Photometric and Polarimetric Studies of Active Galactic Nuclei in St.Petersburg University

Valeri Larionov,
Vladimir Hagen-Thorn, Svetlana Jorstad, Daria Morozova, Dmitry Blinov, Tatiana Grishina, Evgenia Kopatskaya, Liudmila Larionova, Elena Larionova, Anna Mokrushina, Sergey Savchenko, Ivan Troitsky, Yulia Troitskaya

Do we have **sharp** multiwavelength eyes?

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Do we have **sharp** multiwavelength eyes?

- **The importance of monitoring projects in blazar studies was clear from the very discovery due to their violent variability on all time scales, from hours and even minutes to years.**
- **The outbursts that may occur unexpectedly for any given source act like a magnifying glass that allow to penetrate deeper in most conspicous regions of inner jet.**
- **Numerous successful campaigns were carried out that lead to systematic accumulation of observational data, either inside one observatory or as large international collaborations**.

Outline

- Historical background (1960-90) & some results
- Colors: Bluer when Brighter ? Redder when Brighter ?
- Telescopes used in the acquisition of data
- Observational targets
- Shock in helical jet ?
- Rotations: real, spurious, hidden and imaginary

In St.Petersburg (Leningrad) University we started photometric and polarimetric observations of AGNs ~50 years ago in Byurakan (photomultipliers+polaroids) and continued until 1990; resumed from 2000, with CCDs and in a wider collaboration

- **Earlier results:**

[1]. Hagen-Torn, V. A., Detailed photographic polarimetry of the M 82 galaxy, 1968, Astrophysics, 4, 26

[2]. Dombrovskii, V. A., & Hagen-Torn, V. A., Polarimetric studies of galactic nuclei, 1968, Astrophysics, 4, 163

[3]. Dombrovskii, V. A., Babadzhanyants, M. K., Hagen-Torn, V. A., & Gutkevich, S. M., Polarimetric investigation of compact extragalactic objects, 1971, Astrophysics, 7, 246

[4]. Hagen-Thorn, V. A., Rapid variability of the compact object OJ 287, 1972, Astronomicheskij Tsirkulyar, 714, 5

POLARIMETRIC INVESTIGATION OF COMPACT EXTRAGALACTIC OBJECTS

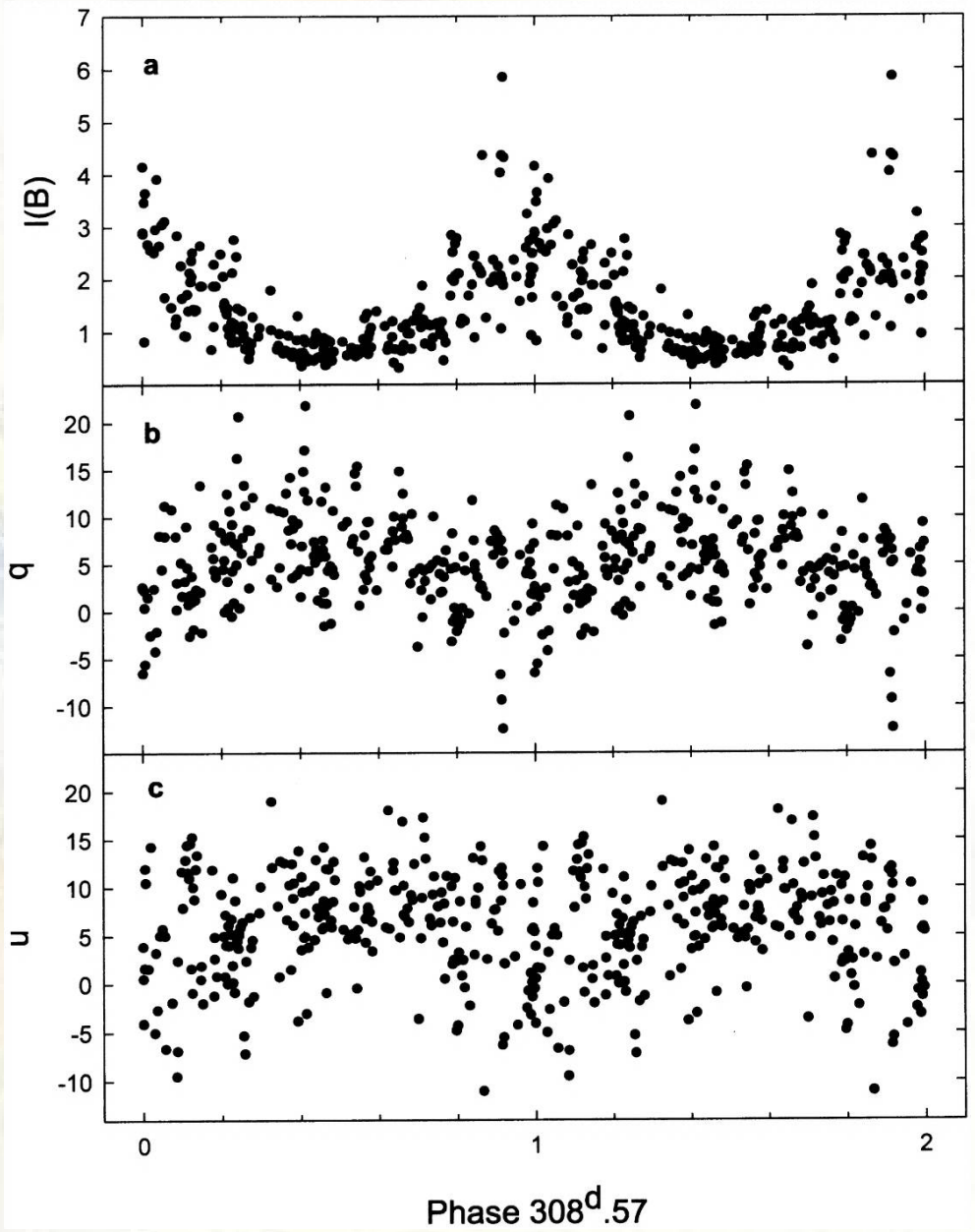
V. A. Dombrovskii, M. K. Babadzhanyants,
V. A. Gagen-Torn, and S. M. Gutkevich

3C 371. The data of Table 3 show that for galaxy 3C 371, which during measurements fits entirely within the 26-inch diaphragm and in whose radiation the radiation of the nucleus dominates, there are variations with time of the degree of polarization and position angle of the plane of predominate vibrations. In Fig. 2 a comparison is made for 1969–1970 between the values of the degree of polarization and the position angle of the plane of predominate vibrations in various color bands, taken from Table 3, and the photographic light curve in system B plotted on the basis of the data of [12]. In September 1970 there was a burst of radiation of this galaxy, which is clearly seen on the graph. A noticeably larger than usual degree of polarization was also observed at this time. However, it seems there is no direct relation between the level of brightness and the degree of polarization. It is important to note that very rapid variations can apparently occur for 3C 371. Actually, in July 1969 the degree of polarization dropped from 8.0 to 5.7% within 24 h. In a number of cases observations lasting 1.5–2 h left the impression that even within these intervals polarization did not remain constant.

Very cautious statement !

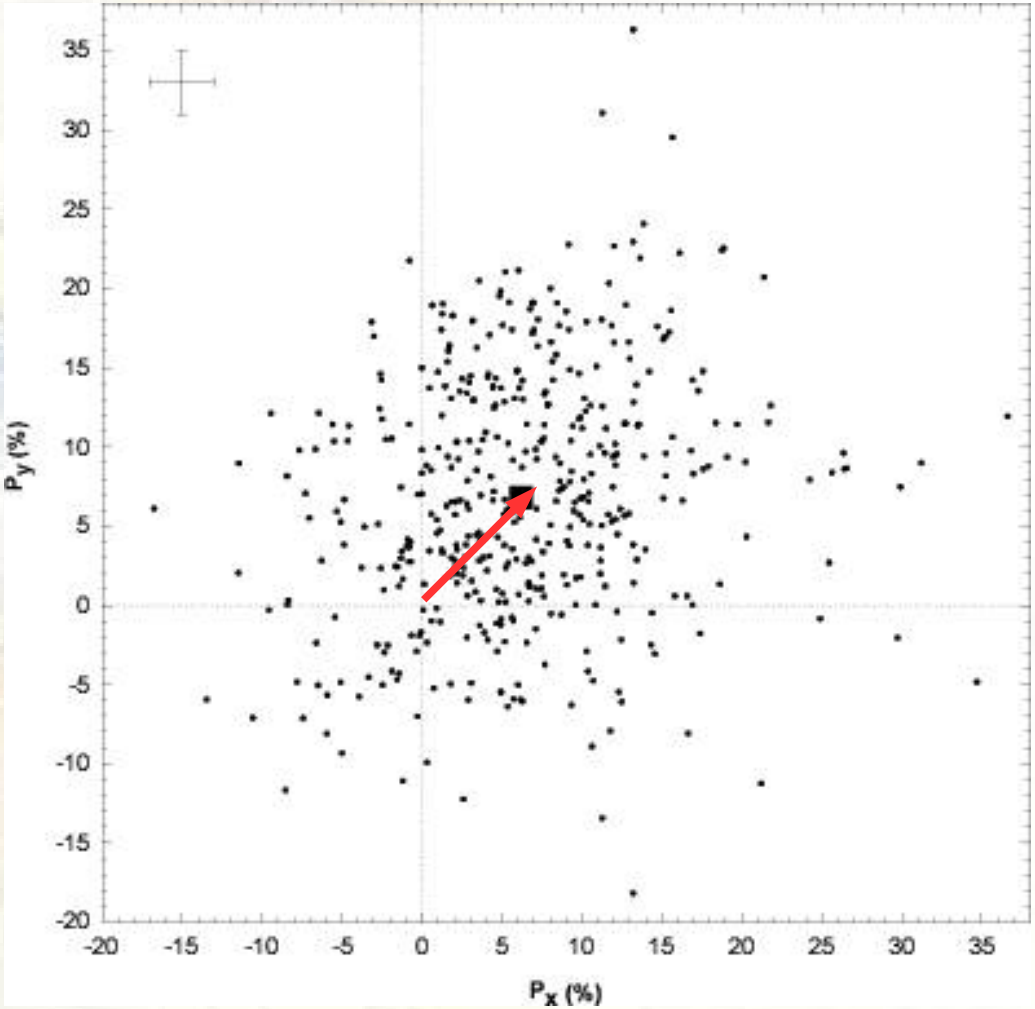
«PERIODIC COMPONENT IN THE VARIATIONS OF BRIGHTNESS AND POLARIZATION OF BL LACERTAE»,
V. A. HAGEN-THORN, V. M. LARIONOV, S. G. JORSTAD, AND E. G. LARIONOVA,
2002, AJ, 124, 3031

We have analyzed a prolonged (22 yr) series of photometric and polarimetric optical observations of BL Lac. We have found evidence for periodicity of the same period (P = 308 days) for variations in both total flux and relative Stokes parameter q in the second half of the data (1980–1991). This is the first time that the same periodic component—over more than 10 cycles—has been found in two observational sets obtained independently. Our results show that, although periodic behavior may exist over a long time interval, periodic variations switch on and off. This might explain discrepant results obtained by different authors who have tested for periodicity different parts of the light curve of the same object.



«**Analysis of the long-term polarization behaviour of BL Lac**»,
V. A. Hagen-Thorn, E. G. Larionova,
S. G. Jorstad, C.-I. Björnsson,
V. M. Larionov,
2002, A&A, 385, 55

An analysis is performed of polarimetric and photometric observations of BL Lac carried out in 1969-1991 at the Astronomical Institute of St. Petersburg State University. The distribution of polarization directions certainly points to the existence of the preferred direction of polarization ($\theta = 22^{o}$) close to the direction of the jet observed by VLBI. High polarization degree and colorimetric data are evidence of the synchrotron nature of the variable source. The relative Stokes parameters are distributed normally over some mean value. The correlations between different parameters characterizing the flux density and polarization of the central point source allow us to consider that in BL Lac there is a continually acting source of polarized radiation on which the sources with randomly distributed polarization directions are superimposed.



Baltic Astronomy, 1999, v.8, p.575-592

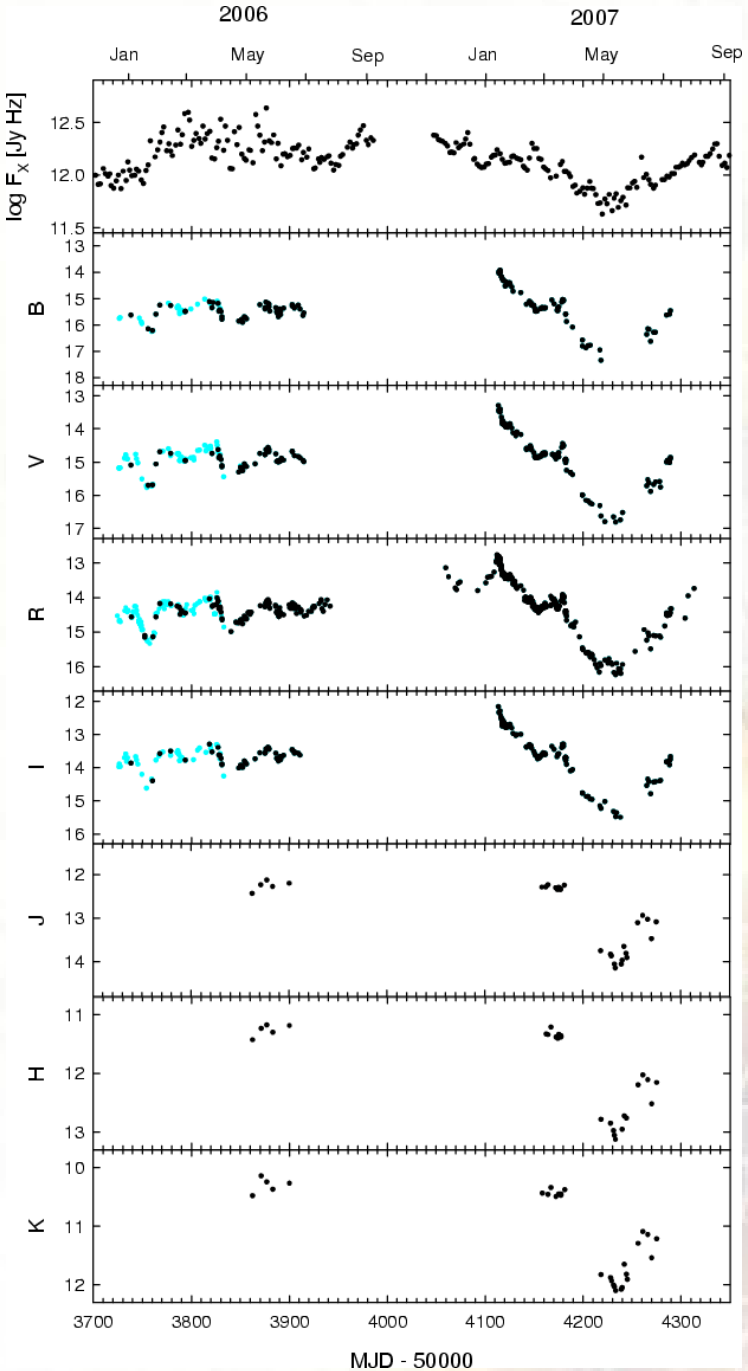
PHOTOMETRY AND POLARIMETRY OF ACTIVE GALACTIC NUCLEI

V. A. Hagen-Thorn and S. G. Marchenko

Astronomical Institute, St.-Petersburg State University,
Bibliotechnaya Pl. 2, Petrodvoretz, 198904 St.-Petersburg, Russia

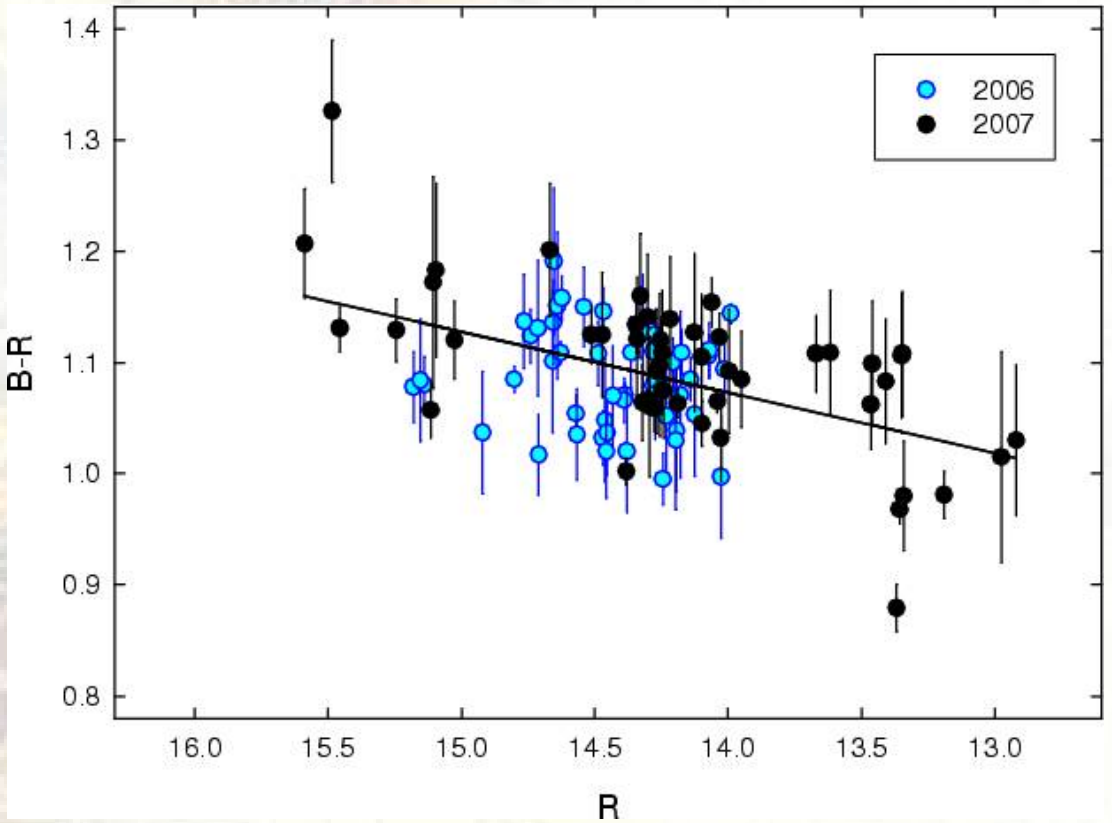
Received January 10, 2000.

Abstract. A method of analysis of polarimetric and photometric observations of AGN with the aim to find the spectral energy distribution and polarization parameters of variable sources responsible for activity is described. Some results of such analyses are given. The properties of the sources point to their synchrotron nature.

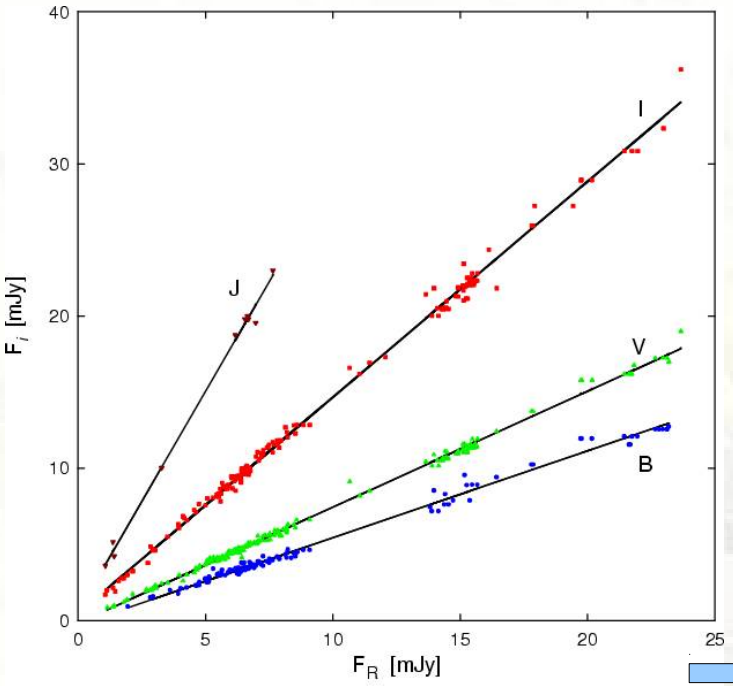


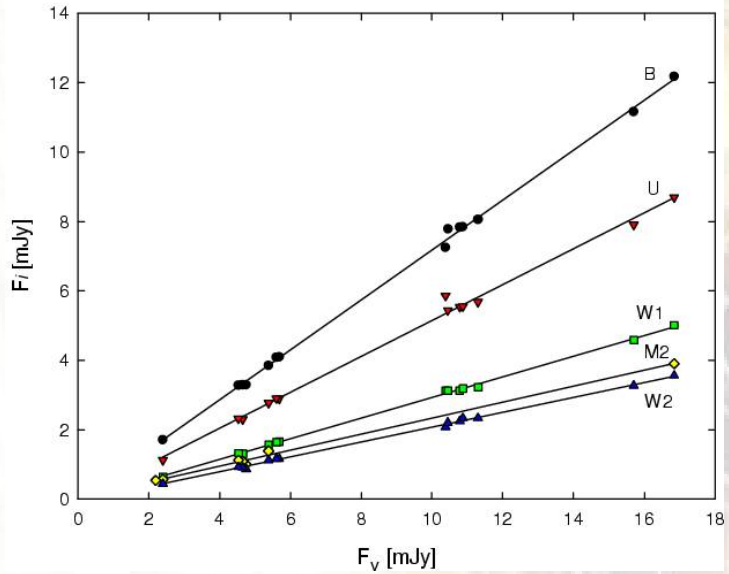
Results of WEBT, VLBA and RXTE monitoring of 3C 279 during 2006-2007,

Larionov, V. M., Jorstad, S. G., Marscher, A. P., Raiteri, C. M., Villata, M., et al., 2008, Astronomy and Astrophysics, 492, 389



«bluer-when-brighter» ?





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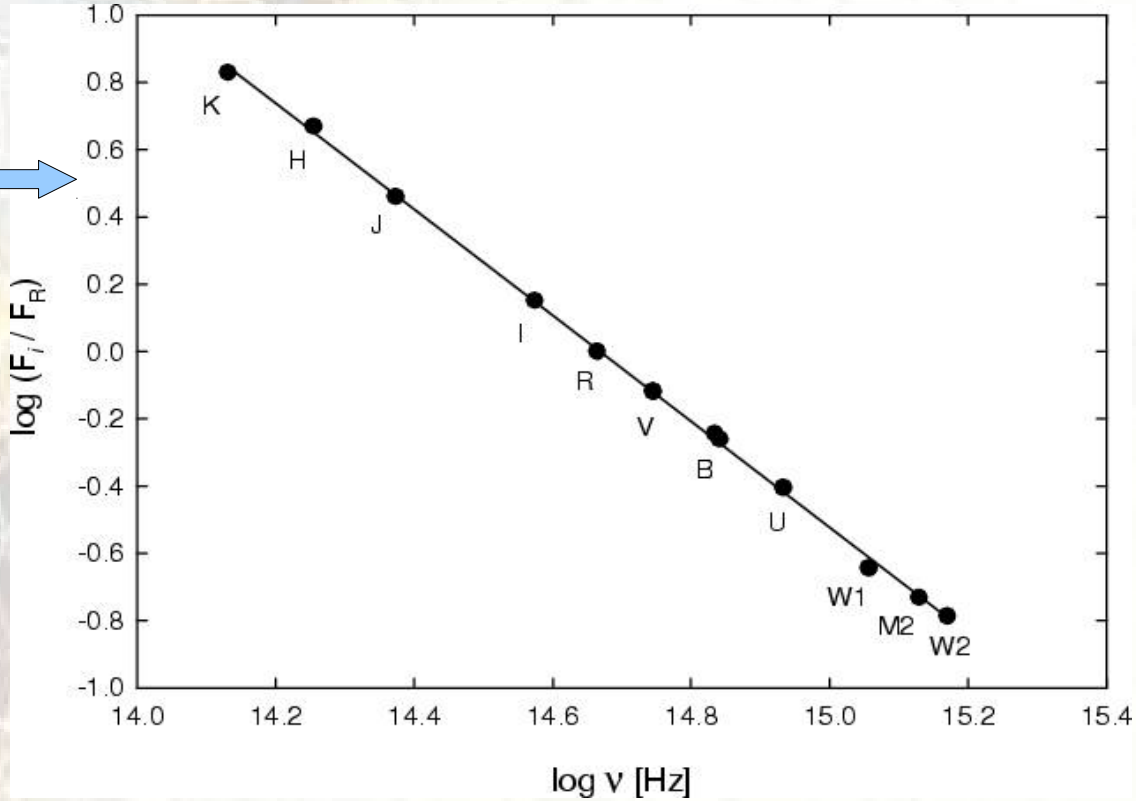
Larionov, V. M., Jorstad, S. G., Marscher, A. P., Raiteri, C. M., Villata, M., et al., 2008, Astronomy and Astrophysics, 492, 389

SED of *variable* source remains **unchanged**

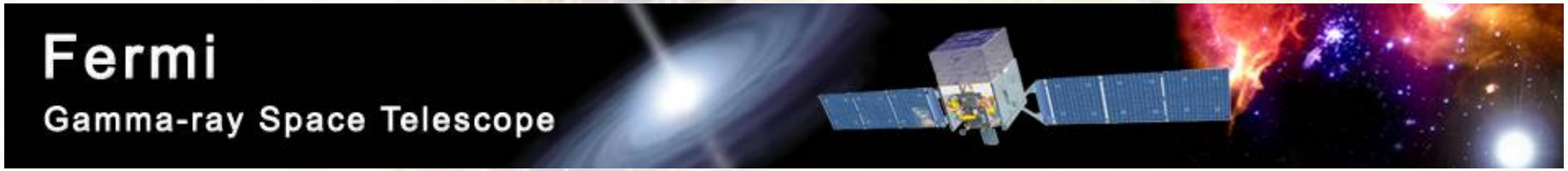


Perkins
Arizona (Lowell)

LX-200
St.Petersburg

AZT-8
Crimea

We collaborate with…



http://vo.astro.spbu.ru/program

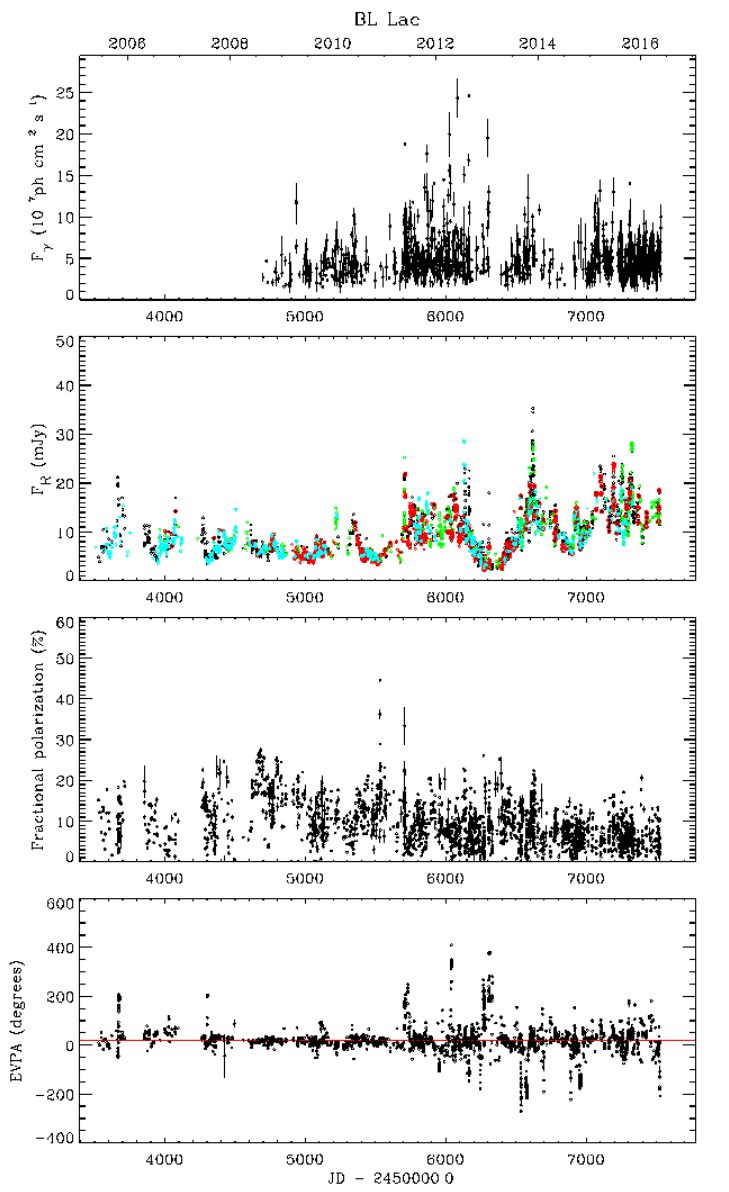
FSRQ

OC 457
PKS 0420-01
PKS 0528+13
1156+29
3C 273
B2 1308+32
PKS 1510-08
1633+38
3C 345
CTA 102
3C 454.3

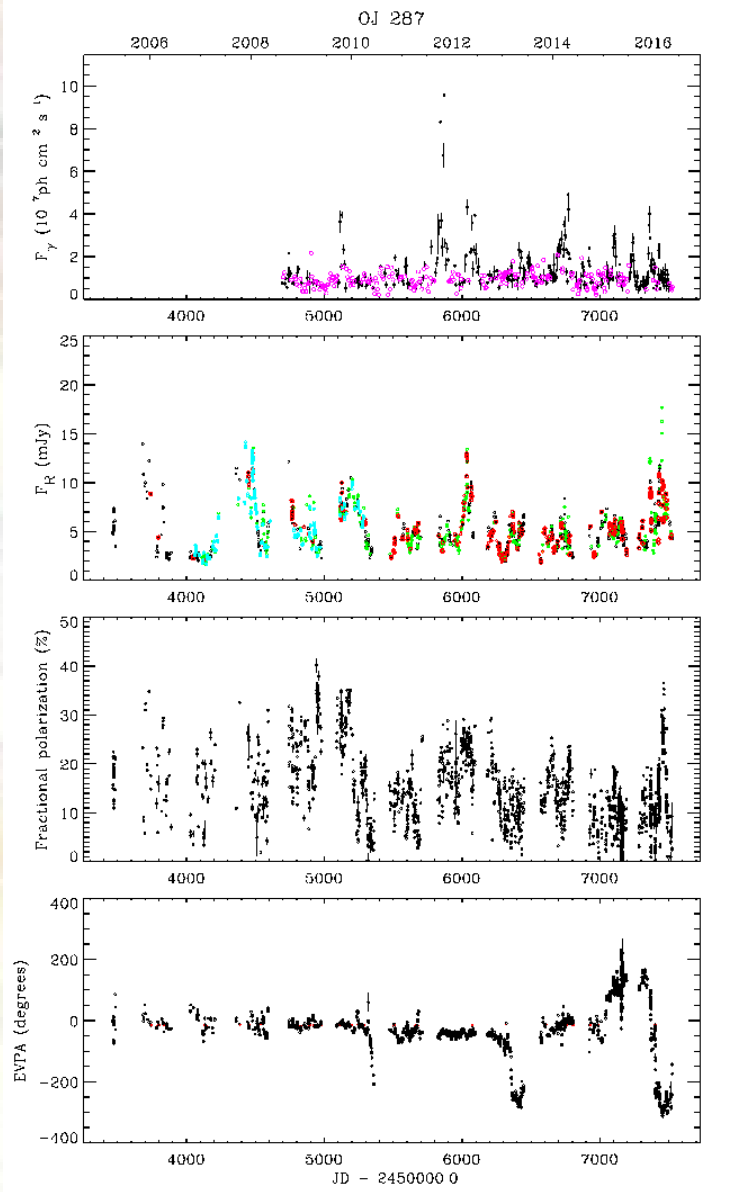
BL Lac

3C66a
AO0235+16
S5 0716+71
PKS 0735+17
OJ287
PKS 1055+01
Mkn 421
W Com
Mkn 501
OT 081
1959+65
BL Lac

BL Lac


BL Lac
2006
2008
2010
2012
2014
2016
F_γ (10^{-7} ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
4000
5000
6000
7000
JD − 2450000.0

OJ 287


OJ 287
2006
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F_γ (10^{-7} ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
4000
5000
6000
7000
JD − 2450000.0

Polarization vector rotations: real, spurious, hidden and imaginary

As you value your life or your reason keep away ***rotations*** **from** ~~**the moor**~~**.**

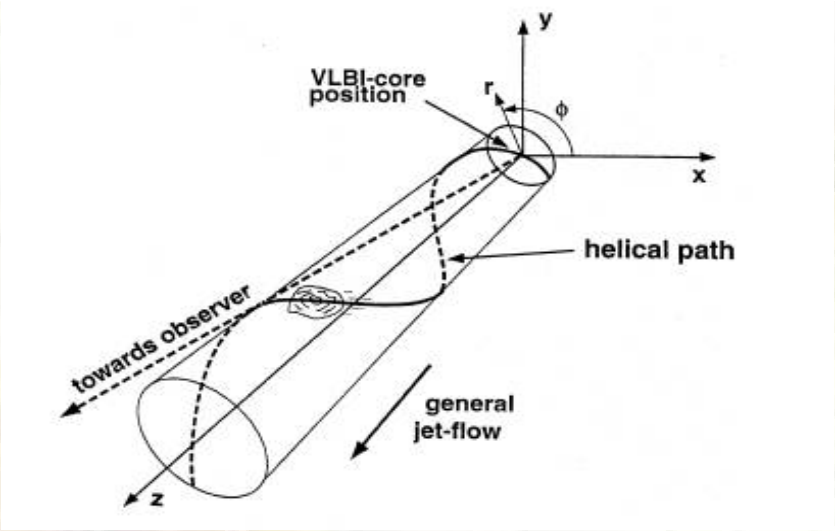
Sir Arthur Conan Doyle
«The Hound of the Baskervilles»

(For those who is already out of reason)

See posters: everyone where 'polarimetry' is mentioned
Listen talks: all Tuesday, Wednesday and Thursday!
Read papers: Dmitry Blinov, Sebastian Kiehlmann….

The main parameters that determine the visible behavior of the outburst

- jet viewing angle θ
- bulk Lorentz factor of the shocked plasma $\Gamma = (1 - \beta^2)^{-1/2}$
- temporal evolution of the outburst $F' = F_0 \cdot \begin{cases} \exp(-|(t-t_0)|/\tau), & t \leq t_0 \\ \exp(-|(t-t_0)|/k\tau), & t > t_0 \end{cases}$; k is responsible for different timescales of the rise and decline of the outburst; primed quantities refer to the plasma frame
- Doppler time contraction in the observer's frame, $\Delta t_{\rm obs} = \delta^{-1} \cdot \Delta t_{\rm src}$
- Shocked plasma compression η
- Spectral index of the emitting plasma α
- Pitch angle ζ of the spiral motion and helical field
- Period of the shock's spiral revolution in the observer's frame $P_{\rm obs}$.



MAIN RELATIONS

The viewing angle of the compact emission region φ is obtained from the relation:

$$\cos\varphi = \cos\theta\cos\zeta + \sin\theta\sin\zeta\cos(2\pi t_{\rm obs}/P_{\rm obs}). \quad (1)$$

Relativistic aberration changes the direction of the normal to the shock front ψ:

$$\psi = \arctan[\sin\varphi/(\Gamma(\cos\varphi - \sqrt{1-\Gamma^{-2}}))]. \quad (2)$$

The fractional polarization of the shocked plasma radiation:

$$p \approx \frac{\alpha+1}{\alpha+5/3}\,\frac{(1-\eta^{-2})\sin^2\psi}{2-(1-\eta^{-2})\sin^2\psi}. \quad (3)$$

The position angle is determined by the direction of the projected minor axis of the shock wave:

$$\Theta = \arctan[\zeta\sin t_{\rm obs}/(\zeta\cos t_{\rm obs} - \theta)]. \quad (4)$$

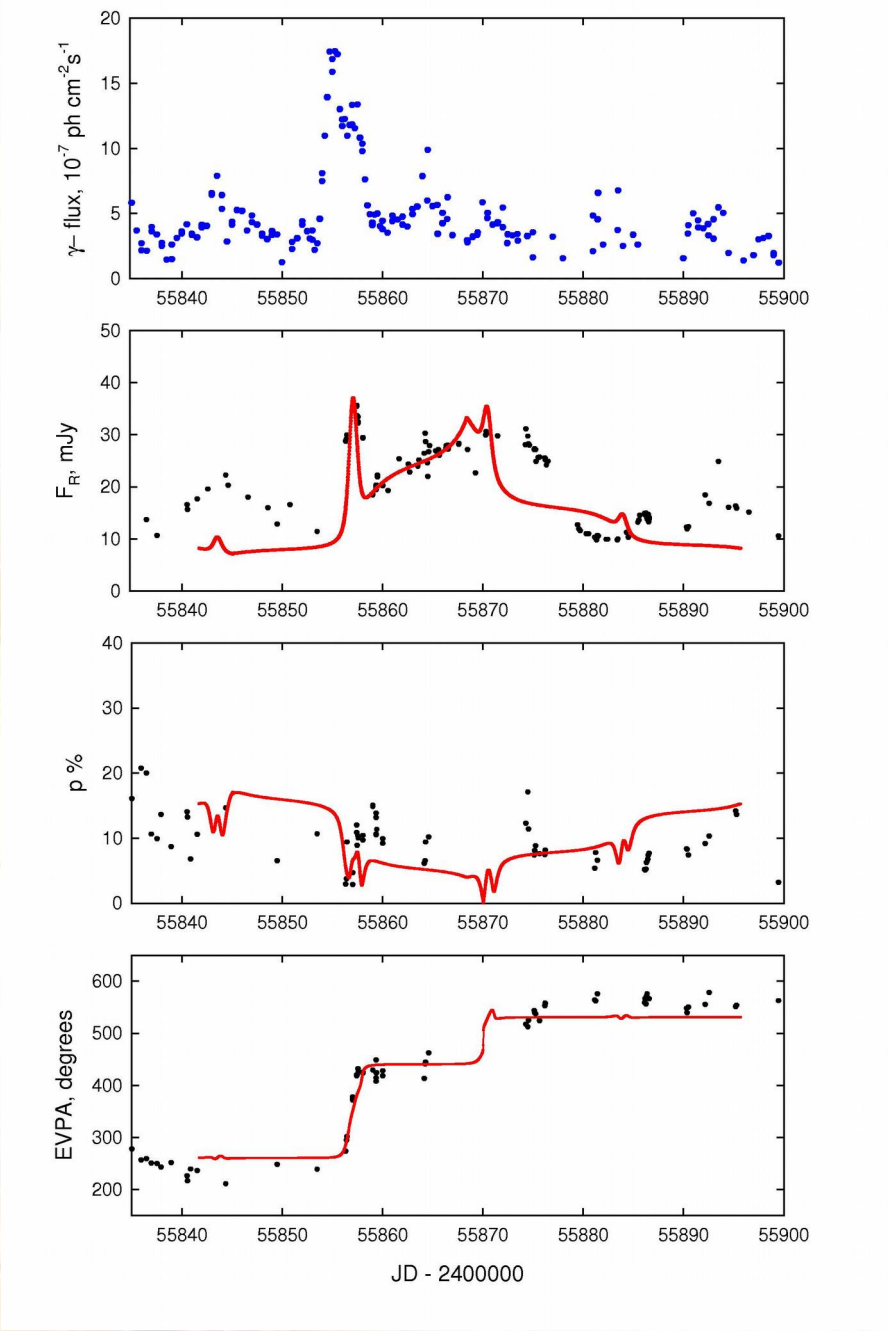
Doppler factor δ:

$$\delta = 1/(\Gamma(1-\beta\cos\varphi)). \quad (5)$$

Rotation periods in observer's frame $P_{\rm src}$ and plasma frame $P_{\rm obs}$ are connected as

$$P_{\rm obs} = P_{\rm src}(1+z)(1-\beta\cos\theta\cos\zeta), \quad (6)$$

where z is object's redshift


γ– flux, 10^-7 ph cm^-2 s^-1
F_R, mJy
p %
EVPA, degrees
JD - 2400000
55840
55850
55860
55870
55880
55890
55900

Fitting parameters for the photometric and polarimetric behavior of S5 0716+71 in 2011 October-November.

$\theta°$ (1)	$\zeta°$ (2)	$p_{\rm jet}$,% (3)	k (4)	Γ (5)	r (6)	$P_{\rm obs}$ (7)	$P_{\rm src}$ (8)	τ (9)	T_0 (10)	$R1$ (11)	$R2$ (12)	a (13)	η (14)	$t_{\rm del}$ (15)	$\Delta\chi°$ (16)
5.8	7.5	22	1.8	10	0.0095	13.2	1.5	0.47	0.11	0.06	132	1.1	1.50	0.47	10

NOTE. — Units of r are parsecs, $P_{\rm obs}$ – days, $P_{\rm src}$ – years. τ, T_0 and $t_{\rm del}$ are fractions of $P_{\rm src}$.

Polarization vector rotations: **real**, spurious, hidden and imaginary

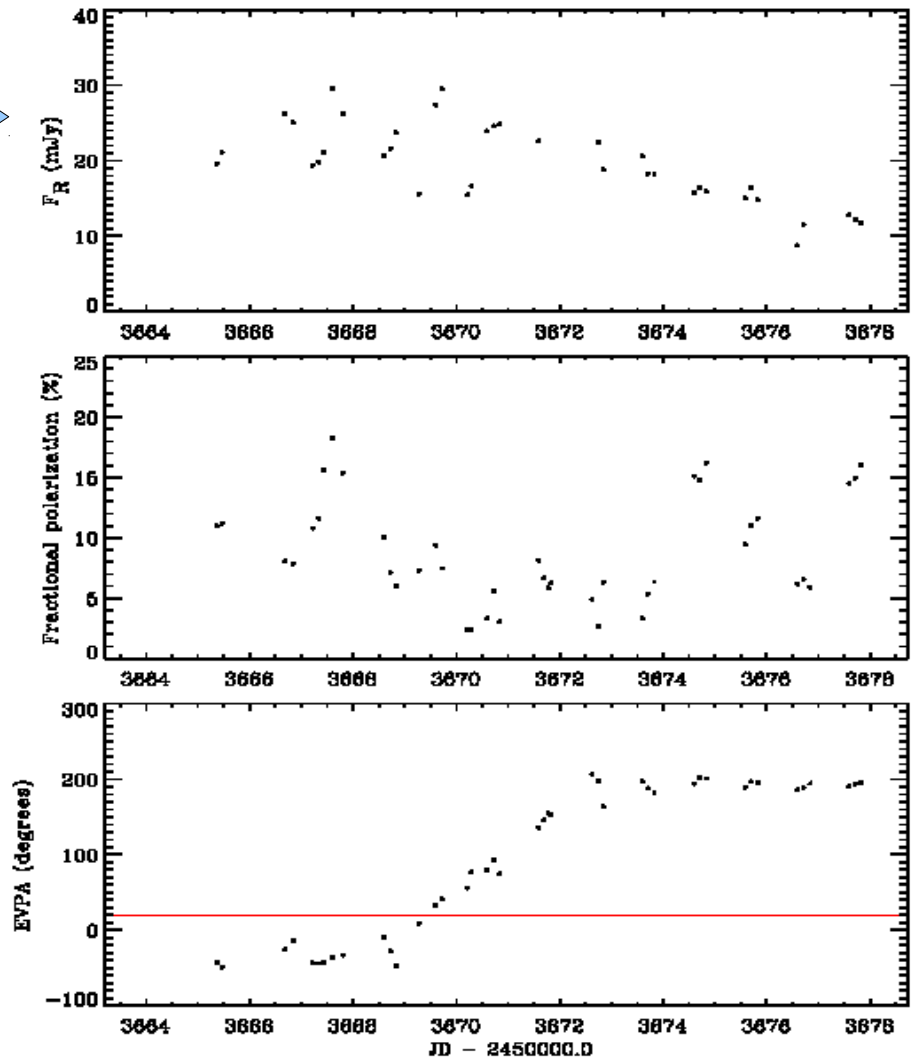
The inner jet of an active galactic nucleus as revealed by a radio-to-γ-ray outburst
A.P.Marscher, S.G.Jorstad, F.D'Archangelo et al., 2008, Nature, 452, 966

Results of WEBT, VLBA and RXTE monitoring of 3C 279 during 2006-2007, Larionov, V. M., Jorstad, S. G., Marscher, A. P., Raiteri, C. M., Villata, M., et al., 2008, Astronomy and Astrophysics, 492, 389

Probing the Inner Jet of the Quasar PKS 1510-089 with Multi-Waveband Monitoring During Strong Gamma-Ray Activity
Marscher, Alan P.; Jorstad, Svetlana G.; Larionov, Valeri M., et al., 2010, ApJL, 710, 126

The Outburst of the Blazar S5 0716+71 in 2011 October: Shock in a Helical Jet
Larionov, V. M.; Jorstad, S. G.; Marscher, A. P., et al., 2013, ApJ, 768, 40

BL Lac



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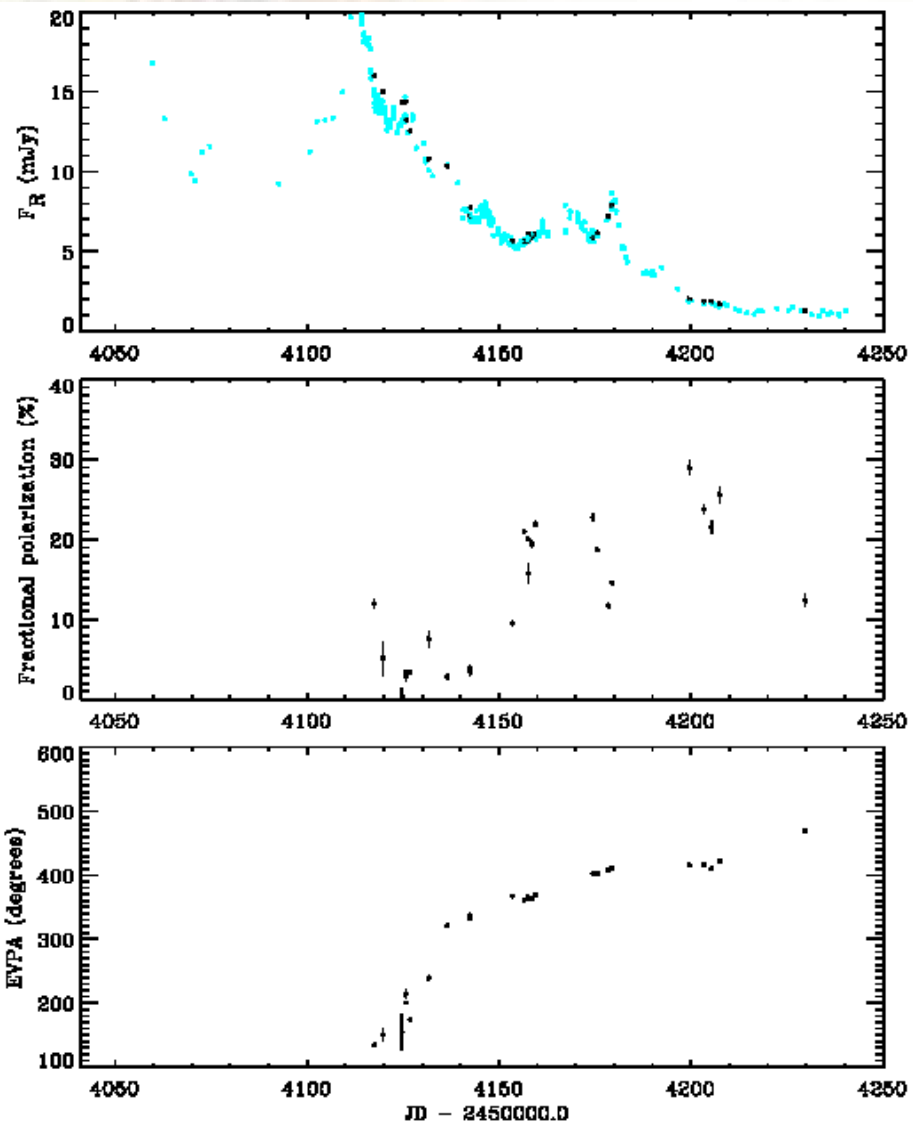
3C 279



Polarization vector rotations: **real**, spurious, hidden and imaginary

PKS 1510-089

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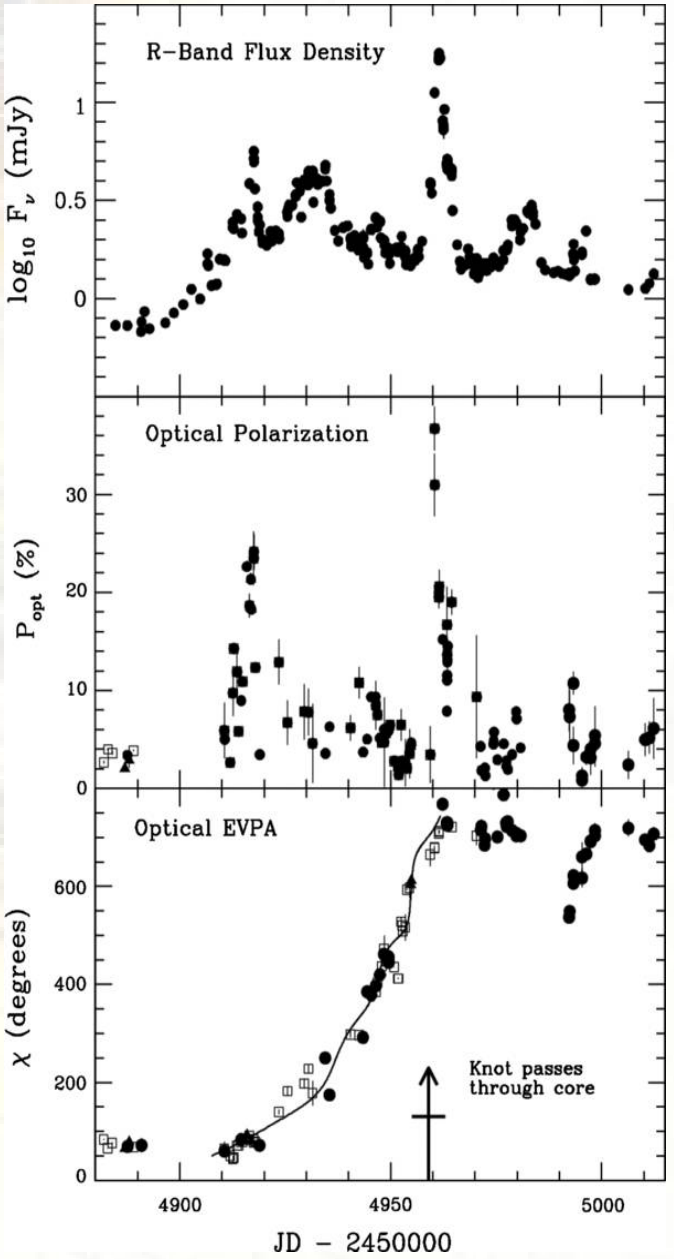

Polarization vector rotations: **real**, spurious, hidden and imaginary

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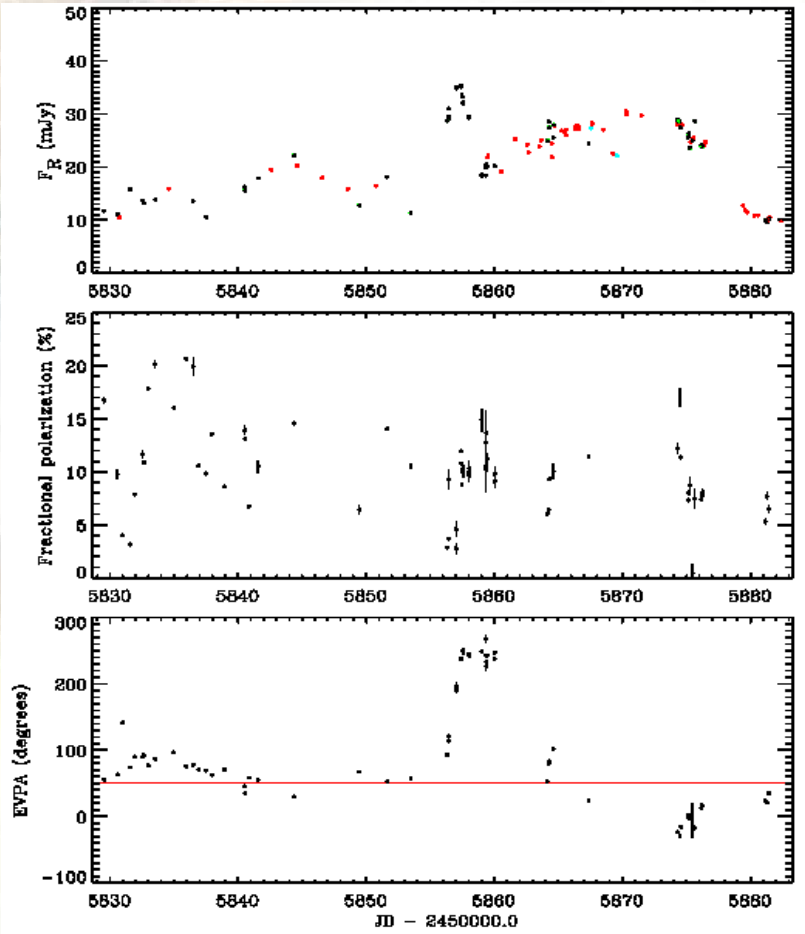
S5 0716+71

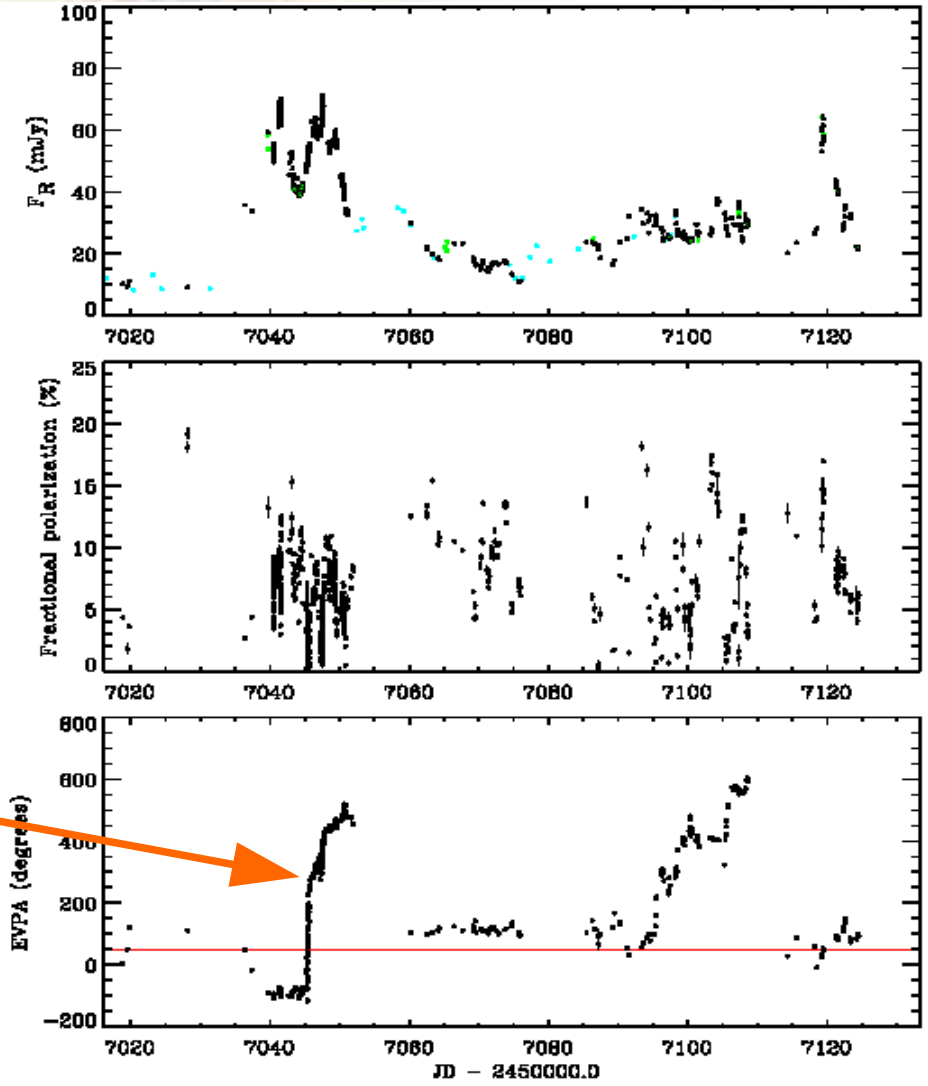


Polarization vector rotations: **real**, spurious, hidden and imaginary

By definition, positional angle χ (=EVPA) is in the range [0°, 180°] or [-90°,+90°]. We resolve the ±180° ambiguity by adding or subtracting 180° each time that the subsequent value of the χ is > 90° less/more than the preceding one **and** time interval between adjacent points is small enough to consider them as causally related.

The best (to my knowledge) example is shown here where we got >600 data points from two hemispheres (St.Petersburg+Crimea+Arizona) within 10 days

S5 0716+71



Polarization vector rotations: real, spurious, hidden and imaginary

To check the reality of rotations we fix the *observed* values of PD and replace EVPAs with a *constant+chance error*.

MC simulations allow to get a lot of **false** rotations based on the same criteria we used to single out real rotations.

Important: spurious rotations mostly occur when PD is small => σ_χ is large

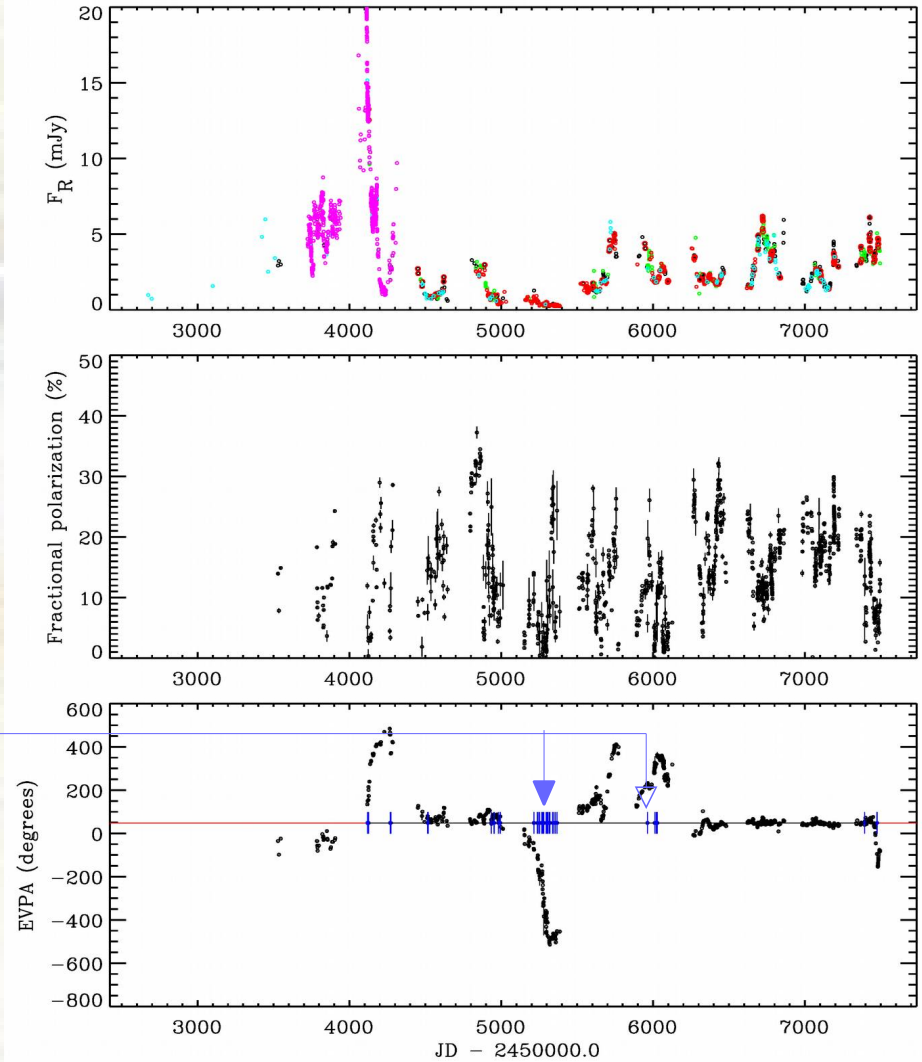
$$\sigma_\chi = 28.6 * \sigma_P / P$$

When the PD is small?

In some of objects — during quiescence
In others — during outbursts

The latter case may lead to erroneous associations of rotations with optical (+γ) outbursts

3C 279

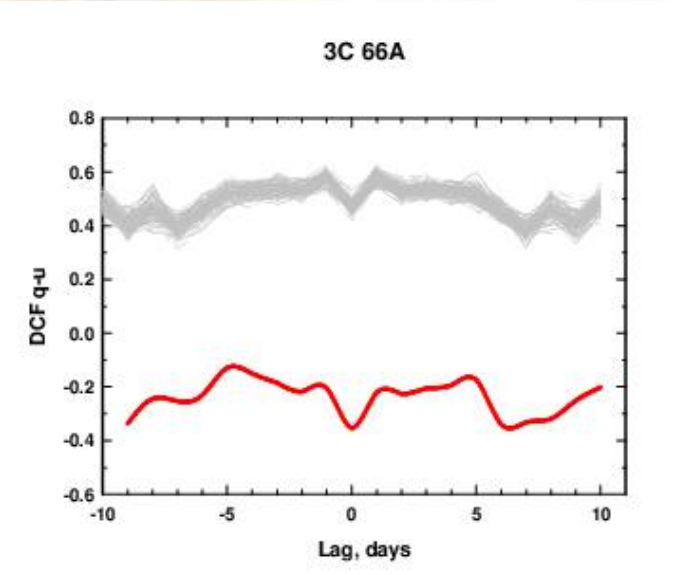


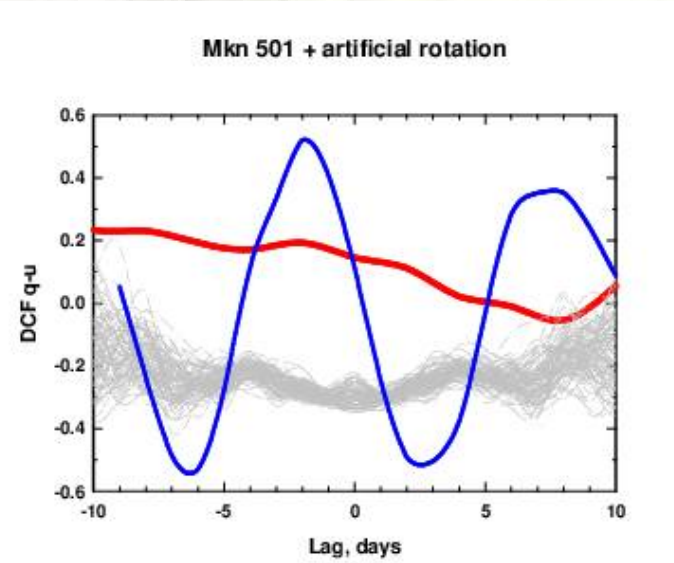
Polarization vector rotations: real, spurious, hidden and imaginary

Spurious → Real
Spurious → False (imaginary)

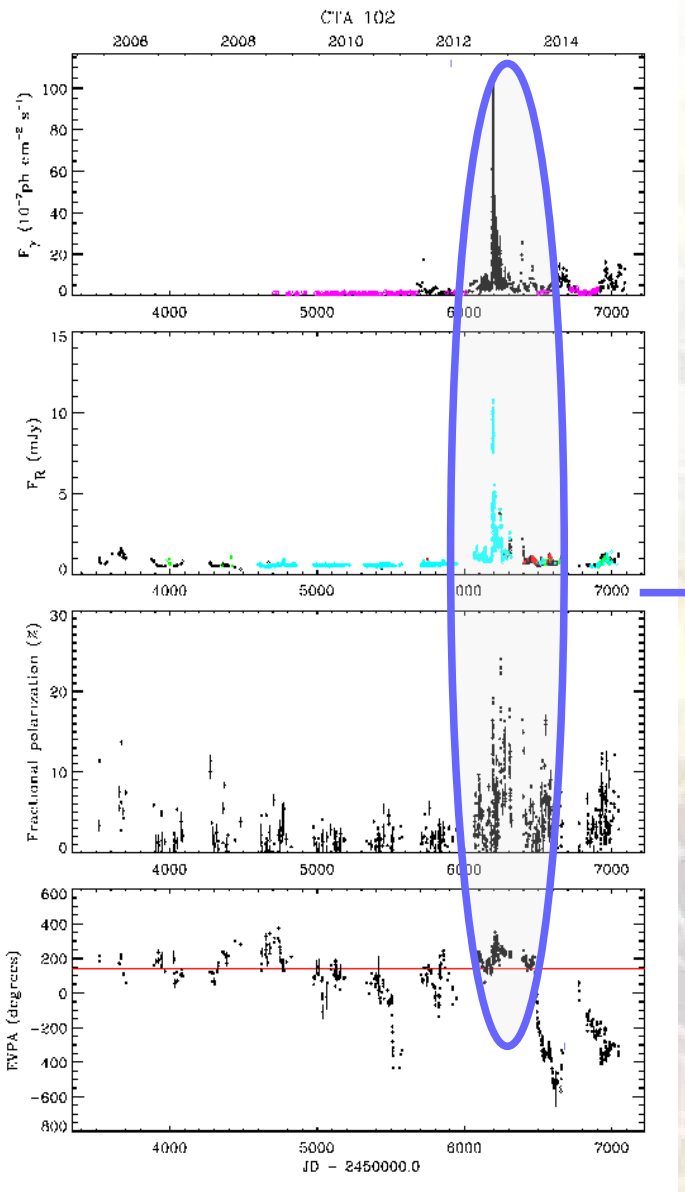
In order to make the choice between these two cases we transform from **p**(t), χ(t) to
q(t)=p*cos(2*χ), u(t)=p*sin(2*χ)
and check whether one curve is shifted relative to another, e.g., using DCF
If the shift is absent (lag=0), rotation is **False**

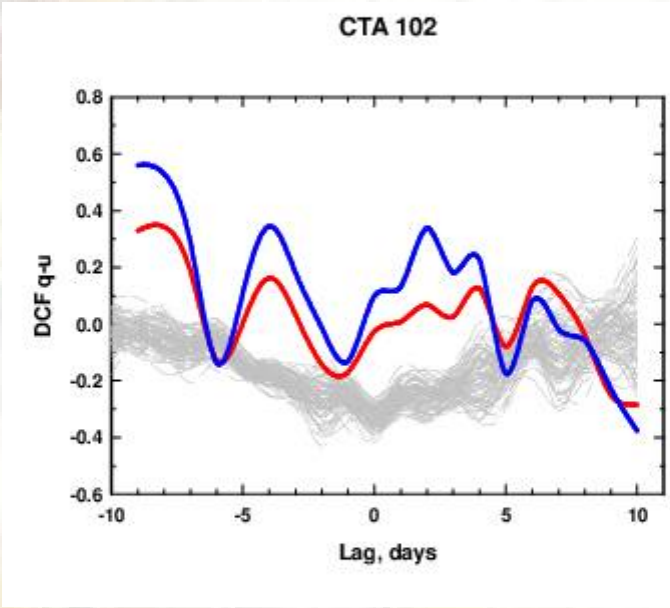
On the contrary, **spurious** becomes **real** when the extremum is shifted relative to 0; the sign of DCF slope at lag=0 determines the sense of rotation (counterclockwise in this example); distance between peaks corresponds to the rate of rotation (here 20^o/day => 9 day period)





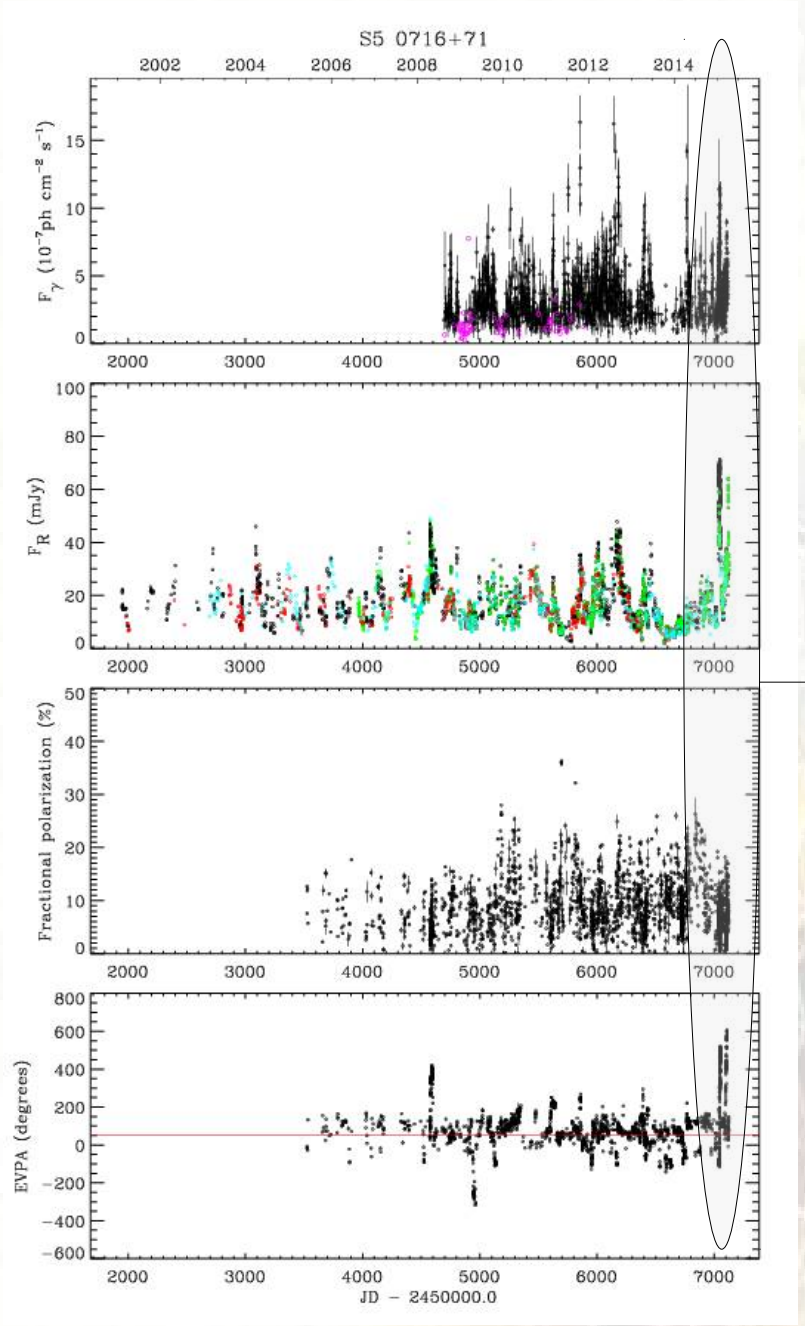
Polarization vector rotations: real, spurious, **hidden** and imaginary

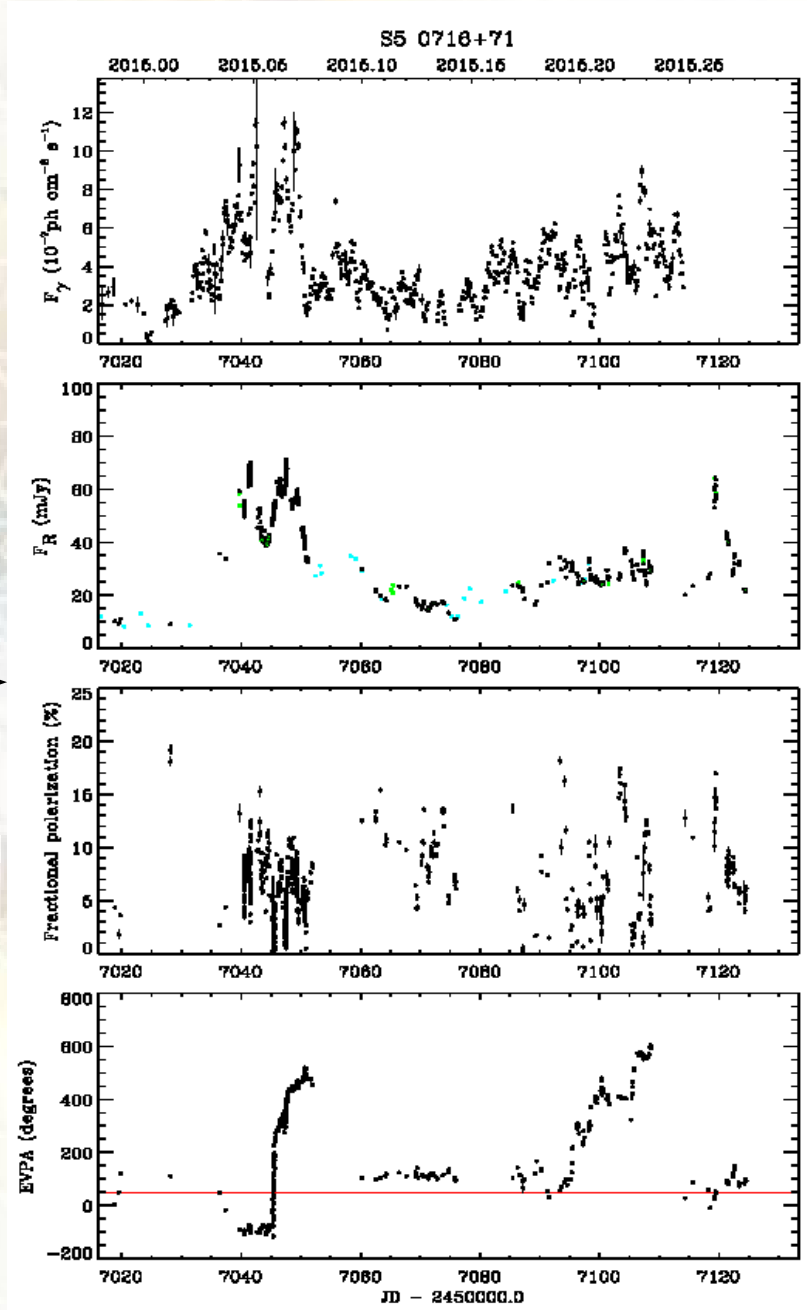




Rotation is:

- Real
- Hidden
- P_{rot} ~5 days


S5 0716+71
2002
2004
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0


S5 0716+71
2015.00
2015.05
2015.10
2015.15
2015.20
2015.25
F_γ (10^{-8}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

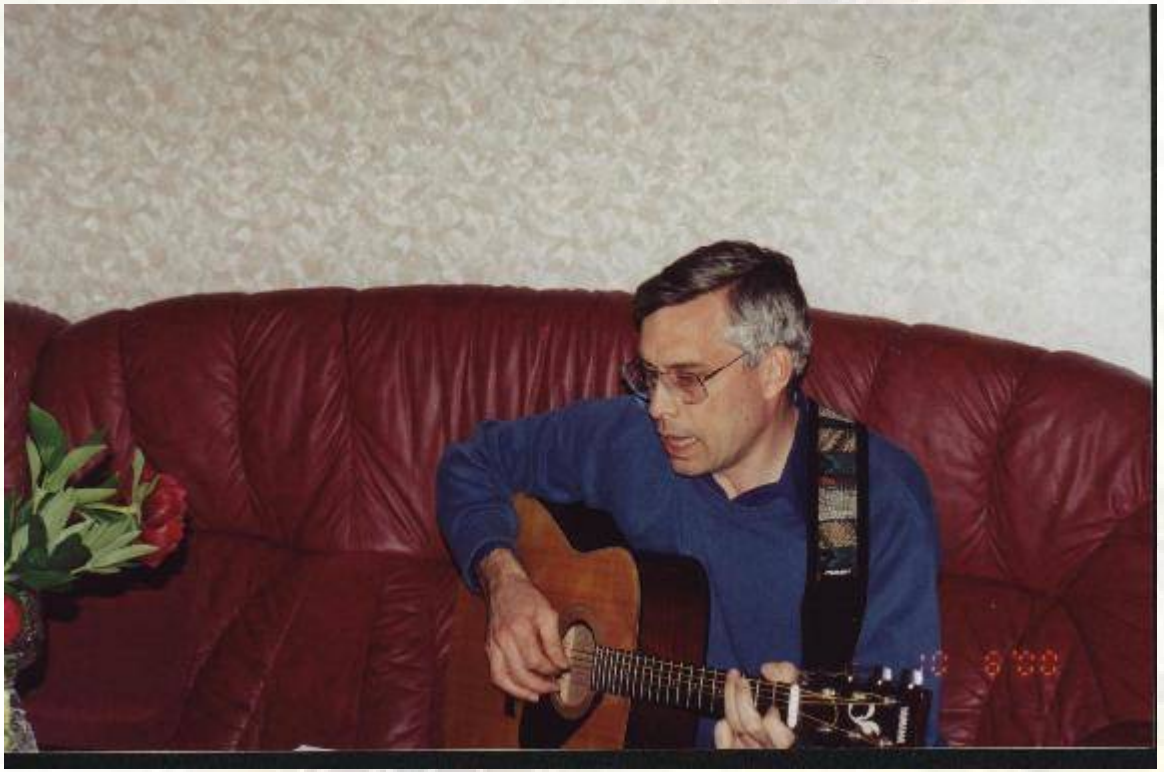
Summary

- Decades of dense photometric and polarimetric monitoring resulted in high-quality data set on ~30 blazars.
- Numerous cases of EVPA rotations, some of them definitely confirming presence of helical structure in jets.
- A new approach to analyse polarimetric data is suggested.

As is well-known…

As is well-known

«…bad data's worse than no data at all!»



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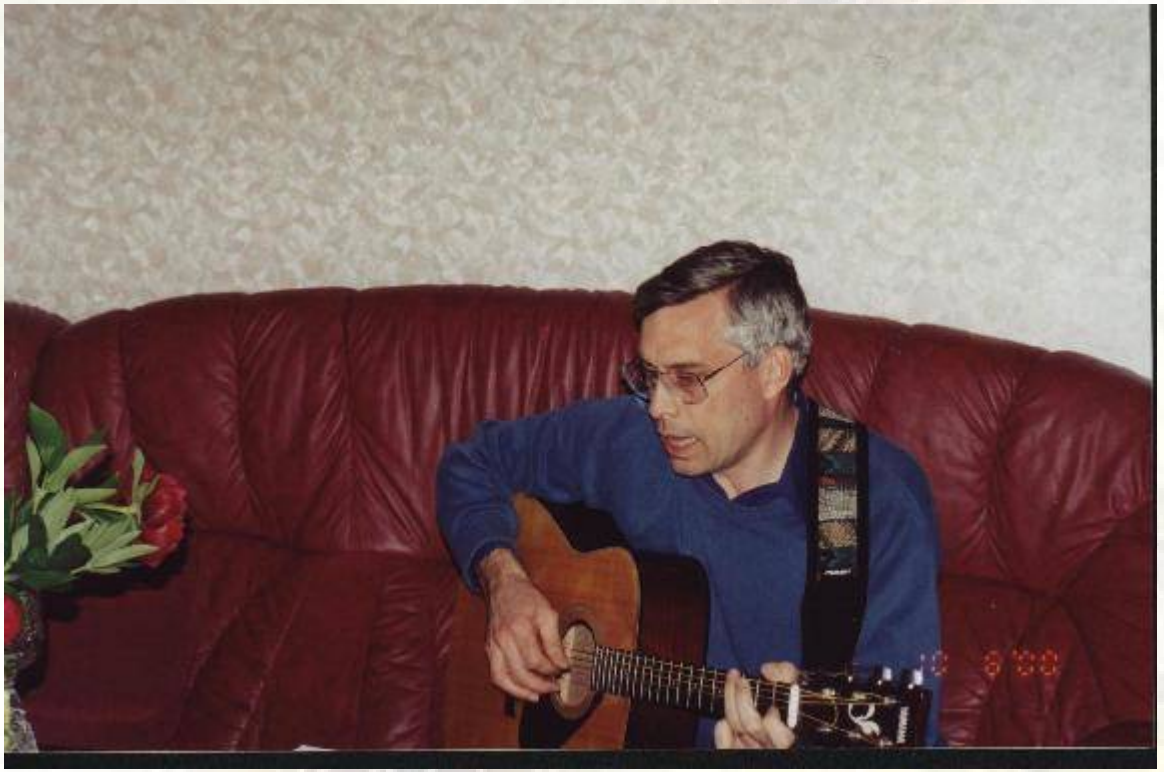

And our data are

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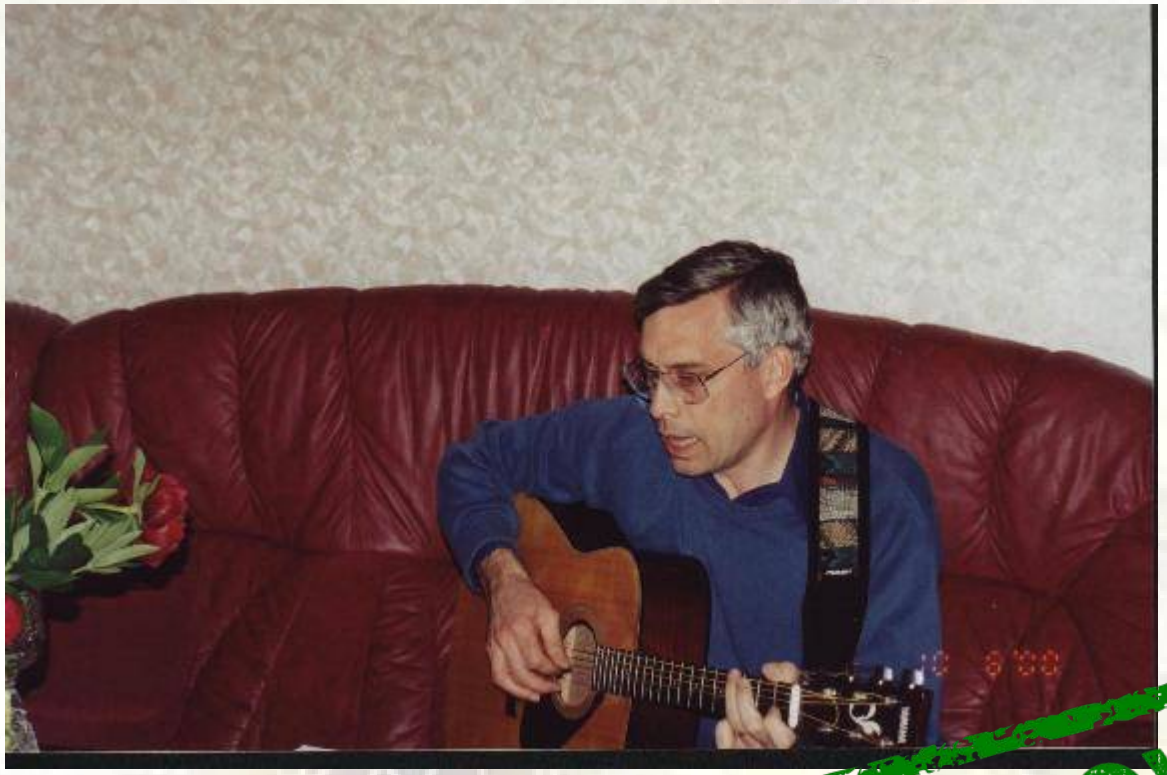

And our data are


Gracias!
Спасибо за внимание !
Thank you !


Gracias!
Thank you !