Black Holes : Close to the Event Horizon

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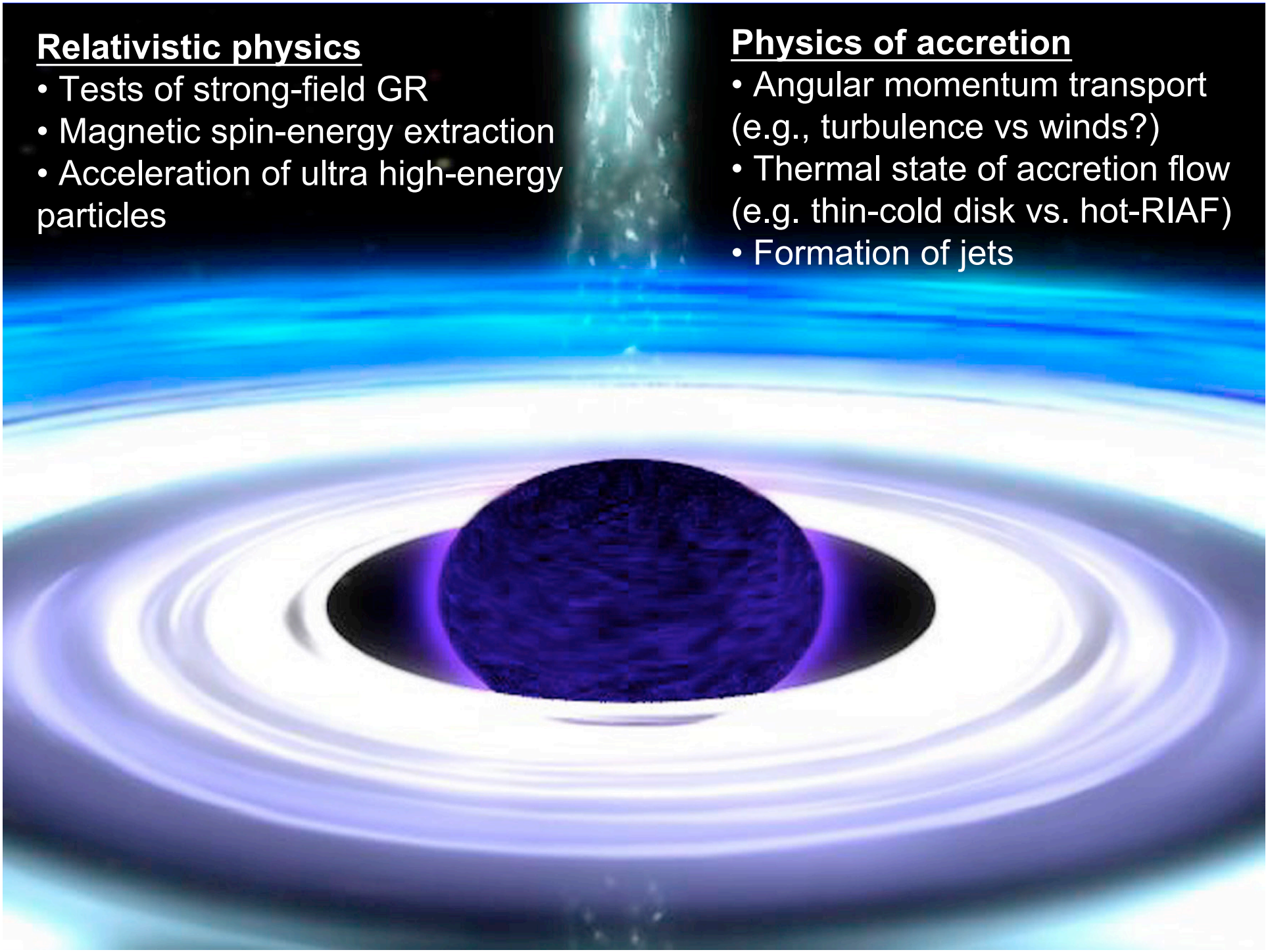
NASA/Dana Berry

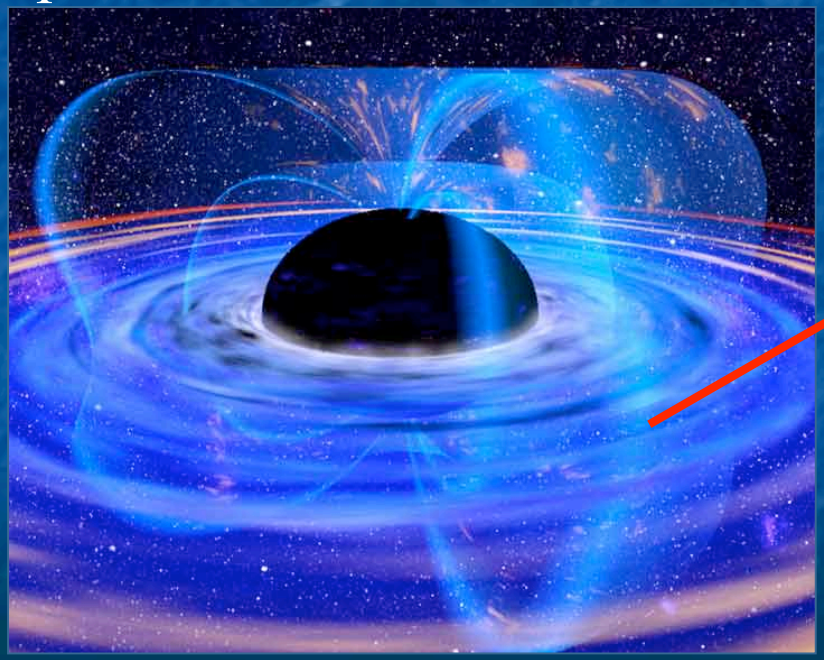

Relativistic physics
• Tests of strong-field GR
• Magnetic spin-energy extraction
• Acceleration of ultra high-energy particles
Physics of accretion
• Angular momentum transport (e.g., turbulence vs winds?)
• Thermal state of accretion flow (e.g. thin-cold disk vs. hot-RIAF)
• Formation of jets

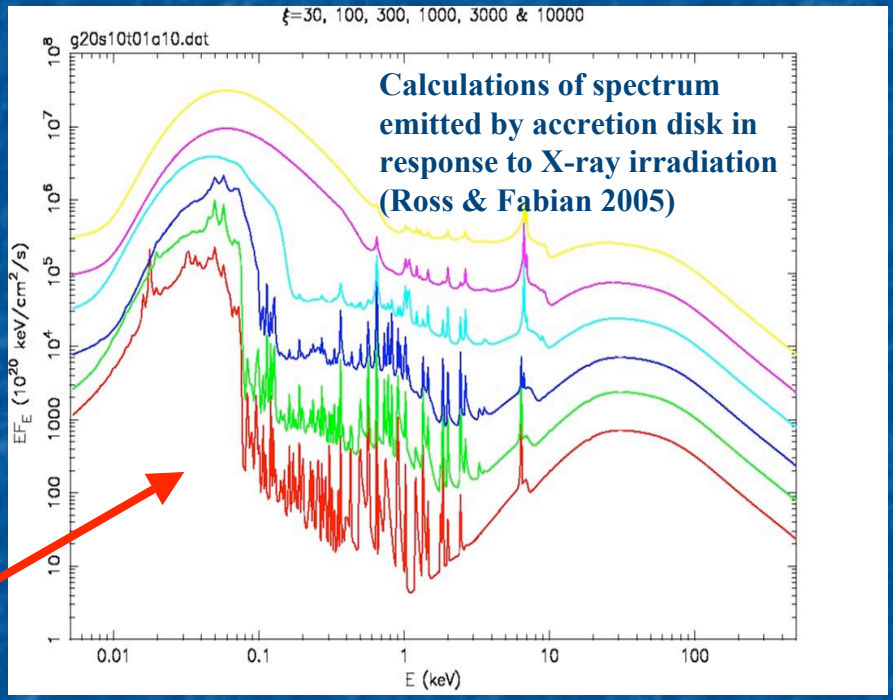
Outline of talk

- Probing black holes with X-ray spectroscopy
  - X-ray reflection and broad iron lines
  - Iron lines and black hole spin
- Contribution of Suzaku
  - Confirmation of disk-reflection paradigm
  - Soft excess as a signature of ionized disks
  - Curious variability of disk reflection spectra
  - Radio-loud/radio-quiet dichotomy
- Conclusions

X-ray reflection from disks

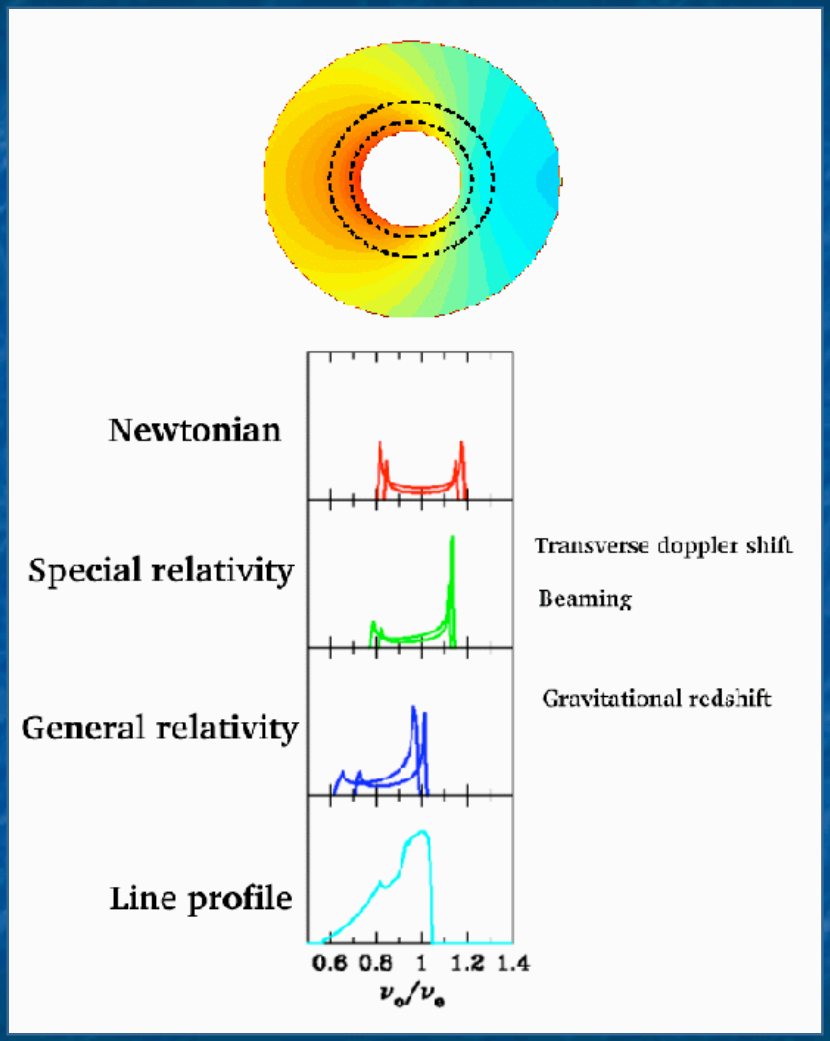
X-rays from corona/jet irradiate accretion disks… creates a backscattered spectrum rich in spectral features



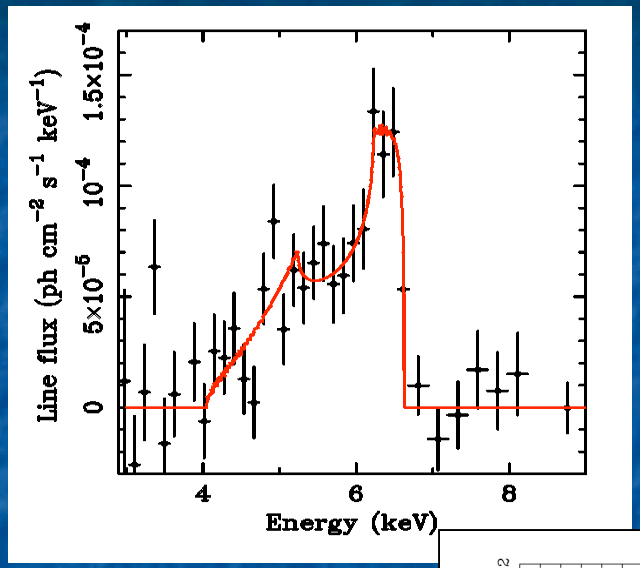


Very similar fluorescence features seen from surface of Sun during X-ray bright solar flare

The effects of strong gravity on iron lines…

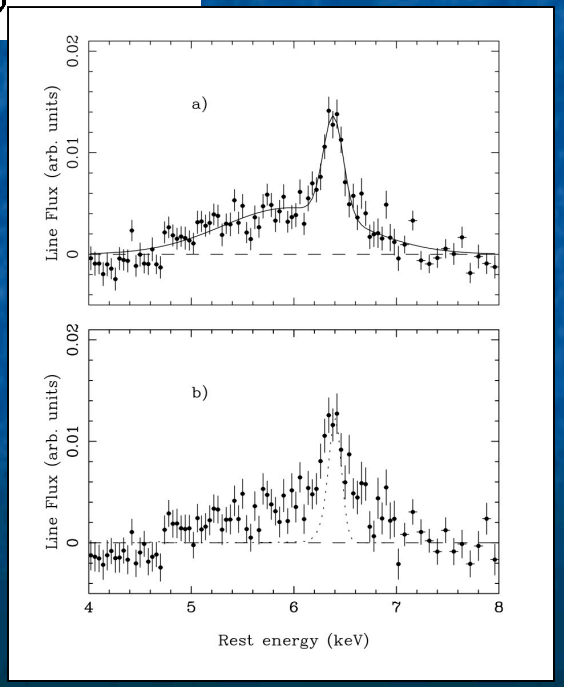


Original concept from Fabian et al. (1989)
Figure courtesy of Andrew Young

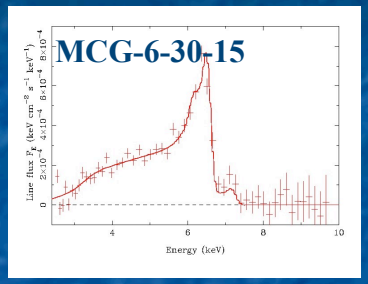


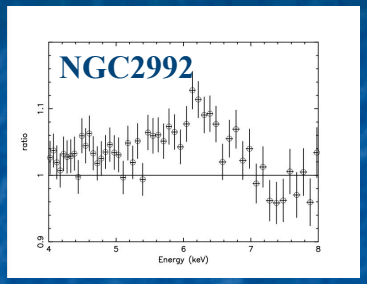
ASCA : MCG-6-30-15
(Tanaka et al. 1995)

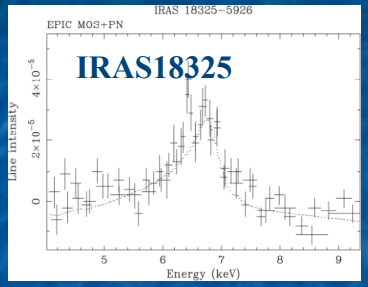
ASCA: composite
(Nandra et al. 1997)

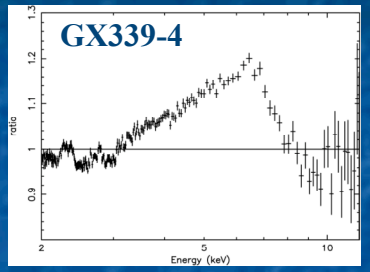


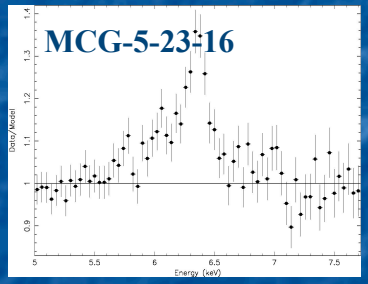
Gallery of broad iron lines from XMM

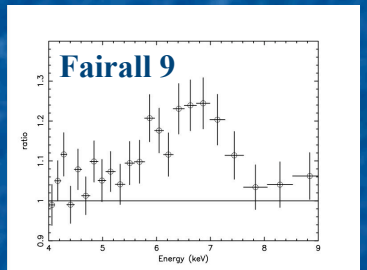


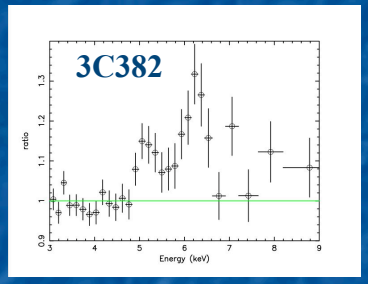


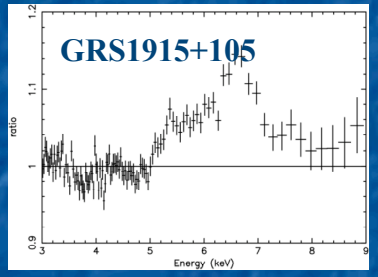


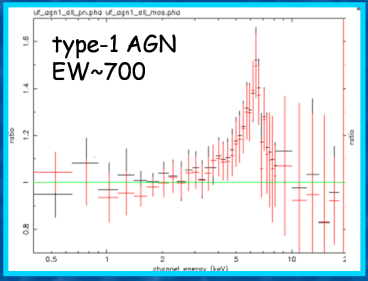


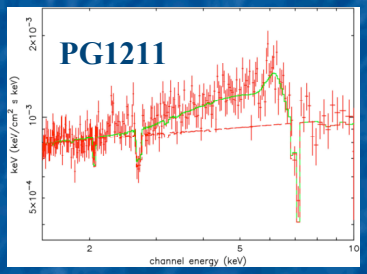


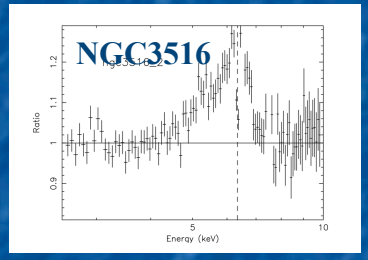


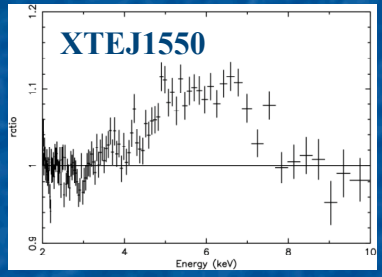


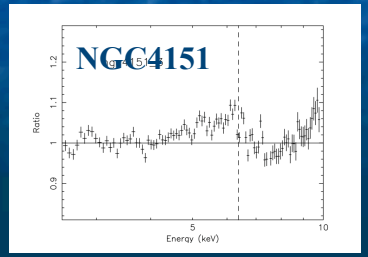


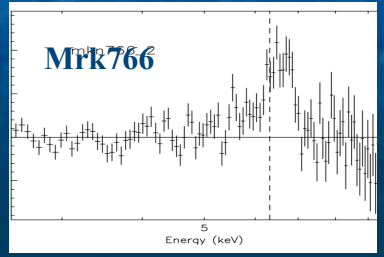




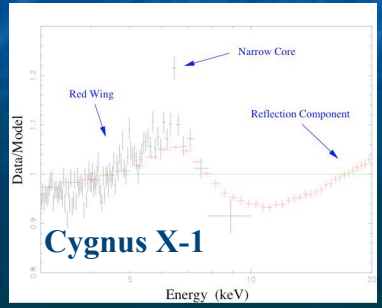




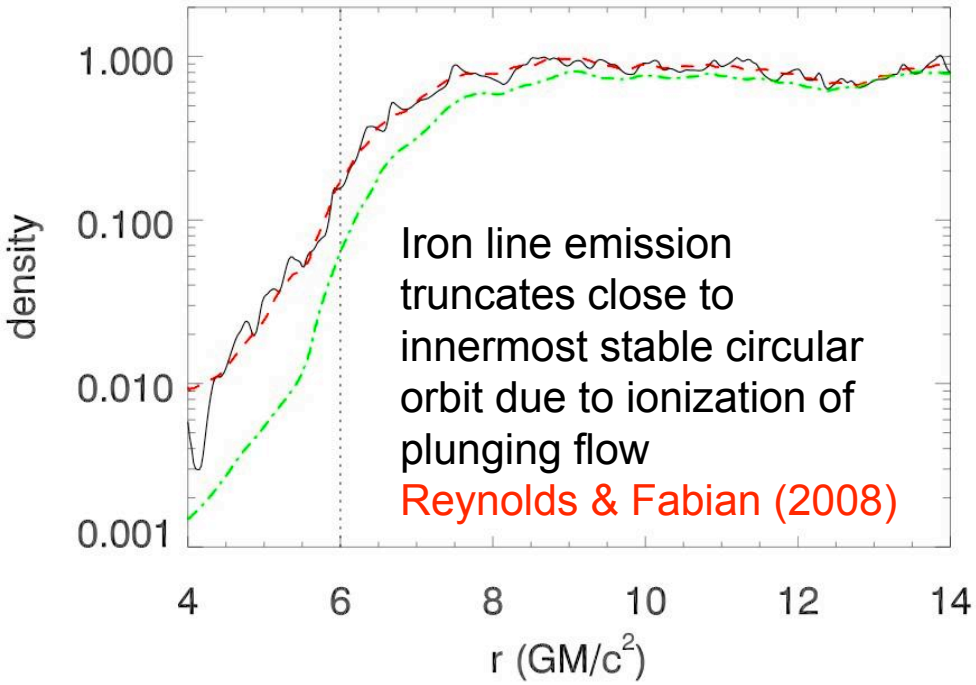


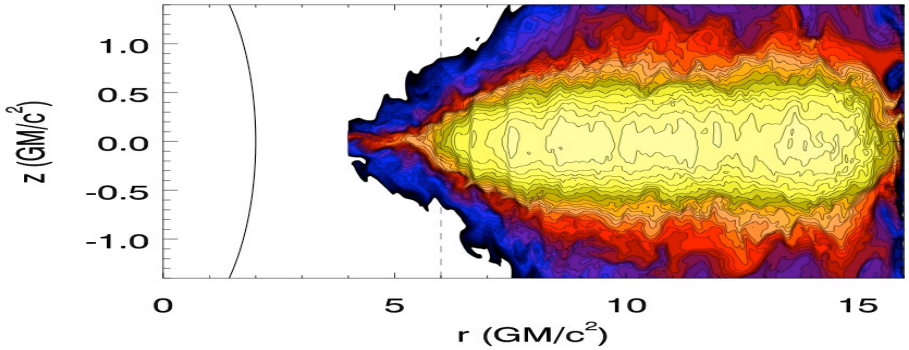


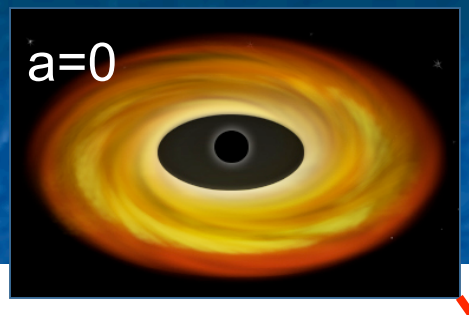
Nandra et al. (2007) find robust "relativistic" lines (r_{in}<50r_g) in 30% of Seyfert nuclei

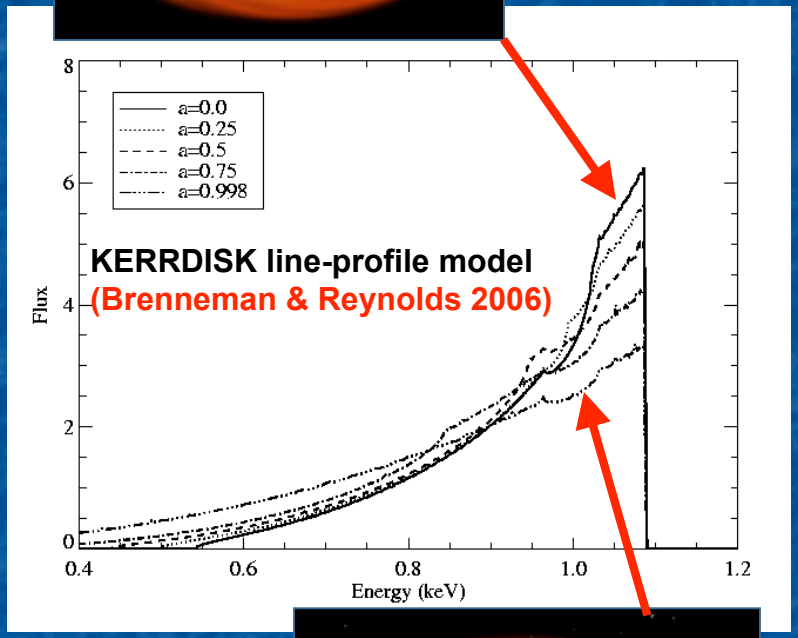


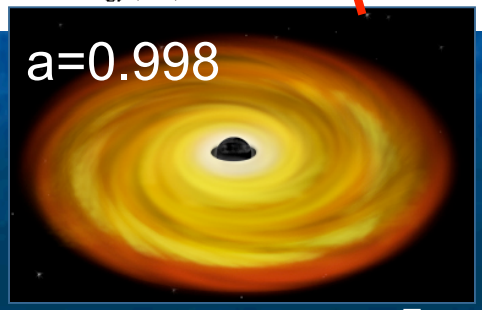
Broad iron lines and black hole spin









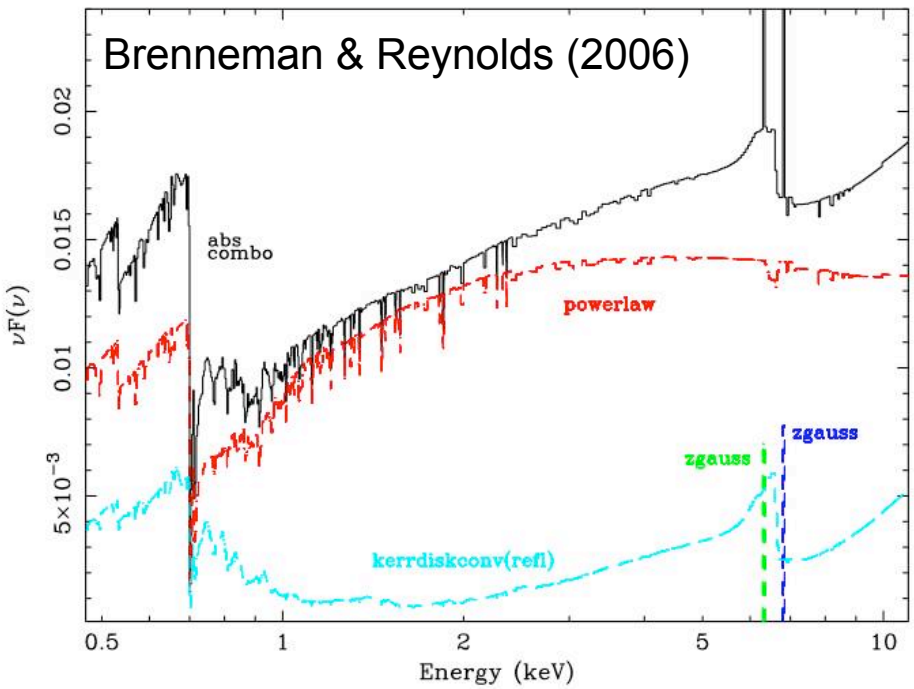


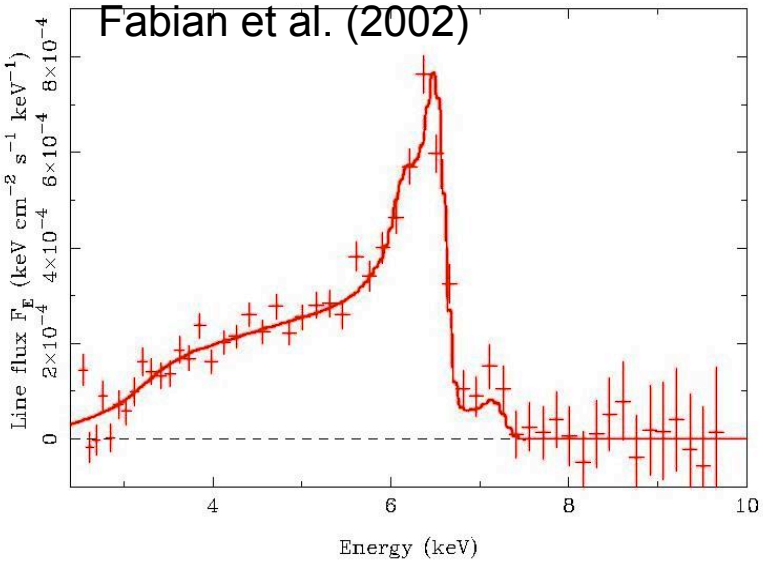
MCG-6-30-15

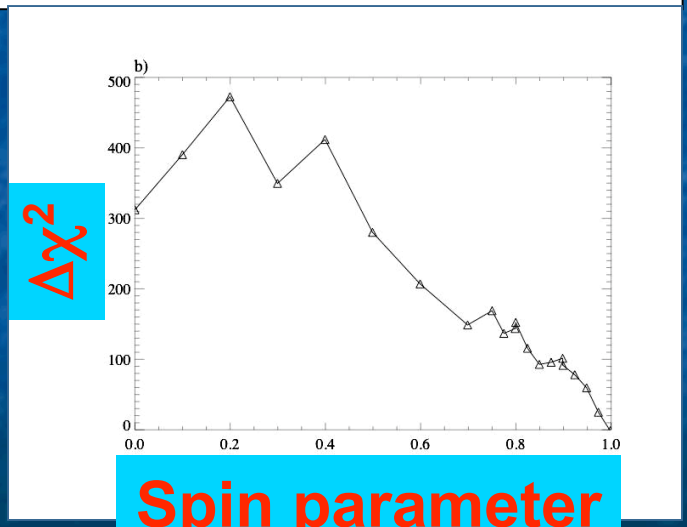
Strict Novikov-Thorne disk (ASCA DM-data) ⇒ a>0.94
(Dabrowski et al. 1997)

Emissivity truncated at ISCO (XMM data)⇒ a>0.987
(Brenneman & Reynolds 2006)

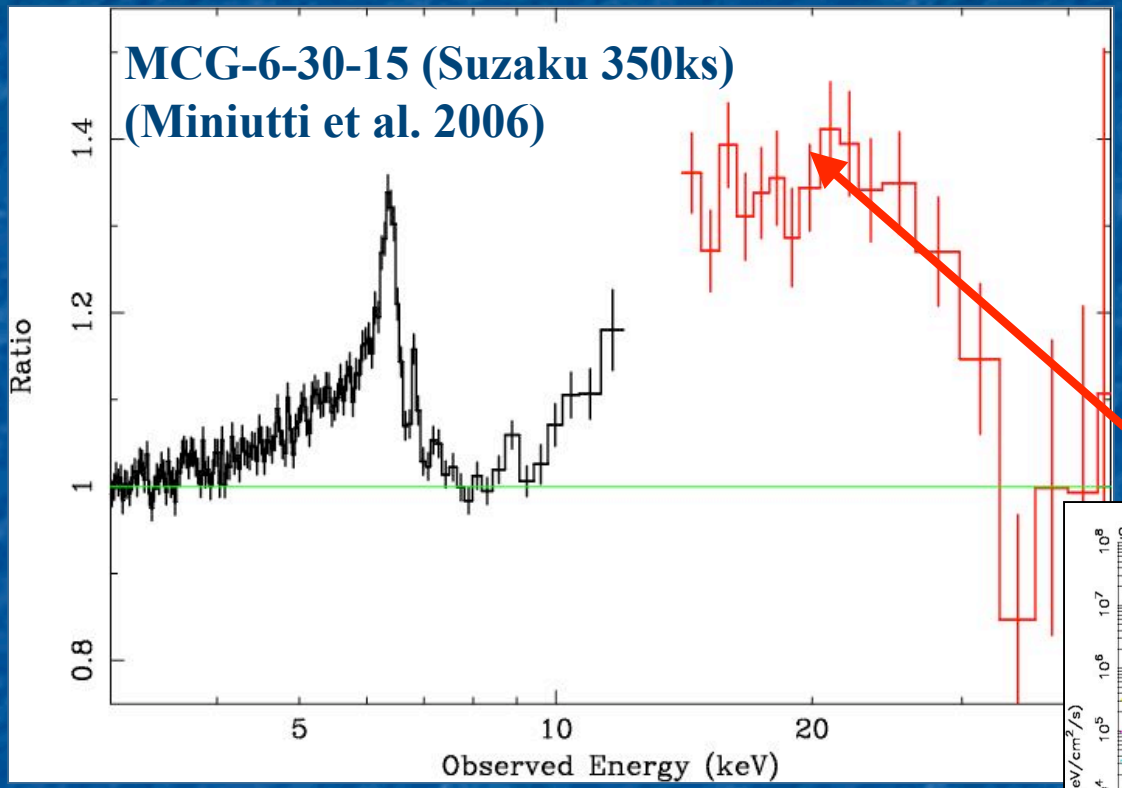
… including uncertain effects of ISCO emission ⇒ a>0.95
(Reynolds & Fabian 2008)

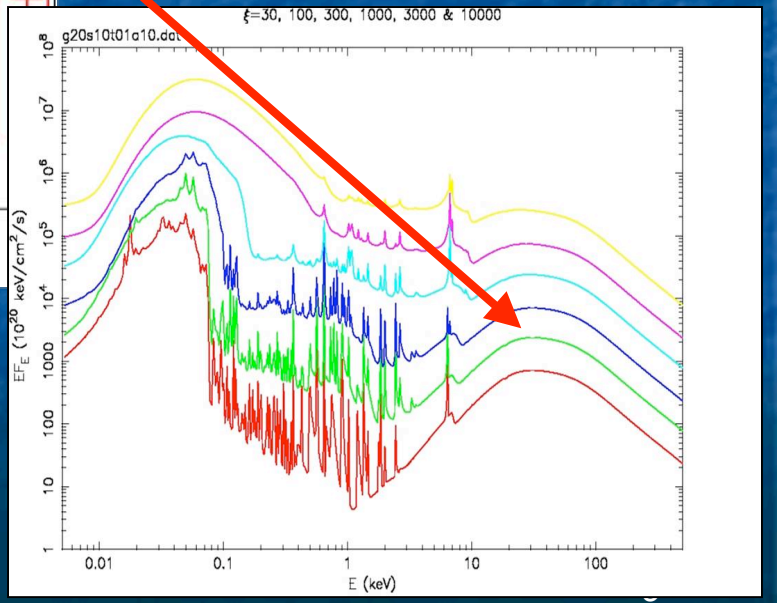






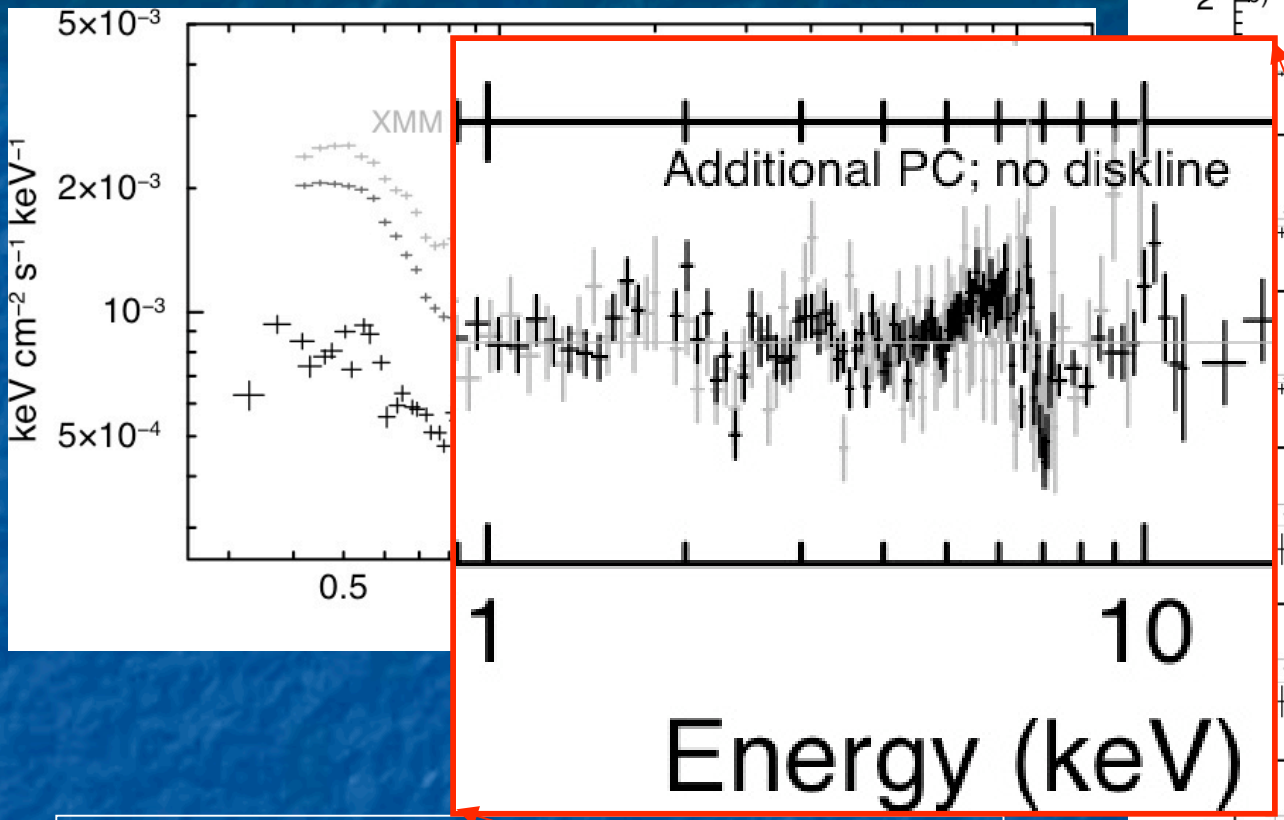
A : Confirming the disk-reflection paradigm

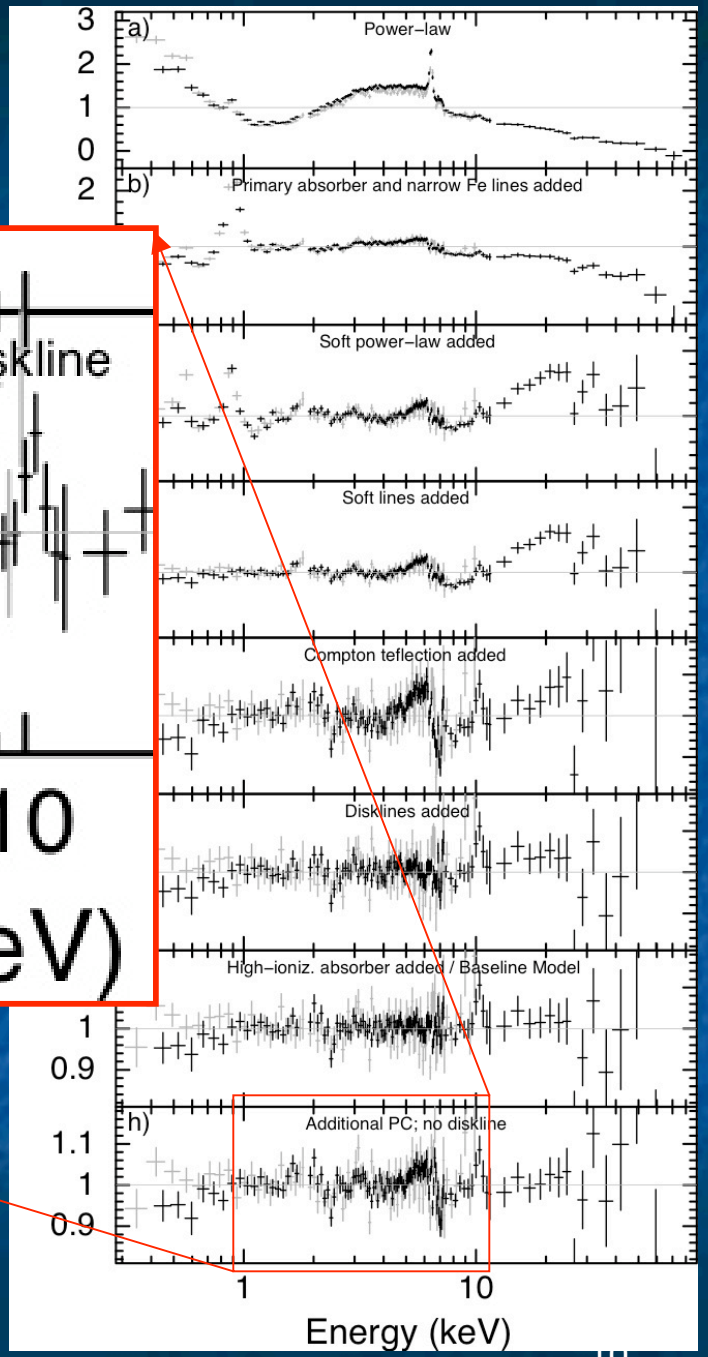




Broad-band coverage allows iron line and reflection “bump” to be observed… powerful constraint on alternative models

NGC 3516 (150ks)
(Markowitz et al. 2007)

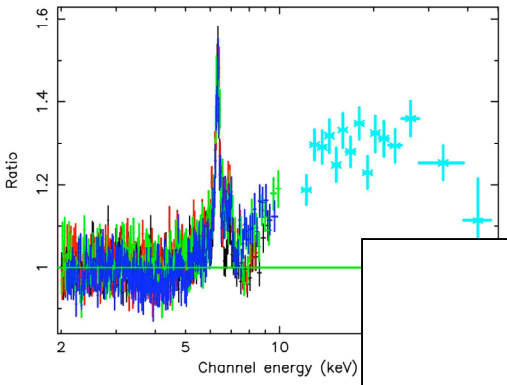


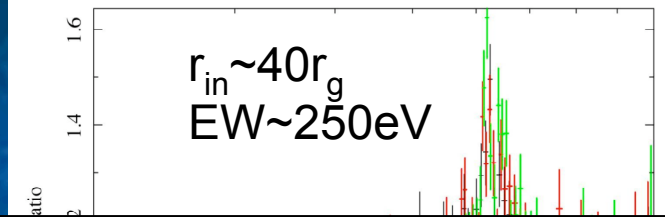


Broad iron line still discernable, despite heavy and complex absorption; $r_{in}<5.5r_g$

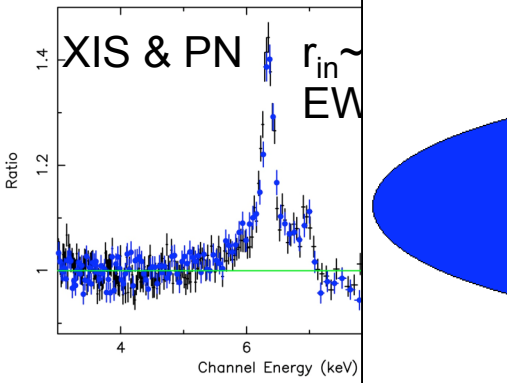
MCG-5-23-16 (100ks)
(Reeves et al. 2007)

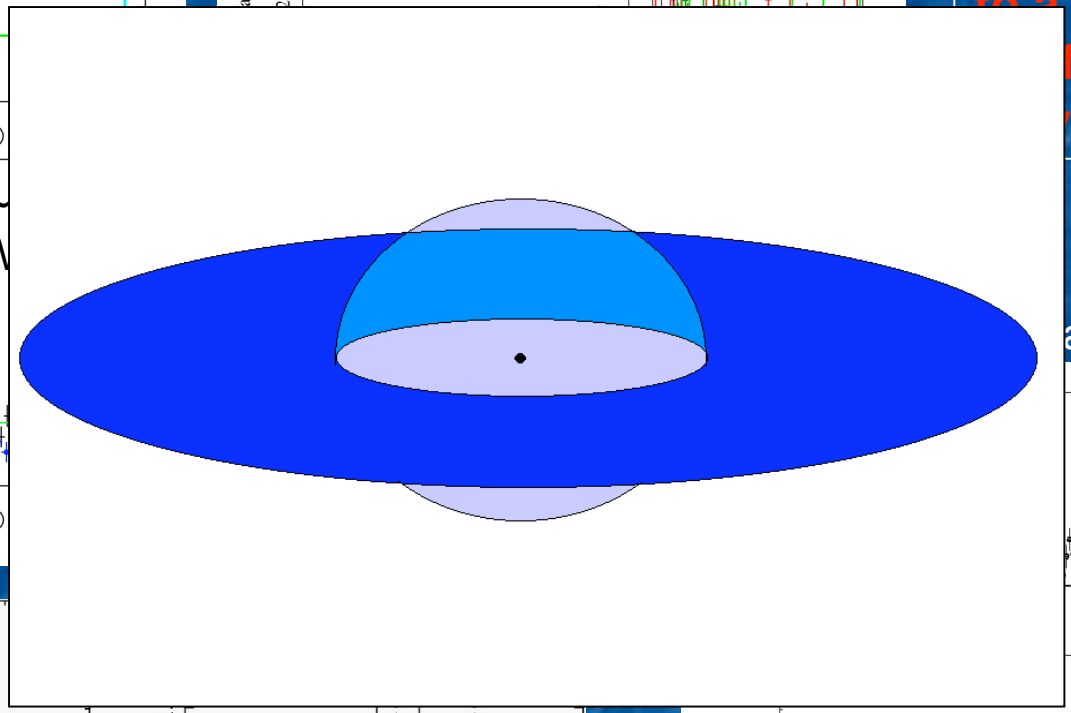
Mrk335 (151ks)
(Larsson et al. 2007)



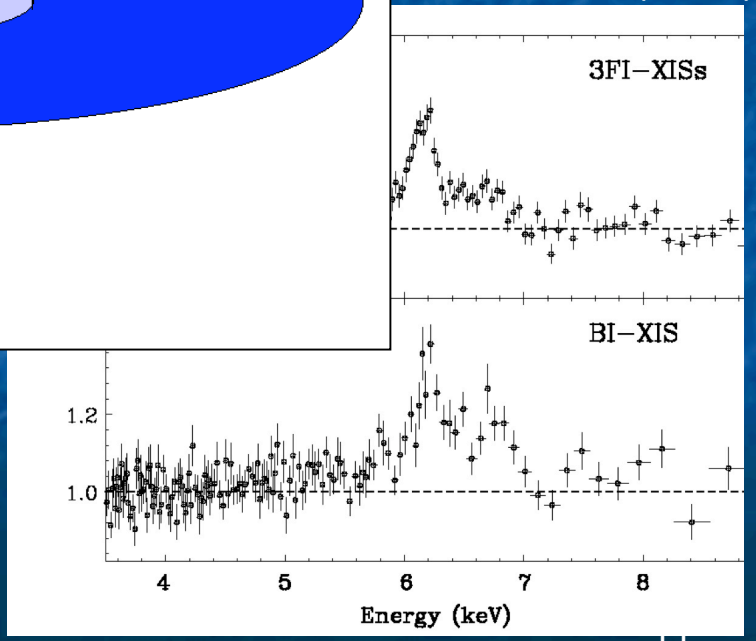


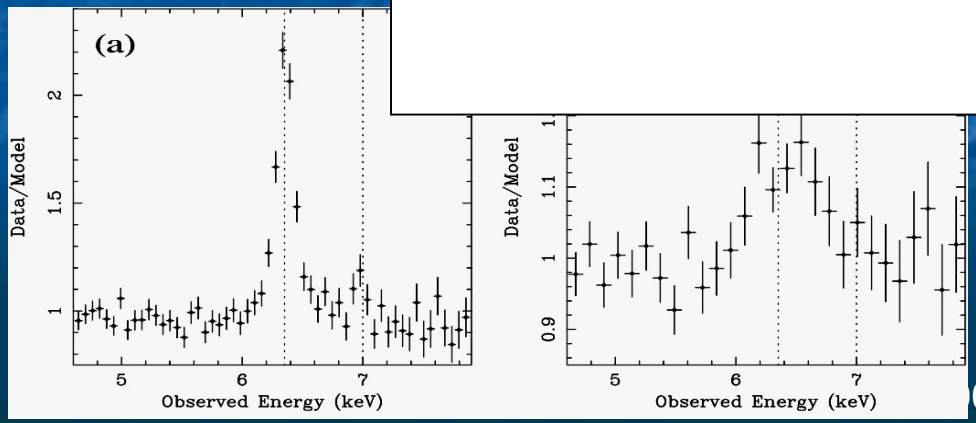
Many AGN seem to have truncated iron line emission regions… **transition to a radiatively-inefficient accretion flow (RIAF)?**





3C120 (160ks)
ataoka et al. (2007)





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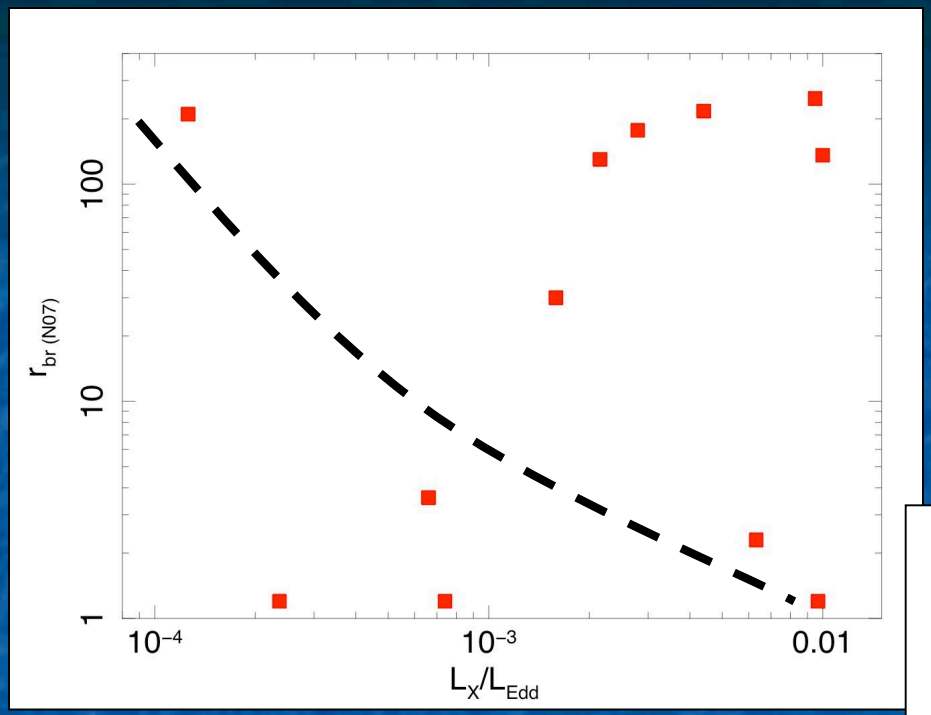
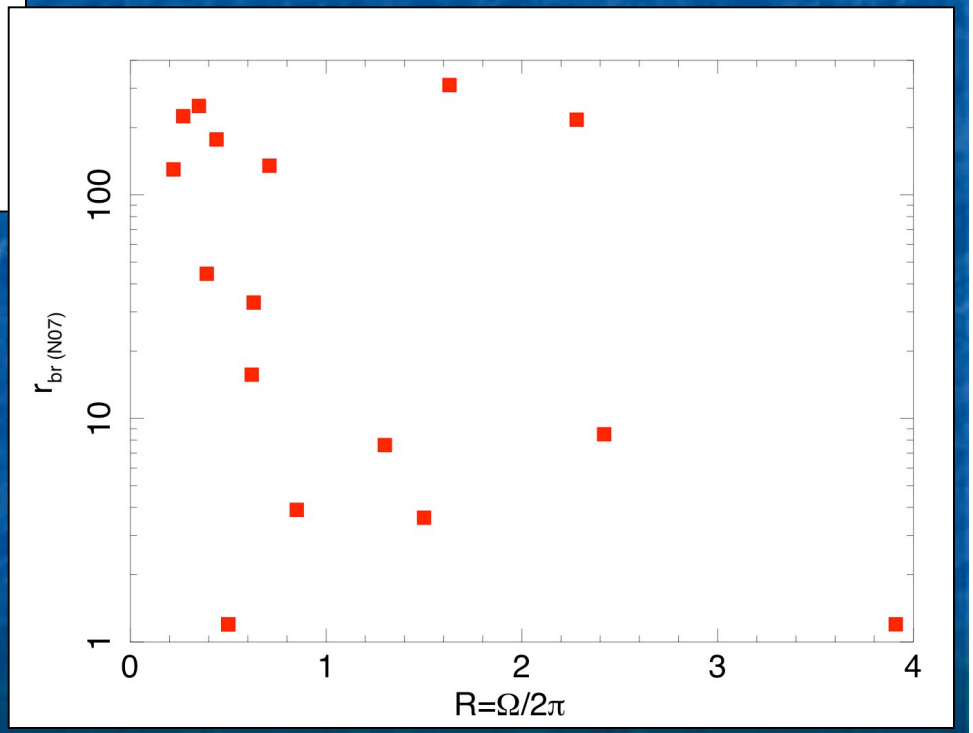


No clear correlation of size of reflecting disk with Eddington ratio… **contrary to predictions of RIAF-transition model**



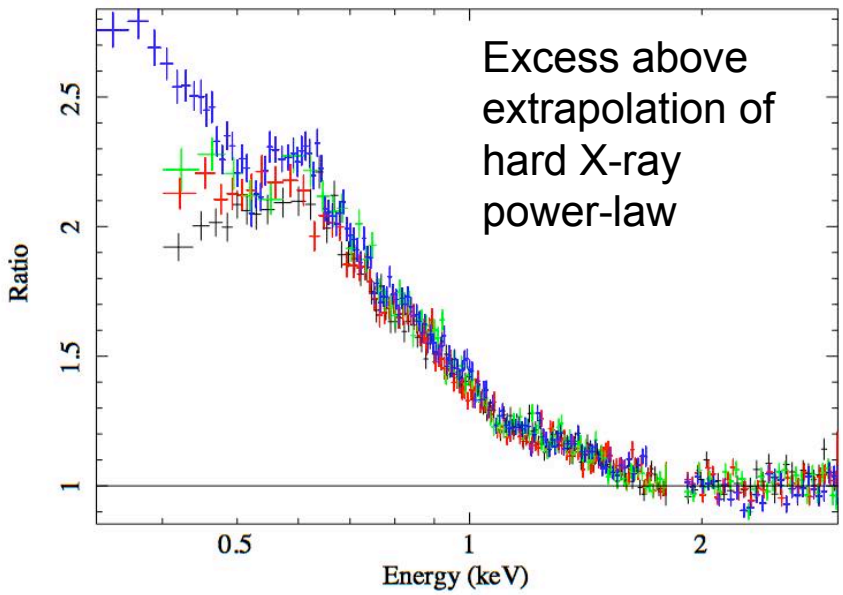
Large dispersions in apparent solid angle of reflecting disk as seen by X-ray source… possibly weak anti-correlation with size of disk. **Surprisingly large dispersion in geometry or anisotropy of X-ray emitting corona.**

Data from Nandra et al. (2007) XMM sample

B : The soft excess as a disk signature

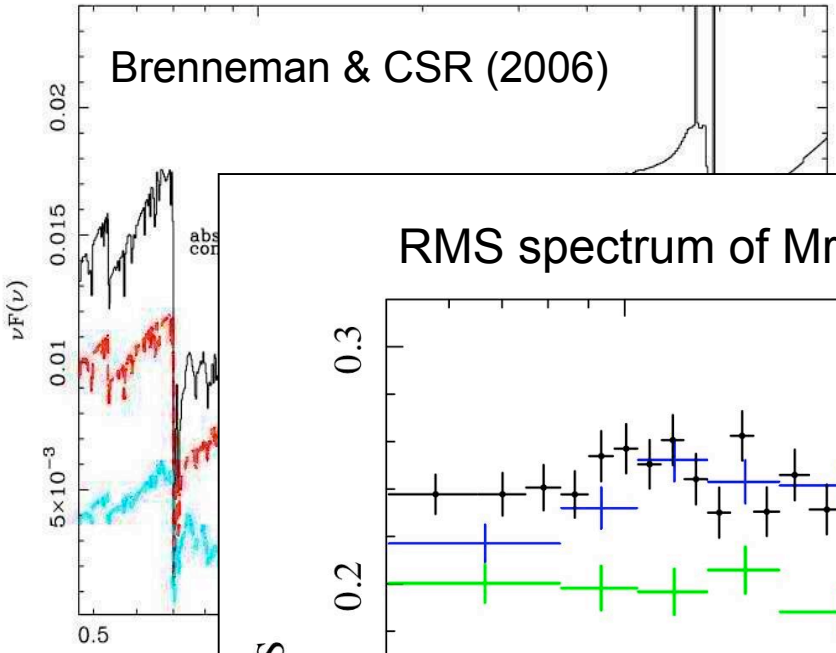
- Smooth soft X-ray excess seen in many AGN
- Supermassive accretion disk not hot enough to produce soft excess
  - Emission/reflection by ionized inner regions of accretion disk? (Fabian et al. (2005)
  - Ionized and velocity smeared absorption features (Middleton et al. 2005)

Mrk335 (Larsson et al. 2007)

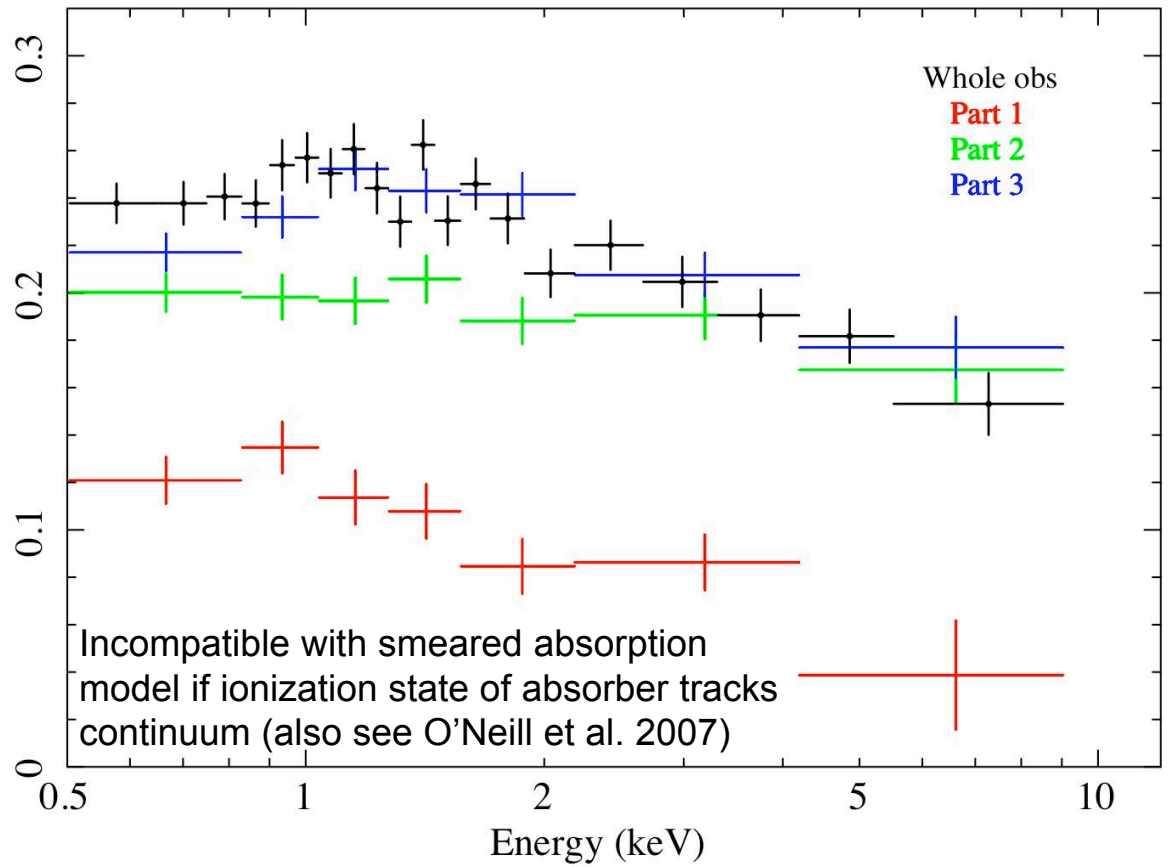


Also see O'Neill et al. (2007)

Brenneman & CSR (2006)



RMS spectrum of Mrk 335 (Larsson et al. 2007)



Incompatible with smeared absorption model if ionization state of absorber tracks continuum (also see O'Neill et al. 2007)

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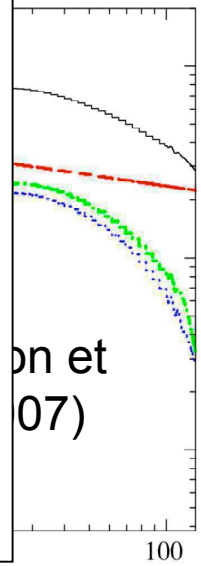

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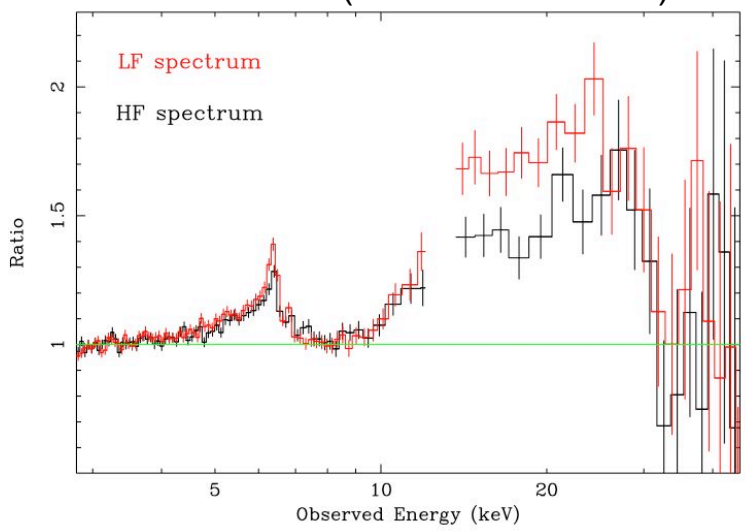
Energy (keV)

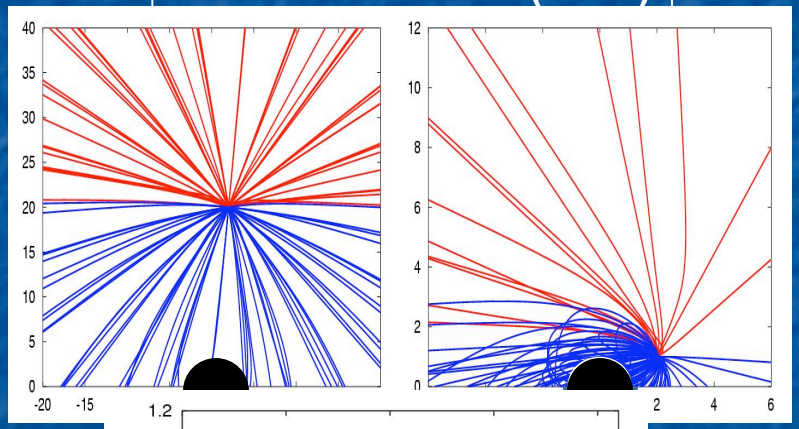
C: Variability of the disk reflection

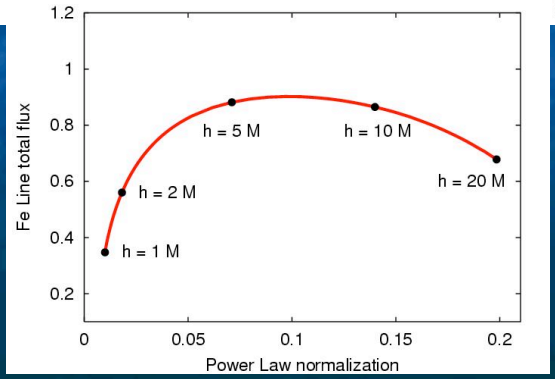
MCG-6-30-15 (Miniutti et al. 2007)

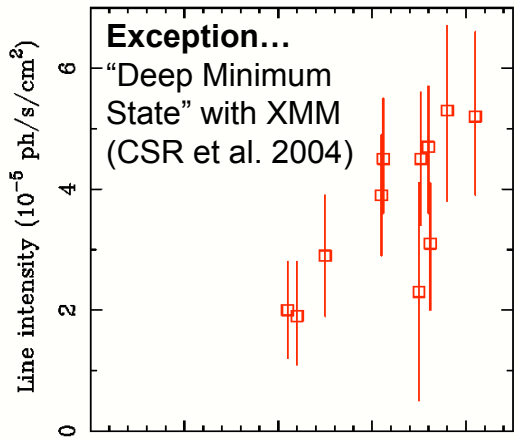


MCG-6-30-15 : Both iron line **and reflection** hump unresponsive to continuum changes… **contrary to naïve expectation**

Light-bending model
Miniutti & Fabian (2004)

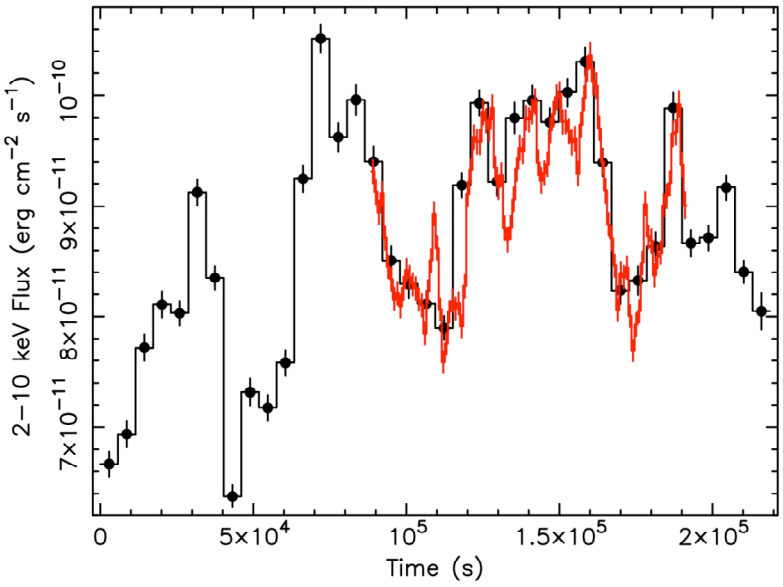






Phenomenon first noted in NGC5548 using ASCA+RXTE data by Chiang et al. (2000)

Suzaku 2007

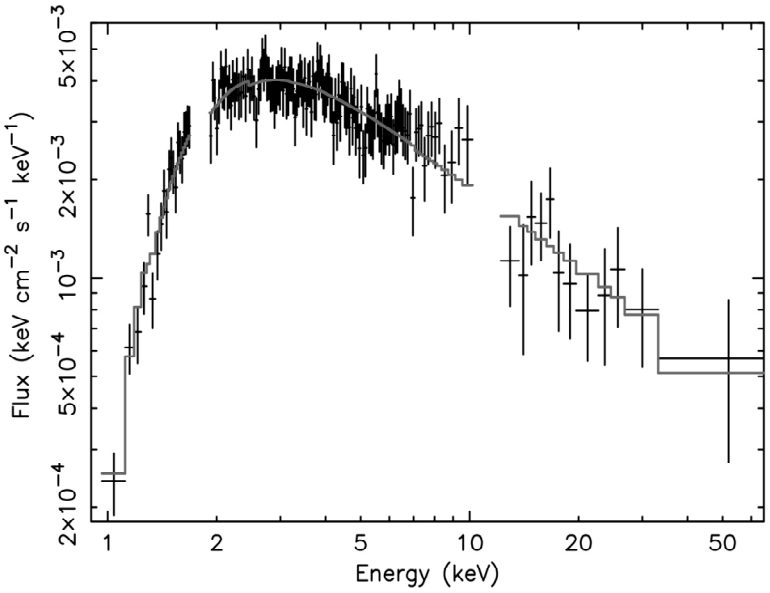


MCG-5-23-16: also see unresponsive iron line and reflection bump.

But, line emission region is too far from black hole to invoke light-bending arguments

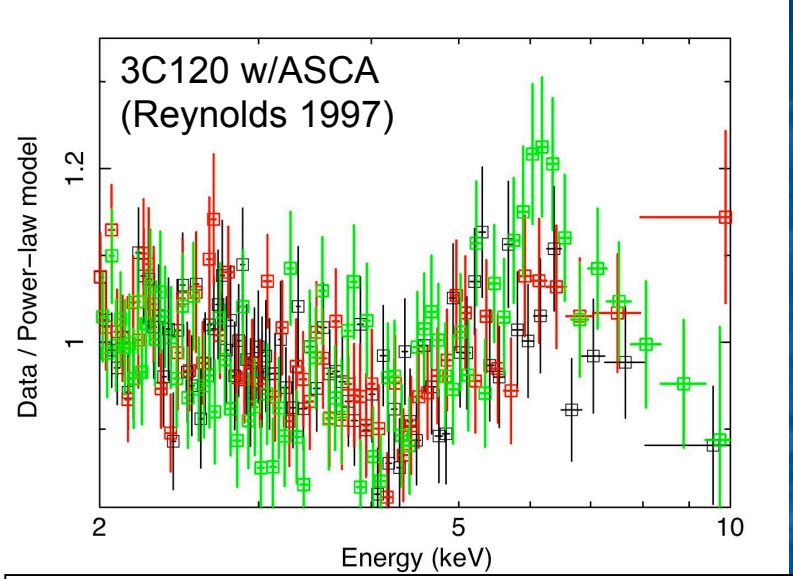
Continuum variability on timescales ~10^4s; light-crossing time of supposed truncation radius in thin-disk.

Suggests a compact X-ray source close to black hole with no associated reflection (also see Brenneman et al. 2007).



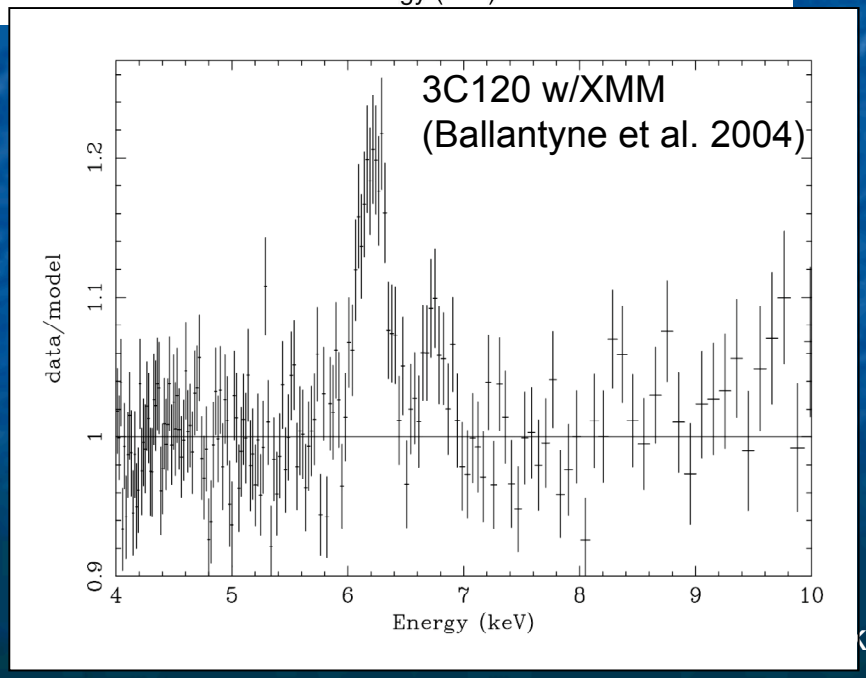
Reeves et al. (2007)

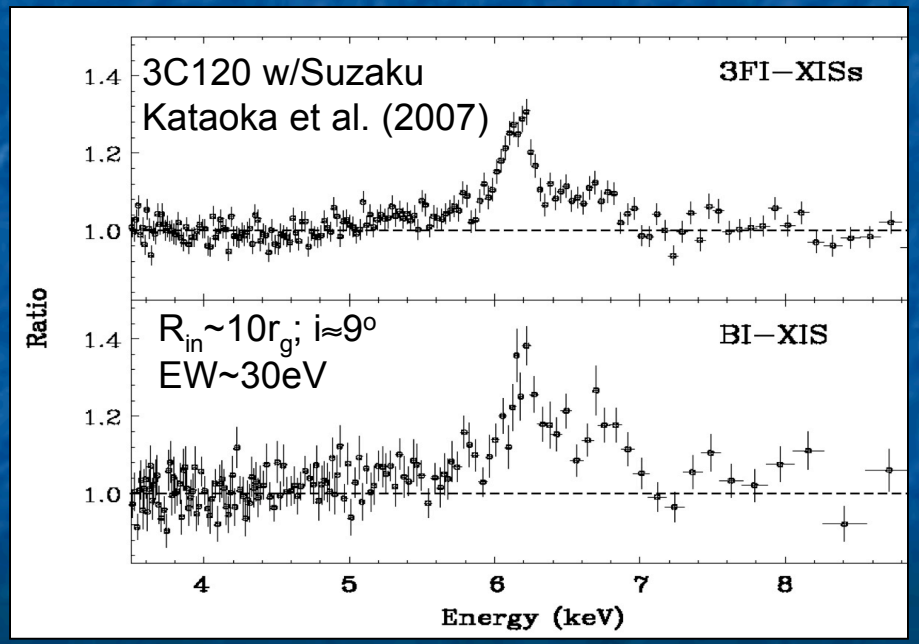
D : Radio-loud AGN



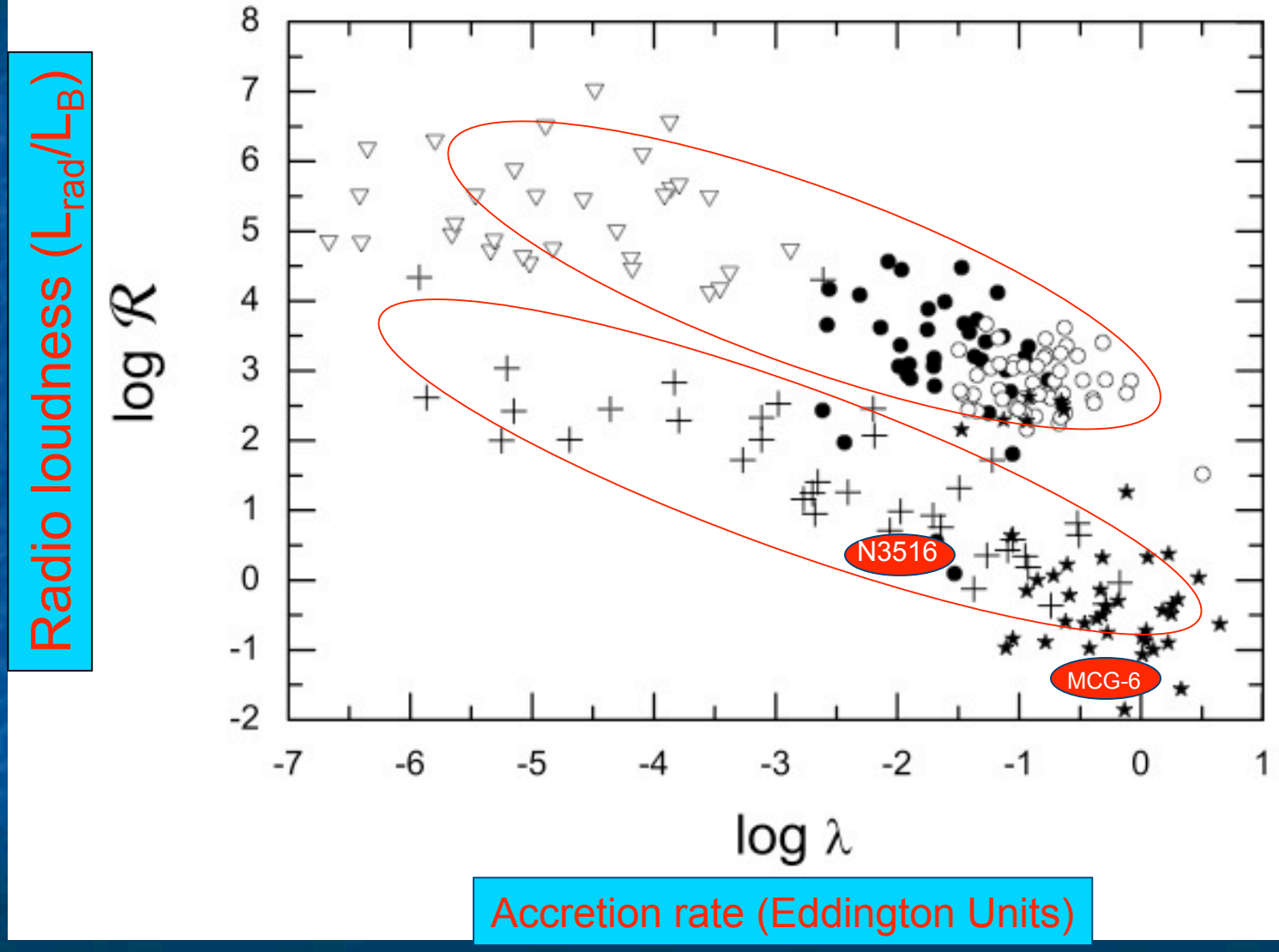
3C120 : Strong evidence for iron line width/profile changes on timescales of years.

3C120 Suzaku-era iron line rather similar parameters to many (radio-quiet) Seyferts (e.g., MCG-5-23-16)



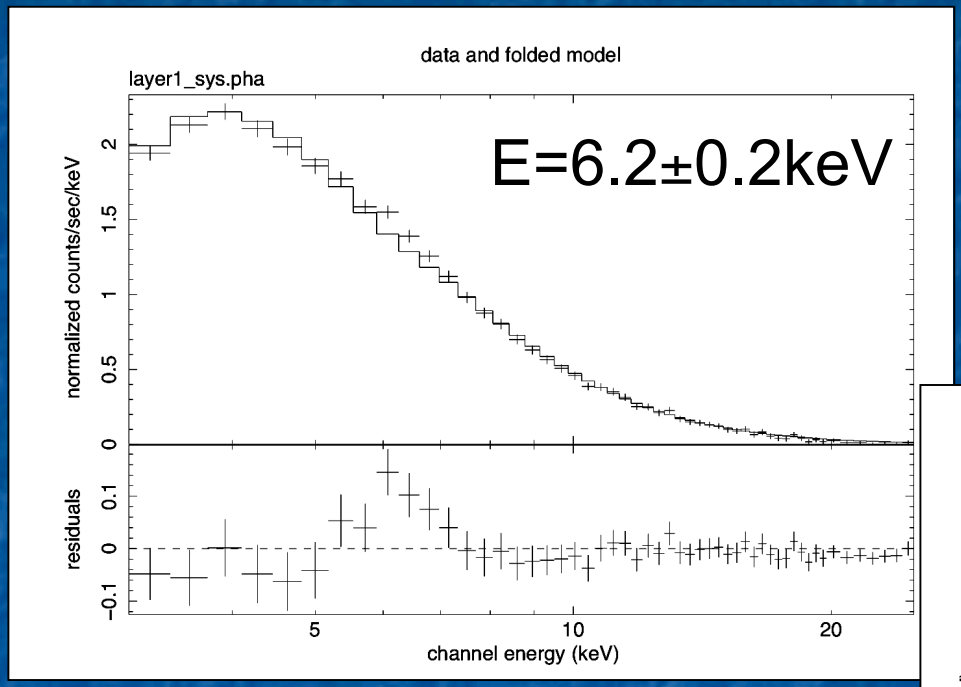


The radio-quiet/radio-loud dichotomy in AGN

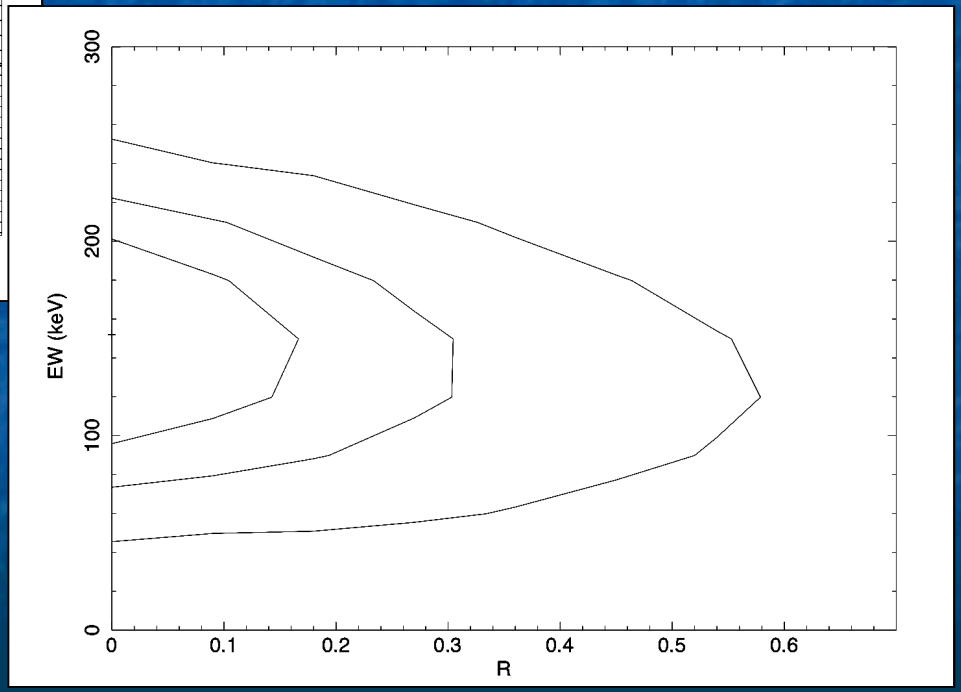


Sikora et al. (2007)

Another mystery…
Iron lines without reflection!



Mrk 279 with RXTE/PCA
(B. Mattson)



In a minority of sources… may be something going on beyond X-ray reflection/fluorescence… particle-induced emission features? (e.g., Cerenkov line-like radiation; Liu et al. 2006)

Conclusions

- Broad-band pass and improved iron-band resolution of Suzaku proving invaluable for studies of relativistic reflection spectra
- Open questions
  - What determines size of X-ray reflection region or the strength of the reflection? [Truncated thin disk? X-ray source geometry?]
  - Confirming the nature of the soft excess…
  - How are we to understand the temporal behaviour of the reflection features? [Changes in X-ray source geometry? Special or general relativistic effects?]
  - What determines radio-quiet/radio-loud nature? [Accretion rate and/or black hole spin? Is magnetic flux a 3rd parameter?]
- Are now addressing issues of fundamental interest…