Rapid variability as a probe of warped space-time around black holes

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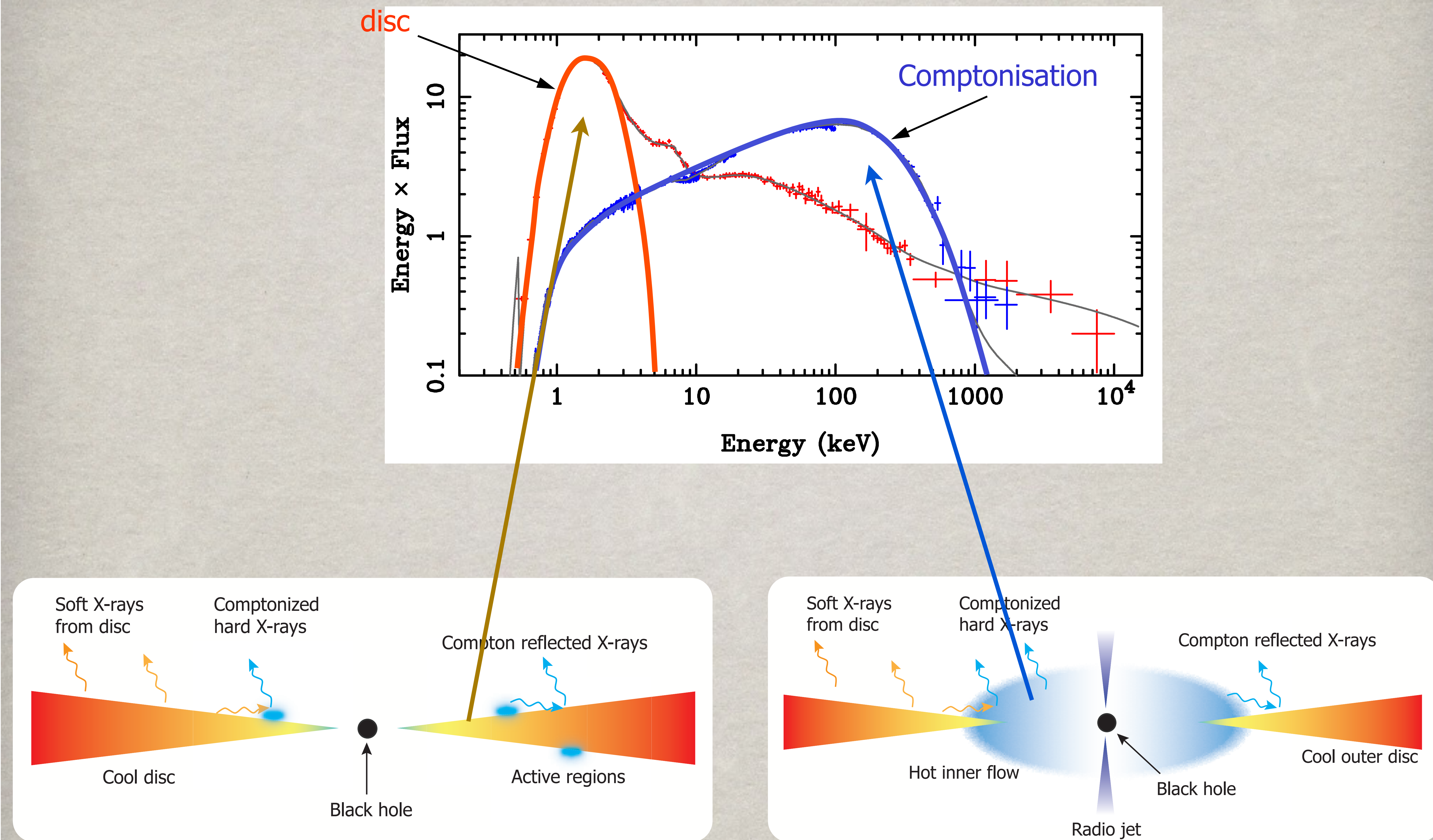
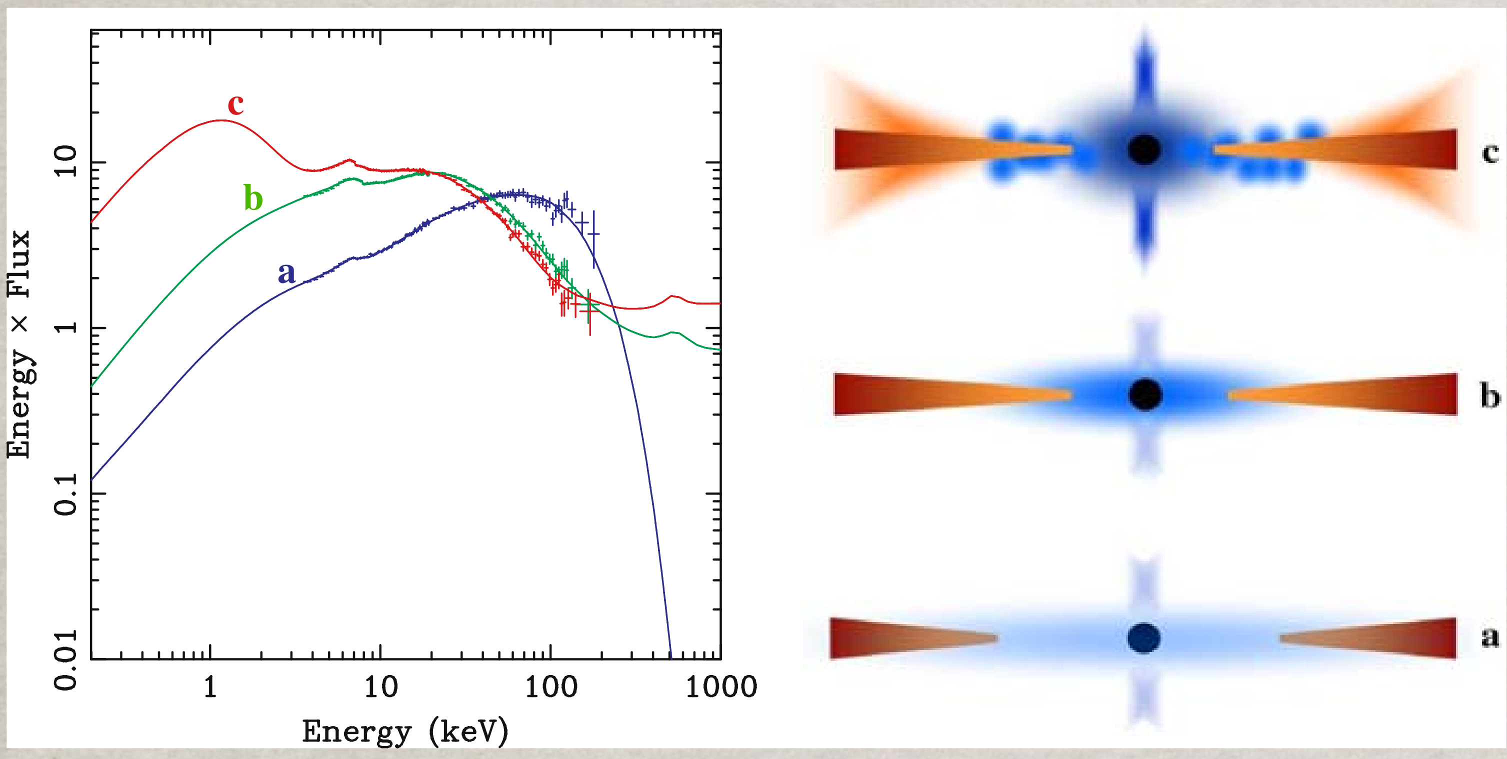


Higher mass accretion
(soft state)

Low mass accretion
(hard state)

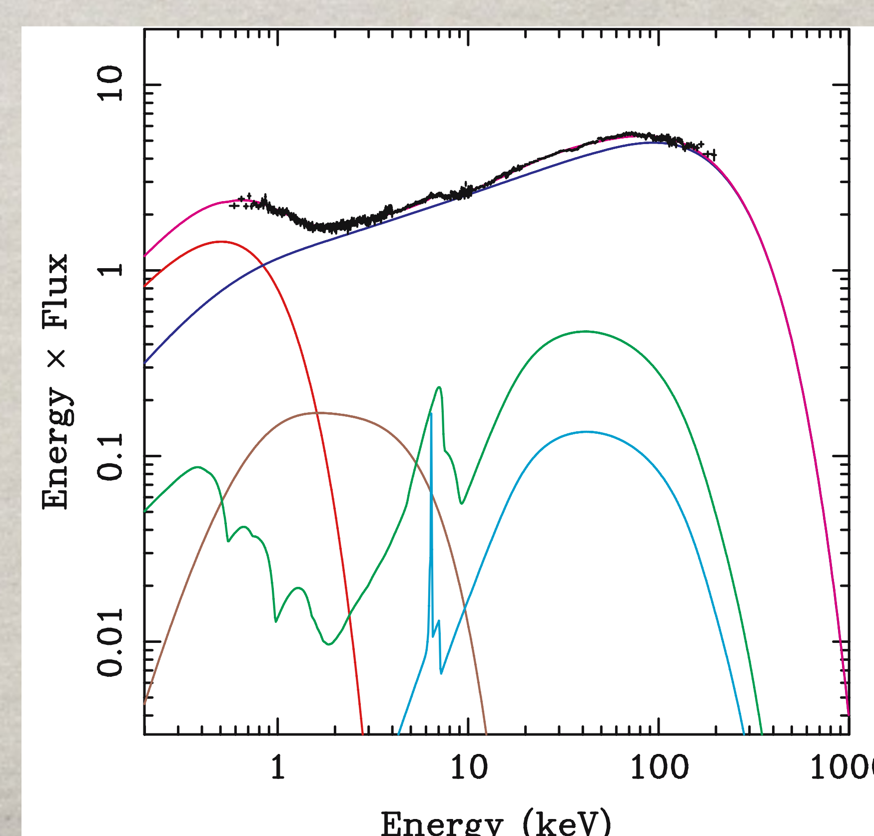
Not so simple...



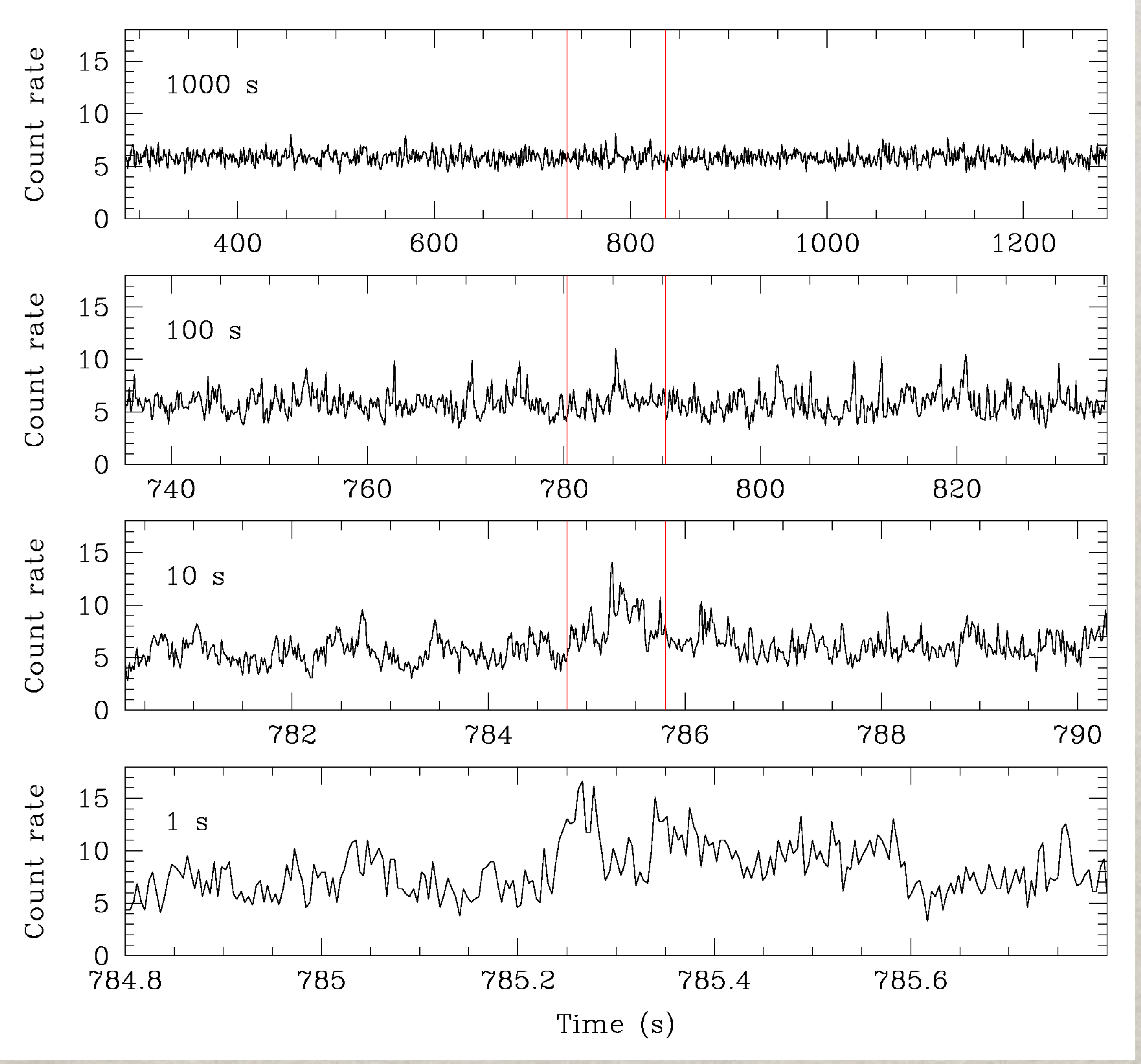
Done et al. (2007)

Many different spectral states and corresponding geometries

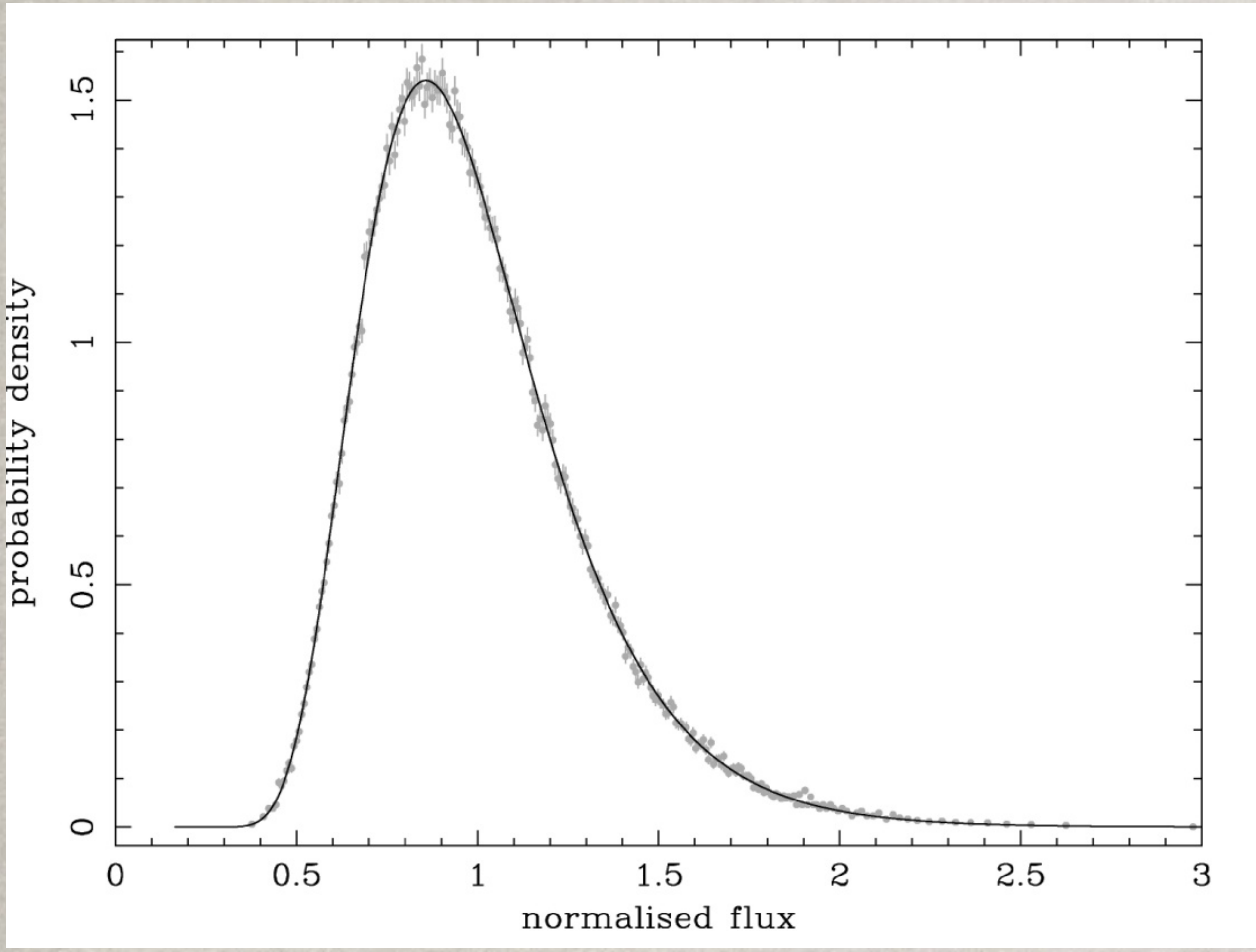
Even in "classic" hard state, there are likely several spectral components.



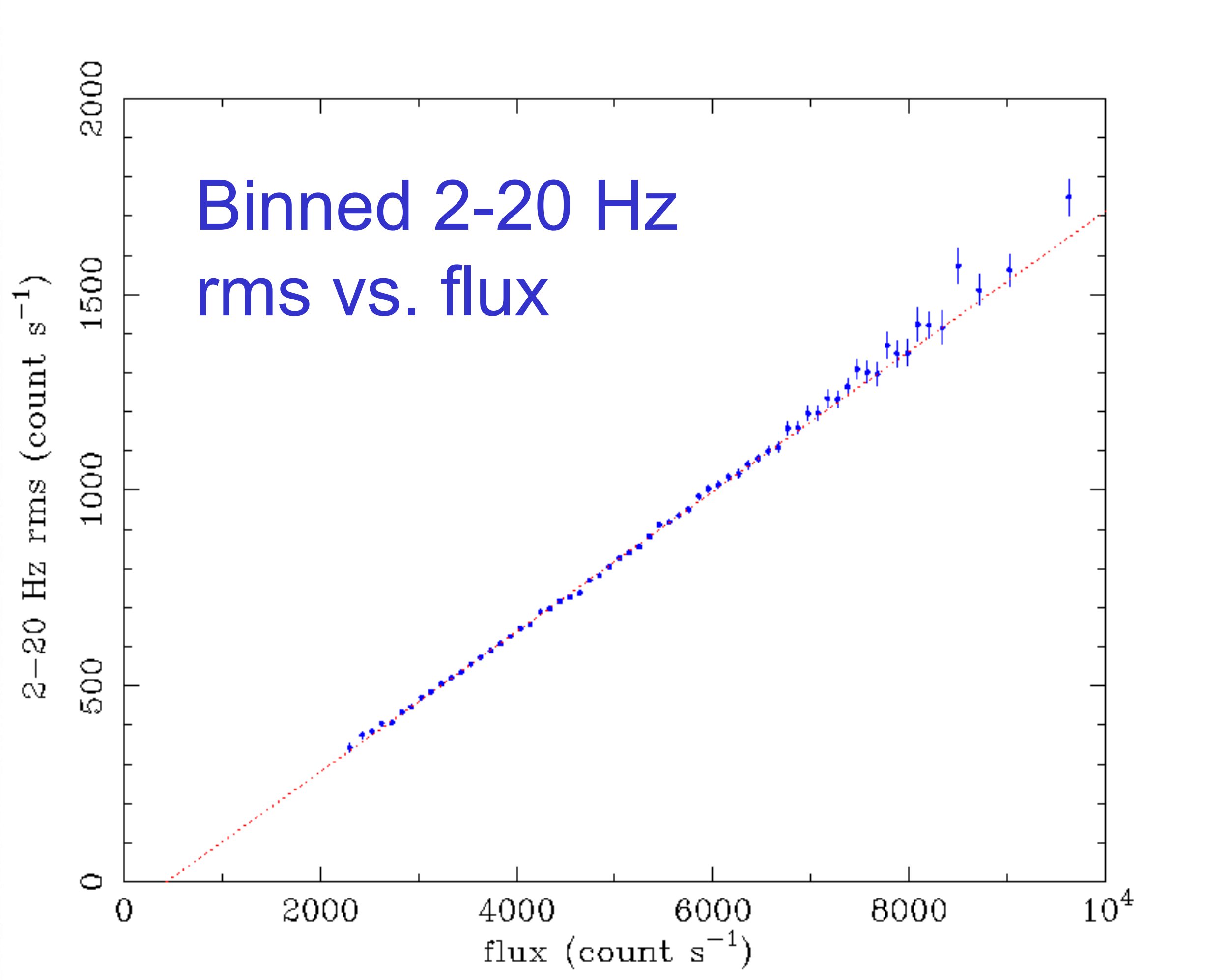
Variability on all timescales



Uttley & McHardy (2001)



rms = sqrt [(1/N) $\sum_{i=1,N}$ (flux$_i$ - mean)^2]

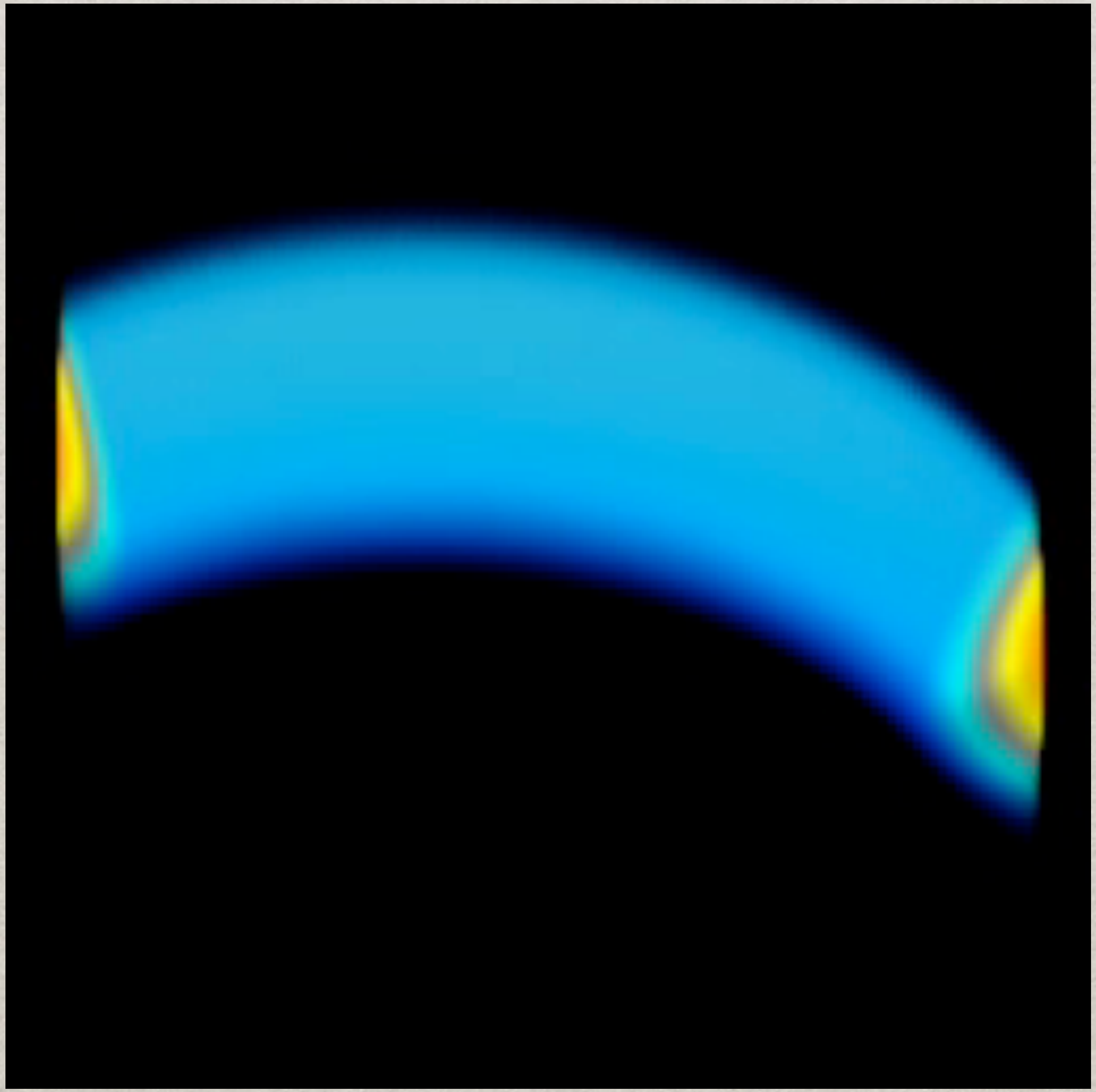


Flux distribution is lognormal

Linear rms-flux relation

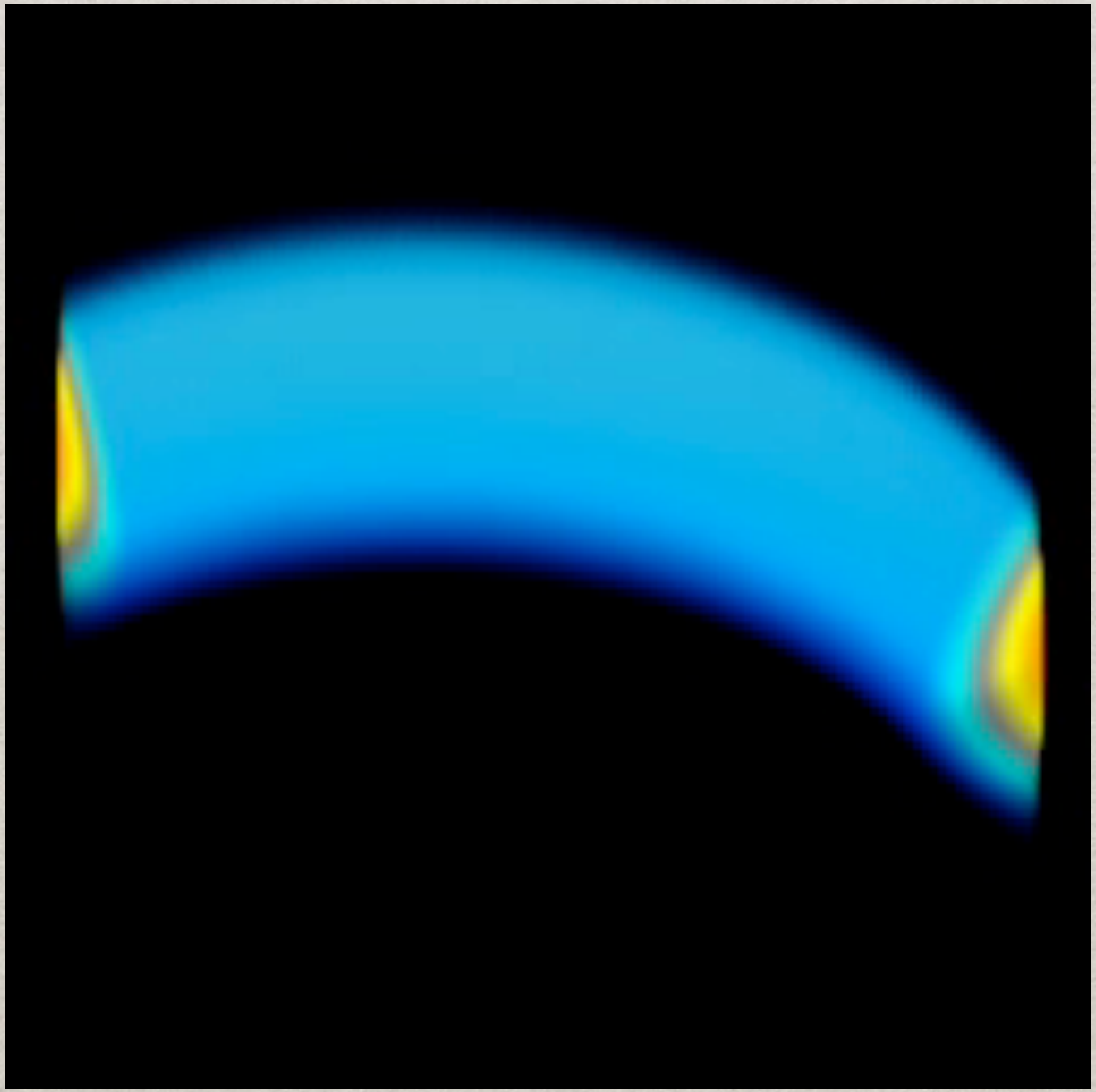
Cannot get this from shot-noise or additive process (sum of independent regions)

MRI causing turbulence



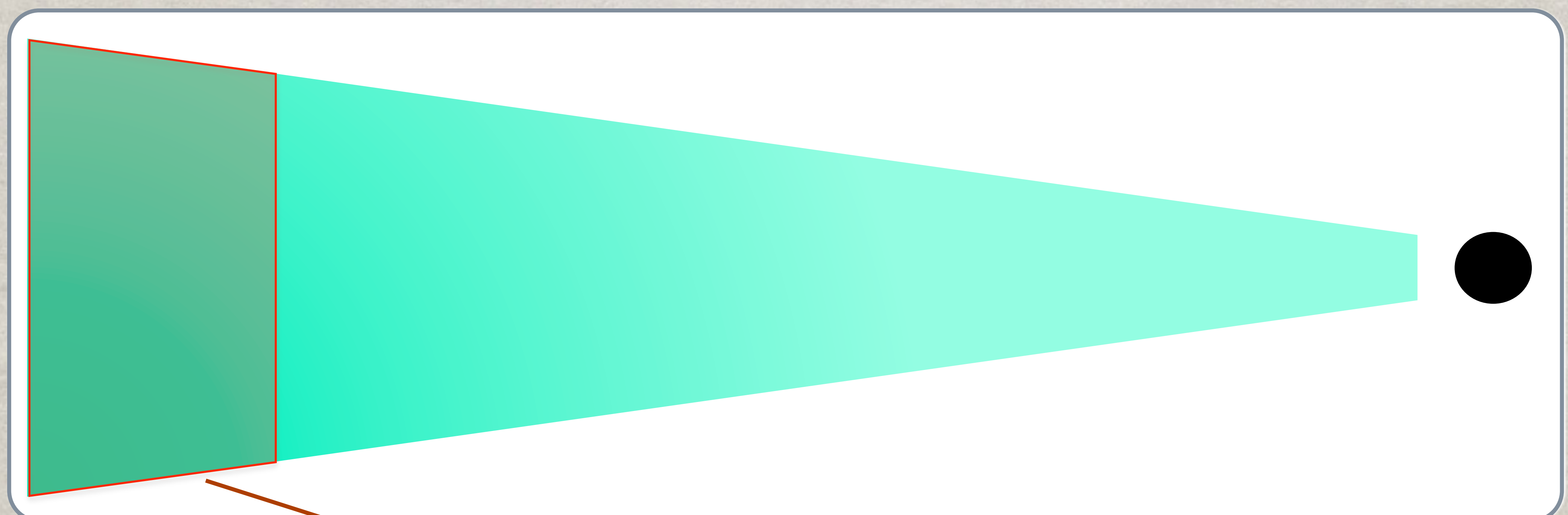
Krolik, de Villiers, Hawley

MRI causing turbulence

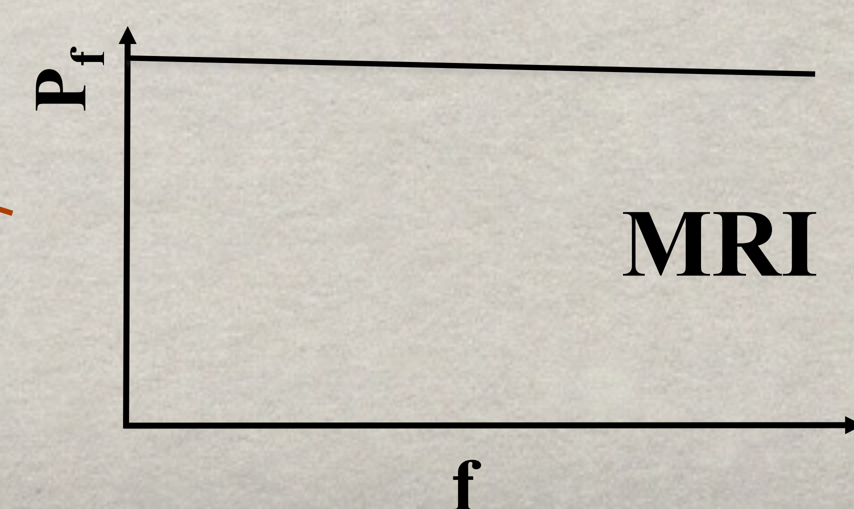


Krolik, de Villiers, Hawley

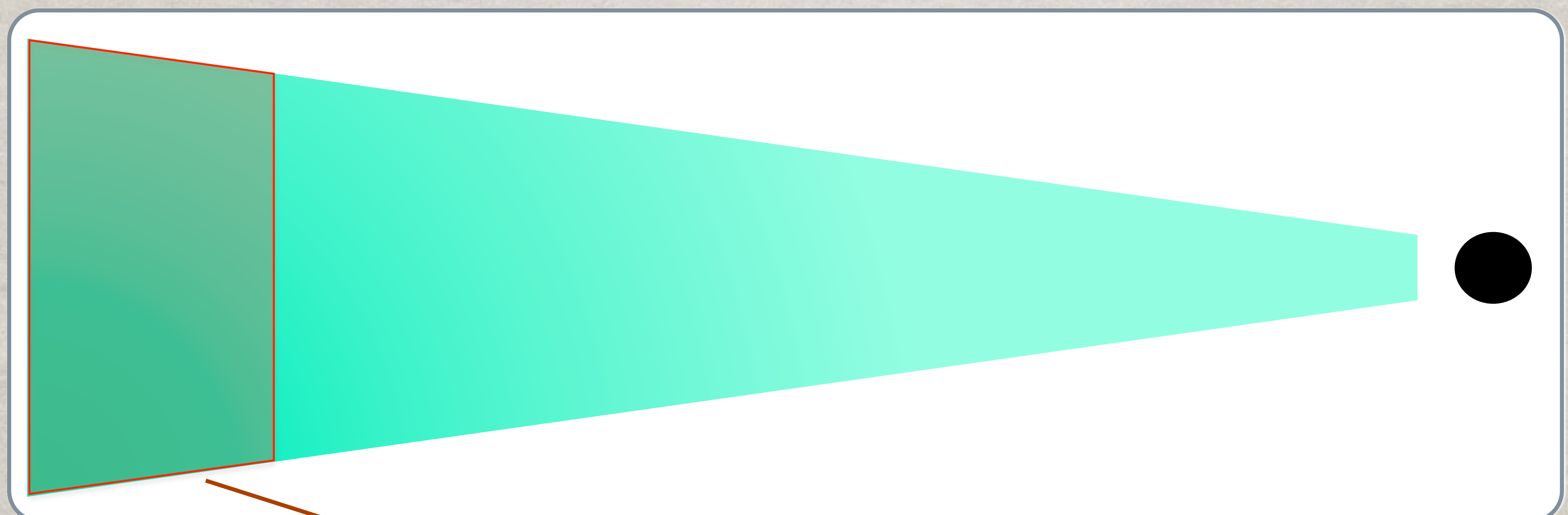
Propagating fluctuations



But emission depends on $\dot{m}$ - cannot vary faster than local viscous timescale!



Propagating fluctuations



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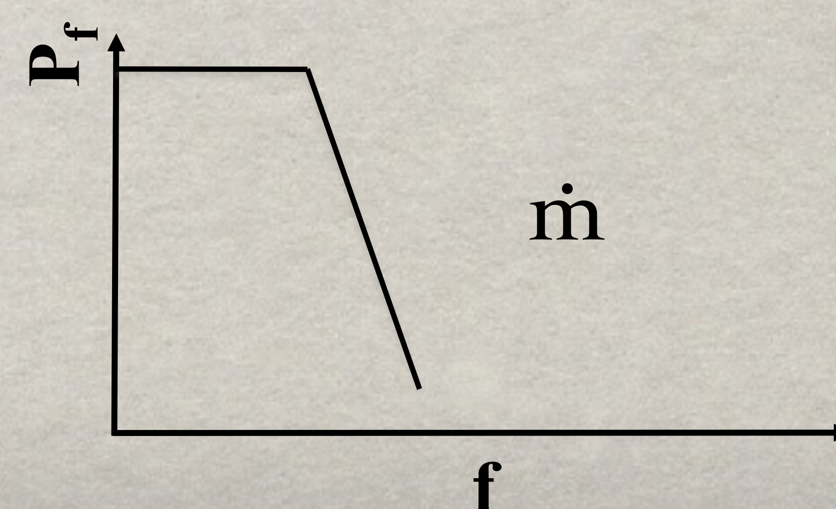
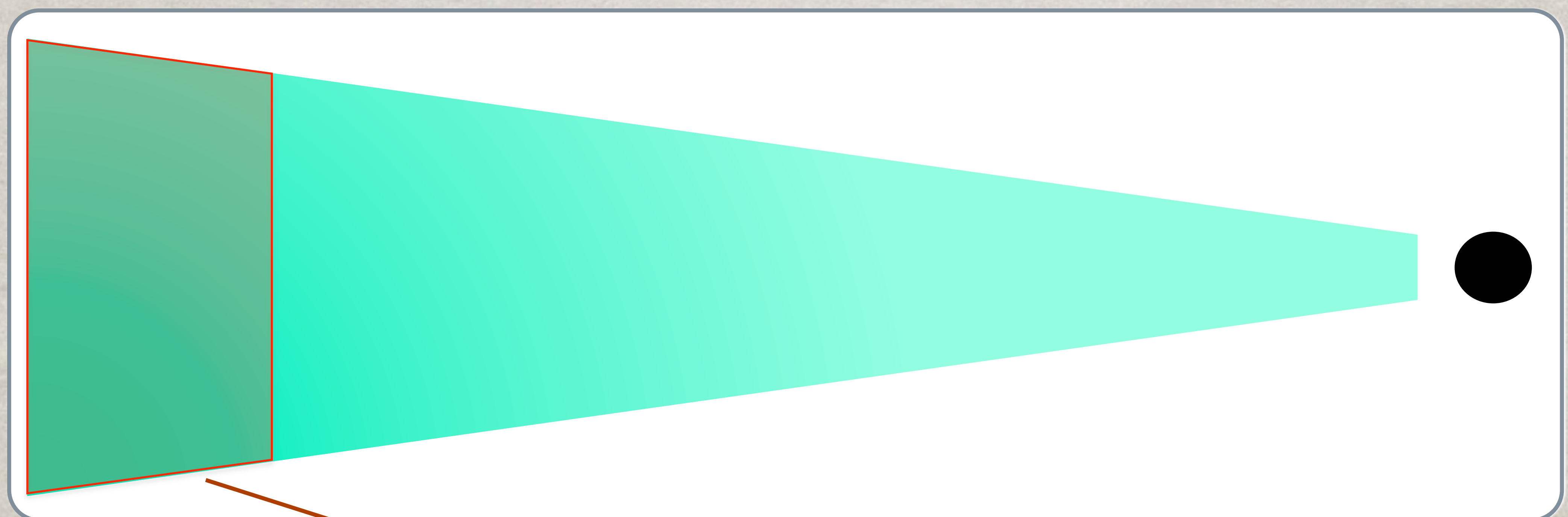


Propagating fluctuations



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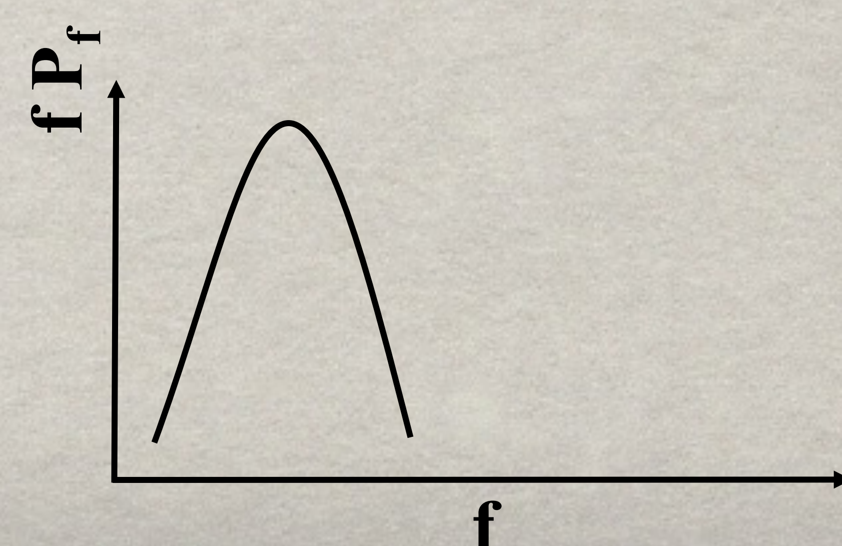
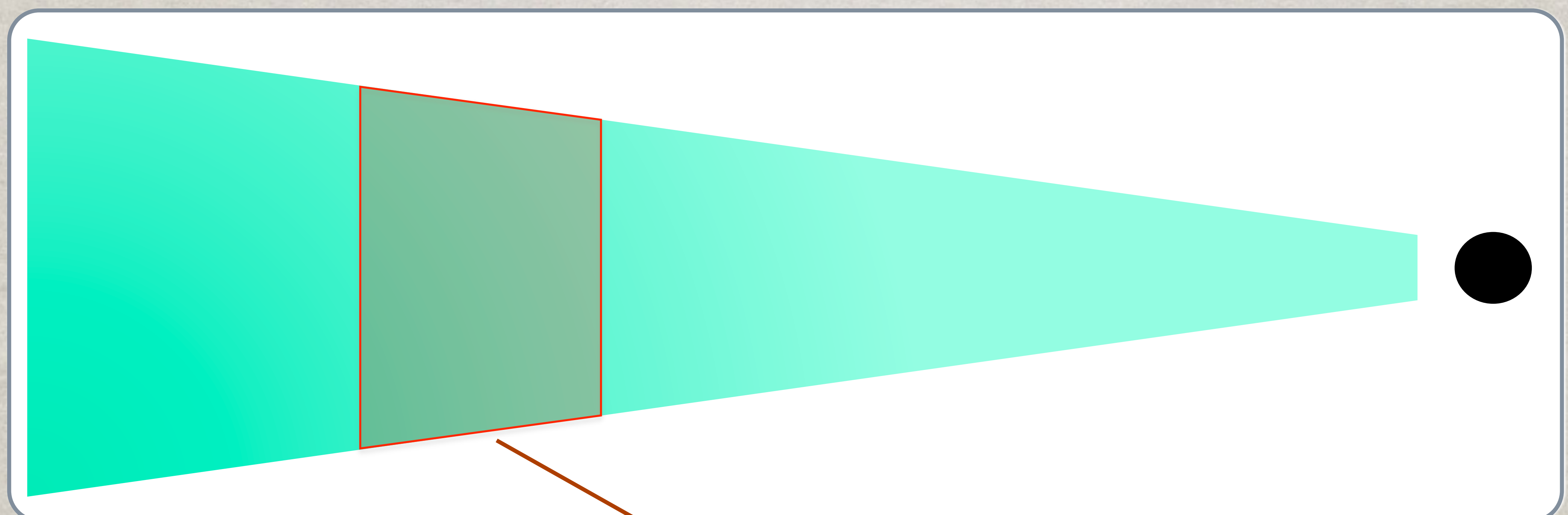


Propagating fluctuations



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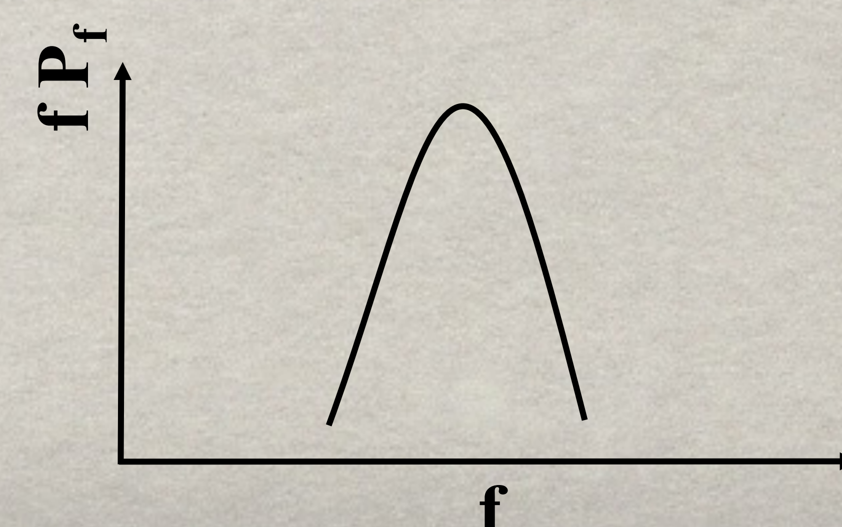
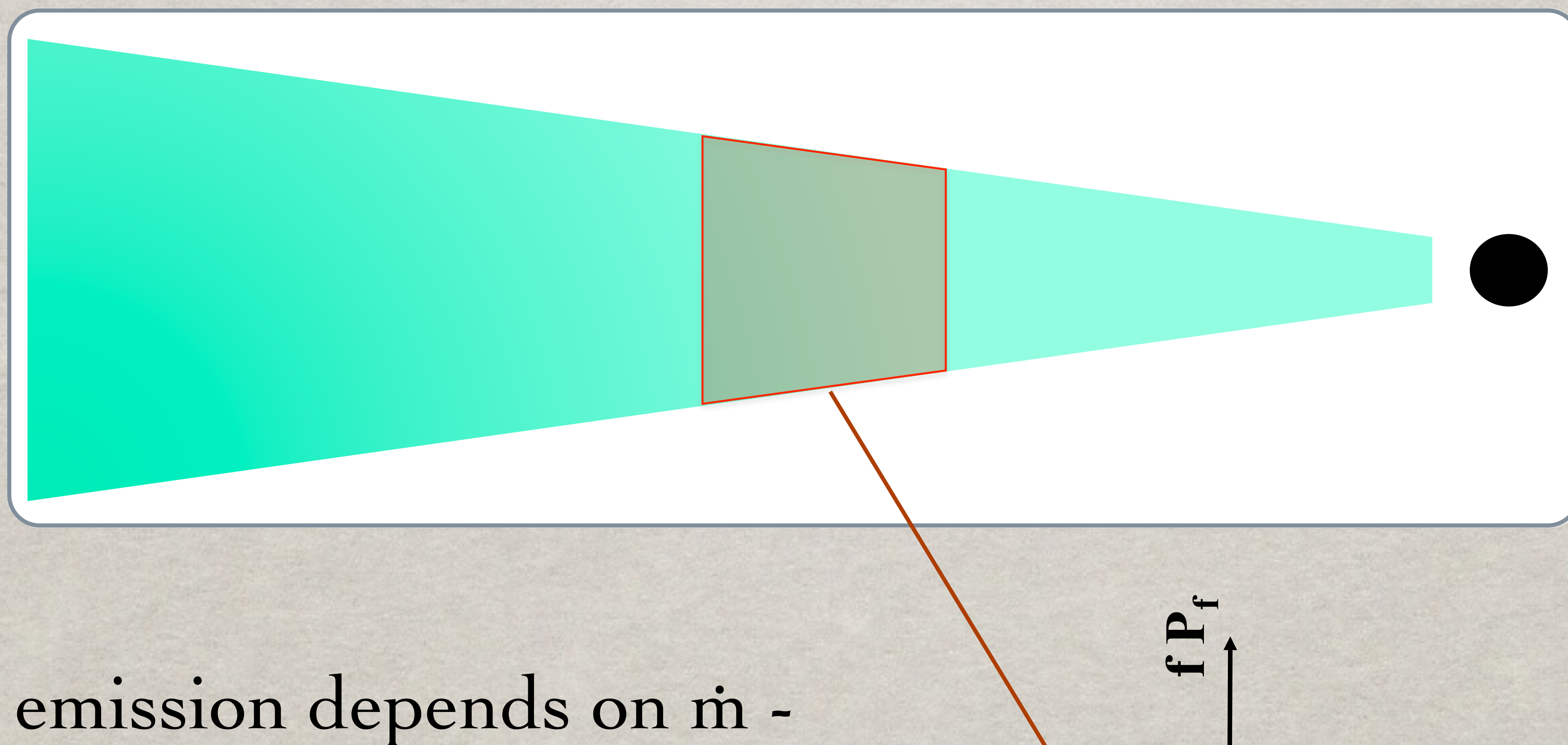
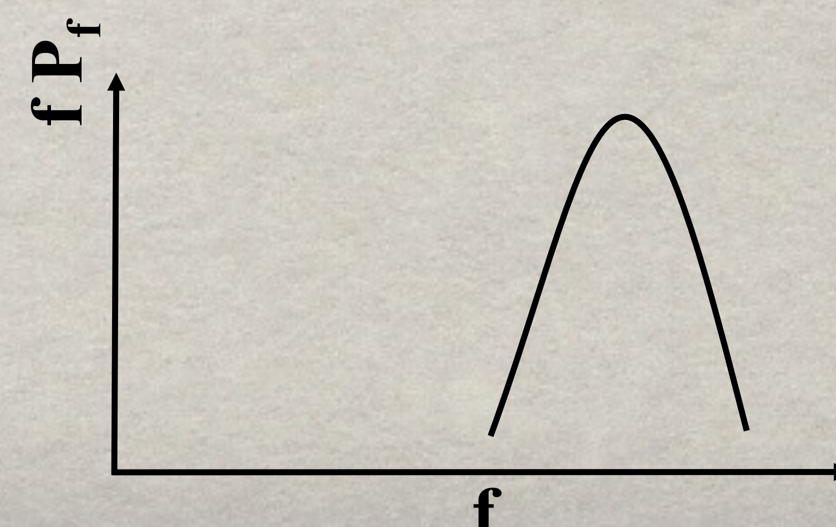


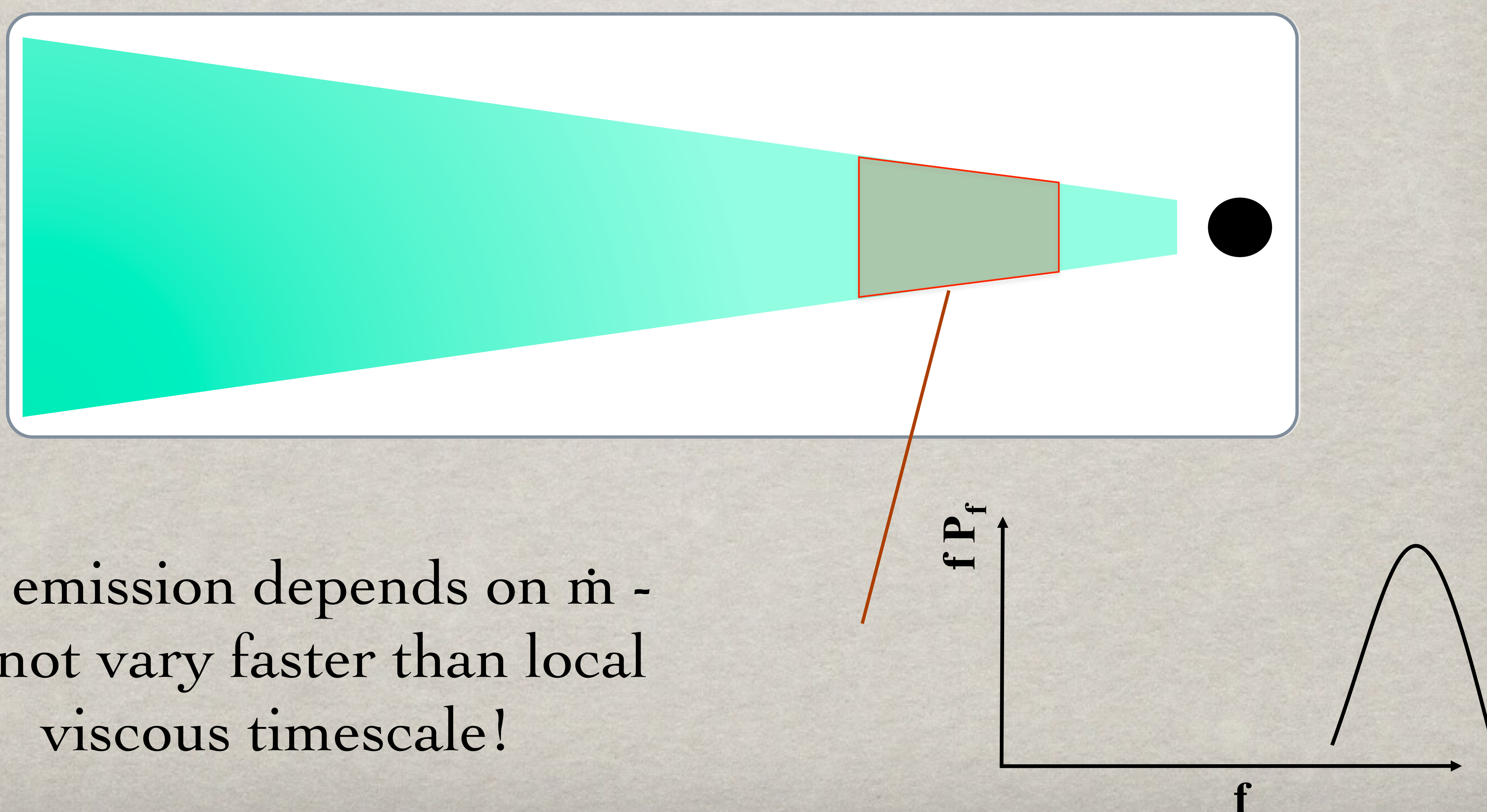
Propagating fluctuations





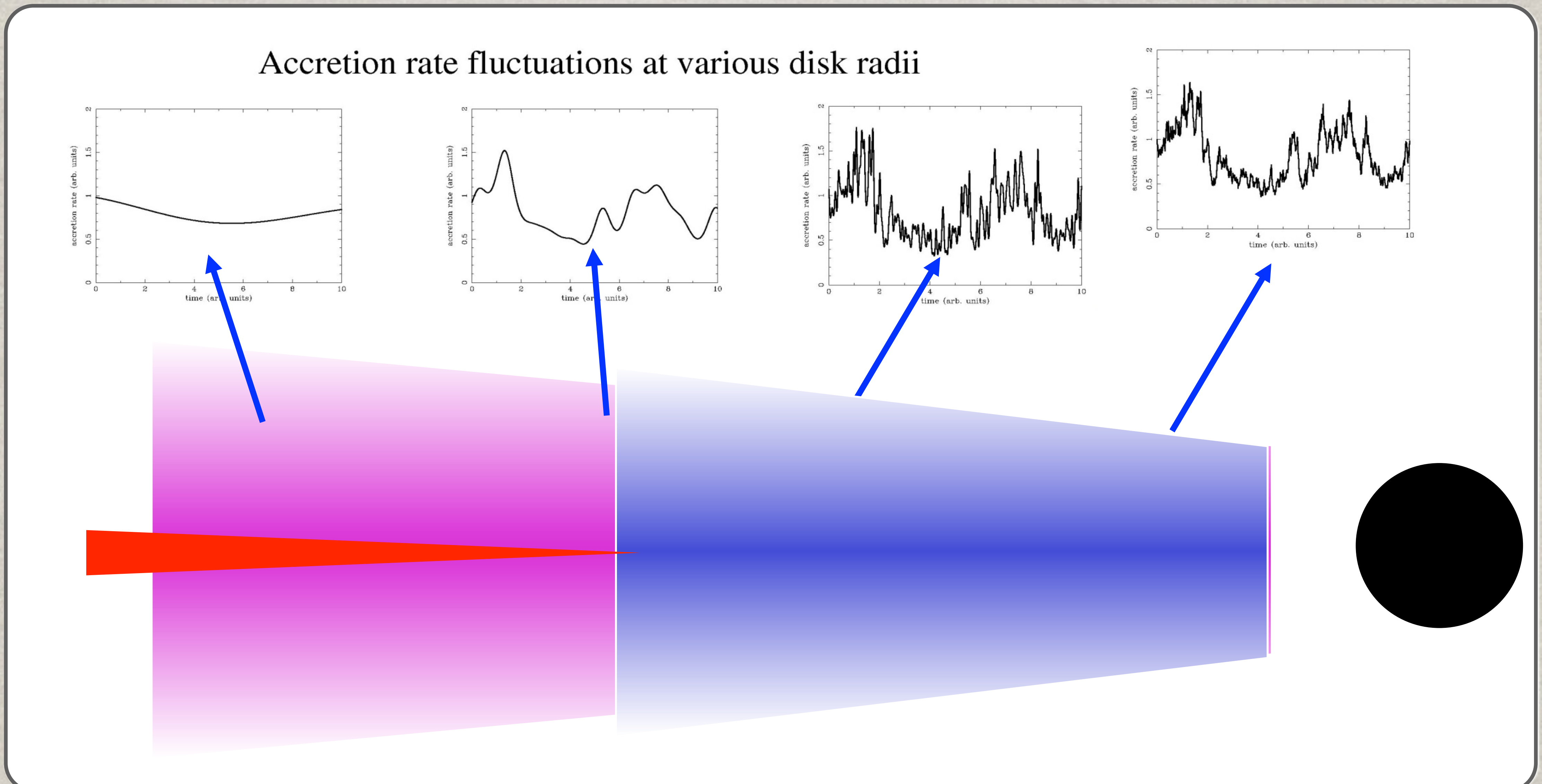
But emission depends on $\dot{m}$ - cannot vary faster than local viscous timescale!

PROPAGATING FLUCTUATIONS



But emission depends on $\dot{m}$ - cannot vary faster than local viscous timescale!

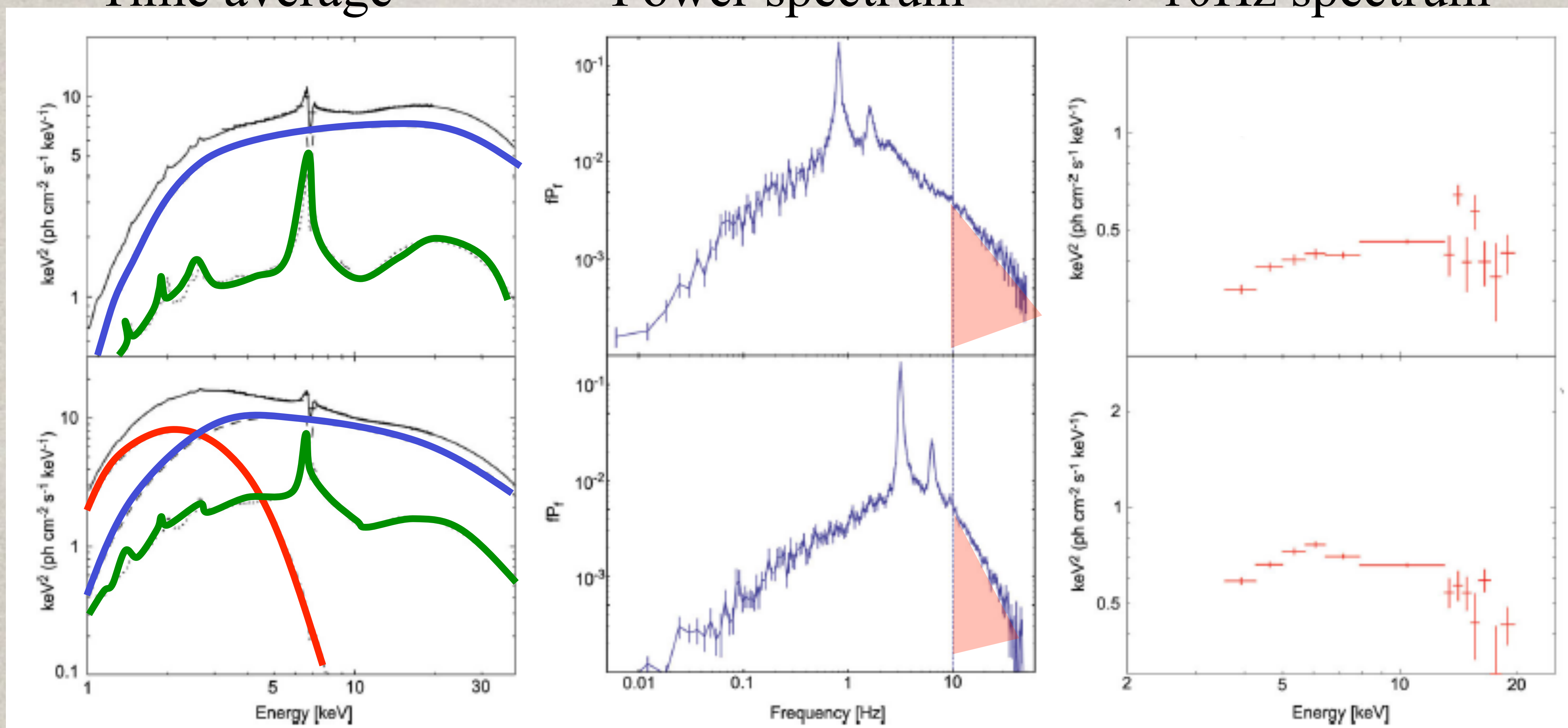
Origin of broad band variability



Fluctuations start at large radii - soft and slow propagate down to smaller radii, where faster variability arises in the hard emission

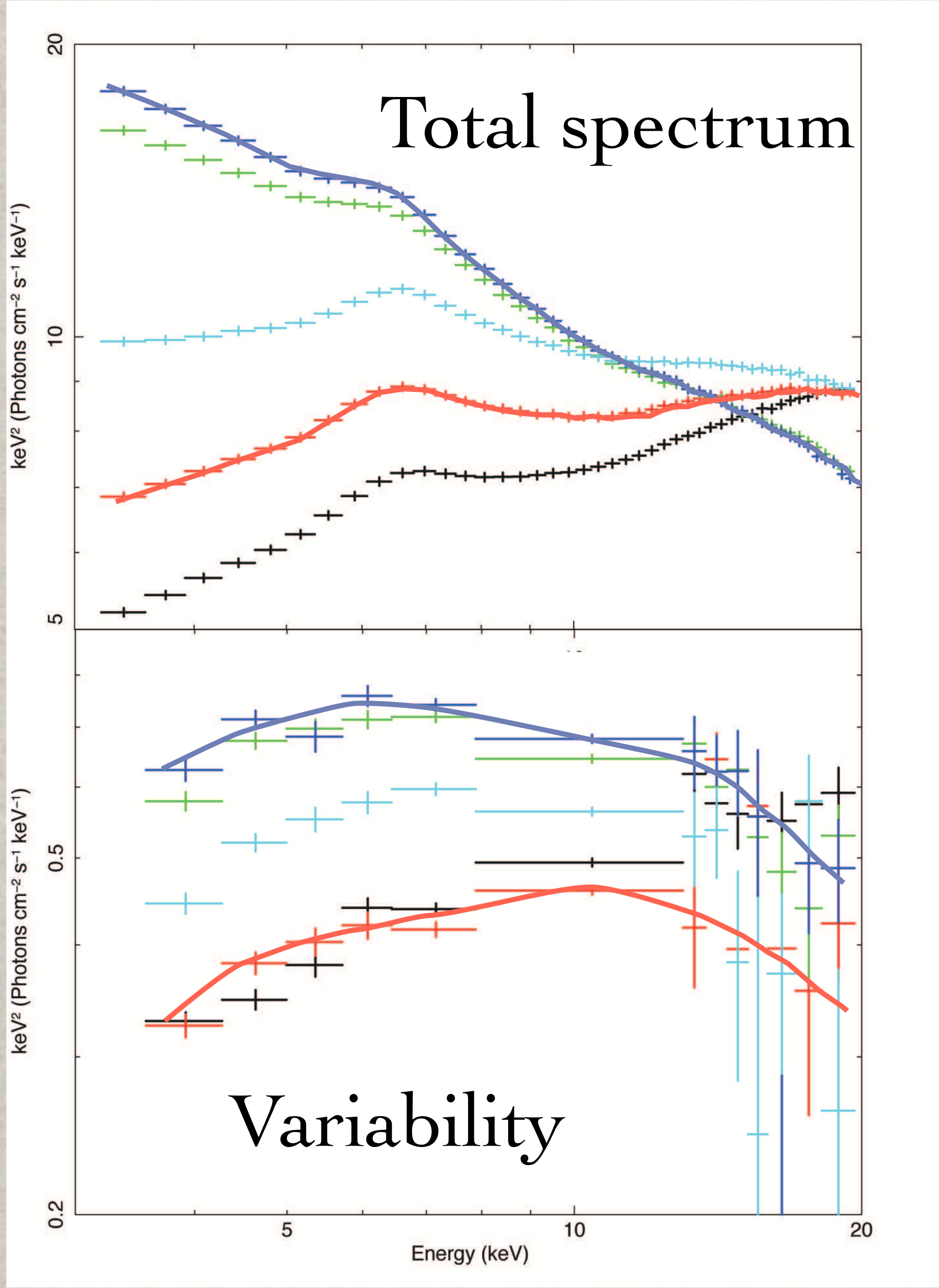
Connecting spectra and variability

Time average Power spectrum >10Hz spectrum



XTE J1550-564

Axelsson et al. (2013)



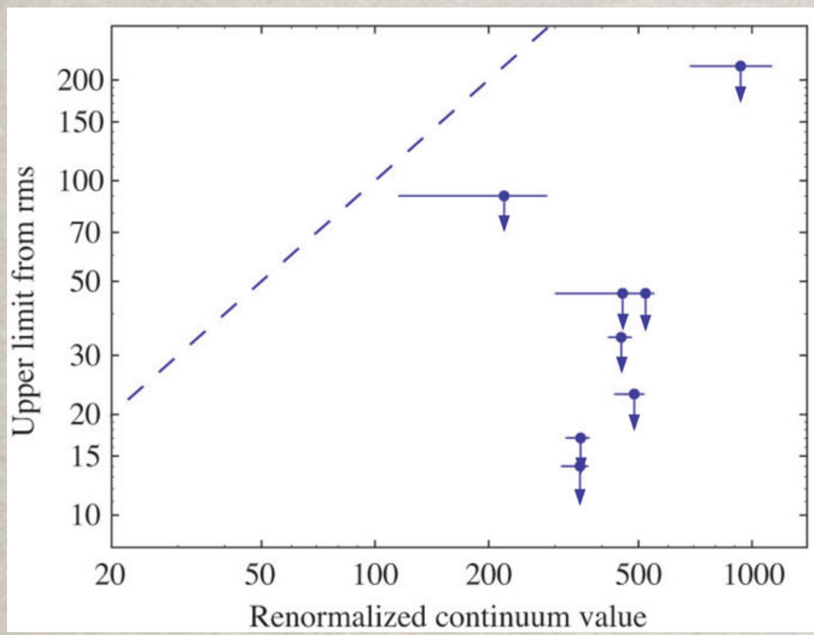
Axelsson et al. (2013)

Large spectral variations in total spectrum

Variability spectrum does not change appearance much

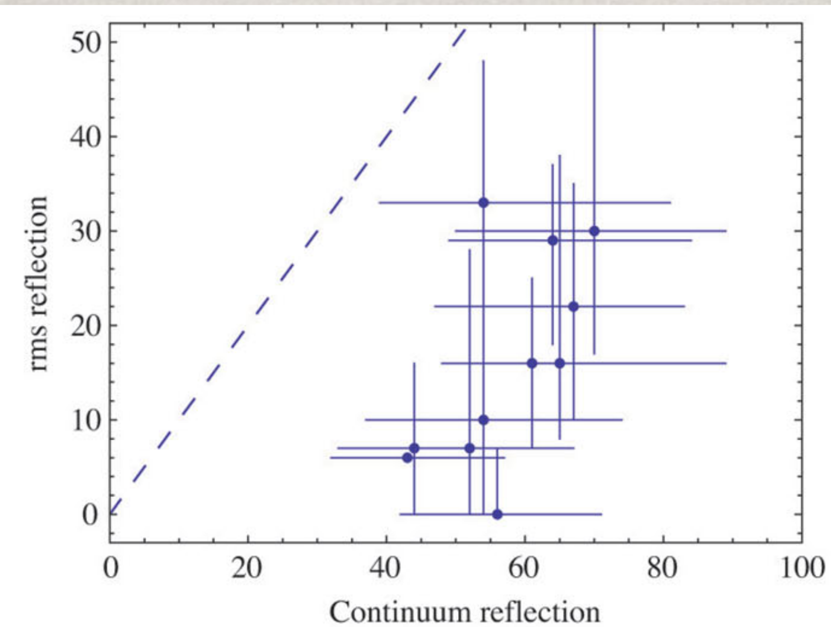
The spectrum of the rapid variability

Disc



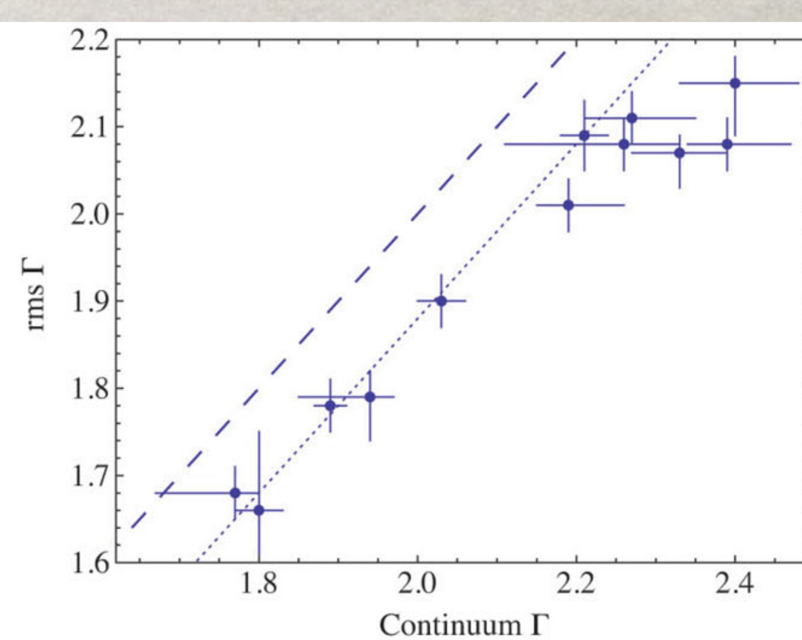
No disc at any time

Reflection



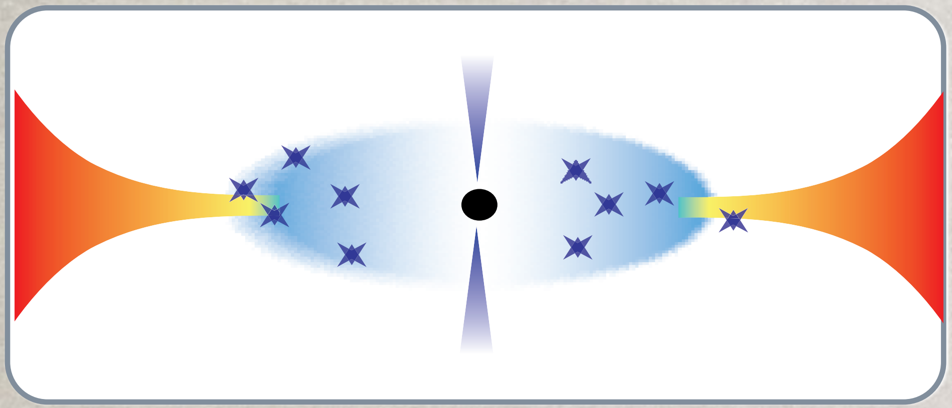
- No reflection in harder states
- Some reflection in softer states, always less than in time averaged spectra

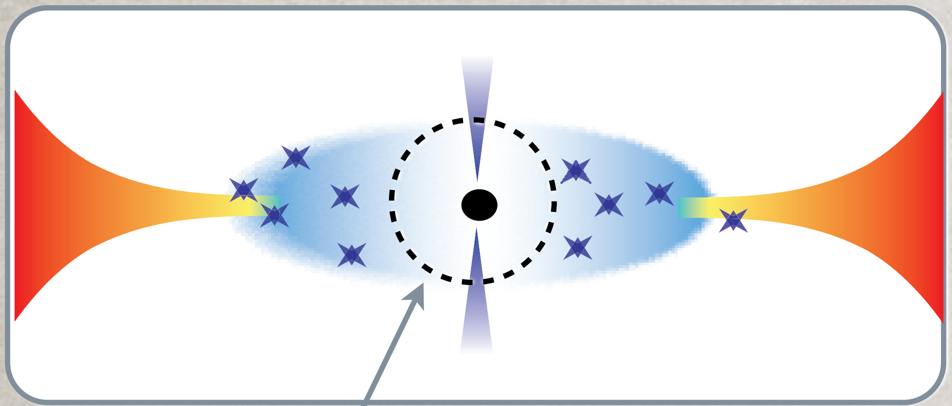
Compton tail



- Compton very similar in harder states
- Increasingly harder than time averaged in softer states

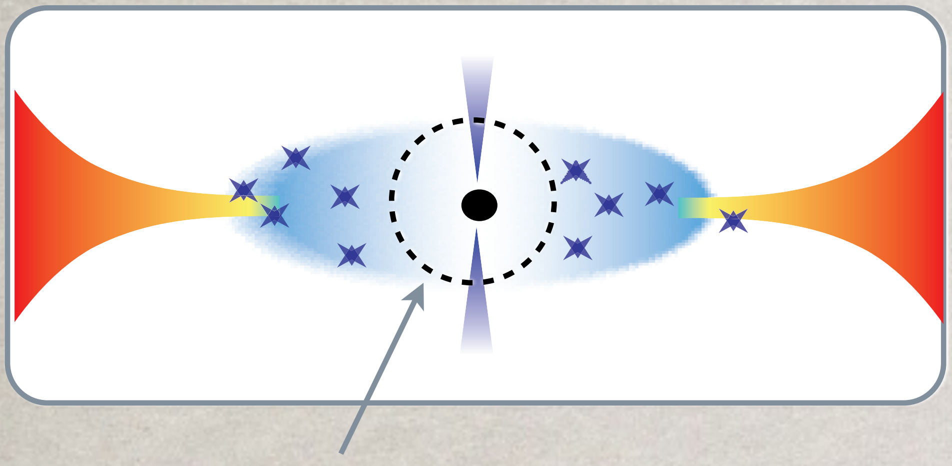
Axelsson et al. (2013)





Region of rapid variability

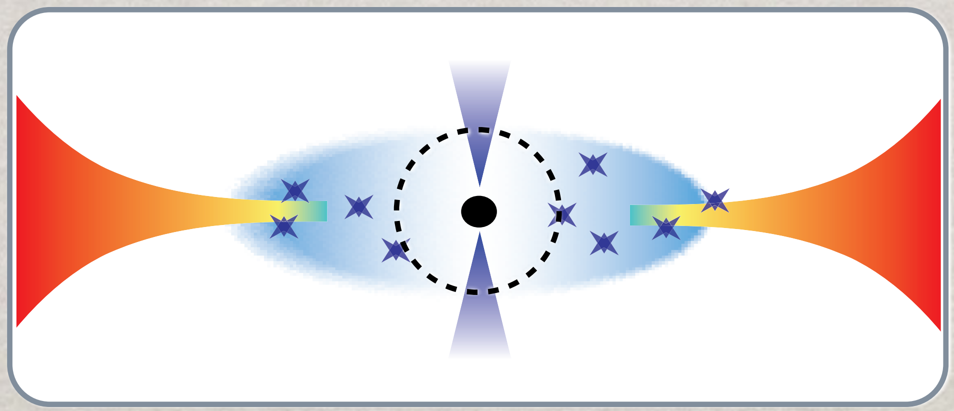
No disc component!

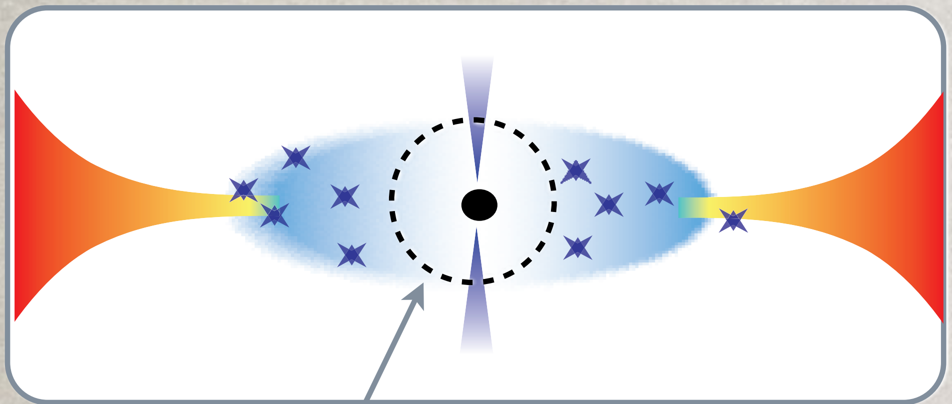


Region of rapid variability

No disc component!

As disc moves closer:
- more seed photons
- stronger reflection





No disc component!

Region of rapid variability

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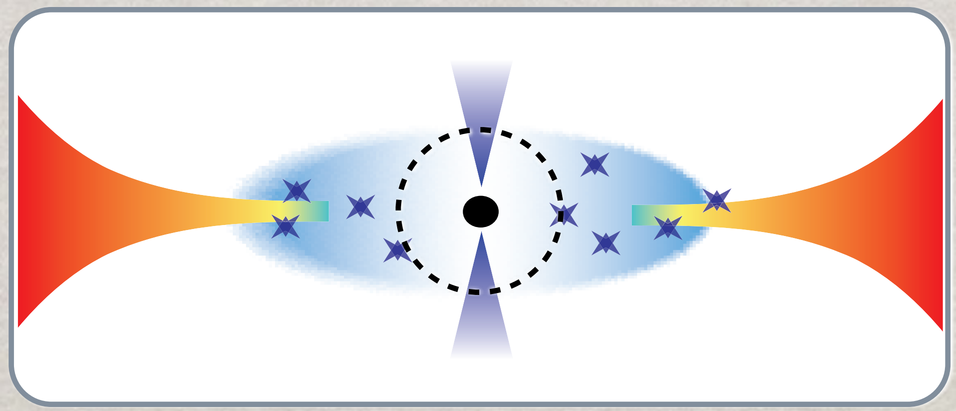
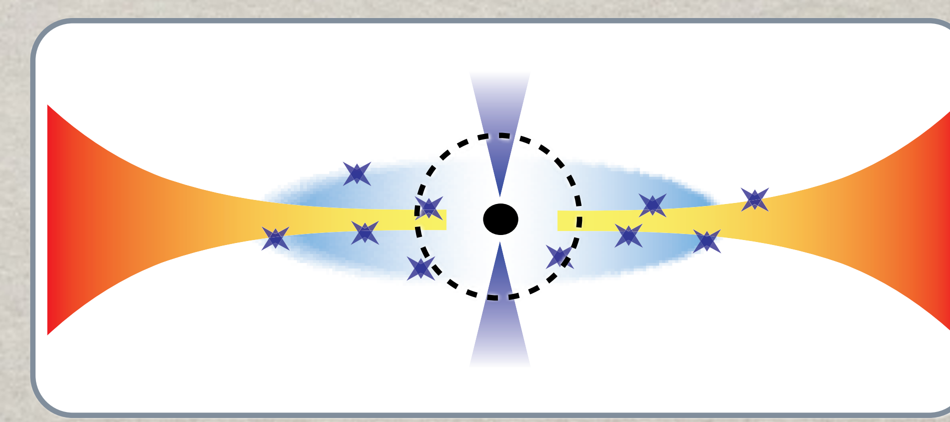
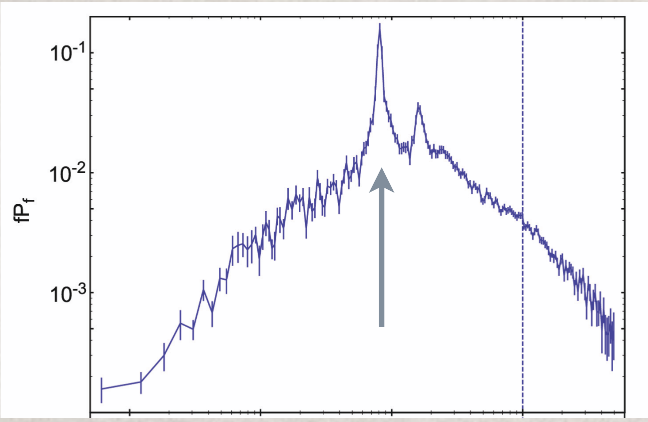


Average Comptonization becomes softer as overlap increases - less change for variability

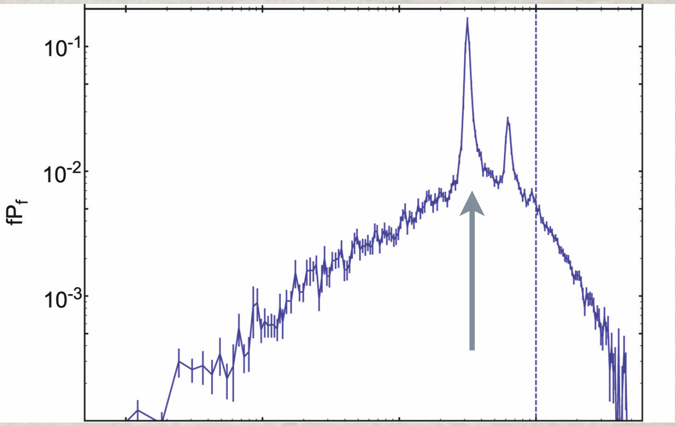


The QPO and harmonic

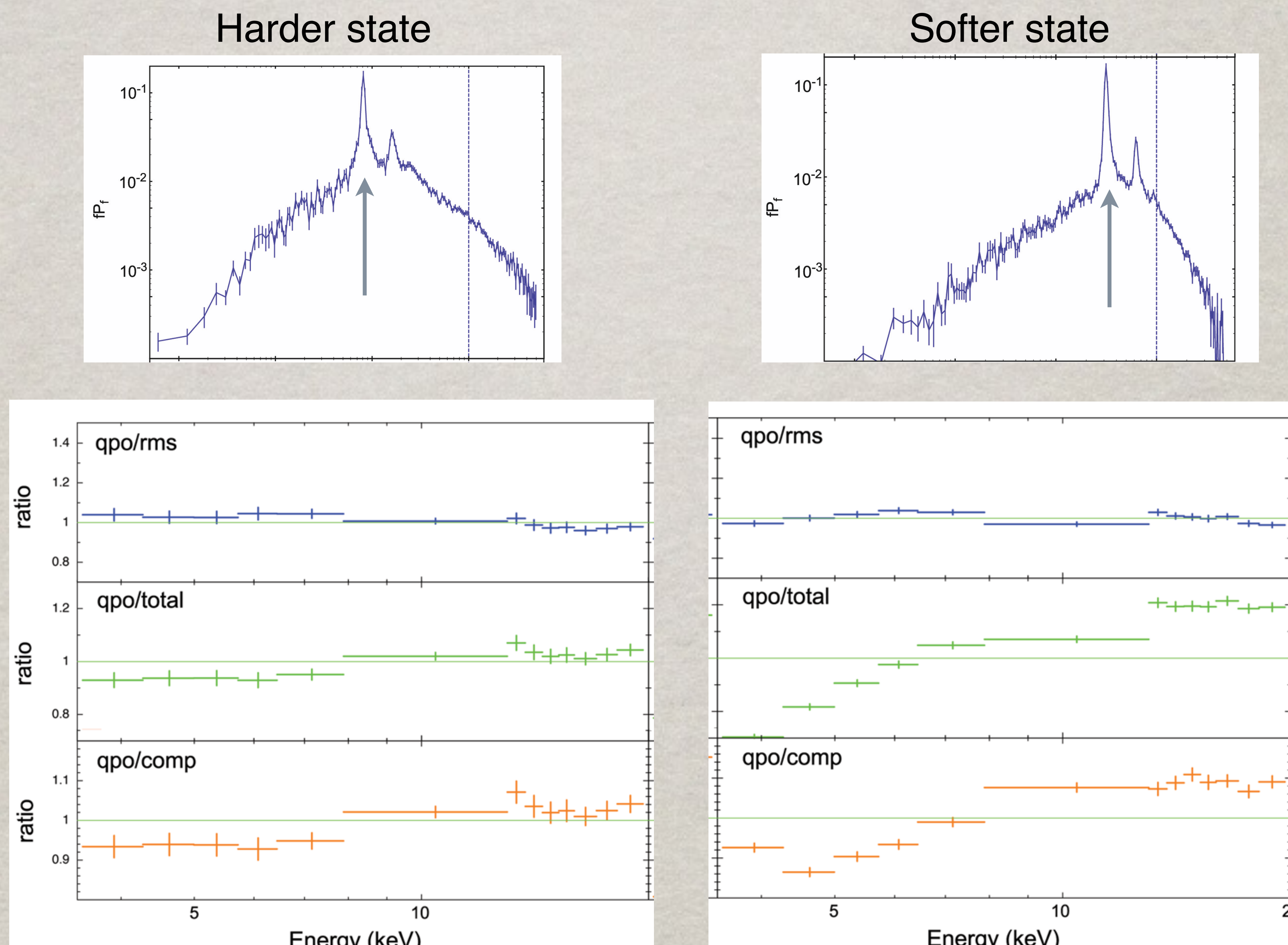
Harder state



Softer state



LOOKING AT THE QPO

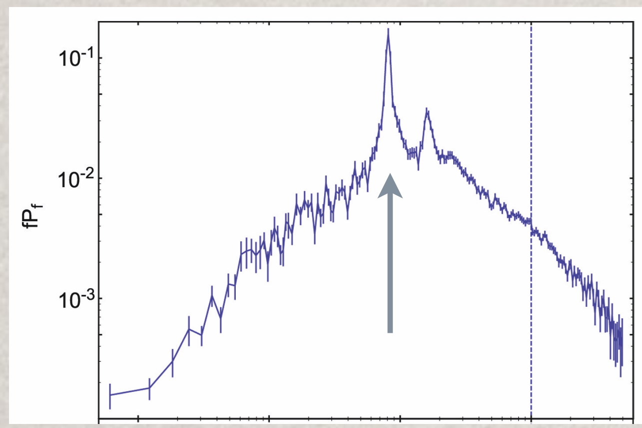


Very similar to
rapid var.

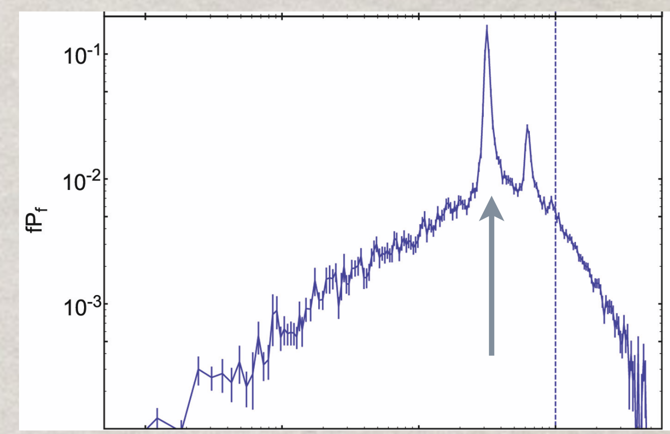
Axelsson et al. (2014)

LOOKING AT THE QPO

Harder state

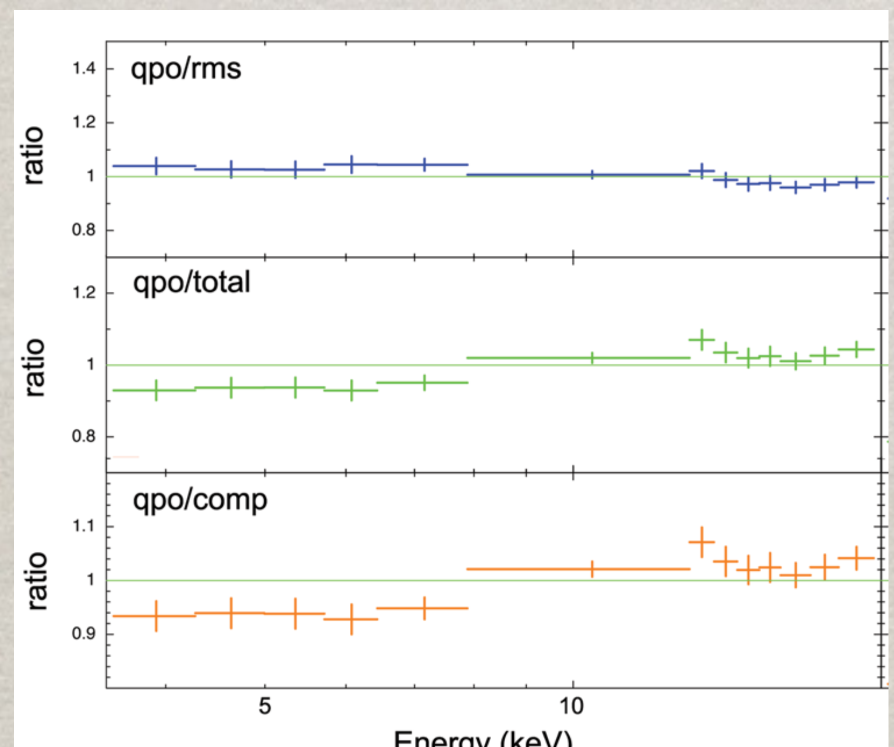


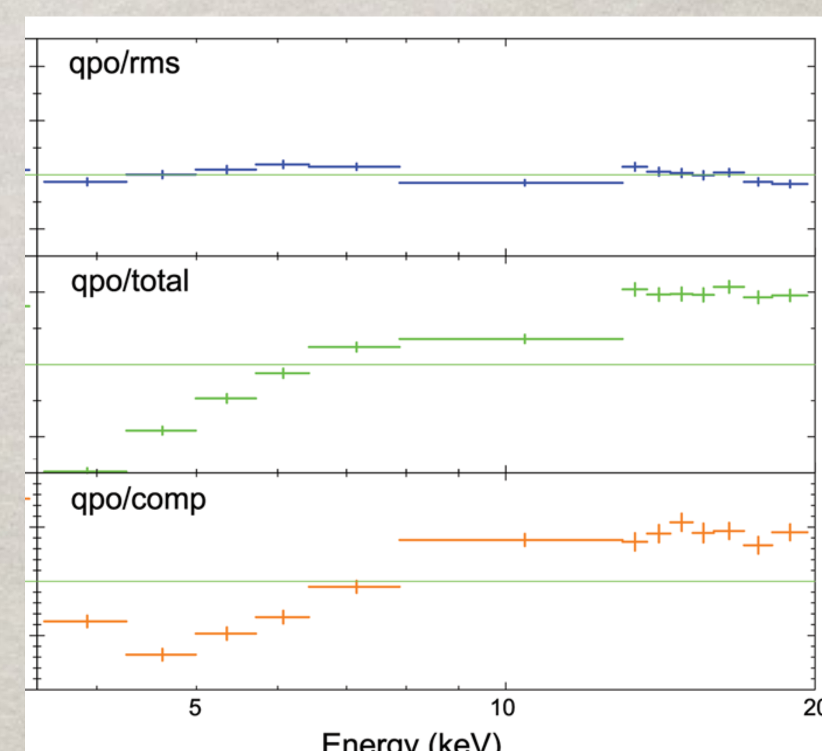
Softer state



Very similar to rapid var.

Harder than average Compt. component

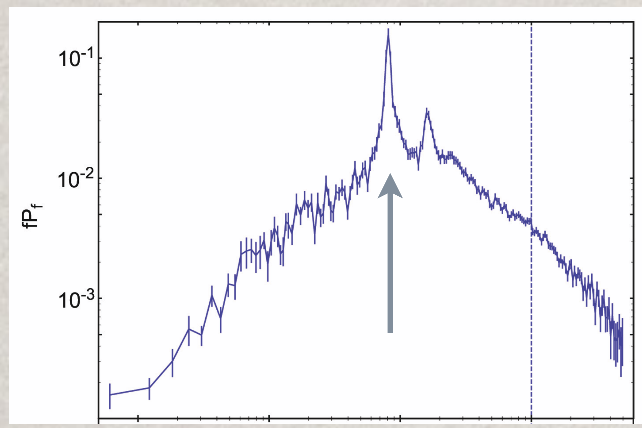




Axelsson et al. (2014)

LOOKING AT THE QPO

Harder state



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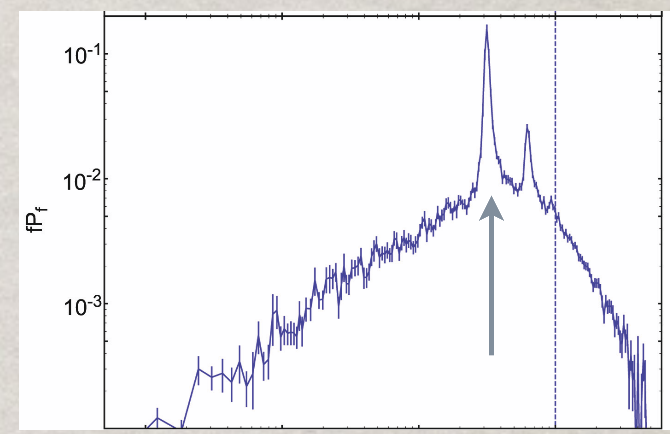

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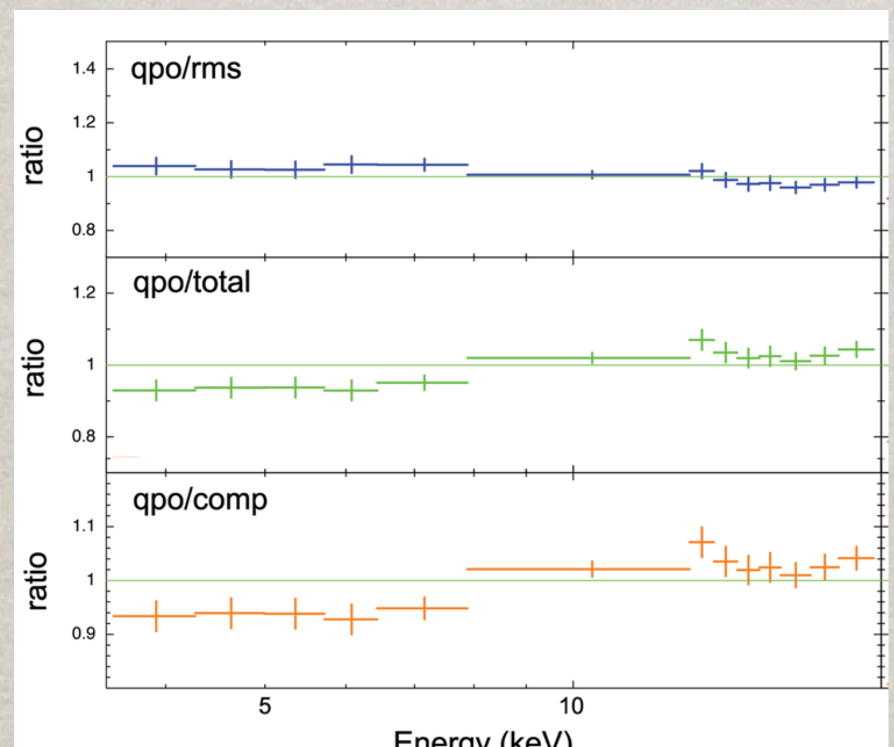
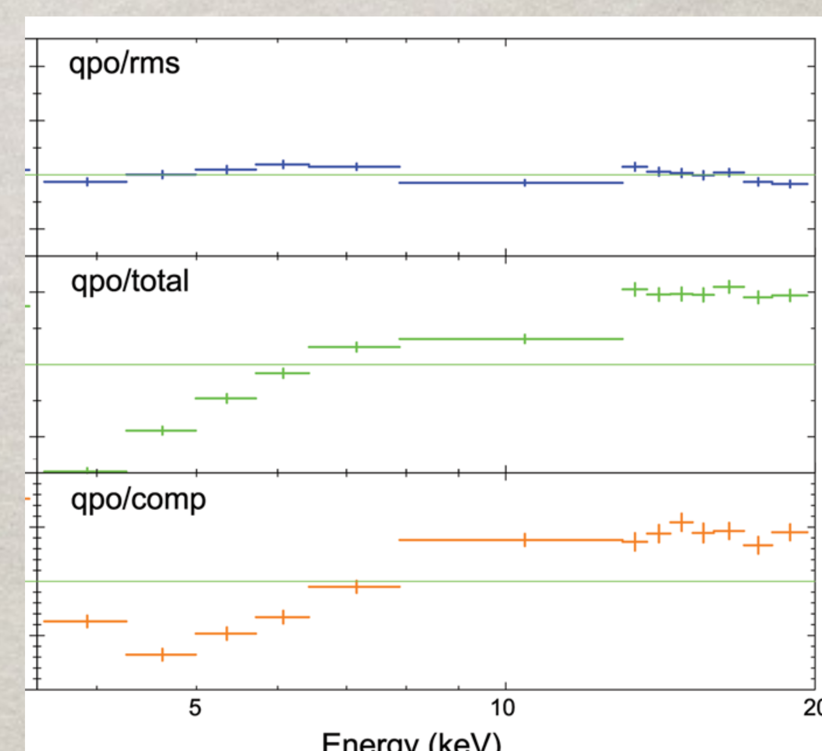
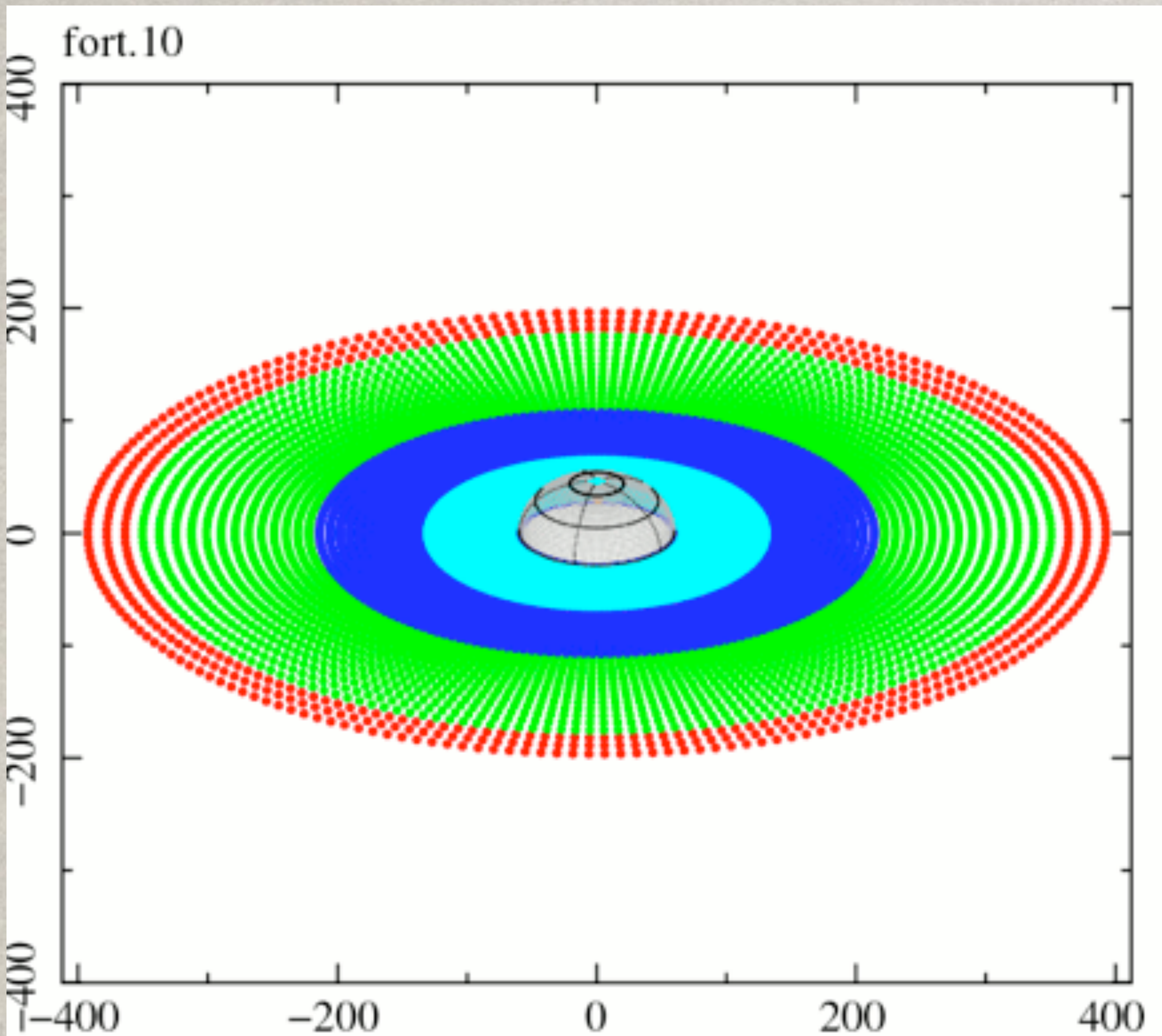




QPO arises in the inner accretion flow!

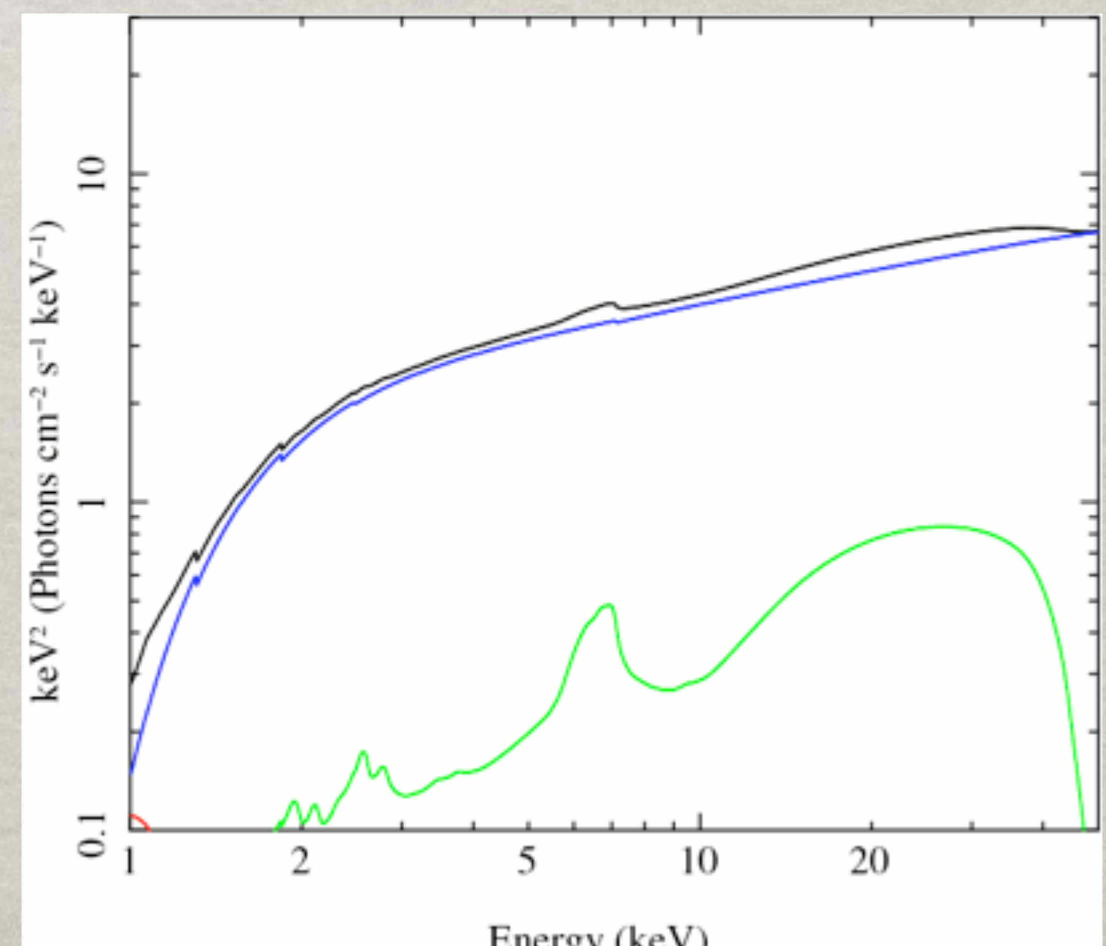
Axelsson et al. (2014)

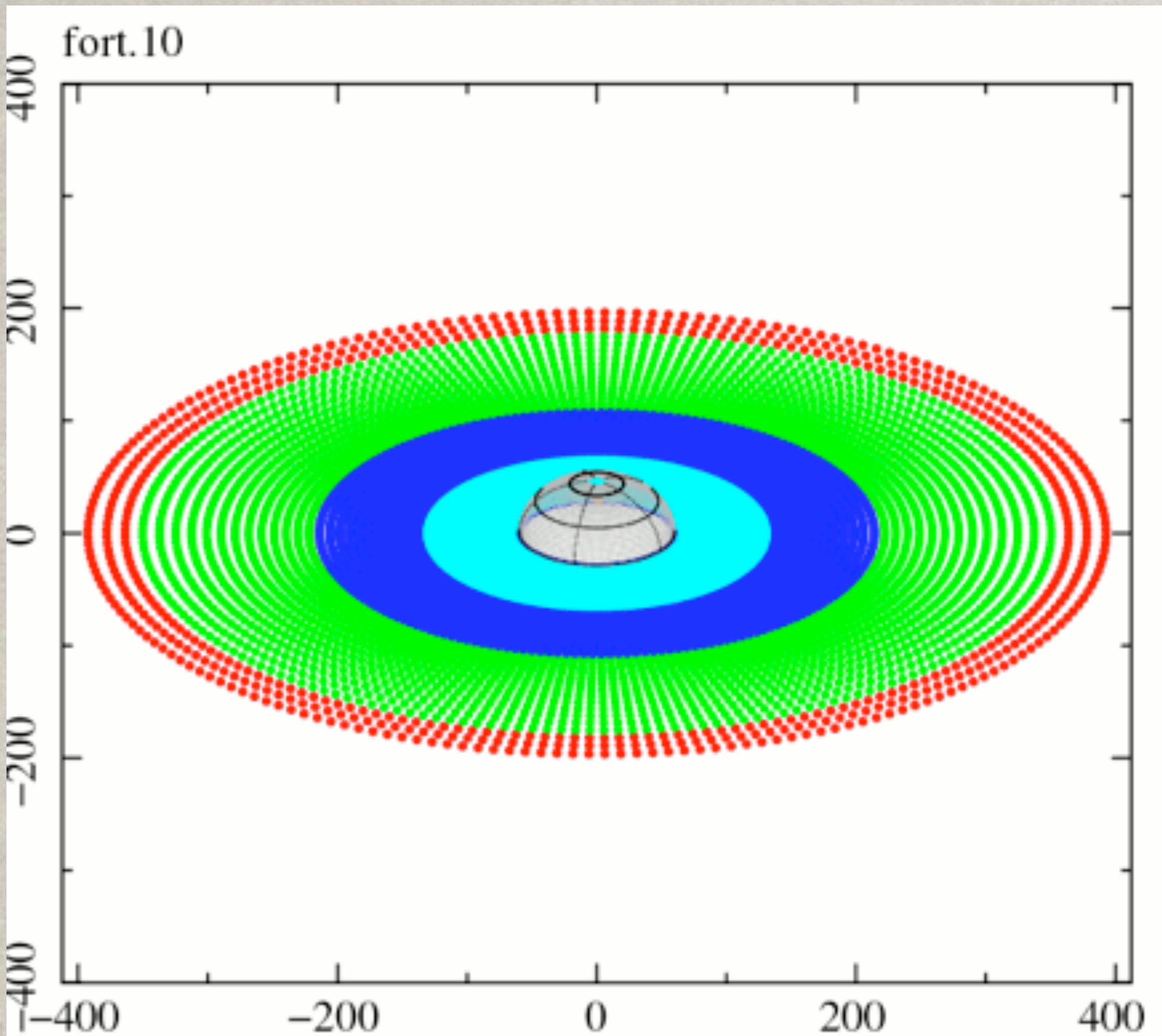


Animations from A. Ingram

Precessing inner flow gives variable illumination of the disc…

…which gives varying spectral components.





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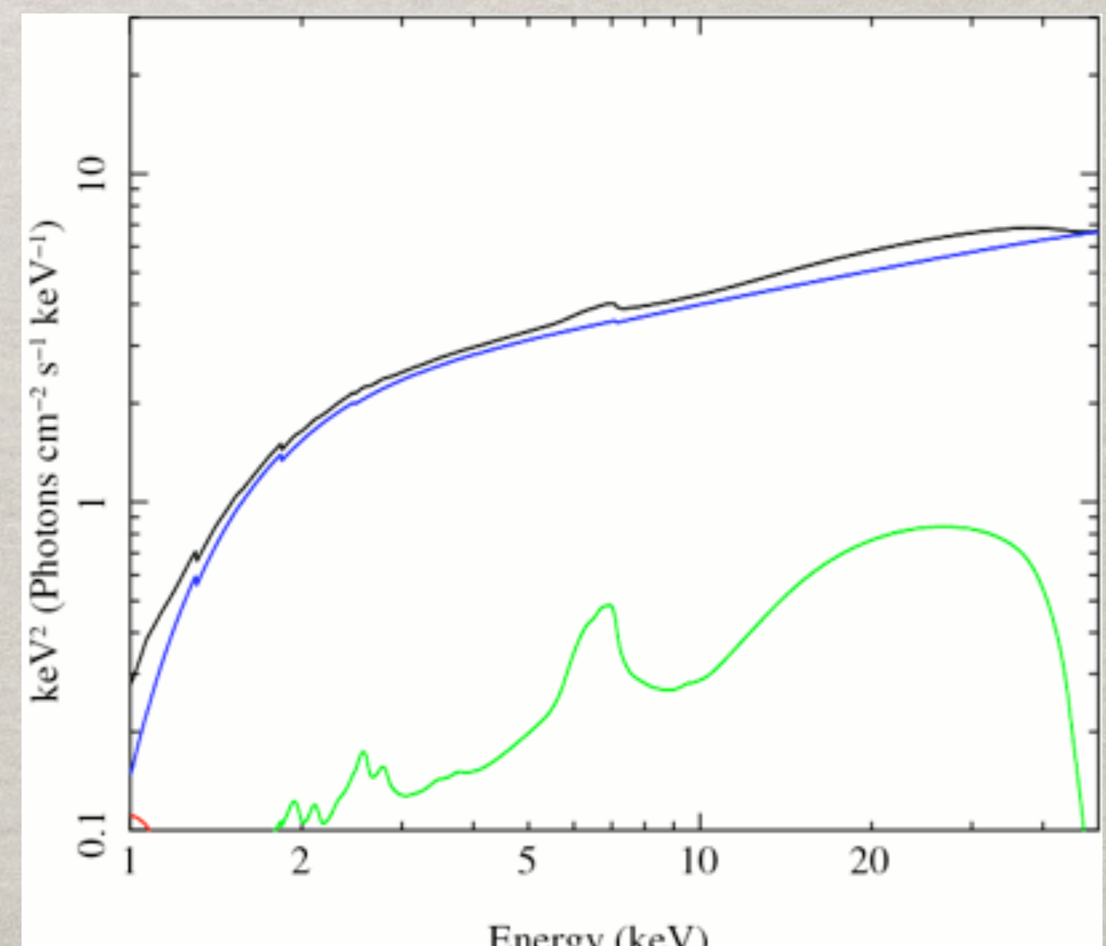
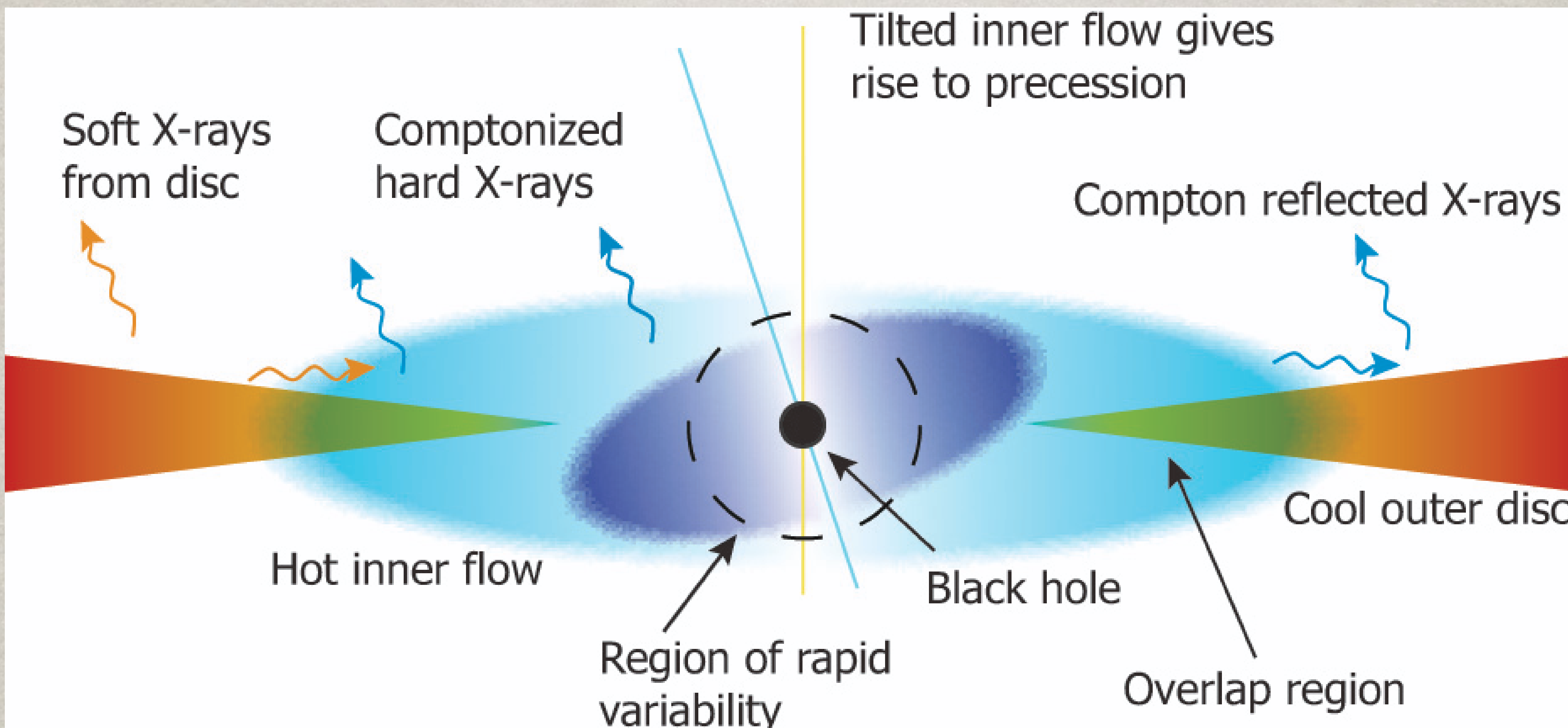
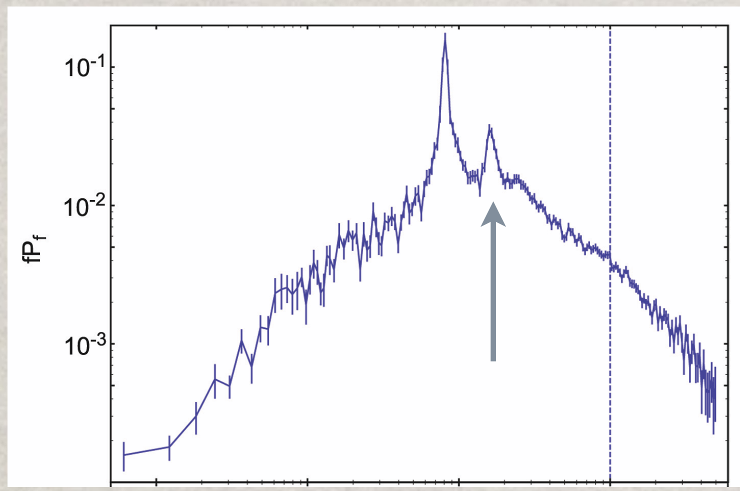
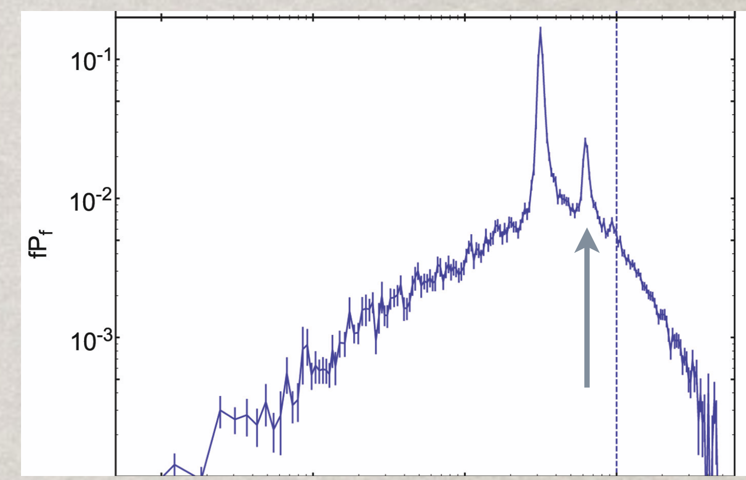


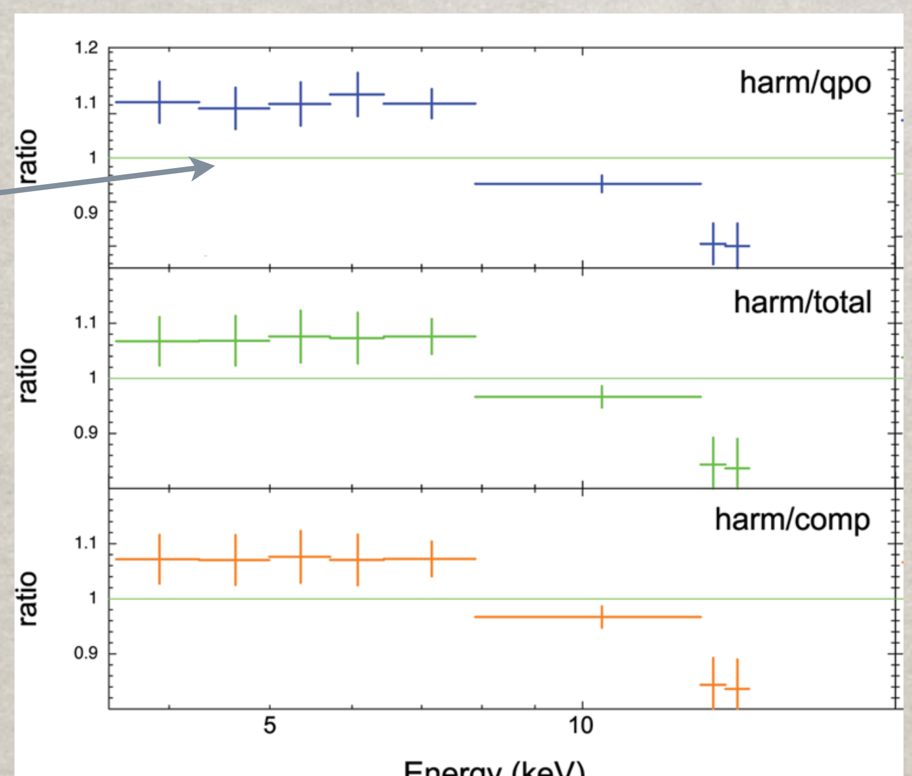

Tilted inner flow gives
rise to precession
Soft X-rays
from disc
Comptonized
hard X-rays
Compton reflected X-rays
Cool outer disc
Hot inner flow
Black hole
Region of rapid
variability
Overlap region

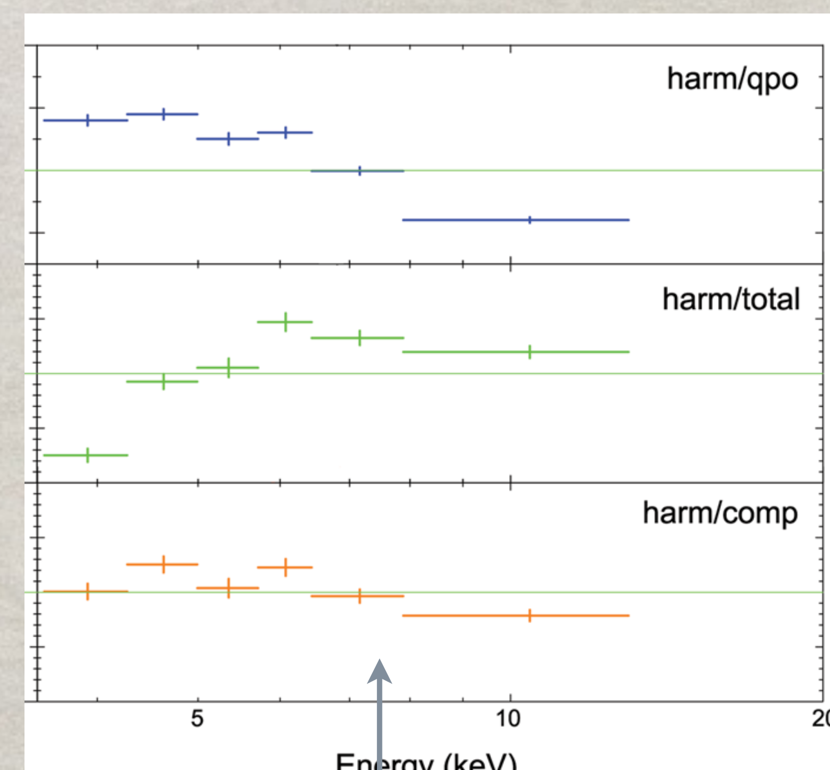
Harmonic





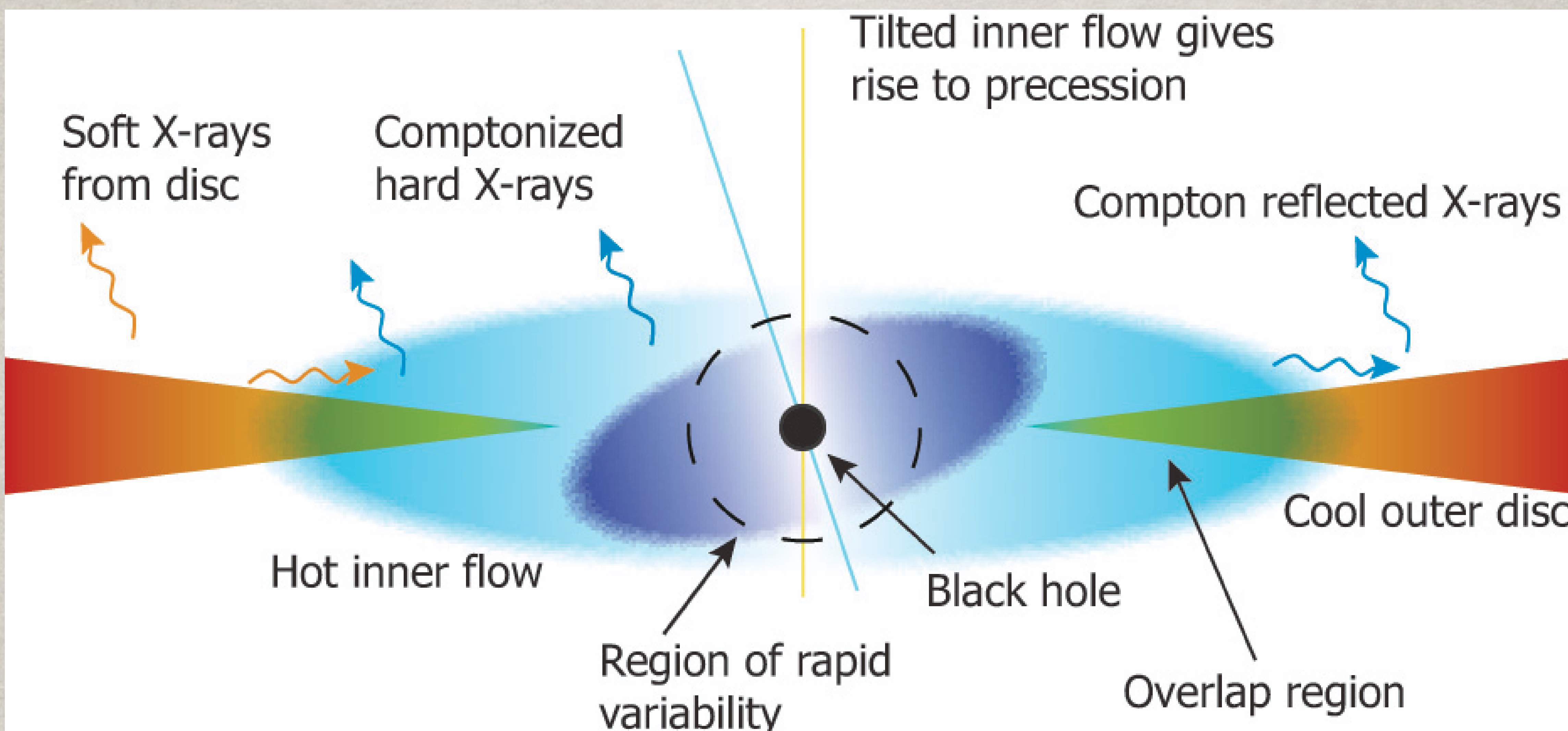
Softer than QPO





Similar to average Compt. in softer states

Axelsson et al. (2014)



Observed flux from Compton region:

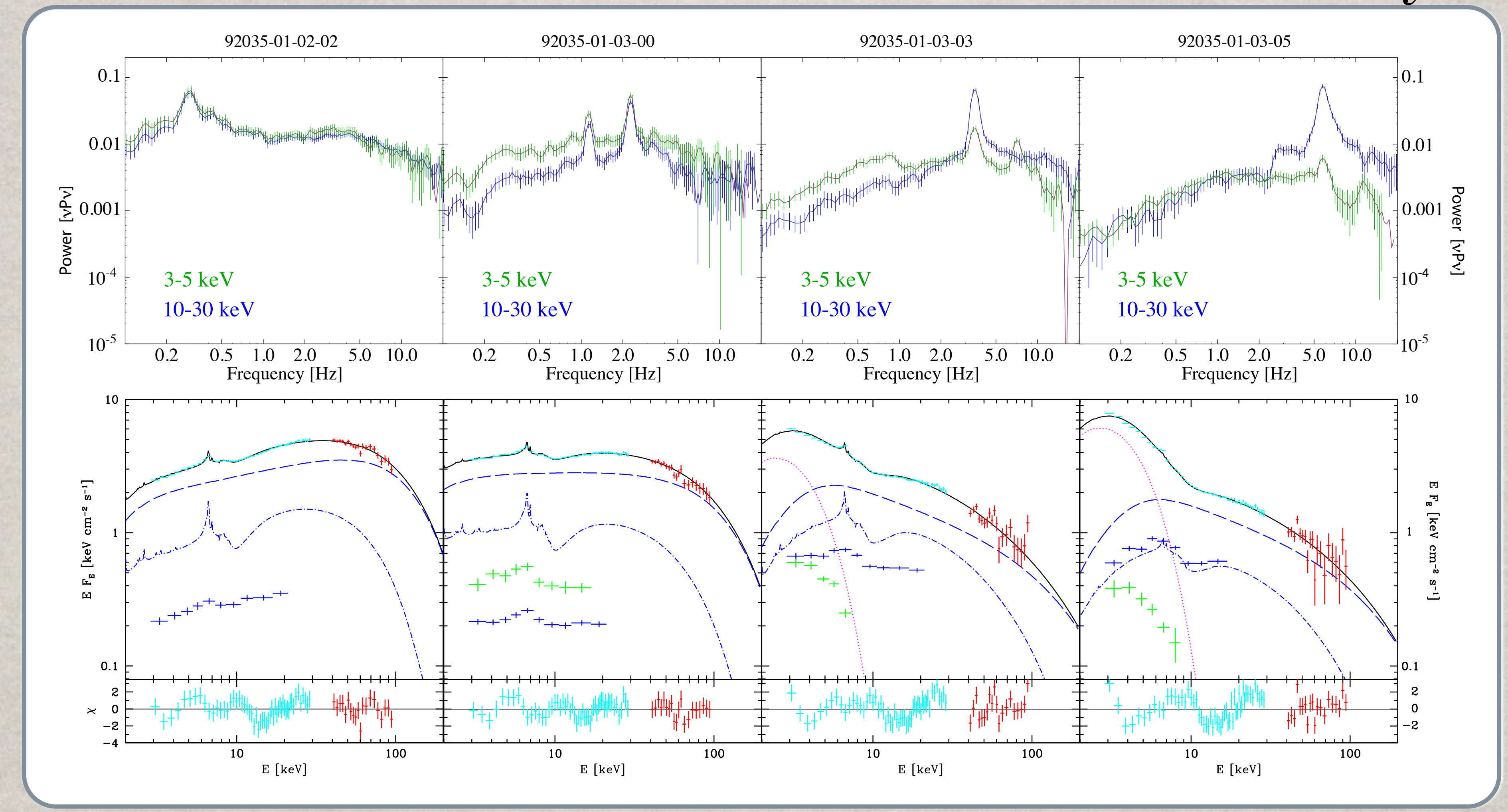
$$F_E(\theta) \propto I(\theta)\cos\theta \approx (1+b\cos\theta)\cos\theta = b/2+\cos\theta+b/2\cdot\cos 2\theta$$

b depends on optical depth - strongest harmonic furthest out!

Viironen & Poutanen (2004)
Veledina et al. (2013)

GX 339-4

Preliminary!

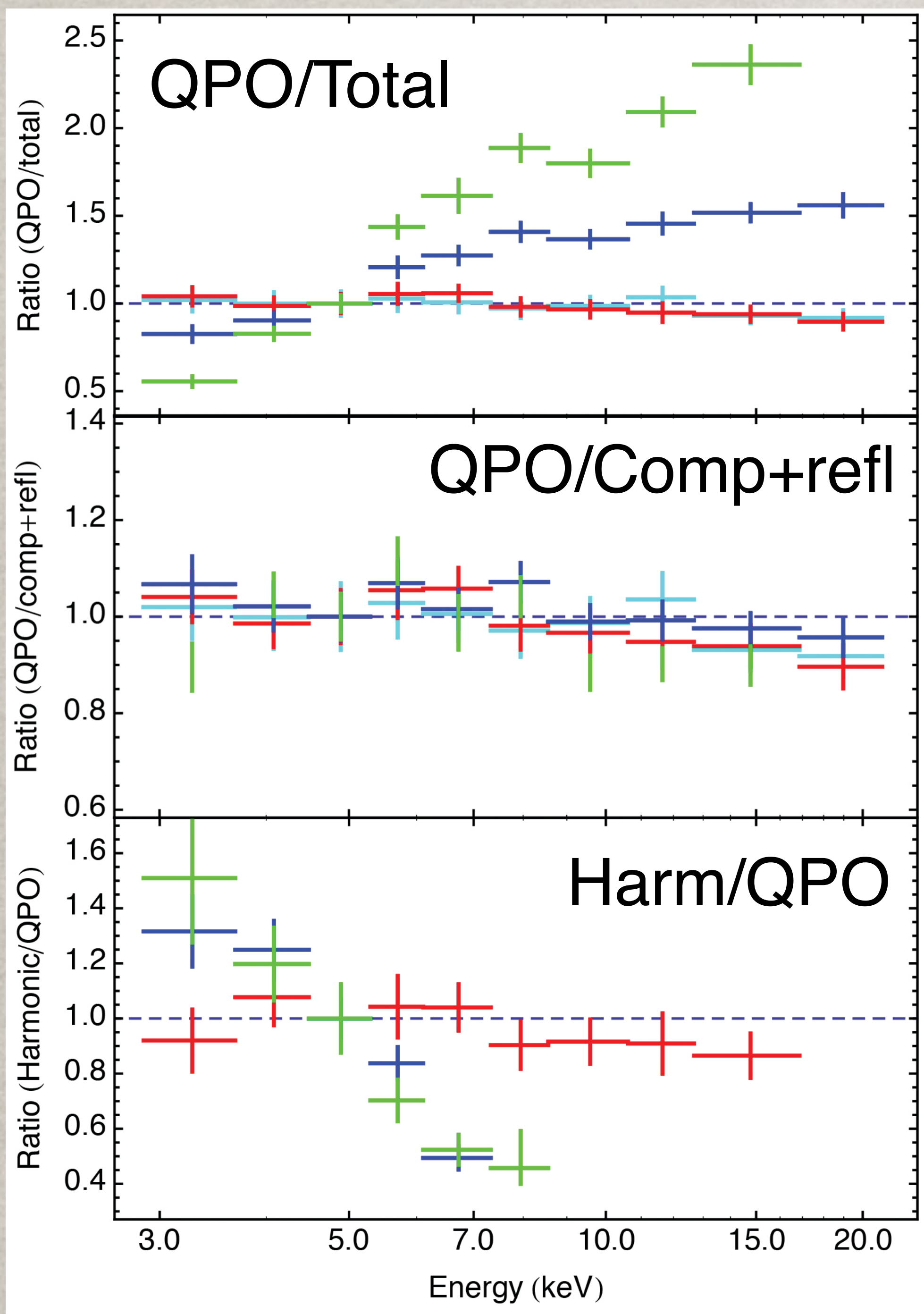


In the hardest state, there is no harmonic. In the softer states, it is only present at low energies.

Time-averaged spectrum (lower panels) in the softer states is not well-fit by disc, comptonisation and reflection. Additional component needed at lower energies (<15 keV). Parameters cannot be constrained by available data…

GX 339-4

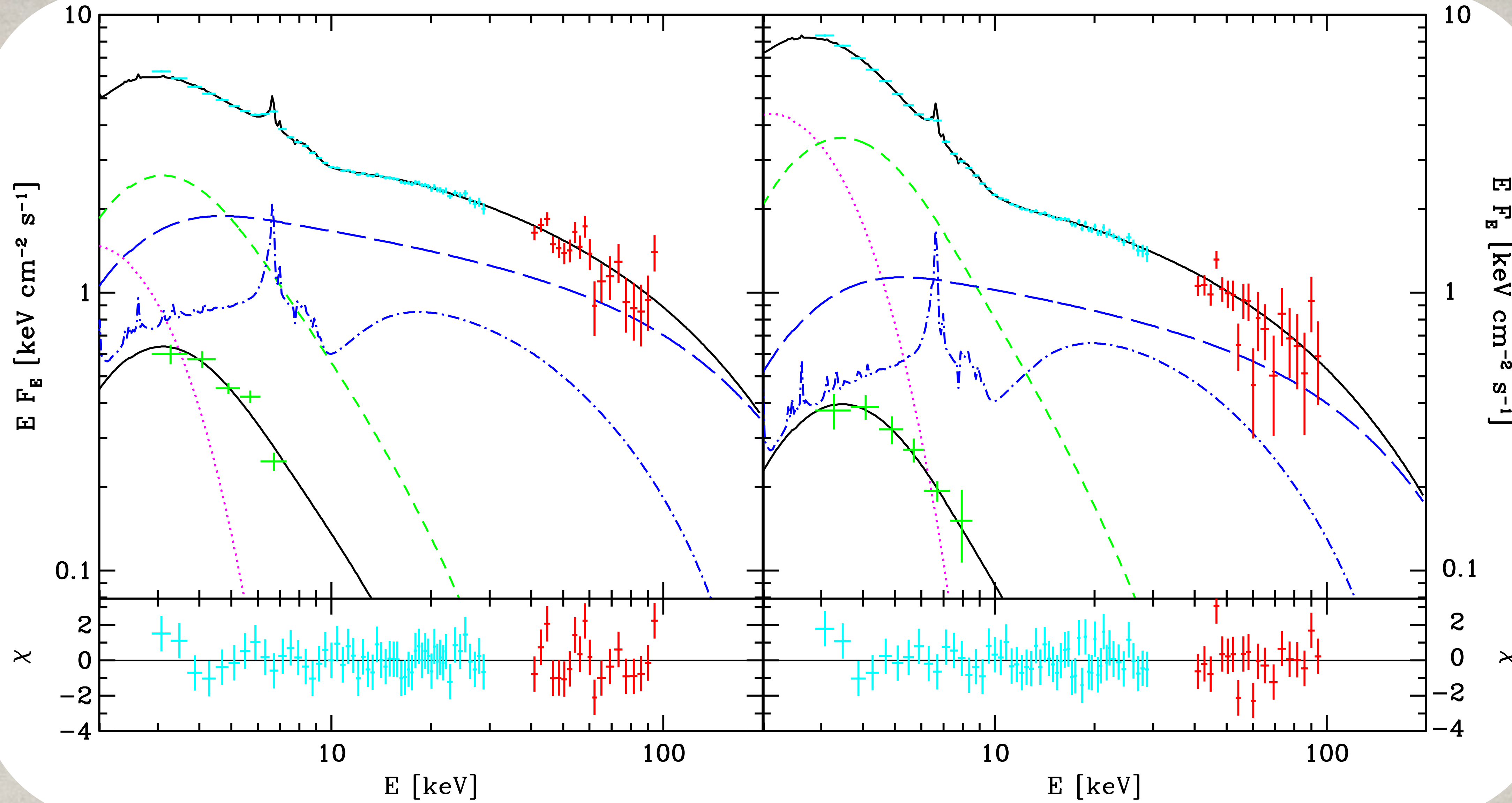
Preliminary!



Compare the QPO to the time-averaged spectrum.

QPO spectrum behaviour similar to J1550: no disc component, very little spectral evolution. Can be fit using Comptonisation+reflection

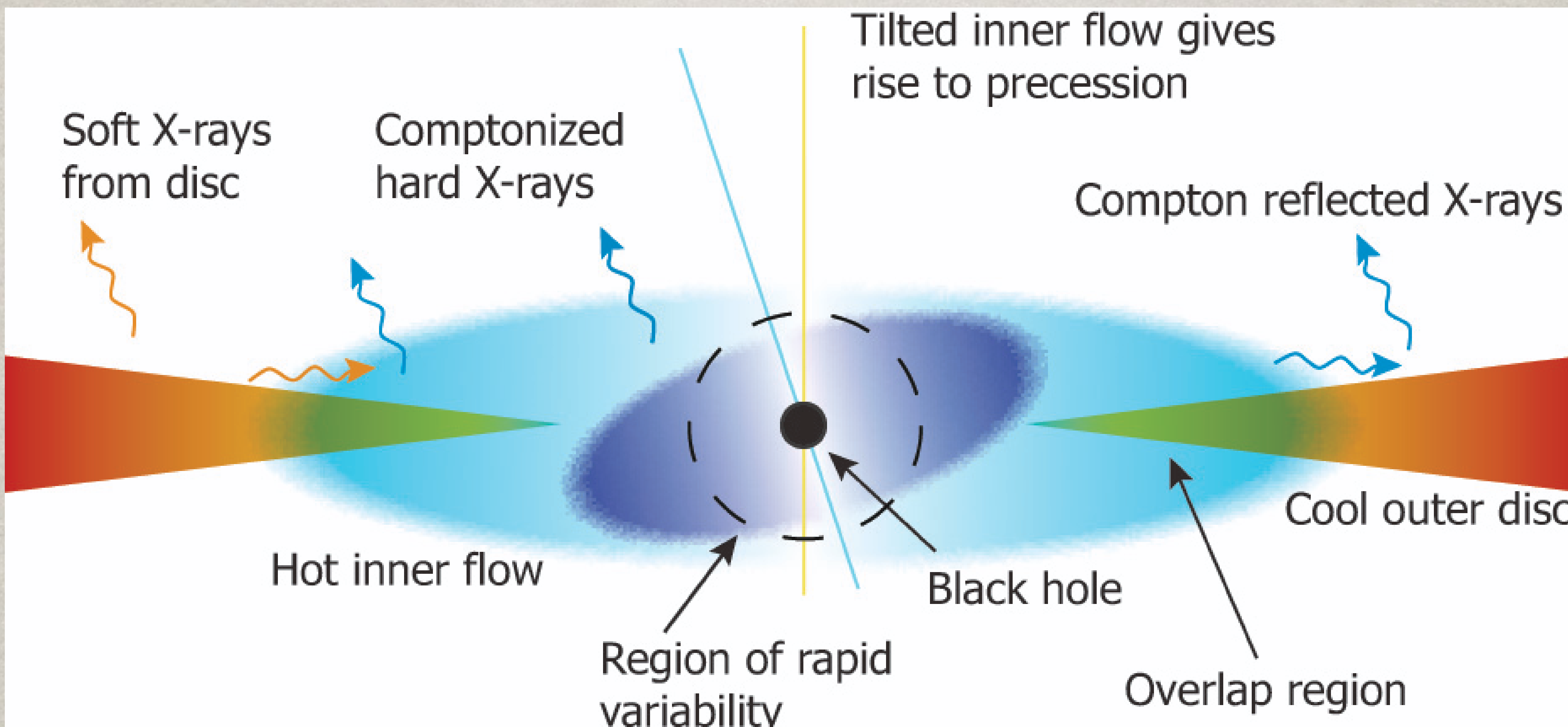
The harmonic behaviour is very different. In the intermediate state it is similar to the QPO, but in softer states it is very different! Cannot be just a geometrical effect…



The harmonic spectrum is very similar to a soft (thermal) Compton component. We can use this to constrain the extra component needed for the time-averaged spectra - very good fit!

The electron temperature of ~9 keV suggests that it arises at the edge of the hot inner flow. Doubling of frequency because of stabilizing disc?

Conclusion: The Comptonization region is inhomogeneous.



Are we seeing two different mechanisms for the harmonic?

If so, does inclination play a role in which one we see?

Conclusions

- Fast timing can probe inner regions of the accretion flow, and thereby the properties of the black hole
- Radiation spectra alone not enough to determine emission components.
- Comptonization region(s) are inhomogeneous!
- QPO spectra support precessing inner flow.
- Harmonic could be angular dependence of flux from edge of Compton region, or oscillations from of the overlap region.

Thank you!