Polarization Swings from Curved Trajectories of the Emitting Regions

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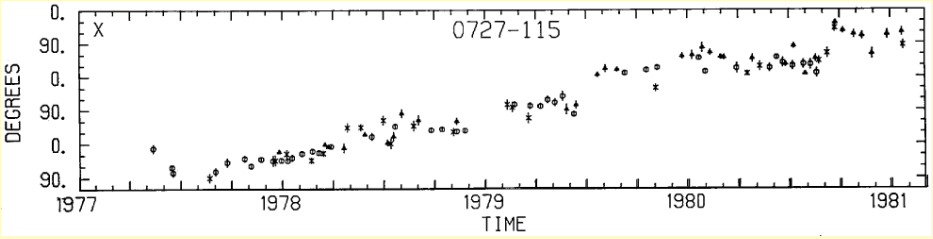
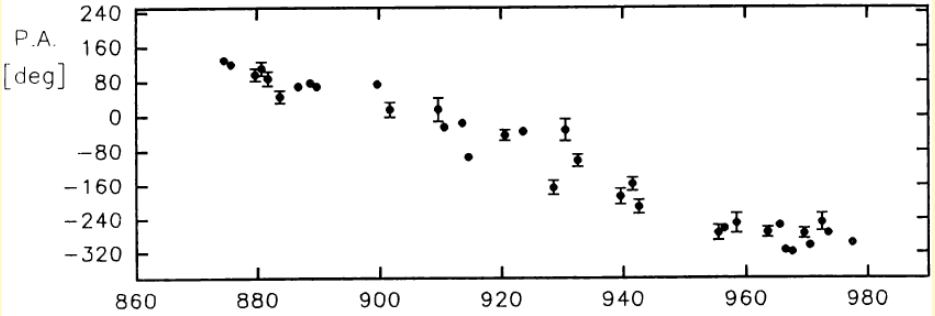
Polarization Angle (PA) Rotations & Swings

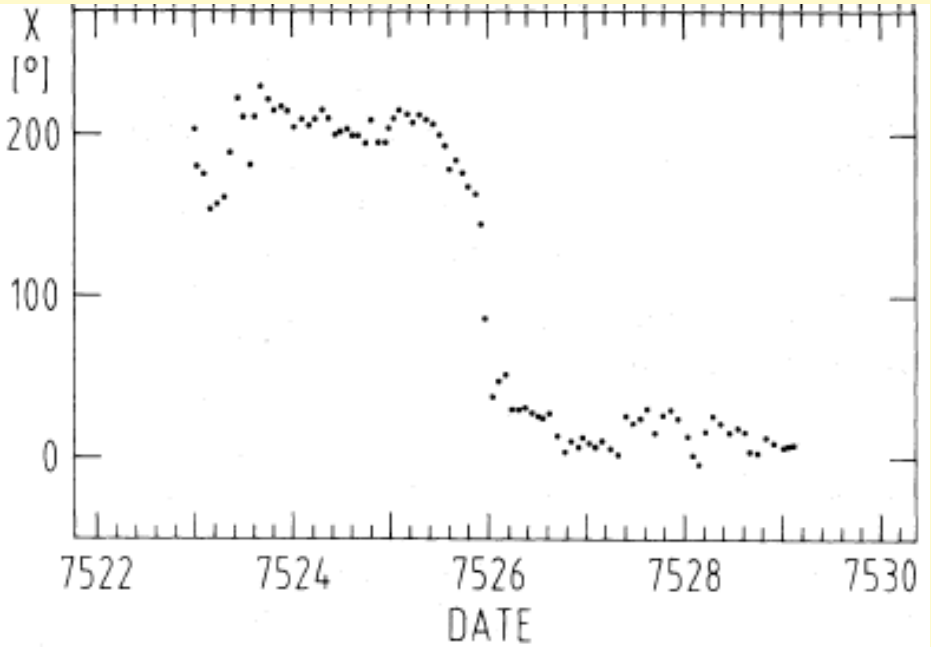
Observed variations of the polarization angle in blazars are characterized by widely different amplitudes and timescales.



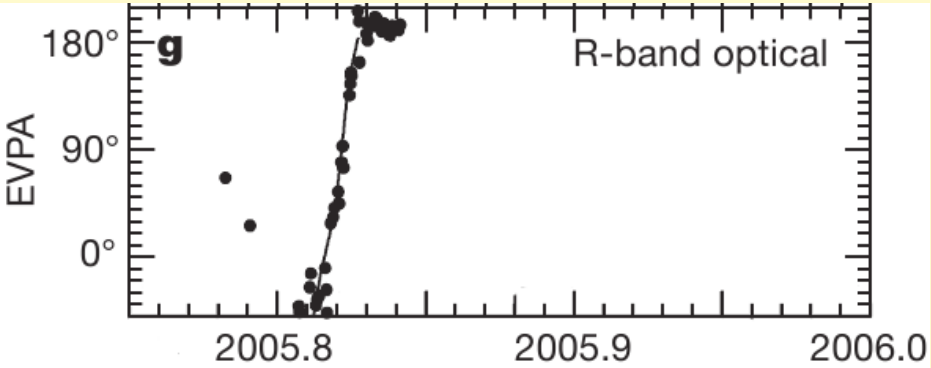
PKS 0727-115, (Aller, Aller & Hodge 1981)



PKS 0521-365, (Luna et al. 1993)



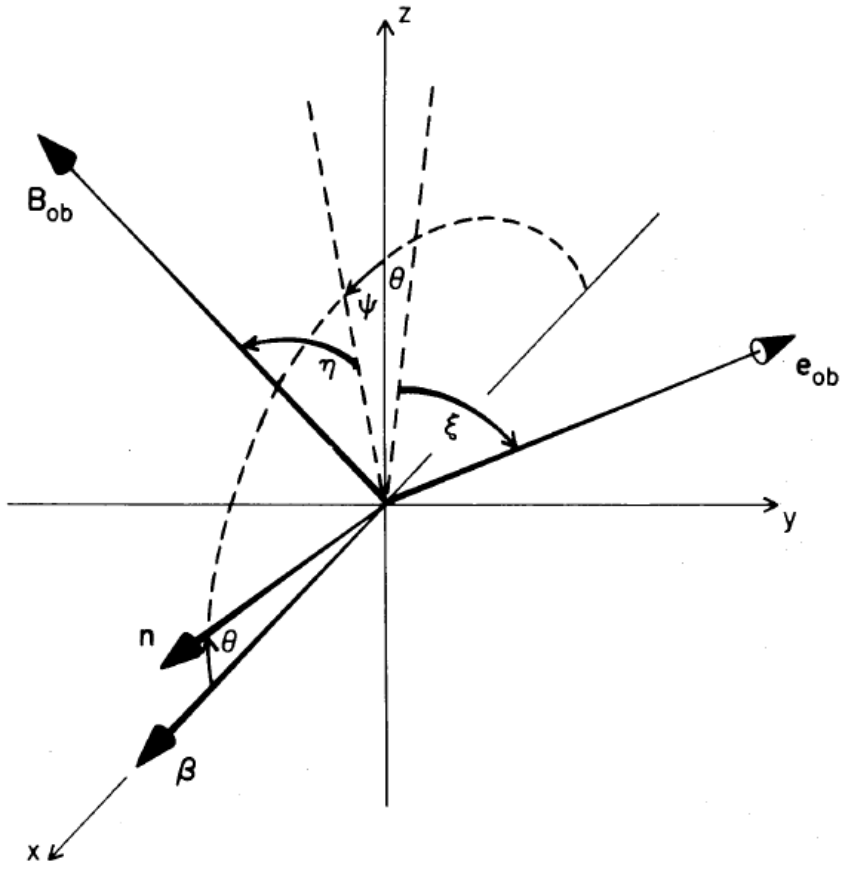
S5 0917+624, (Quirrenbach et al. 1989)

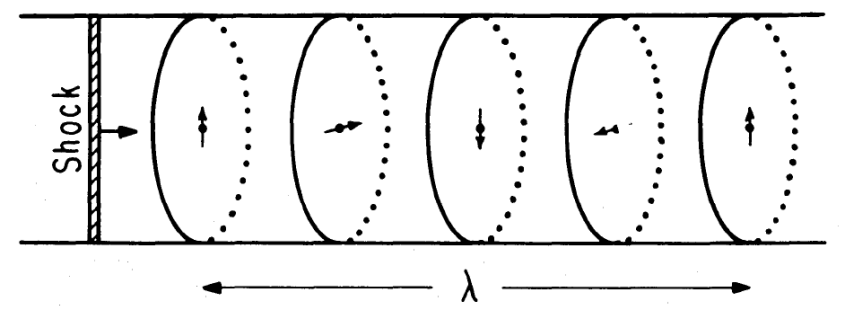


BL Lac, (Marscher et al. 2008)

Interpretations

- *(Blandford & Königl 1979)*
  Acceleration of the emitting region:
  - assumes net averaged magnetic field,
  - can produce swings of no more than 180°.
- *(Björnsson 1982)*
  Changes in the co-moving viewing angle or varying relative luminosities of two regions of different polarization.
  - Statistical distributions of magnetic fields studied.
- *(Königl & Choudhuri 1985)*
  Propagation of a shock through a helical magnetic field:
  - can produce PA rotations of arbitrarily large value.





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Our approach

- To reduce the number of degrees of freedom, we adopt the simplest description of the magnetic fields: perpendicular and axially symmetric.
- The properties of the polarization swings depend only on the kinematics of the dominant emitting region (shock, blob).

Curved trajectory

- globally bent jet;
- a path of individual blob.

Symmetry of the Emitting Region

The simplest possible structure of the emitting region would be axially symmetric with respect to it's velocity vector direction.

Stokes parameters

- Let χ be the polarization angle, measured from the projected jet direction.
- Note that $Q \propto \cos(2\chi)$ (even) and $U \propto \sin(2\chi)$ (odd).
- Spatially averaged $\langle U \rangle = 0$, so there are two possibilities only:
  - parallel polarization (when $\langle Q \rangle > 0$),
  - perpendicular polarization (when $\langle Q \rangle < 0$).

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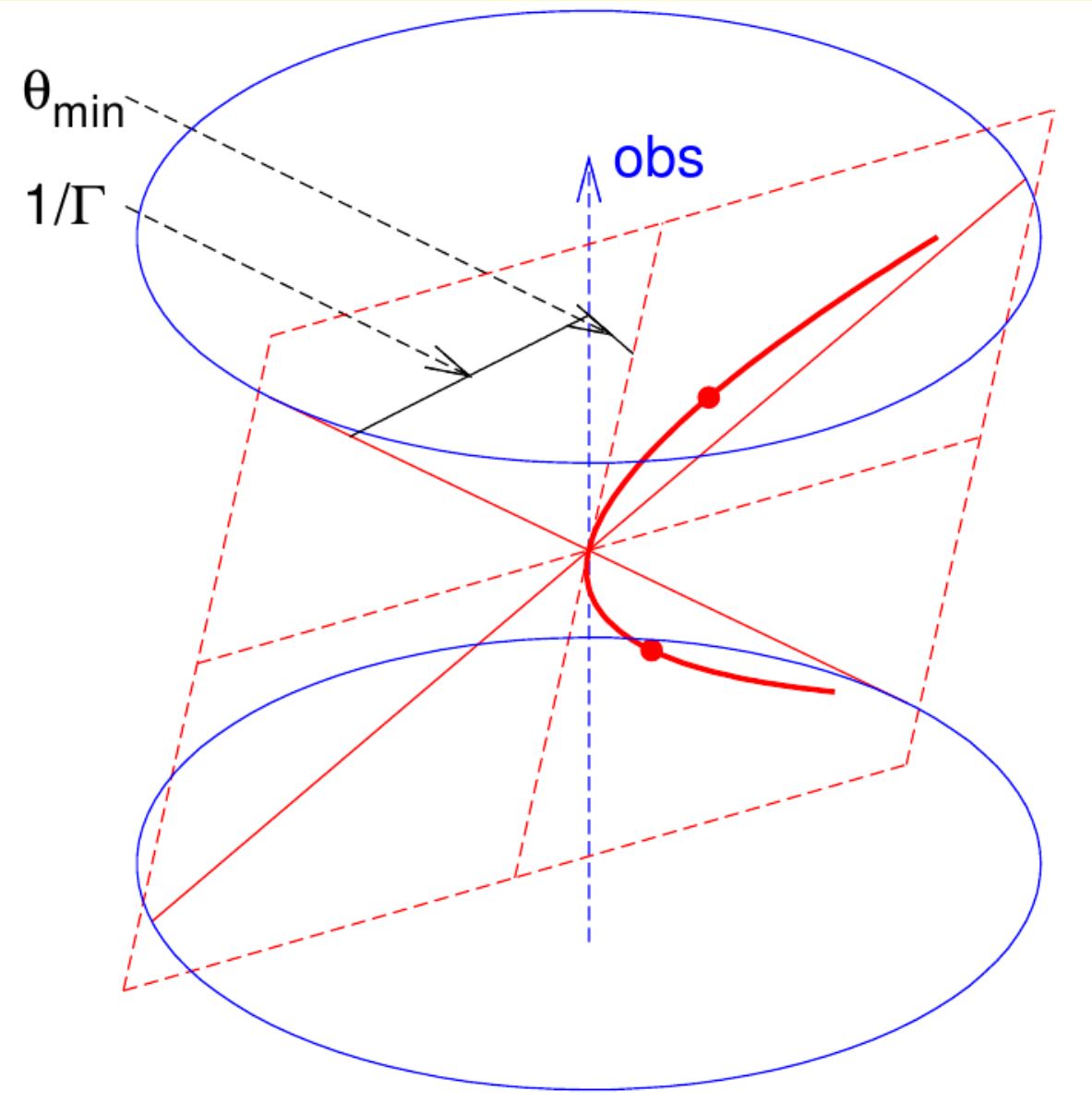
How to obtain a **smooth** rotation of the polarization angle?

- The blob trajectory must be curved,
- The line of sight must be off the plane containing blob velocity and acceleration.

The simplest case:

- circular (planar) trajectory,
- constant Lorentz factor Γ,
- transverse magnetic field only (parallel polarization).

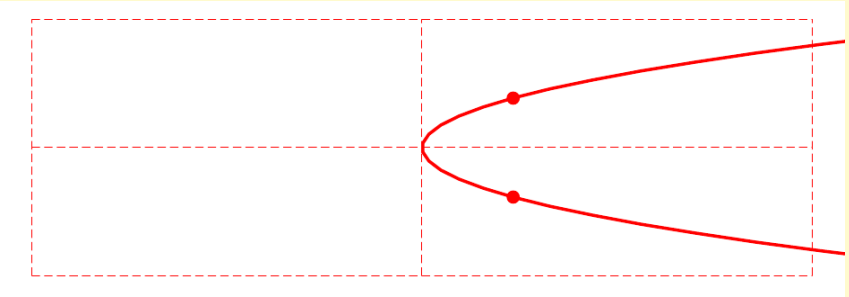
3D jet orientation



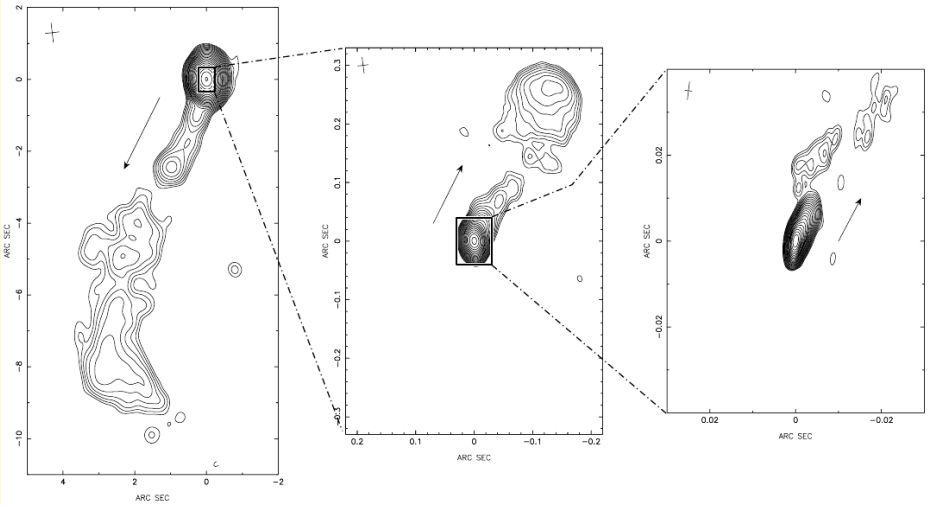
- A "Doppler cone" is defined by $\theta \simeq 1/\Gamma$, as measured from the line of sight.
- **Jet trajectory** is confined to a plane inclined to the line of sight by $\theta_{\min} < 1/\Gamma$.

'Extreme' Jet Bending

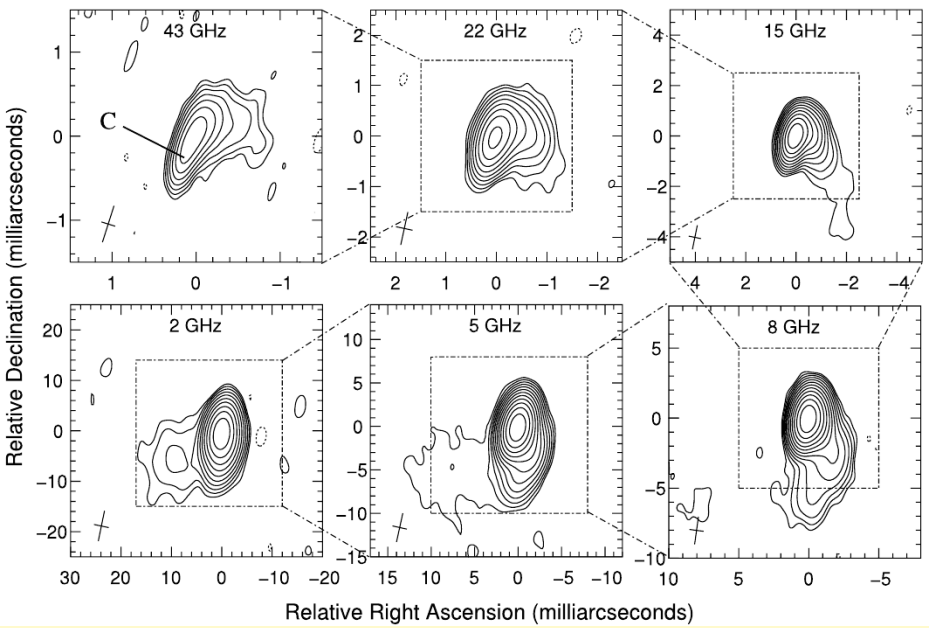
Jet trajectory projected onto the plane of the sky



If the PA is tightly related to the jet orientation, the swing would be accompanied by a very strong apparent jet bending.

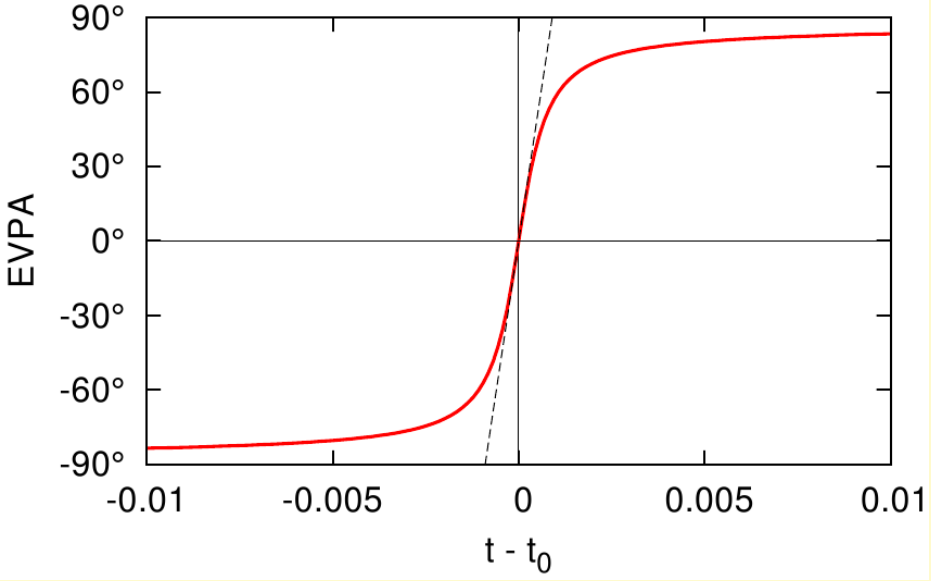


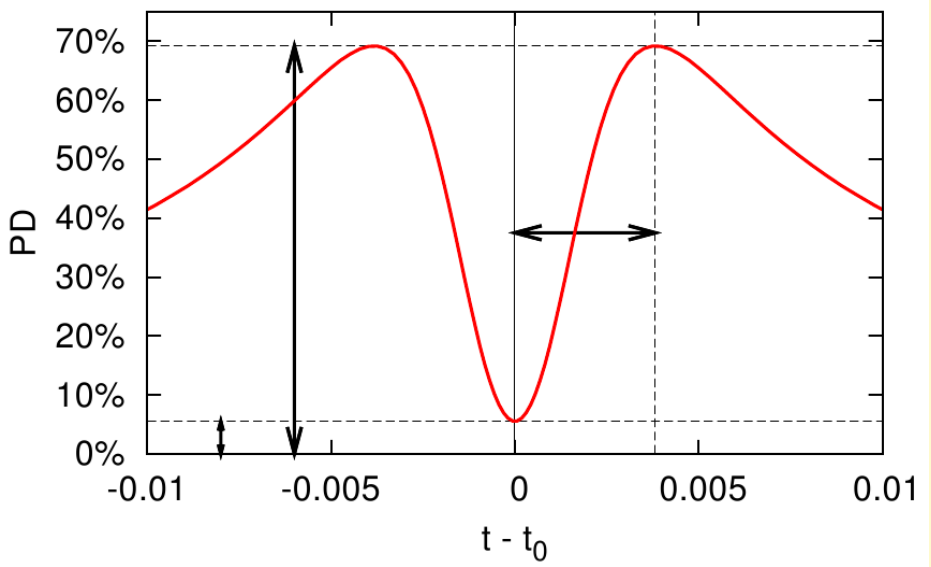
(PKS 1510-089, Homan et al. 2002)



(PKS 2136+141, Savolainen et al. 2006)

Variations of Polarization Angle and Degree





- t_0 – the moment defined by the minimum of the angle between the velocity vector and the line of sight: $\theta(t_0) = \theta_{\min}$.

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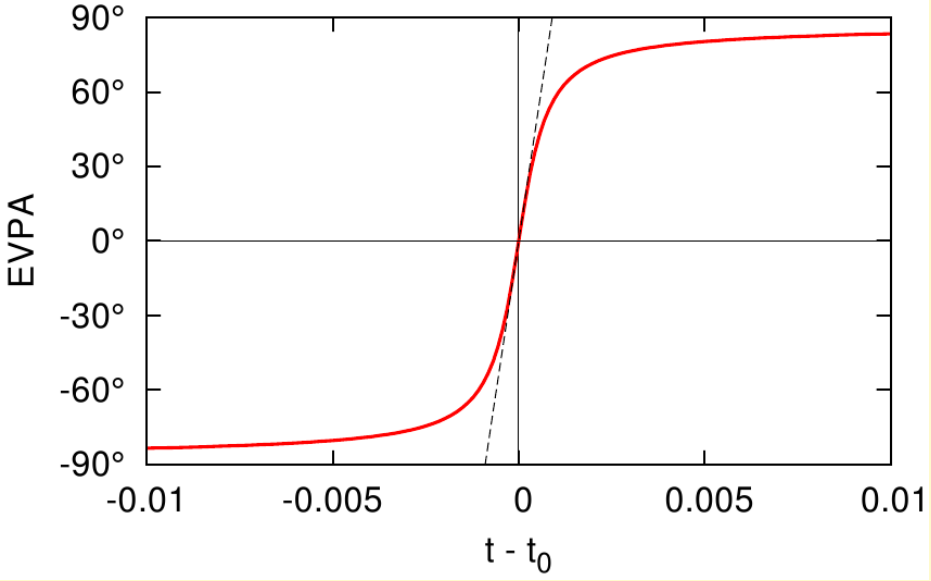

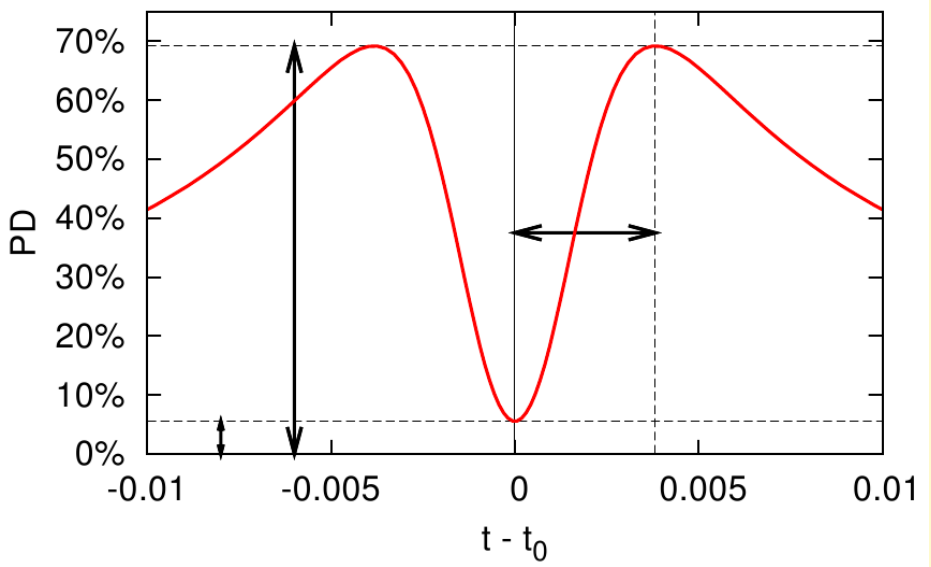

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- Polarization angle should have a maximal rate of rotation at t_0, polarization degree should have a simultaneous minimum.

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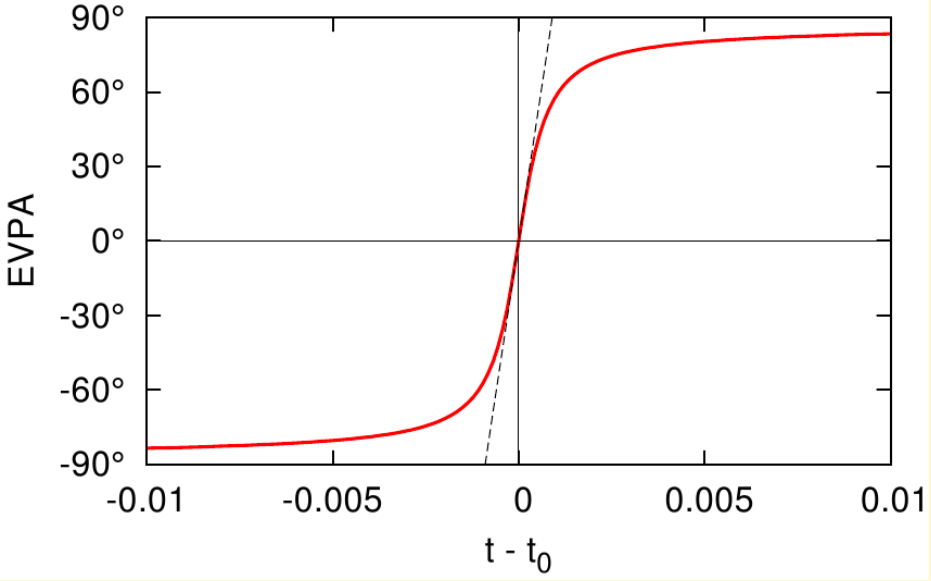

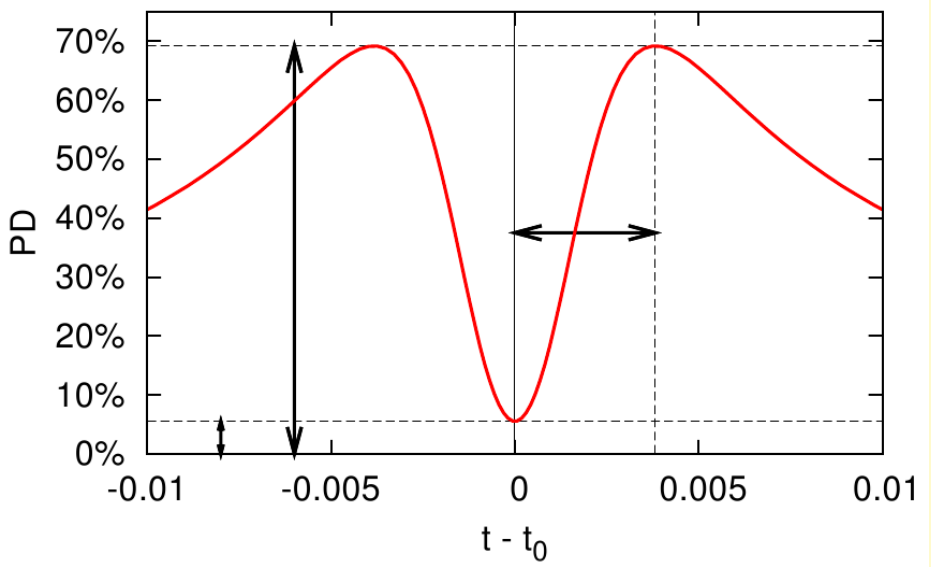

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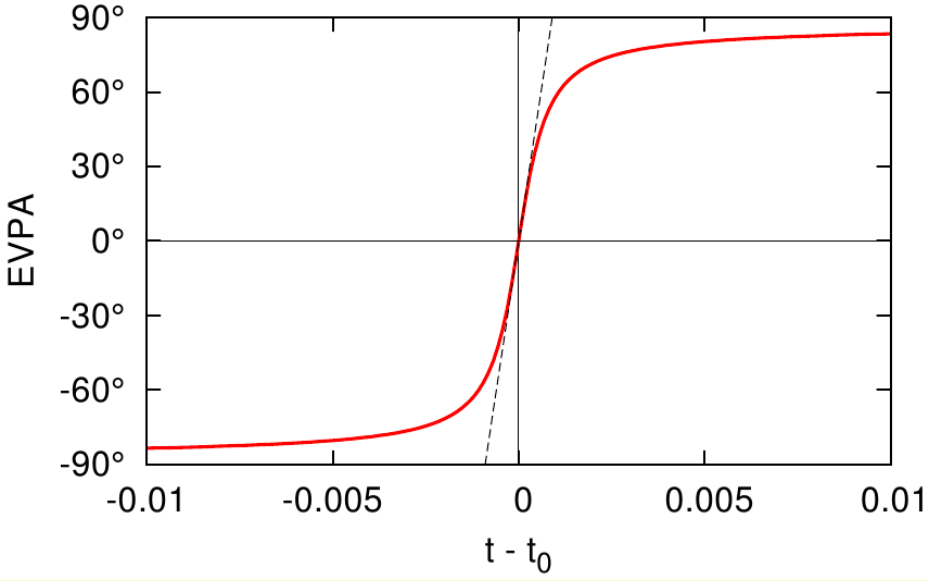

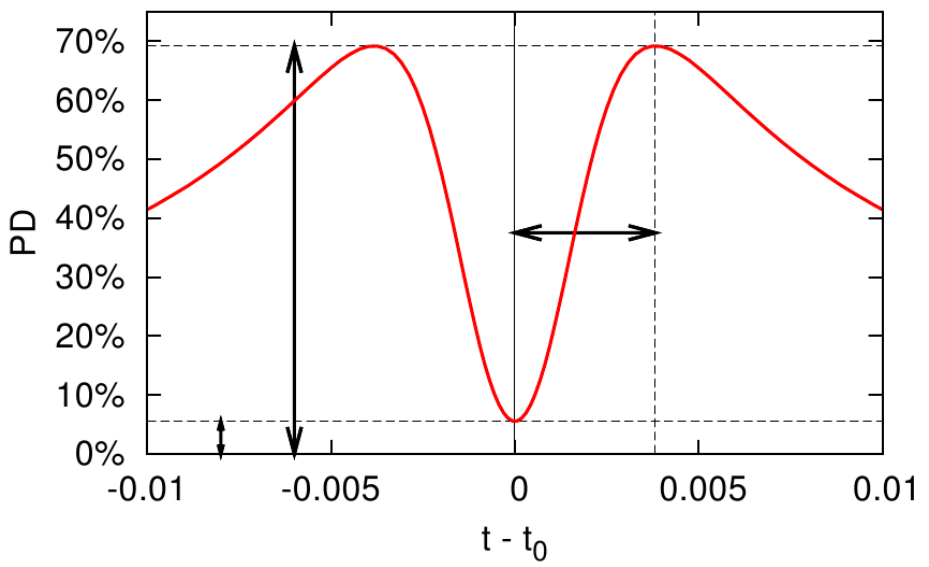

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- Polarization angle should have a maximal rate of rotation at t_0, polarization degree should have a simultaneous minimum.
- As a function of time, polarization angle should be antisymmetric, while polarization degree – symmetric, with respect to t_0.
- The swing amplitude should be 180°. Larger values can be obtained, allowing for some helicity (non-planar trajectories).

Parameters of the trajectory

Maximum rate of PA rotation

$$\dot{\chi}_{\mathrm{obs,max}} = \frac{\Omega}{(1-\beta_{\mathrm{blob}}\cos\theta_{\mathrm{min}})\sin\theta_{\mathrm{min}}}$$

Time between the PD extrema

$$t_{\Pi\mathrm{obs,max}} = \frac{1}{\Omega}\left[\arccos\left(\frac{\beta_{\mathrm{jet}}}{\cos\theta_{\mathrm{min}}}\right) - \beta_{\mathrm{blob}}\sqrt{\cos^2\theta_{\mathrm{min}} - \beta_{\mathrm{jet}}^2}\right]$$

The ratio of PD minimum to maximum value

$$\frac{\Pi_0}{\Pi_{\mathrm{max}}} = \frac{\sin^2\theta_{\mathrm{min}}}{2\Gamma_{\mathrm{jet}}^2\left(1-\beta_{\mathrm{jet}}\cos\theta_{\mathrm{min}}\right)^2 - \sin^2\theta_{\mathrm{min}}}$$

We distinguish Γ_{jet} – the Lorentz factor of the jet flow and Γ_{blob} – the Lorentz factor of the emitting element. Ω is the rate of rotation of the blob's velocity vector, it is related to the curvature radius of the trajectory $R = \beta_{\mathrm{blob}}c/\Omega$.

The distance covered by the emitting region

Position of the emitting region

$$r_{\mathrm{blob}} \gtrsim \Delta r_{\mathrm{blob}}$$

The distance covered by the blob between the positions corresponding to PD maxima

$$\Delta r_{\mathrm{blob}} = \frac{2\beta_{\mathrm{blob}} c}{\Omega} \arccos\left(\frac{\beta_{\mathrm{jet}}}{\cos\theta_{\mathrm{min}}}\right)$$

The distance covered by the emitting region

Position of the emitting region

$$r_{\rm blob} \gtrsim \Delta r_{\rm blob}$$

The distance covered by the blob between the positions corresponding to PD maxima

$$\Delta r_{\rm blob} = \frac{2\beta_{\rm blob} c}{\Omega} \arccos\left(\frac{\beta_{\rm jet}}{\cos\theta_{\rm min}}\right)$$

Approximate formula

- Assuming $\Gamma_{\rm jet}\theta_{\rm min} \ll 1$:

$$\Delta\theta \sim \frac{2}{\Gamma_{\rm jet}} \,.$$

- Difference between emission times:

$$\Delta t_{\rm em} = \frac{\Delta\theta}{\Omega} \sim \frac{2R}{\Gamma_{\rm jet} c} \,.$$

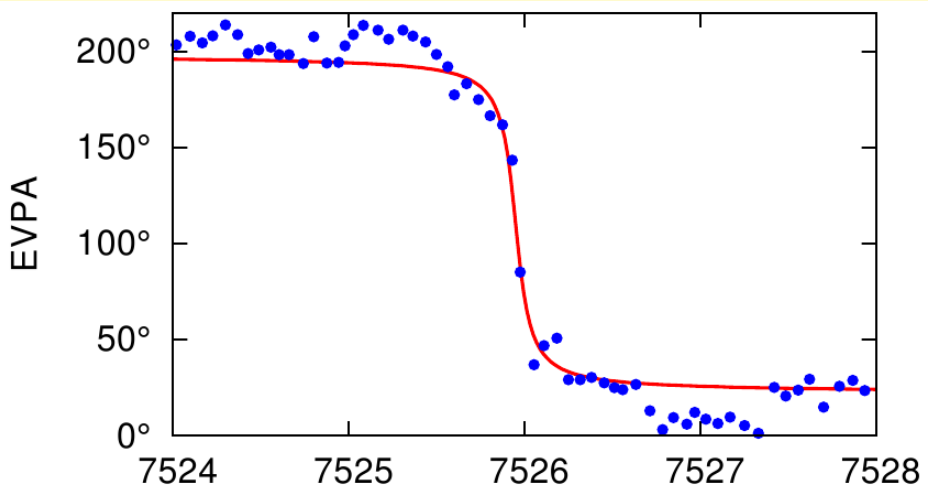
- Difference between observation times:

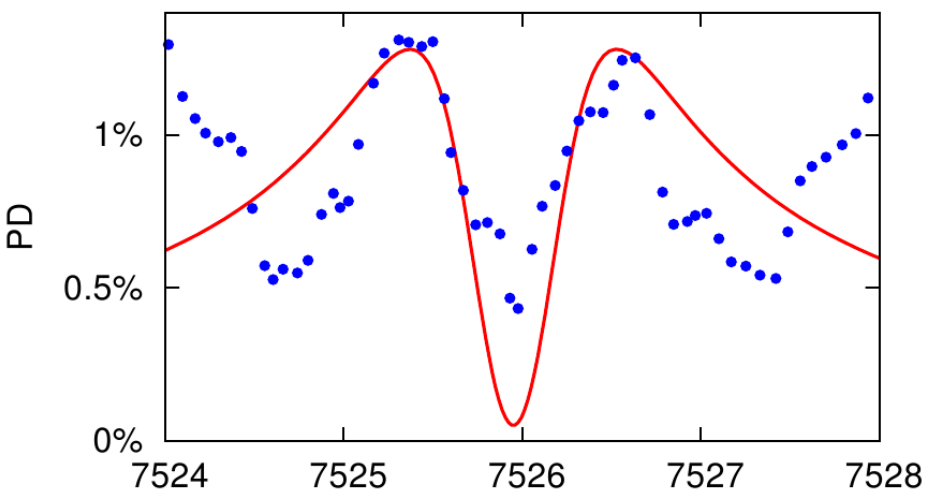
$$\Delta t_{\rm obs} \sim \frac{\Delta t_{\rm em}}{2\Gamma_{\rm blob}^2} \sim \frac{R}{\Gamma_{\rm blob}^2 \Gamma_{\rm jet} c} \,.$$

- The distance is related to R:

$$\Delta r_{\rm blob} = R\,\Delta\theta \sim \frac{2R}{\Gamma_{\rm jet}} \sim \underline{2\Gamma_{\rm blob}^2 c\,\Delta t_{\rm obs}} \,.$$

Application to S5 0917+624





Data from (Quirrenbach et al. 1989)

We assume $\Gamma_{\rm jet} = \Gamma_{\rm blob} = 15$

Measured parameters

- $\dot{\chi}_{\rm obs,max} \simeq 912^\circ/{\rm d}$
- $t_{\Pi{\rm obs,max}} \simeq 0.58$ d

Calculated parameters

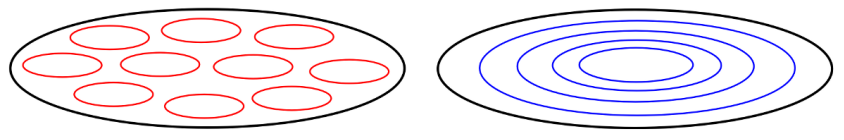
- $\Gamma \times \theta_{\rm min} \sim 0.14$
- Curvature radius: $R \sim 2.5$ pc
- Distance travelled by the emitting region between PD maxima: $\Delta r_{\rm blob} \sim 0.32$ pc

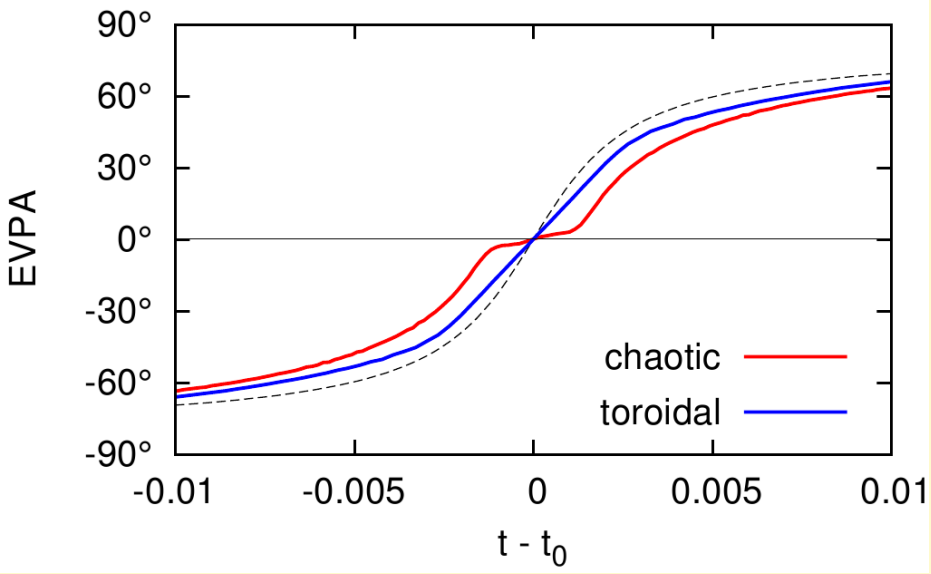
Finite-Size Effects

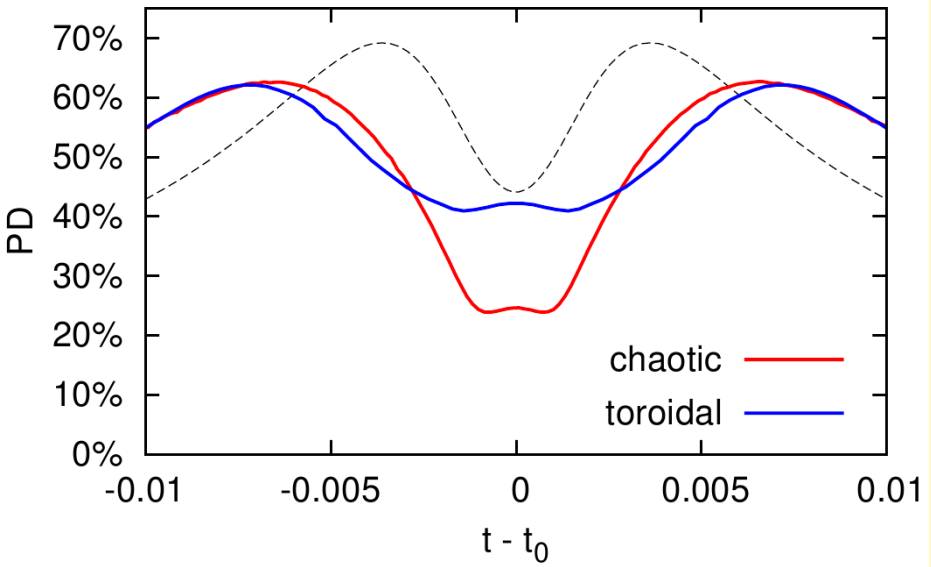
- a – transverse radius of the blob
- R – curvature radius of the blob trajectory
- The delay times for signals emitted accross the blob become important, when

$$\frac{a}{R} > \frac{2}{3\Gamma_{\rm jet}^2} .$$

- Predicted effect for the variations of polarization depends on the magnetic field structure: **chaotic** or **toroidal**.







Summary

- We propose a model for the polarization swings in relativistic jets, based on symmetric emitting regions propagating on curved trajectories.

- From observational data we deduce three parameters:
  - the maximal rate of polarization angle rotation,
  - the time elapsed between a polarization degree minimum and maxima,
  - the ratio of polarization degree minimum and maximum value.

- Parameters that can be estimated, using our model:
  - the curvature radius of the blob trajectory,
  - the distance covered by the blob,
  - the minimum angle between the blob velocity and the line of sight.