# Revealing Accretion On To Black Holes

## X-ray reflection throughout three full outbursts of the black hole binary GX 399-4

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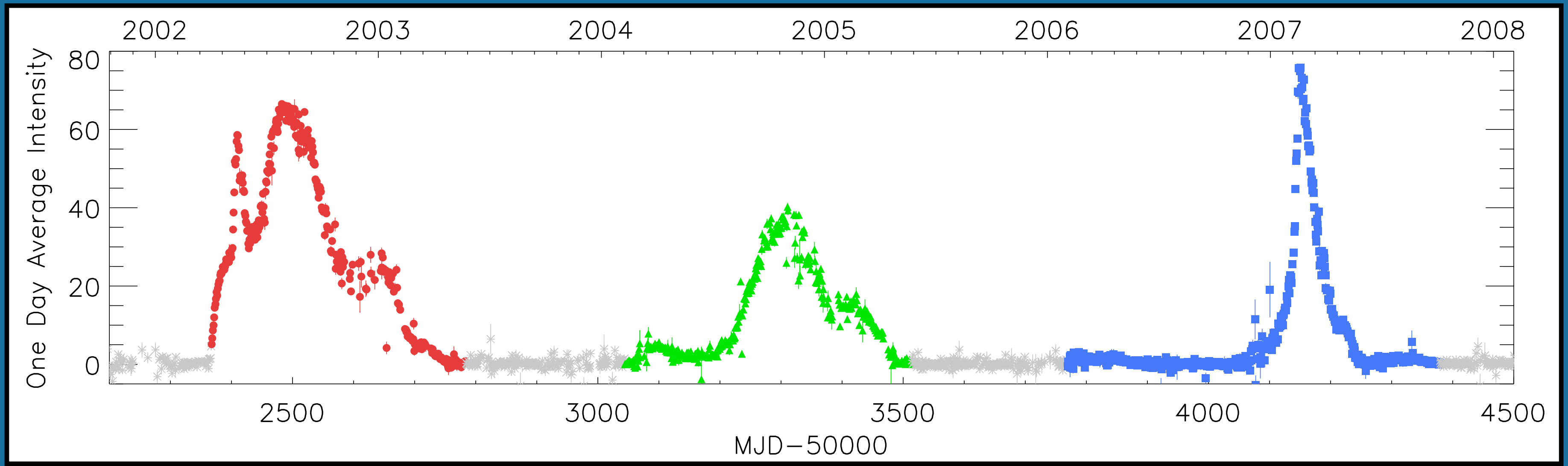
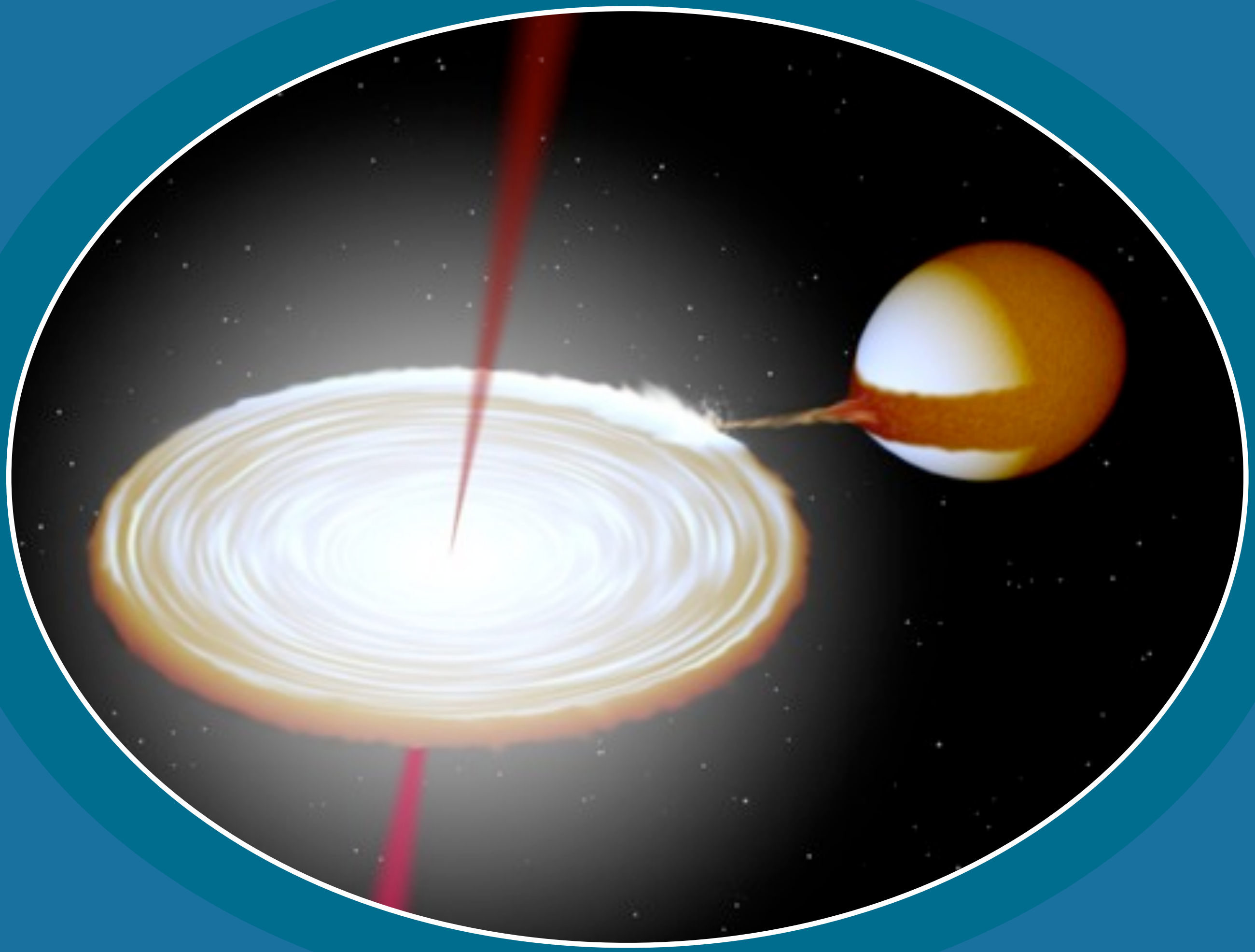



- Low-mass X-ray binary
- Discovered in 1973 (Markert+1973)
- Exhibits outbursts every few years (see the light-curve above)
- Due to the large number of outbursts GX 339-4 has become one of the best studied black hole X-ray binaries



# Three full outbursts of GX 399-4 with RXTE

3 outbursts covered, limited to where the PCA (3-50 keV) and HEXTE (25-200 keV) were both available (up to 2009)

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500+ observations

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Over 1Ms of PCA exposure time

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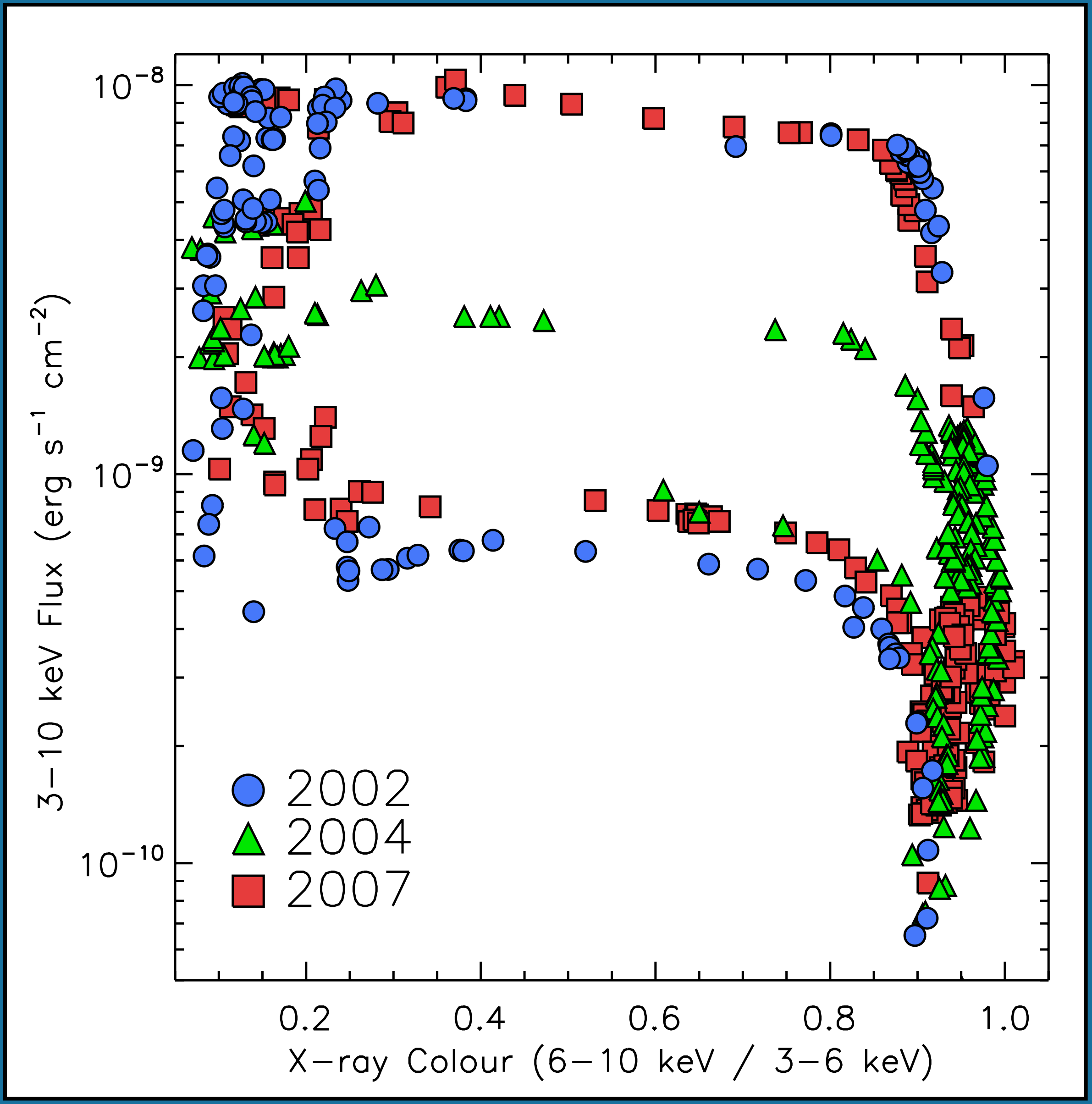
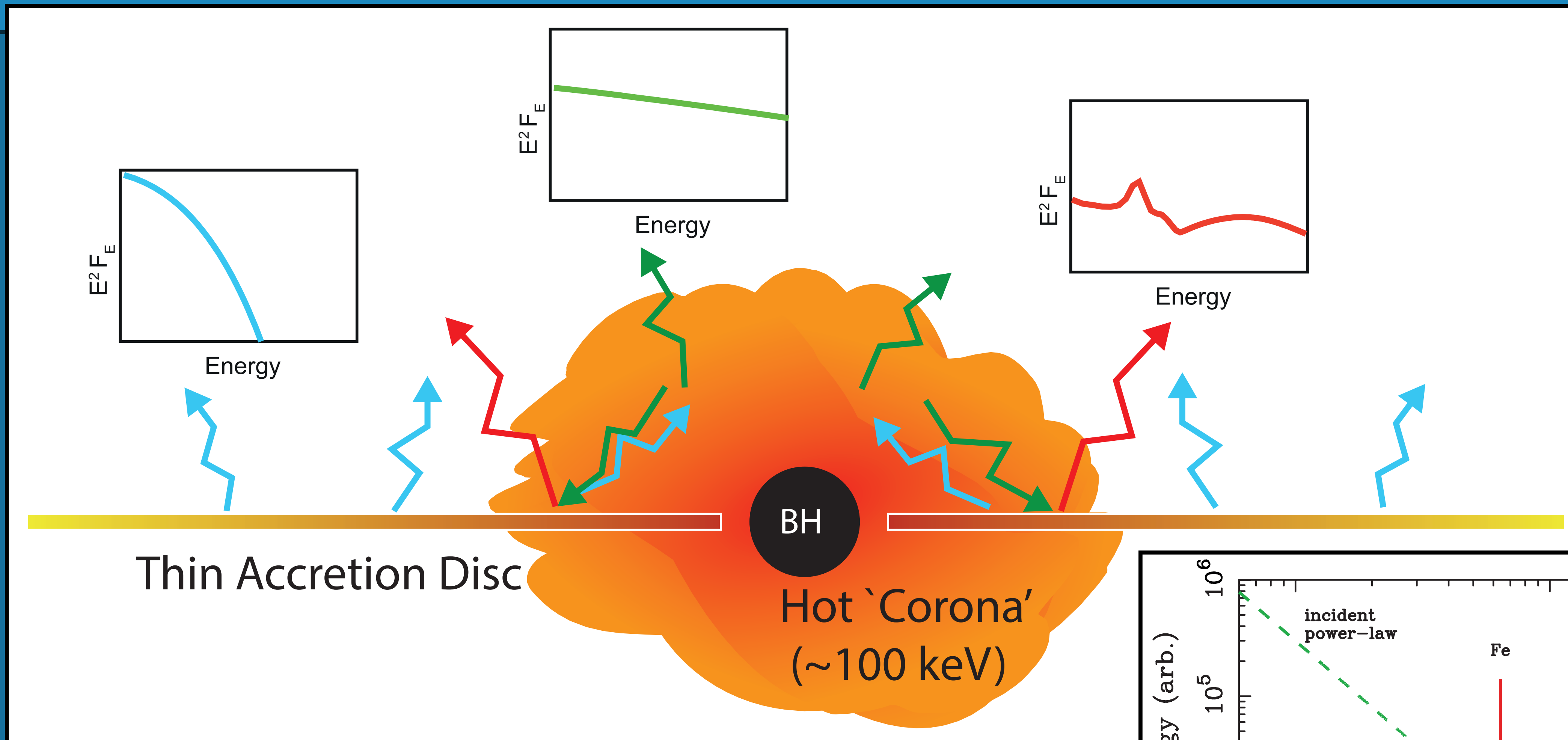
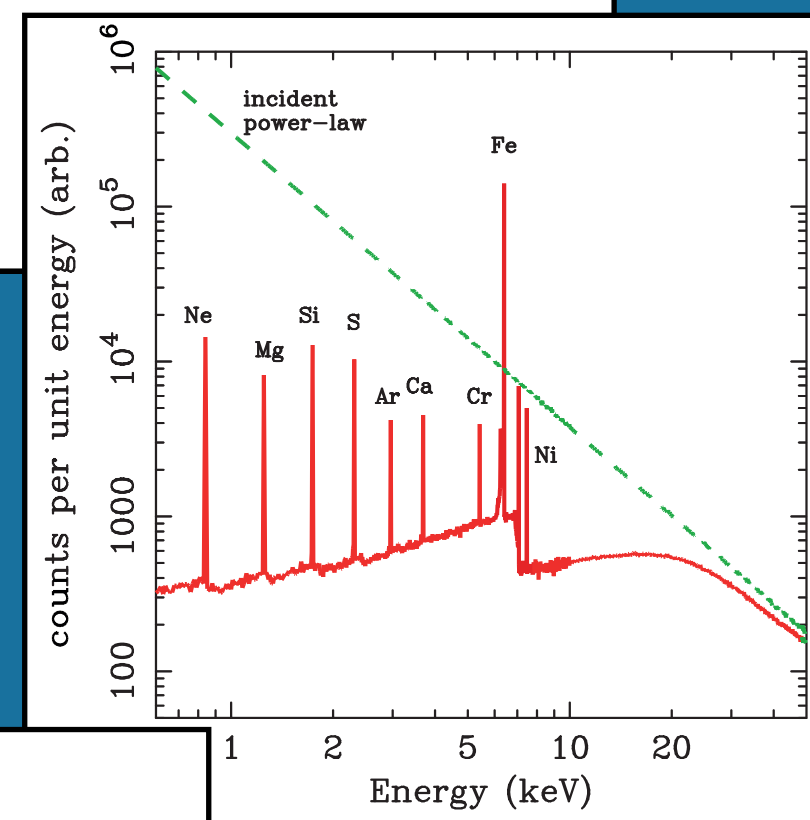
We applied a self-consistent, angle-resolved, reflection model (XILLVER-A; Garcia+13)

Hardness-Intensity Diagram (HID)



# X-ray Reflection



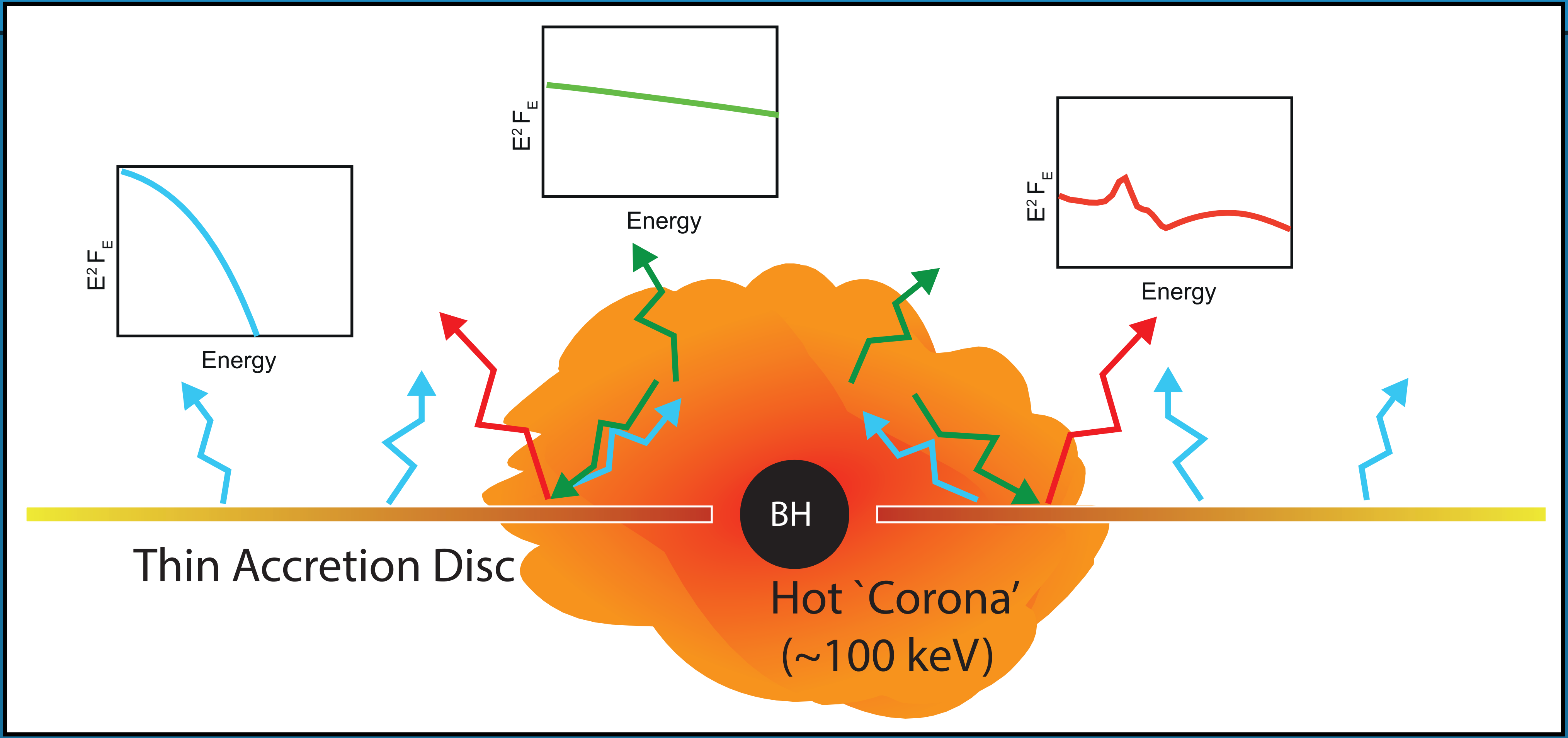




Accretion Disc: Thermal (peak ~1 keV) multi-colour blackbody

Power-law: Disc photons up-scattered in a hot (~100 keV) 'corona'

Reflection: Power-law photons irradiating the disc
Photo-absorption -- Fluorescent emission (Fe Kα)
Down-scattering -- Compton hump at ~30 keV

# Reflection vs. Power-law




For a stable accretion geometry, the power-law and reflection components should evolve in the same way.

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For example, if the power-law flux doubles, the reflection should double as well.

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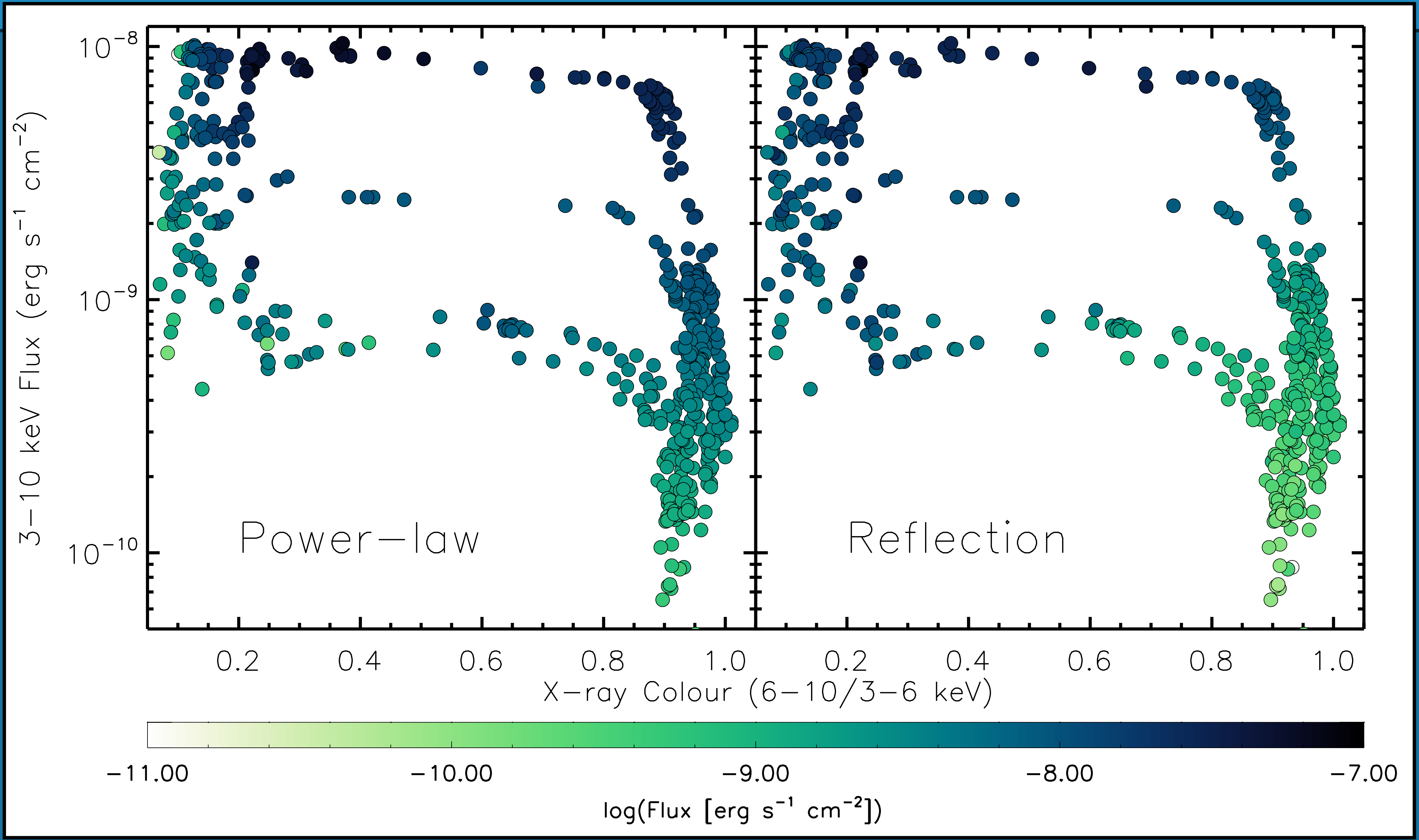
Any alternative evolution should represent changes in the accretion geometry.

# Reflection vs. Power-law

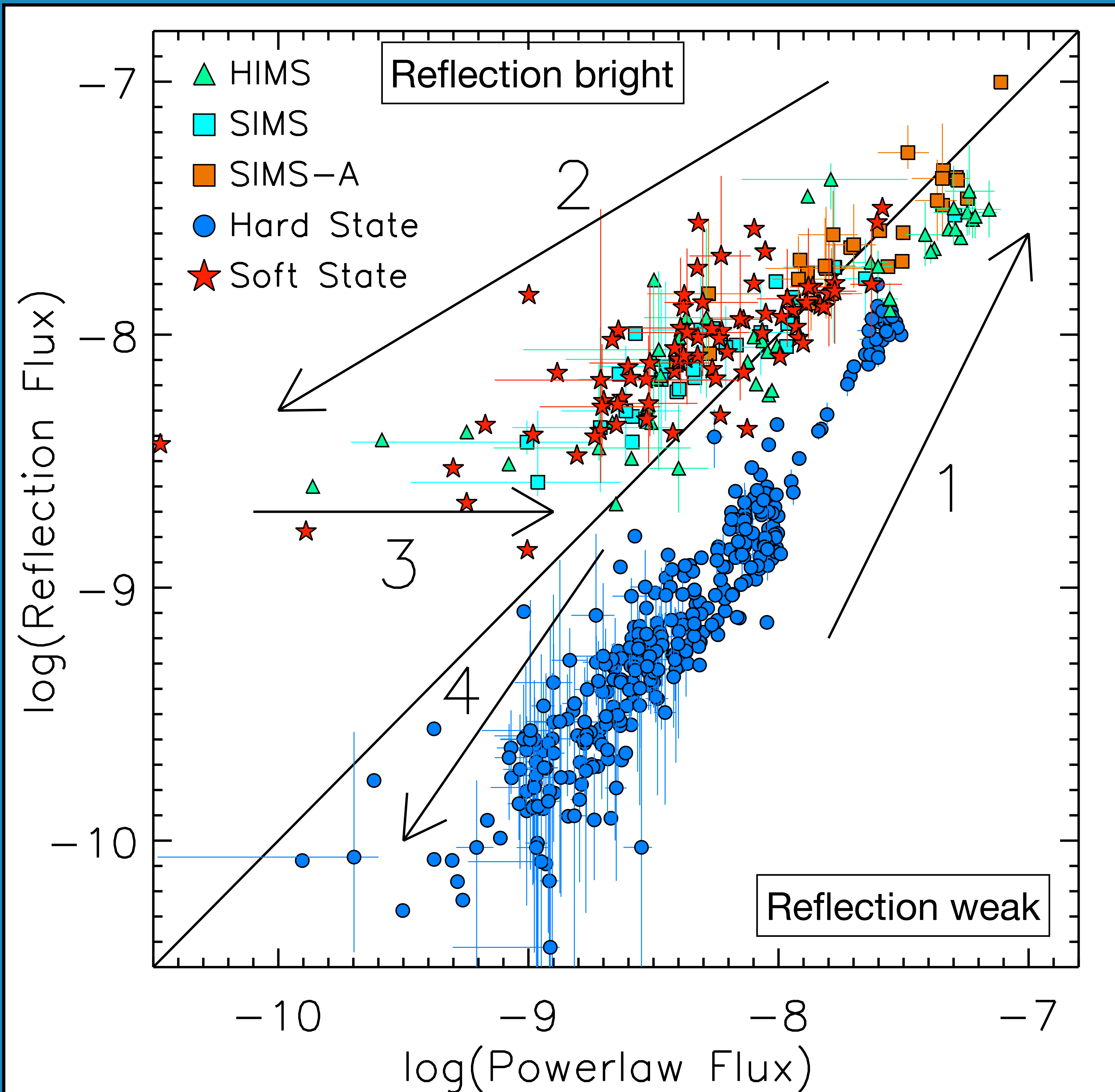
Plant+(2014a)




Clearly, the power-law and reflection evolve differently in outburst

# Reflection vs. Power-law

Plant+(2014a)



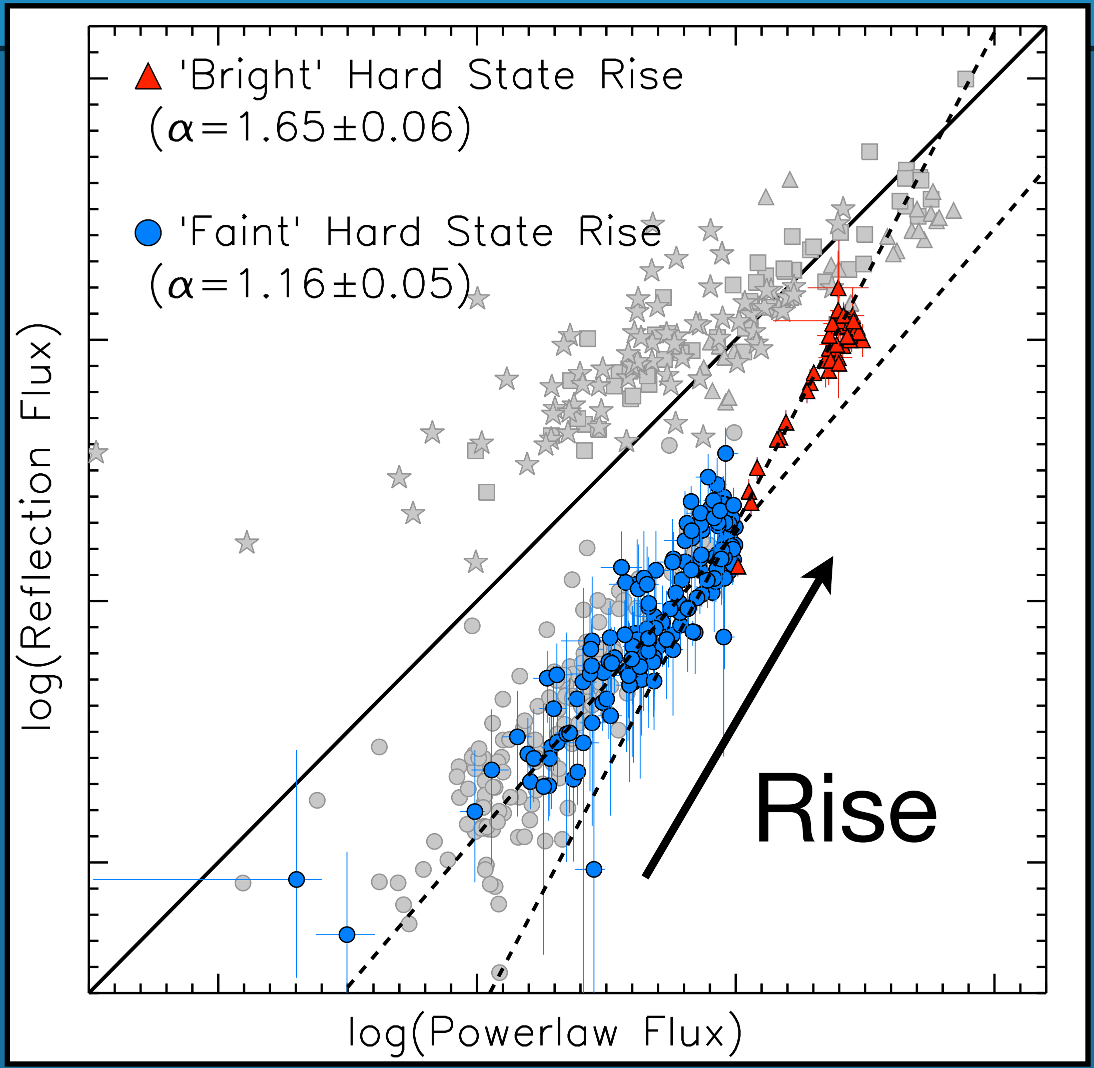

The hard state (blue) is reflection weak.

The soft state (red) is reflection bright.

During the state transition (green), the two components are similar in strength.

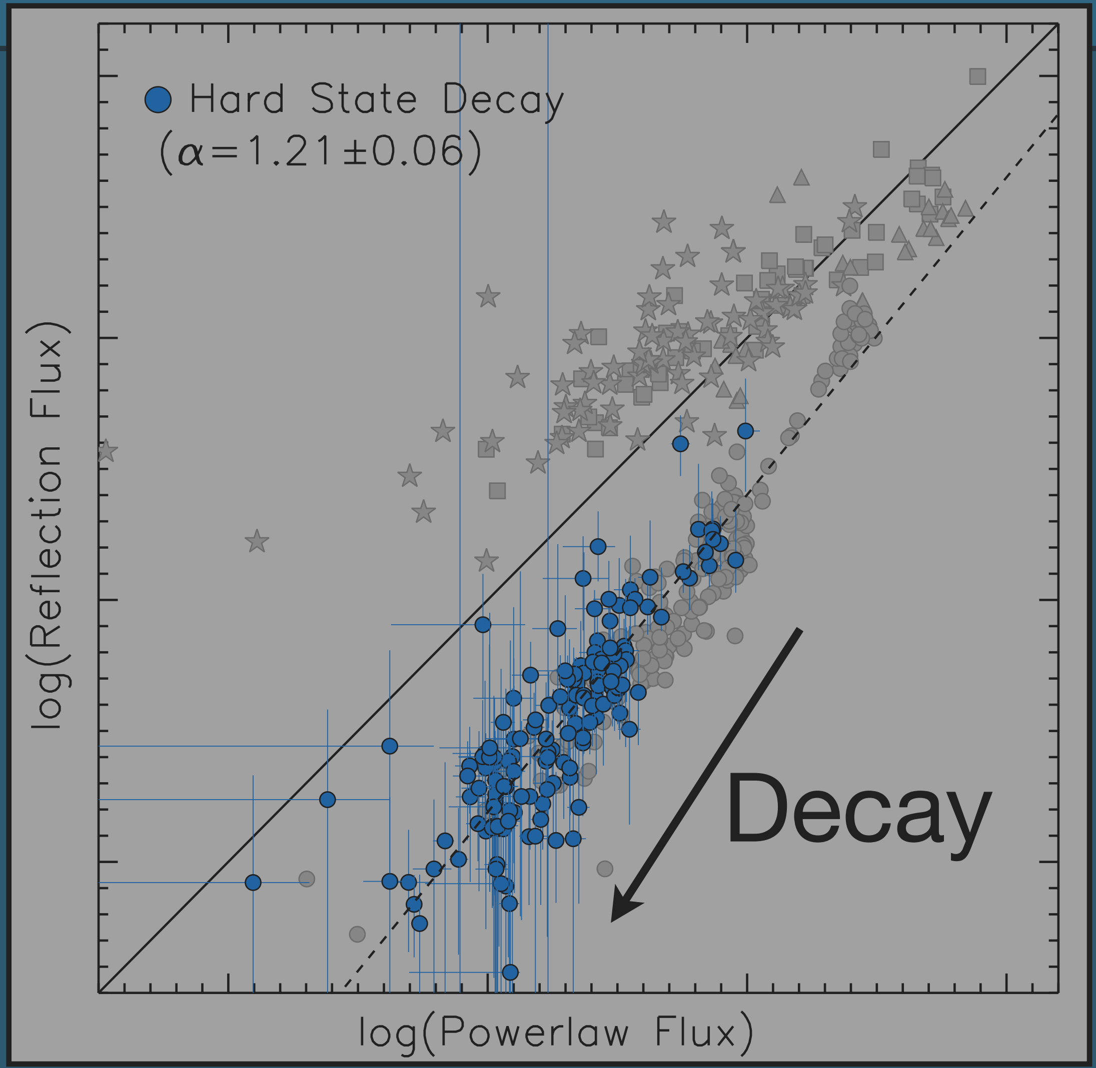
# Reflection vs. Power-law -- The Hard State

Plant+(2014a)




The rising phase of the hard state has a slope > 1, which becomes much steeper above ~5% $L_{Edd}$.

Therefore as the source luminosity increases, the reflection flux increases faster than the power-law




The decaying phase of the hard state follows the same slope as the rise below ~5% $L_{Edd}$, suggesting the same process leads to the system to and from quiescence.

# Reflection vs. Power-law -- The Hard State

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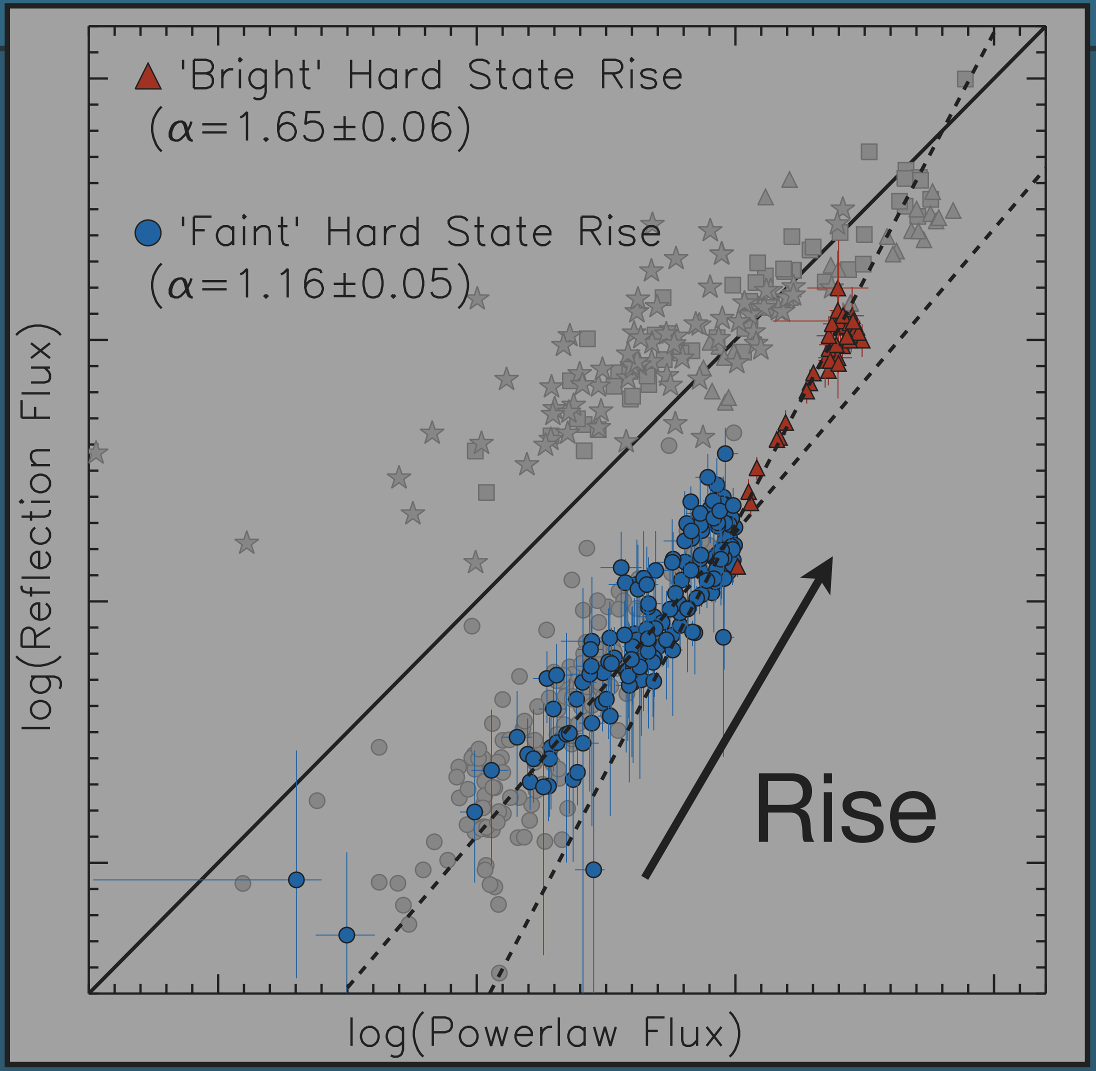


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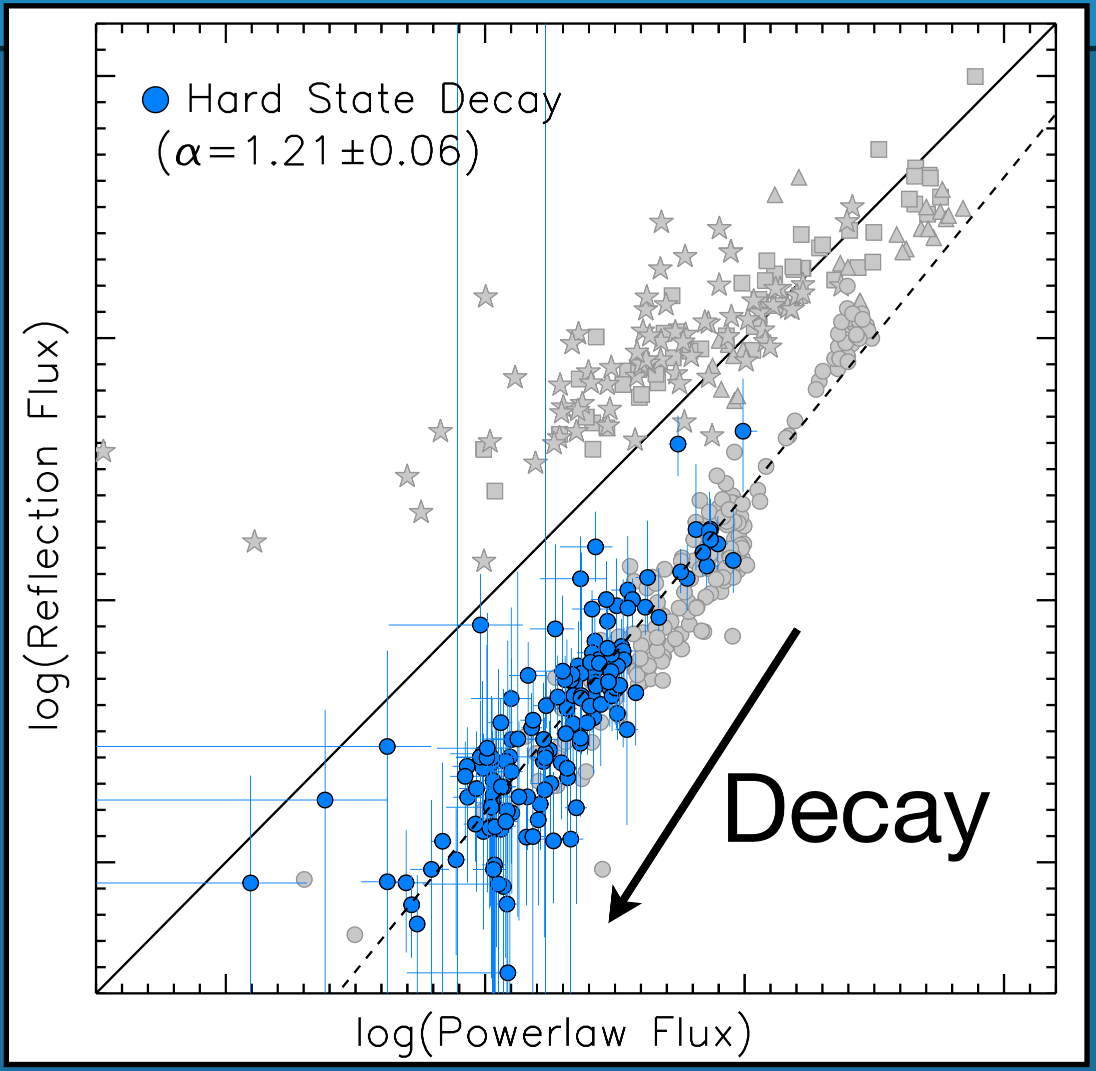



The decaying phase of the hard state follows the same slope as the rise below ~5% $L_{Edd}$, suggesting the same process leads to the system to and from quiescence.

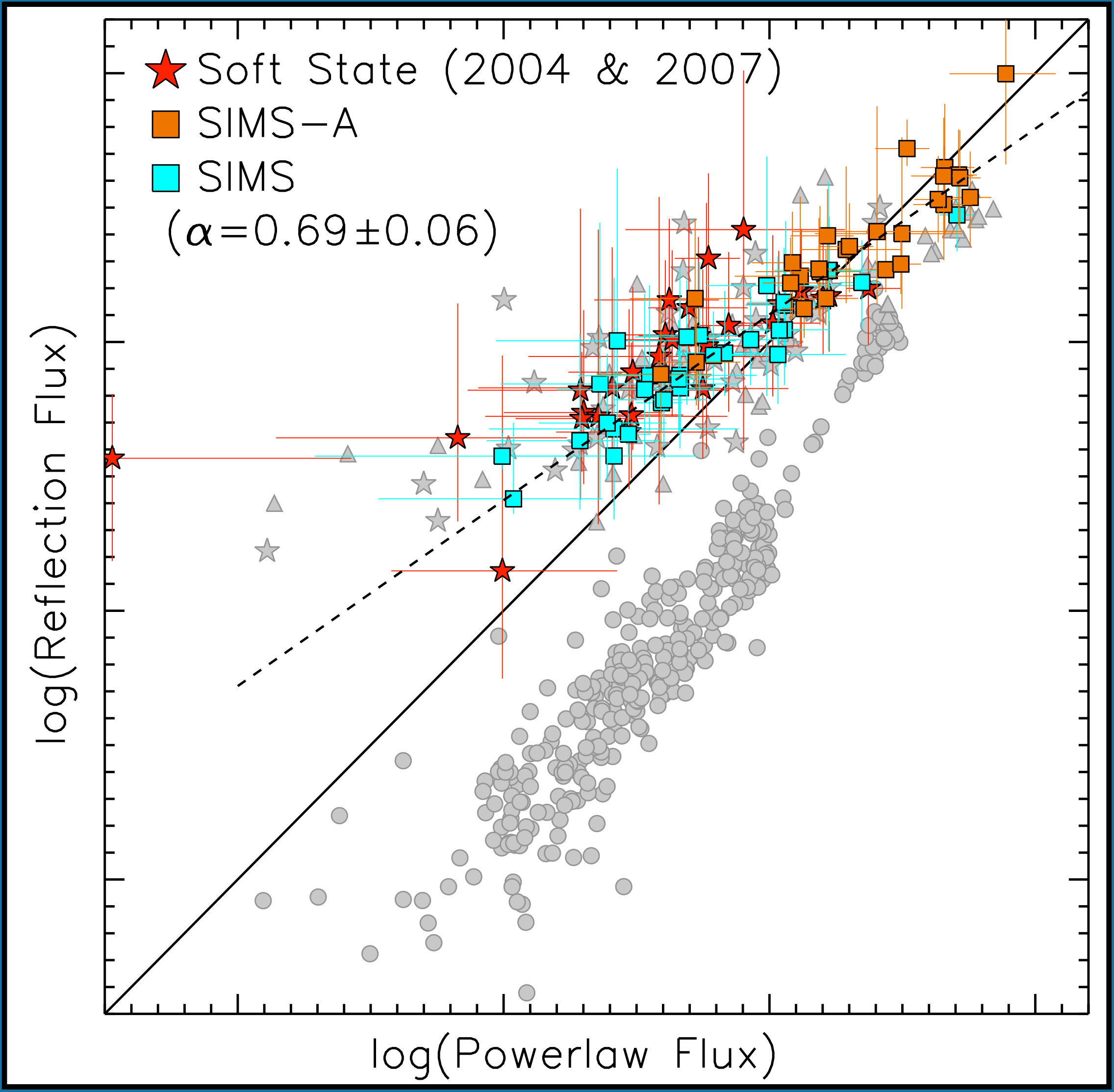
# Reflection vs. Power-law -- The Soft State

Plant+(2014a)

As the source decays through the soft state, the reflection decays slower than the power-law (slope < 0.7).

We also see that the reflection flux is now larger than the power-law -- the source becomes more and more reflection dominated as it decays

In comparison, in the hard state the reflection flux can be less than 20% of the power-law.




Clearly the accretion geometry is much different between the hard and soft states.

# Solution I -- A varying disc inner radius

As the disc area increases, a larger amount of coronal photons are intercepted by the disc (the solid angle of the disc increases)

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The reflection flux and reflection/ power-law ratio increase as a result

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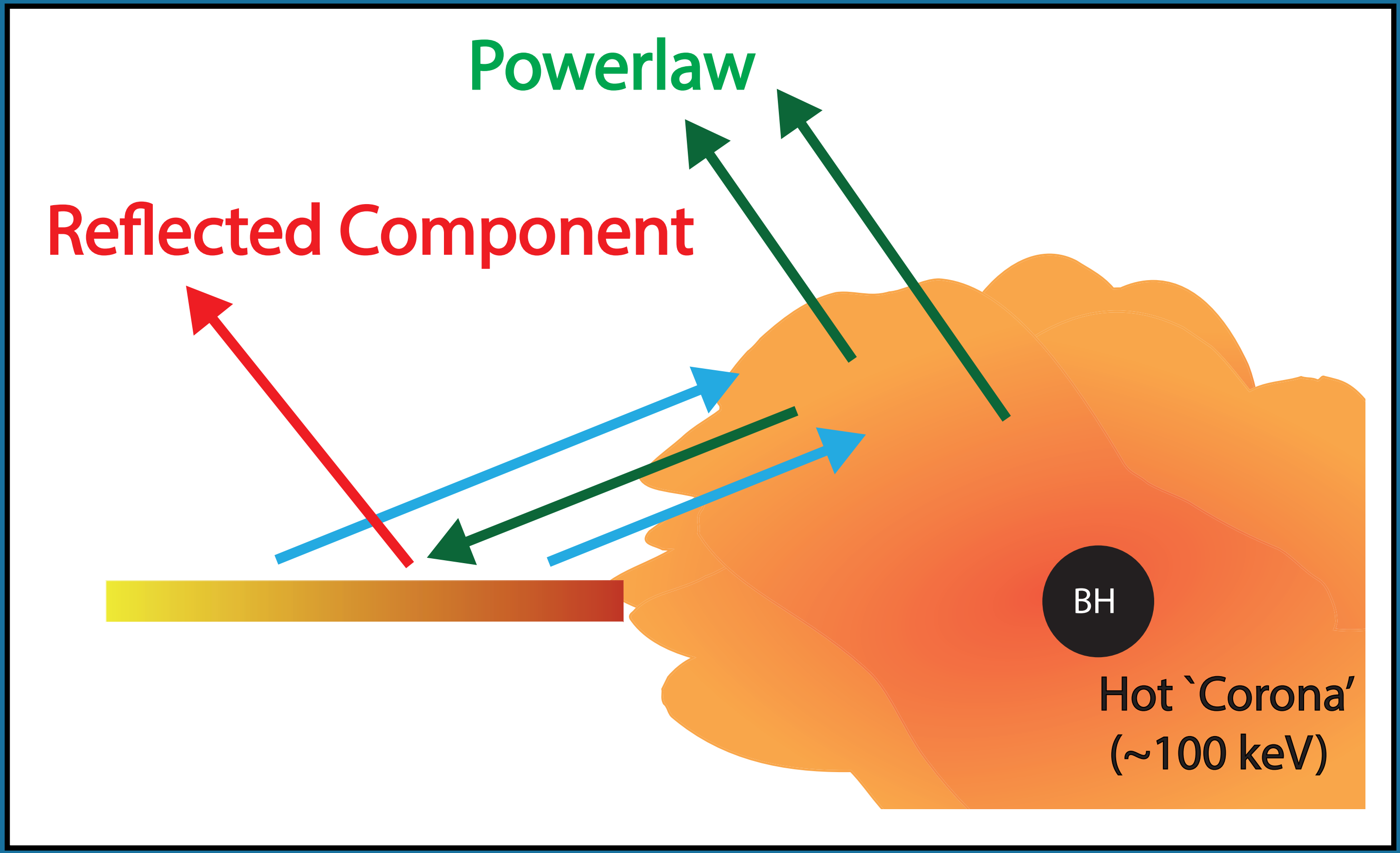
Furthermore, as the disc nears the black hole light-bending will focus increasing amounts of up-scattered photons onto the disc, allowing reflection to dominate the power-law



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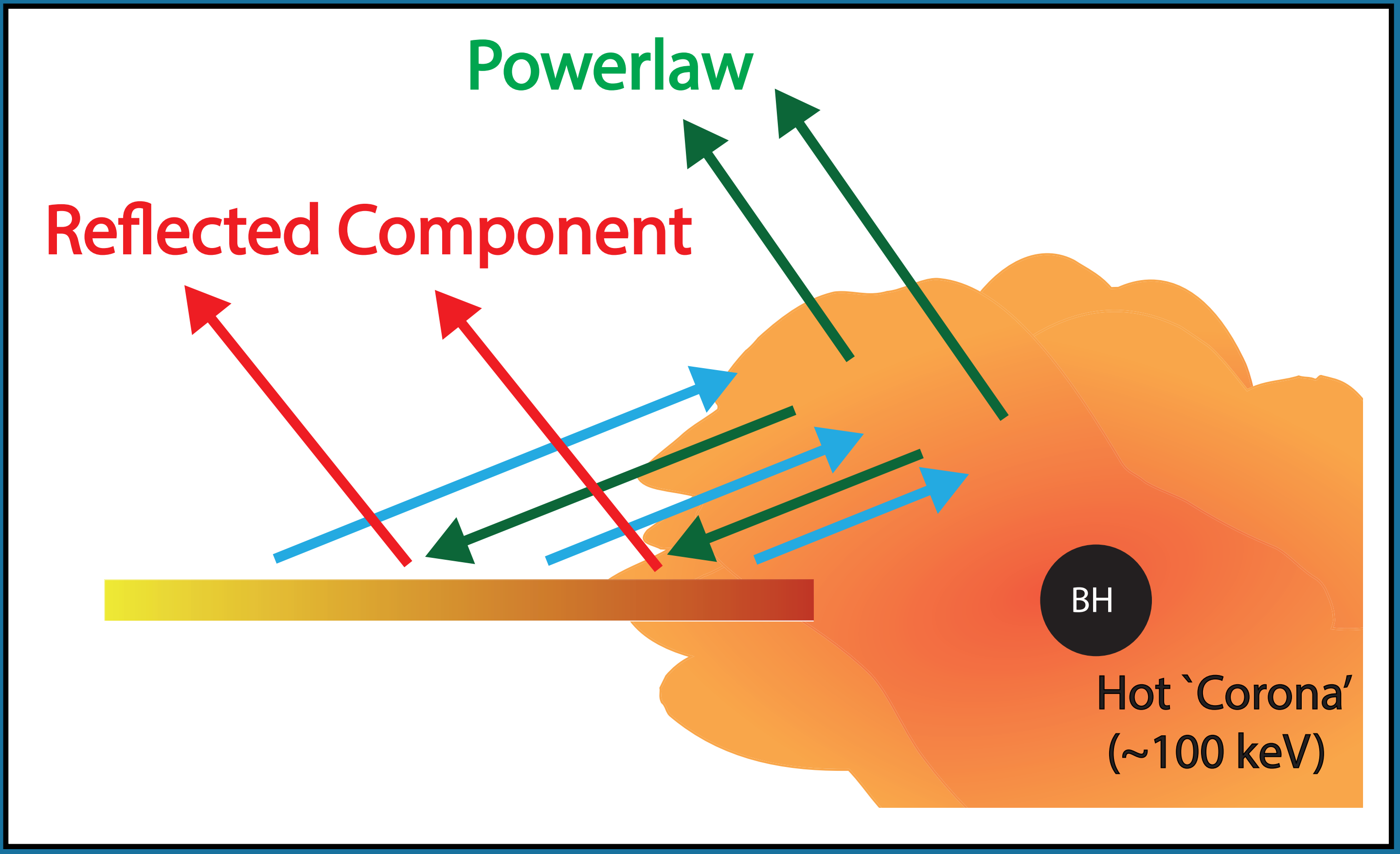

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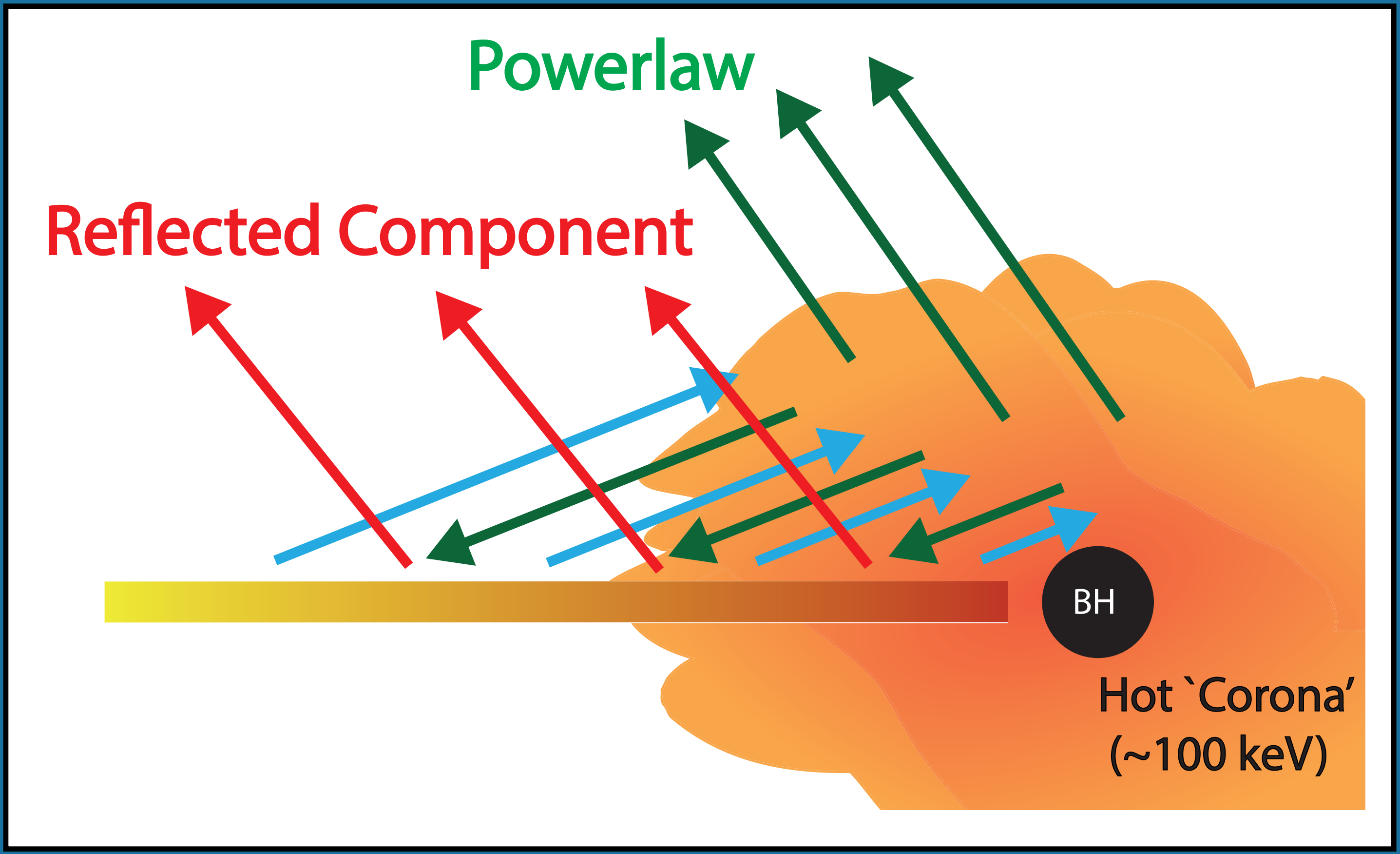
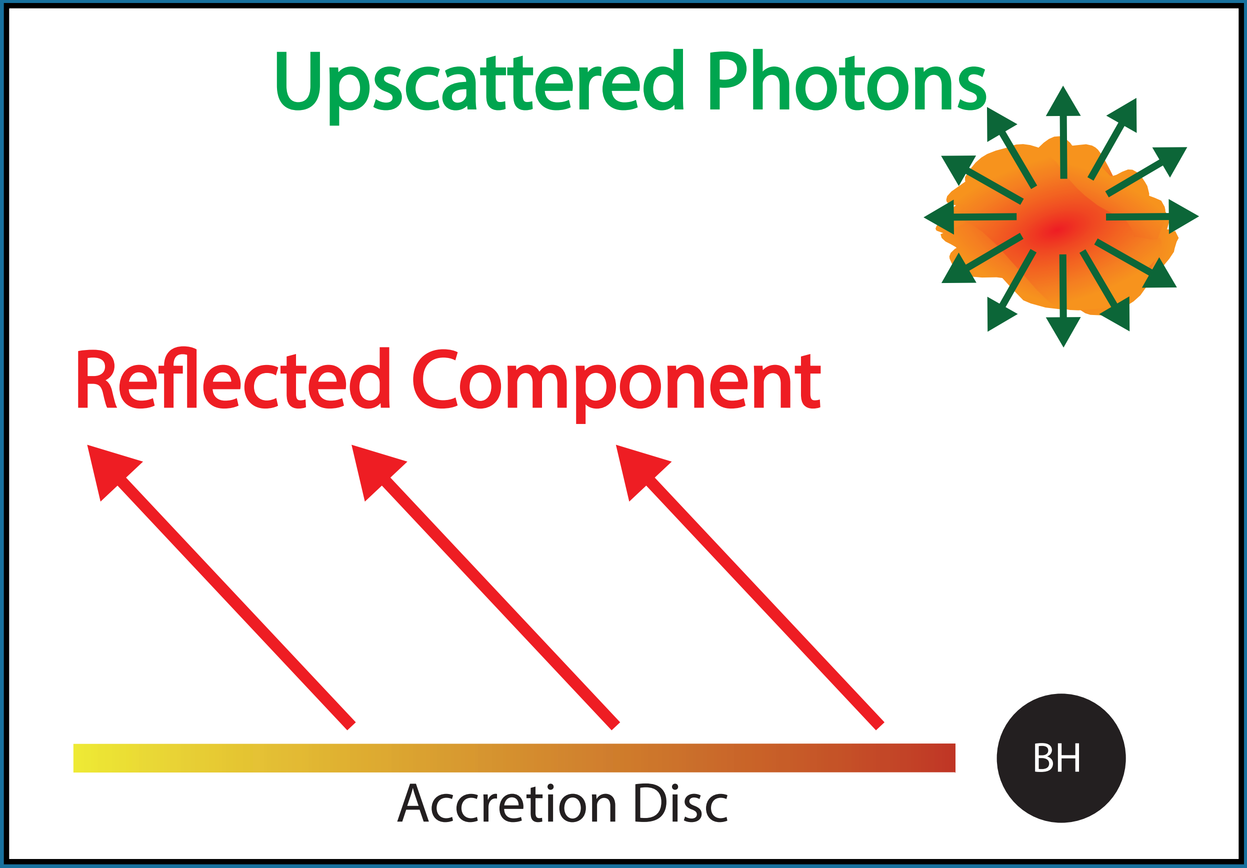


# Solution II -- A varying corona height

If the corona height decreases, a larger fraction photons will be intercepted by the disc.

This will lead to a larger amount of reflection observed and a higher reflection/power-law ratio.

As the corona height decreases, a larger portion of coronal photons will be focused onto the inner disc due to light bending, increasing the reflection/power-law ratio above unity.



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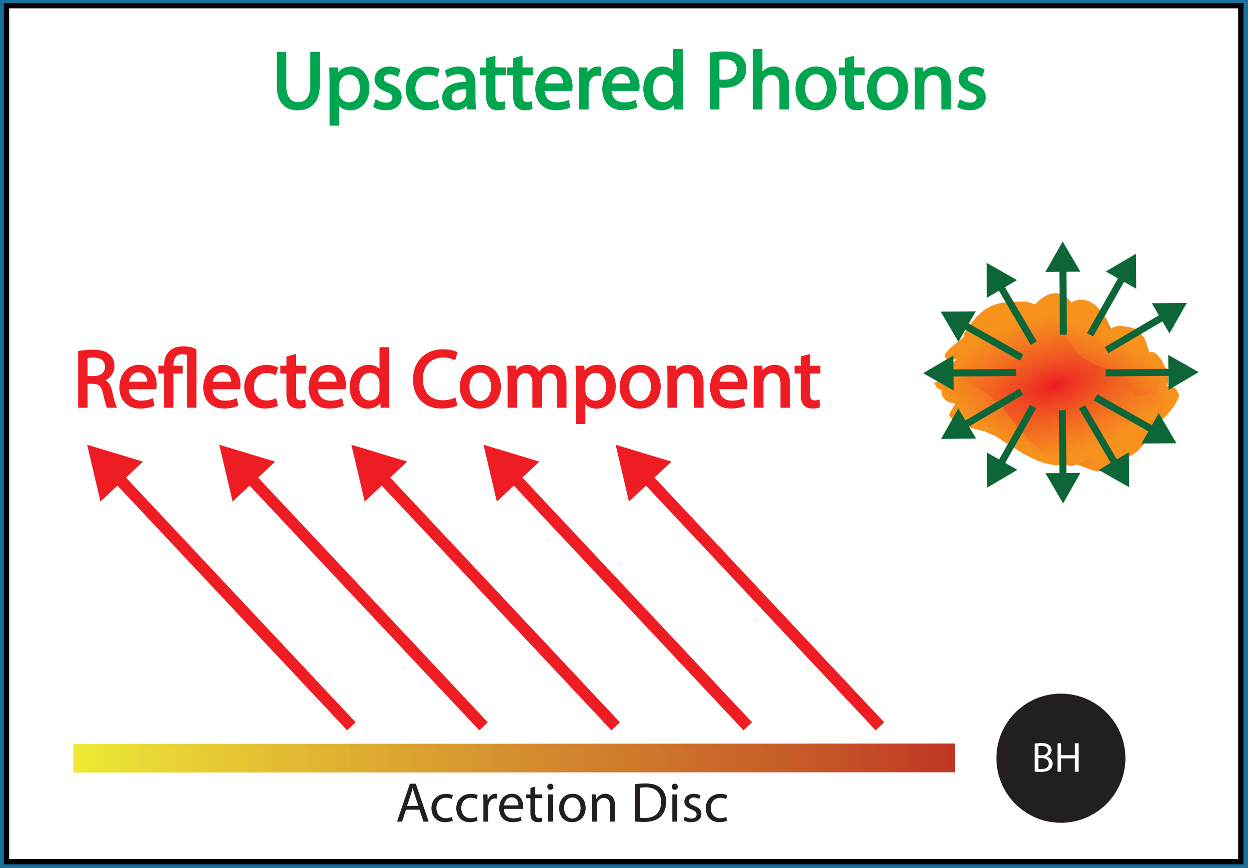

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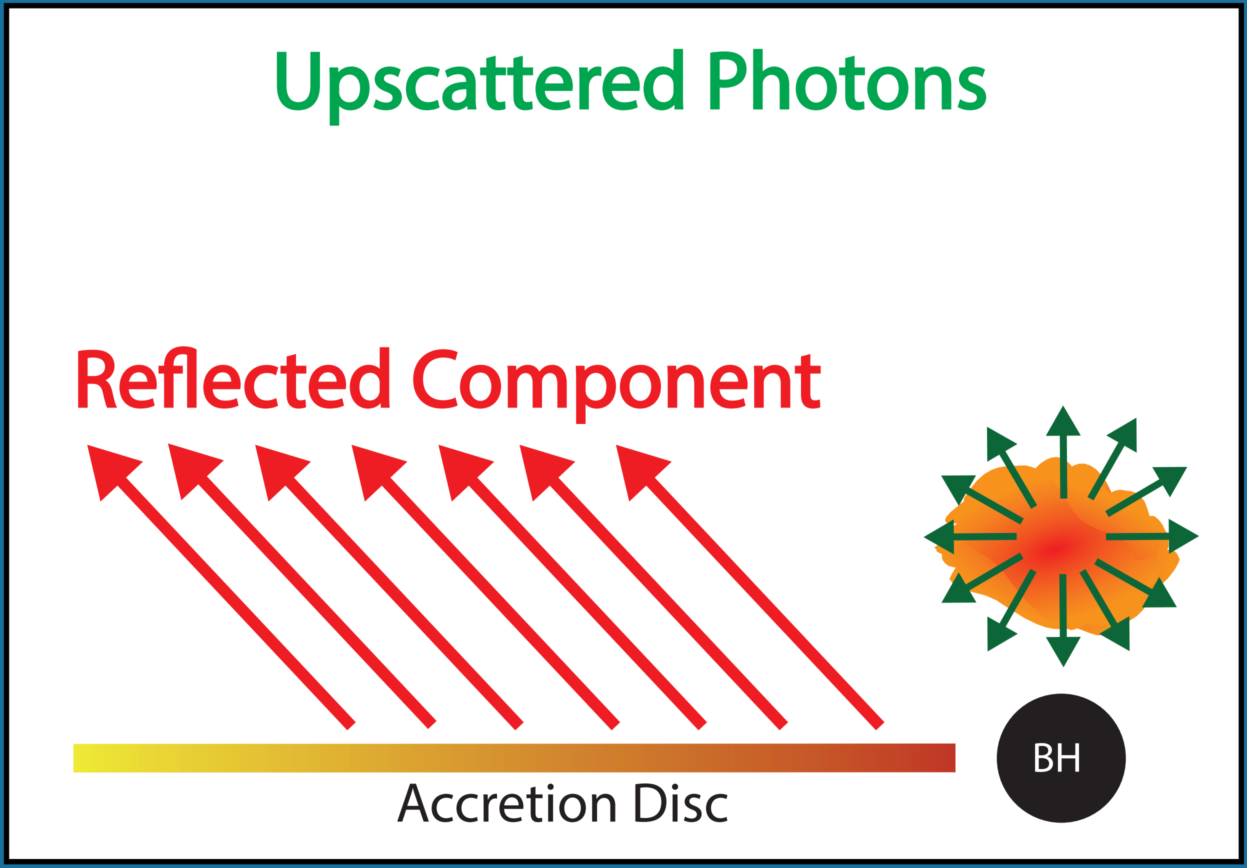
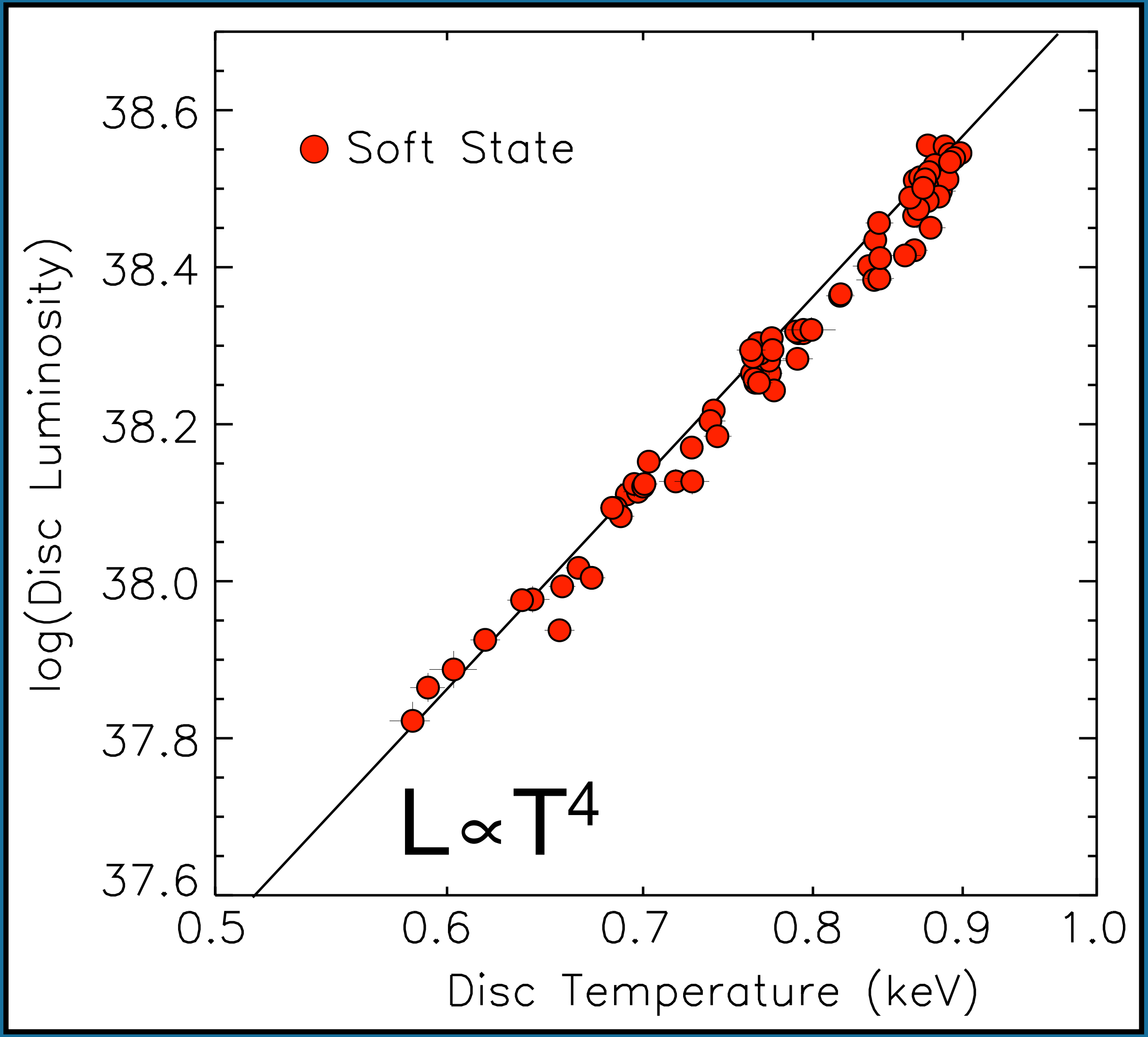


# The Soft State -- A constant disc inner radius

Plant+(2014a)




$L \propto r_{in} T^4$

Over three outbursts the soft state follows the $L \propto T^4$ relation (solid line), thus implying that the inner radius remains constant during this phase.

(see also Gierlinski+(2004); Steiner+(2010); Dunn+(2011))

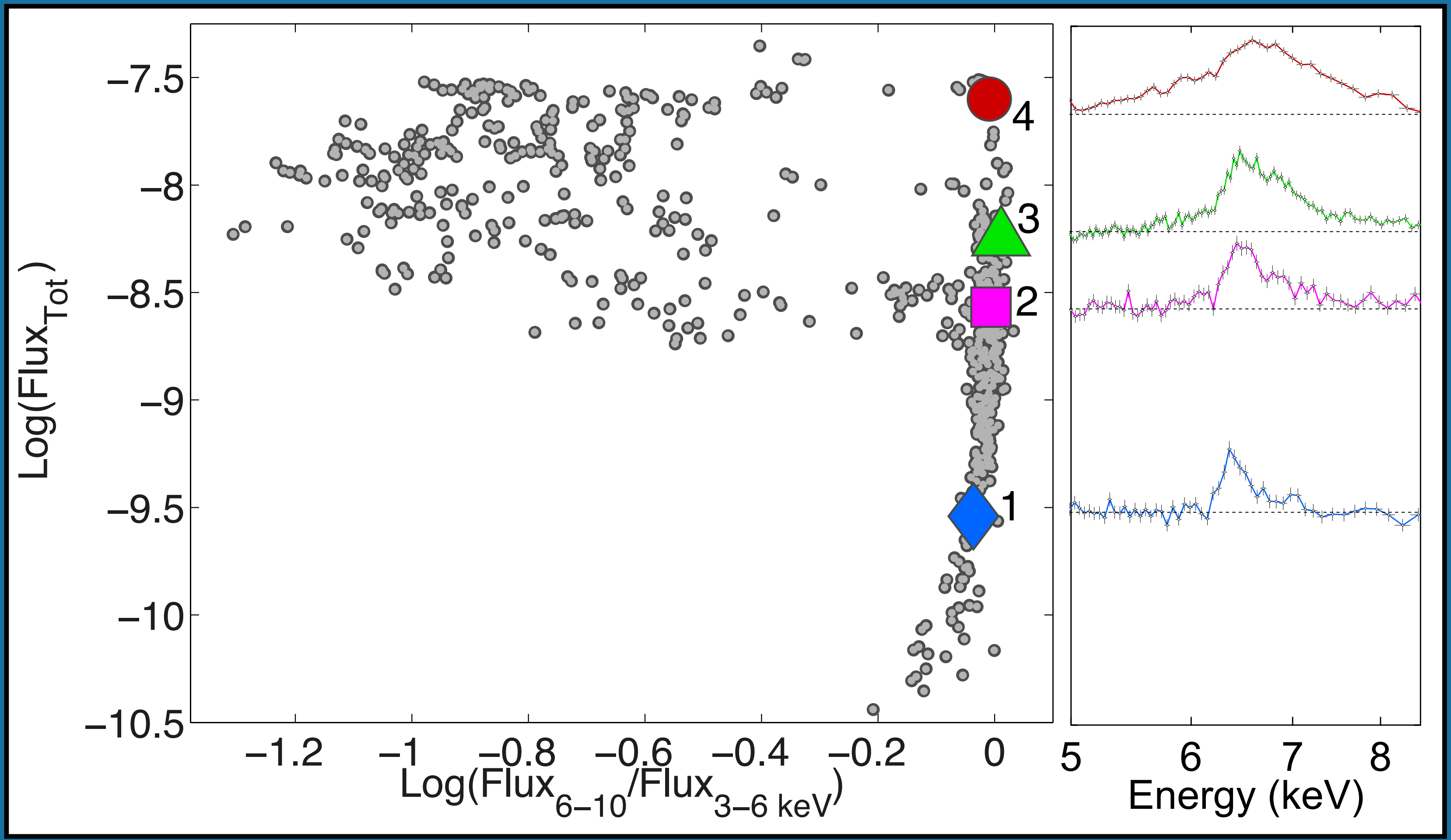
But, the reflection/power-law ratio increases during this phase -- this must therefore be driven by changes in the corona.

# The Hard State -- A varying disc inner radius

Plant+(2014b)

We analysed four hard state observations of GX 339-4 taken with XMM-Newton and Suzaku.

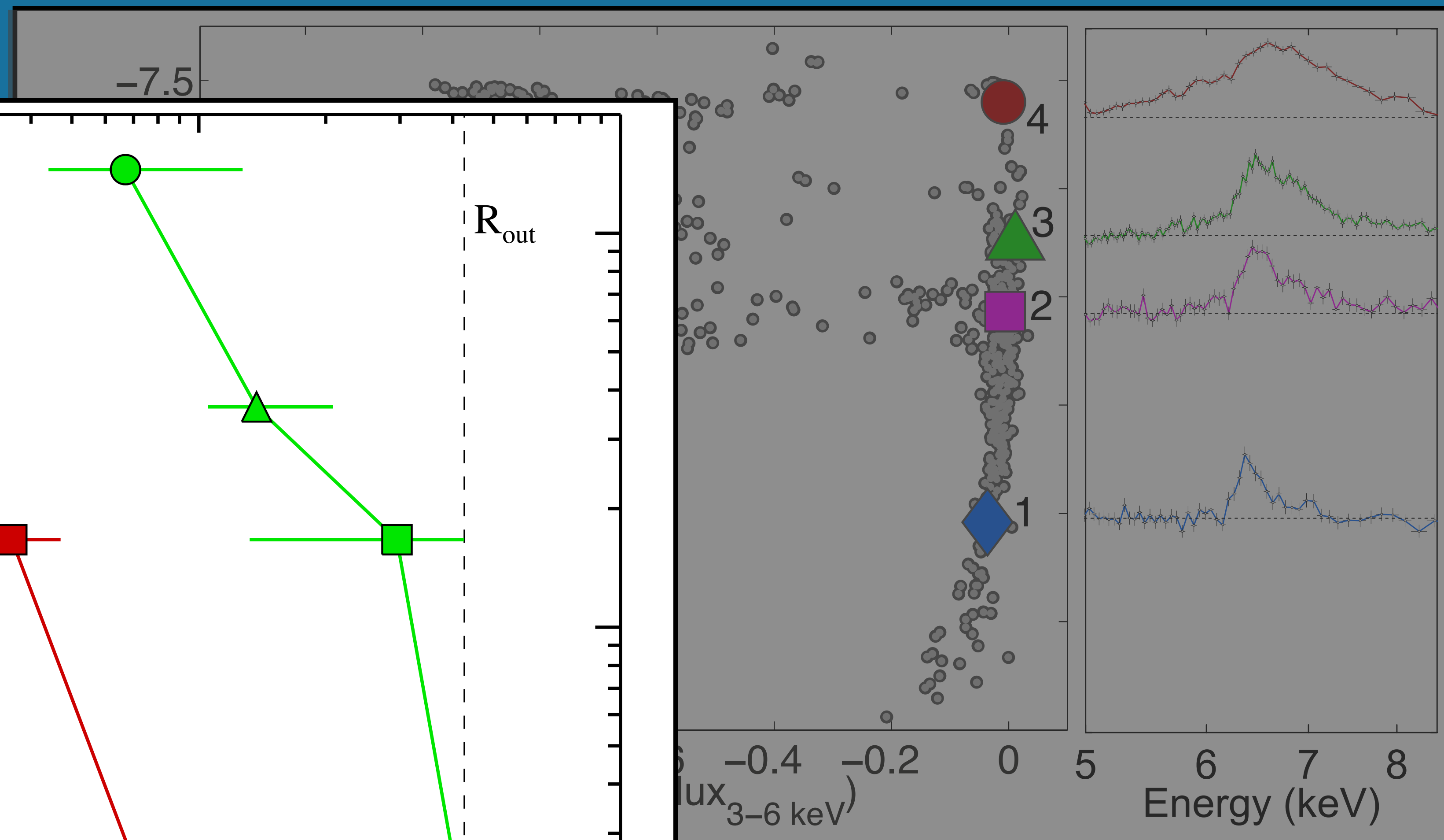
The Fe-Kα profile is clearer broader at higher luminosity.

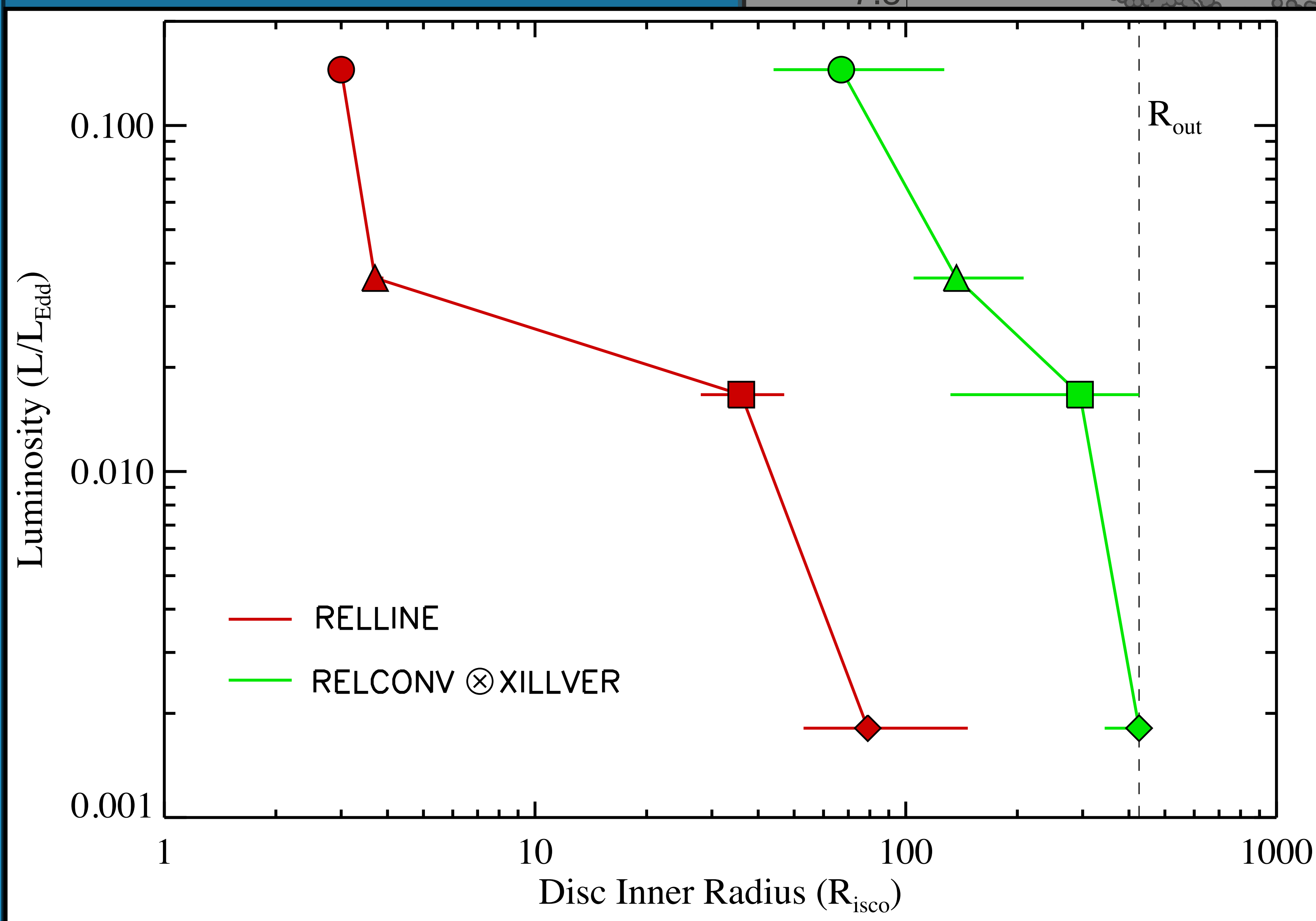



**Relativistic effects due to a smaller disc inner radius?**

# The Hard State -- A varying disc inner radius

Plant+(2014b)




The fitted disc inner radius is smaller at higher luminosity.

The inner disc moving inwards increases the reflection/power-law ratio.

see also Kolehmainen+(2014); Petrucci+(2014)

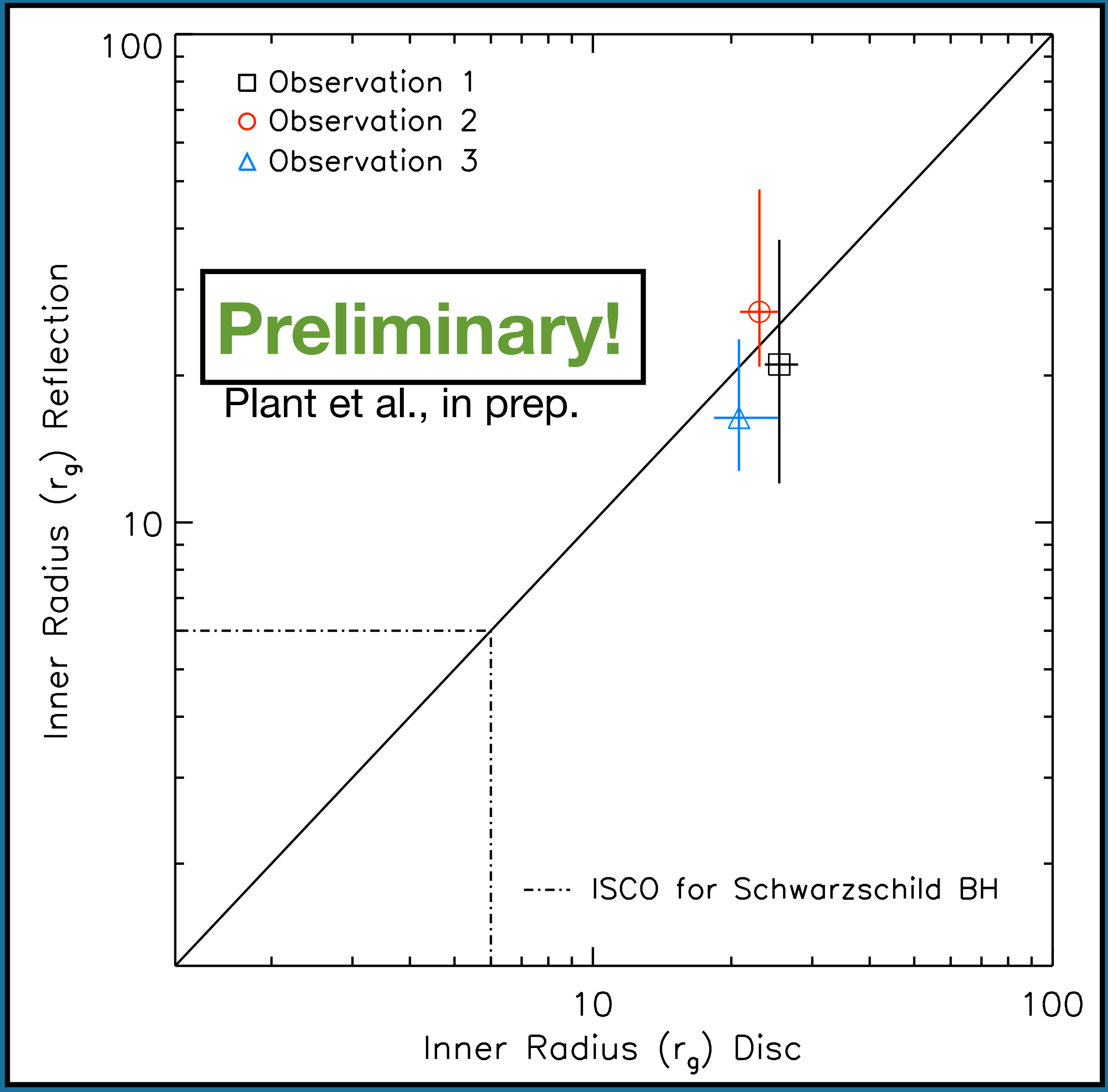
# The Hard State -- New evidence for disc truncation

In Sept. 2013 we observed GX 339-4 three times over ~6 days at ~3% $L_{Edd}$ with *XMM-Newton*

We used the PN small window imaging mode -- this provides a well calibrated bandpass down to 0.3 keV (fast modes > 0.7keV + extra calibration issues).

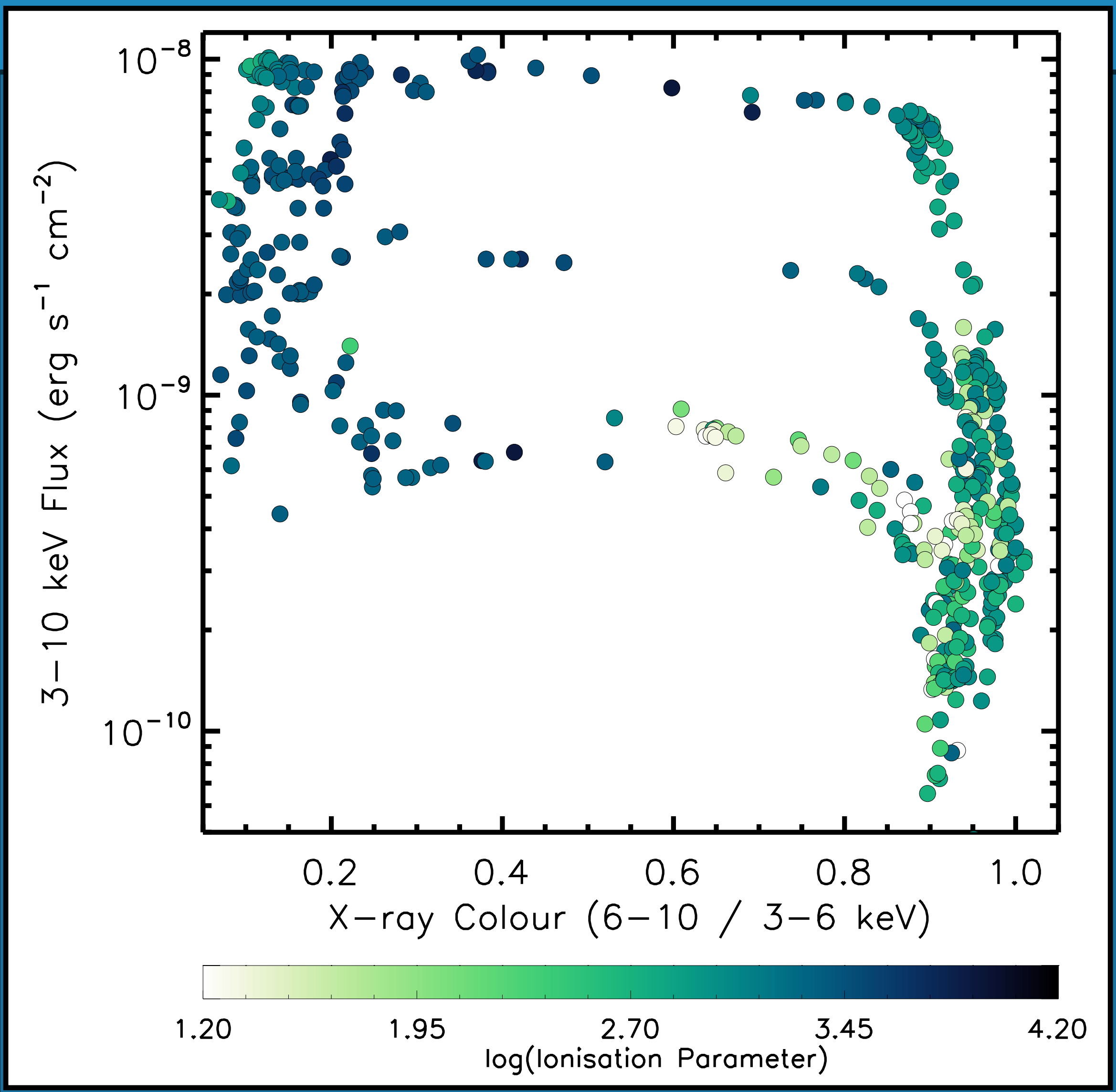
We were able to simultaneously constrain the disc and reflection components, <u>which agree on a truncated inner disc radius</u> -- this wasn't possible in a recent study using the timing mode (Kolehmainen+2014)

This was achieved even though the net exposures were relatively short.



# Ionised reflection

Plant+(2014a)




Ionisation Parameter ($\xi$) = $4\pi F/n_e$

The surface layers of the disc are significantly more ionised in the soft state.

However, I showed earlier that the illuminating flux (the power-law) is similar in the hard and soft states.

1. The significantly larger disc flux in the soft state may be ionising the surface layers.

or

2. The reflection spectrum is dominated by emission from the inner disc; which, if truncated, would be intercepting much less irradiation than if it was at the ISCO

# Conclusion -- The Overall Picture