Unification of accreting black holes over the entire mass range

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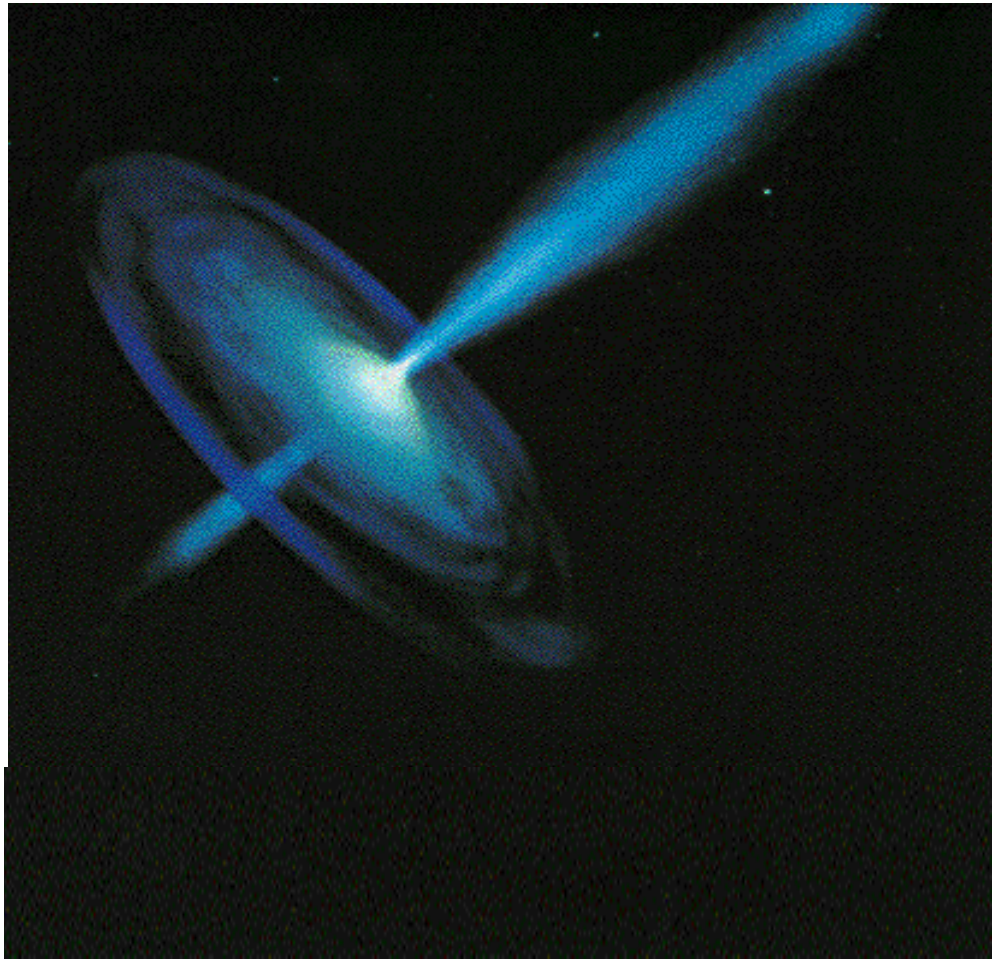
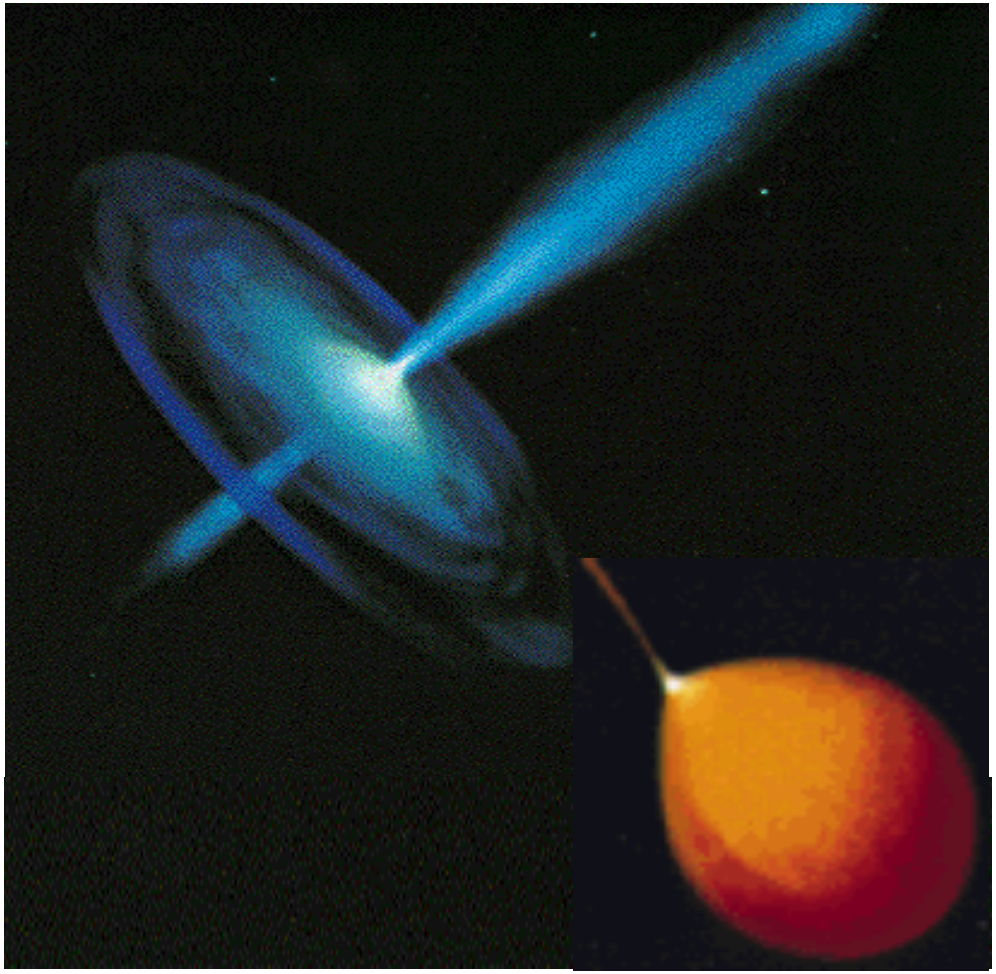
Supermassive black holes

- Understand the accretion flow
- And AGN feedback via jet & winds from flow
- And cosmology..
- 3 fundamental parameters
- Mass, Mdot, spin
- Plus maybe some second order effects from non steady state or history or environment

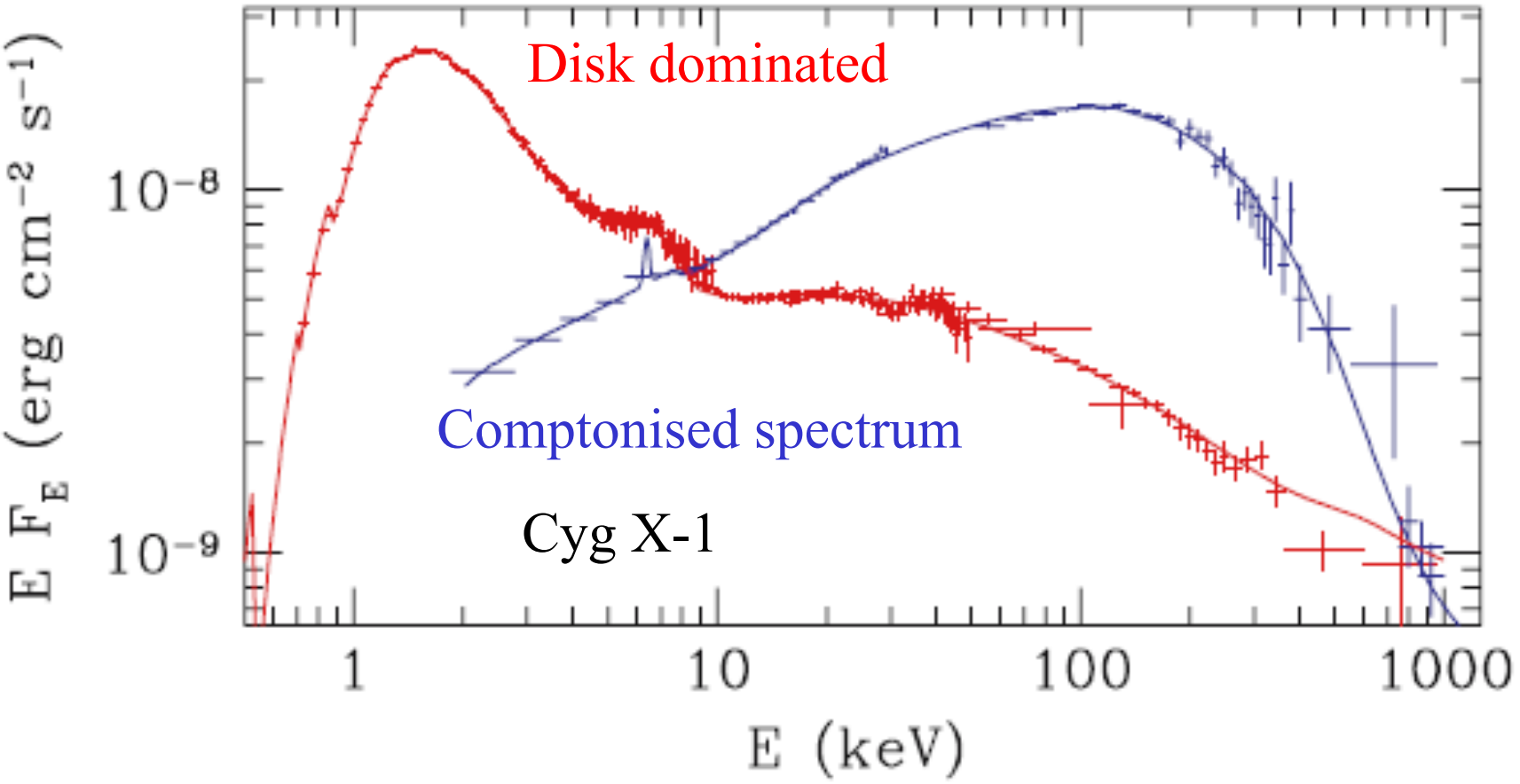


Scaling Black holes – TALK PLAN

- Bonus set BHB
- same mass (factor 2)
- Same spin CC SNR (?) low/moderate GW (??)
- Main parameter: Mdot
- Use these as training set
- Scale to AGN – see what works (CLQ) and what doesn't (SX)
- Explore SX by intensive monitoring campaigns
- Unexpected new stuff!!



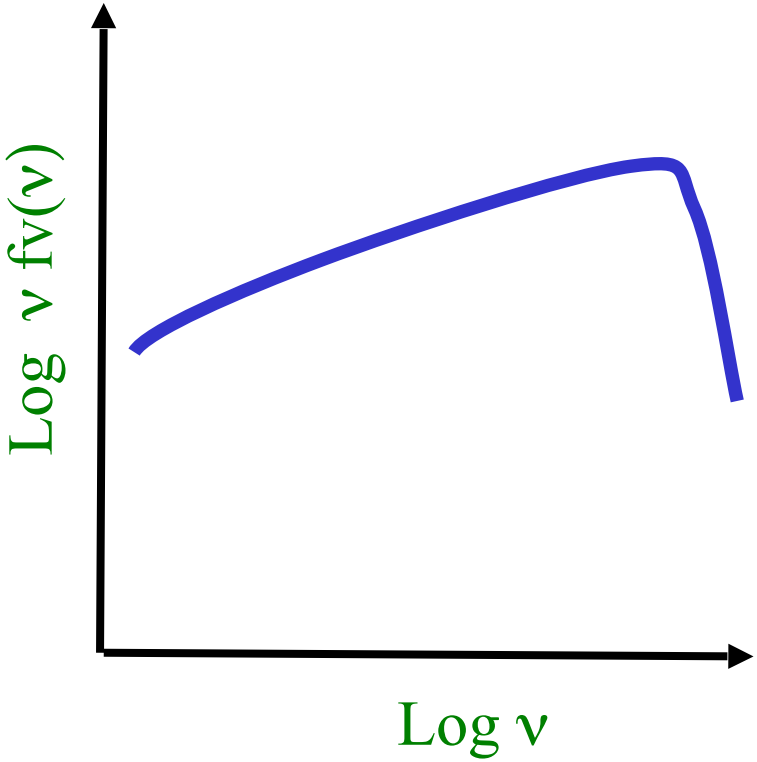
Two types of spectra in stellar BH

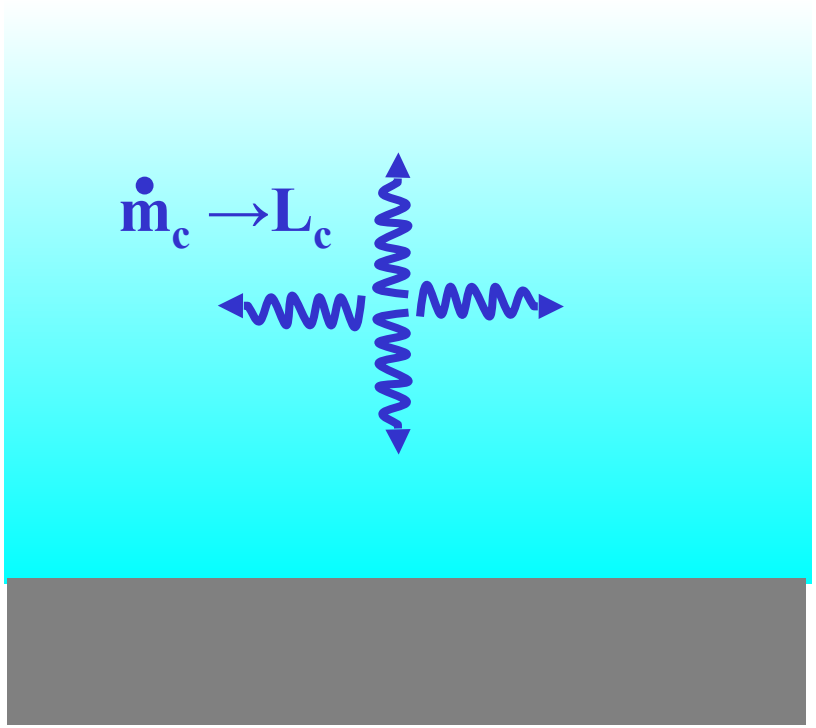


Gierlinski et al 1999

How to make hard spectra

- Limit when $\dot{m}_d=0$ – no intrinsic emission from disc
- Hardest possible spectra

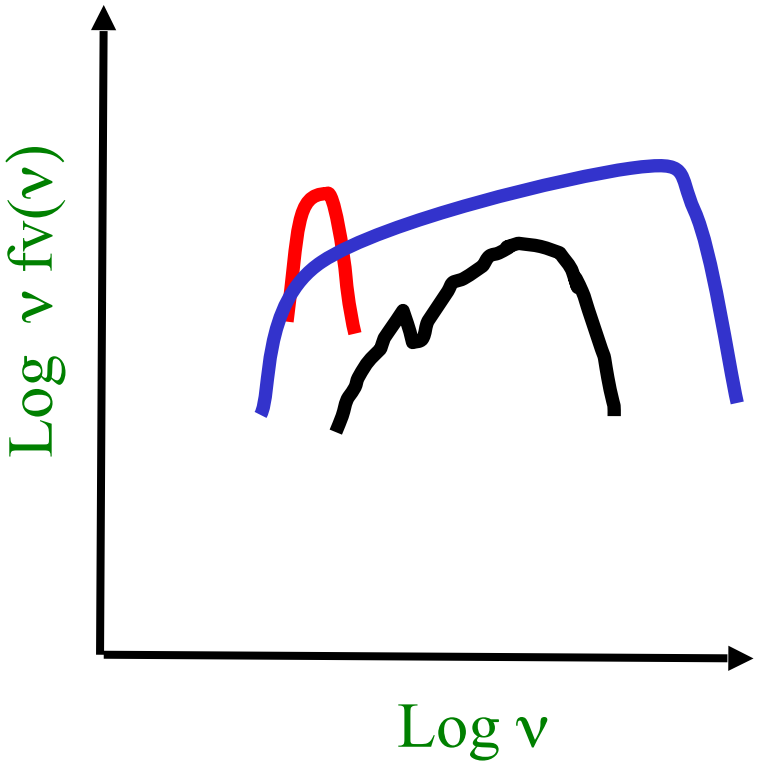


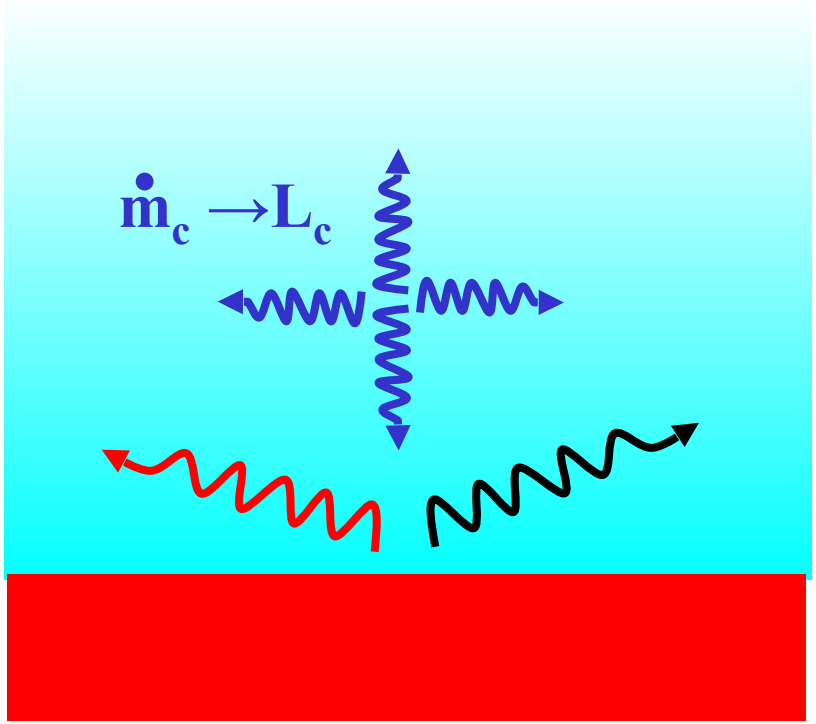


Haardt & Maraschi 1991,1993
Malzac et al 2005
Poutanen et al 2017

How to make hard spectra

- Cold matter intercepts half of hard X-rays – reflects
- Rest reprocessed: thermal!





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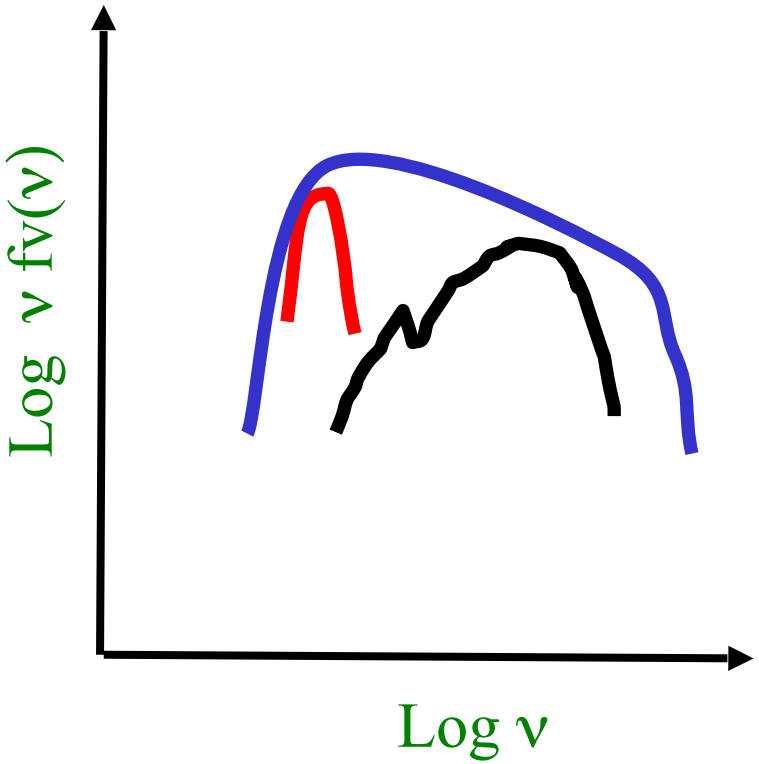
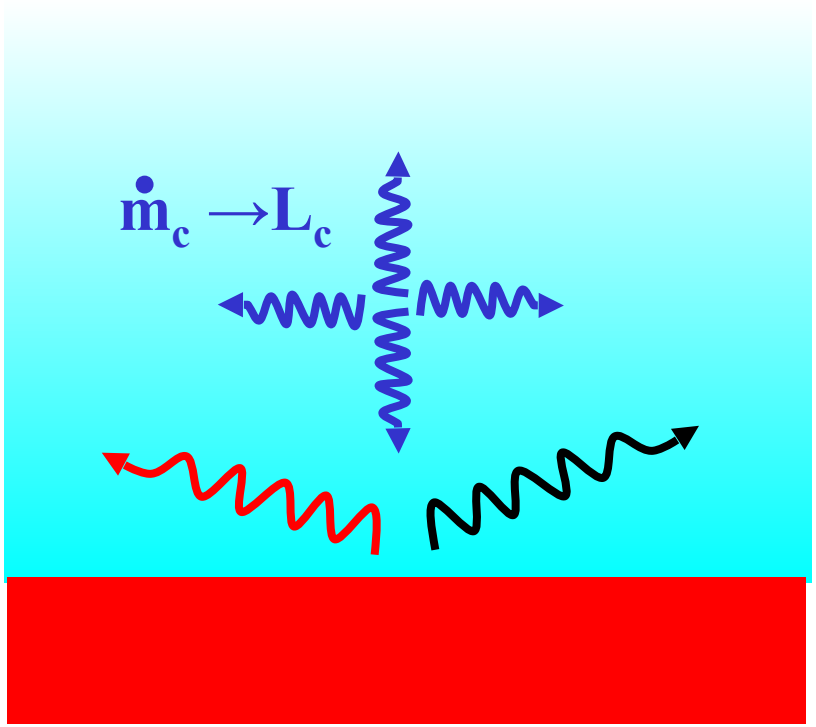
How to make hard spectra

- Seed photons cool corona and spectrum goes SOFT





Haardt & Maraschi 1991,1993
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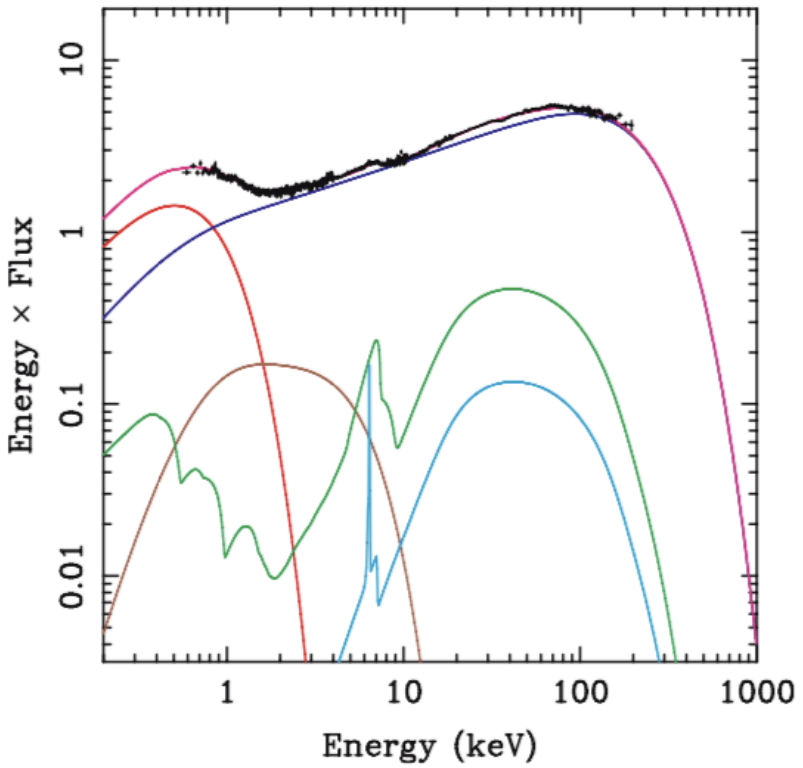
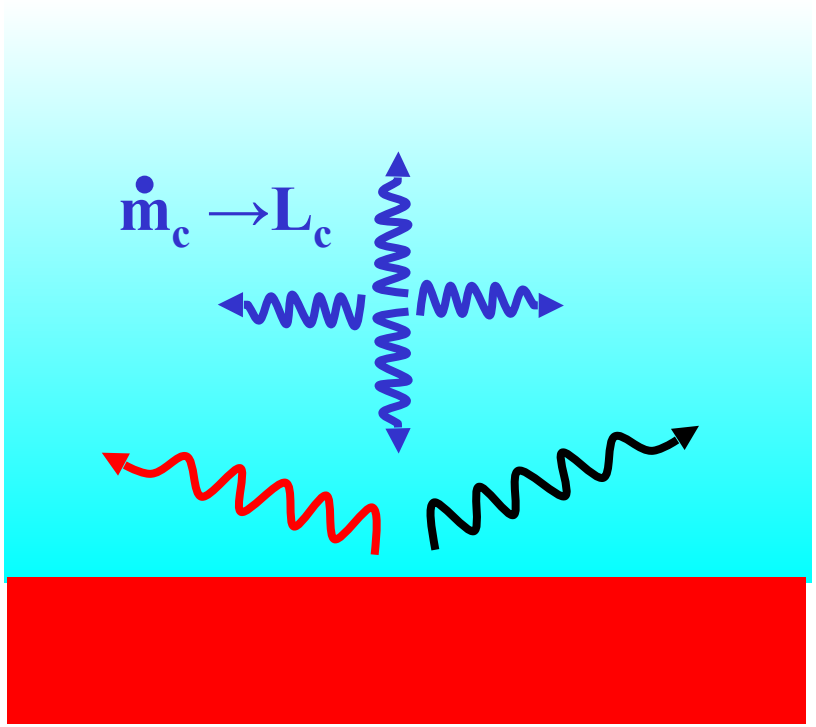
How to make hard spectra

- Reprocessing means Γ>1.95
- But we can see Γ~1.6-1.7!!!





Haardt & Maraschi 1991,1993
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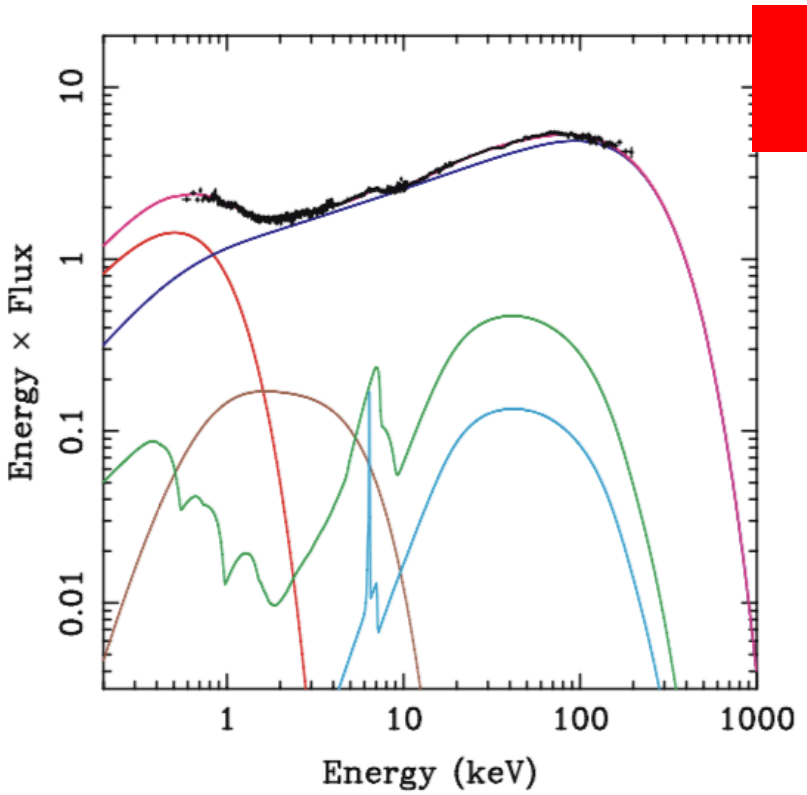
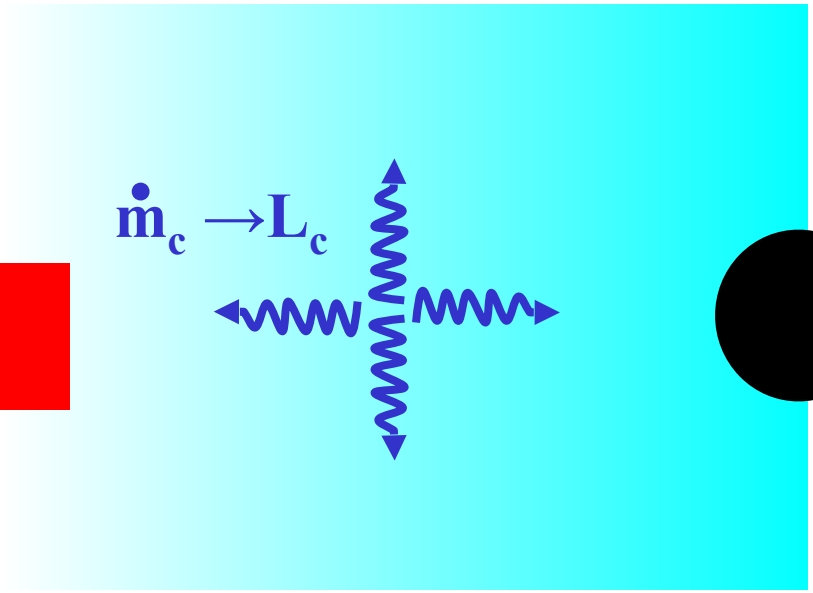
How to make hard spectra

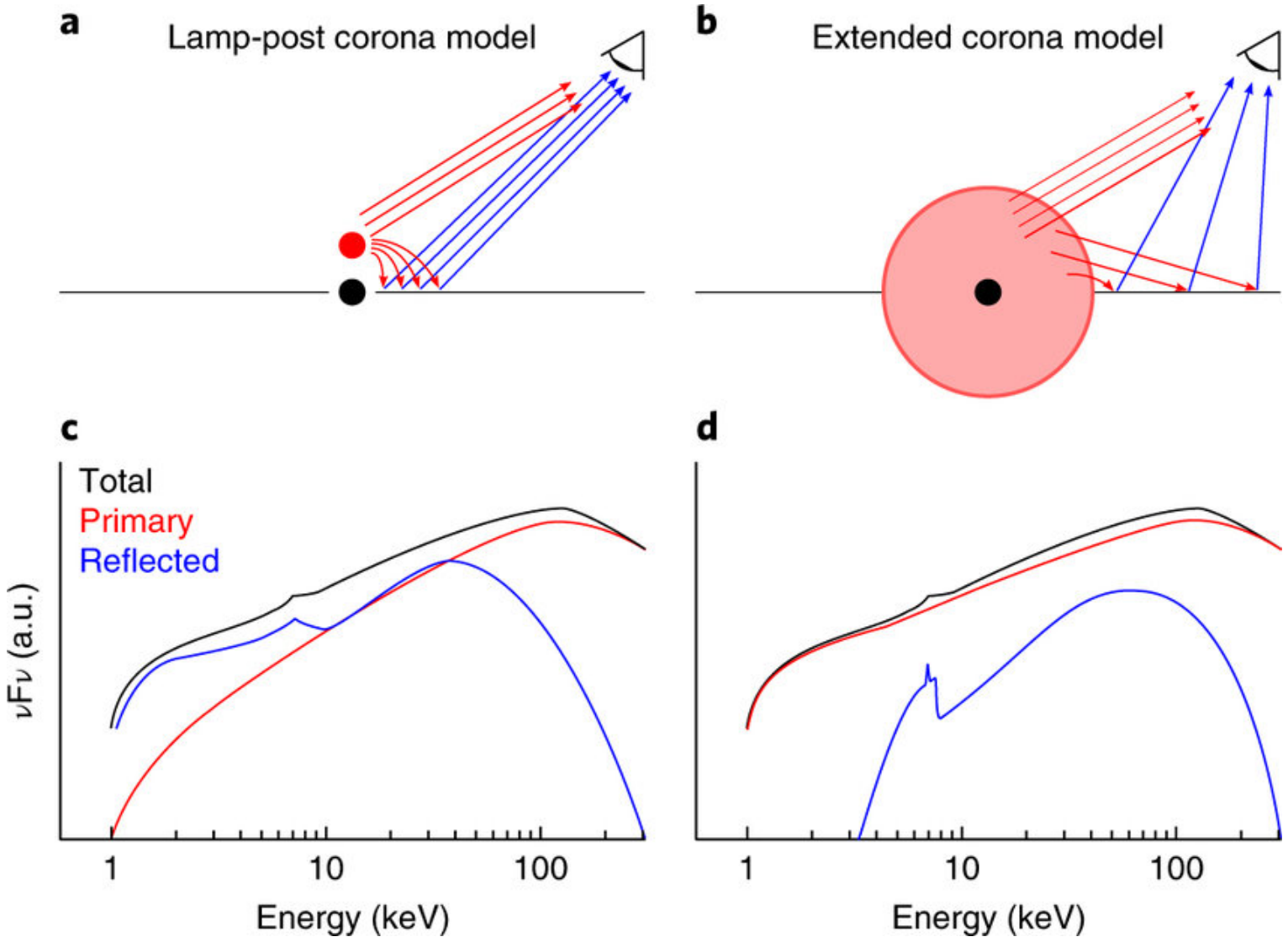
- Reprocessing means Γ>1.95
- But we can see Γ~1.6-1.7!!!
- Truncated disc/hot inner flow





Haardt & Maraschi 1991,1993
Malzac et al 2005
Done, Gierlinski & Kubota 2007
Poutanen et al 2017

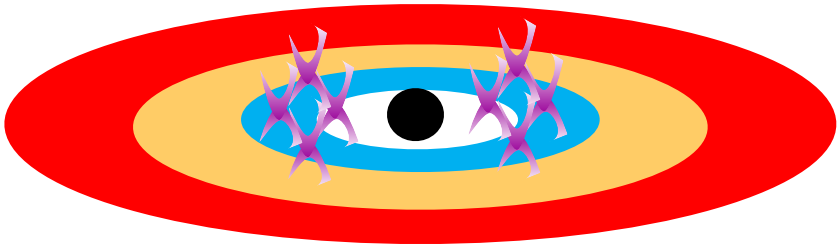
How to make hard spectra?



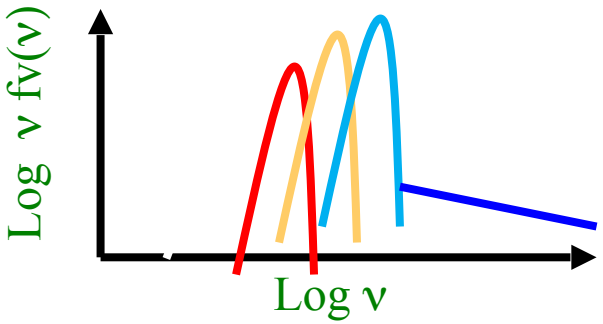
Fabian et al 2012 for Cyg X-1

Chauvin et al 2018

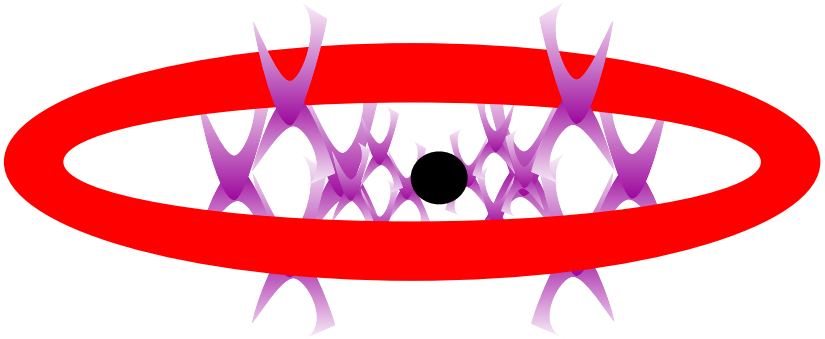
Theory of accretion flows



IR opt UV X-ray



Discs – geometrically thin, cool, optically thick SS73
Plus X-ray tail/corona



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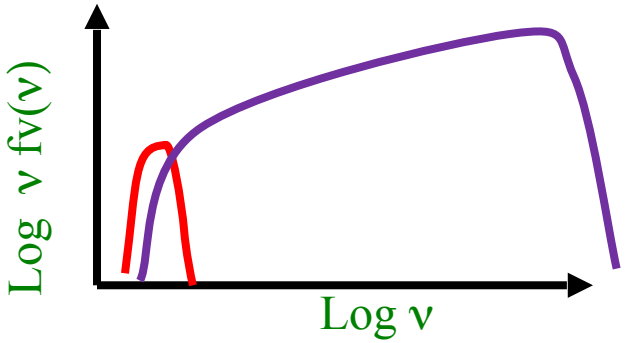
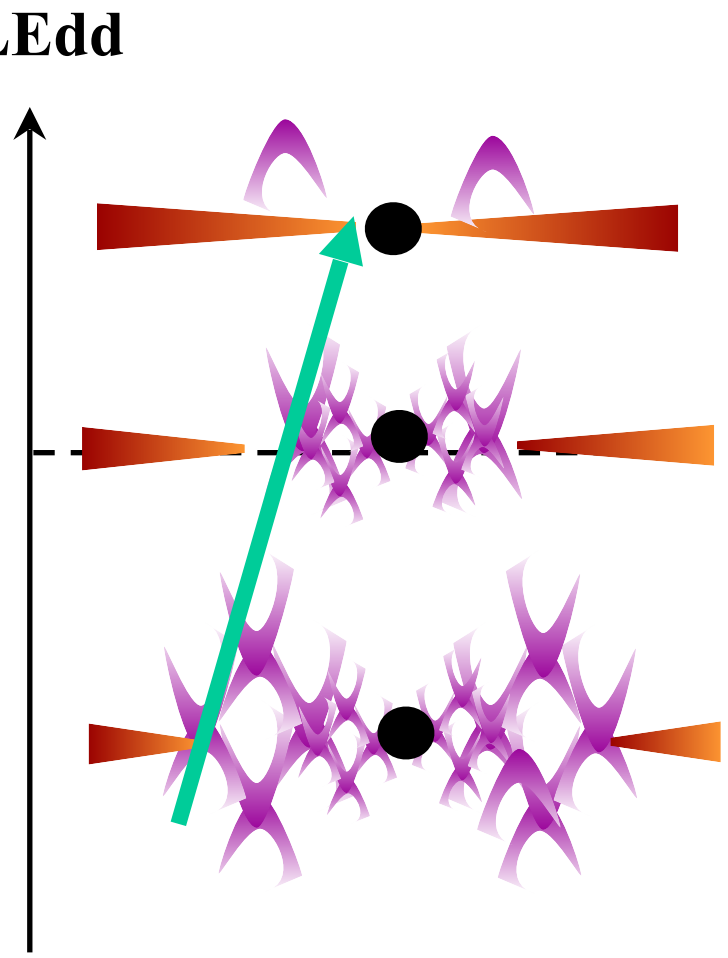


'ADAF'– geometrically thick, hot, optically thin
Only low L/Ledd
Narayan & Yi 1995

BHB accretion – spectral transitions, jets, fast variability….

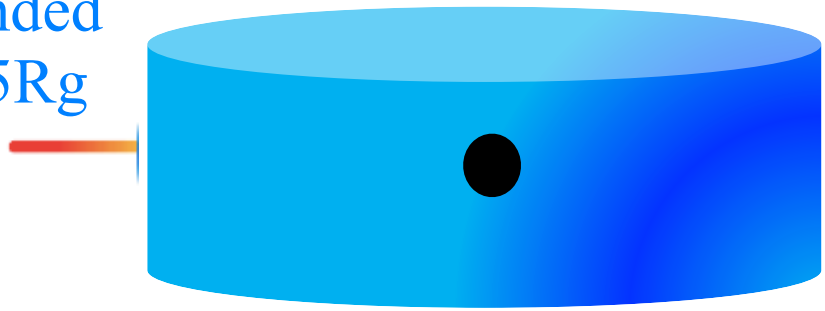
- Complex around Ledd?
- Disc dominated state – Shakura-Sunyaev disc equations!!
- X-ray corona
- Complex transition ~0.02LEdd when slow
- moving Rin-moving QPO / all power spectral features
- ADAF – X-ray hot flow, disc truncated at >20Rg
- BUT WHY?? And HOW??



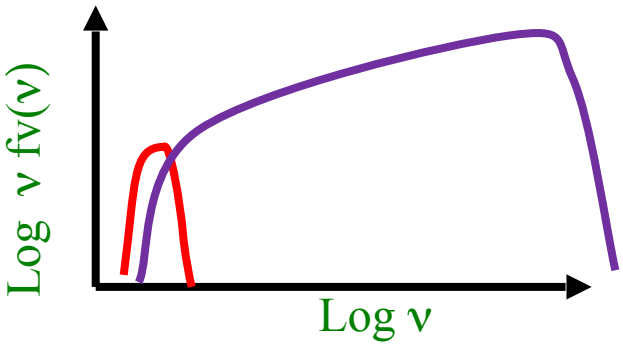
Geometry of corona?

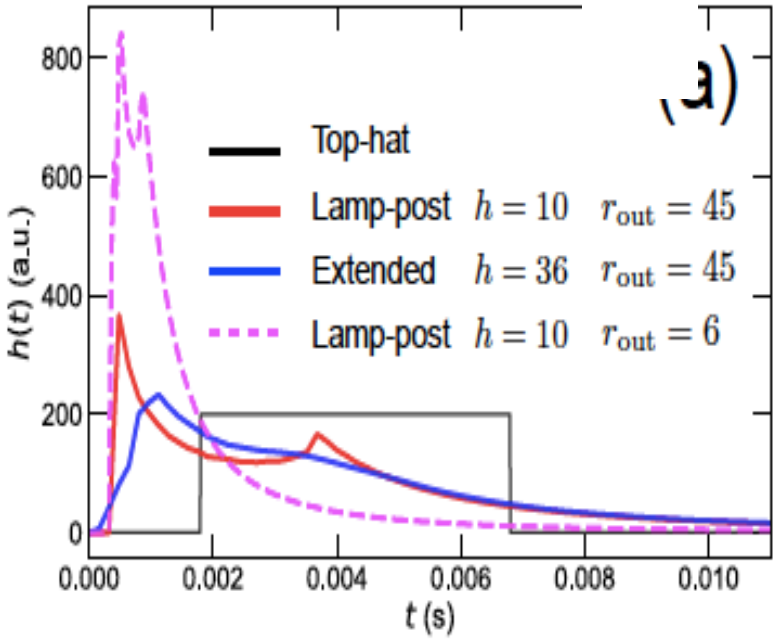
Lamppost
R=45Rg

Extended
R=45Rg



Lamppost
R<6Rg





Kawamura, CD et al 2021

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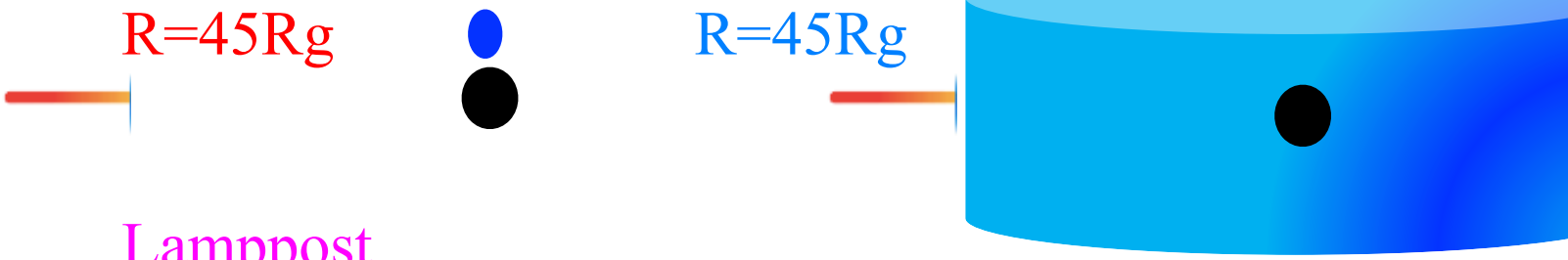

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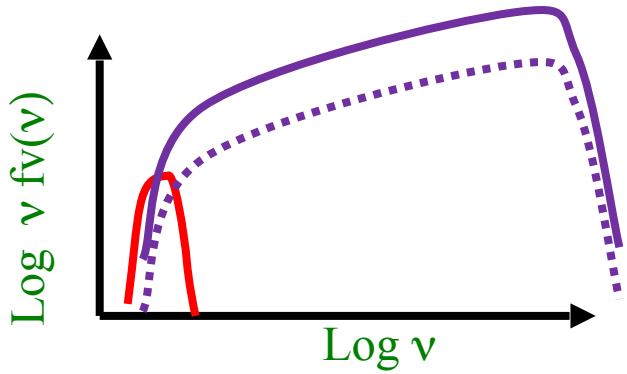

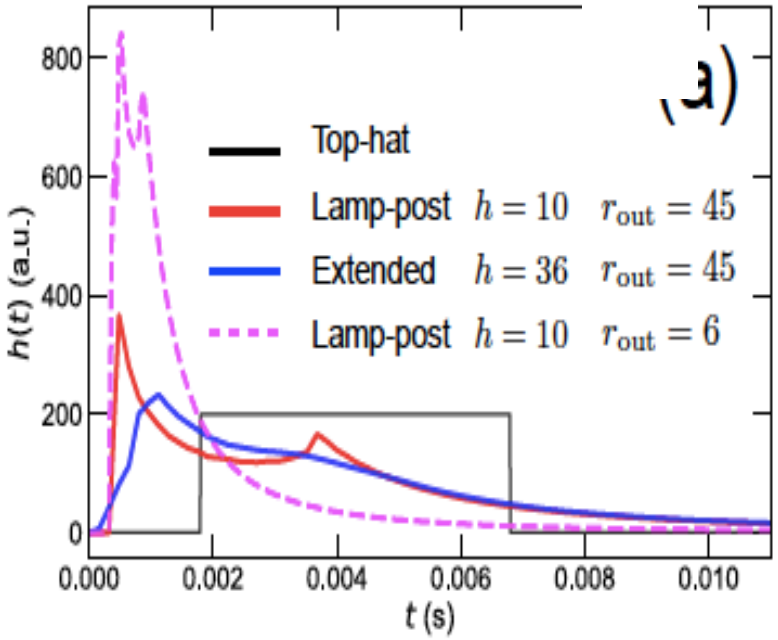

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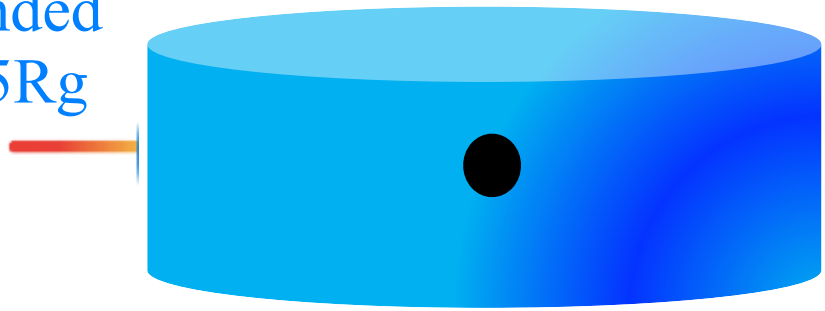

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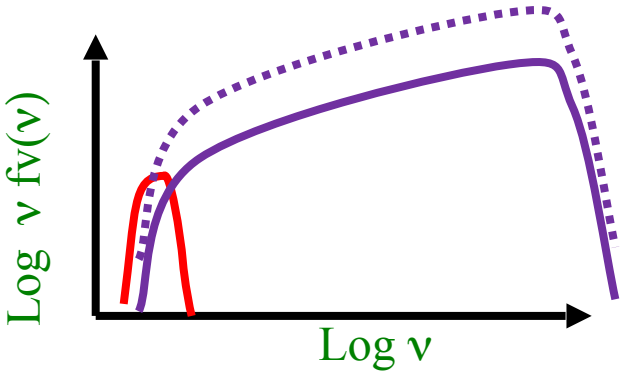

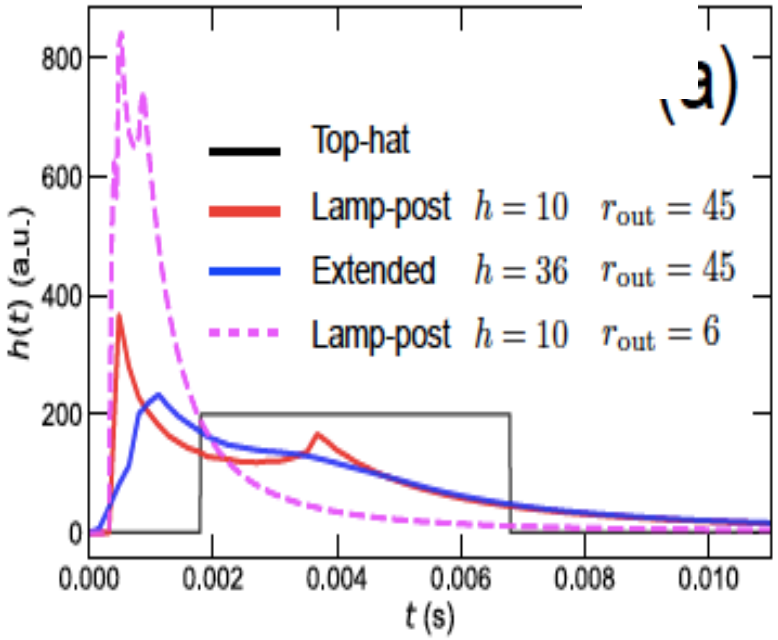

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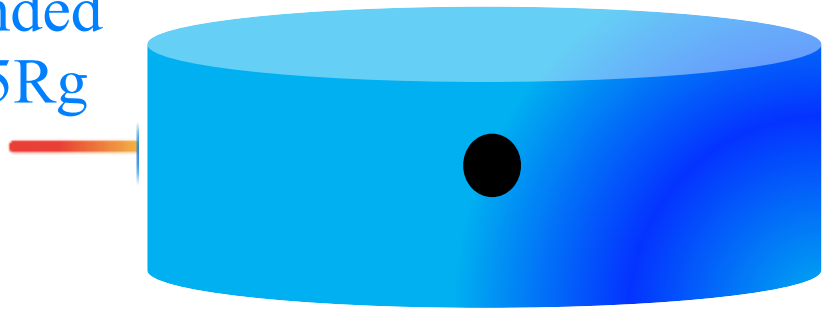

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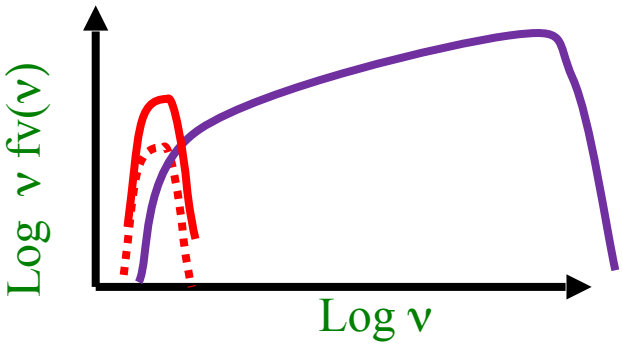
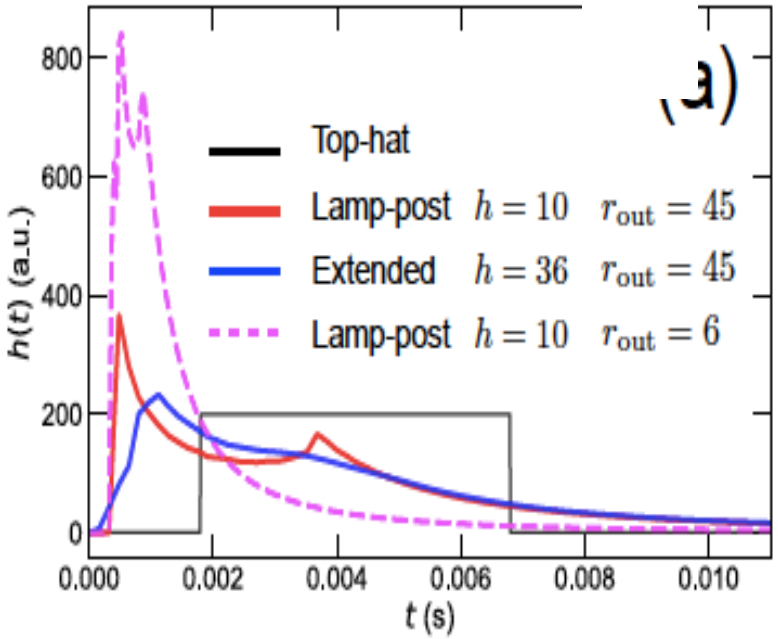
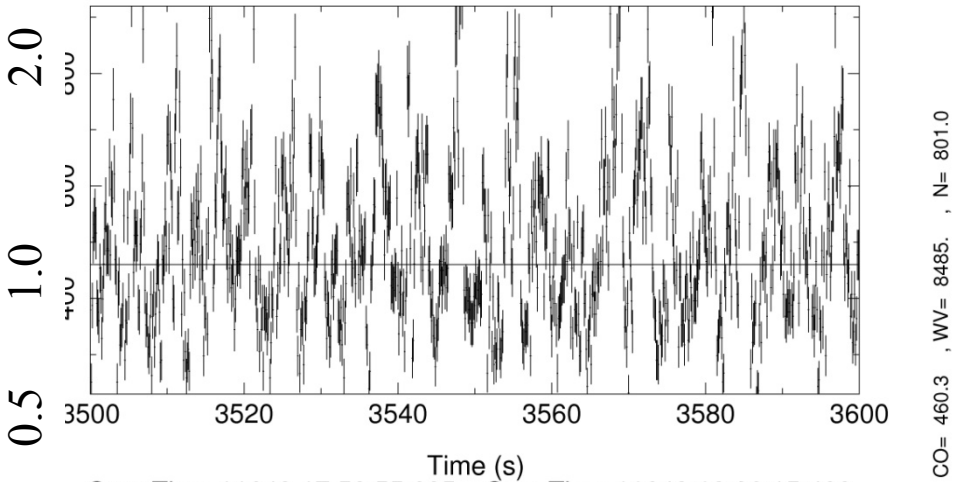


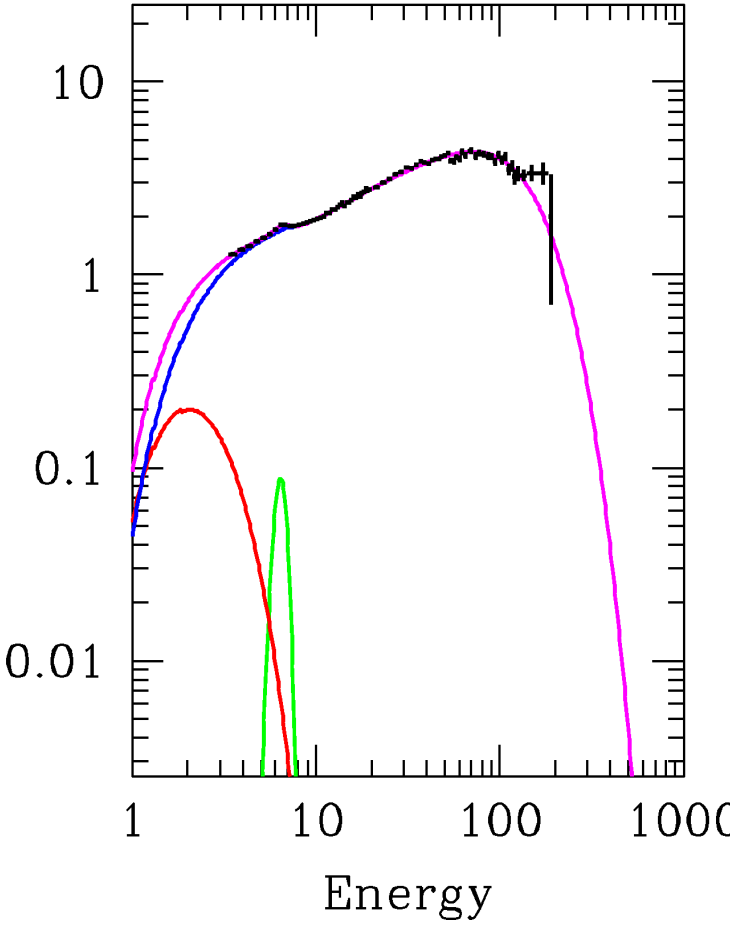


Kawamura, CD et al 2021

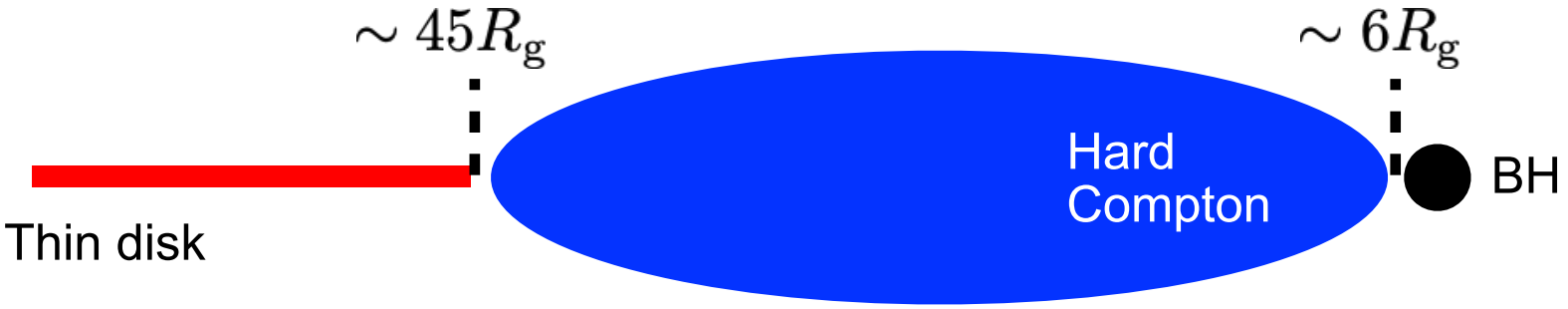
Fast variability low/hard state

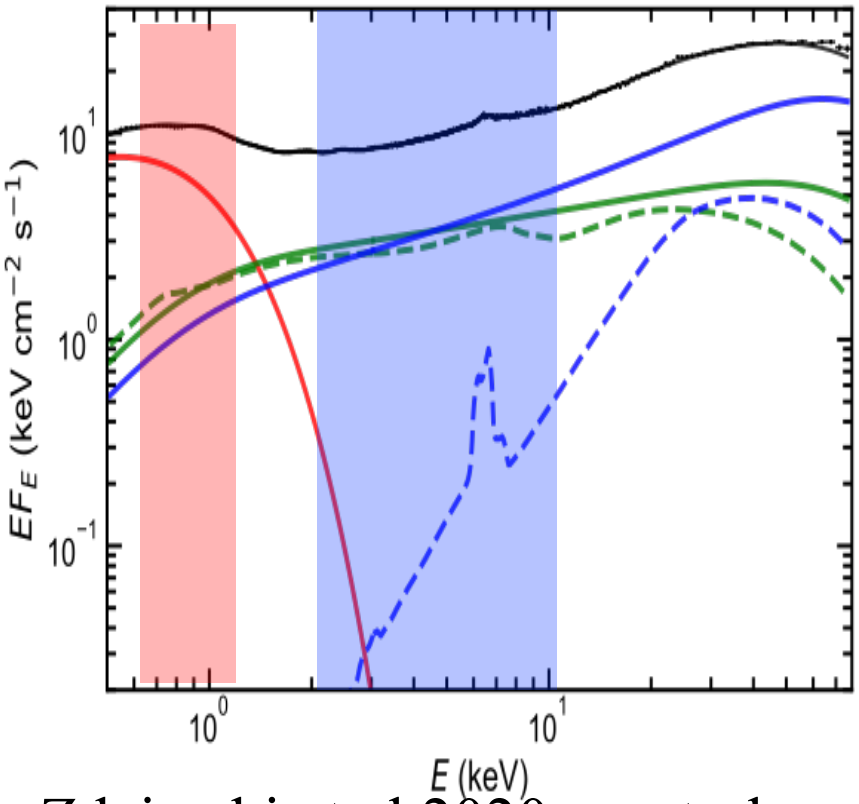
- Low/Hard state variability down to few 10s of ms
- accretion timescale?
- tvisc= 5 α^{-1} $(H/R)^{-2}$ $(r/6)^{-3/2}$ ms need H/R~1
- Accretion time for flow with large scale B field?

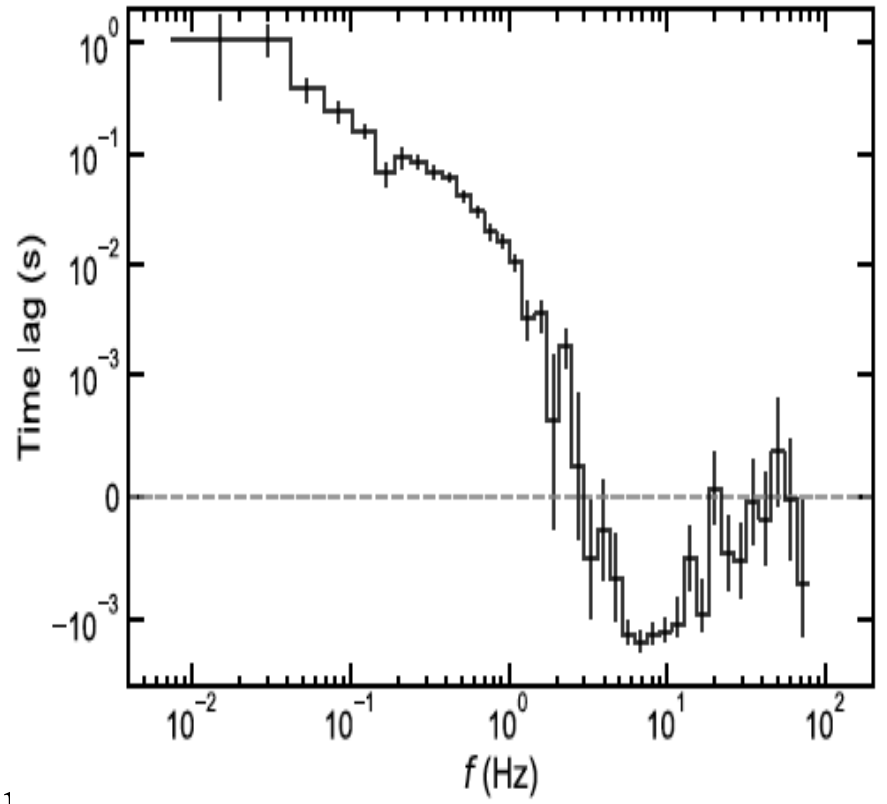




Fast variability



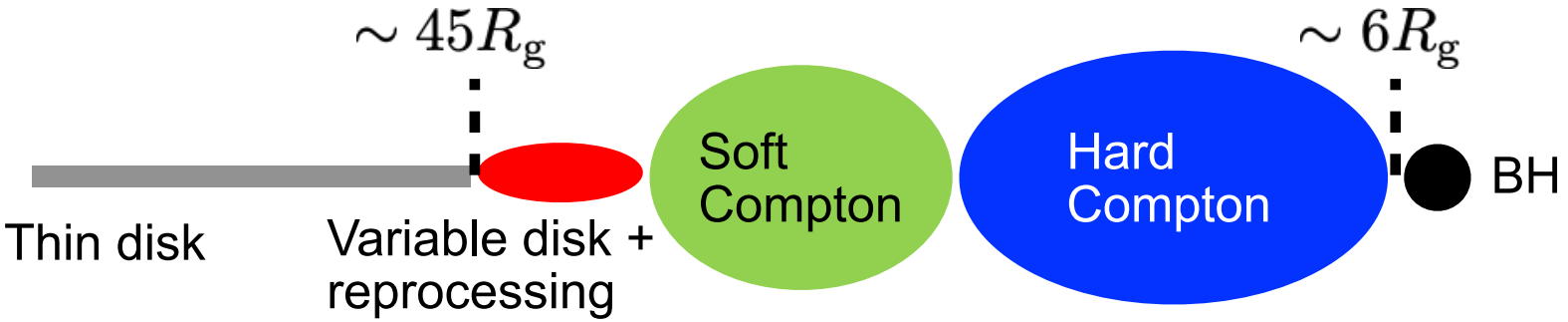


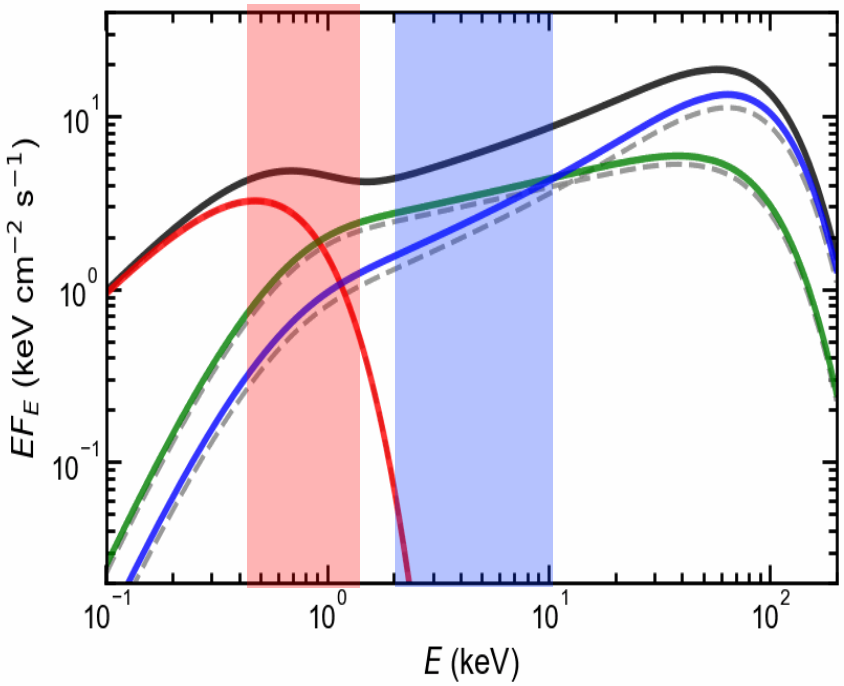


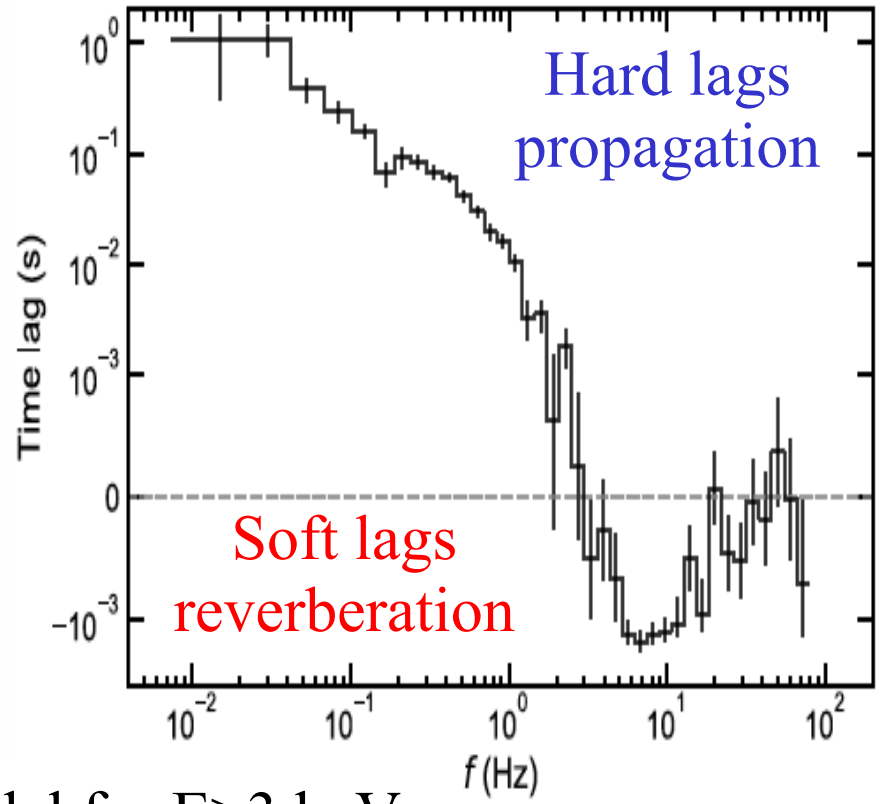
Kawamura, CD et al 2021

Zdziarski et al 2020 spectral model for E > 5 keV

Fast variability



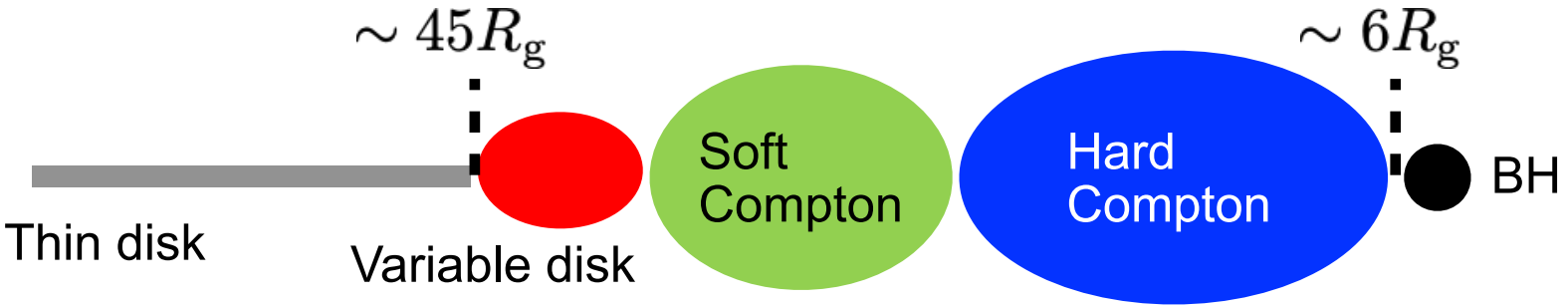


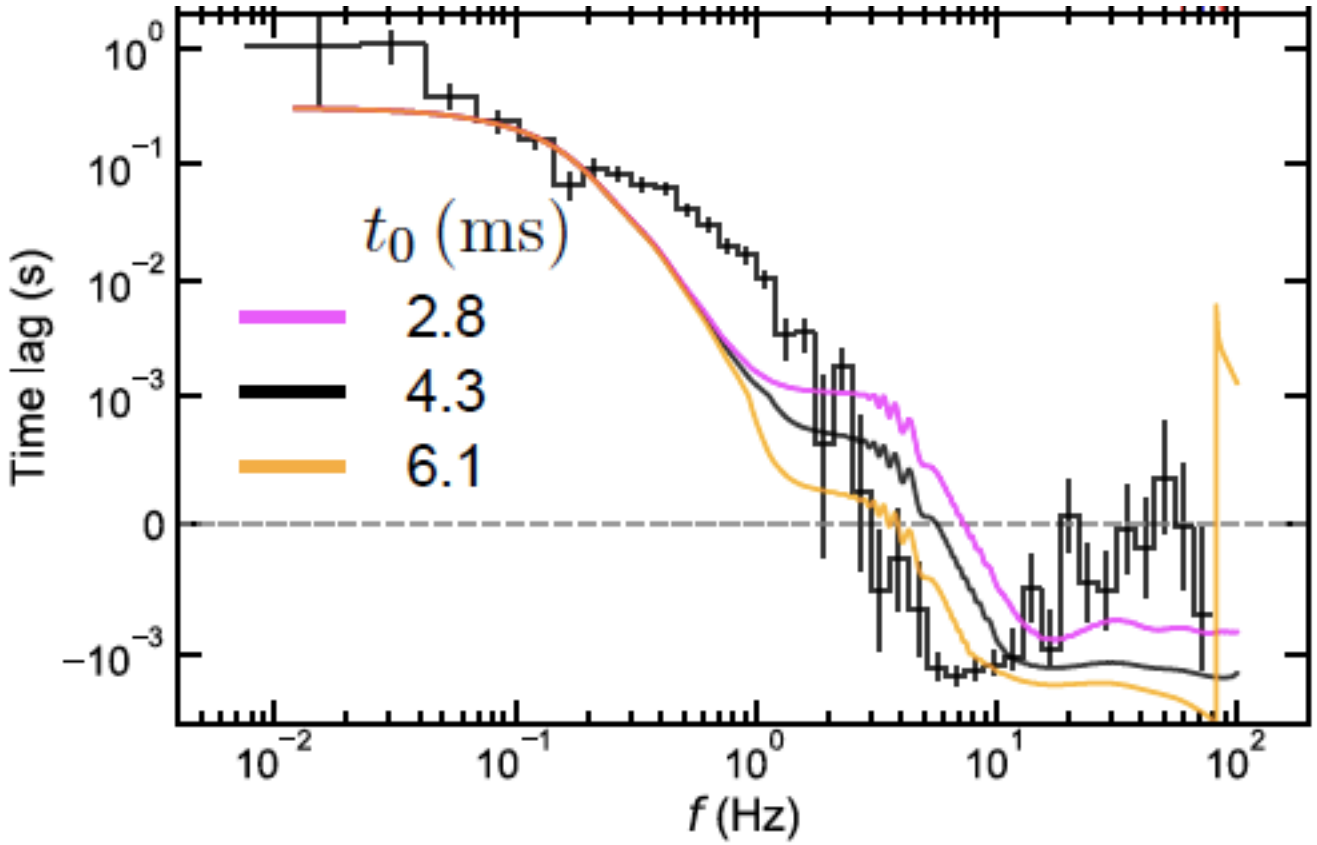


Kawamura, CD et al 2021

Zdziarski et al 2020 spectral model for E>3 keV

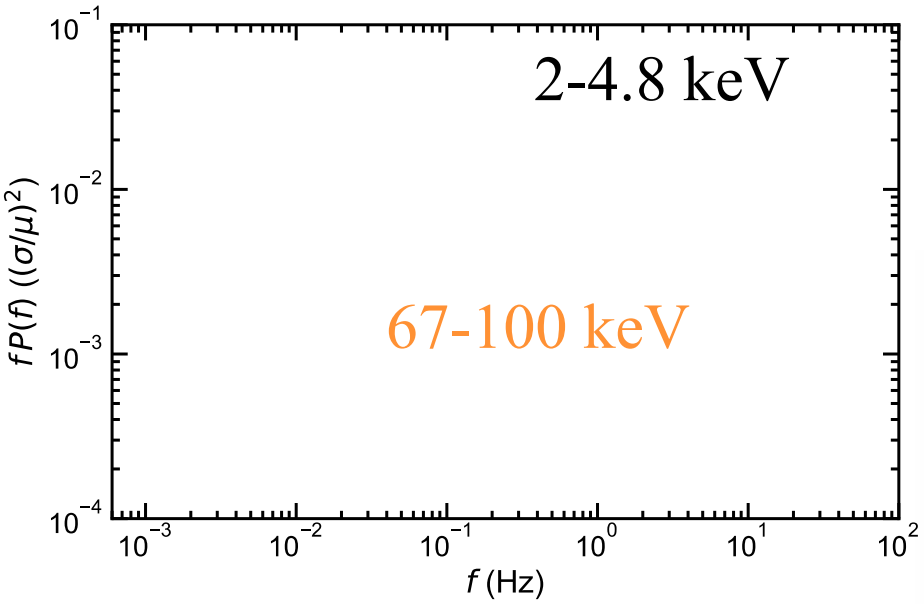
Propagation+reprocessing LAGS

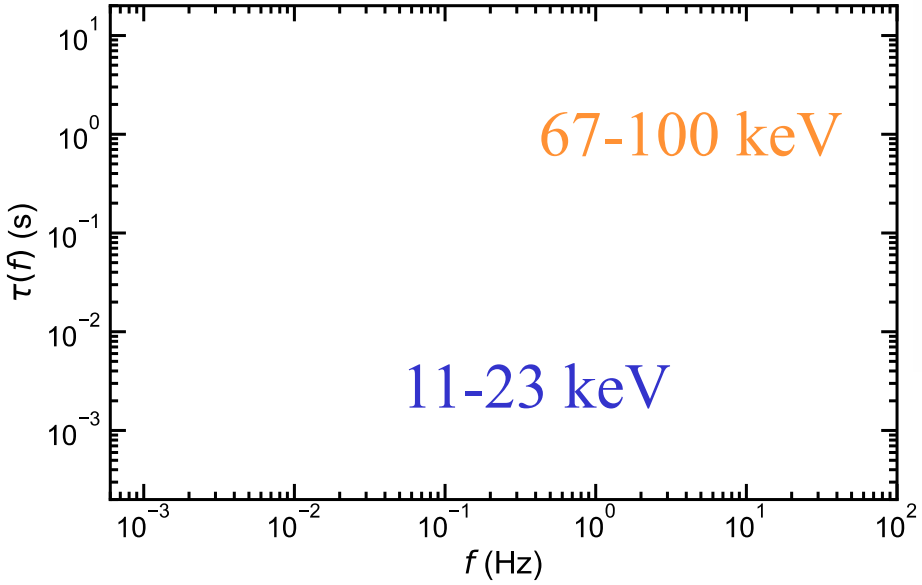


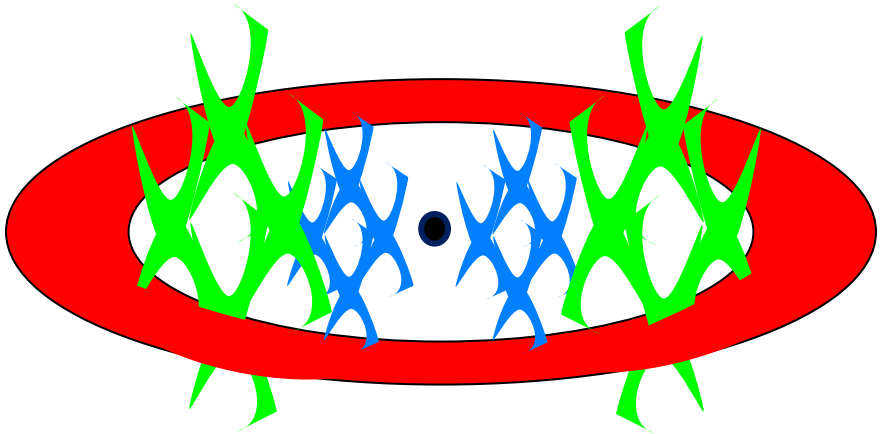


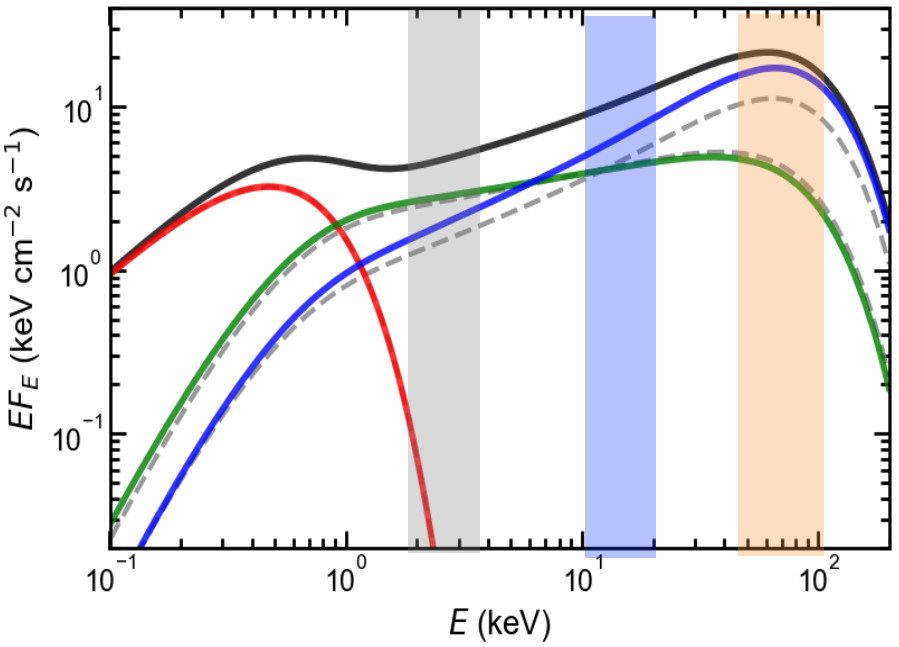
Kawamura, CD et al 2021

Propagation lags



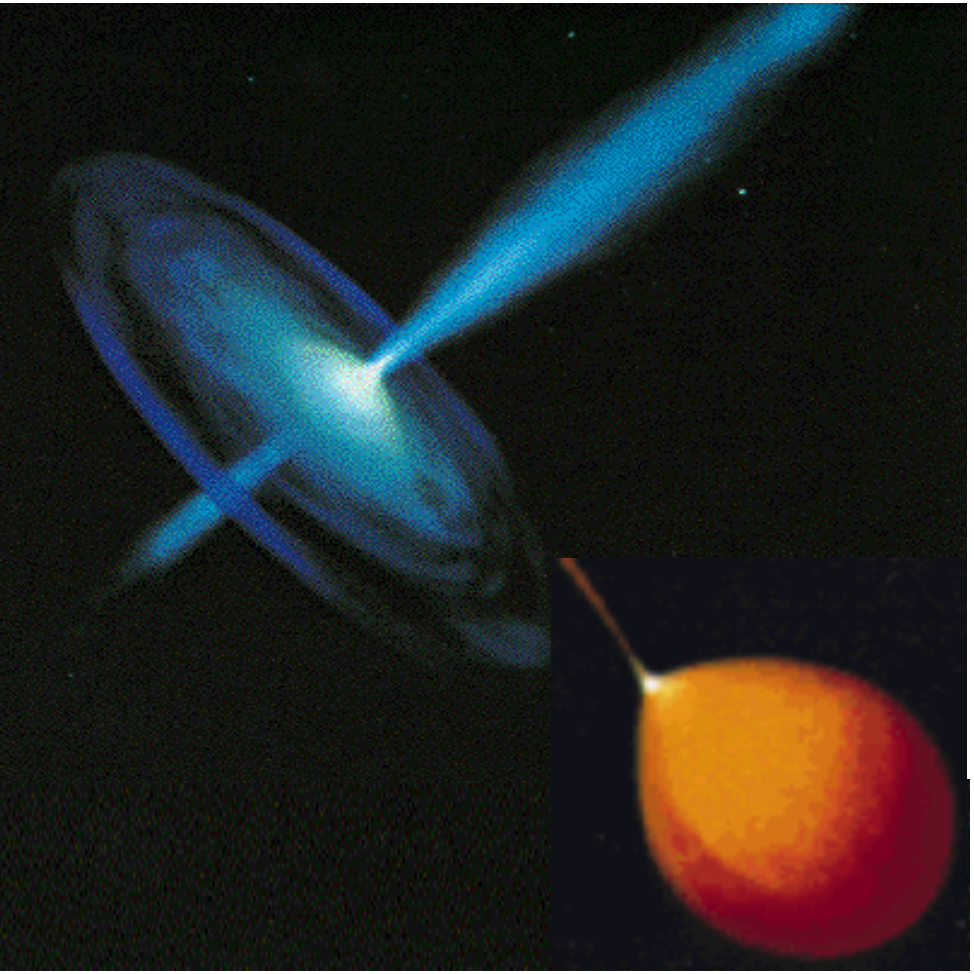


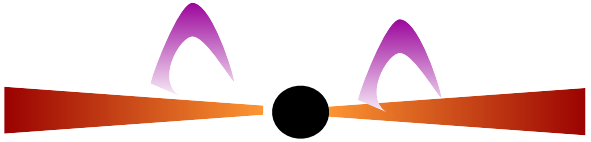


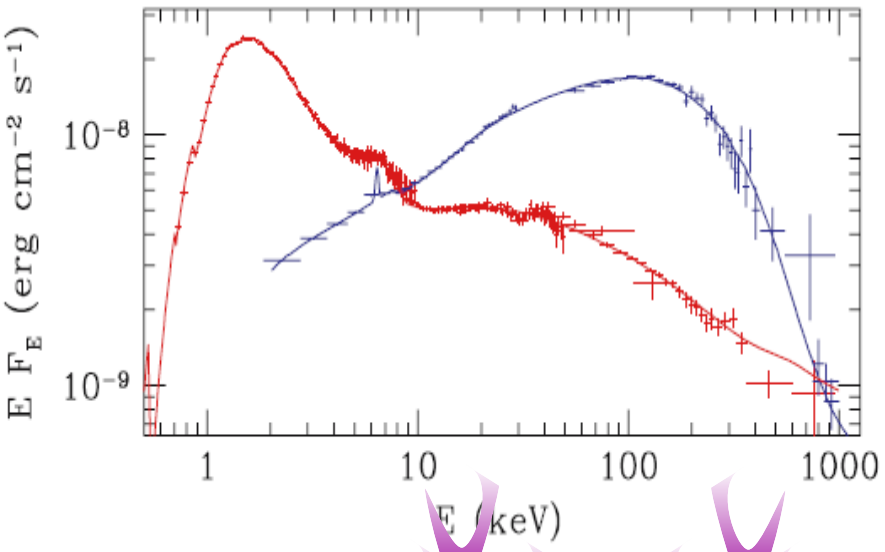


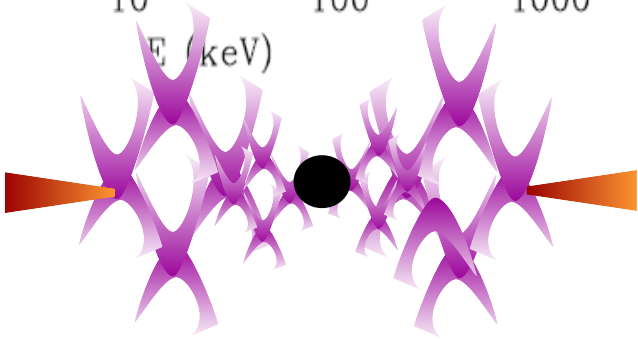
Kawamura CD…2001,2022

Spectral states - BHB



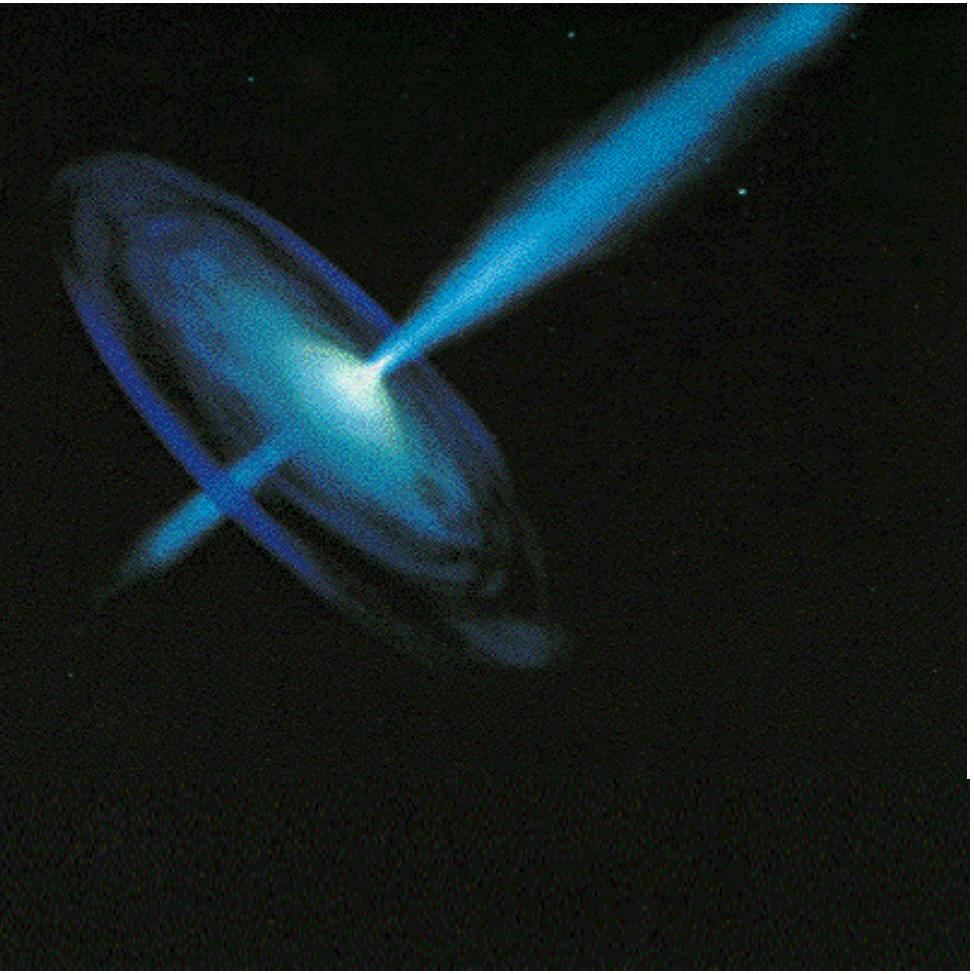






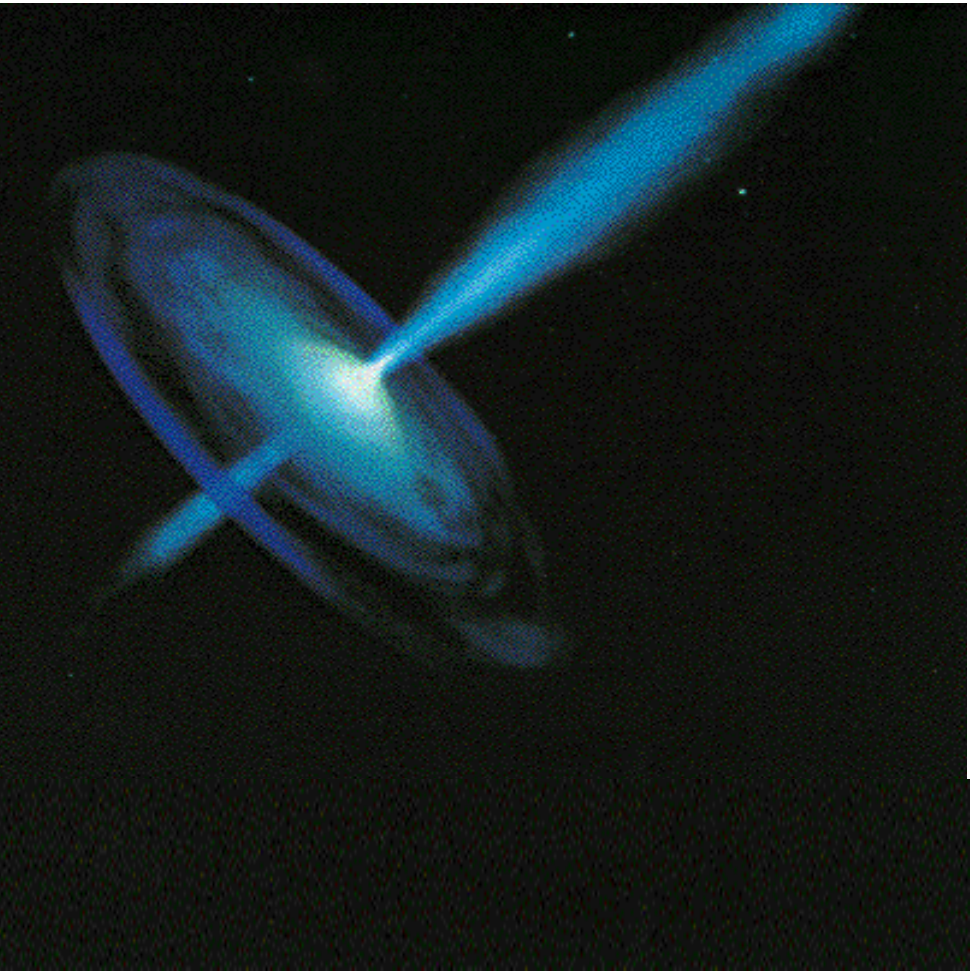
Gierlinski & Done 2003

Scaling black hole accretion flow



- Scale up to AGN
- Bigger mass!
- Bigger RANGE in mass 10^5-10^{10}M
- Bigger RANGE in Mdot and hence L
- Bigger RANGE in spin

Scaling black hole accretion flow



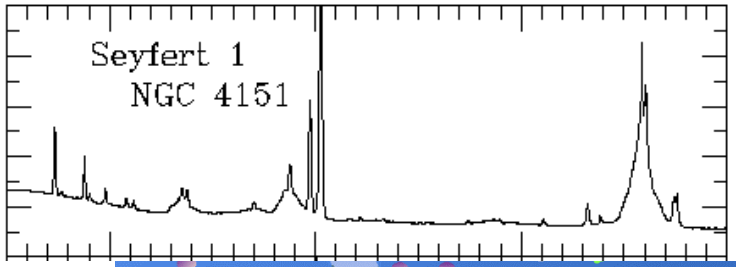
- Scale up to AGN
- Bigger mass

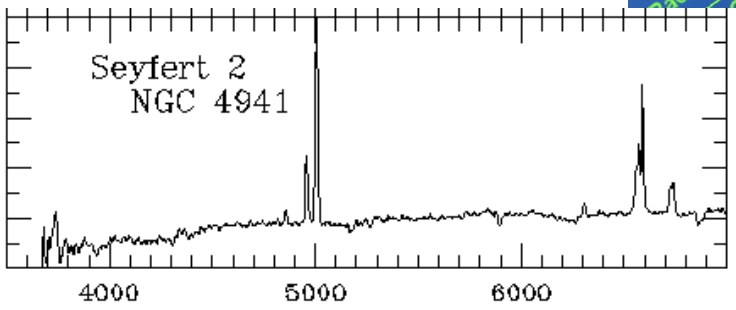
- Disc temp lower – peaks in UV (more power, but more area!)
- ATOMIC PHYSICS – breaks scaling

- Radiation pressure more dominant – breaks scaling

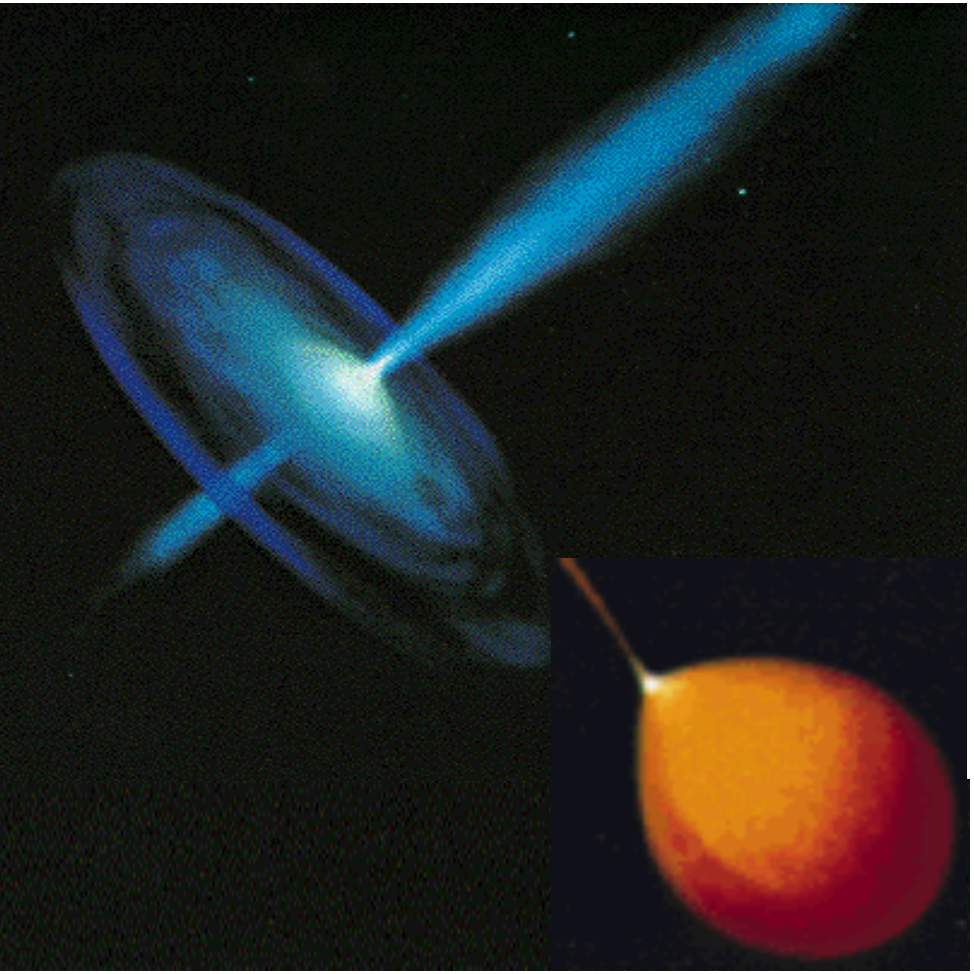
And environment/inclination

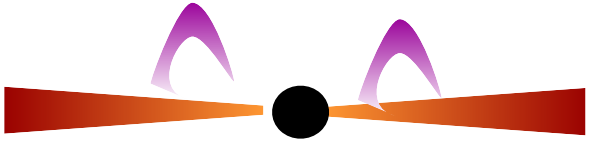
- AGN: complex environment
- From now on do NOT take obscured objects
- (we have enough problems with the ones we CAN see)

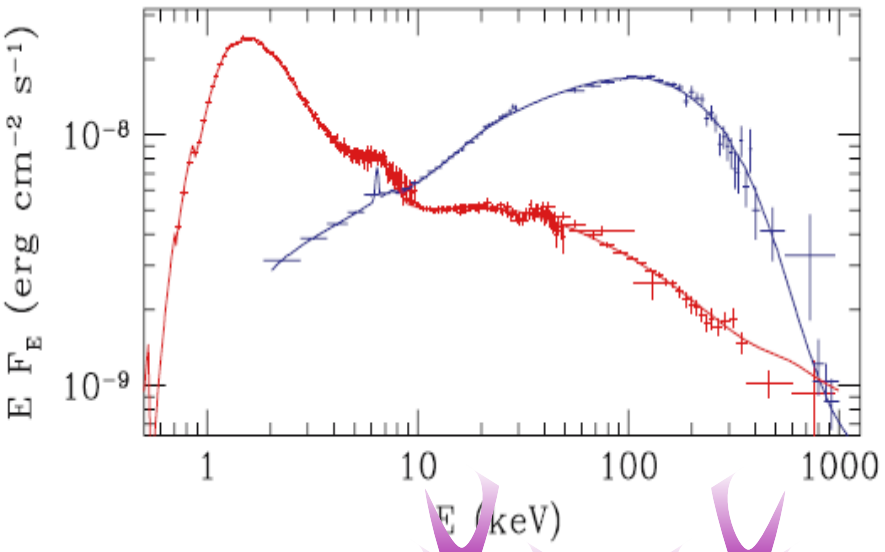


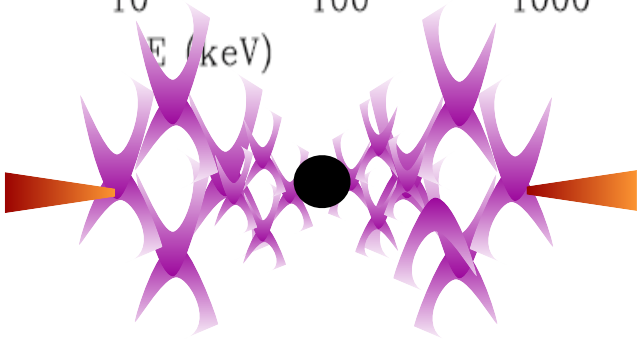


Spectral states - BHB





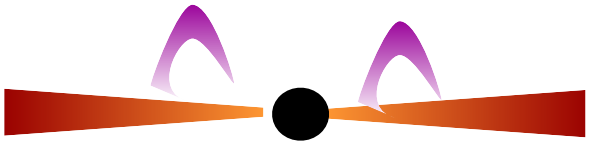


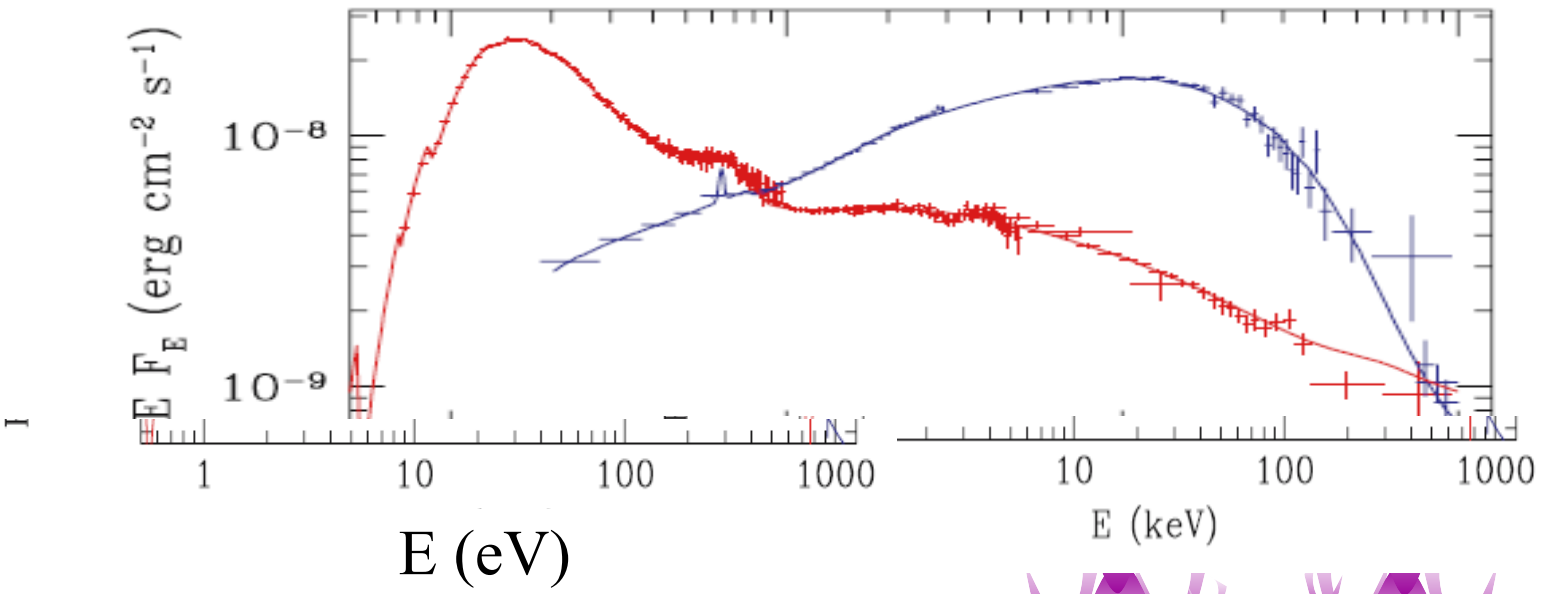


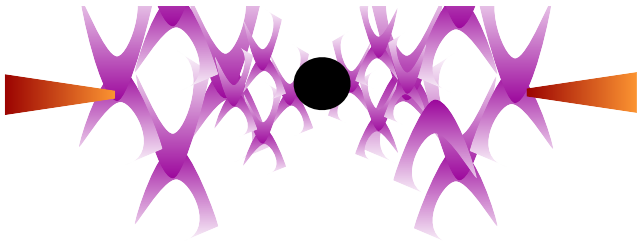
Gierlinski & Done 2003

Spectral states – AGN

- $T^4 \sim (\dot{M}/M)$
- 10Msun to 10^8 Msun



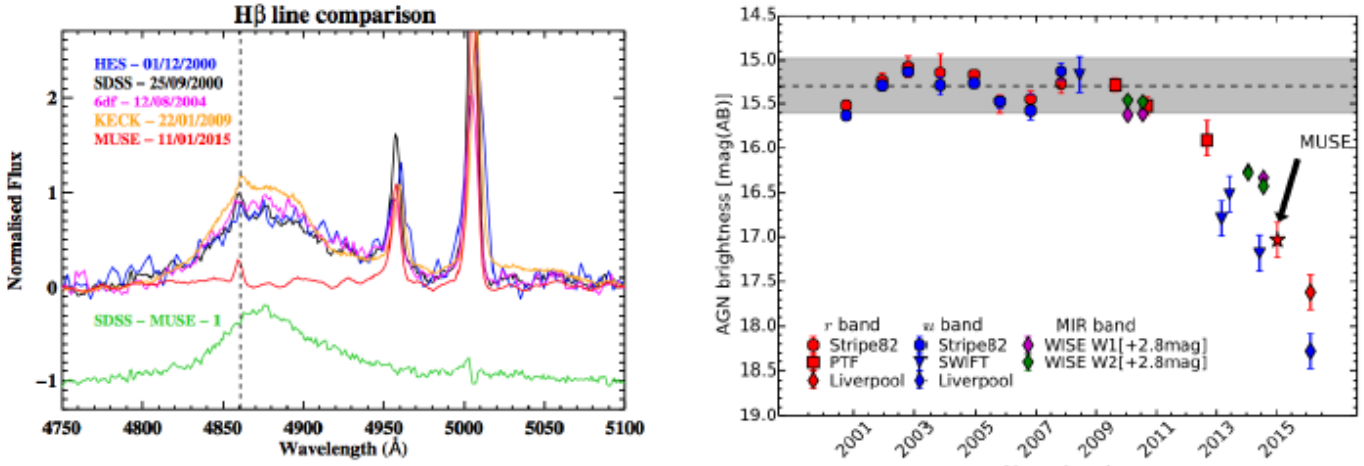




Gierlinski & Done 2003

Changing look (state!) AGN – Mrk 1018

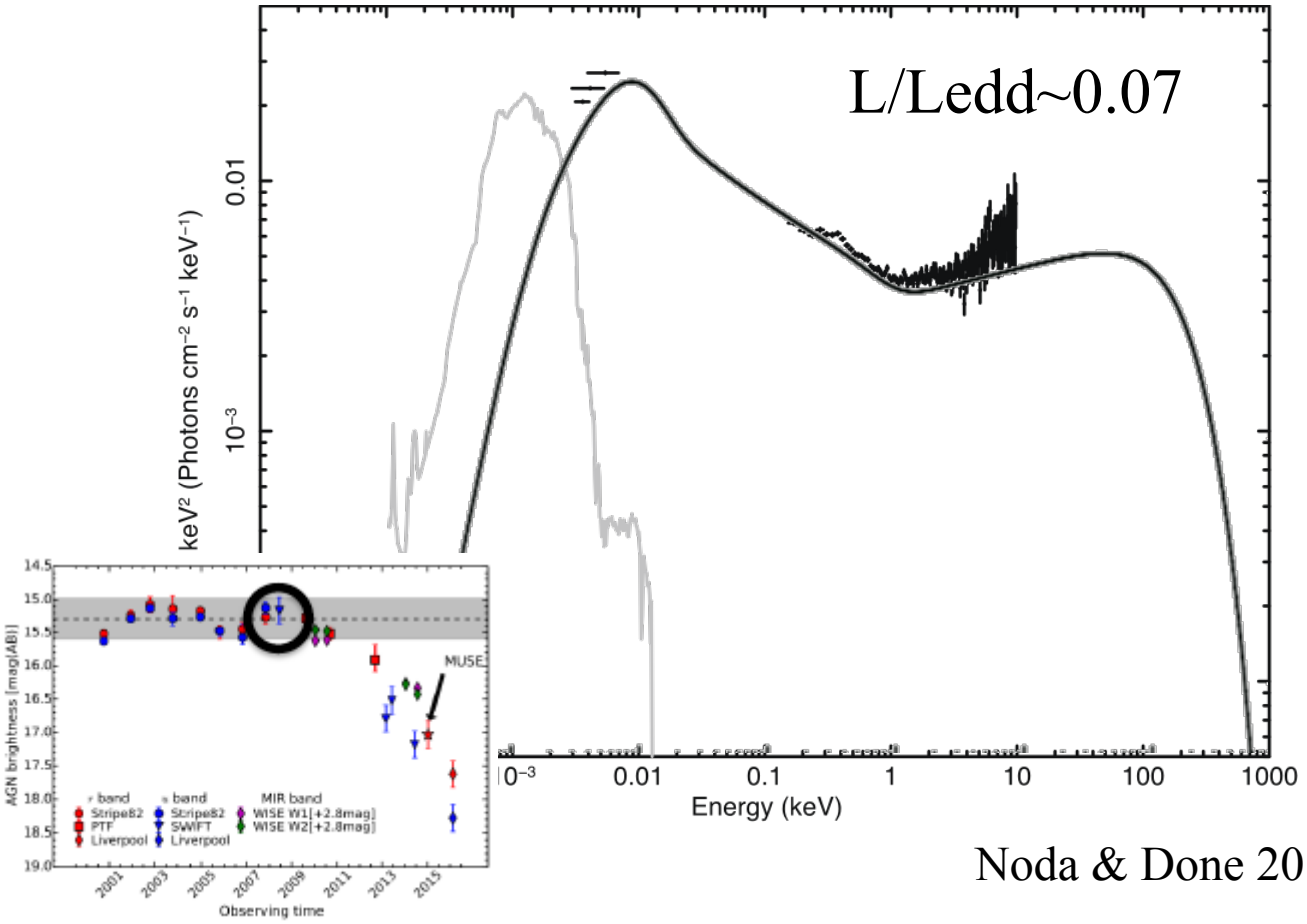
- Broad lines disapear/drop substantially
- Disc continuum (opt/UV) drops substantially



Mrk 1018 (McElrony+16)

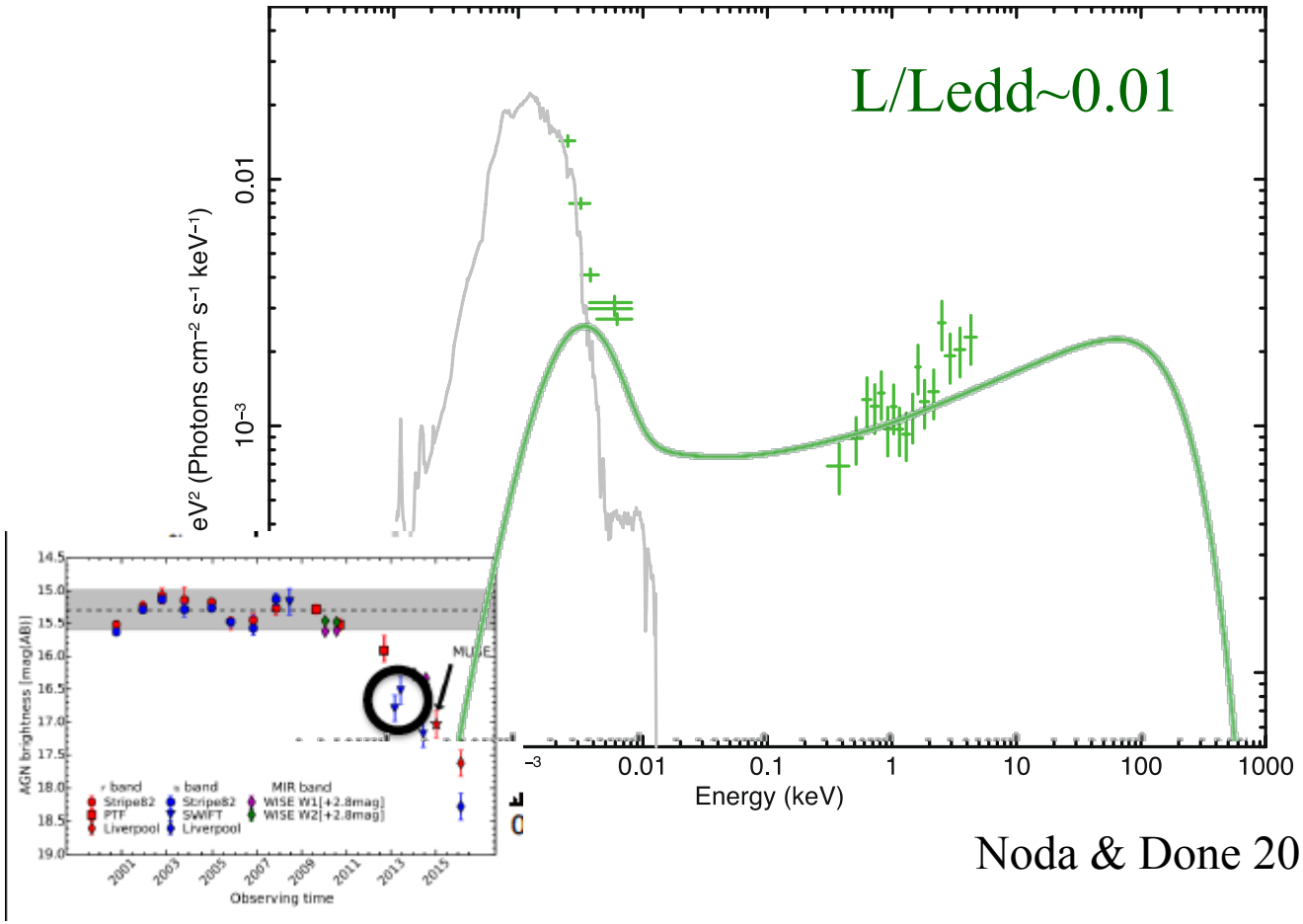
Host galaxy contaminates optical

Changing look (state!) AGN – Mrk 1018



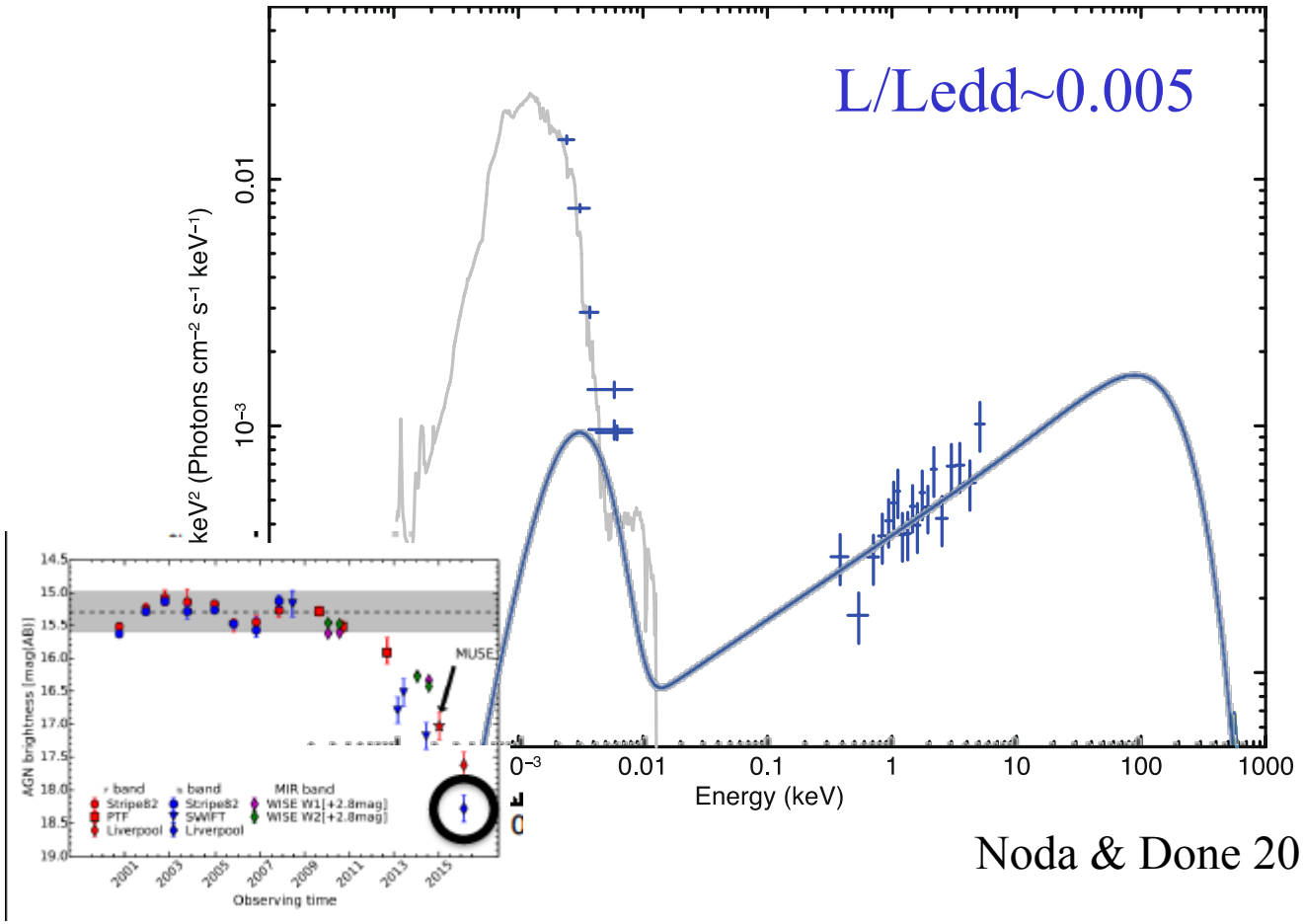
Noda & Done 2018

Changing look (state!) AGN – Mrk 1018



Noda & Done 2018

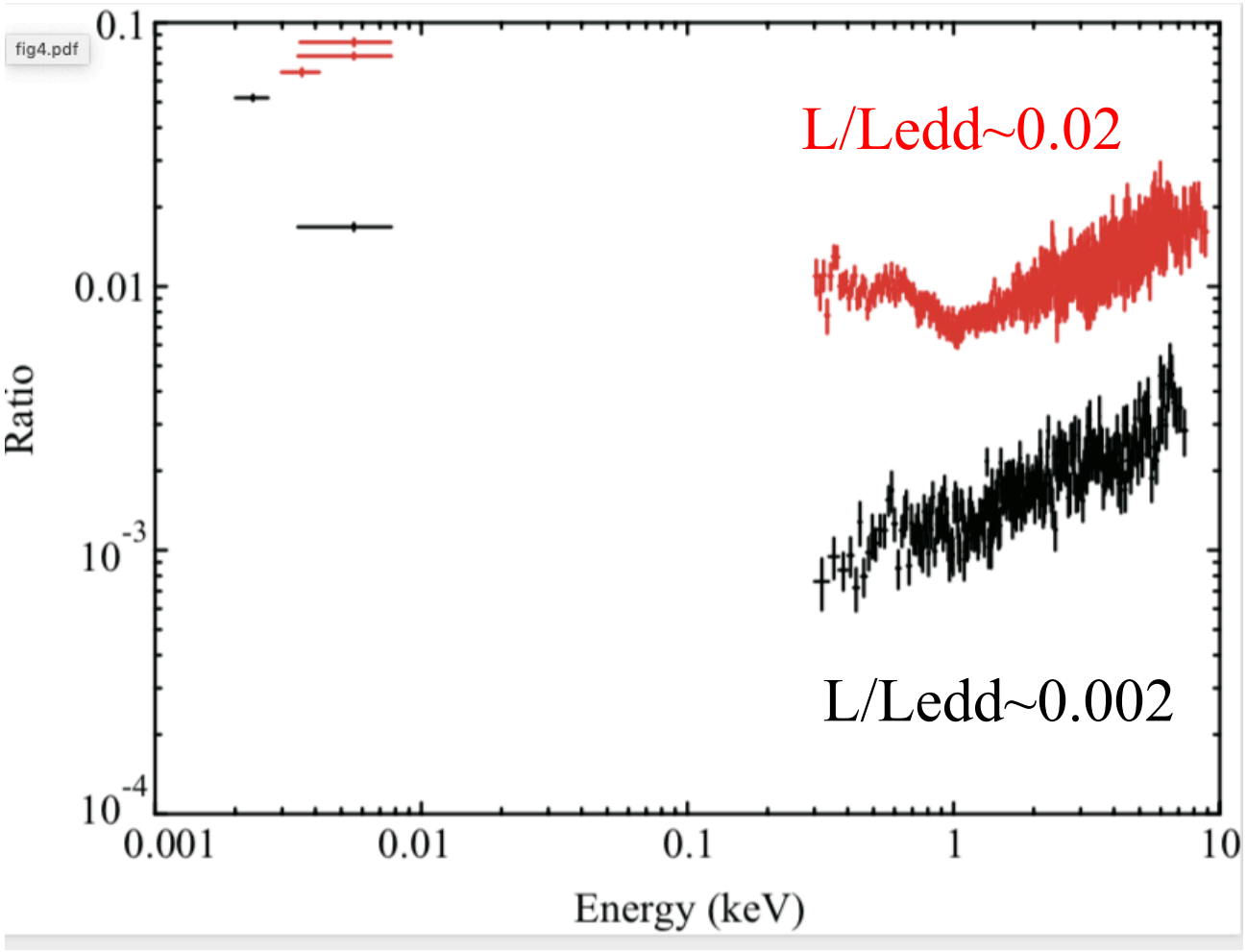
Changing look (state!) AGN – Mrk 1018



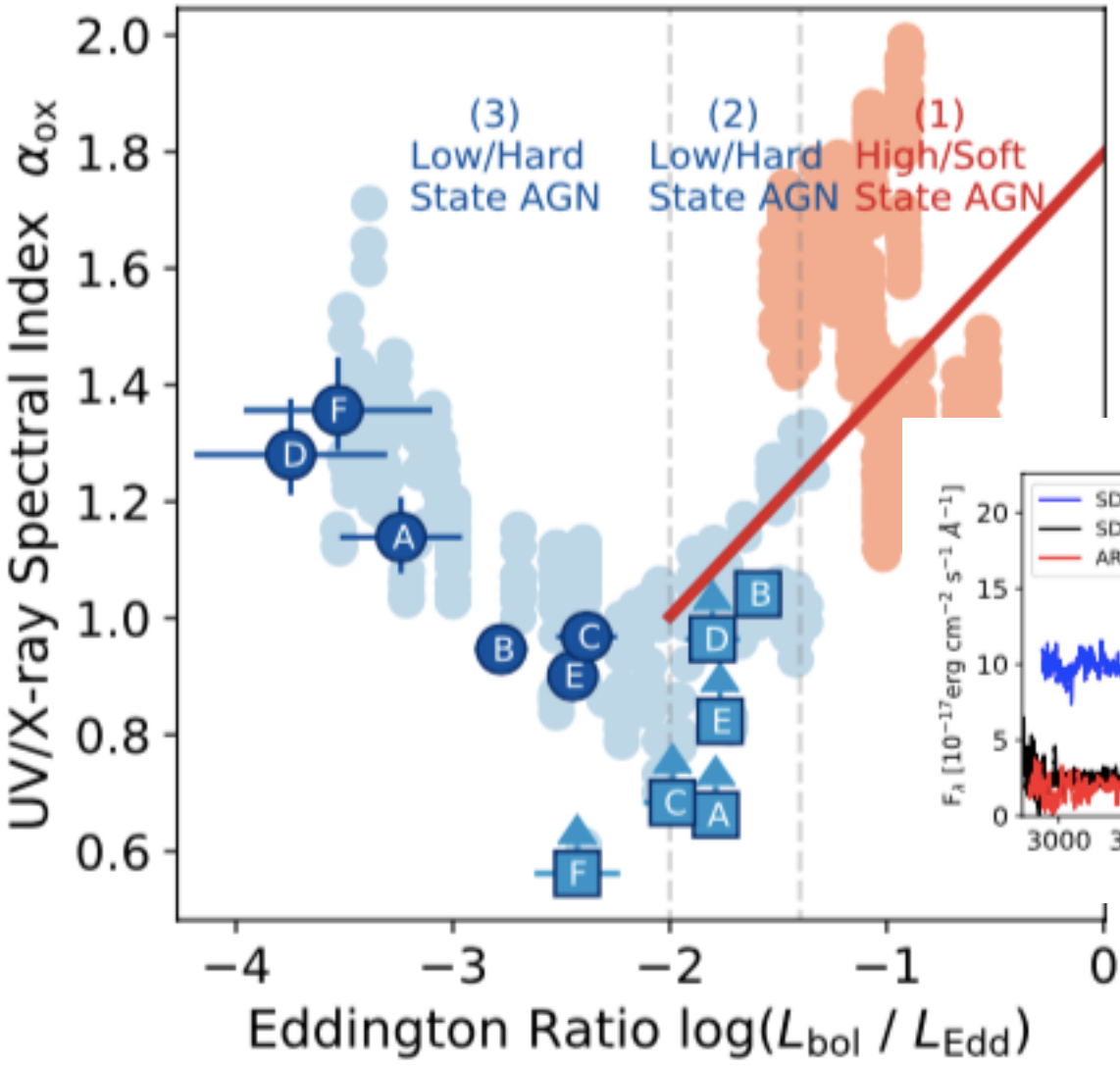
Noda & Done 2018

Changing look (state!) AGN – NGC6814

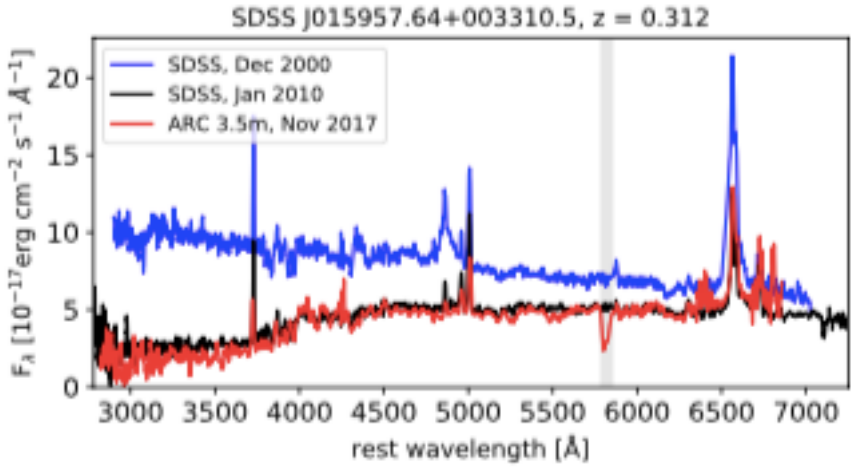
Noda & Done 2020



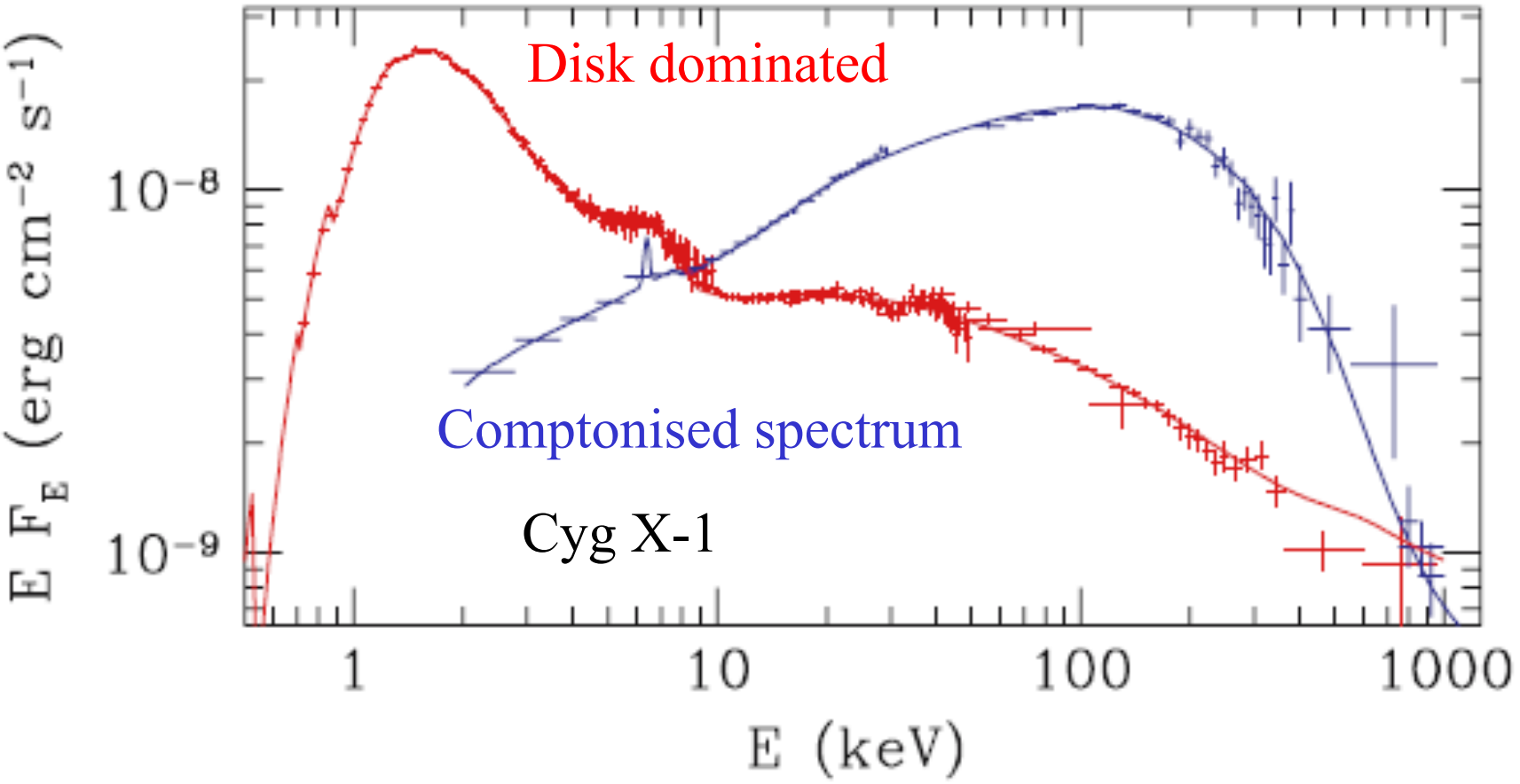
Sample of changing state AGN ~ 0.01Ledd



Ruan et al 2019
Squares – type 1
Circles - 1.9-2



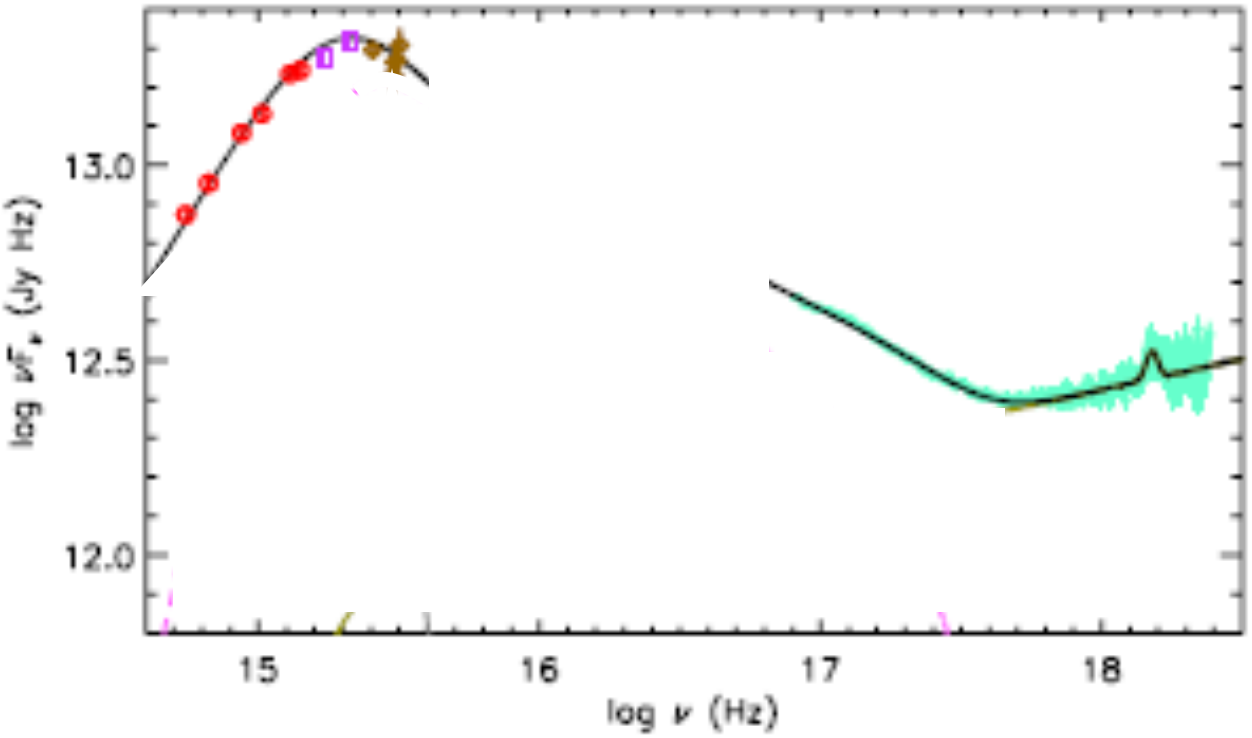
Transitions seen in stellar BH AND IN CL-AGN



Gierlinski et al 1999

Accretion flow at L~0.1 LEdd

- Mkn 509 - 10^8M L/LEdd~0.1 (take out warm abs!)
- Not disc dominated - far too low temperature!
- Hard X-ray spectrum >2keV, soft X-ray excess <1keV



Medhipour et al 2011

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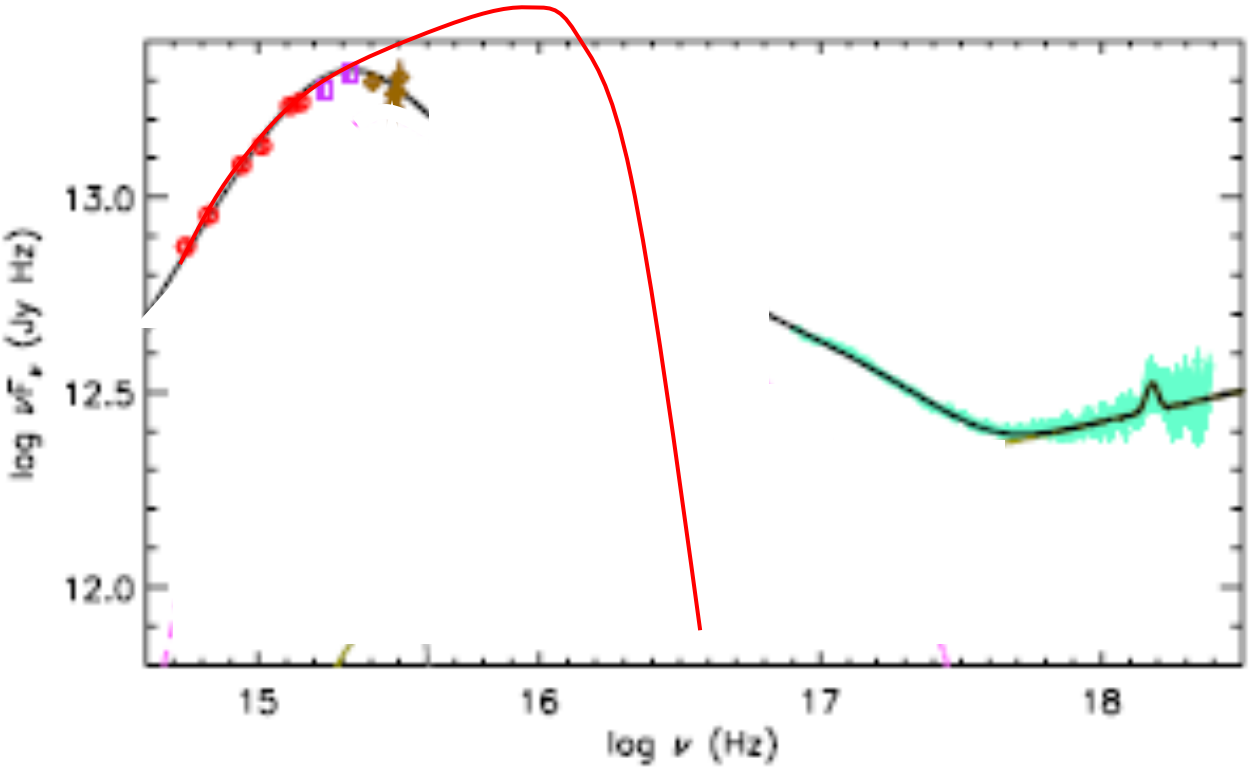

Medhipour et al 2011

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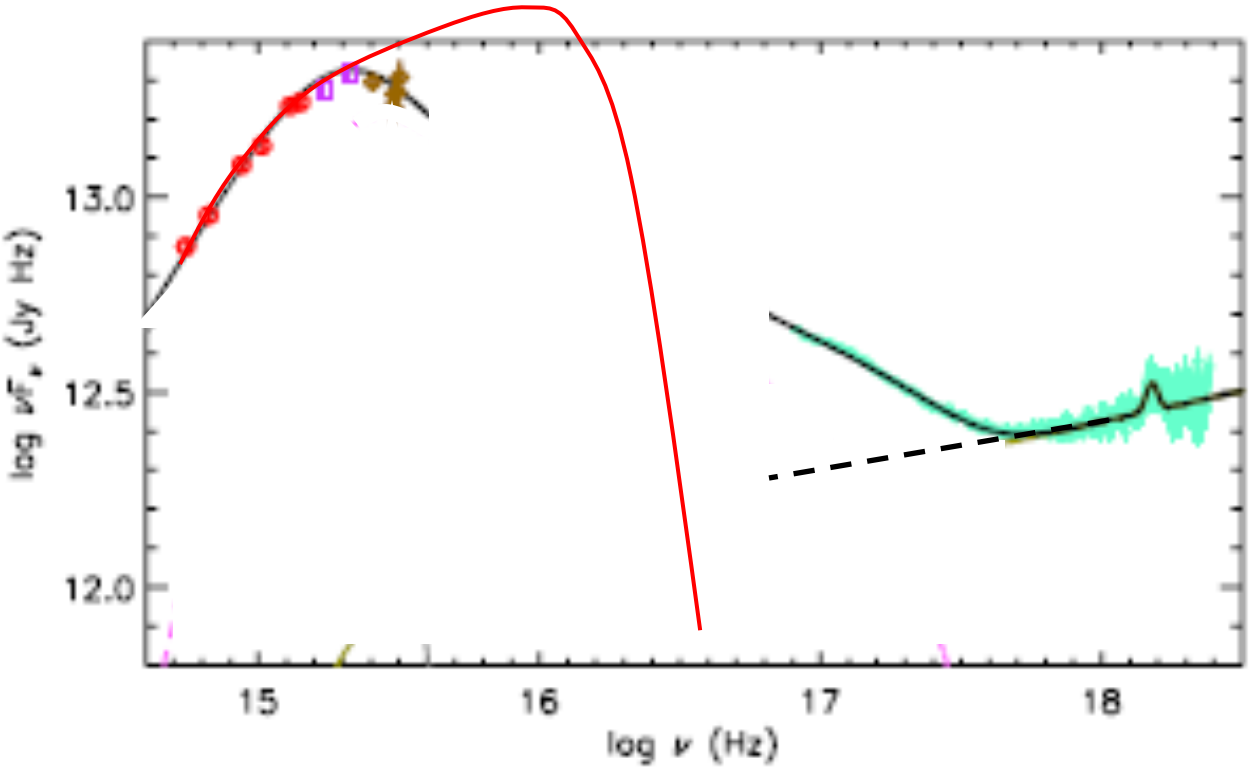

Medhipour et al 2011

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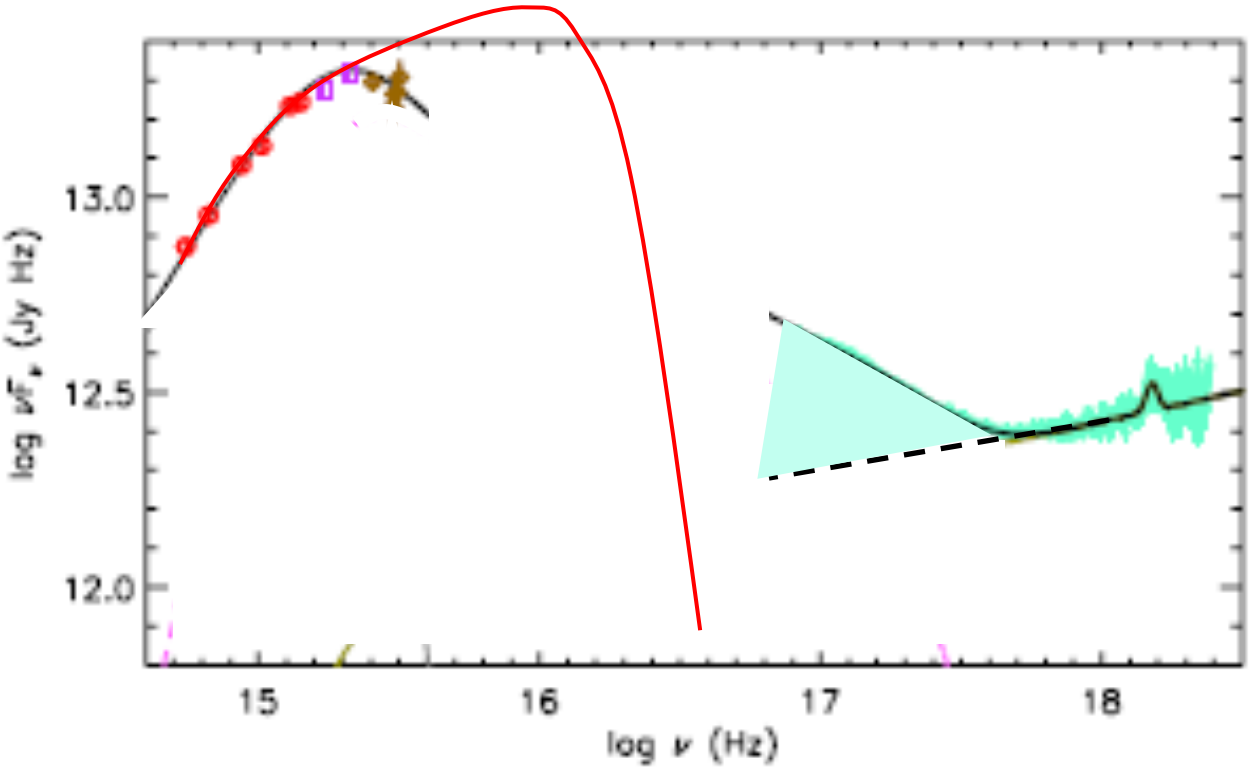
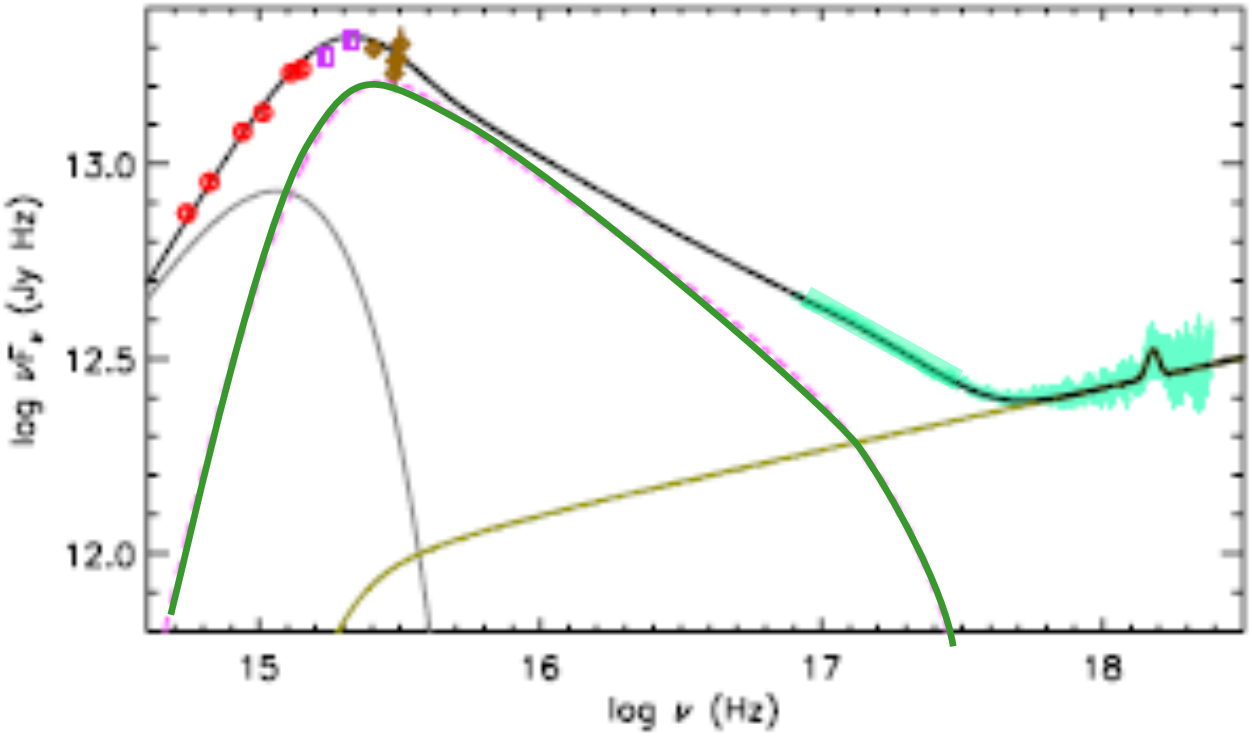


Medhipour et al 2011

Accretion flow at L~0.1 LEdd

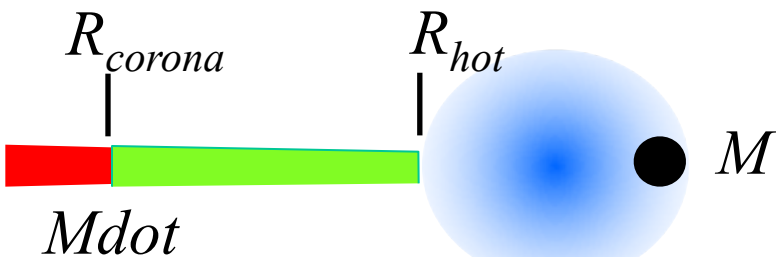
- Single low temperature, optically thick compton component connecting UV-SX (Mehdipour et al 2011)
- 3 regions: outer standard disc, soft X-ray excess, hot flow

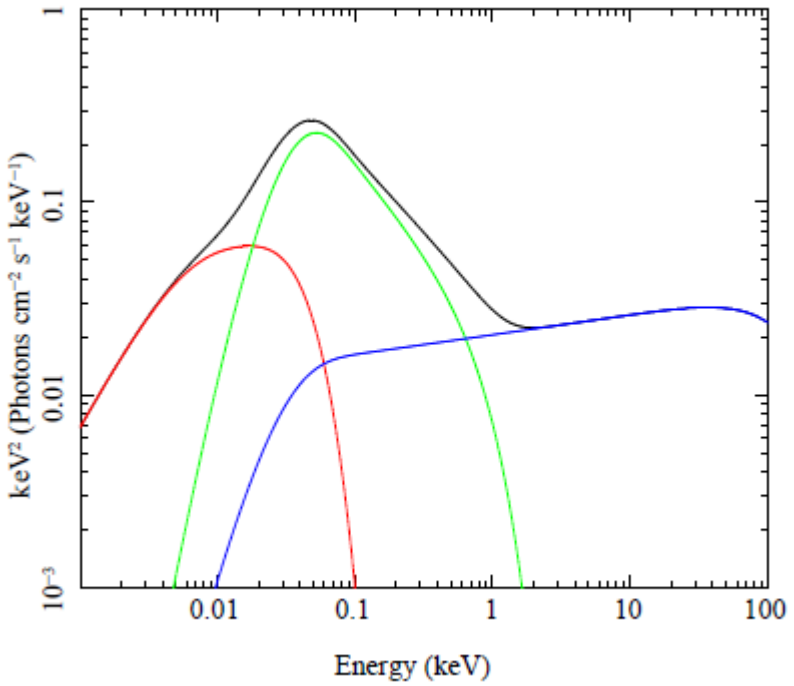


Medhipour et al 2011

Conserving energy: L=ηMdot c²

- Standard disc
- Soft Compton from disc not quite thermalising?
- Rcorona defined by Lsoft
- Hot corona
- Rhot defined by radius within which the gravity is sufficient to power Lx
- AGNSED: 6 parameters
- M Mdot, soft/hard Compton shape, soft/hard radii to define luminosity

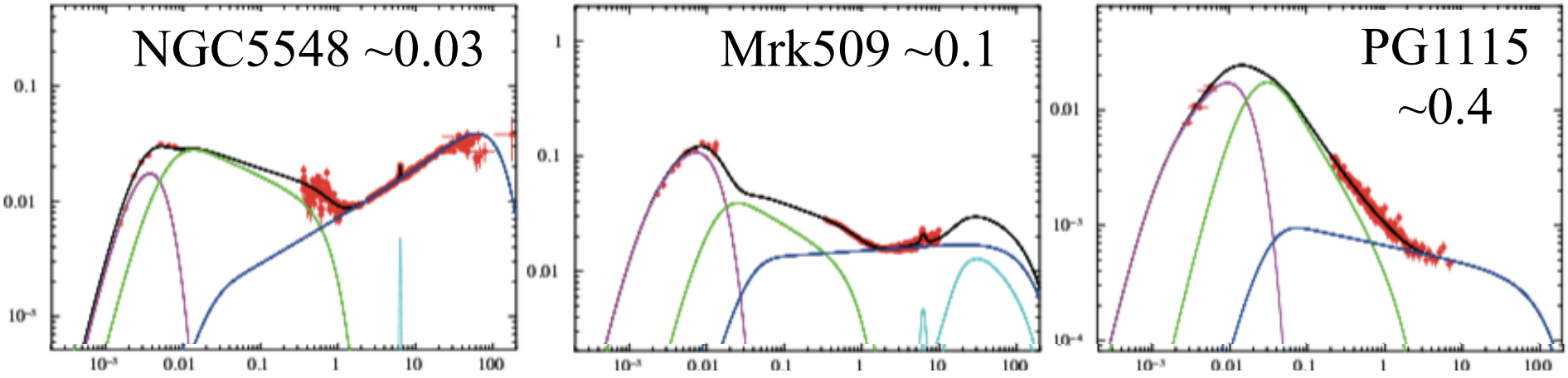




Done et al 2012, Petrucci et al 2017, Done & Kubota 2018

Systematic change in SED:

Lbol ~ 2e44 ~1e45 ~6e45

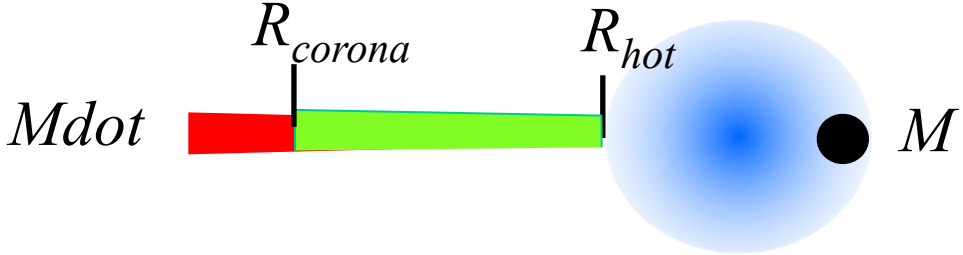


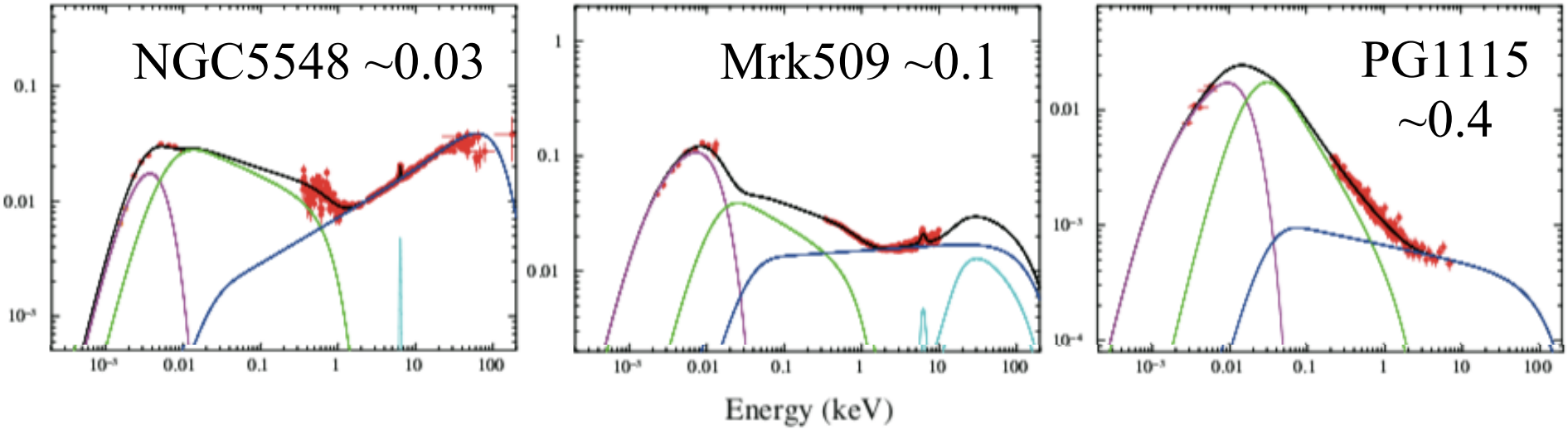
Kubota & Done 2018

- All same (~factor 2) mass!!
- Increasing L is increasing L/LEdd,
- αox steepens – Lx/Lbol decreases Lusso et al 2018
- Γ(2-10) steepens Shemmer et al 2007
- UV spectrum becomes more disky (bluer)

AGNSED: fits the data…

Hot corona properties

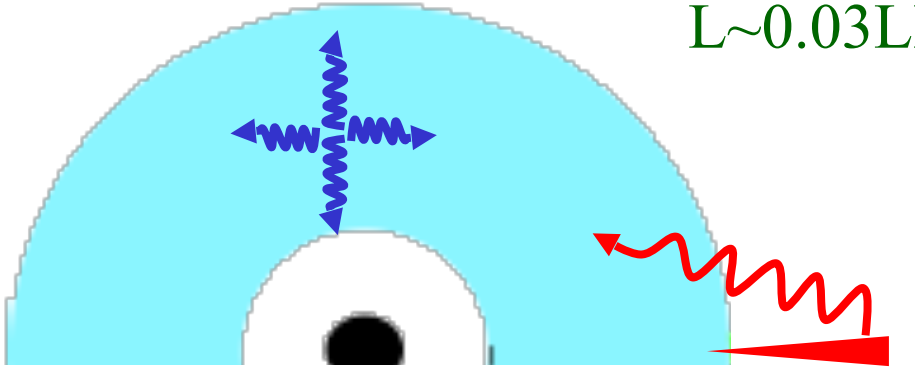




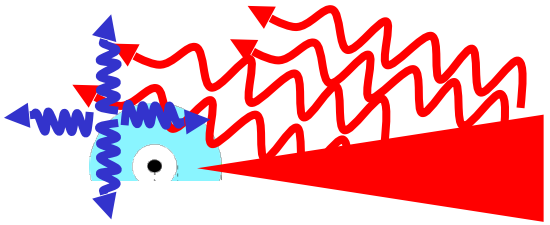
Rhot	~50	~20	~10
Γ	1.65	1.85	2.2
Lx	~0.02LEdd	~0.02LEdd	~0.02Ledd

Lx=0.02LEdd then Lseed/Lx sets Γ

L~0.03LEdd



L~LEdd



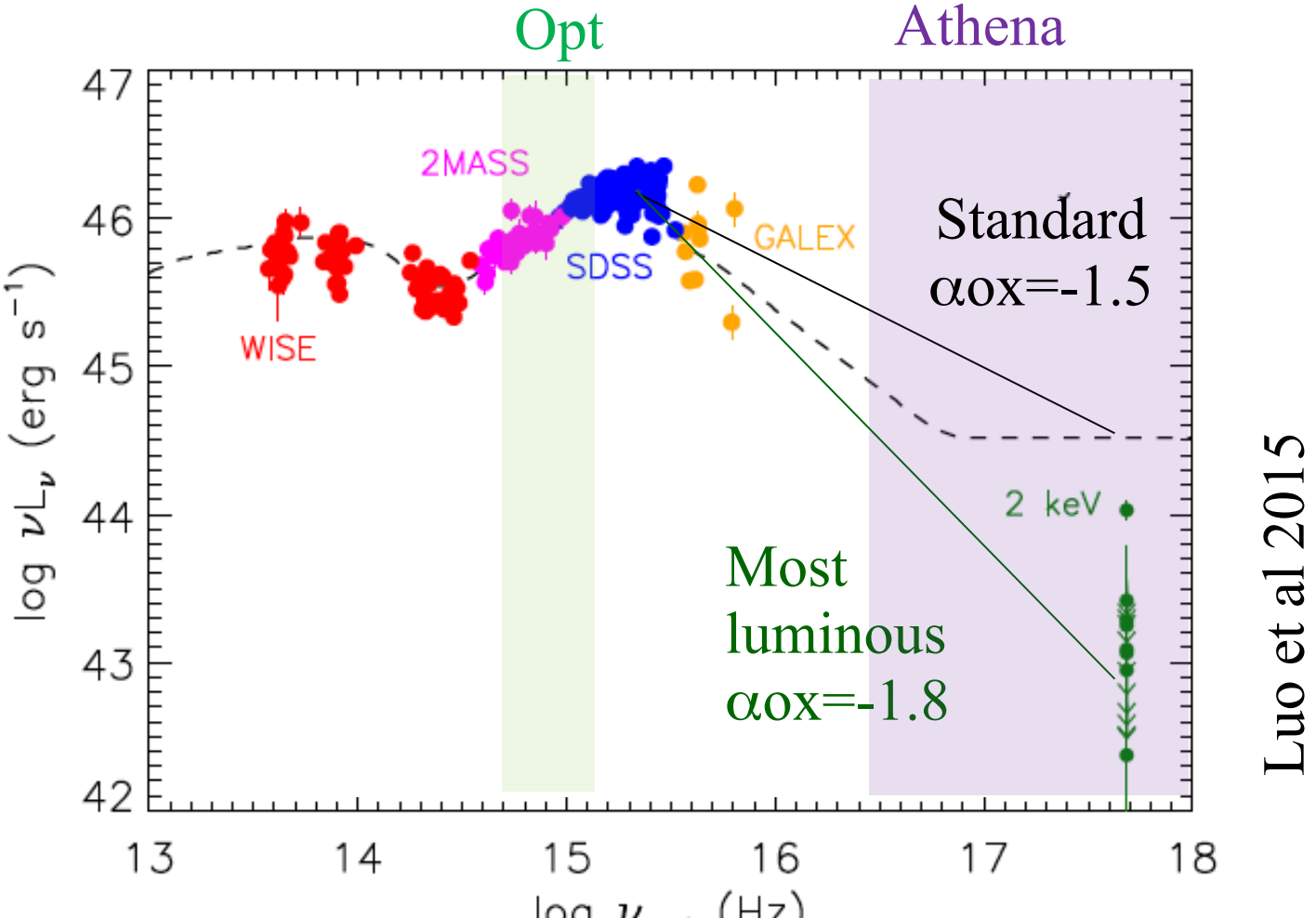
- Lx=0.02LEdd,
- Luv=Lbol-Lx=0.01LEdd
- Rhot large!!
- LUV/Lx small, little Compton cooling: X-ray spectrum hard

- Lx=0.02LEdd,
- Luv=Lbol-Lx=0.98LEdd
- Rhot small!!
- LUV/Lx big, strong Compton cooling: X-ray spectrum soft

Kubota & Done 2018

Broad band SED - energetics

- Understand (model) the SED as function of M and L/Ledd
- Often characterised as αox = log[L(2keV)/L(2500A)]/2.61

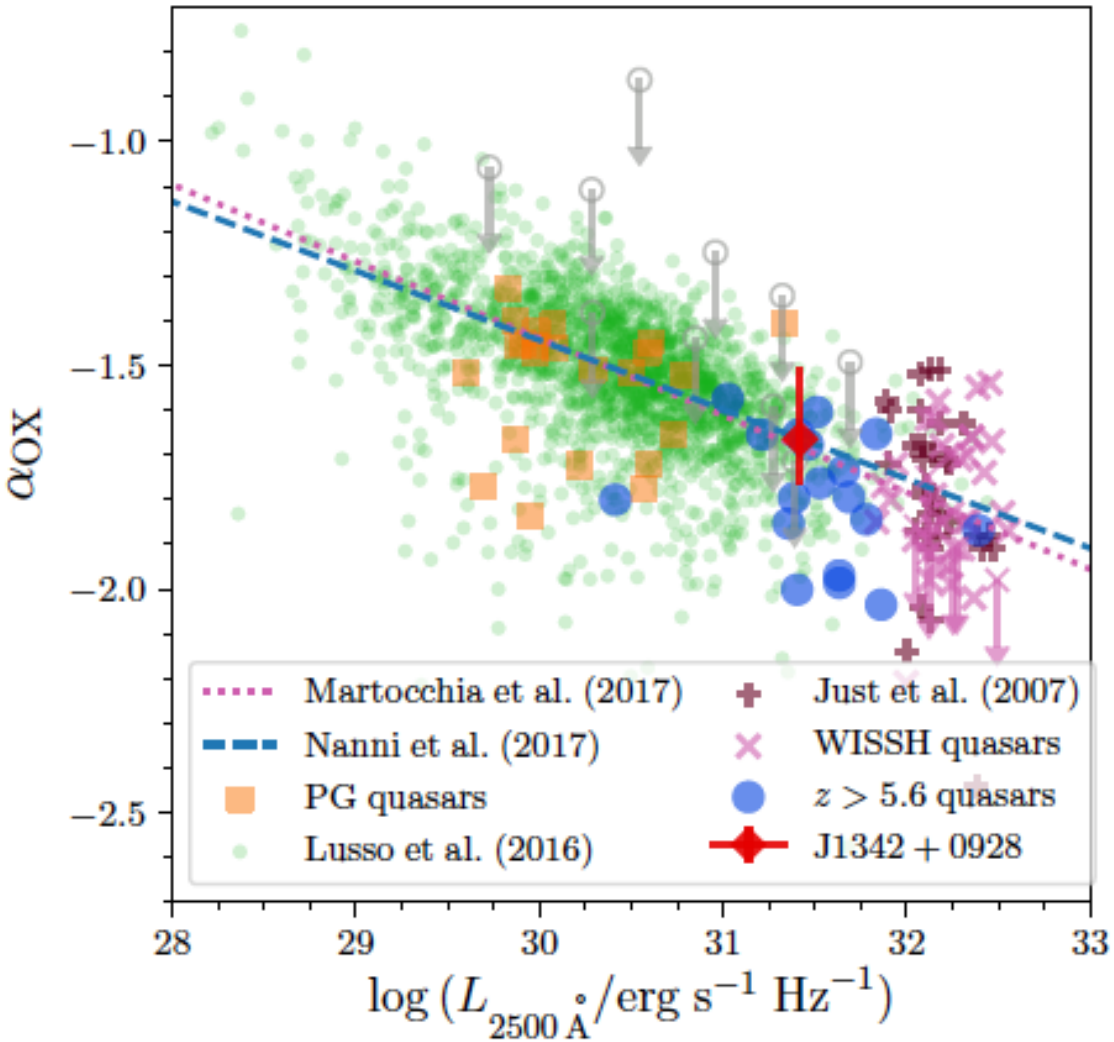


Luo et al 2015

Quasar SED – systematic change

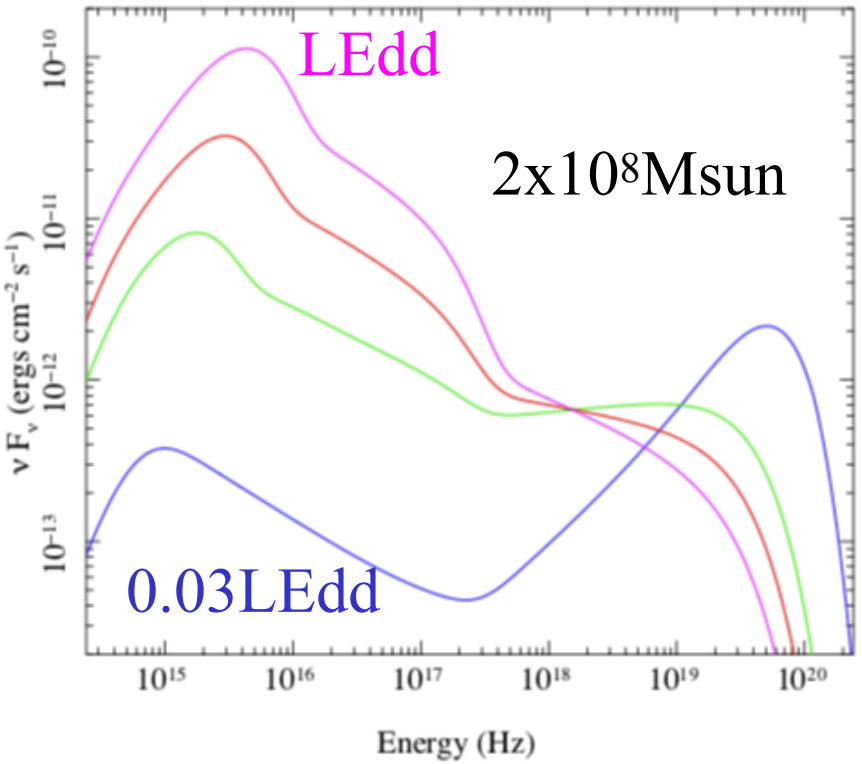
- Ratio of UV to X-rays systematically bigger in more luminous QSO Lusso et al 2017
- relation holds to z>5.6
- BUT IS IT DRIVEN BY L?
- OR BY L/LEdd?

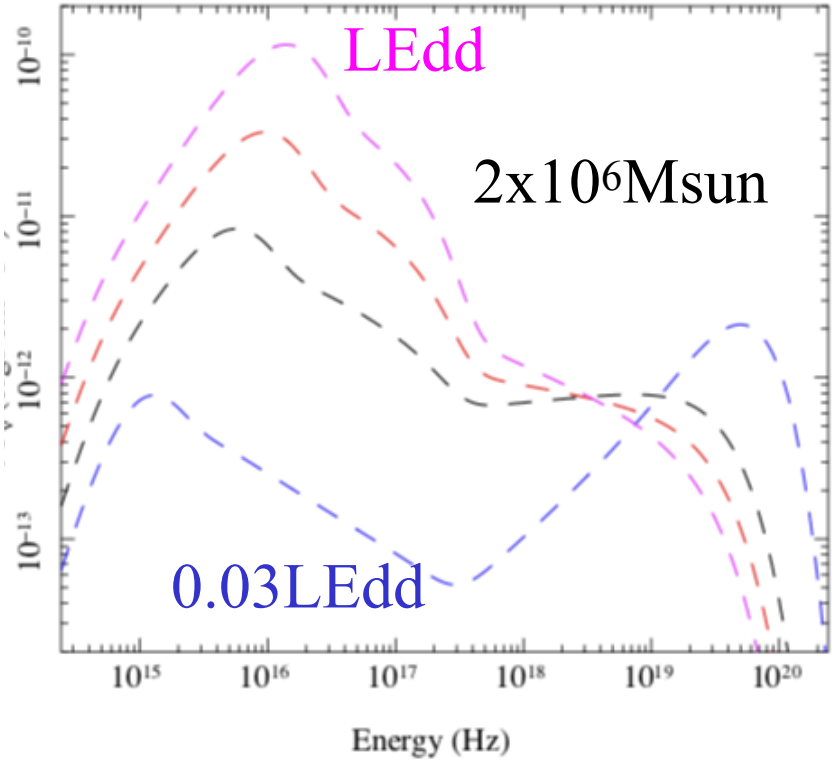
Banados et al 2018



QSOSED – mass and L/LEdd

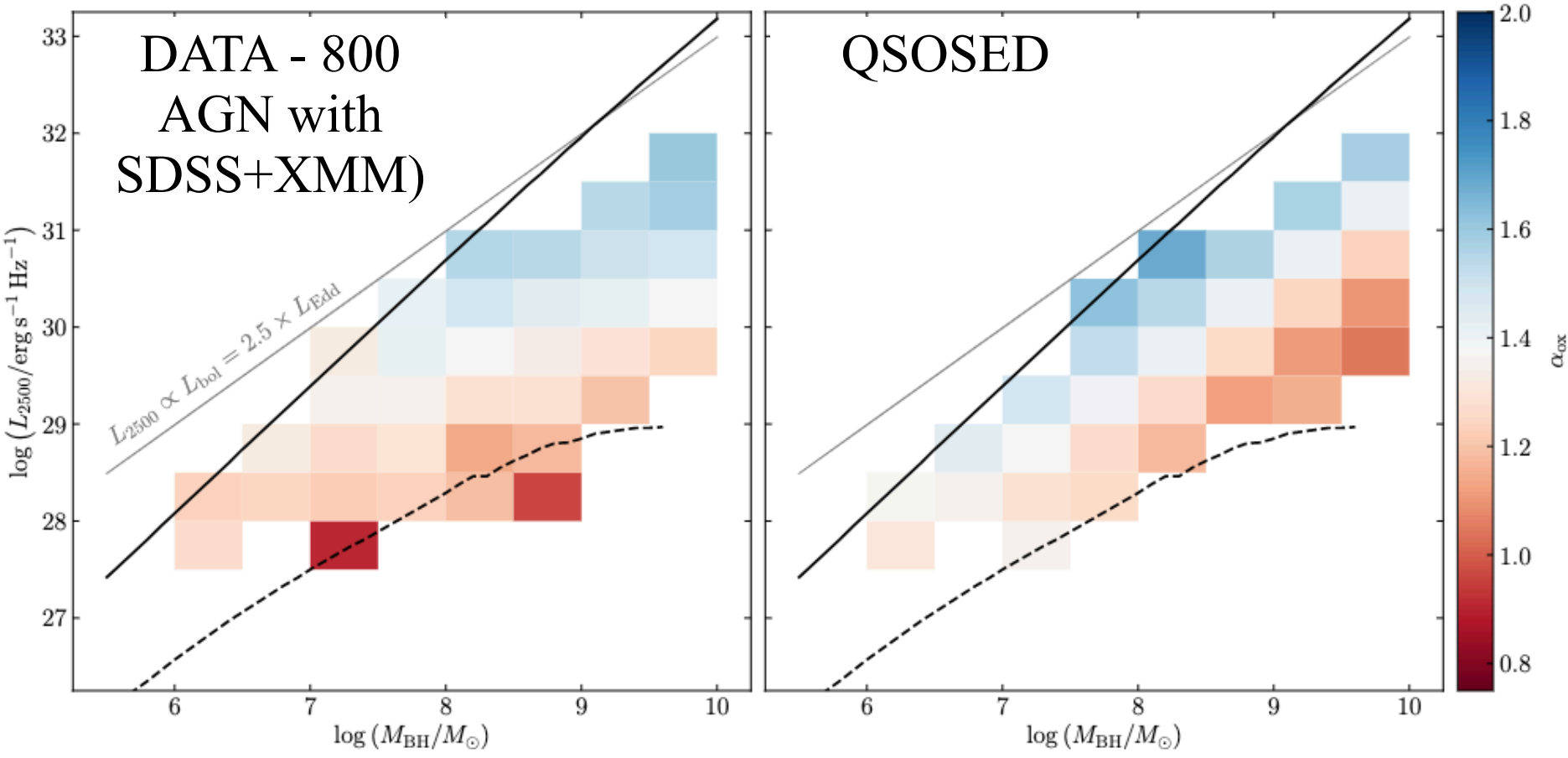
- Model based on energy release from disc accretion.
- Luv/Lx and Γx increases with L/LEdd
- KEY ASSUMPTION IS Lx=0.02LEdd





Kubota & Done 2018

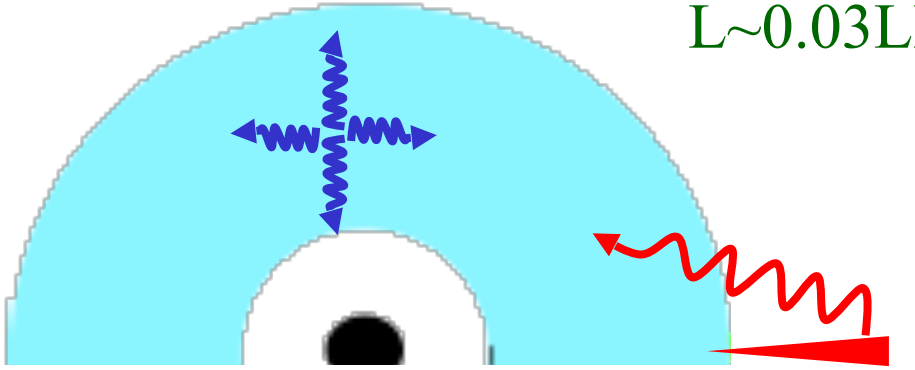
So does it work??



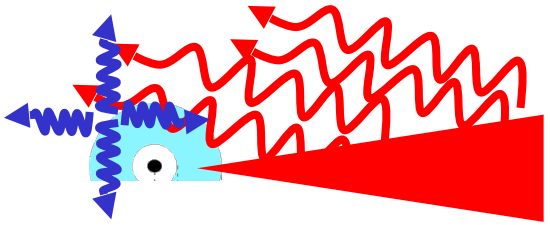
Kynoch…CD… 2022, see also Mitchell, CD et al 2022

Hole in the disc at L/Ledd>0.02?

L~0.03LEdd



L~LEdd



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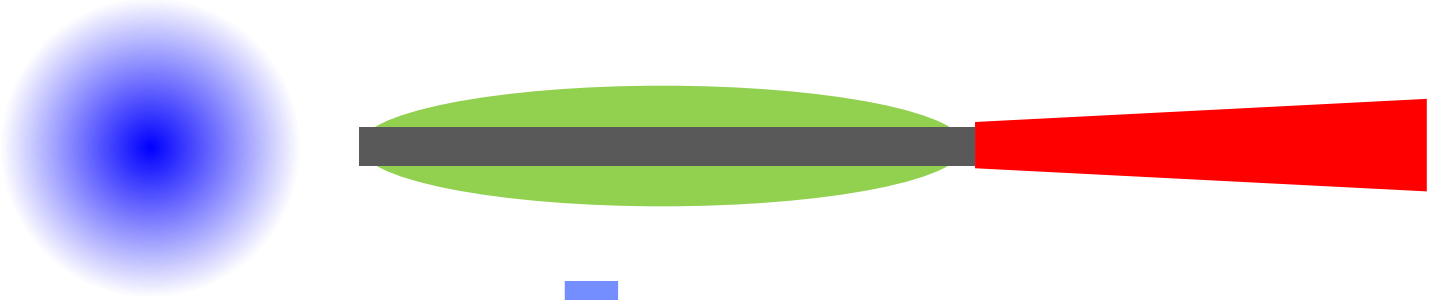
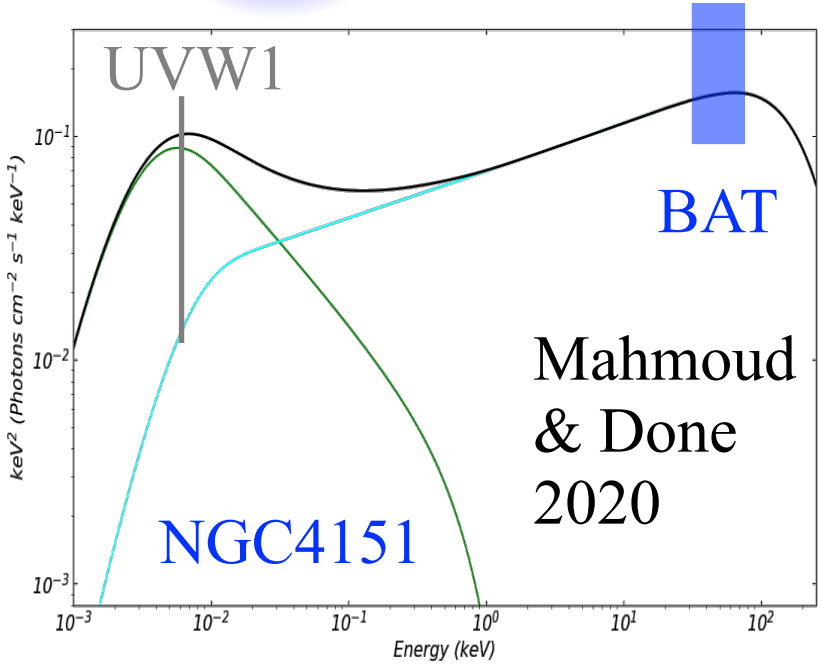
- Lx=0.02LEdd,
- Luv=Lbol-Lx=0.98LEdd
- Rhot small!!
- LUV/Lx big, strong Compton cooling: X-ray spectrum soft

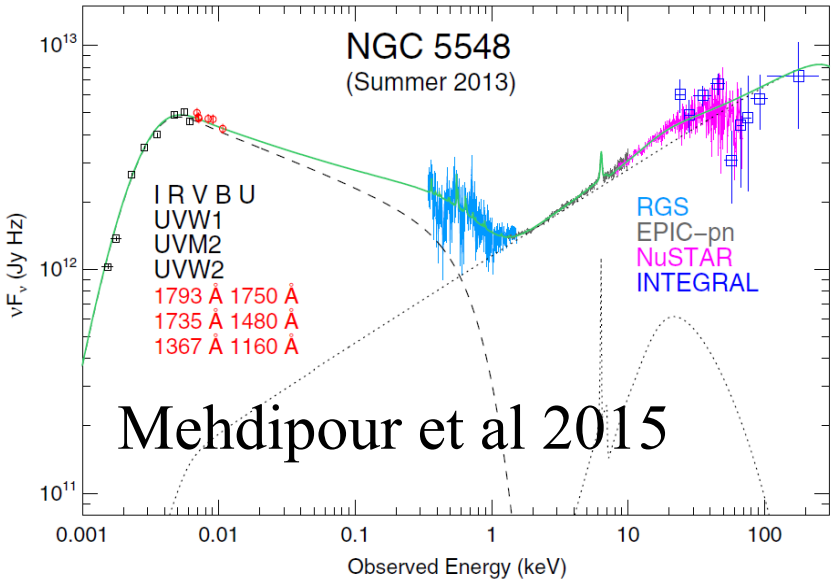
Kubota & Done 2018

TEST; λλλ continuum reverberation

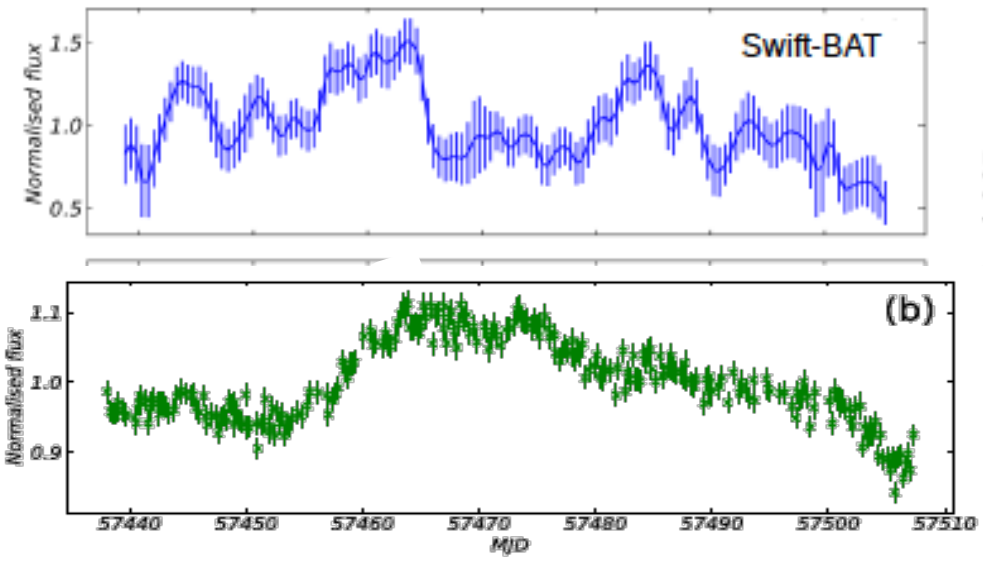
- Lowest L/Ledd - Hard X-ray source Γ~1.7
- Need all gravitational power from <50Rg to power Lx

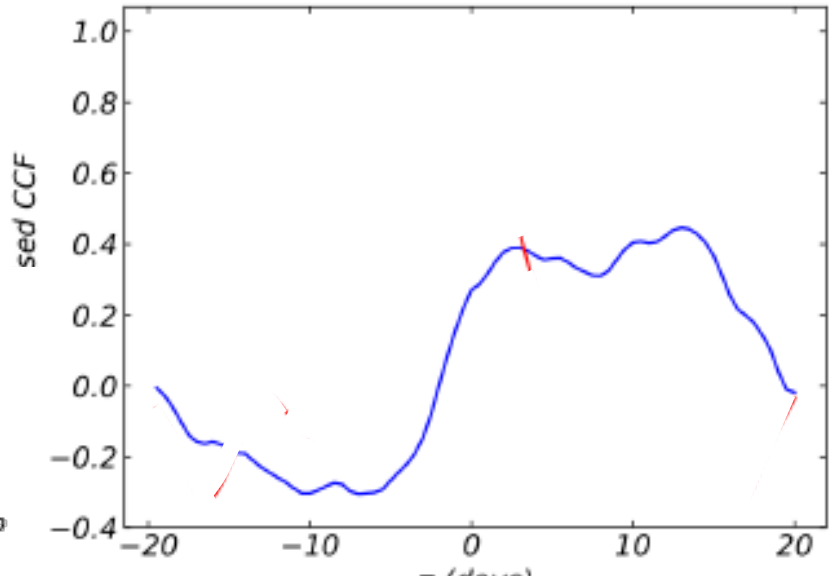






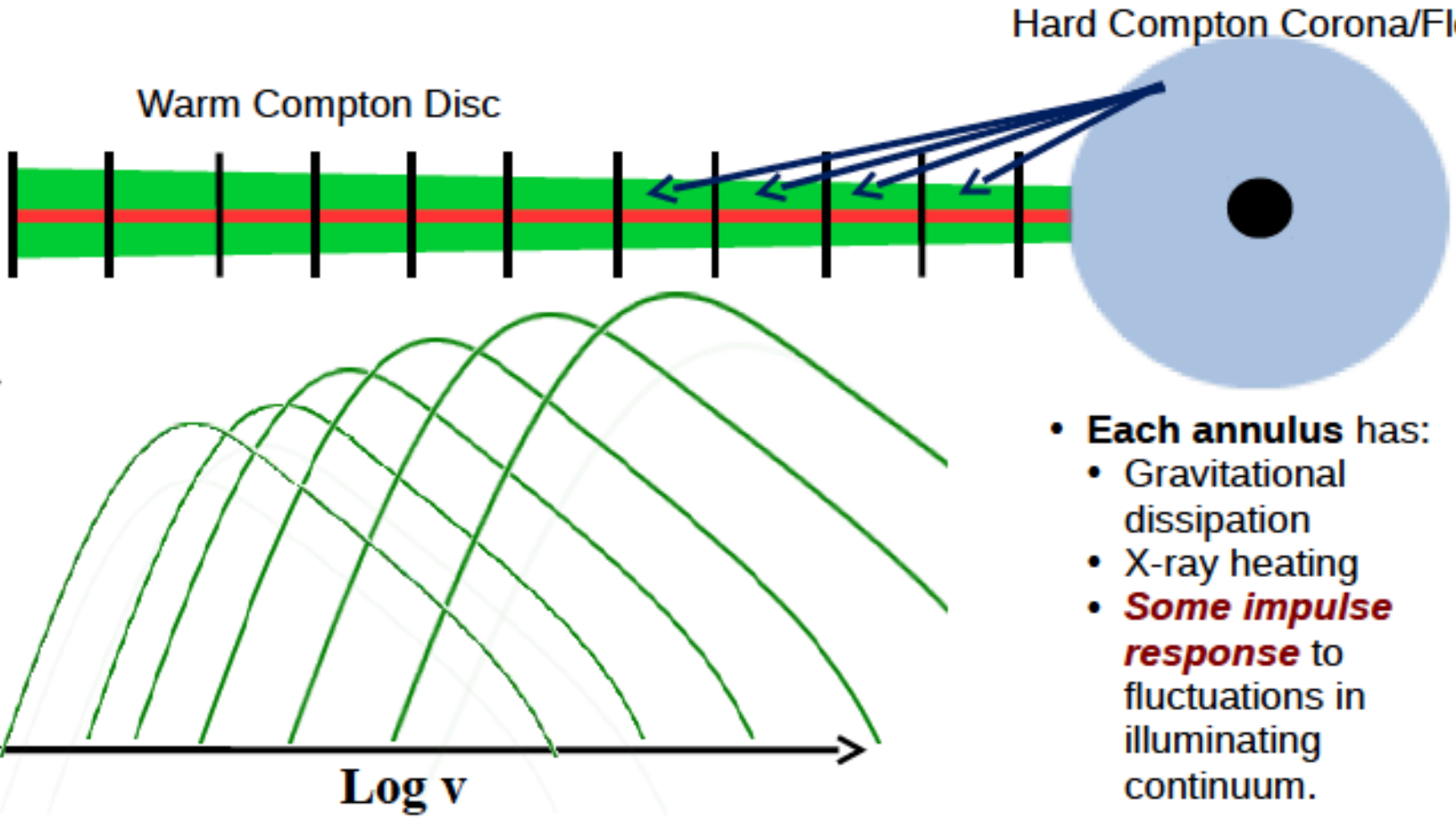
X-ray not well correlated with UV





- X-ray variable timescale ~1 day
- UV variable timescale ~20 days!!!
- So UV-X not well correlated!!

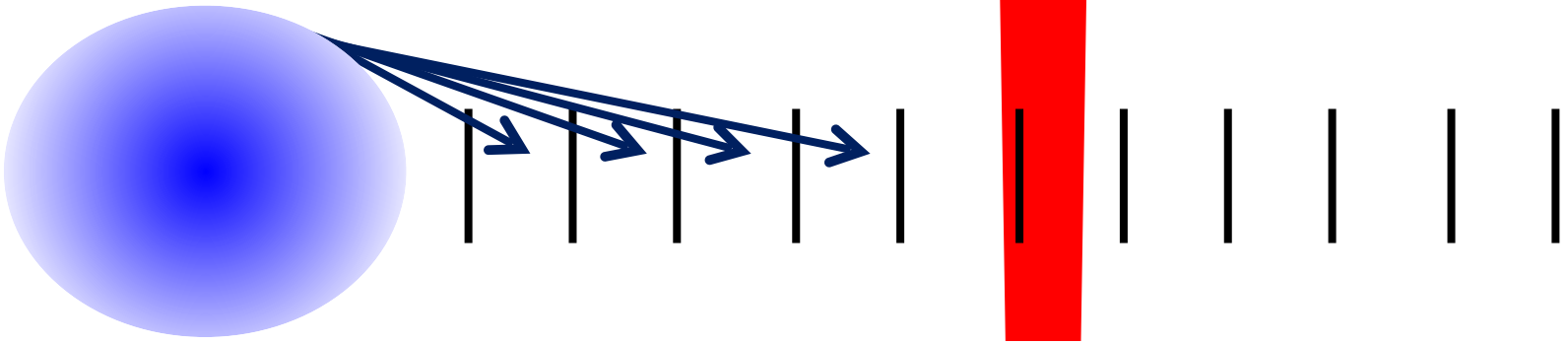
Simple Disc-Geometry Reprocessing

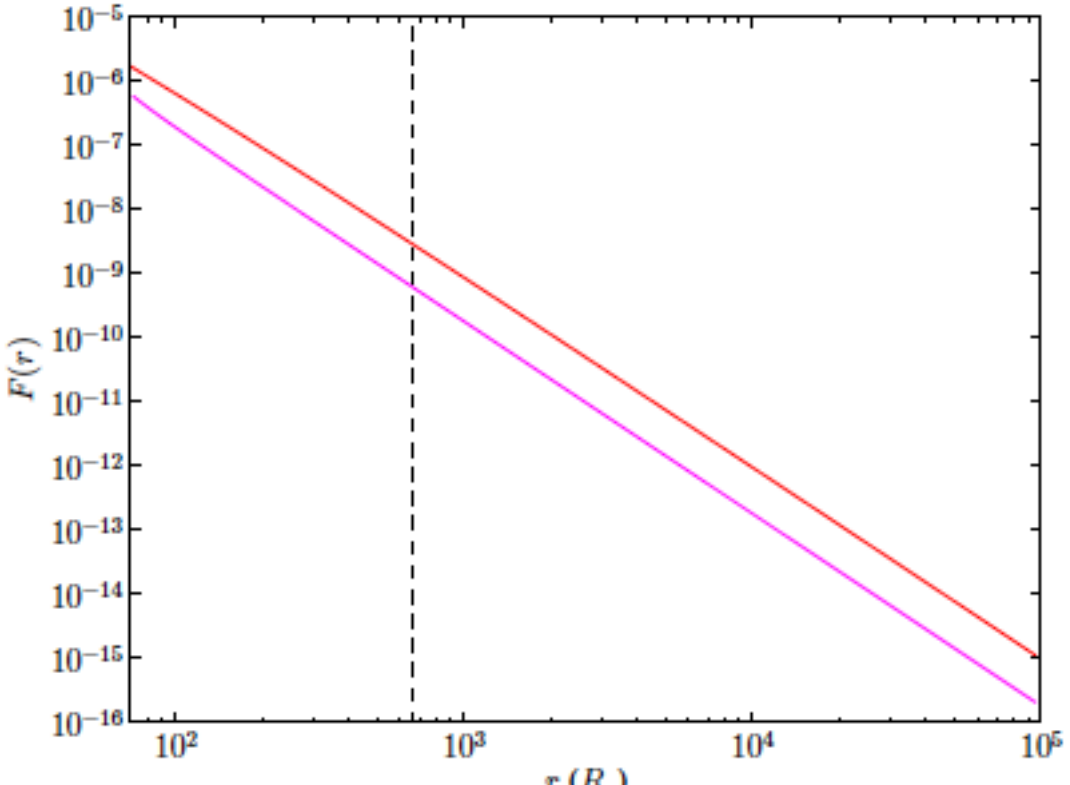


- **Each annulus** has:
  - Gravitational dissipation
  - X-ray heating
  - ***Some impulse response*** to fluctuations in illuminating continuum.

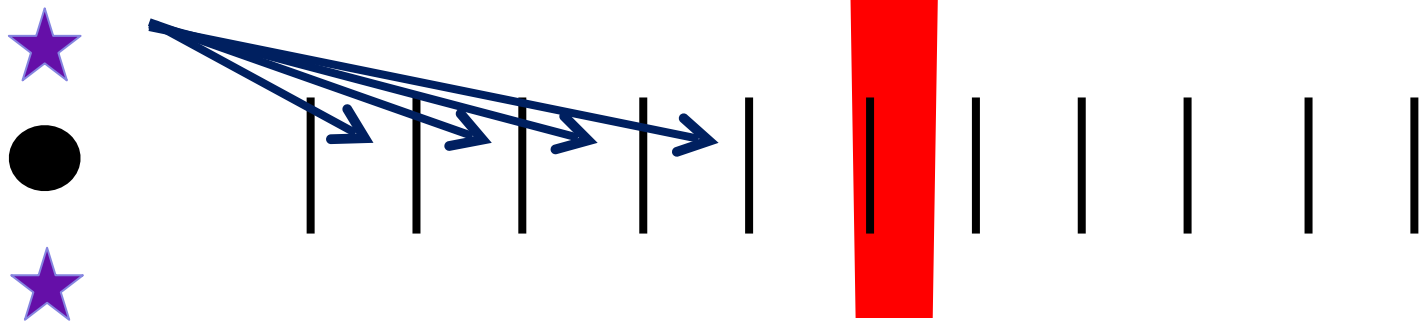
$$T_{seed}(r,\,t) = \quad T_{grav}(r)\left(\frac{F_{rep}(r,\,t)+F_{grav}(r)}{F_{grav}(r)}\right)^{1/4}$$

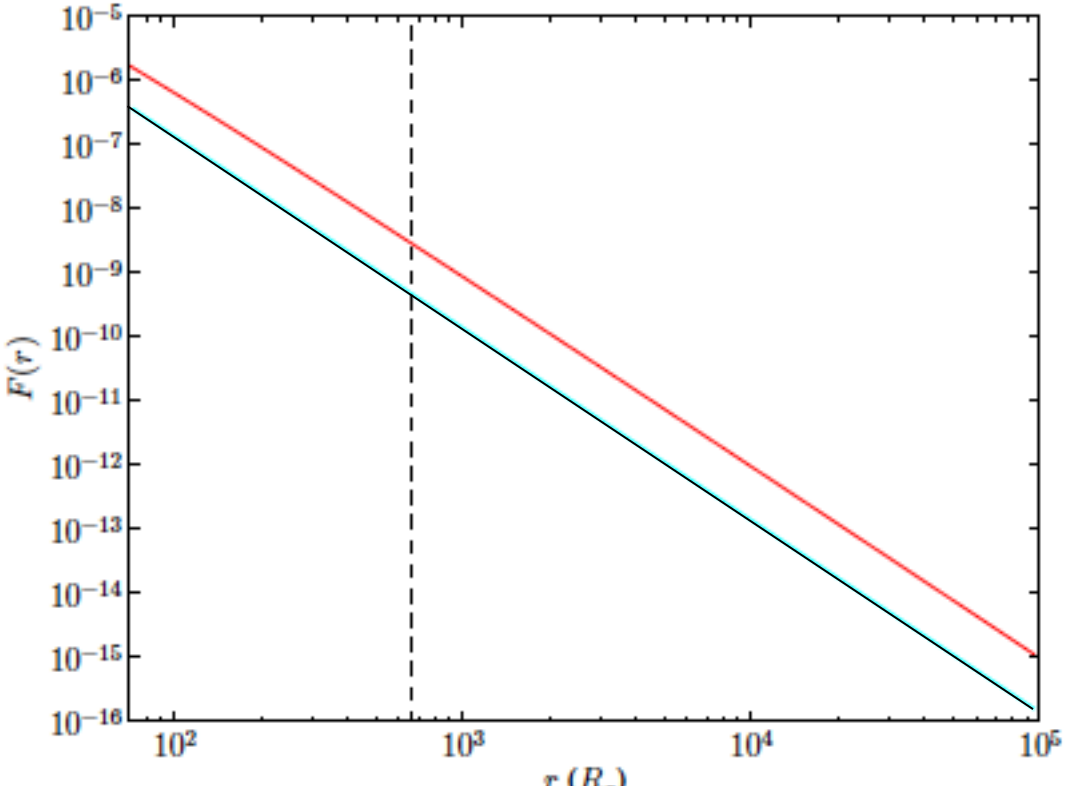
Illumination by extended source powered by gravity





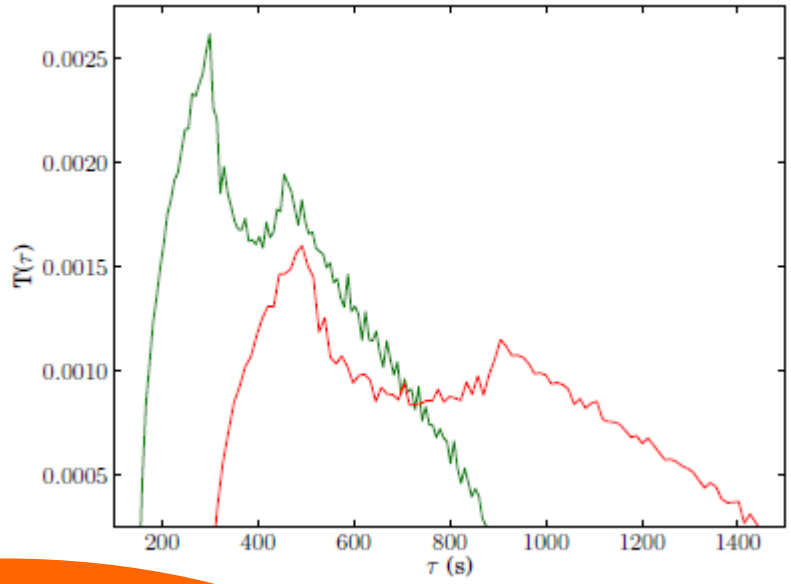
Similar to 10 Rg lamppost!!

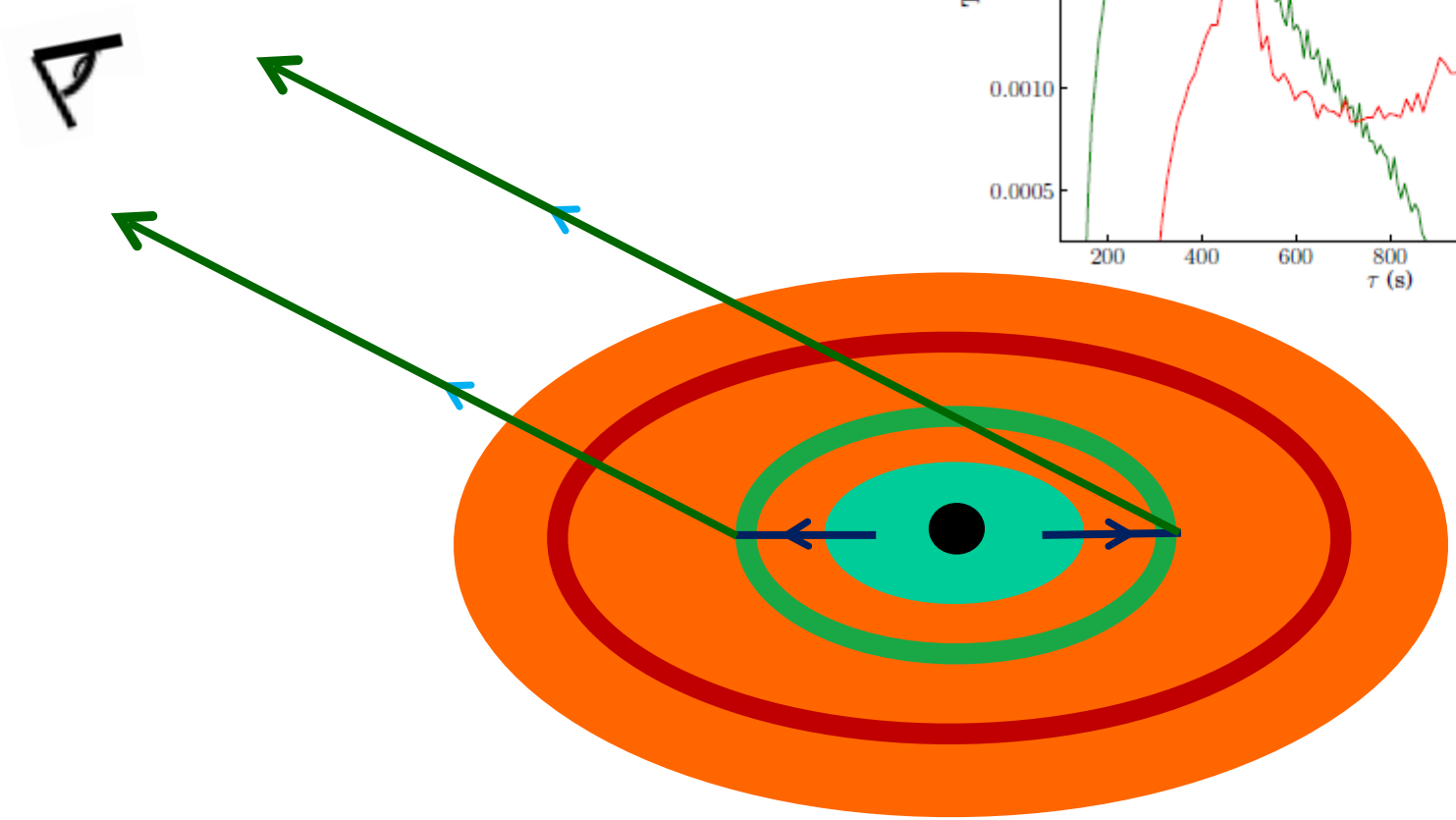




Disc Transfer Functions

Smoothing ~ lag timescale





Disc Transfer Functions

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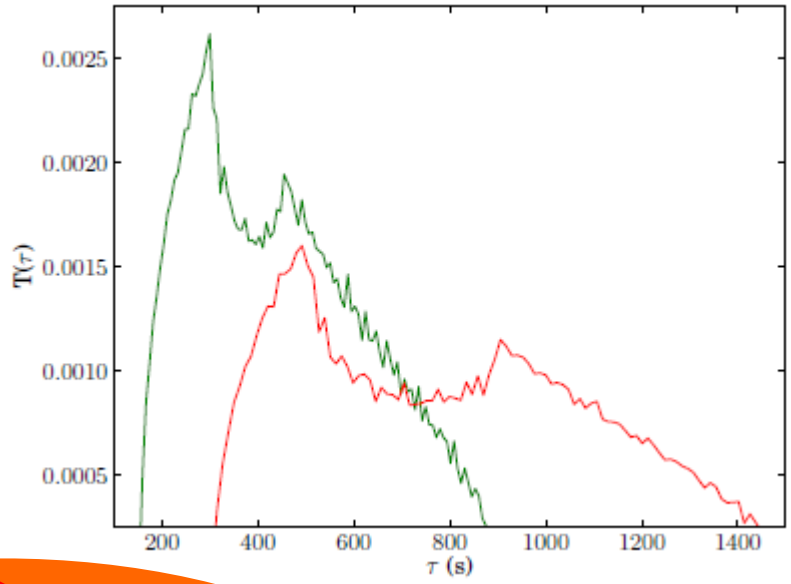
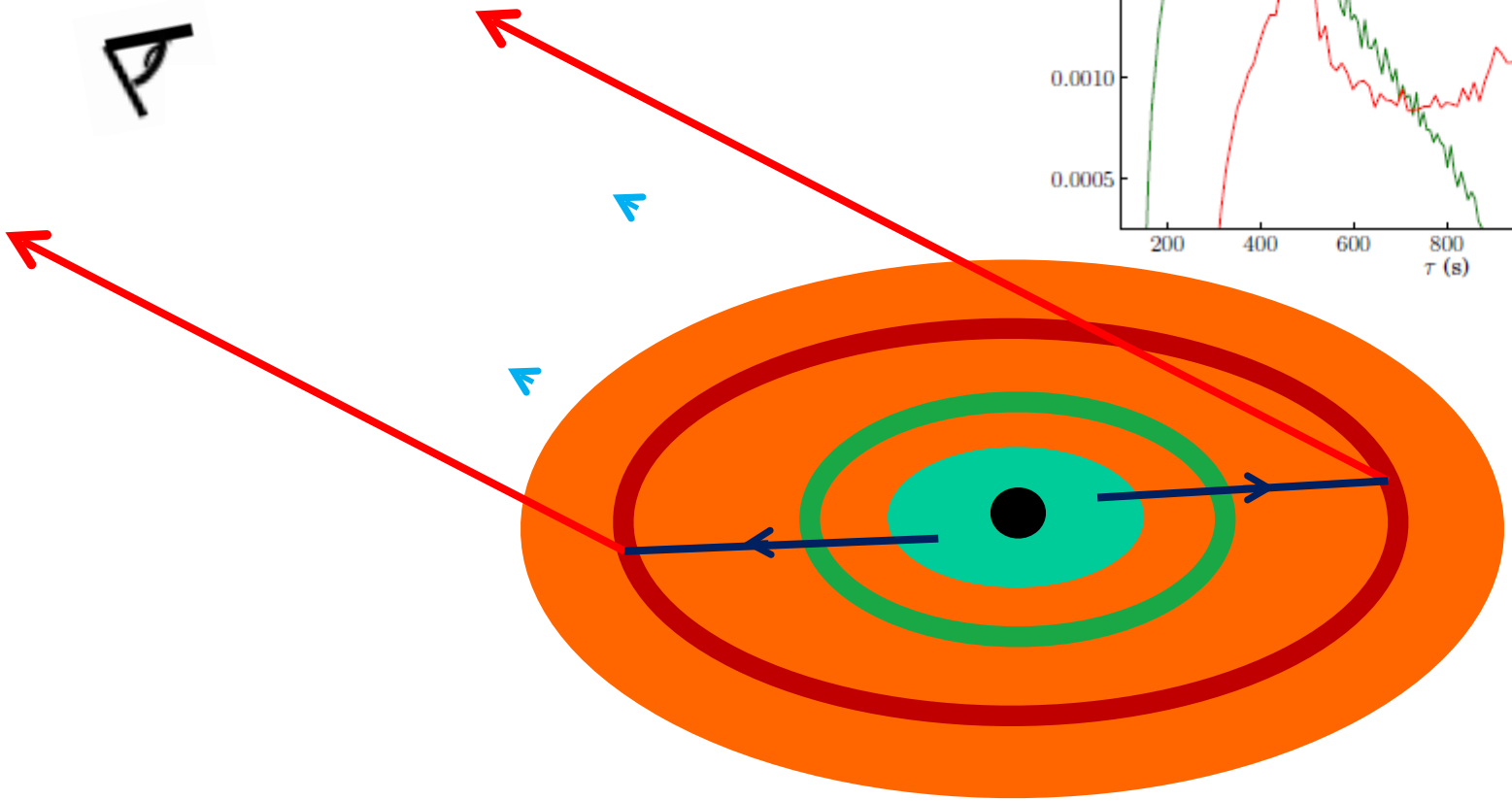
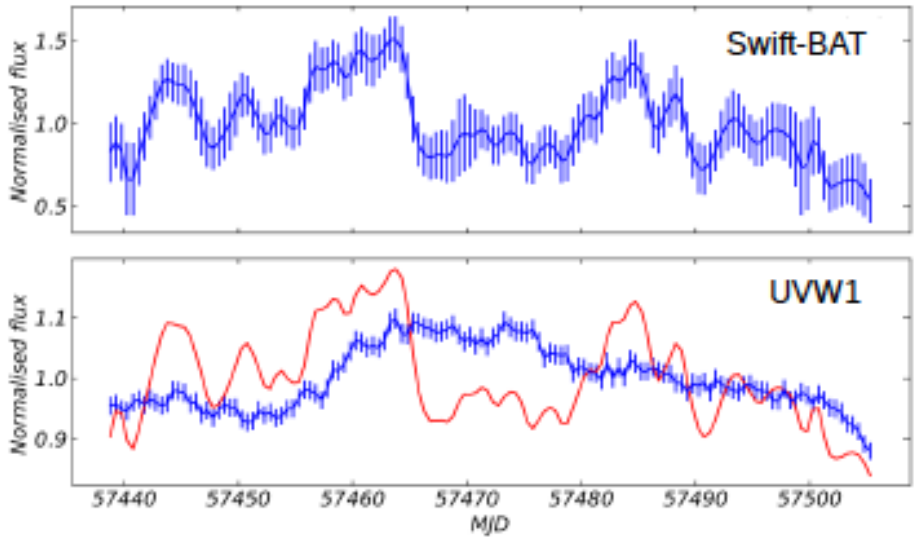
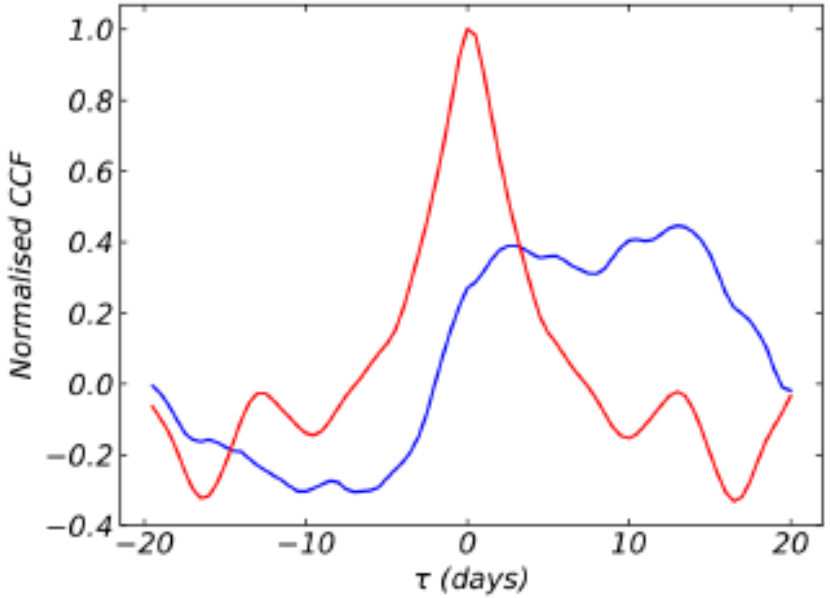




Simple Disc-Geometry Reprocessing

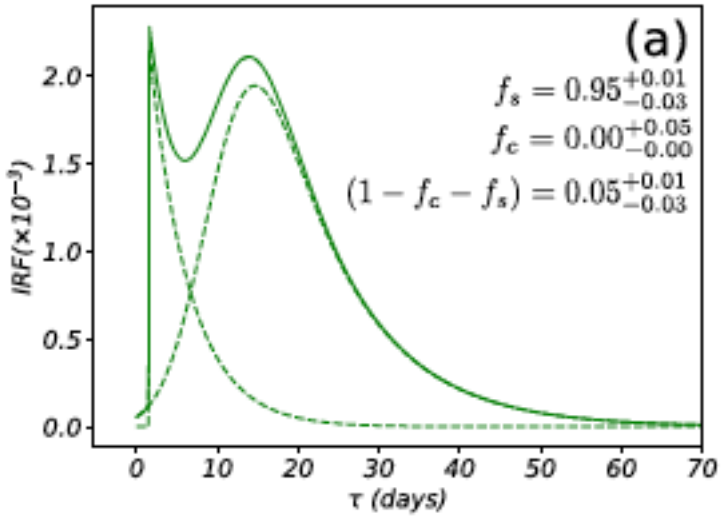
- Blue is data, red is model

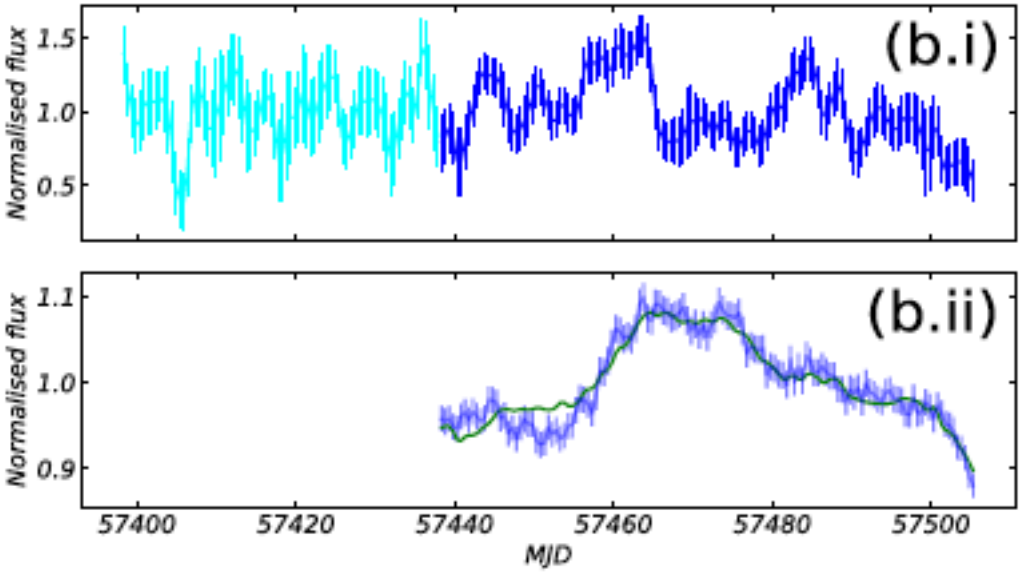




- UVW1 lightcurve and BAT/UVW1 cross-correlation are not having a good time!
- Model predicts ***much*** higher cross-correlation than observed.
- Our data doesn't agree with a UV response on small size scales. We've seen this before. (Gardner + Done 2017; Buisson+ 2018)

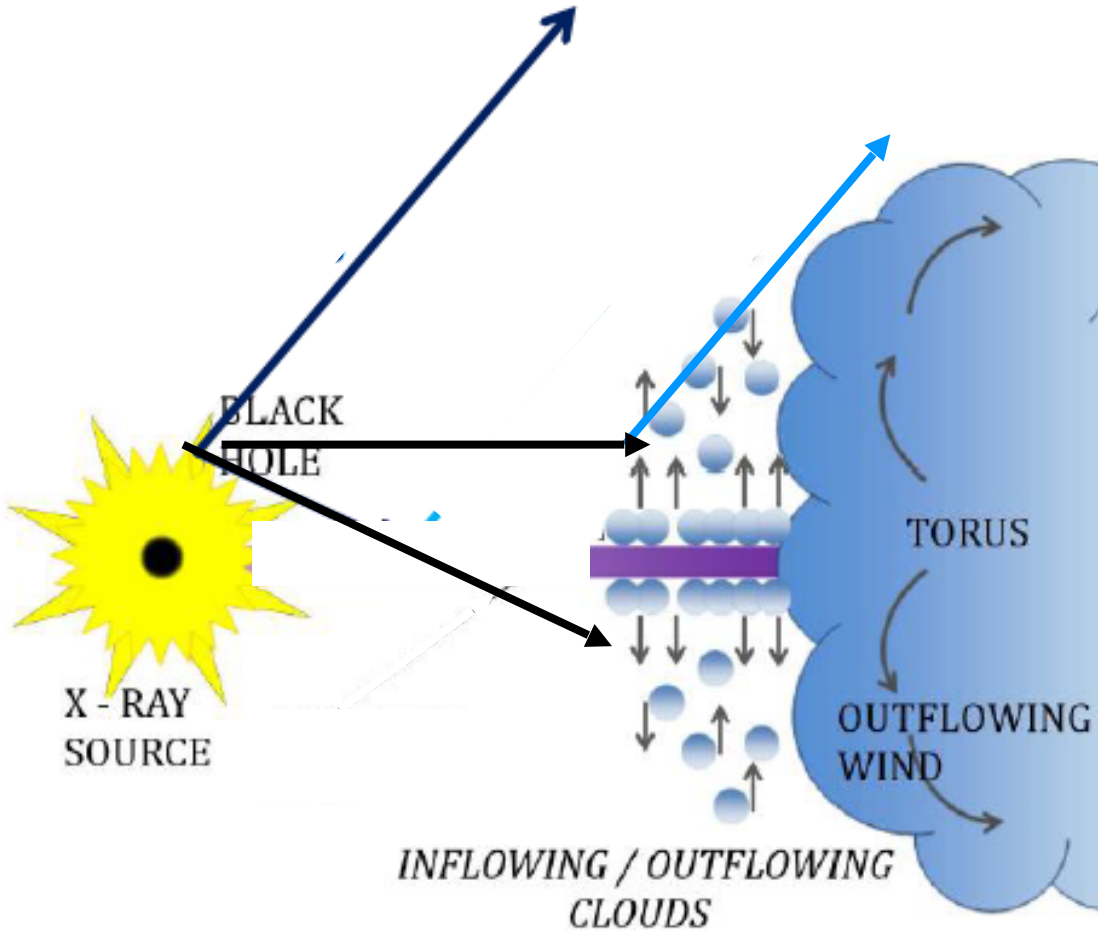
What can work ?





- No response on <2 days
- NOTHING on 50Rg!!
- Big spike at 2 days (??)
- And then a broad response to 20 days - BLR

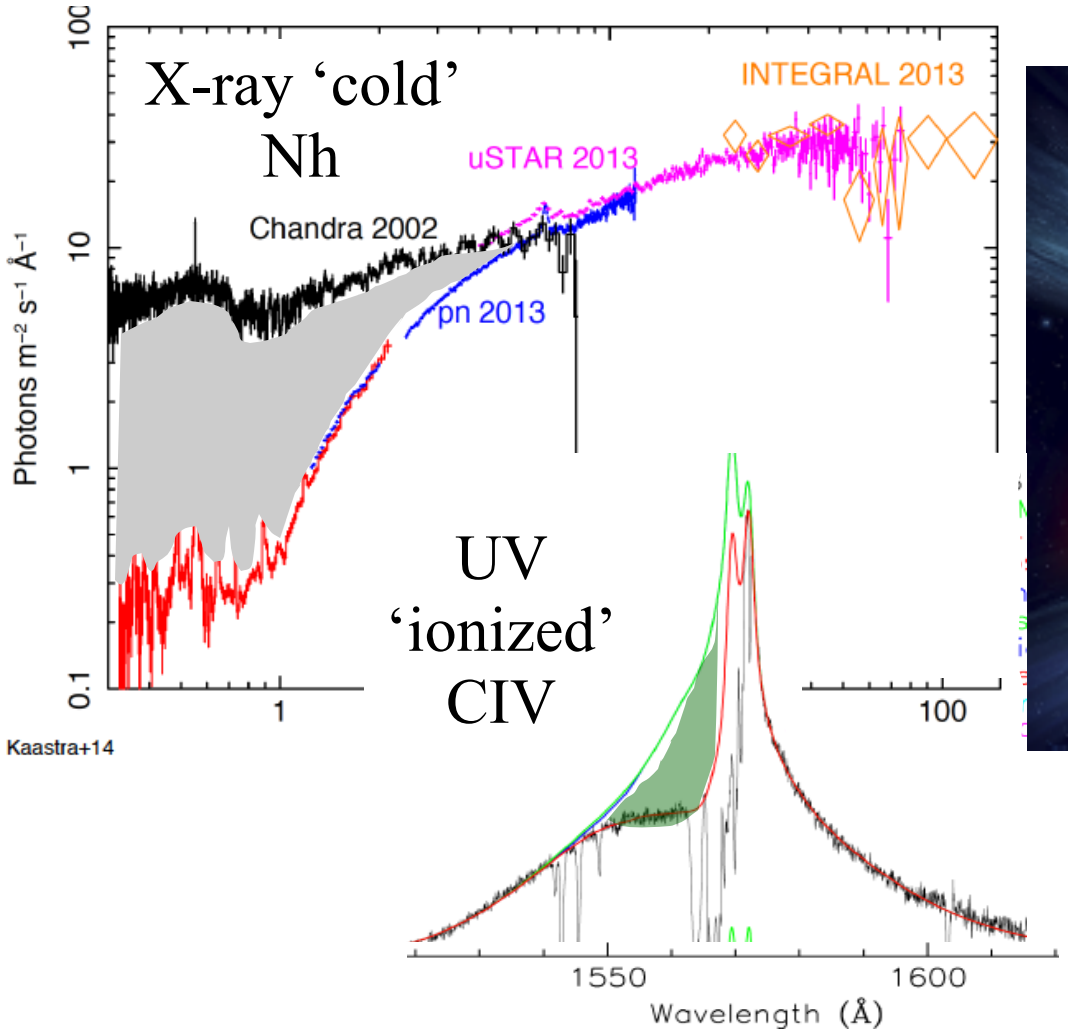
BLR/inner BLR size scale 500-1000Rg lines+diffuse UV

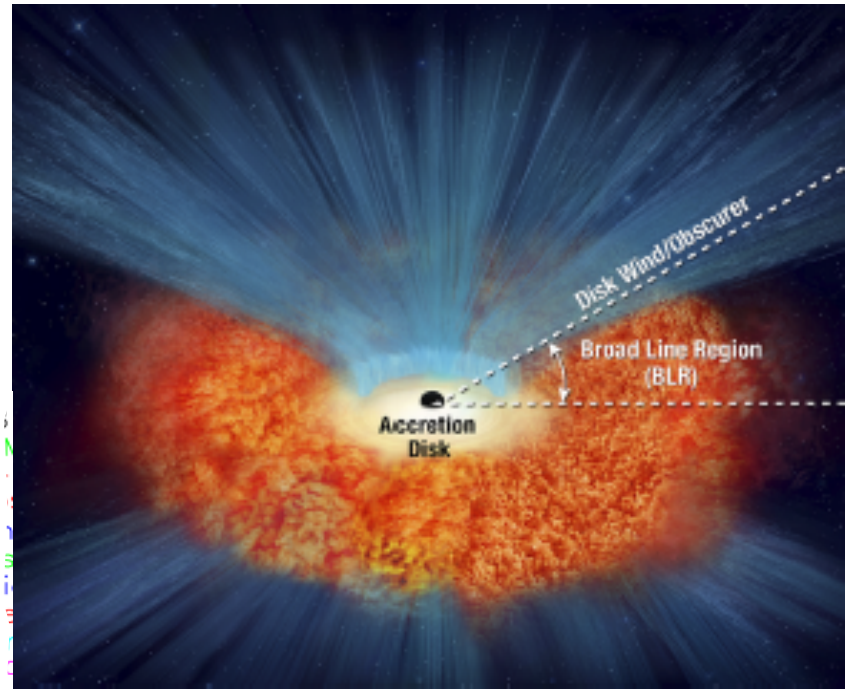


- Disc truncation!!
- BUT iron line profile
- (Keck et al 2016)
- BUT reverberation
- (Zoghbi et al 2012)

Now say X-ray Fe line is narrow,
3 days Fe lag
Zoghbi, Cackett & Miller 2020

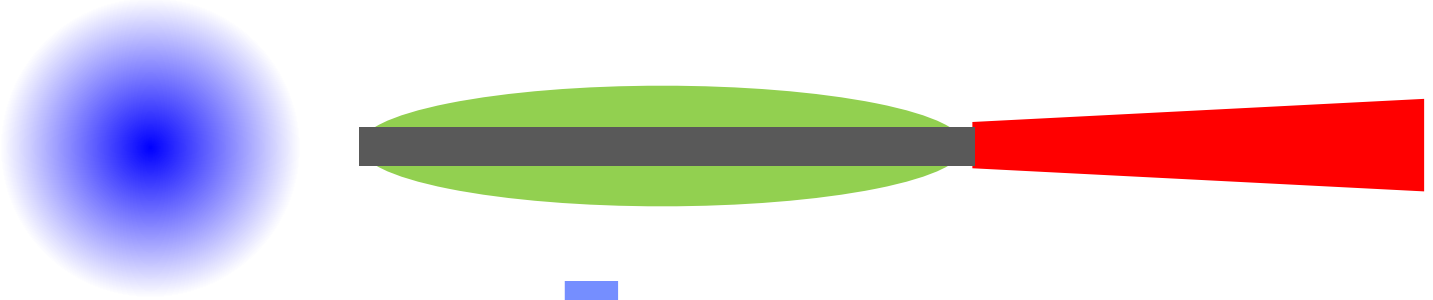
NGC5548 monitoring campaign

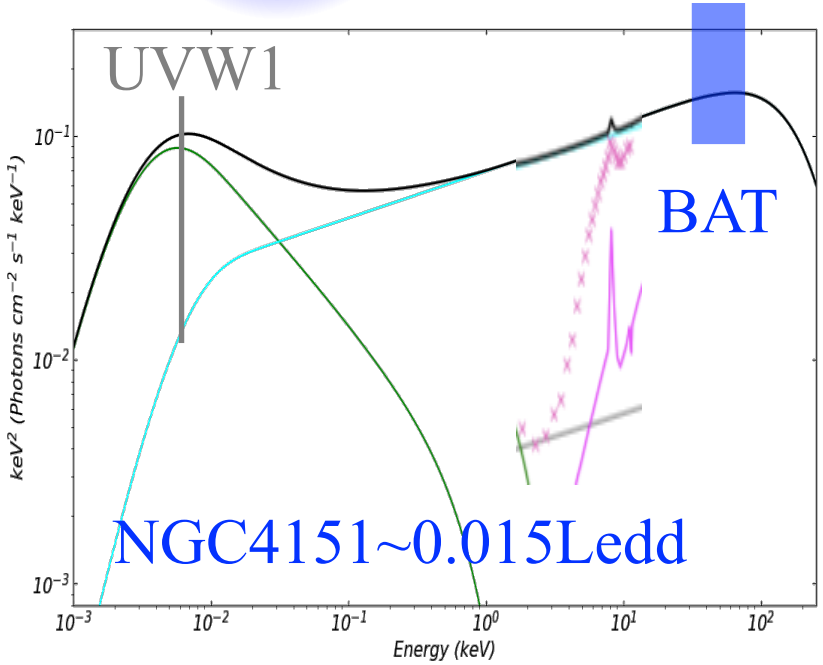


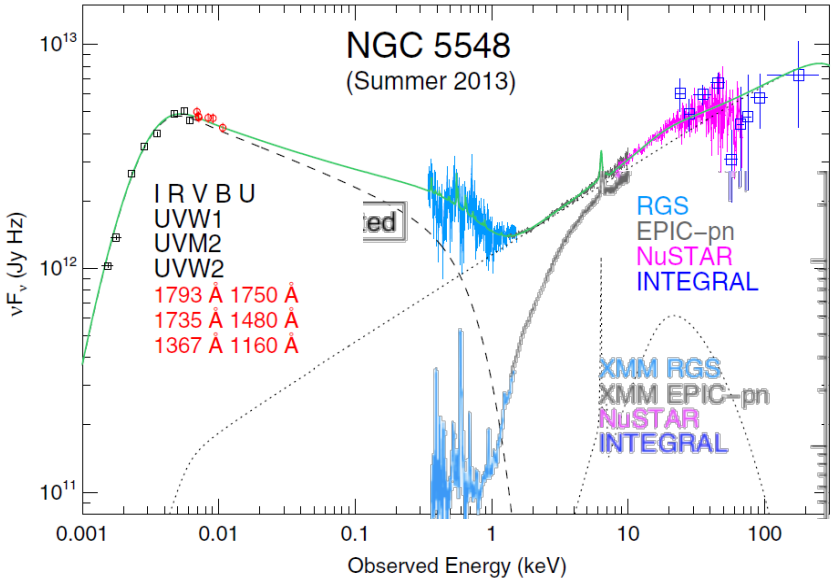


Dehghanian et al 2019b,2020
Kaastra et al 2014

Most Opt variability – LEAST DISC +complex variable X-ray absorber +redder UV spectrum

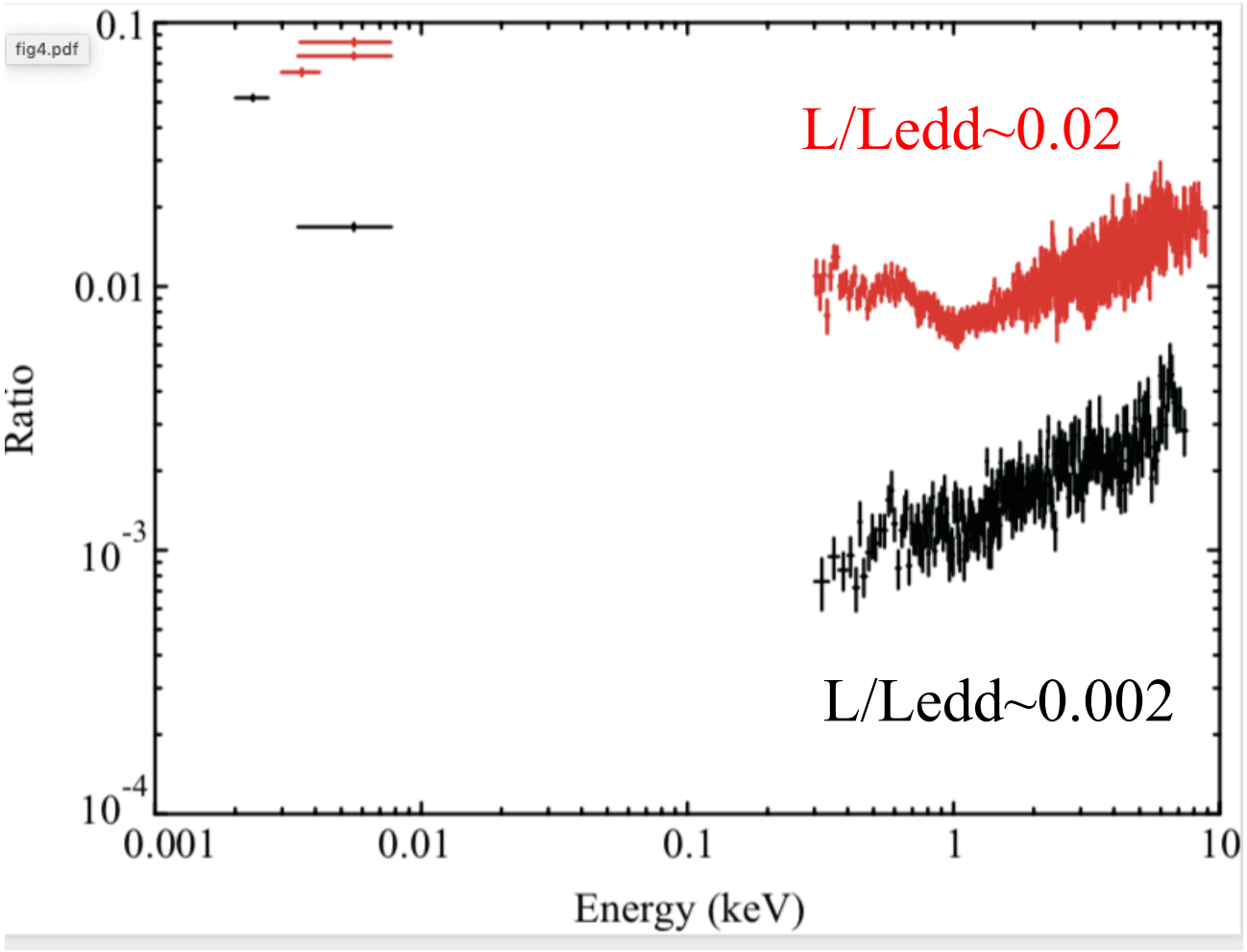






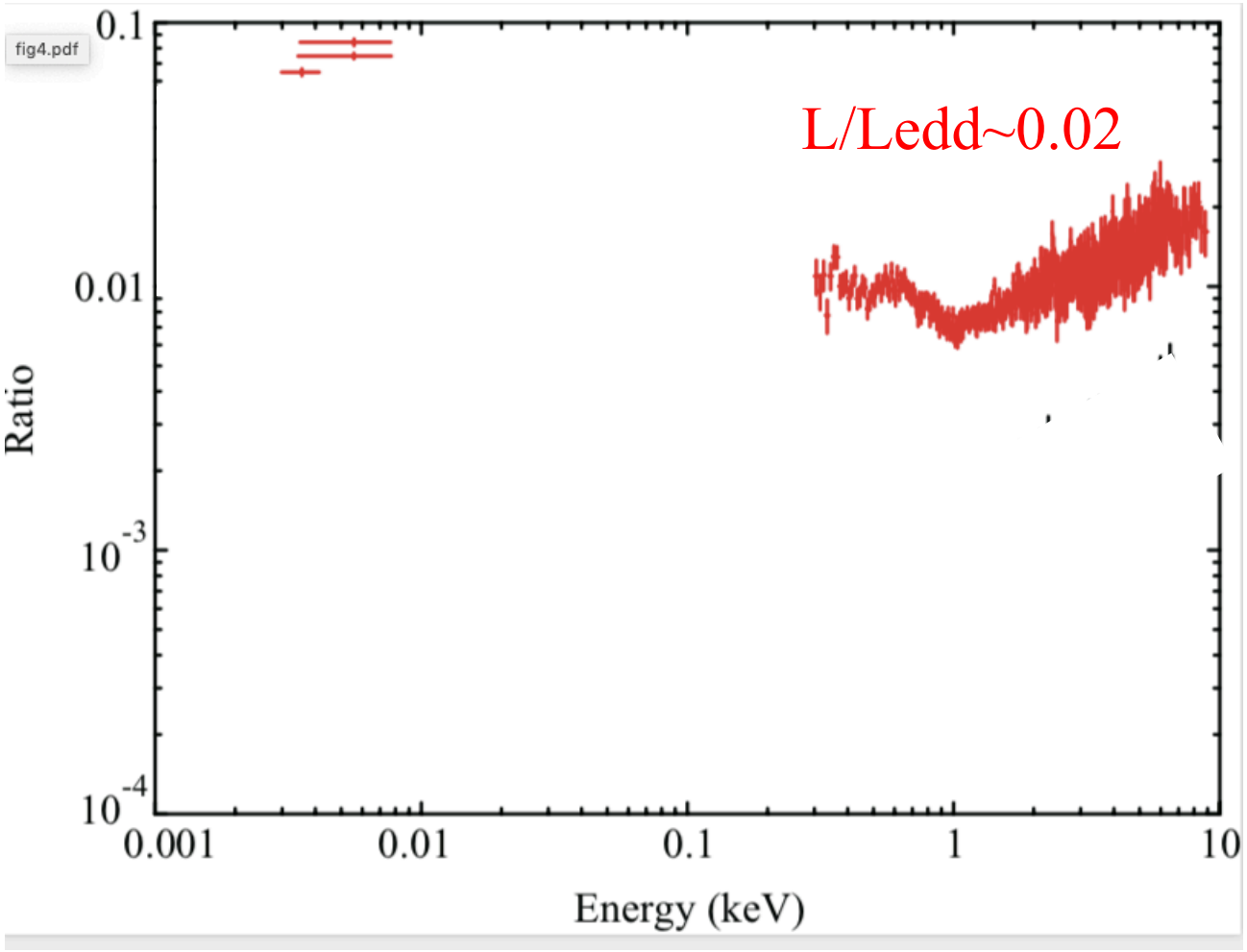
Changing look (state!) AGN – NGC6814

Noda & Done 2020



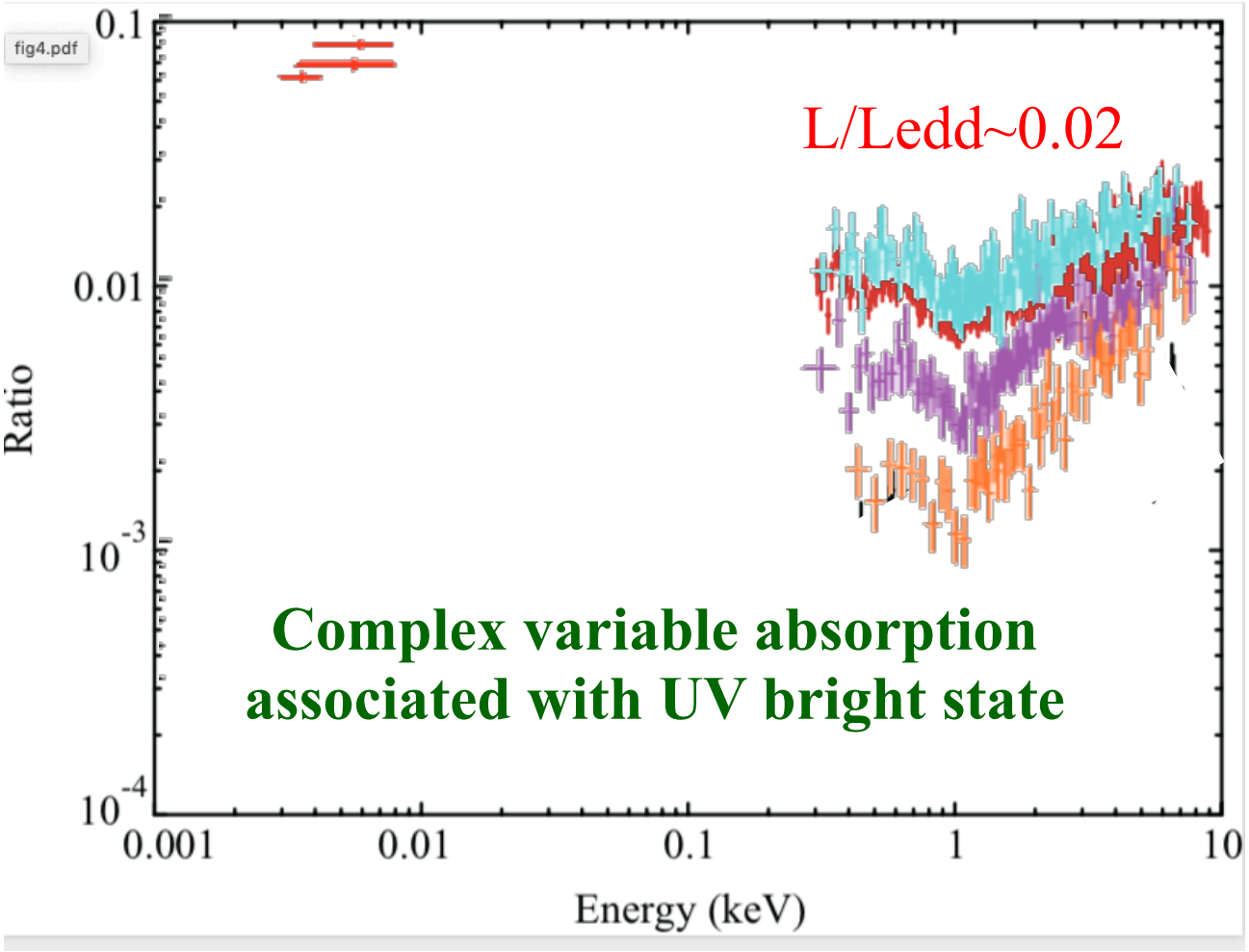
Changing look (state!) AGN – NGC6814

Noda & Done 2020



Changing look (state!) AGN – NGC6814

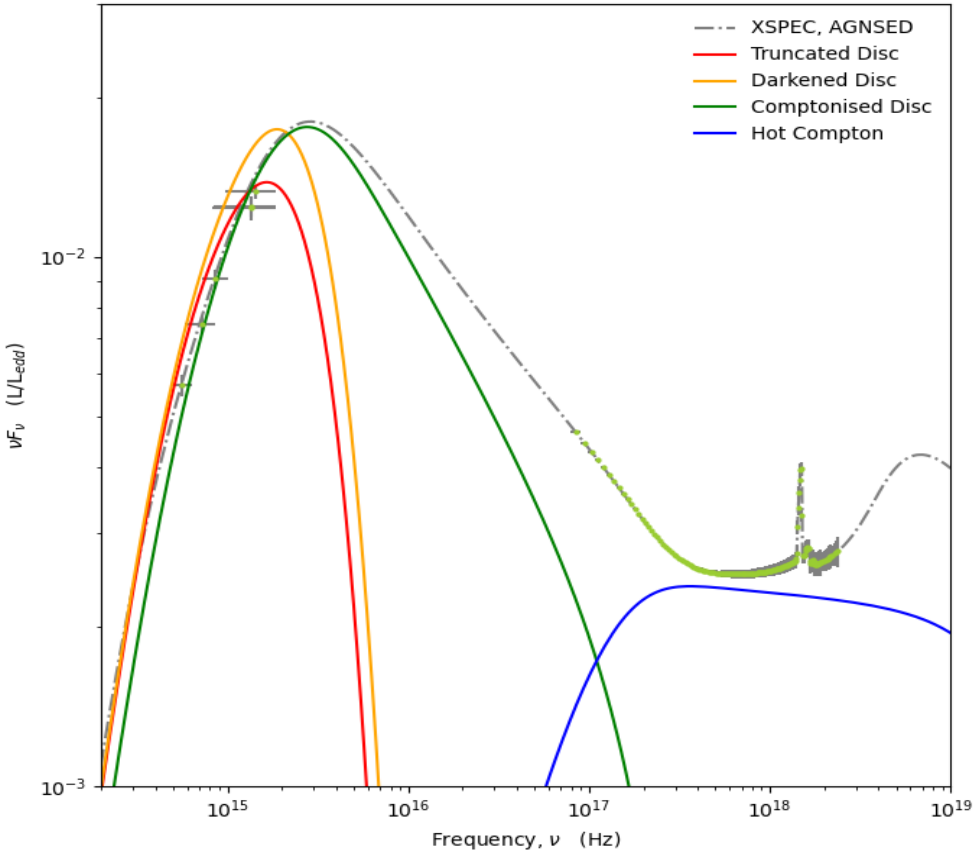
Noda & Done 2020

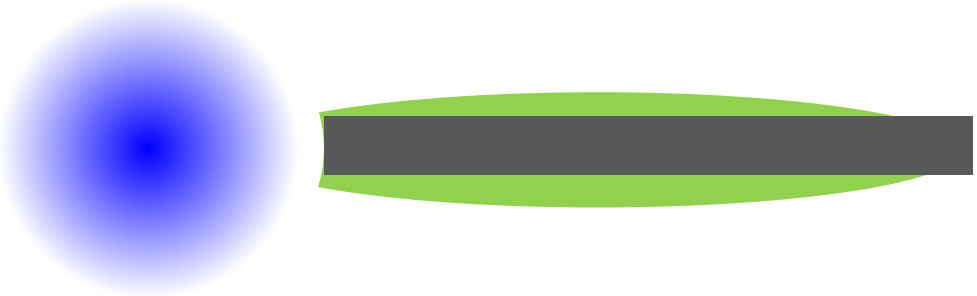


TEST; λλλ continuum reverberation

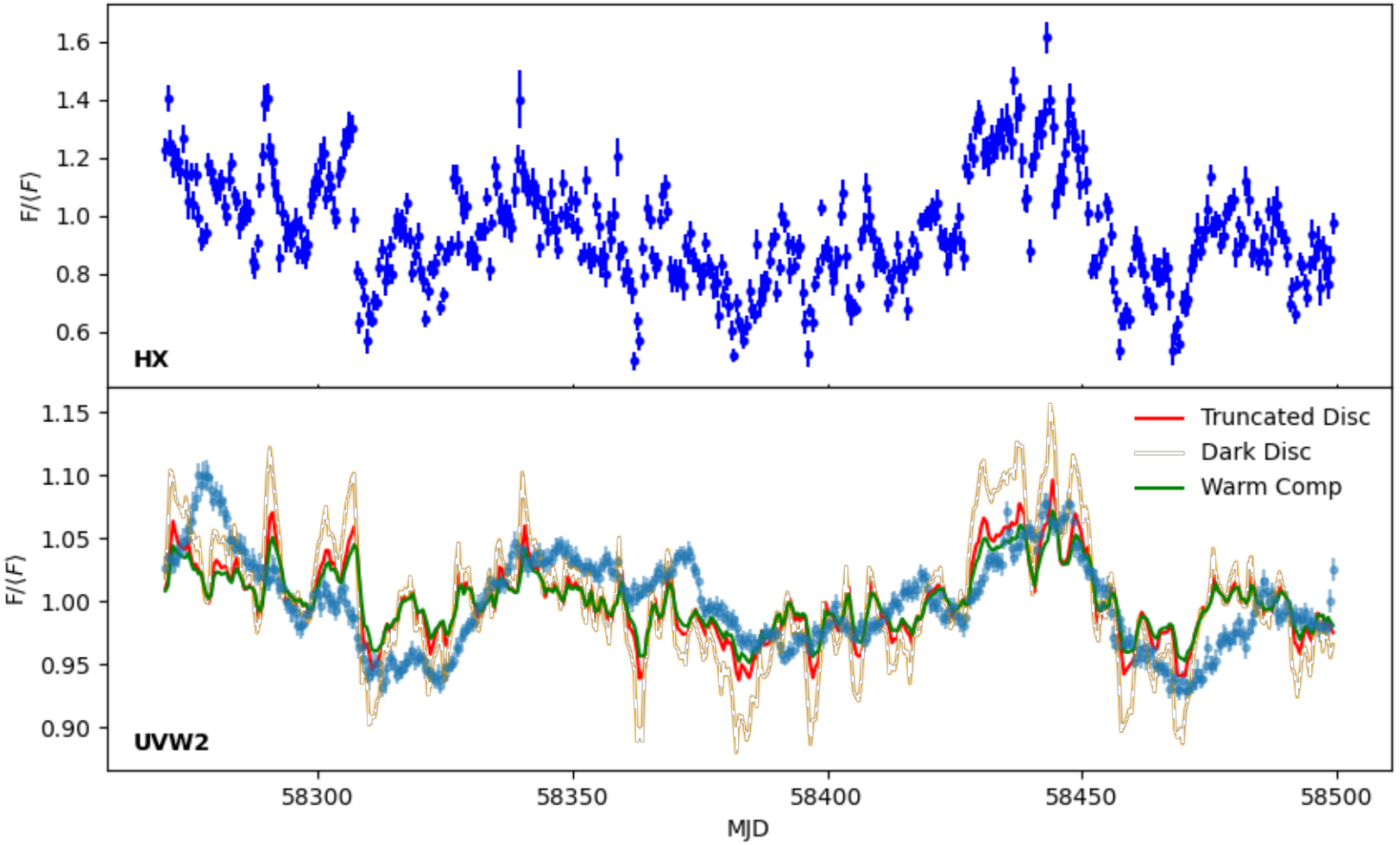
- F9 L/Ledd~0.08
- X-ray Γ~2
- Gravitational power from <20Rg to power Lx

- Hagen, CD…2022





TEST; λλλ continuum reverberation (high frequency)

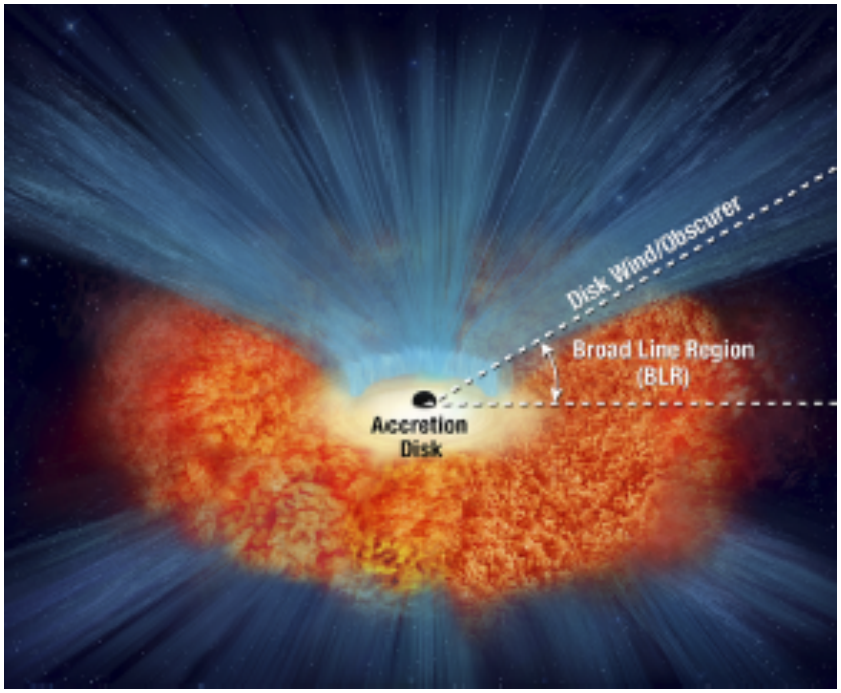


Black hole accretion flows

- Depend on mass, L/Ledd and spin.
- BHB transition : Inner Disc to ADAF ~0.01Ledd
- Radial truncation - HOW?? And WHY???
- AGN: Use optical spectra to get M and L/LEdd
- SED changes SUBSTANTIALLY with L/Ledd
- SHOW THE SED!!!
- AGN transition – Changing Look/STATE Quasars
- UV-SX collapses ~0.01LEdd, BLR mostly disappears
- WHAT IS THE SX?? warm Compton from disc? WHY??
- Reverberation map it and it looks good for L/Ledd~0.1!

- But NOT for lower L/Ledd as also get strong UV component from wind/BLR…

- We need to understand the winds to understand the continuum
- XRISM 2023
- Athena ~2030



Deghanian et al 2019b,2020
Kaastra et al 2014