Optical Photometric and Polarimetric Monitoring of Selected Blazars

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Svetlana Jorstad, Alan Marscher, Paul Smith, Massimo Villata, Claudia Raiteri, Ivan Agudo, Dmitry Blinov, George Borman, Tatiana Grishina, Vladimir Hagen-Thorn, Evgenia Kopatskaya, Liudmila Larionova, Elena Larionova, Daria Morozova, Ivan Troitsky, Yulia Troitskaya

*St.Petersburg University, Boston University, Steward Observatory, Torino Observatory,
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- 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.

- Telescopes used in the acquisition of data
- Observational targets
- Examples of light curves
- Outbursts and rotations of EVPA
- Shock in helical jet ?
- Statistics: p *vs* F, p *vs* EVPA
- Colors: Bluer when Brighter ? Redder when Brighter ?

Perkins
Arizona (Lowell)

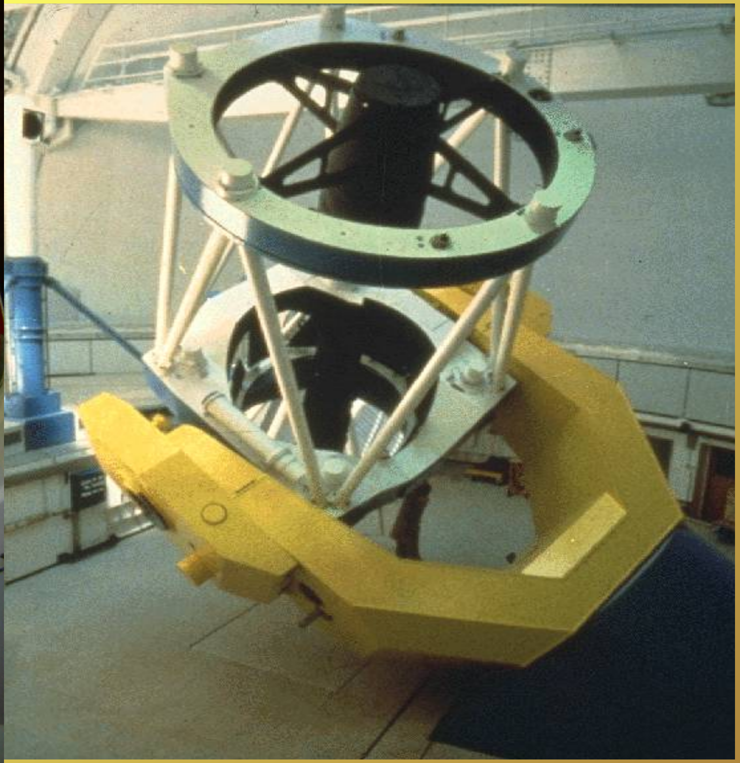
LX-200
St.Petersburg

AZT-8
Crimea

Kuiper
Arizona (Steward)

AZT-24
Campo Imperatore

2.2 m
Calar Alto



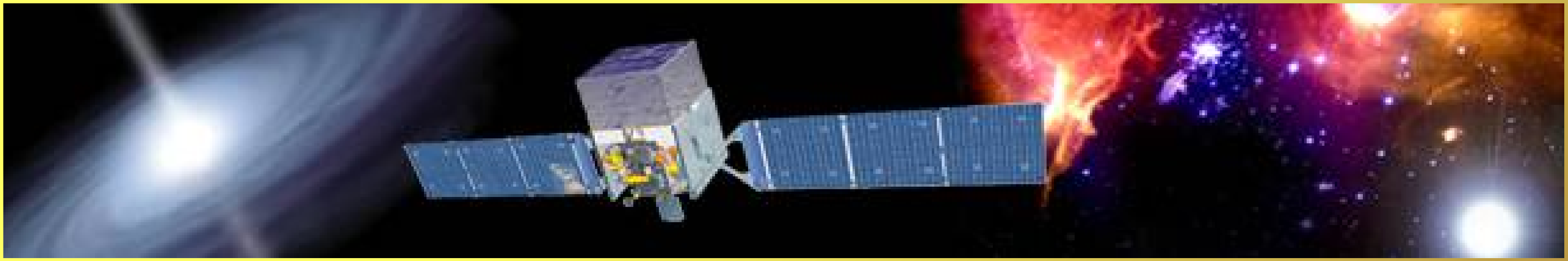
Pictures of the telescopes are scaled to show that they all supply data of similar quality :=)

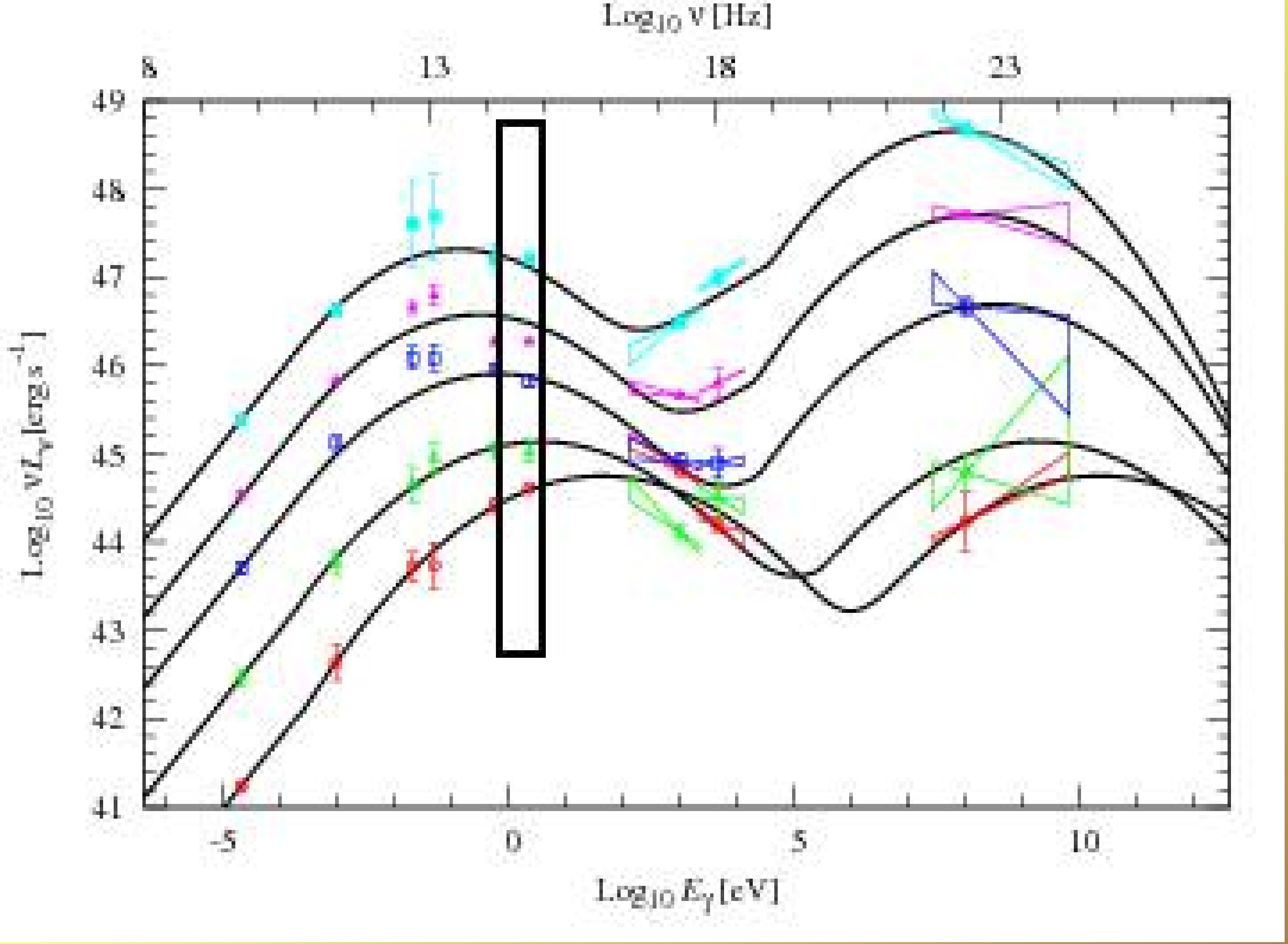
We collaborate with...

VLBA

Mauna Kea
Hawaii
Owens Valley
California
Brewster
Washington
North Liberty
Iowa
Hancock
New Hampshire
Kitt Peak
Arizona
Pie Town
New Mexico
Fort Davis
Texas
Los Alamos
New Mexico
St. Croix
Virgin Islands

Fermi
Gamma-ray Space Telescope





Log$_{10}$ ν [Hz]
8
13
18
23
49
48
47
46
45
44
43
42
41
Log$_{10}$ νL$_ν$ [erg s^{-1}]
-5
0
5
10
Log$_{10}$ E$_γ$ [eV]

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

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

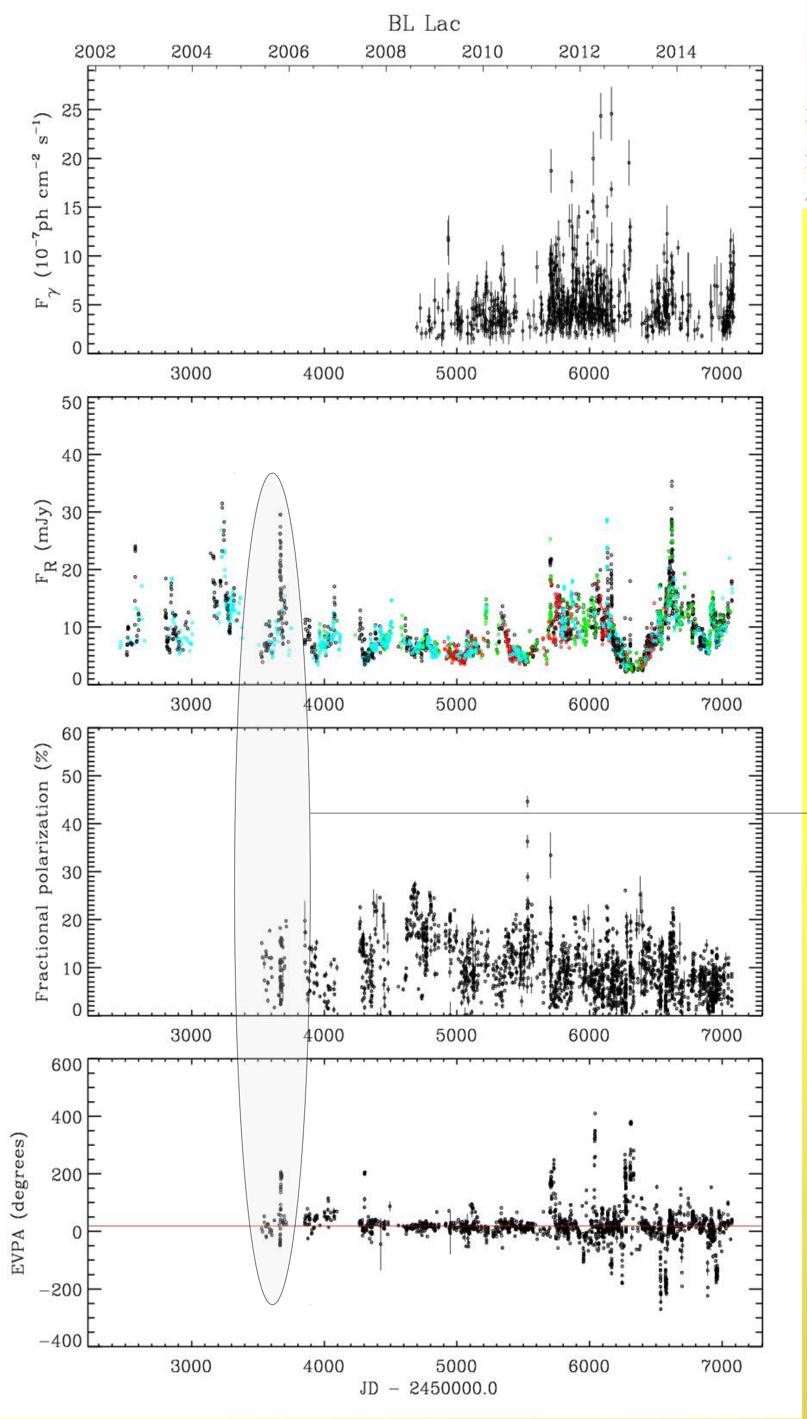
V. A. Dombrovskii, M. K. Babadzhanyants,
V. A. Gagen-Torn, and S. M. Gutkevich

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.

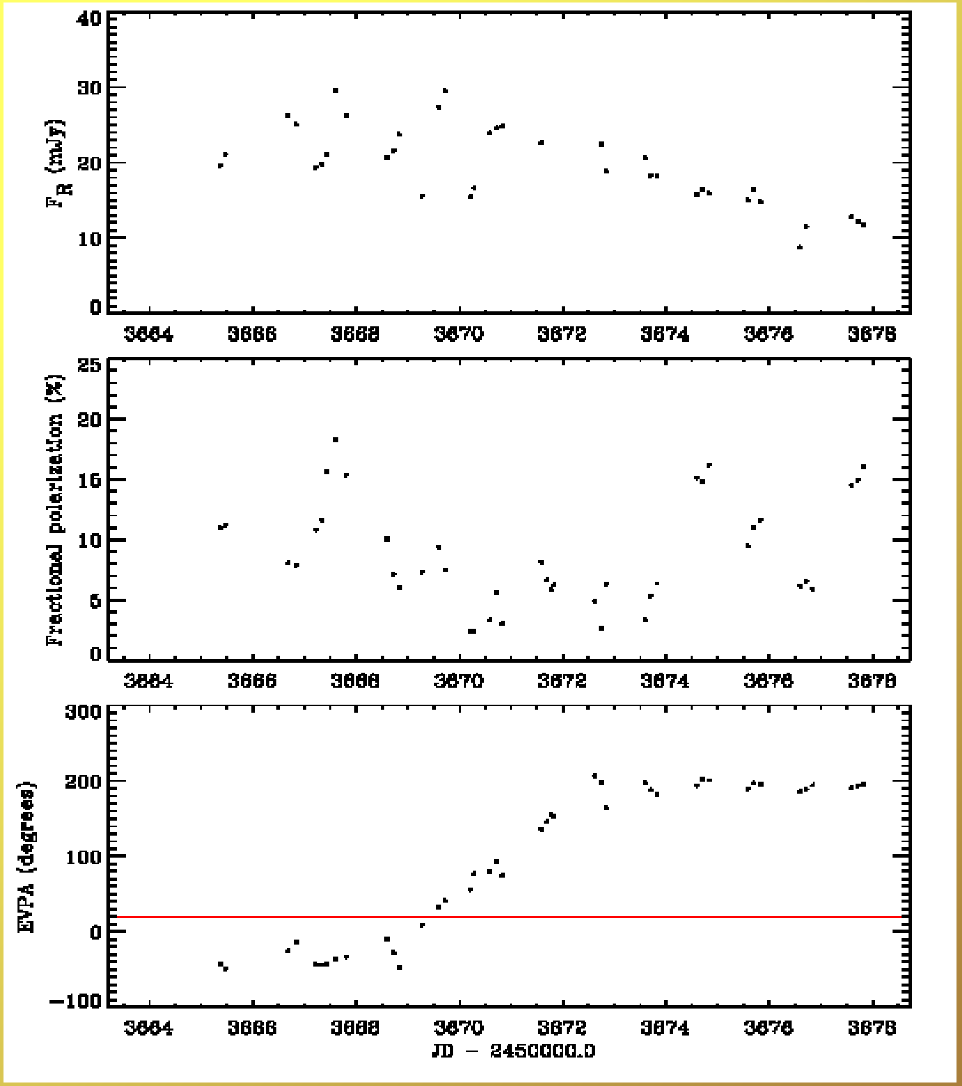
Very cautious statement !

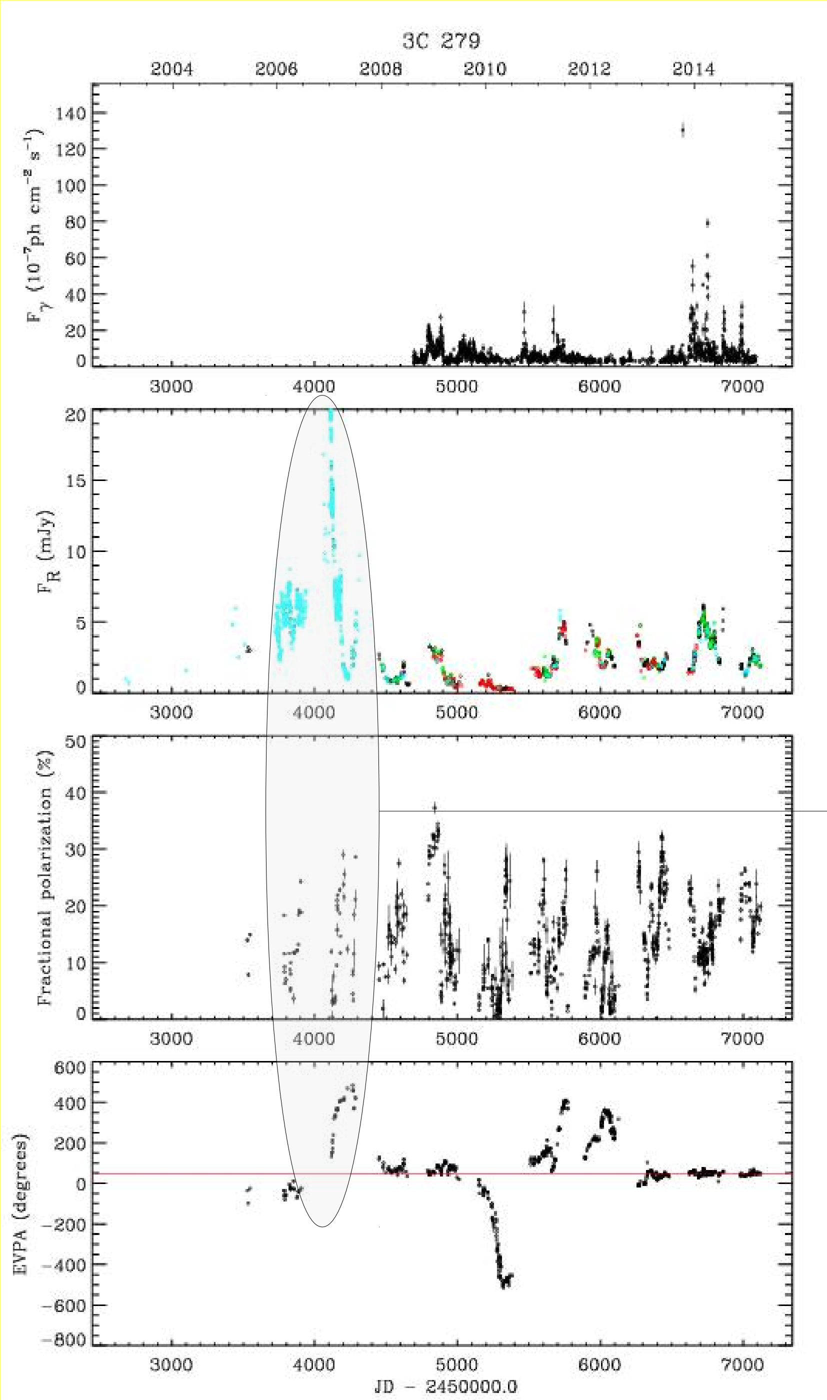
The inner jet of an active galactic nucleus as revealed by a radio-to-γ-ray outburst

Alan P. Marscher[1], Svetlana G. Jorstad[1,2], Francesca D. D'Arcangelo[1], Paul S. Smith[3], G. Grant Williams[4], Valeri M. Larionov[2], Haruki Oh[1]†, Alice R. Olmstead[1], Margo F. Aller[5], Hugh D. Aller[5], Ian M. McHardy[6], Anne Lähteenmäki[7], Merja Tornikoski[7], Esko Valtaoja[8,9], Vladimir A. Hagen-Thorn[2], Eugenia N. Kopatskaya[2], Walter K. Gear[10], Gino Tosti[11], Omar Kurtanidze[12], Maria Nikolashvili[12], Lorand Sigua[12], H. Richard Miller[13] & Wesley T. Ryle[13]

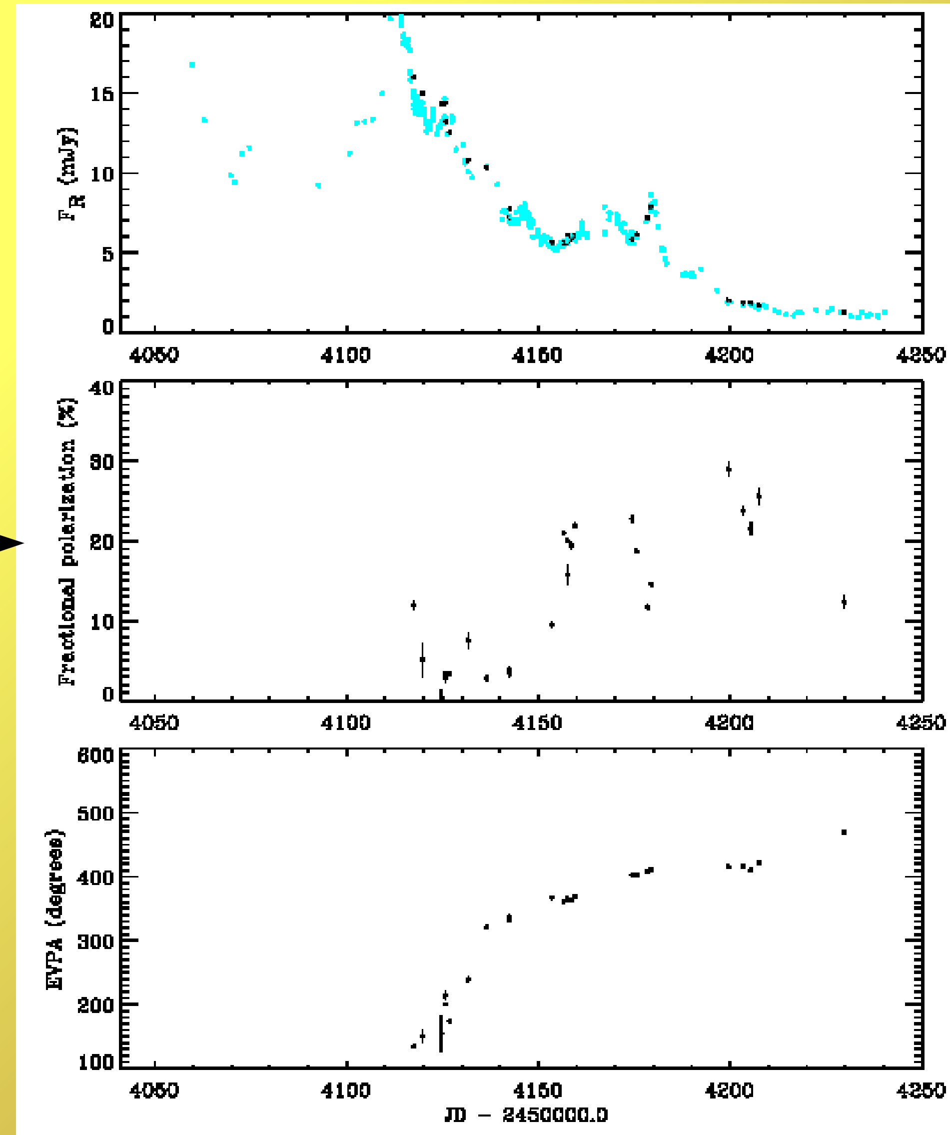


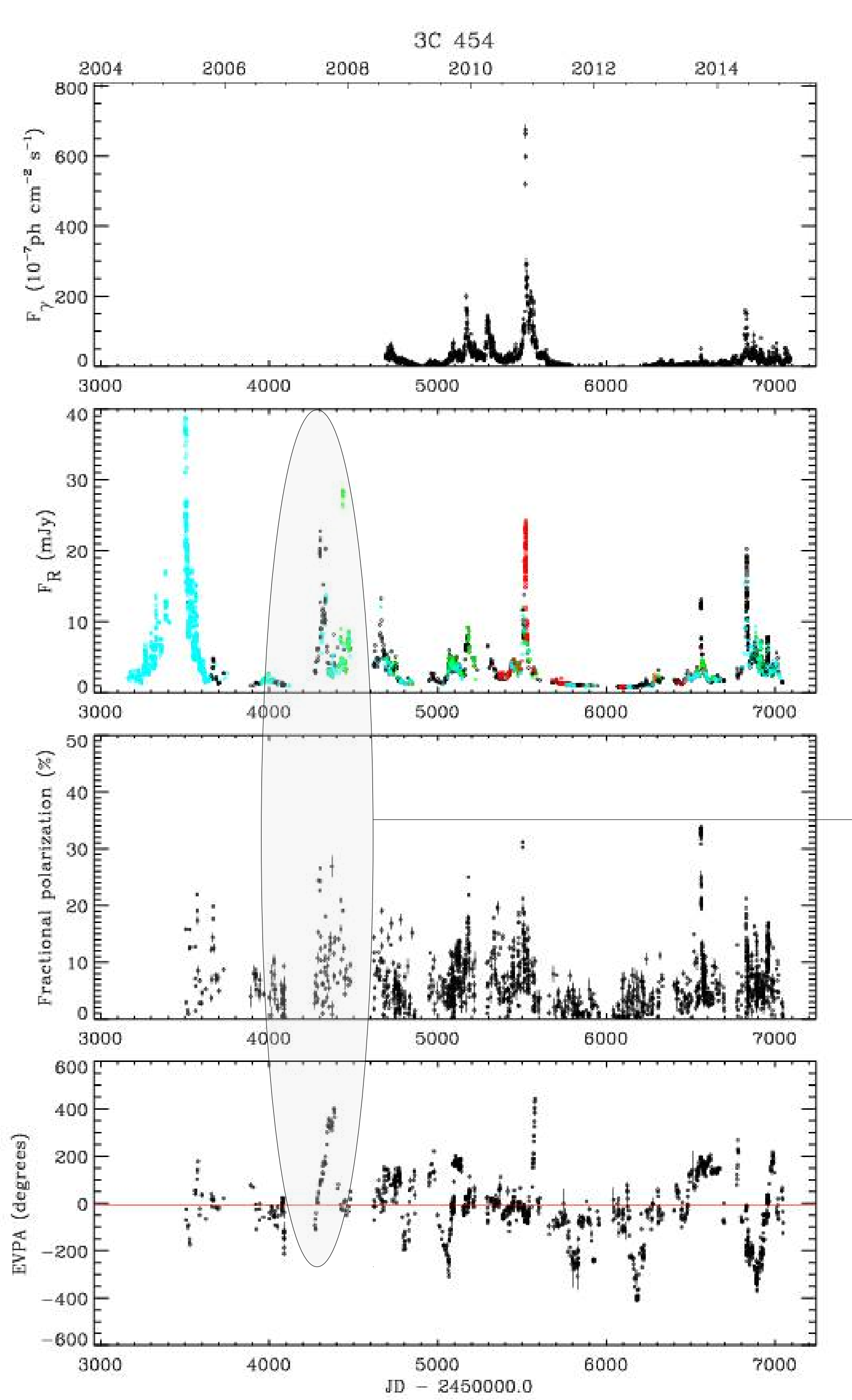
BL Lac encouraged us to look for rotations





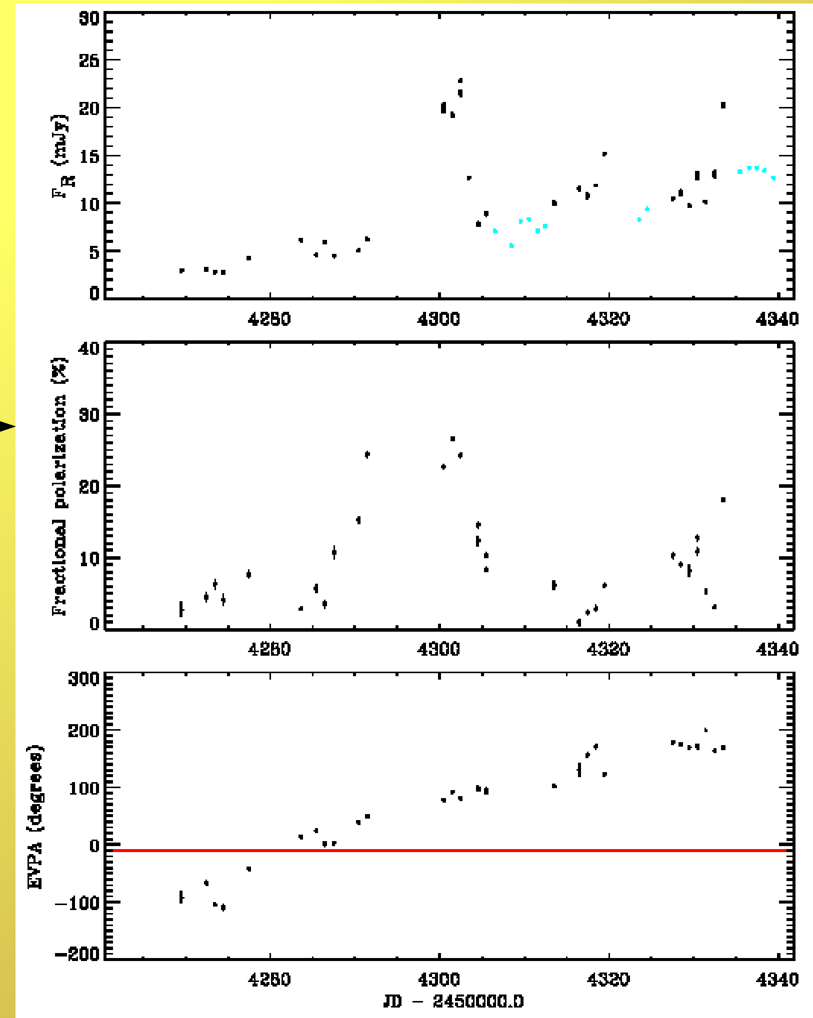
Larionov, V. M., Jorstad, S. G., Marscher, A. P., Raiteri, C. M., Villata, M., et al., Results of WEBT, VLBA and RXTE monitoring of 3C 279 during 2006-2007, 2008, Astronomy and Astrophysics, 492, 389

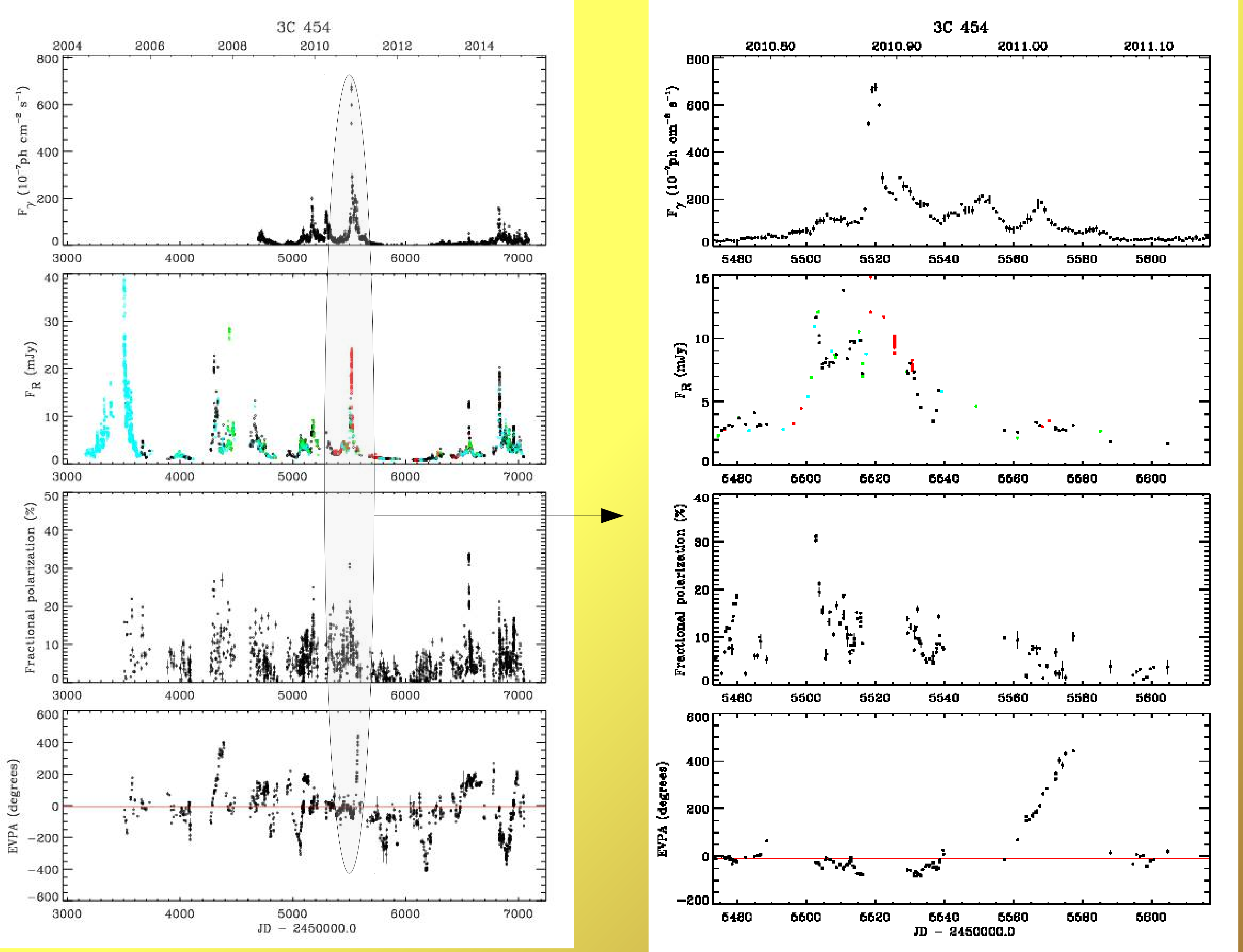


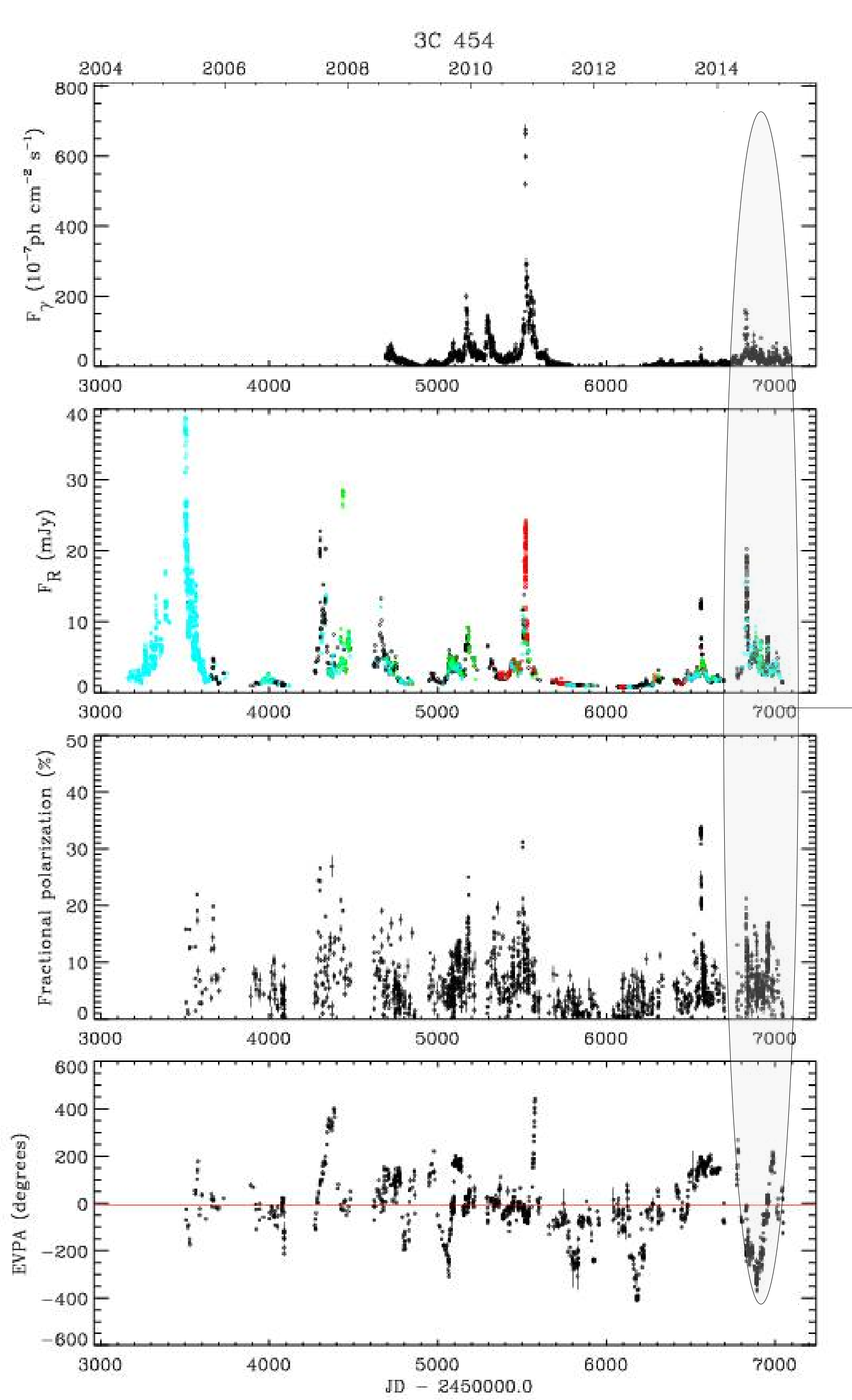


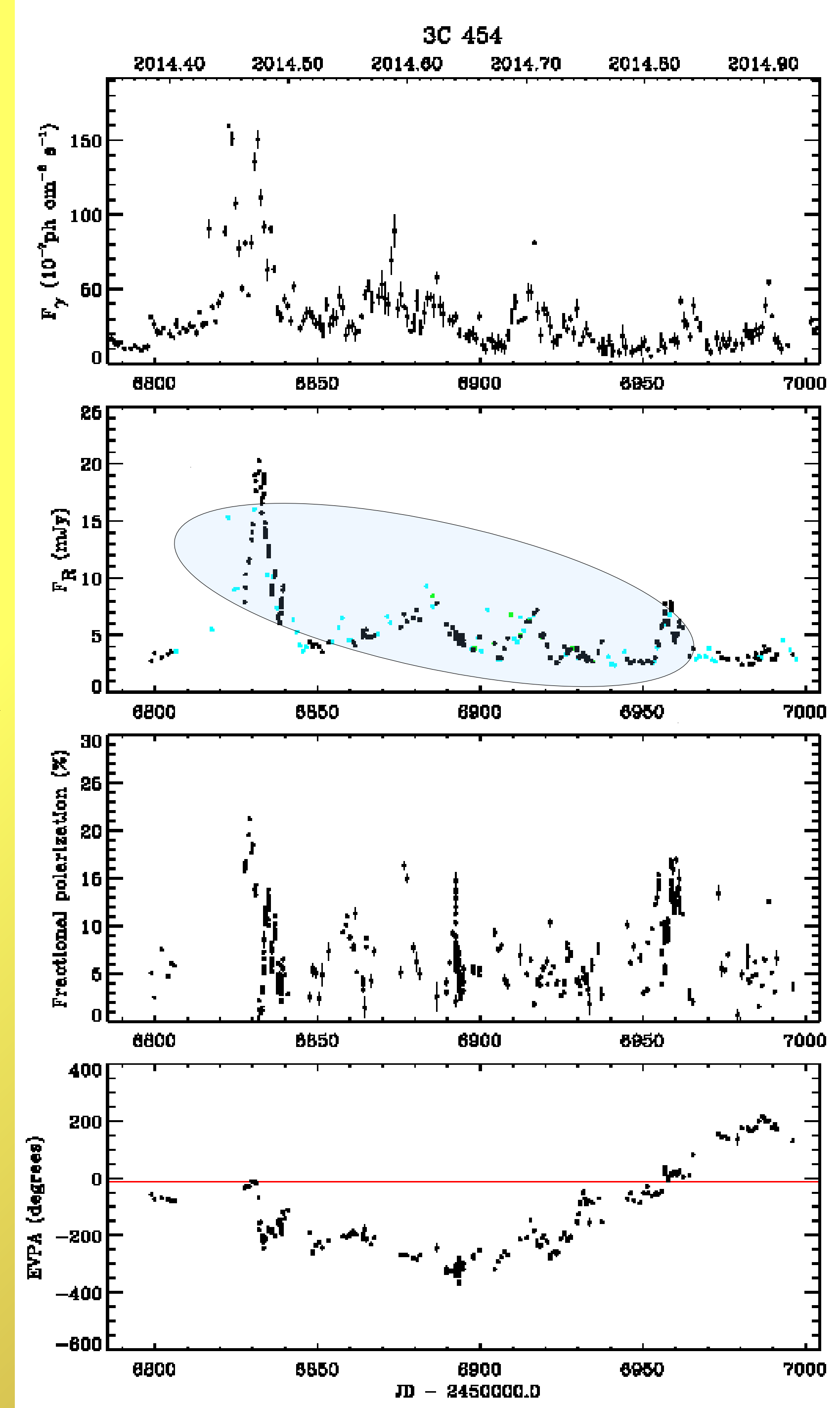
Jorstad, S. G., et al., A Tight Connection between Gamma-Ray Outbursts and Parsec-scale Jet Activity in the Quasar 3C 454.3, 2013, The Astrophysical Journal, 773, 147

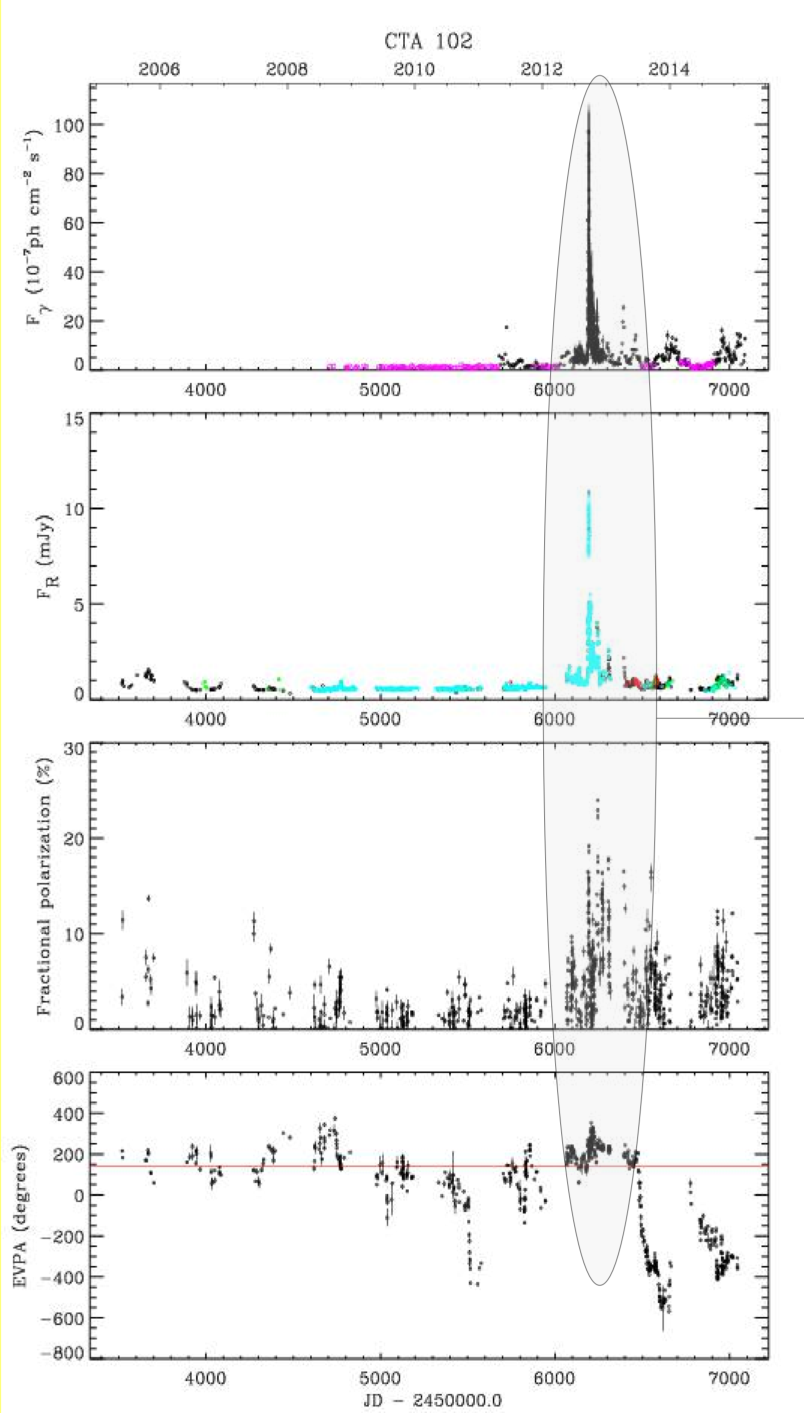
Jorstad, S. G., et al., Flaring Behavior of the Quasar 3C 454.3 Across the Electromagnetic Spectrum, 2010, The Astrophysical Journal, 715, 362

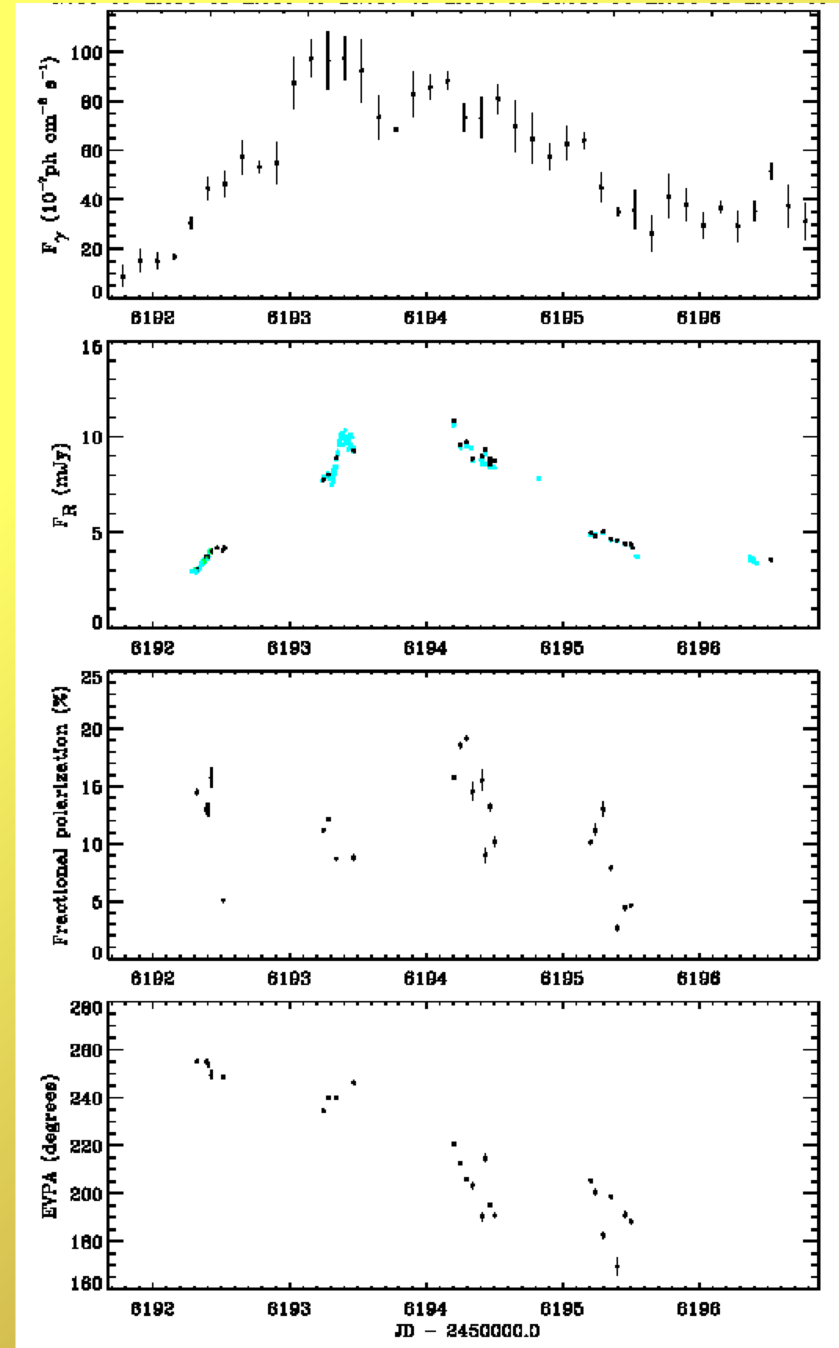


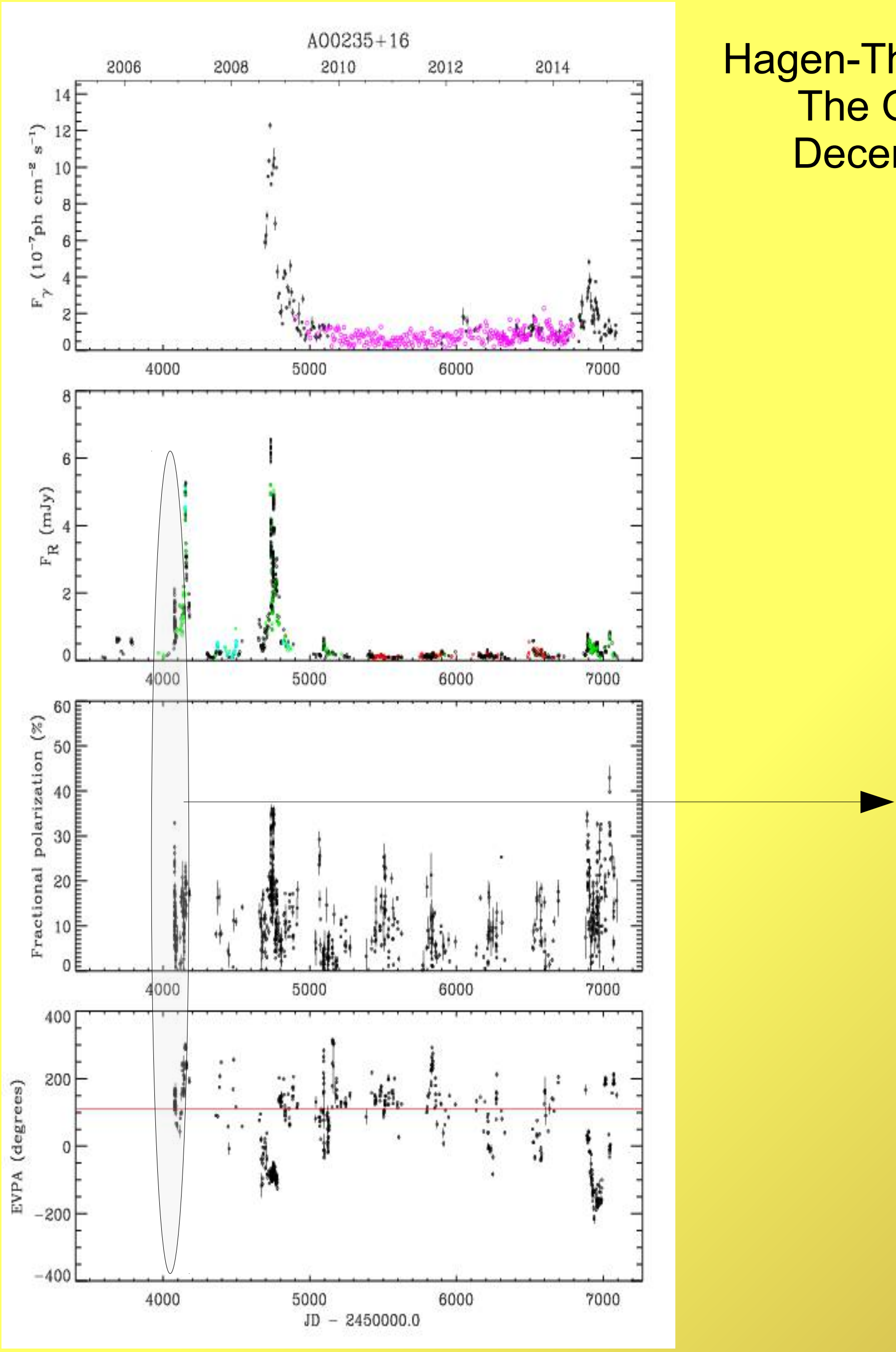

3C 454
2004
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0
3C 454
2010.80
2010.90
2011.00
2011.10
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0


3C 454
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

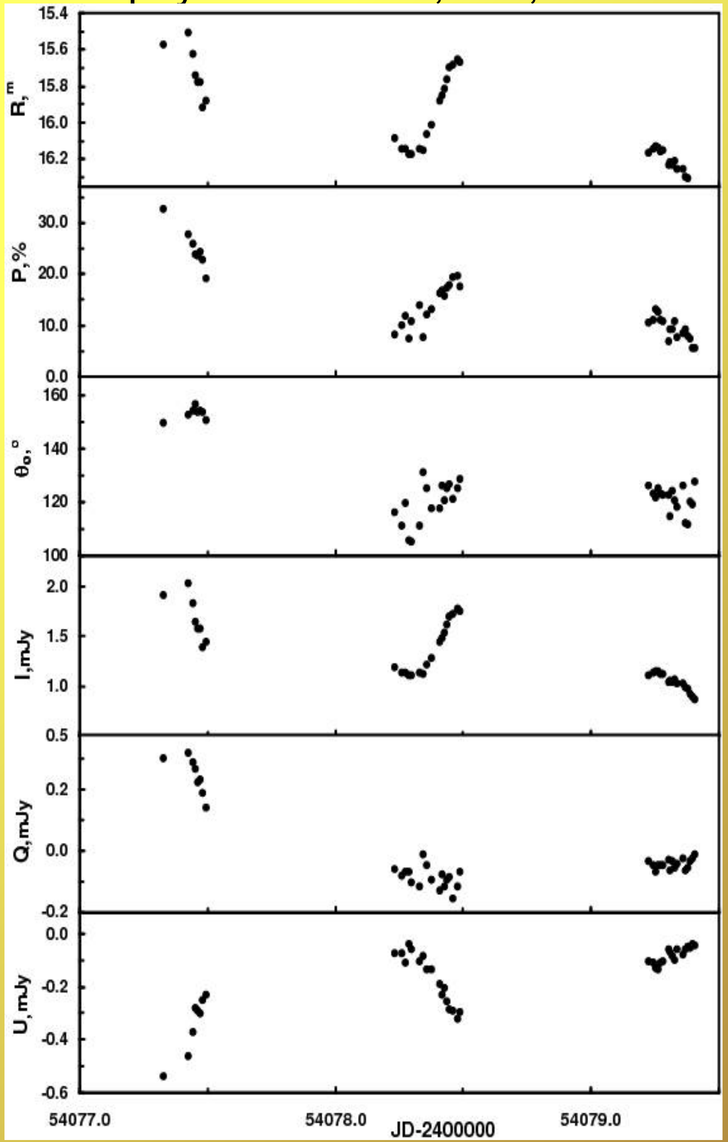

3C 454
2014.40
2014.50
2014.60
2014.70
2014.80
2014.90
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

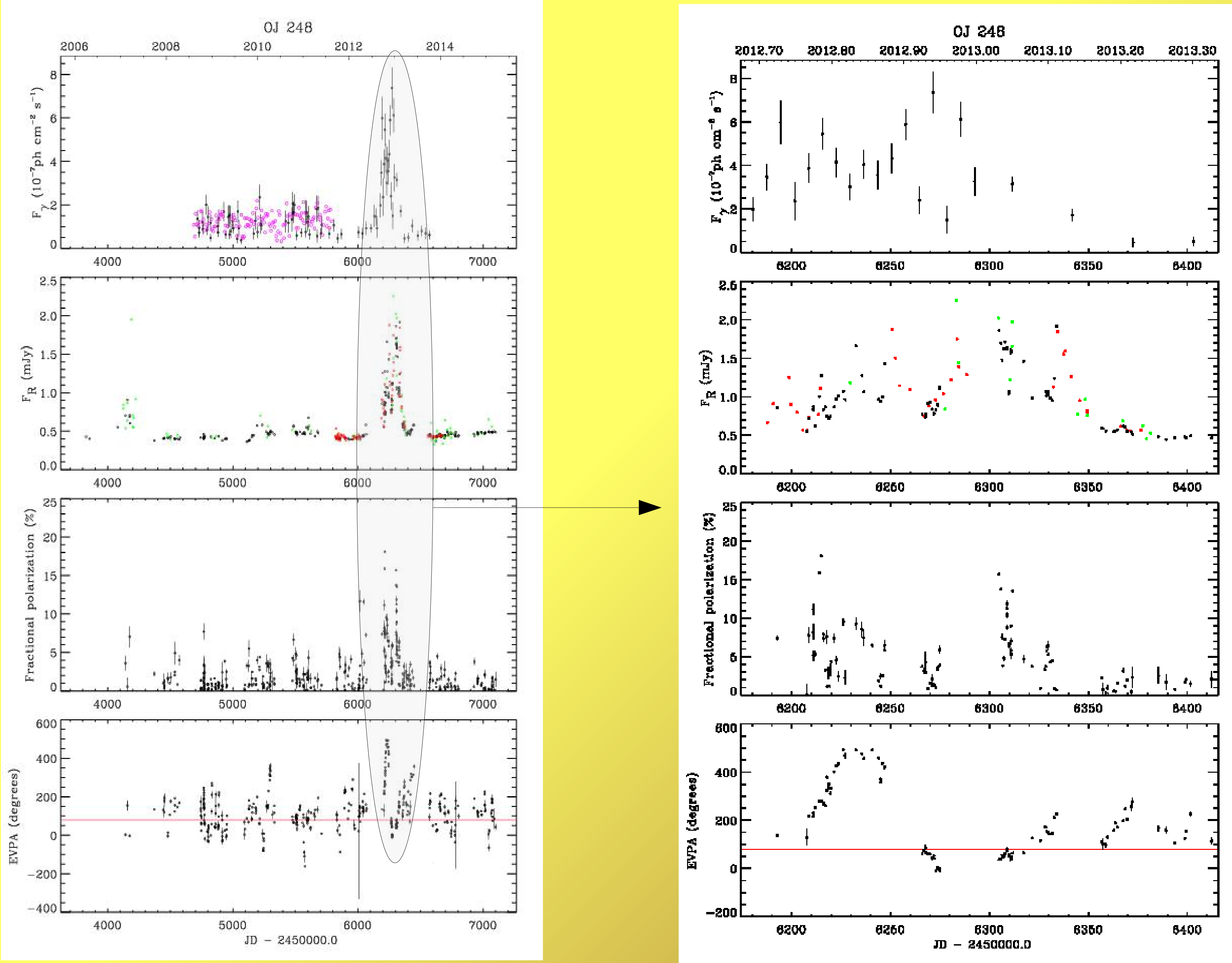

CTA 102
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

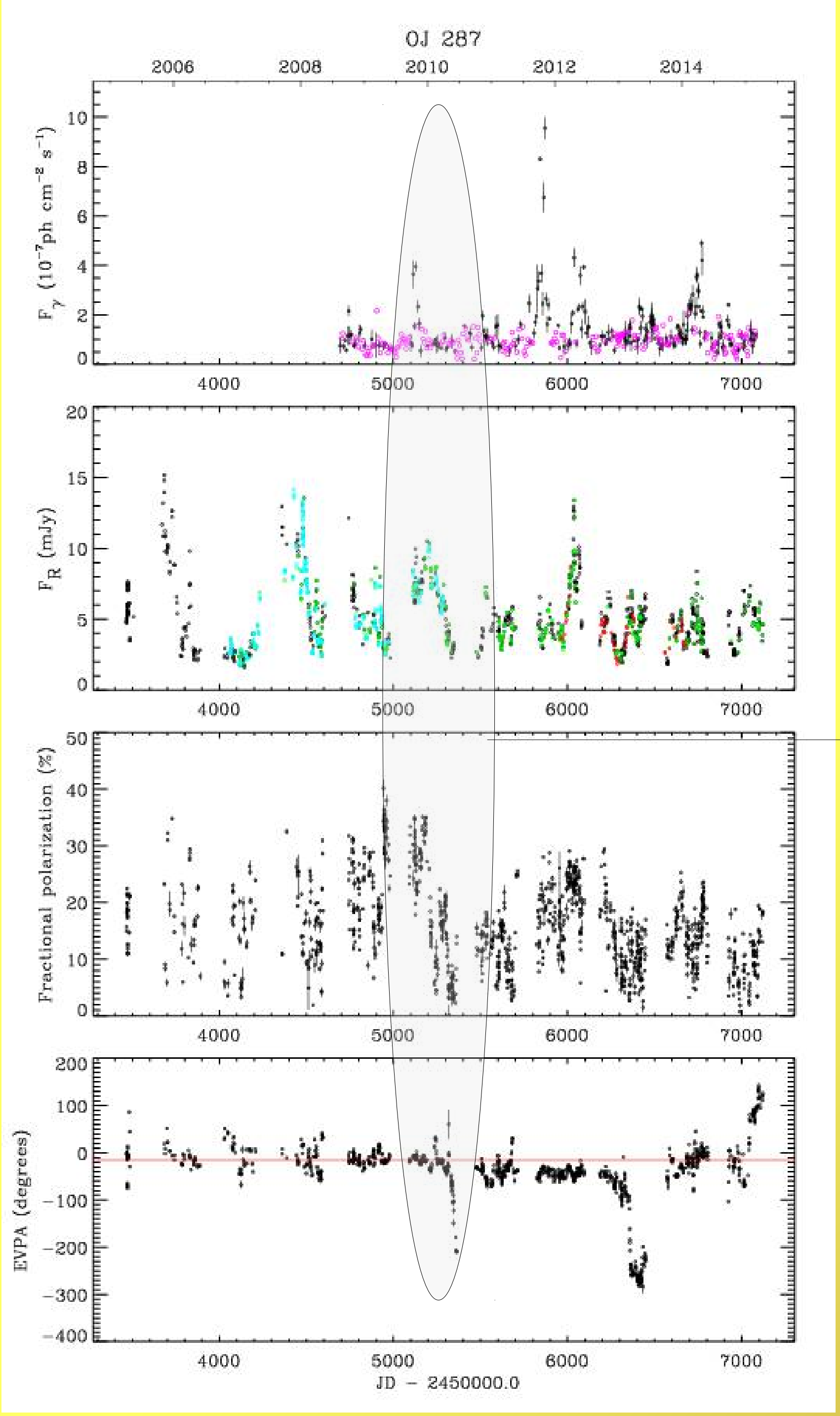

F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

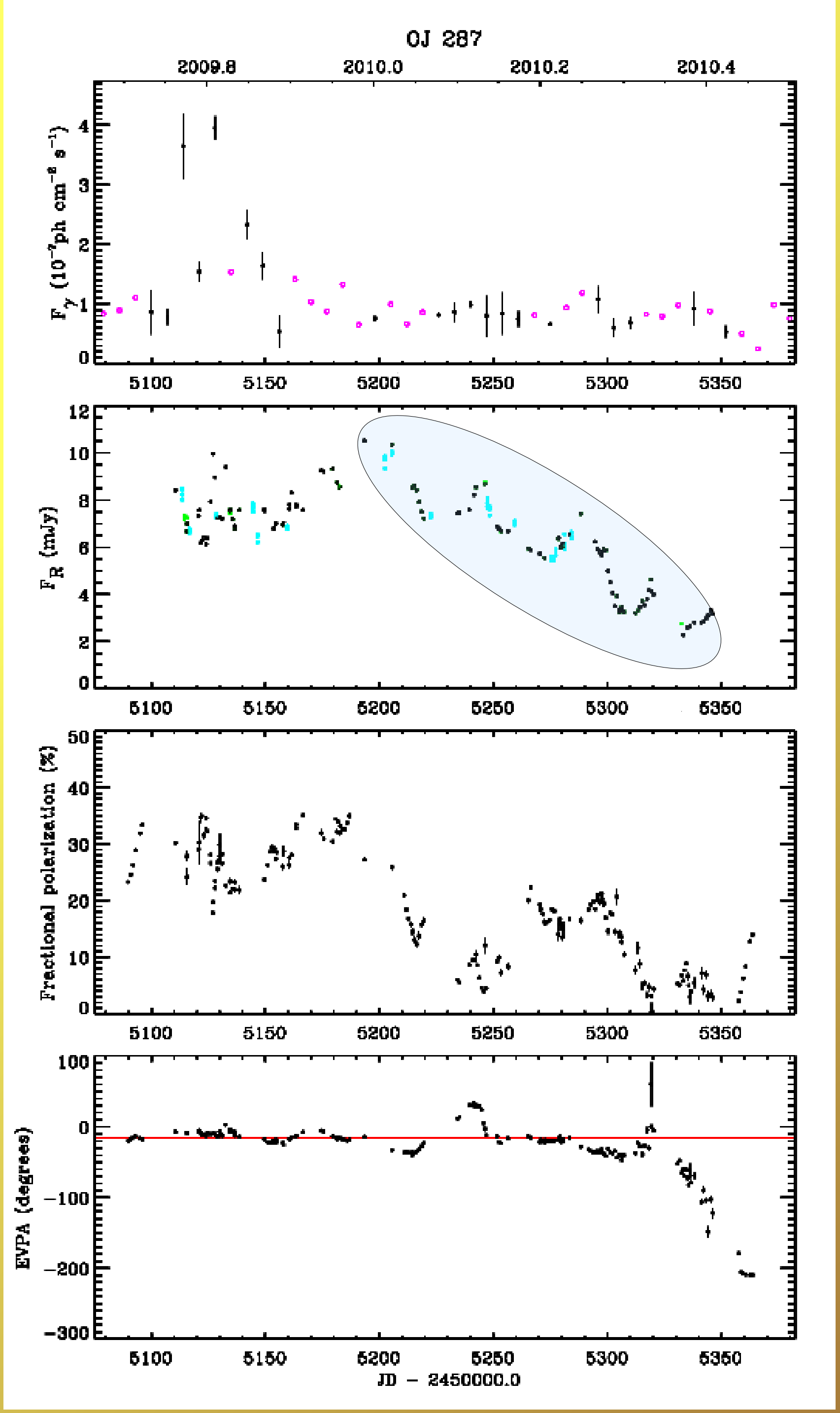


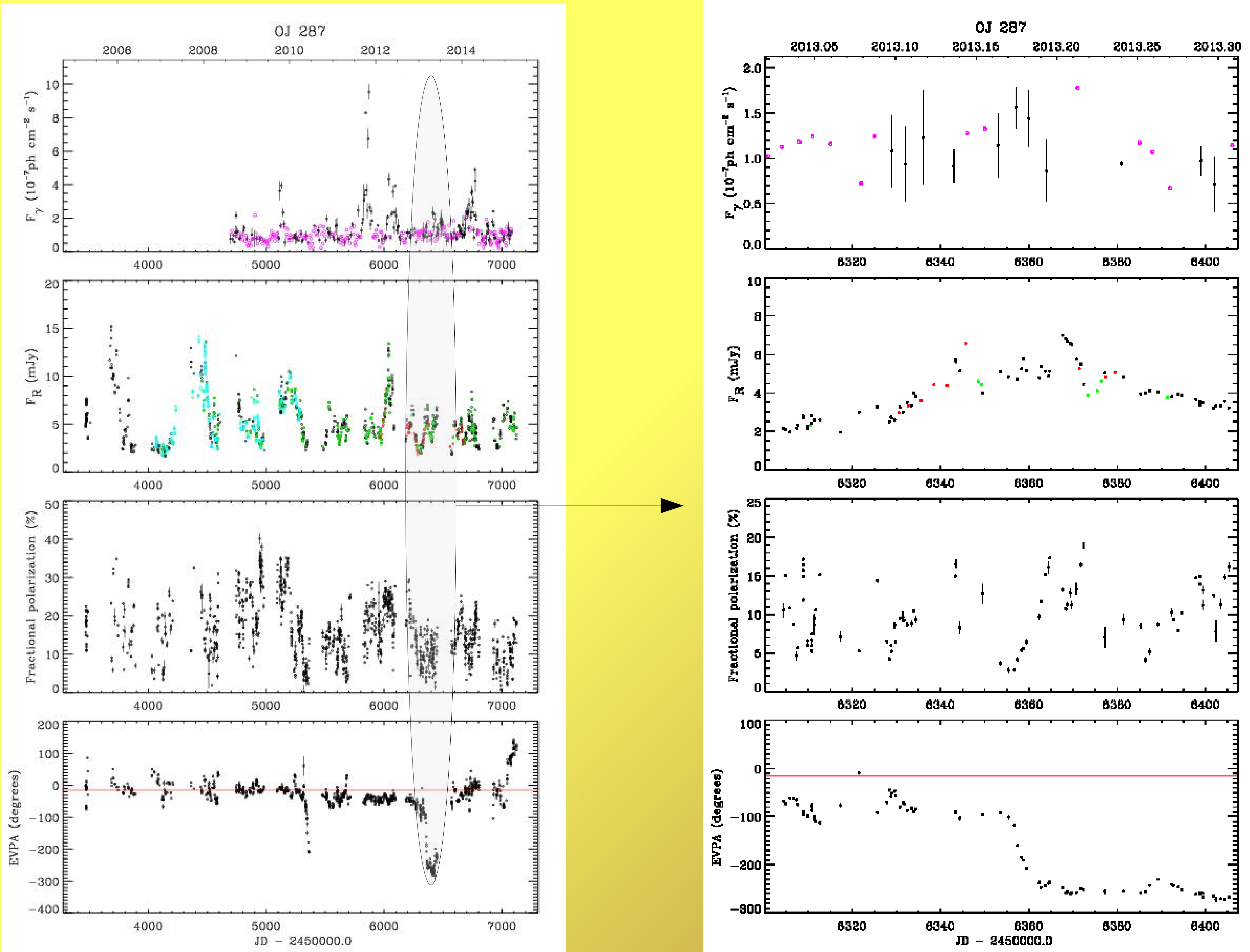
Hagen-Thorn, V. A., Larionov, V. M., Jorstad, S. G., et al., The Outburst of the Blazar AO 0235+164 in 2006 December: Shock-in-Jet Interpretation, 2008, The Astrophysical Journal, 672, 40

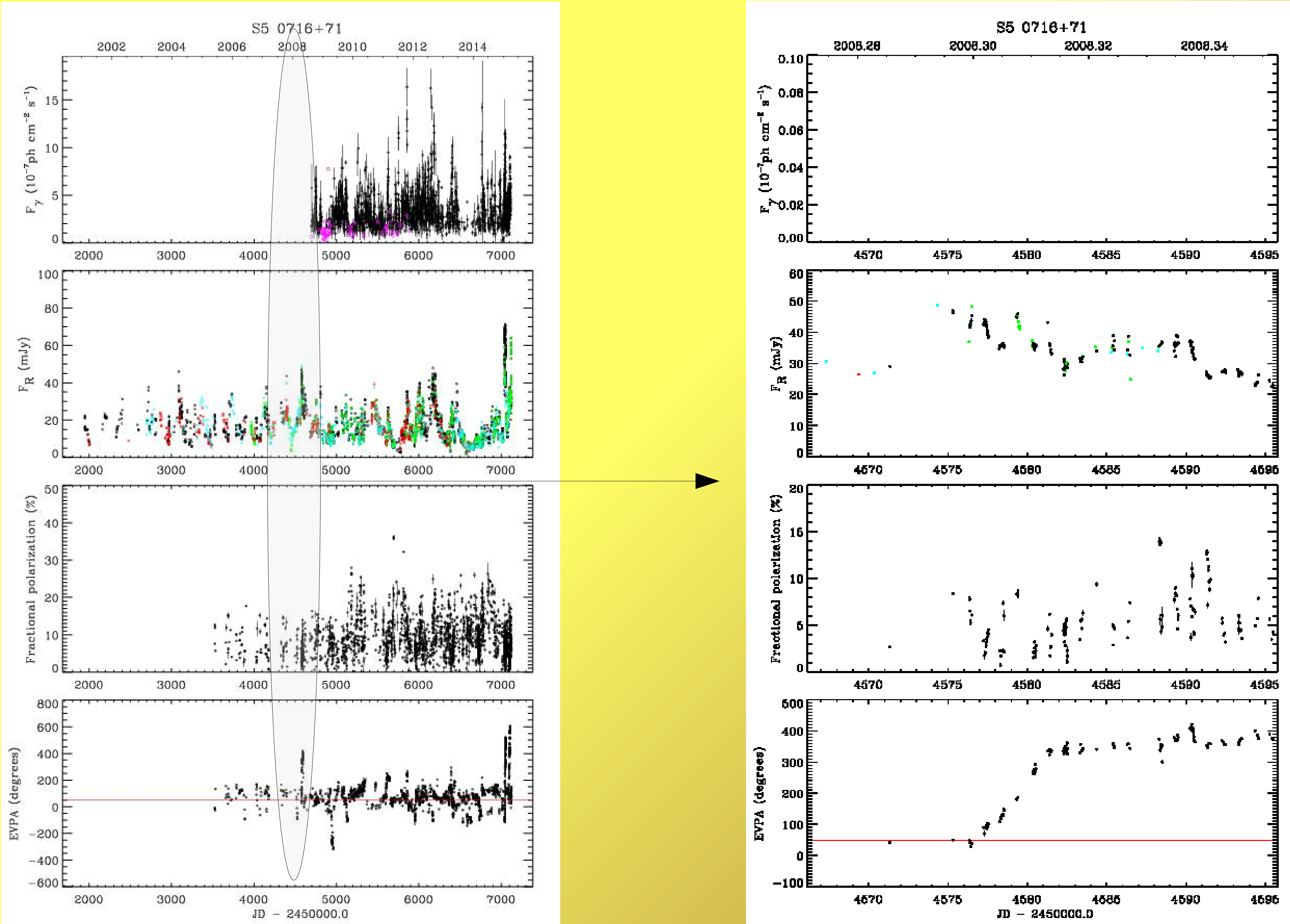


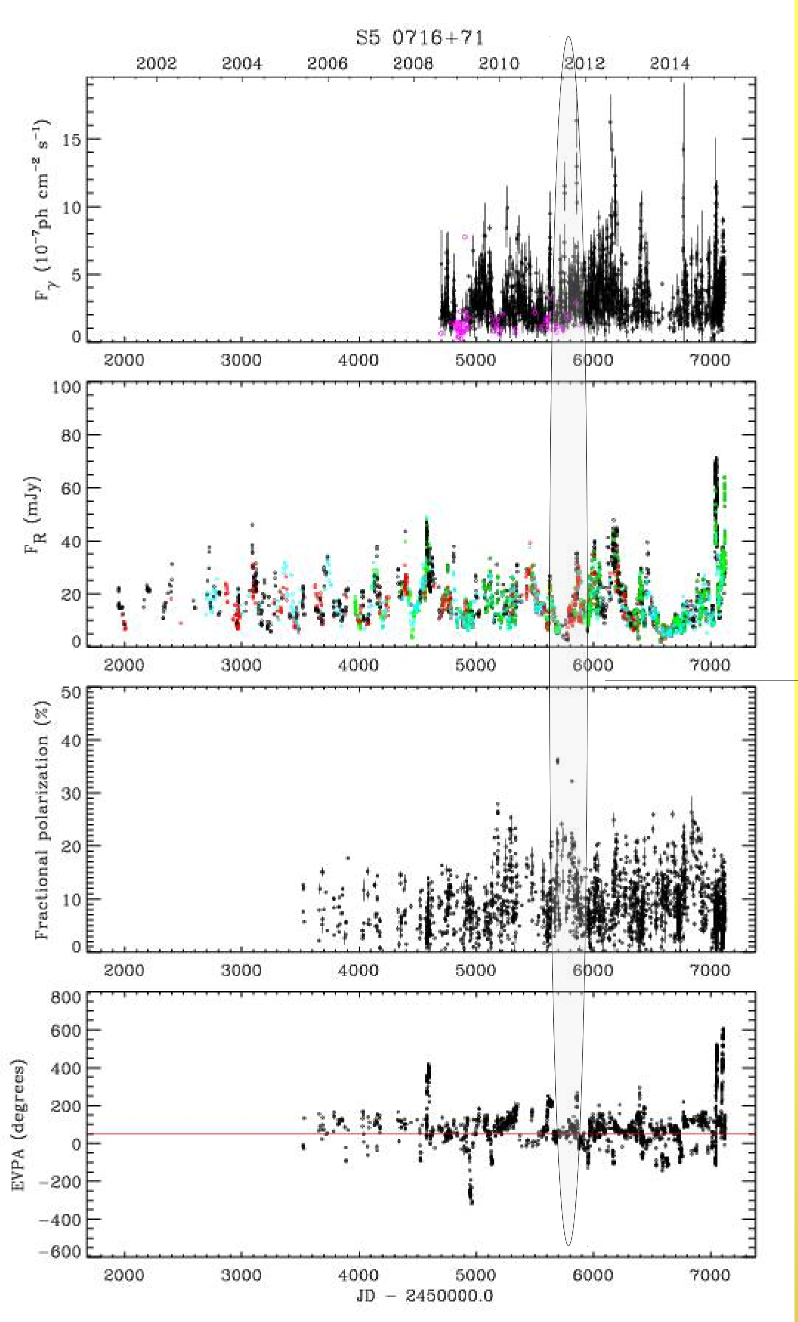

OJ 248
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0
OJ 248
2012.70
2012.80
2012.90
2013.00
2013.10
2013.20
2013.30
JD − 2450000.0


OJ 287
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

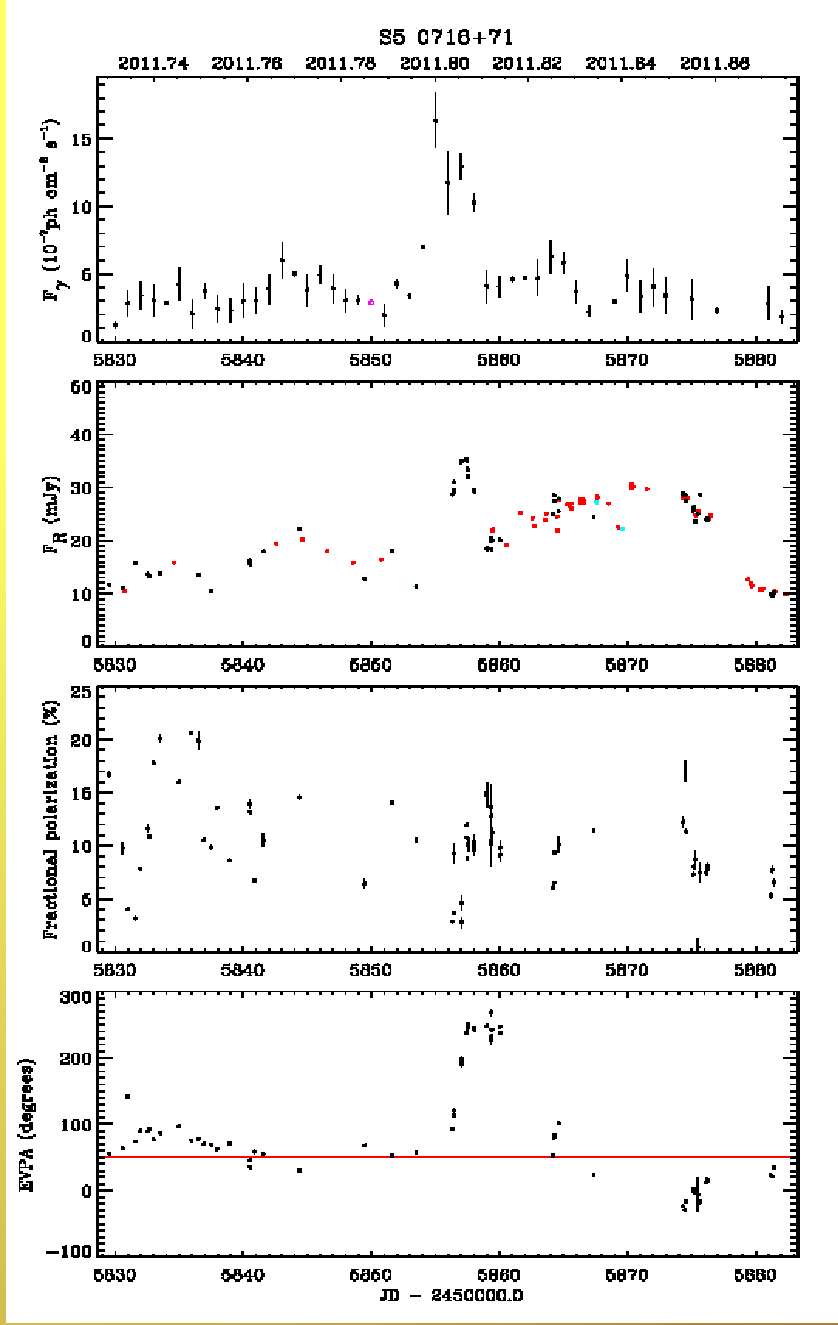

OJ 287
2009.8
2010.0
2010.2
2010.4
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0


OJ 287
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0
OJ 287
2013.05
2013.10
2013.15
2013.20
2013.25
2013.30
JD − 2450000.0

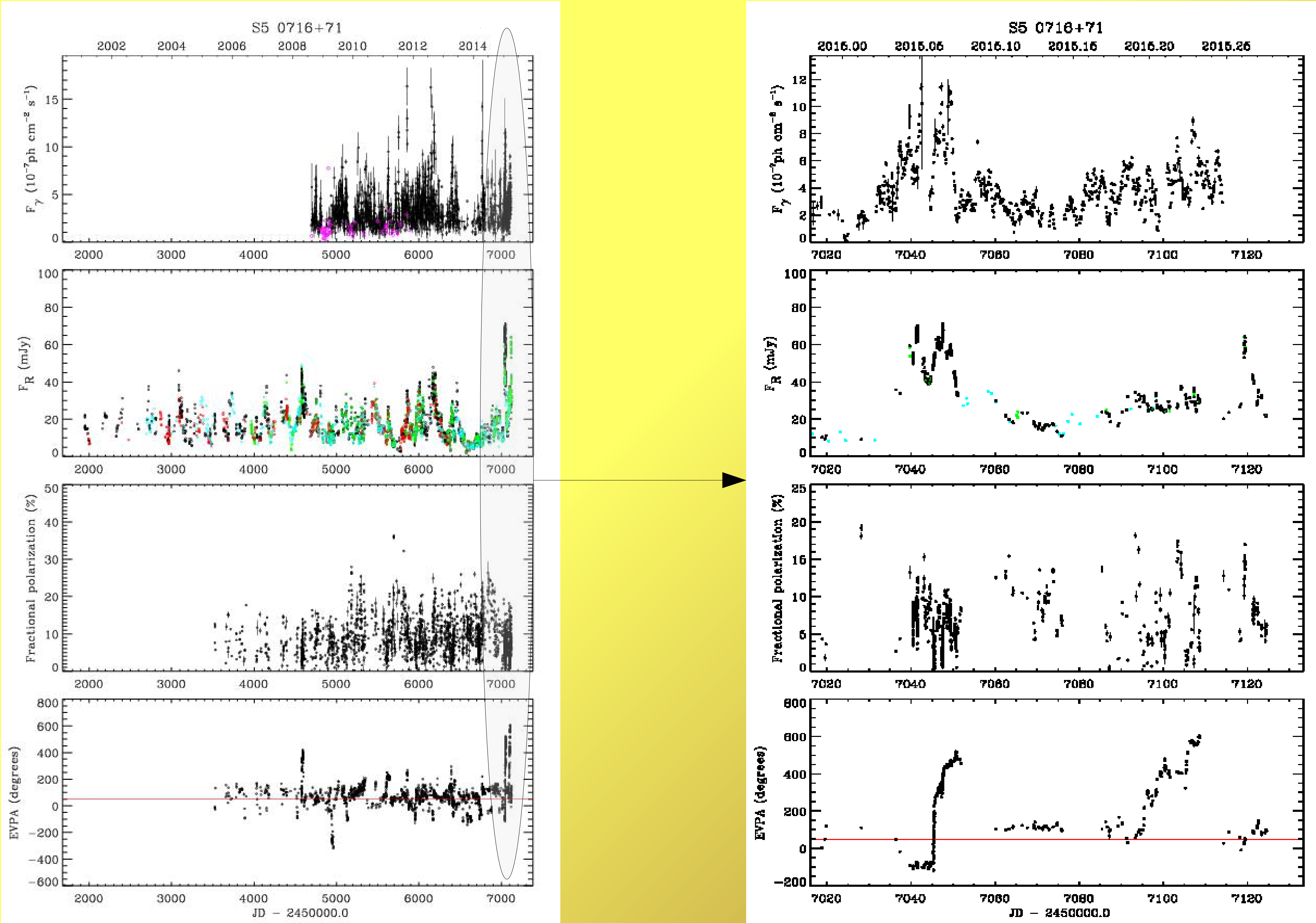

S5 0716+71
2002
2004
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0
S5 0716+71
2008.28
2008.30
2008.32
2008.34
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0



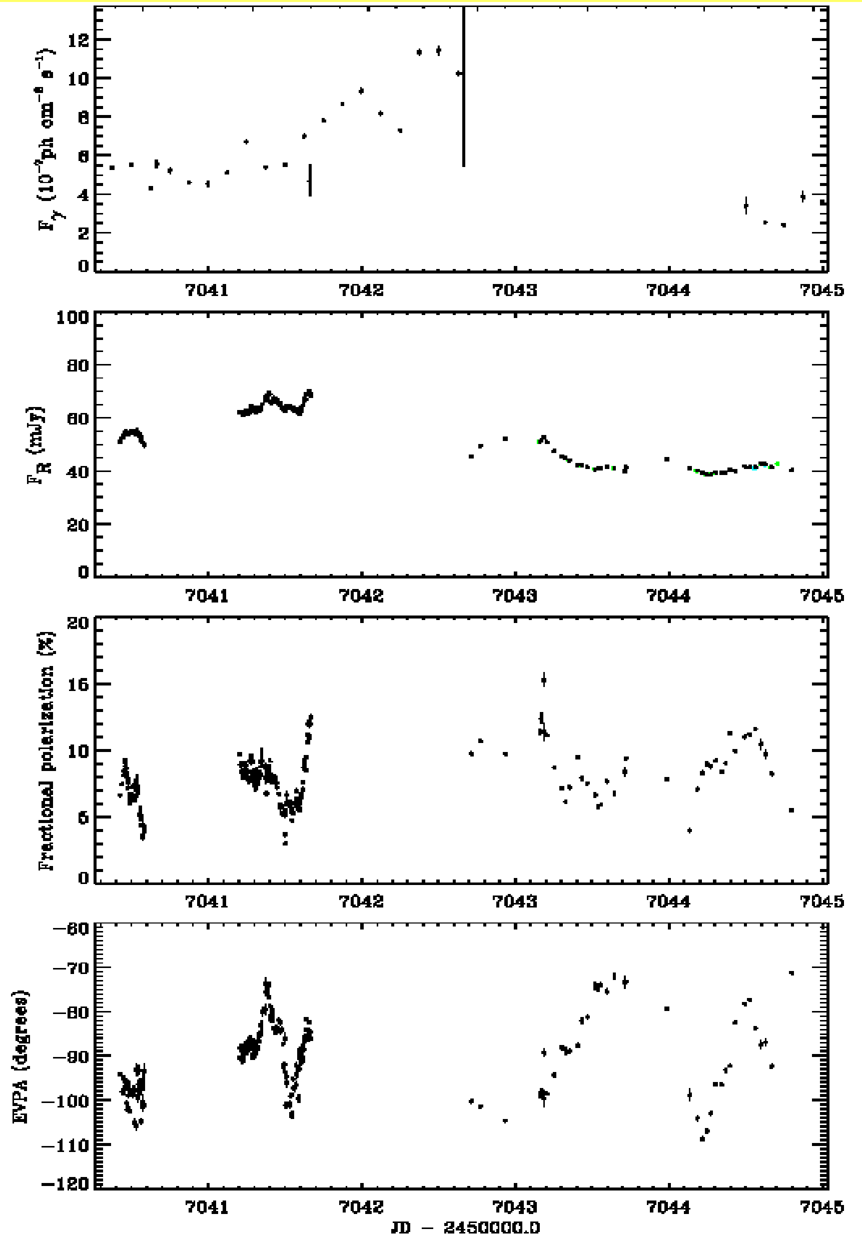
S5 0716+71
2002
2004
2006
2008
2010
2012
2014
F_γ (10^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

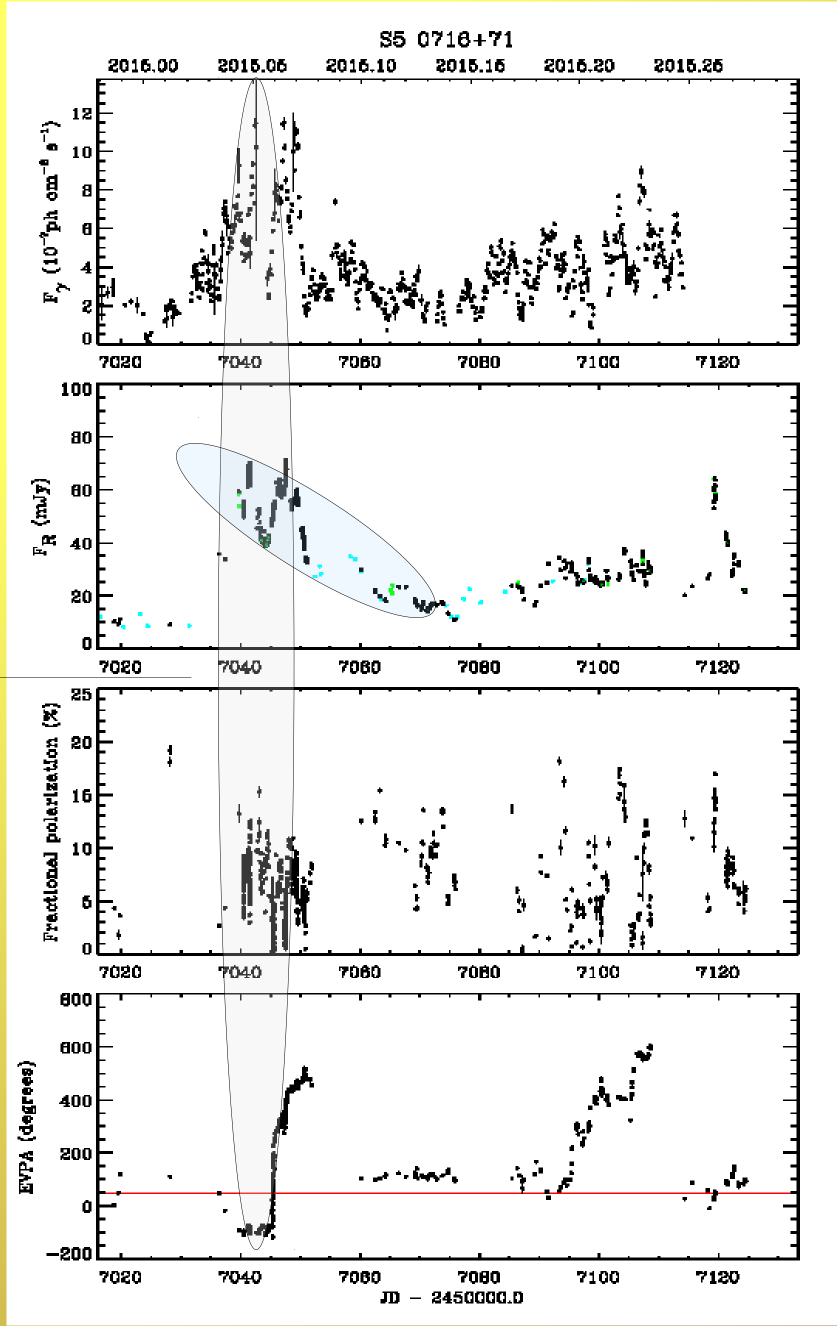


S5 0716+71
2011.74
2011.76
2011.78
2011.80
2011.82
2011.84
2011.86
F_γ (10^{-6}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0


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^{-7}ph cm^{-2} s^{-1})
F_R (mJy)
Fractional polarization (%)
EVPA (degrees)
JD − 2450000.0

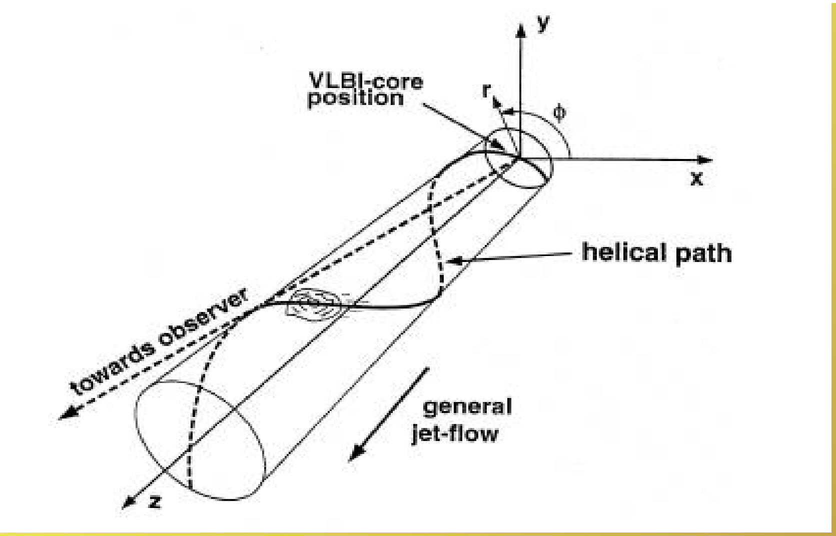
See poster by Troitskaya et al





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:

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

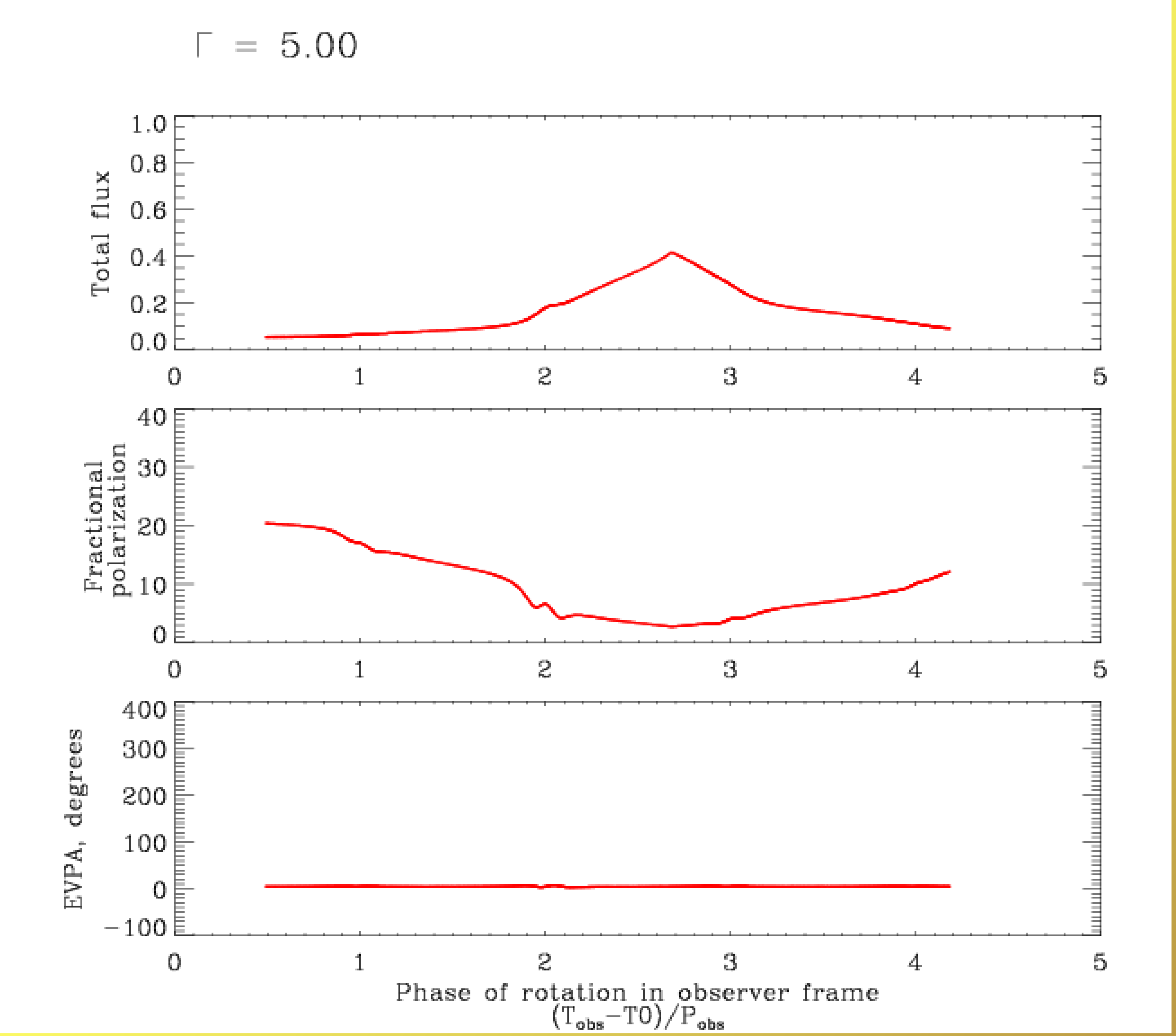
Doppler factor δ:

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

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 = 5.00
Total flux
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Fractional polarization
40
30
20
10
0
EVPA, degrees
400
300
200
100
0
−100
Phase of rotation in observer frame
$(T_{obs}-T0)/P_{obs}$

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

θ° (1)	ζ° (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)	$\Delta\chi^\circ$ (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 $P_{\rm src}$.

There are three kinds of lies: lies, damned lies and

Statistics

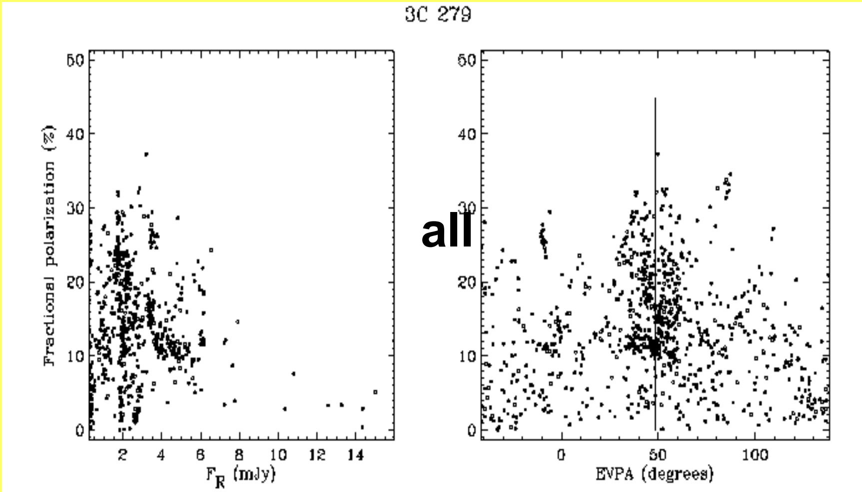
(Somebody et al., XIX c.)

Distributions of polarization *vs* flux, polarization *vs* EVPA

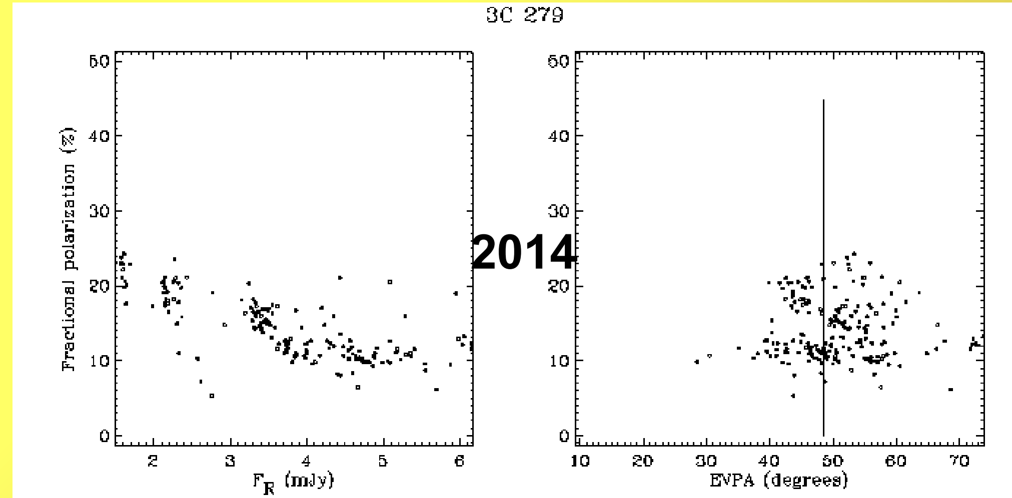
Q1: are they the same for total data set and for active states?
Q2: positive or negative correlations between flux and polarization?
Q3: do EVPA values concentrate around parsec jet direction?

Is there any time lag between gamma-rays and optical?

3C 279

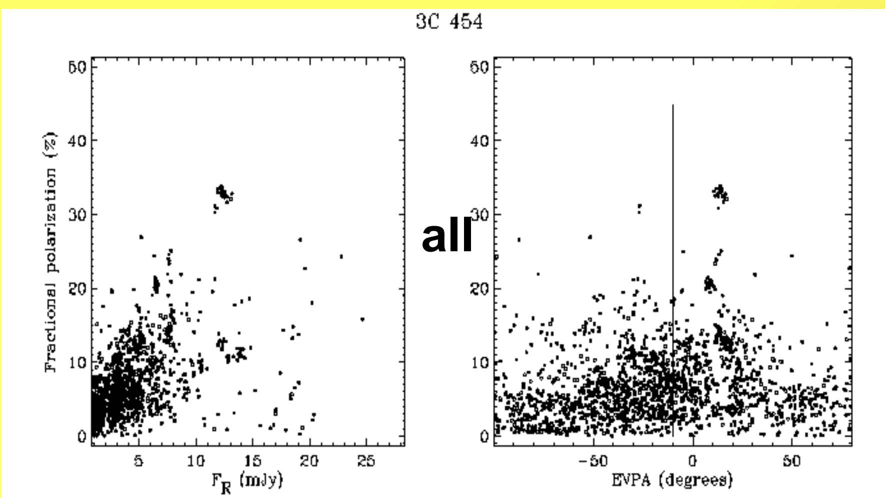


all

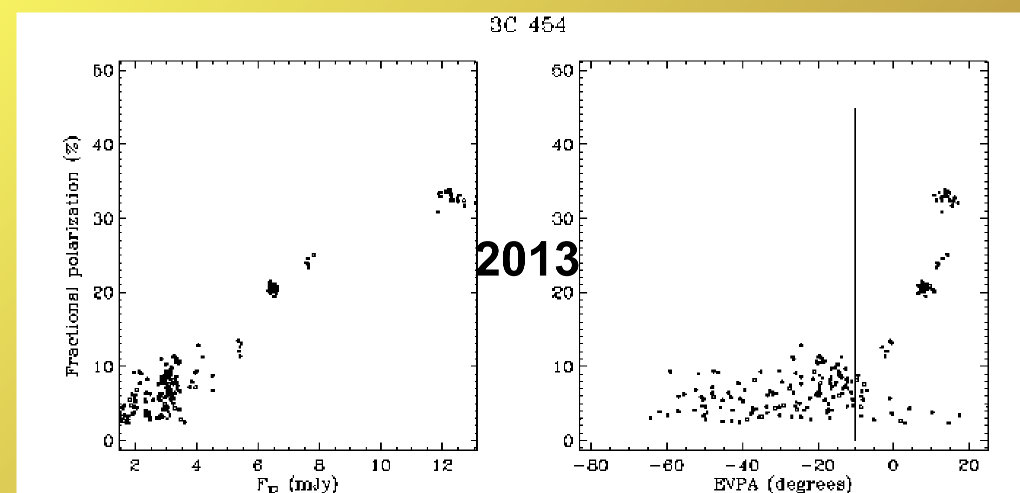


2014

3C 454.3

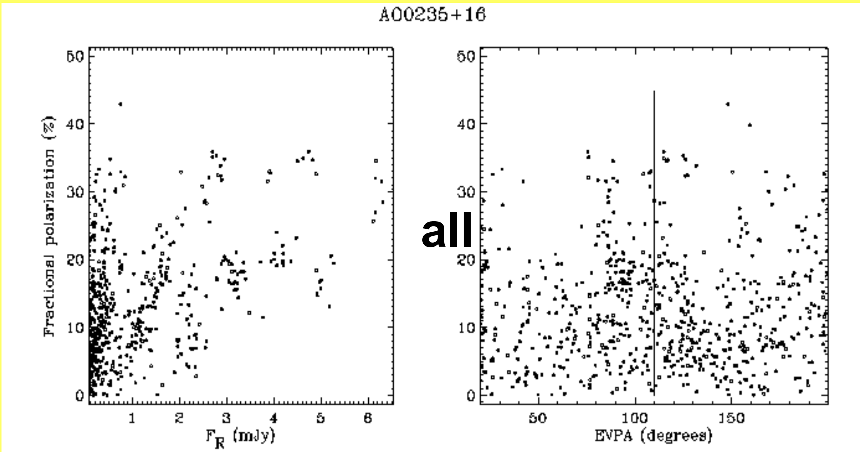


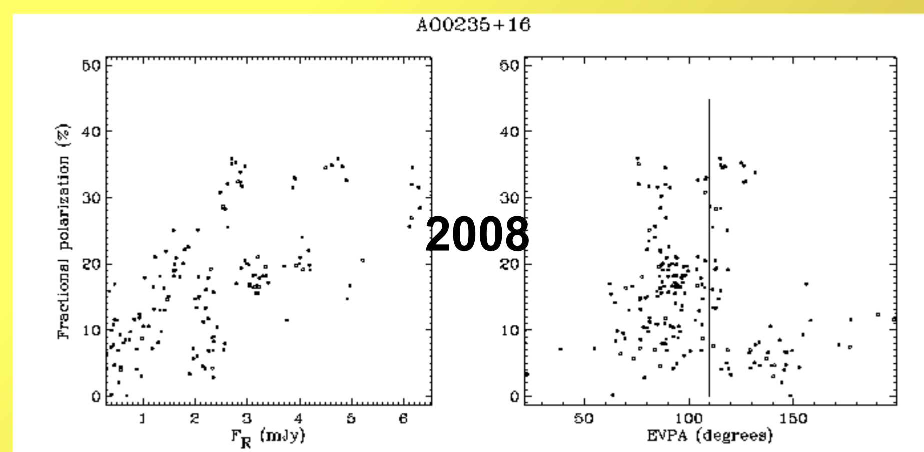
all



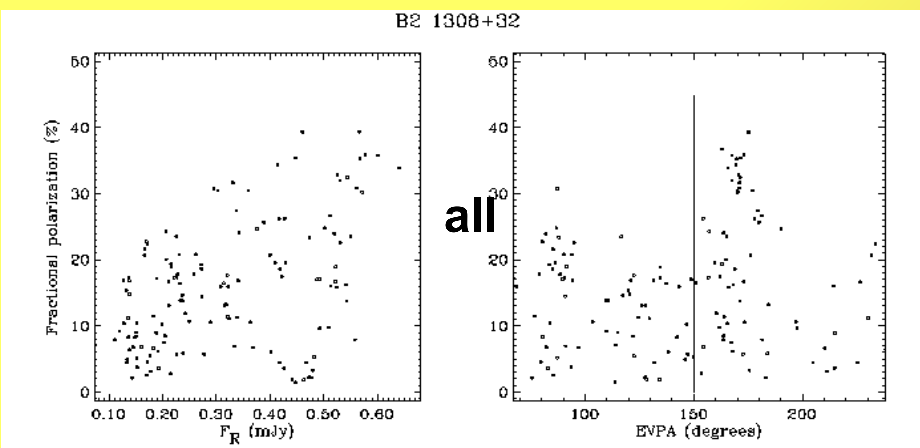
2013

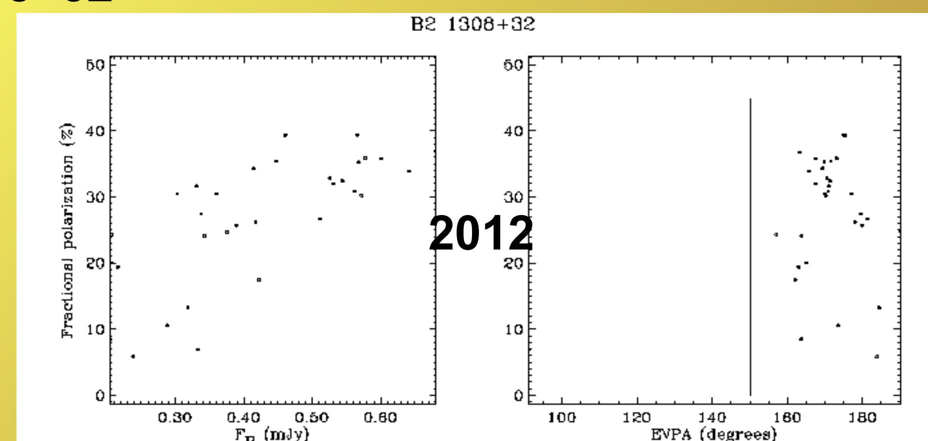
AO 235+16



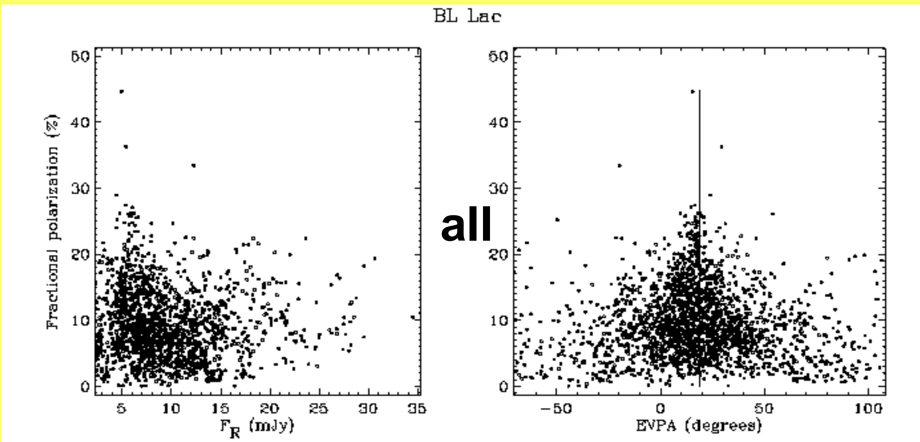


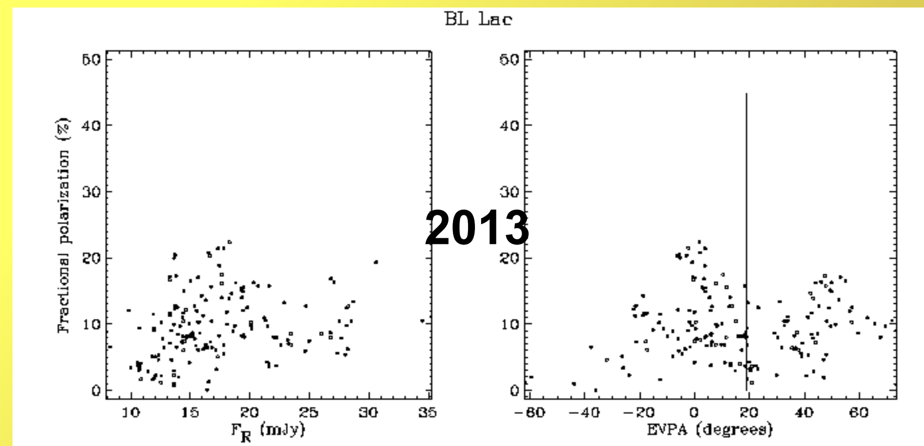
B21308+32



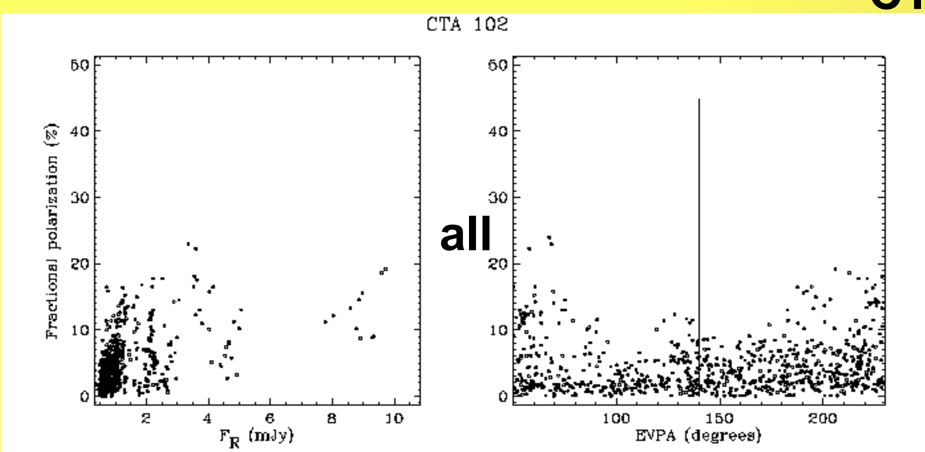


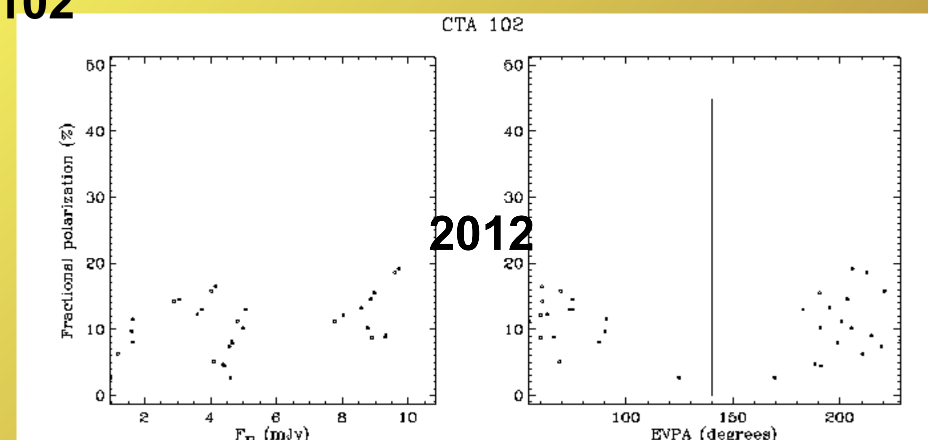
BL Lac



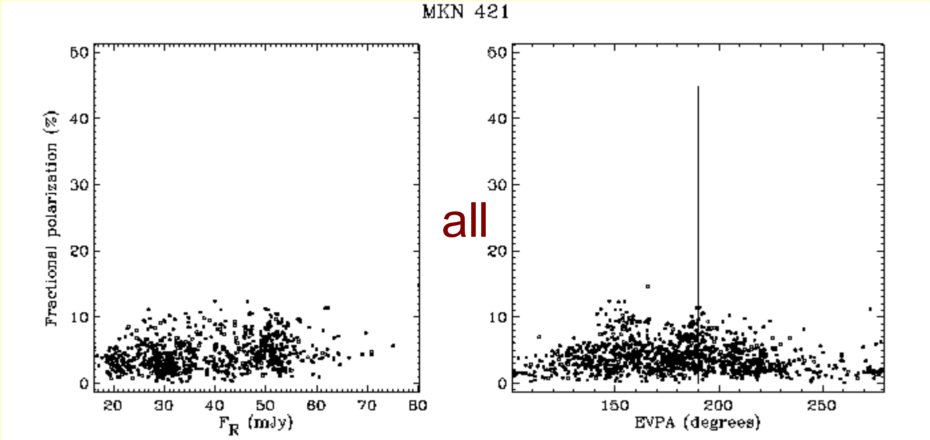


CTA 102

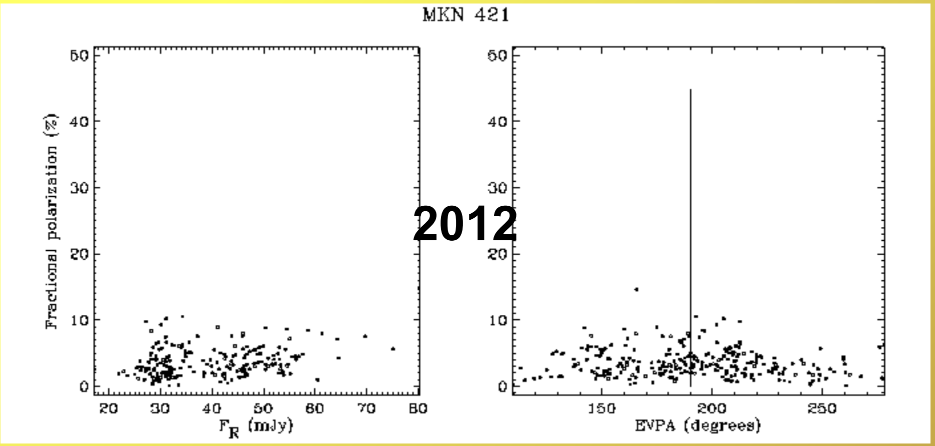




Mkn 421

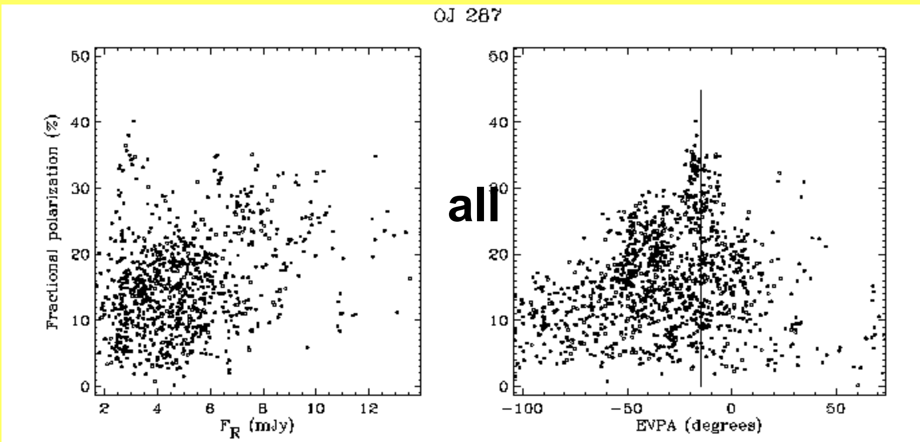


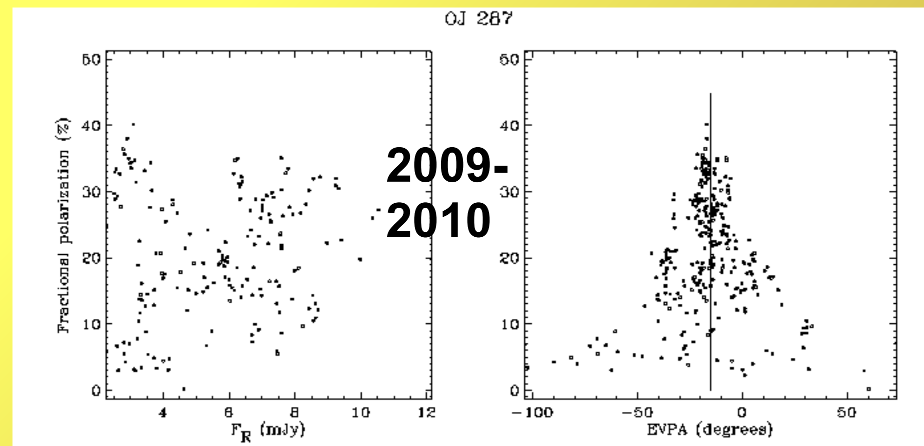
MKN 421
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
all

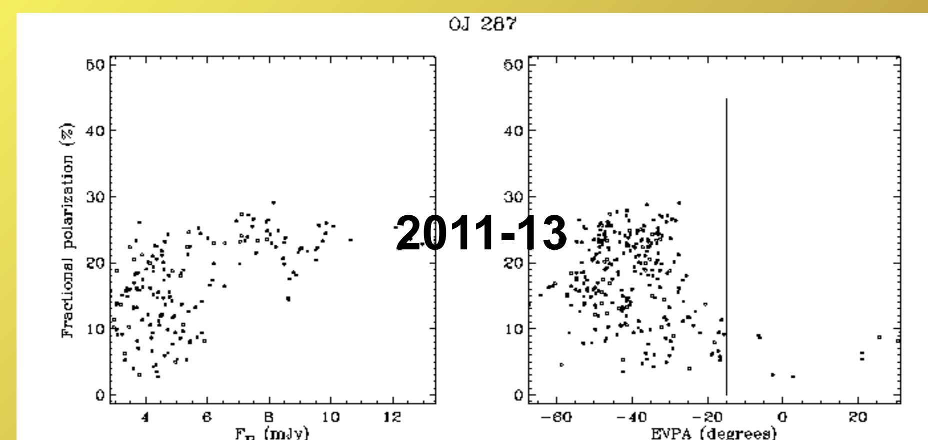


MKN 421
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
2012

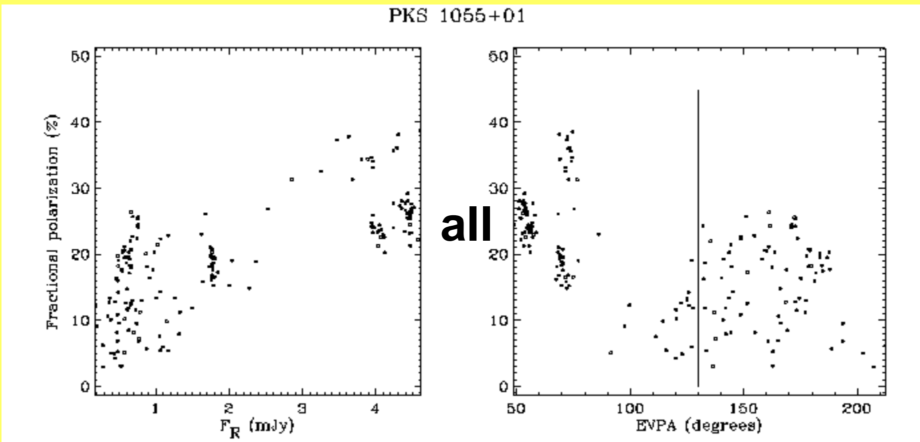
OJ 287

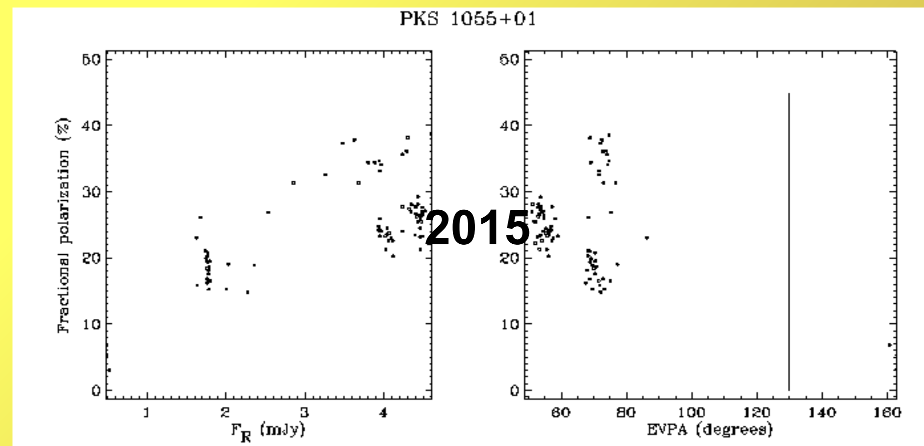

OJ 287
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
all


OJ 287
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
2009-
2010

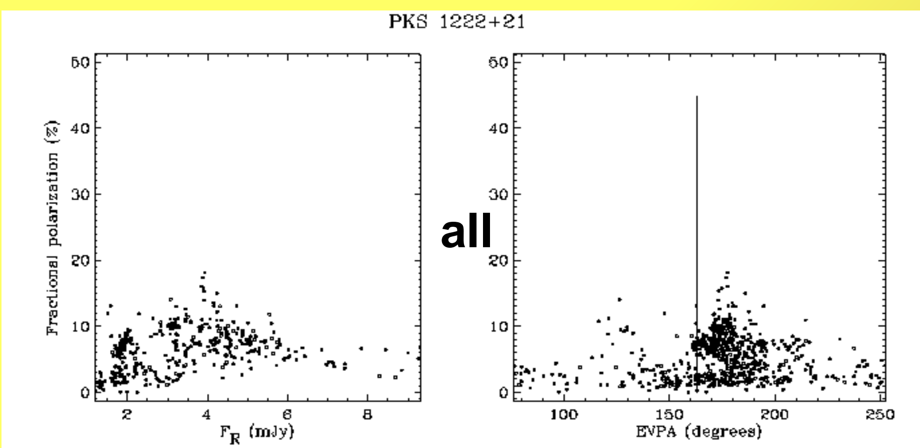

OJ 287
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
2011-13

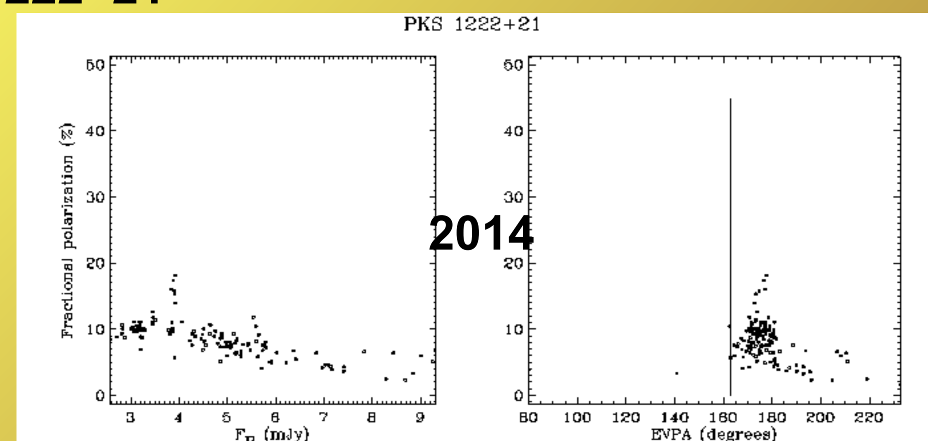
PKS 1055+01



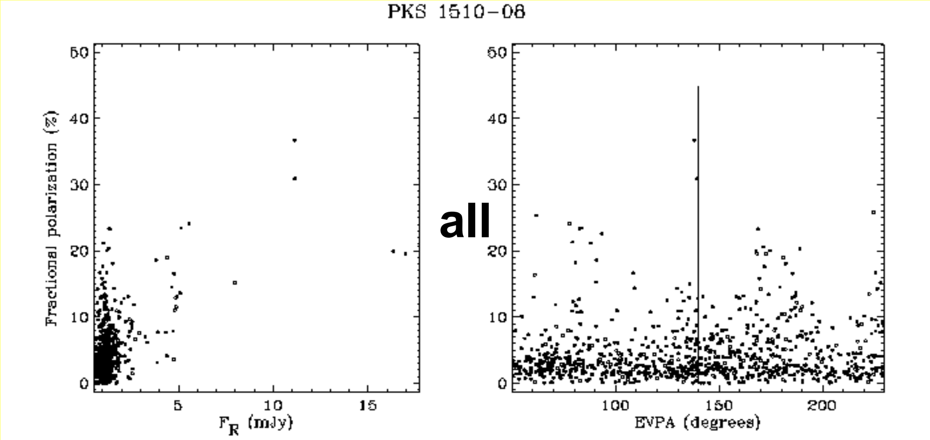


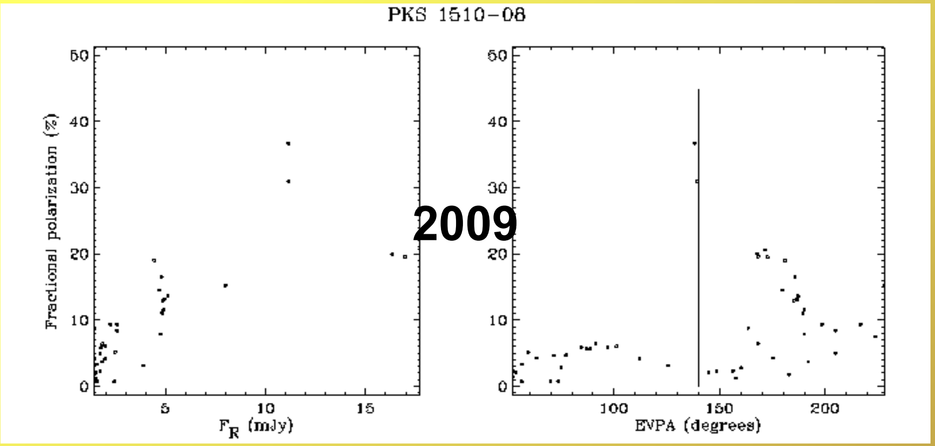
PKS 1222+21



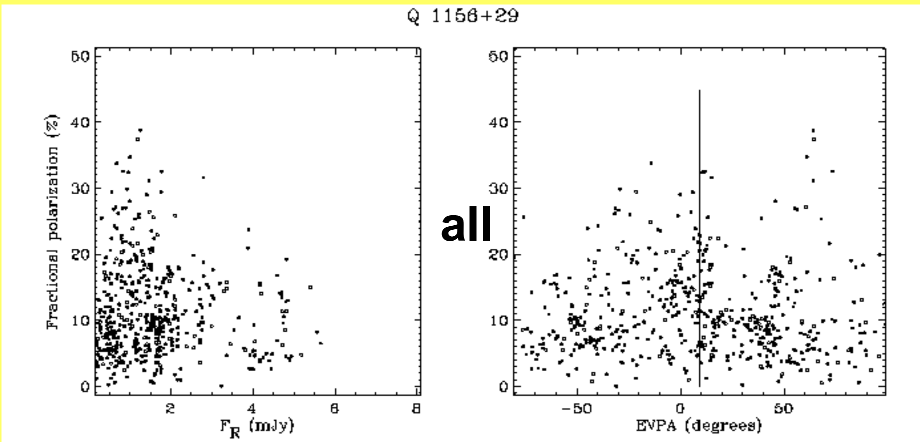


PKS 1510-08

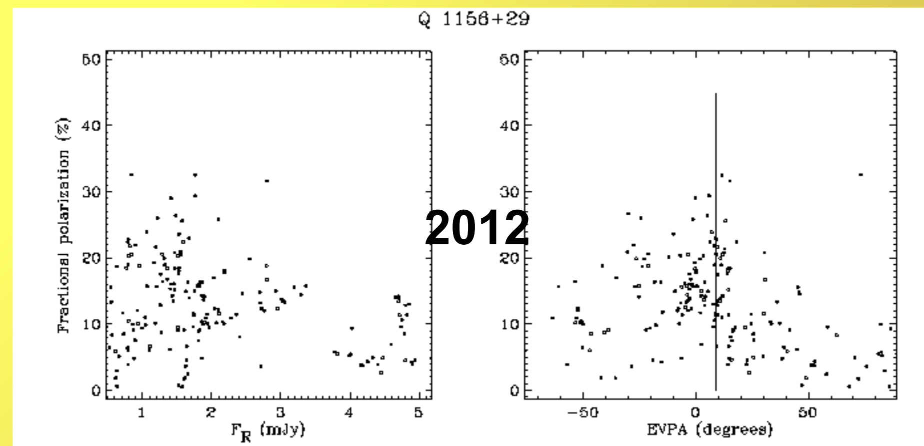

PKS 1510−08
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
all


PKS 1510−08
Fractional polarization (%)
F_R (mJy)
EVPA (degrees)
2009

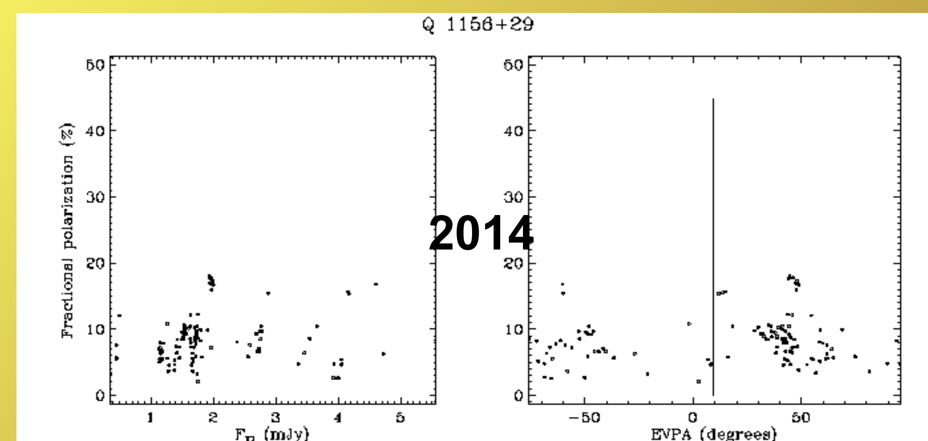
1156+29



all

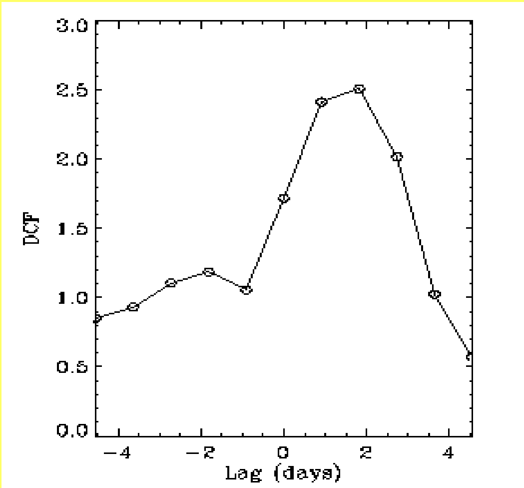


2012

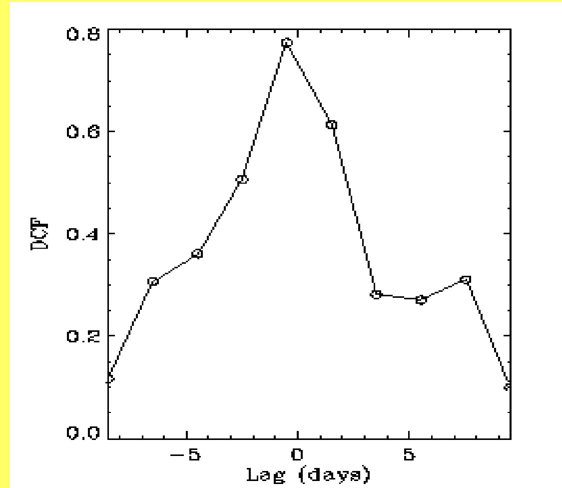


2014

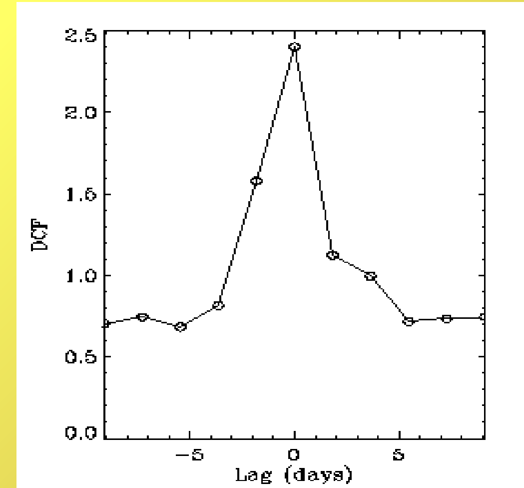
3C454.3



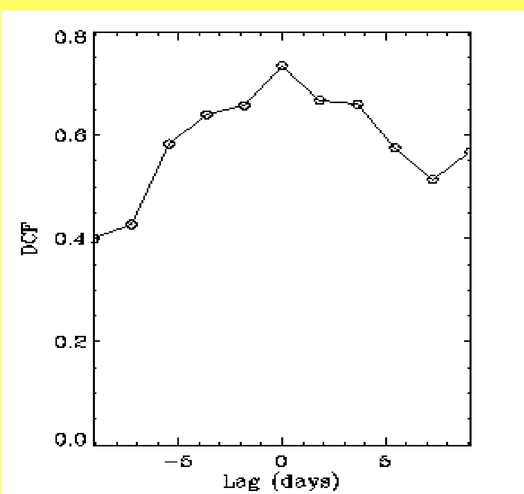
BL Lac



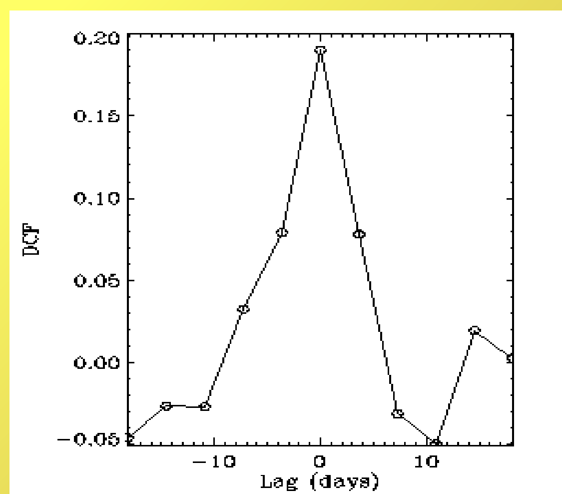
CTA 102



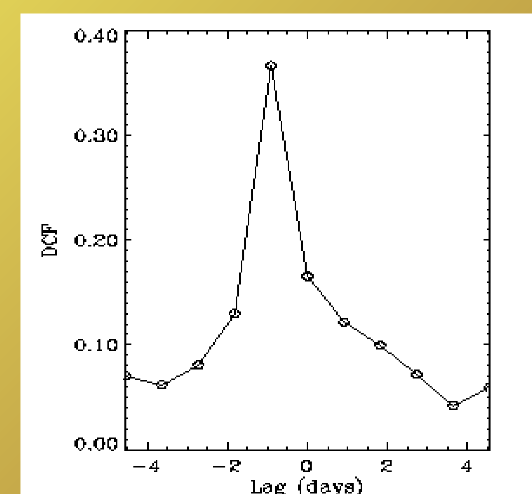
MKN 421



OJ 287



PKS 1510-08



Q1: are the distributions the same for **total** data set and for **active** states?
Q2: positive or negative correlations between flux and polarization?
Q3: do EVPA values concentrate around parsec jet direction
(a) for the total set
(b) for outbursts?

Q4: Is there any time lag between gamma-rays and optical?

A1: No, in most (not all) cases they are quite different.
In «statistical» terms they do not belong to the same population.
A2: Yes! (7) No! (3) Both... (2)
A3a: Yes! (7) No!(2) Both! (3)
A3b: Yes! (4) No! (6) Both! (2)

A4: When the data are not biased, we do not see statistically meaninful time lag; gamma and optics are co-spatial

Color variability

The problem of color variations in blazars' radiation (BwB, RwB) is discussed in many papers.

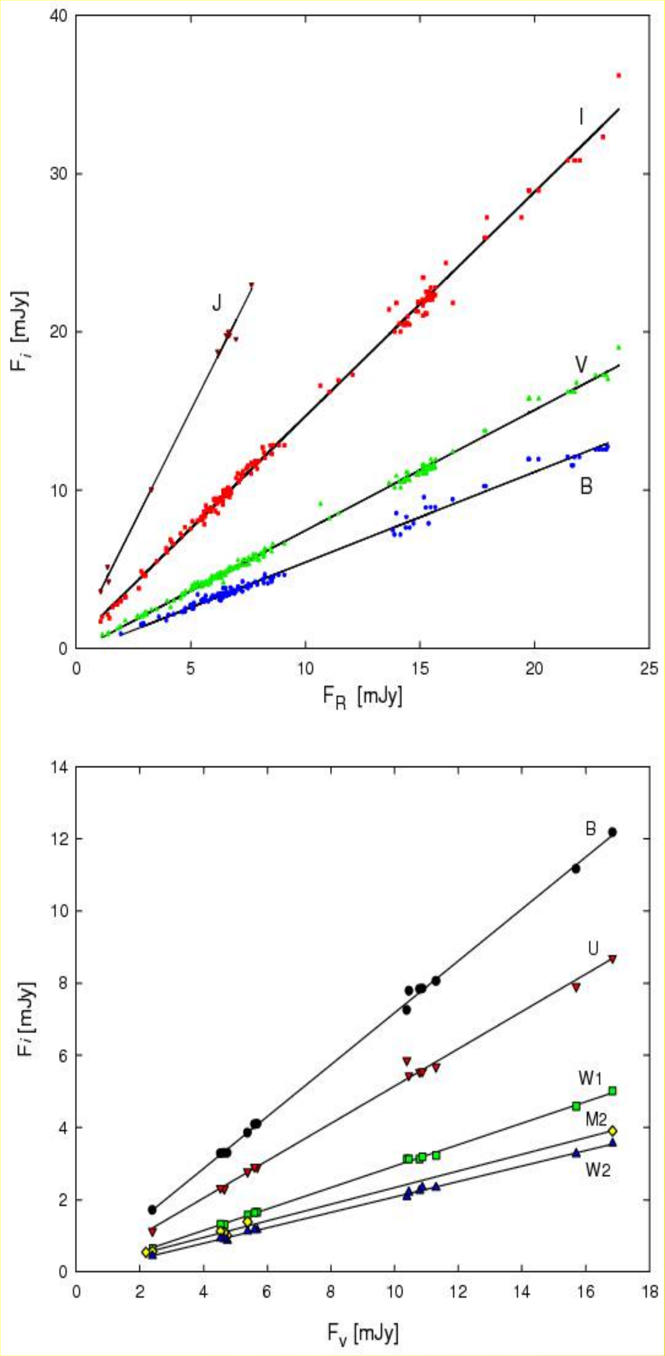
- Intrinsic reasons for variability, e.g. different and/or variable spectrum of radiating electrons
- Difference in relative input of variable (synchrotron) radiation and constant (or slowly variable) sources (BBB, emission lines, host galaxy)

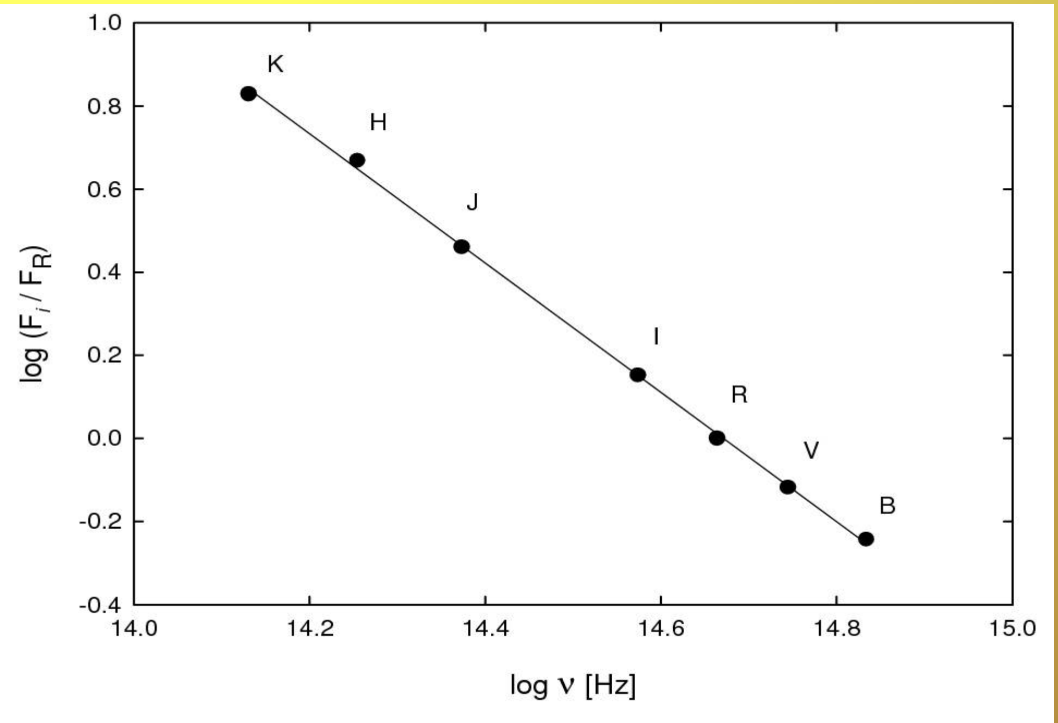
However, a long ago a method was suggested allowing to trace evolution of **variable** source without preliminary knowledge of contribution of **constant** sources

Choloniewski, J., The Shape and Variability of the Nonthermal Component of the Optical Spectra of Active Galaxies, 1981, Acta Astronomica, 31, 293

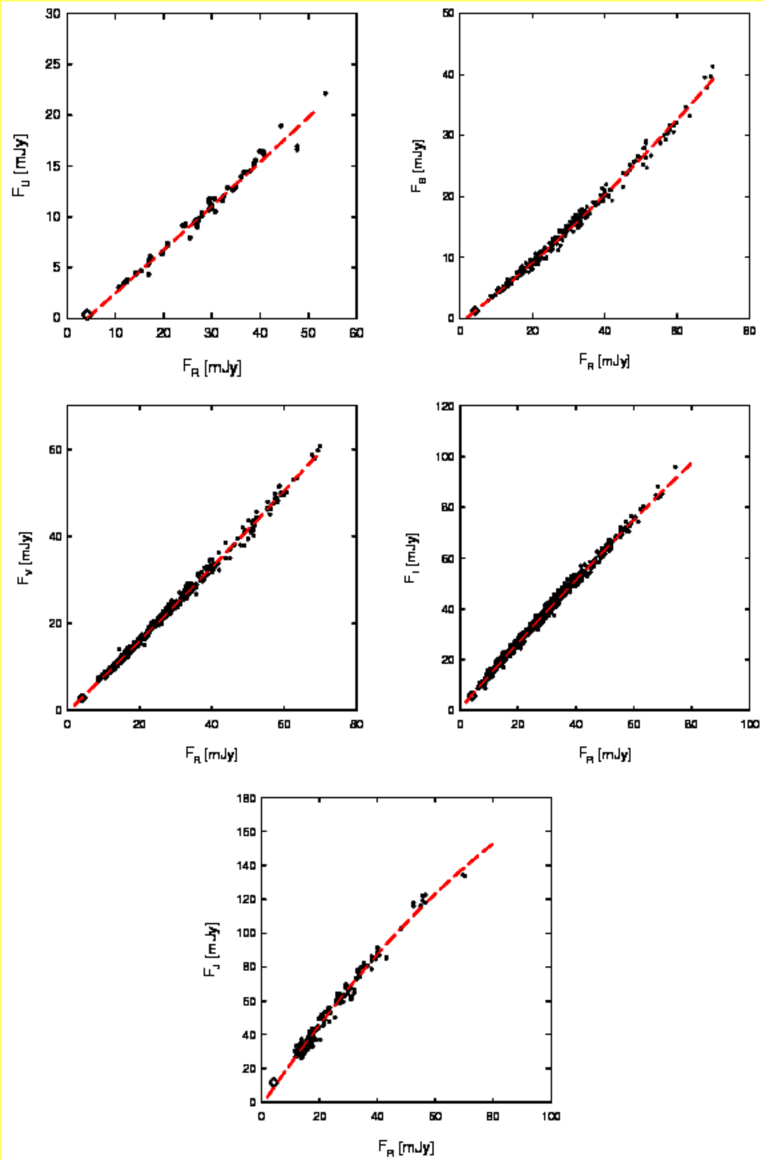
...the optical spectrum of the nonthermal radiation coming from nuclei of active galaxies... for type 1 Seyfert galaxies, lacertides and quasars this spectrum does not change its shape despite its strong variability of bolometric flux. This fact permit us to obtain this shape, which is, for type 1 Seyferts, concave with a mean spectral index close to 0.6, and for lacertides fulfills the power law with spectral index close to -1.

3C 279

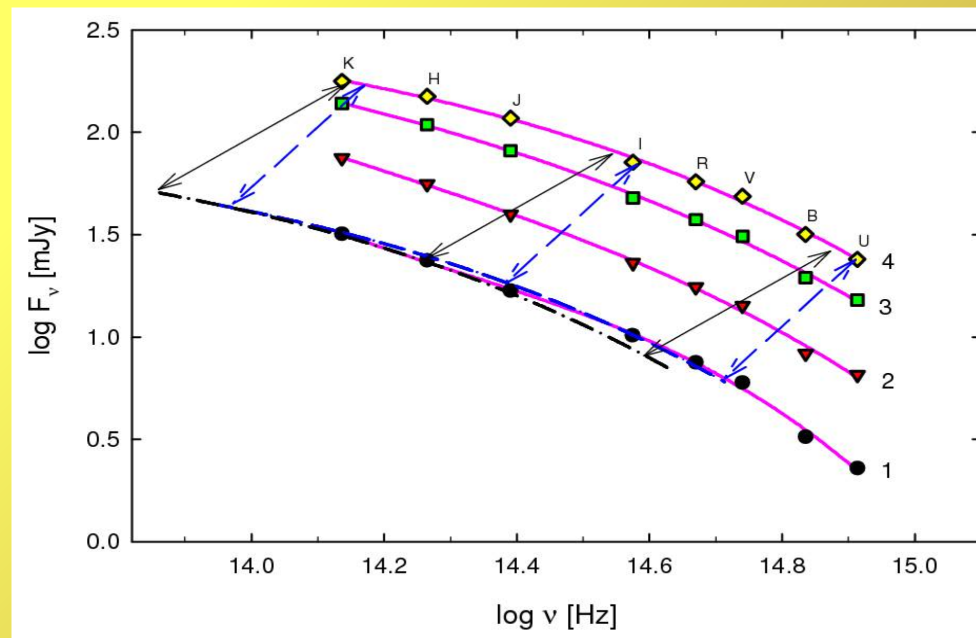




BL Lac



F_U [mJy]
F_B [mJy]
F_V [mJy]
F_I [mJy]
F_J [mJy]
F_R [mJy]



log F_ν [mJy]
log ν [Hz]
K
H
J
I
R
V
B
U
1
2
3
4

Summary

- 10 years 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.
- Independently the same conclusion may be drawn from photometry (lighthouse effect).
- Unexpectedly short (intranight) regular variations of EVPA may be a hint on existence of a fine structure of magnetic field.