# Exploring into the inner jet-regions of BL Lac S5 0716+714 through intra-day optical photo-polarimetric observations


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**In Collaboration with whole earth blazar telescope (WEBT)**


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Blazar through Sharp Multi-wavelength Eyes, Malaga Spain, 2016

# *Motivation*

i. To investigate the nature (statistical properties) of rapid blazar variablity on the timescales ranging from minutes up to days.

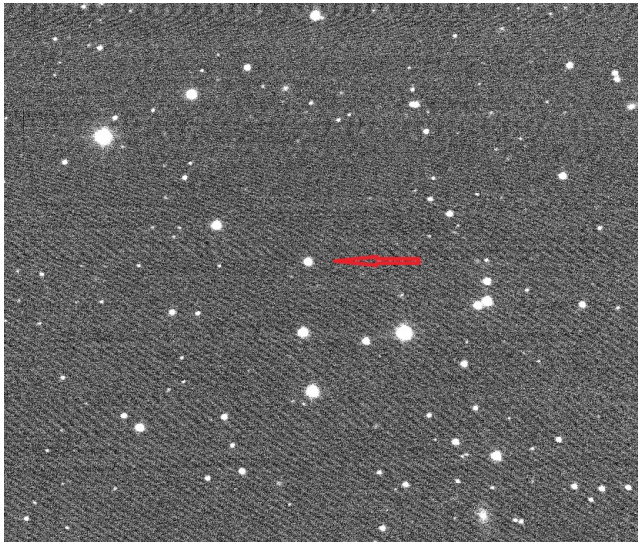
ii. To search for a possible blazar periodicity in the previously unexplored/hardly explored time domain.

iii. To constrain the internal (sub)-structure of blazar jets.

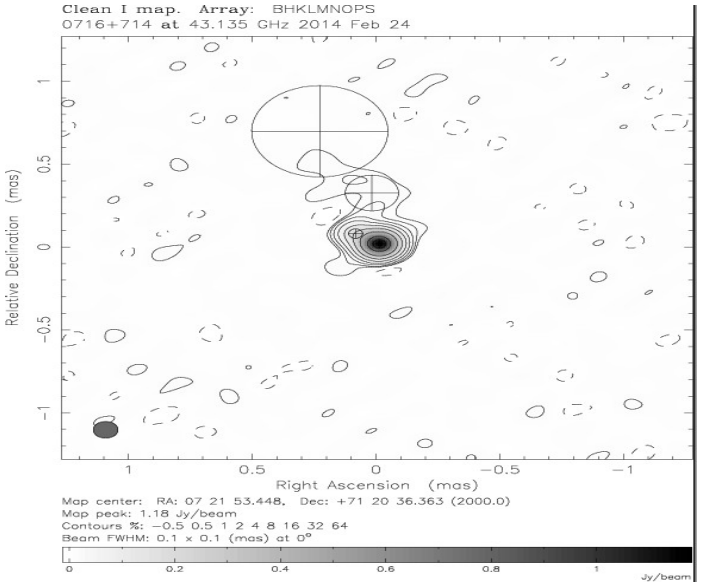
iv. To recognize the dominant particle acceleration processes shaping the rapid blazar variability.

# BL Lac S5 0716+714

- **One of the most studied sources by most of the current instruments.**
- **One of the brightest blazars located at z= 0.31 ± 0.01**
- **Bright, and highly variable (nearly 100% DC) in all frequencies (radio to gamma ray) and time scales (minutes to decades)**
- **Classified as 'Intermediate Synchrotron Peaked' IBL**
- **Superluminal radio features ejected with apparent speeds up to 37c**

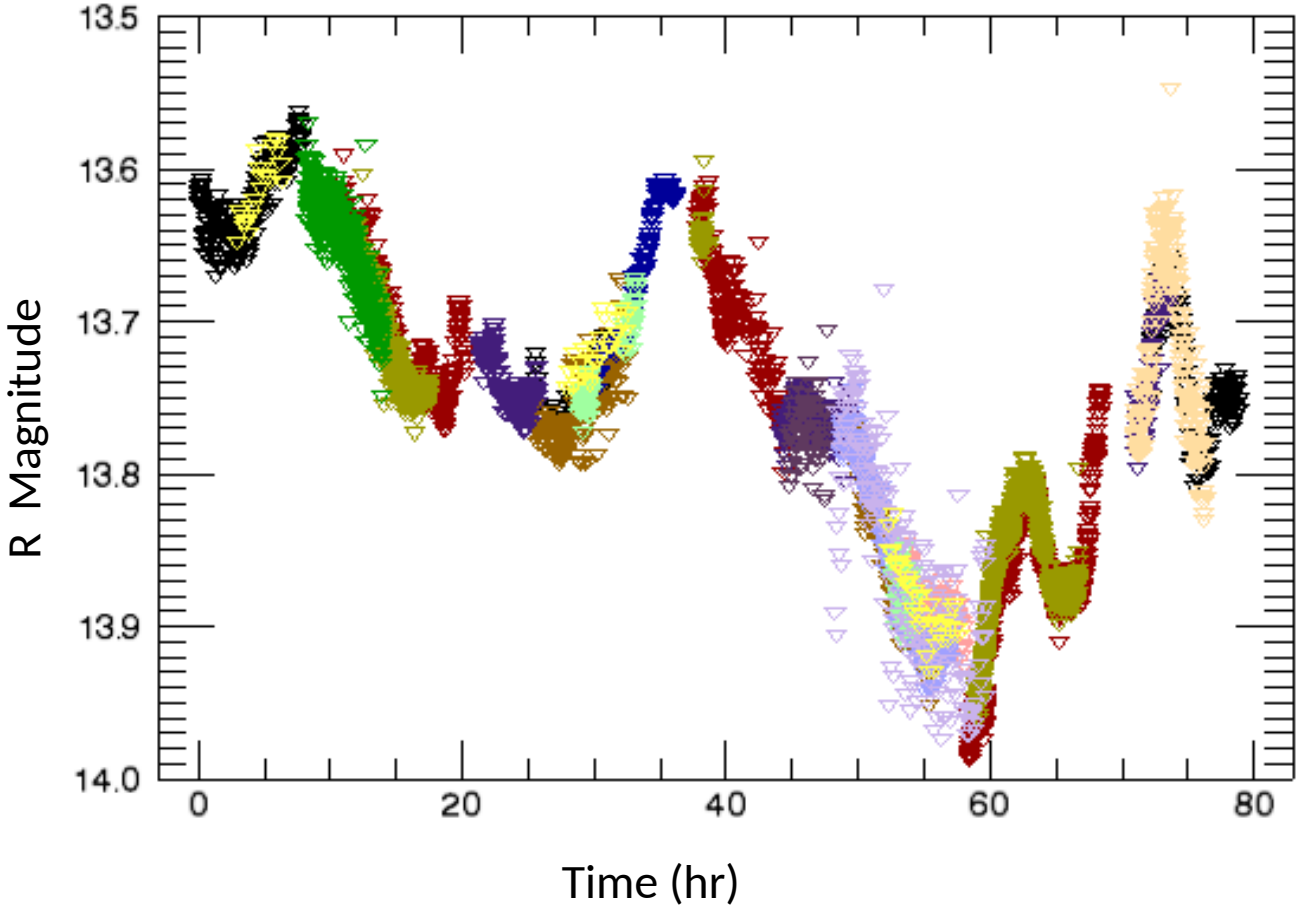


Optical CCD Image




Radio Image at 43.135 GHz on February 2014 (BU blazar group)

# *2009: Multi-site WEBT Campaign in the Optical*




*Statistics*

**Length of Campaign...7. hrs.**

**Mean Magnitude (R).....13.75**

**Faint Magnitude (R).....13.96**

**Bright Magnitude (R).....13.57**

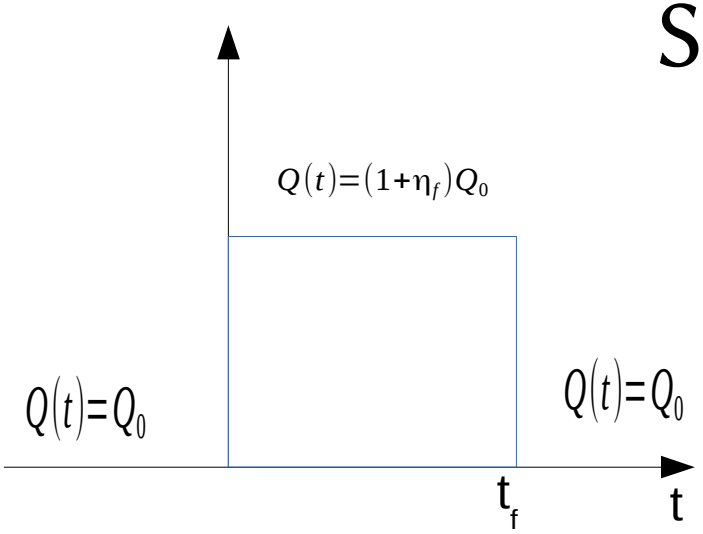
**Amplitude (mag).....0.31**

**Standard Deviation .....0.09**

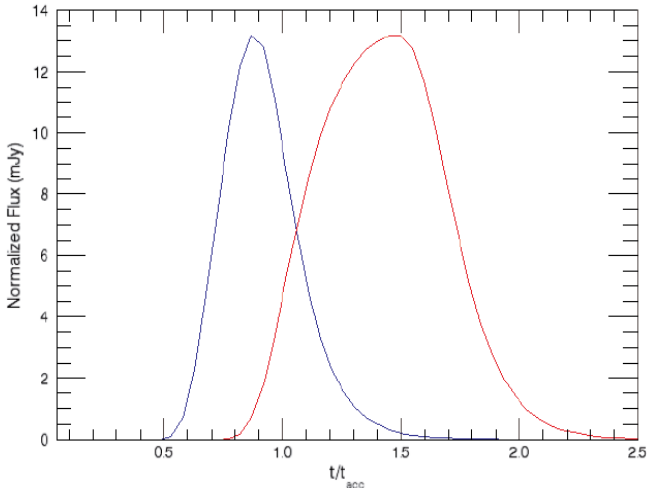
**Standard Deviation (NV)....0.017**

**Bhatta et al. 2013 A&A, 55A, 92B**

# Modeling the Light Curve as a Convolved Synchrotron Pulses

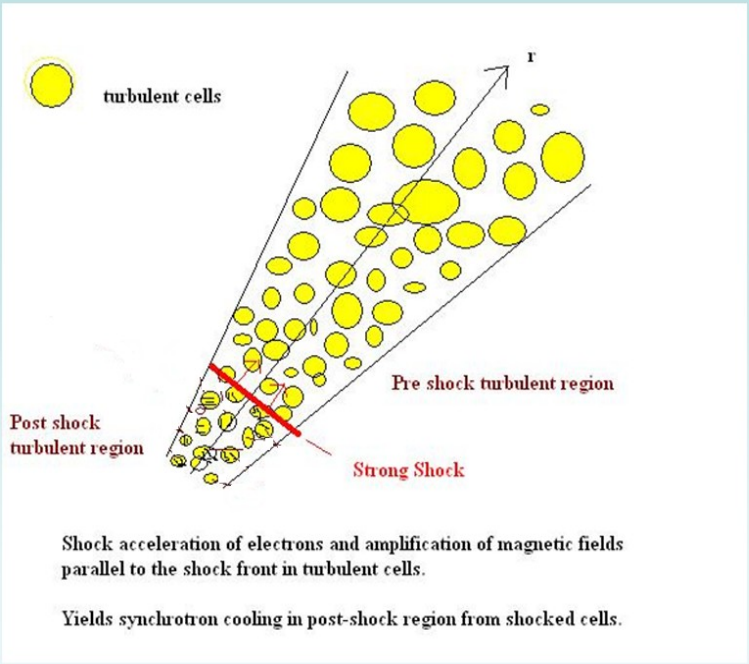



**Shot-noise type particle injection**




The resulting pulse shapes for frequencies $4.3X10^{16}$ (blue) and $4.3X10^{17}$ Hz (red)

## *Turbulent Synchrotron Sources Energized by a Plane Shock*



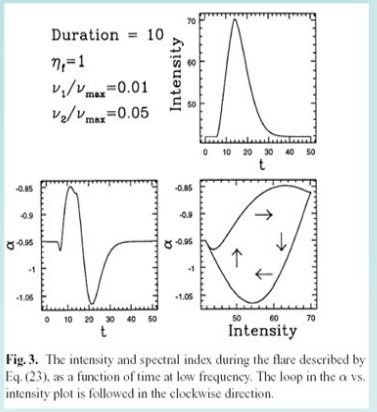
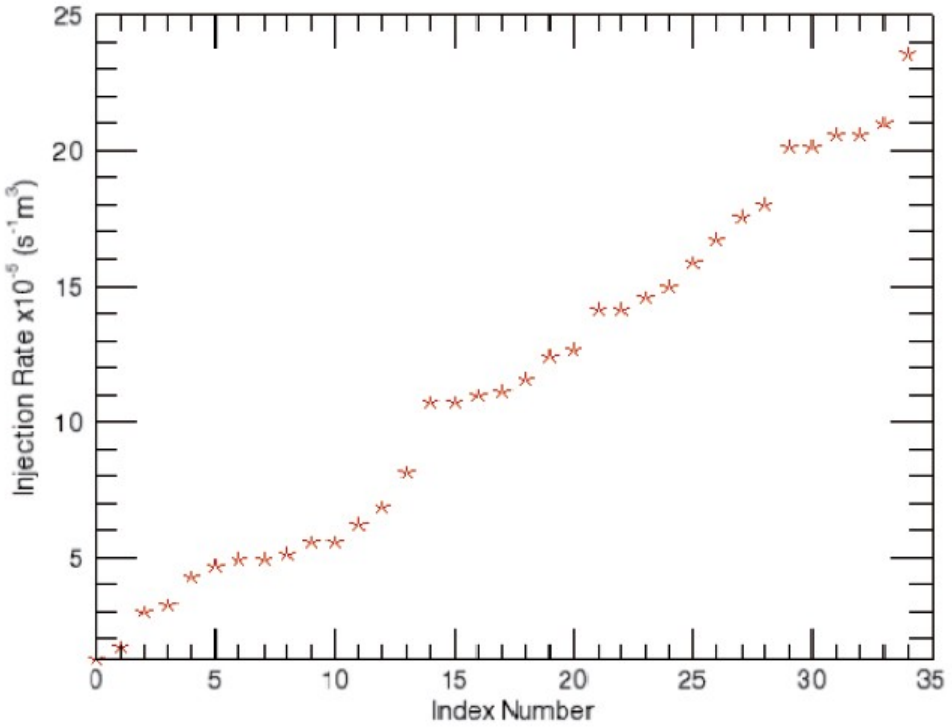



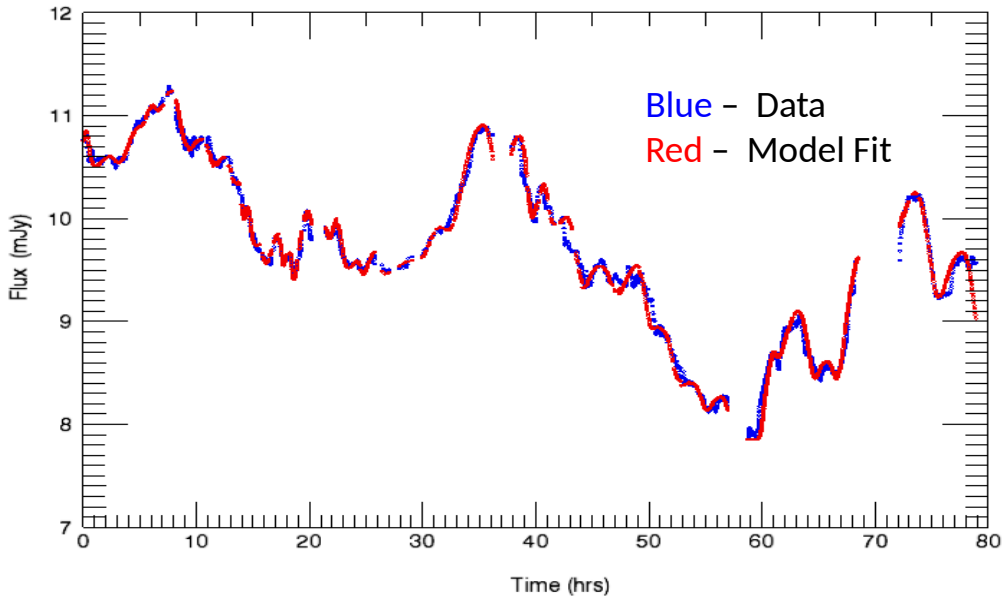

Fig. 3. The intensity and spectral index during the flare described by Eq. (23), as a function of time at low frequency. The loop in the $\alpha$ vs. intensity plot is followed in the clockwise direction.

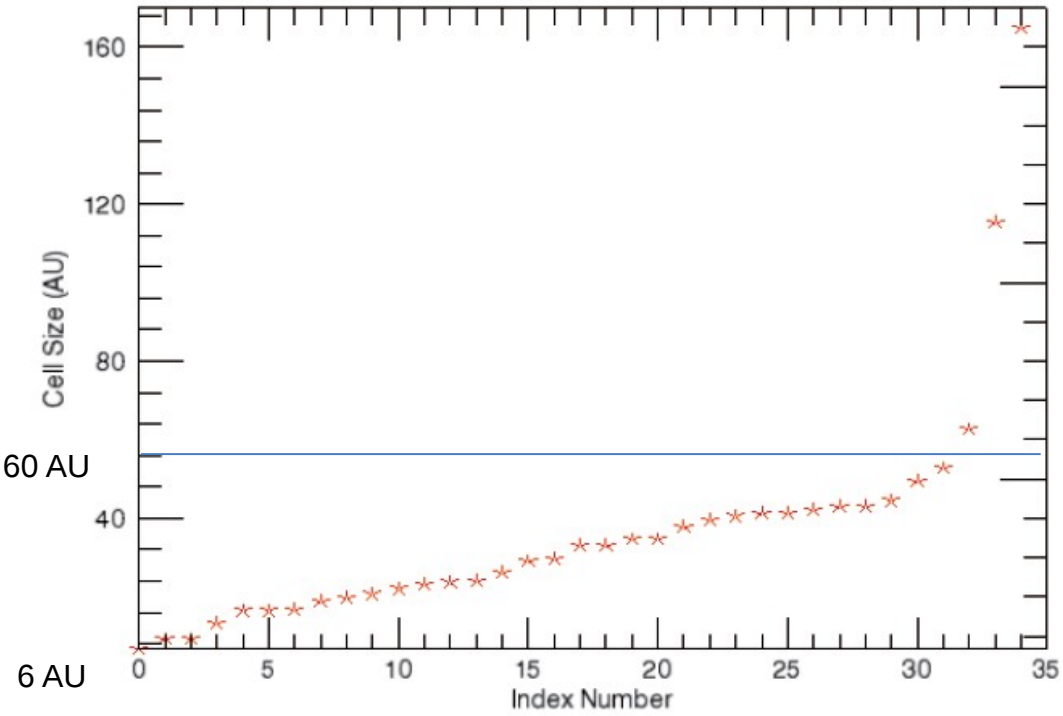
***Figure 3*** **above is taken from *Kirk et al. (1998)*. This top right panel shows the time dependence of the intensity of a cylindrical source.**

# Results :Particle Injection Rate and Cell Size Distribution




Possibly discrete injection rates in the particle acceleration ?

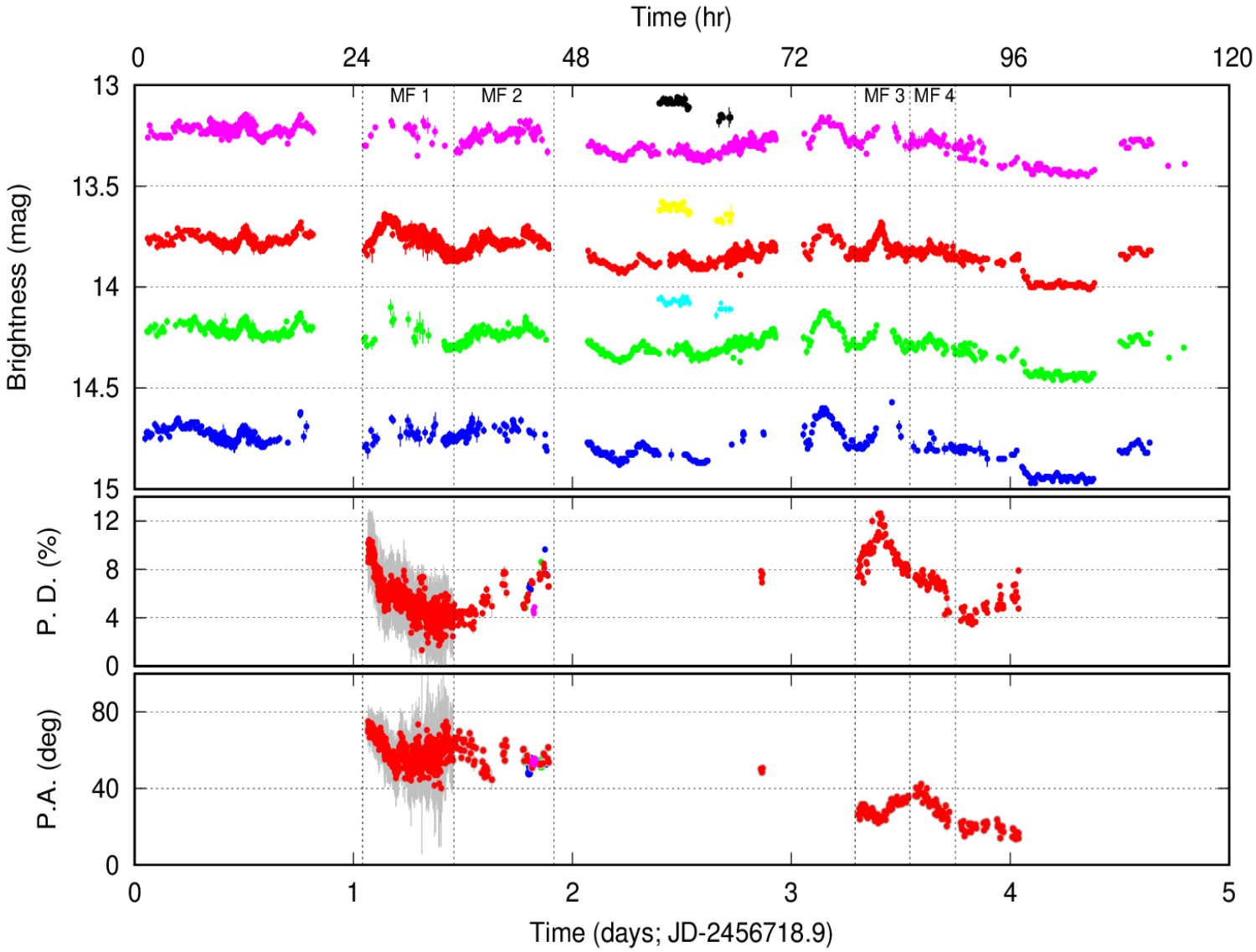



For statistical properties of variability: see poster by S. M. Hu.

Turbulent regions of smaller size dominate the emission site in the jet

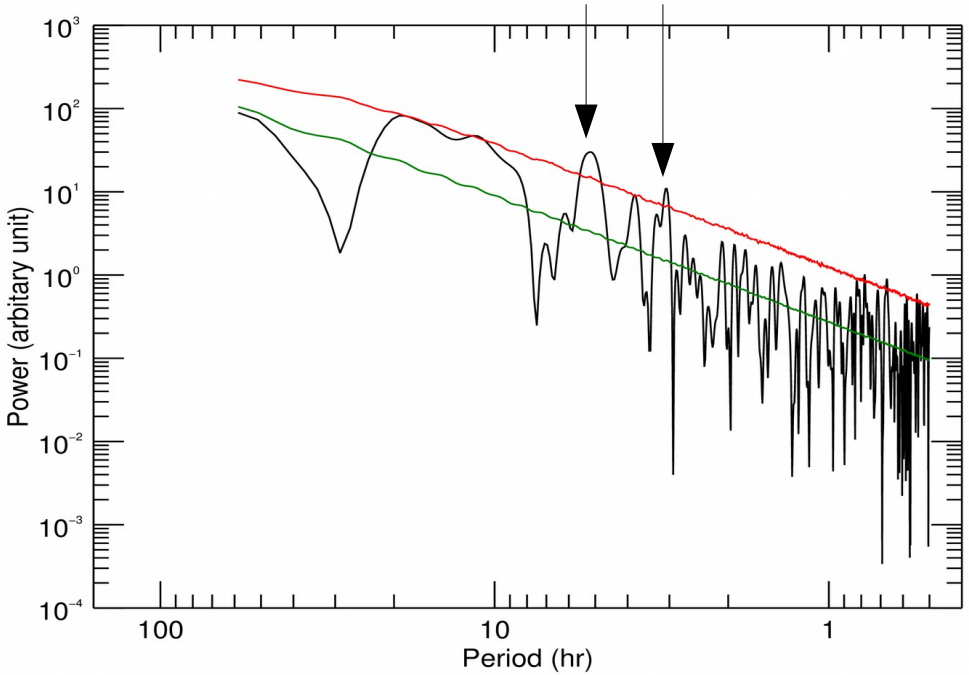
# 2014: 5-day Multi-frequency photo-polarimetric WEBT Campaign




**Bhatta et al. 2016 submitted to ApJ**

# Periodicity search and red-noise PSD

5 h 3 h

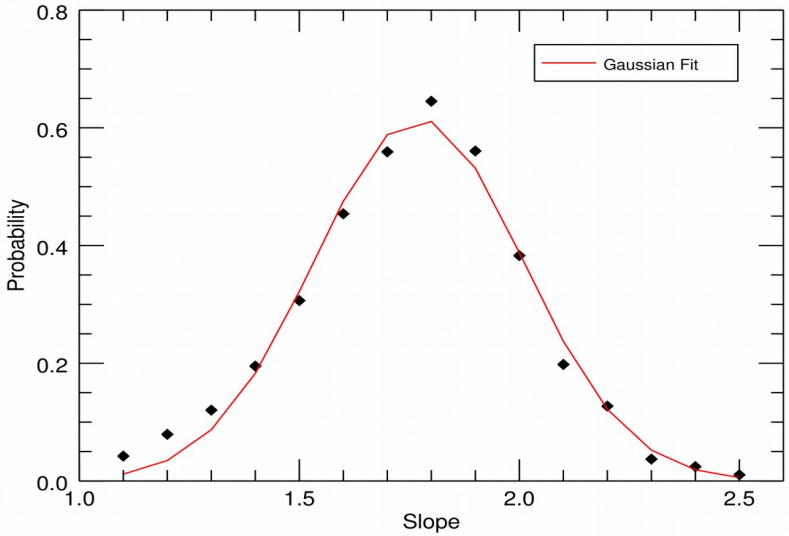



Lomb-Scargle periodogram (black), mean simulate periodogram (green) and 99% confidence contour from the simulations (red)

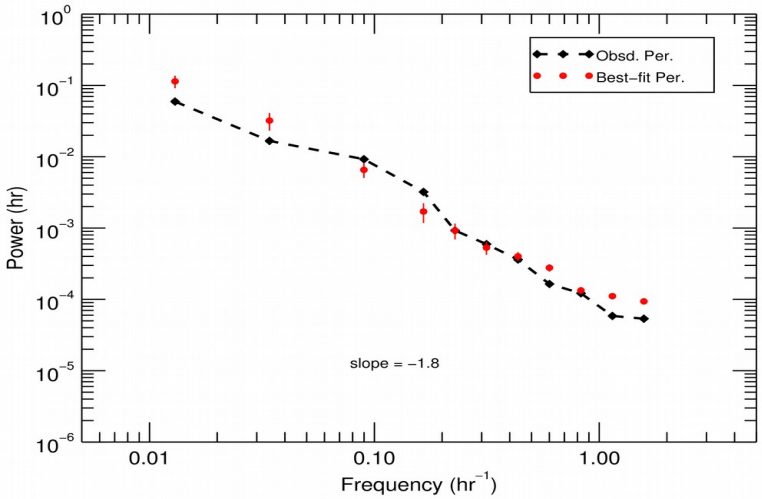
Hints for the presence of quasi- periodic oscillations at timescales of 3 h and 5 h were seen.

For QPO search in OJ 287: see poster by S. Zola

PSRESP: Uttley et al.(2002)



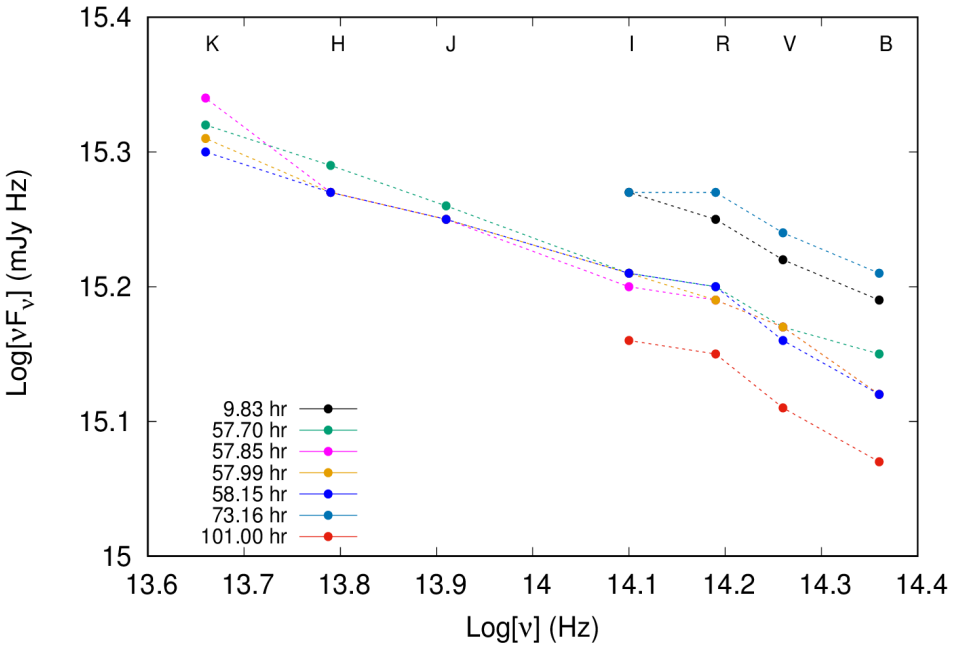

Probability that the power-law slope is acceptable

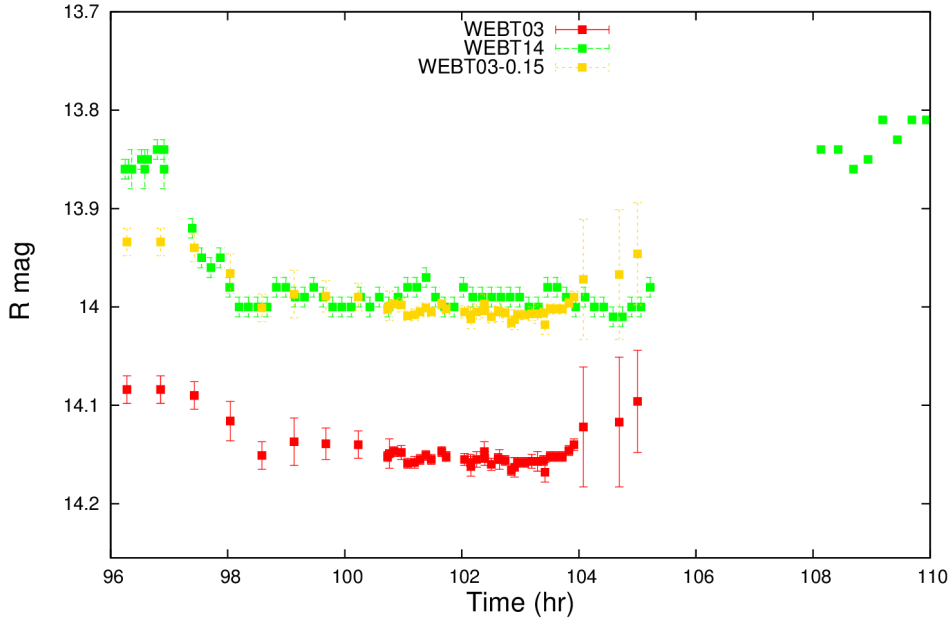



Binned PSD and the best-fit model

# The Plateau - Jet Activity Choked ?

From Shao Ming Hu, Weihai obs.




The optical spectra during the campaign.

Keplerian Period around the ISCO

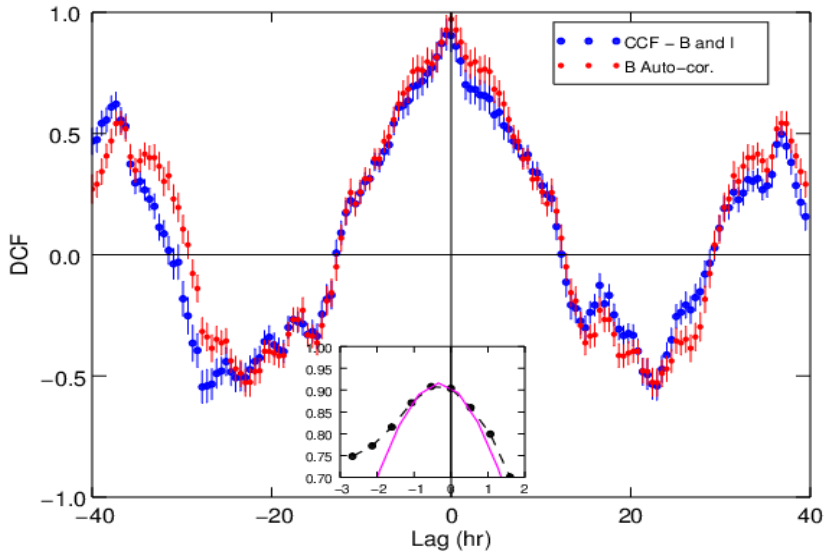
$$\tau_K = \tau_g \left(\frac{r_{isco}}{r_g}\right)^{3/2} \simeq 500 \left(\frac{\mathcal{M}}{10^8 M_\odot}\right) \left(\frac{r_{isco}}{r_g}\right)^{3/2} \text{ s}$$

$$\tau_g = r_g/c = G\mathcal{M}/c^3$$

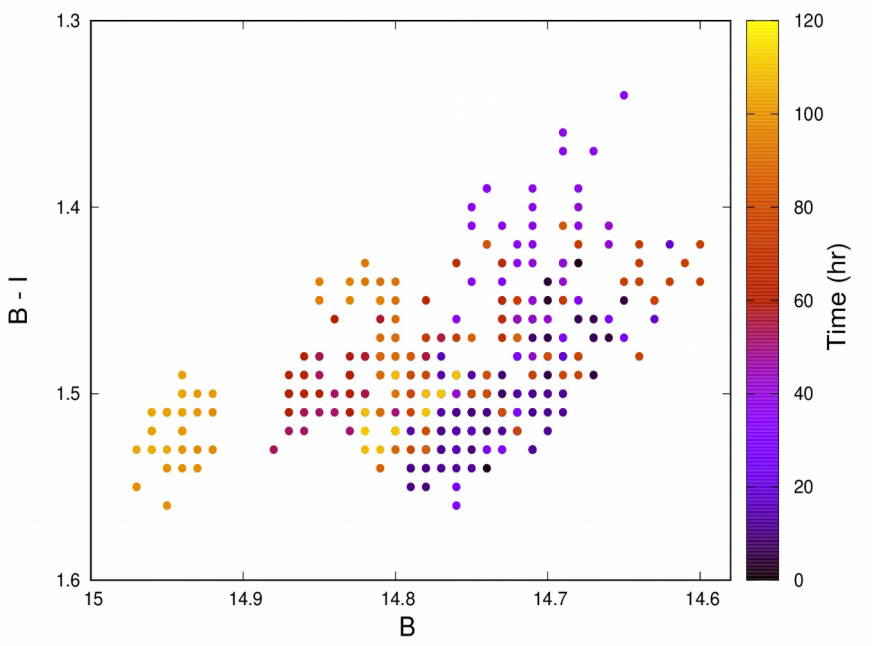
**This could be result of temporarily suppressed flow at the jet base !!**

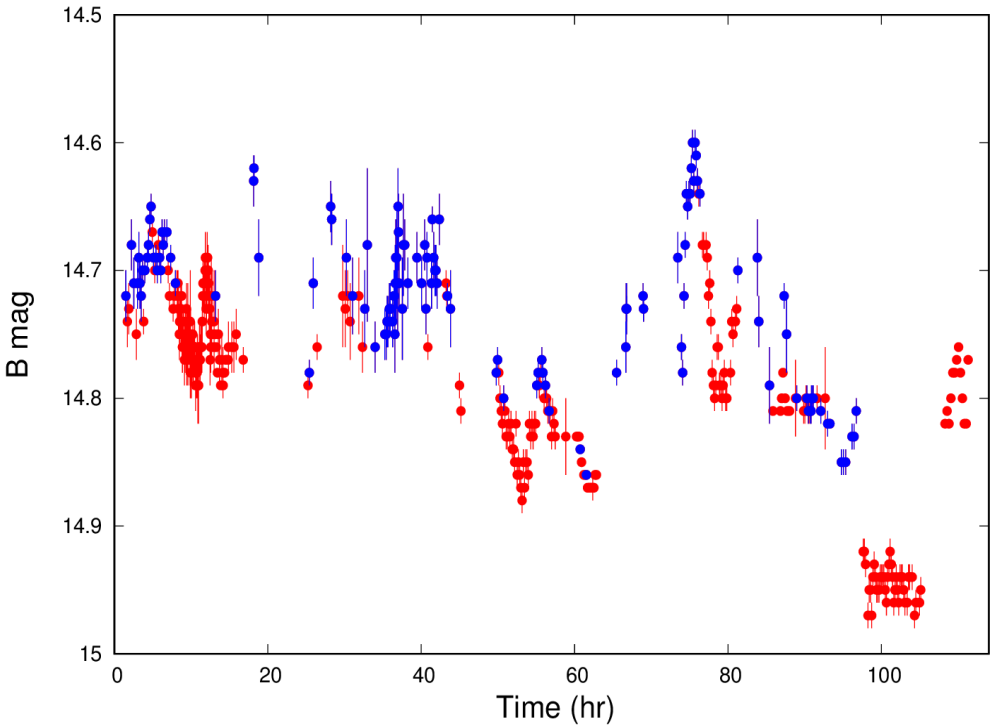
$\mathcal{M} \simeq 3 \times 10^8 M_\odot$ assuming very low spin values ($r_{isco} \simeq 6\, r_g$)

# Multi-band variability and Color Variability



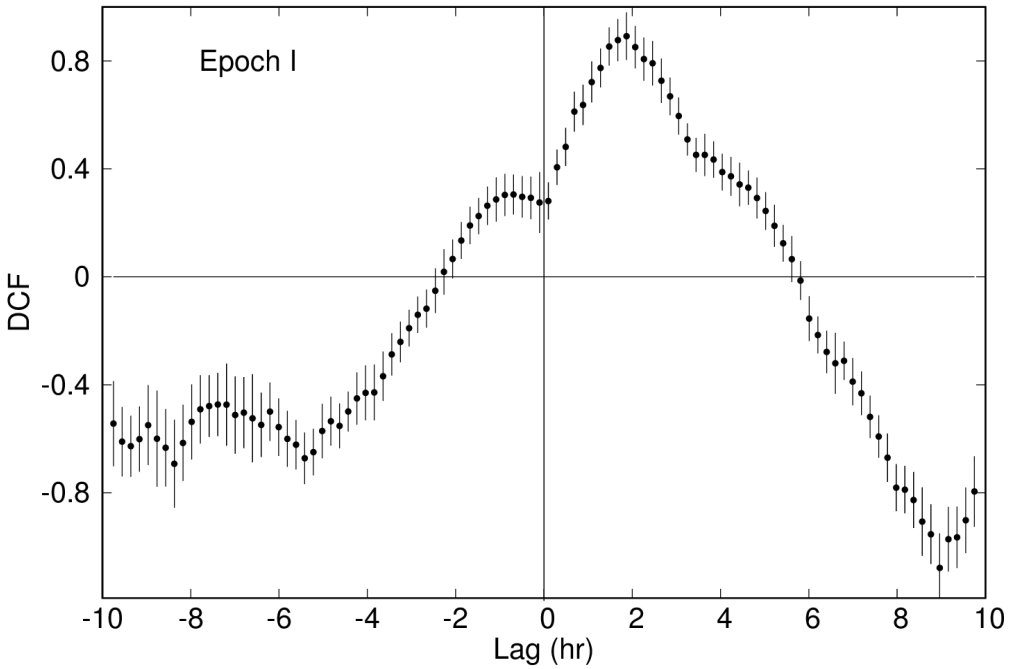

B- and I-band emission are highly correlated at large with a small possible lead of HE emission over LE emission

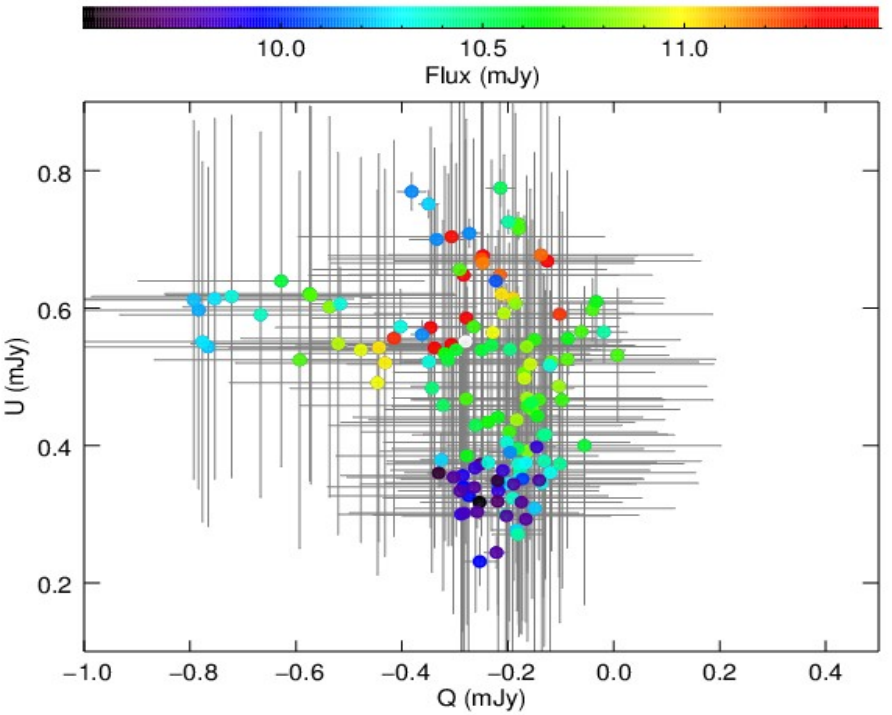


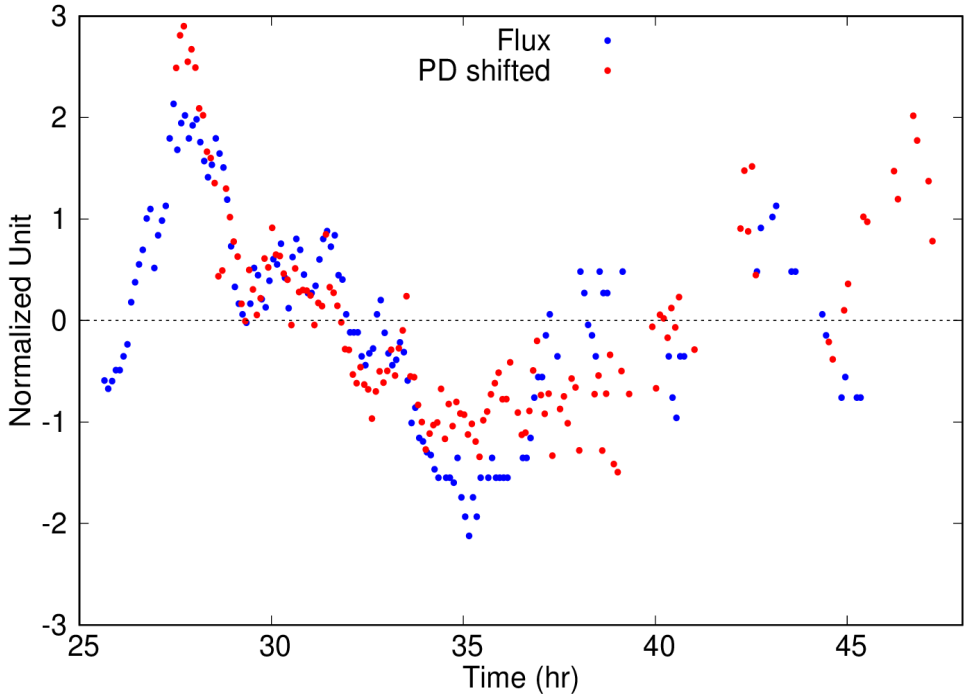

*"Bluer-when-brighter"* trend was observed in the color-magnitude diagram (lower left) and in the B-band light curve color coded with high (blue) and low (red) color value (above).

# Epoch I:Flux-PD-PA Correlation



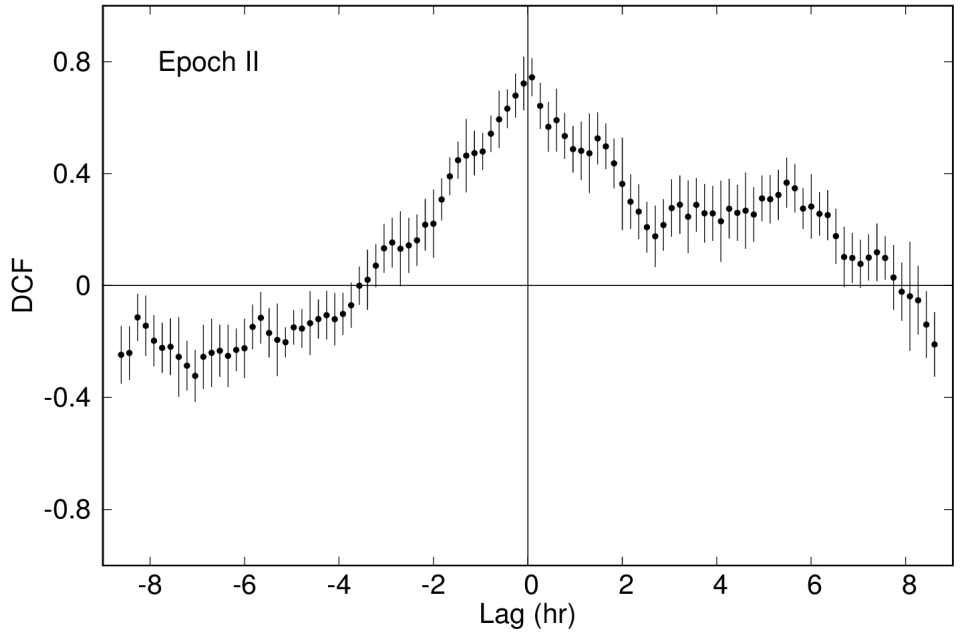



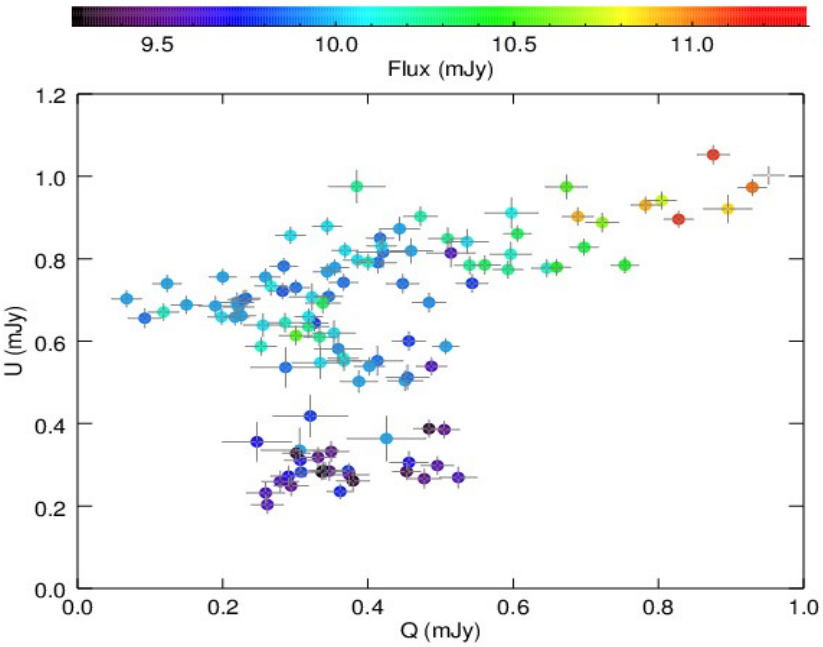

The evolution of Stokes parameters Q and U during Epoch I



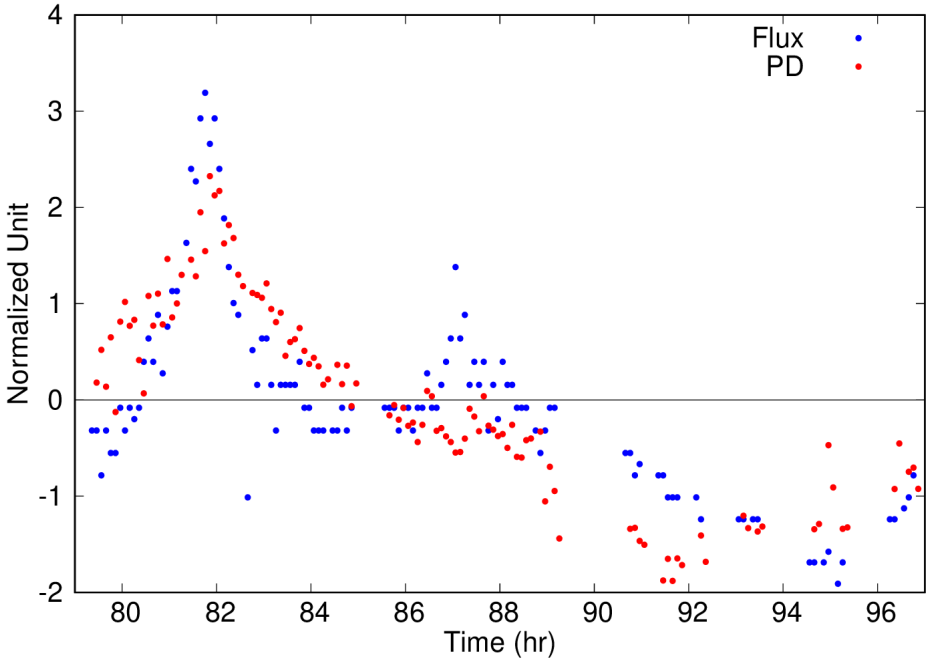

The discrete correlation function between flux and PD shows flux lagging behind PD by 2 hrs (above). It can be also be seen in normalized flux and PD shifted by 2 hrs (below)

# Epoch II: Flux-PD-PA Correlation



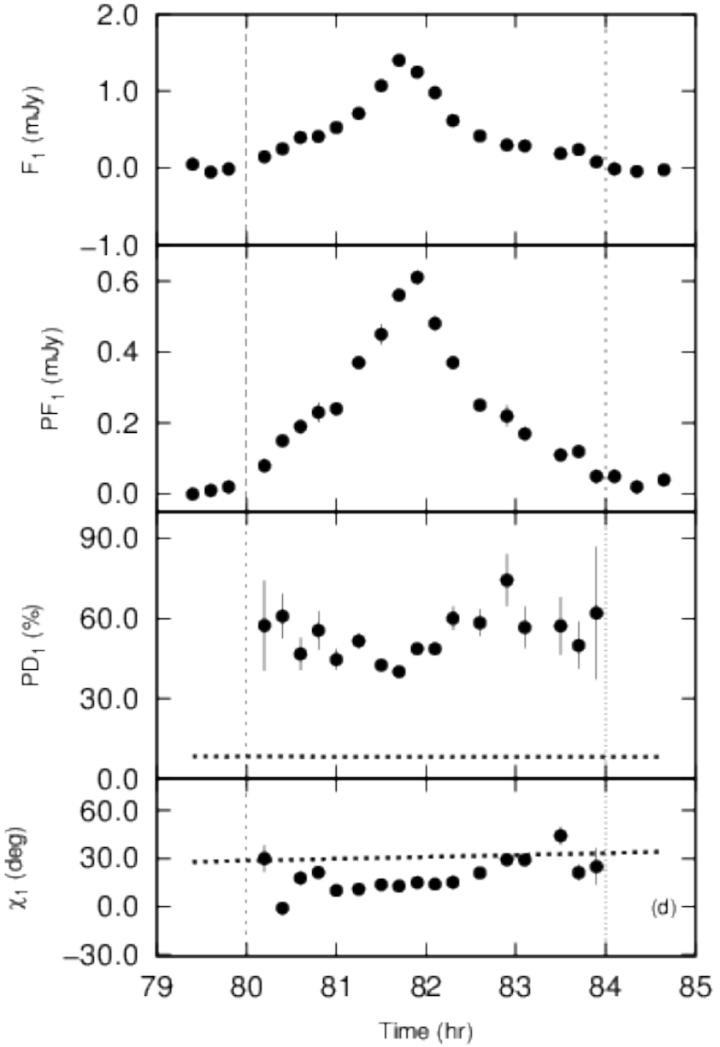

The evolution of Stokes parameters Q and U during Epoch II




The discrete correlation function between flux and PD showing high correlation (above). It can be also be seen in normalized flux and PD (below).

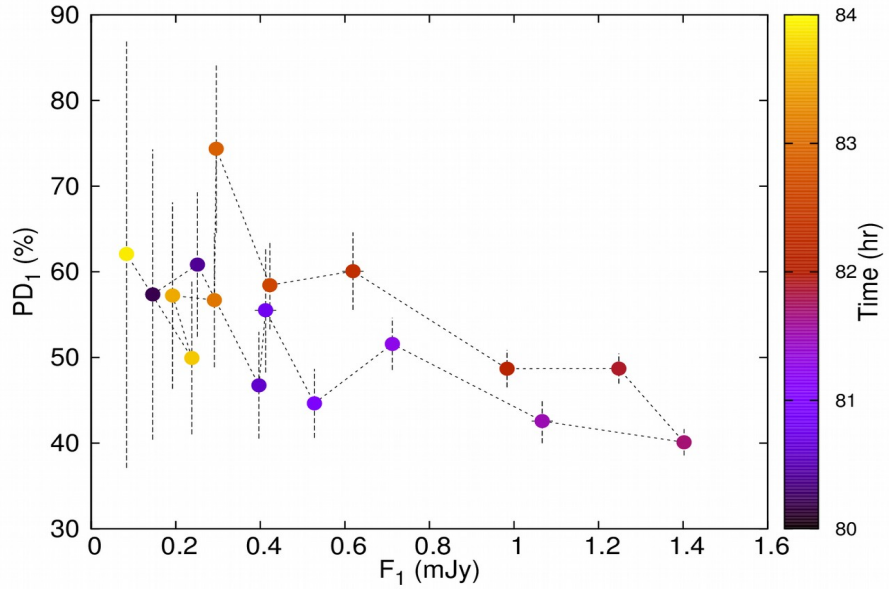
# Modeling of Individual Microflares

From Larionov V. M. and group

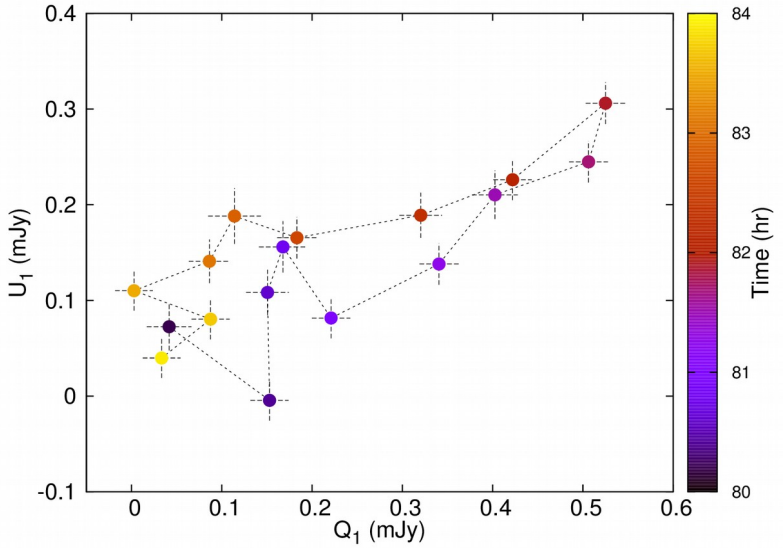



The modeling shows presence of highly polarized microflares during the campaign

**Bhatta et al. 2015, ApJL, 09, L27**

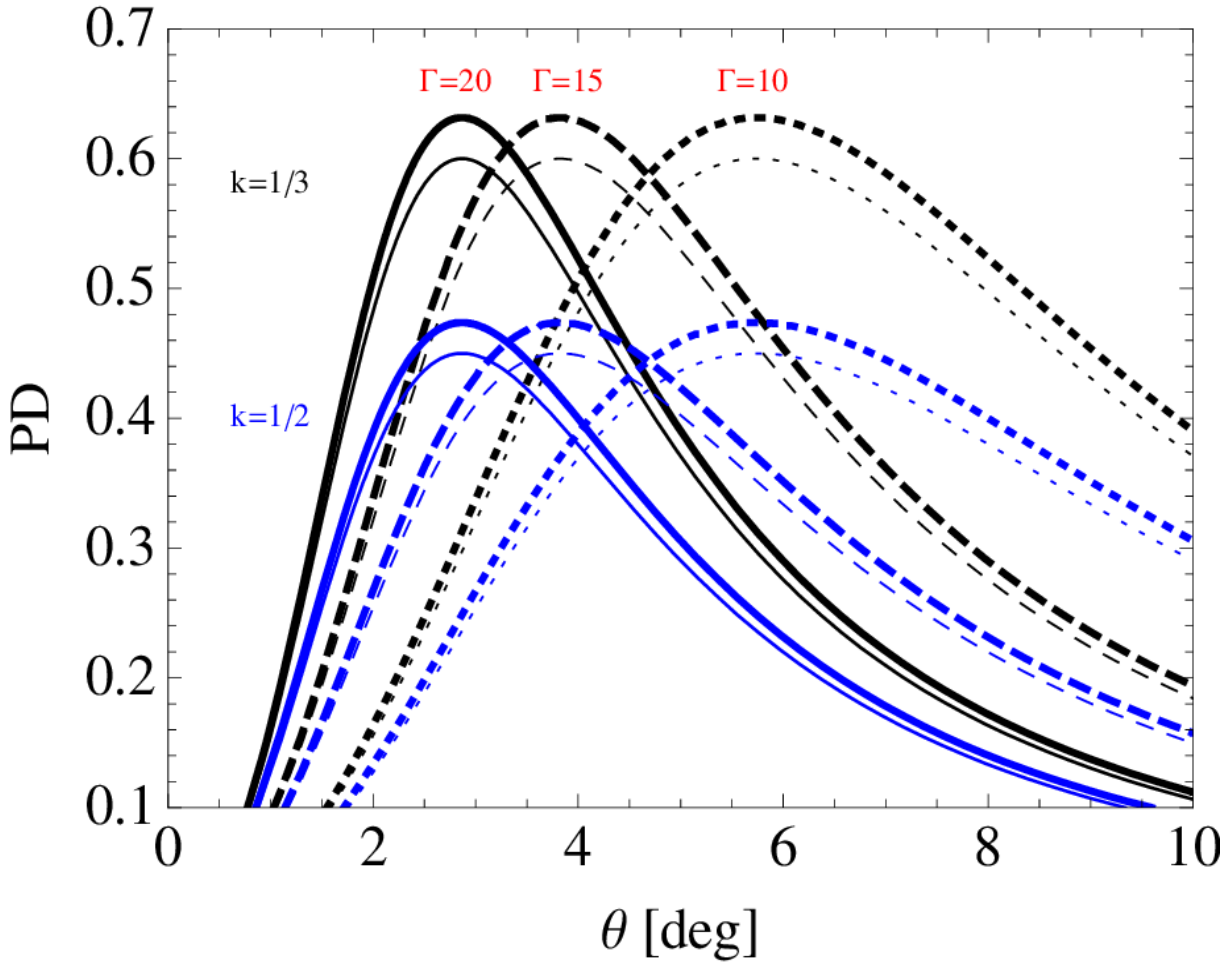



The modeled flux and PD for the flaring component appear in anti-correlation




The flaring component exhibits loop-like behavior in the Q-U plane

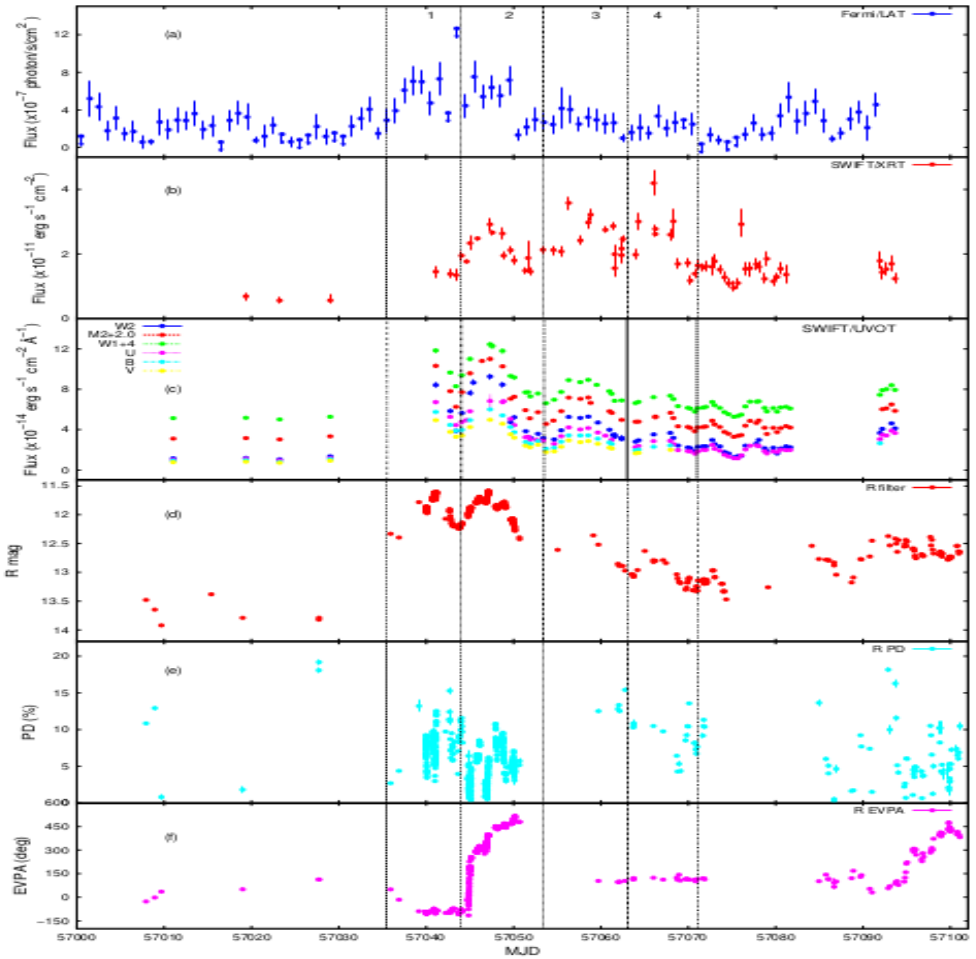
# Could it be shocks ?




$$PD = \frac{3+3\alpha}{5+3\alpha} \frac{\delta^2\left(1-k^2\right)\sin^2\theta}{2-\delta^2\left(1-k^2\right)\sin^2\theta}$$

**Highly polarized microflares showing anti-correlation between flux and PD, could be explained as the result due to variation in the angle with the line of sight.**

# Unprecedented Multi-frequency Flaring in the Begining of 2015

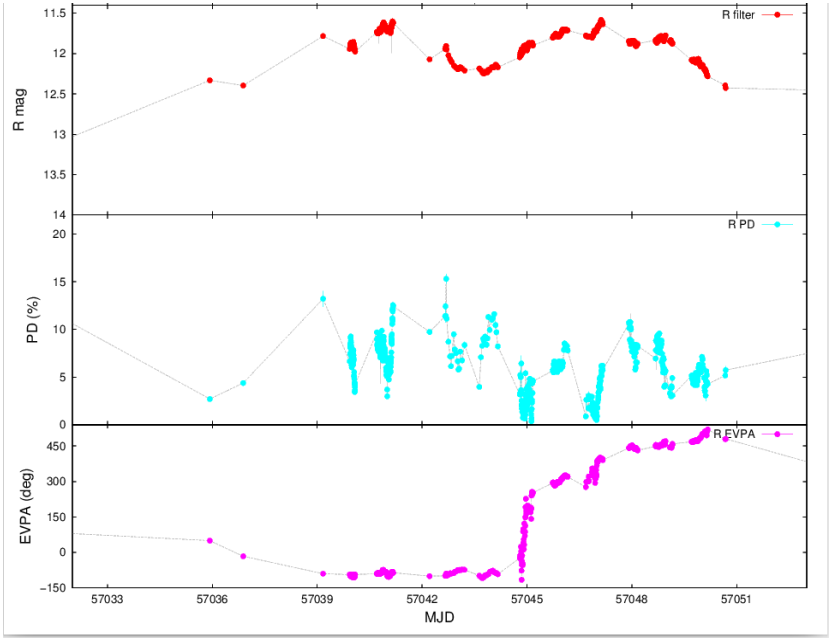


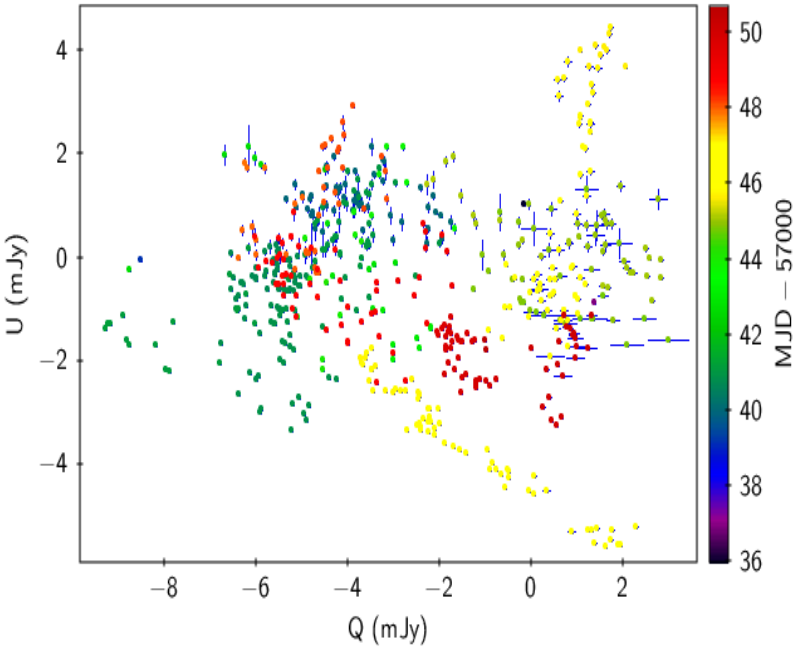

**The higly correlated optical and gamma ray emission increased by 7 times**

**Bhatta et al.2016 in prep.**

# Unprecedented EVPA Rotation: ~400 Deg. in a Day

From Larionov V. M. and group




**The evolution of Stokes parameters Q and U during the above EVPA rotation**

**The EVPA going under several rotations during the flare: 400 deg, rise, 1 day and further monotonic rise of 150 deg in 4 days !!**

- Marscher et al. 2008, BL Lac, 248 deg.,rise, 5 days
- Marscher et al. 2010, PKS 1510, 720 deg., rise, 50 days
- Abdo et al. 2010, 3C 279, 180 deg., decay, 20 days
- Valeri et al. 2013, 0716+714, 250 deg., rise, 2 days

# Summary

I. To investigate the nature (statistical properties) of rapid blazar variablity on the timescales ranging from minutes up to days.
- the overall variability of the source is of the red noise type (consistent with a random-walk process).

II. To search for a possible blazar periodicity in the previously unexplored/hardly explored time domain.
- Hints for quasi-periodic oscillations at timescales of ∼3h and ∼5h were found as well, though there are indications that they do not represent highly significant departures from a pure red-noise power spectrum.

III. To constrain the internal (sub)-structure of blazar jets.
- The observed optical flux is produced in compact emission sites within the outflow, with range of sizes and range of distances from the core;
- only sometimes polarization properties reveal any coherence in the magnetic field evolution (e.g. PD leading the total flux changes, hysteresis in the PD-F plane, large PA swings, etc.).

IV. To recognize the dominant particle acceleration processes shaping the rapid blazar variability.
-Compact emission sites may be identified with either turbulent cells, merging magnetic island related to magnetic reconnection, or small-scale internal shocks.
- only a further systematic investigation of flaring polarization properties and statistics (duty cycle, sell size distribution, etc.) may help to distinguish between the above mentioned possibilities