Radio Loud AGN Unification: Connecting Jets and Accretion

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Invited Talk
The Innermost Regions of Relativistic Jets and Their Magnetic Fields
Granada, Spain
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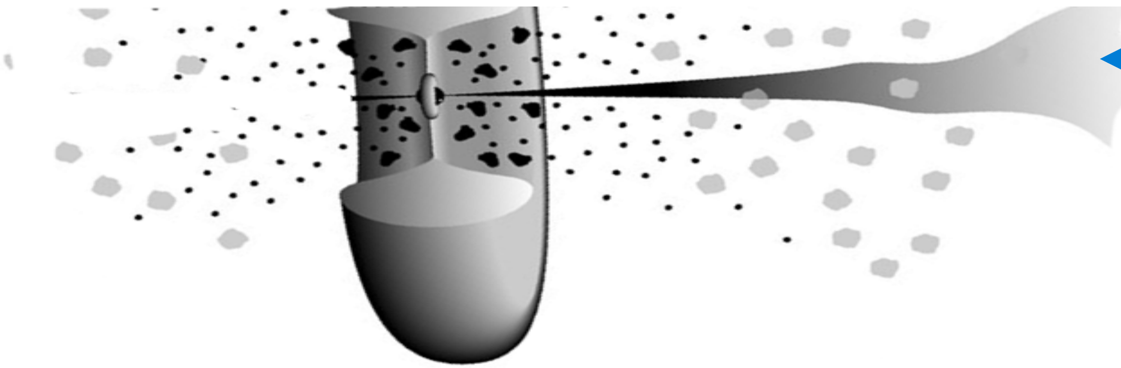
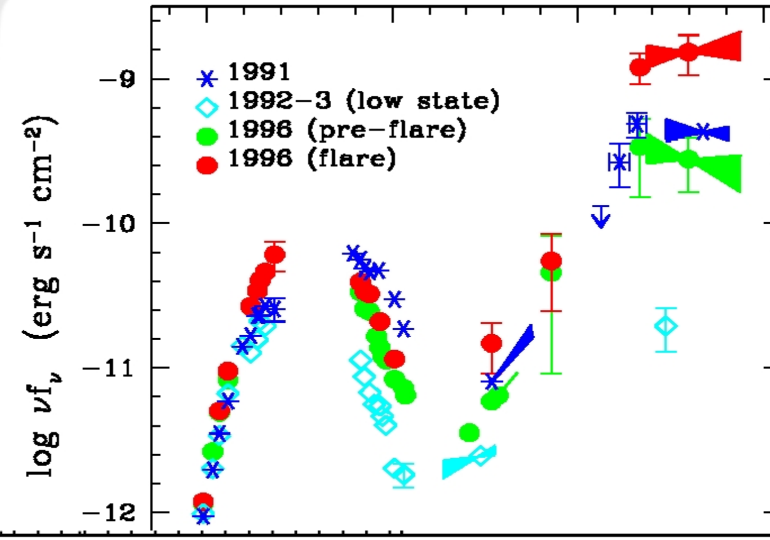
Zeroth Order: Orientation-based Unification:

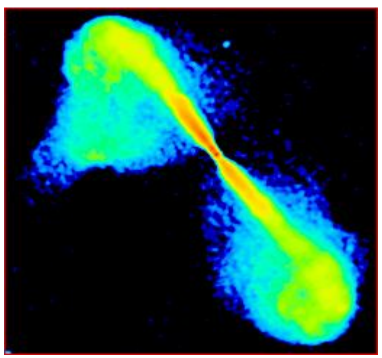


Blazars

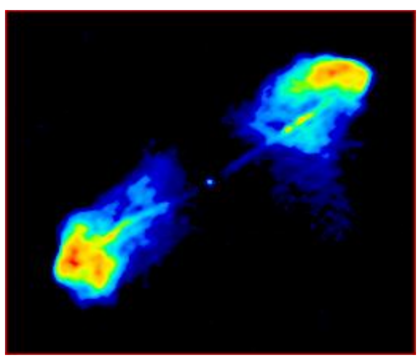
Direct view of the jet!



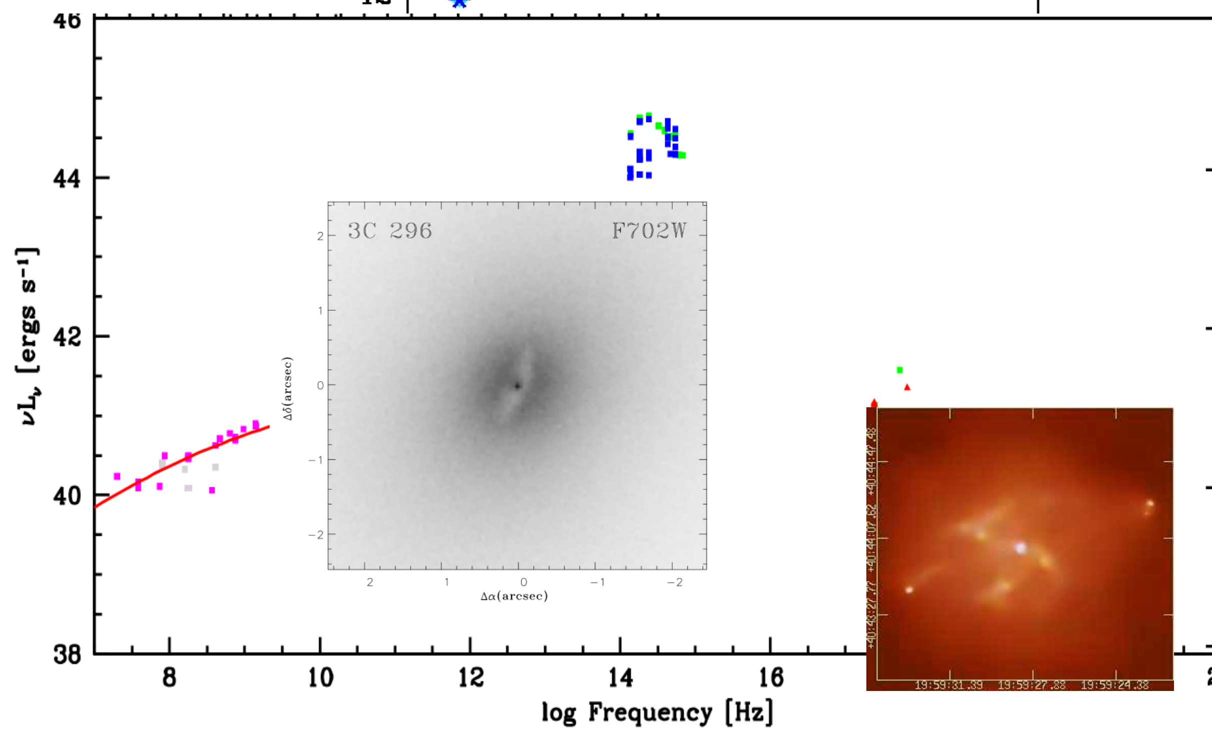
Radio Galaxy



FR I: brightest at the center, “plumey jets”

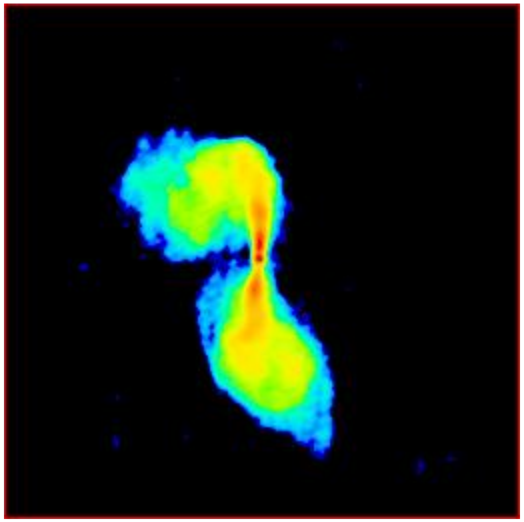


FR II: brightest in the lobes, collimated jets



Radio Loud AGN Unification

(beyond orientation)



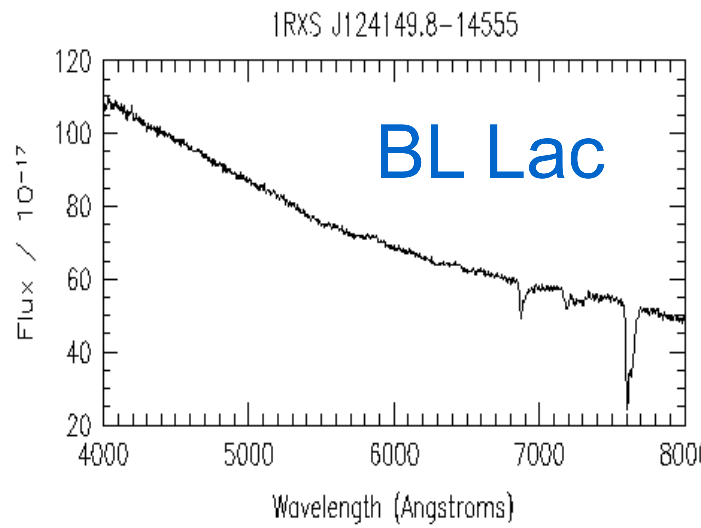
Radio Galaxy Morphology

FR I →

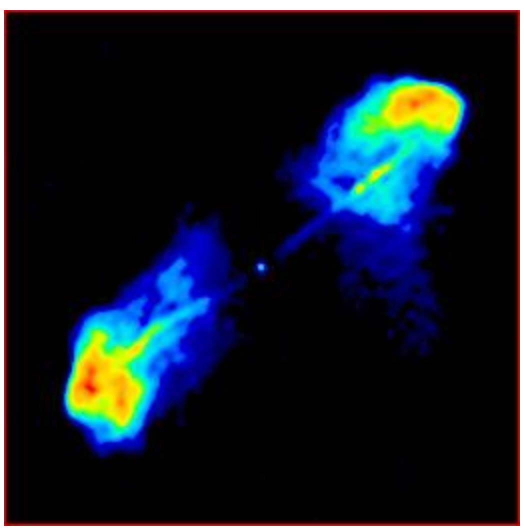
Low power, weak lines)

ADAF

Blazar Spectral Type



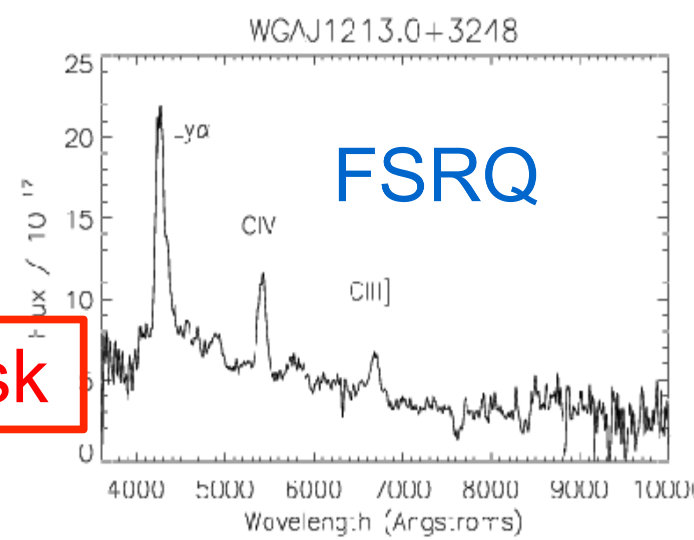
(Many notable exceptions!)



FR II →

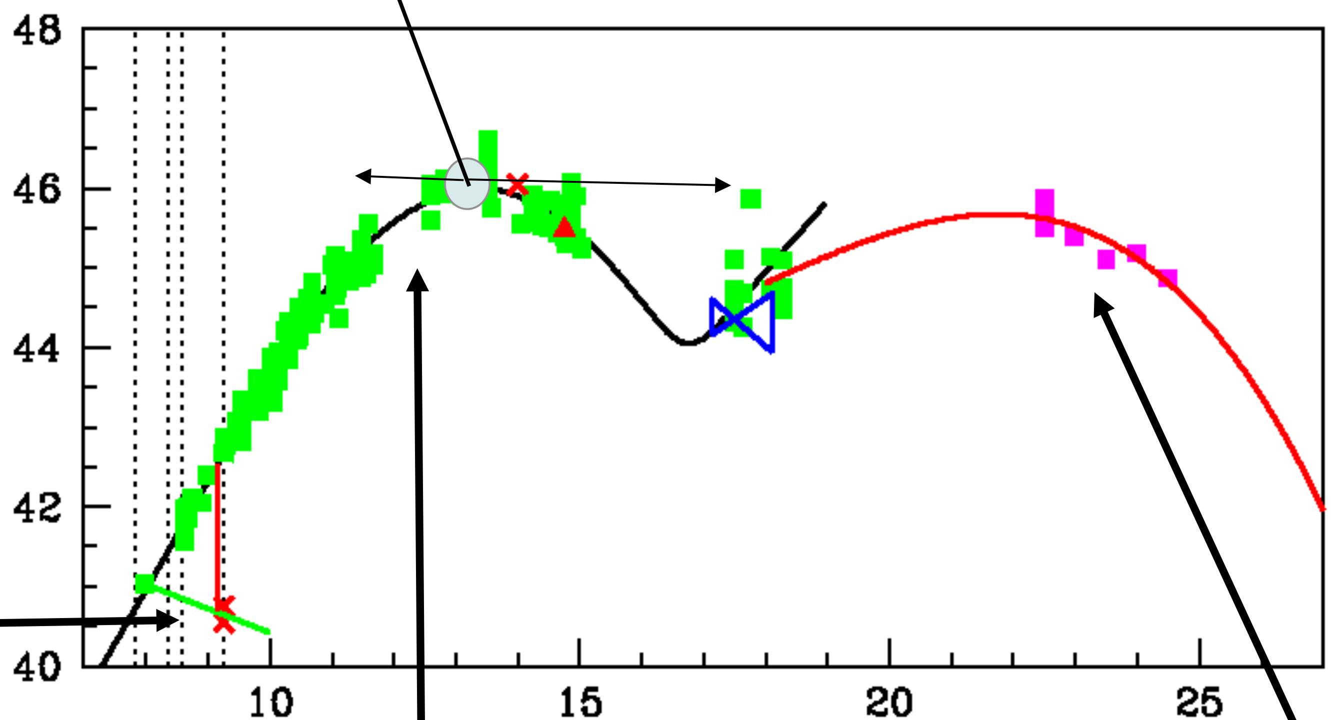
High power, high excitation spectra

Thin disk



The Blazar View of the Relativistic Jet

Peak frequency,
wide range

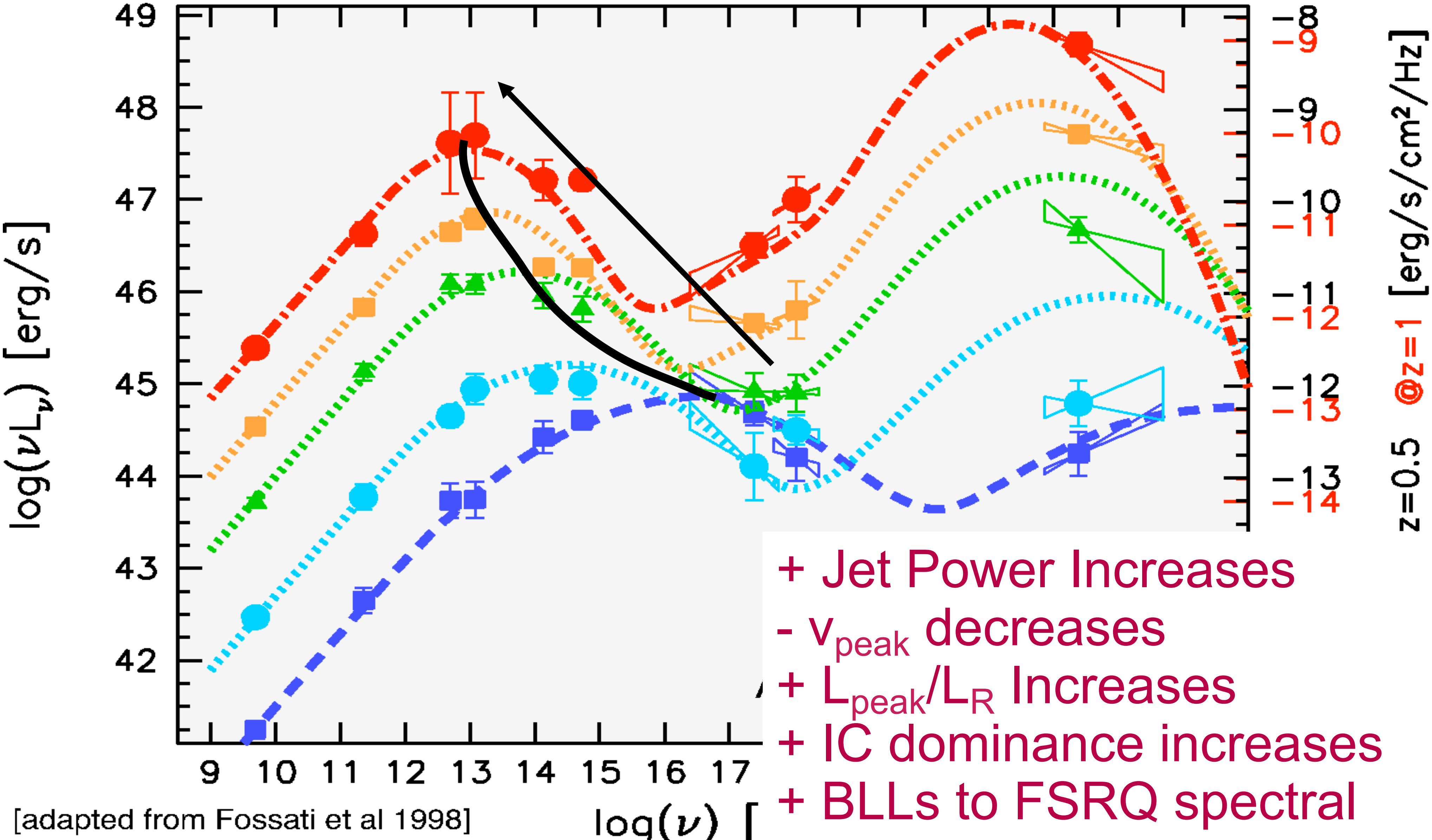


Isotropic Radio Emission from Slowed Plasma in the Lobes

Synchrotron emission

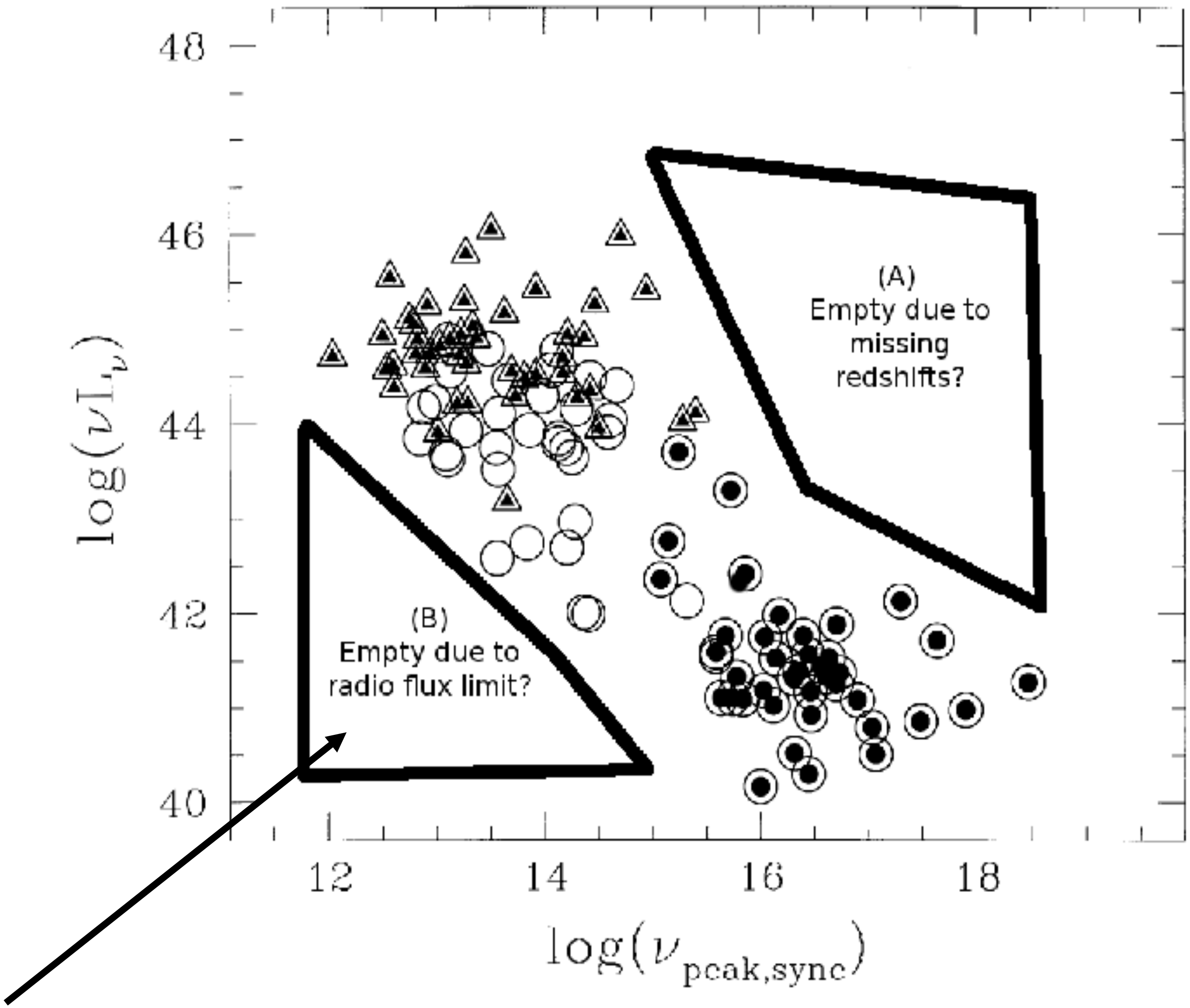
Inverse Compton
(source of upscattered photons not well understood)

The Blazar Sequence



[adapted from Fossati et al 1998]

+ Jet Power Increases
- ν_{peak} decreases
+ L_{peak}/L_R Increases
+ IC dominance increases
+ BLLs to FSRQ spectral change



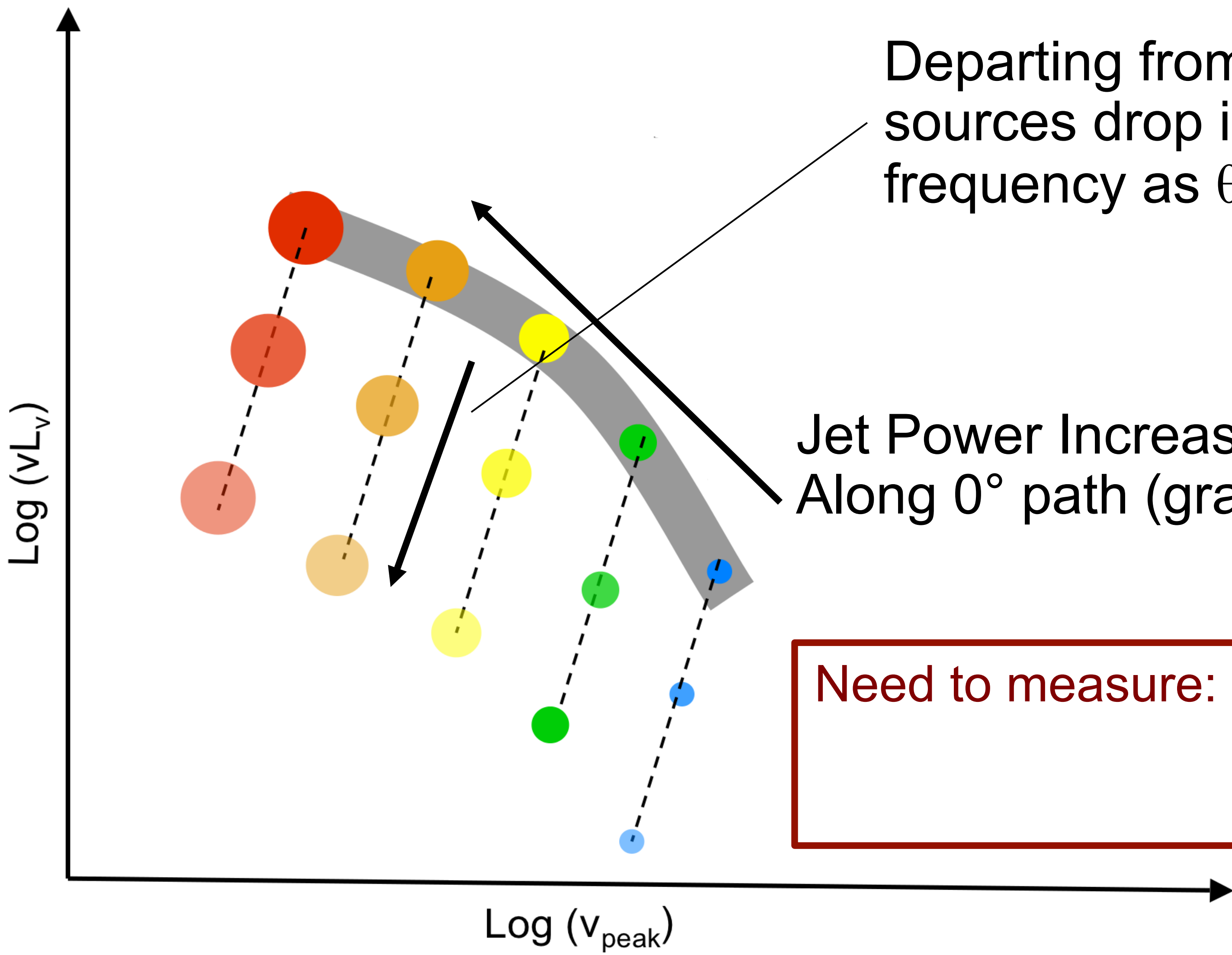
Sources here were found (Nieppola 2006, Landt 2006, Caccianiga 2004)

BL Lacs: Jet Power uncorrelated with ν_p

RL AGN Unification - Problems

- How does a continuous blazar sequence fit in with a dichotomy in spectral type/morphology ?
- What is going on with the blazar sequence?
- Other oddities: BL Lac has broad lines?
- Kharb et al., 2009 found BL Lacs with hotspots in VLBI monitoring
- Many low-power FSRQ blazars have been found
- Evolution Measures suggest high-synchrotron peaking sources are “negatively evolved” vs. low-peaking
- Spectral type in Radio Galaxies found to be rather mixed: low-excitation FR IIs, high-excitation FR Is

Hypothesis: The Blazar Sequence
Envelope



Departing from the sequence, sources drop in Luminosity and frequency as θ increases

Jet Power Increases (blue → red)
Along 0° path (gray): L_p increases
ν_p decreases

Need to measure: Orientation (θ)
Intrinsic Jet Power
(good $L_{p,}$ ν_p)

Part I: Revisiting the Blazar Sequence

- Is there a monoparametric Sequence?

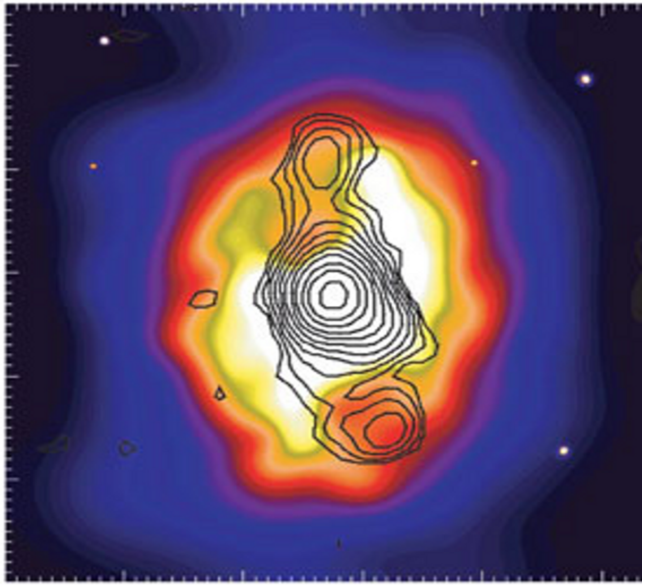
  (1) Measure (unbeamed) Jet Power

  (2) Measure the alignment – how does angle of observations affect what we see?

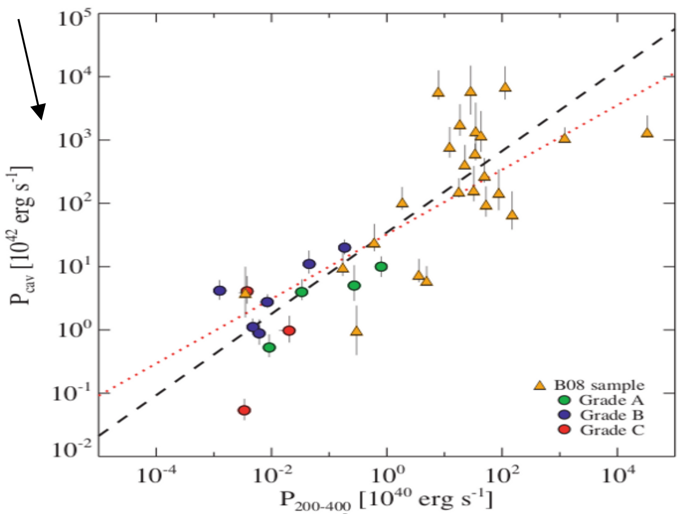
  - Hint: Jet structure may become more apparent at large θ

  (3) Build Up a large Sample – better SED sampling

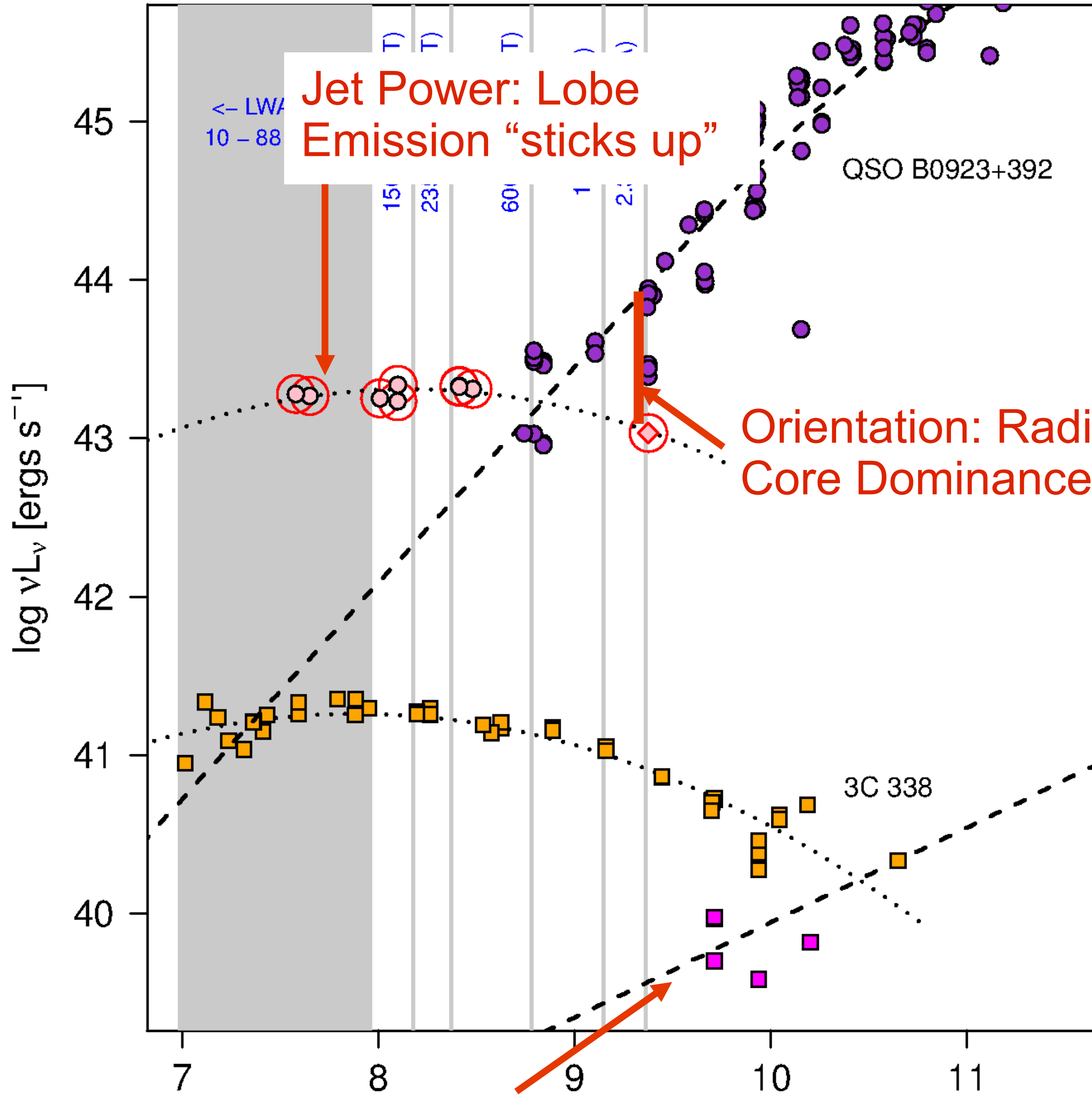
Methods



Cavity Power
(P*ΔV/time)

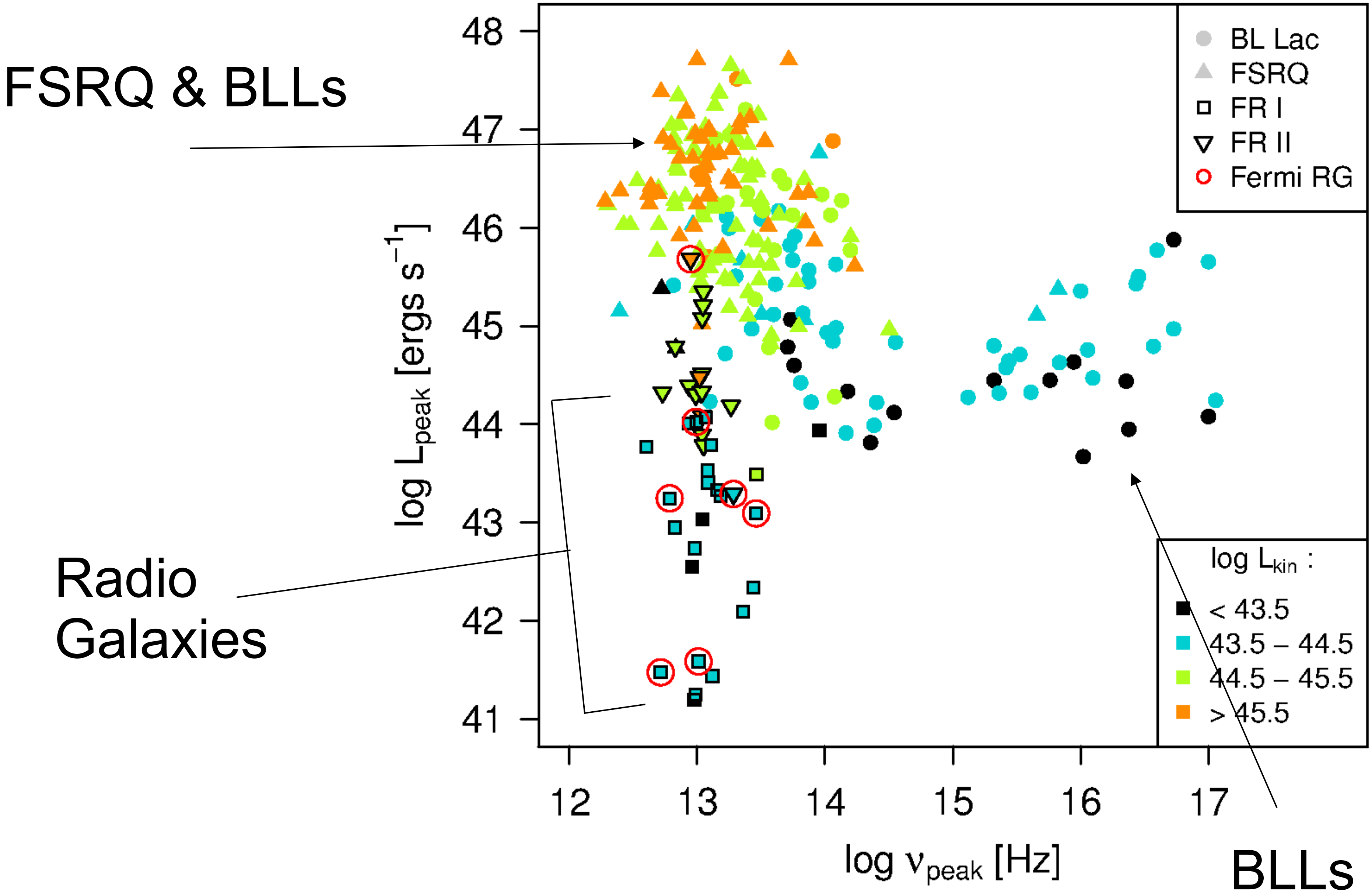


Extended, Low-frequency Power
Cavagnolo, et al. 2010



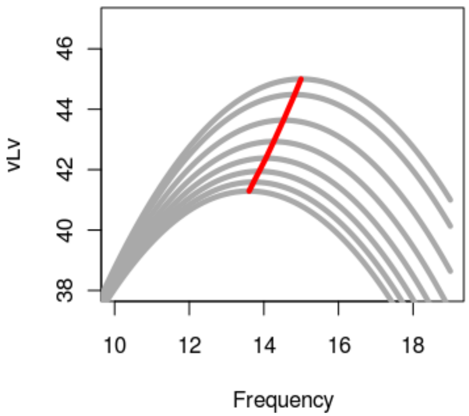
Core is faint in the radio (not beamed)

Results

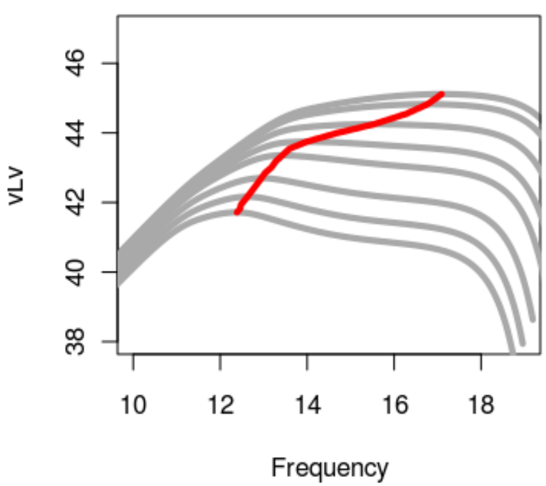

FSRQ & BLLs
Radio
Galaxies
BLLs
log L_{peak} [ergs s^{-1}]
log ν_{peak} [Hz]
48
47
46
45
44
43
42
41
12
13
14
15
16
17
BL Lac
FSRQ
FR I
FR II
Fermi RG
log L_{kin} :
< 43.5
43.5 – 44.5
44.5 – 45.5
> 45.5

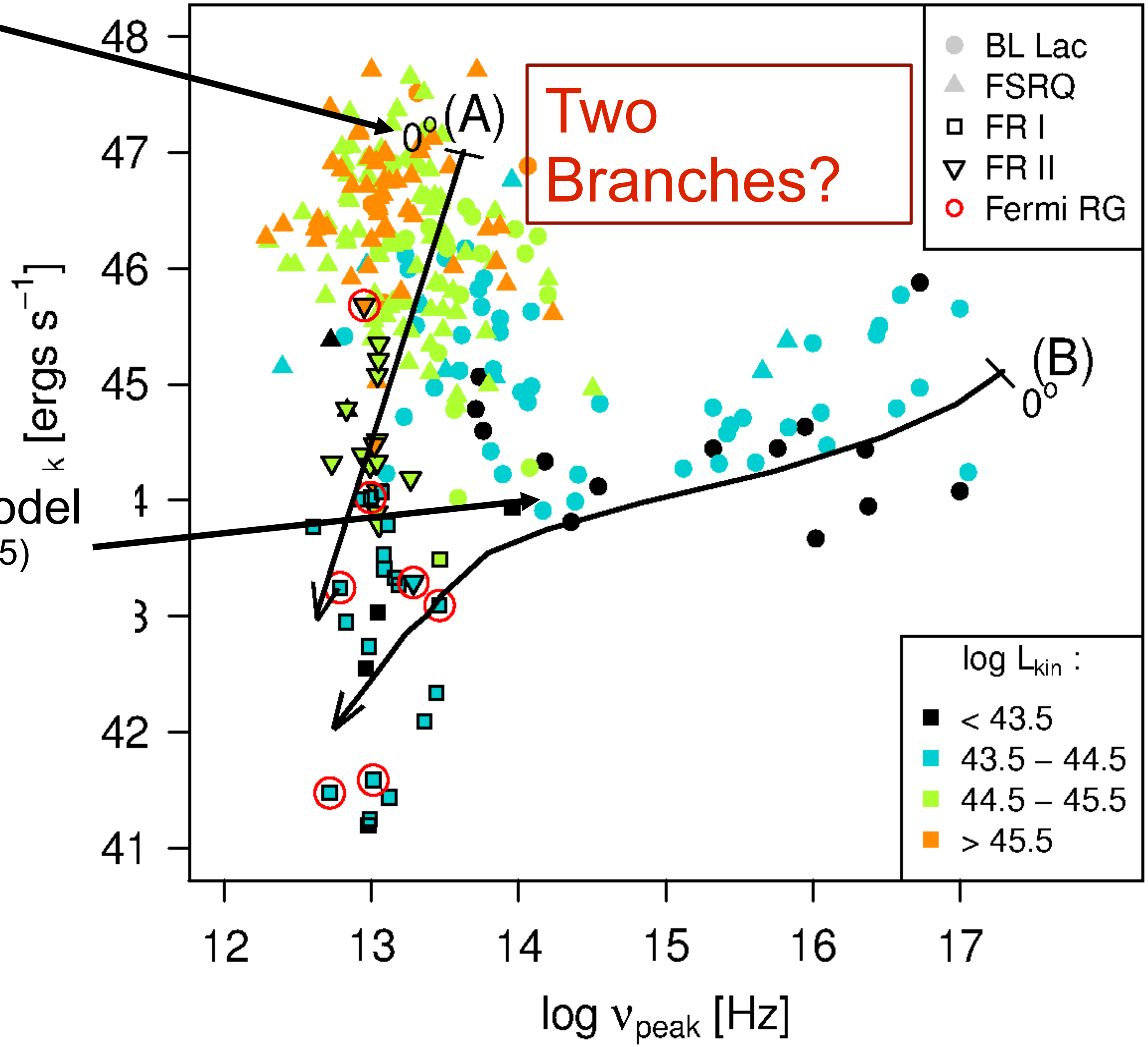
Results

"Simple jet" (single



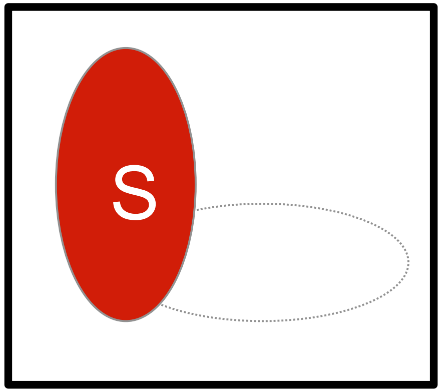
"Decelerating Flow" model
(Georganopoulos et al 2005)



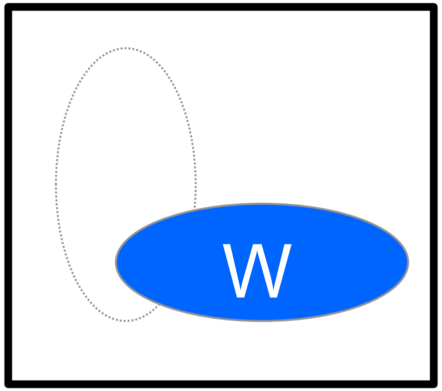


New Hypothesis: A Strong/Weak Dichotomy?

- Strong Jets:
  - All High L_{kin} (> $10^{44.5}$ erg s^{-1}), *some lower L_{kin}*
  - (Nearly) All FSRQ, *many BL Lacs*
  - Low ν_p (< 10^{15} Hz)
  - Associated with FR IIs (based on L_{kin})



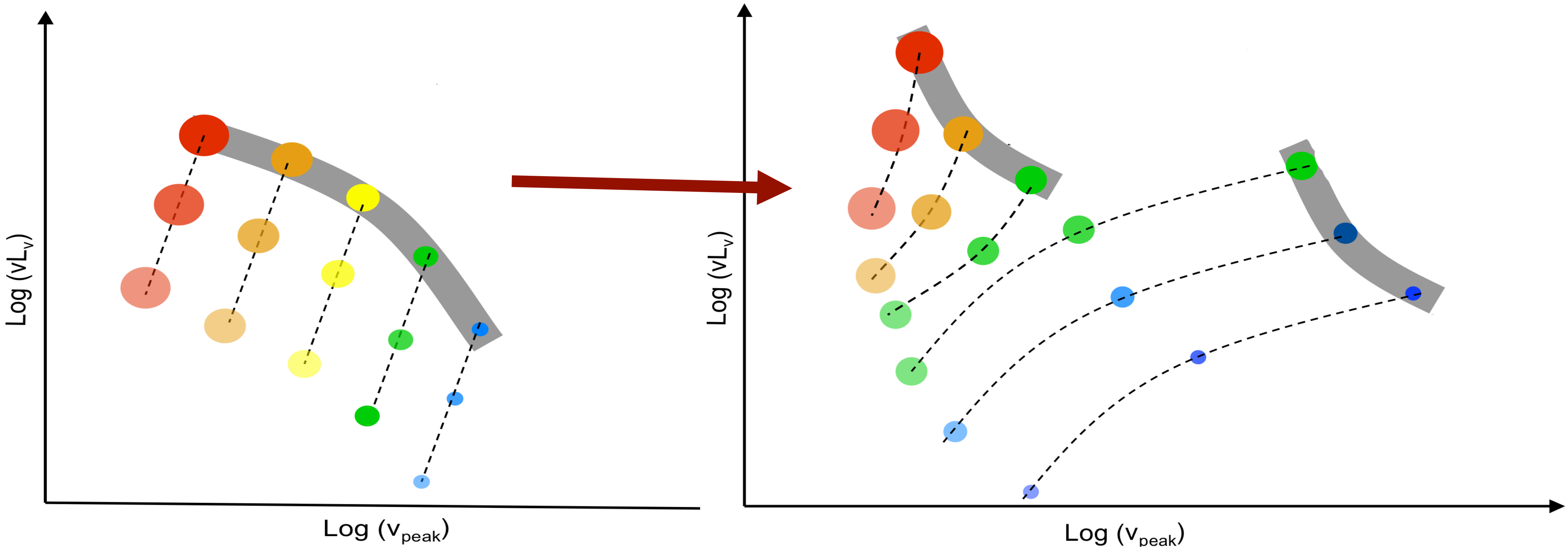
- Weak Jets:
  - Only at low L_{kin} (< $10^{44.5}$ erg s^{-1})
  - (Nearly) All BL Lacs
  - All high ν_p (> 10^{15} Hz), some low ν_p?
  - Associated with FR Is (based on L_{kin})



New Hypothesis: A Strong/Weak Dichotomy?

Next Questions:

1) Is the divide real?
2) Linked to Accretion Mode? Spectral Type mixed?
3) Jet Power? (not clean divide)
4) Sequence 'broken'?



Some Questions Answered

- *Low ν_p, low L_p sources?*

→ *These appear to be misaligned.*

- *L_{kin} (L_{ext}) does not vary with ν_p for BL Lacs?*

→ Consistent with our findings: Horizontal movement due to velocity gradients in jet

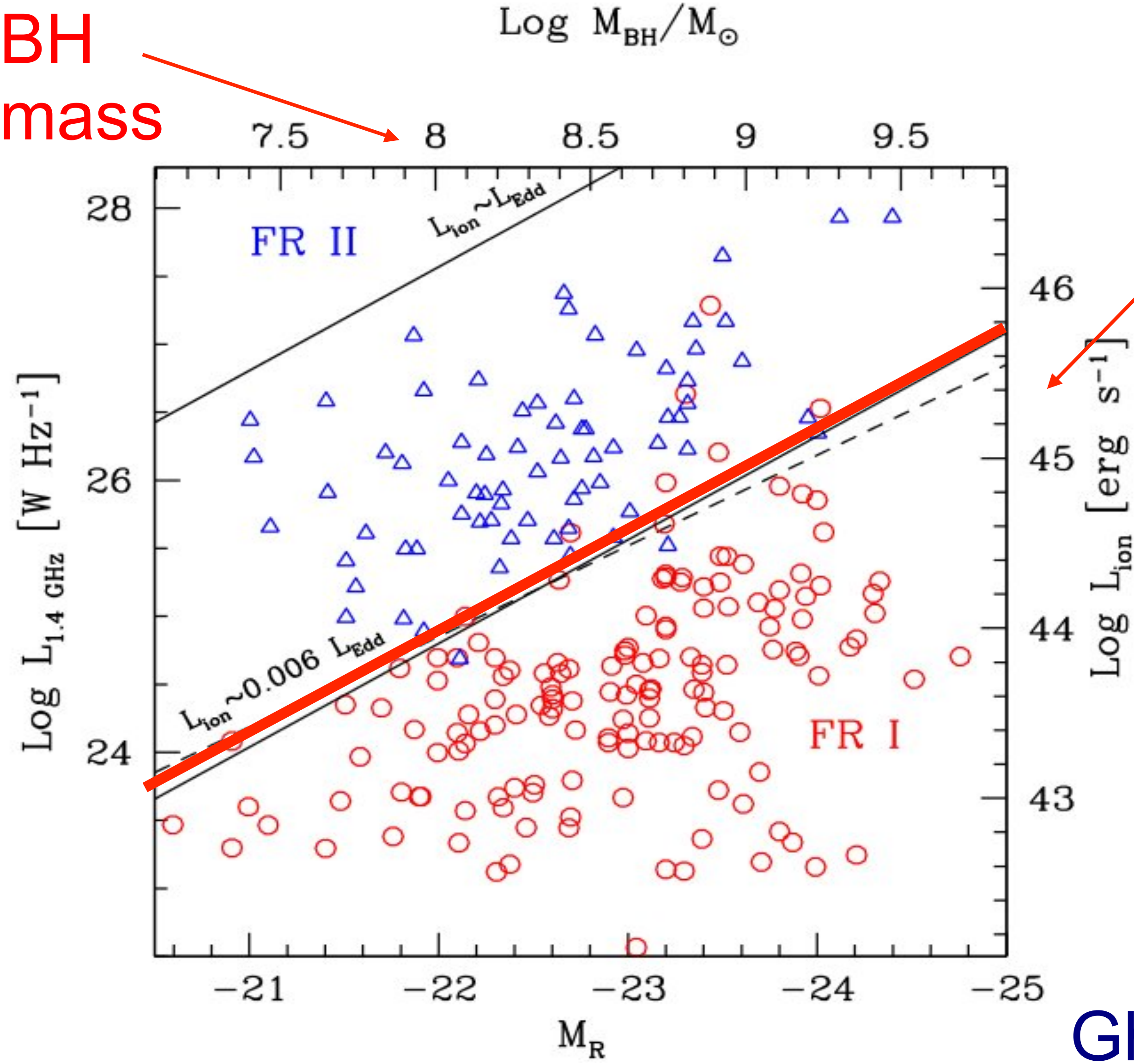
- Sources at low ν_p have range of L_{kin}?

⟶ Consistent with our findings: All 'misalignment paths' meet at low ν_p

Part II: Accretion Mode and the Broken Power Sequence

Accretion Modes – driving the FR I/FR II divide?

BH mass

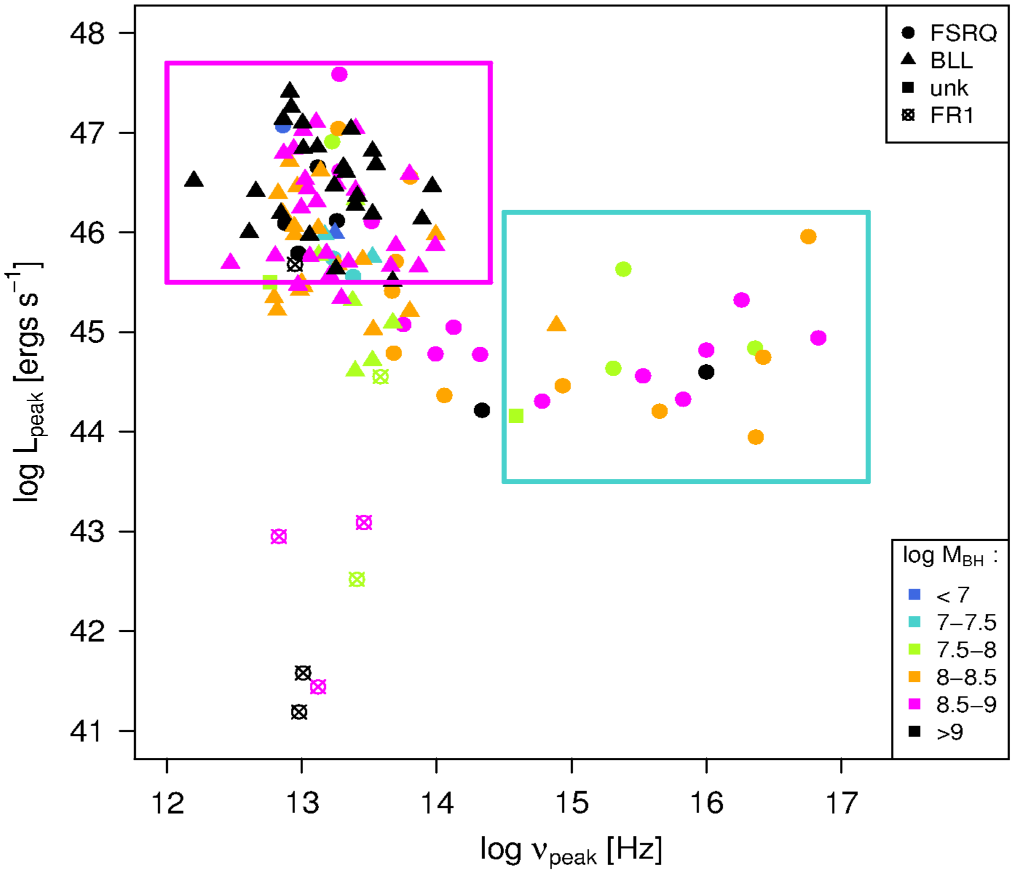


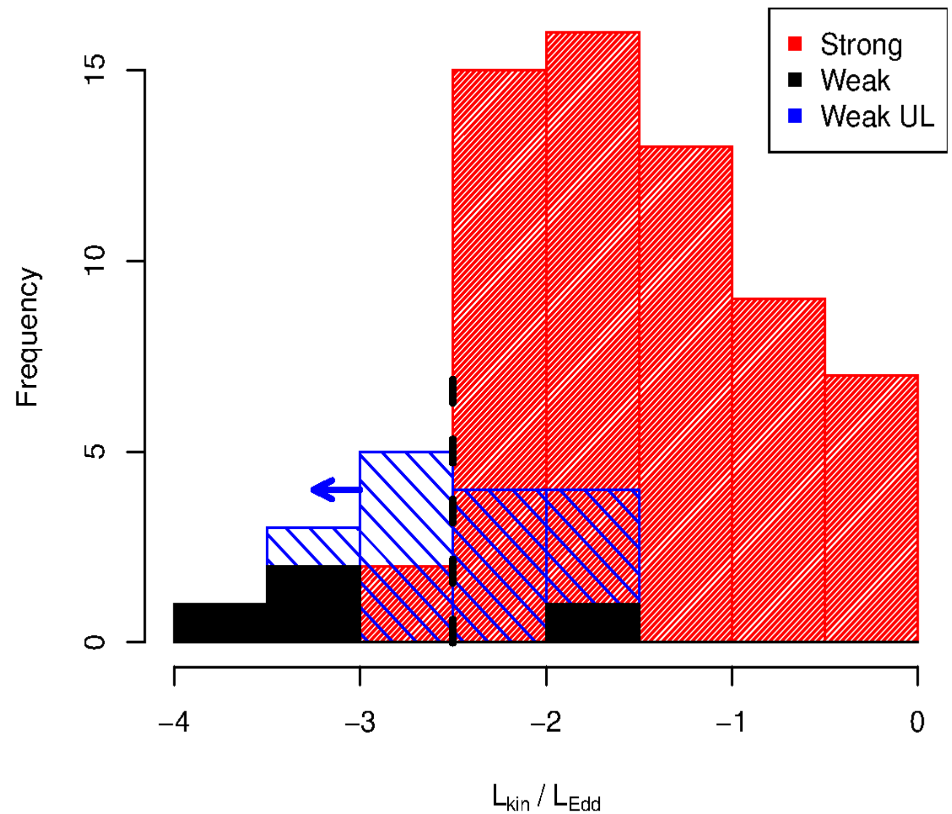
Jet Power

$$\dot{m} = \frac{\dot{M}}{\dot{M}_{Edd}} = \dot{m}_{crirt} \sim 0.01$$

Ghisellini et al. 2001

L_{kin}, θ, … $\mathring{m}$?

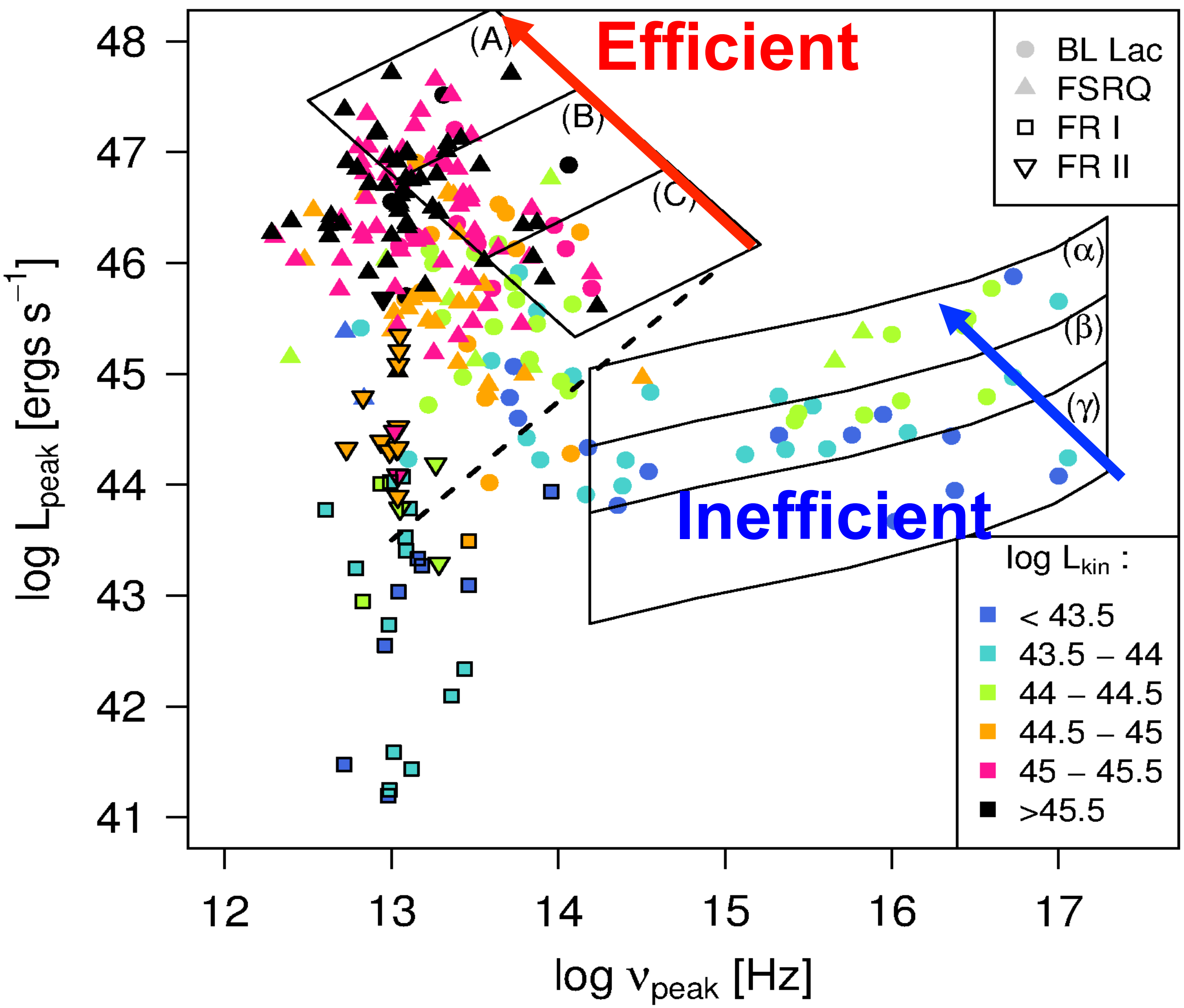




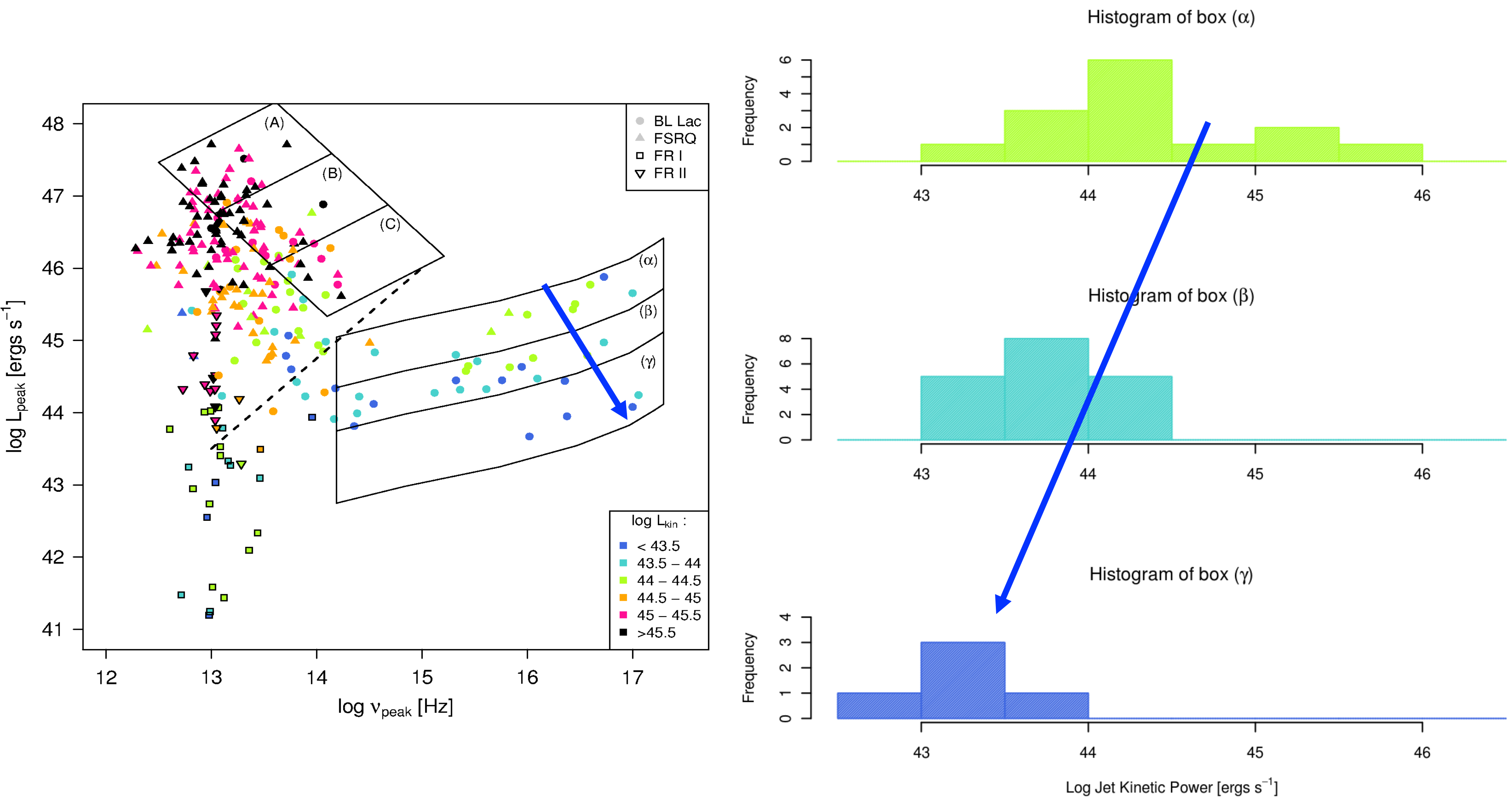
(Mass estimates from reverberation mapping, velocity dispersions, mass-luminosity scalings)

Weak Jets = Inefficient
Strong Jets = Efficient

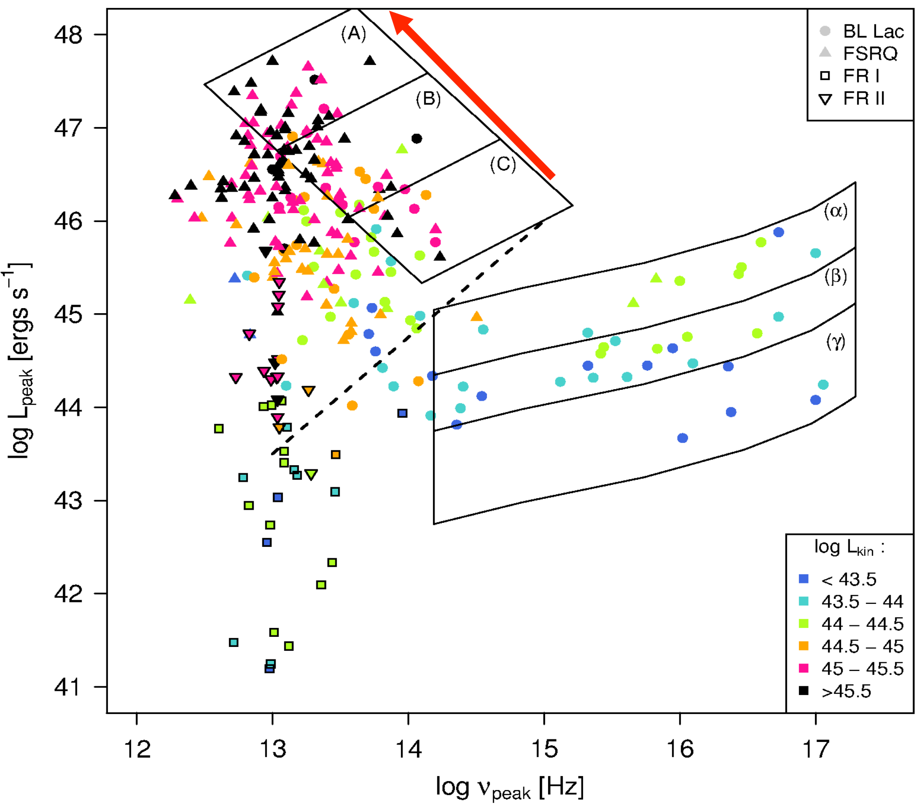
What is the role of Jet Power? A Broken Power Sequence?

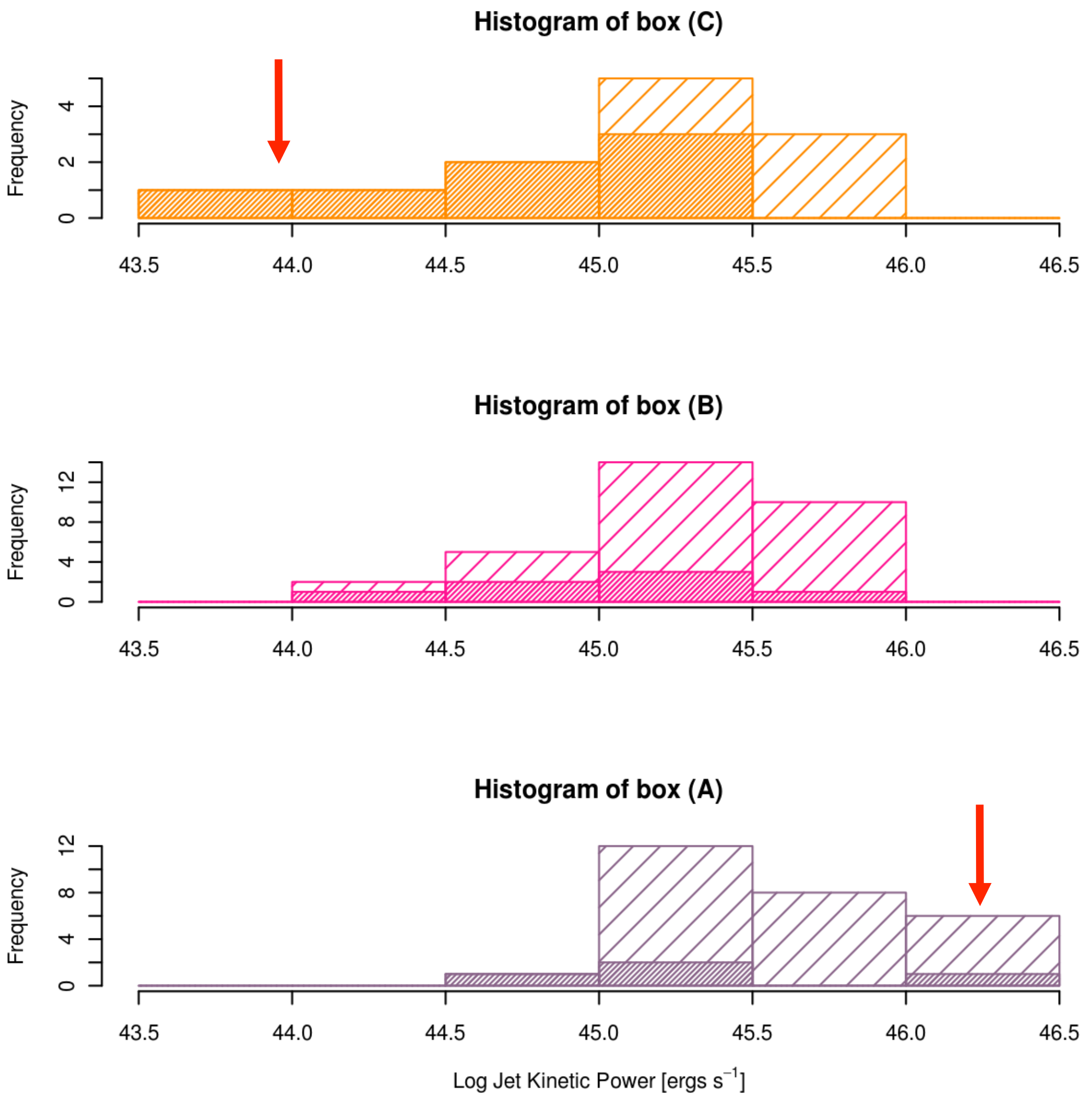


The Weak-Jet Sequence

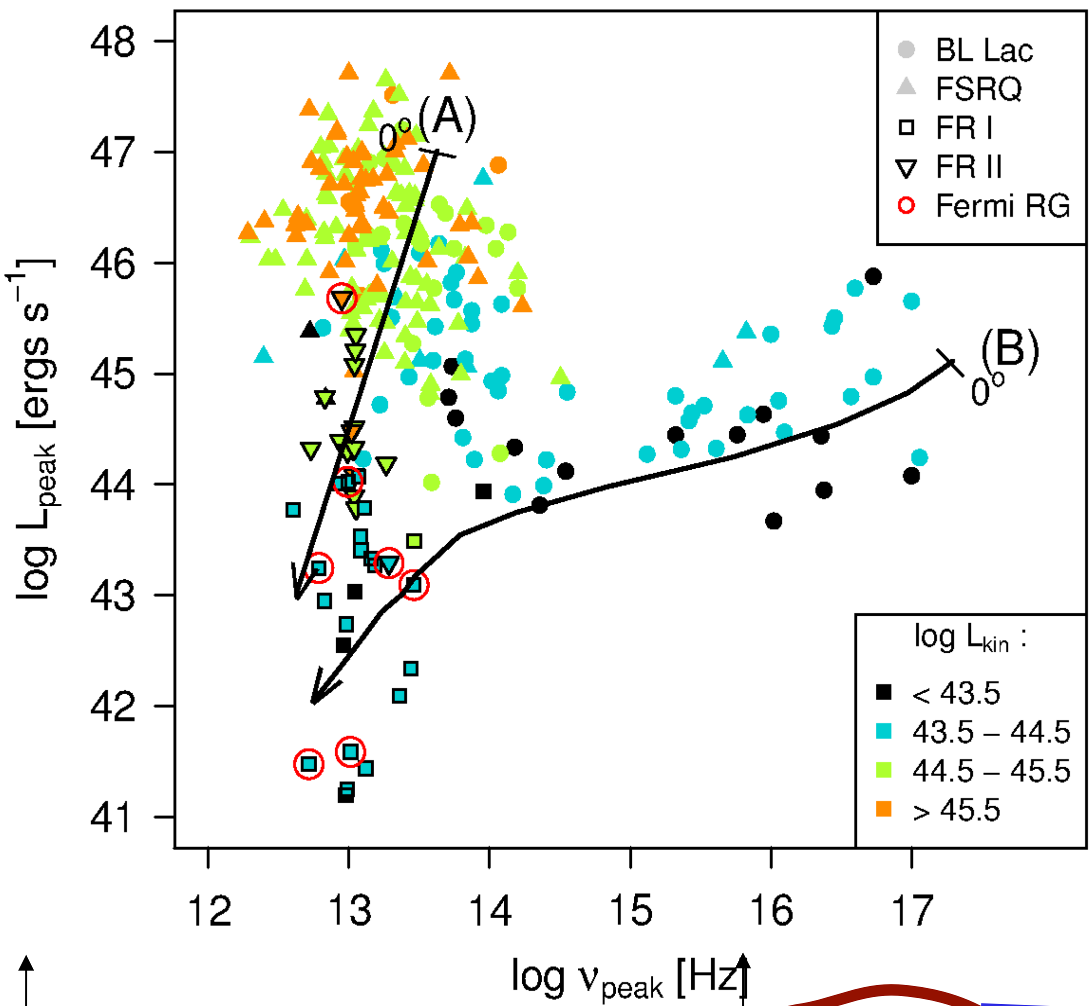


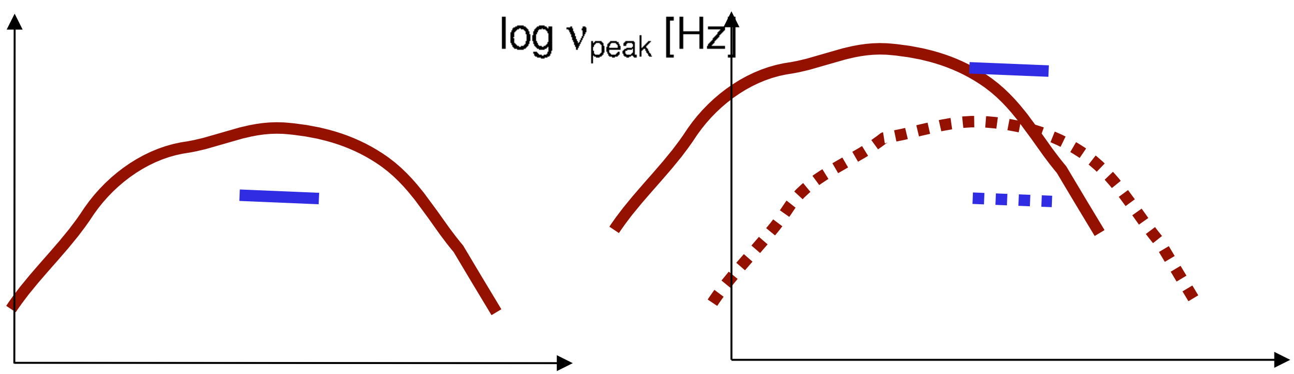
The Strong-Jet Sequence



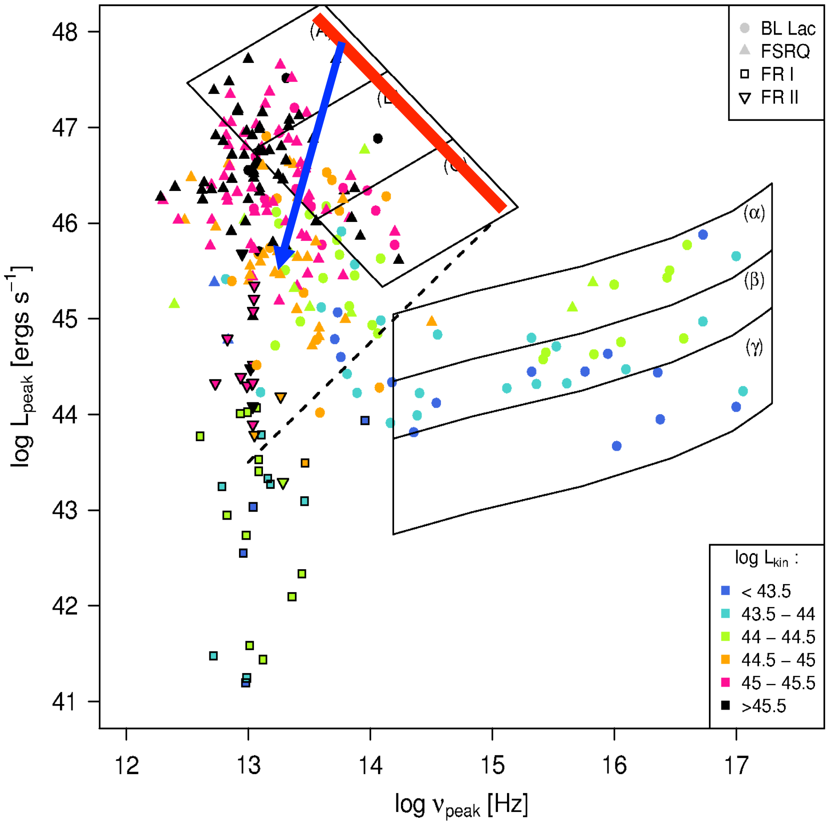


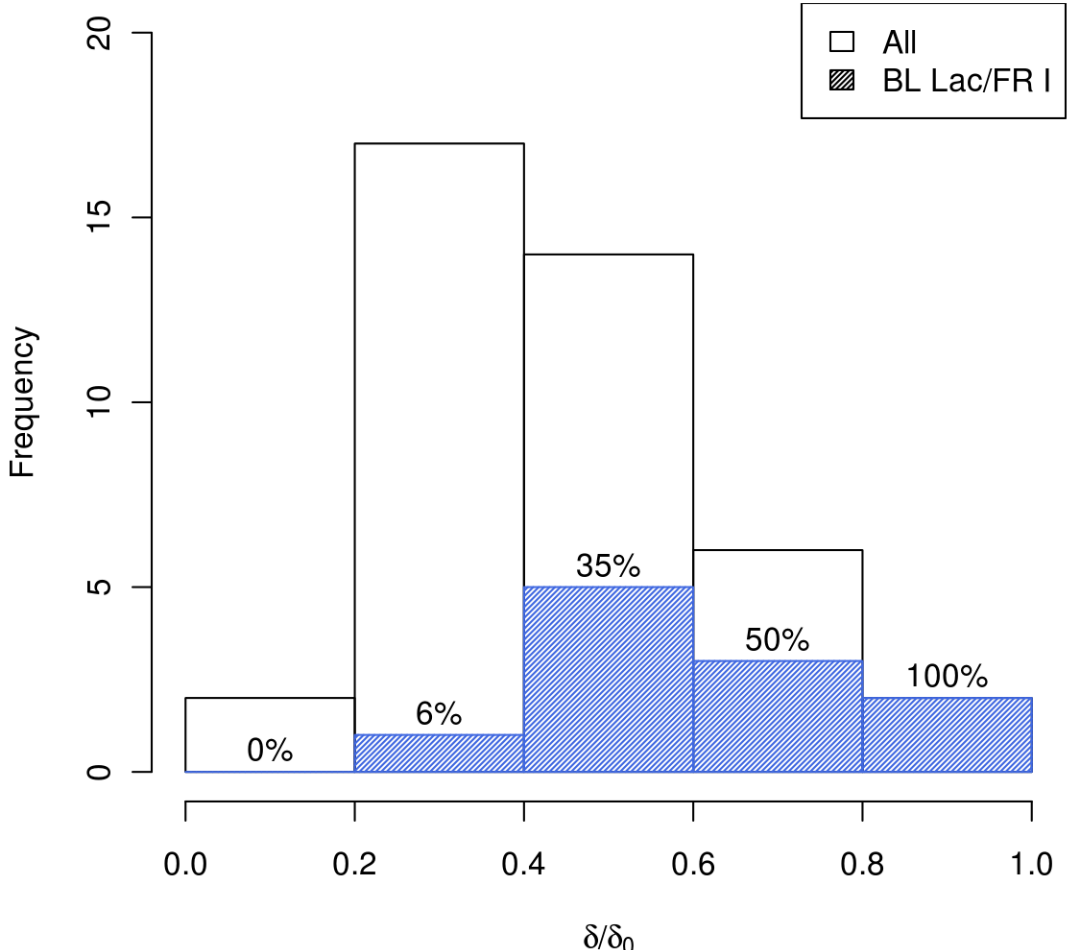
IMPOSTER BL Lacs in the Strong Branch





BL Lac fraction in the strong branch: increases with beaming and as peak shifts into optical



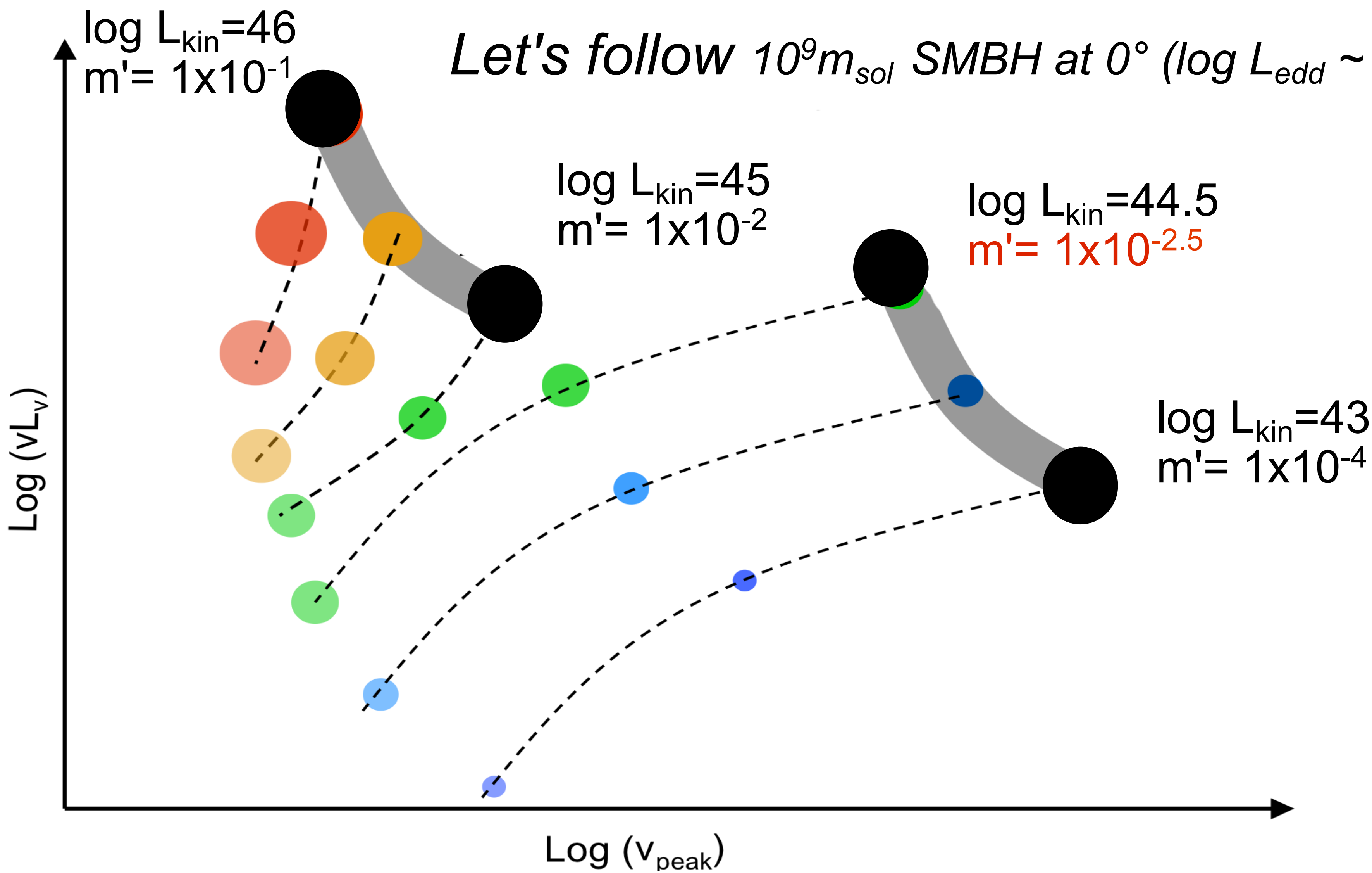


1:4 Δfrequency:ΔLuminosity

$\delta/\delta_0 = \nu_{peak}/\nu_0$

Summary: The Broken Power Sequence

Let's follow $10^9 m_{sol}$ SMBH at 0° (log L_{edd} ~ 47)



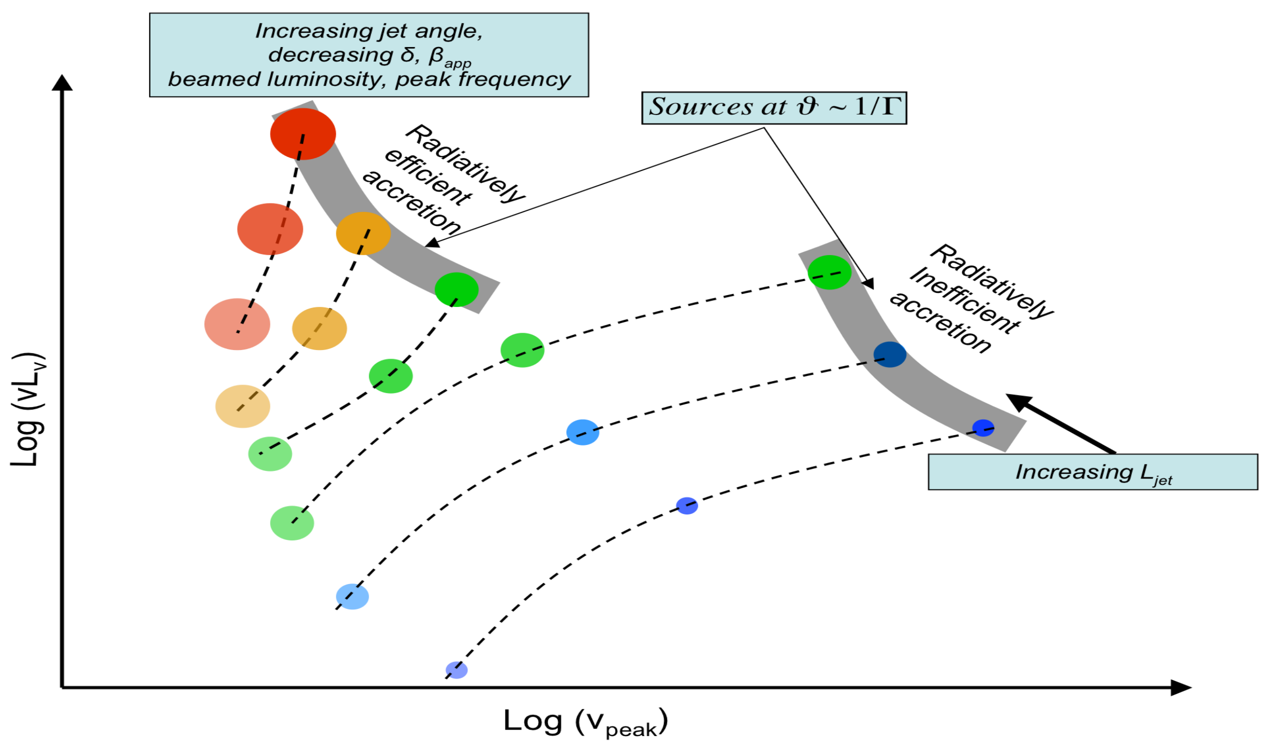
Conclusions/Key Observations

+ Suggestion of Two populations: “weak” and “strong” with very different jet profiles, different spectral properties

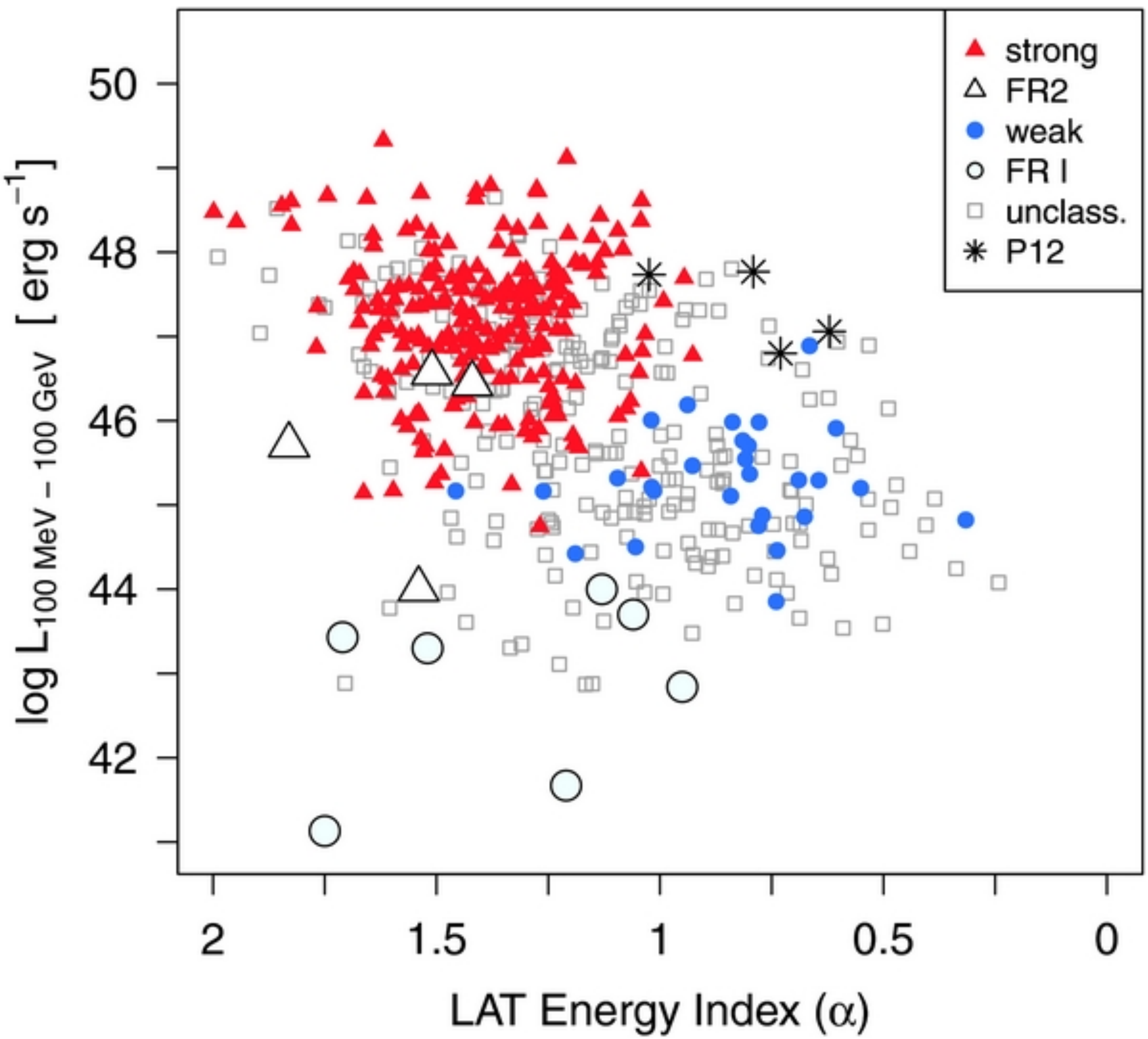
+ Weak jet branch maxes out at $10^{45.5}$ erg/s in jet power – exactly what you expect if there is an accretion mode switch at 10^{-2}, given maximum observed black hole size of ~ $10^9\ M_\odot$

+ There are IMPOSTER BL Lacs out there

+ The sequence may exist in 'broken' form:



What can we learn from Fermi ?



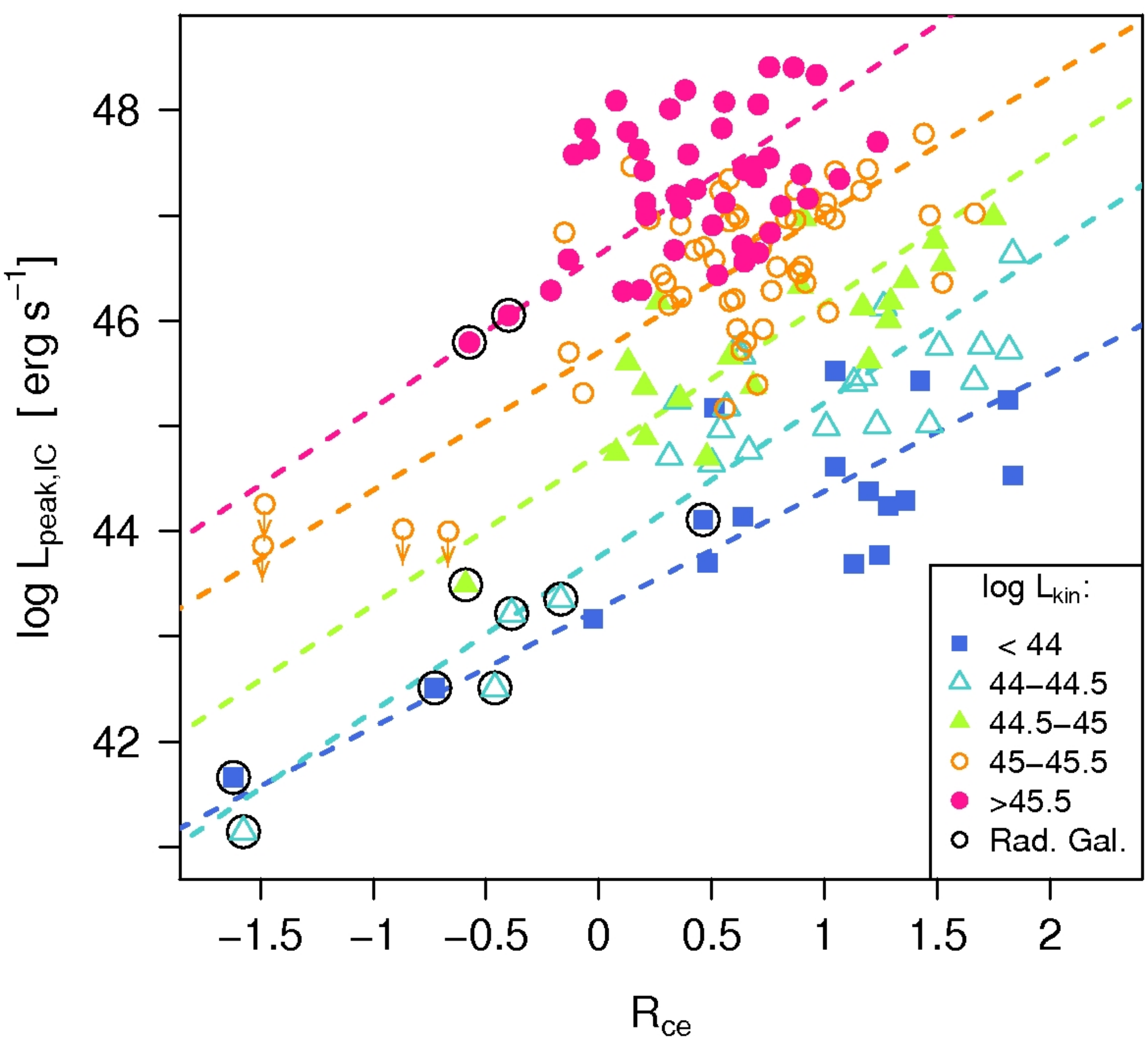
Very similar to the synchrotron envelope.

FR II below FSRQ (red)

FR I below and to the left of BLs (blue).

* are the Padovani 2012 sources claimed to be high peak frequency BL Lacs.

What can we learn from Fermi ?



Are the Γ-rays of powerful quasars of SSC or EC nature?

SSC – upscatters synchrotron photons

-beaming pattern is the same as the synchrotron one

For sources of the same jet power the Compton dominance (IC over synchrotron power) is not a function of the core to extended ratio

EC – upscatter photons from outside the jet (BLR or molecular torus)

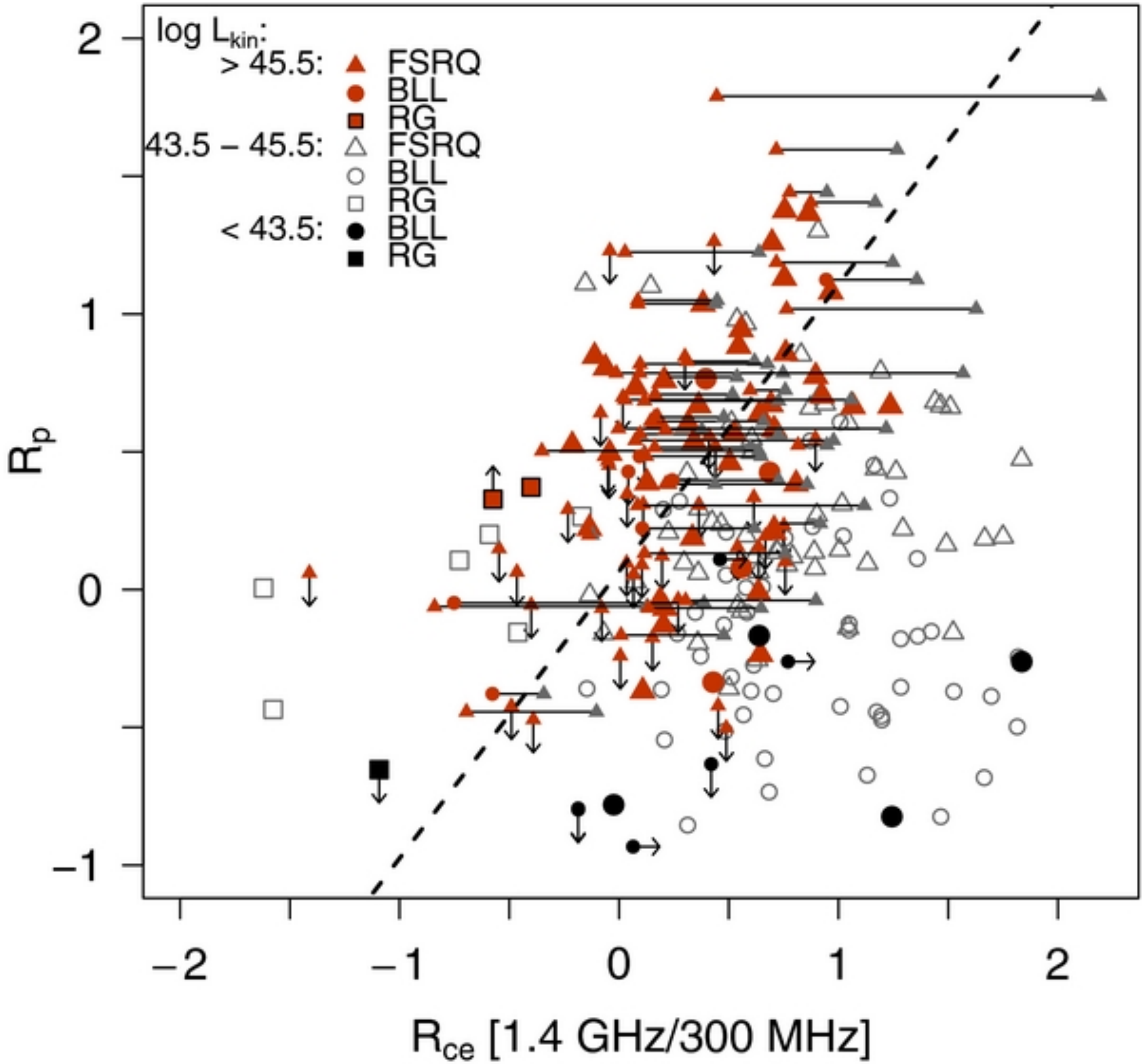
-beaming pattern is different:

$L \sim \delta^4$ synchrotron peak

$L \sim \delta^6$ IC peak

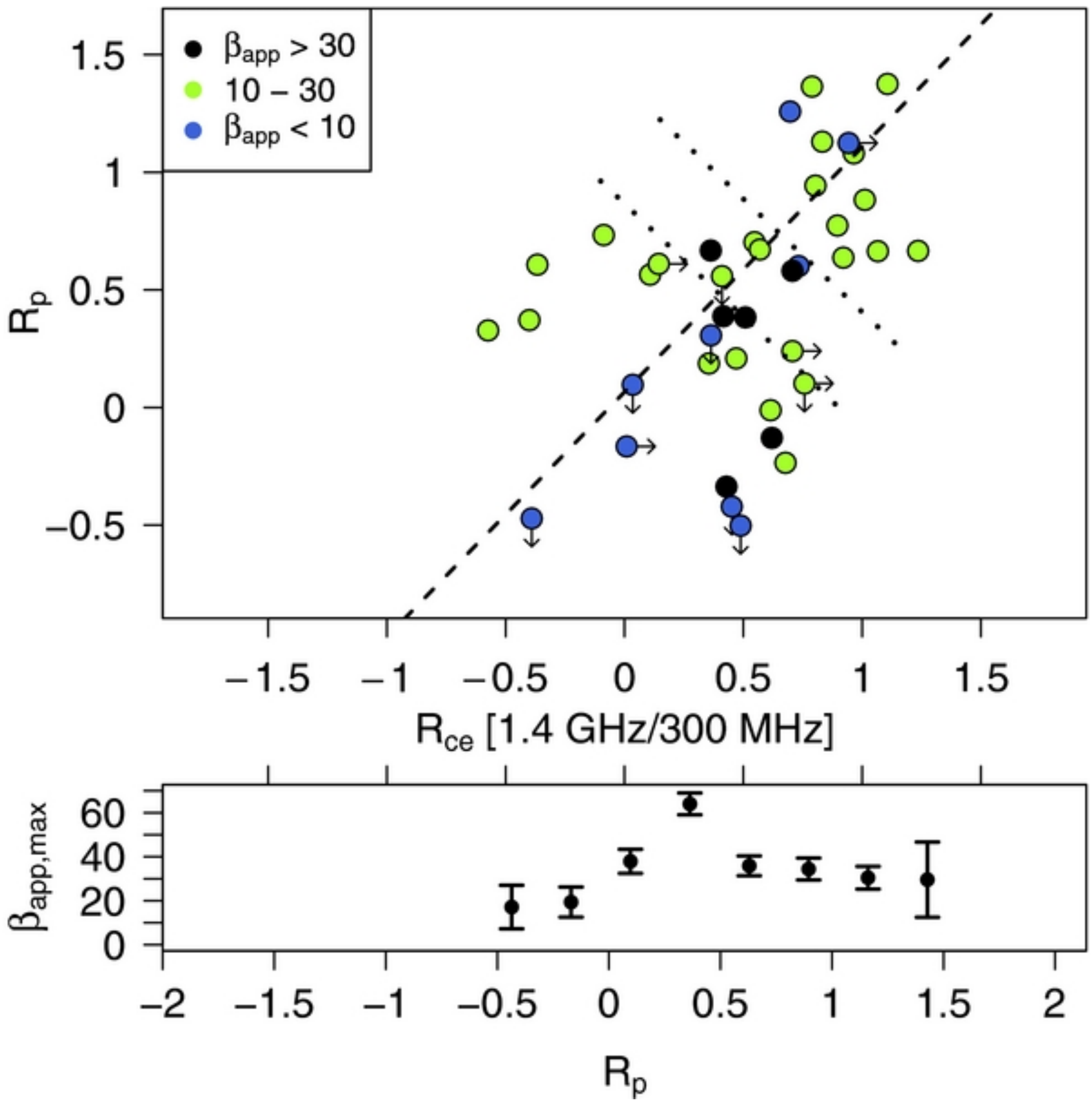
(For radio, $L_{core}/L_{ext} \sim L \sim \delta^{3+\alpha}$, $\alpha \sim 0.2$)

For sources of the same jet power the Compton dominance (IC over synchrotron power) should increase with increasing core to extended ratio



The Compton dominance of the most powerful sources increases with increasing Core to extended ratio. At lease for the most powerful quasars the γ-ray emission mechanism seems to be external Compton scattering.

Check: We expect the superluminal speeds exhibited by these sources to peak at intermediate alignments, which corresponds to intermediate Compton dominances.



Conclusions

The collective properties of radio loud AGN suggest the following picture:

1. There is a critical mass accretion rate, $\dot{m} = \frac{\dot{M}}{\dot{M}_{Edd}} = \dot{m}_{crirt} \sim 0.01$, below

   which, the accretion is a radiatively inefficient with weak or no broad line region and molecular torus.

   Above this, the accretion is a radiatively efficient thin disk with a broad line region and molecular torus (Narayan et al. 97, Ghisellini et al. 09)

2. All jets of a given kinetic power and the same accretion environment are physically similar and their observed properties depend on their orientation.

3. Weak jets (radiatively inefficient accretors) are characterized by decelerating flows in their sub-pc scale jets. .

Relevant Papers:

Meyer et al. 2011: *From the Blazar Sequence to the Blazar Envelope: Revisiting the Relativistic Jet Dichotomy*
ApJ (2011) 740:98

Meyer et al. 2012: (proceedings on arXiv:1205.0794, paper in preparation)

Meyer et al. 2012: *Collective Evidence for Inverse Compton Emission from External Photons in High-power Blazars*
ApJ (2012) 752:4

Orientation (Rce)

Clear break between RG, blazars

"striping" - indicates that Lkin and L0 are linked