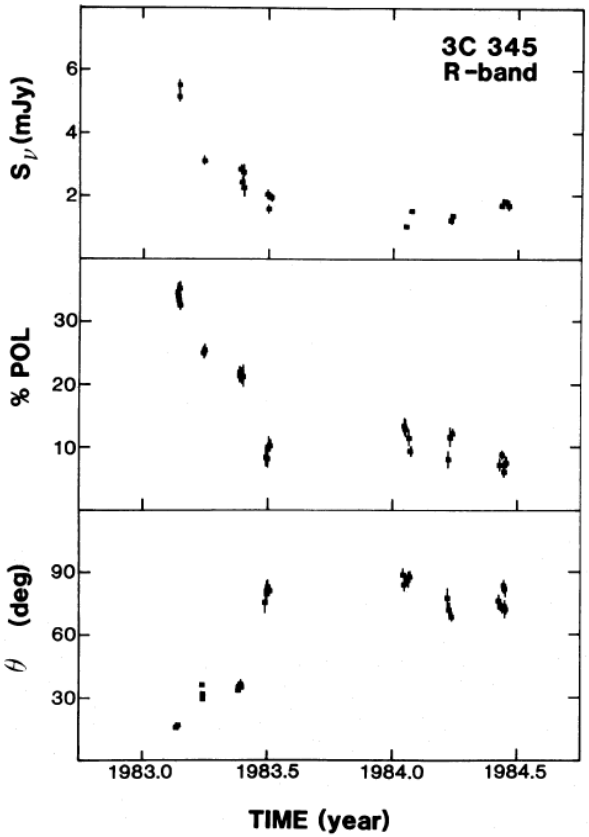
Makoto Uemura (Hiroshima University, Japan), and the "Kanata" team

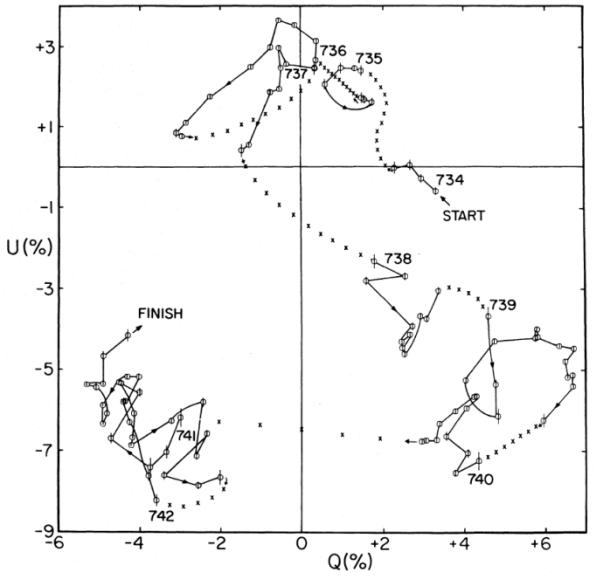
Bayesian approach to find a long-term trend in erratic polarization variations observed in blazars

Polarization variations in blazars

- Erratic variations
  - Random motion in the QU plane?
  - Blinks of a number of polarization components?
- Systematic variations
  - Increase of the polarization degree (PD) with flares
  - Rotation of the polarization angle (PA)
  - A probe of the magnetic field in jets
- Are there universal characteristics in blazar polarization?
  - The main theme of this talk
  - We want to find a kind of "rules" in apparently erratic variations.

Positive correlation between the flux and PD. (Smith, et al. 1986)





Apparently random motion in the QU plane (Moore, et al. 1982)

Multiple polarization components?

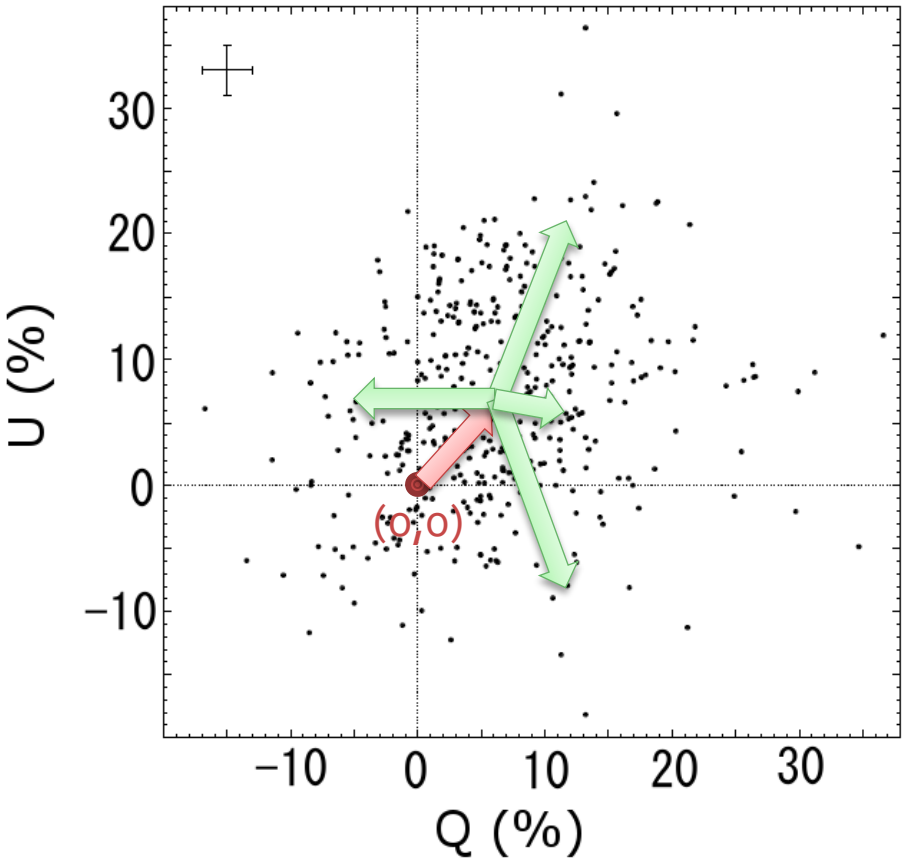
Stokes parameters for linear polarization

$$P = \frac{\sqrt{Q^2 + U^2}}{I}$$

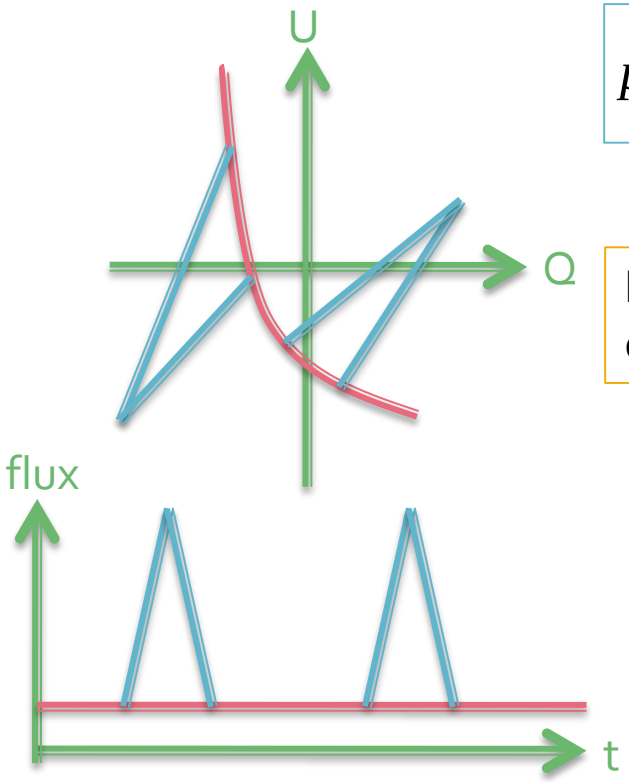
$$\theta = \frac{1}{2} \arctan \frac{U}{Q}$$

- Systematic variation could be hidden by the presence of another polarization component.
  - Preferential direction of polarization for years
- Our model assumptions:
  - A flare is always associated with the flare of the polarized flux.
  - There is a long-term variation trend in polarization.

Stokes' QU parameters of BL Lac for ~20 yr (Hagen-Thorn, et al. 2002)



Bayesian method to estimate a long-term trend in polarization



$$p(Q_0, U_0 \mid f, Q_{\text{obs}}, U_{\text{obs}}) = \frac{L(f, Q_{\text{obs}}, U_{\text{obs}} \mid Q_0, U_0) \times \pi(Q_0, U_0)}{C}$$

Posterior distribution of the long-term trend

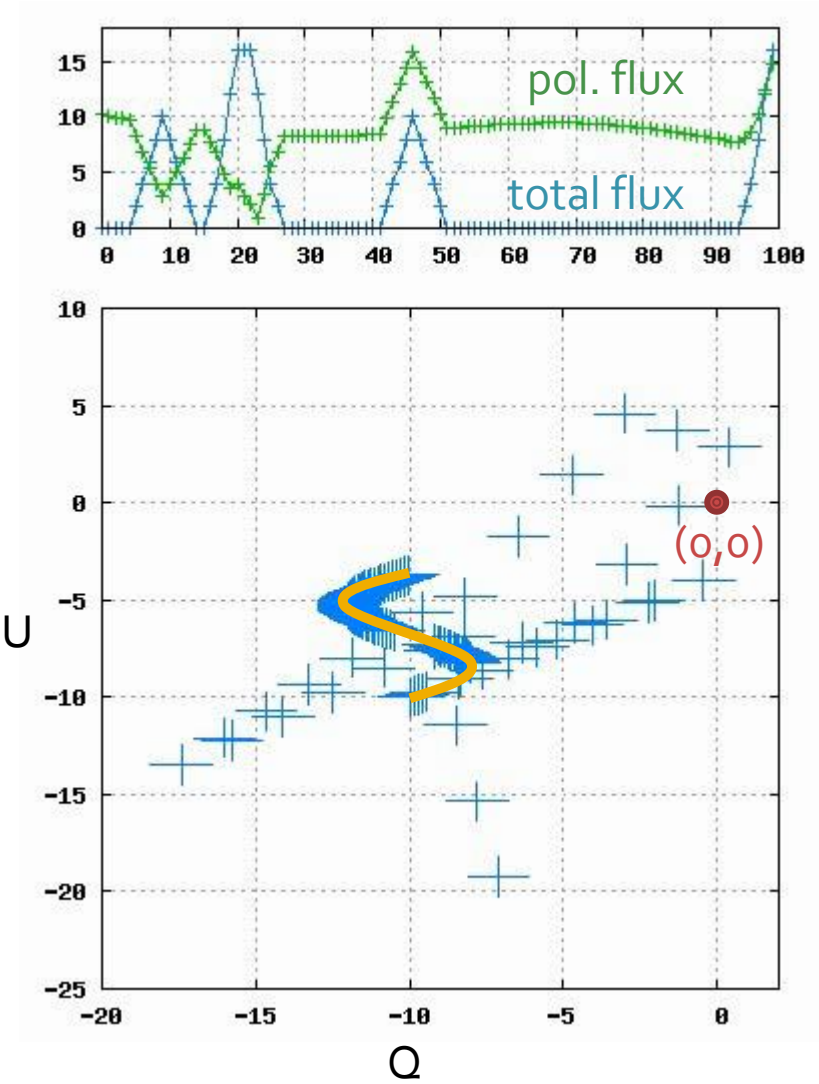
Likelihood function, maximized when the total flux and polarized flux completely correlate.

Prior distribution of the long-term trend (smoother curve is preferred).

$$\pi(Q_0) = \prod \frac{1}{\sqrt{2\pi w^2}} \exp\left\{-\frac{(Q_{0,i} - Q_{0,i-1})^2}{2w^2}\right\}$$

- The estimation of the parameters is done with the Markov Chain Monte Carlo (MCMC) method.

Demonstration with artificial data
Test 1: Case for low frequency flares



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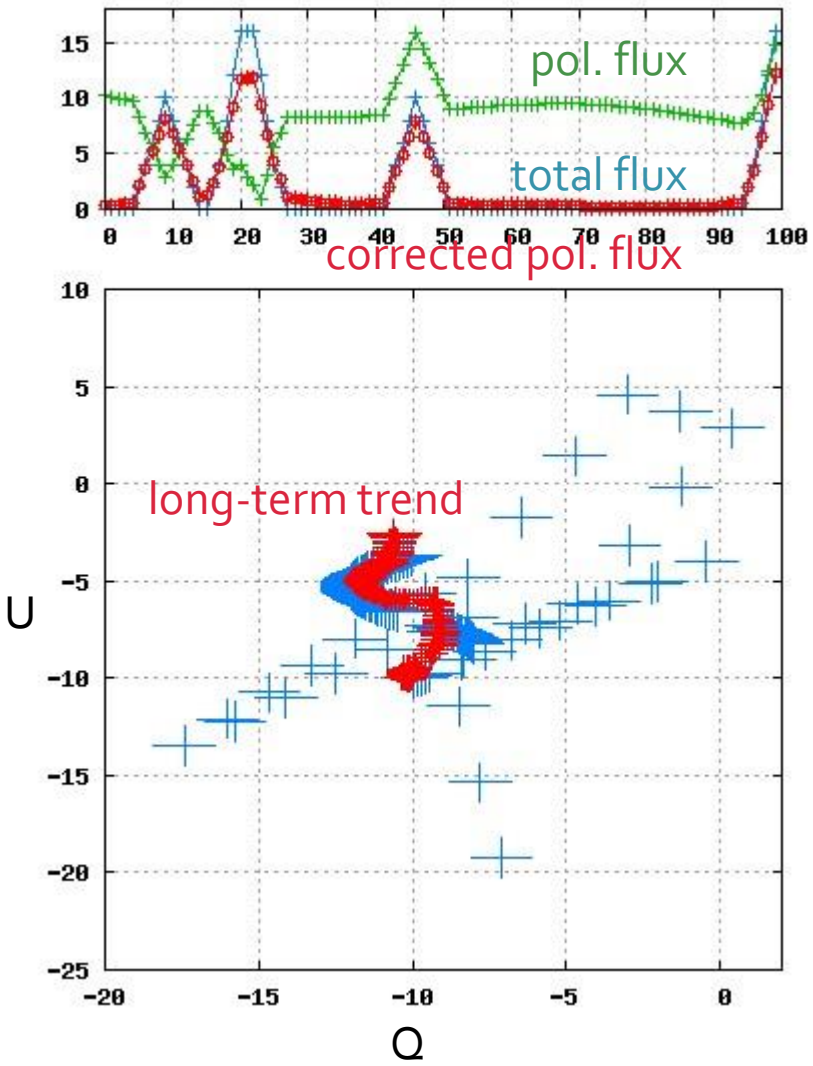

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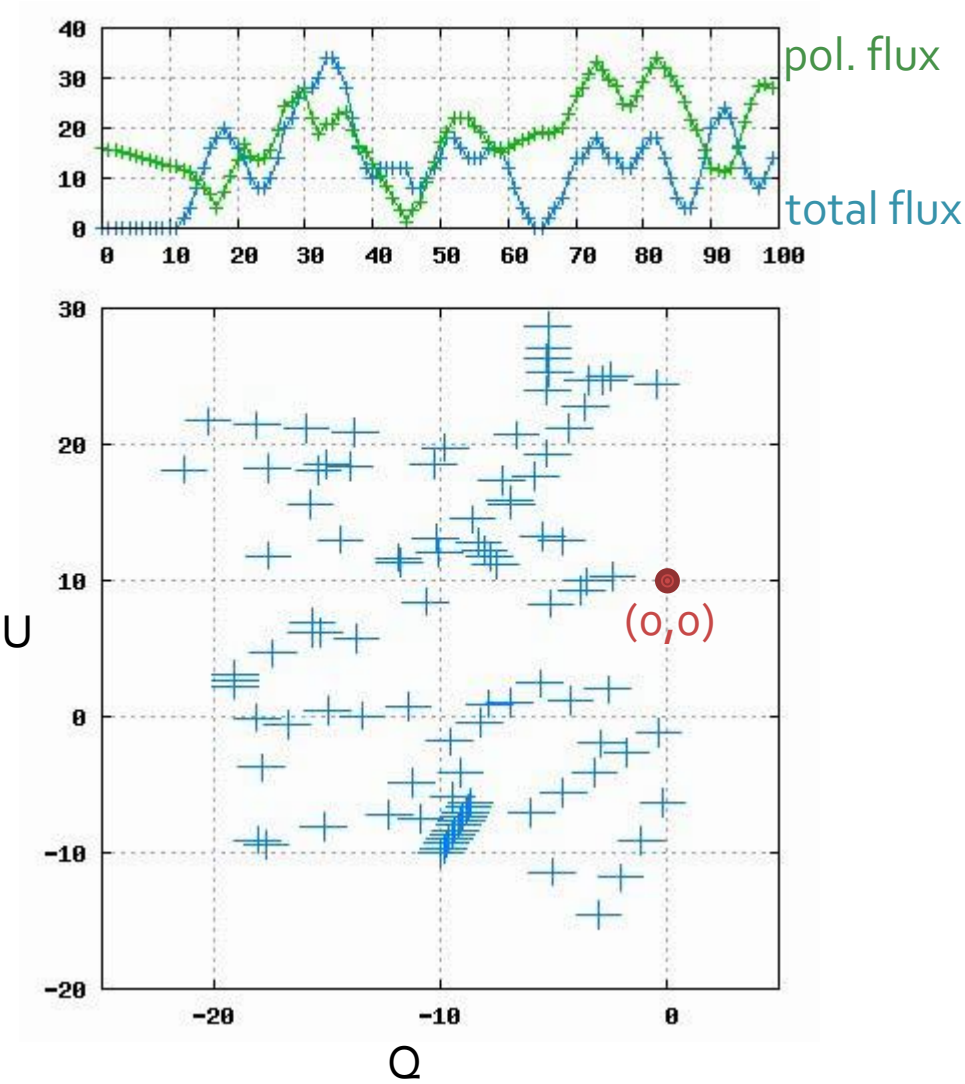

- The long-term trend is successfully estimated.
- This method can extract a long-term trend even if observed variations are apparently just erratic.

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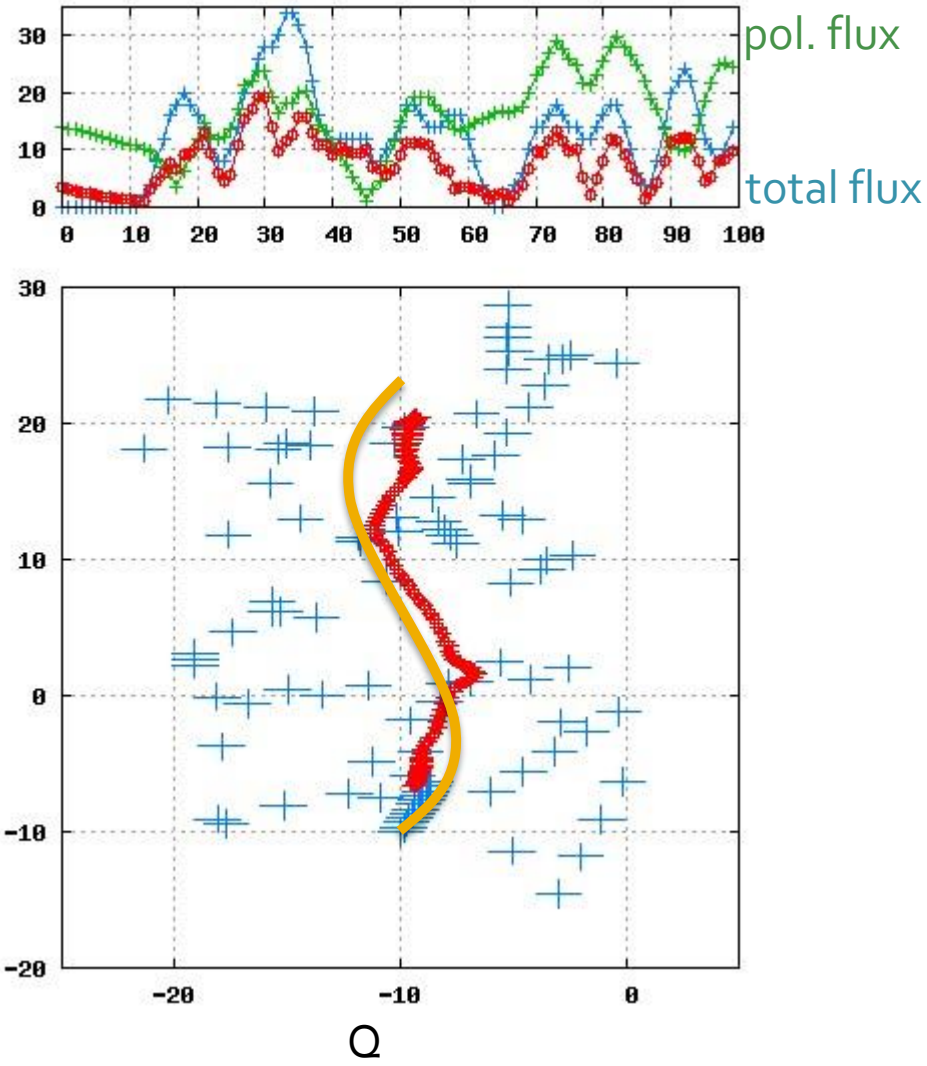

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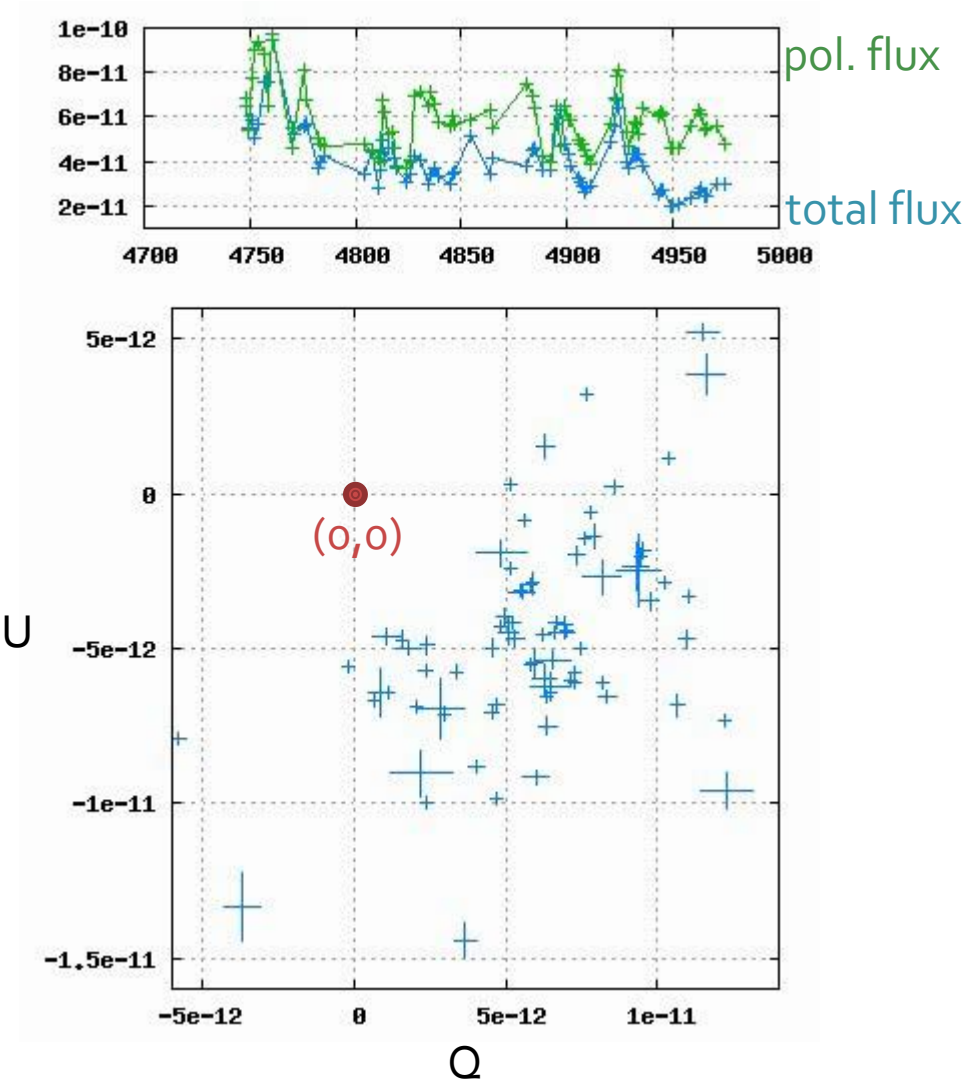
Blazar monitoring with the 1.5-m "Kanata" Telescope

- Since 2006
- TRISPEC
  - developed by Nagoya Univ.
  - Simultaneous optical and near-infrared observation
  - photo-polarimetric mode is available
- Monitoring of blazars
  - since 2007
  - 42 sources

Case 1: OJ 287



- Data: Oct. 2008 – May 2009
- Observed Q,U distribute NOT around (Q,U)=(0,0)
  - A long-term trend is expected to be present.
- As expected, our method shows a long-term trend, possibly oscillating in a small range of PA with a time scale of a few tens of days.
- Good example for our model.

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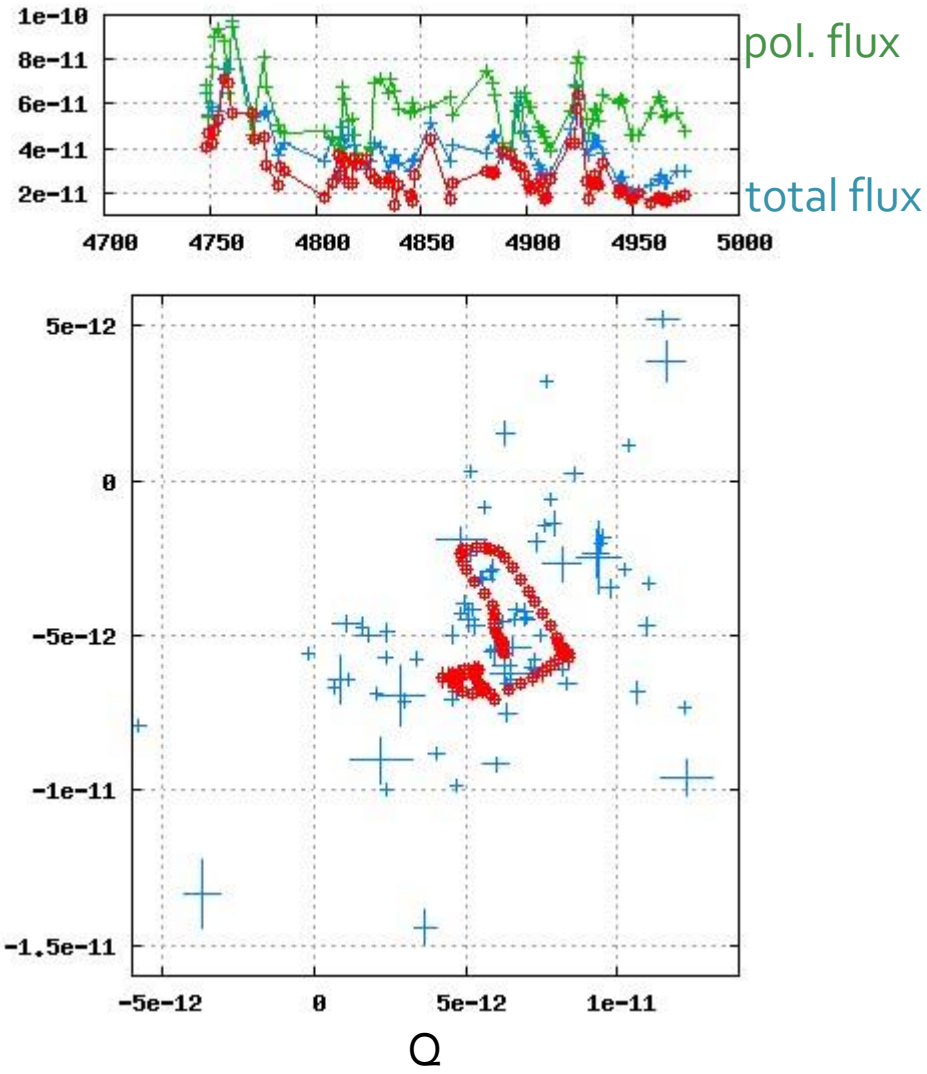

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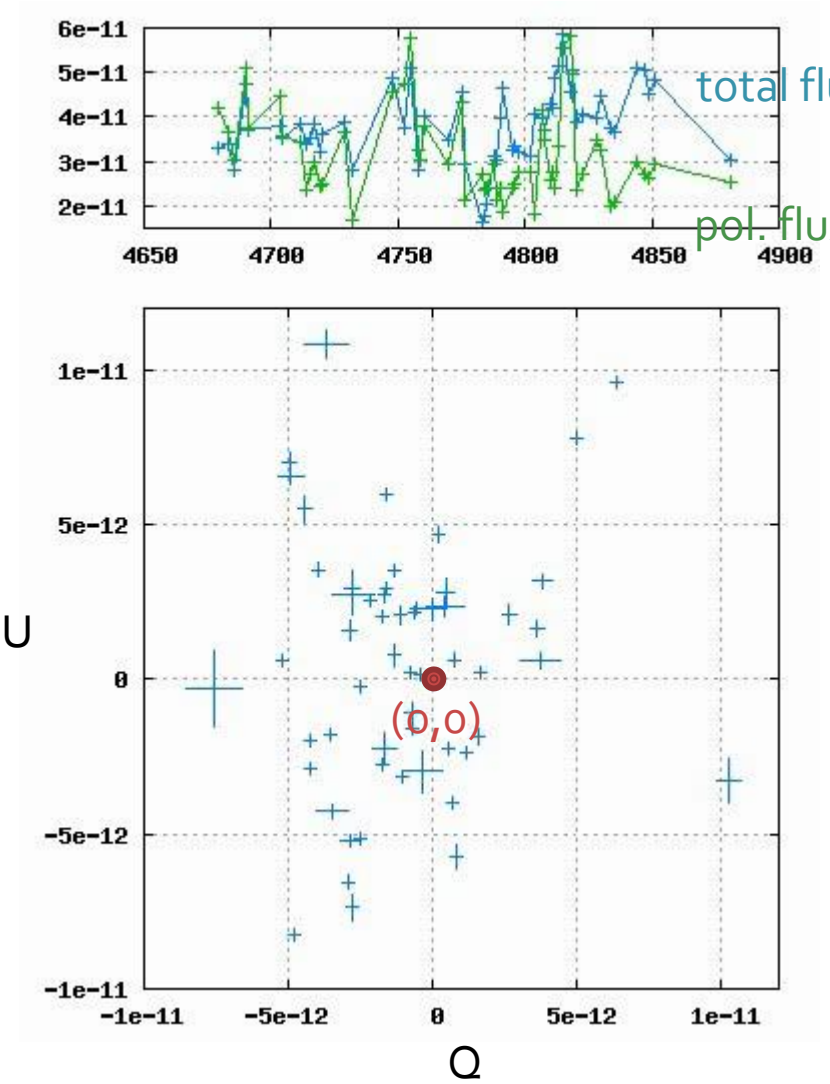
Case 2: S2 0109+224



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- Growth and decay of long-term trends?
  - Another trend was born in the latter period?

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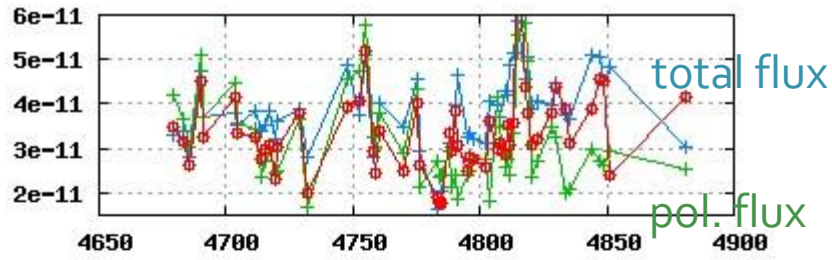

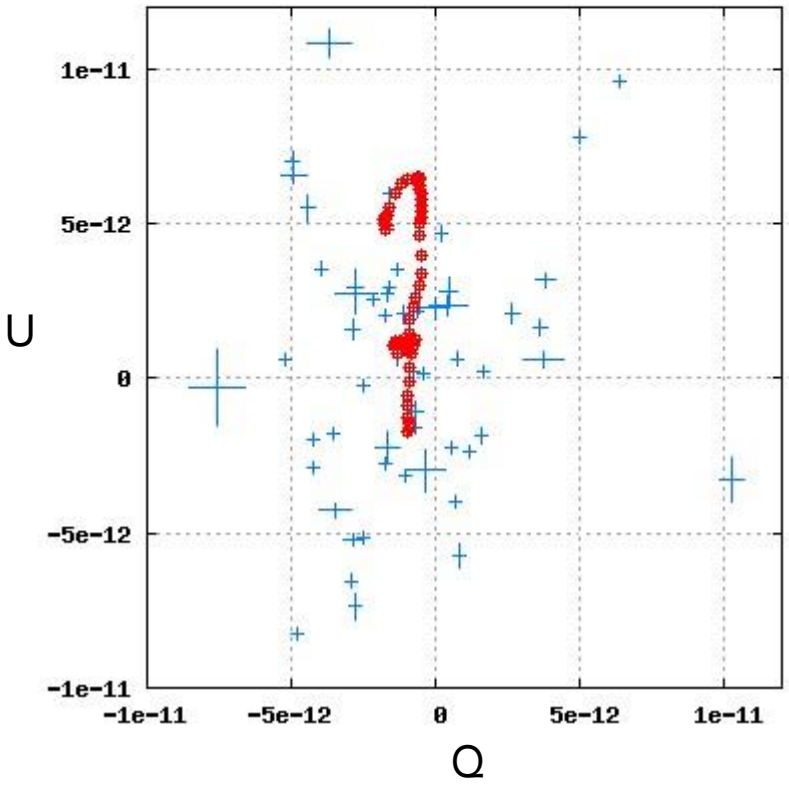

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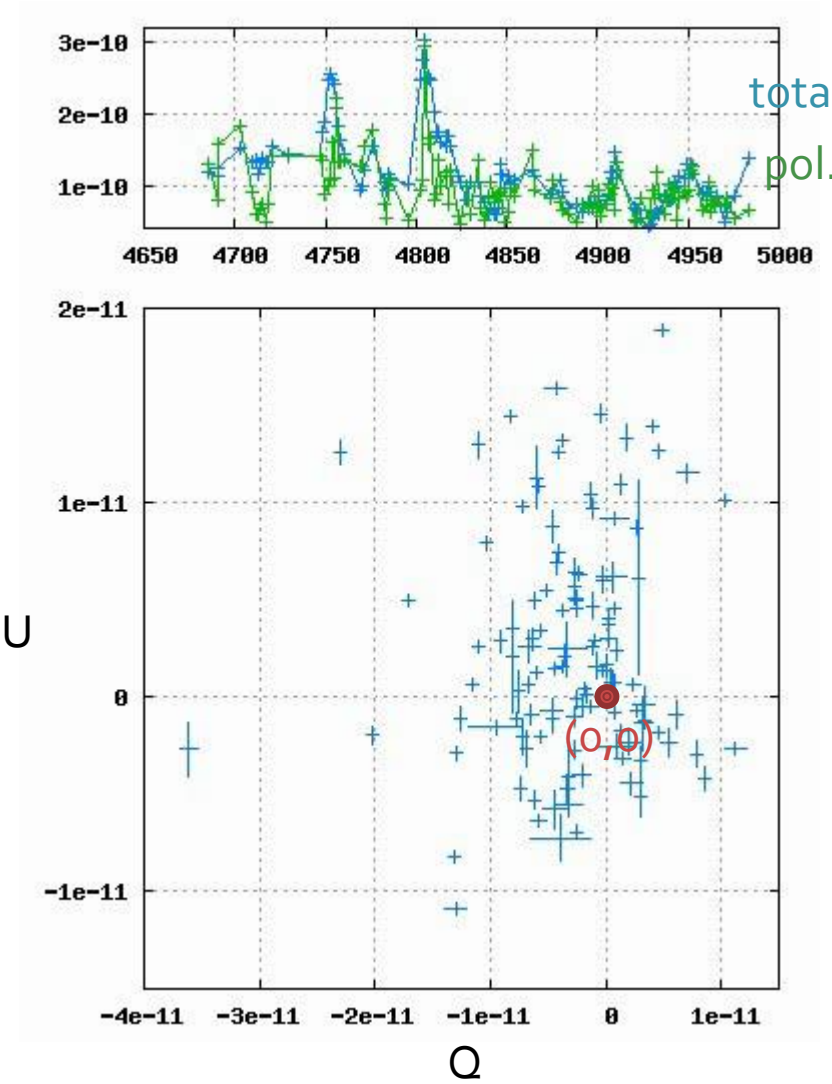

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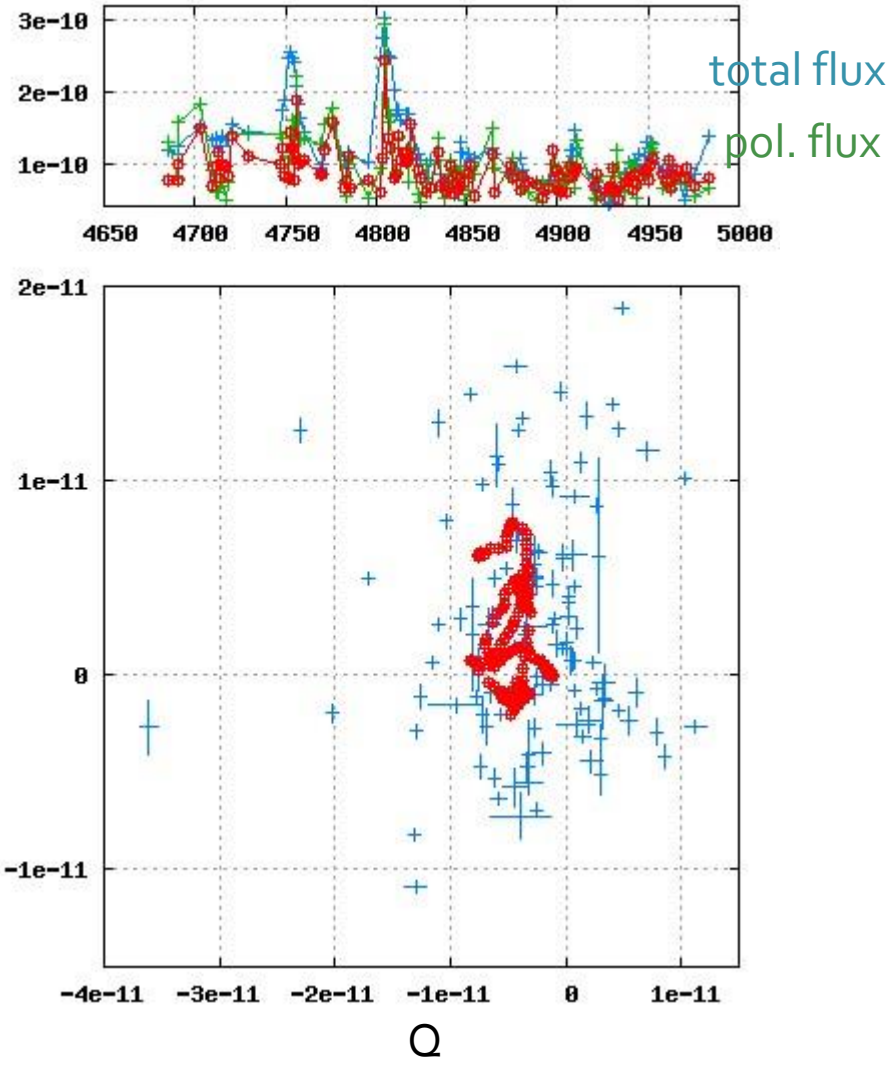

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Summary: advantage and disadvantage

- Advantages of our Bayesian model
  - We can extract a systematic long-term trend from the observed variation, even if it is apparently erratic.
  - The model may be useful for the test of the presence of the long-term trend.
    - The long-term trend is NOT always obtained.
- Disadvantages of our Bayesian model
  - The model is only valid for the polarized flux, not for the polarization degree in % (, or Q/I, U/I).
    - better definition of the likelihood function or prior distribution?
  - The model do NOT provide evidence for the long-term trend.
    - Confirmation is needed by another kind of observations