Polarization Variability in Leptonic and Hadronic Blazar Models

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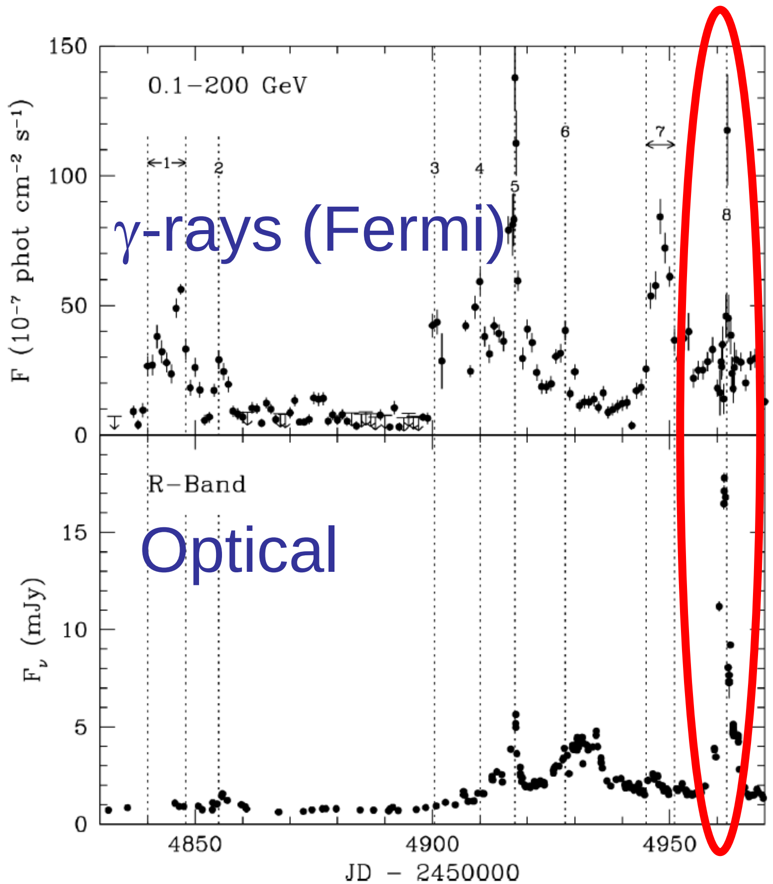
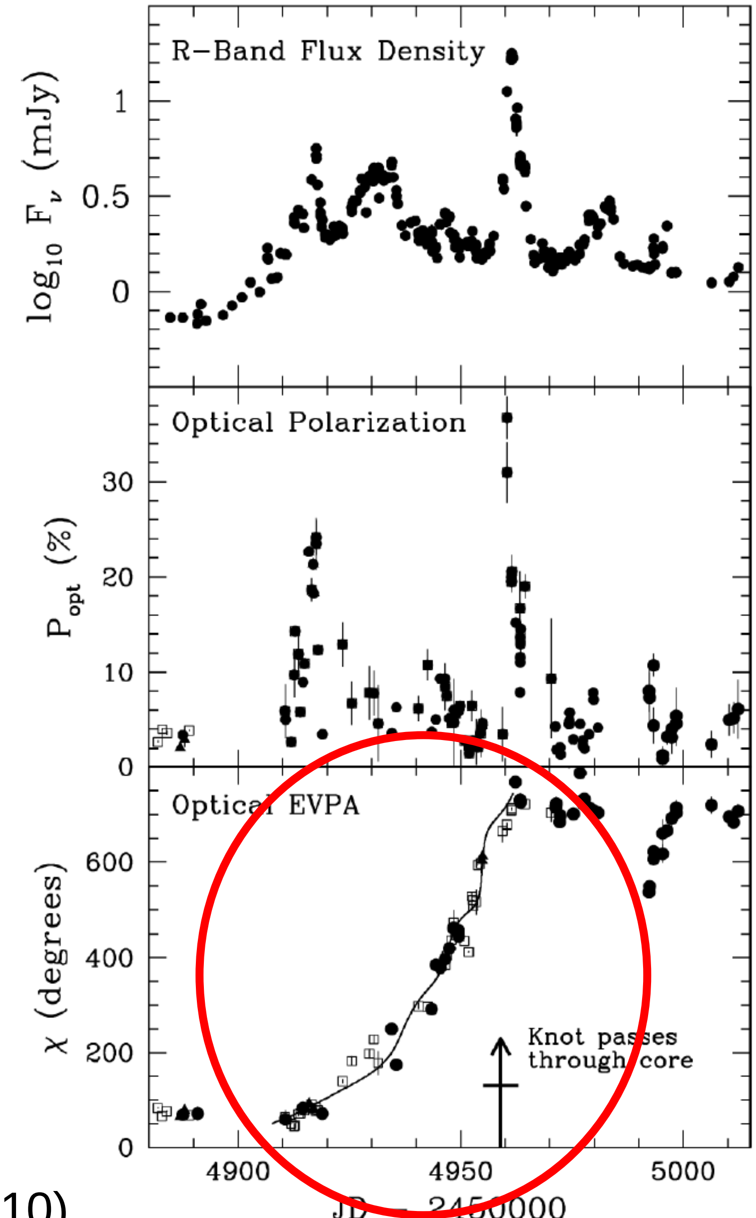
Optical Polarization Variability

- Optical polarization degree and EVPA are rapidly varialble.
- Sometimes Opt./γ flares correlated with rapid changes in optical polarization and multiple rotations of the polarization angle (PA)

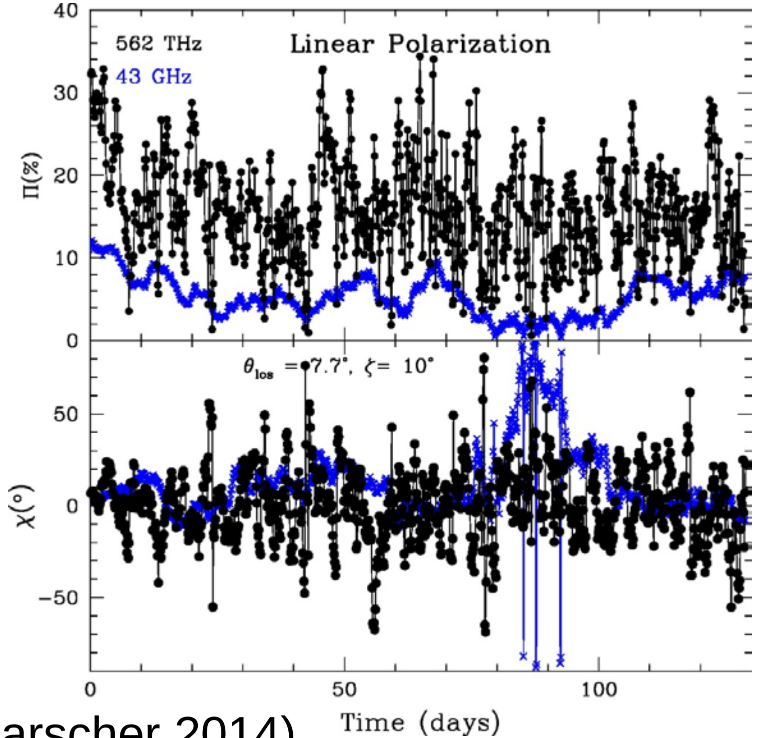




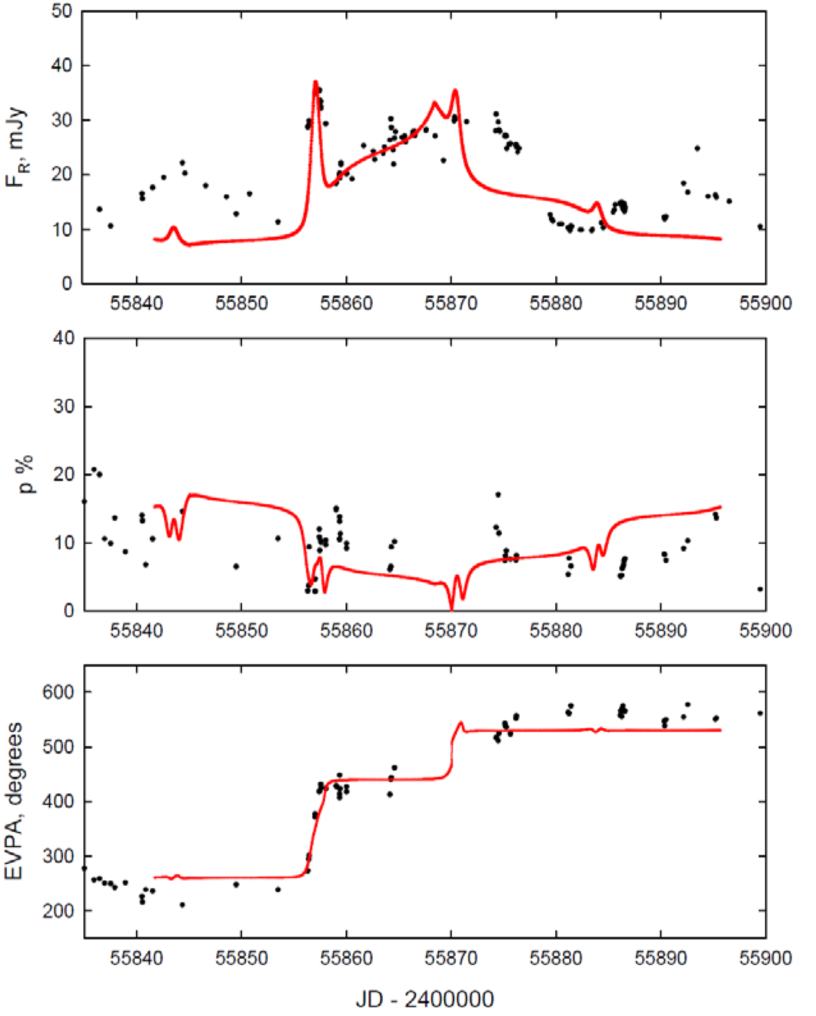
PKS 1510-089 (Marscher et al. 2010)

Proposed Models

- Helical magnetic fields in a bent jet (e.g., Marscher et al. 2010)
- Helical streamlines, guided by a helical magnetic field (Larionov et al. 2013, 2016)
- Turbulent Extreme Multi-Zone Model (Marscher 2014)

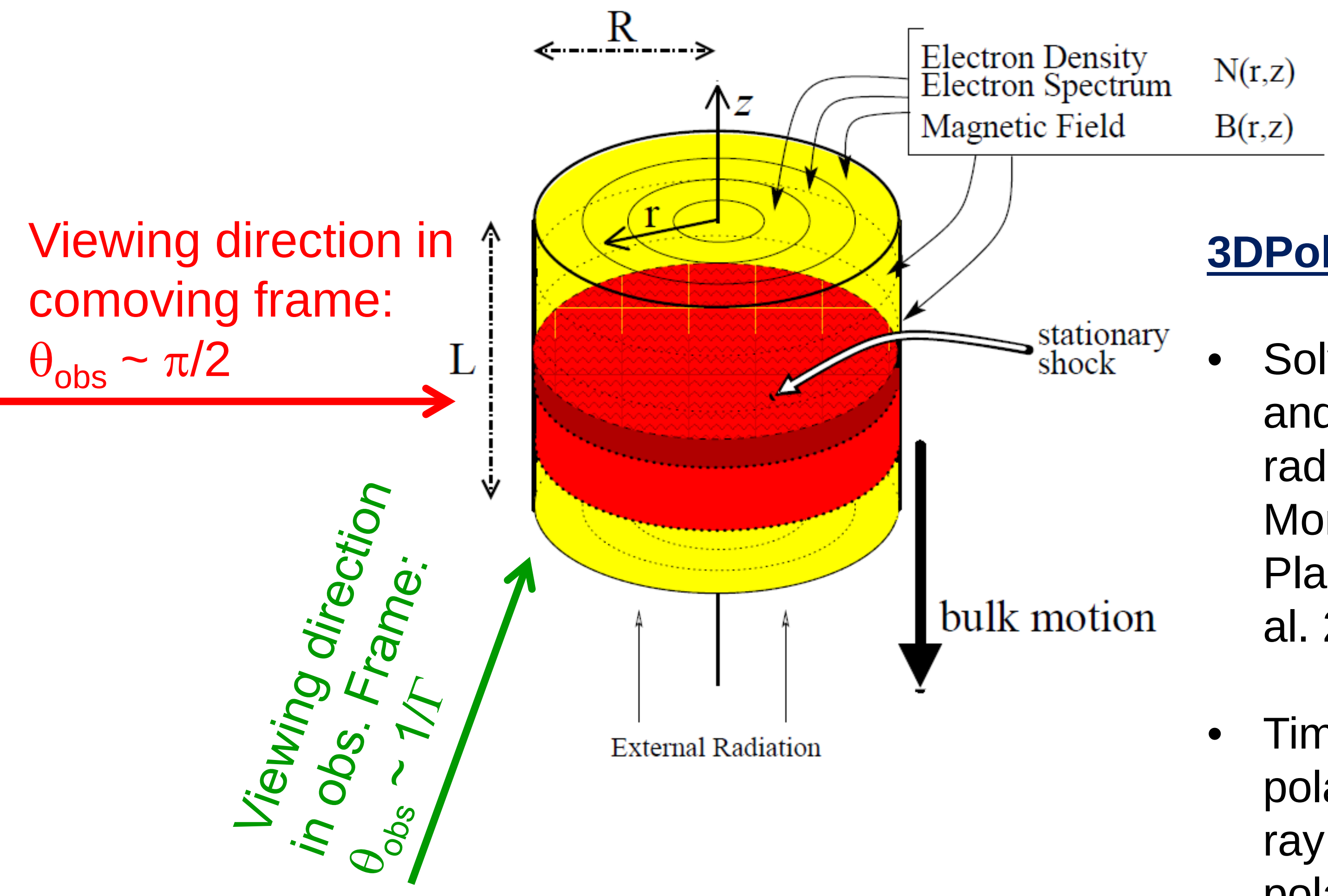


(Marscher 2014)



(Larionov et al. 2013)

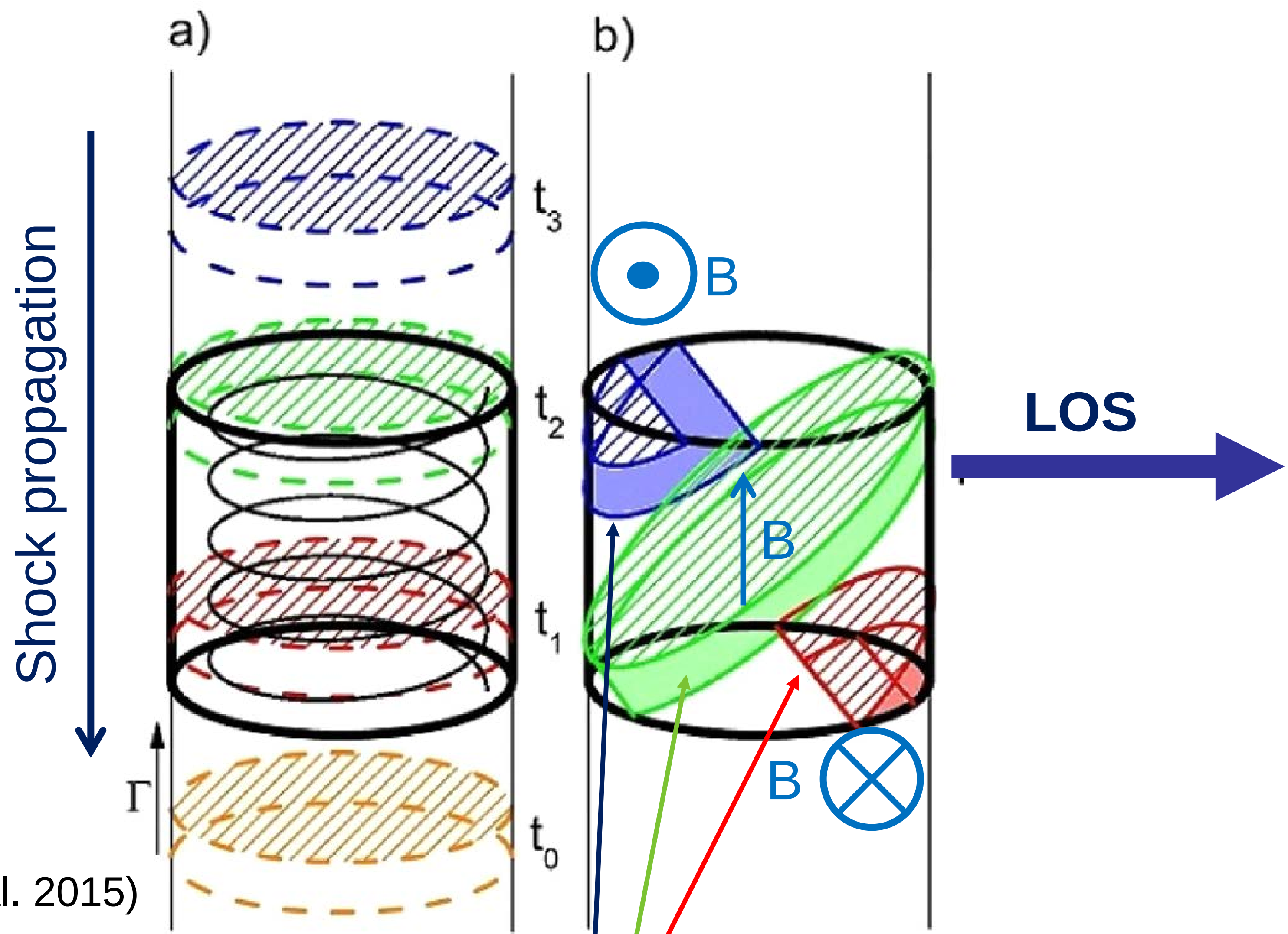
Tracing Synchrotron Polarization in the Internal Shock Model



3DPol (Zhang et al. 2014)

- Solve electron dynamics and (unpolarized) radiation transfer with Monte-Carlo / Fokker-Planck scheme (Chen et al. 2011, 2012)
- Time-dependent, polarization-dependent ray tracing for polarization signatures

Light Travel Time Effects

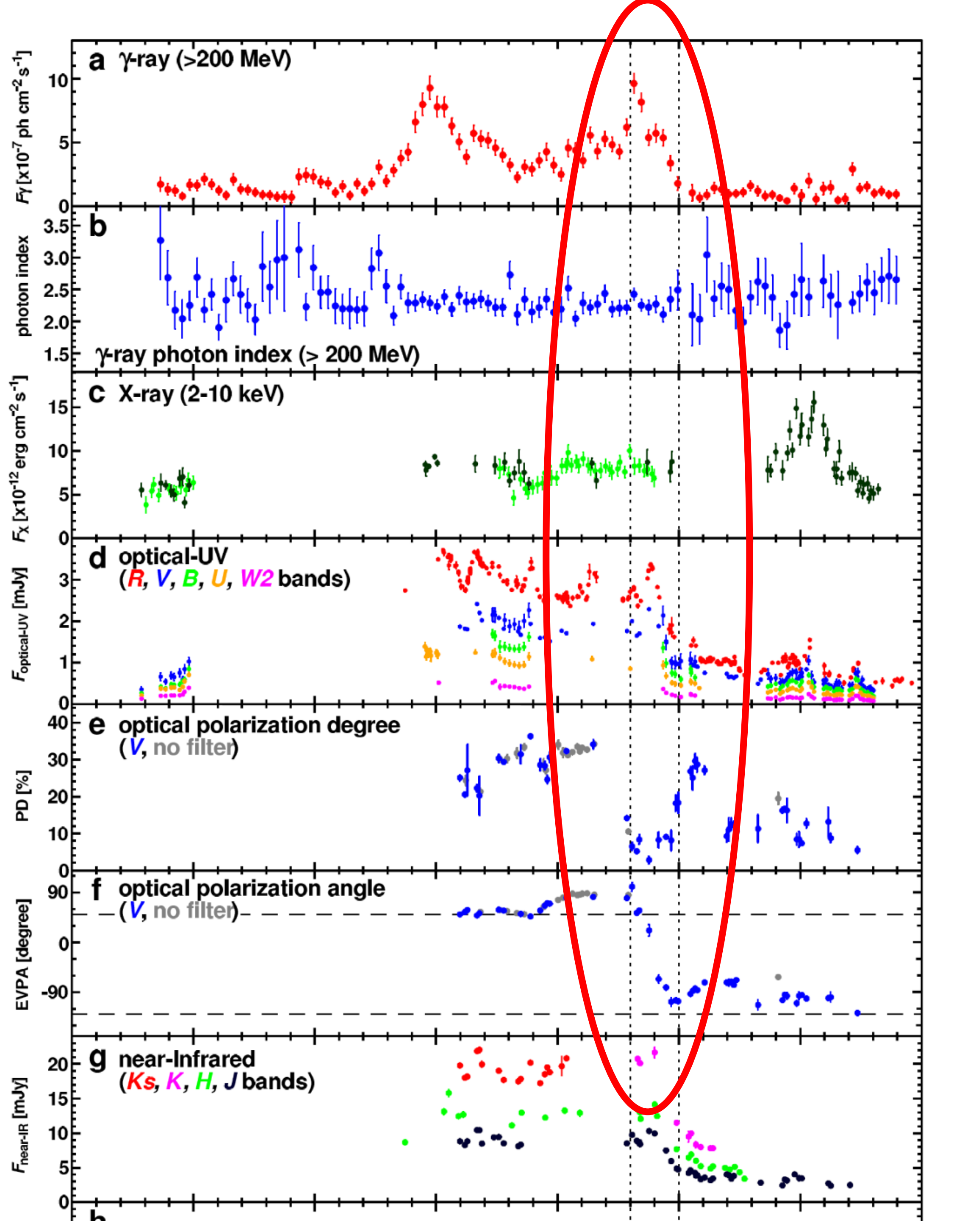


(Zhang et al. 2015)

Shock positions at equal photon-arrival times at the observer

Application to the FSRQ 3C279

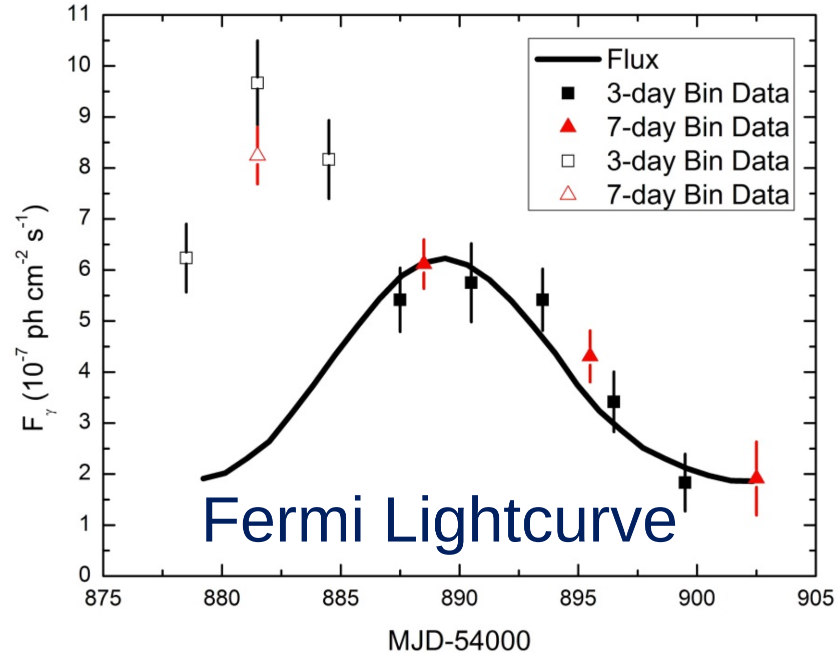
Simultaneous optical + γ-ray flare, correlated with a 180° polarization-angle rotation .

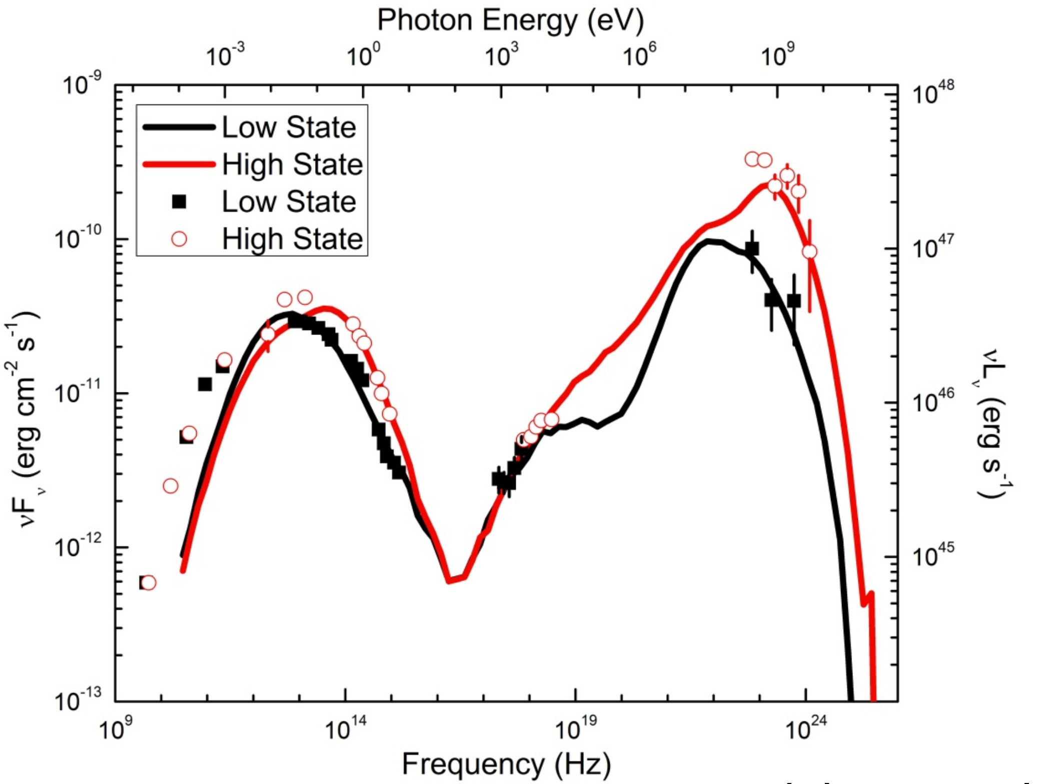


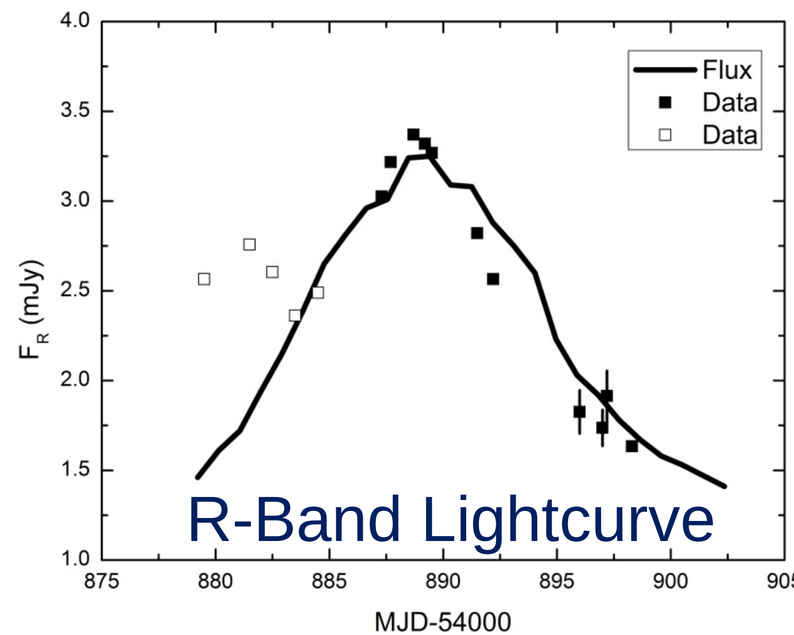
(Abdo et al. 2009)

Application to 3C279

Simultaneous fit to SEDs, light curves, polarization-degree and polarization-angle swing



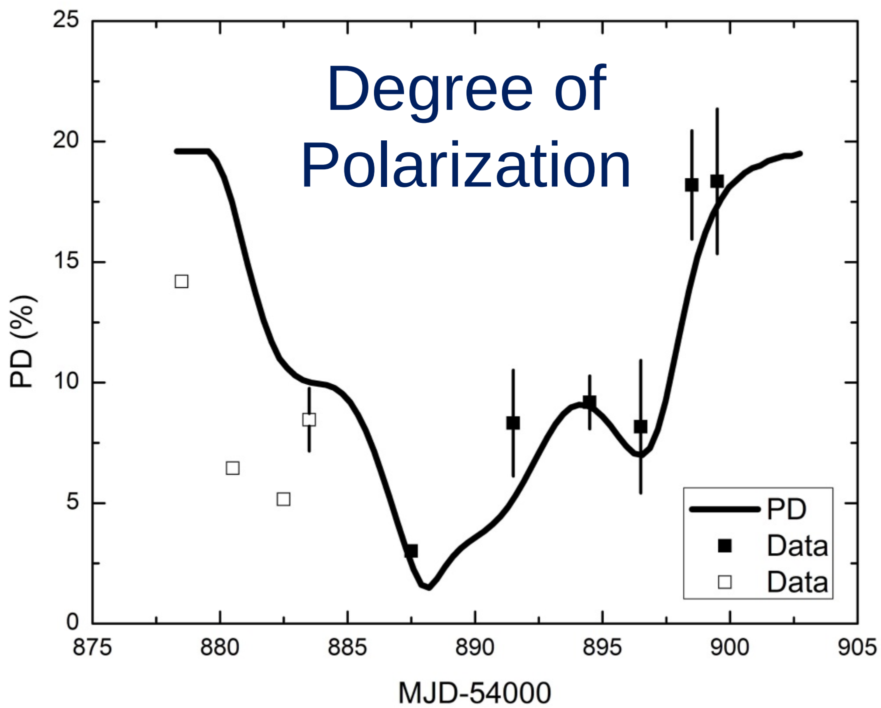


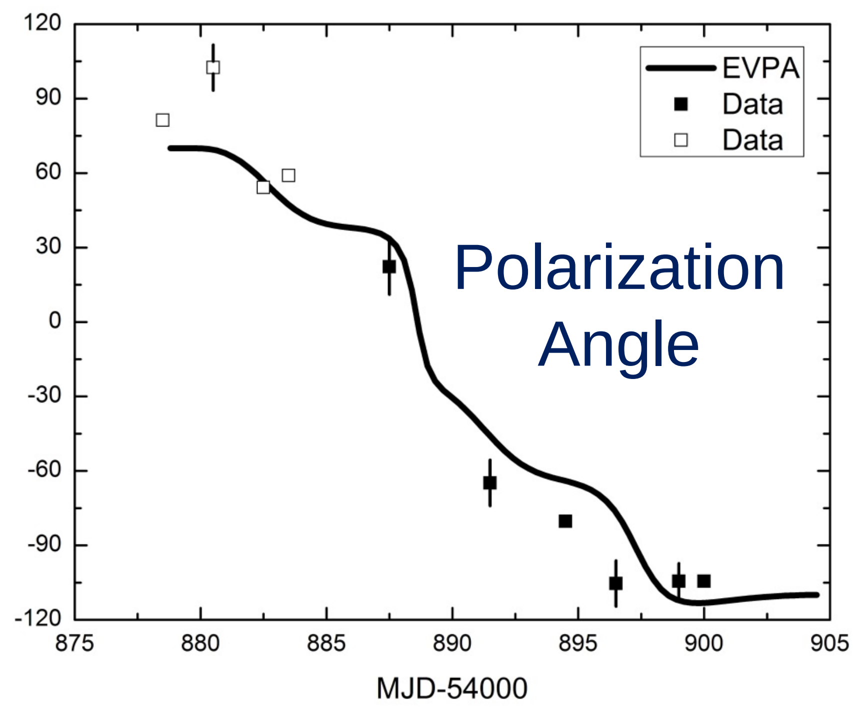


(Zhang et al. 2015)

Application to 3C279

Requires particle acceleration
and reduction of magnetic field,
as expected in magnetic reconnection!





(Zhang et al. 2015)

Coupling to Realistic MHD Simulations

- Ideal RMHD Simualtions (LA-COMPASS [LANL]) of relativistic shocks

- Jets initially pervaded by purely helical B-fields with magnetization parameter

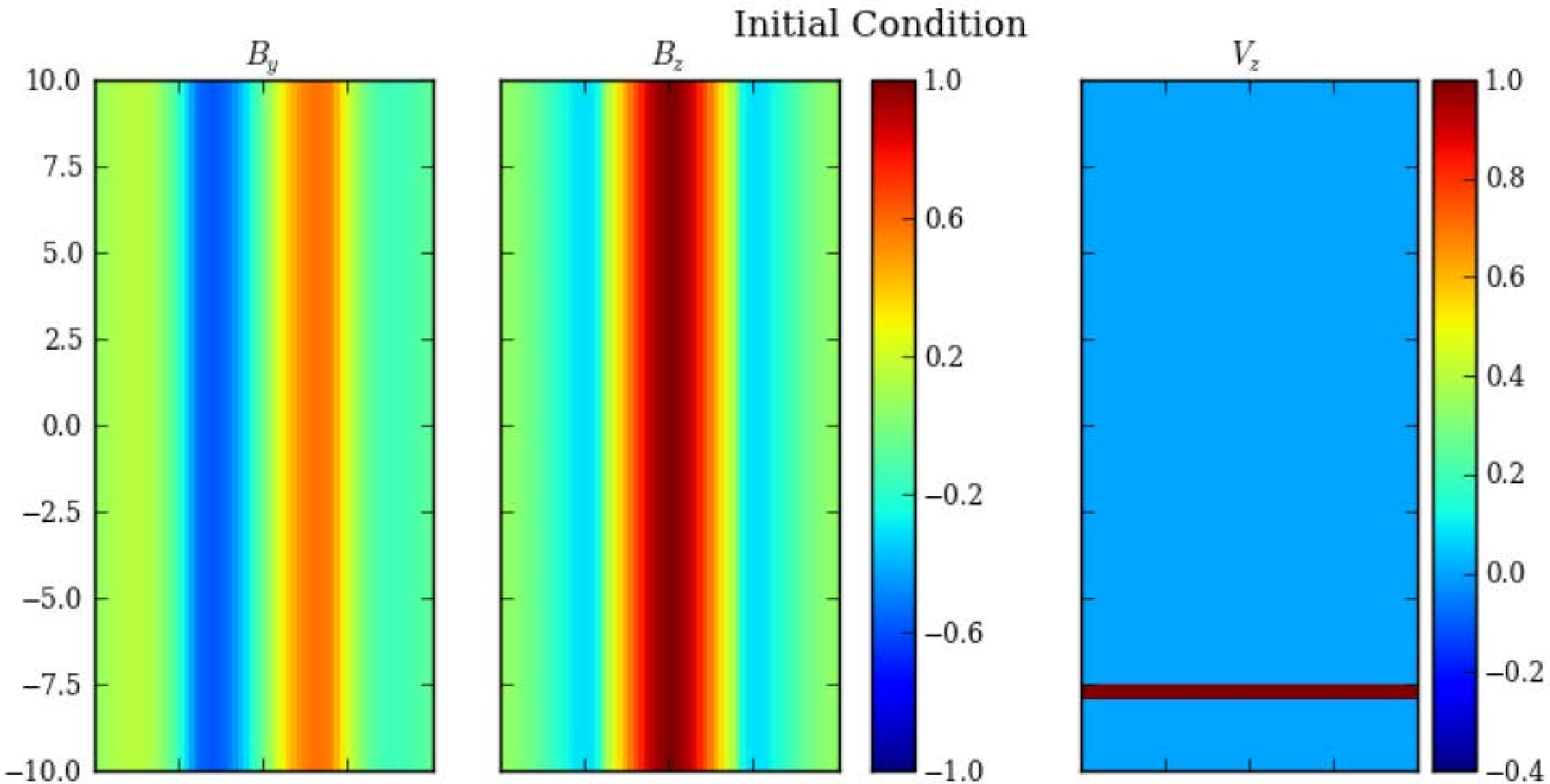
$$\sigma = \frac{E_{em}}{h} \qquad E_{em} = \frac{E^2+B^2}{8\pi} \qquad h = \rho c^2 + \frac{\gamma p}{\gamma - 1}$$

- Fixed fraction of liberated energy converted to the injection of power-law non-thermal electrons

- Follow particle evolution, radiation, and time-dependent polarization signatures using 3DPol.

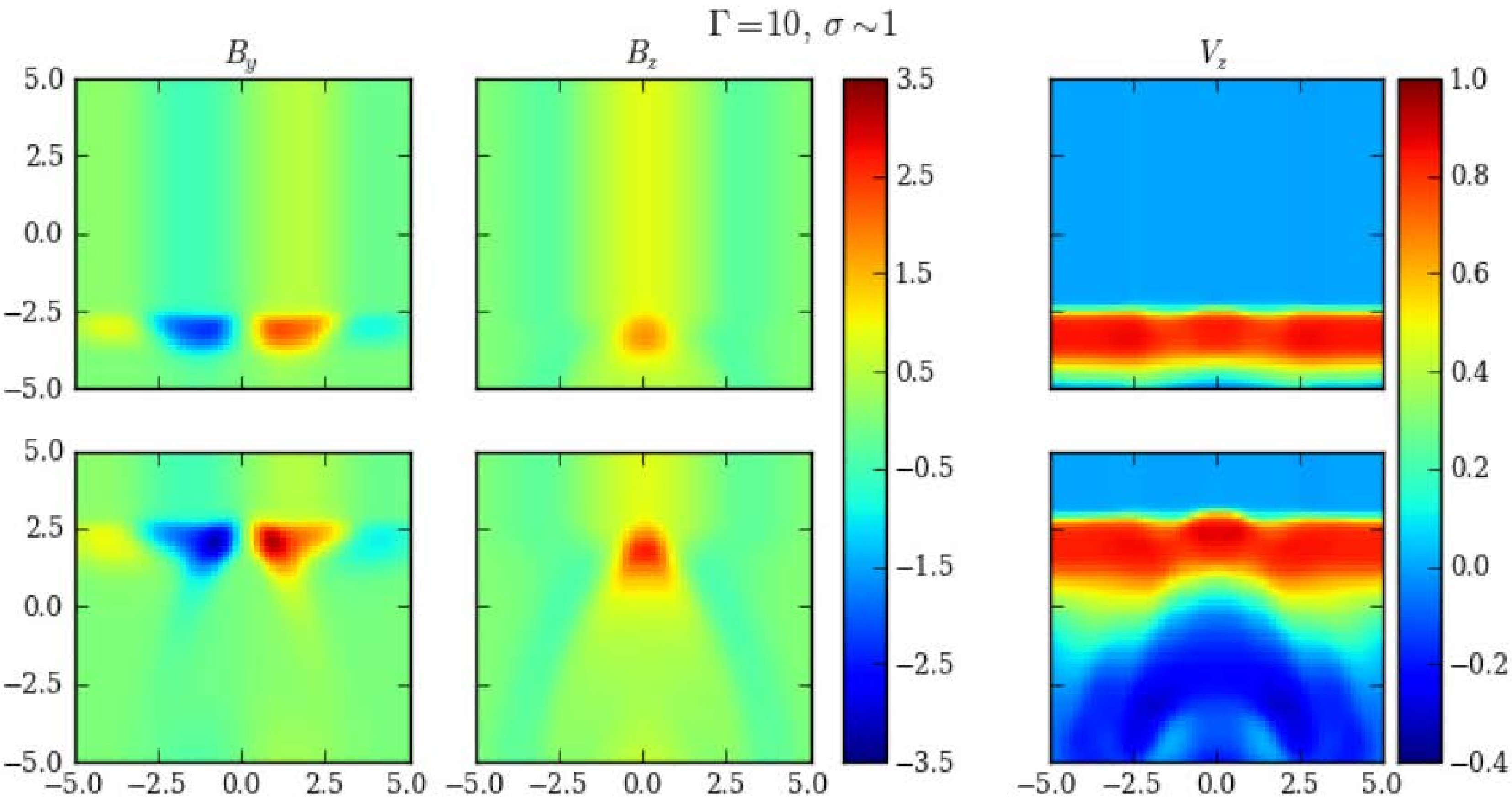
(Zhang et al. 2016a)

Simulation Setup



(Zhang et al. 2016a)

B-Field Evolution

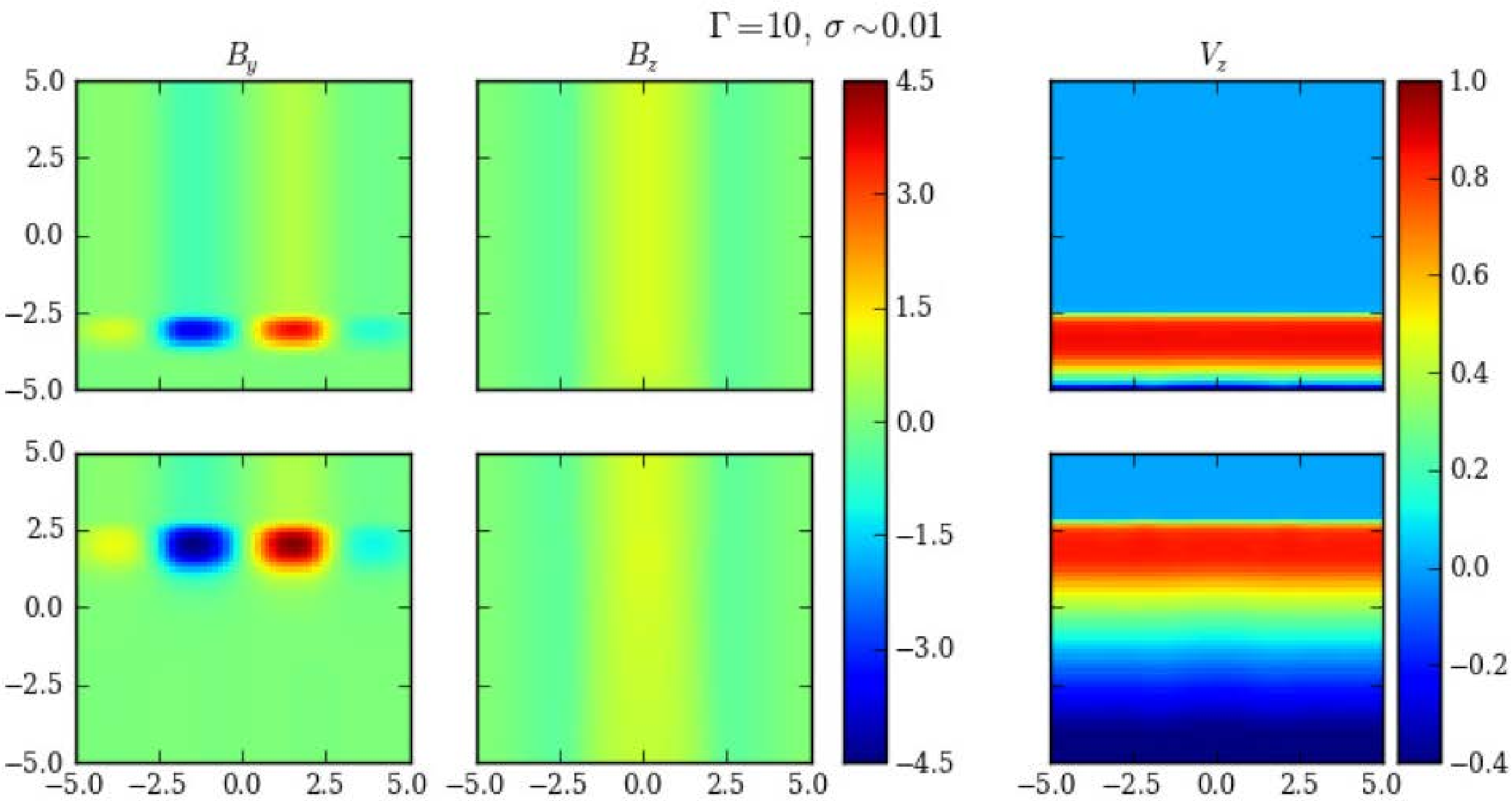


(Zhang et al. 2016a)

<u>High / moderate magnetization</u>

- Weak shock
- velocity field strongly disturbed
- B-field restored to its original topology after passage of the shock

B-Field Evolution

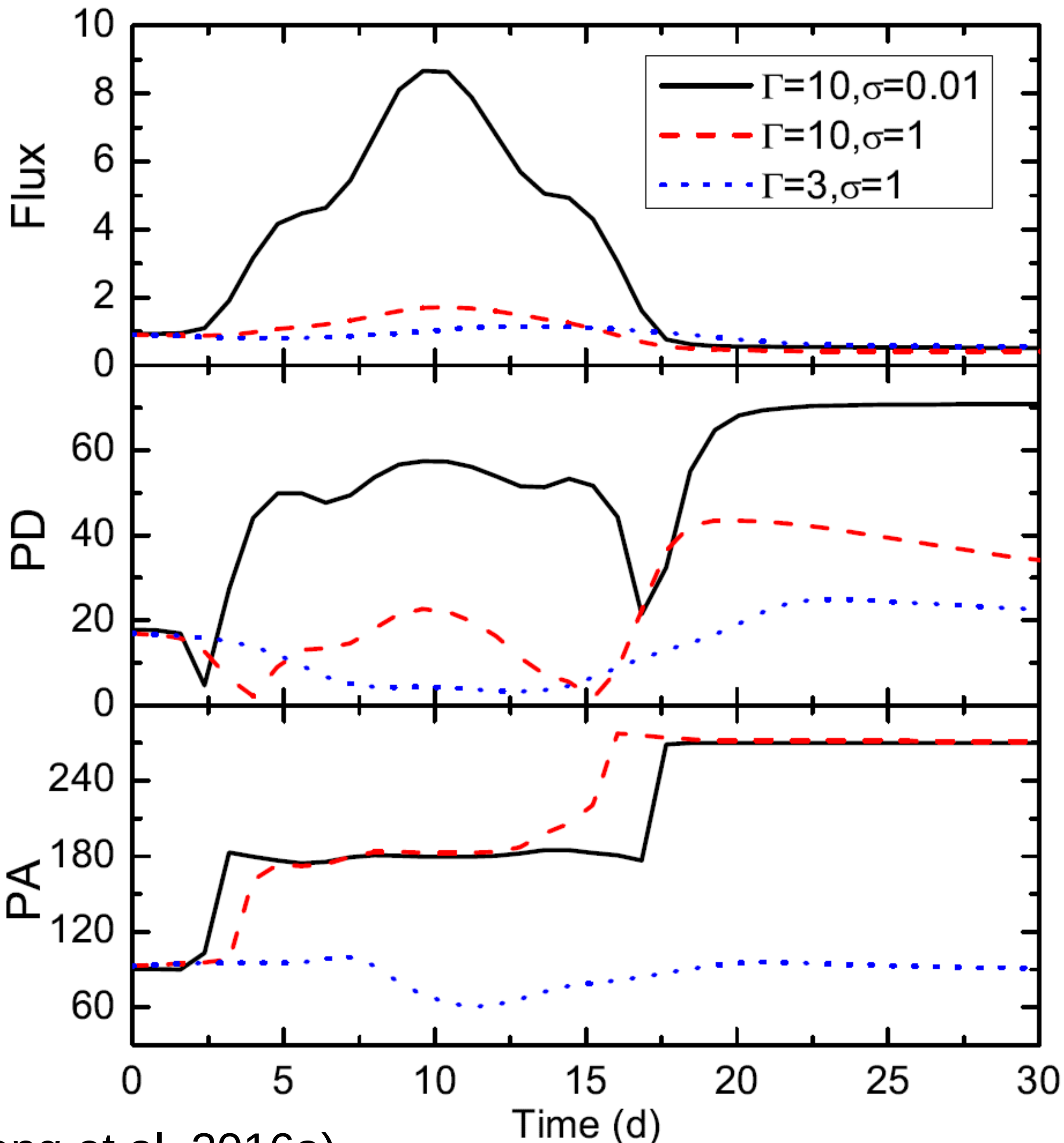


(Zhang et al. 2016)

Low magnetization

- Strong shock
- velocity field almost undisturbed
- B-field topology significantly altered after passage of the shock

Polarization Signatures

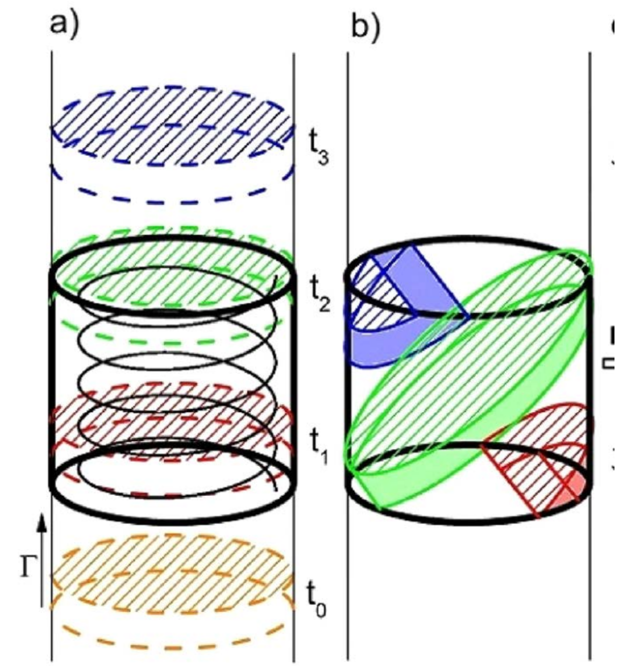


(Zhang et al. 2016a)

- PA swings with PD recovering to its pre-flare level require high / moderate magnetization ($\sigma \geq 1$) - otherwise B-field is not restored to its original topology
- Significant flares require strong shocks, i.e., moderate / high shock speed and moderate / low magnetization

The Lepto-Hadronic Version

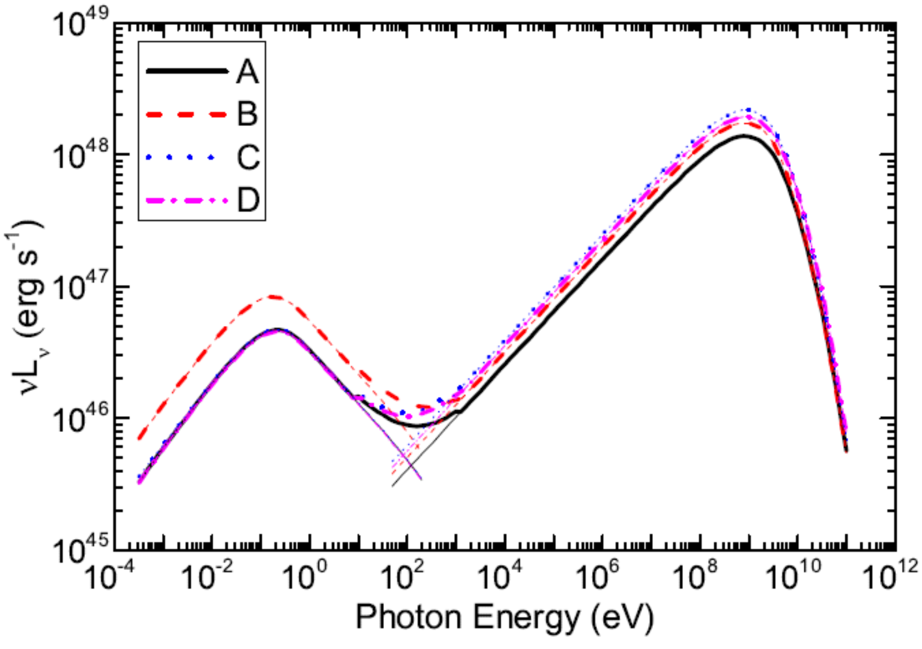
- Lepto-hadronic (p-synchrotron dominated) 3D time- and polarization-dependent internal shock model (Zhang, Diltz & Böttcher 2016b)
- Model setup as for leptonic (3DPol) model, but include injection of ultrarelativistic protons
- Electron + proton evolution with locally isotropic Fokker-Planck equation
- Fully time- and polarization-dependent ray tracing



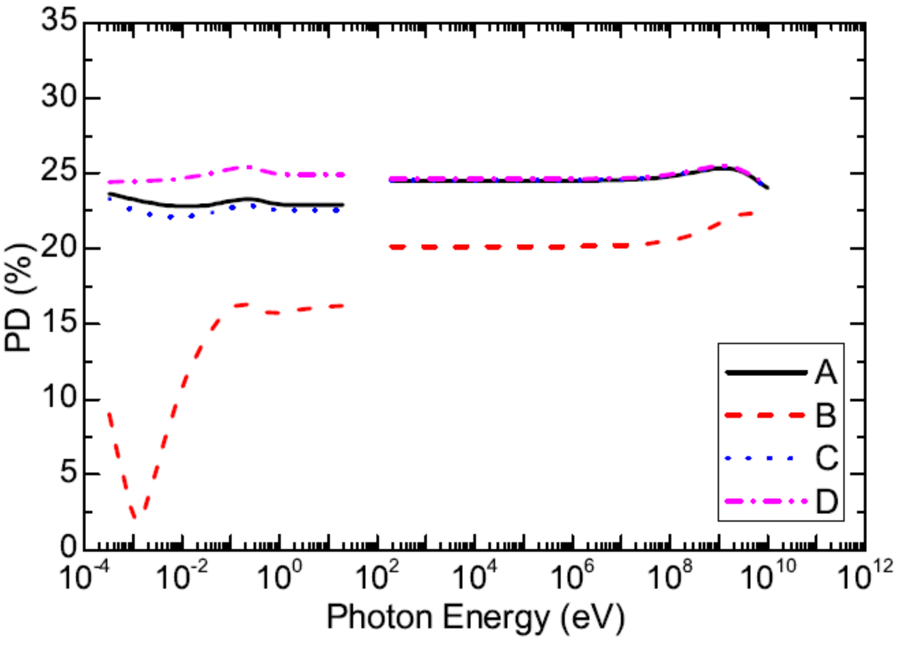
3D Lepto-Hadronic Internal Shock model

Example case: Magnetic energy dissipation (reducing B-field, additional e and p injection)

(Zhang et al. 2016b)

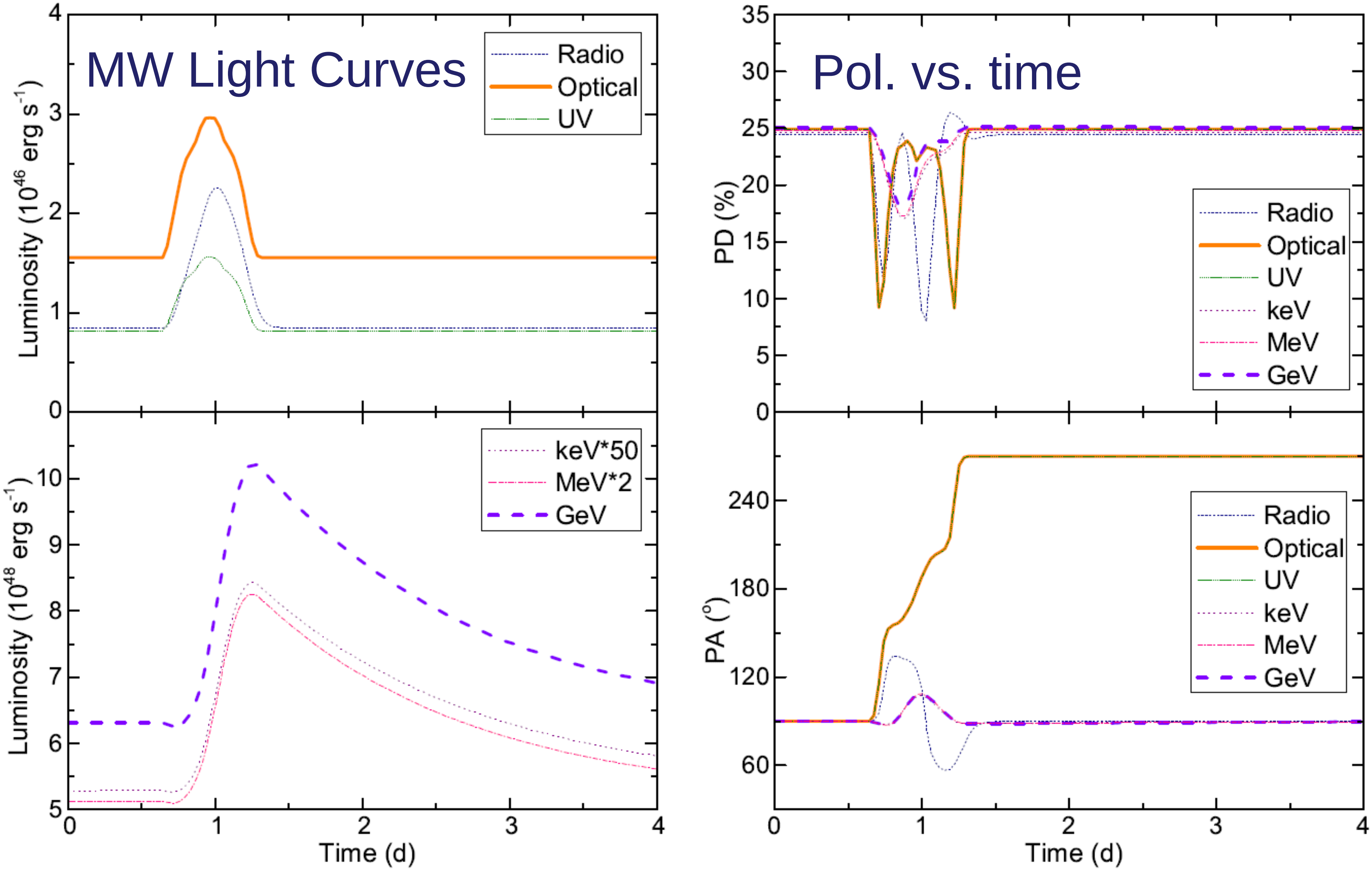


Snap-Shot SEDs



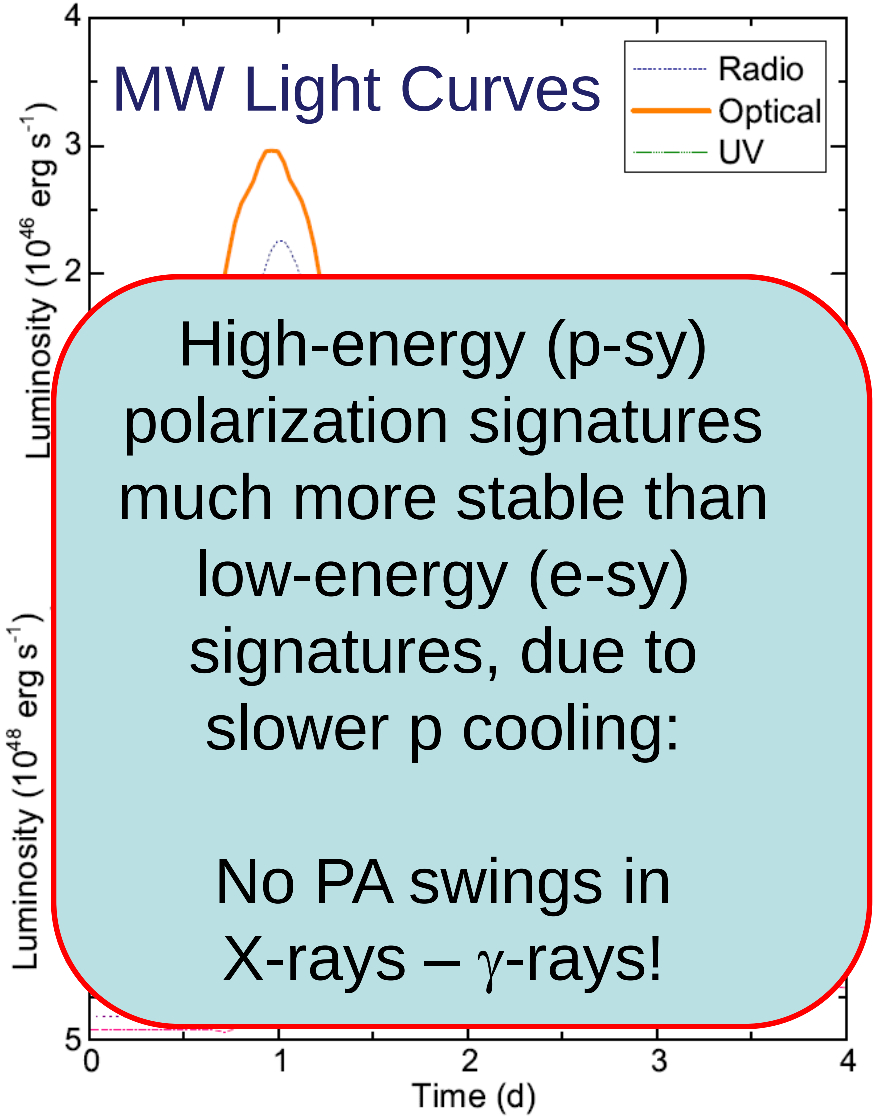
Pol. Deg. vs. Photon Energy

3D Lepto-Hadronic Internal Shock model



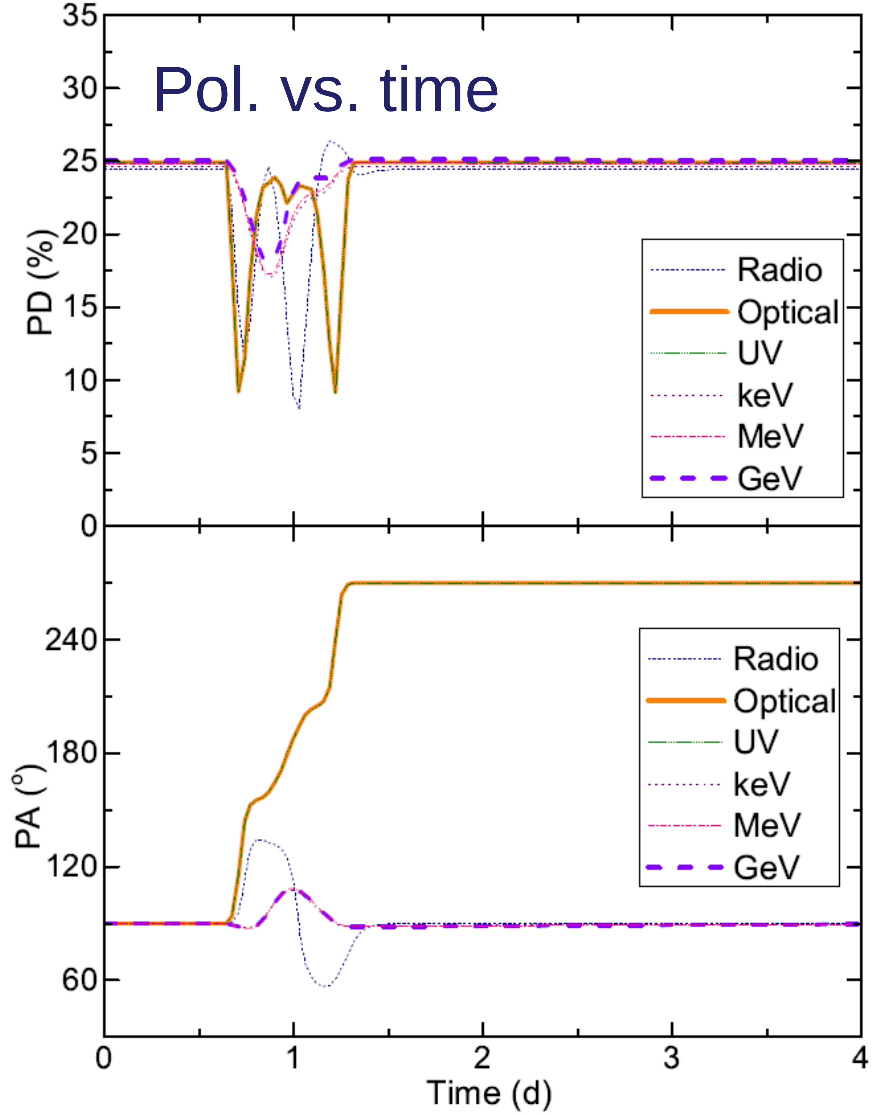
(Zhang et al. 2016b)

3D Lepto-Hadronic Internal Shock model



High-energy (p-sy) polarization signatures much more stable than low-energy (e-sy) signatures, due to slower p cooling:

No PA swings in X-rays – γ-rays!



(Zhang et al. 2016b)

Summary

1. Polarization-angle swings correlated with MW flares are possible with a straight jet, pervaded by a helical B field. Fit to 3C279 event suggests magnetic energy dissipation as driver of flaring activity.

2. Coupling with MHD simulations → PA rotations with MW flares require moderate magnetizations ($\sigma \sim 1$) and strong (fast) shocks.

3. 3D time- and polarization-dependent radiation transfer simulations for a proton-synchrotron dominated lepto-hadronic model: High-energy (X-ray/gamma-ray) polarization signatures are expected to be less variable than low-energy (e-synchrotron) ones. PA swings in X-rays / γ-rays are unlikely if high-energy emission has hadronic origin.