Millimeter-Wave and Optical Polarimetric Behavior of Blazars

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Essential ingredients:

- The gravitational potential of the rotating BH
- Material from the rotating accretion disk
- Co-rotating magnetic fields

Studying magnetic fields is crucial to understand the jet phenomenon at all scales

McKinney & Blandford (2009)
Location of short millimeter emission region

Marscher et al. 2008, 2010; Agudo et al. 2011a,b; Fuhrmann et al. 2014; From et al. 2015

mm emission region located at [~1, ~10] pc from central engine
Blazars display optically thin radiation at short millimeter wavelength in general.

- Not affected by opacity effects like at cm wavelength (angle rotation, depolarization, and shift of the emission region towards further downstream regions)
- Few exceptions happen for flaring sources only
Optical emission region in the jet not so easy to locate
Degenerate problem, therefore also at γ-rays

Millimeter and Optical Polarimetric Behavior of Blazars, Iván Agudo (IAA-CSIC)
This work showed the value of mm-VLBI and optical polarimetry for the study of blazars and motivated the community to intensify their pol. obs.
• Superluminal jet ejection coincident in time with:
  - Gamma-ray flare
  - Optical flare
  - Radio and millimeter flare
  - Sharp optical polarization peak
  - End of optical polarization swing \( \Delta \chi \approx 700^\circ \)

• If simultaneous, these events must be all produced at the same location (causality arguments)

• For the case of PKS 1510-089, such site, i.e. the innermost VLBI jet feature (radio core), is located at \(~20\, \text{pc}\) from the central engine.

PKS 1510-089

Marscher et al. (2010)
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Without mm-VLBI it is not possible to make the absolute location the emission regions.
Optical EVPA swings & γ-ray emission

- Optical polarization angle swing coincident in time with:
  - Gamma-ray flare
  - Optical-NIR flare
  - Drop of optical polarization deg.

Alternative interpretation: Pure geometrical effect by a knot propagating through a bent jet
Stable optical-mm EVPAs & $\gamma$-ray emission

- No polarization swing during MWL flare
- Different phenomenology
Stable optical-mm EVPAs & $\gamma$-ray emission

All events located at (or beyond) the mm-VLBI core, and hence the $\gamma$-ray emission should have been produced at more than 12 pc from the central black hole (where the core is estimated to be located).

- No polarization swing during MWL flare
- Different phenomenology

Agudo et al. (2011b)
Proposed model for multi-spectral range emission behavior

- Scenario where radio, mm, optical flares produced at the 7mm core (conical shock) by particle acceleration in a moving blob (Qs) when it crosses a standing shock. Qs also contributes to flare.

- Shortly after, $\gamma$-ray flares are produced by inverse Compton scattering of these optical-IR photons (SSC).

Stable optical-mm EVPAs & γ-ray emission: another case

- Two kinds of events related at high conf. to the reported γ-ray outbursts (A_γ and B_γ):.

1. Rising phase of two most luminous 1mm flares in OJ287 (A_{mm} and B_{mm})

2. Two sharp and high peaks of linear polarization (∼14% and ∼22%) in bright jet feature C1 > 14 pc from the central engine.

- No polarization swing during MWL flare
A different case: The BL Lac object S5 0716+714

- Although there is fast and extreme variability along the spectrum
- There is no clear relation of events at different spectral ranges
- No formal correlation is found in general
- Only one clear superluminal ejection is found

S5 0716+714

Agudo et al. (in prep.)
• Millimeter VLBI allows us to actually resolve the jet evolution, and sometimes allows to make the absolute location of emission regions along the spectrum up to $\gamma$-rays.

• Millimeter and optical polarimetry is a powerful tool to make identification of events along the spectrum, and provides direct information about magnetic field in the emission regions.

• Blazars studies involving polarimetry locate $\gamma$-ray emission far outwards BLR.
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• Actually, every blazar seem to behave in a somehow different way!
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Models for polarization swings

- Helical trajectory of jet feature driven by a helical magnetic field
  - Marscher et al. (2008; 2010)

- Helical magnetic fields in a bent jet
  - Abdo et al. (2010)

- Internal shock model in helical field distorted by light travel time effects
  - Zhang et al. (2014)

- Turbulent Extreme Multi-Zone Model (TEMZ)
  - Marscher (2014)
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