Accreting compact objects

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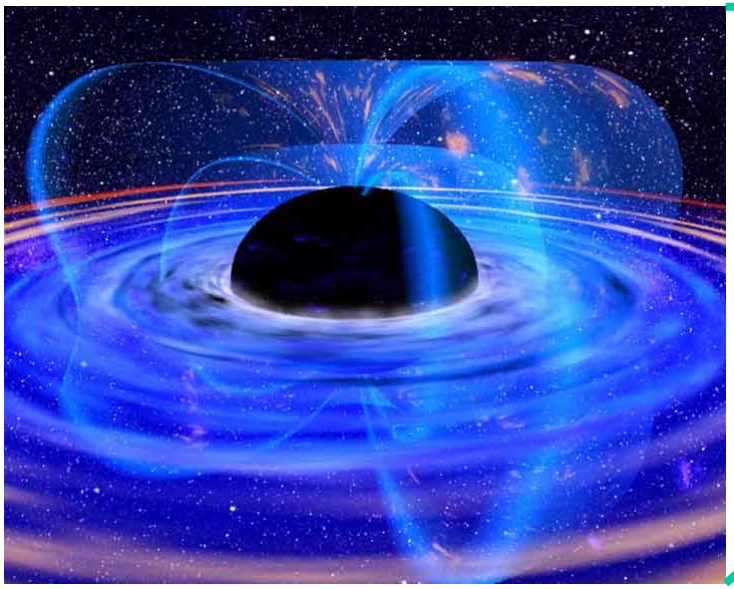
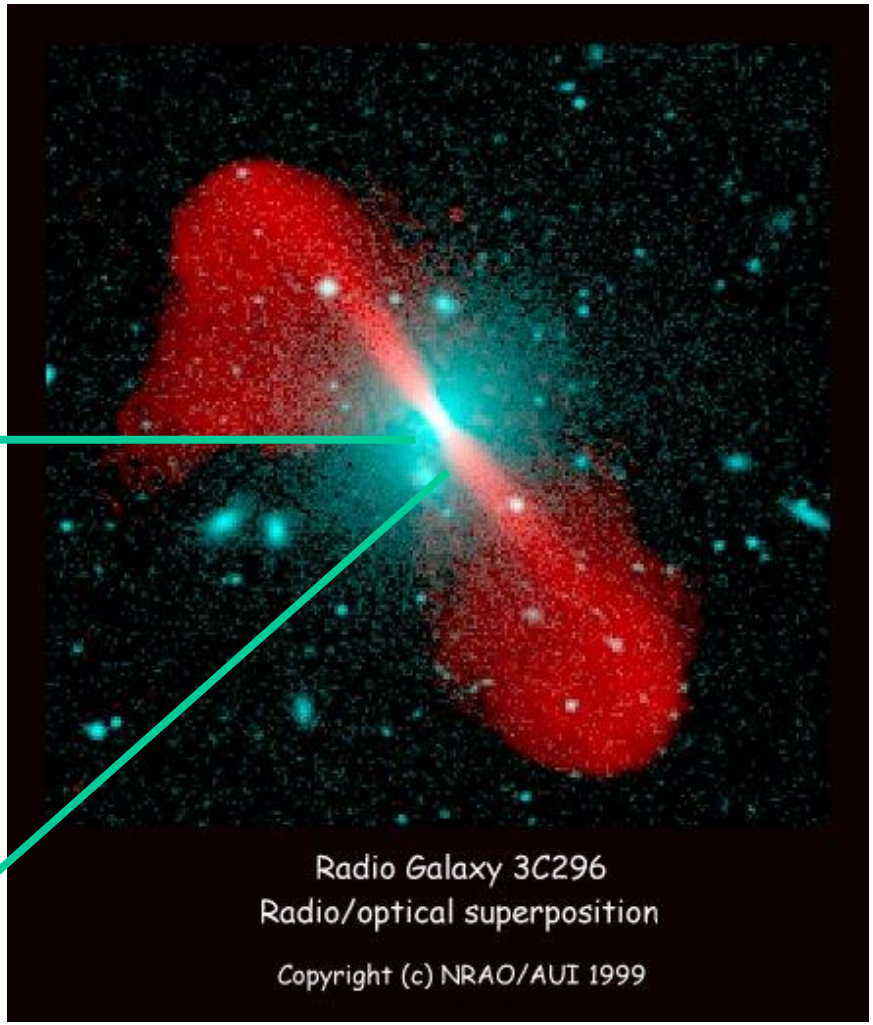
Accretion onto black holes

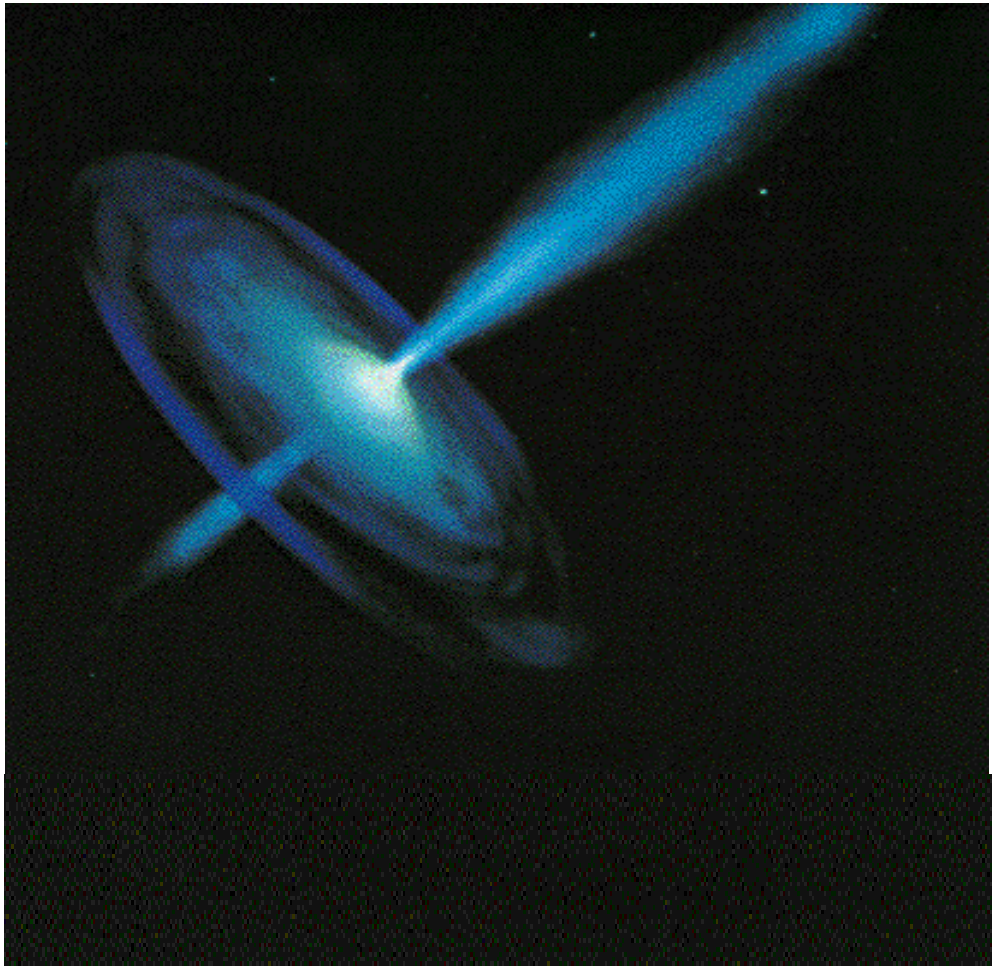
- Ultra-relativisitic jets in AGN are ultimately powered by accretion flow close to the black hole





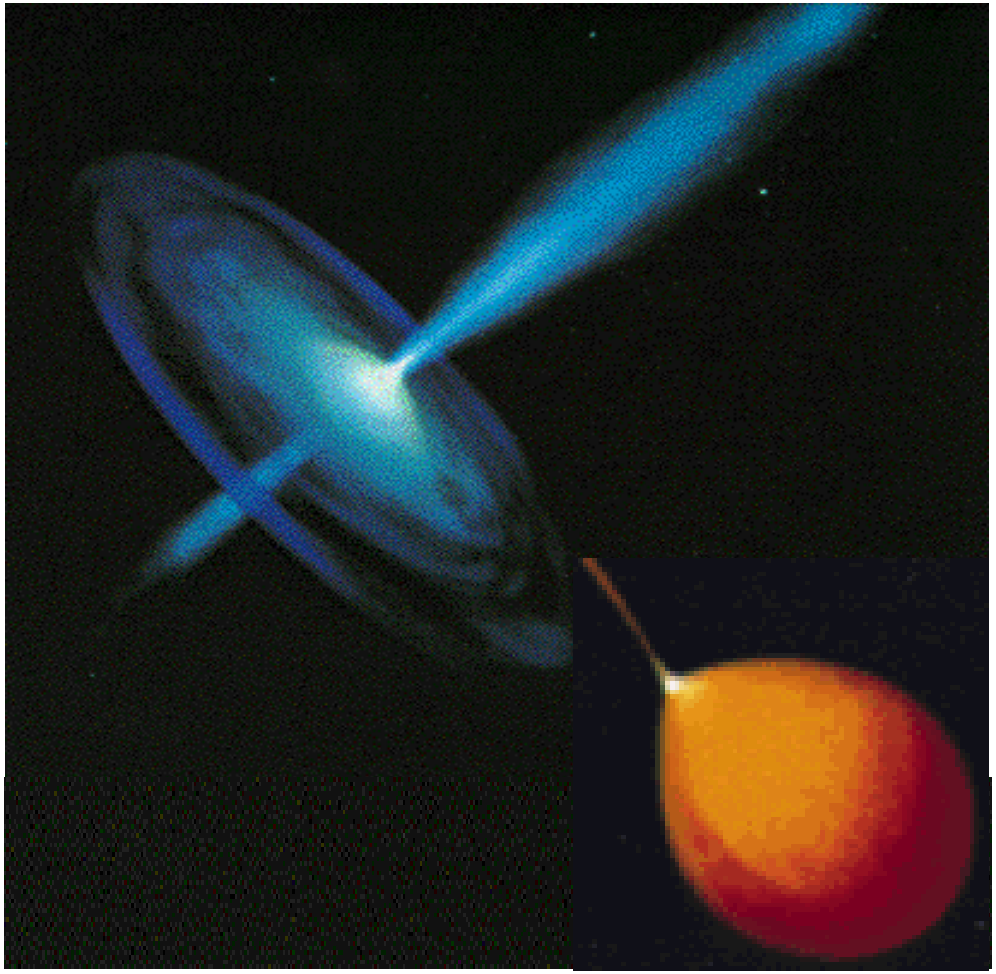
Black hole accretion and jets

- 3 fundamental parameters
- Mass, Mdot, spin



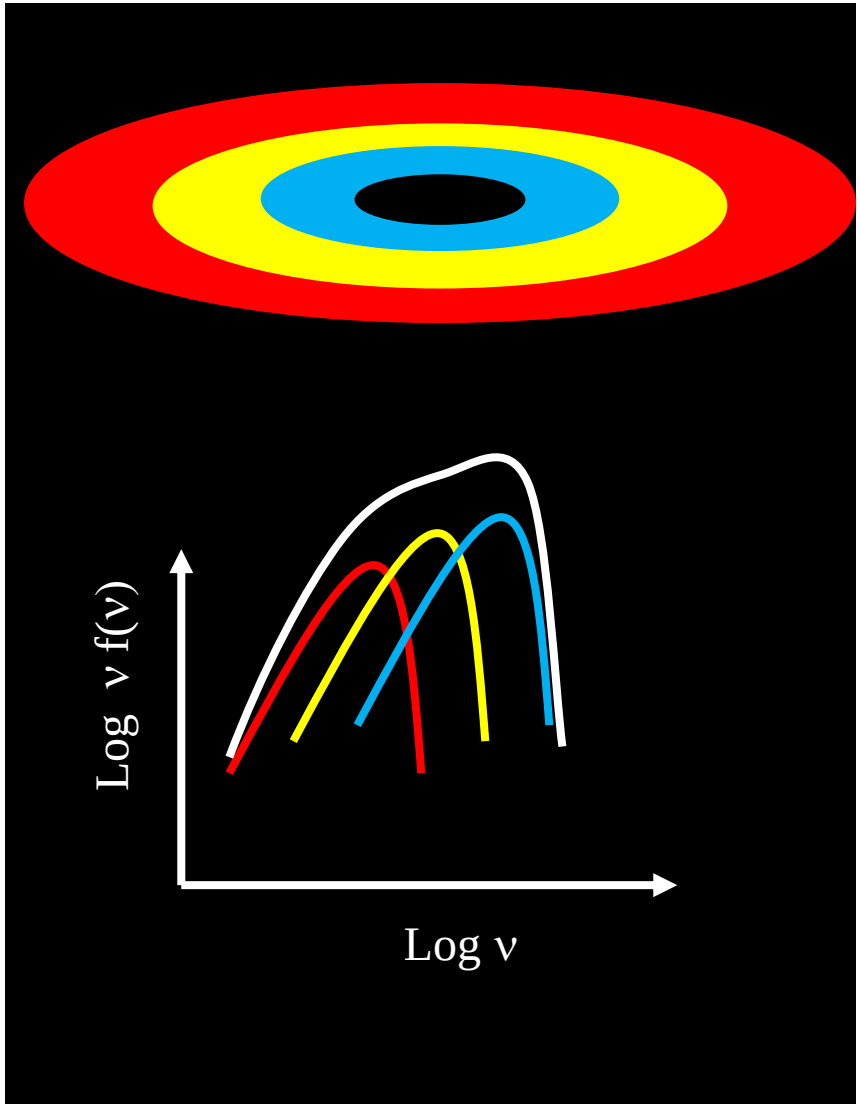
Scaling Black holes

- 3 fundamental parameters
- Mass, Mdot, spin
- BONUS SET – BHB
- Same mass (factor 2)
- Same spin CC SNR (?)
- One main parameter: Mdot



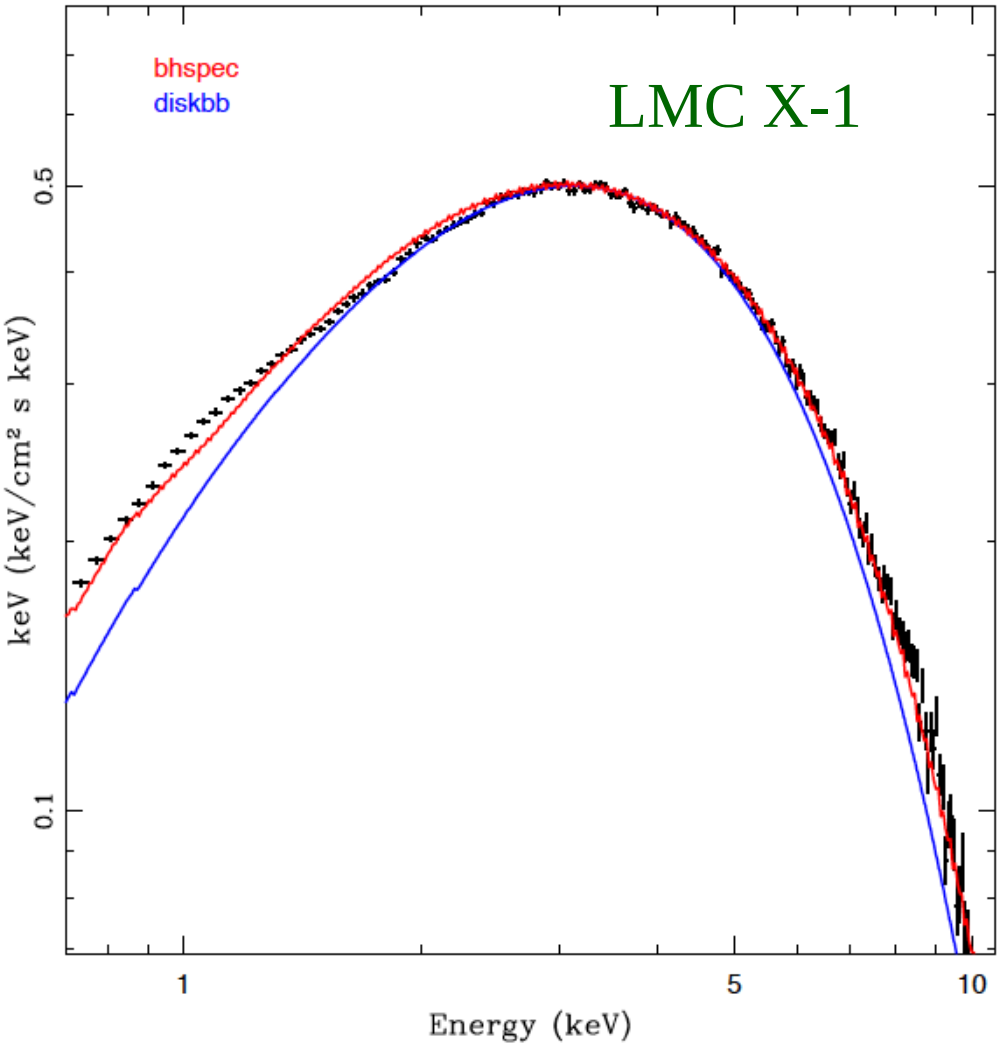
Ultimately from accretion flow

- Differential Keplerian rotation.
- B field dynamo (MRI) converts gravity to heat
- Thermal emission:
- $L = A \sigma T(r)^4$
- 10 Msun, L=LEdd $Tmax \sim (L/LEdd)^{1/4} M^{-1/4}$ keV
- 1 keV 10M BHB
- 10eV 10^8M AGN



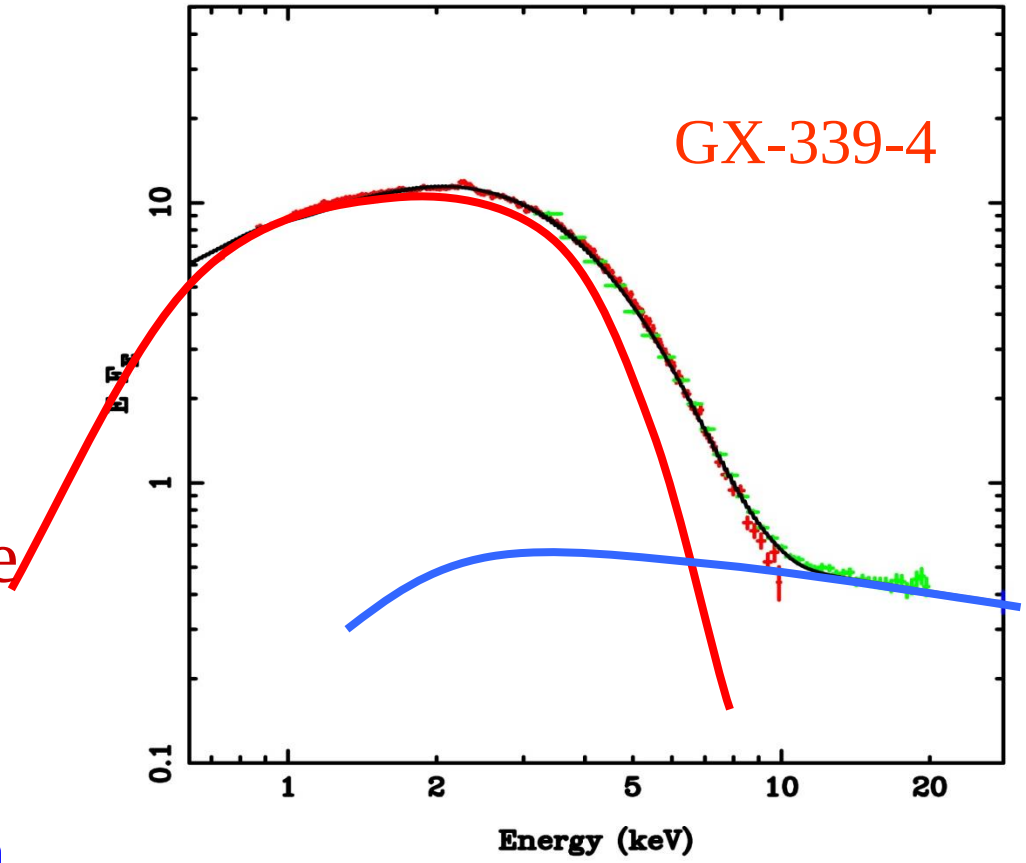
Observed disc spectra in BHB!!

- Sum of blackbodies (diskbb)
- XMM-Newton data from LMC X-3
- Fully relativistic energy generation and ray tracing and full radiative transfer (bhspec)
- WORKS WELL!!



Observed disc spectra in BHB!!

- Sum of blackbodies (diskbb)
- XMM-Newton data from LMC X-3
- Fully relativistic energy generation and ray tracing and full radiative transfer (bhspec)
- WORKS WELL!!
- Small corona gives high energy tail

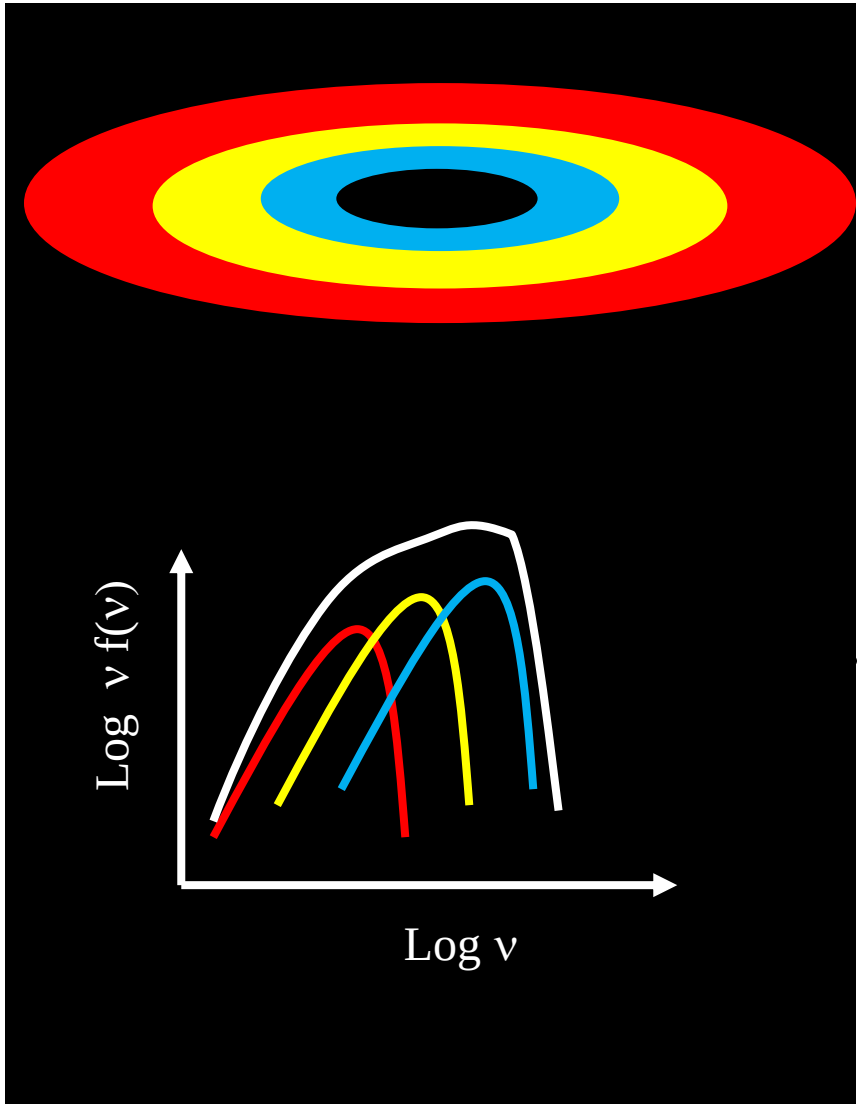


Kolehmainen et al 2010

Spectra of accretion flow: disc

- Thermal emission:

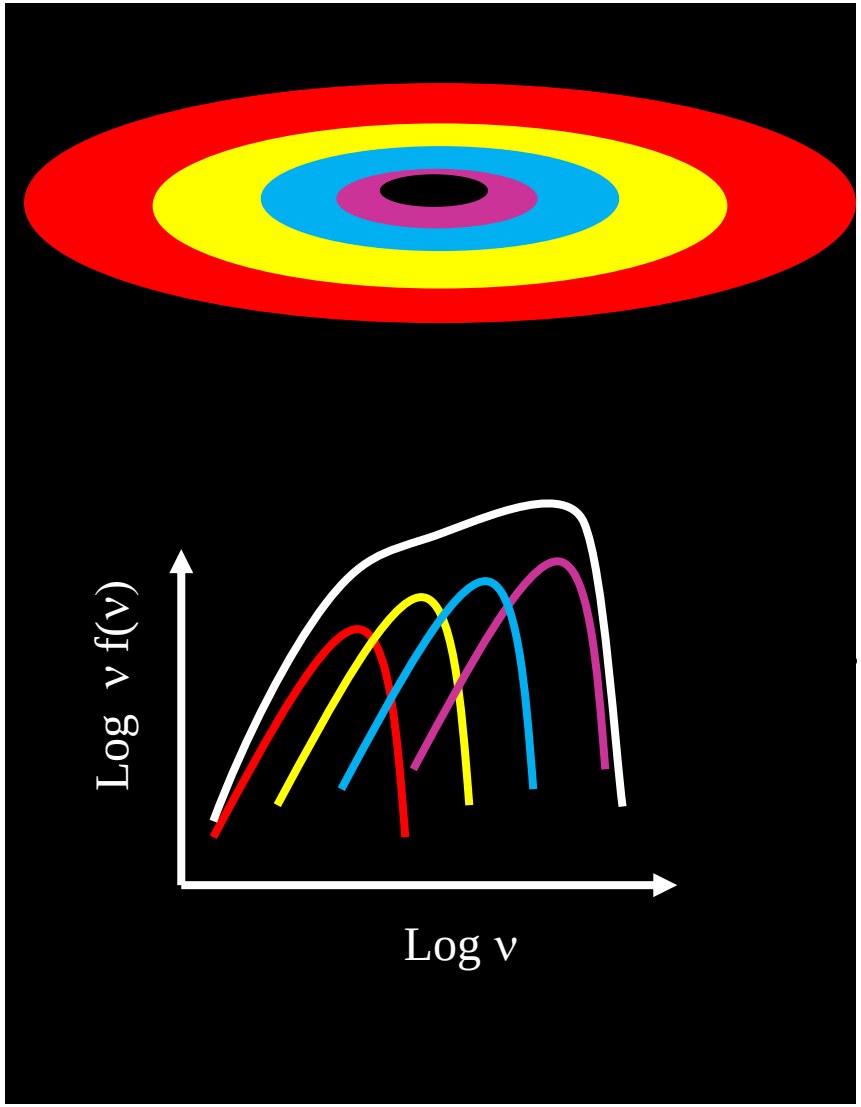
  $L = A\sigma T^4$
- Last stable orbit sets maximum temperature – X-ray



Spectra of accretion flow: disc

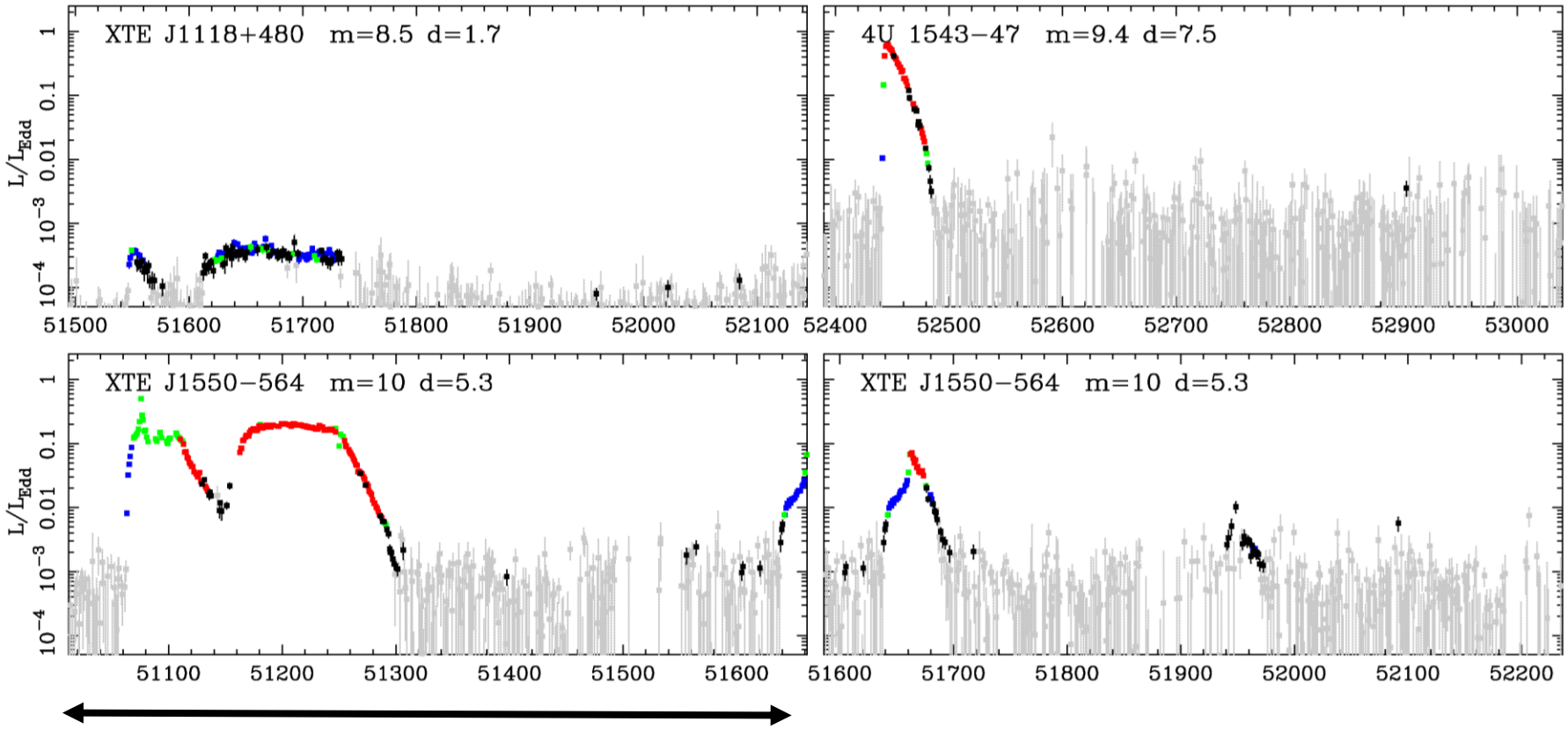
- Thermal emission:

  $L = A\sigma T^4$
- Last stable orbit sets maximum temperature – X-ray
- Depends on spin!

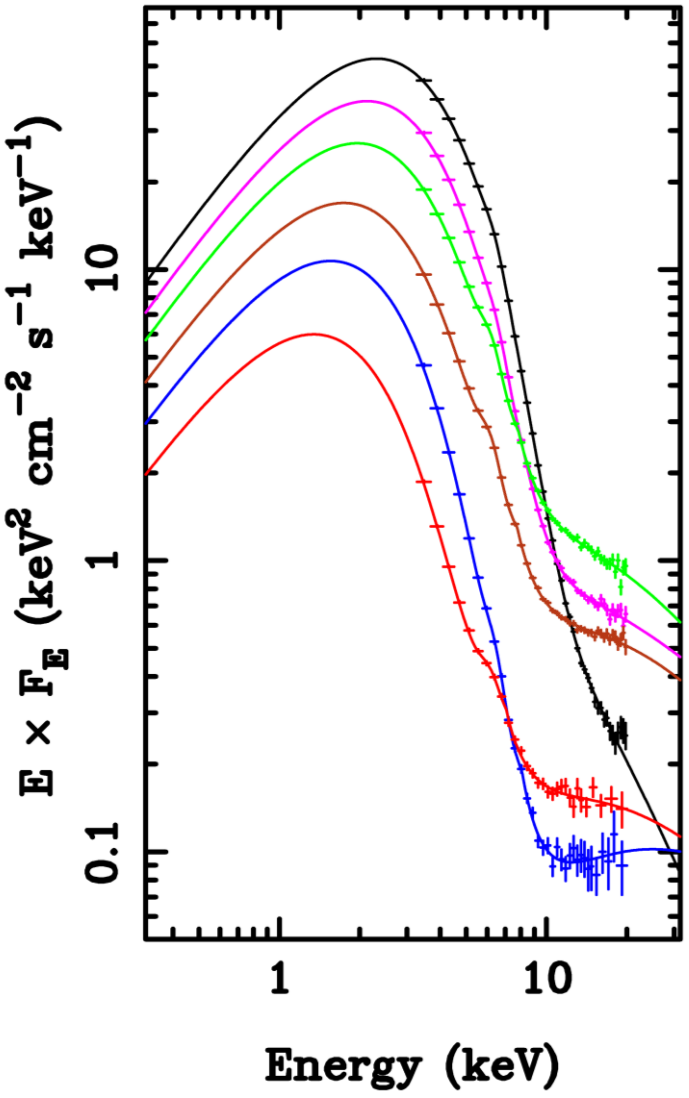


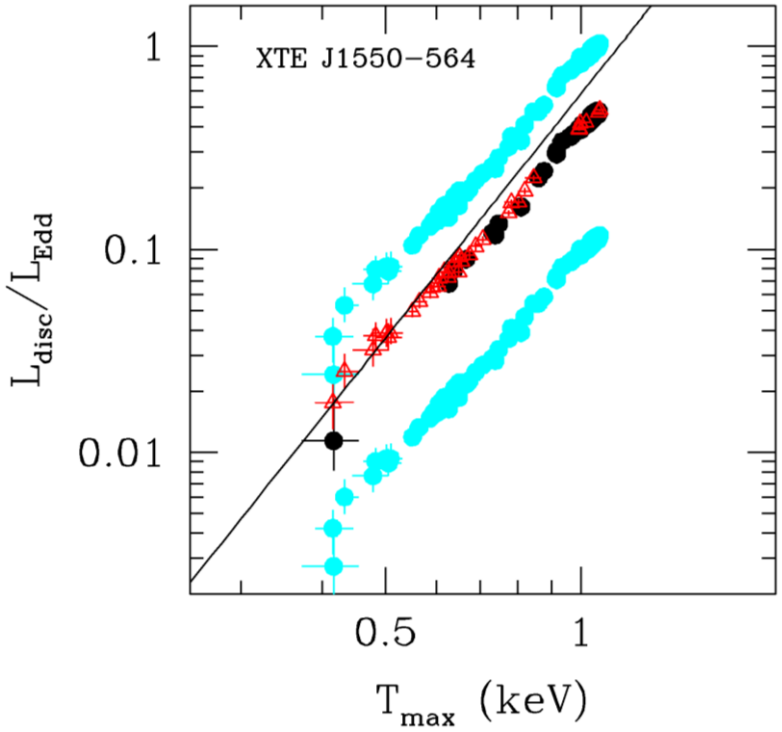
Stellar mass BH disc varies!

- Mass accretion rate through the disc varies on timescales of days/weeks/months
- Not often L>LEdd – but H instability and binary orbit!



Variability of disc:long timescale

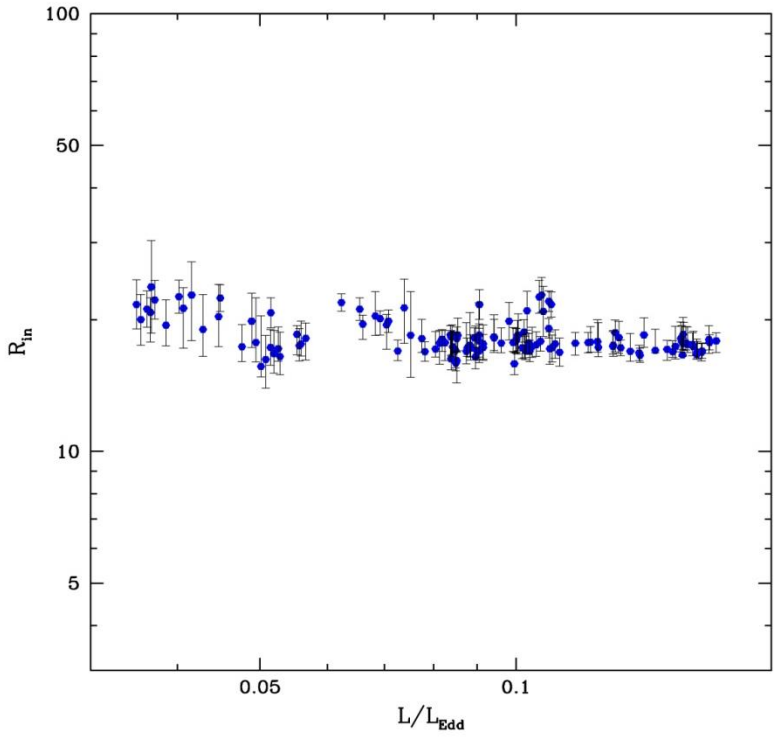




- $L/L_{Edd} \propto A T^4_{max}$ Kubota et al 1999; 2001

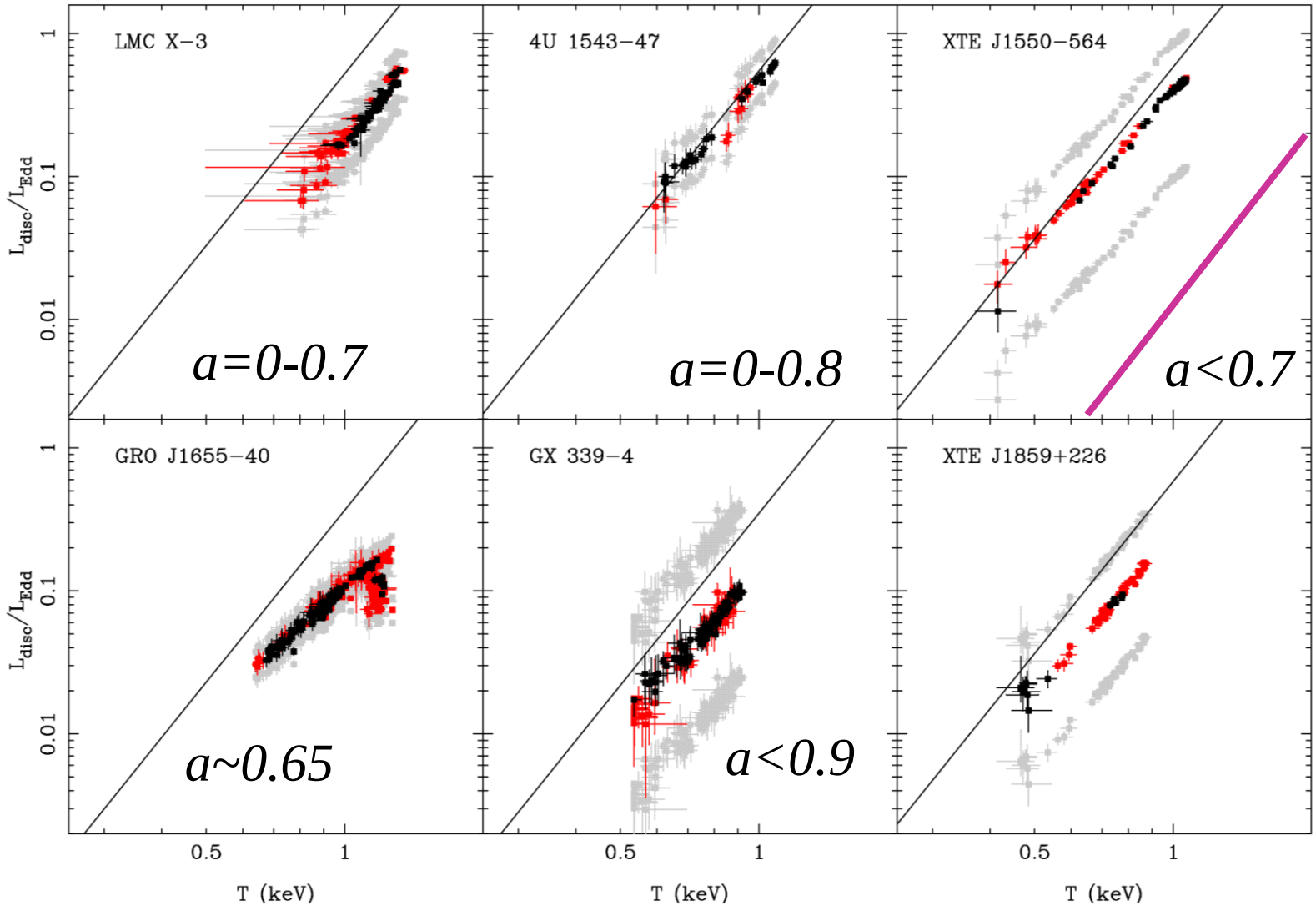
Disc spectra: last stable orbit

- Constant size scale – last stable orbit!! Ebisawa et al 1993)
- Shaffee et al 2006; Davis et al 2006 Steiner et al 2010; 2011



Kolehmainen et al 2010

Low/moderate spin like GW



Gierlinski & Done 2004, Davis, Done & Blaes 2006, Shaffee et al 2006, Kohlemainen & Done 2009, Kubota et al 2009; Steiner et al 2010;2012….

Stellar mass BH disc varies!

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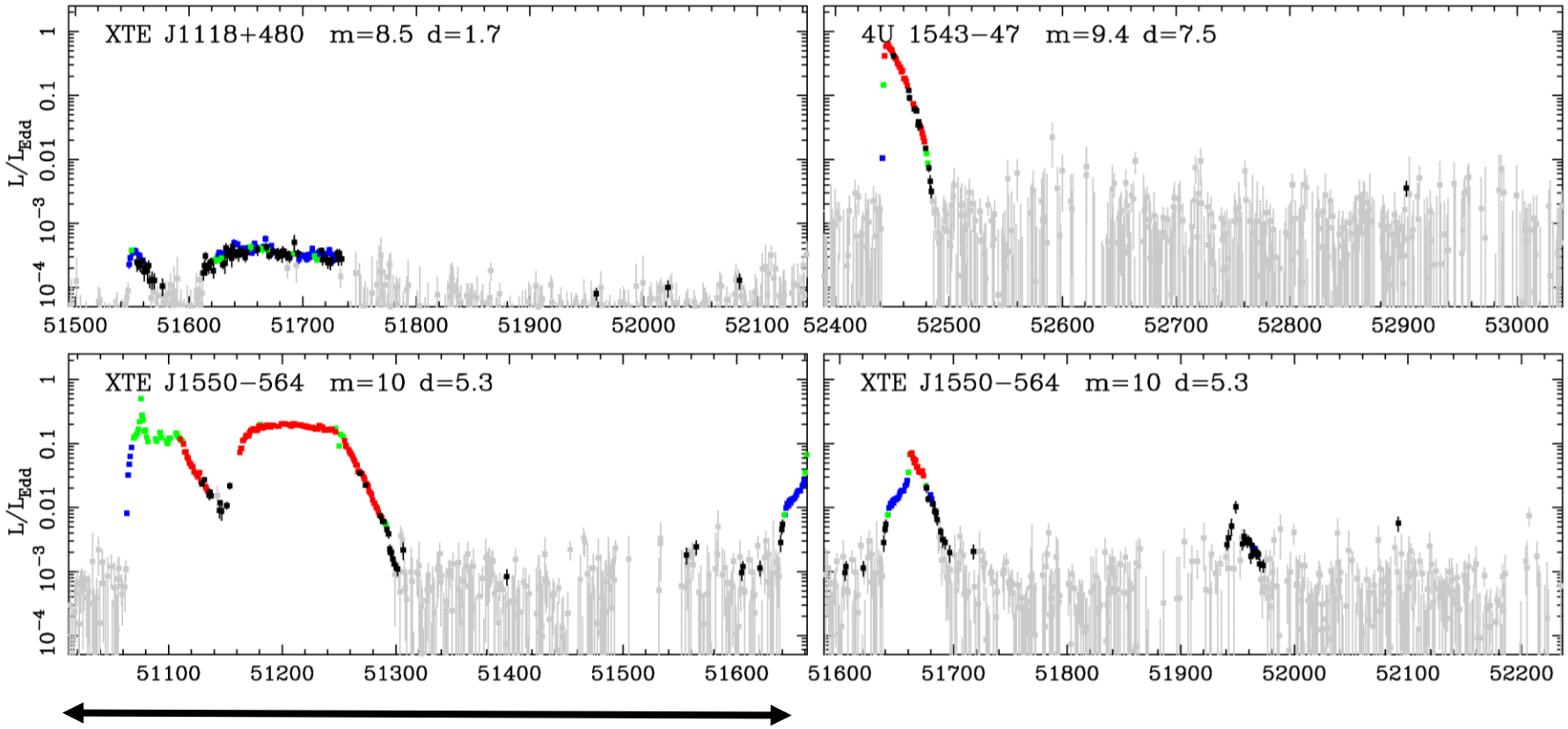
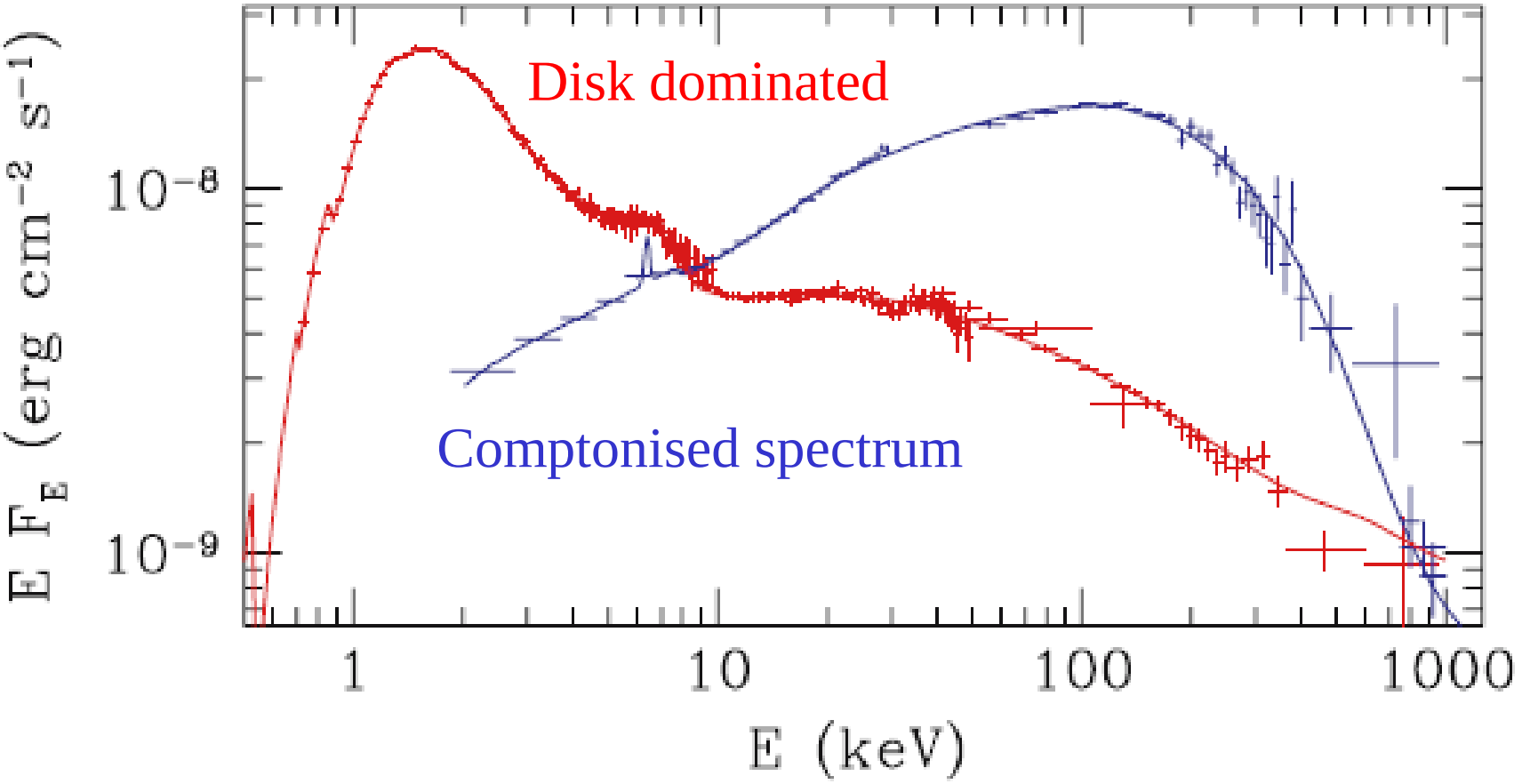
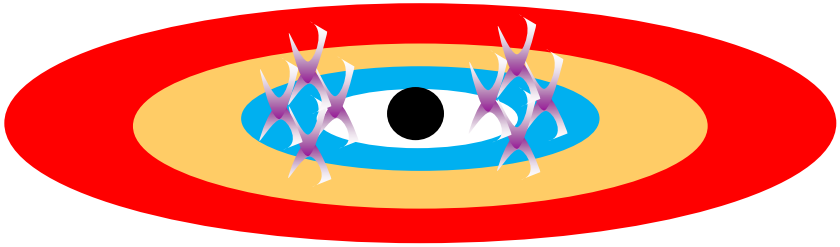


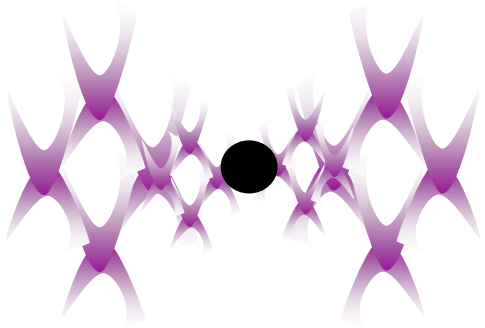
Dramatic transition at ~0.02LEdd
Two types of spectra in stellar BH



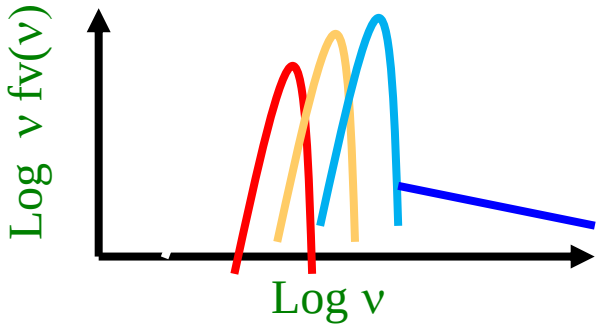
Gierliński et al 1999

Theory of accretion flows





IR opt UV X-ray



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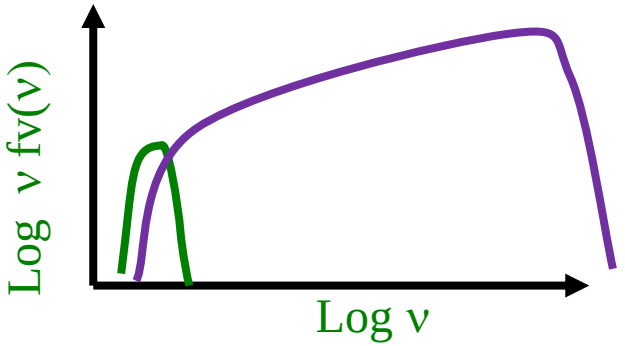
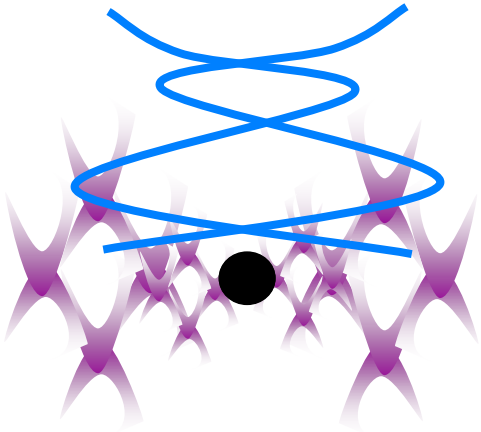


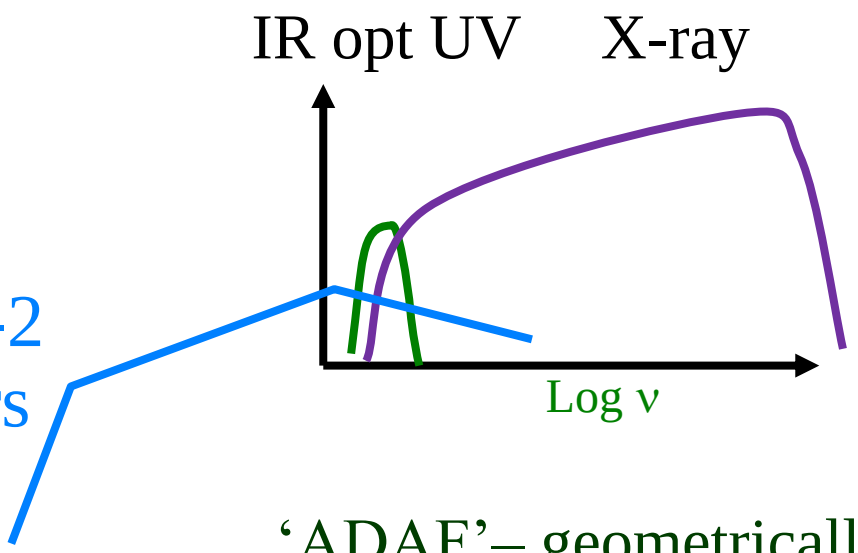
Discs – geometrically thin, cool, optically thick SS73
Plus X-ray tail/corona

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

Theory of accretion flows

- Low/hard state BHB
- Optically thin (tau~1-2)
- We see the MRI directly!
- X-ray variability
- And jet!! L_R – Lx
- (Fender et al 2004)
- BUT NOT HIGHLY RELATIVISTIC Γ~1.5-2 NOT 10-20 as in Blazars

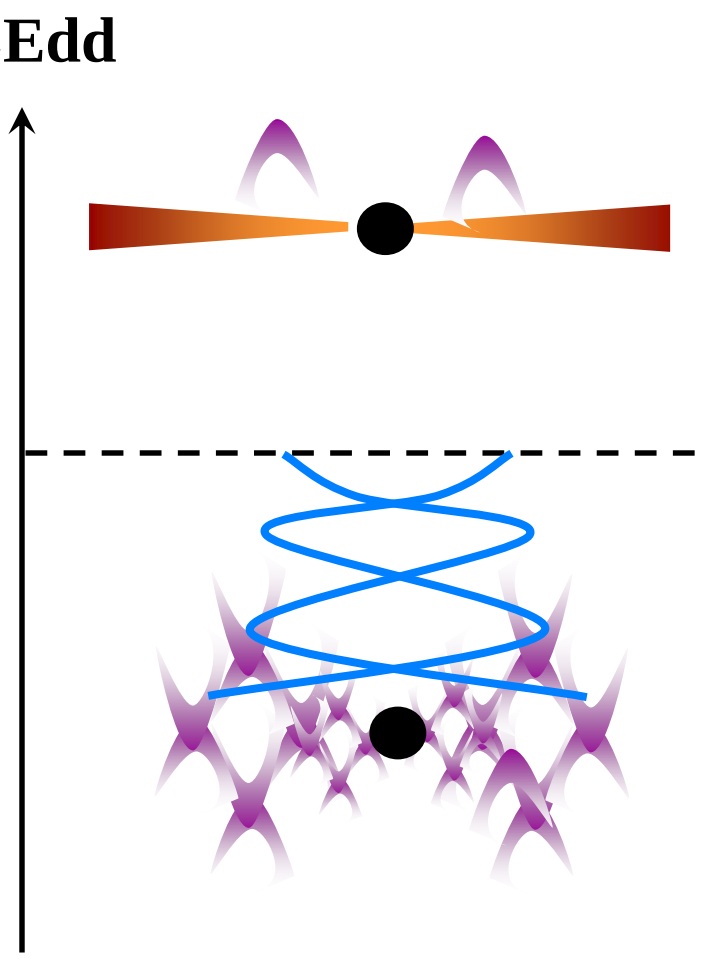




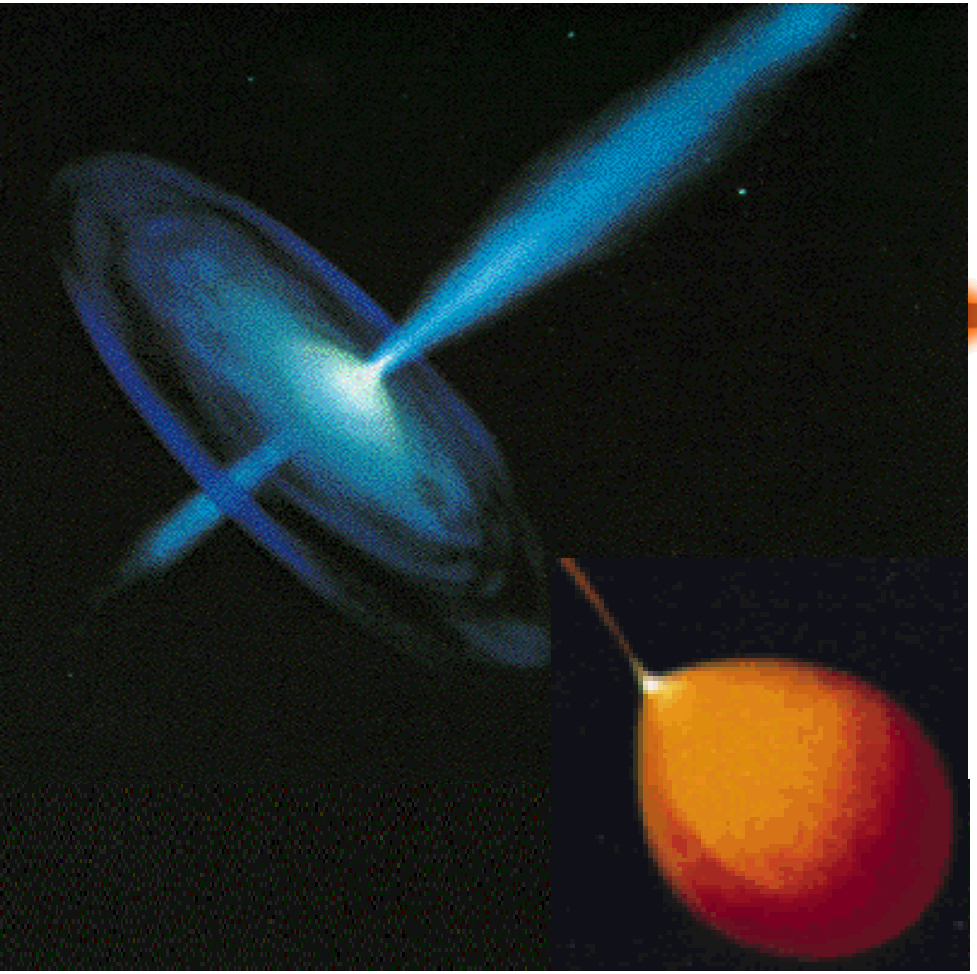
'ADAF'– geometrically thick, hot, optically thin
Only low L/Ledd

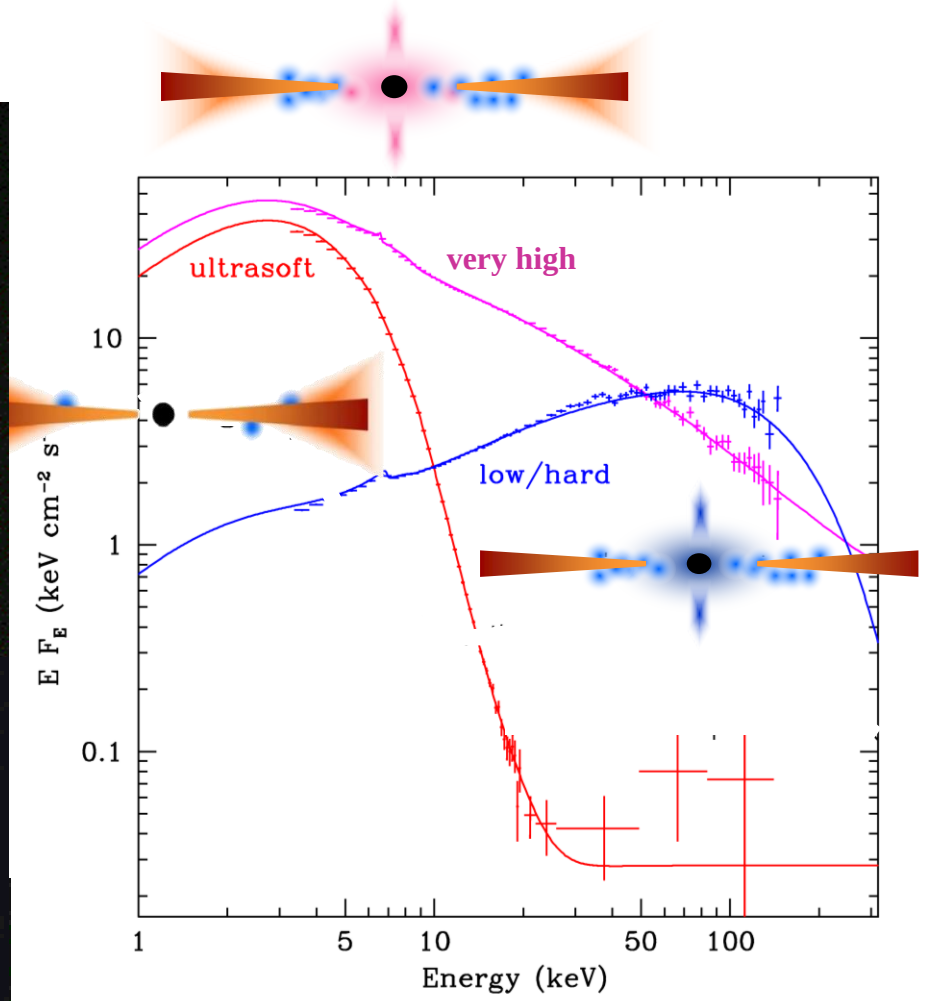
BHB accretion + jet
10Msun: a*<~0.6

- Can be complex at L~LEdd
- Disc dominated state – Shakura-Sunyaev disc equations!!
- transitions are complex!
- ADAF/RIAF + steady compact jet (bulk Γ~1.5-2)



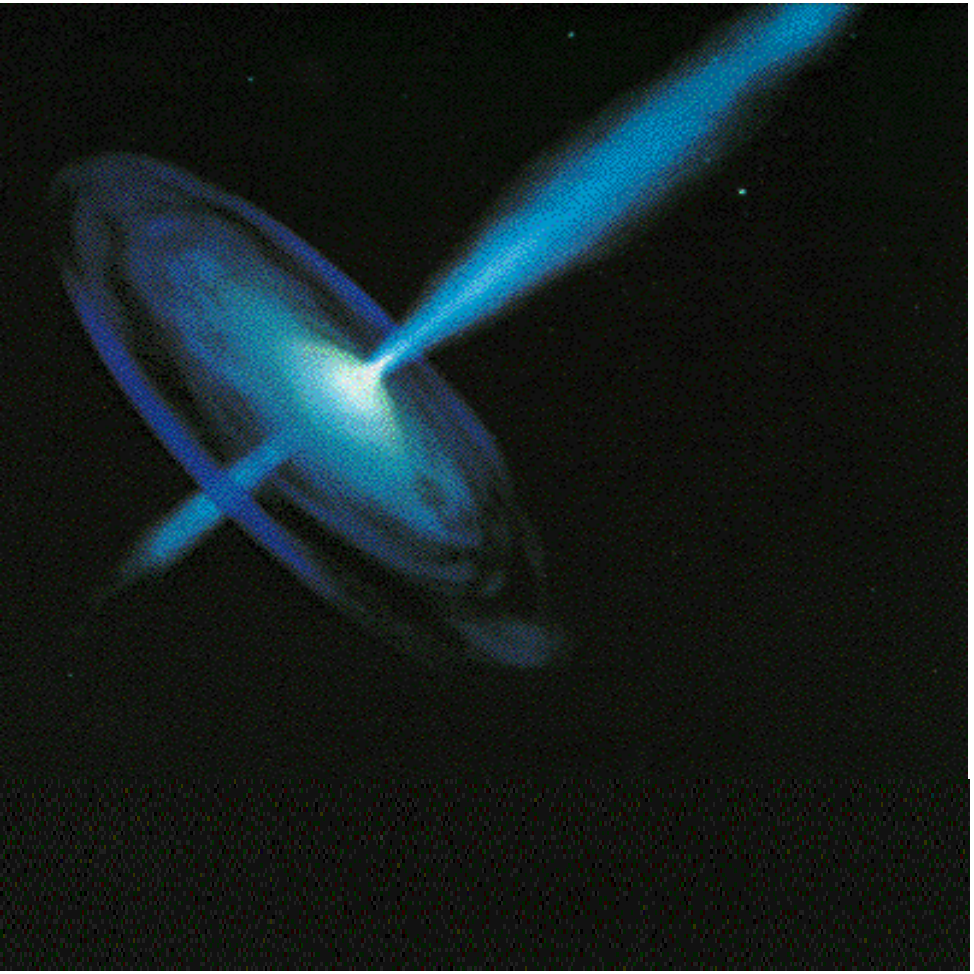
BHB: template for AGN SED?





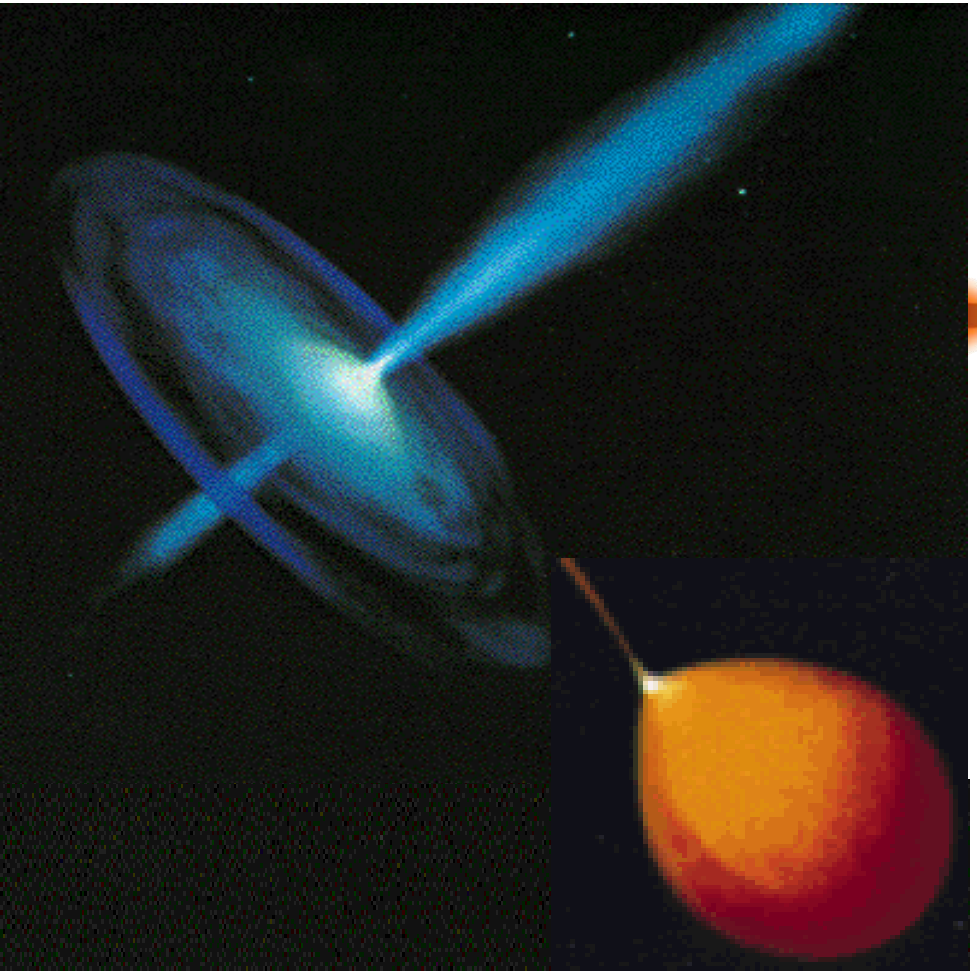
Gierlinski & Done 2003

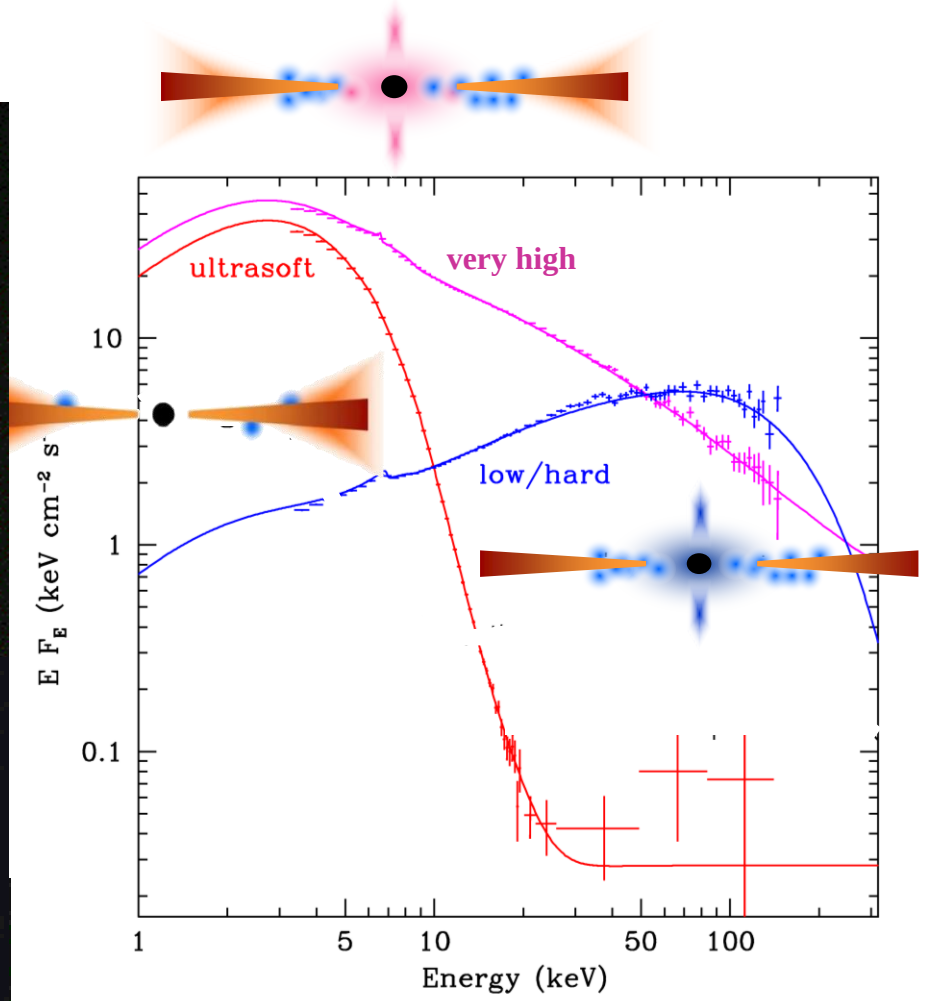
Scaling black hole accretion flow



- Scale up to AGN
- Bigger mass!
- Disc temp lower – peaks in UV (more power, but more area!)
- ATOMIC PHYSICS
- Larger RANGE in mass –from 10^5-10^{10}M
- AGN need 2 parameters
- And maybe bigger range in spin??

BHB: template for SED L/Ledd?

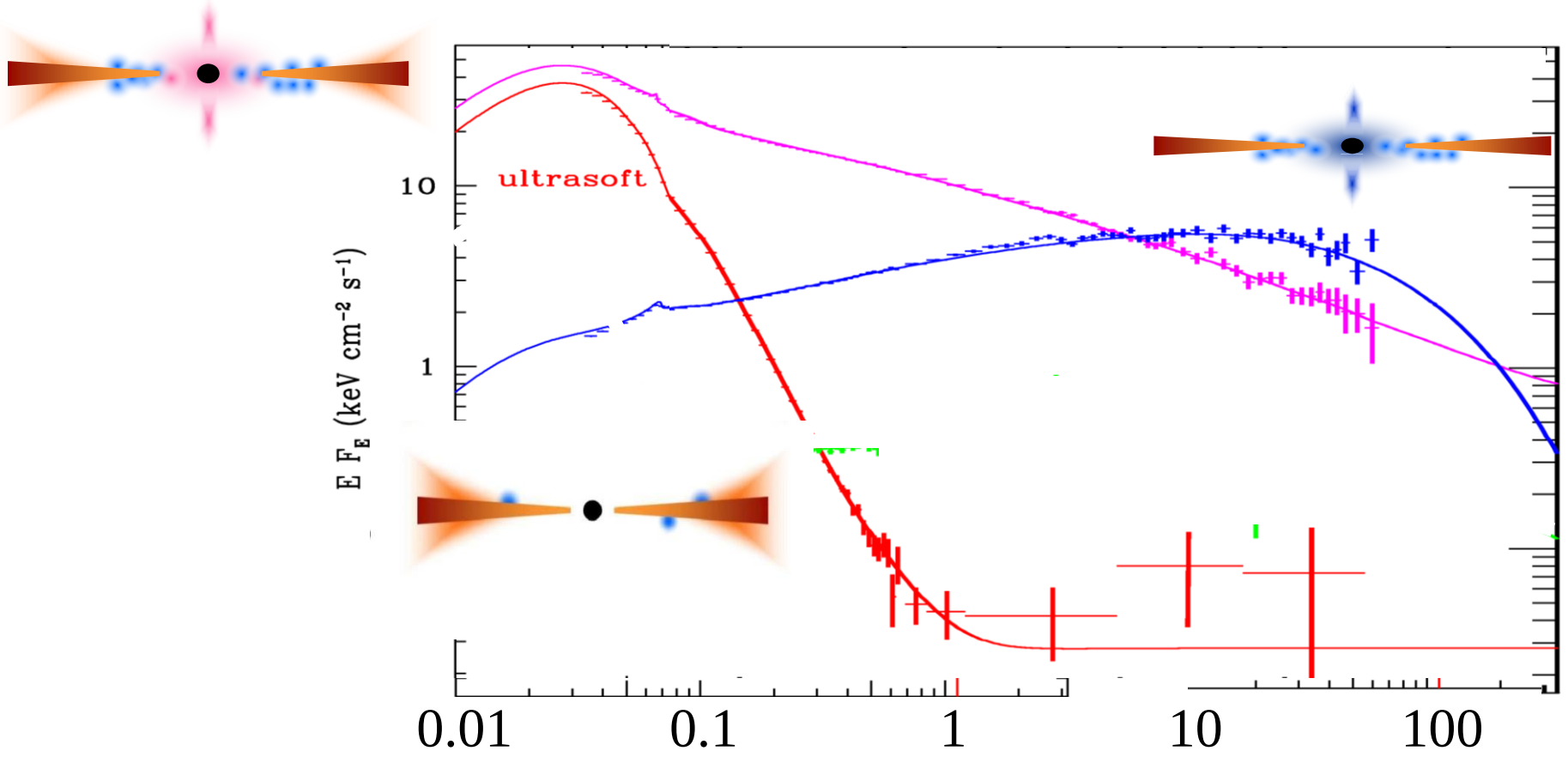




Gierlinski & Done 2003

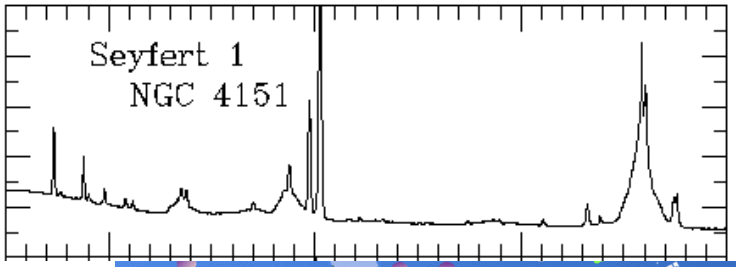
‘Spectral states in AGN’

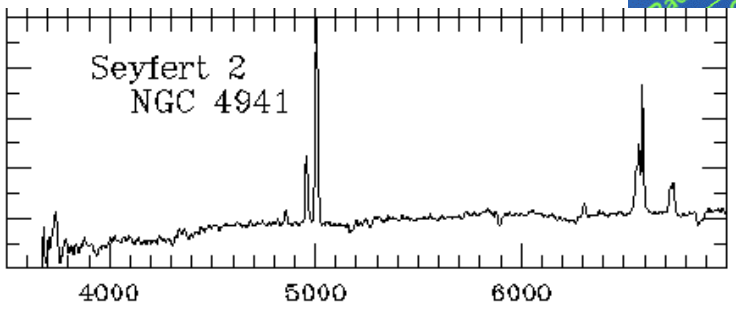
Disc BELOW X-ray bandpass. Only see tail.



And Inclination

- AGN: complex environment
- From now on take only UNOBSCURED





Unobscured AGN: LINERS-S1-NLS1

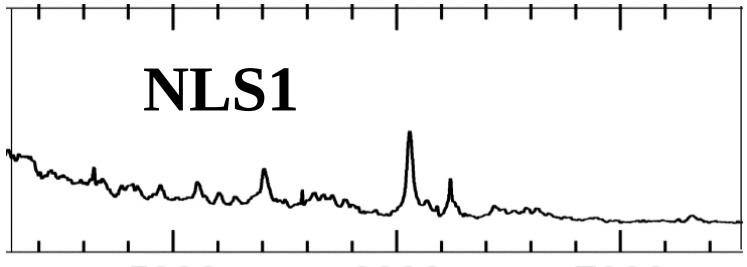
Similar mass.

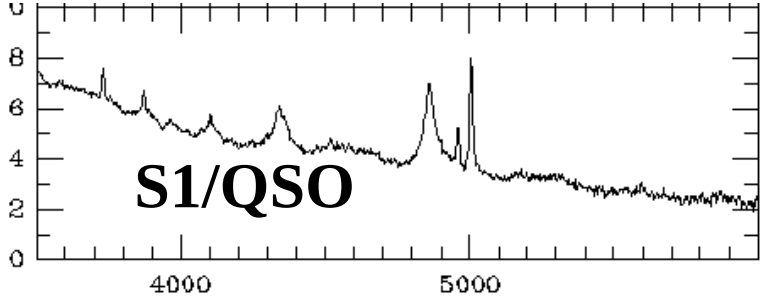
Different L/L_{Edd}

Different ionisation

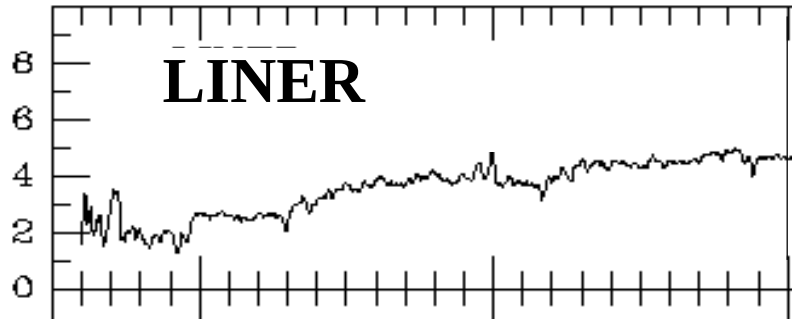
Increasing L/L_{Edd}

Boroson 2002

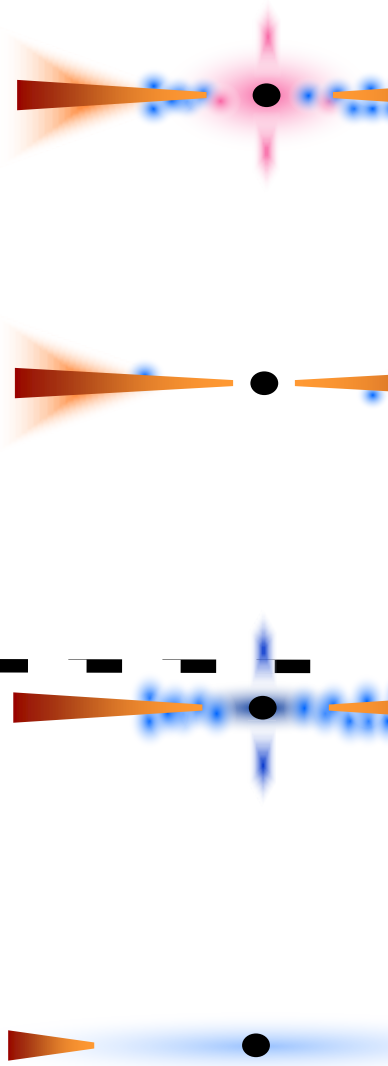




disc



Hot inner flow, no disc – true Seyfert 2s



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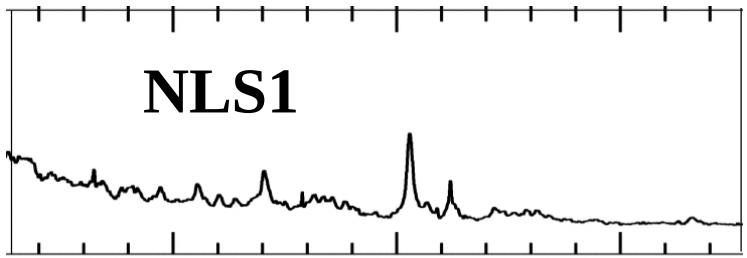

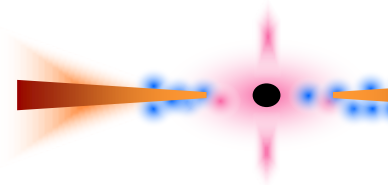

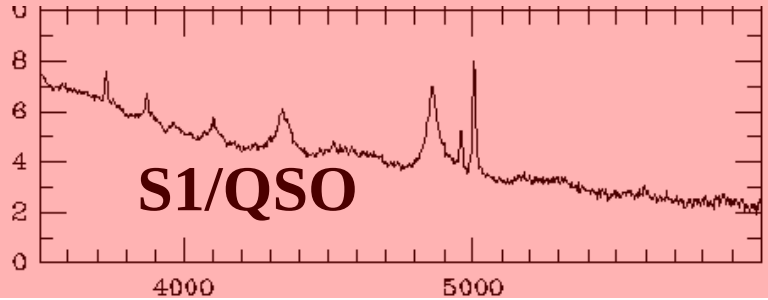

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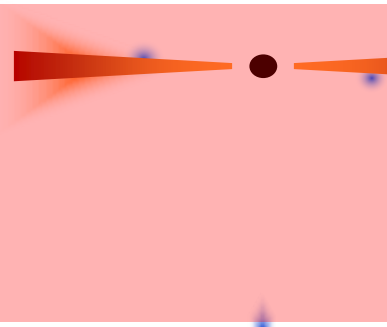
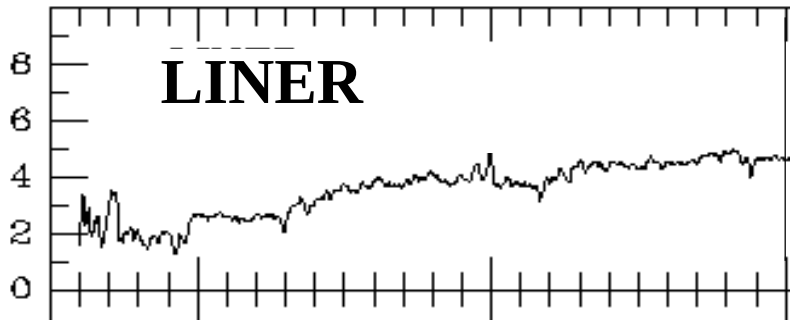
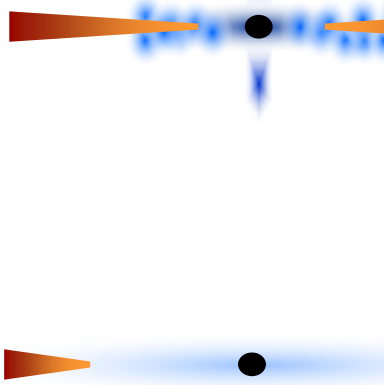


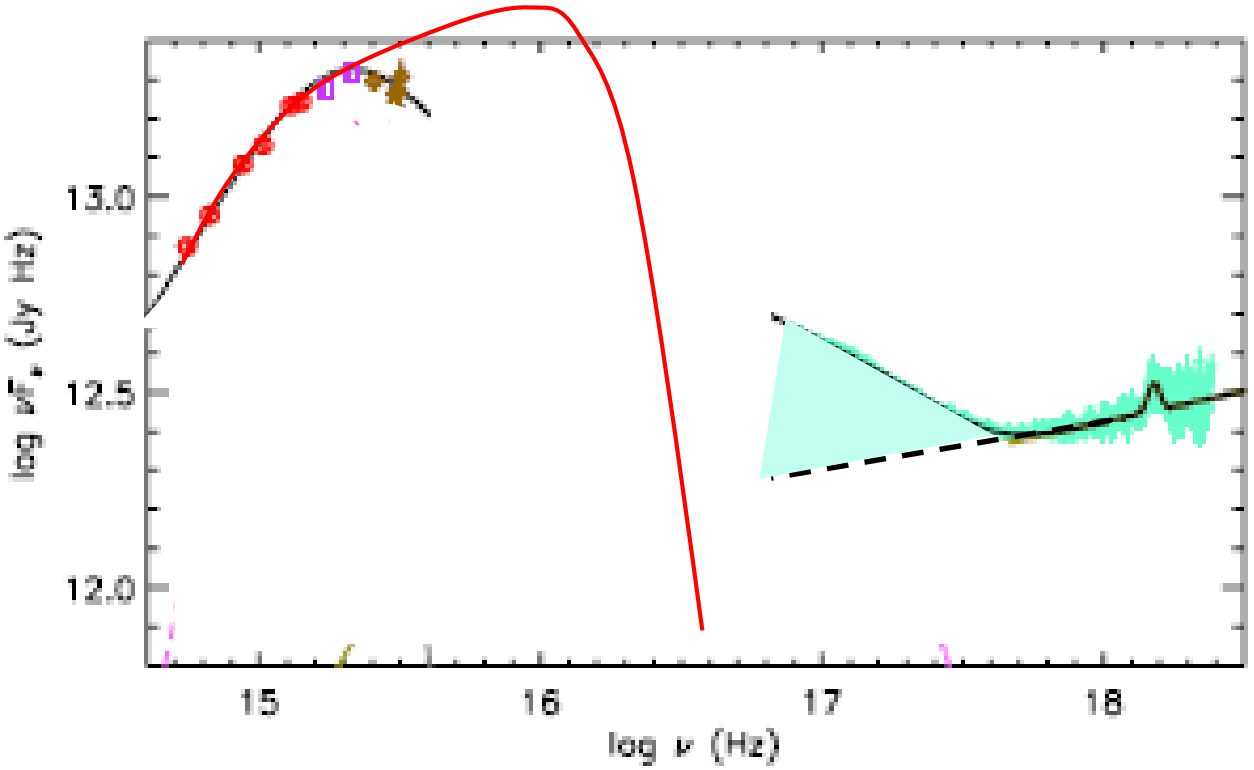




Hot inner flow, no disc – true Seyfert 2s

Classic QSO – most common shape

- Mkn 509 - 10^8M L/LEdd~0.1 (take out warm abs!)
- Not disc dominated - far too low temperature! Plus strange soft X-ray excess….What is this????



Medhipour et al 2011

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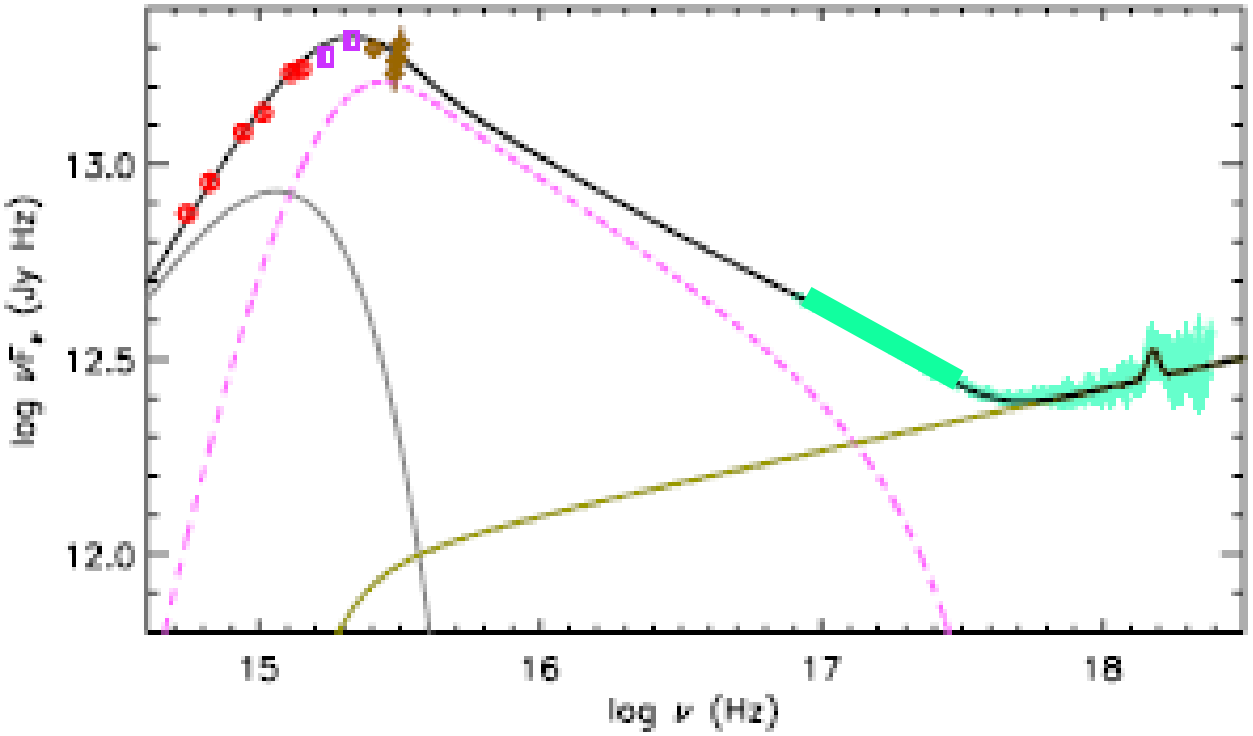

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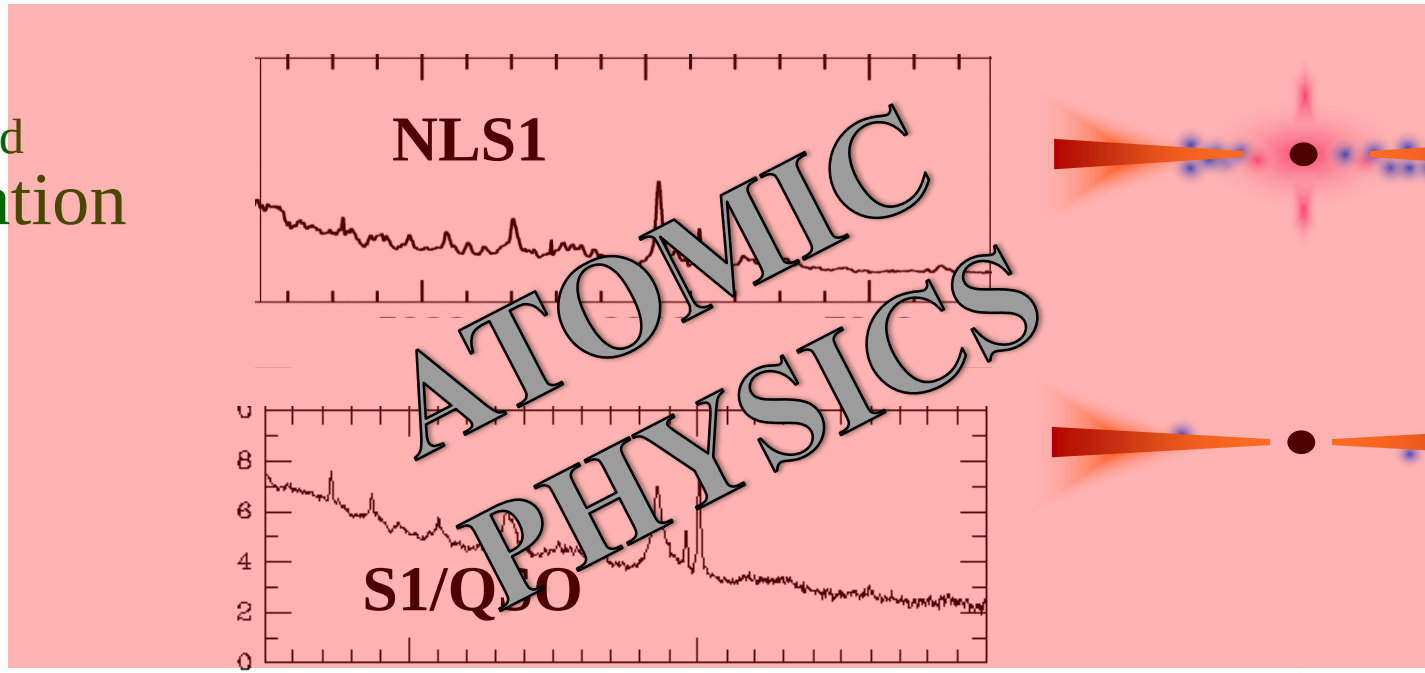
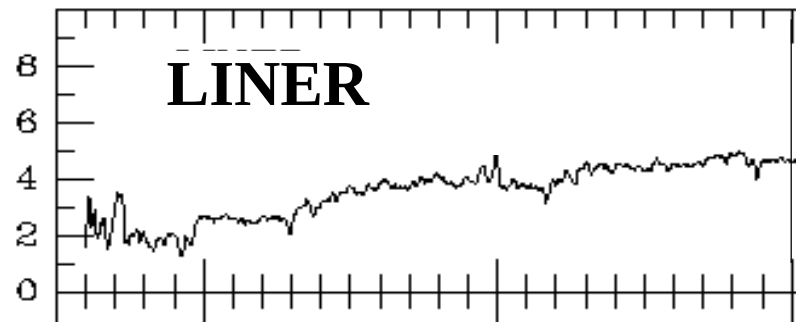


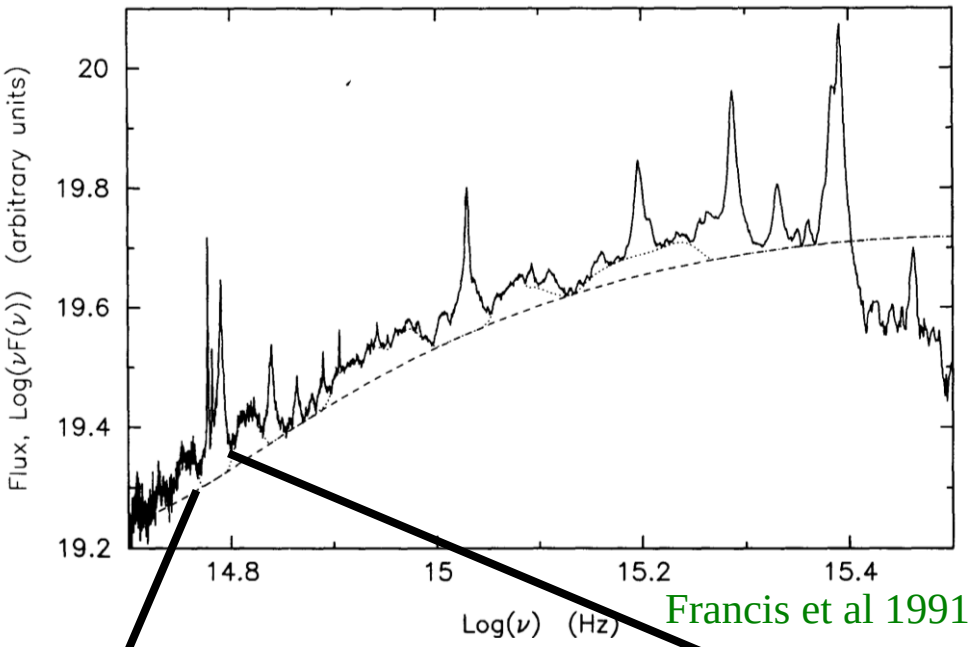
disc



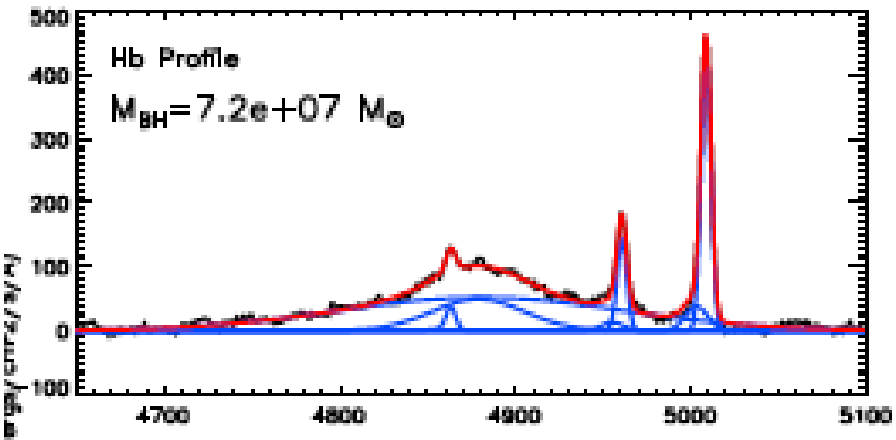
Hot inner flow, no disc – true Seyfert 2s

UV disc seen in Quasars!

- Bright, blue/UV continuum from accretion disc – photoionises gas!
- Broad permitted lines ~ 5000 km/s (BLR) including FeII
- Narrow forbidden lines ~ 200 km/s (NLR)
- Mass from FWHM Hb
- Lbol from L5100

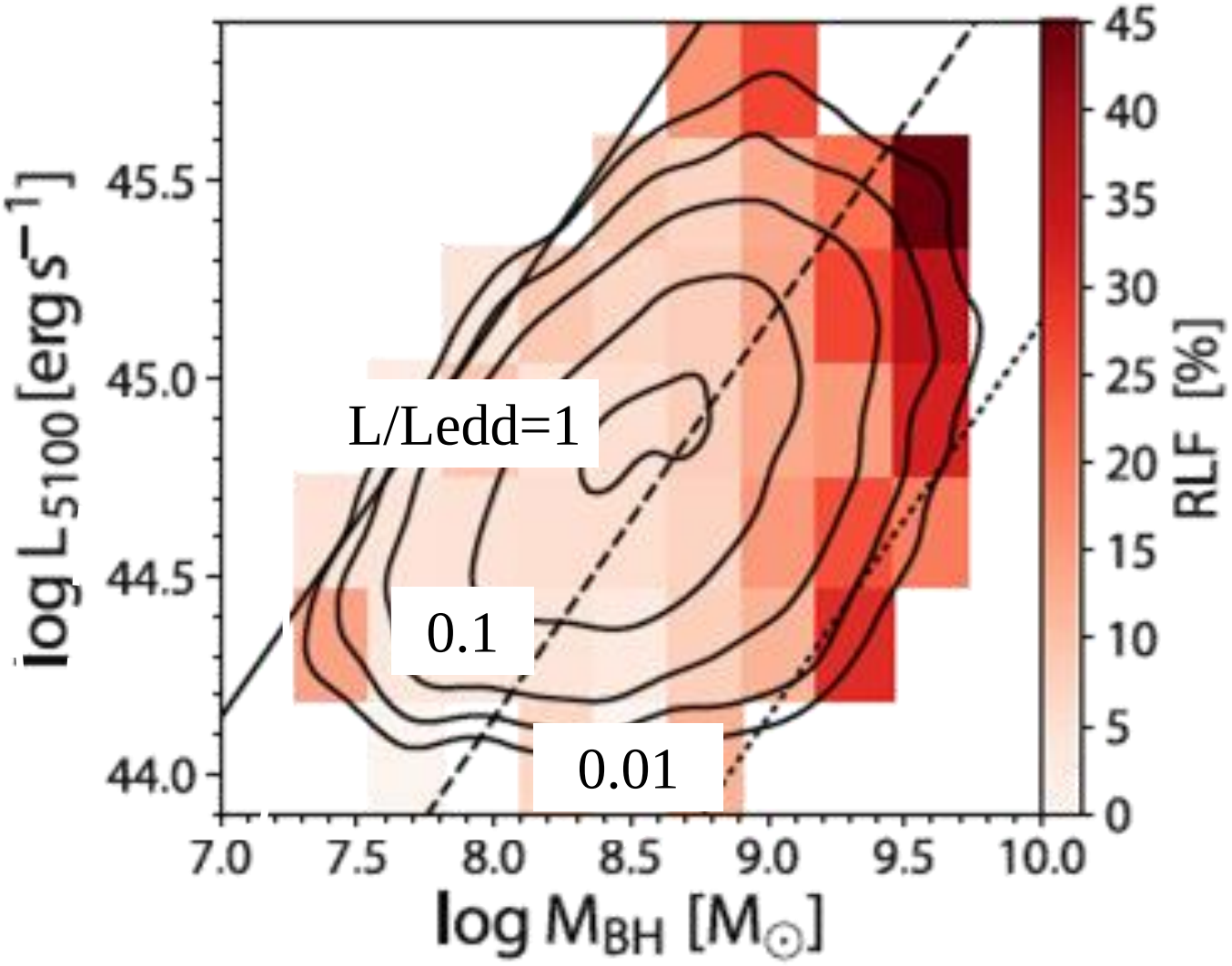


Francis et al 1991



SDSS Quasars: RL - M not Mdot

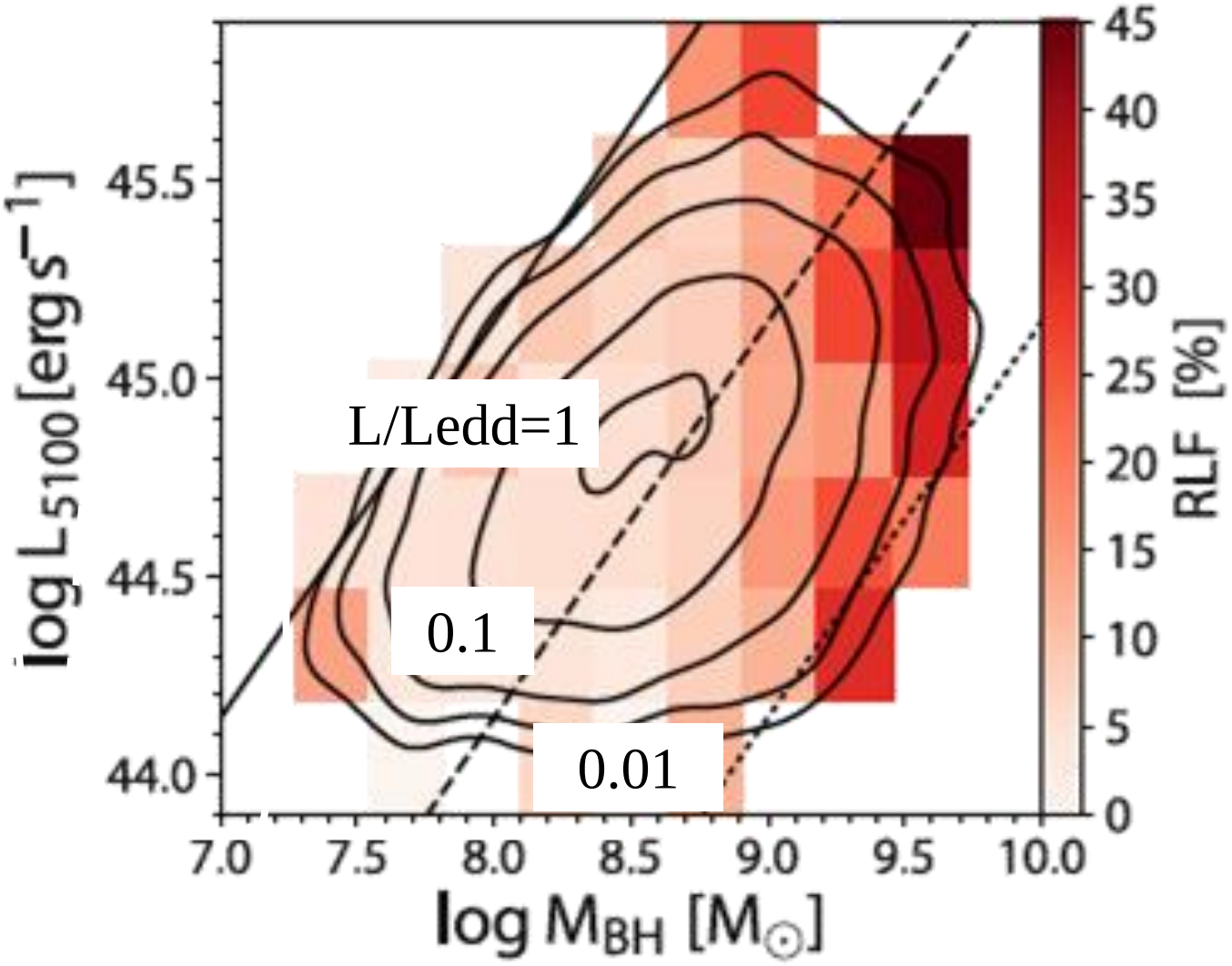
- SDSS QSO with Hb $0.3<z<0.8$
- $L_{bol}=9L_{5100}$
- No ADAFs!
- i>22 QSO selection and FIRST footprint
- LR/Lo>10



Shultze, Done et al 2018

SDSS Quasars: RL - M not Mdot

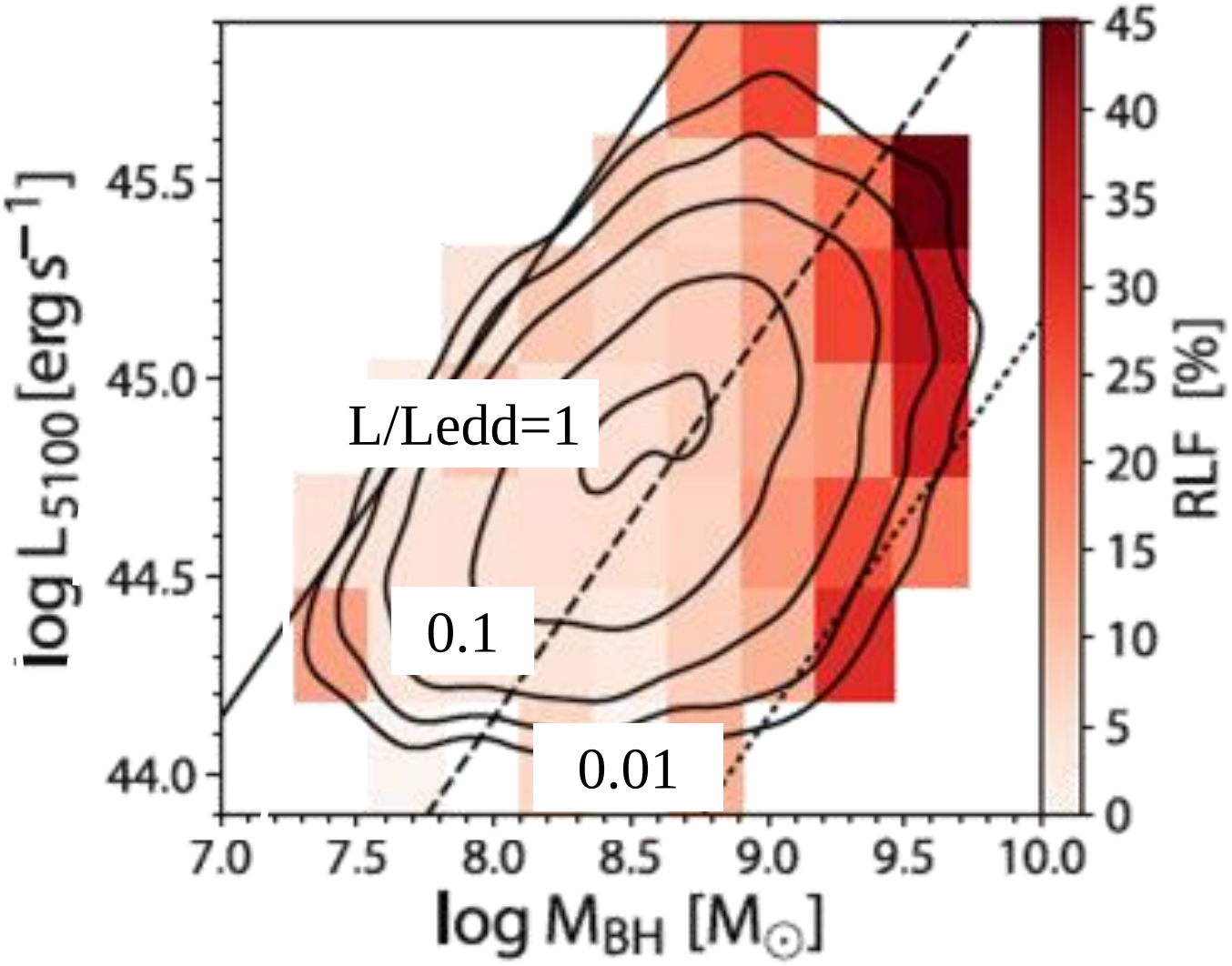
- Jet in disc regime!
- Not like BHB ADAF+jet systems
- Jet depends on mass not mdot! Mclure & Jarvis 2004



Shultze, Done et al 2018

SDSS Quasars: RL - M not Mdot

- Don't compare RL and RQ at same L
- Different mass and L/LEdd!
- No BLR when ADAF



Shultze, Done et al 2018

Unobscured AGN: LINERS-S1-NLS1

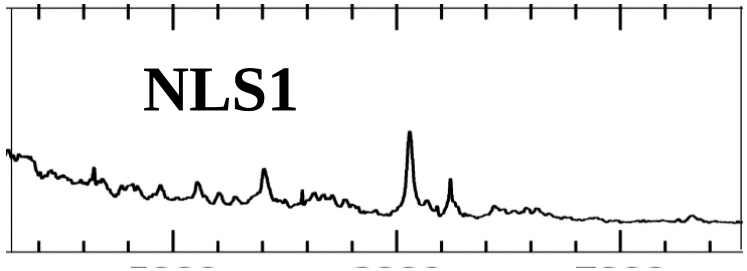
Similar mass.

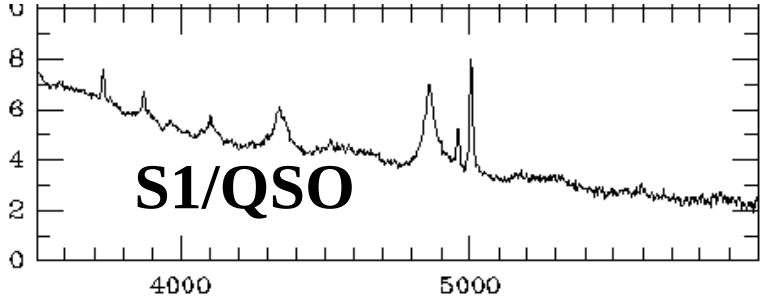
Different L/L_{Edd}

Different ionisation

Increasing L/L_{Edd}

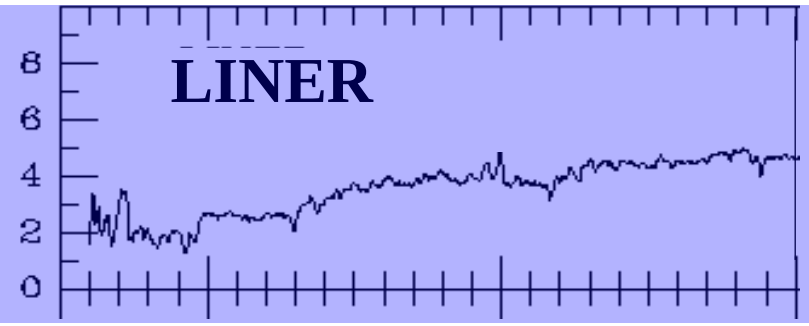
Boroson 2002

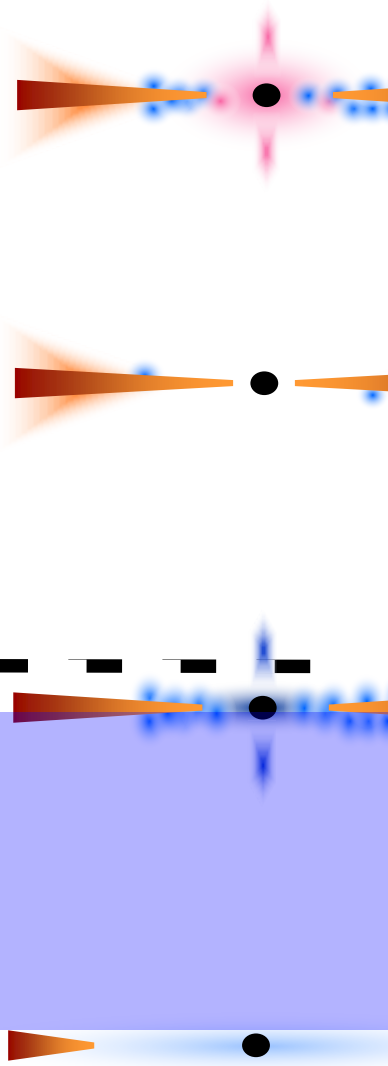




disc

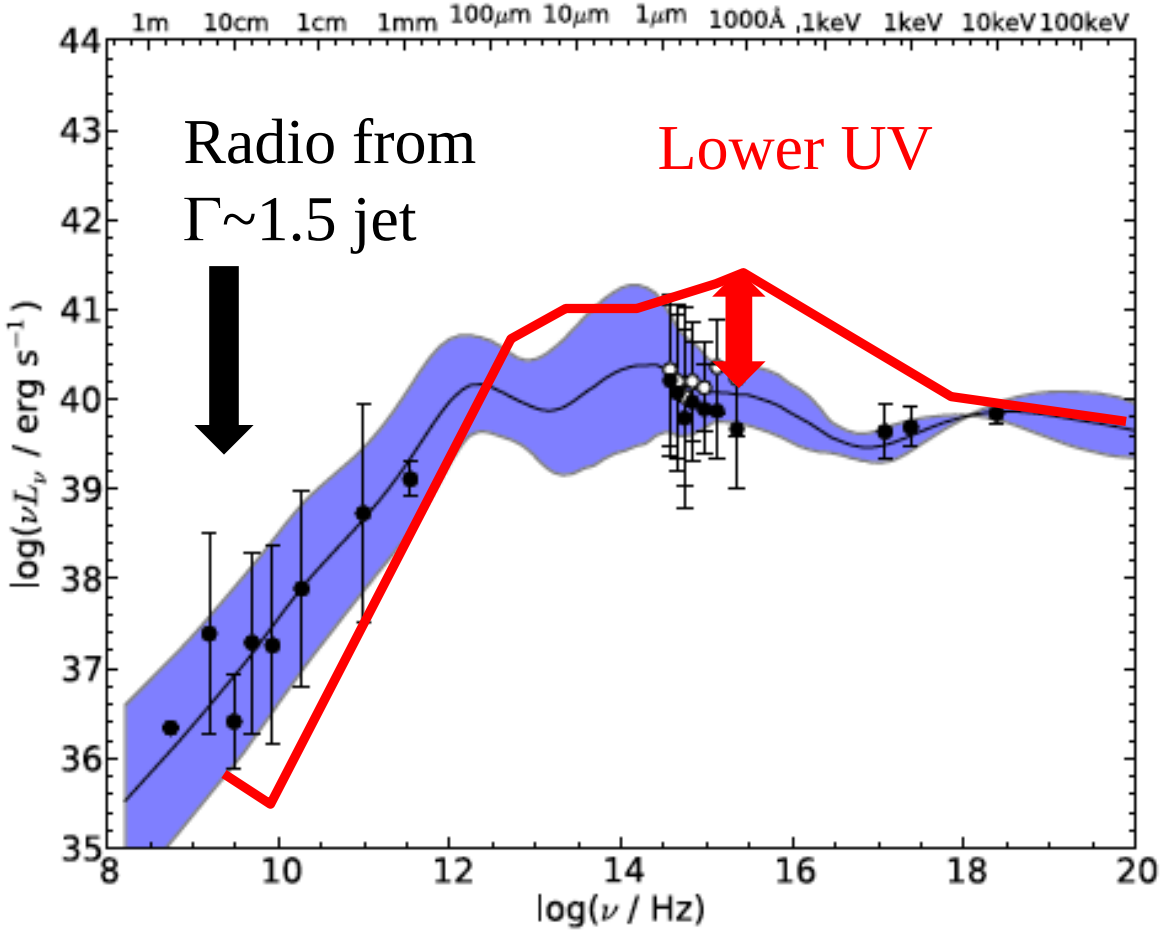
Hot inner flow, no disc – true Seyfert 2s





AGN spectral states: LINERS

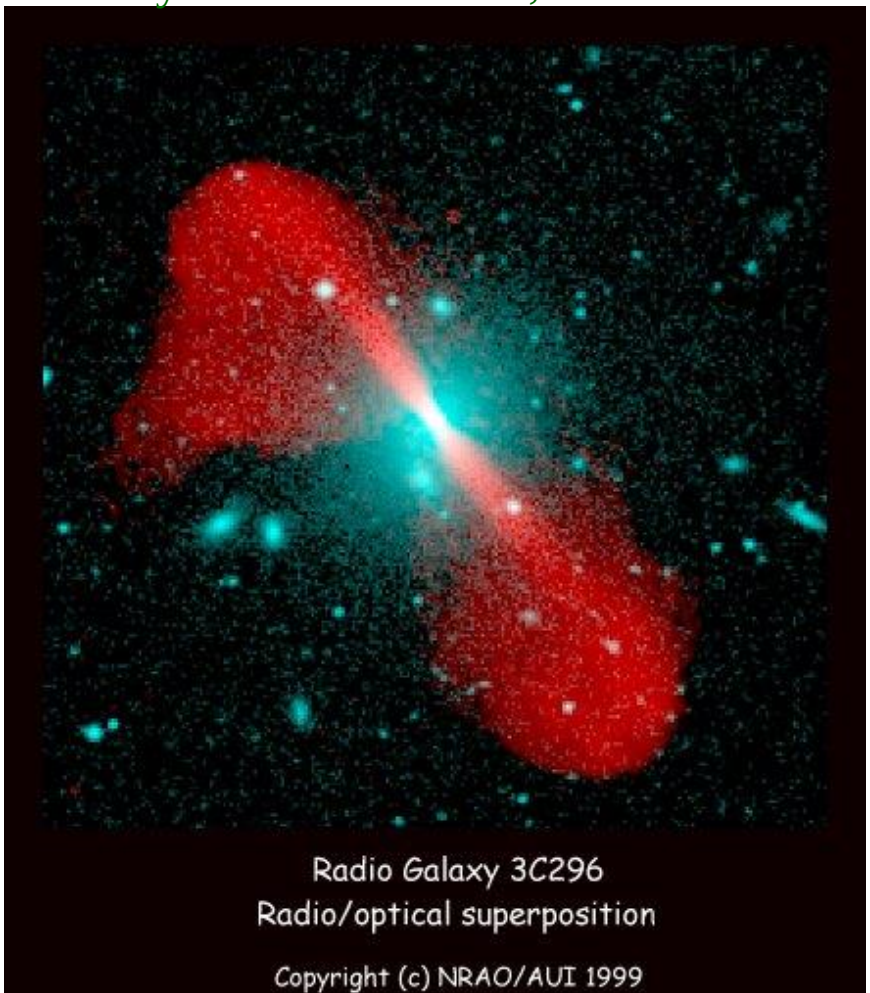
- Look like hot flow – truncated disc + Γ~1.5 jet
- No strong UV bump from disc so not much BLR

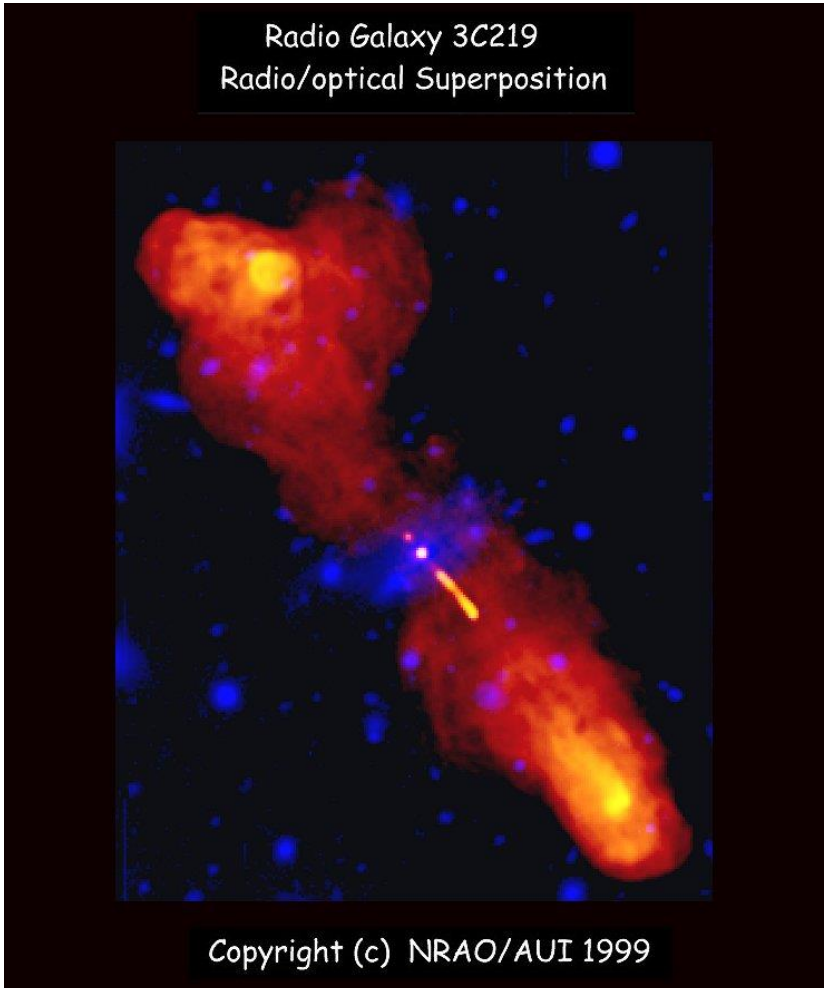


Nemmen et al 2014

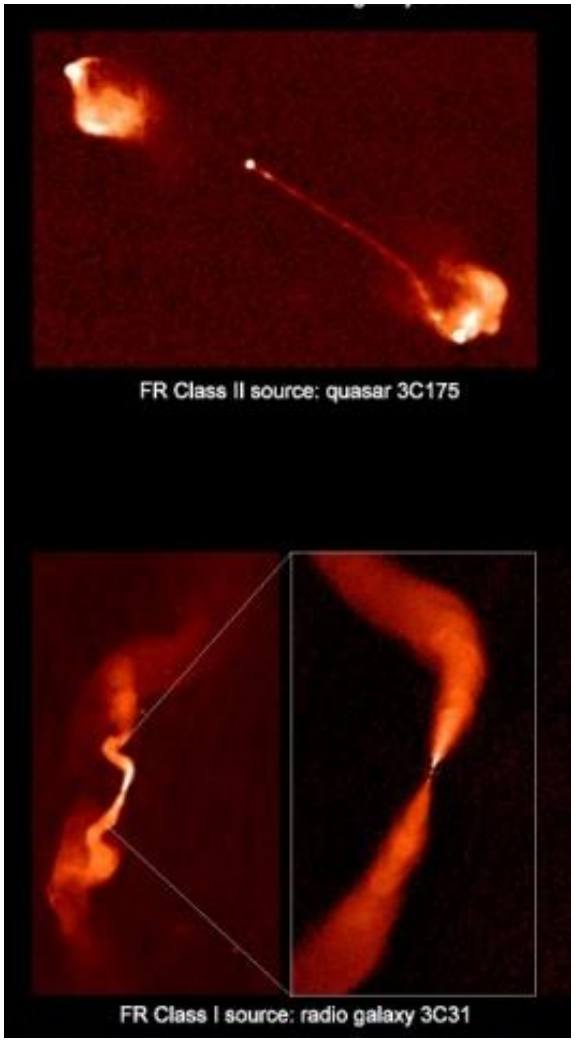
AGN/QSO Zoo!!! Radio loud

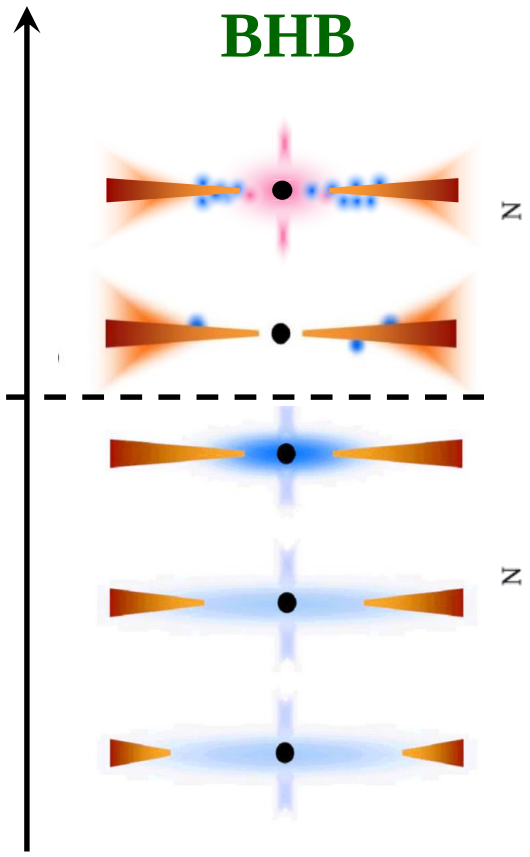
- Enormous, powerful, relativistic jets on Mpc scales
- FRI (fuzzy) - BL lacs FRII (hot spots) – FSRQ
- Urry & Padovani 1992; 1995

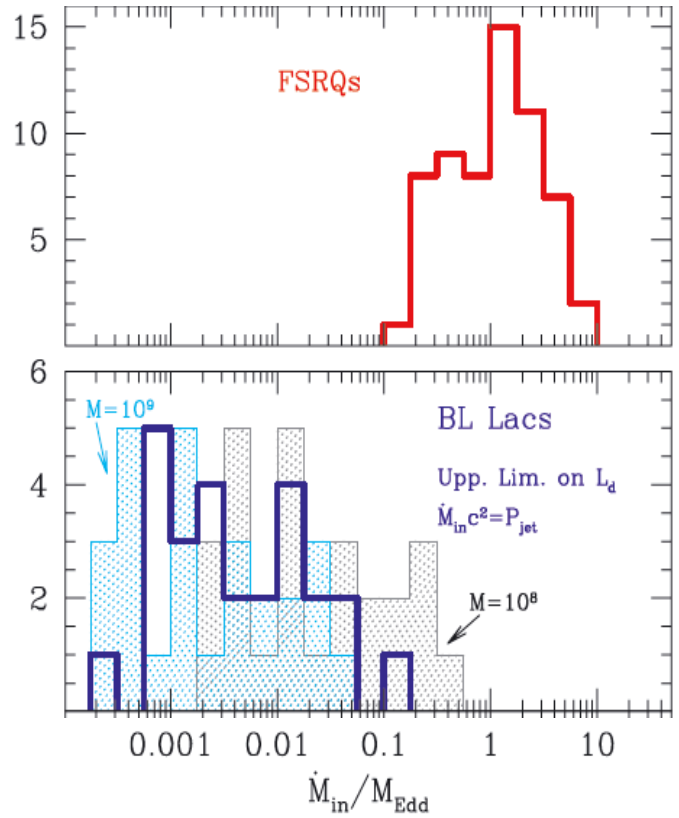




FRI is top of ADAF branch (low/hard state BHB) but Γ=15!

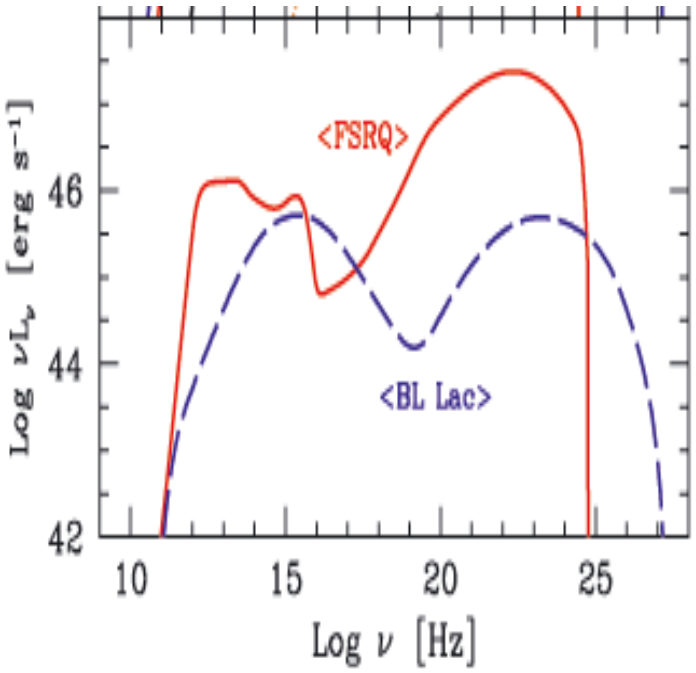




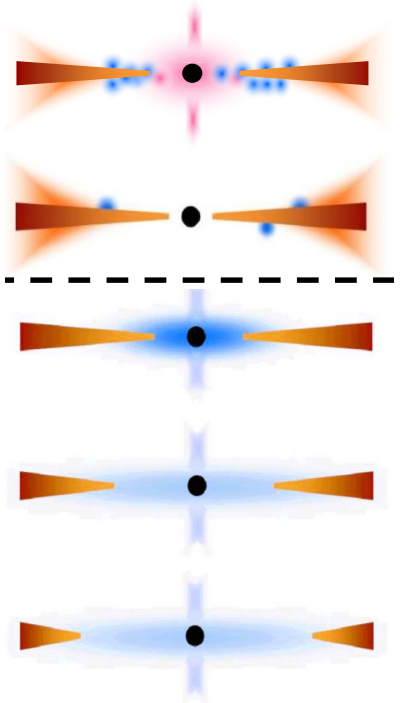


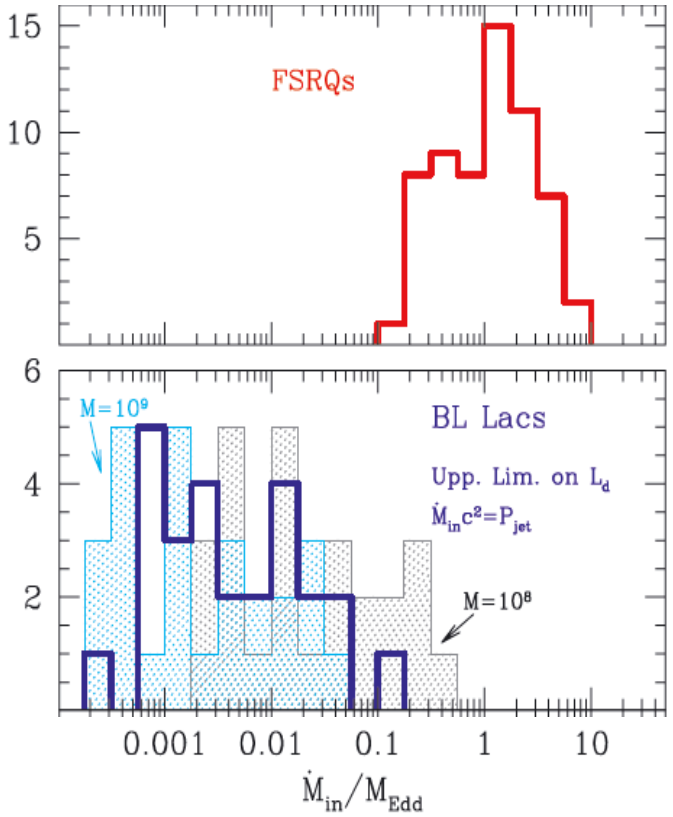
Ghisellini et al 2010

FRI is top of ADAF branch (low/hard state BHB) but Γ=15!



BHB

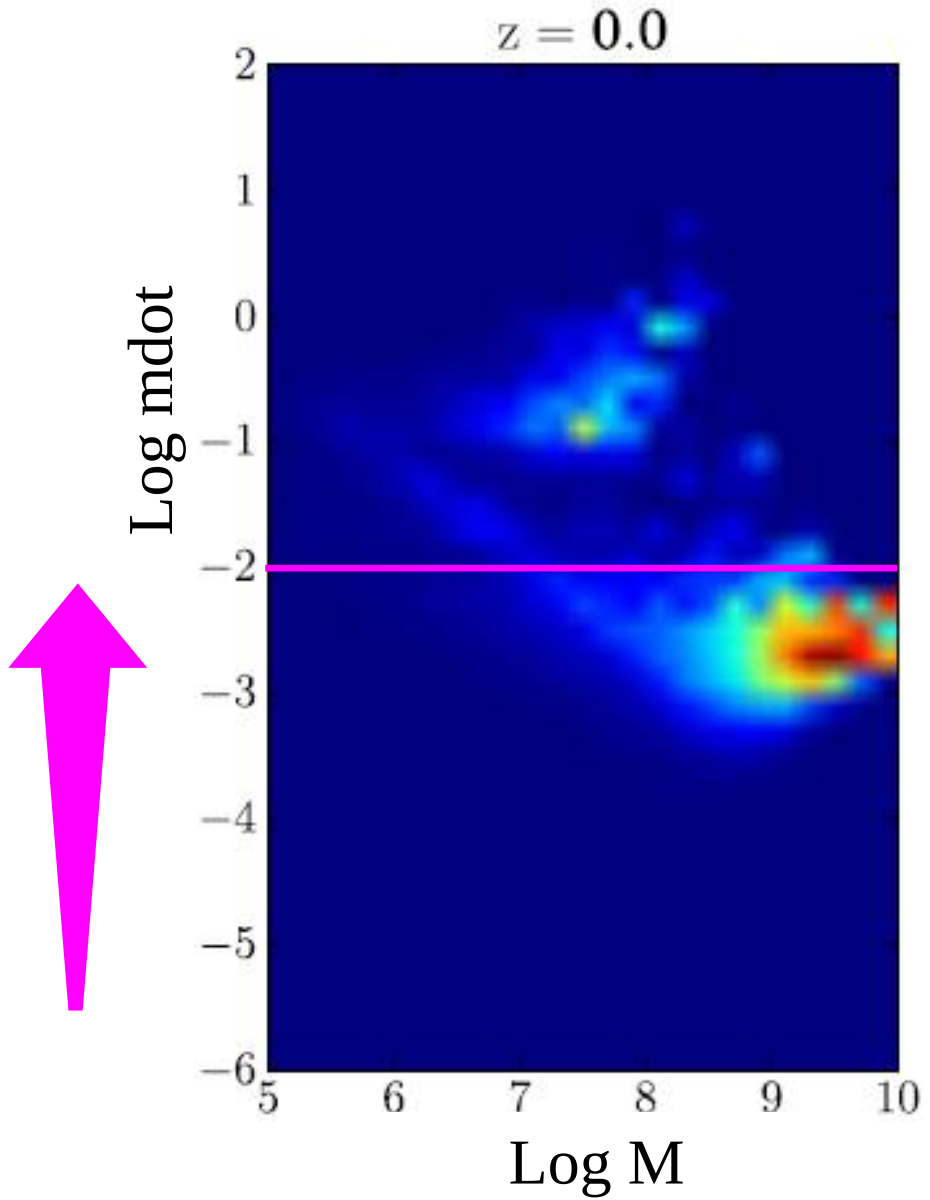




Ghisellini et al 2010

Black hole mass & mdot

- Cosmological simulations gives number densities (M, mdot)…
- …With cosmic time (Fanidakis et al 2011)
- Colours are luminosity density
- ADAF mdot<0.01 evolve very differently to bright AGN



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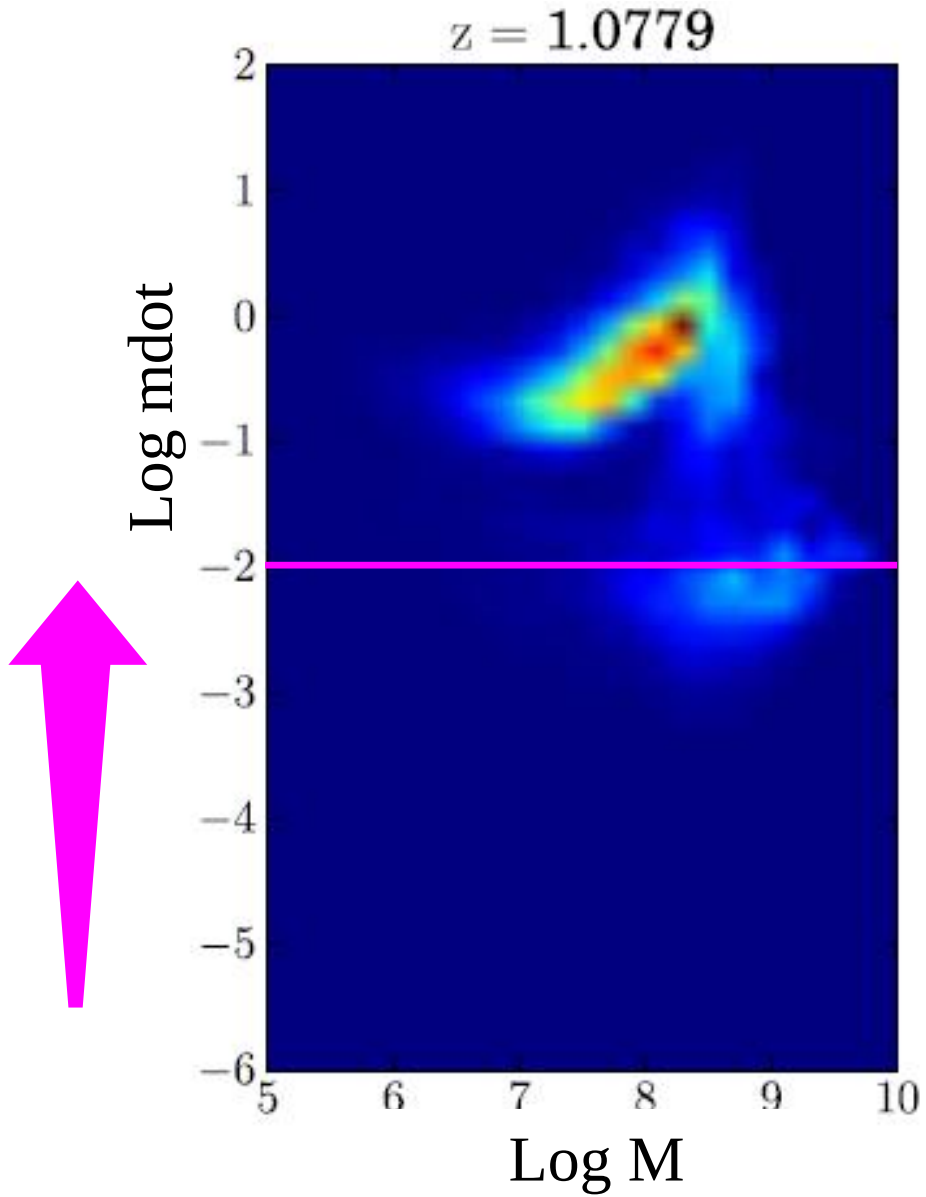

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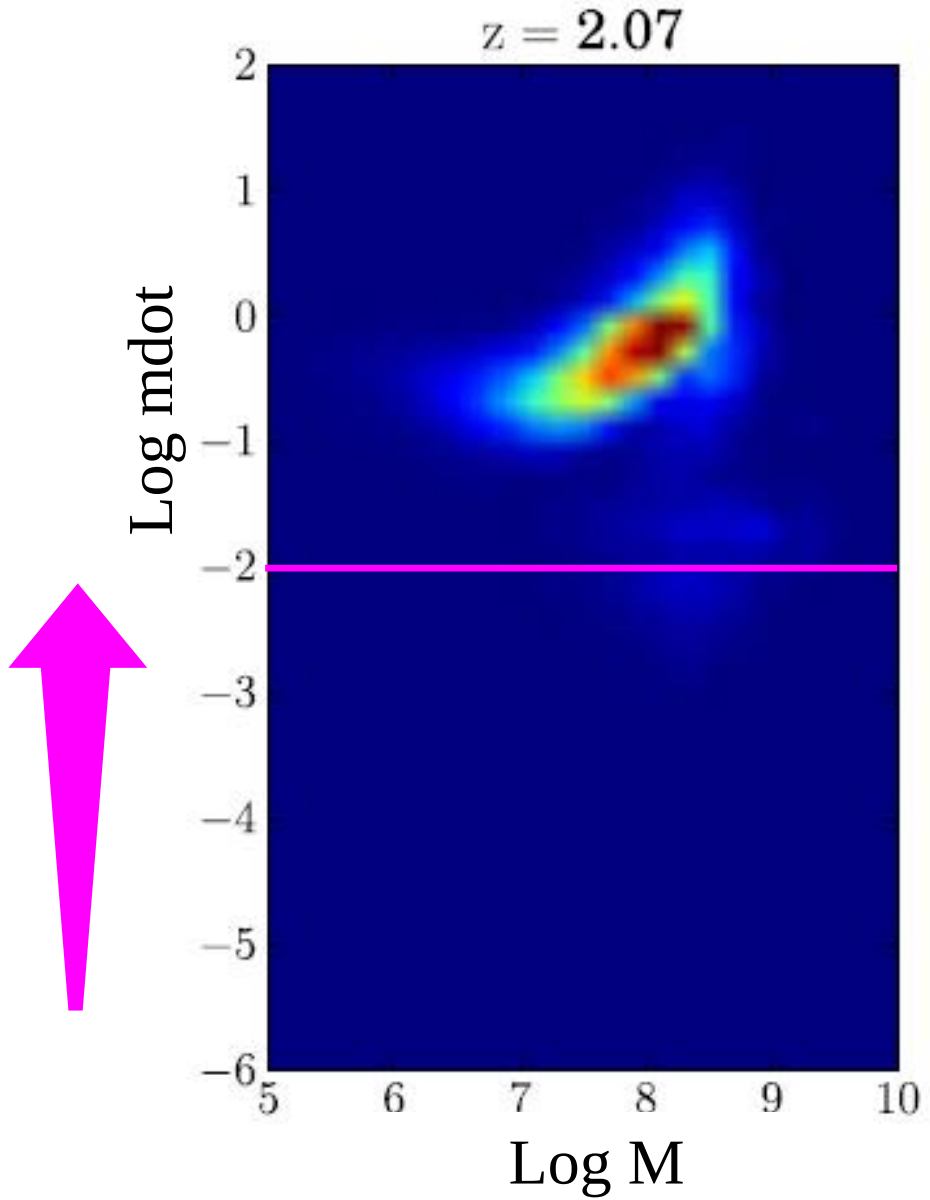
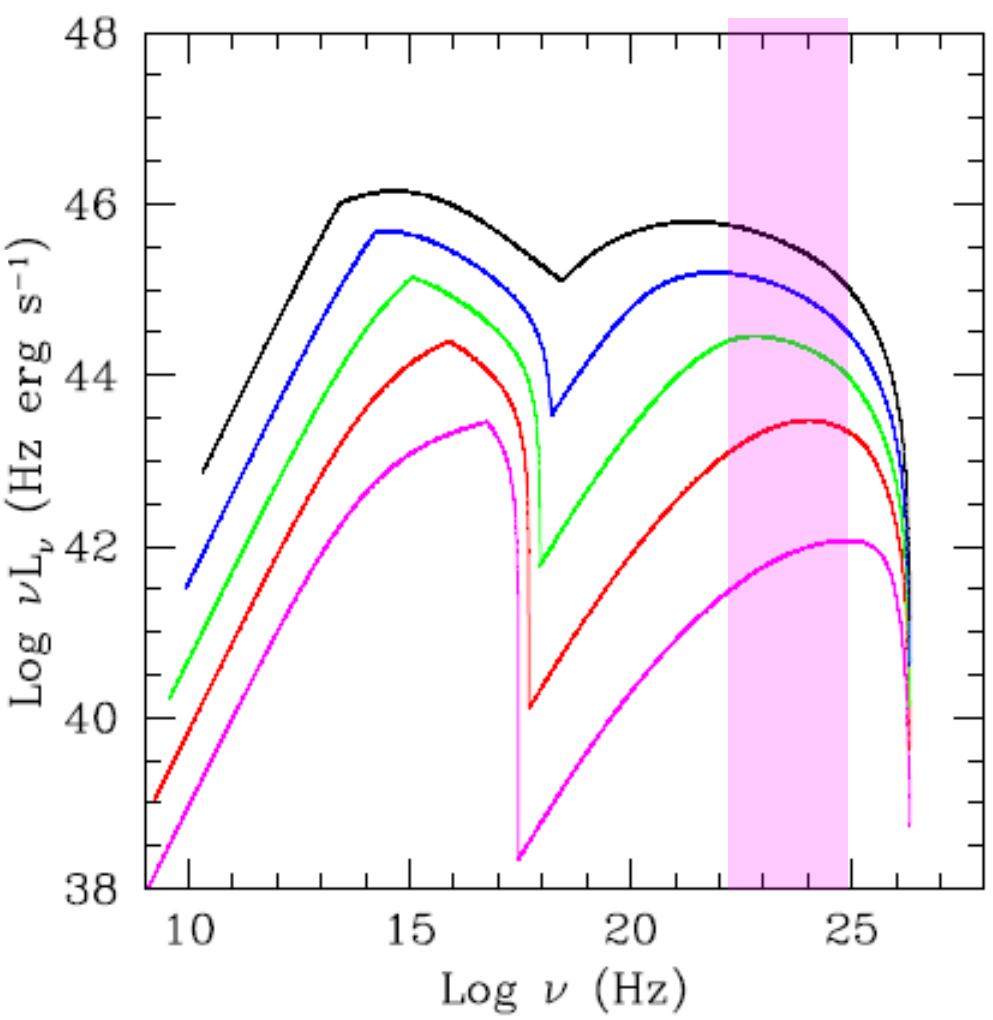


Black hole mass & mdot: ADAF

- Sync-self-Compton (SSC)
- Inject e^-, cool
- Average BL Lac jet parameters (Ghisellini et al 2010) Γ=15
- Scale jet kinetic power to M and mdot - LBL to HBL (Heinz & Merloni 2004)

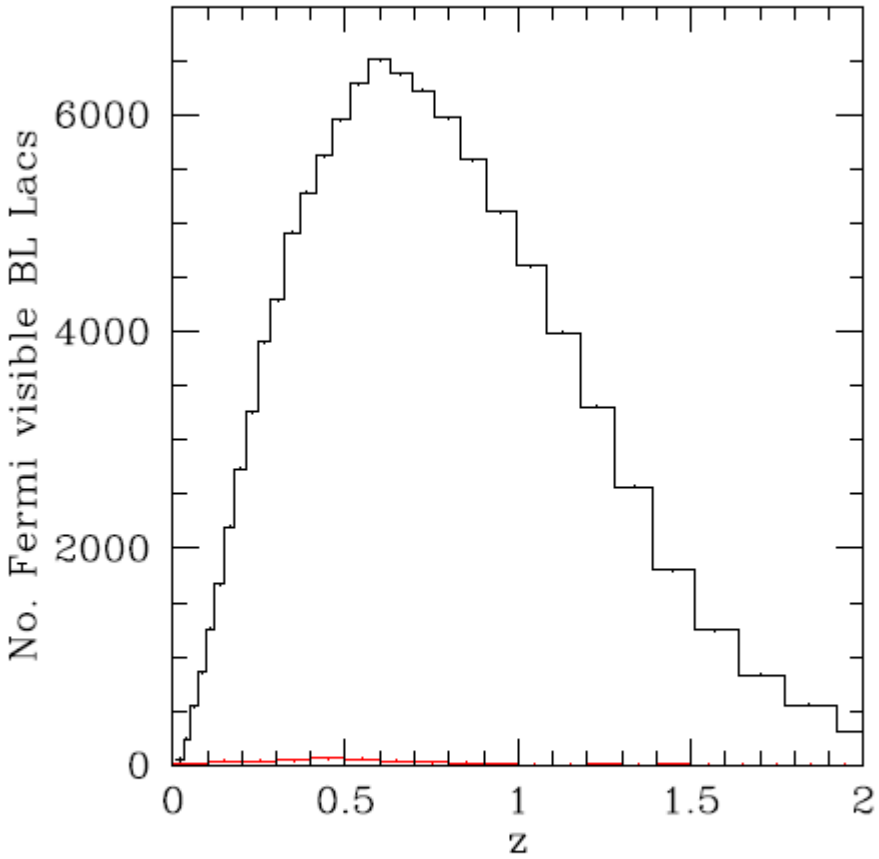
L/L_{Edd}



1000x more Fermi BL Lacs!!

- Paste scaled jet onto all mdot<0.01 AGN
- Random direction
- Predicted Fermi numbers of BL Lacs

Gardner & Done 2014a

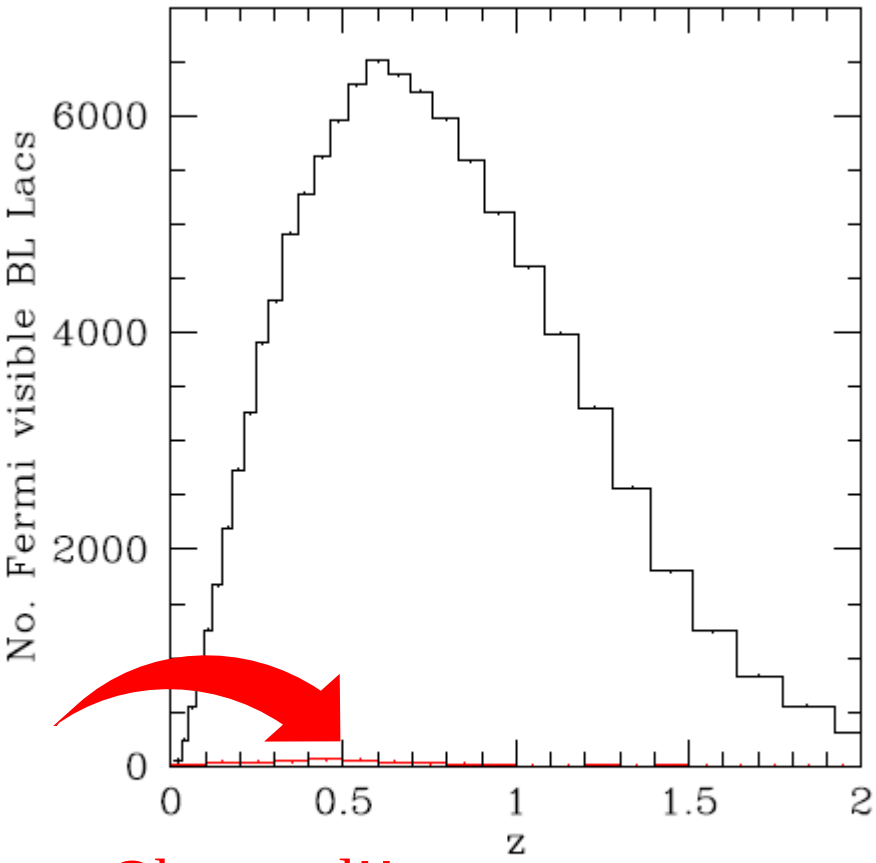


1000x more Fermi BL Lacs!!

- WRONG!!
- need to pick mainly the highest mass SMBH!
- Spin-mass correlation from BH-BH mergers in cosmology structure formation??

- Cant test as no disc! ADAF flows

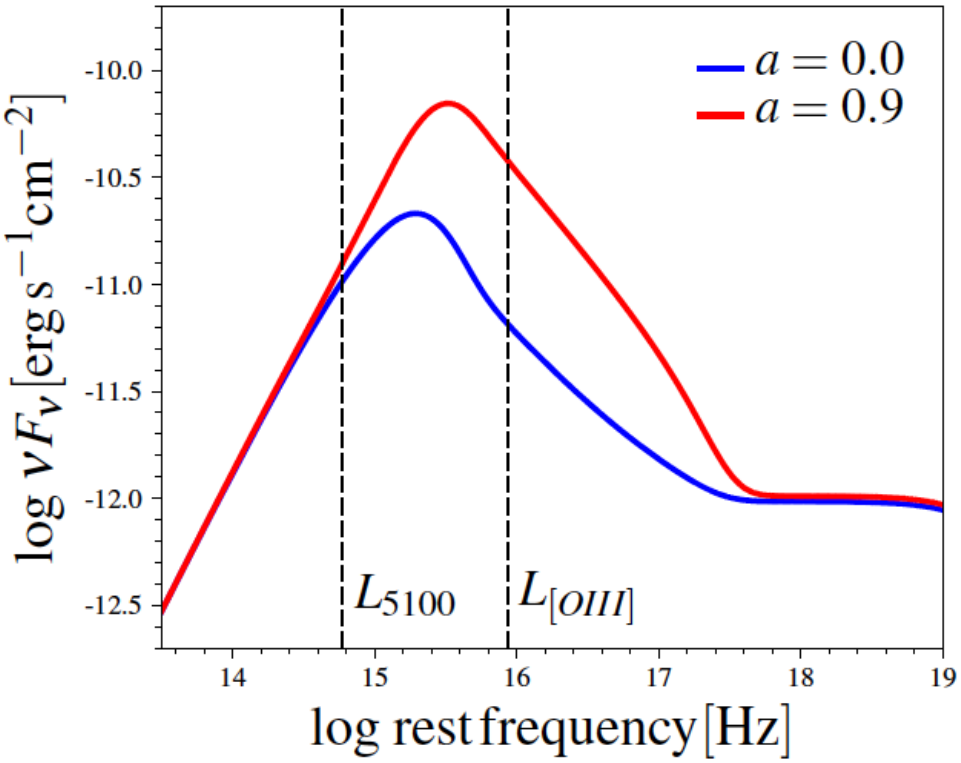
Gardner & Done 2014a



Observed!!

Higher Spin in RL AGN?

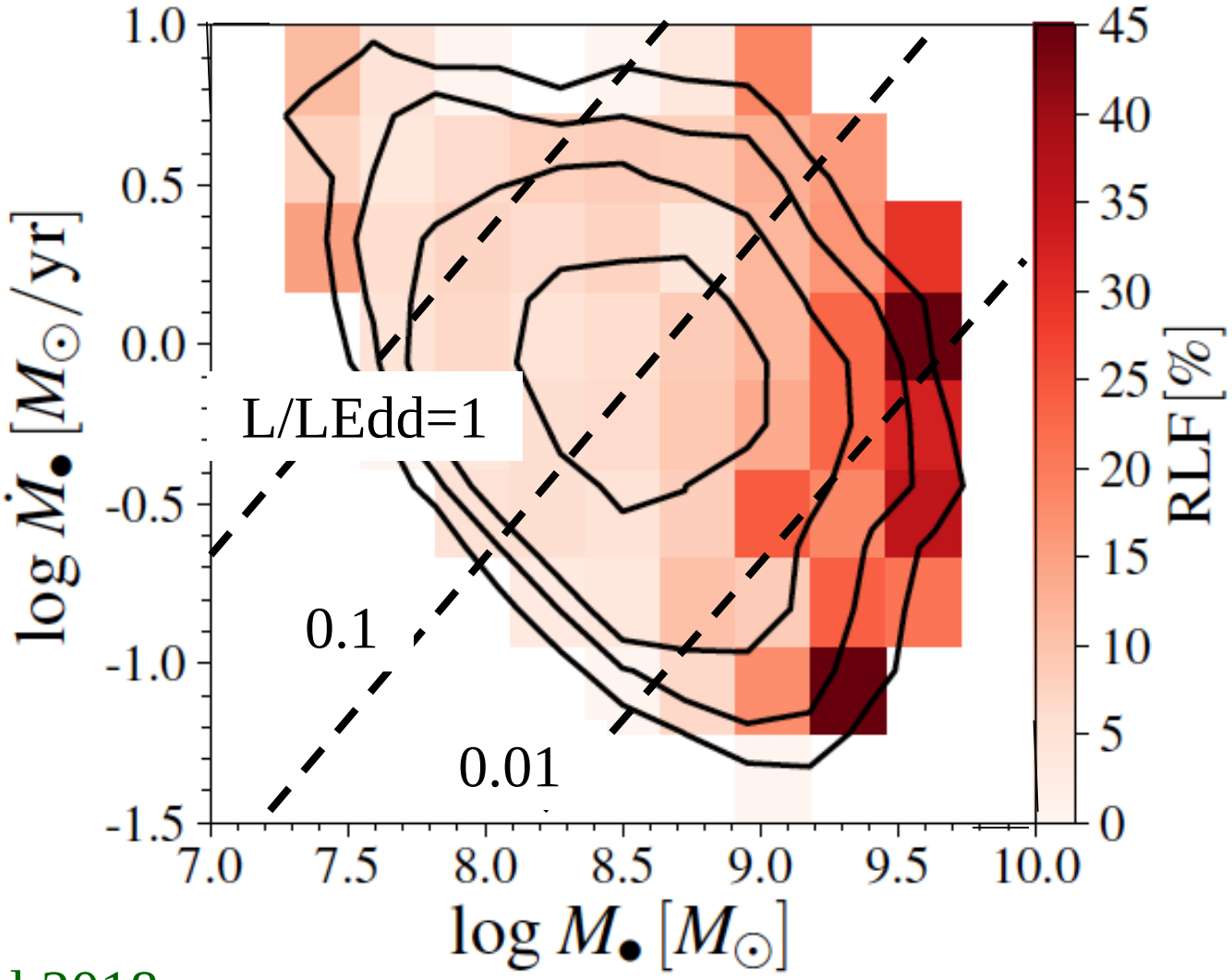
- Same Mdot gives higher Lbol and Lionising for higher spin
- We can't see ionising flux as ISM, but OIII lines can!
- Compare RL and RQ at SAME mass AND Mdot



Shultze, Done et al 2017

Compare L [OIII] RL and RQ for same BH M and Mdot!!

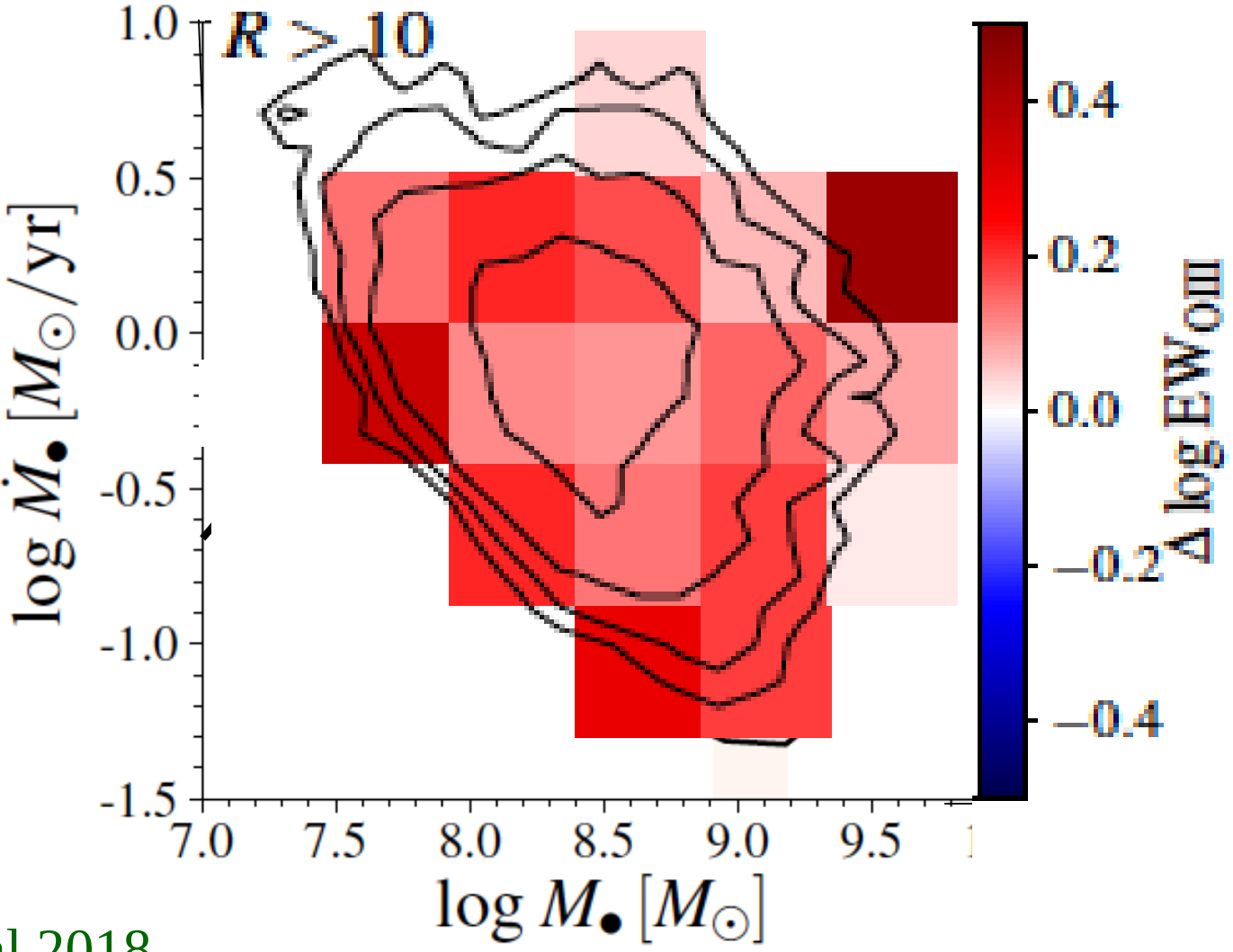
- L_{bol} -$L^{3/2}_{5100}$
- L>LEdd
- Lowest M
- Shultze, Done et al 2018



Shultze, Done et al 2018

Compare L [OIII] RL and RQ for same BH M and Mdot!!

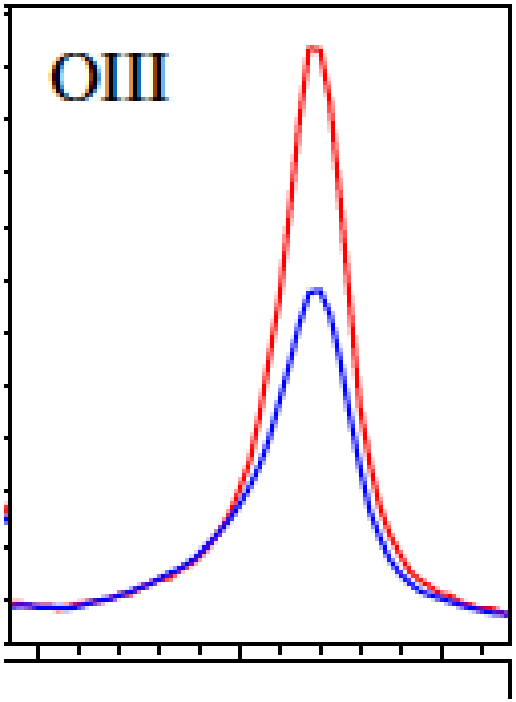
- L_{bol} -$L^{3/2}_{5100}$
- L>LEdd
- Lowest M
- Shultze, Done et al 2018
- ALL RED
- NO BLUE
- So more OIII in RL



Shultze, Done et al 2018

Compare L [OIII] RL and RQ for same BH M and Mdot!!

- Not kinematically distinct so NOT from jet shocking ISM
- Just bigger
- Consistent with higher spin in RL (higher mass) than RQ (lower mass)
- Shultze, Done et al 2018

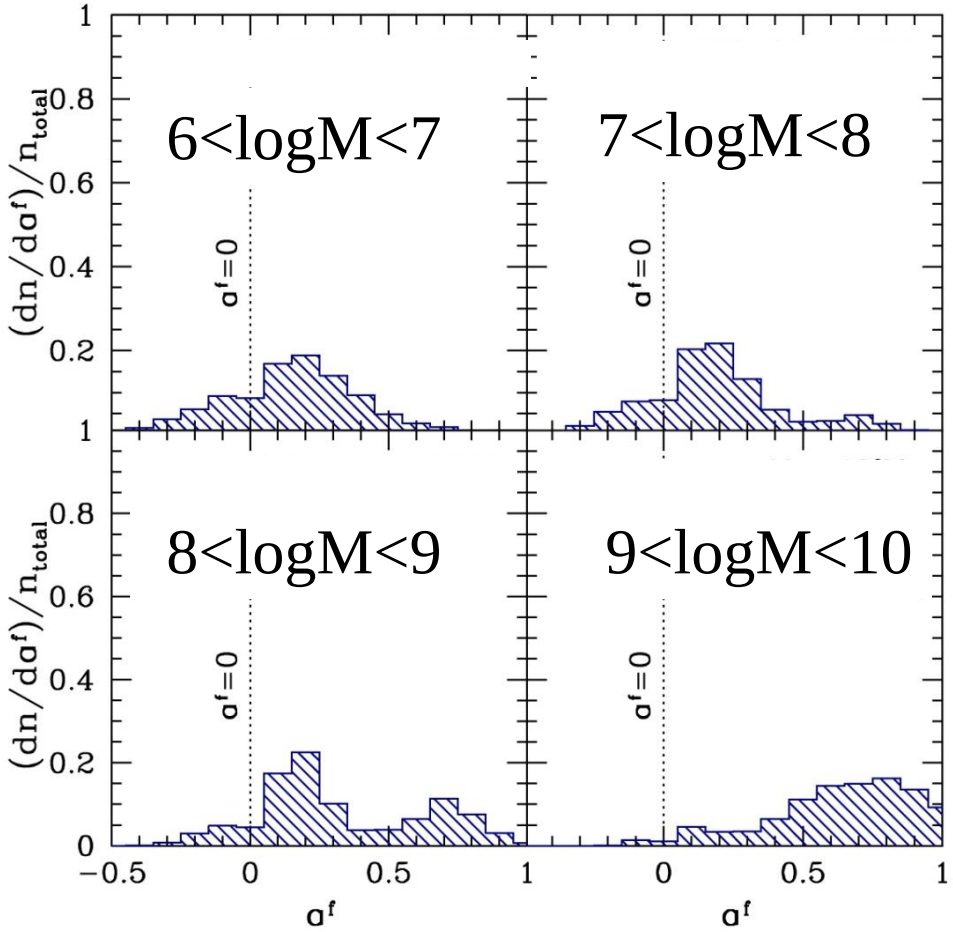


Shultze, Done et al 2017

SMBH spin in cosmology: Chaotic accretion

- Growth of large scale structure – coevolution of black hole and host galaxy
- Gas has random angular momentum direction
- Low BH spin
- BH – BH mergers spin UP the most massive BH to 0.7

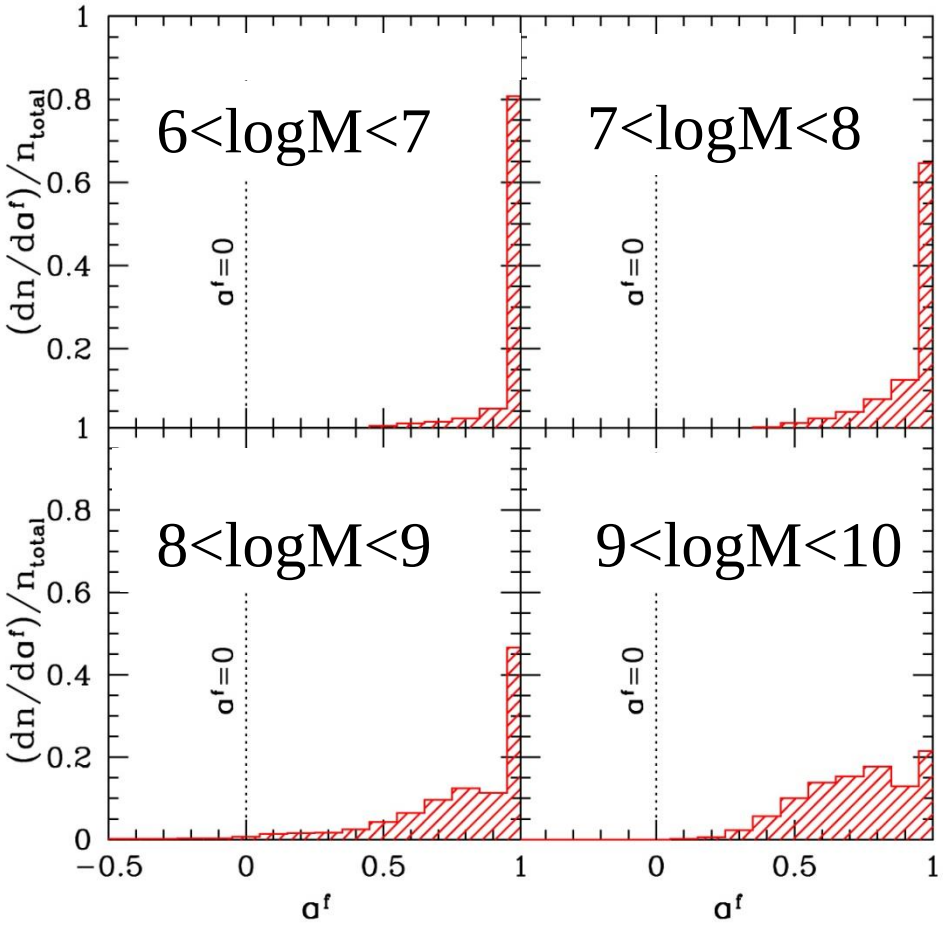
Fanidakis et al 2011



SMBH spin in cosmology: Prolonged accretion

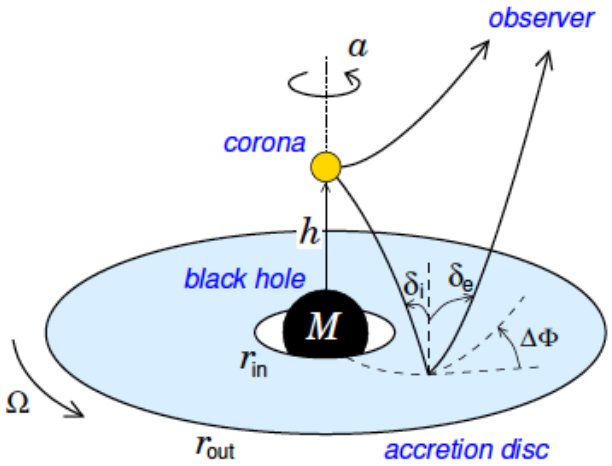
Fanidakis et al 2011

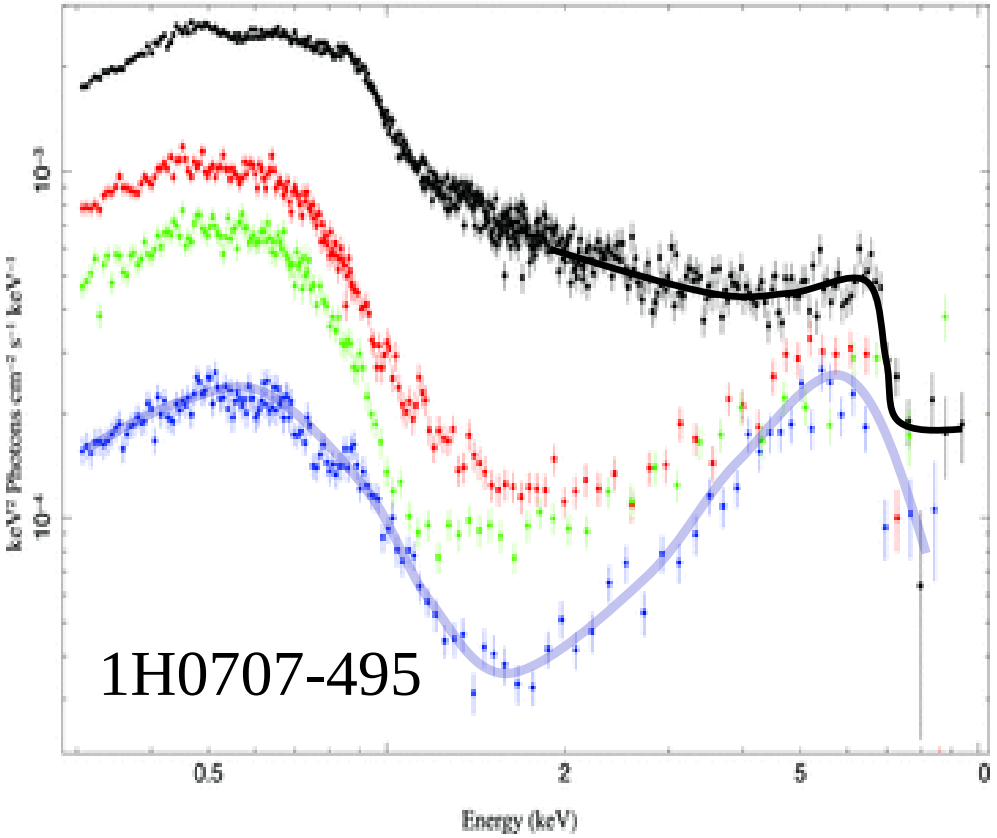
- Gas all has same angular momentum direction
- Spin BH up to a ~ 1
- BH – BH mergers spin DOWN the most massive BH to 0.7



Complex NLS1 – X-ray view

- ‘Complex’ NLS1 (Gallo 2006) eg 1H0707-495
- Deep dips – hard spectra, large Fe features
- Extreme spin!!

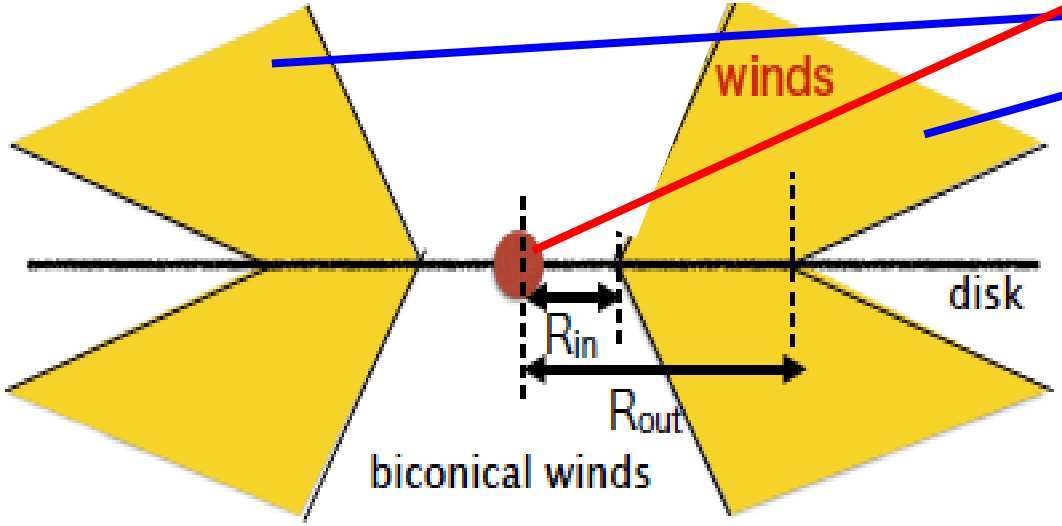


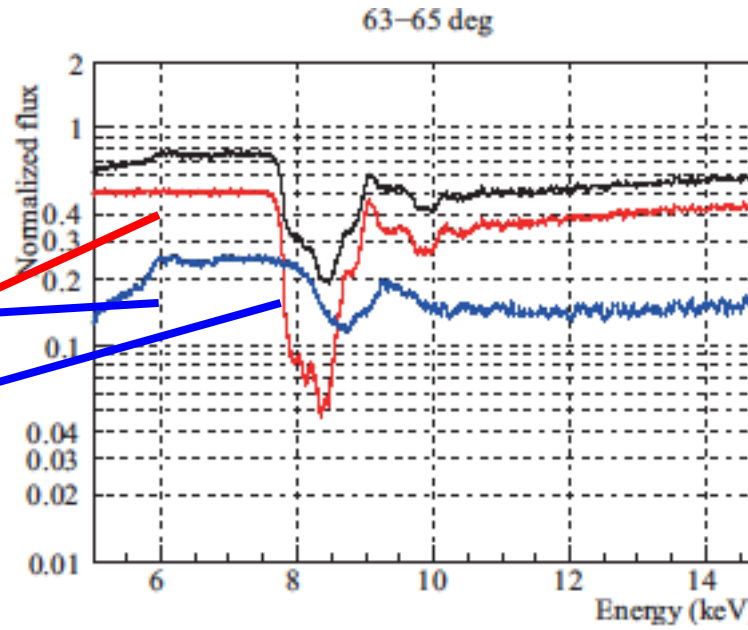


Fabian et al 2009

Complex NLS1 – X-ray view

- Absorption on line of sight – blueshifted
- Emission from all wind – blue and redshift, rotation plus outflow velocity components

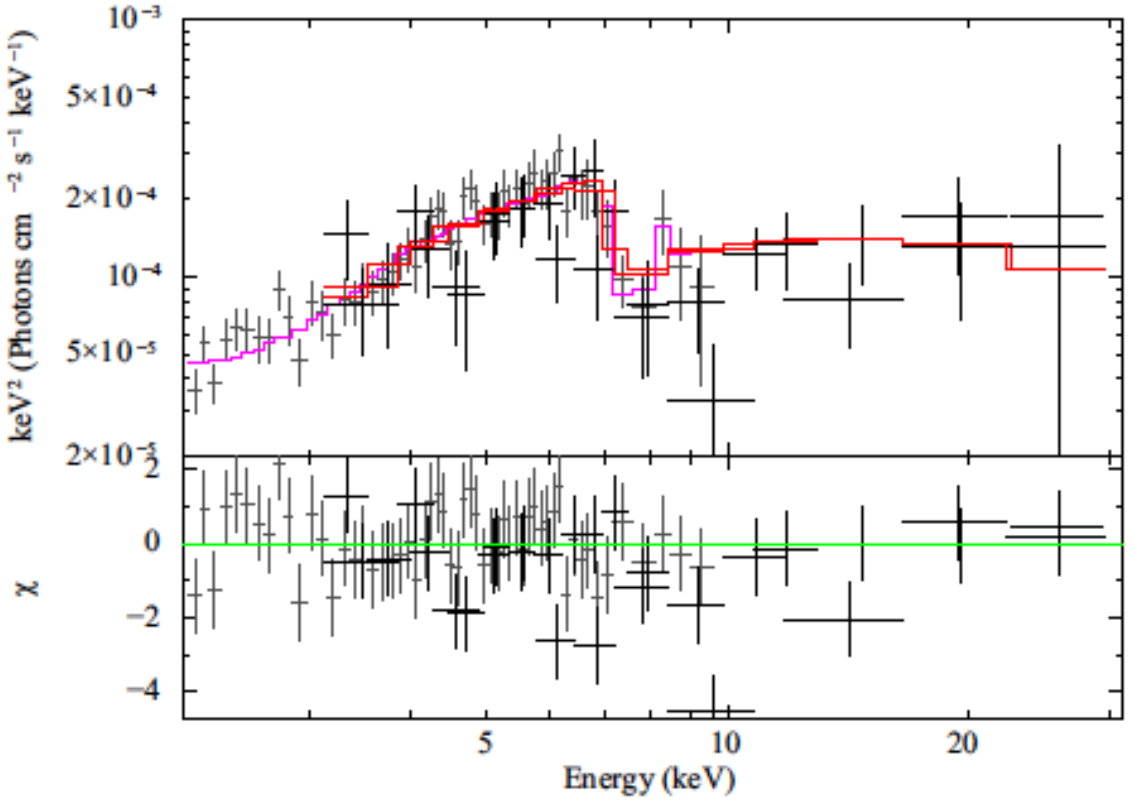




Hagino et al 2016

Complex NLS1 – X-ray view

- Extreme spin with reflection from flat disc
- Or superEddington wind absorption with no constraints on spin!! Hagino et al 2016
- Kosec..Fabian et al 2018



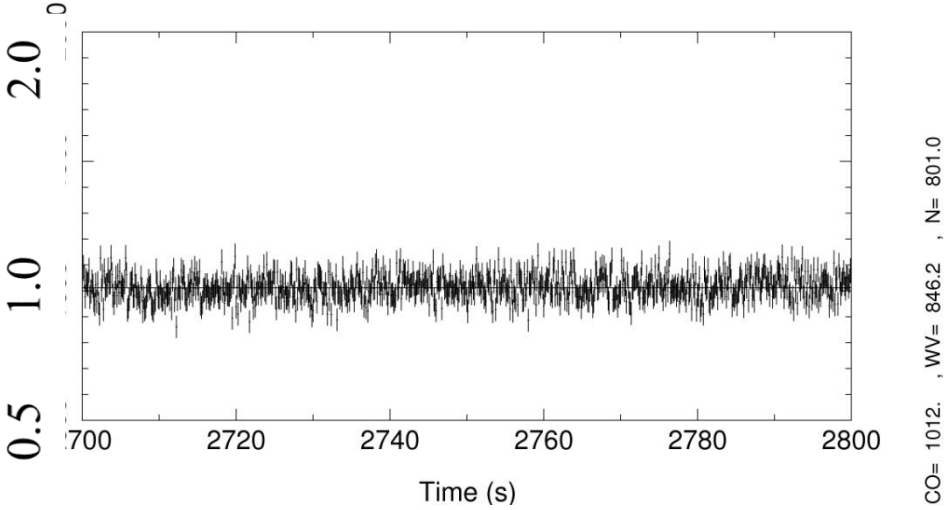
Hagino et al 2016

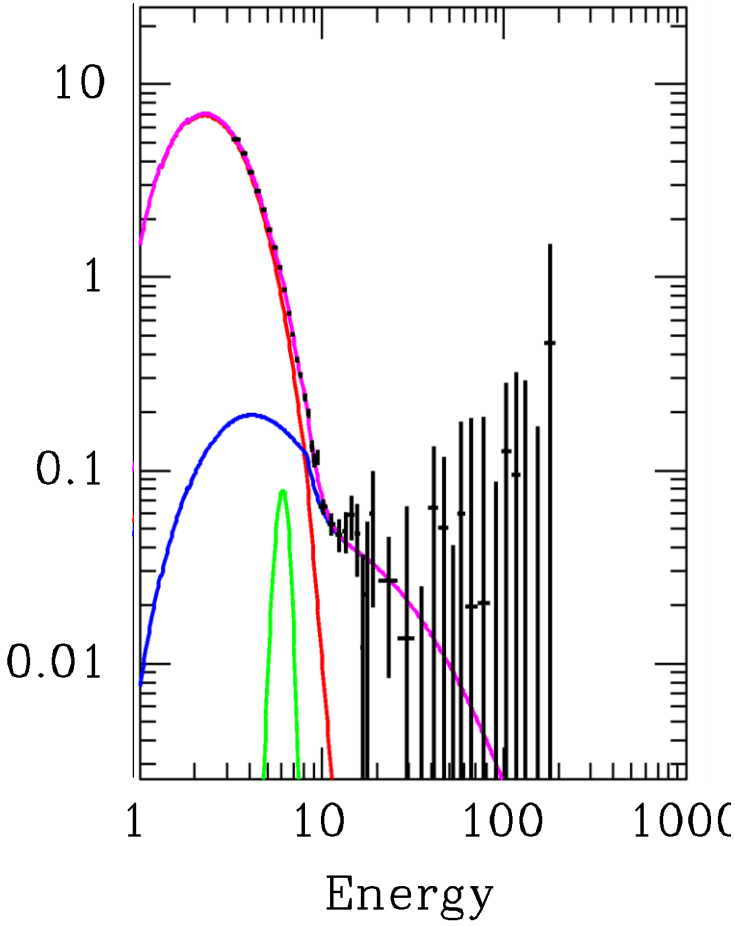
Conclusions

- BH accretion and ejection - mass, L/Ledd and spin.
- BHB – mostly just 1 parameter!
- Disc spectra at high L/Ledd, low/moderate spin – GW, ADAF + moderate velocity jet at low L/LEdd
- SMBH – really 3 parameters matter!
- AGN with BLR (high L/Ledd) – QSO RL and RQ: need RL to be preferentially high mass.
- Jet is highly rel – seen directly in FSRQ
- AGN without BLR (low L/LEdd) – LINERS and FRI
- Jet is highly rel in high mass – seen directly in BL Lacs
- High spin = highly relativistic jet spine powered by BZ

Variability of disc: short timescale

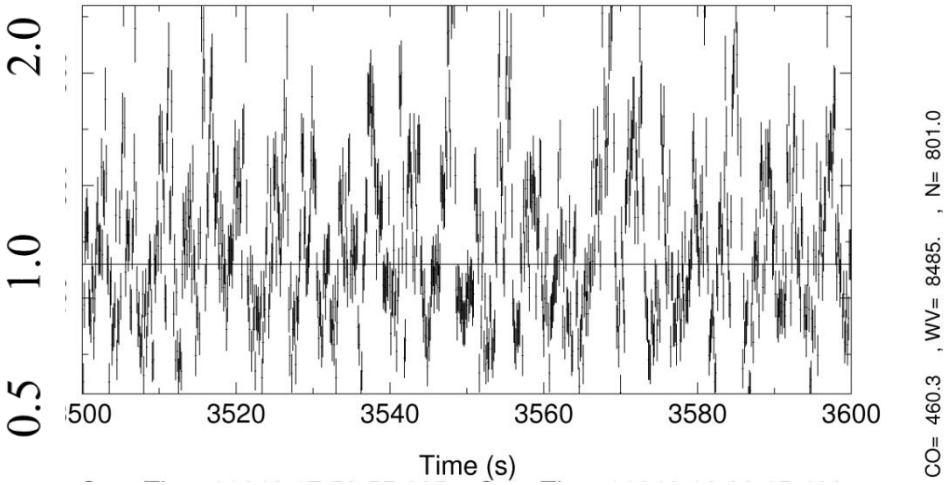
- Timescale to change mass accretion rate through disc
- tvisc= α^{-1} $(H/R)^{-2}$ torb
  $=5\ \alpha^{-1}\ (H/R)^{-2}\ (r/6)^{-3/2}$ ms
- ~ 500s at last stable orbit for 10M
- No rapid variability of disc

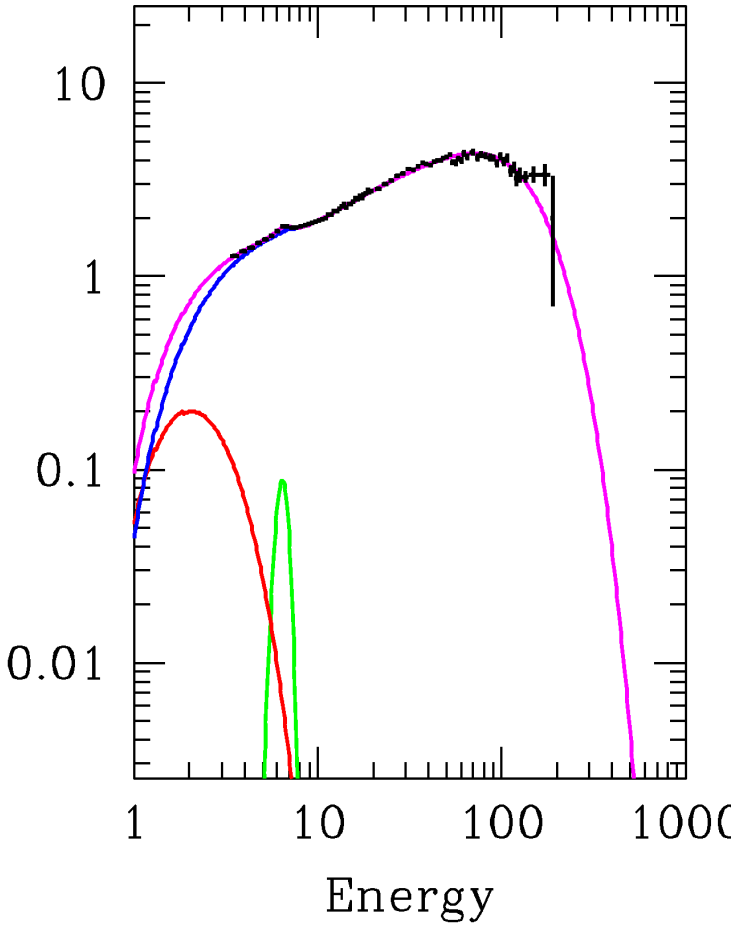




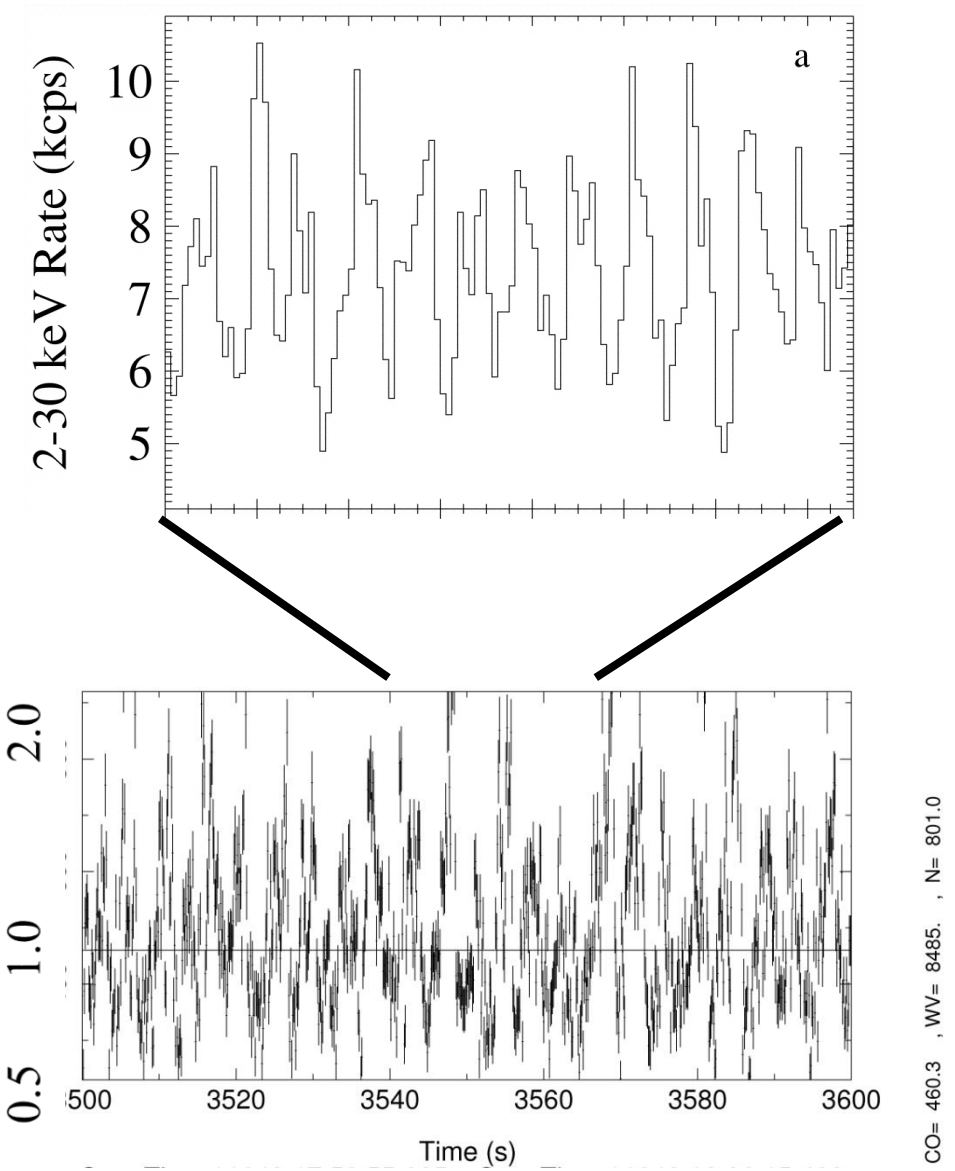
Low/hard state variability

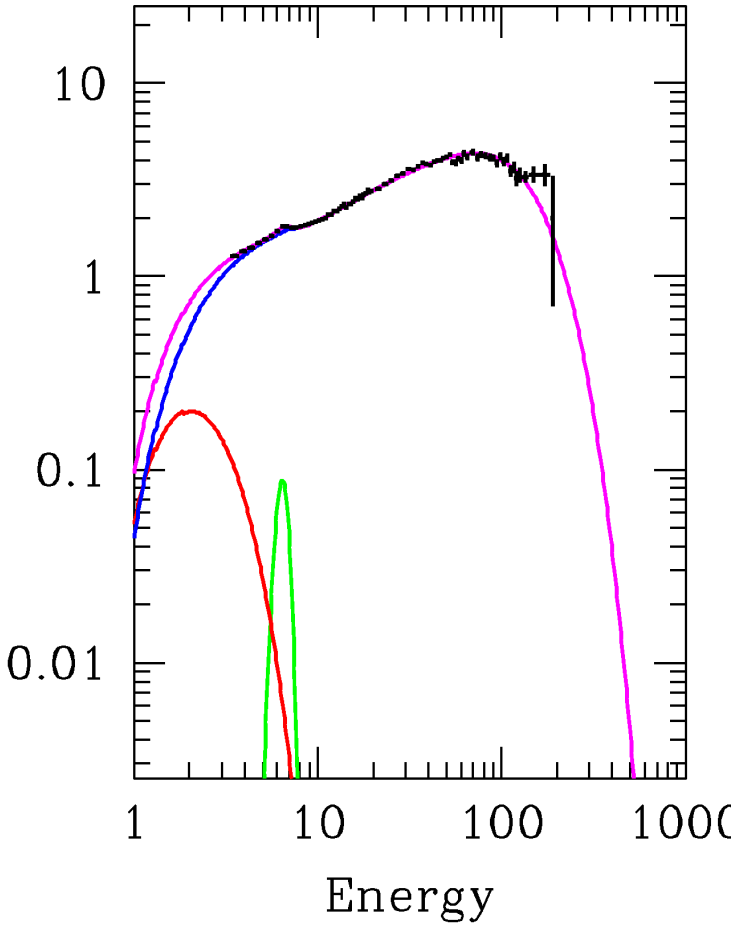
- Low/Hard state variability down to few 10s of ms
- tvisc= α^{-1} $(H/R)^{-2}$ tdyn = 5 α^{-1} $(H/R)^{-2}$ $(r/6)^{-3/2}$ ms
- IF viscous timescale then H/R~1





Low/hard state variability- QPO

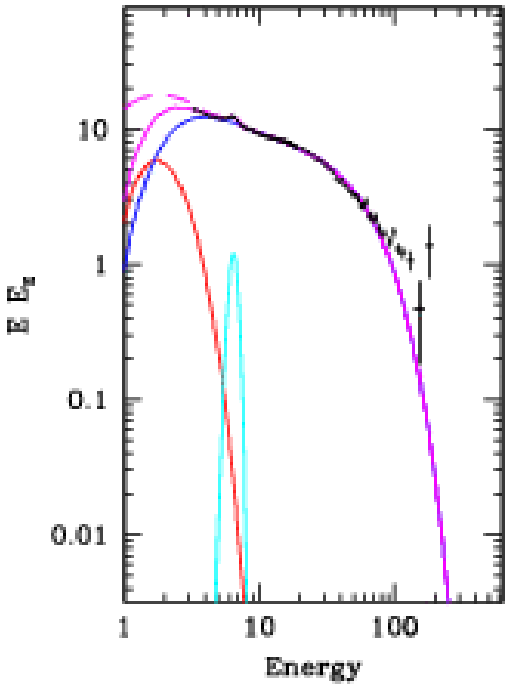


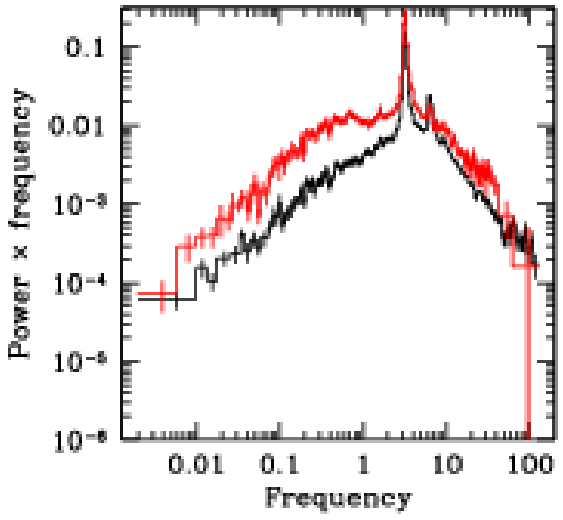


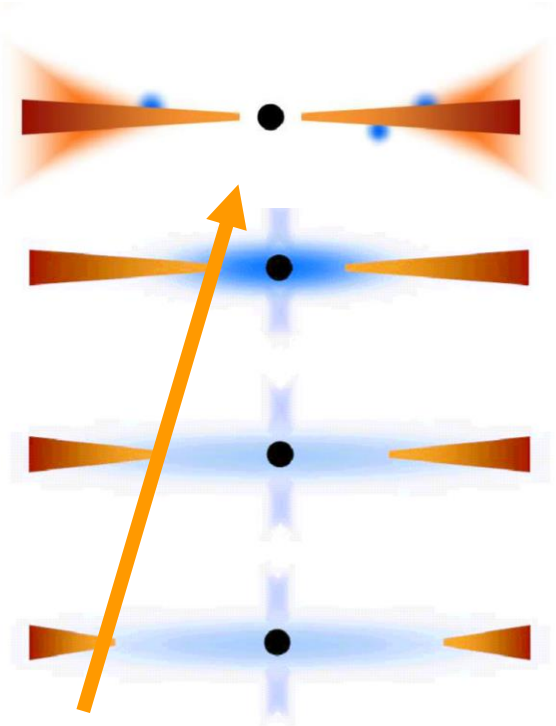
Moving disc – moving QPO

- 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

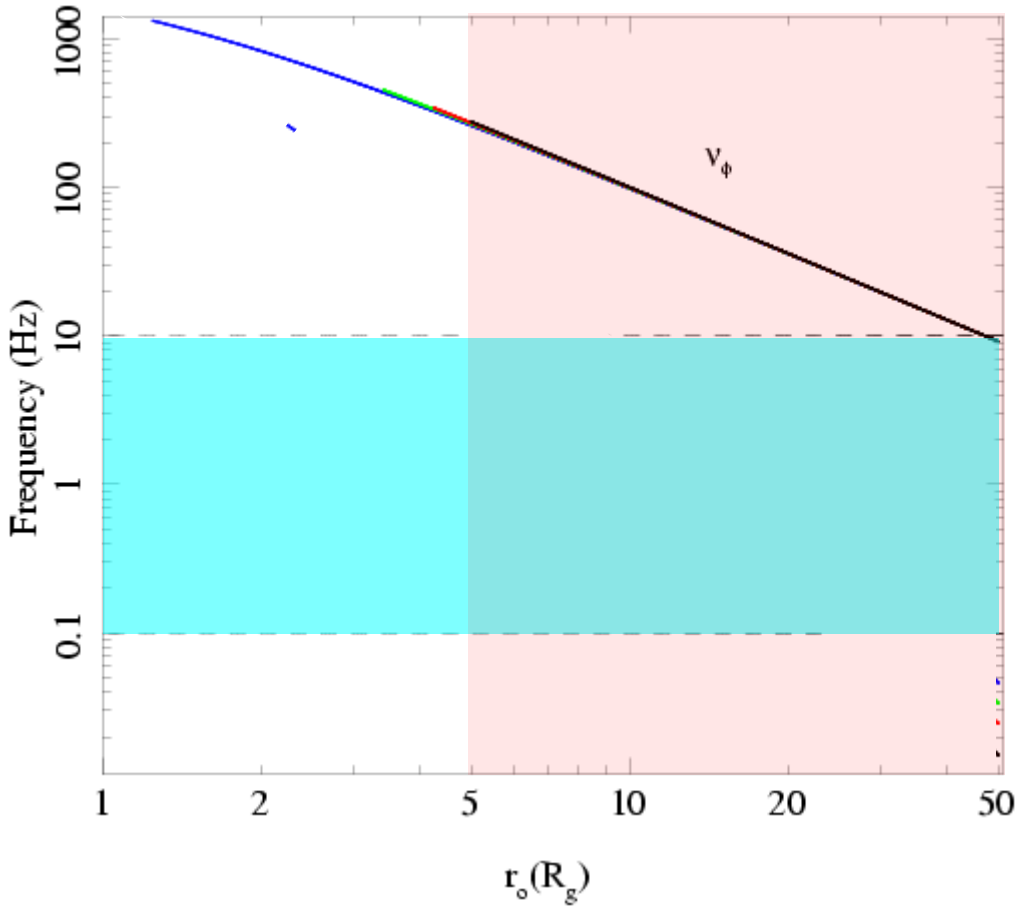






Low frequency QPO

- Spectra need disc to move from R_{tr} = 50-6ish R_g as make transition
- Observed QPO frequencies go from ~0.1-10 Hz
- See similar range in ALL BHB – so either all BHB have same spin or not much spin dependence on QPO
- Not ν(φ) as too fast!



Ingram, Done & Fragile 2009

Low frequency QPO

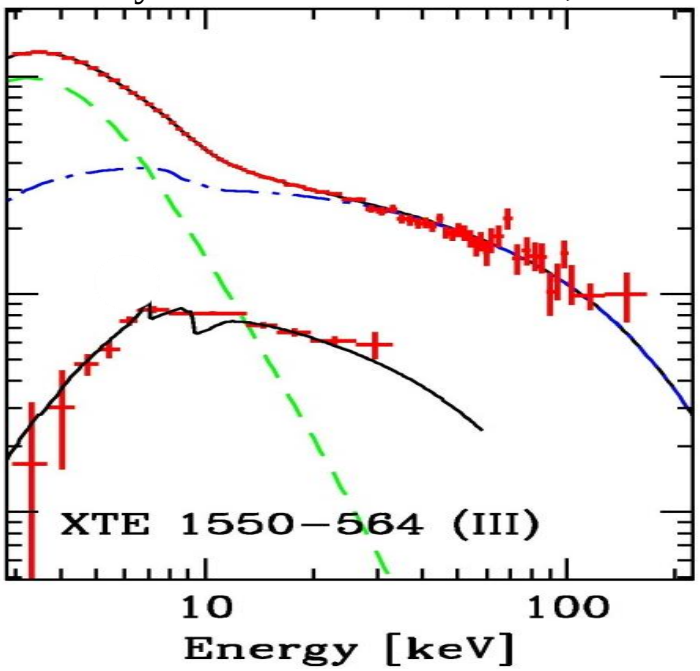
- Stella & Vietri 1998 – GR potential not spherically symmetric so vertically offset circular orbit has $\nu(\theta) \neq \nu(\varphi)$
- Lense-Thirring precession $\nu_{LT} = \nu(\theta) - \nu(\varphi)$

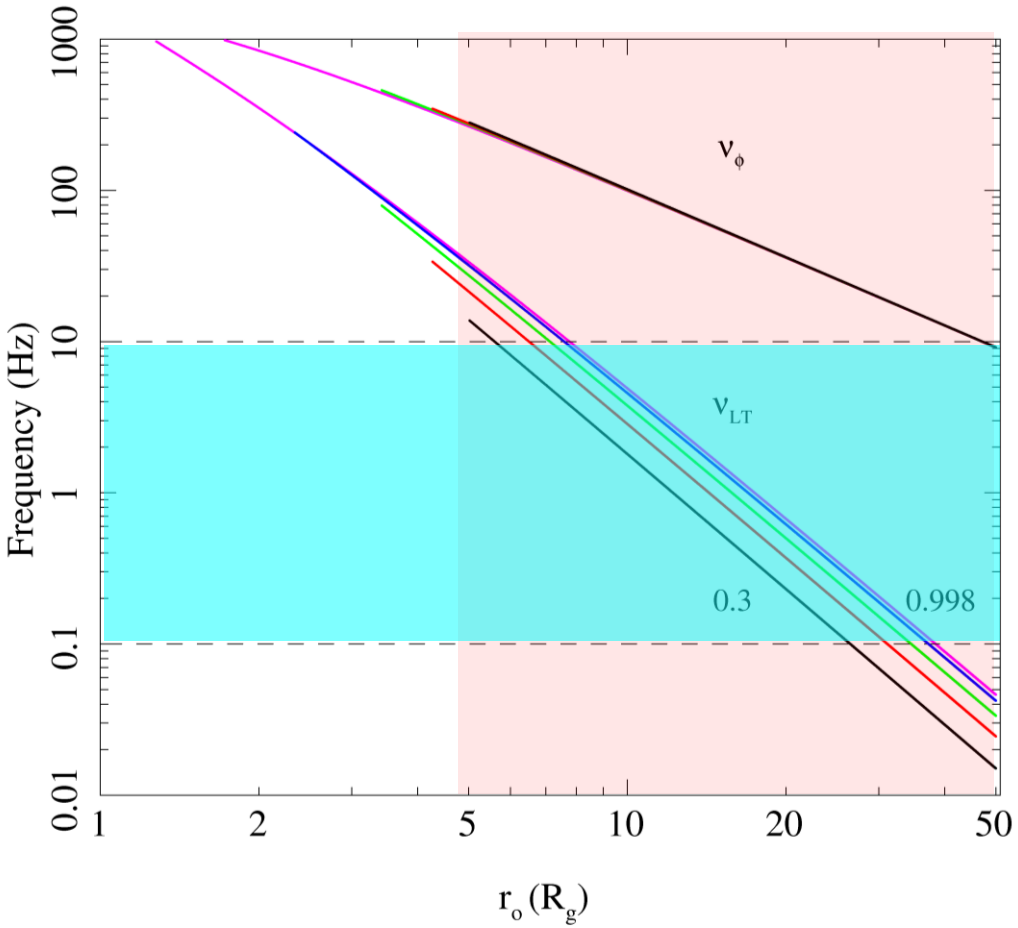
Lamb & Markovic

Does it work ?

- Not really
- Edge of disc would have blackbody spectrum. QPO has spectrum of hot inner flow!

Zycki & Sobolewska 2005; 2006



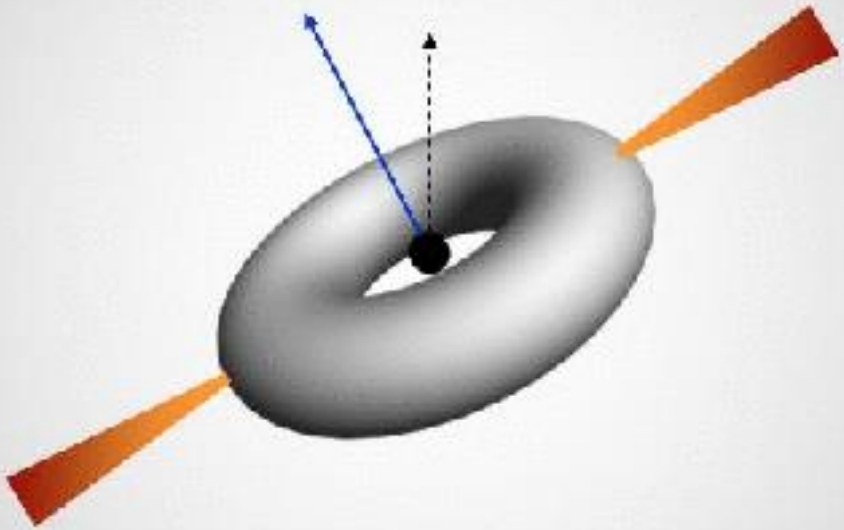


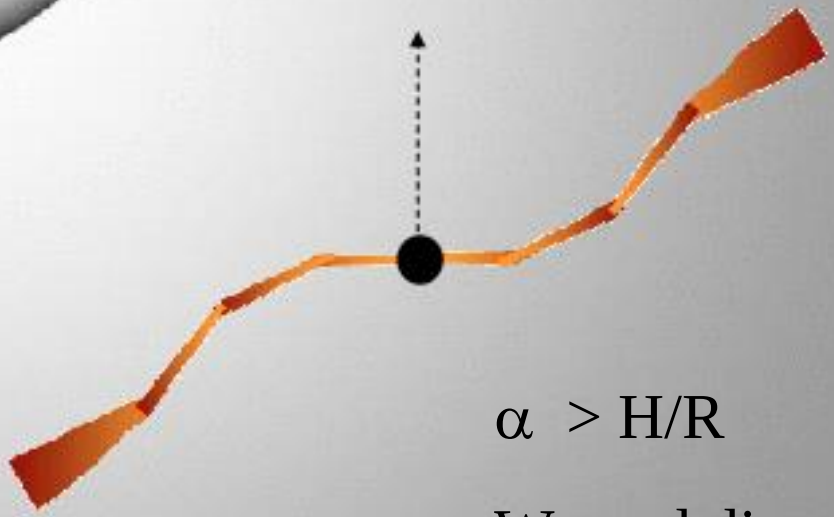
Ingram, Done & Fragile 2009

Solid body precession of the flow

α < H/R

precession





α > H/R

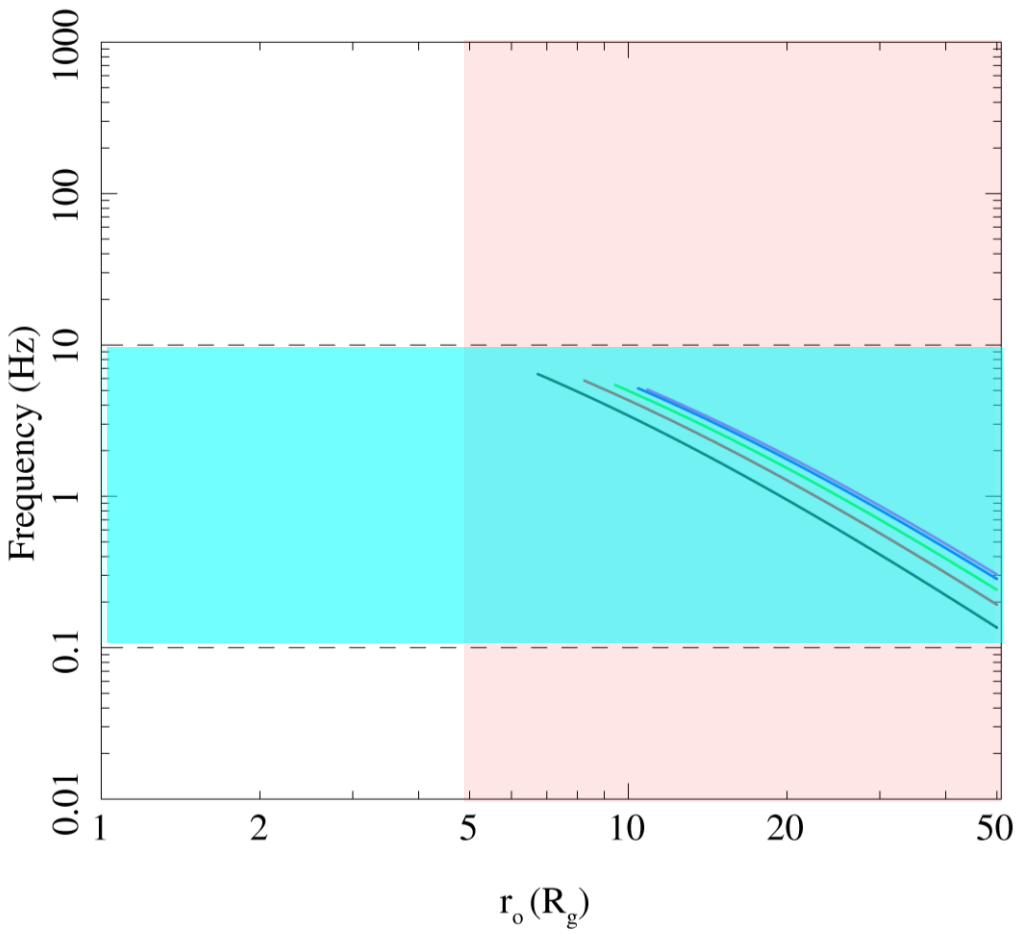
Warped disc

Ingram, Done & Fragile 2009

LT precession of hot flow?

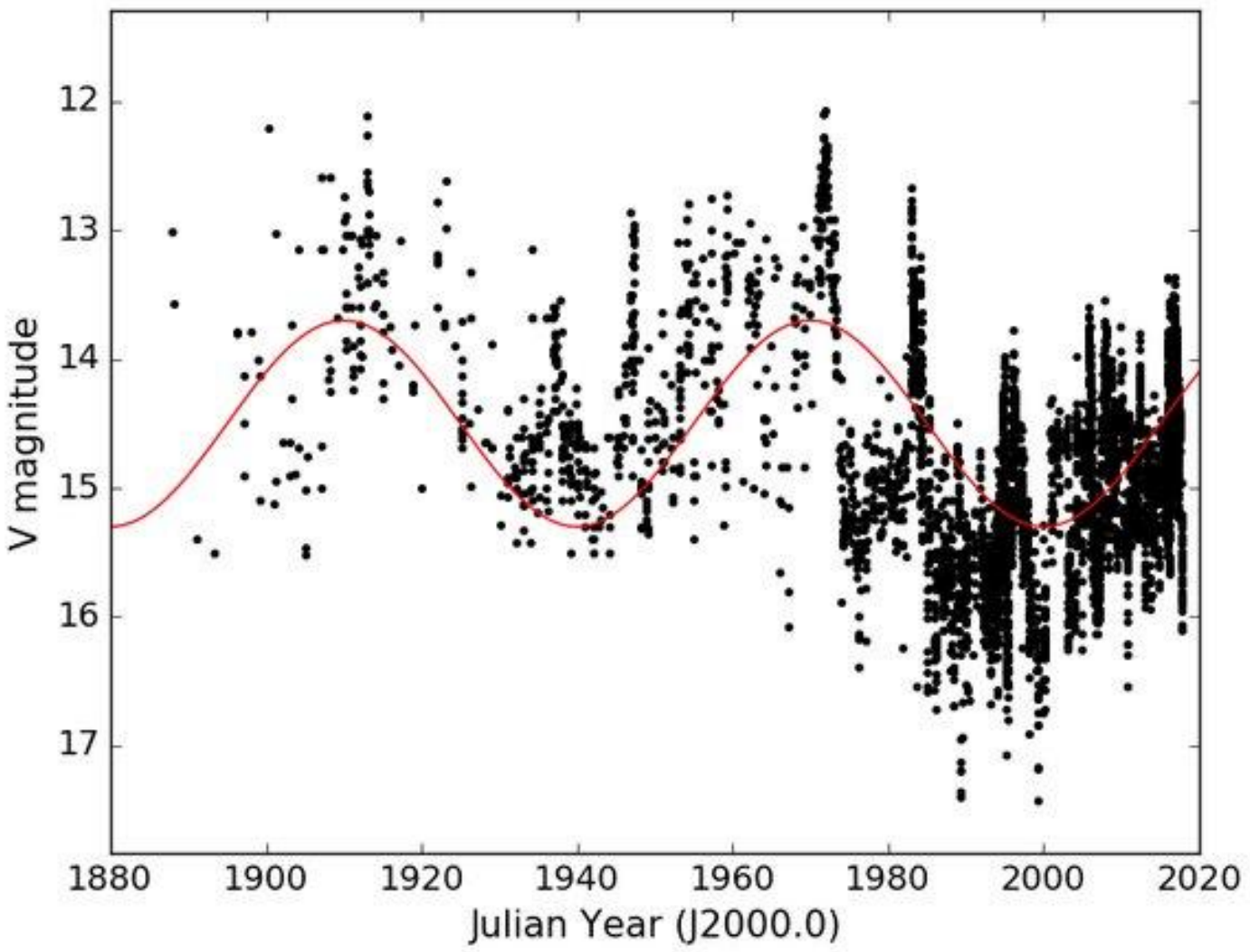
- QPO frequency given by weighted average of LT precession frequency over all radii in hot flow
- Gets the frequencies correct!!
- Modulates Compton region so gets spectrum

- Truncates at ~ bending wave radius

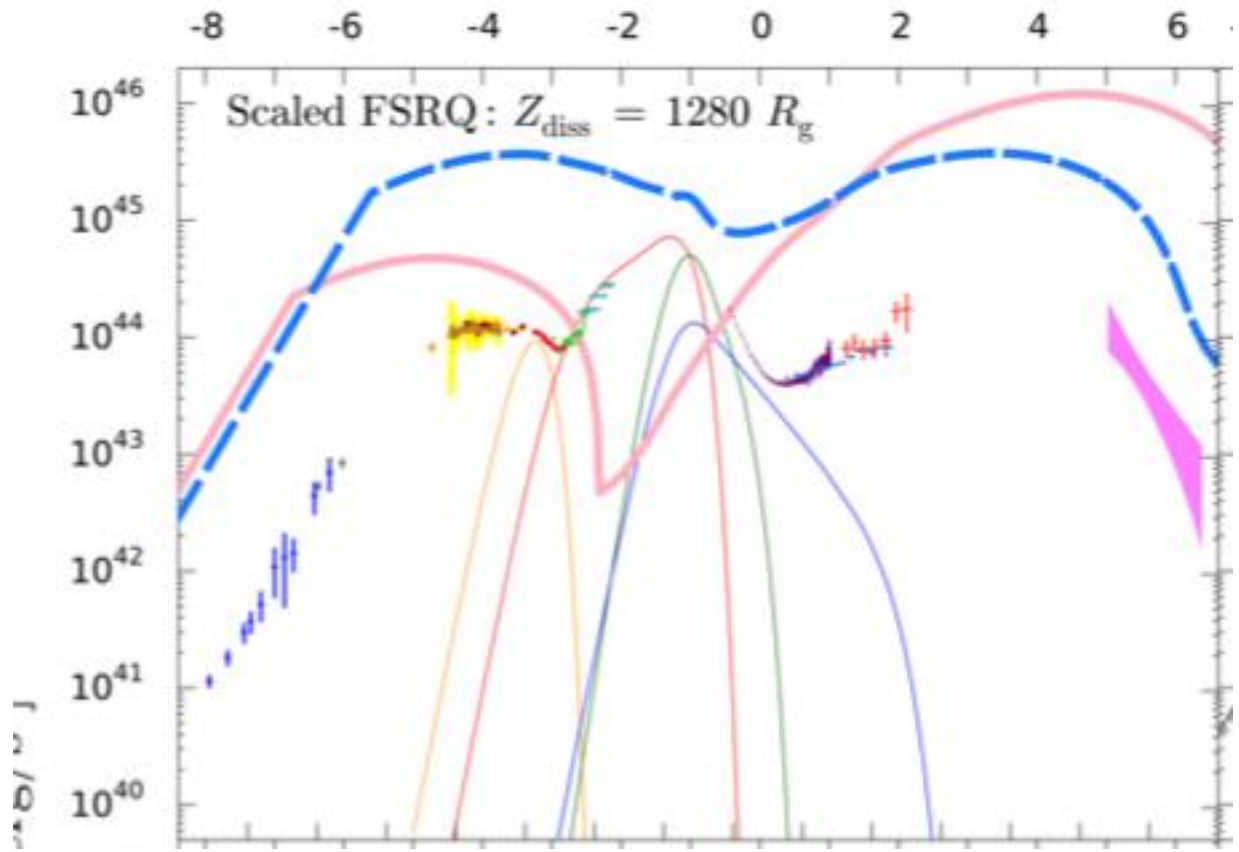


Ingram, Done & Fragile 2009

OJ287 – BL Lac: QPO flow wobbles jet?



RL NLS1 – underpowered jet?



Kynock . Done et al 2017

AGN black holes grow by accretion

- Number density of galaxies from CDM completely wrong shape!
- Supernovae can push out gas in small galaxies but NOT large ones –AGN!
- Need to understand accretion to understand AGN feedback to understand galaxy formation Bower et al 2006