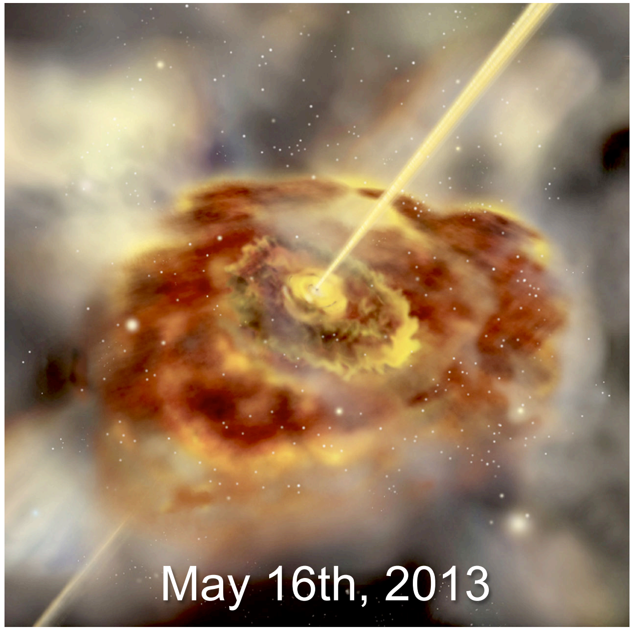
# Probing the evolution of Active Galactic Nuclei using the Fe Kα line


***Claudio Ricci***

***Kyoto University***



*Y. Ueda (Kyoto Univ., Japan)*

*S. Paltani (ISDC, Switzerland)*

*H. Awaki (Ehime Univ. Japan)*

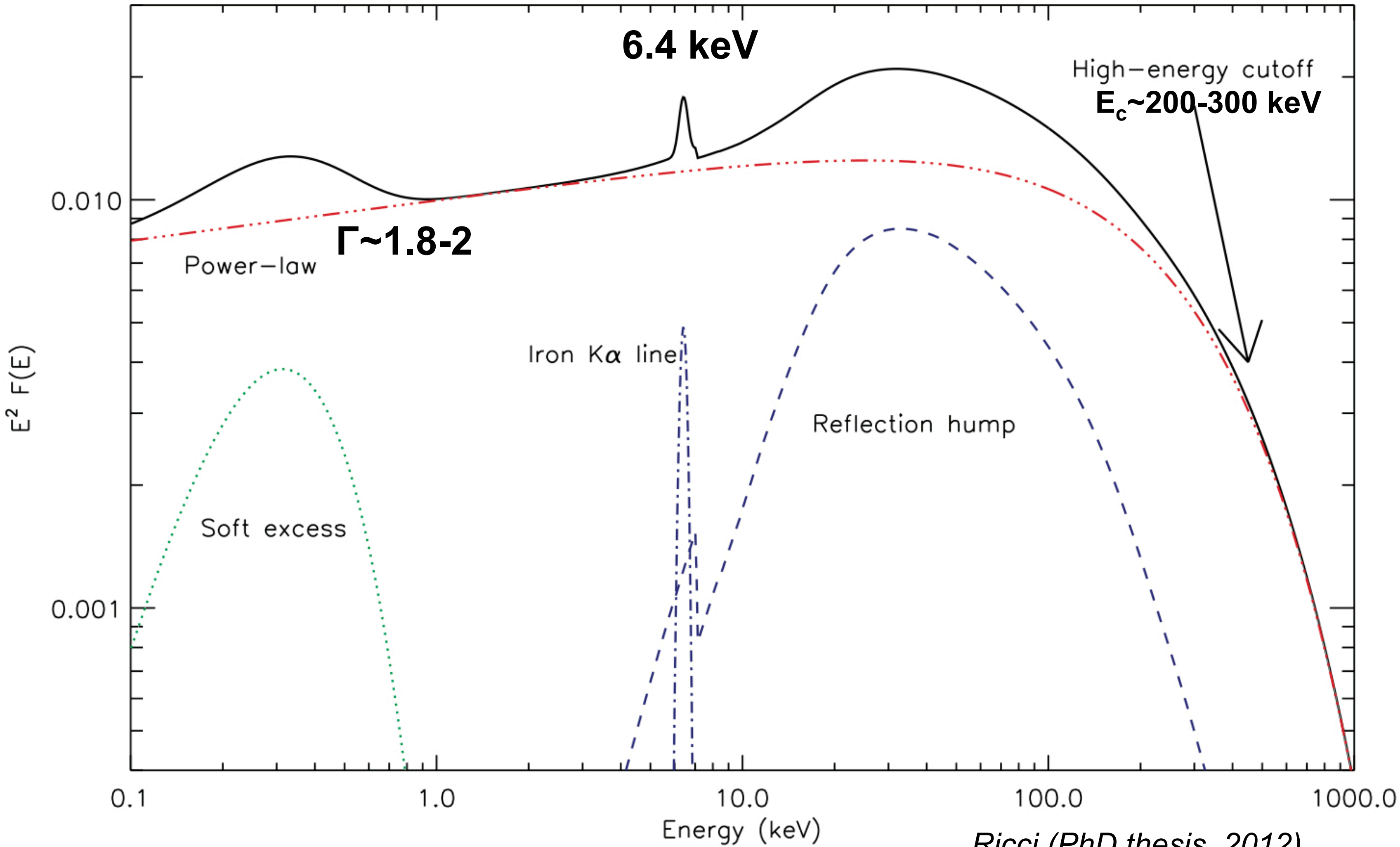
*M. Brightman (MPE, Germany)*

*P. O. Petrucci (UJF, France)*

*K. Ichikawa (Kyoto Univ., Japan)*

# The iron Kα line

*X-ray spectrum of unabsorbed AGN*




*Ricci (PhD thesis, 2012)*

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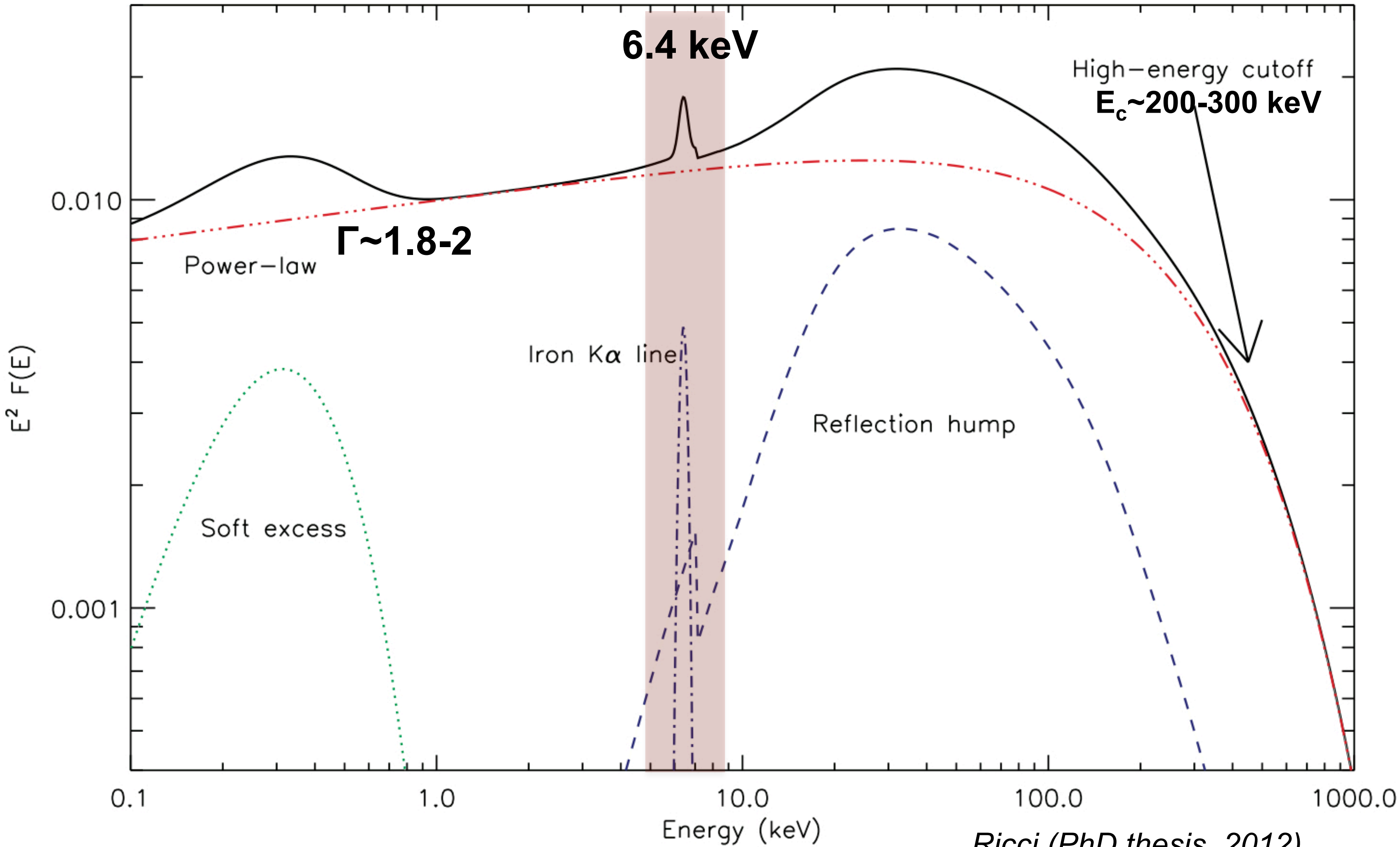
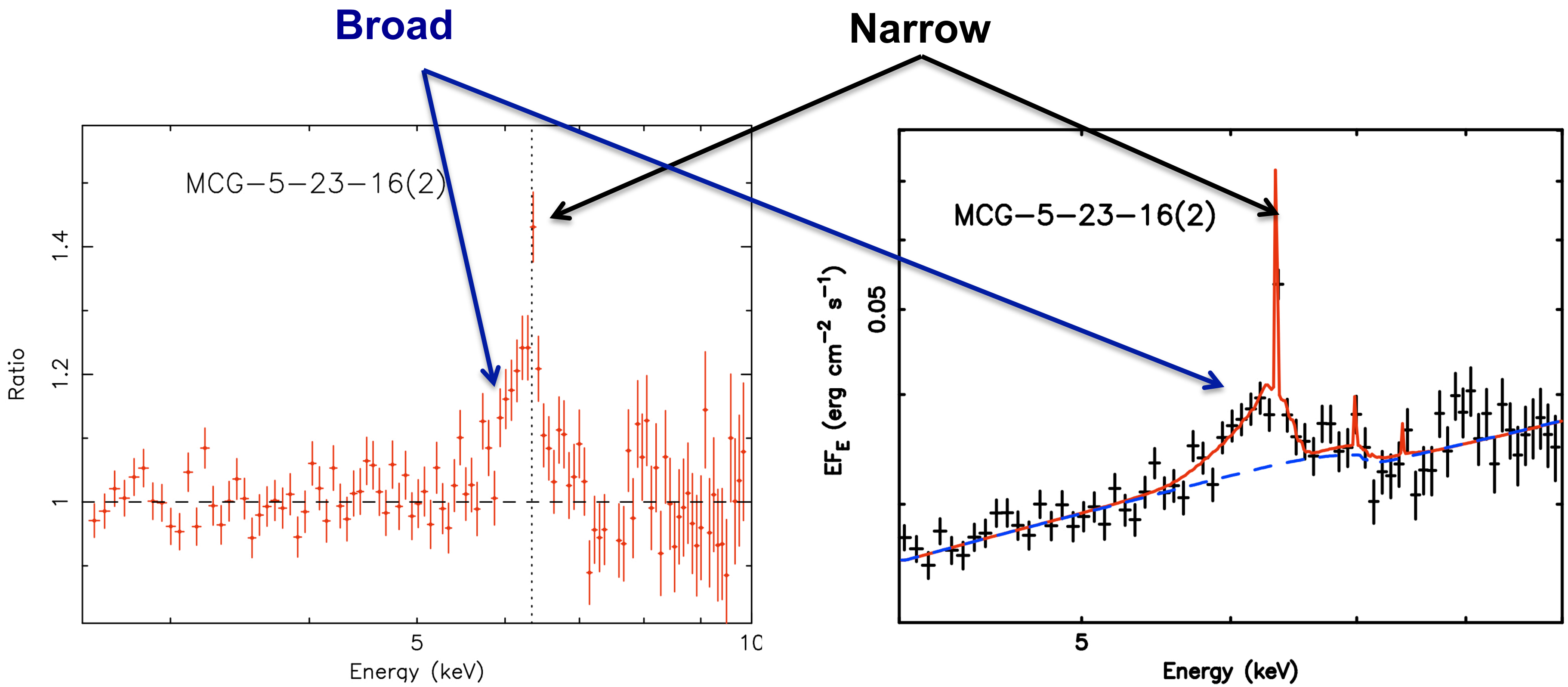



*Ricci (PhD thesis, 2012)*

# The iron Kα line

**Iron Kα line: 2 components with different origins**



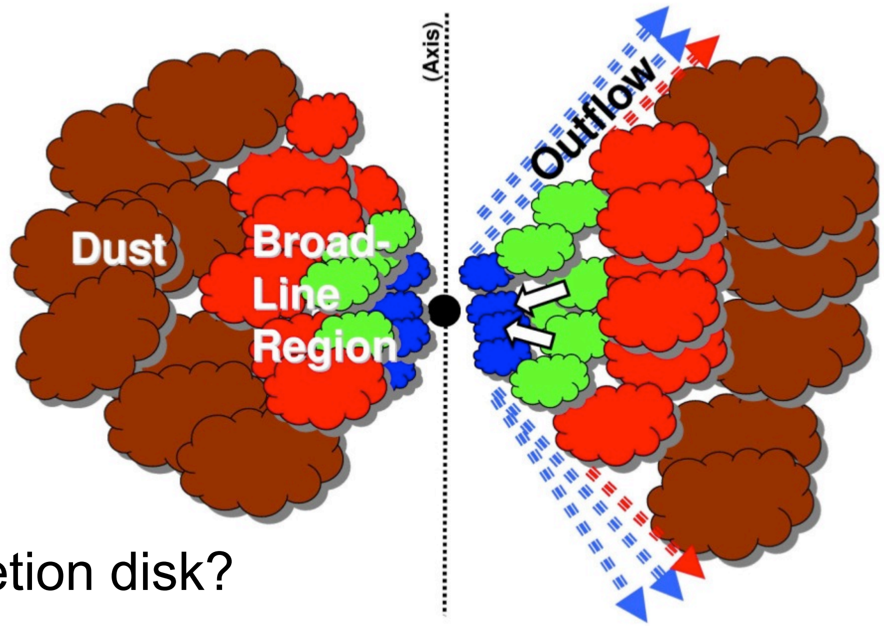

*Nandra et al. (2007)*

# The narrow core of the iron Kα line

**Narrow core of the iron Kα line is a tracer of dense material around the central engine**

Where is the bulk of the iron Kα line emission produced?

- BLR?
- Outer part of the accretion disk?
- **Molecular torus?**




*Gaskell, 2011*

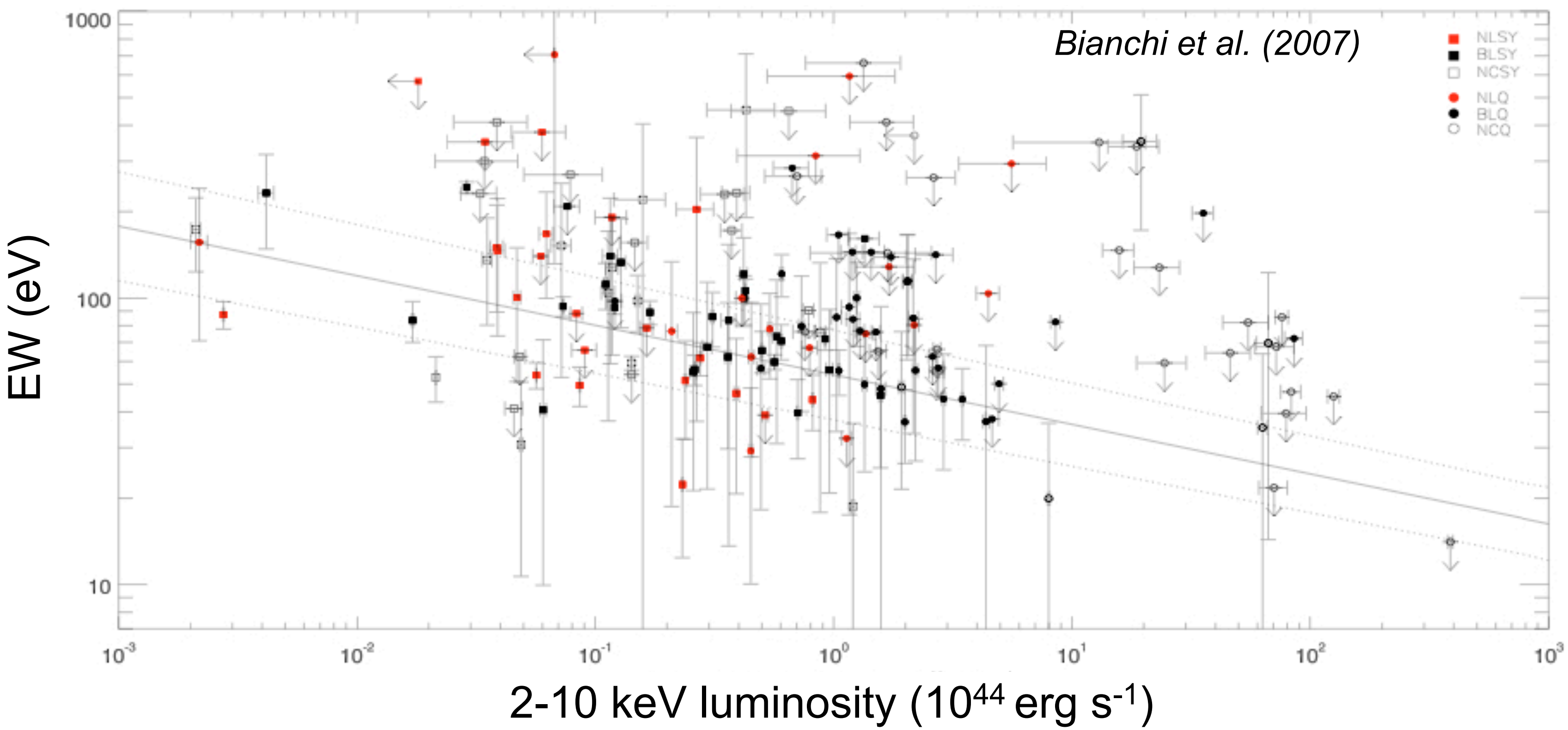
**From Chandra/HEG average FWHM → $r_{K\alpha}$~3*$R_{BLR}$ *(Shu et al. 2012)***

# The X-ray Baldwin effect

**Decrease of the EW of the iron Kα line with the luminosity in type-I AGN**
**(and the Eddington ratio $\lambda_{Edd}$)**

*Iwasawa & Taniguchi (1993)*

$$\log(EW) = (1.73 \pm 0.03) - (0.17 \pm 0.03)\log(L_{X\,44})$$



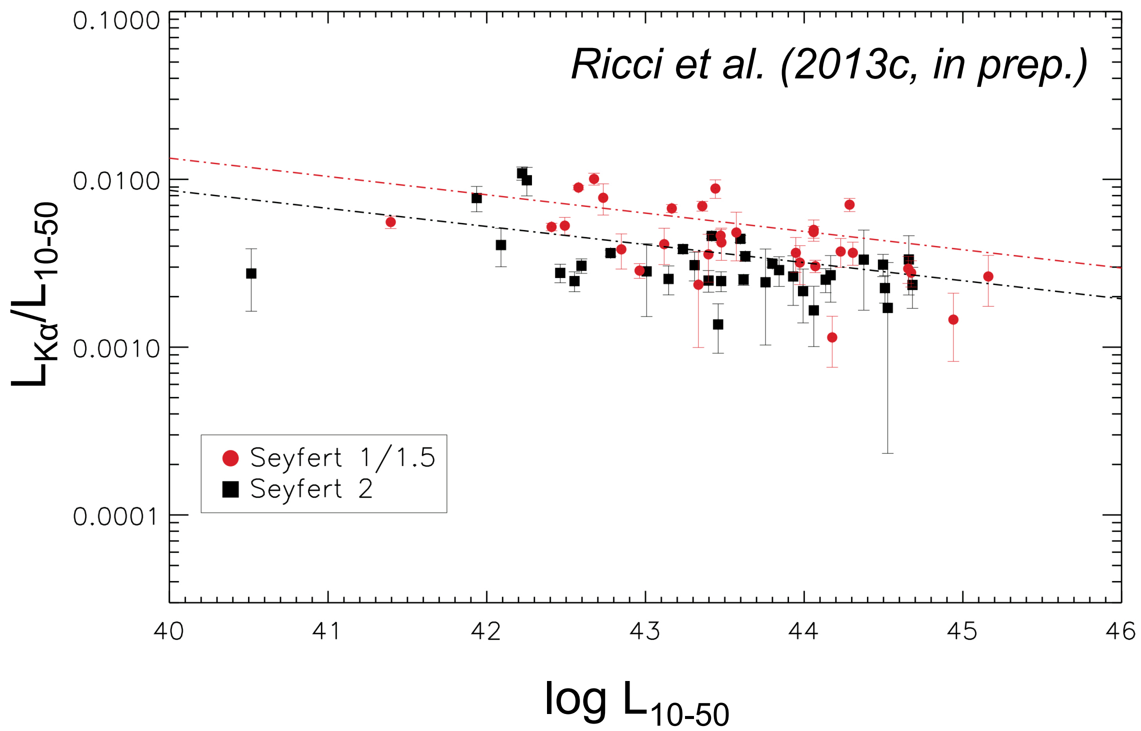
# The X-ray Baldwin effect

**Detection of the X-ray Baldwin effect in type-II AGN using a *Suzaku* sample of 80 AGN**

*Corrected for absorption using physical AGN models (photoelectric abs.+ Compton scatter)*

Type-II AGN have the same slope as type-I

**The mechanism at work is the same**



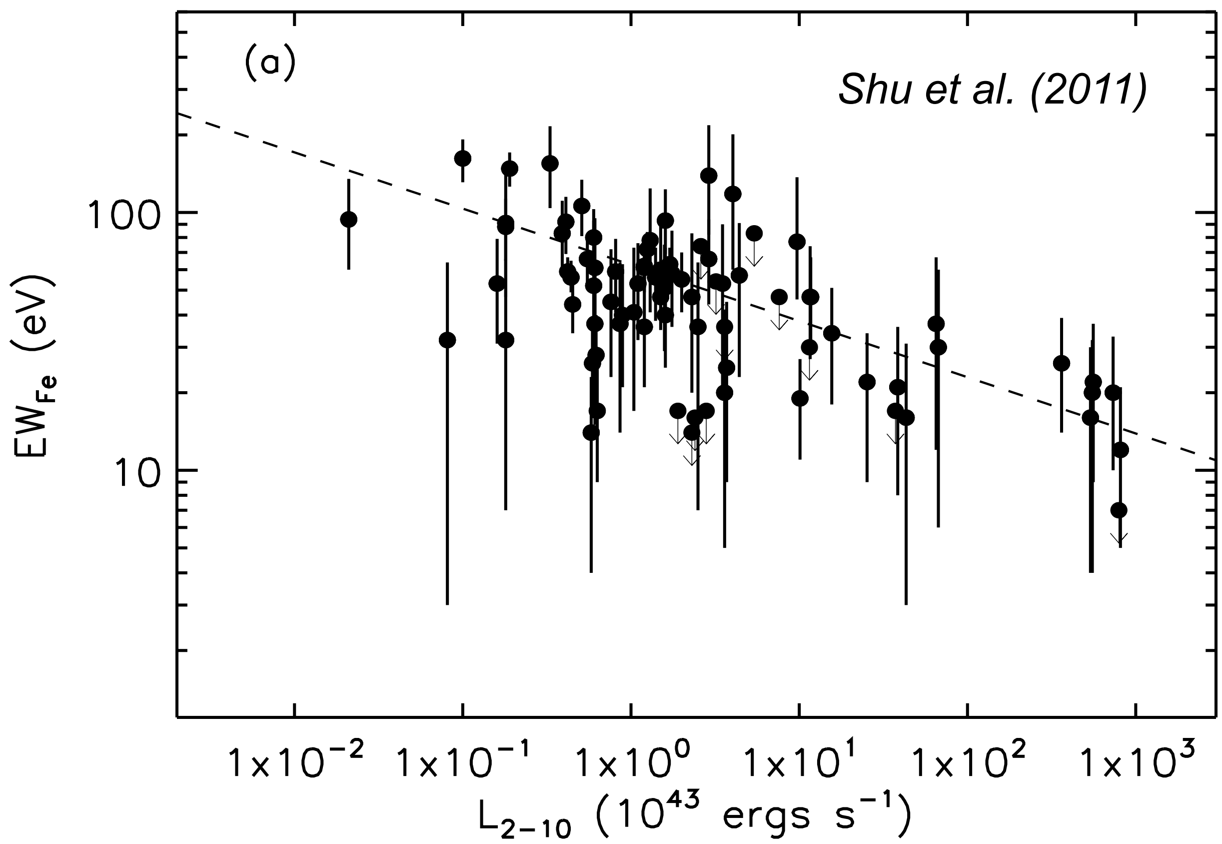
# The X-ray Baldwin effect

**Possible explanations**

- **Due to variation of the relativistically broadened component?** ***(Nandra et al. 1997)***
- Related to continuum variability? *(Jiang et al. 2006)*
- Due to the dependence of the continuum with $\lambda_{Edd}$? *(Ricci et al. 2013b)*
- Luminosity-dependent unification? *(Page et al. 2004, Ricci et al. 2013a)*

# The X-ray Baldwin effect

High quality *XMM-Newton*/EPIC and *Chandra*/HEG data confirmed that X-ray Baldwin effect is due to the narrow component



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- Luminosity-dependent unification? *(Page et al. 2004, Ricci et al. 2013a)*

# The X-ray Baldwin effect

Most studies use all available observations for all sources of the sample

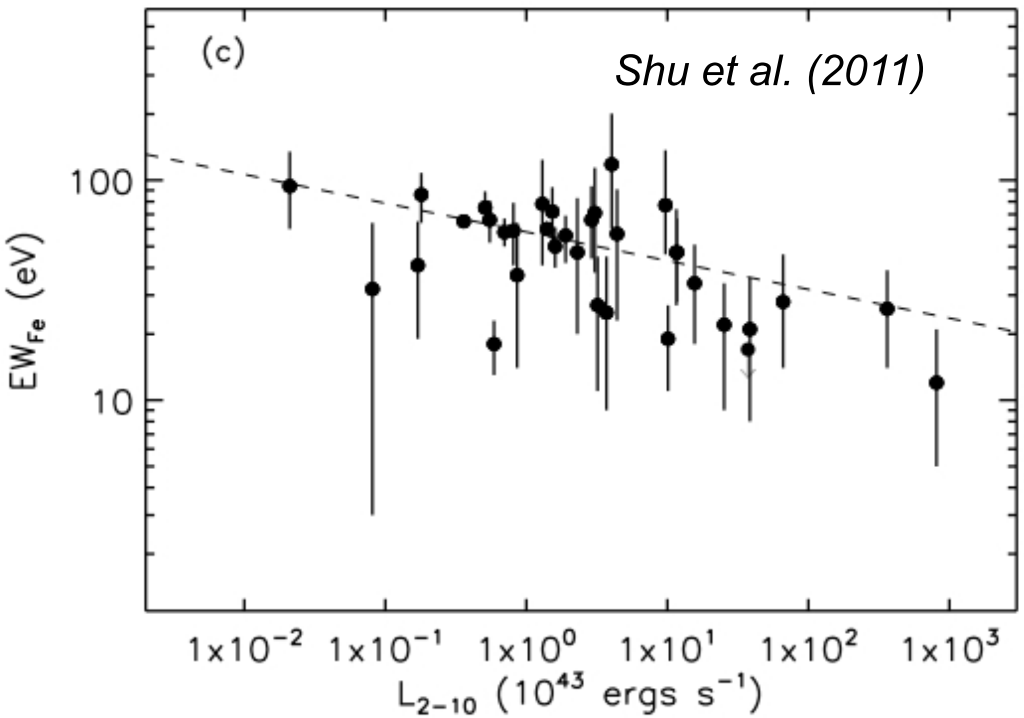
**Fit per observation:** $\log(EW) \propto -(0.22 \pm 0.03)\log(L_{X\,44})$

The correlation is significantly attenuated when the values are averaged over different observations
*(Shu et al. 2010, 2012)*

**Fit per source:**

$\log(EW) \propto -(0.13 \pm 0.04)\log(L_{X\,44})$

Monte Carlo simulations showed that variability fails to explain the whole trend



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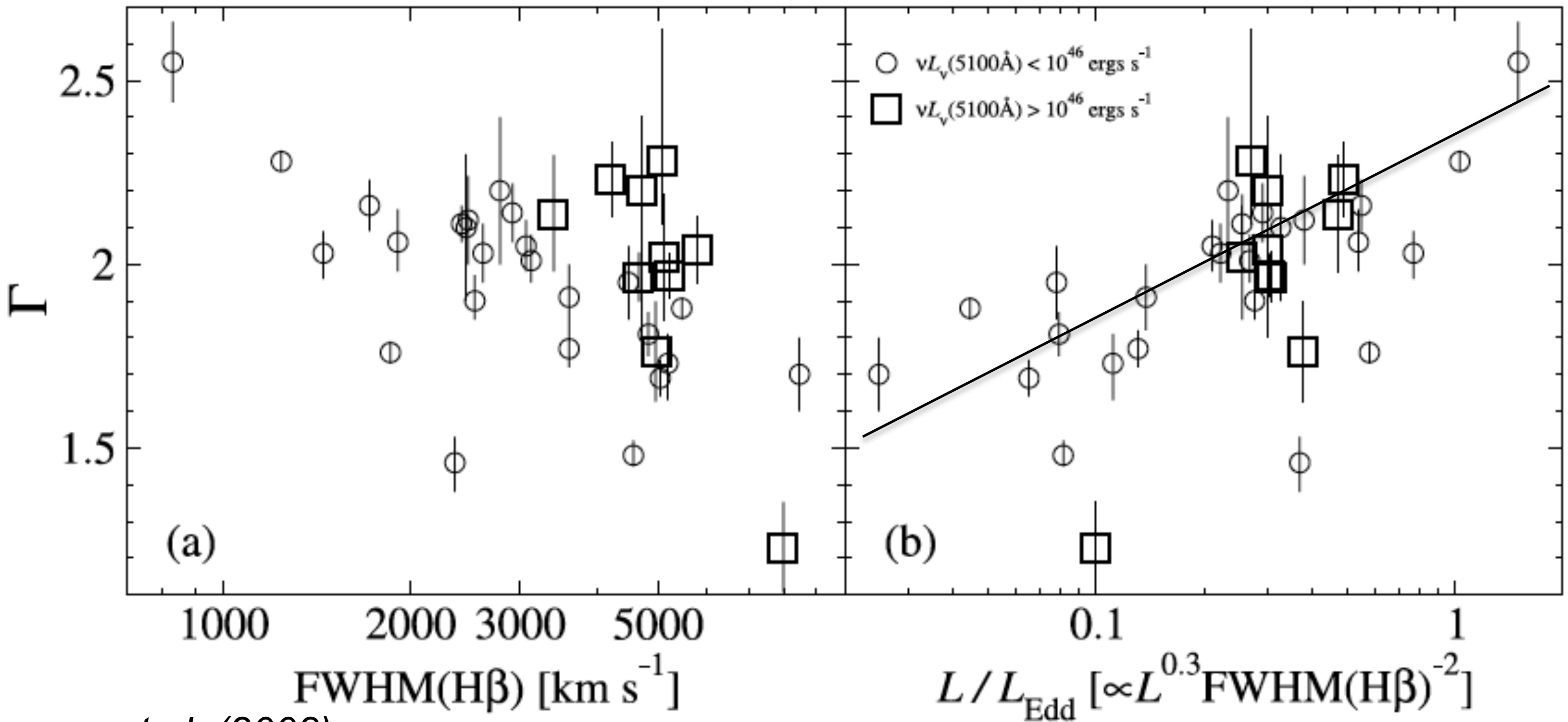
- Luminosity-dependent unification? *(Page et al. 2004, Ricci et al. 2013a)*

# Simulating the X-ray Baldwin effect

The photon index increases with the Eddington ratio $\Gamma \propto 0.31 \log \lambda_{Edd}$

For increasing values of the Eddington ratio the number of photons in the iron region decreases




$\lambda_{Edd}$

*Shemmer et al. (2008)*

# Physical torus models

**Recently several works have carried out montecarlo simulations to understand the contribution of the torus to the X-ray spectrum**

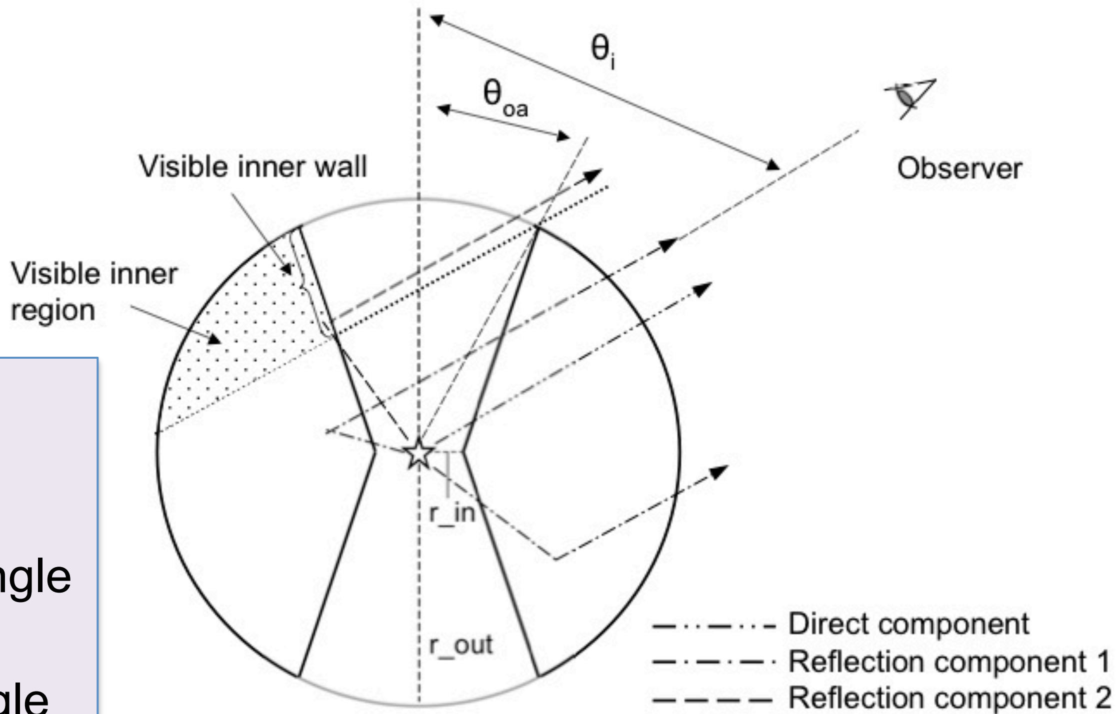
→ Murphy & Yaqoob (2009)

→ Brightman & Nandra (2011)

→ Ikeda et al. (2009)

**Parameters**

| | |
|---|---|
| $N_H$ | Eq. column density |
| $\theta_i$ | Observer's inclination angle |
| $\theta_{oa} = \pi/2 - \sigma$ | Opening angle |



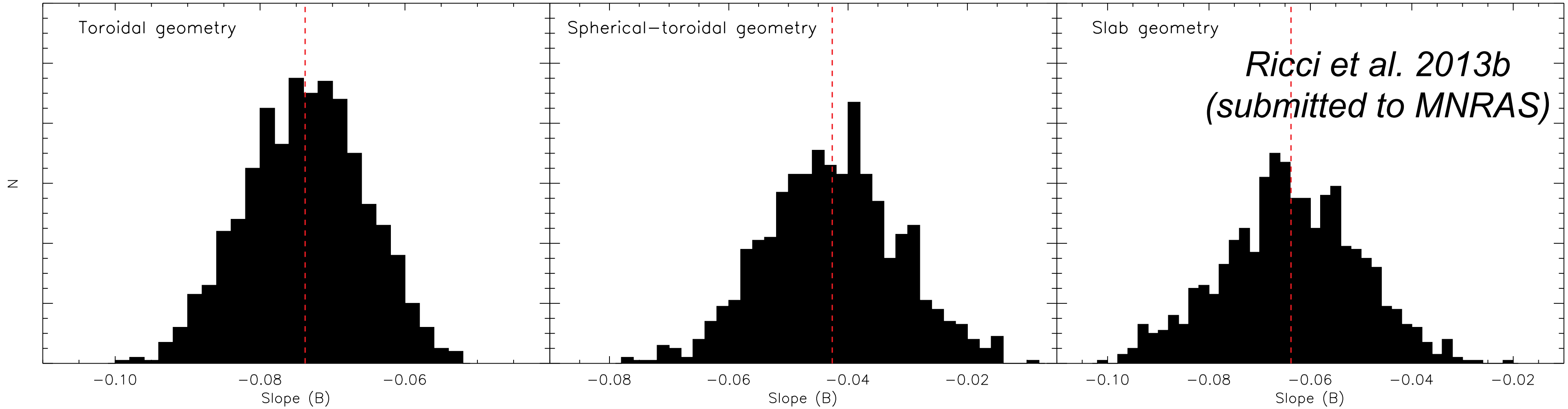

*Ikeda et al. (2009)*

# The X-ray Baldwin effect

We simulated the spectra of unabsorbed AGN populations using three different geometries for the reflecting material

→

**Slopes obtained not steep enough**




Only using a steeper dependence of Γ on $\lambda_{Edd}$ we obtained slopes consistent with the observed value → $\Gamma \propto 0.58 \log \lambda_{Edd}$ *(Risaliti et al. 2009, Jin et al. 2012)*

# The X-ray Baldwin effect

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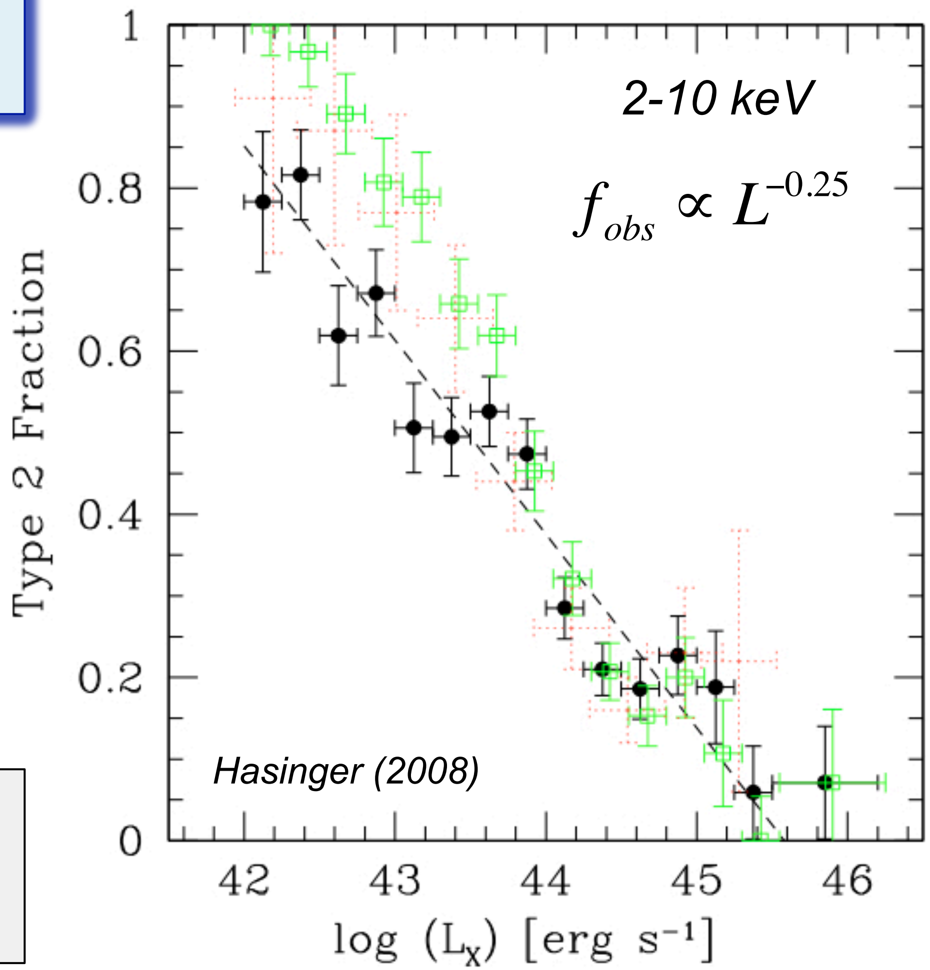
- Related to continuum variability? *(Jiang et al. 2006)*
- Due to the dependence of the continuum with $\lambda_{Edd}$? *(Ricci et al. 2013b)*
- **Luminosity-dependent unification?** ***(Page et al. 2004, Ricci et al. 2013a)***

# Luminosity-dependent unification

**The fraction of absorbed AGN ($f_{obs}$) decreases with increasing luminosities**

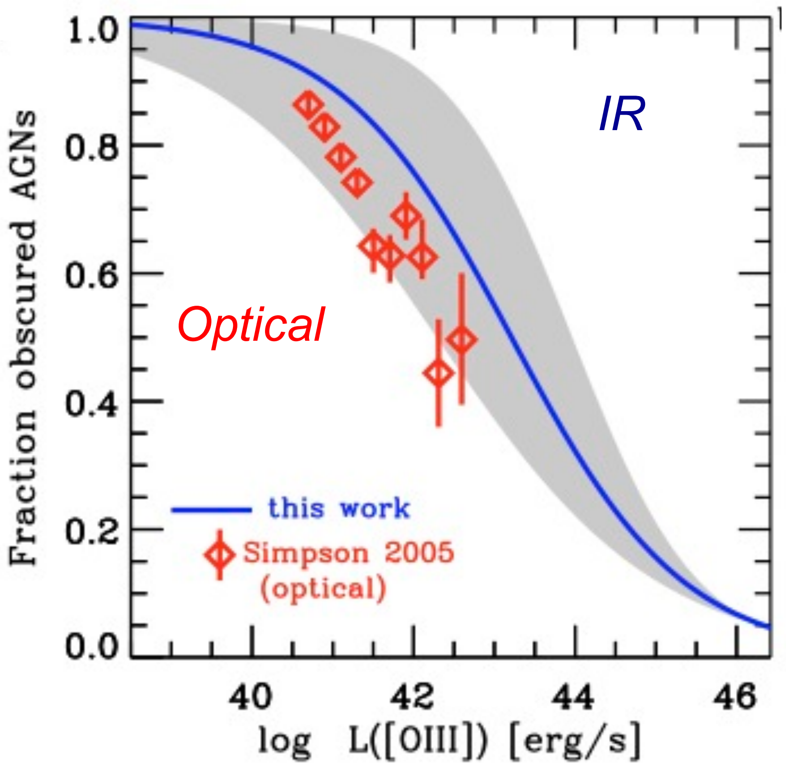
*Lawrence (1991), Ueda et al. (2003), Simpson (2005), Maiolino et al. (2007),Hasinger (2008), Fiore et al. (2009), Beckmann et al. (2009), Mor et al. (2009), Burlon et al. (2011), Ueda et al. (2011), Hiroi et al. (2012)*

**Is it related to a decrease of the covering factor of the obscuring torus with the luminosity?**

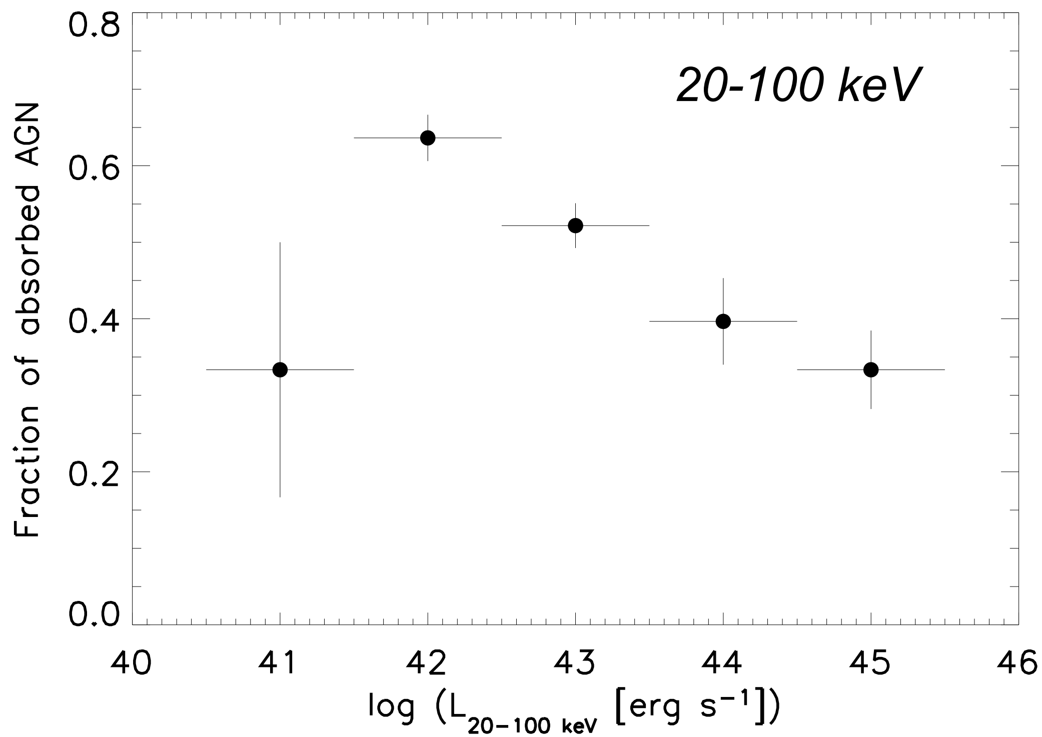


# Luminosity-dependent unification

**Decrease of the $f_{obs}$ with the luminosity: not only in the soft X-rays**




*Maiolino et al. 2007*

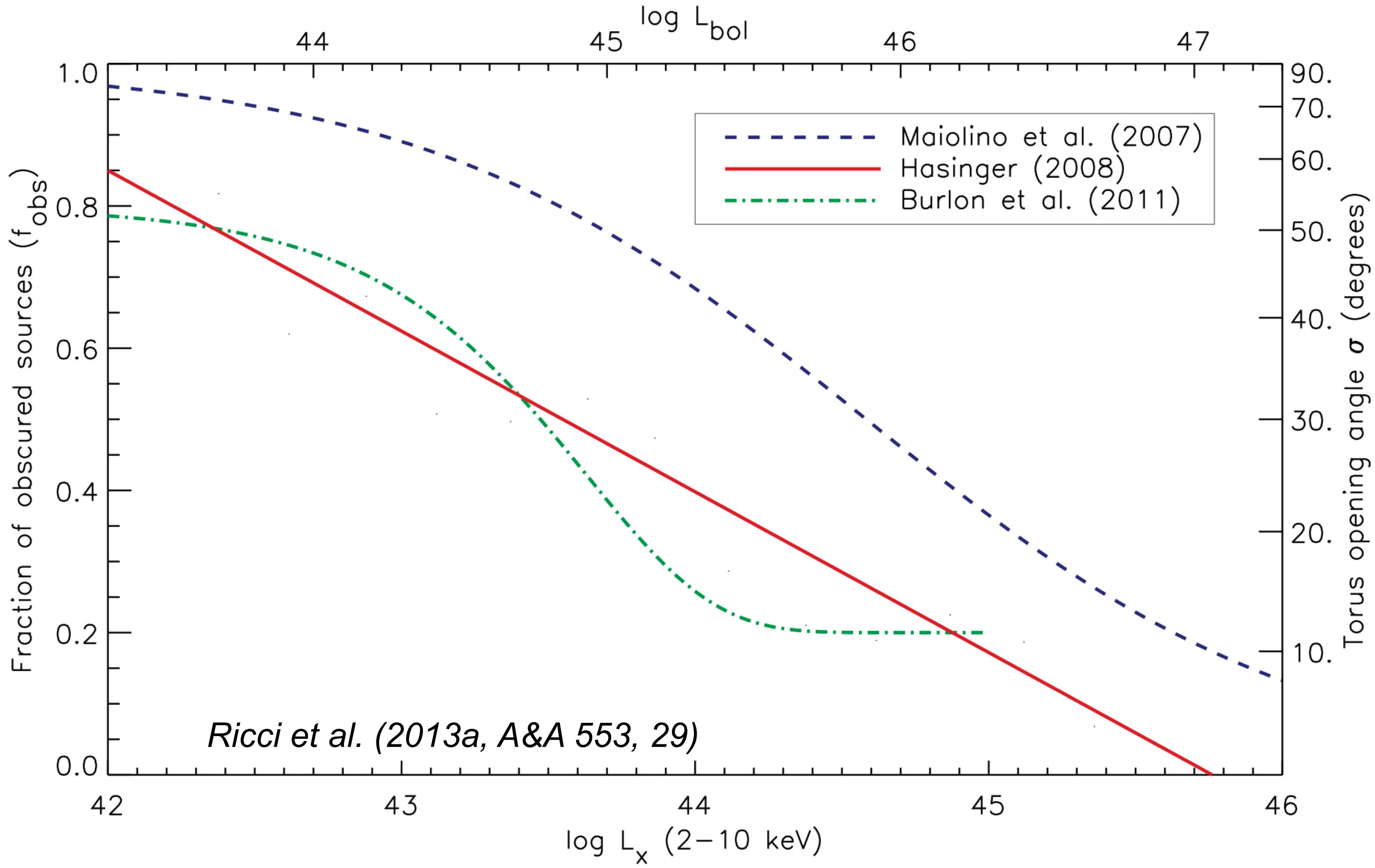



*Beckmann et al. 2009*

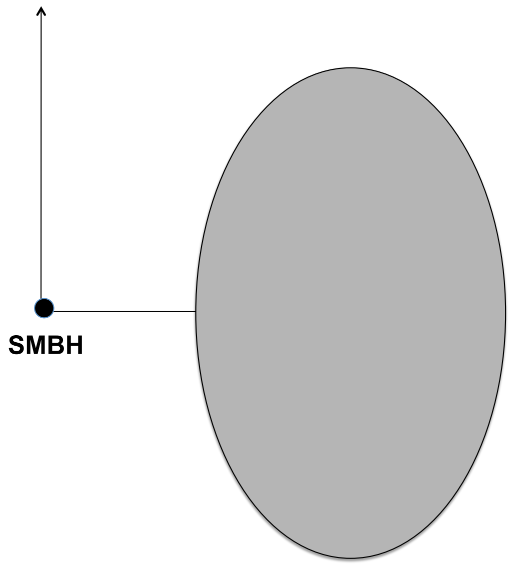
# Simulating the X-ray Baldwin effect

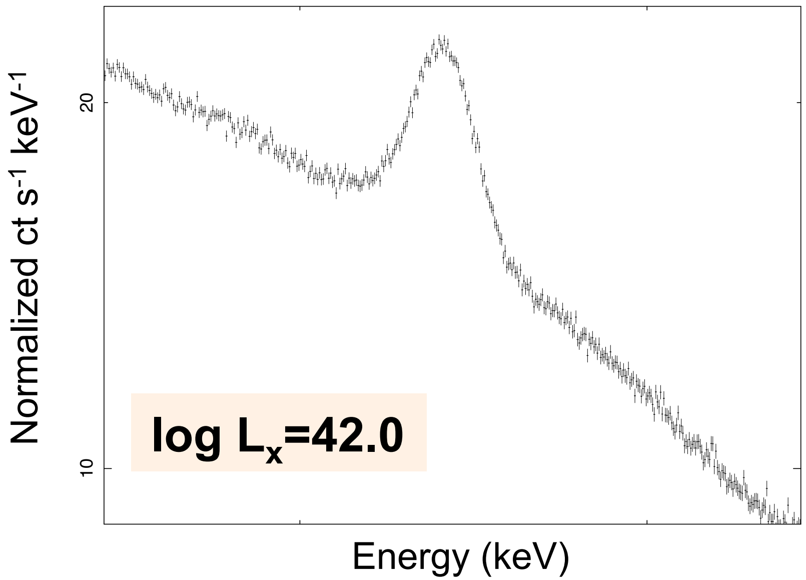
Opening angle calculated from the decrease of obscured sources with luminosity

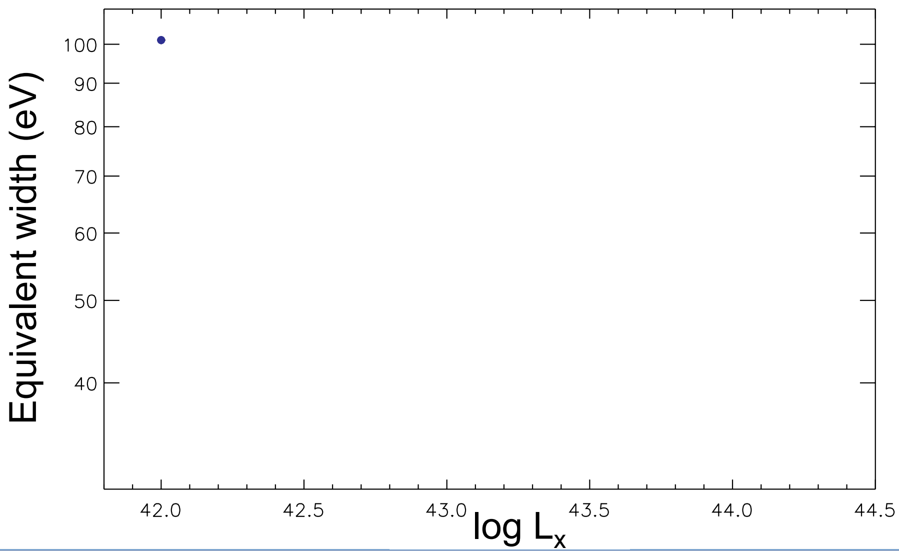
$$f_{obs} \Rightarrow \sigma$$



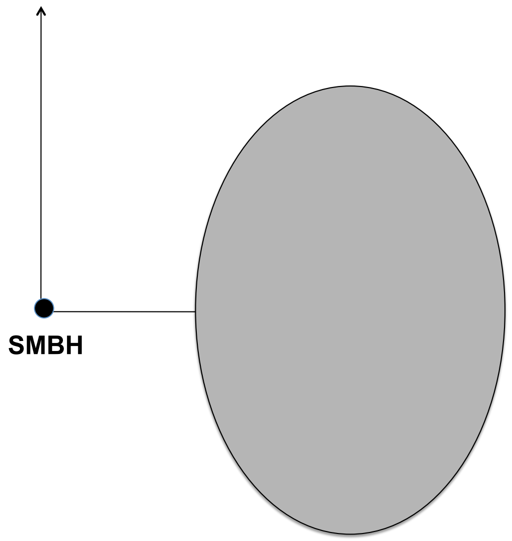
# Simulating the X-ray Baldwin effect

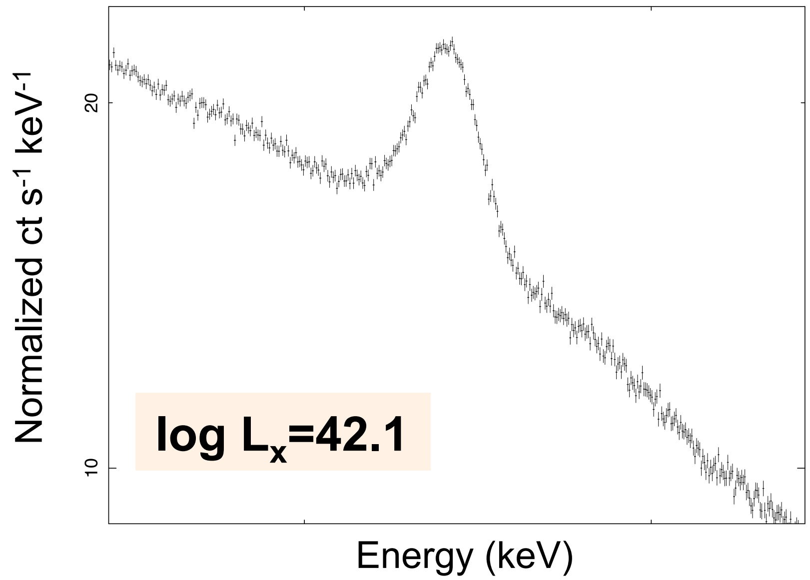


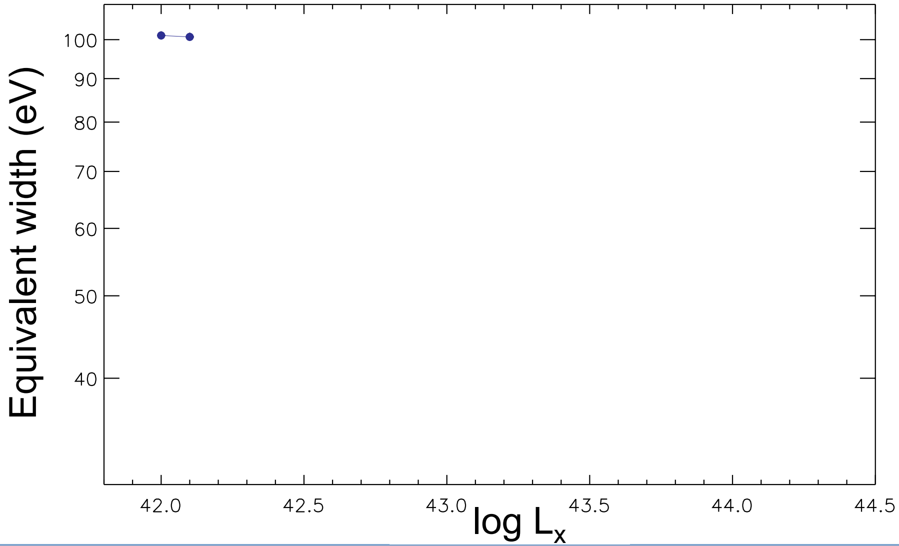



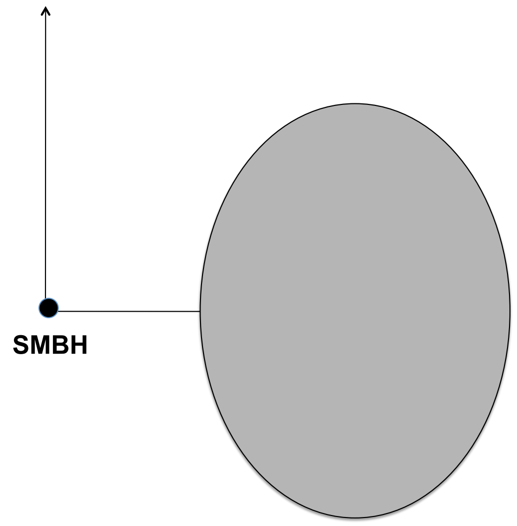



# Simulating the X-ray Baldwin effect

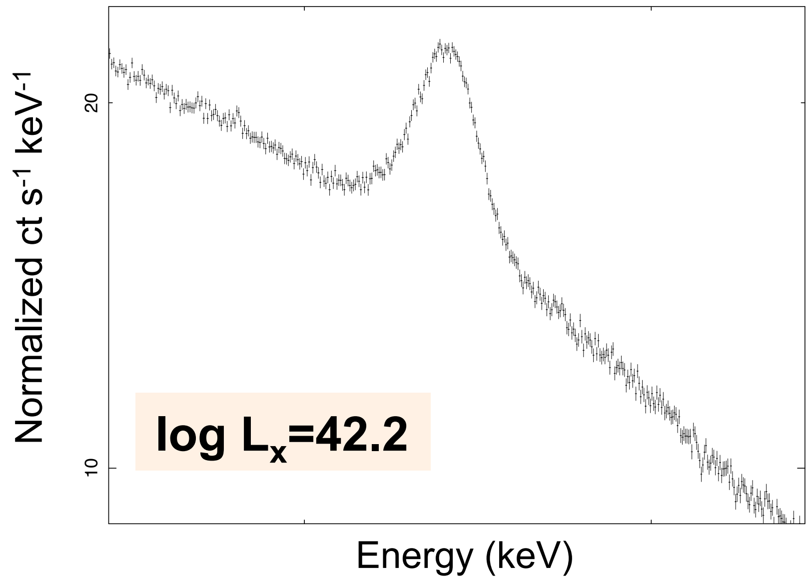


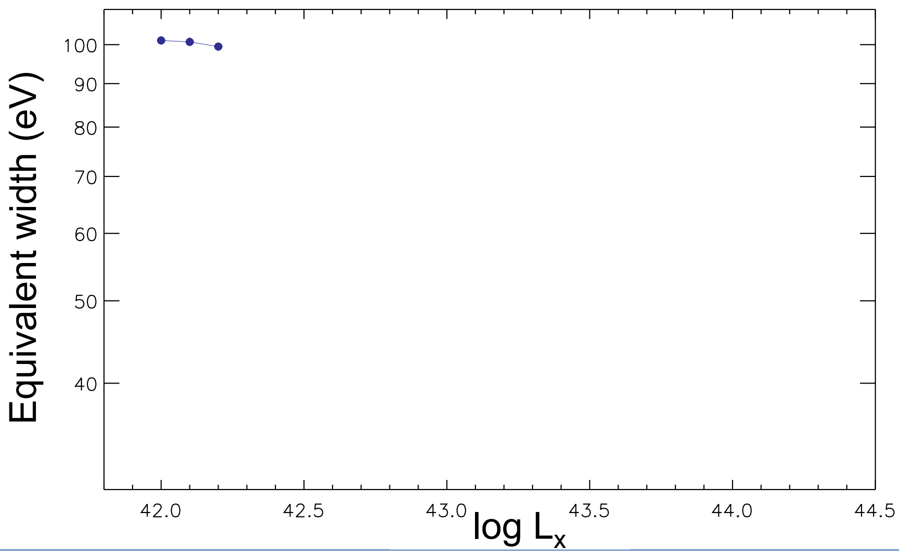





SMBH

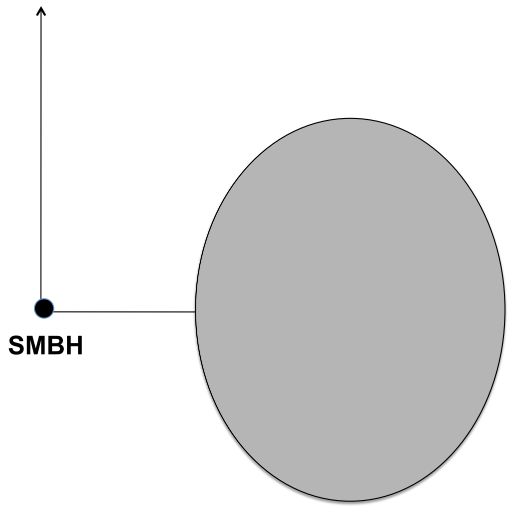



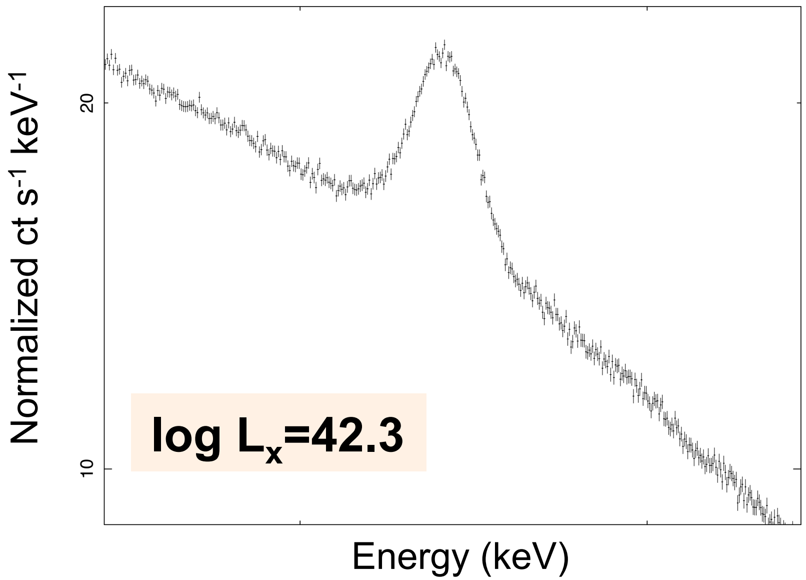
Normalized ct s-1 keV-1
20
10
log Lx=42.2
Energy (keV)

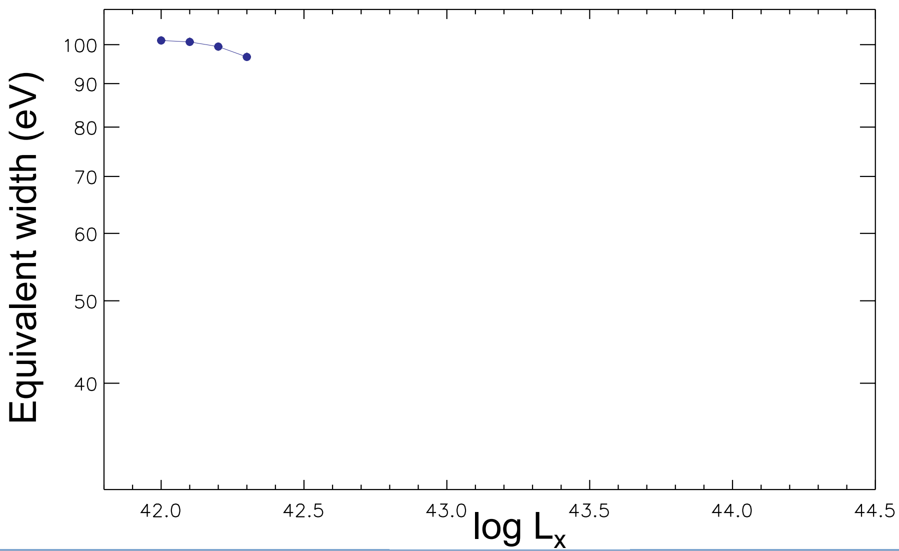



Equivalent width (eV)
100
90
80
70
60
50
40
42.0
42.5
43.0
43.5
44.0
44.5
log Lx

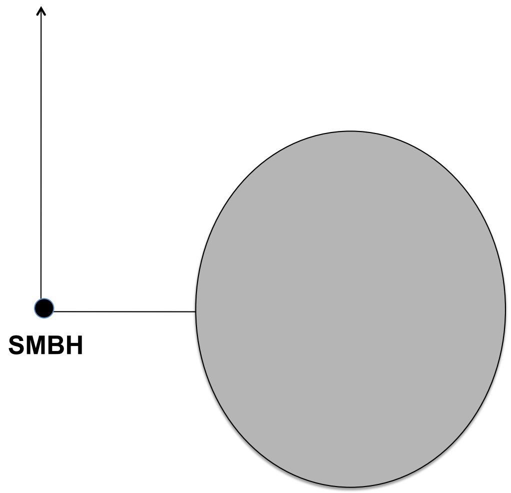
# Simulating the X-ray Baldwin effect

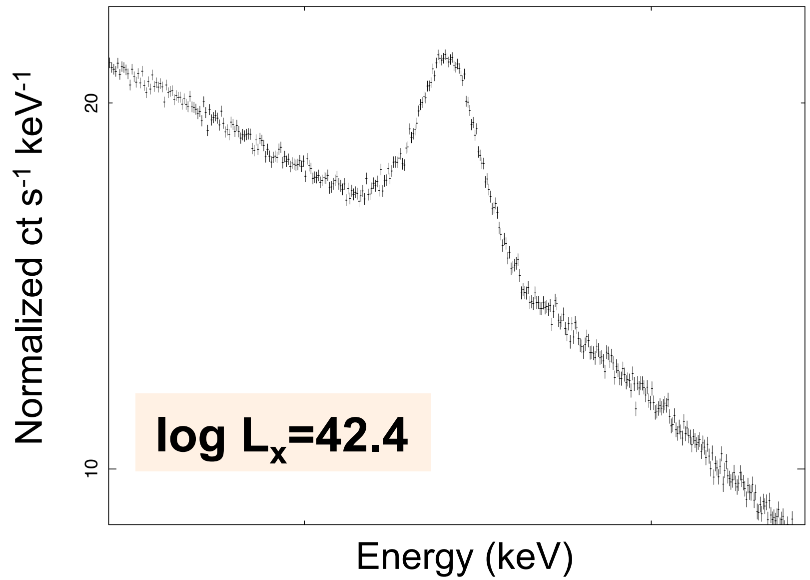


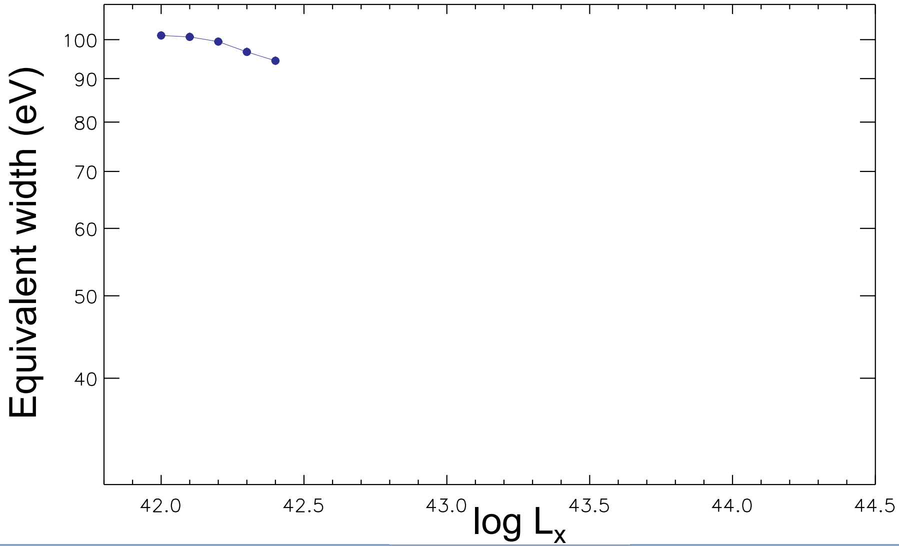



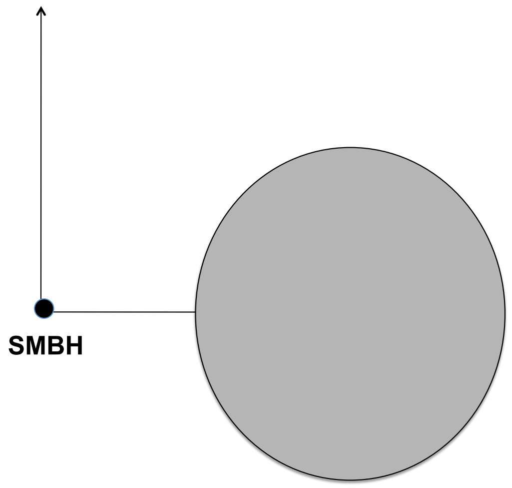
# Simulating the X-ray Baldwin effect

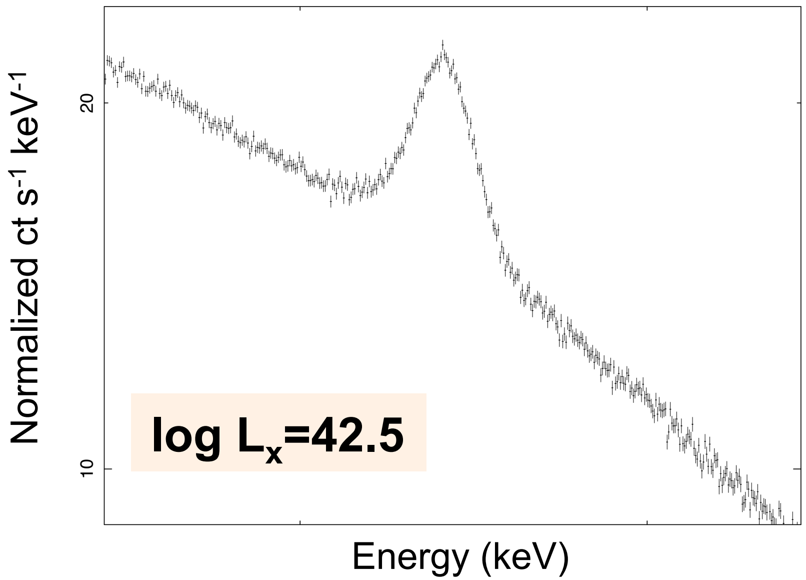


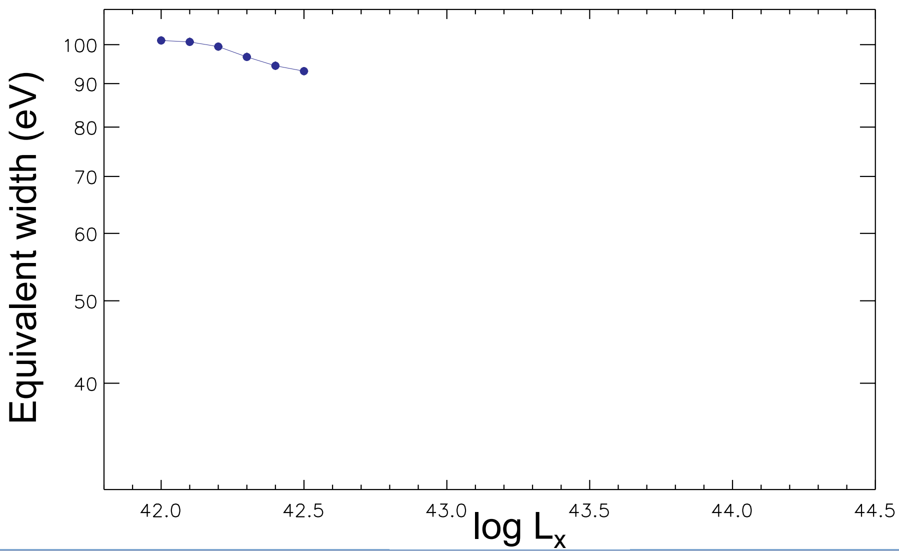



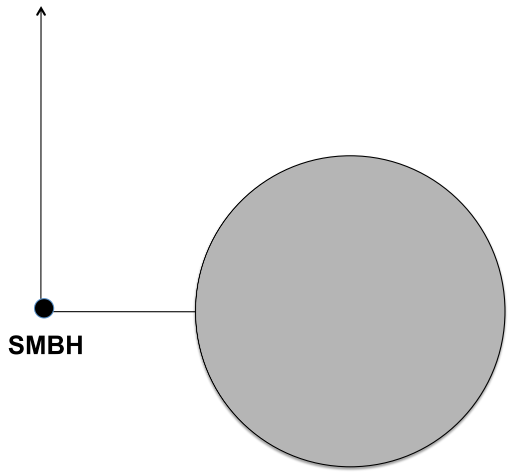
# Simulating the X-ray Baldwin effect

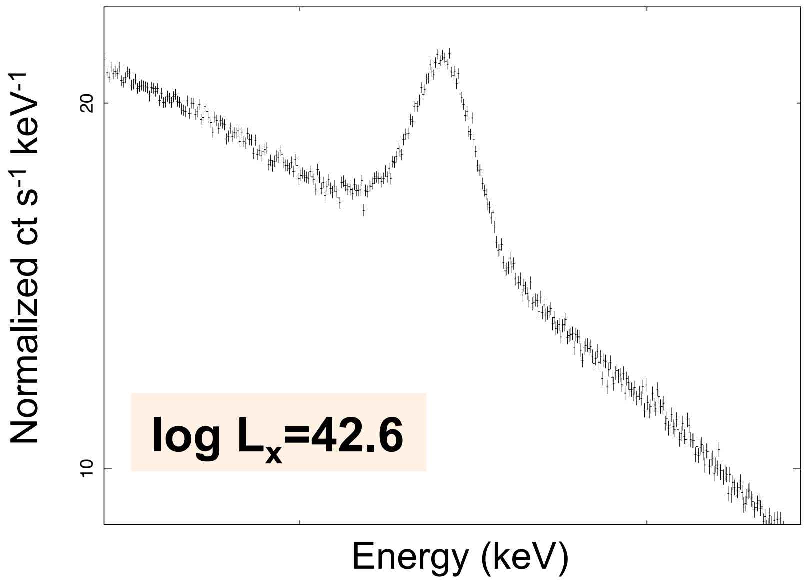


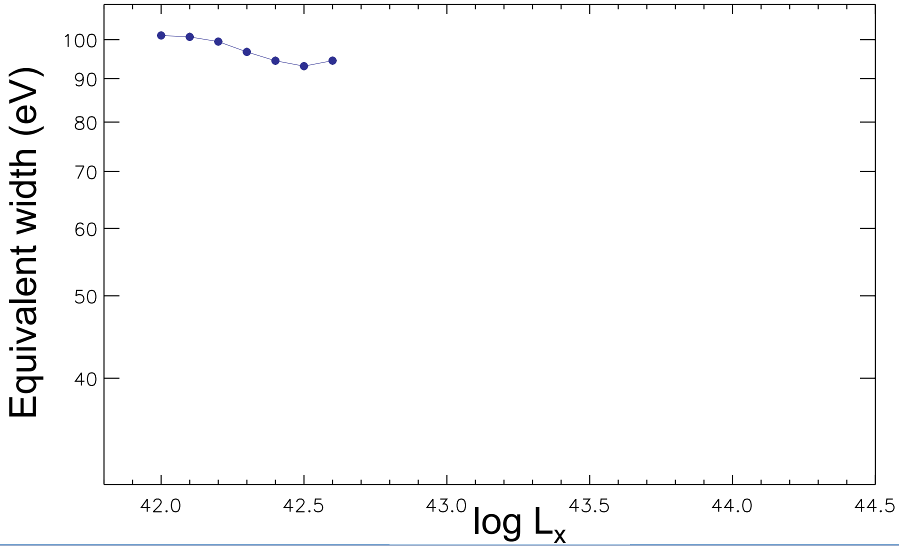



# Simulating the X-ray Baldwin effect



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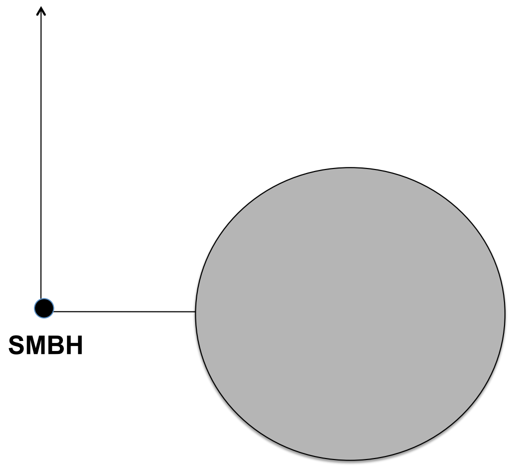
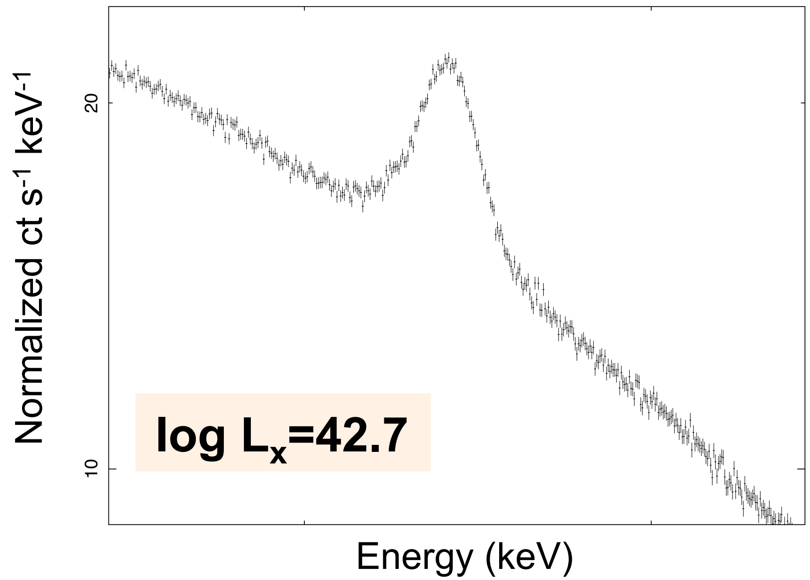
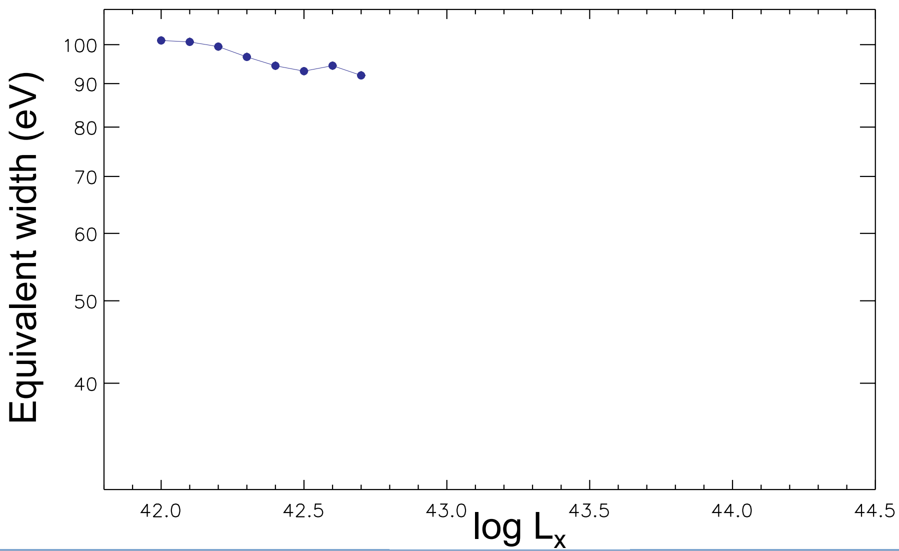
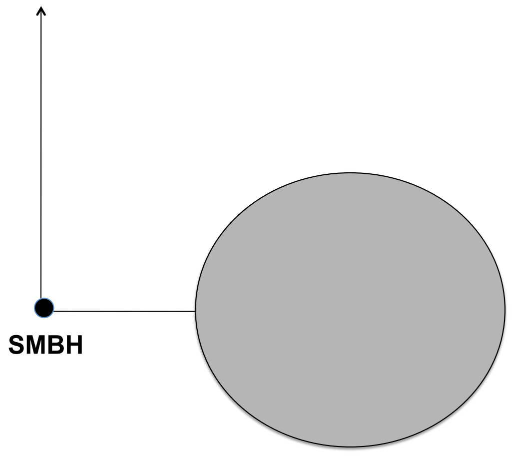
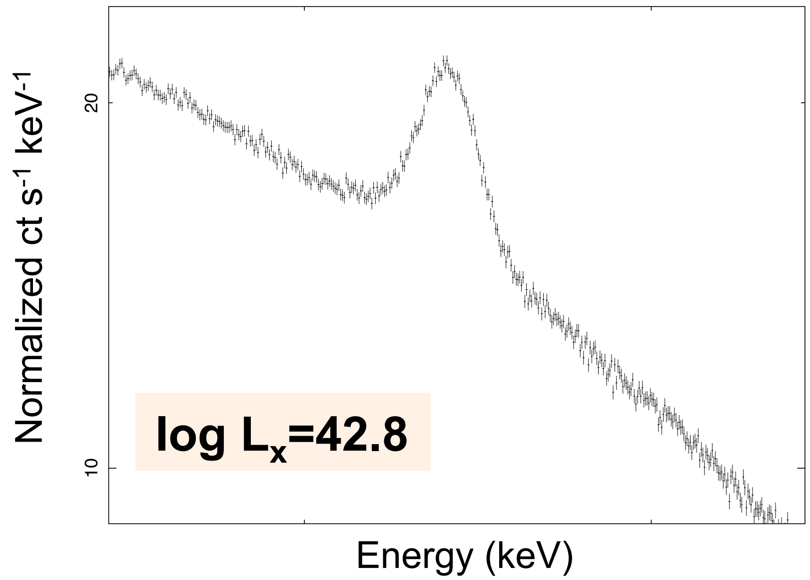


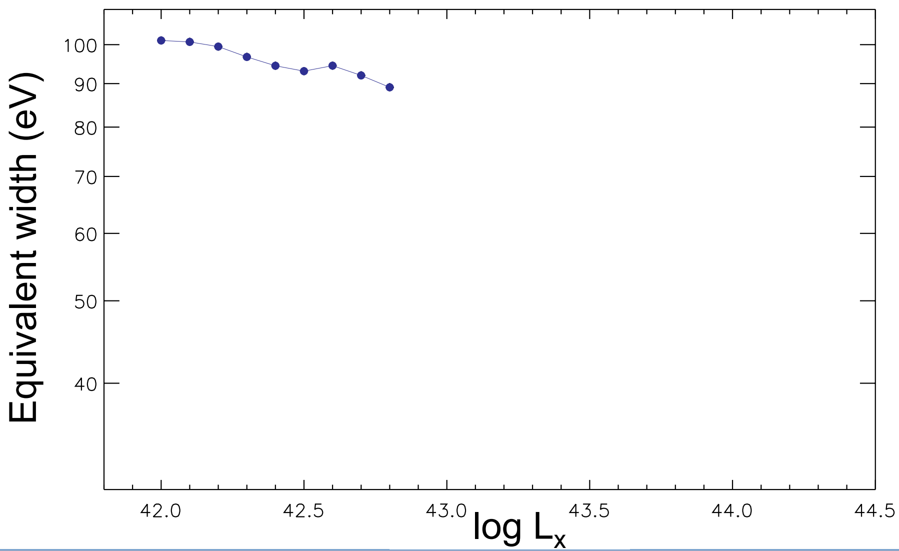



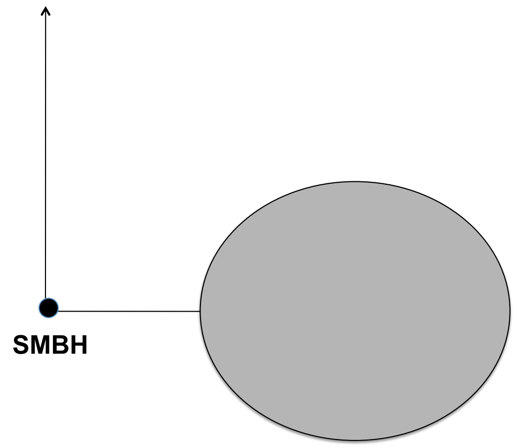



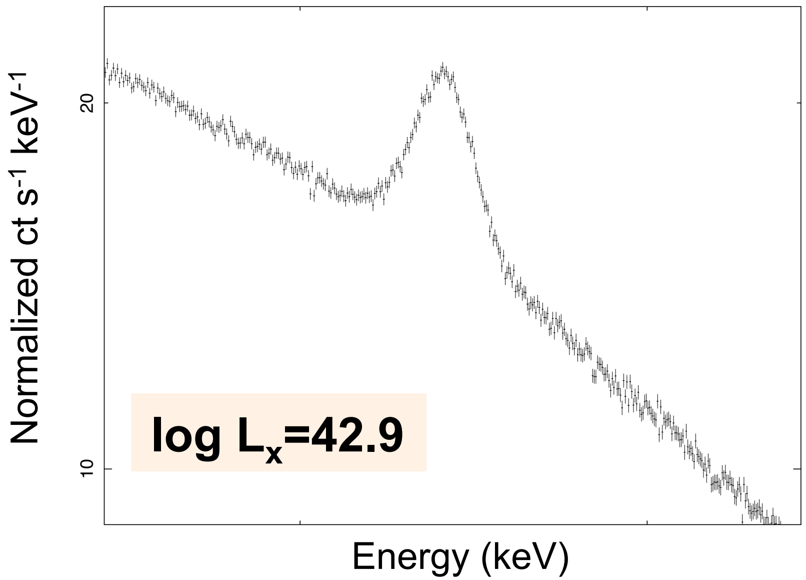
# Simulating the X-ray Baldwin effect

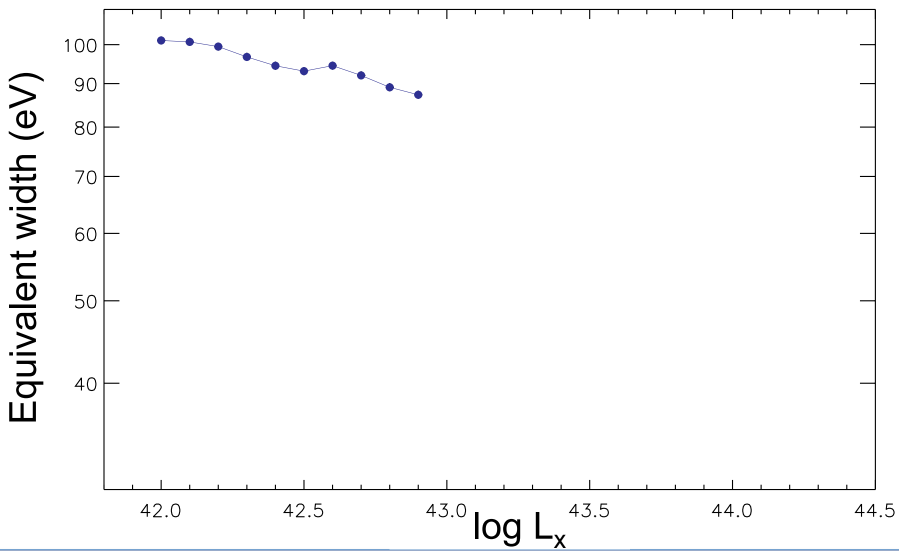


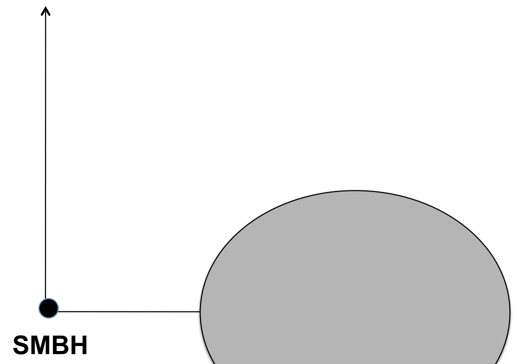



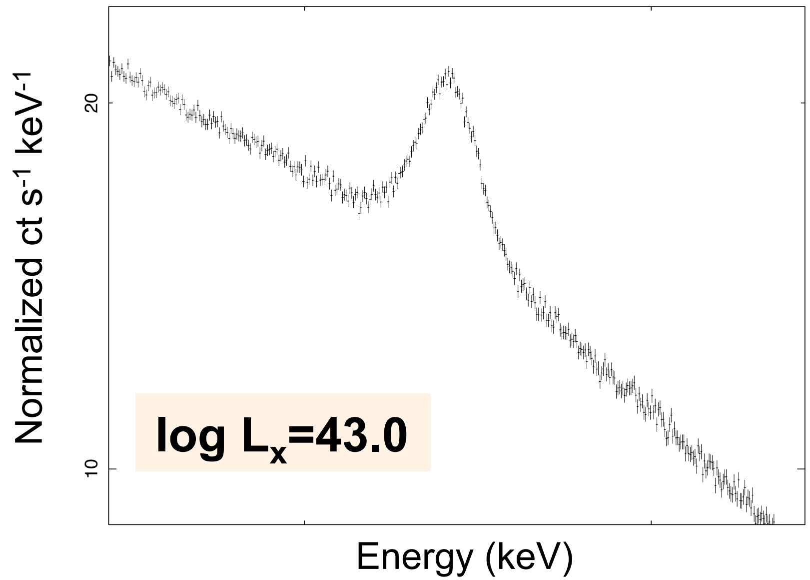

SMBH


Normalized ct s$^{-1}$ keV$^{-1}$
20
10
log $L_x$=42.9
Energy (keV)

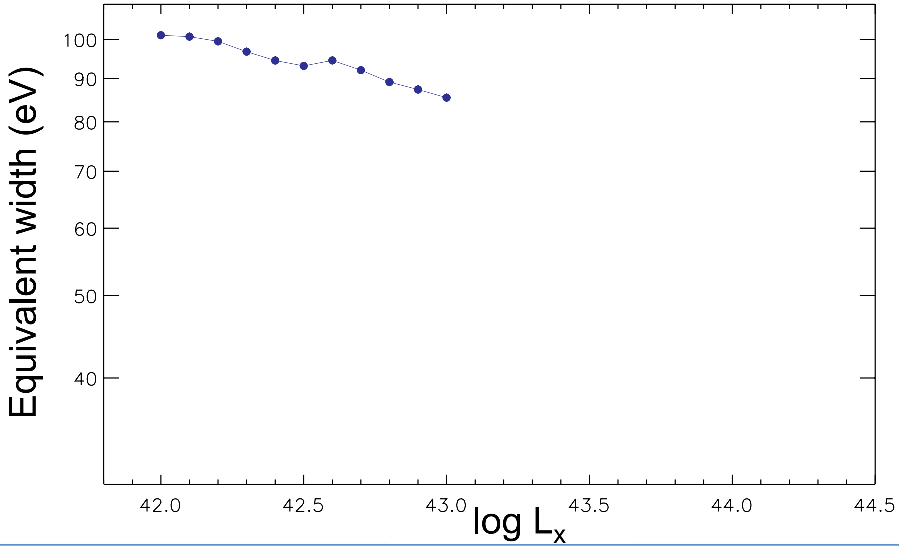

Equivalent width (eV)
100
90
80
70
60
50
40
42.0
42.5
43.0
43.5
44.0
44.5
log $L_x$



SMBH

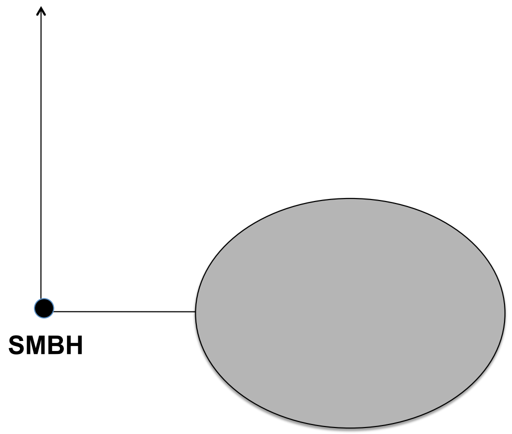



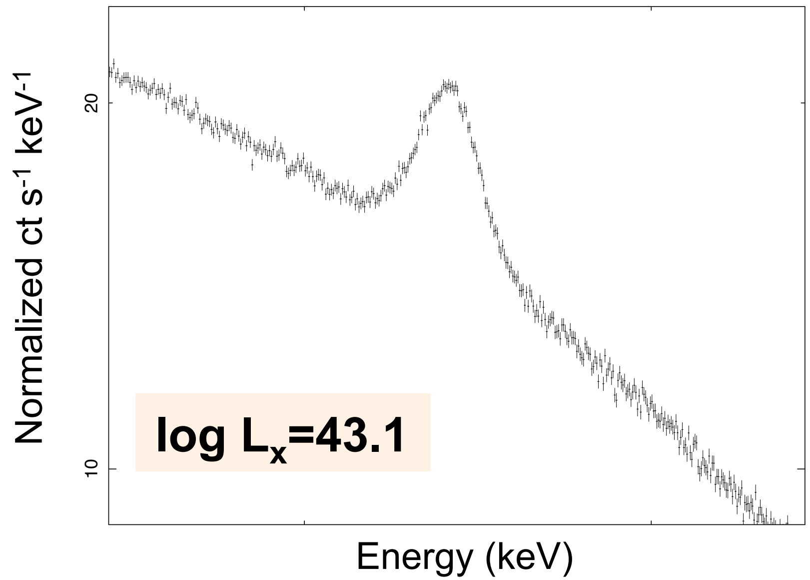
Normalized ct s-1 keV-1
20
10
log Lx=43.0
Energy (keV)

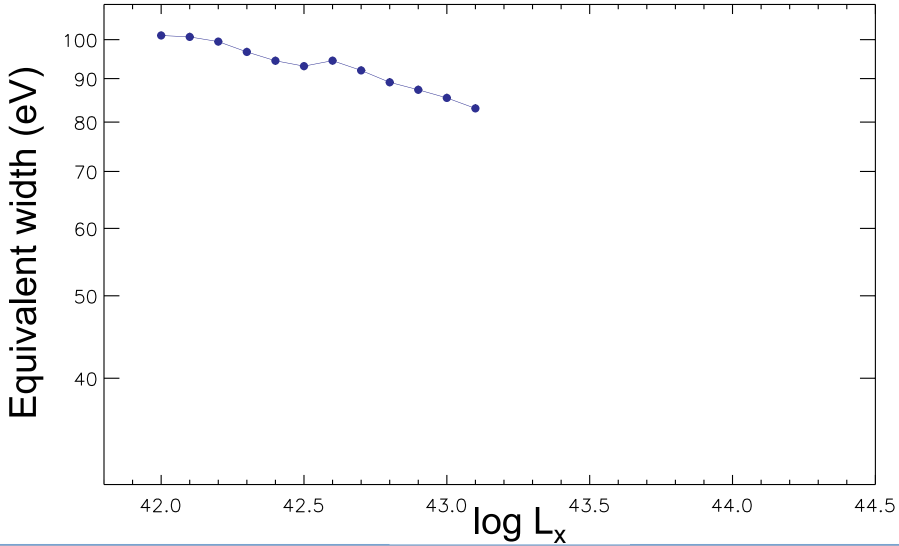



Equivalent width (eV)
100
90
80
70
60
50
40
42.0
42.5
43.0
43.5
44.0
44.5
log Lx

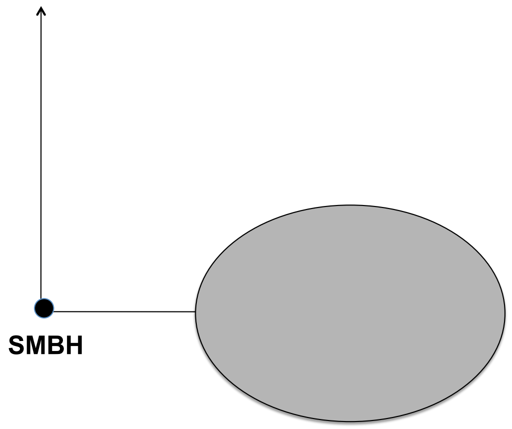
# Simulating the X-ray Baldwin effect

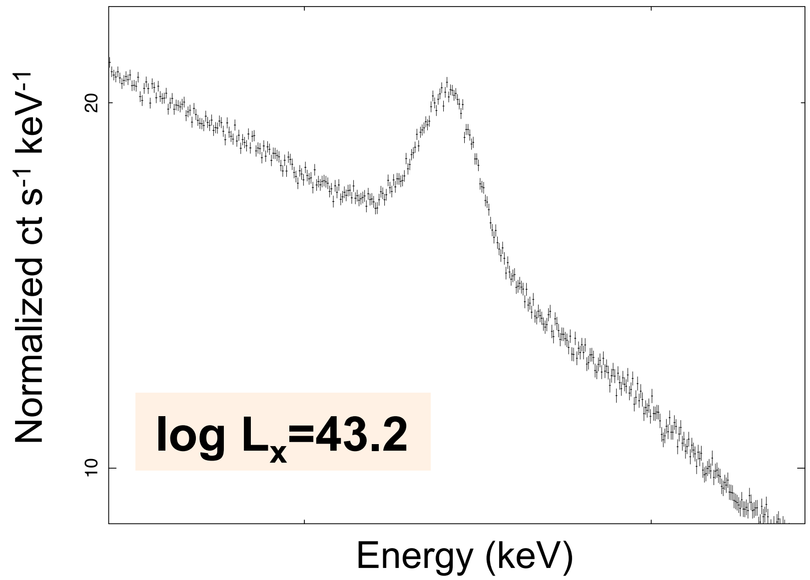


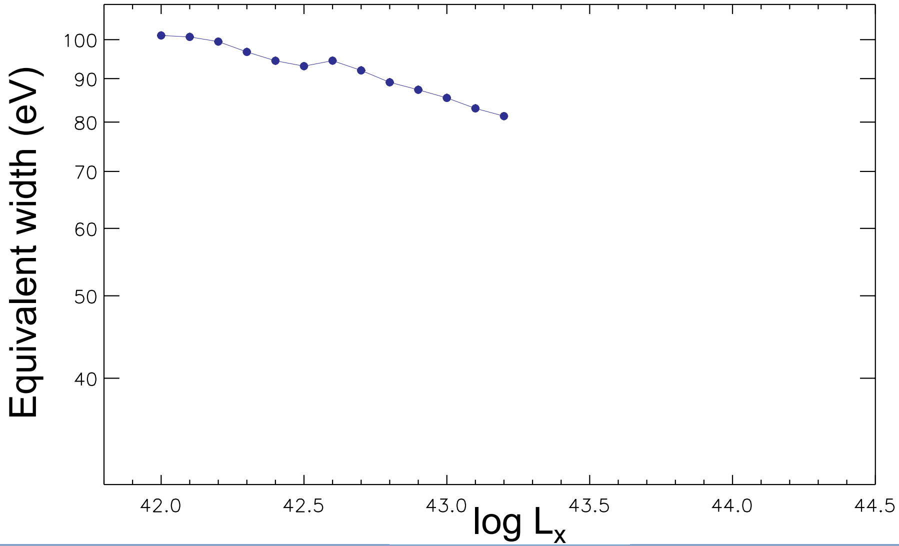



# Simulating the X-ray Baldwin effect



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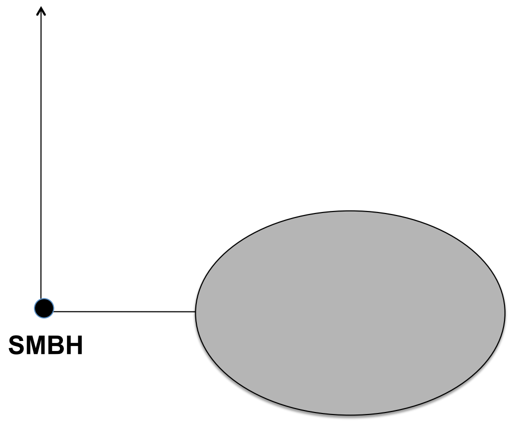
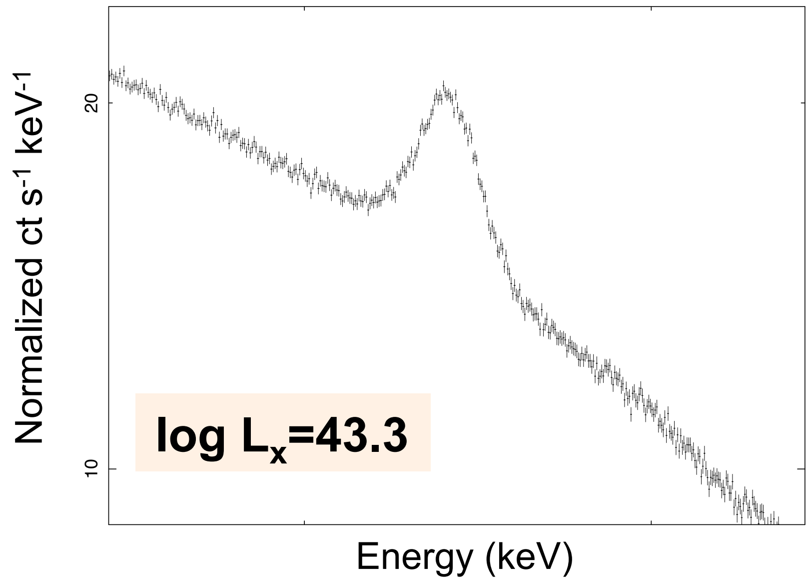
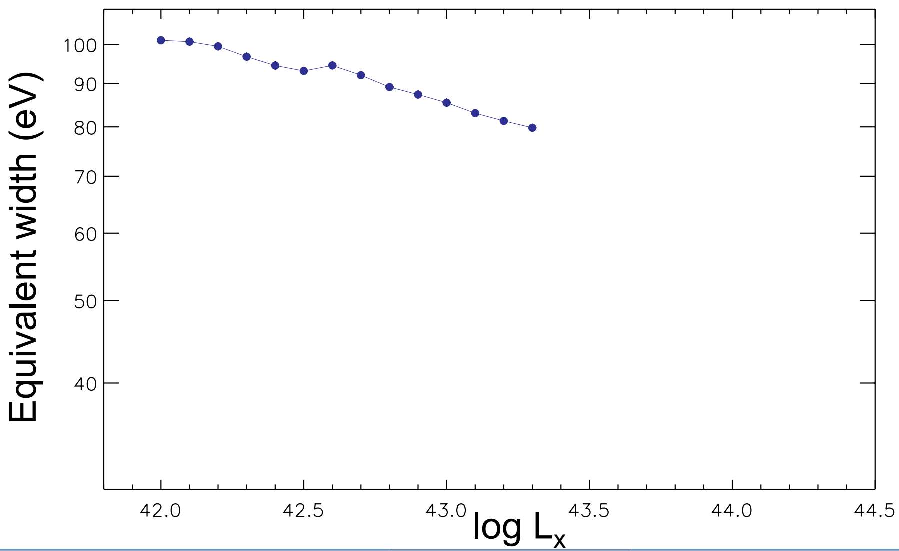
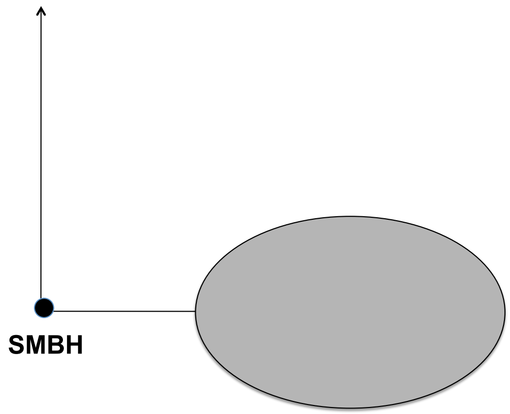
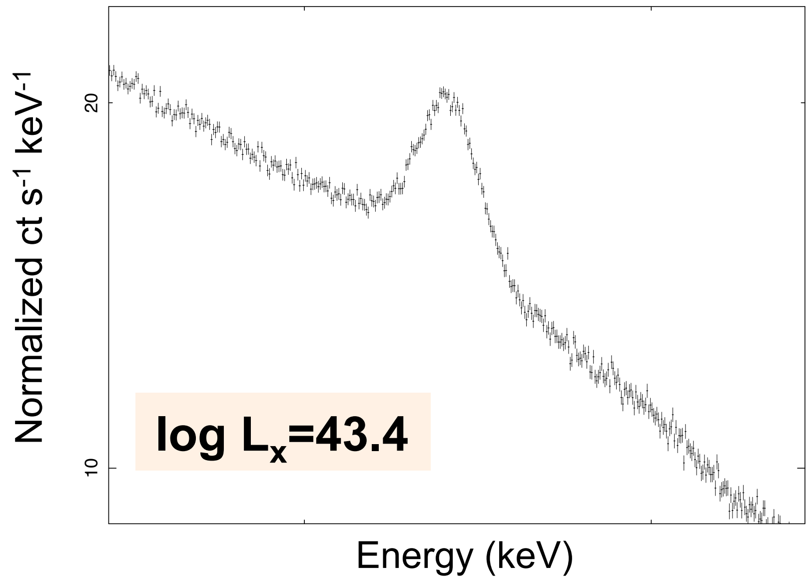


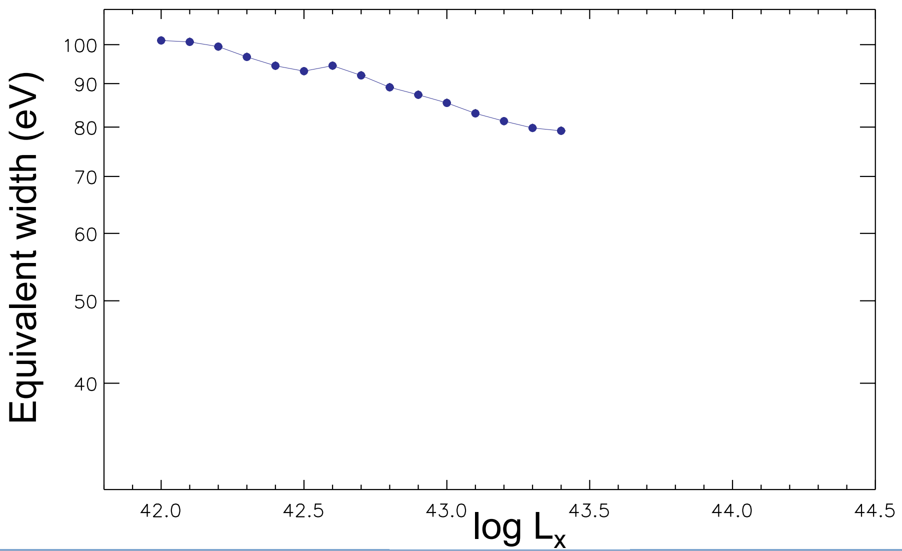



# Simulating the X-ray Baldwin effect



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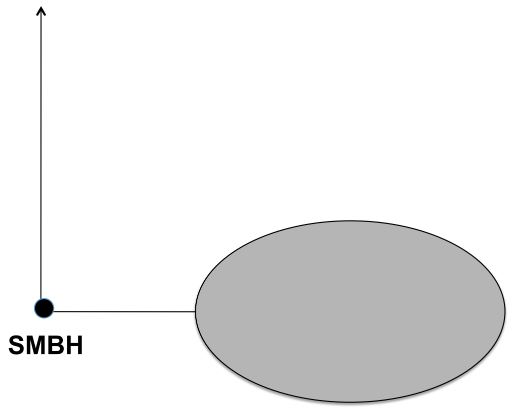


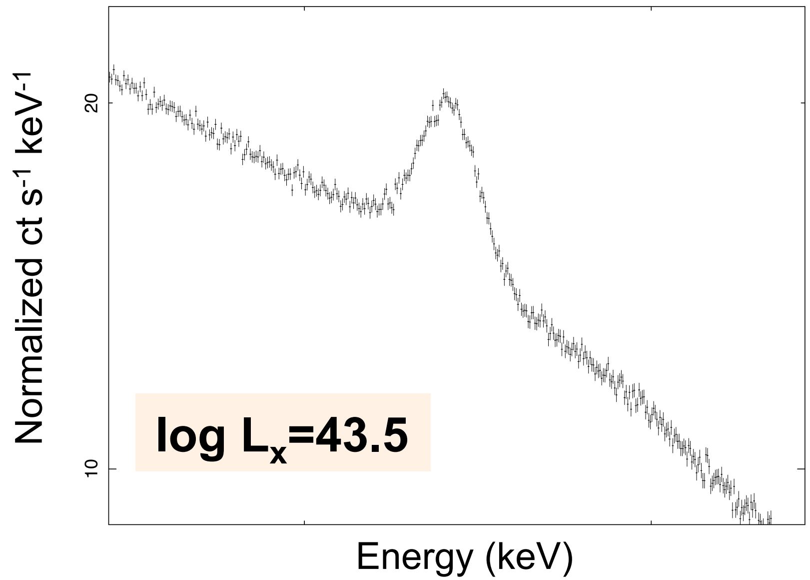


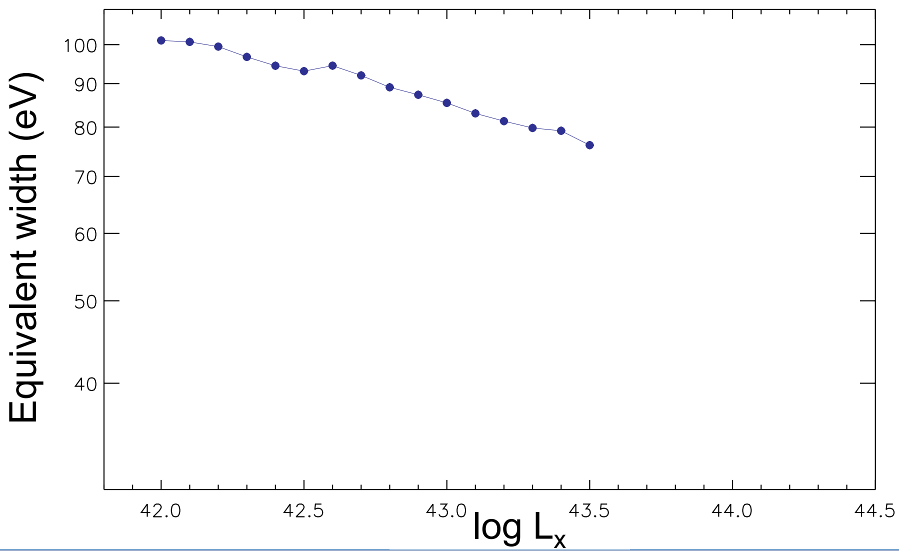

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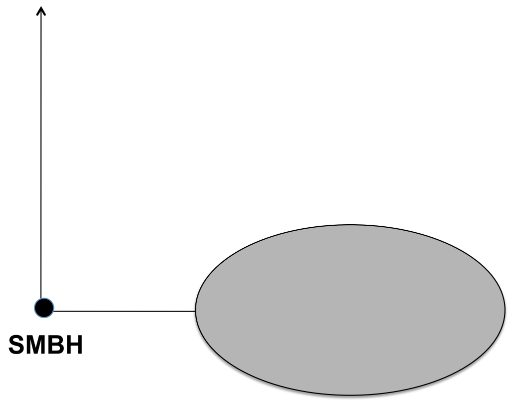
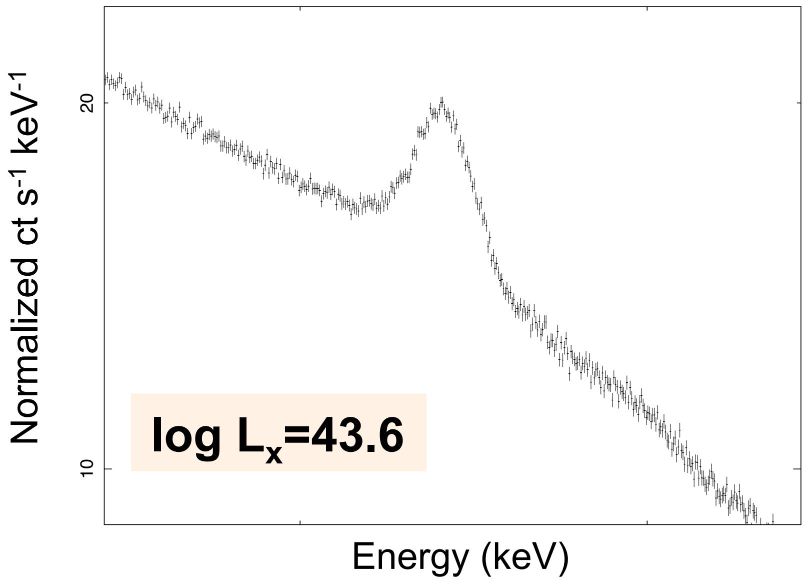
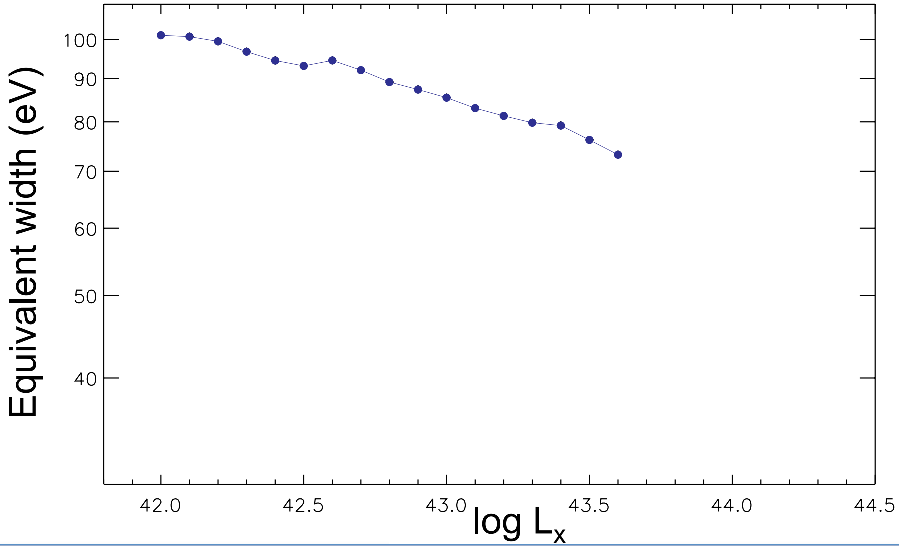
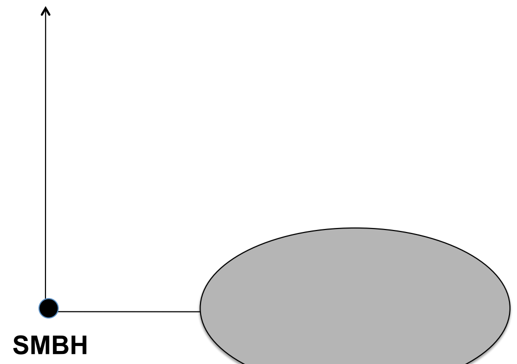
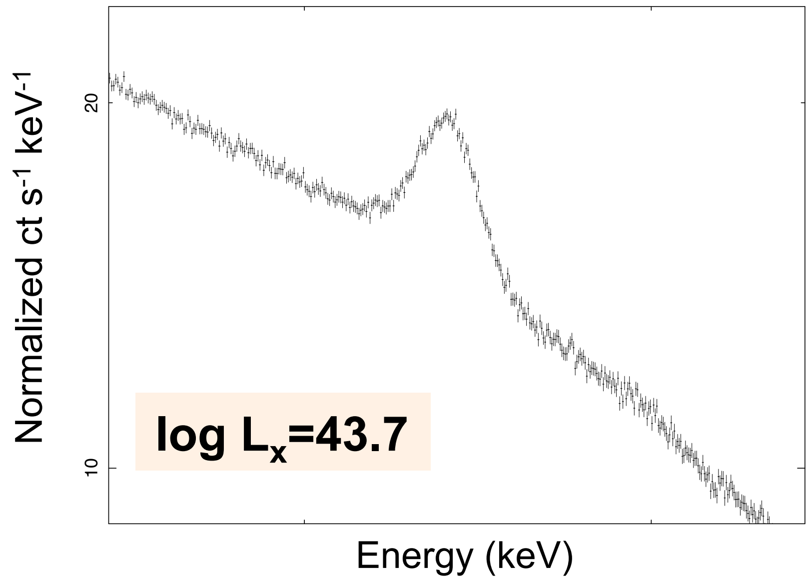


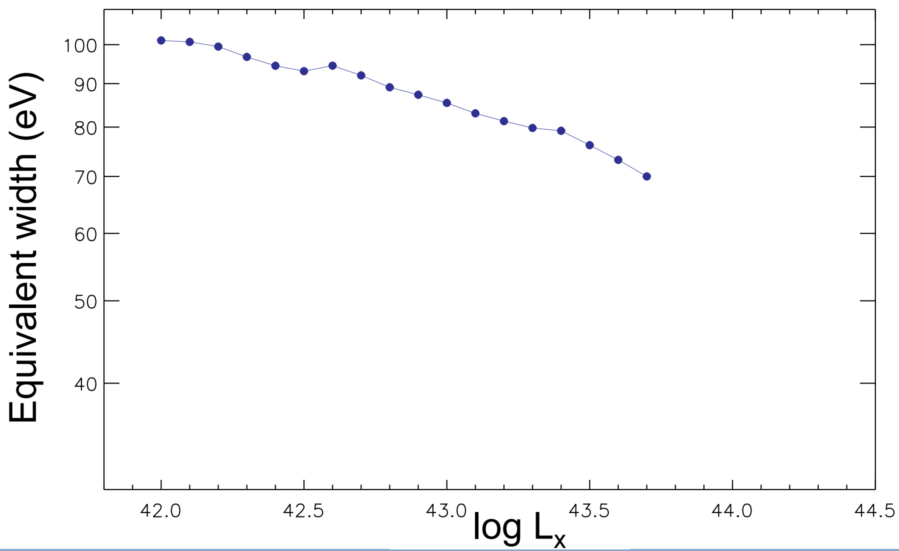



# Simulating the X-ray Baldwin effect



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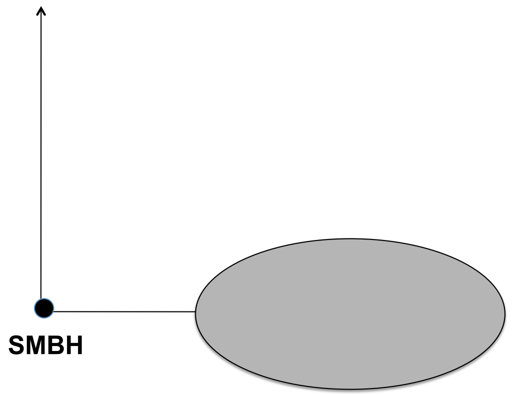
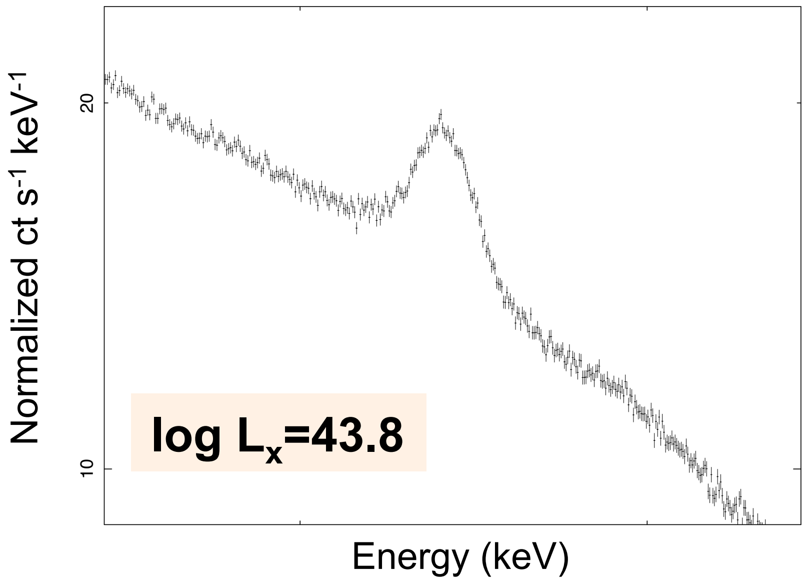
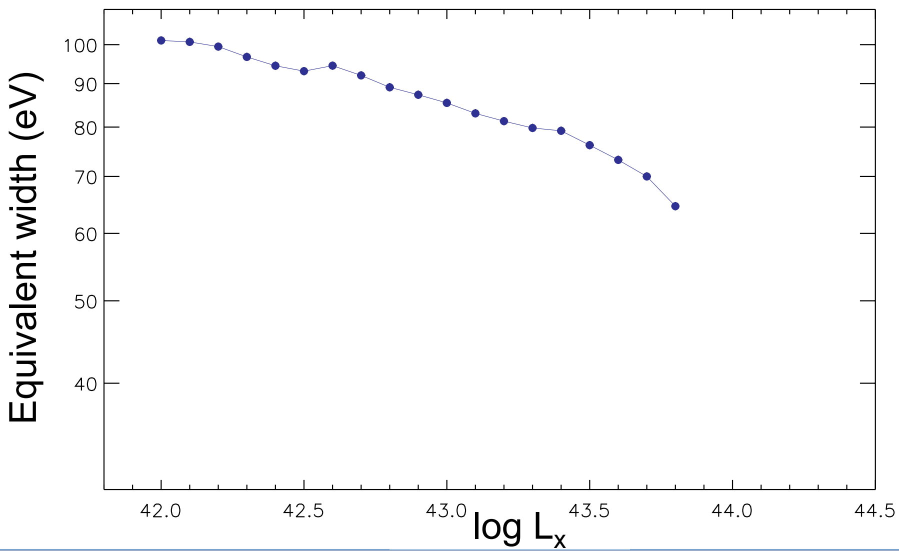
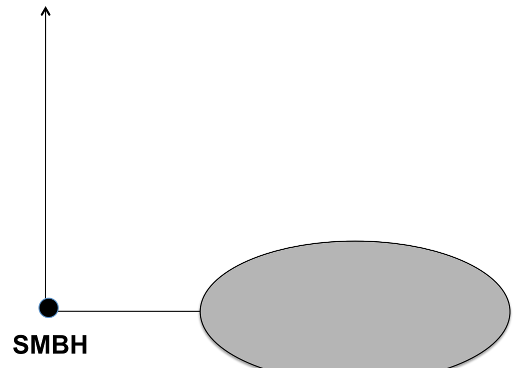
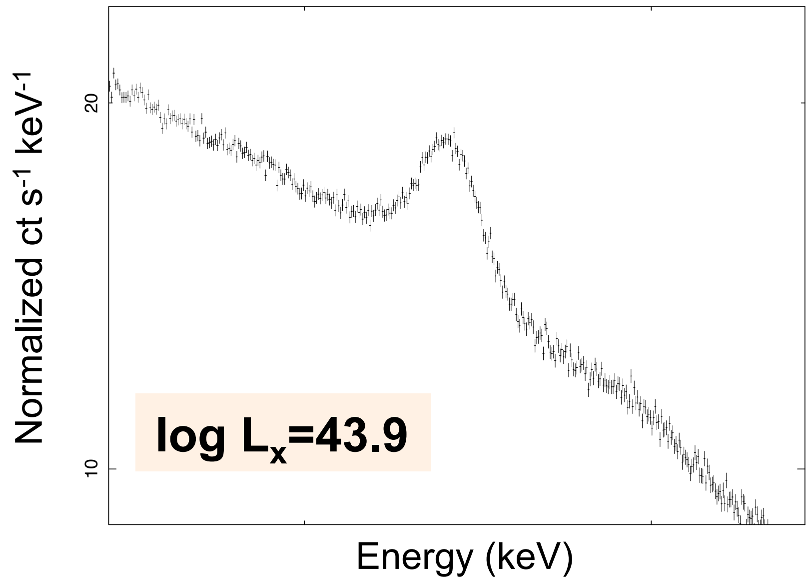
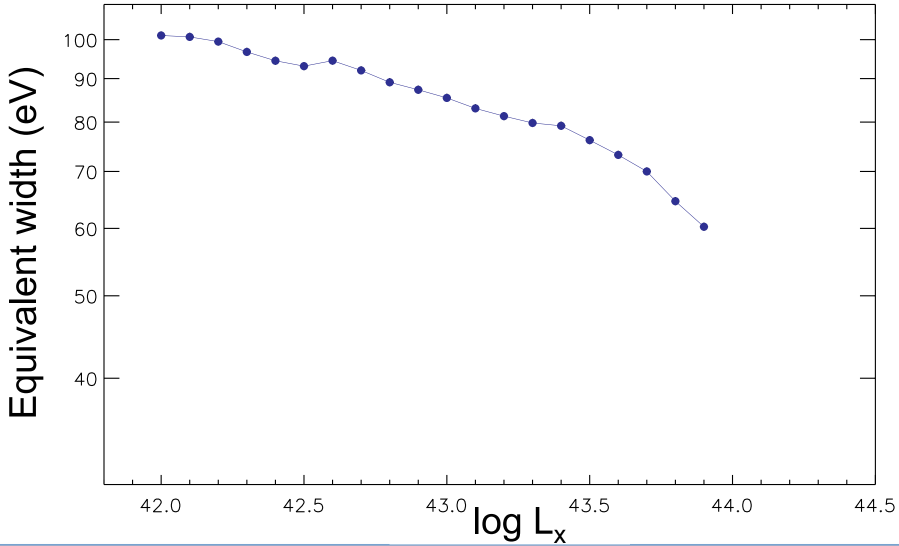


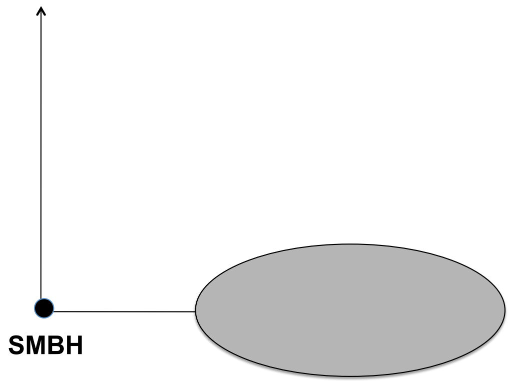



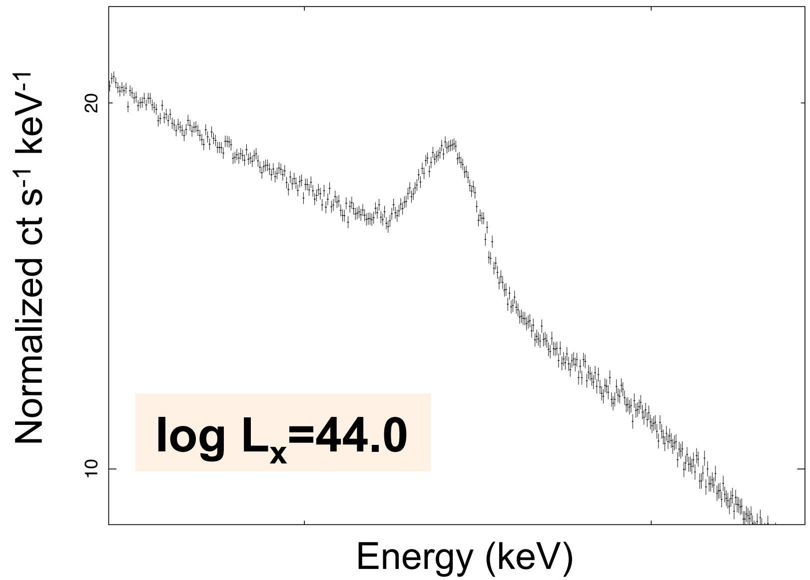

SMBH

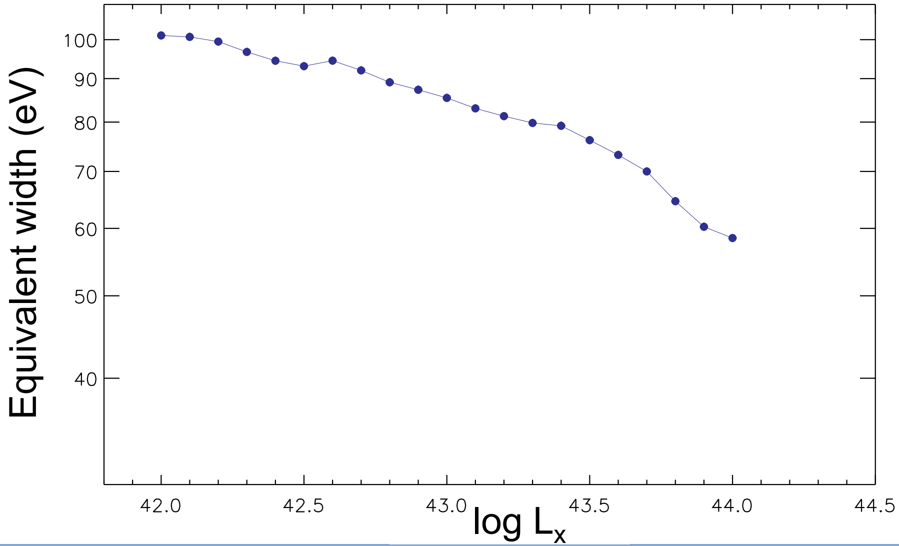

20
10
Normalized ct s-1 keV-1
log Lx=43.9
Energy (keV)


100
90
80
70
60
50
40
Equivalent width (eV)
42.0
42.5
43.0
43.5
44.0
44.5
log Lx

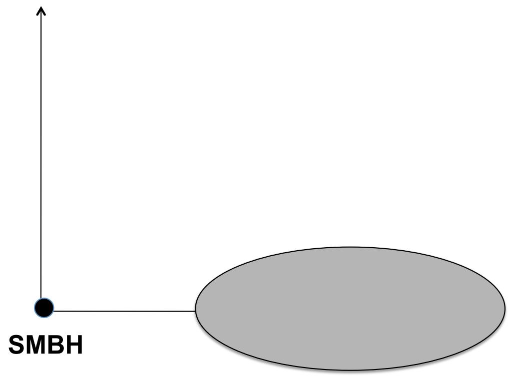
# Simulating the X-ray Baldwin effect

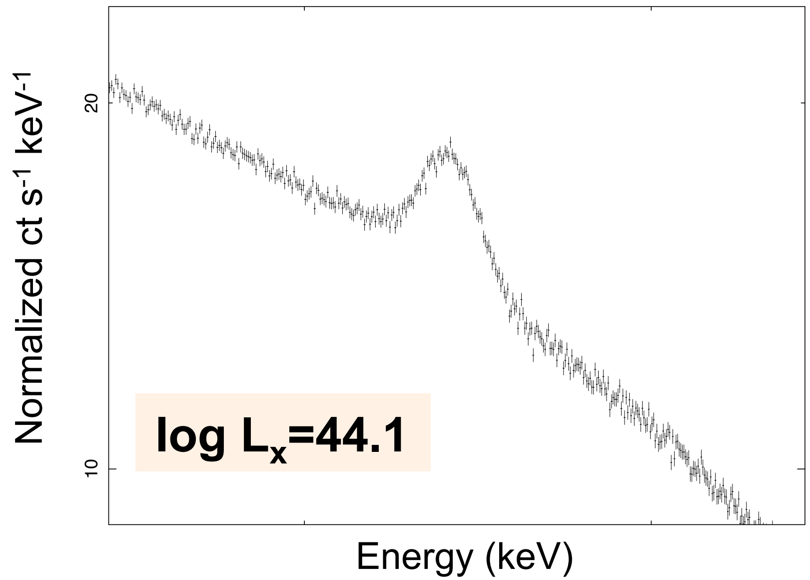


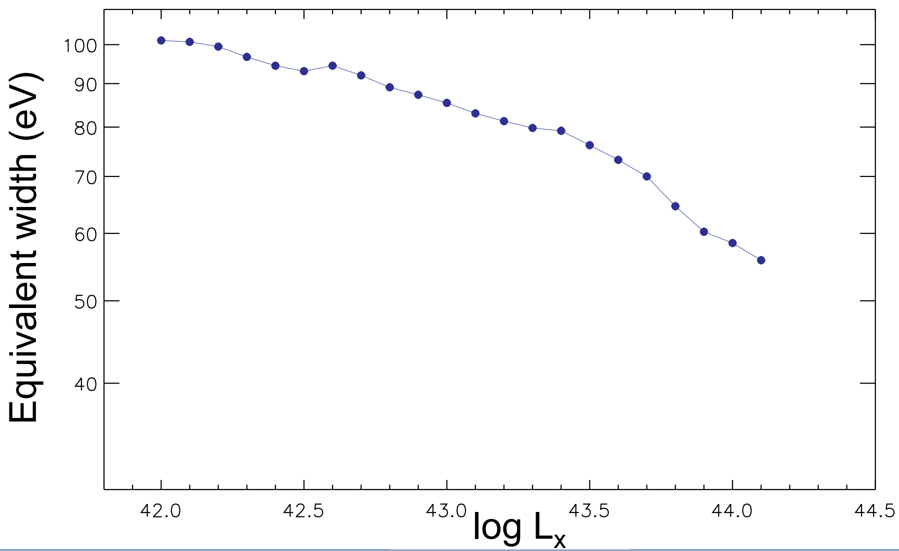



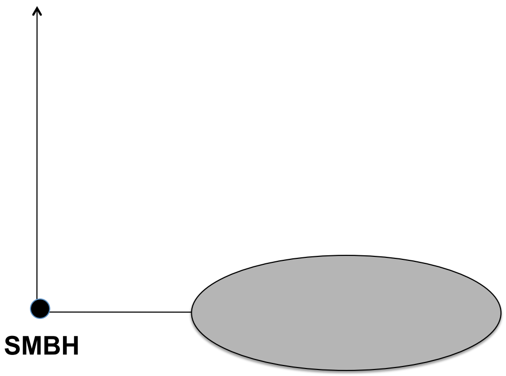
# Simulating the X-ray Baldwin effect

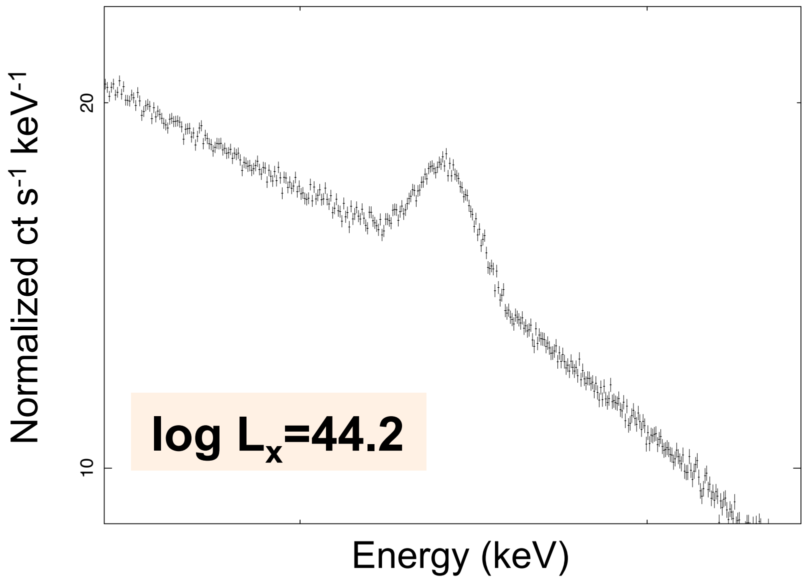


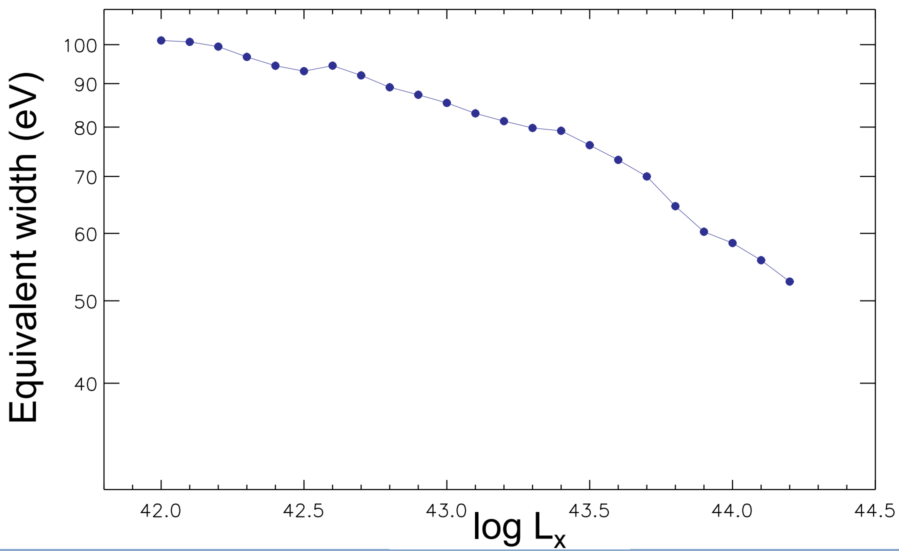



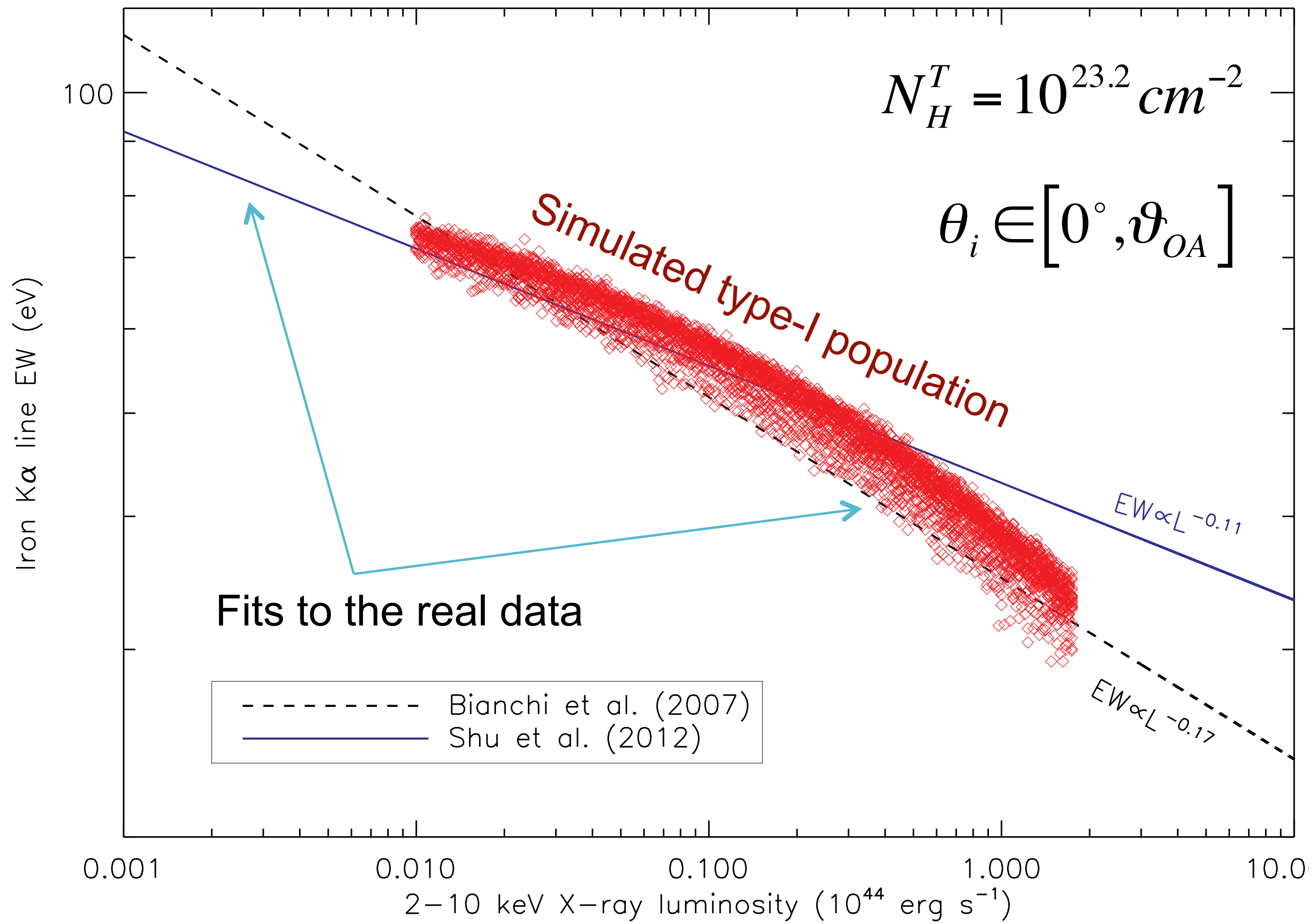
# Simulating the X-ray Baldwin effect



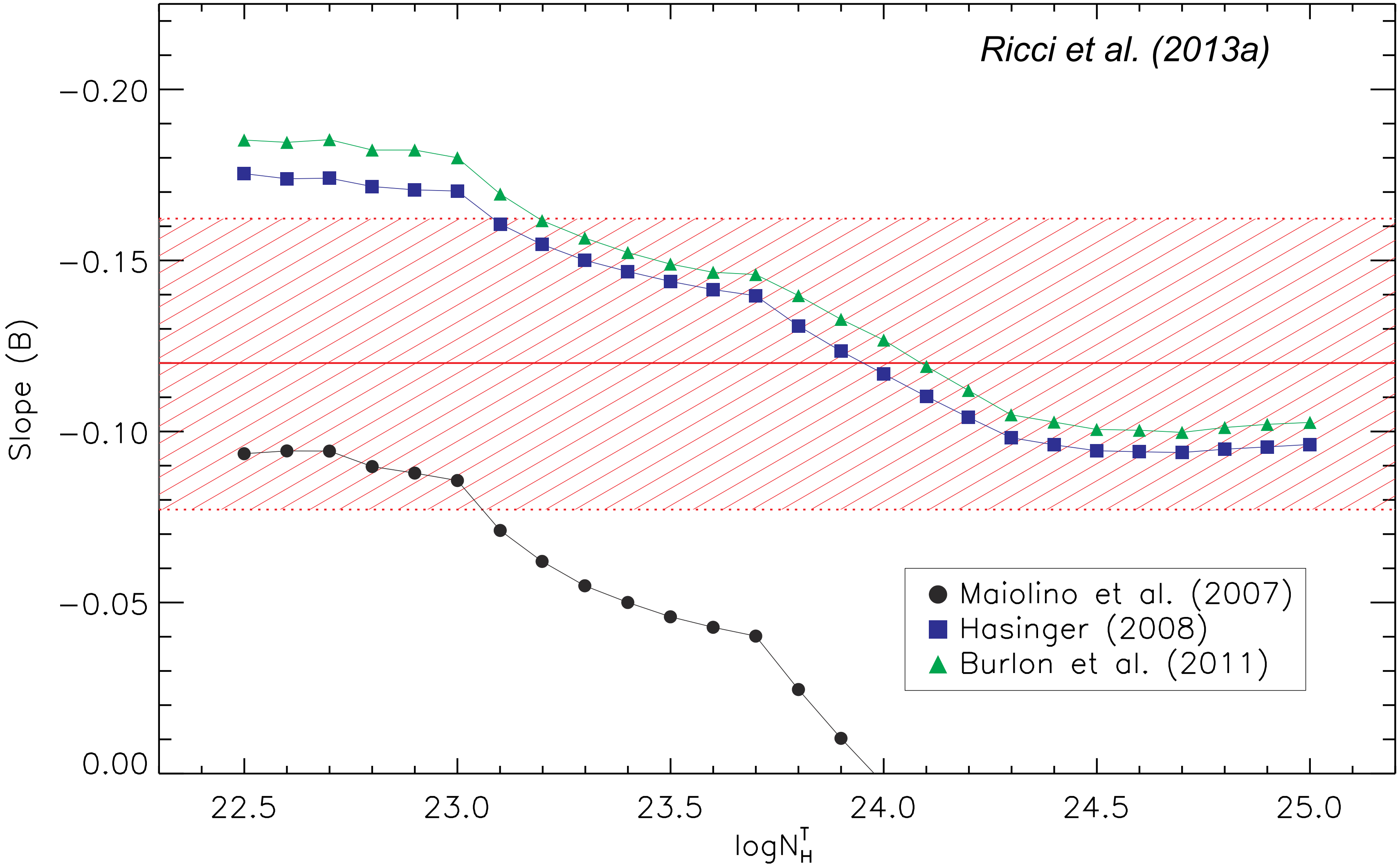



# Simulating the X-ray Baldwin effect




*Ricci et al. (2013a)*

# Simulating the X-ray Baldwin effect



# Summary & Conclusions

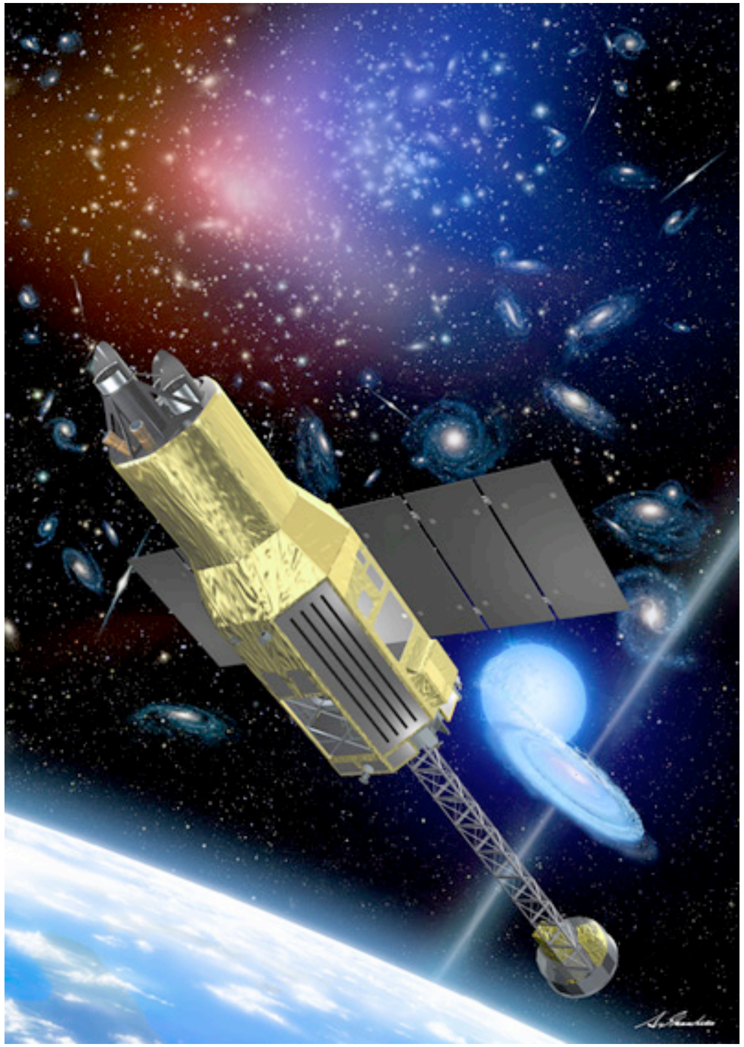
- The narrow Fe Kα: the most important tracer of neutral material surrounding the supermassive black hole.

- First evidence of an X-ray Baldwin effect in type-II AGN, with the same slope as type-I, probably the same mechanism is at work in the two classes.

- The positive $\Gamma$-$\lambda_{Edd}$ correlation fails to reproduce the slope of the X-ray Baldwin effect, unless a steeper trend (as found by Risaliti et al. 2009) is considered

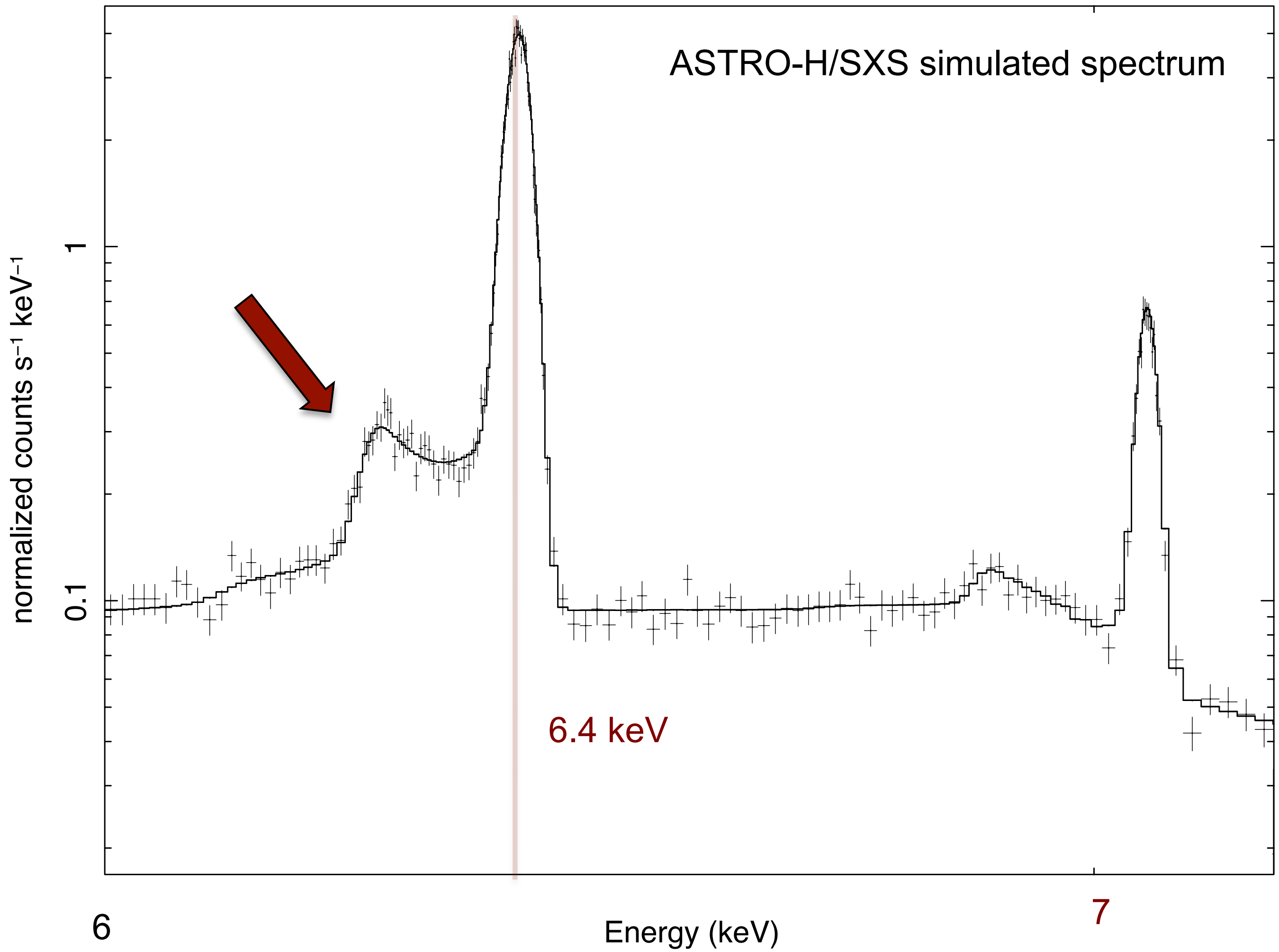
- A torus with a luminosity-dependent covering factor is able to reproduce the slope of the X-ray Baldwin effect for a large range of values of the equatorial column density.

- *ASTRO-H* (launch in 2015) will shed much light on the origin of the narrow Fe Kα line (FWHM 300 km/s @6.4keV)



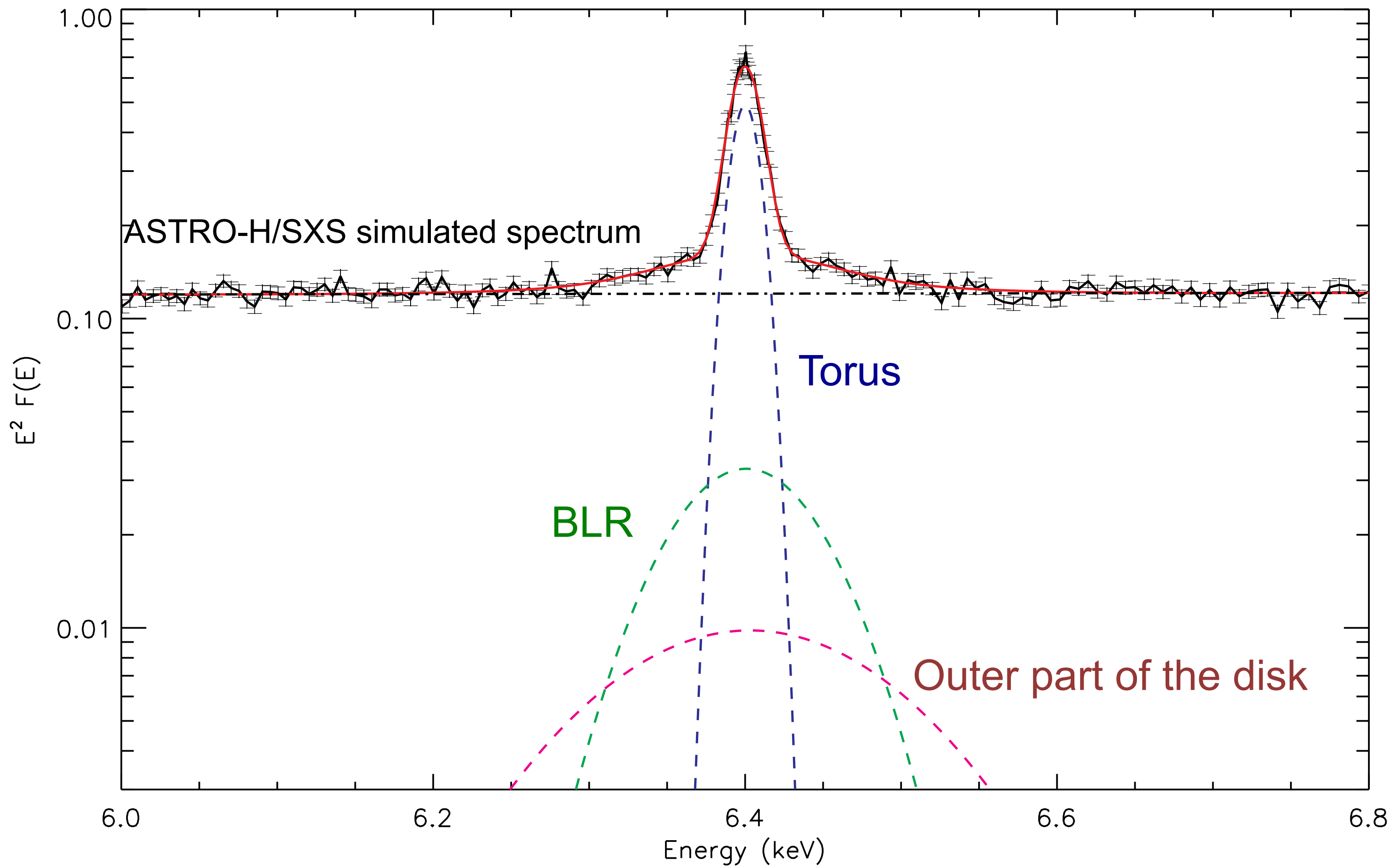
*ASTRO-H, Credits:JAXA*

# The narrow core of the iron Kα line



# The origin of the iron Kα line

Narrow core likely due to the contribution of several components



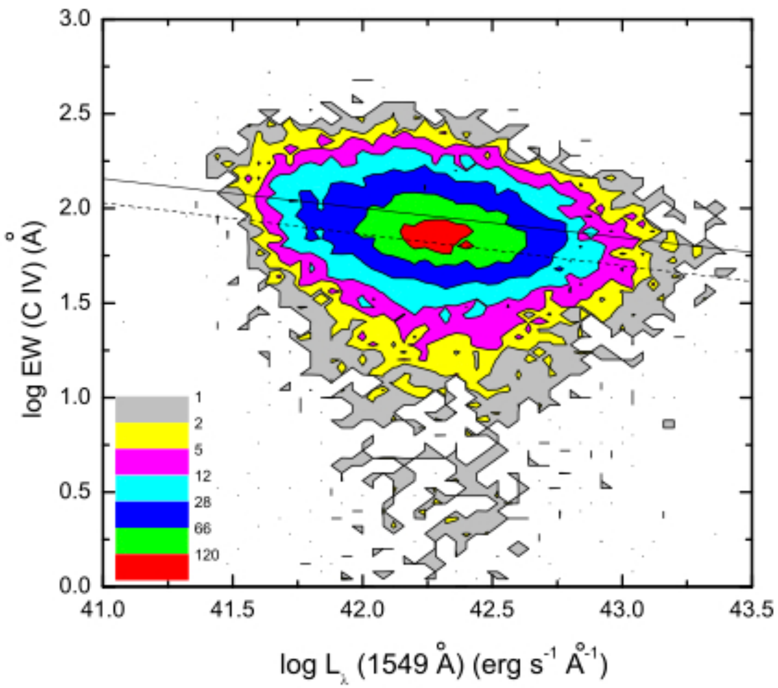
# The Baldwin effect

**Baldwin effect**: inverse proportionality of the EW of CIV (λ1549) and the luminosity *(Baldwin 1977)*

Possible explanations
- Change in ionizing continuum and gas metallicity?
- Change in the BLR covering factor?

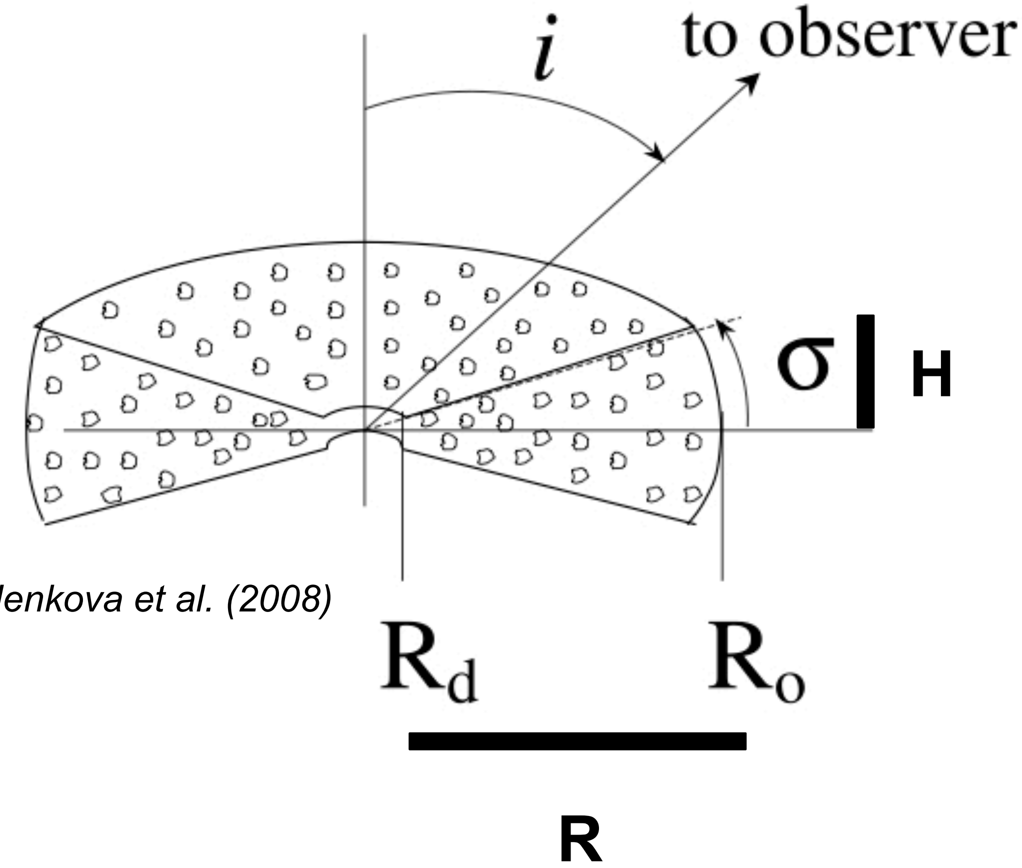
| | Sample | redshift | Slope |
|---|---|---|---|
| Xu+ 08 | 26223 | 1.5<z<5.1 | -0.156±0.001 |
| Kinney+90 | 200 | z<2.0 | -0.17±0.04 |
| Dietrich+02 | 788 | 0<z<5.0 | -0.14±0.02 |

Also found for:
Lyα, [CIII]λ1908, Si IVλ1396, MgIIλ2798 *(Dietrich et al. 2002)*, UV iron emission lines *(Green et al. 2001)*, mid IR lines *(Honig et al. 2008)*, forbidden lines *(Croom et al. 2002)*



*Xu et al. (2008)*

# Simulating the X-ray Baldwin effect




Nenkova et al. (2008)

**Fraction of obscured sources**

$$f_{obs} = \sin\sigma$$

# The X-ray Baldwin effect

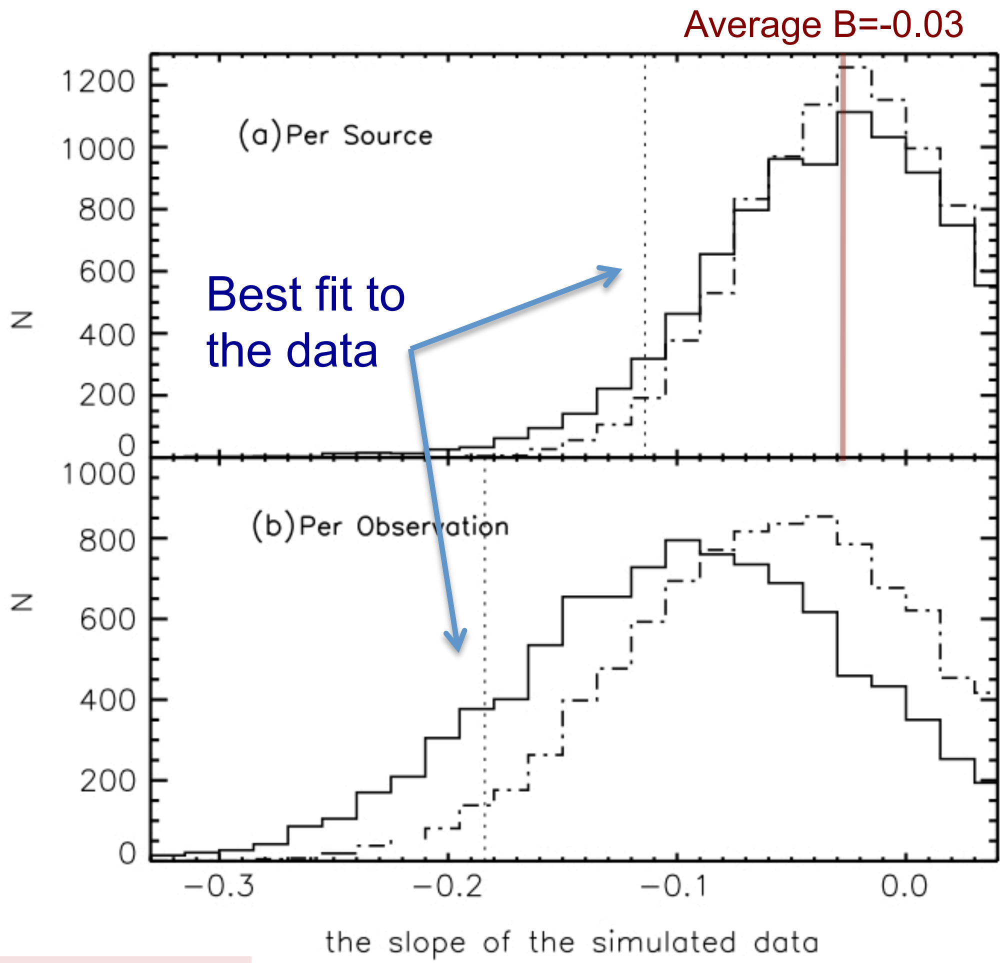
**Study of the influence of variability**

Shu et al. (2012) simulating spectra using

$$F_{\text{var}} \propto L_X^{-0.135}$$

*Markowitz & Edelson (2004)*

Only a very small percentage of their simulations (8%) can reproduce the observed X-ray Baldwin effect




*Shu et al. (2012)*

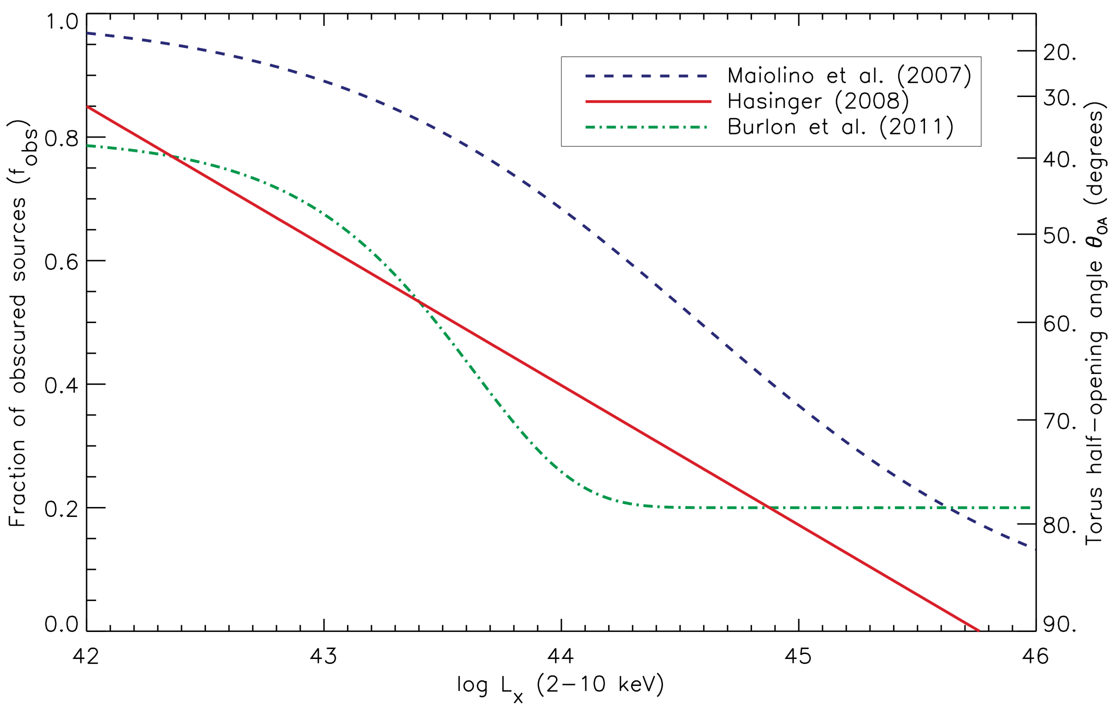
**<u>Variability alone cannot account for the whole correlation</u>**

# Luminosity-dependent unification

**The fraction of absorbed AGN ($f_{obs}$) decreases with increasing luminosities**

*e.g., Lawrence (1991), Ueda et al. (2003), Simpson (2005), Maiolino et al. (2007), Hasinger (2008), Fiore et al. (2009), Beckmann et al. (2009), Mor et al. (2009), Burlon et al. (2011), Ueda et al. (2011), Hiroi et al. (2012)*

***Is it related to a decrease of the covering factor of the obscuring torus with the luminosity?***




*Ricci et al. 2013a, A&A 553, 29*

# The X-ray Baldwin effect

**<u>Possible explanations</u>**

- Due to variation of the relativistically broadened component? *(Nandra et al. 1997)*
- **Influence of radio-loud (RL) AGN ?**
  ***(Jimenez Bailon et al. 2005)***
- Related to continuum variability? *(Jiang et al. 2006)*
- Due to the dependence of the continuum with $\lambda_{Edd}$?
  *(Ricci et al. 2013b)*
- Luminosity-dependent unification?
  *(Page et al. 2004, Ricci et al. 2013a)*

# The X-ray Baldwin effect

- Studies of large radio-quiet (RQ) AGN samples have confirmed the X-ray Baldwin effect *(Bianchi et al. 2007, Shu et al. 2012)*
- X-ray Baldwin effect found also in RL AGN *(Grandi et al. 2006)*

| | Sample | Observatory | Slope |
|---|---|---|---|
| Shu+ 12 | 32 (RQ) | *Chandra*/HEG | -0.18±0.03 |
| Shu+ 10 | 33 (RQ+RL) | *Chandra*/HEG | -0.22±0.03 |
| Bianchi+ 07 | 157 (RQ) | *XMM-Newton*/EPIC | -0.17±0.03 |
| Jimenez Bailon+ 05 | 38 (RQ) | *XMM-Newton*/EPIC | -0.06±0.20 |
| Zhou & Wang 05 | 66 (RQ+RL) | *XMM-Newton*/EPIC | -0.19±0.04 |
| Page+ 04 | 53 (RQ+RL) | *XMM-Newton*/EPIC | -0.17±0.08 |

*Most studies found a slope of* $B \cong -0.20$