



# Determining the Directions for the Jet Poloidal B-field and BH Rotation in AGN

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**Circular polarisation (CP)** of synchrotron radiation – very low ( $< 0.1\%$ ) for B fields thought to be typical ( $\sim$  tenths of mG)

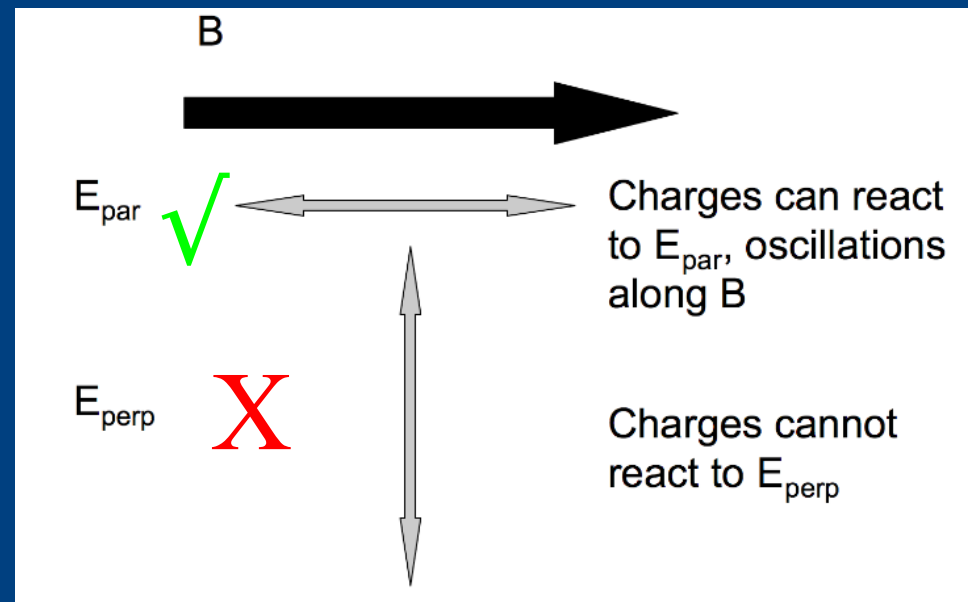
Observed CP  $\sim$  a few tenths of a %, usually in VLBI core (e.g. Homan & Lister 2006)

Most likely mechanism generating CP:

**“Faraday conversion”** as EM wave travels through magnetised plasma (Jones & O’Dell 1977)

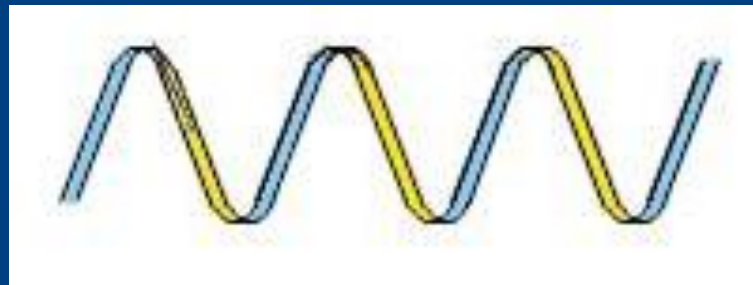
Delay of  $E_{\text{par}}$   
relative to  $E_{\text{perp}}$

$\Rightarrow$  Conversion of small  
amount of linear pol  
(LP) to CP



Angle between plane of LP (E) and local B field determines **sign** of CP produced. This angle must differ from 0 or 90° to get conversion (otherwise no delay!).

**Helical B-field geometry can facilitate conversion** – some of LP emitted near “back” of helix is converted to CP as it passes through “front” of helix (Wardle & Homan 2002, Ensslin 2003, Gabuzda et al. 2008, Homan 2012).



Angle between background synchrotron E and foreground B is determined by (1) **pitch angle of the helical field**, (2) **direction of azimuthal B ( $B_\phi$ )** and (3) **direction of poloidal B ( $B_p$ )** (Gabuzda et al. 2008).

Analysis technique proposed by Gabuzda et al. (2008):

1) **Pitch angle** – from observed LP structure

- “small” pitch angle ( $< 45^\circ$ )  $\Rightarrow$  dominant B field along jet
- “large” pitch angle ( $> 45^\circ$ )  $\Rightarrow$  dominant B field  $\perp$  to jet

2) **Direction of azimuthal B ( $B_\varphi$ )** – from direction of RM gradient across jet (Faraday RM  $\propto$  LOS B field)

3) **Direction of poloidal B ( $B_p$ )** – from above + sign of CP

Yields full 3D info about helical field, can infer direction of rotation of accretion disk on the sky (assuming  $B_p$  is wound up to yield  $B_\varphi$ ).

We have applied this analysis to data for all 12 AGNs with reliable data for

- ✓ Clear LP structure  $\Rightarrow$  pitch angle regime
- ✓ Transverse RM gradient  $\Rightarrow$  direction of  $B_\varphi$
- ✓ Sign of CP  $\Rightarrow$  direction of  $B_p$

Direction of rotation of BH+accretion disk and direction of  $B_\varphi$  described as CW or CCW on the sky

CW rotation = angular velocity vector  $\Omega$  inward,

CCW rotation =  $\Omega$  outward

Sources of data: Homan & Lister 2006; Vitrishchak et al. 2008; Hovatta et al. 2012; Gabuzda et al. 2014, 2015, in prep

## Measured

## Derived

Source	Pitch	B $\varphi$	CP	B $p$	Rotation	$\Omega$
0133+476	Large	CCW	—	Out	CW	In
0300+470	Large	CW	—	In	CW	In
0333+321	Small	CW	—	Out	CCW	Out
0735+178	Large	CW	—	In	CW	In
0945+408	Large	CW	+	Out	CCW	Out
1156+295	Large	CW	—	In	CW	In
3C273	Small	CCW	—	In	CCW	Out
1334-127	Small	CCW	+	Out	CW	In
1504-166	Large	CW	+	Out	CCW	Out
1633+382	Large	CW	—	In	CW	In
1749+096	Large	CW	—	In	CW	In
2230+114	Small	CW	—	Out	CCW	Out

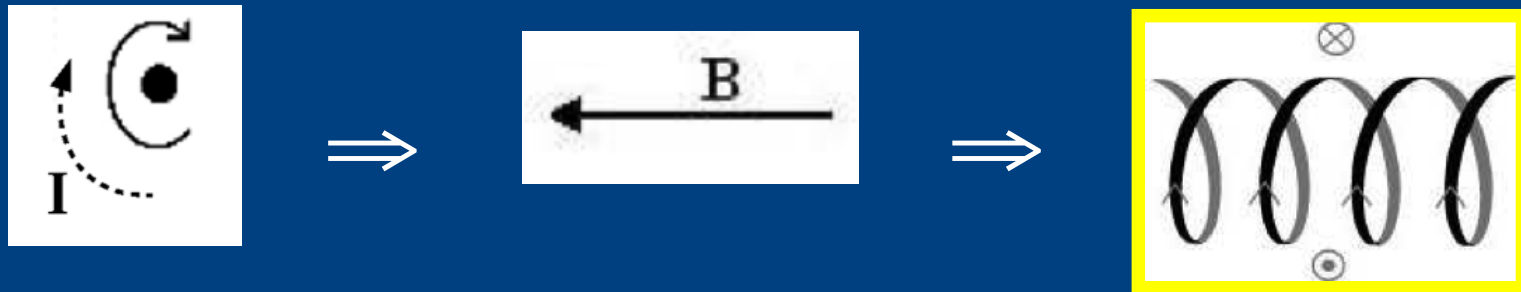
## Summary of results:

- Statistically equal numbers of inward (6) and outward (6) poloidal B fields ✓
- Statistically equal numbers of central BHs and accretion disks rotating CW (7) and CCW (5) on sky ✓
- 12 of 44 AGNs with detectable VLBI CP have significant transverse RM gradients (27%) — seems a fairly high fraction, supporting idea CP and RM have same origin (helical jet B field)
- First time both  $B_\varphi$  and  $B_p$  have been reliably determined and used to infer the direction of rotation of central BH and its accretion disk.

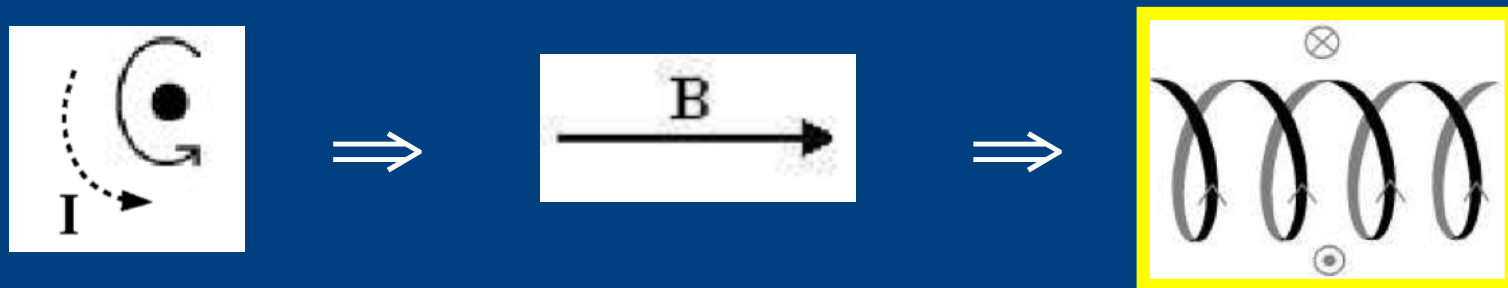
“Cosmic Battery” model of Christodoulou et al. (2016);  
Contopoulos et al. (2017), Yiannis’ talk on Monday

Poynting–Robertson drag generates currents in the  
accretion disk in direction of rotation, linking the  
directions of rotation ( $\Omega$ ) and  $B_p$ :

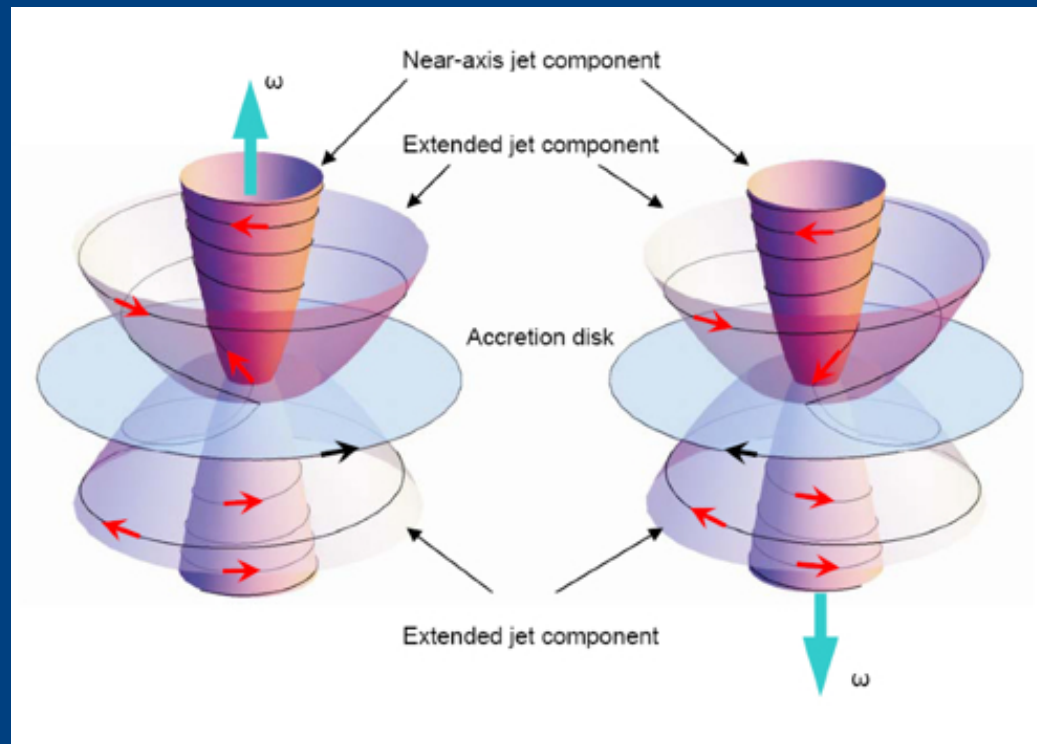
CW rotation on sky  $\Rightarrow$  inward  $B_p$  along jet  $\Rightarrow$  CW  $B_\phi$



CCW rotation on sky  $\Rightarrow$  outward  $B_p$  along jet  $\Rightarrow$  CW  $B_\phi$







When loops of B field generated by this “battery” (e.g. Contopoulos et al. 2017) are wound up, they produce

**CW  $B_\phi$ /inward current** near jet axis (dominates on small scales)

**CCW  $B_\phi$ /outward current** in more extended region farther from jet axis (dominates on large scales)

## Can we see this pattern?

✓ Dominance of CW B $\varphi$  (inward current) on parsec scales.

✓ Evidence for correlation between  $\Omega$  and Bp.

Also reflected in collected parsec-scale data:

50 AGNs with significant transverse RM gradients

35 CW B $\varphi$  , 15 CCW B $\varphi$

Prob. Chance  $\sim 0.33\%$

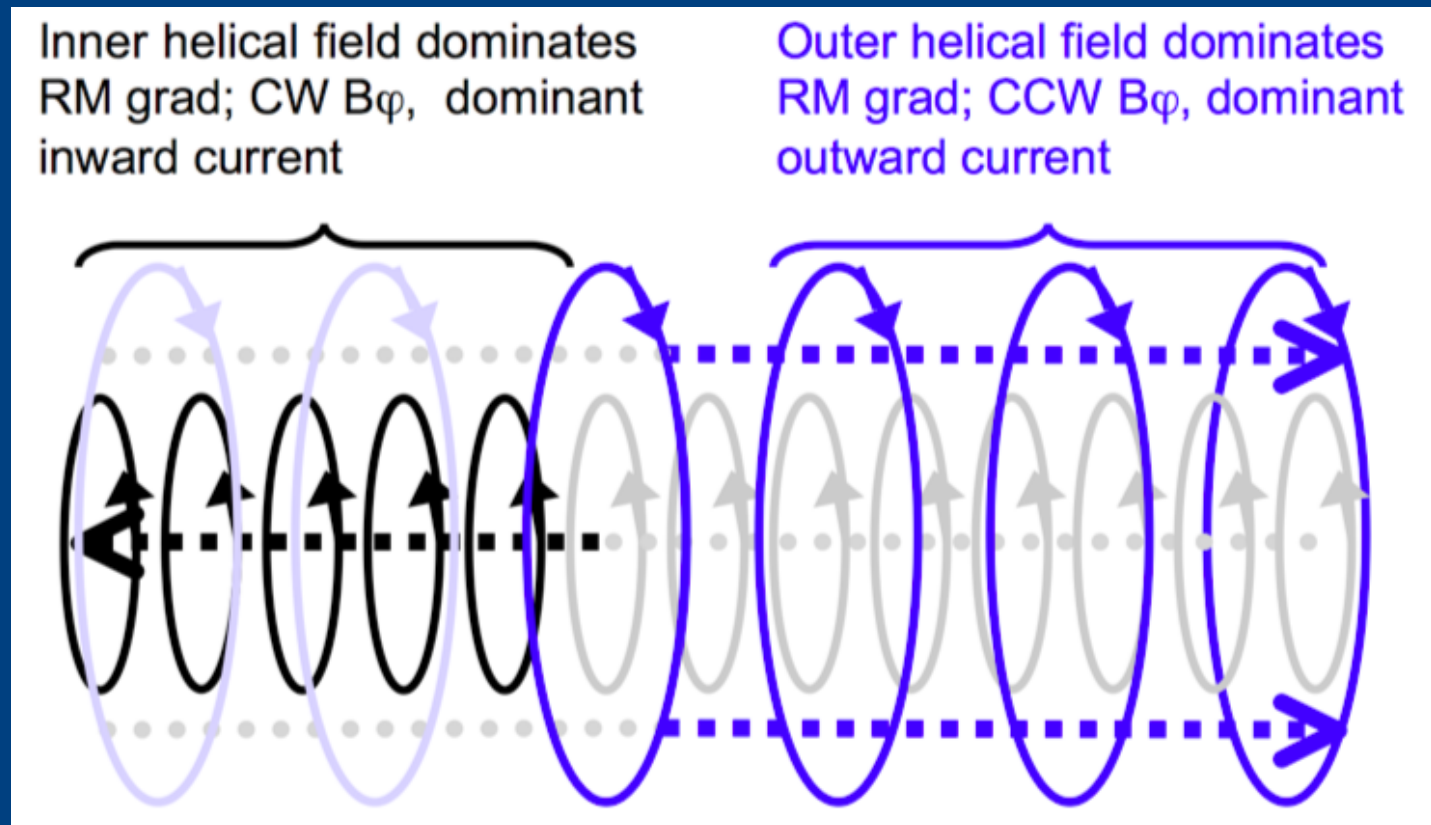
Source	$\Omega$	B $\varphi$	Bp
0133+476	In	CCW	Out
1334-127	In	CCW	Out
0300+470	In	CW	In
0735+178	In	CW	In
1156+295	In	CW	In
1633+382	In	CW	In
1749+096	In	CW	In
3C273	Out	CCW	In
0333+321	Out	CW	Out
0945+408	Out	CW	Out
1504-166	Out	CW	Out
2230+114	Out	CW	Out

## Summary

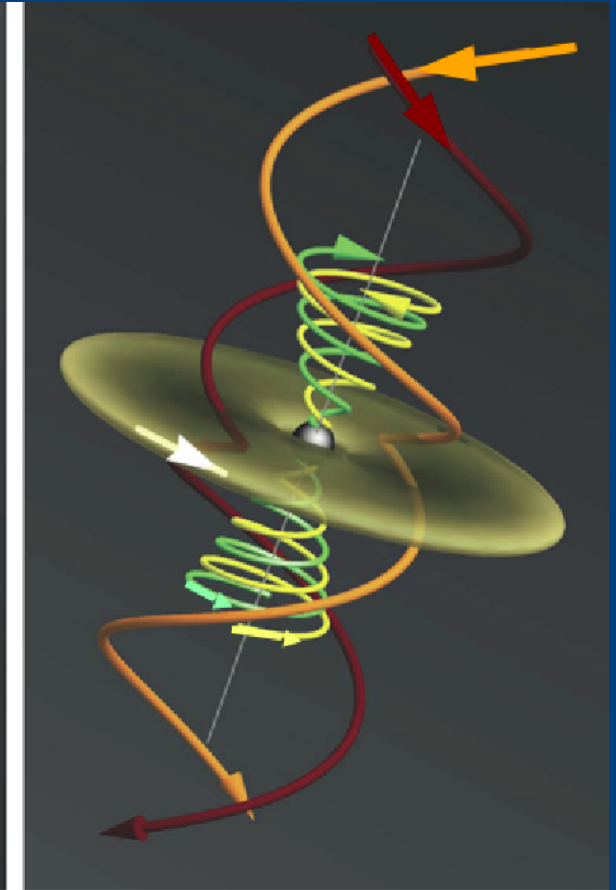
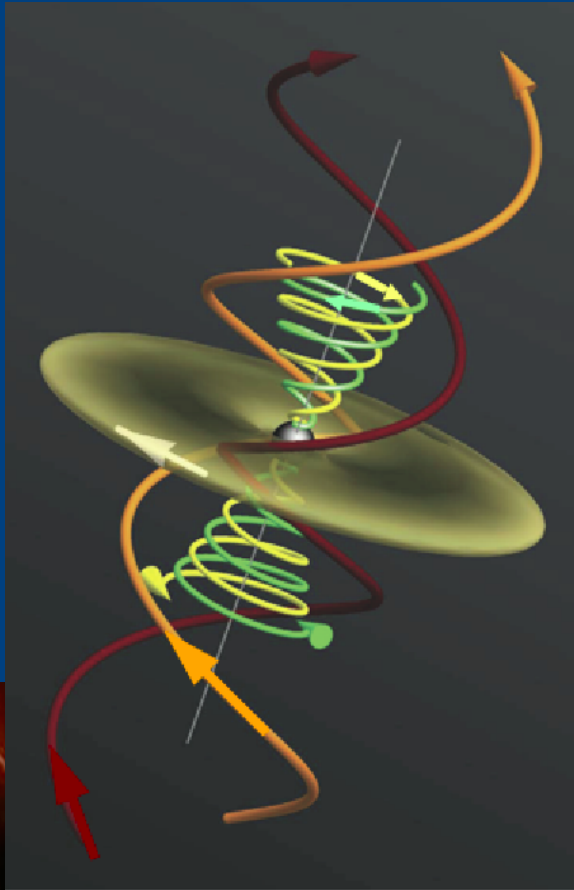
- If AGN jets carry helical B fields, which give rise to clear LP structure, transverse RM gradients and CP from Faraday conversion in the helical field, can use this to derive direction of  $B_\varphi$  and  $B_p$ .
- $B_p + B_\varphi$  together yield direction of rotation of the central BH and its accretion disk (assumes  $B_p$  has been wound up to yield  $B_\varphi$ )
- Analysis for 12 AGNs with all necessary data indicates statistically equal numbers of inward and outward  $B_p$ , and of CW and CCW rotation on the sky, as expected.

- Evidence that  $B_p$  and the direction of rotation are **linked**, suggesting action of a mechanism such as the “**cosmic battery**” model of Christodoulou et al. (2016).
- This mechanism gives rise to a system of B fields and currents resembling a giant co-axial cable!

Central  
BH



*Thanks for your  
attention —*



*Questions  
welcome!*