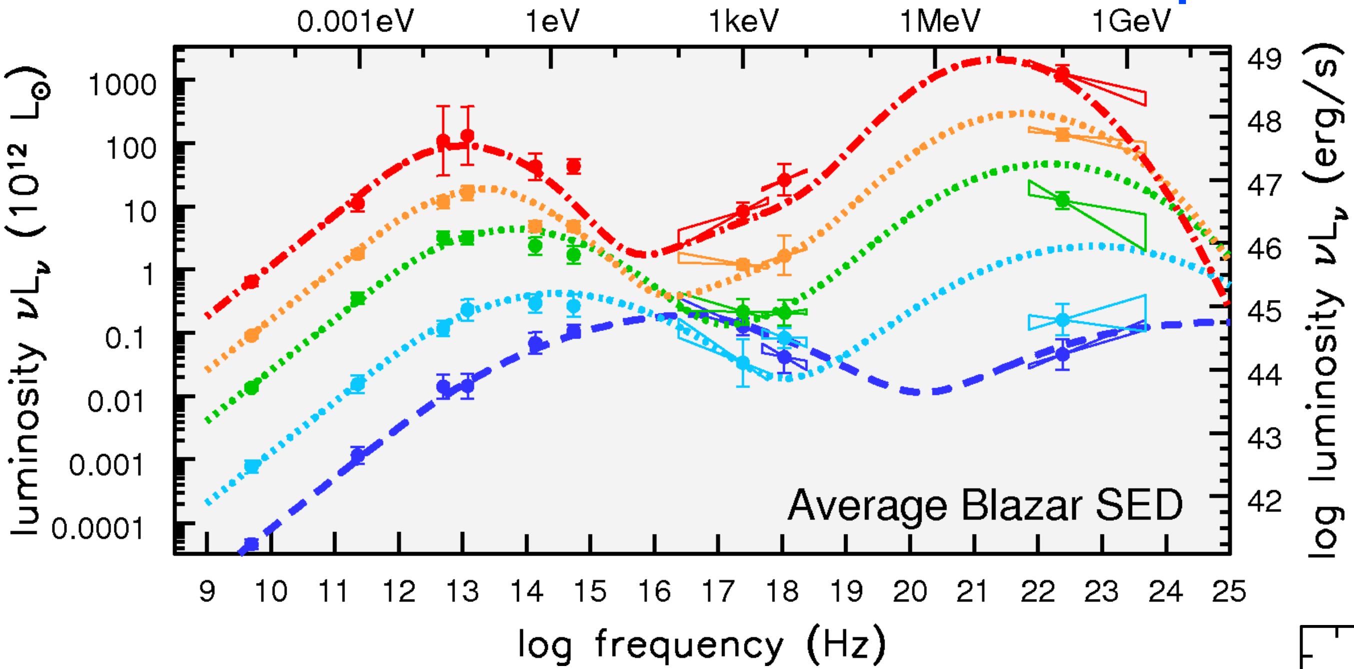
From Blazar Sequence to Envelope

Giovanni Fossati (Rice)

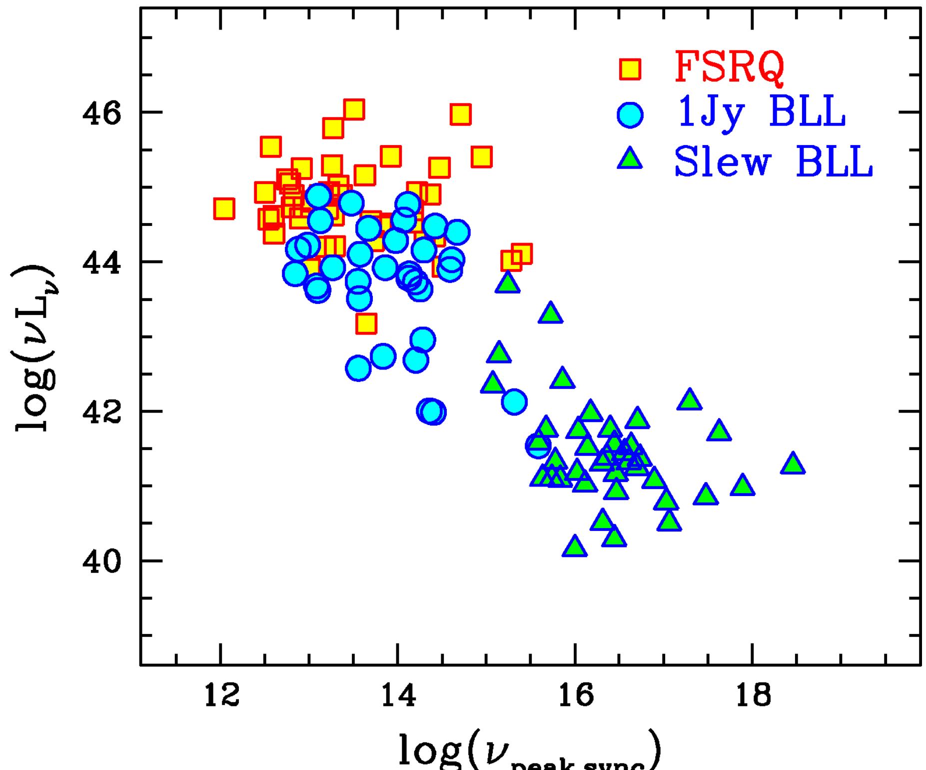
Eileen Meyer (Rice)
Markos Georganopoulos (UMBC)
Matthew Lister (Purdue)

Thanks to NASA for
Chandra, XMM, Swift, Fermi, RXTE
GO/GI grants

The blazar sequence



Blazar SEDs averaged in bins of source power (Fossati et al. 1998).



Observational evidence that source power and SED spectral properties are linked forming a sequence of blazar types.

The “thermal” properties also seem to dovetail with this correlation, in particular with the presence of a luminous emission lines and accretion disk limited to the most luminous types.

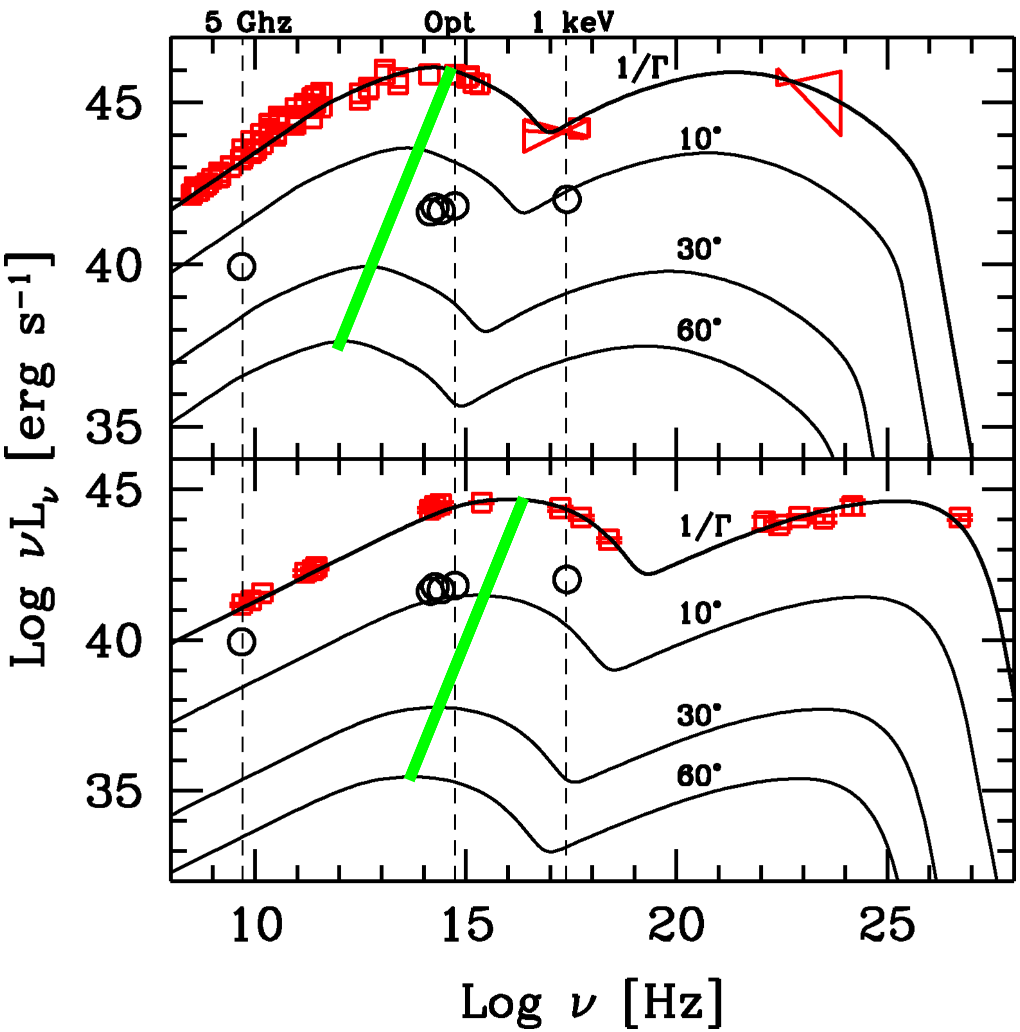
Blazar “sequences”

- There are several observational properties which seem to be all tightly connected to each other, possibly through a common correlation with the jet power:
  - Non-thermal jet emission.
  - Optical emission line properties (i.e. thermal component associated with accretion).
  - Cosmological evolution.
- Blazar phenomenology *as we see it* seems to be governed by a high degree of internal order.
- There is a strong suggestion that the true dimensionality of the blazars parameter space is reduced to a few (2?) key physical properties.
- The hypothesis of “**blazar sequence**” was introduced.

From sequence to envelope

Even in the simplest scenario of intrinsic jet properties being governed by just one fundamental parameter and all jets had the same Lorentz factor, observationally at some point we should be seeing the spread produced by the varying beaming / viewing angle.

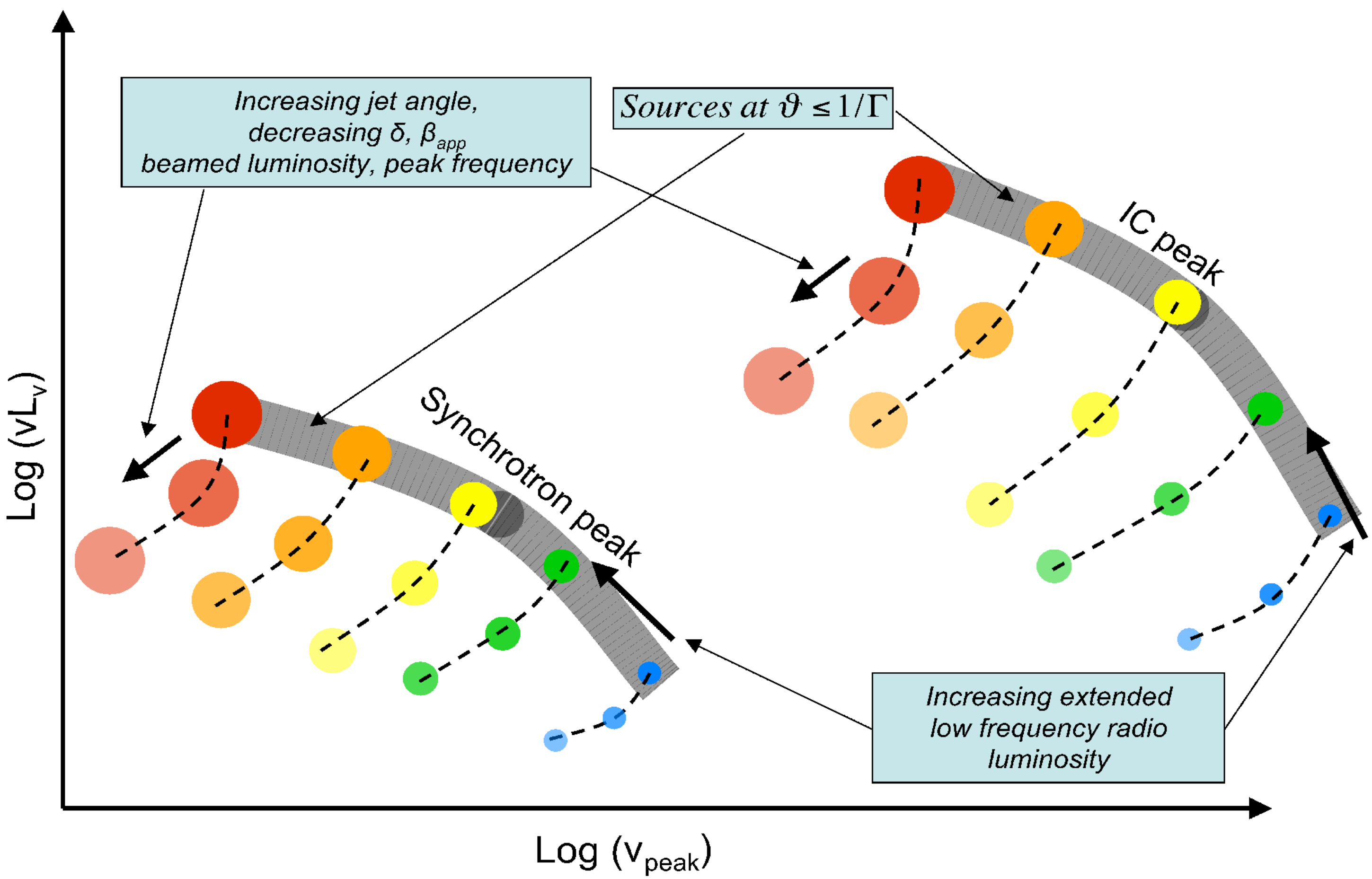
- If we could see a given source from a different direction, its luminosity would appear lower and the SED peaks would be shifted to lower frequencies.
- These would be found in the *sequence space* below the "starting point".
- If what we had been seeing were the most highly beamed sources, preferentially selected because of limited sensitivity, more sensitive surveys should progressively detect less beamed objects.



[Chiaberge+ 2000]

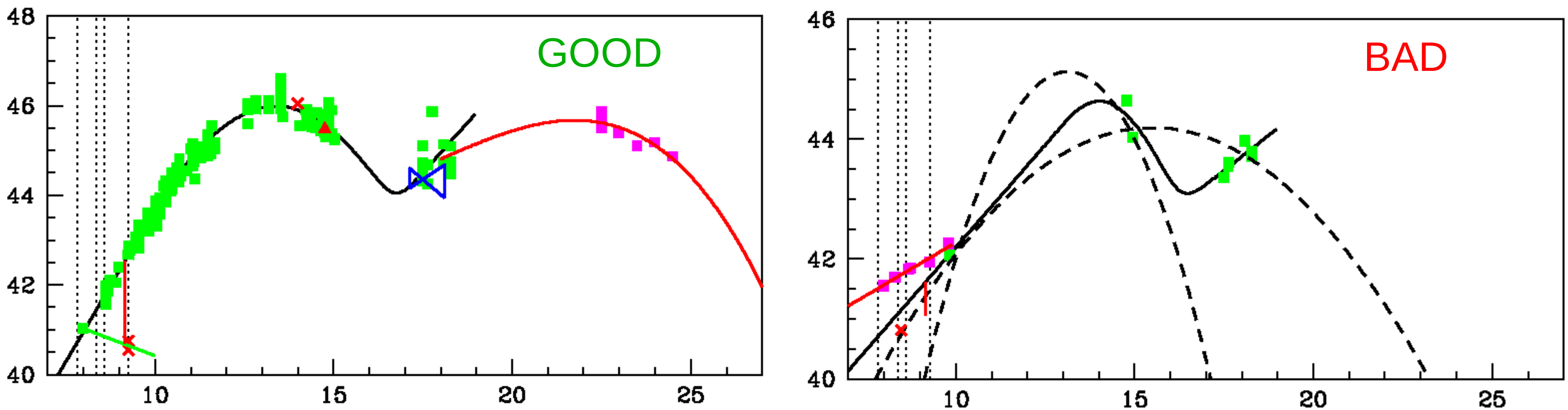
The extended observational hypothesis

1. Intrinsic jet power determines the position of a “jet” along the *aligned blazar sequence,* i.e. its SED (radiative) luminosity and synchrotron peak position.
2. Misaligned blazars would fill the space below it, along tracks of changing viewing angle. Unfortunately we can not measure this latter directly.
3. The slope and possibly the shape of the tracks are sensitive to some aspects of jet dynamics and structure.



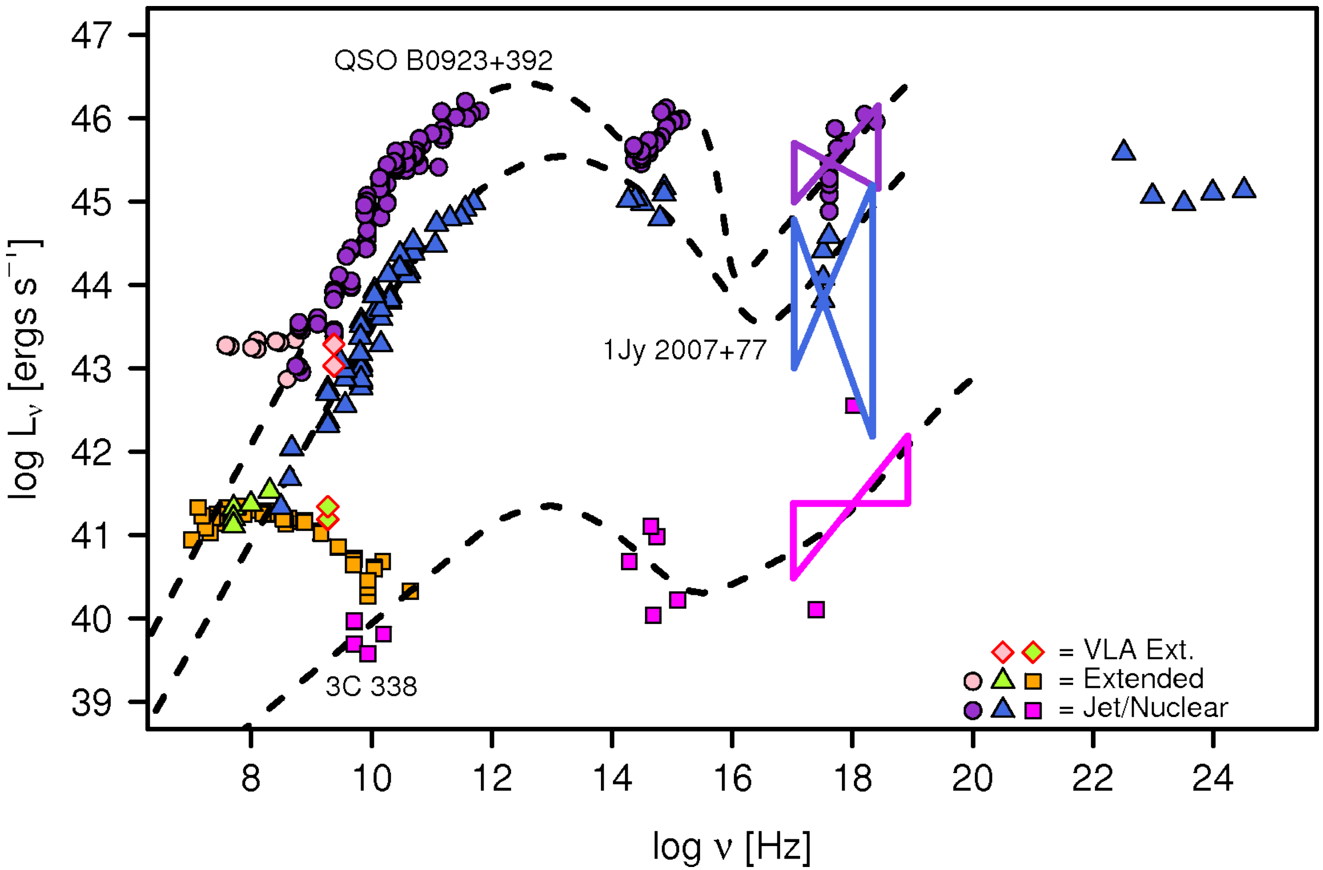
Unveiling the envelope: SED characterization

- We need to expand the sample and improve our ability to determine the basic SED parameters, peak frequency and luminosity of the two main non-thermal continuum emission components.
  - Unprecedented data mining effort to collected and organize the most comprehensive multiwavelength observations database.
  - Of about 3000+ *candidates* comprising all sources from every flux-limited sample of radio-loud AGN (blazars and radio-galaxies), 1700 with sufficient radio to X-ray data coverage.
  - Direct fitting of the synchrotron SED.
  - For about 700 of these we obtain a satisfactory SED fit, yielding reliable ν_{peak} and L_{peak} .



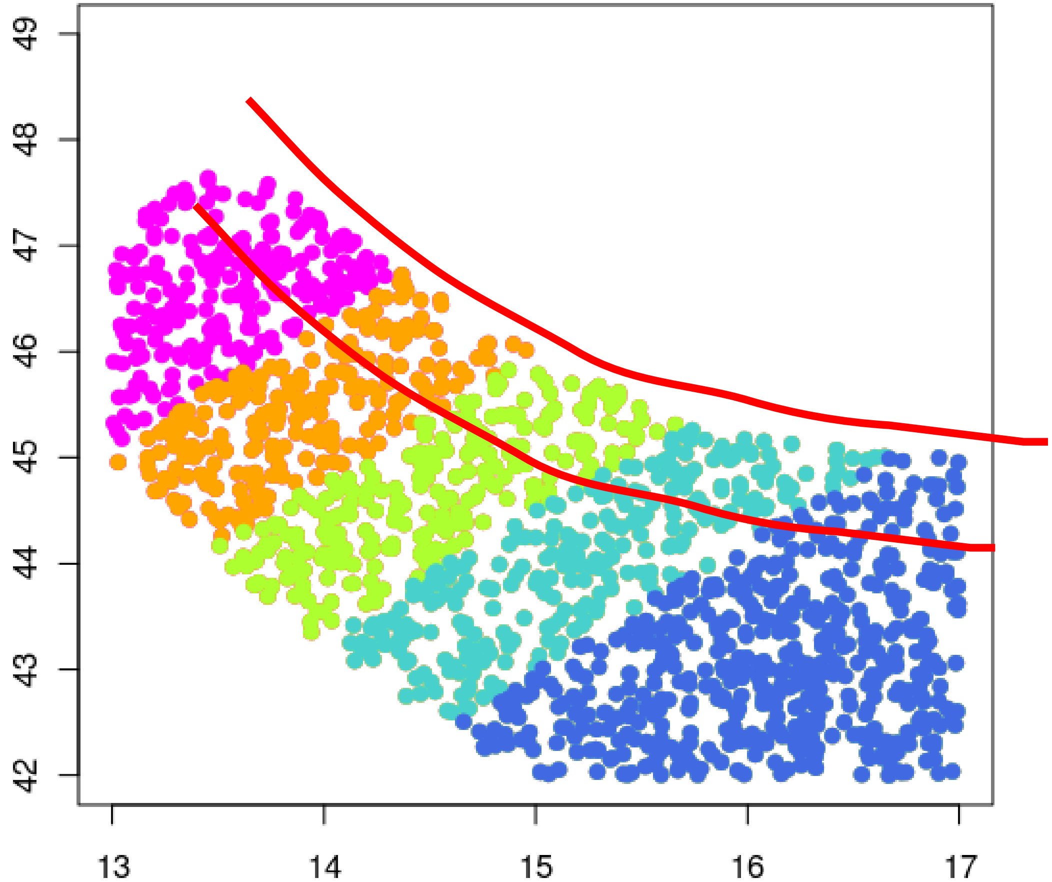
Unveiling the envelope: intrinsic jet power by proxy

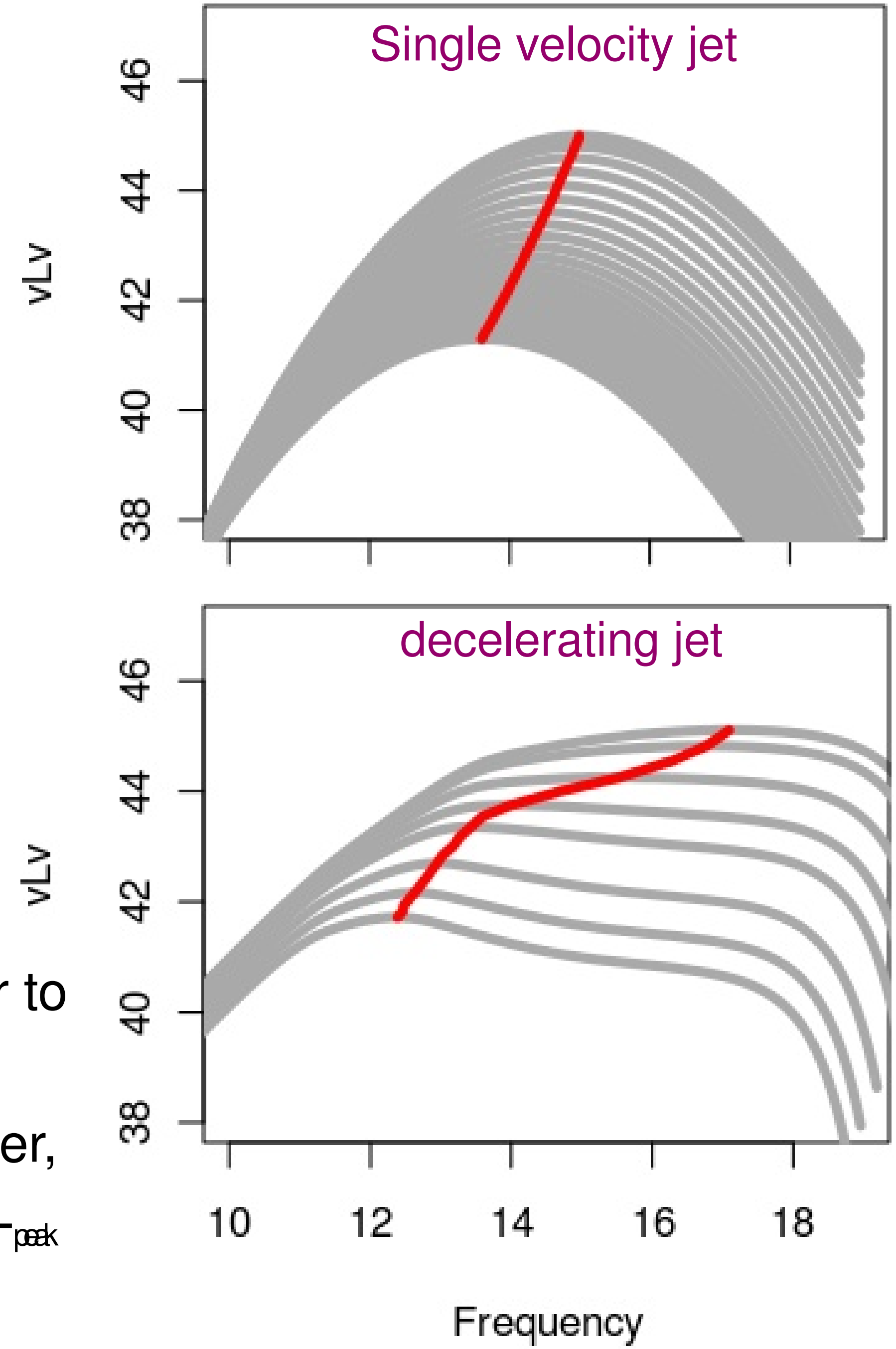
- We need a measure of the **intrinsic** jet power, non altered by the effects of relativistic beaming. The best consensus estimator is the luminosity of the extended radio emission:
  - It is assumed to be emitted isotropically.
  - It represents a long term average of the jet power.
  - It is not variable.



- It typically dominates the spectrum at low frequencies (below the GHz range) because of its different –steep- spectral shape.
  - We combined spectral decomposition to recognize the steep component and
  - imaging radio data allowing a direct estimate of the spatially extended flux.

The naïve expectation

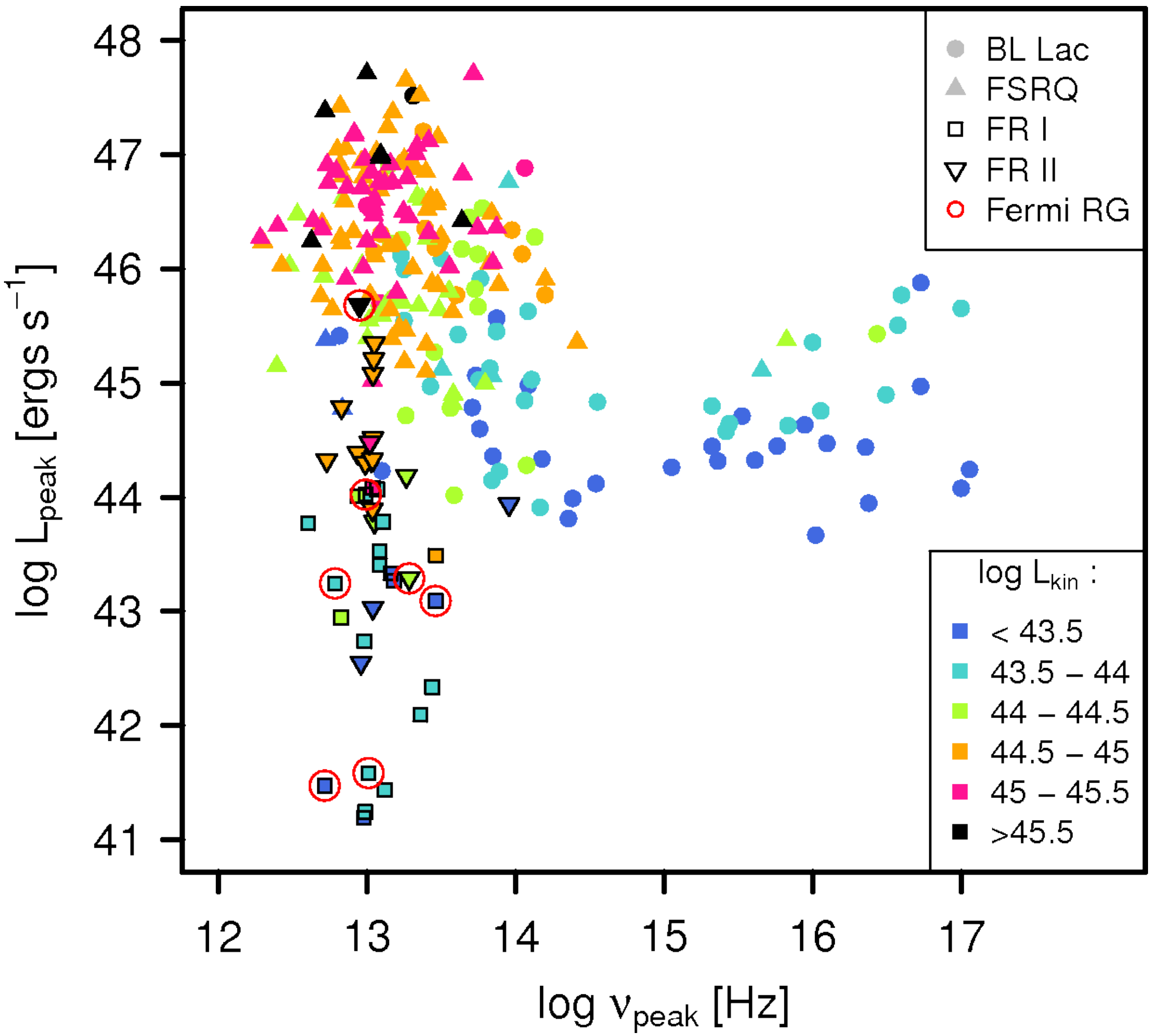




- Objects will fill the space below the "original equence" that was traced by the object easier to detect, i.e. most beamed ones.
- Swaths of source with similar intrinsic jet power, occupying different positions in the ν_{peak} and L_{peak} space depending on the viewing angle.

The *blazar envelope* space

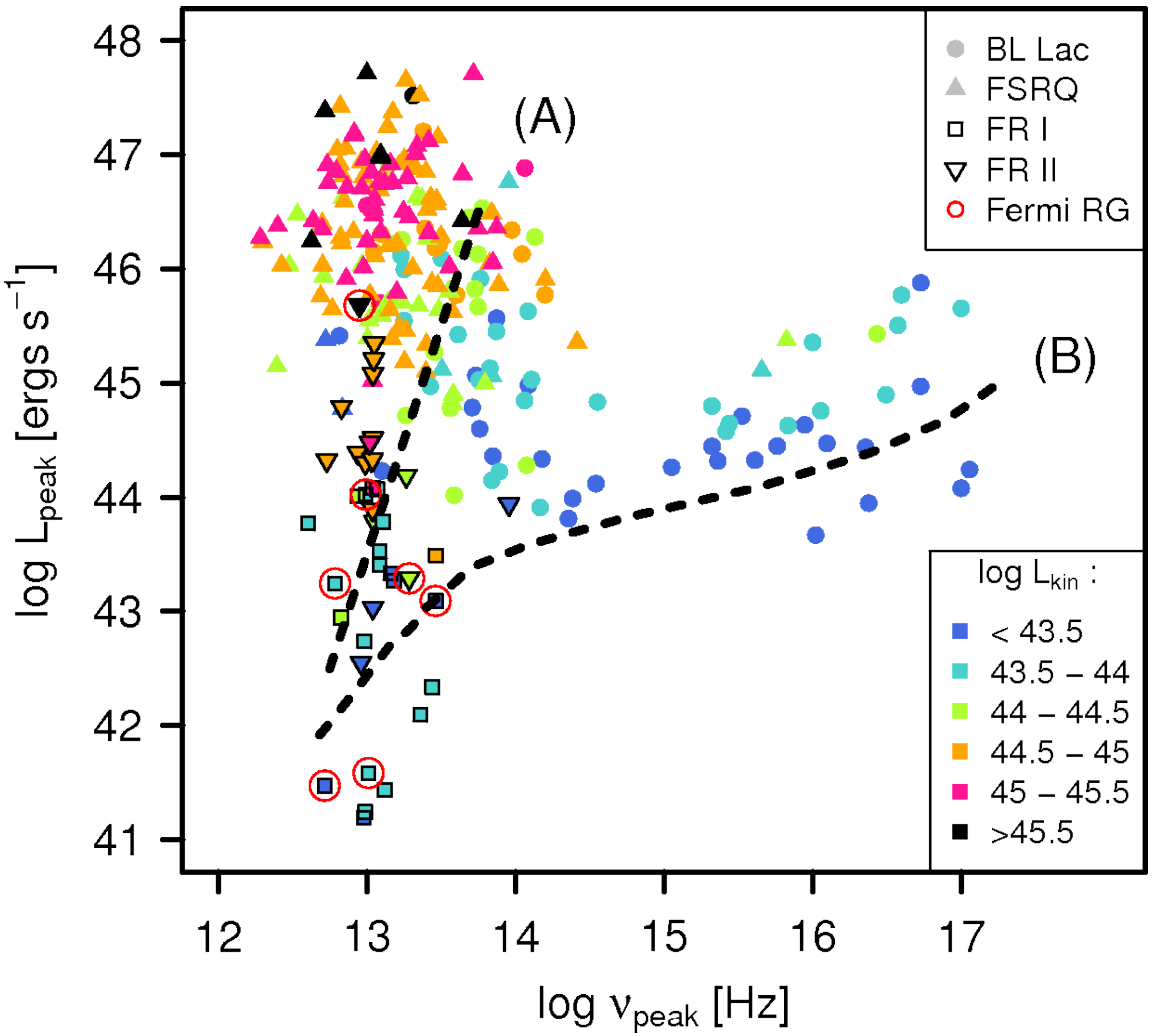
- Synchrotron SED peak frequency and power.
- Color coding on intrinsic jet power (3rd dimension).



- No strong indication of tracks, nor *striping!*
- Wide range of SED peak position below some value of jet power!
- Radio-galaxies cluster at low ν_{peak} .
- BL Lac (circles) are the only type of source with high ν_{peak} , but they also exist at low ν_{peak} .
- All FSRQ (triangles) are in a narrow range at low ν_{peak} .
- Lack of objects with intermediate SED properties.

Jet structure dichotomy?

- The source distribution and absence of the expected "patterns" may hint at a dichotomy of jet properties, perhaps related to intrinsic jet power.

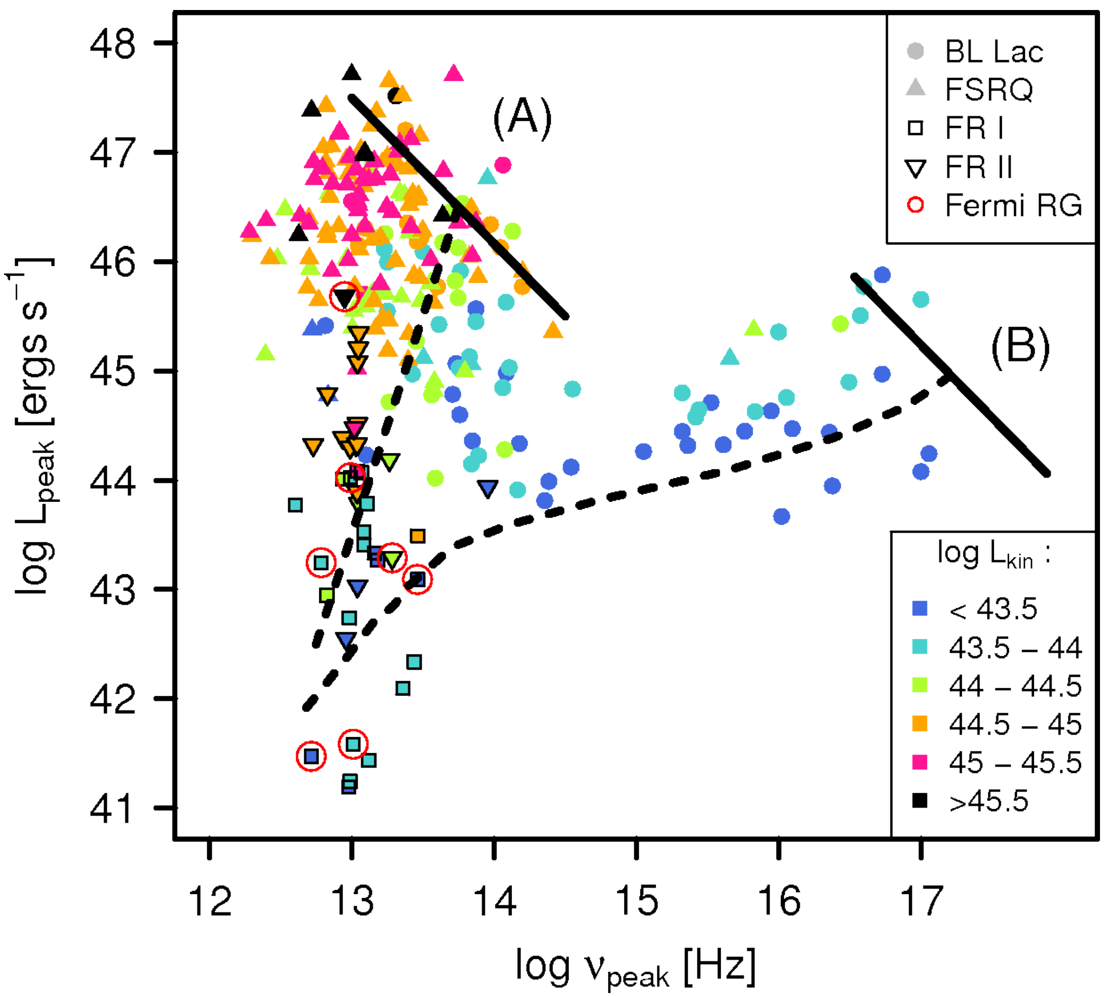


- Black tracks correspond to the predictions of the *mis-alignment tracks* for:
  - (A) a single speed jet.
  - (B) a decelerating jet.
- In a decelerating jet we observe emission from regions affected by different degrees of beaming.

  The drop due to (de)beaming is tempered by the fact that the emission from slower regions doesn't have a strong dependence on viewing angle.

Strong and *weak* jets conjecture.

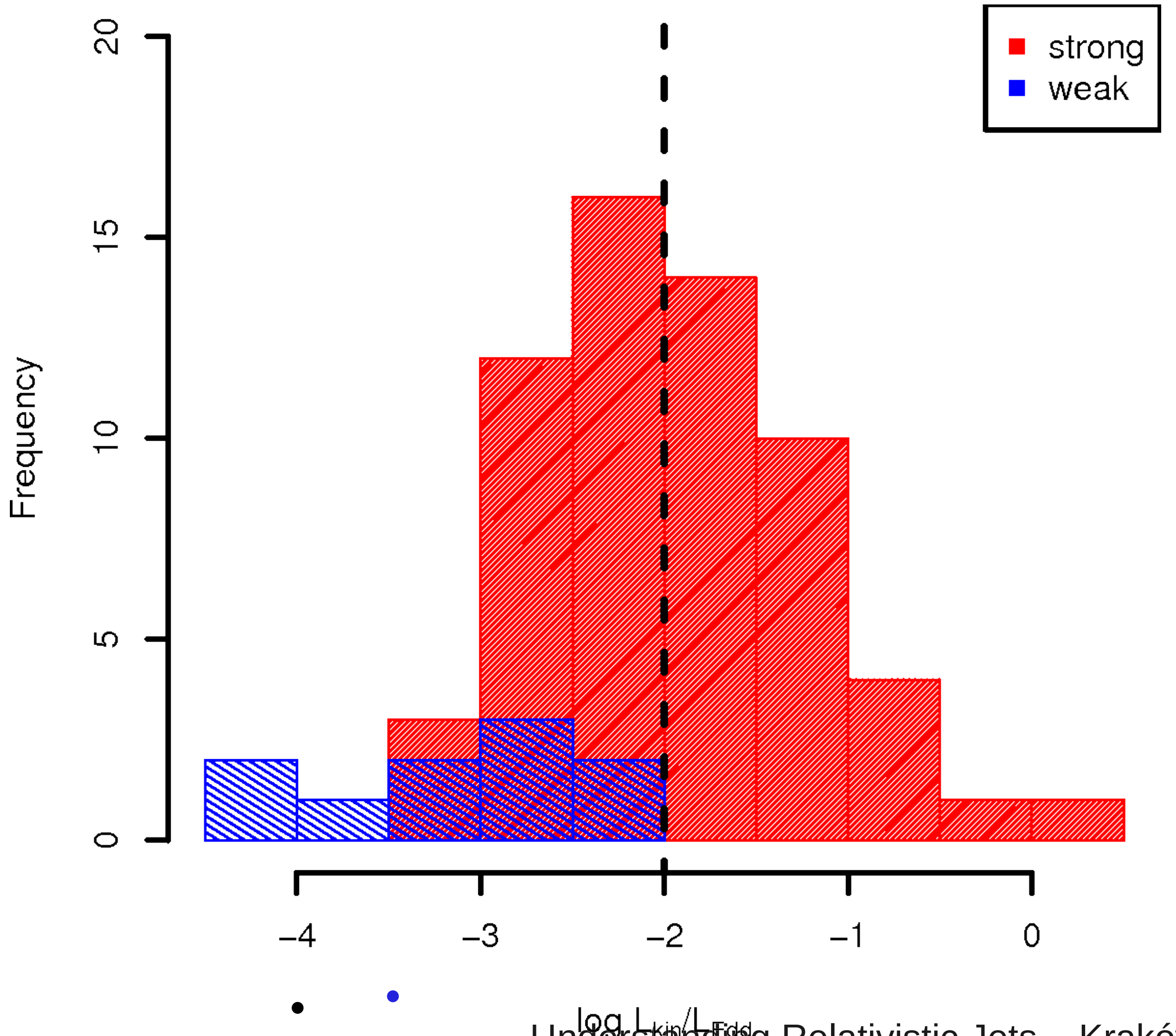
- Radio-loud AGNs might come in two different flavors.
- The approximate correspondence between jet *strength* and optical spectral classification may suggest that the jet type depends on the accretion properties, commonly characterized in terms of Eddington-scaled mass accretion rate, $\dot{m}_{dsk}$.



- Black tracks correspond to the predictions of the *mis-alignment tracks,* as shown previously, with the addition of the possibility that within each jet type there remains a sequence/correlation between SED luminosity and peak frequency.

Jet type and L_{kin}/L_{Edd} ($\dot{m}$)

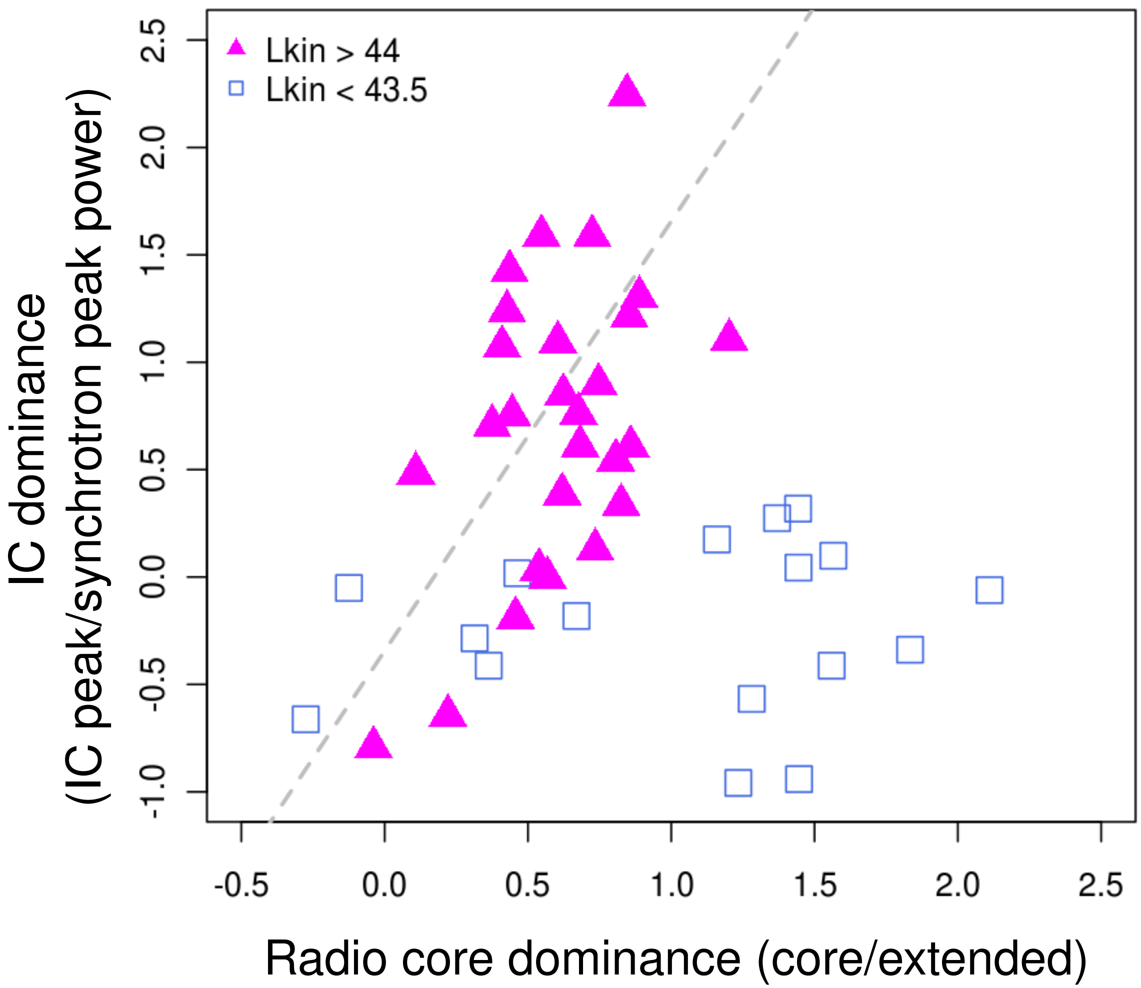
- In red objects belonging to the strong jet branch, all FSRQs, i.e. sources where we expect high $\dot{m}_{dsk}$, based on their *thermal* emission properties.
- In blue objects from the weak jet branch, all BL Lacs, i.e. sources that we would associate with low $\dot{m}_{dsk}$.



- Weak-jet objects seem to be limited to values of $\dot{m}_{jet}$, up to what it has been conjectured to be the critical value for $\dot{m}_{dsk}$.
- Strong-jet objects, however don't seem to *obey* this threshold: they can have jets weaker than their accretion power $\dot{m}_{jet} < \dot{m}_{dsk}$ (also Fernandes+ 2011).

γ-ray dominance

- The ratio between the peak luminosities of the γ-ray (IC) and synchrotron components behaves differently as a function of radio core dominance for high and low jet power sources.



- Radio core-dominance is sensitive to beaming.
- The trend between these two quantities is sensitive to differences in beaming (if any) between the IC and synchrotron components.
  - SSC and external Compton (EC) origins for the γ-ray emission would yield different trends.

Key points

- SED properties and thermal emission.
  - High-peak sources are almost exclusively BL Lacs (i.e. blazars not showing signs of emission from accretion disk or other non-jet thermal source.)
  - Low-peak sources encompass the full range of thermal emission properties.
- Intrinsic jet power:
  - It does not show the simple relationship with SED properties that would be expected if the traditional blazar sequence hypothesis was correct.
  - There seems to be a dichotomy in jet properties, possibly associated with simple vs. complex jet (velocity) structures.
  - However, this apparent dichotomy does not match well with jet power being the sole fundamental parameter.
    Black hole spin and accretion rate are obvious candidates.
- The accretion power may only set an upper limit on the jet power.