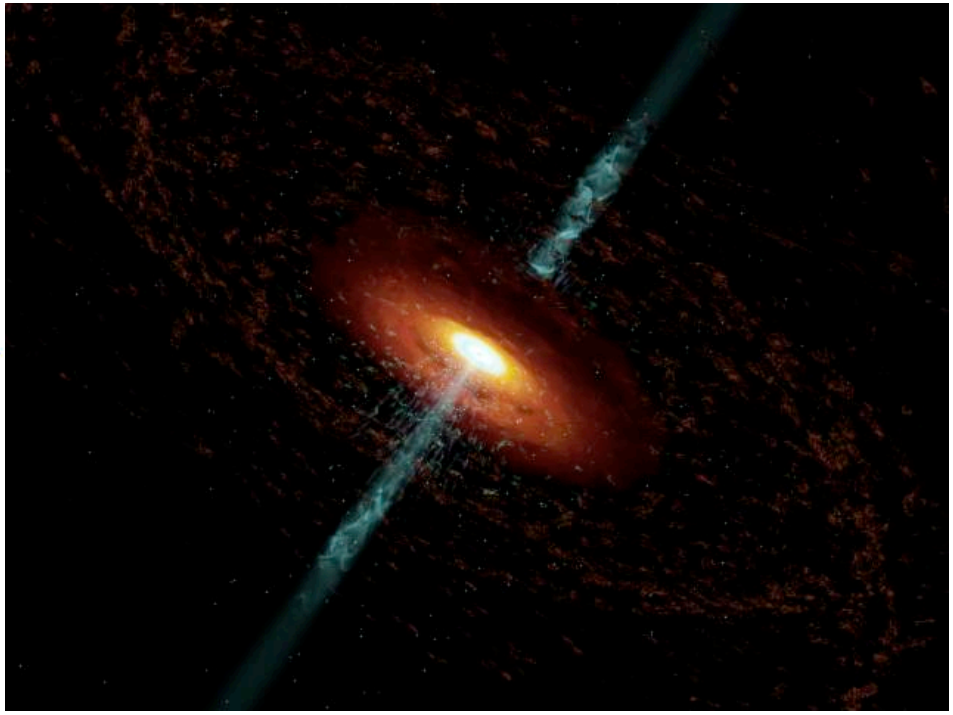


Probing the Inner Jet of the Quasar PKS 1510-089 with Multi-waveband Monitoring

Alan Marscher

Boston University

Research Web Page: www.bu.edu/blazars

Main Collaborators in the Study

Svetlana Jorstad (Boston University)

Valery Larionov (St. Petersburg State U., Russia)

Ivan Agudo (IAA, Spain)

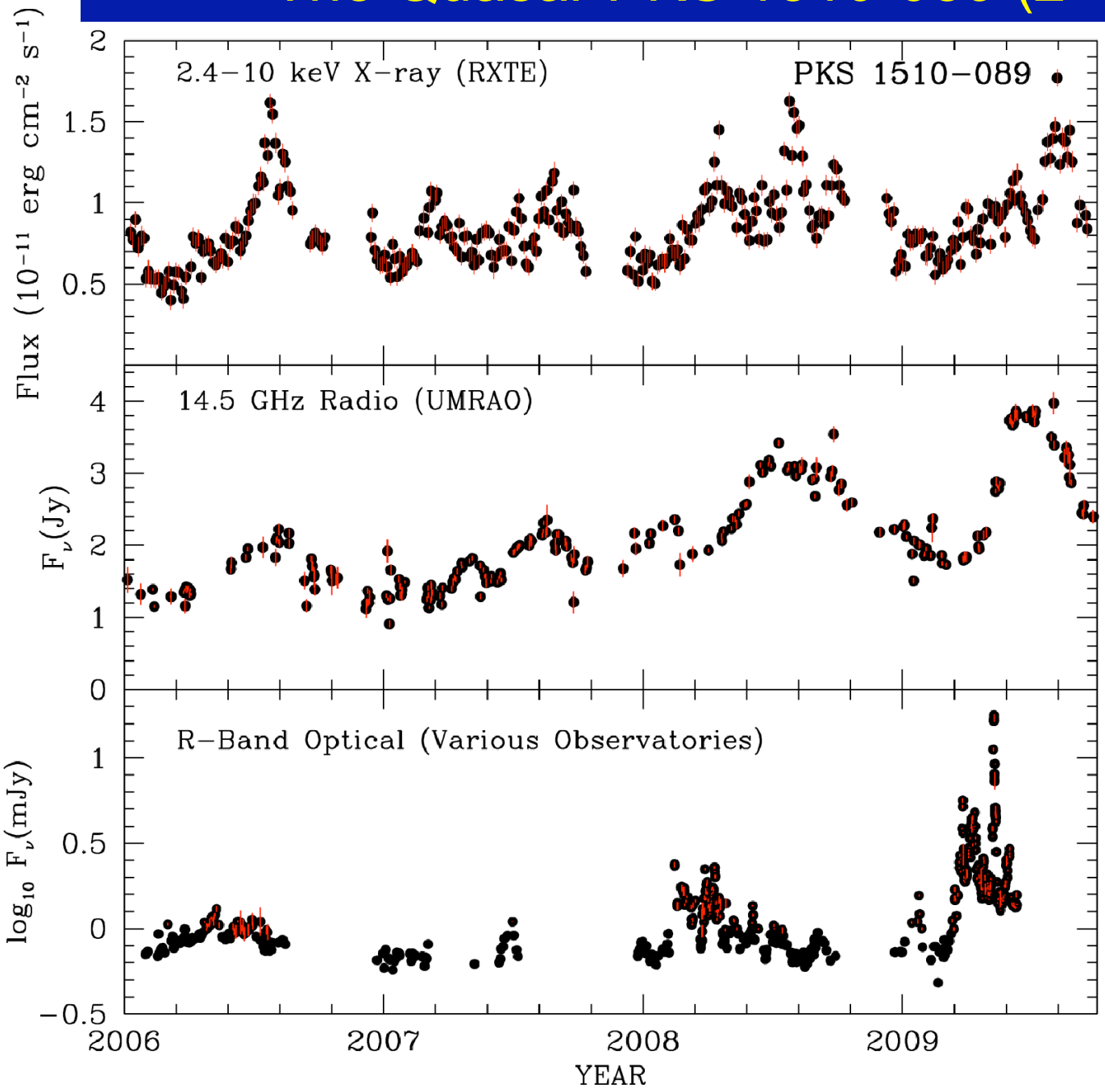
Margo Aller (U. Michigan)

Paul Smith (Steward Obs.)

Anne Lähteenmäki (Metsähovi Radio Obs.)

Funded by NASA (Fermi & ADP grants) & NSF

The Quasar PKS 1510-089 (z=0.361)



Long-term connection between X-ray & radio

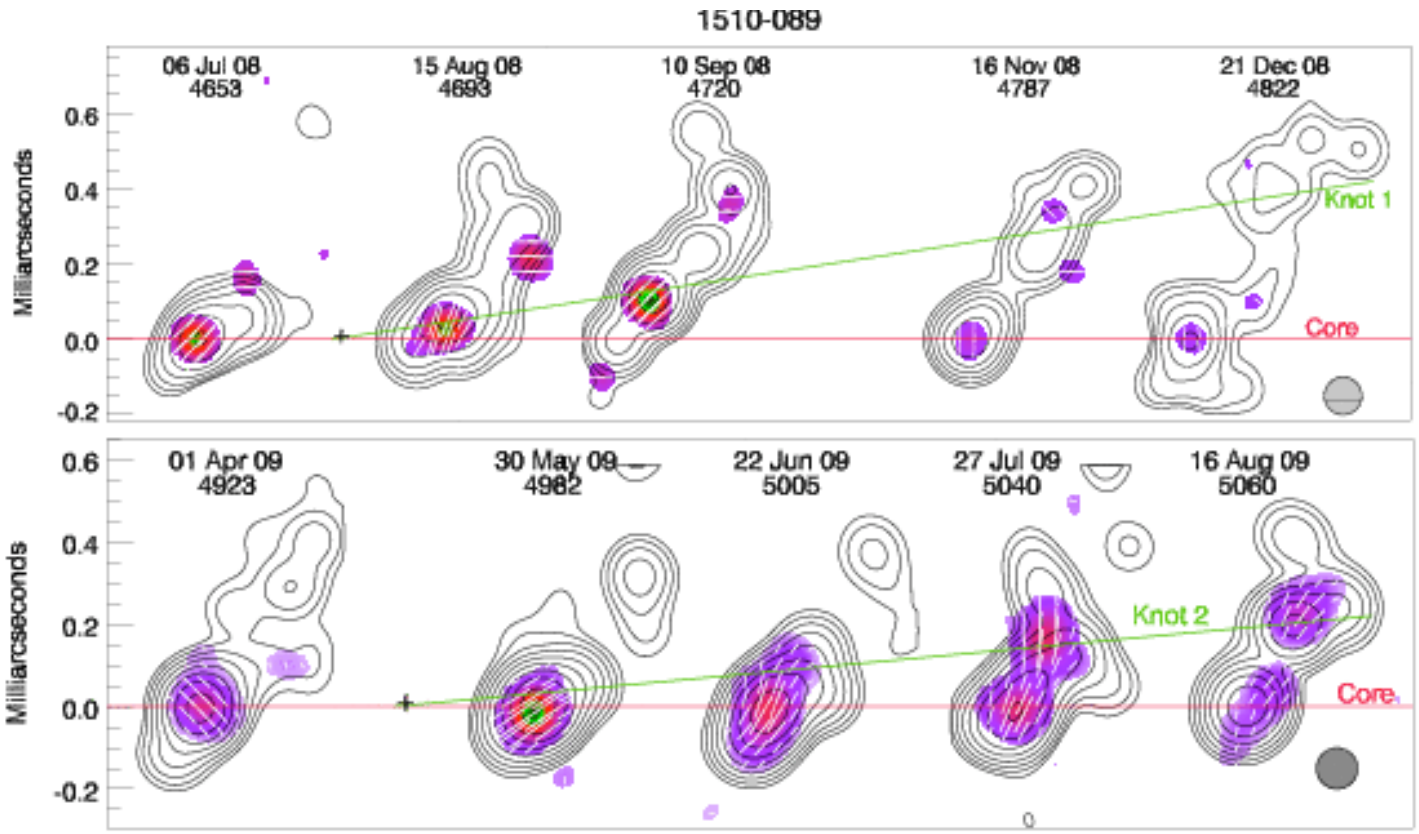
Optical flux not so well correlated with radio, X-ray

Conclusion: X-rays are mainly external Compton by low-E electrons

- supports Madejski et al. & Kataoka et al.

Marscher et al. (2009, Astrophysical Journal, submitted)

43 GHz VLBA Images of PKS 1510-089



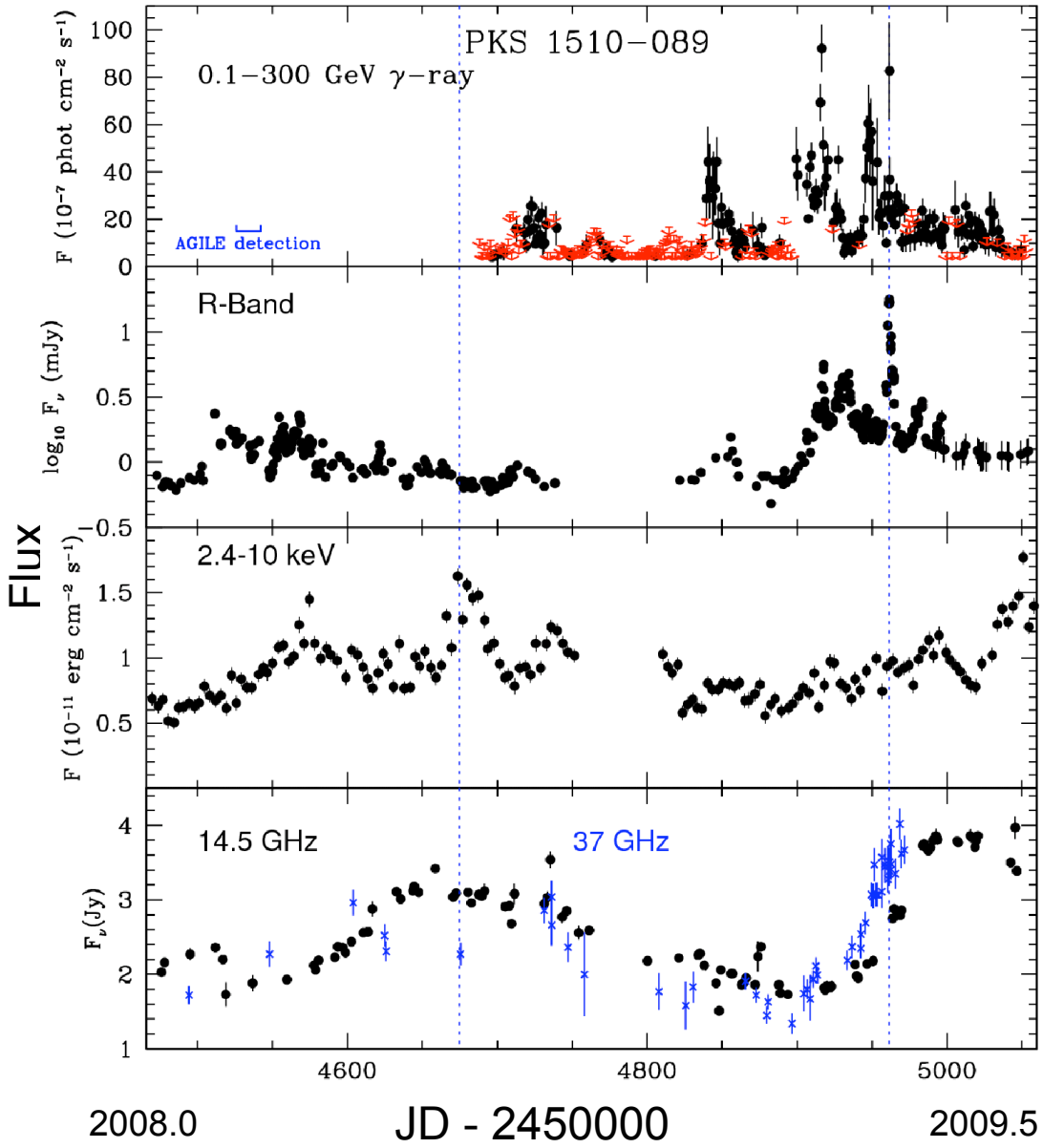
Contours: intensity
Colors: polarization

V_{app} = 23c

Two bright superluminal blobs emerged during the outbursts in brightness during the 2nd half of 2008 & the 1st half of 2009

Marscher et al. (2009, Astrophysical Journal, submitted)

γ-ray Blazar PKS 1510-089

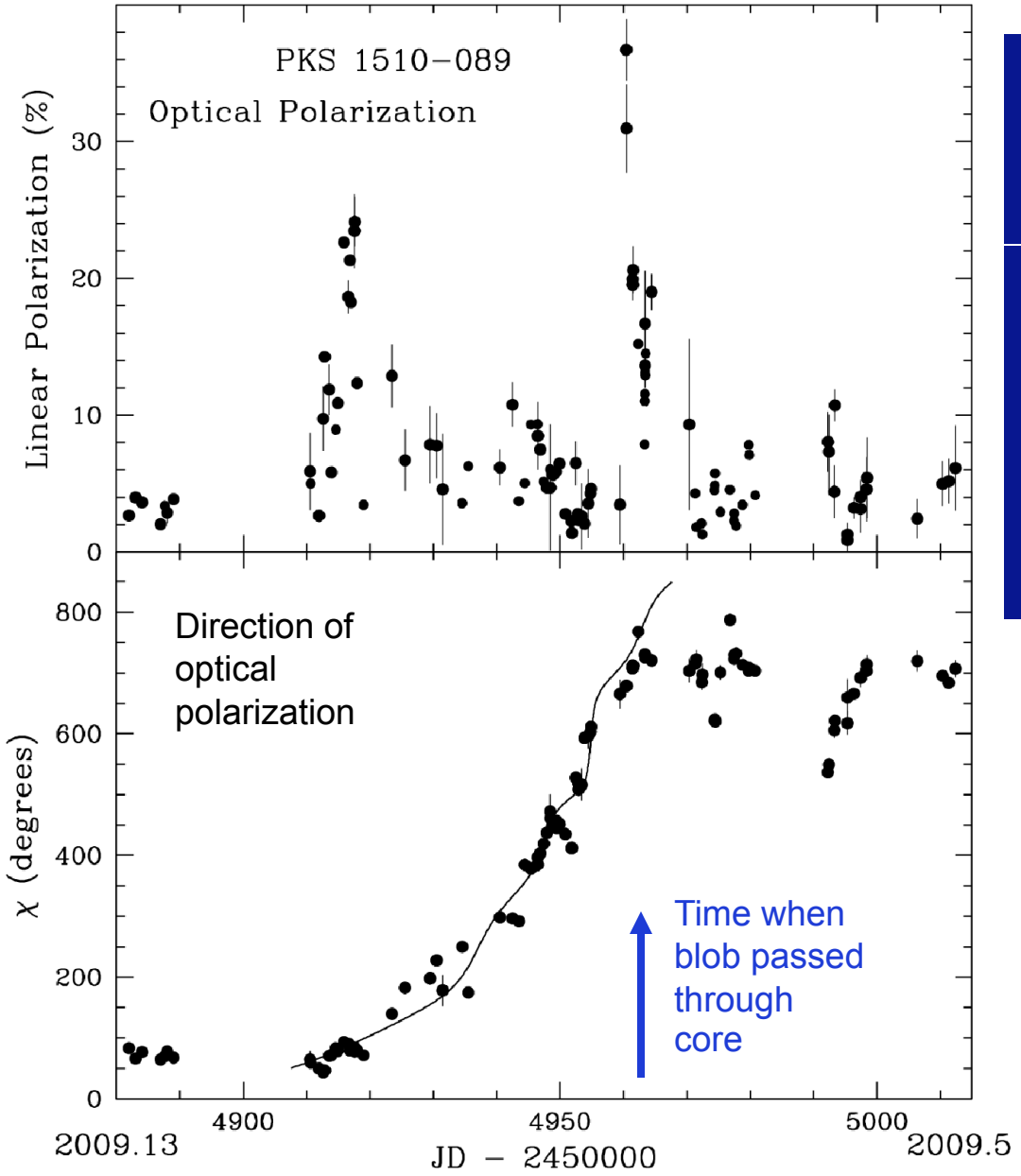


Simultaneous γ-ray & optical flares but relative amplitudes & lags vary

Superluminal knot passed through core during largest optical flare (day 4962)

Marscher et al. (2009, Astrophysical Journal, submitted)

Rotation of Optical Polarization in PKS 1510-089

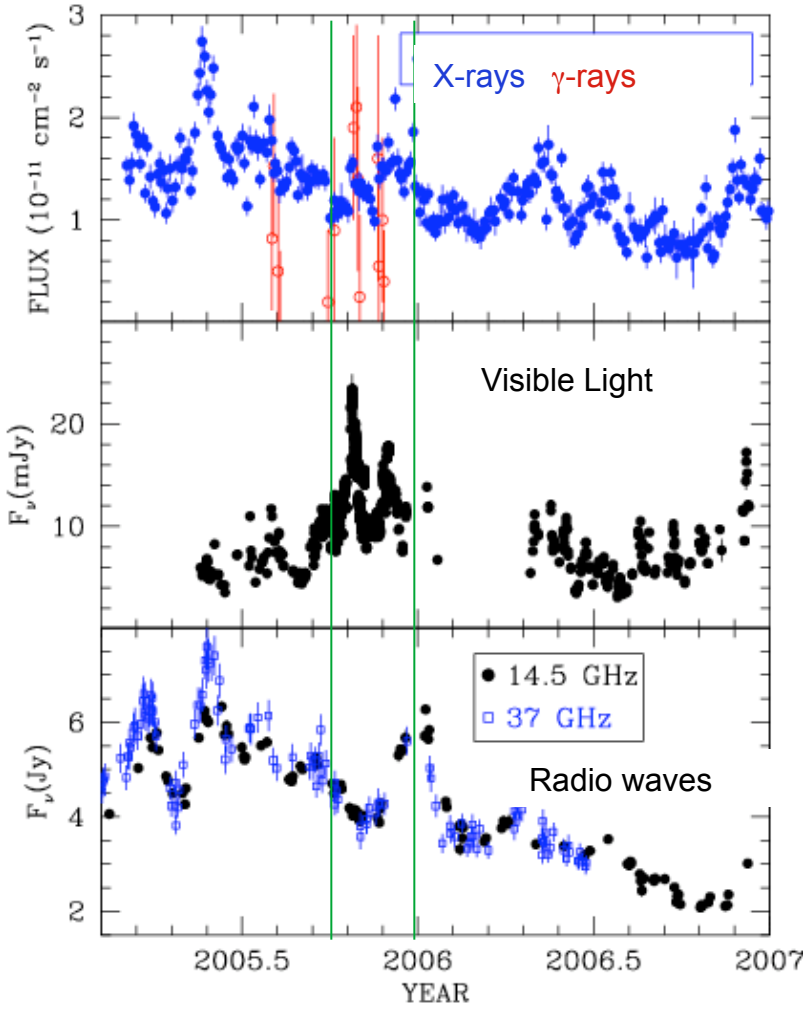


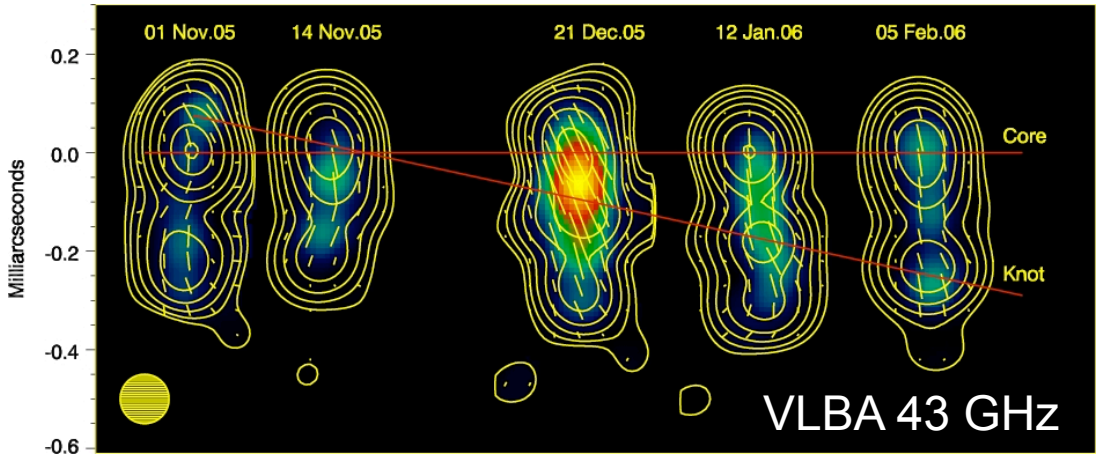
Rotation by ~ 720° during spring 2009 outburst

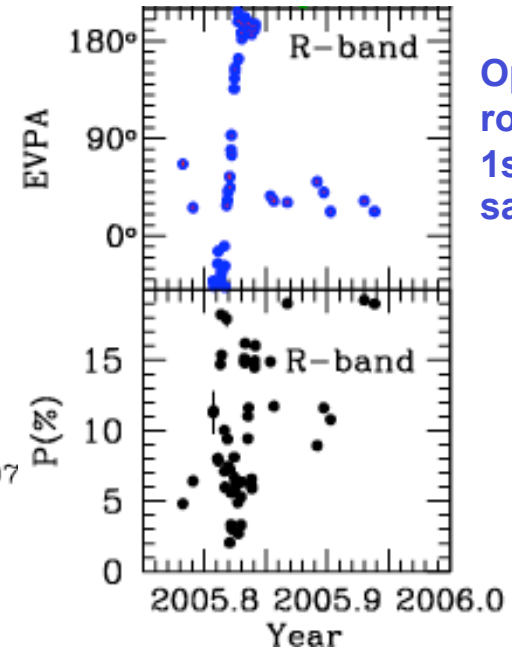
Very sharp, high-amplitude, strongly polarized optical (+ γ-ray) flare at end of rotation as new superluminal blob passed through core

BL Lac: pol. rotation, blob first seen upstream of core

Late 2005: Double optical/X-ray flare, detection at TeV γ-ray energies







Optical polarization angle rotated smoothly during 1st flare, then became same as that of blob

TeV γ-ray data: Albert et al. (2007, ApJL, 666, L17

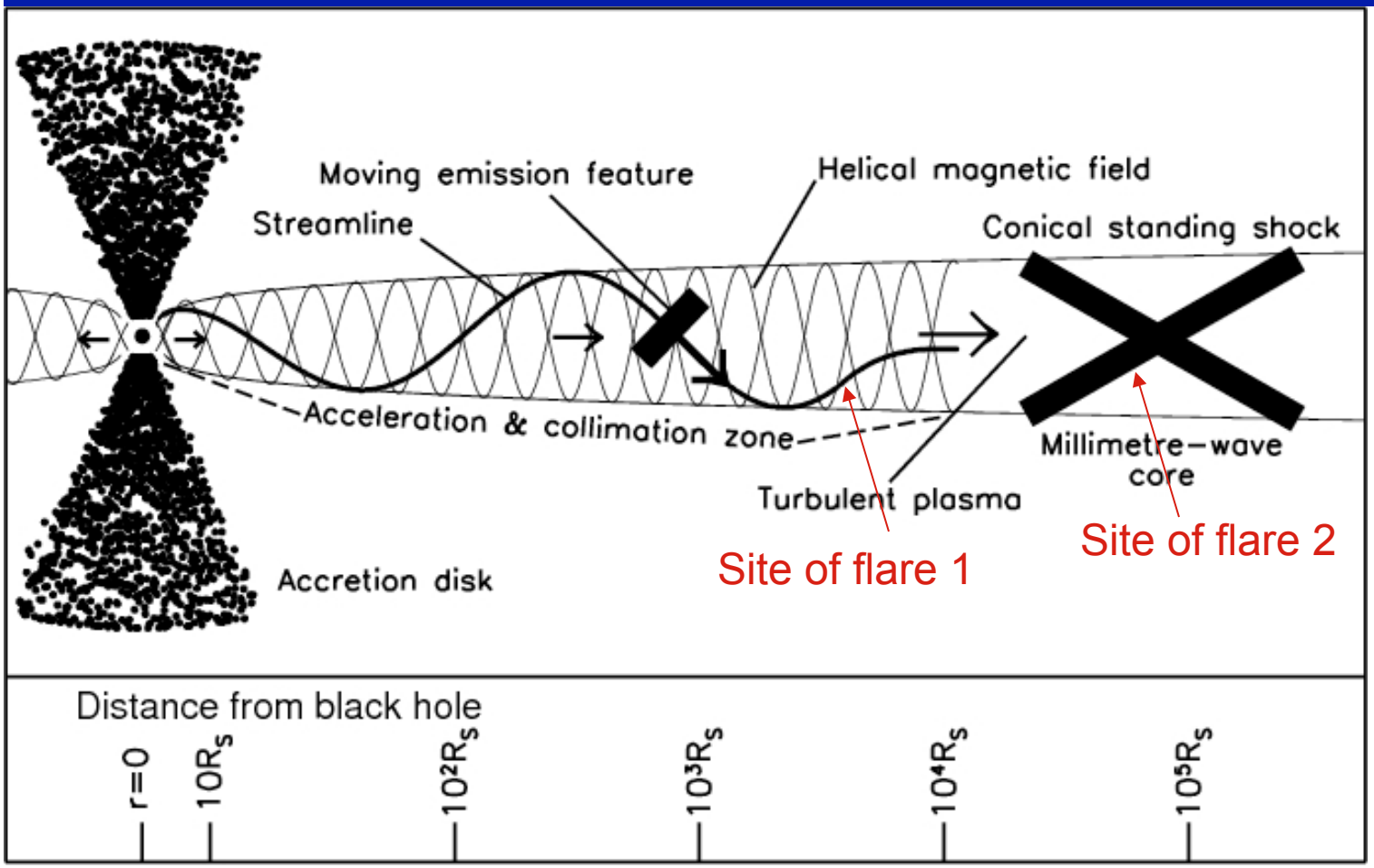
Marscher et al. (2008, Nature, 452, 966)

Physical Picture of BL Lac: As Predicted*

Moving blob/shock follows spiral streamline through toroidal magnetic field in zone where the flow of the jet accelerates + becomes focused

Polarization direction rotates as blob passes through different magnetic field orientations

Blob enters standing shock wave in core, causing flare 2



*Vlahakis (2006, in Variability of Blazars: Entering the GLAST Era)

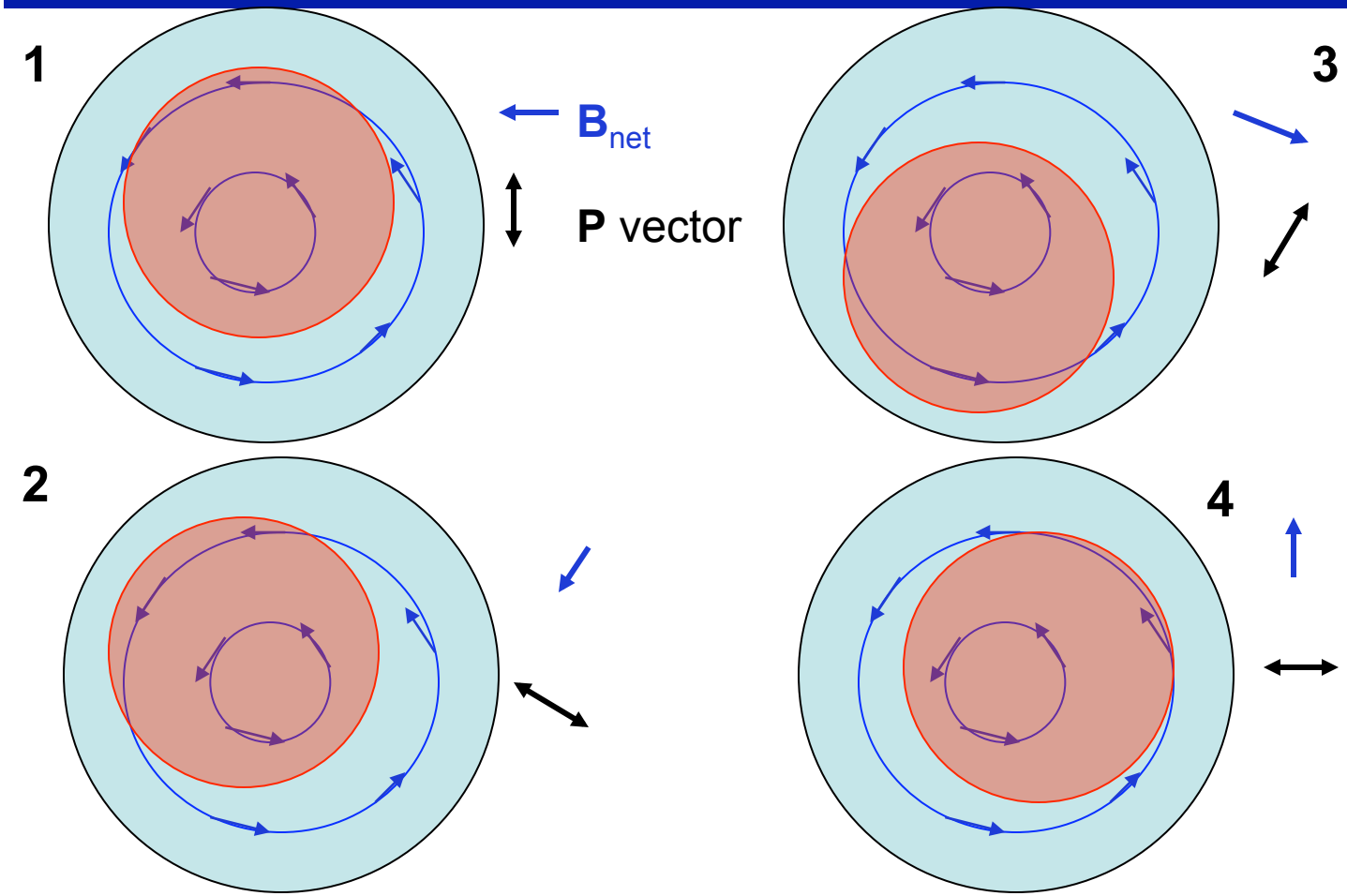
Marscher et al. (2008, Nature, 452, 966)

Emission feature following spiral path down jet

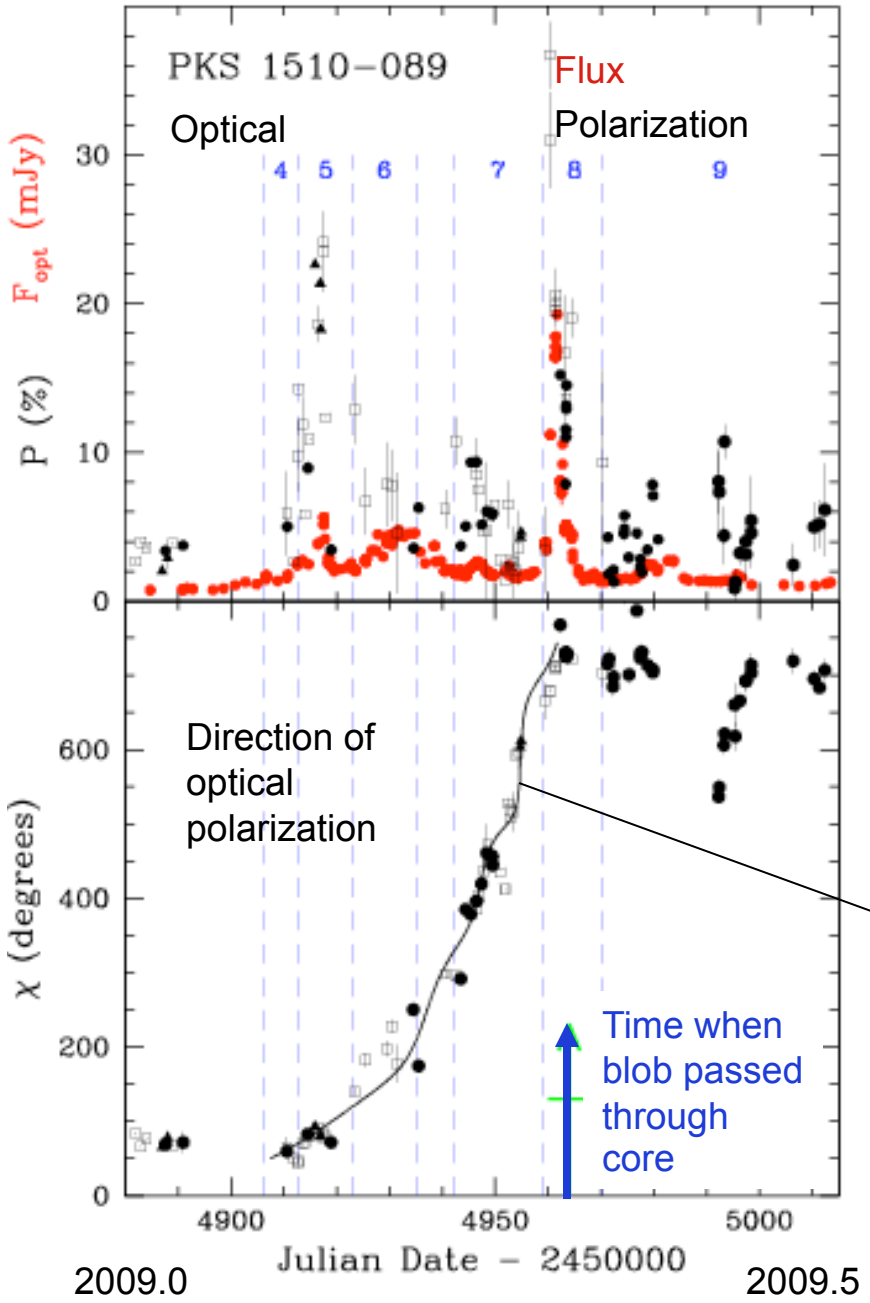
Feature covers much of jet cross-section, but not all

Centroid is off-center

→ Net **B** rotates as feature moves down jet, **P** perpendicular to **B**



Rotation of Optical Polarization in PKS 1510-089



Rotation starts when major optical activity begins

Rotation ends when major optical activity ends + superluminal blob passes through

- Timing argues against rotation resulting from random walk caused by turbulence

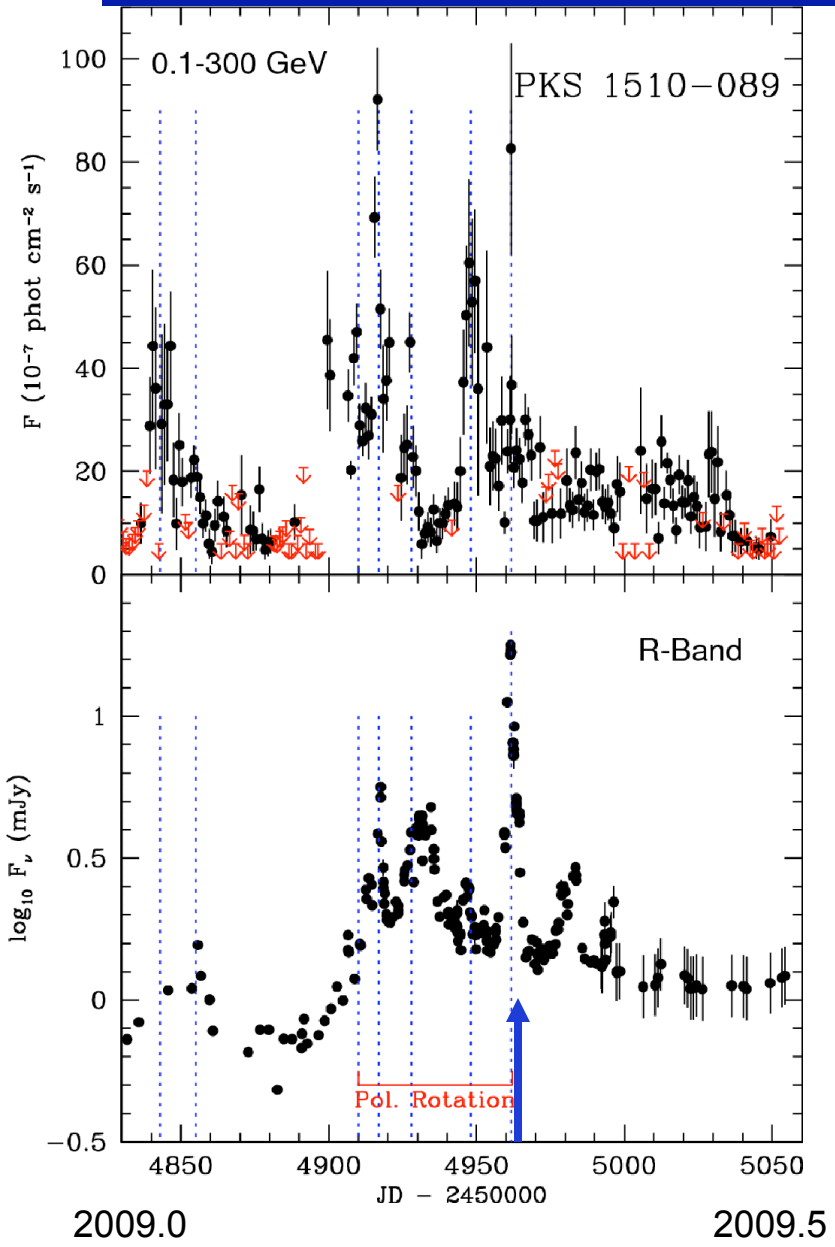
- Also, polarization rotation from days 4990 to 5000 similar to end of earlier rotation, as expected if caused by geometry of B as a weak blob approaches core

Curve: emission feature following a spiral path in an accelerating flow

Γ increases from 8 to 24, δ from 15 to 38

Core = 17 pc from central engine
Blob moves 0.3 pc/day as it approaches core

Flares during 1st Half of 2009 in PKS 1510-089



γ-ray to optical flux ratios vary greatly from flare to flare

- from ~70 on day 4847 to <10 on days 4928 & 4962

Interpretation:

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

B ~ 1 G at start, 0.2-0.4 G at core (from timescale of flare decay)

Flares with high γ:opt ratios occur as blob passes location of *local* source of external seed photons, L_{ext} ~ 3×10^{43} erg/s

→ 1st flare: BLR?

→ Later: synchrotron in slower sheath of jet?

Sharp flare on day 4962 probably SSC (1st + 2nd order) as blob is compressed by standing shock wave inside core

Conclusions

- γ-ray and X-ray flares in jets are caused by superluminal knots ("blobs") that move down the jet & are seen in VLBA images

- See also poster by Svetlana Jorstad today

- Relativistic jets of AGN are connected to black hole & accretion disk

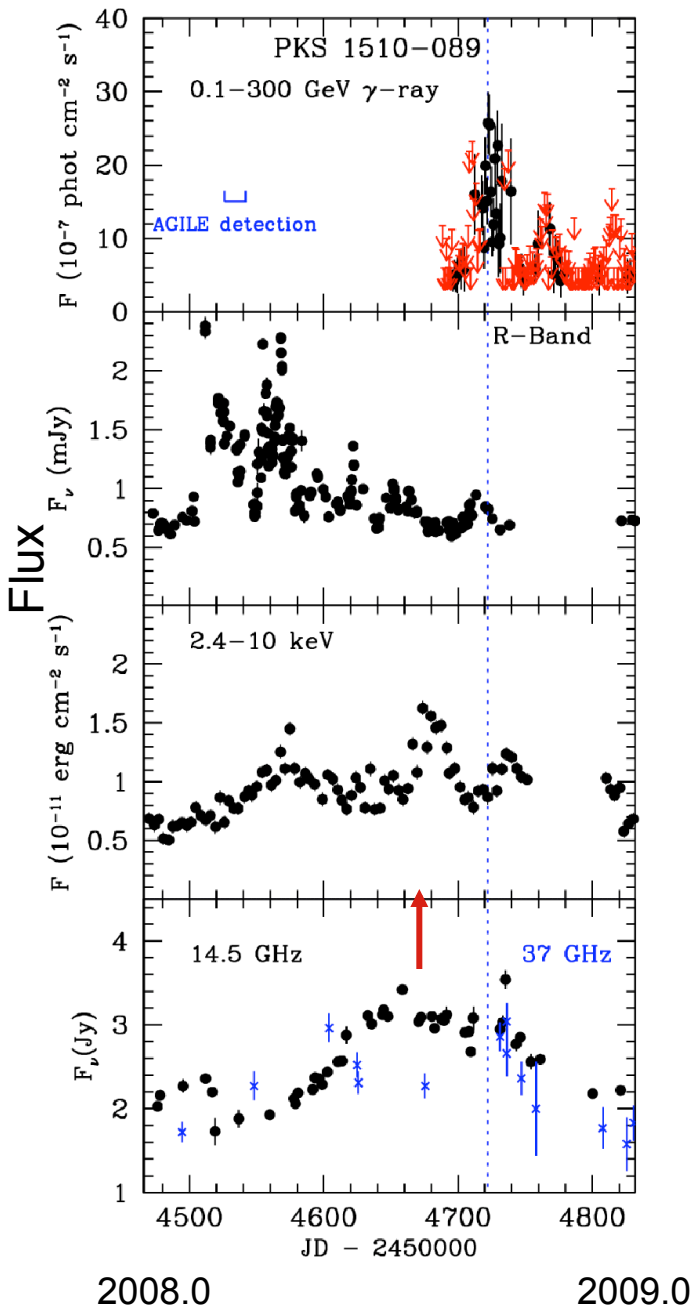
- Disturbances creating superluminal knots + outbursts in brightness start in the central engine near the supermassive black hole

- Rotations of polarization & timing of flares agree with magnetic-launching models of jets

- High-E photon emission in the jet occurs by both SSC & EC in multiple zones, sometimes because electrons are energized & radiate more, other times because electrons in jet encounter extra light from local sources (probably sheath) & knock it up to high energies

- Combination of VLBA imaging + multi-waveband flux & polarization monitoring is a powerful probe of inner jets of blazars

PKS 1510-089: Flare in Aug-Sep 2008



Time delays of peaks:

Optical first

γ-ray 1 week later

X-ray & radio 10 days after γ-ray

Superluminal knot (red arrow) passed through core before this flare

AGILE detection early in 2008 during optical flaring activity, at start of X-ray/radio rise

Marscher et al. (2009, Astrophysical Journal, submitted)