Optical Photopolarimetric Study of Blazar Outbursts

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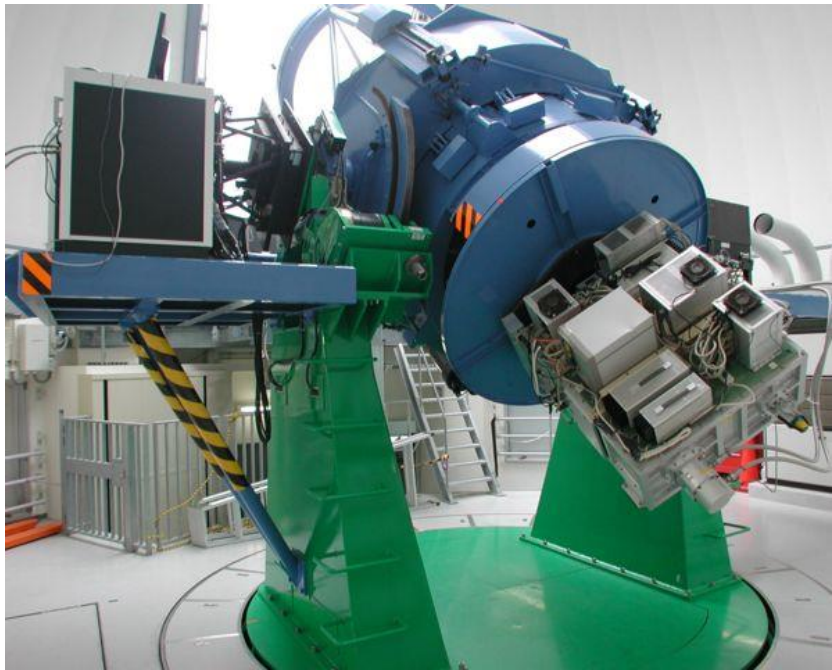

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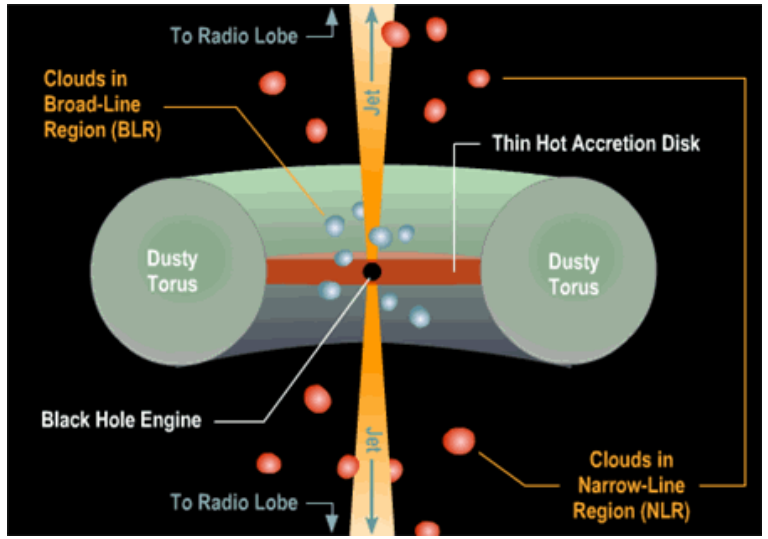
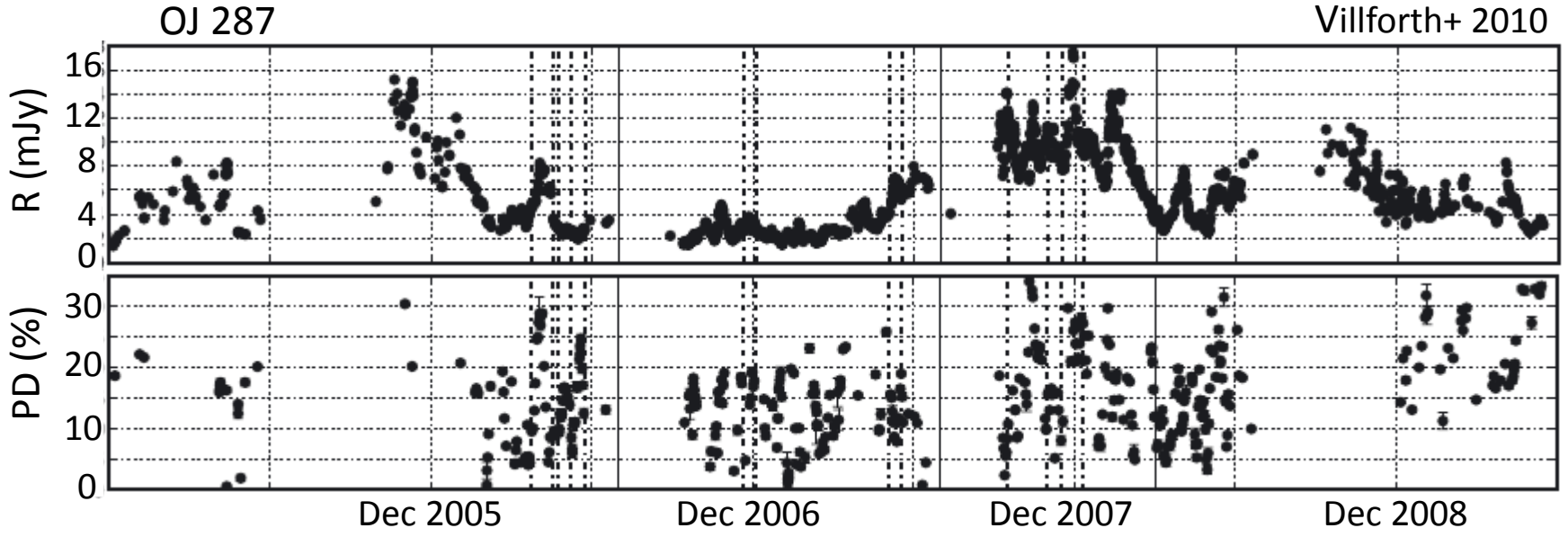
Optical Variability of Blazars



Original Image credit: Brooks/Cole Thomson Learning.

- An optical emission is radiated from an inner region of jets.
- Rapid and violent variability
  - Blazars often show 100 times brighter than its quiescent.
  - Time-scales are ranging from minutes to years.
- High and variable linear polarization
  - A degree of polarization, *P*, shows several percentage, but up to 50 % in our monitoring.

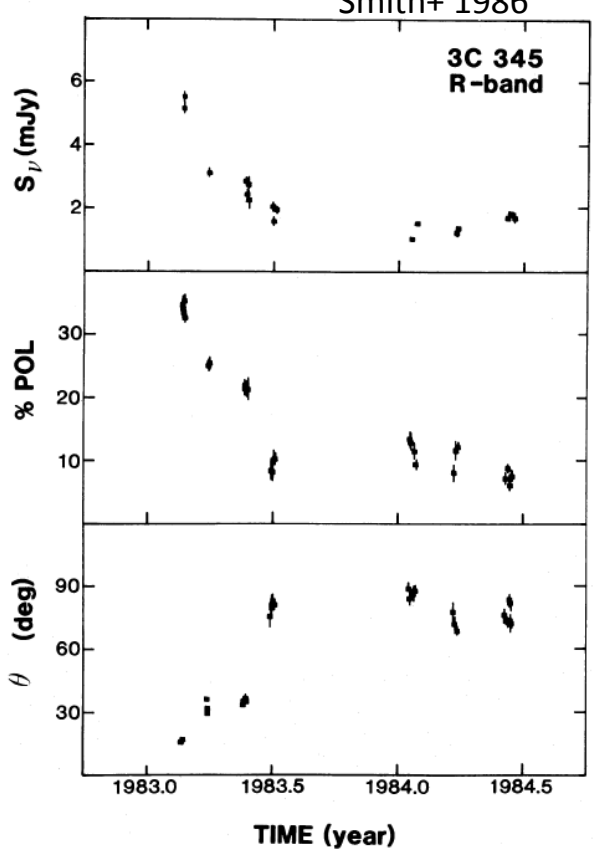


Correlation between Flux and Polarization

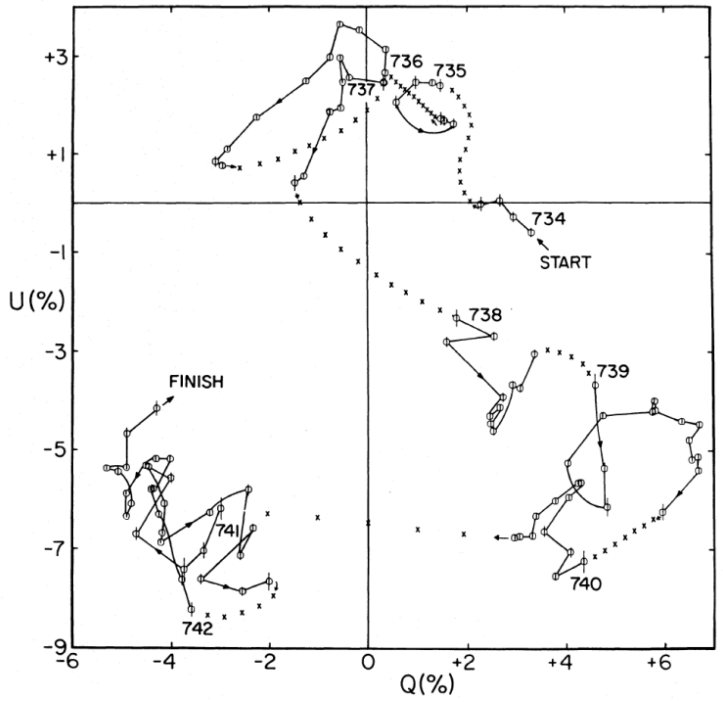
- Positive correlation between the flux and *P* (e.g. Smith+ 1986)
- Apparently random motion in the QU plane (e.g. Moore+ 1982)
- Recent papers suggest that the polarization vector can be separated in two components; short- and long-term components.

(e.g. Villforth+ 2010; Uemura+ 2010; Sakimoto+ 2013)

Smith+ 1986



Moore+ 1982



The flux and polarization of blazars show complex behaviors.

Kanata 1.5-m Optical Telescope

- Higashi-Hiroshima Obs. Japan
  - 1.5-m reflecting telescope
  - **Dense and continuous monitoring**
- Instruments (HOWPol and HONIR)
  - **Simultaneous optical and near-infrared observations** (HONIR)
  - **Obtain linear polarization** (both instruments)

Kanata telescope is suitable for monitoring blazars.

Monitoring Project of Blazars using Kanata

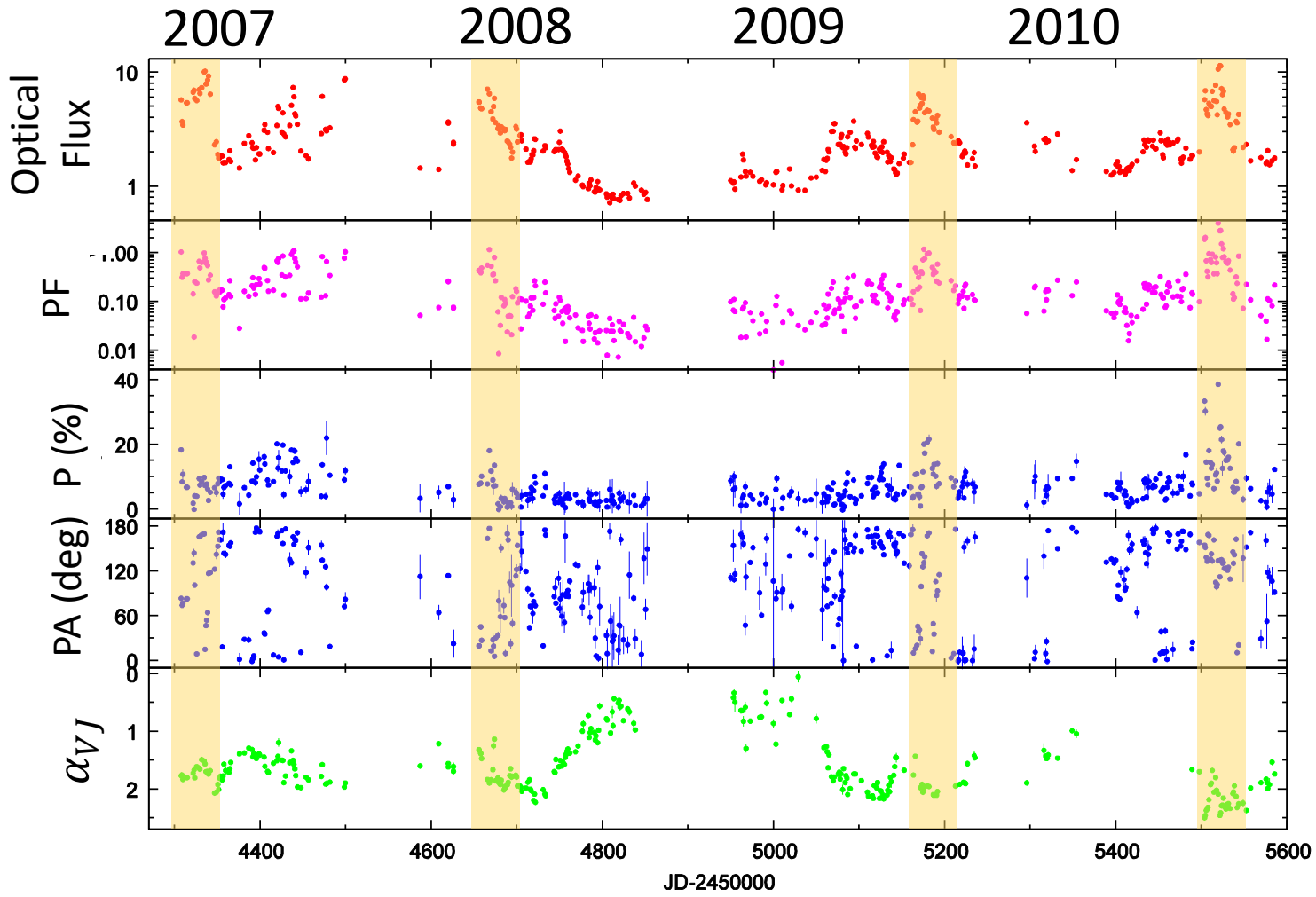
- Investigate the origin of flux and polarization variabilities.
- We monitored 44 blazars in the multi-band photopolarimetric mode.
- Obs. Period: May 2008 --- Dec. 2010

1ES 0323+022	3C 371	Mis V1436	PG 1424+240	PKS 1510-089	S2 0109+224
1ES 0647+250	3C 454.3	Mrk 421	PG 1553+113	PKS 1749+096	S4 0954+65
1ES 0806+524	3C 66A	Mrk 501	PKS 0048-097	PKS 2155-304	S5 0716+714
1ES 1959+650	4C 14.23	OJ 287	PKS 0215+015	QSO 0324+341	S5 1803+784
1ES 2344+514	4C 49.22	OJ 49	PKS 0422+004	QSO 0454-234	
1H 0323+342	AO 0235+164	ON 231	PKS 0754+100	QSO 0954+550	
3C 273	BL Lacertae	ON 325	PKS 1222+216	QSO 1239+044	
3C 279	H 1722+119	OQ 530	PKS 1502+106	RX J1542.8+6129	

3C 454.3: Four Outbursts

- The object has occurred four large-amplitude long-term outbursts for our monitoring period.
- In outbursts, the *P* increased.
  - Maximum *P* were 39 % and 47 % in the optical and near-infrared bands.
- In the 2007, 2008 and 2009 outbursts, there were rotation events of polarization vector.

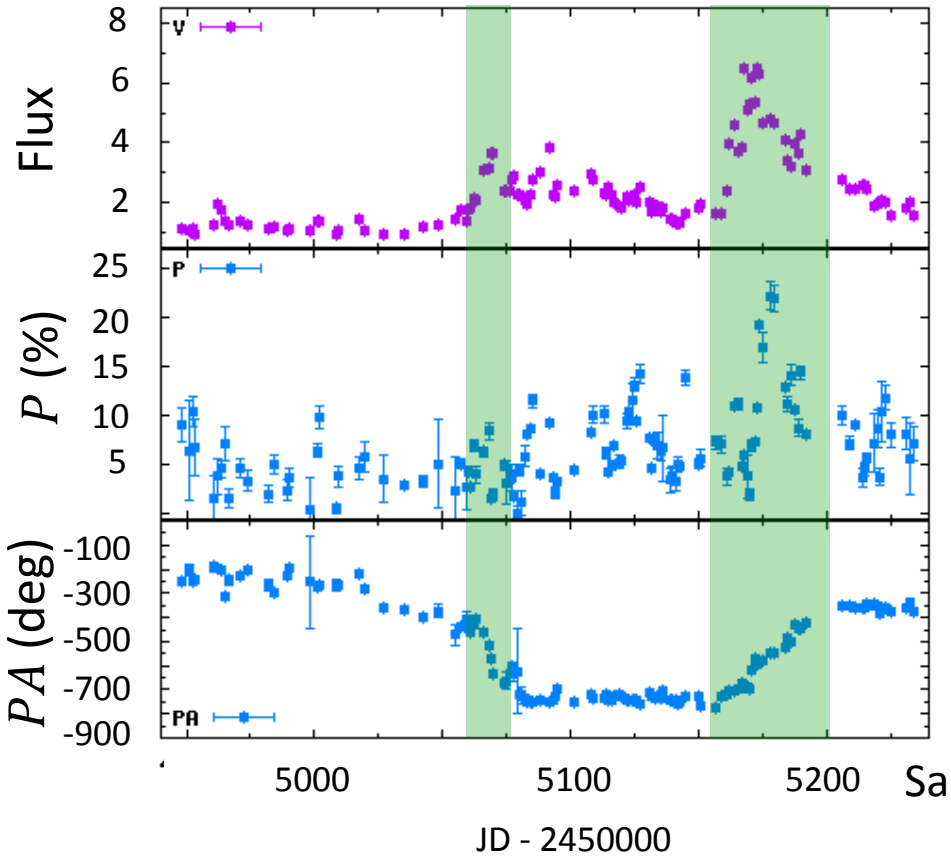
➢Polarization is likely to be varied associated with outbursts.



Sasada et al. 2010, 2012, 2014

3C 454.3: Rotation of Polarization in 2009

- During the outburst, the polarization vector has been rotated in clockwise direction.
  - $\Delta \mathrm{PA} = 400$ deg
- The polarization vector was also rotated in counterclockwise before the outburst.
  - $\Delta \mathrm{PA} = 270$ deg

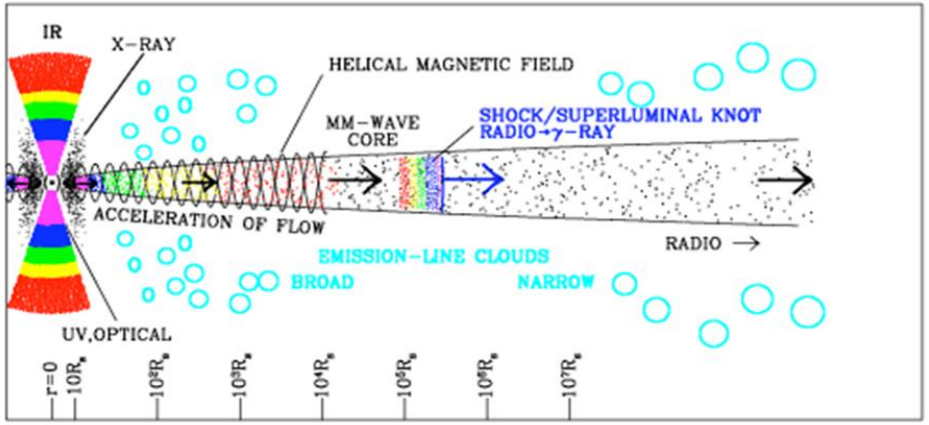


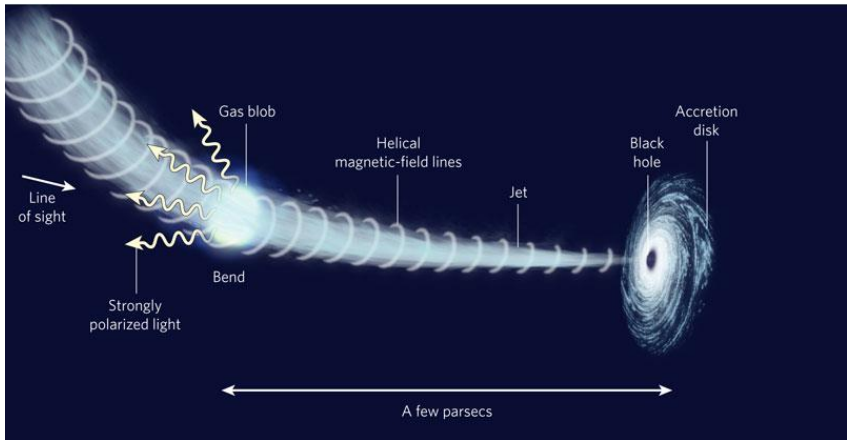
Sasada+ 2010

In 3C 454.3, other three rotation events were also detected.

Explanation of Rotation Events

- Helical magnetic field and enter the emission region (Marscher+ 08)
- Bending Jet model for both-direction rotations (Abdo+ 10)





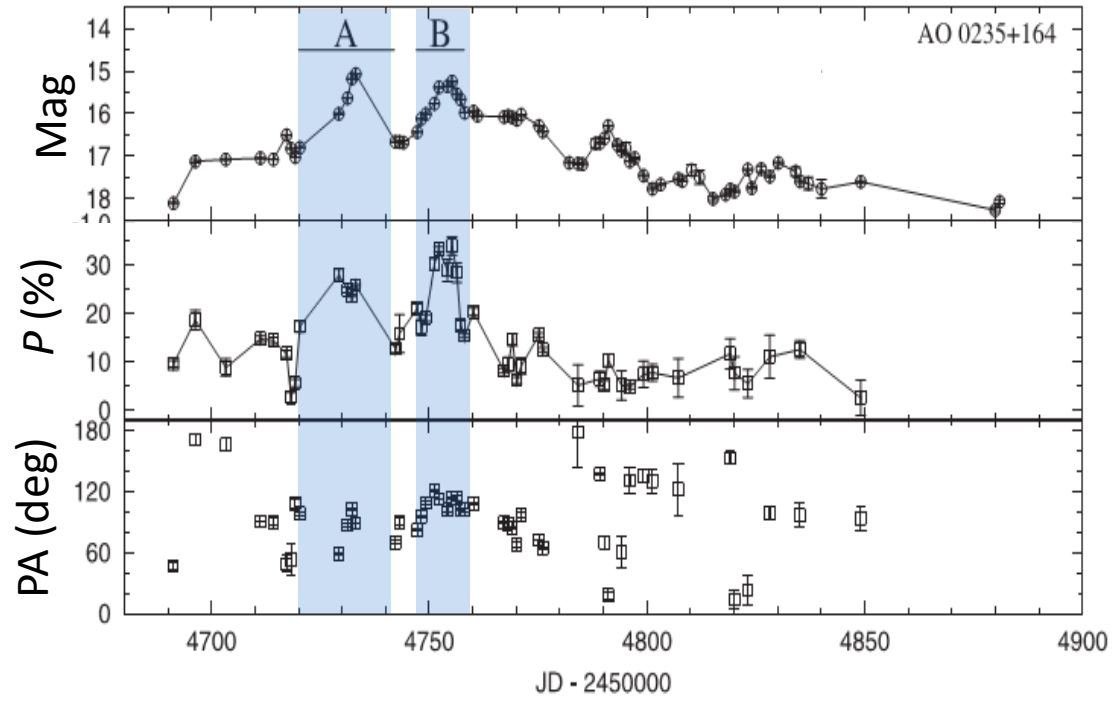
⇨ **Polarization leads to jet structure and magnetic field.**

We can obtain the information of inner jet region from rotation events.

Outburst and Polarization

☐Blazar AO 0235+164

- The object exhibited an outburst, and 20 times brighter than the quiescent level.
- There were two large-amplitude flares. Then, the *P* became high, up to 35 %.

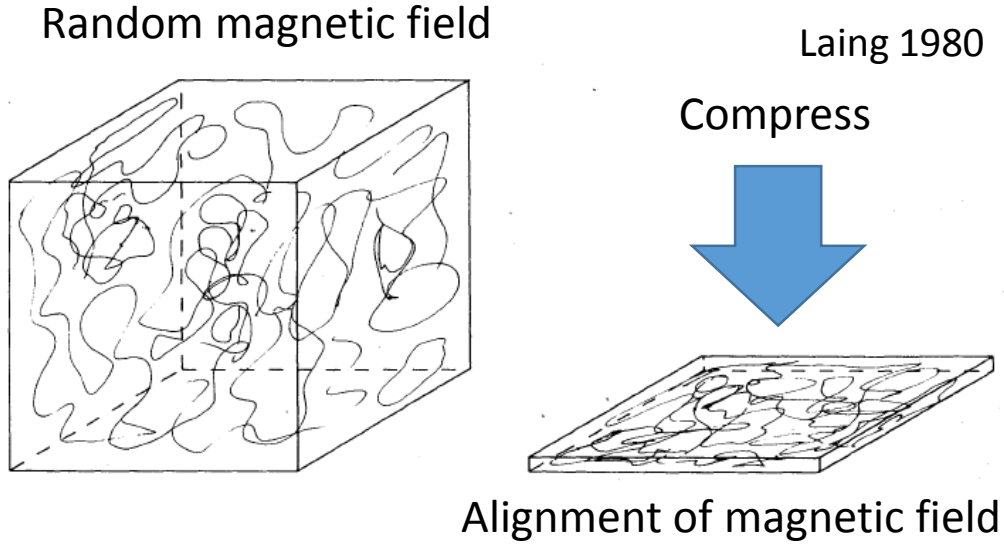


Sasada+ 2011

Similar increases of *P* in flares and outbursts are shown in other our monitoring blazars.

Alignment of Magnetic Field by Compression

- An observed degree of polarization is proportional to a degree of alignment of the magnetic field in an emitting region.
- The magnetic fields are compressed by a shock in a jet.
- The magnetic fields should be aligned by the compression. The synchrotron radiation is polarized emitting from the compressed region.



The polarization is induced from the compression of the magnetic fields caused by a shock.

Flares and Magnetic fields

Result : Large amplitude flares are associated with polarization variations.

+

Consideration :

1. If there is a shock, particles accelerated by the first-order Fermi acceleration process in a shocked region can be occurred.
2. The magnetic fields causing the observed polarization can be aligned by the compression of the shock.

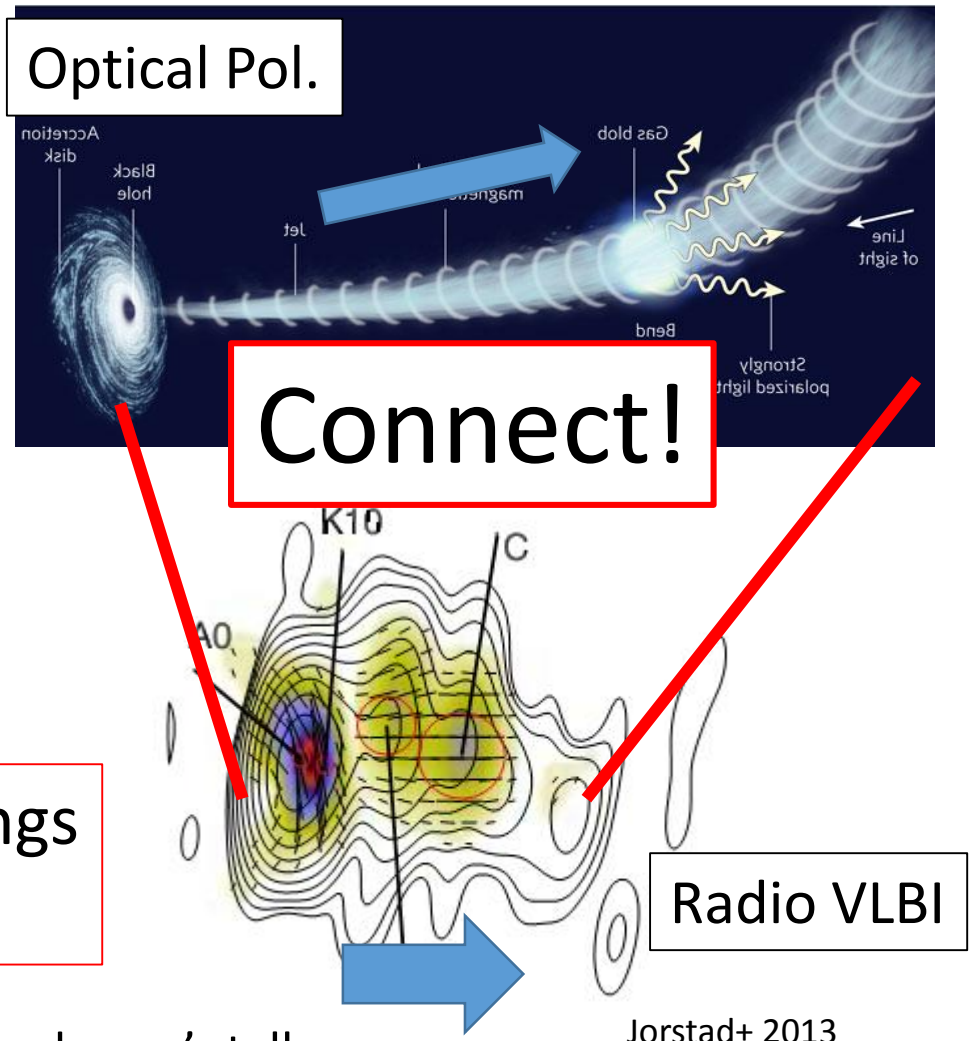
II

Shocks produce flares and alignments of the magnetic fields.

Connection between Radio and Optical

- The generation of shocks is involved to the outbursts and flares.
- Superluminal knots were associated with large-amplitude outbursts. (e.g. Agudo+ 2011)
- An optical emission is the indicator of inner region of the jet.
  - An inner region of magnetic fields comes from the optical polarization.
- Radio images with mas-scale resolution can trace the superluminal knots generated by outbursts.

Abdo+ 10



Jorstad+ 2013

Connection between radio and optical monitorings can trace the emission region of outburst.

Radio and Optical collaborate monitoring with VERA is ongoing -> Sawada-san's talk

Summary

- Optical flux and polarization of blazars show large-amplitude and violent variations.
- Rotation events of polarization were detected during large-amplitude outbursts of 3C 454.3.
- Increases of degree of polarization were observed during flares and outbursts.
- The connection between radio and optical monitorings of blazars can have a potential to study the emission region of inner jet.

Thank you for your attention.