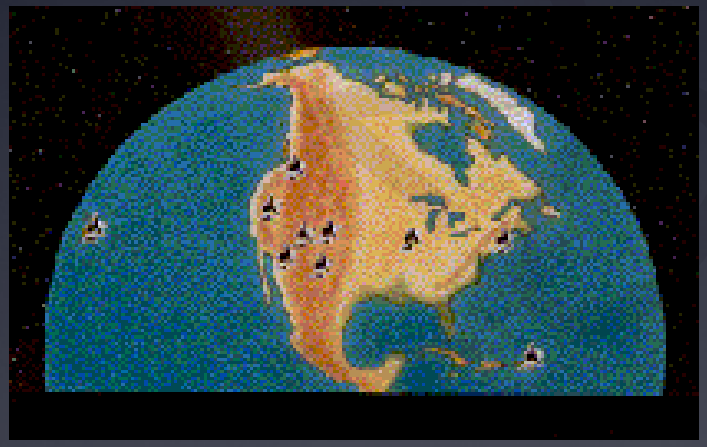
Localization of the gamma-ray emission site using multi-waveband data and mm-VLBI

Svetlana Jorstad



http://www.bu.edu/blazars

BOSTON UNIVERSITY

List of Main Collaborators

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Paul Smith (Steward Obs.)

Valery Larionov (St. Petersburg State U., Russia)

Mark Gurwell (CfA)

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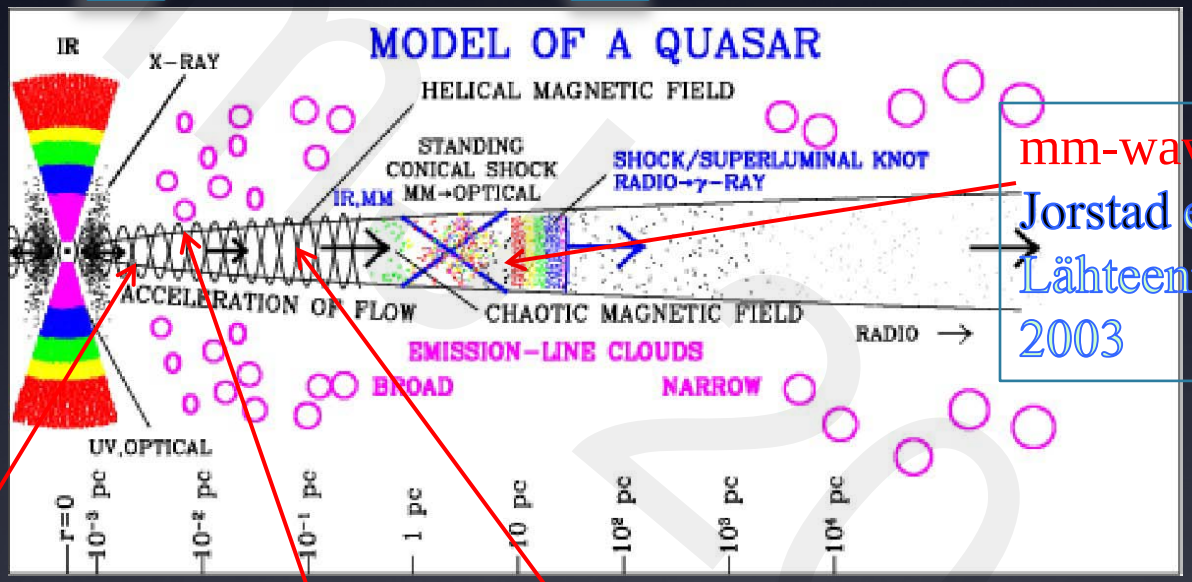
Different Points of View on Sites of Gamma-Ray Emission in Blazars

Various Sites: Marscher et al. 2008, 2010 ; Katarzynski & Ghisellini 2007



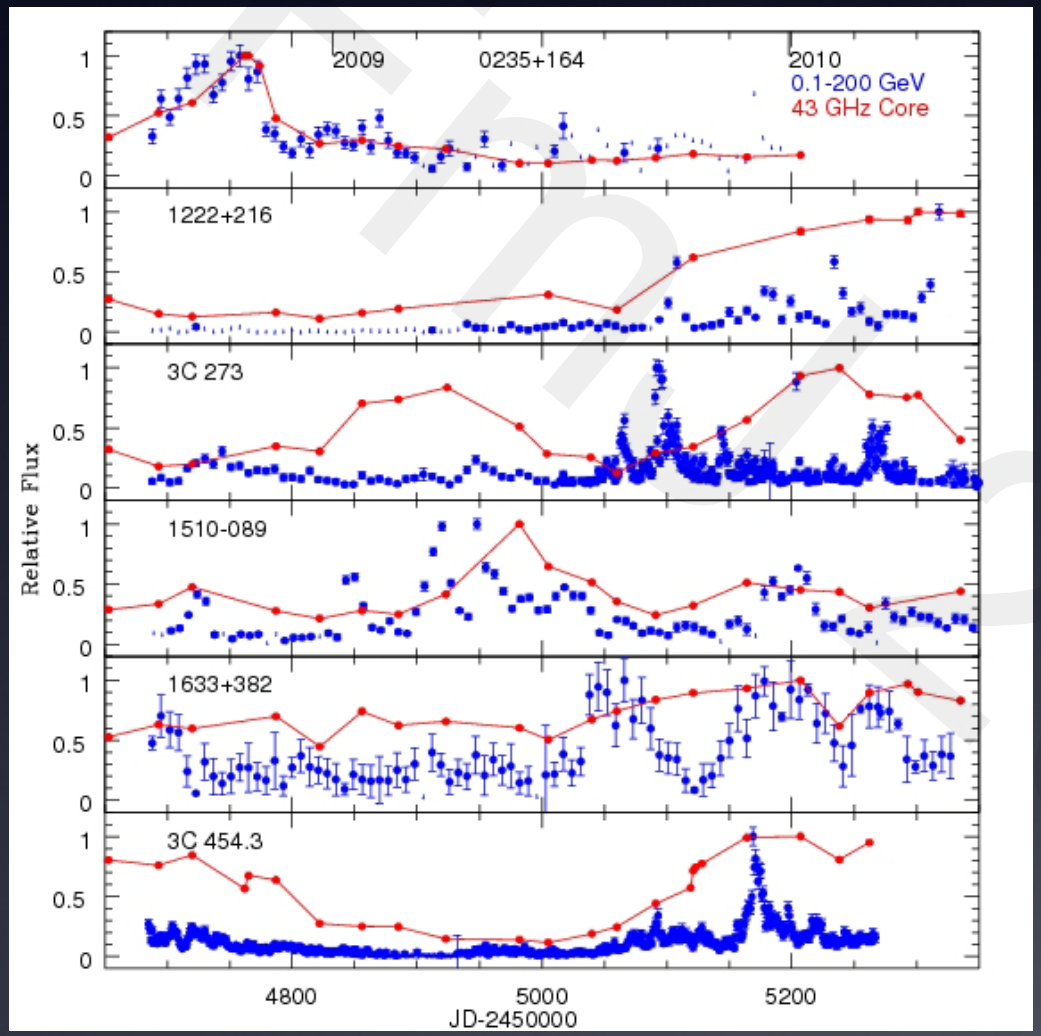
mm-wave VLBI Core : Jorstad et al. 2001, 2010 Lähteenmäki & Valtaoja 2003

Within 1 light yr. : Dermer & Schlickeiser 1994; Tavecchio et al. 2010; Poutanen & Stern 2010

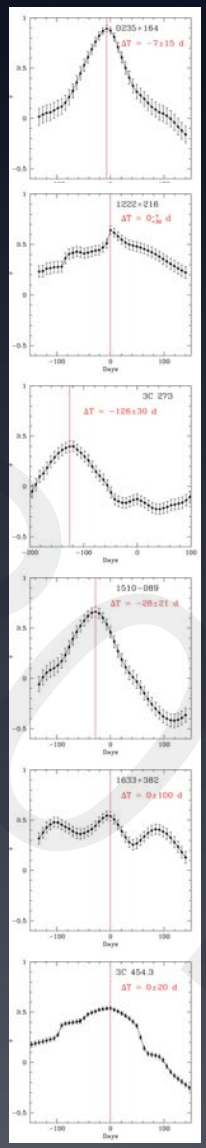
BLR: Sikora, Begelman, & Rees 1994; Vercellone, et al 2010; Finke & Dermer 2010

Dust Torus: Sikora, et al. 2008; Costamante et al. 2010

Flaring Blazars in the Gamma-Ray Sky



Fermi LAT Light Curves



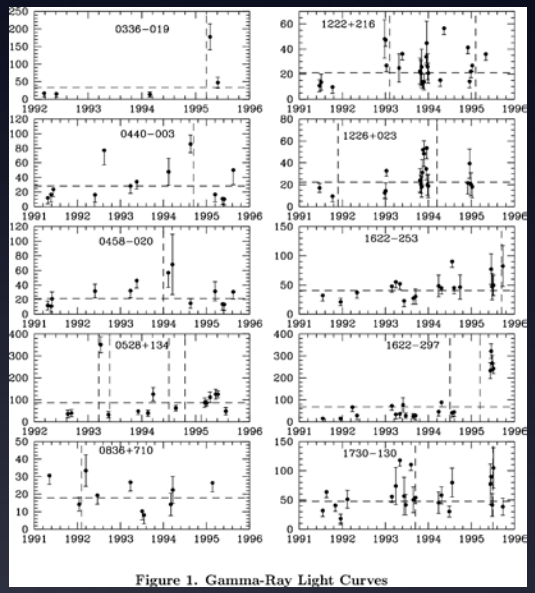
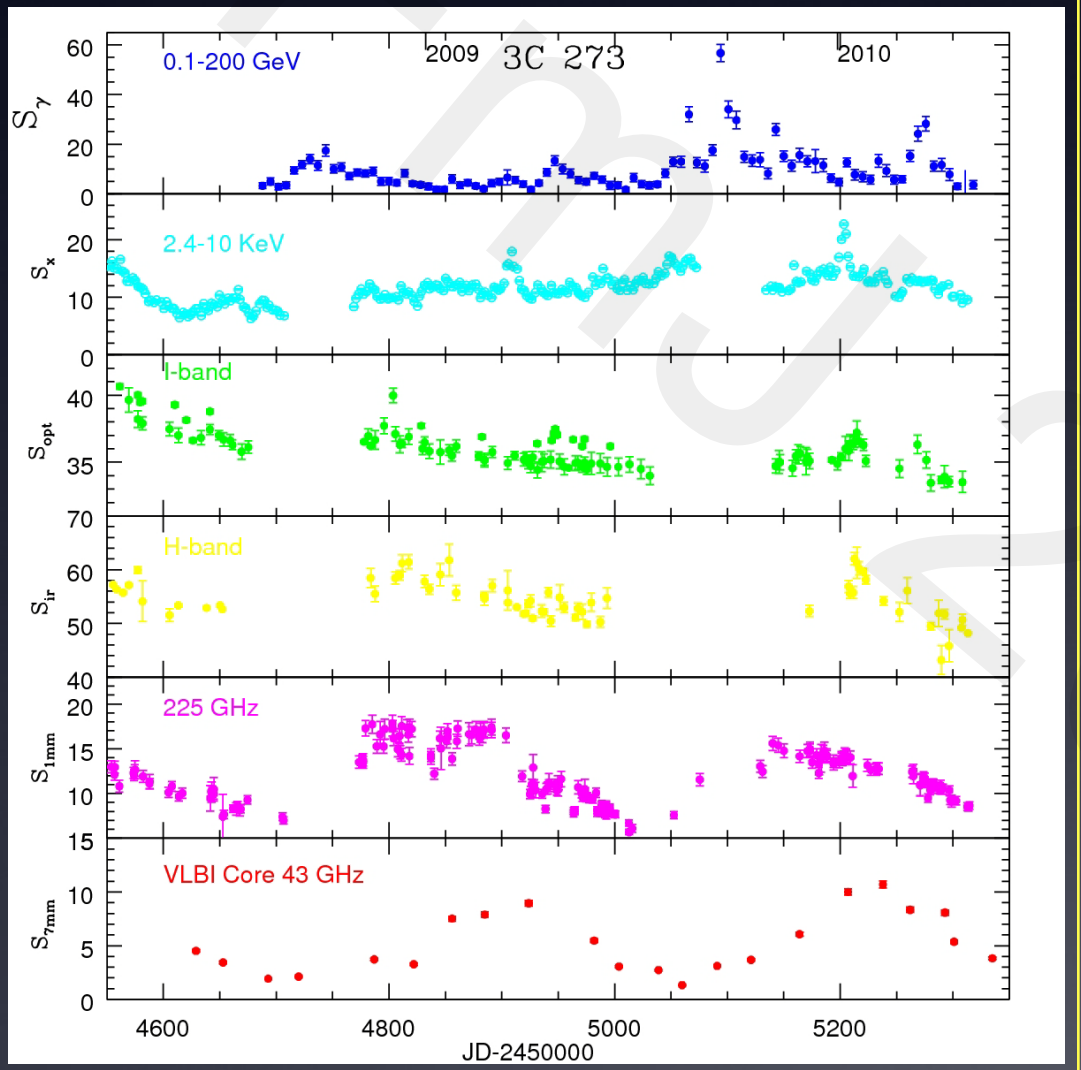


Figure 1. Gamma-Ray Light Curves

EGRET Light Curves

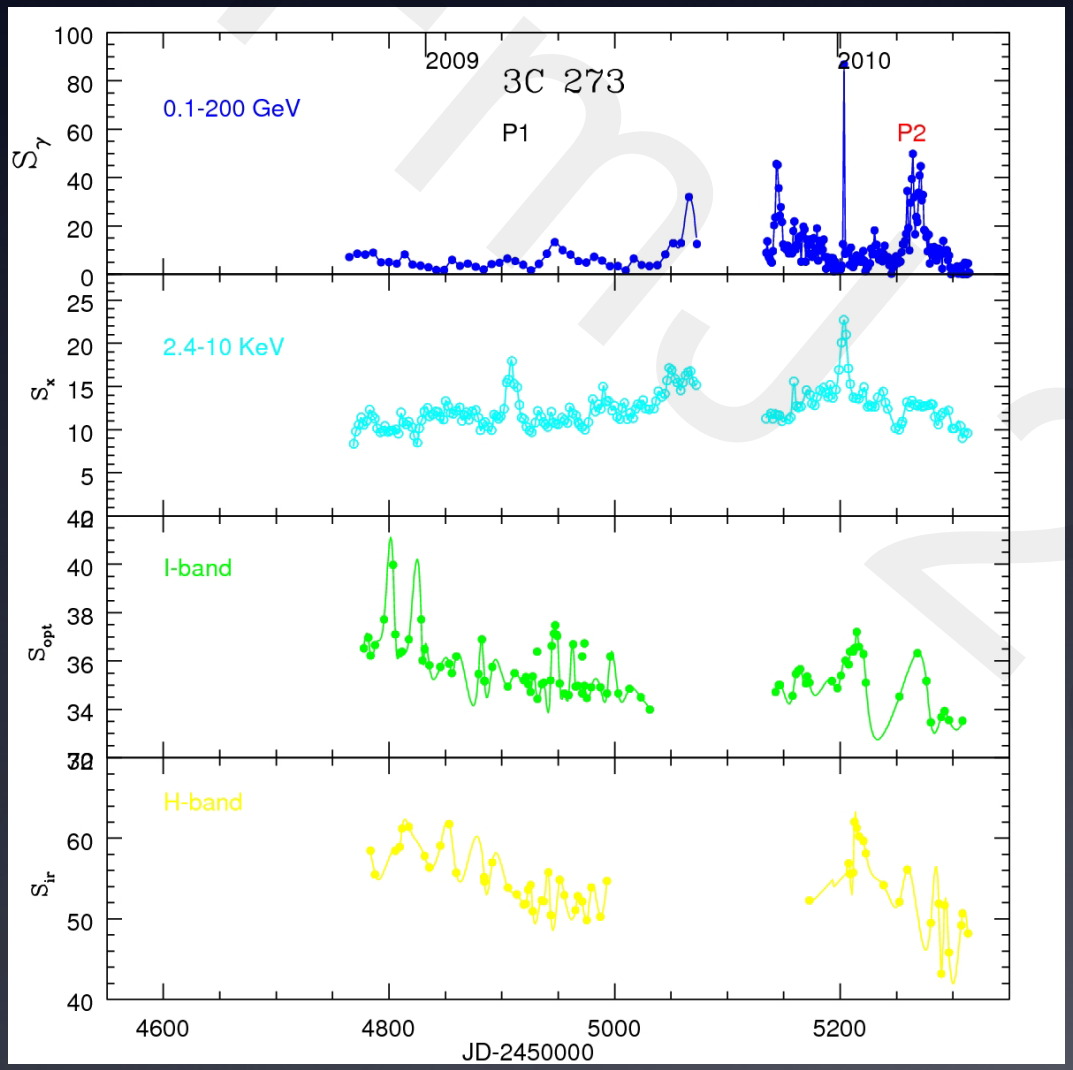
1. A high γ-ray state lasts for months as an excited state of the mm-wave core.
2. A low γ-ray state coincides with a quiescent state of the mm-wave core

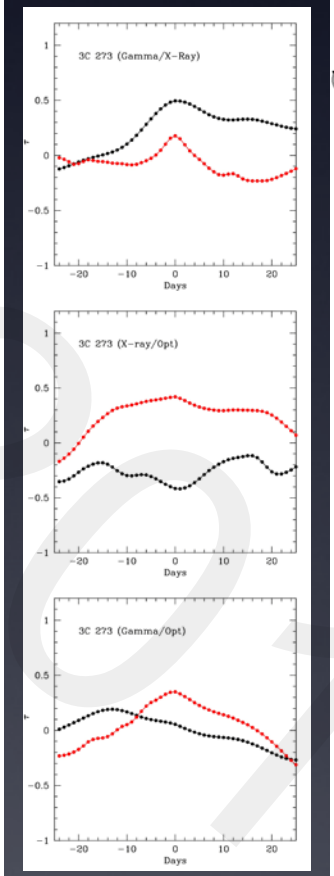
Multi-Frequency Light Curves of the Quasar 3C 273

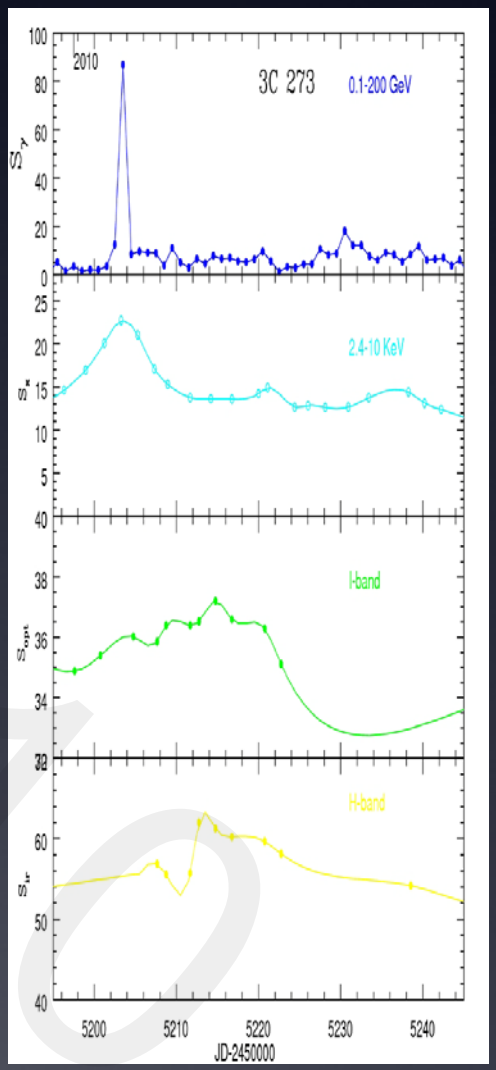


1. Strong correlation between 225 GHz emission from the whole source and 43 GHz VLBI core flux with delay of the core variability by ~ 70 days.
2. Good correlation between 225 GHz and IR emission with delay of sub-mm waves by ~ 25 days.
3. General trend of optical emission behavior similar to mm/sub-mm/IR waves.
4. General γ/X-ray behavior is different from variability at longer wavelengths.
5. Beginning of γ-ray high activity state coincides with flux increase at sub-mm/mm waves.

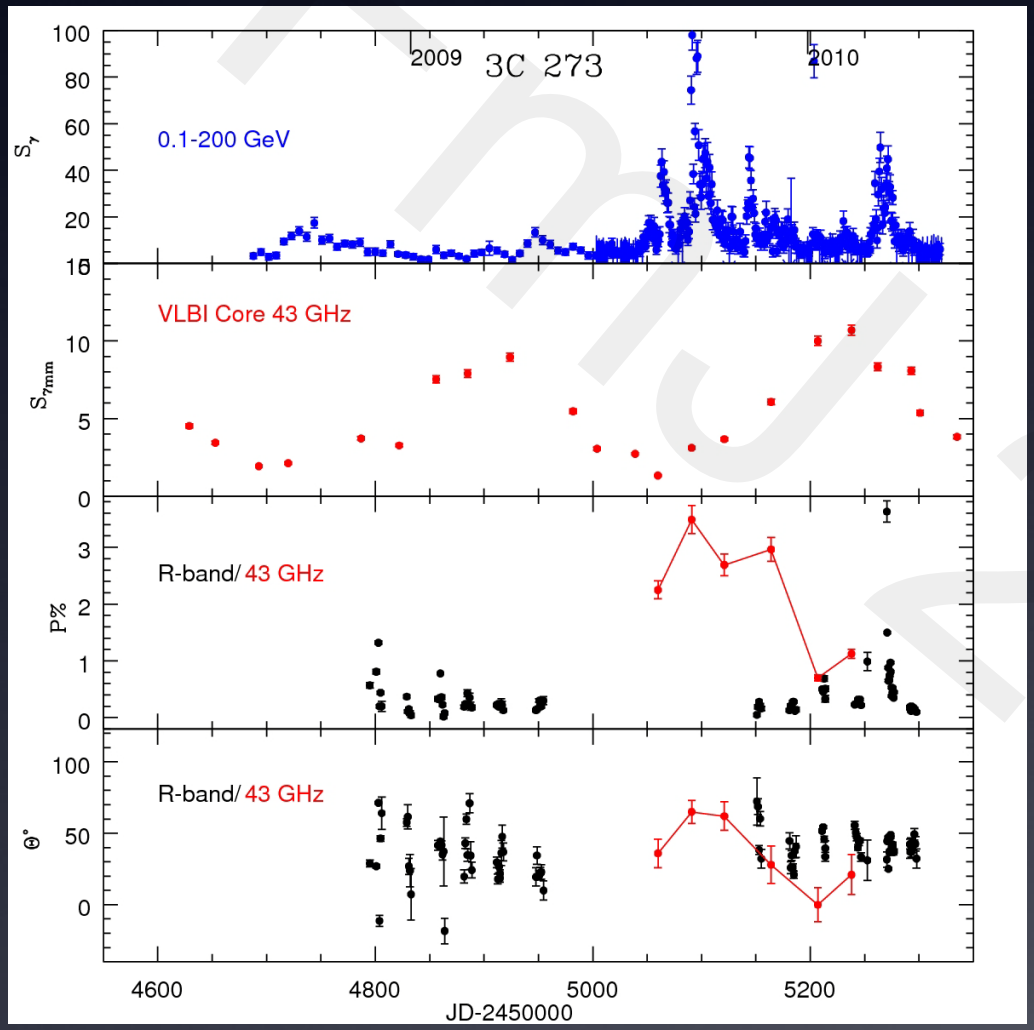
Correlation between High Energy Light Curves of the Quasar 3C 273





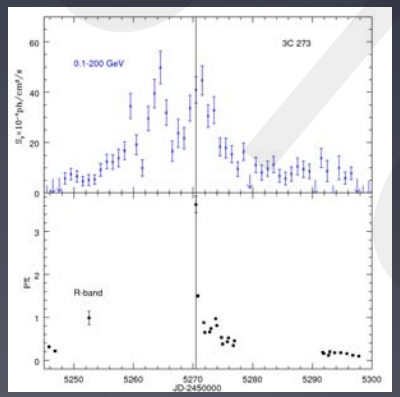


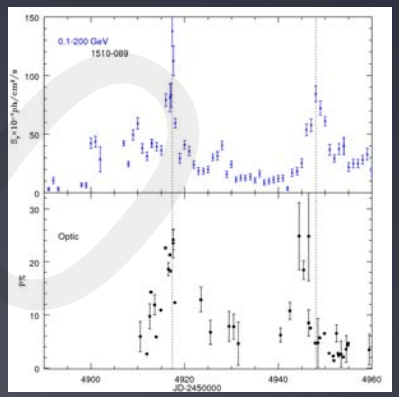
Polarization Behavior of the Quasar 3C 273



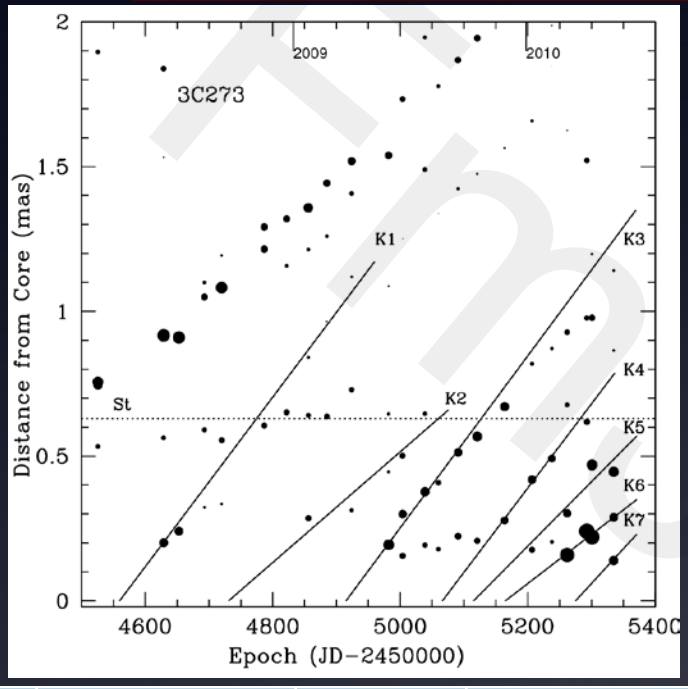
1. Significant increase of degree of polarization in the 43 GHz core during the most pronounced γ-ray activity.
2. Flare of degree of optical polarization along with the pronounced γ-ray outburst.
3. The maximum of degree of optical polarization precedes the γ-ray peak.

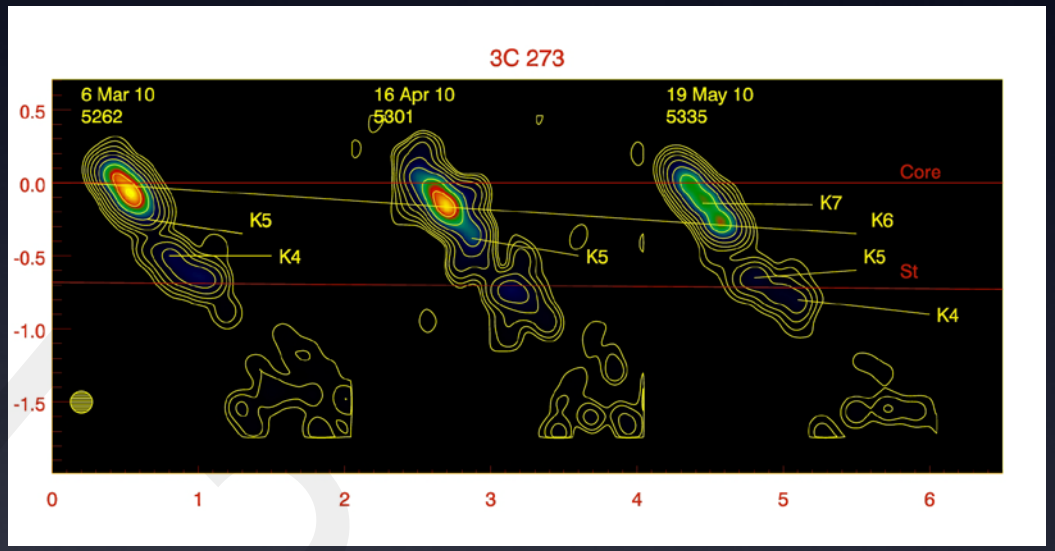
First: ordering of magnetic field
Second: γ-ray peak



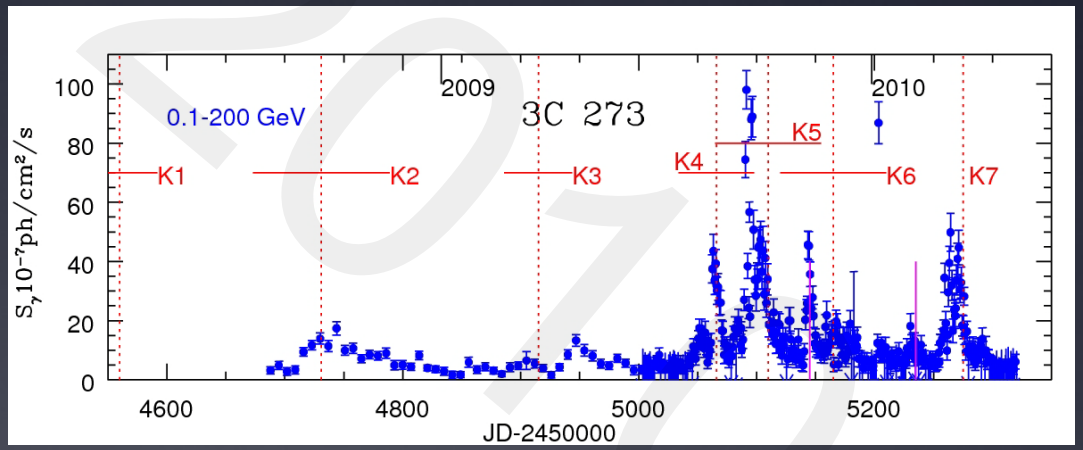


Kinematics of Parsec Scale Jet of 3C 273



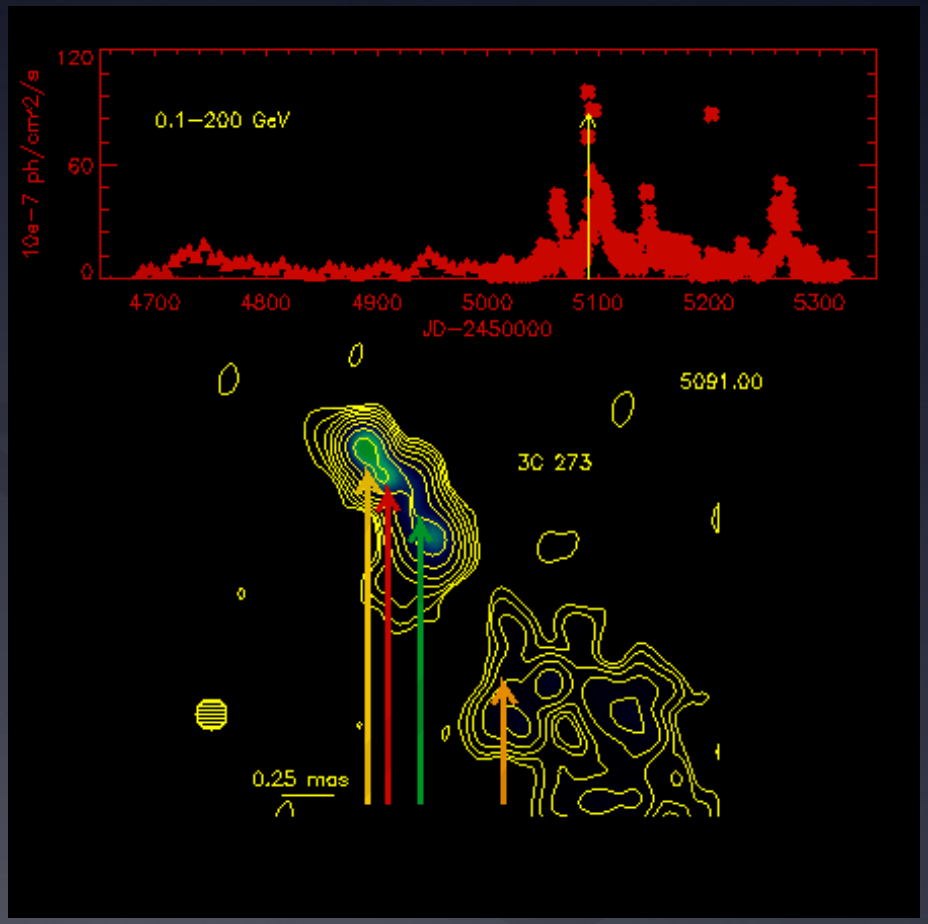


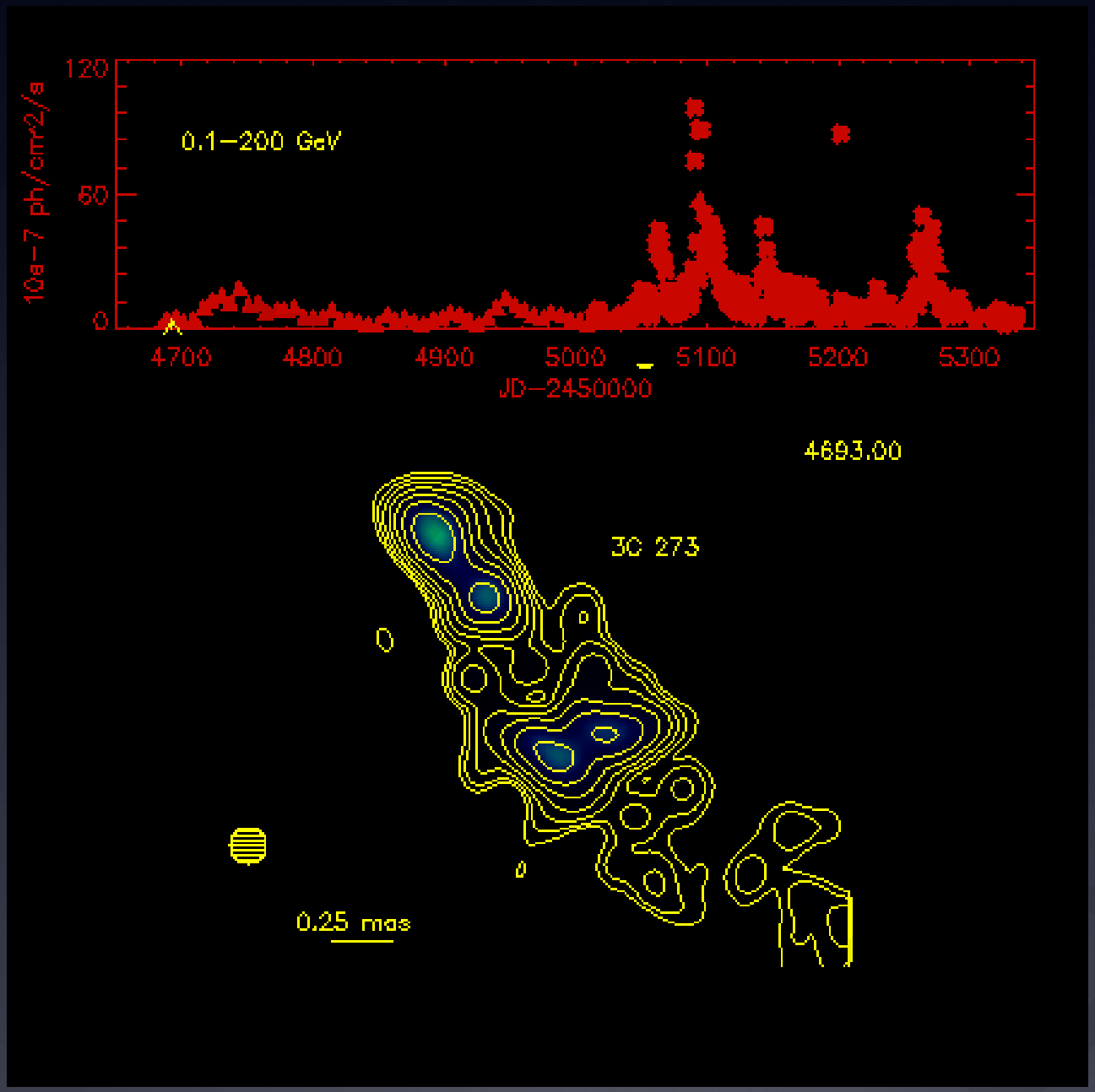
	β_{app} (c)	S_{max}	T_o (RJD)
K1	9.8±0.4	3.13	4560±32
K2	6.9±1.4	0.83	4731±58
K3	9.4±0.6	8.52	4915±29
K4	10.7±2.4	2.81	5066±32
K5	9.0±1.8	4.26	5110±45
K6	6.1±1.2	9.65	5165±36
K7	?	3.16?	5275?



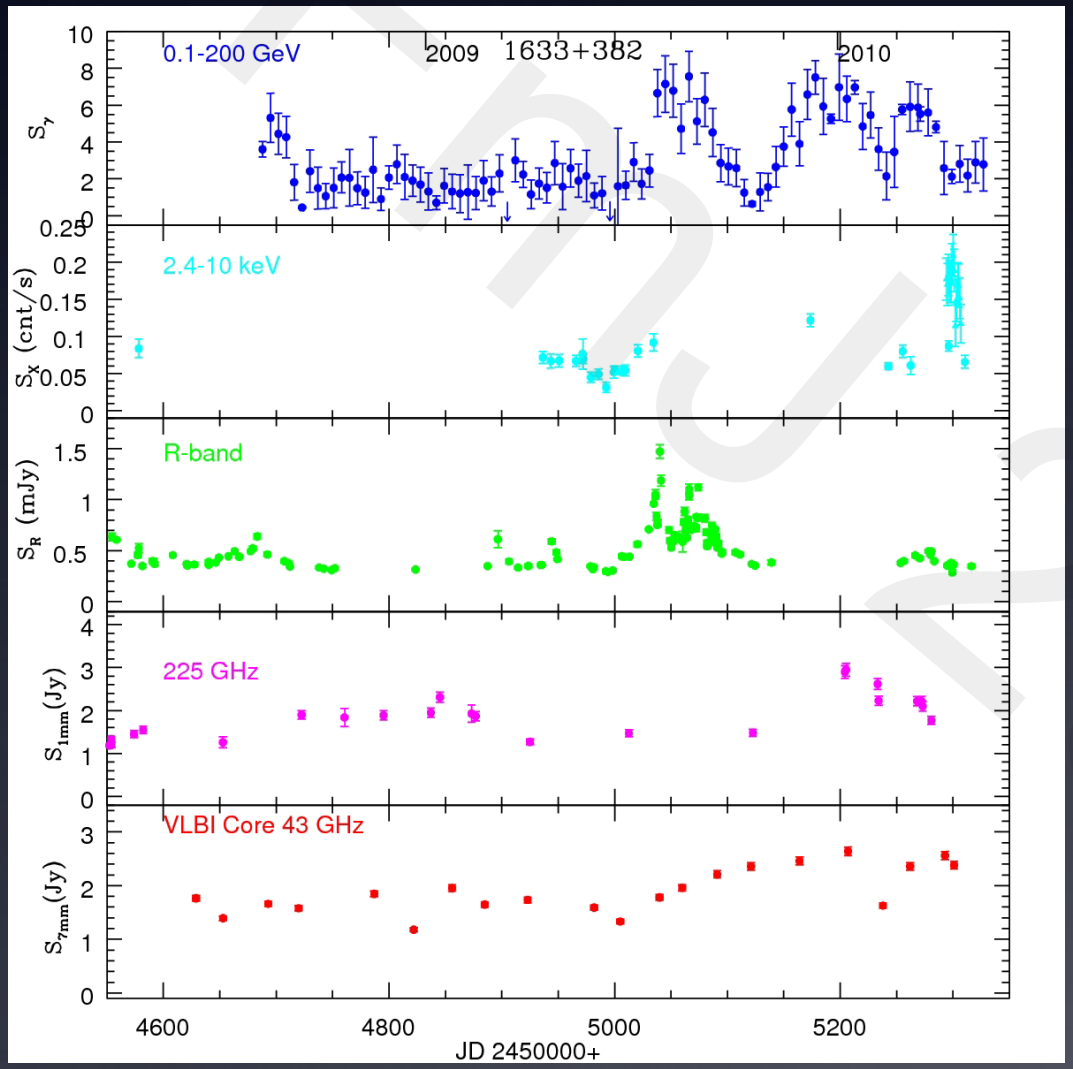
Gamma-Ray and Parsec Scale Jet Behavior of 3C 273

Actor I: Gamma-ray light curve -
7-day binning – August 2008 – June 2009
1-day binning –July 2009 – May 2010
Actor II: Total intensity images of parsec scale jet at 43 GHz - 89 images based on 23 VLBA images obtained from August 2008 to May 2010




0.1–200 GeV
10e–7 ph/cm^2/s
120
60
0
4700
4800
4900
5000
5100
5200
5300
JD–2450000
4693.00
3C 273
0.25 mas

The Quasar 1633+382 (Z=1.814)



1. Simultaneity of a relatively quiescent state at γ-rays and at optical, mm wavelengths and in the mm-wave VLBI core from 2008 September to 2009 June,

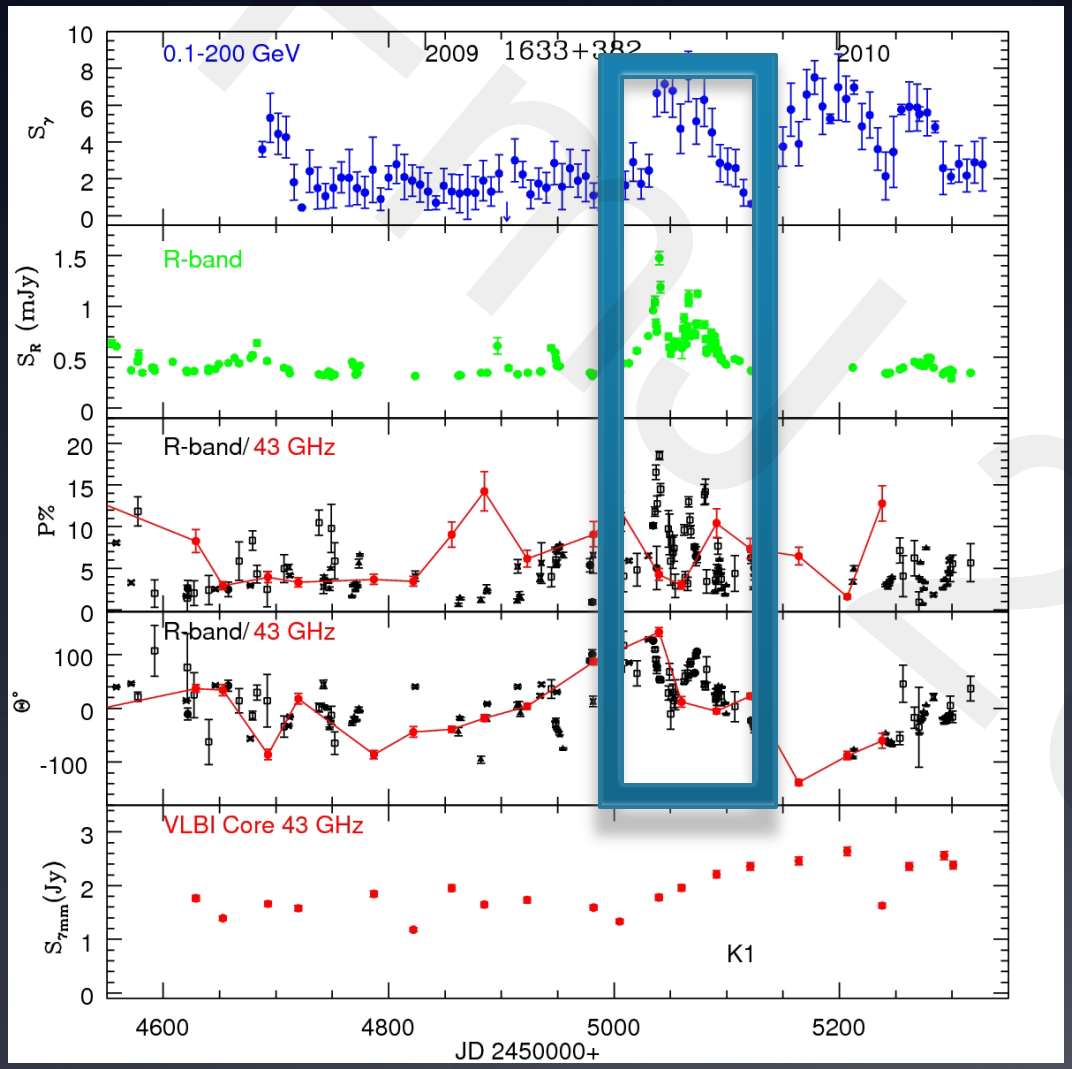
RJD: 4750-5000.

2. Increase of γ-ray variability coincides with the beginning of an optical flare and an increase of the flux in

in the VLBI core at RJD~5000.

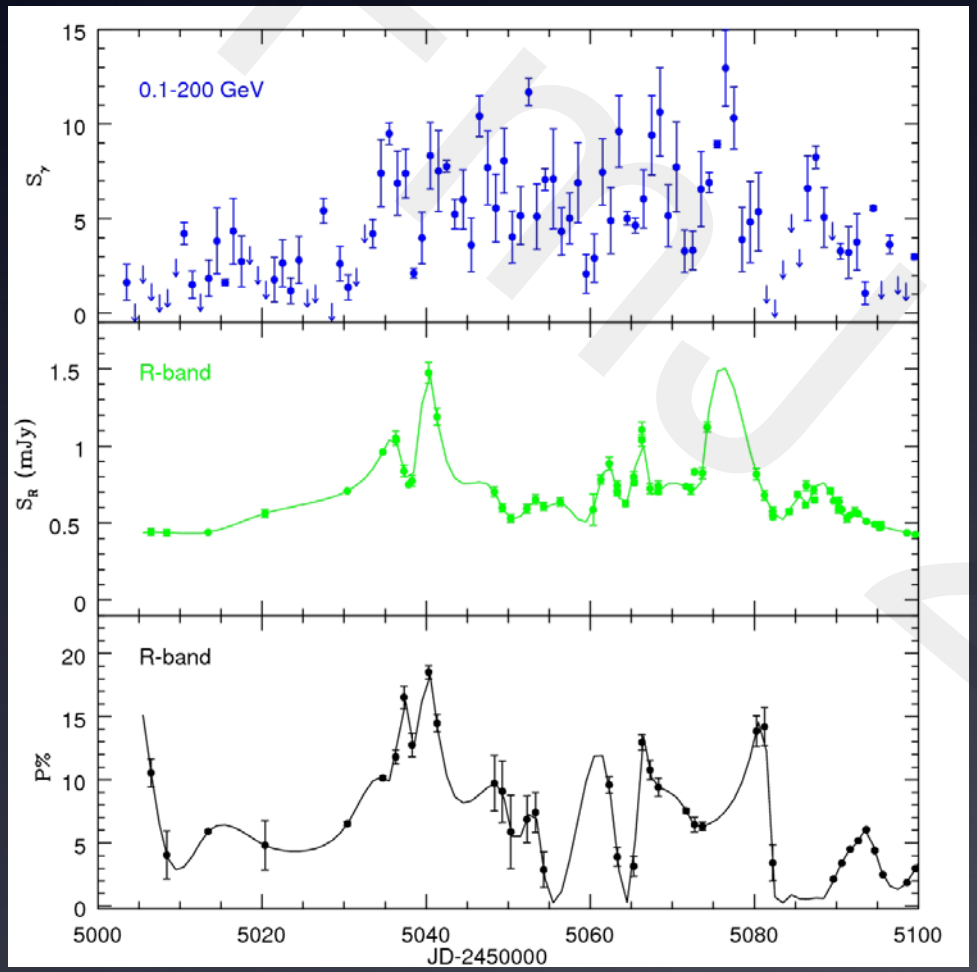
3. A possible rise of X-ray activity at the same time.

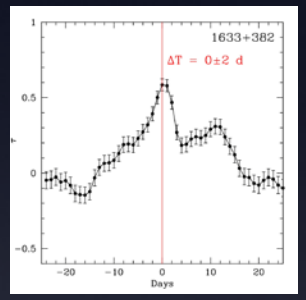
Polarization Behavior of the Quasar 1633+382

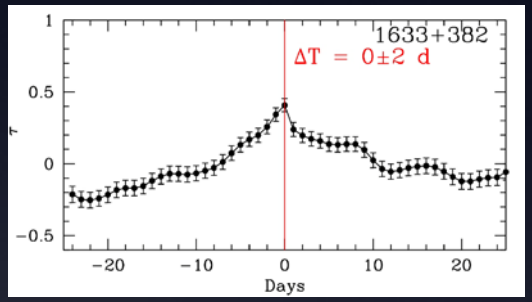


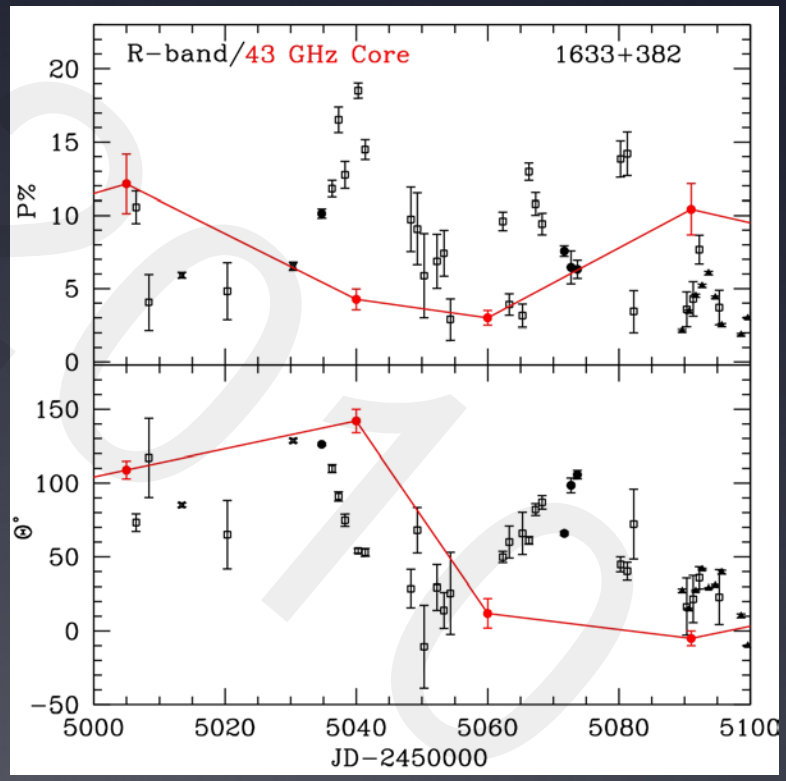
1. Optical polarization flare (p from ~3% to ~20%) simultaneous with the γ-ray/ optical flare and with the beginning of the VLBI core flux increase.
2. Some increase of degree of polarization in the VLBI core during the γ-ray/optical flare.
3. Rotation of optical polarization position angle during the γ-ray/optical flare.
4. Similar trend in EVPA of the VLBA core at 43 GHz behavior.

Gamma-Ray/Optical Flare in 1633+382

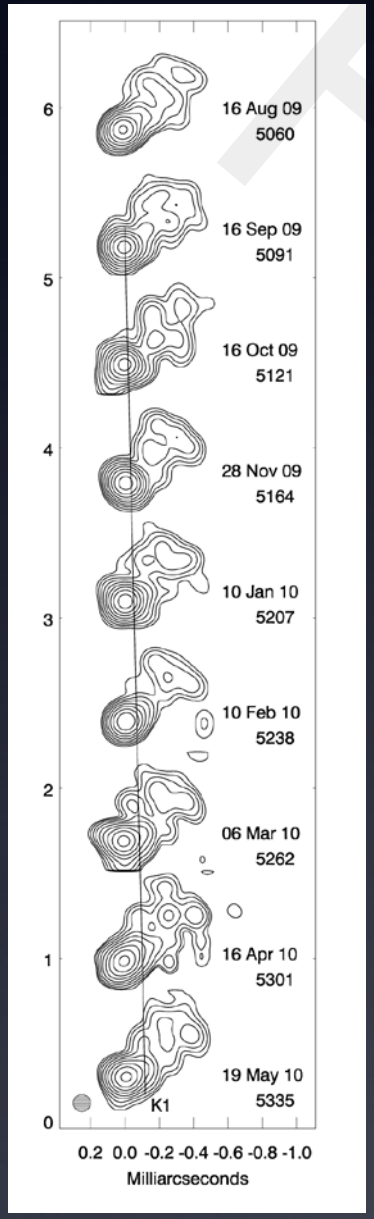


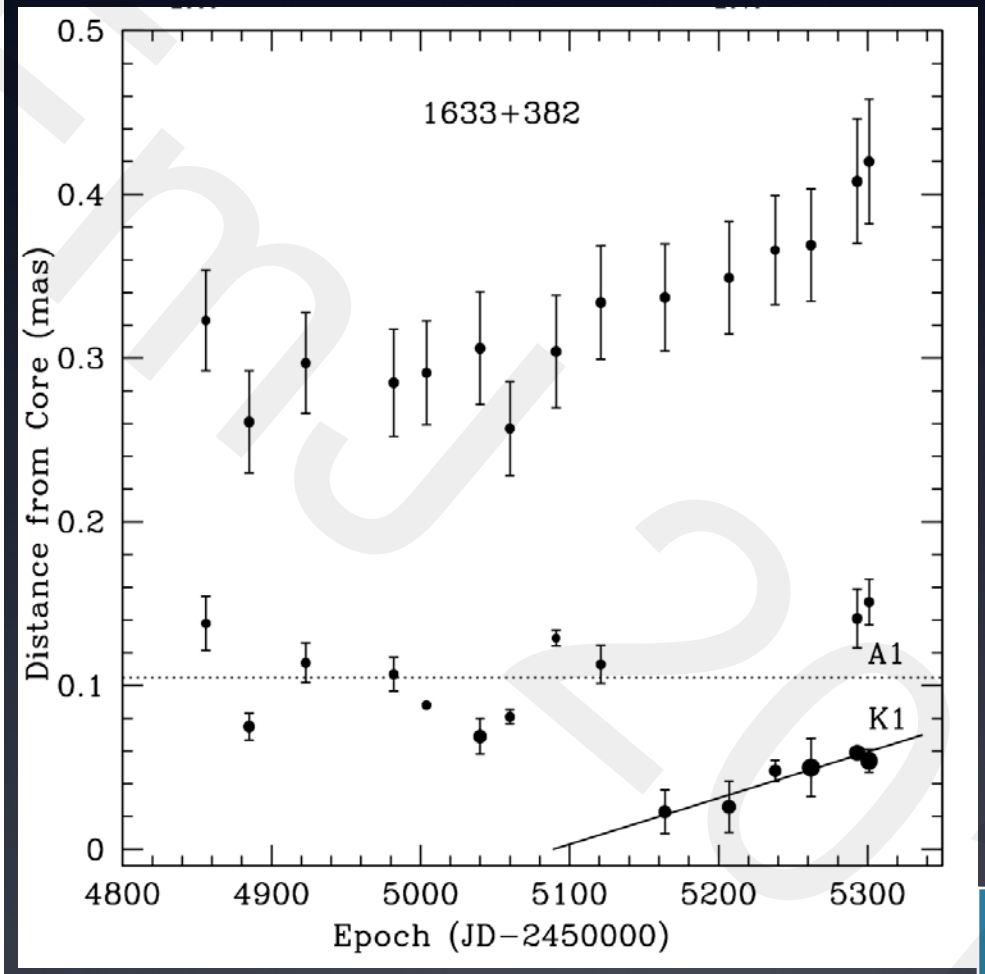






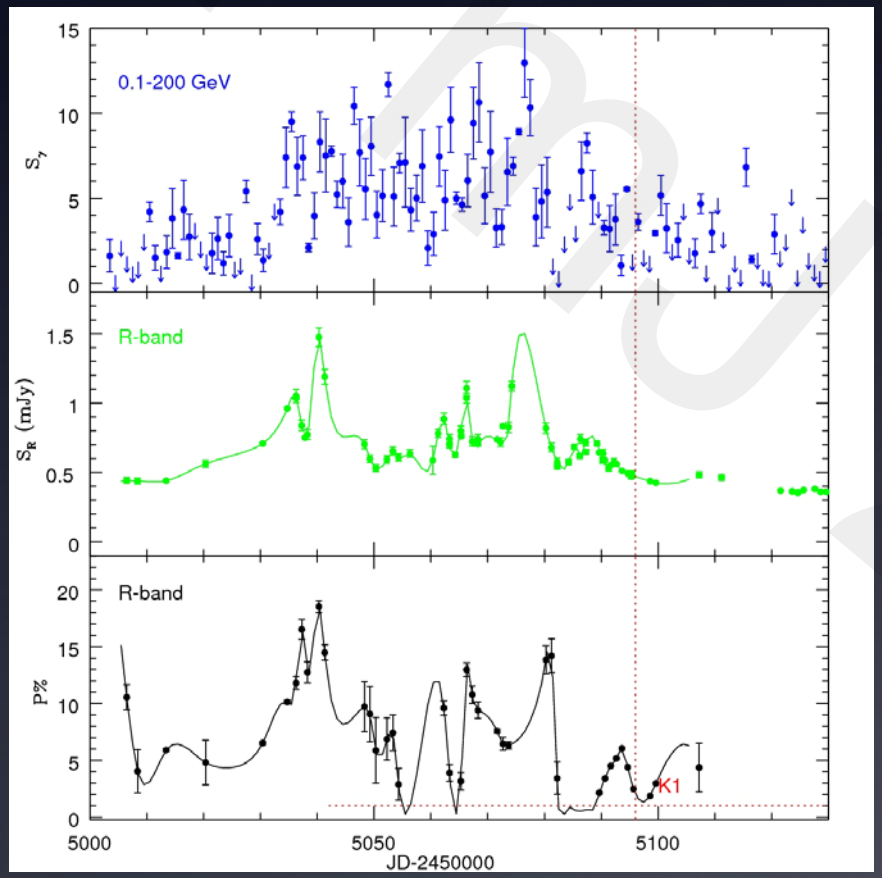
Kinematics of Parsec Scale Jet of 1633+382

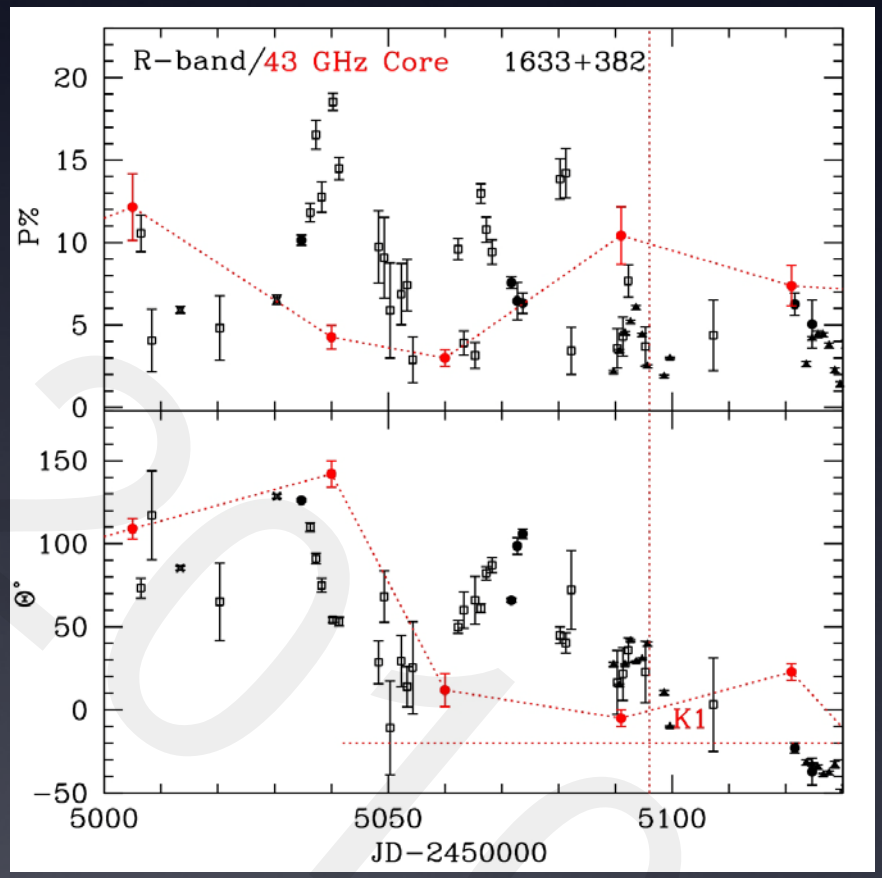




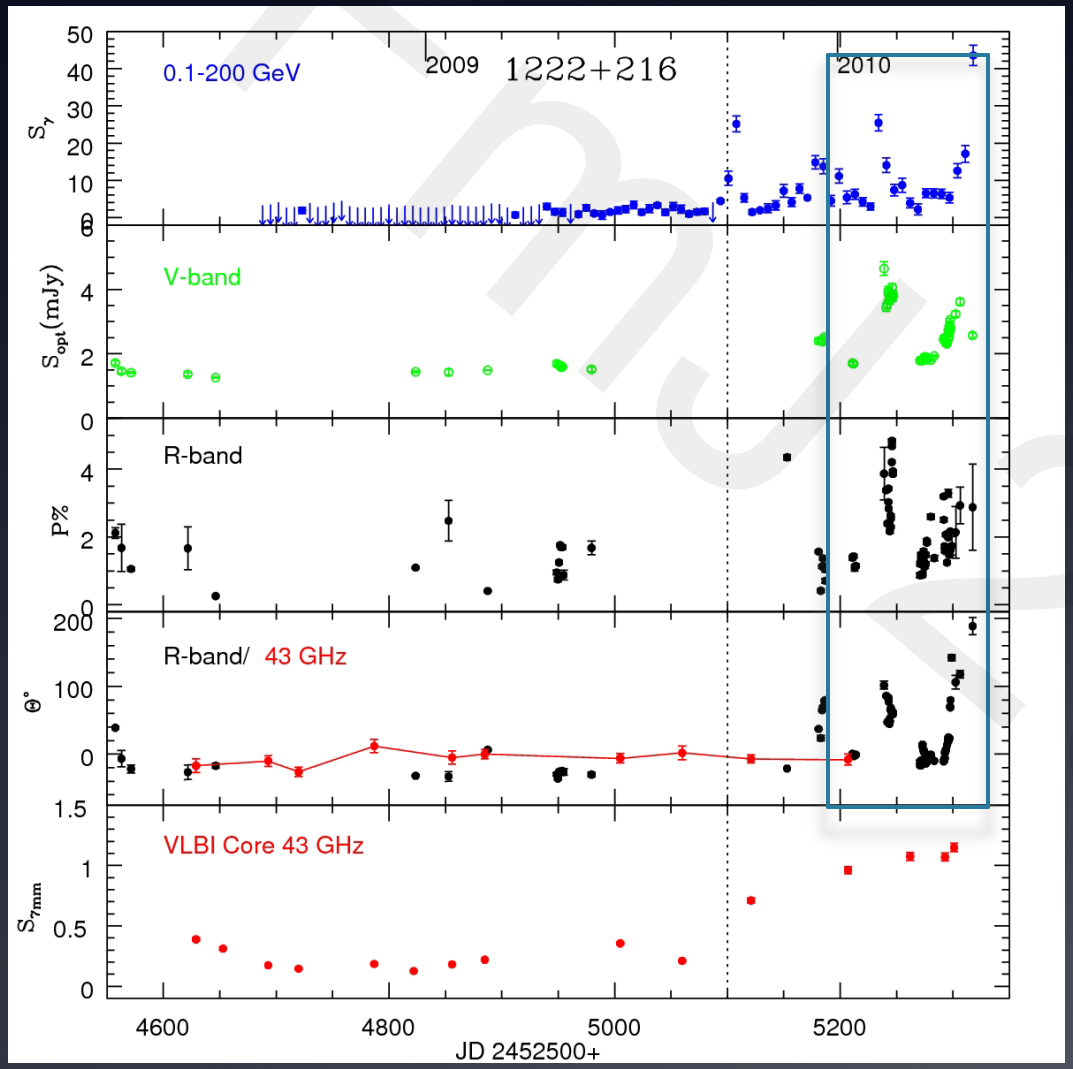
βapp	7.8±2.2 c
S_{max}	1.42 Jy
T_o (RJD)	5096±54

Timing of the Disturbance with respect to Gamma-Ray/Optical Flare



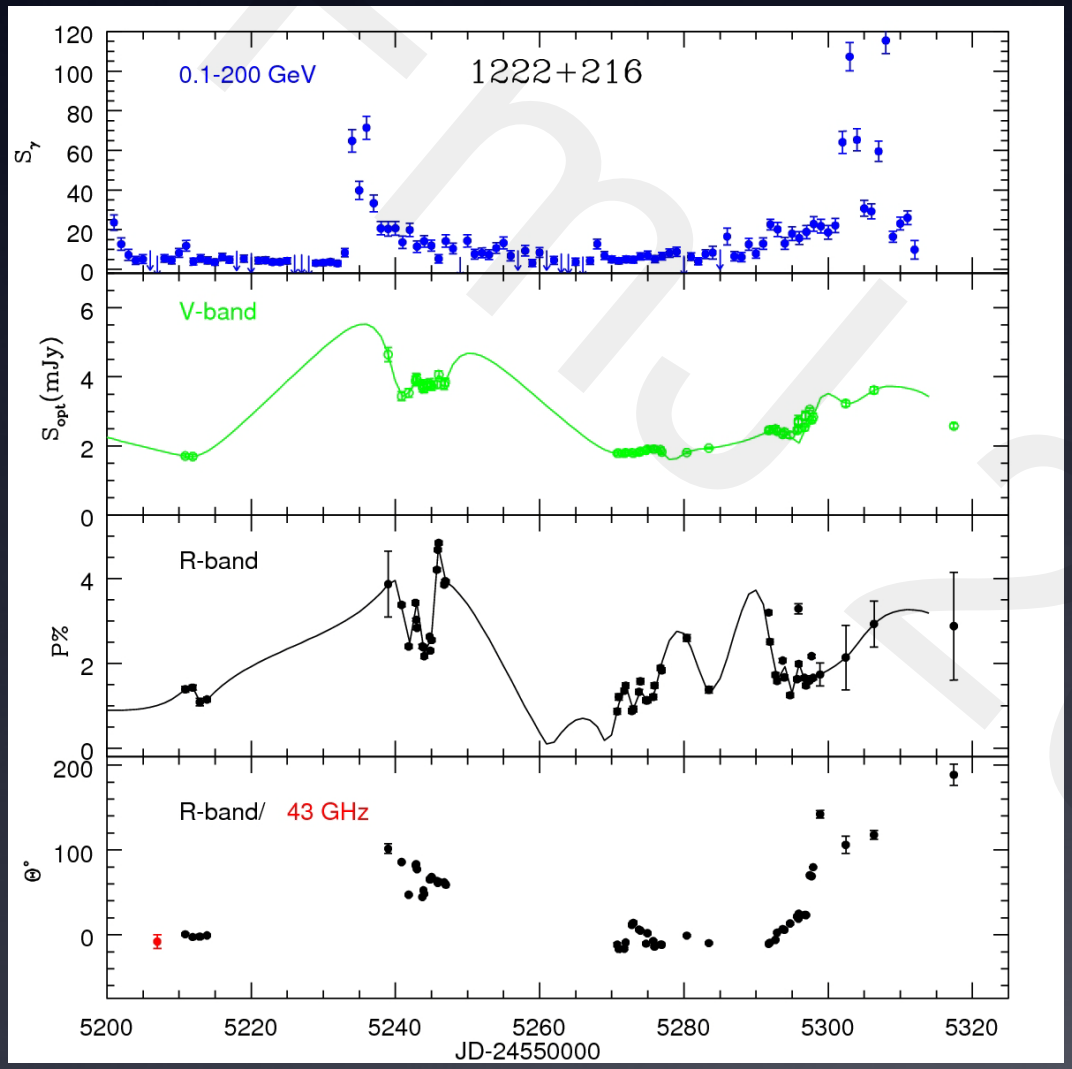


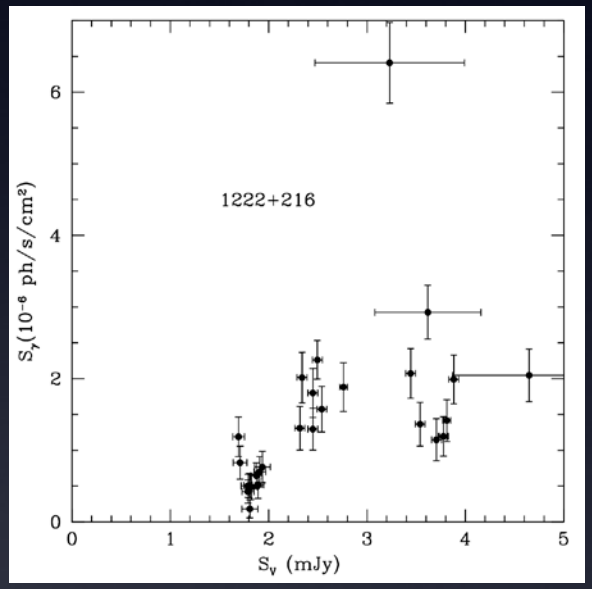
The Quasar 1222+216 (Z=0.435)

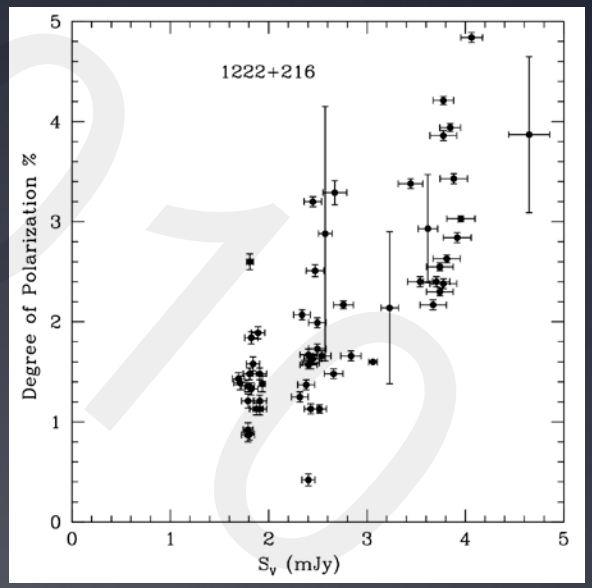


1. Quiescent period at all wavelengths from 2008 August to 2009 September:
 γ-ray flux, $S_\gamma < 10^{-9}$ ph cm^{-2} s^{-1}
 V-band flux, $S_v \sim 1.3$ mJy,
 $P_R < 2\%$; low flux in VLBA core, $S_{43GHz} \sim 0.25$ Jy,
 stable optical and 43 GHz EVPAs.
2. Active period started at all wavelengths in the end of 2009 September:
 $S_\gamma^{max} \sim 10^{-5}$ ph cm^{-2} s^{-1}
 $S_v^{max} \sim 4.7$ mJy
 $S_{43GHz}^{max} \sim 1.1$ Jy
 $P_R^{max} \sim 4.8\%$
 Strong variability of optical EVPA.

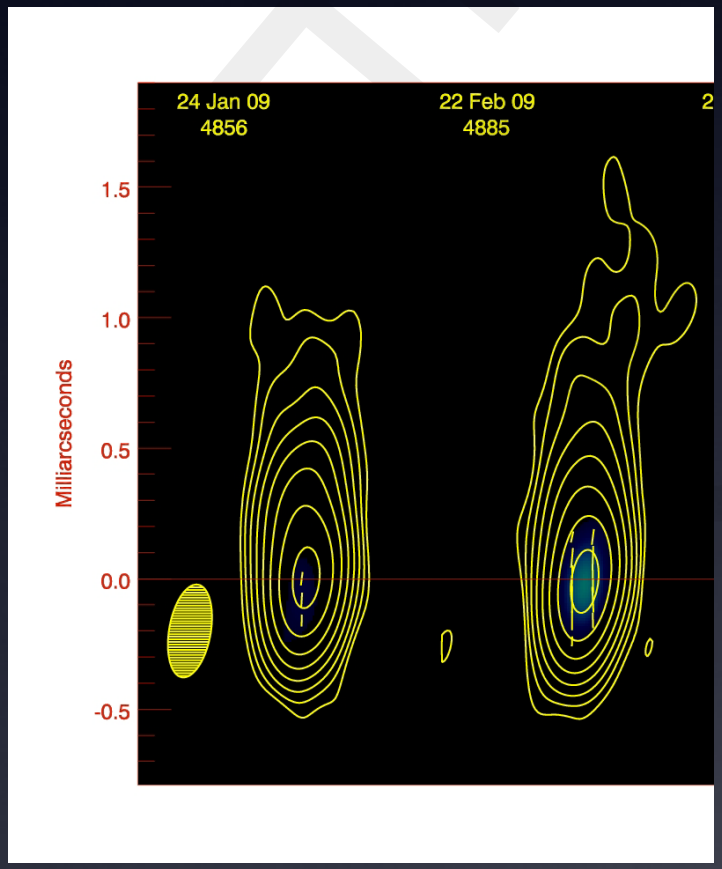
Polarization behavior of the Quasar 1222+216

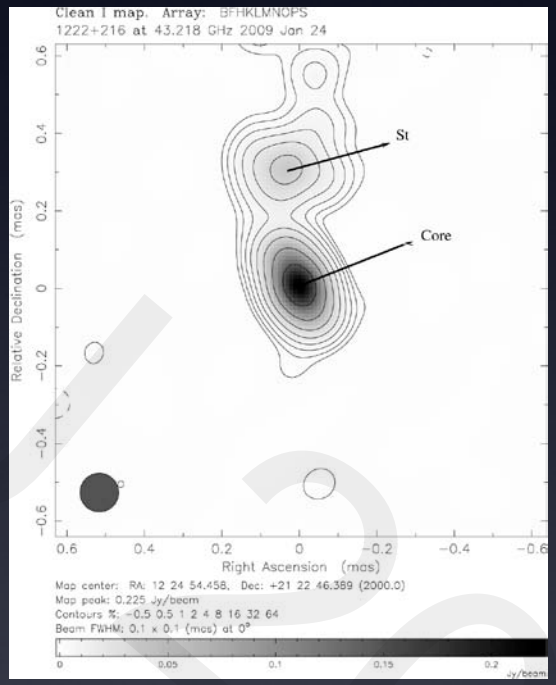


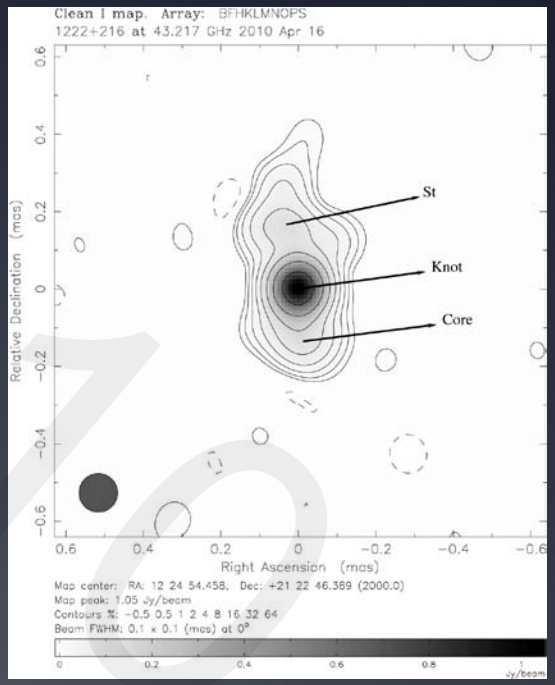




Parsec Scale Jet of 1222+216

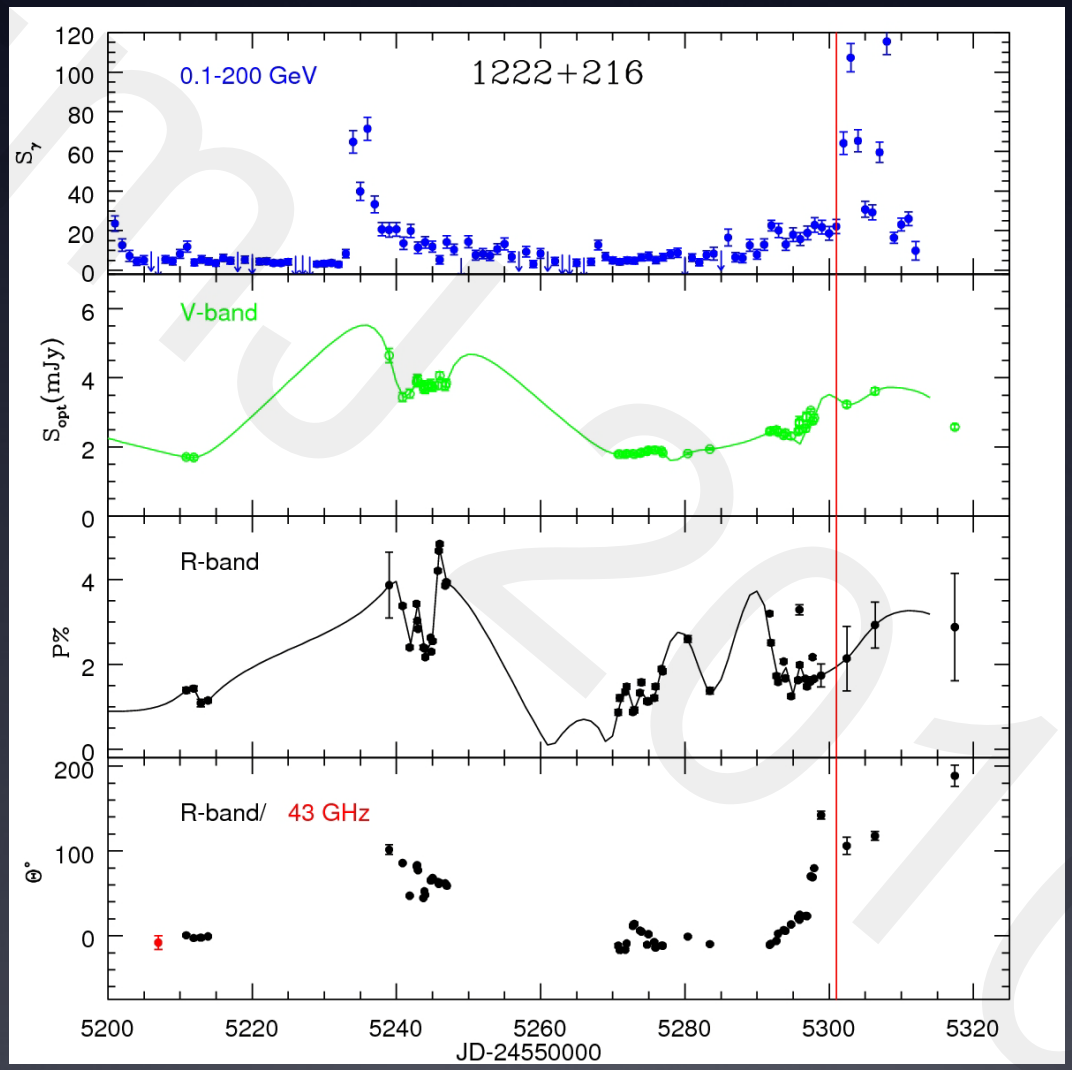






Beam: 0.36 × 0.16 mas, PA=-10°
S_{max} = 0.32 Jy/beam;
S_{max}^{P} = 17 mJy/beam

Timing of the Disturbance with respect to Gamma-Ray/Optical Flare



Conclusion

1. Gamma-rays of blazars originate in their relativistic jets.
2. A high γ-ray state is connected with disturbance(s) propagating down the jet.
3. An interaction between a disturbance and the mm-wave VLBA core causes a γ-ray flare.
4. A γ-ray flare associated with a disturbance is simultaneous within a day with an optical synchrotron flare.
5. A pronounced rotation of optical polarization position angle is often observed during the rising branch of such γ-ray/optical flares.
6. Position angle of optical polarization aligns with jet direction in second half of γ-ray/optical flares, consistent with transverse shocks.
7. Maximum degree of optical polarization during a flare tends to lead the γ-ray peak.