Intraday variations of polarization vector in blazars: a key to the optical jet structure?

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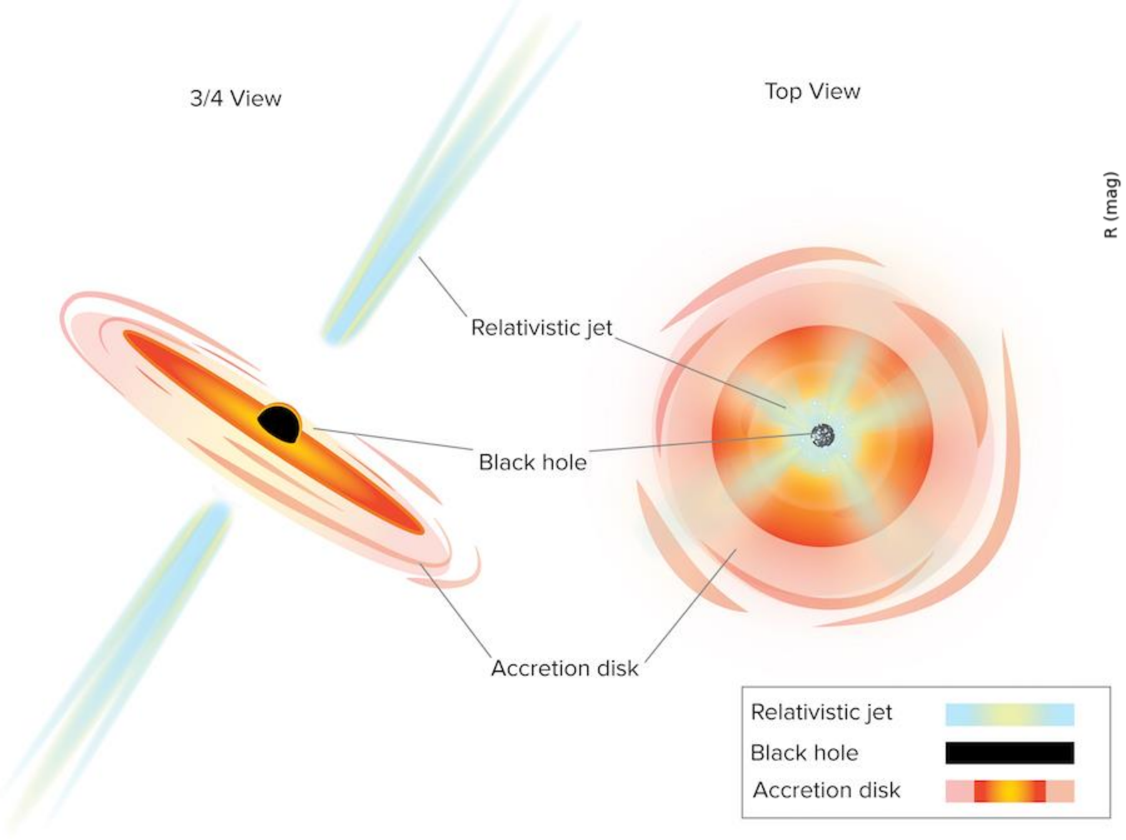
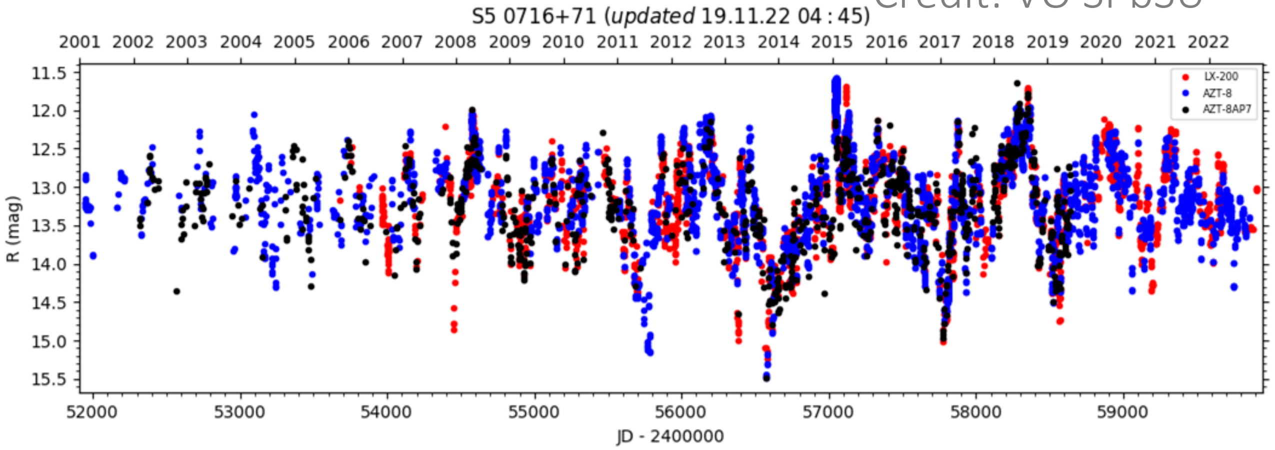
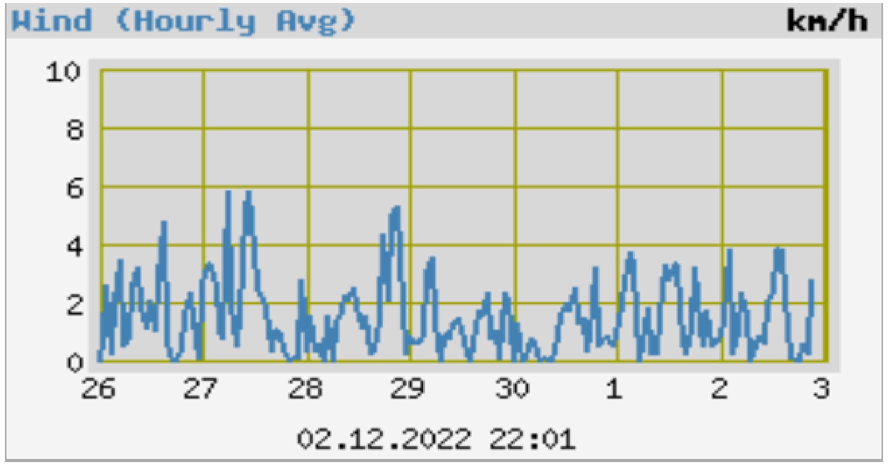
14th SCSLSA, 22/06/2023

Credit: Sophia Dagnello, NRAO/AUI/NSF



Credit: VO SPbSU





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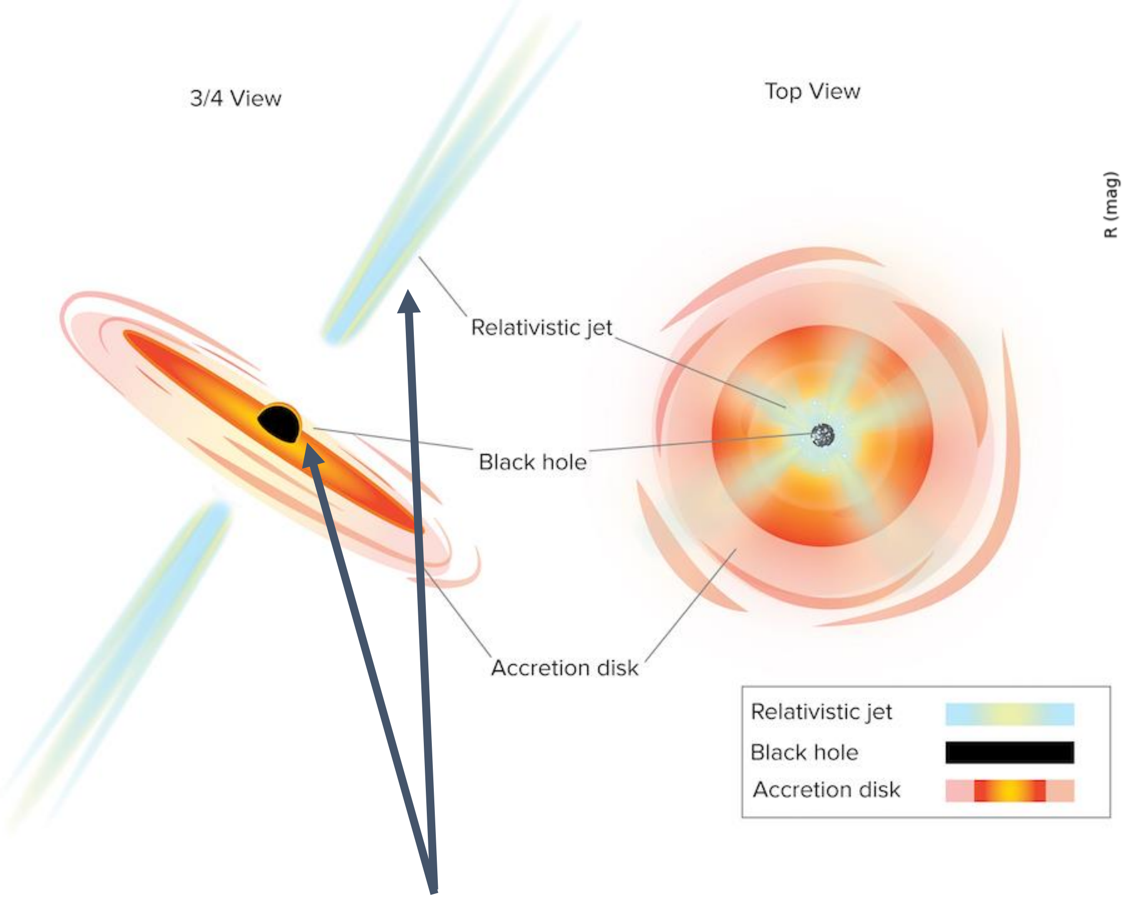

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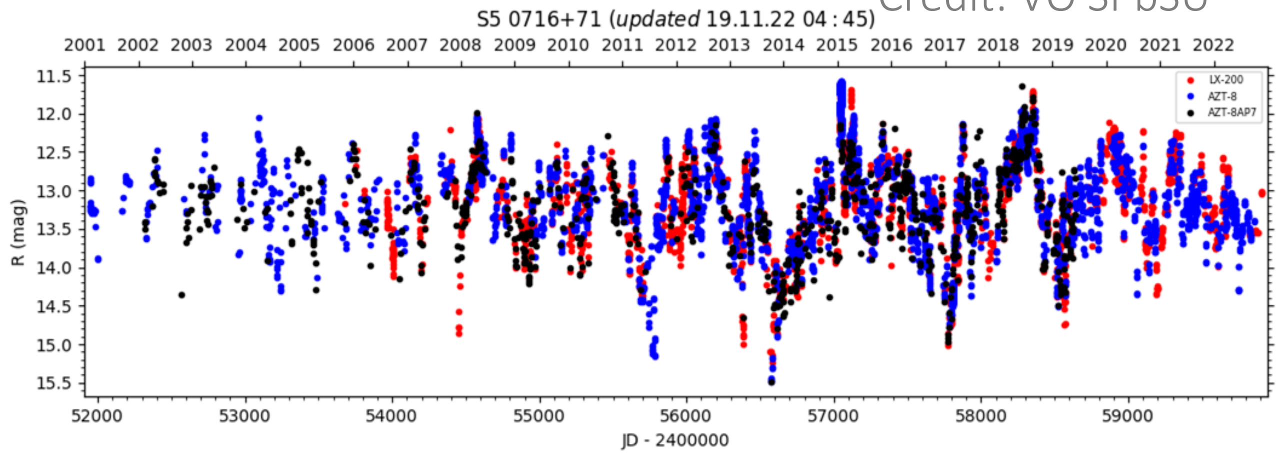
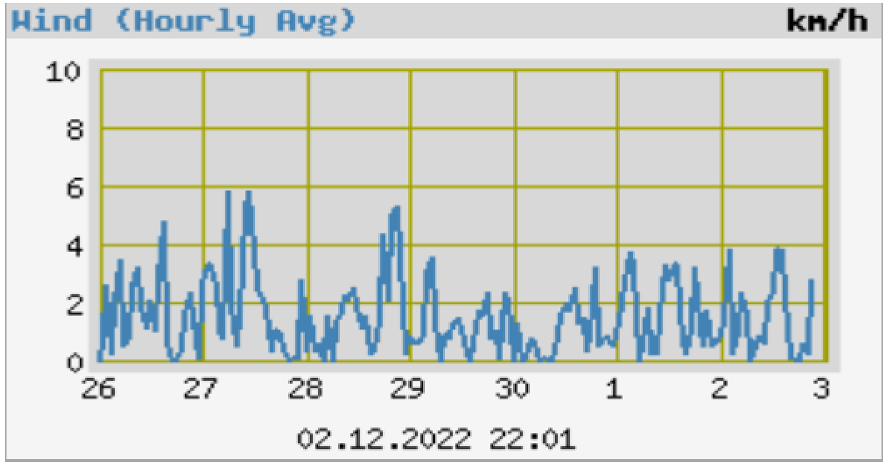
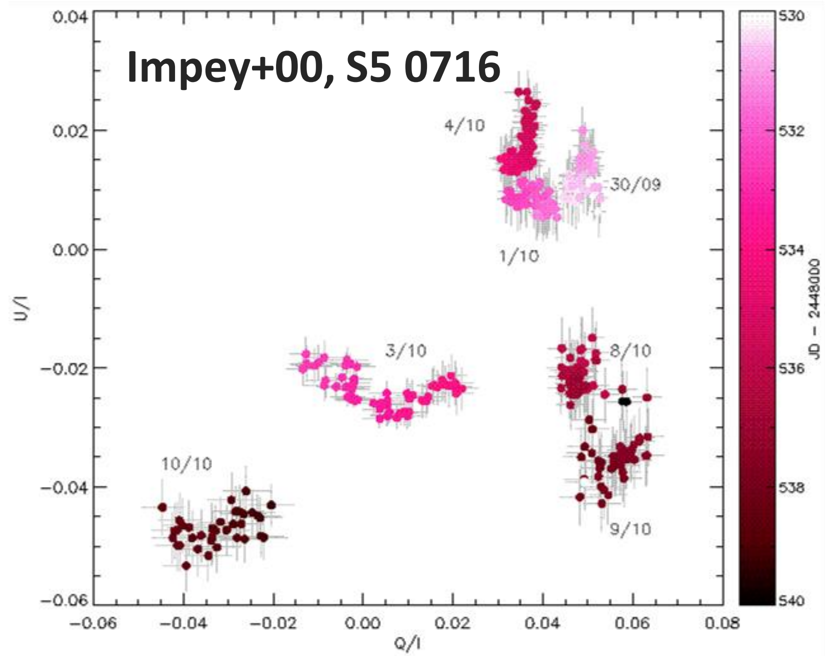


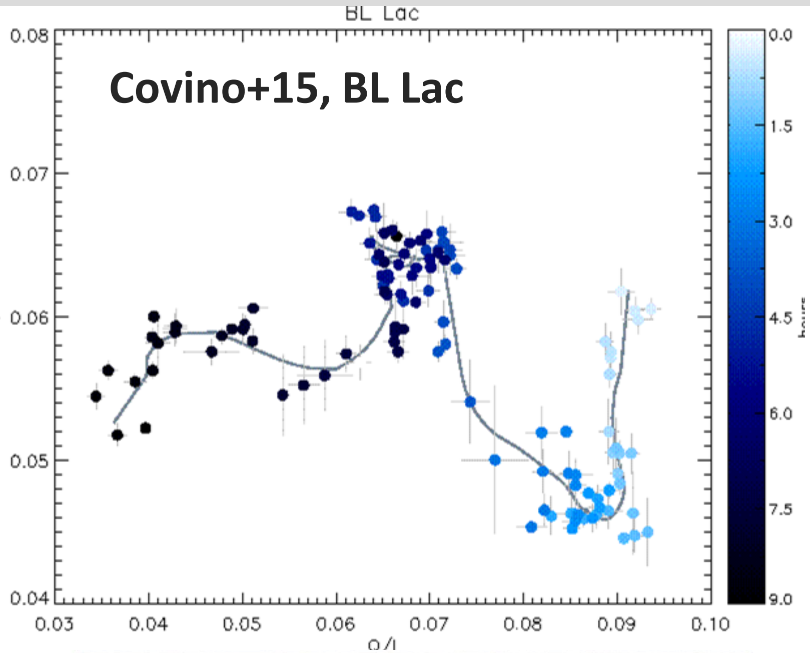


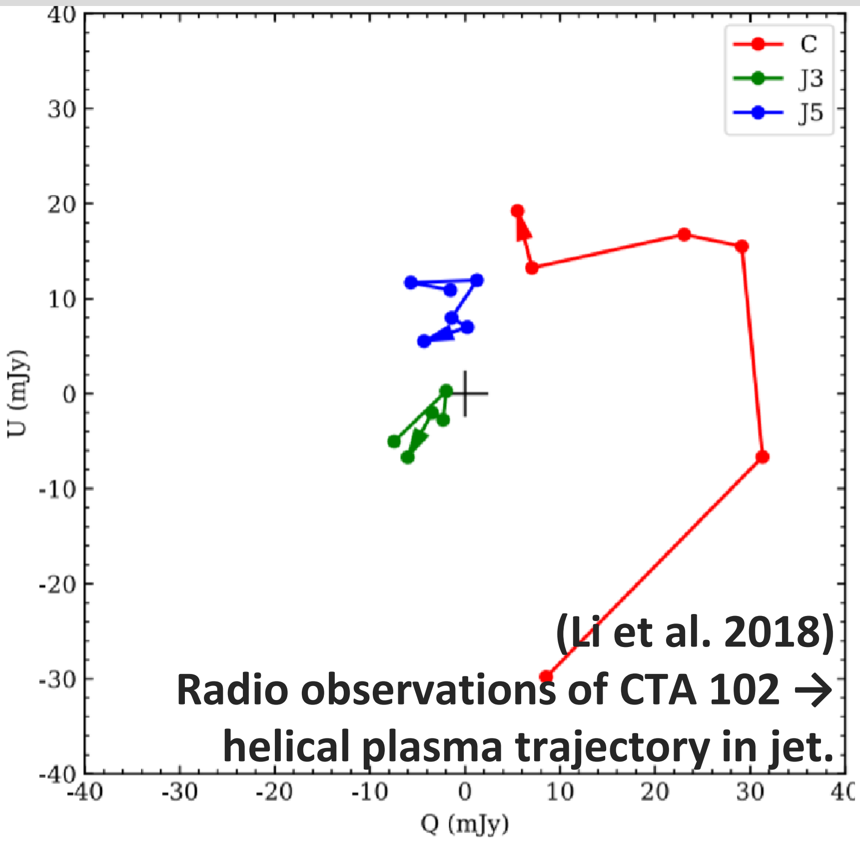
Polarimetry:

1. **Jet structure**
2. **Magnetic field**

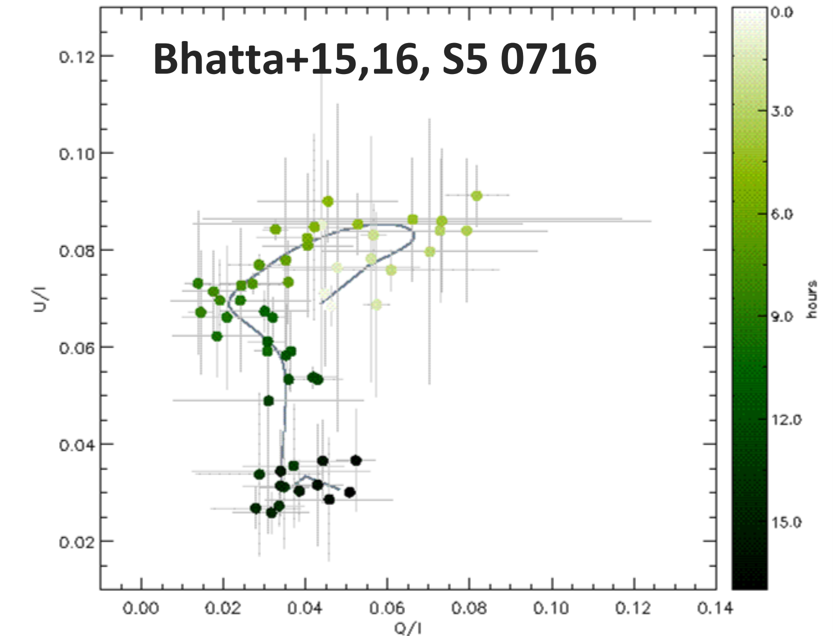
Polarization rotations in blazars

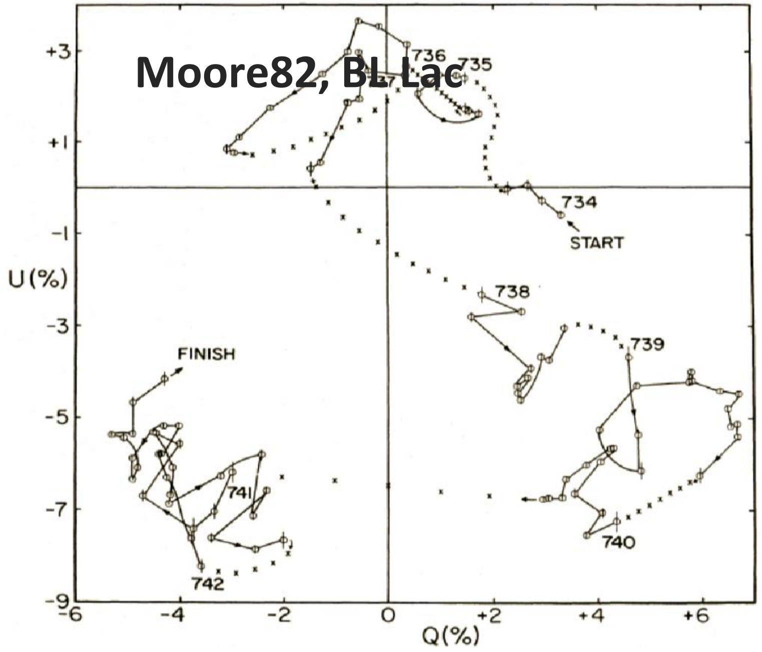






(Li et al. 2018)
Radio observations of CTA 102 → helical plasma trajectory in jet.

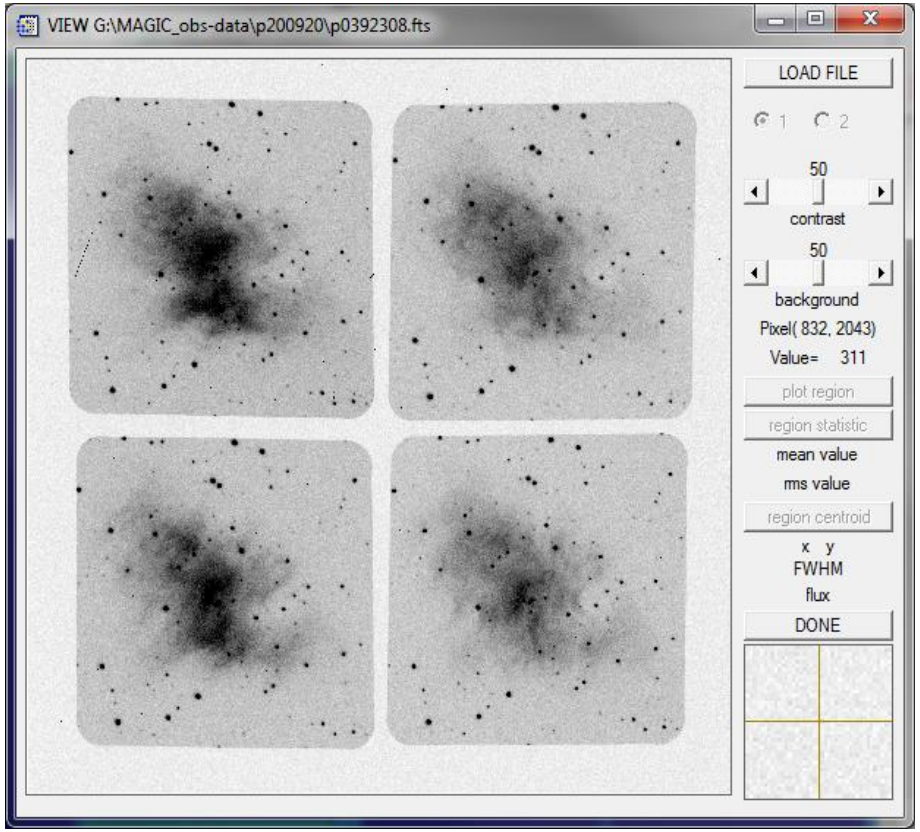




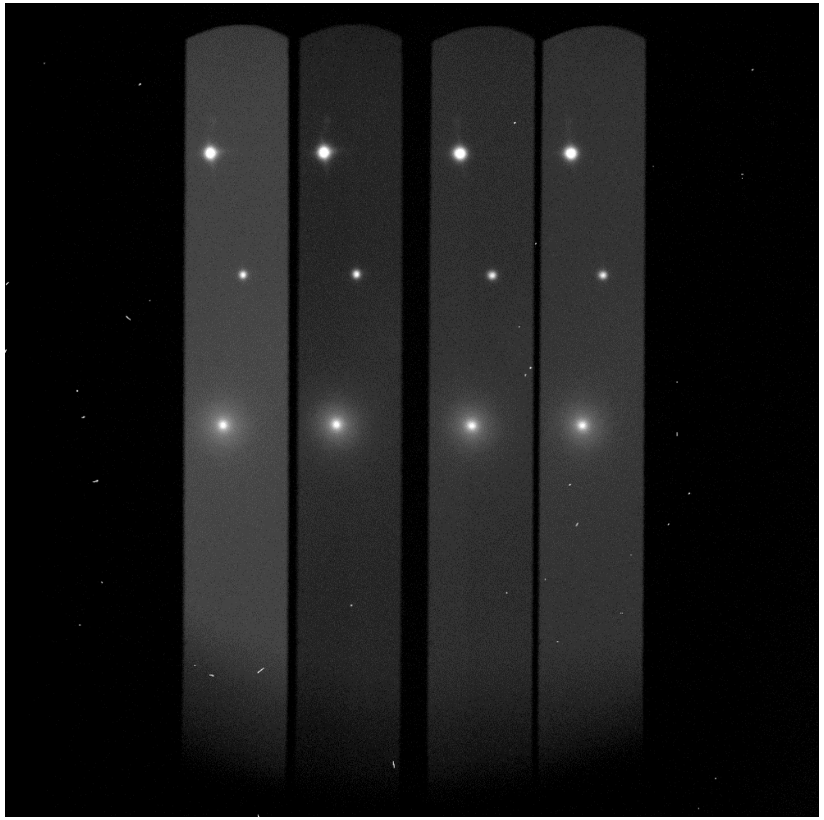
<u>What to study?</u>

1. helical(?) structure of optical jet
2. rotations in different states → trust the observations

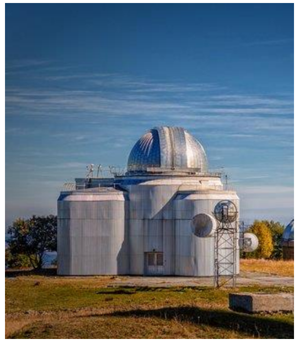
Observations



Quadrupole double Wollaston prism



Wedged double Wollaston prism



10.1134/S1990341321010028

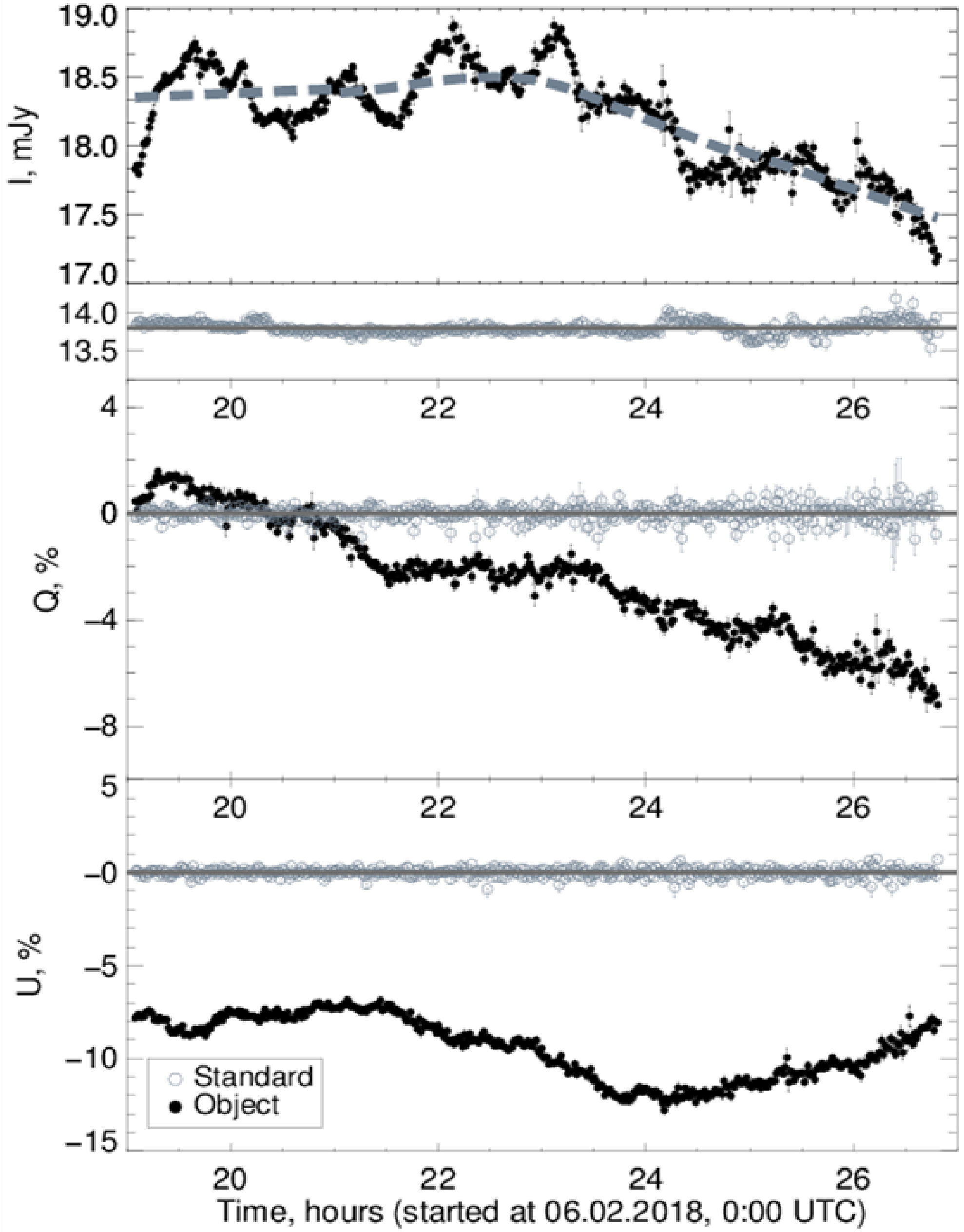
10.1002/asna.20210104

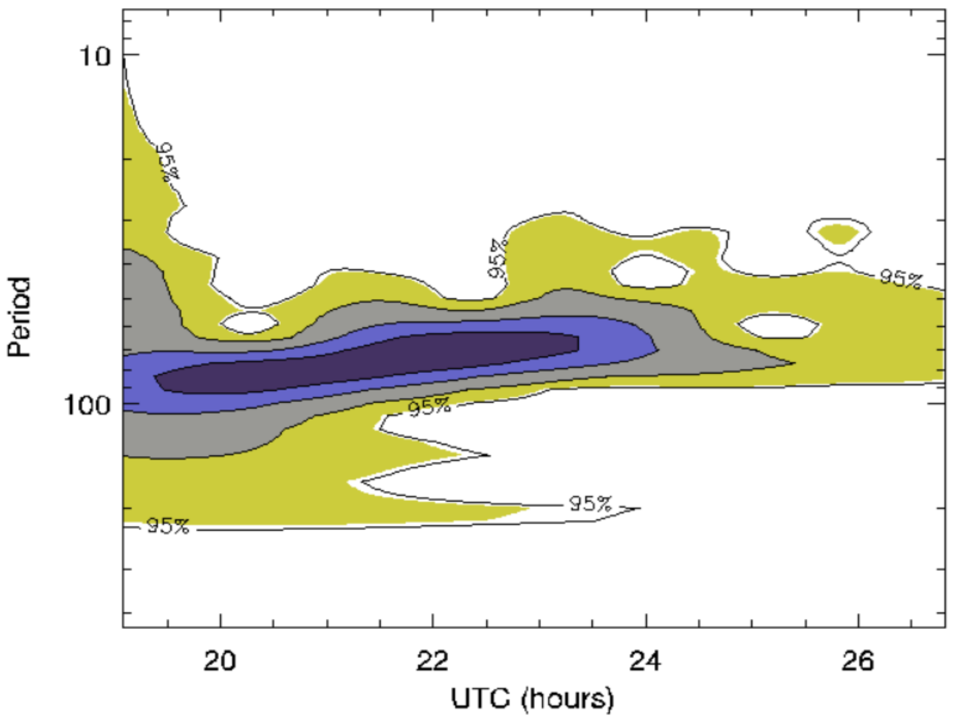
10.1134/S1990341312040074

Double Wollaston prism (=one-shot polarimetry) + differential measurements = up to 0.1% accuracy of polarimetry:

$$Q = \frac{I_0 - I_{90} D_Q}{I_0 + I_{90} D_Q} \qquad U = \frac{I_{45} - I_{135} D_U}{I_{45} + I_{135} D_U}$$

S5 0716+714



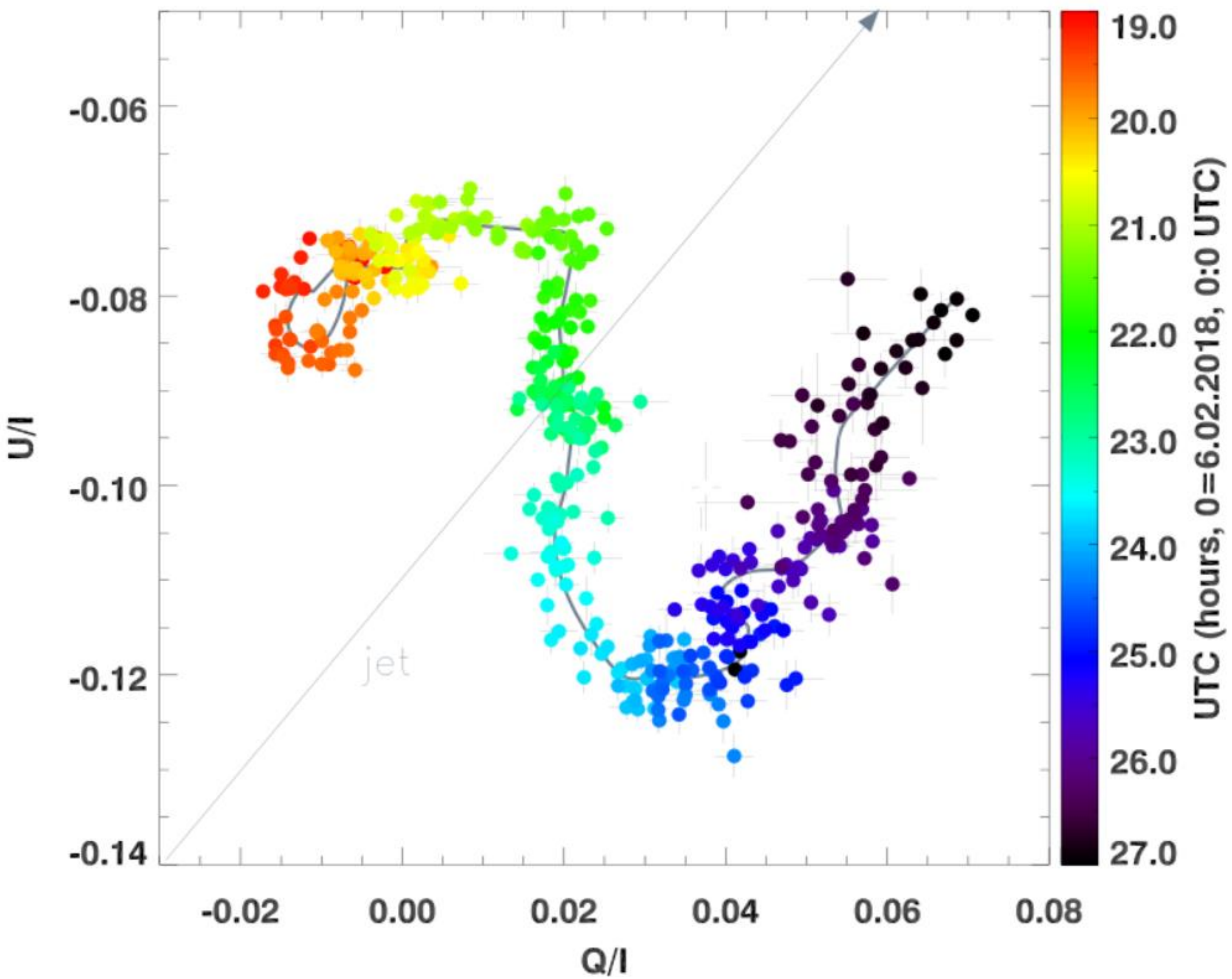


9-hour monitoring, 6m BTA/SCORPIO-2 (Afanasiev&Moiseev 2011)

1. Brightness variations with ~77 minutes
2. Polarization variations

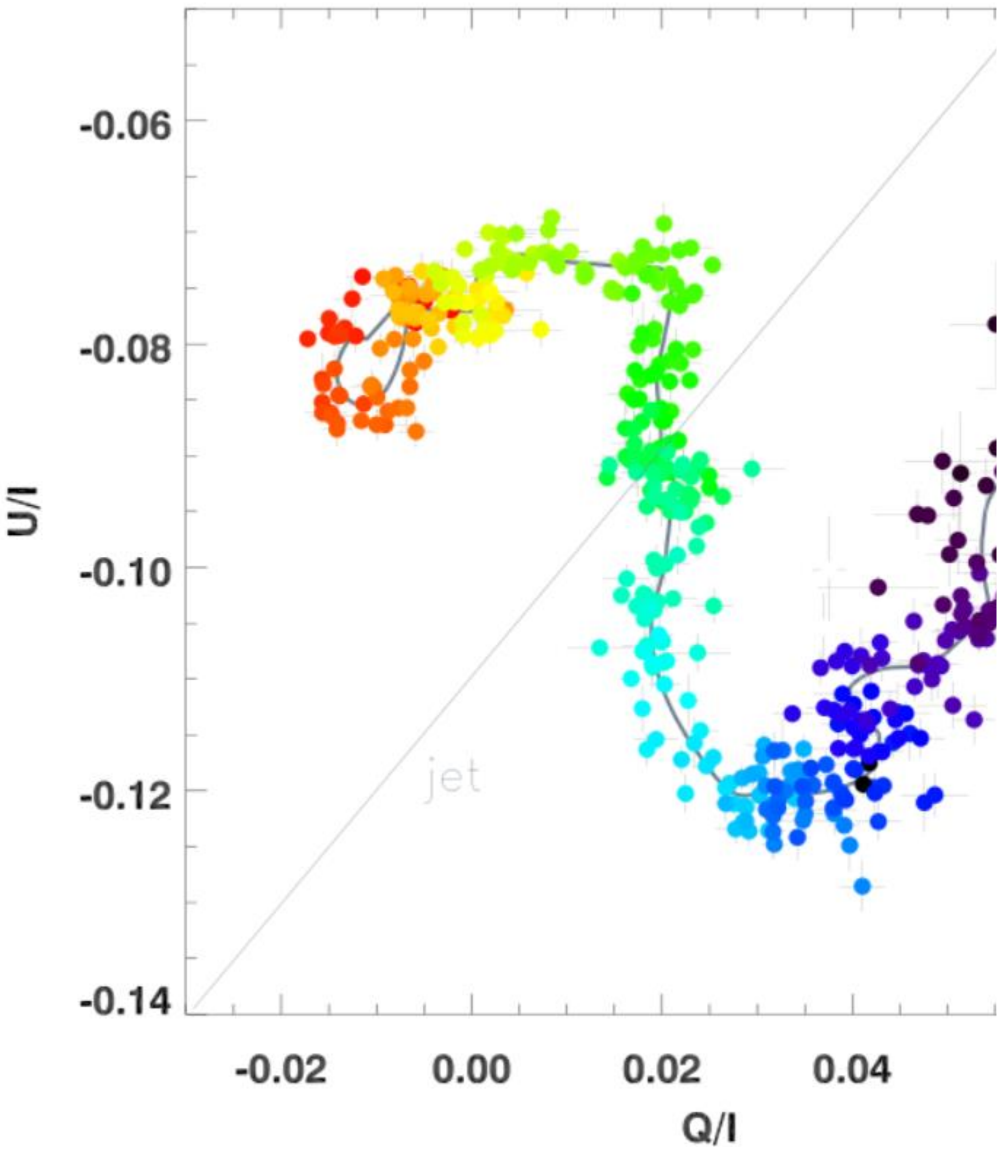
Webb+16,17,21 – no periods

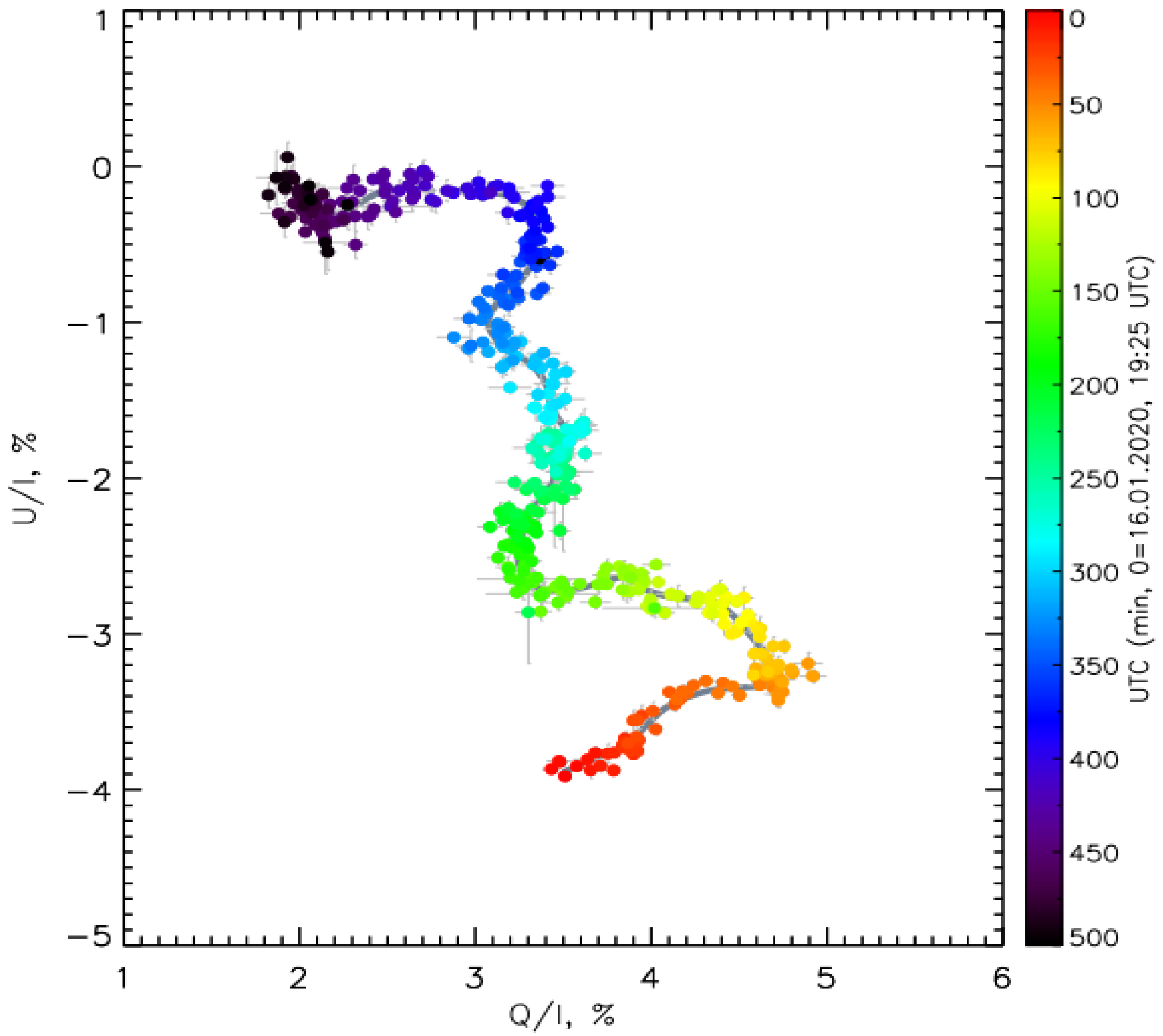
S5 0716+714



Polarization vector switch direction every ~1.5 hour → 1.5×10^{-5} pc = 10 a.u.

S5 0716+714 – two years after





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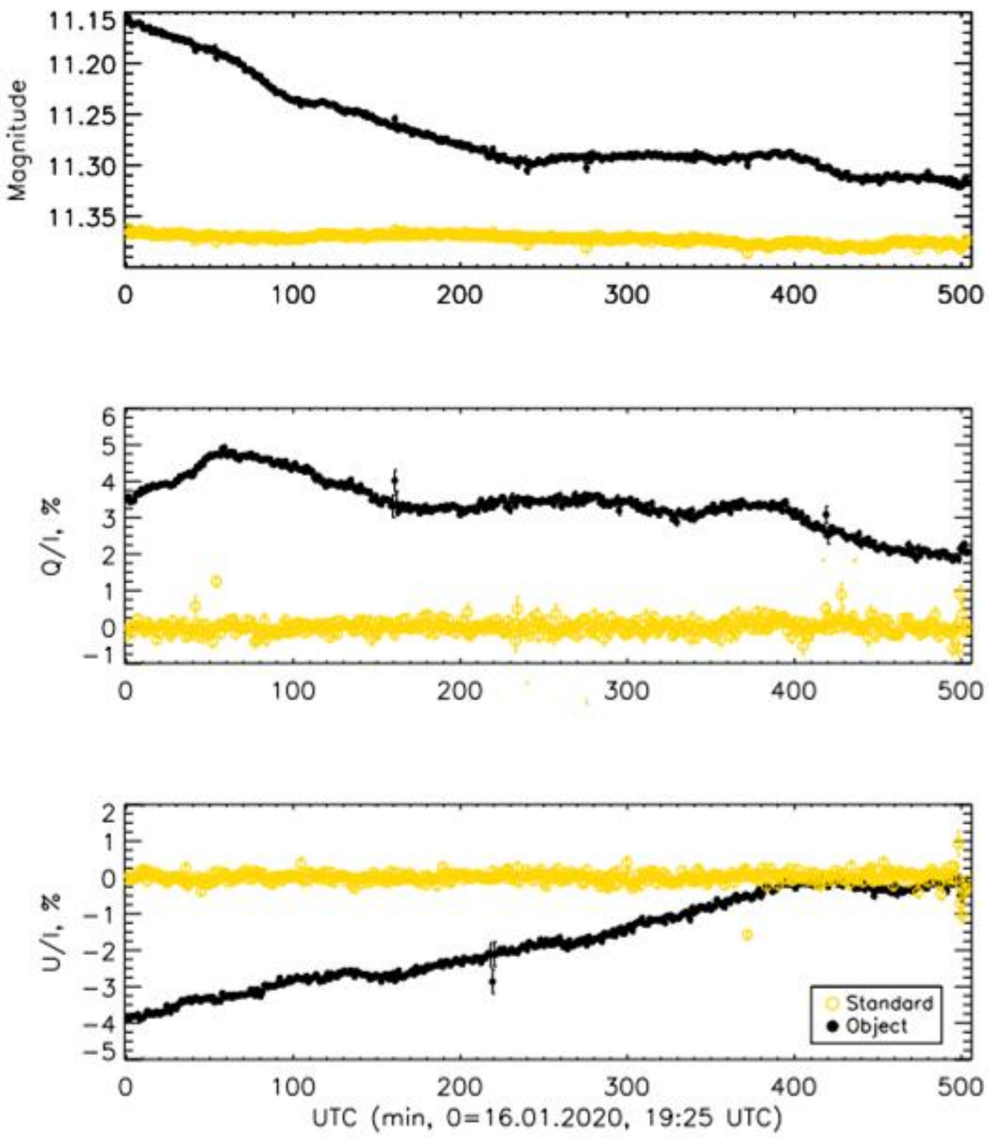
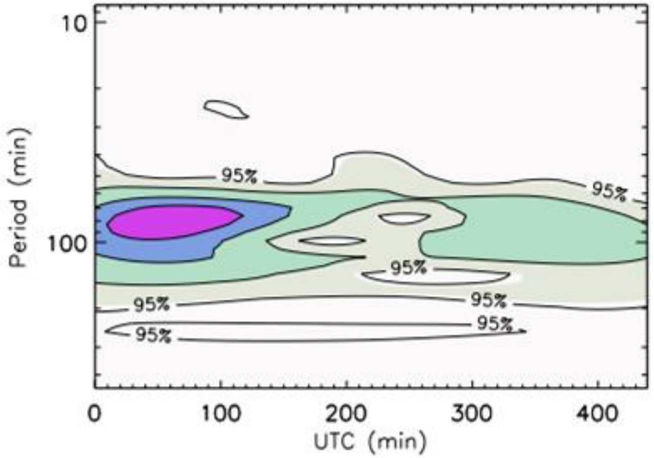
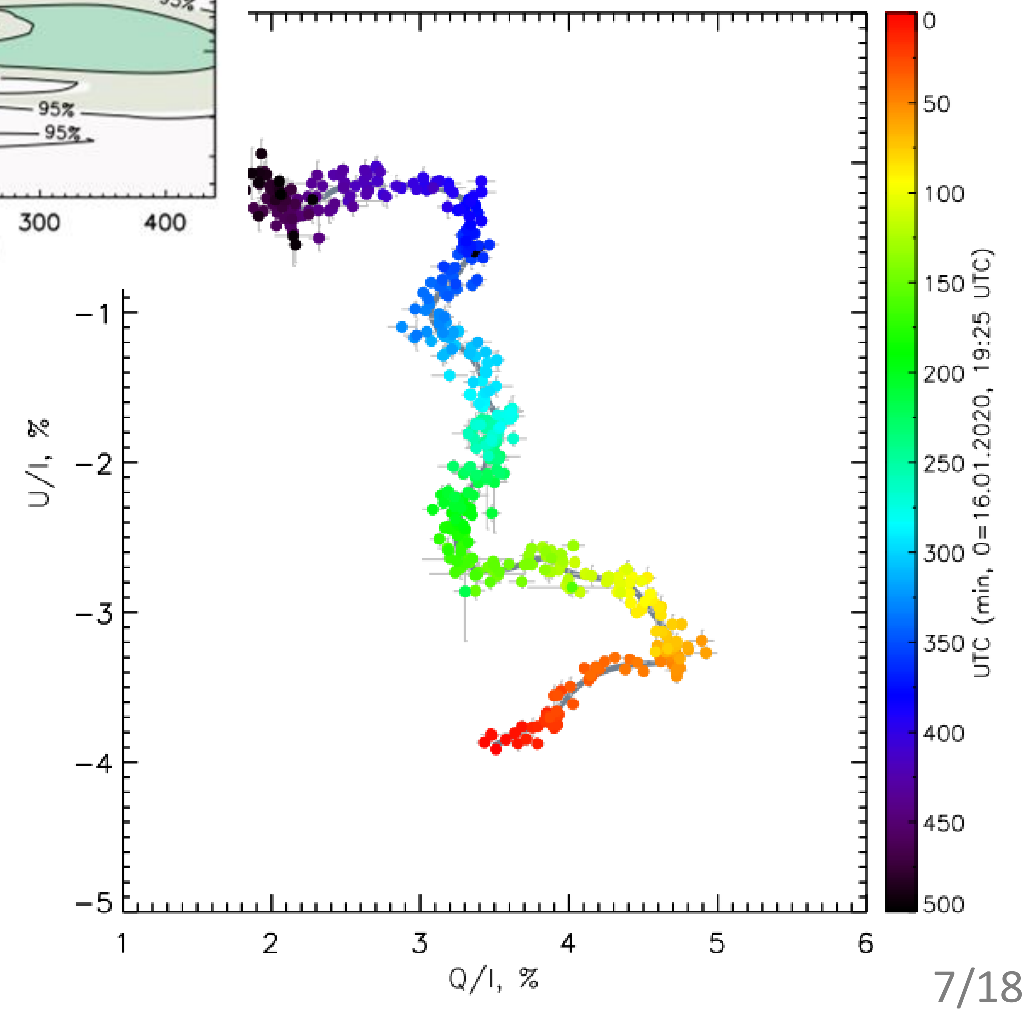




Same ~77 minutes period

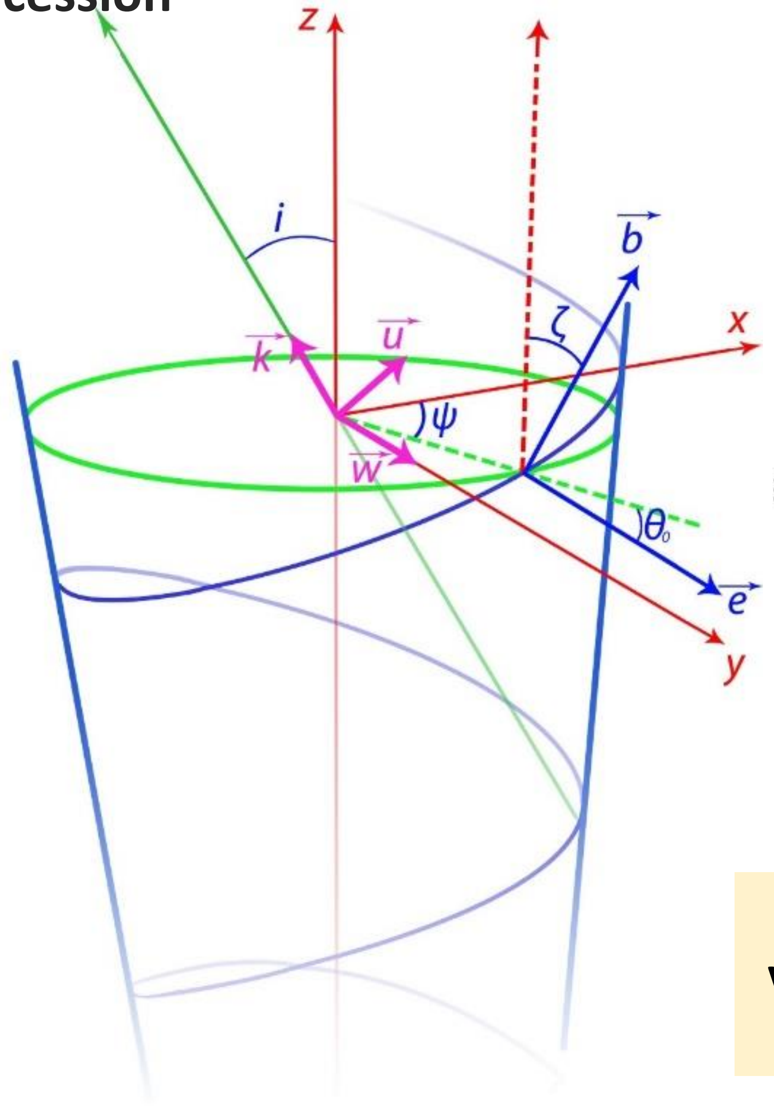


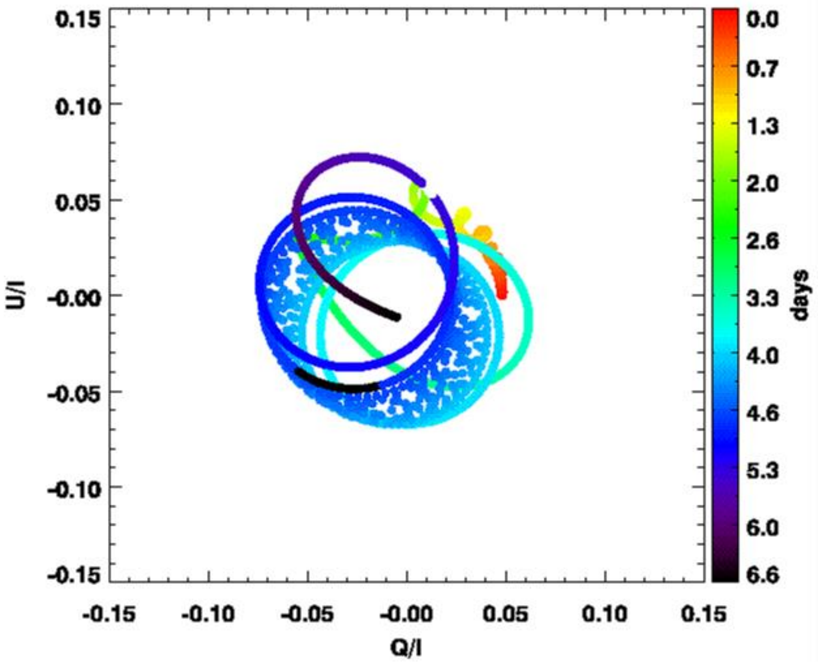
Geometrical model

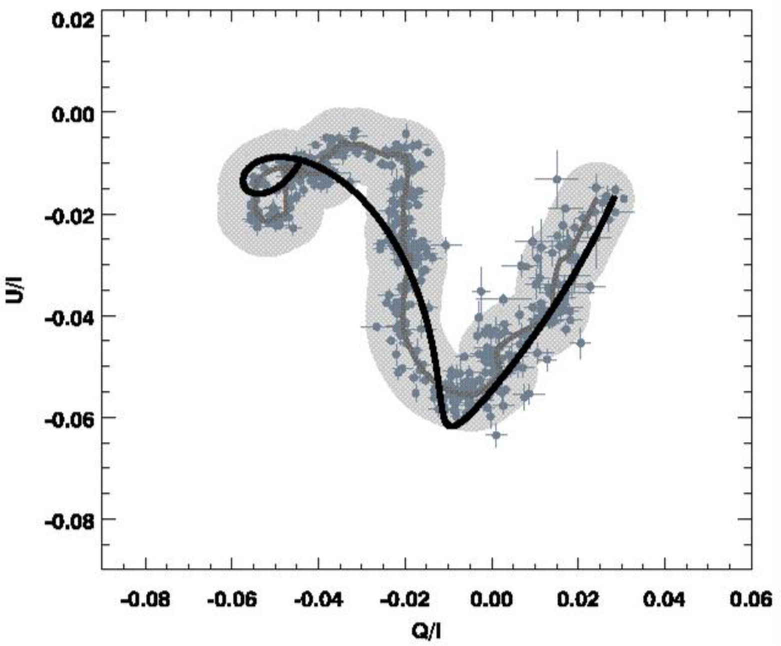
(Nalewajko 2009, Steffan+95) + **precession**

+ (Butuzova 2018,2020): magnitude variation due to the Doppler factor changes:

$$\Delta m = -2.5(3+\alpha)\log\frac{\delta_1}{\delta_2}$$







Both polarimetric and photometric variations could be explained with plasma rotation in helical magnetic field

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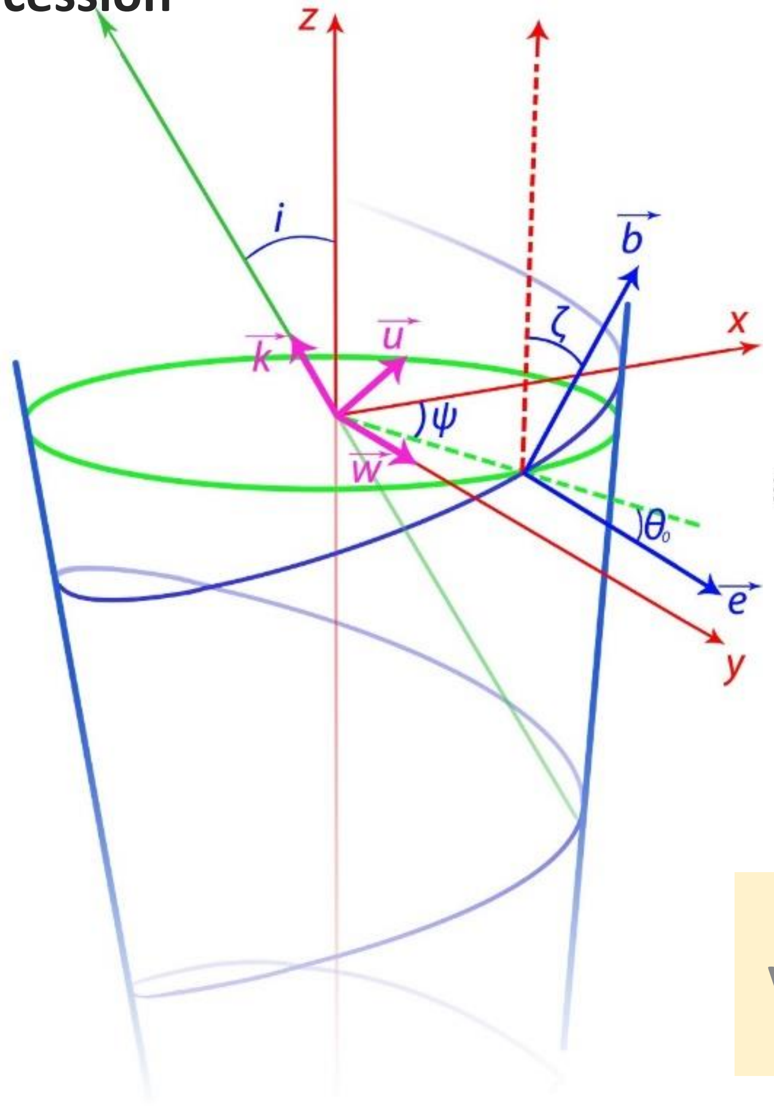
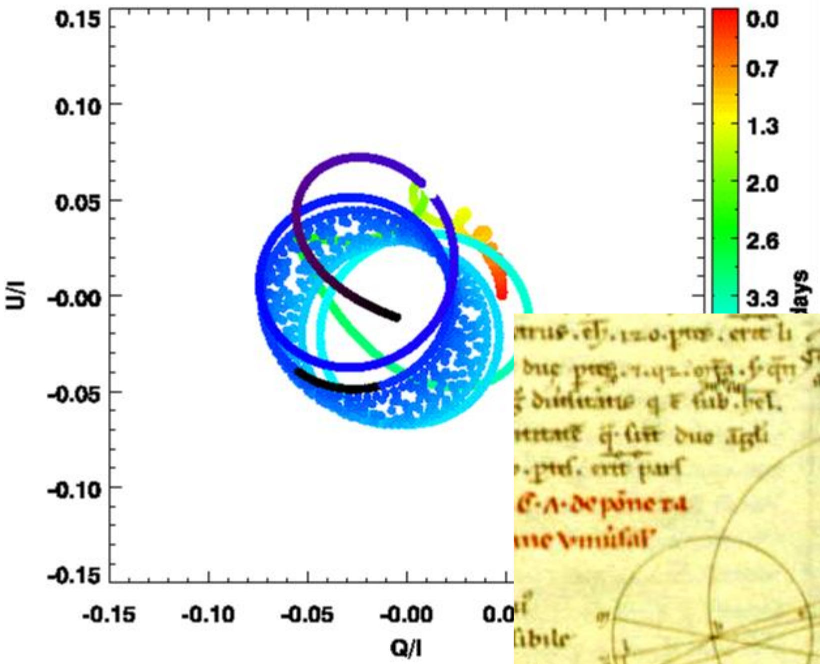
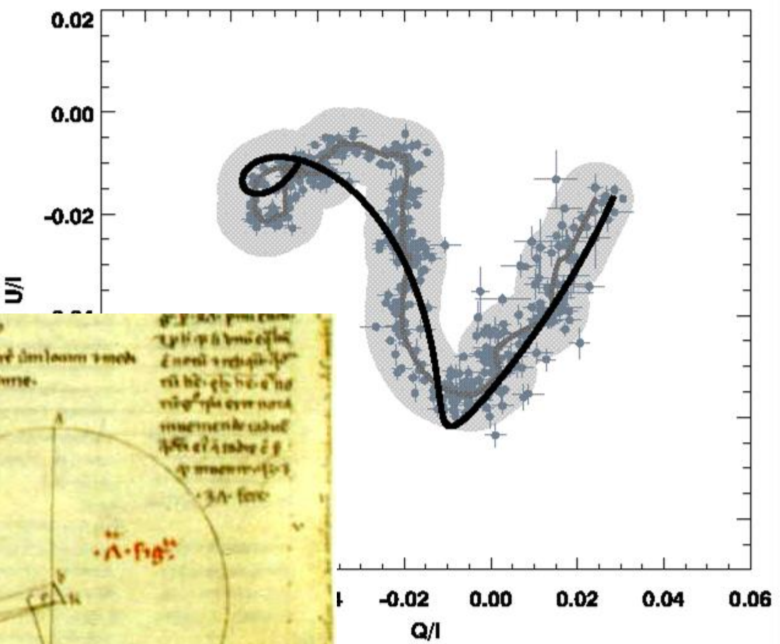
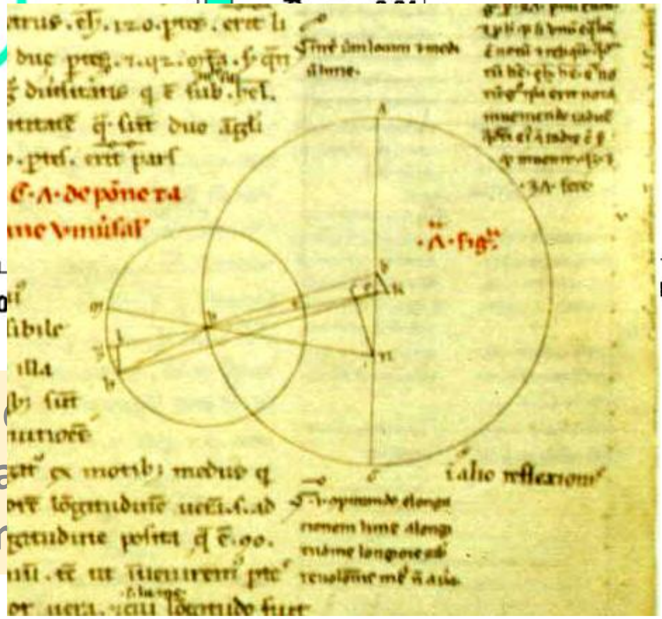


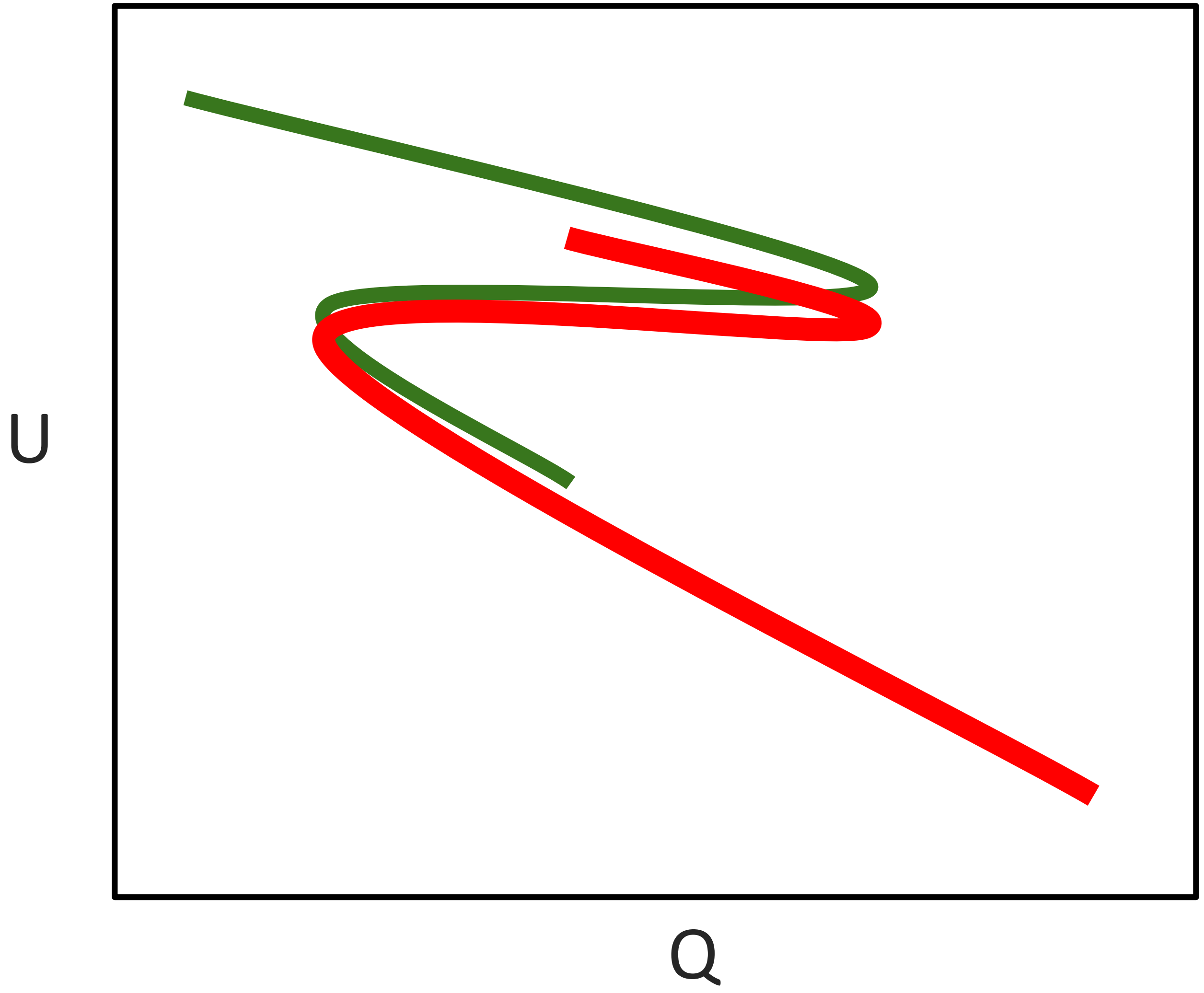






Both polarimetric an
variations could be expla
rotation in helical m

Polarization in different colours?



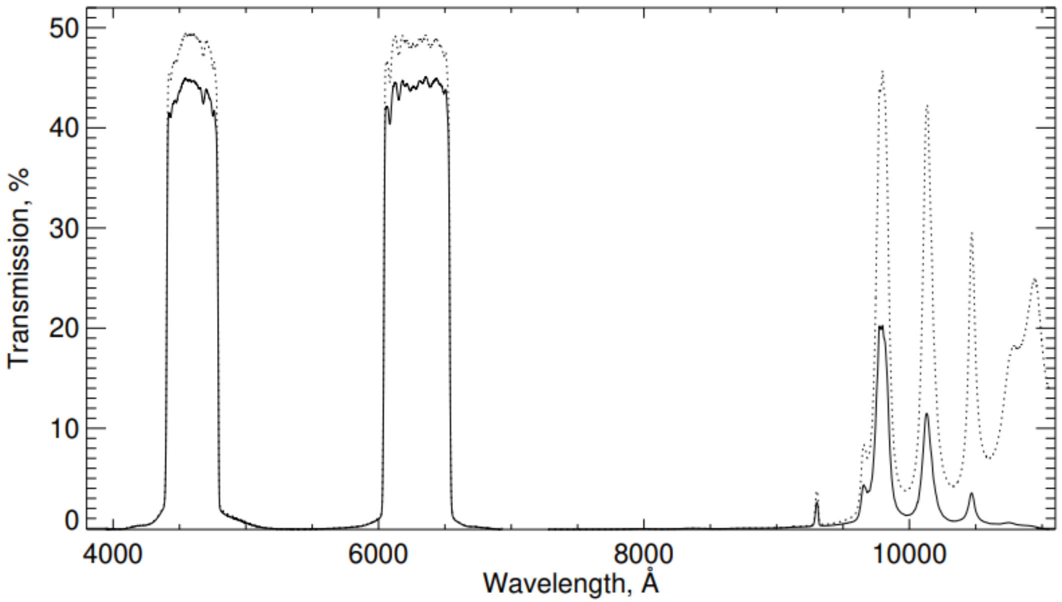
Synchrotron losses → MF estimation (Papadakis et al. 2003, Chiappetti et al. 1999)

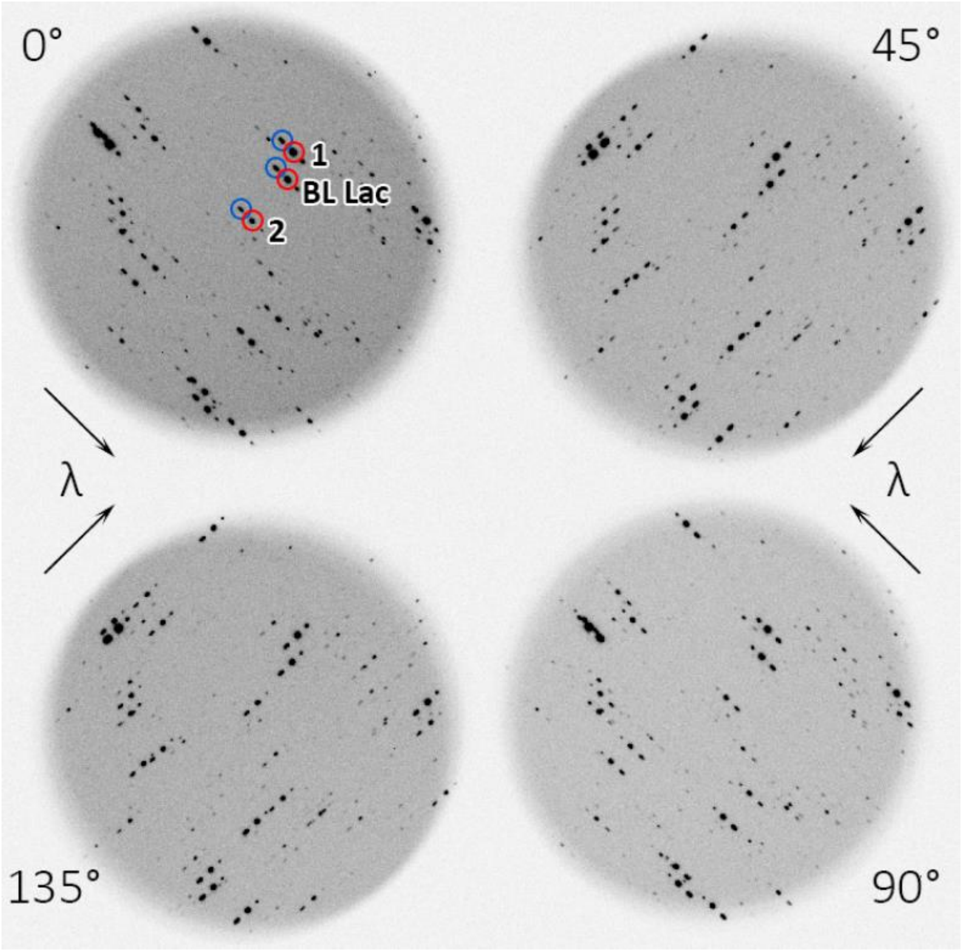
$$B\delta^{1/3} \sim 300 \left(\frac{1+z}{\nu_I}\right)^{1/3} \left[\frac{1-(\nu_I/\nu_V)^{1/2}}{\tau}\right]^{2/3}$$

Observations

	Date	JD	Device	Filter(s)	Duration	Δt
1	22/06/2020	022.981	S	$V + I$	95	8
2	30/06/2020	030.946	S	V	140	1.5
3	24/07/2020	054.920	S	V	313	1
4	23/08/2020	084.941	S	$V + I$	321	2
5	24/08/2020	085.839	S	$V + I$	109	2
				I	172	1
6	24/10/2020	146.802	M	CAMEL	260	2
7	25/10/2020	147.785	M	CAMEL	265	2
8	28/06/2022	758.937	M	CAMEL	170	3.5
9	29/06/2022	759.908	M	CAMEL	236	5
10	30/06/2022	760.918	M	CAMEL	247	5
11	30/08/2022	821.904	M	SED550 + SED650	409	7

CAMEL filter transmission curve

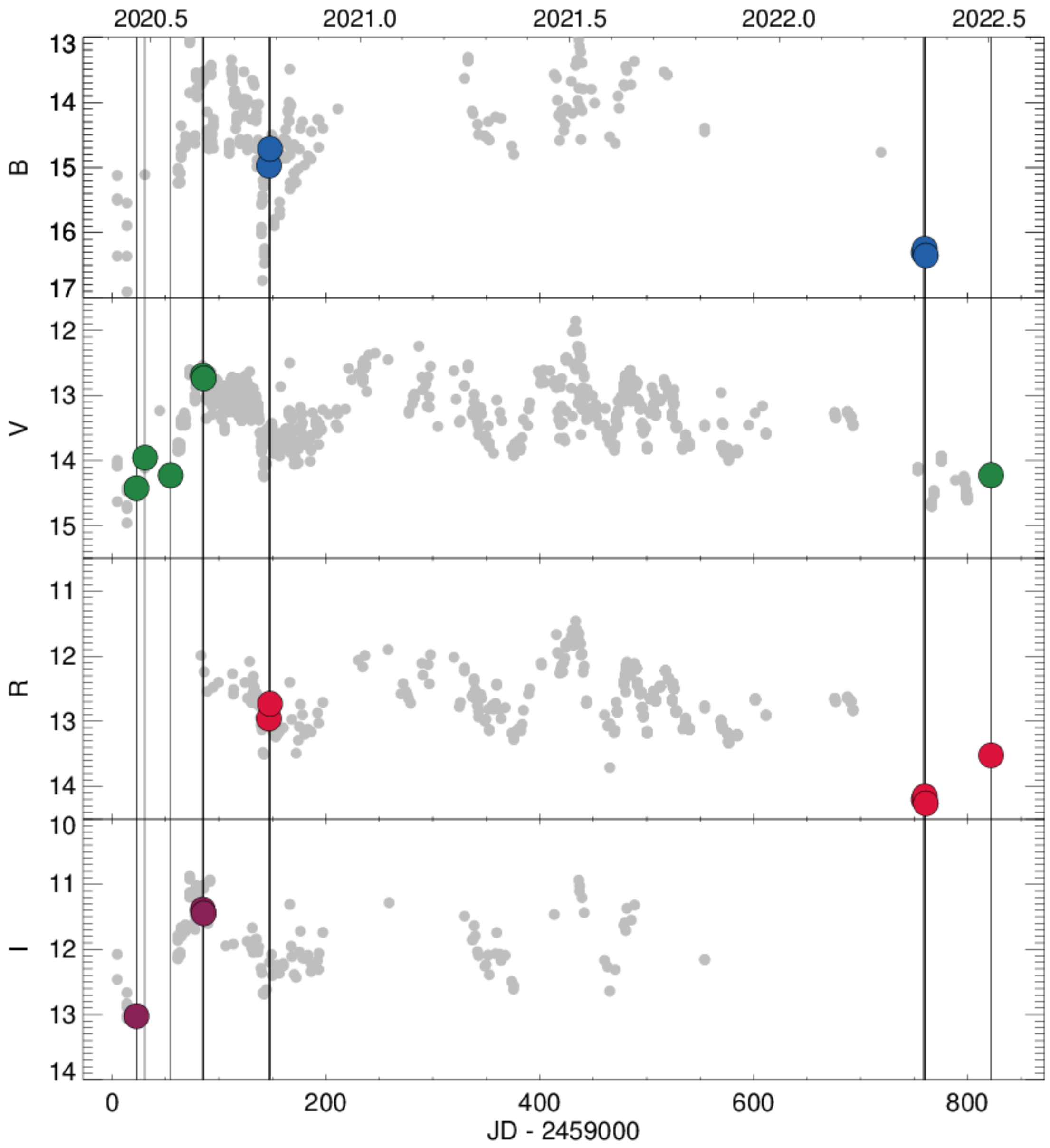




CAMEL + Zeiss-1000/MAGIC*

*Monitoring of Active Galaxies by Investigations of their Cores

I – pre-flare: June-July, 2020;
II – flare: August, 2020;
III – post-flare: October, 2020;
IV – minimum: June, 2022;
V – post-minimum: August, 2022;



Credit: AAVSO

BL Lac

I – pre-flare: June-July, 2020;
II – flare: August, 2020;
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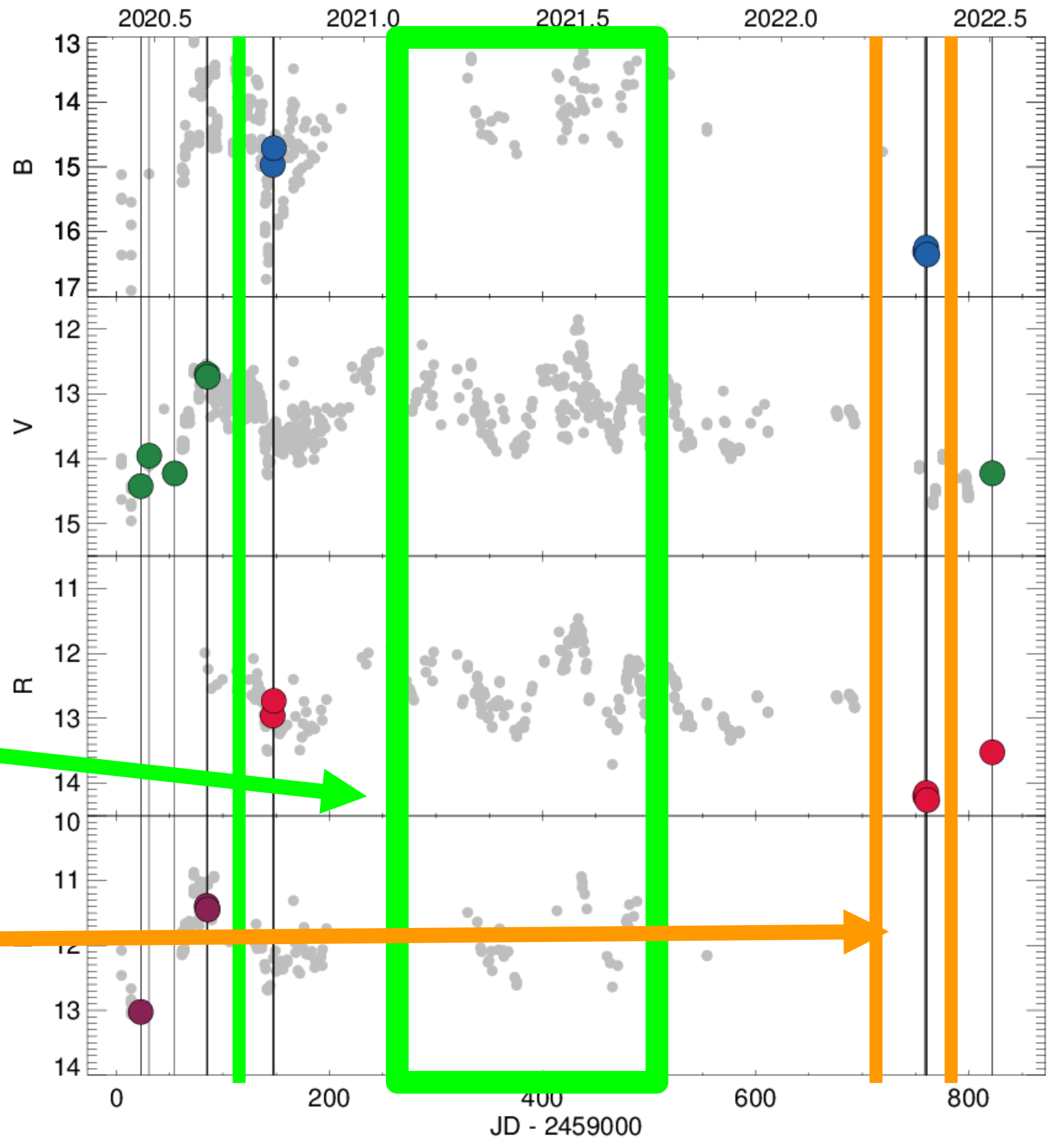
Imazawa+2022, [10.1093/pasj/psac084](https://doi.org/10.1093/pasj/psac084)

Middei+2022, [arXiv:2211.13764](https://arxiv.org/abs/2211.13764)



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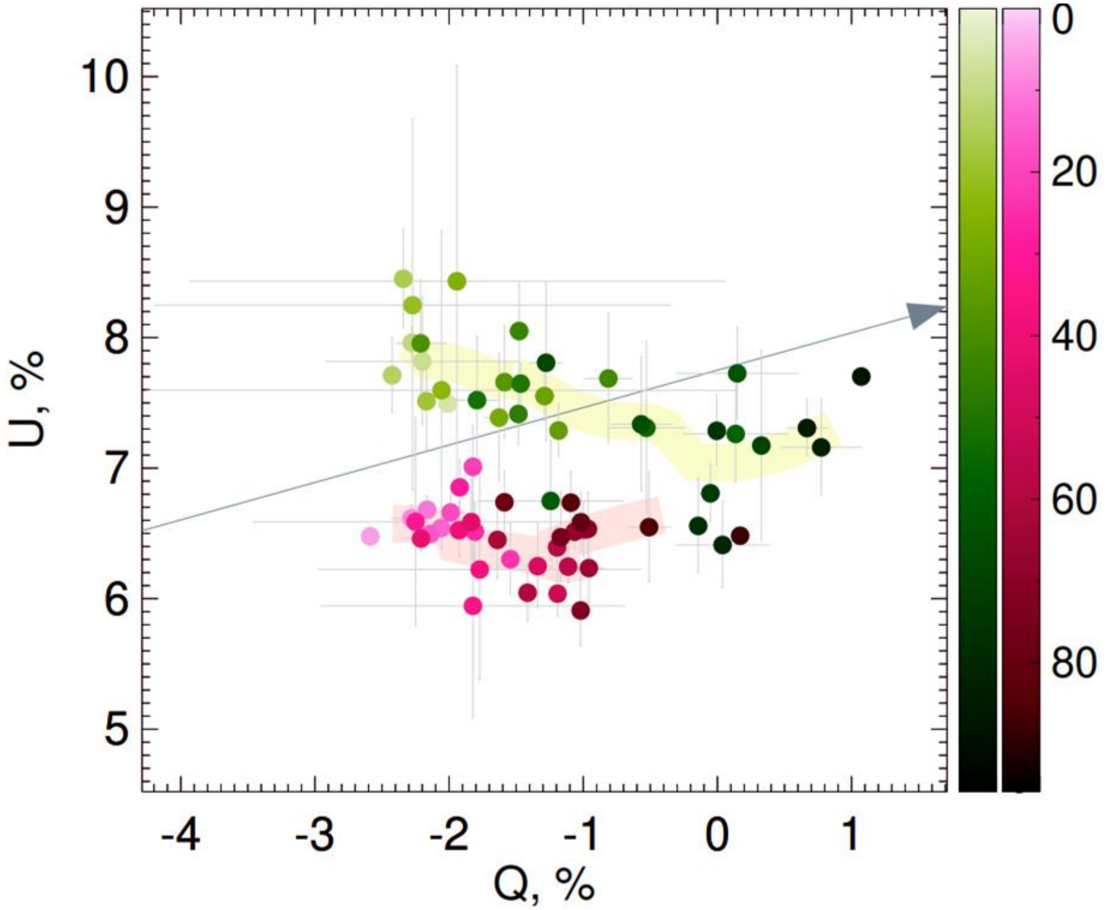
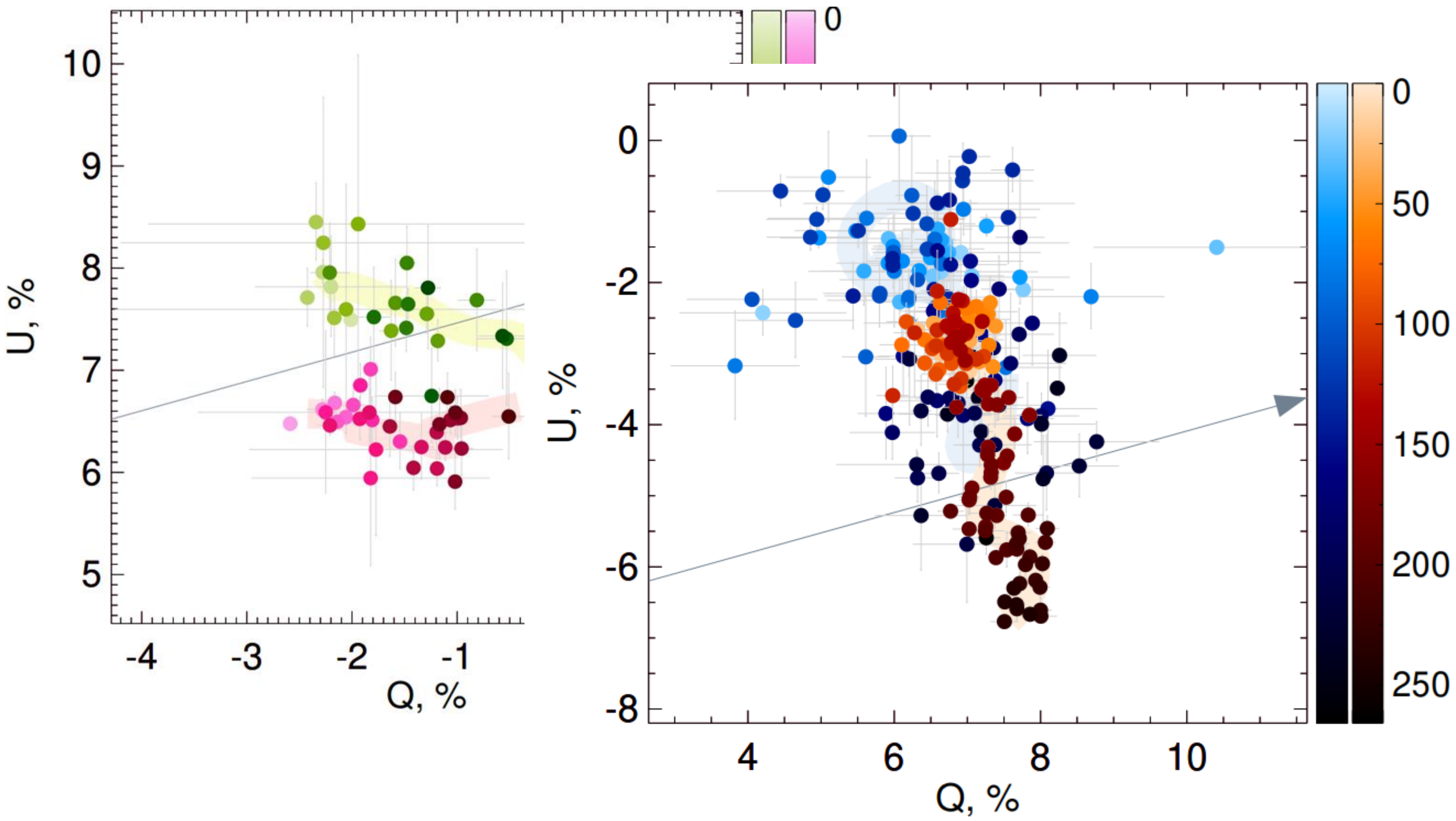


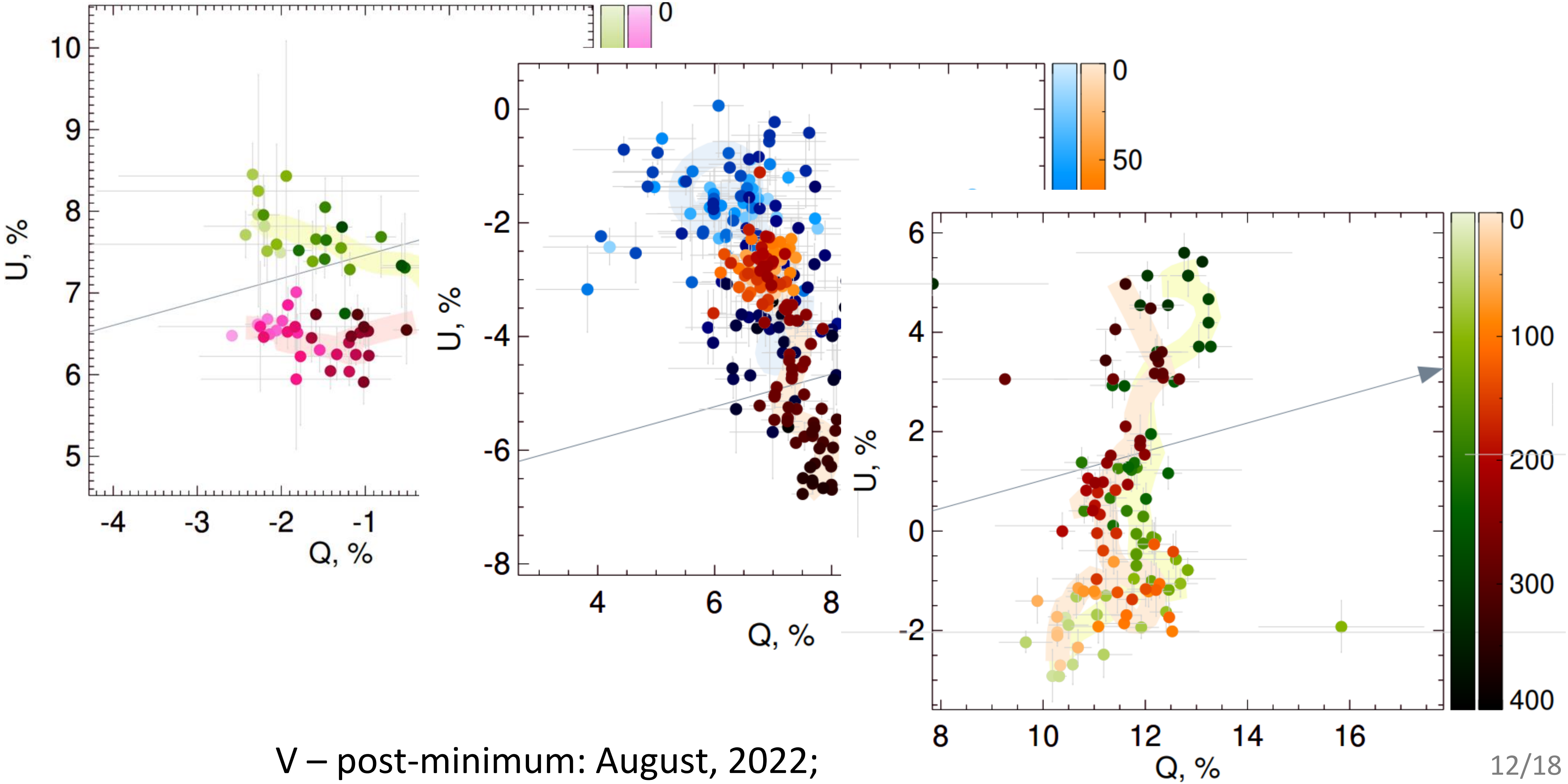
I – pre-flare: June-July, 2020

BL Lac



III – post-flare: October, 2020;

BL Lac

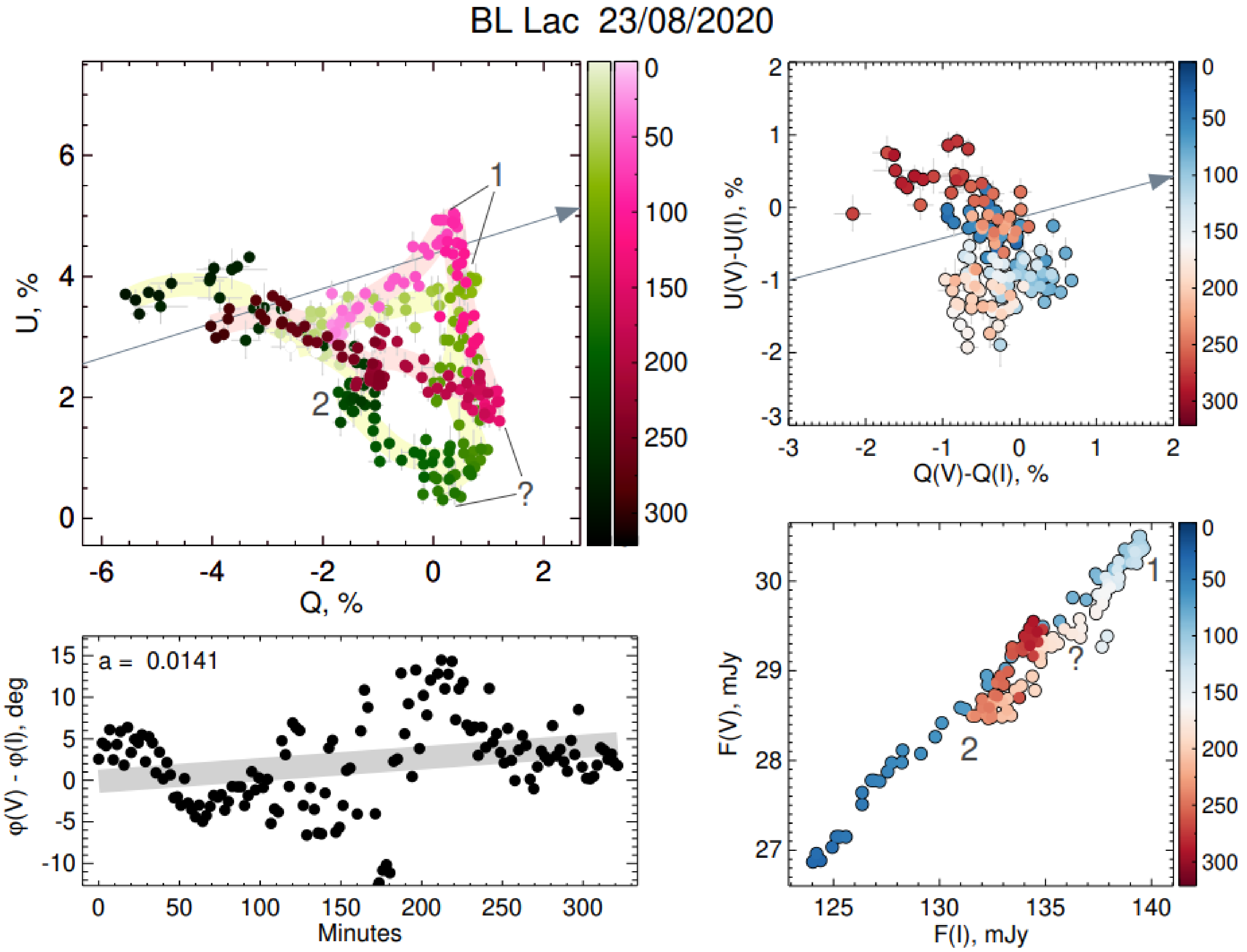


V – post-minimum: August, 2022;

BL Lac

II – flare: August, 2020

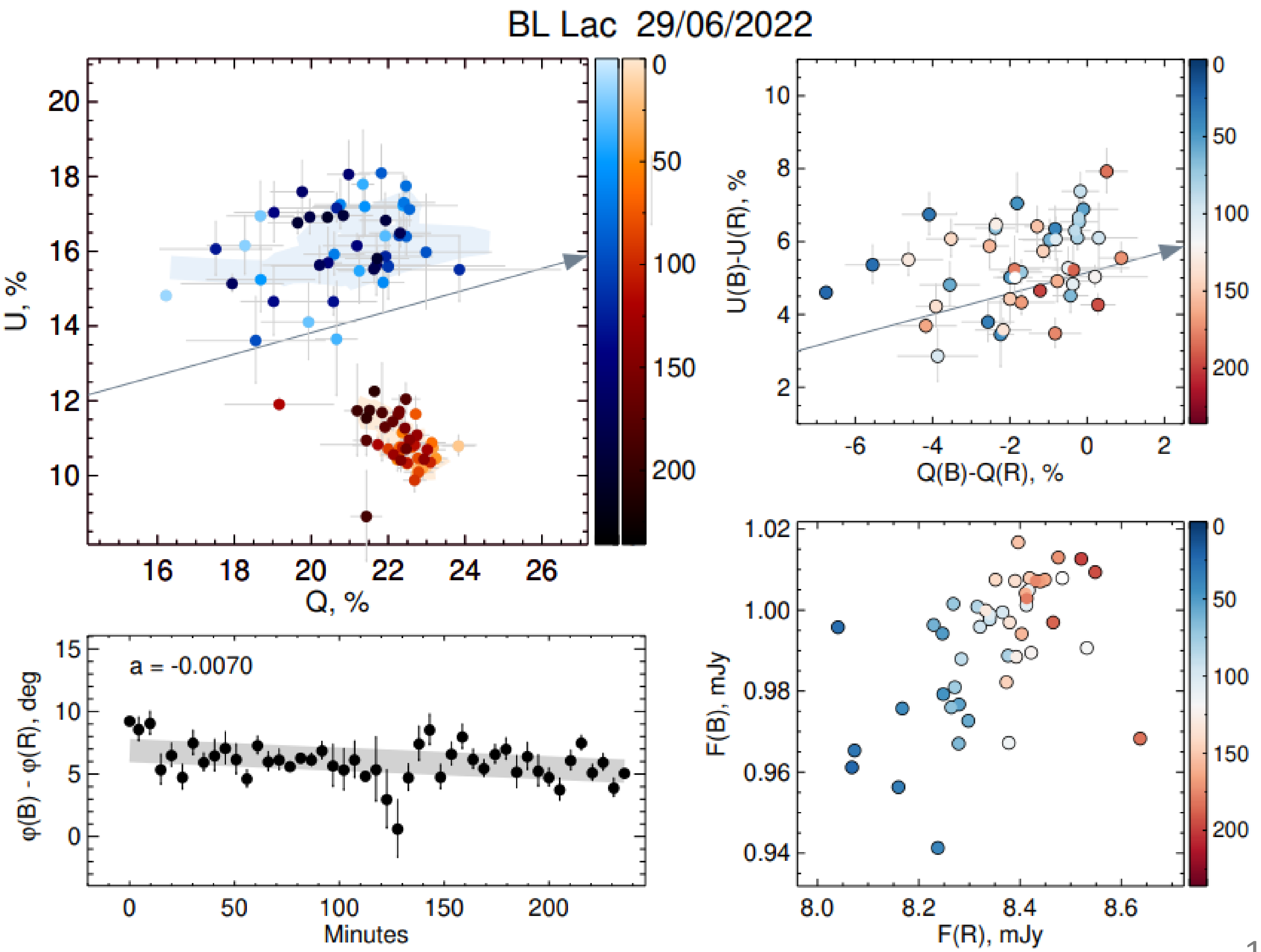
- low PD ~ 1-8%
- fast changes
- moderate chromatism



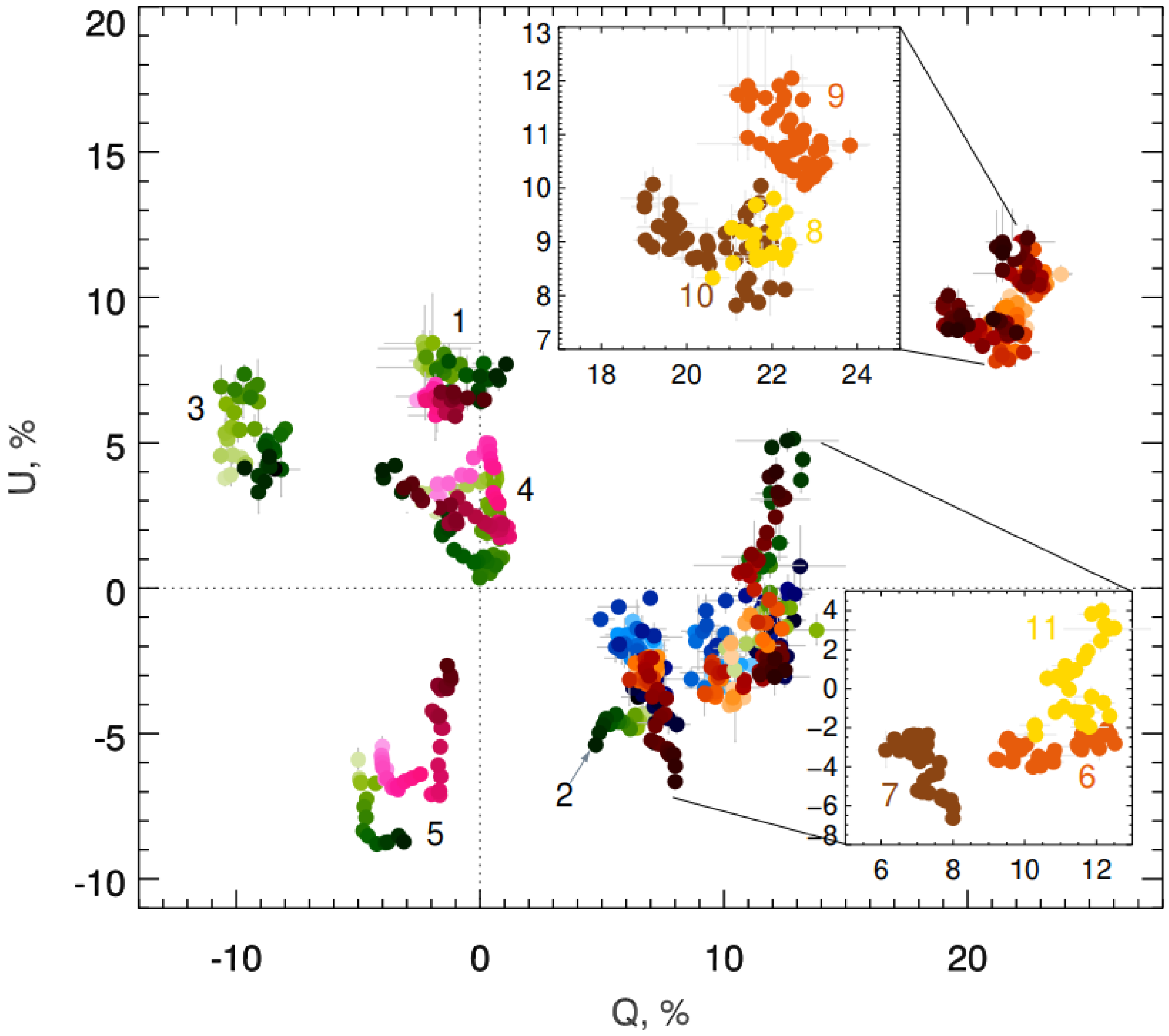
BL Lac

IV – minimum: June, 2022

- strongly chromatic
- PD up to 30%
- slight variations

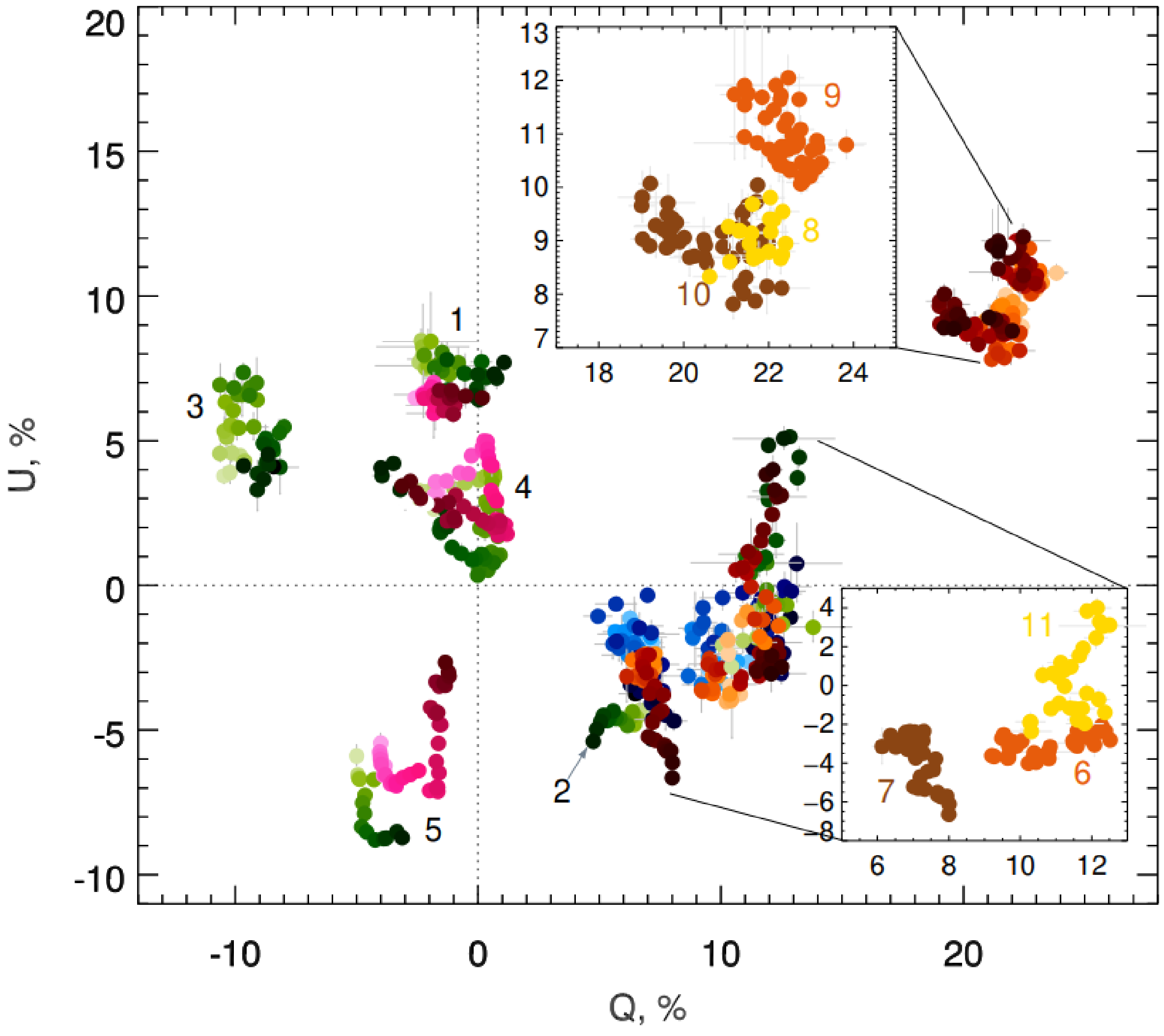


BL Lac

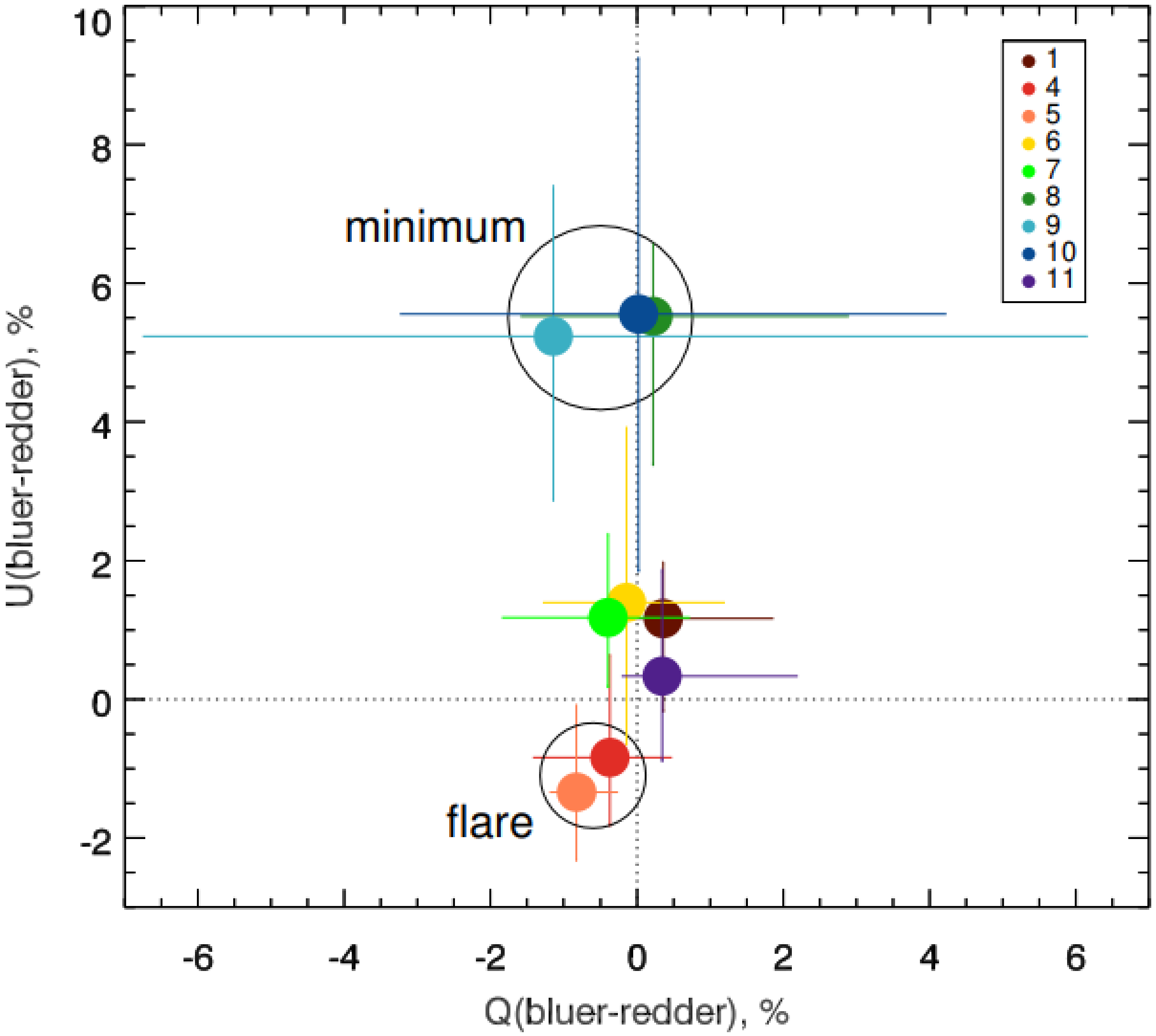


no typical pattern or location

BL Lac



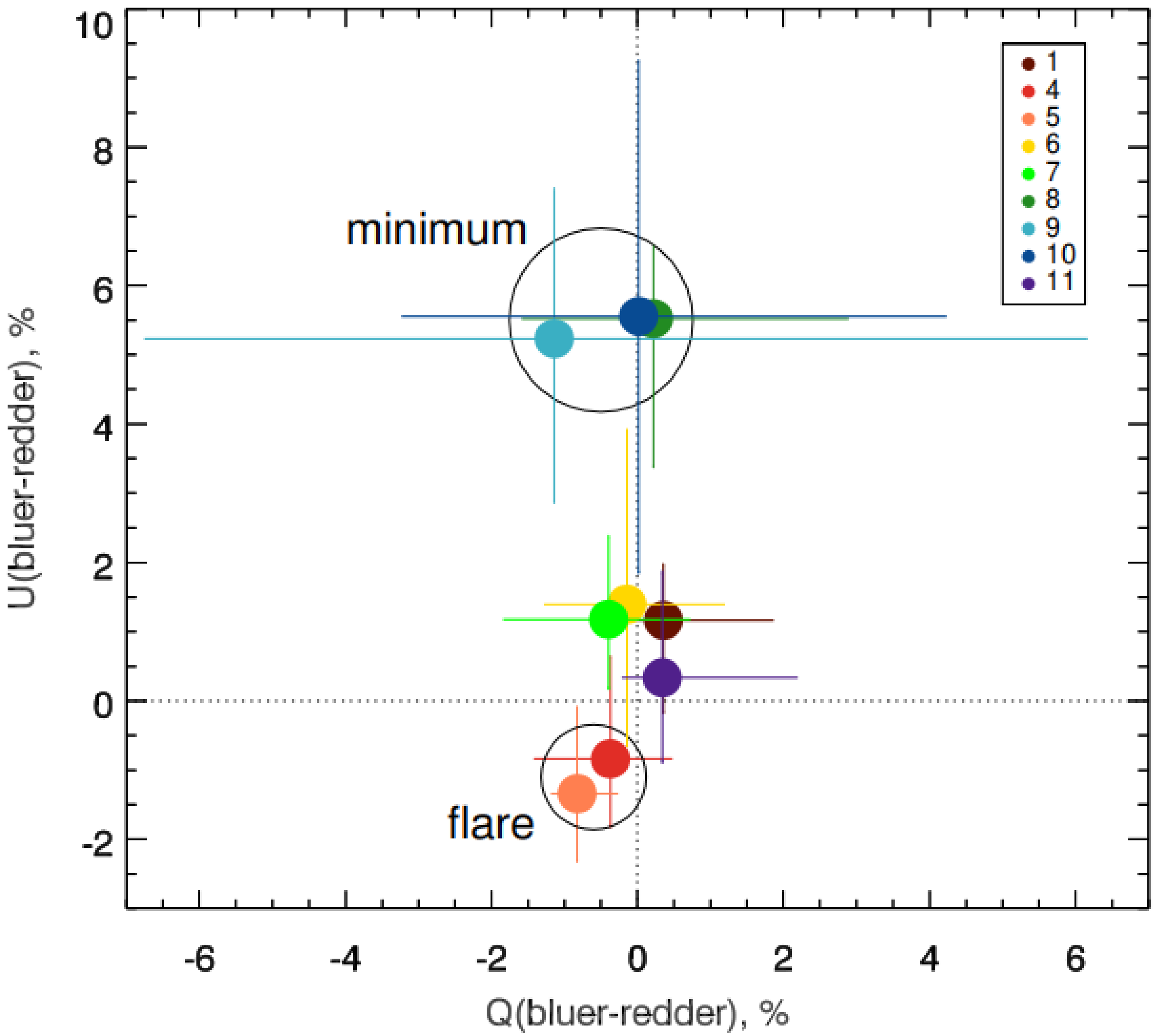
U, %
Q, %
1
2
3
4
5
6
7
8
9
10
11



minimum
flare
U(bluer-redder), %
Q(bluer-redder), %
1
4
5
6
7
8
9
10
11

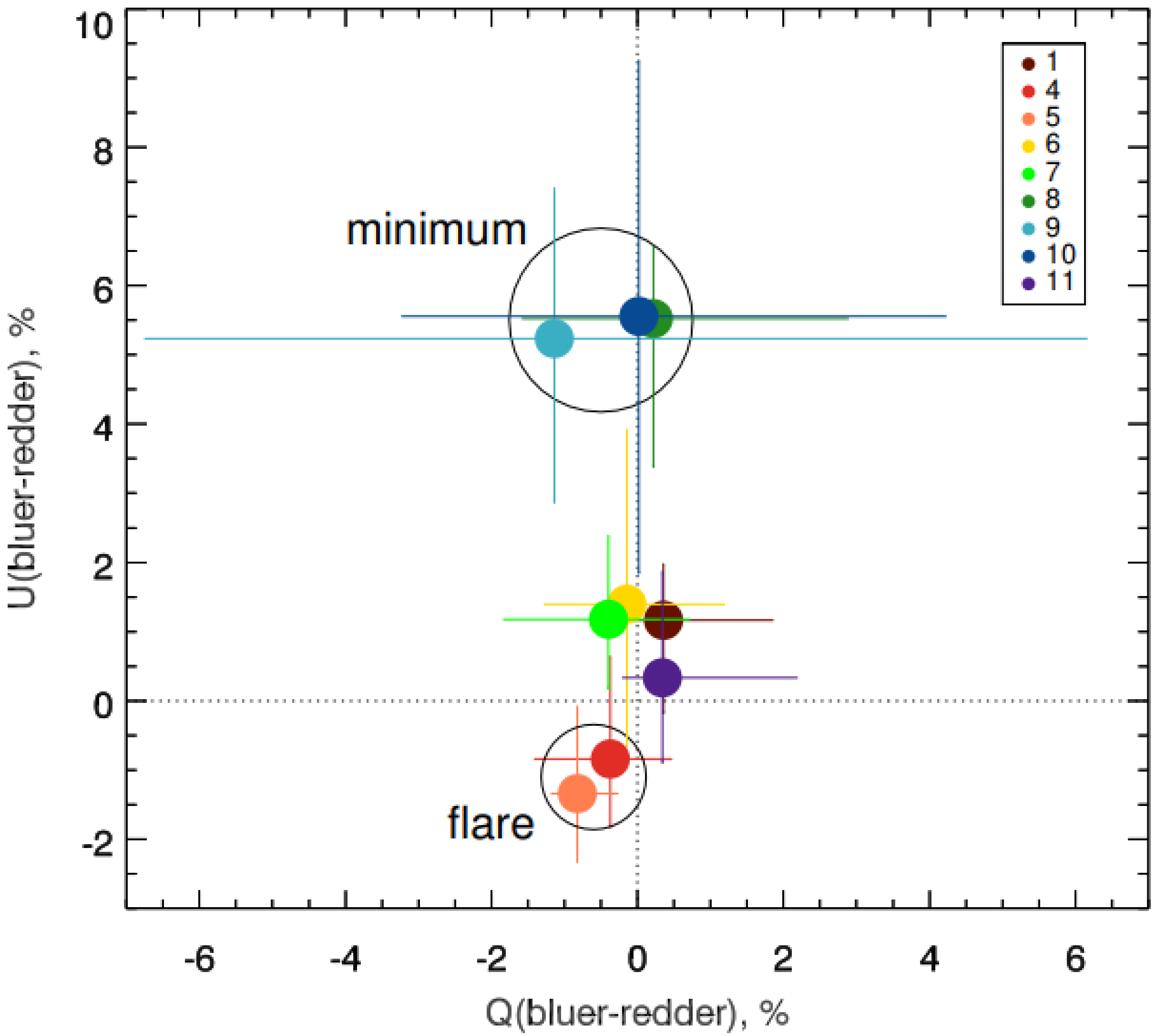
BL Lac

- External processes (ISM, etc)
  - ❌ IDV



BL Lac

- External processes (ISM, etc)
  - ❌ IDV
- Accretion disk contribution
  - ❌ high PD in minimum



BL Lac

- External processes (ISM, etc)
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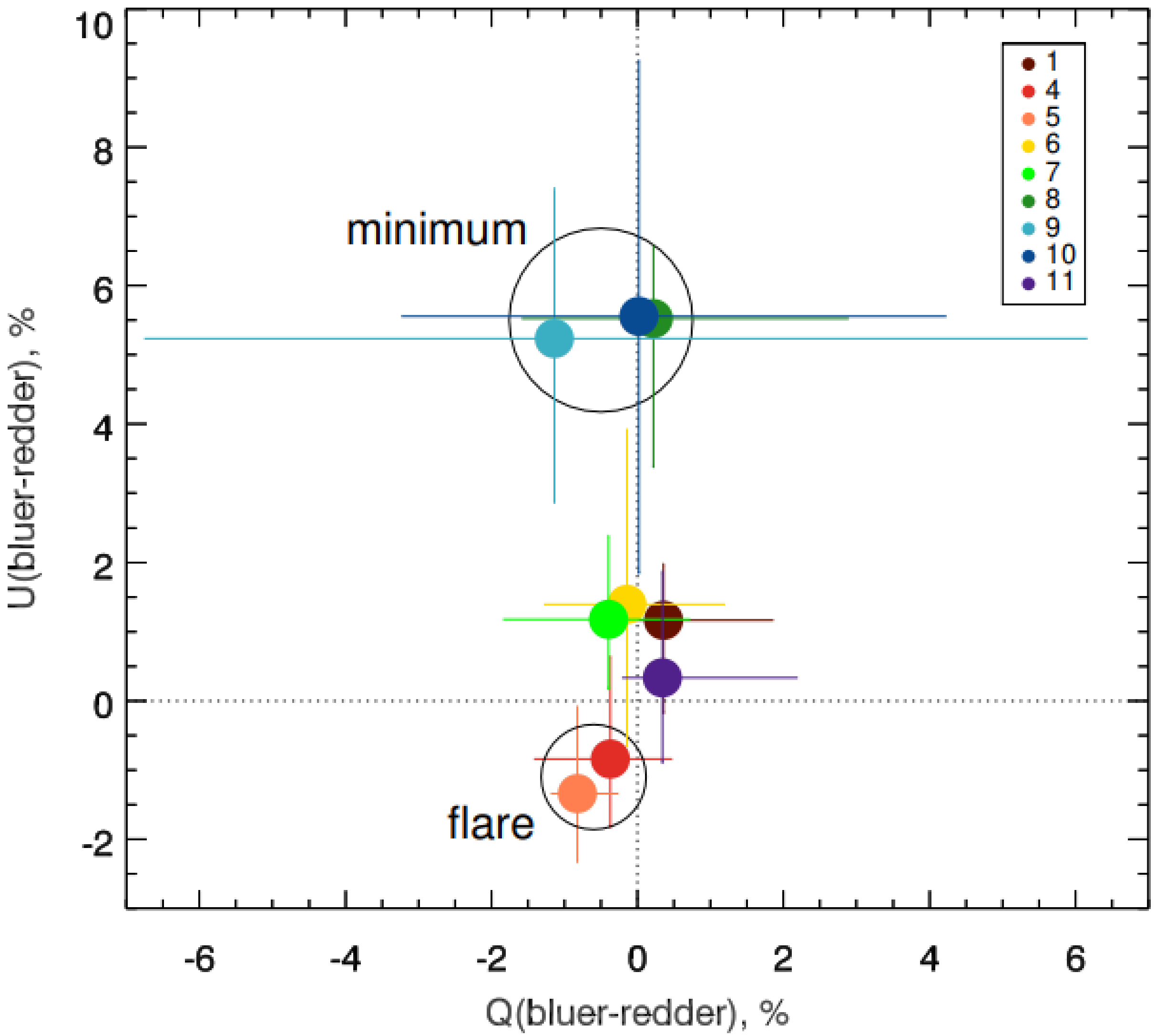
- Accretion disk contribution
  - ❌ high PD in minimum
- Faraday rotation

  τ = 2 min → B ≈ 10 G

$$B\delta^{1/3} \sim 300 \left(\frac{1+z}{\nu_I}\right)^{1/3} \left[\frac{1-(\nu_I/\nu_V)^{1/2}}{\tau}\right]^{2/3}$$



- External processes (ISM, etc)
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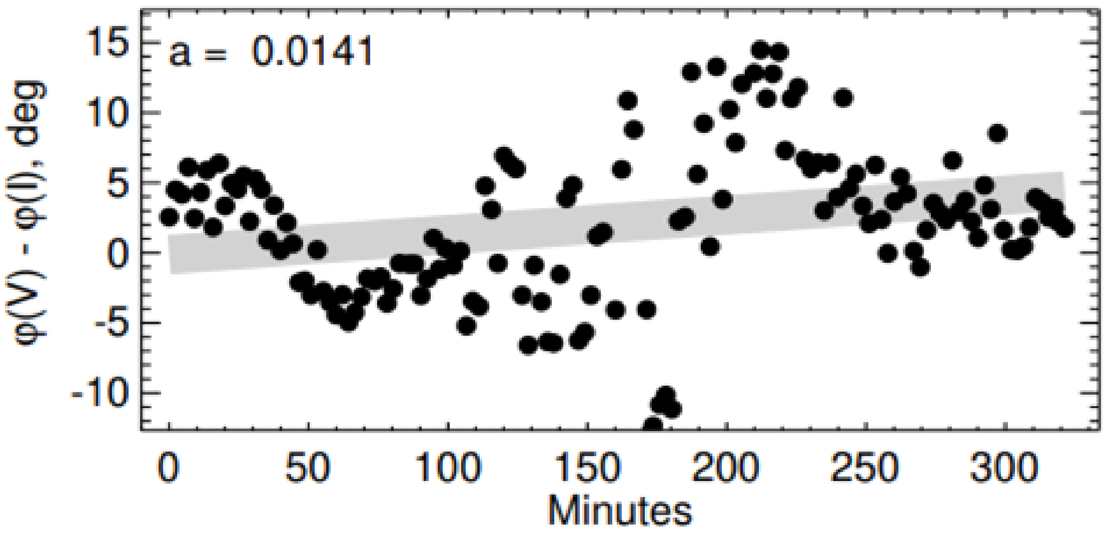
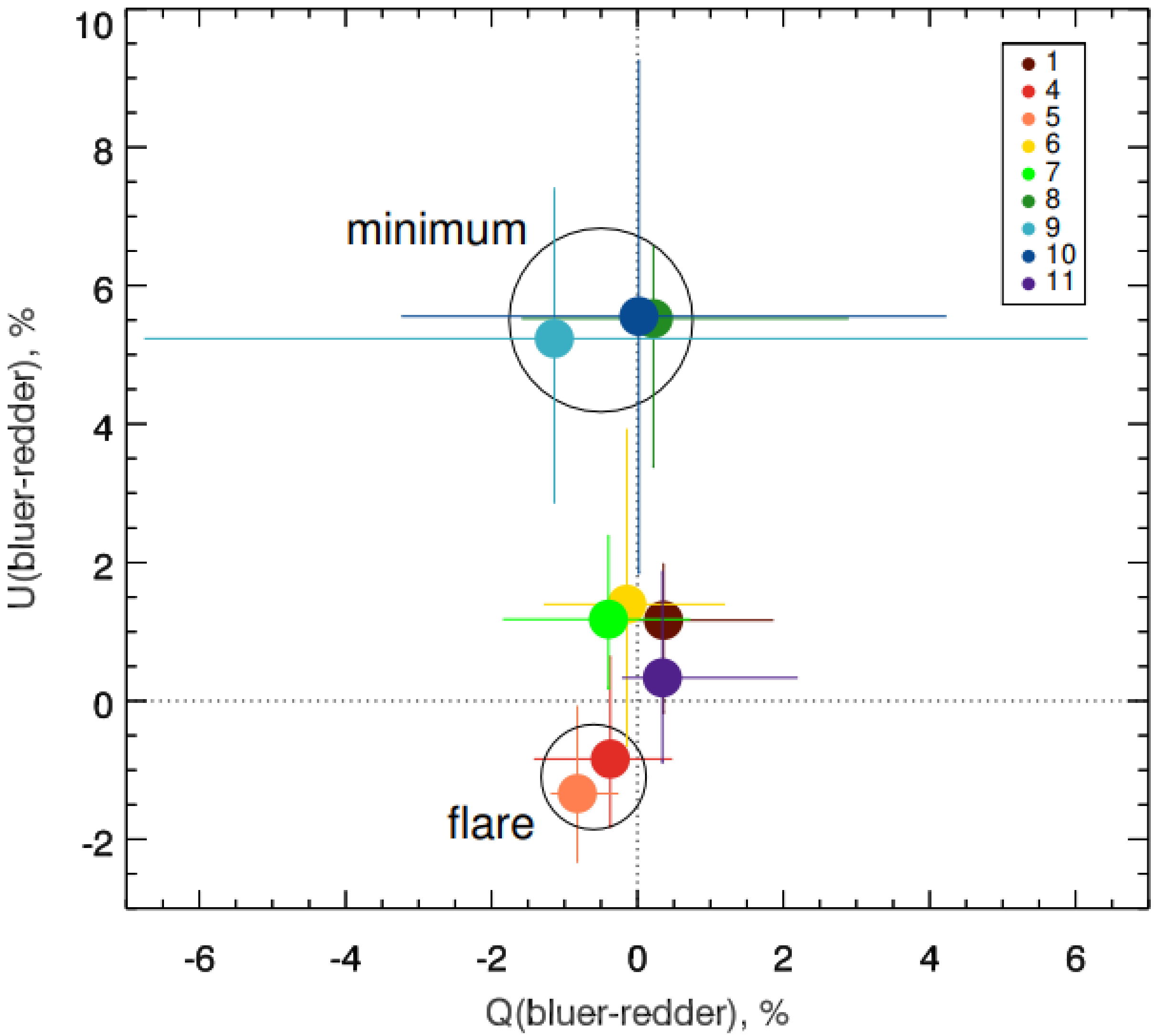
  $\tau = 2$ min → $B \approx 10$ G

  $\Delta\phi \approx 5°$





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  - ❌ high PD in minimum
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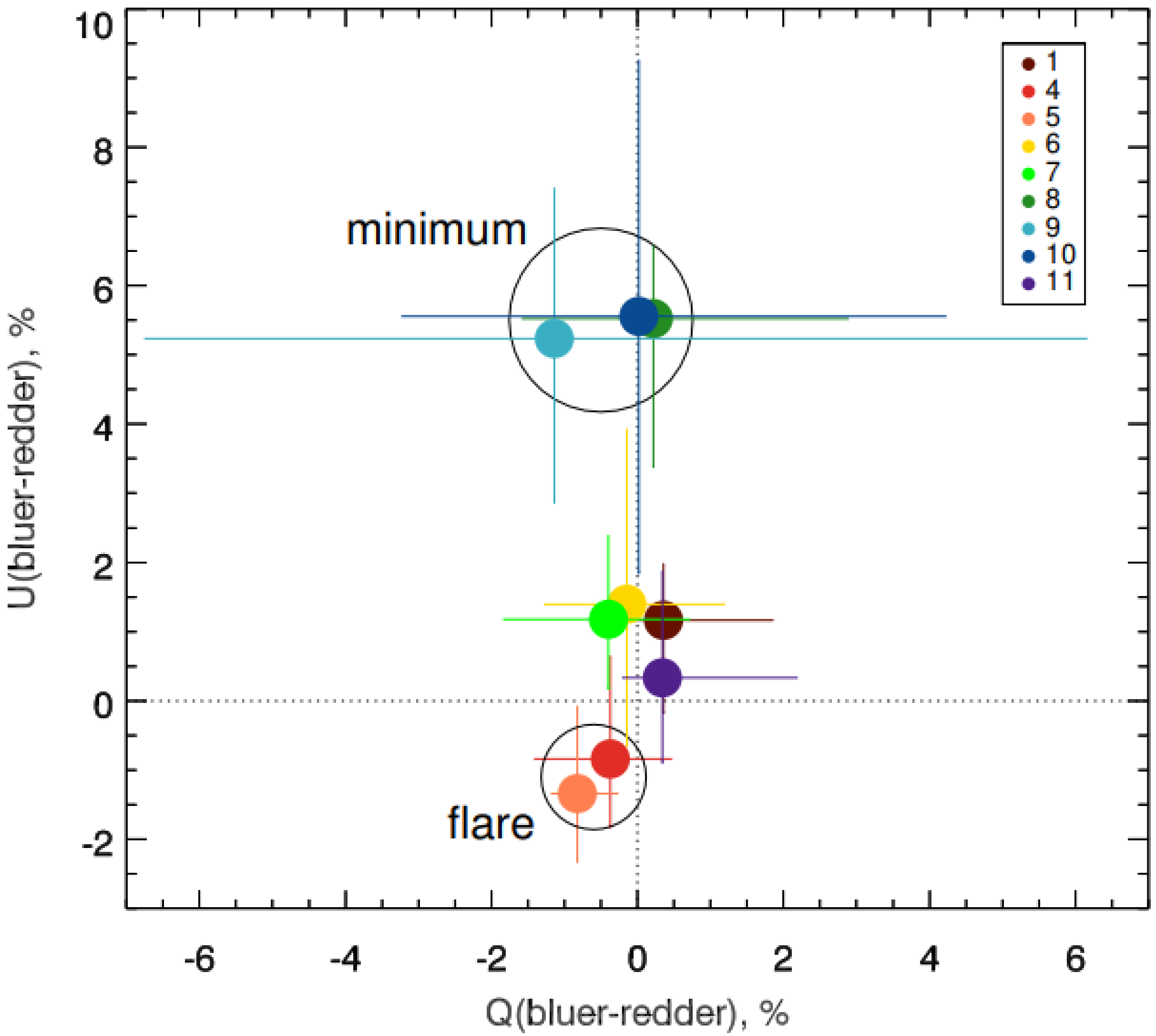
  $\Delta\phi \approx 5°$ →

  $\langle n_e D \rangle = 6 \times 10^{10}$ pc cm^{-3}



BL Lac

- External processes (ISM, etc)
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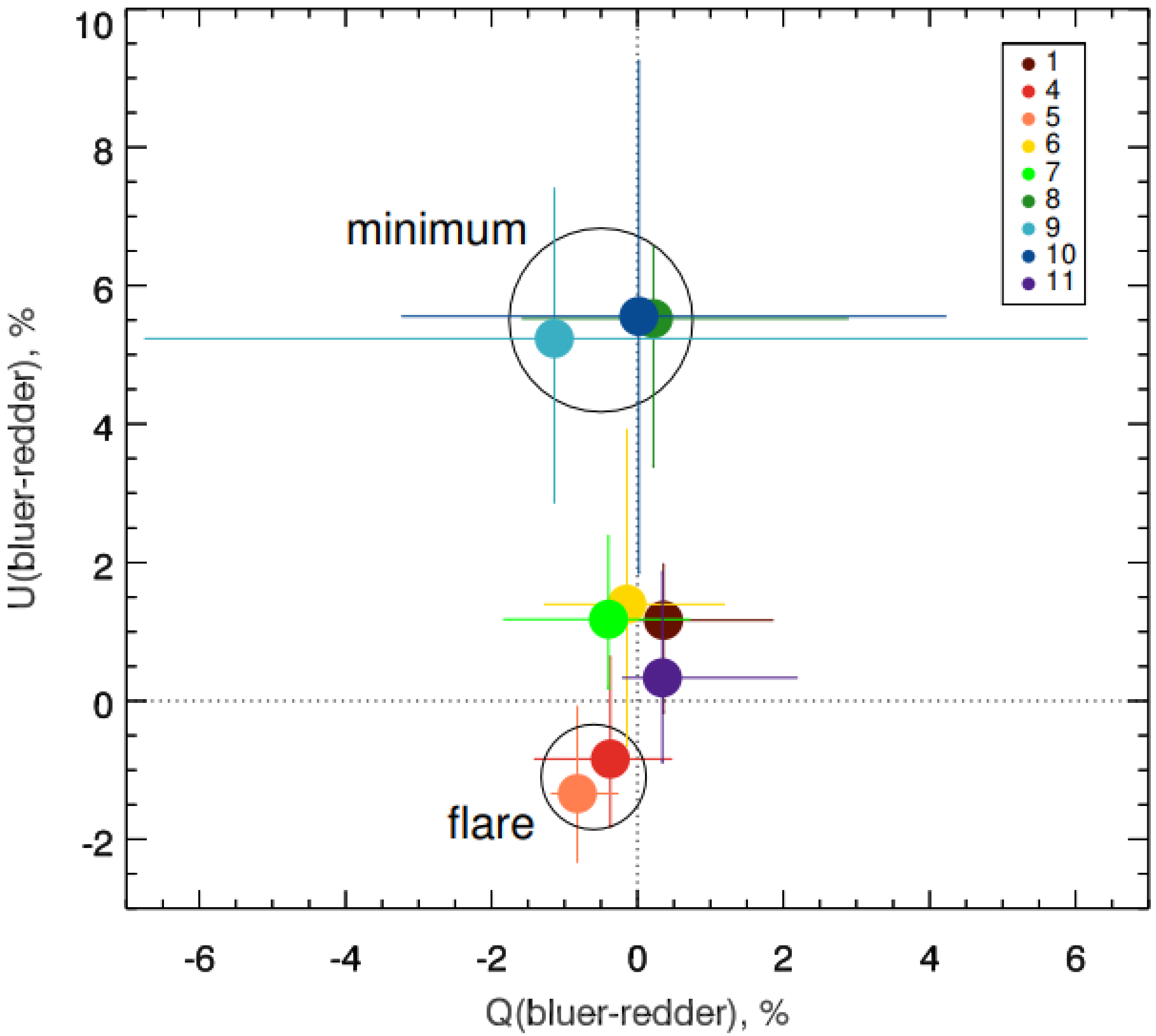
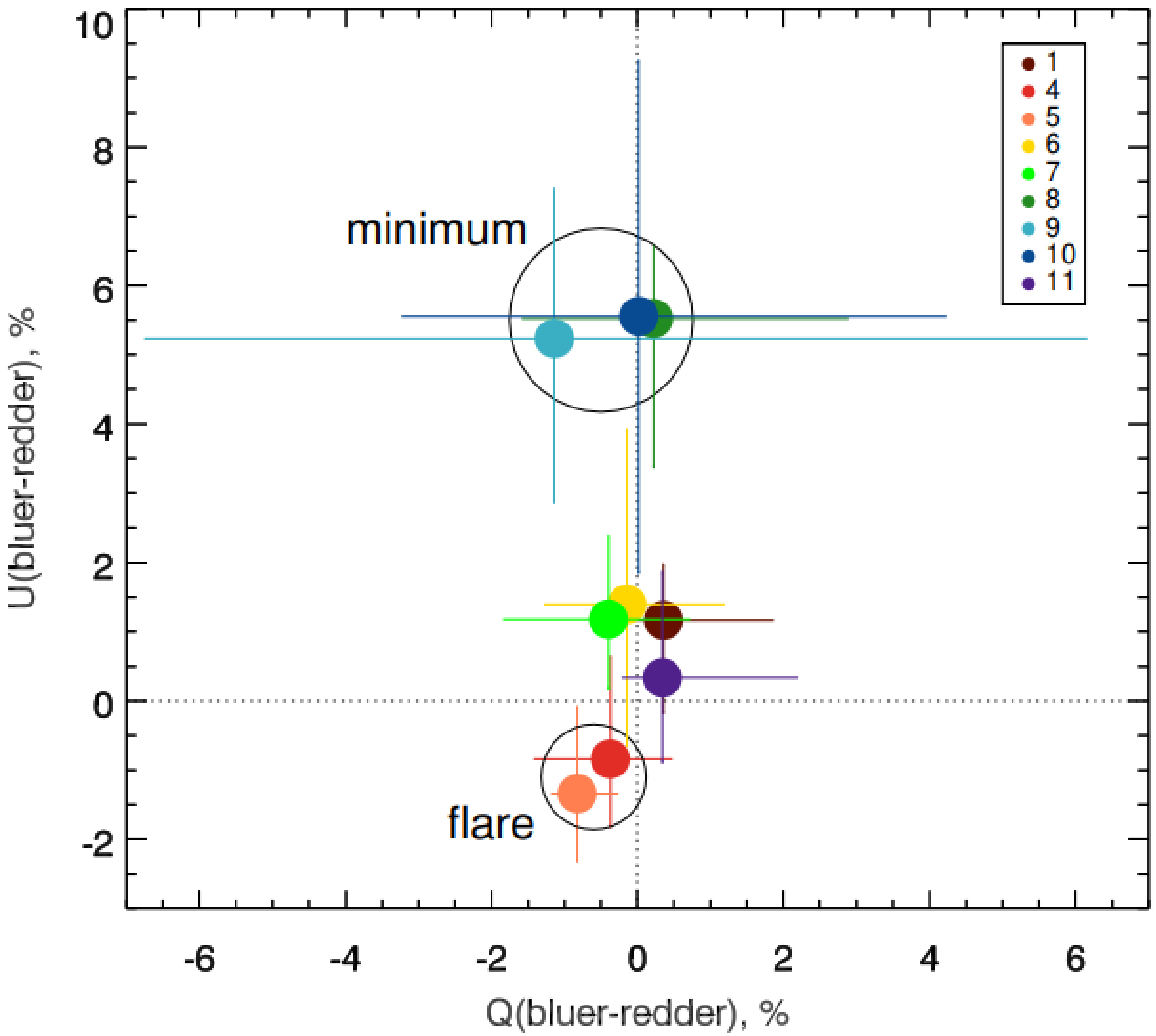
- Accretion disk contribution
  - ❌ high PD in minimum
- Faraday rotation
  - ❌ not physical



BL Lac

- External processes (ISM, etc)
  - ❌ IDV
- Accretion disk contribution
  - ❌ high PD in minimum
- Faraday rotation
  - ❌ not physical
- Multi-zone with different α
  - ❌ well-correlated



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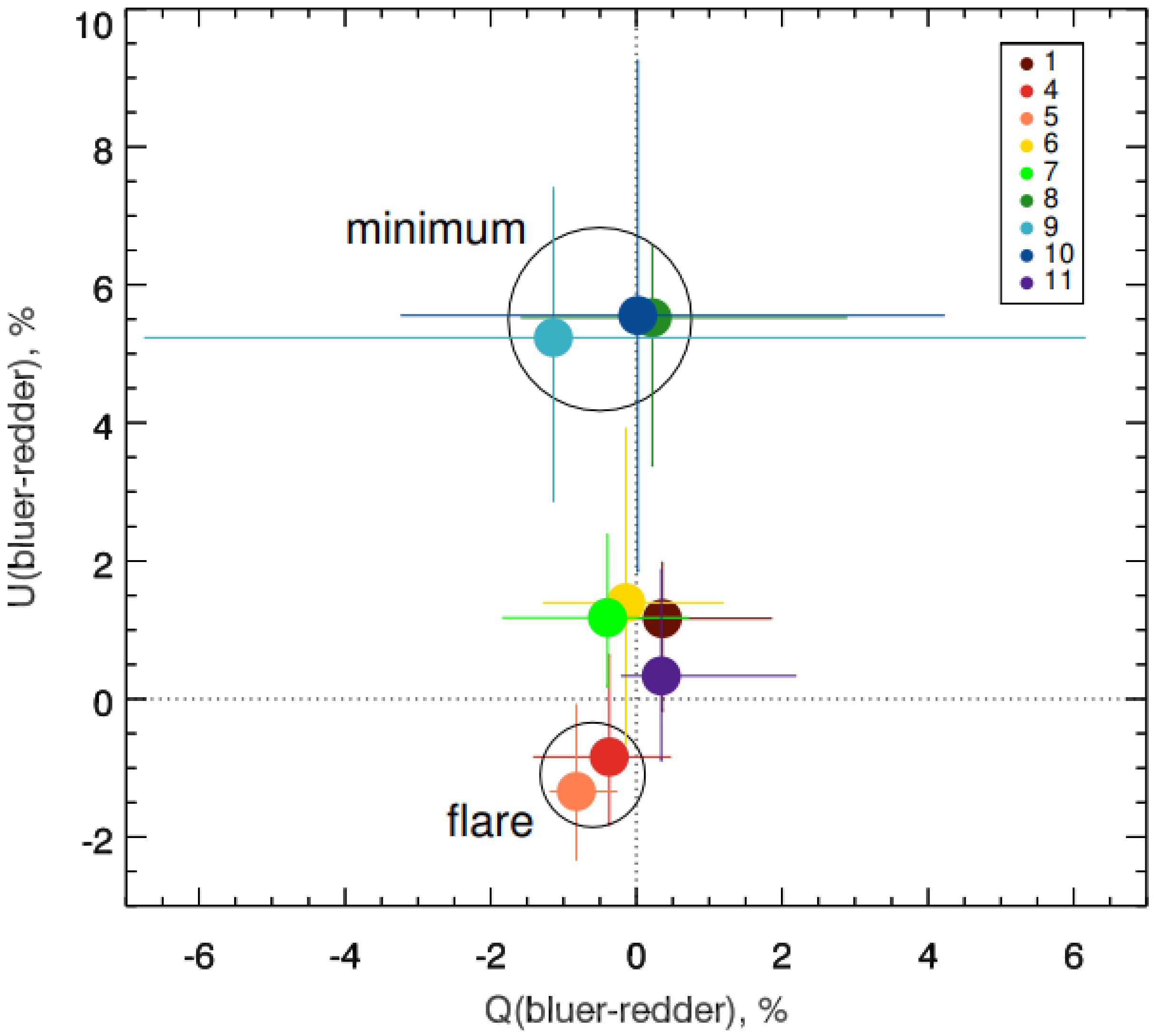
    - ❌ well-correlated
- Turbulent cells, no shock (TEMZ)
    - ❌ too long time-scale, “jumps”



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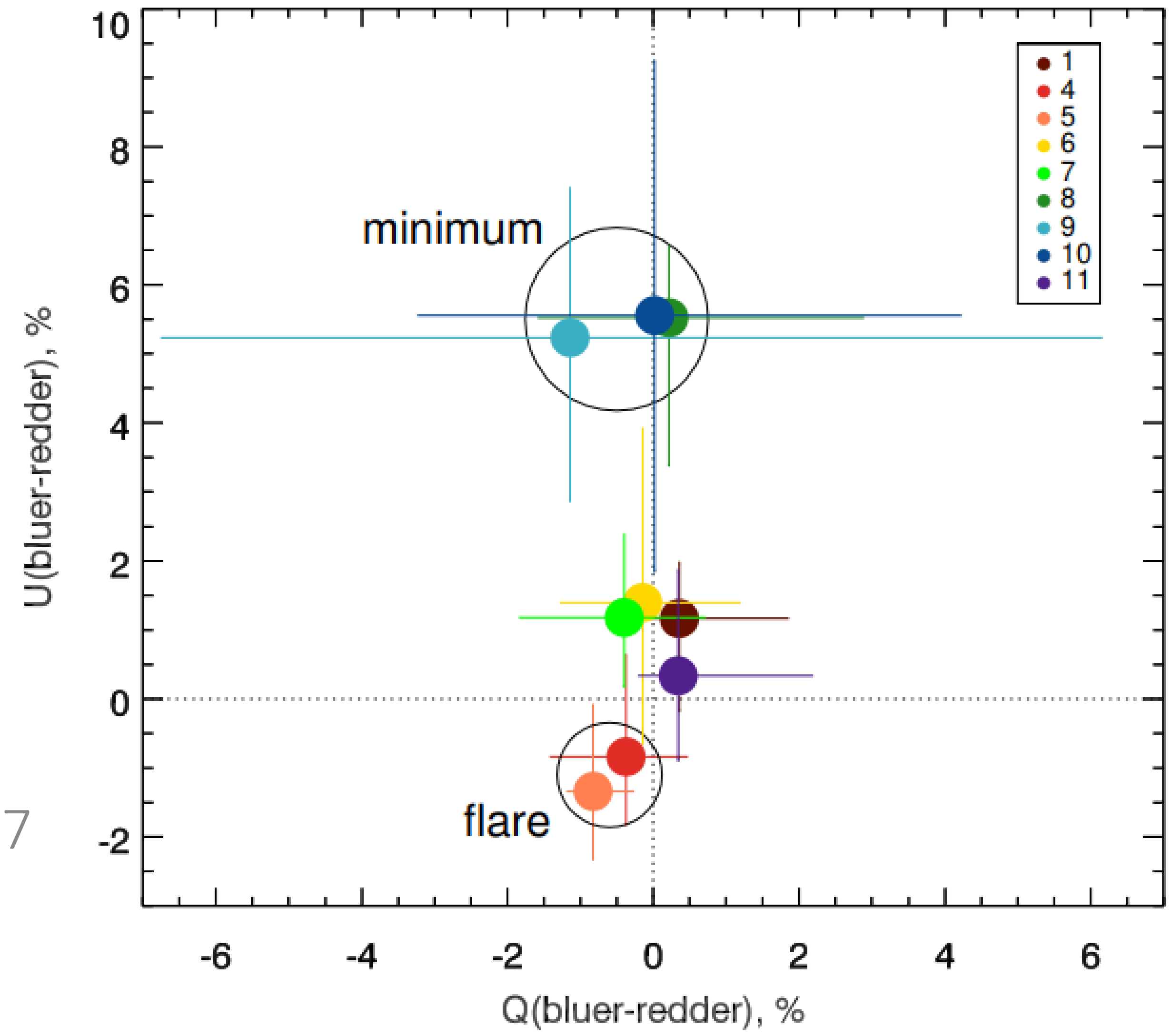
- Turbulent cells + shock (TEMZ)
  - ❎ too long time-scale

Marscher 14,+17



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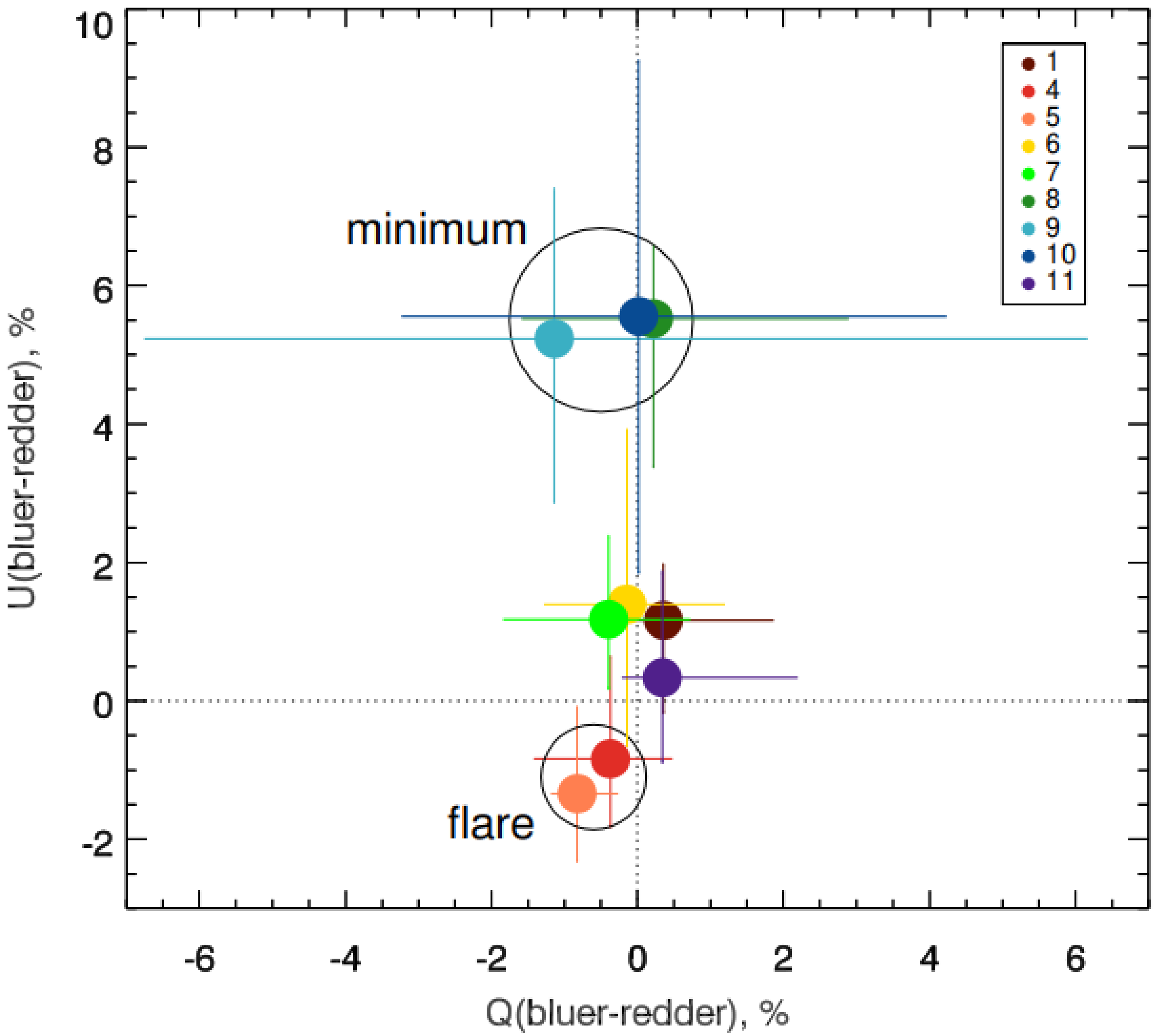
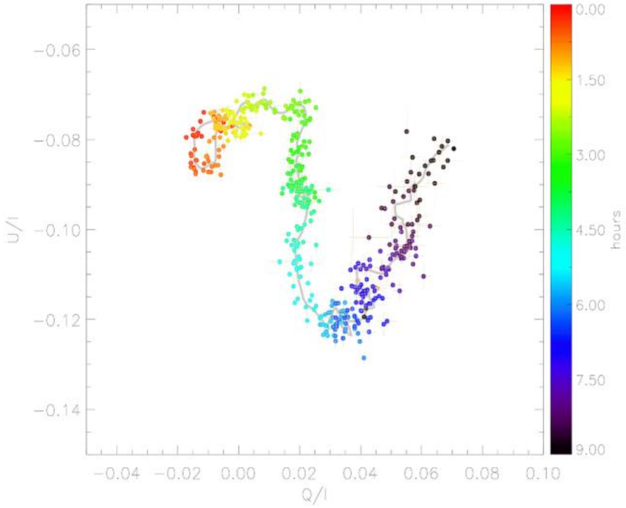
- Turbulent cells, no shock (TEMZ)
  - ❌ too long time-scale, “jumps”
- Turbulent cells + shock (TEMZ)
  - ❎ too long time-scale
- Synchrotron
  - ❎ broken, fast changing *N(E)*



Conclusions

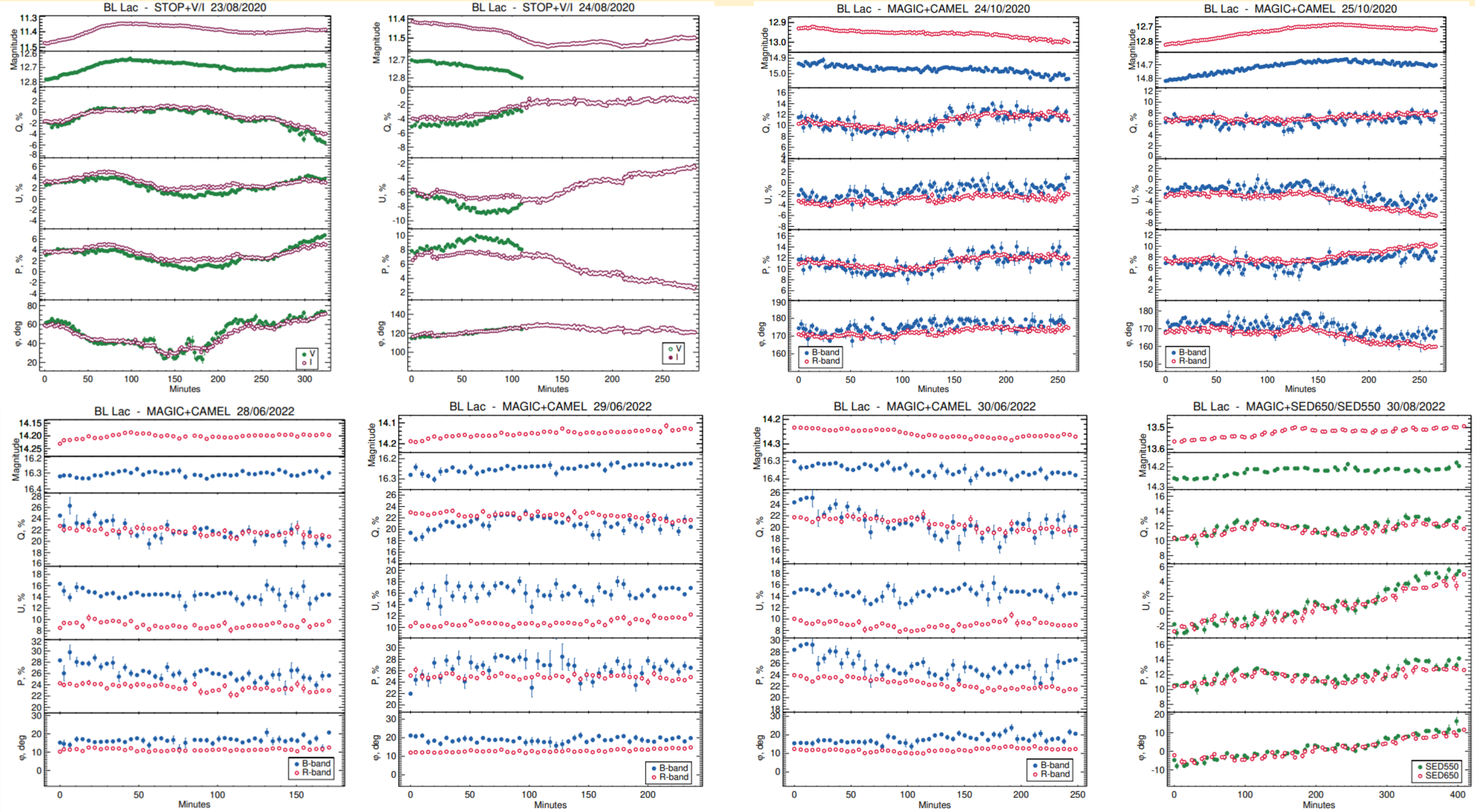
- Pure geometrical model is good but not enough
- In optical band synchrotron losses (if are) provide 10 G MF
- IDV on *QU*-plane form a patterns zoo with no trends
- Polarization chromatism tends to depend on activity state – more statistics is needed
- Model combination is needed: synchrotron polarization of varying N(E), turbulent cells evolution…



Shablovinskaya & Afanasiev 2019, *MNRAS*, 10.1093/mnras/sty2943
Shablovinskaya+2022, MNRAS, arXiv:2212.03200

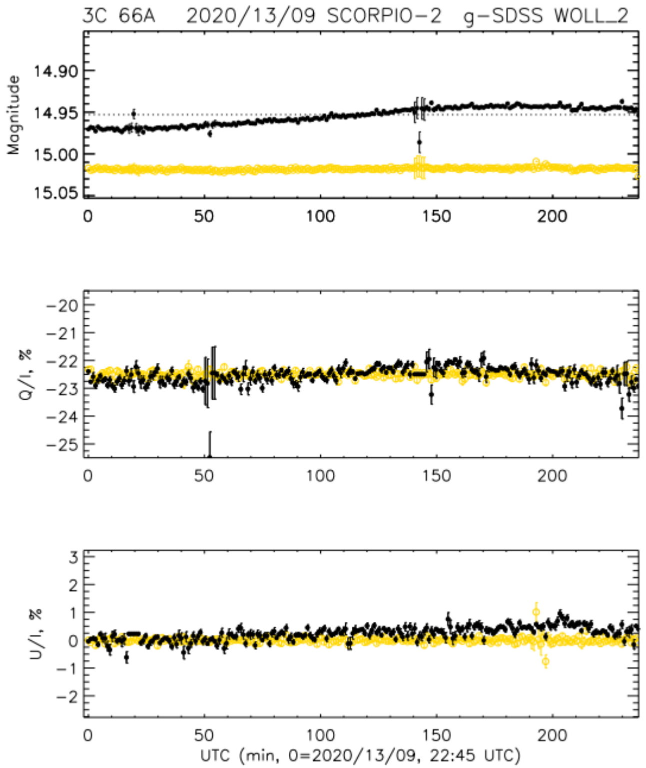
Appendix

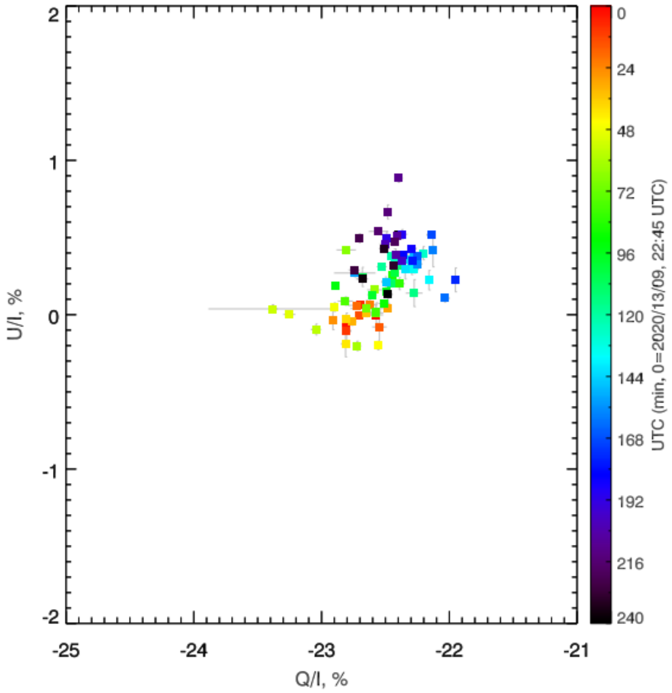
BL Lac

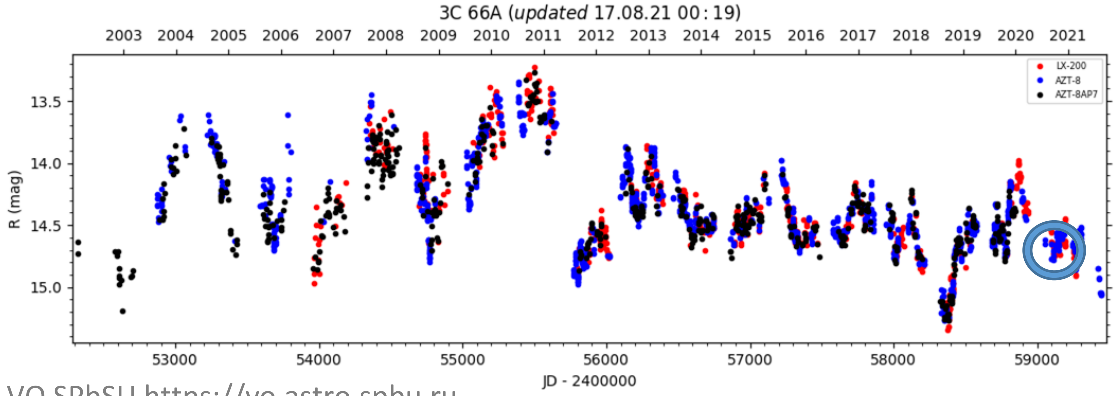


BL Lac - STOP+V/I 23/08/2020
BL Lac - STOP+V/I 24/08/2020
BL Lac - MAGIC+CAMEL 24/10/2020
BL Lac - MAGIC+CAMEL 25/10/2020
BL Lac - MAGIC+CAMEL 28/06/2022
BL Lac - MAGIC+CAMEL 29/06/2022
BL Lac - MAGIC+CAMEL 30/06/2022
BL Lac - MAGIC+SED650/SED550 30/08/2022
Magnitude
Q, %
U, %
P, %
φ, deg
Minutes
V
I
B-band
R-band
SED550
SED650

3C 66A





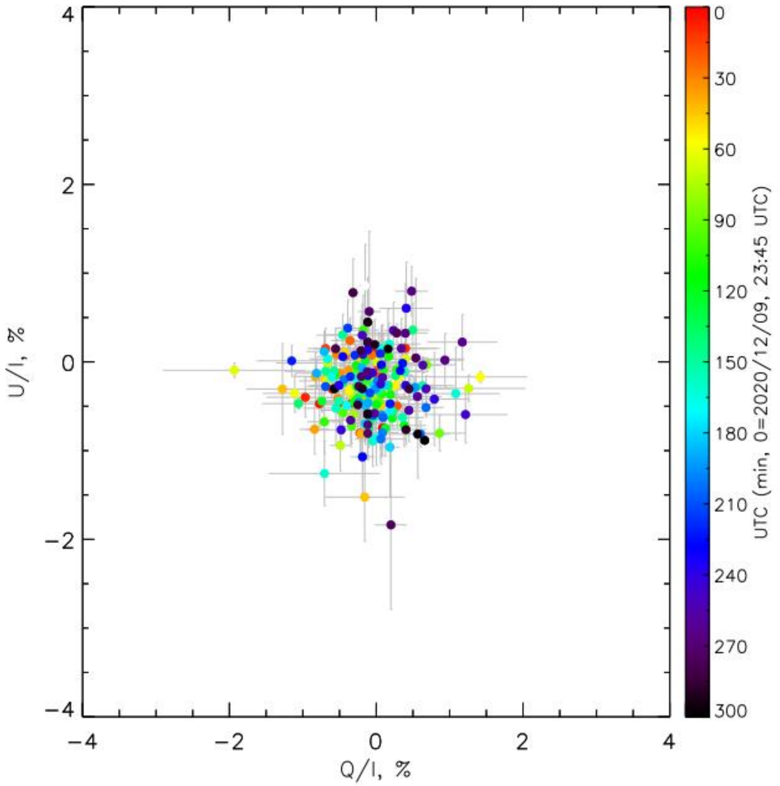


Credit: VO SPbSU https://vo.astro.spbu.ru

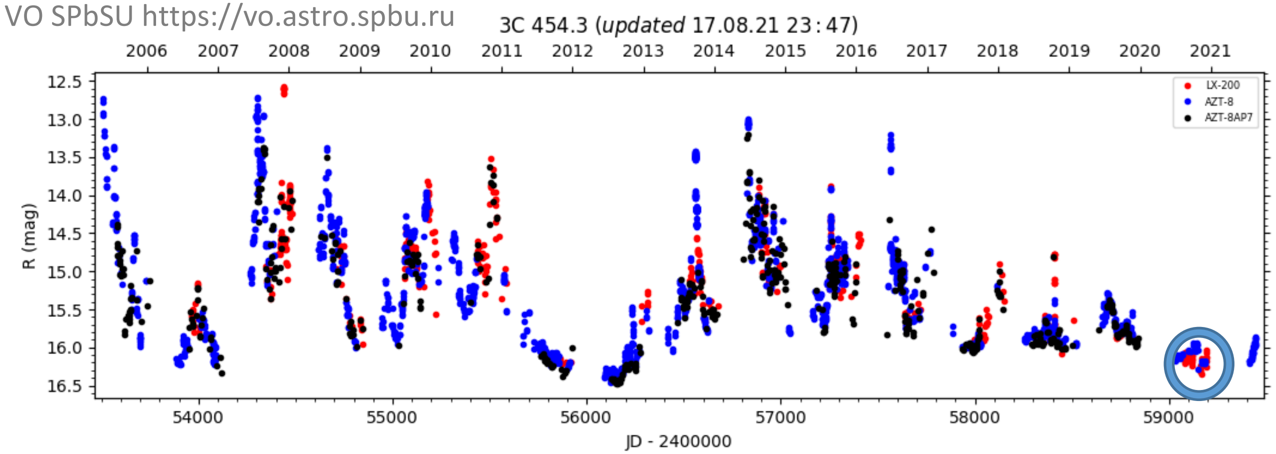
BTA+SCORPIO-2

Only about 2 hours of observations, but the polarization changes are detected. Blazar was in relatively low state.

3C 454.3



Credit: VO SPbSU https://vo.astro.spbu.ru



BTA+SCORPIO-2

5 hours of monitoring, but **no significant changes at all**! Very low state.

The global question: does IDV depend on the state? More observations for statistics are needed!

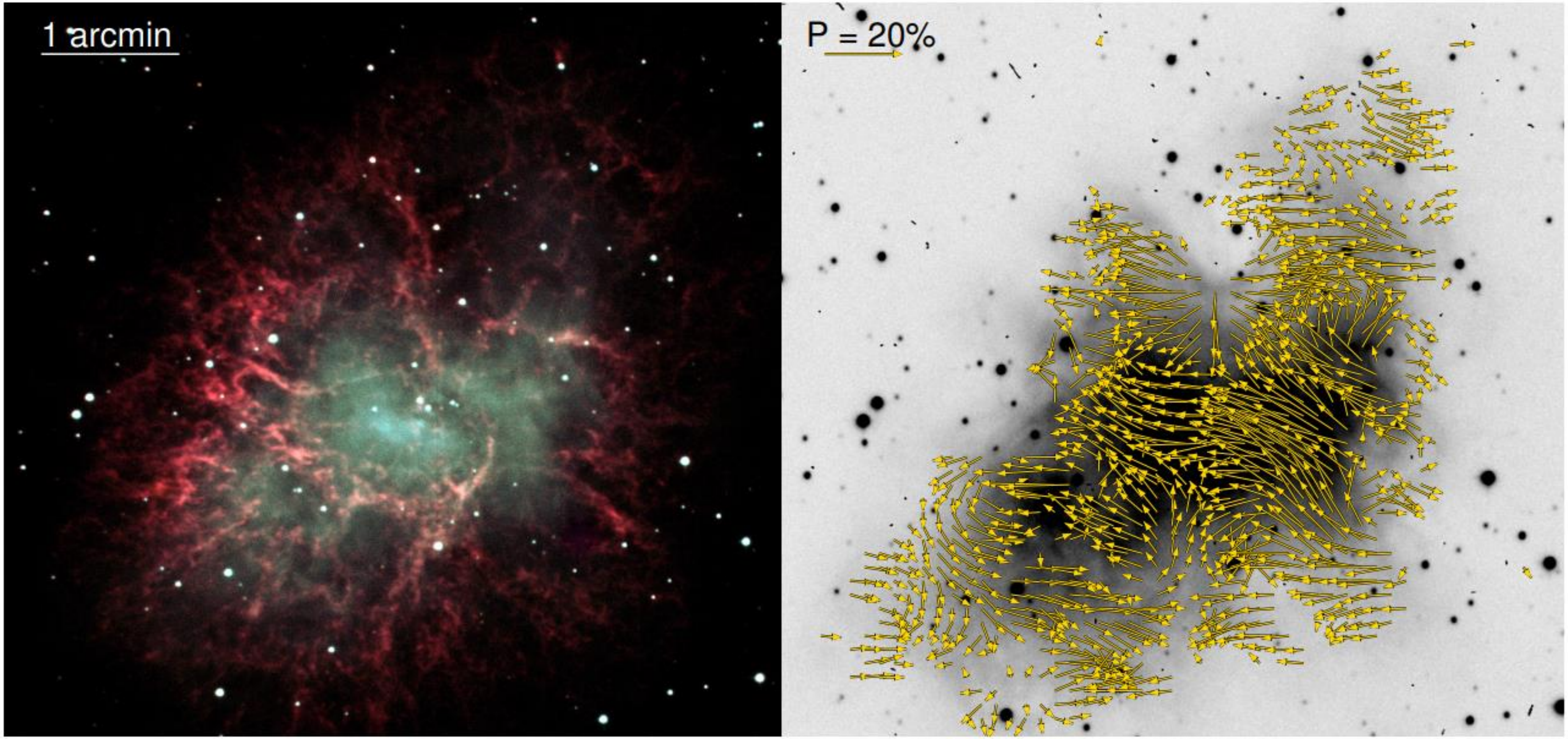


Fig. 16 Results of observations of the M1 nebula: *on the left*, a combined photometric image of the nebula in the B (blue), V (green), and SED650 (red) filters; *on the right* is the polarization map of the nebula obtained with the Wollaston quadrupole prism in the SED600 filter.