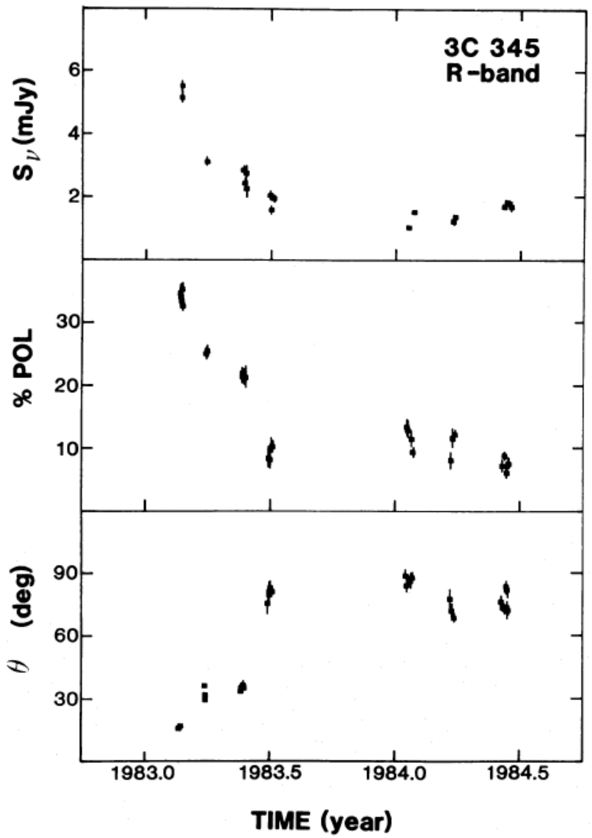
# Bayesian approach to find a long-term trend in erratic polarization variations observed in blazars

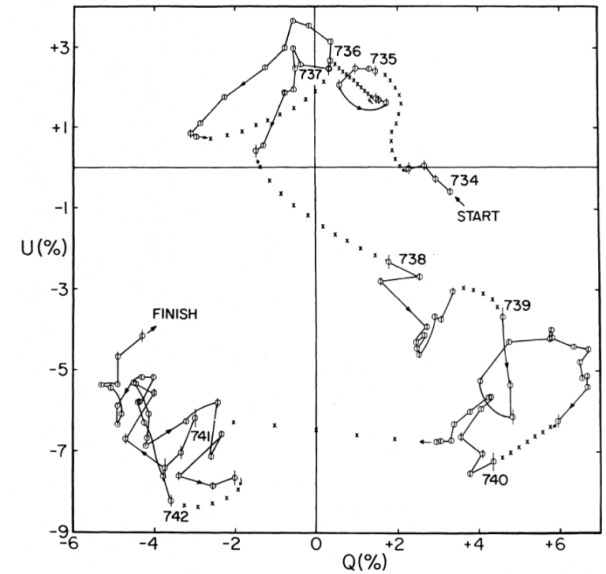
Makoto Uemura (Hiroshima University, Japan), and the “Kanata” team

# 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 features 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 (BL Lac; Moore, et al. 1982)

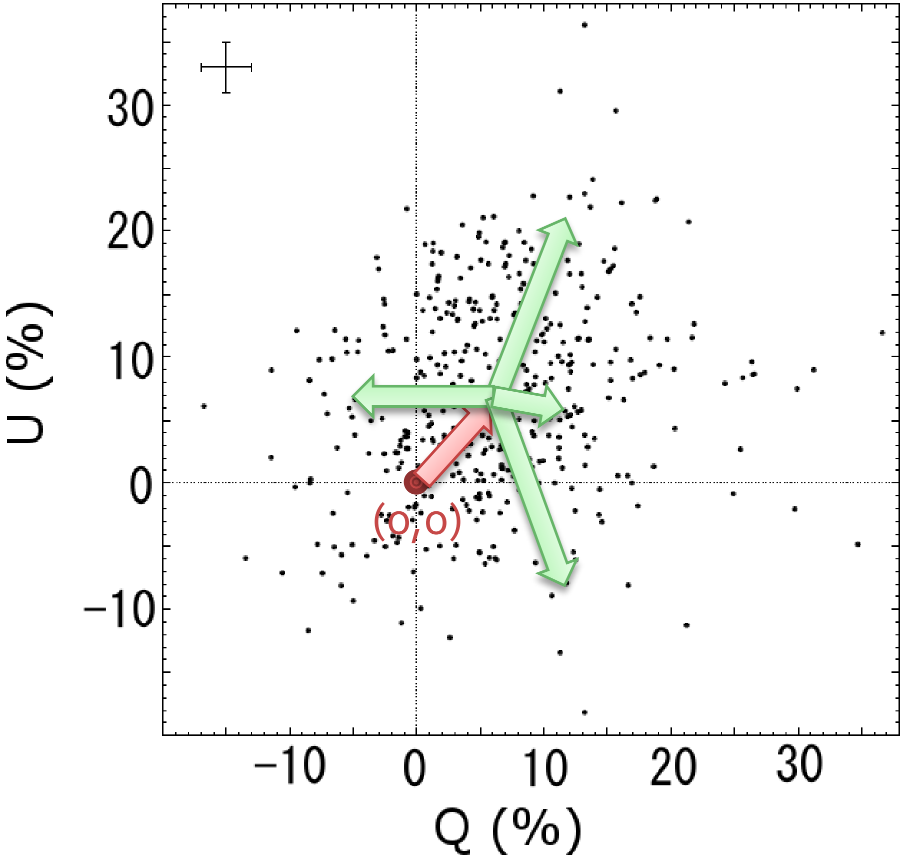
# Multiple polarization components?

Stokes parameters for linear polarization

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

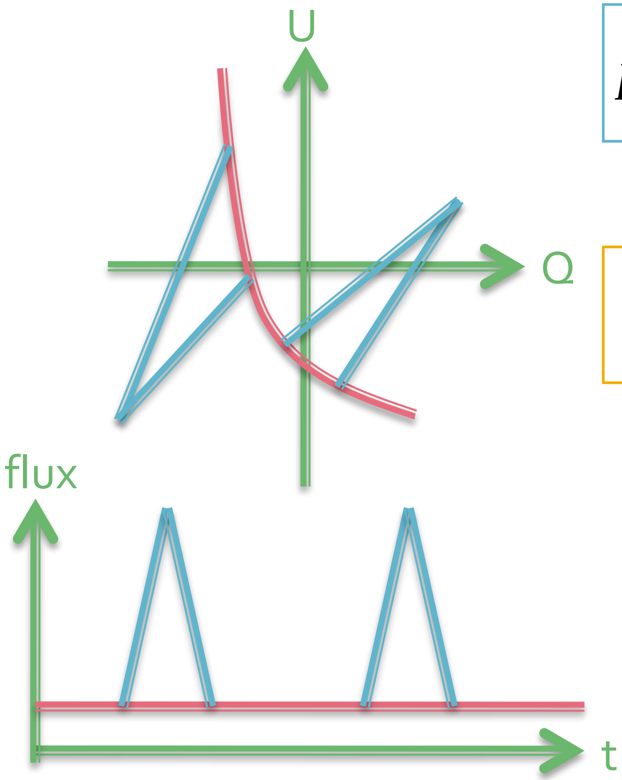
$$\theta = \frac{1}{2} \arctan \frac{U}{Q}$$

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




- Systematic variation could be hidden by the presence of another polarization component.
  - Preferential direction of polarization for years
  - e.g. BL Lac, OJ 287

# Bayesian method to estimate a long-term trend in polarization




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

Posterior distribution of the long-term trend

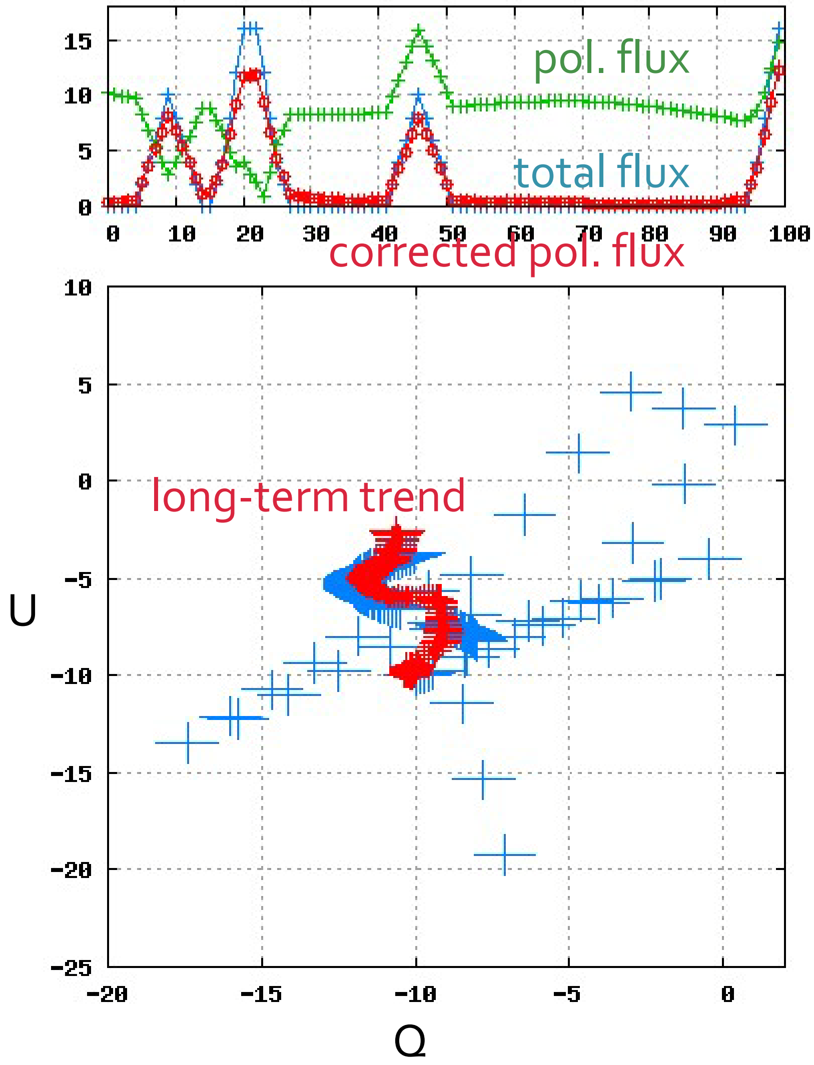
Likelihood function, maximized when the total flux and polarized flux completely correlate.

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

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

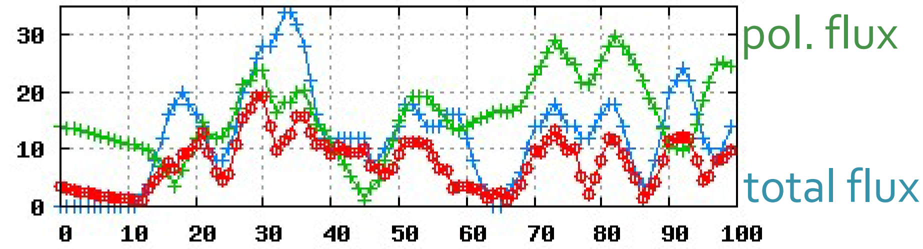
- The estimation of the parameters is done with the Markov Chain Monte Carlo (MCMC) method.
- For details, see, Uemura, et al. 2010, PASJ, 62, 69

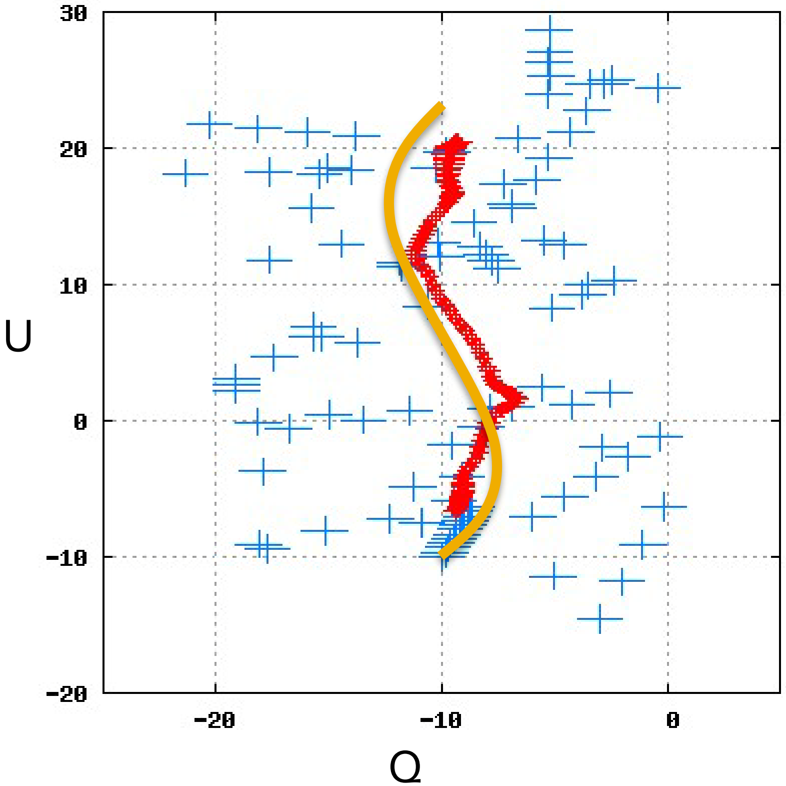
# Demonstration with artificial data
# Test 1: Case for low frequency flares




- The long-term trend is reproduced as assumed

# Demonstration with artificial data
# Test 2: Case for High frequency flares



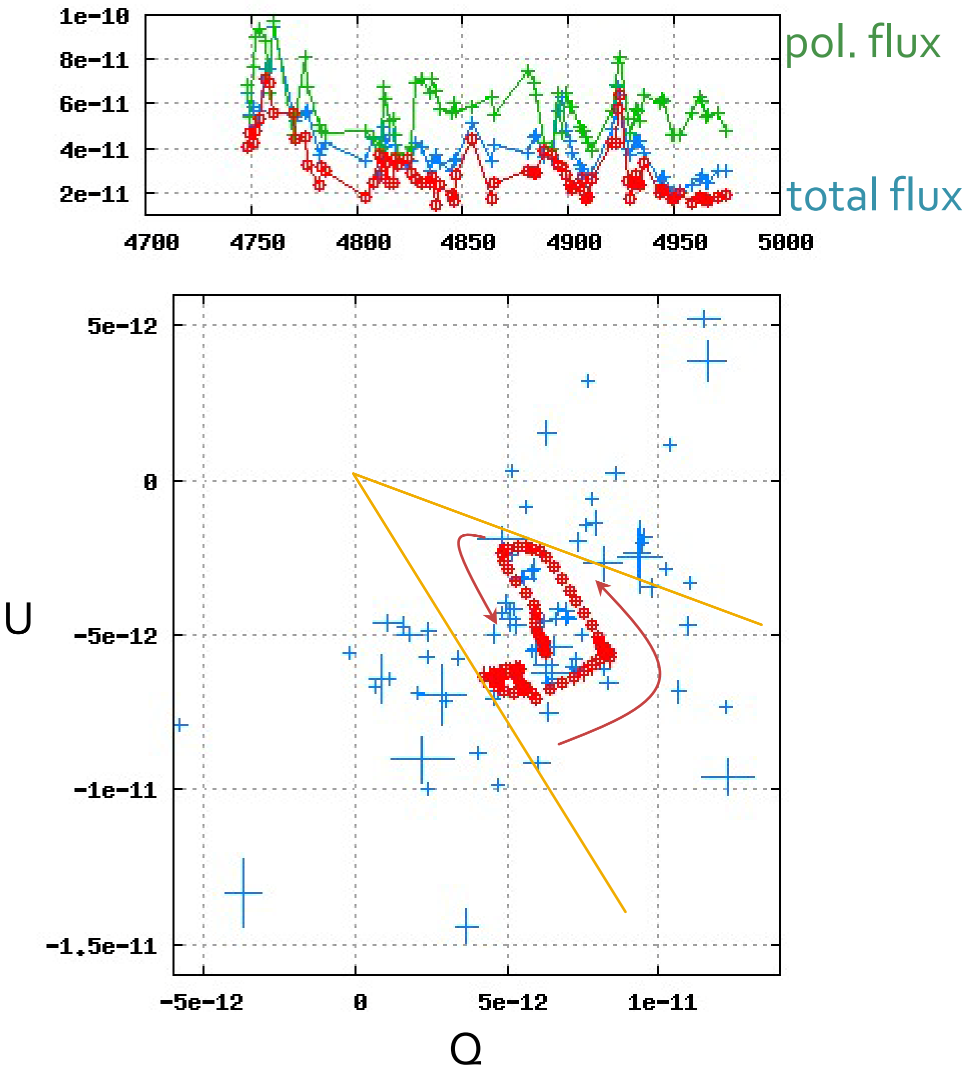




- The long-term trend is successfully estimated.
- This method can extract a long-term trend even if observed variations are apparently erratic.

# Blazar monitoring with the 1.5-m "Kanata" Telescope

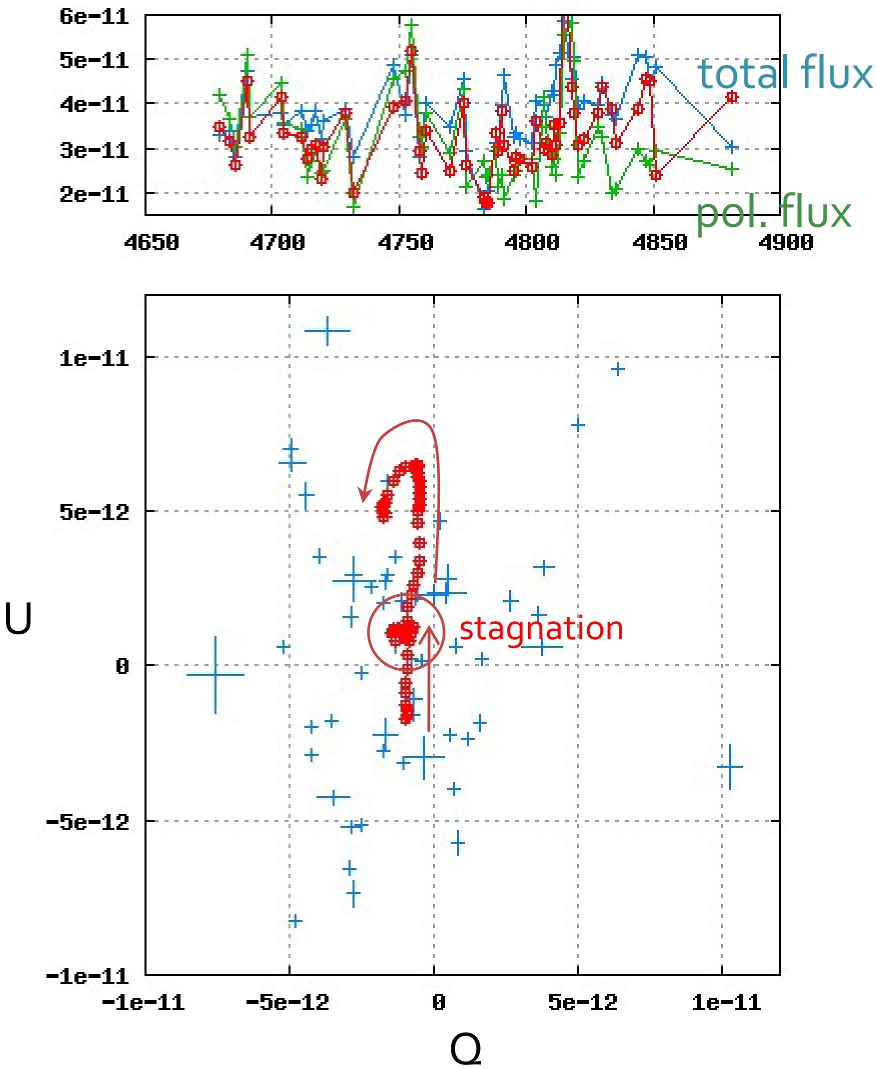
- Since 2006
- TRISPEC
  - developed by Nagoya Univ.
  - Simultaneous optical and near-infrared observation
  - photo-polarimetric mode is available
- Monitoring of blazars
  - since 2007
  - 42 sources

# Case 1: OJ 287



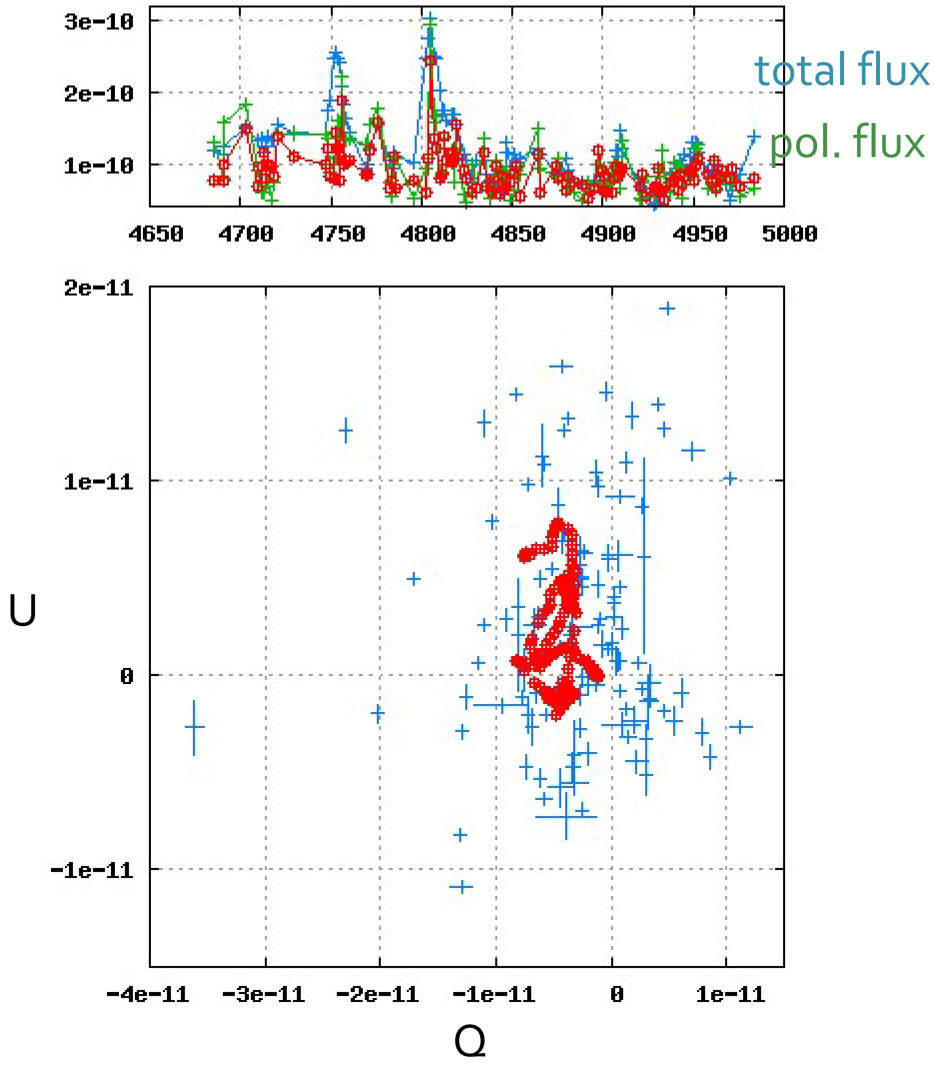

- As expected, our method shows a long-term trend, possibly oscillating in a small range of PA with a time scale of a few tens of days.
- Good example for our model.

# Case 2: S2 0109+224




- Our model works well, even if the observed Q,U apparently distribute around (Q,U)=(0,0).
- Growth and decay of long-term trends?
  - Another component was born in the latter period?

# Case 3: S5 0716+714




- The estimated long-term trend leads to no significant improvement of the correlation between the light curve and the polarized flux.
- No long-term trend that defined in our model

# 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 is 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

(all results have already been published in Uemura, et al., 2010, PASJ, 62, 69)