The most rapidly growing black holes: Narrow Line Seyfert 1s across cosmic time

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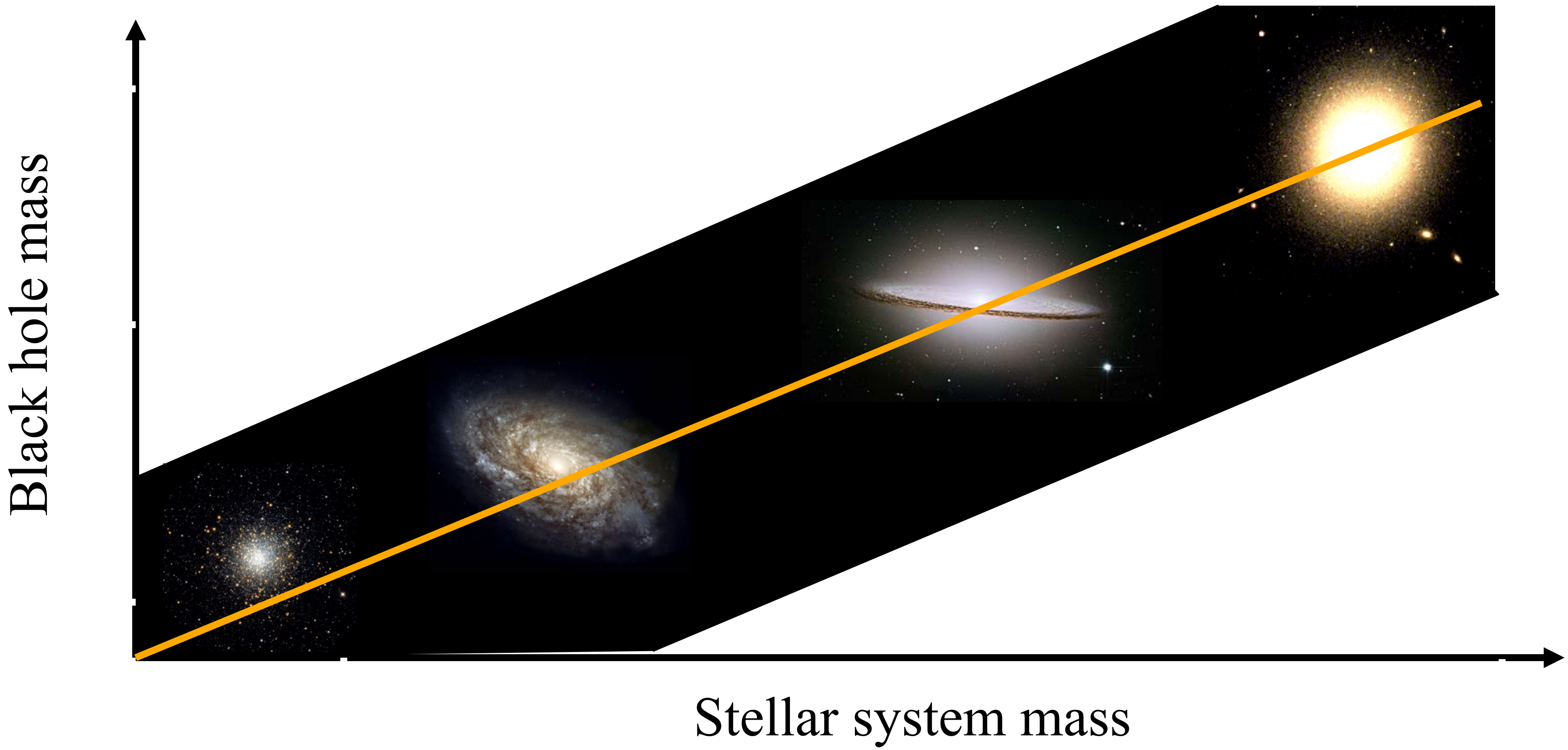
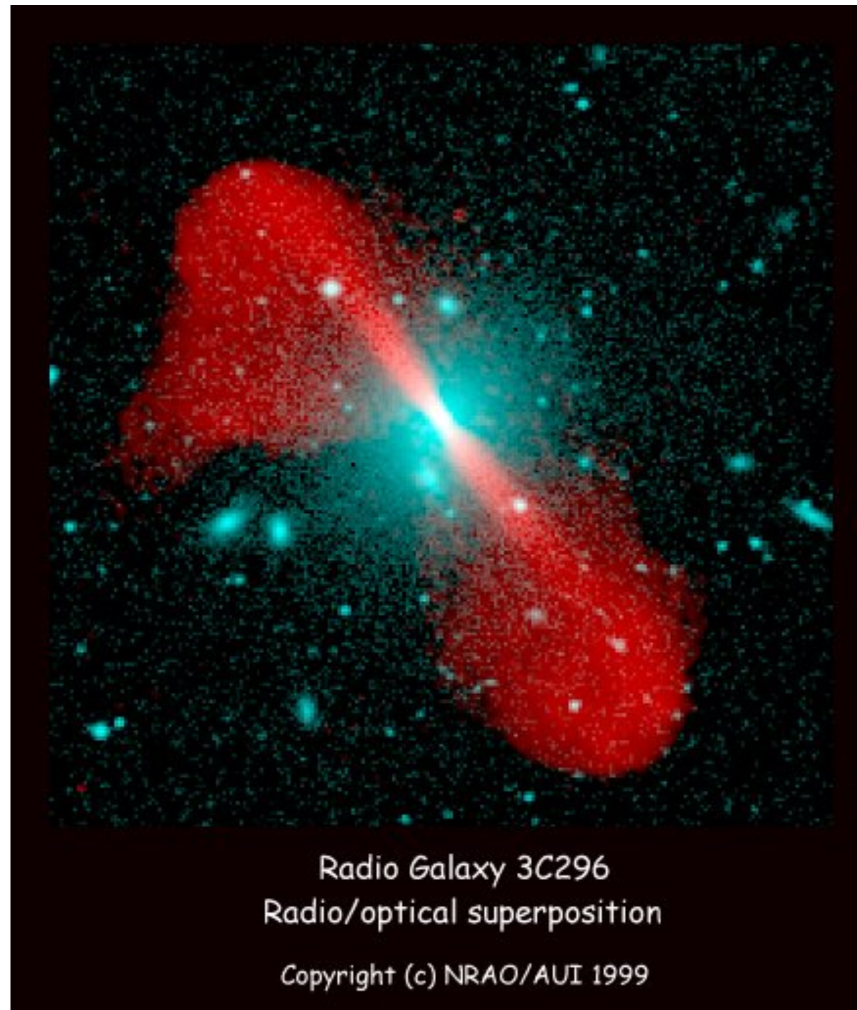
AGN feedback

- Host galaxies grow by star formation across cosmic time
- But big black holes live in big host galaxies M-σ
- Connected!!



Quasar mode (winds) feedback

- Obvious energy transport from large scale radio jets
- Too good! Dumps energy in halo rather than bulge…

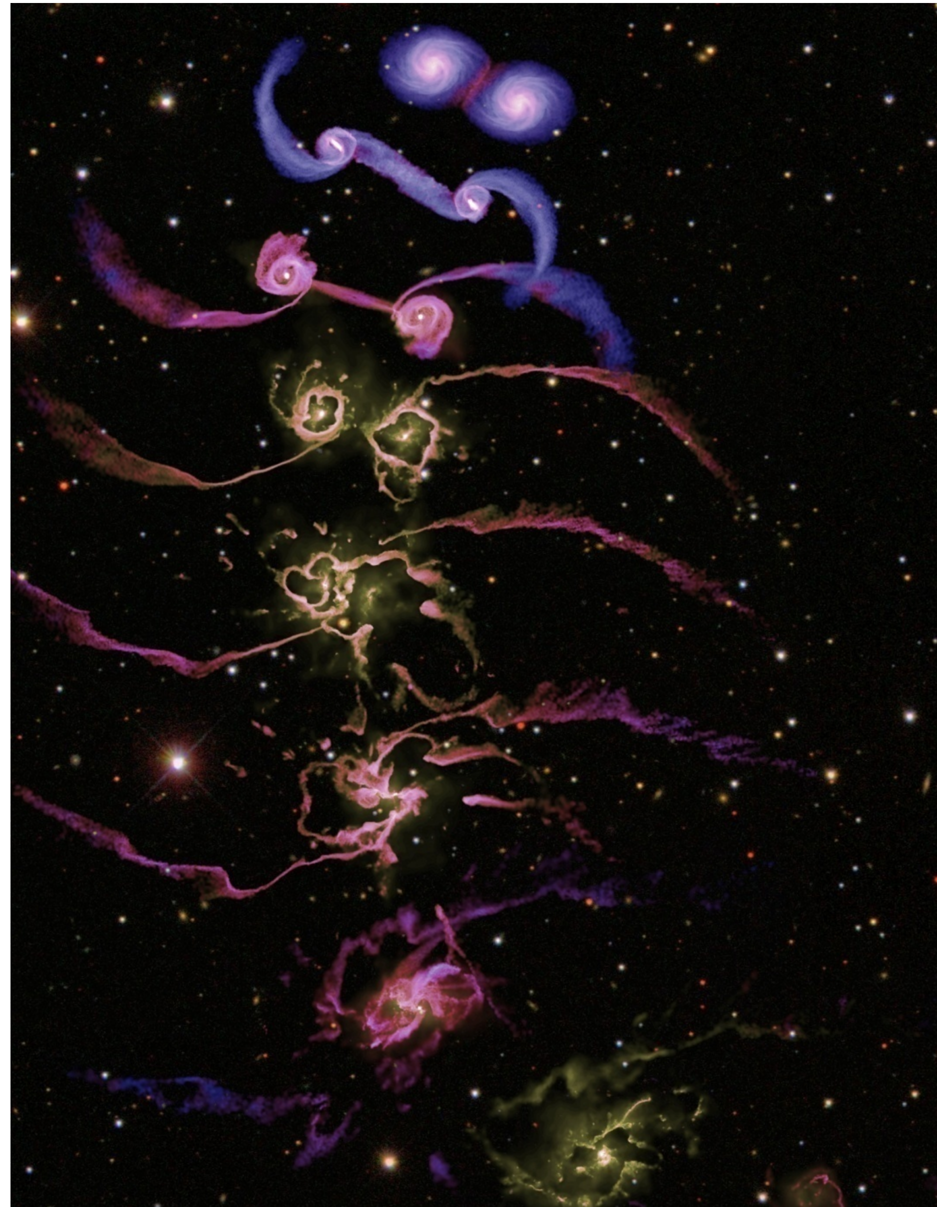


Quasar mode (winds) feedback

- Winds better than jet at dissipating energy in bulge to affect starformation and set M-σ relation (King 2008)

Coevolution of BH and host

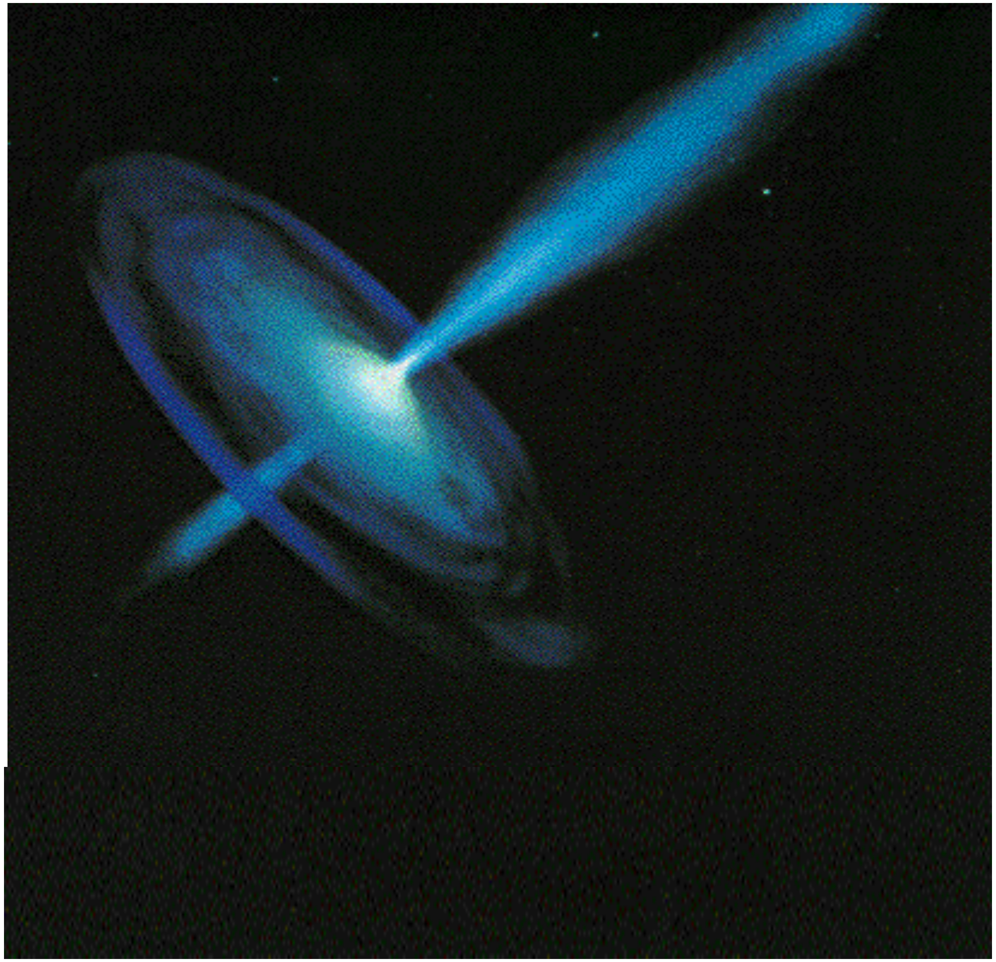
- Gas supply to nucleus
  - Galaxy disc instabilities
  - Major mergers
  - Minor mergers
  - Cooling flow of hot gas from halo
- Regulated by feedback
  - Supernovae
  - Kinetic energy from jet
  - Momentum from wind and/or radiation
- Need to understand accretion to understand feedback and galaxy growth



Di Matteo et al 2005

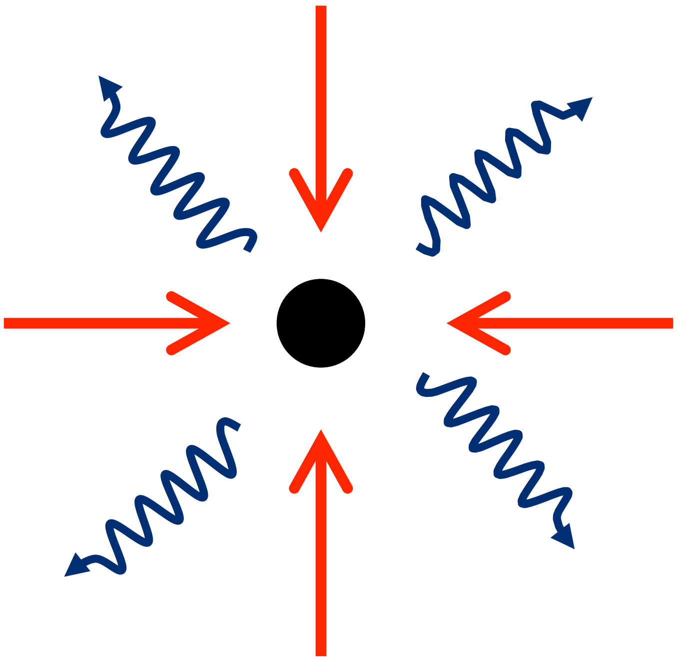
Supermassive black holes

- Accretion powers AGN which powers feedback
- But accretion also increases black hole mass
- Bright AGN = highest mass accretion rate = fastest growing black holes



Eddington limit – growth rate limit

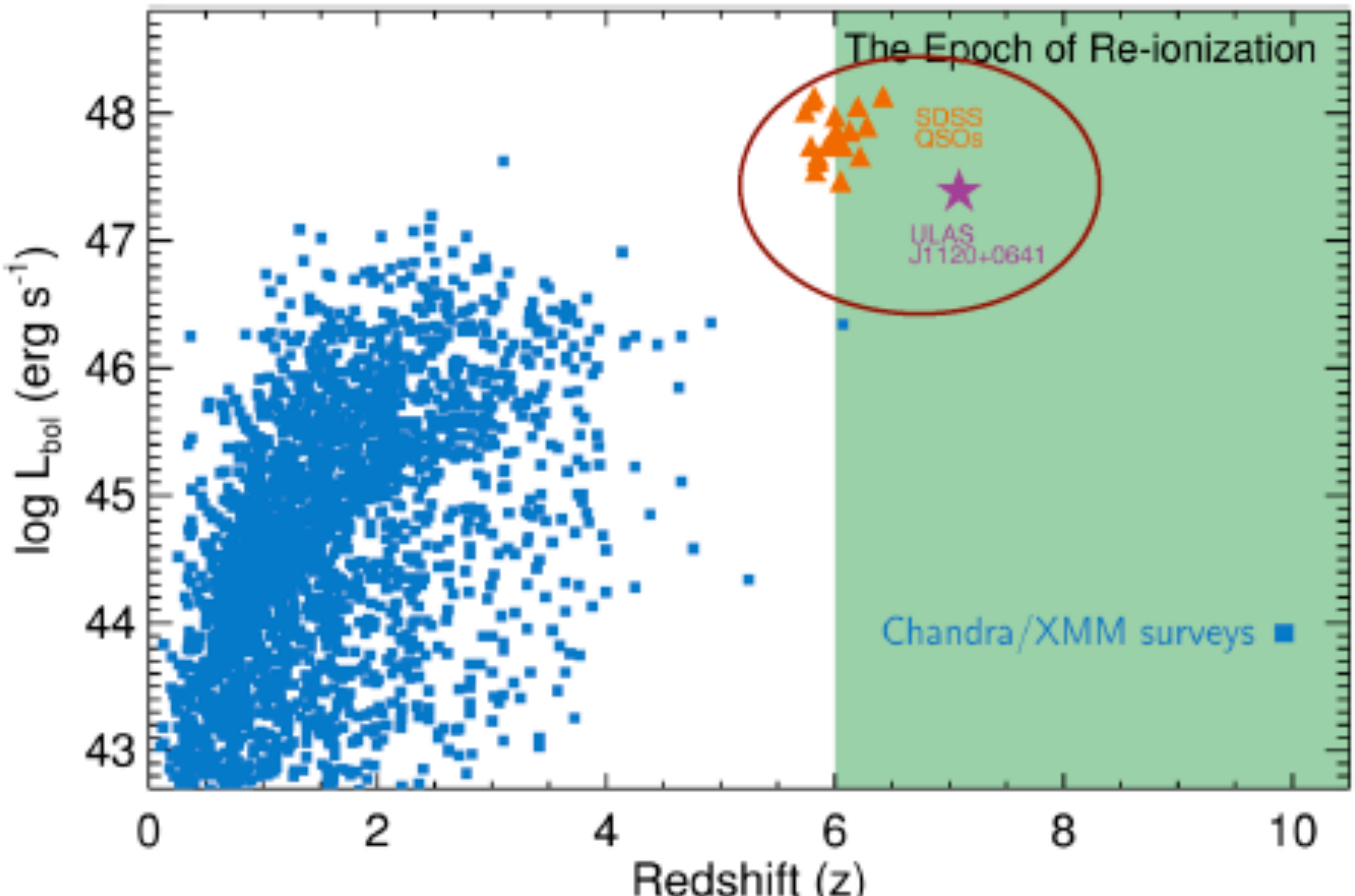
- Gravity pulls in on gas and releases energy as radiation
- Outward radiation pressure eventually balances gravity!
- Eddington limit



- $LEdd = 4\pi GMm/\sigma_T$
- $L = \varepsilon$ Mdot $c^2 < LEdd$
- $M < M_0 e^{t/\tau}$
- $\tau = \frac{\varepsilon c^2 \sigma_T}{4\pi Gm} = 5\text{x}10^7$ years

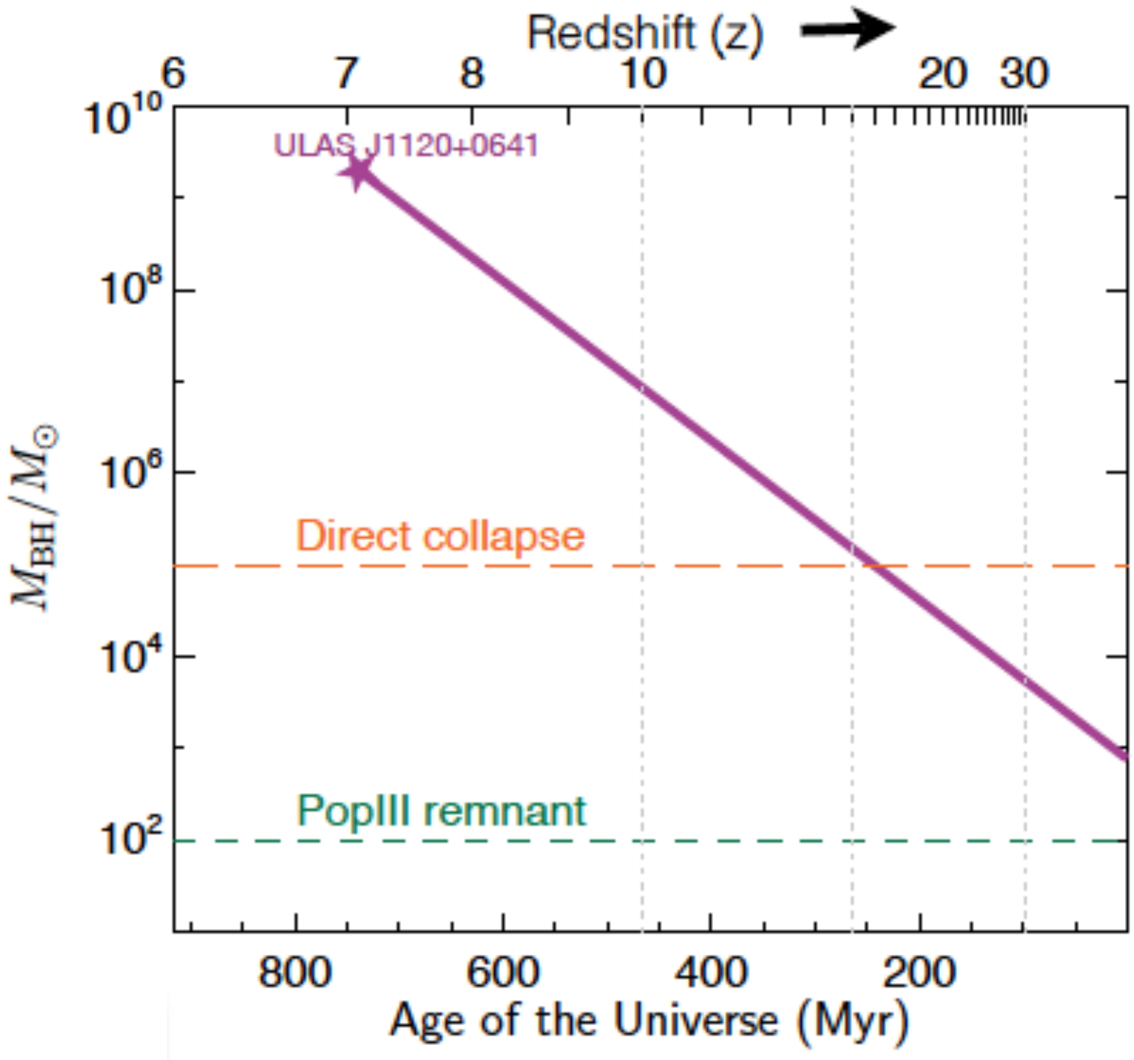
High redshift QSO

- Lbol < Ledd=1.4 x 10^{38} M ergs/s so M> 10^9Msun



How to make massive BH at high z

- Start from stellar remnant black holes from first stars
- z=30-6 for reionisation – first stars (popIII)!
- Start with bigger seeds? From direct collapse?
- Or grow faster than LEdd?

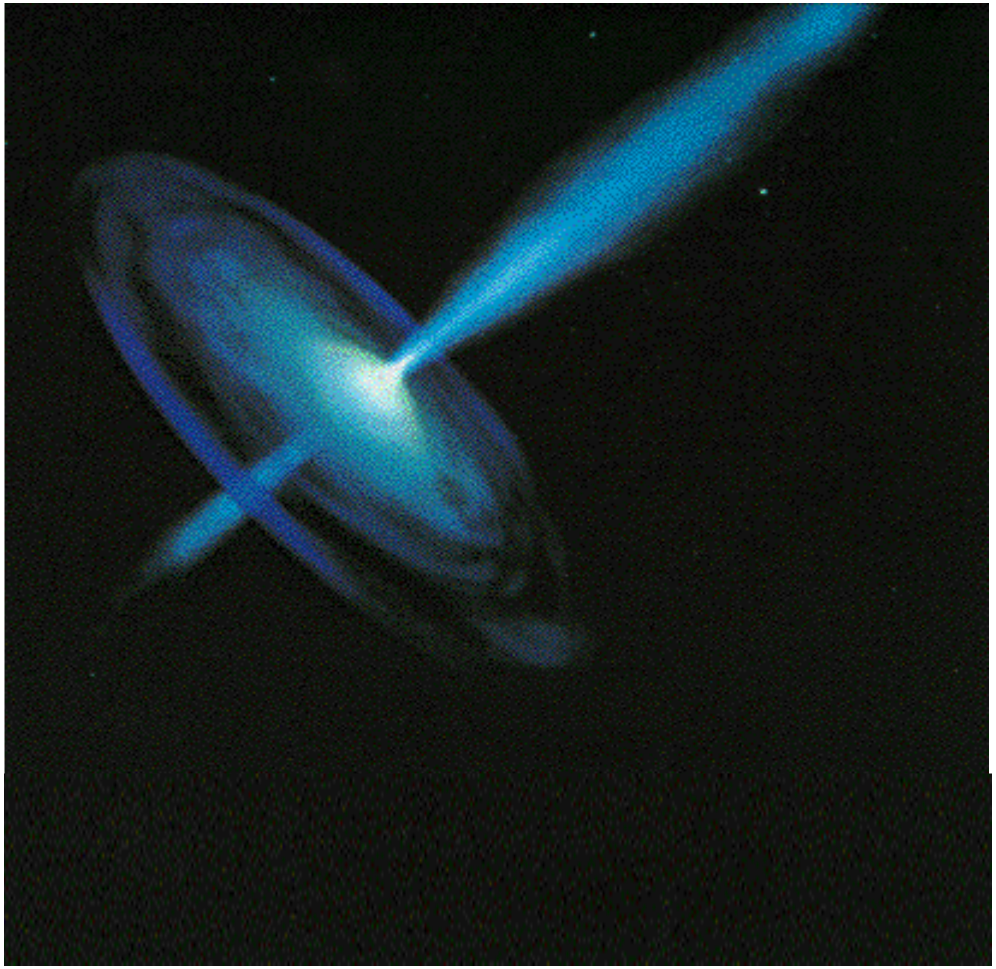


Plan of the talk

- Find local black holes at high mass accretion rates
- See if LEdd is a real limit – if not we can grow black holes faster and make highest z QSOs from popIII stellar remnant black hole seed.
- See if L>Ledd powers winds – if so we can do AGN feedback

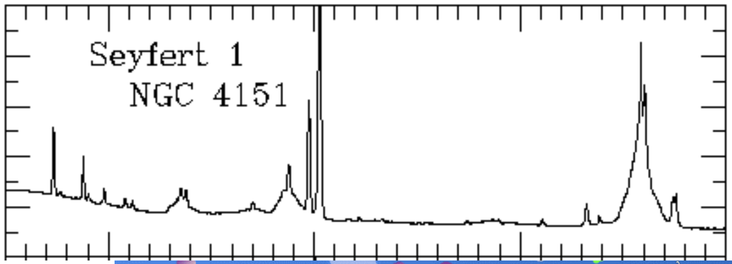
Accreting black holes

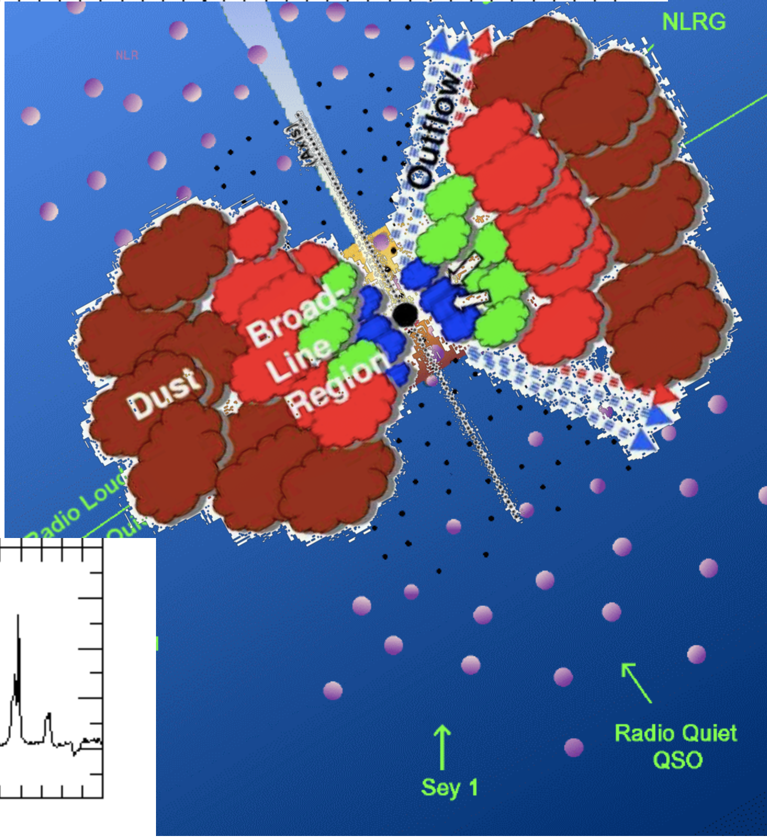
- Black holes are the simplest possible objects
- Mass, spin
- See them through accretion – Mdot
- 3 fundamental parameters plus inclination

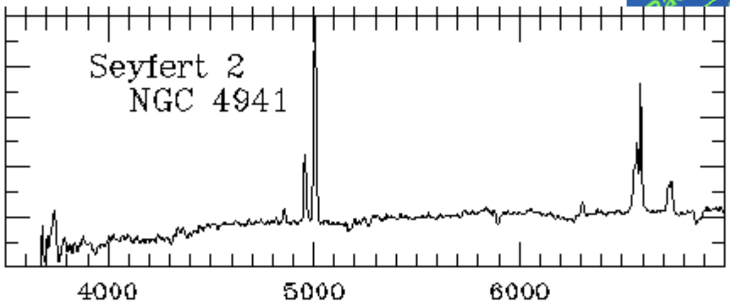


And Inclination

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

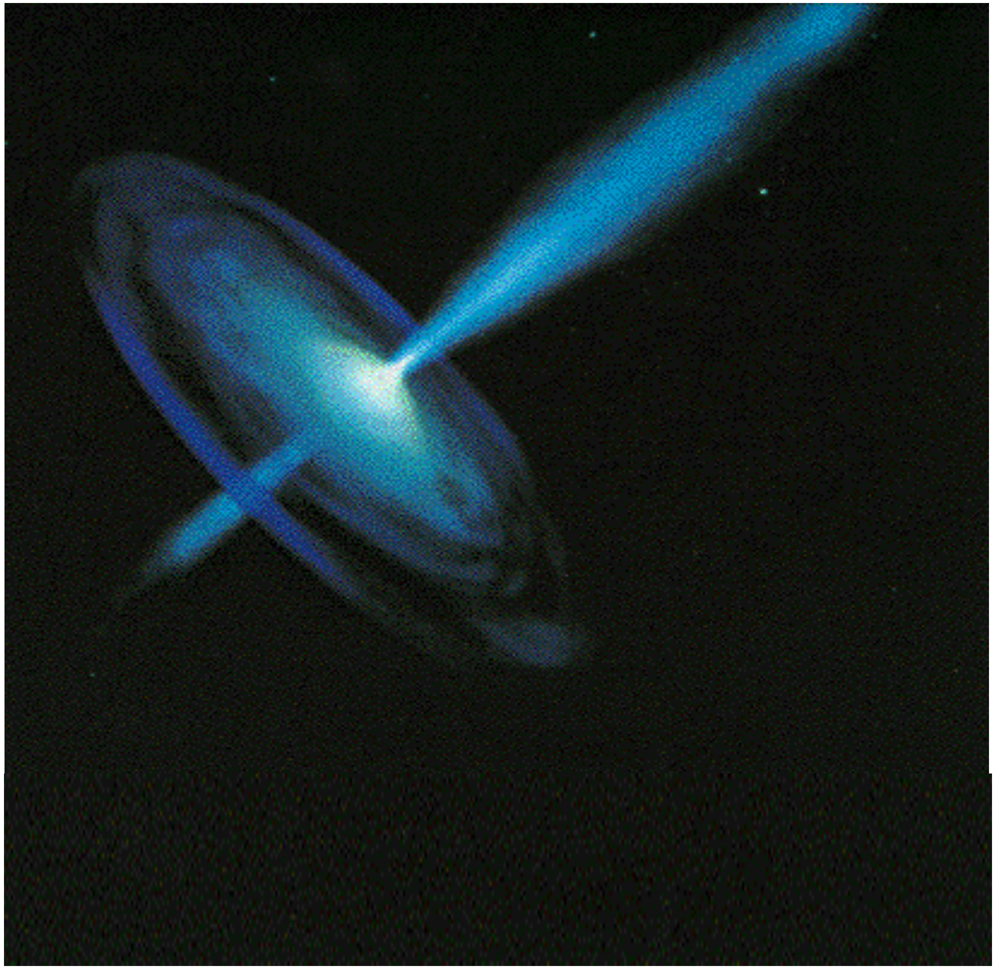






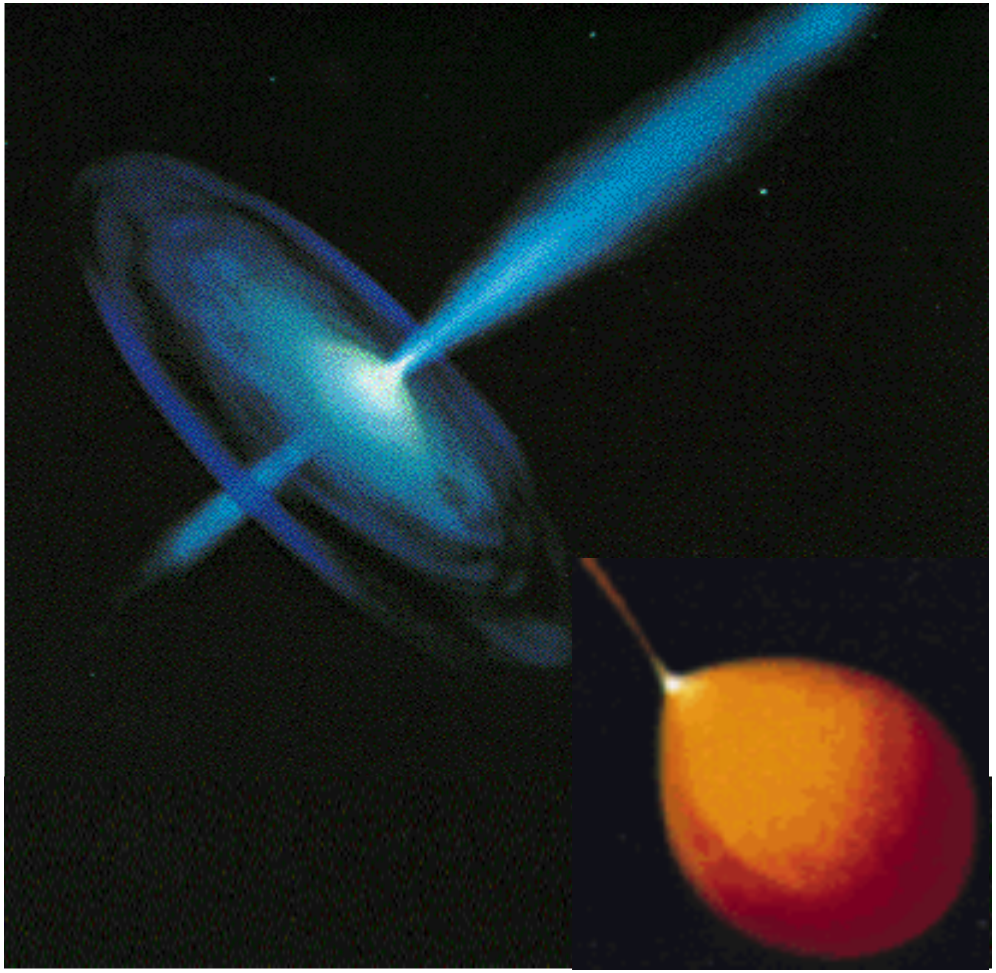
Black hole accretion and jets

- 3 fundamental parameters
- Mass, Mdot, spin



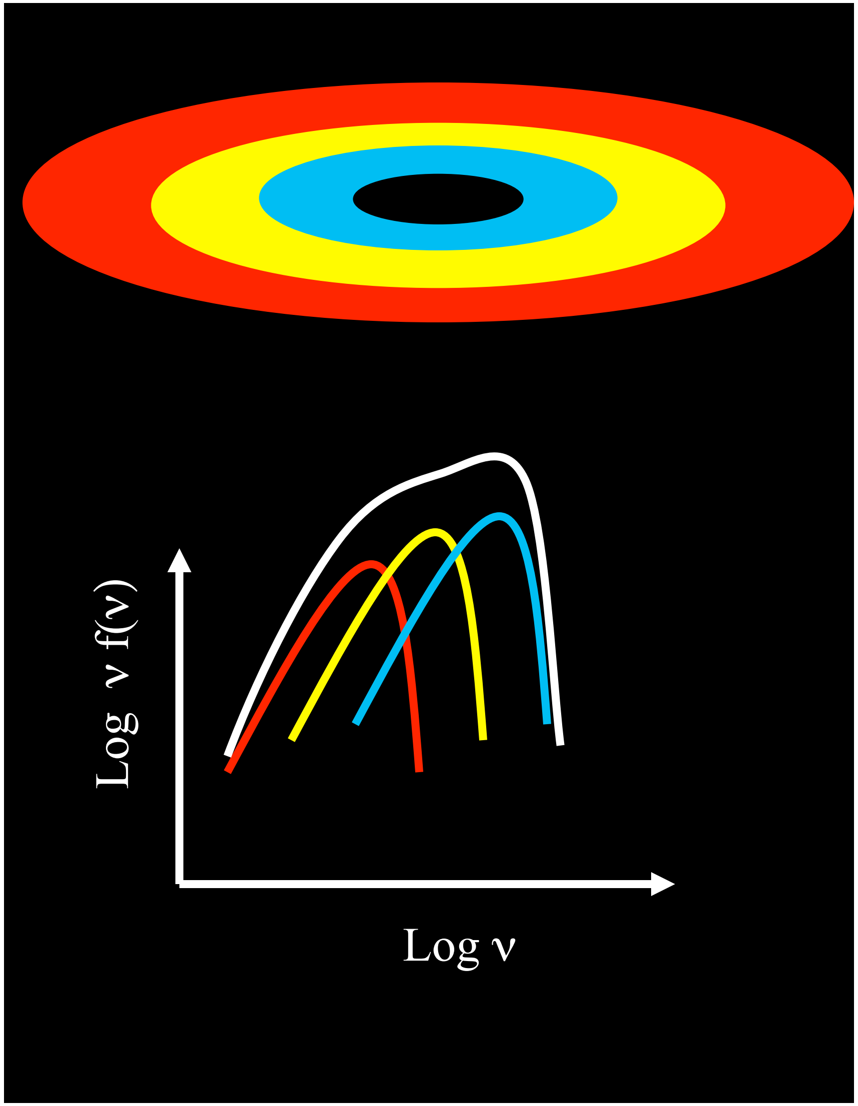
Scaling Black holes

- BONUS
- We get a test set!
- Stellar mass BHB
- All same mass (x2) – maybe also similar spin
- Observational template of how accretion flows behave with L/L_{Edd}



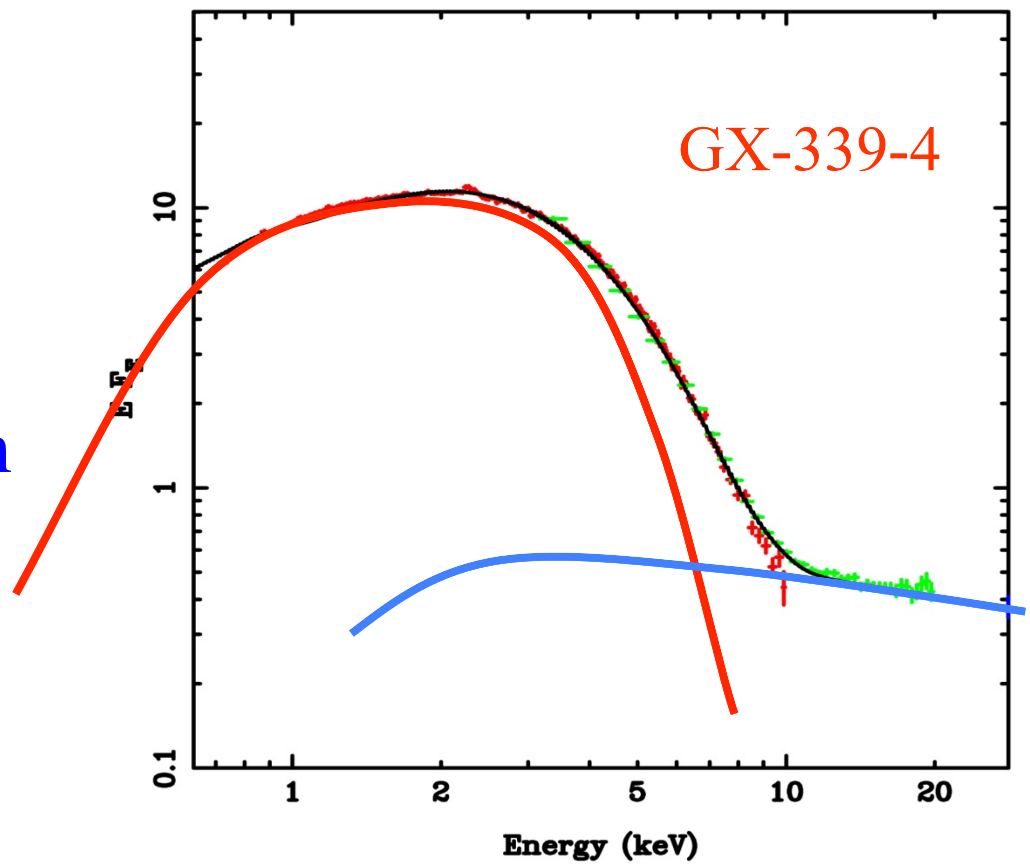
Ultimately from accretion flow

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



Observed disc spectra in BHB!!

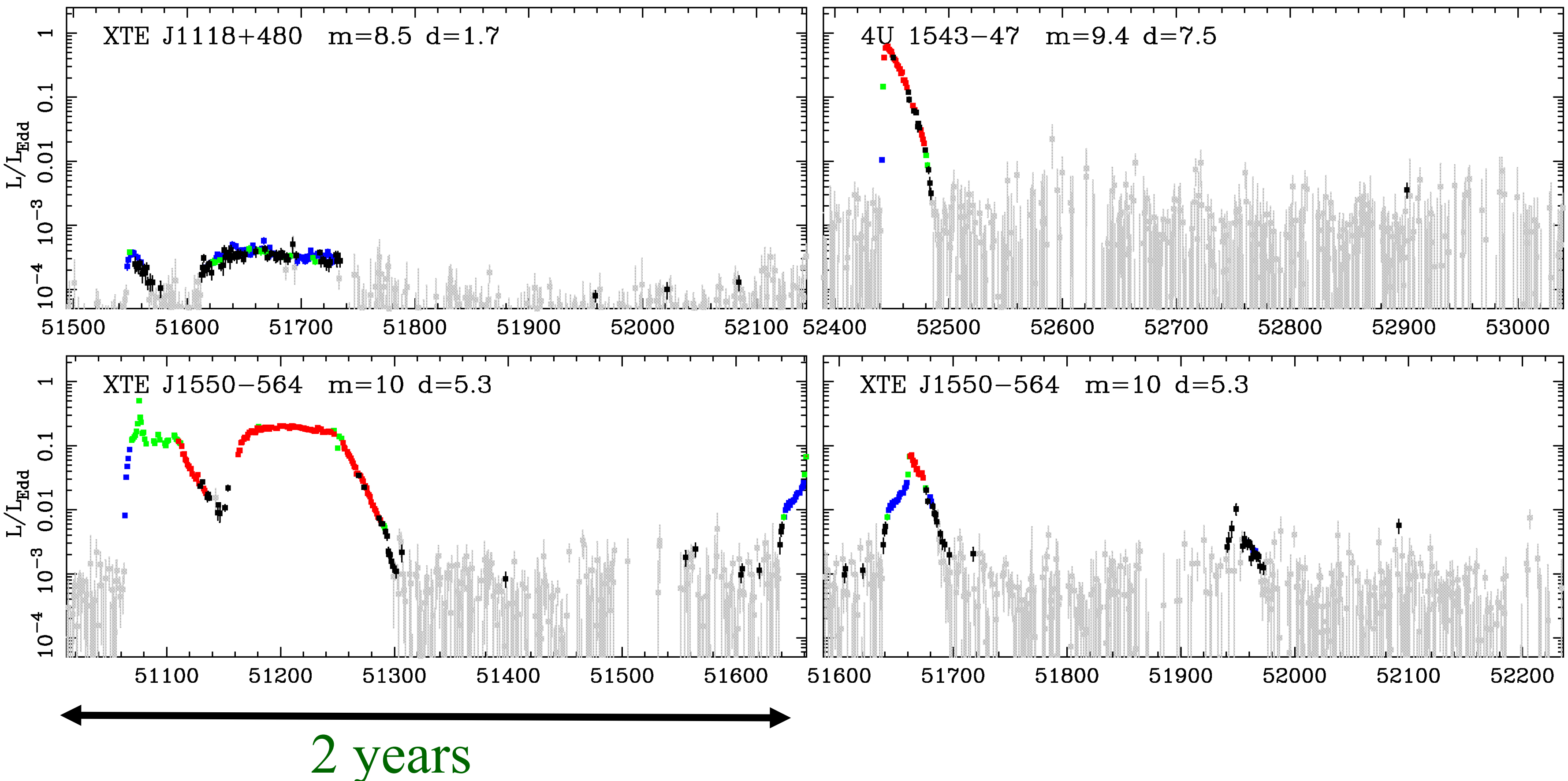
- Fit Shakura-Sunyaev disc (with GR and photosphere)
- WORKS WELL!!
- Small corona gives high energy tail



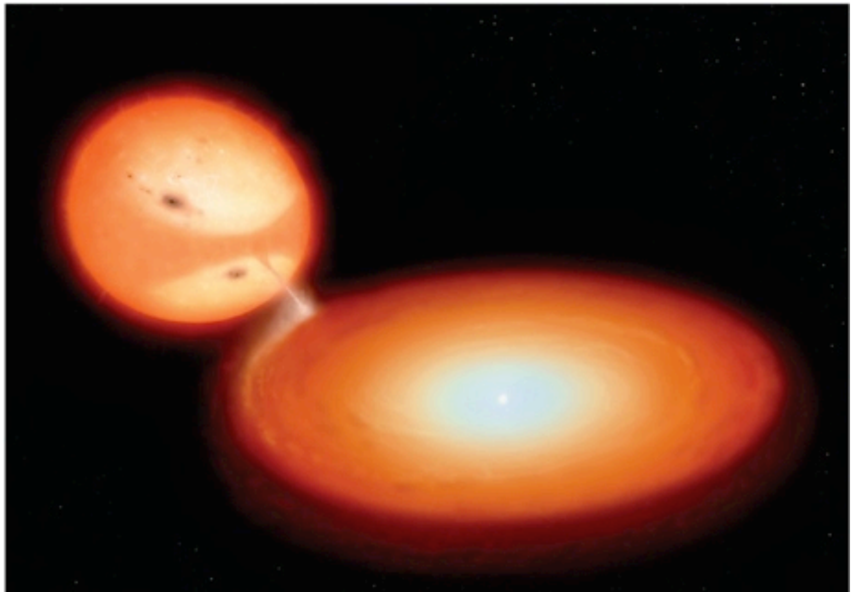
Kolehmainen et al 2010

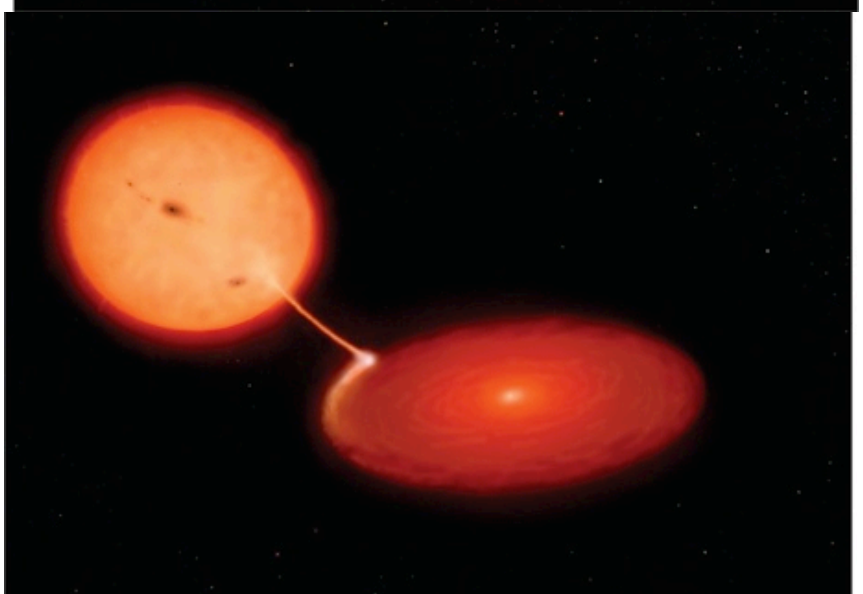
Stellar mass BH disc varies!

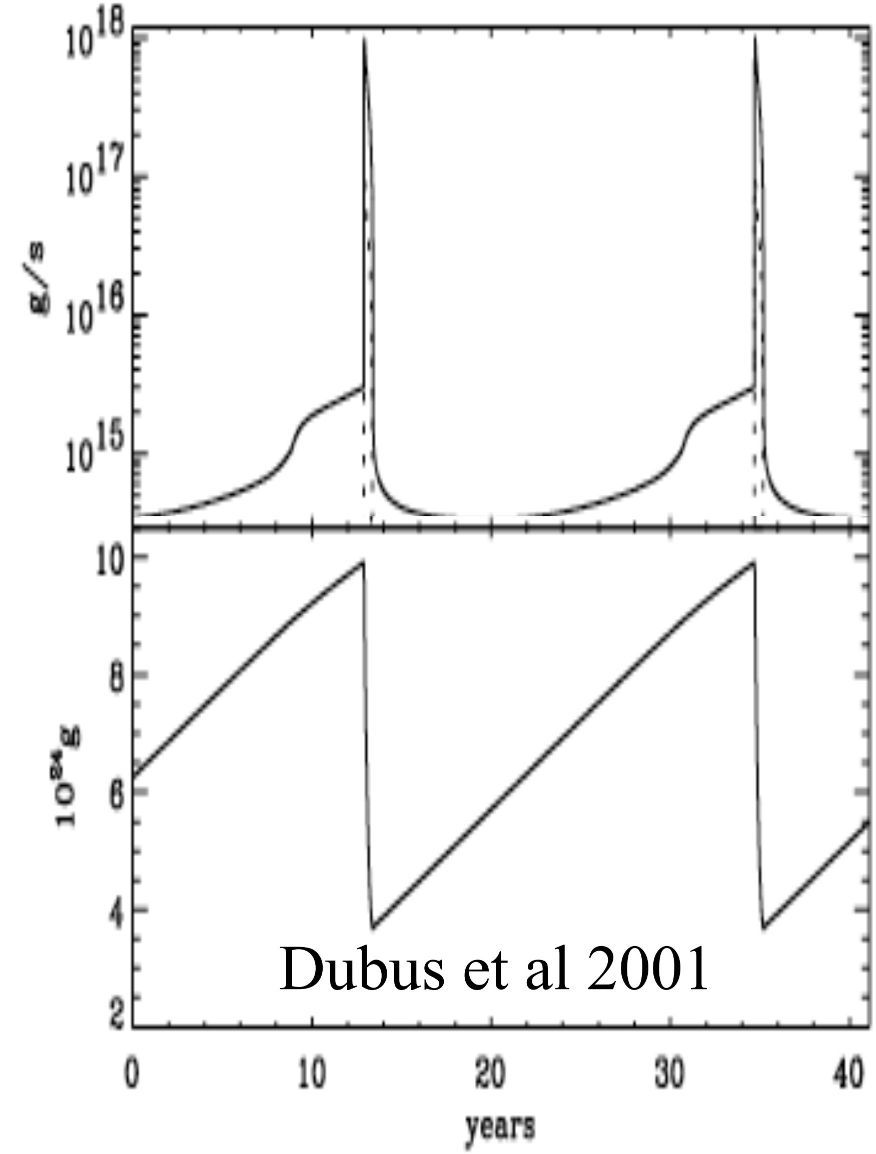
- Mass accretion rate through the disc varies on timescales of days/weeks/months
- Not often L>LEdd – but H instability and binary orbit!



Disk Instability & Roche lobe

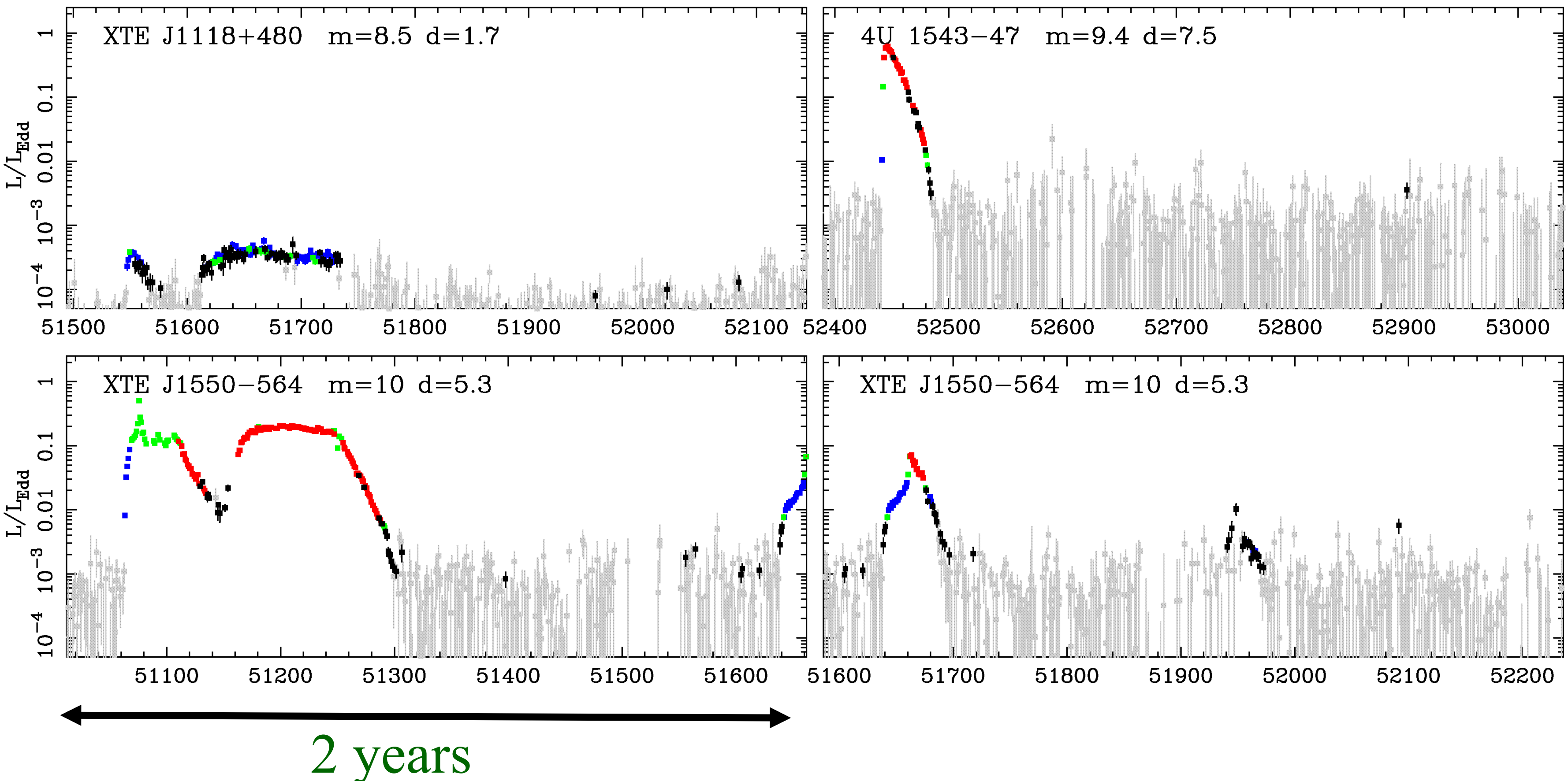




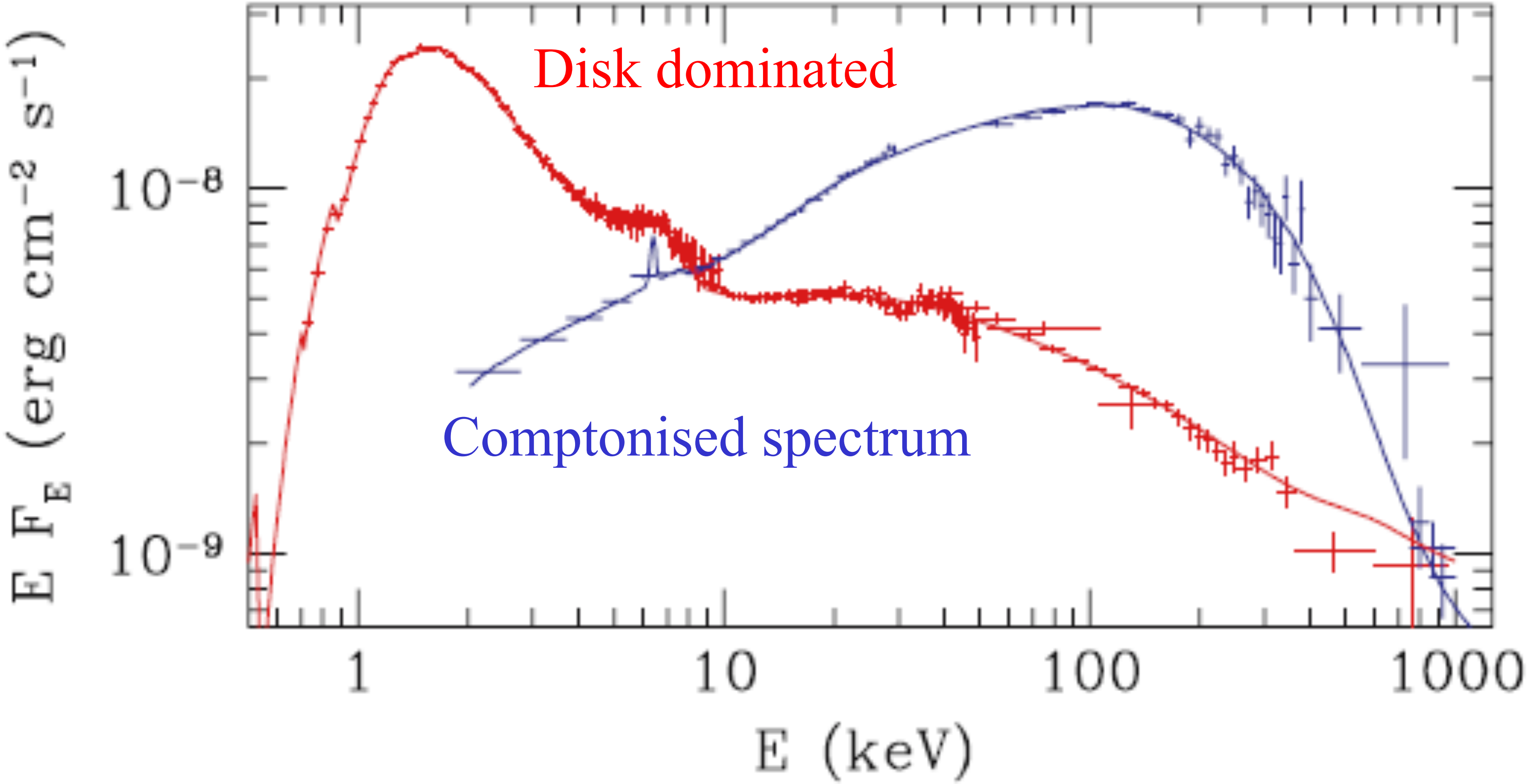


SubEddington accretion flows

- Transient outbursts of unstable disc as H neutral-ionised
- Size of disc set by Roche lobe overflow determines Lpeak<~ LEdd (King 2000)

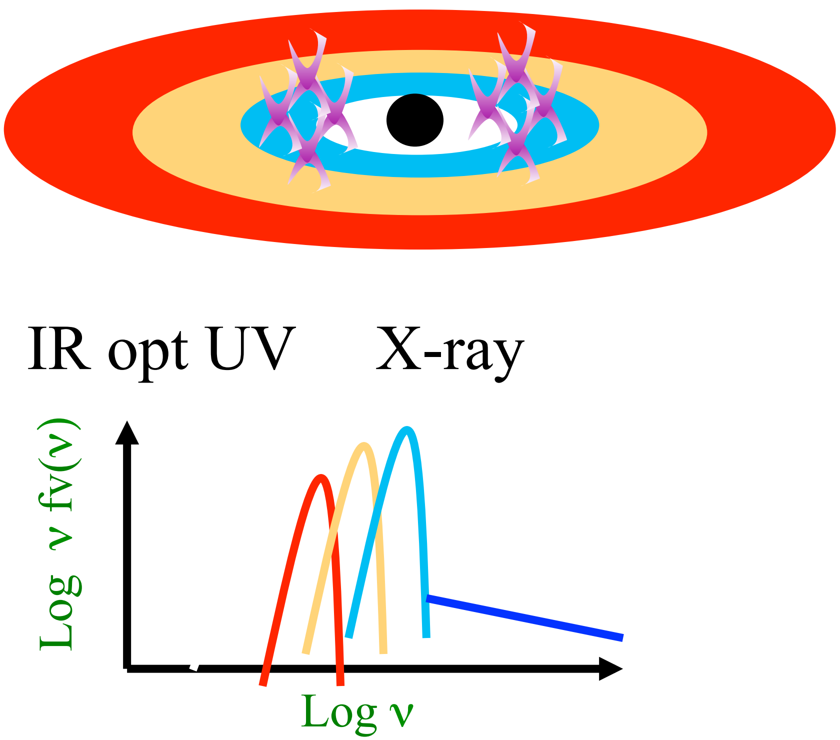


Two types of spectra in stellar BH

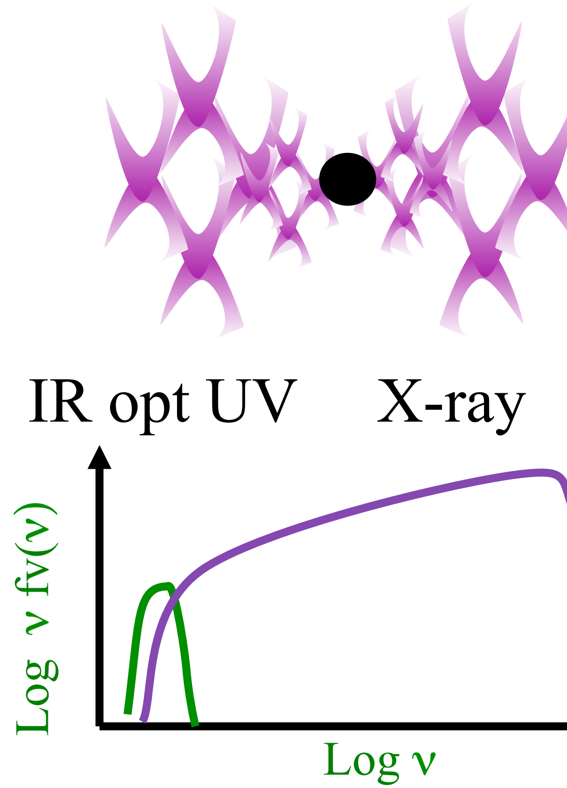


Gierlinski et al 1999

Theory of accretion flows



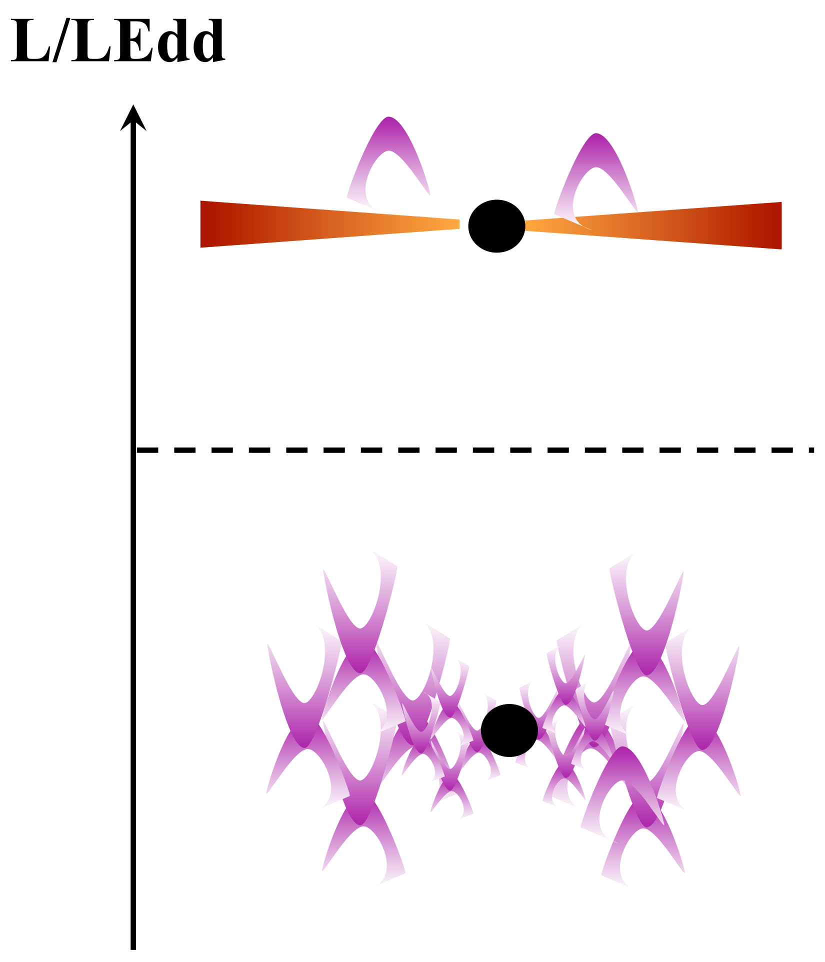
Discs – geometrically thin, cool, optically thick SS73
Plus X-ray tail/corona



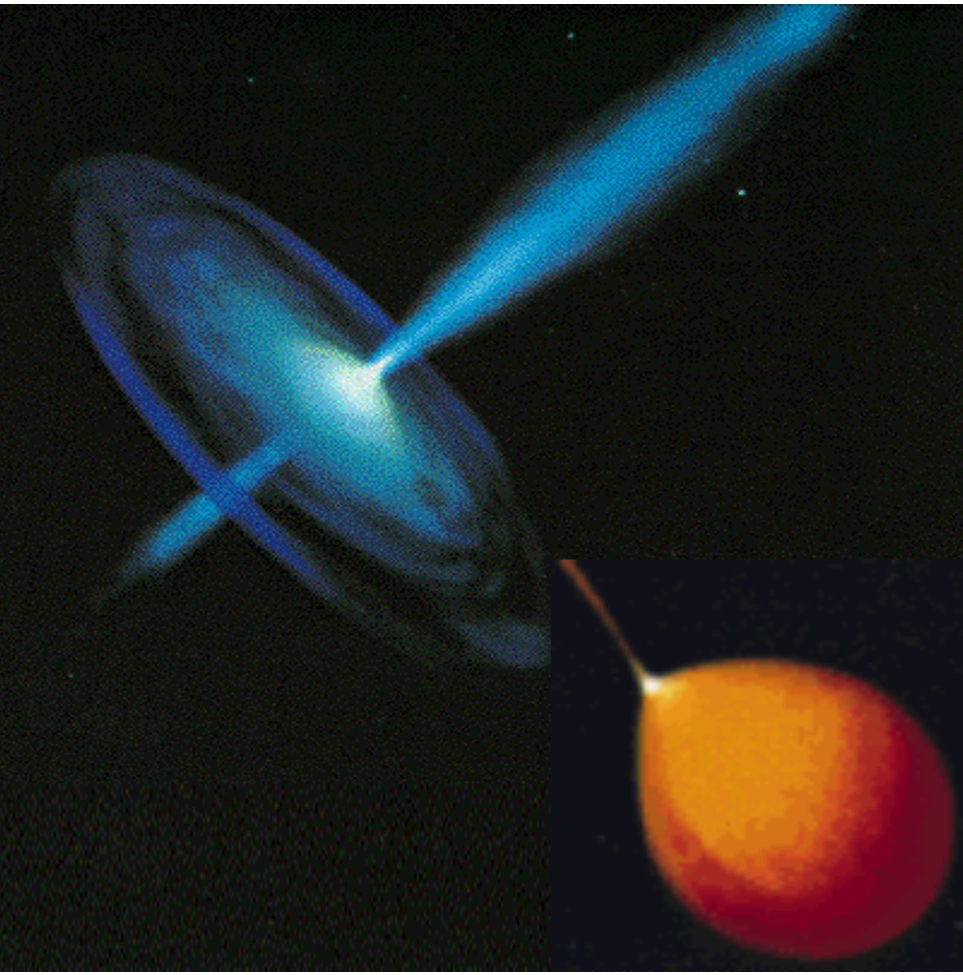
‘ADAF’– geometrically thick, hot, optically thin
Only low L/Ledd
Narayan & Yi 1995

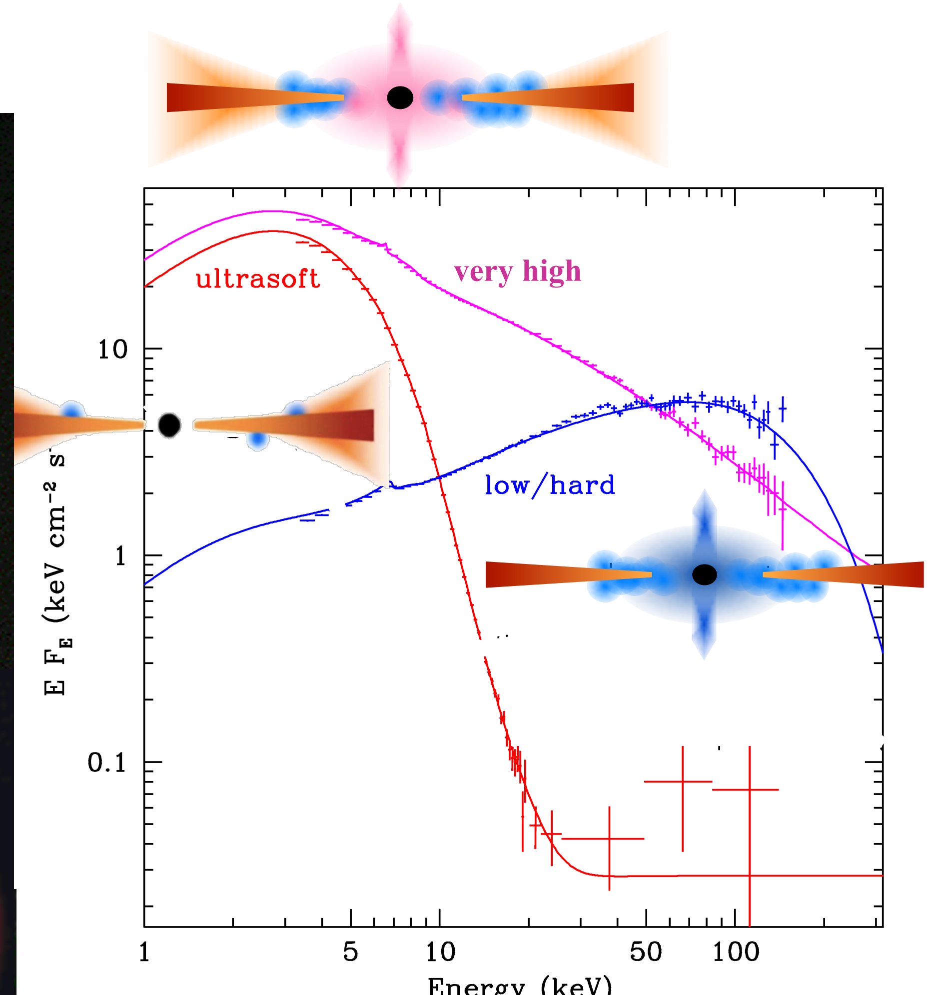
BHB accretion + jet

- Can be complex at L~LEdd
- Disc dominated state – Shakura-Sunyaev disc equations!!
- transitions are complex!
- ADAF/RIAF



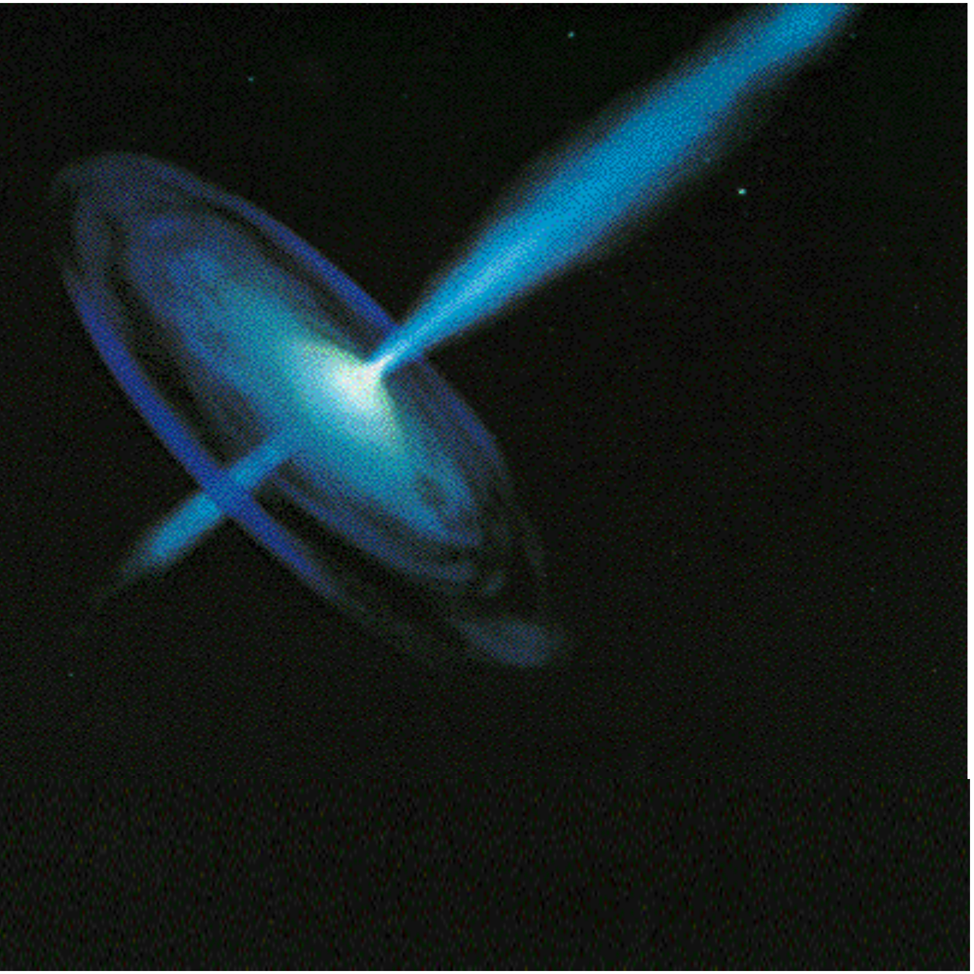
BHB: template for SED L/Ledd?





Gierlinski & Done 2003

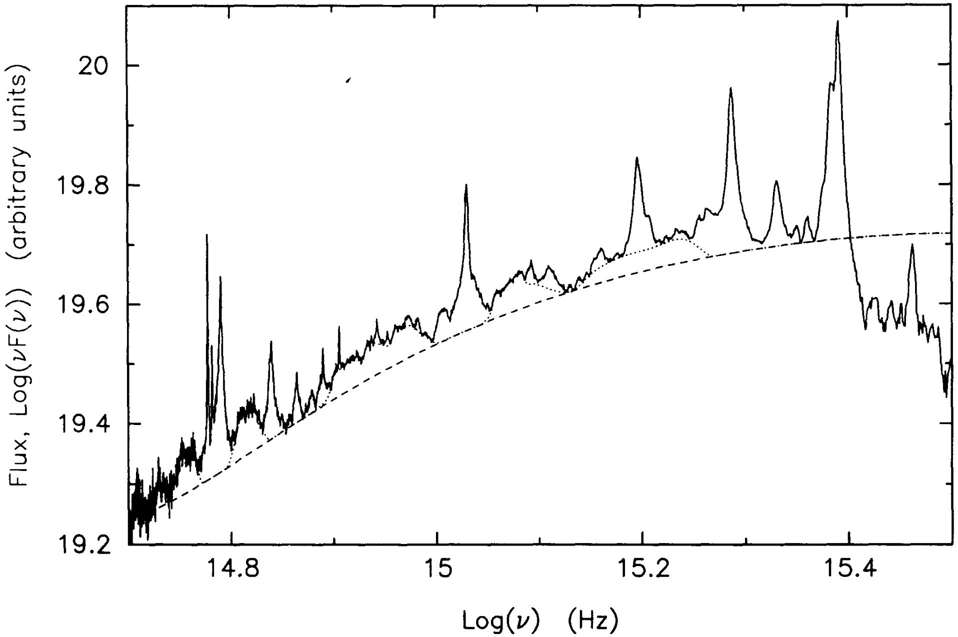
Scaling black hole accretion flow



- 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??

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)



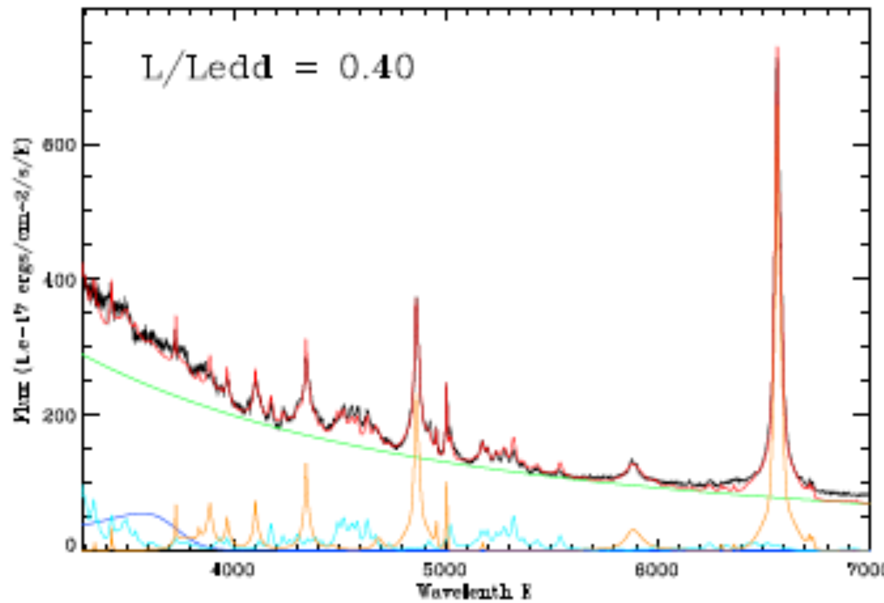
Francis et al 1991

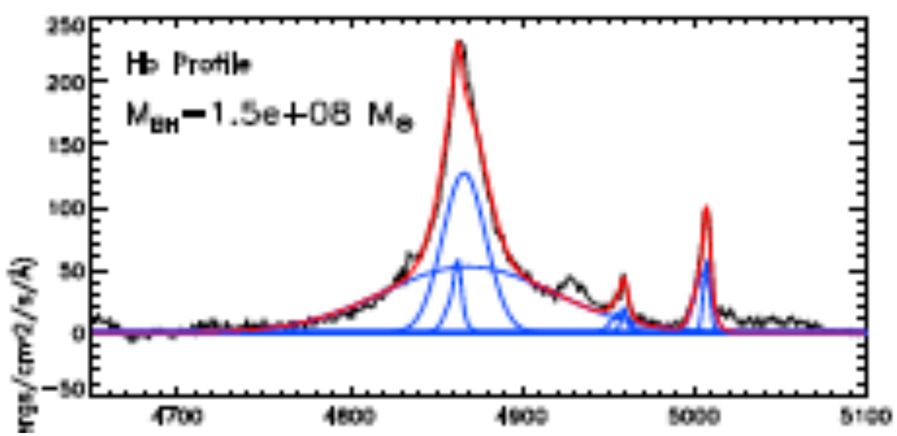
Need M and L/LEdd – SDSS!

Jin, Ward, Done Gelbord 2012

- BH mass from optical spectra (Hβ & Lopt)
- FWHM Hβ $v^2=GM/R$
- Line emissivity peaks $\xi_c = \mathrm{Lion}/n_c R^2$
- R α $\mathrm{Lion}^{1/2}$
- Assume Lion α L_{5100}
- M α $v^2 R$

  α $\mathrm{FWHM}^2\, L_{5100}{}^{1/2}$

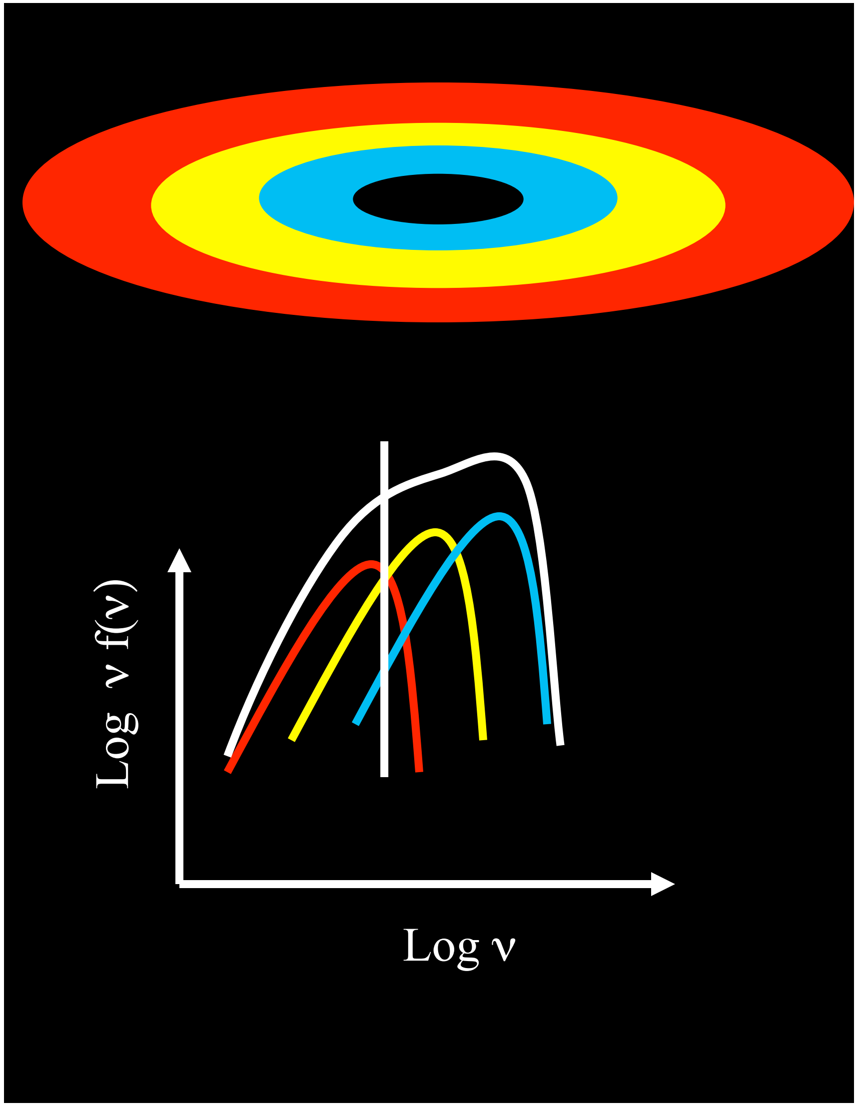




Get Lbol from same spectrum!

- Anywhere below the peak ($h\nu < kT_{max}$) but above $kT(R_{max})$
- Monochromatic luminosity
- $L_\nu = \int B_\nu(T_R)\, 2\times2\pi\, R\, dR$
  $\propto (M\, \dot{M})^{2/3} \cos i$

SS73, Collin & Kawaguchi 2004, Davis & Laor 2011

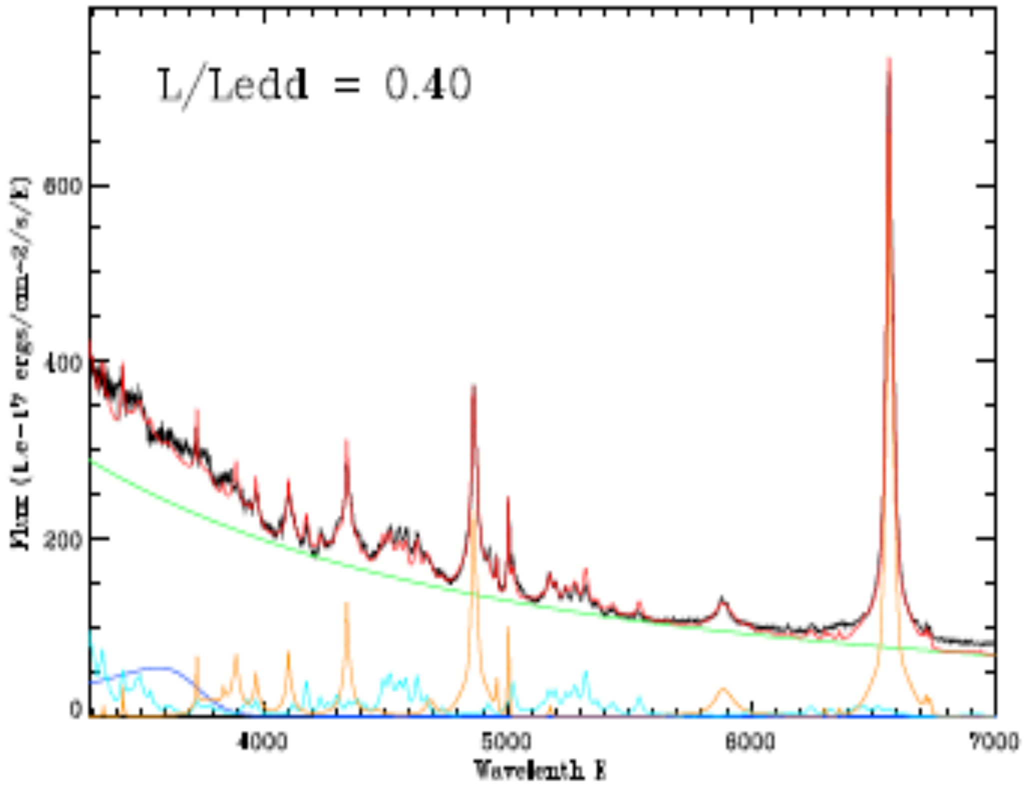


Need M and L/LEdd – SDSS!

Jin, Ward, Done Gelbord 2012

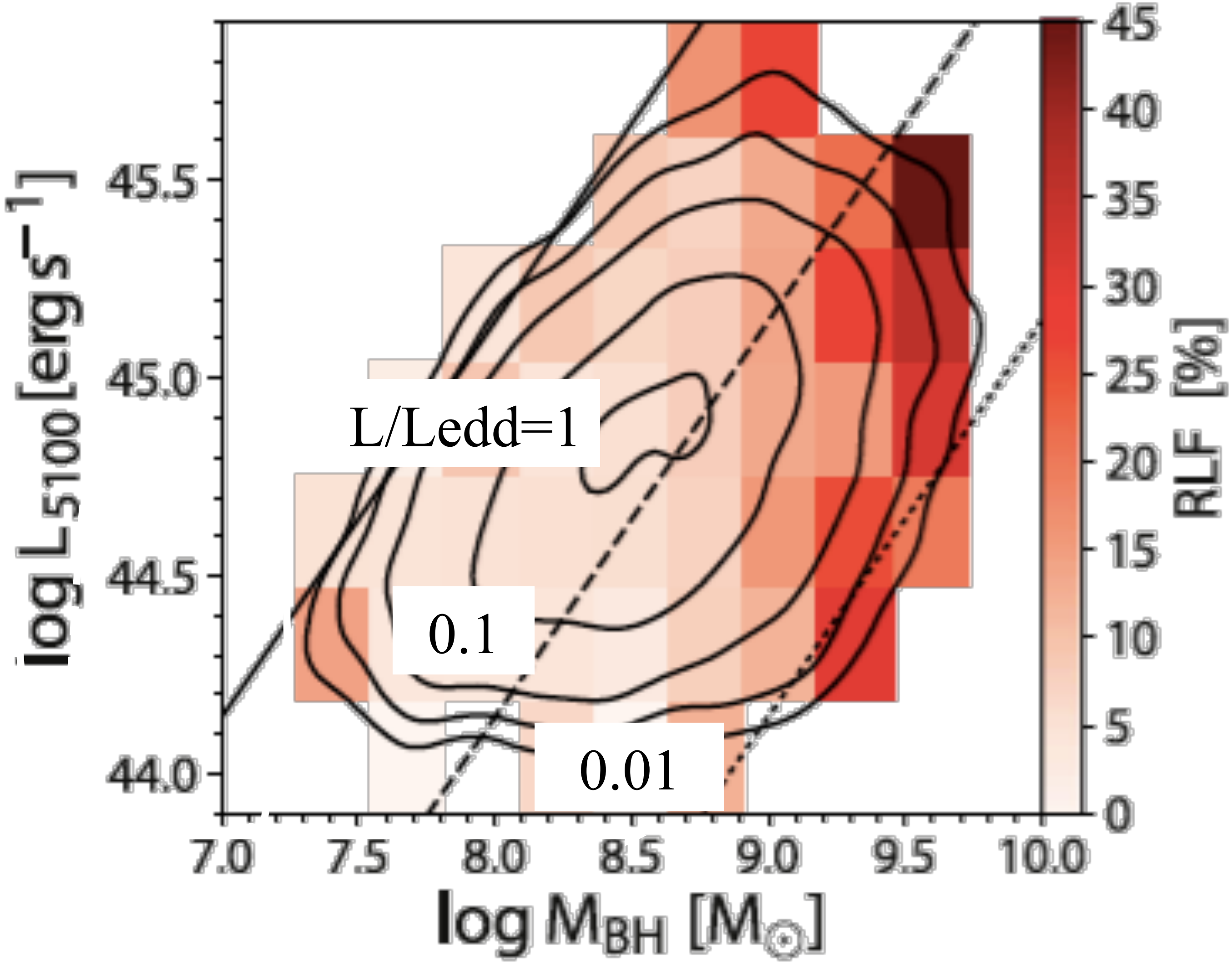
- Mdot as well as M from optical spectra
- L_{5100} α (M Mdot)$^{2/3}$
- Lbol = η Mdot c^2

  α $L_{5100}{}^{1.5}$
- NOT α L_{5100}



SDSS Quasars:

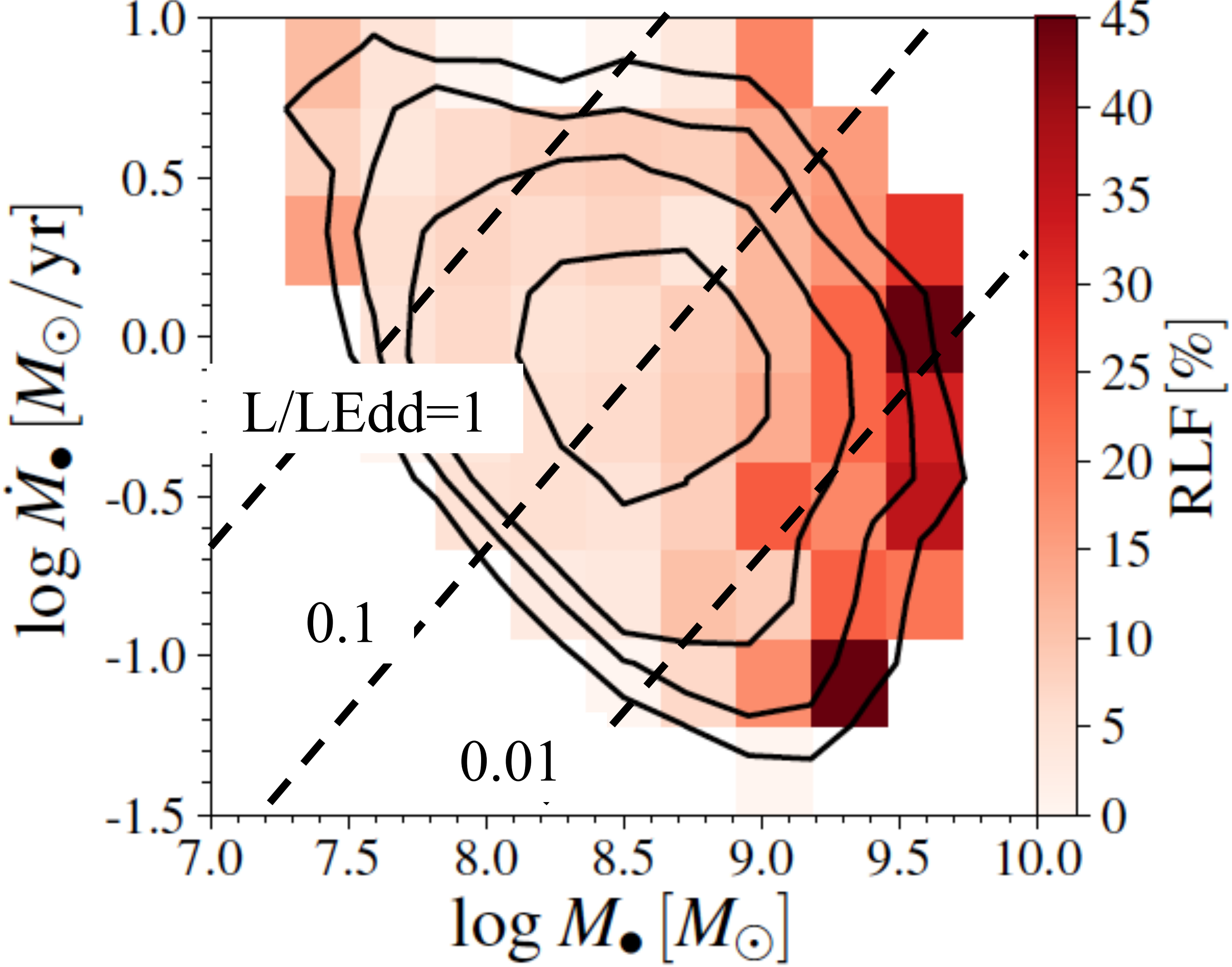
- SDSS QSO with Hb 0.3<z<0.8
- $L_{bol}=9L_{5100}$
- No ADAFs!
- L<LEdd, $M>10^7$ for i>22 QSO selection
- Shultze, Done et al 2018



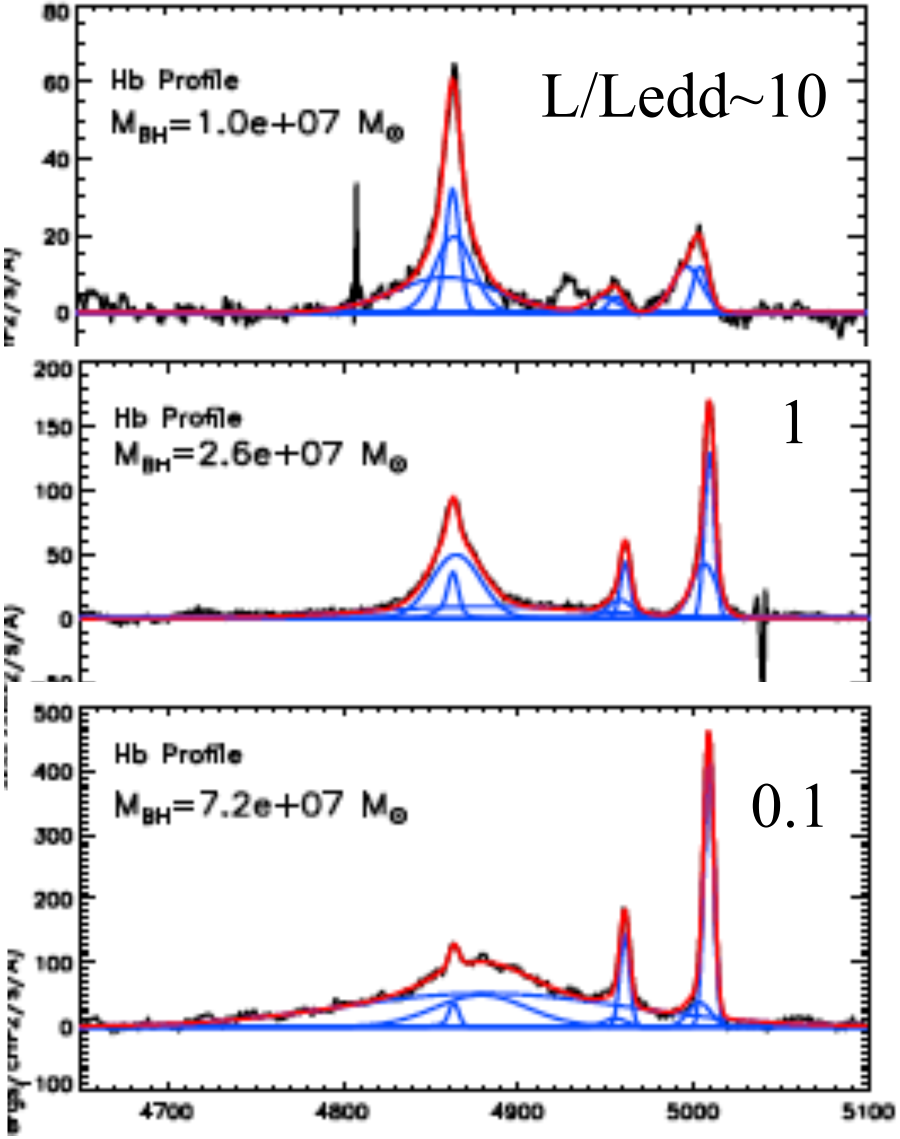
SDSS Quasars

- L_{bol} -$L^{3/2}_{5100}$
- L>LEdd
- Go a bit below ADAF but not much
- Shultze, Done et al 2018

Shultze, Done et al 2018



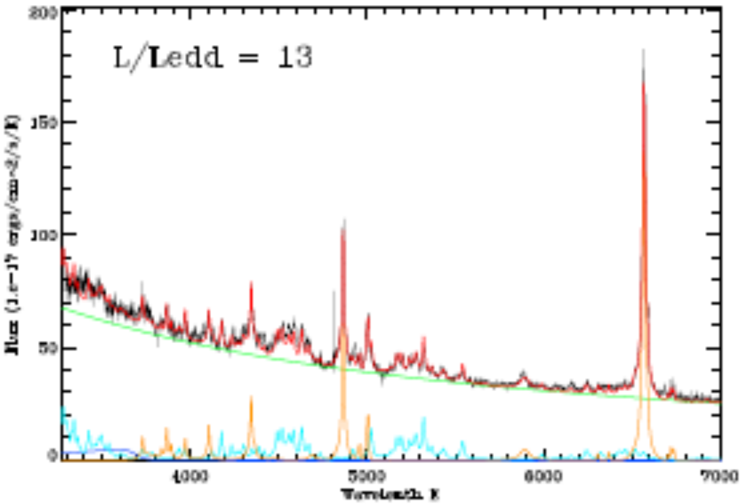
BLS1 - NLS1 –eigenvector1



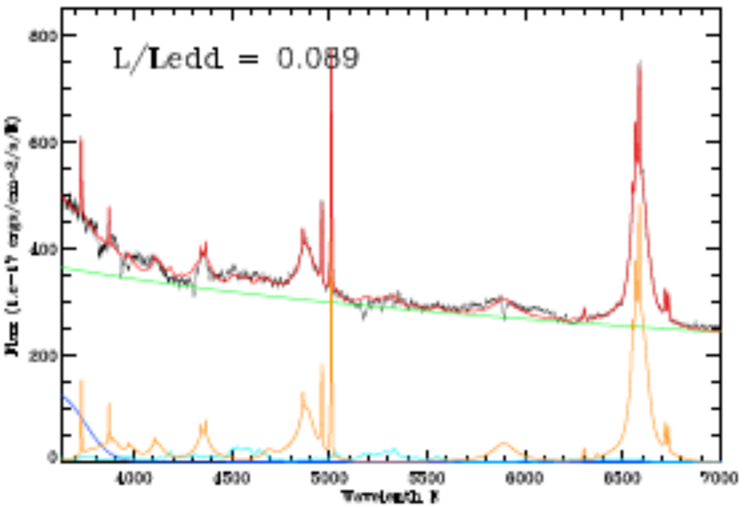
Major changes are

a) Hb width decreases
b) OIII/Hb decreases
c) FeII increases

BLS1 - NLS1 –eigenvector1



(No:07 - b) RBS 0769



(No:02 - b) MRK 1018

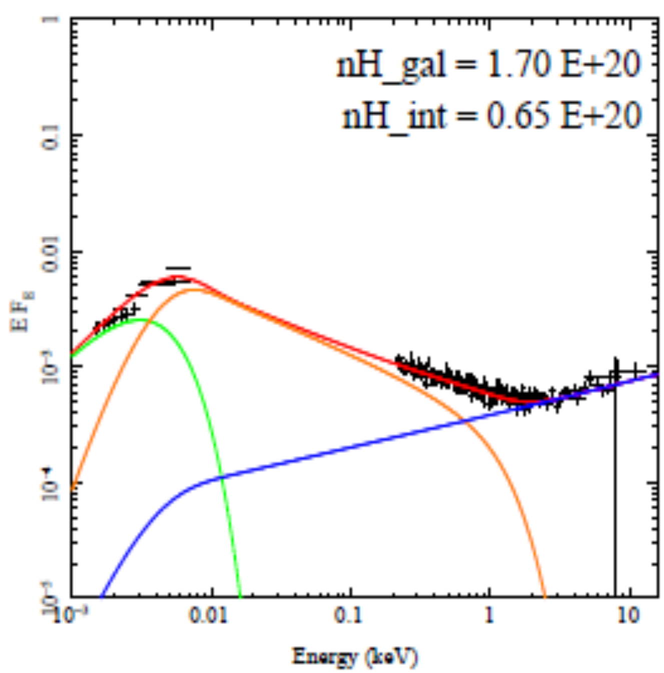
Major changes are

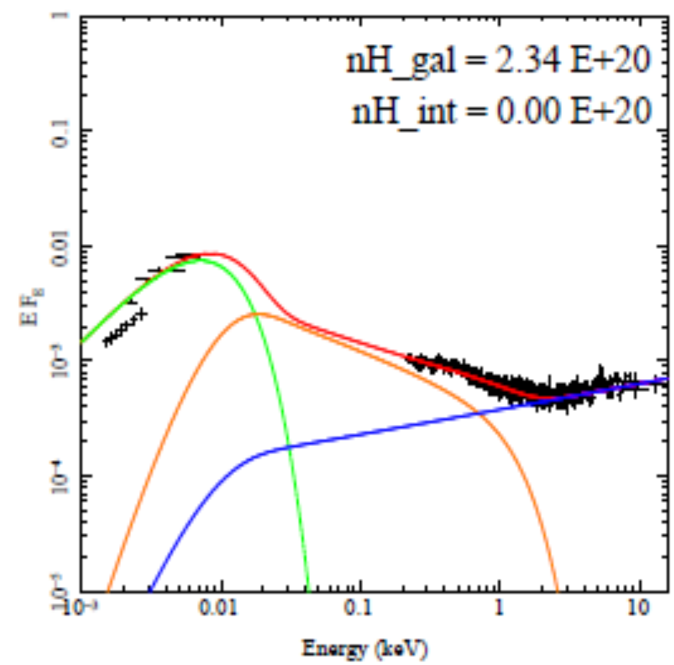
a) Hb width decreases
b) OIII/Hb decreases
c) FeII increases

Changing lines maybe signal changing SED?

Typical AGN SED- not like BHB !!

- Most standard BLS1/QSO <M>~10^8, <L/LEdd>~0.1
- BHB at 0.1LEdd mainly standard disc+weak steep tail
- AGN: strong UV peak, soft X-ray excess, hard X-ray tail

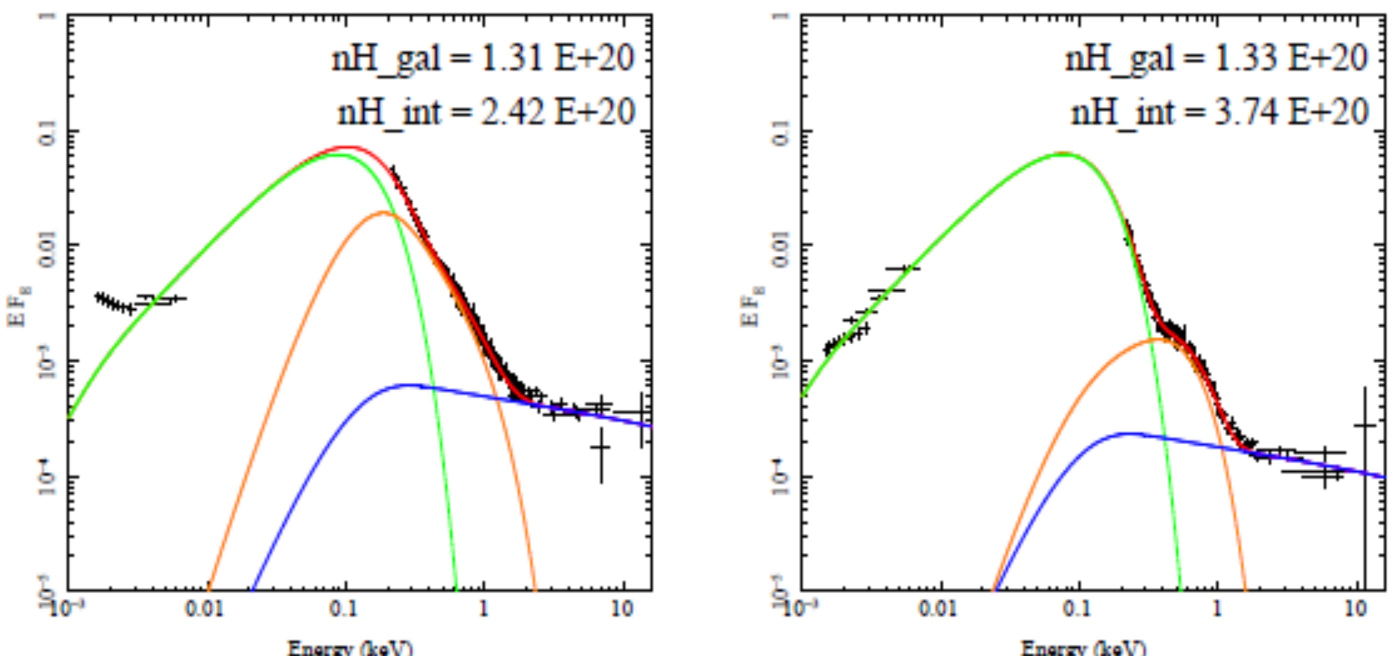




Jin et al 2012

Very different to NLS1

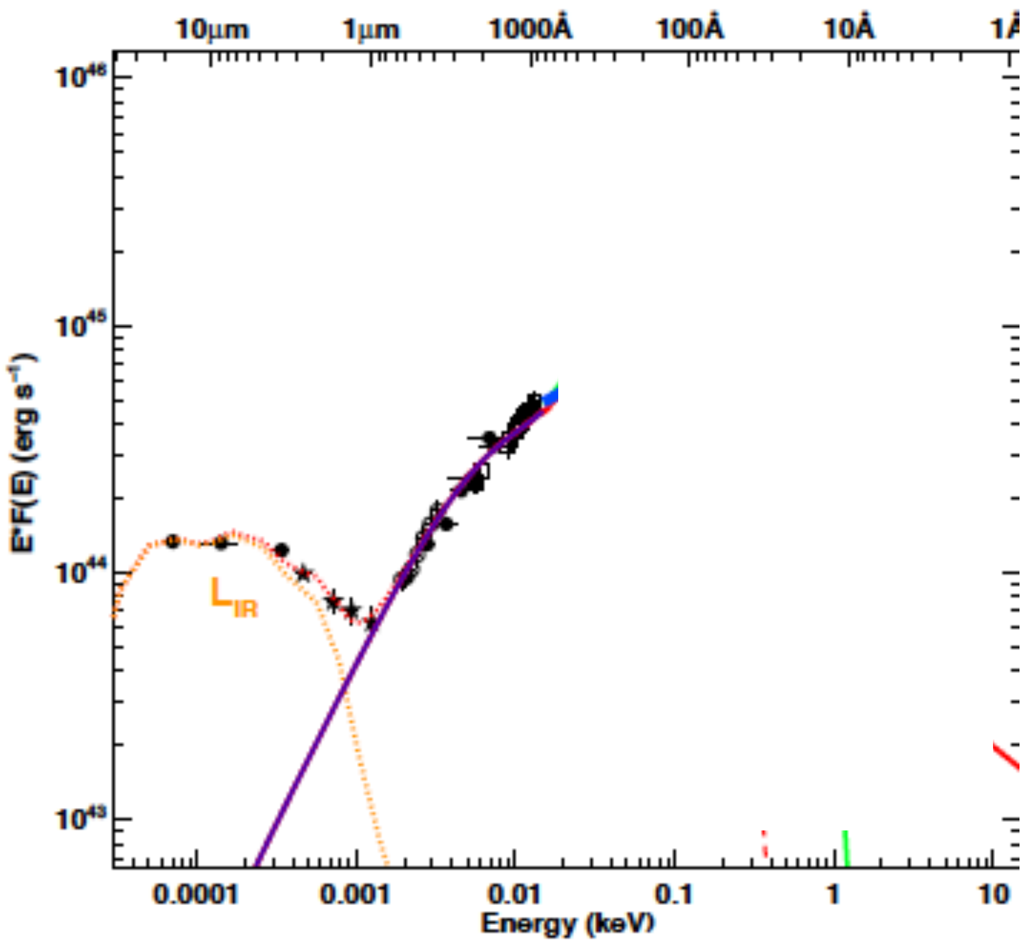
- $\langle M \rangle \sim 10^7$, $\langle L/L_{Edd} \rangle \sim 1$ NLS1 in local universe
- AGN small SX, weak and steep X-rays –looks like BHB in disc dominated states!



Jin et al 2012

Extreme NLS1 RX0439

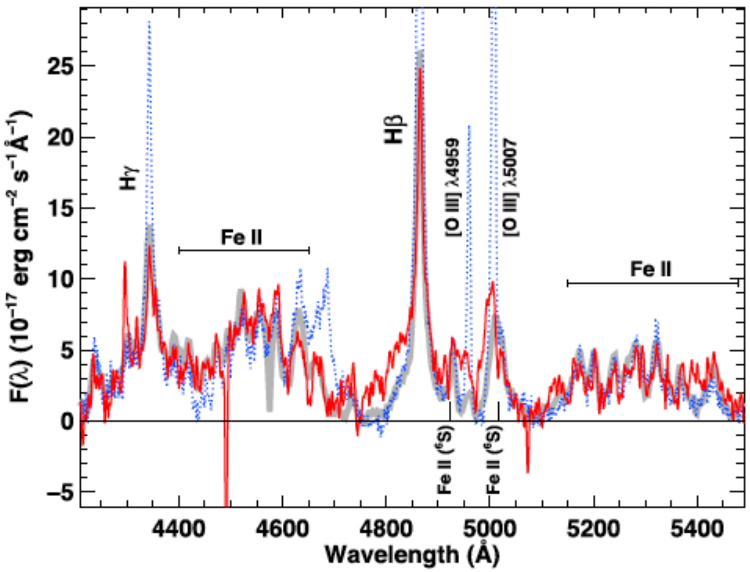
- $M=7x10^6$ Msun
- Mdot though outer disc is 12x Eddington for zero spin (bigger if high spin!!)

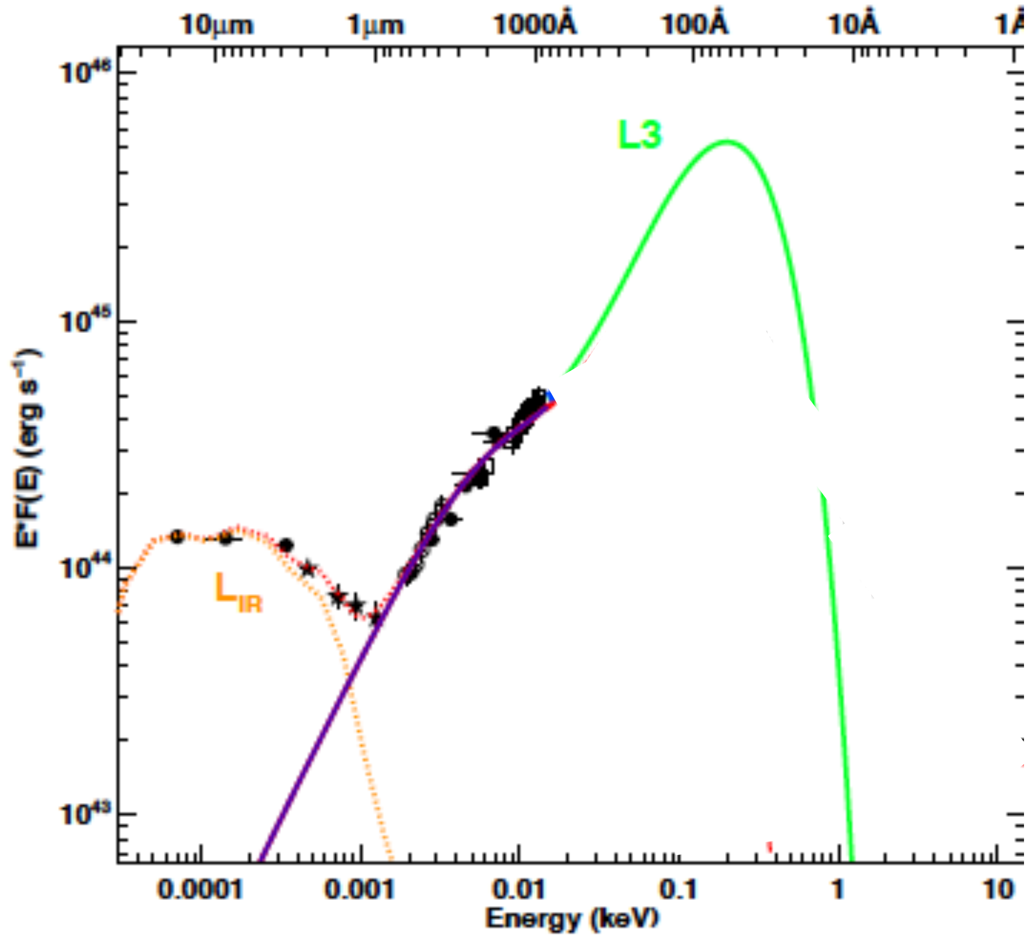


Jin et al 2017

Extreme NLS1 RX0439

- Mdot=12MdotEdd

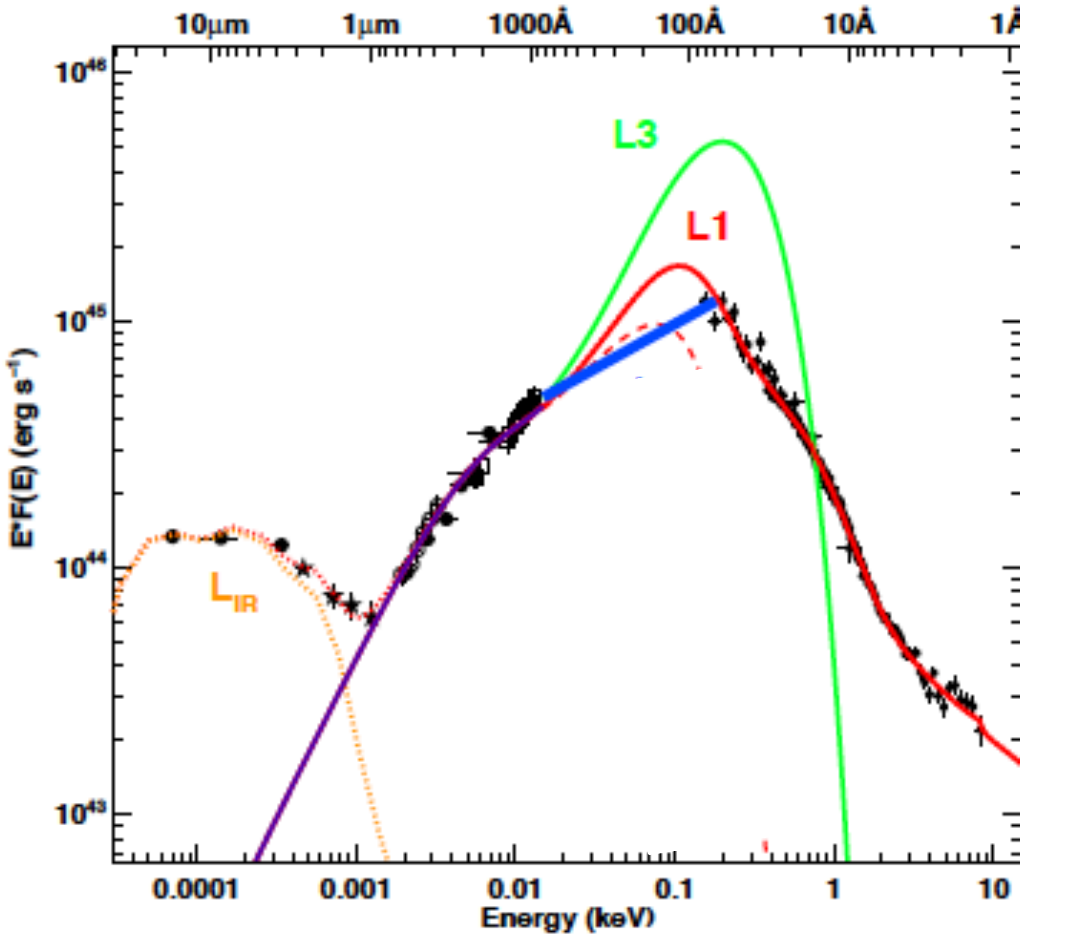




Jin et al 2017

Extreme NLS1 RX0439

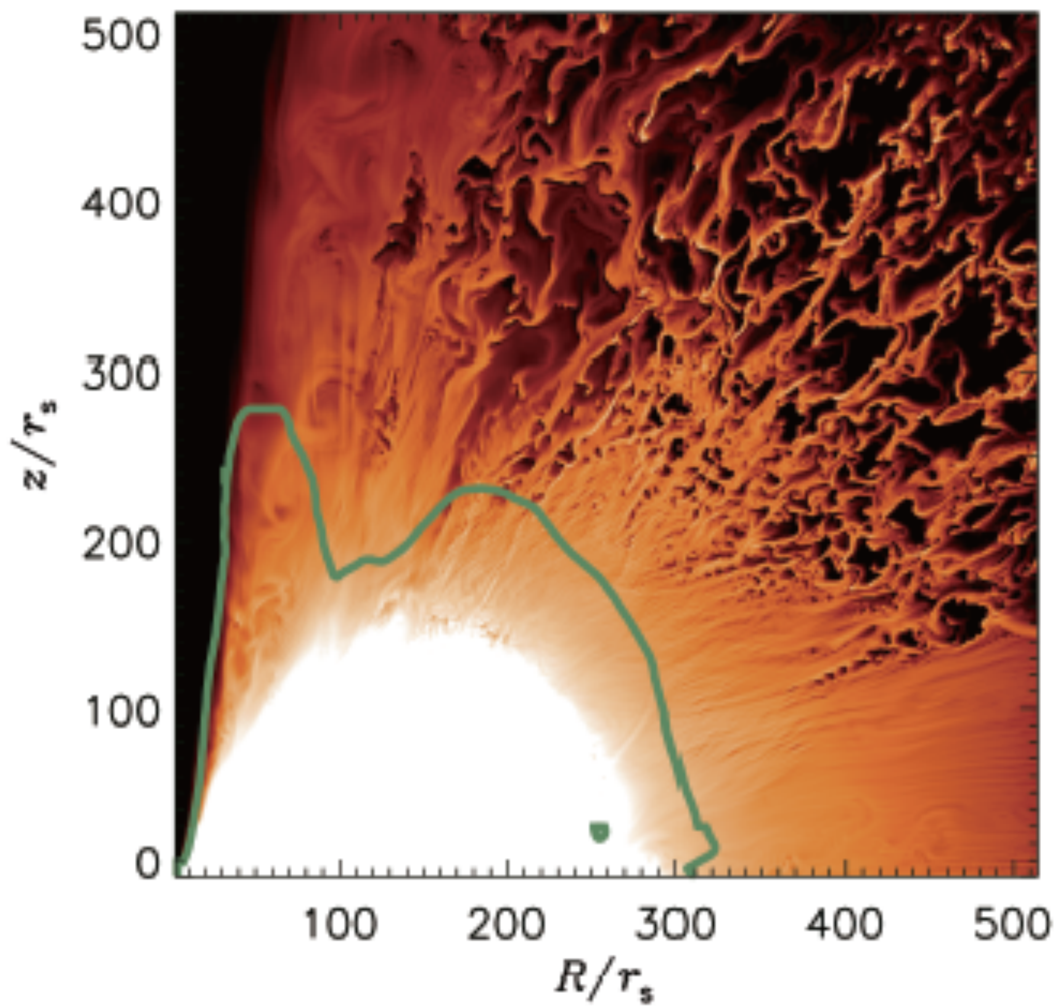
- Mdot=12MdotEdd
- Lobs=4.6LEdd wind and/or advection
- Lose ½ of accretion power



Jin et al 2017

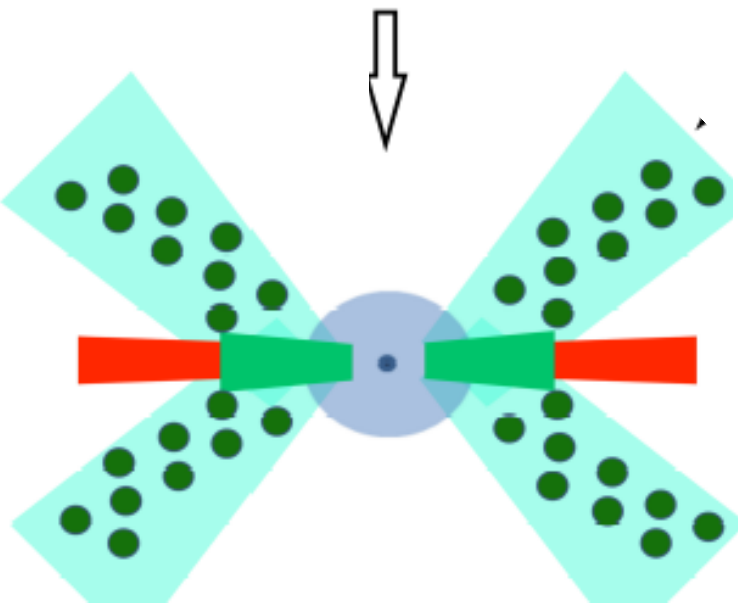
SuperEddington winds

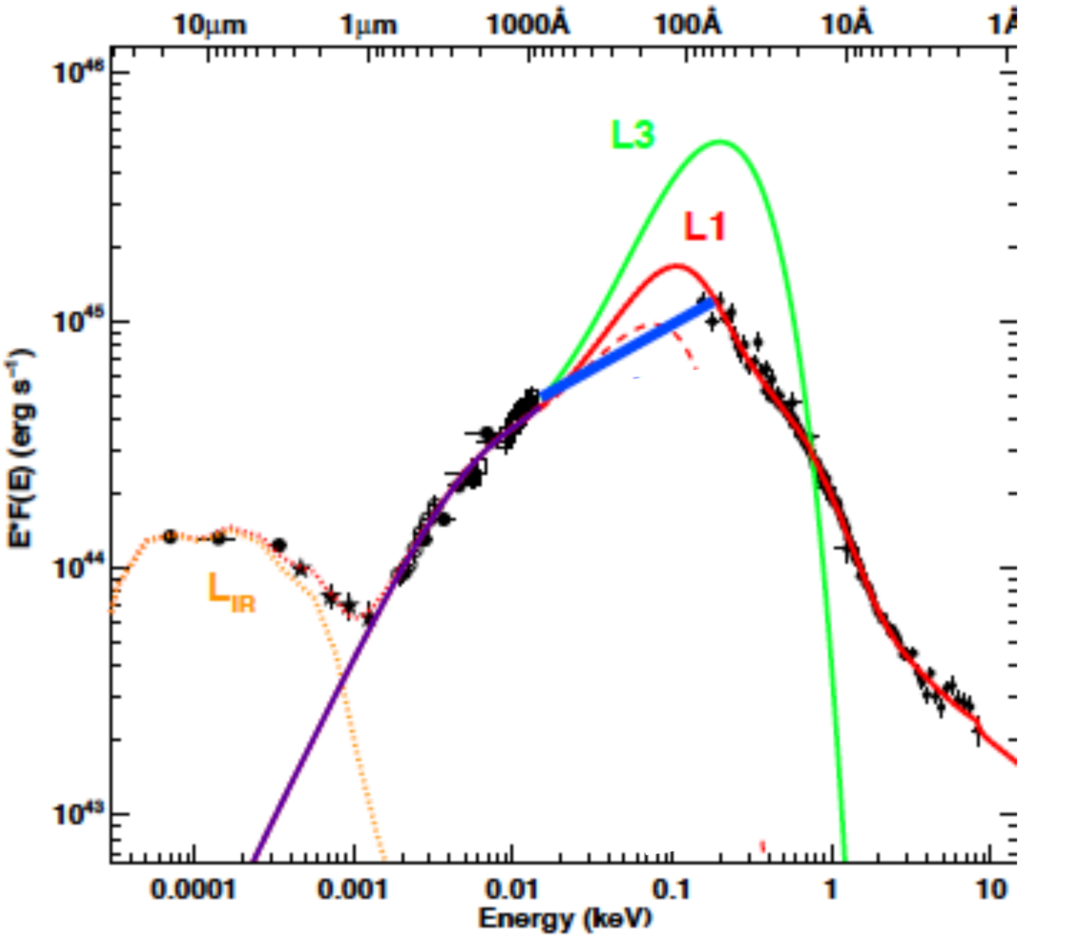
- Powerful $L_{KE} \sim L_{rad}$
- Clumpy, complex
- Takeuchi, Ohsuga, Mineshige (2013)
- mdot>mdotEDD but lose lots in wind so black hole growth rate not much bigger than mdotEDD….
- Most massive QSO at z>7 still an issue!



Extreme NLS1 RX0439

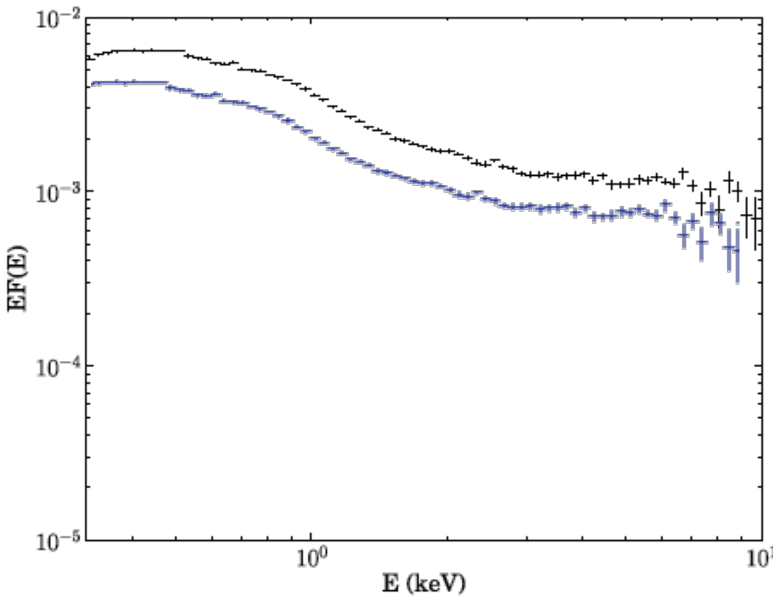
- Mdot=12MdotEdd
- Lobs=4.6LEdd wind and/or advection
- Lose ½ of accretion power WINDS??

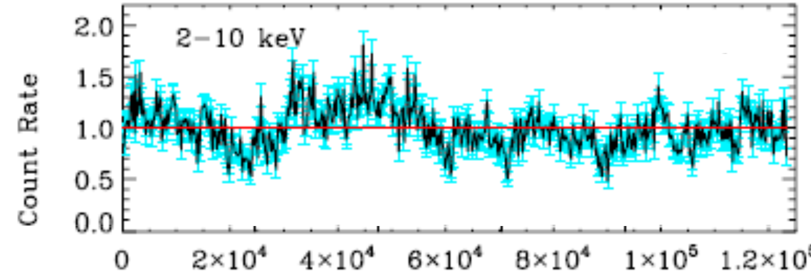


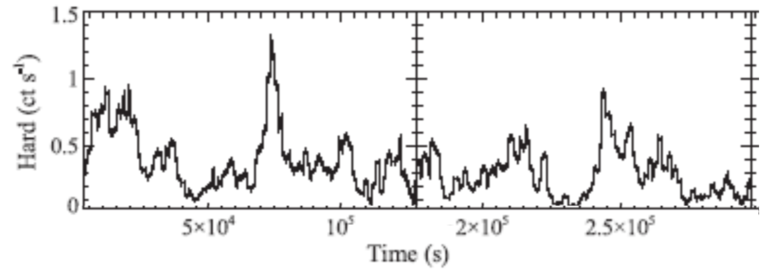


Jin et al 2017

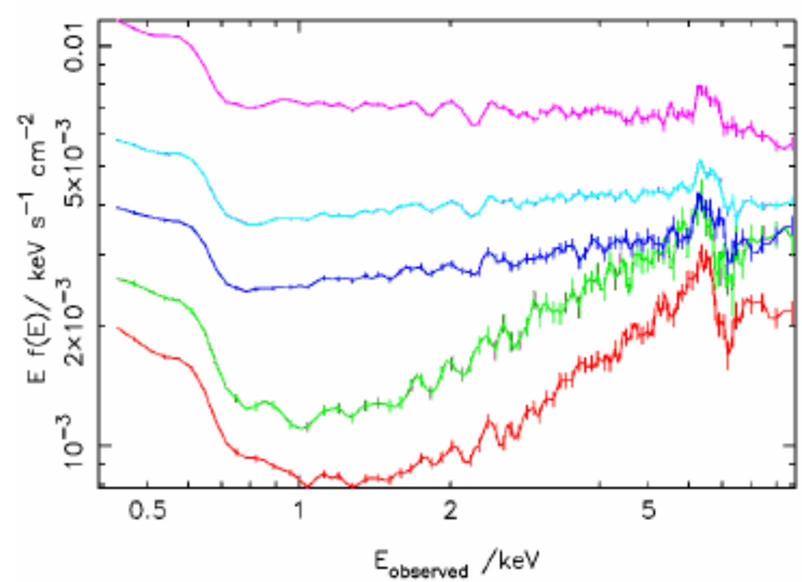
Simple NLS1

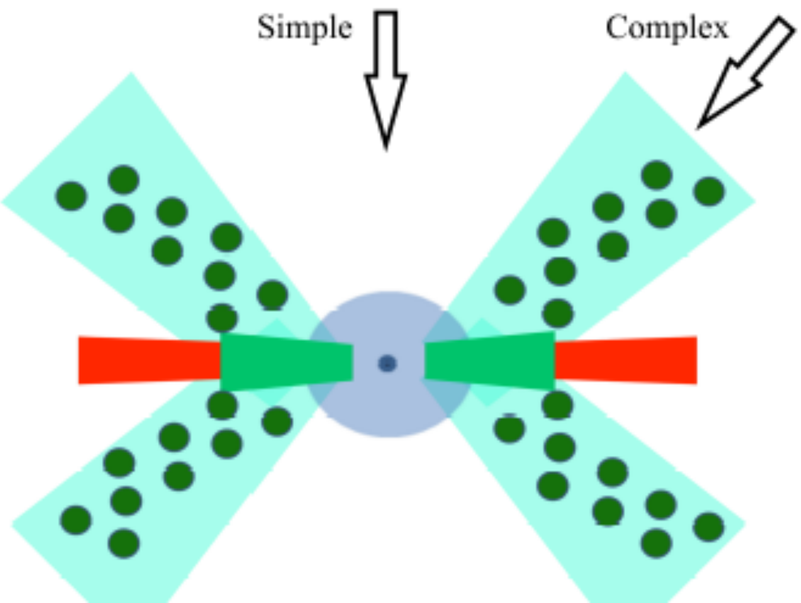






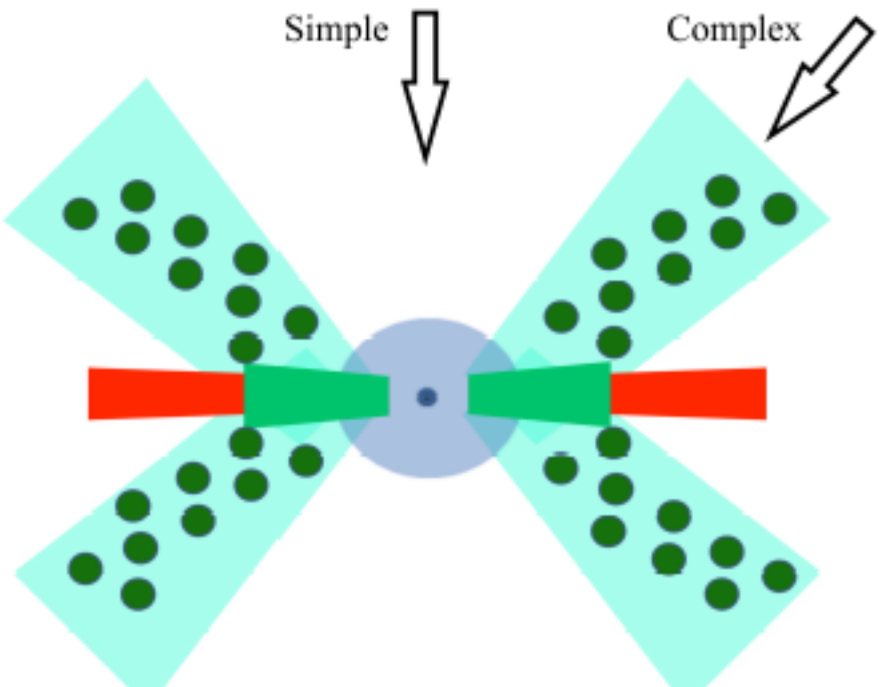
Complex NLS1

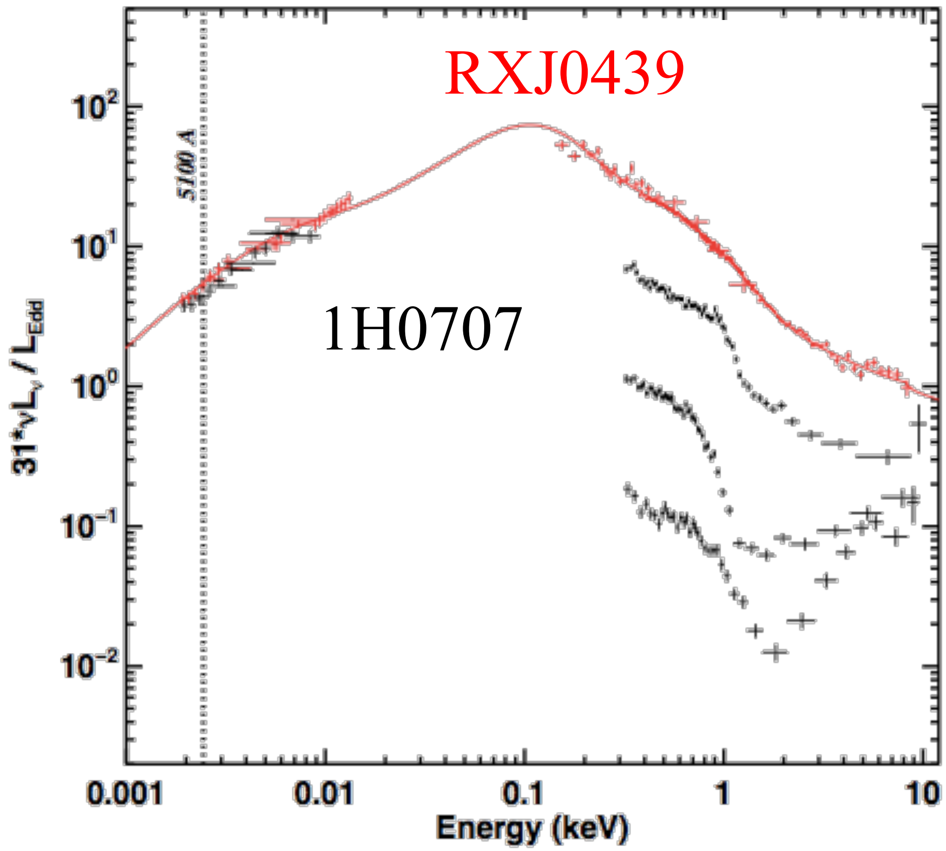




Extreme NLS1 – simple / complex

- RXJ 0439 'simple' NLS1
- 1H0707 'complex' NLS1 – see wind absorption?



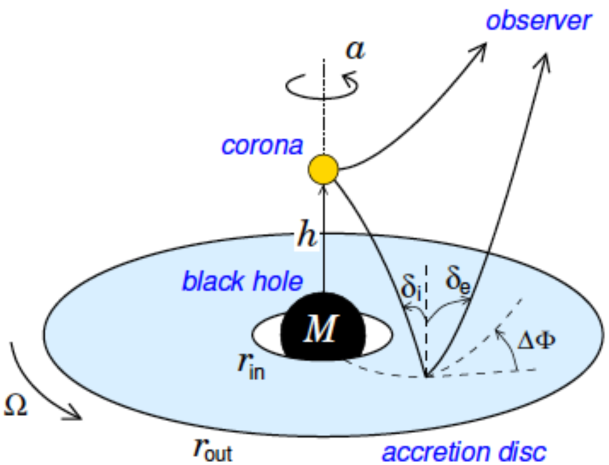


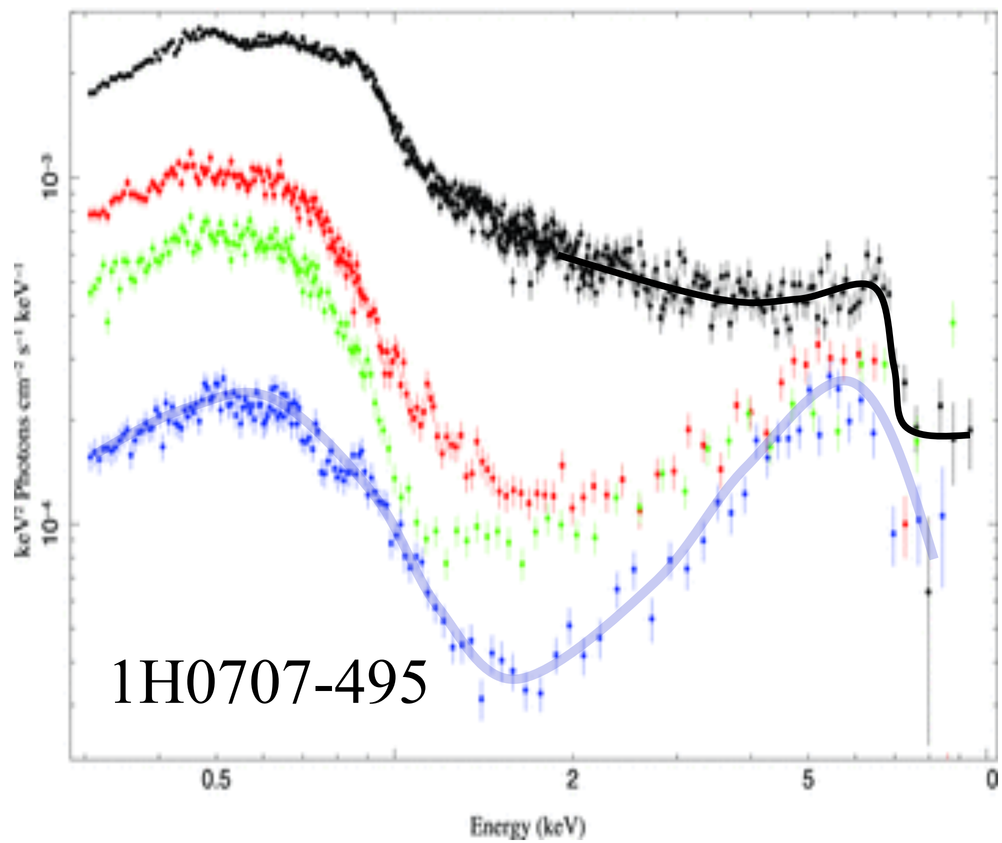
Done & Jin 2016
Jin et al 2017

Done & Jin 2016, Luo et al 2015, Leighly 2004

Complex NLS1 – X-ray view

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

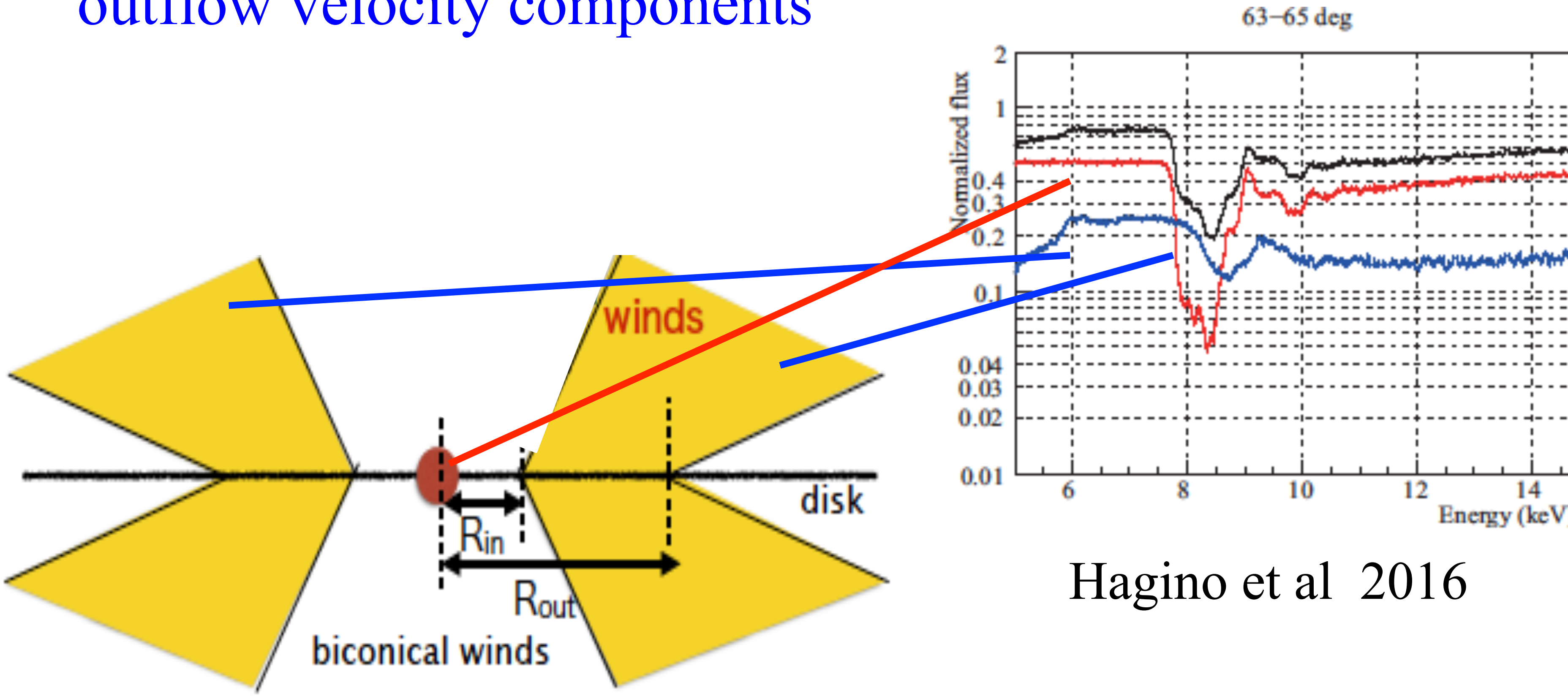




Fabian et al 2009

Complex NLS1 – X-ray view

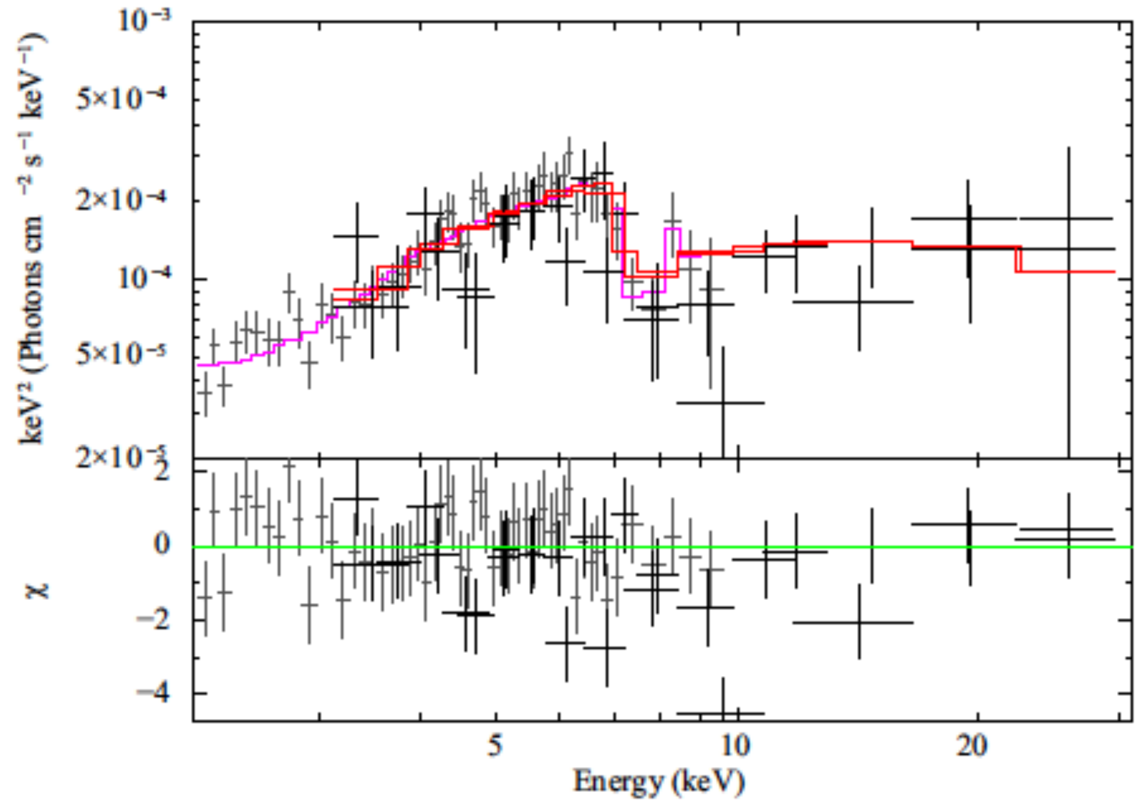
- Absorption on line of sight – blueshifted
- Emission from all wind – blue and redshift, rotation plus outflow velocity components



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

Quasar mode (winds) feedback

- Mechanism for AGN feedback: supereddington winds to set M-σ relation (King 2008)
- Wind power set by M Mdot, spin THIS IS QUANTATITIVE model
- (can also have additional winds from UV line driving in subEddington AGN)

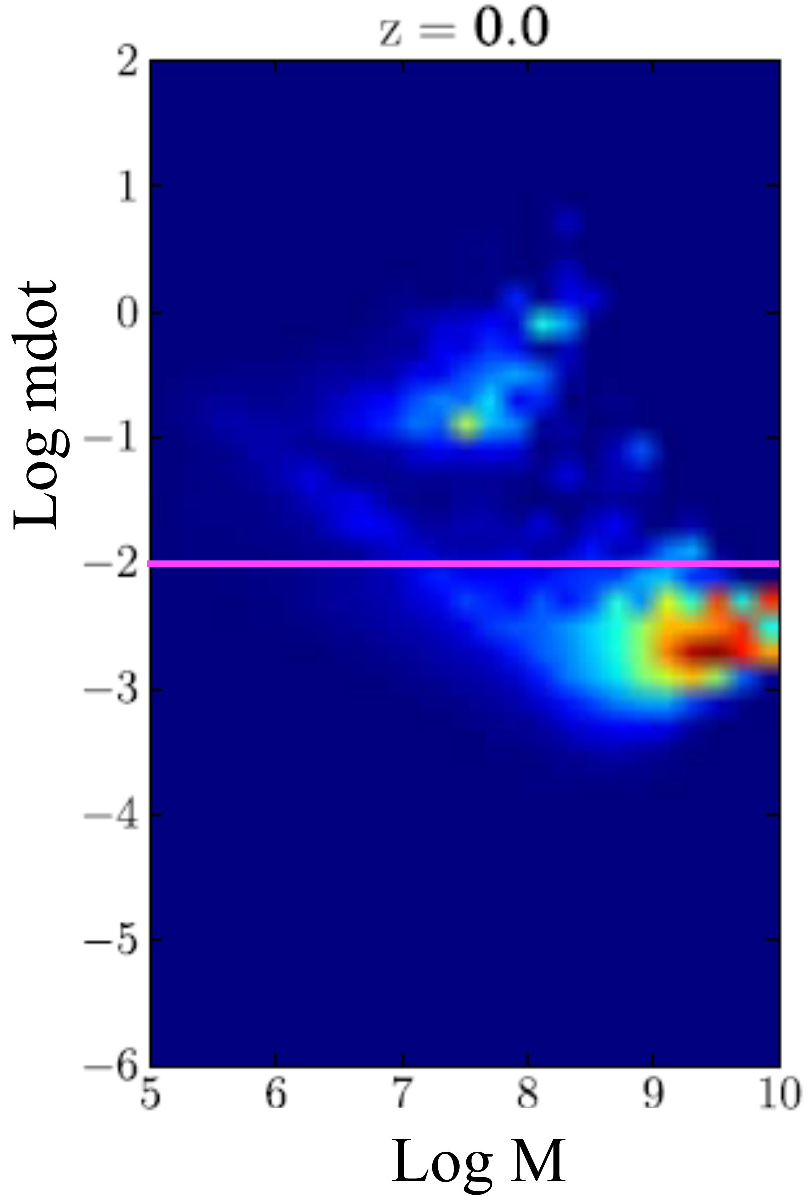
Structure formation - AGN feedback

Standard movie of structure formarion across cosmic time – but so big I had to take it out!

Di Matteo et al 2005

Black hole mass & mdot

- Cosmological simulations gives number densities (M, mdot)…
- …With cosmic time (Fanidakis et al 2011)
- Colours are luminosity density



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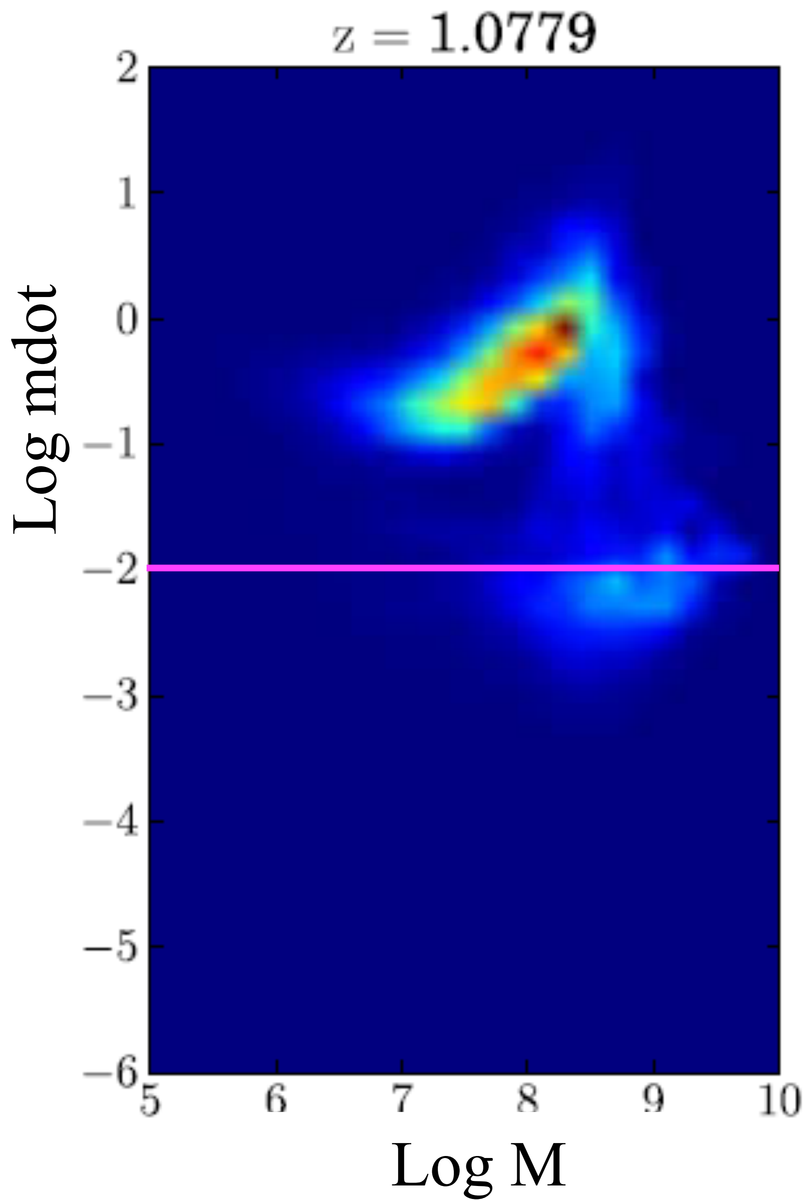

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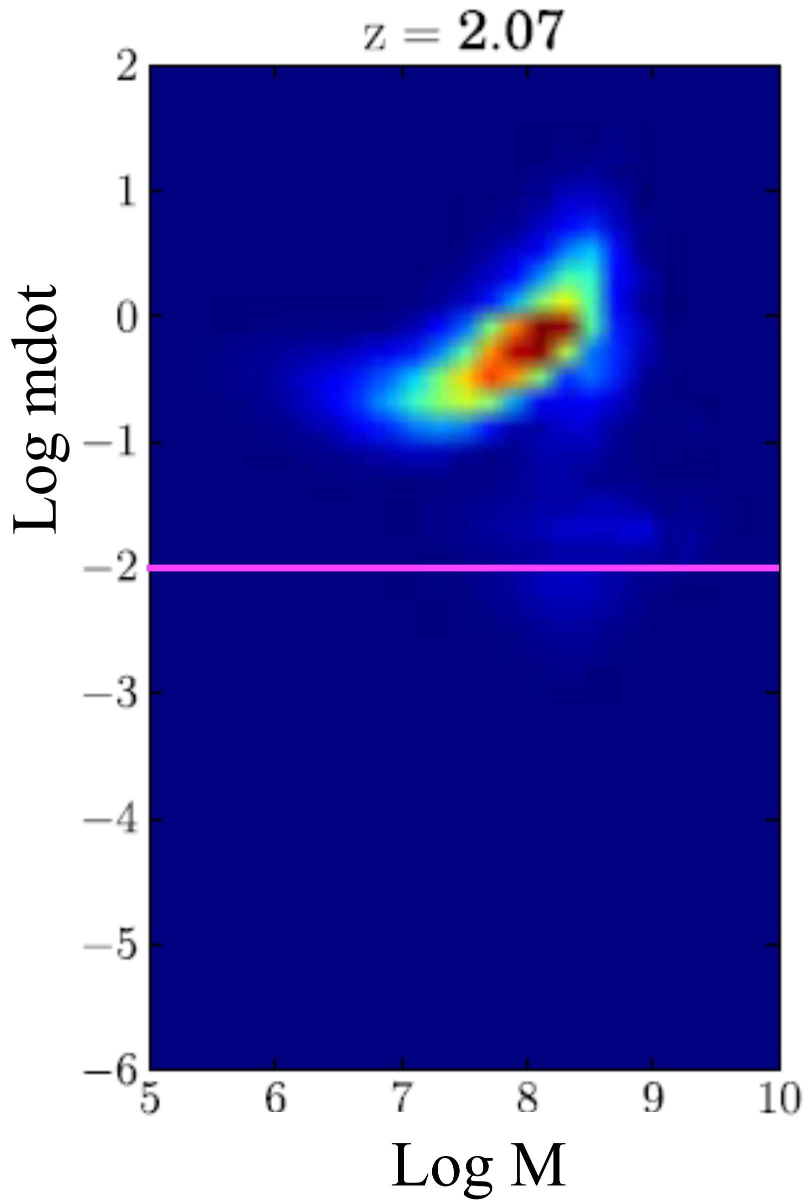
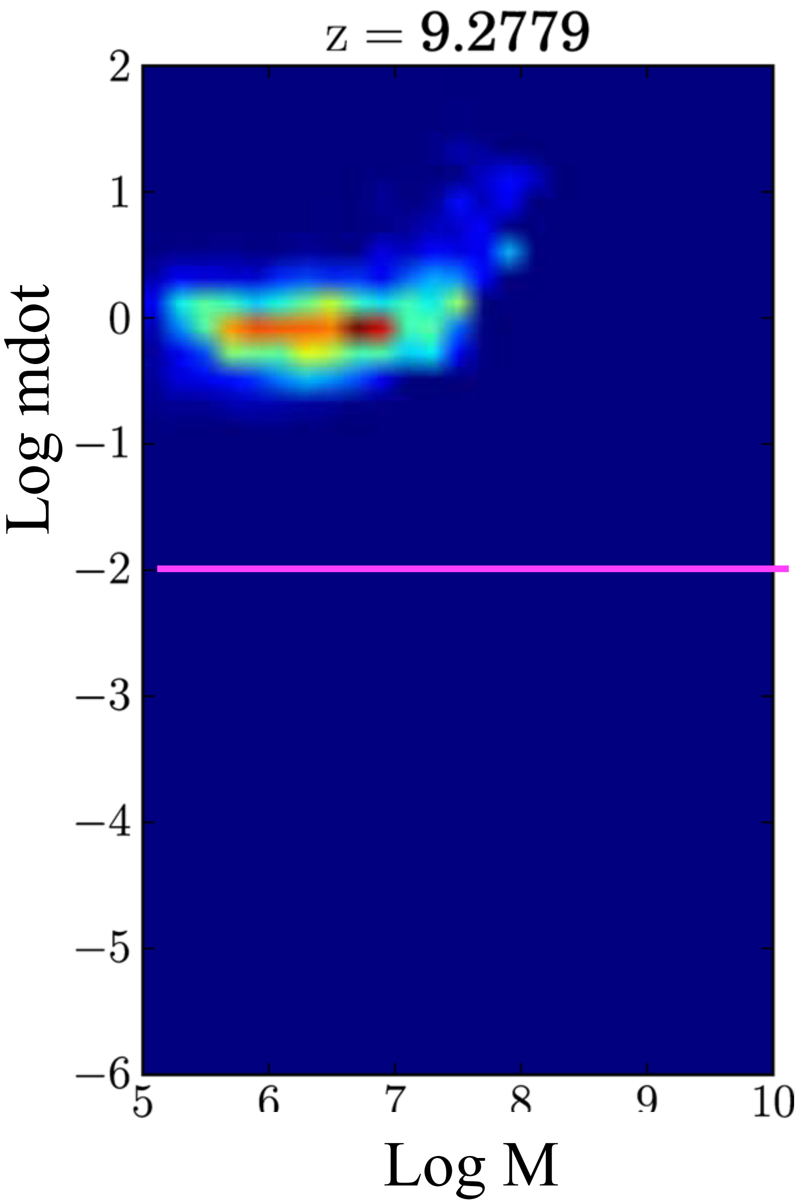


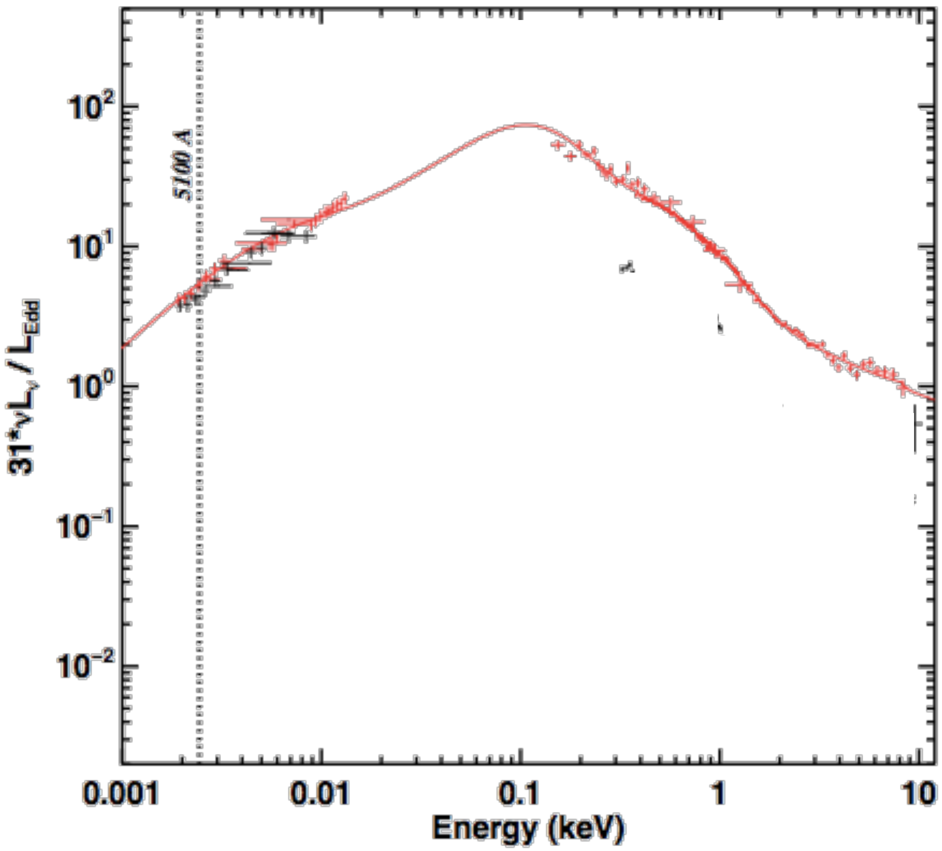
Black hole mass & mdot

- Most common objects at z>7 are low mass, high mass accretion rate black holes!
- Like our local Narrow Line Seyfert 1s!!



But how to find them???

- Put this at high z
- X-rays are intrinsicallly weak
- And steep….



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- Put this at high z
- X-rays are intrinsicallly weak
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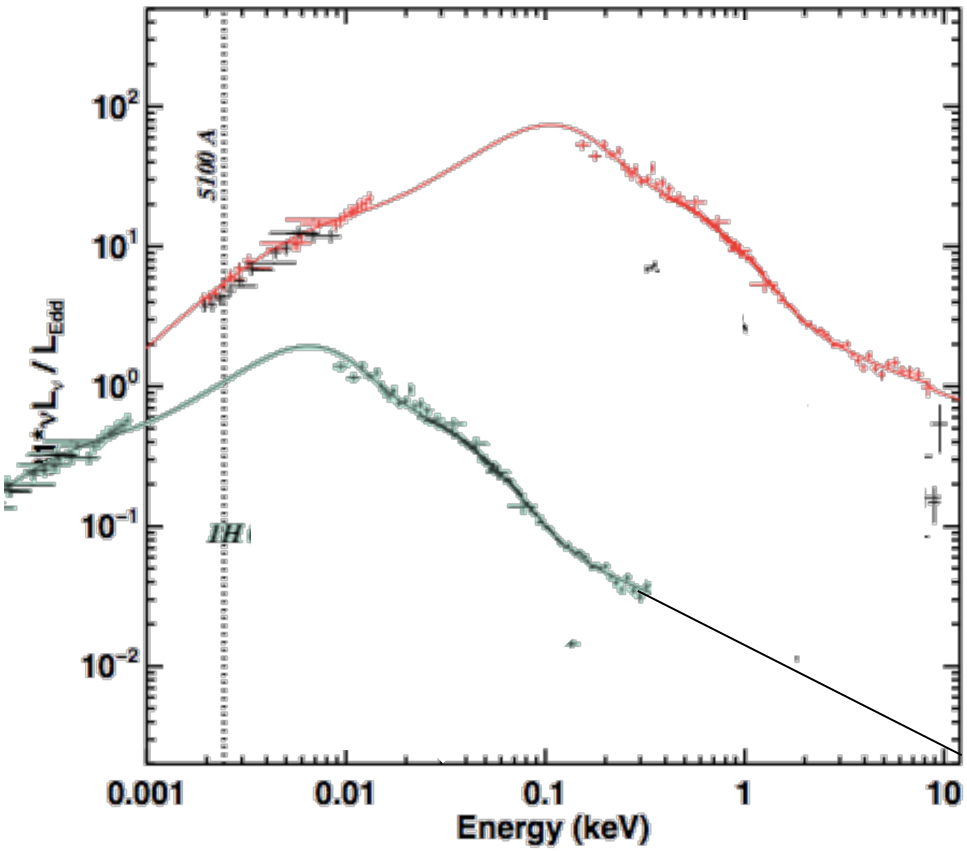
- So we LOSE them in X-rays faster than we expect
- We do much better in IR/opt



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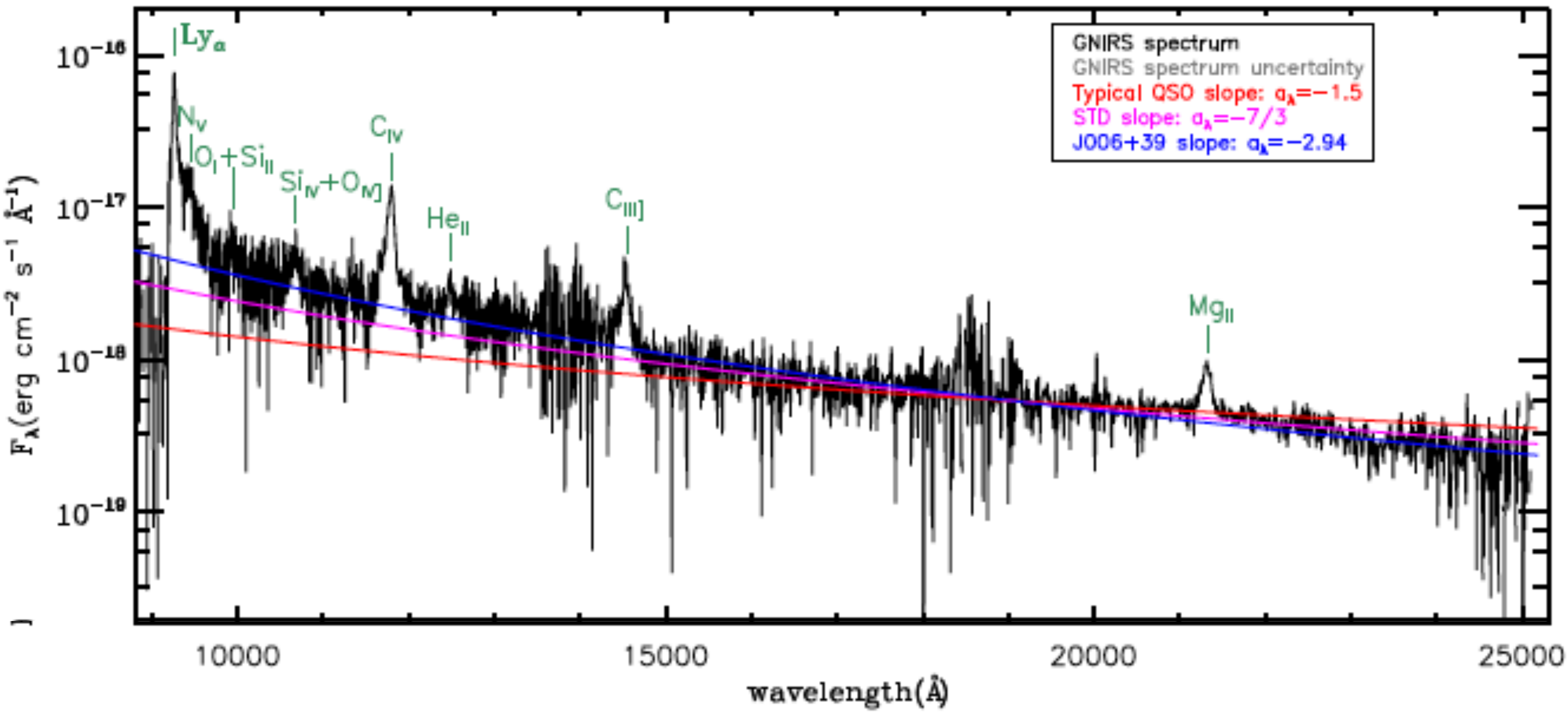
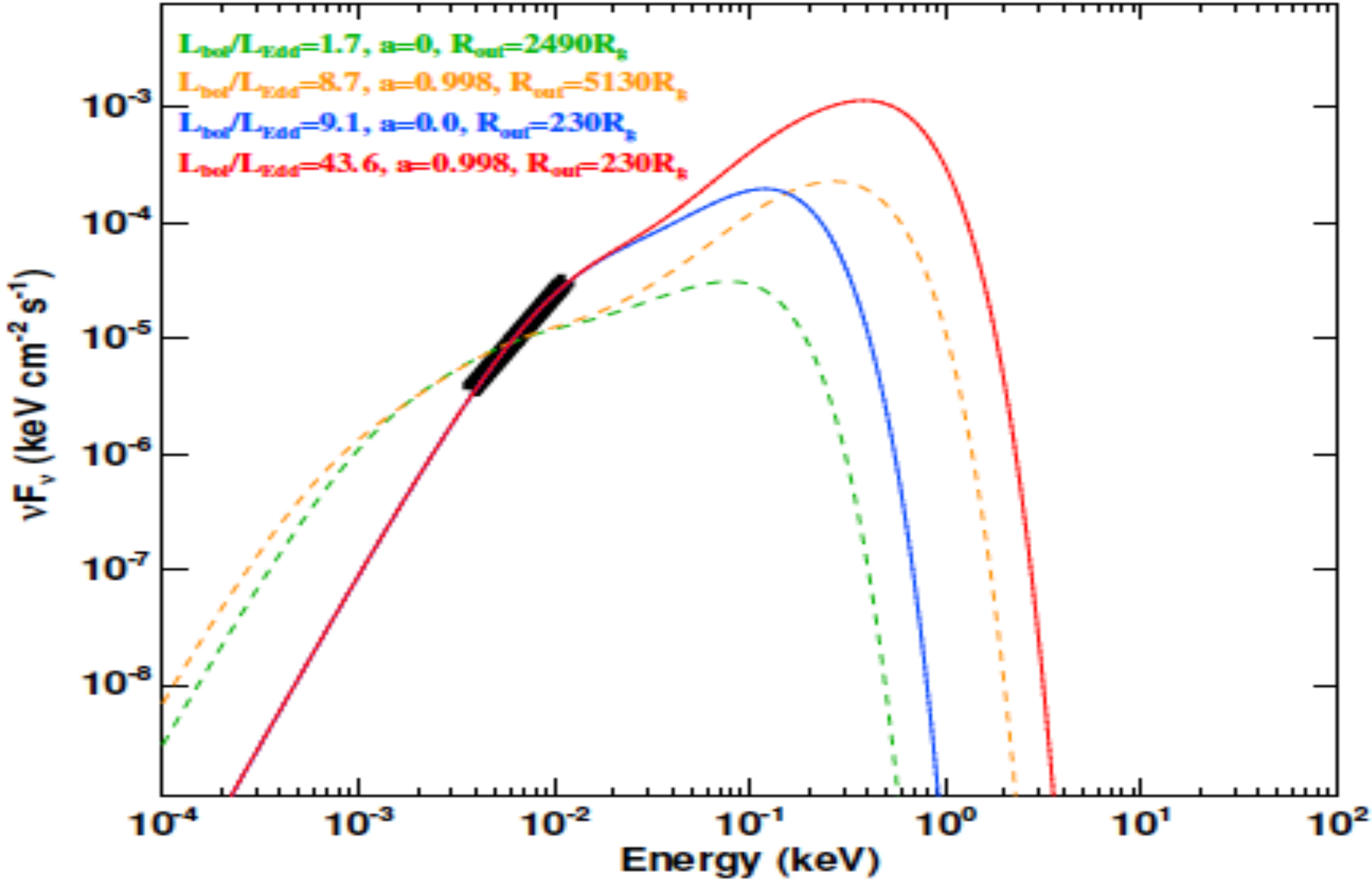


- PanSTARS PS006+39 z=6.6 GNIRS spectrum IR=rest UV
- M~10^8 Msun (smallest known at z>6)
- Tang.. Done et al 2018

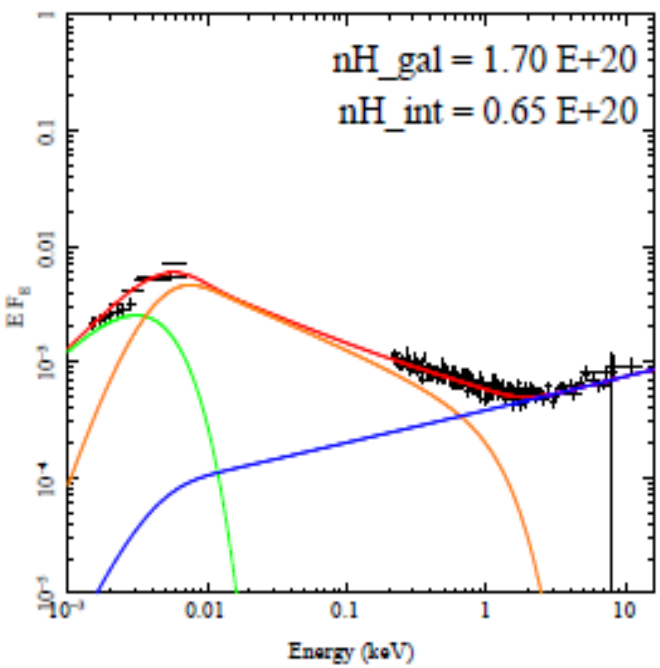
L>~10 LEdd

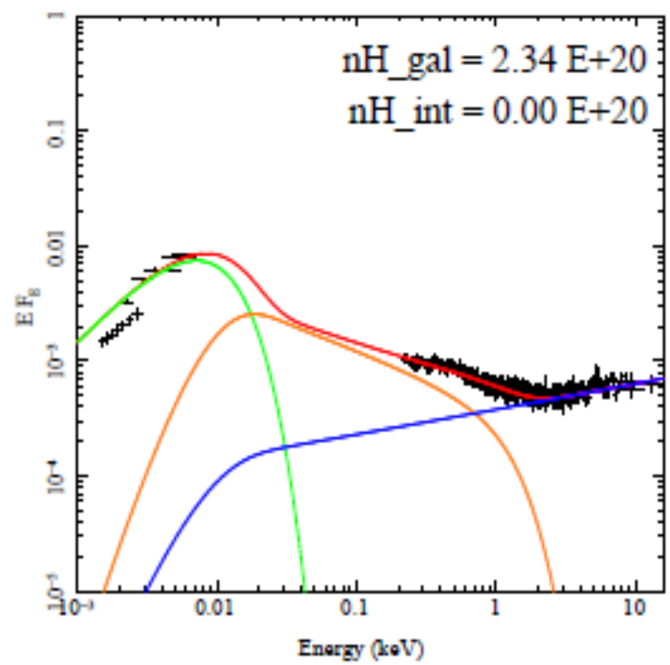
Tang.. Done et al 2018



Typical AGN SED- not like BHB !!

- Most standard BLS1/QSO <M>~10^8, <L/LEdd>~0.1
- BHB at 0.1LEdd mainly standard disc+weak steep tail
- AGN: strong UV peak, soft X-ray excess, hard X-ray tail

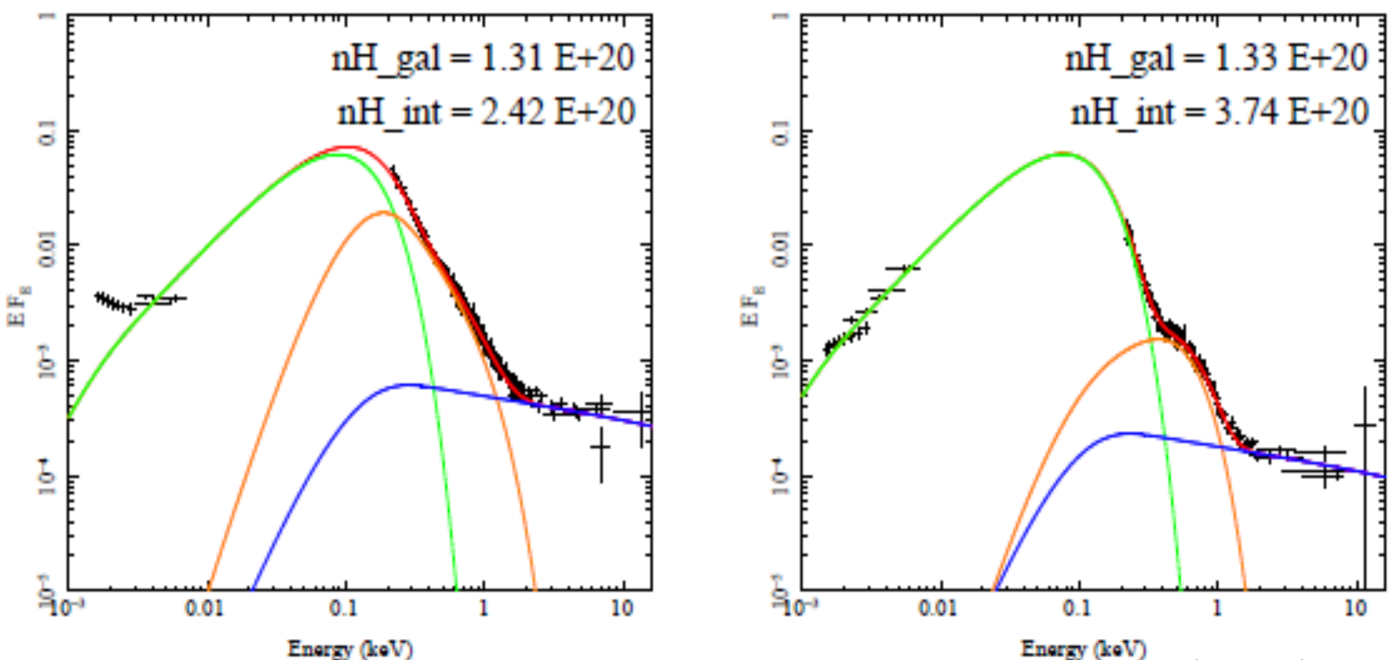




Jin et al 2012

Very different to NLS1

- <M>~10^7, <L/LEdd>~1 NLS1 in local universe
- AGN small SX, weak and steep X-rays –looks like BHB in disc dominated states!

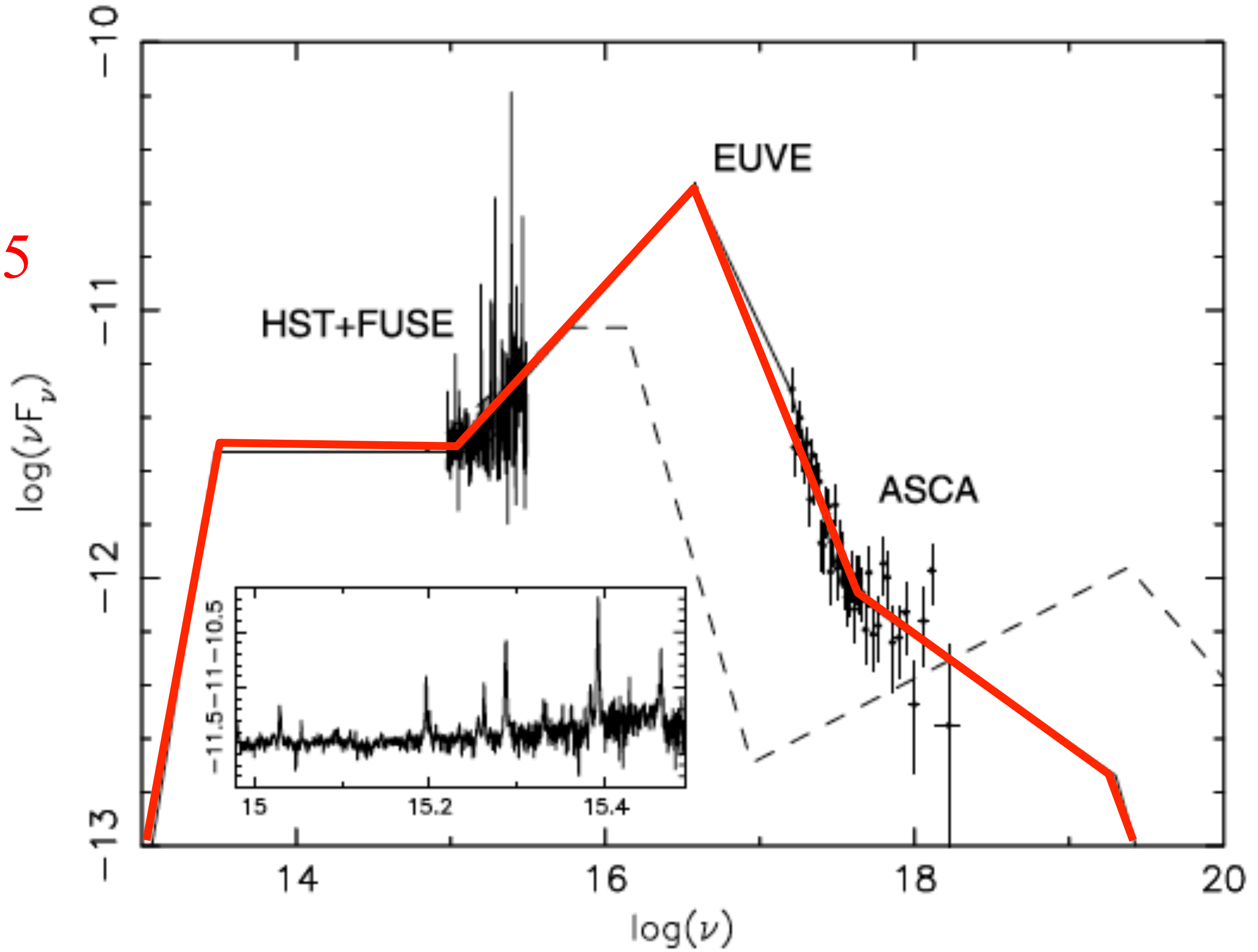


Jin et al 2012

SED of high L/Ledd is different to lower L/Ledd AGN !

Local NLS1 L~LEdd
Casebeer et al 2006,
Puchnarewicz et al 1995

Cloudy mean AGN
SED from local AGN
With L~0.1LEdd



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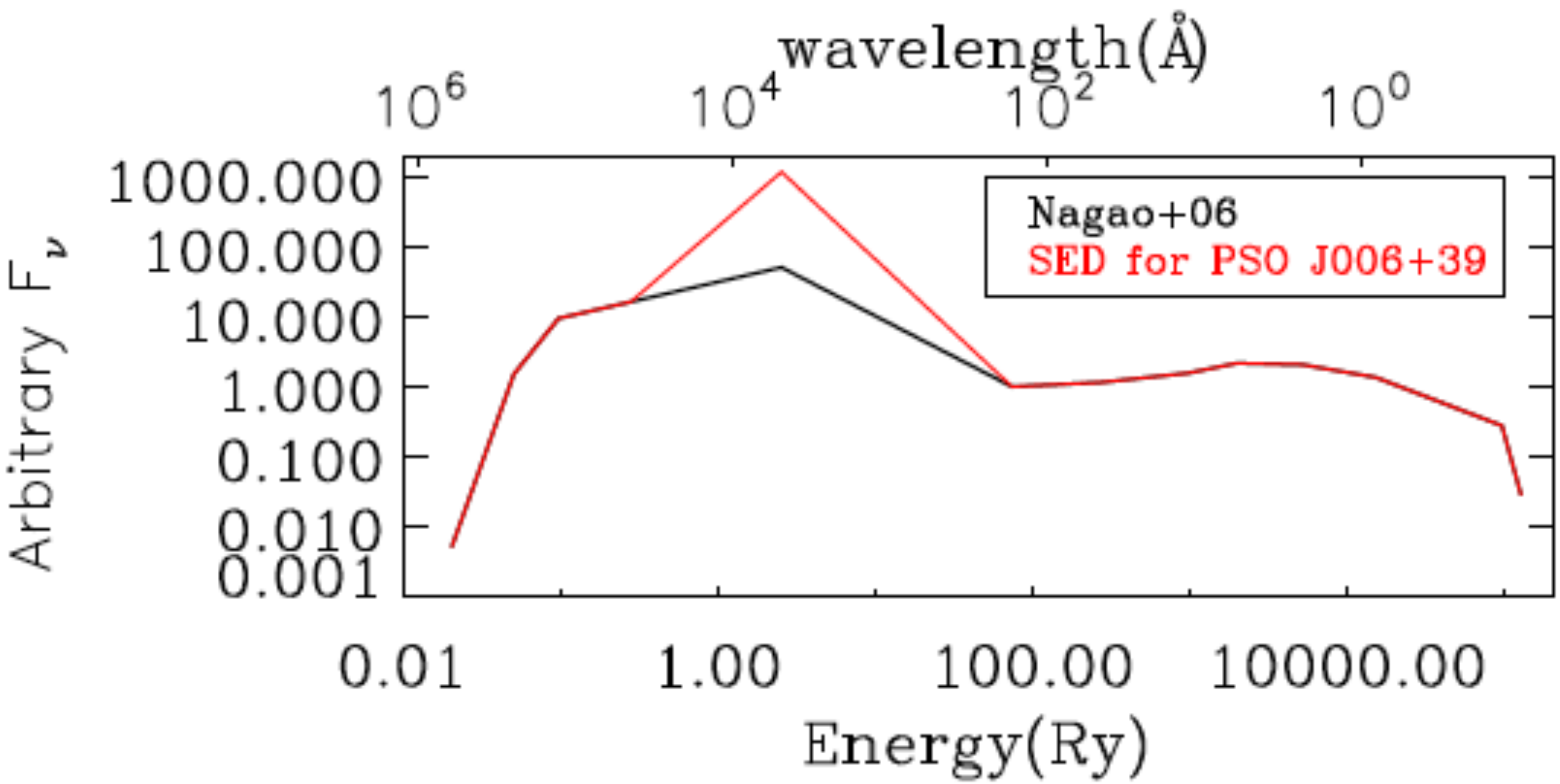

Tang.. Done et al 2018

Many more ionising photons – in the epoch of re-ionization????

But how to find them???

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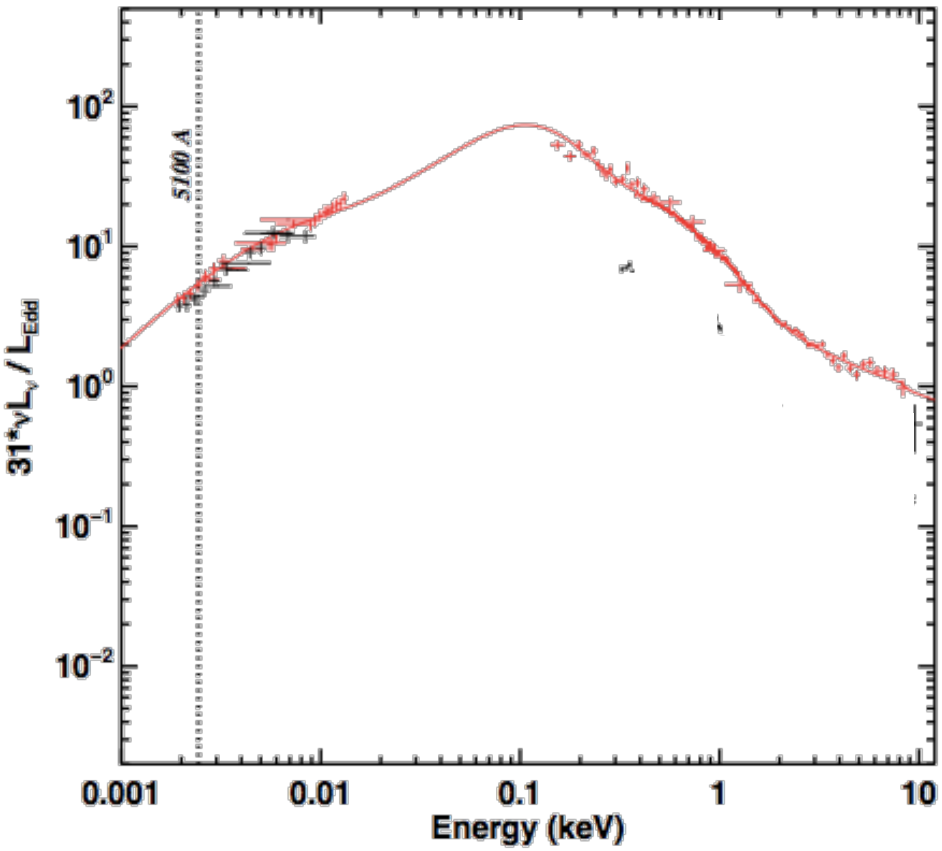
- And steep….



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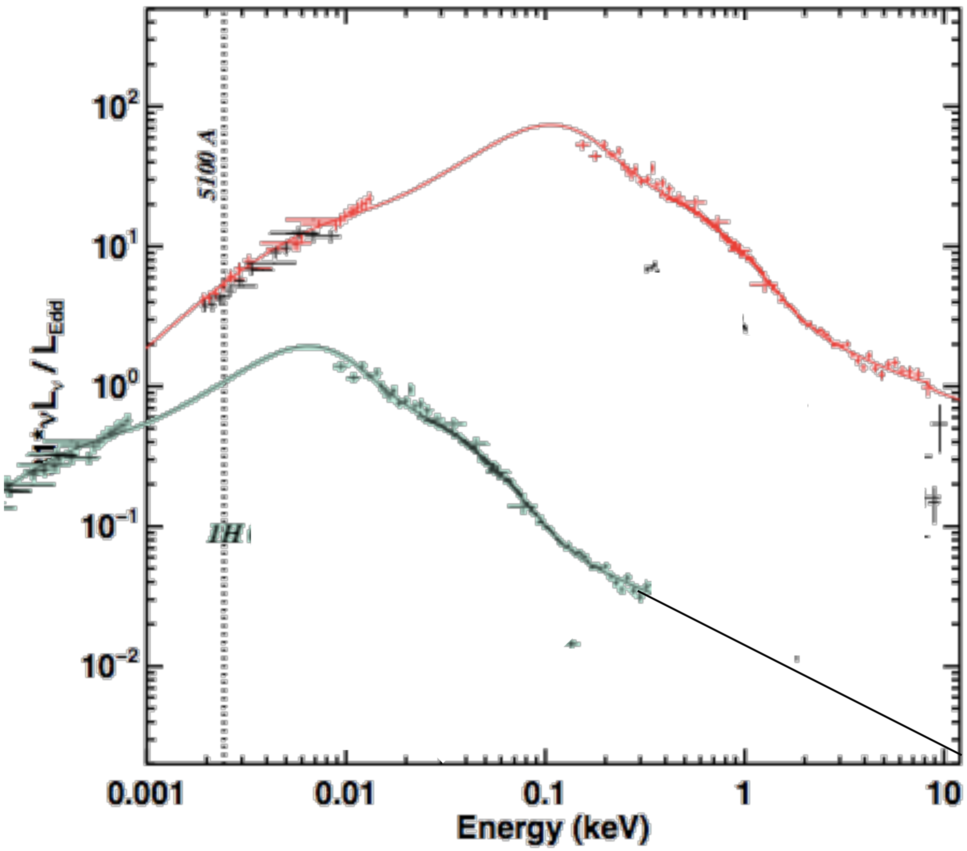
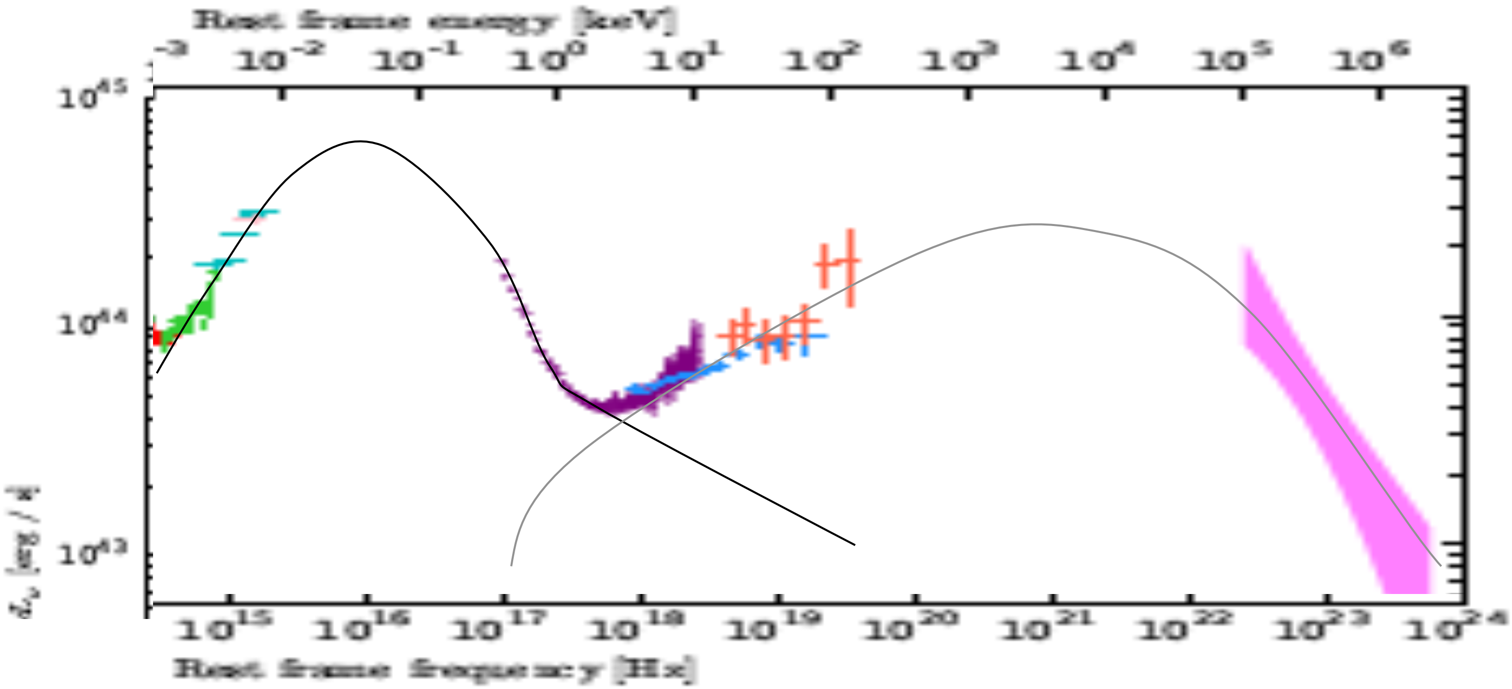


BUT if they are RL NLS1….



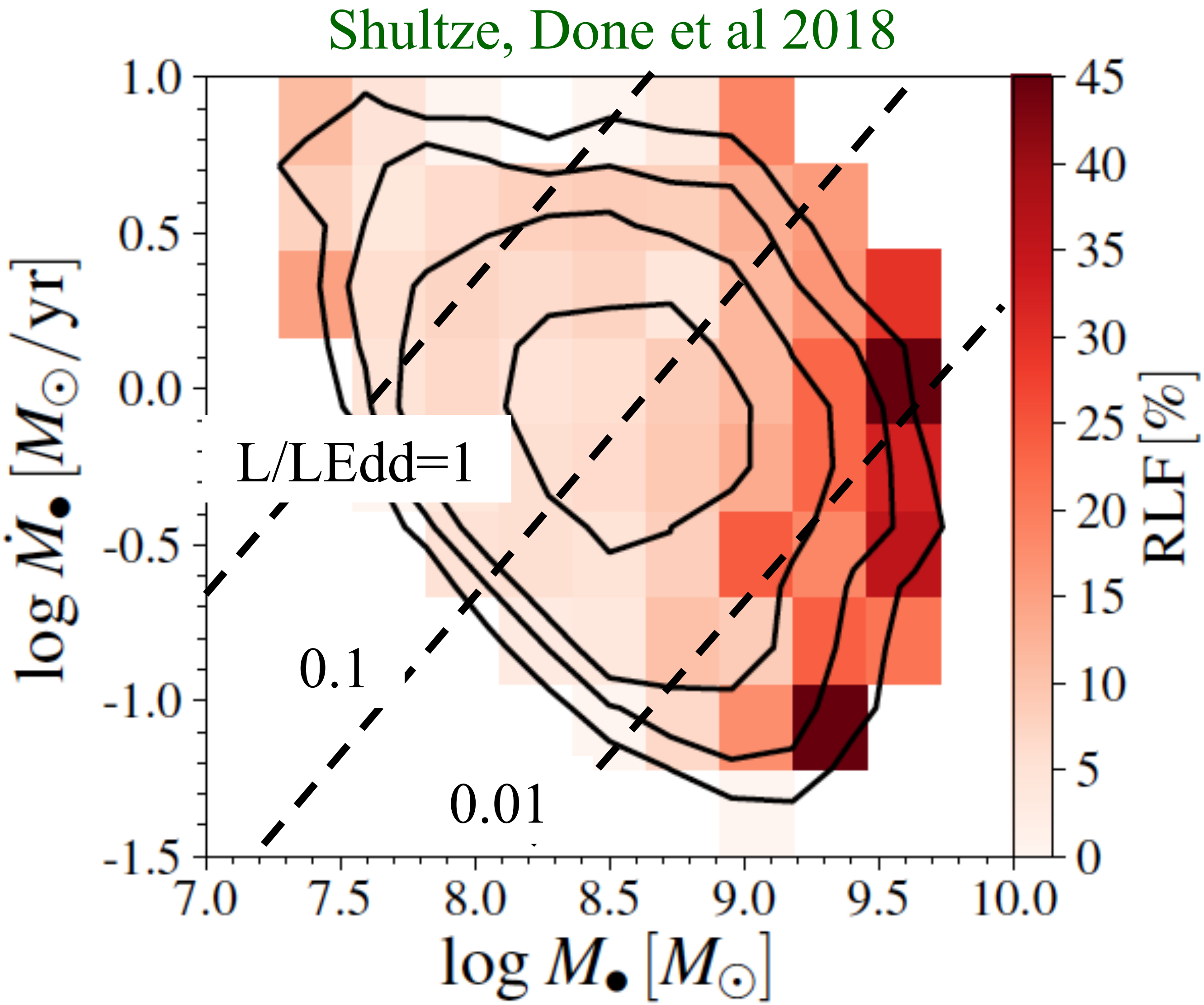
Kynock . Done et al 2017

We could MUCH more easily detect them in X-rays

Maybe high spin=highly relativistic jet and high spin is more common at high z????

Jet – BH spin??

- RL fraction depends mostly on mass=spin?!
- a few RL NLS1 in local universe
- Shultze, Done et al 2018



Conclusions

- AGN accretion/ejection should depend on mass, L/Ledd and spin. 3 parameters – don't look just at EV1
- M and L/Ledd can be estimated easily from single optical spectrum. Define on these parameters!!
- NLS1 are lowest mass, highest Mdot in local universe (downsizing of activity): dominant population at z=7-10
- Understanding these is the key to understanding
  - AGN winds (not extreme GR) and AGN feedback
  - First black hole seeds (still hard 10^9Msun at z~7)
  - AGN contribution to re-ionisation
  - Finding them easier in X-rays if RL (jet) – spin?