Radio and γ-ray connection in relativistic jets

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The extragalactic γ-ray sky

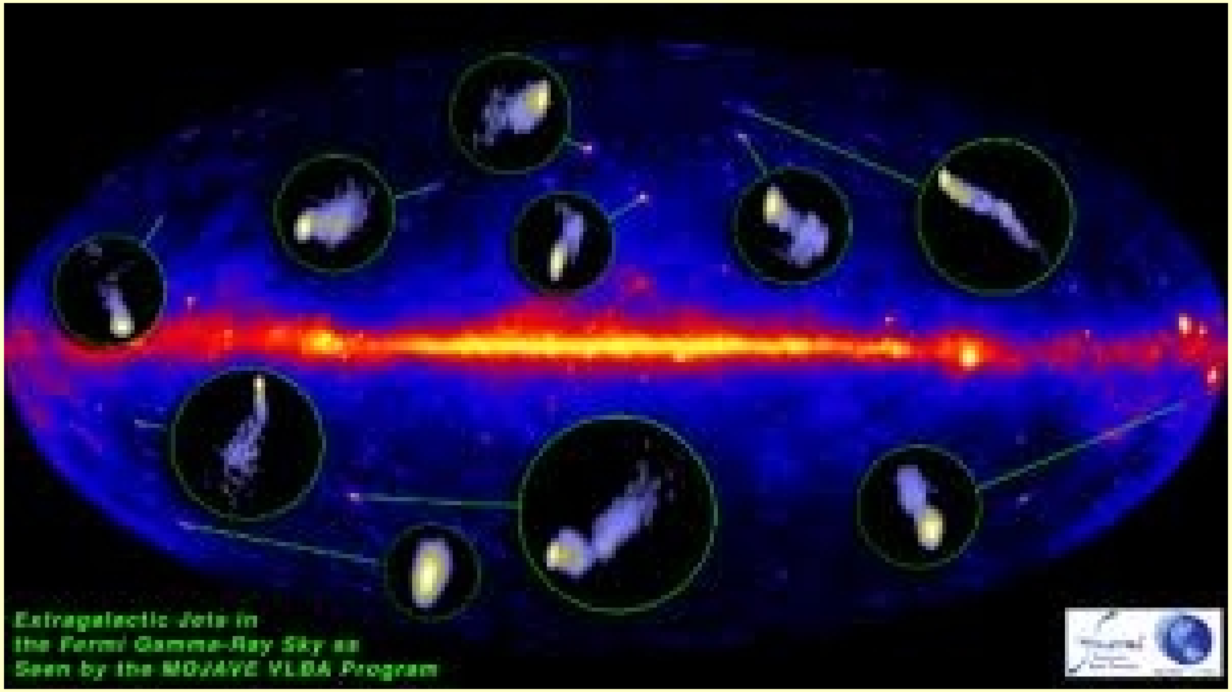
EGRET: 100% RL-AGN

In the 2LAC (Ackermann+11):

- 97% blazars
- 3% other objects

 - MAGN
  - CenA lobes (Abdo+10)
 - RL-NLsy1
 - RQ AGN+SFG (CR)
  - NGC1068 (CR+AGN)

Hayashida+13



Strong γ-ray emitters:

- High radio luminosity
- Fast apparent jet speed
- High variability Doppler

Savolainen+ 2010, Lister+ 09, Kovalev+ 2009

Extragalactic γ-ray sky dominated by radio-loud AGN

Relativistic jets

Non-thermal emission

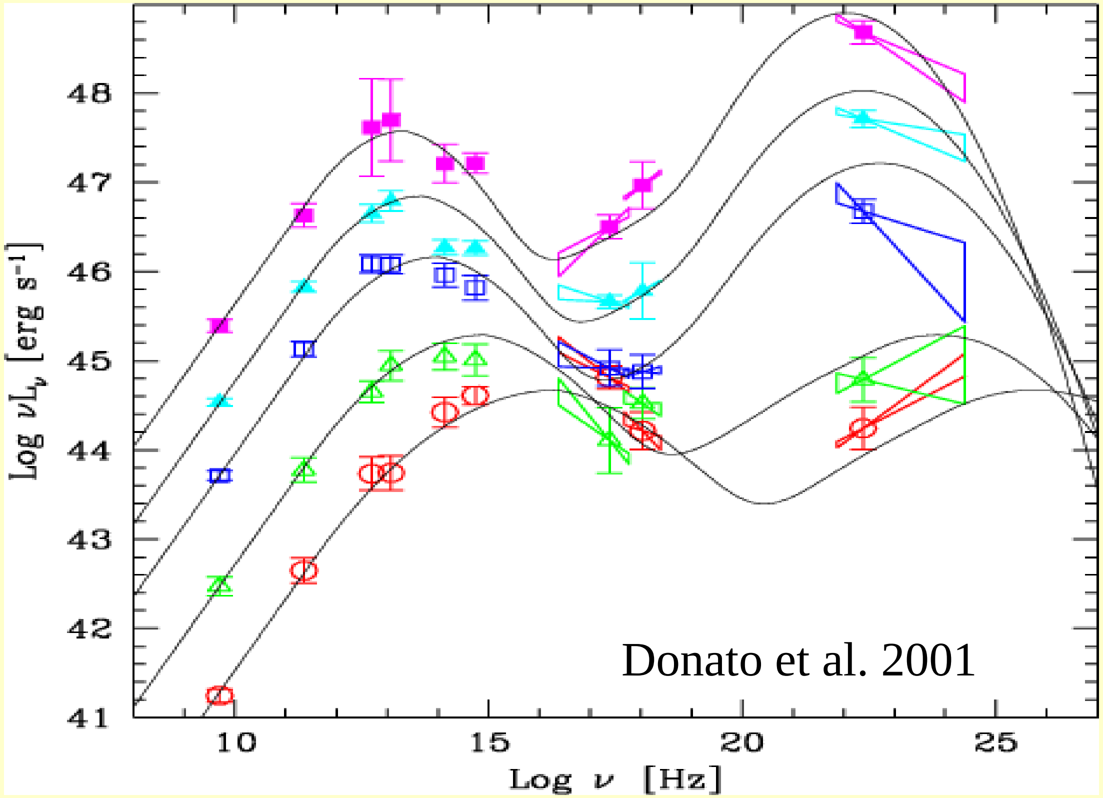
- Low energy: **synchrotron**

Relativistic electrons can scatter low energy photons

- High energy: **inverse Compton**

Seed photons:

- external photons from torus, disk, BLR... (External Compton)
- their own synchrotron photons (Synchrotron-self Compton)



Luminosity ~ $10^{49} - 10^{50}$ erg/s
Linear size ~ (sub-)pc to Mpc

Relativistic jets

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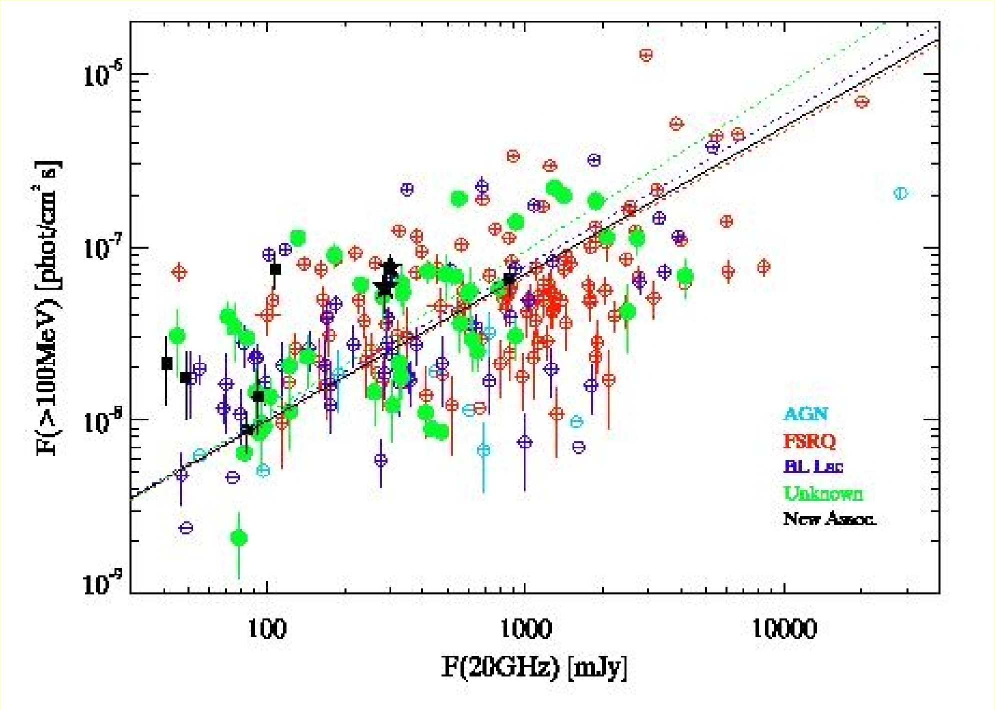


Ghirlanda et al. 2010

Existence of radio-gamma correlation for both BL Lacs and FSRQ

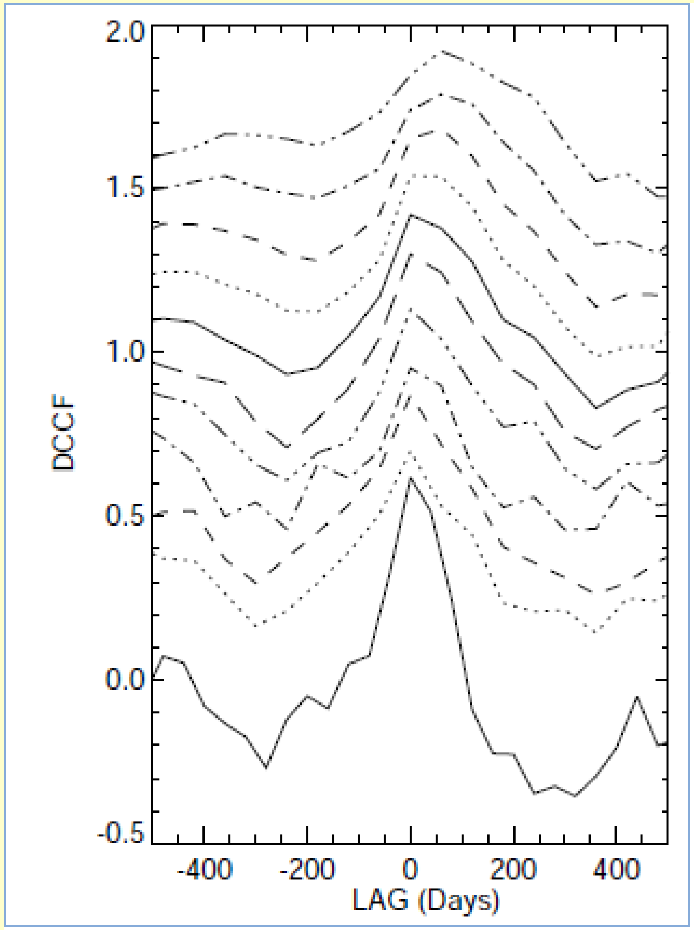
Open questions

- What is the γ-ray emitting mechanism?
- Where is the region responsible for γ-ray emission?
- Shock propagation, turbulence, velocity gradient?
- What is the structure of the magnetic field in the jet?
- .....

Single-dish studies of large samples: F-GAMMA

Cross-correlation between the γ-ray and radio light curves of a sample of 54 Fermi blazars observed between 11 cm and 2 mm.
Additional 0.8 mm APEX data for 25 blazars.

Fuhrmann et al. 2014



γ-ray leads the radio variability

Time delay increases with frequency:

- 76±23 days at 11 cm
- 7±9 days at 2 mm

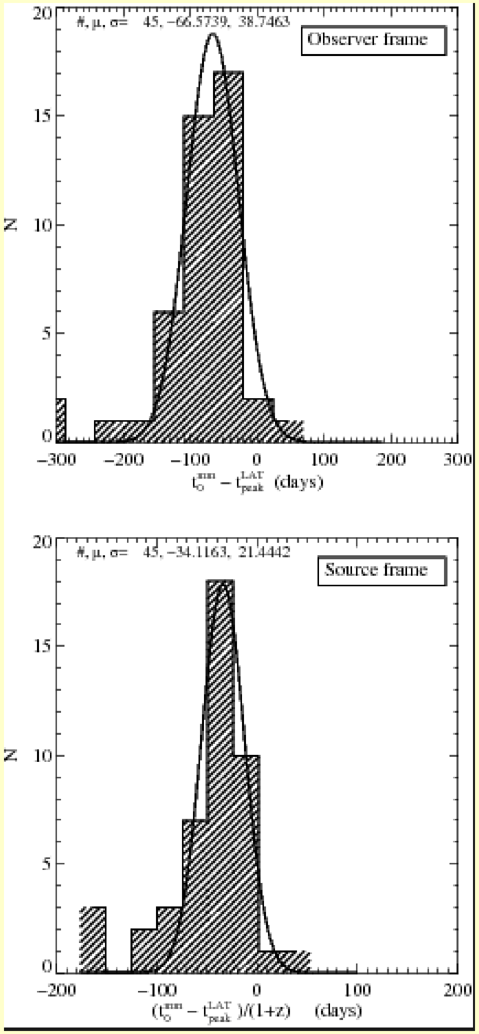
The γ-ray/radio distance decreases with frequencies:

- 9.8±3.0 pc at 11 cm
- 0.9±1.1 pc at 2 mm

Single-dish studies of large samples: Metsähovi

Cross-correlation between the radio and γ-ray light curves of a sample of 60 Fermi blazars observed at 37 GHz.

Leon-Tavares et al. 2011



Radio leads the γ-ray variability in FSRQ

Time delay between the onset of the mm flare and the peak of the γ-ray flare

- 70 days - observer frame
- 30 days - source frame

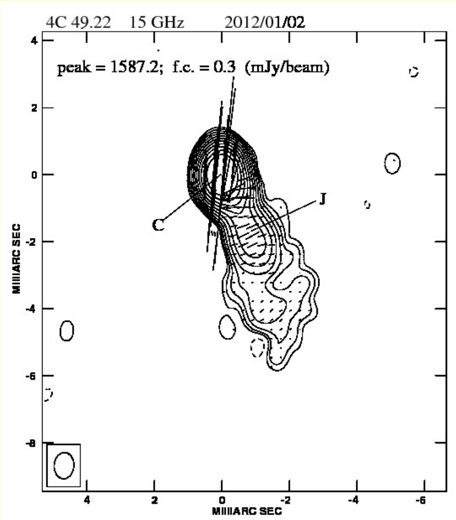
The γ-ray region should be located ~ 7.4±1.3 pc downstream along the jet:

No obvious radio/γ-ray correlation in BL LAC

How can we answer (or try to..)?

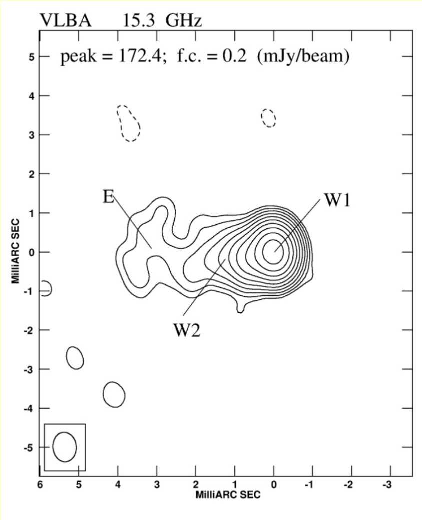
High-resolution + multifrequency + multiepoch + polarimetry

VLBI



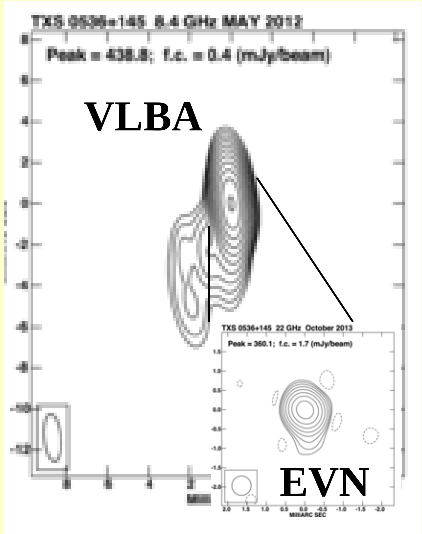
Cutini+14

FSRQ



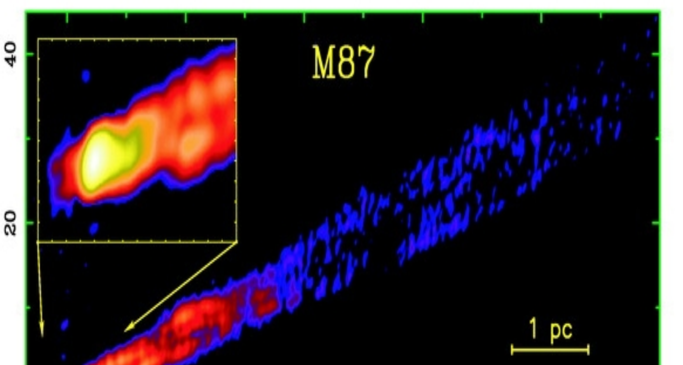
D'Ammando+13

NLSy1



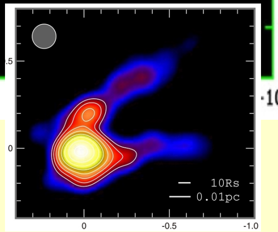
Orienti+14

High-z FSRQ



Kovalev+07

RG

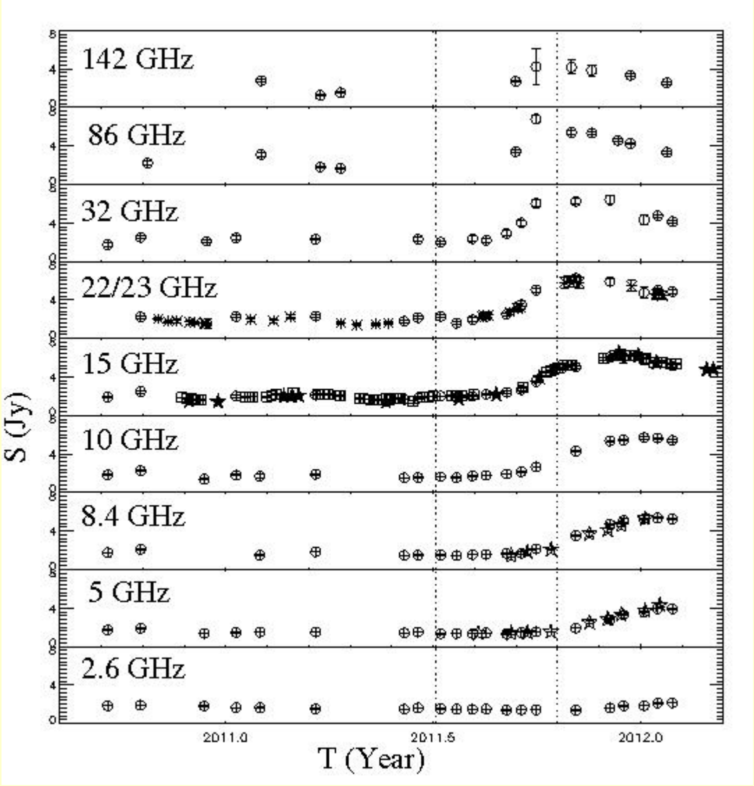


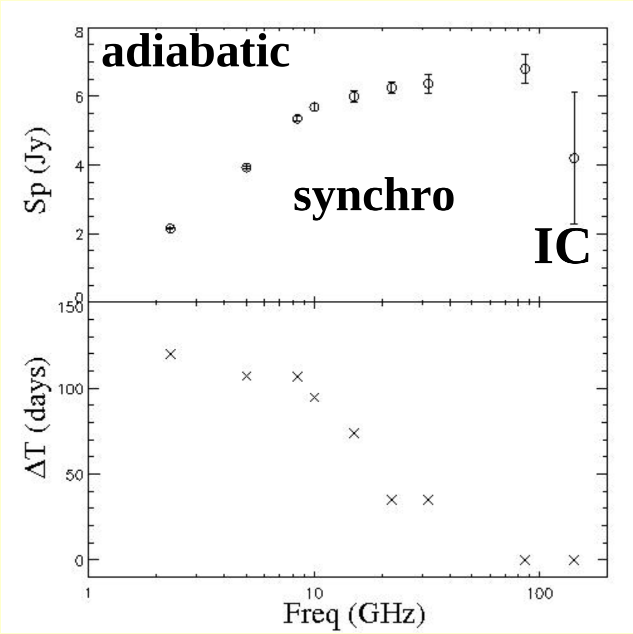
Hada+13

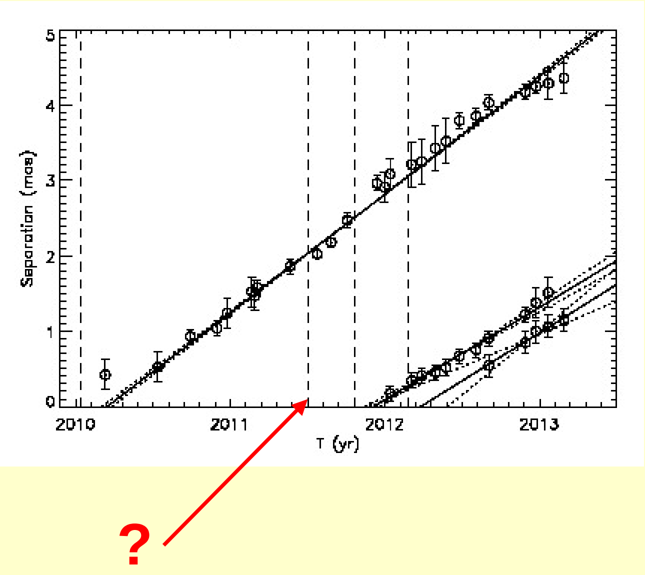
The trigger: shock-in-jet

Multifrequency: schock stages + VLBI: Detection of superluminal knots

Orienti+13 PKS 1510-089







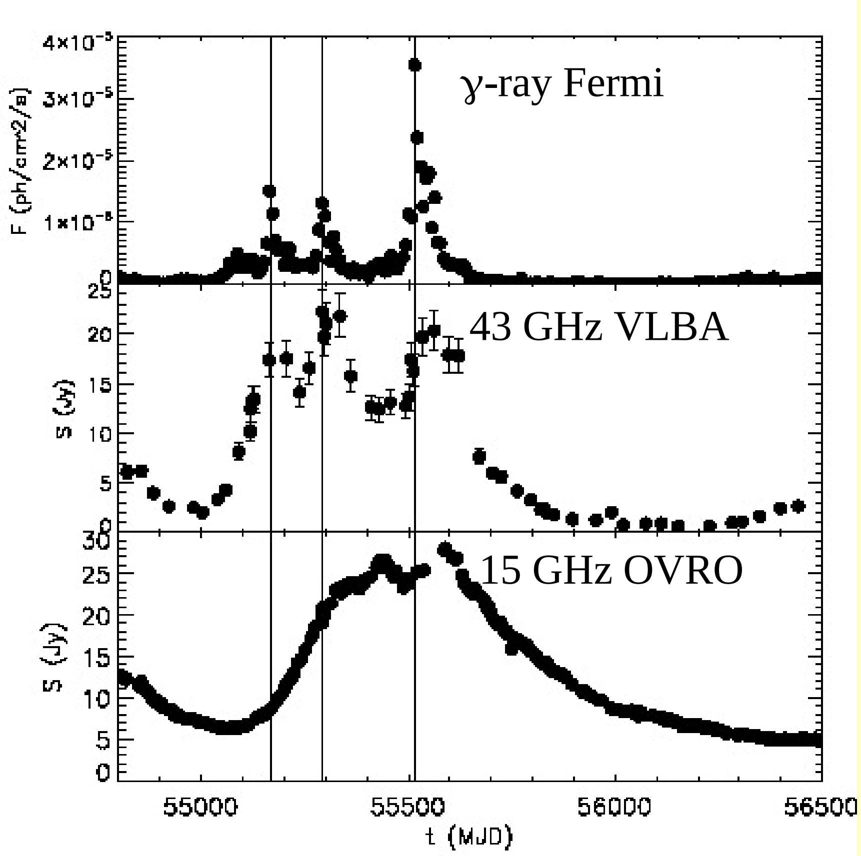
Delay due to opacity

Peak flux density depends on the shock stage:

- IC: increase
- Synchro: plateau
- Adiabatic: decrease

γ-ray flare close in time with the ejection of superluminal knots

The γ-ray region



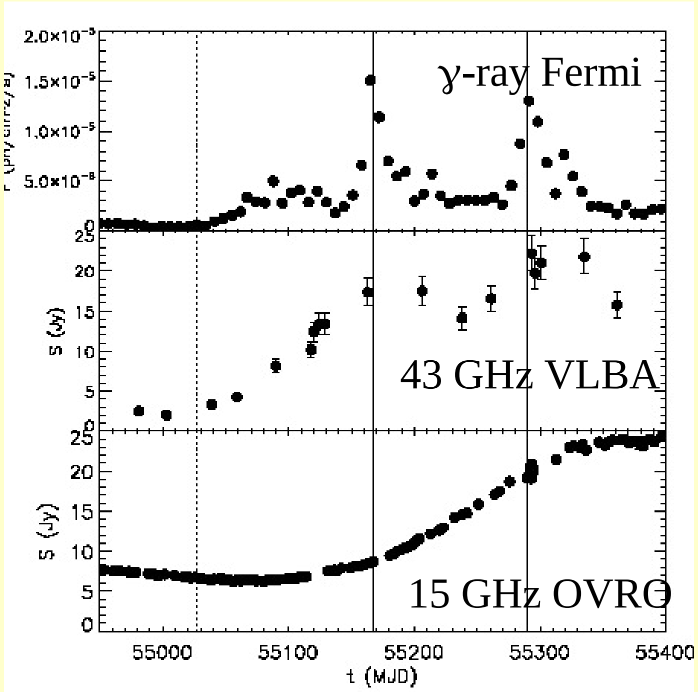
The rise of the mm flux density precedes the γ-ray flare

γ-ray produced pc away from the core

γ-ray region opaque to cm emission

The γ-ray region

3C 454.3



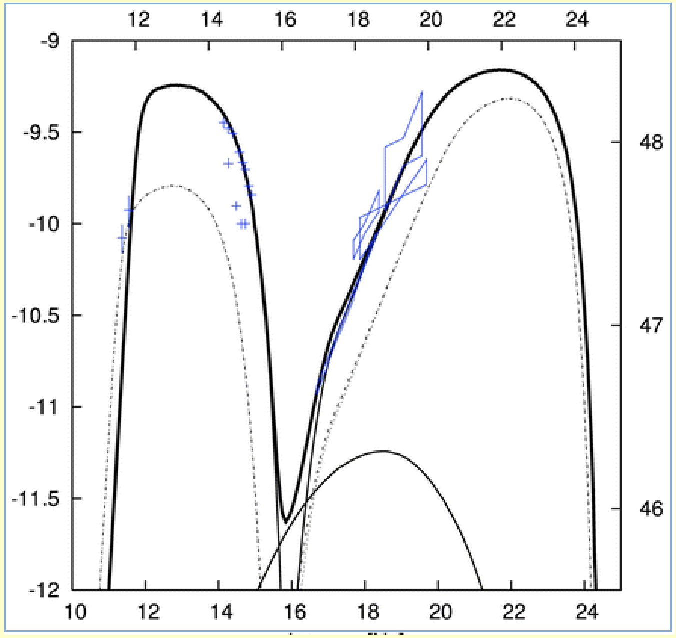
The increase of **γ-ray and mm emission** seems **simultaneous**.
At 15 GHz it is delayed by about 2 months.

↓

Co-spatiality of γ-ray and mm emission produced on pc scale

↓

- IR photons from the dusty torus
- Synchro photons from different e⁻ population



Sikora+08

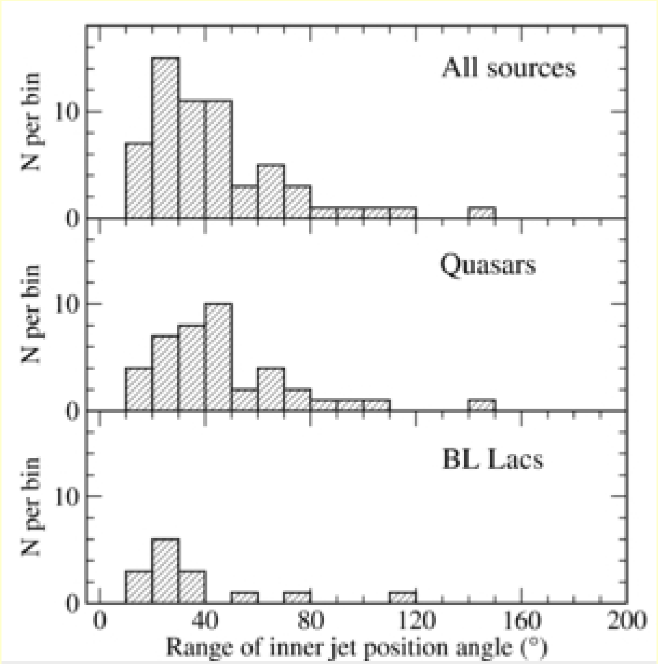
Reconfinement shock in toroidal magnetic field + IR photons

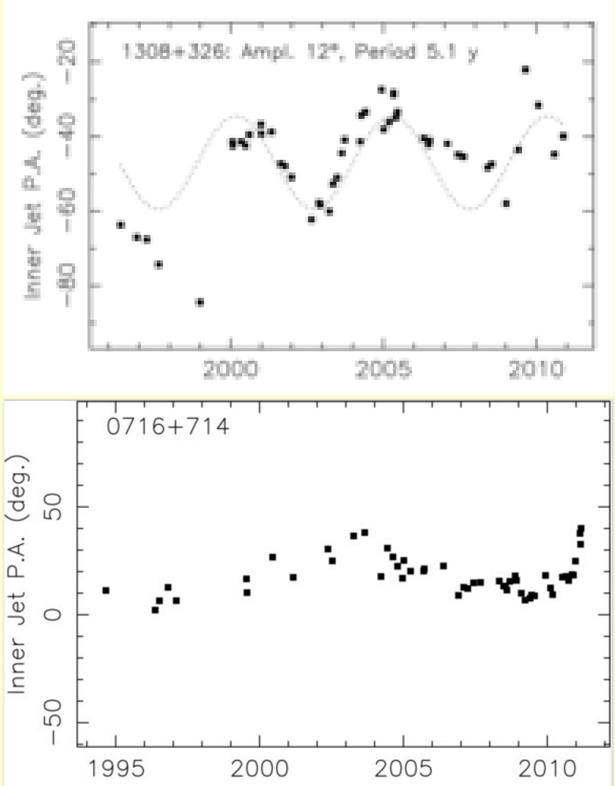
The γ-ray region

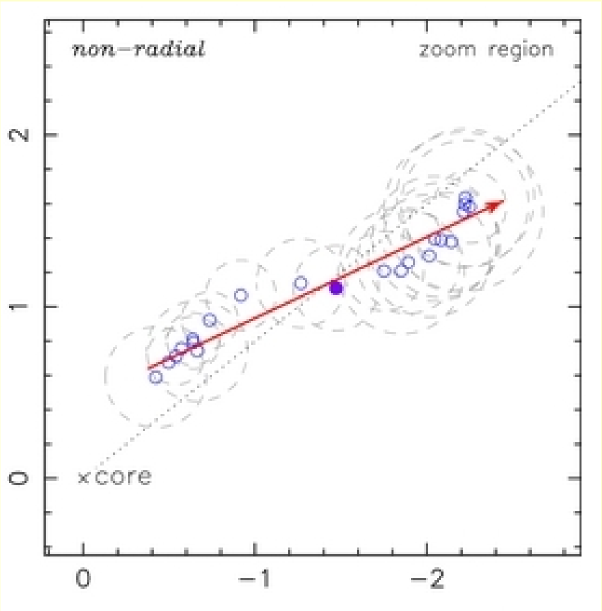
Pc-scale distance → Causality argument < 10^{16} cm

Large changes in the inner jet position angle → Jet knot occupies only a fraction of the jet cross-section

Lister+13

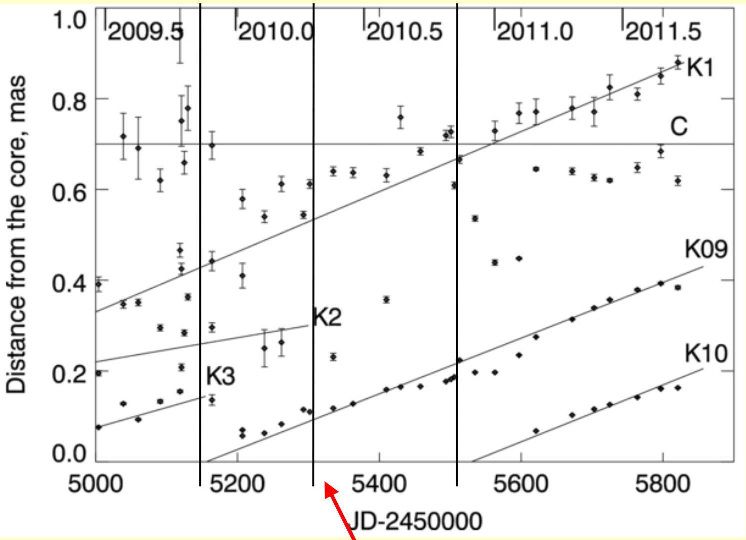


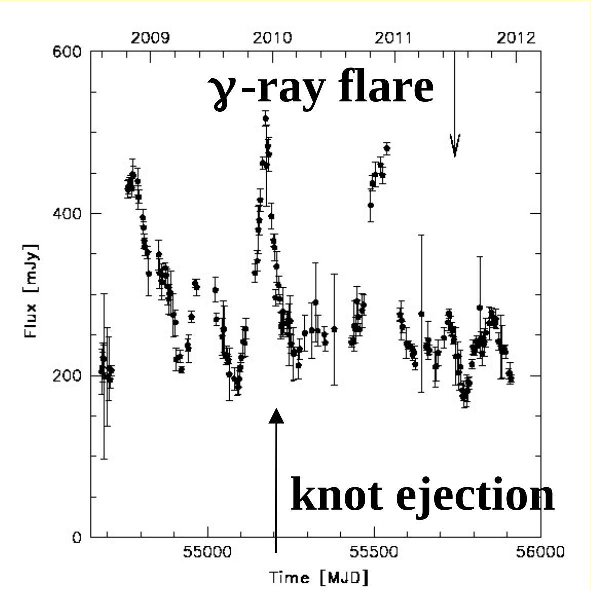




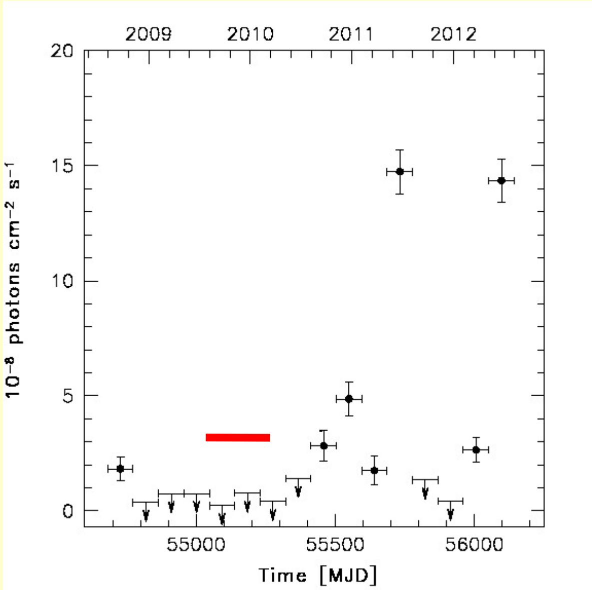
The γ-ray region

Jorstad+13





D'Ammando+13



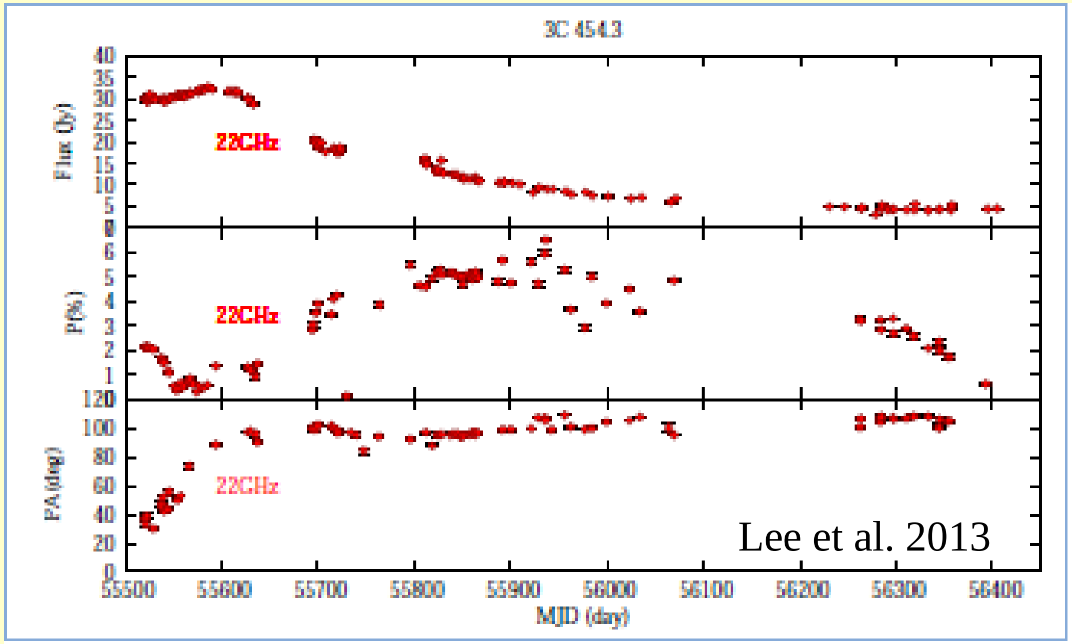
What about γ-ray flares without knot ejection and radio variability? → γ-ray region at sub-pc scales opaque to radio?

e.g. BLLac Marscher+08; 3C279, Abdo+10

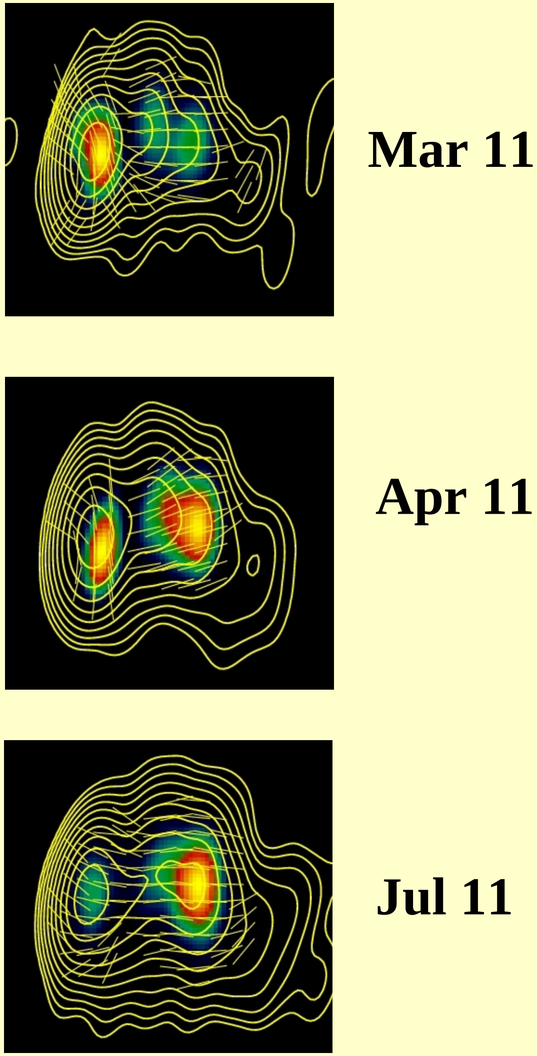
What about radio flares and knot ejection without γ-ray variability? → No seed photons? Sensitivity limitaiton? ..... ?

e.g. NLSy1 0846+513

Magnetic field



Jorstad et al. 2013



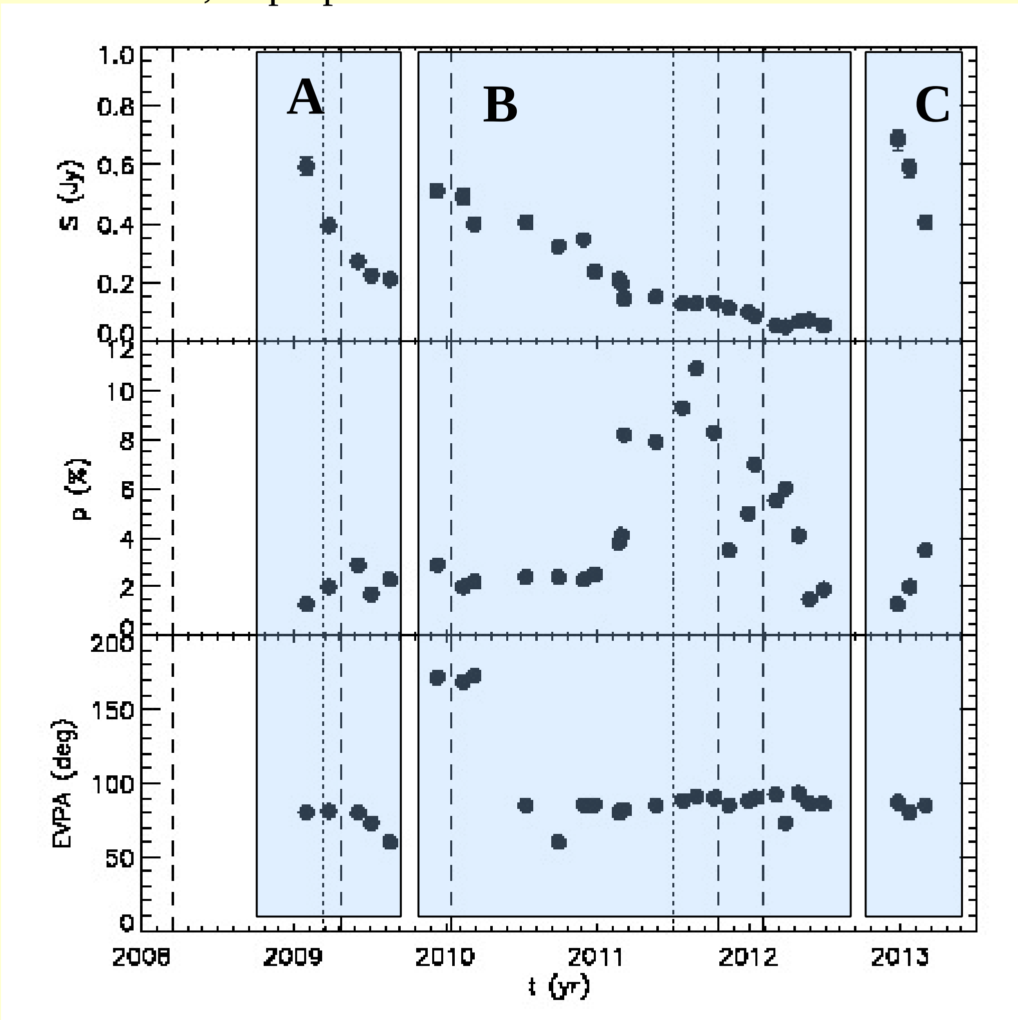
- Single dish: EVPA rotates of about 90°

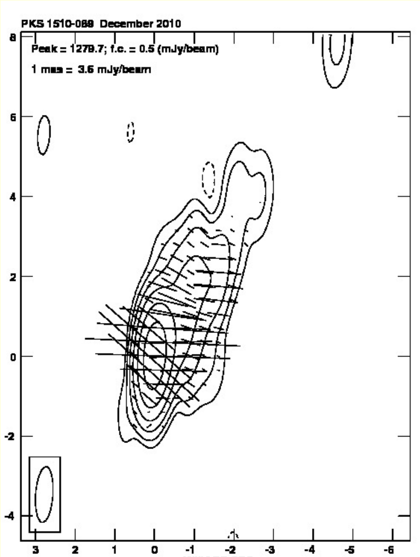
- VLBI: Flux and polarization dominated by the knot ejected in Dec 2009.

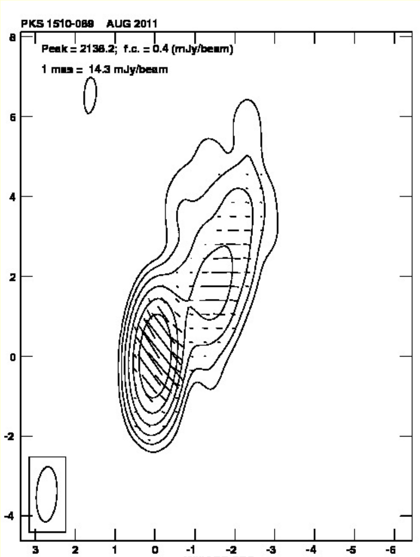
Knot EVPA parallel to the jet axis, as expected for internal shock or reconfinement shock in a **toroidal magnetic field** (e.g. Sikora+08)

Magnetic field

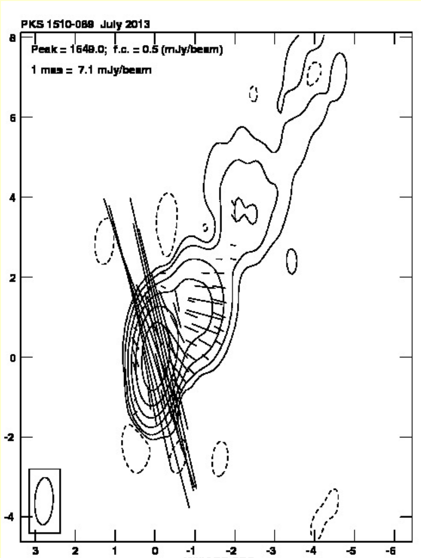
Orienti+, in prep







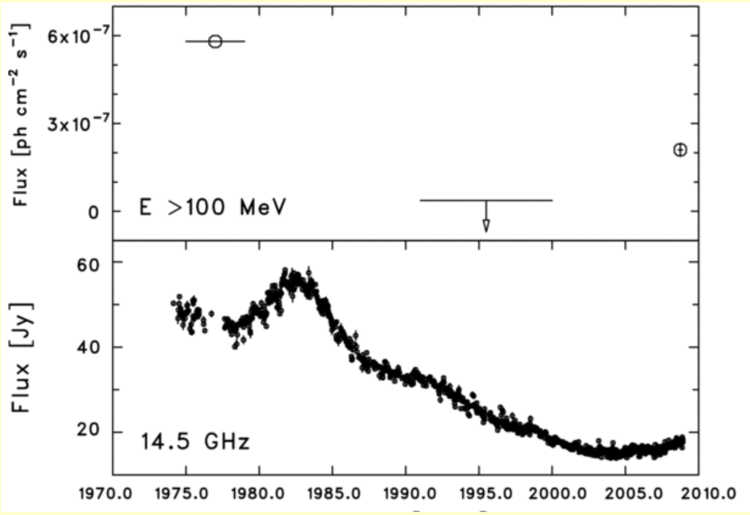
EVPA of the knots is roughly ⊥ to the jet axis:

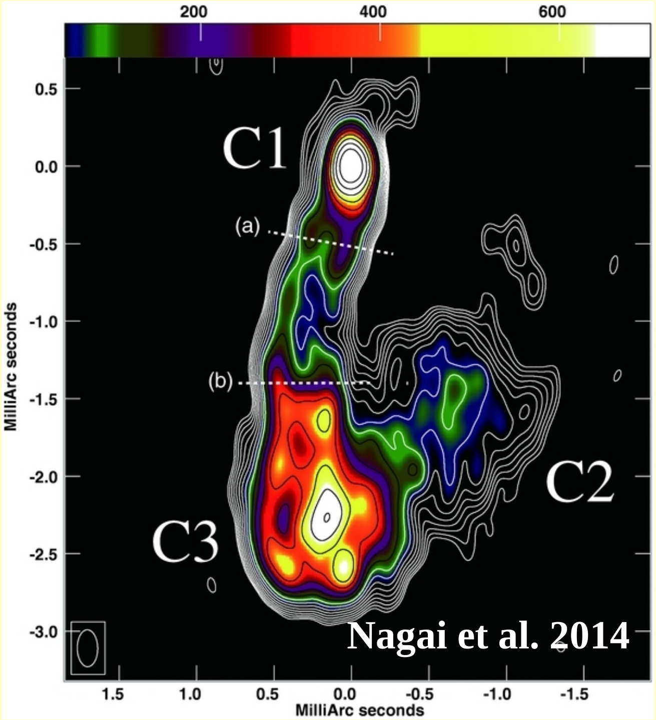


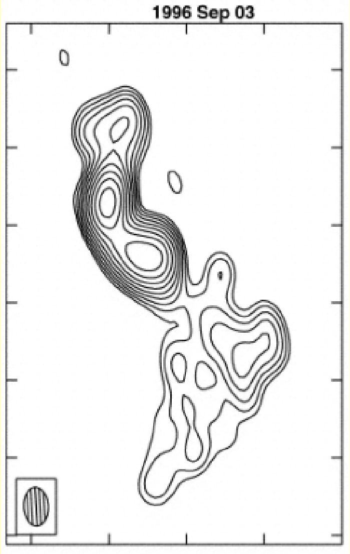
Reconfinement shock in a chaotic magnetic field?

As the knot emerges from the core its EVPA aligned to ~ 80°

The trigger: two zone model – 3C 84







Dhawan et al. 1996

Detected at VHE by MAGIC

No radio/γ-ray correlation

No evidence of propagating shock

Limb-brightened when γ-ray-loud

Edge-brightened when γ-ray-quiet

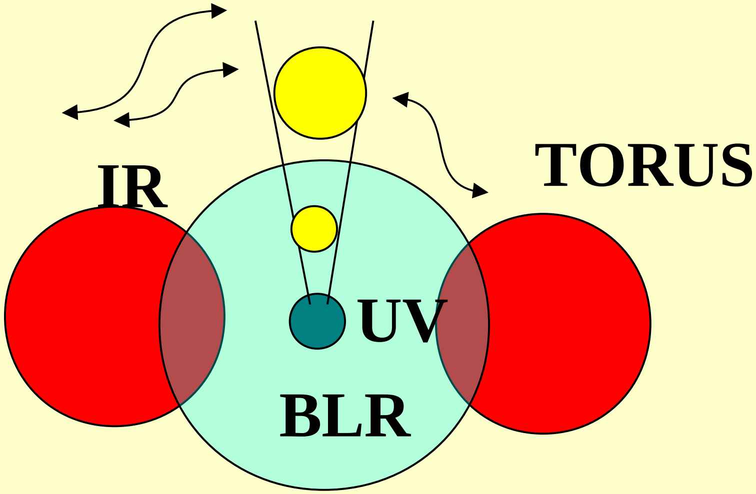
→

SED NOT consistent with one-zone region, e.g. shock

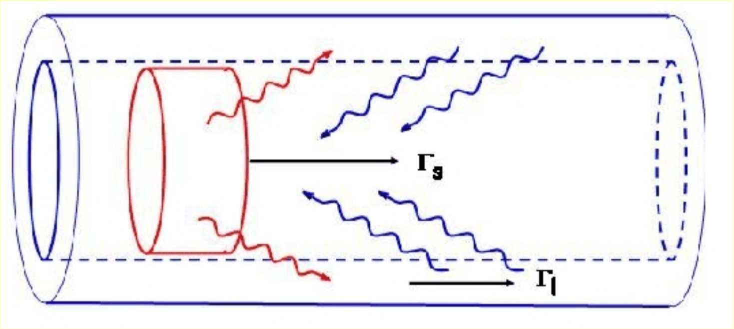
SED consistent with a spine-layer model

Tavecchio & Ghisellini 2014

Open questions



Ghisellini+08



WHERE?

- Sub-pc scale
- pc scale
- > 10 parsec
- Two-zone model

WHO?

Magnetic field reconnection

Internal shock

Reconfinement shock

Standing conical shock

Velocity gradient

HOW?

UV, optical from BLR

IR from torus

Synchro from different e^- population

Synchro from different e^- population