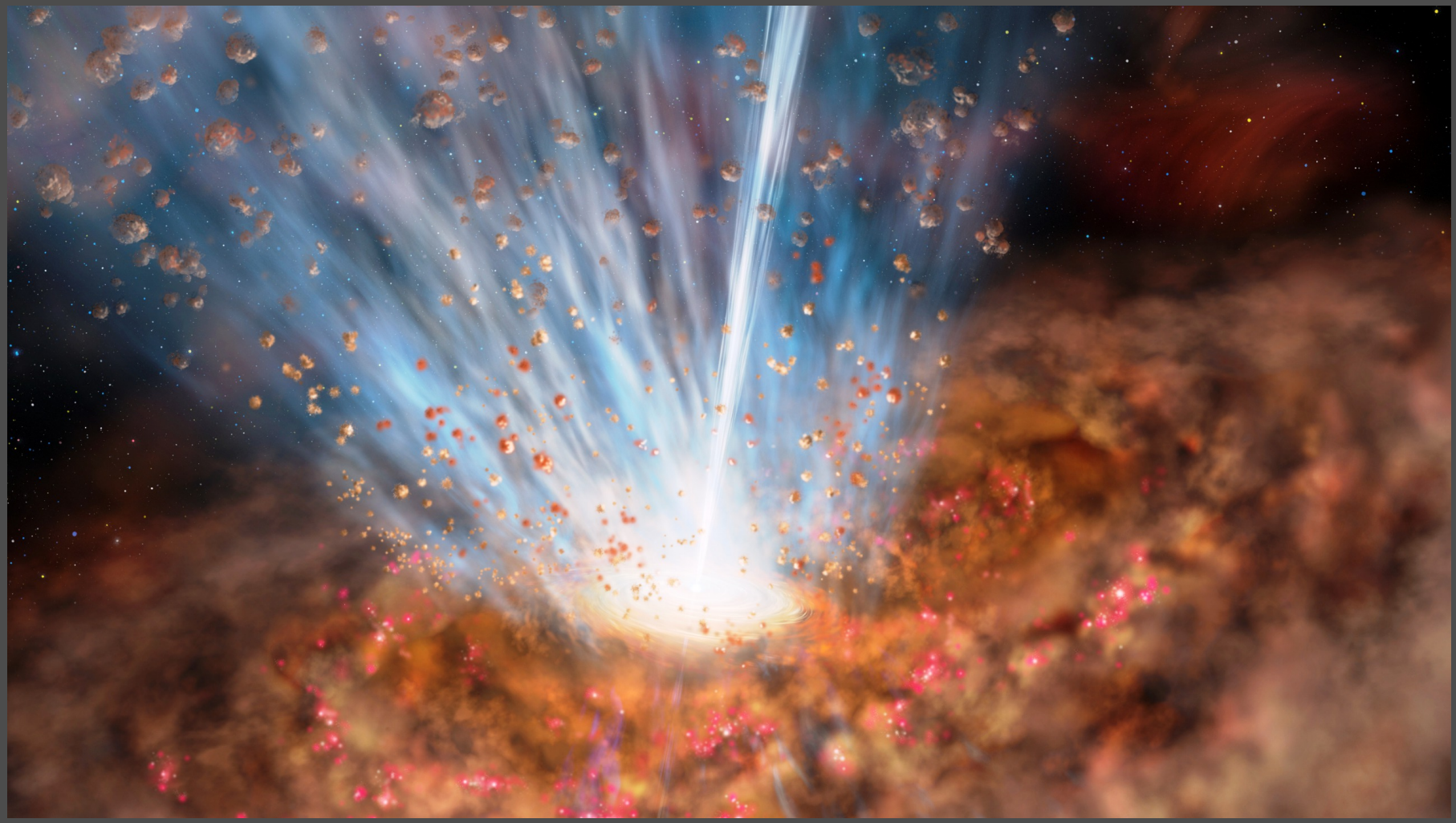
Revising the Blazar Sequence

Eileen Meyer
Postdoctoral Fellow, STScI

"What are we learning from the gamma-ray Sky?" Workshop
University of Minnesota
11 October 2013

Active Galaxies – What do we know?



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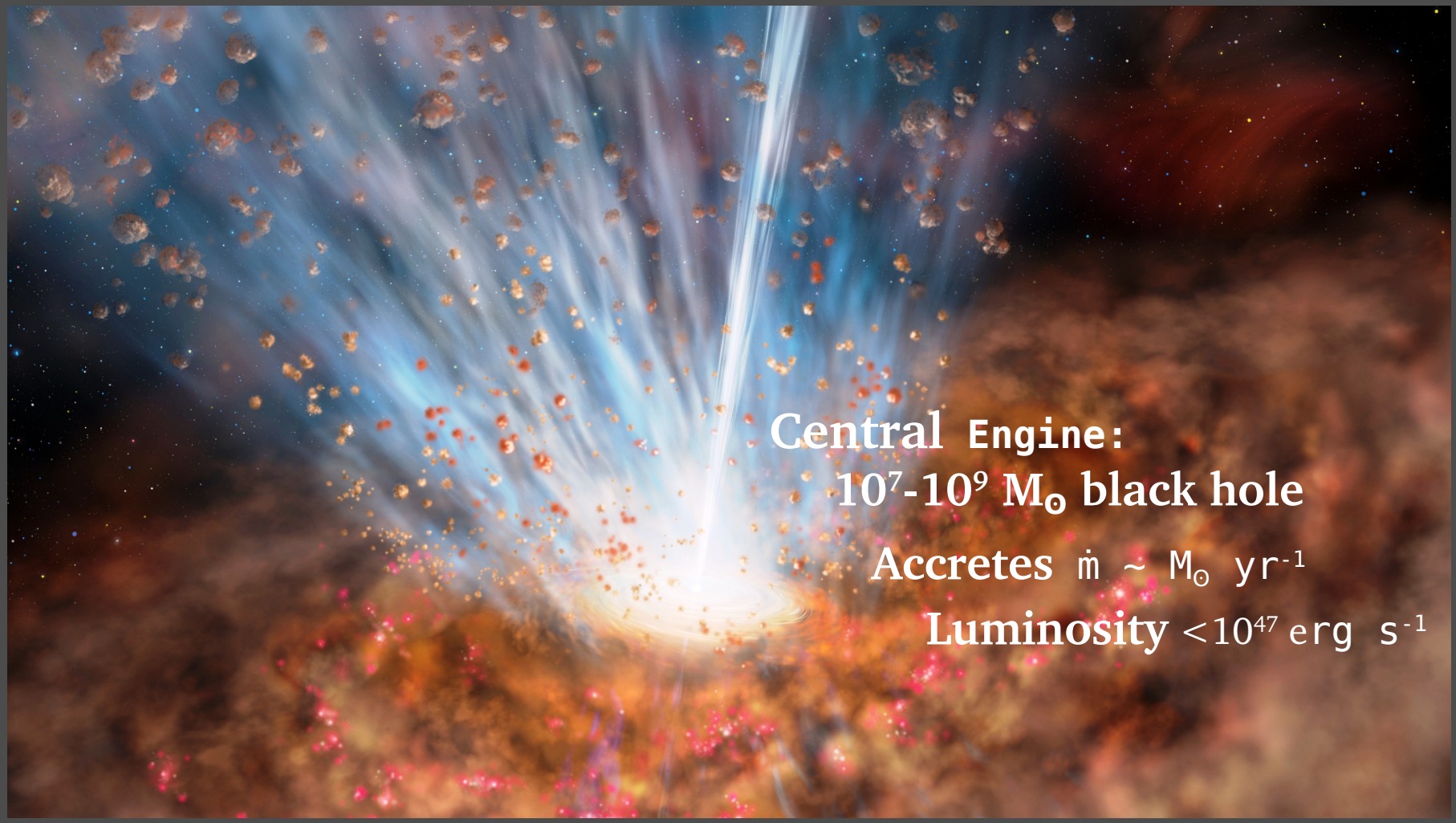

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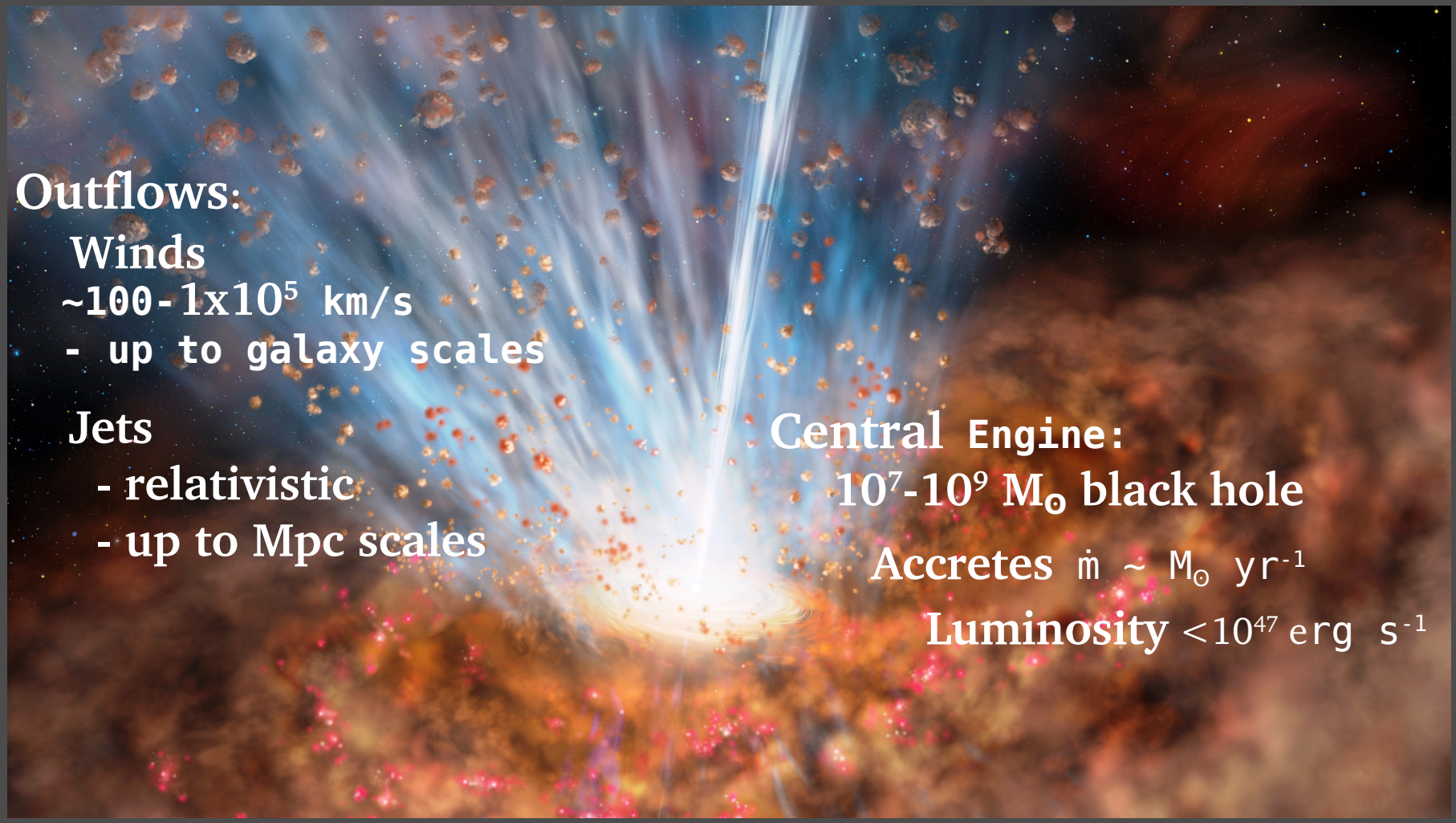
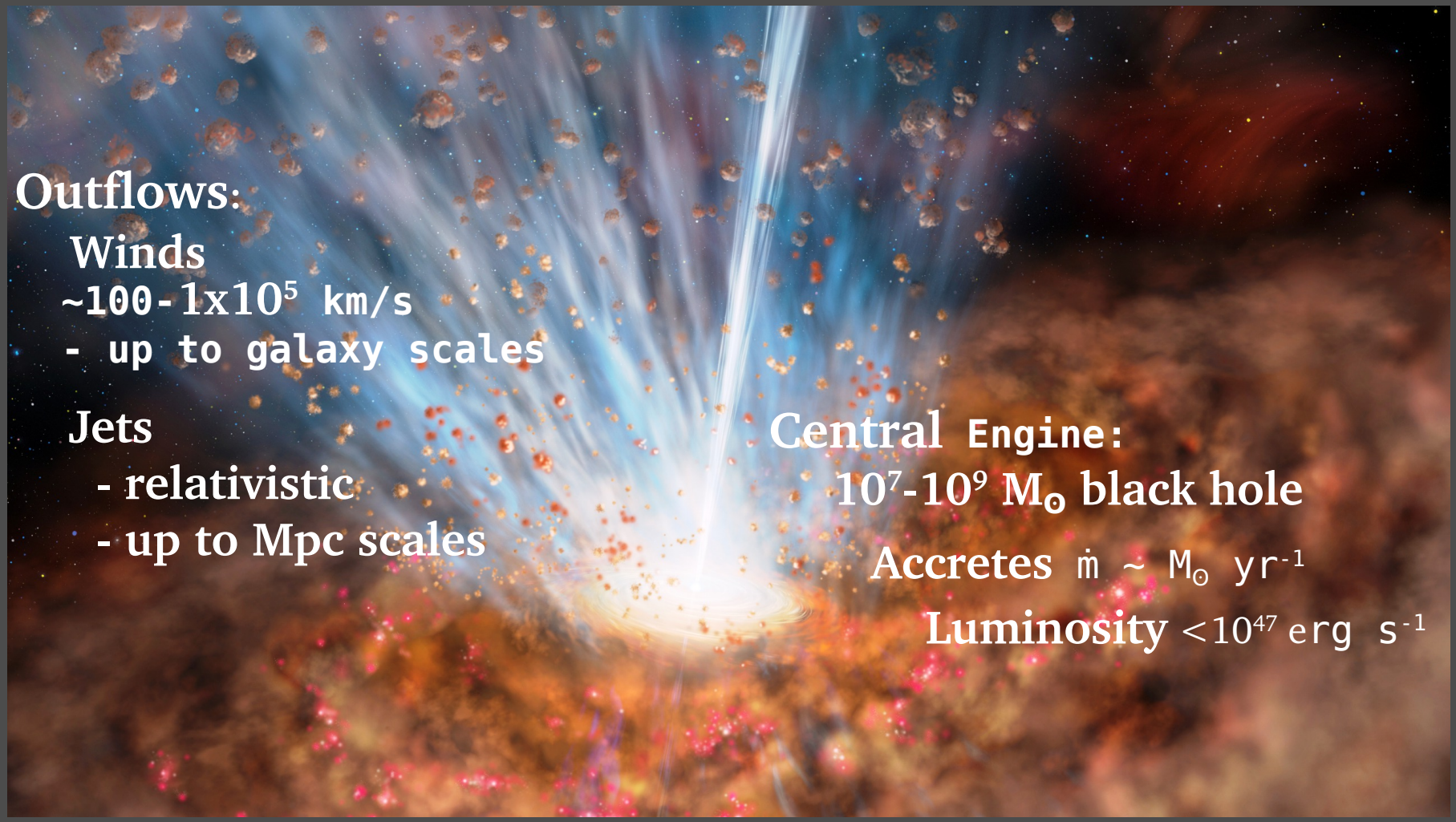


Active Galaxies – What do we know?



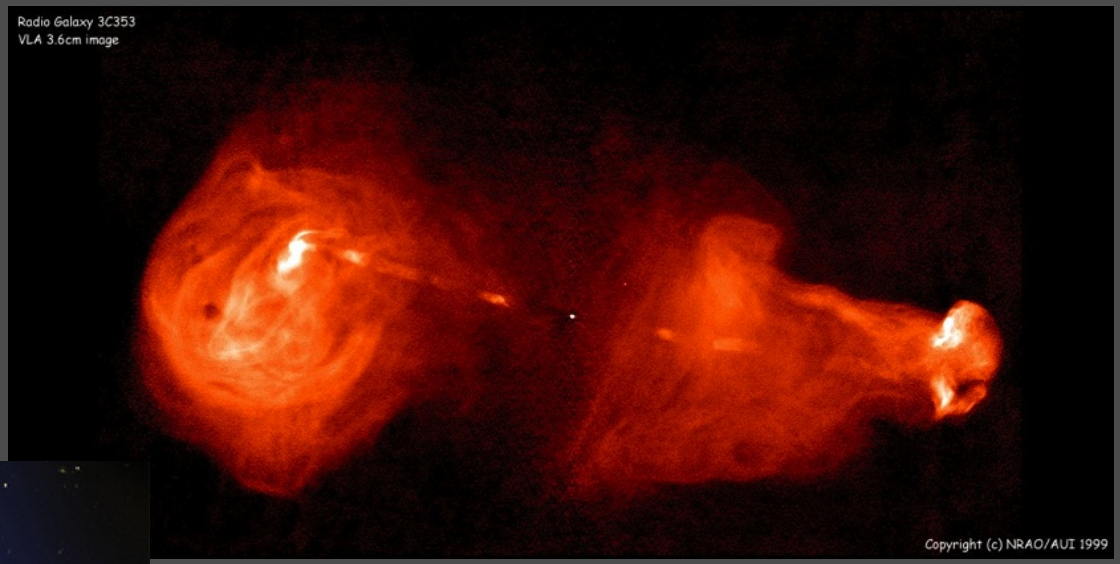
Appearance:

Viewing angle matters – very non-isotropic

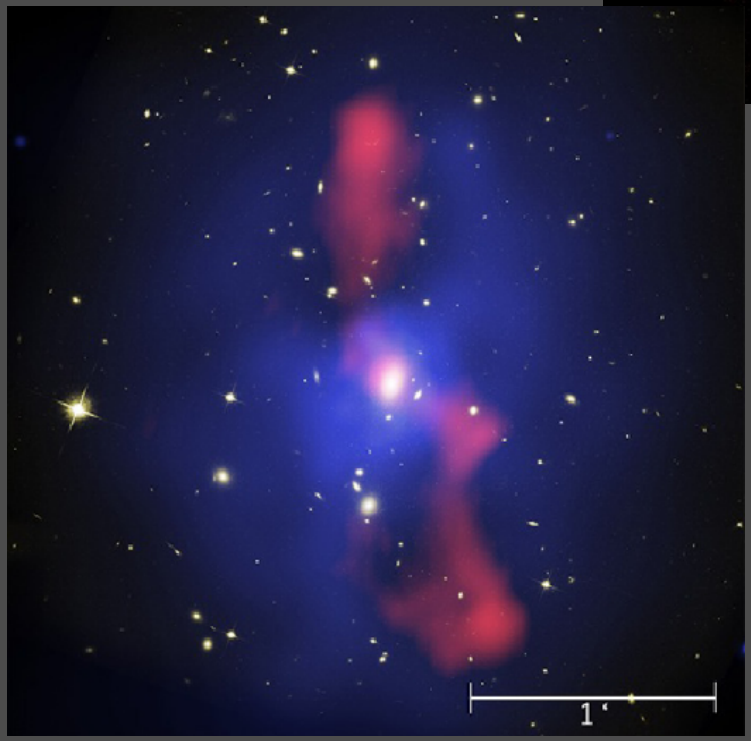
Obscuration from Molecular Torus

About 10% of AGN have Relativistic Jets

Synchrotron radiation from Radio to X-rays



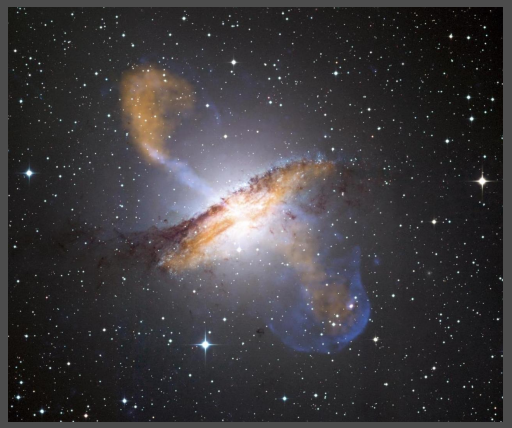
3C 353 (NRAO)

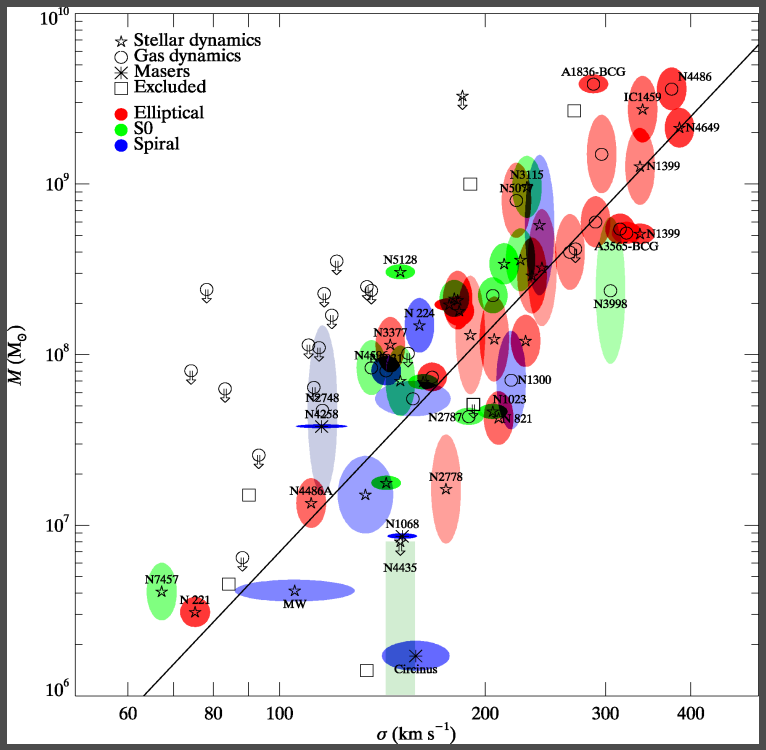


MS0735.6 (McNamara et al 2009)

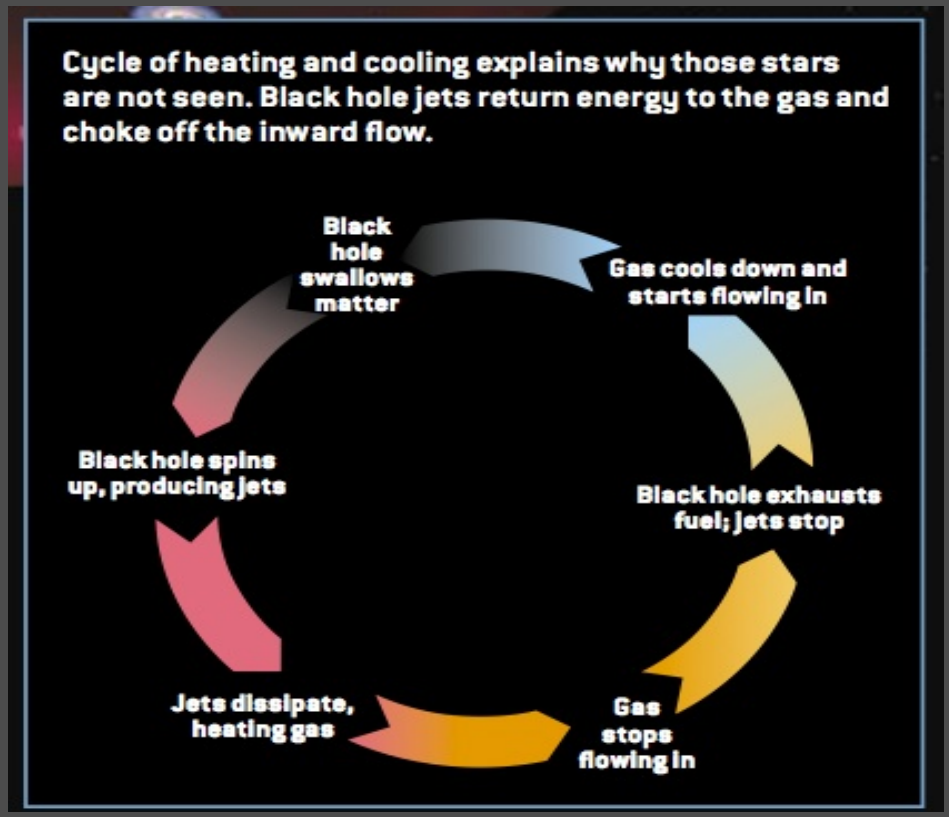
Kinetic Powers up to 10^{46} erg s^{-1}
Lifetimes ~ 10^{7} yr (?)
Jet lengths can reach ~1 Mpc
Heating of the galaxy-scale gas and cluster medium

How important are Jets and Winds in the life cycle of a galaxy?

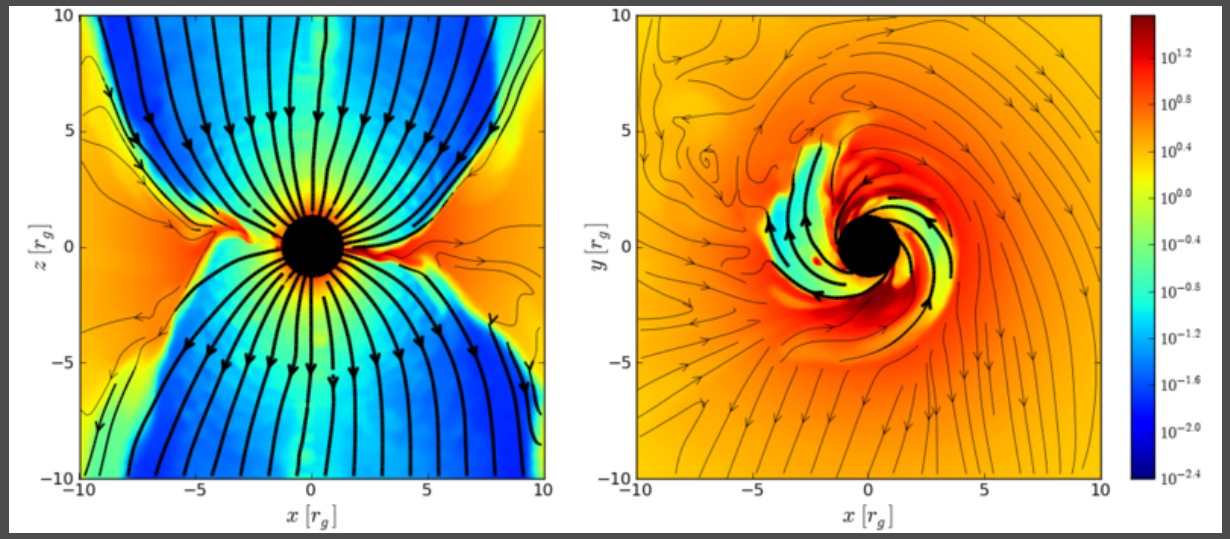


Gultekin, et al. 2009



The to-do List: Unsolved Issues in Radio-Loud AGN

How are these Relativistic Jets Launched and Collimated?

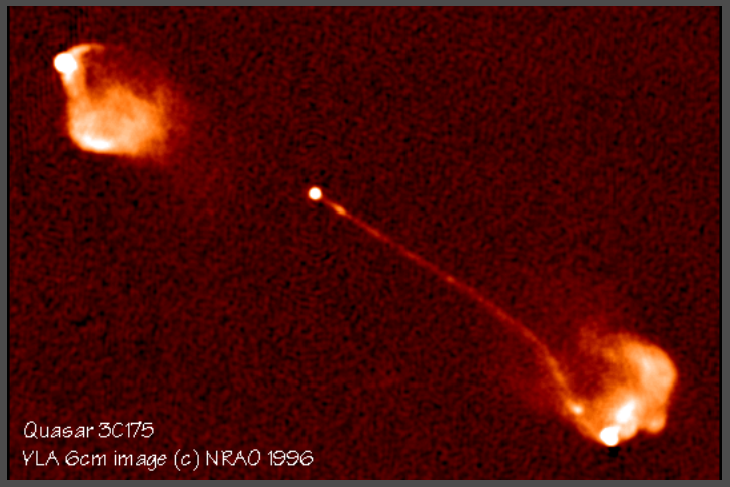


Why do only some AGN produce jets?

What is the typical lifetime of a jet? How do they evolve, and how do they impact the host galaxy?

The to-do List: Unsolved Issues in Radio-Loud AGN

What is the difference between strong (FR II)
and wimpy (FR I) jets?



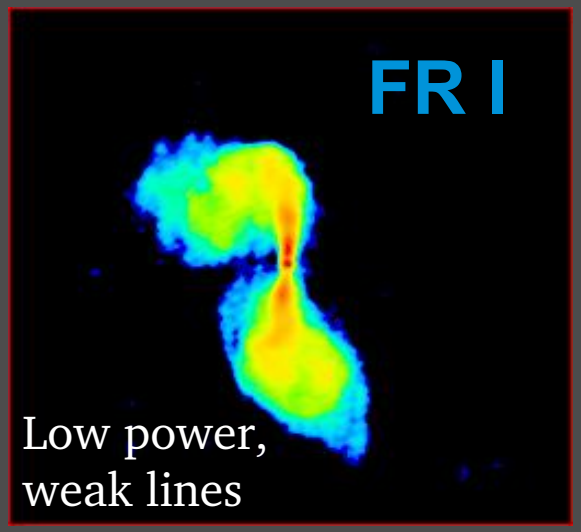
What are they made of? ‘Heavy’ versus ‘Light’ Jets

What is the large-scale jet structure? How fast? How much energy?

Radio Loud AGN Unification: Beyond Orientation

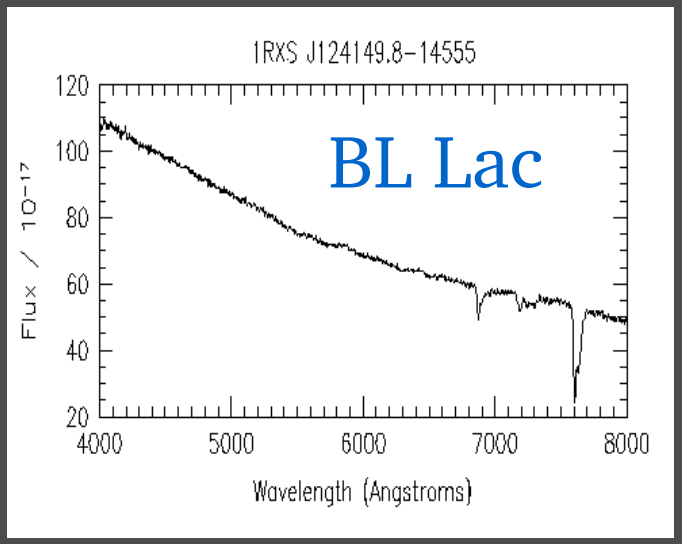
The conventional View

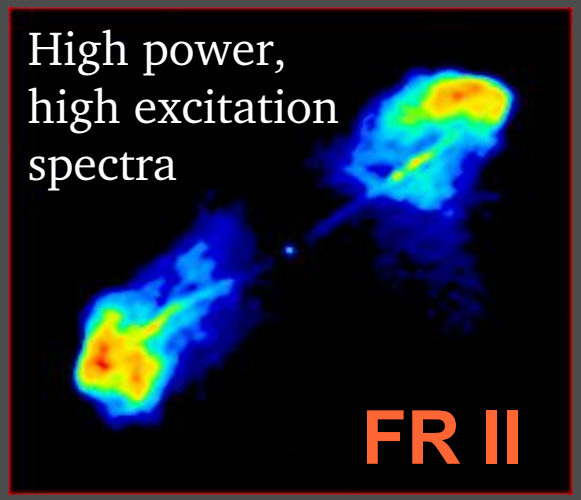
Radio Galaxy Morphology



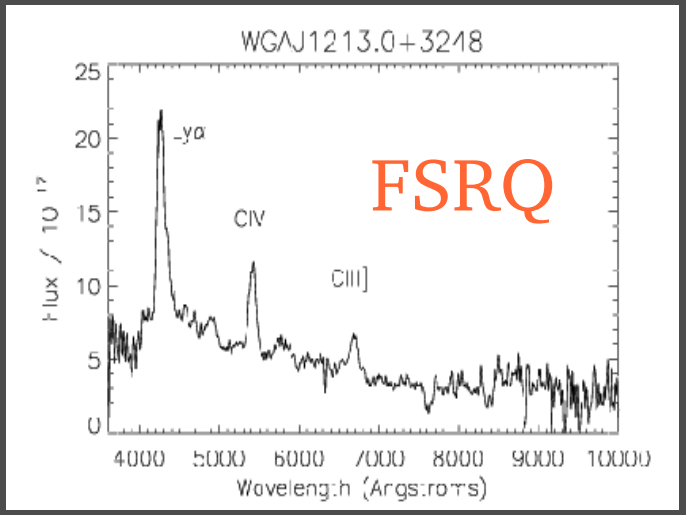
ADAF

Blazar Spectral Type

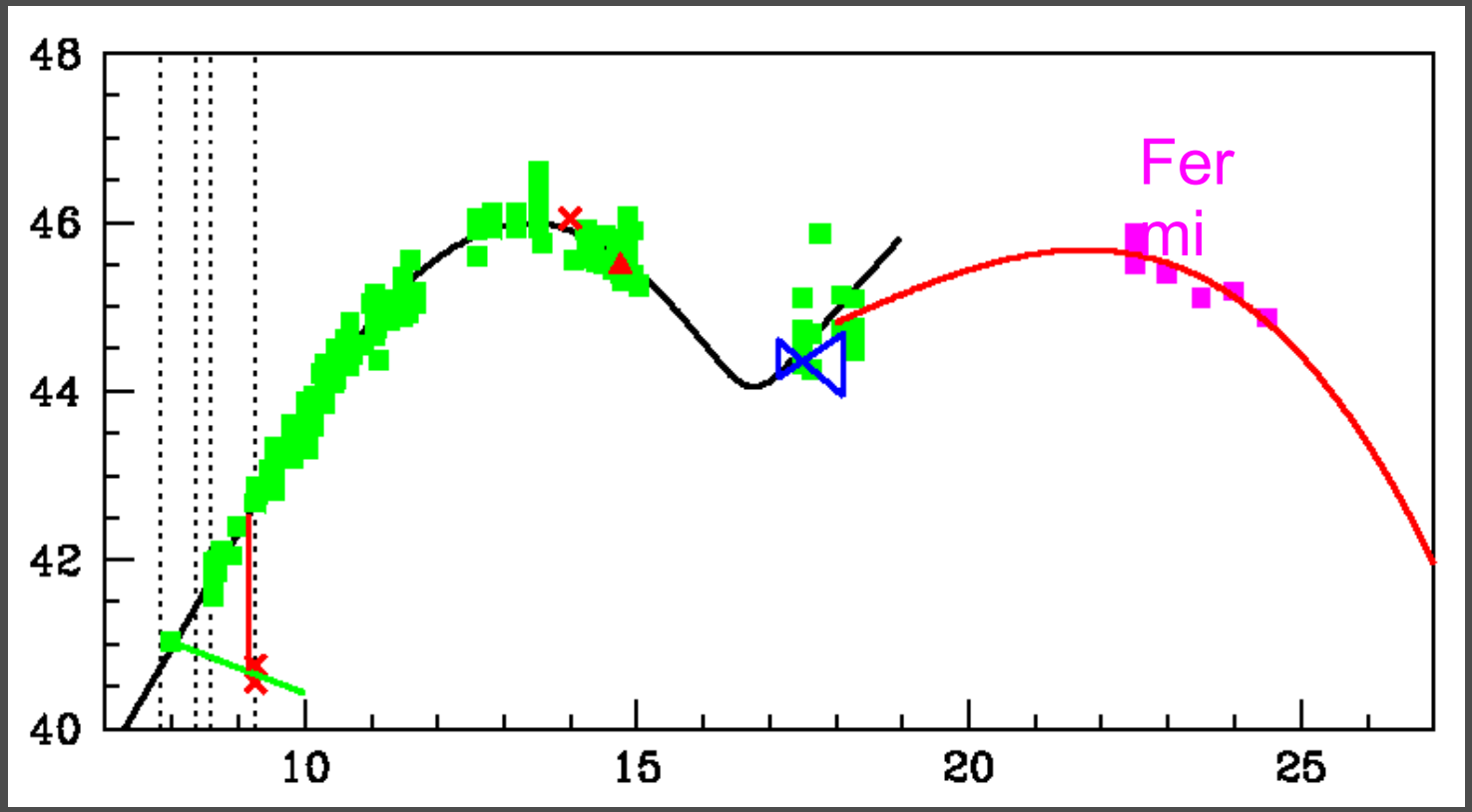




Thin disk

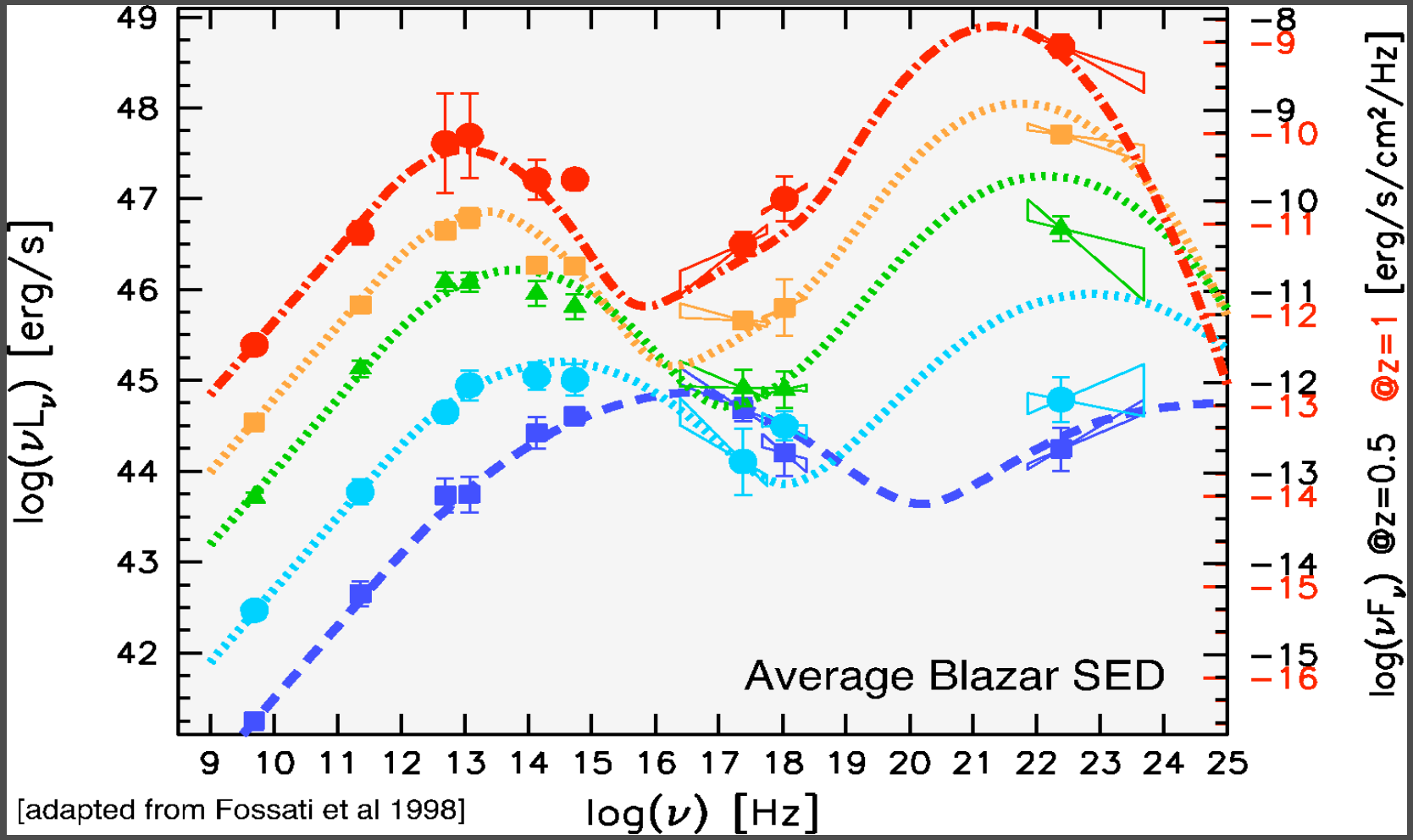


Blazars: A close-up of Jet Emission



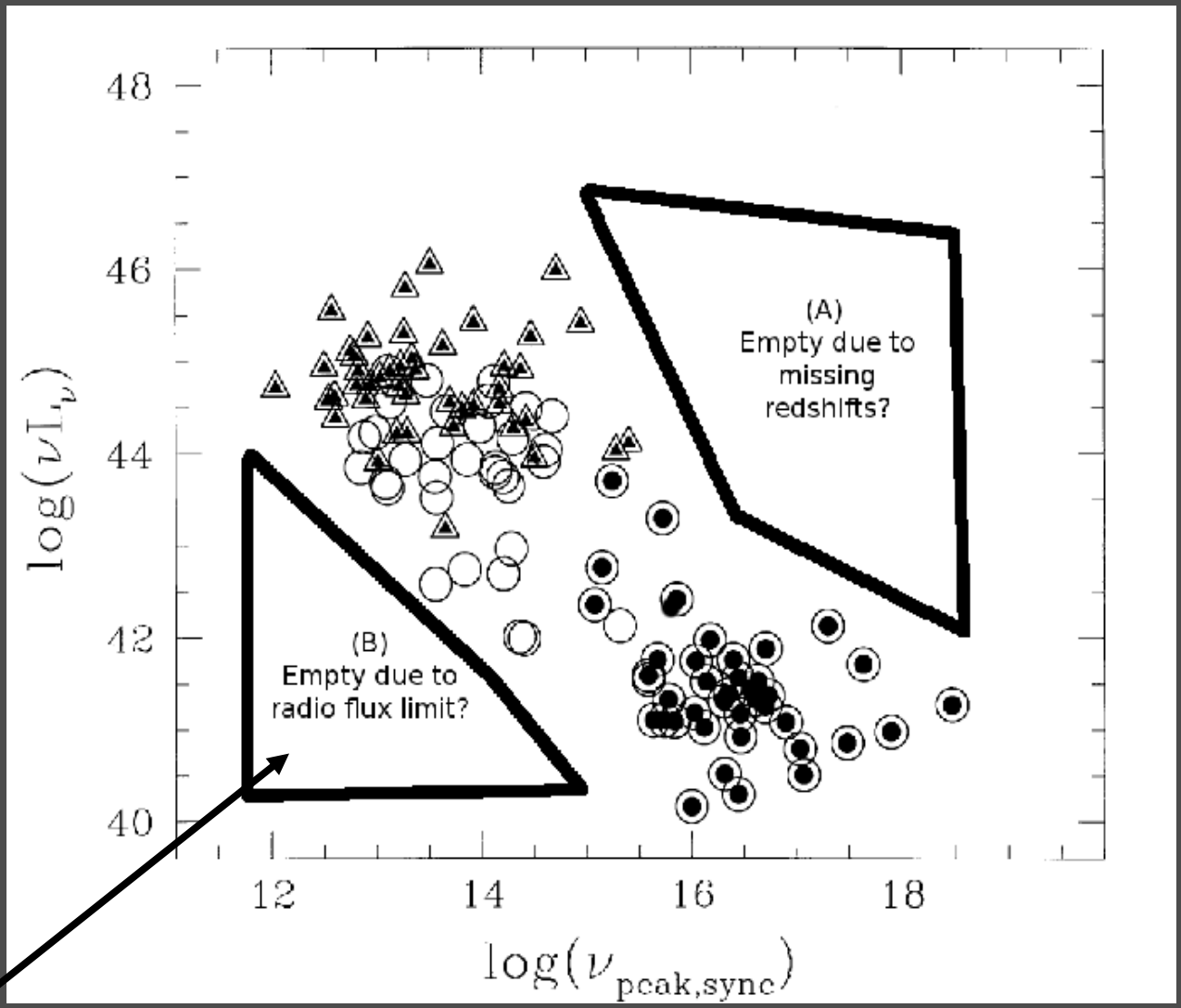
SED: Synchrotron (Radio – X-ray) + Inverse Compton (X-ray to TeV)
Highly Variable, need LOTS of data to characterize

1998: The Blazar Sequence



Increased External Photon Field with Power: (1) More EC (IC dom)
(2) lower ν_{peak}

Suggests a mono-parametric sequence based solely on jet power



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

RL AGN: Unification Problems

- FR I/II morphology divide not strictly luminosity

  (how do the “parent populations” go with the sequence?)

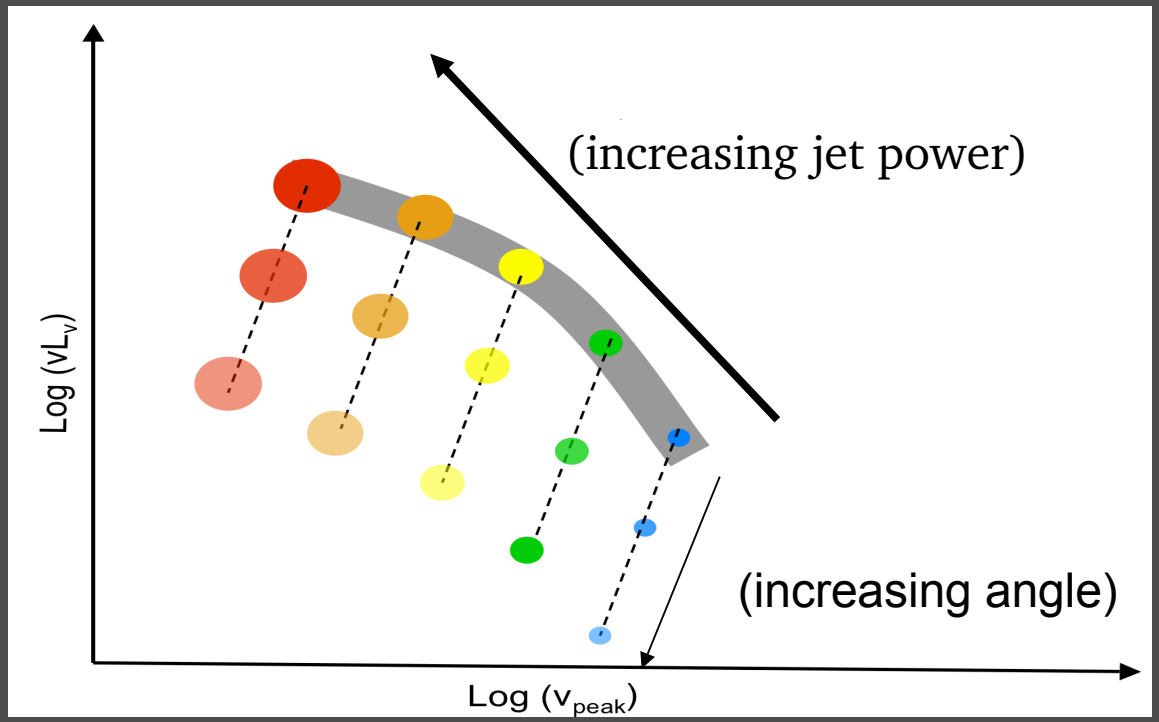
- Evolution – positive for FSRQs and LBLs? Just FSRQ?

  (how does this match the evolution signatures of FR I/II)

- Anti-sequence: low-power FSRQ, high-power BL Lacs

  (what is the significance of spectral type?)

Hypothesis: The Blazar Envelope



What if we are picking up misaligned AGN?
Can a sequence + misaligned “envelope” explain the counter-sequence blazars?

Testing the Blazar Envelope Hypothesis

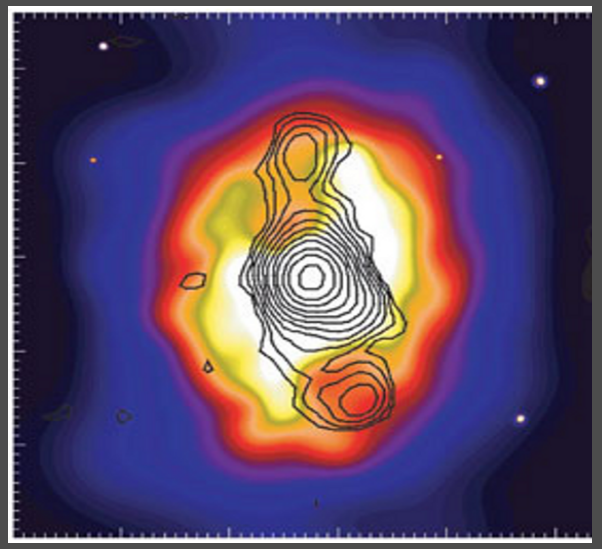
(1) Measure (unbeamed) Jet Power

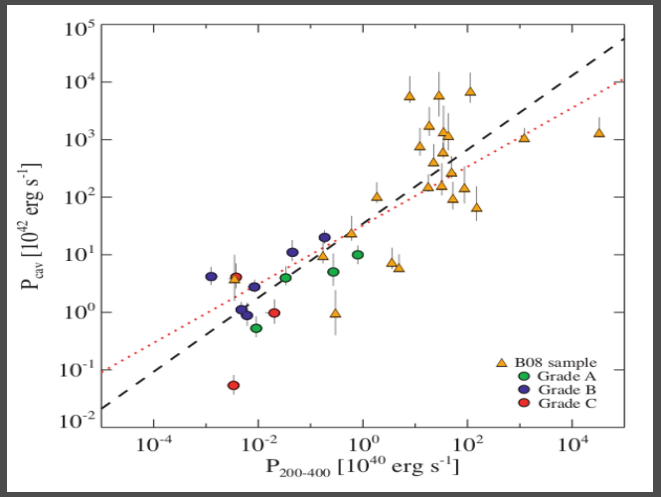
(2) Measure the alignment

Hint: Jet structure may become more apparent at large θ

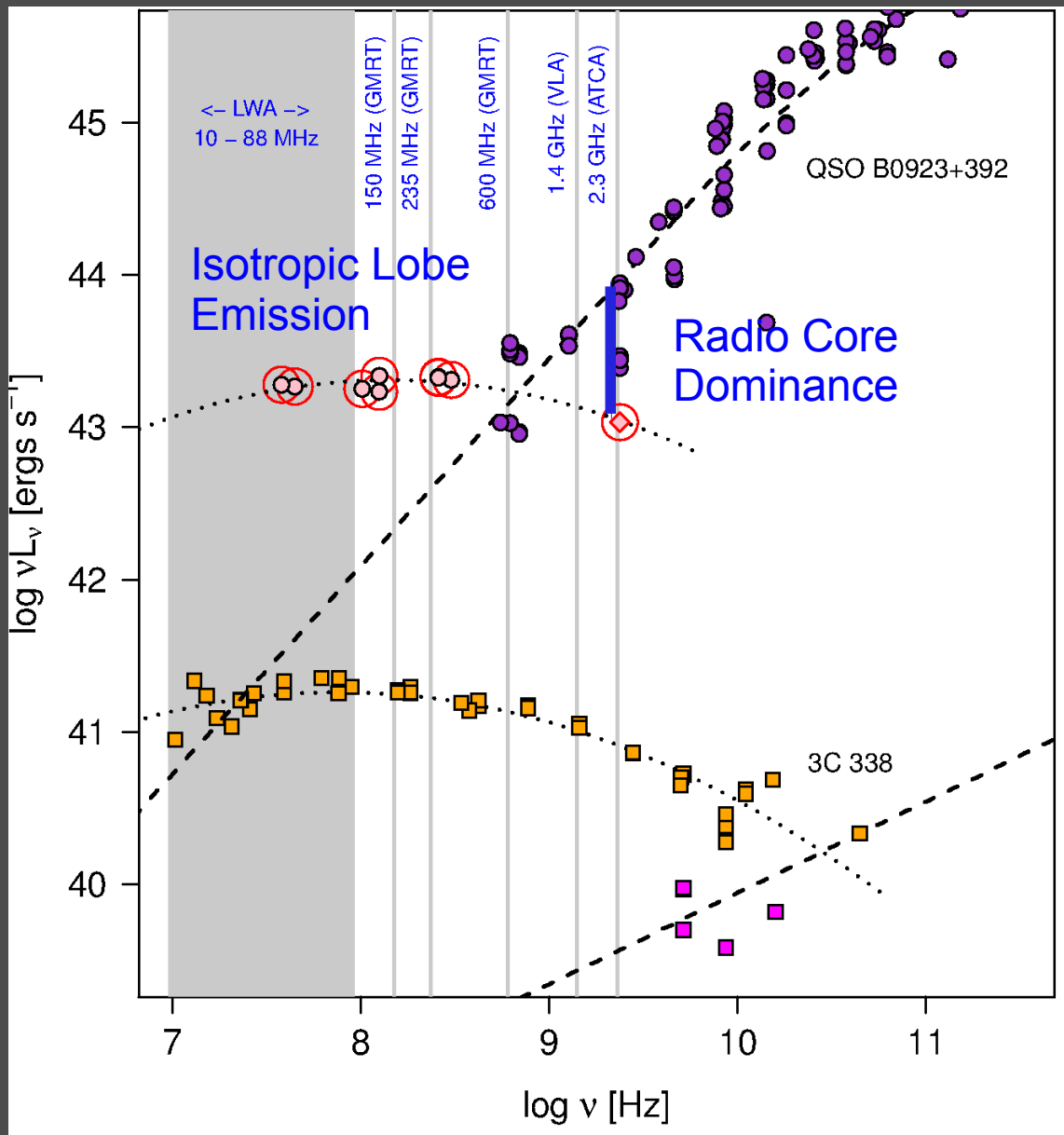
(3) Build Up a large Sample – better SED sampling

Methods: Radio

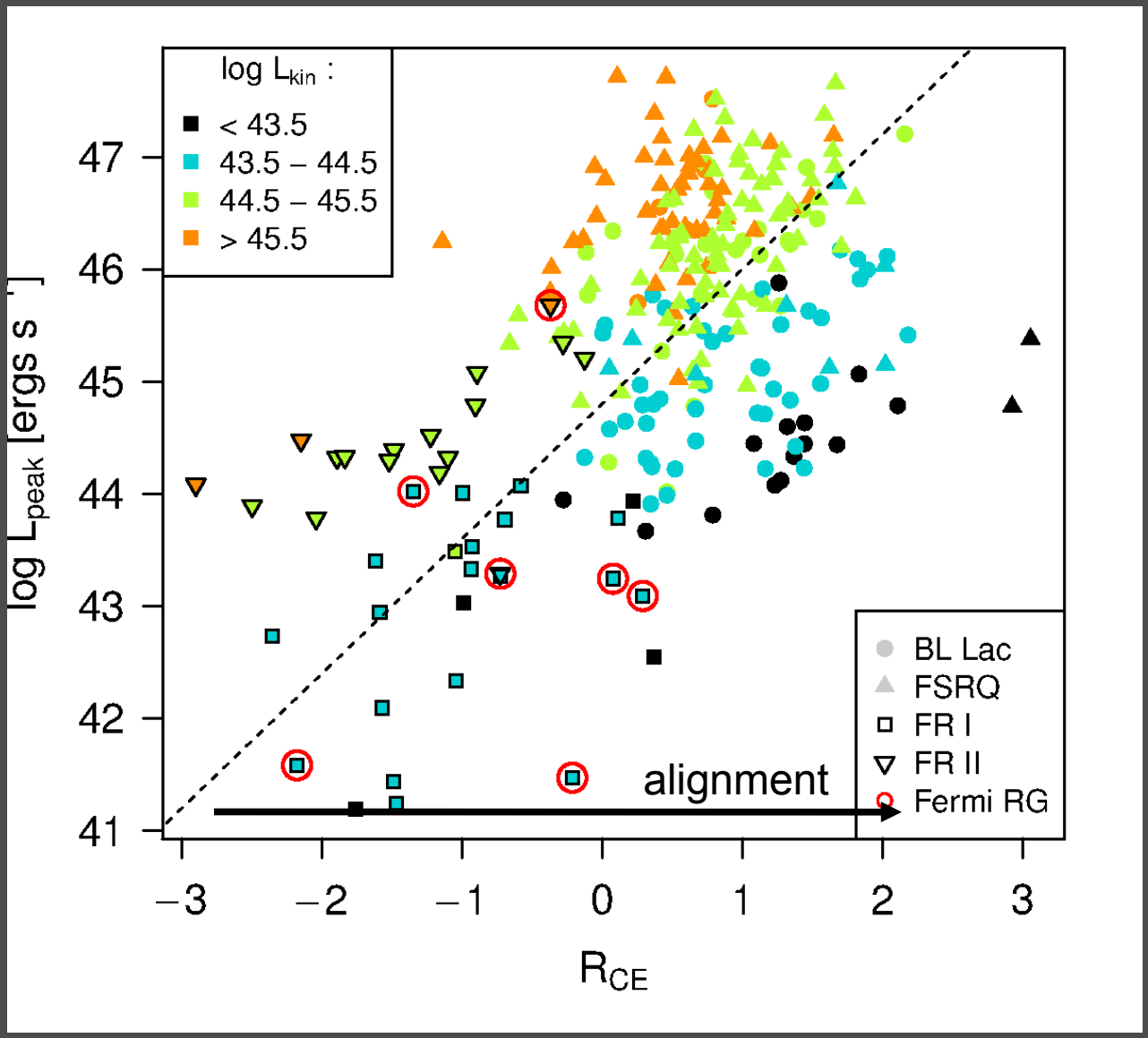




Cavity Power vs. Extended, Low-frequency Power (Cavagnolo, et al. 2010)

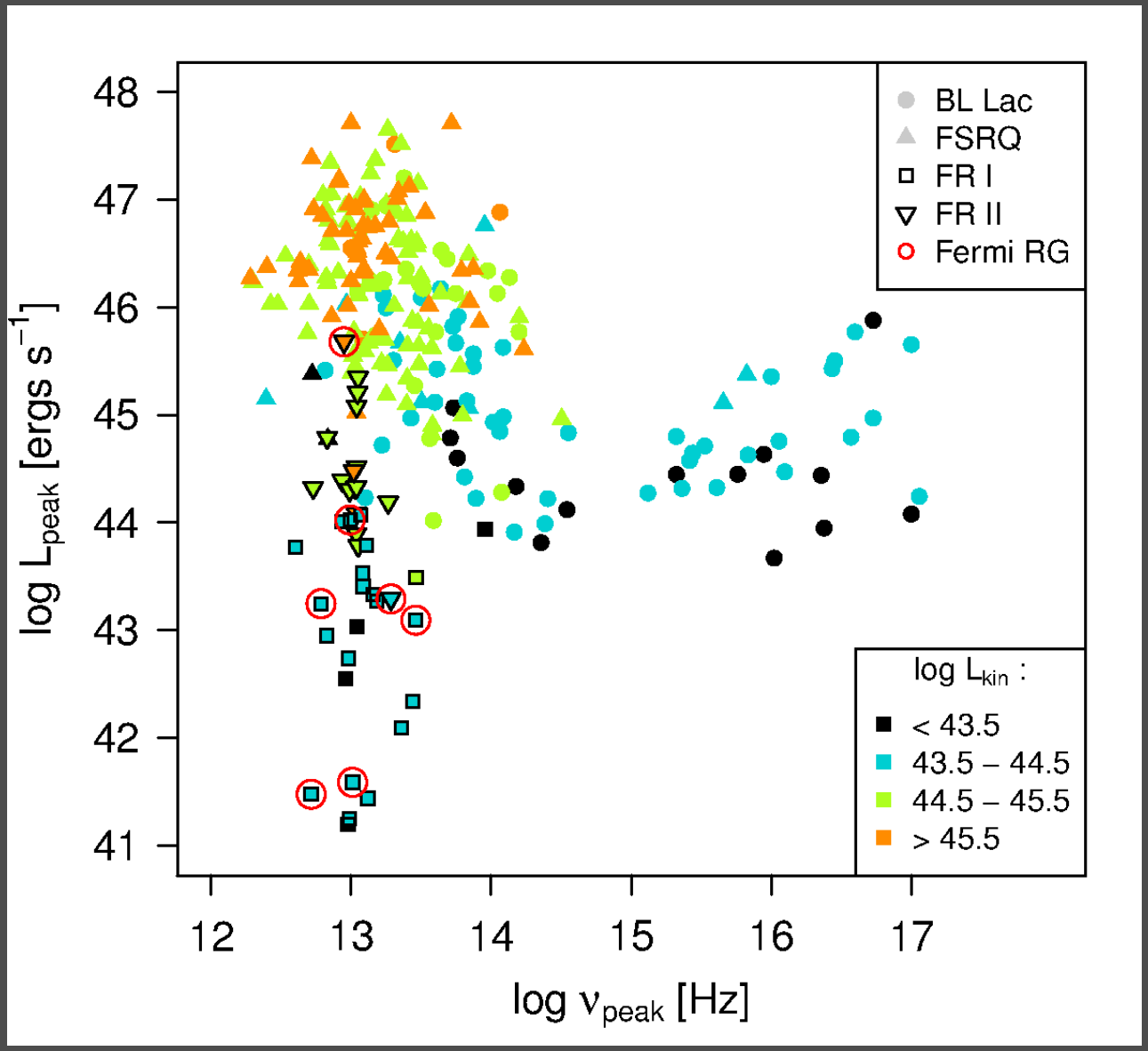


Full Sample: > 200 blazars, several dozen radio galaxies



Isampling the full range of alignments for jets

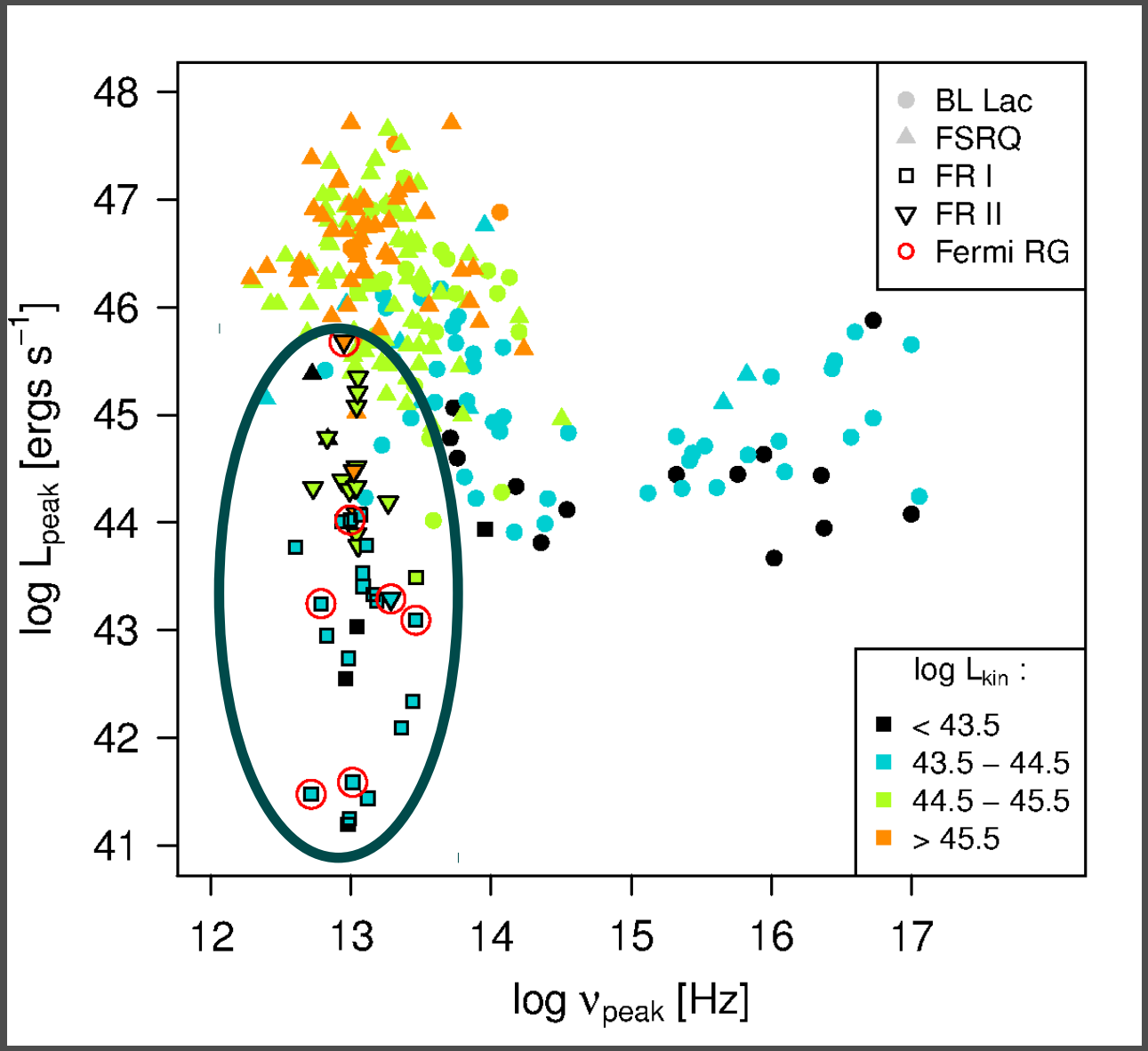
The Blazar Envelope (now with more radio galaxies!)



Observation #1:

Not very Sequency

The Blazar Envelope (now with more radio galaxies!)



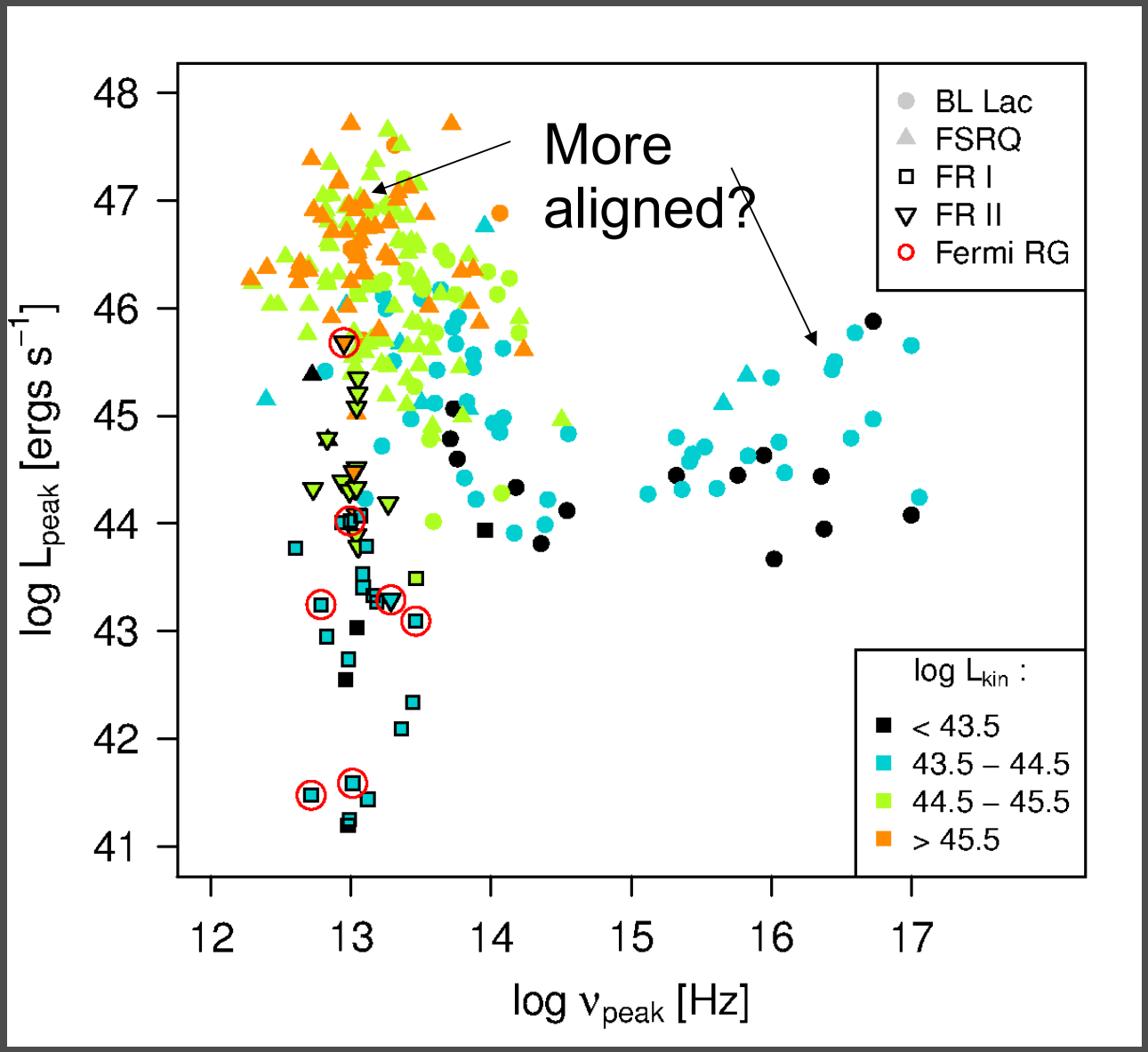
Observation #1:

Not very Sequency

Observation #2:

All the radio galaxies Are at **low** ν_{peak}

The Blazar Envelope (now with more radio galaxies!)



Observation #1:

Not very Sequency

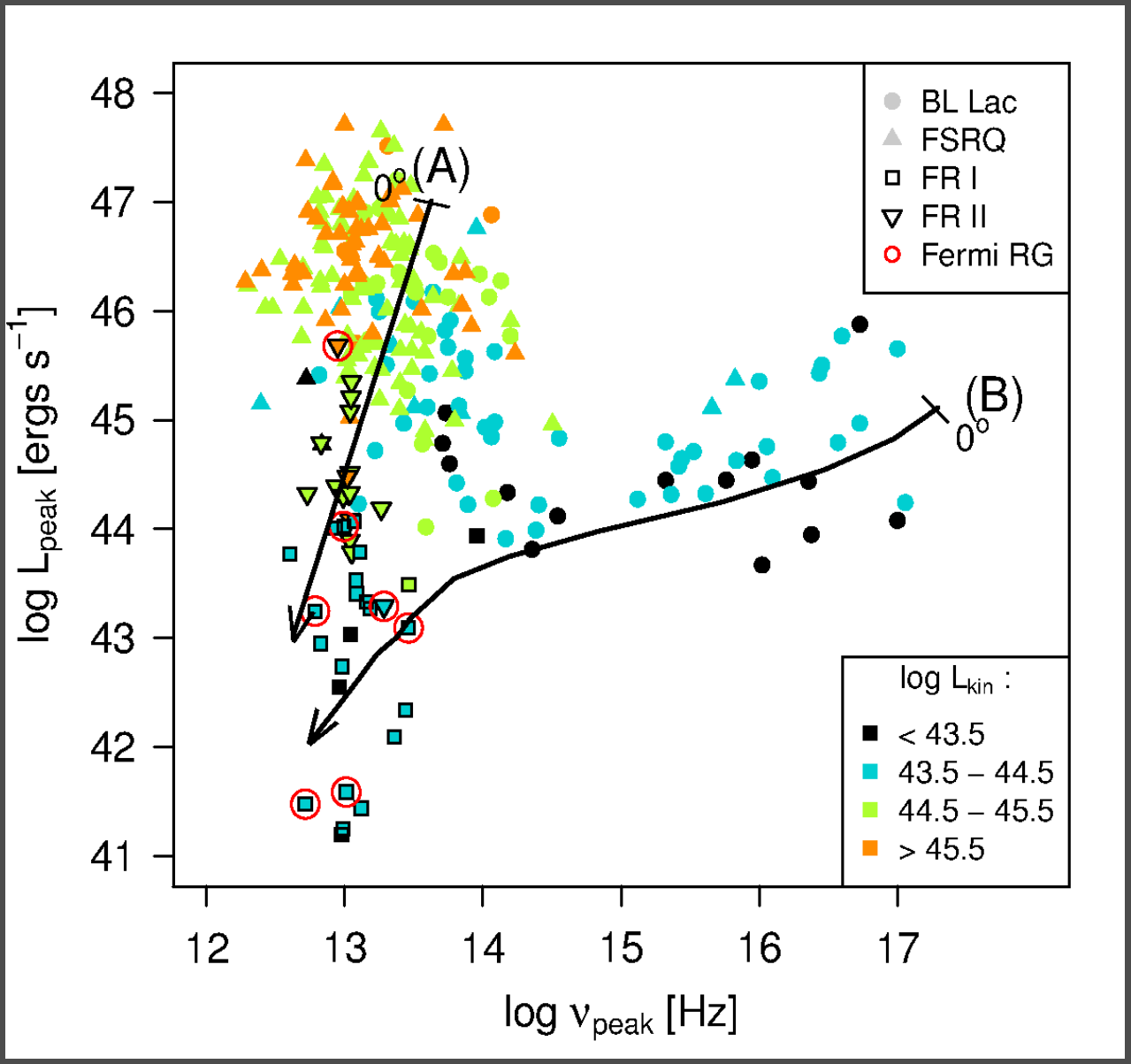
Observation #2:

All the radio galaxies
Are at **low** ν_{peak}

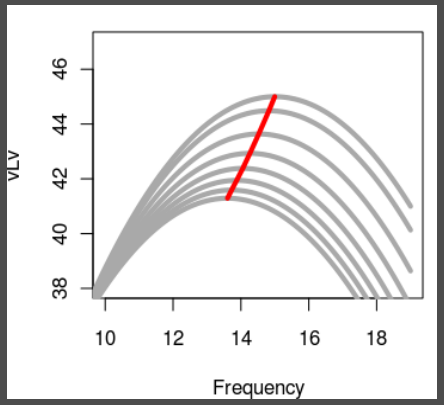
Observation #3:

Radio Core dominance increases
With Luminosity

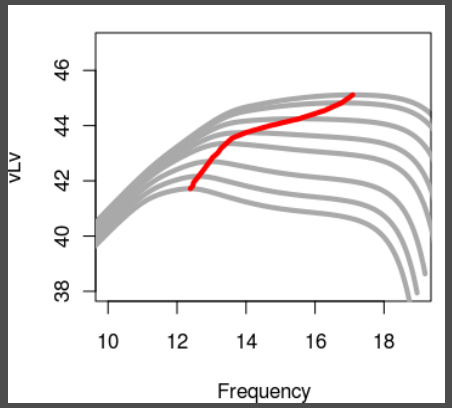
The Blazar Envelope: A dichotomy?



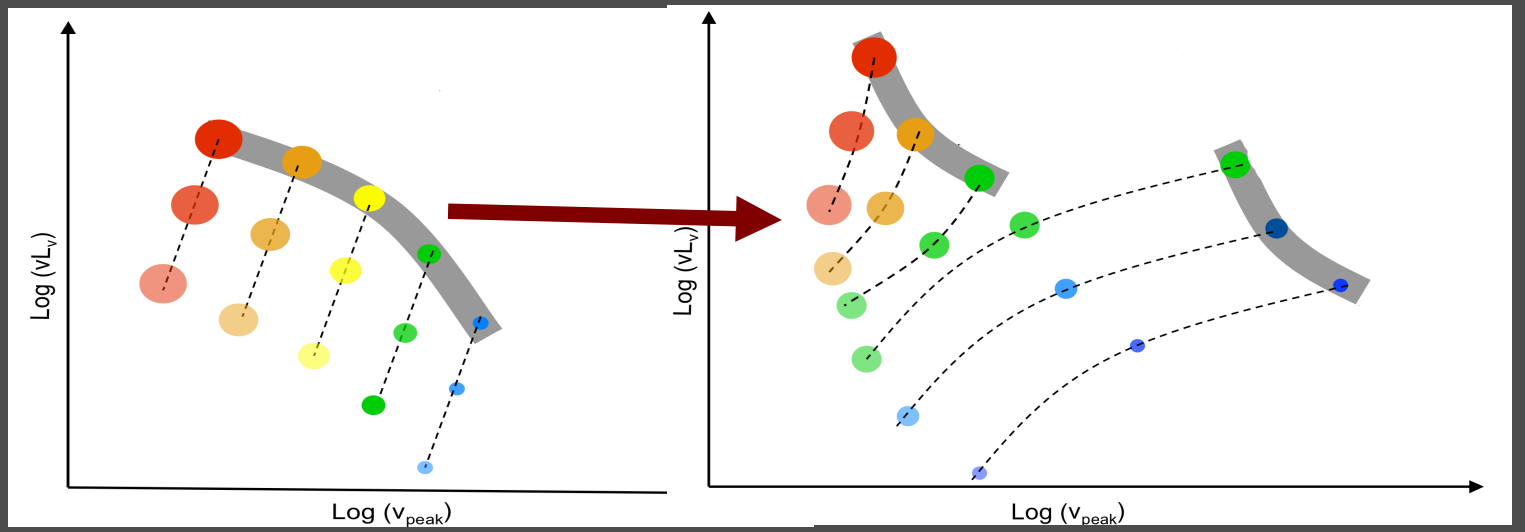
"Simple jet" (single Γ)



"Decelerating Flow" model (Georganopoulos et al 2005)



New Hypothesis: A Spectral Jet Dichotomy?

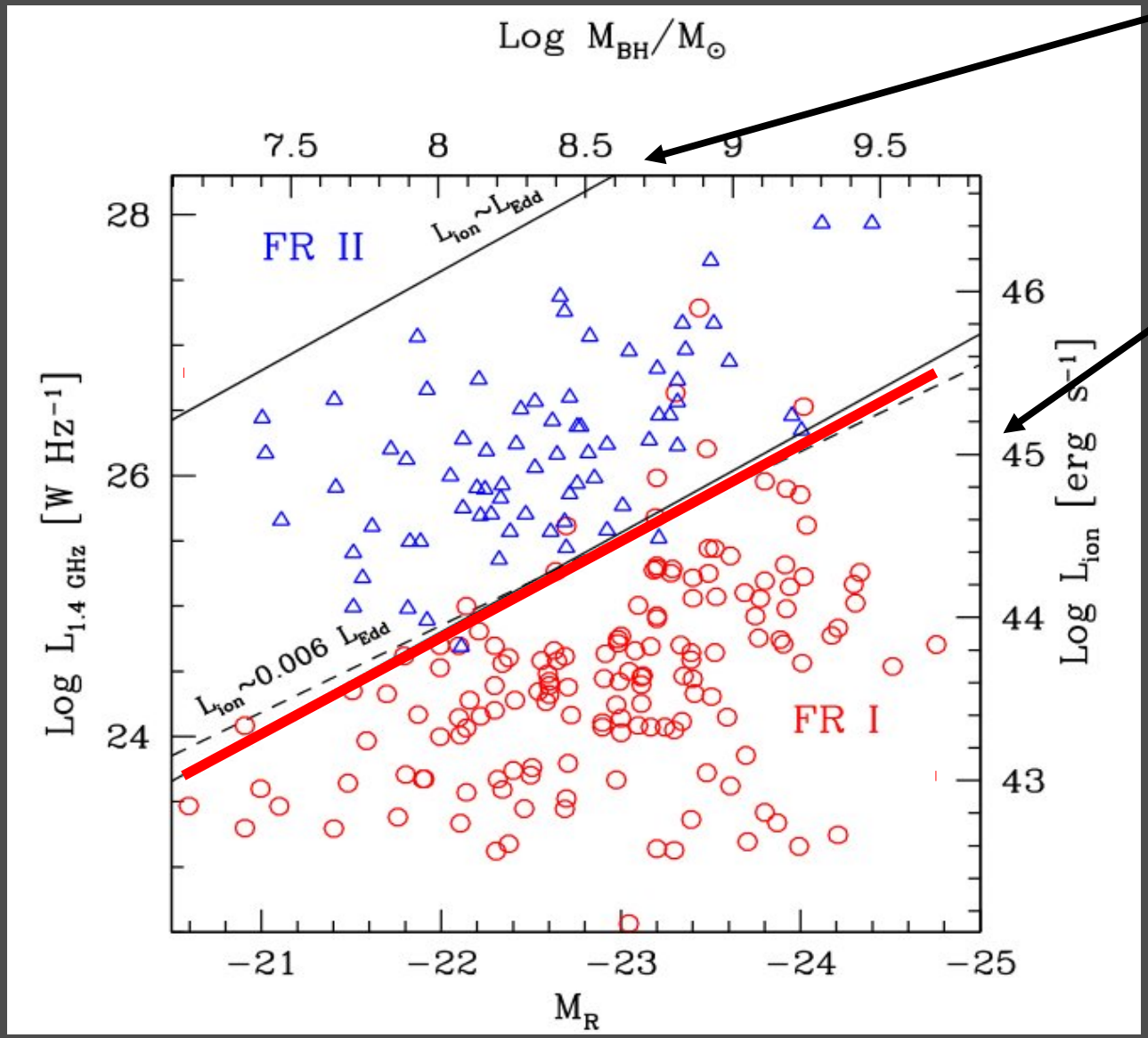


Takeaways:

+ Orientation is important

+ If there is a divide, it is evidently *not on power (L_{kin}), black hole mass, or linked to spectral type*

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



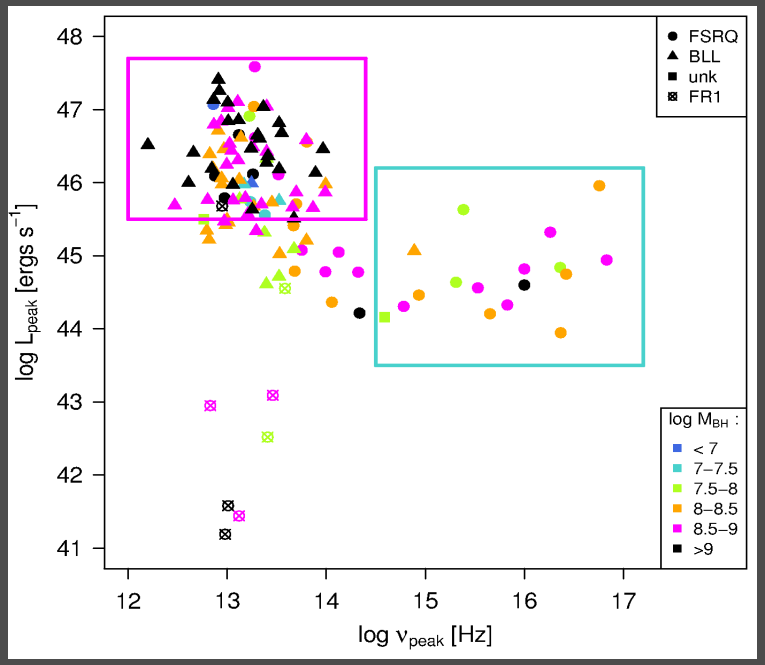
BH Mass

Jet Power

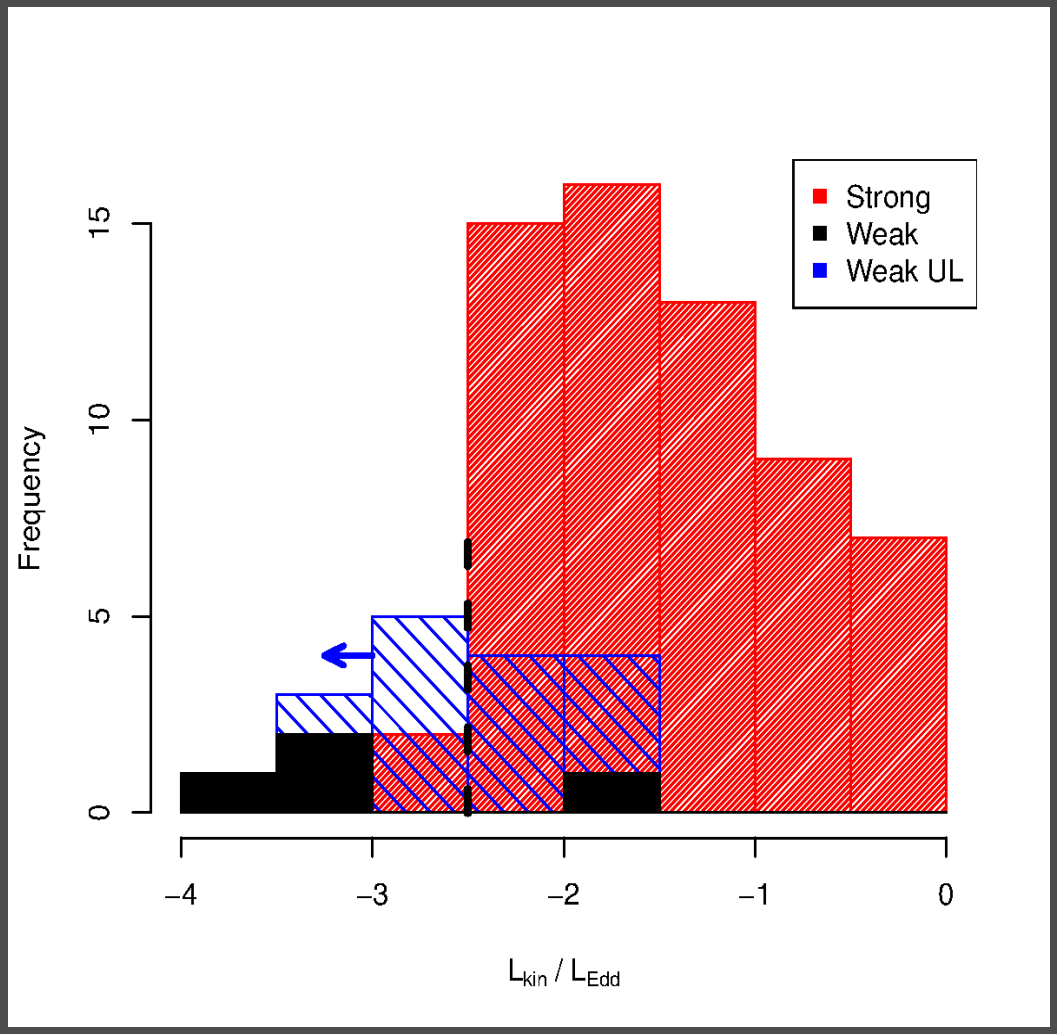
critical value
$\dot{m} \sim 10^{-2.5}$

(Ghisellini et al. 2001)

Can the jet divide be an accretion mode switch?



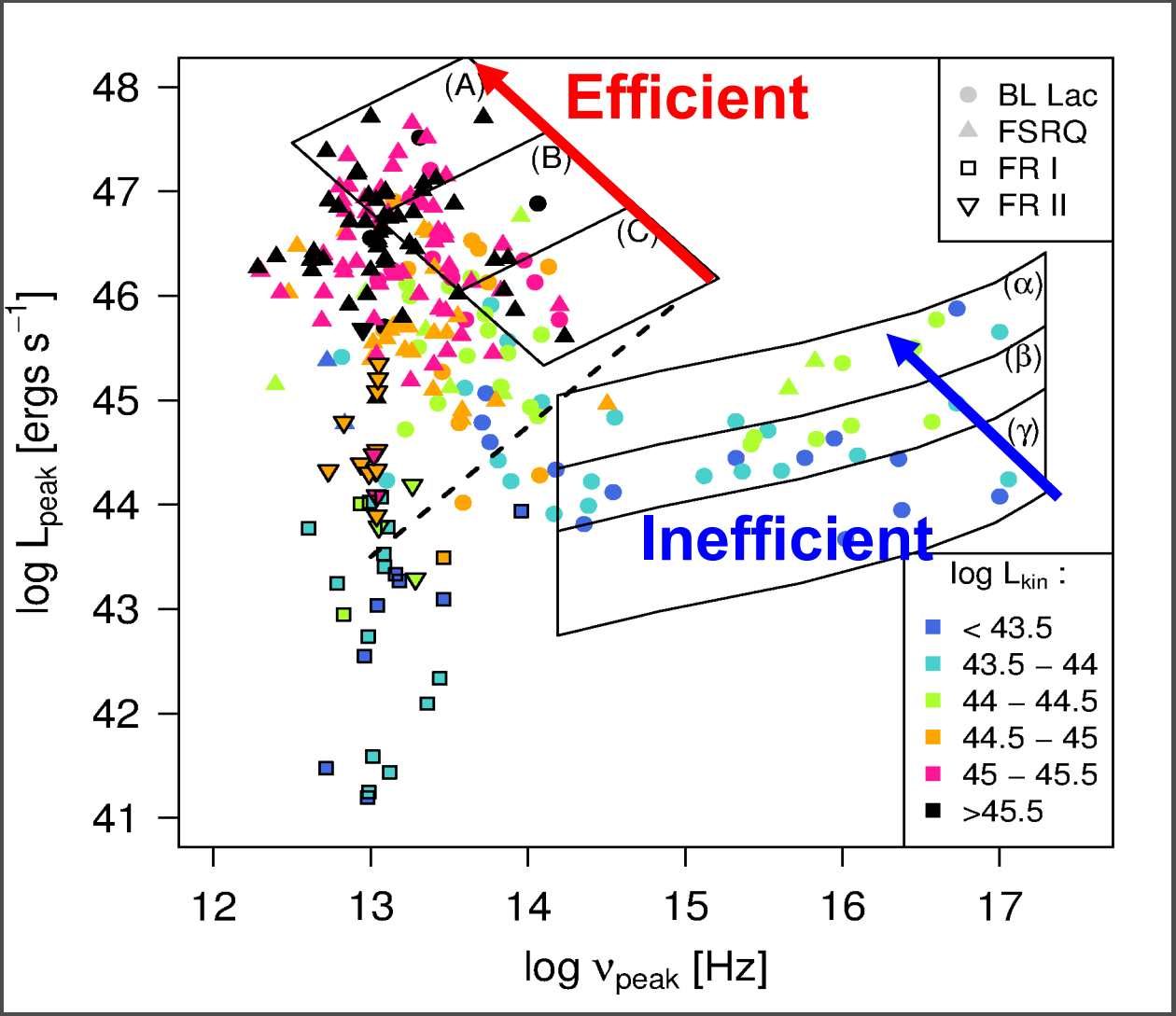
(Mass estimates from reverberation mapping, velocity dispersions, mass-luminosity scalings)



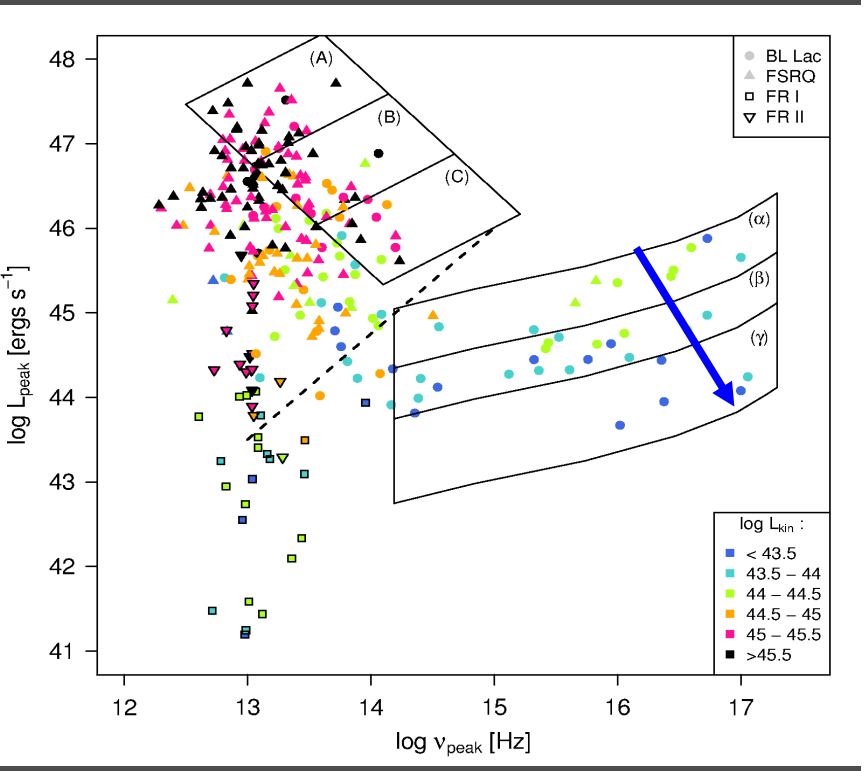
Weak Jets = Inefficient

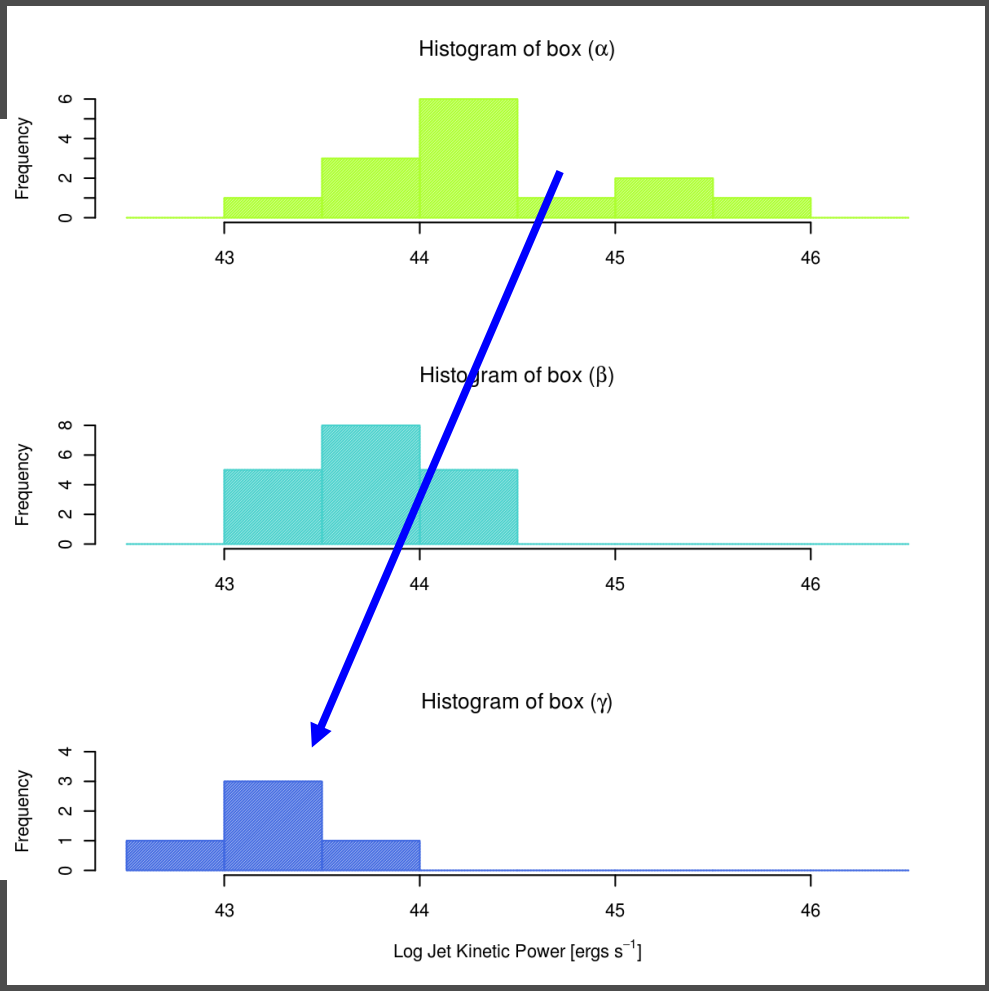
Strong Jets = Efficient

The Broken Power Sequence



The Broken Power Sequence





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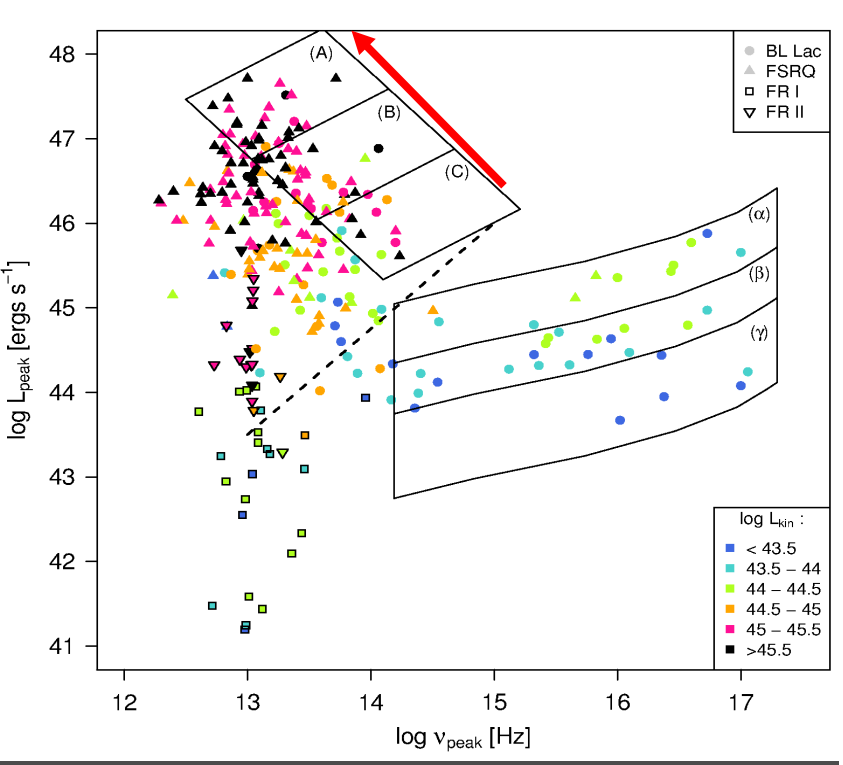
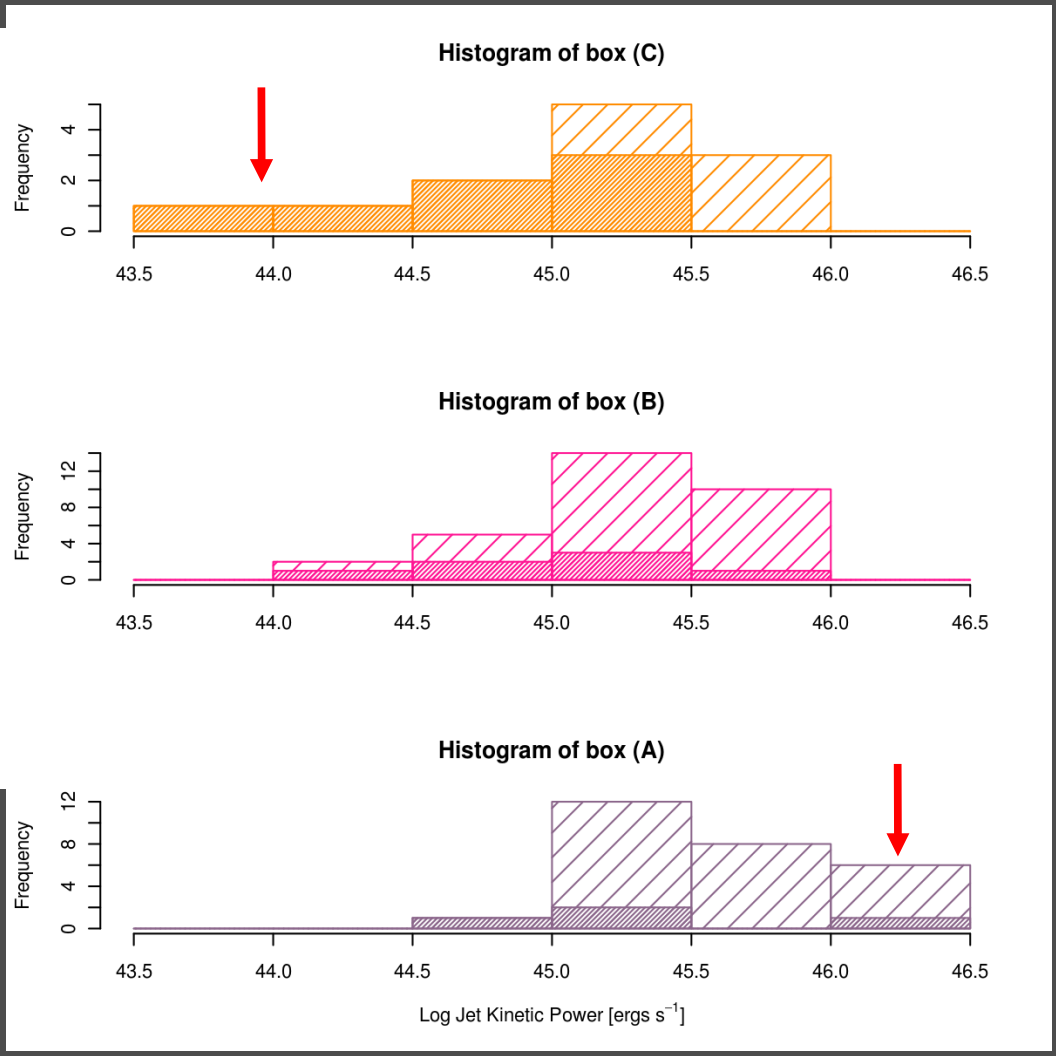




What has changed?

+ Suggestion of Two populations: “weak” / “strong”

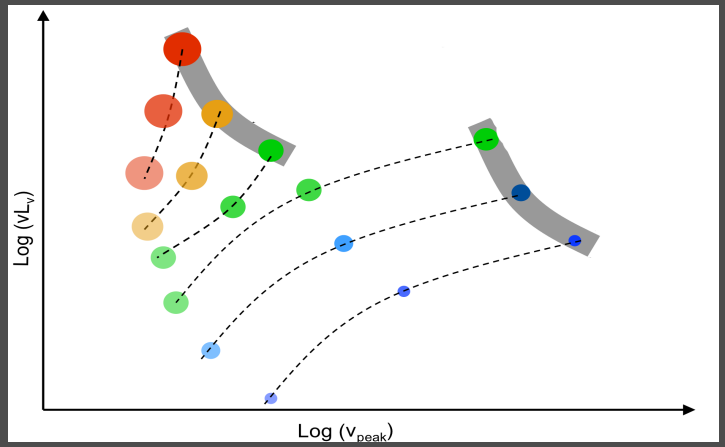
  NOT BLL/FSRQ, but probably FR I/FR II

+ Jet Power important, but not *the* single parameter (but weak jets are all have $L_{kin} < 10^{45.5}$ erg s^{-1}

+ Spectral types (FSRQ, BLL) are affected by beaming, *not reliable!*

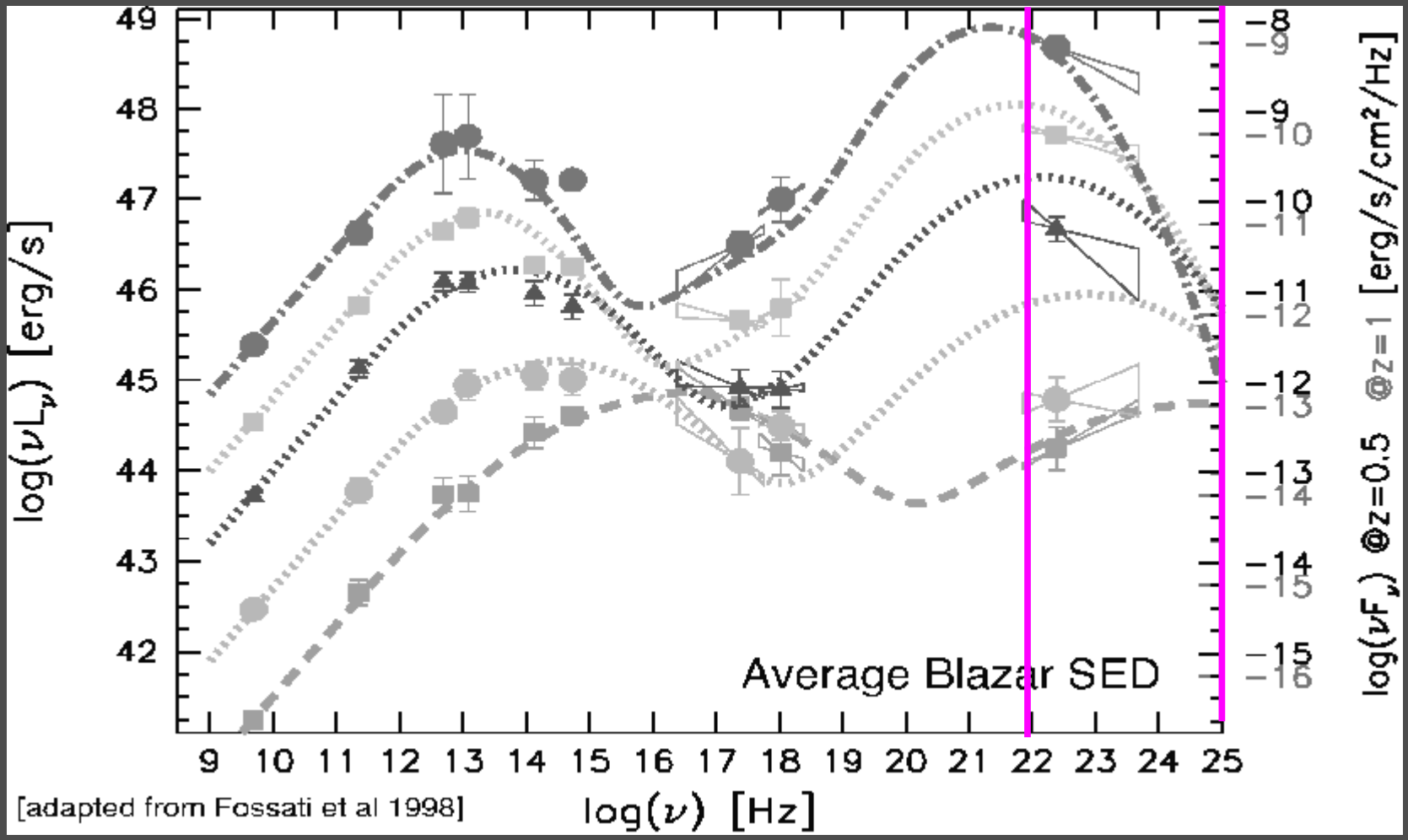
+ Observations consistent with a change in accretion mode at a critical rate of $\sim 10^{-2}$ Eddington rate, *linked to a divide in jet SED characteristics.*

+ The sequence may exist in 'broken' form:



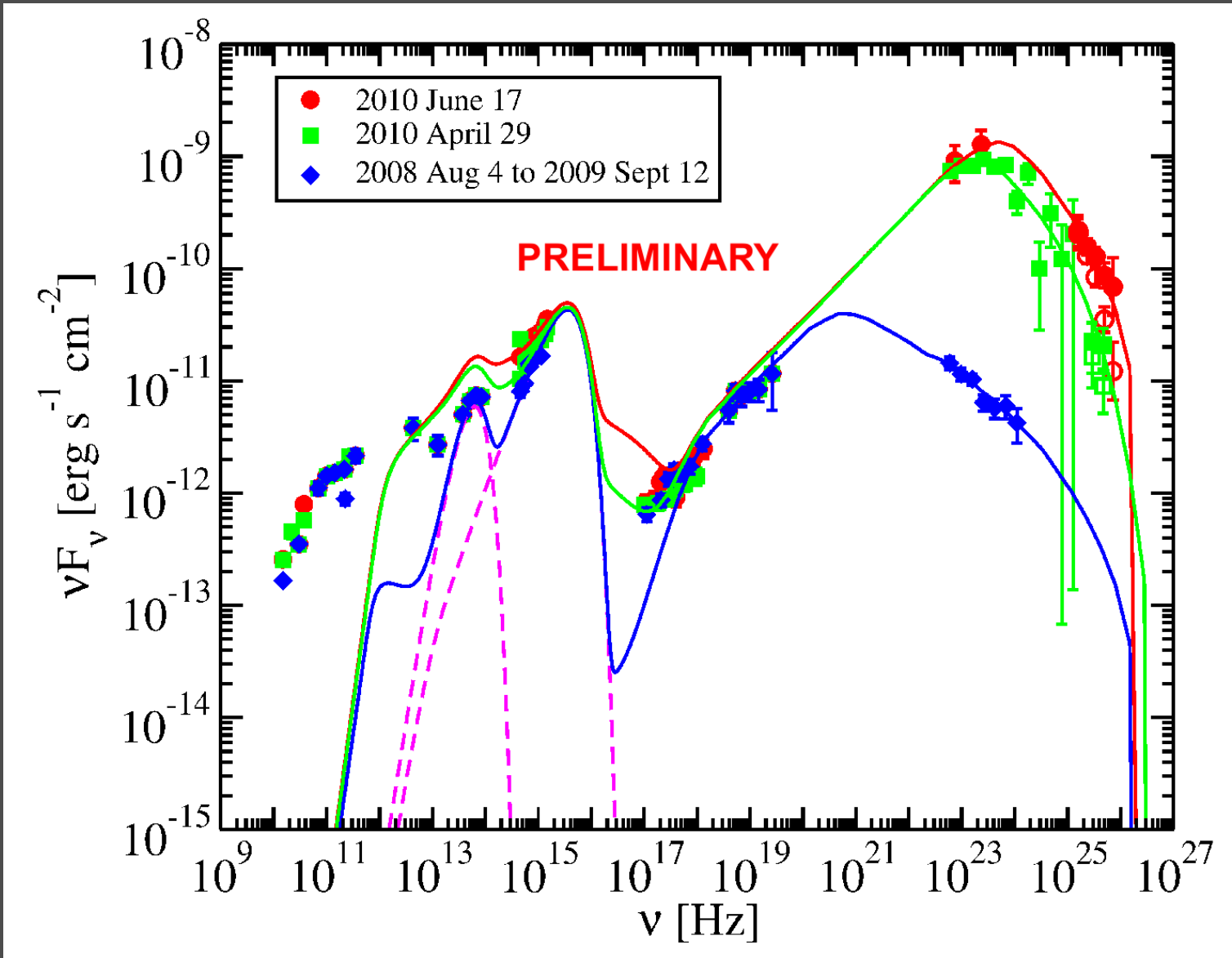
The Fermi View of AGN

Fermi (usable) band: 100 MeV – 100 GeV



Revolutionary for understanding the IC spectrum
Egret Era: ~ 60 blazars, often flaring – Fermi Era: 1800 and counting

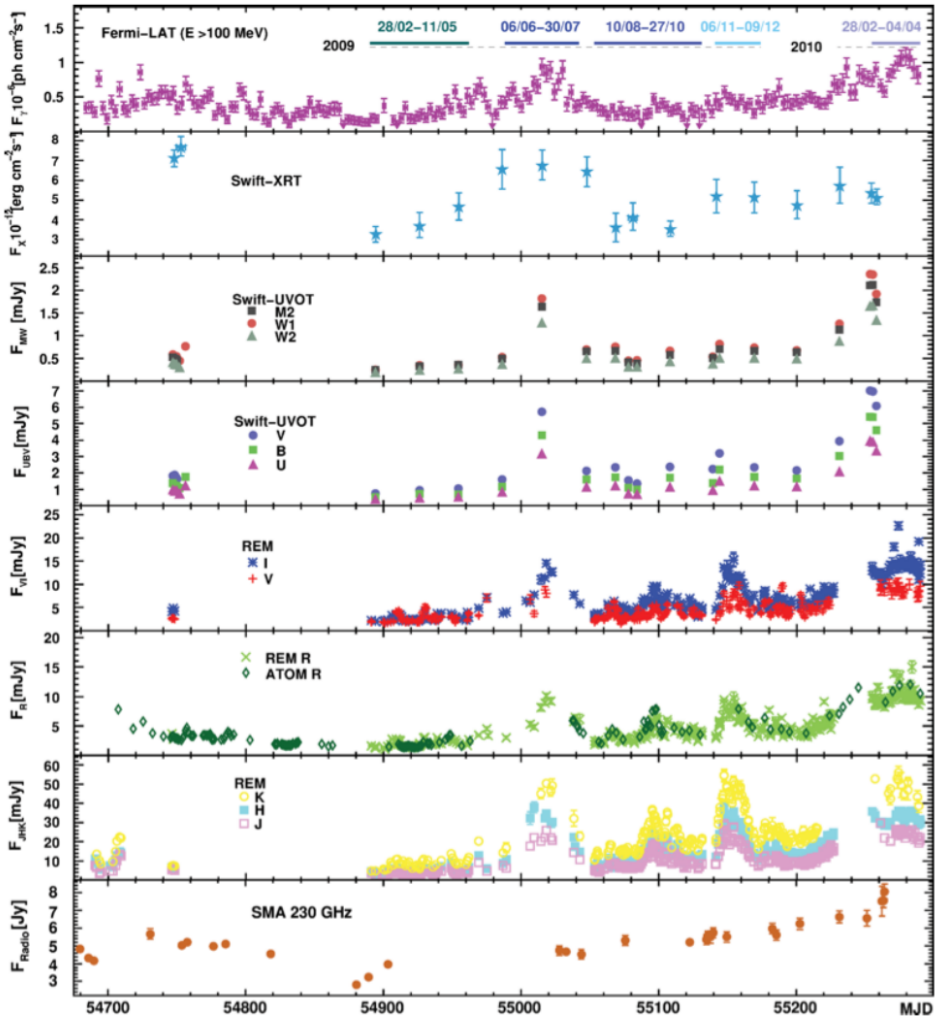
Fermi Sensitivity: Large Dynamic Range



Justin Finke/NRL & The Fermi/LAT Collaboration

All-Sky: Scans the sky once ever 3 hours

PKS 0537-441



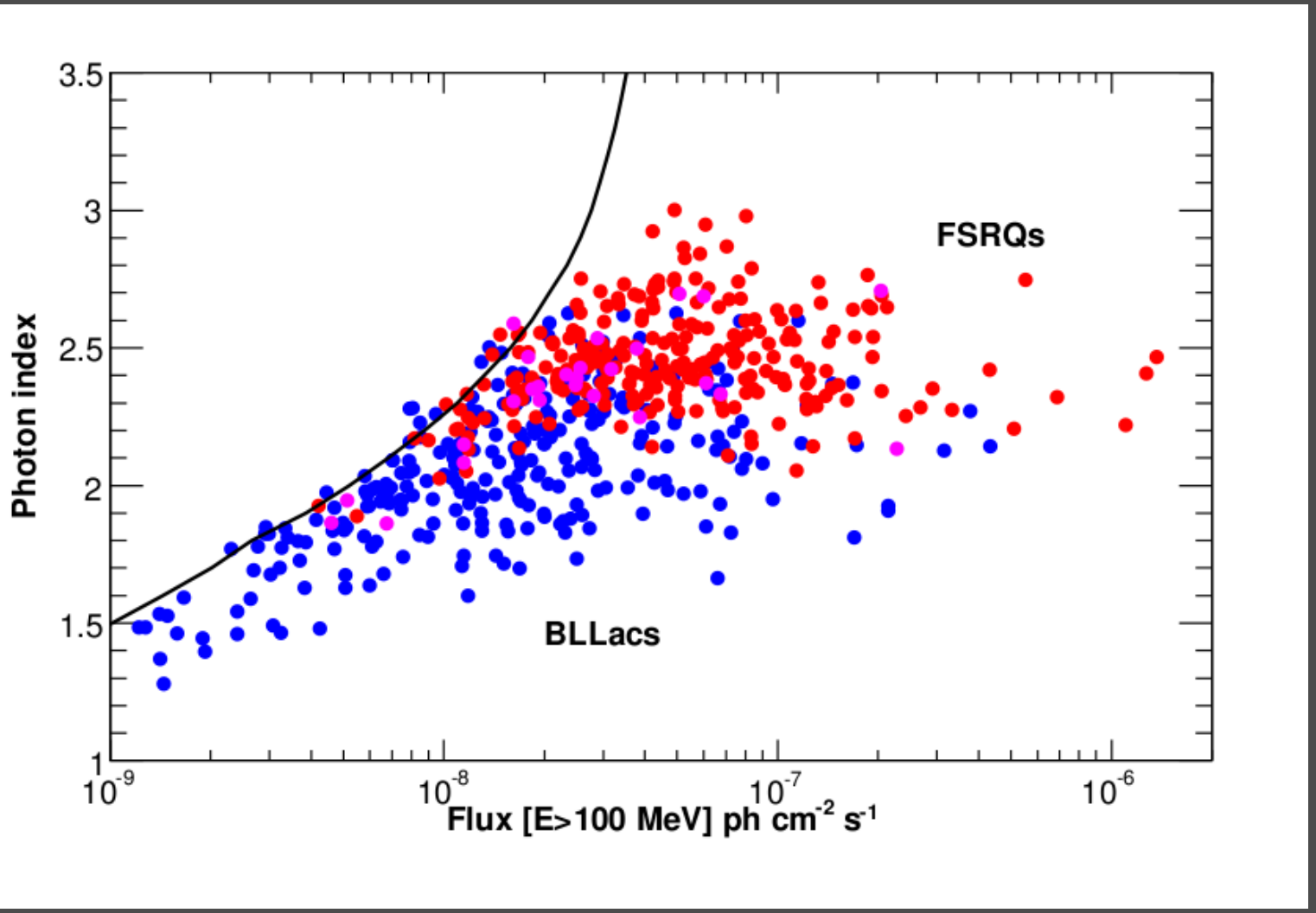
In the EGRET days there was maybe one blazar with correlated γ/optical variability.

In the Fermi era, plots like this have become very common.

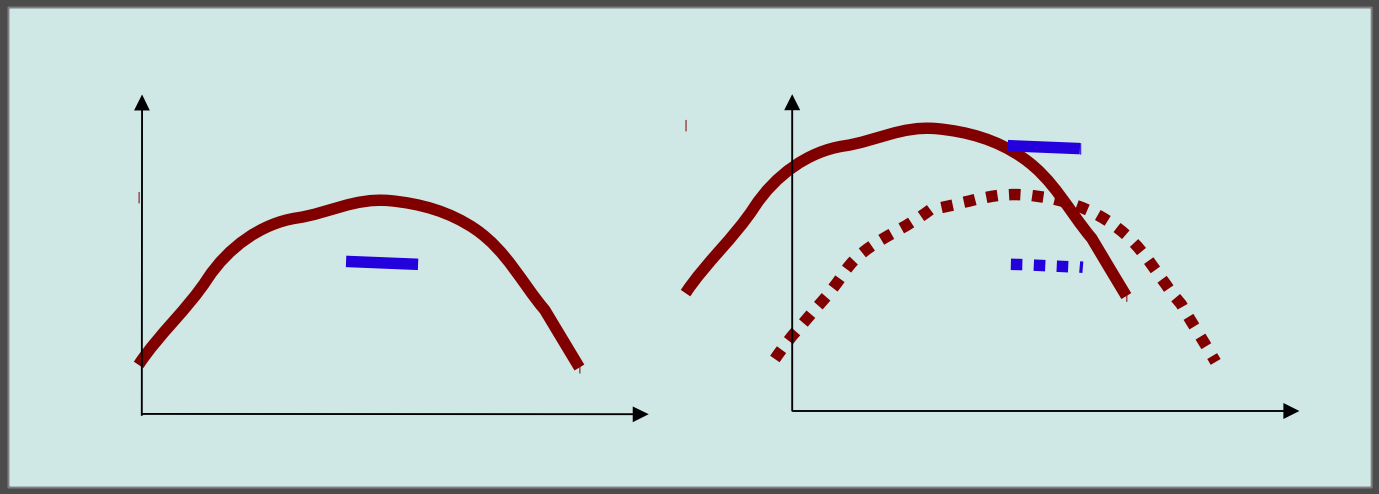
Correlations with Fermi has led to the unambiguous identification (as opposed to association) of 28 sources according to 2FGL.

One-zone models can be justified in many cases.

Looking at Jets Differently: How should we classify radio-loud AGN?



What if we can't see the emission lines?



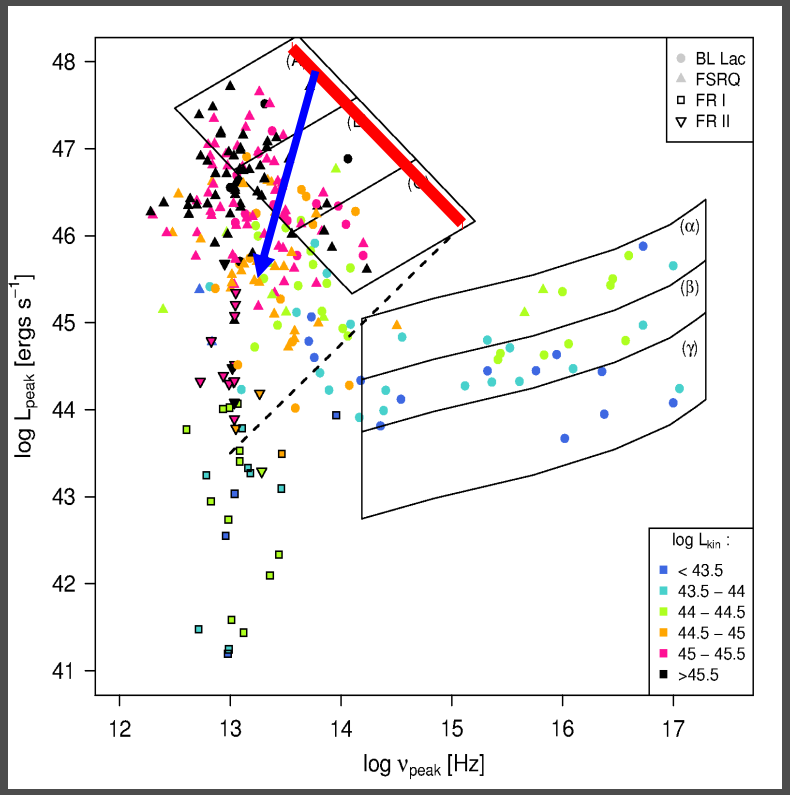
= Doppler-boosted jet

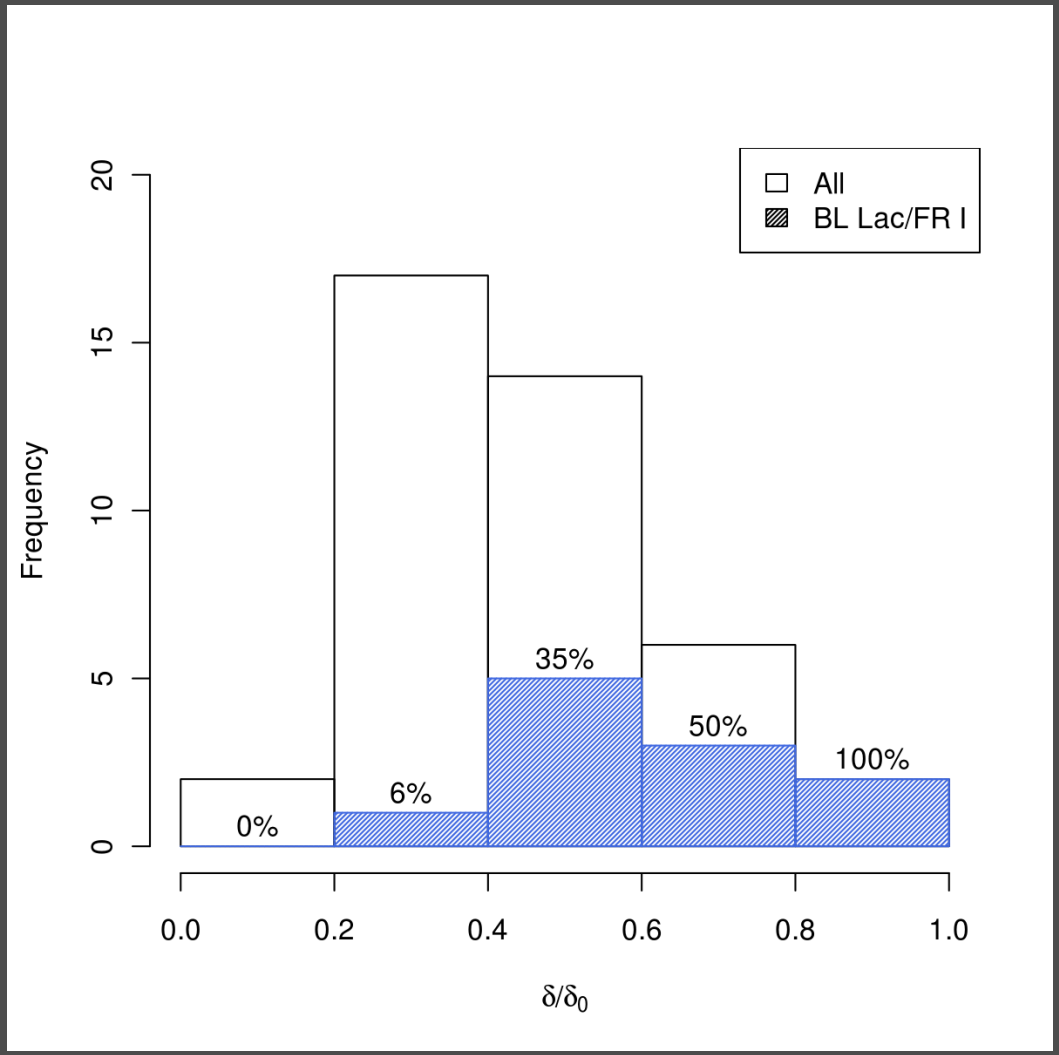
= emission lines

Increasing L_{kin} = Line & Jet Luminosity Increases

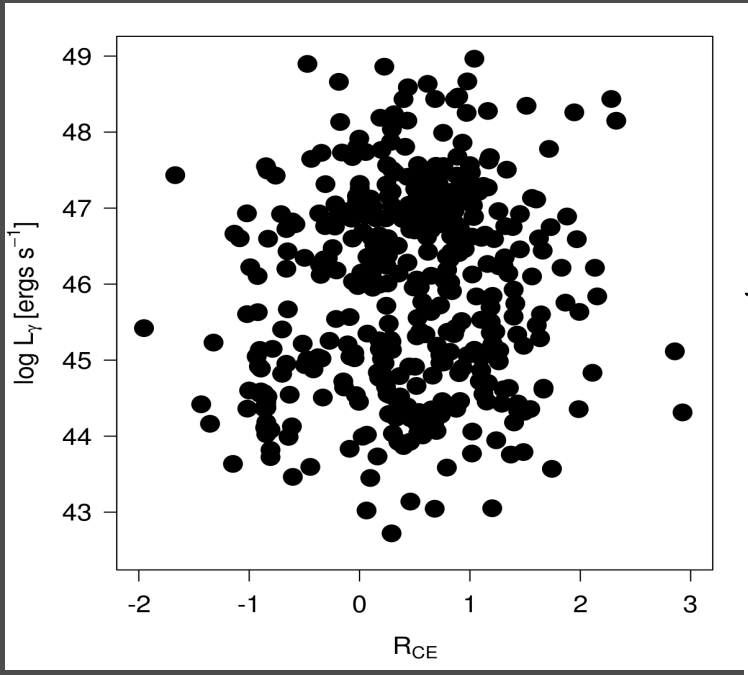
= Cooling Increases, v_{peak} shifts out of optical

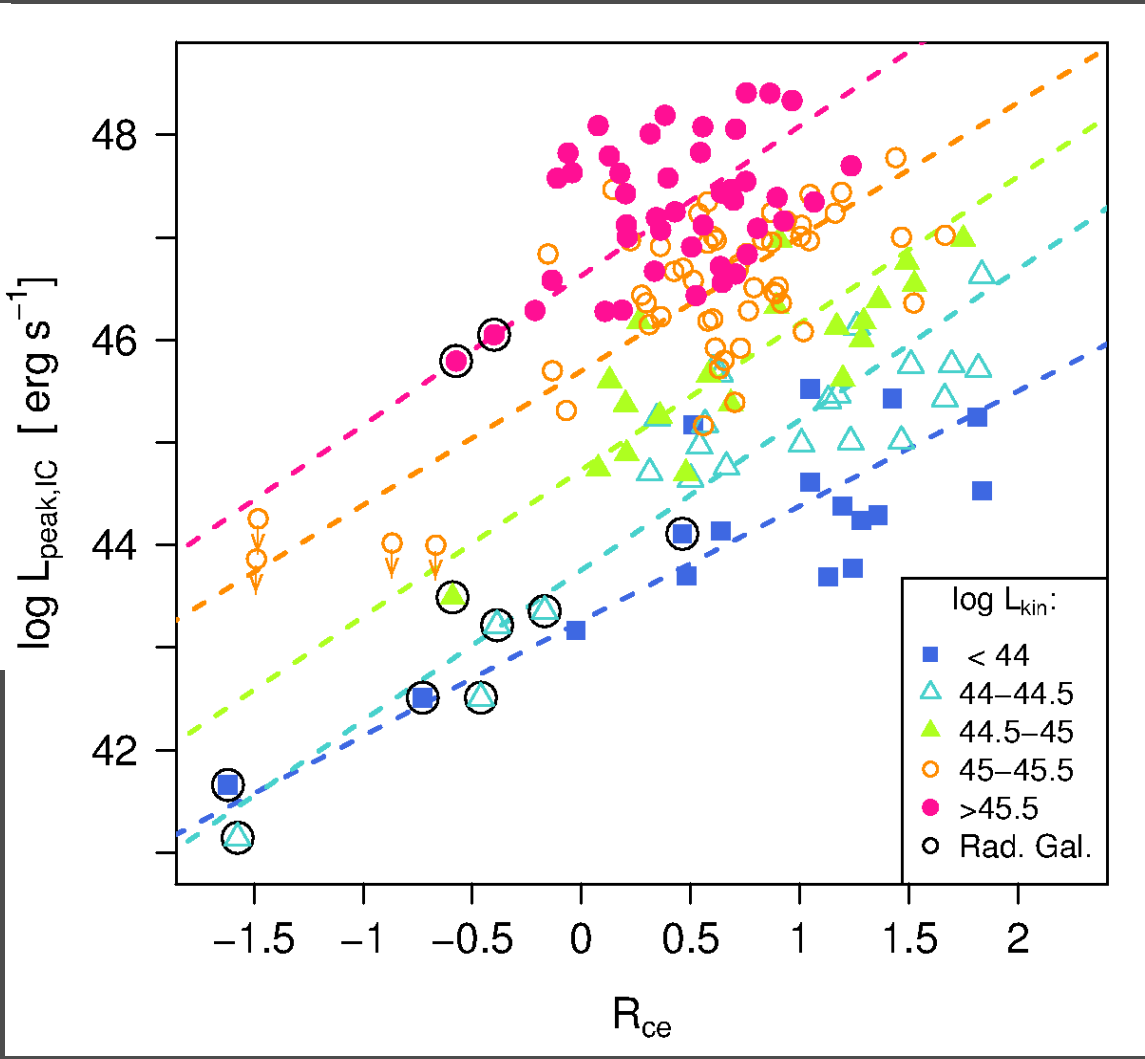
Evidence that strong-branch “BL Lacs” are just lower-power FSRQ with hidden lines





What can we learn from Fermi ?

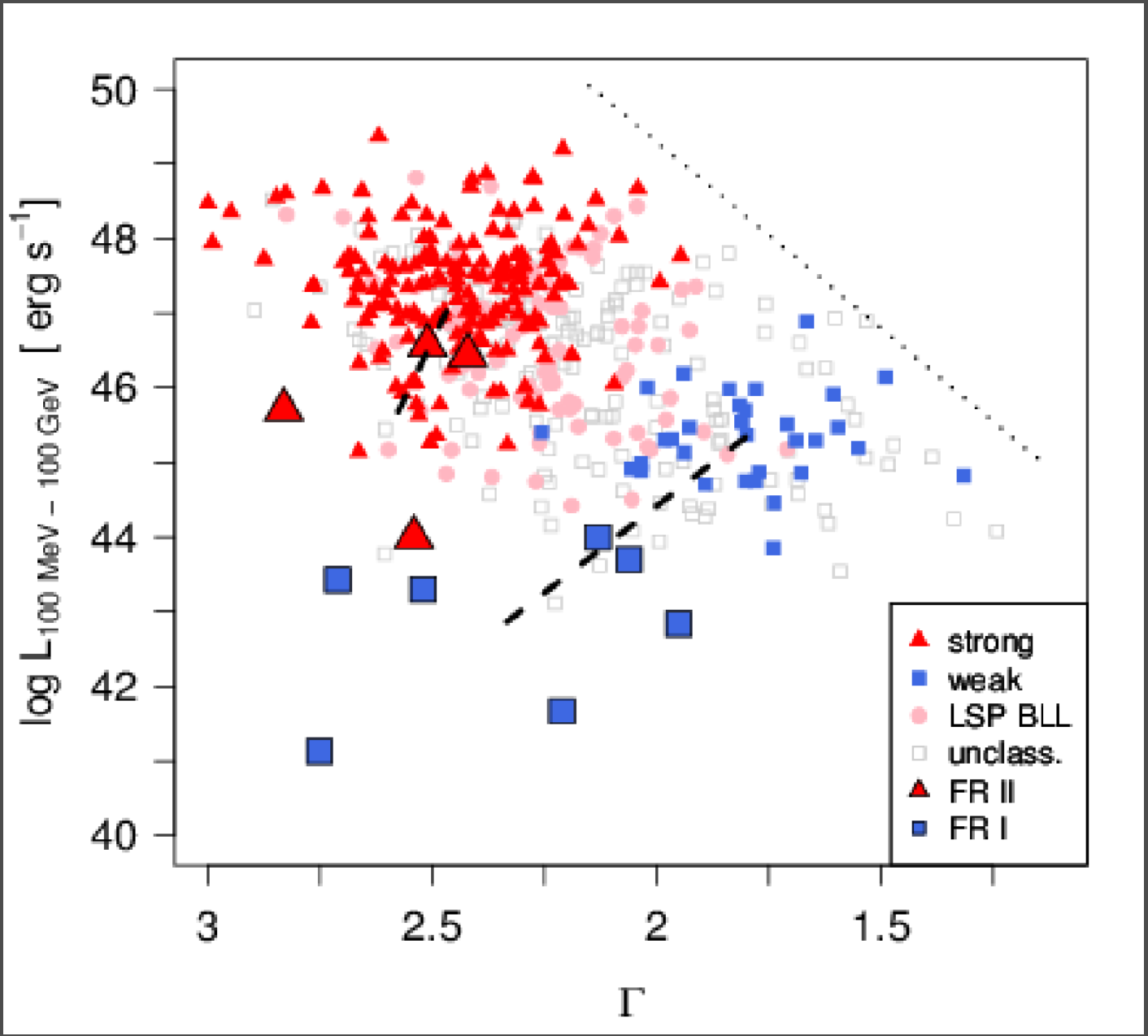




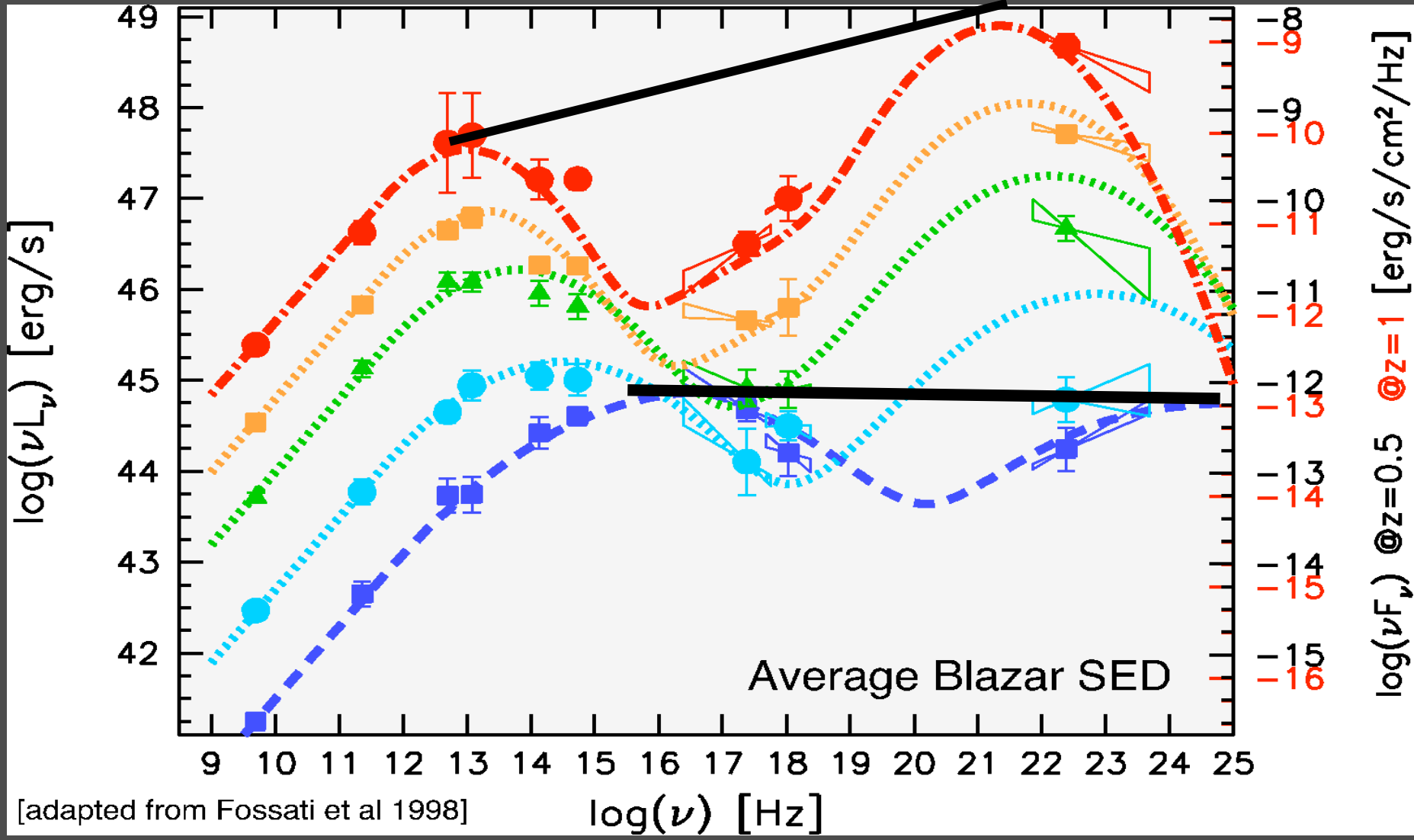
$R_{ce} + L_{kin} = L_{gamma}$

(radio core dominance, i.e., alignment, plus jet power, tells you level of gamma-rays for whole jet population: aligned + misaligned)

The Fermi 'envelope': a first look



What can we learn from Fermi populations: where is the gamma-ray emission located?



Synchrotron Self-Compton (SSC) versus External Compton (EC)

SSC – upscatter synchrotron photons

-IC peak is a “copy” of synchrotron

-beaming pattern is the same:

$L \sim \delta^{3+\alpha}$ synchrotron peak or IC peak

EC – upscatter photons from outside the jet (BLR, molecular torus, accretion disk?)

-beaming pattern is different:

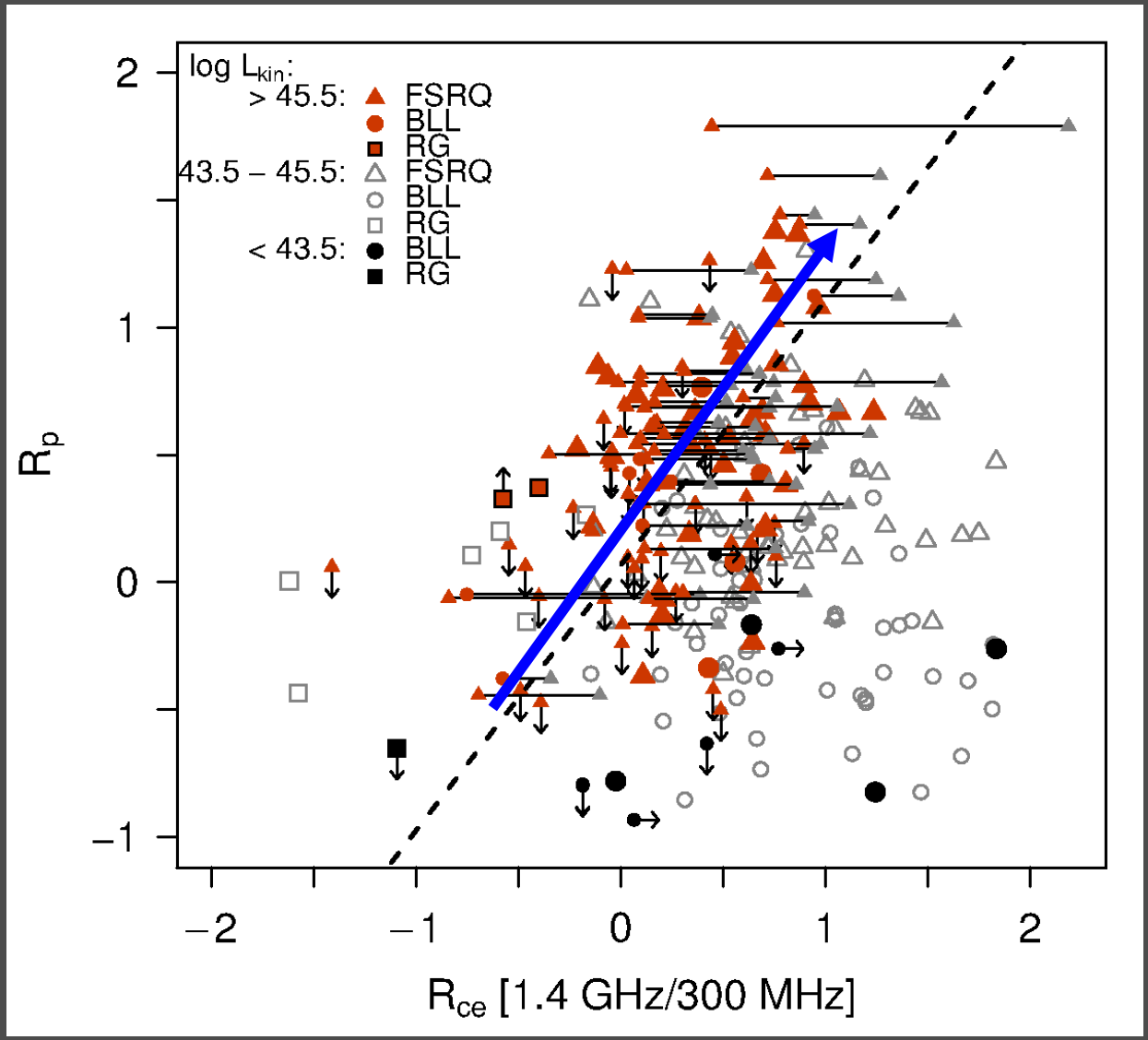
$L \sim \delta^{3+\alpha}$ synchrotron peak

$L \sim \delta^{4+2\alpha}$ IC peak

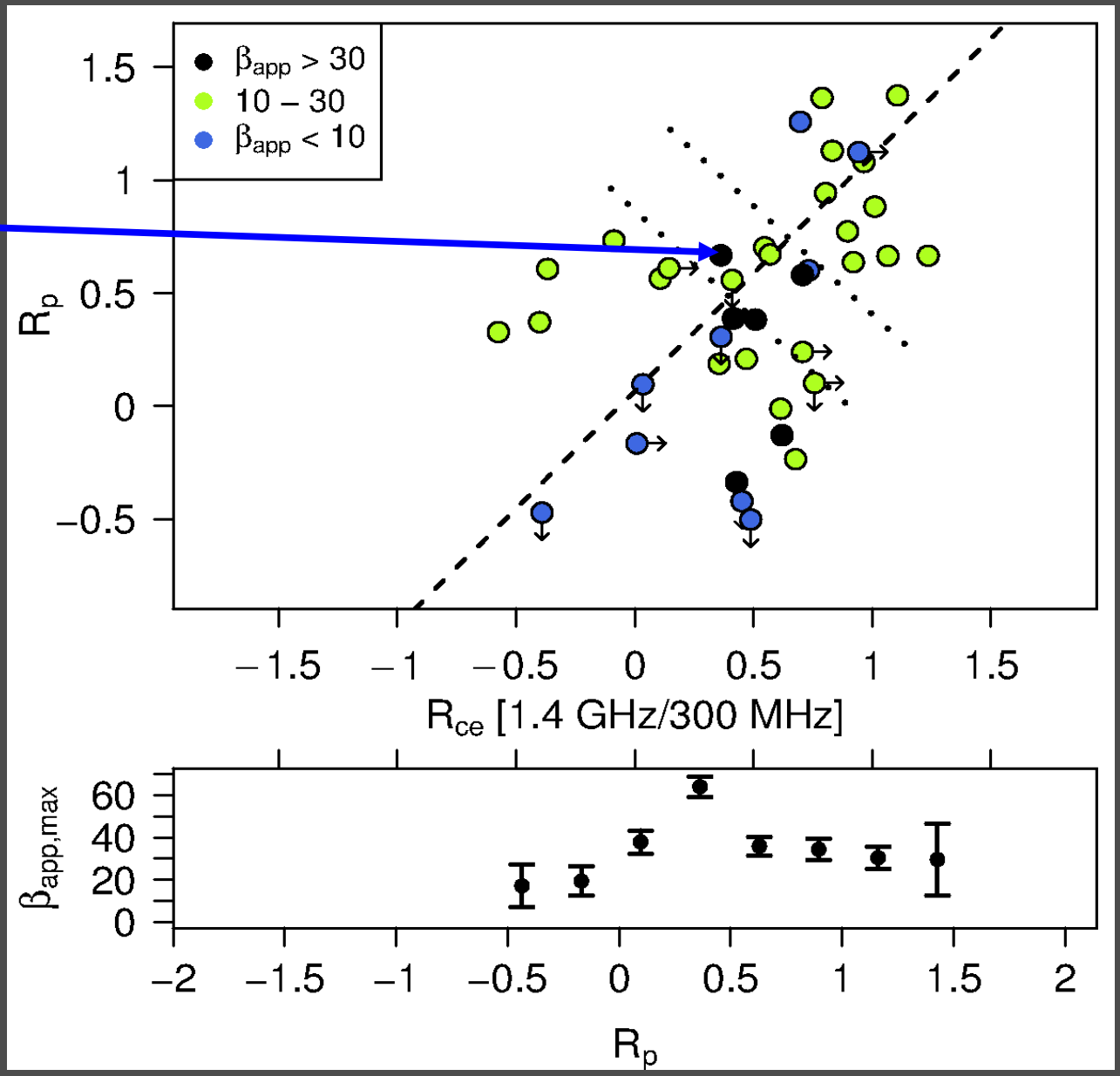
(For radio, $L_{core}/L_{ext} \sim L \sim \delta^{3+\alpha}$, $\alpha \sim 0.2$)

Signature of External Compton emission only for very powerful jets?

Trend of increasing Compton Dominance (R_p) with R_{ce} – *only for most powerful sources!*



Apparent speed is maximum in the middle of the correlation, *as expected.*



Future Directions

Fermi is continuing to monitor many sources: long-term variability is apprently significant, not well understood.

Fermi is giving us an unprecedented amount of data on jets at all angles, in low and high states

Population studies will be greatly aided by the “multiplying effect” of correlated observations, follow-up observations of Fermi sources

Future questions: looking again at the role of accretion mode, spin, black hole mass, merger history, environment in the population of radio-loud and radio-quiet sources.

Revising the Blazar Sequence

Eileen Meyer
Postdoctoral Fellow, STScI

"What are we learning from the gamma-ray Sky?" Workshop
University of Minnesota
11 October 2013