Radio Loud AGN Unification: Connecting Jets and Accretion

Eileen Meyer
Space Telescope Science Institute

Giovanni Fossati, Rice University
Markos Georganopoulos, UMBC
Matthew Lister, Purdue University

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

Radio Galaxy

FR I: brightest at the center, “plumey jets”
FR II: brightest in the lobes, collimated jets

Blazars

Direct view of the jet!
Radio Loud AGN Unification
(beyond orientation)

Radio Galaxy Morphology

FR I
Low power, weak lines

FR II
High power, high excitation spectra

Blazar Spectral Type

LFRS J12149.8-1455
BL Lac

FSRQ

(Many notable exceptions!)

ADAF

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

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

[adapted from Fossati et al 1998]
Sources here were found (Nieppola 2006, Landt 2006, Caccianiga 2004)

**BL Lacs: Jet Power uncorrelated with $\nu_p$**
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

Jet Power Increases (blue → red)
Along 0° path (gray): $L_p$ increases, $\nu_p$ decreases

Departing from the sequence, sources drop in Luminosity and frequency as $\theta$ increases

Need to measure: Orientation ($\theta$)
Intrinsic Jet Power (good $L_p$, $\nu_p$)
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 $\theta$

(3) Build Up a large Sample – better SED sampling
Part I: The Blazar Envelope

Methods

Jet Power: Lobe Emission “sticks up”
Orientation: Radio Core Dominance

Cavity Power (P*ΔV/time)
Extended, Low-frequency Power Cavagnolo, et al. 2010
Core is faint in the radio (not beamed)
Part I: The Blazar Envelope

Results

FSRQ & BLLs

Radio Galaxies

BLLs

\[ \log L_{\text{peak}} \text{ [ergs s}^{-1}] \]

\[ \log v_{\text{peak}} \text{ [Hz]} \]
Part I: The Blazar Envelope

Results

“Simple jet” (single)

“Decelerating Flow” model (Georganopoulos et al. 2005)

Two Branches?
New Hypothesis: A Strong/Weak Dichotomy?

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

- **Weak Jets:**
  - Only at low $L_{\text{kin}} (< 10^{44.5} \text{ erg s}^{-1})$
  - (Nearly) All BL Lacs
  - All high $\nu_p (> 10^{15} \text{ Hz})$, some low $\nu_p$?
  - Associated with FR Is (based on $L_{\text{kin}}$)
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 $\nu_p$, low $L_p$ sources?*
  $\rightarrow$ These appear to be misaligned.

- *$L_{kin}$ ($L_{ext}$) does not vary with $\nu_p$ for BL Lacs?*
  $\rightarrow$ Consistent with our findings: Horizontal movement due to velocity gradients in jet

- *Sources at low $\nu_p$ have range of $L_{kin}$?*
  $\rightarrow$ Consistent with our findings: All 'misalignment paths' meet at low $\nu_p$
Part II: Accretion Mode and the Broken Power Sequence

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

\[ \log \frac{M_{\text{BH}}}{M_\odot} \]

\[ \log L_{\text{ion}} \text{[W Hz}^{-1}] \]

\[ \log M_R \]

\[ \dot{m} = \frac{\dot{M}}{\dot{M}_{\text{Edd}}} = \dot{m}_{\text{crit}} \sim 0.01 \]

Ghisellini et al. 2001
Part II: Accretion and the Broken Sequence

$L_{\text{kin}}, \theta, \ldots m$?

(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?

![Graph showing the role of Jet Power in the context of a broken power sequence.](image)

- **Efficient**
- **Inefficient**

Log $L_{peak}$ [ergs s$^{-1}$] vs. Log $v_{peak}$ [Hz] with different categories of $L_{kin}$ indicated.
The Weak-Jet Sequence

Part II: Accretion and the Broken Sequence
The Strong-Jet Sequence
Part II: Accretion and the Broken Sequence

IMPOSTER BL Lacs in the Strong Branch

\[ \log L_{\text{peak}} \text{ [ergs s}^{-1}] \]

\[ \log \nu_{\text{peak}} \text{ [Hz]} \]

- BL Lac
- FSRQ
- FR I
- FR II
- Fermi RG

\[ \log L_{\text{kin}} : \]
- \(< 43.5\)
- \(43.5 - 44.5\)
- \(44.5 - 45.5\)
- \(> 45.5\)
BL Lac fraction in the strong branch: increases with beaming and as peak shifts into optical

1:4 $\Delta$frequency:$\Delta$Luminosity

$\delta/\delta_0 = \nu_{\text{peak}}/\nu_0$
Summary: The Broken Power Sequence

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

- $\log L_{kin}=46$, $m'=1\times10^{-1}$
- $\log L_{kin}=45$, $m'=1\times10^{-2}$
- $\log L_{kin}=44.5$, $m'=1\times10^{-2.5}$
- $\log L_{kin}=43$, $m'=1\times10^{-4}$
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 $\sim 10^9 M_\odot$

+ 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 $\Gamma$-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:

\[ L \sim \delta^4 \text{ synchrotron peak} \]
\[ L \sim \delta^6 \text{ IC peak} \]

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

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 least 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, \( \dot{m} = \frac{\dot{M}}{M_{\text{Edd}}} = \dot{m}_{\text{crit}} \sim 0.01 \), 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
Part I: The Blazar Envelope

Orientation (Rce)

Clear break between RG, blazars

“striping” - indicates that $L_{\text{kin}}$ and $L_0$ are linked