AGN and Black Hole Physics with Constellation-X

Chris Reynolds
Department of Astronomy &
Cntr. for Theory & Computation
University of Maryland

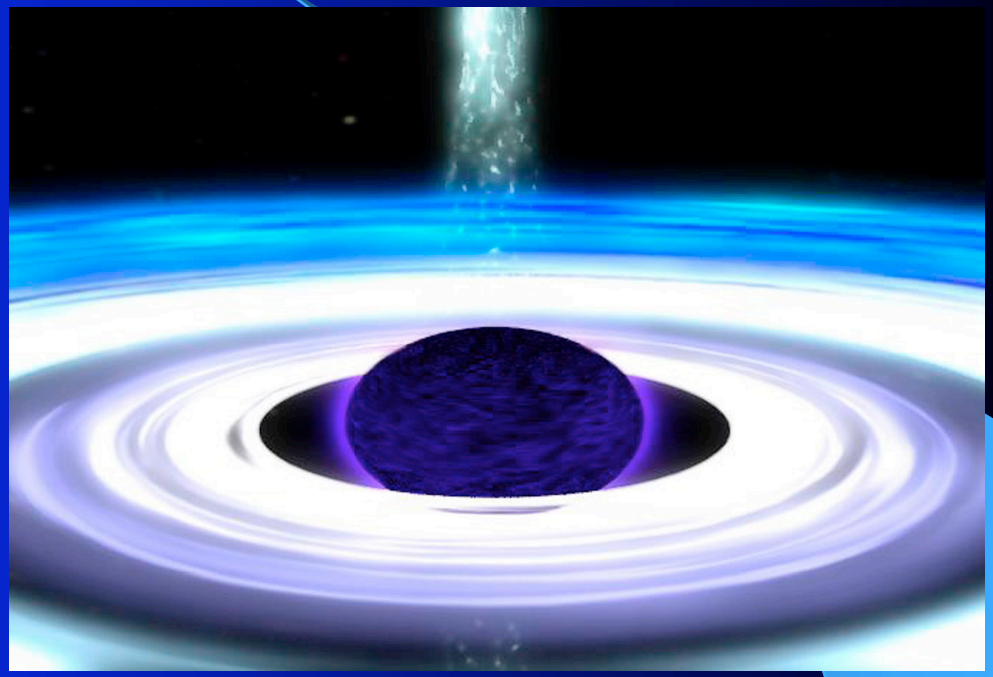
AGN Science Objectives

- **Core "Beyond Einstein" objectives…**
- Strong Gravity
  - Is GR correct in the strong-field domain?
- Relativistic matter and fields
  - Physics of accreting plasma close to black holes
  - Testing the electromagnetic part of GR
  - Formation and physics of relativistic jets
- Other AGN-stuff
  - Structure of the central engine as function of AGN type
  - AGN populations out to high redshift

Core science is best addressed through <u>detailed</u> studies of relativistically broadened emission lines from inner accretion disk (<u>iron</u> Kα line, in particular)

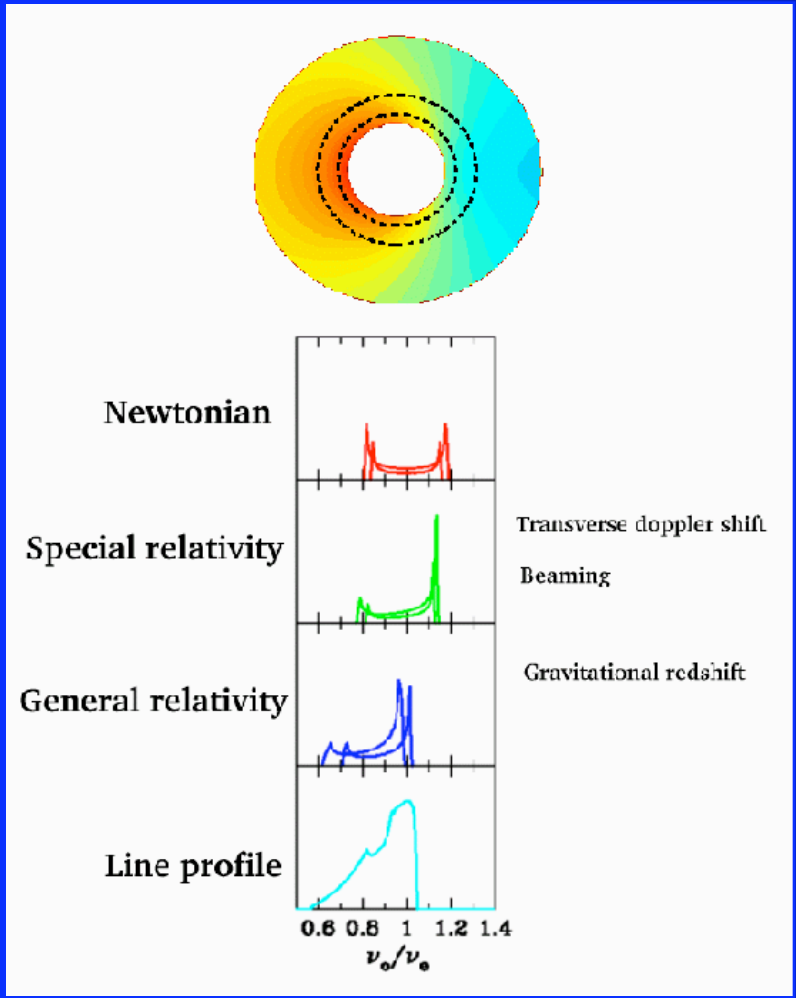
Basics…

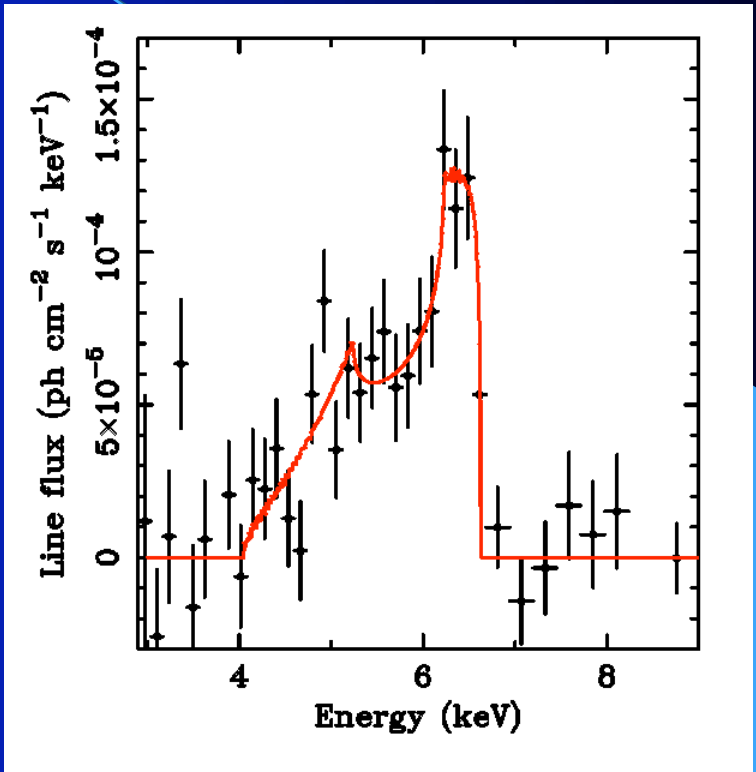
- Supermassive black holes grow by **radiatively-efficient** accretion
  - Soltan argument; compare QSO background light with BH mass density
  - Luminous AGN must be efficient sources
- There is optically-thick, cold matter reaching very close to BH horizon in such sources
  - Continuity & Energy eqn.
- X-rays coming from very compact region (~horizon scales)
  - Variability



∴Ingredients for X-ray reflection from inner accretion disk are all present!

Relativistic (iron) emission lines

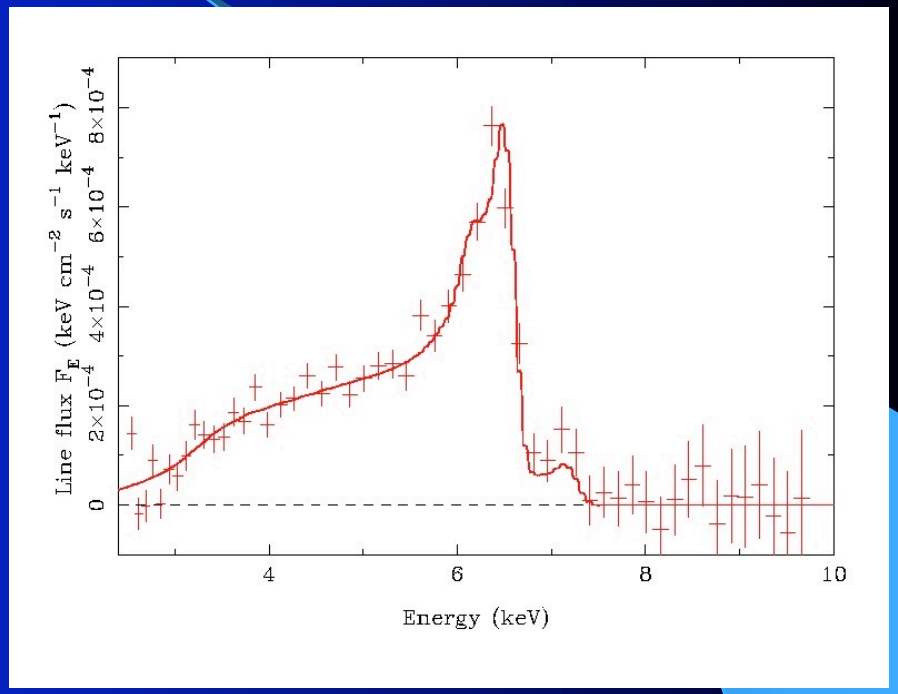




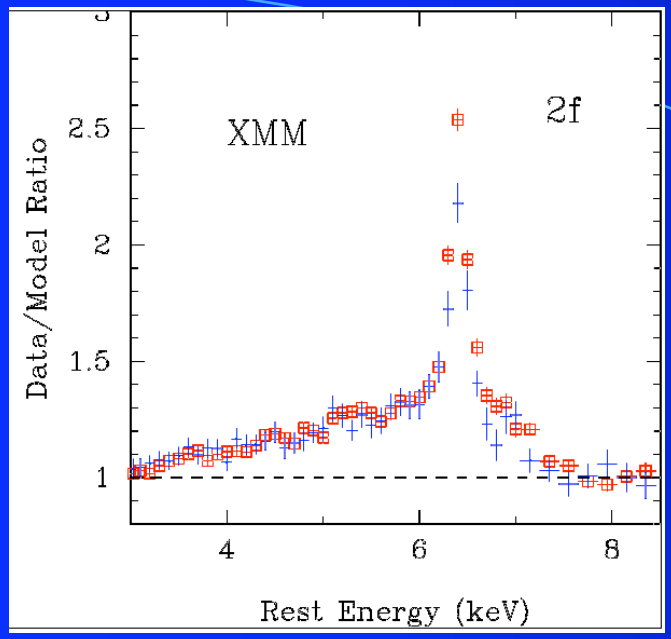
Iron line profile in MCG-6-30-15 (Tanaka et al. 1995)

Strong gravity & accretion physics

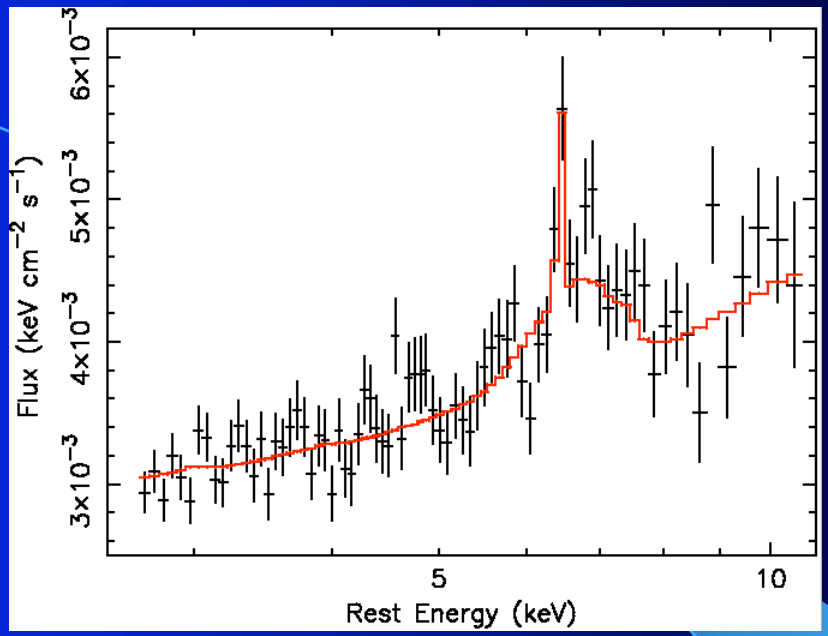
- Broad emission lines are the best understood probe of relativistic gravity
- Study of these features is alive and well in the XMM era



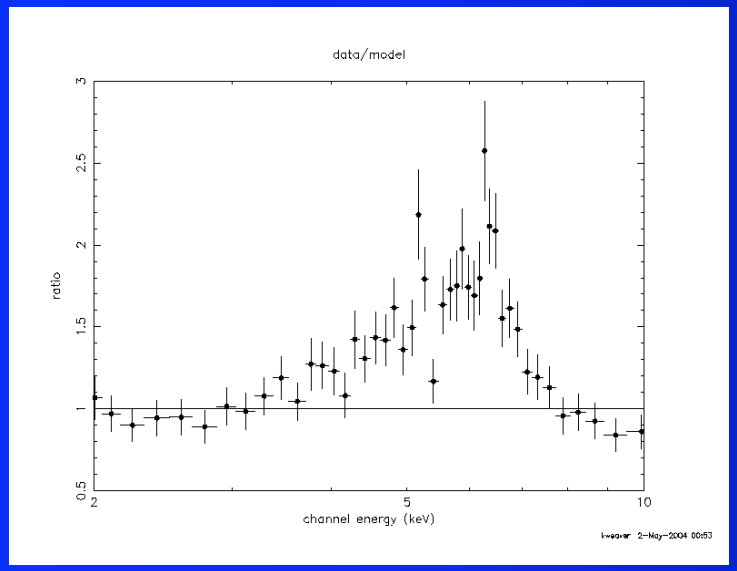
MCG-6-30-15
Fabian et al. (2002)



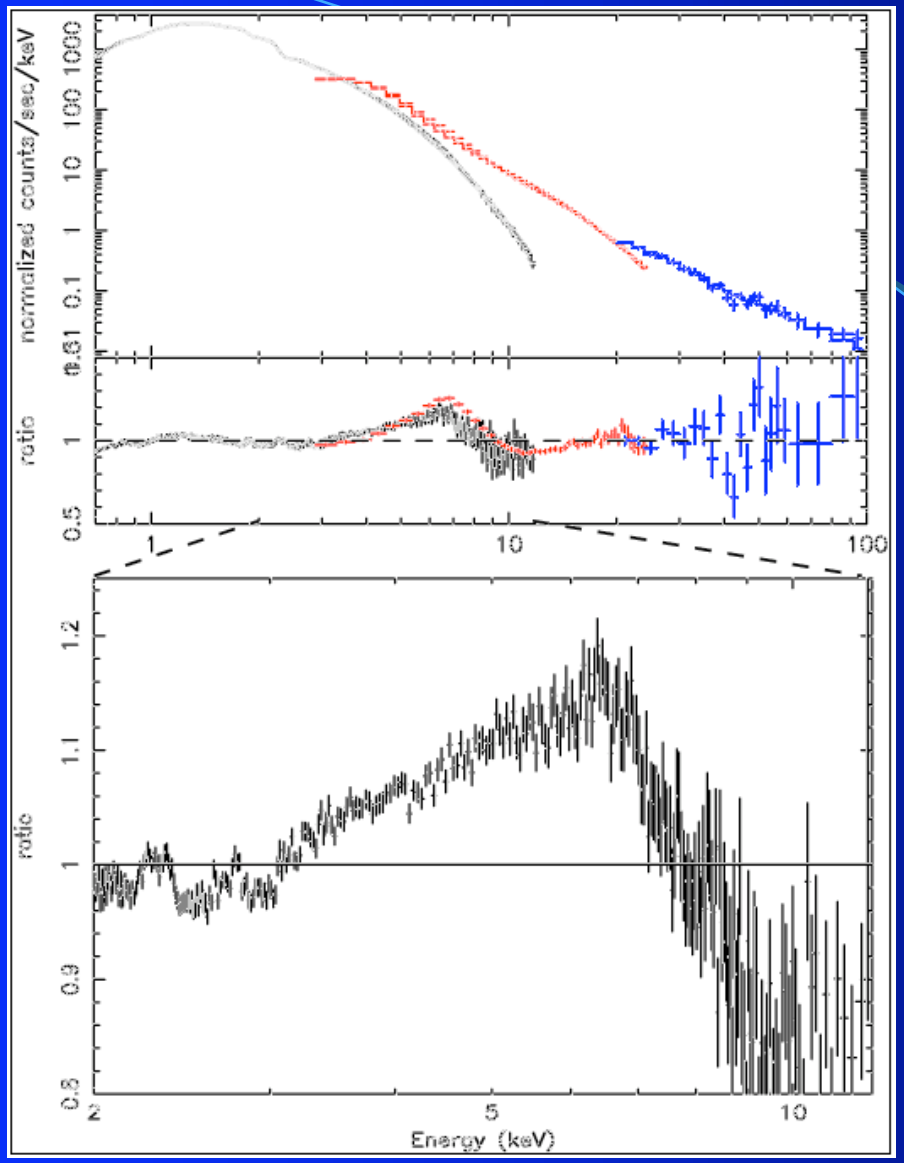
NGC3516
Turner et al. (2002)



Mrk205
Reeves et al.



LINER
(K.Weaver, in prep.)



J. Miller et al. (2004)

Galactic Black Hole Binaries…GX339-4

Iron lines in the XMM era…

- How robust is evidence that we're seeing strong relativistic effects?
  - Complex absorption (photoionized absorption etc.)?
  - Continuum curvature (including reflection continuum)?
  - Other broadening mechanisms?

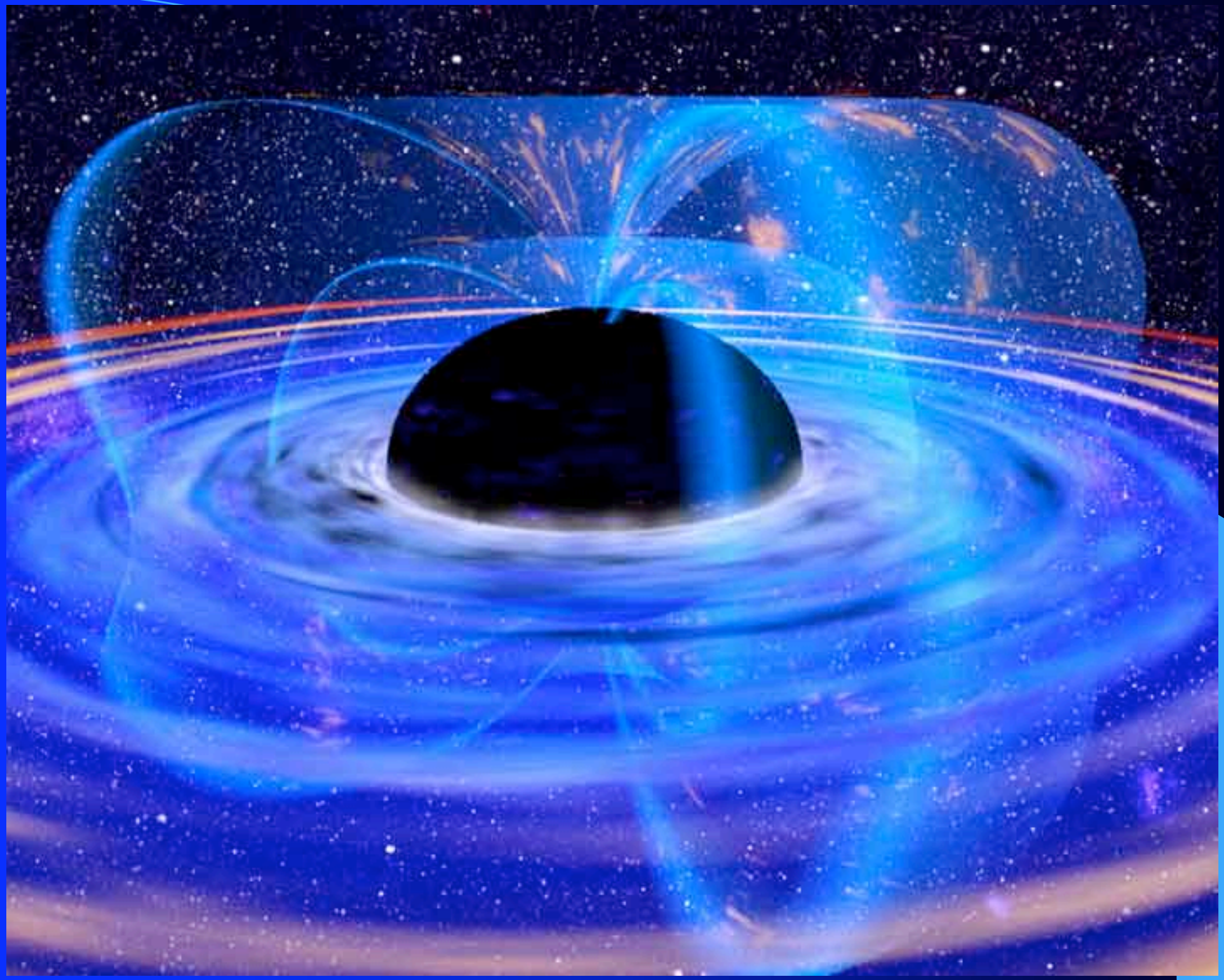
- All these effects are calculable, producing detailed model predictions that can be compared with XMM spectra. But one needs to be careful!
  - Must stick to physical models (no random edges at arbitrary Es)
  - Must use variability info where possible
  - Distinguish "absence of evidence" from "evidence of absence"

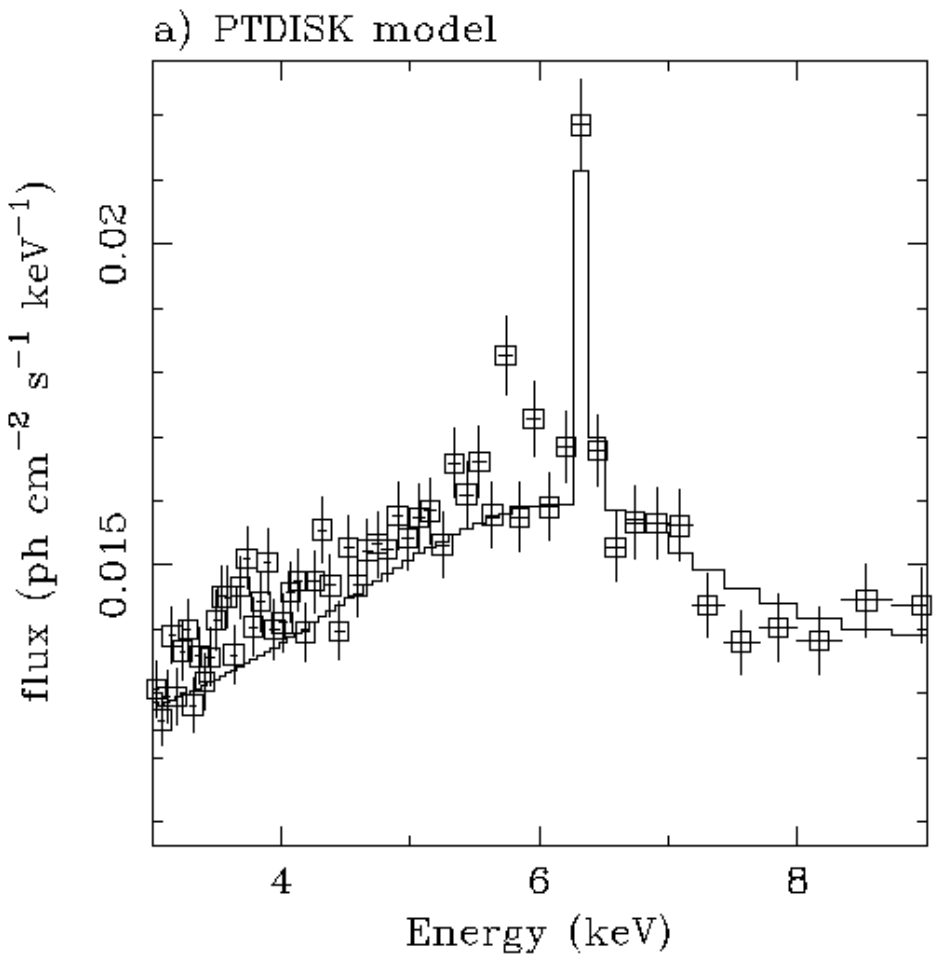
- Bottom line from XMM
  - There are a small number of very robust relativistic iron emission lines (MCG-6-30-15; GX339-4)
  - At a lower level of robustness, ~25% of bright AGN have detected relativistically broad iron lines
  - Many more may have undetected (weaker) broad lines
  - The systematic, careful survey still has to be done.

- **Even a few solid examples of relativistic iron lines in bright AGN allows Constellation-X to address its core scientific goals!**

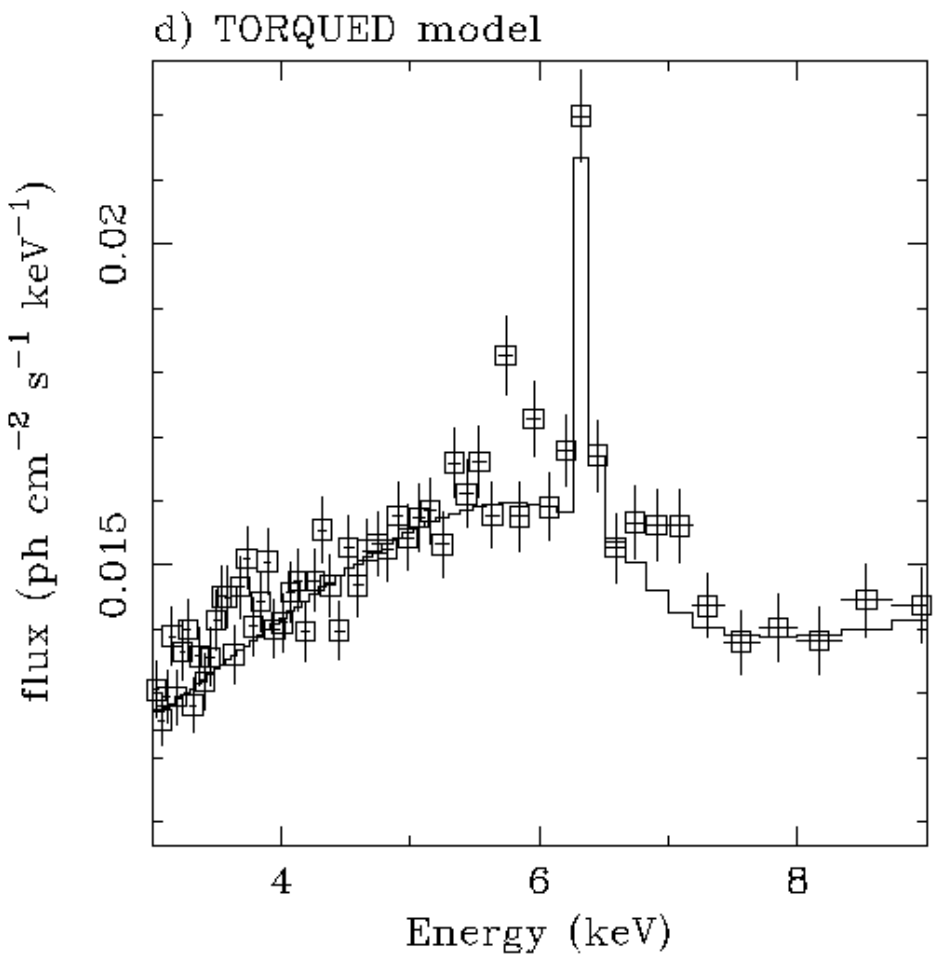
A taster of the science currently being debated…

- We see **very** broad lines in MCG-6-30-15 and GX339-4
- Assuming validity of GR, the need for rapidly-rotating black holes is unambiguous
- **Very** centrally concentrated pattern of X-ray illumination needed to produce such lines
  - Strong light bending effects? (Fabian, Minutti, Vaughan et al.)
  - Magnetic torquing of inner accretion disk by spinning black hole? (Reynolds, Wilms et al.)
- Either way, we're debating processes occuring within the inner 2-3GM/c^2

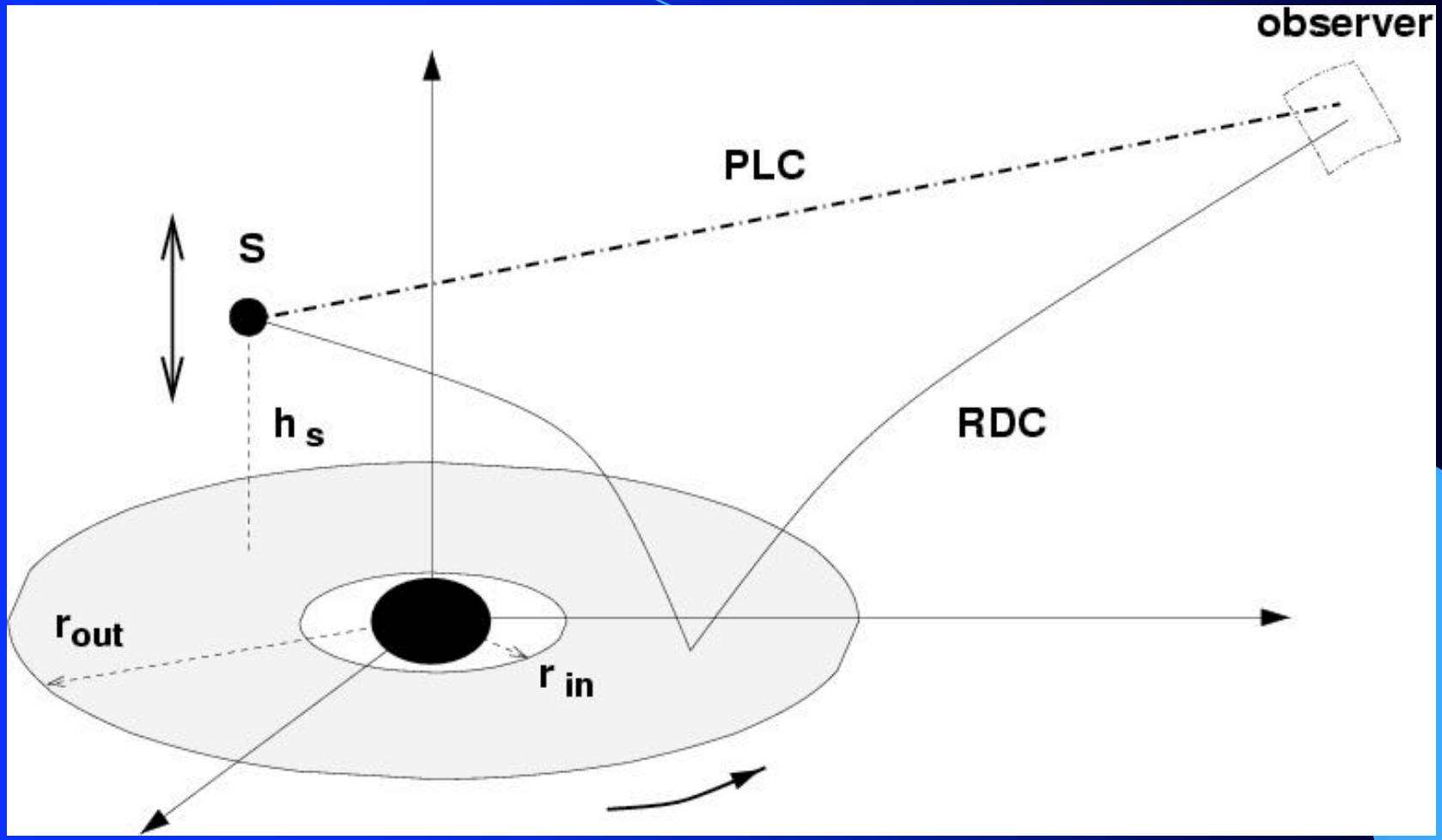


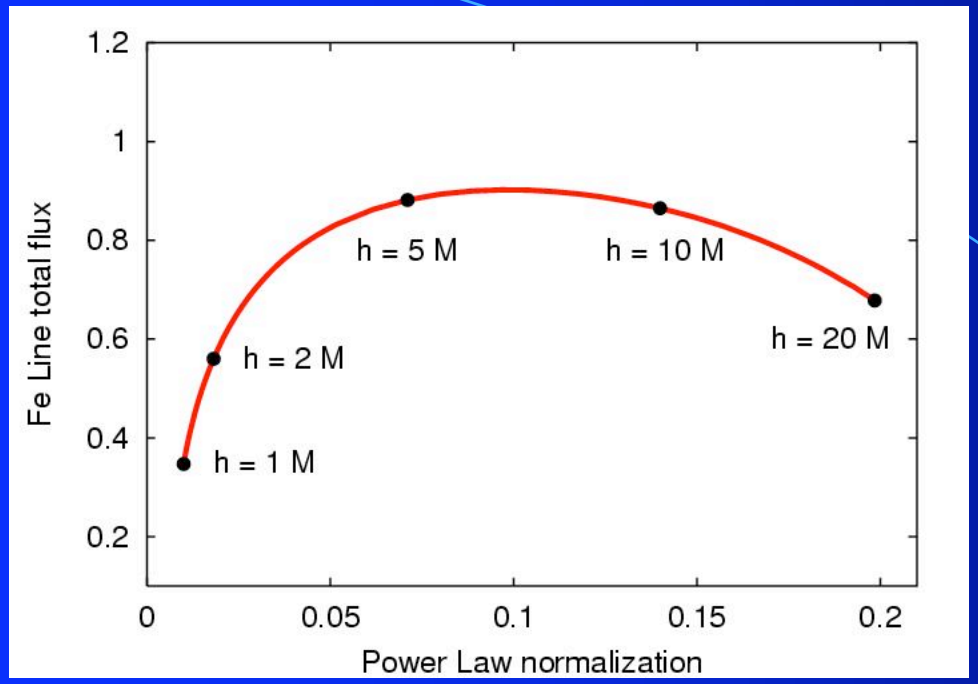


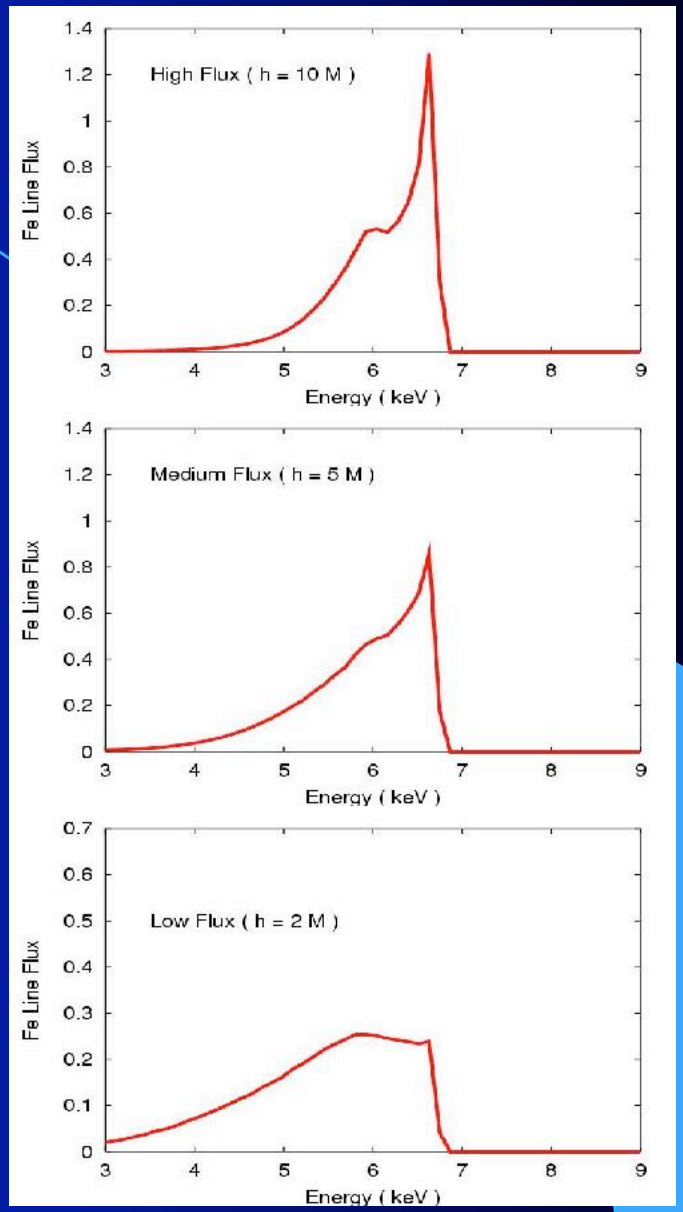
MCG-6-30-15
Fit with a Novikov & Thorne disk



Fit with a Agol & Krolik torqued disk (need "infinite efficiency case)


observer
PLC
S
h s
RDC
r out
r in



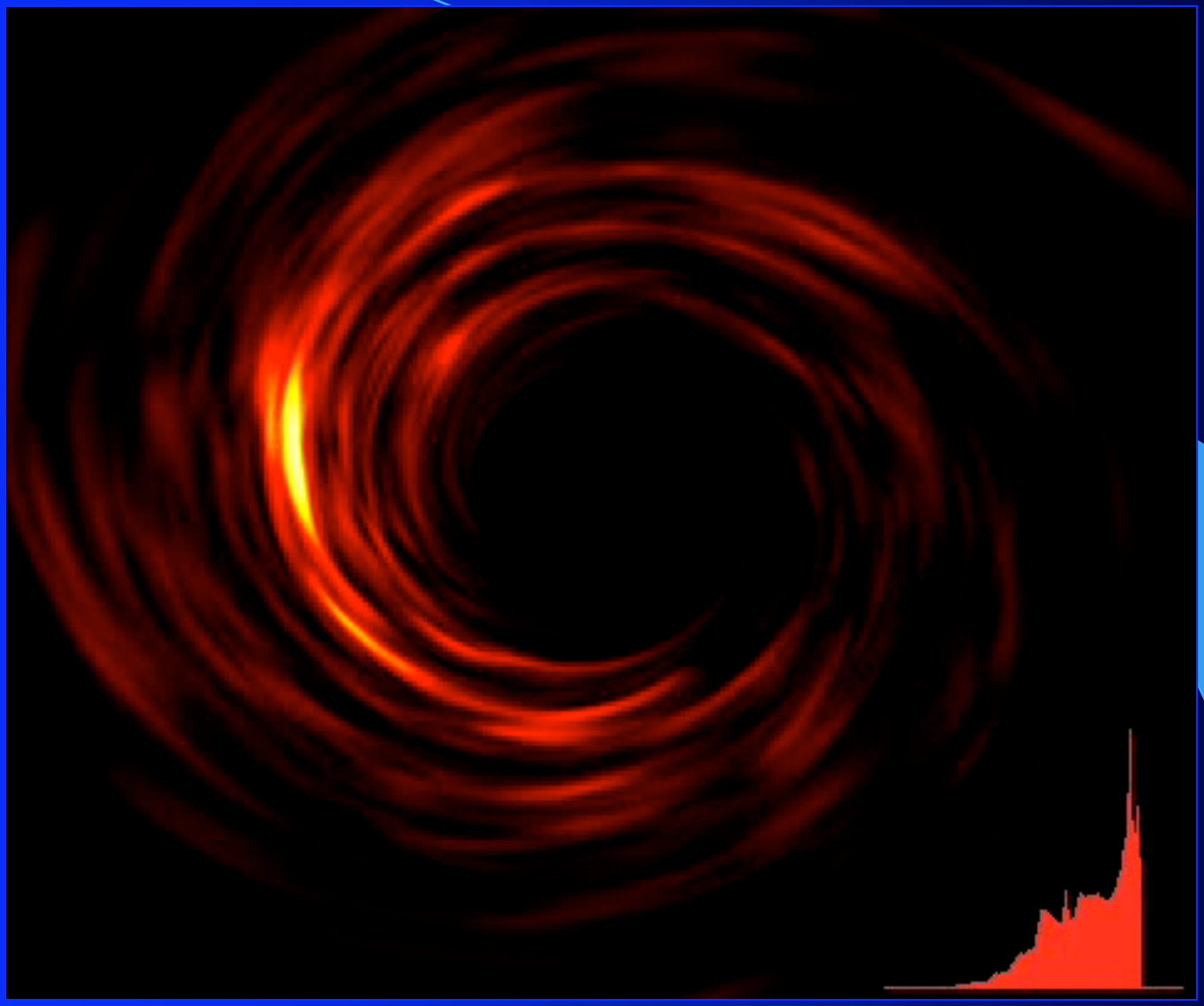


G.Minutti & A.C.Fabian

What can Con-X do?

- Core science from detailed iron line variability
  - Structural changes in disk/corona (viscous timescale; XMM+)
  - Accretion disk dynamics (dynamical timescale; XMM++)
  - Reverberation effects (lightcrossing timescale; TRIP baseline+)

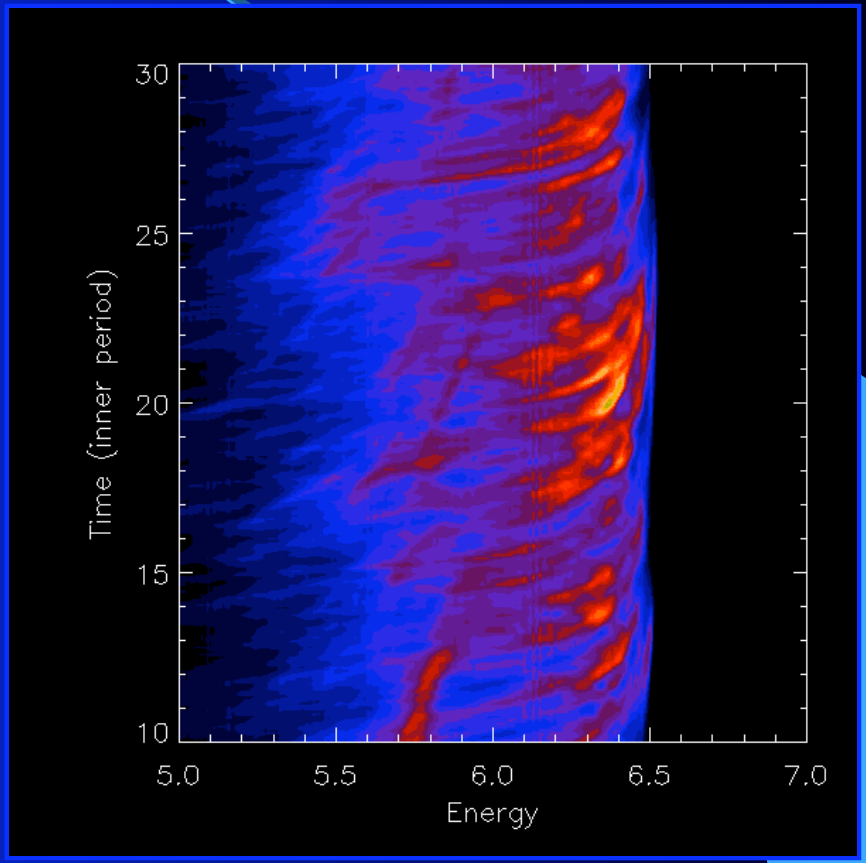
- Spectral properties of faint and distant AGN
  - Accretion history of BHs through cosmic time (how do BHs grow?); see Ann's talk.
  - Plasma physics of very low-luminosity AGN



Armitage & CSR (2003)

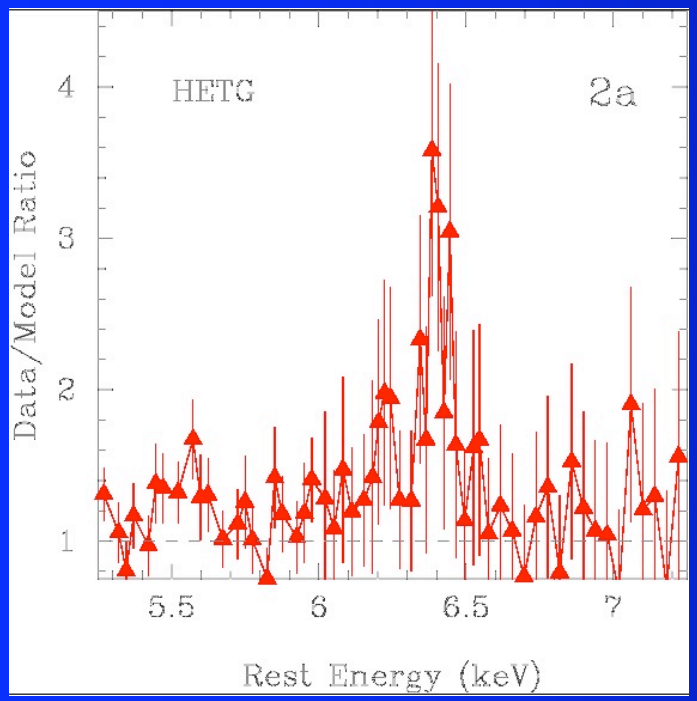
Iron line variability

- Con-X will allow detailed study of line variability
- See effects of non-axisymmetric structure orbiting in disk
  - Follow dynamics of individual "blobs" in disk
  - **Quantitative** test of orbital dynamics in strong gravity regime

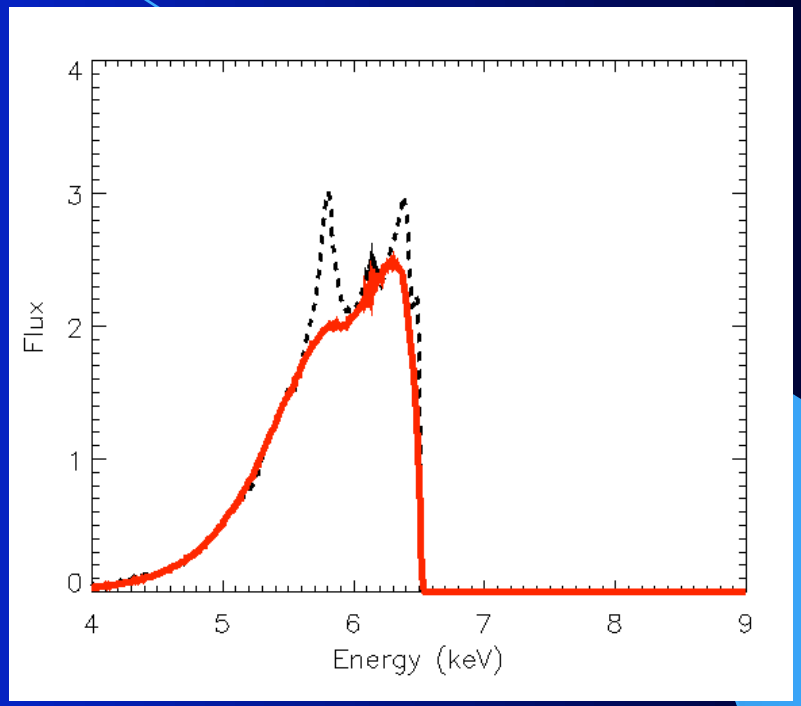


Armitage & CSR (2003)

Non-axisymmetric structure may have been seen already…



Chandra-HETG data on NGC3516
(Turner et al. 2002)

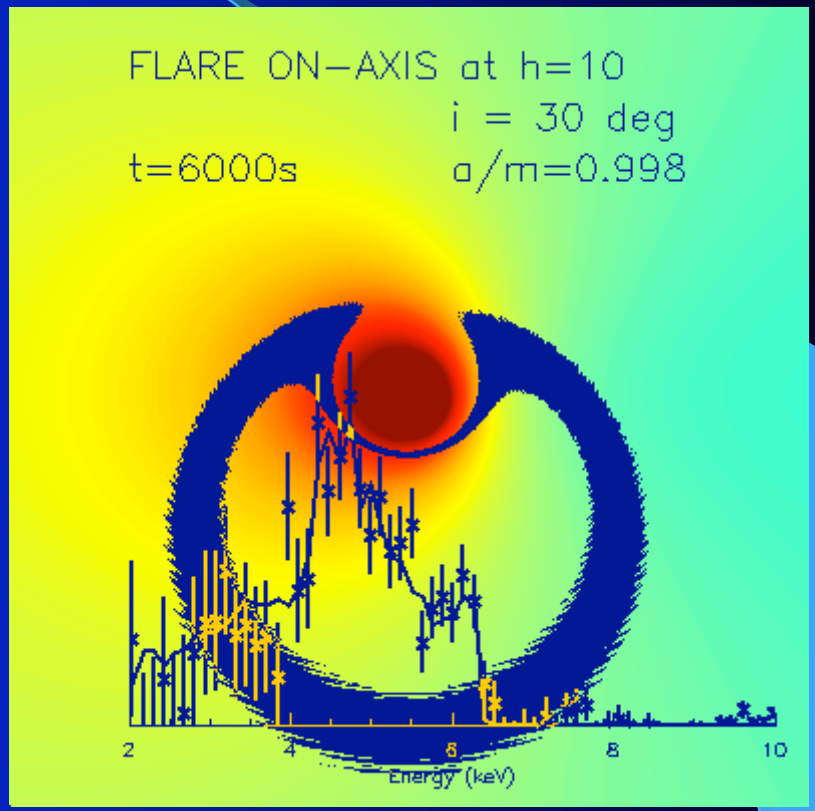


Simulation results for inclination
of 20 degs (summed over 2 full orbits)

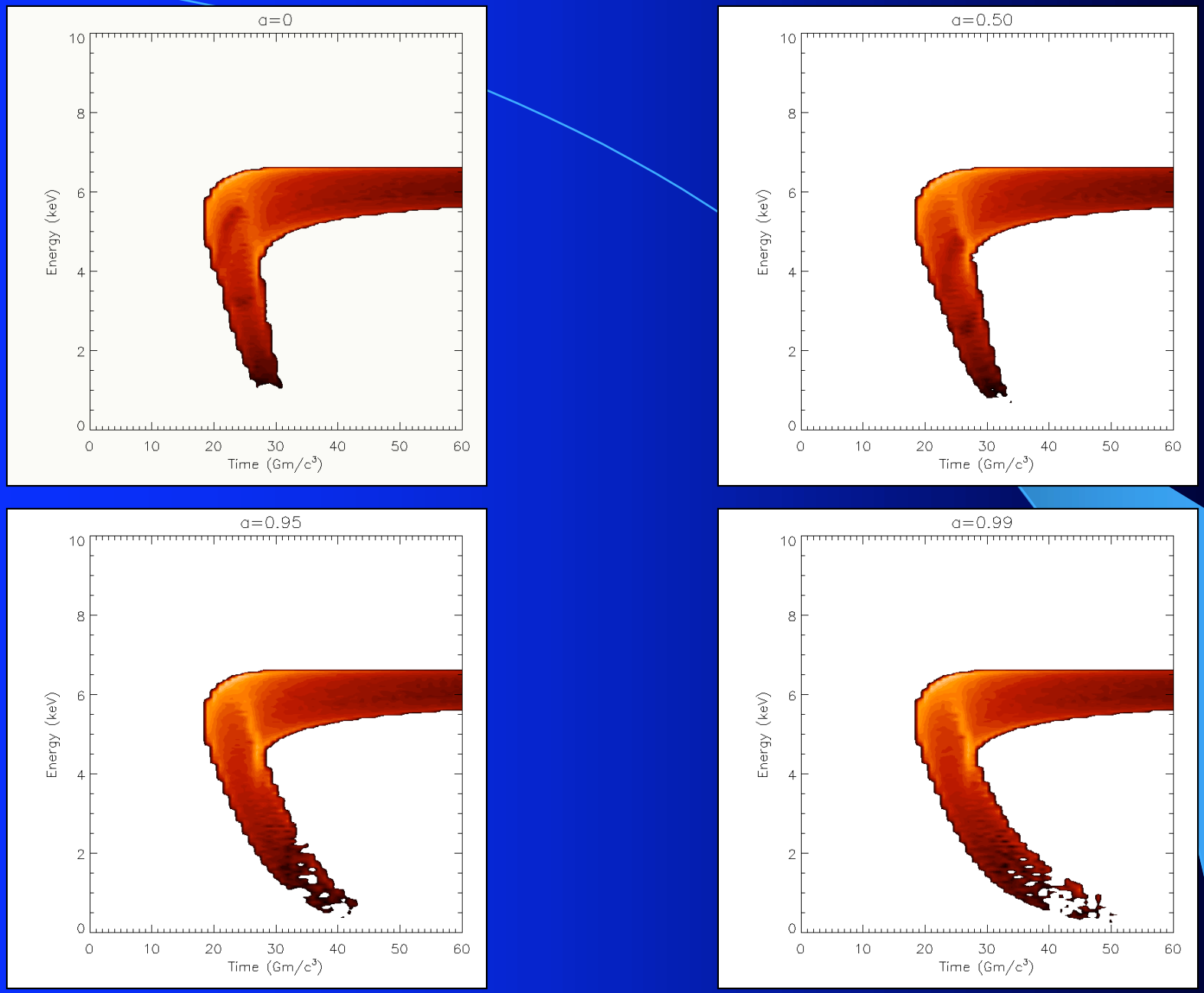
Astro-E will further study of these features… but need Con-X to realize full potential.

Relativistic iron line reverberation…

- Reverberation
  - X-ray source displays dramatic flares
  - Iron line profile will change as echo sweeps across disk
  - Needs high throughput spectroscopy – but probably within reach of $3m^2$ Con-X
- Current line variability results have **<u>nothing</u>** to say about feasibility of reverberation!



CSR et al. (1999)
Young & CSR (2000)



Reynolds et al. (1999)

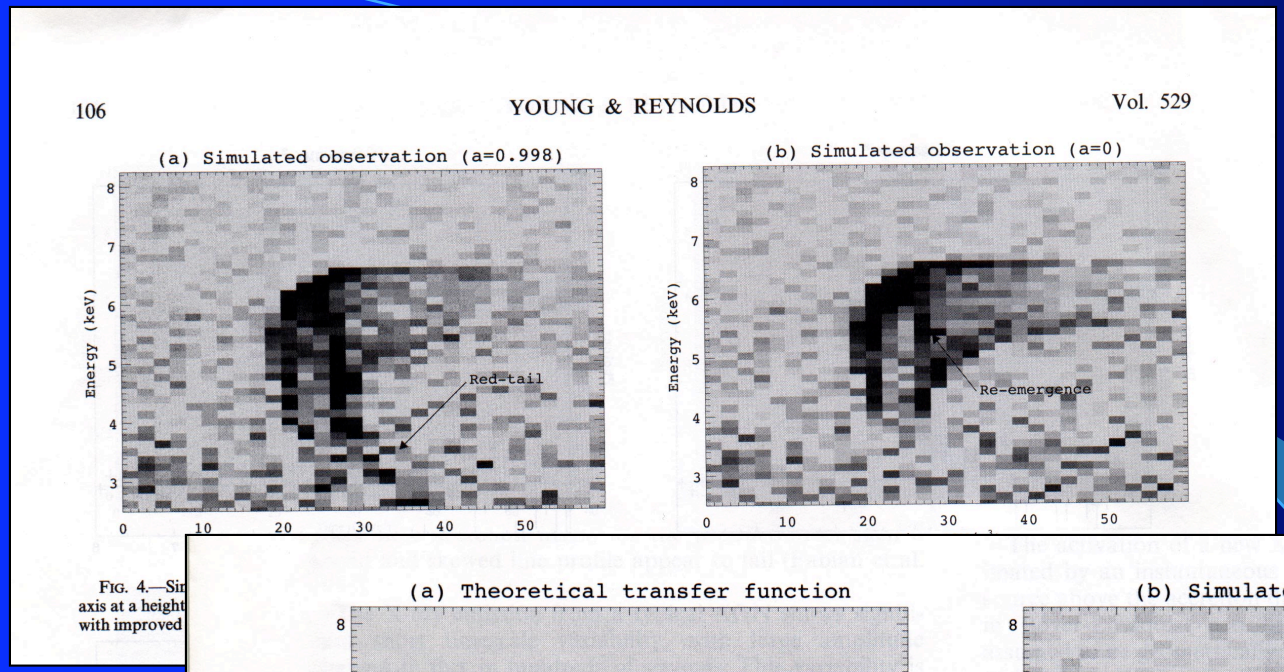


FIG. 4.—Sir
axis at a height
with improved

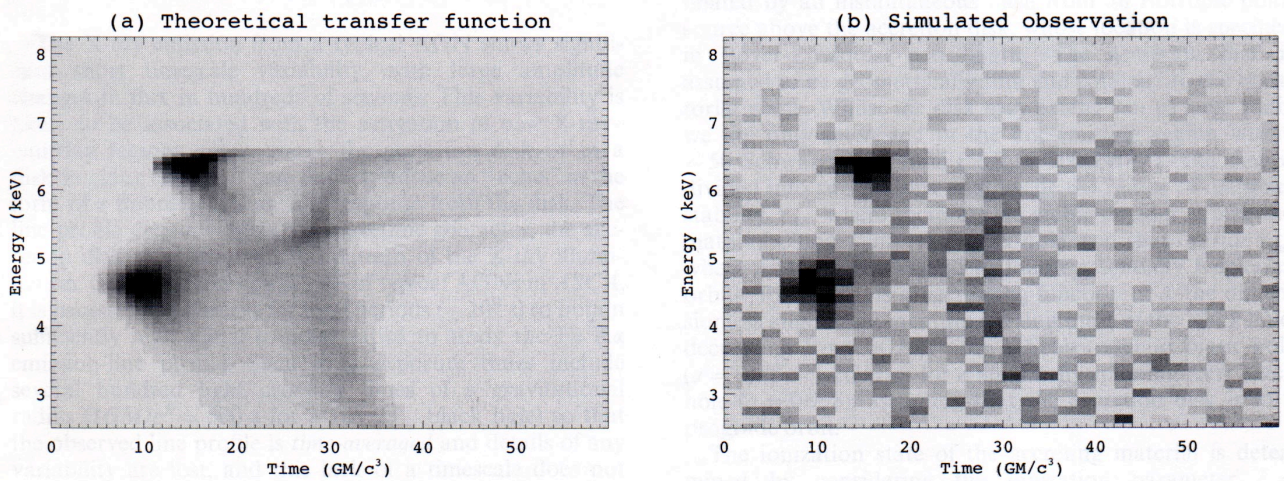
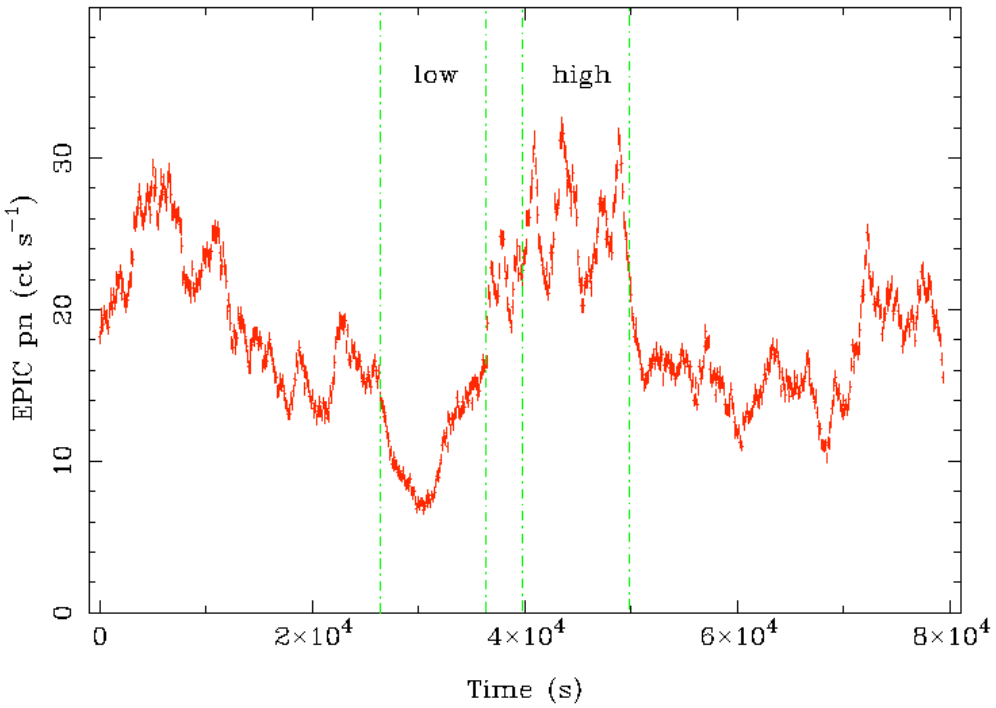


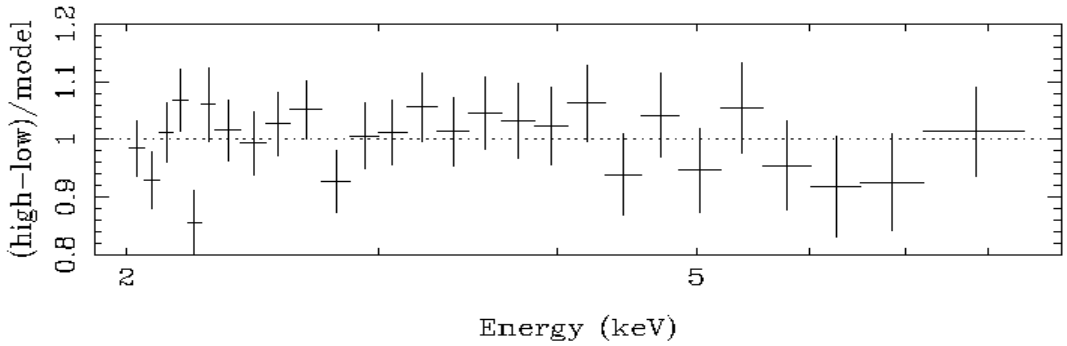
FIG. 7.—Panel *a* shows the theoretical line response to the two overlapping flares described in the text. Panel *b* shows the simulated line response as seen by *Constellation-X*. The individual transfer functions of the two flares can be discerned. The data have been rebinned to produce these figures with improved signal-to-noise ratio.

Constellation-X simulations

Conclusions

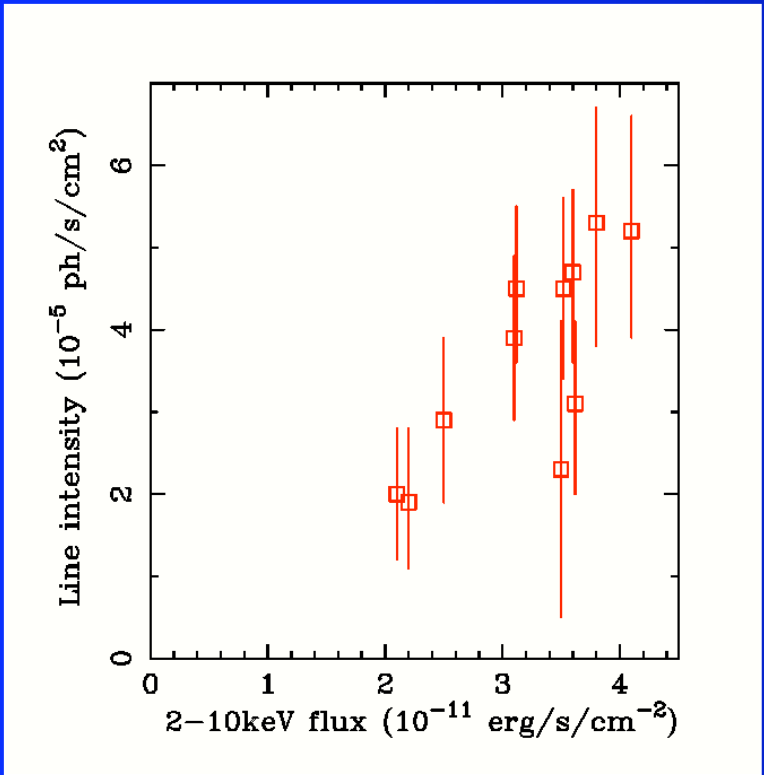
- **<u>Black-hole core science</u>** crucial to Con-X science case (at least while we're part of the Beyond Einstein Program)
- **Much of core science is accessed through variability of relativistically broad (iron) emission lines**
  - There are at least a few robust targets
  - We have well developed ideas of how to get at the big science questions
- **Need <u>AREA</u> and <u>SPECTRAL RESOLUTION</u> at iron K-band energies.**

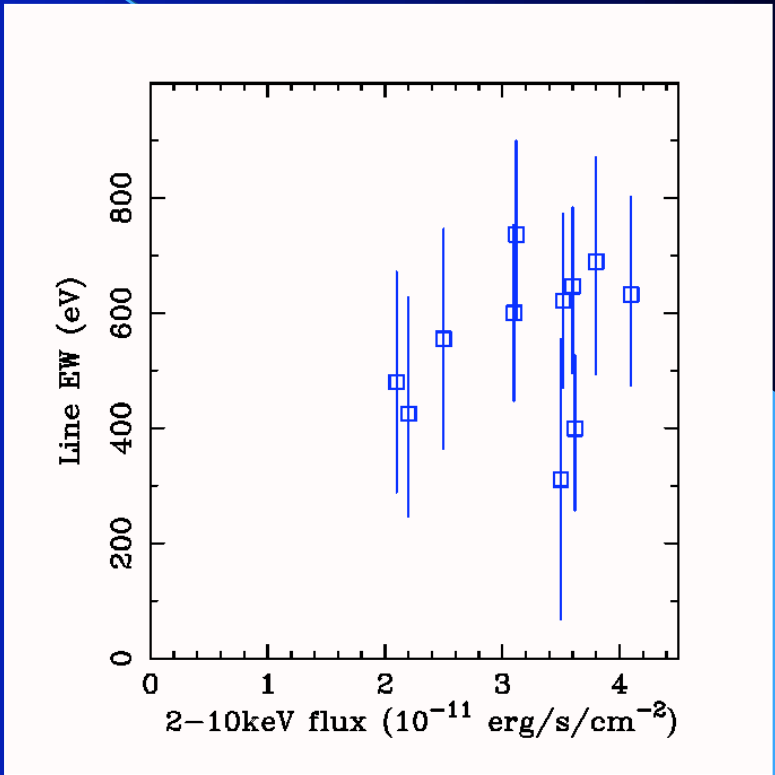




Fabian et al. (2002)

Iron line tracks continuum flux in Deep Minimum State…





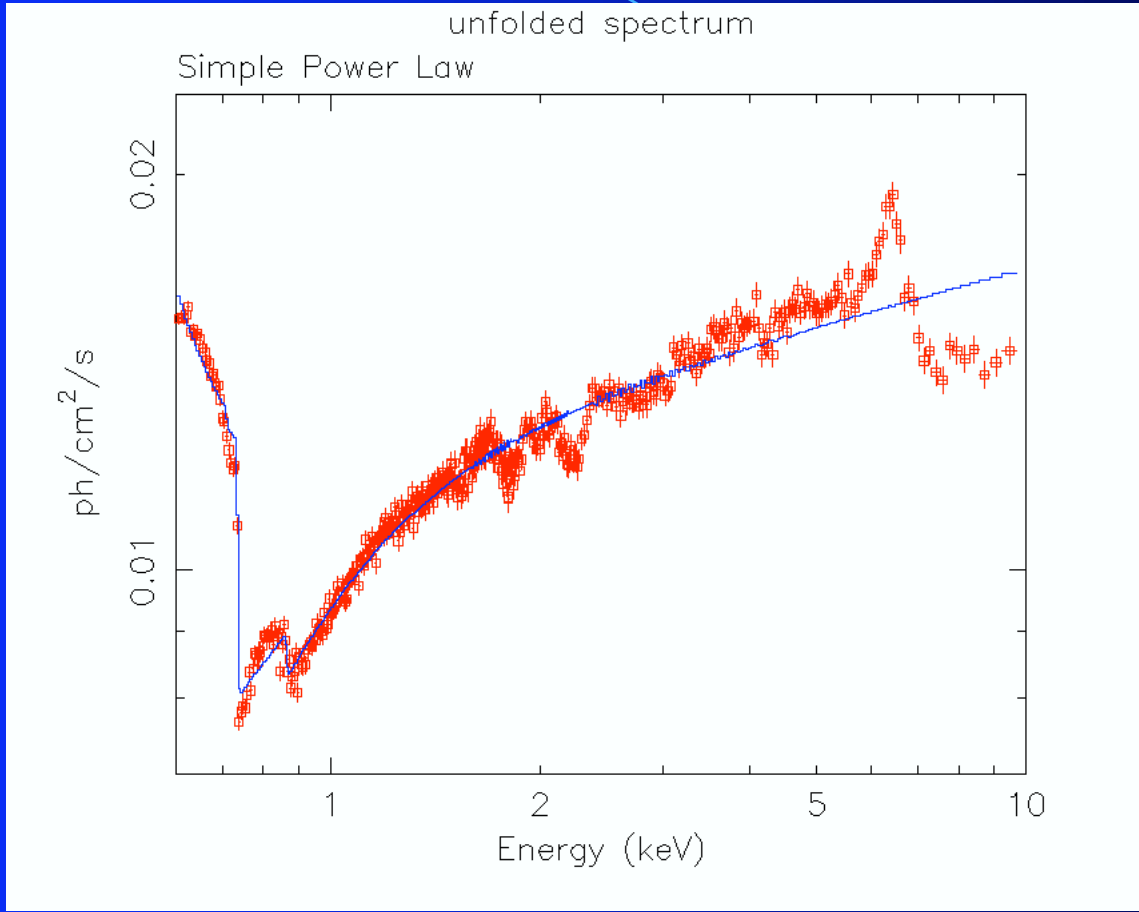
Overall behaviour is <u>quantitatively</u> explained by strong light bending together with changes in the size/height of part of the X-ray source… the "Two Component Model" (Fabian, Vaughan and collaborators)

Iron lines in the XMM era…

- How robust is evidence that we're seeing strong relativistic effects?
  - Complex absorption (photoionized absorption etc.)?
  - Continuum curvature (including reflection continuum)?
  - Other broadening mechanisms?

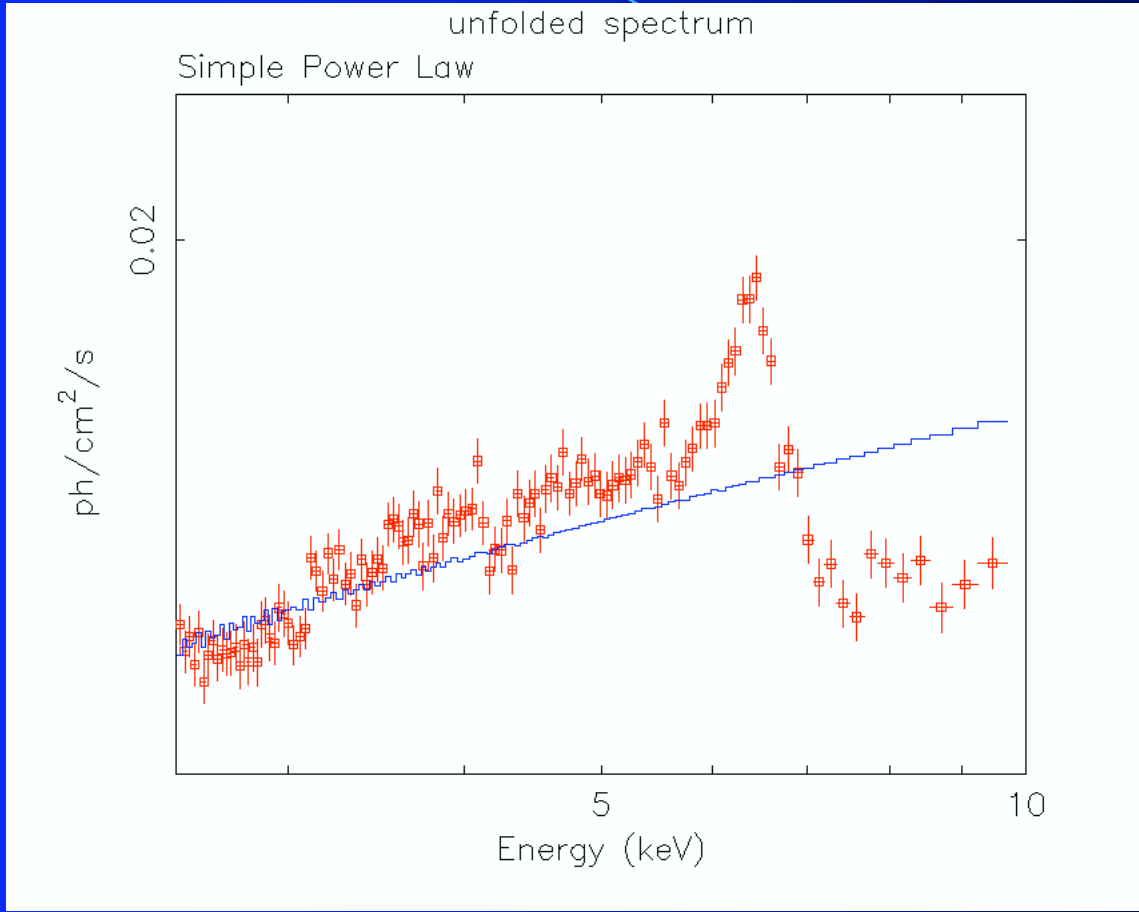
- All these effects are calculable, producing detailed model predictions that can be compared with XMM spectra. But one needs to be careful!
  - Must stick to physical models (no random edges at arbitrary Es)
  - Must use variability info where possible
  - Distinguish "absence of evidence" from "evidence of absence"

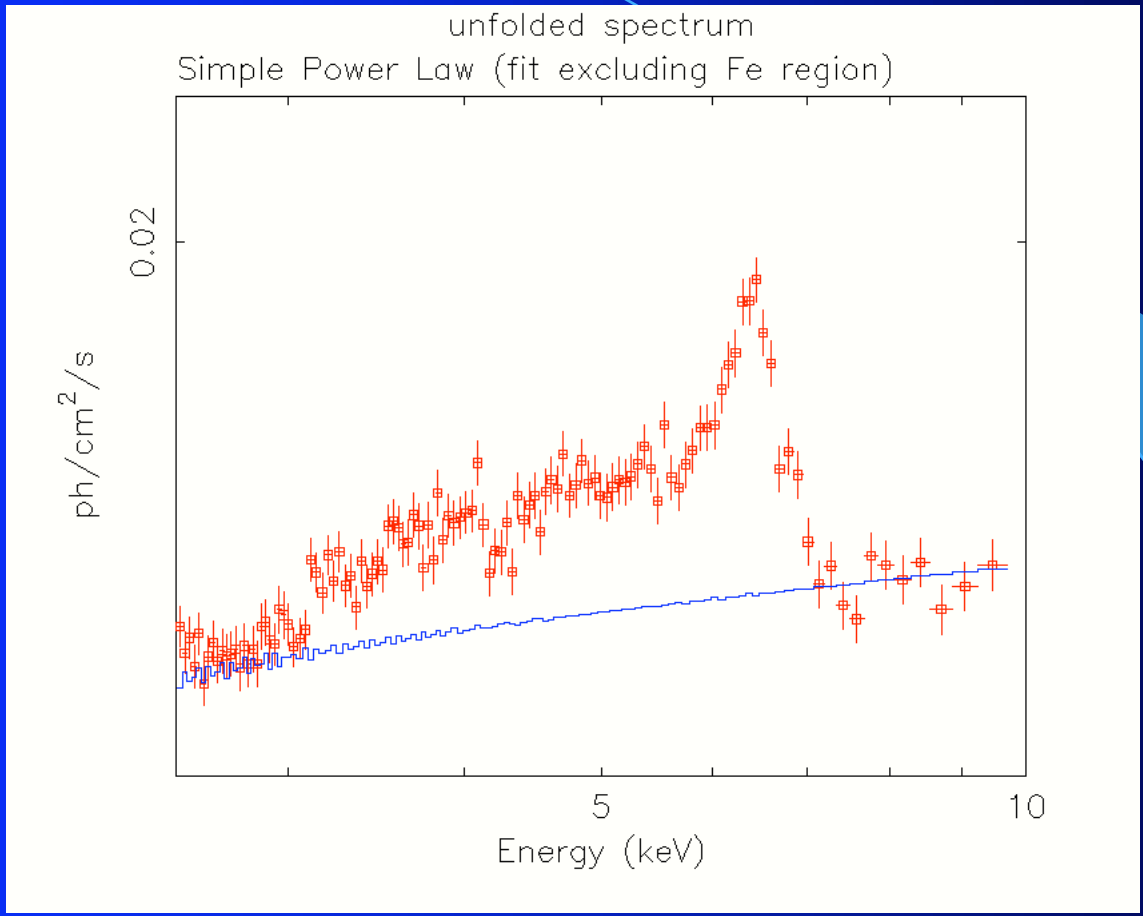
The poster child… MCG-6-30-15

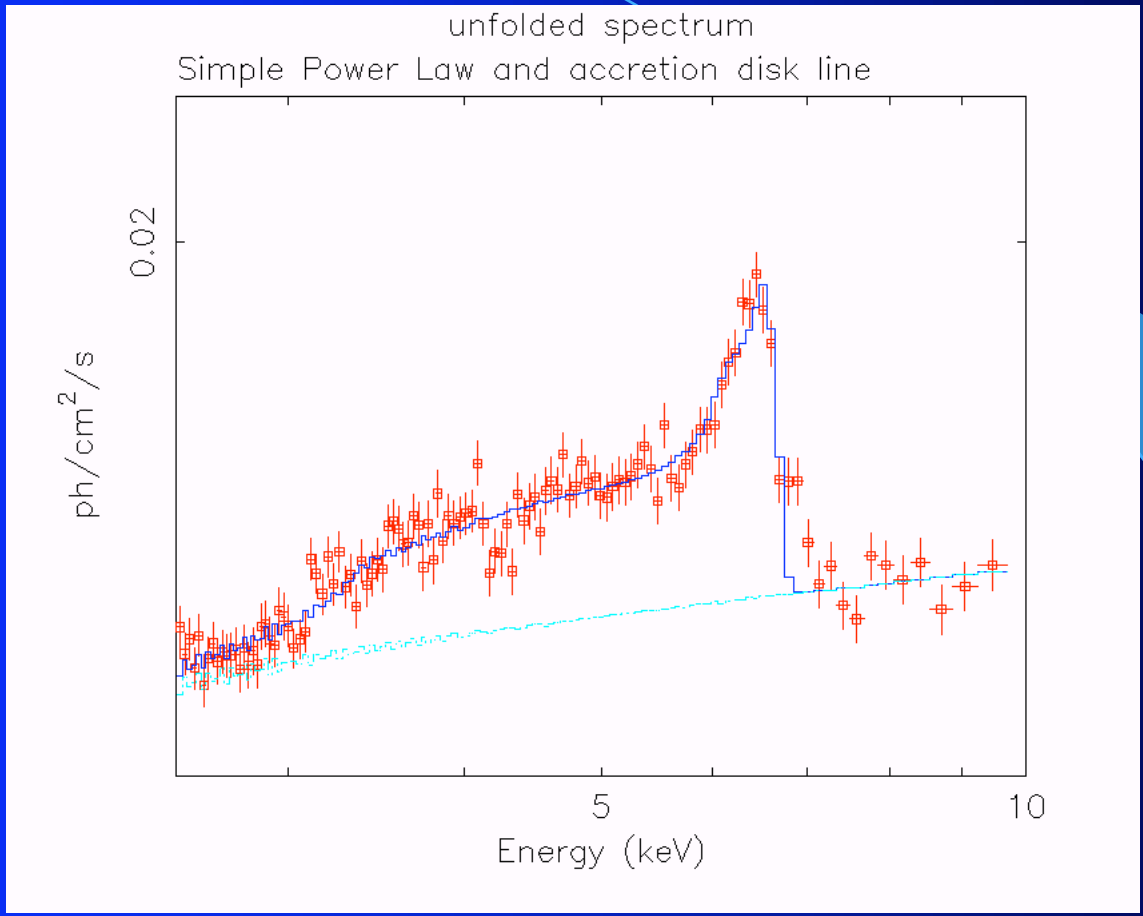


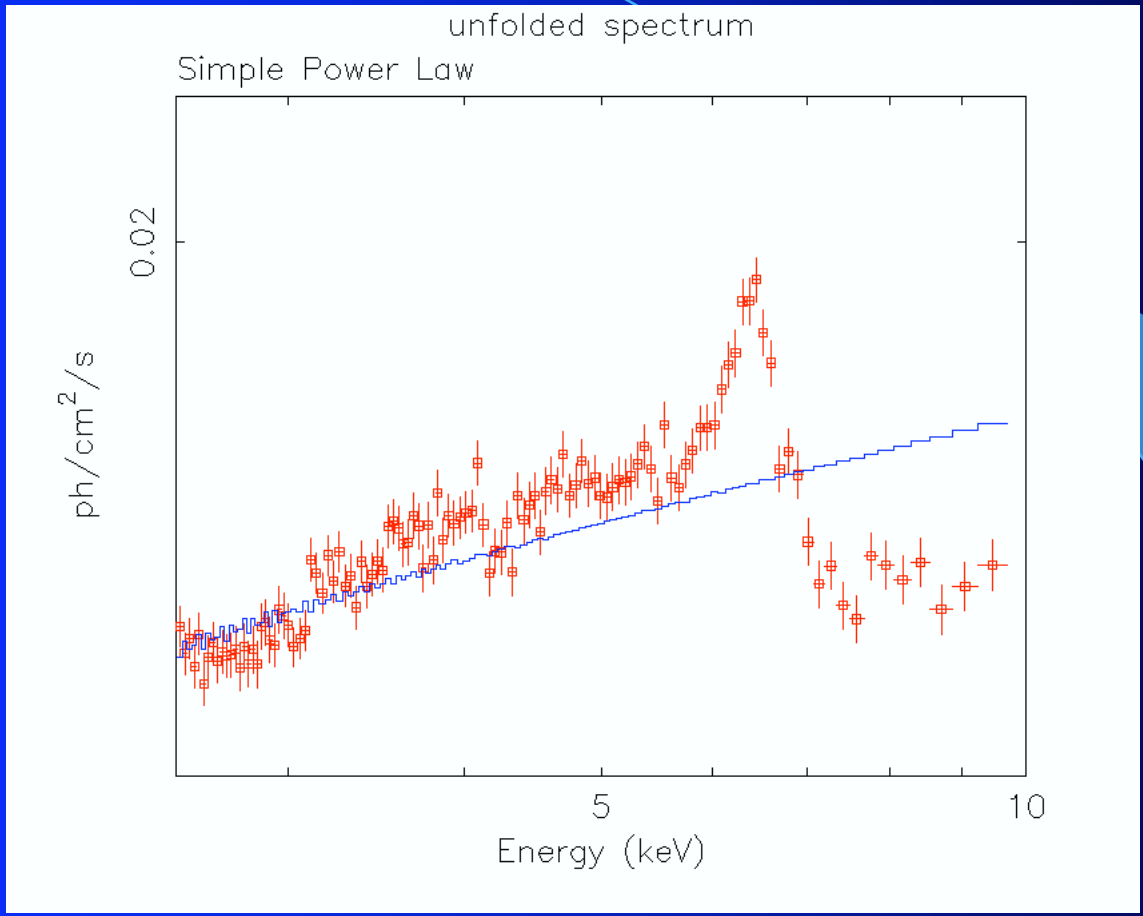
"Warm absorber" and "soft excess" included

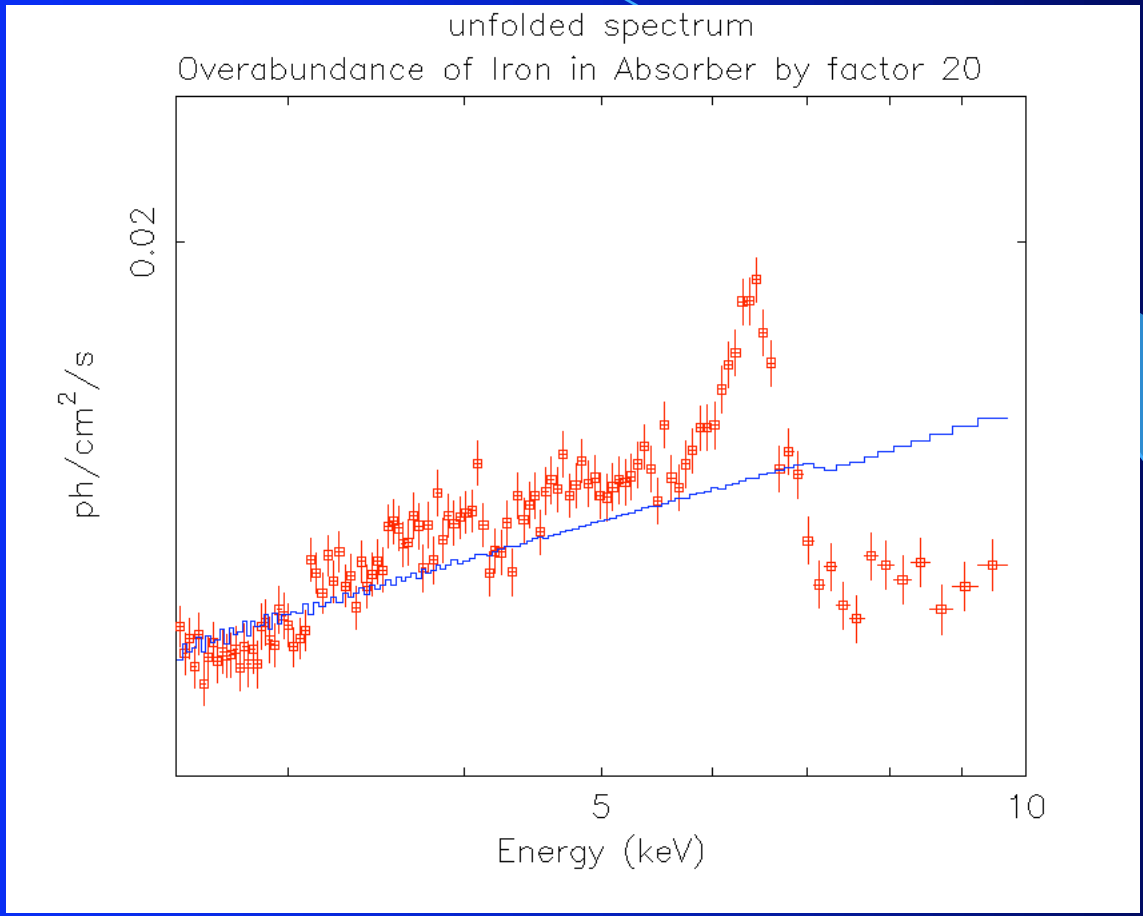
MCG-6-30-15

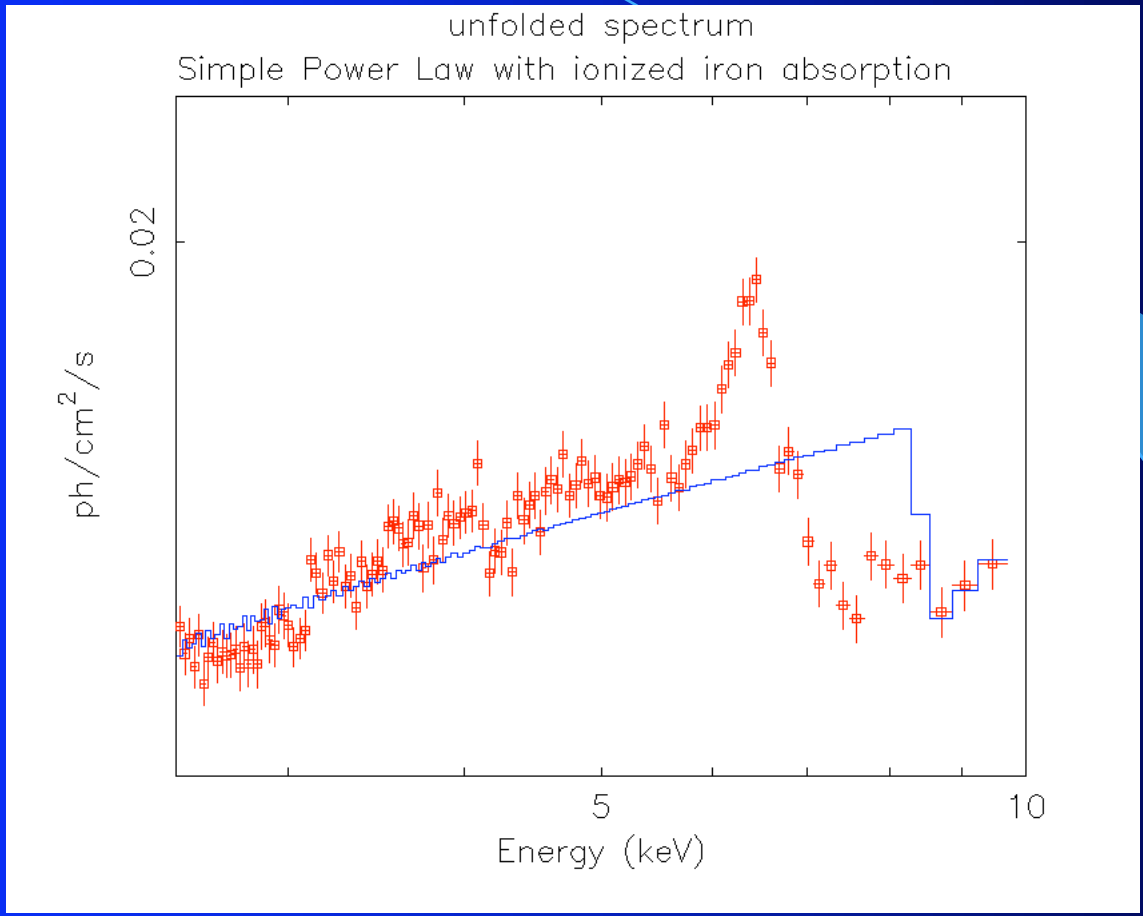

unfolded spectrum
Simple Power Law
0.02
ph/cm^2/s
5
10
Energy (keV)

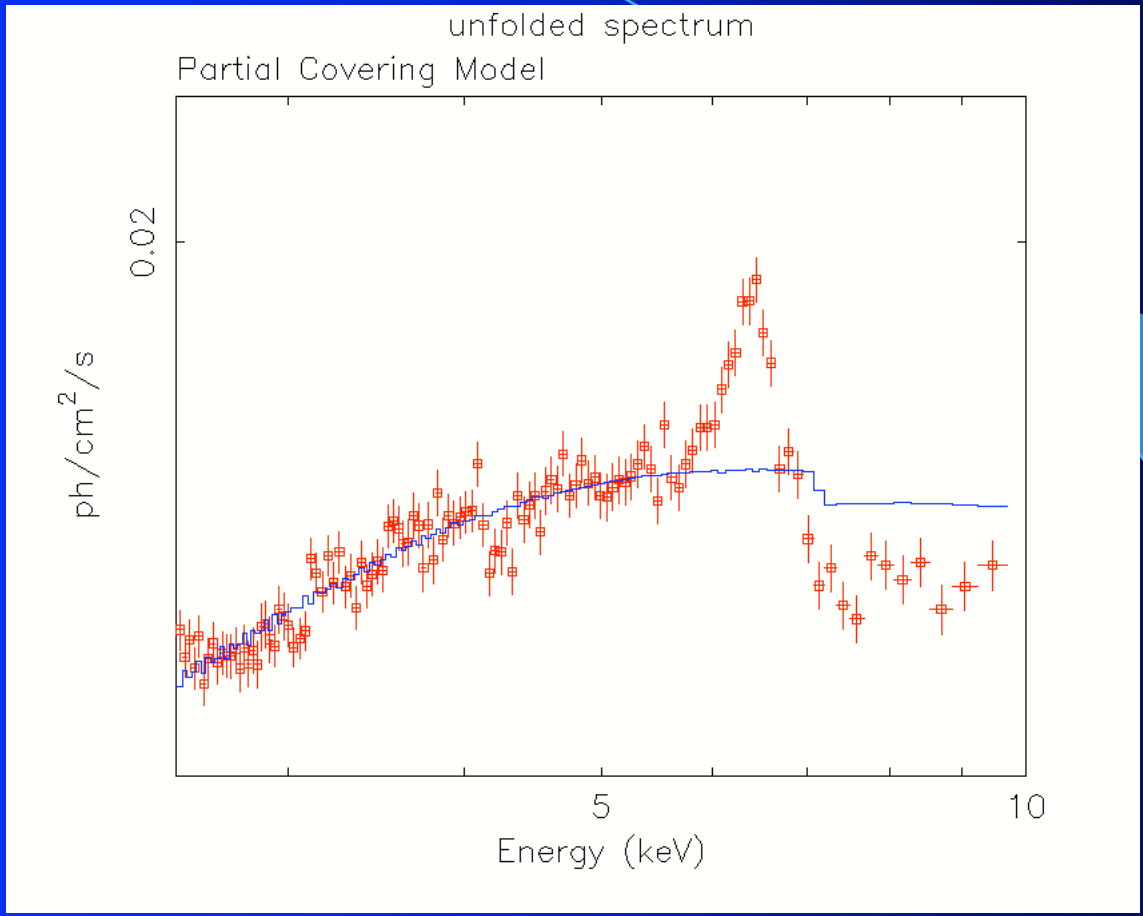

unfolded spectrum
Simple Power Law (fit excluding Fe region)
0.02
ph/cm^2/s
5
10
Energy (keV)

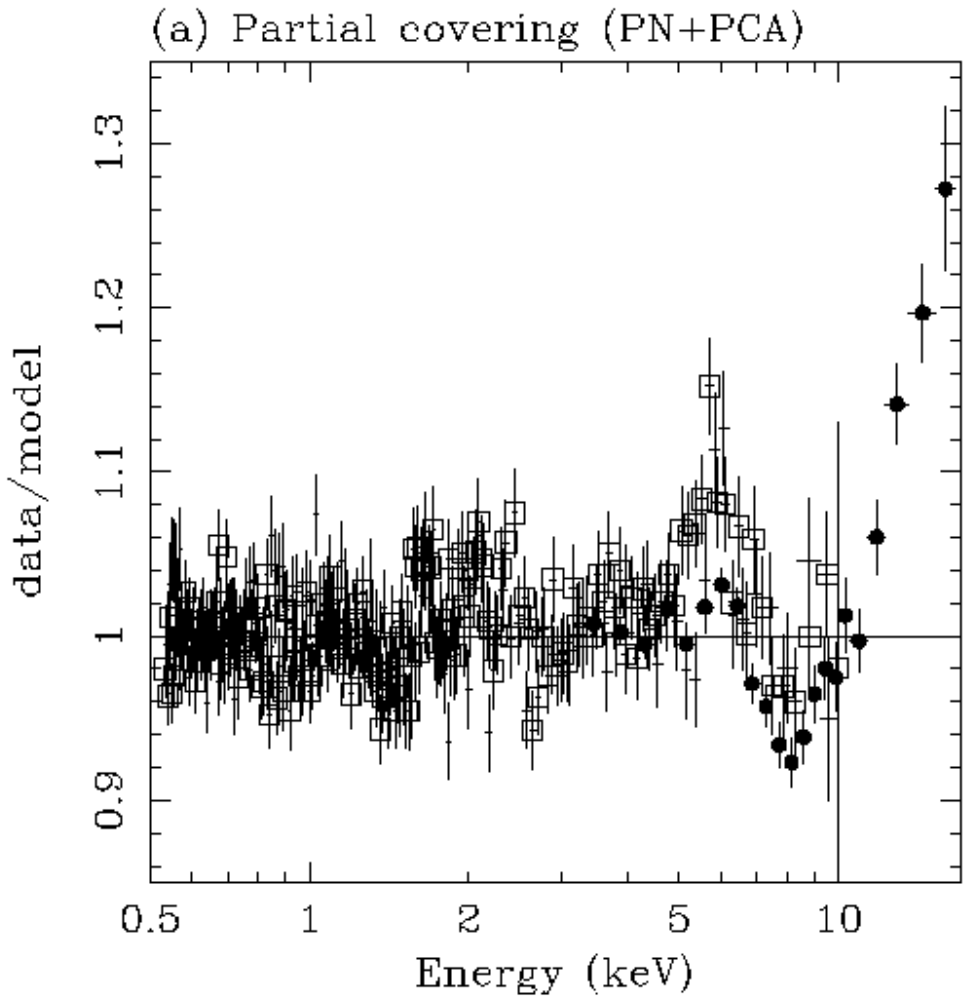

unfolded spectrum
Simple Power Law and accretion disk line
0.02
ph/cm^2/s
5
10
Energy (keV)


unfolded spectrum
Simple Power Law
0.02
ph/cm^2/s
5
10
Energy (keV)


unfolded spectrum
Overabundance of Iron in Absorber by factor 20
0.02
ph/cm^2/s
5
10
Energy (keV)

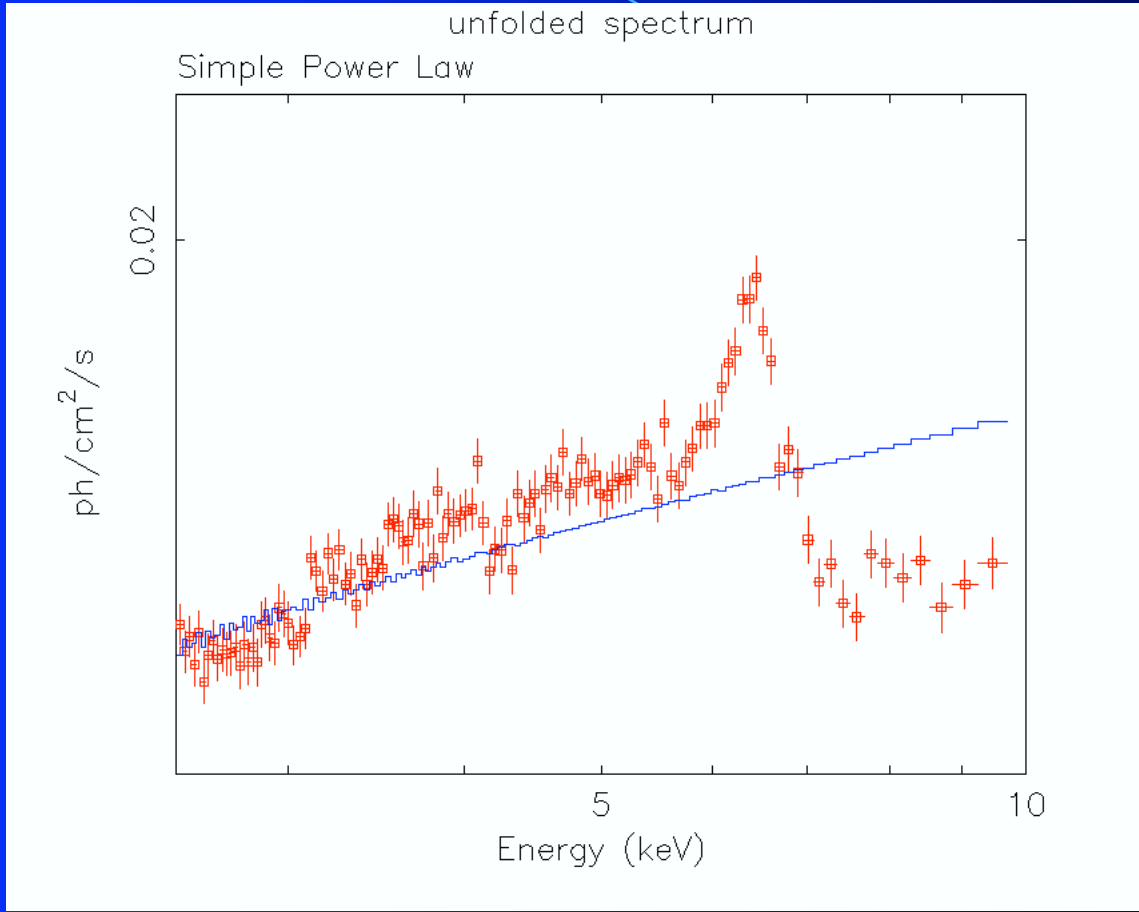

unfolded spectrum
Simple Power Law with ionized iron absorption
0.02
ph/cm^2/s
5
10
Energy (keV)

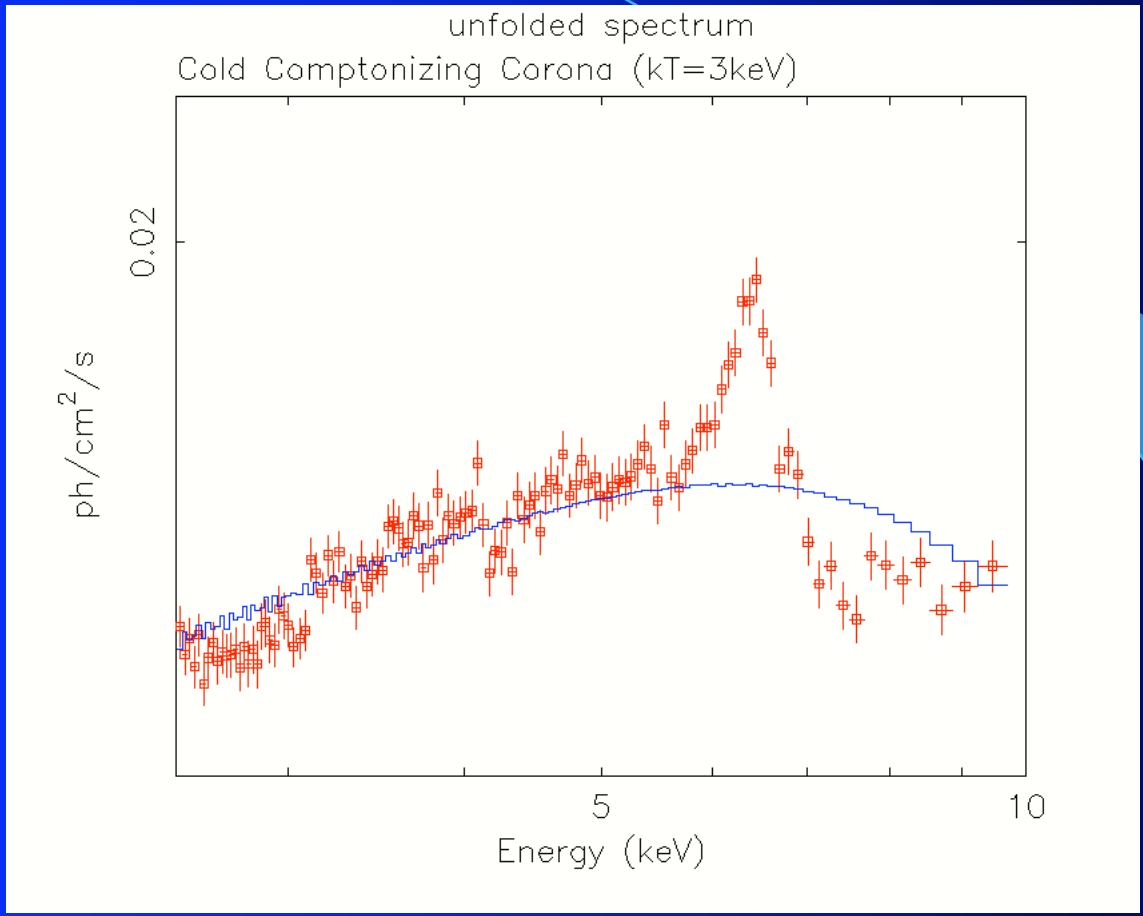

unfolded spectrum
Partial Covering Model
0.02
ph/cm^2/s
5
10
Energy (keV)



Partial covering requires steep continuum… disagrees with higher-energy data (e.g. RXTE)

Complex continuum shape?




unfolded spectrum
Cold Comptonizing Corona (kT=3keV)
0.02
ph/cm^2/s
5
10
Energy (keV)