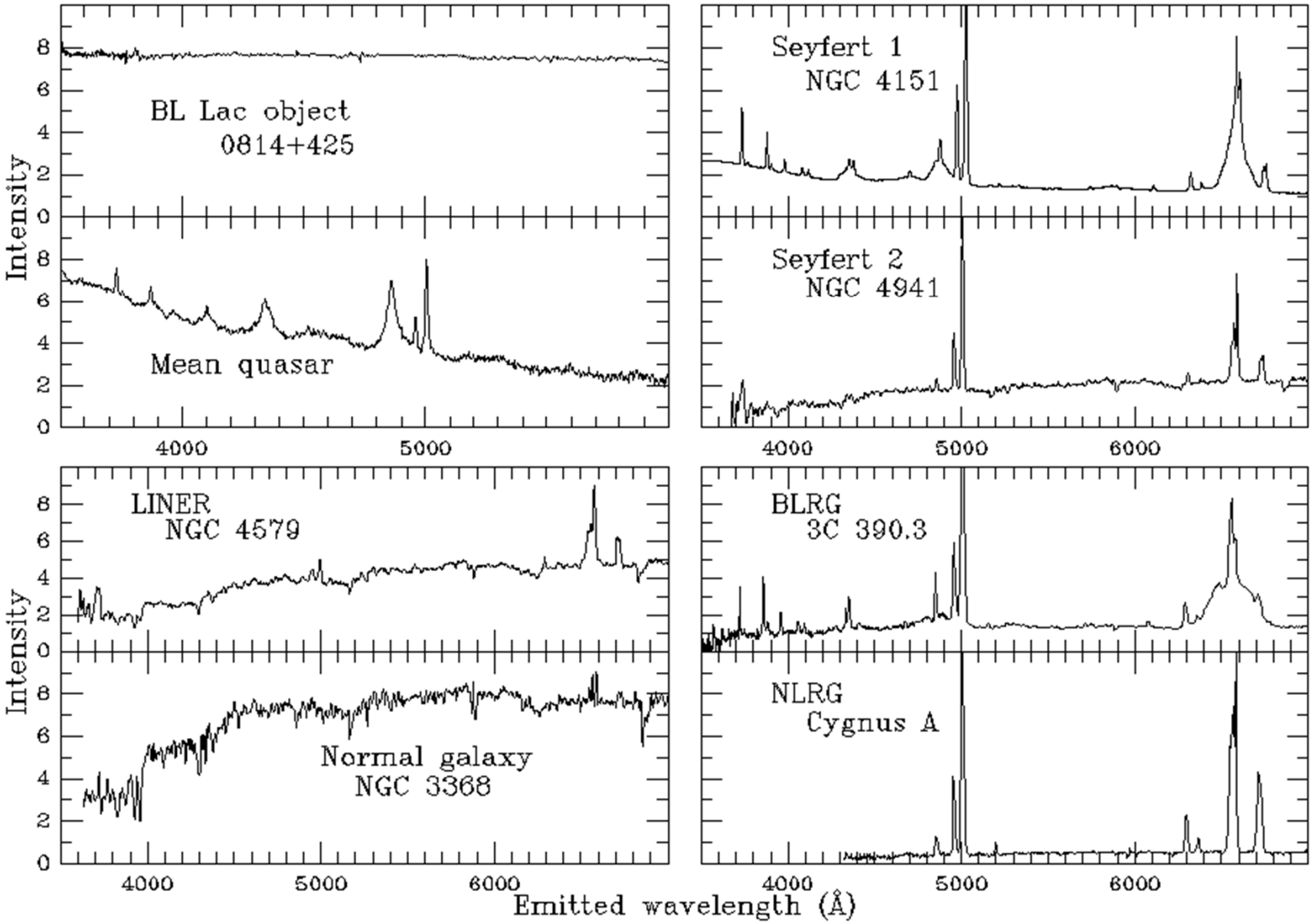
The disc-jet-spin connection: 3C273

Chris Done
Charles Finn, Emma Gardner…
University of Durham

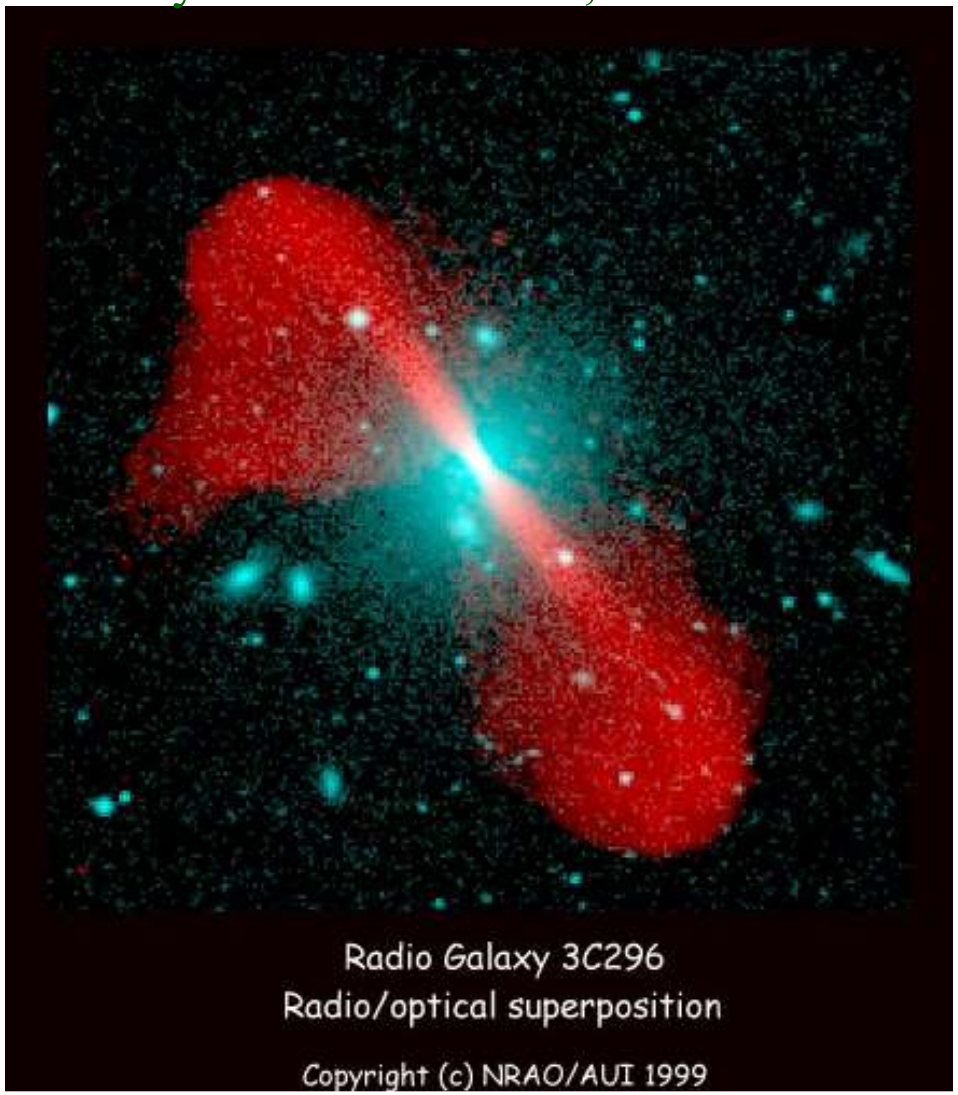
AGN/QSO Zoo!!! Optical

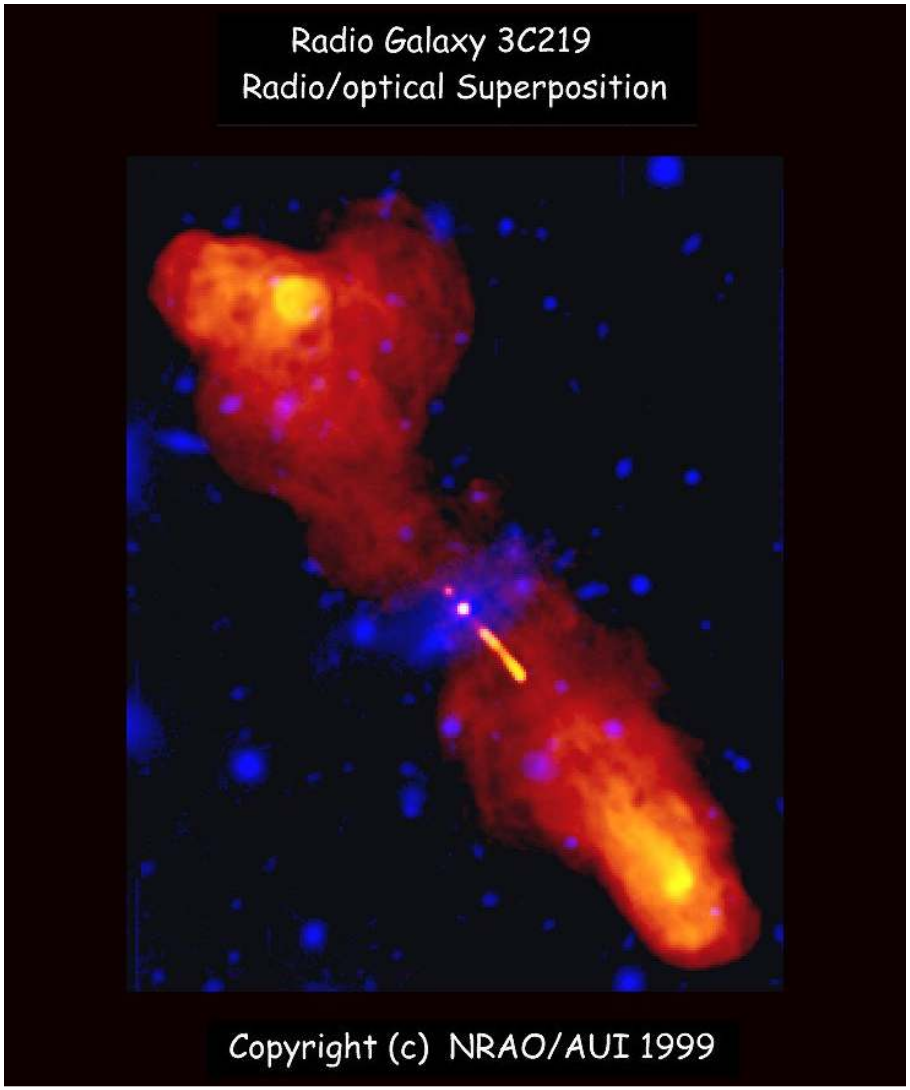
- Mass, mass accretion rate, spin and inclination….



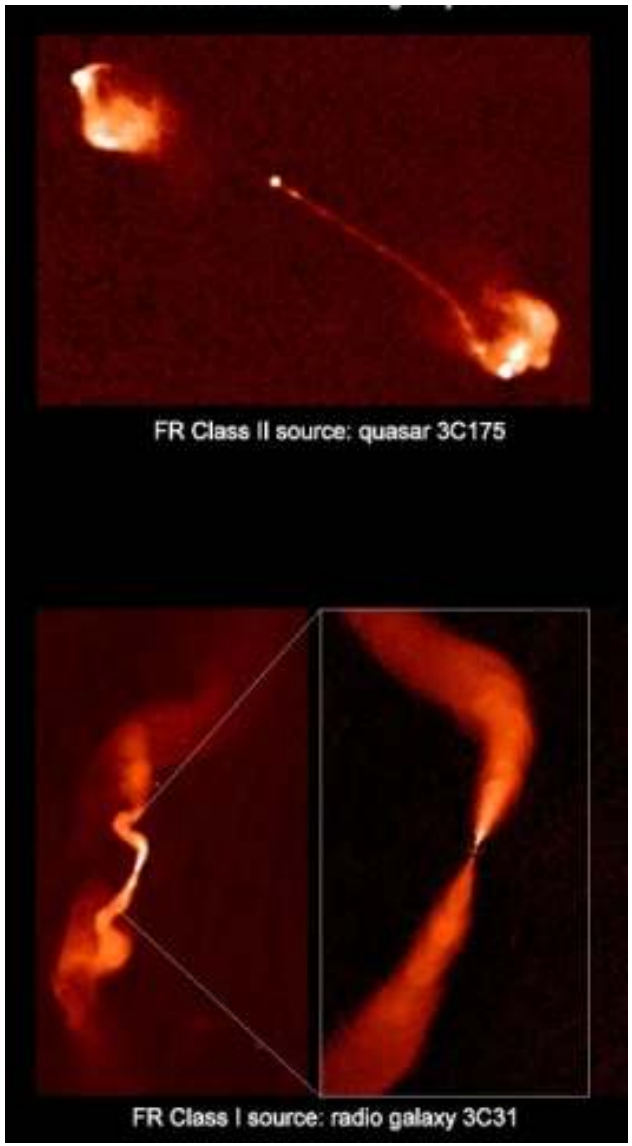
AGN/QSO Zoo!!! Radio loud

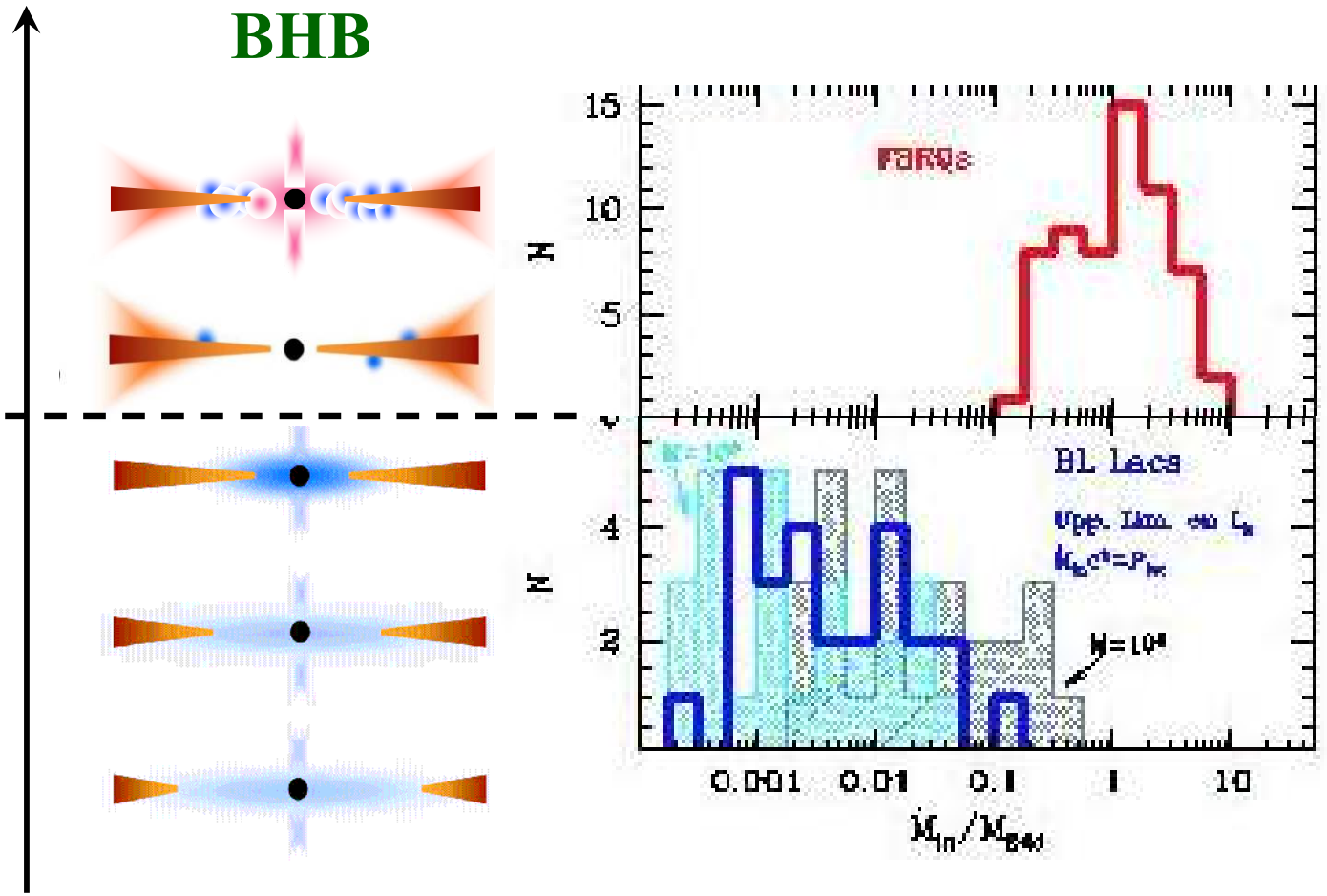
- Enormous, powerful, relativistic jets on Mpc scales
- FRI (fuzzy) - BL lacs FRII (hot spots) – FSRQ
- Urry & Padovani 1992; 1995





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





Ghisellini et al 2010

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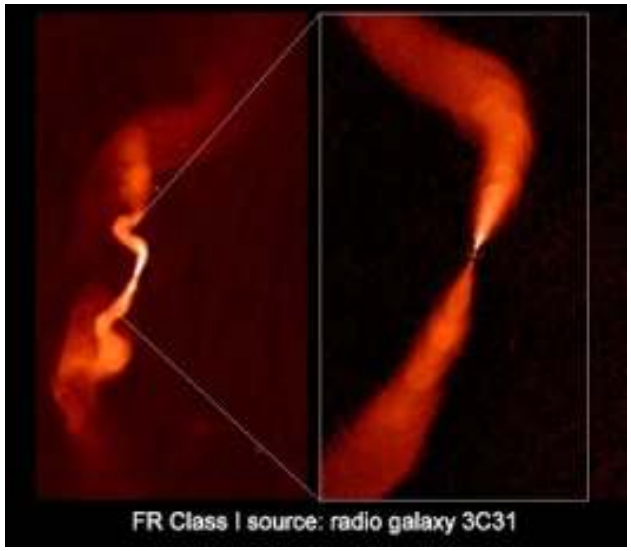
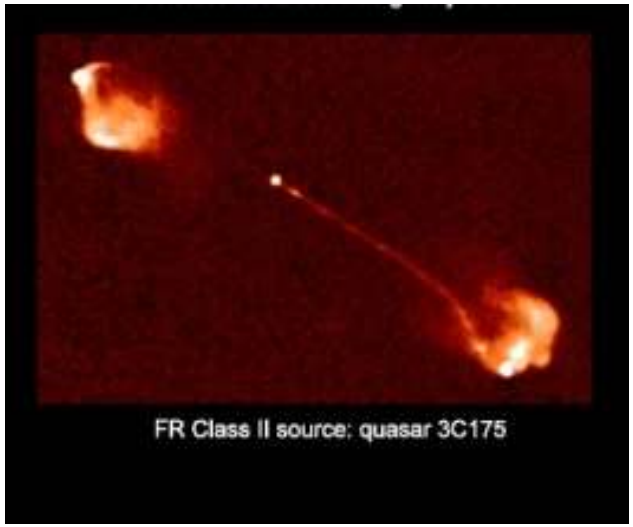


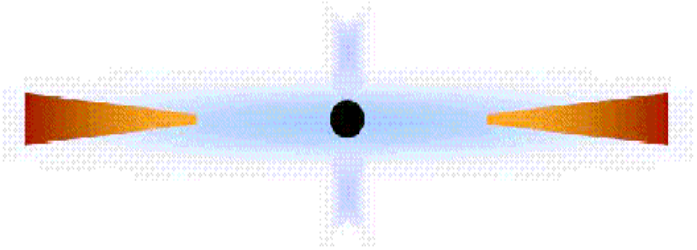


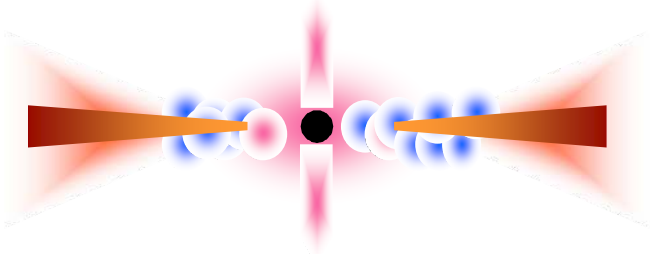
No UV inner disc – no BLR

Sync-self compton (SSC)

UV bright, BLR

SSC+External compton





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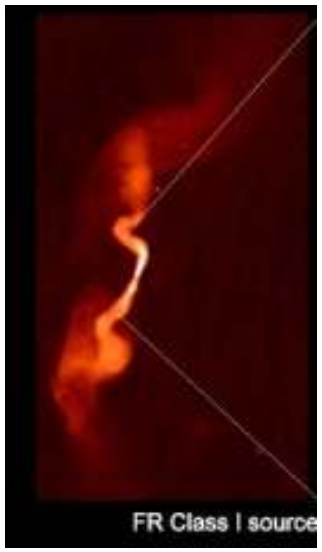

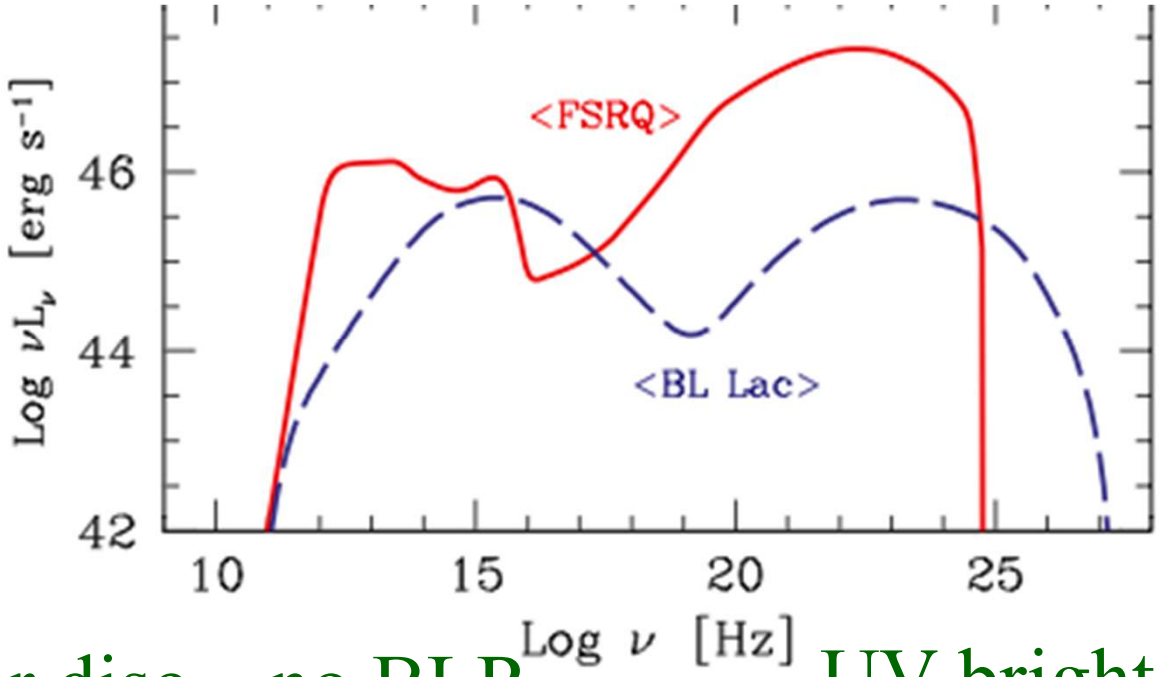

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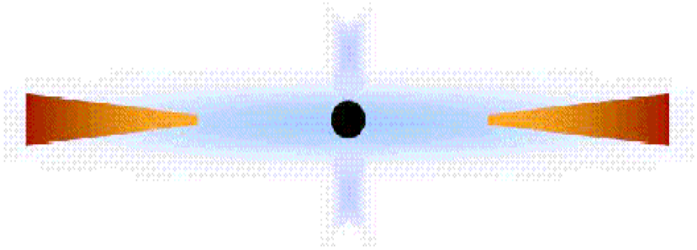
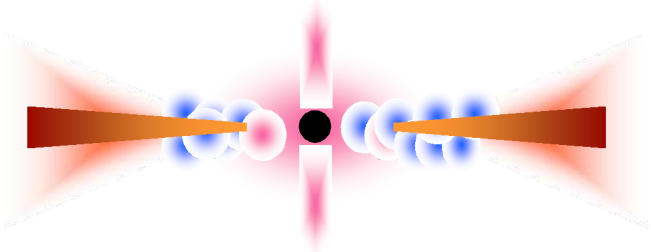
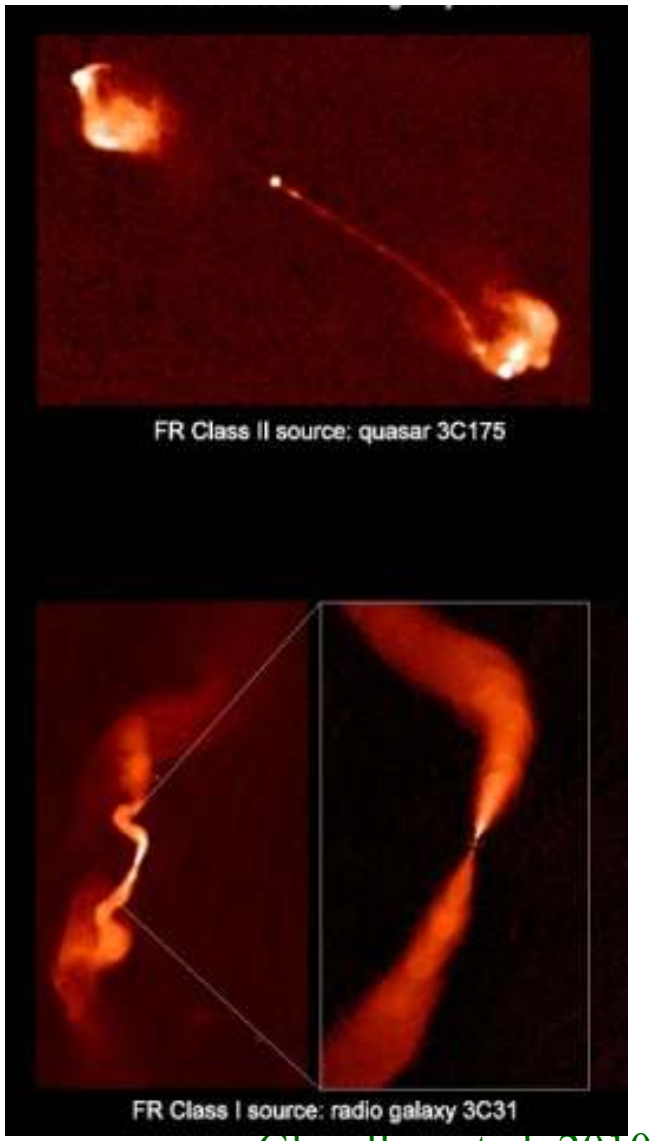




Ghisellini et al 2010

Spin-jet paradijm

- Uncontroversial – very high spin to get Γ=10-15?



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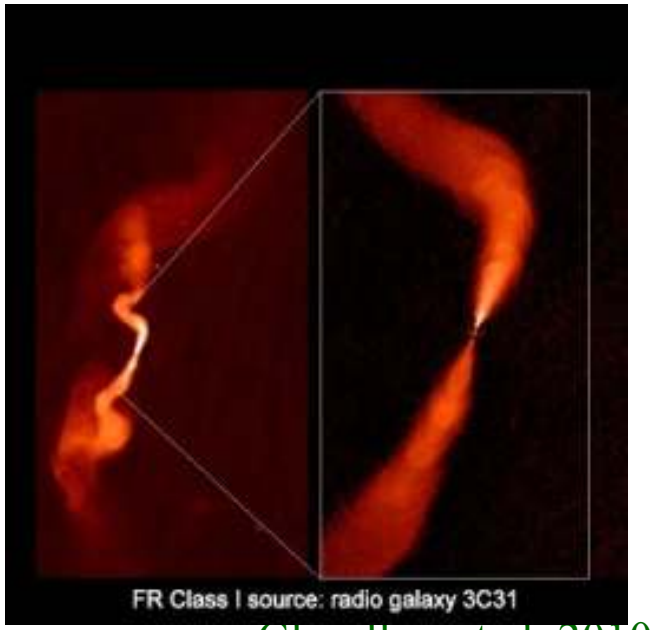
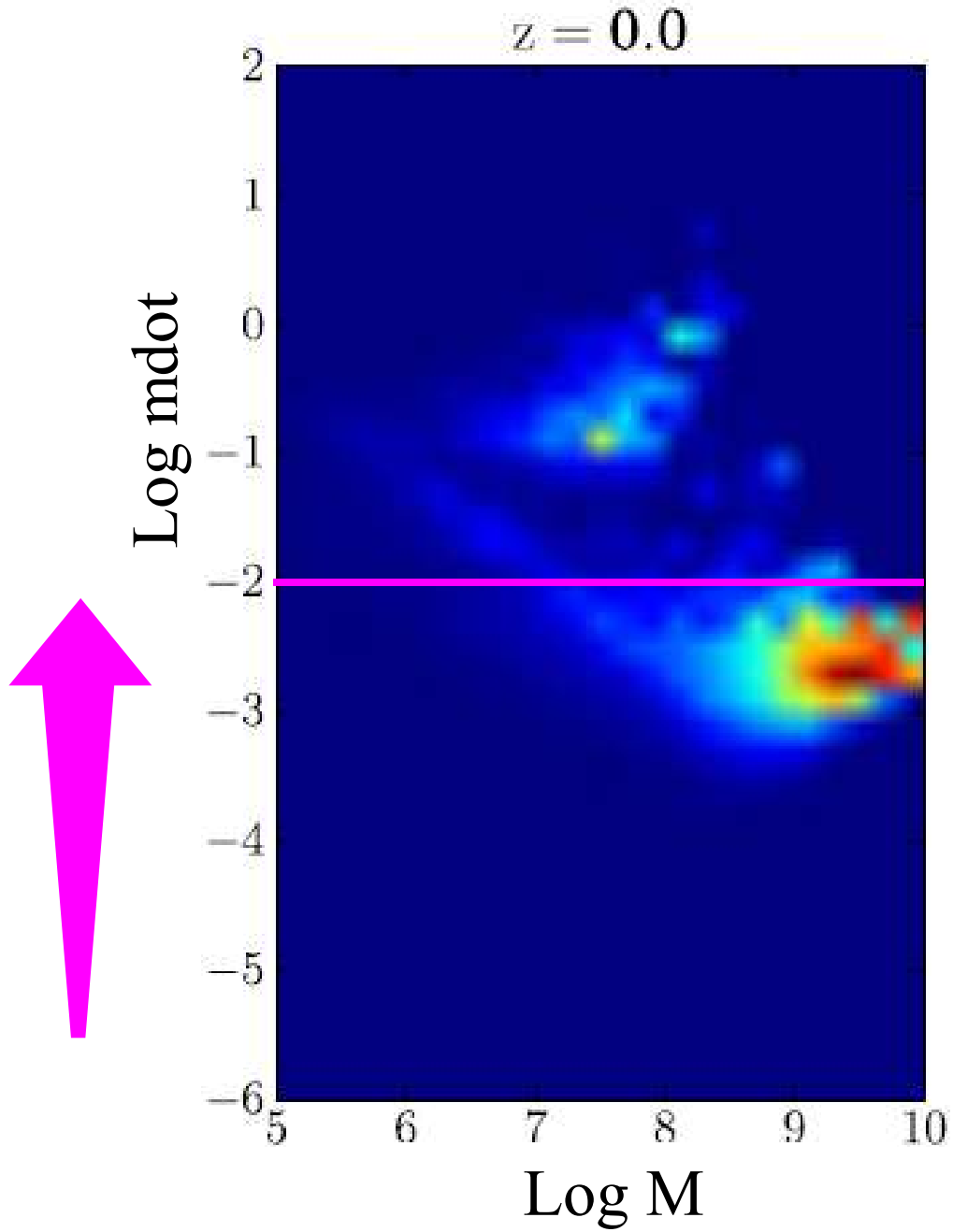


Ghisellini et al 2010

Black hole mass & mdot

- Cosmological simulations gives number densities (M, mdot)…
- …As a function of cosmic time
- Colours are luminosity density
- ASSUME all RIAF (mdot<0.01) produce BL Lac jet



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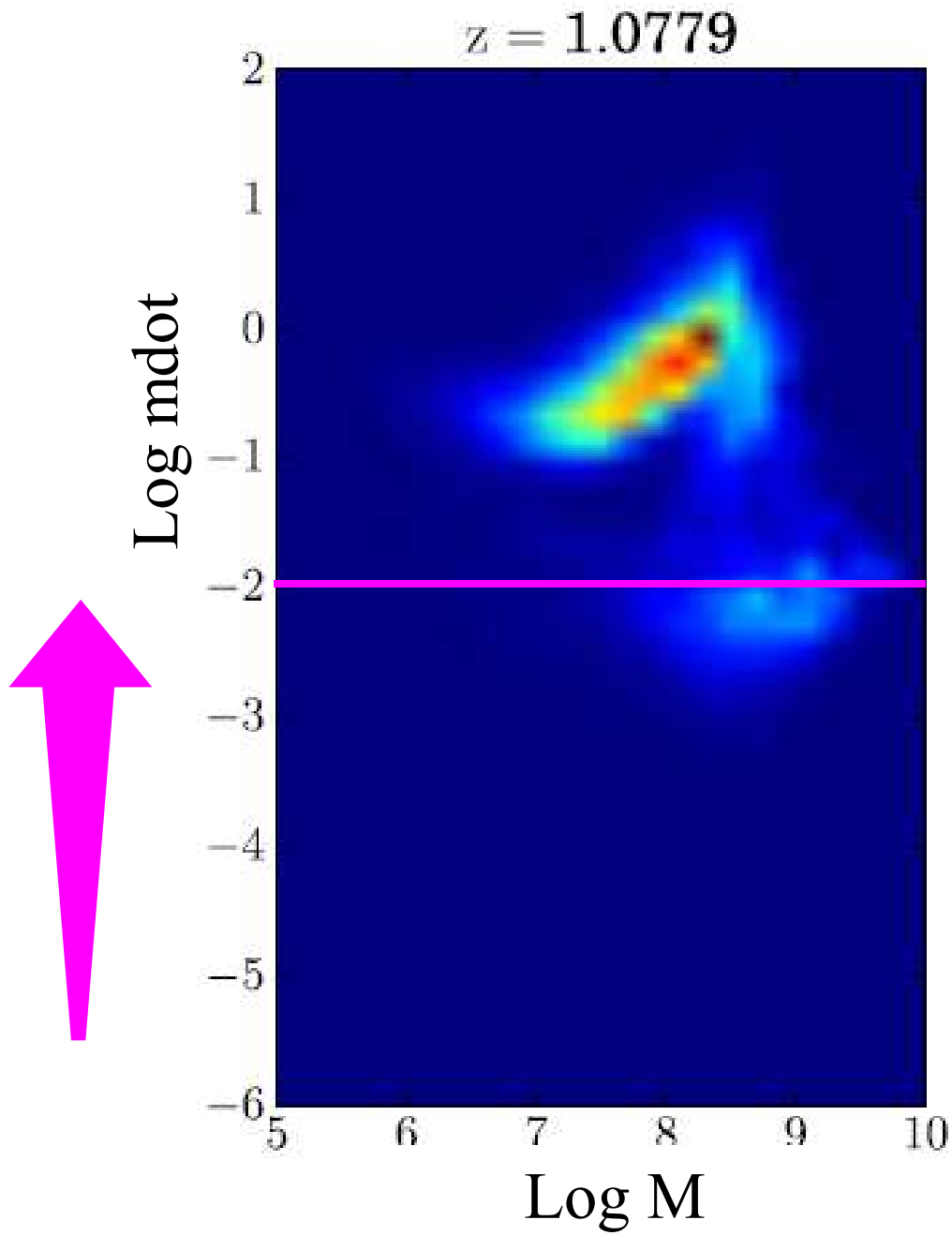

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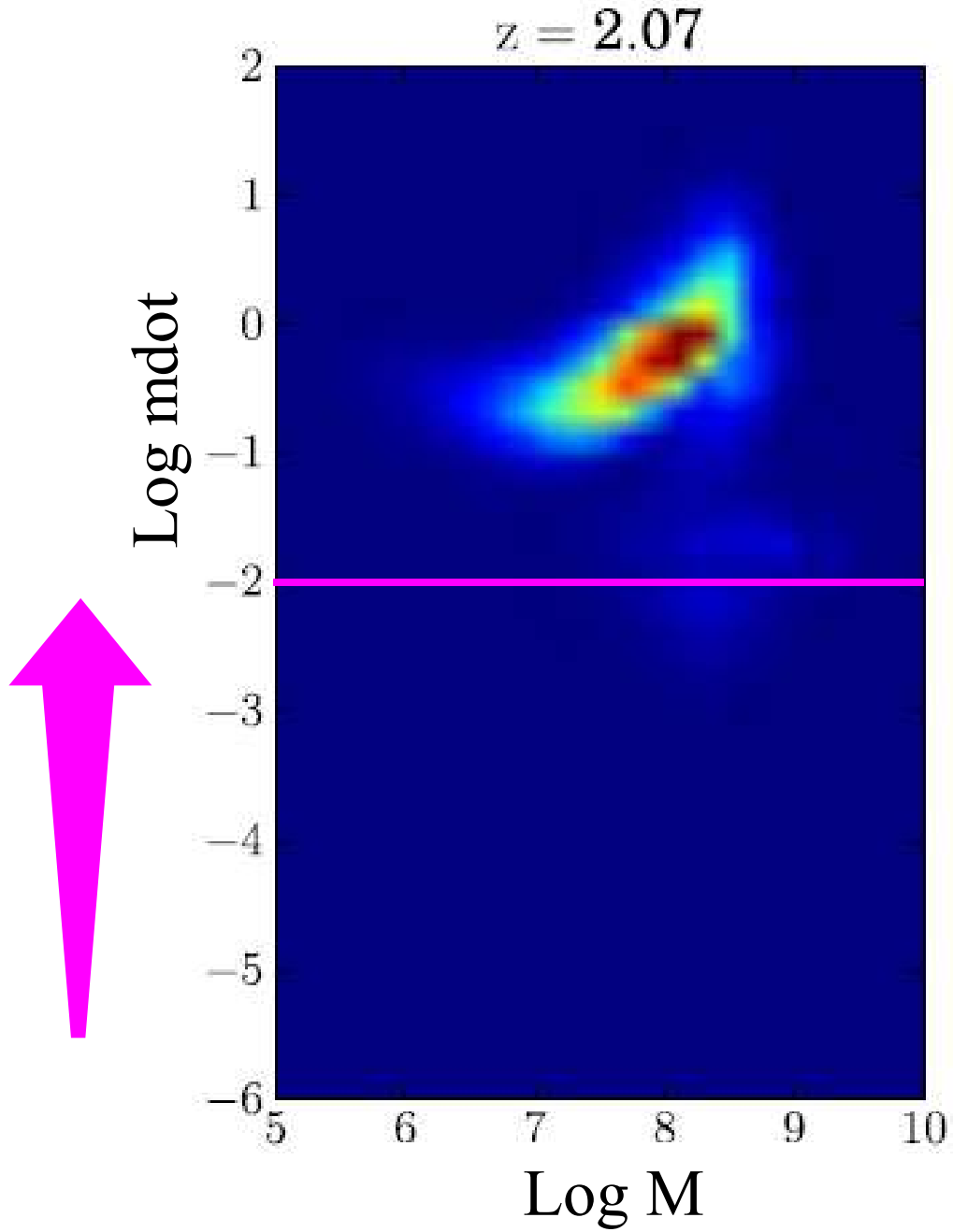
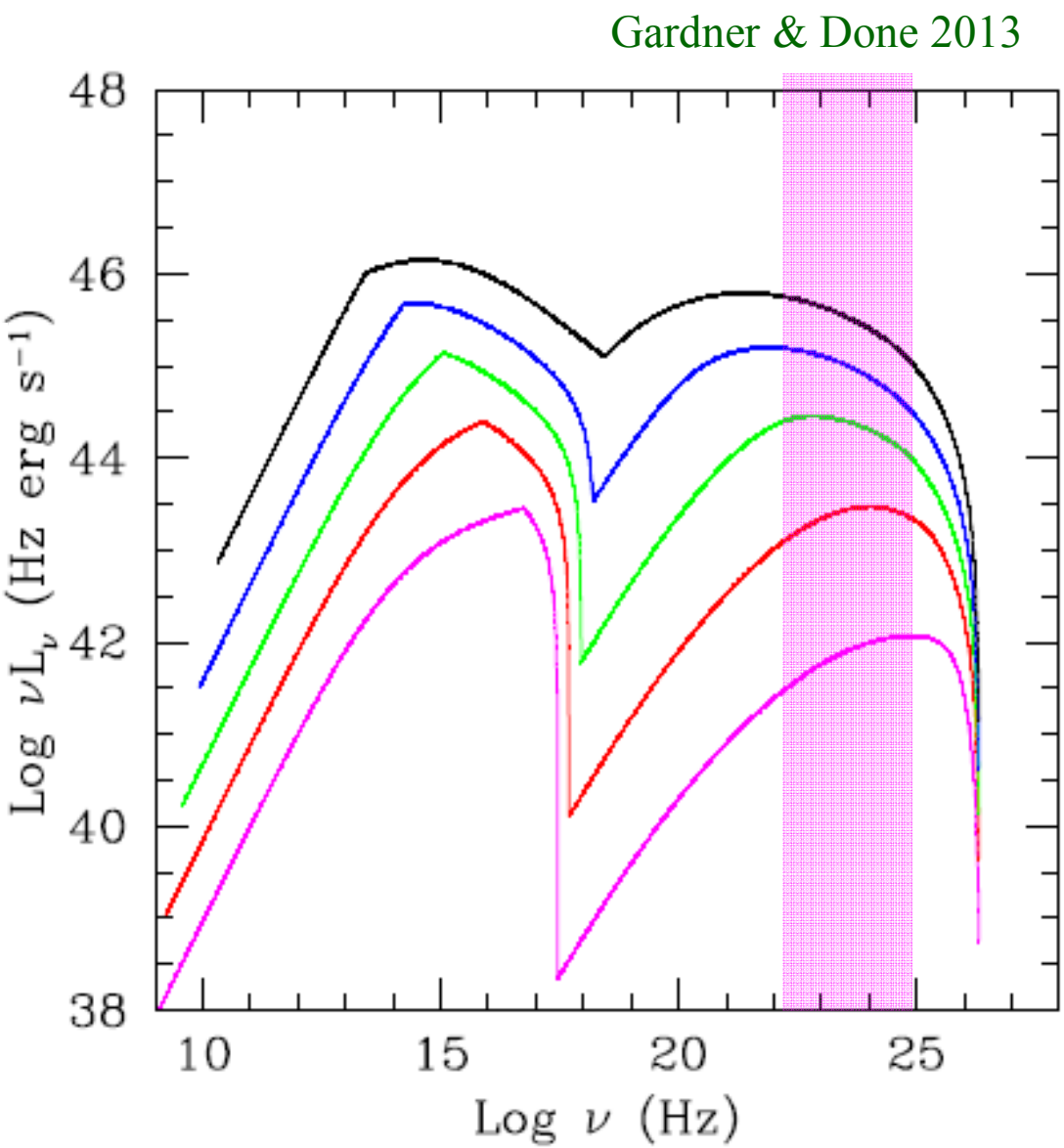


Black hole mass & mdot

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

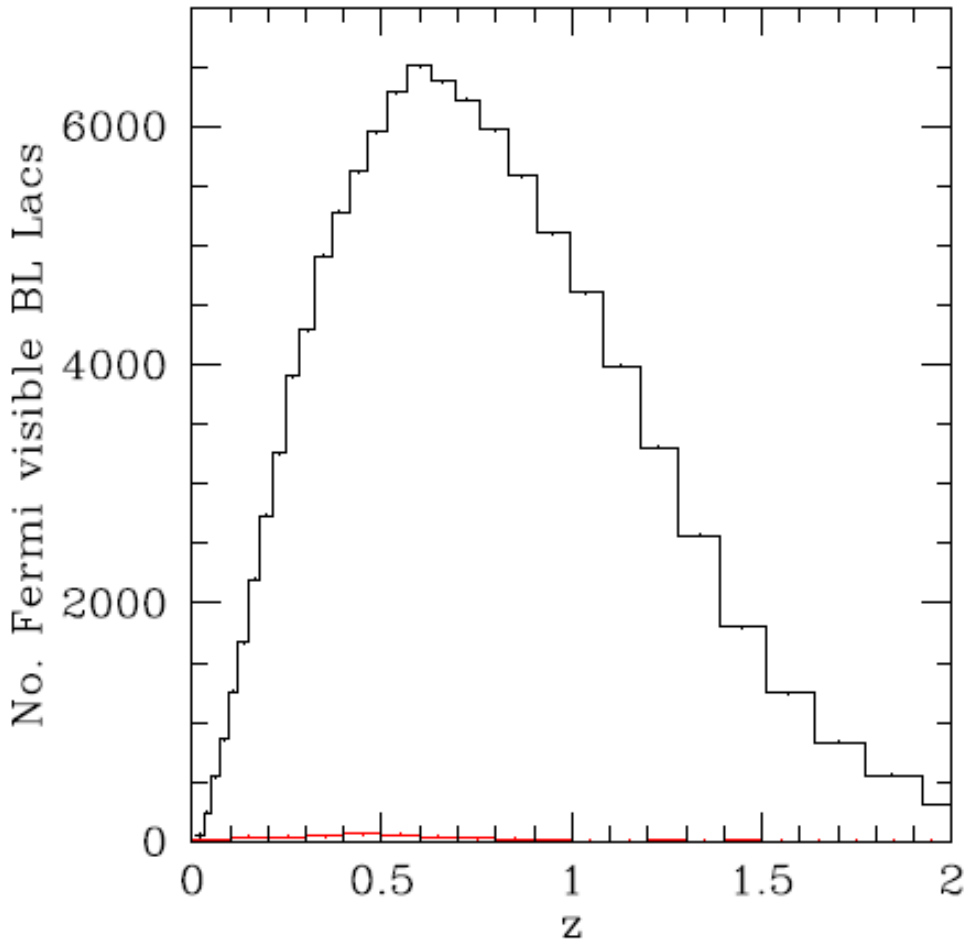
L/L_{Edd}



1000x more Fermi BL Lacs!!

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

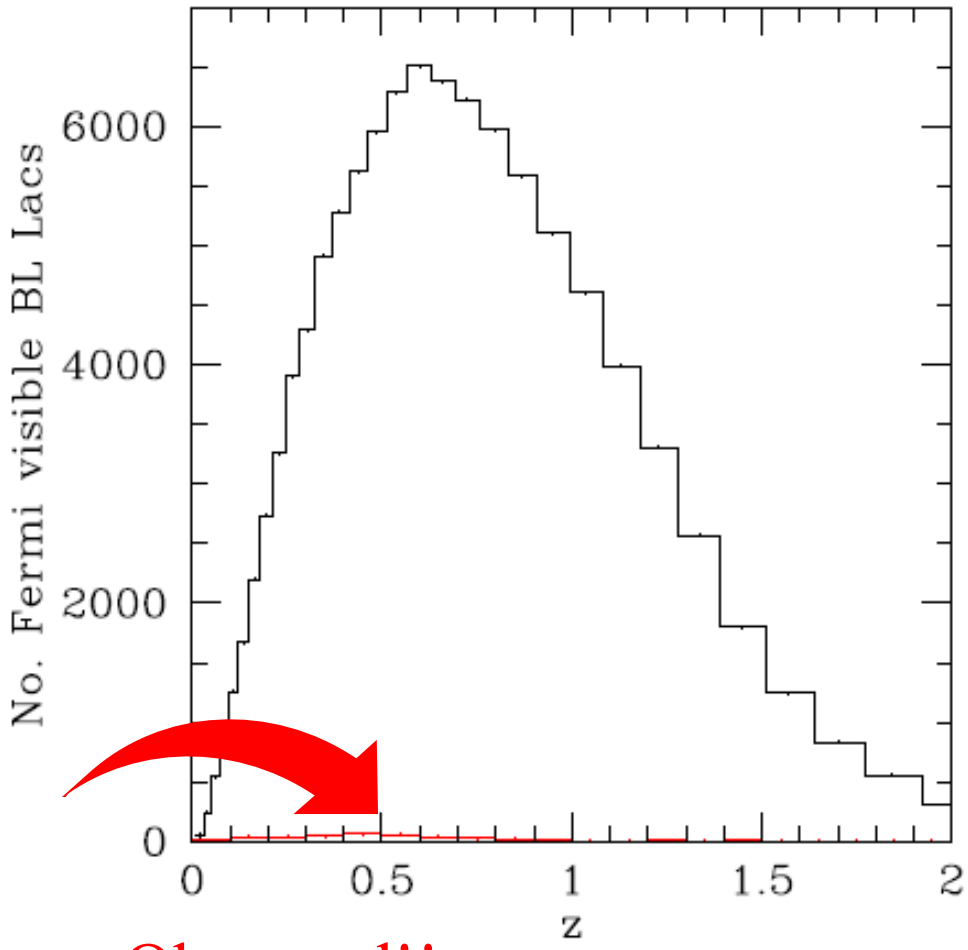
Gardner & Done 2013



1000x more Fermi BL Lacs!!

- WRONG!!

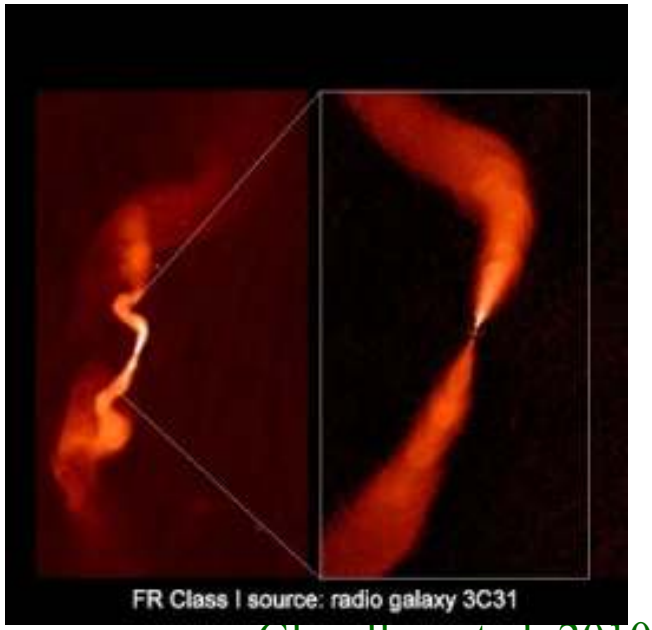
Gardner & Done 2013



Observed!!

Spin-jet paradijm BL Lacs

- So high Γ jets RARE
- High spin rare (chaotic accretion, $a_*>0.8$)
- High spin common, B flux rare (Sikora & Begelman 2013)
- Retrograde spin rare eg Garofalo et al 2014
- BL lacs – no inner disc so hard to get spin constraints



Ghisellini et al 2010

Spin-jet paradijm: FSRQ

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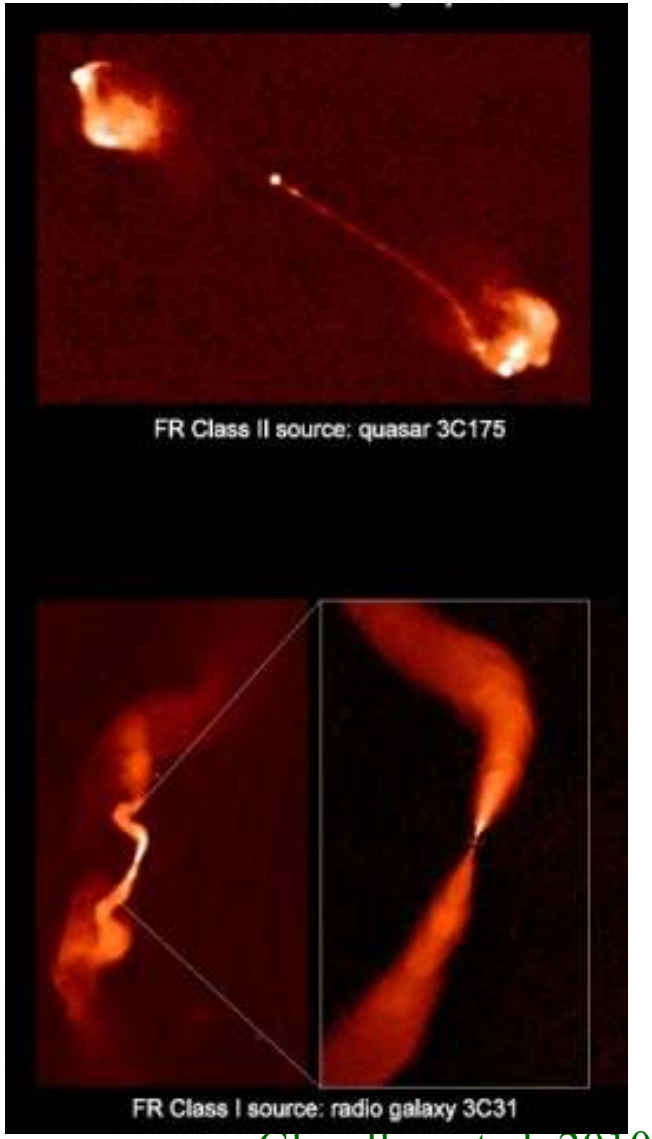
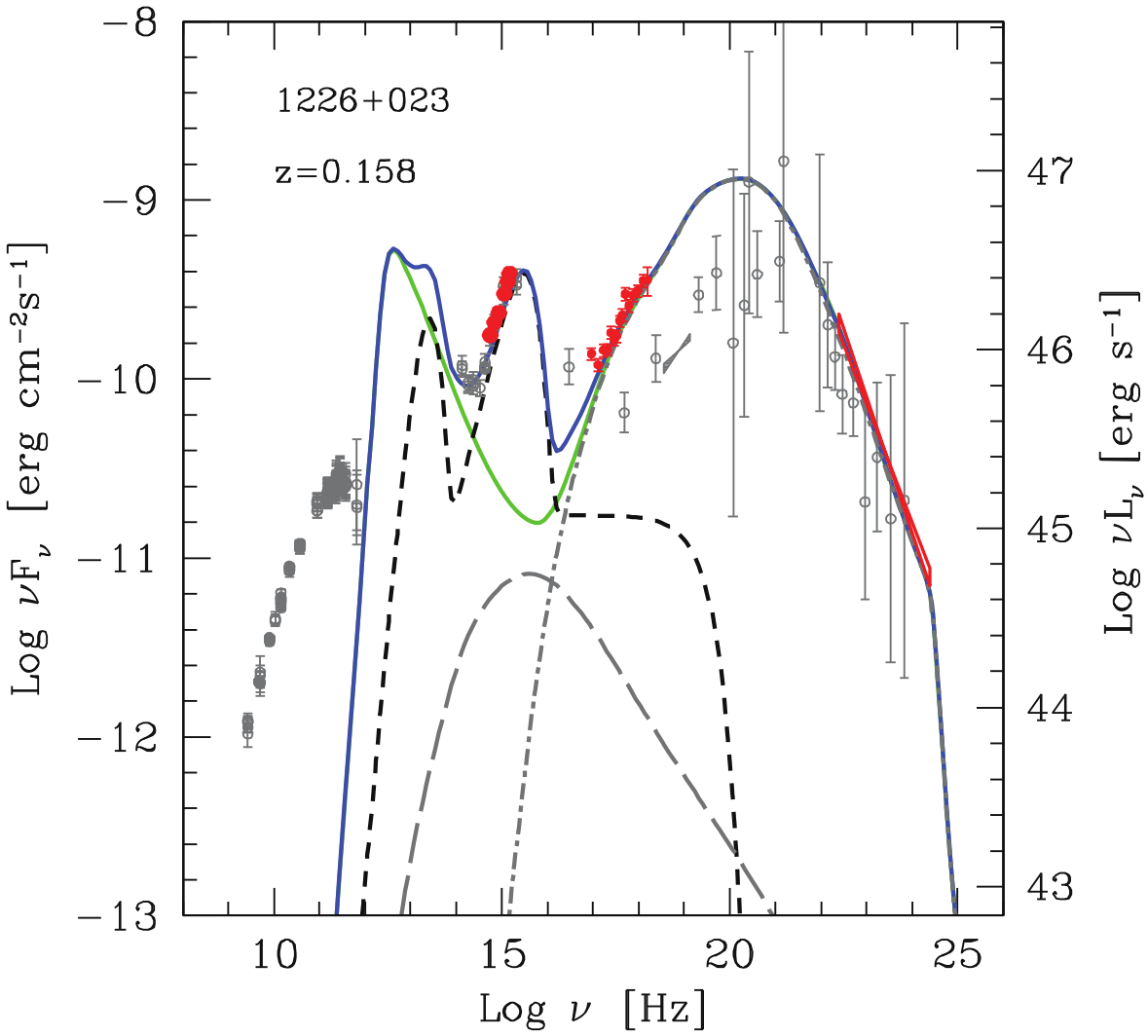
- BL lacs – no inner disc so hard to get spin constraints
- FSRQ – retrograde thin disc or prograde large H/R flow?



Ghisellini et al 2010

Spin-jet paradijm

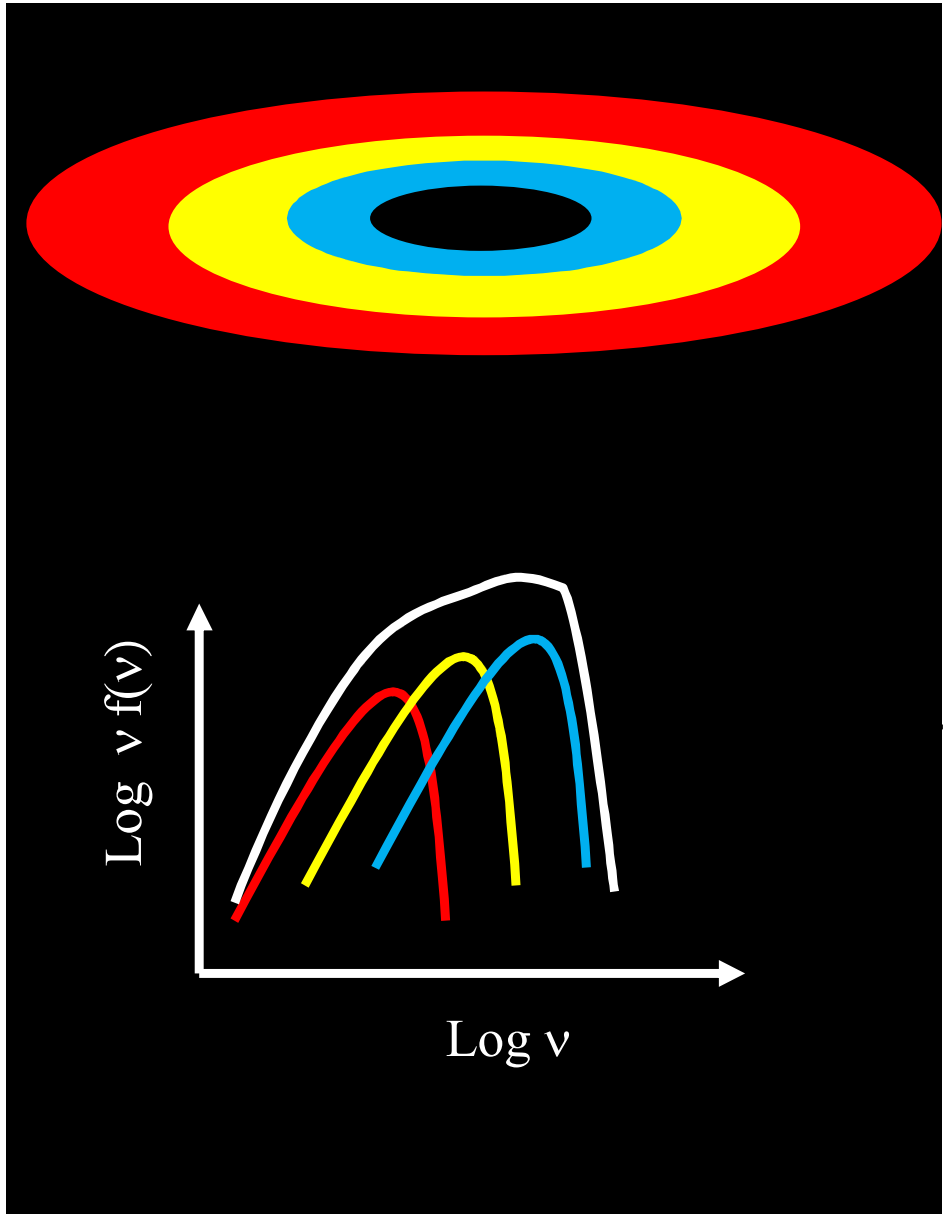
- Can't use Fe line as the jet dominates the X-ray flux
- But can use disc continuum...



Ghisellini et al 2010

Spectra of accretion flow: disc

- Thermal emission:
  $L = A\sigma T^4$
- Last stable orbit sets maximum temperature
- Tmax - $(\dot{m}/M)^{-1/4}$
- X-ray for NLS1 ~ 10^7 M
- FUV for ~ 10^9 M FSRQ



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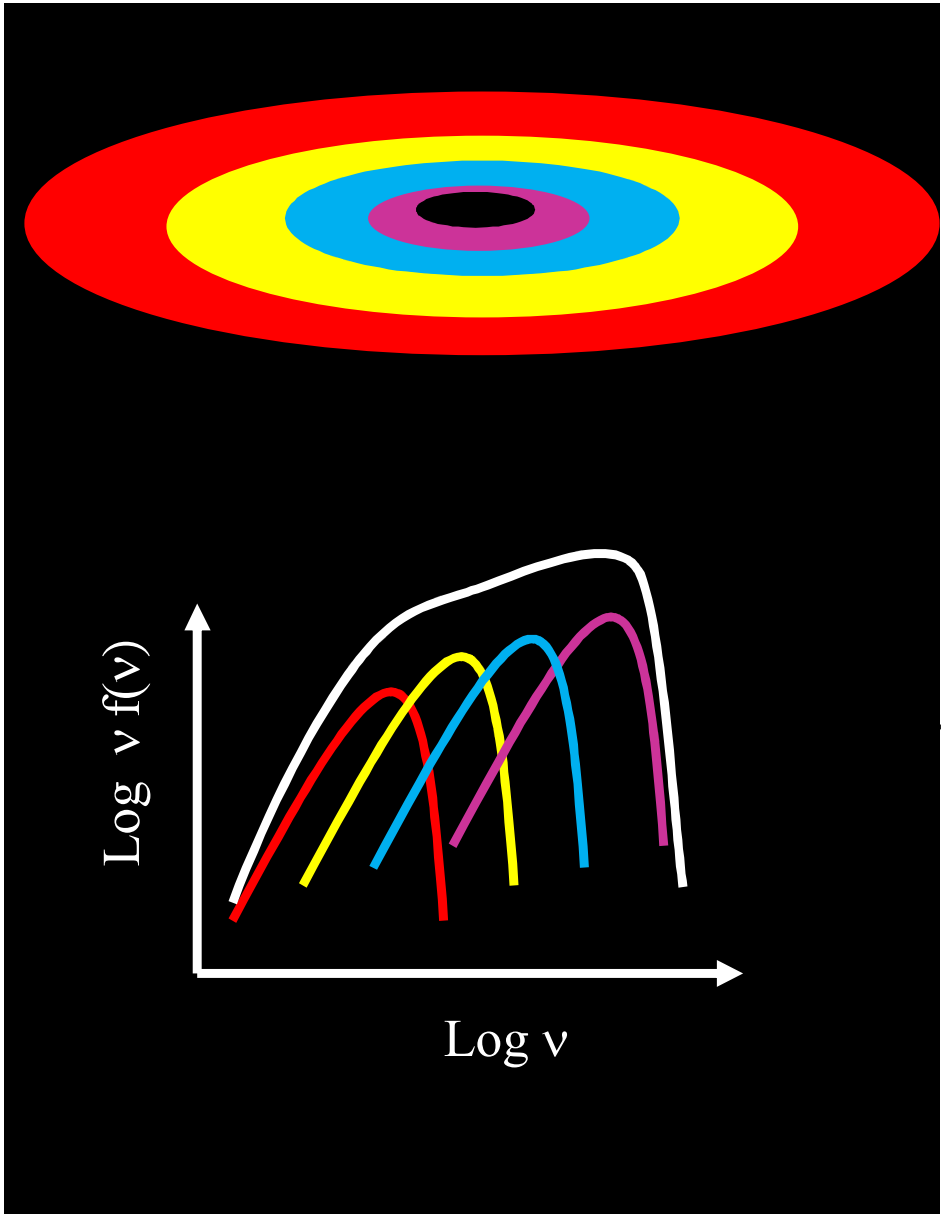
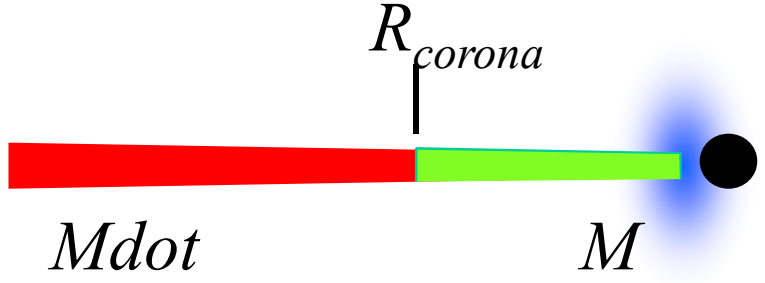
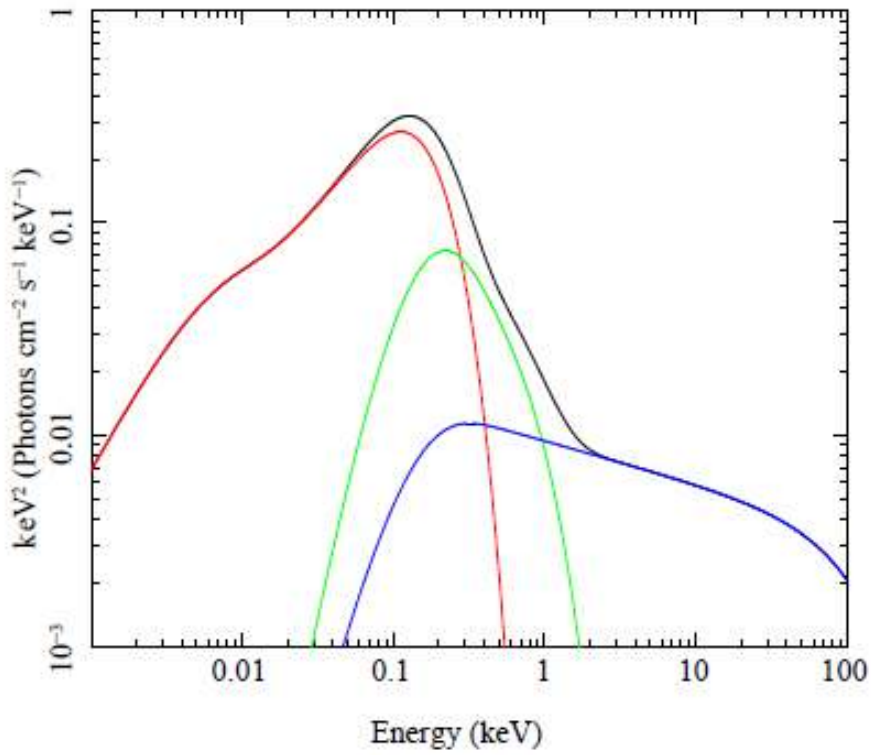
- Depends on spin!



Optxagnf: conserving energy!

- Outer standard disc with colour temp correction down to R_{corona} – quick way to model full photosphere results
- Then luminosity not completely thermalised to make soft X-ray excess ?
- Inner corona as in BHB
- NLS1: R_{corona} small so disc dominated, and Γ steep

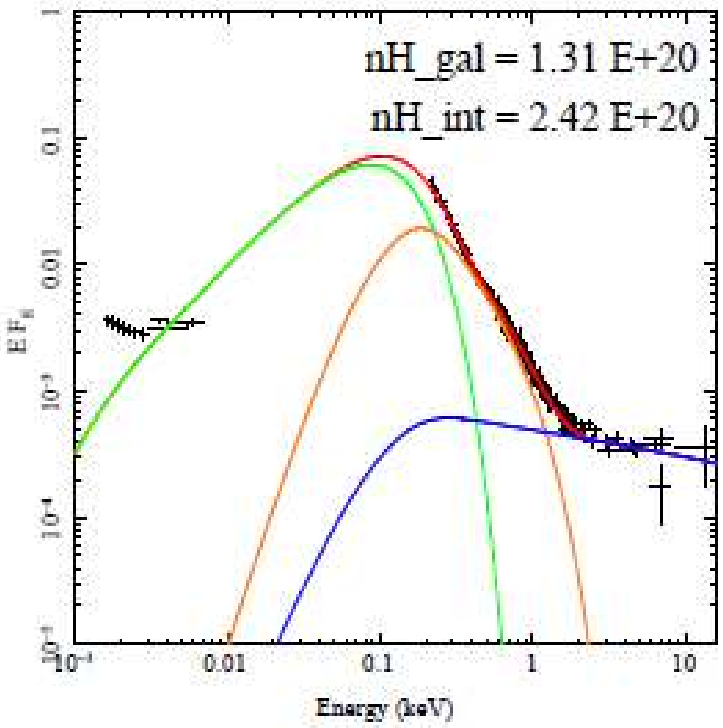


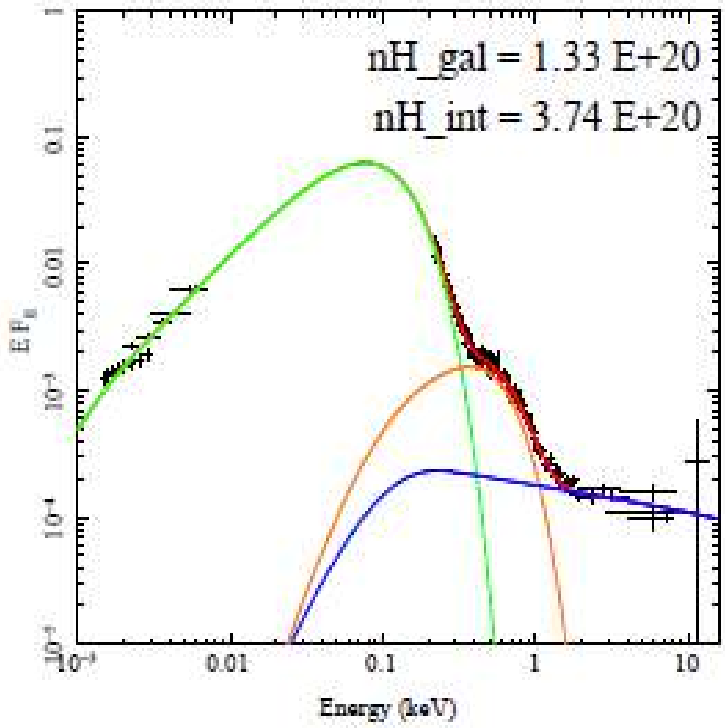


Done et al 2012

Simple NLS1

- Smaller R_{corona} means spectra are dominated by disc!
- NLS1 have small SX and big disc - NOT huge SX





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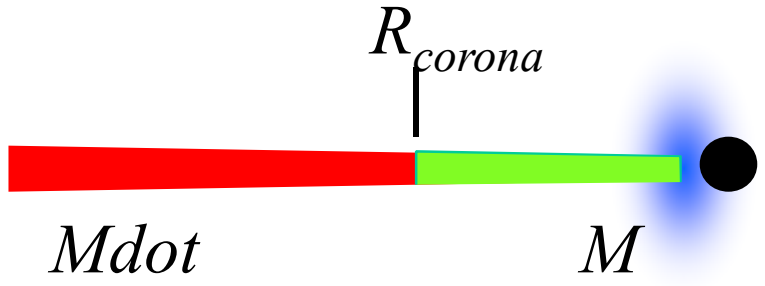
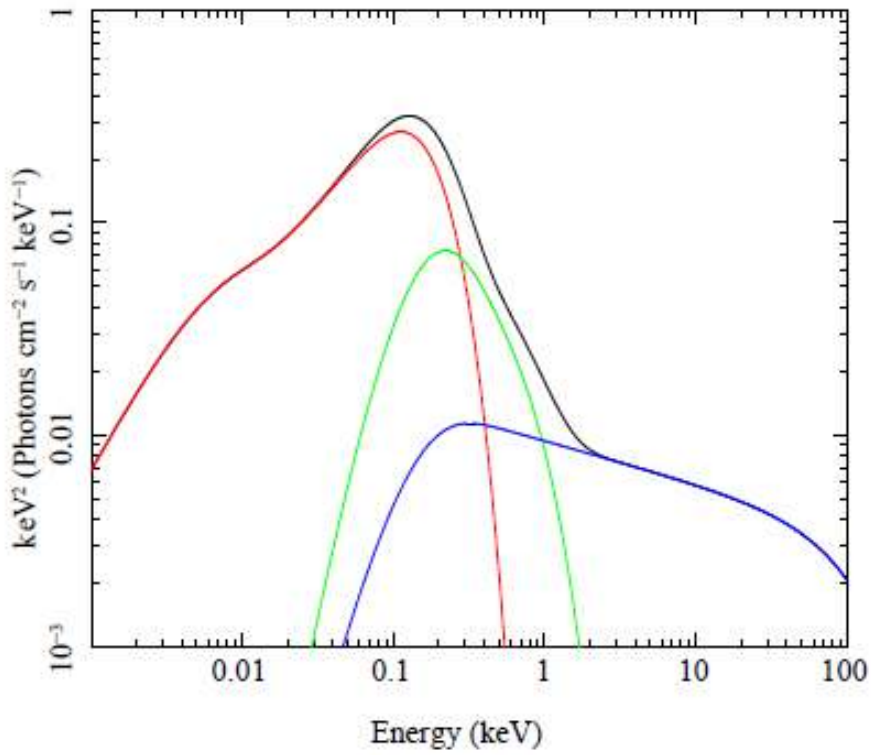
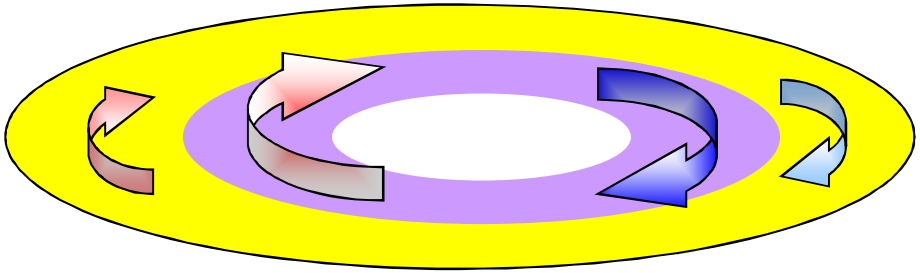


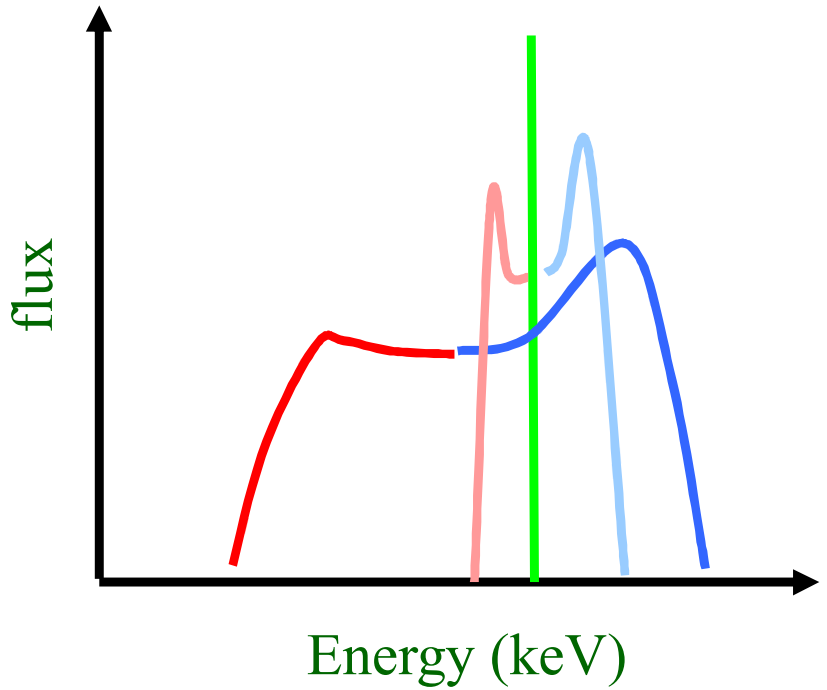


Done et al 2012

Relativistic effects

- Relativistic effects (special and general) affect all emission (Cunningham 1975)
- Emission from the side of the disc coming towards us is blueshifted and boosted by Doppler effects, while opposite side is redshifted and suppressed.
- Also time dilation and gravitational redshift
- Broadens spectrum at a give radius from a narrow blackbody

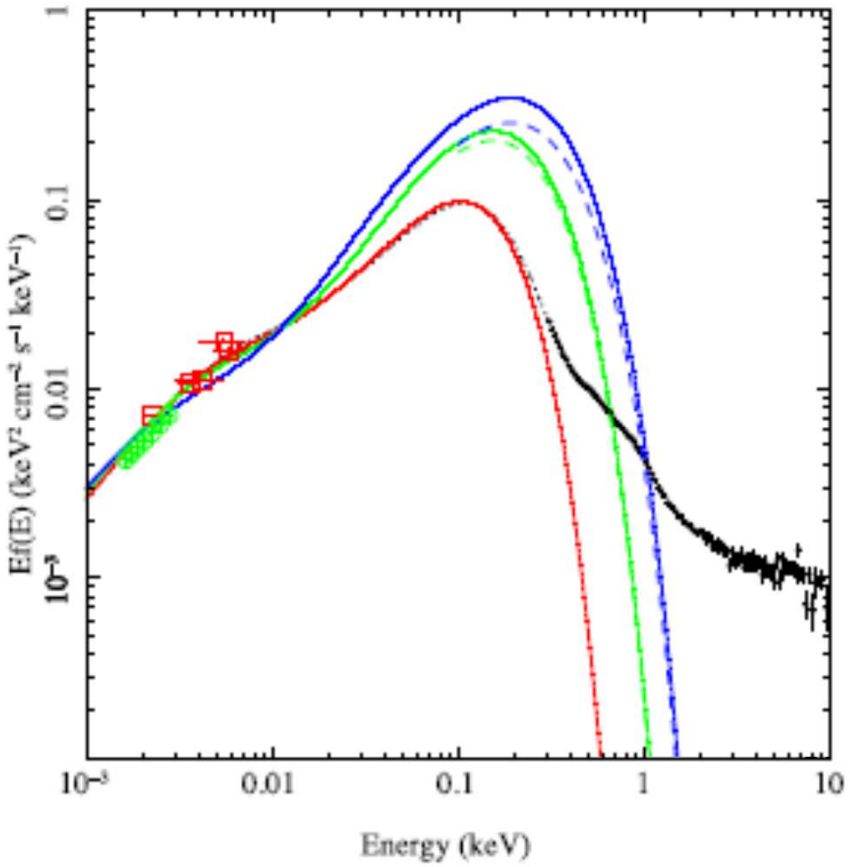




Fabian et al. 1989

Optxconv: spin PG1244+026

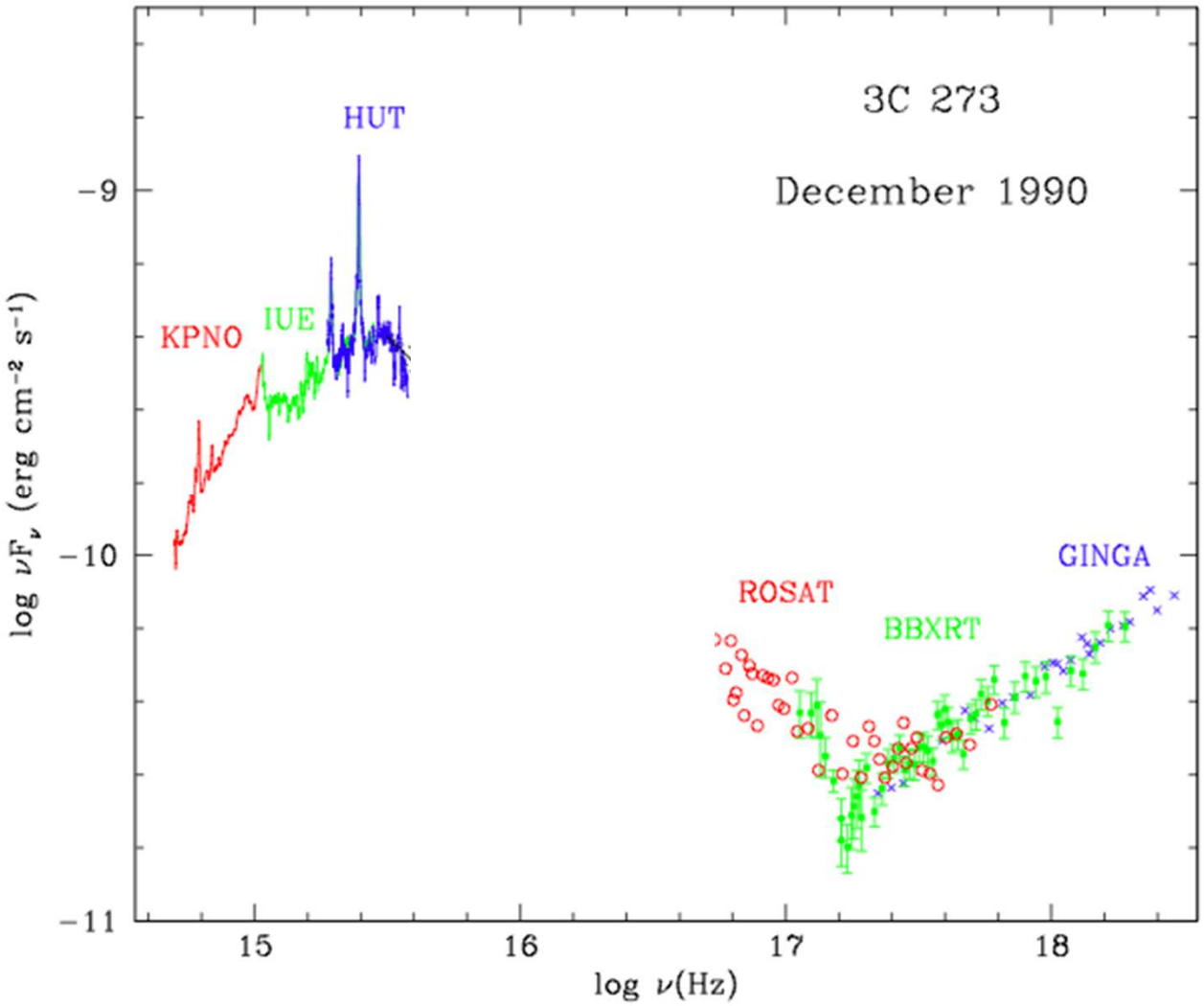
- ‘Simple’ NLS1
- Dominated by disc
- So can get spin!
- M: 0.2 - 2×10^7
- Inclination 0-60
- But low spin a<0.8



Done, Jin, Middleton Ward 2013

Nearest FSRQ – 3C273

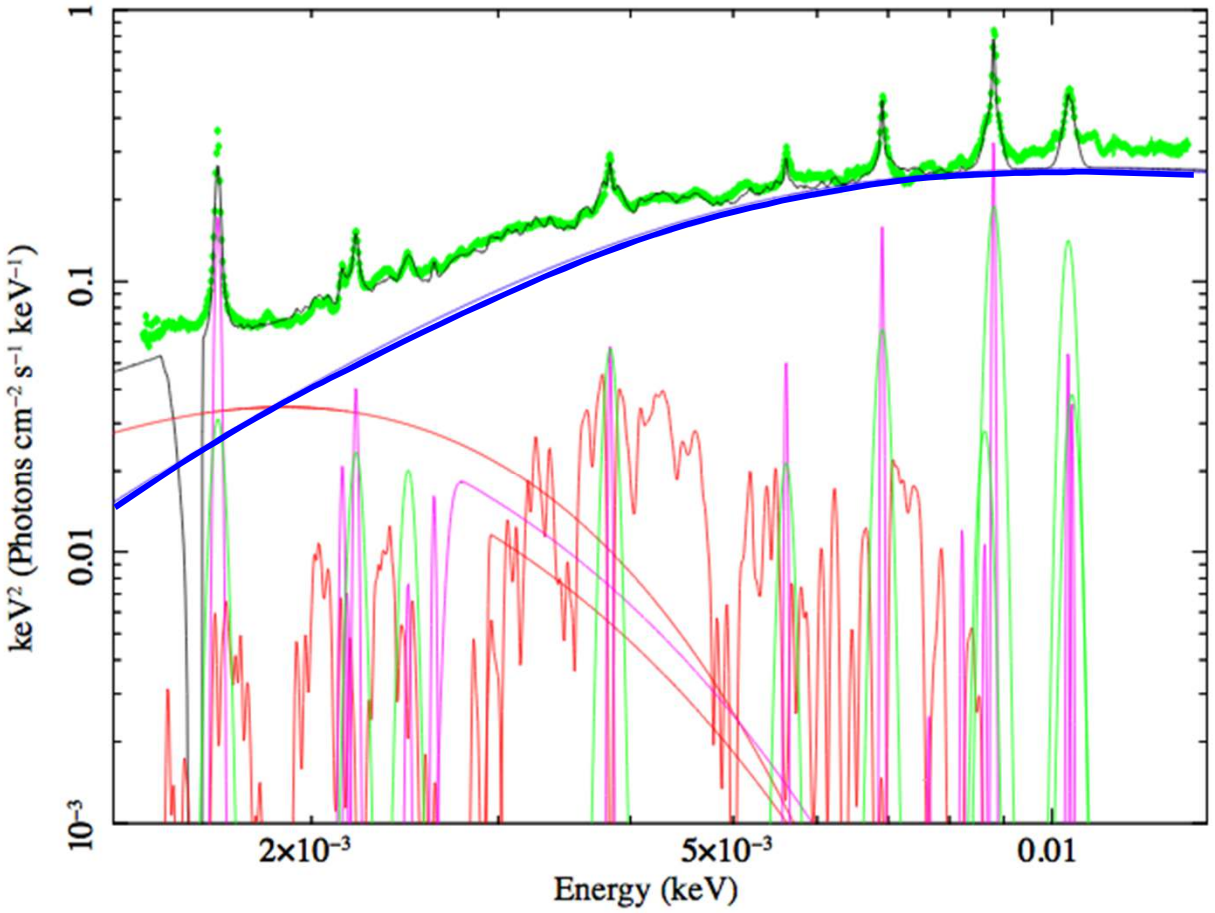
- Dec 1990 Astro-1 (Shuttle) mission UV and X-ray with simultaneous optical + soft and hard X-rays
- Very low Nh and E(B-V) so see peak of disc (Sembach et al 2000)



Kriss 2000

3C273: Amazing data

- Is it disc dominated?
- Reverb. mass $8.9 \pm 1.9 \times 10^8$ M (Peterson et al 2004)
- i=6±1 from jet VLBA (Jorstad et al 2005)
- a*=0: rcor=6, plus broad and narrow lines and FeII and Balmer continuum….



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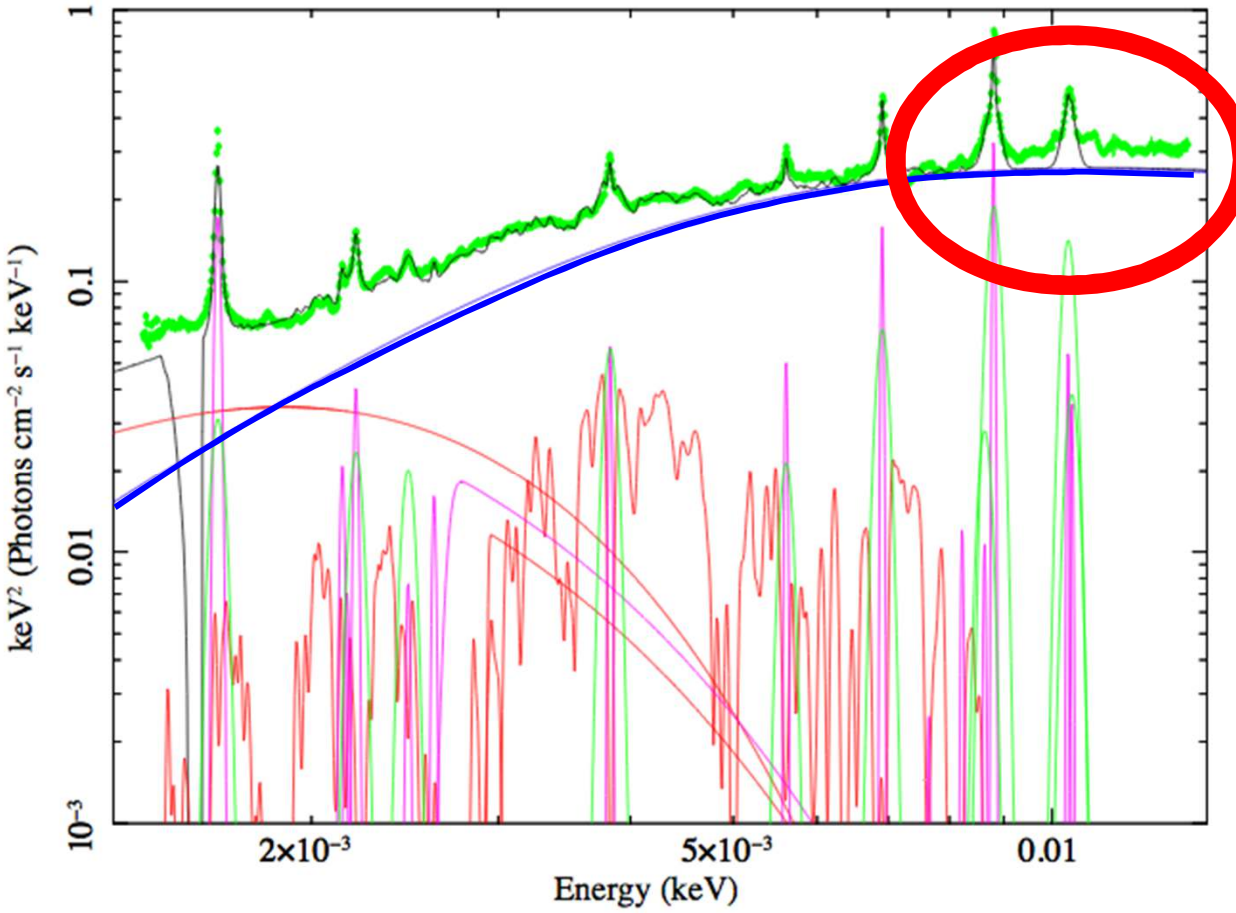
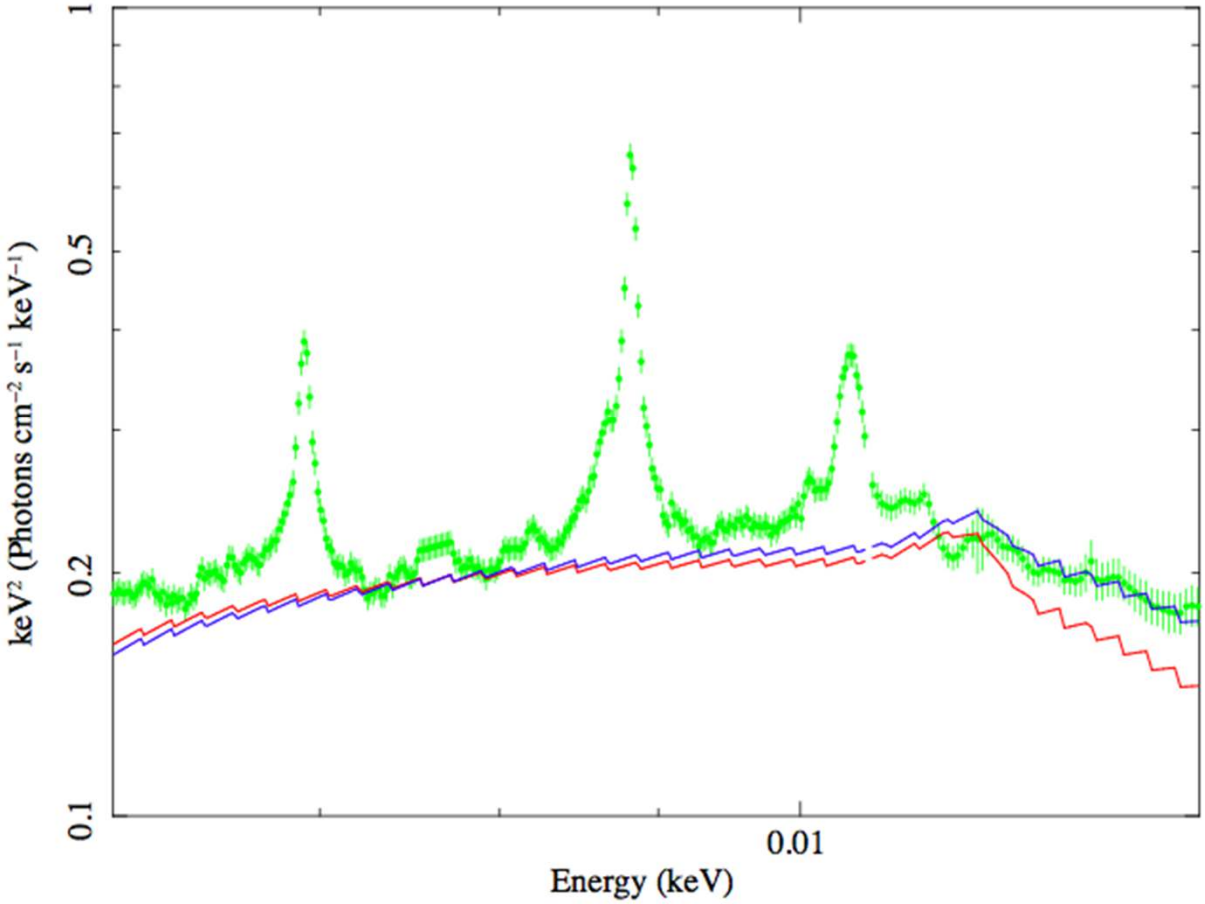


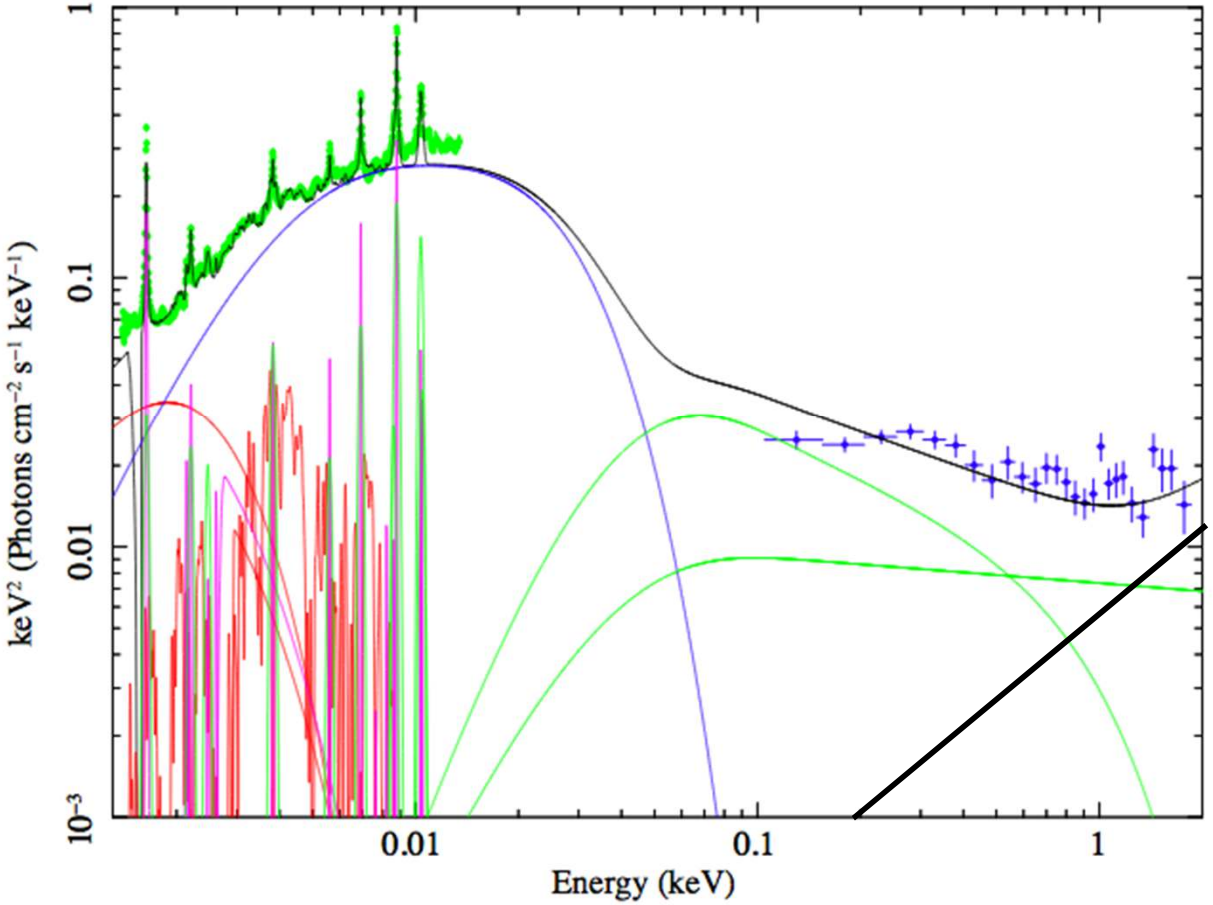
3C273: Amazing data

- disc dominated as need Rcor<6Rg to get through FUV data
- Hubeny – full disk models
- a*=0
- Underpredicts FUV
- a*=0.9 better
- Need mdot constant from R<6-100 Rg



3C273: Amazing data

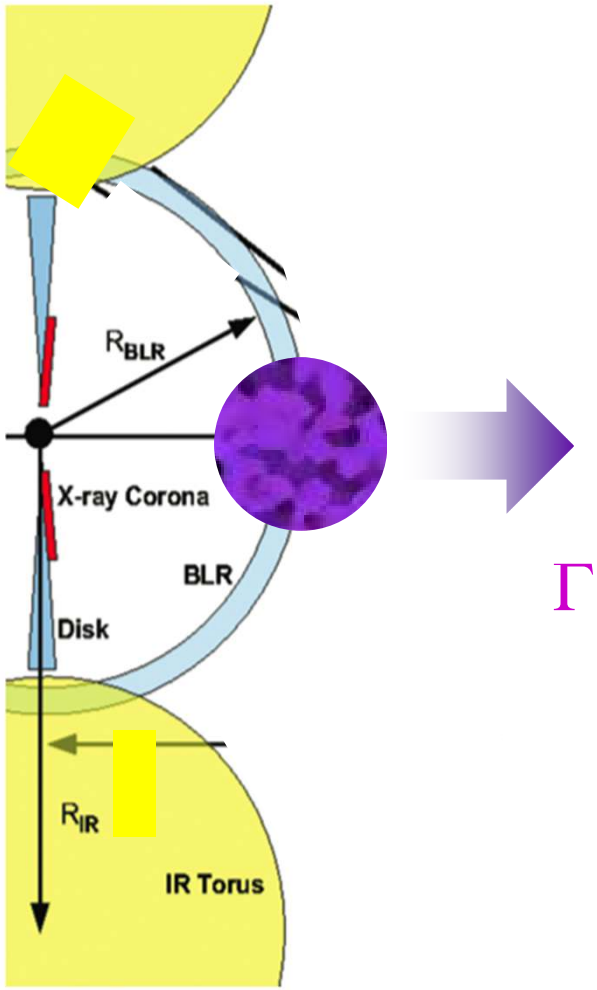
- But Rcor>Rmsco to make Lx
- Mdot = 9e26 though outer disc
- $L=\eta \dot{M} c^2$
- L_opt-UV+L_x =6-8e46 requires a*=0.7 (η=0.1)
- Black hole is spinning!! As expected from jet



FSRQ jets

- Add a jet!! Standard FSRQ from Ghisellini et al 2010
- Cooling by Sync, and Compton scattering of sync and BLR photons (and torus)
- make spectrum from self consistent N(γ) after cooling

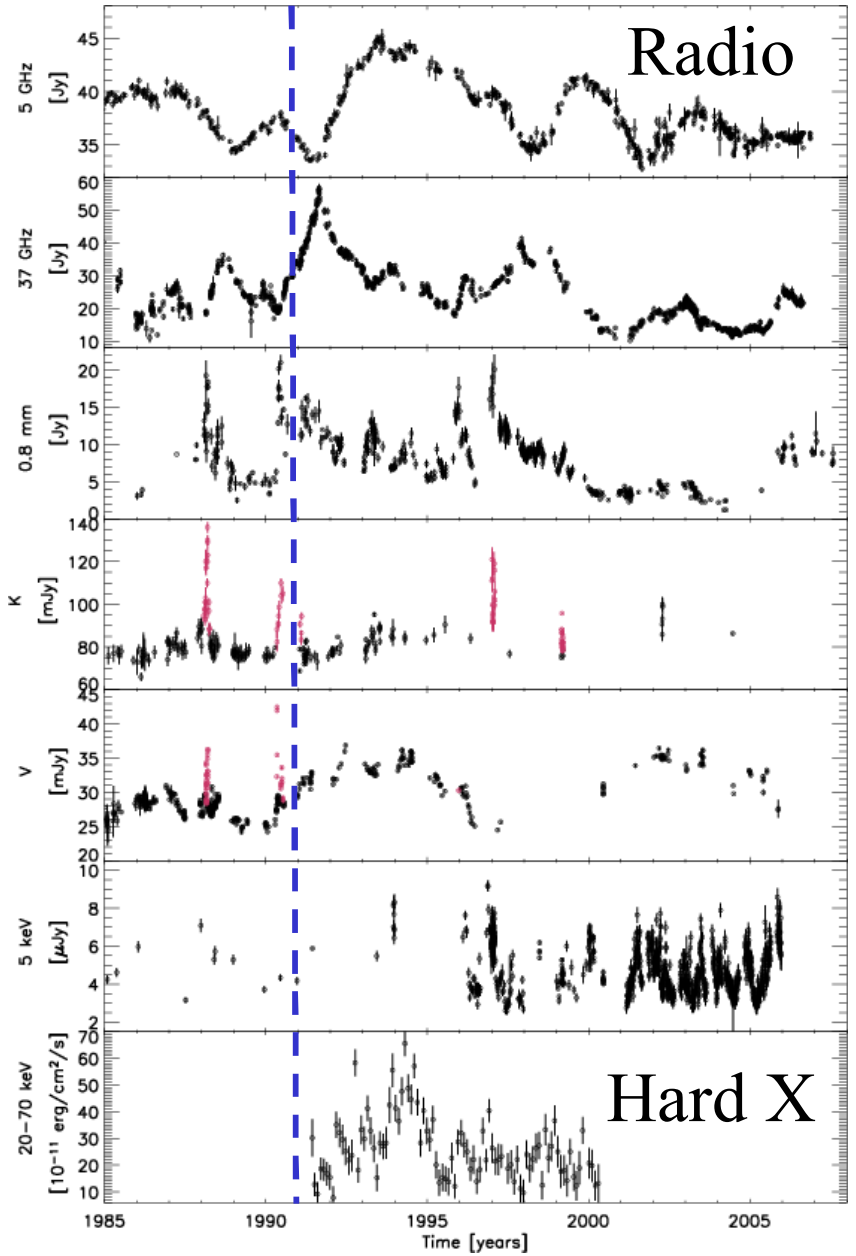
□ Γ=10±2 from VLBA



Ghisellini & Tavecchio 2009

Amazing data (>20 years)

- interpolate on other wavelengths – comes out very close to mean level



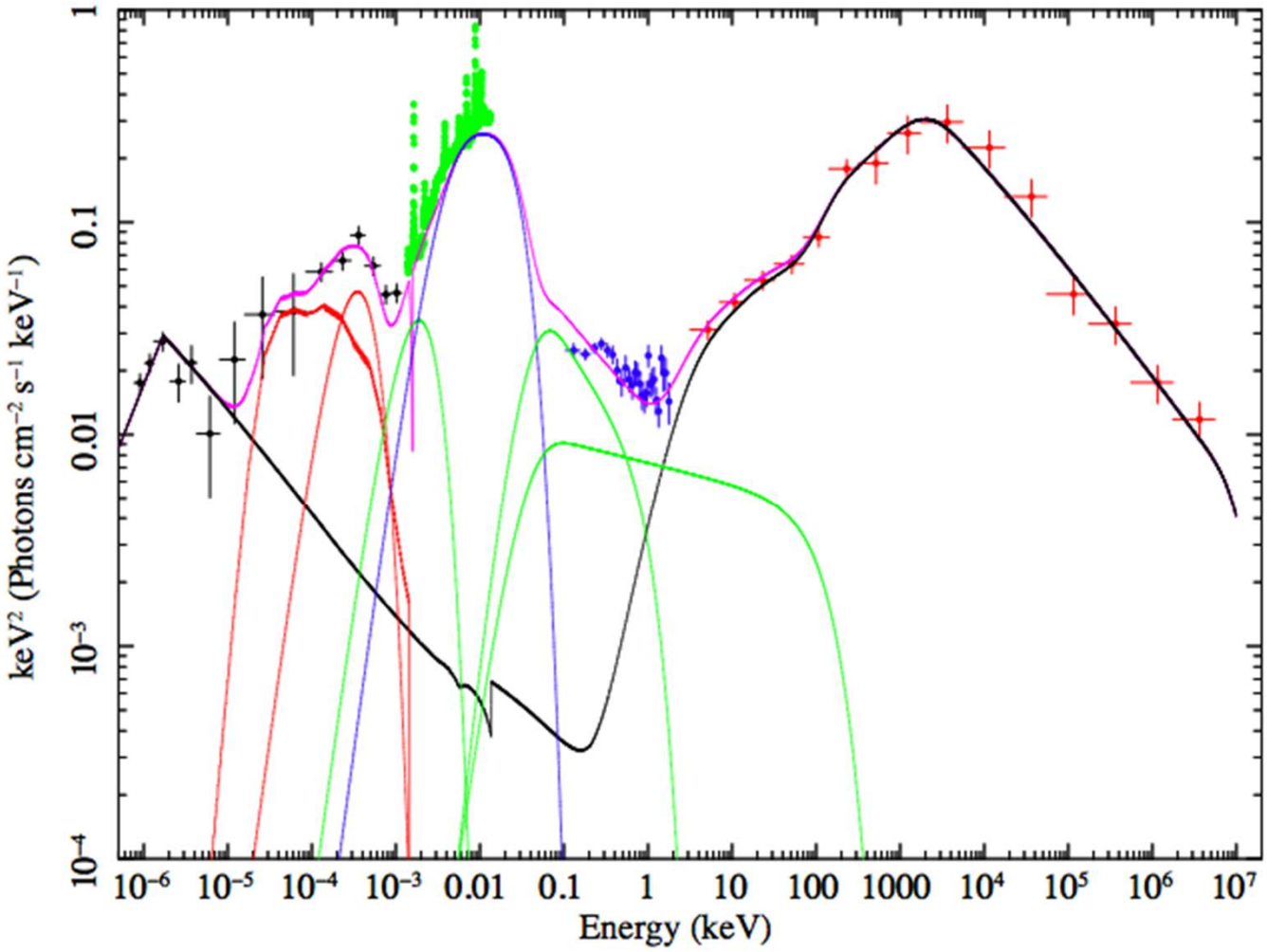
Soldi et al 2008

3C273: radio-TeV!

- Add a jet EC+SSC
- Ljet>3×10^{46} ergs/s
- Ltot=1.1×10^{47}
  $=\eta \dot{M} c^2$

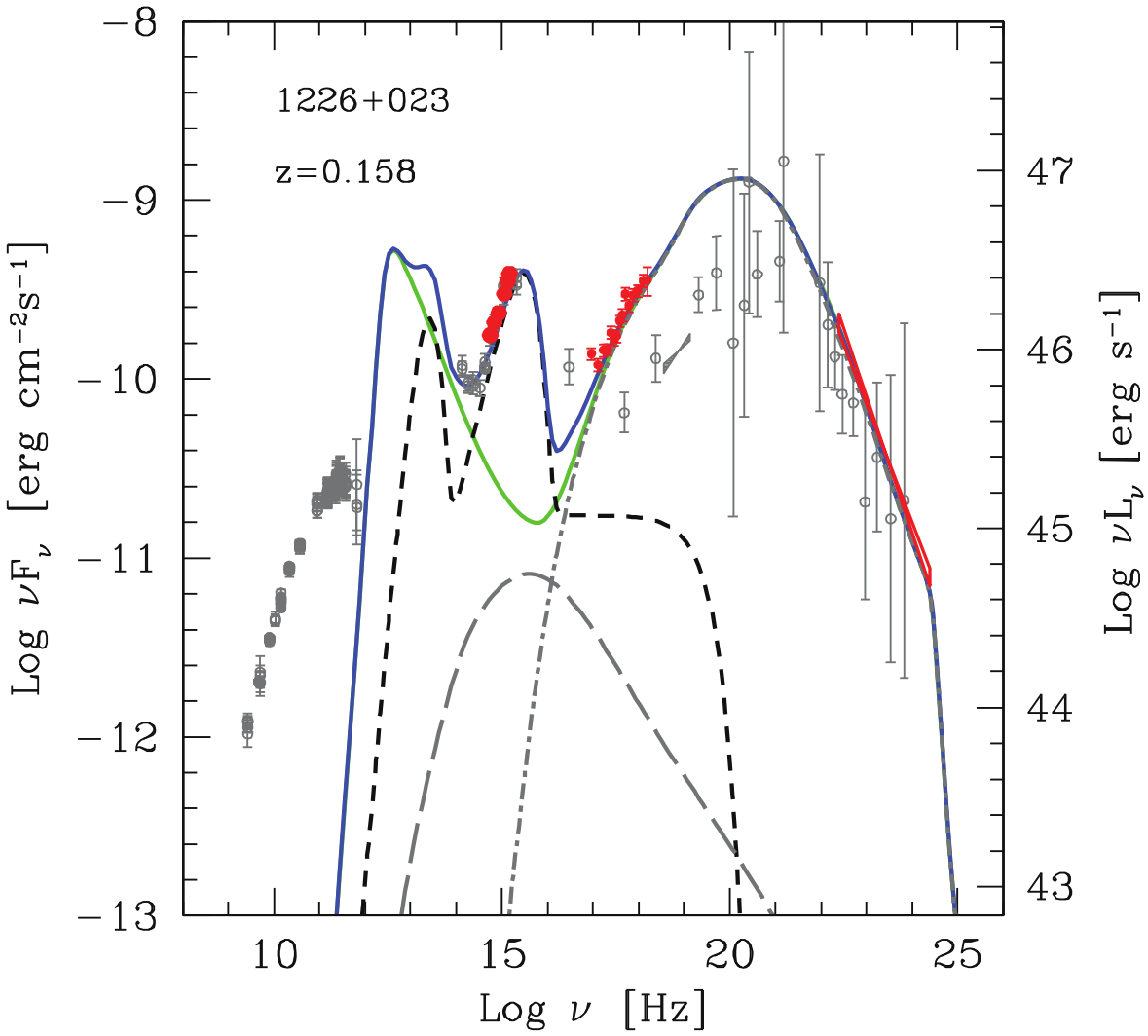
□ $\eta > 0.15$ i.e

- $a_* > 0.9$
- Very high spin…



Spin-jet paradijm

- Ljet = $\sum_i \pi\ r_{diss}^2\ \Gamma^2\ \beta\ U_i'$
- Dominated by protons with energy density $U_p' = m_p c^2 \int N(\gamma)\, d\gamma$ □ depends on γ_{min}
- Ghisellini had Ljet=3e47!!!
- 10x larger as $\gamma_{min} \sim 1$ (ours 40)



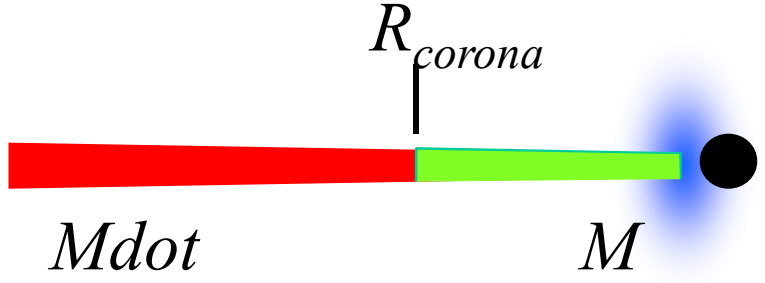
Ghisellini et al 2010

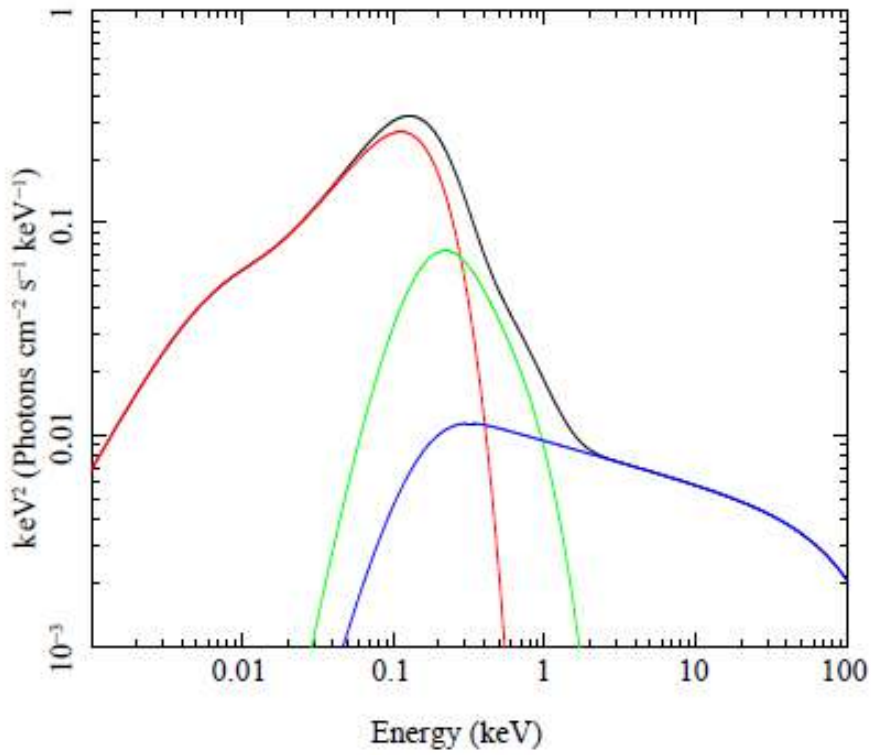
Conclusions: 3C273

- Fermi BL lacs show $\Gamma \sim 15$ jets rare
- Spin rare, spin common but B flux rare, retrograde rare?
- FSRQ Accretion flow – optical gives Mdot
- Total accretion power $L=\eta \dot{M} c^2$ (Davis & Laor 2009)
- Observed L(UV+X) already requires $a^*>0$
- And have L(jet) $\geq$ L(UV+X) - need $a_*>0.9$ in order to power both accretion flow radiation and jet (and wind?)
- FSRQ 3C273 is high spin, spin-jet paradijm (not retrograde!) but doesn't say if B field + spin or just spin
- There is actually enough accretion power to power the flow and the jet….
- ….but the MHD models all tap spin at these high a_*

Optxagnf: conserving energy!

- Outer standard disc with colour temp correction down to R_{corona} – quick way to model full photosphere results
- Then luminosity not completely thermalised to make soft X-ray excess ?
- Inner corona as in BHB
- NLS1: R_{corona} small so disc dominated, and Γ steep





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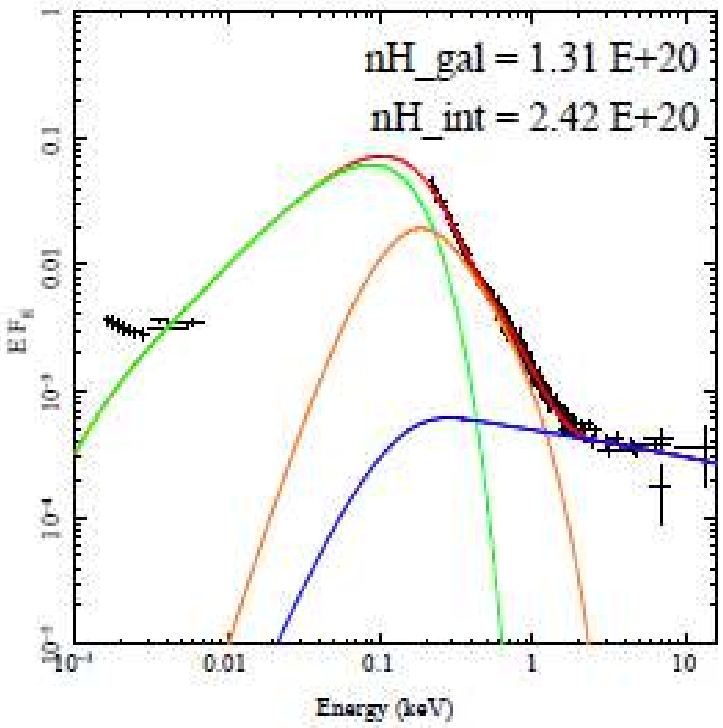
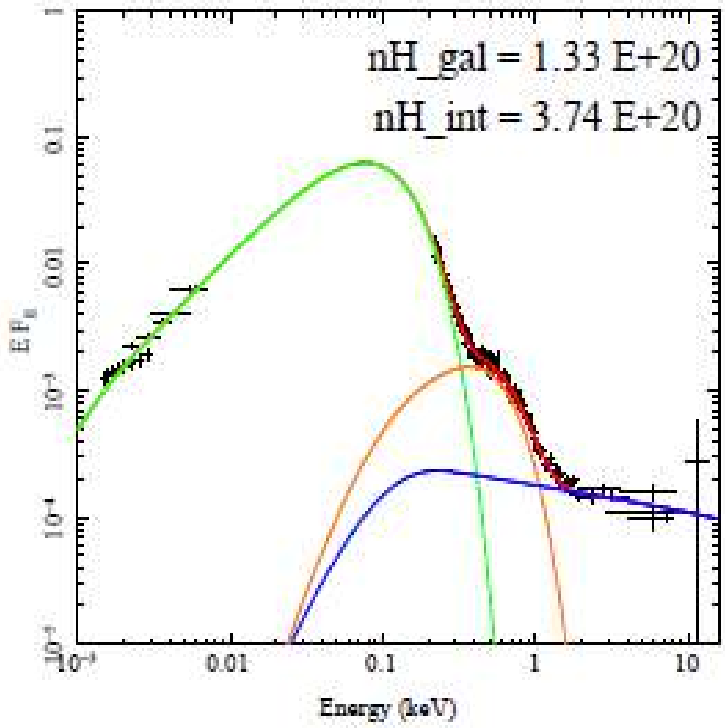
Simple NLS1

- Smaller R_{corona} means spectra are dominated by disc!
- NLS1 have small SX and big disc - NOT huge SX

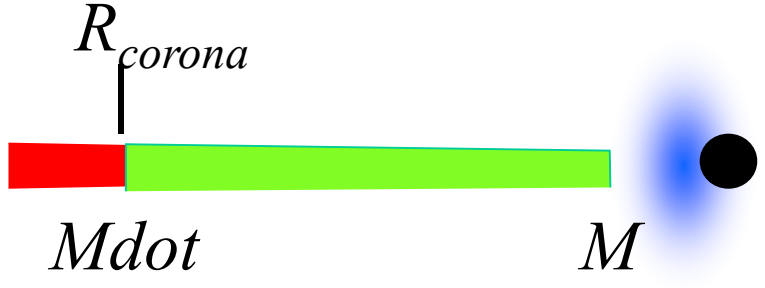


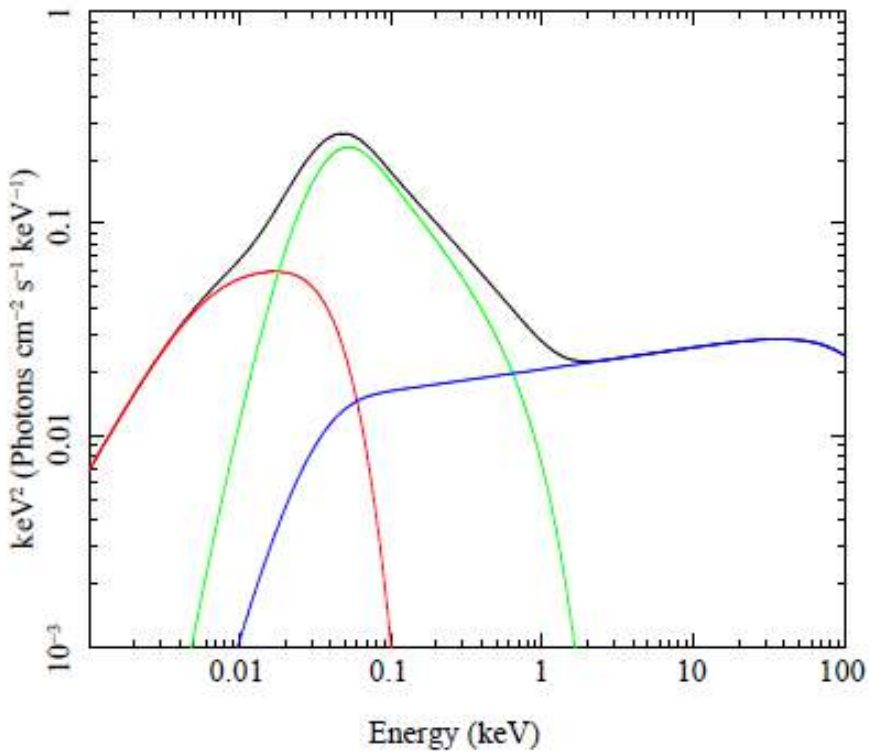


Jin et al 2012

Models conserving energy!!

- Outer standard disc with colour temp correction down to R_{corona}
- Then luminosity not completely thermalised to make soft X-ray excess ?
- Inner corona as in BHB
- difference is R_{corona} larger and Γ flat





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Optxagnf: conserving energy!

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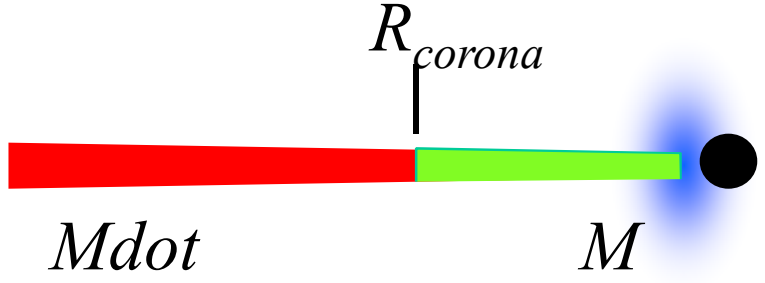

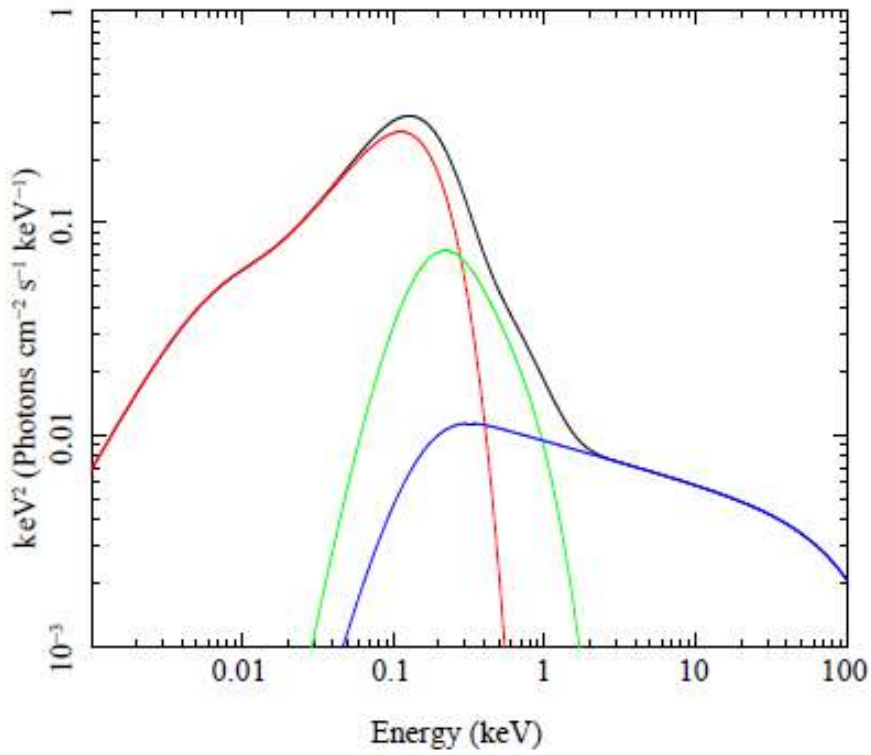

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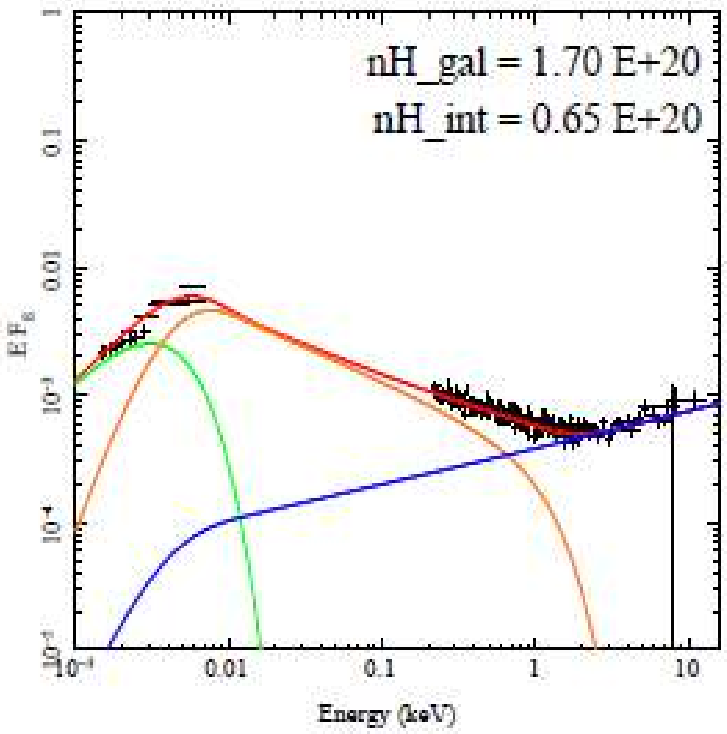
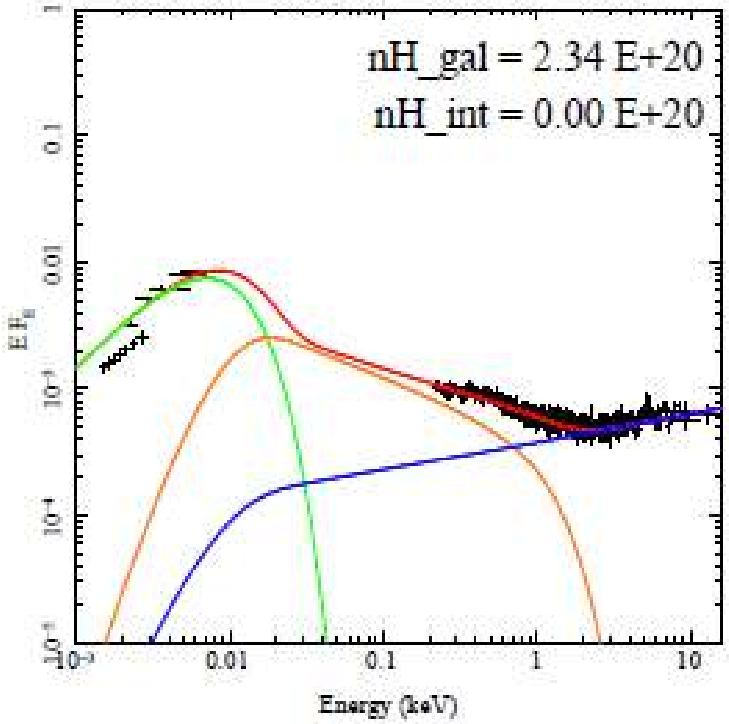
So what do AGN look like?

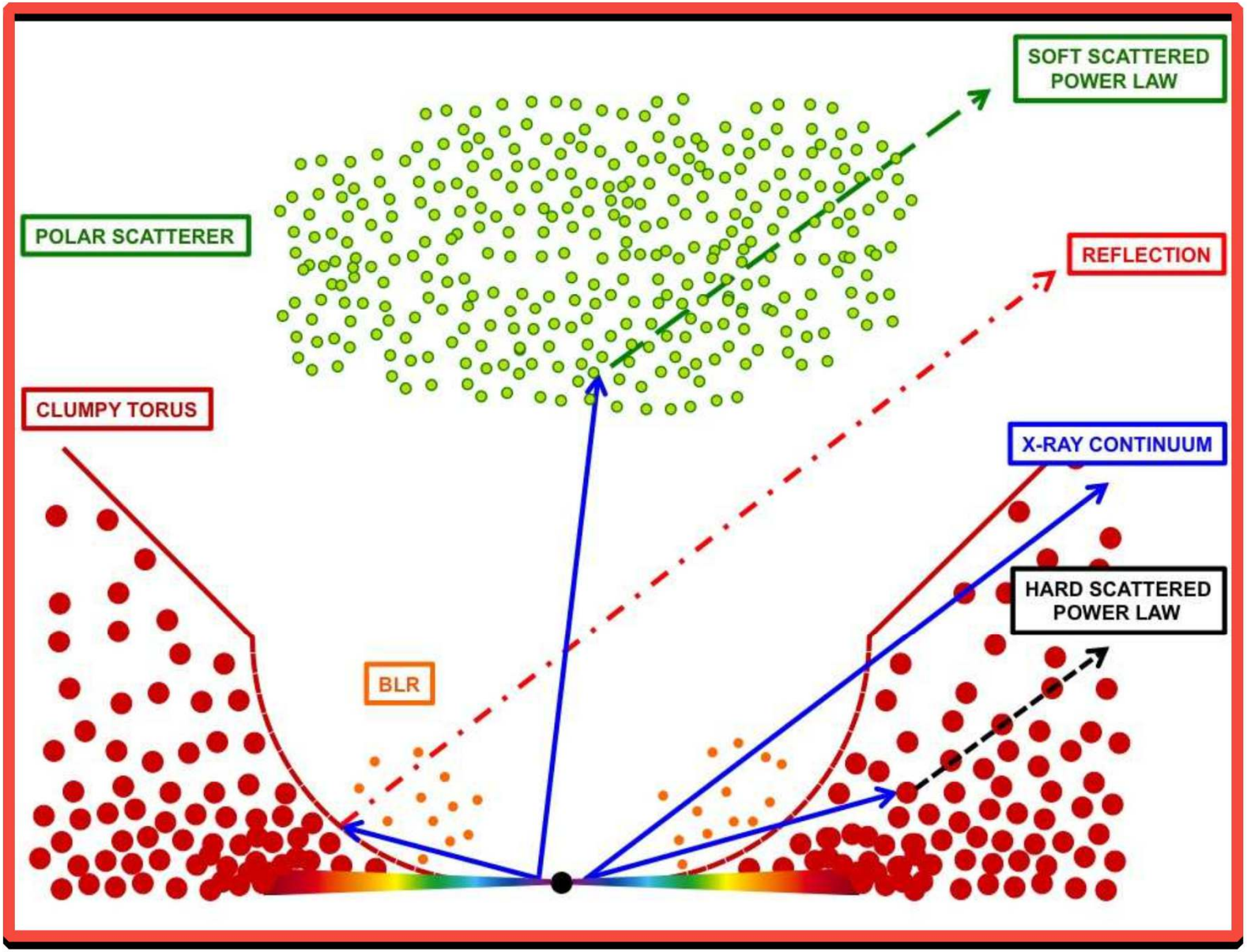
- More standard BLS1/QSO <M>~10^8, <L/LEdd>~0.1
- Not disc dominated so can't use to get BH spin



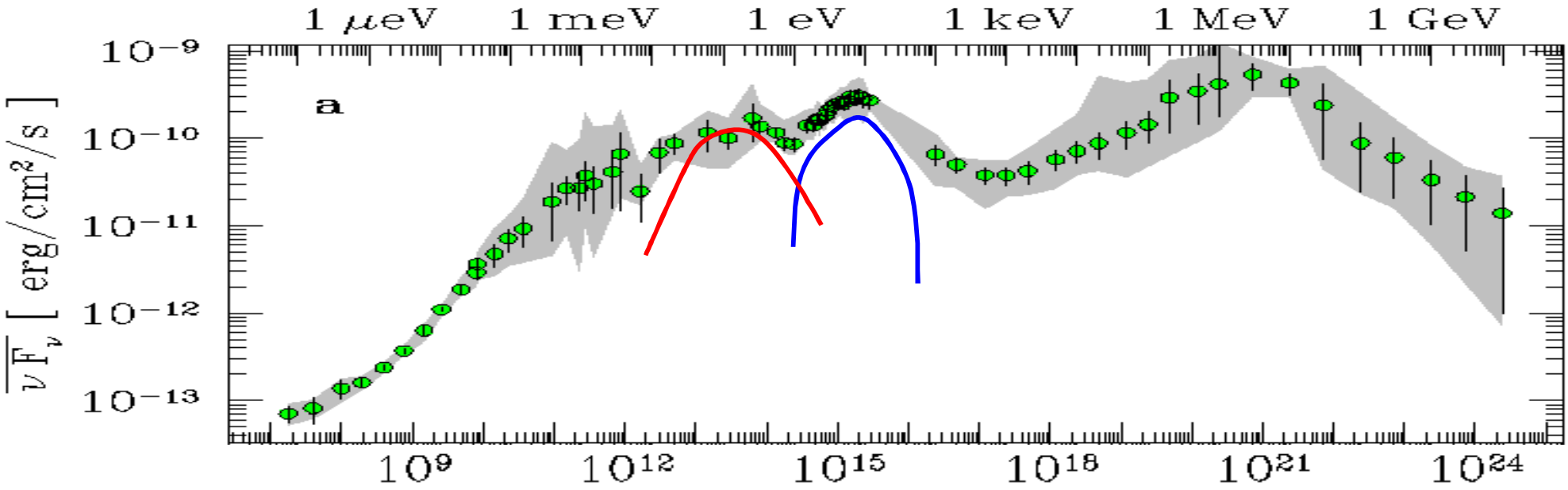


Jin et al 2012

So what do AGN look like?

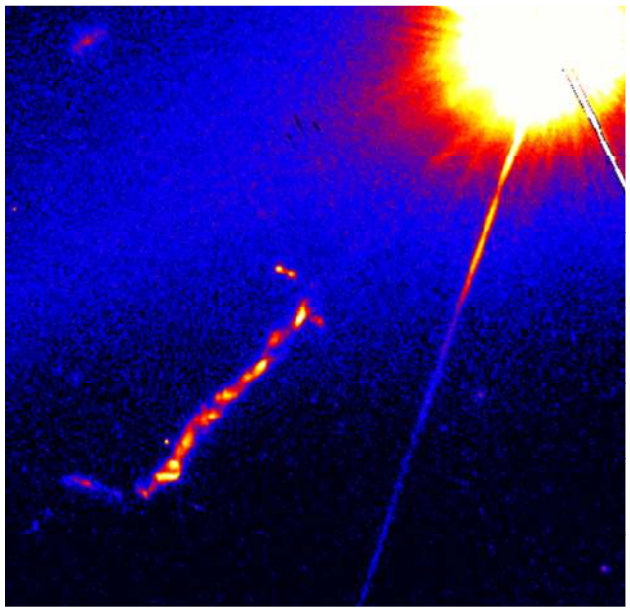


3C273 Nearest bright QSO with jet



Soldi et al 2008

- Accretion disc
- IR dust



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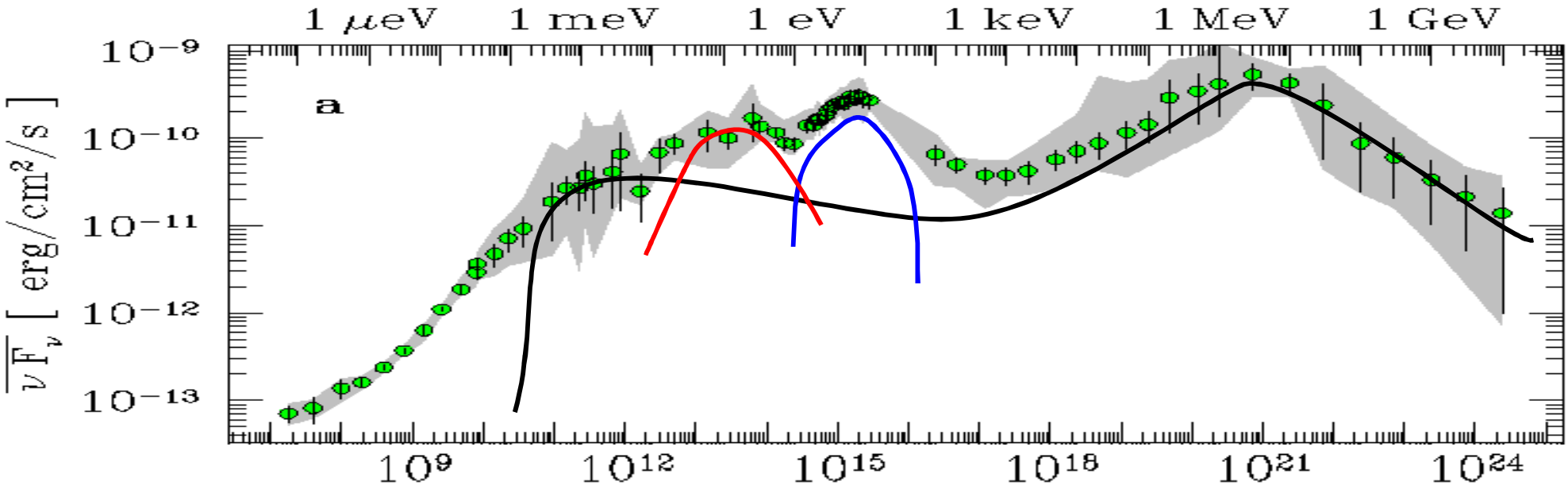
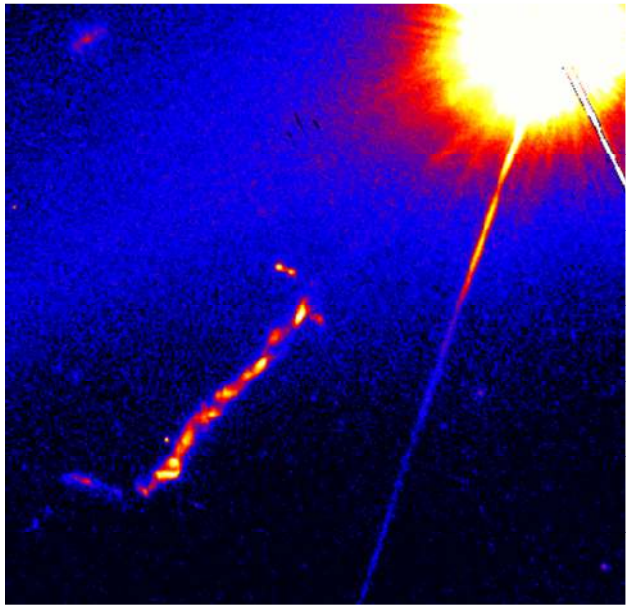
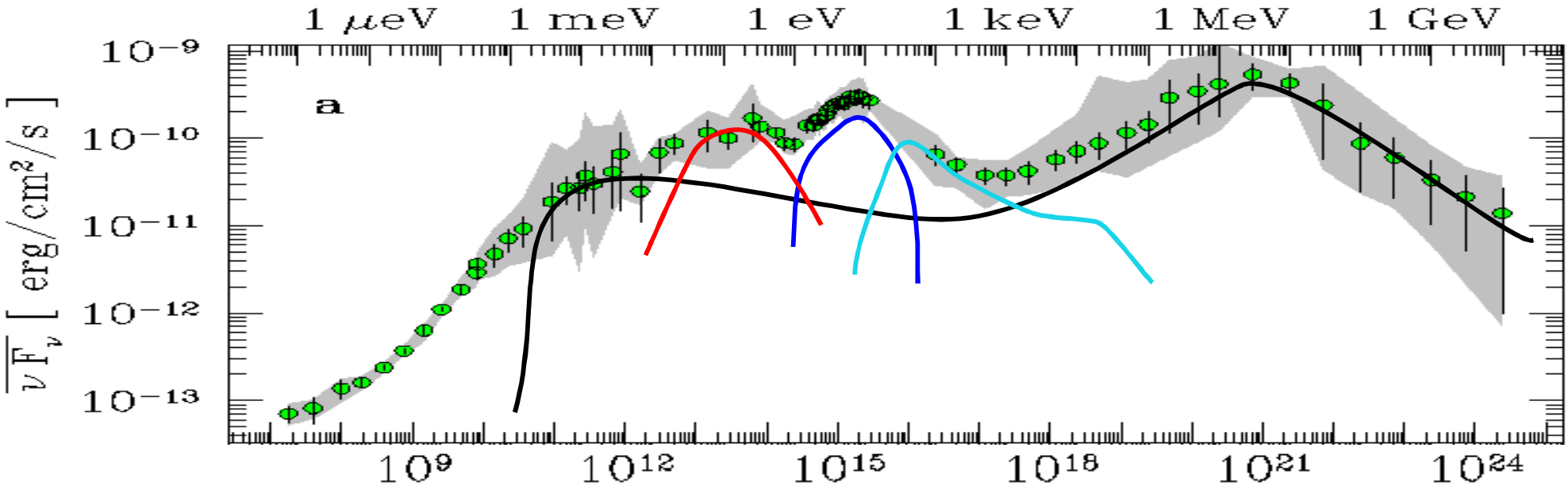


- Accretion disc
- IR dust
- Base of compact jet

Soldi et al 2008

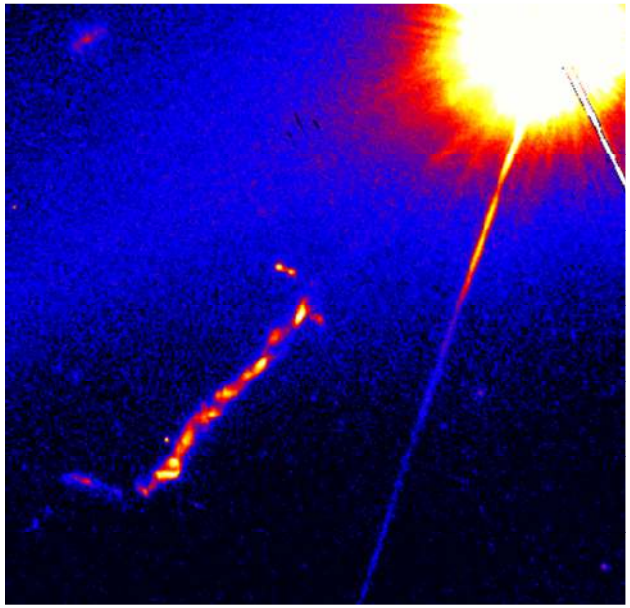


3C273 Nearest bright QSO with jet

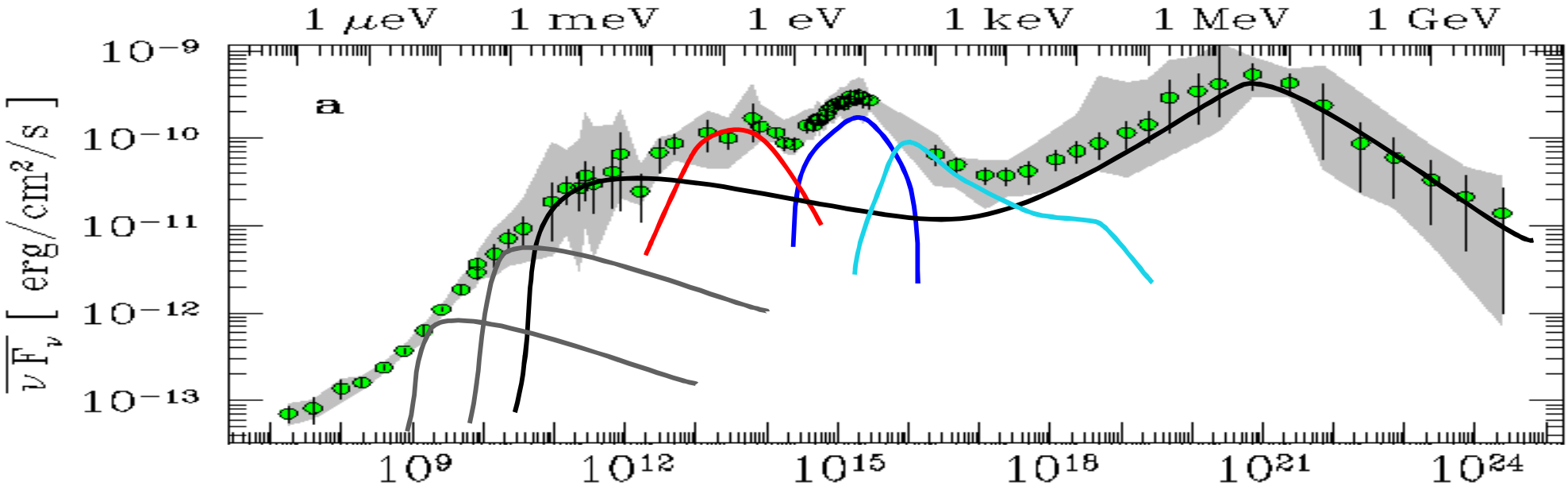


- Accretion disc + flow
- IR dust
- Base of compact jet

Soldi et al 2008

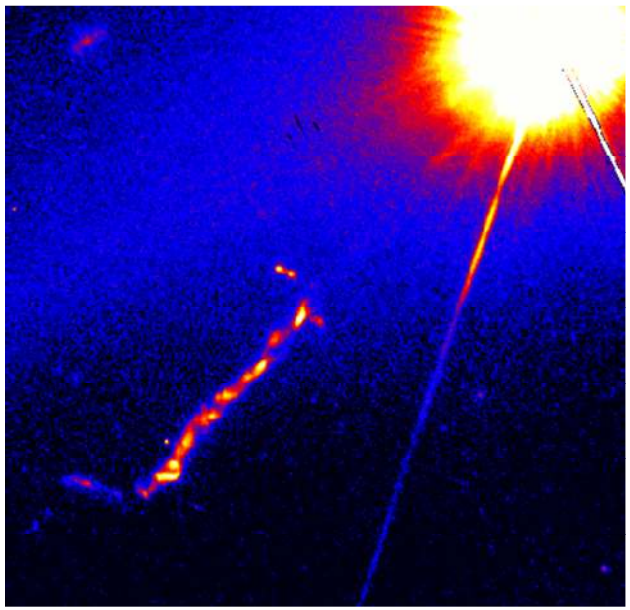


3C273 Nearest bright QSO with jet

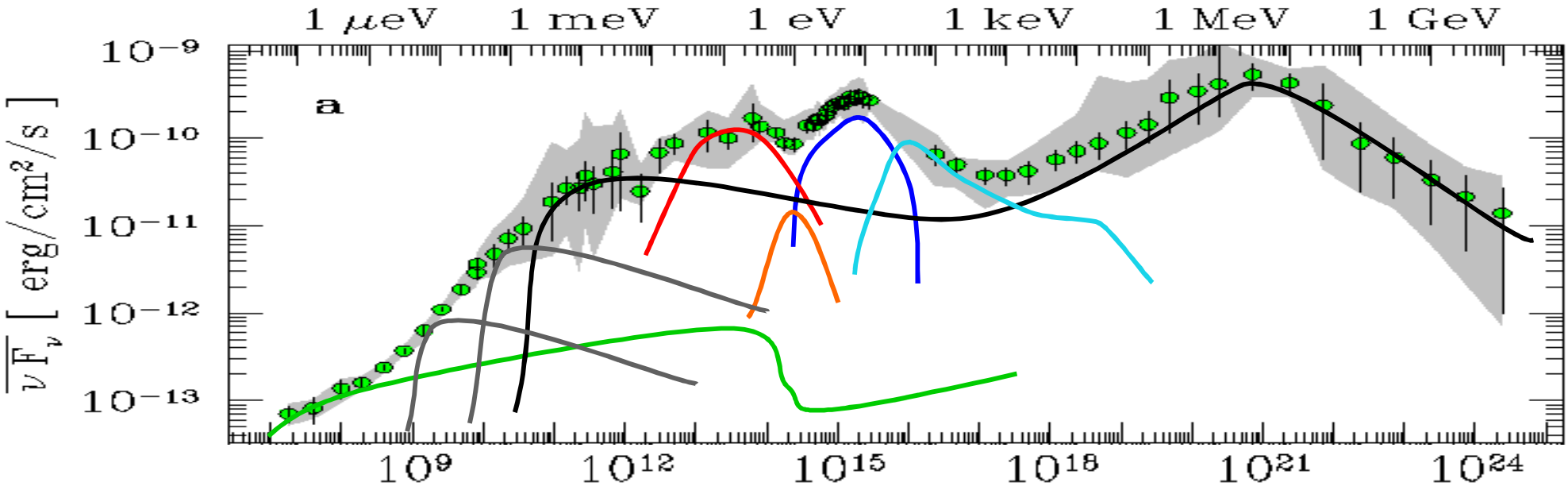


- Accretion disc + flow
- IR dust
- Base of compact jet
- Conical compact jet

Soldi et al 2008



3C273 Nearest bright QSO with jet



Soldi et al 2008

- Accretion disc + flow
- IR dust
- Base of compact jet
- Conical compact jet
- Host galaxy (E4)
- Extended jet