

On the time variable rotation measure in the core region of Markarian 421

*Eating VLBI Workshop 2017
Jeju, Korea
30 October 2017*

Presented by:

Rocco Lico,

J.L.Gómez, K. Asada, A. Fuentes, M. Giroletti, M. Orienti, D'Ammando, G. Giovannini, et al.



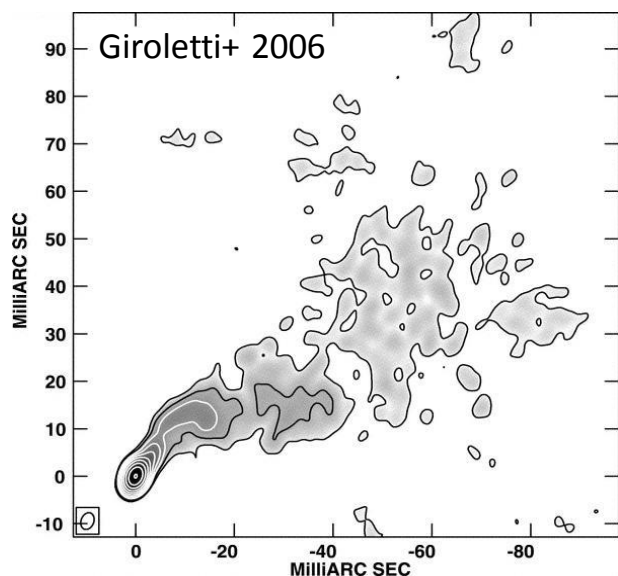
East Asia To Italy: Nearly Global VLBI Workshop 2017

The HSP blazar Markarian 421

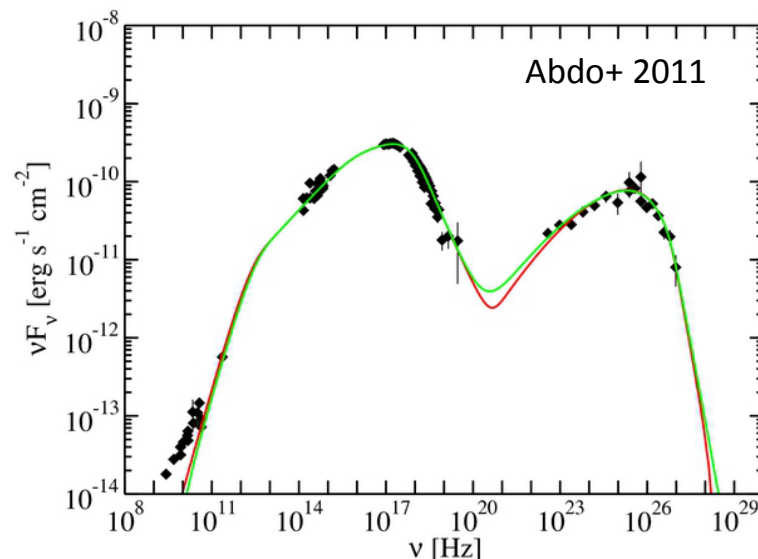
Mrk421 is a nearby BL Lac object ($z = 0.031$)

$$M_{\text{BH}} \sim 2\text{-}9 \times 10^8 M_{\odot}$$

$$R_s \sim 2.7 \times 10^{14} \text{ cm } (8.6 \times 10^{-5} \text{ pc})$$



It shows a jet structure oriented in North-West direction, starting from the core and extending for several tens of mas.



- HSP object.
- Detected by EGRET.
- It is a bright Fermi source.
- Multi-wavelength study by Abdo et al.

It is the first extragalactic object revealed in TeV band

Multi-frequency dataset

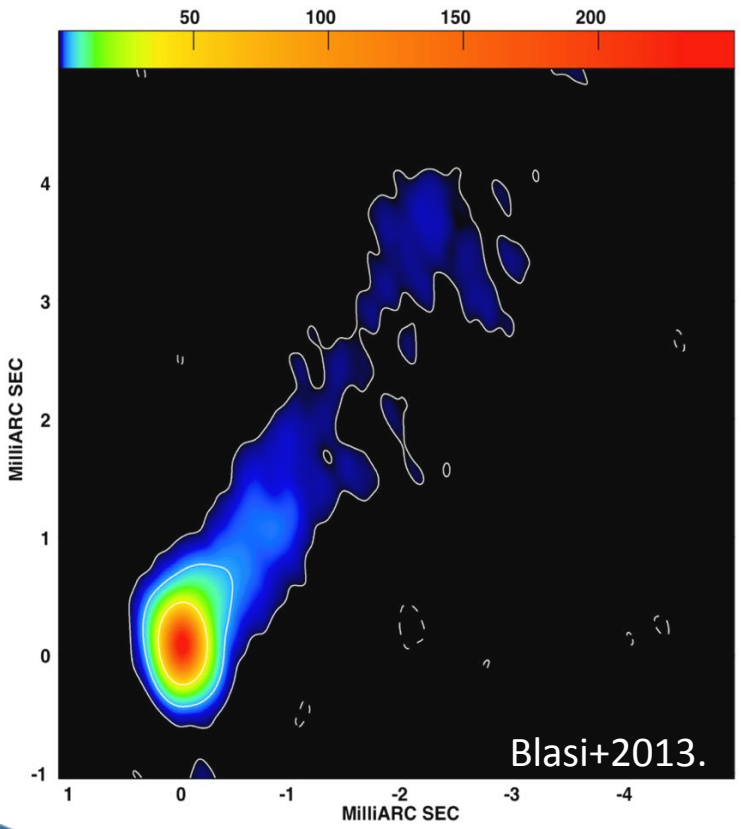


VLBA obs. at 15, 24 and 43 GHz



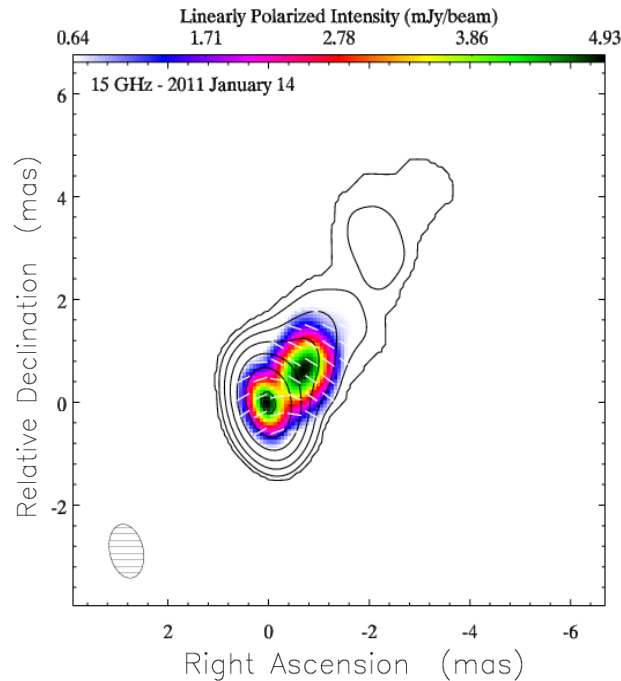
12 epochs during 2011

in total and polarized intensity



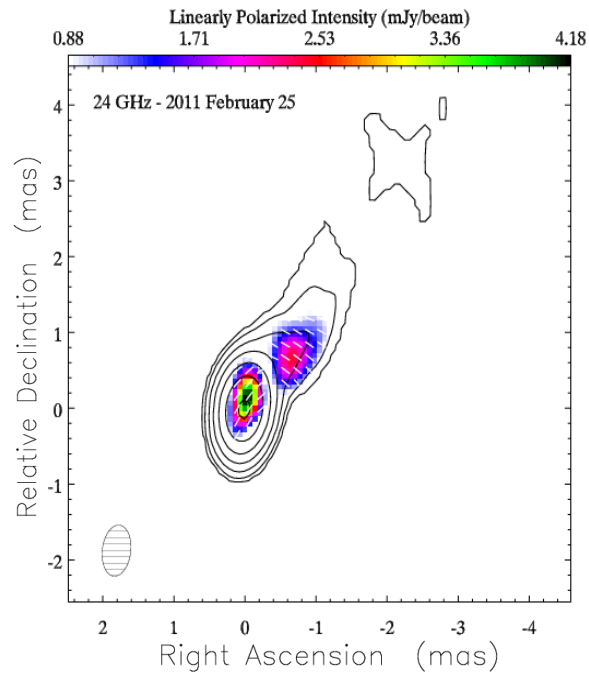
- Well defined **Jet** structure in NW direction (PA $\sim -35^\circ$), extending over of ~ 4.5 mas (~ 2.67 pc @ $z=0.03$).
- The mean **flux density** of nuclear region is ~ 350 mJy.
- Detected only stationary components within the jet, by using obs. over a 12-month period.

Polarized intensity images



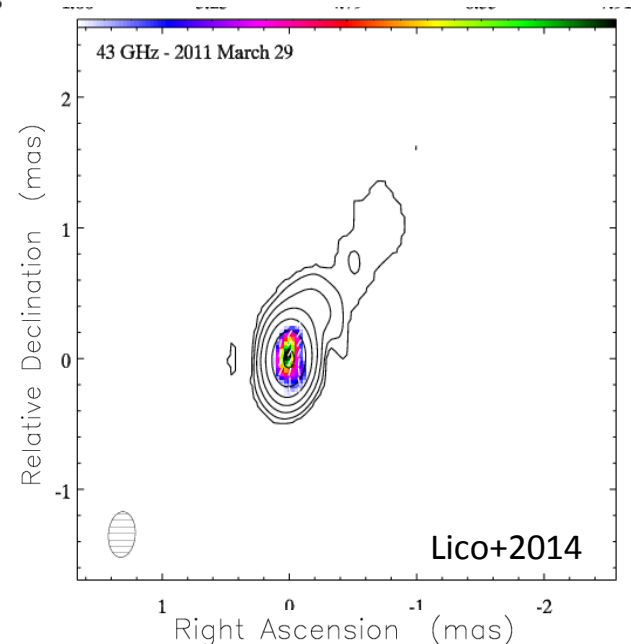
15GHz

Beam: 0.92mas x 0.54mas



24GHz

Beam: 0.58mas x 0.35mas



43GHz

Beam: 0.42mas x 0.27mas

- The polarized emission extends for about 1 mas from the core region at 15 and 24 GHz.
- At 43 GHz we only detect polarized emission within the core region.
- The mean degree of polarization for the core is ~1%, while for the Jet ~15%.

Polarization parameters: core region at 43 GHz

Total intensity emission



S (mJy)

Polarized emission



P (mJy)

Fractional polarization

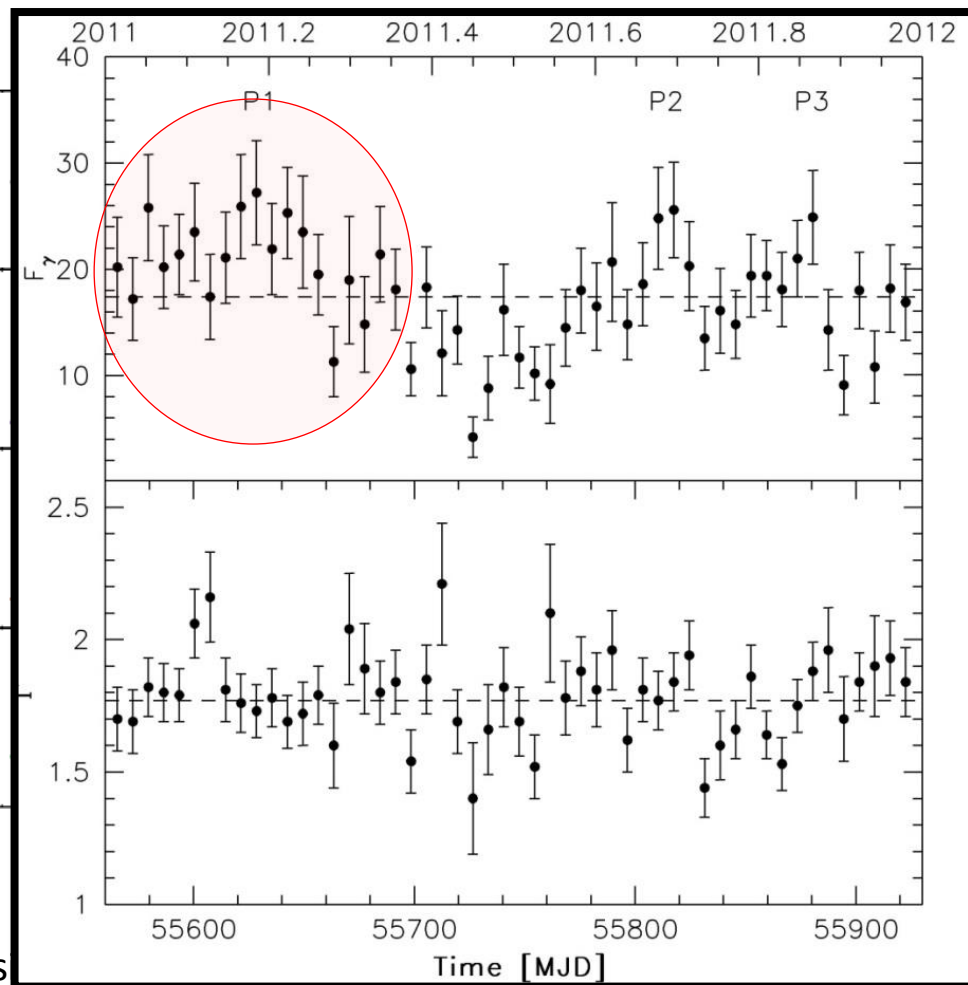


m (%)

EVPAs



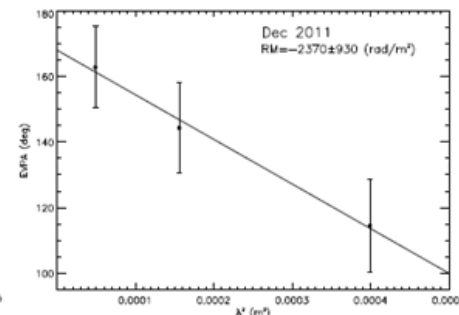
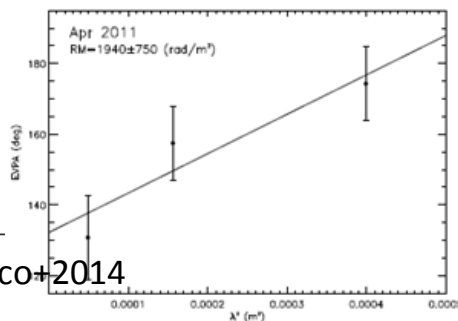
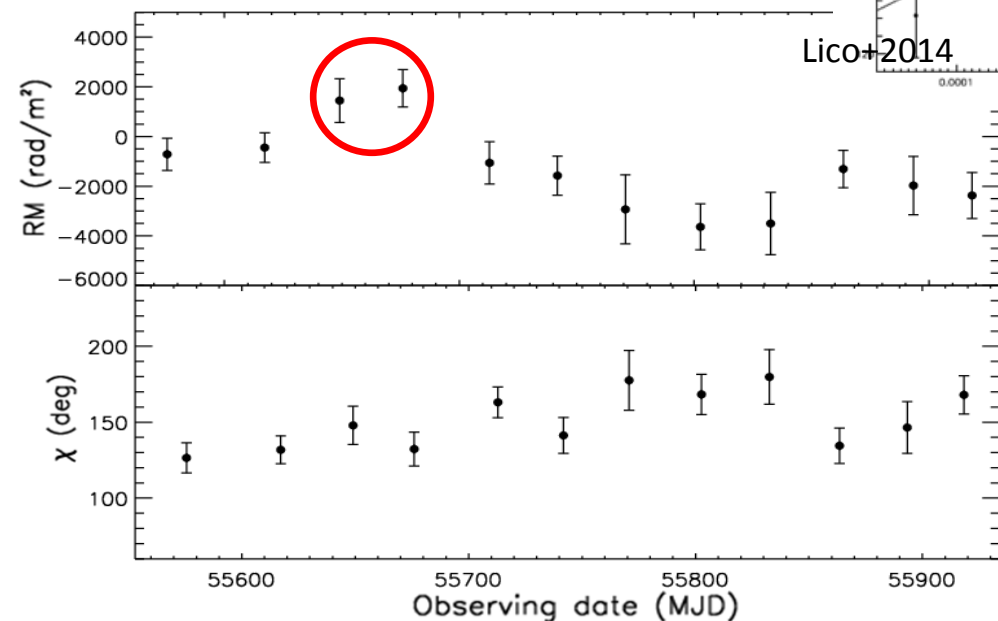
EVPA (deg)



- There is a main peak in the total intensity emission.
- The polarized flux reaches a 12 mJy peak during the 3th observing epoch.
- The mean degree of polarization for the core is ~2%.
- EVPAs have a stable behavior with the time around 150° (i.e. magnetic field transverse to the jet PA).

Faraday rotation analysis

$$\chi_{\text{obs}} = \chi_{\text{int}} + RM \times \lambda^2$$



❖ Time variable RM with sign reversals.

❖ Intrinsic pol. angle roughly stable around ~150°.

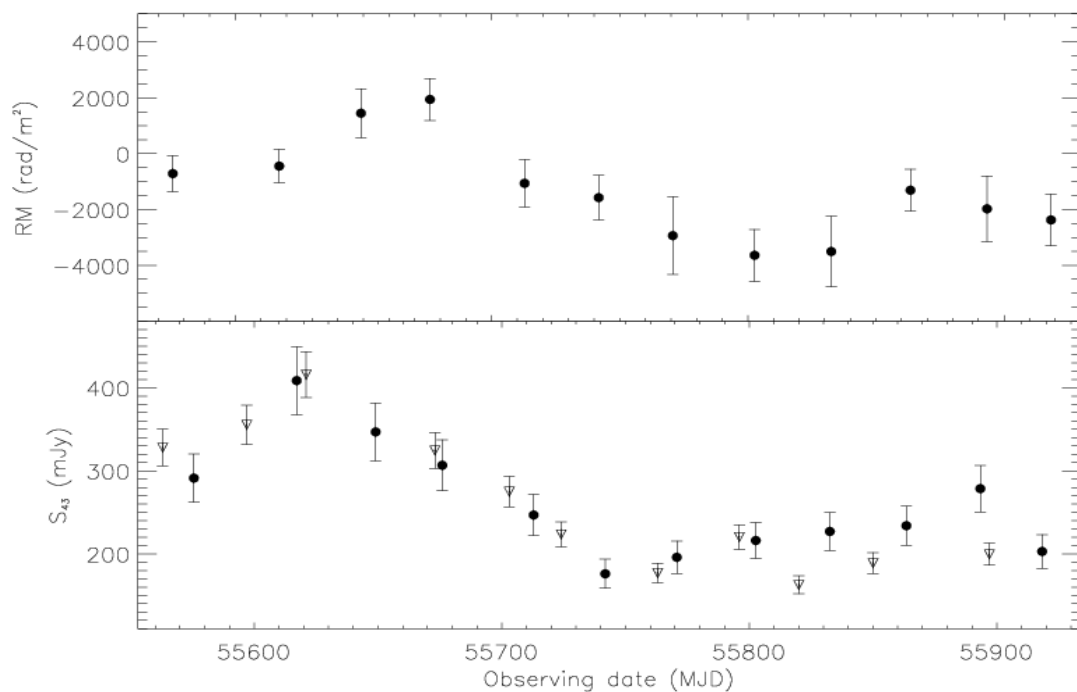
Assumptions:

- Faraday screen mostly external to the emitting region.
- Most of the observed RM produced by thermal electrons.

Where is the Faraday screen?

RM vs. 43 GHz flux density

$$RM = 812 \int n_e \mathbf{B}_{\parallel} \cdot d\mathbf{l} \quad [\text{rad m}^{-2}]$$



RM time evolution

43 GHz Tot int light curve

- ❖ RM and core flux density \rightarrow similar trend
- ❖ RM variability related to changes in the accretion rate?

Accretion rate from the observed RM

Assumptions:

- ✓ roughly spherical accretion flow;
- ✓ power-law radial density profile $n \propto r^{-\beta}$, with β ranging from 3/2 (ADAF) to 1/2 (CDAF);
- ✓ radial, ordered and of equipartition strength magnetic field.

$$\dot{M} = 2.2 \times 10^{-9} [1 - (r_{\text{out}}/r_{\text{in}})^{-(3\beta-1)/2}]^{-2/3} \times \left(\frac{M_{\text{BH}}}{6.6 \times 10^9 M_{\odot}} \right)^{4/3} \left(\frac{2}{3\beta-1} \right)^{-2/3} r_{\text{in}}^{7/6} \text{RM}^{2/3} \text{ rad m}^{-2} \rightarrow \boxed{\dot{M} \sim 2.5 \times 10^{-5} M_{\odot}/\text{yr}}$$

Kuo+ 2014.

By using the bolometric luminosity: $\rightarrow \boxed{\dot{M} \sim L/(0.1 \times c^2) \sim 1.5 \times 10^{-2} M_{\odot}/\text{yr}}$

- ❑ Accretion flow is not spherical (possibly disc/torus like).
- ❑ Magnetic field weaker than the equipartition value and/or is not ordered (tangled);

Sign reversals!

RM from the jet sheath

- ❑ Thermal electrons in the jet sheath can act as a foreground Faraday screen.
- ❑ RM gradient transverse to the jet axis → helical magnetic fields.

Christodoulou+2016

Poynting-Robertson cosmic battery effect (Contopoulos+1998, 2009).

Differential rotation of the accretion disk



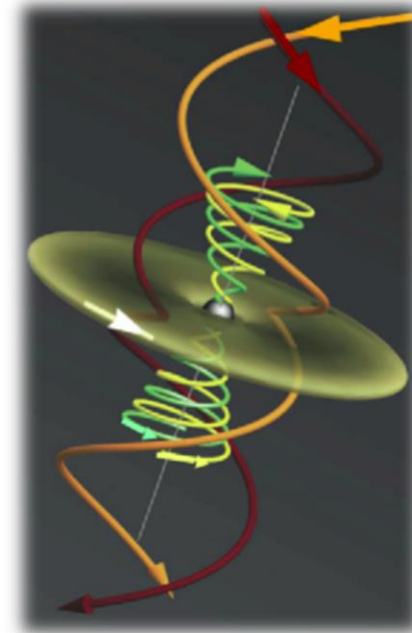
two nested helical fields in the jet:

- **inner component** near the disk symmetry axis, with same helicity as the accretion disk rotation;
- **outer component** further from the axis, with opposite helicity.

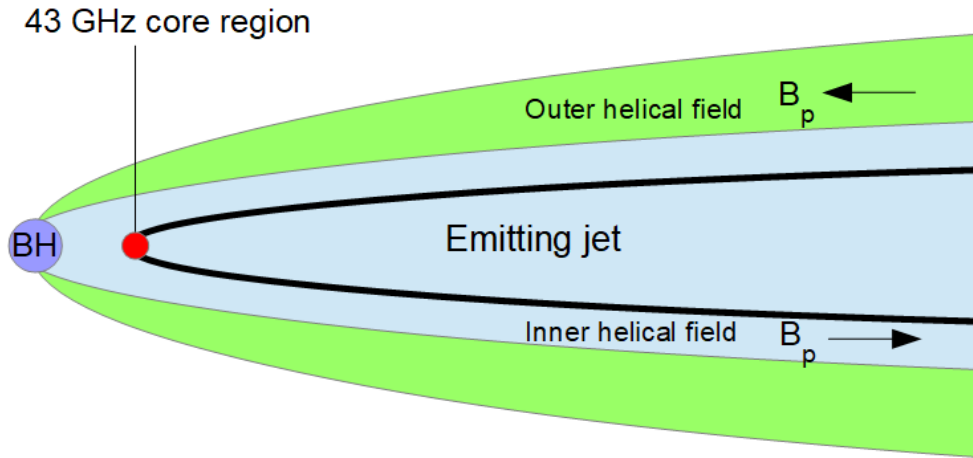
The poloidal fields (\mathbf{B}_p) in the inner/outer helical components have opposite directions:

- inner field \mathbf{B}_p parallel to the angular velocity vector ($\boldsymbol{\omega}$);
- outer field \mathbf{B}_p antiparallel to $\boldsymbol{\omega}$.

The net observed RM includes the contribution from both inner/outer field components.



Drawing a scenario for Mrk 421



We use the numerical model described in Gómez+(1995, 1997):

- ✓ viewing angle = 5° ;
- ✓ bulk flow Lorentz factor $\Gamma = 1.7$;
- ✓ different pitch angle ϕ values.

We assume that:

inner helical field: B_p in the observer's direction \rightarrow positive RM;

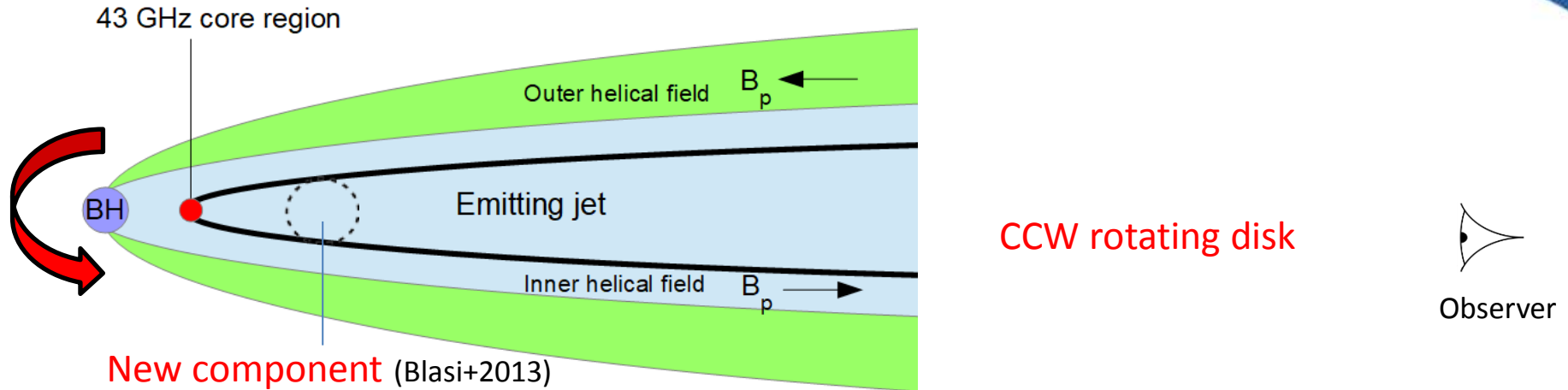
outer helical field: B_p in the opposite observer's direction \rightarrow negative RM.



Dominant contribution to the observed RM.

- the magnetic field toroidal component only affects the transverse RM gradient.
- $\phi \geq 70^\circ$ required to obtain an intrinsic polarization angle $\sim 150^\circ$.

Drawing a scenario for Mrk 421



Inner helical field: positive RM.

Outer helical field: negative RM.

RM sign change if the inner helical field temporarily dominates the RM contribution



increased activity in the central engine, possibly followed by the ejection of a new jet comp., producing a bow shock expanding in the neighboring regions (e.g. Gomez+1997, Fromm+2016).

Concluding remarks

Accounting for RM sign reversals:

- Faraday screen in the jet sheath.
- PR cosmic battery effect -> two nested helical fields with opposite helicities in the jet.

Lico+2017 (MNRAS 469, 1612)

Thank You!

Additional scenarios:

- ❑ Small changes in the jet speed and/or slight bends of the parsec scale jet (by assuming that the Faraday rotating sheath is moderately relativistic, O'Sullivan & Gabuzda 2009). **(Jongho Park Talk)**
- ❑ RM sign reversals can arise in the transition regions between ultra-relativistic and moderately relativistic helical motion in the AGN core proximity (Broderick & Loeb 2009).
- ❑ Blend of multiple sub-components with different polarization properties (Hovatta+2012, Kravchenko+2017).

