Millimeter-Wave and Optical Polarimetric Behavior of Blazars

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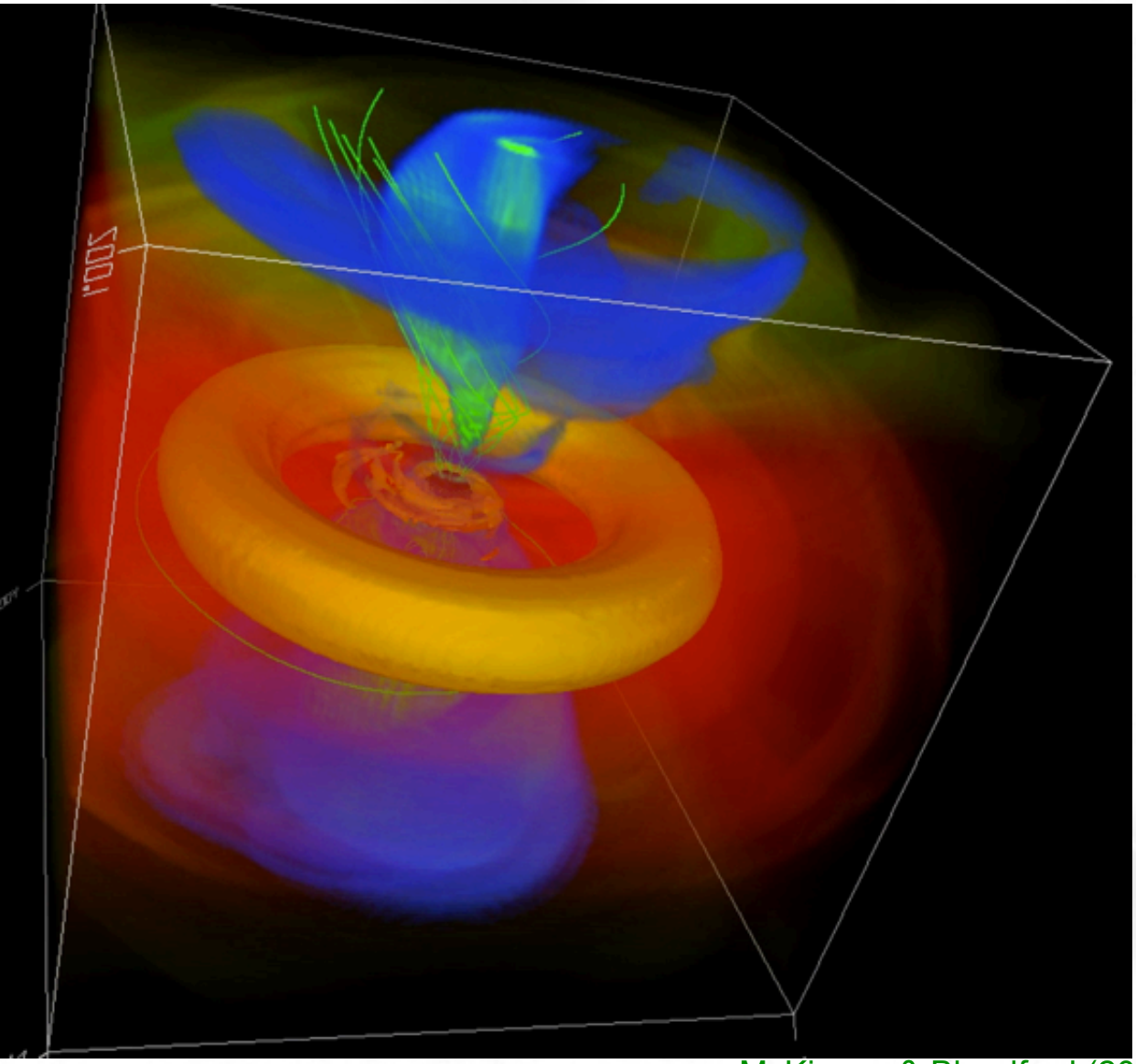
Magnetic fields in relativistic jets

3D RMHD simulations of relativistic jet formation



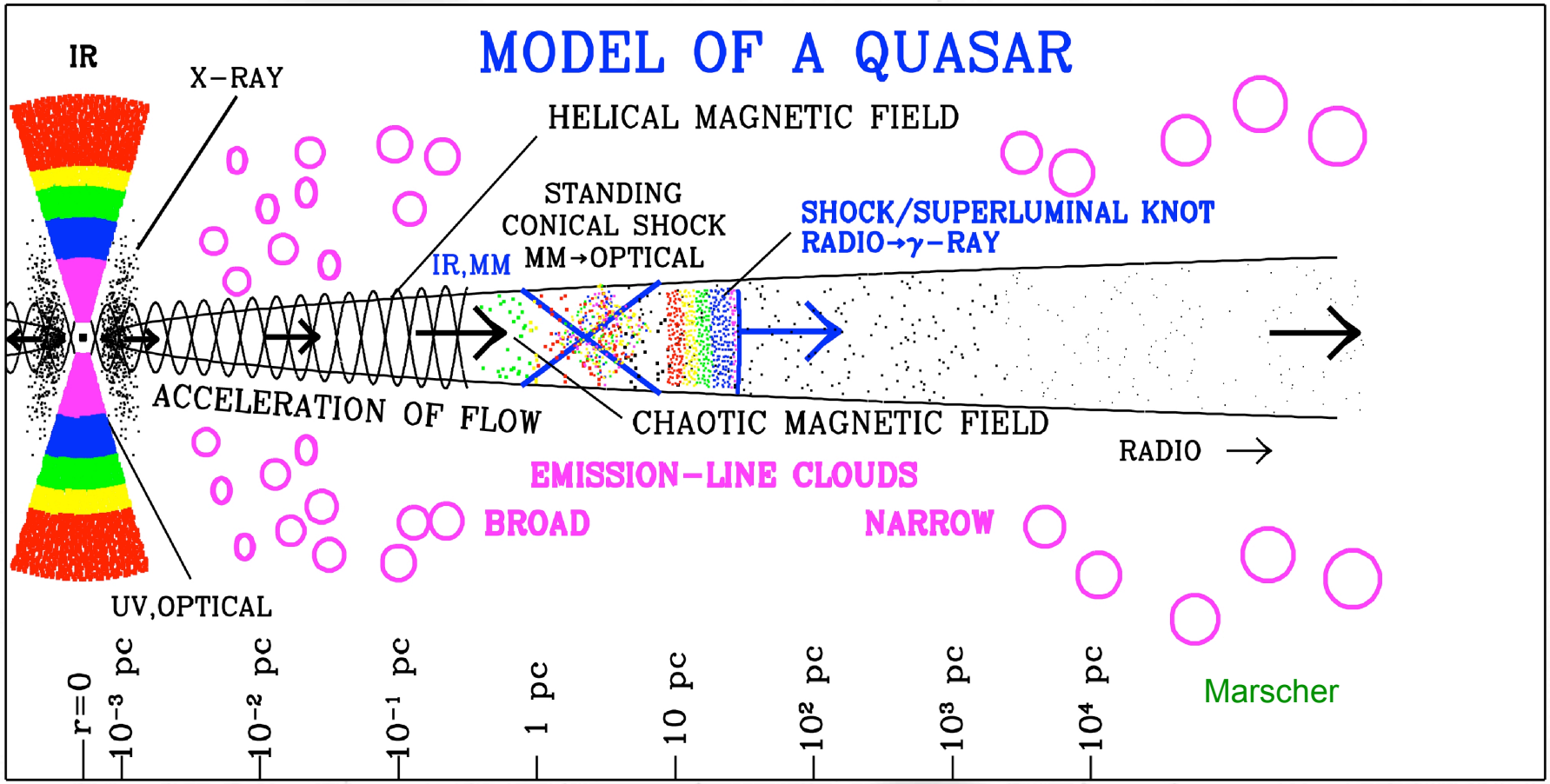
McKinney & Blandford (2009)

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

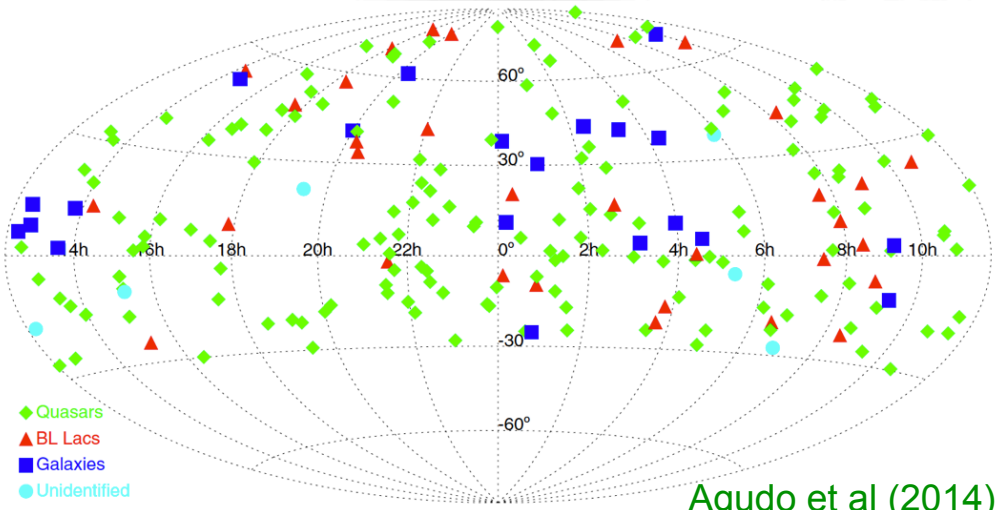
Location of short millimeter emission region



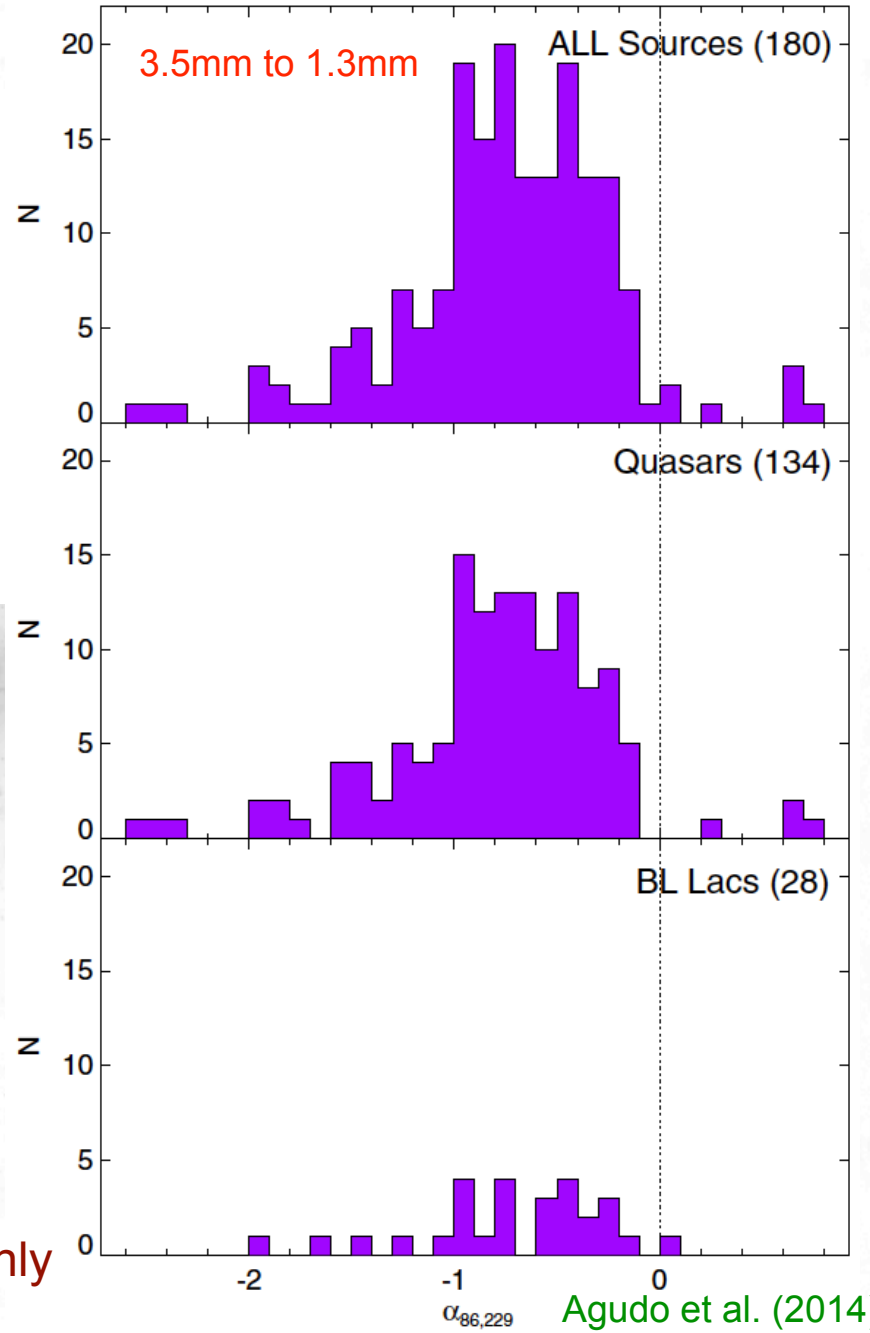
mm emission region located at [~1,~10] pc from central engine

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

Millimeter spectral index



Agudo et al (2014)



Agudo et al. (2014)

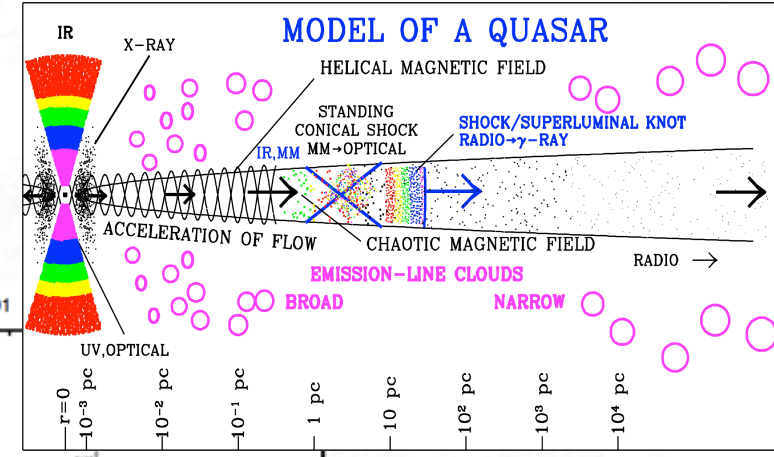
Blazars display optically thin radiation at short millimeter λλ in general

- Not affected by opacity effects like at cm λλ (angle rotation, depolarization, and shift of the emission region towards further downstream regions)

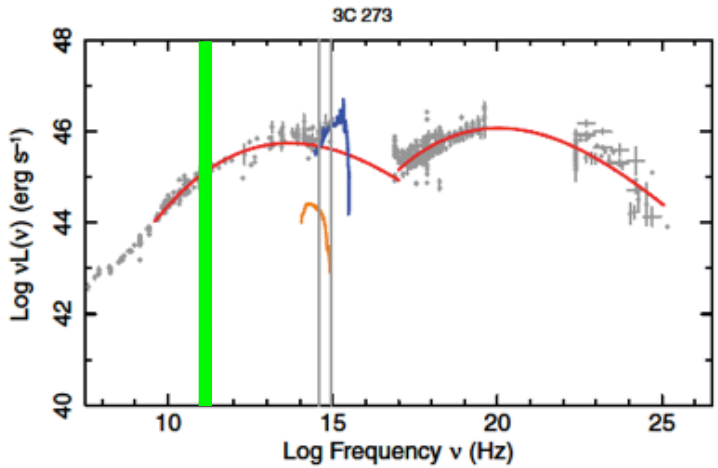
- Few exceptions happen for flaring sources only

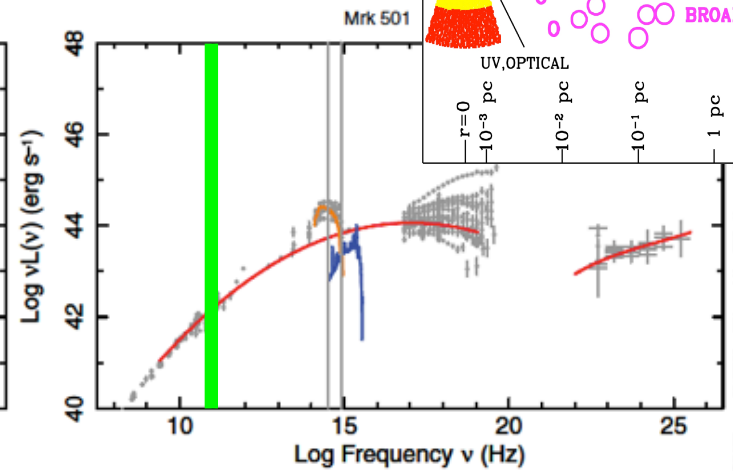
MWL emission regions & mechanisms

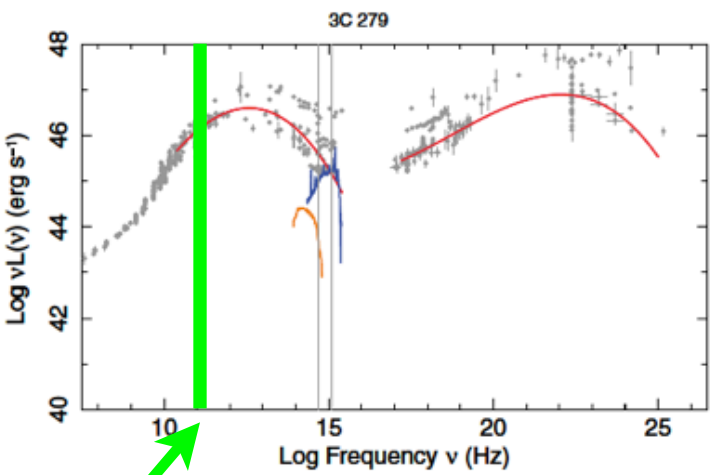
Optical emission region in the jet not so easy to locate
Degenarate problem, therefore also at γ-rays

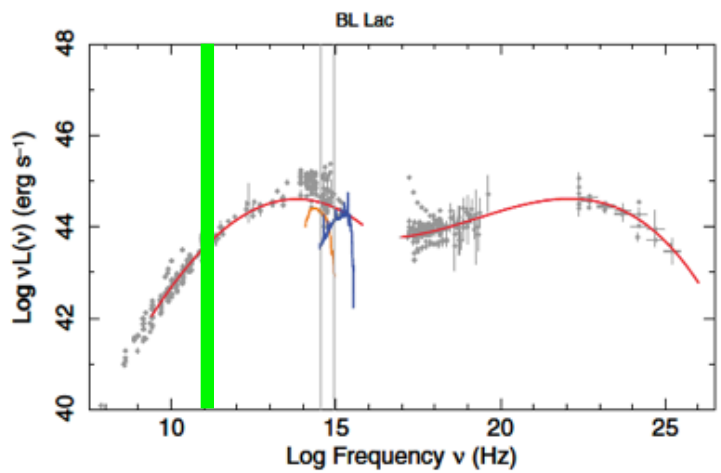


Marscher







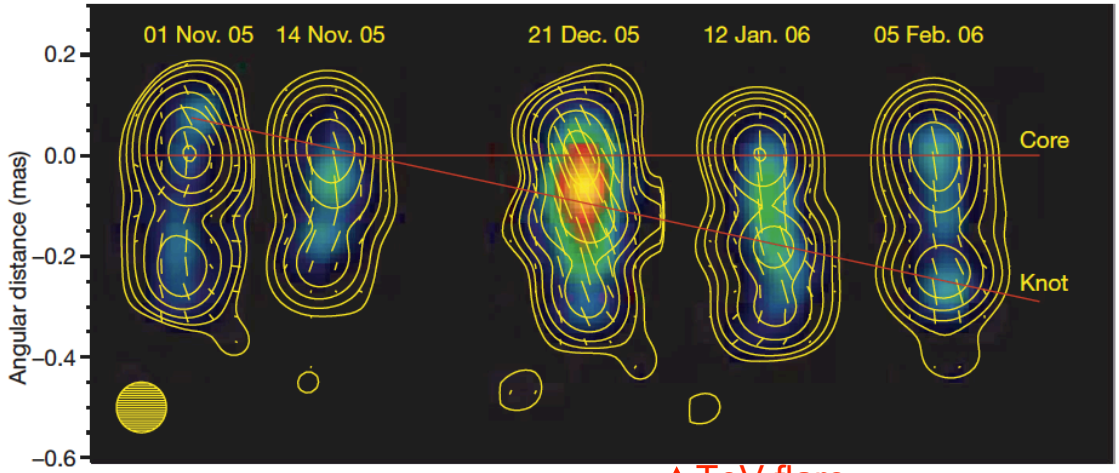


Giommi et al. (2012)

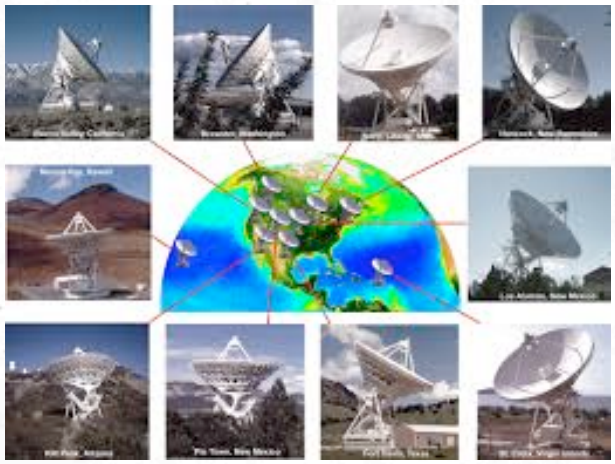
100 GHz -300 GHz

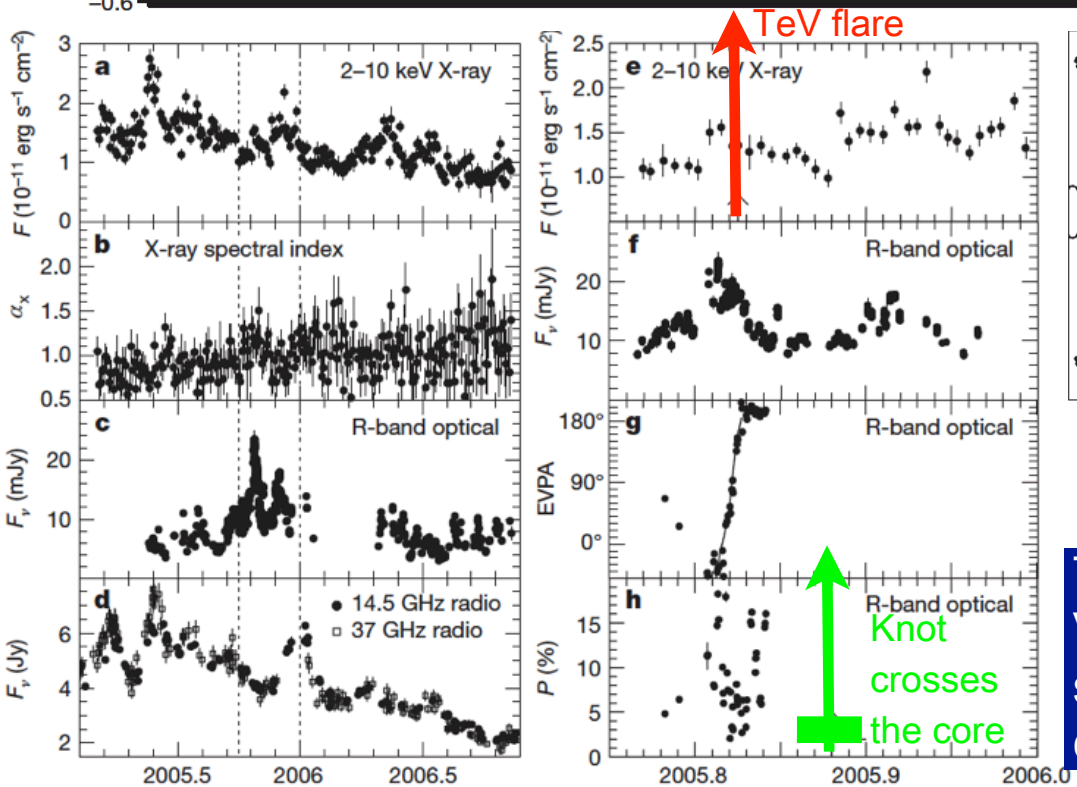
Optical EVPA swings & γ-ray emission

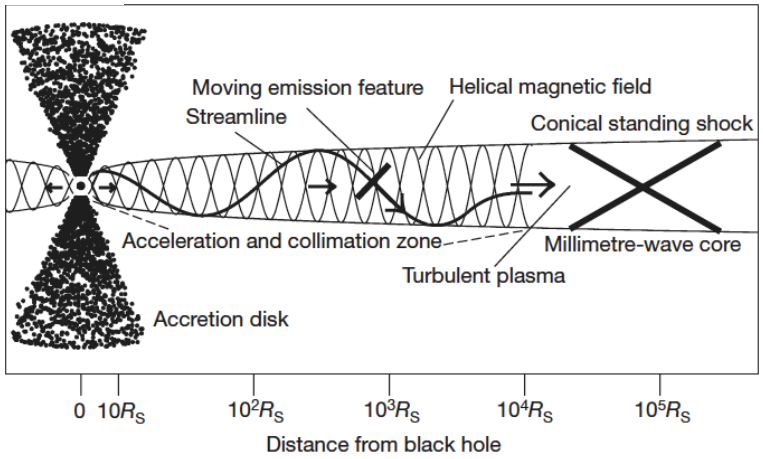
BL Lac



43 GHz VLBA







Marscher et al. (2008, Nature)

This work showed the value of mm-VLBI and optical polarimetry for the study of blazars and motivated community to intensify their pol. obs.

Optical EVPA swings & γ-ray emission

- 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 $\Delta\chi \sim 700^{o}$
- 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 ~20pc from the central engine

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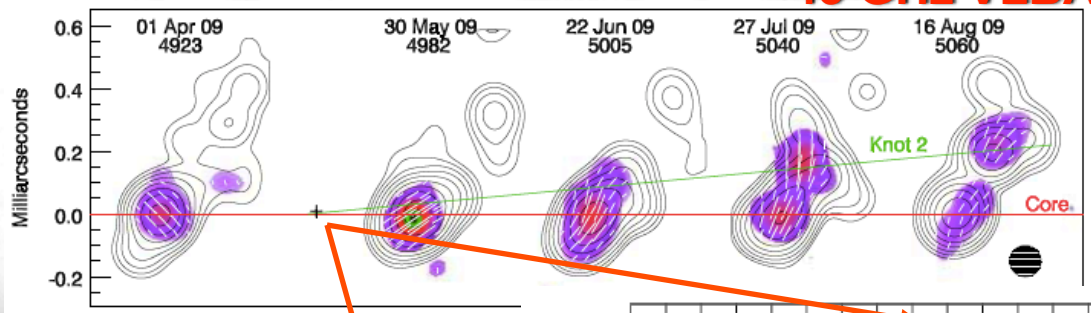
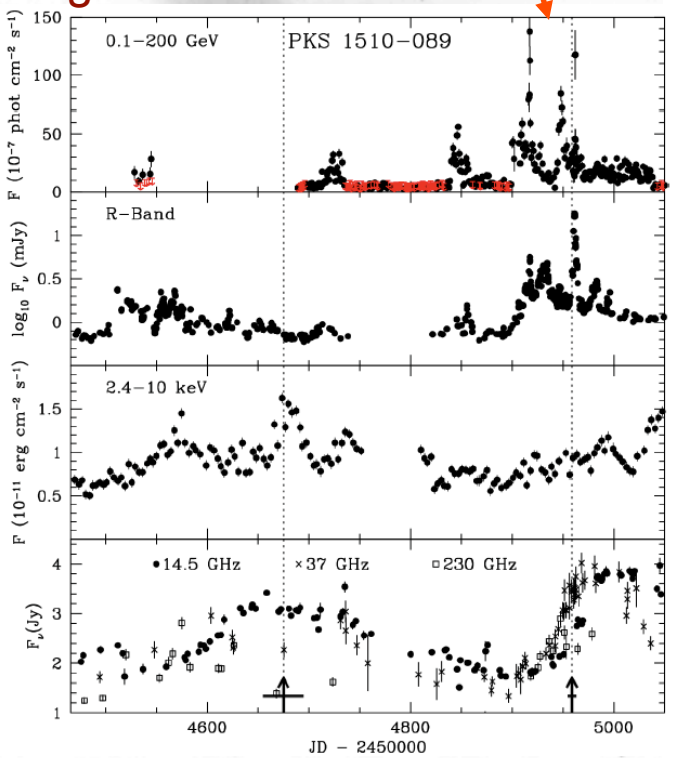
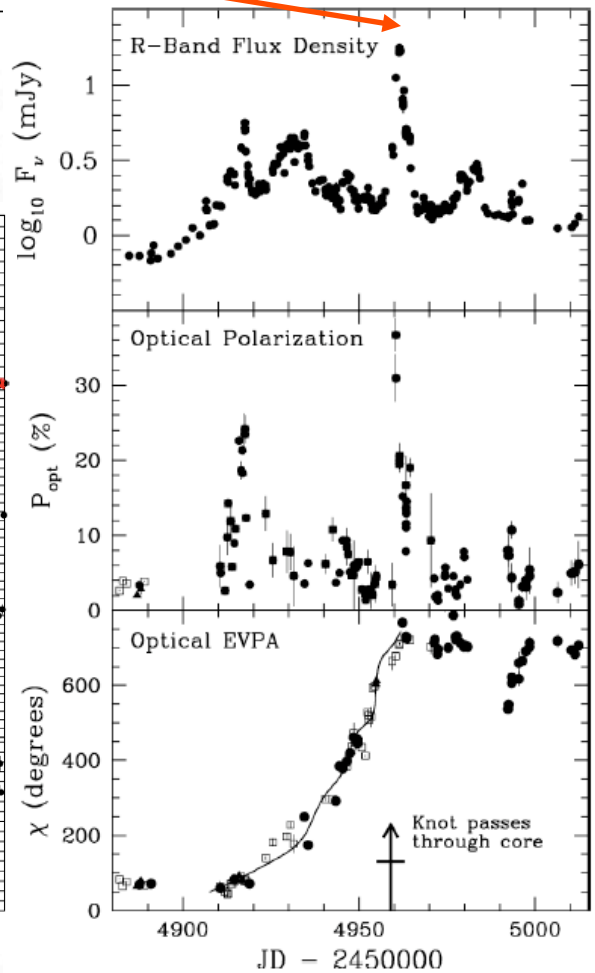


Marscher et al. (2010)

PKS 1510-089





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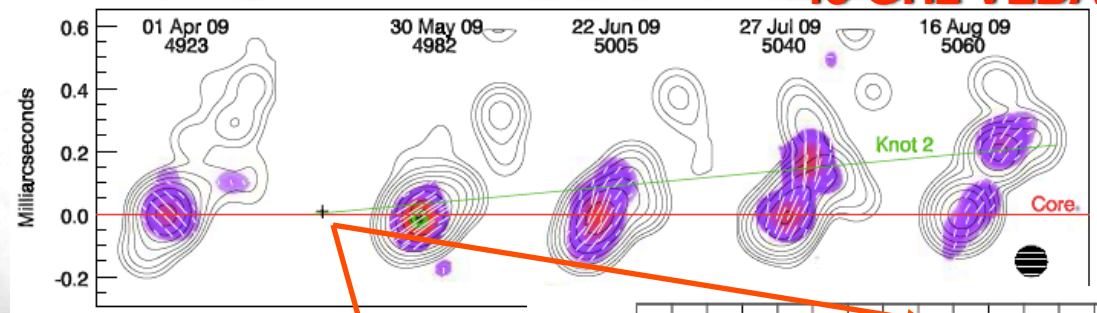
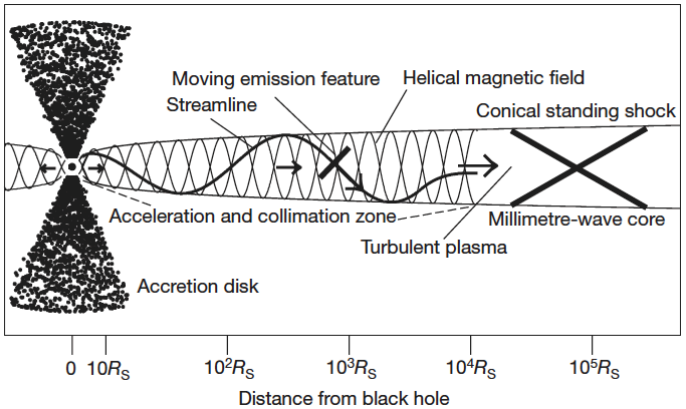
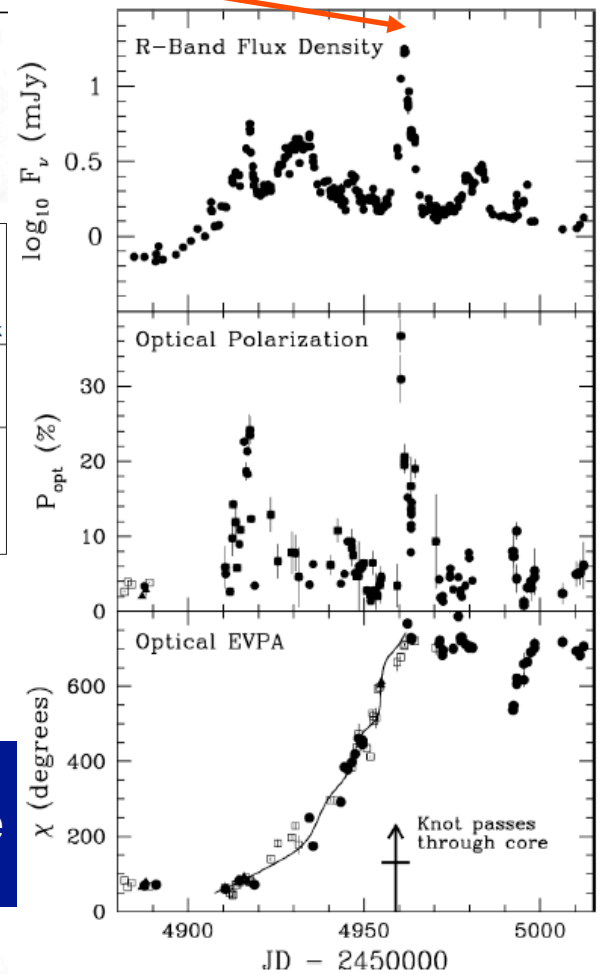


Marscher et al. (2010)

PKS 1510-089

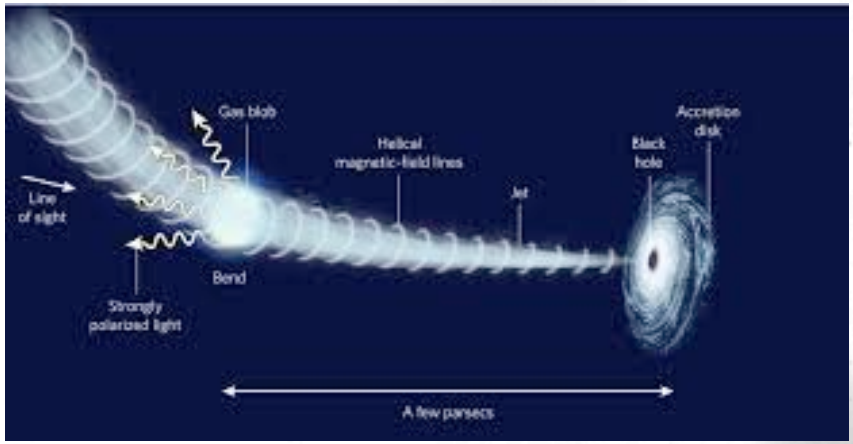




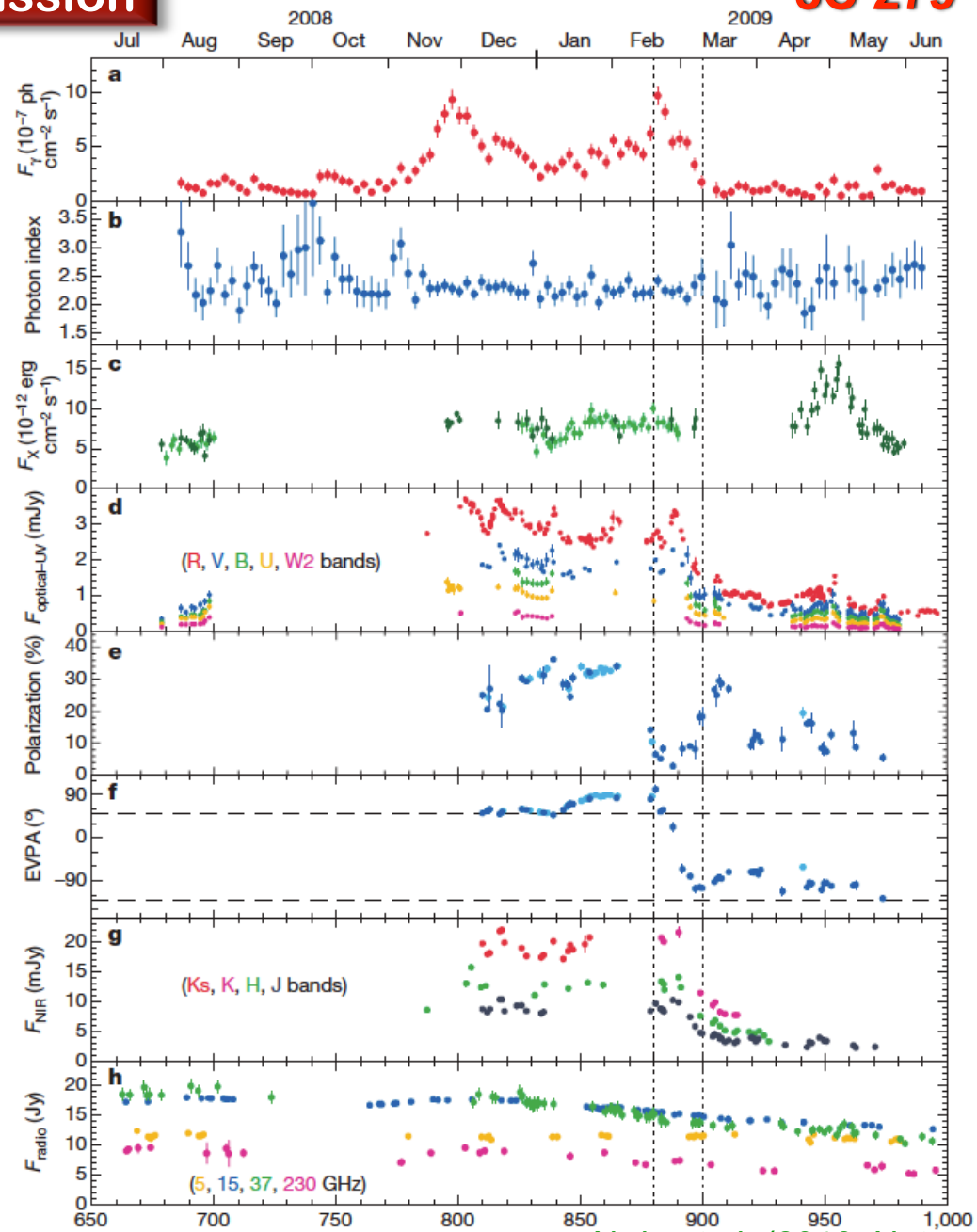
Without mm-VLBI it is not possible to make the absolute location the emision regions

Optical EVPA swings & γ-ray emission

3C 279



Abdo et al. (2010, Nature)



Abdo et al. (2010, Nature)

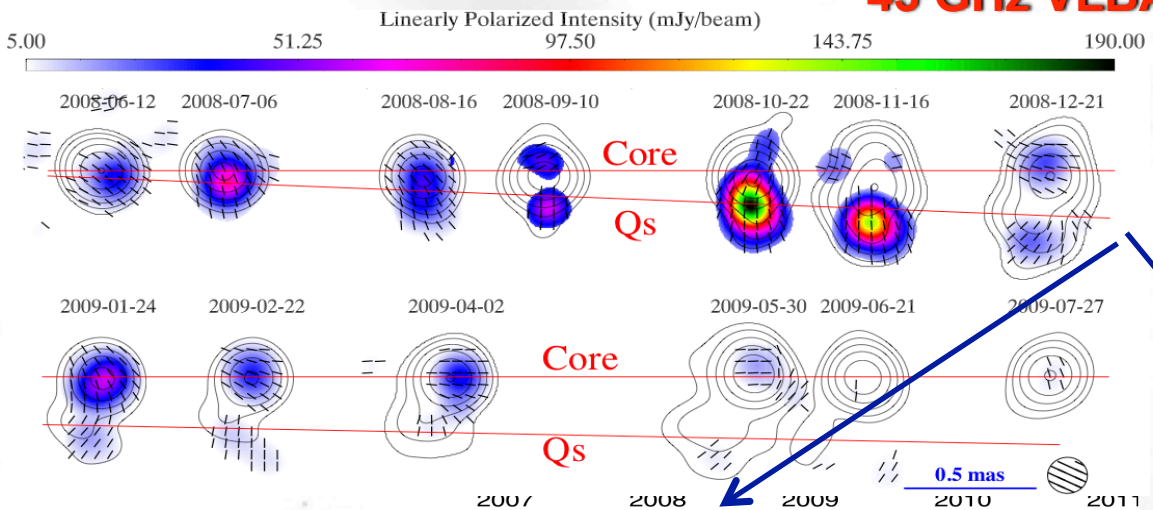
- Optical polarization angle swing coincident in time with:
  - -Gamma-ray flare
  - -Optical-NIR flare
  - -Drop of optical polarization deg.

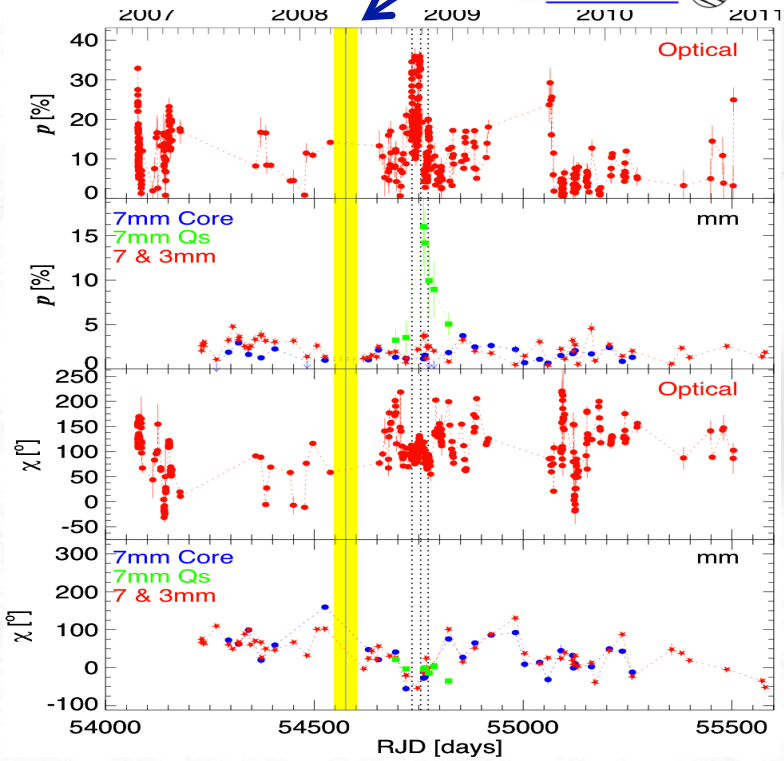
Alternative interpretation: Pure geometrical effect by a knot propagating through a bent jet

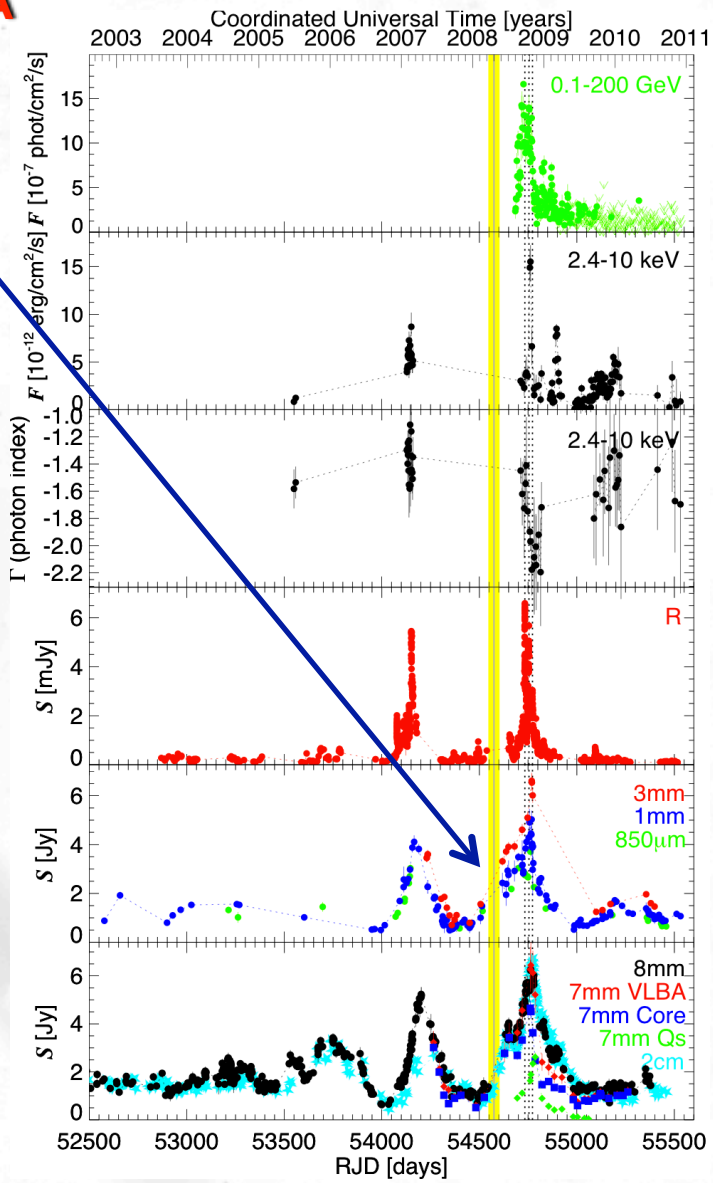
Stable optical-mm EVPAs & γ-ray emission

AO 0235+164

43 GHz VLBA







- No polarization swing during MWL flare
- Different phenomenology

Agudo et al. (2011b)

Stable optical-mm EVPAs & γ-ray emission

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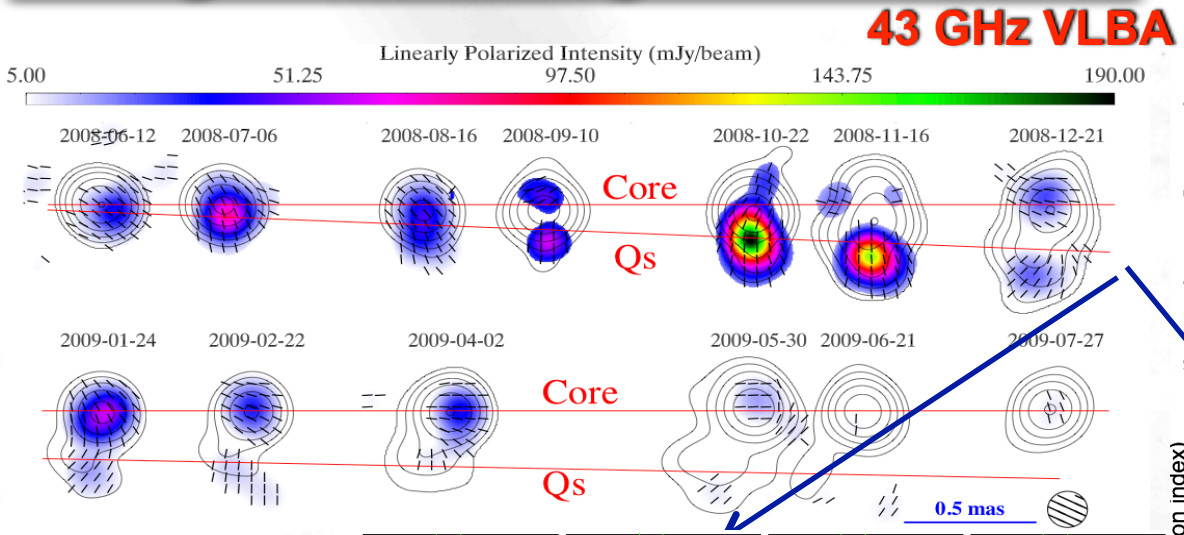
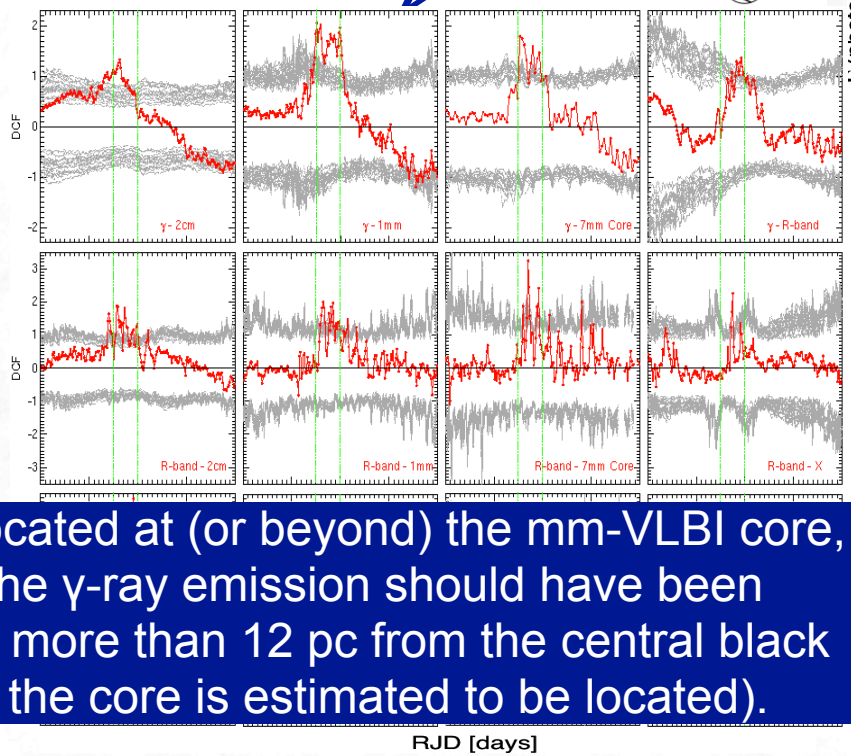
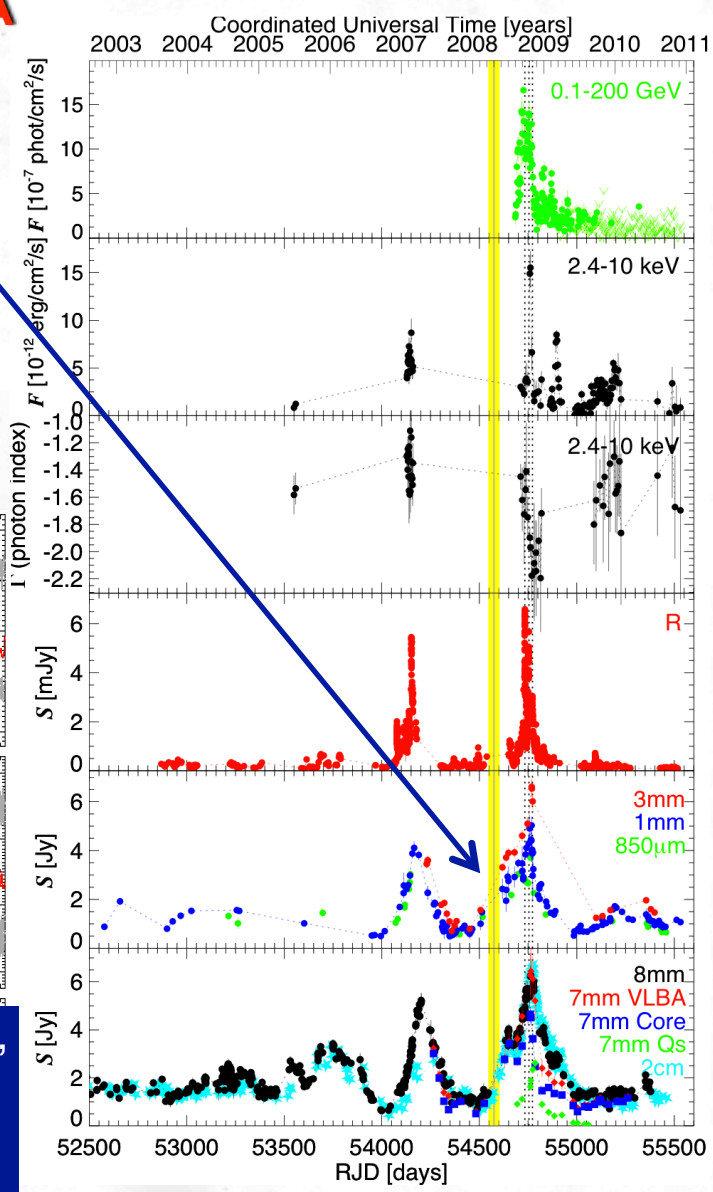






- No polarization swing during MWL flare
- Different phenomenology

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

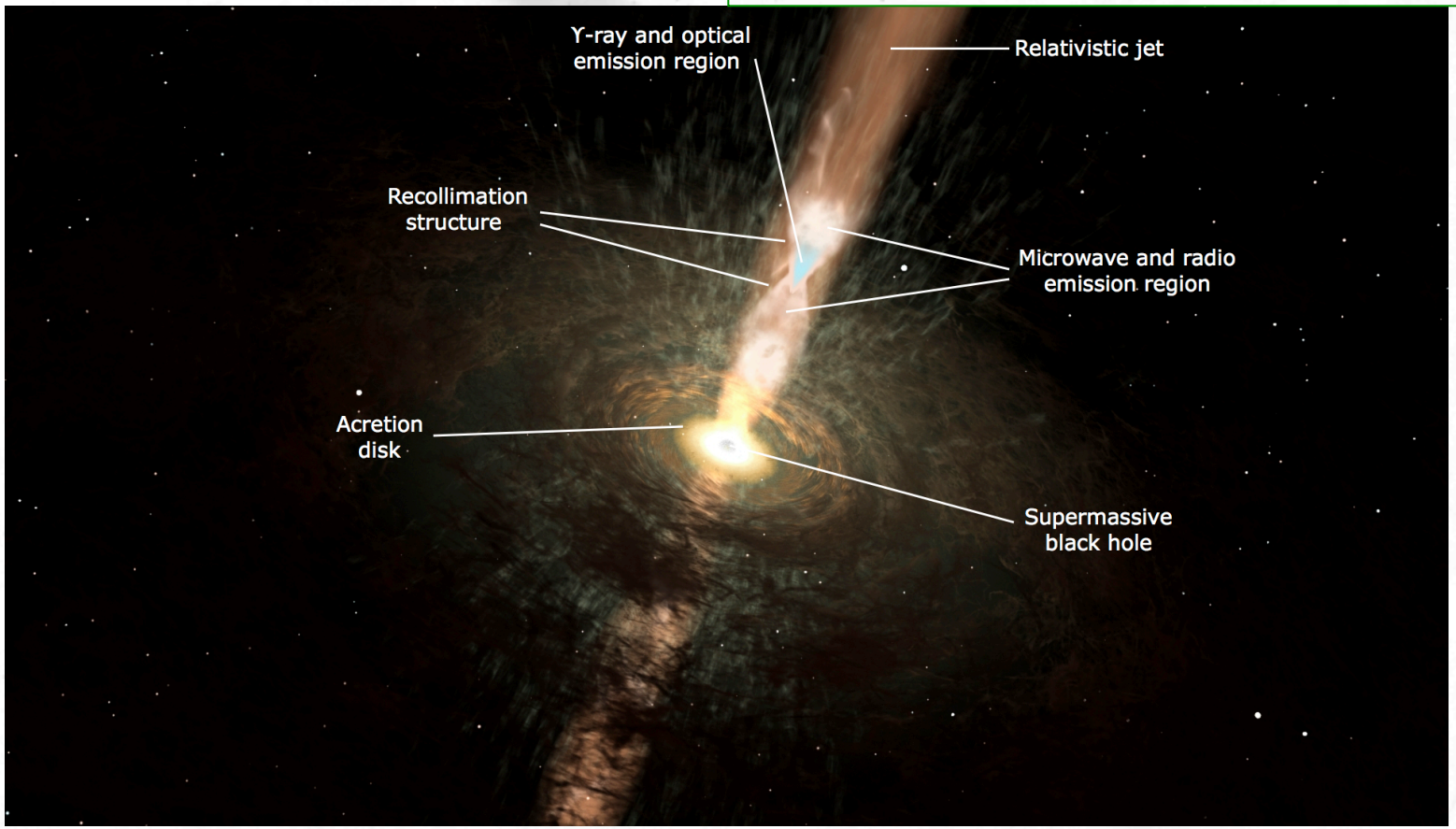
Agudo et al. (2011b)

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, γ-ray flares are produced by inverse Compton scattering of these optical-IR photons (SSC)

AO 0235+164: Agudo et al. (2011b, ApJL,735, L10)



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

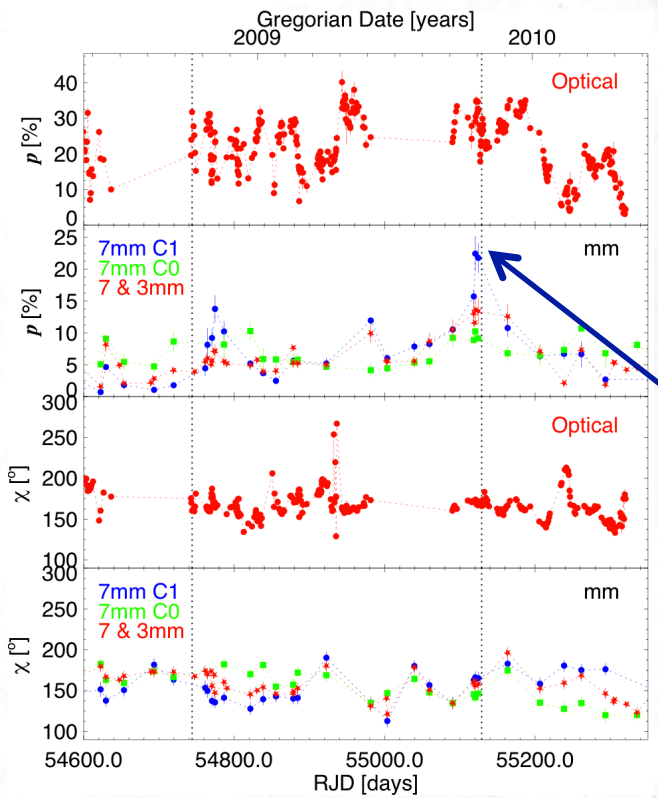
OJ 287

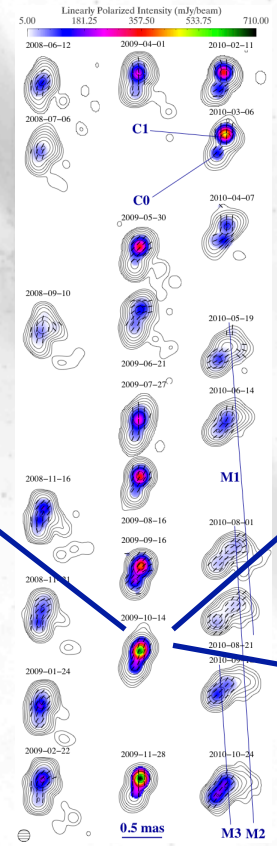
- Two kinds of evens related at high conf. to the reported γ-ray outbursts (A_γ and B_γ).:

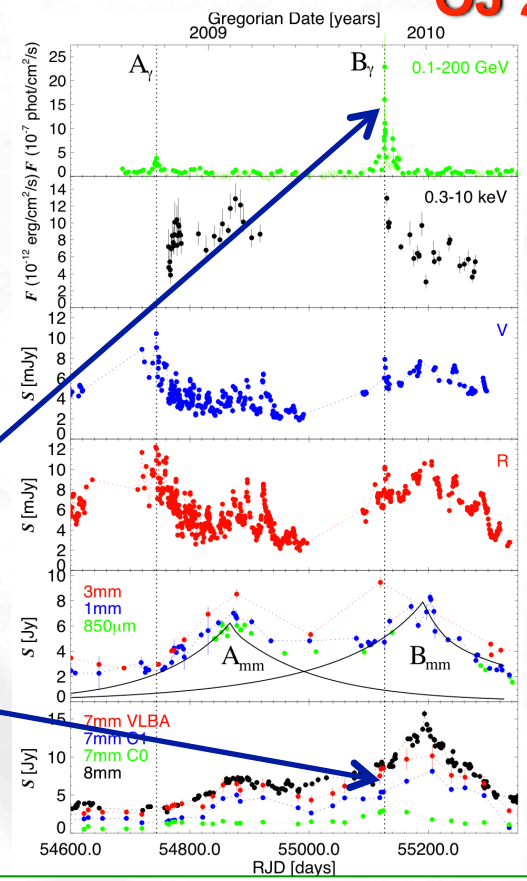
(1) Rising phase of two most luminous 1mm flares in OJ287 (A_{mm} and B_{mm})

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

OJ 287



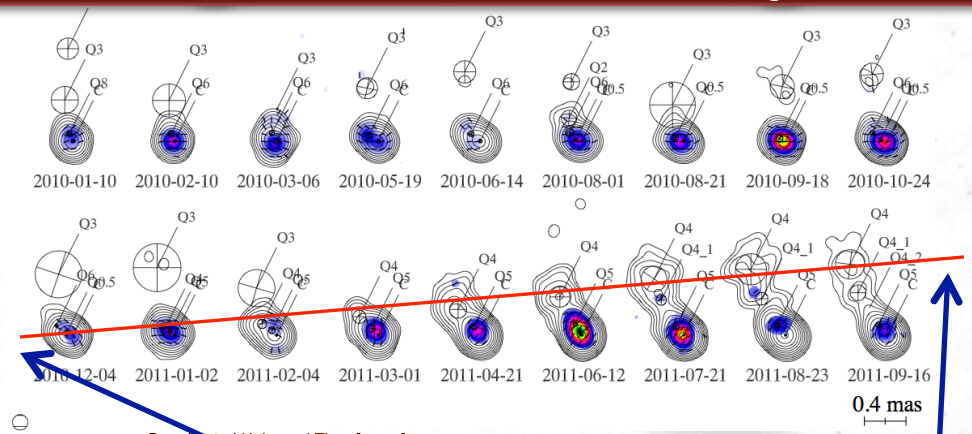




- No polarization swing during MWL flare

Agudo et al. (2011a, ApJL,726, L13)

A different case: The BL Lac object S5 0716+714



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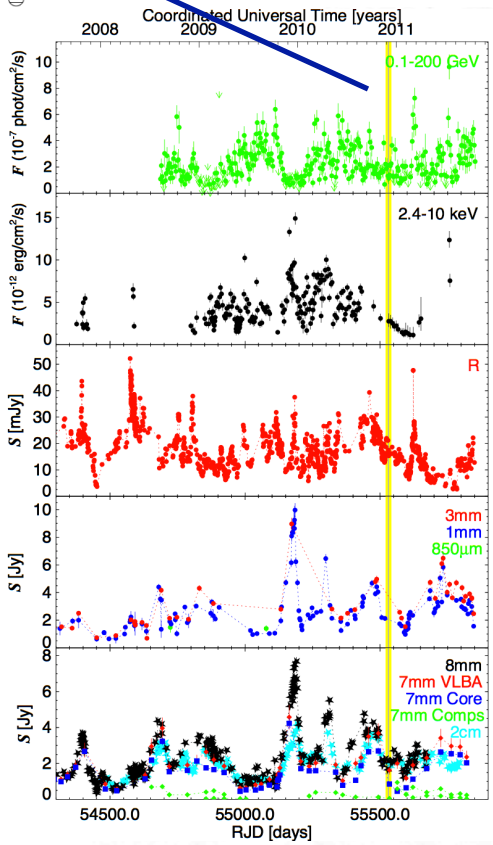

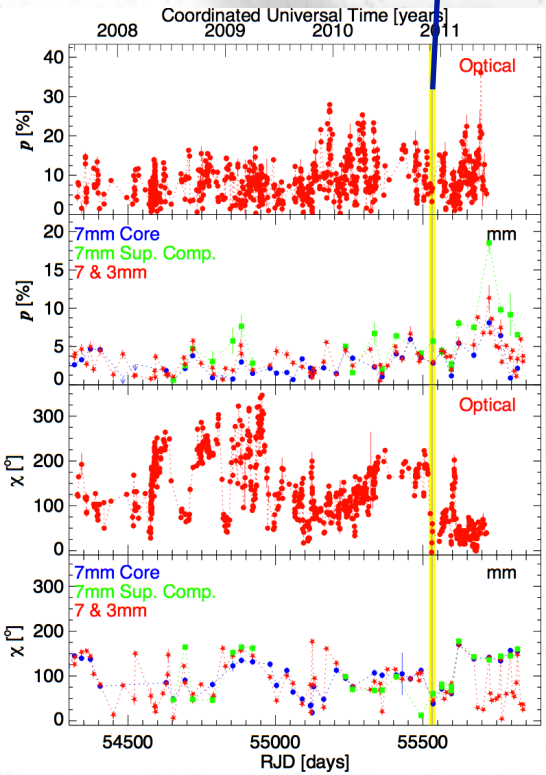

- Although there is fast and extreme variability along the spectrum
- There is no clear relation of events at different spectral ranges
- No formal correlation is found in general
- Only one clear superluminal ejection is found

Agudo et al. (in prep.)

Summary

- 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 γ-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 γ-ray emission far outwards BLR

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- Actually, every blazar seem to behave in a somehow different way!

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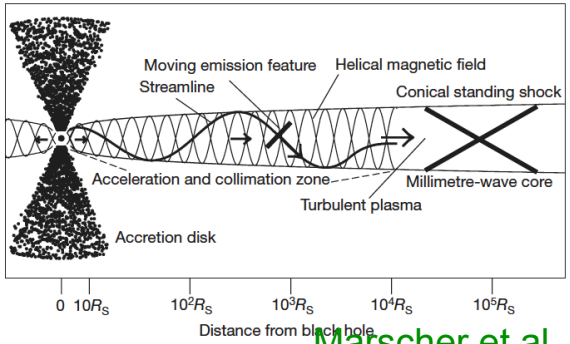
- For that we will need to study as much sources as possible in as much detail as possible, to try to dentify any common phenomenology that can allow to start drawing general conclussions. (More sources, more flares!)

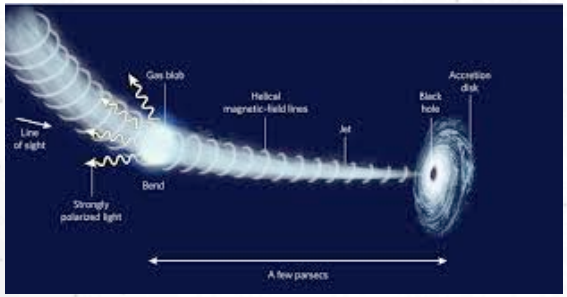
Models for polarization swings

- Helical trajectory of jet feature driven by a helical magnetic field



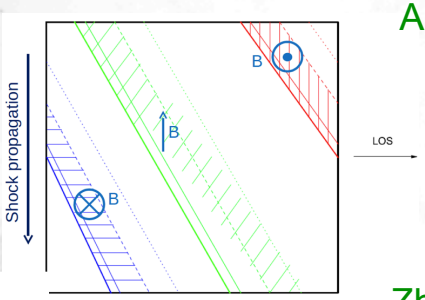
Marscher et al. (2008; 2010)

- Helical magnetic fields in a bent jet



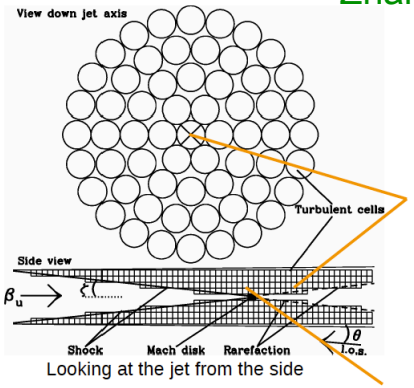
Abdo et al. (2010)

- Internal shock model in helical field distorted by light travel time effects



Zhang et al. (2014)

- Turbulent Extreme Multi-Zone Model (TEMZ)



Mach disk

Marscher (2014)

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