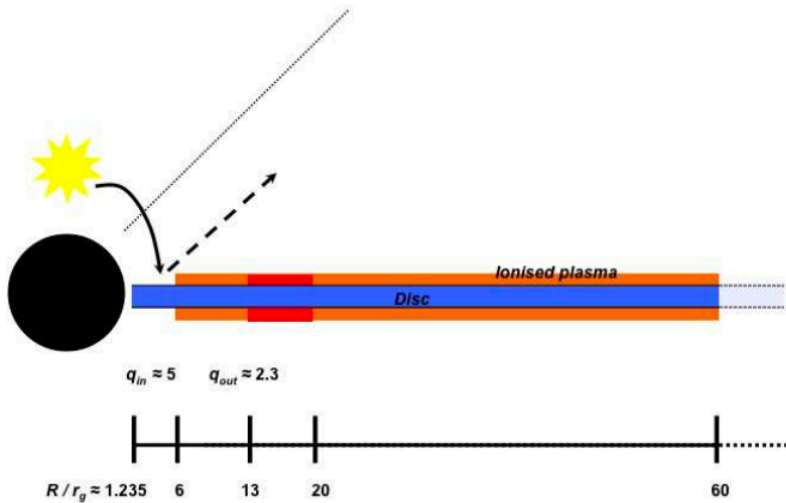
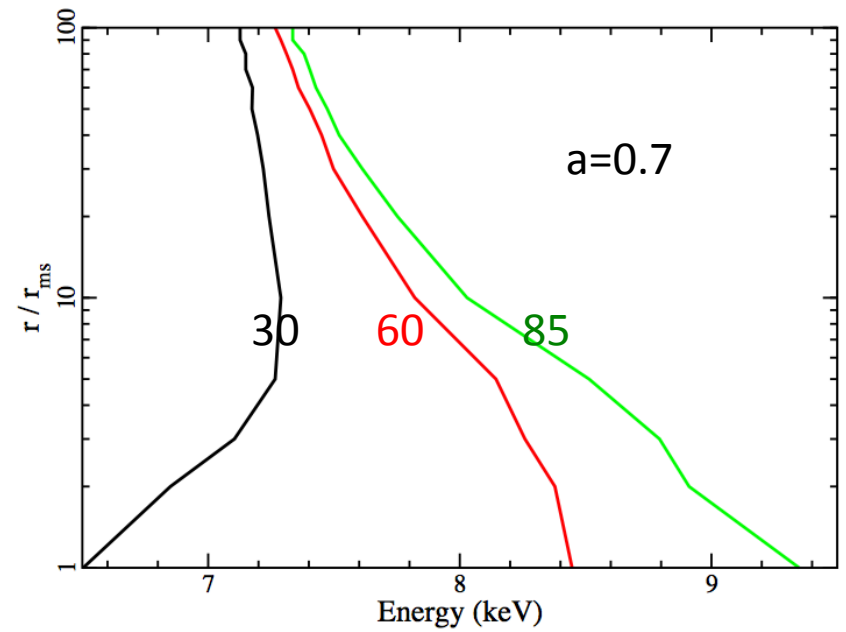
Parker+17b



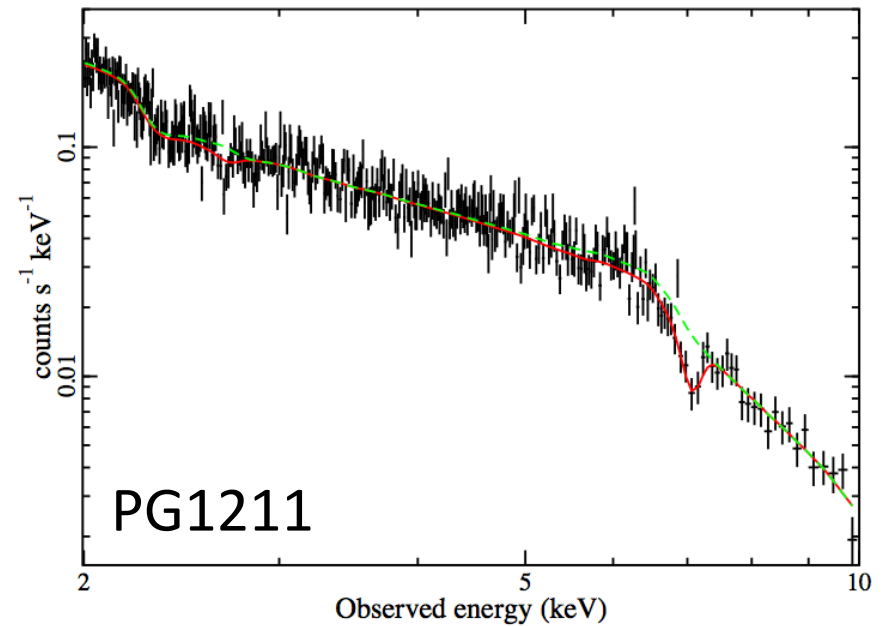




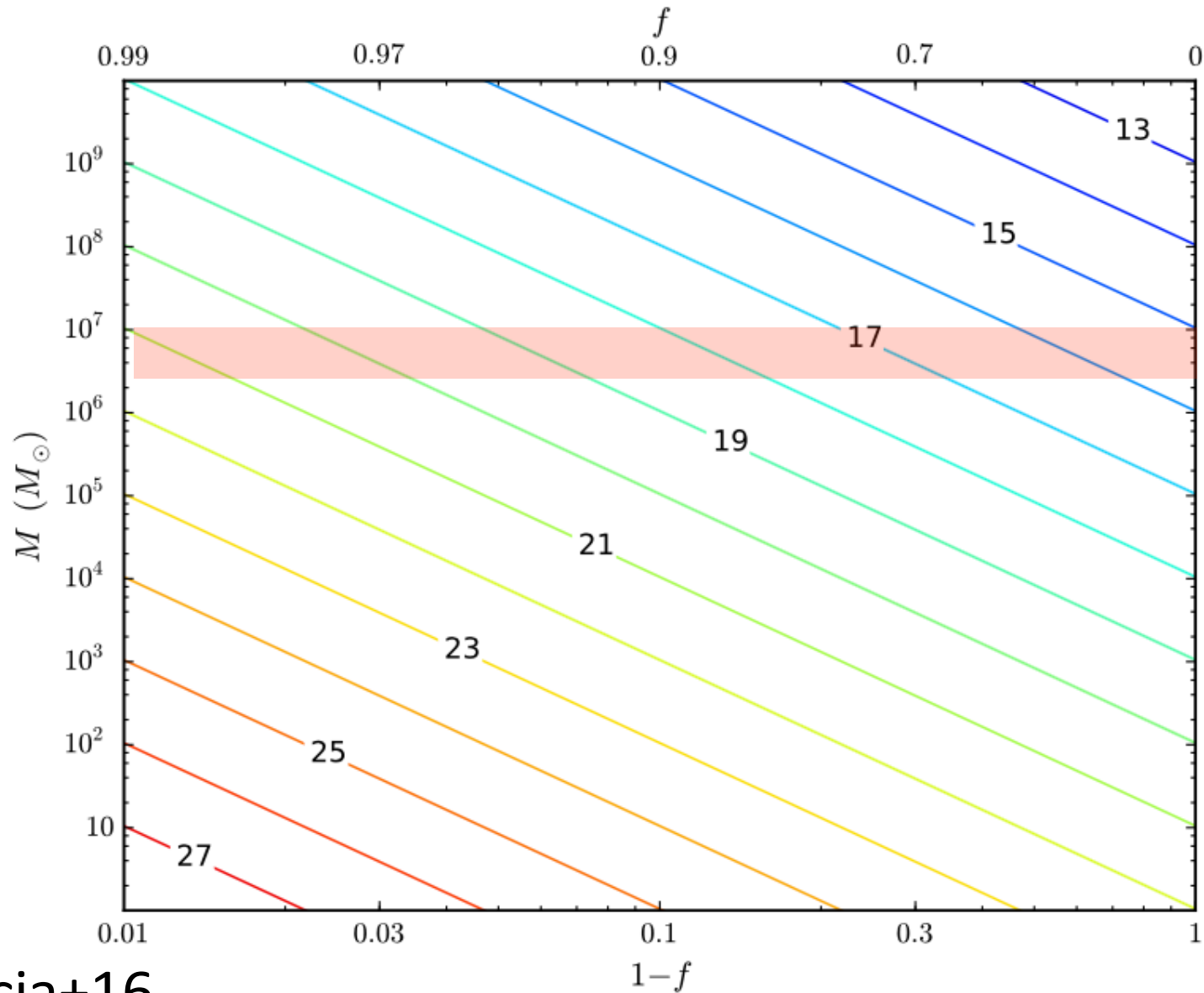
Gallo+Fabian11

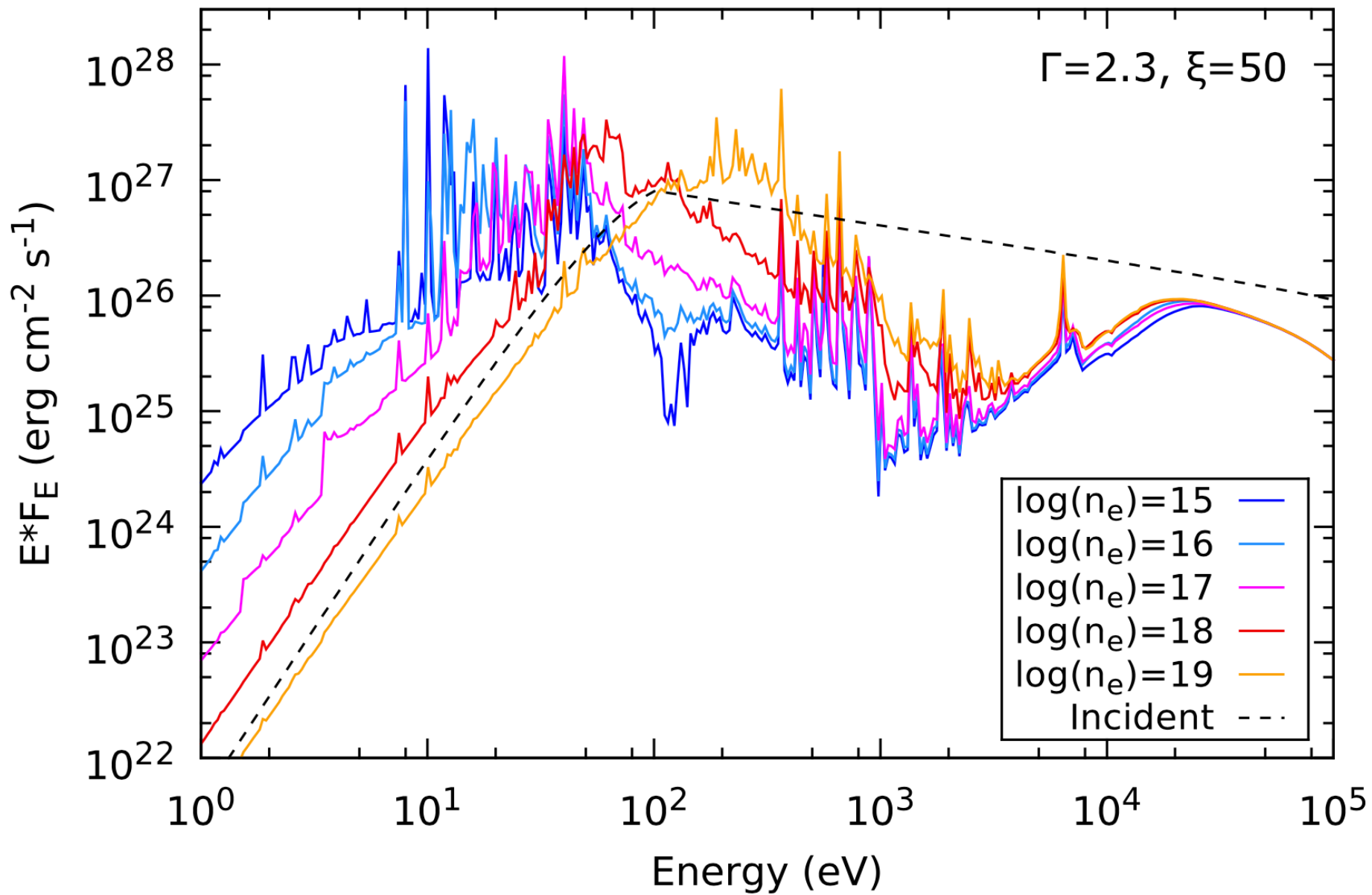


Gallo+Fabian13

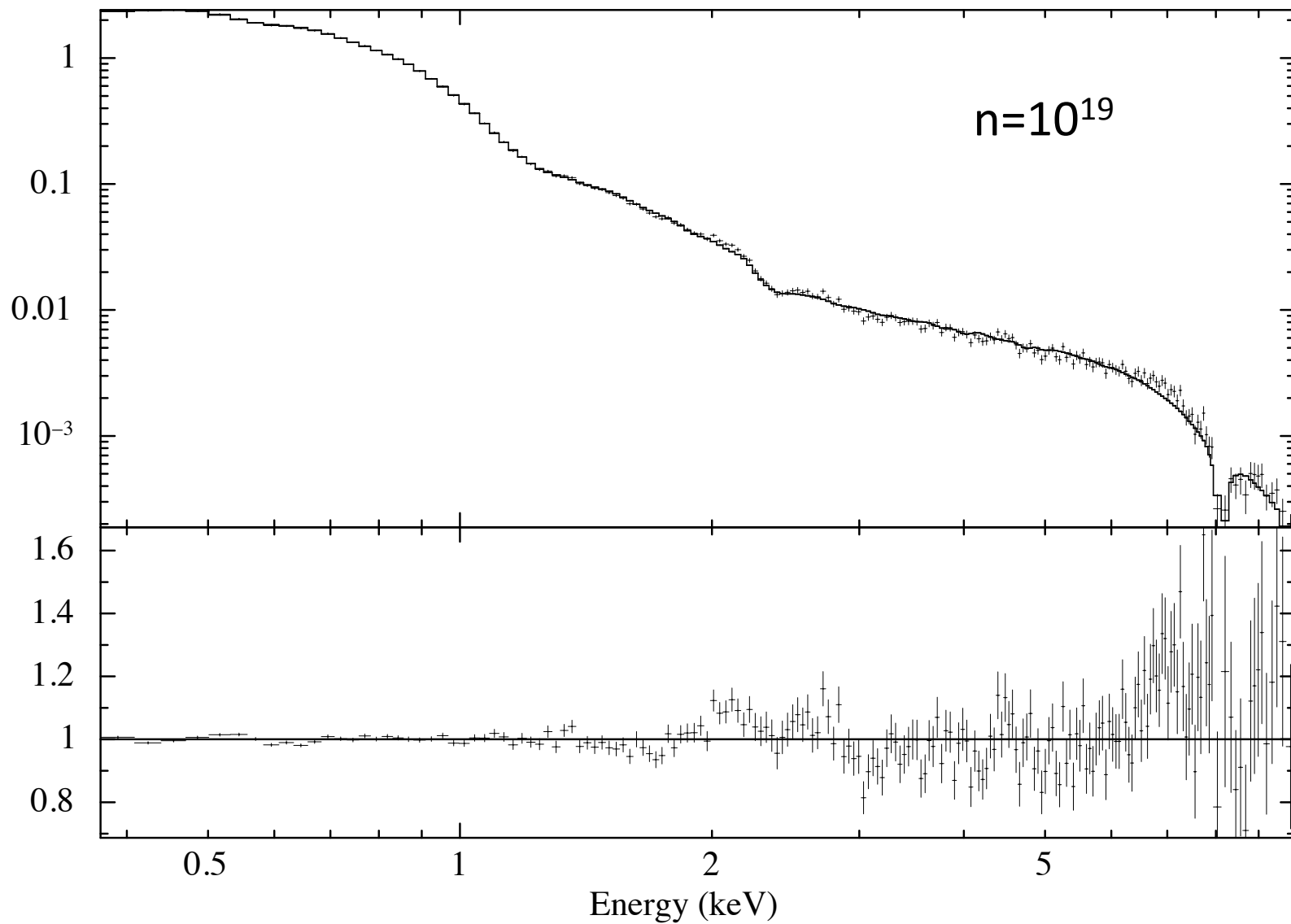


HIGH Density Reflection Models appropriate

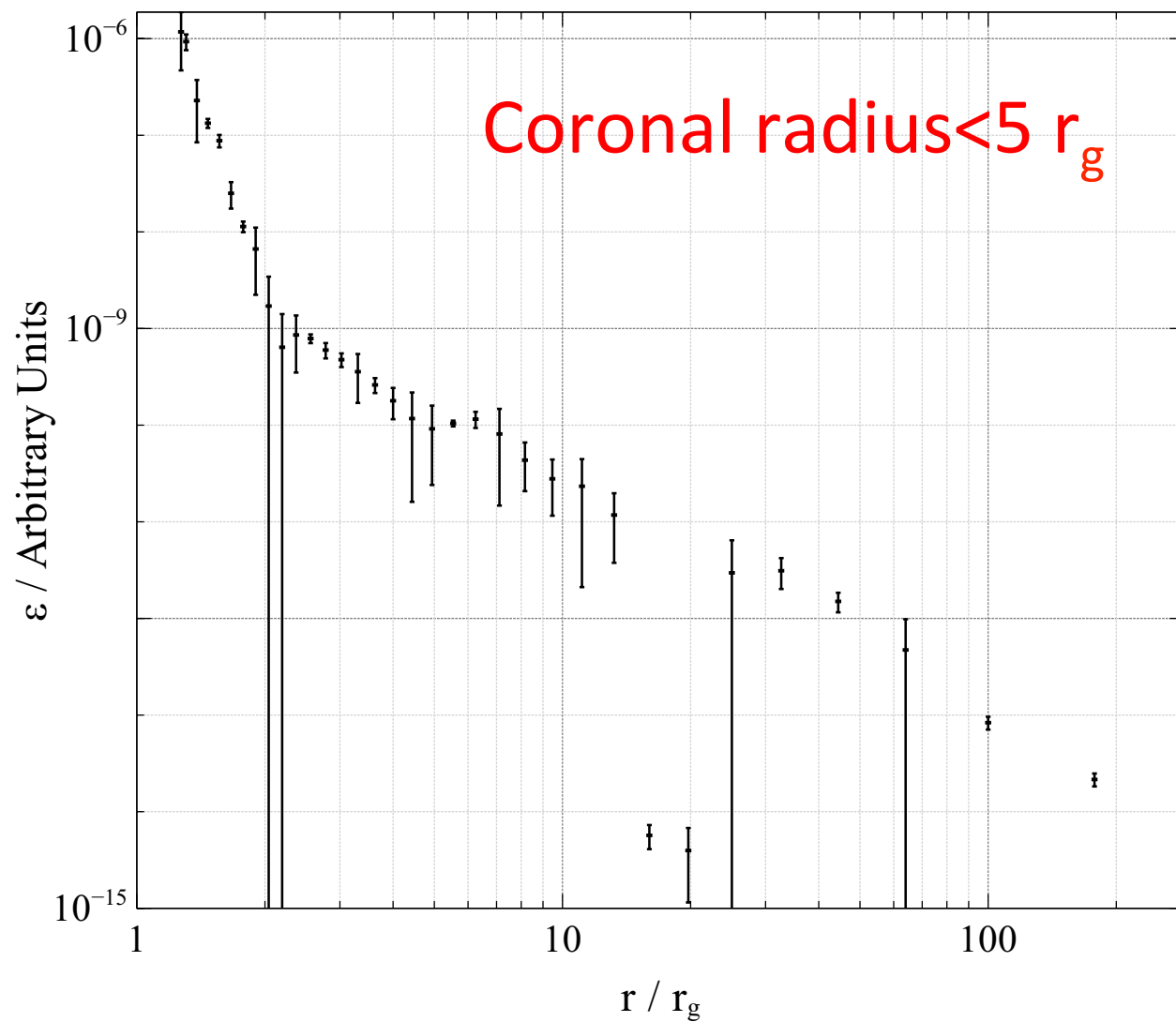


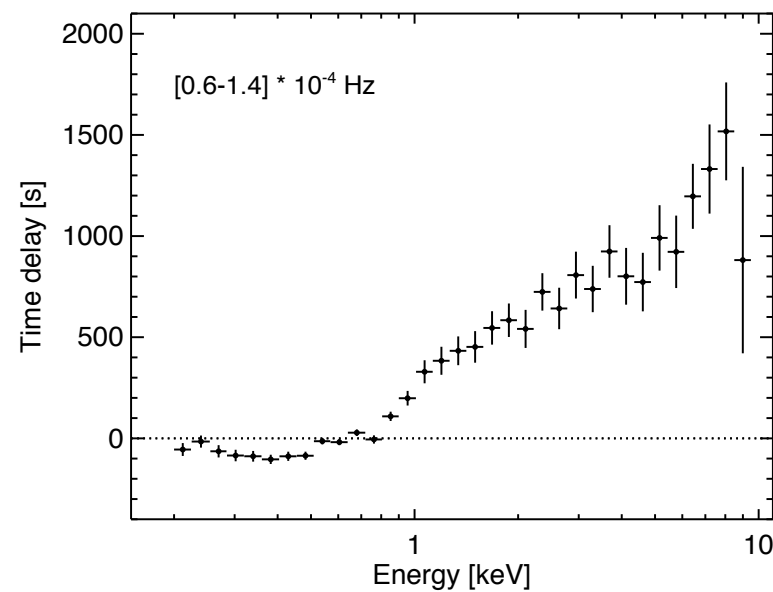
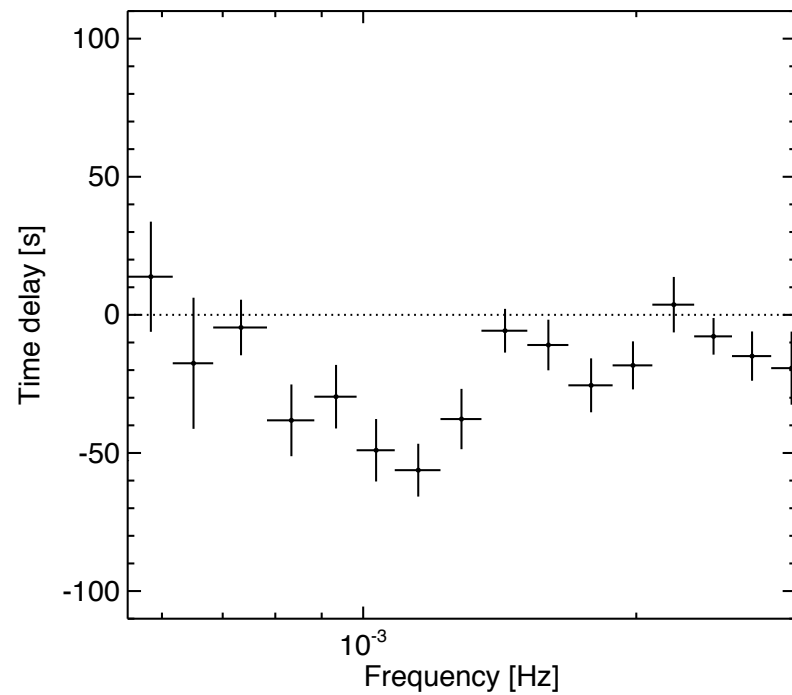
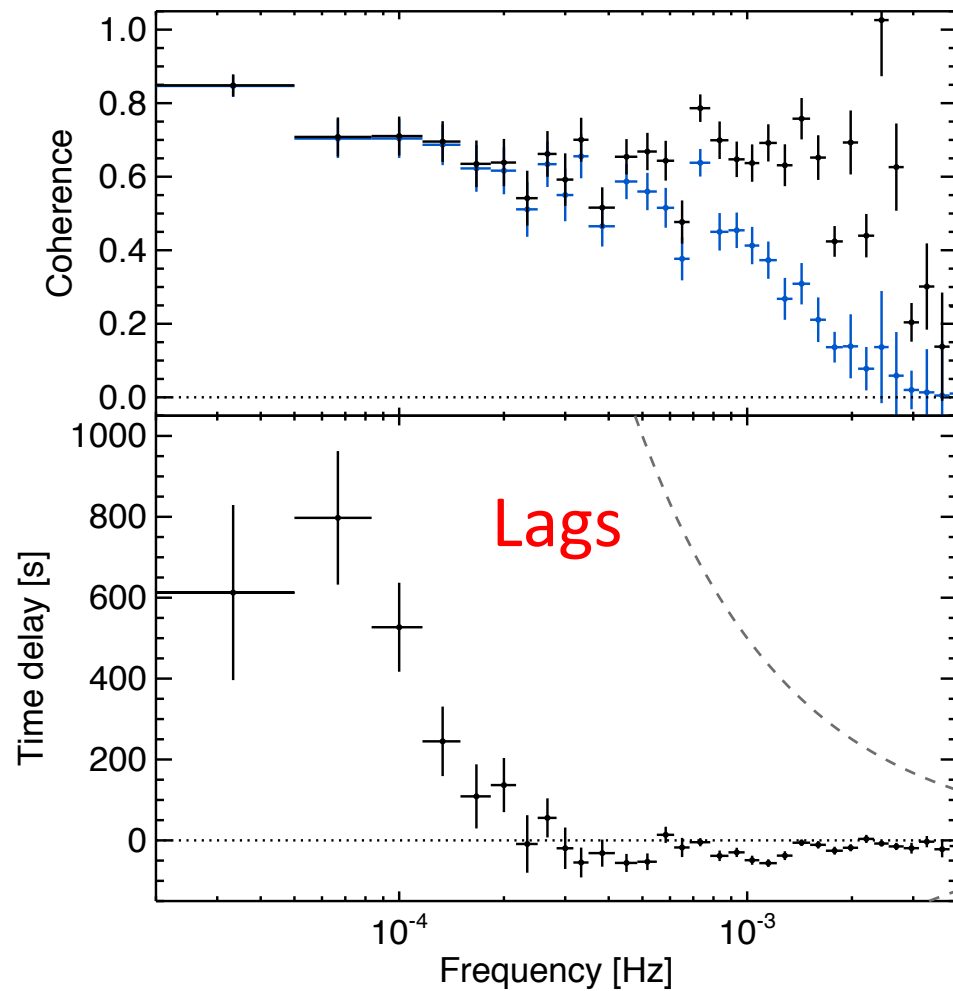


High Density Fit to low state

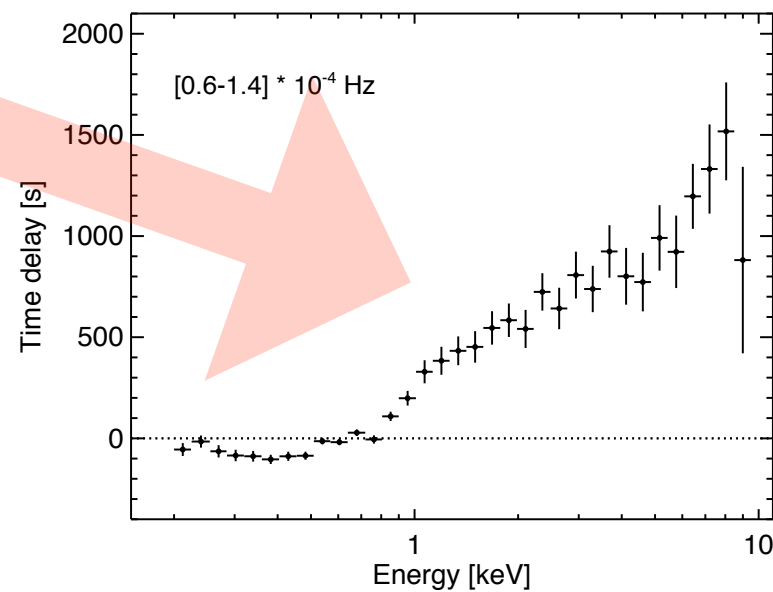
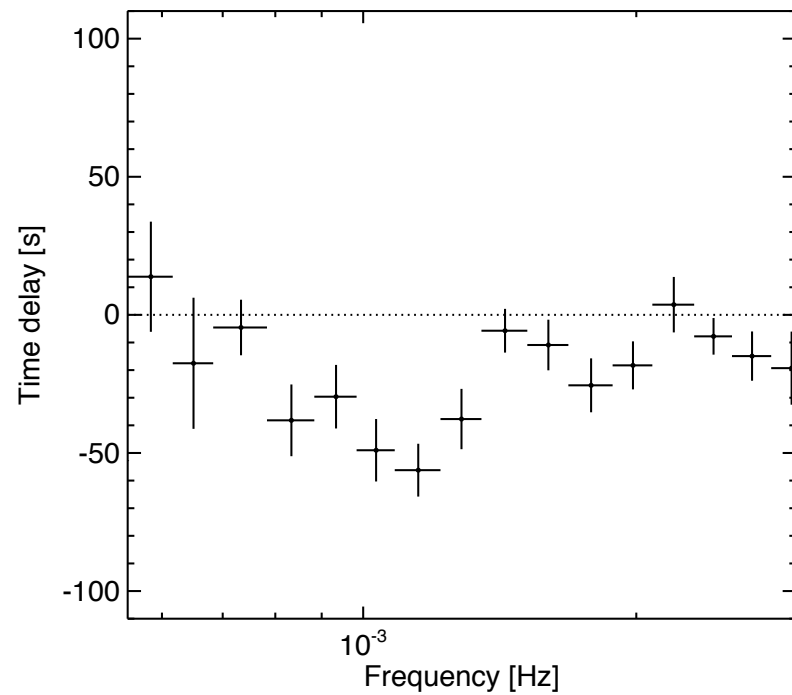
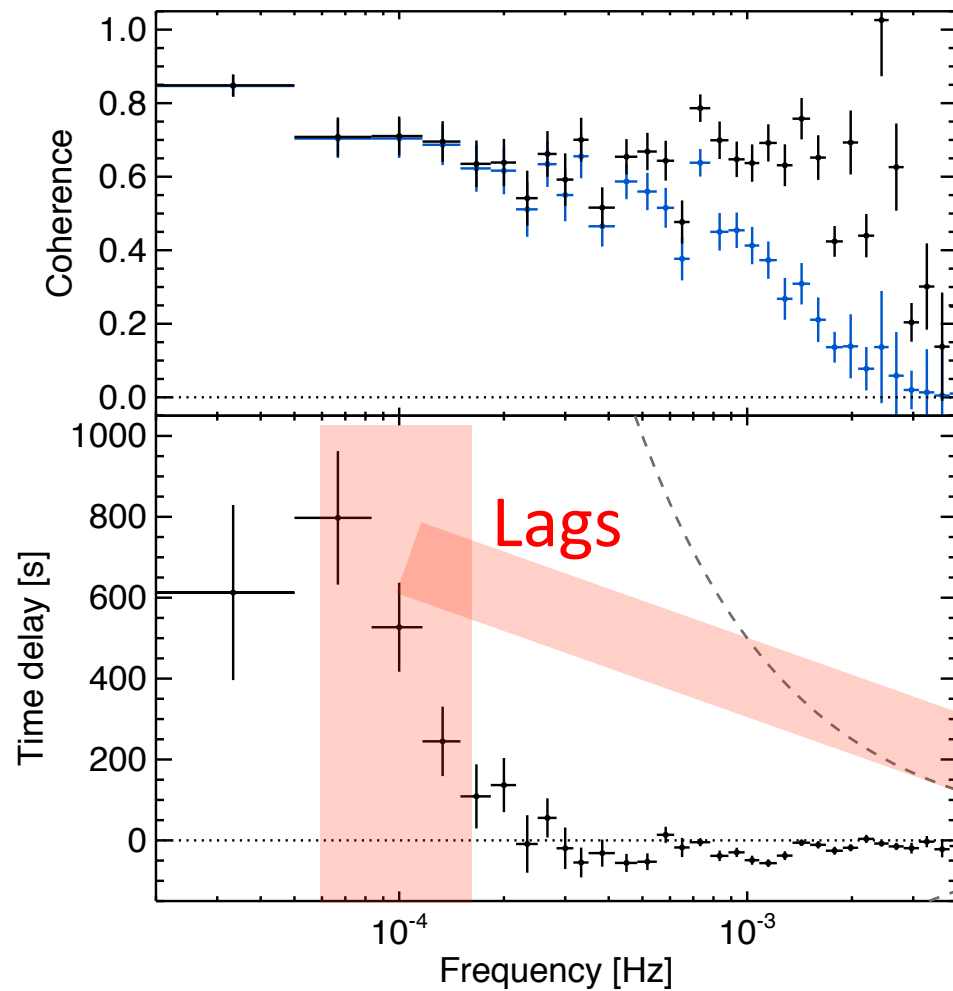


Emissivity Profile (D. Wilkins)

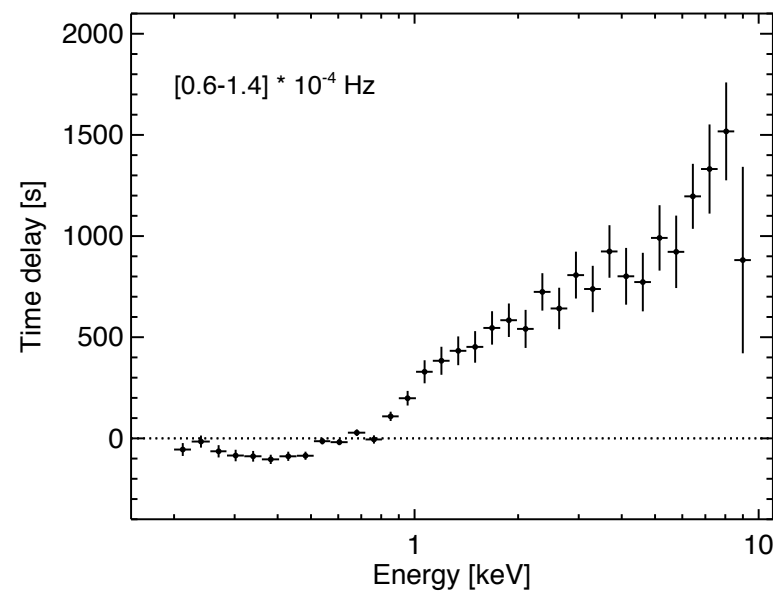
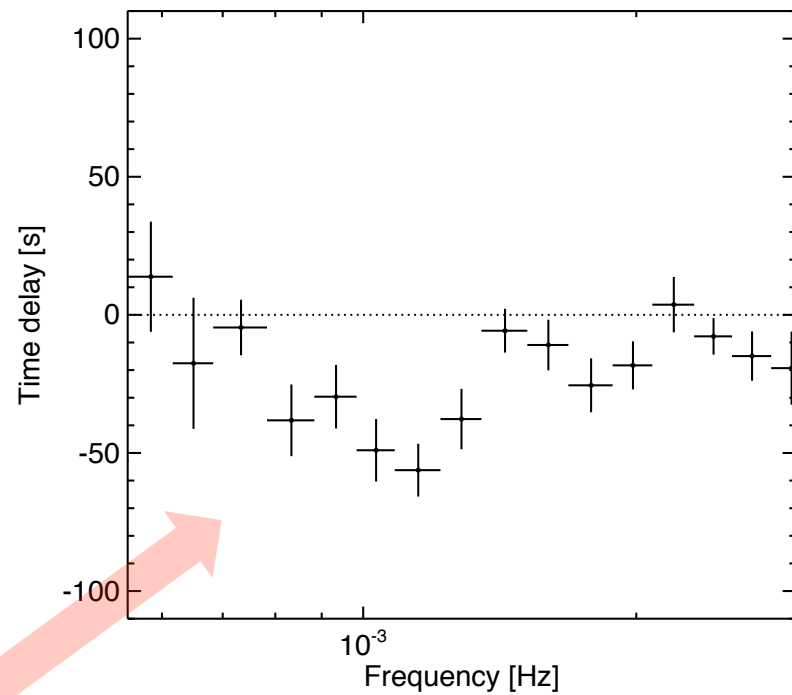
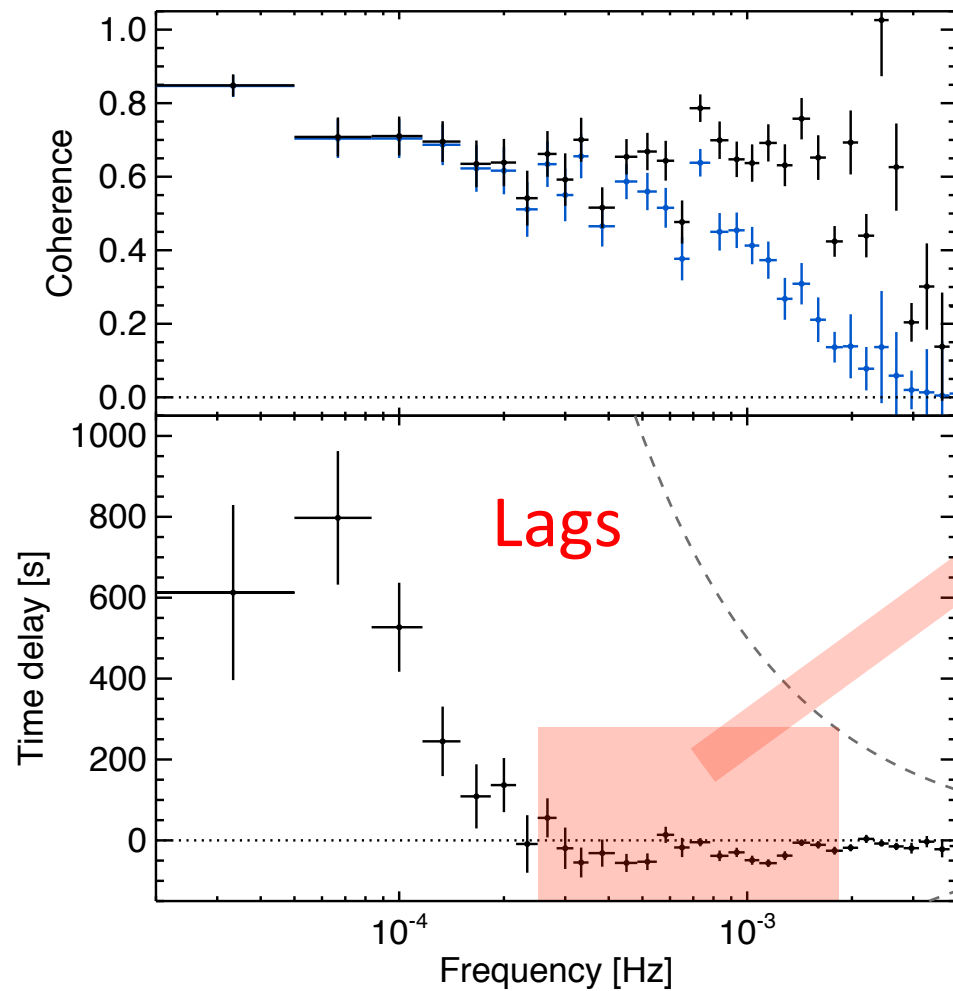




Will Alston

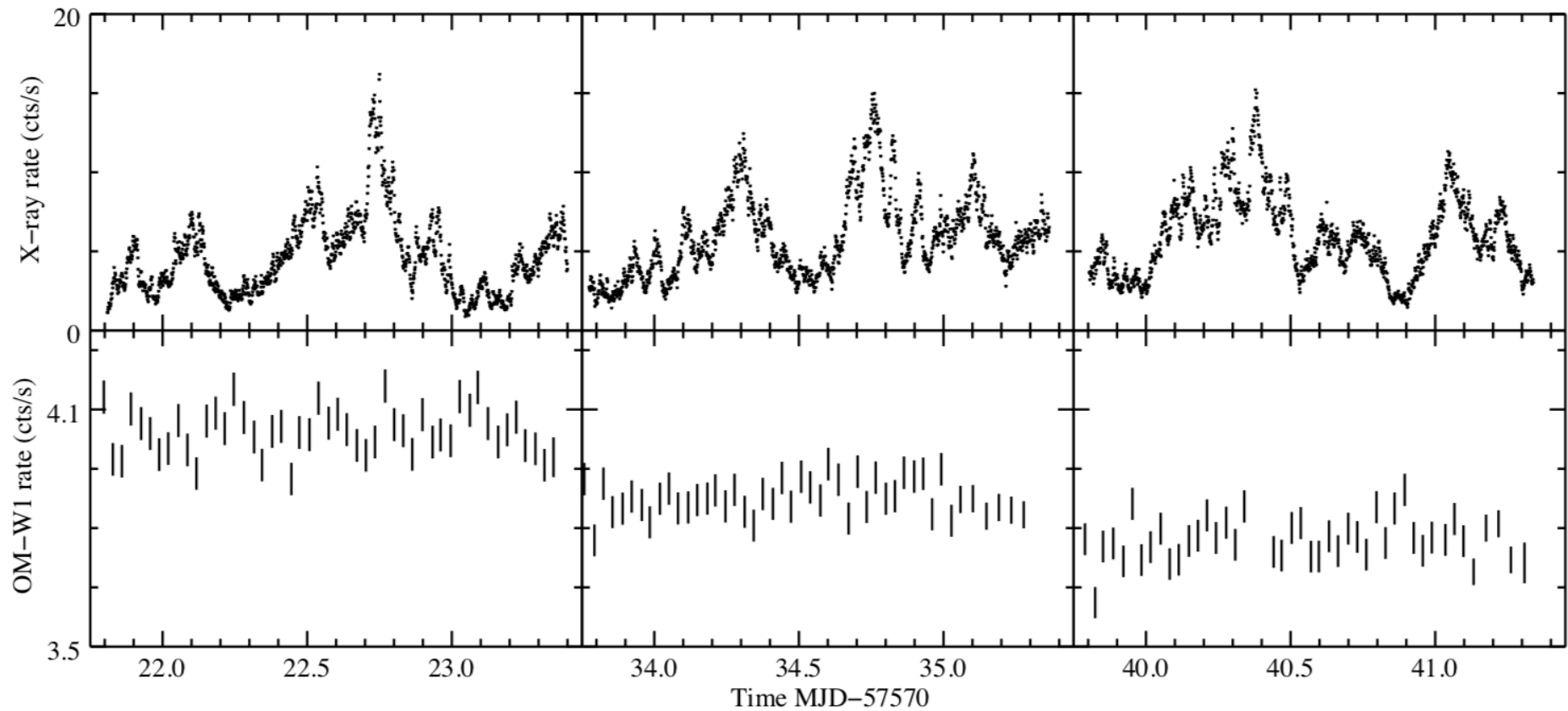


Will Alston



Will Alston

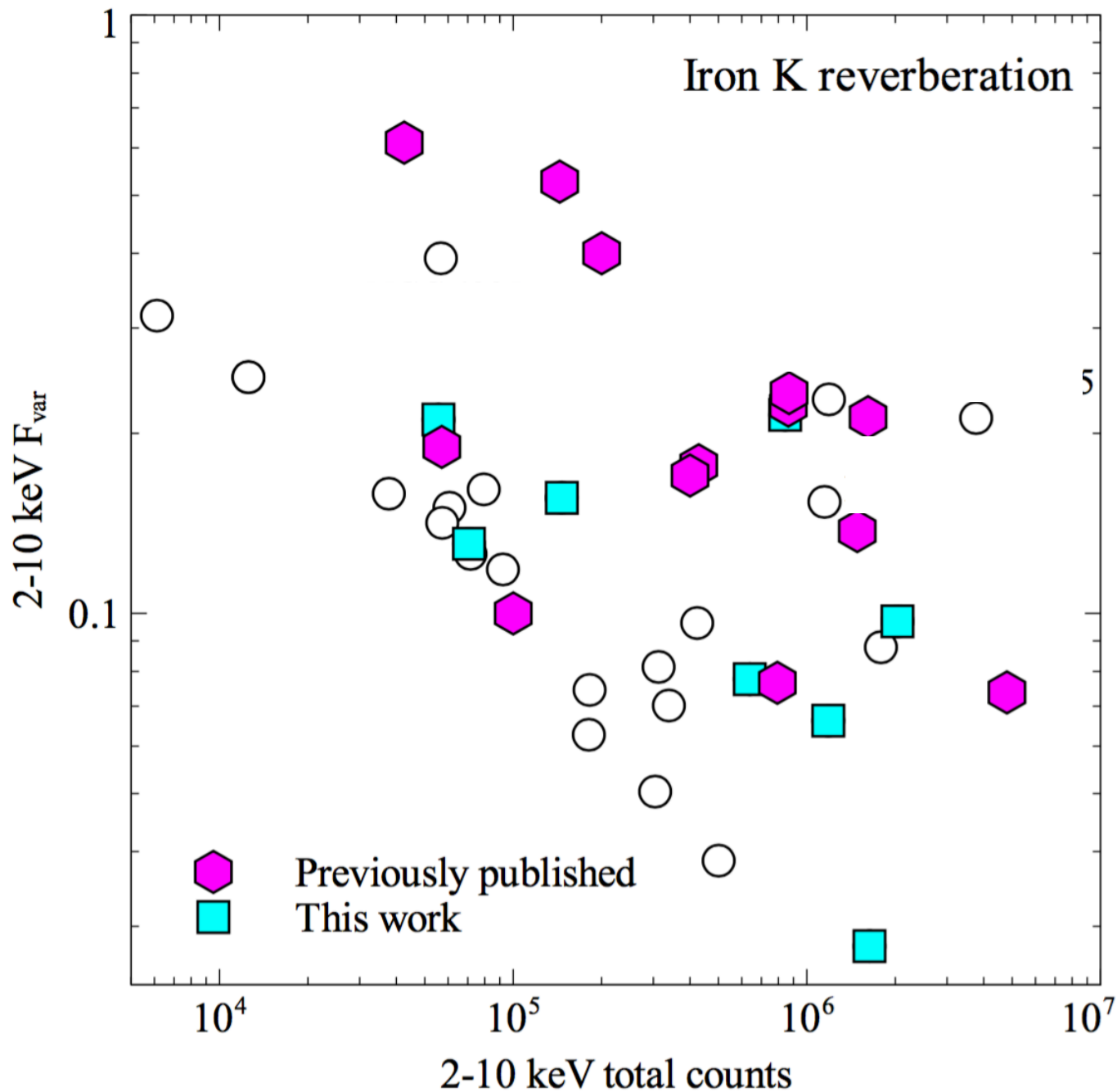
NO UV response to large X-ray variations



Summary

- We're now doing Relativistic Astrophysics of the immediate region around rapidly spinning accreting Kerr black holes – the central engine of quasars – using X-ray relativistic reflection and reverberation.

Corona is compact

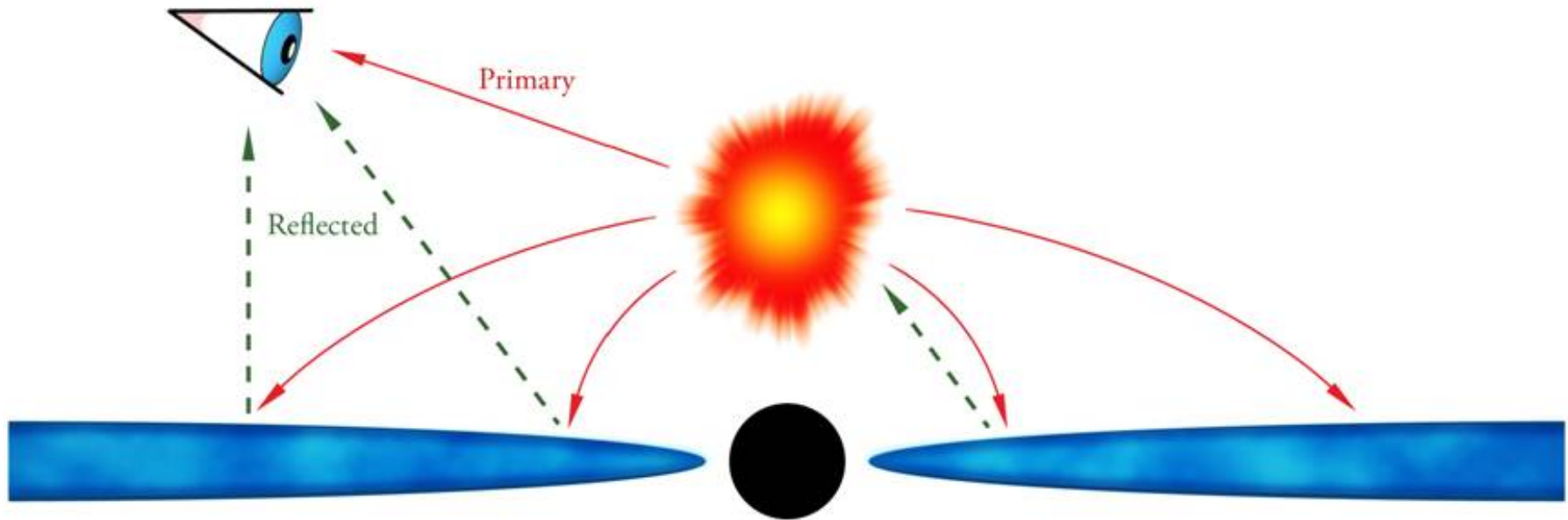


XMM
archive

Fe K lags
42 sources
13 published
8 new

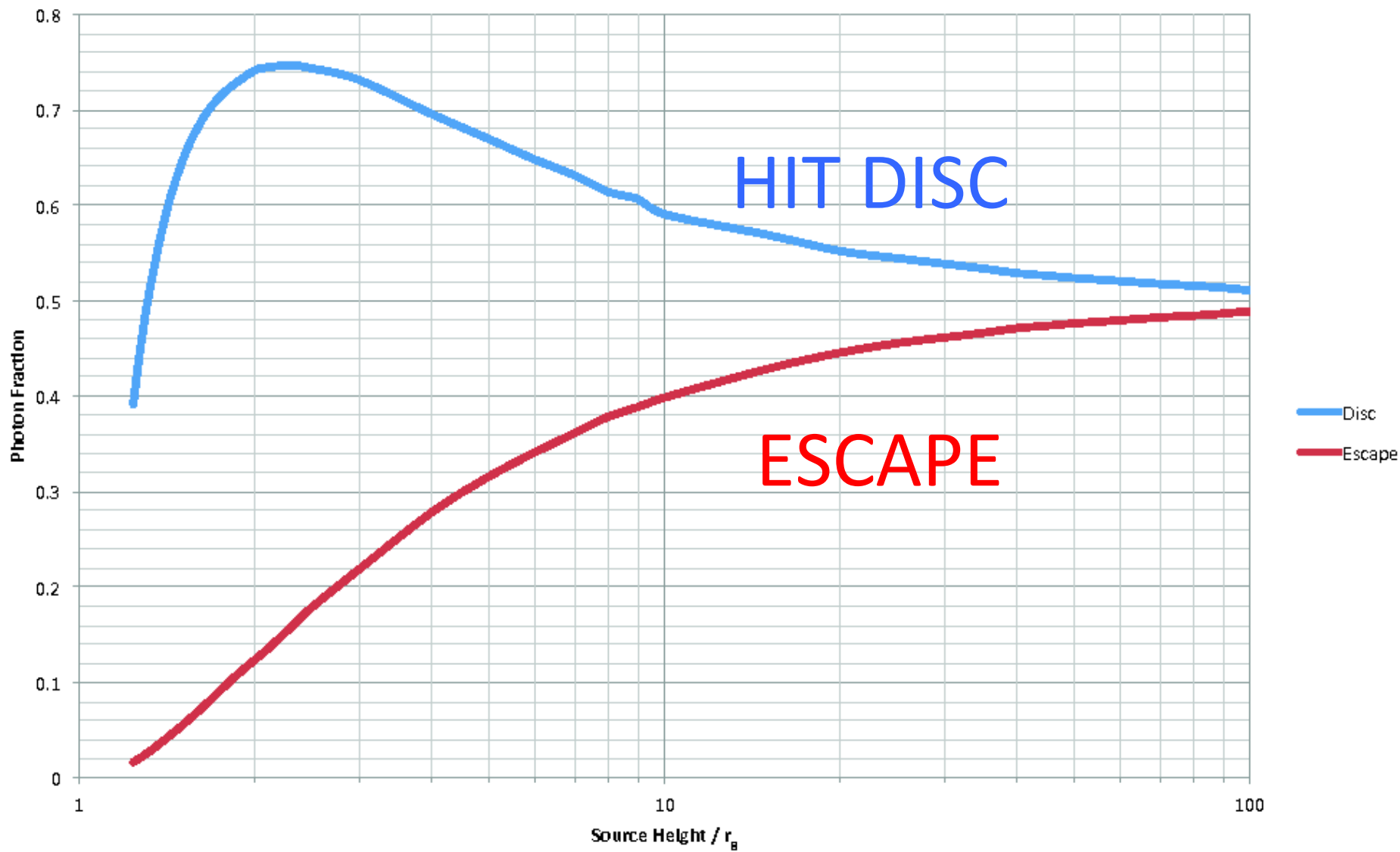
Kara+16

Strong light bending close to BH



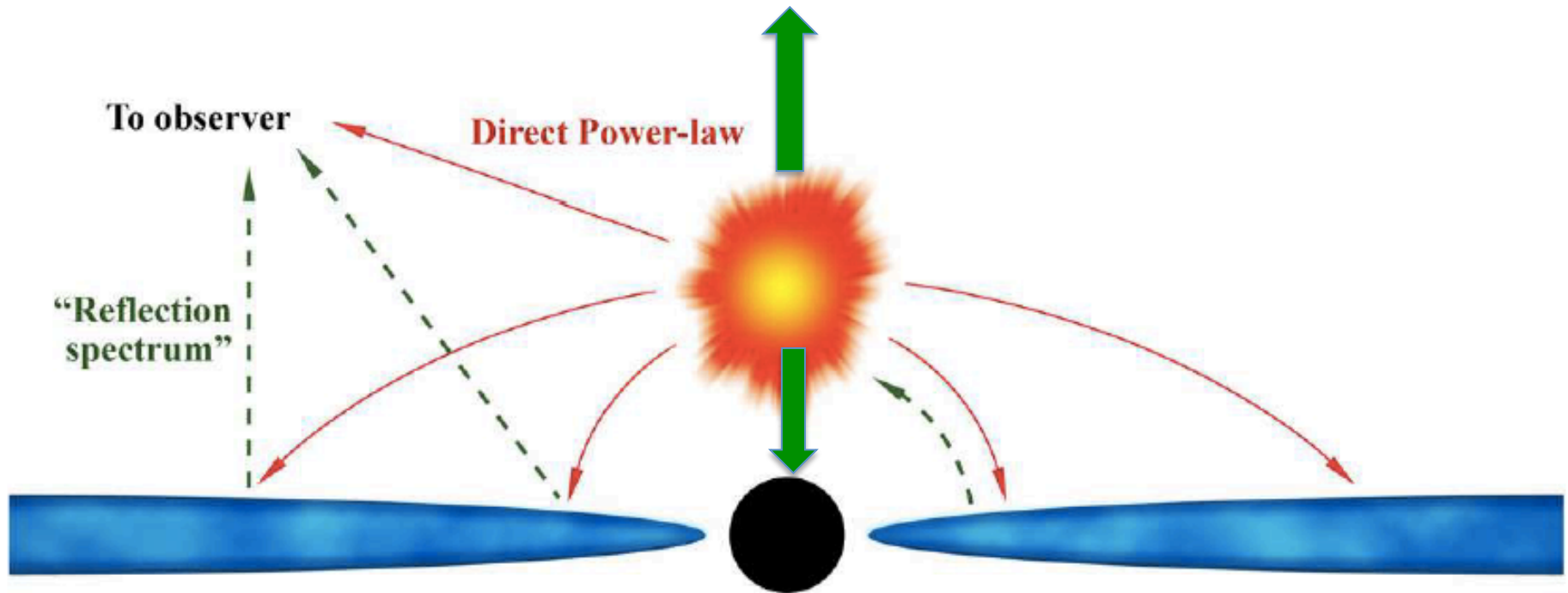
Martocchia&Matt, Miniutti&Fabian

GR + lightbending make emissivity steep



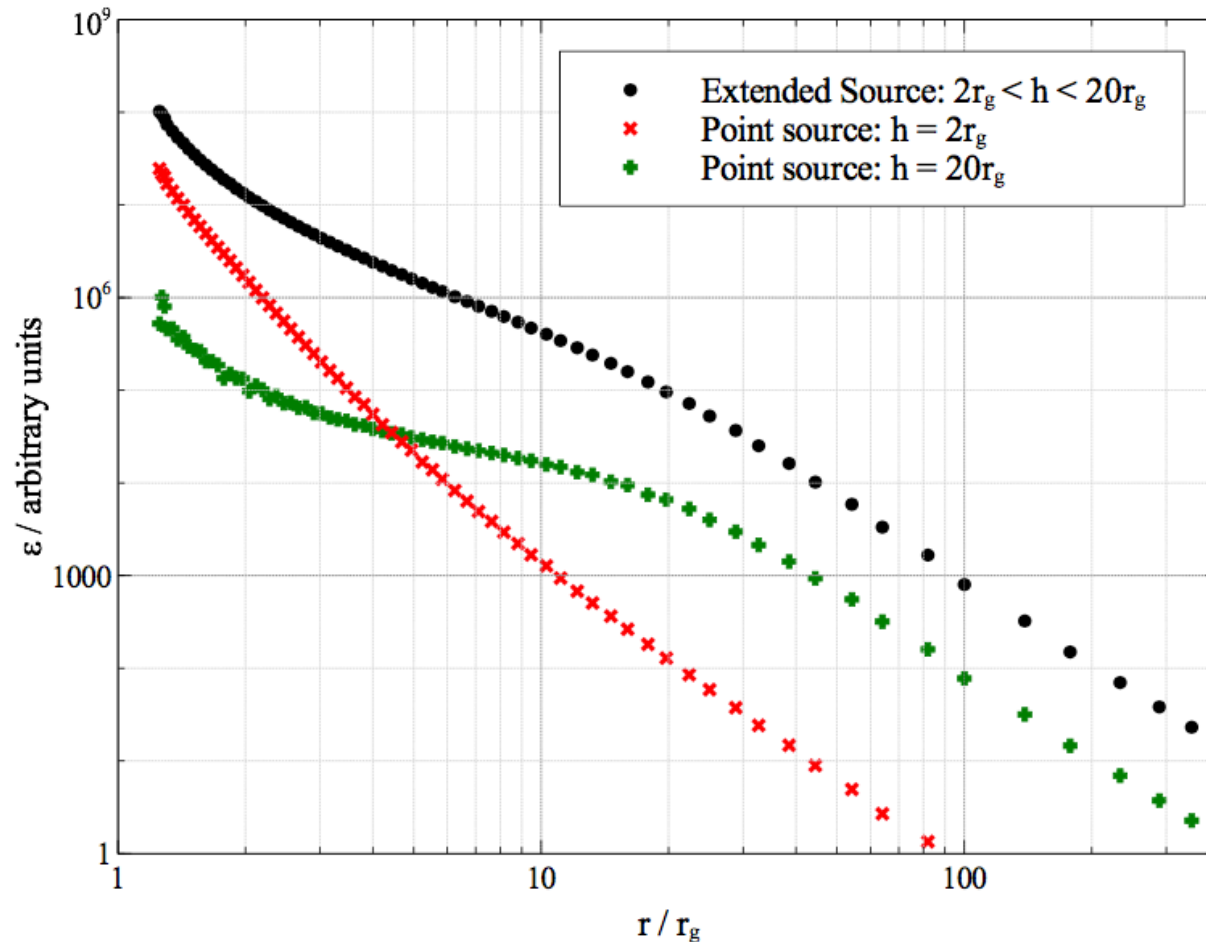
HEIGHT

Change in height of corona -
more or less light bending

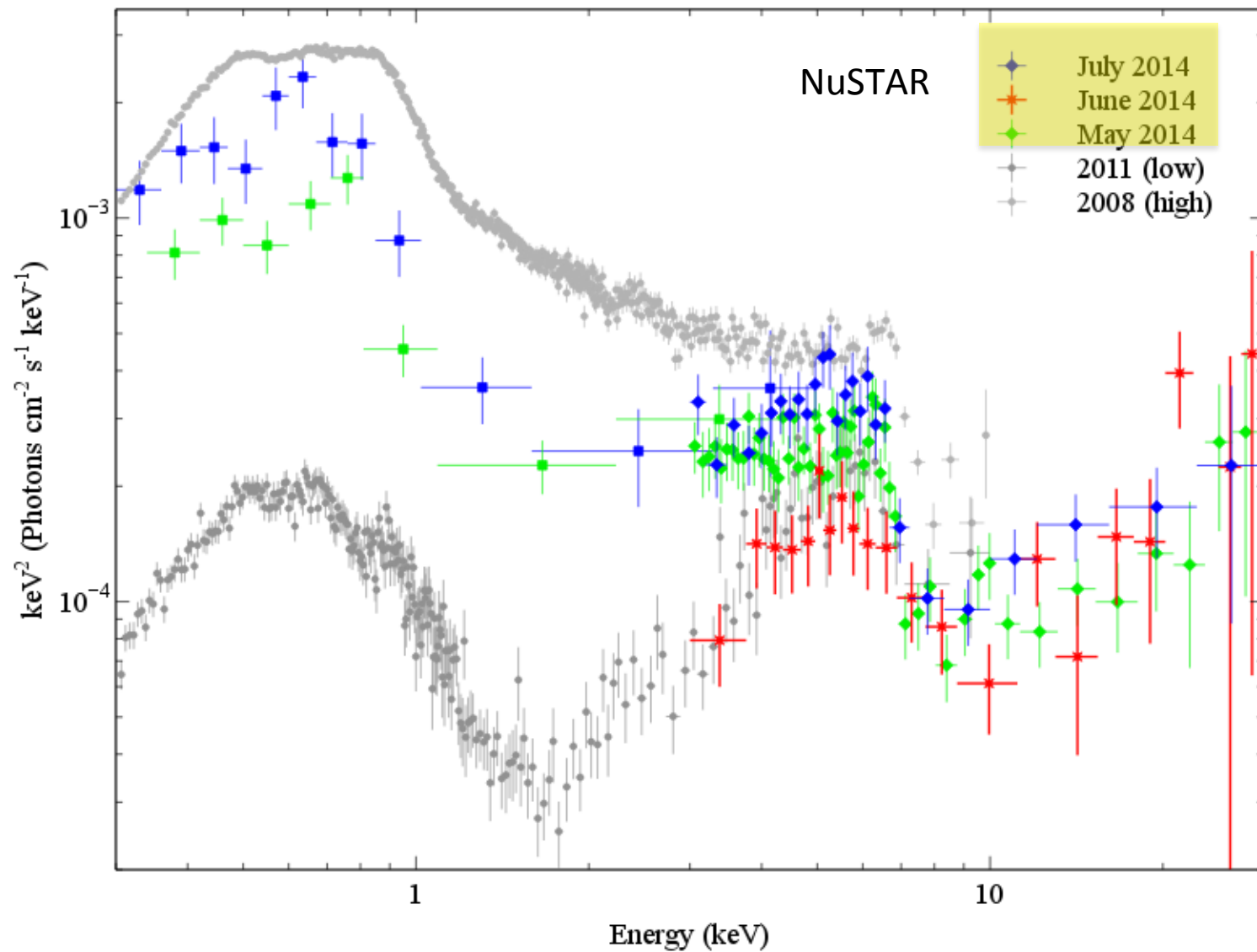


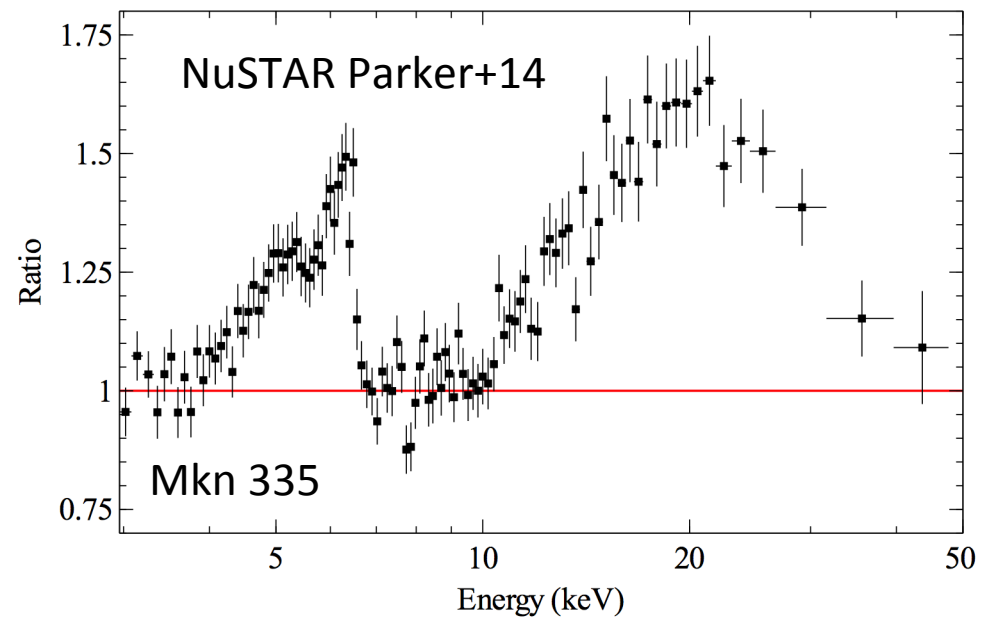
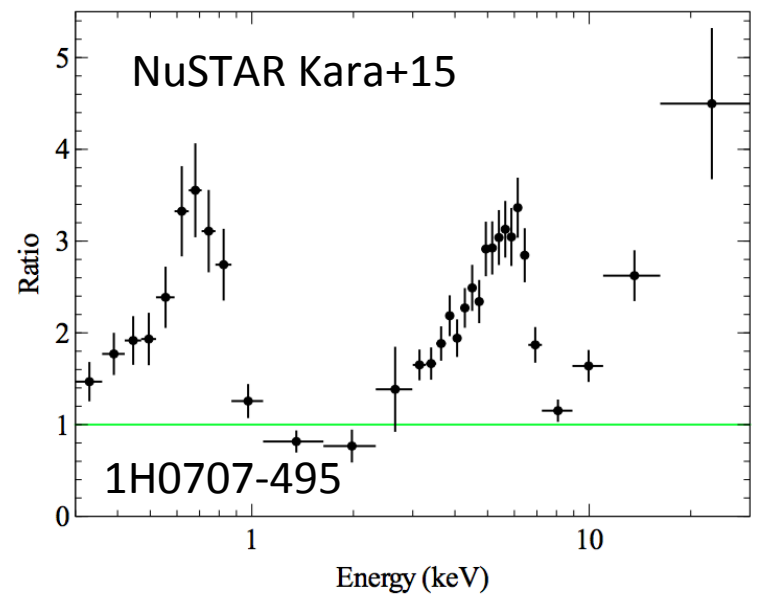
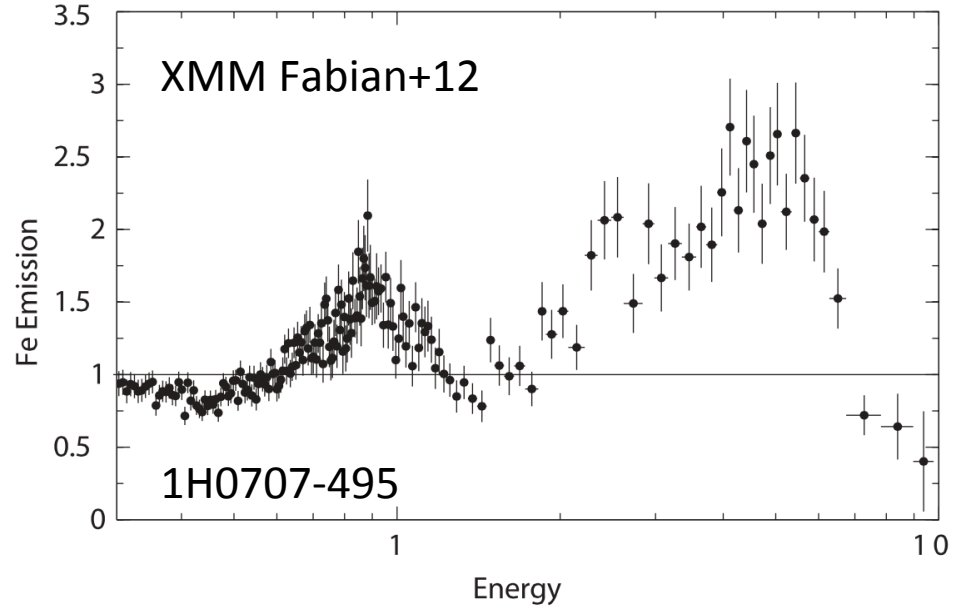
Emissivity profiles enable coronal height and radius to be determined

Wilkins+Fabian12



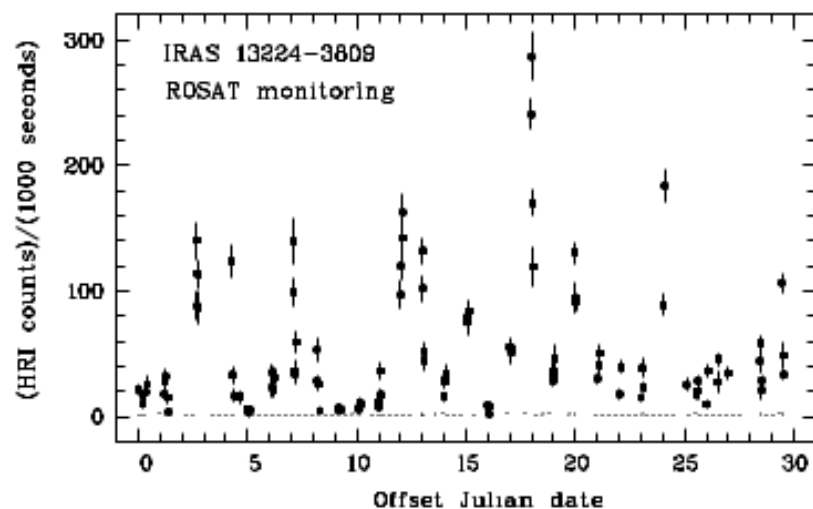
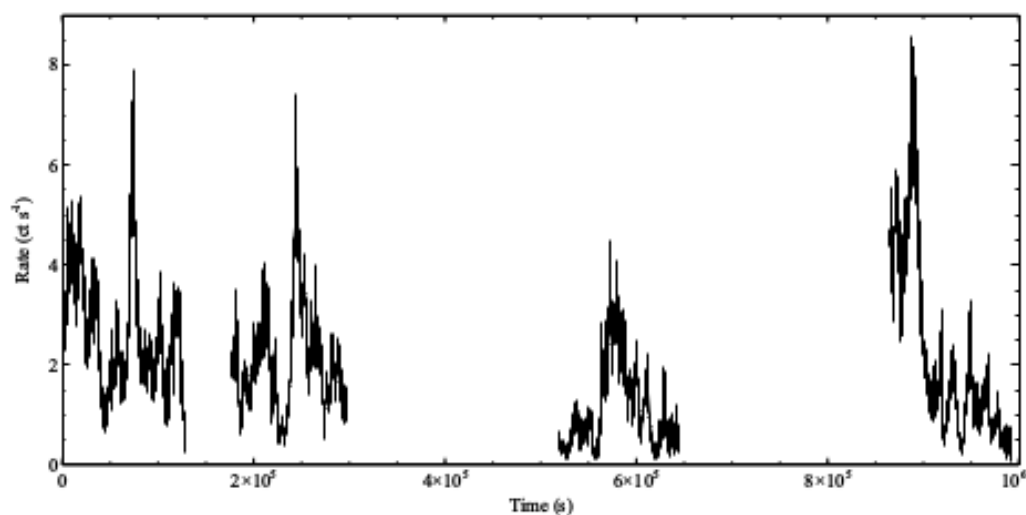
Into the Abyss

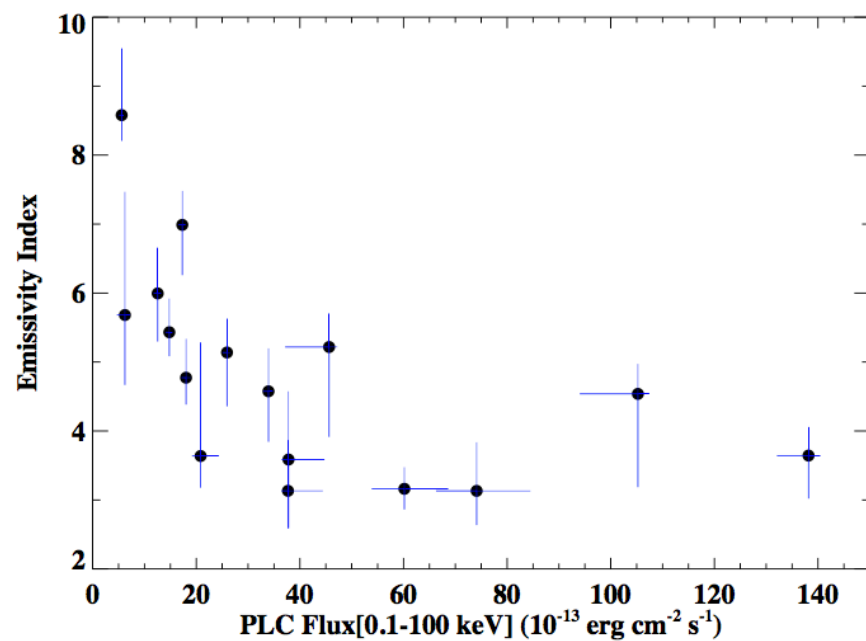
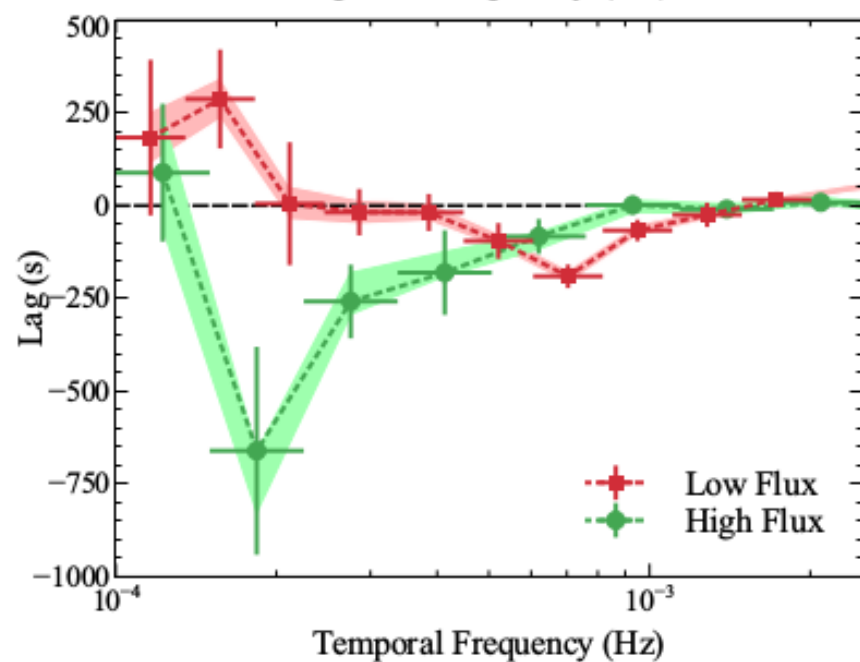
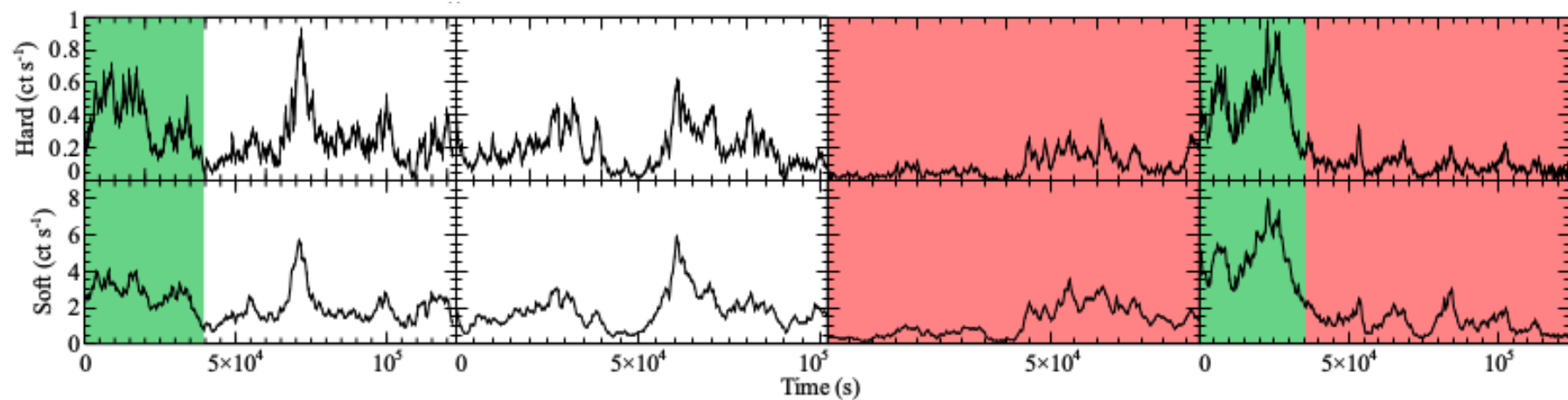




Results from within $2 r_g$

IRAS13224-3809 - Example of a key object

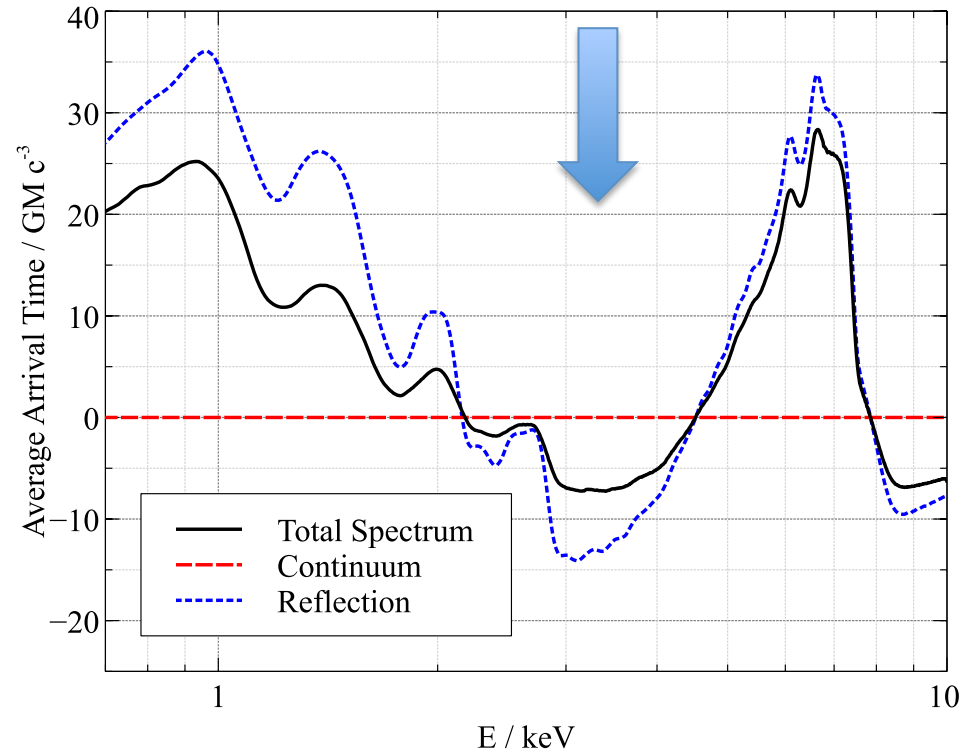
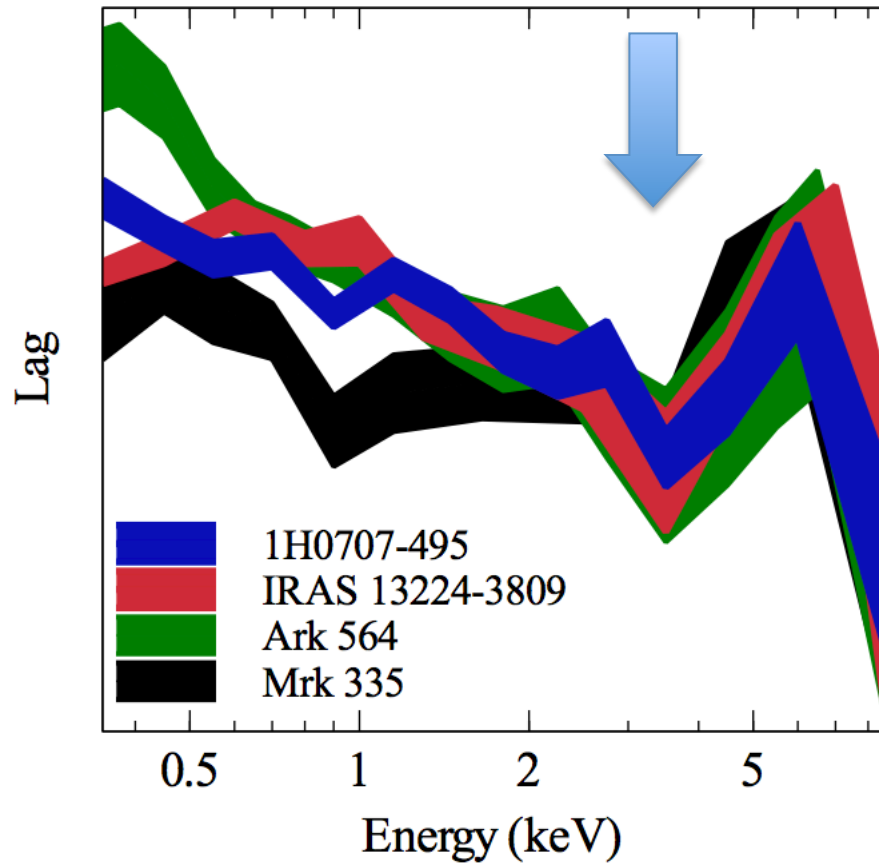


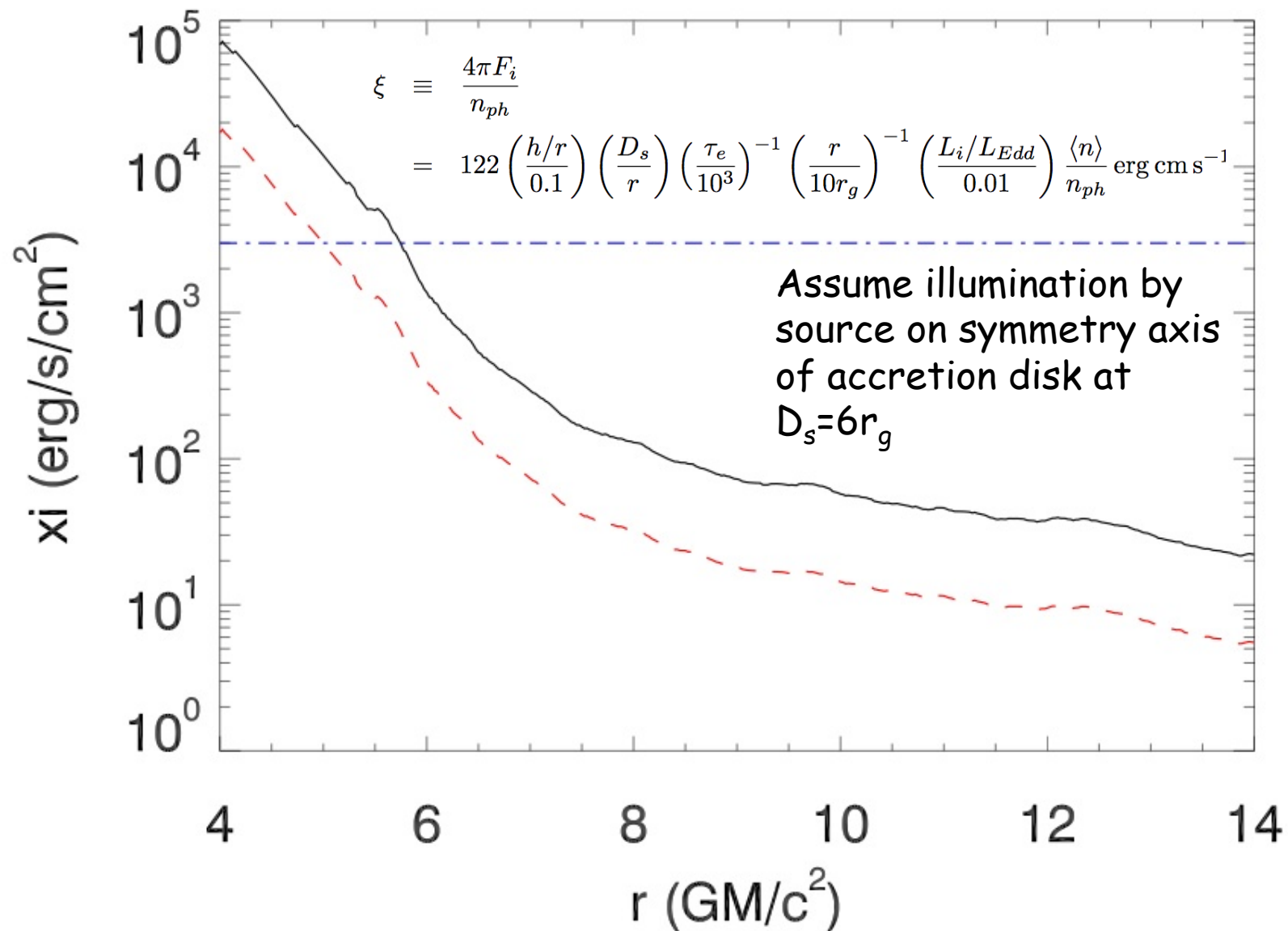


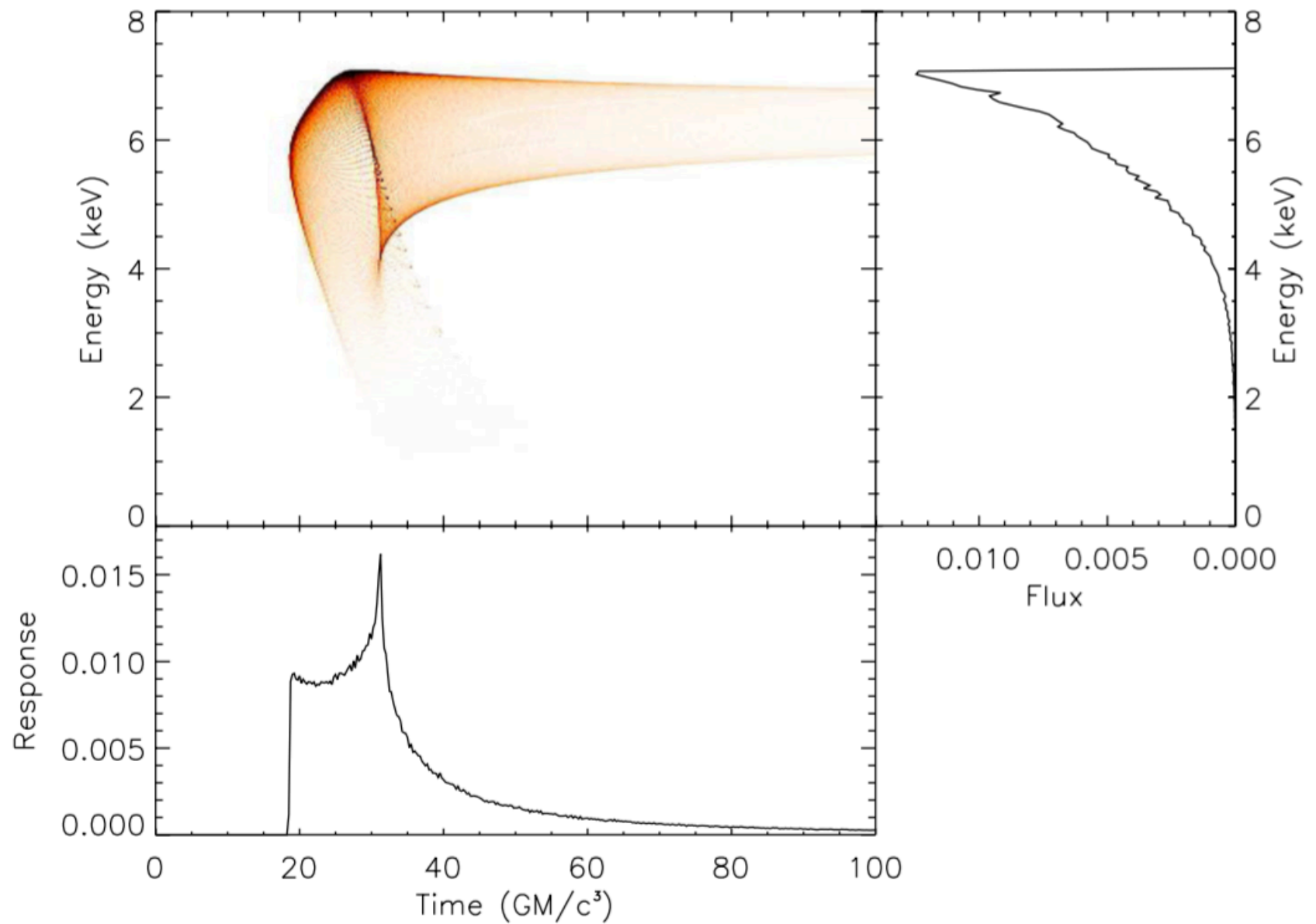
STRONG GRAVITY

- Gravitational redshift ✓ Red wing
- Strong Light Bending (radian scale) ✓ Reflection Strength
- Shapiro delay ✓ Reverberation
- Dragging of Inertial Frame ✓ High Spin

Rise of corona can explain 3.5 keV dip



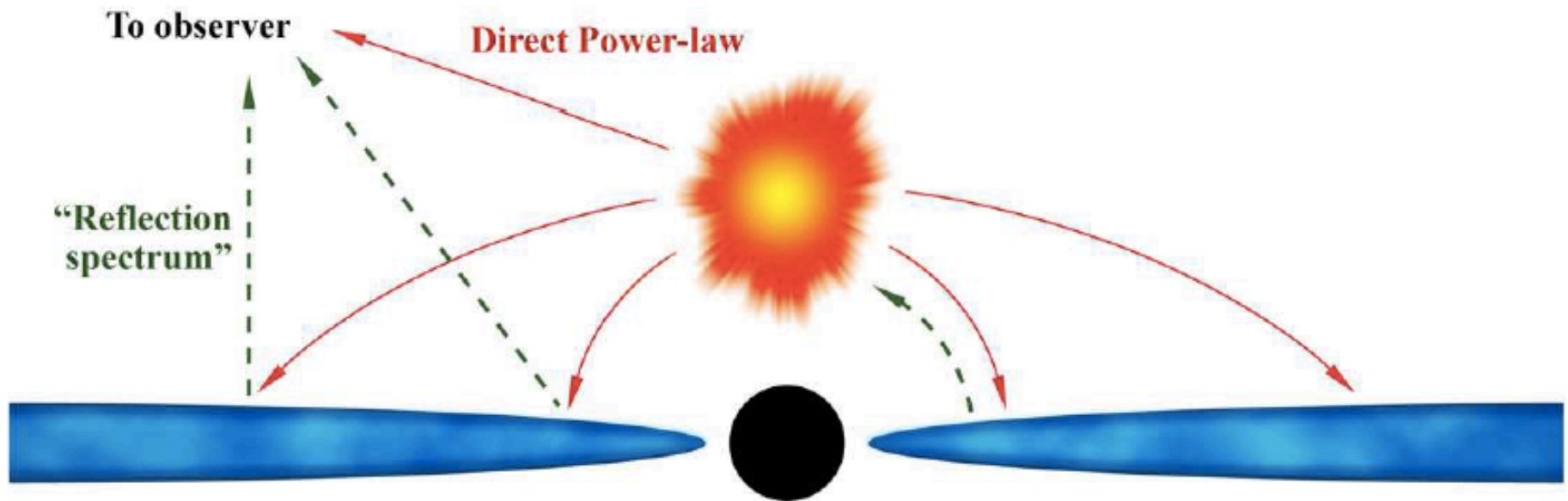




Cackett+14

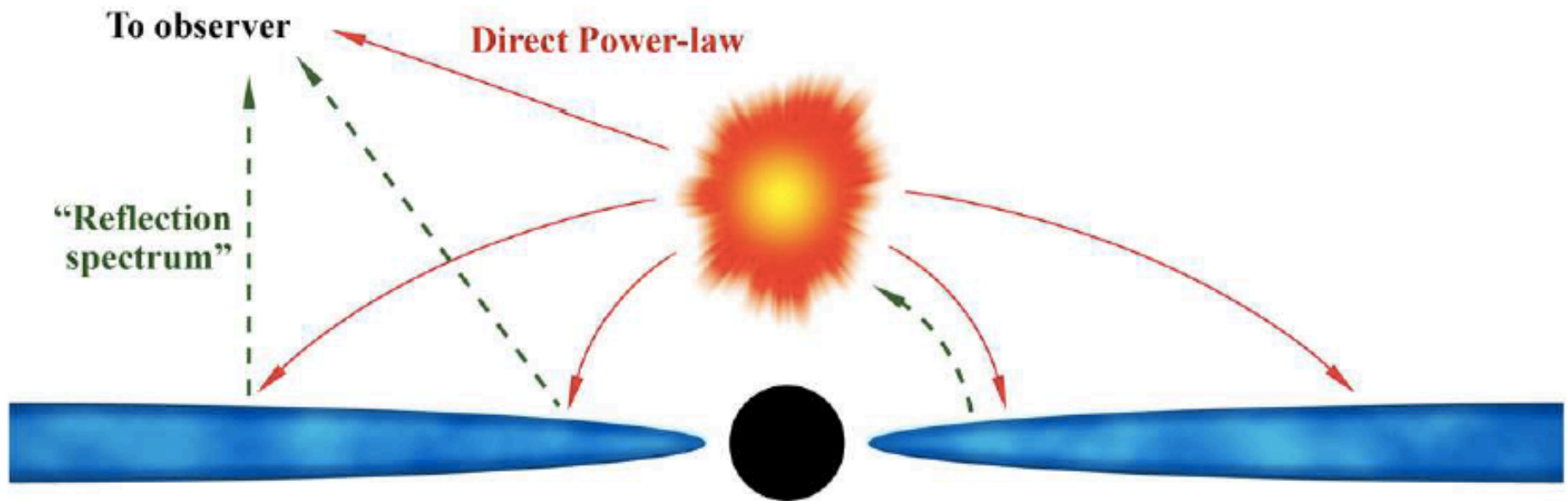
after Campana+Stella95, Reynolds+99

Relativistic Reflection is a common feature of luminous accreting black holes

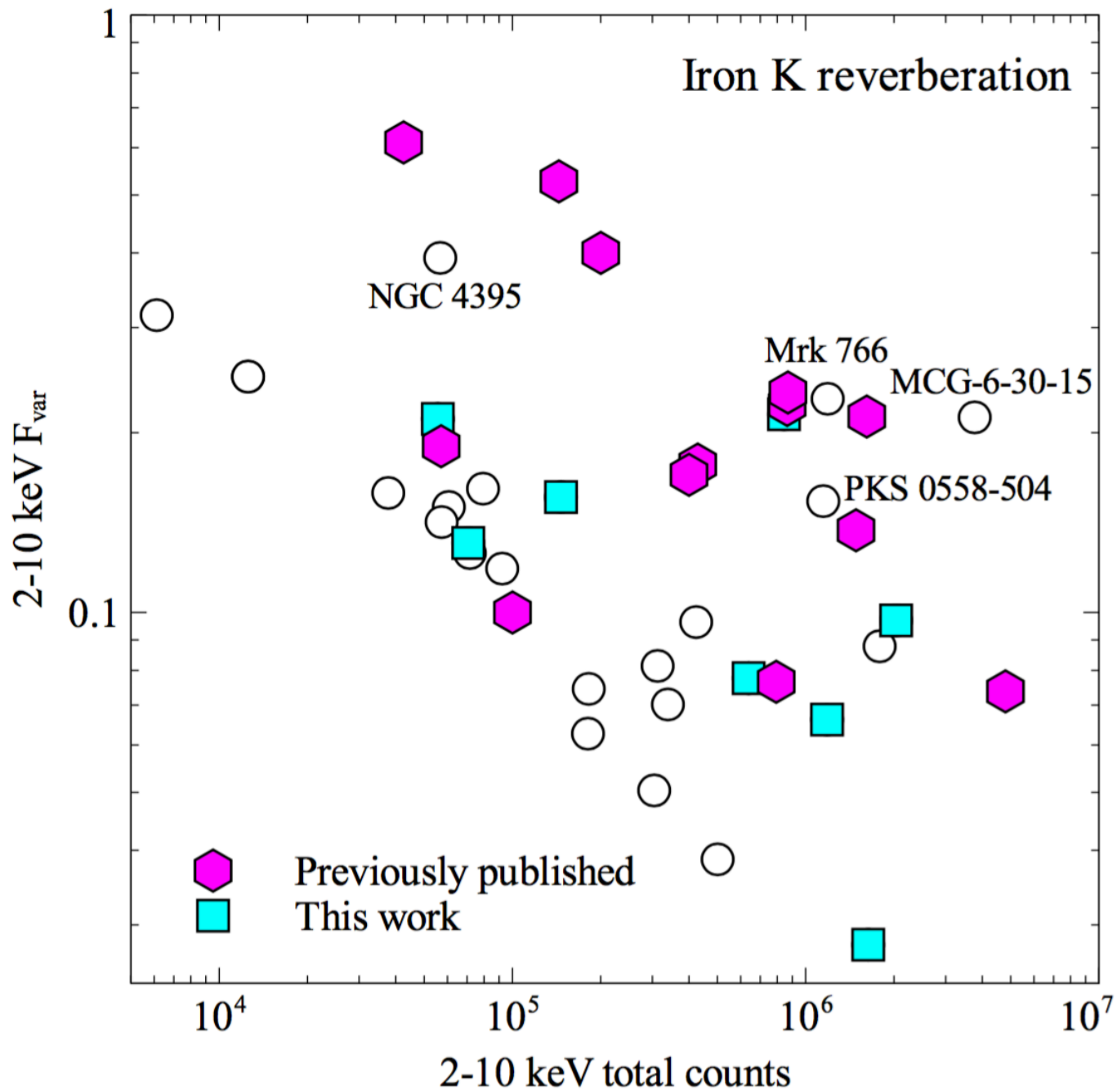


Spectral-timing analyses reveal inner strong gravity regime

Relativistic Reflection is a common feature of luminous accreting black holes

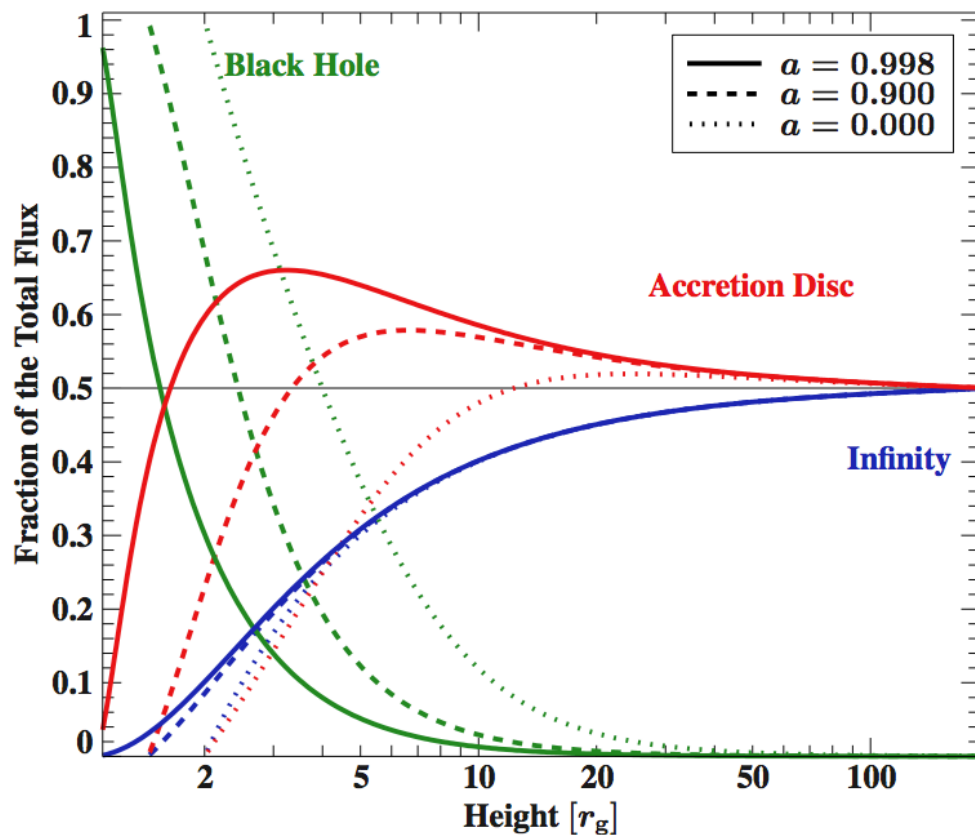


Strong gravitational effects (redshift, light bending etc) are INEVITABLE

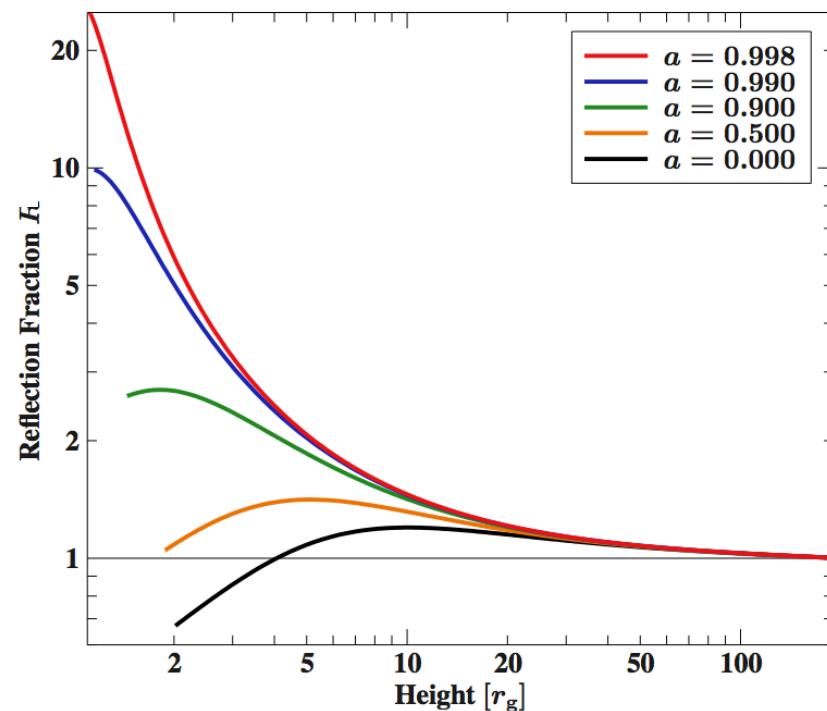


Fe K lags
42 sources
13 published
8 new

Kara+16



High Reflection Fractions
= Strong Light Bending



Outflowing Corona

Mild relativistic outflow in corona can beam primary radiation outward

Coronal Collapse

When h drops from 10 to $2r_g$



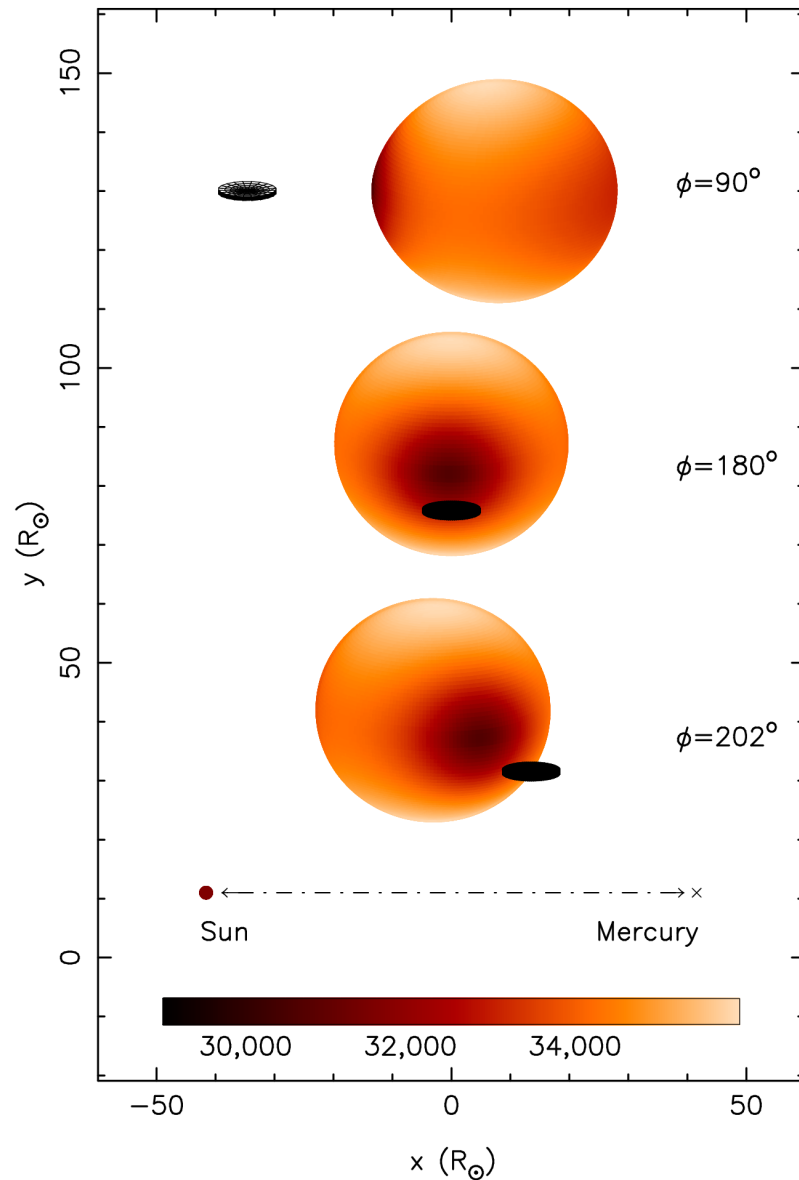
M33

$D = 840 \pm 20 \text{ kpc}$

Only BH eclipsing system

X-7 ↘

M33 X-7: Mass



O7 giant

$$M_2 = 70.0 \pm 6.9 M_{\odot}$$

$$R_2 = 19.6 \pm 0.9 R_{\odot}$$

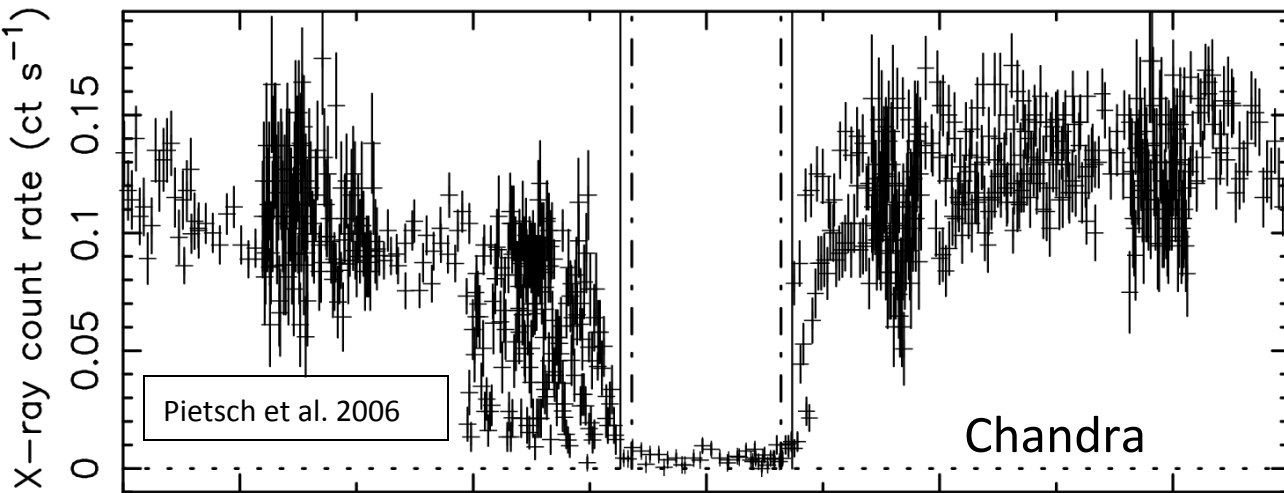
$$T_{\text{eff}} = 35,000^\circ \pm 1000^\circ$$

Age $\sim 2 - 3$ Myr

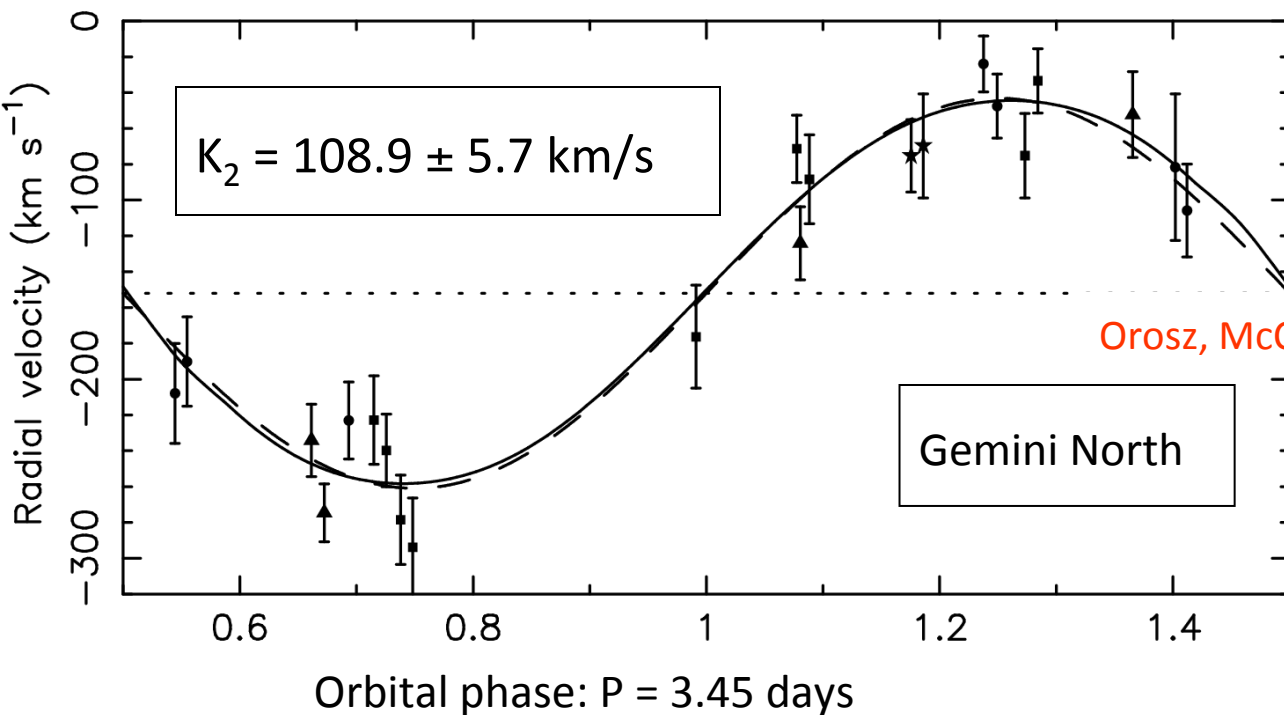
→ Spin is natal

Orosz, McClintock, Narayan, et al. 2007

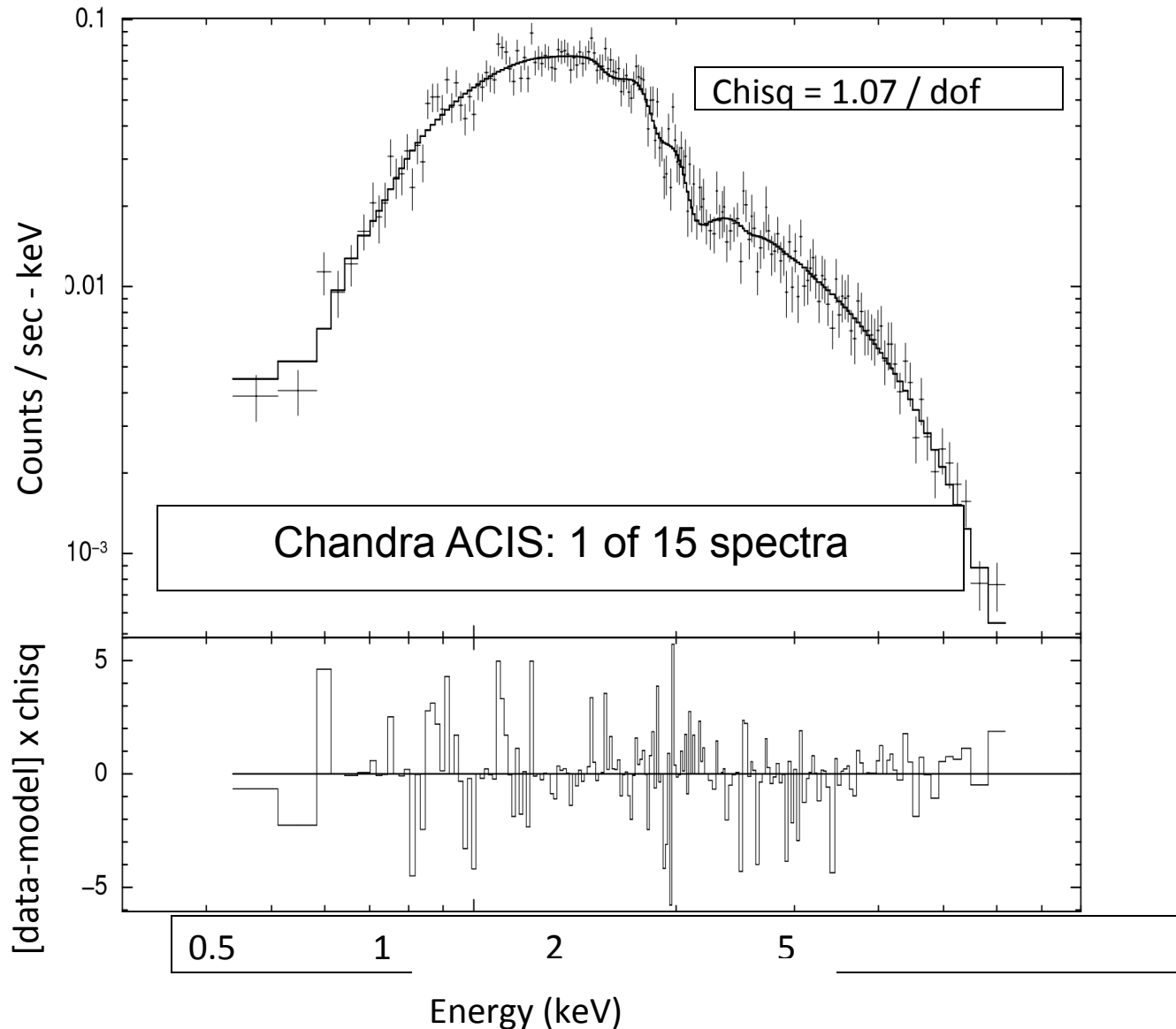
M33 X-7: Mass



$$D = 840 \pm 20 \text{ kpc}$$
$$i = 74.6^\circ \pm 1.0^\circ$$
$$M = 15.65 \pm 1.45 M_\odot$$



M33 X-7: Spin



Model =
phabs x kerrbb
(i.e. no Fe or PL)

$$a_* = 0.751 \pm 0.026$$

$$L_{\text{bol}} / L_{\text{edd}} = 0.10$$

$$f = 1.78$$

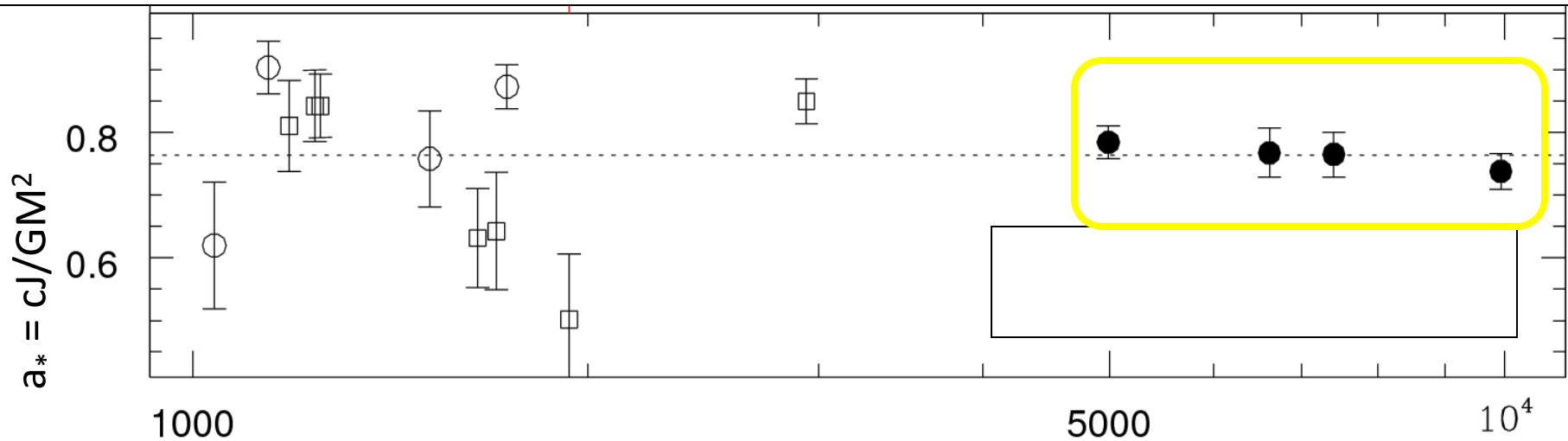
$$\dot{M} = (1.9 \pm 0.1) \text{E18 g/s}$$

$$N_{\text{H}} = (1.1 \pm 0.1) \text{E20 cm}^{-2}$$

Liu, McClintock, Narayan,
Davis & Orosz 2007

M33 X-7: Spin

15 total spectra: 4 “gold” + 11 “silver”



Photon counts (0.3 - 8 keV)

Complete description of
60 km object at ~ 1 Mpc

Liu, McClintock, Narayan,
Davis & Orosz 2007

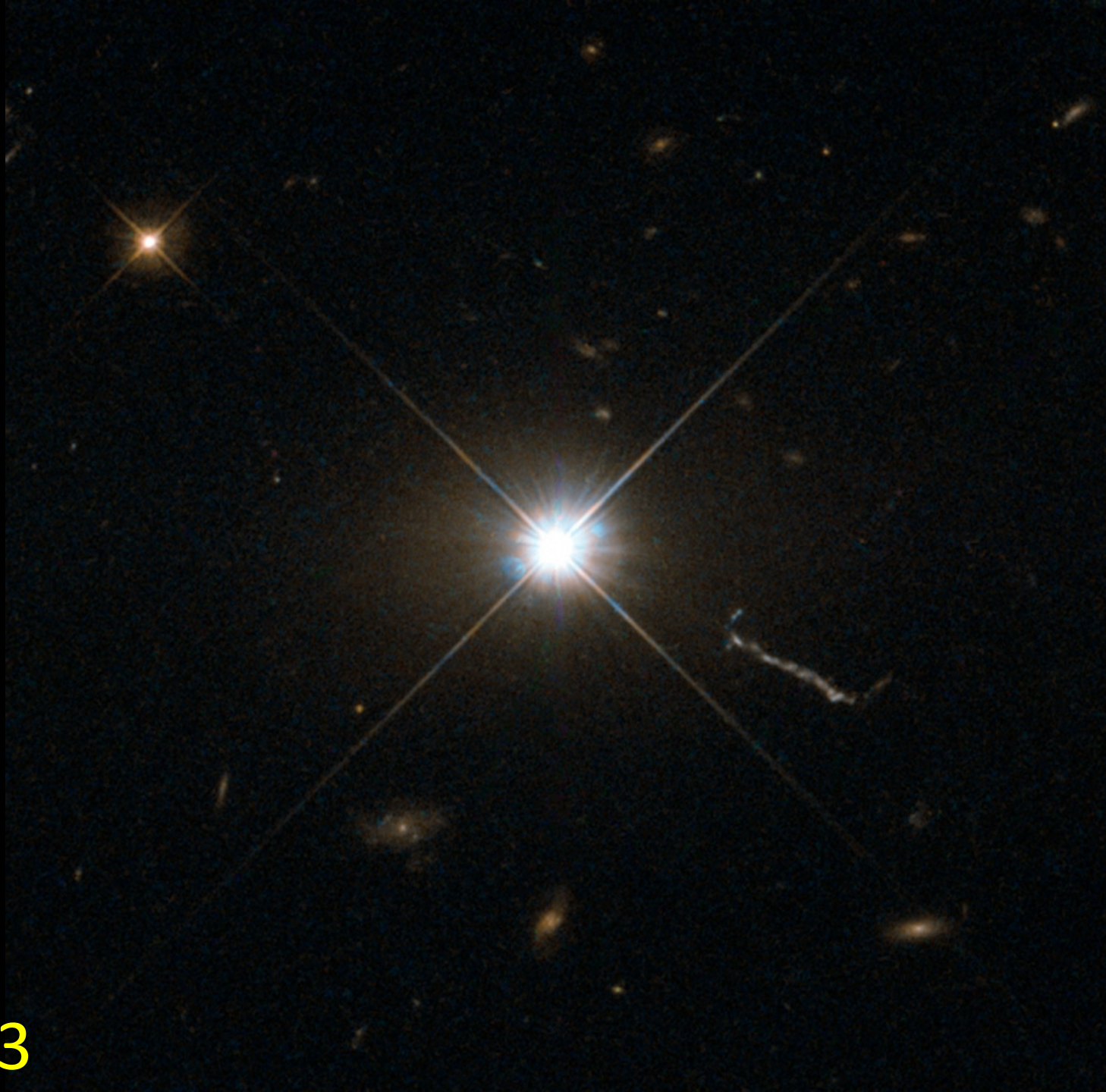
4 gold spectra

$a_* = 0.77 \pm 0.02$

Including uncertainties in D , i & M

$a_* = 0.77 \pm 0.05$

3C273



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IRAS13224-3809

