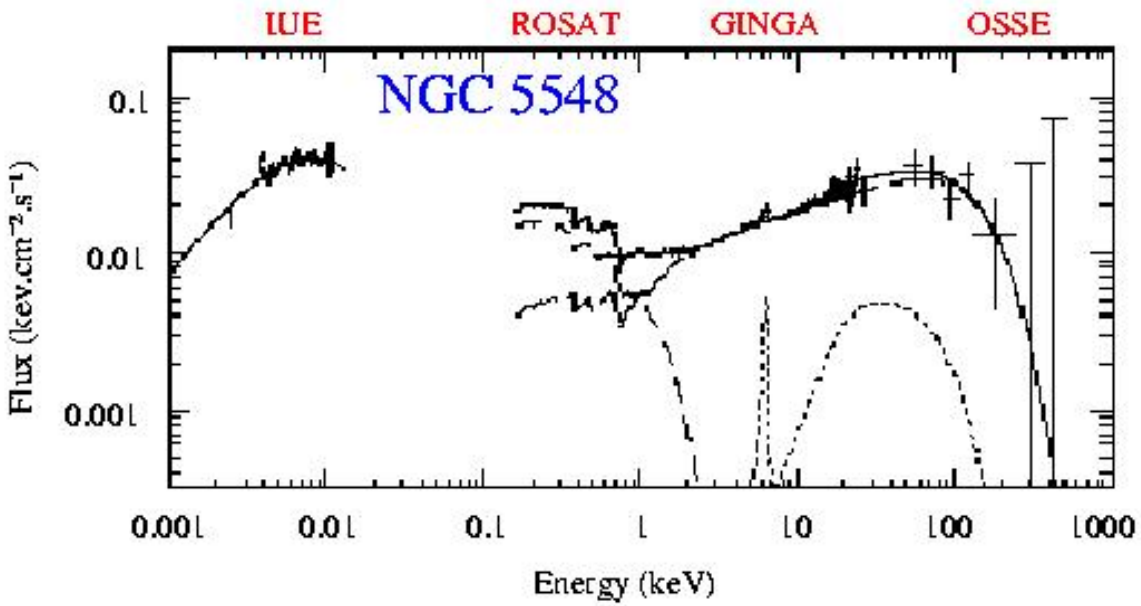
Multiwavelength campaign on Mkn 509

Testing realistic comptonization models

P.O. Petrucci

Collaborators: S. Paltani, J. Malzac, J.S. Kaastra, M. Cappi, G. Ponti, B. De Marco, G.A. Kriss, K.C. Steenbrugge, S. Bianchi, G. Branduardi-Raymont, M. Mehdipour, E. Costantini, M. Dadina, and P. Lubinski

UV-X-Gamma spectrum of Seyfert galaxies



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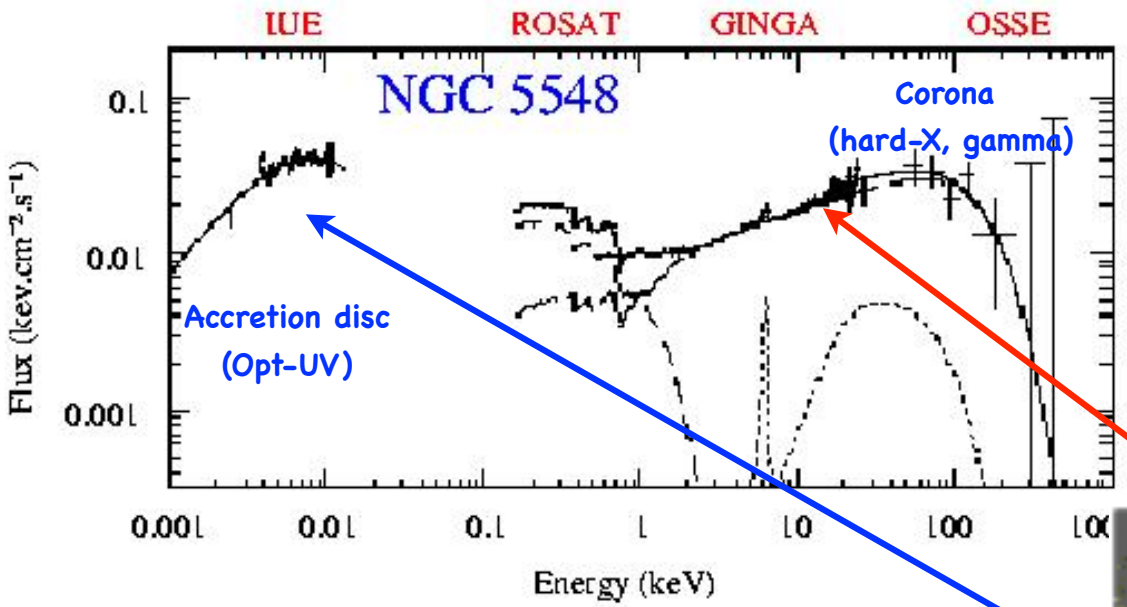
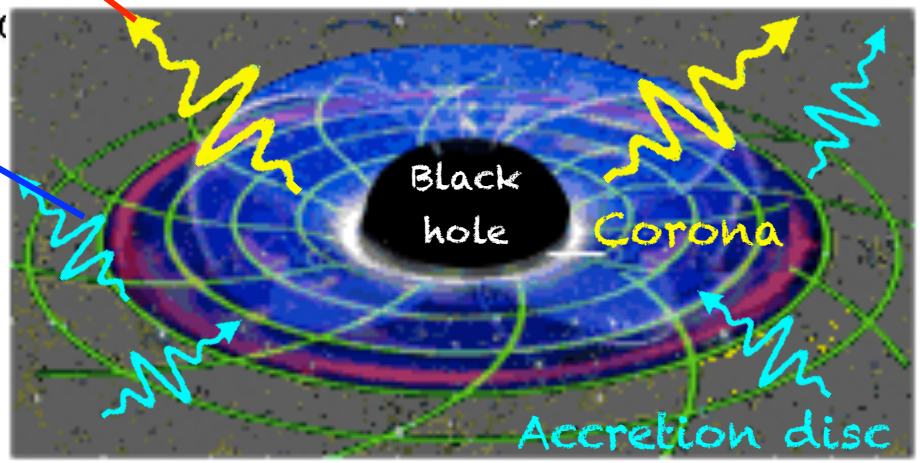
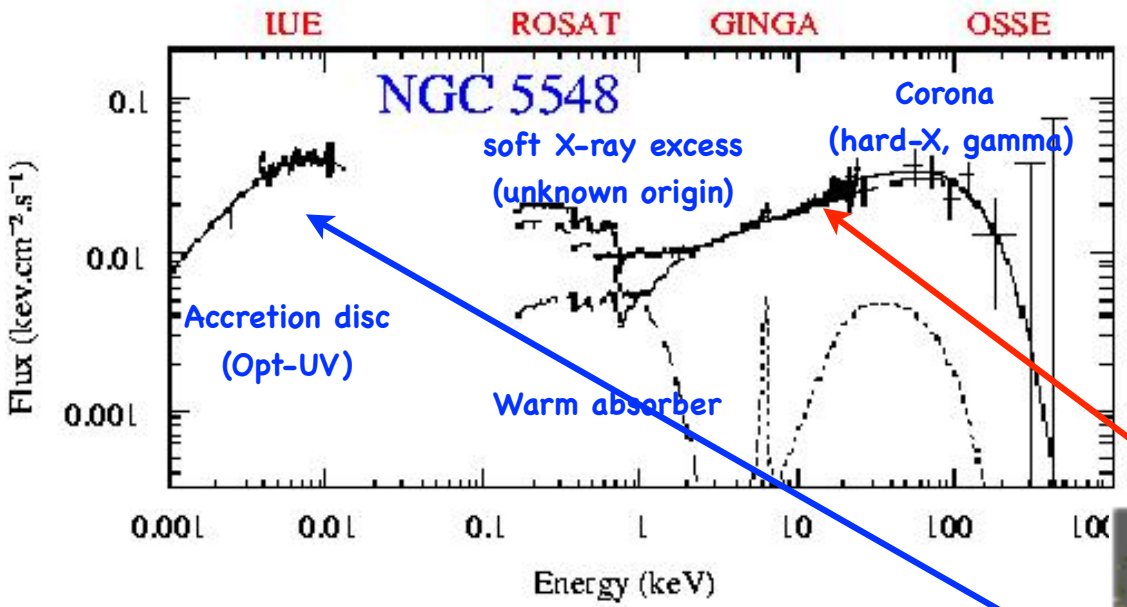
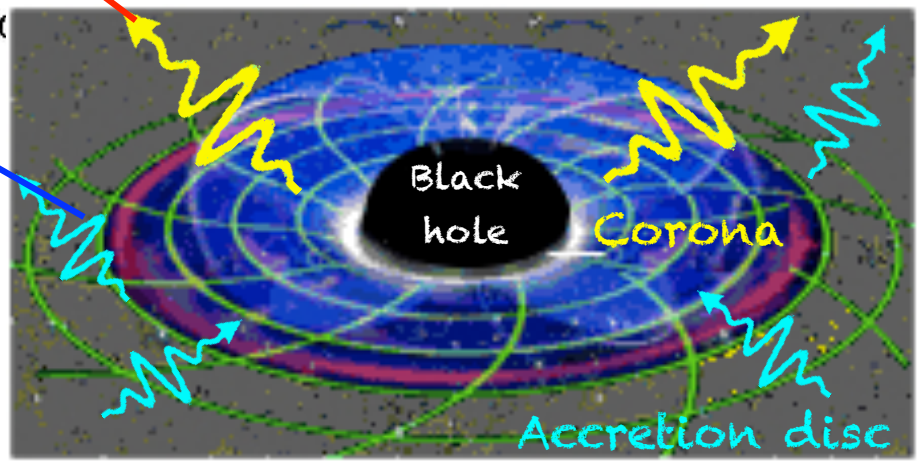


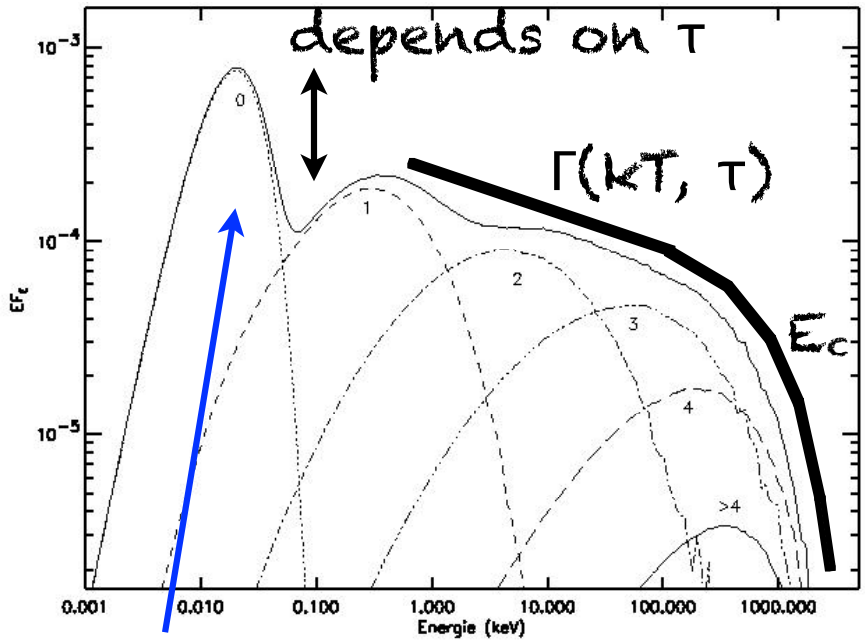


UV-X-Gamma spectrum of Seyfert galaxies





Comptonisation Spectrum



0th order
i.e. soft photons
crossing the corona
without being scattered

Compton spectrum often approximated by a cut-off power law

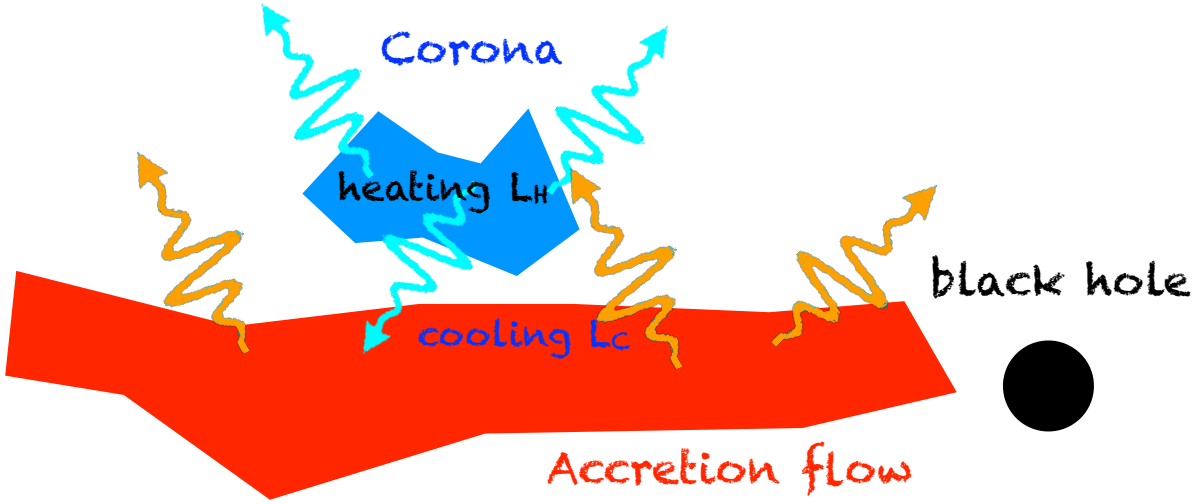
$$F_E \propto E^{-\Gamma(kT,\tau)} \exp - \left(\frac{E}{E_c(kT)} \right)$$

E_c depends on kT

Compton parameter

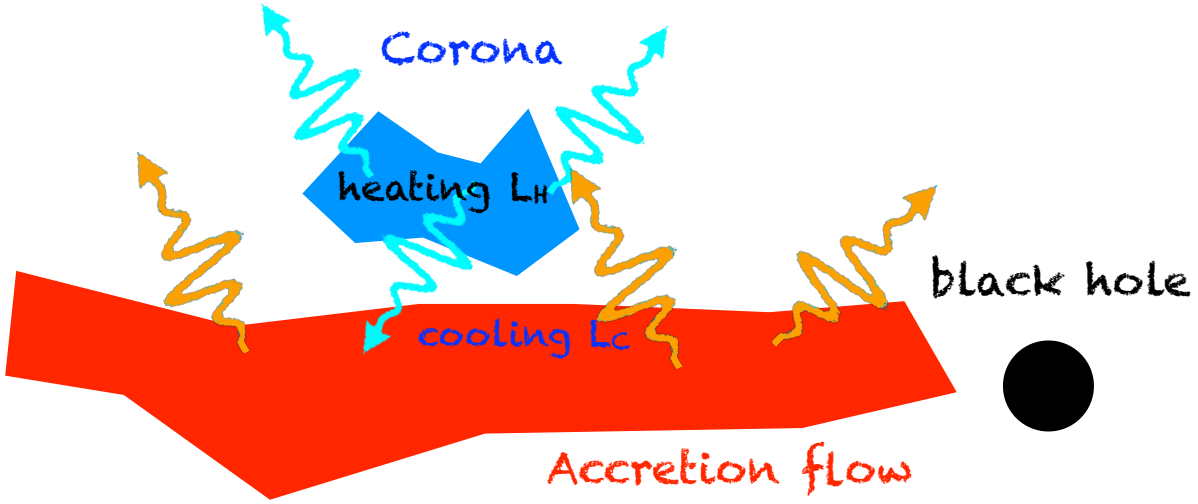
$$y = 4 \left(\frac{kT_e}{m_e c^2} \right) \tau$$

Energetics dependency



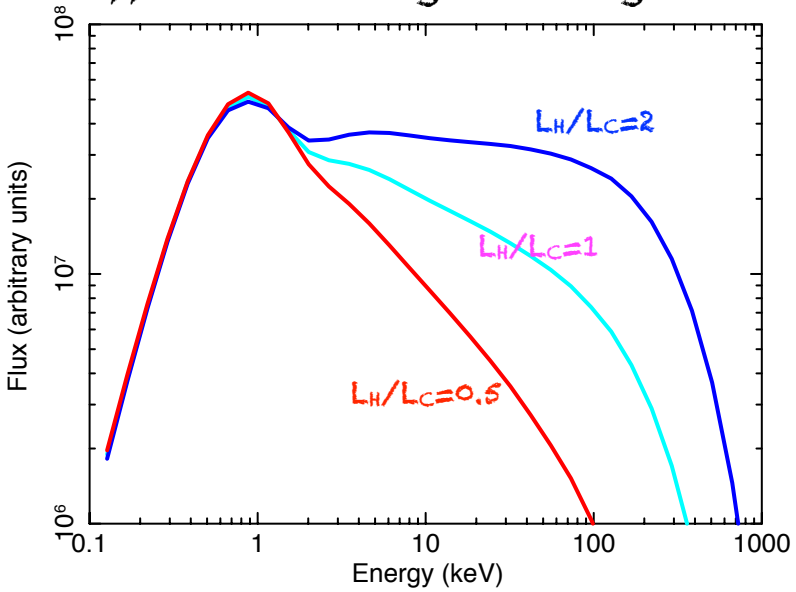
Spectral shape depends on L_H/L_C

Energetics dependency

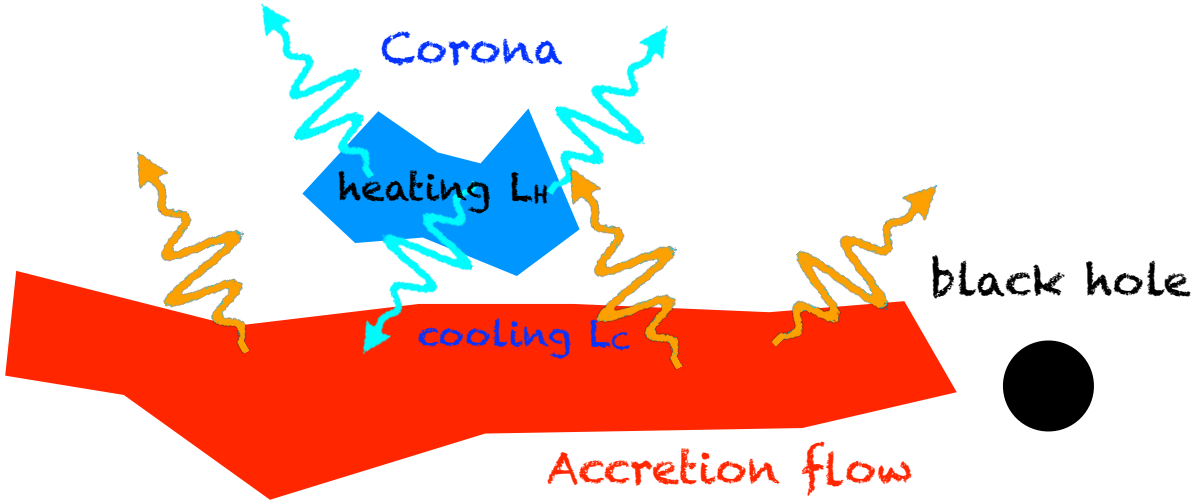


Spectral shape depends on L_H/L_C

Spherical geometry, τ=0.1 but different Heating/Cooling ratios



Energetics dependency



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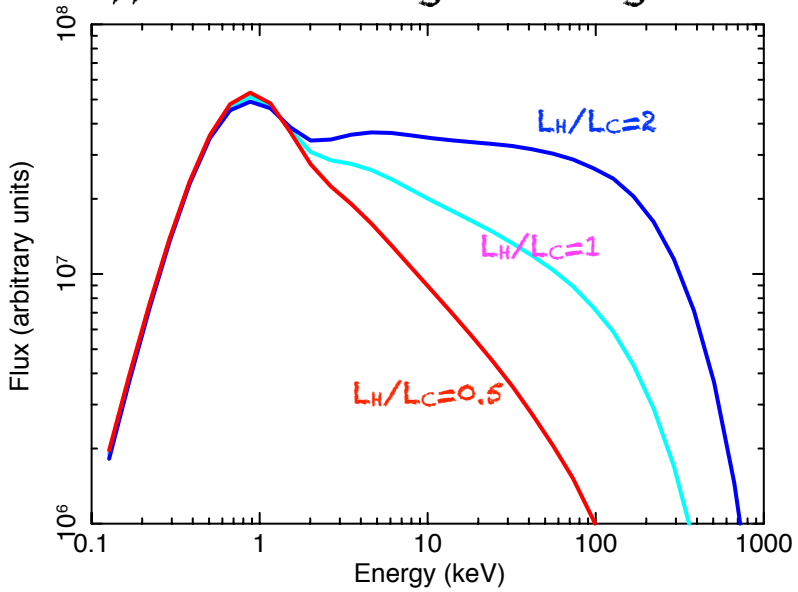
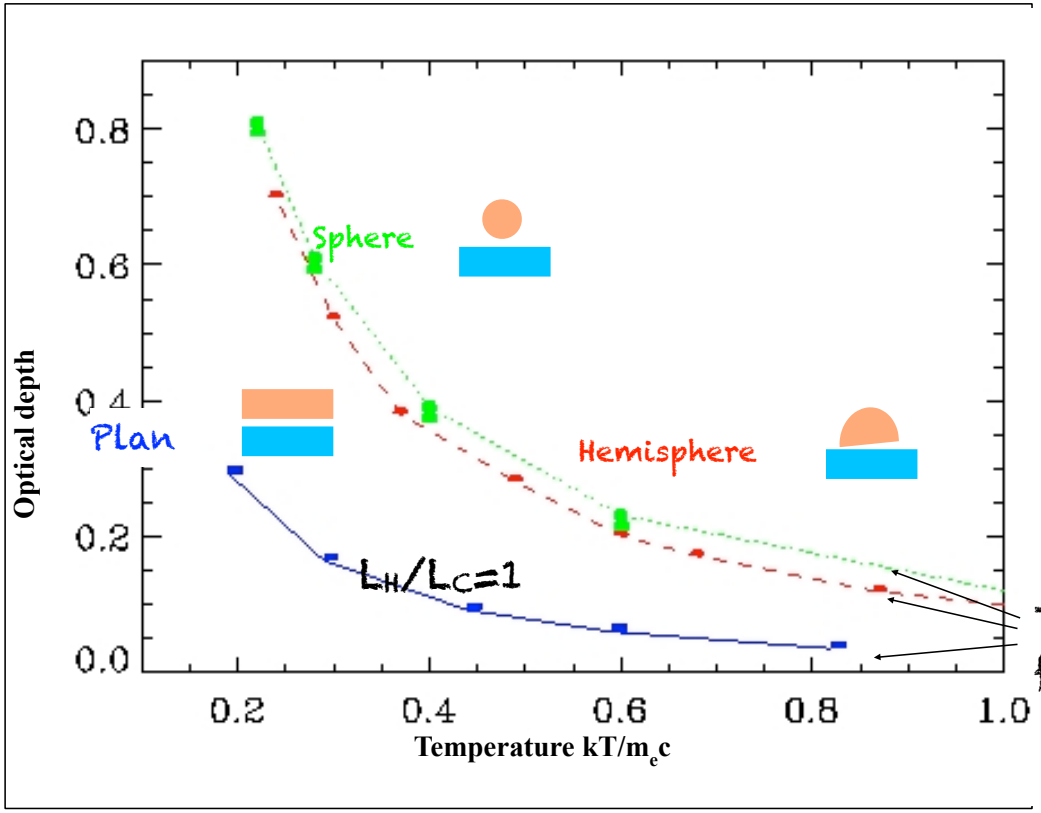


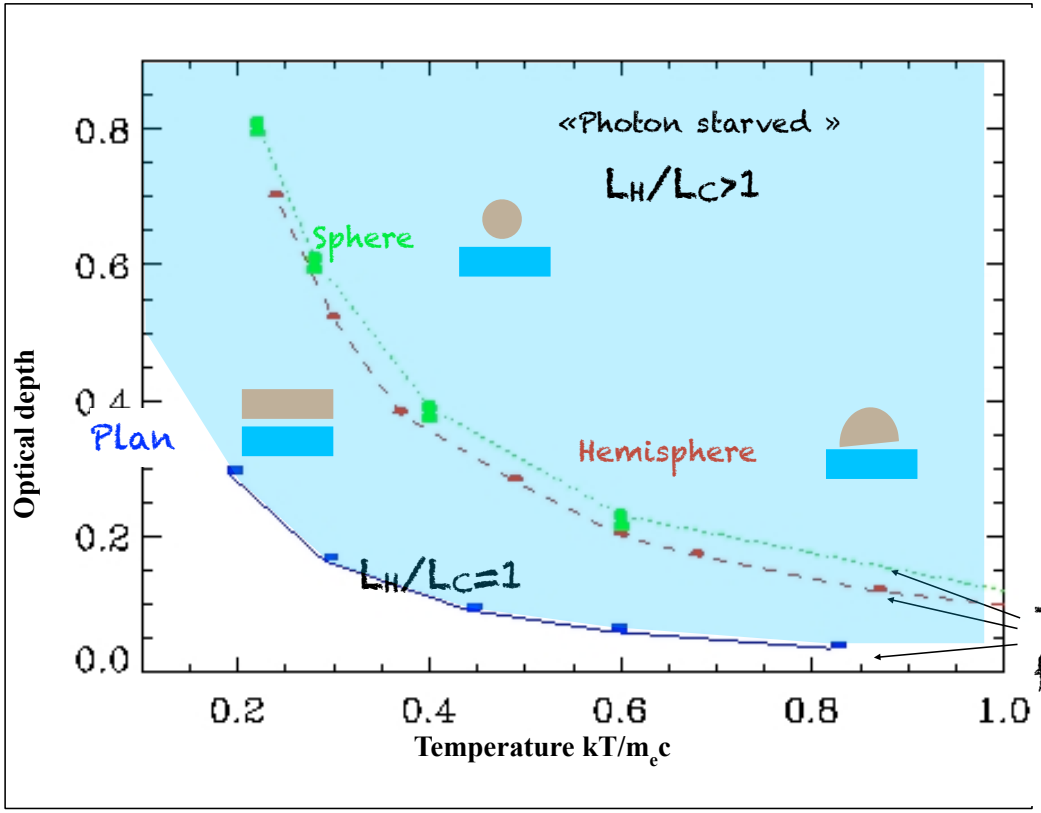
e.g. slab corona above a passive disc → L_H/L_C=1

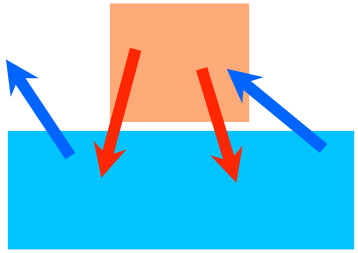
Radiative equilibrium



Theoretical predictions for different ratio L_H/L_C

Radiative equilibrium





Theoretical predictions
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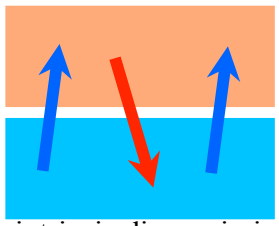
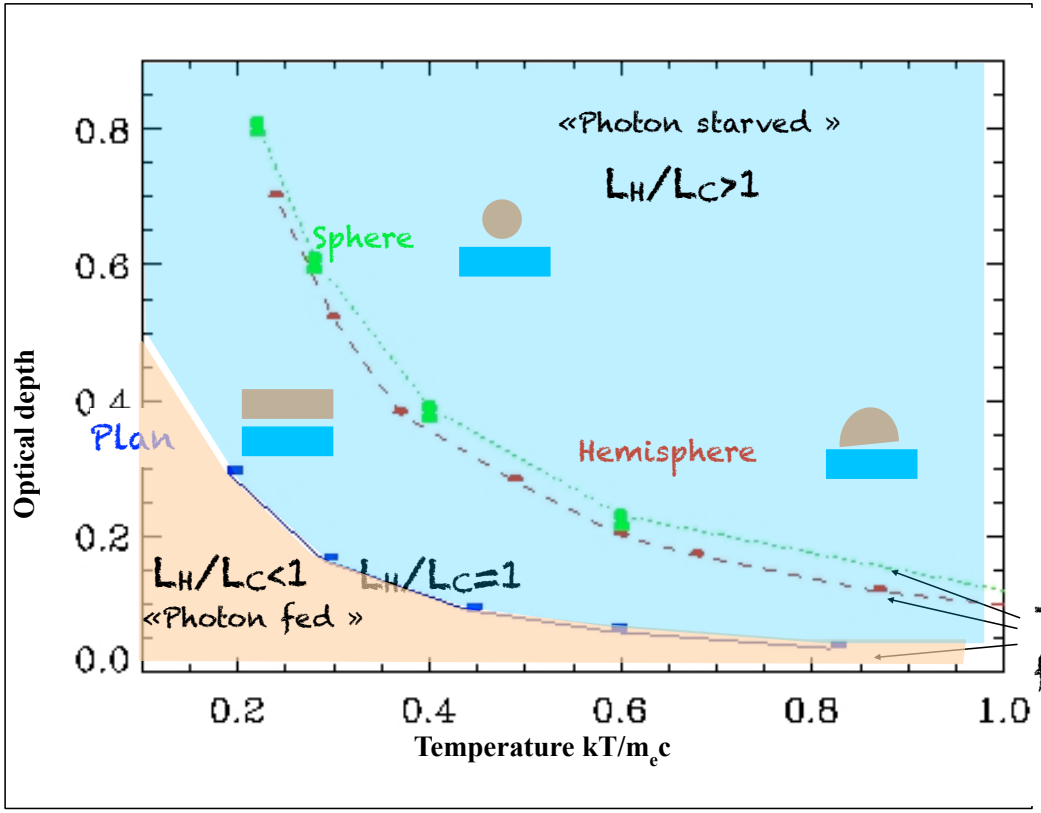
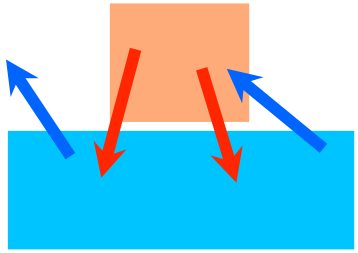
Radiative equilibrium



Ex: intrinsic disc emission

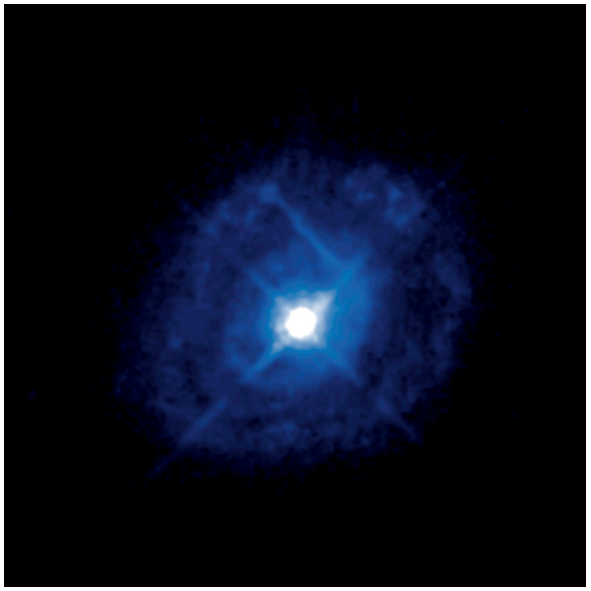




Theoretical predictions for different ratio L_H/L_C

The case of Mrk 509

- Seyfert 1, $M_{BH} \sim 10^8 M_{sun}$
- One of the brigtest Seyfert in X-rays
- X-ray spectrum with all the common spectral components
  - ✓Big blue bump
  - ✓iron line (+ reflection hump)
  - ✓ soft X-ray excess
  - ✓ WA



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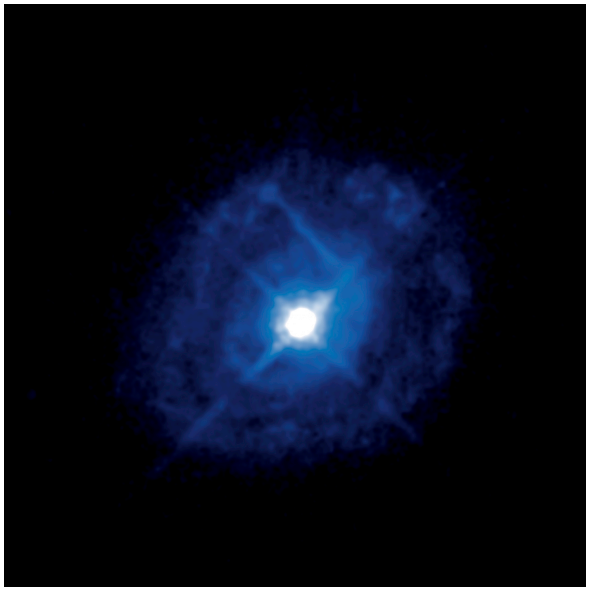
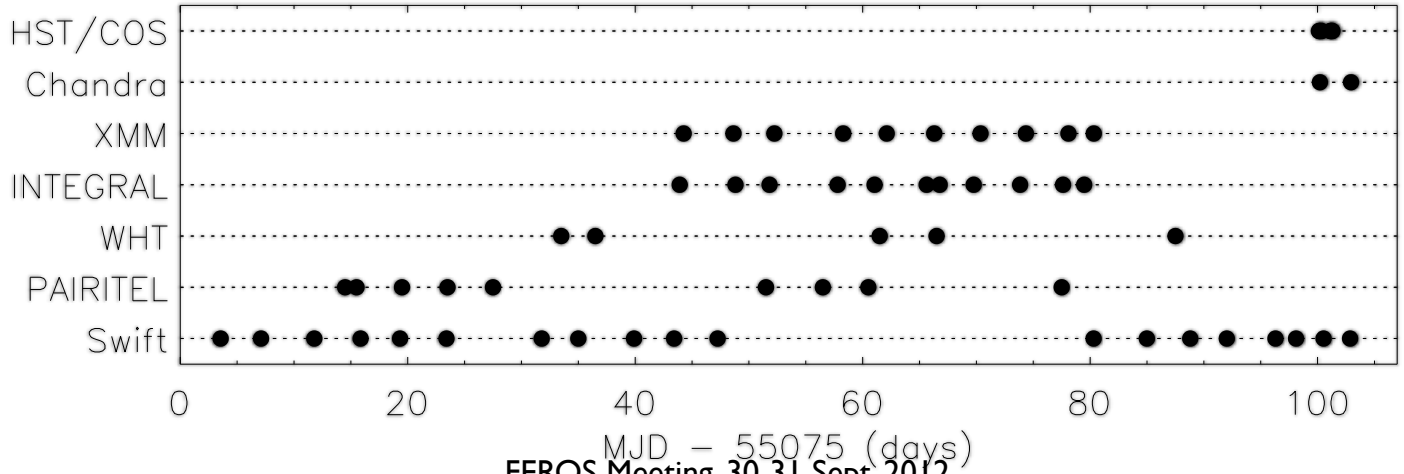
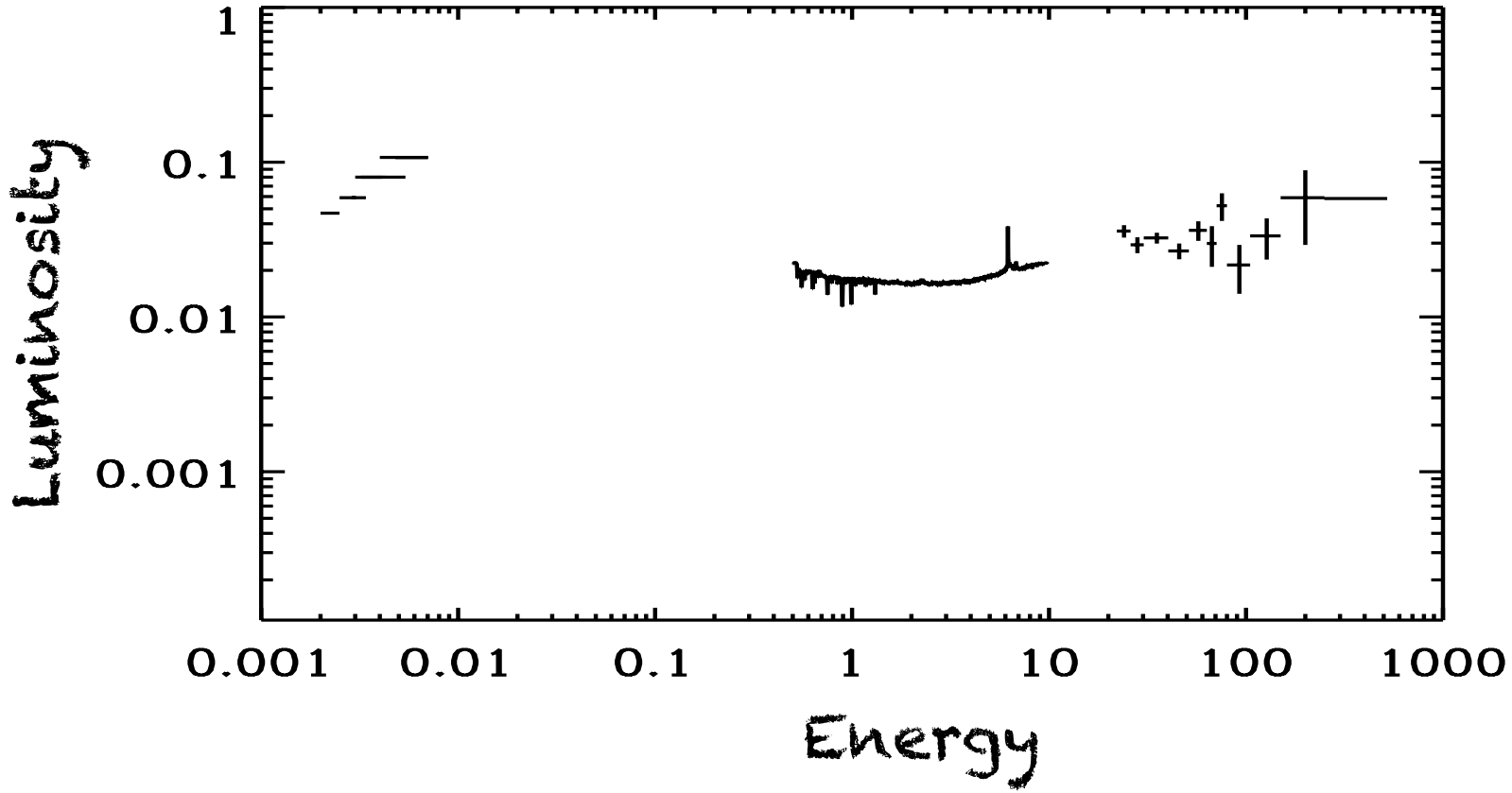


- Broad band monitoring coordinated by J. Kaastra (SRON, Netherland)



Mean spectrum



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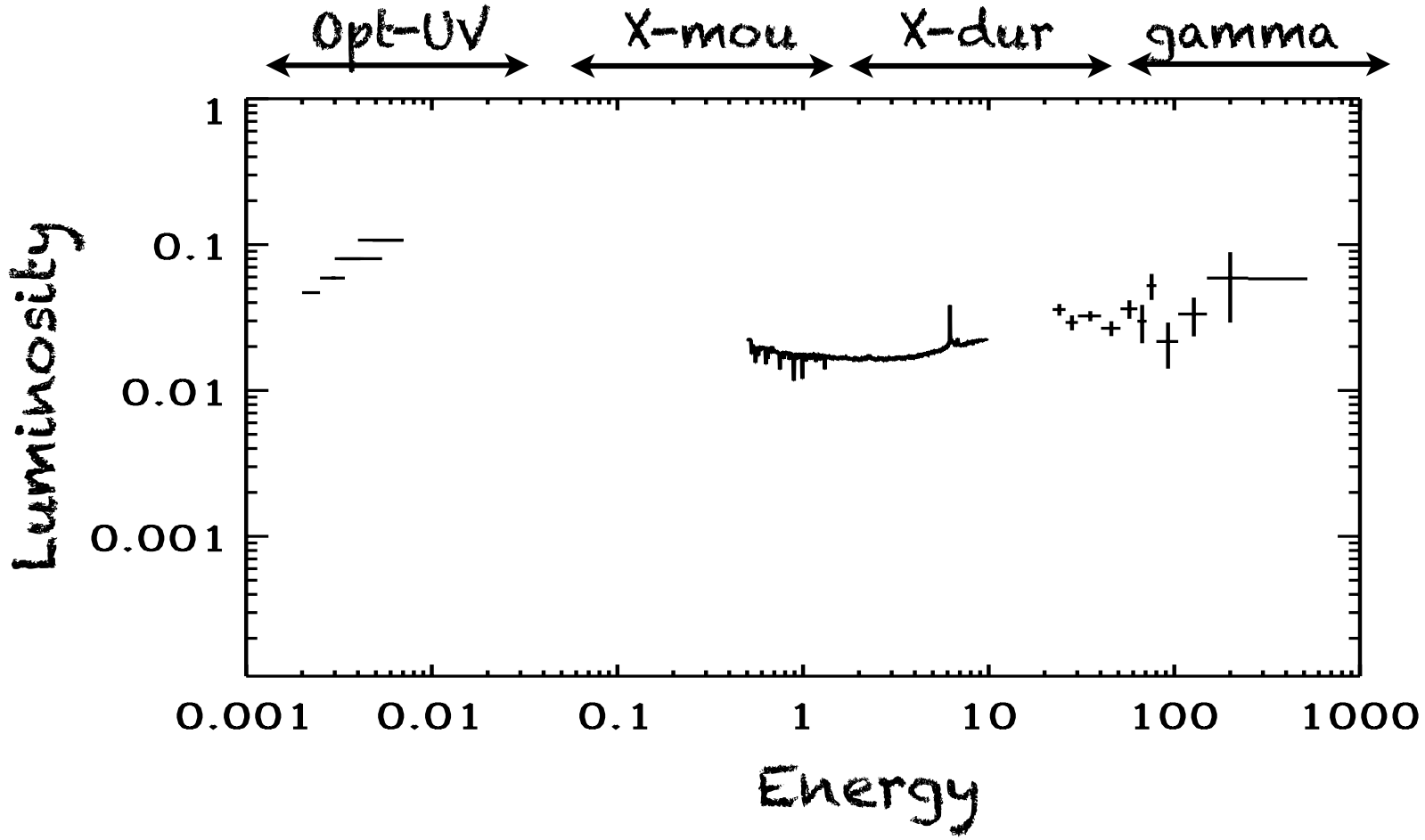
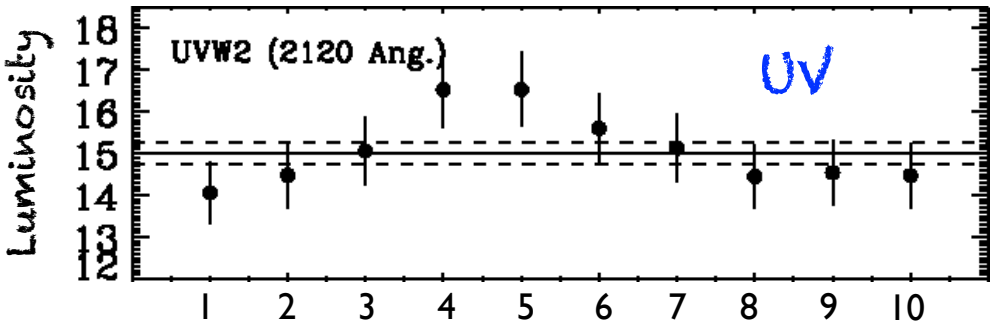
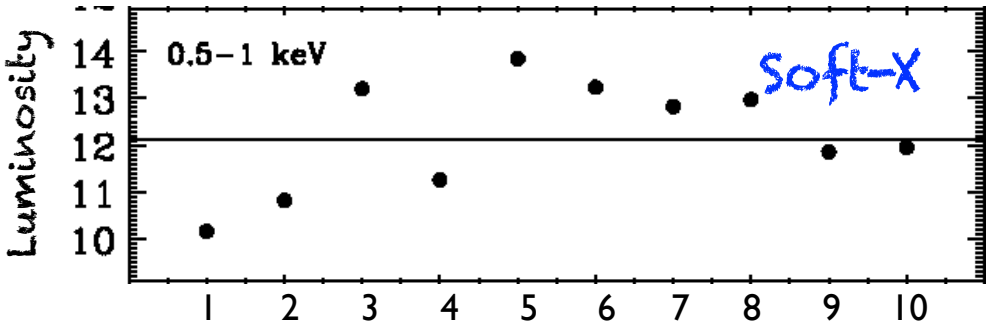
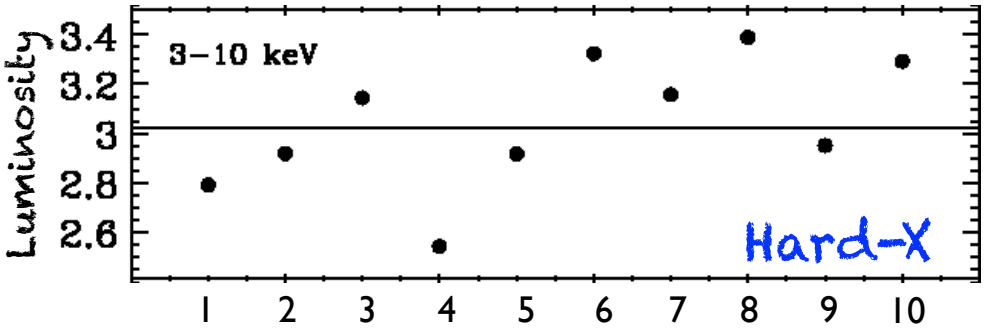


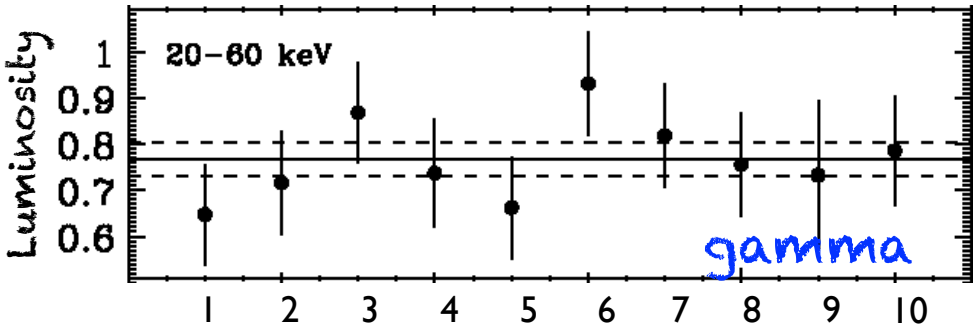
Light curves

Light curves









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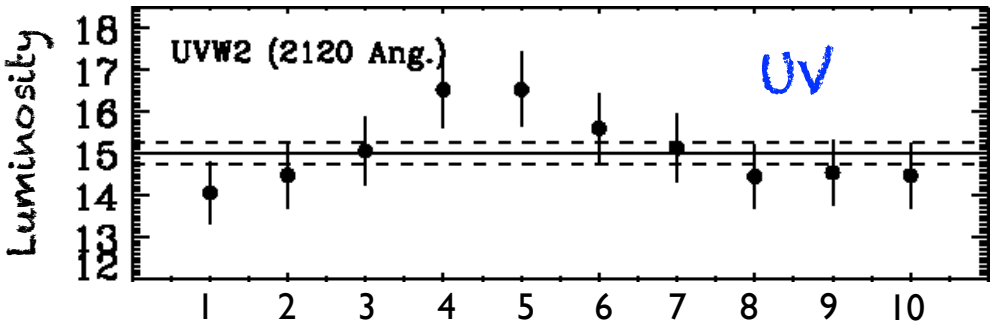
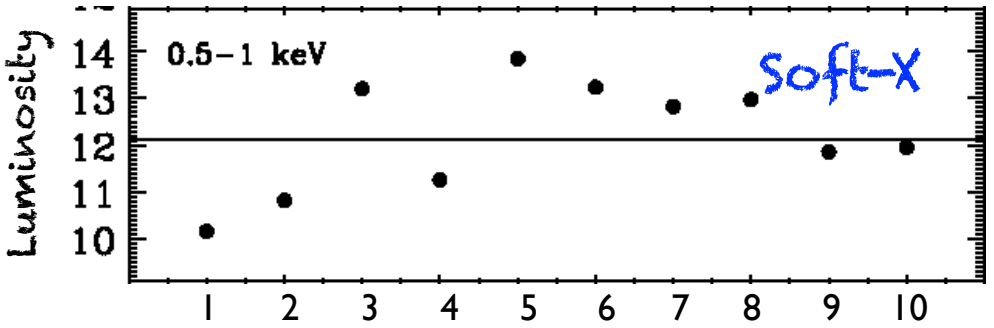
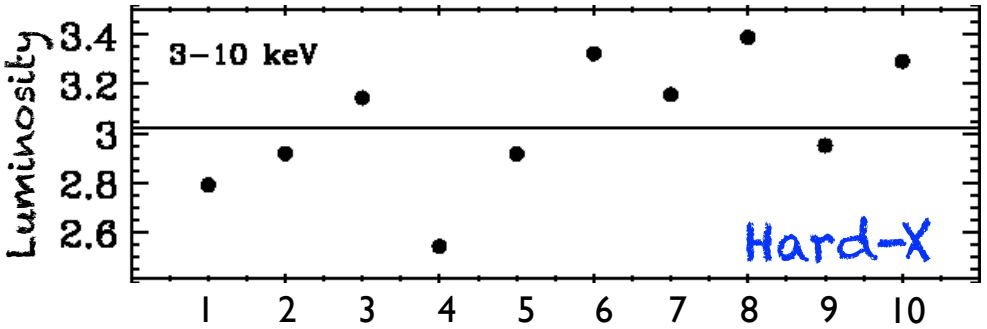
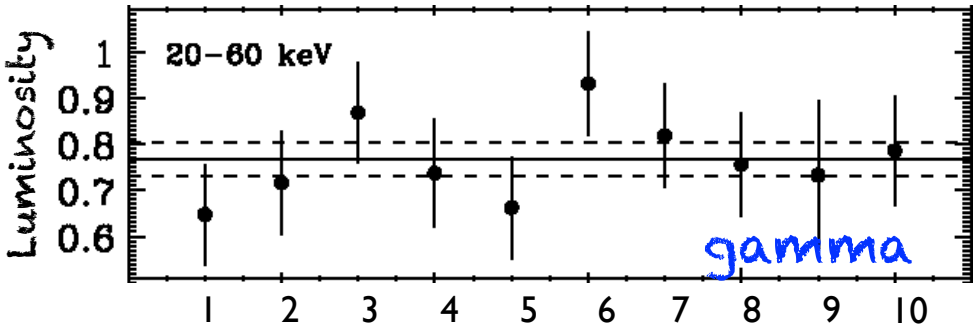


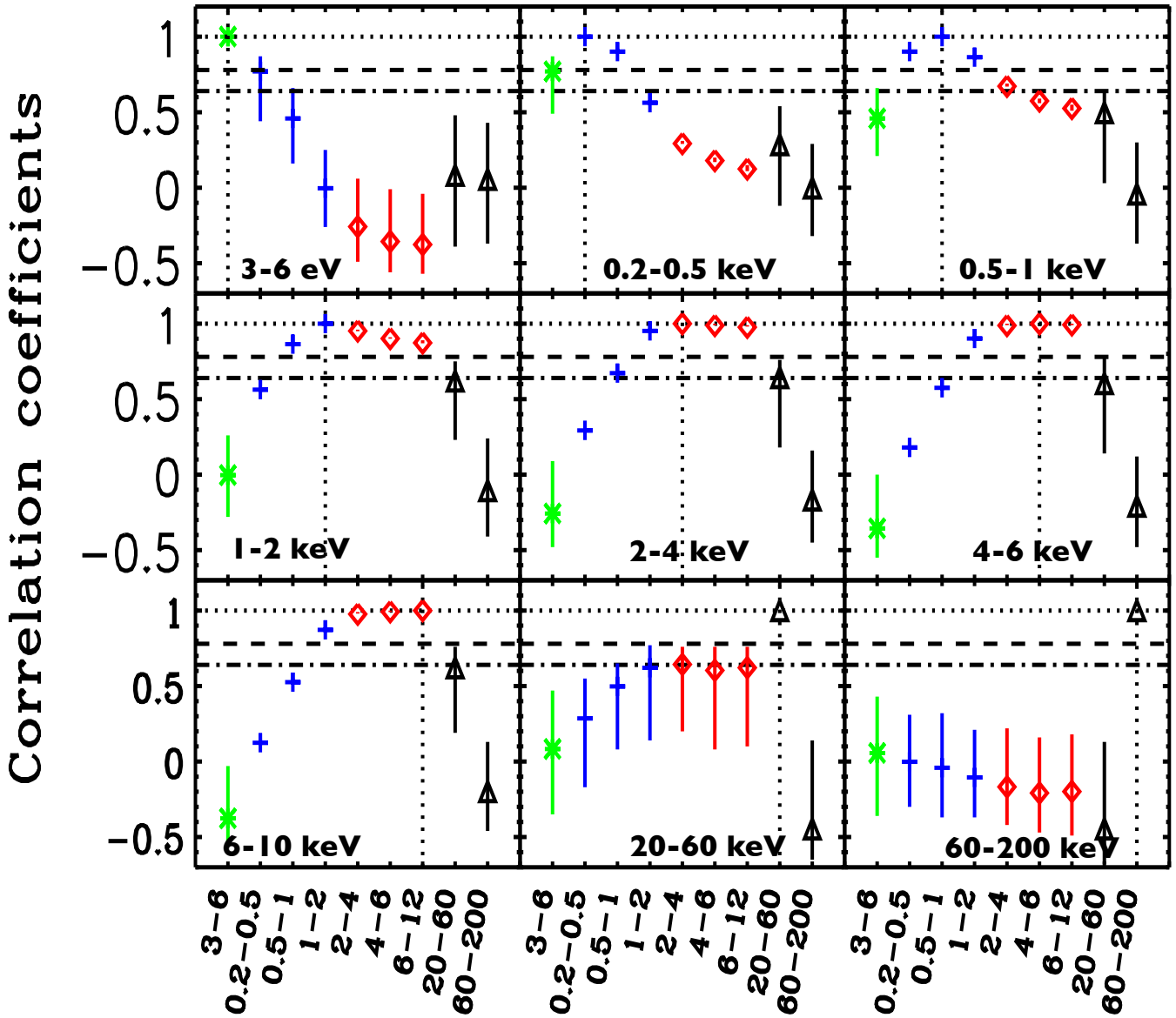






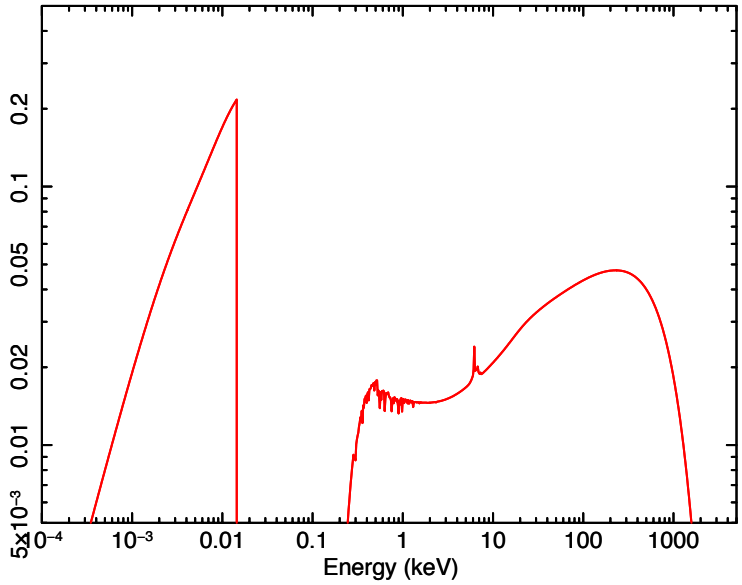
Variability in UV, X. Not clear in gamma (limited by stat.)

Correlations

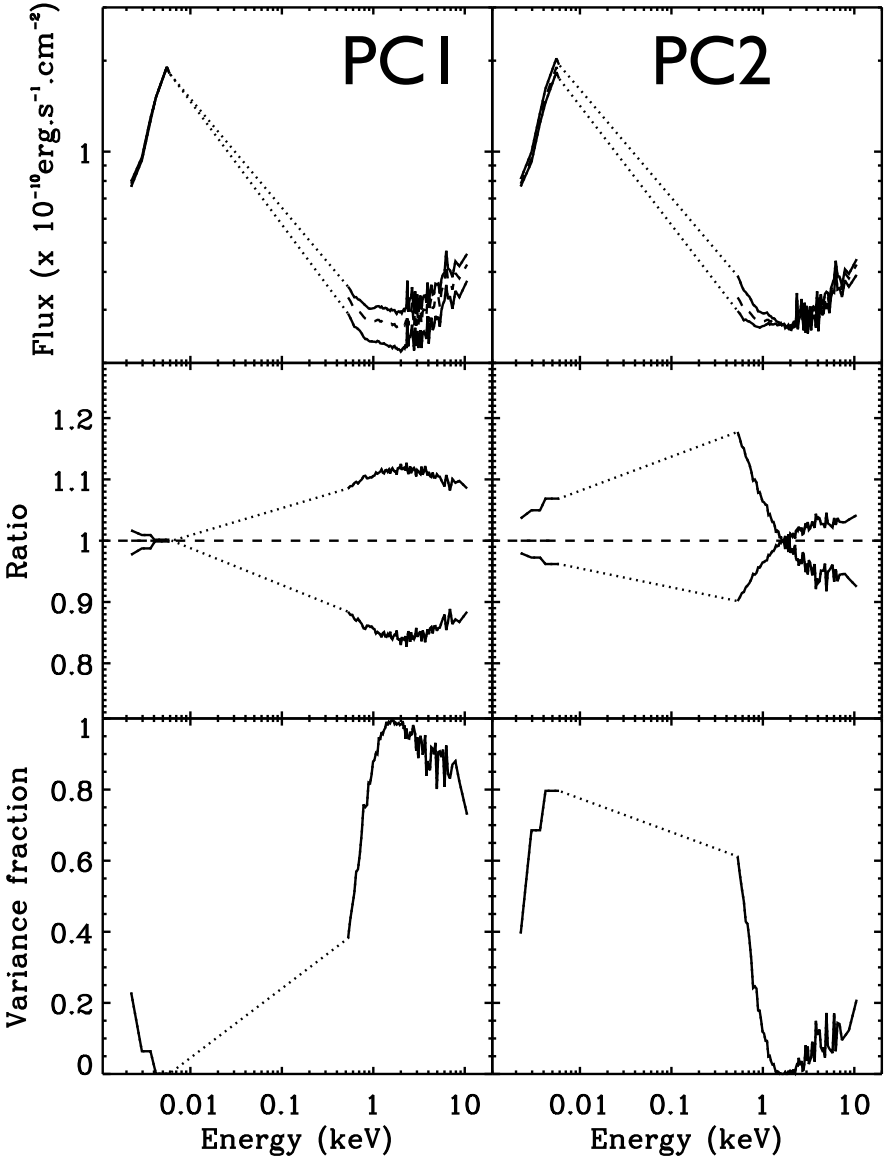


Principal Component Analysis

PCA transform a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components.



In agreement with two independent spectral components



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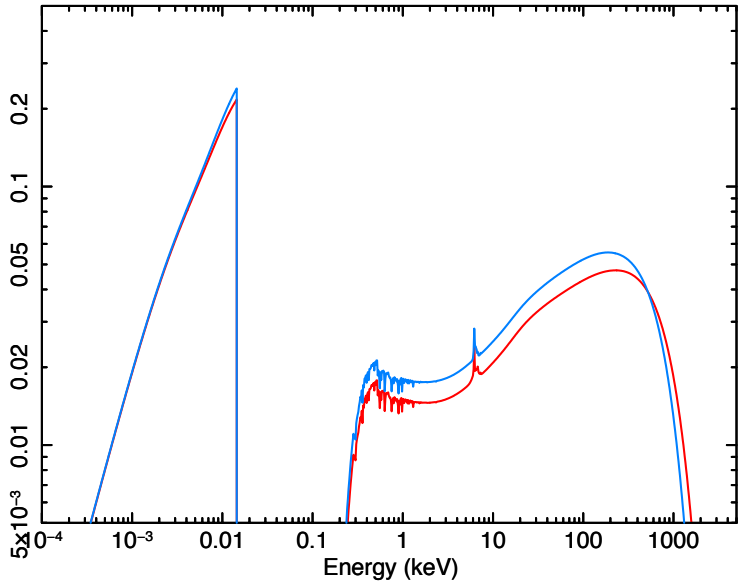

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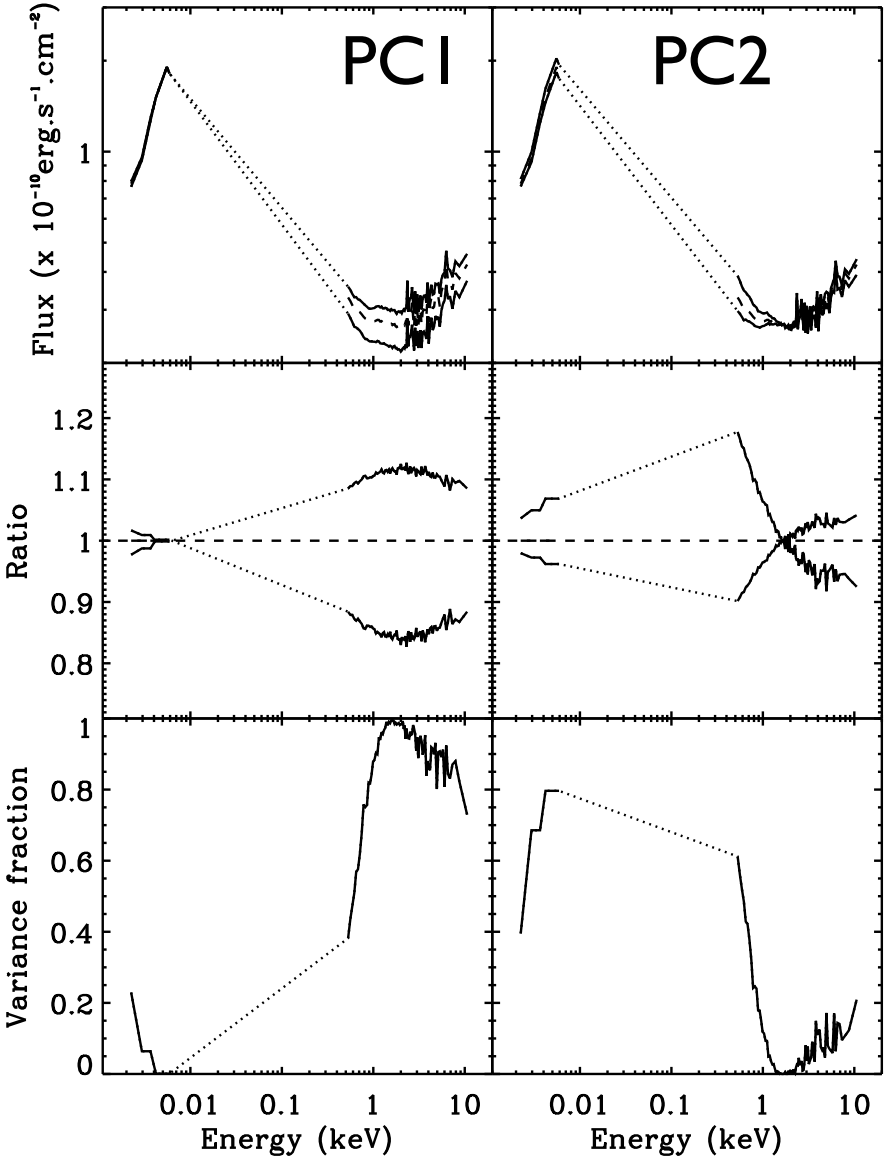
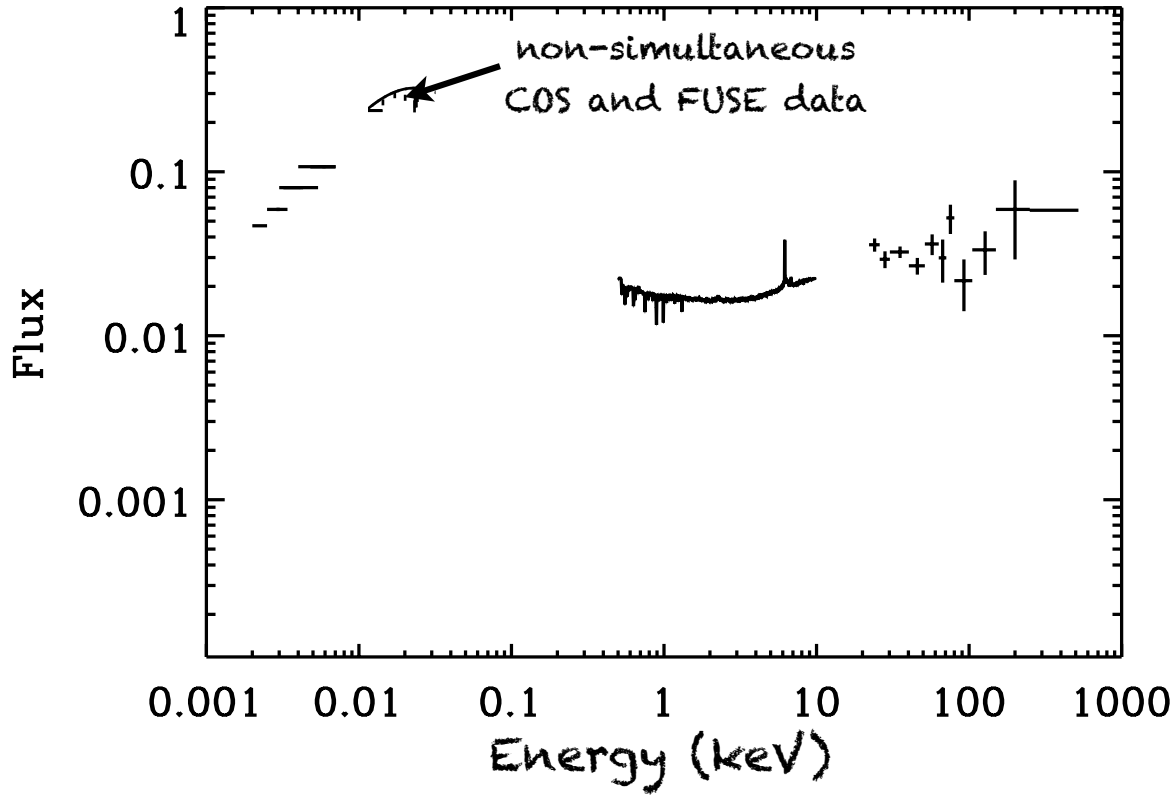
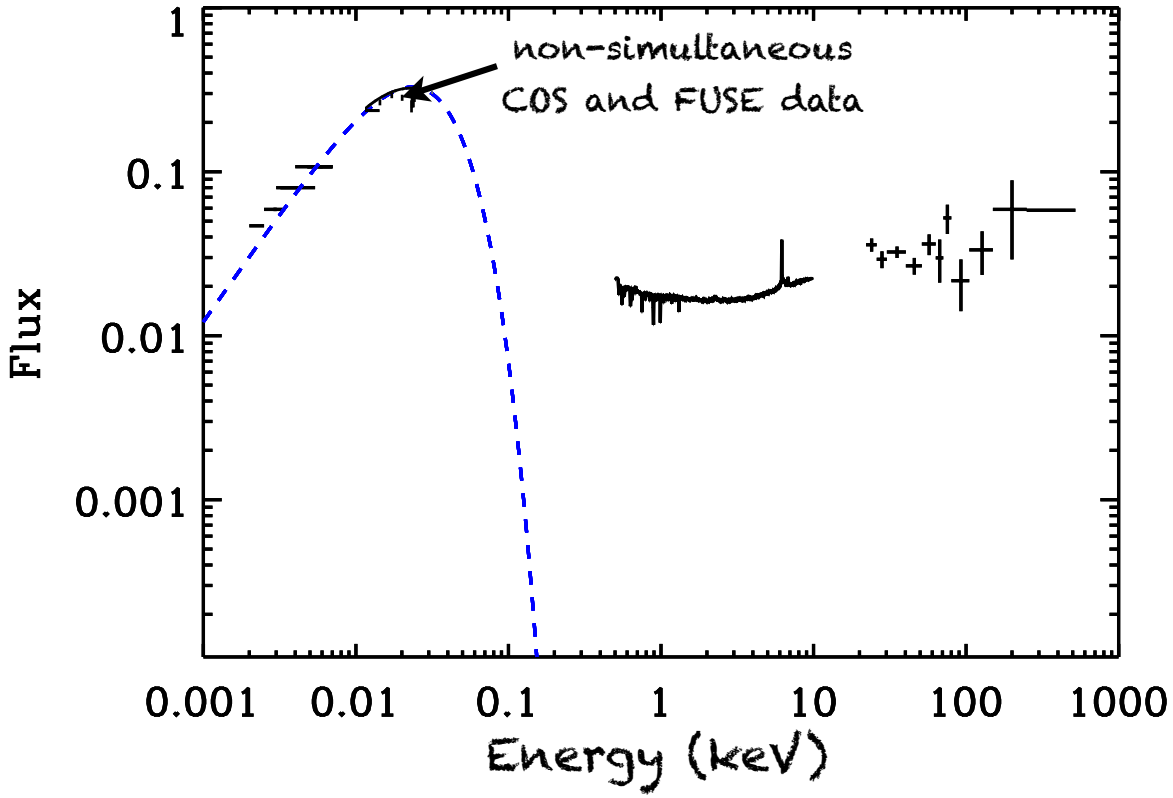


The Model

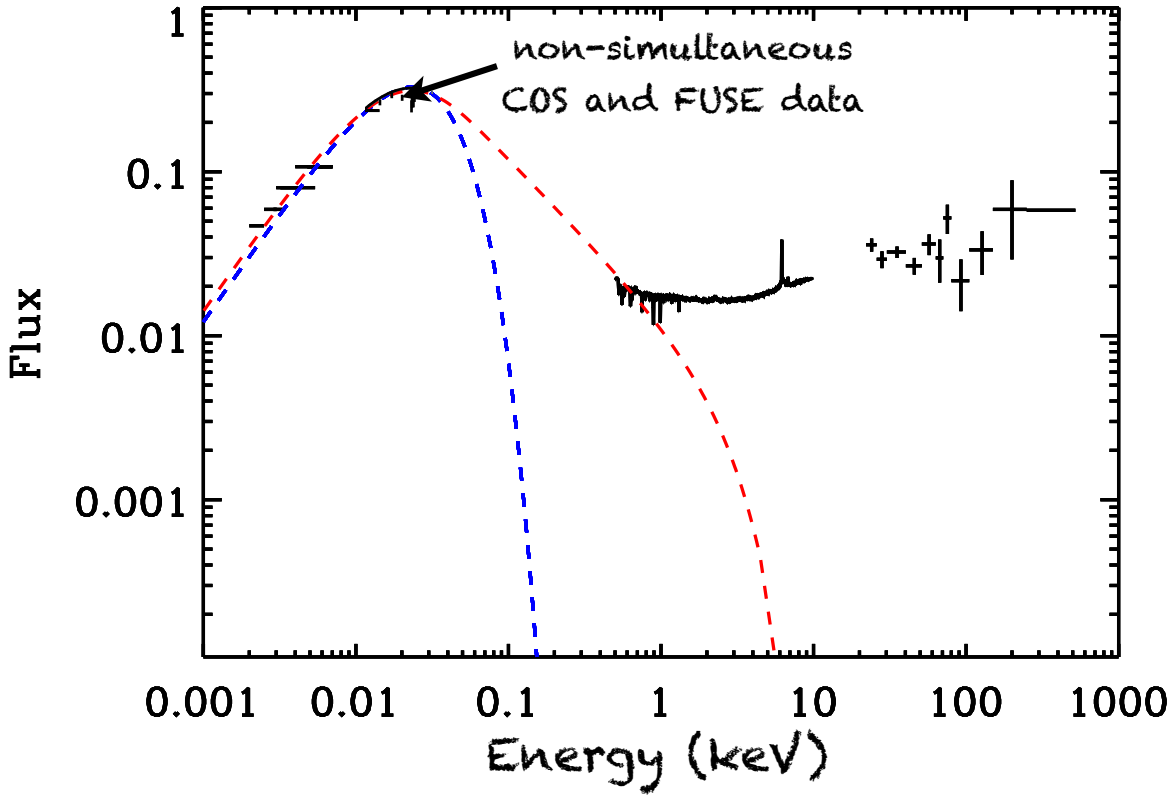

non-simultaneous
COS and FUSE data
Flux
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
1000
Energy (keV)

The Model



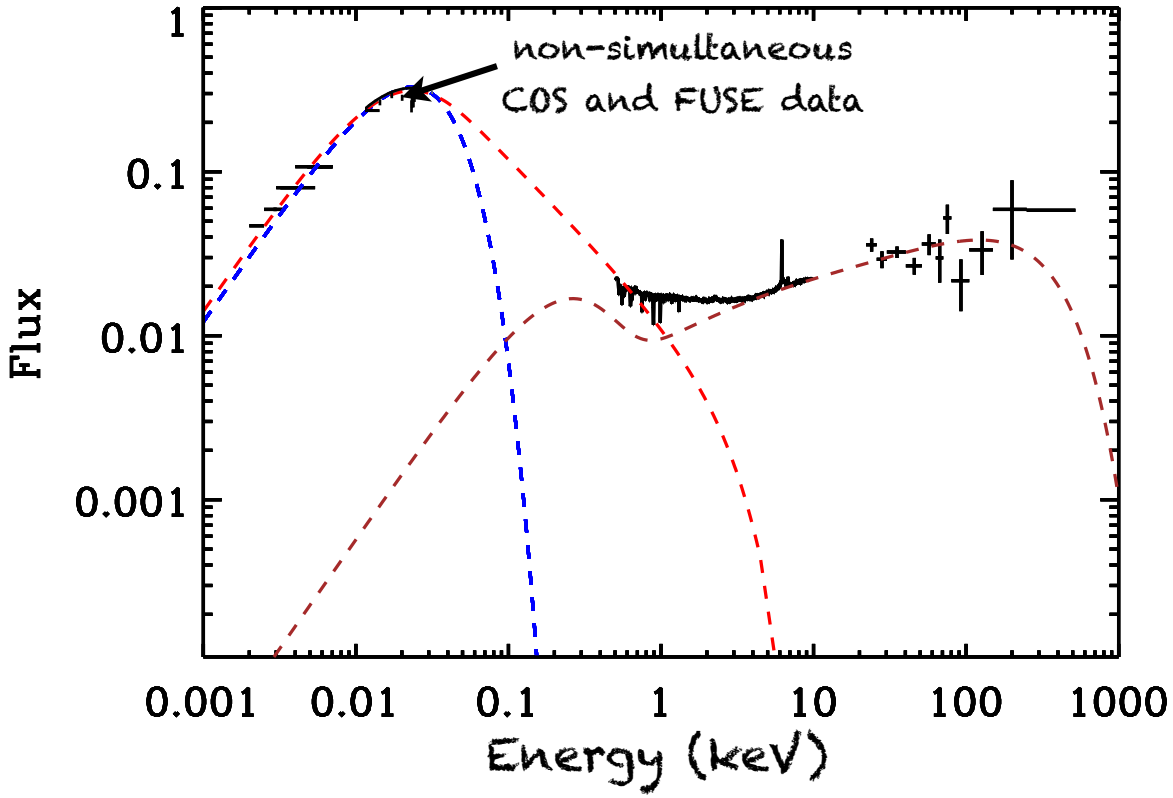
- A multi-black body disc to fit the optical-UV data

The Model



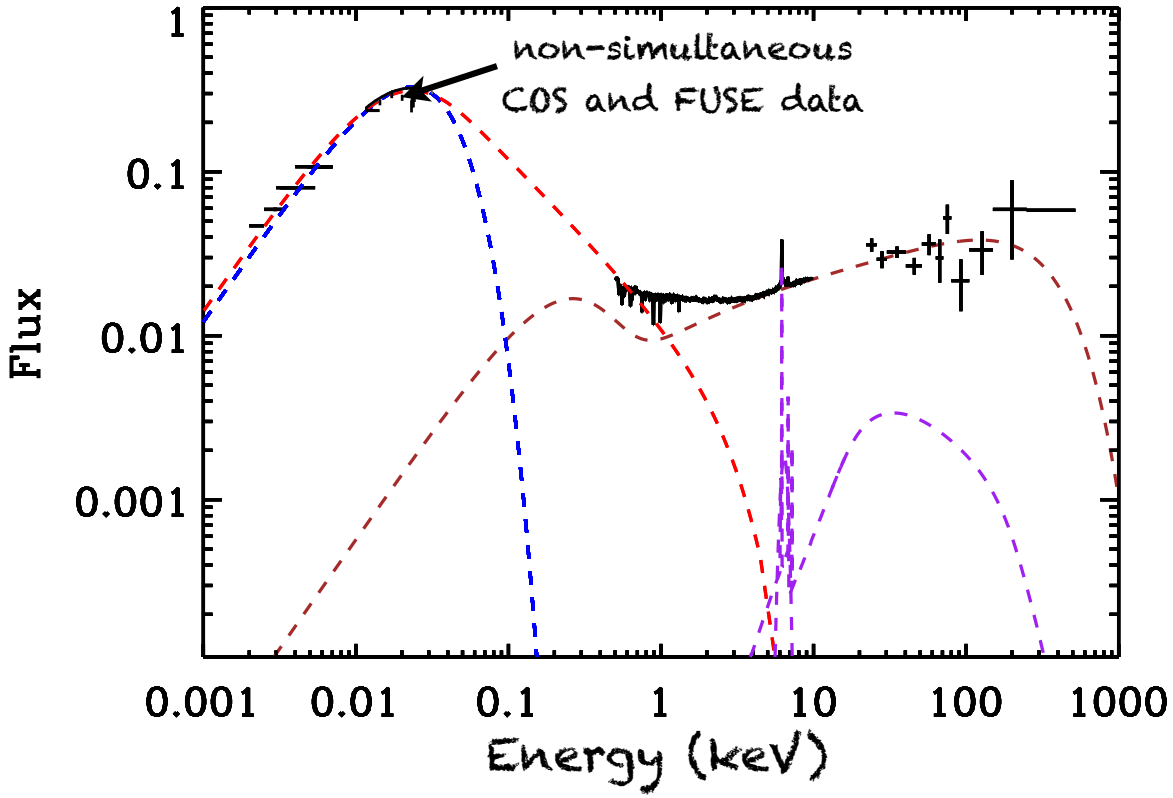
- A multi-black body disc to fit the optical-UV data
- A "warm" corona to fit the soft X-ray emission

The Model



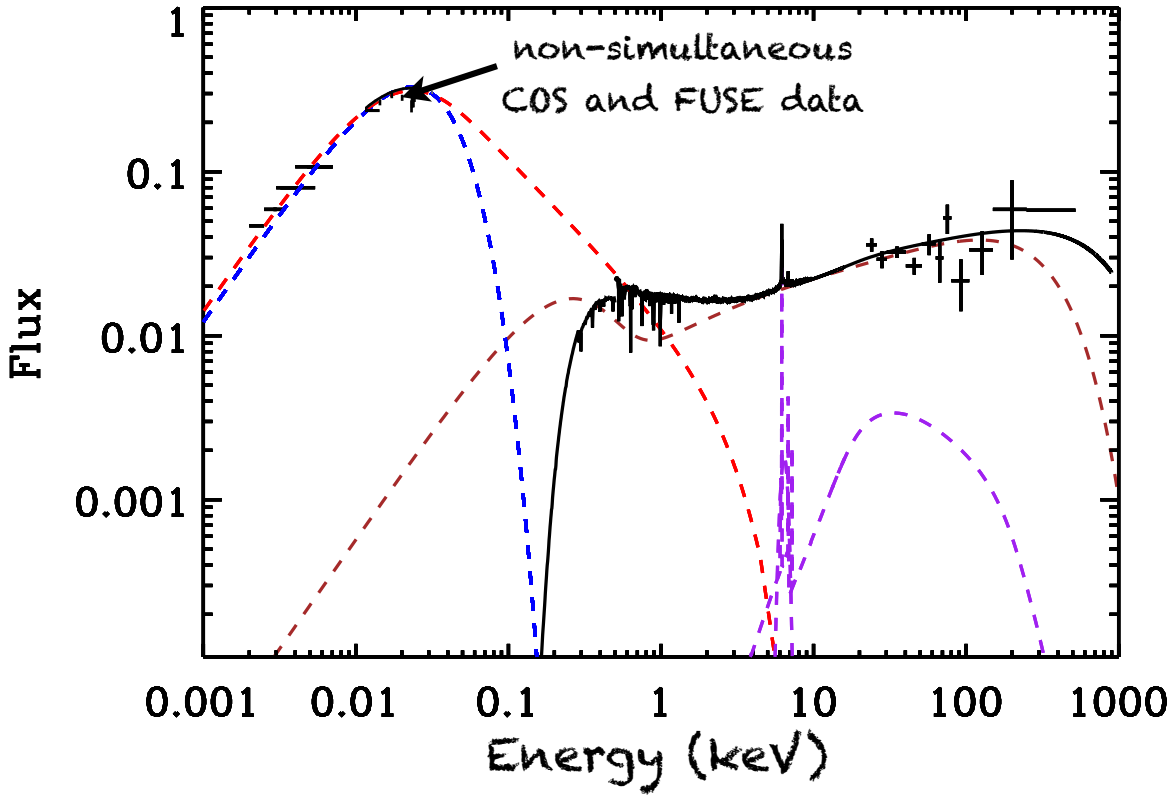
- A multi-black body disc to fit the optical-UV data
- A "warm" corona to fit the soft X-ray emission
- A "hot" corona to fit the hard X-rays

The Model



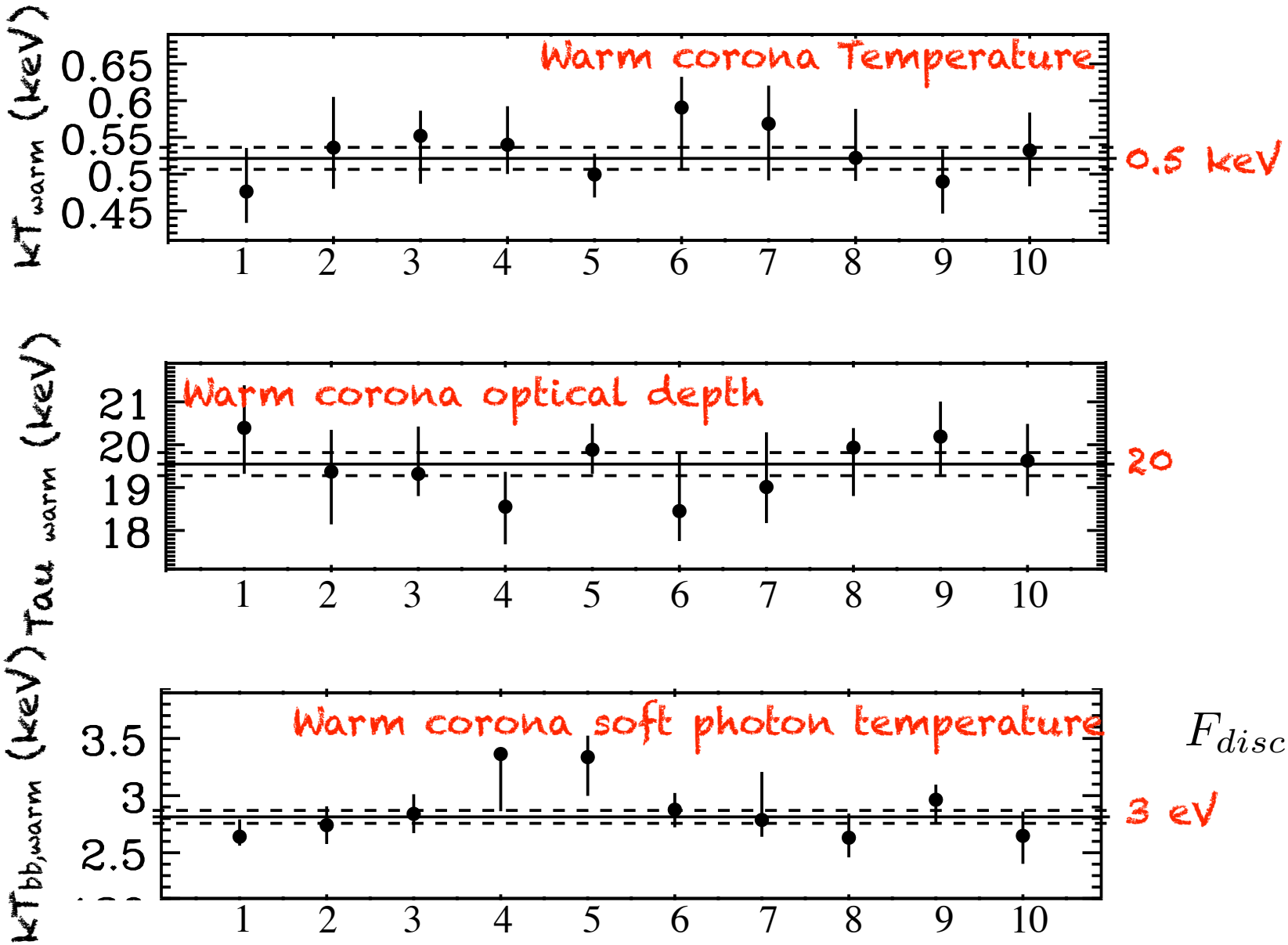
- A multi-black body disc to fit the optical-UV data
- A "warm" corona to fit the soft X-ray emission
- A "hot" corona to fit the hard X-rays
- Reflection components to fit the iron line profile

The Model



- A multi-black body disc to fit the optical-UV data
- A "warm" corona to fit the soft X-ray emission
- A "hot" corona to fit the hard X-rays
- Reflection components to fit the iron line profile
- A warm absorber from the outflow analysis

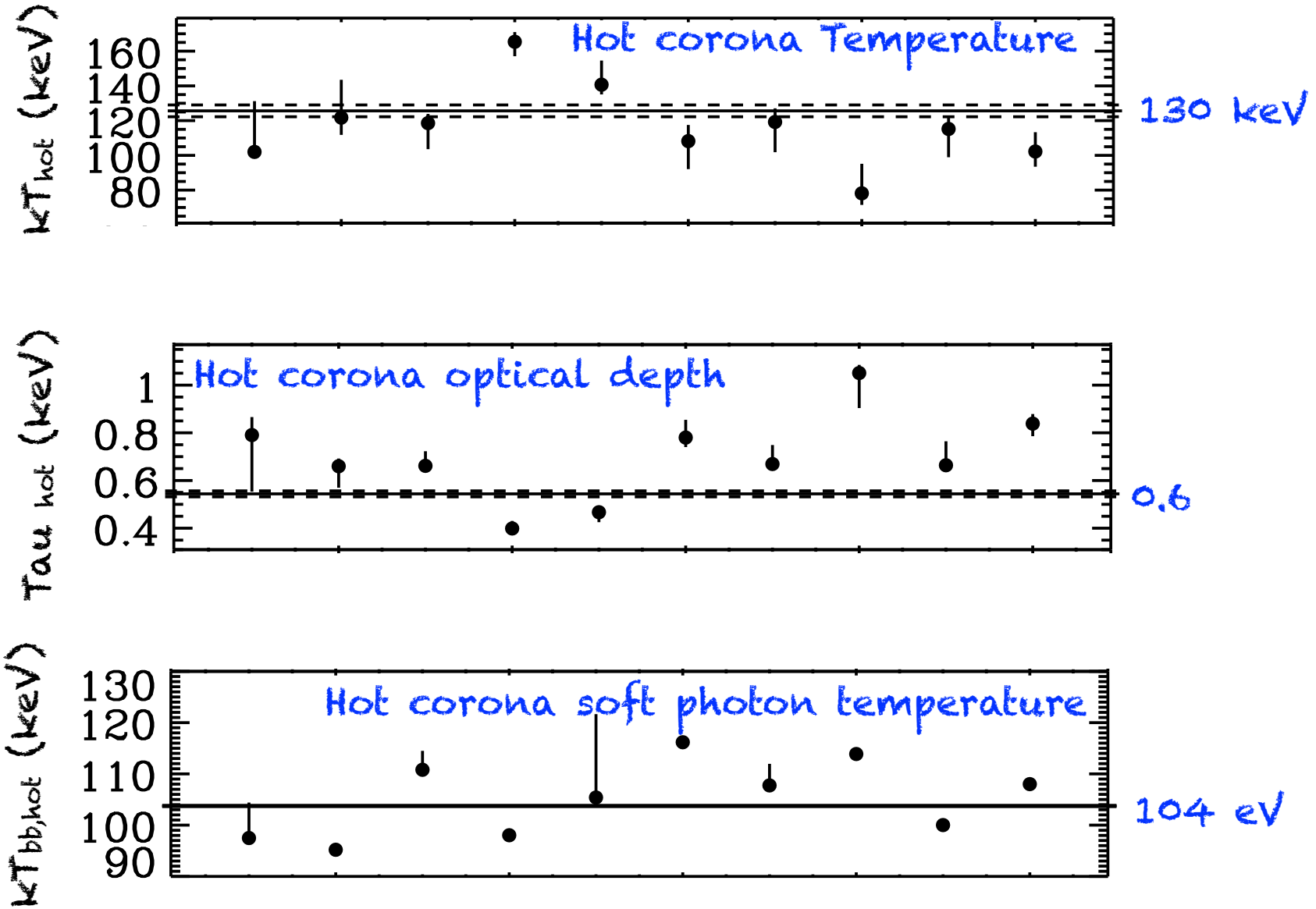
Warm Corona Parameters

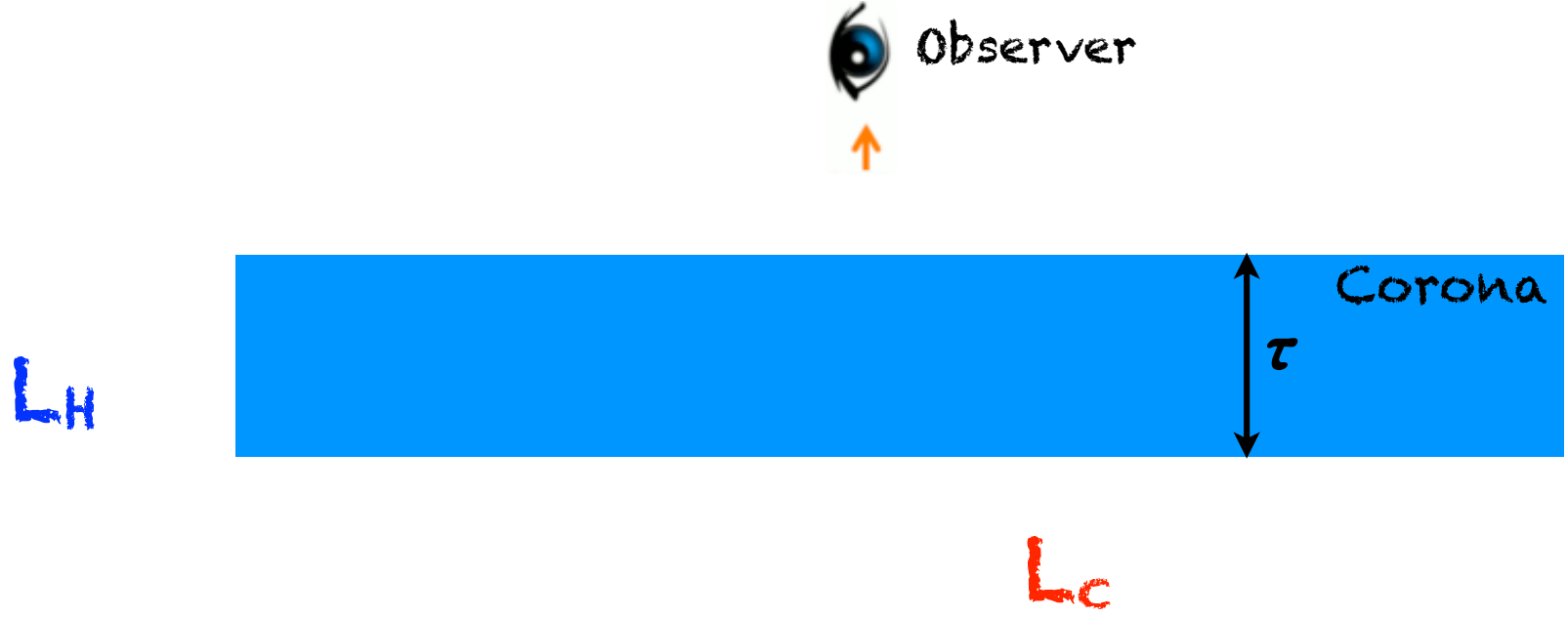


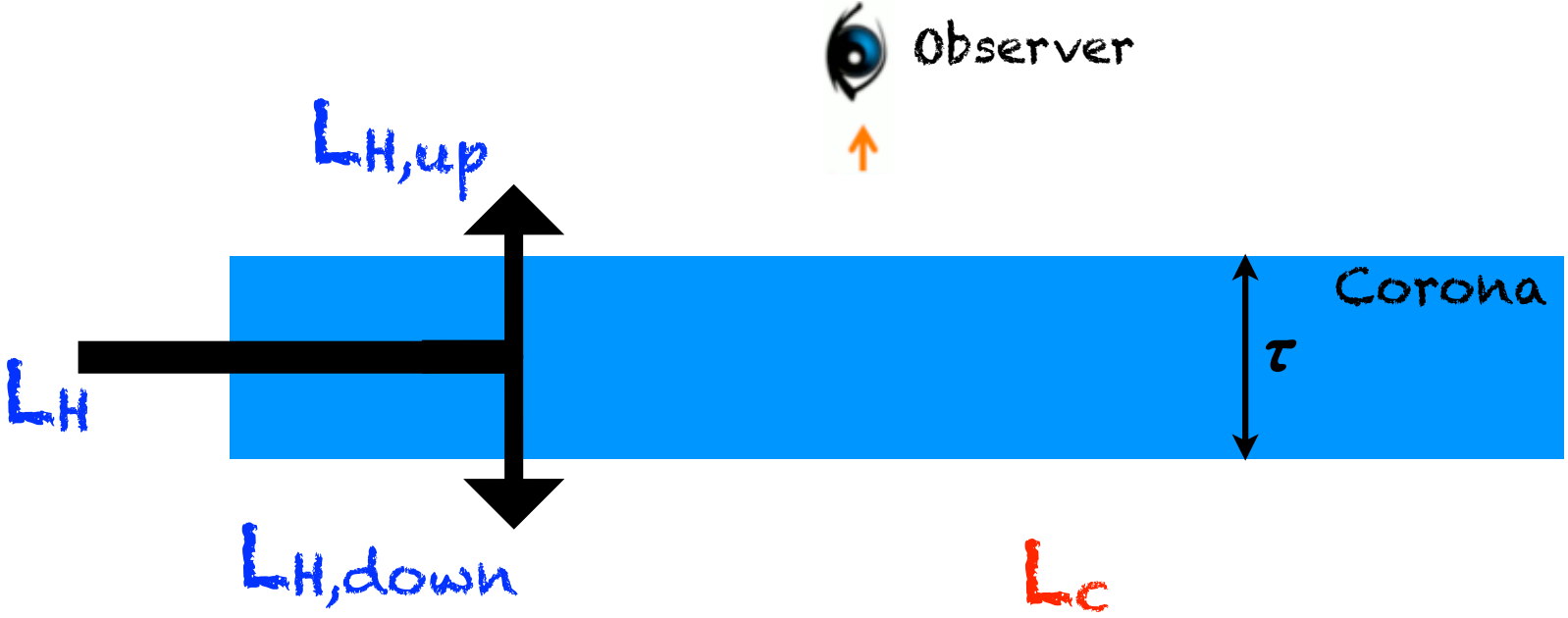
$$F_{disc} \simeq \pi R_{in}^2 \sigma T_{in}^4$$

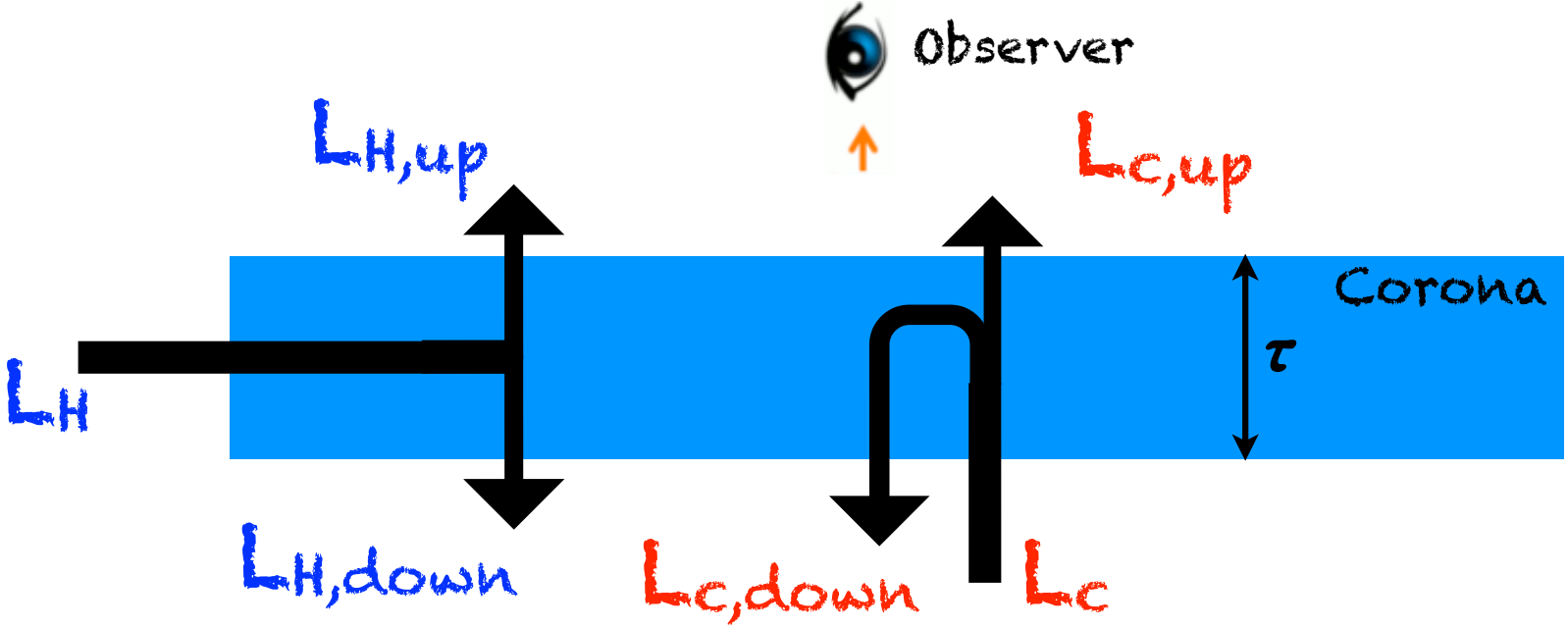
The disc flux agrees with the presence of the disc down to a few R_{Sch}

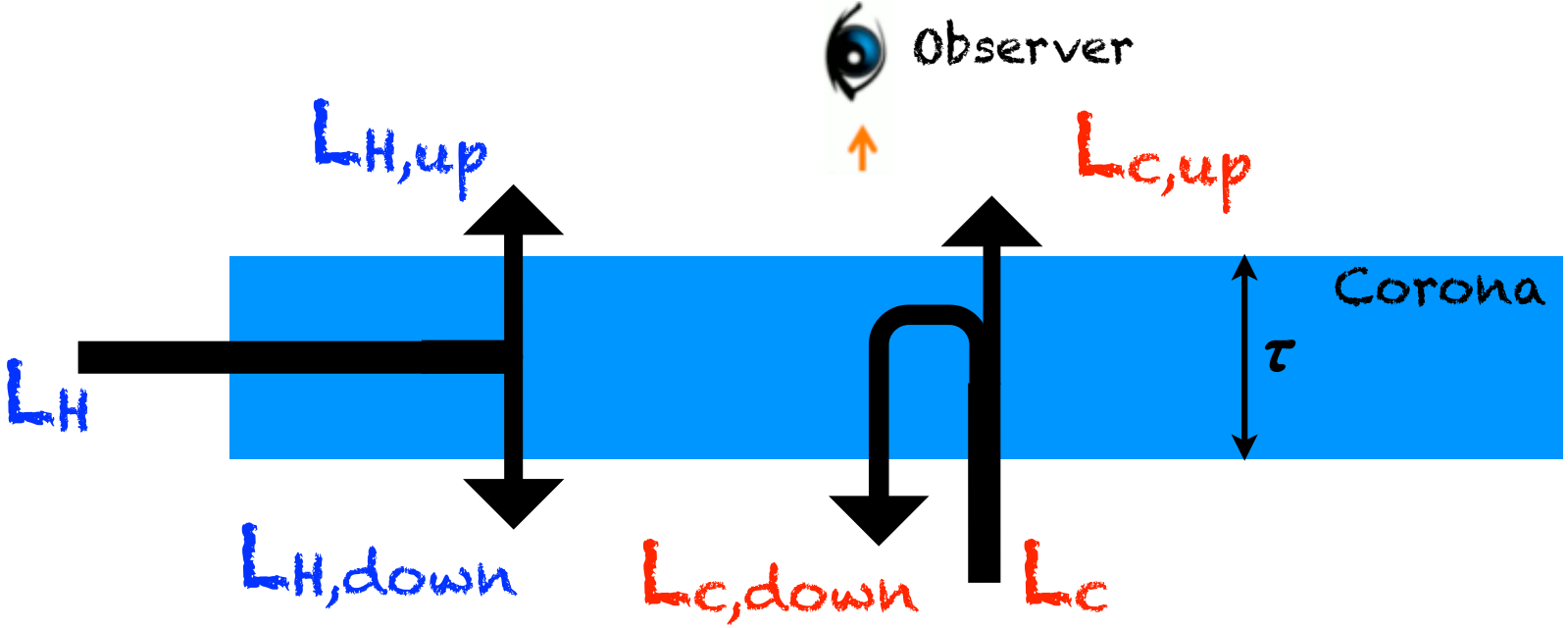
Hot Corona Parameters



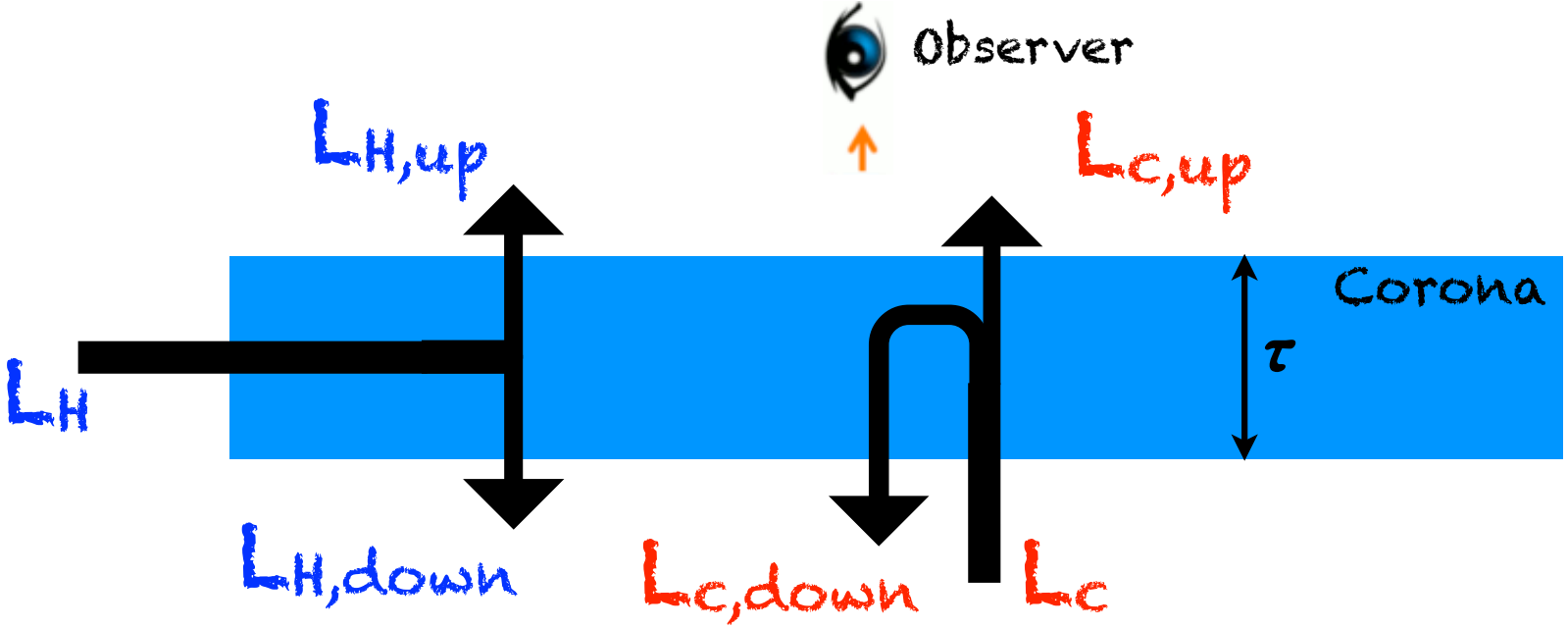

Observer
Corona
τ
L_H
L_C


Observer
$L_{H,up}$
L_H
$L_{H,down}$
Corona
τ
L_C

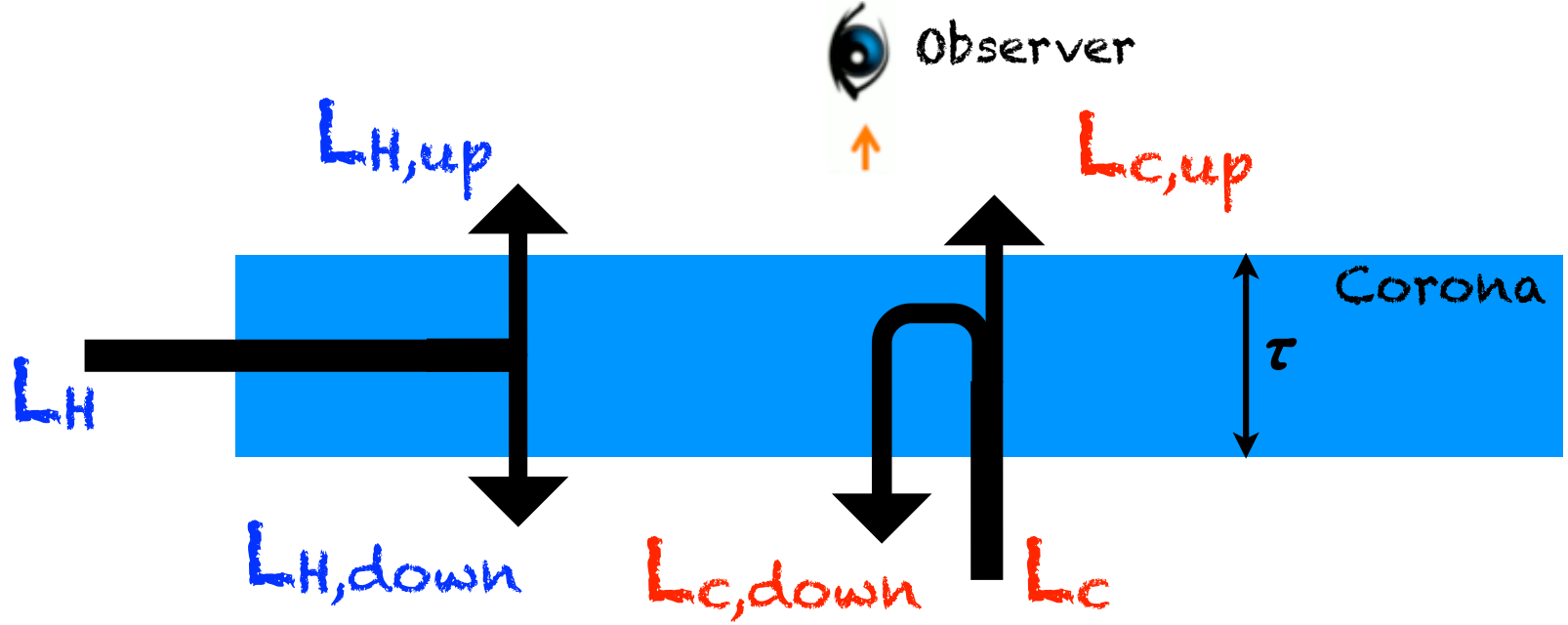

Observer
$L_{H,up}$
$L_{c,up}$
Corona
τ
L_H
$L_{H,down}$
$L_{c,down}$
L_c



- $L_{tot} = L_H + L_c$
- $L_{obs} = L_{H,up} + L_{c,up}$



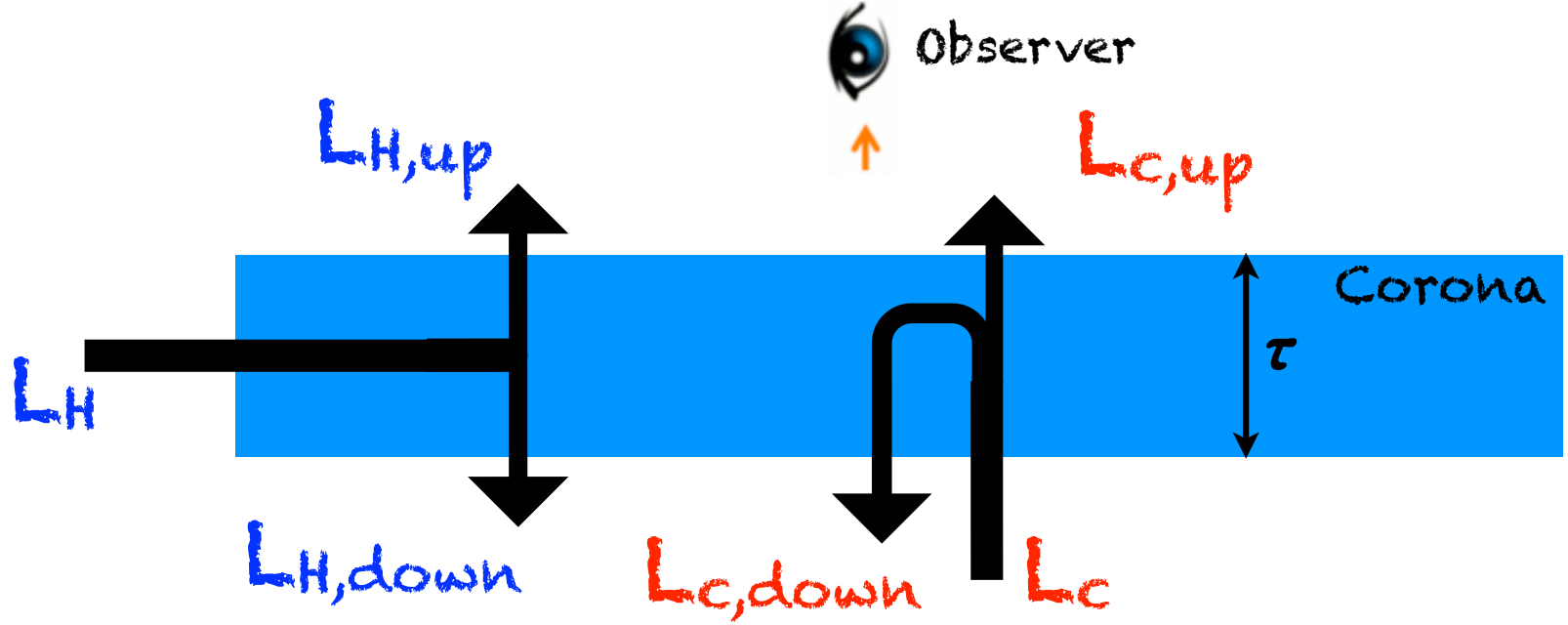
- $L_{tot} = L_H + L_c$
- $L_{obs} = L_{H,up} + L_{c,up}$
- L_c from photon conservation



- $L_{tot} = L_H + L_c$
- $L_{obs} = L_{H,up} + L_{c,up}$
- L_c from photon conservation

$$n_{ph,obs} \approx n_{ph,c} e^{-\tau} + n_{ph,c}(1-e^{-\tau})/2$$

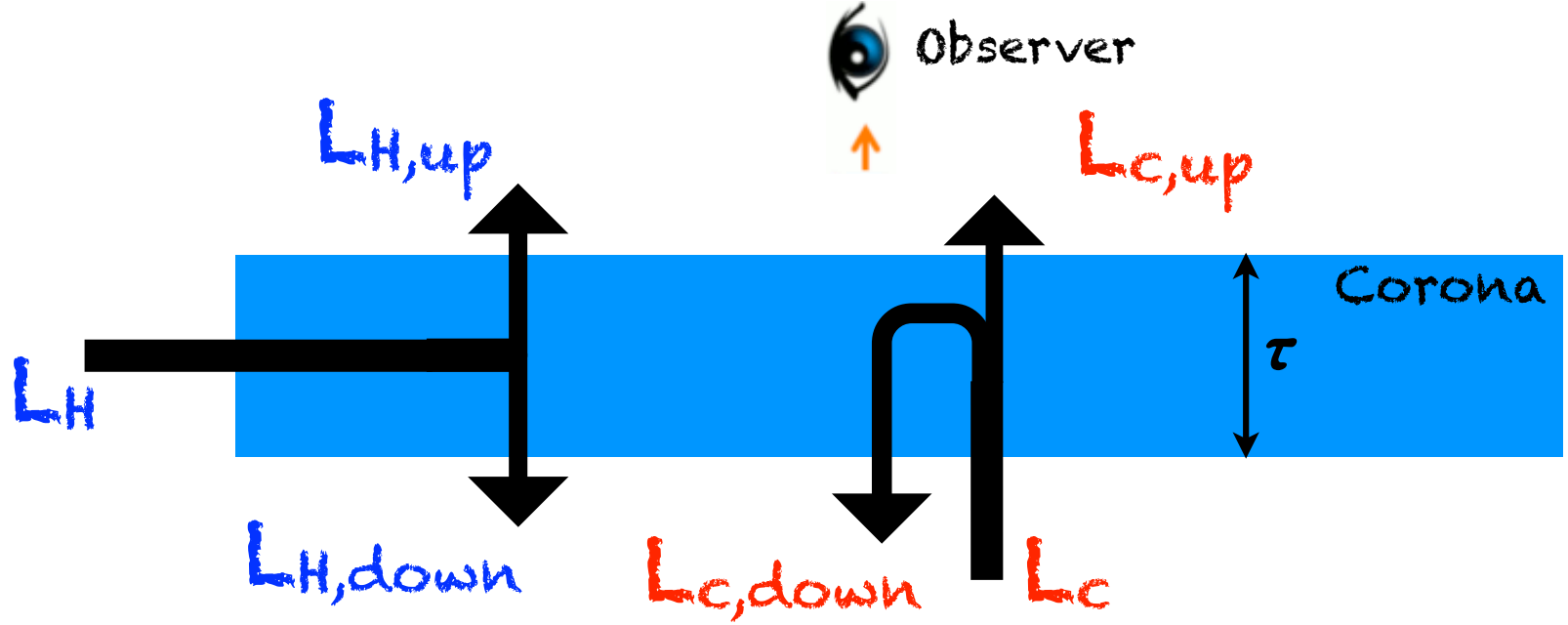
- $n_{ph,obs}$: given by the fits
- $n_{ph,c} e^{-\tau}$: 0^{th} order
- $n_{ph,c}(1-e^{-\tau})/2$: half of the other orders



- $L_{tot} = L_H + L_c$
- $L_{obs} = L_{H,up} + L_{c,up}$
- L_c from photon conservation

$n_{ph,obs} \approx n_{ph,c} e^{-\tau} + n_{ph,c}(1-e^{-\tau})/2 \rightarrow n_{ph,c} \approx 2\, n_{ph,obs}/(1-e^{-\tau})$

given by the fits — 0^{th} order — half of the other orders

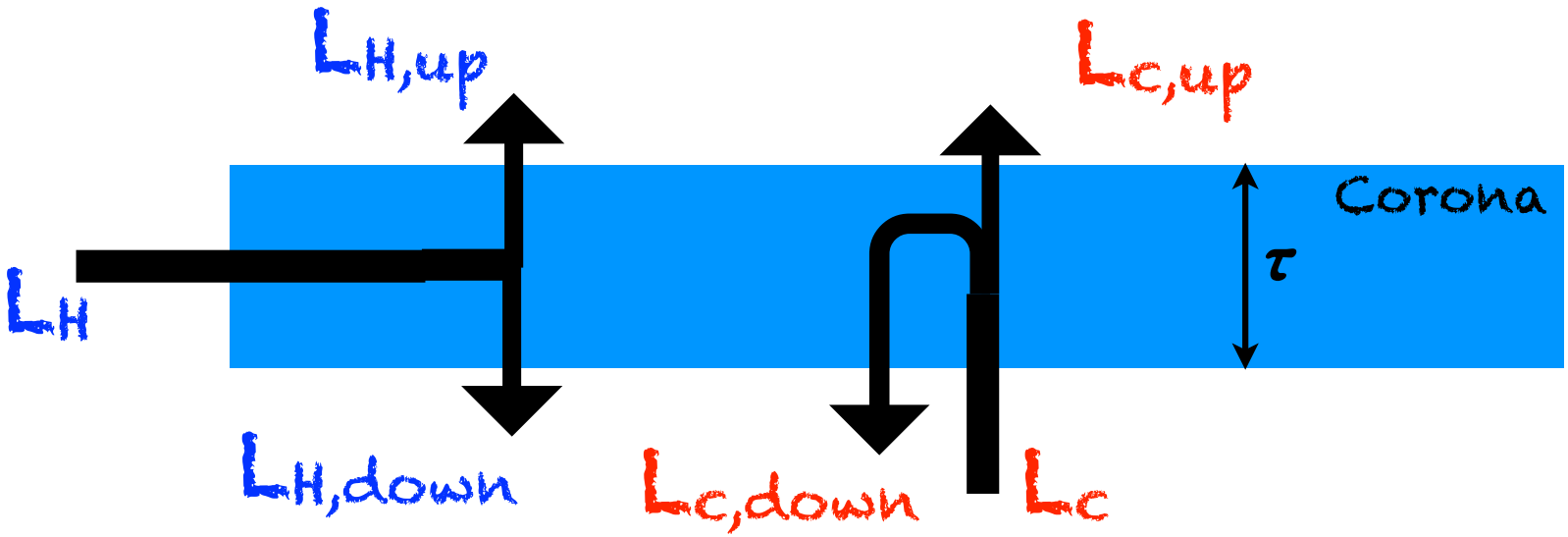


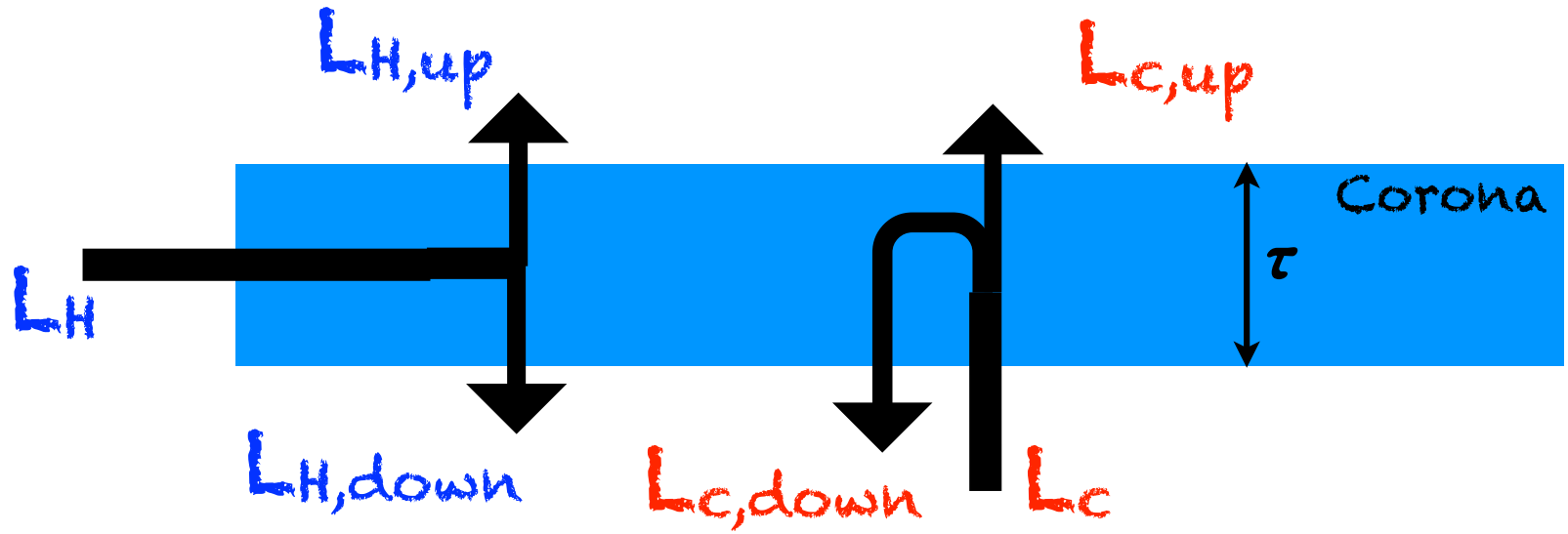
- $L_{tot} = L_H + L_c$
- $L_{obs} = L_{H,up} + L_{c,up}$
- L_c from photon conservation

$n_{ph,obs} \approx n_{ph,c} e^{-\tau} + n_{ph,c}(1-e^{-\tau})/2 \rightarrow n_{ph,c} \approx 2\, n_{ph,obs}/(1-e^{-\tau})$

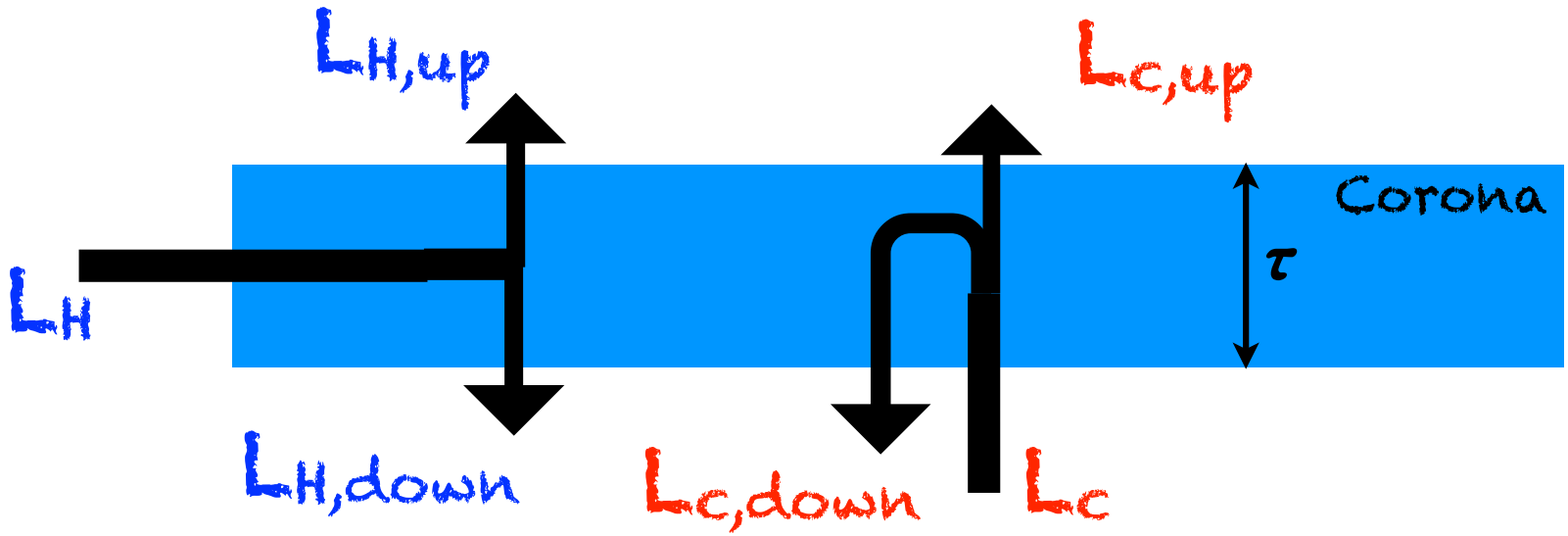
- $n_{ph,obs}$: given by the fits
- $n_{ph,c} e^{-\tau}$: 0^{th} order
- $n_{ph,c}(1-e^{-\tau})/2$: half of the other orders

Knowing $n_{ph,c}$ and the multicolor disc temperature (given by the fits) we deduce L_c


$L_{H,up}$
$L_{c,up}$
Corona
τ
L_H
$L_{H,down}$
$L_{c,down}$
L_c



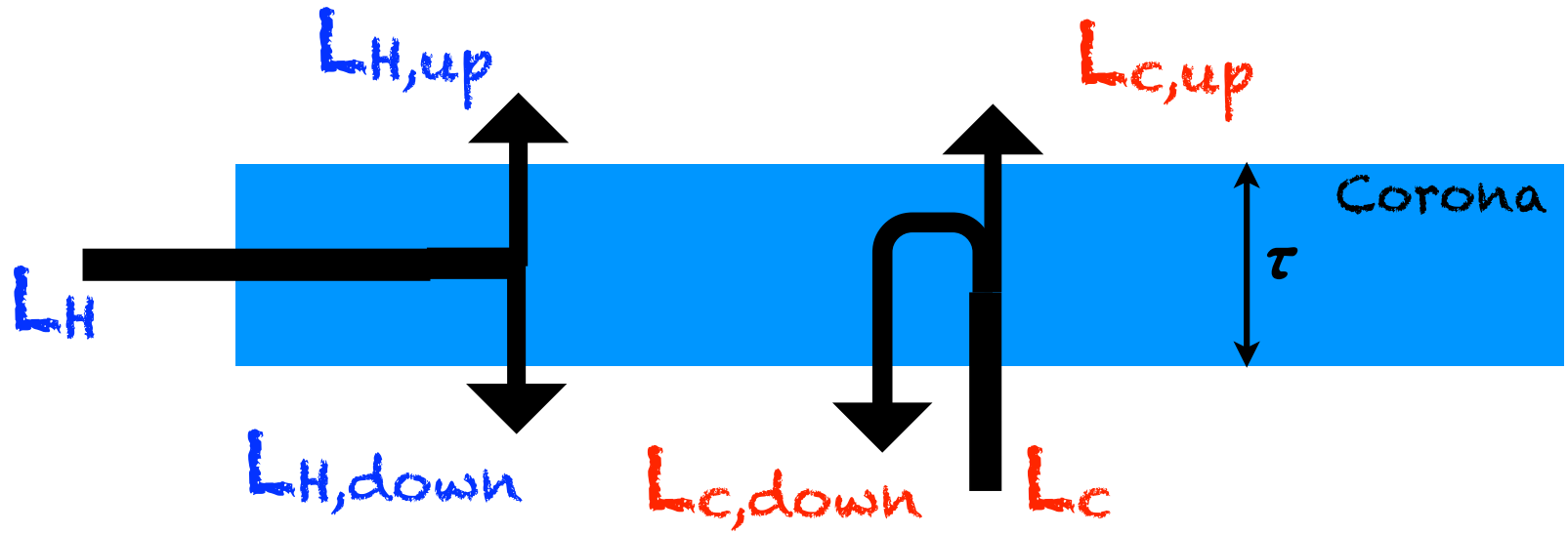
- $L_H = L_{H,up} + L_{H,down} \approx 2L_{H,up}$ (isotropic)



- $L_H = L_{H,up} + L_{H,down} \approx 2L_{H,up}$ (isotropic)
- $L_{c,up} \approx L_c e^{-\tau} + L_c(1-e^{-\tau})/2$

0^{th} order

half of the other orders



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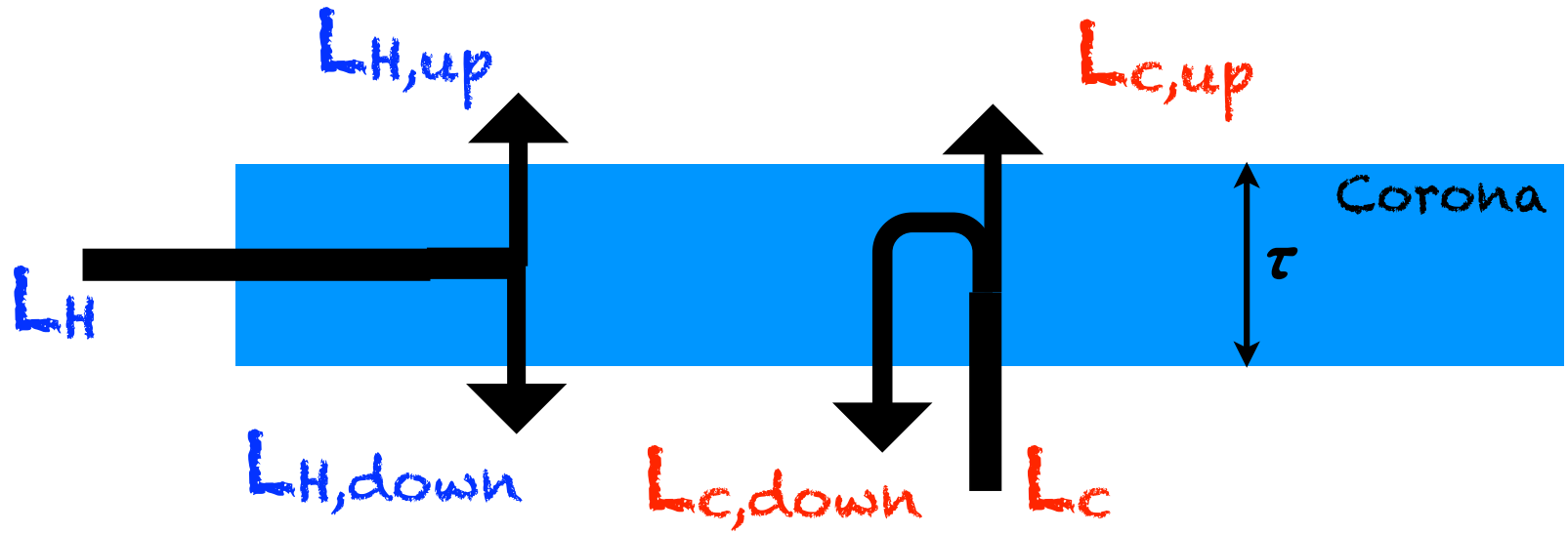
  - 0^{th} order
  - half of the other orders
- $L_{c,down} \approx L_c(1-e^{-\tau})/2$
  - the other half



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  - 0^{th} order
  - half of the other orders
- $L_{c,down} \approx L_c(1-e^{-\tau})/2$
  - the other half

→ $L_{tot} = 2L_{obs} + L_c e^{-\tau}$

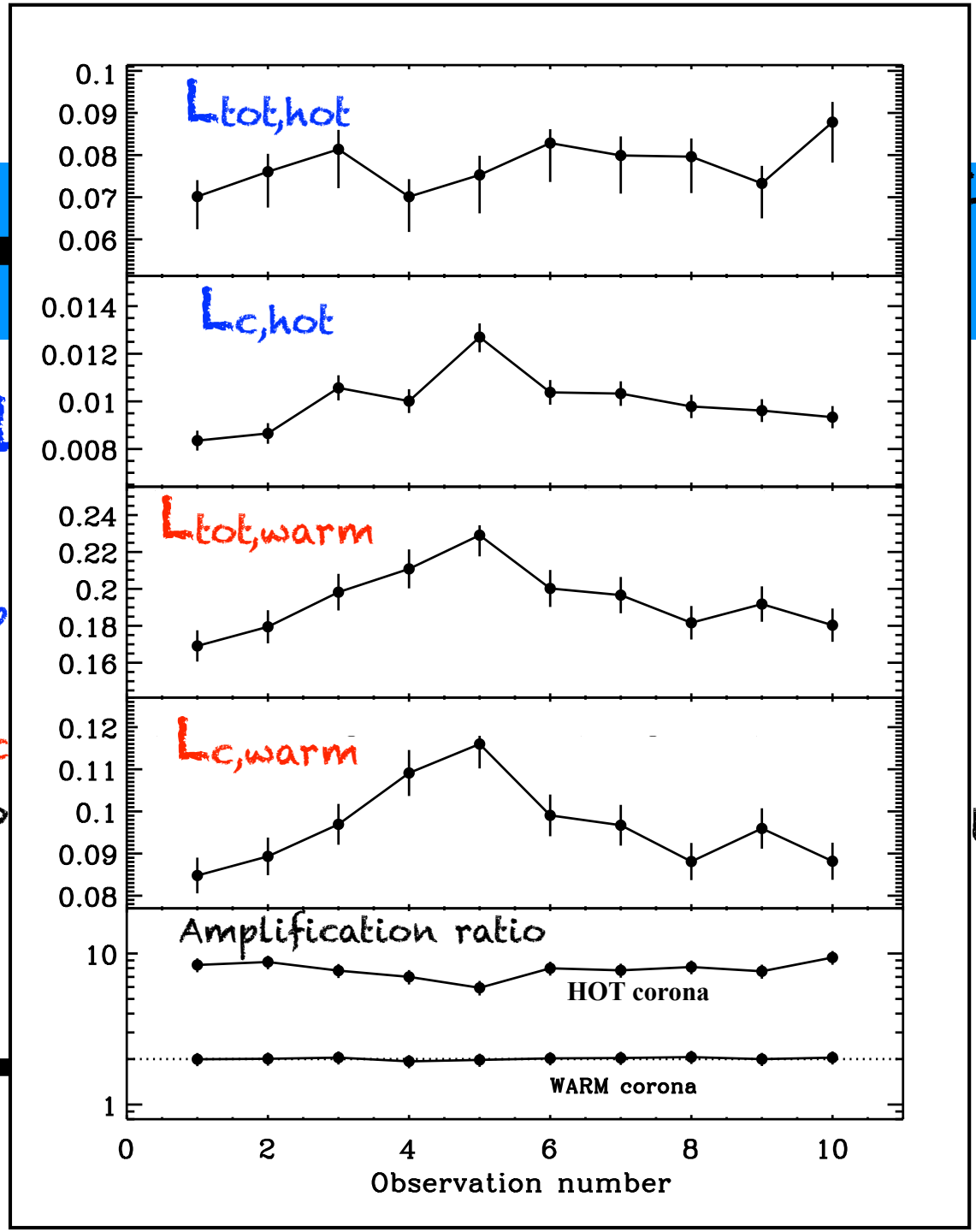
L_H

orona

- $L_H = L_{H,up}$
- $L_{c,up} \approx L_c$ $L_c(1-e^{-\tau})/2$

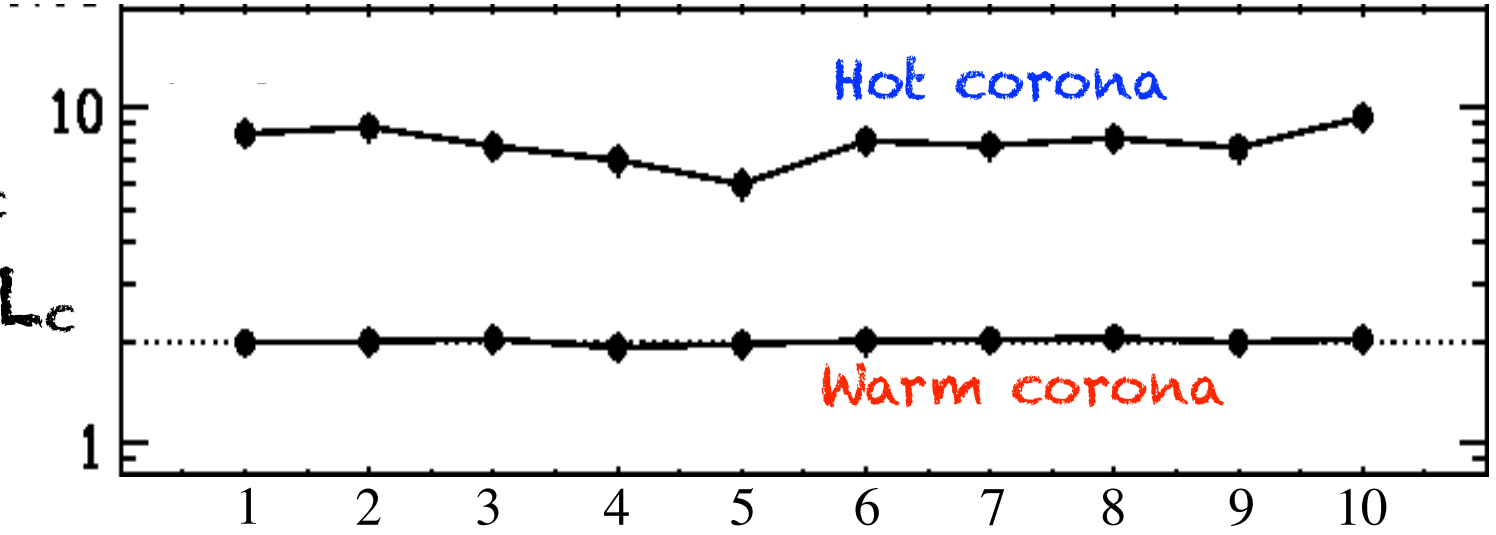
0^{th} o

the other half

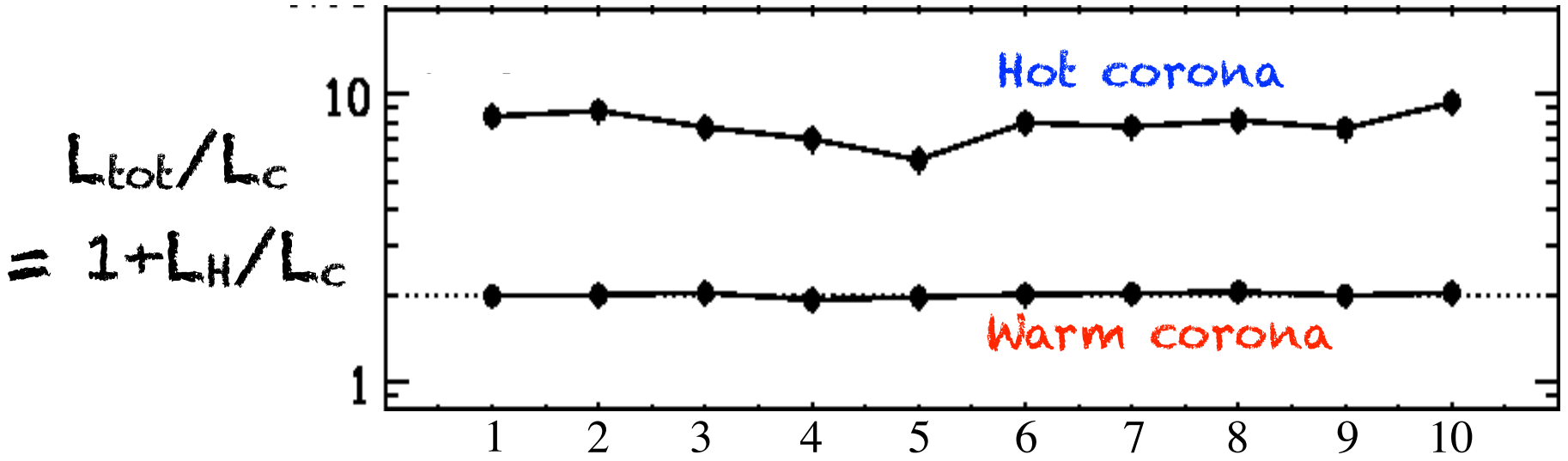


Disc-Corona configurations

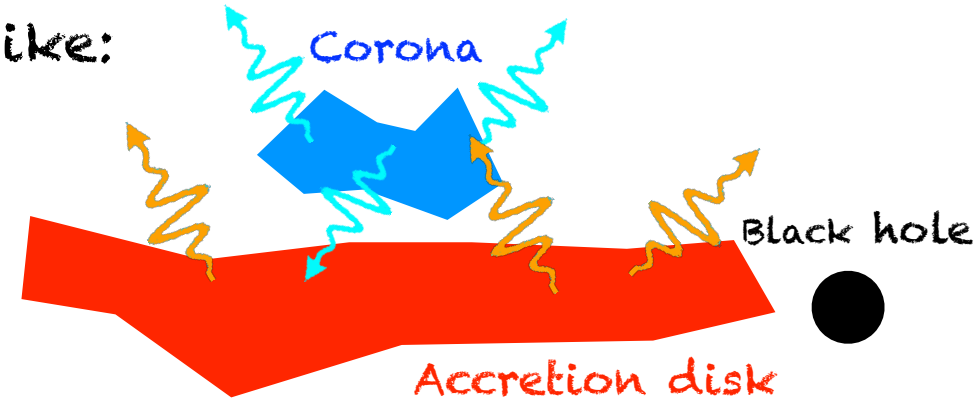
$L_{tot}/L_c = 1 + L_H/L_c$



Disc-Corona configurations



The Hot corona looks rather like:



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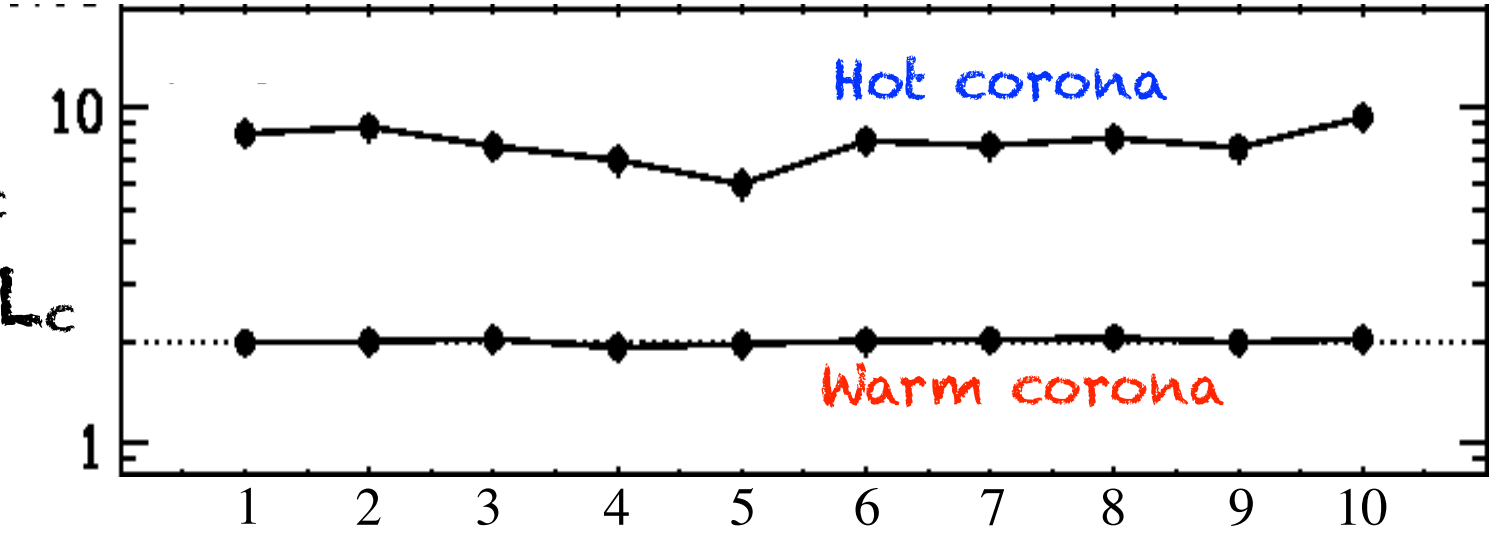

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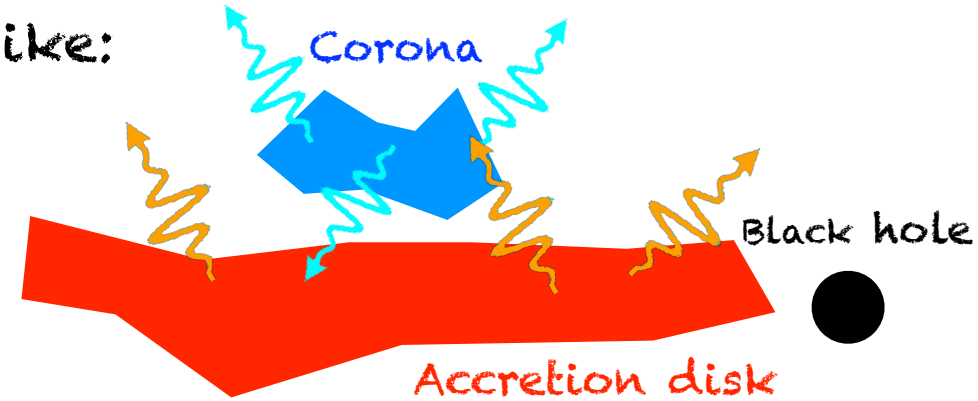
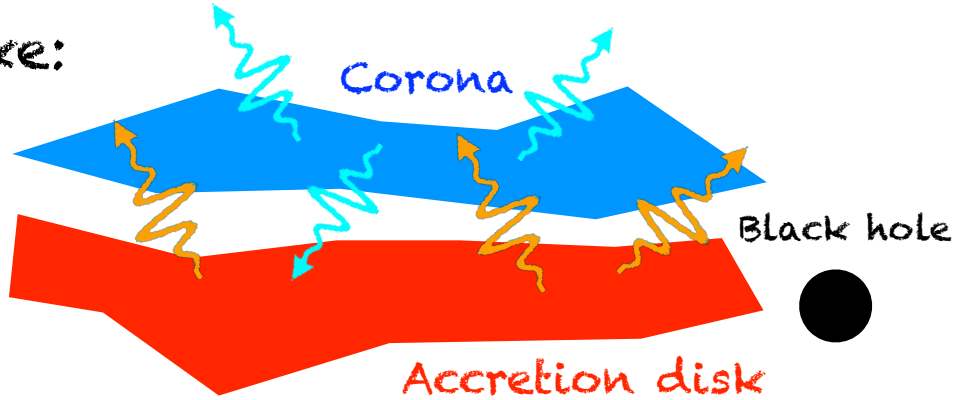
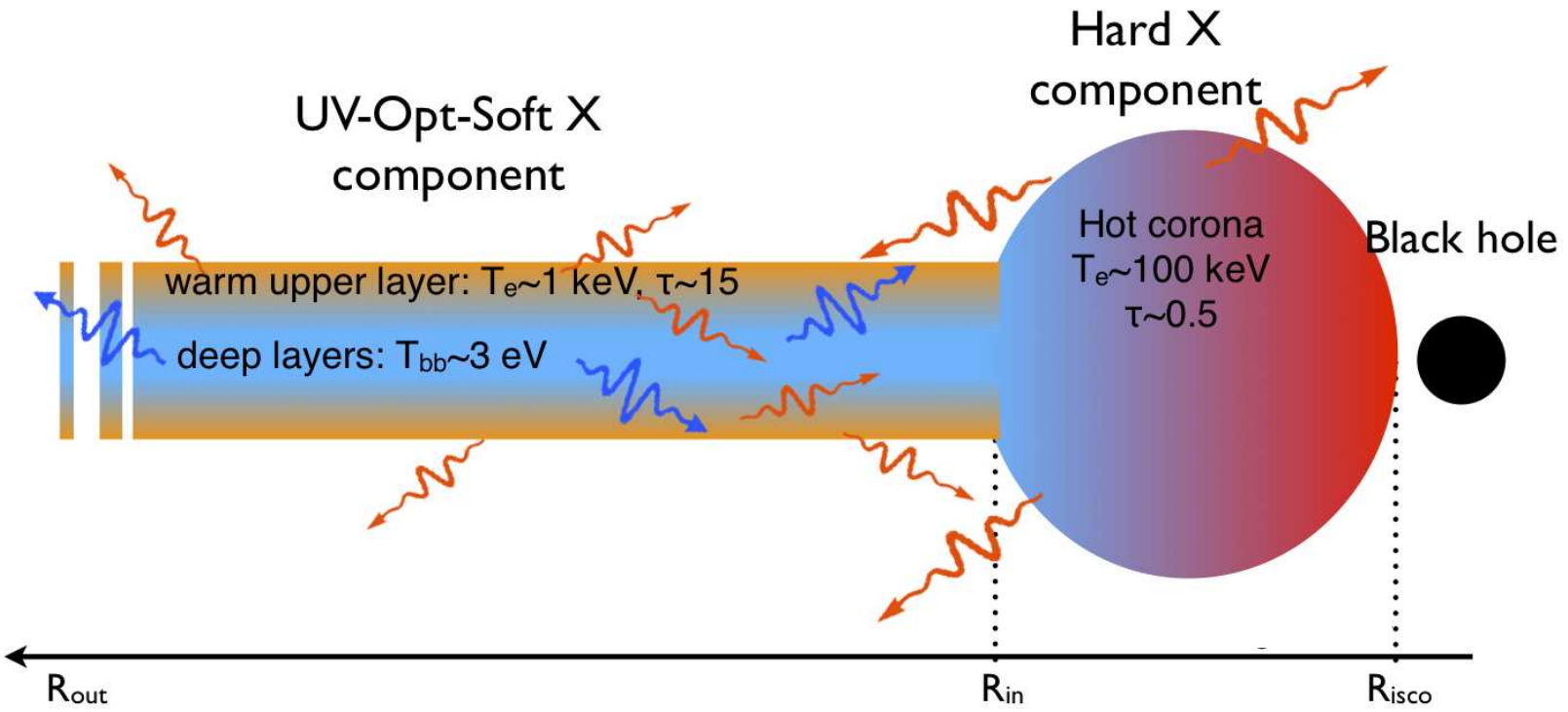


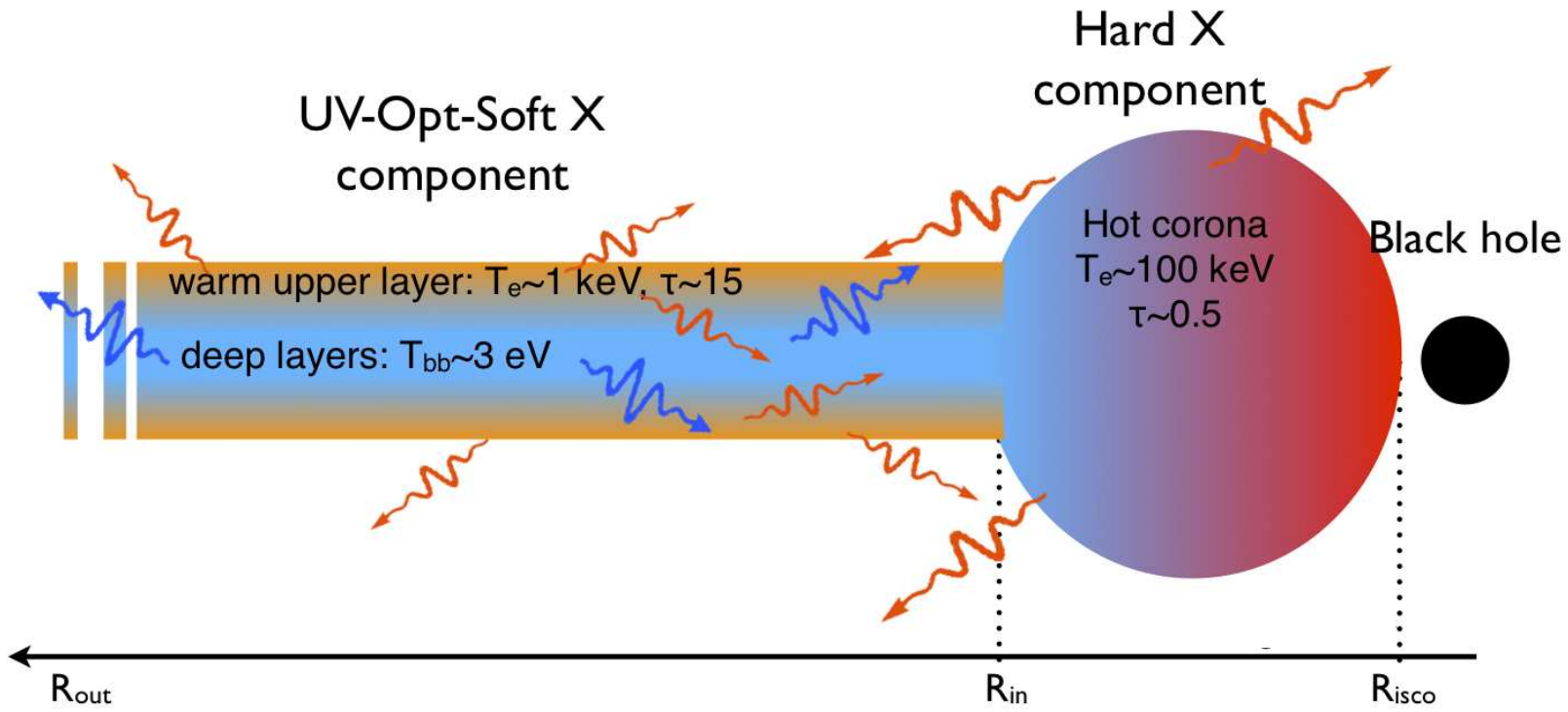
Warm corona looks rather like:



A Tentative Picture

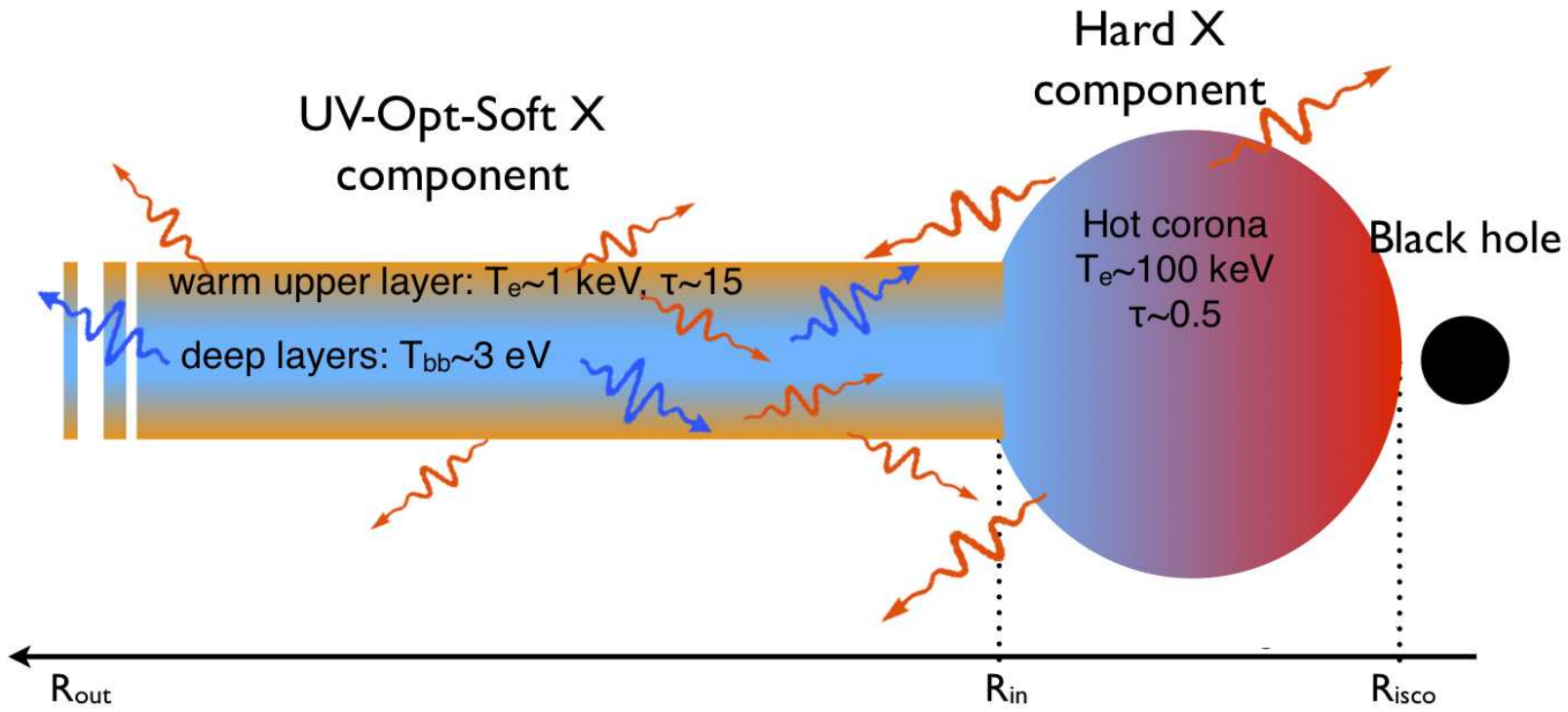


A Tentative Picture



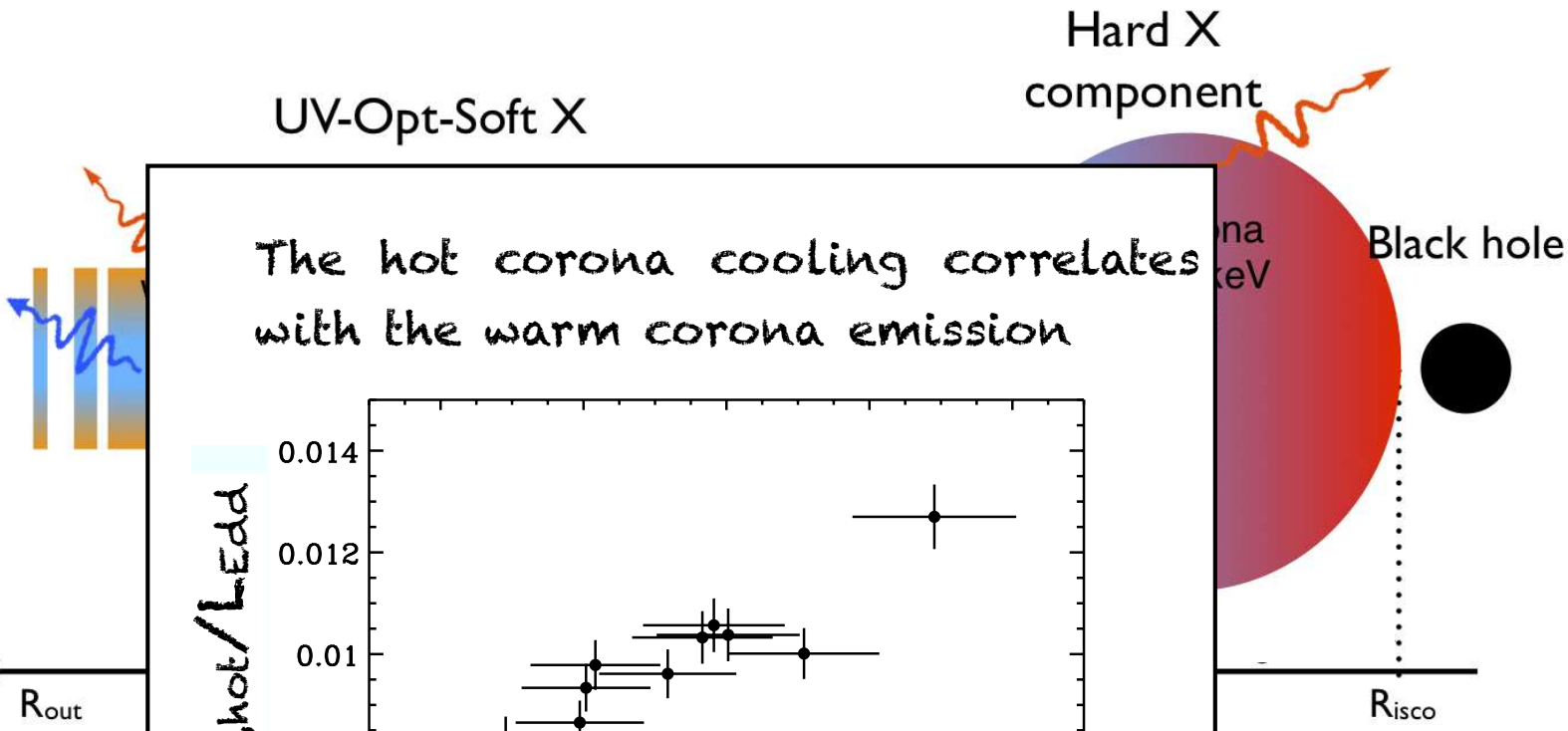
- Warm corona: upper layer of the accretion disc?
  - ➡ soft photon (3 eV) from the deeper layers?
  - ➡ accretion power mainly released in the warm corona

A Tentative Picture



- Warm corona: upper layer of the accretion disc?
  - ➡ soft photon (3 eV) from the deeper layers?
  - ➡ accretion power mainly released in the warm corona
- Hot corona: inner part of the accretion flow?
  - ➡ contributes to the formation of the warm corona through X-ray irradiation
  - ➡ soft photon (100 eV) from the warm corona?

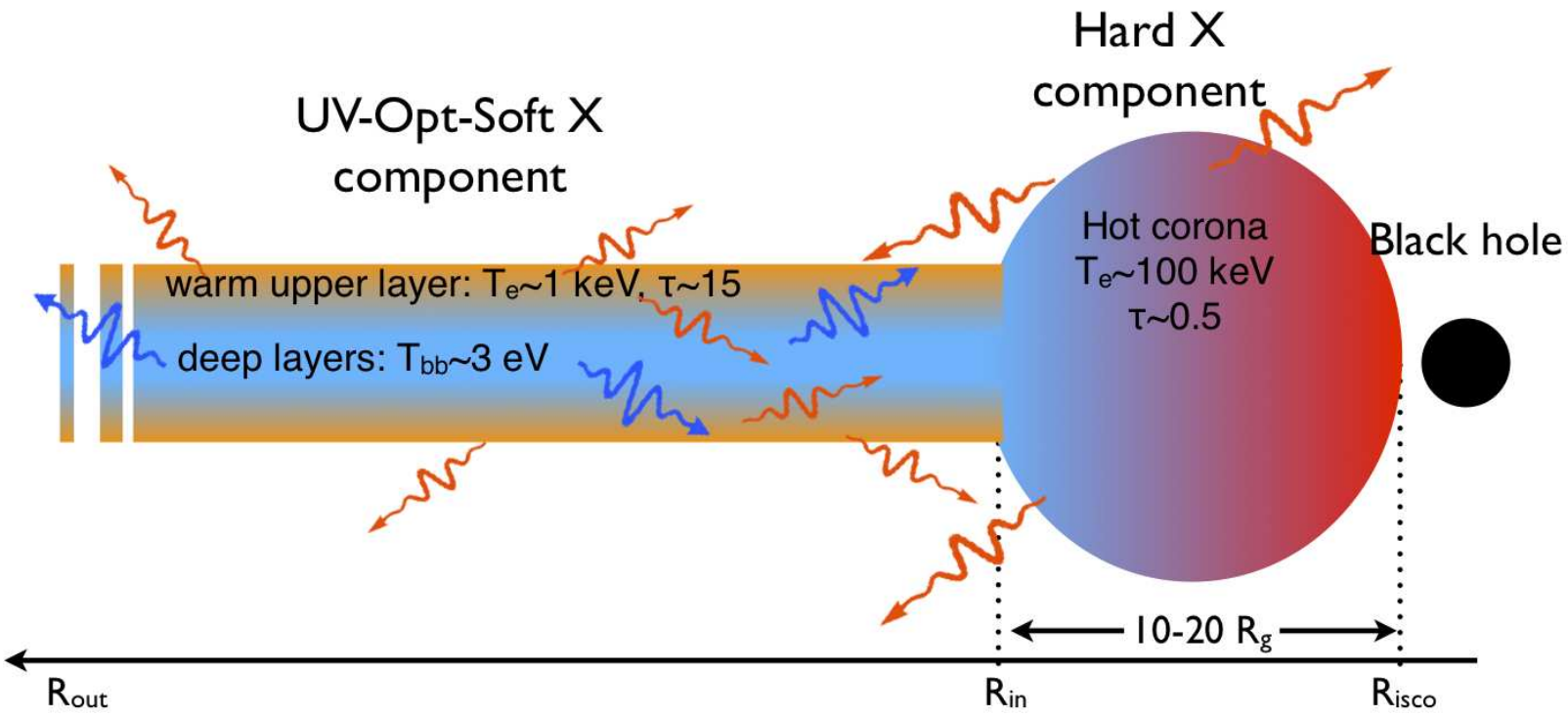
A Tentative Picture



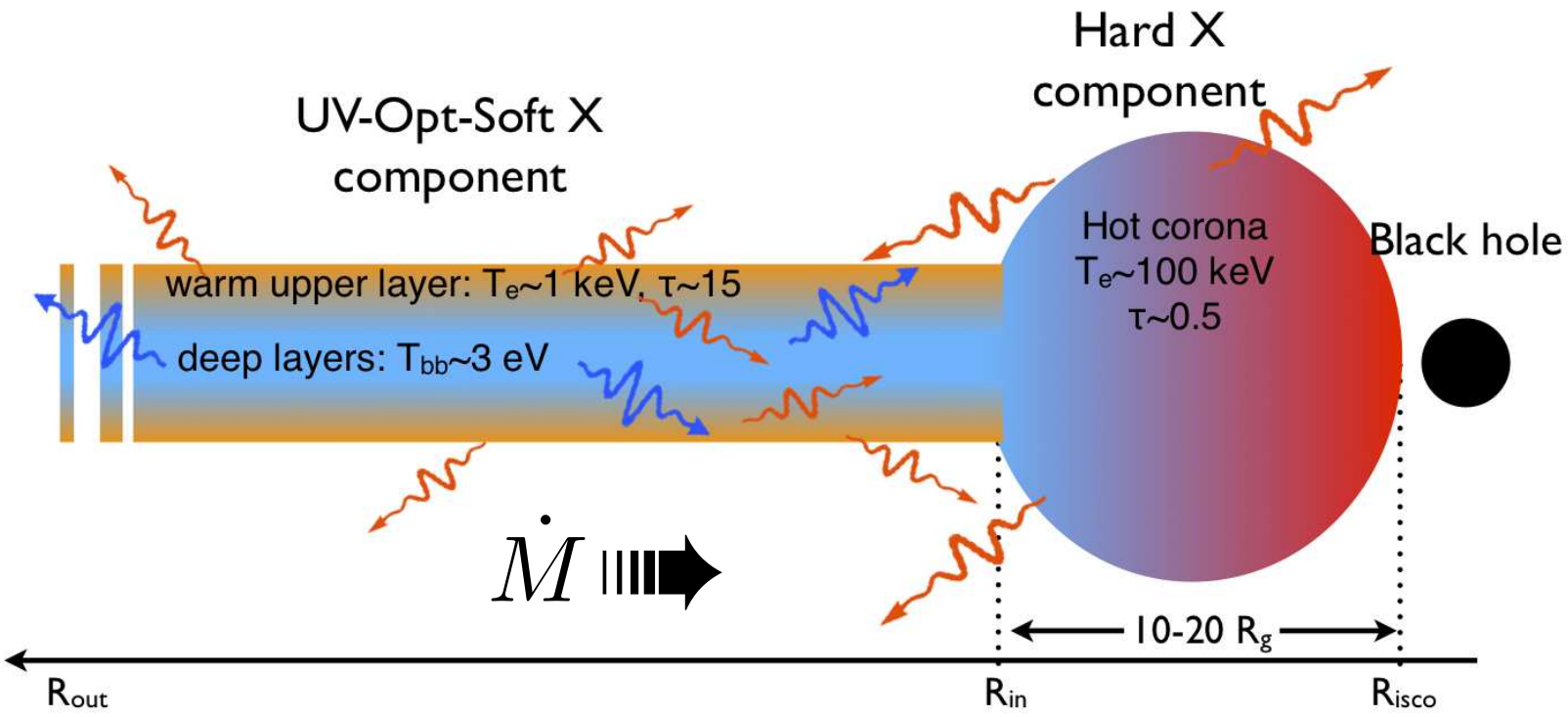
The hot corona cooling correlates with the warm corona emission

- Warm c… …n disc?
  - ➡ soft … …ayers?
  - ➡ accr… …e warm corona
- Hot cor… …low?
  - ➡ contributes to the formation of the warm corona through X-ray irradiation
  - ➡ soft photon (100 eV) from the warm corona?

Energetics


Hard X
component
UV-Opt-Soft X
component
Hot corona
T_e~100 keV
τ~0.5
Black hole
warm upper layer: T_e~1 keV, τ~15
deep layers: T_{bb}~3 eV
10-20 R_g
R_{out}
R_{in}
R_{isco}

Energetics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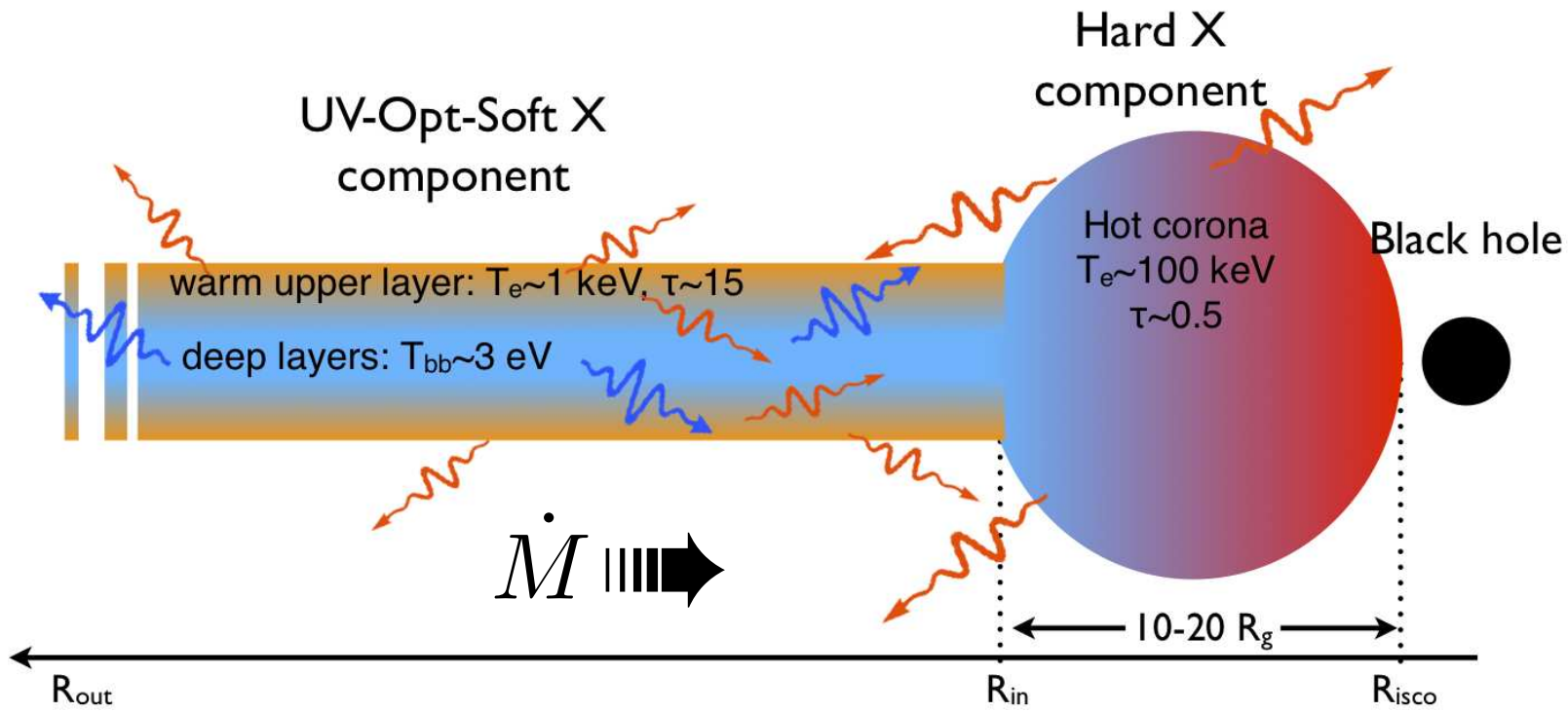
$\dot{M}$
10-20 R_g
R_{out}
R_{in}
R_{isco}

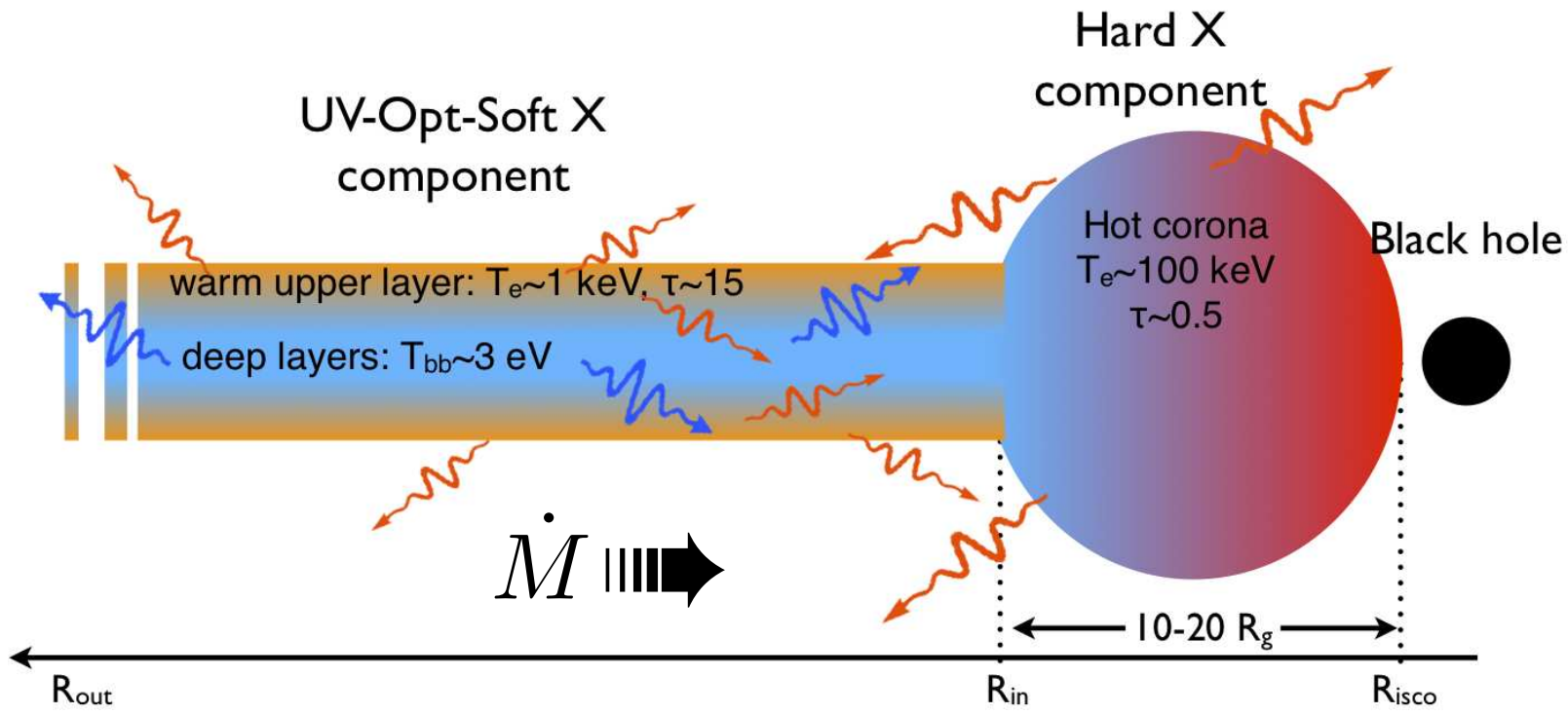
Energetics



$$P_{acc,wc} = \frac{GM\dot{M}}{2R_{in}}\left[1 - \frac{R_{in}}{R_{out}}\right]$$

$$P_{acc,hc} = \frac{GM\dot{M}}{2R_{isco}}\left[1 - \frac{R_{isco}}{R_{in}}\right].$$

Energetics

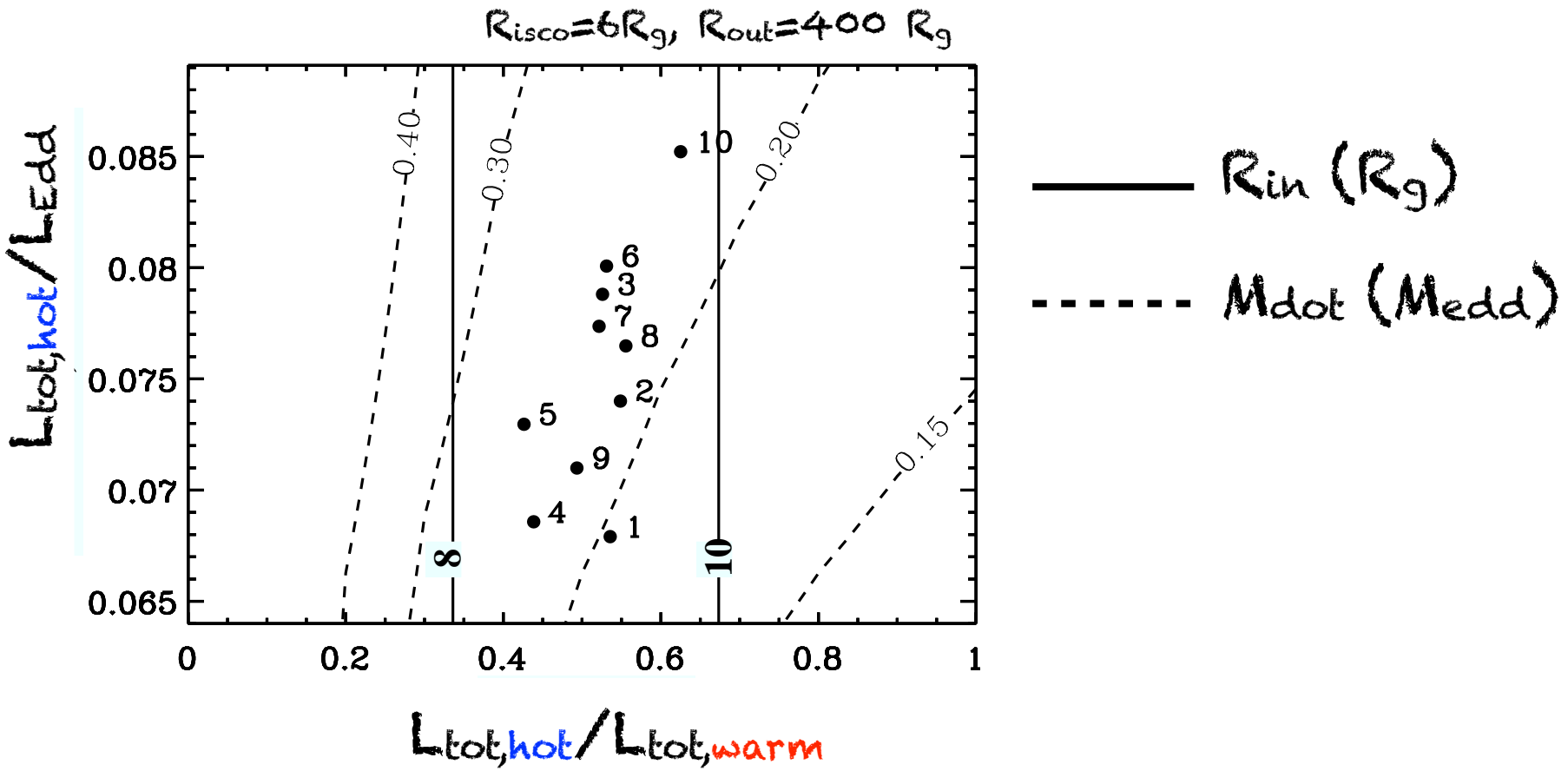


$$P_{acc,wc} = \frac{GM\dot{M}}{2R_{in}}\left[1 - \frac{R_{in}}{R_{out}}\right]$$

$$P_{acc,hc} = \frac{GM\dot{M}}{2R_{isco}}\left[1 - \frac{R_{isco}}{R_{in}}\right].$$

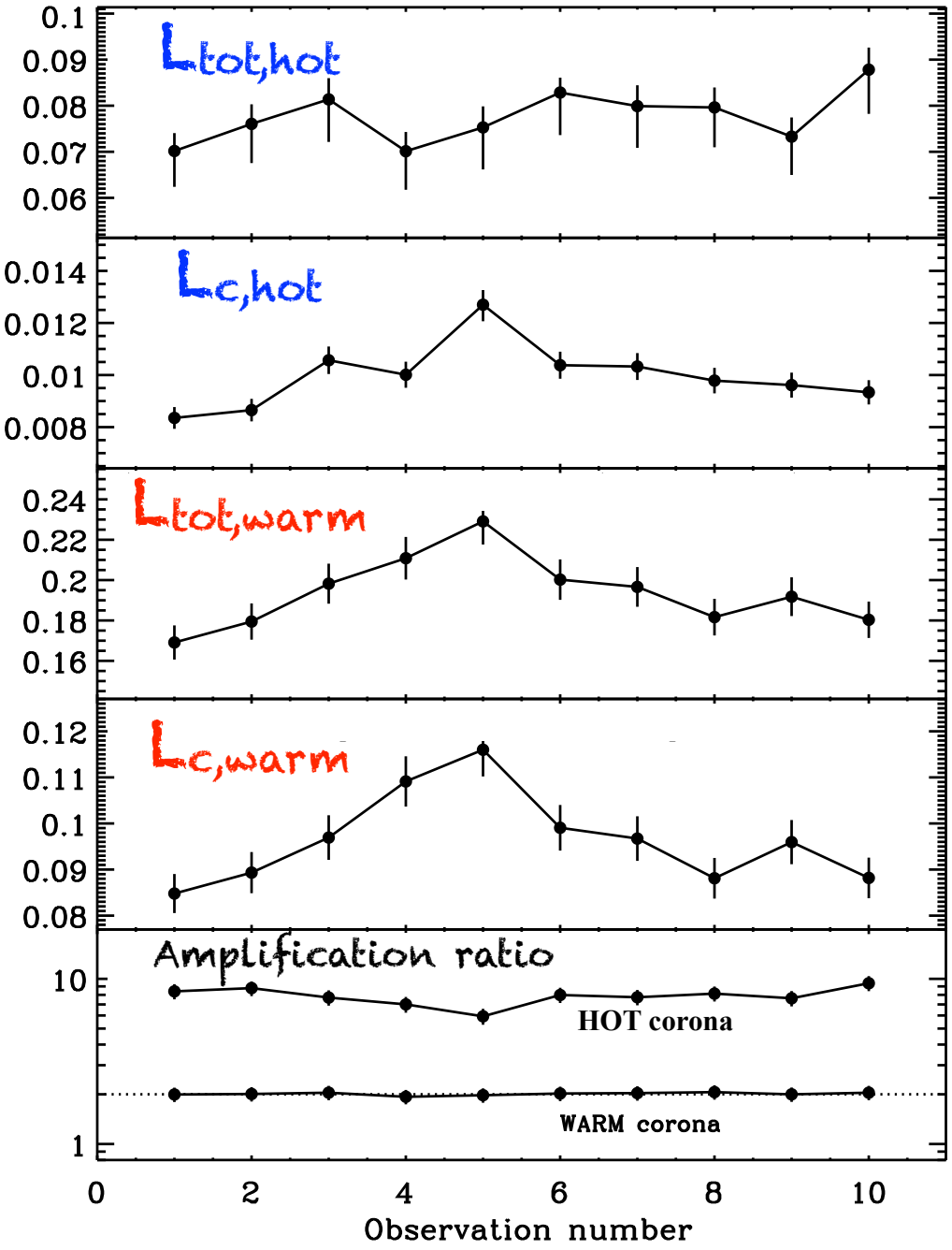
If no advection, $P_{acc,corona} = L_{tot,corona}$

Constraints on Rin and Mdot



→ Rin ~10 Rg and Mdot~ 0.2-0.3 Medd

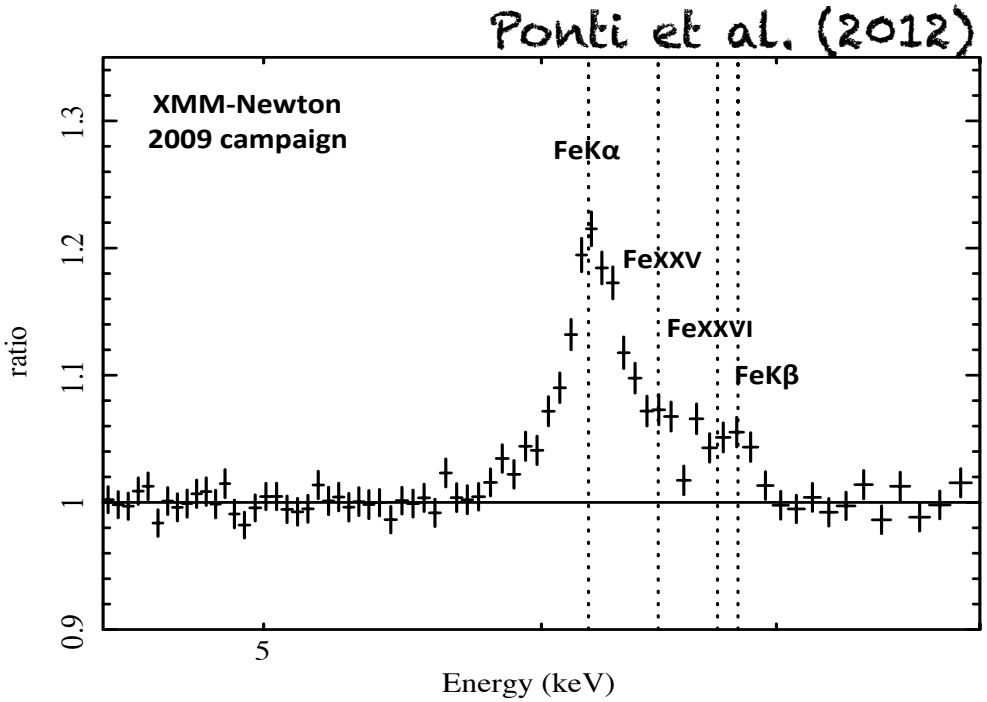
Geometry variation?



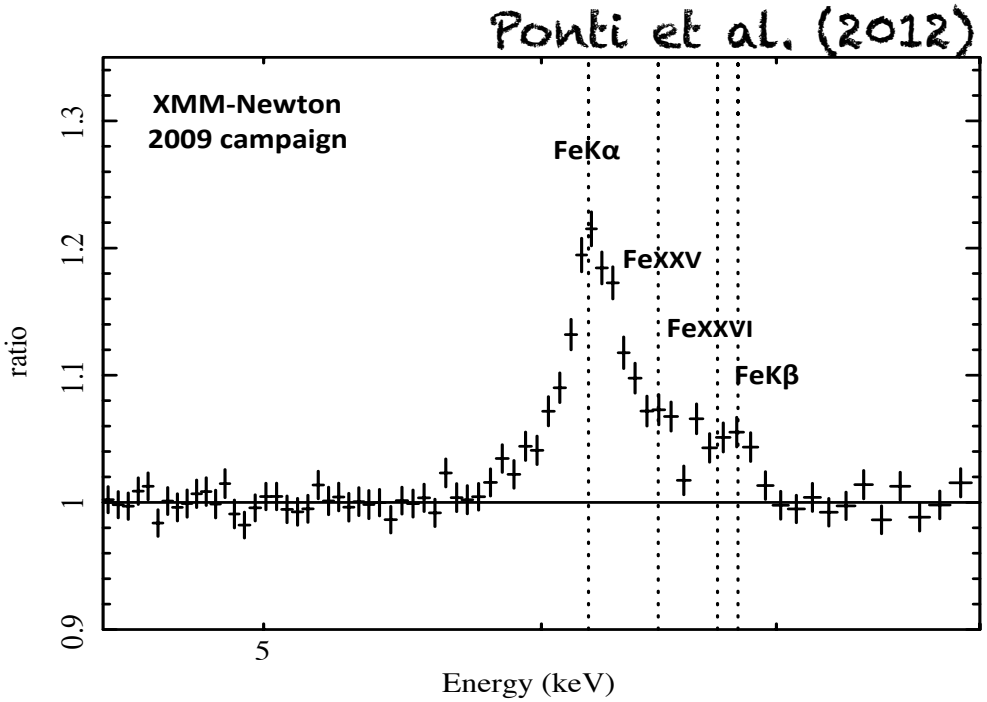
The WARM corona luminosity increases in the middle of the campaign, while the amplification ratio of the HOT corona decreases.

Consistent with a variation (decrease) of R_{in}

And the iron line?

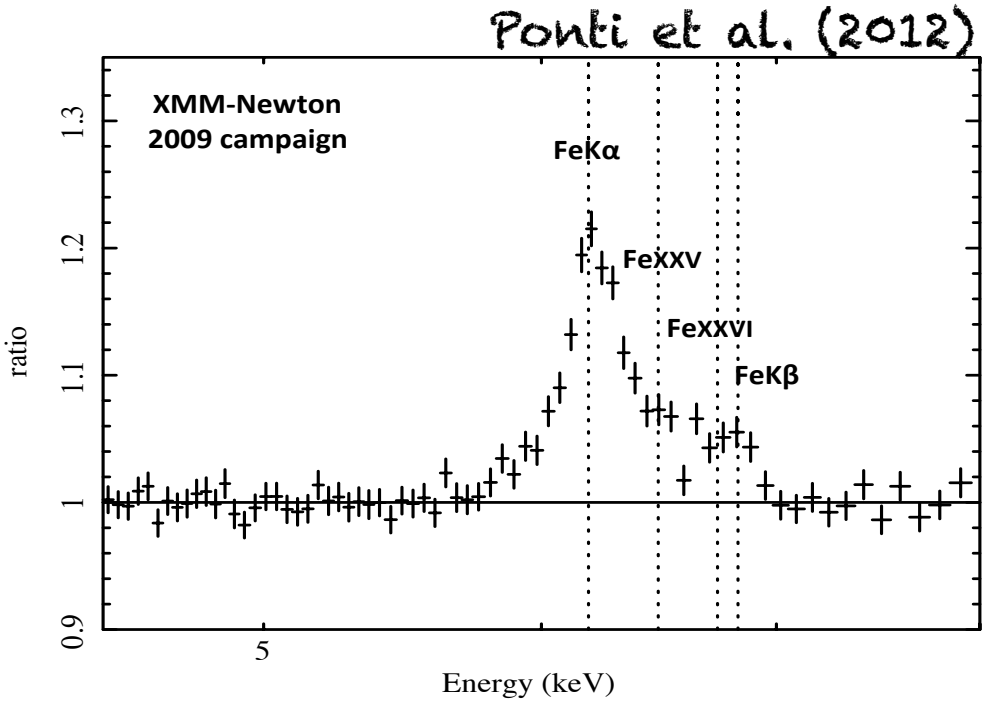


And the iron line?



- A narrow FeKα core (σ=0.03 keV)
  - ➡ Constant flux on year time scale
  - ➡ Signature of remote reflection

And the iron line?



- A narrow FeKα core (σ=0.03 keV)
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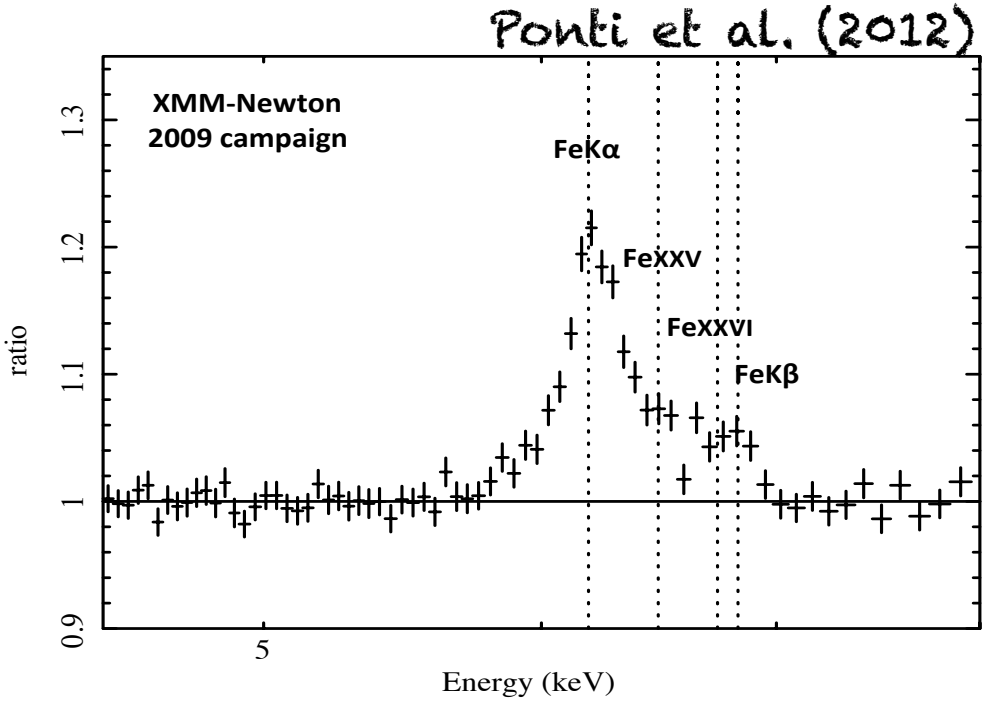
- A "broad" FeKα line (σ=0.22 keV)
  - ➡ Constant EW on day time scale
  - ➡ Originates from outer disc or BLR

And the iron line?



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  - ➡ Signature of remote reflection
- A "broad" FeKα line (σ=0.22 keV)
  - ➡ Constant EW on day time scale
  - ➡ Originates from outer disc or BLR

- A ionized line (E_{line} = 6.7-6.96 EW~20 eV)
  - ➡ Consistent with ionized reflection from inner disk ($R_{in} > 7\ R_g$)

Pair-dominated Hot-corona?

- Compacity: $l_h = \frac{L_h \sigma_T}{R m_e c^3}$ $l_c = \frac{L_c \sigma_T}{R m_e c^3}$

Pair-dominated Hot-corona?

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- In a pair-dominated plasma $(l_h, l_h/l_c) \leftrightarrow (\alpha, \tau)$

Pair-dominated Hot-corona?

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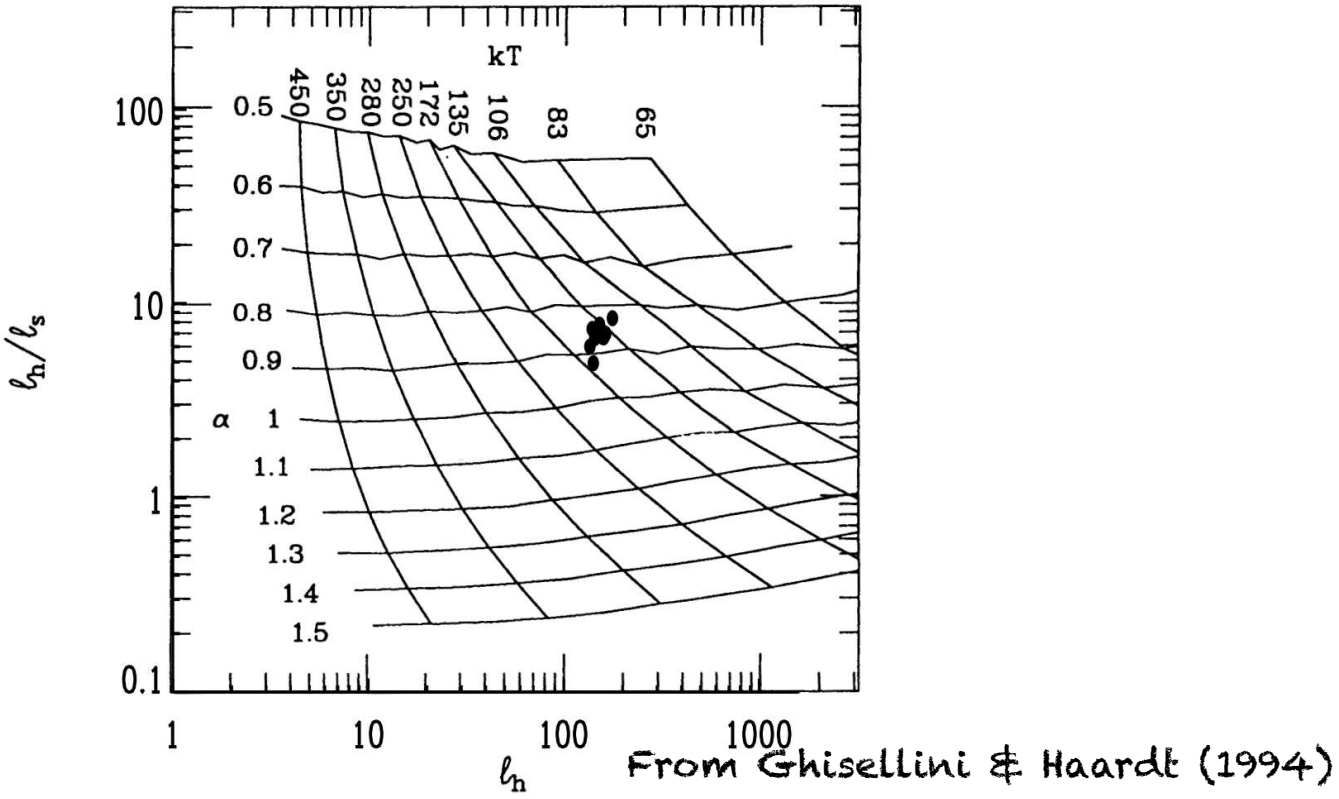

From Ghisellini & Haardt (1994)

Pair-dominated Hot-corona?

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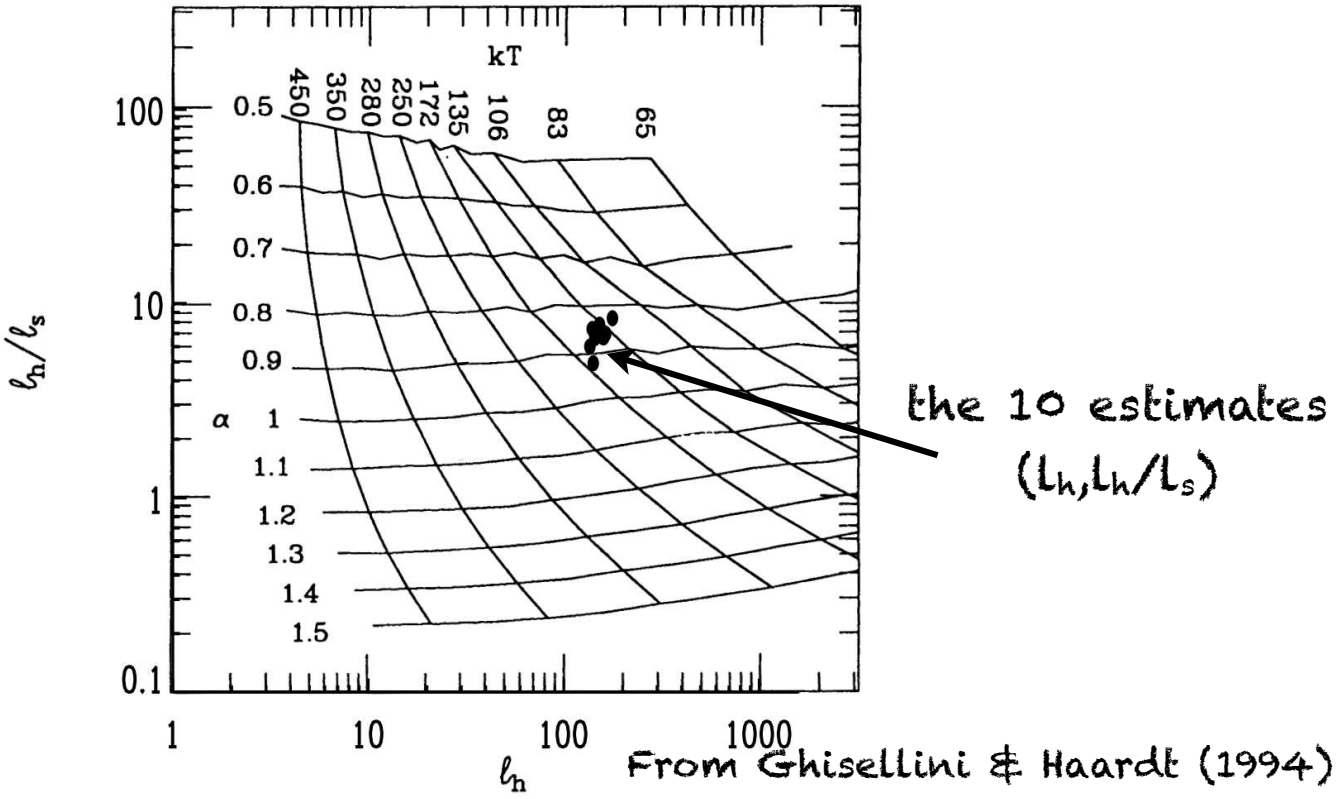

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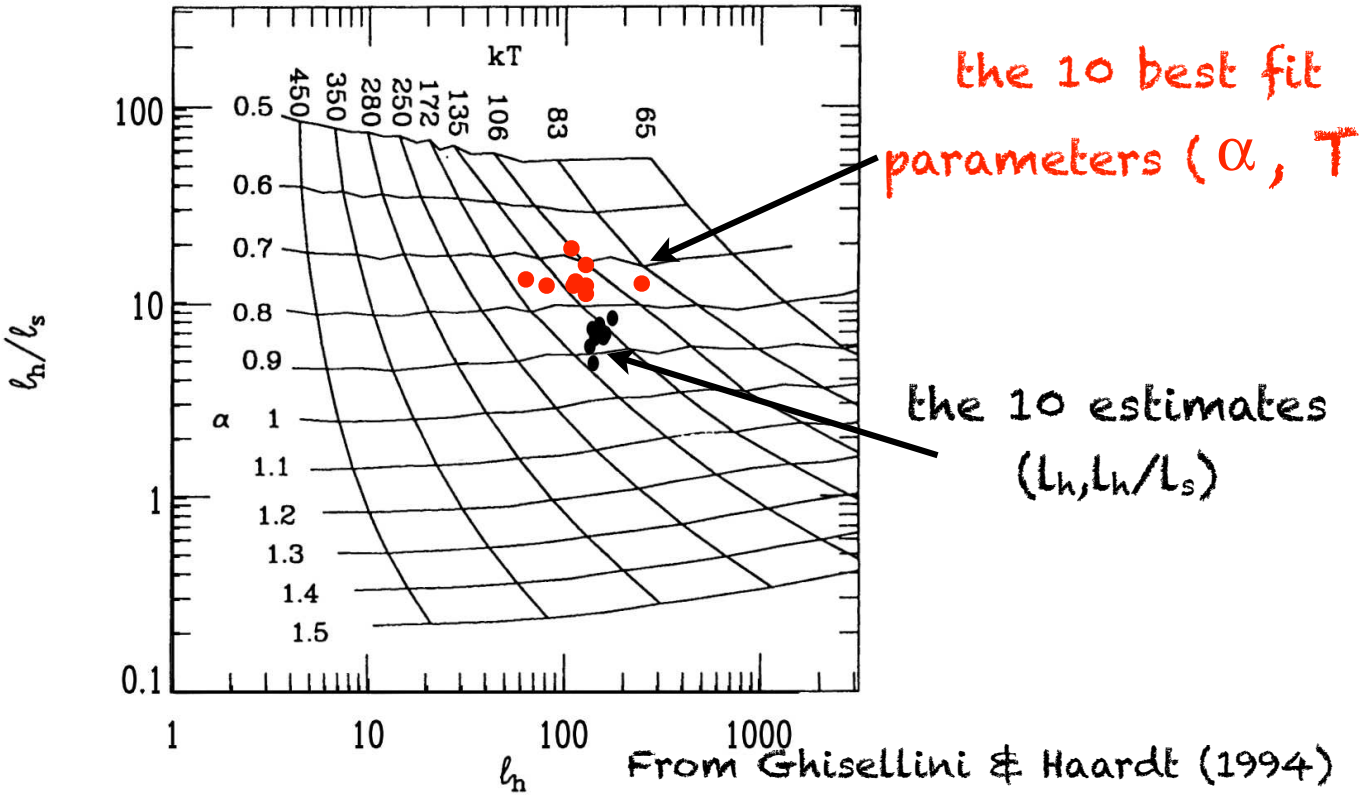
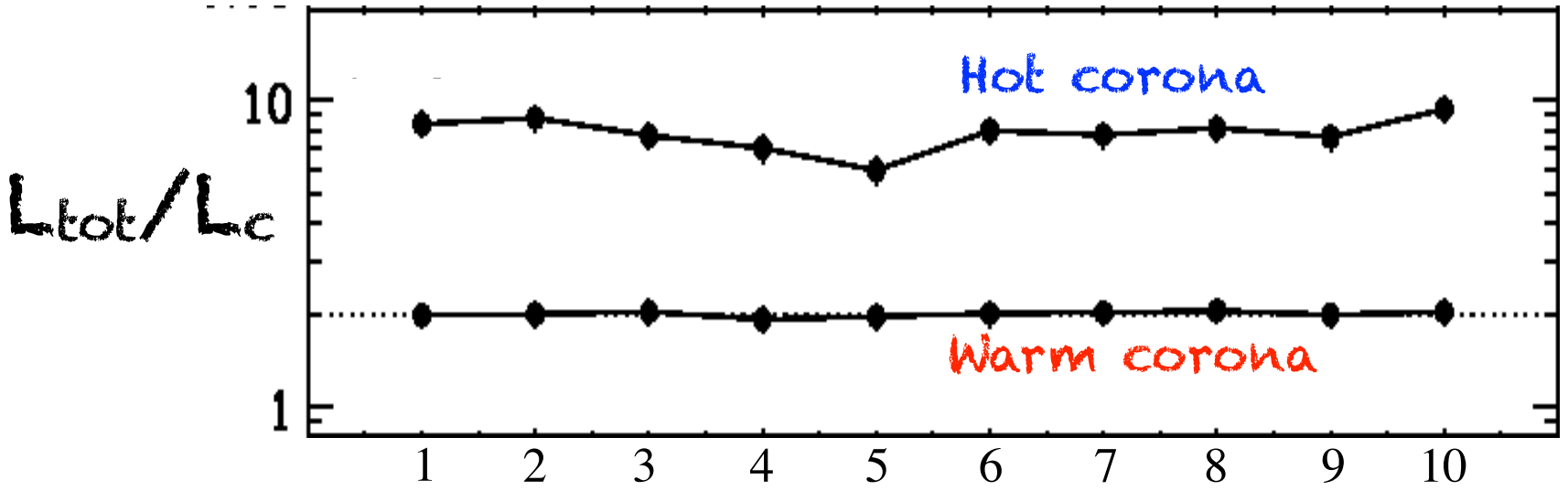


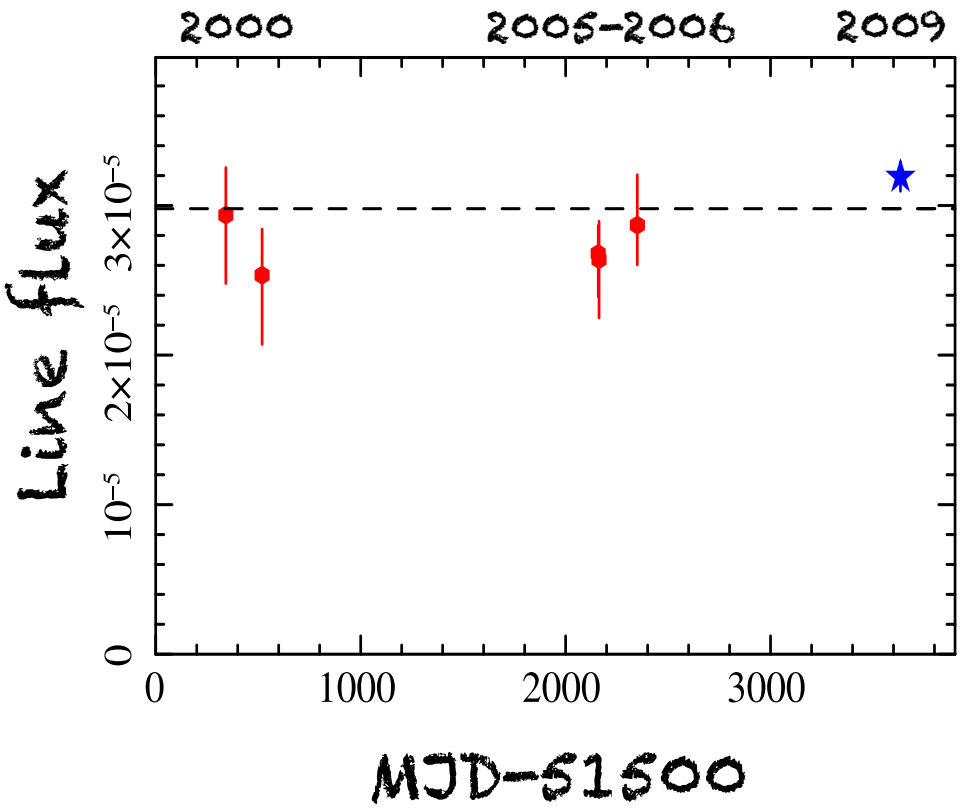
From Ghisellini & Haardt (1994)

The soft-X-ray excess



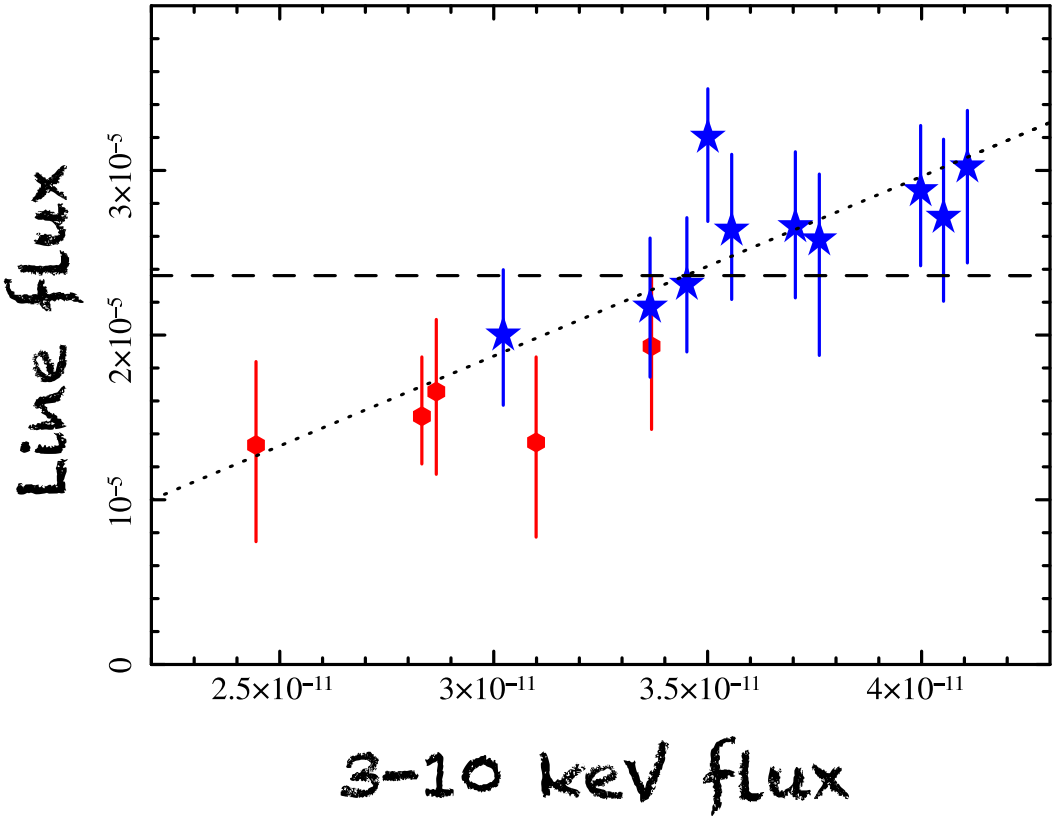
Its roughly constant spectral shape observed in AGNs of different BH masses and luminosities could be due to its configuration which implies a constant L_{tot}/L_c

Narrow component



Constant on year time scale

The Broad Kα component



The broad line follows the continuum on day time-scale

- May come from the disk at R = 300 - 1000 R_g
- May come from the BLR