Understanding the physics behind the Blazar Sequence using a realistic model for jet emission

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Talk Outline

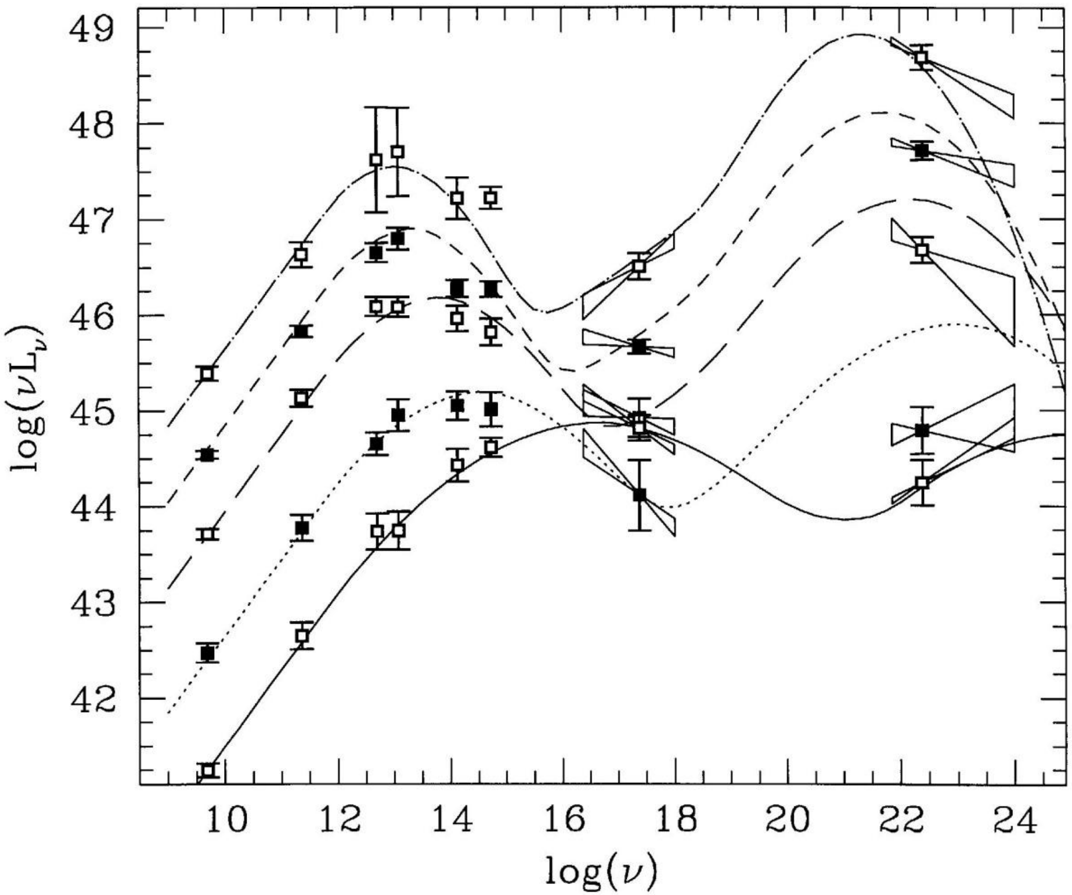
- Outline of our knowledge of jet structure: observations, MHD simulations.
- Developing a realistic, extended model for jet emission.
- Constraining jet properties using blazar spectra.
- Understanding the physics behind the blazar sequence.

Observations and simulations of jets

- VLBI observations of M87 show the jet starts with a parabolic shape and this transitions to conical at $10^5 r_s$ (Asada and Nakamura 2011).
- Simulations show a jet which starts magnetically dominated and parabolic (Mckinney et al. 2006...).
- The jet stops accelerating at equipartition and tends to become ballistic and conical (Komissarov et al. 2009).
- MHD simulations are computationally intensive so radiation processes are ignored, we need an emission model which can compare jet structure and dynamics to observations of jets.

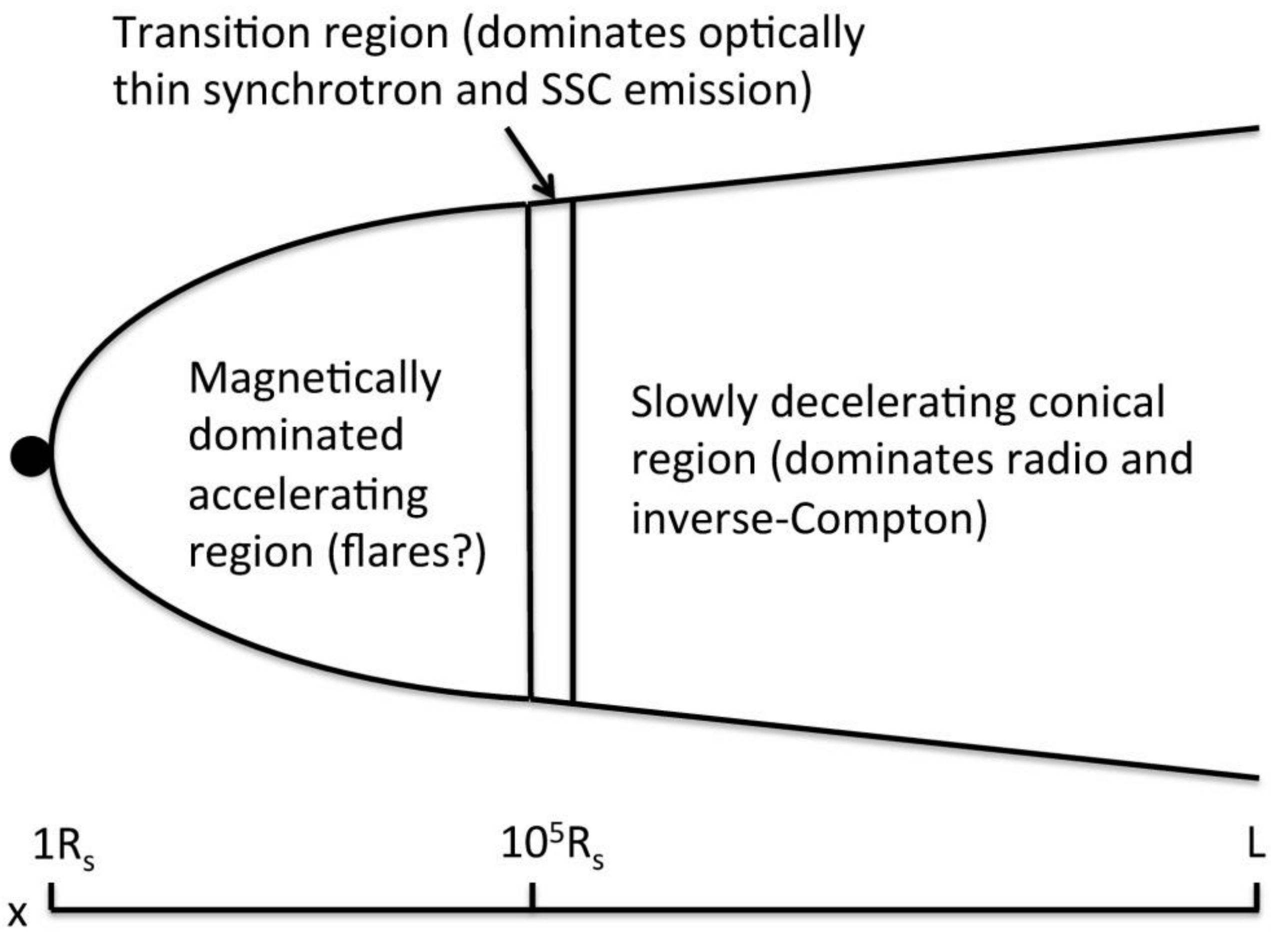
The Blazar Sequence

- Blazar spectra change systematically with jet power.
- BL Lacs - low power with high peak frequency emission.
- FSRQs - high power with low peak frequency emission and high Compton-dominance.



Fossati et al. 1998

A realistic, extended model for jet emission



Potter and Cotter 2013a

Calculating the synchrotron and inverse-Compton emission

- Divide the jet into cylindrical sections.
- Calculate the synchrotron and inverse-Compton emission from a population of non-thermal electrons each section.
- Integrate the synchrotron and pair-production opacity to a section and sum the emission from all sections.
- Include treatment of relevant external photon sources: accretion disc, BLR, dusty torus, NLR, starlight and CMB.

Conservation Laws

- Conserve total relativistic energy-momentum including electron radiative and adiabatic losses and in situ acceleration as they travel along the jet.

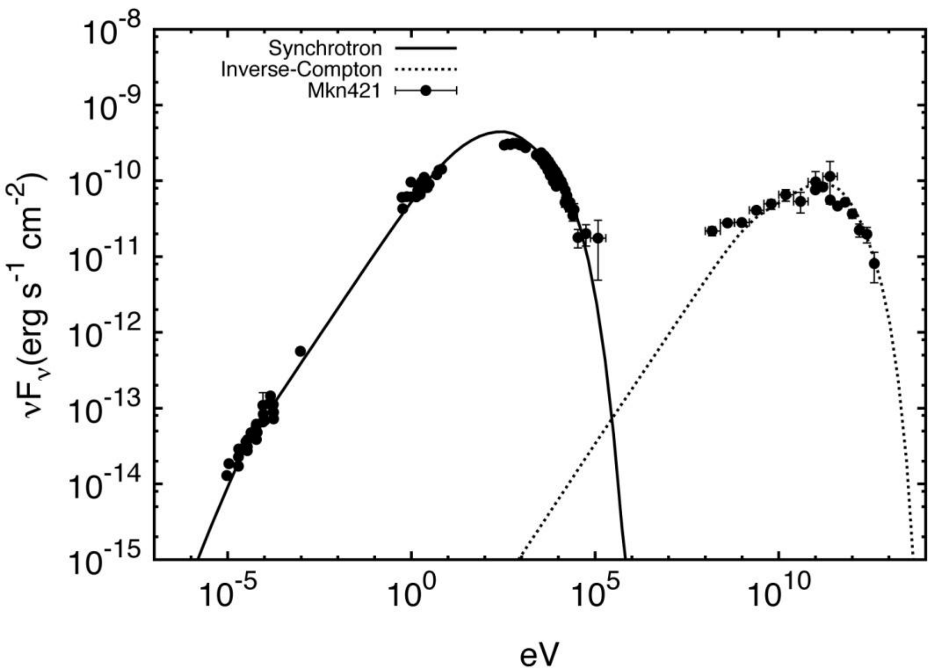
$$\nabla_\mu\left(T^{\mu\nu}_{EM} + T^{\mu\nu}_{p} + T^{\mu\nu}_{rad}\right) = 0$$

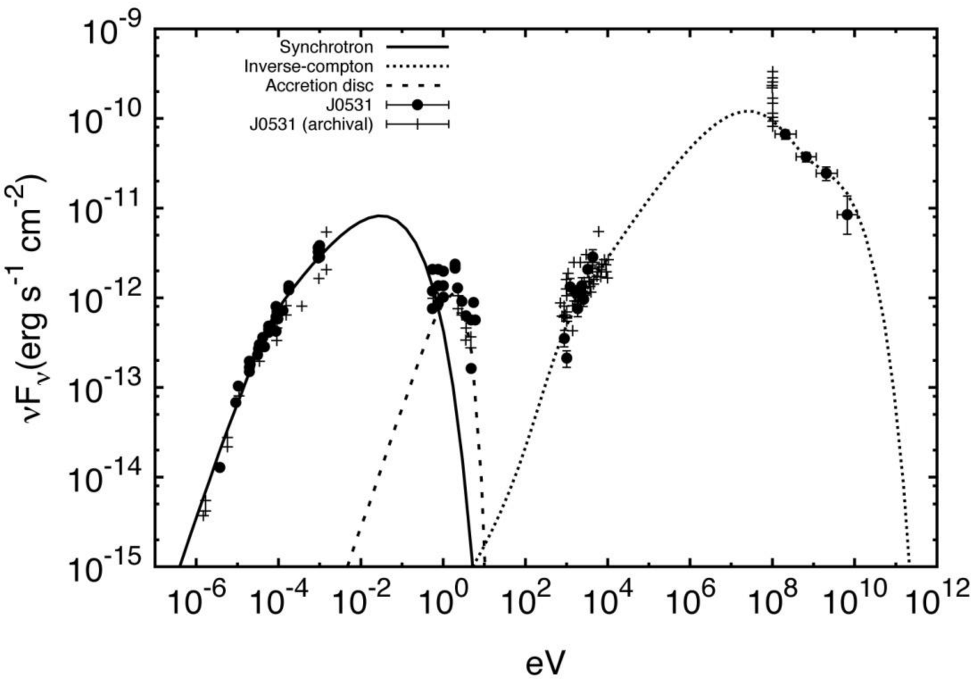
- Conserve particle flux along jet.

$$\nabla_\mu(\rho U^\mu) = 0$$

Fitting the model to spectra

- For the first time the model fits to both radio and gamma-ray blazar observations simultaneously.

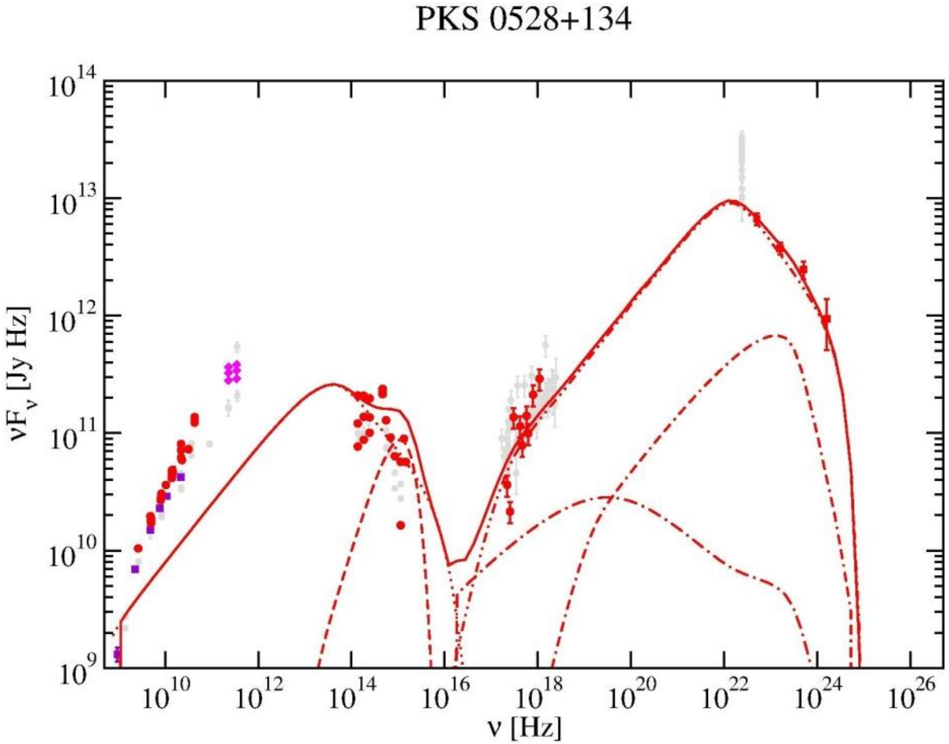


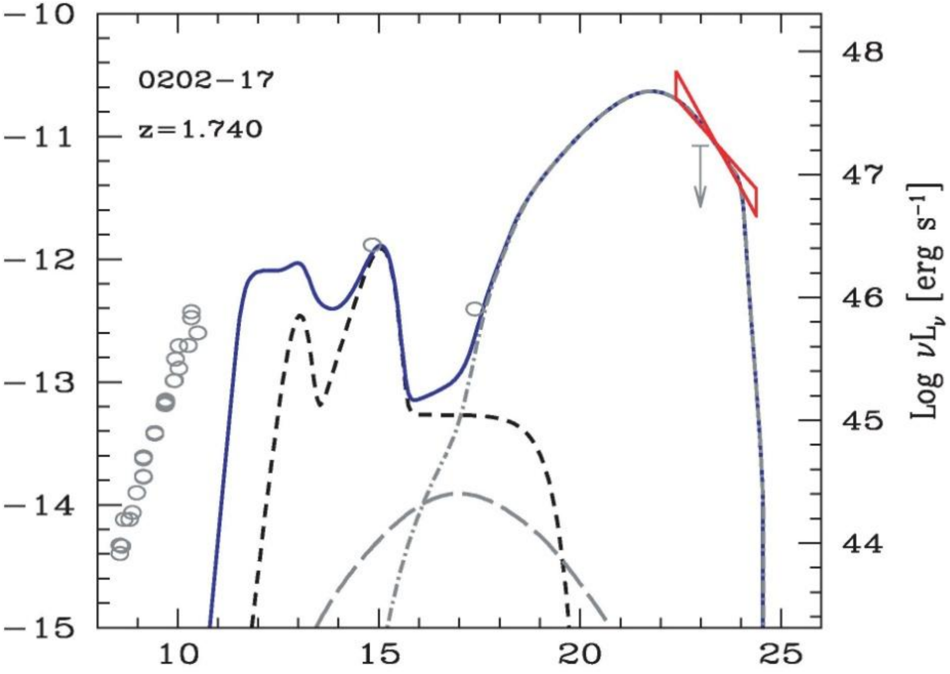


Potter and Cotter 2013b and 2013c (in prep.)

Comparison to existing models

- Existing compact emission models are successful at high frequencies but cannot reproduce the observed radio emission produced by the large scale structure of the jet.

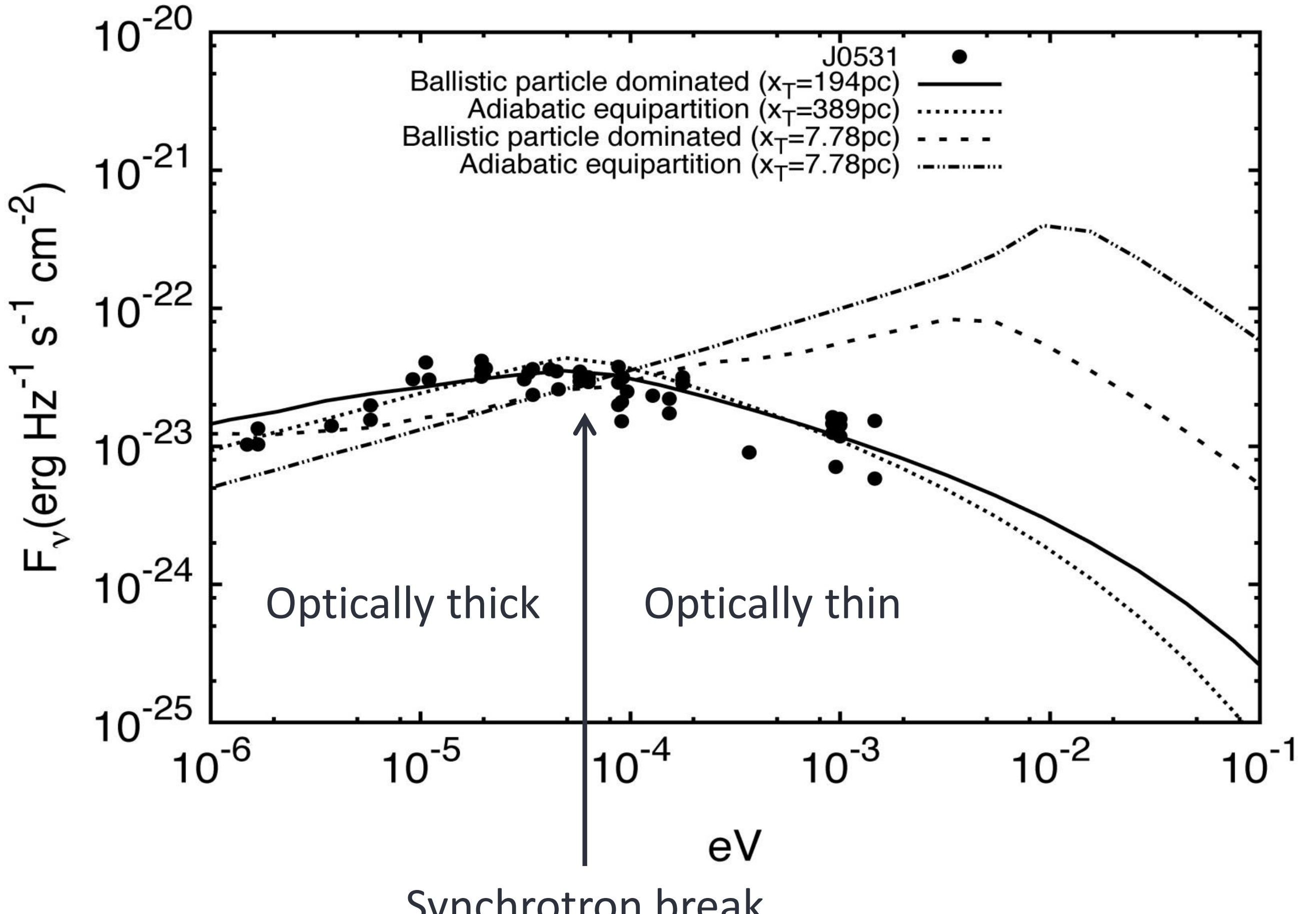




Bottcher et al. 2013

Ghisellini et al. 2009

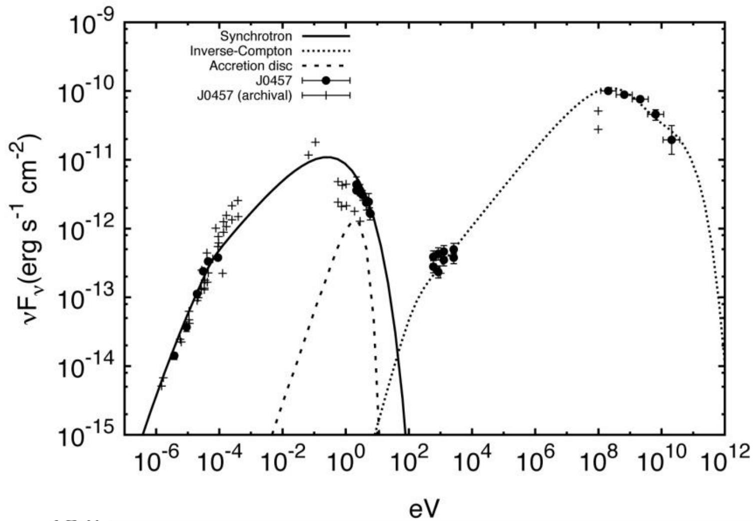
Constraining the radius of the transition region

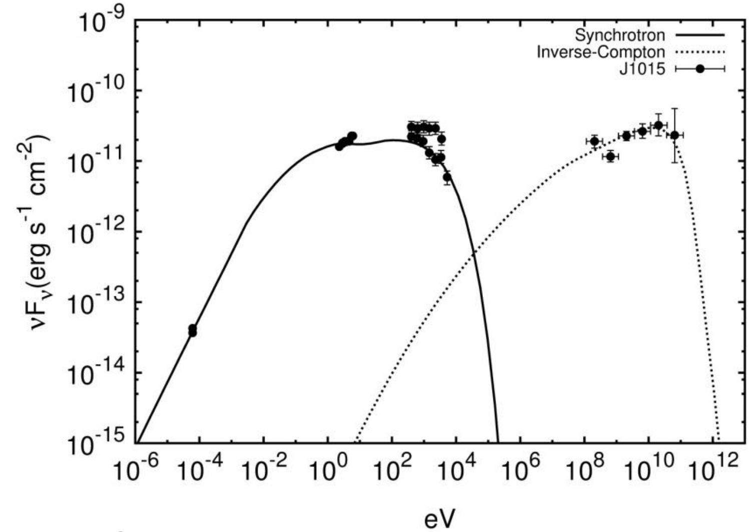


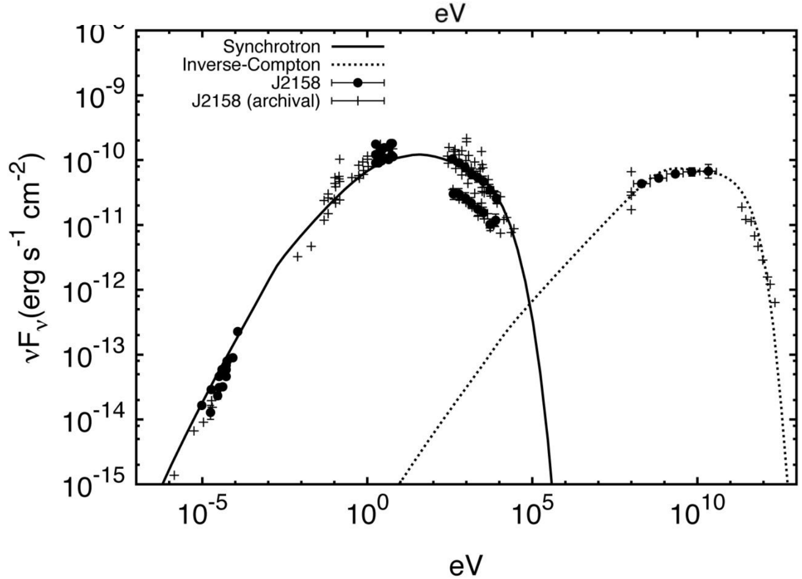
- R_{trans}=2000r_s
- D_{trans}=$10^5 r_s$

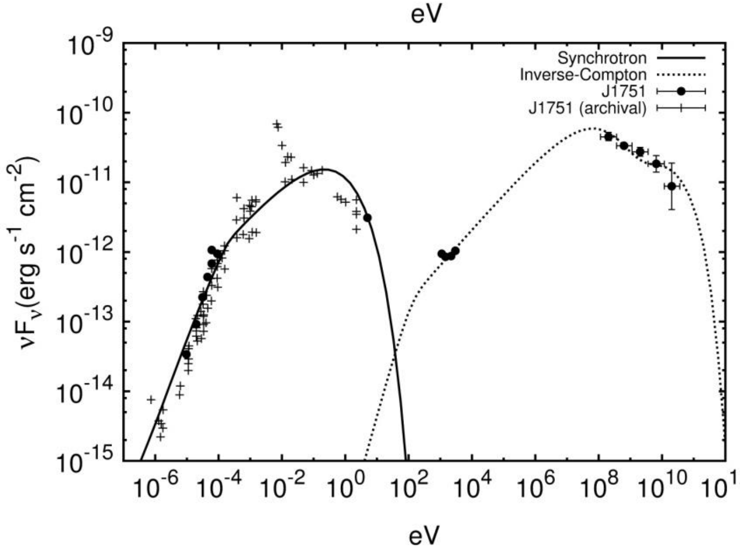
Potter and Cotter 2013b

Fitting to the sample of 36 FERMI blazars







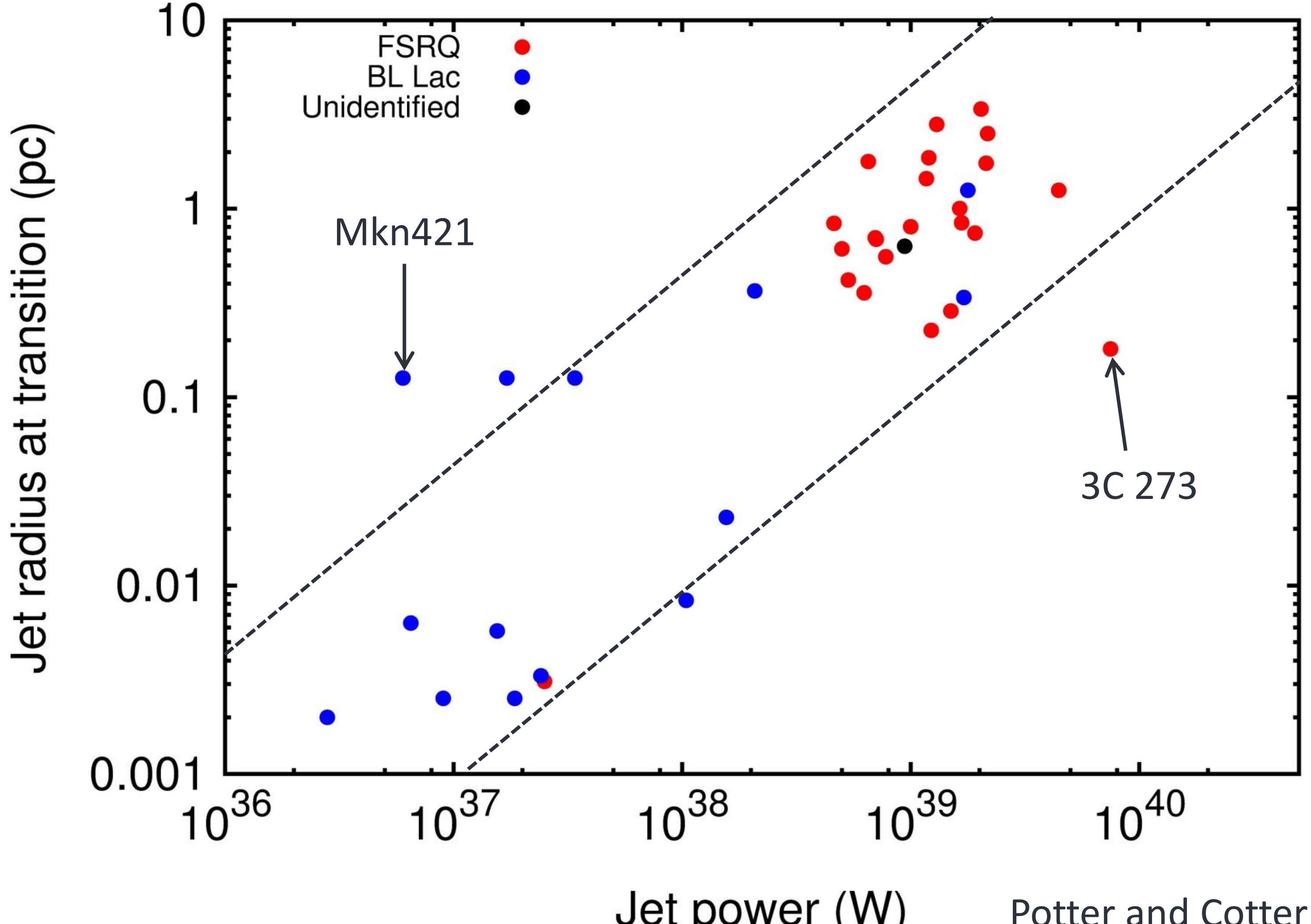


Potter and Cotter 2013b and Potter and Cotter 2013c (submitted)

Jet properties

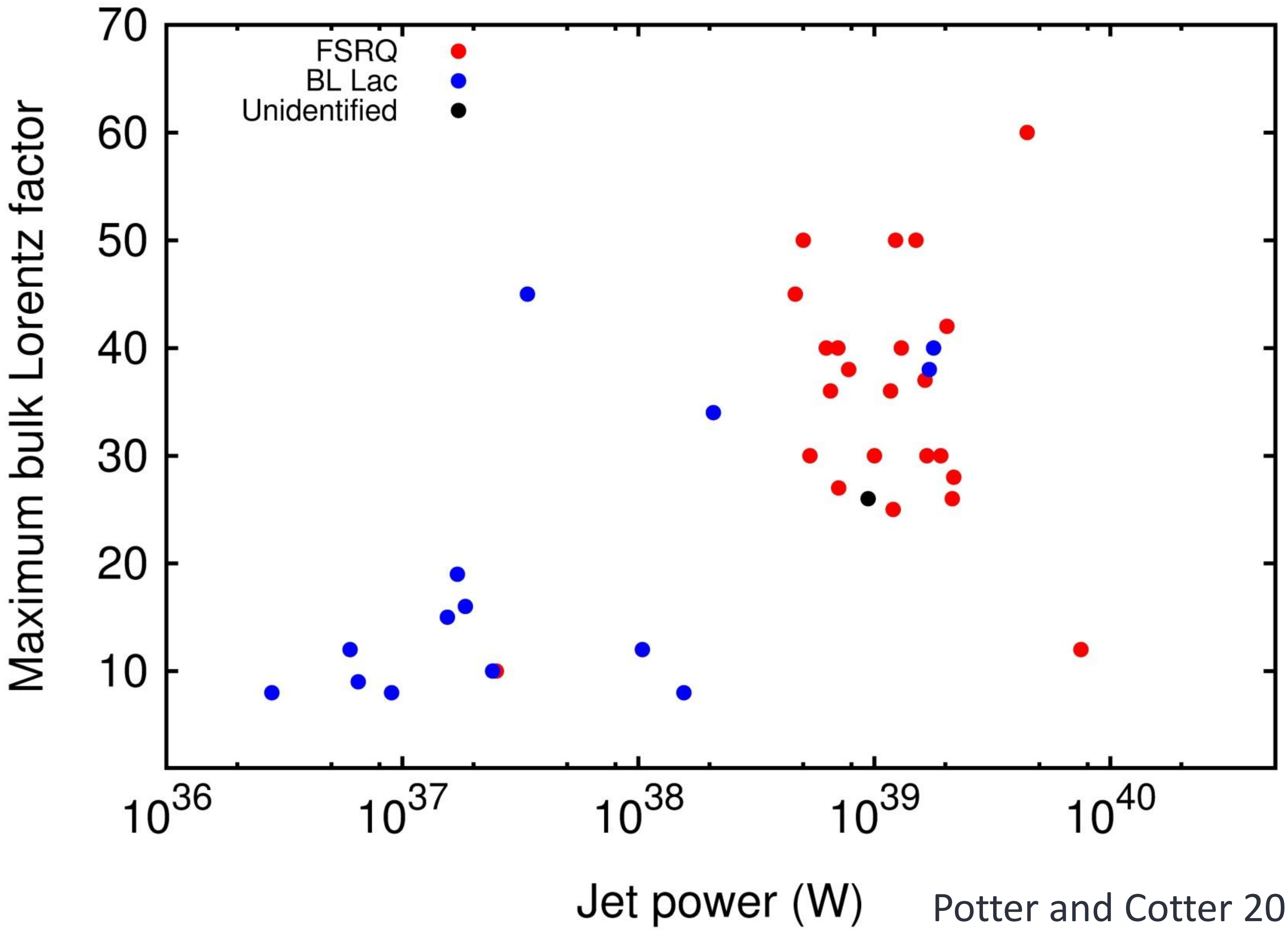
- At these large distances compatible with the synchrotron break, the quiescent IC emission of FSRQs is well fitted by scattering of CMB and NLR photons if the jets have large bulk Lorentz factors (~30).
- The radio spectra of FSRQs are systematically steeper than BL Lacs.
- BL Lac radio observations are well fitted by a conical ballistic equipartition jet.
- FSRQs require a jet which is initially in equipartition becoming particle dominated at large distances (as suggested in David Meier's talk).

An approximately linear relation between jet power and transition region radius!



Potter and Cotter 2013d (in prep.)

Jet power vs. bulk Lorentz factor



Potter and Cotter 2013d (in prep.)

The physics behind the blazar sequence

- Low power BL Lacs have high magnetic field strengths at the transition region so high peak frequency synchrotron emission and SSC.

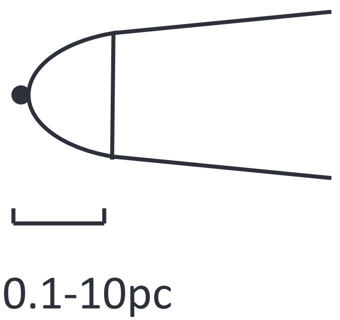
$$B^2 \propto \frac{Jet\ power}{Radius^2} \propto \frac{1}{Jet\ power}$$

- High power FSRQs have lower B fields at transition region so lower peak frequencies and less powerful synchrotron emission relative to inverse-Compton.
- FSRQs have larger bulk Lorentz factors so Compton dominance is due to scattering external CMB and NLR photons outside the BLR and dusty torus.

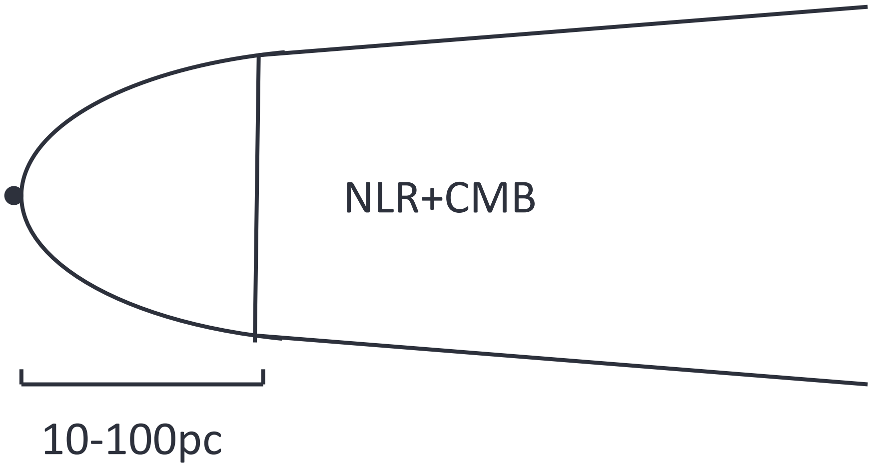
Summary

- Blazar spectra are very well fitted by a model with a parabolic accelerating base transitioning to a conical jet at equipartition.
- The radius of the jet at equipartition appears to scale linearly with jet power.

BL Lacs (10^{36}-$5x10^{38}$W)



FSRQs ($5x10^{38}$-10^{40}W)



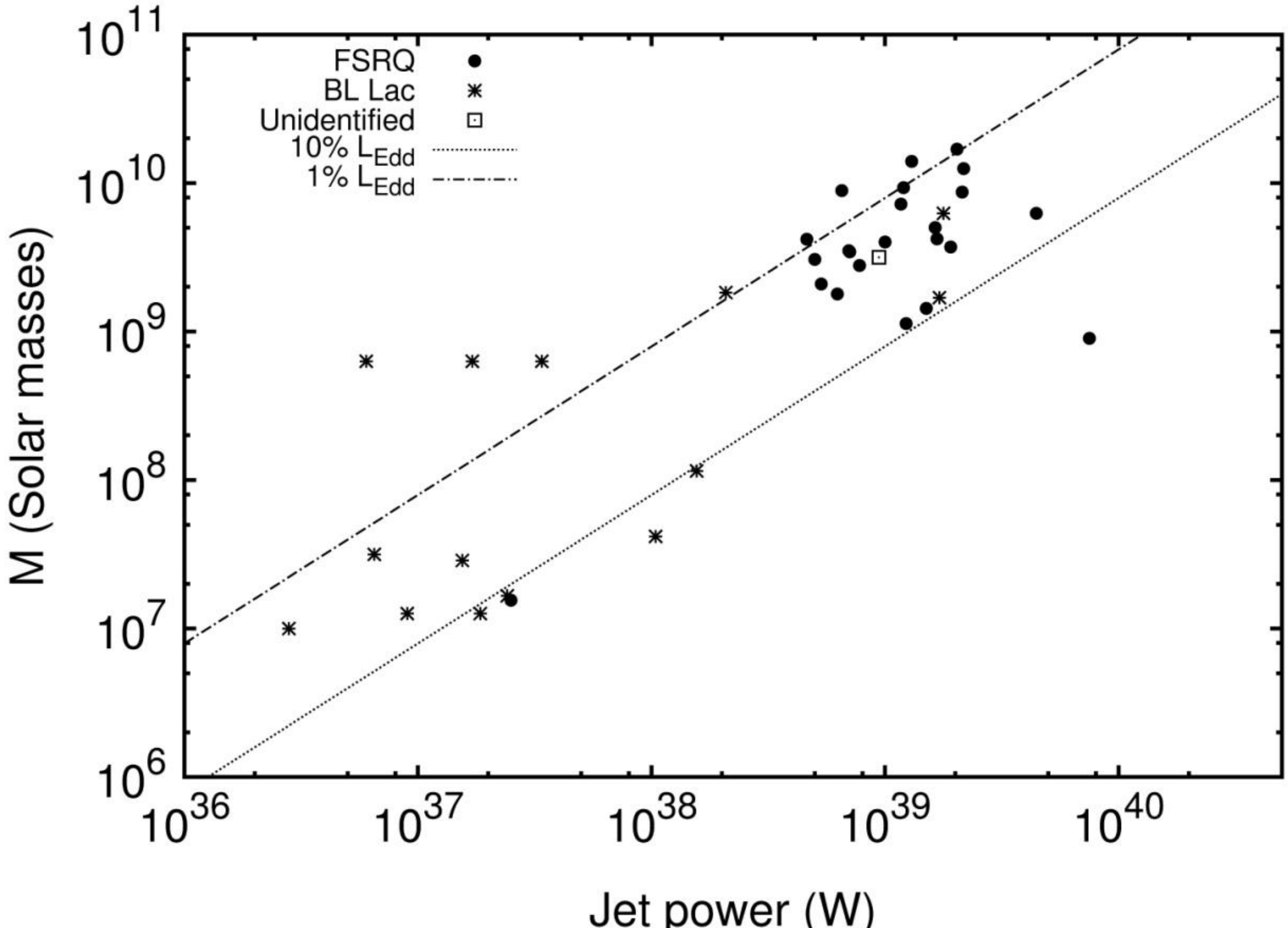
Physical interpretation

- Mass loading determines final bulk Lorentz factor at equipartition, results suggest FSRQ jets are lighter initially.
- Consistent with a dichotomy in accretion modes between BL Lacs (hotter, thick disc) and FSRQs (thin disc).
- In addition we find that the radio spectrum of FSRQs are systematically steeper than in BL Lacs.
- FSRQs are well fitted by a jet which becomes more particle dominated at large distances while BL Lacs maintain equipartition fraction (as David Meier suggested from morphology in simulations).
- This suggests a quantitative difference in FSRQ and BL Lac jets and could also be valid for FRI and FRII dichotomy.

A universal Jet geometry or accretion mode dichotomy?

- If we assume a M87 geometry scaled linearly with BH mass we find an inferred BH mass for each fit.
- This leads to...

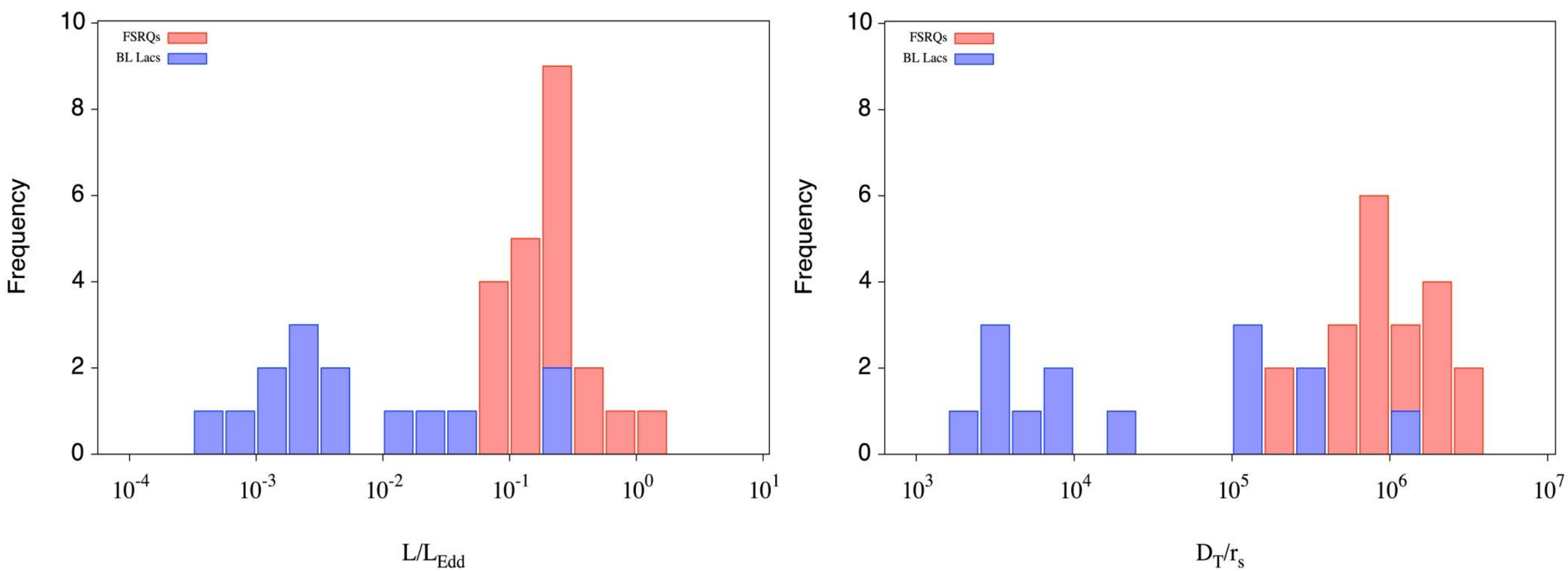
A linear relation between jet power and black hole mass?



Potter and Cotter 2013d (in prep.)

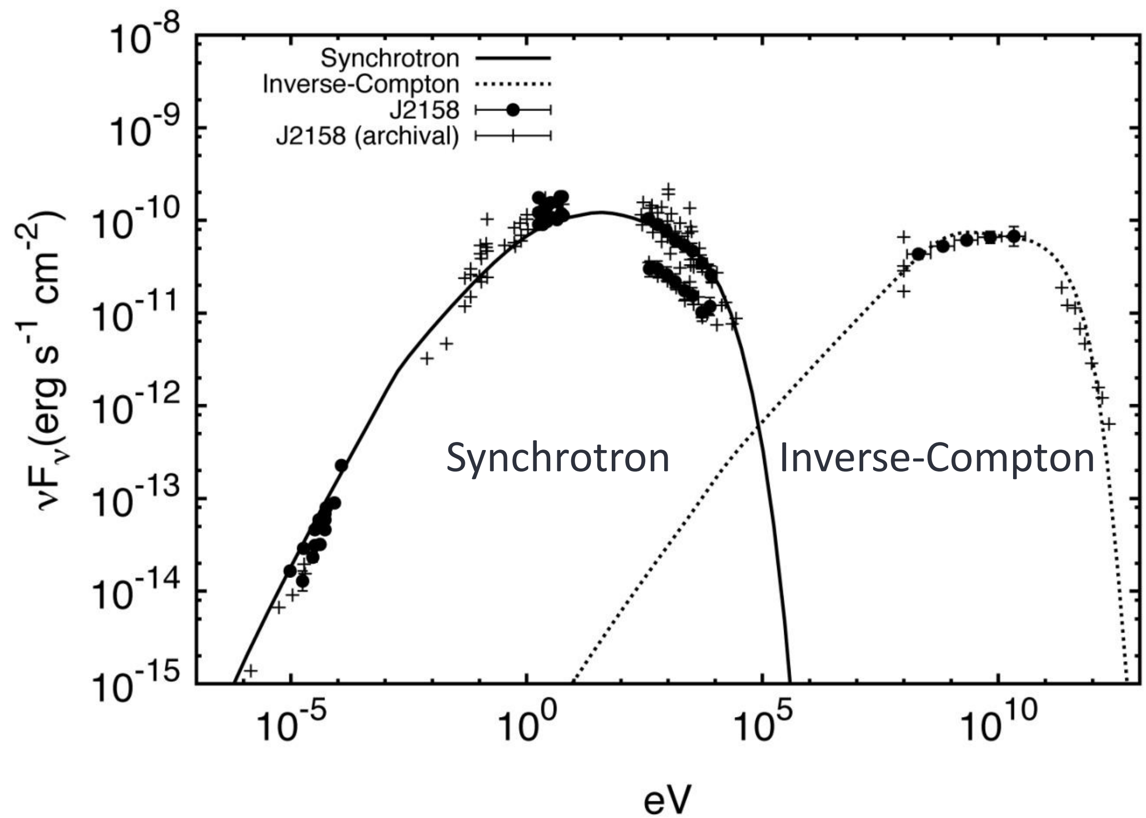
Alternatively… an accretion mode dichotomy

- Assuming a fiducial mass MBH=$5 \times 10^8 M_{Sun}$ for all FSRQs and BL Lacs.
- The distance in r_s at which the jet comes into equipartition is much larger in FSRQs than BL Lacs.
- The Eddington accretion rate is much lower in BL Lacs than FSRQs.



Blazar spectra

- Blazar spectra are characterised by two bumps, well fitted by synchrotron and inverse-Compton emission of high-energy elec



What are blazars?

- AGN with jets pointing close to our line of sight.
- Jet emission is Doppler-boosted so often outshines that of the host galaxy.
- So they give us a good idea of the emission processes and plasma conditions in the jet.

Why model the emission?

- There seems to be a reasonable consistency between observations, simulations and theory.
- Unfortunately the information we posses comes from observing emission and so we really need a model for jet emission to test our understanding by comparing to observations of real jets.
- Most existing models of blazar emission use one or two spherical blobs and aren’t able to reproduce the radio emission which would offer additional constraints on the jet properties.