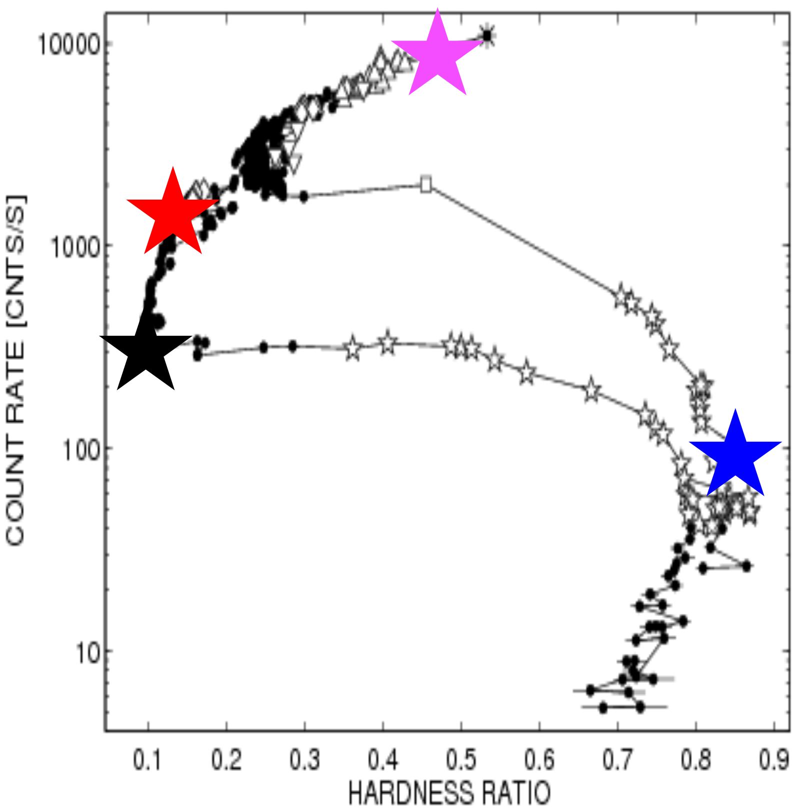
Accretion in BHB and AGN

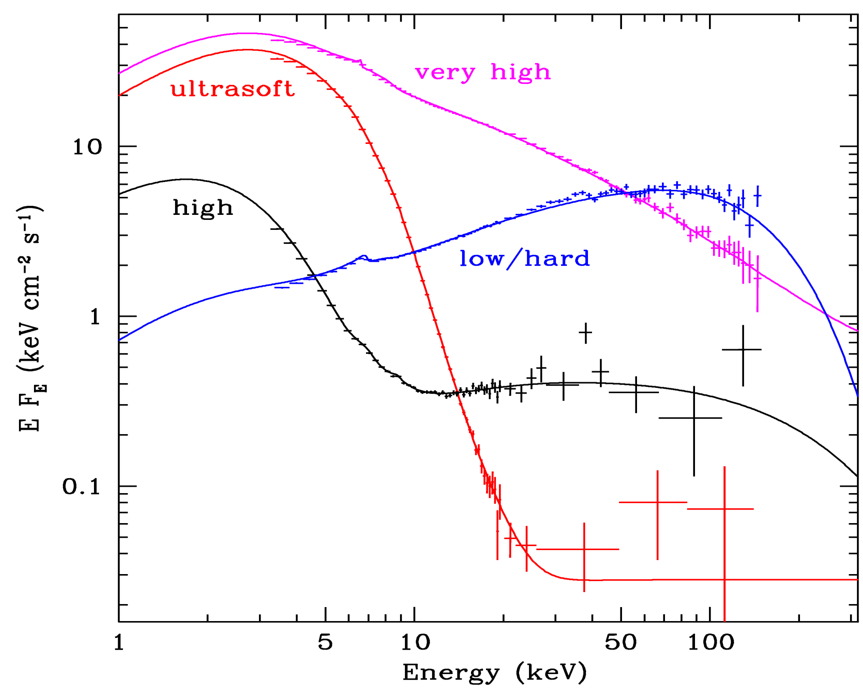
Chris Done,
University of Durham

Black hole binaries

GRO J1655-40



Observe dramatic changes in SED with mass accretion rate onto black hole

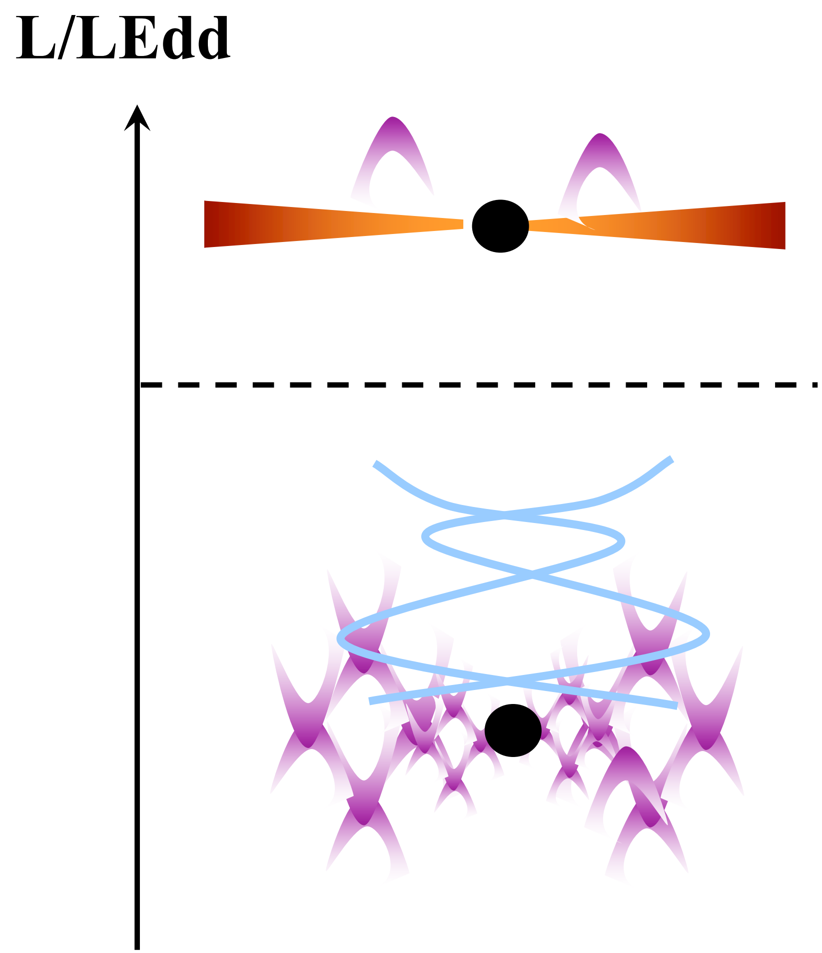


Uncontroversial

- No-one talks much about the very high state!!
- Disc dominated state – Shakura-Sunyaev disc equations!!

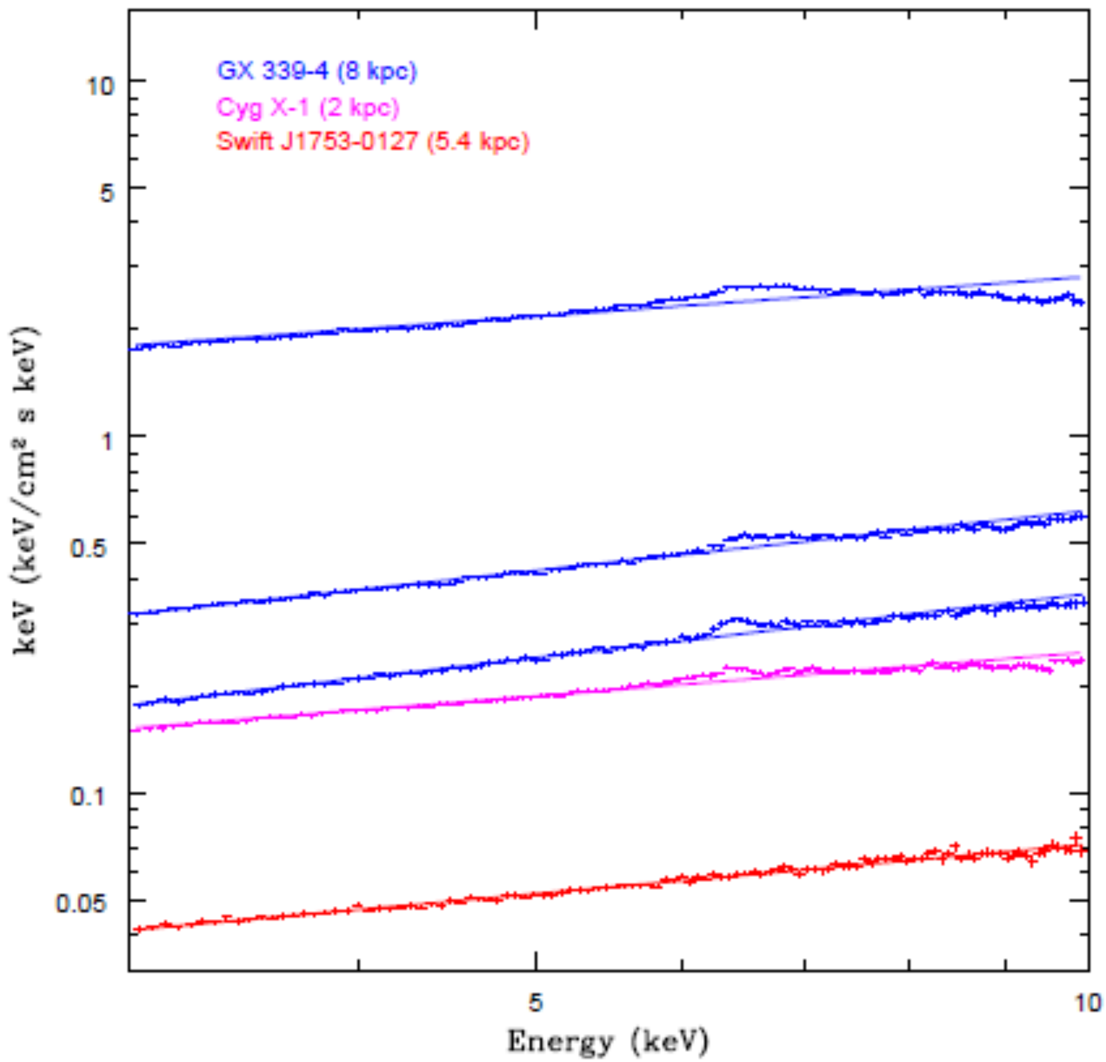
- TRANSITIONS??
- Hard-soft not fixed
- Soft-hard mainly 0.02LEdd

- L<0.001LEdd, X-ray hot flow, no inner disc
- steady compact jet (bulk $\Gamma \sim 1.5$-2)



Moving disc with iron line - YES

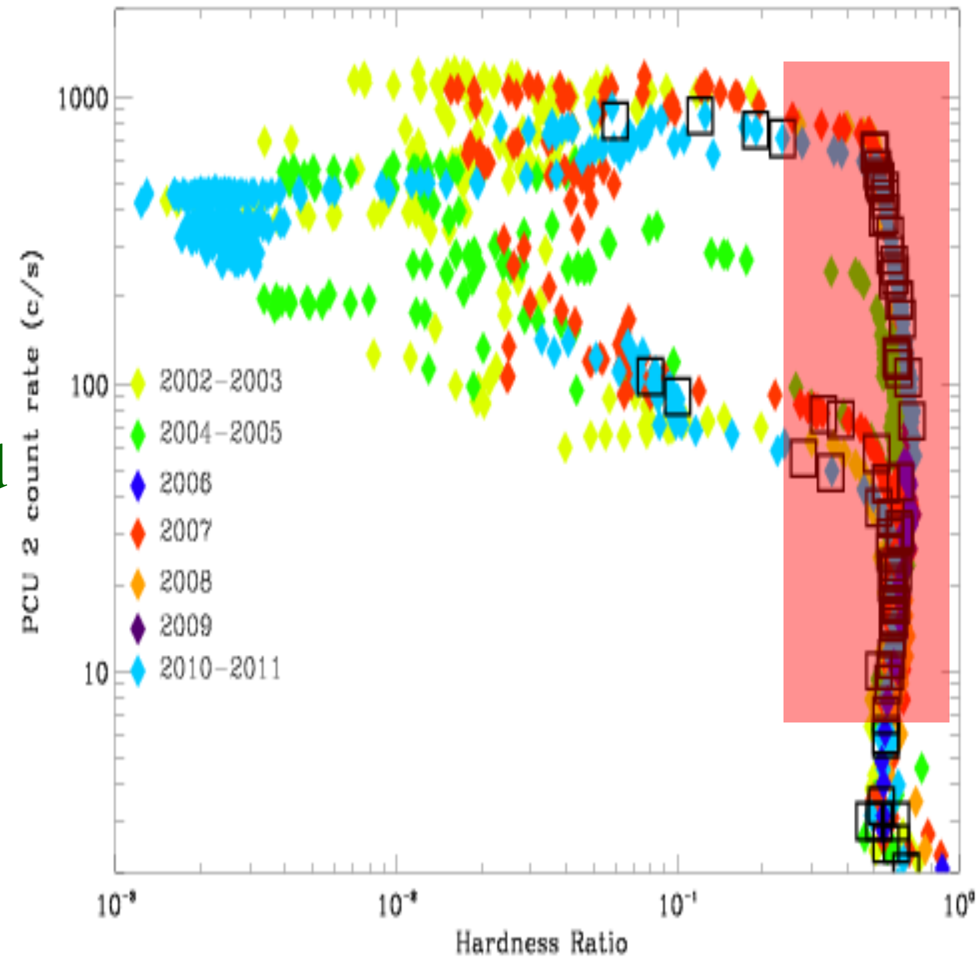
- Iron line should be very small and narrow for low L/LEdd
- Gets bigger and broader as disc moves in
- XMM-Newton timing mode
  Kolehmainen Done & Diaz Trigo 2011 cf Tomsick et al 2010



What is the structure on this branch?

- TRANSITIONS??
- Hard-soft not fixed
- Soft-hard mainly 0.02LEdd

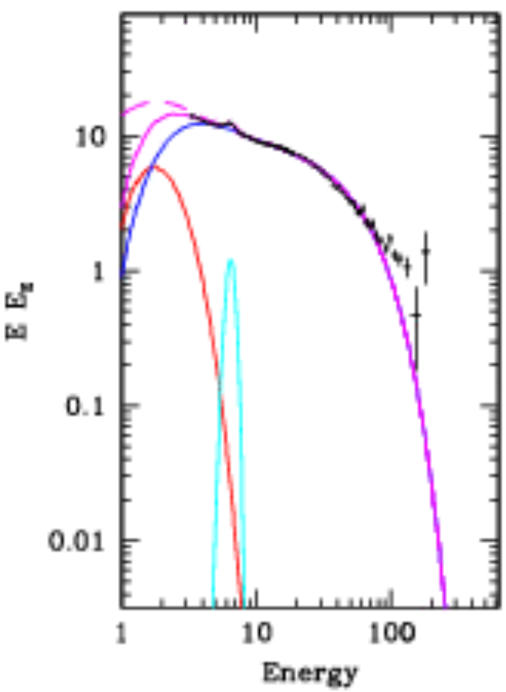
GX339-4 Corbel et al 2013

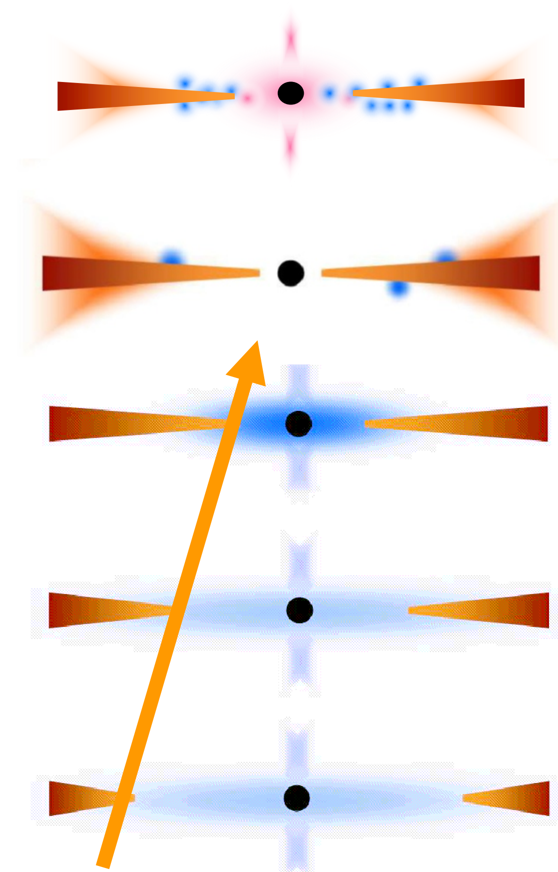


Truncated disc/hot inner flow

- Energy spectra need disc to move from 50-6ish Rg as make transition

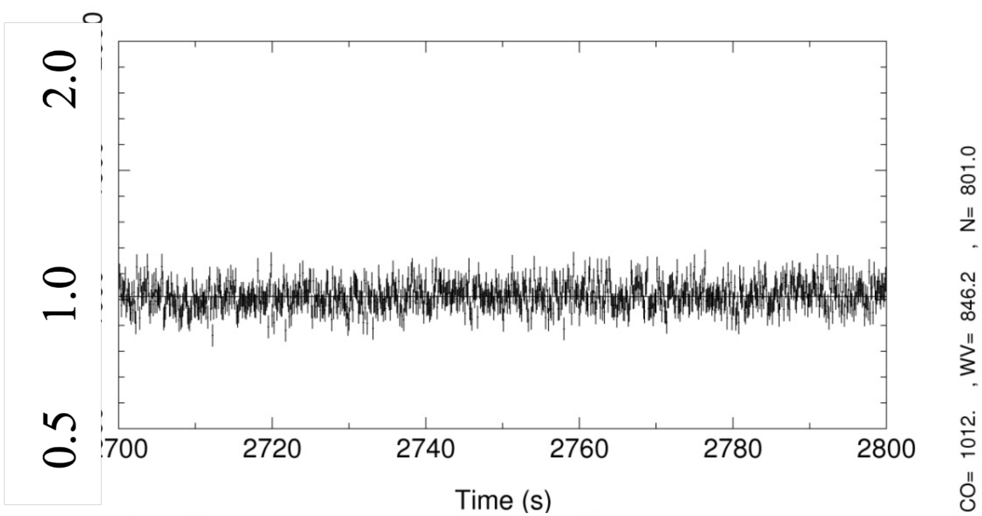
DGK07

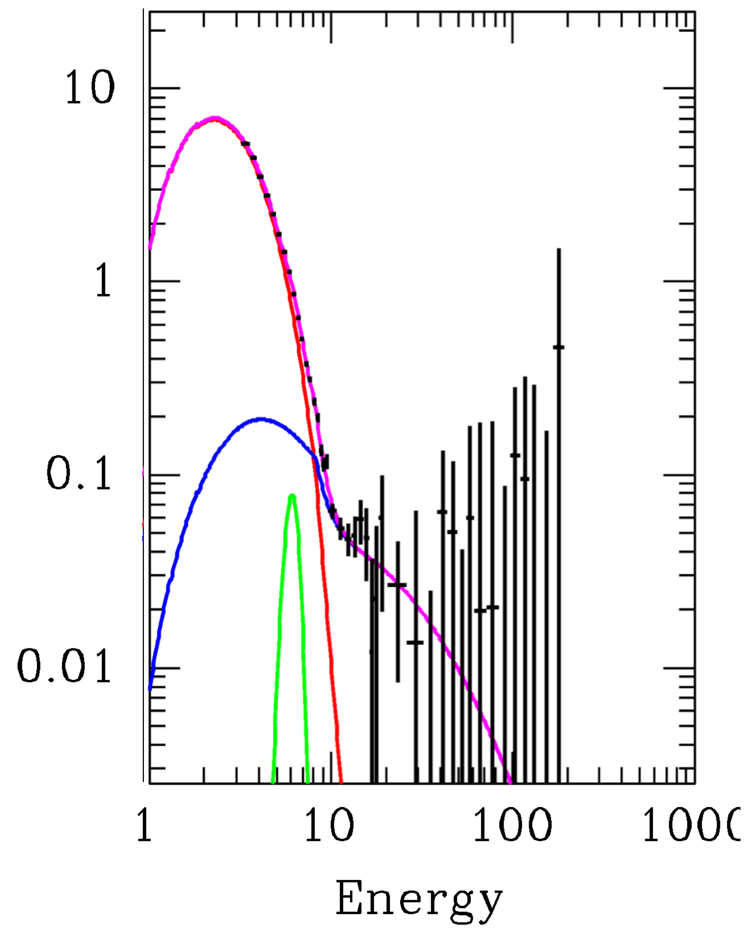




Variability of disc:short timescale

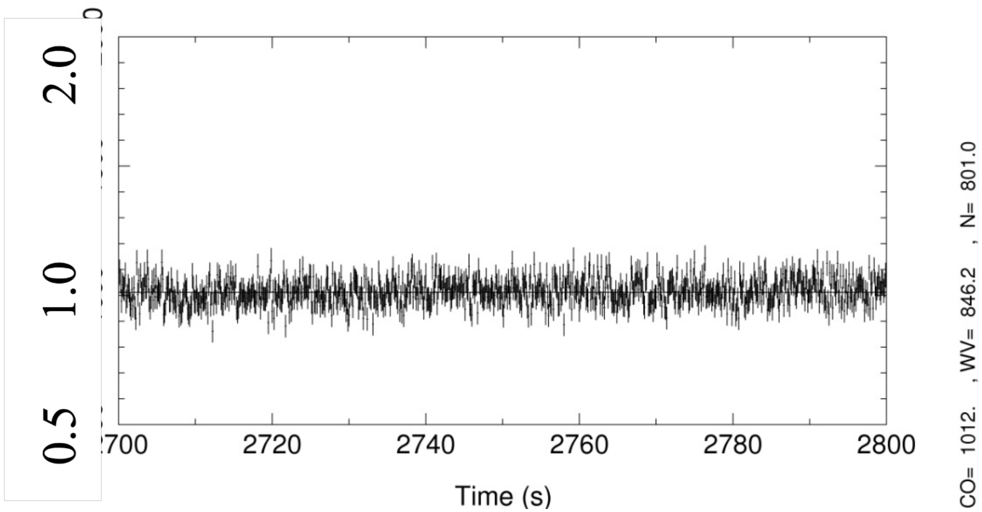
- No rapid variability of disc in disc dominated states!
- Disc very stable

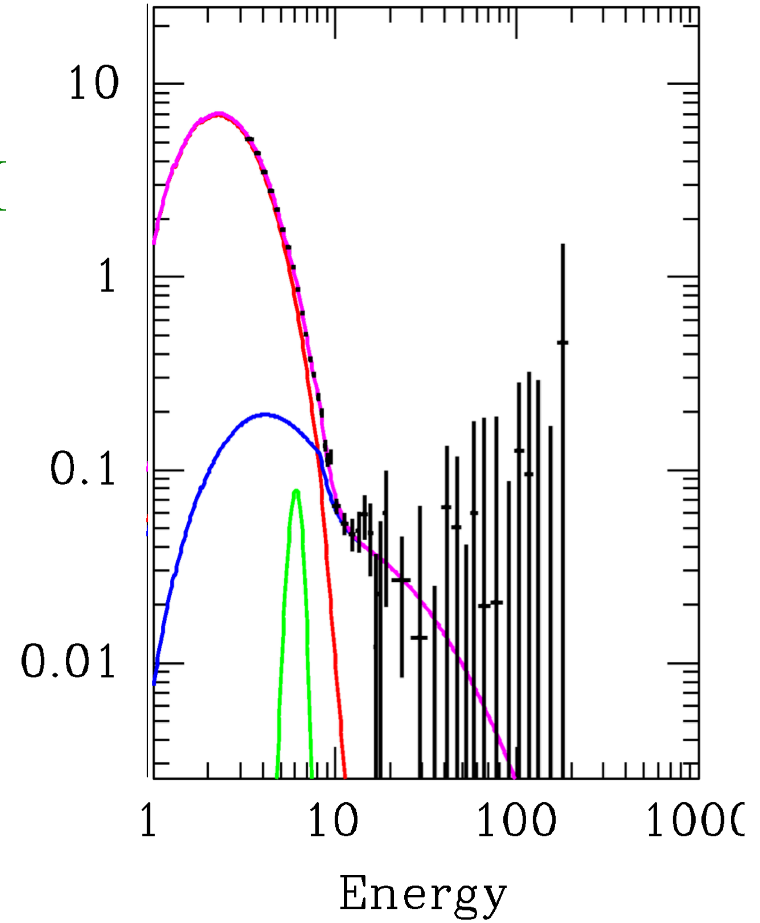




Variability of disc:short timescale

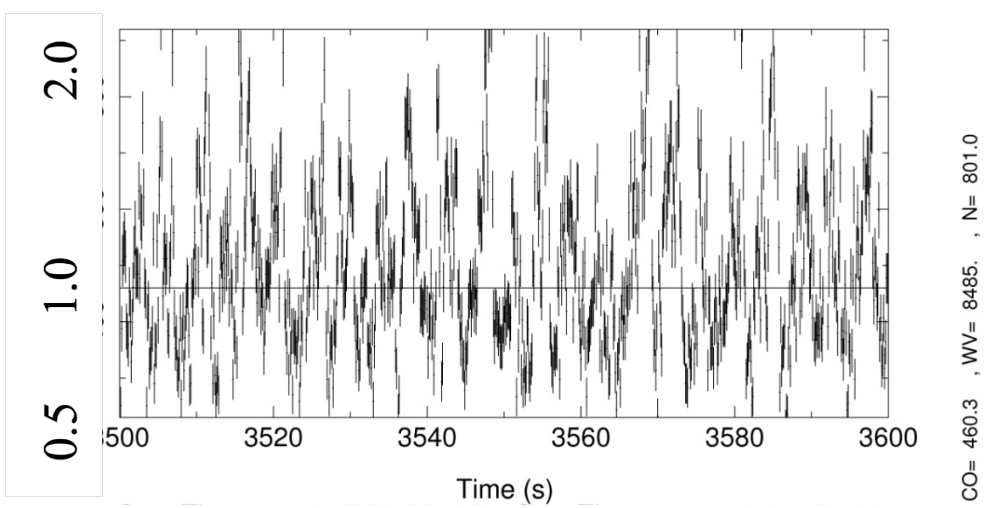
- Timescale to change mass accretion rate through disc
- tvisc= α^{-1} $(H/R)^{-2}$ torb
  =5 α^{-1} $(H/R)^{-2}$ $(r/6)^{-3/2}$ ms
- ~ 500s at last stable orbit for 10M
- No rapid variability of disc

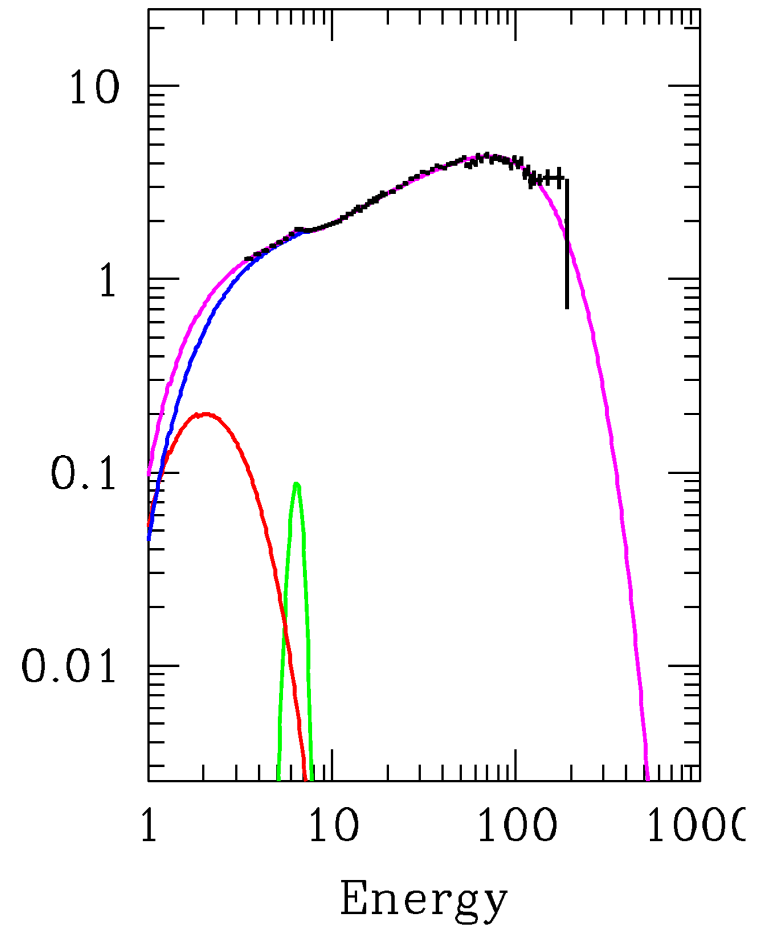




Low/hard state variability

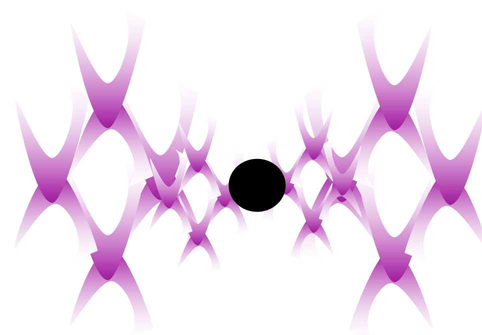
- Low/Hard state variability down to few 10s of ms
- tvisc= α^{-1} $(H/R)^{-2}$ tdyn = 5 α^{-1} $(H/R)^{-2}$ $(r/6)^{-3/2}$ ms
- IF viscous timescale then H/R~1

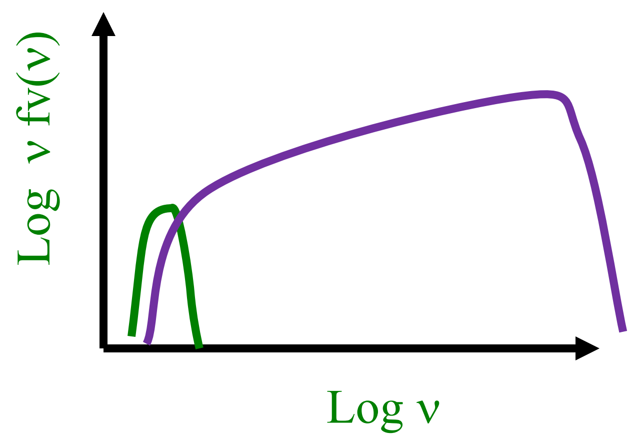




Accretion flows without discs

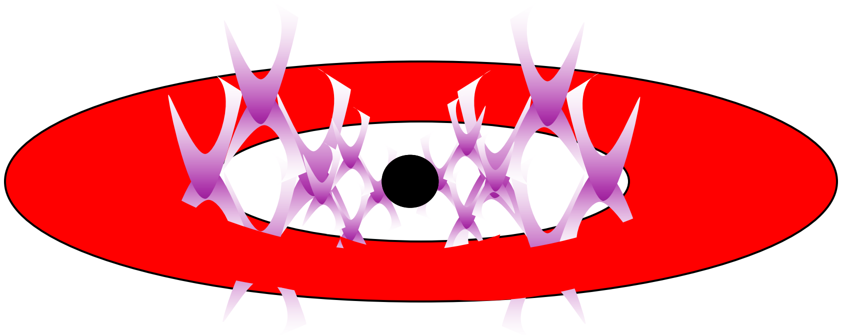
- Other stable state
- hot, optically thin, geometrically thick inner flow replacing the inner disc (Shapiro et al. 1976; Narayan & Yi 1995)
- Hot electrons Compton upscatter photons from cyclo-sync in optical ? Veledina et al 2013; Gardner & Done 2013

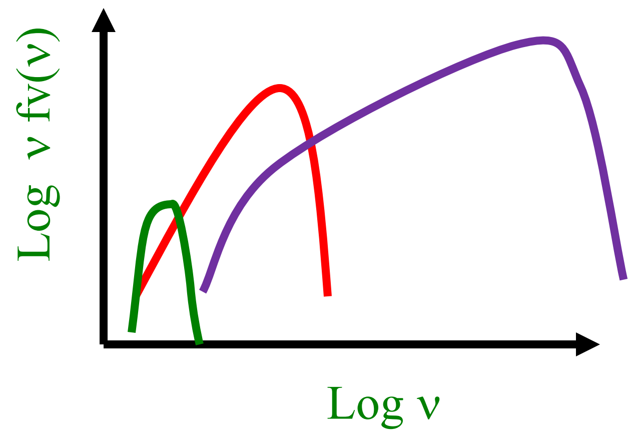




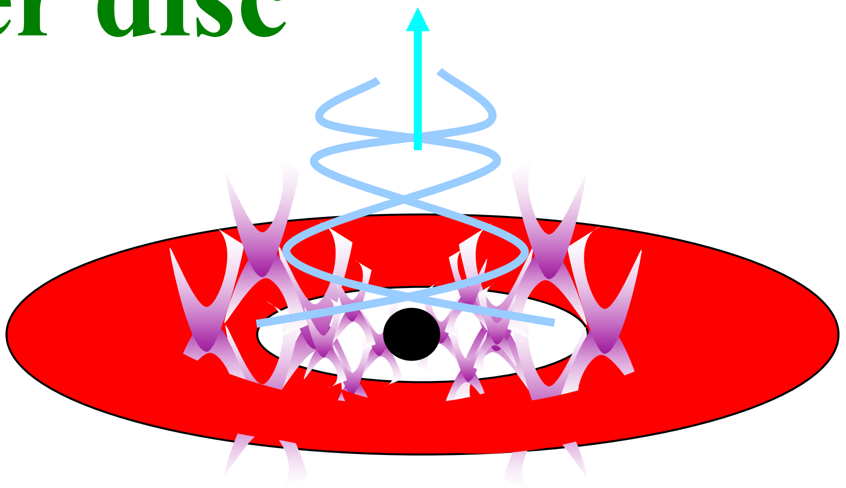
Accretion flows without discs

- But see some disc as well in bright low/hard states
- not easy to put it under flow as hard spectra required Ls<<Lh
- so truncate disc radially

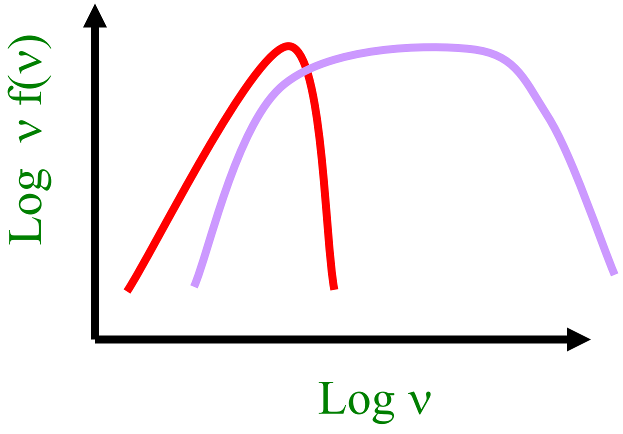




No inner disc



- Hot electrons Compton upscatter photons from outer cool disc
- Few seed photons, so spectrum is hard
- Jet from large scale height flow



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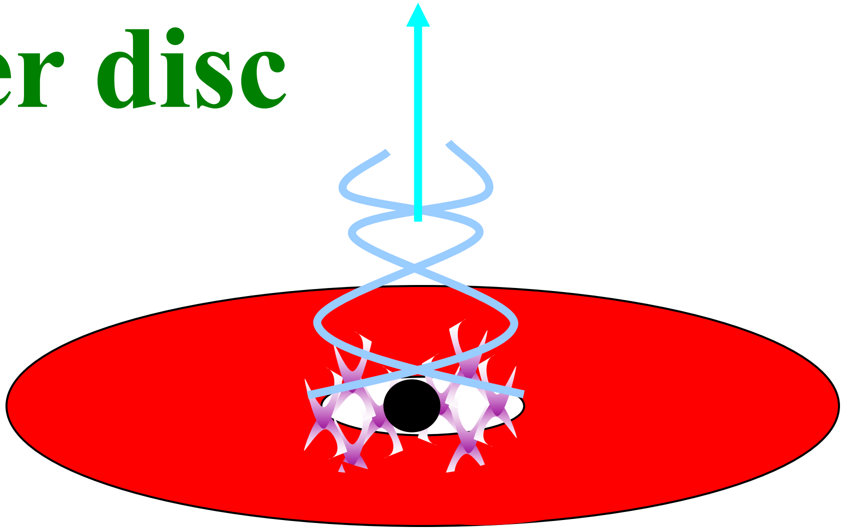
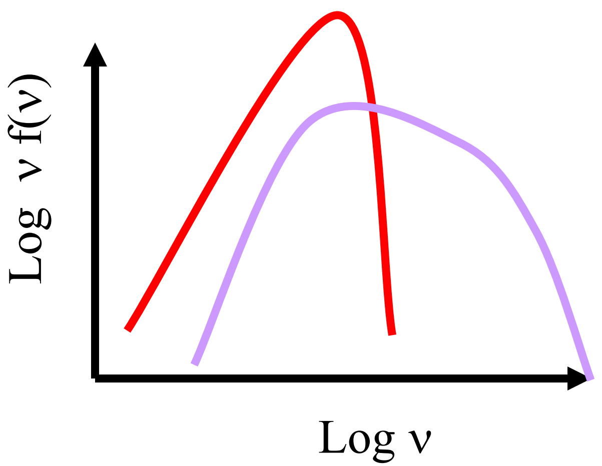
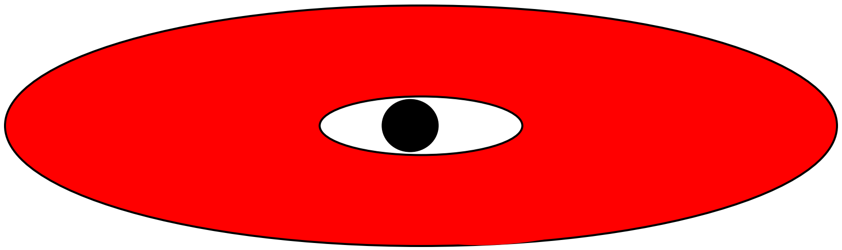
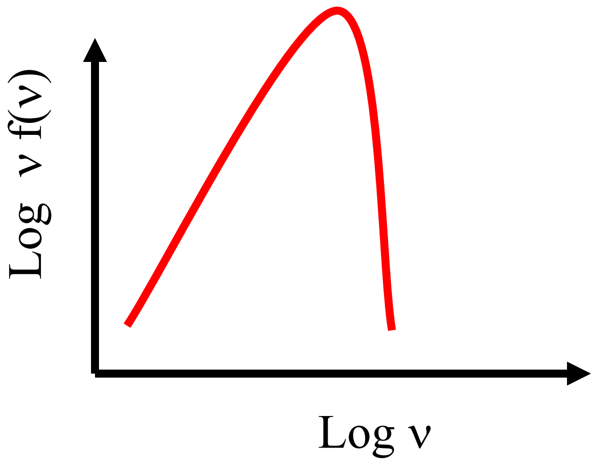




Collapse of hot inner flow

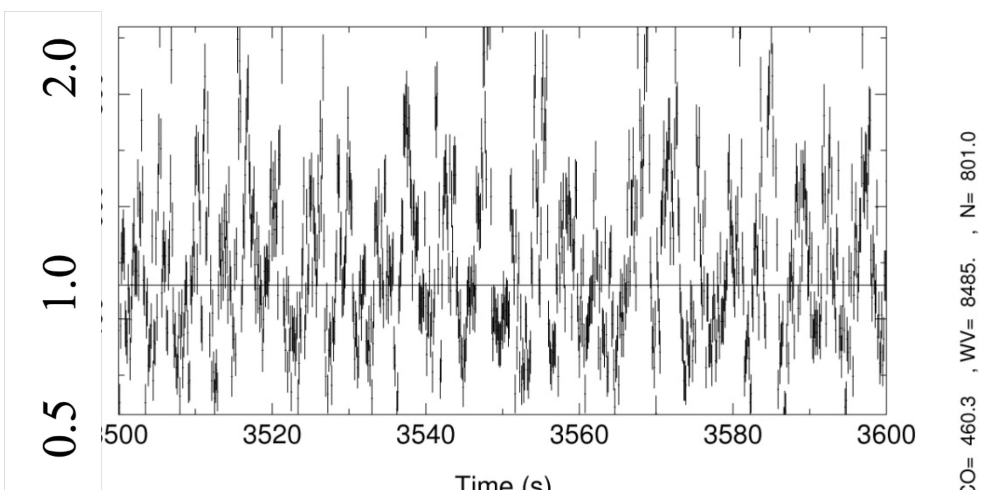
- Hot electrons Compton upscatter photons from outer cool disc
- Few seed photons, so spectrum is hard
- Jet from large scale height flow
- collapse of flow=collapse of jet

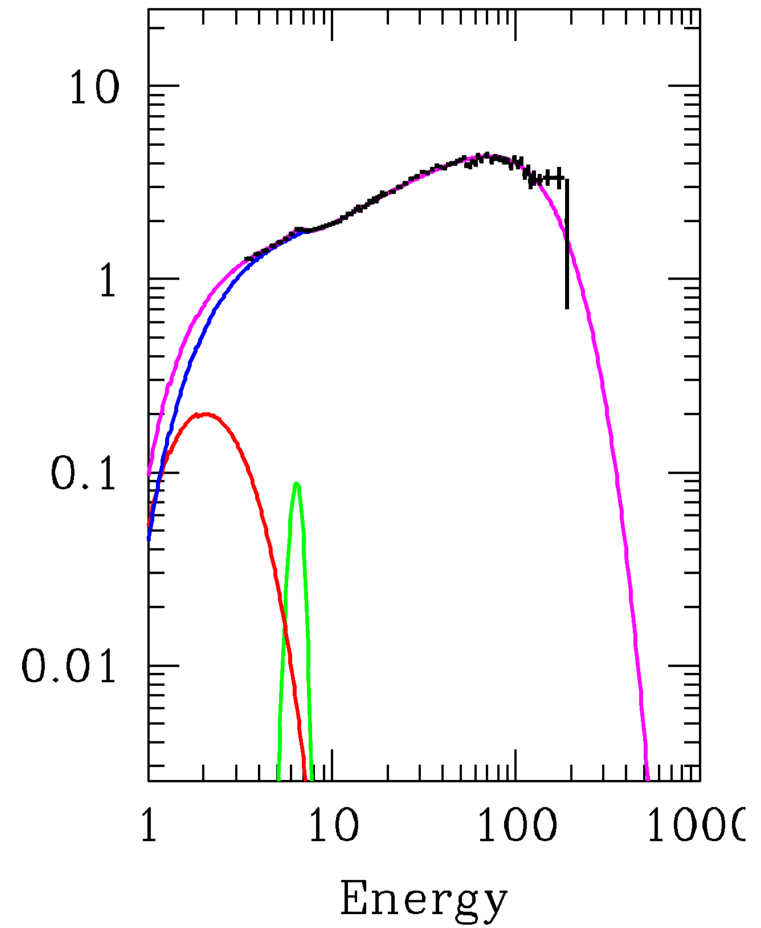




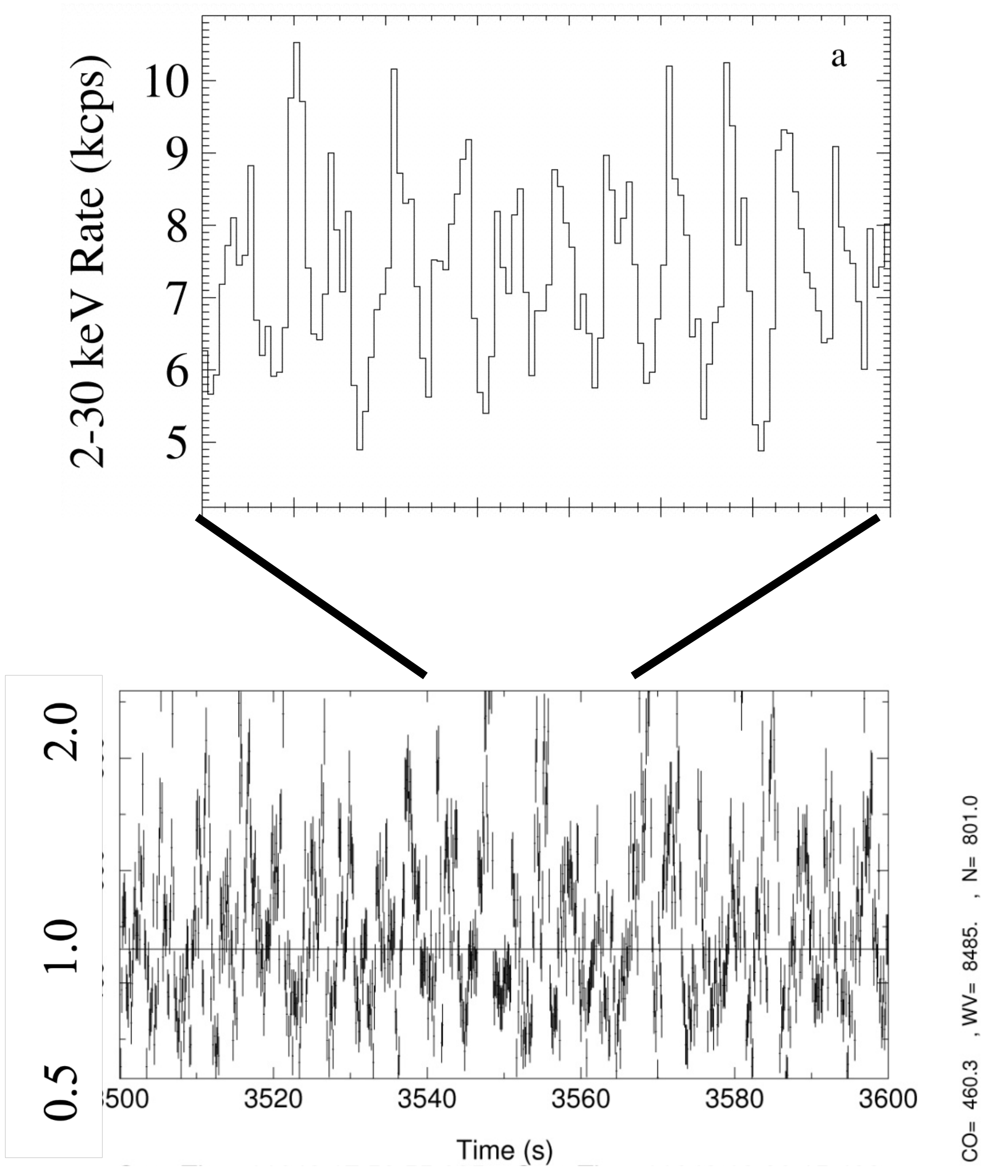
Low/hard state variability

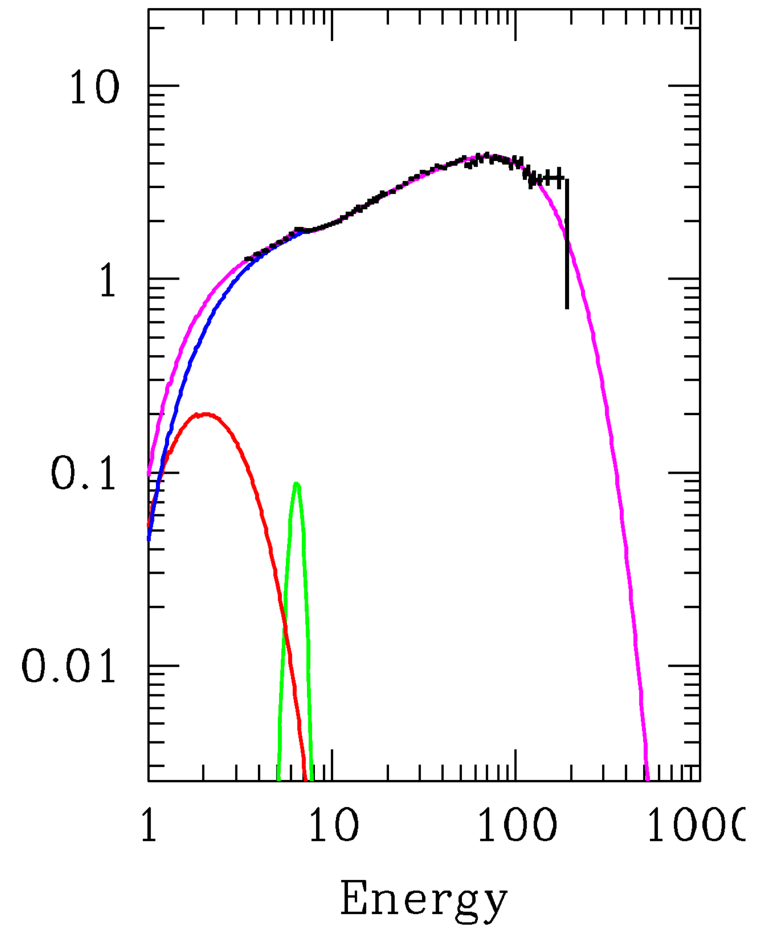
- Low/Hard state variability down to few 10s of ms
- tvisc= α^{-1} $(H/R)^{-2}$ tdyn = 5 α^{-1} $(H/R)^{-2}$ $(r/6)^{-3/2}$ ms
- viscous timescale then H/R~1
- Fluctuations stirred up by MRI
- WE NEED FULL MRI!!!



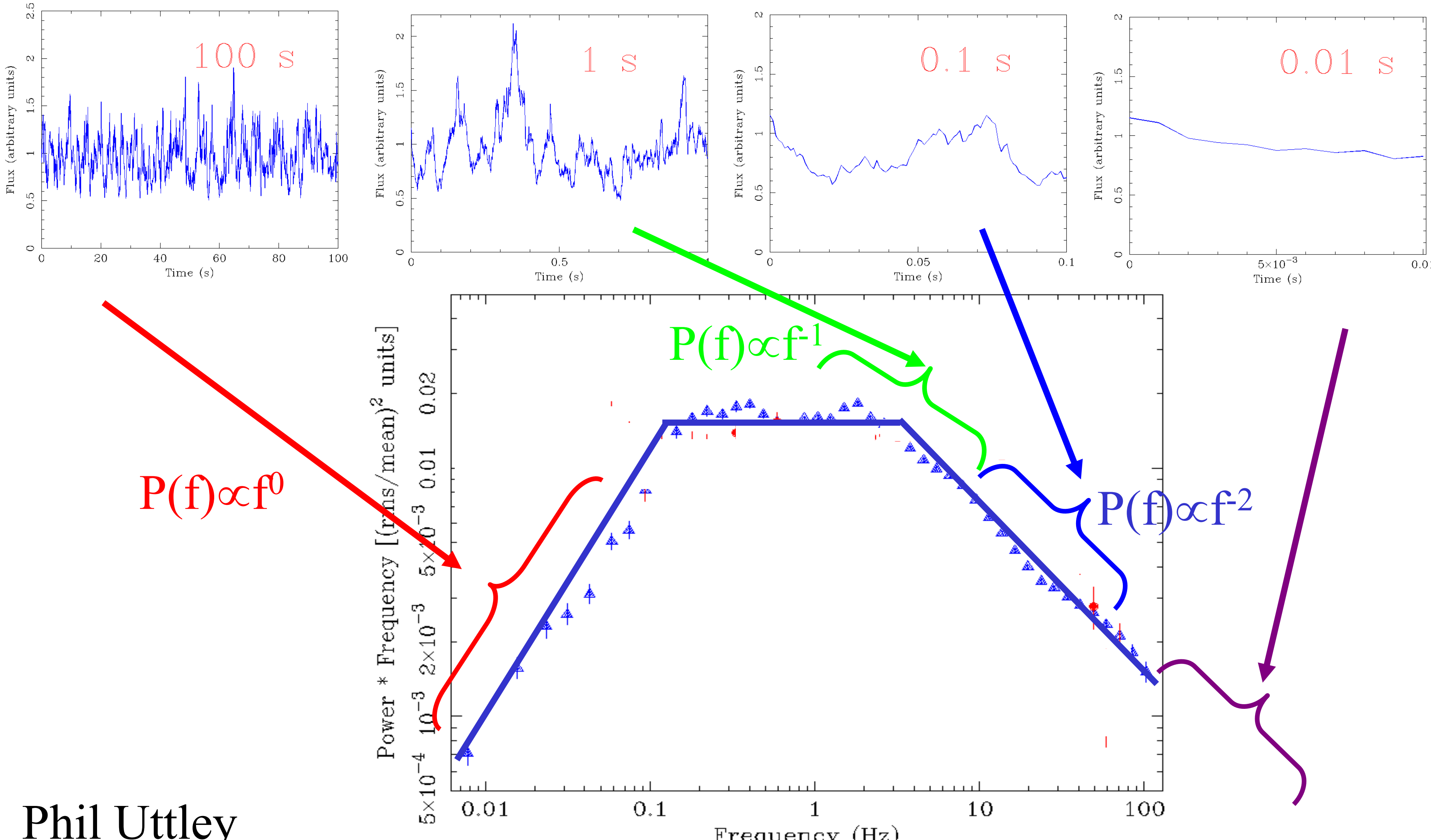


Low/hard state variability- QPO





Quantifying variability: the power spectral density (PSD) of Cyg X-1

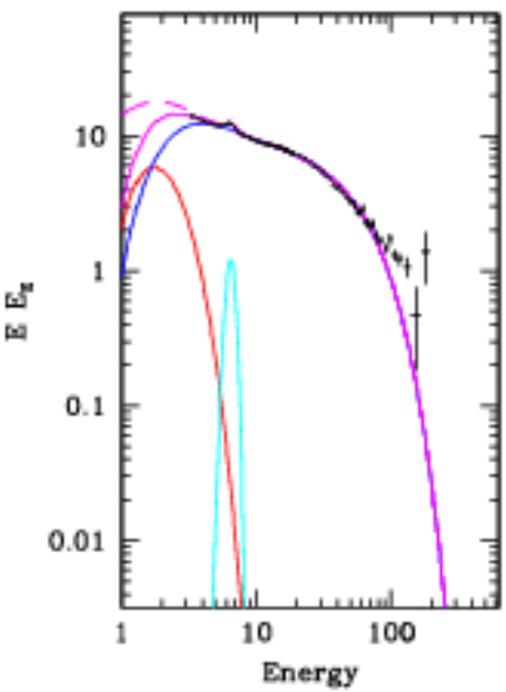


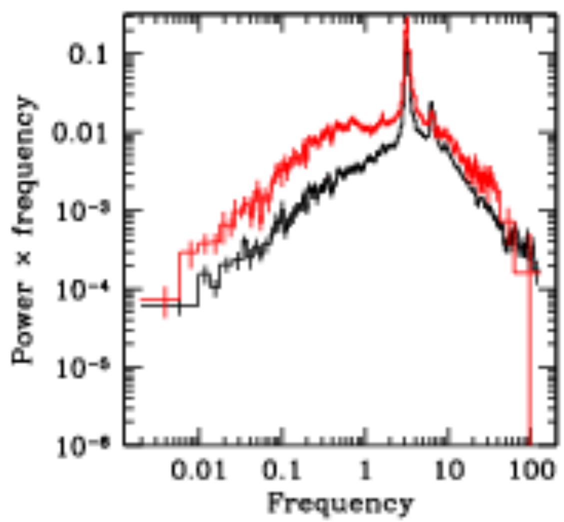
Phil Uttley

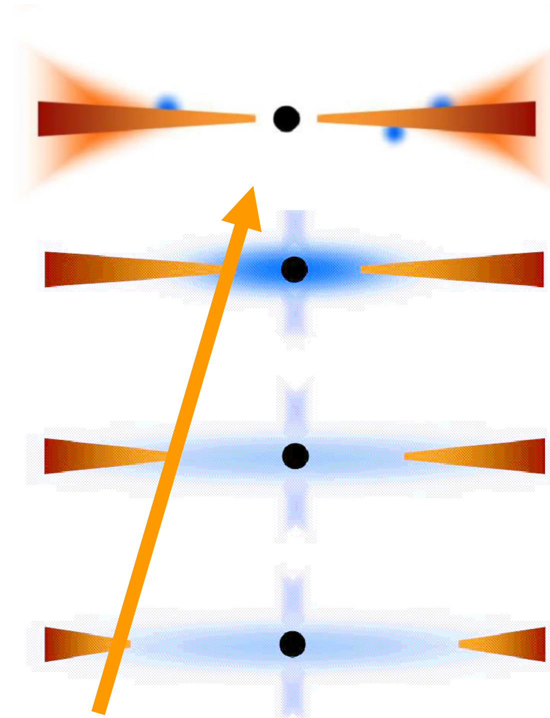
Moving disc – moving QPO

- Energy spectra need disc to move from 50-6ish Rg as make transition
- Power spectra: low frequency break moves, high frequency power more or less constant! Large radius moves, Small radii constant
- Low frequency QPO moves with low frequency break
- QPO big, must be fundamental

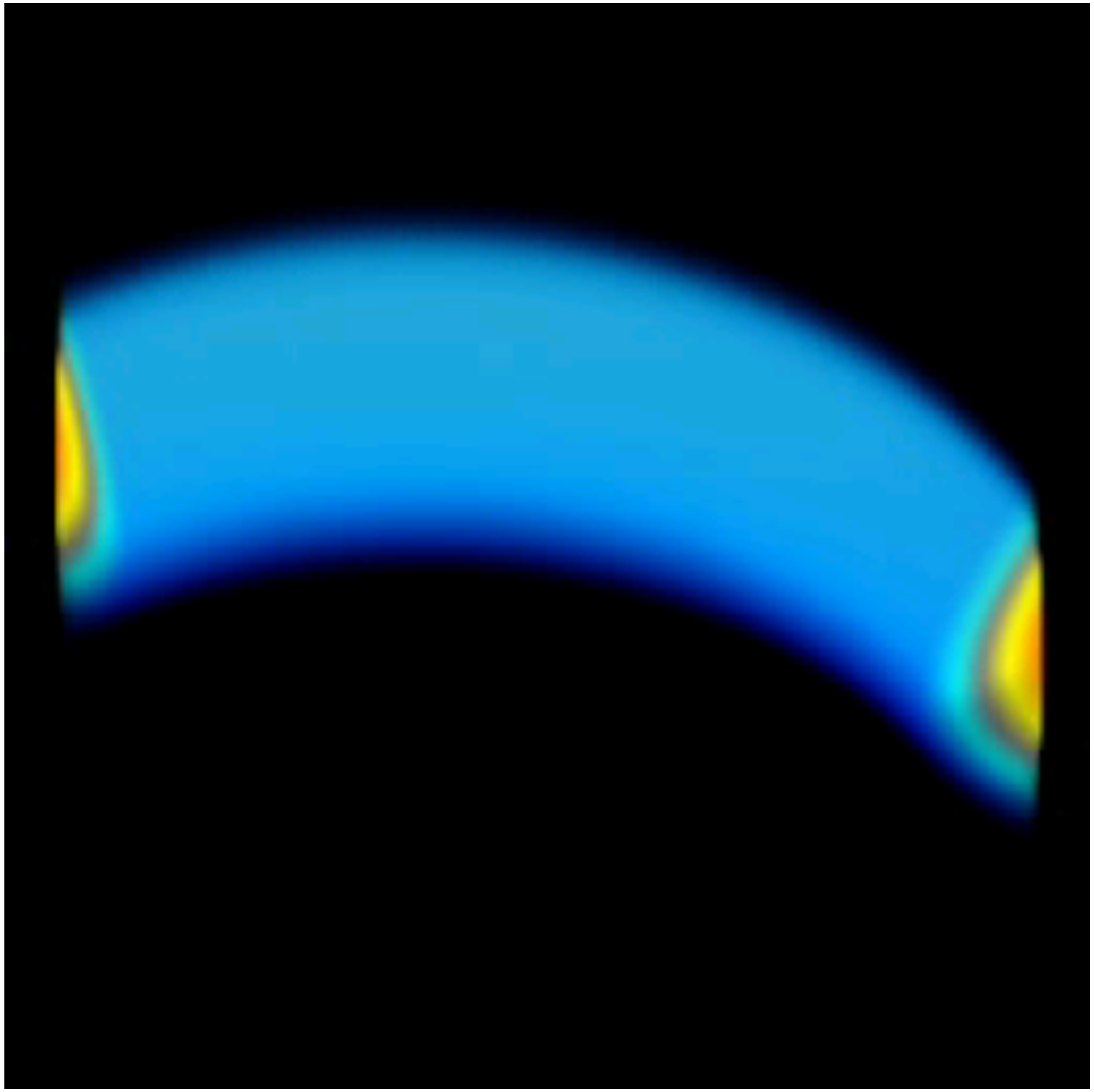
DGK07



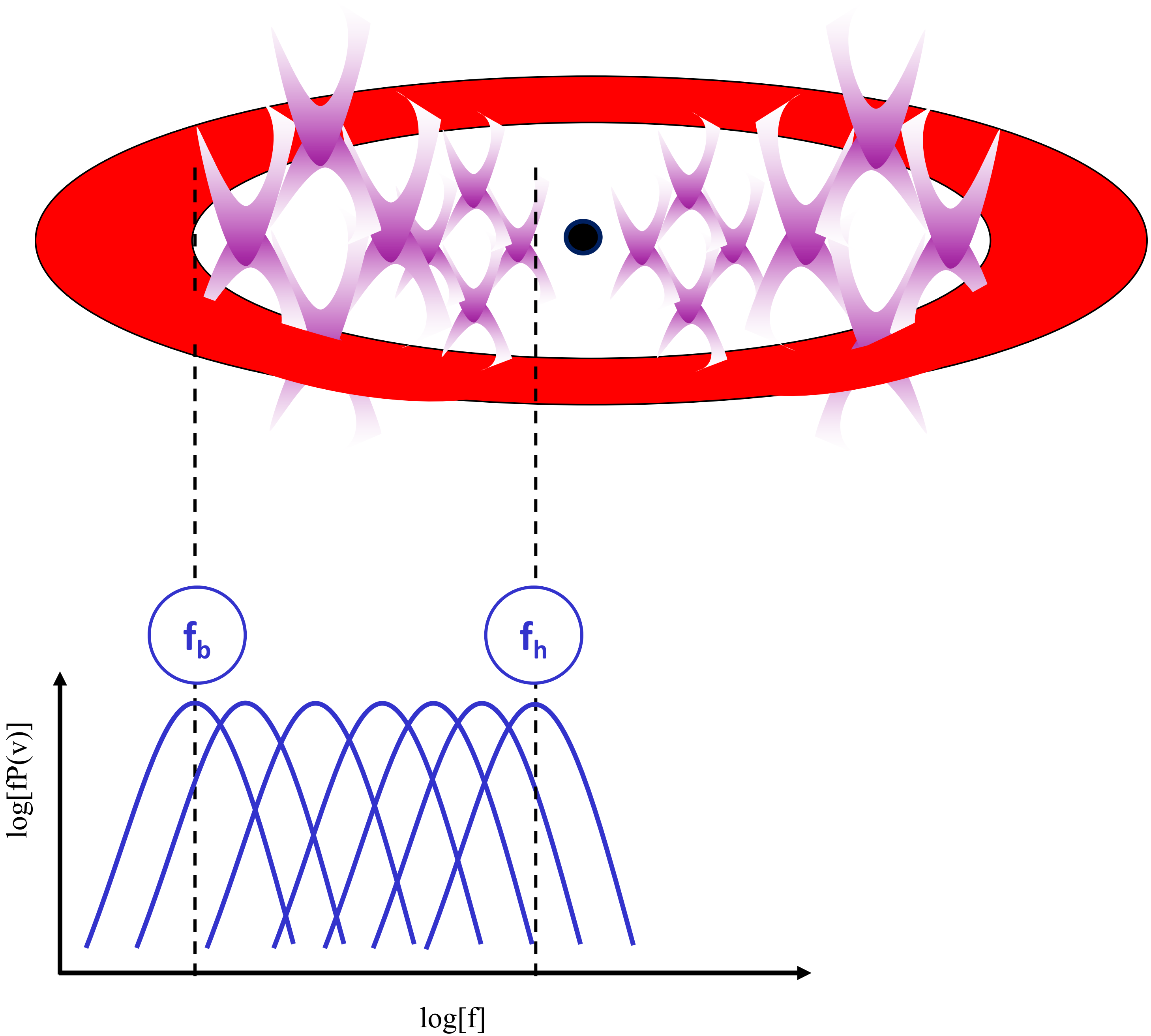




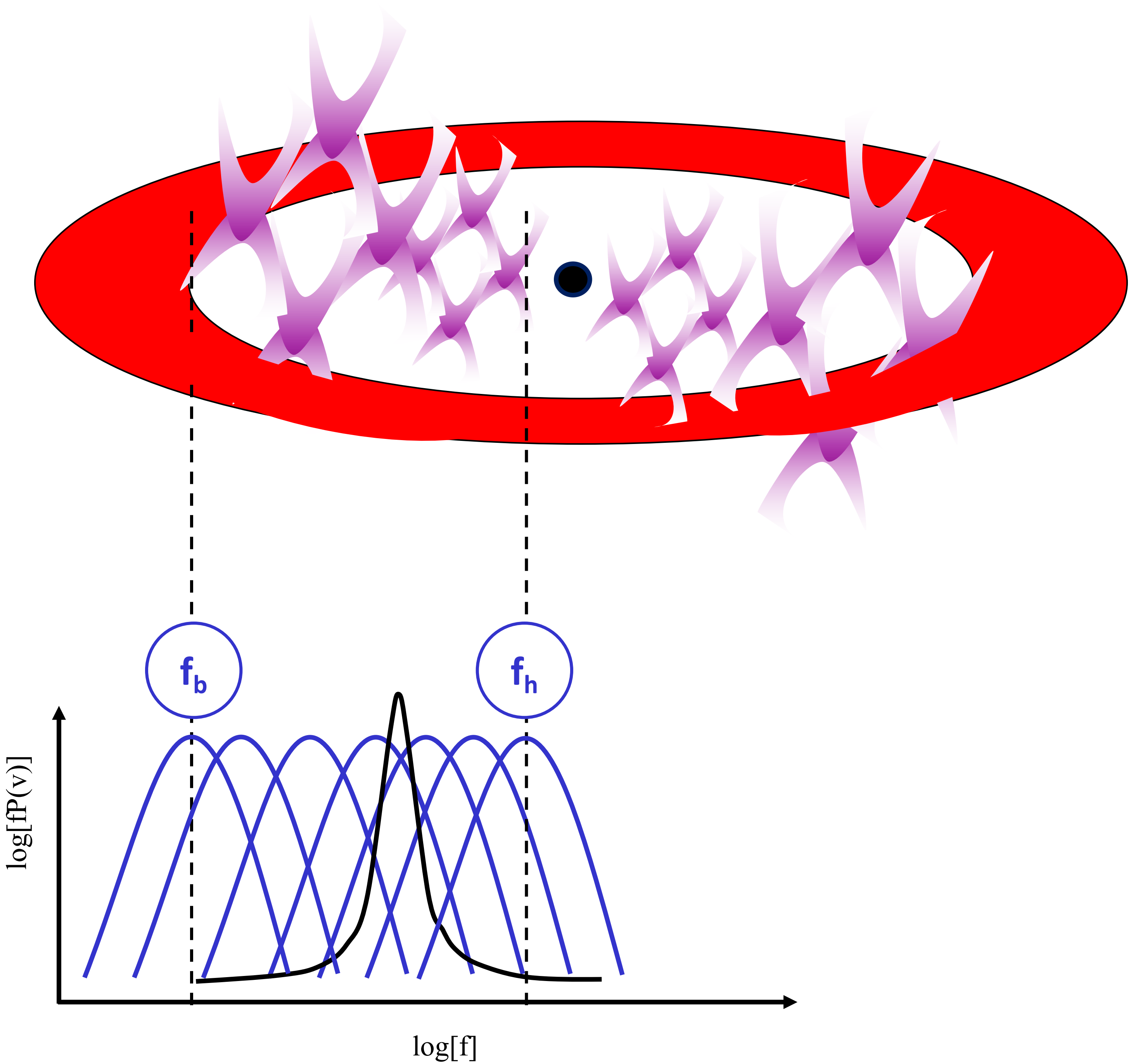
Origin of variability: MRI



Krolik, de Villiers, Hawley



f_b
f_h
log[fP(v)]
log[f]



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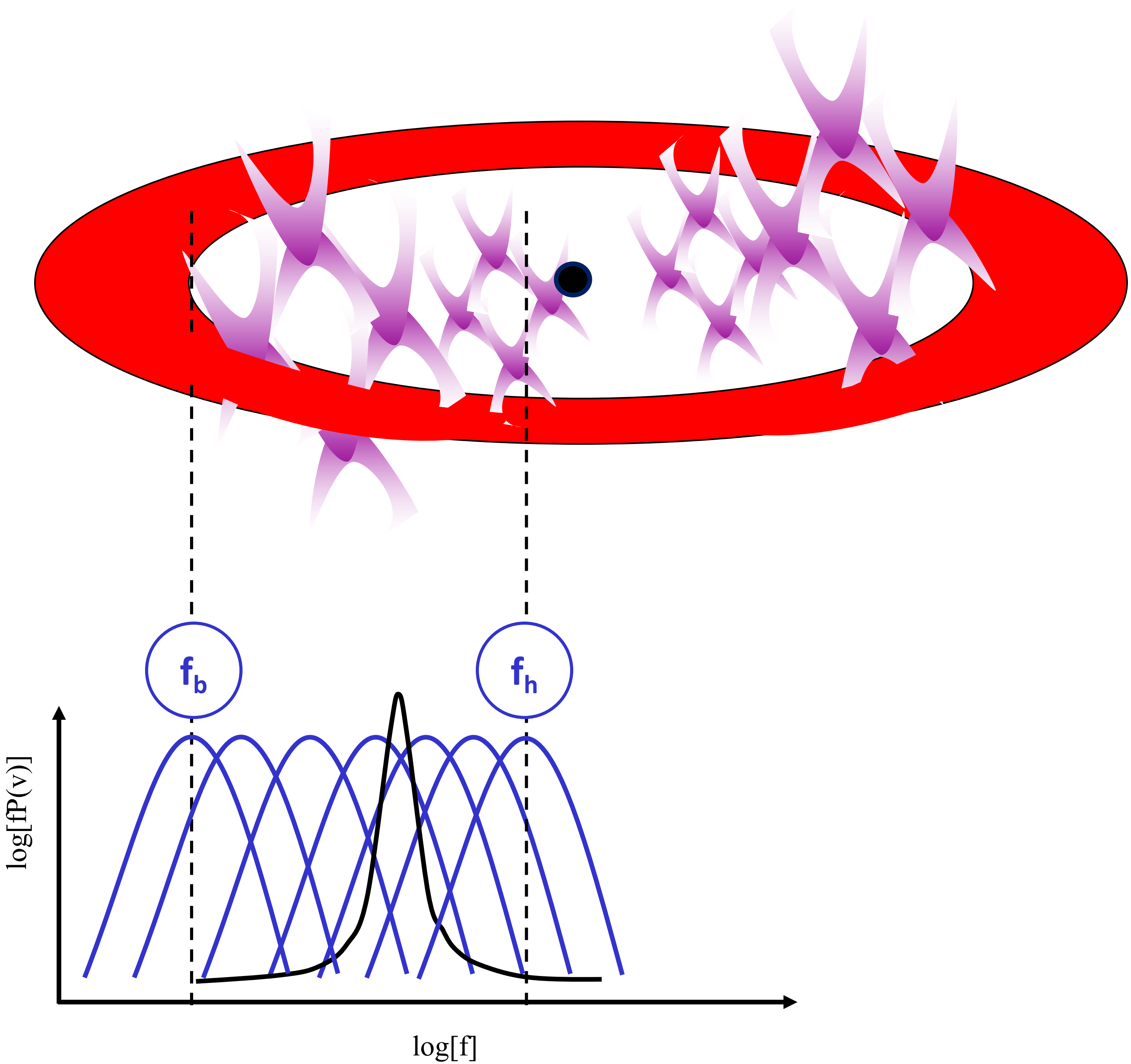

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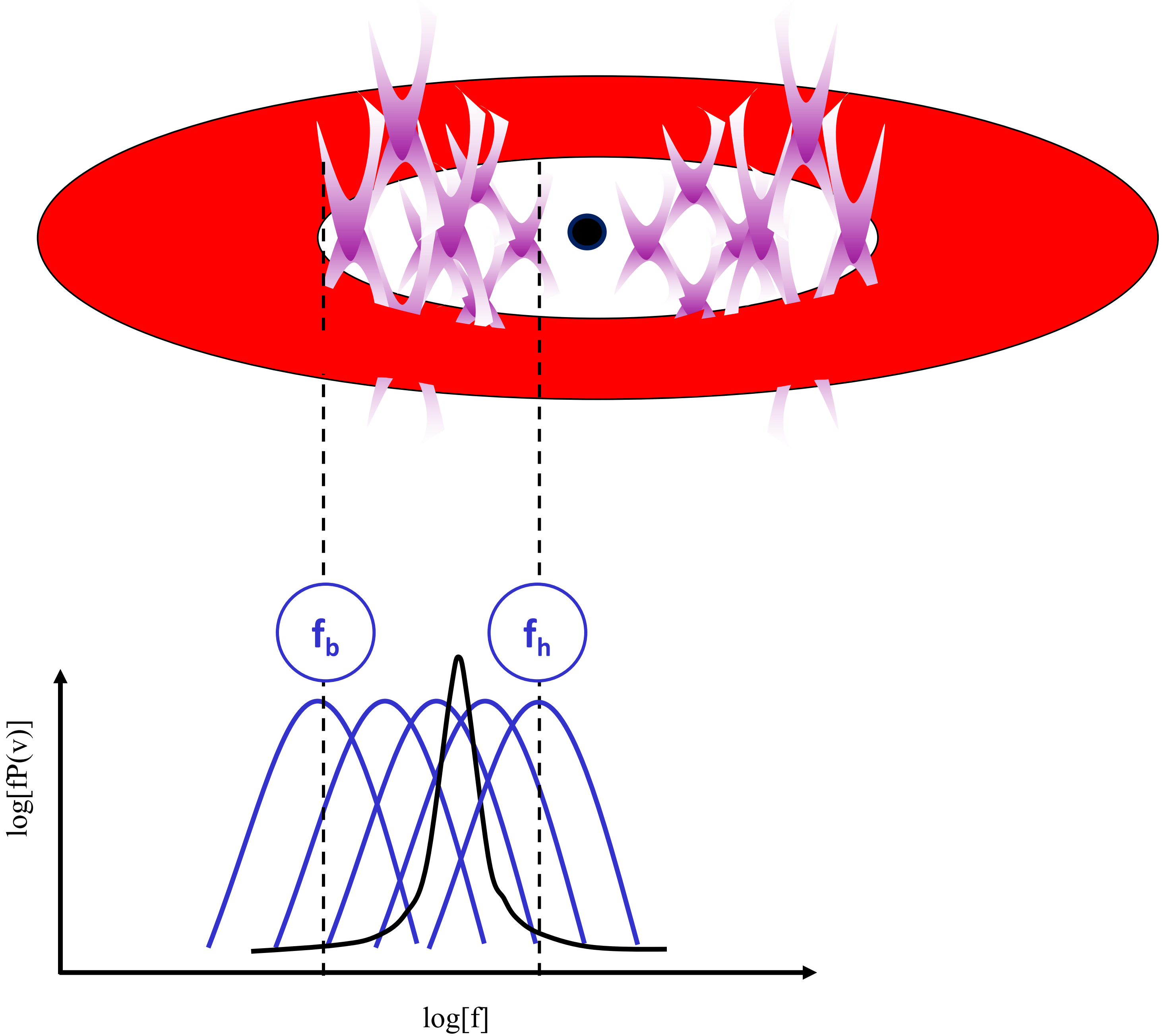

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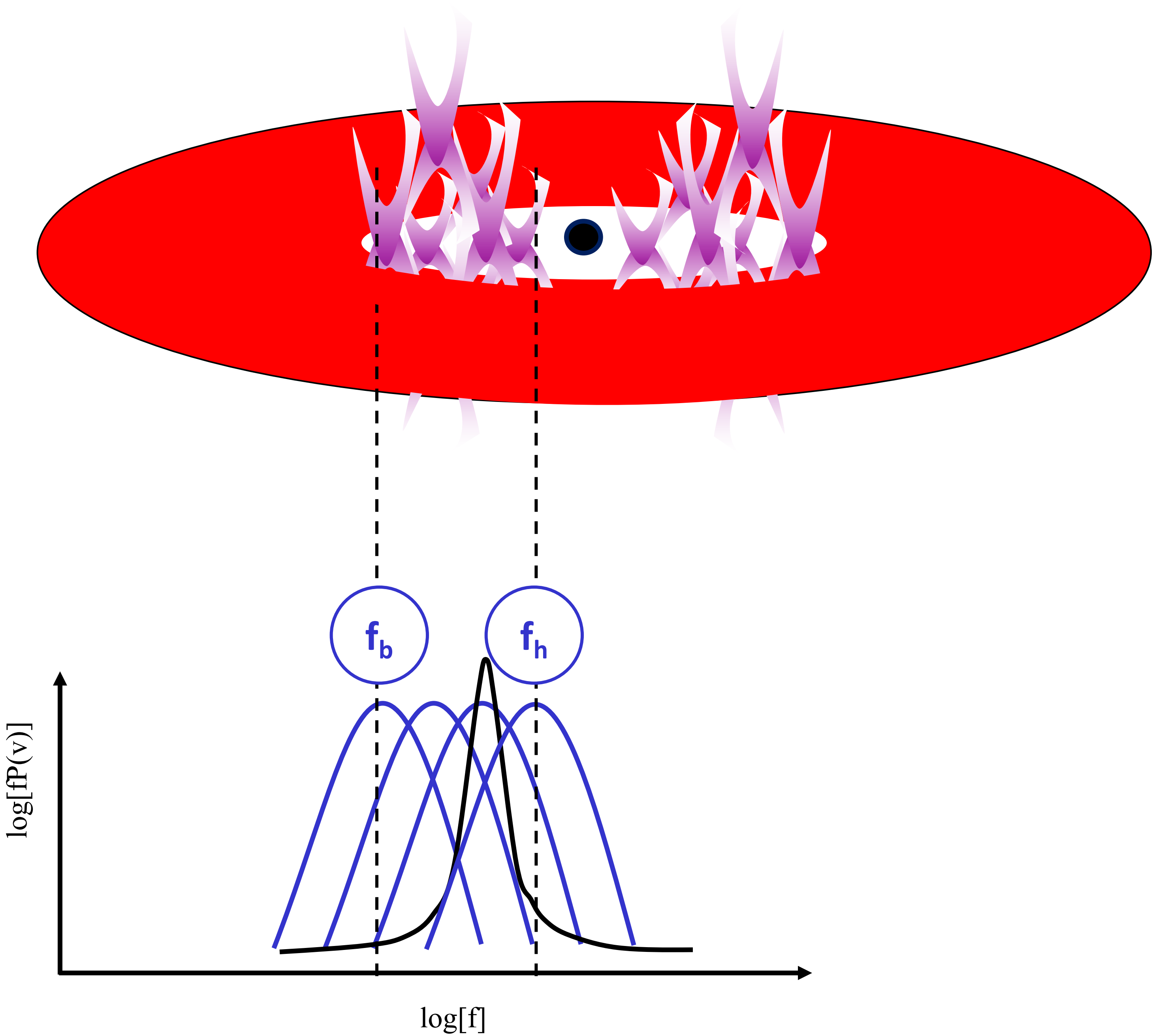
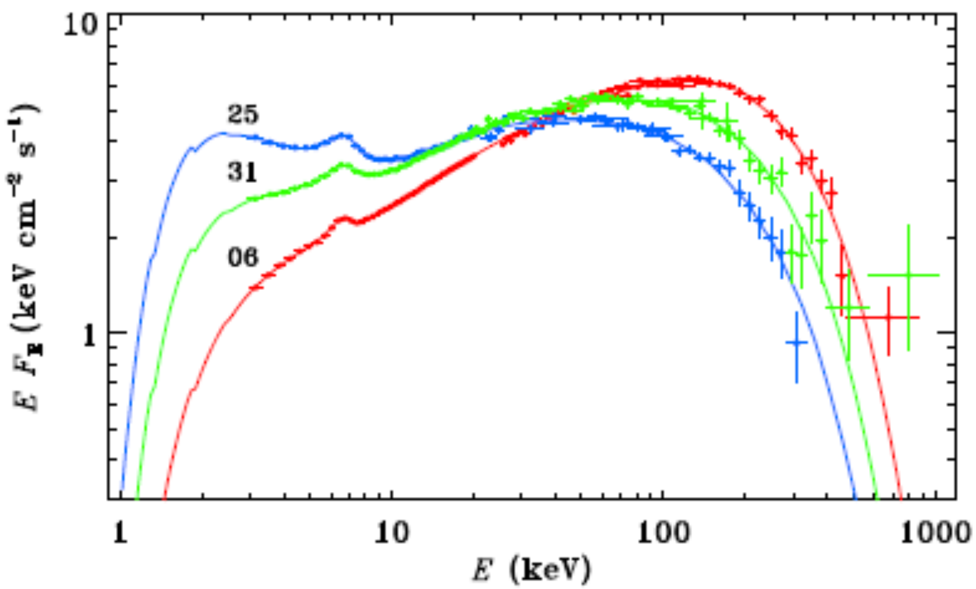


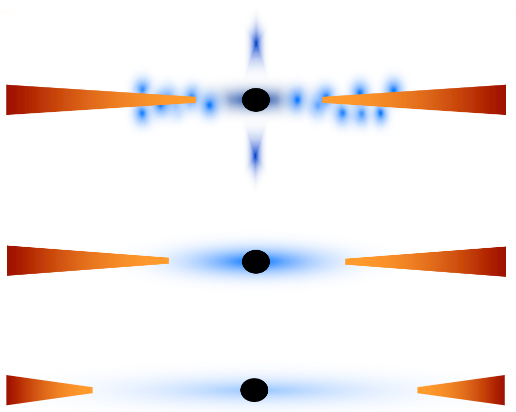
f_b
f_h
log[fP(v)]
log[f]

Moving disc

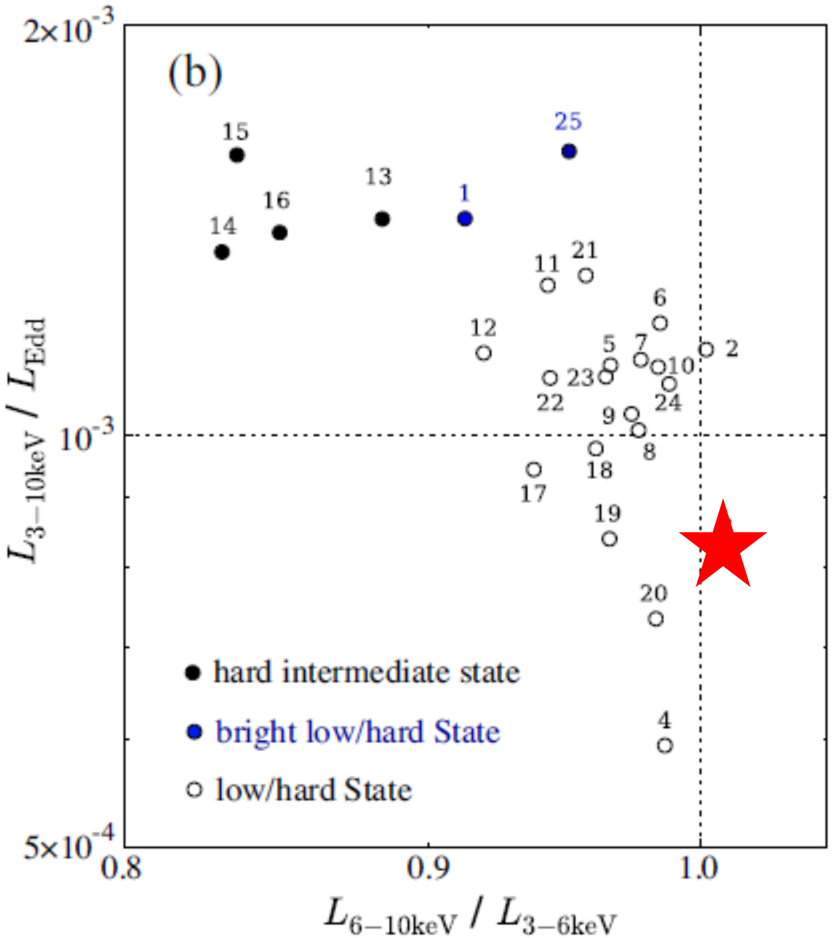
- Disc closer in, more soft photons from disc so softer spectra
- Disc down to last stable orbit and collapse of hot flow gives physical mechanism for hard/soft transition + jet collapse

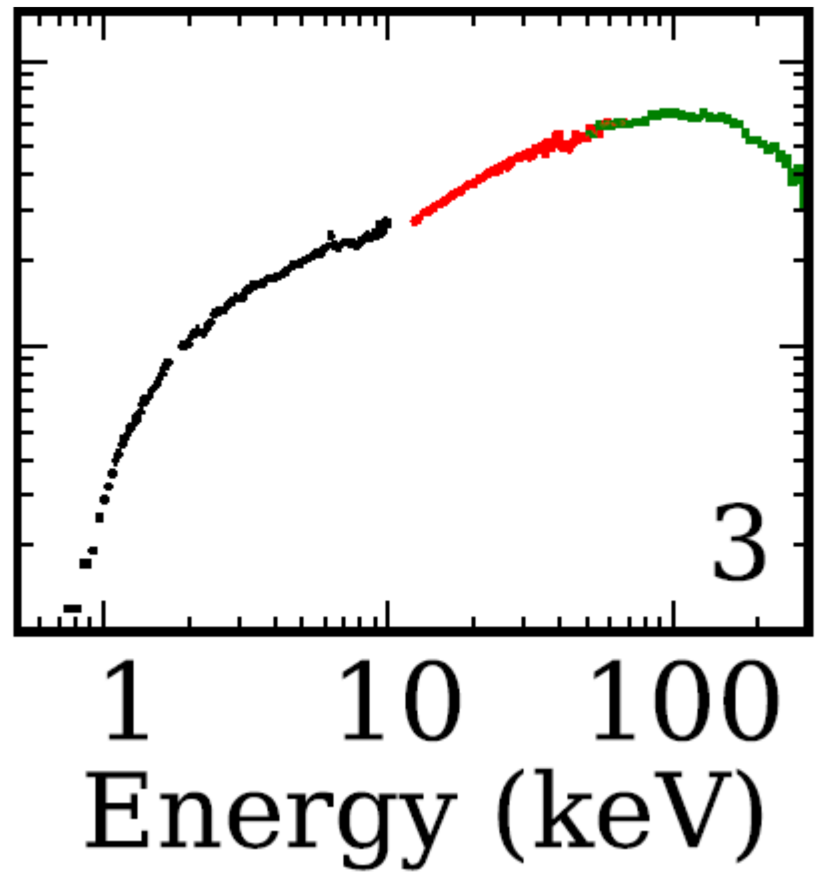


Ibragimov et al 2005



Compton spectrum softens?





Yamada et al 2013

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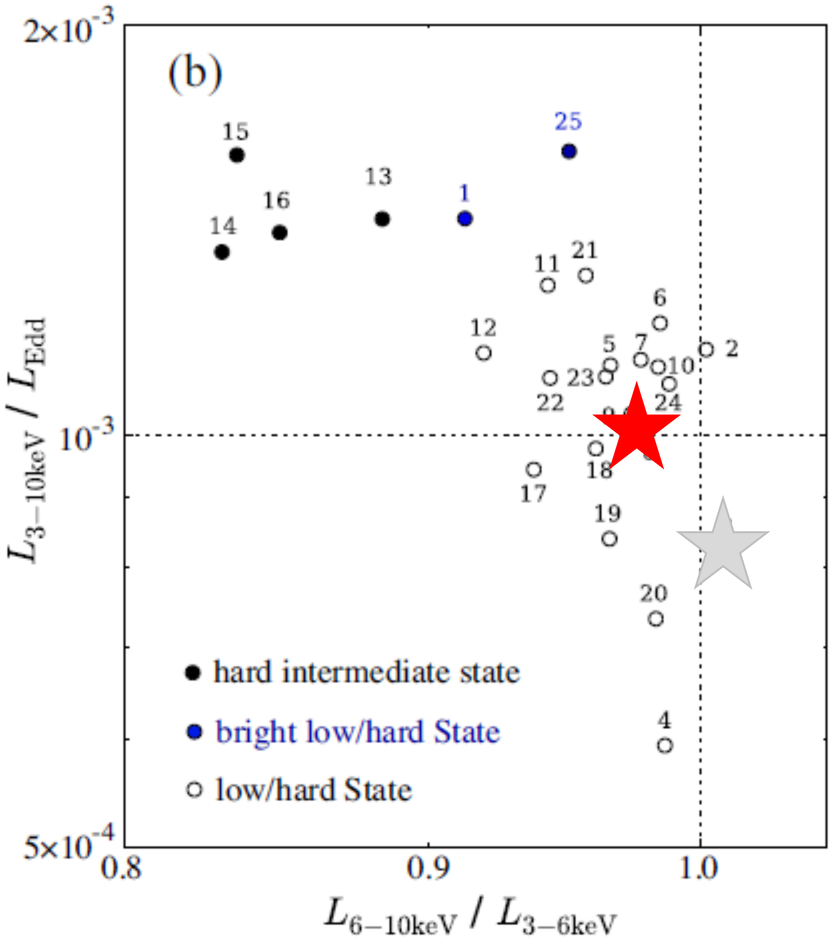

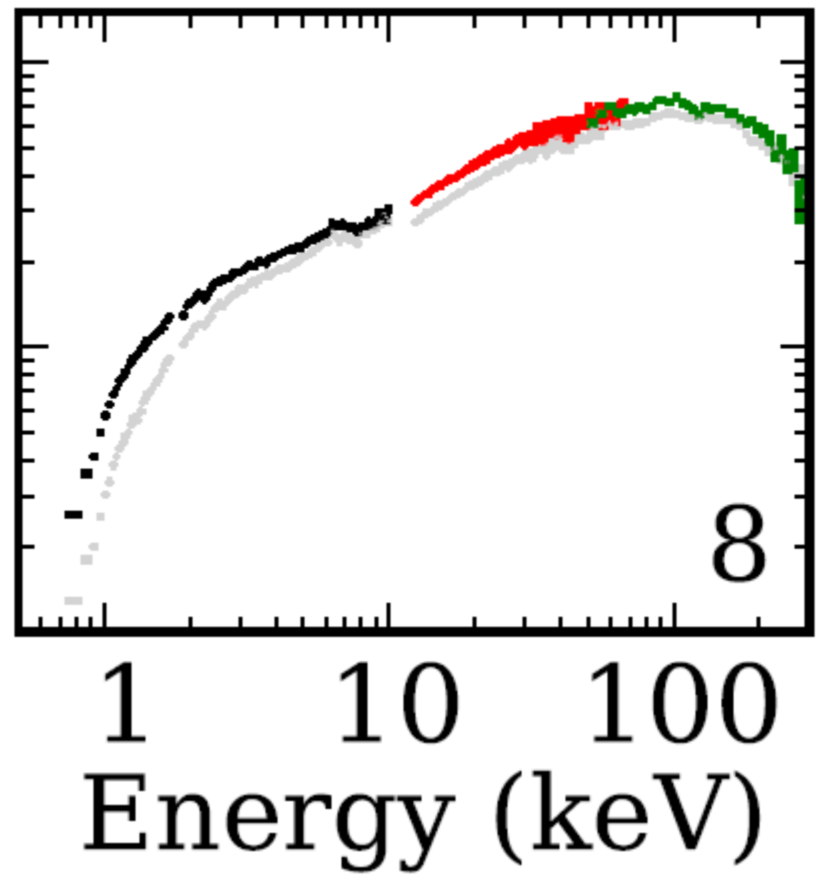

Yamada et al 2013

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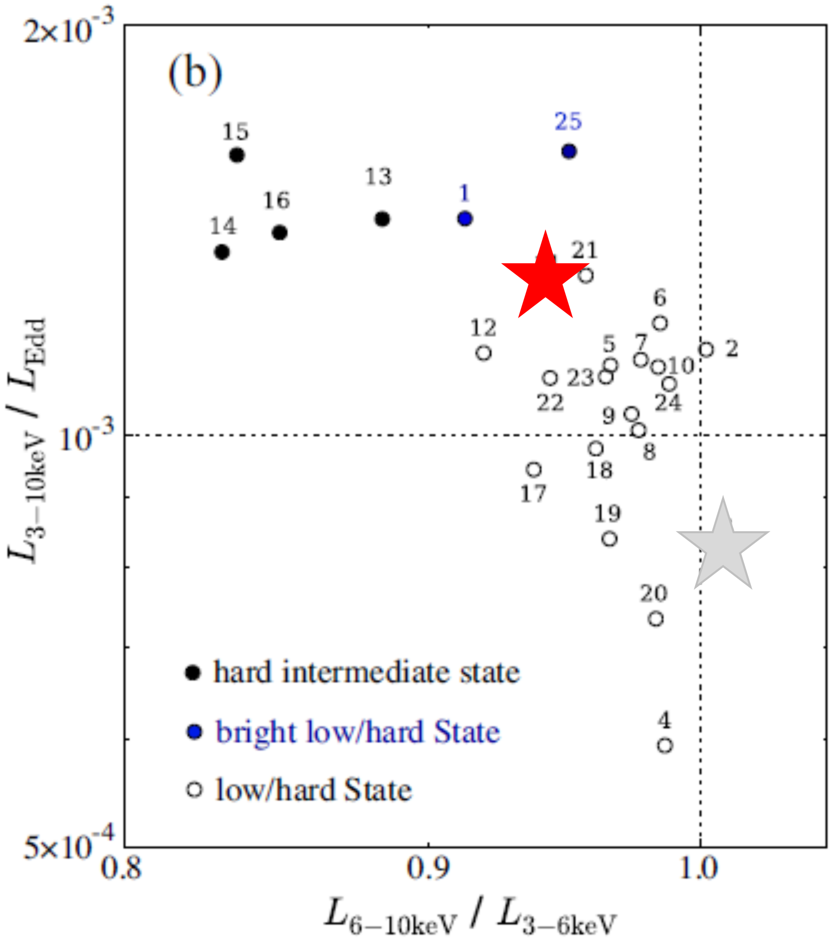
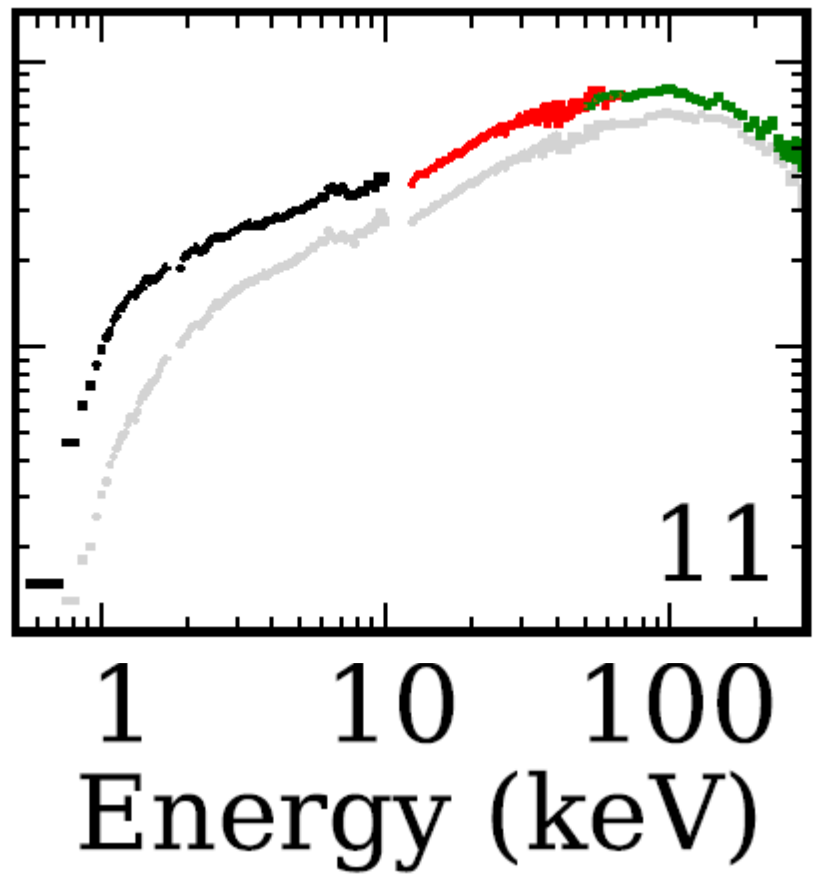
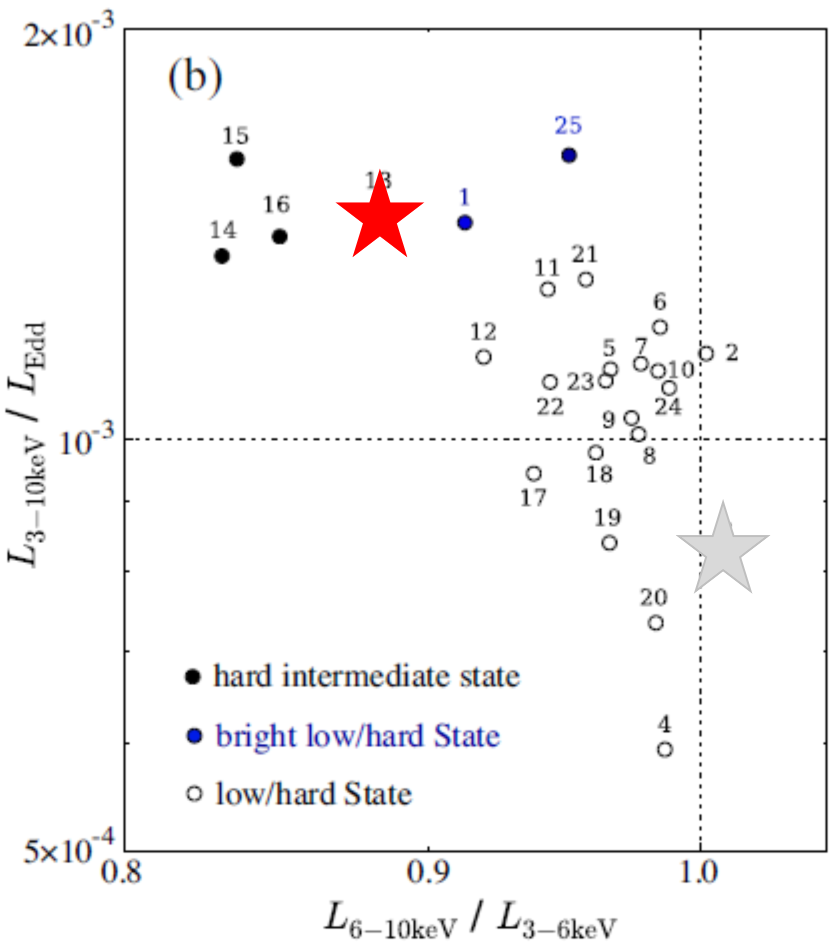
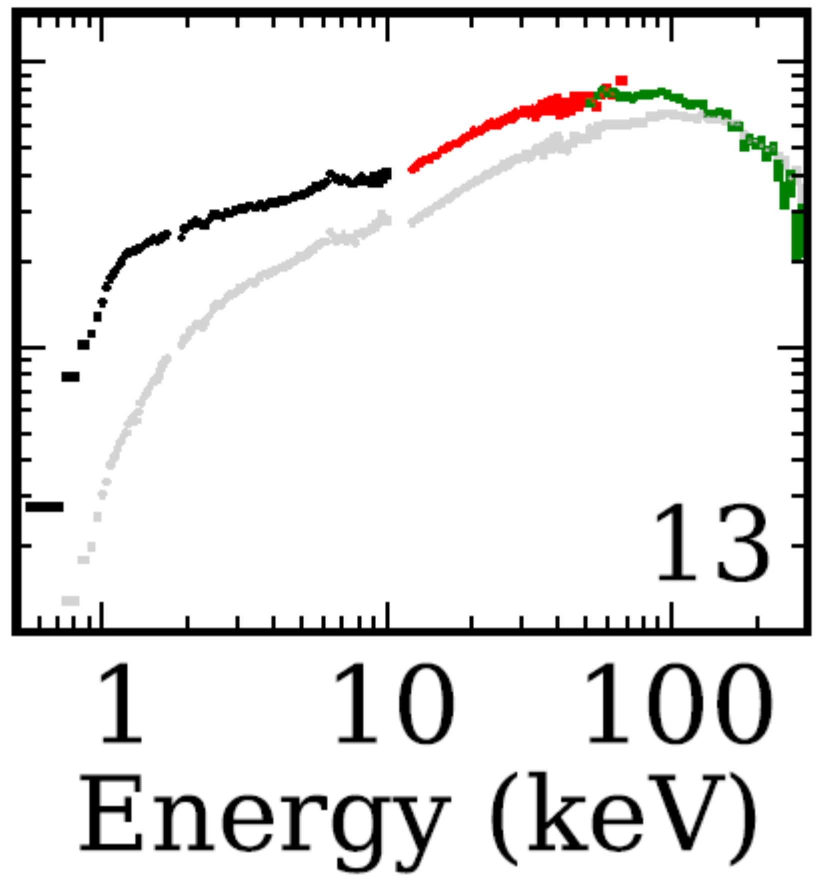




Yamada et al 2013

Compton spectrum softens?





Yamada et al 2013

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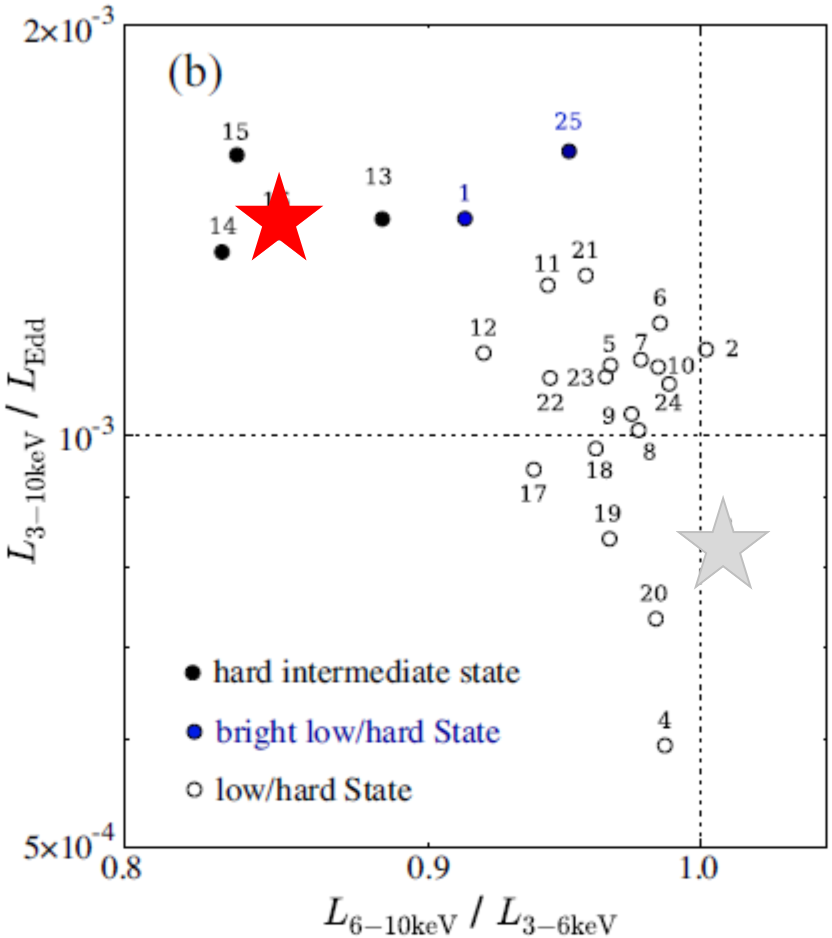

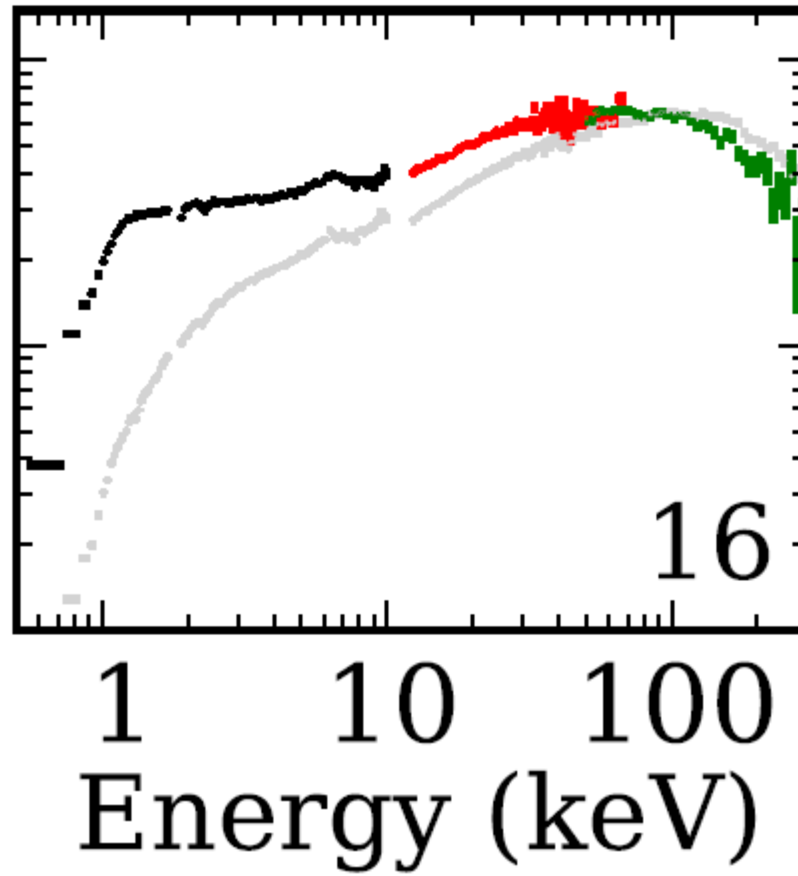

Yamada et al 2013

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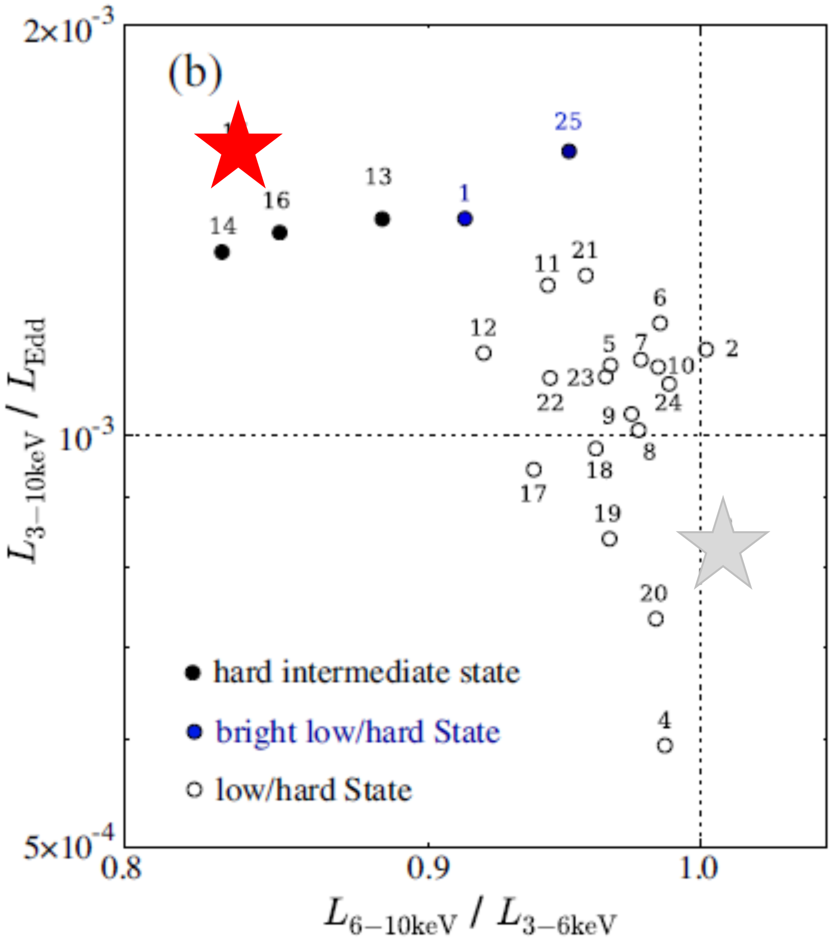
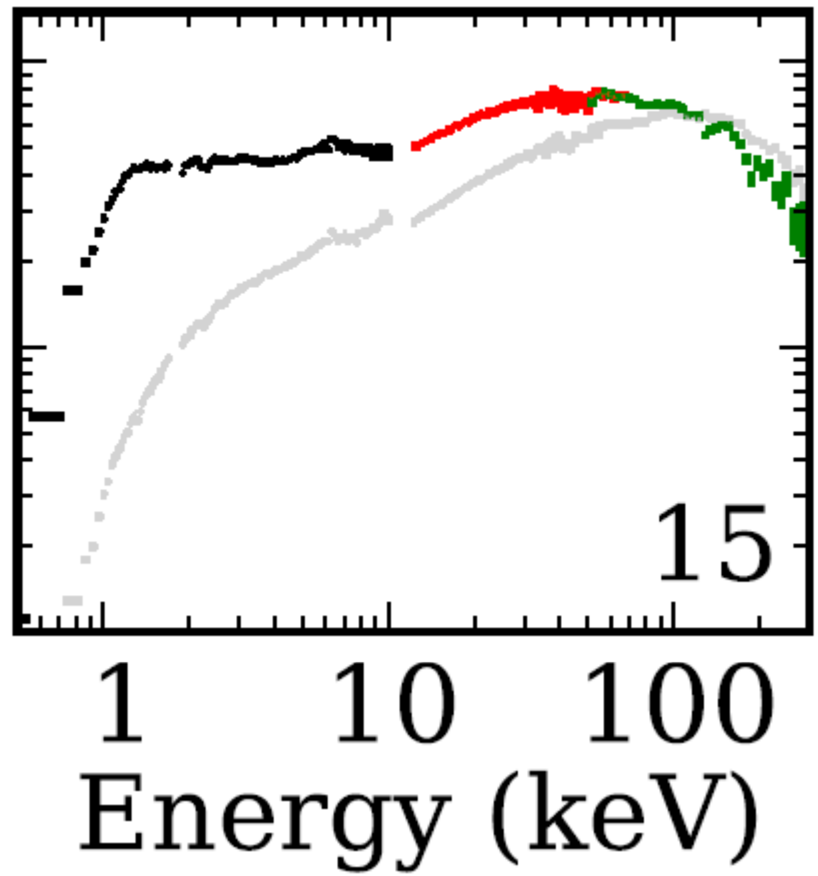
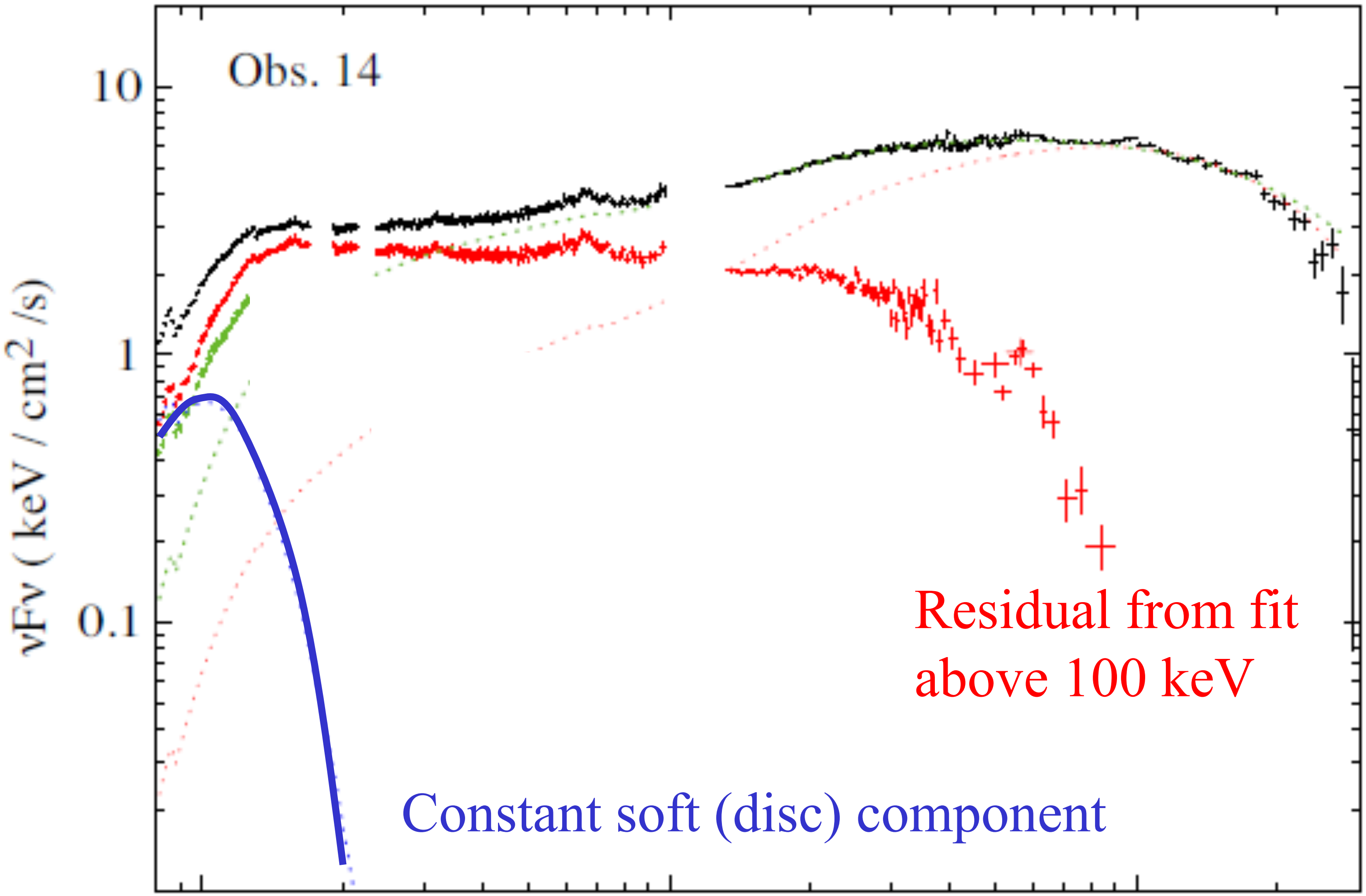




Yamada et al 2013

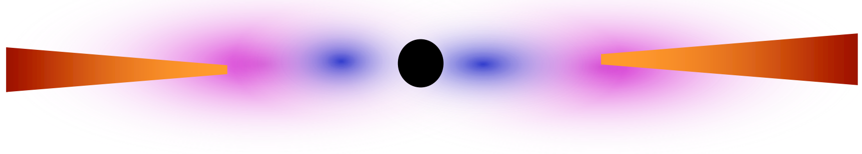
Not single T compton spectrum!



Yamada et al 2013

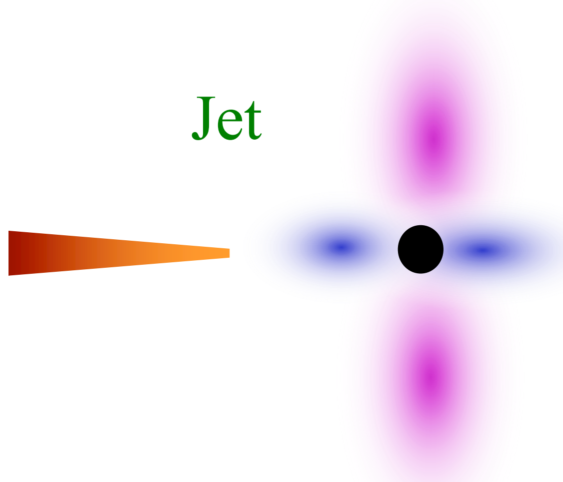
Everyone agrees on data

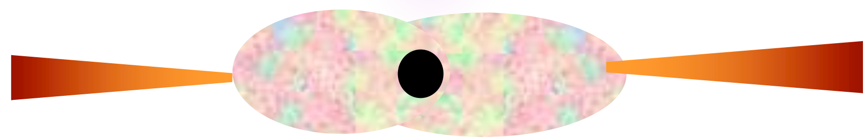
Inhomogeneous compton
Makishima et al 2008



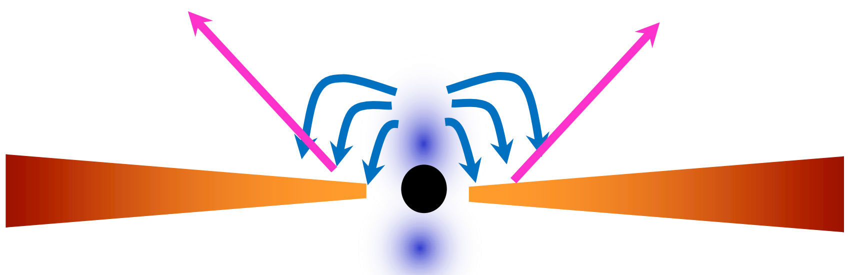
Jet

Markoff,
Nowak

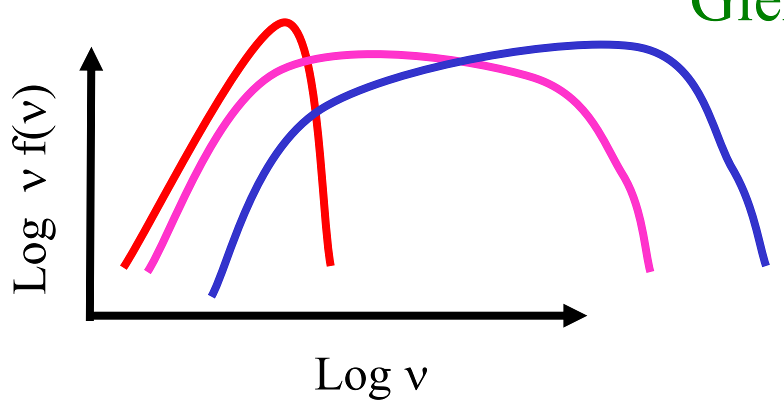




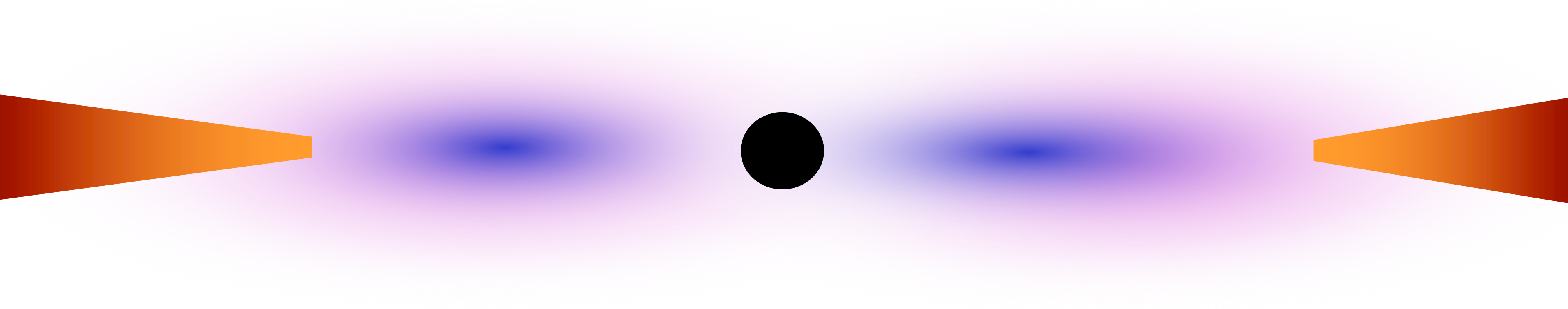
ionised, blurred reflection
Fabian et al 2012

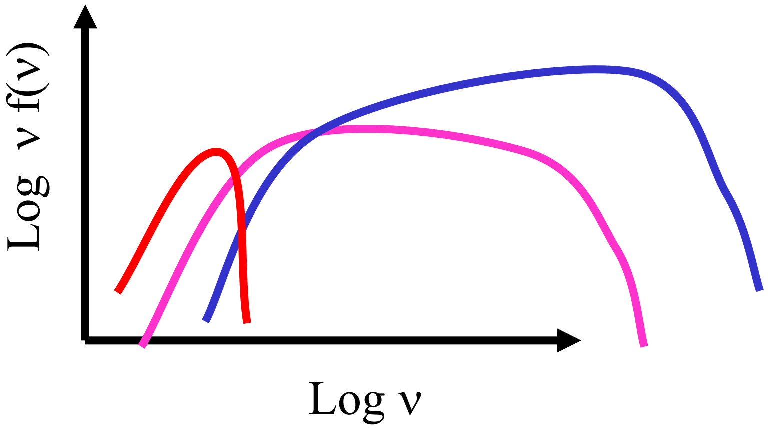


hybrid (thermal-nonthermal)
Gierlinski et al 1999



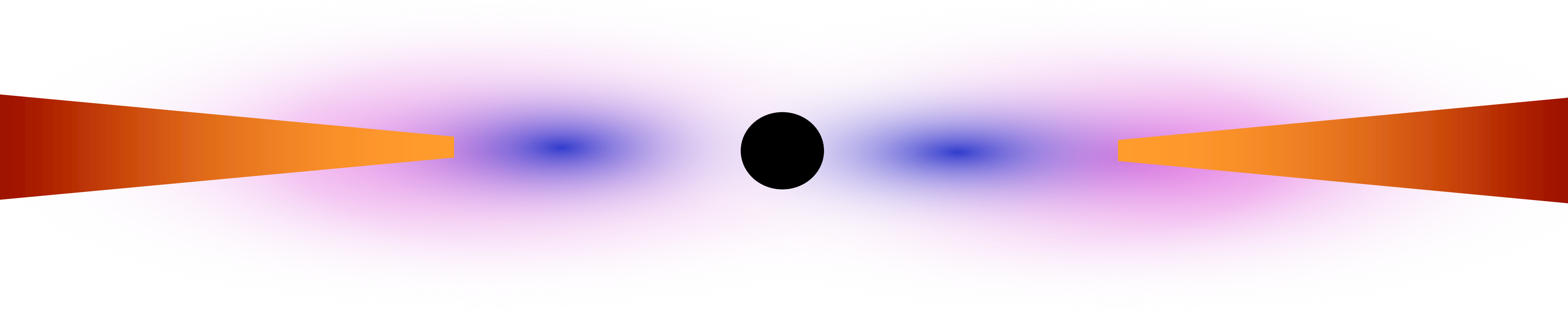
During transition?

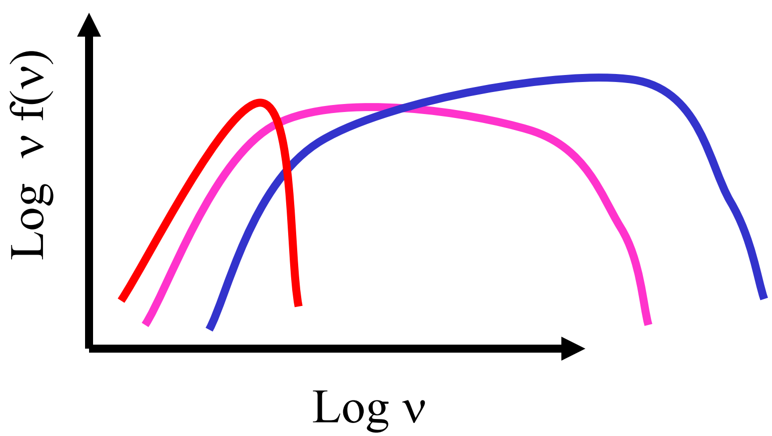




- Overlap softer (and more reflection)
- Inner region harder (and less reflection)
- WE SEE THIS!!

During transition?





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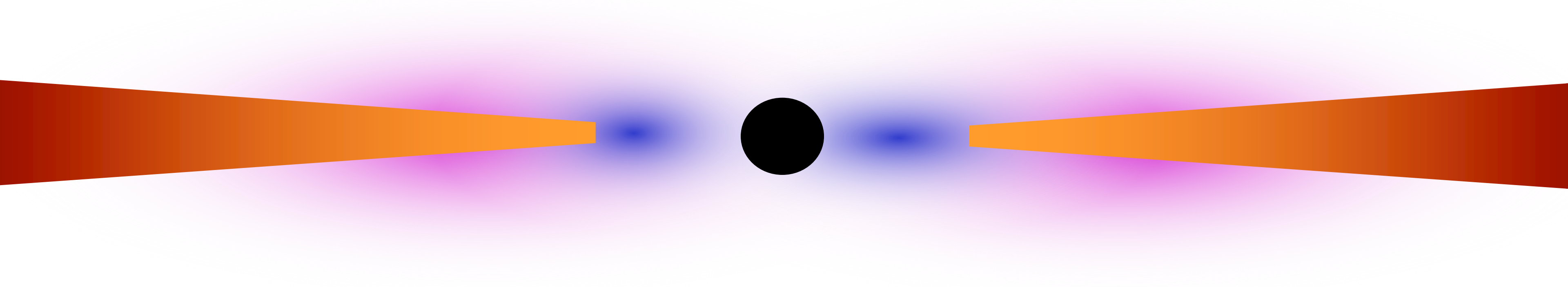

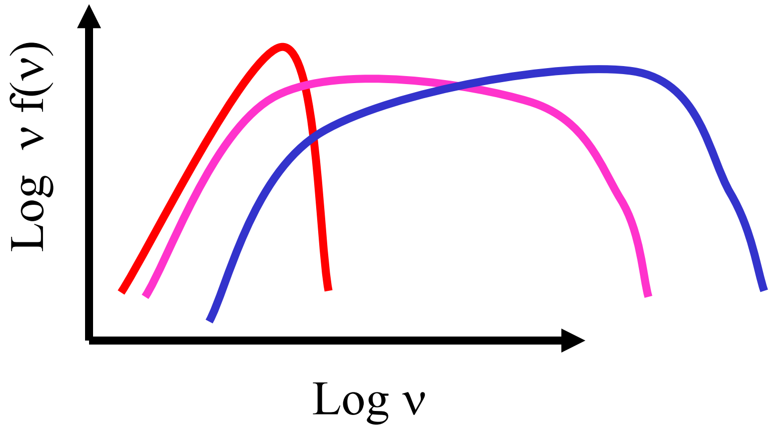

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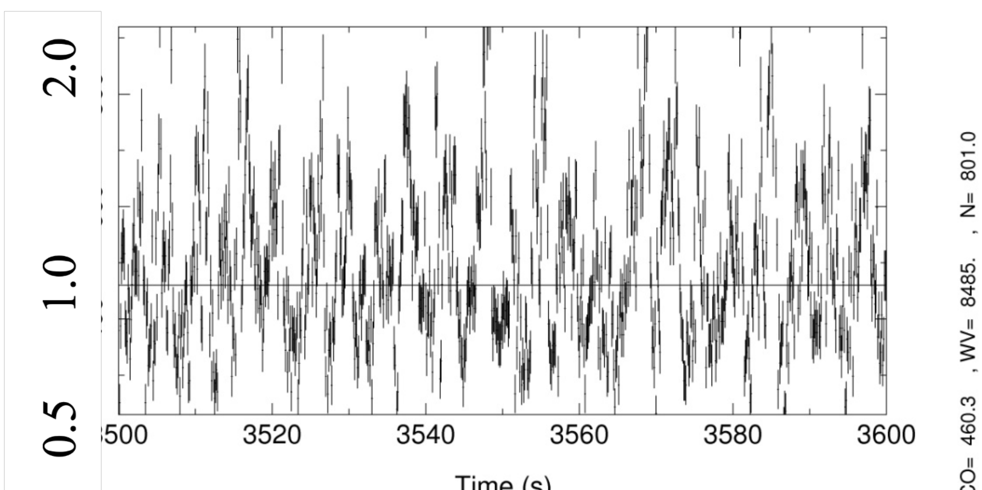
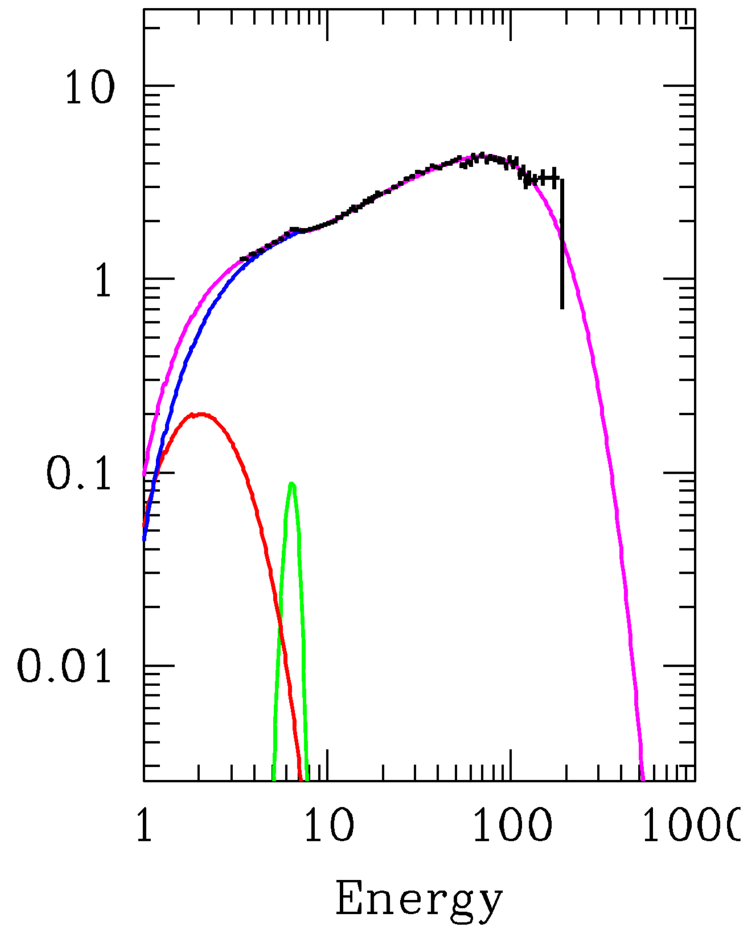
- Inner region harder (and less reflection)

Low/hard state variability

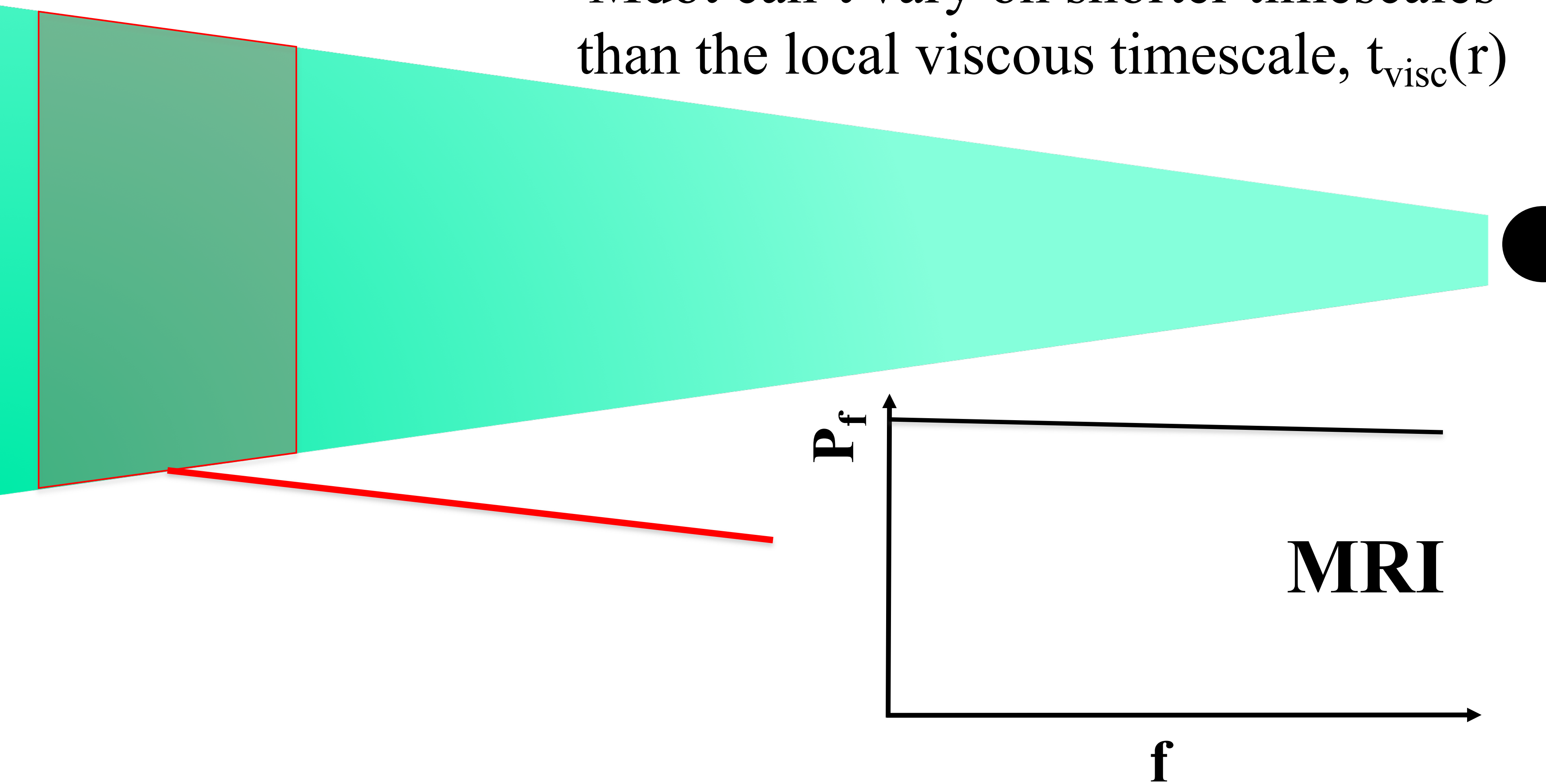
- Hard X-rays vary fast
- tvisc= α^{-1} $(H/R)^{-2}$ tdyn = 5 α^{-1} $(H/R)^{-2}$ $(r/6)^{-3/2}$ ms
- IF viscous timescale then H/R~1





Propagating fluctuations

- But emission depends on Mdot
- Mdot can't vary on shorter timescales than the local viscous timescale, $t_{visc}(r)$



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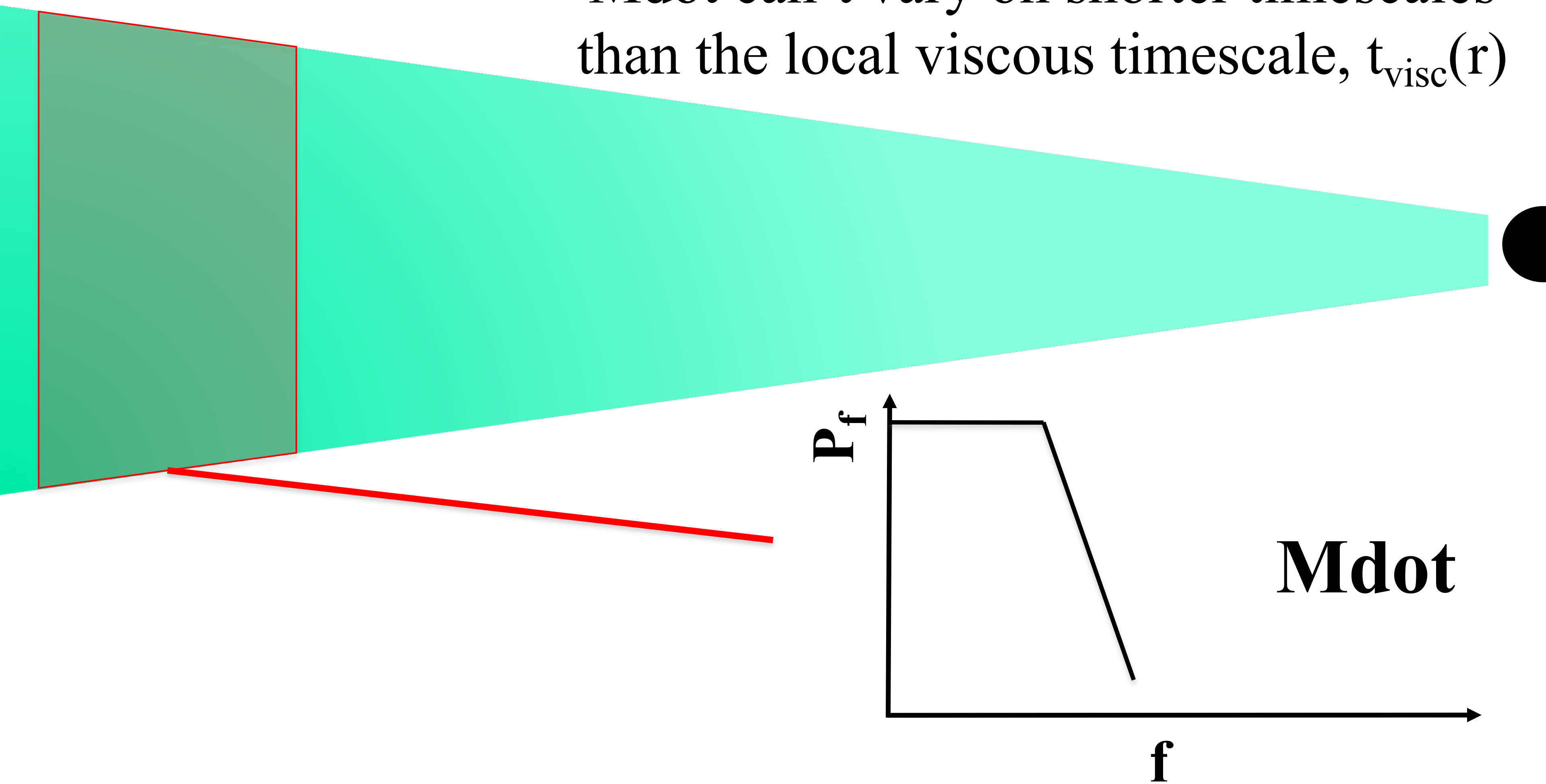

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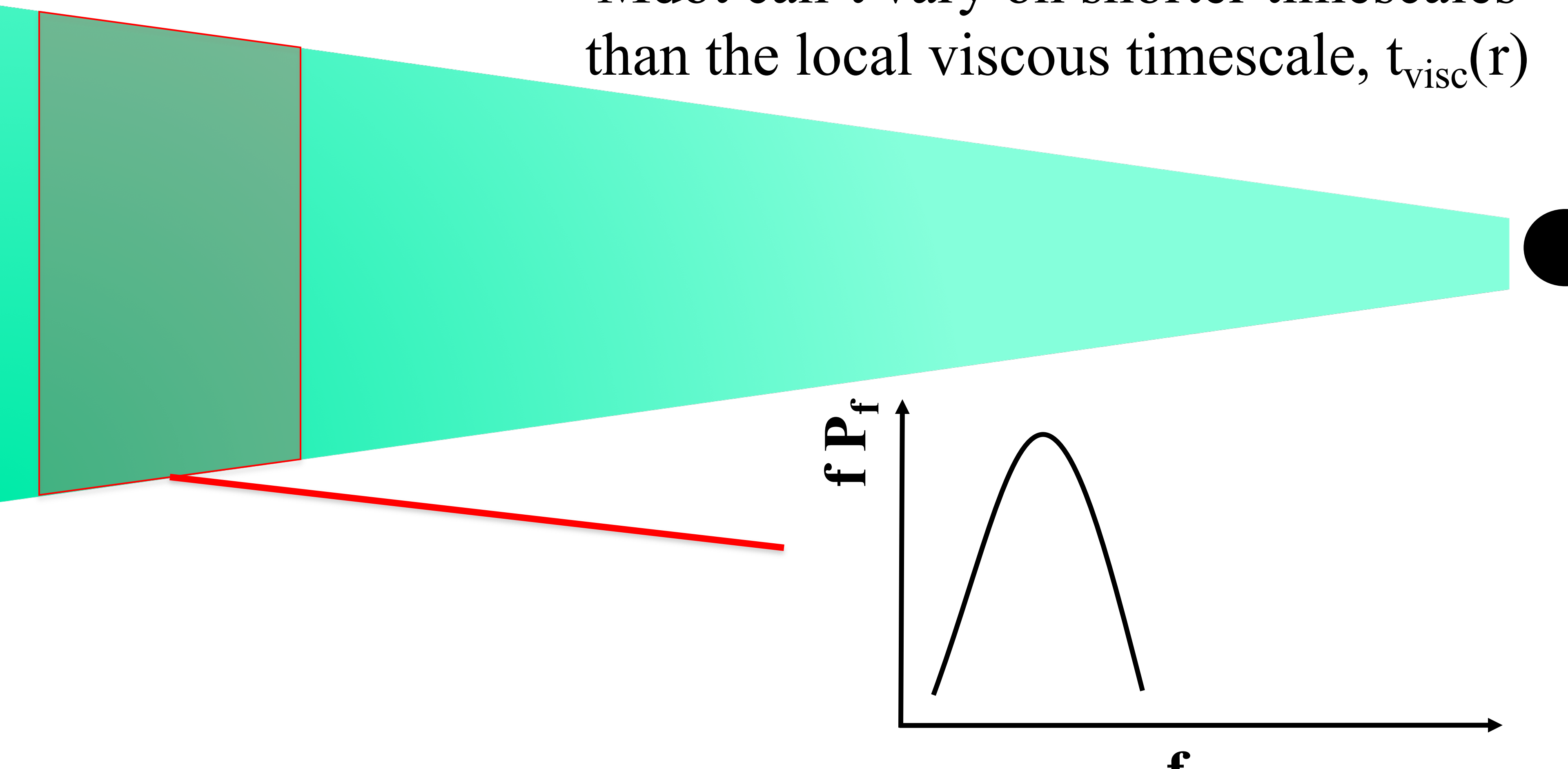

Kotov et al 2001; Arevelo & Uttley 2006

Propagating fluctuations

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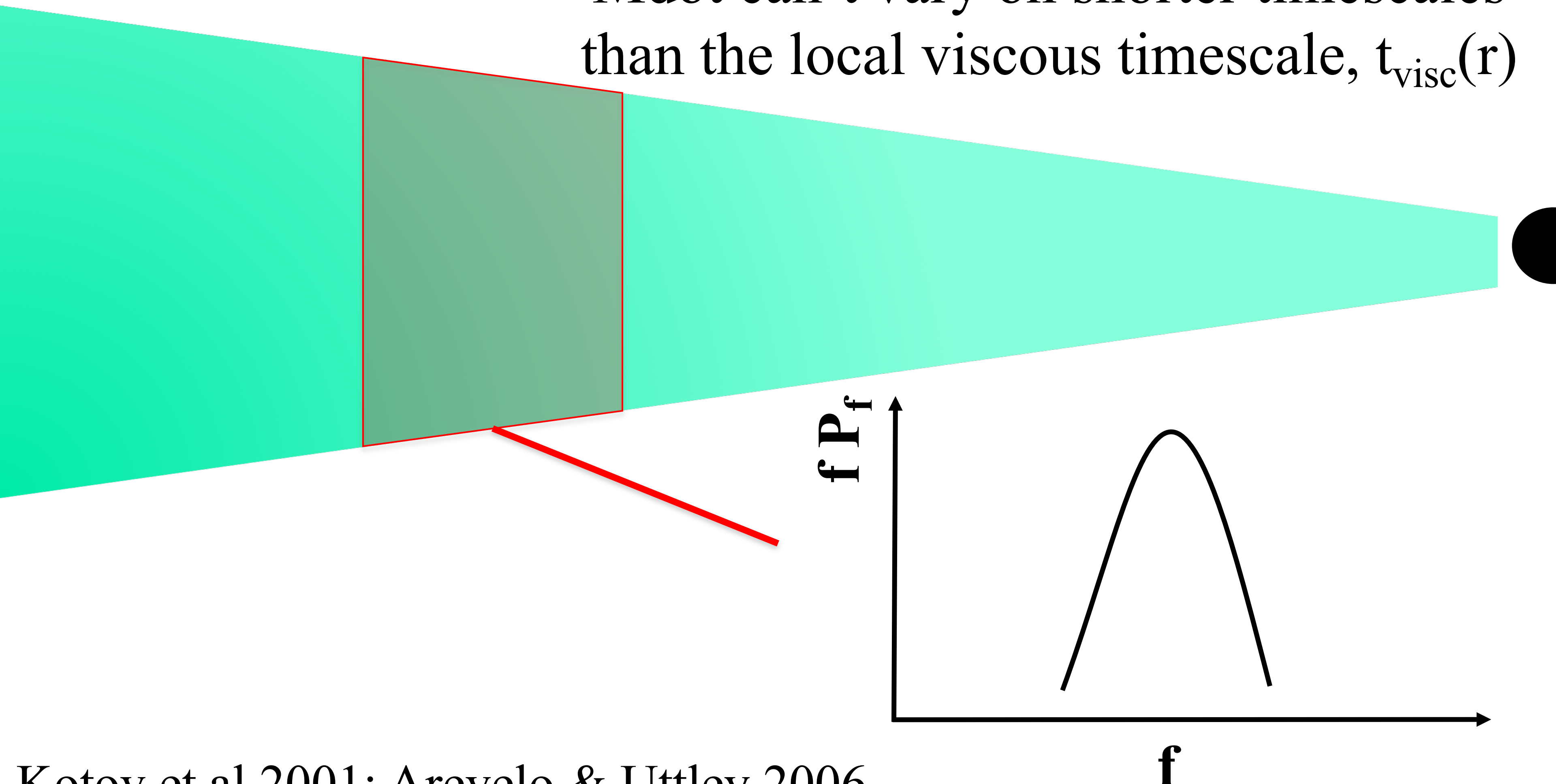

Kotov et al 2001; Arevelo & Uttley 2006

Propagating fluctuations

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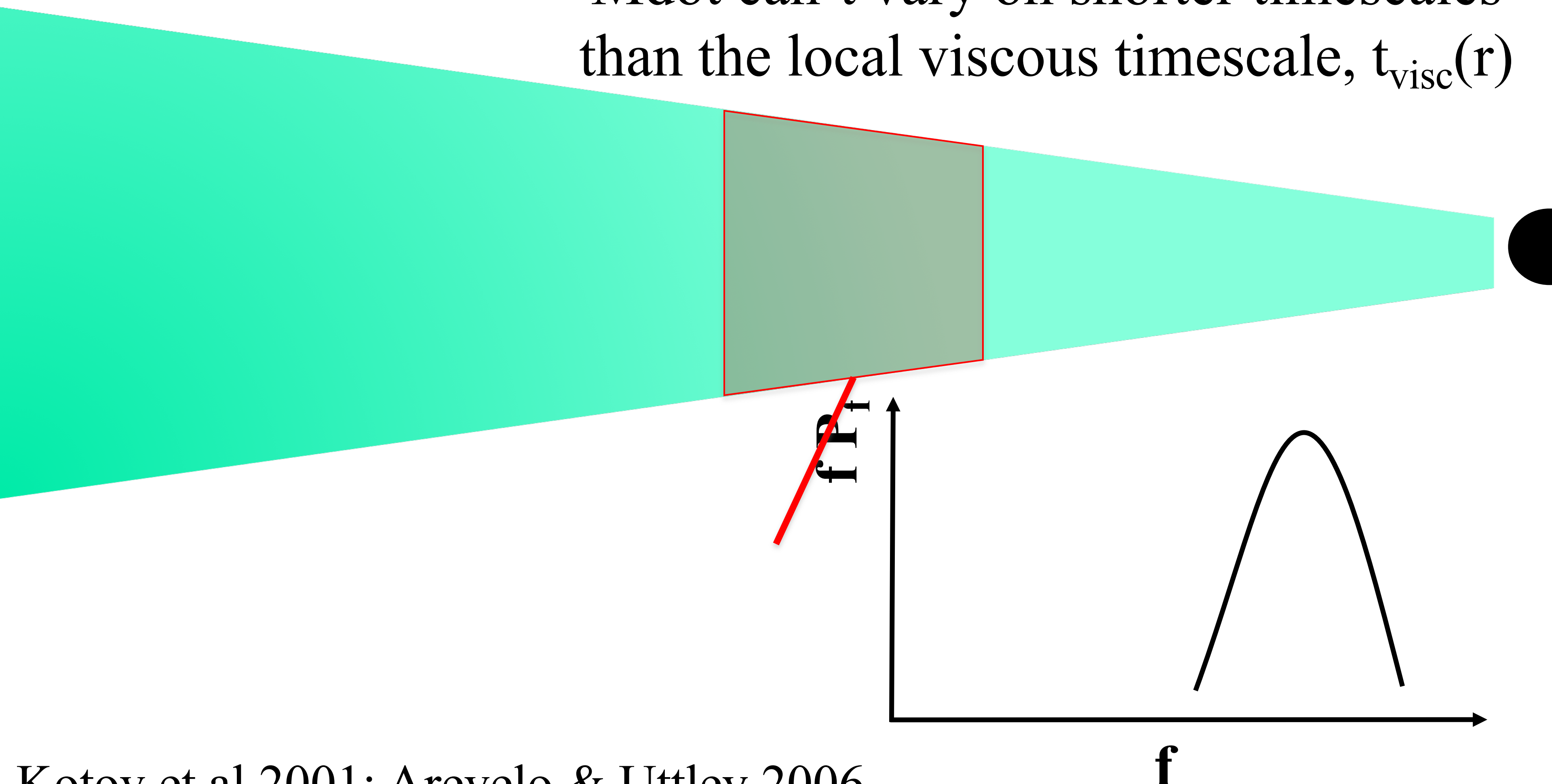

Kotov et al 2001; Arevelo & Uttley 2006

Propagating fluctuations

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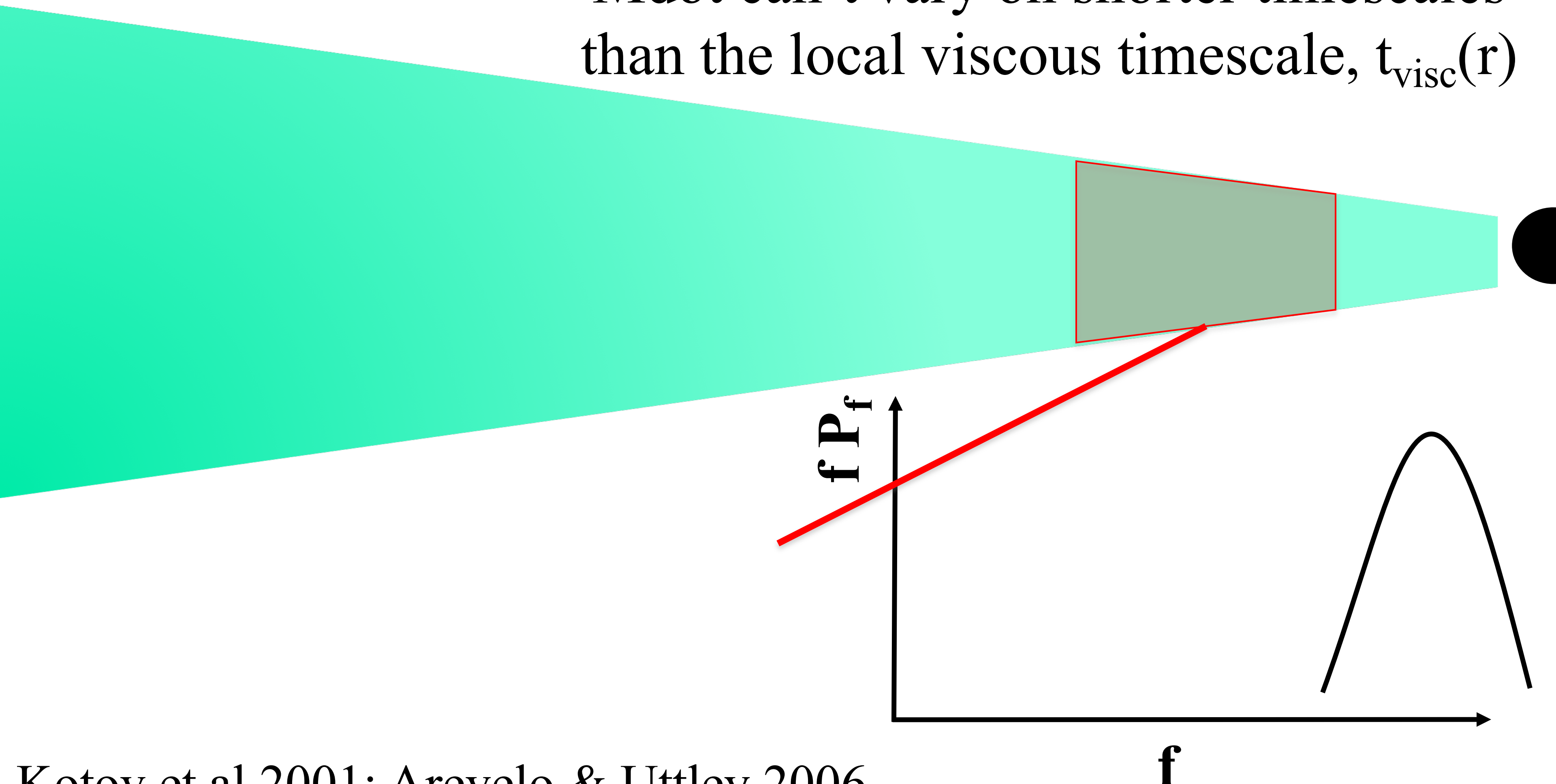
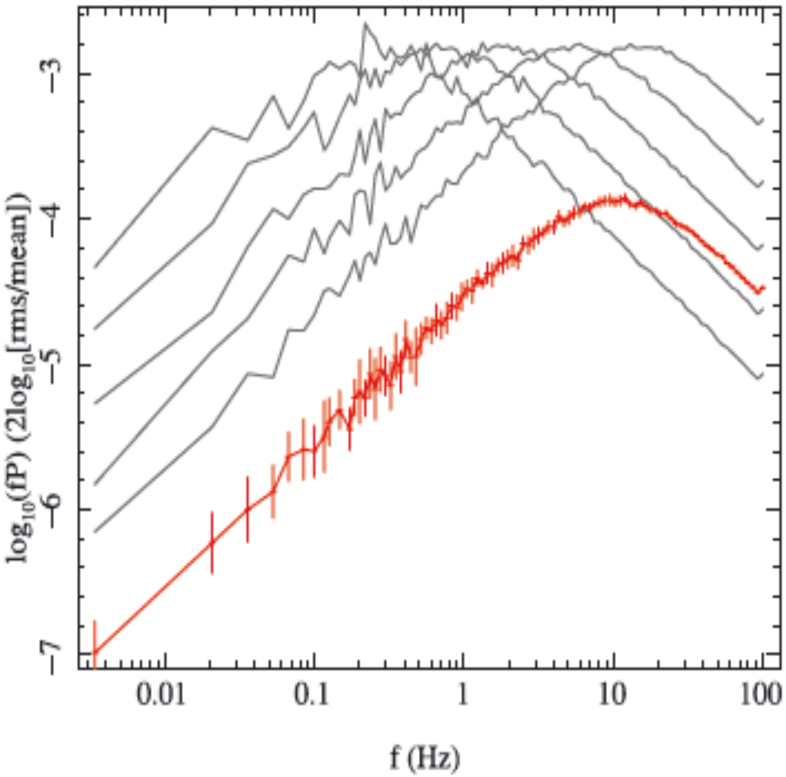
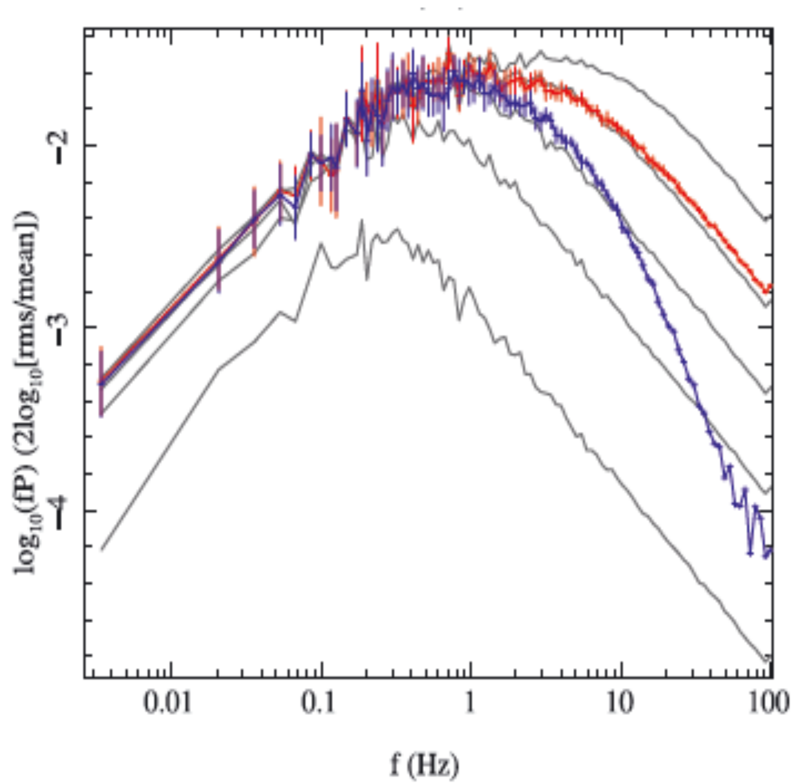


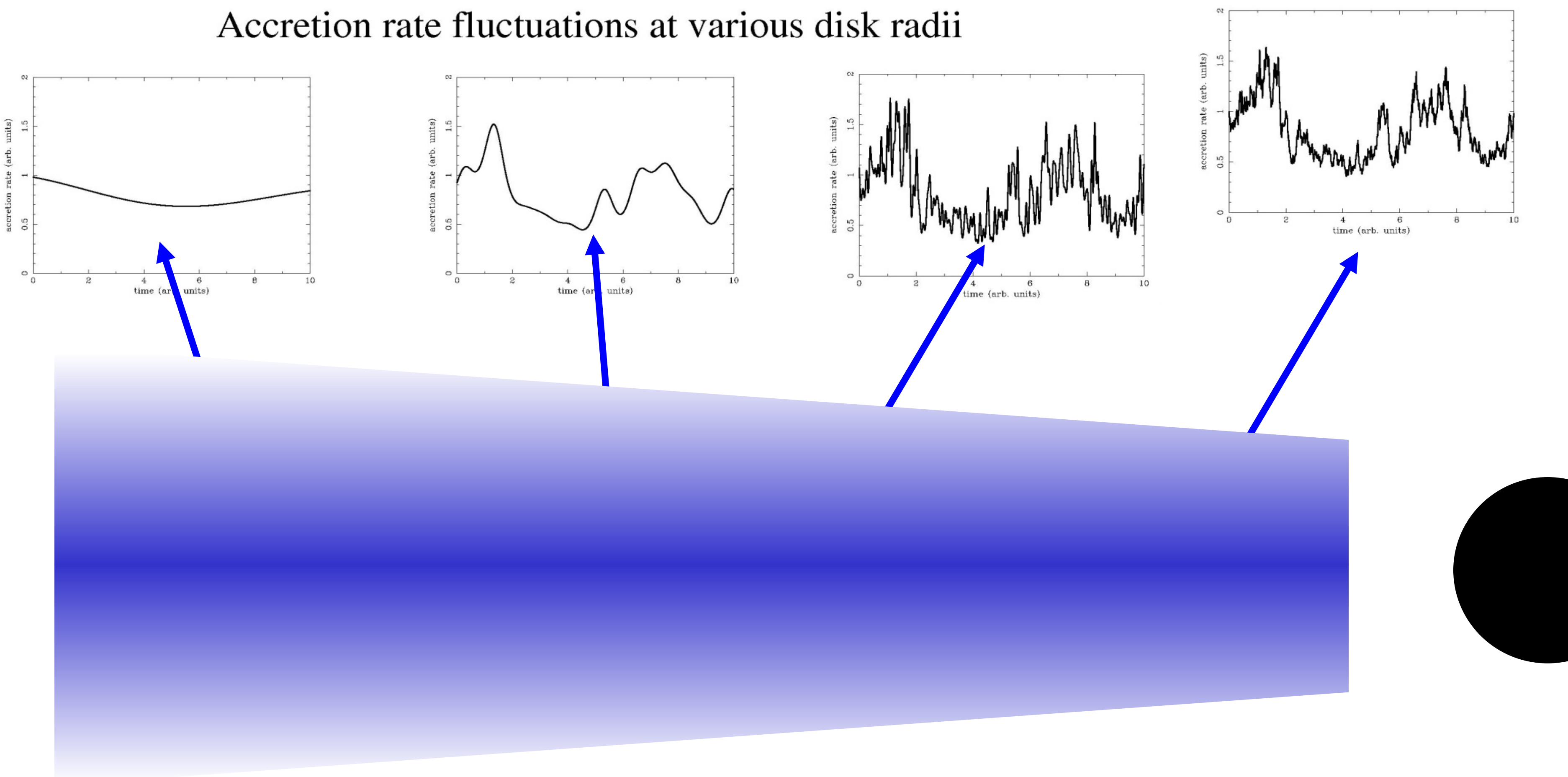
Kotov et al 2001; Arevelo & Uttley 2006

Propagation not independent Lorenzians as decohere!





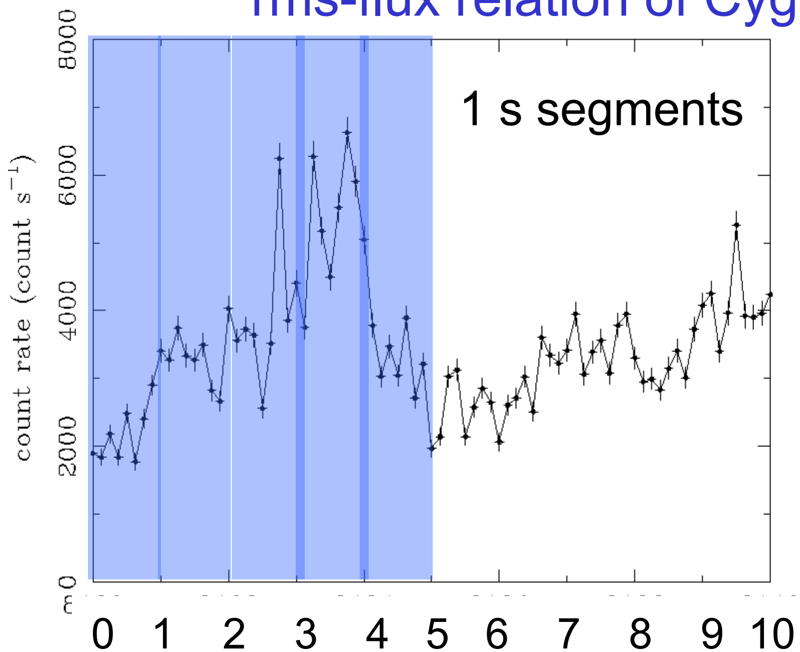
Origin of broad band variability

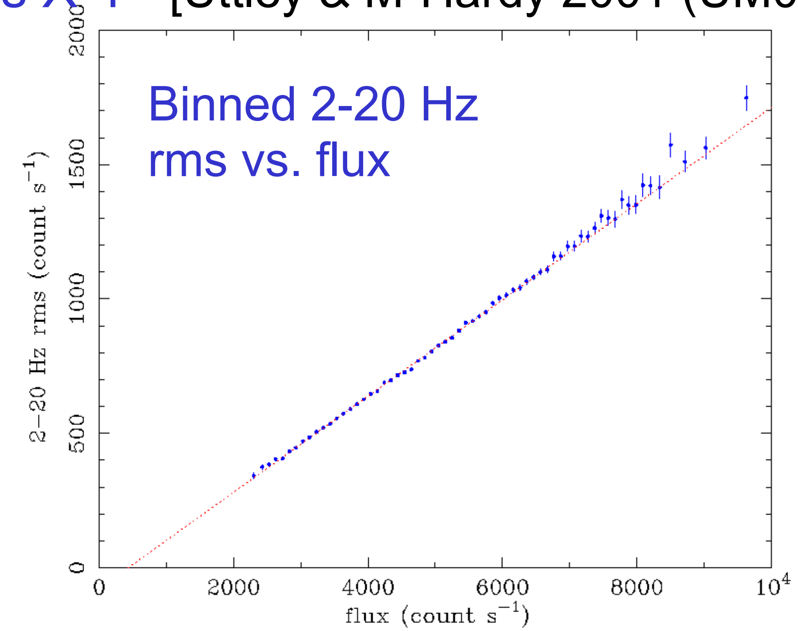


Fluctuations start at large radii – first, soft and slow with R
propagate down to smaller radii – lagged, harder and faster less R

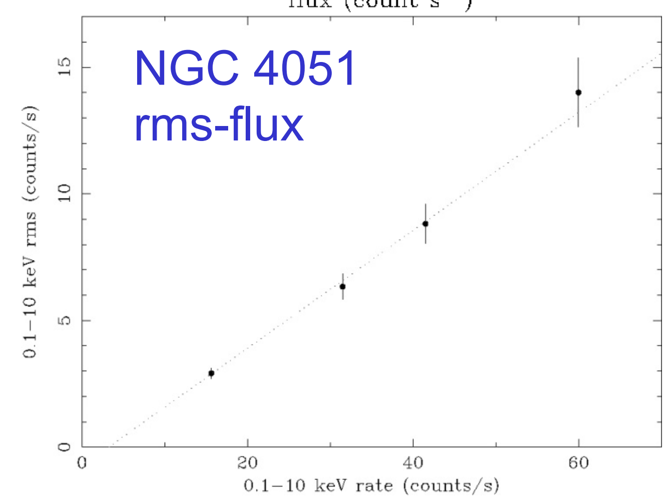
The rms-flux relation

rms-flux relation of Cygnus X-1 [Uttley & McHardy 2001 (UM01)]





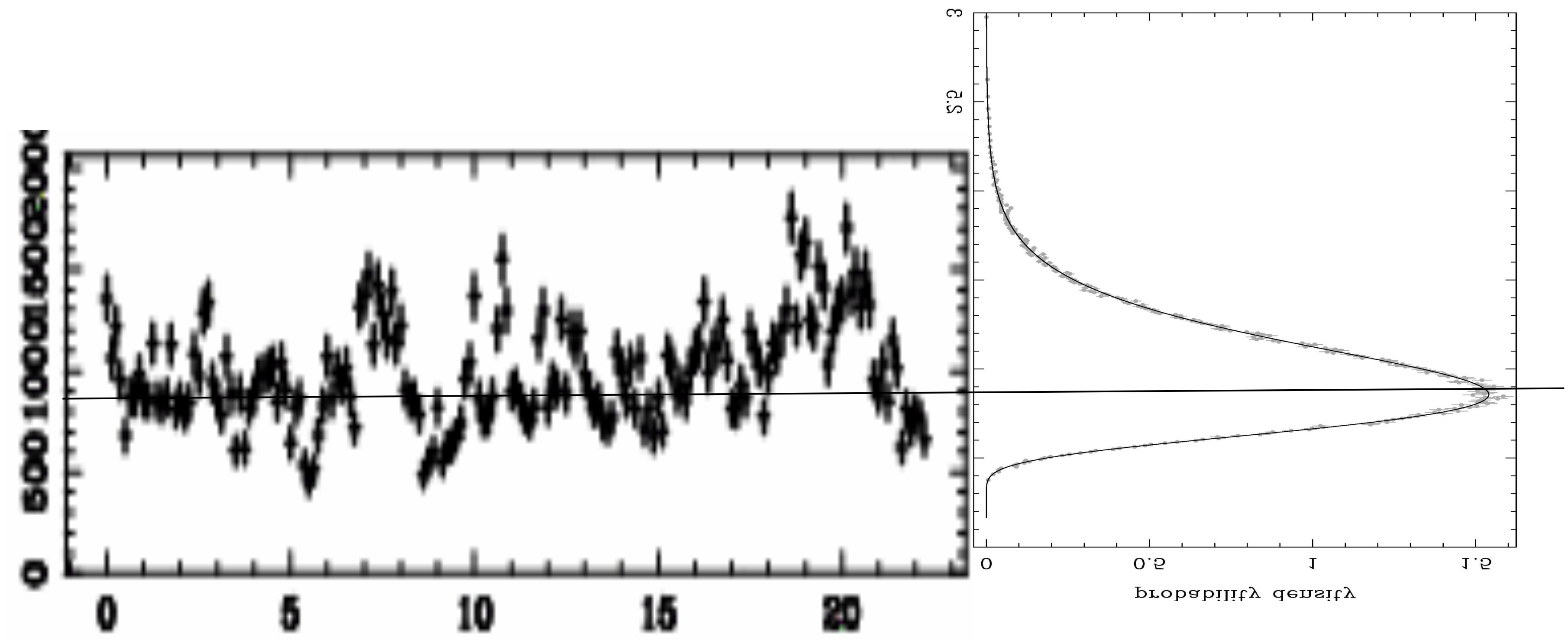
rms = sqrt [(1/N) $\sum_{i=1,N}$ (flux$_i$ - mean)^2]



Linear rms-flux relations are also seen in AGN, e.g. NGC 4051

(UM01, McHardy et al. 2004)

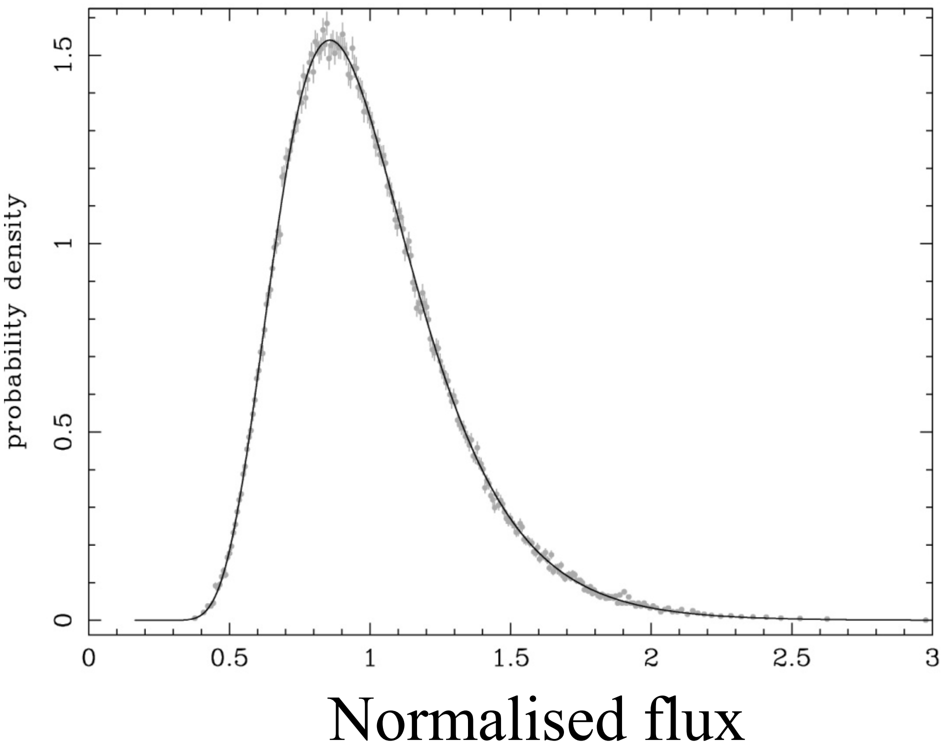
Flux distribution of variability

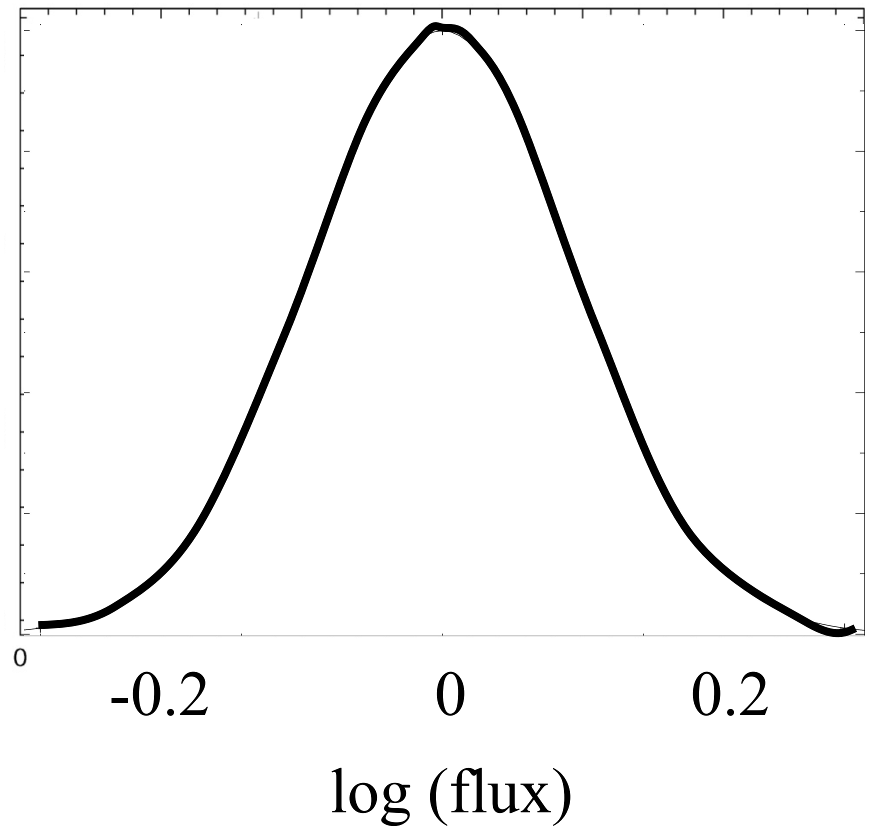


Has very characteristic shape – not symmetric. Skewed to higher flux levels. Lightcurve is ‘flare-y’

Uttley, McHardy & Vaughan 2005

Implies log normal flux distribution

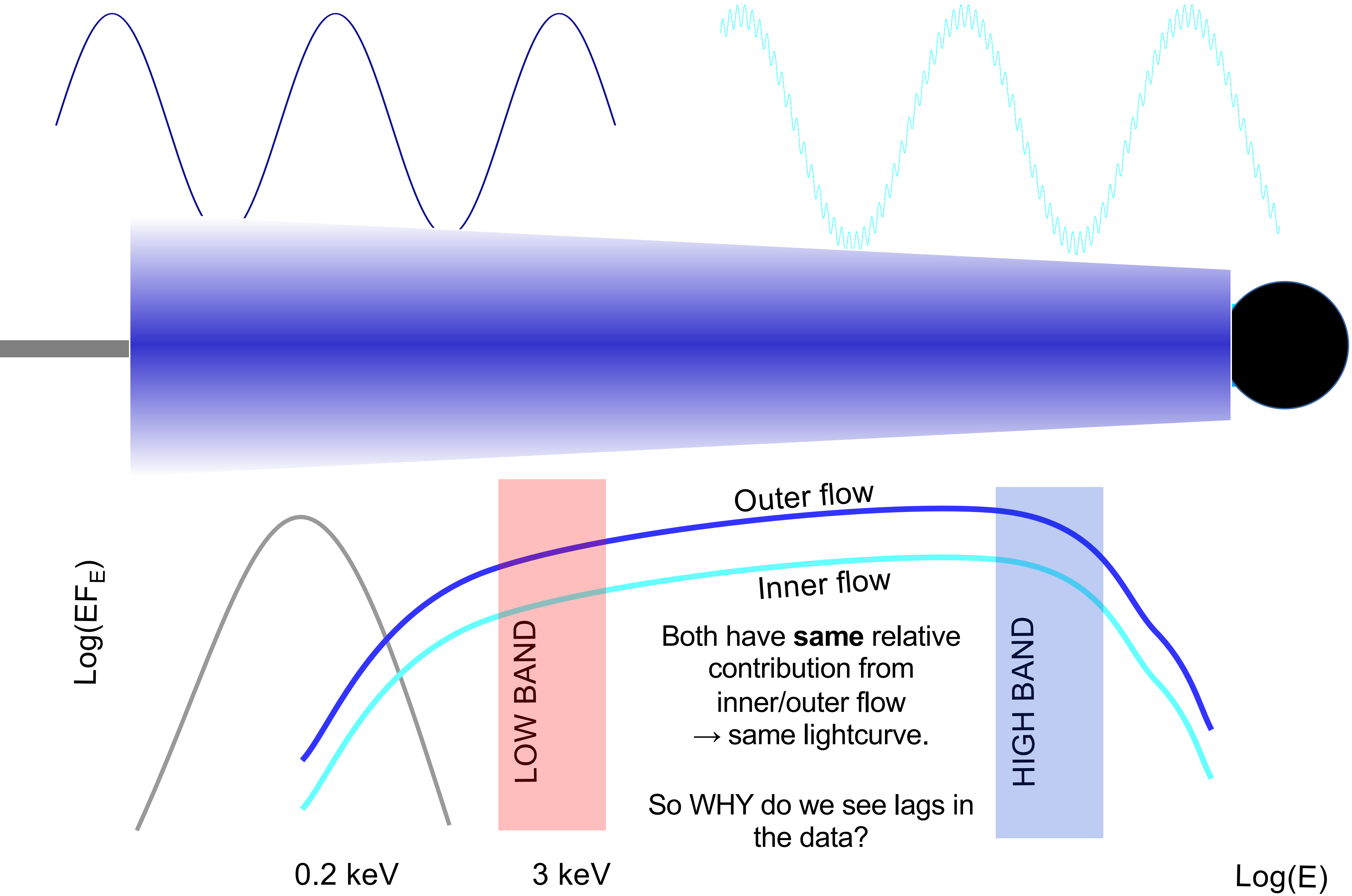




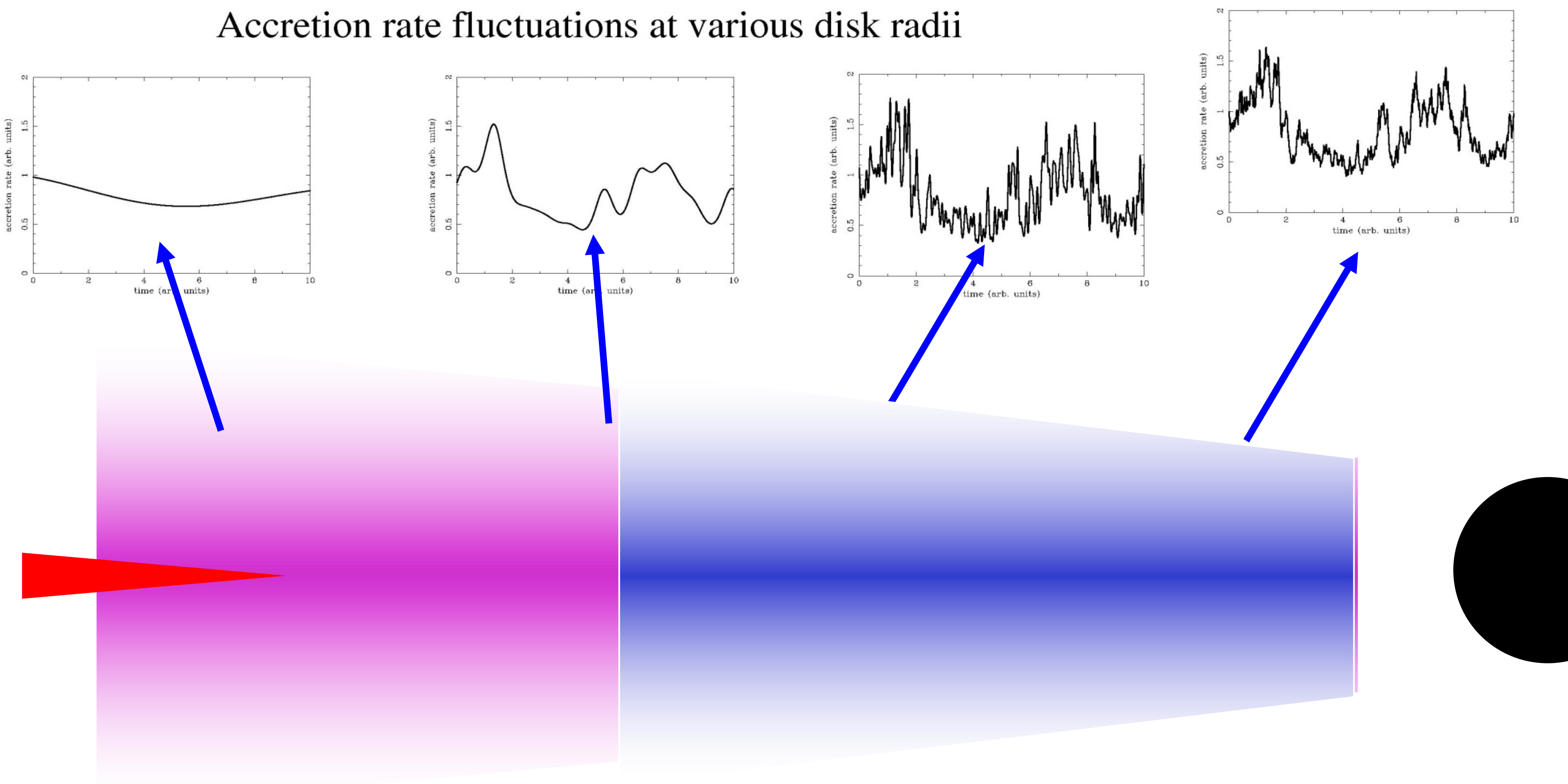
Cannot get this from SHOTS, or any SUM of independent events
Or from self organised criticality (wait till critical value to trigger)

Uttley, McHardy & Vaughan 2005

Lags from Homogeneous Comptonisation?

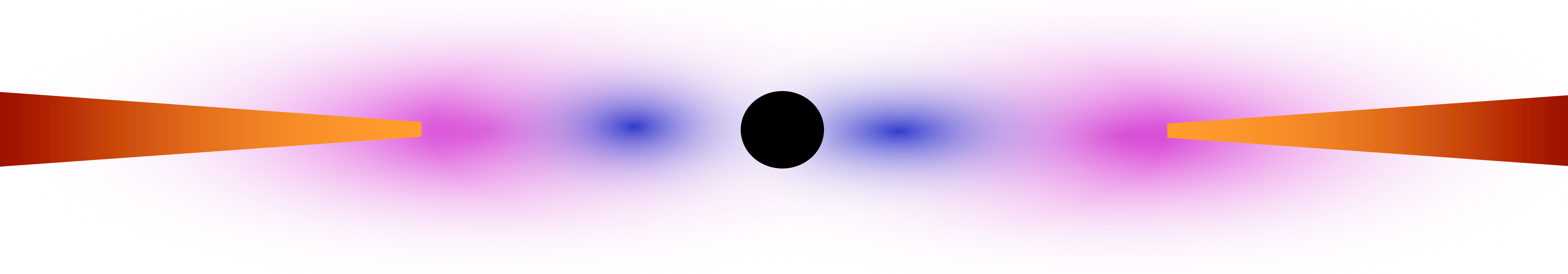


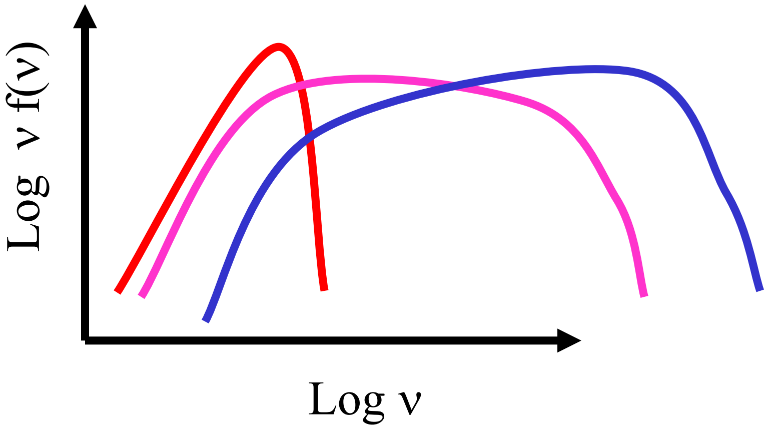
Origin of broad band variability



Fluctuations start at large radii – first, soft and slow with R
propagate down to smaller radii – lagged, harder and faster less R

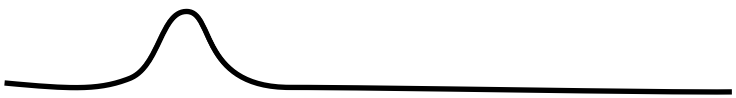
Slow variability

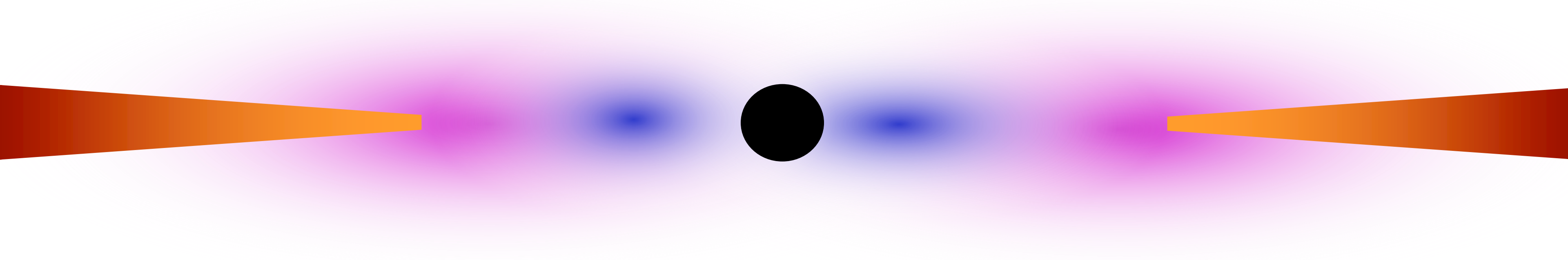


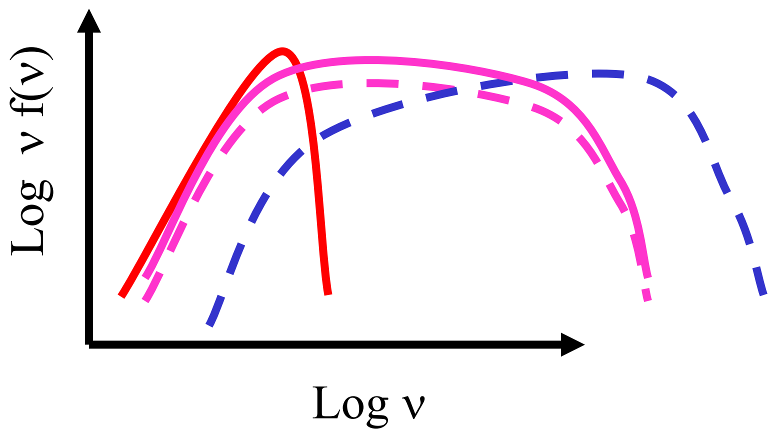


- Mass accretion rate fluc.
- Starts in soft region
- propagates down to hard

Slow variability







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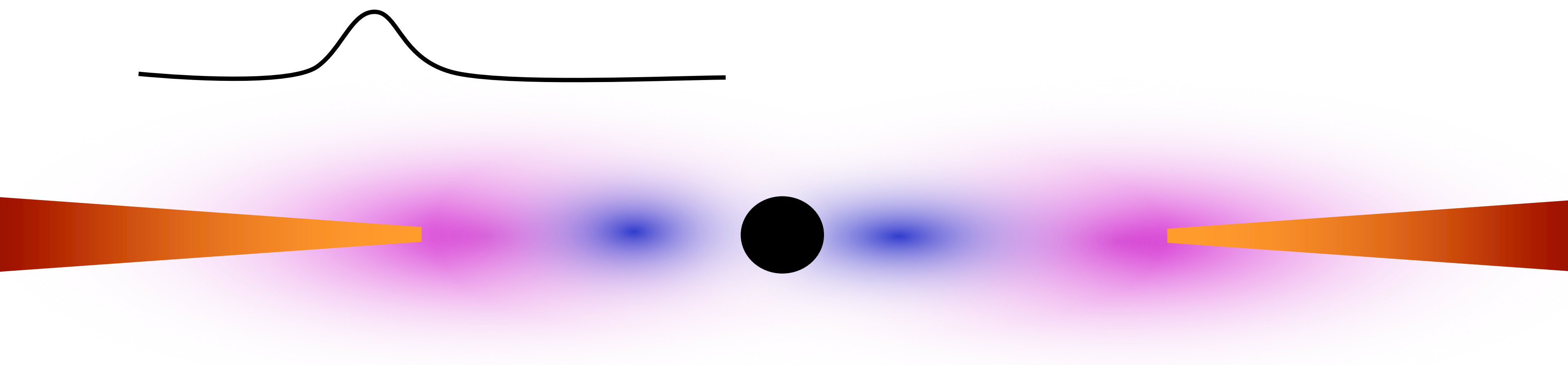
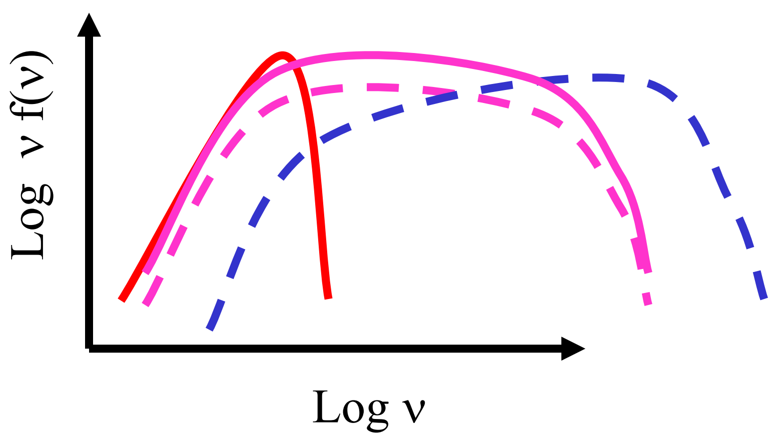
Slow variability





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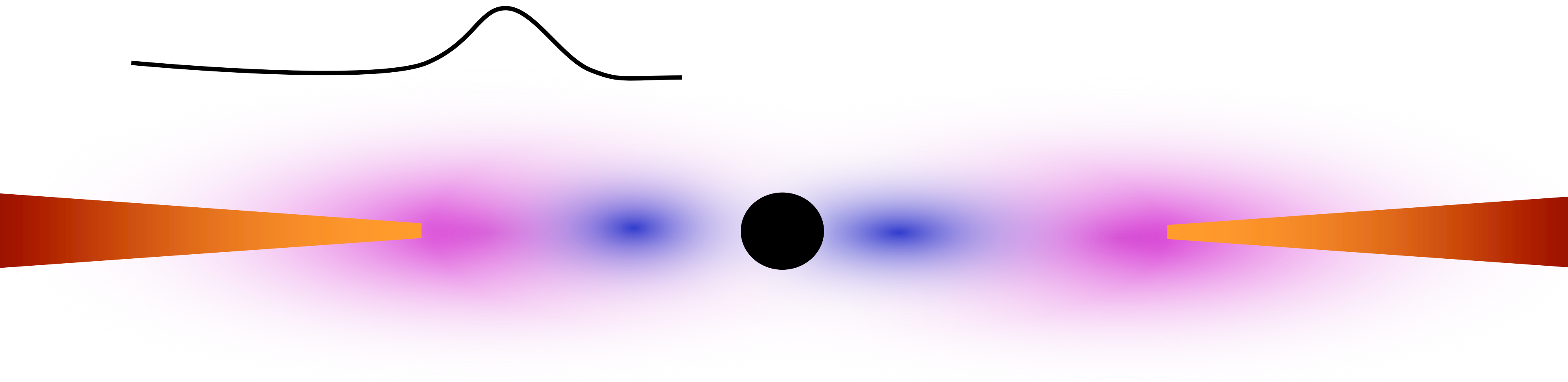

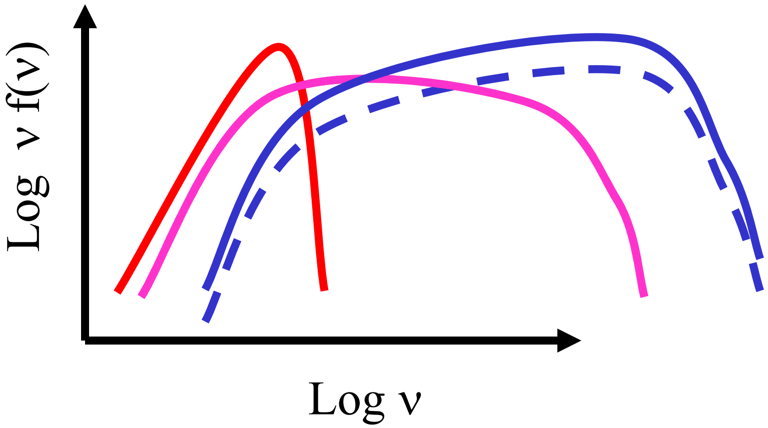

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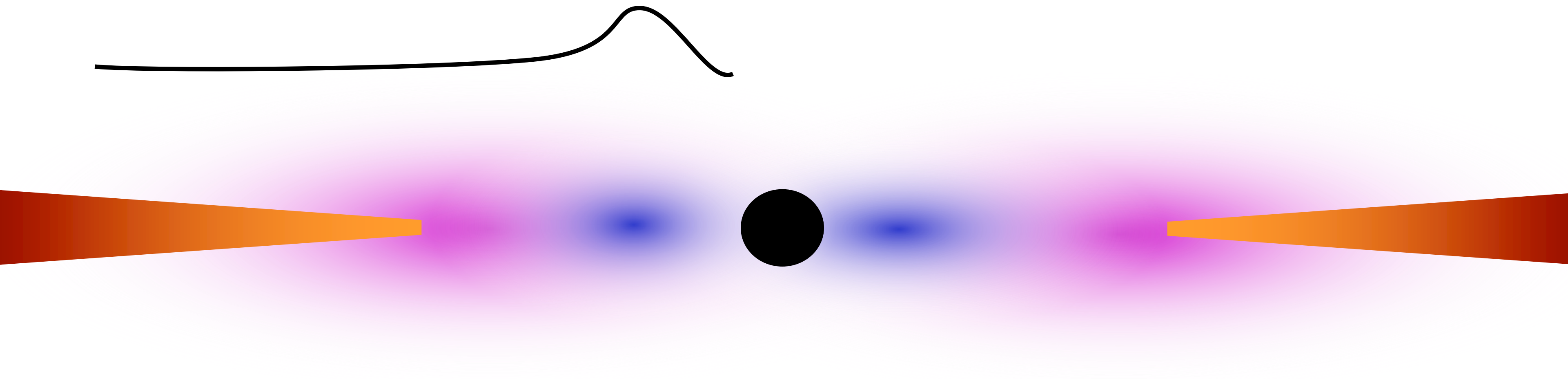
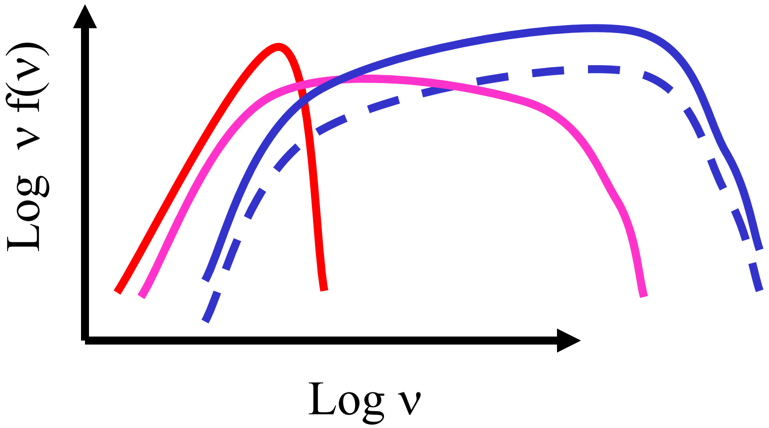
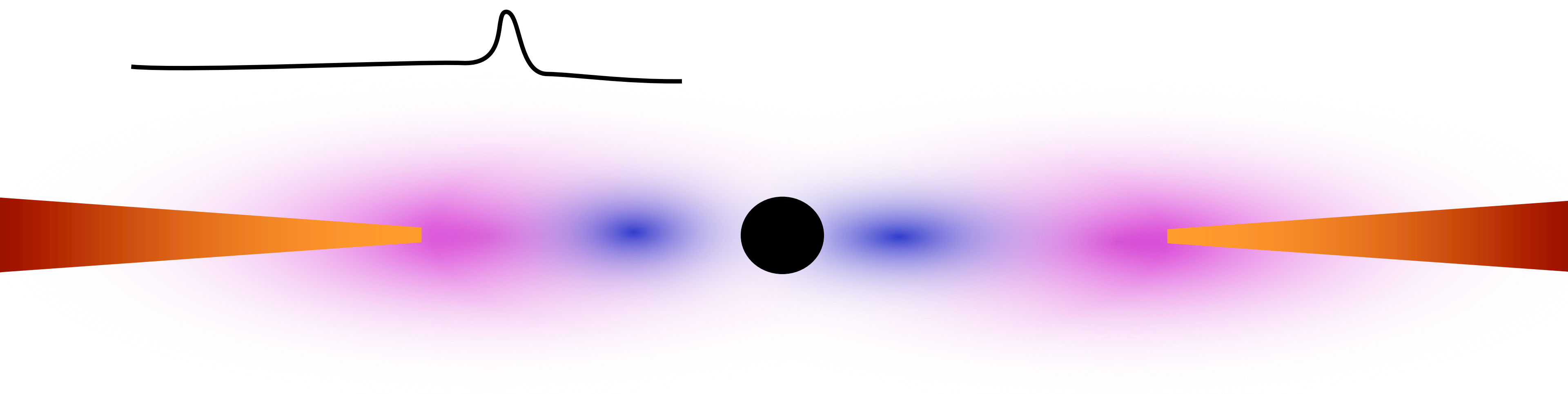
Slow variability

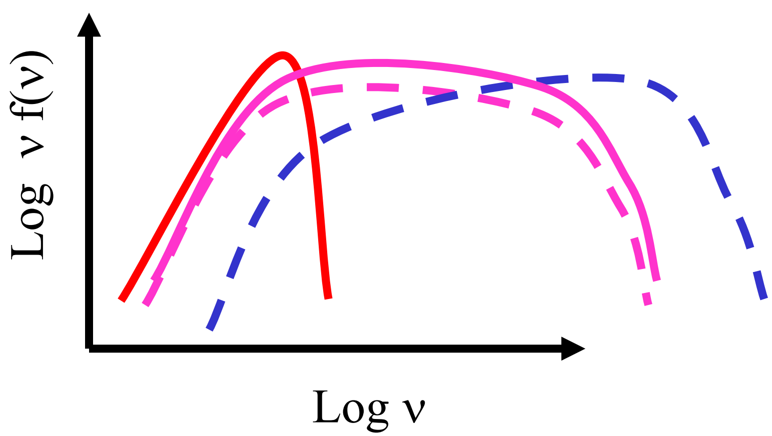




- Mass accretion rate fluc.
- Starts in soft region
- propagates down to hard
- Long time lag (viscous)

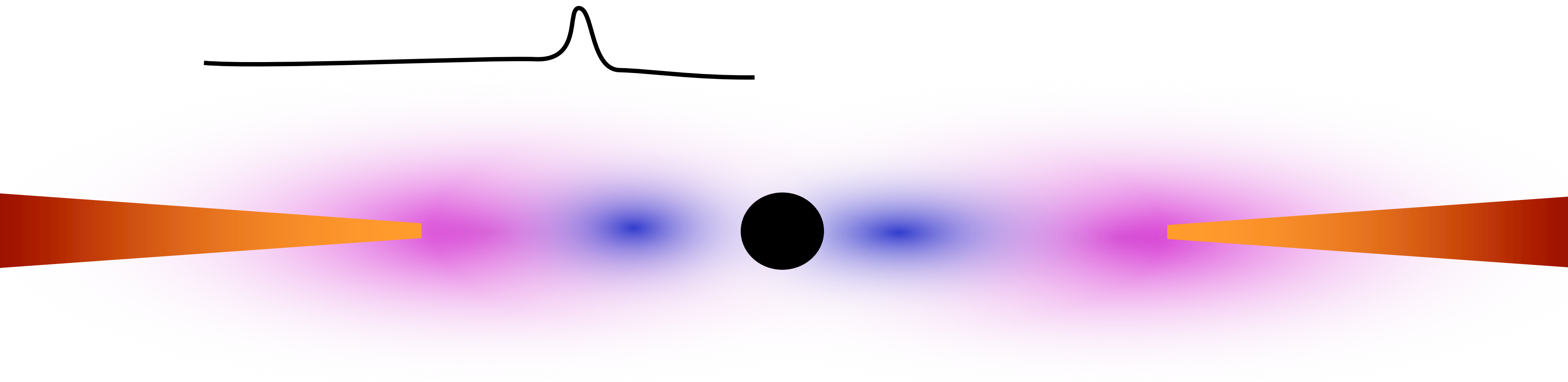
Faster variability

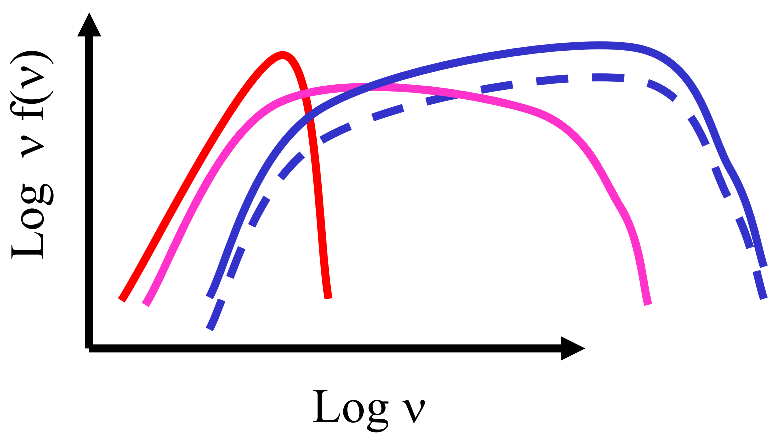




- Can only start further in.
- So has less far to travel

faster variability





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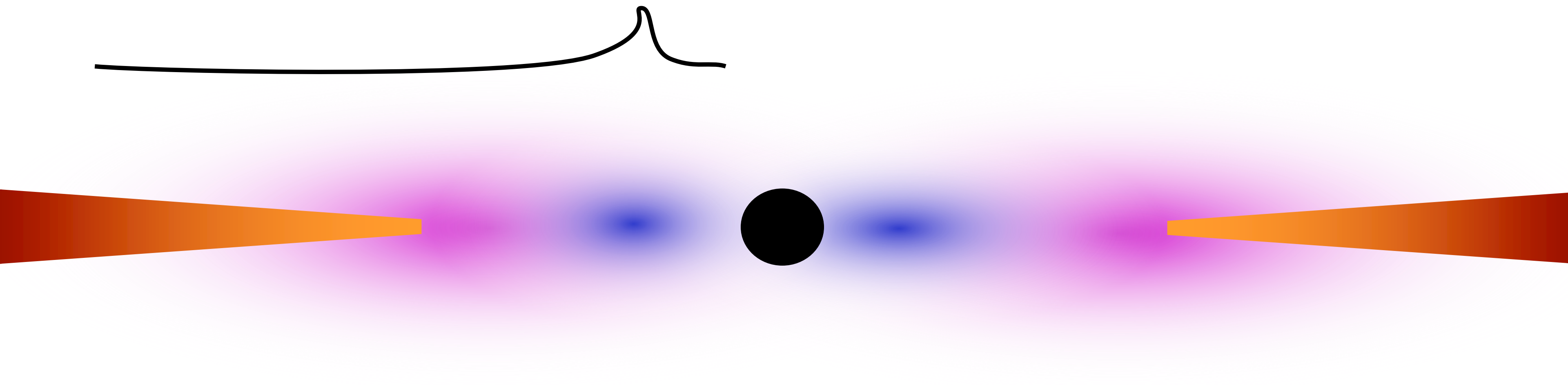
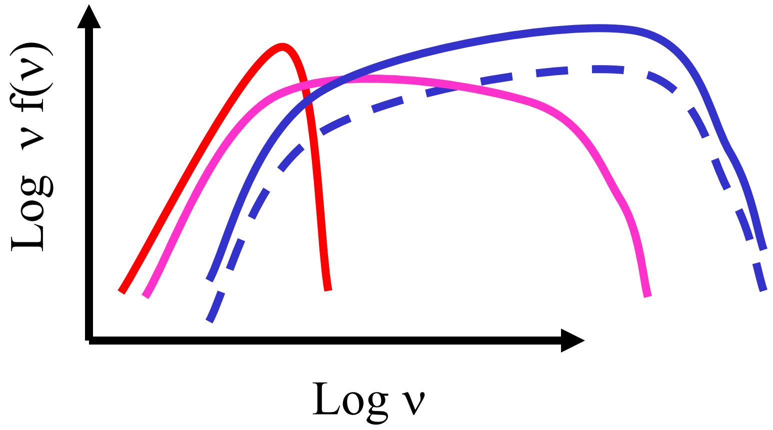
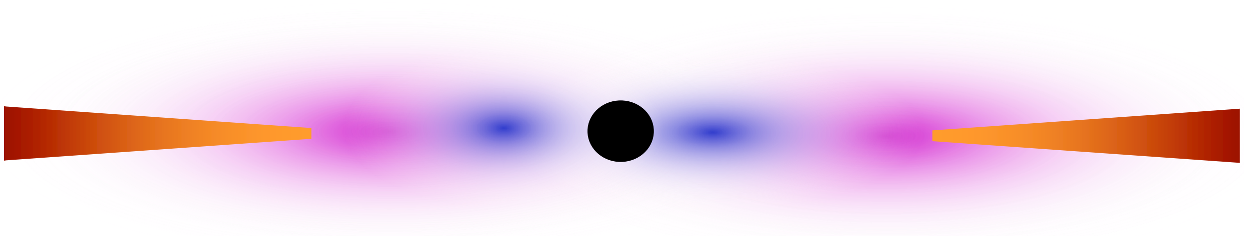
faster variability

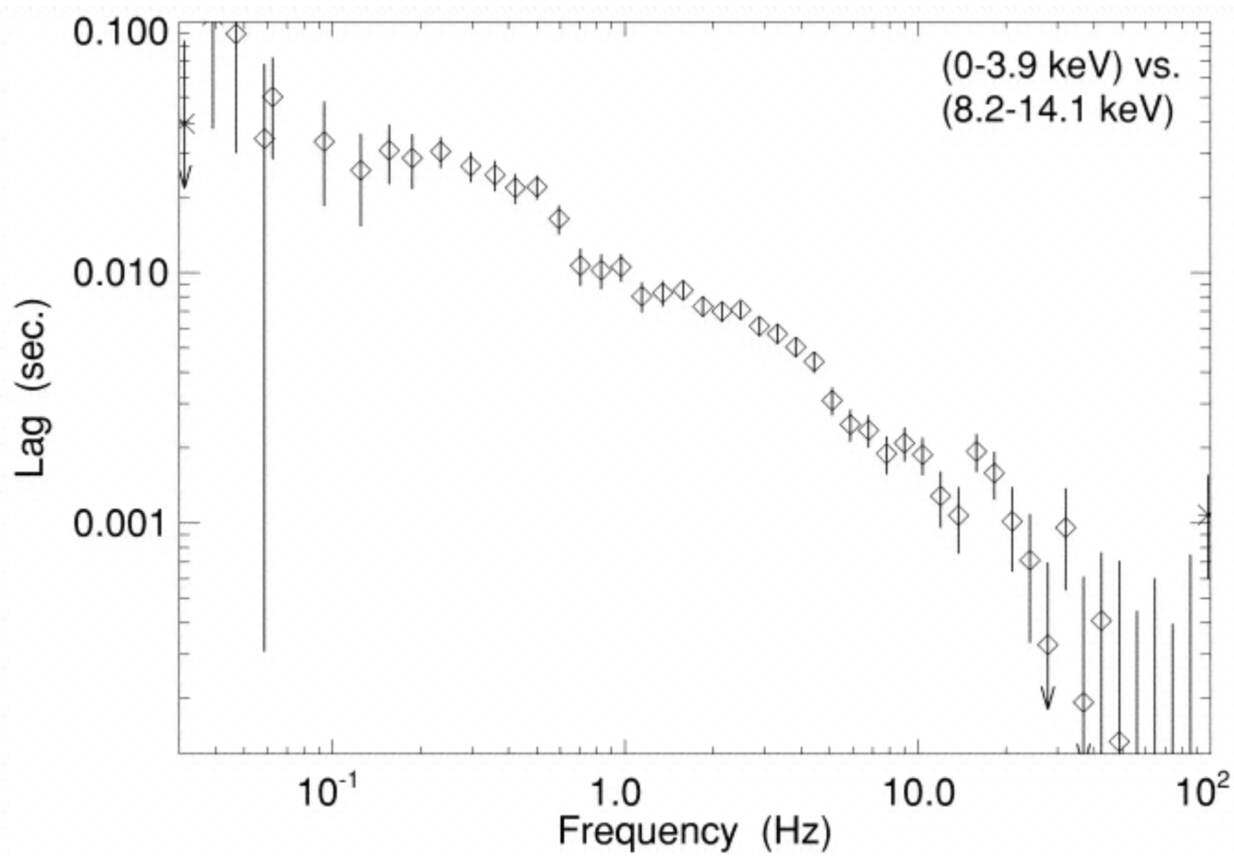




- Can only start further in.
- So has less far to travel

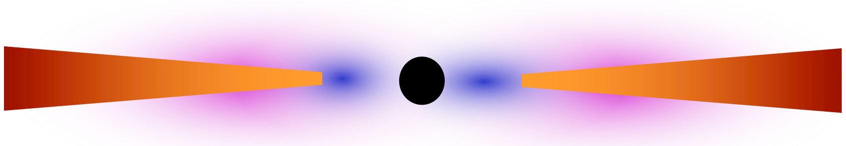
Inhomogeneous close to transition

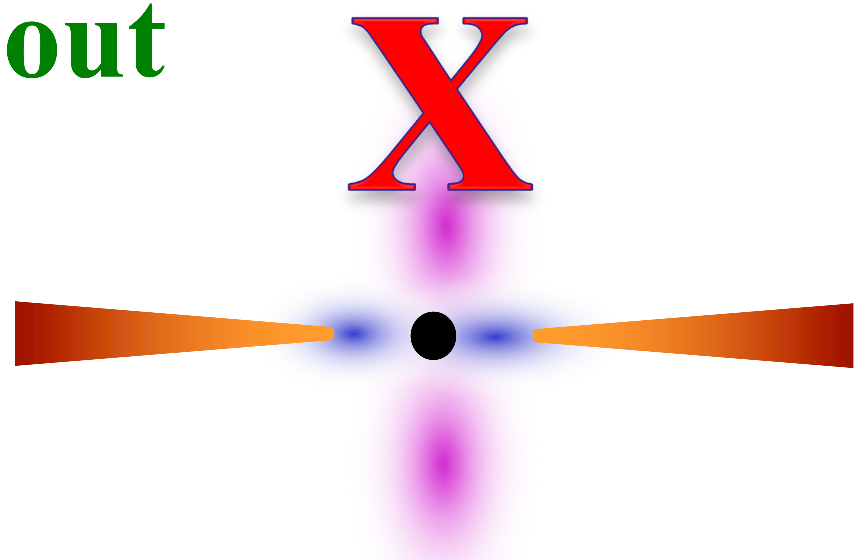


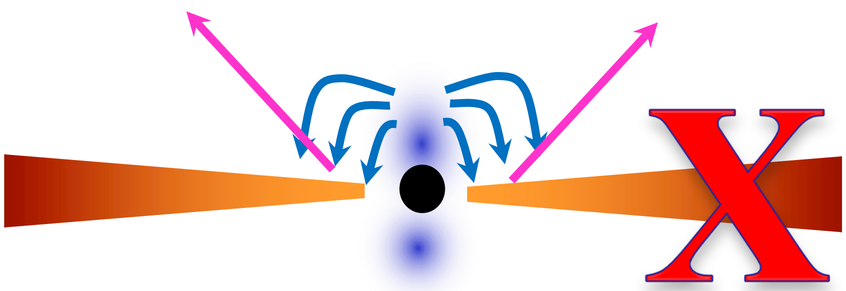


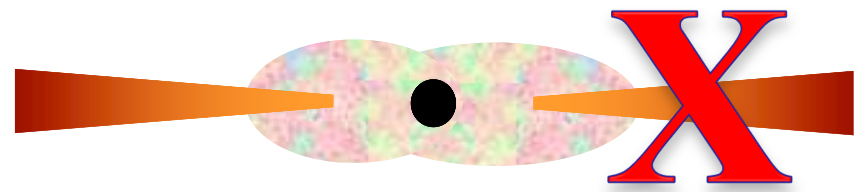
- Overlap softer, slower variability
- Fluctuations propagate down to inner region – lagged. But this has harder spectrum. So hard lags soft. But smaller region so faster variability.
- Miyamoto & Kitamoto 1988; Kotov et al 2001, Nowak et al 1999, Arevalo & Uttley 2006

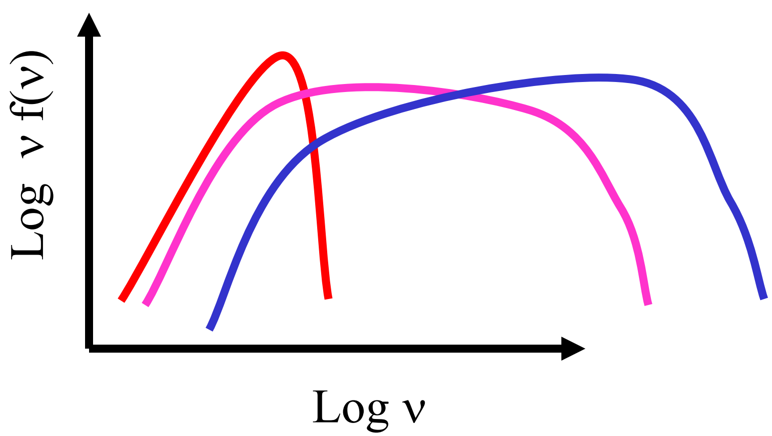
Lags already rule out





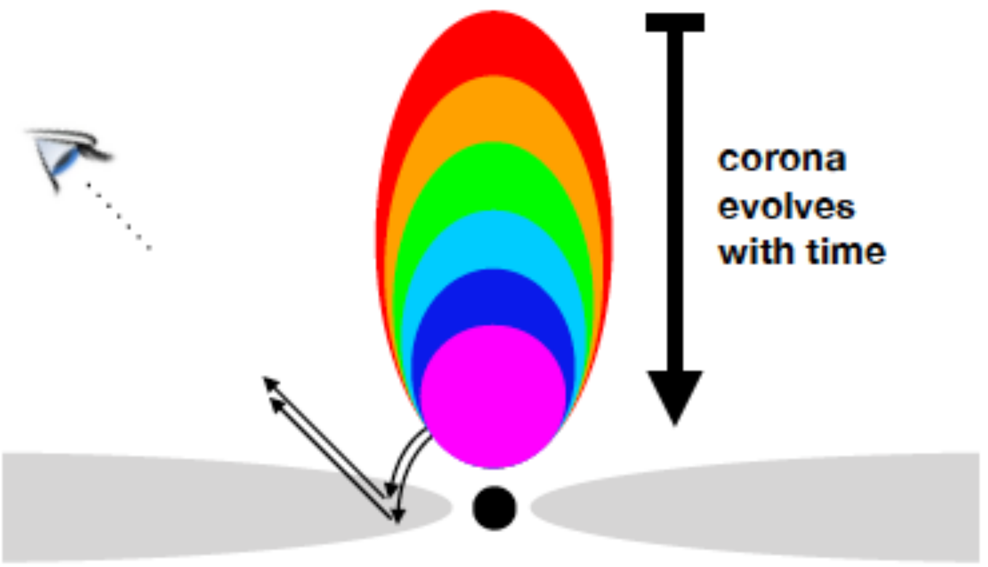






- Inhomogeneous compton, hybrid (thermal-nonthermal), jet, ionised, blurred reflection. All fit! Makishima et al 2007; Nowak et al 2011, Fabian et al 2012, Gierlinski et al 1999

Can they test this also? Need propagation from down through the flow….



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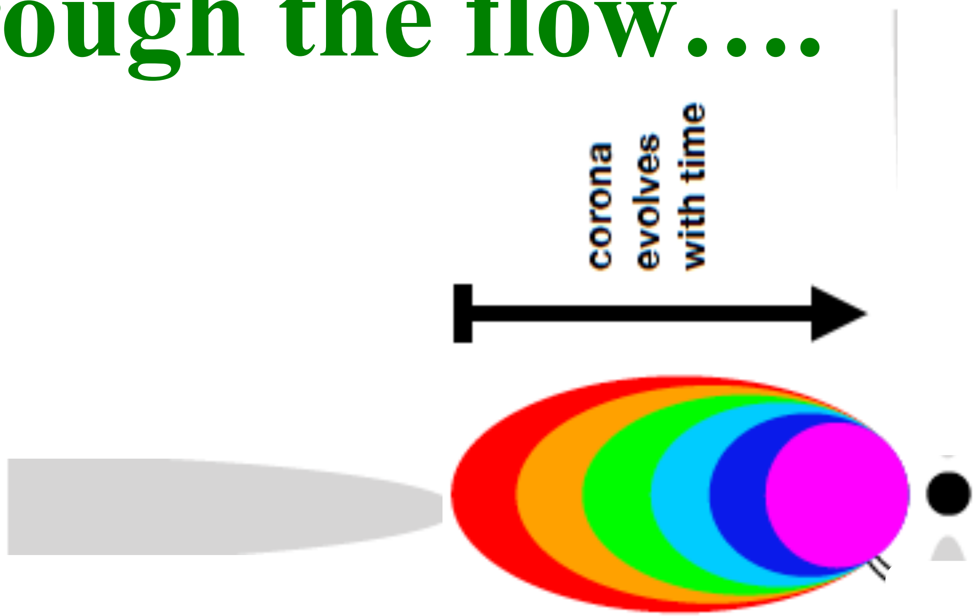
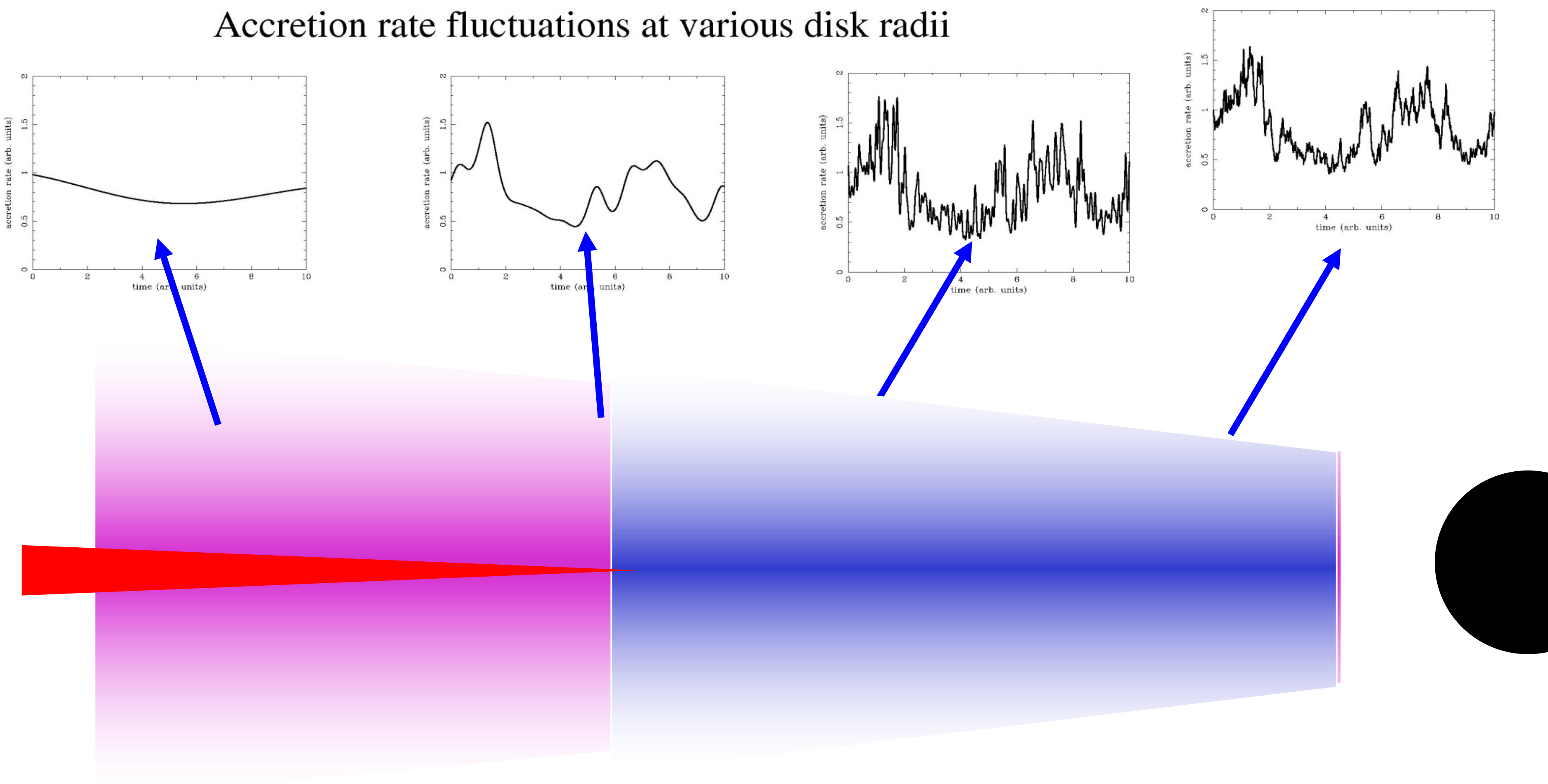
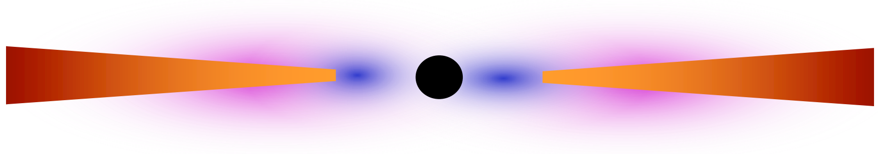


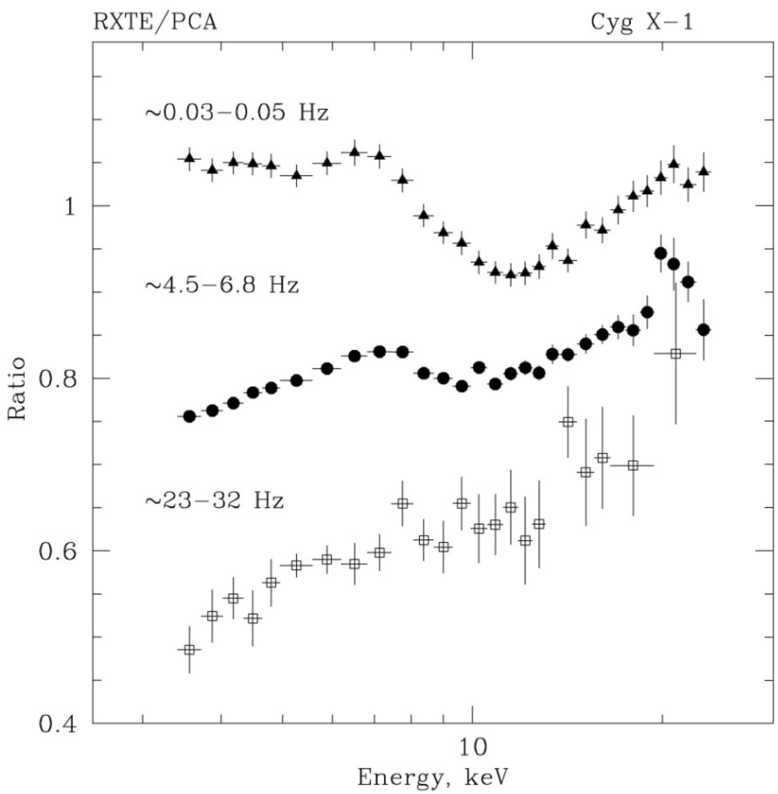
Origin of broad band variability



Slow fluctuations propagate – soft with R and hard no R
Fast fluctuation only from smaller radii – hard and no R

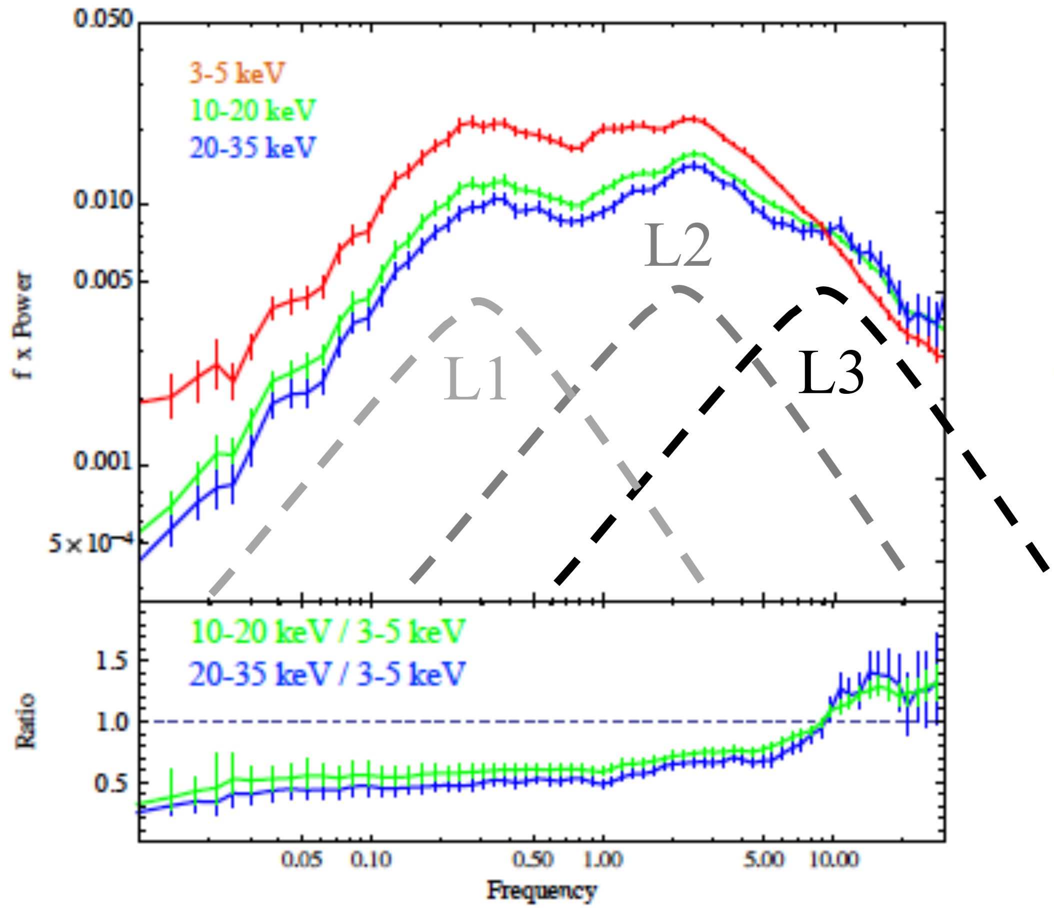
Single spectrum from Cyg x-1

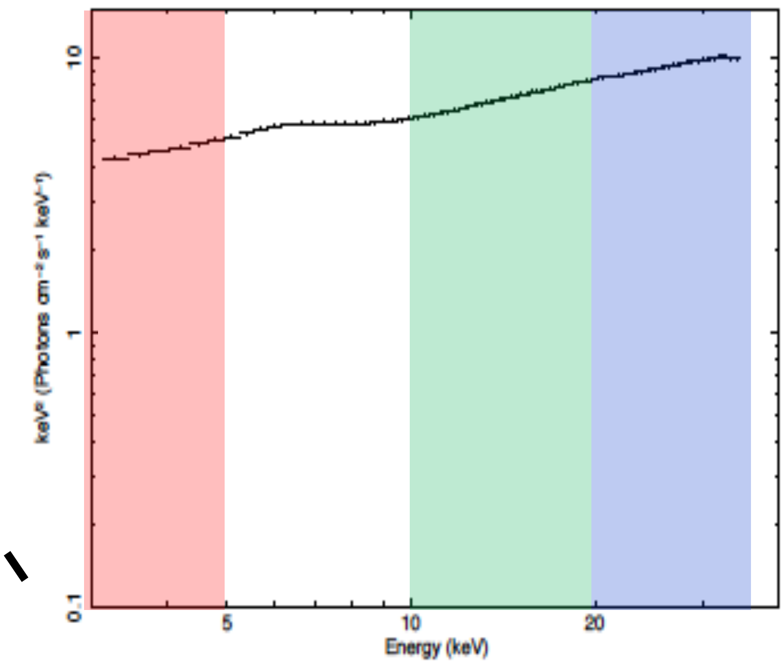




- Overlap softer, and more reflection, slow
- Fluctuations propagate down to inner region – smaller so faster variability. Fewer seed photons so harder spectrum and less reflection
- WE SEE THIS IN SINGLE SPECTRUM OF Cyg X-1
  Revnivtsev et al 1999

Power spectra more complex

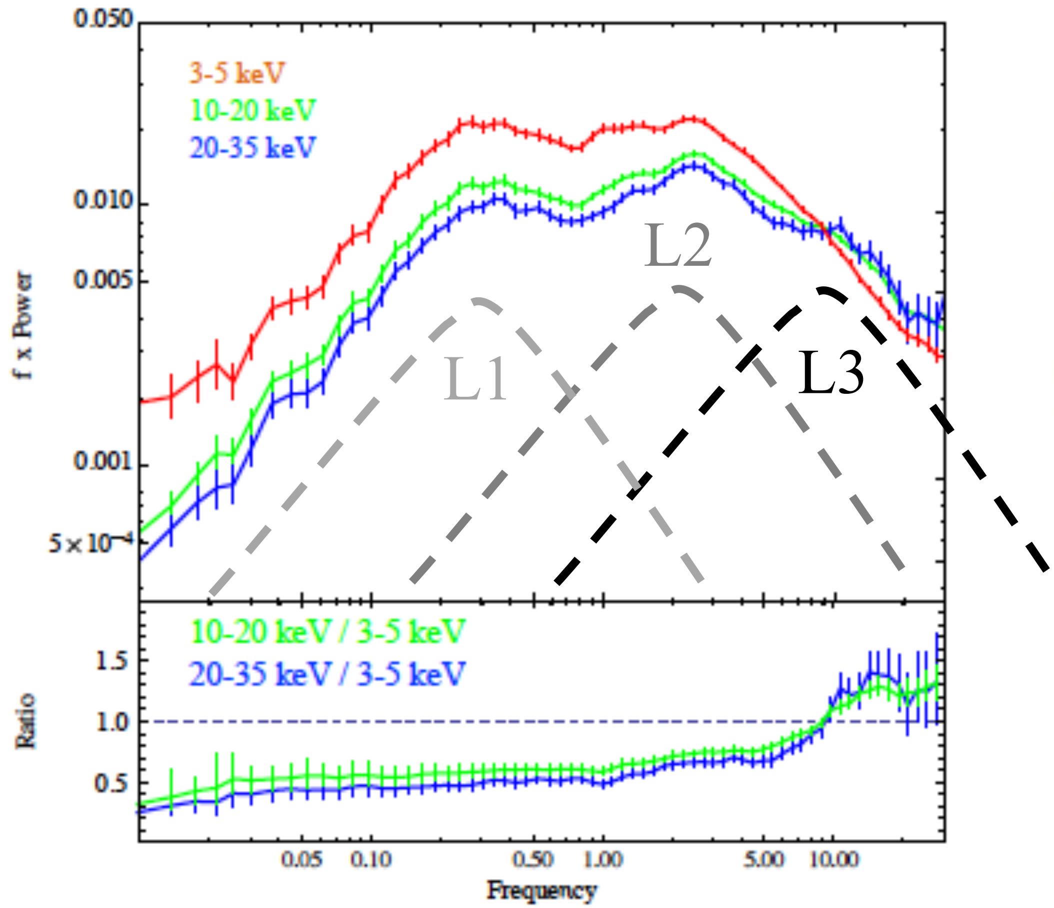


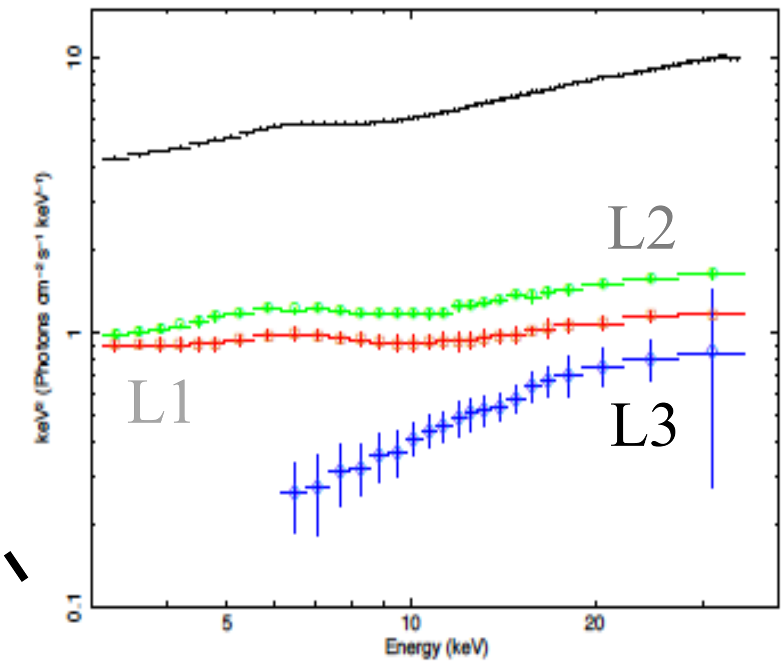


- Bumpy – specific Lorenzian timescales
- Energy dependent

Axelsson & Done 2018

Power spectra more complex

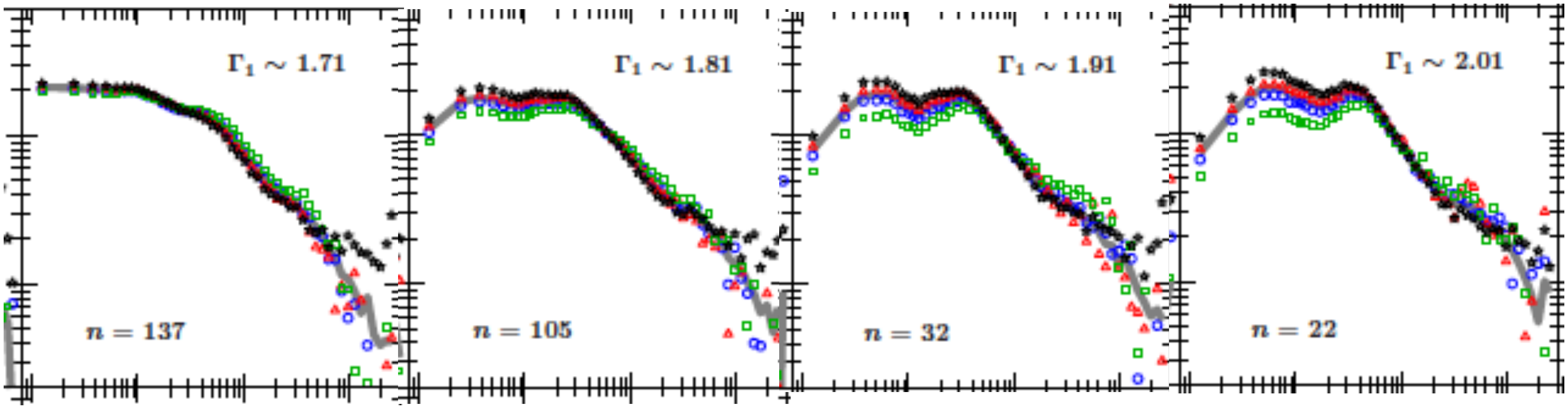




- Frequency resolved spectra
- Revnivtsev et al 1999

Axelsson & Done 2018

Both bumpiness and energy dependence increase in transition



Grinberg et al 2014

Conclusions:

- Truncated disc models can really give a framework to explain a lot of spectral-timing behaviour in transitions
- Coupled to inhomogeneous Compton
- Becomes more inhomogeneous during transition