On the role of accretion and spin in powering AGN

and the connection between jet power and accretion power in AGN
Outline

Revisiting the blazar sequence

Population studies in the Fermi Era

A link between jet power and accretion power

The Blandford Znajek mechanism: a unification theory for AGN?
Jet scales

Resolved X-ray jet
10 - 100 kpc scale

Blazar emission region
sub-pc scale

Accretion region
Jet origin
R_S scale
Jet power

\[ P_{\text{jet}} = \pi R^2 \Gamma^2 \beta c U \]

where

\[ U = U_B + U_e + U_p \]

\[ U_p + U_e = n m_e c^2 \left( < \gamma > + \frac{m_p}{m_e} \right) \]

The jet power depends on the total energy density in the flow, and can be estimated at different scales along the jet...
MWL evolution along the jet

1136-135, z=0.554

Compton/Sincro decreases with distance from the nucleus

Sambruna et al. 2006
Large scale jets from gamma-ray blazars

0954

1229

2251
Jet power vs Jet Lum. and Disk Lum.

For “red” SEDs, $P_{\text{jet}} \sim 10 \times L_{\text{disk}} \sim P_{\text{acc}}$

Grey points: M & Tavecchio 2003, red circl. Tavecchio et al. 2007
The Blazar Sequence - SEDs of the nuclei

Synchro

Inverse Compton

SELECTION EFFECTS?
FERMI confirms the “facts”: steep FSRQs / hard BL Lacs
The FERMI selected BLAZAR SEDs fully confirm the “Blazar sequence” hypothesis

In particular the “sequence” induces a systematic steepening of the gamma-ray SEDs with increasing gamma-ray luminosities. This can be interpreted as due to different cooling losses for jets propagating in a photon rich or photon poor environment.

The very remarkable fact is that BL Lacs (“blue”) and FSRQs (“red”) occupy different regions of the Hardness/Luminosity plane.

The transition between the two regions should correspond to the accretion rate threshold separating the accretion regimes giving rise respectively to an optically thick accretion disk or to an optically thin accretion flow.
The sequence in color is also a sequence in luminosity.
Fermi: 2 years– $4\sigma$  

Ackermann+ 2011

Energy index $\alpha_{\gamma}$ vs. $L_{\gamma}$ [erg s$^{-1}$]

$M/M_{\text{Edd}}$

GG, Maraschi, Tavecchio 2009
Fermi: 2 years– $4\sigma$  Ackermann+ 2011

Energy index $\alpha_\gamma$

$L_\gamma$ [erg s$^{-1}$]

ADAF

Rad efficient
Fermi: 2 years– $4\sigma$  Ackermann+ 2011
jet power and accretion luminosity

\[ P_r = \text{radiation} \sim \frac{L_{\text{obs}}}{\Gamma^2} \]

\[ P_e = \text{relat. electrons} \]

\[ P_p = \text{protons} \]

\[ P_B = \text{B-field} \]

\[ P_{\text{jet}} = P_e + P_p + P_B \]

Shakura-Sunyaev disk: \( L_d \)

\[ \sim 10^{17} \text{ cm} \]
If one proton per emitting electron

\[ P_j \sim \dot{M} c^2 \]

\[ L_d \sim \dot{M}^2 c^2 \]

\[ P_j \sim L_d^{1/2} \]
$P_r \sim \frac{L_{\text{obs}}}{\Gamma^2}$  "model independent"

$P_r = L_d$

$P_r$ is the absolute minimum of $P_{\text{jet}}$
WHY ARE THE POWERS OF JETS RELATED TO THE ACCRETION RATE??

- $P_{jet} \sim \dot{M}c^2 \sim P_{acc}$
- For every $\dot{M}/\dot{M}_{Edd}$
- BL Lacs $\rightarrow$ ADAF  FSRQs $\rightarrow$ SS
- $L/L_{Edd}$ divides BL Lacs from FSRQ
BACK TO THE CENTRAL ENGINE

Matter accretes onto the BH dissipating energy in an accretion disk or rad. inefficient accretion flow.

At the center, highly relativistic powerful jets are launched, radiating up to gamma-rays.
The Blandford - Znajek mechanism (1977)

This mechanism, extremely complex, physically and mathematically (MHD in GR) allows to extract the free energy associated with the BH spin through a surrounding force free magnetosphere

“Translated” by Macdonald and Thorne (1982)
The Blandford Znajek mechanism (1977)

illustrated by Macdonald and Thorne (1982)
Revisiting the B - Z formula

\[ L_{BZ} \approx \frac{1}{32} \frac{\Omega_F}{\Omega_H^2} \left( \Omega_H - \Omega_F \right) B_H^2 r_H^2 a^2 c \]

Where \( \Omega_F \) is the rotation freq. of the mag.field lines and \( \Omega_H \) that of the BH

\[ L_{BZ} > 0 \text{  only if  } \Omega_F < \Omega_H \]
The power scaling factor for the BZ mechanism can be connected to the accretion power via a simple argument

Assuming equipartition between kinetic and magnetic energy densities in the plunging region

\[ B^2 r_H^2 c \sim 2 M^\dot{\text{}} c^2 \]


However the BZ power also depends importantly on the BH ang. mom. (as \(a^2\) up to \(a^6\))

A close connection as observed can occur only if the range of BH spin is small close to 1
Direct numerical simulations of BH magnetosphere:

Komissarov 2001, 2004 (confirms BZ approx.)

From BZ to jet properties:

Mc Kinney 2005, 2006 ($\Gamma = 10$, $\theta = 5^\circ$.....)

......very encouraging !!!

Comparing Omega(ISCO) with Omega H at a=0.4

Rudimentary approach

Omega particle at ISCO

\[ \frac{\Omega}{c^3/(GM_{BH})} \]
Deep studies of relativistic jet production from massive spinning BHs at the core of an accretion disk by Narayan, Mc Kinney and Tchekhovskoy (2012) have recently produced important results demonstrating that high efficiency is reachable! In fact for maximum BH spin the outflowing energy is larger than the incoming one, showing that energy is indeed extracted from the Rotation of the BH!

(movie at http://youtu.be/nRGCNaWST5Q)
BHs with razor-thin disks ($H/R=0$):
- BZ6, $P_{\text{jet}} \propto \Omega_H^2 [1 + \alpha (\Omega_H r_g/c)^2 + \beta (\Omega_H r_g/c)^4]$ (TNM10)
- BZ2, $P_{\text{jet}} \propto \Omega_H^2$ (TNM10)
- BZ, $P_{\text{jet}} \propto a^2$ (BZ77)

BHs with thick disks ($H/R=1$):
- BZ6, $P_{\text{jet}} \propto \Omega_H^4$ (TNM10)
SUMMARY

The BZ process contains a “physical” scaling, the magnetic energy flux, which is proportional to the accretion power. Recent simulations of jets (TKN 12) show that indeed, for high values of the BH spin, the jet power reaches values of the order of the accretion power.

This clarifies why the properties of the accretion flow (ADAF or Standard SS accretion disk) and the power of the jet are strongly related so that weak jets live in slowly accreting objects while powerful jets are produced at high accretion luminosities.

This basic concept explains the “blazar sequence” and the overall systematic Gamma-ray properties of blazars in the FERMI survey.

More generally we can envisage a “unified model” of AGNs in terms of three parameters, mass, accretion rate and spin.
FRI—FRII: a mass dependent luminosity and morphology division

Ghis & Celotti 2001

Ledlow and Owen diagram in terms of jet power
The fundamental AGN plane

No jet \( a < 0.5 \) ?

Optically thick disc

\( \ddot{m} \)

Optically thin hot flow

\( a > 0.5 \) Powerful jet

FR II

FSRQ

FR I

BL Lac