Blazar Variability and Polarization Probe Radiation and Particle Acceleration

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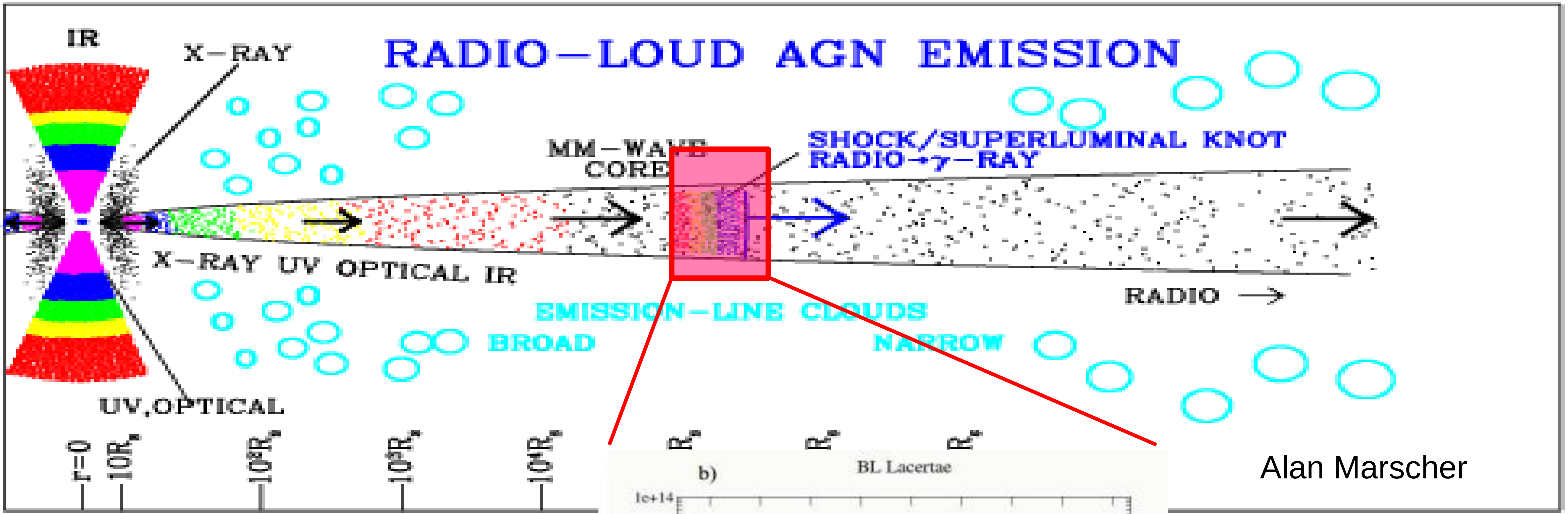
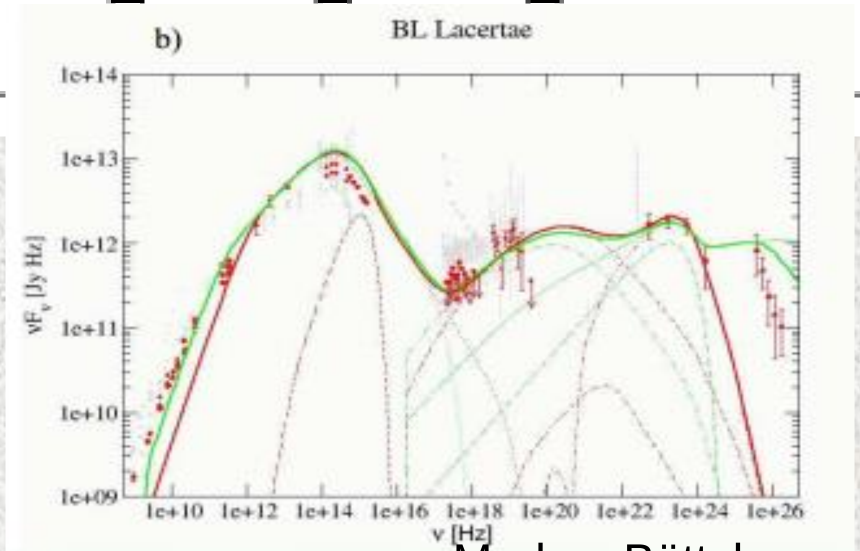
Inner Harbor, MD

Blazar Jet



Alan Marscher



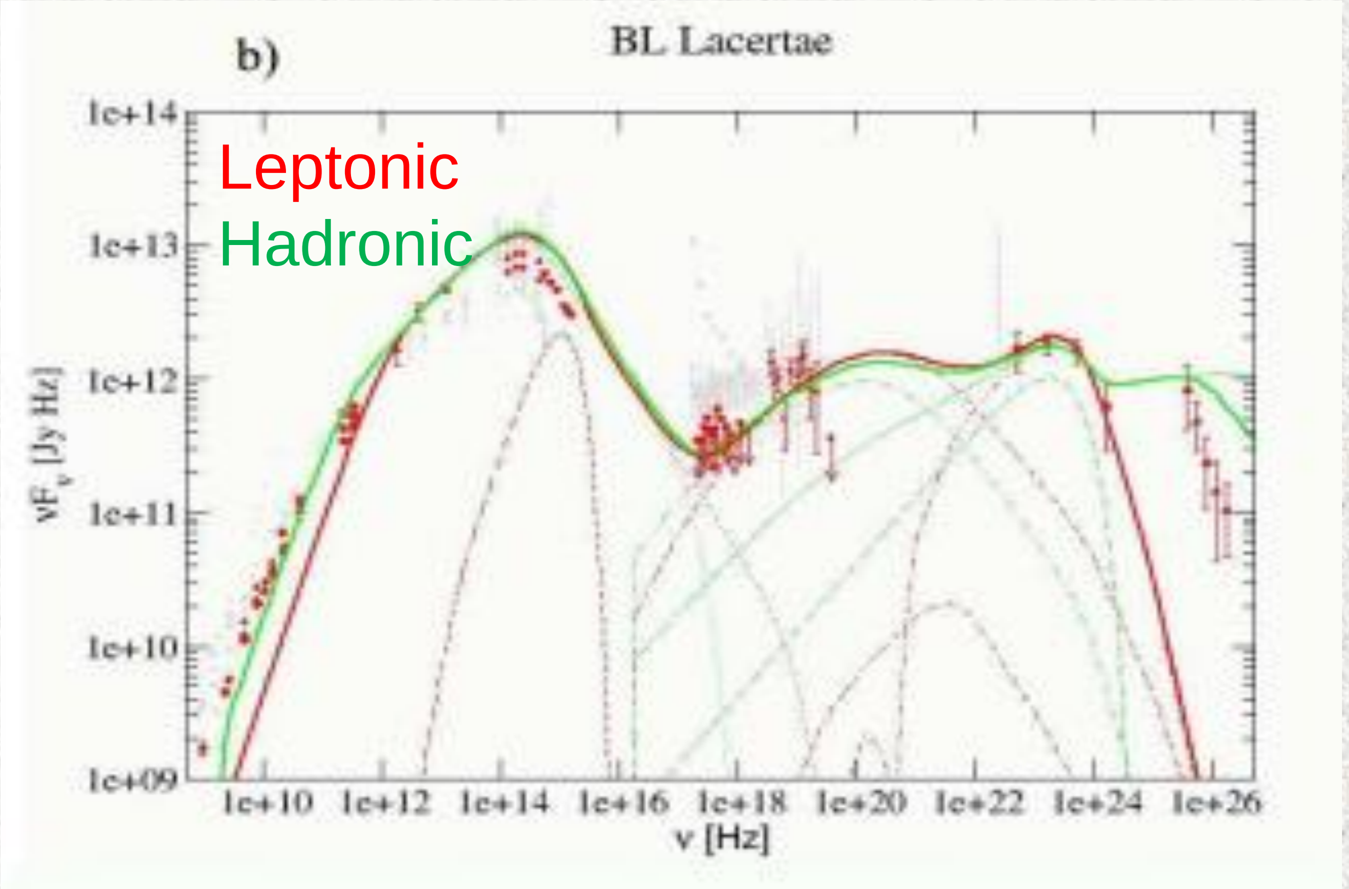
Blazar zone!

Markus Böttcher

Blazar Jet

Big questions:

1. How does the jet radiate?
2. What causes the variability?



Strongly Variable
in all bands!

Blazar Jet

Big questions:

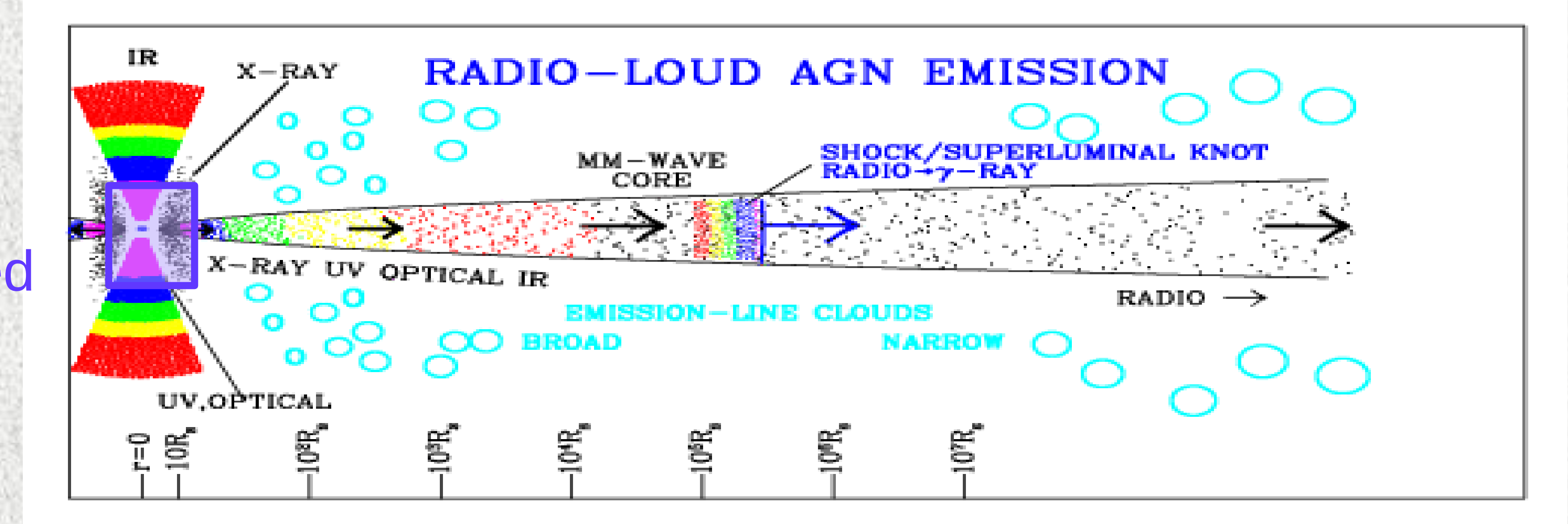
1. How does the jet radiate?
2. What causes the variability?

Real question:

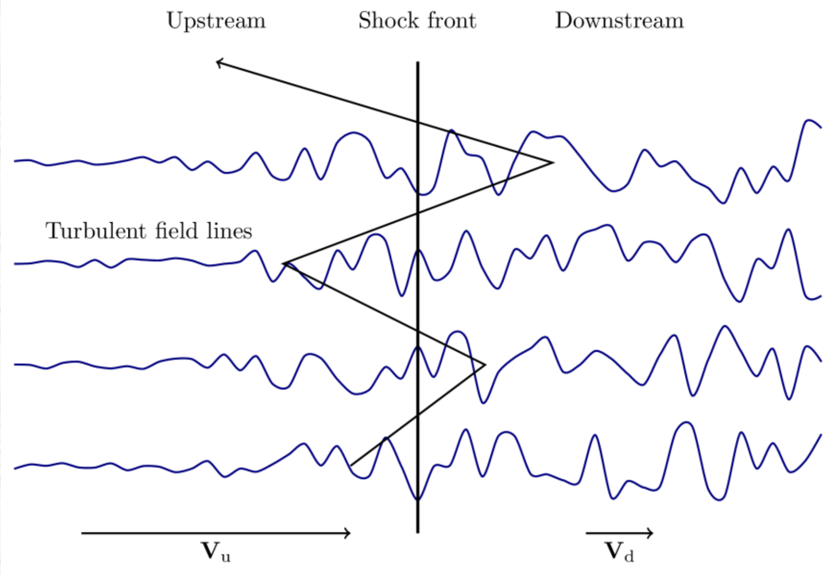
How does the jet convert its initial magnetic energy to accelerate particles and make radiation?

Polarization can probe the magnetic field!

Highly magnetized



Shock vs Magnetic Instability



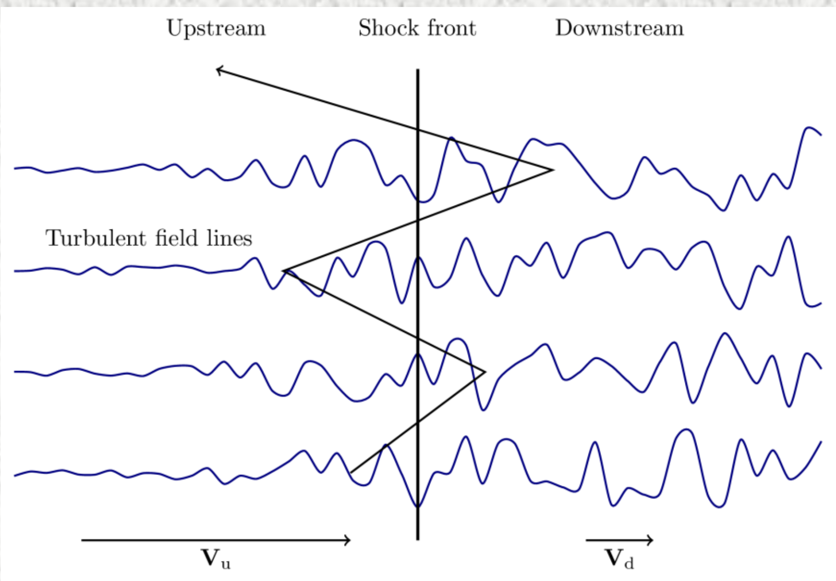
Shock

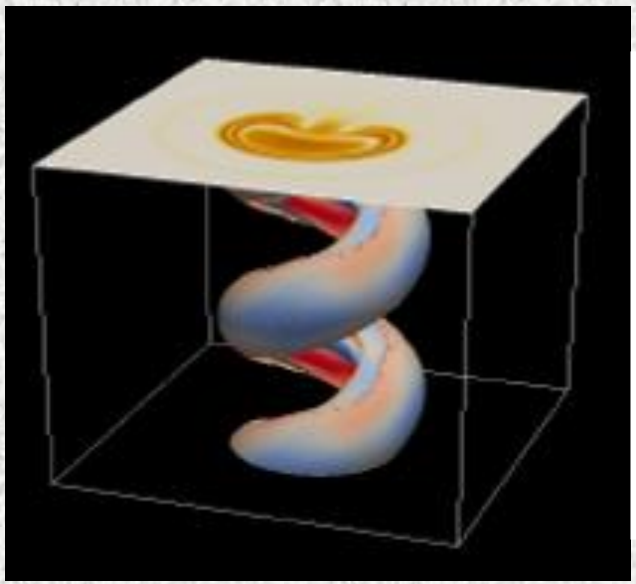
Magnetic Energy → Bulk Kinetic Energy

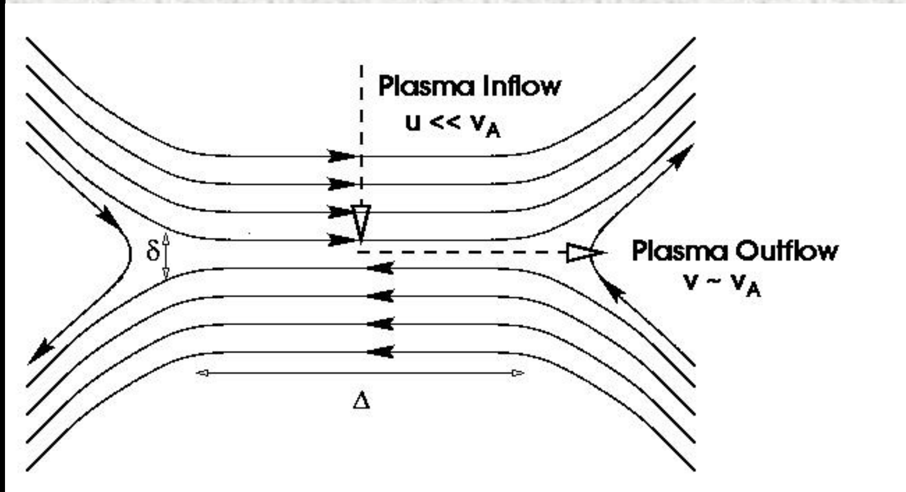
↓

Variability ← Shock

Shock vs Magnetic Instability







Shock

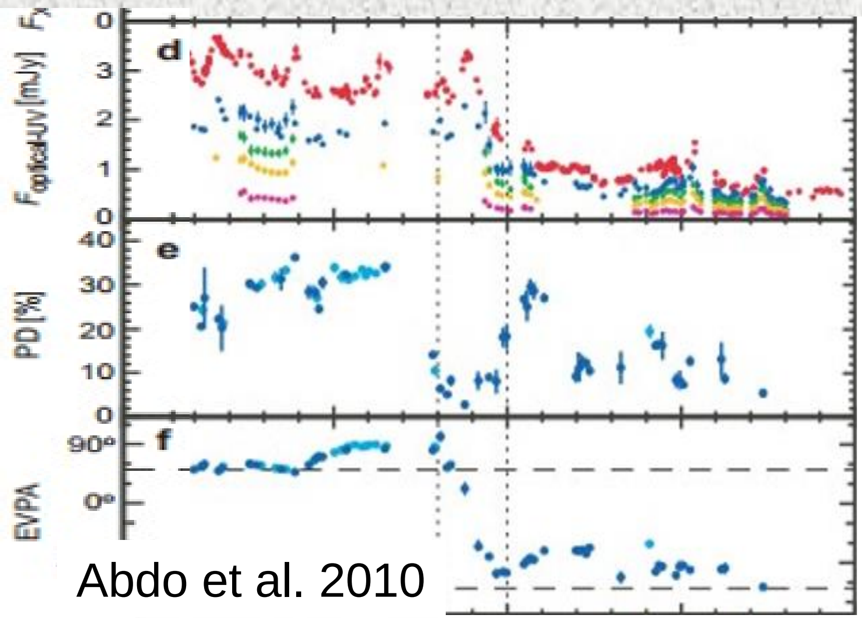
Magnetic Energy → Bulk Kinetic Energy → Shock → Variability

Kink and Magnetic Reconnection

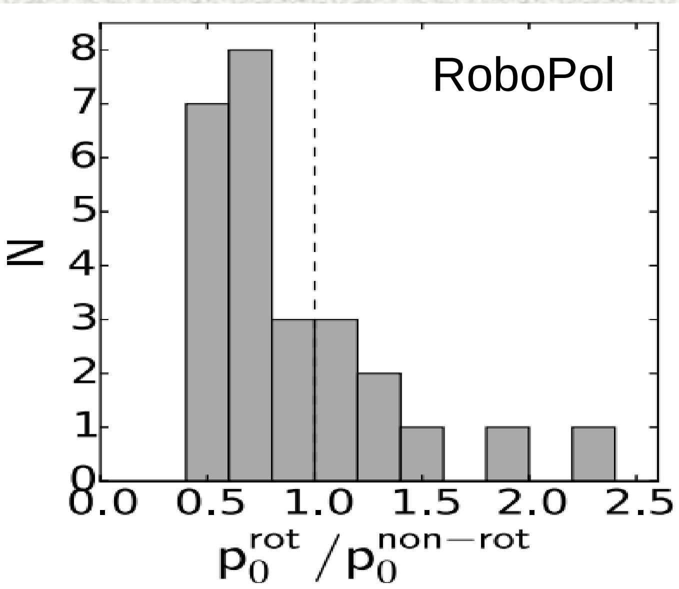
Magnetic Energy → Magnetic Instability → Variability

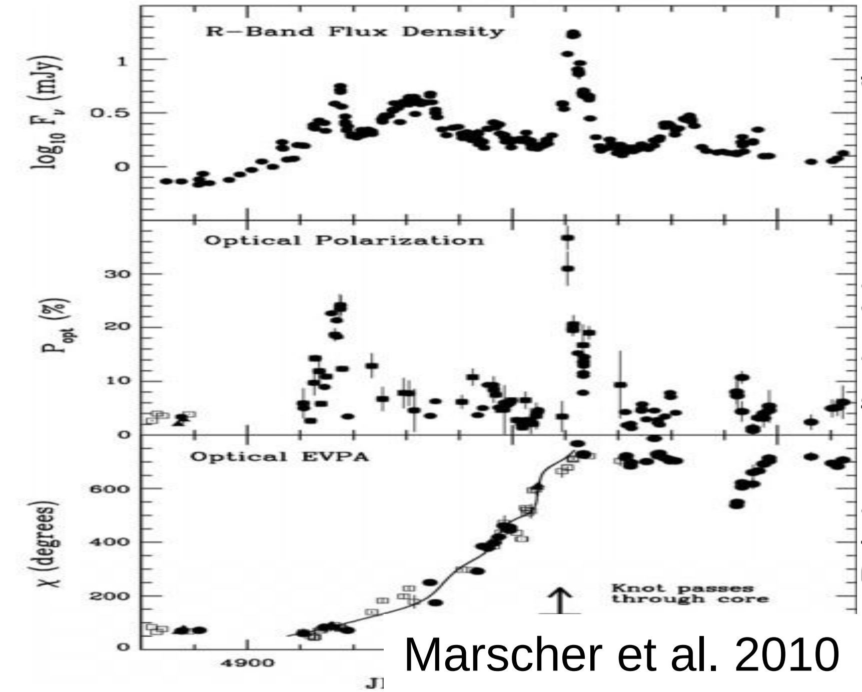
Both can produce power-law spectra and usual light curves, but they involve very different magnetic field evolution!

Polarization Observations

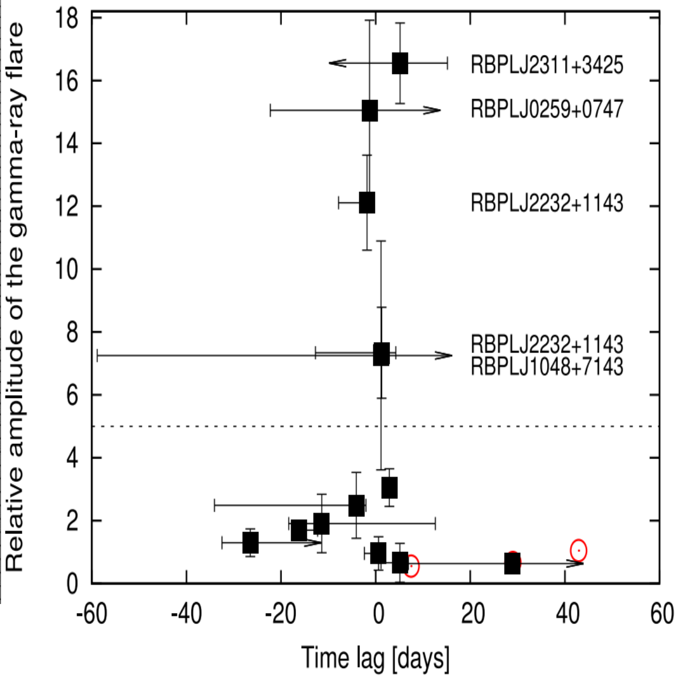


Abdo et al. 2010





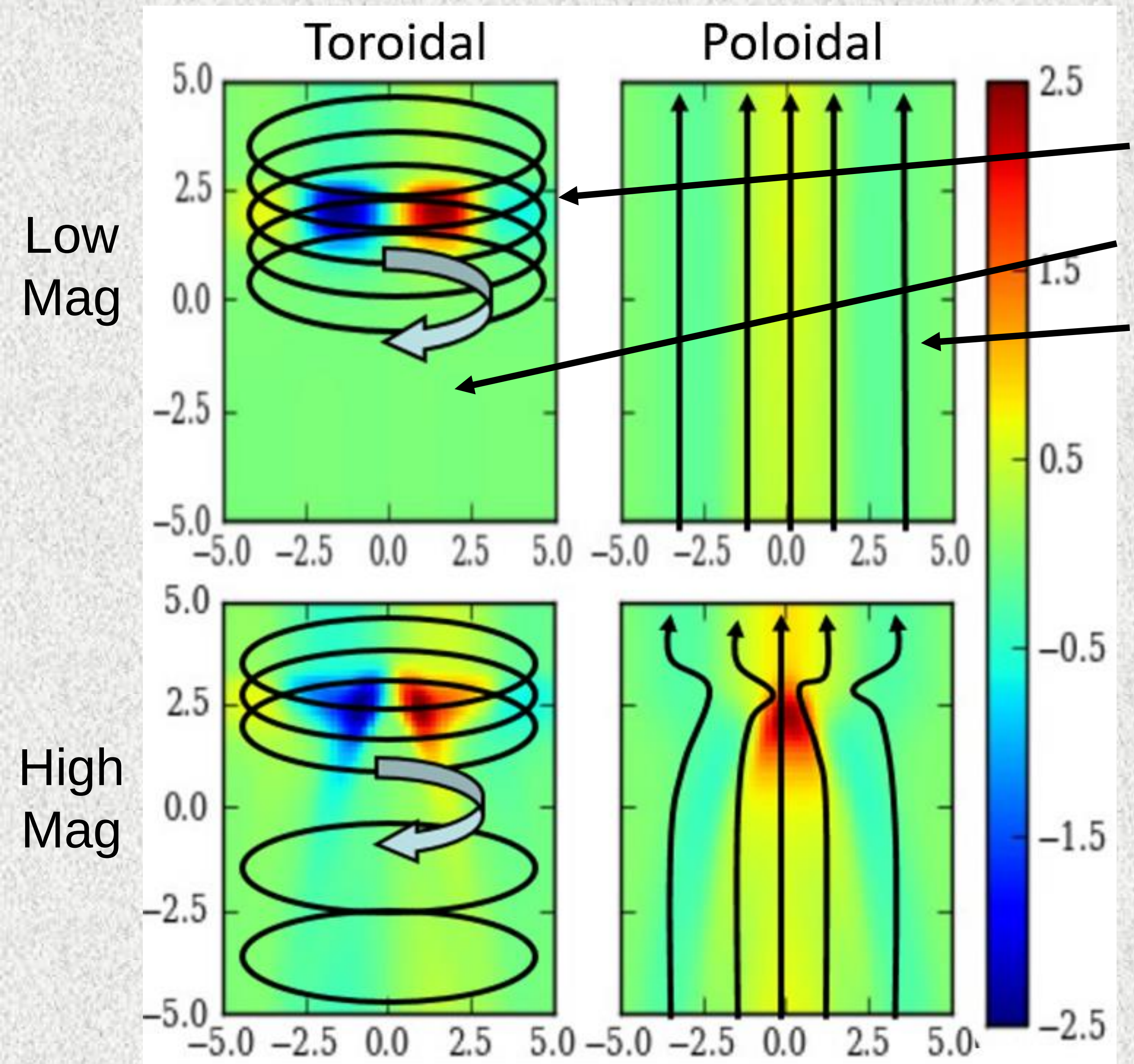
Marscher et al. 2010



1. Polarization degree generally stays below 30%.
2. Polarization angle can make swings, occasionally larger than 180 degree.
3. Polarization angle swings are accompanied by multi-wavelength flares.
4. Polarization degree is generally lower during swings.

Magnetic field actively participates in the particle acceleration!

Shock—Magnetic Field and Polarized Radiation

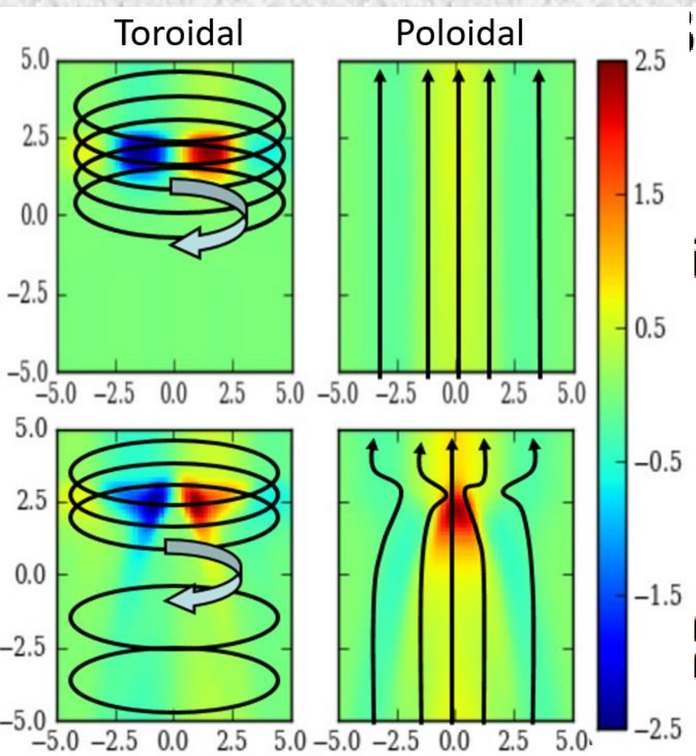


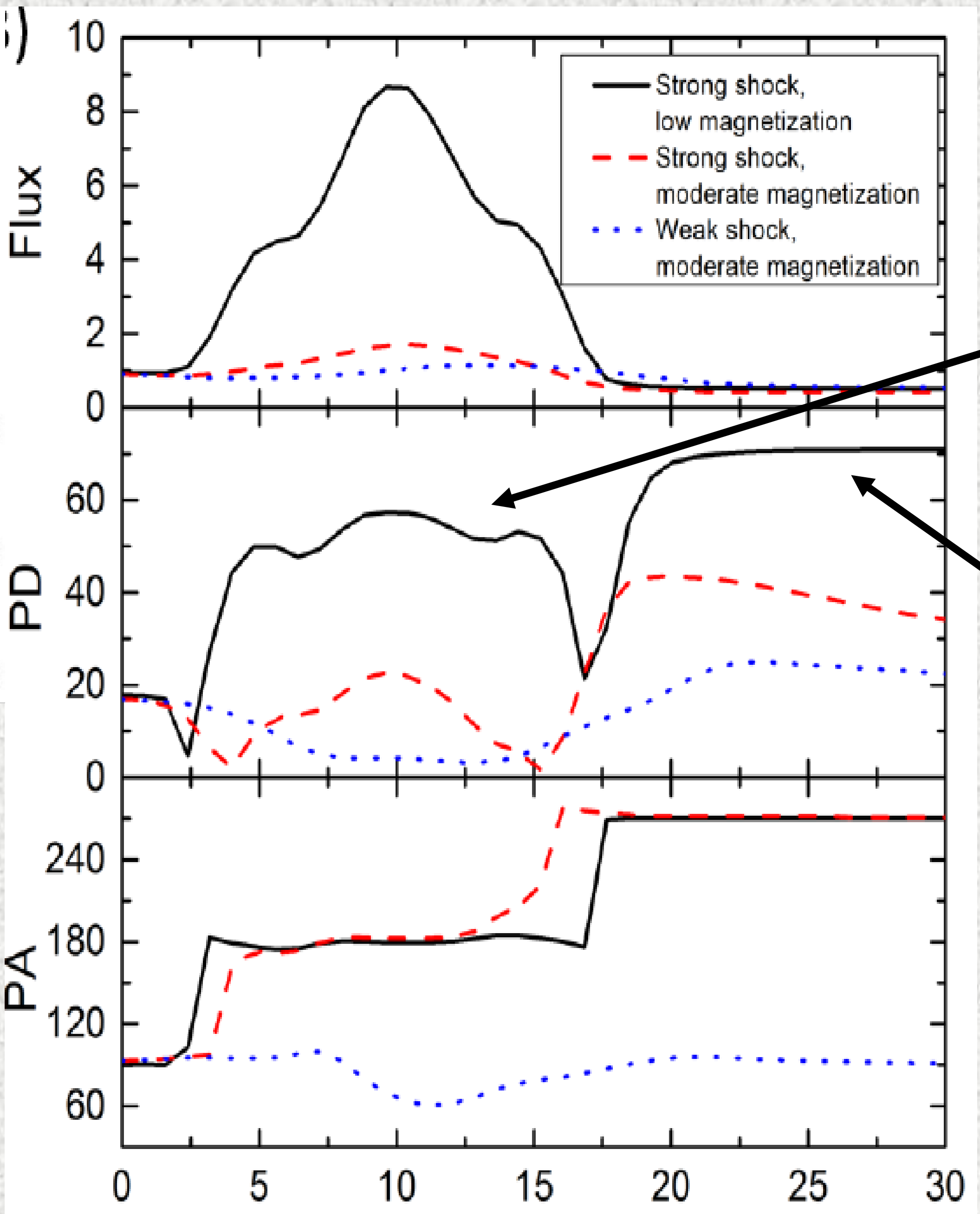
Low Magnetization:

1. Strong compression at shock front
2. Toroidal component is wiped out
3. Poloidal component is unaffected

Zhang et al. 2016 ApJ 817, 63

Shock—Magnetic Field and Polarized Radiation



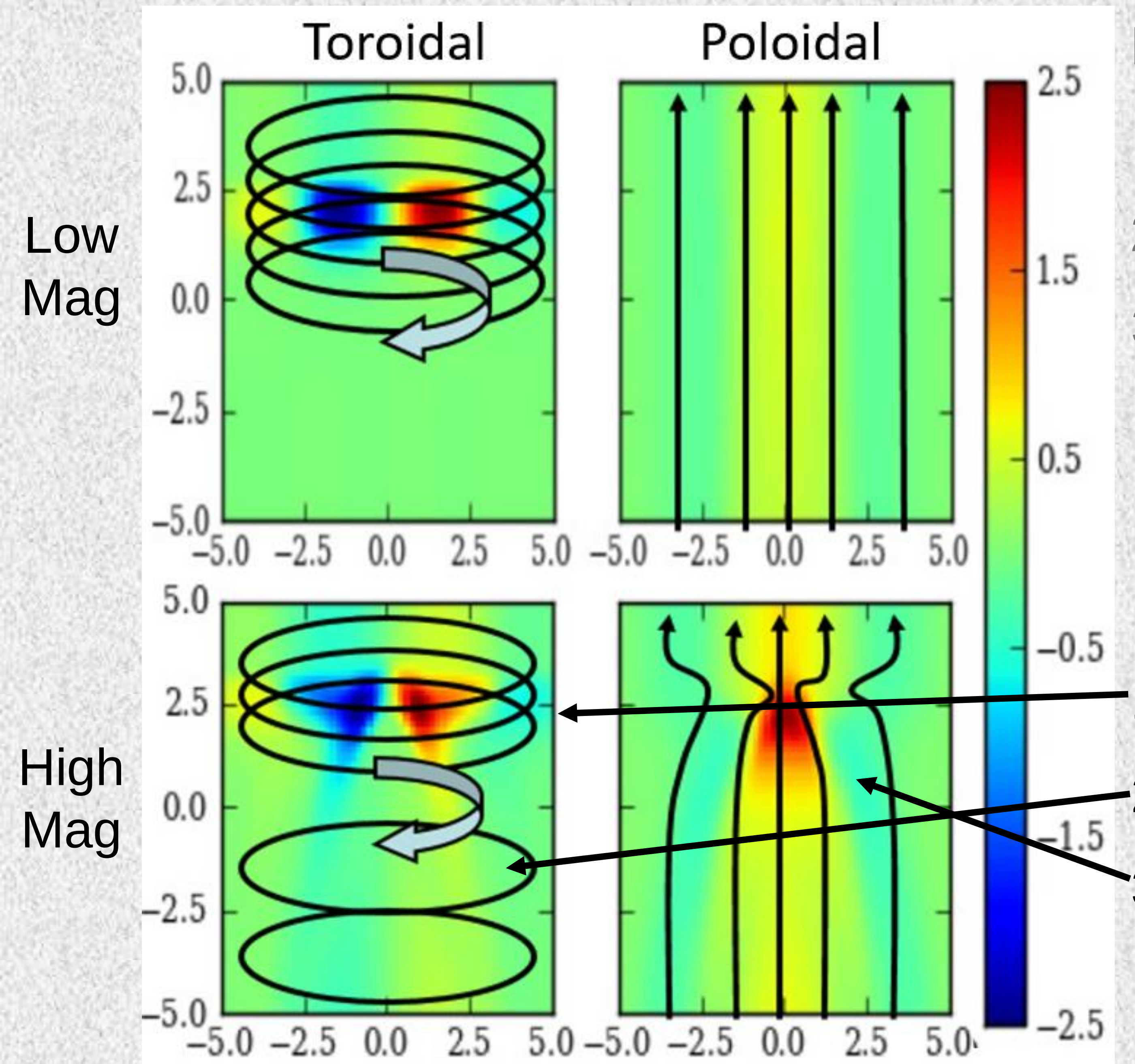


Low magnetization:

1. Strong shock disrupts the magnetic field, leading to PD>30% during flare
2. PD cannot revert to the initial level after flare.

Zhang et al. 2016 ApJ 817, 63

Shock—Magnetic Field and Polarized Radiation



Low Magnetization:

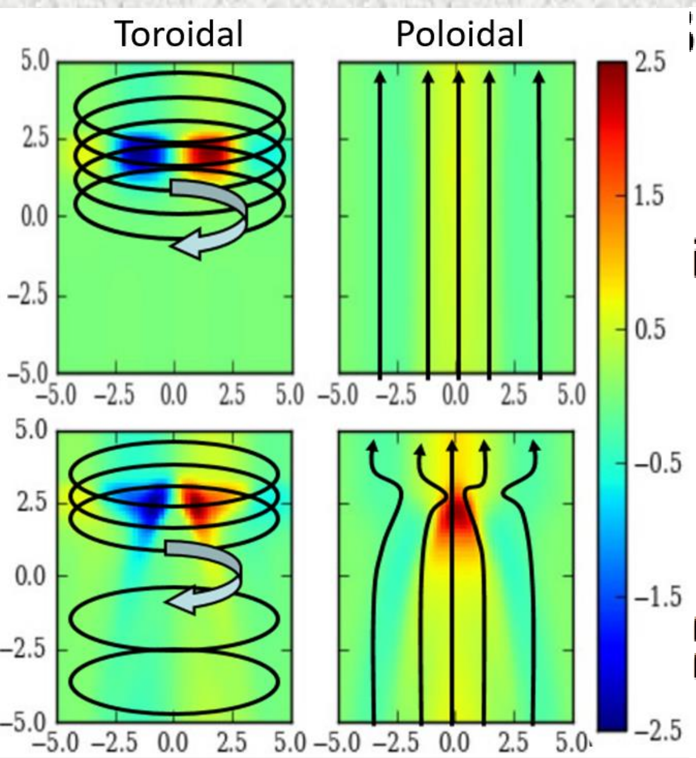
1. Strong compression at shock front
2. Toroidal component is wiped out
3. Poloidal component is unaffected

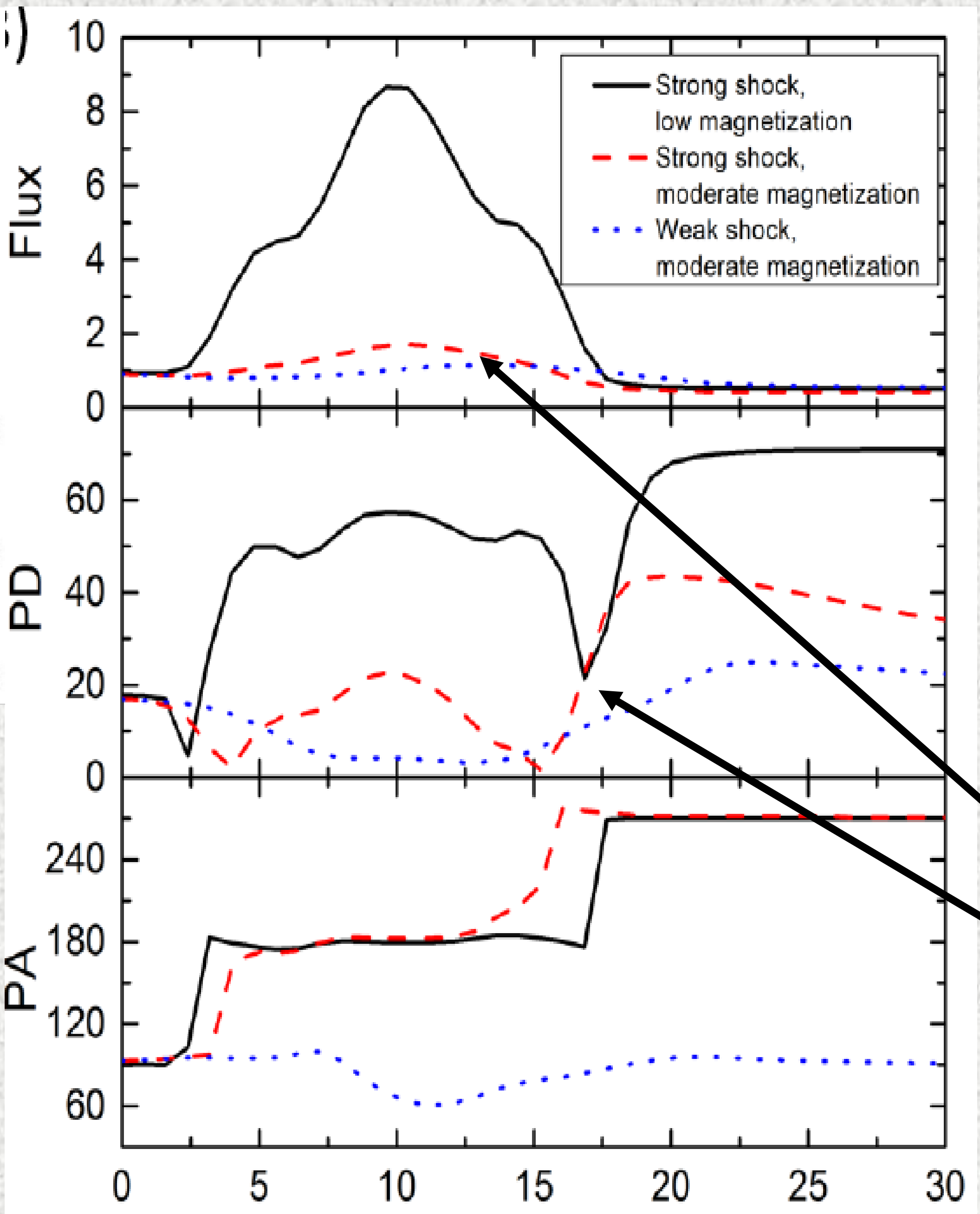
High Magnetization:

1. Shock front changes the shape
2. Toroidal component is left over
3. Poloidal component is squeezed

Zhang et al. 2016 ApJ 817, 63

Shock—Magnetic Field and Polarized Radiation





Low magnetization:

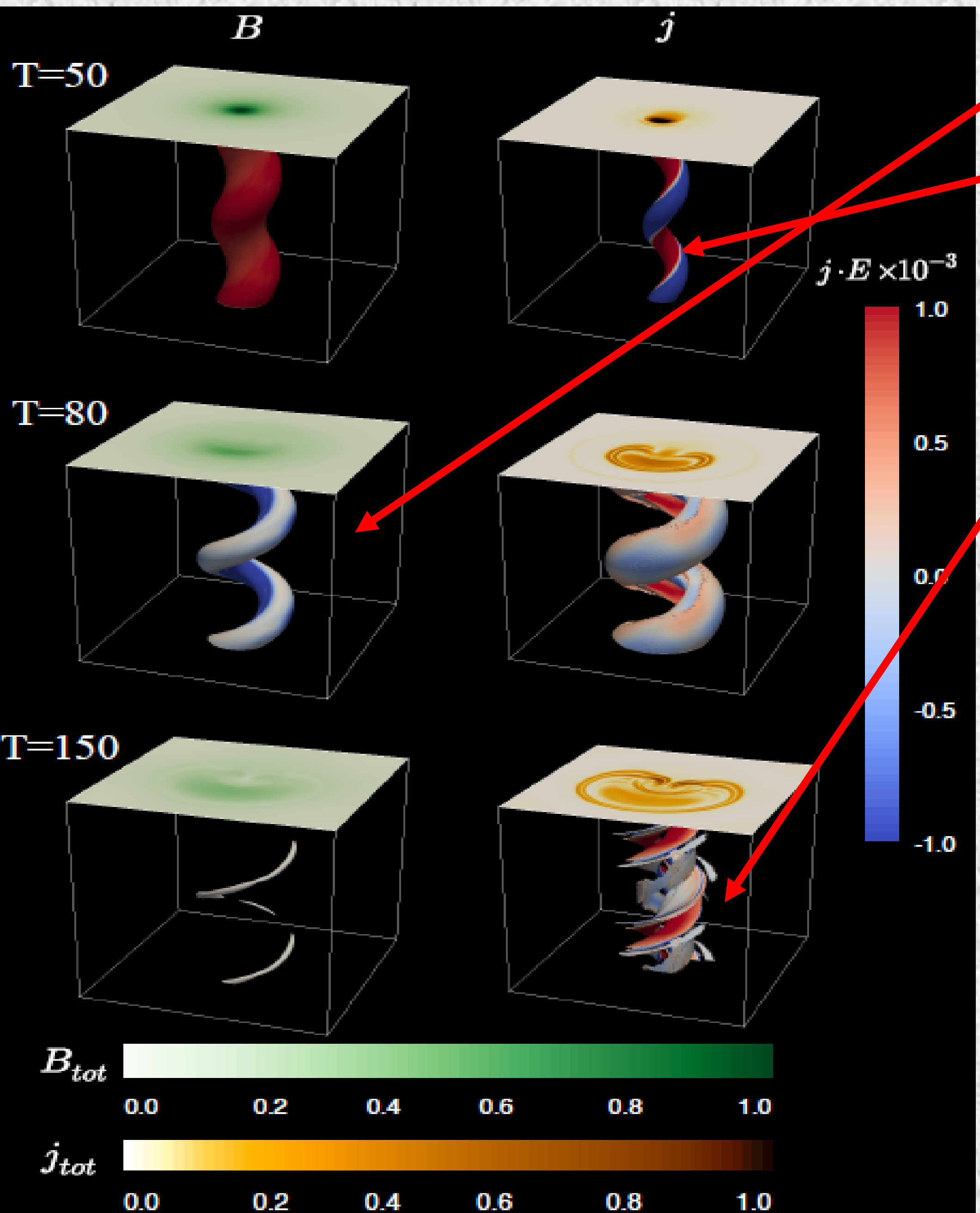
1. Strong shock disrupts the magnetic field, leading to PD>30% during flare
2. PD cannot revert to the initial level after flare.

High magnetization:

1. Shock is weak.
2. PD stays low and can revert to the initial level.

Zhang et al. 2016 ApJ 817, 63

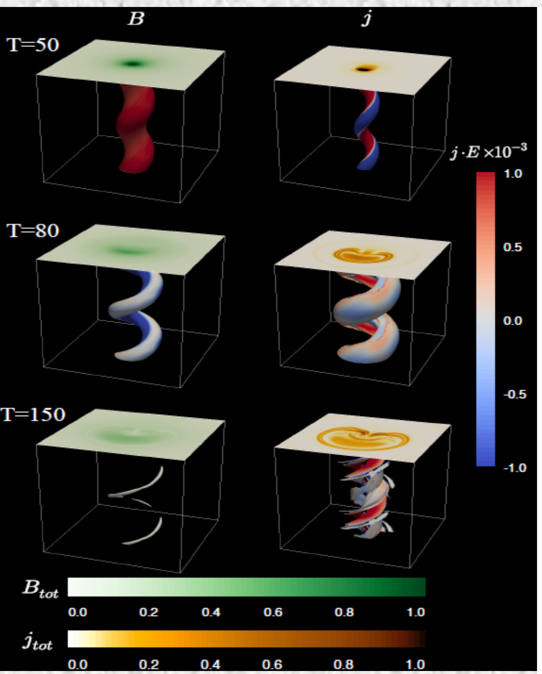
Kink—Magnetic Field and Polarized Radiation

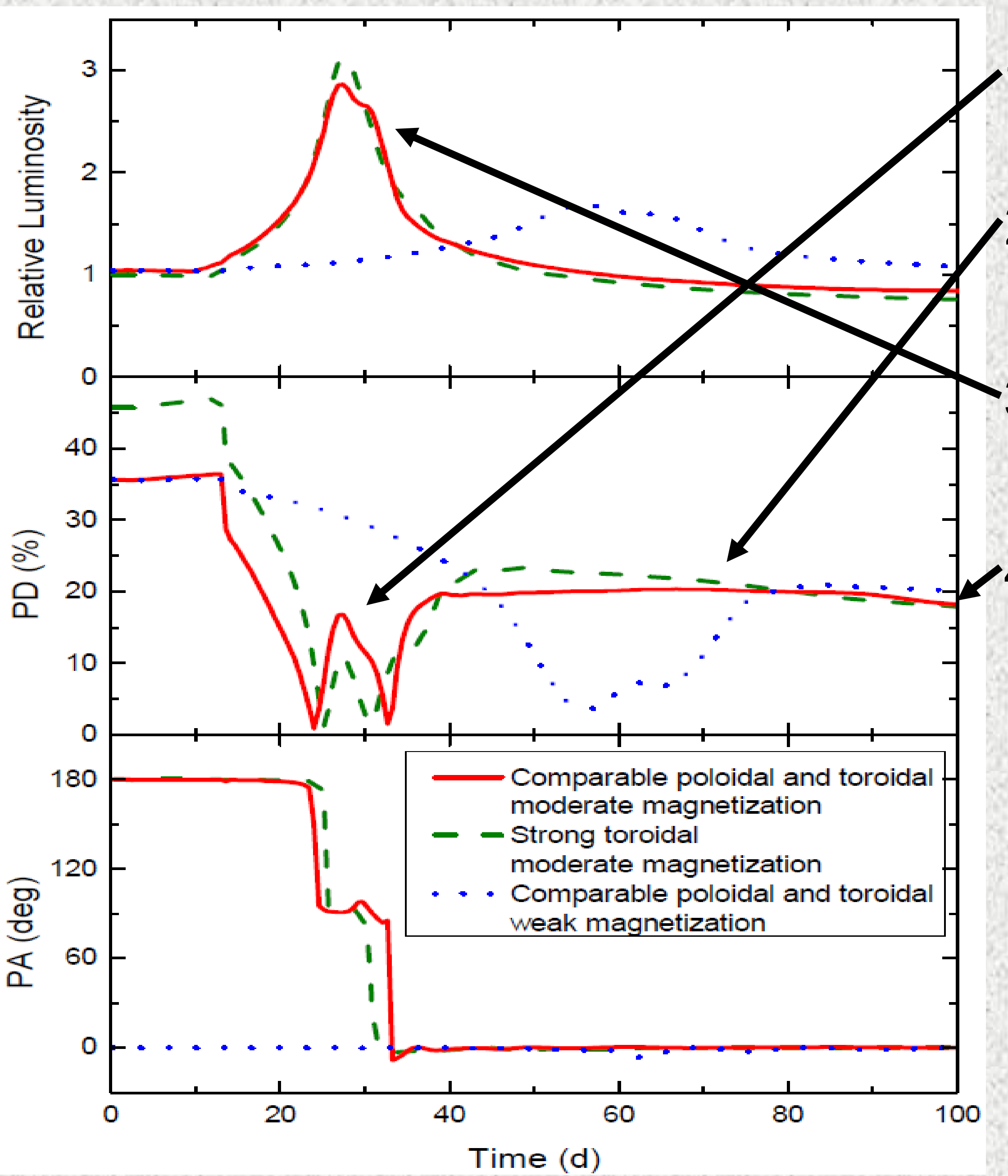


1. Magnetic field becomes twisted
2. Magnetic power is strong and positive on the inner side of kink patterns, but weak or even negative on the outer side
3. Magnetic field becomes turbulent in the end

Zhang et al. 2017 ApJ 835, 125

Kink—Magnetic Field and Polarized Radiation

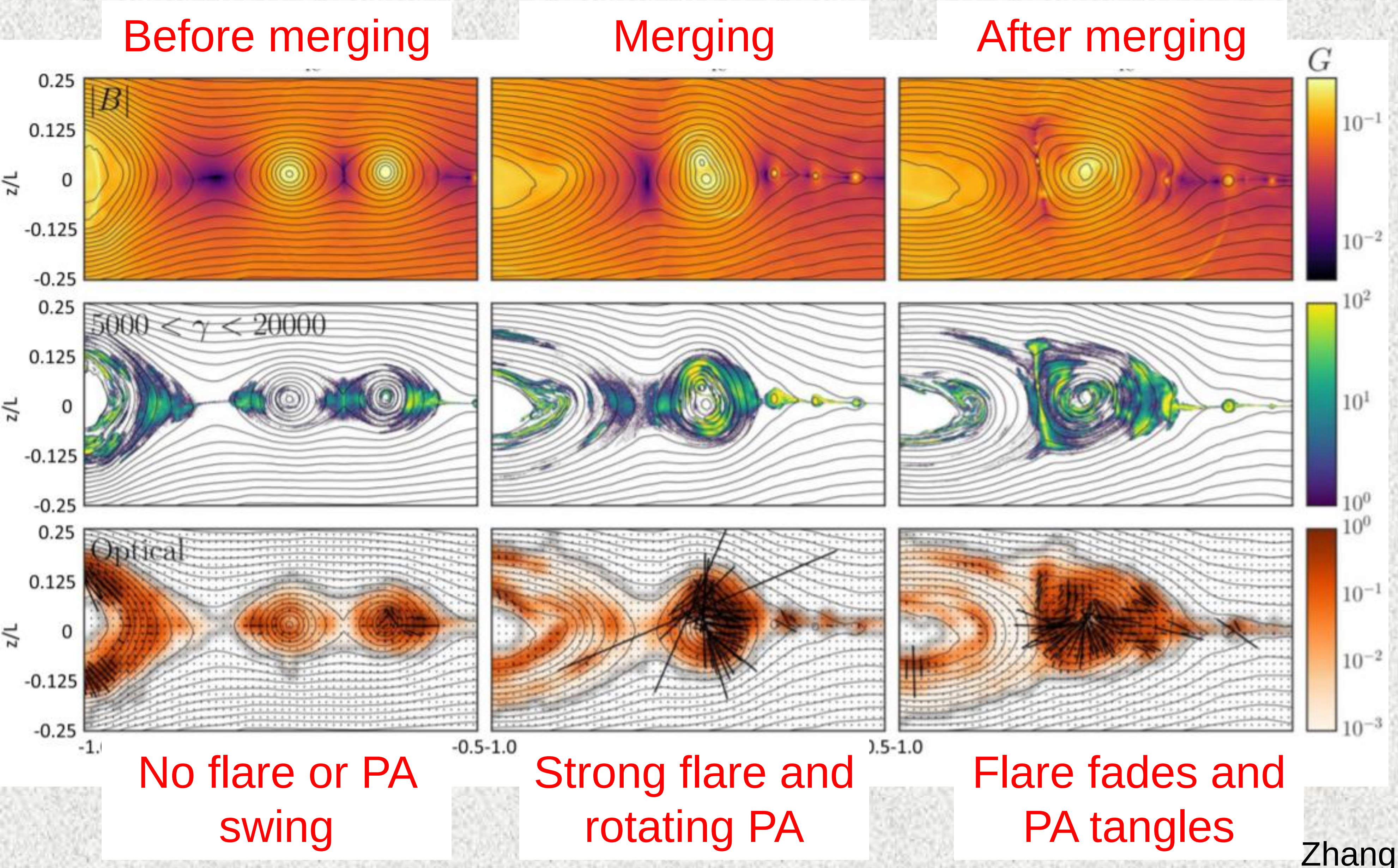




1. Polarization degree always drops during flares
2. Polarization degree stays at low level
3. Kink can make adequate flare level
4. Polarization degree ends between 10-20%

Zhang et al. 2017 ApJ 835, 125

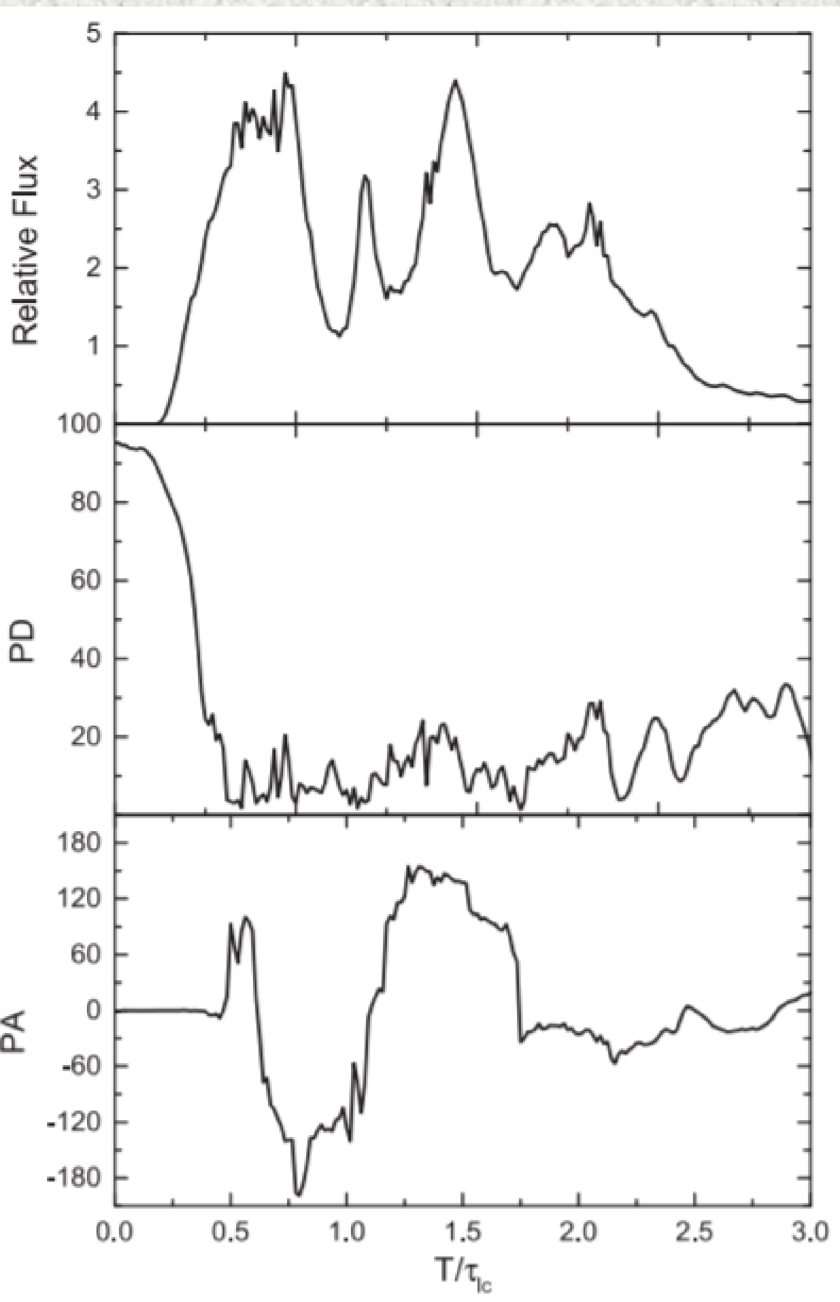
Magnetic Reconnection



Plasmoid coalescence leads to flares and large PA swings!

Zhang et al. 2018 ApJL 862, L25

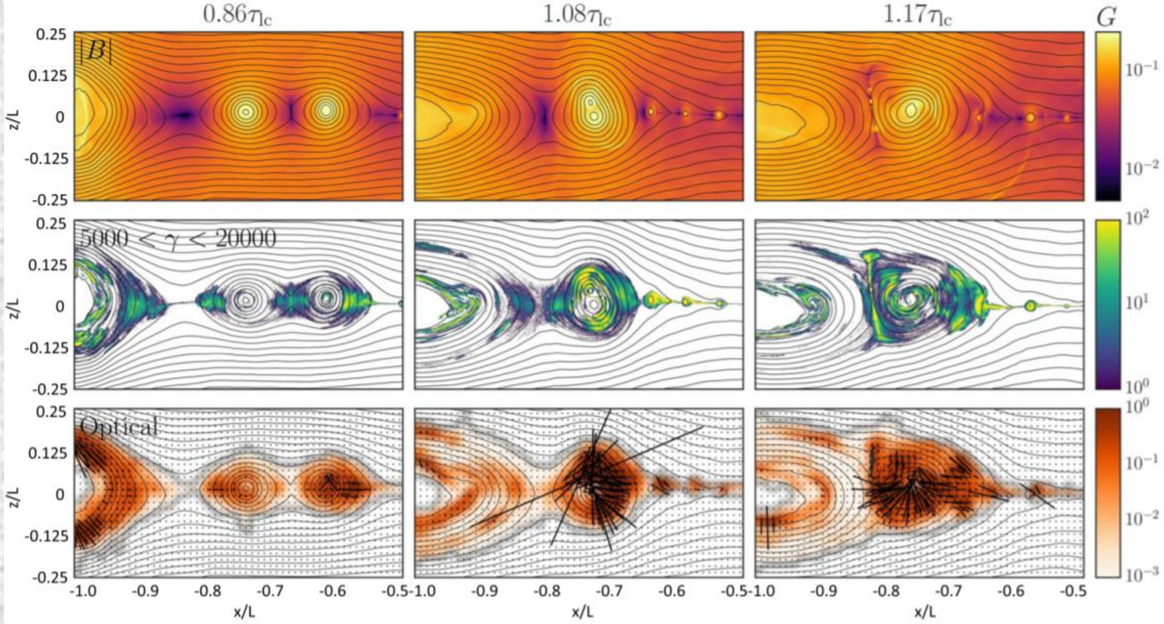
Magnetic Reconnection



Multiple mergers give multiple flares

PD stays low and fluctuates

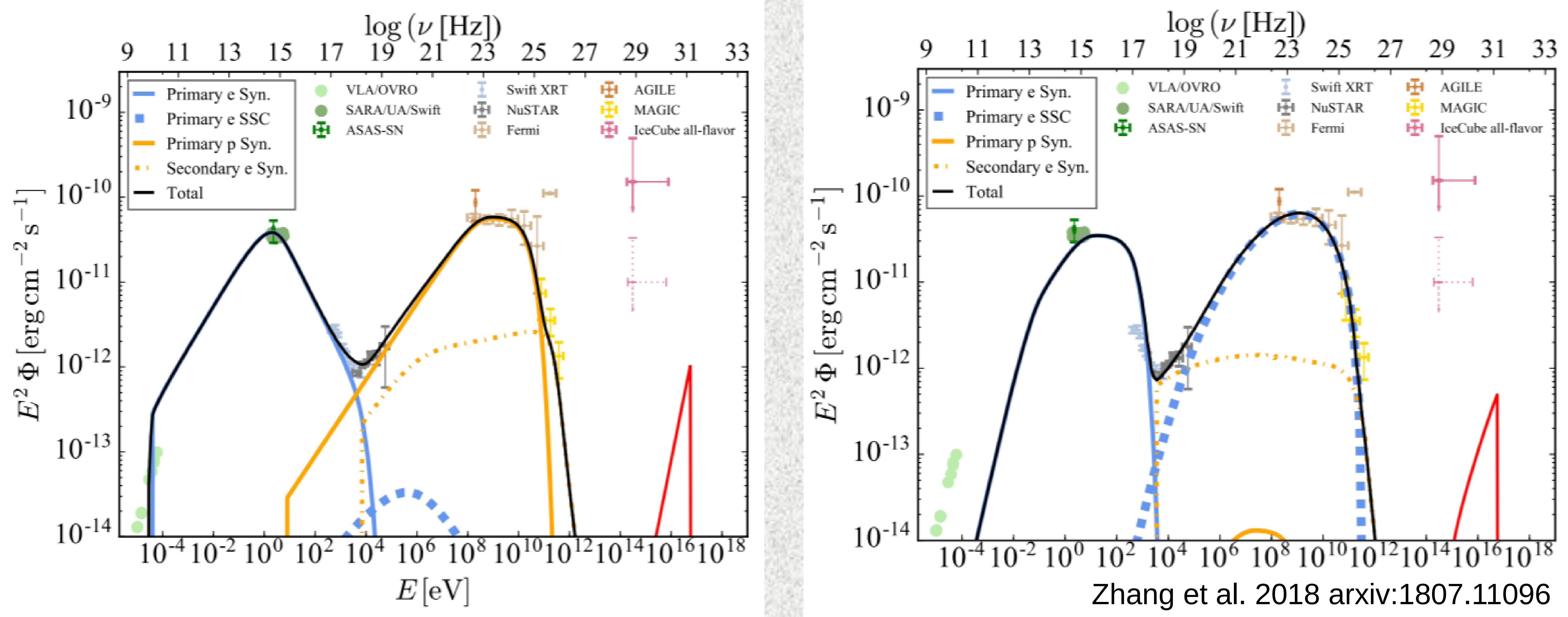
Large PA swings that can go in both directions



Multiple flares + low and fluctuating PD + >180 deg PA swing can be unique signatures of magnetic reconnection in jets!

Zhang et al. 2018 ApJL 862, L25

Hadronic Blazars



Zhang et al. 2018 arxiv:1807.11096

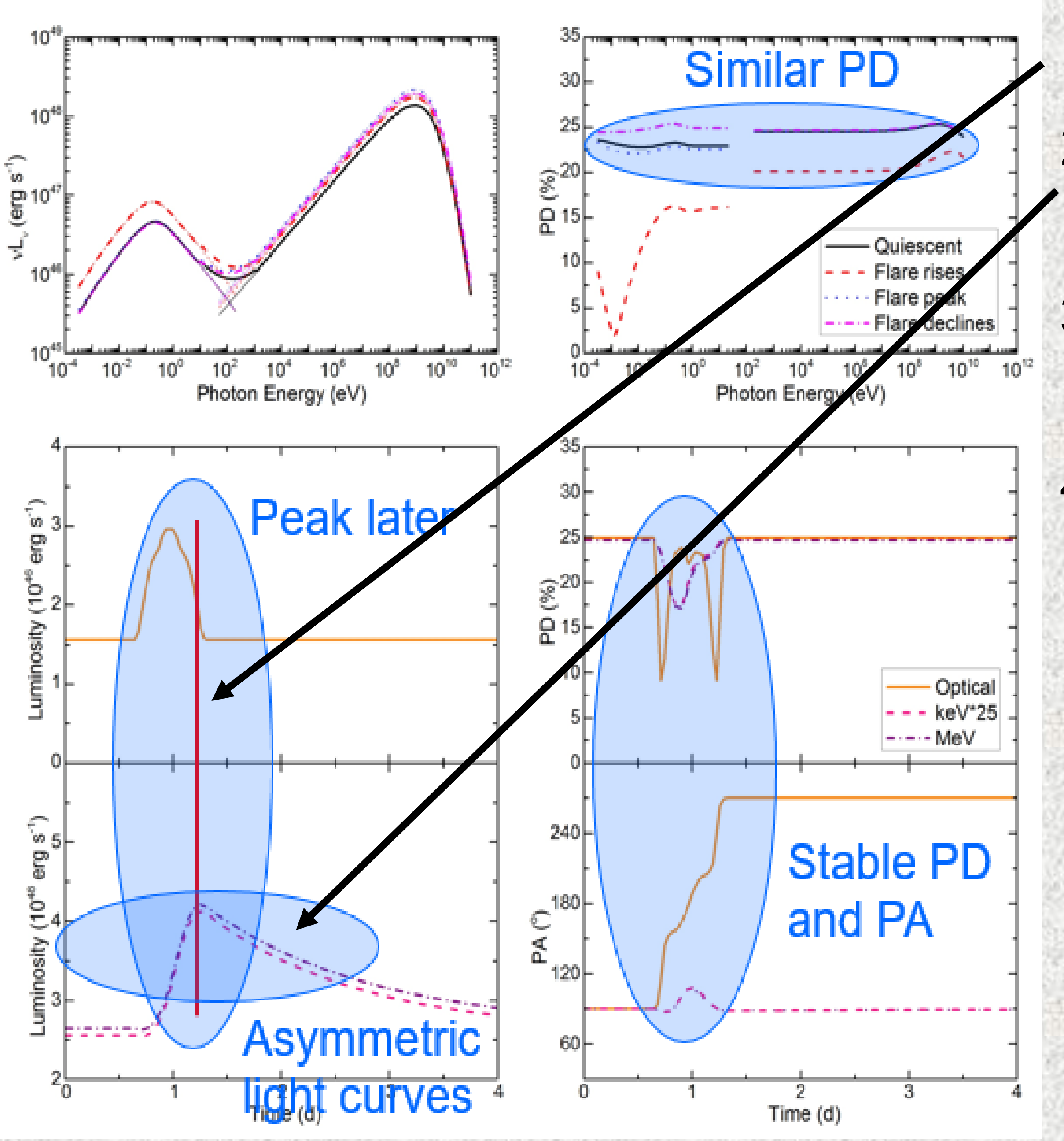
Proton synchrotron:

- High magnetic strength
- High magnetization

Inverse Compton scattering:

- Low magnetic strength
- Low magnetization

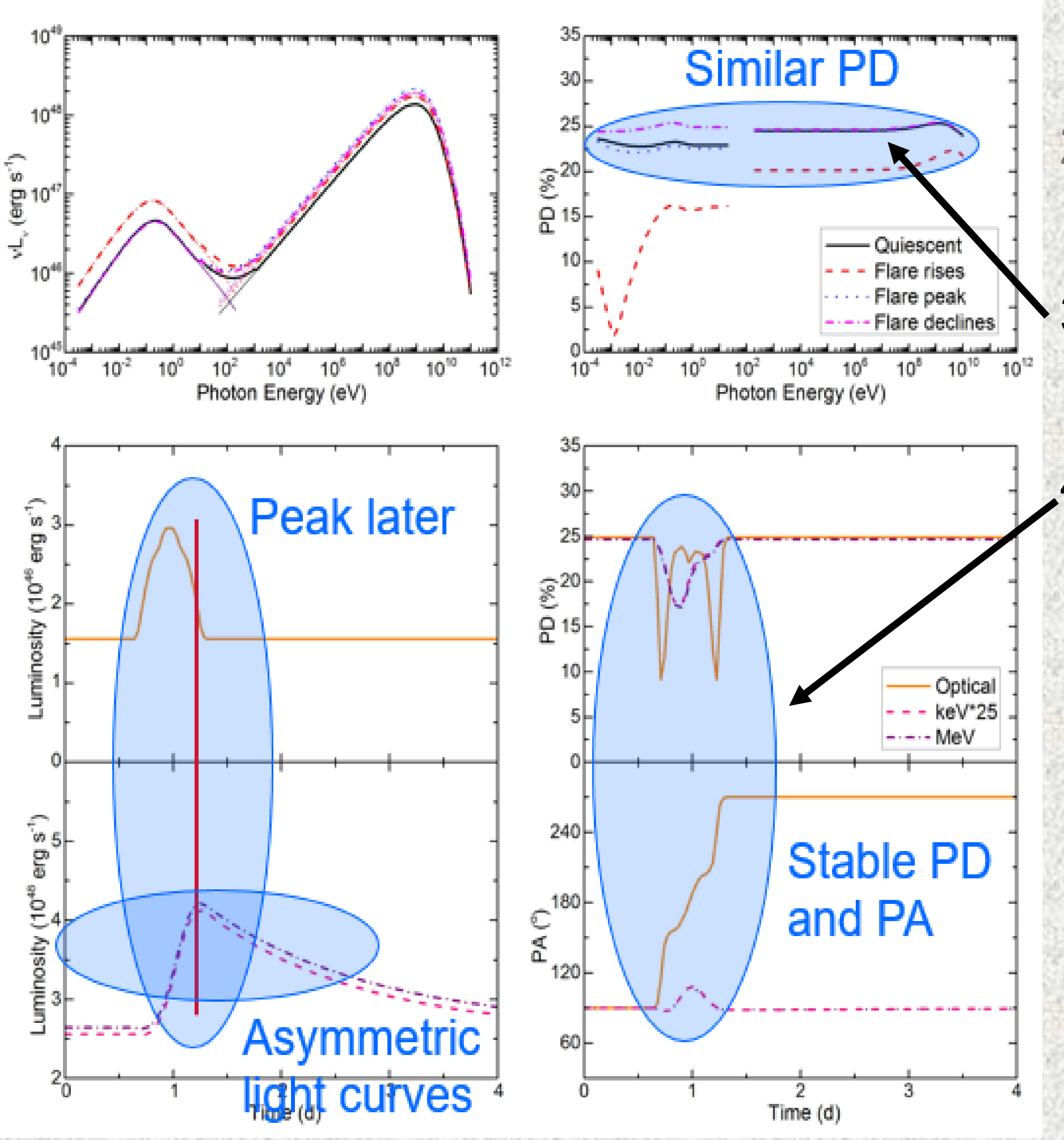
Hadronic Blazars



1. High-energy light curve peaks later
2. High-energy light curve appears asymmetric
3. X-ray and gamma-ray light curves peak slightly later than the optical.
4. X-ray and gamma-ray polarization degree and angle are less variable than the optical.

Zhang et al. 2016 ApJ 829, 69

Hadronic Blazars—Multi-Wavelength Polarimetry



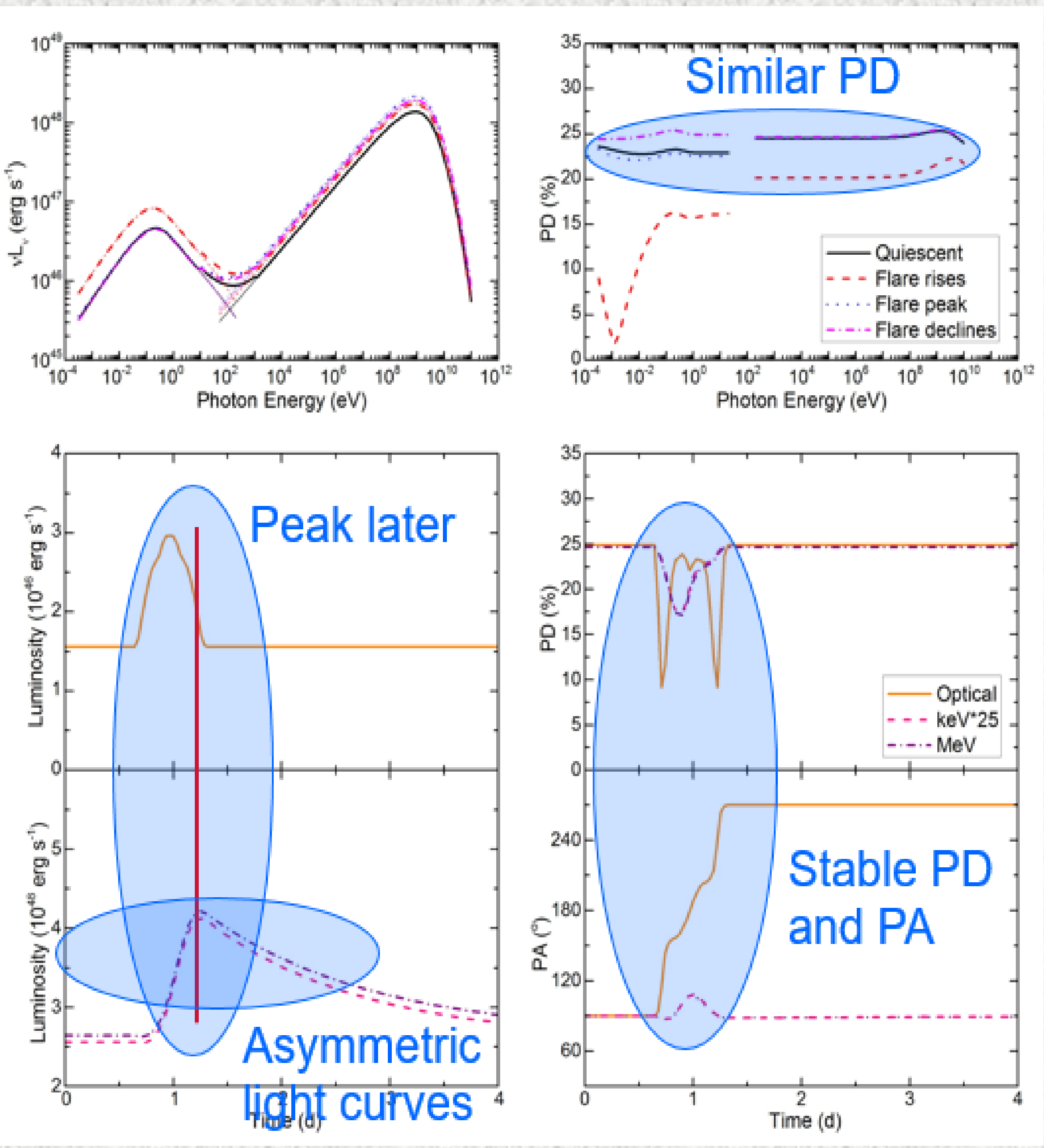
1. High-energy light curve peaks later
2. High-energy light curve appears asymmetric
3. X-ray and gamma-ray polarization degree is similar to optical bands
4. X-ray and gamma-ray polarization signatures are less variable due to slow proton cooling

In particular, gamma-ray polarization can put strong constraints on cosmic ray acceleration and neutrino production.

We need self-consistent magnetic field evolution and photomeson processes.

Zhang et al. 2016 ApJ 829, 69

Hadronic Blazars—Multi-Wavelength Polarimetry



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High-energy polarimeters coming soon!

X-ray: IXPE (selected), XPP, etc.

Gamma-ray: AMEGO, e-ASTROGAM, etc.

Zhang et al. 2016 ApJ 829, 69

Summary

1. Optical polarization signatures suggest that the blazar emission region has considerable magnetic energy.
2. Multi-wavelength light curves and optical polarization can diagnose the shock- and kink-driven flares.
3. Multiple flares, low and fluctuating polarization degree, and >180 degree polarization angle swing can be unique signatures of magnetic reconnection in blazars.
4. Multi-wavelength polarimetry provides independent constraints on cosmic ray acceleration and neutrino production, as well as jet energy dissipation, complementary to neutrino observations.
5. Progress of synergized self-consistent theoretical simulations and polarization-sensitive observational programs is ongoing, stay tuned!

Acknowledgement

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RoboPol team

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LANL institutional computing

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