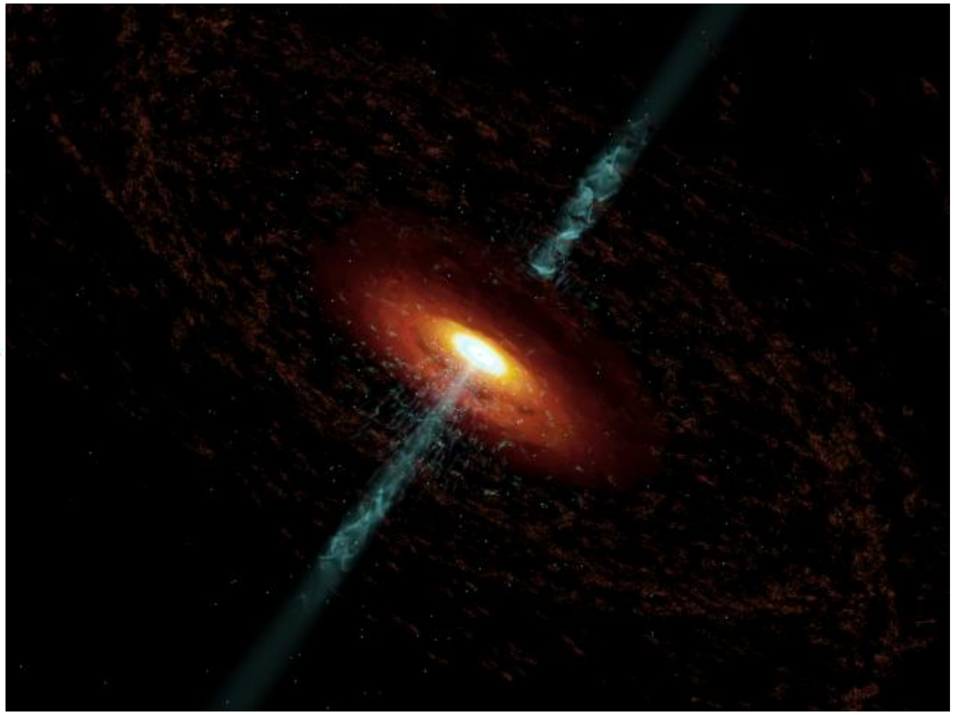

Relation between Events in the mm-wave Core and γ-ray Outbursts in Blazar Jets

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Telescopes: VLBA, GMVA, EVLA, Fermi, RXTE, Swift, Herschel, IRAM, UMRAO, Lowell Obs., Crimean Astrophys. Obs., St. Petersburg U., Pulkovo Obs., Abastumani Obs., Calar Alto Obs., Steward Obs., + many others

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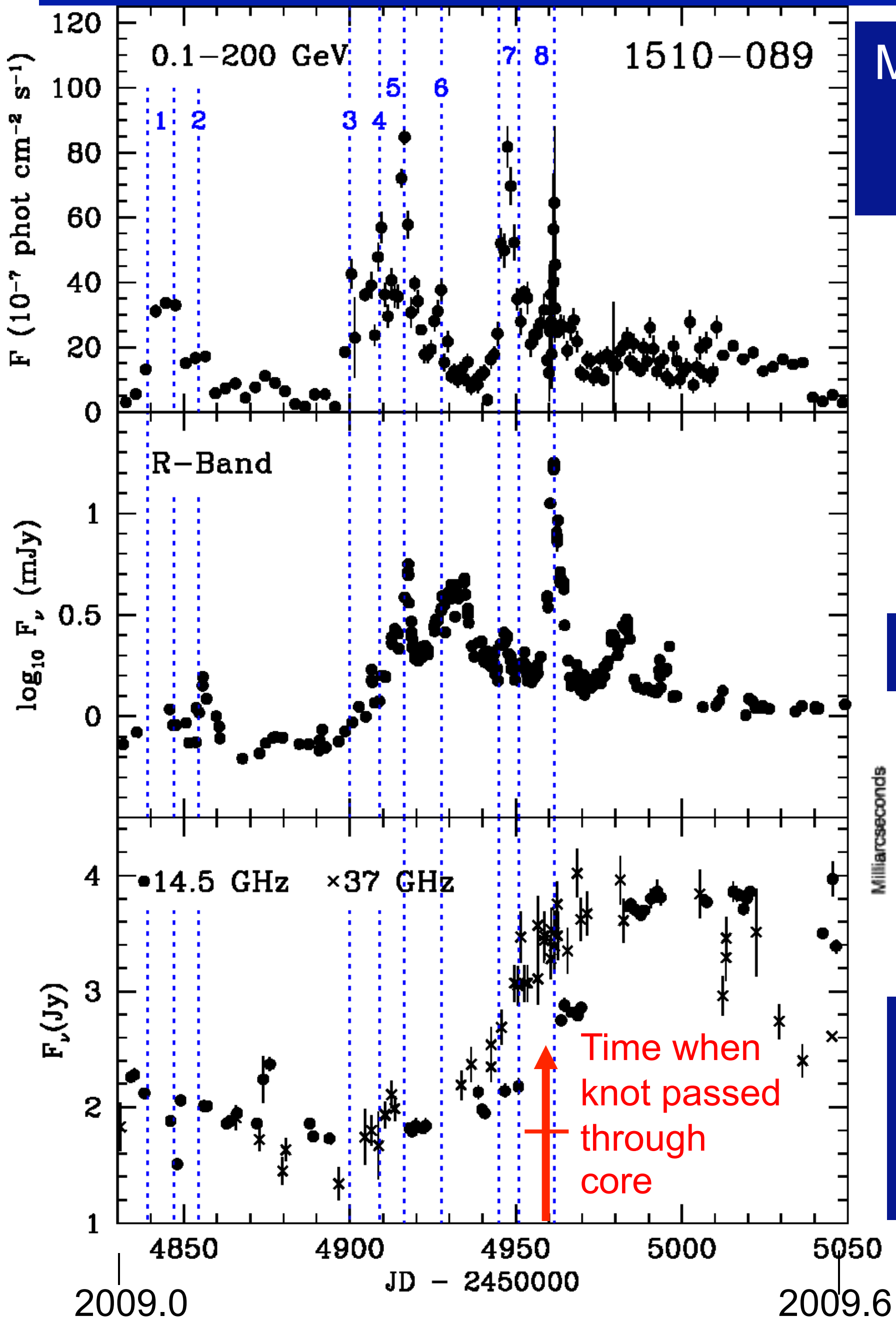
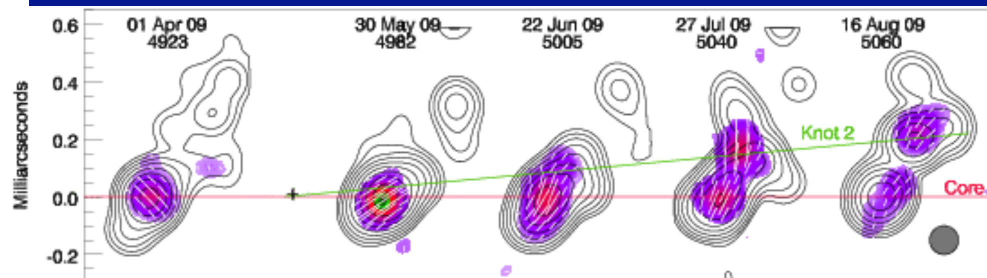
Quasar PKS 1510-089 (z=0.361) in 2009



Multiple γ-ray & optical flares before disturbance passes through the mm-wave core to emerge as a superluminal knot

VLBA images at 43 GHz



Color: linearly polarized intenisty Contours: total intensity

Bright superluminal knot passed "core" at time of extreme optical/γ-ray flare

Apparent speed = 21c

Marscher et al. (2010, Astrophysical Journal Letters, 710, L126)

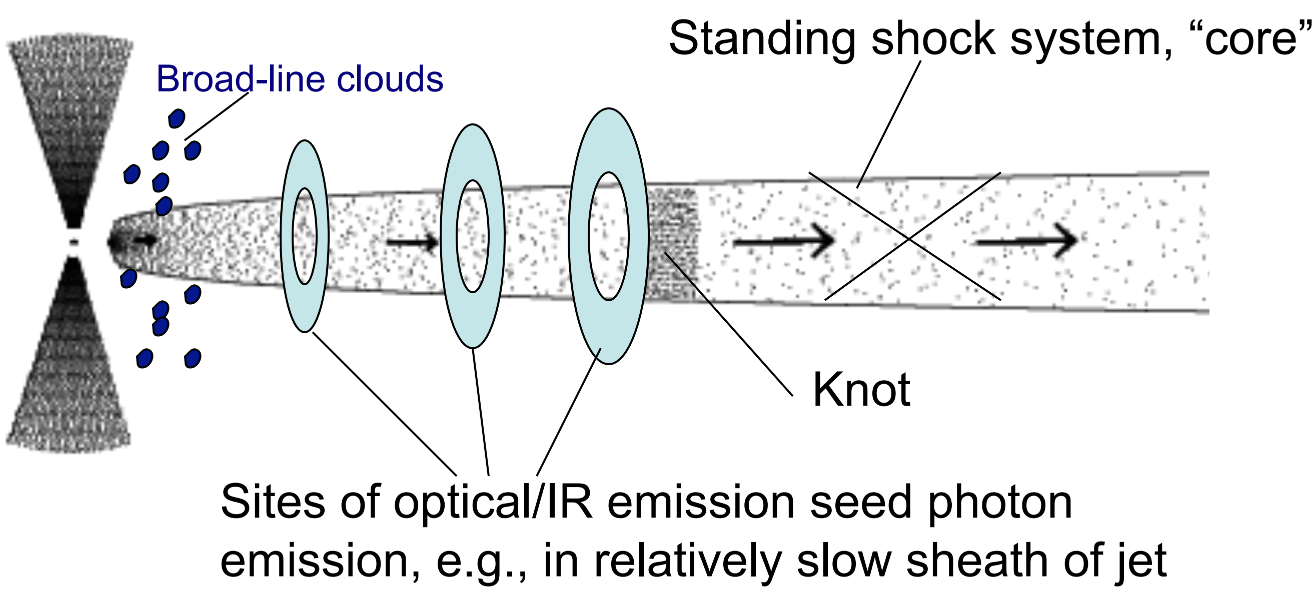
Sites of γ-ray Flares in PKS 1510-089

Interpretation:

All flares in early 2009 caused by a single superluminal knot moving down jet

Sharp flares occur as knot passes regions of high photon density or standing shocks that compress the flow or energize high-E electrons

If so, pattern of flares before knot appears should repeat

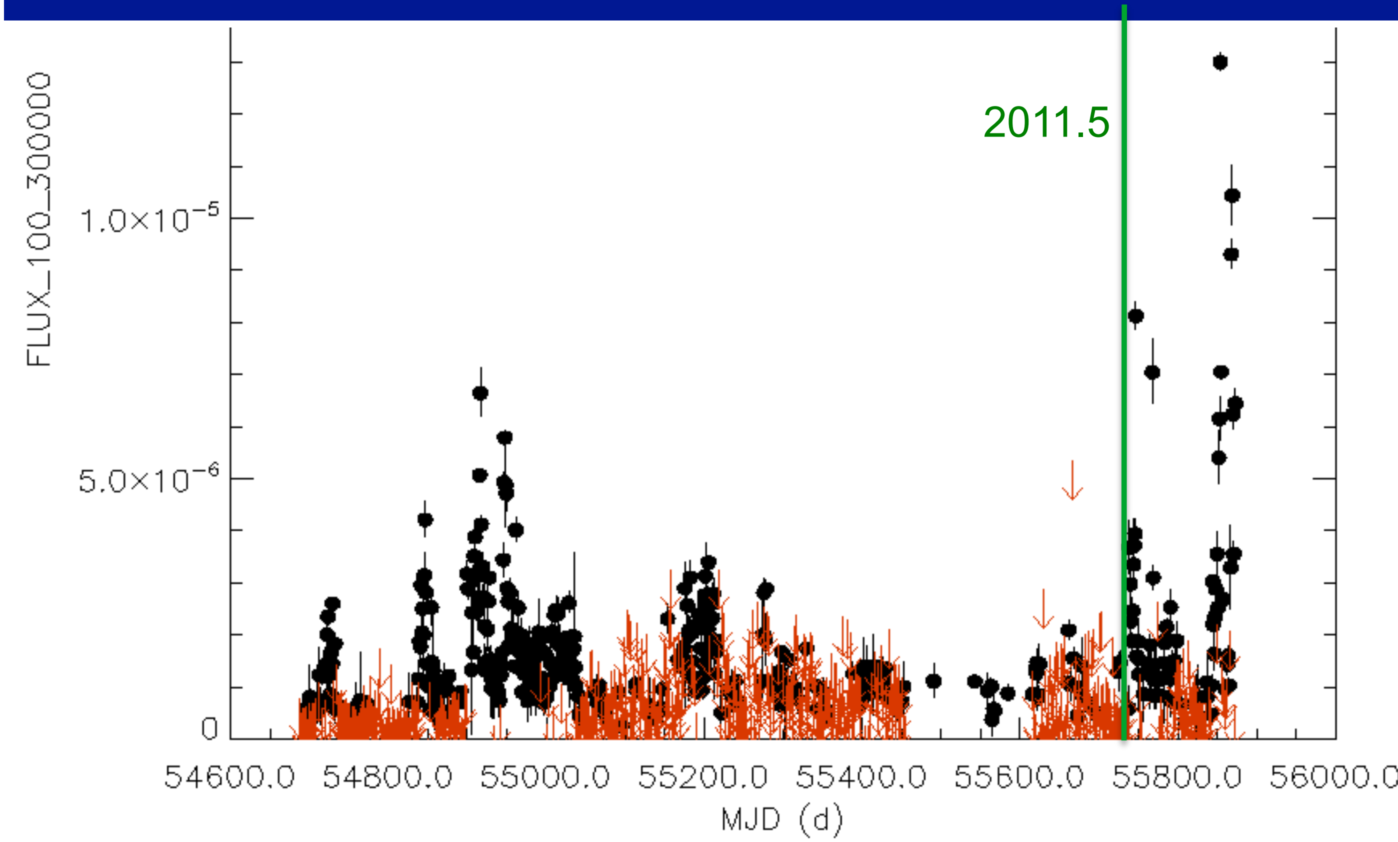


PKS 1510-089 in 2011

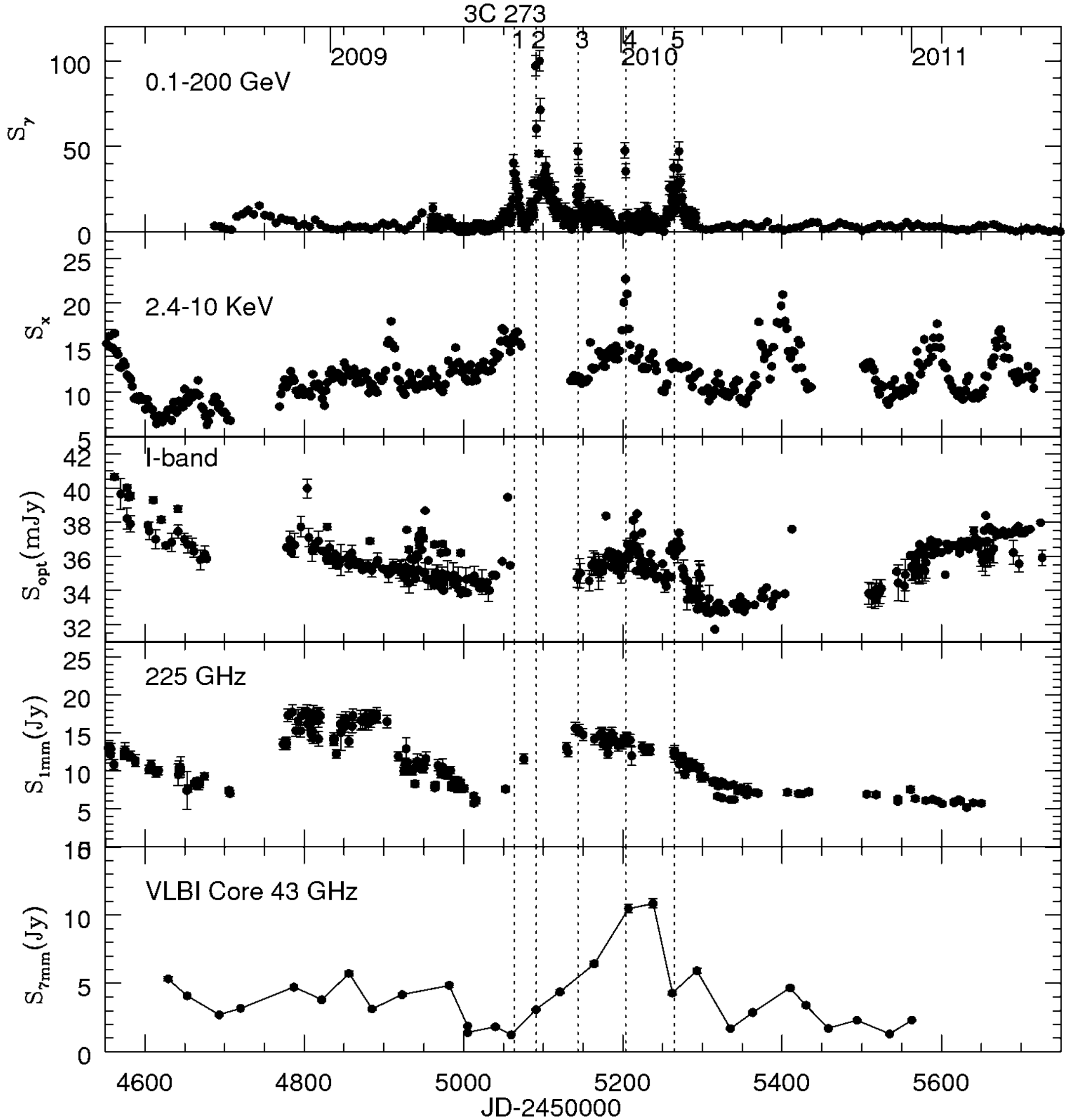
In summer/autumn 2011, no significant event in 7 mm VLBA images until 16 October when core went from 1-2 Jy to 5.5 Jy

→γ-ray & optical flares started before knot passed through core, as in 2009

→ Expect to see very bright new knot later in 2011/early in 2012



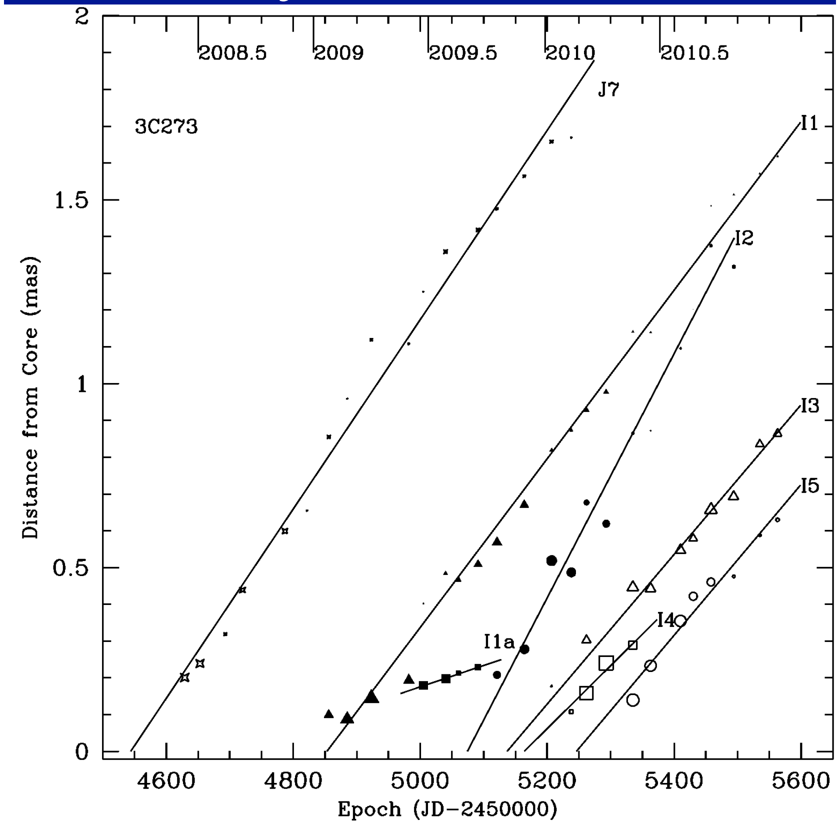
3C 273



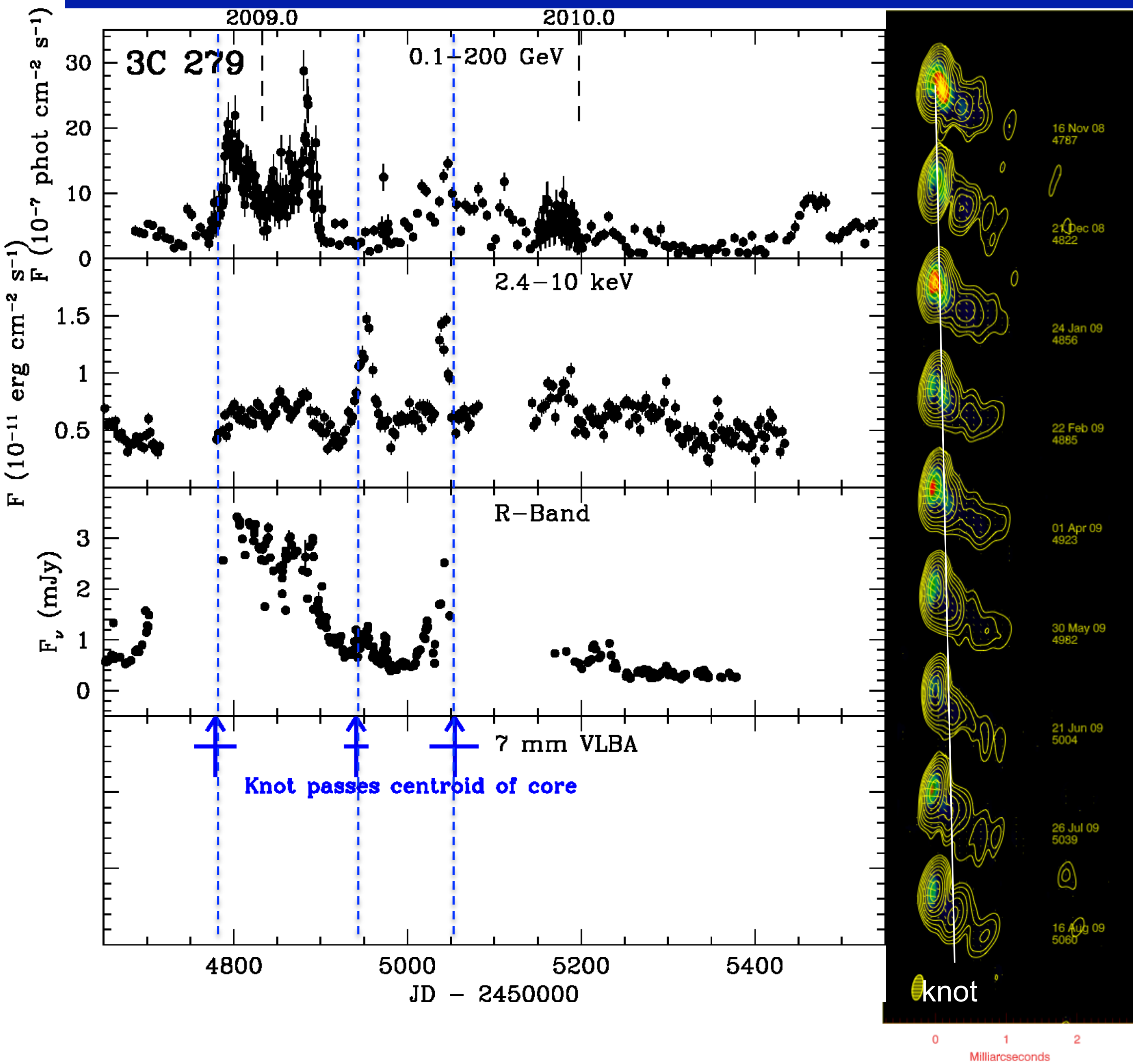
Jet bright at 7 mm throughout γ-ray outburst

-γ-ray peaks associated with ejections of knots

- Dormant at mm & γ-ray after early 2010



3C 279

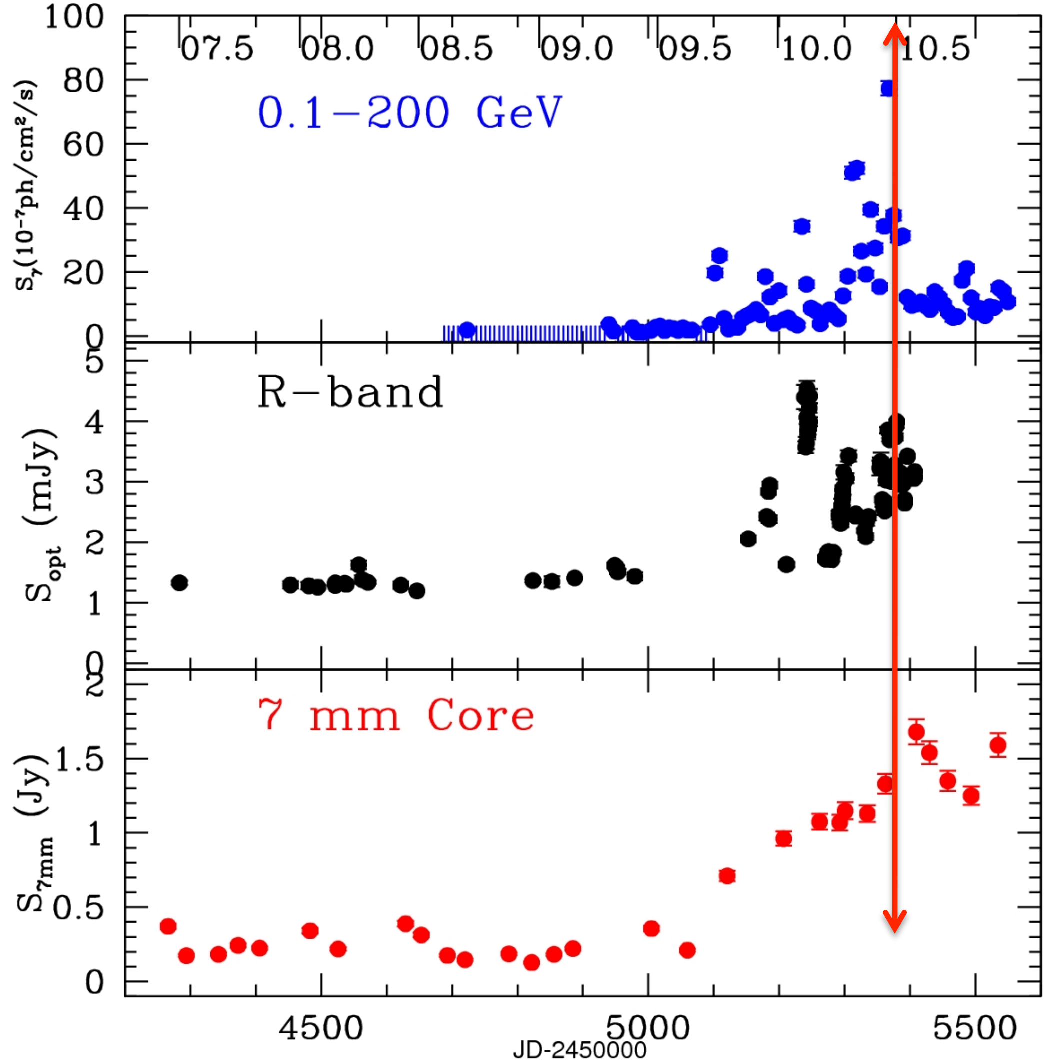


1. High-energy outbursts occur after or same time as new superluminal knot appears

2. Major mm & γ-ray flare in core Sep 2010 until at least July 2011

3. Note optical/γ-ray general correlation but poor detailed correspondence on short time-scales.

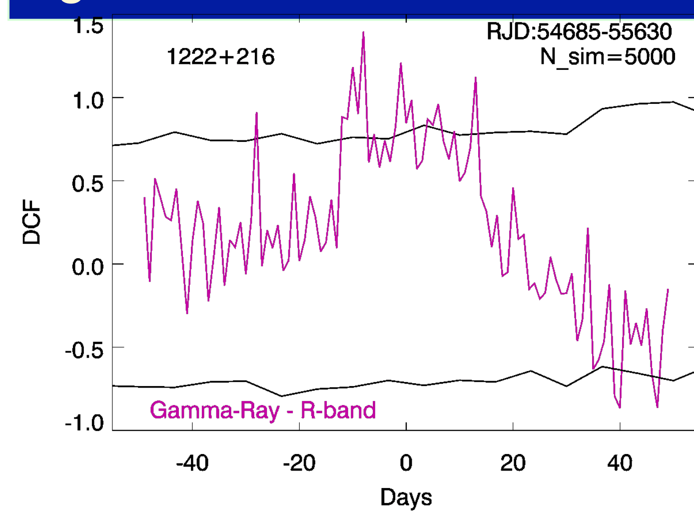
Strong Outburst in 4C21.35 (1222+216) in 2010



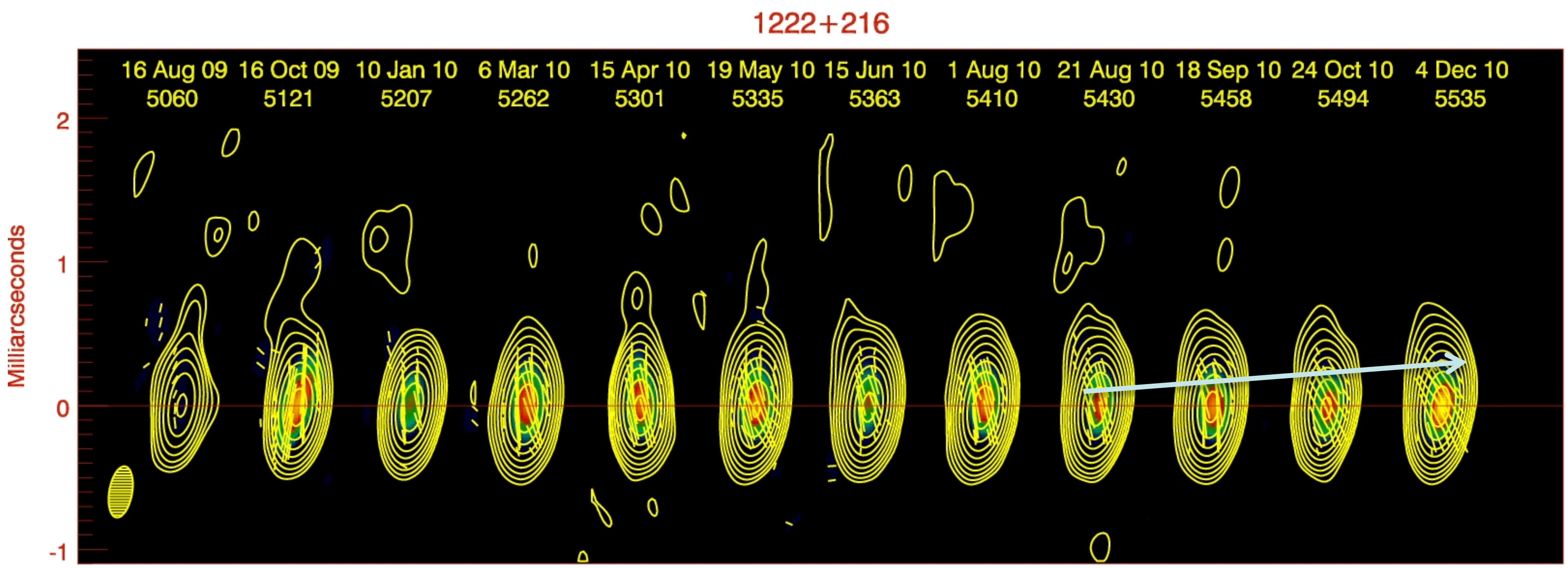
Outburst started at mm wavelengths

Detection at 0.4 TeV (Aleksic et al. 2011) ➔ flare must occur on pc scales to avoid high pair-production opacity

Good optical-gamma correlation but not detailed agreement



Parsec Scale Jet of 1222+216 (4C21.35, z=0.435)

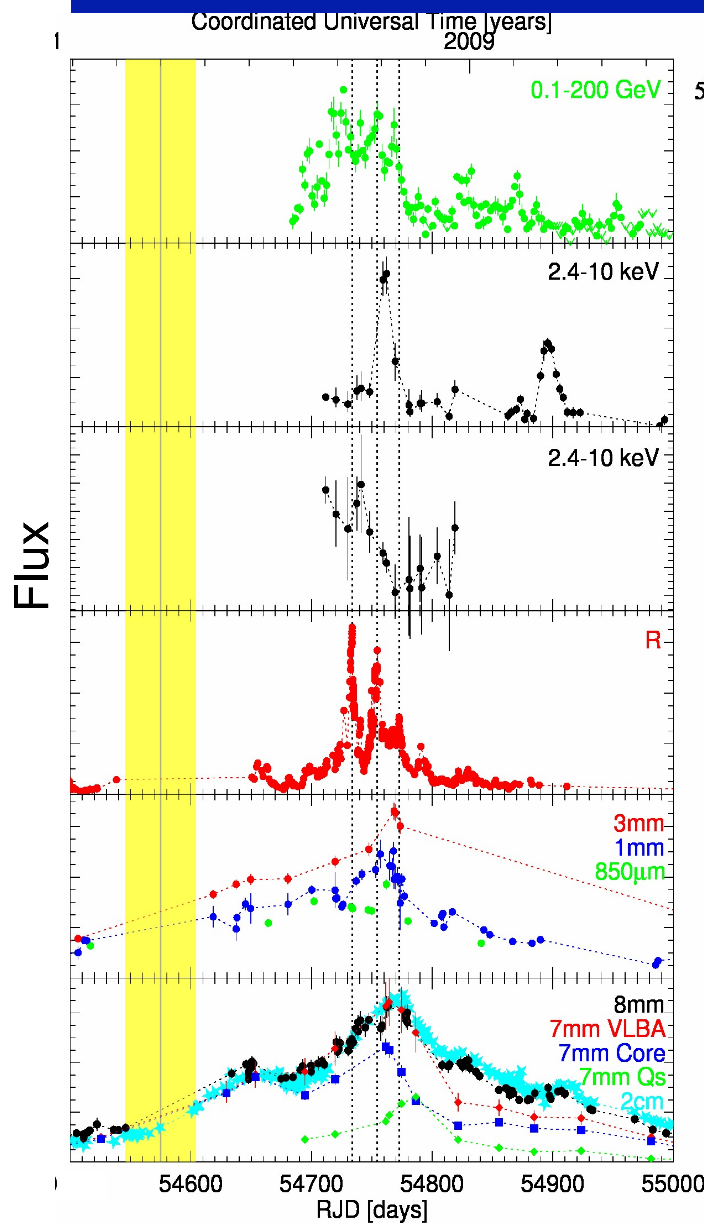


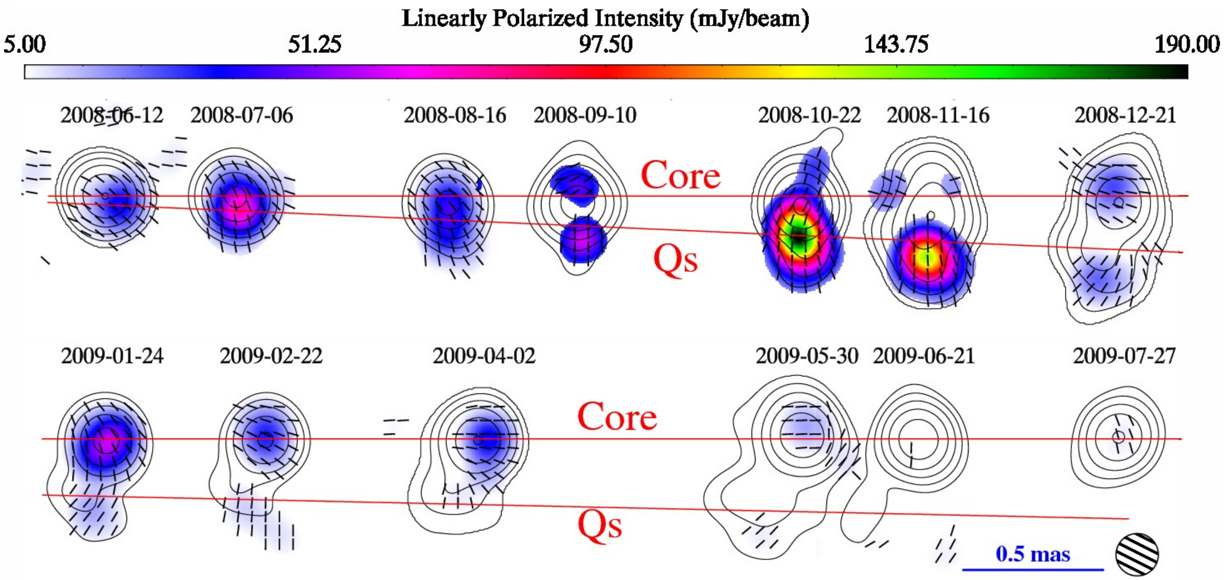
Knot:

β_{app}= 7.6±0.4c

Time of passage through the core between 19 May and 15 June 2010

BL Lac Object AO 0235+164 (Agudo et al. 2011 ApJL)



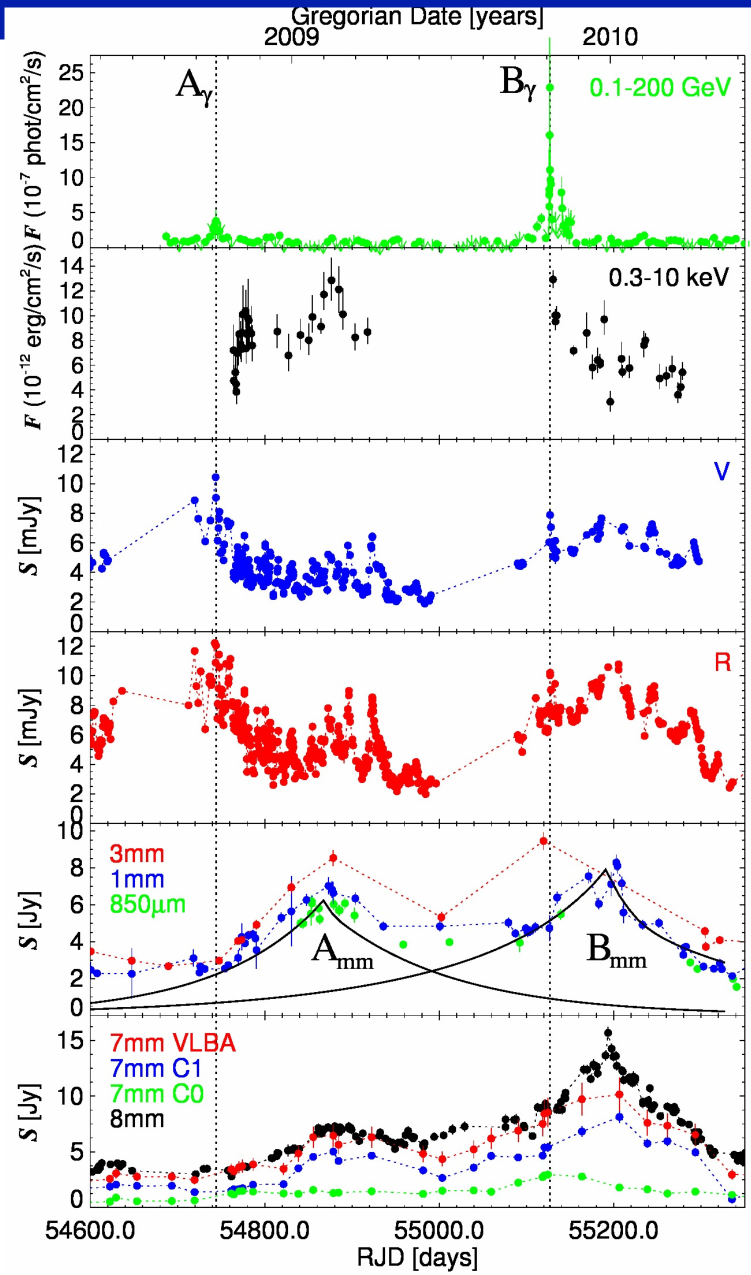


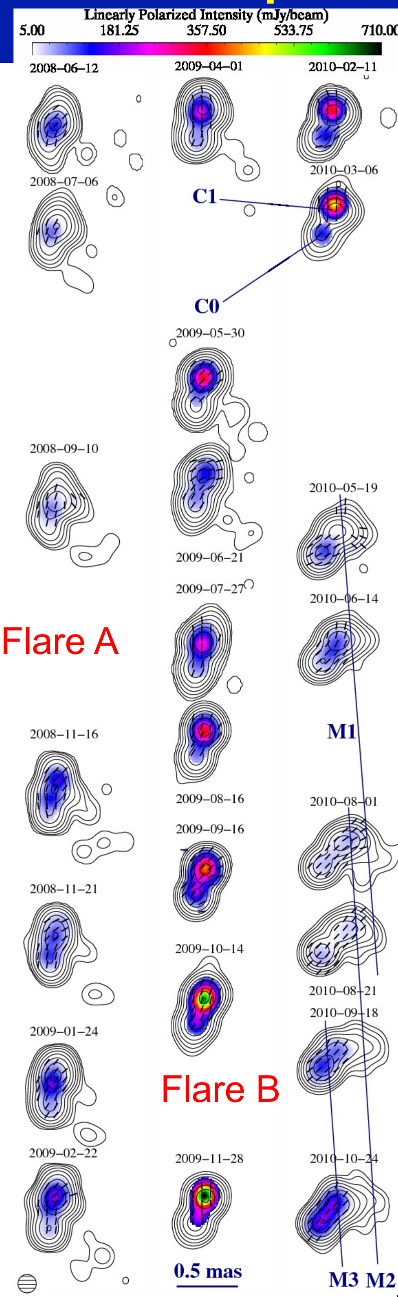
Multi-waveband outburst started when knot passed through core

Peaks in flux occurred months later when knot became highly polarized and then changed direction

Direction of jet ~ 180° from previous value

OJ287 (Agudo et al. 2011, ApJL, 726, L13)





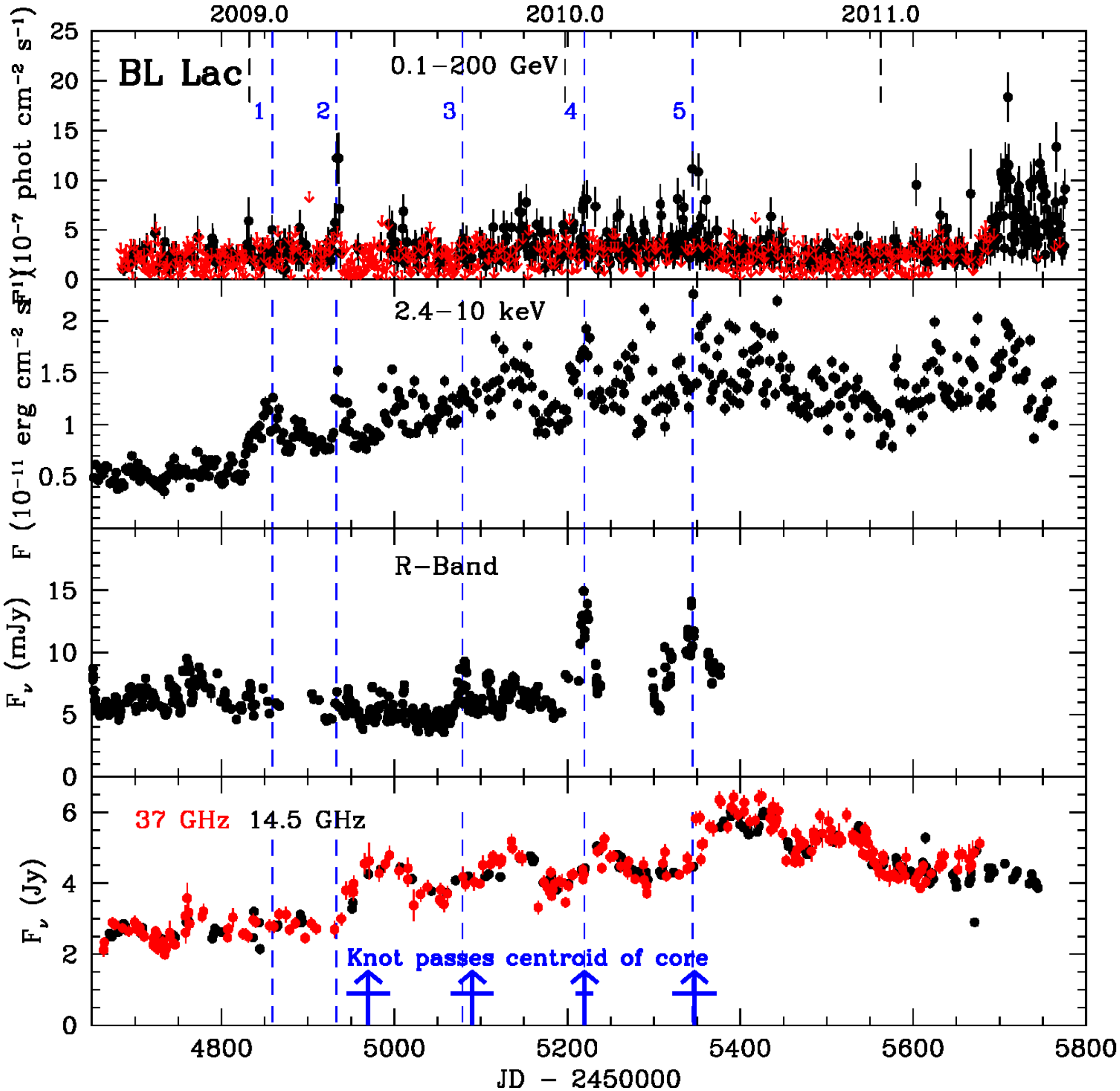
Change in jet direction starting ~ 2005

Core is the more southern compact feature, C0

As in other blazars, change in jet direction sets up a bright stationary feature (C1) downstream of core

Flare B occurs as superluminal knot passes through C1, which is probably a quasi-stationary shock. The same may be true for Flare A based on the increase in polarization of C1

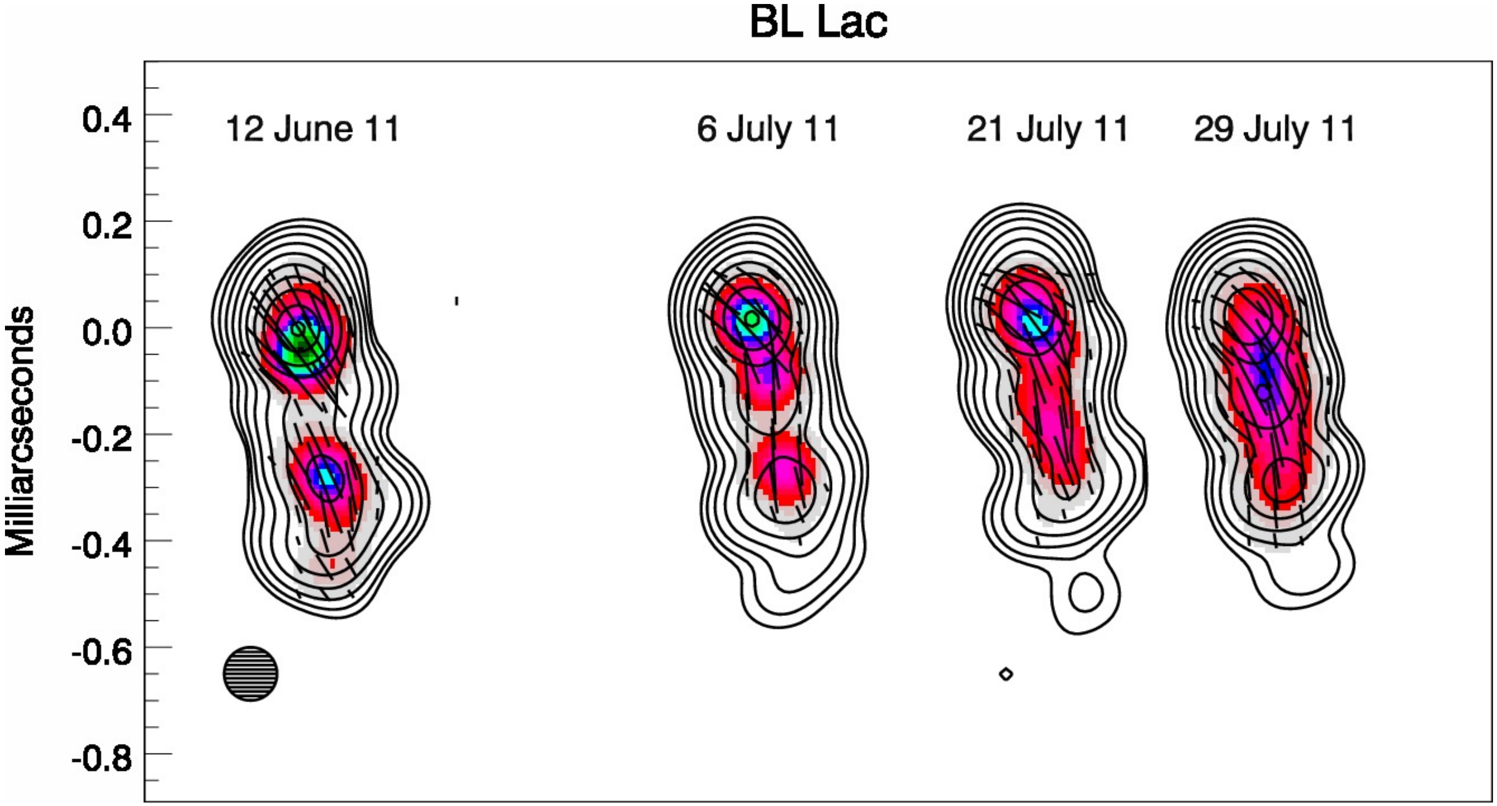
BL Lac



Most prominent flares associated with knot passing through 43 GHz core, either at ~ same time or 2-3 weeks later

→Similar to flares in late 2005

BL Lac TeV Flare/Jet Activity in Summer 2011



In collaboration with M. Beilicke & W.C. Walker

Fermi LAT: γ-ray outburst from Apr to Sep, peak in June
VERITAS: TeV flare on 28 June

→ New, polarized knot passed through core near TeV flare

Behavior of Jet during γ-ray Flares in 34 Blazars

Ejection of bright superluminal knot:

*** Knot passes core near peak of flare within error bars: 27 events in 14 sources

- Flare prior to knot passing through core: 5 in 4 sources [3 included in ***]
- Flare after knot passes through core: 7 in 6 sources [all different from ***]

-[4 of these (3 sources) are associated with polarization increase in knot]

Contemporaneous outburst in core region with no bright knot (yet) confirmed: 12 in 11 sources (6 included in ***)

Gamma-ray flare with no jet event observed: 5 in 4 sources (2 included in ***)

Superluminal ejection or major core flare without observed gamma-ray flare: 8 in 7 sources (2 included in ***)

Quiescent jet + quiescent in gamma-rays: 5 sources

→ Of 64 γ-ray flares, 43 are simultaneous within errors with a new superluminal knot or a major outburst in the core at 7 mm

→ Even accounting for chance coincidences, > 50% of γ-ray flares occur in the "core" seen in 7 mm images

Implications

- **Many γ-ray flares in blazars occur in superluminal knots that move down the jet & are seen in VLBA images**

⇒ Usually in 43 GHz core (sometimes upstream or downstream)

⇒ Observed intra-day γ-ray/optical variability can occur in mm-wave regions

⇒ Broad-line region is not major source of seed photons for most flares

- **General correlation of γ-ray/optical variations but differences in details implies that turbulence is important**

- **More rapid γ-ray than optical variations in many flares implies that seed photon field varies rapidly (not large as dust torus)**

- **Some γ-ray flares seem unrelated to events in parsec-scale jet**

→ These can occur upstream in broad-line region

Explaining Rapid Variability Parsecs from the Black Hole

Distance from central engine does not necessarily imply a large size of the emission region!

The highest-Γ jets are very narrow, < 1° (Jorstad et al. 2005), so at 10 pc from the central engine, jet < 6 lt-months across

Doppler factors can be very high, >50 (Jorstad et al. 2005; MOJAVE)

Volume filling factor of γ-ray & optical emission << 1 if very high-energy electrons are difficult to accelerate or there are fine-scale Doppler factor variations (as in turbulent jet scenarios of Marscher & Jorstad 2010; Narayan & Piran 2011)

Numerical model is under development