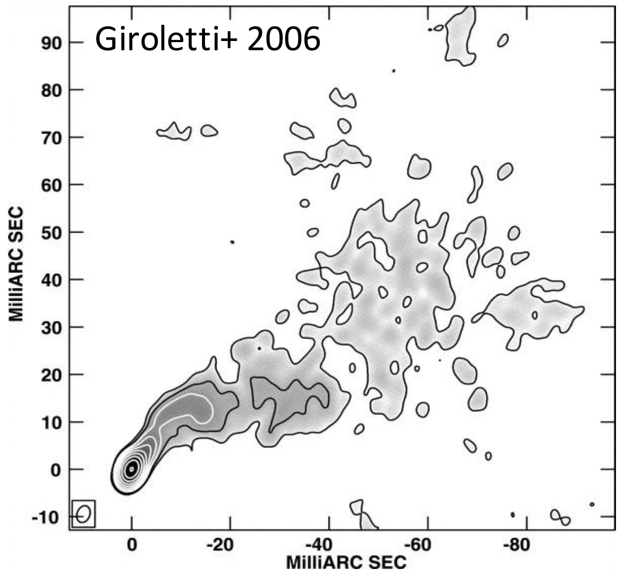
On the time variable rotation measure in the core region of Markarian 421

Extreme 2019
Padova, Italy
22-25 January 2019

Presented by:
Rocco Lico,
J.L.Gómez, K. Asada, A. Fuentes, M. Giroletti, M. Orienti, D'Ammando, G. Giovannini, et al.

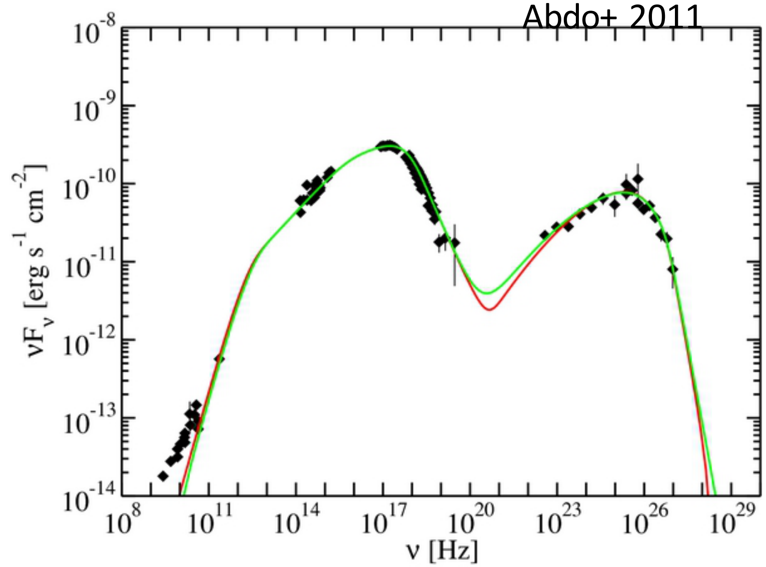
The HSP blazar Markarian 421

Mrk421 is a nearby BL Lac object (***z* = 0.031**)
$M_{BH} \sim 2\text{-}9 \times 10^8\ M_\odot$
$R_S \sim 2.7 \times 10^{14}$ cm (8.6×10^{-5} pc)



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

(David Paneque's Talk)



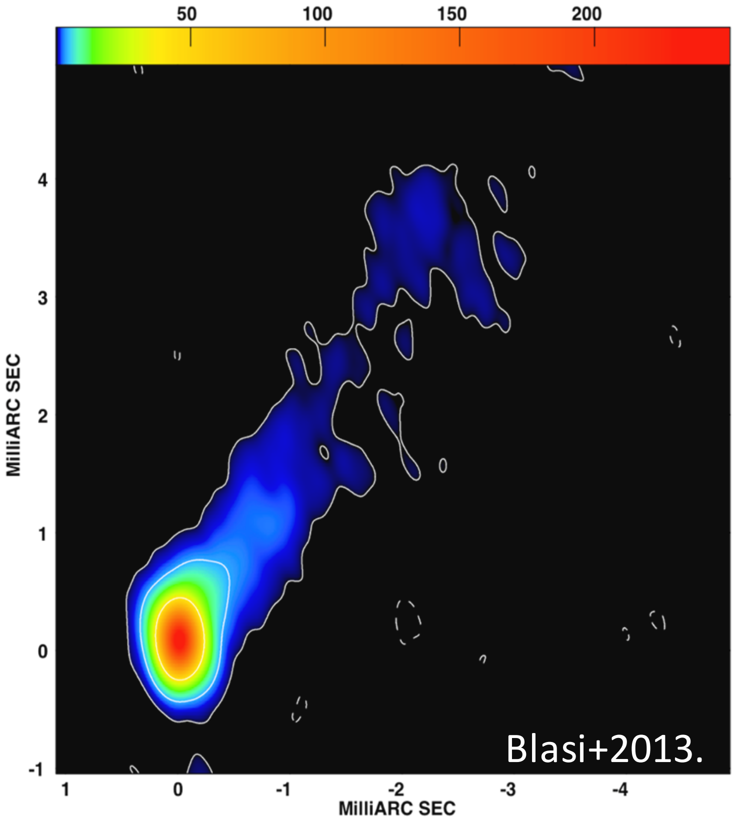
- HSP object.
- Detected by EGRET.
- It is a bright Fermi source.
- Multi-wavelength study by Abdo et al.

It is the first extragalactic object revealed in TeV band

Multi-frequency dataset

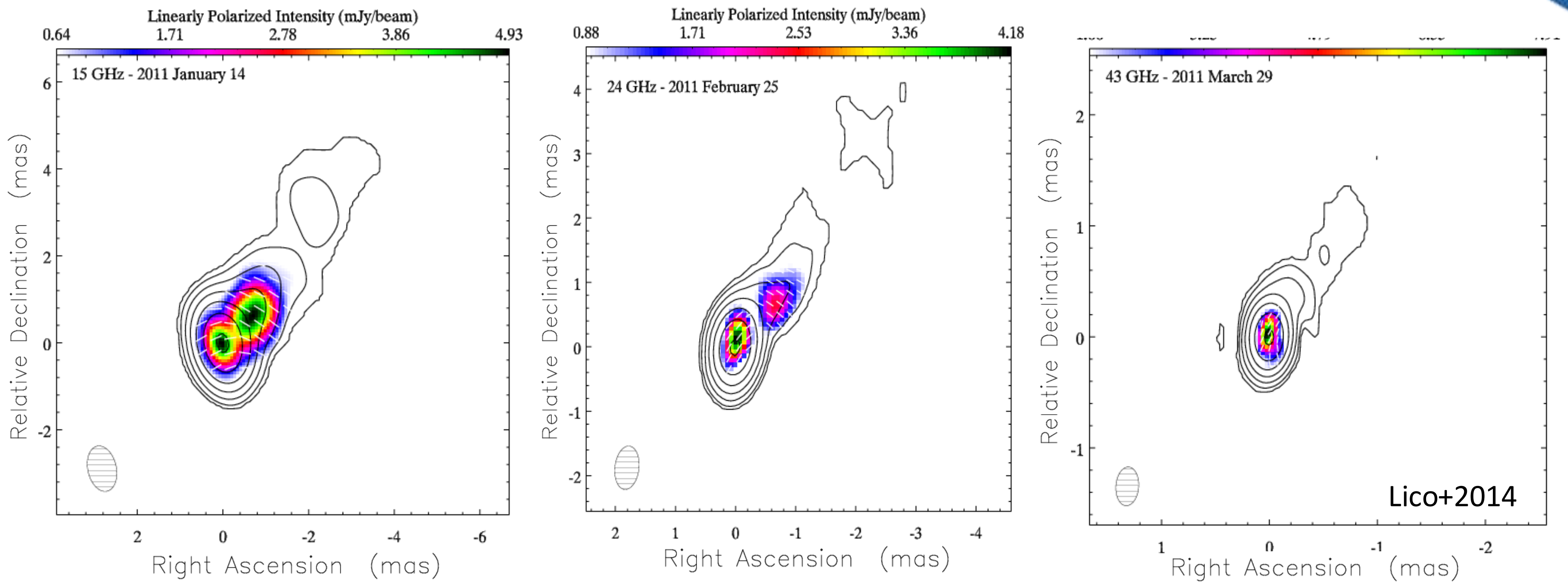
VLBA obs. at 15, 24 and 43 GHz ⇔ 12 epochs during 2011

in total and polarized intensity



- Well defined **Jet** structure in NW direction (PA ~ -35°), 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%.

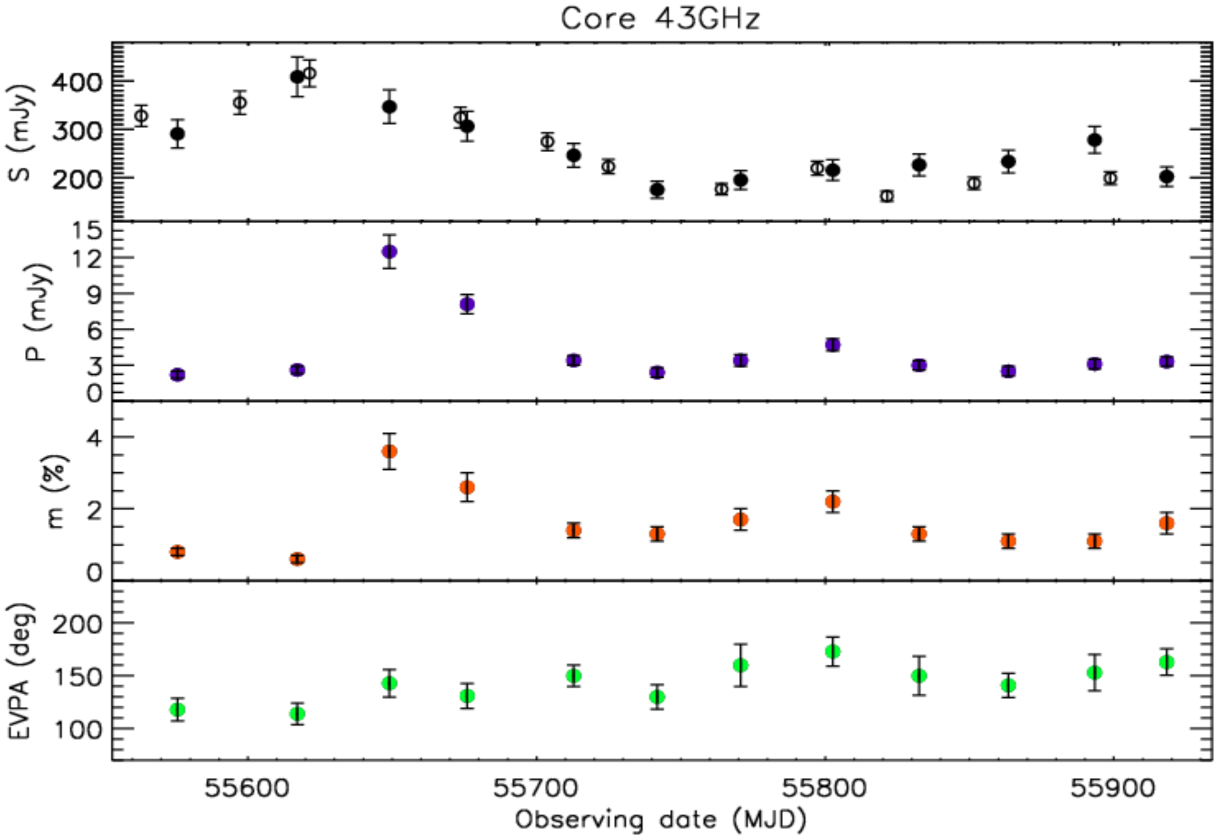
Polarization parameters: core region at 43 GHz

Total intensity emission

Polarized emission

Fractional polarization

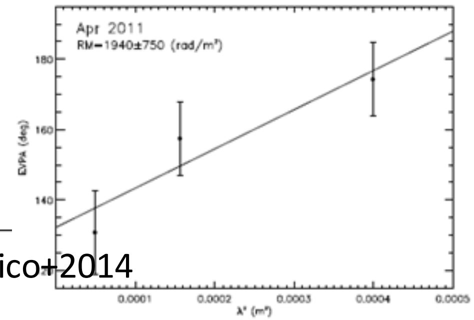
EVPAs

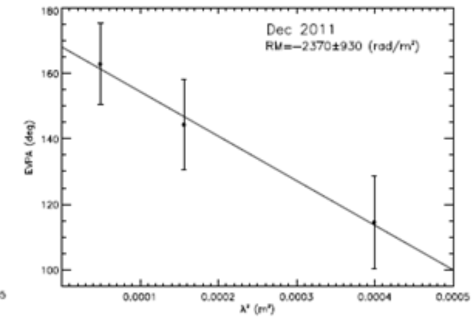


- There is a main peak in the total intensity lightcurve
- The polarized flux reaches a 12 mJy peak during the 3th observing epoch.
- The mean degree of polarization for the core is ~2%.
- EVPAs have a stable behavior with the time around 150° (i.e. magnetic field transverse to the jet PA).

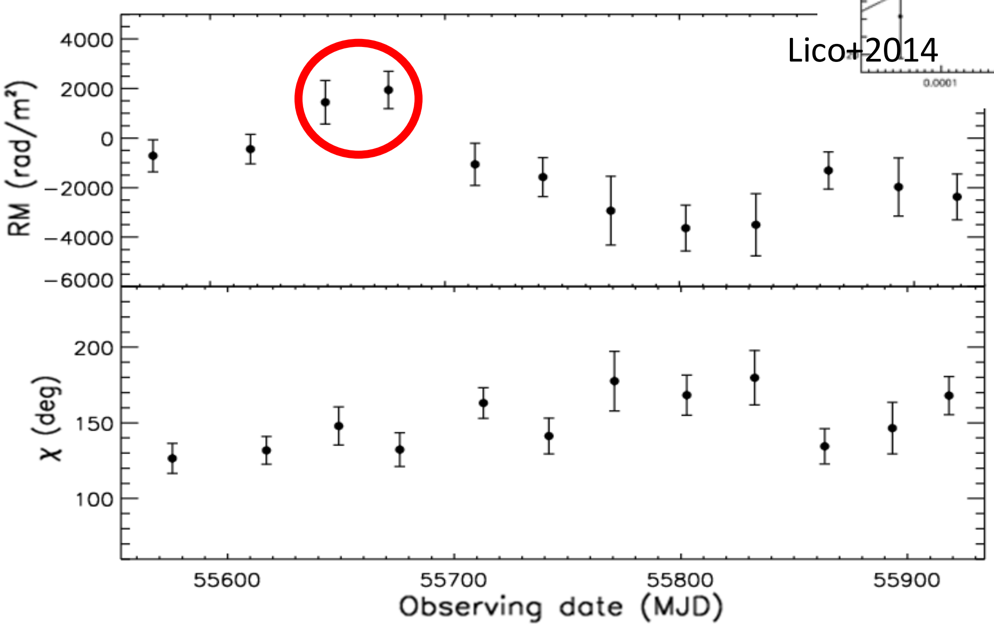
Faraday rotation analysis

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





Lico+2014



- Time variable RM with sign reversals.
- Intrinsic pol. angle roughly stable around ~150°.

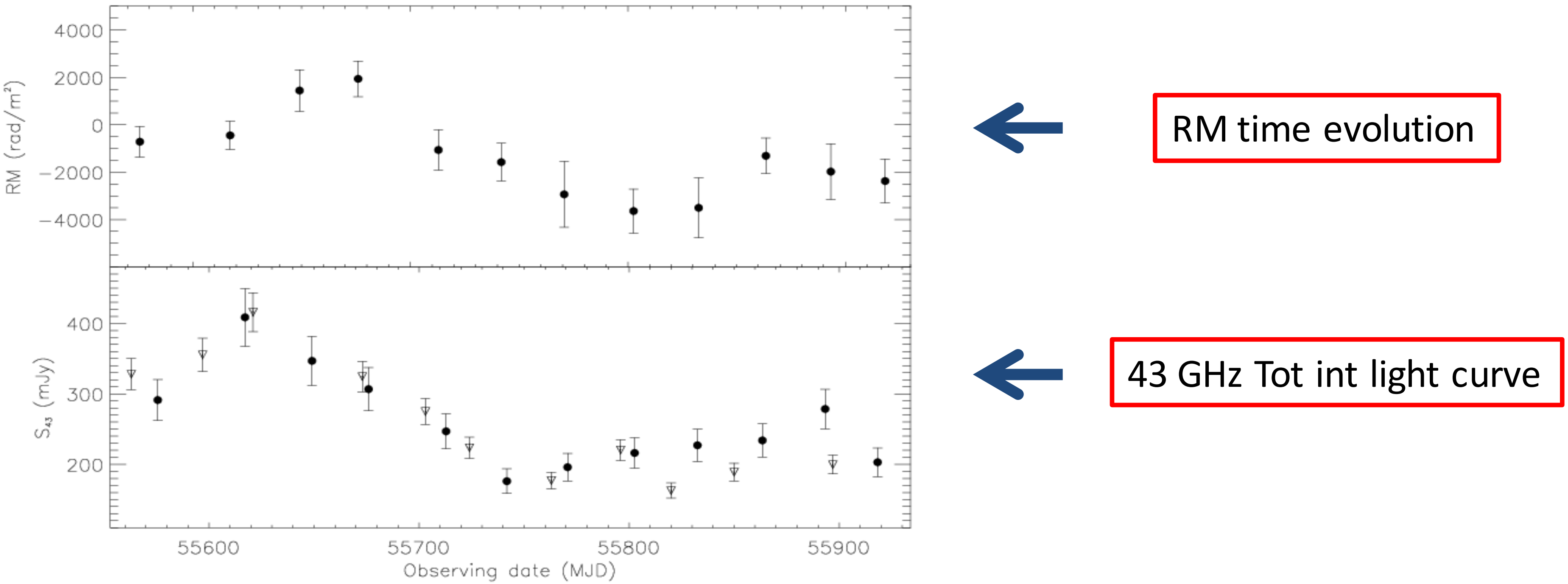
Assumptions:

- 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

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



- RM and core flux density → 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.

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

→ $\dot{M} \sim 2.5 \times 10^{-5}\ {\rm M_\odot/yr}$

Kuo+ 2014.

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

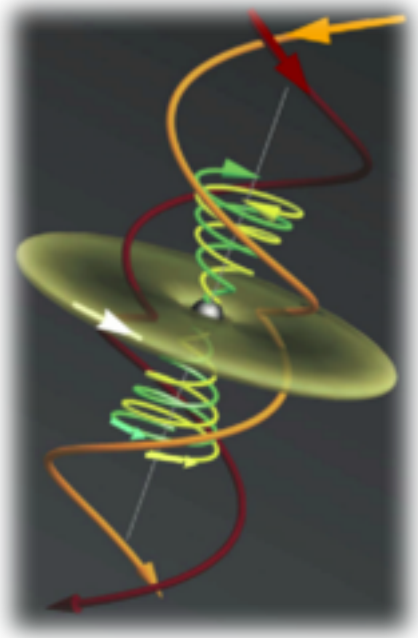
- ❑ Accretion flow is not spherical (possibly disc/torus like).
- ❑ Magnetic field weaker than the equipartition value and/or is not ordered (tangled);

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

↓

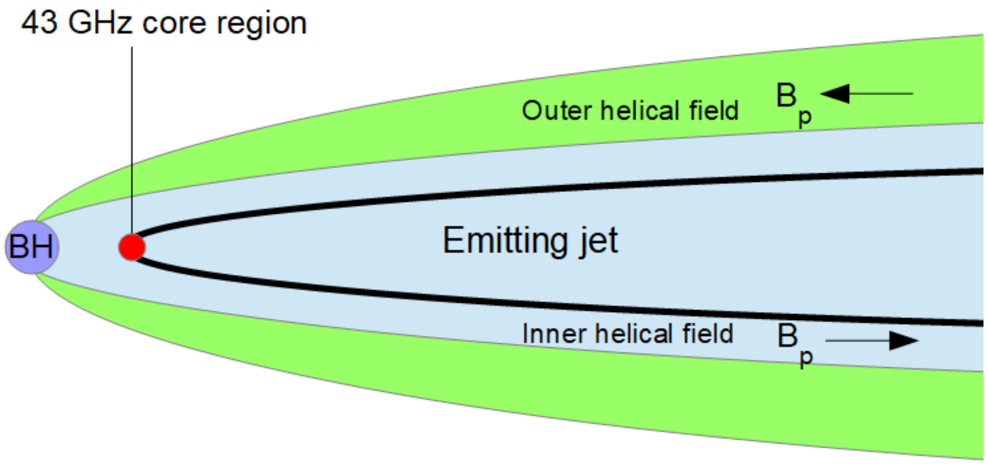
two nested helical fields in the jet:

- **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):

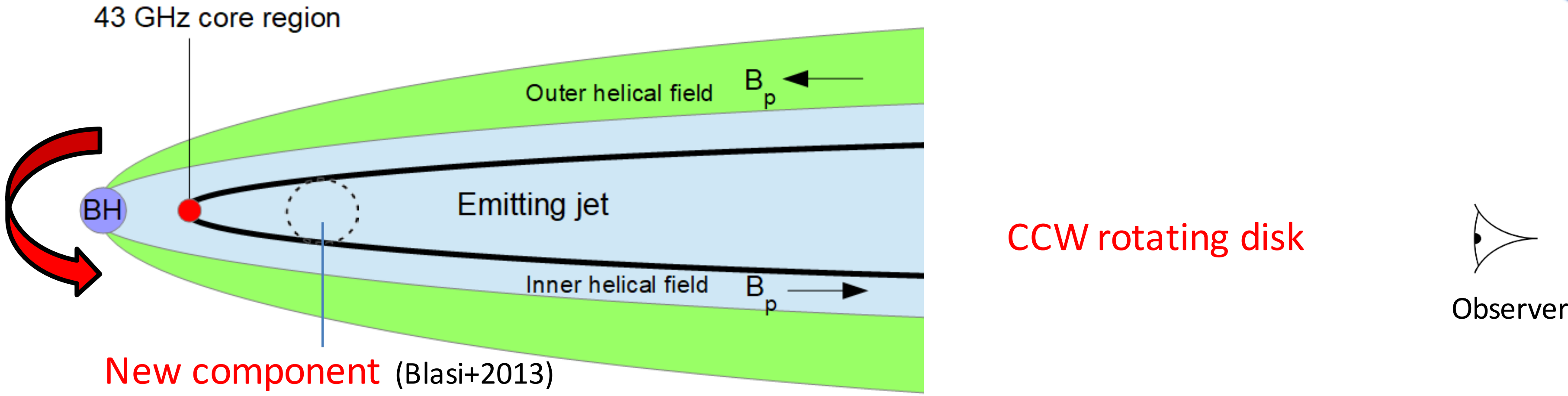
✓ viewing angle = 5°;
✓ bulk flow Lorentz factor Γ = 1.7;
✓ different pitch angle ϕ values.

We assume that:
inner helical field: $\mathbf{B_p}$ in the observer's direction -> positive RM;
outer helical field: $\mathbf{B_p}$ in the opposite observer's direction -> negative RM.

↳ Dominant contribution to the observed RM.

- the magnetic field toroidal component only affects the transverse RM gradient.
- ϕ ≥ 70° required to obtain an intrinsic polarization angle ~150°.

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

⇩

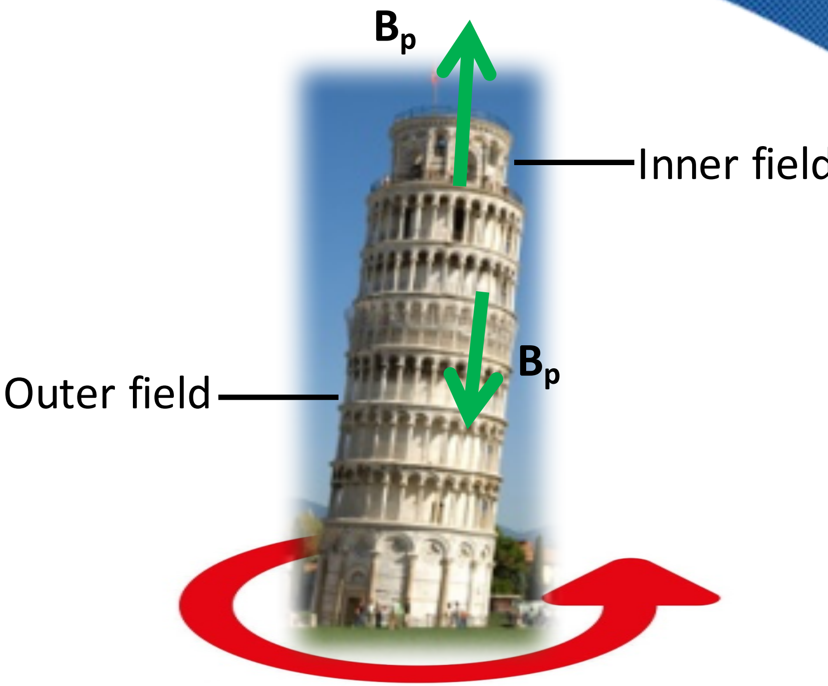
increased activity in the central engine, possibly followed by the ejection of a new jet comp., producing a bow shock expanding in the neighboring regions (e.g. Gomez+1997, Fromm+2016).

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).
- 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).