The Magnetic reconnection model for blazar emission

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Blazars:
Jets in AGN moving towards us
Blazars: bright at all frequencies

e.g., Fossati et al. 1998

synchrotron

inverse Compton scattering
Blazars flaring from weeks down to \(~5\) minutes!

3C279; e.g., Collmar et al. 2007

Aharonian et al. 2007; Albert et al. 2007; Aleksic et al. 2011
Basic Observed/inferred properties of blazars

Effective particle accelerators up to multi TeV energies, at least

Efficient radiators $\sim 10\%$ radiative efficiency or more!

Radiating particles and magnetic field in, very rough, equipartition:

$$U_e \sim U_B$$

Extreme variability variable $t_{\text{var}} < < R_g / c$ in some cases!
Source of blazar flares: “Blobs” of energetic $\epsilon$ and $B$ fields

Doppler factor $\delta = [\Gamma_{\text{em}}(1 - \beta_{\text{em}} \cos \theta)]^{-1} \sim \Gamma_{\text{em}}$

Notation: $d = 50 \, \text{cm}$, $t = 300 \, \text{s}$
Stringent requirements for emitting region

Emitter must be very compact and extremely fast and form at ~1 pc distance!

Some big questions:

Which process accelerates the particles that radiate?
What determines the distance & size/shape of the emitting region?
A theory view of jets

Blandford & Znajek 1977
Begelman & Li 1992
Meier et al. 2001
Koide et al. 2001
Komissarov, Lyubarky, McKinney, Tchekhovskoy…

\[
\text{initial} = \frac{B^2}{4pc^2} >> 1
\]

“blazar” zone
magnetic reconnection region

\[
diss \quad 1
\]

acceleration
launched

Disk
 Disk
Magnetic reconnection due to MHD instabilities in jets

Magnetized jets may be prone to the kink instability

Barniol-Duran, Tchekhovskoy & Giannios
A very promising dissipative mechanism: Magnetic Reconnection

- An efficient convertor of magnetic energy into bulk motion, heat, energetic particles
- Cold, magnetized plasma enters the reconnection region
- Plasma leaves the reconnection region at the Alfvén speed
- Reconnected material contains energetic (nonthermal) particles
Reconnection Plasmoids = Blazar Blobs?

Giannios et al. 2009; 2010; Giannios 2013

- Current sheet fragments to plasmoids Loureiro et al. 2007; Uzdensky et al. 2010; Loureiro et al. 2012+++.

- Plasmoids merge/grow fast leaving the layer at $V_A \sim c$.

- Large plasmoids can power blazar flares Giannios 2013.
Magnetic reconnection from first-principle simulations

Sironi & Spitkovsky 2014; Sironi, Petropoulou & Giannios 2015;
Sironi, Giannios & Petropoulou 2016; Petropoulou, Giannios & Sironi 2016
Particle acceleration from first principle simulations
Sironi, Petropoulou & Giannios 2015
Relativistic reconnection is efficient

\[ f_{\text{rec}} \equiv \frac{\sum_i \int_{V_i} U_e dV_i}{\sum_i \int_{V_i} (e + \rho c^2 + U_B) dV_i} \]

(Sironi, Petropoulou, Giannios 15)

Relativistic reconnection:

✓ it transfers \( \sim 50\% \) of the flow energy (electron-positron plasmas) or \( \sim 25\% \) (electron-proton) to the emitting particles
(2) Equipartition of particles and fields

\[
\left\langle \frac{U_e}{U_e + U_B} \right\rangle \equiv \frac{\sum_i \int_{V_i} U_e \frac{U_e}{U_e + U_B} dV_i}{\sum_i \int_{V_i} U_e dV_i}
\]

Blazar phenomenology:

- rough energy equipartition between emitting particles and magnetic field

Relativistic reconnection:

✓ in the magnetic islands, it naturally results in rough energy equipartition between particles and magnetic field
Extended non-thermal distributions

Blazar phenomenology:
- extended power-law distributions of the emitting particles, with hard slope

\[ \frac{dN}{d\mu} \mu^{-p}, \quad p \geq 2 \]

Relativistic reconnection:
- it produces extended non-thermal tails of accelerated particles, power-law slope can be harder than \( p=2 \)
(4) Extreme temporal variability?

Blazar phenomenology:

- at TeV energies, fast (~10 minutes) flares on a high-state envelope lasting for ~days
From first principle simulations to lightcurves
Sironi, Giannios & Petropoulou 2016
From simulations to lightcurve: Single Plasmoid
Petropoulou, Giannios & Sironi 2016

Small & Fast Plasmoid

Large & Slow plasmoid
From simulations to lightcurve: the whole reconnection layer
Christie et al., in prep.
Concluding

- Jets are observed to be efficient particle accelerators, highly variable
- Magnetic reconnection can produce fast variability, efficient particle acceleration, equipartition conditions
  - Blazar “blobs” = reconnection plasmoids?
- Lots of work left
  - Connection to the large-scale jet
  - long wavelength emission (larger scales)
  - polarization (radio through gamma-rays)
Large-scale jet and emission
Magnetic reconnection in the jet

- Jet may contain field reversals on small scale $\sim 100 \ R_g$
- Magnetic-reconnection becomes effective when

$$t_{\text{exp}} \sim t_{\text{rec}}$$

where $v_{\text{rec}} = \varepsilon c$

$$r_{\text{diss}} / c \sim 100 \ R_g / c$$

$$r_{\text{diss}} \sim 100R_g / \sim 1M_{8j,10} \ pc$$