Rich Information to be Obtained from 1.35-1.85 GHz VLBI Polarization Observations of Active Galactic Nuclei

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Strengths of multi-frequency L-band polarization observations of AGNs

o Intensity and polarization structures can be traced far from the core, probing scales between parsecs and kiloparsecs

o Faraday rotation measure (RM) map can also be derived – ideal for this, as these frequencies are sensitive to Faraday rotatin, and all sample very similar spatial scales

RM is due mainly to our Galaxy (uniform) + immediate vicinity of AGN (non-uniform)

Technical issues that can limit results:

o Presence of RFI can limit quality of data at some or all frequencies used, substantial editing may be needed

o Observed EVPAs are strongly affected by Faraday rotation and must be corrected to derive intrinsic B-field direction; Faraday rotation must be derived accurately

o Uncertainties in overall flux calibration can hinder ability to make reliable spectral index maps

Two sets of multi-frequency L-band VLBA observations made at 1.358 – 1.665 GHz:

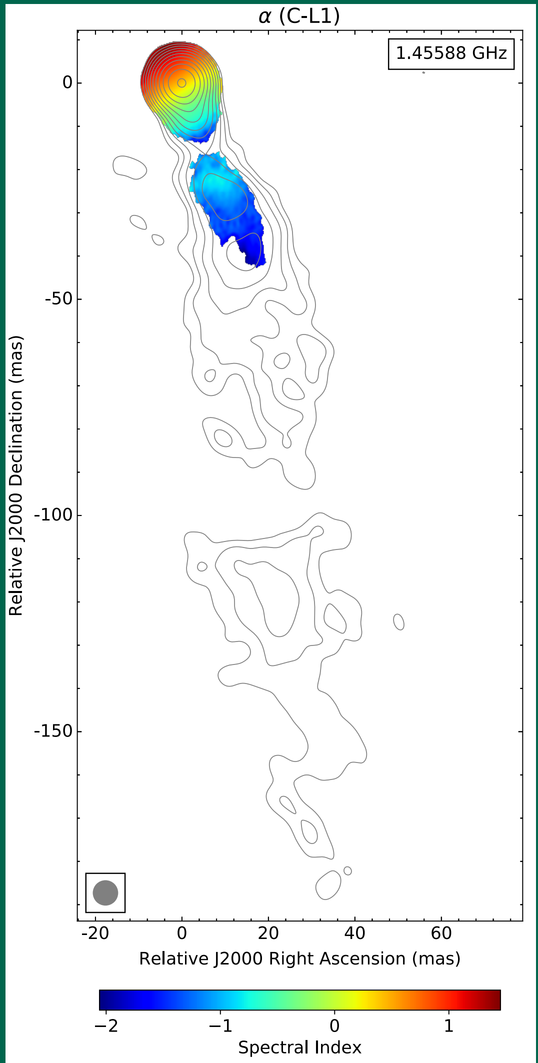
o BG139 – 34 BL Lac objects (2004)

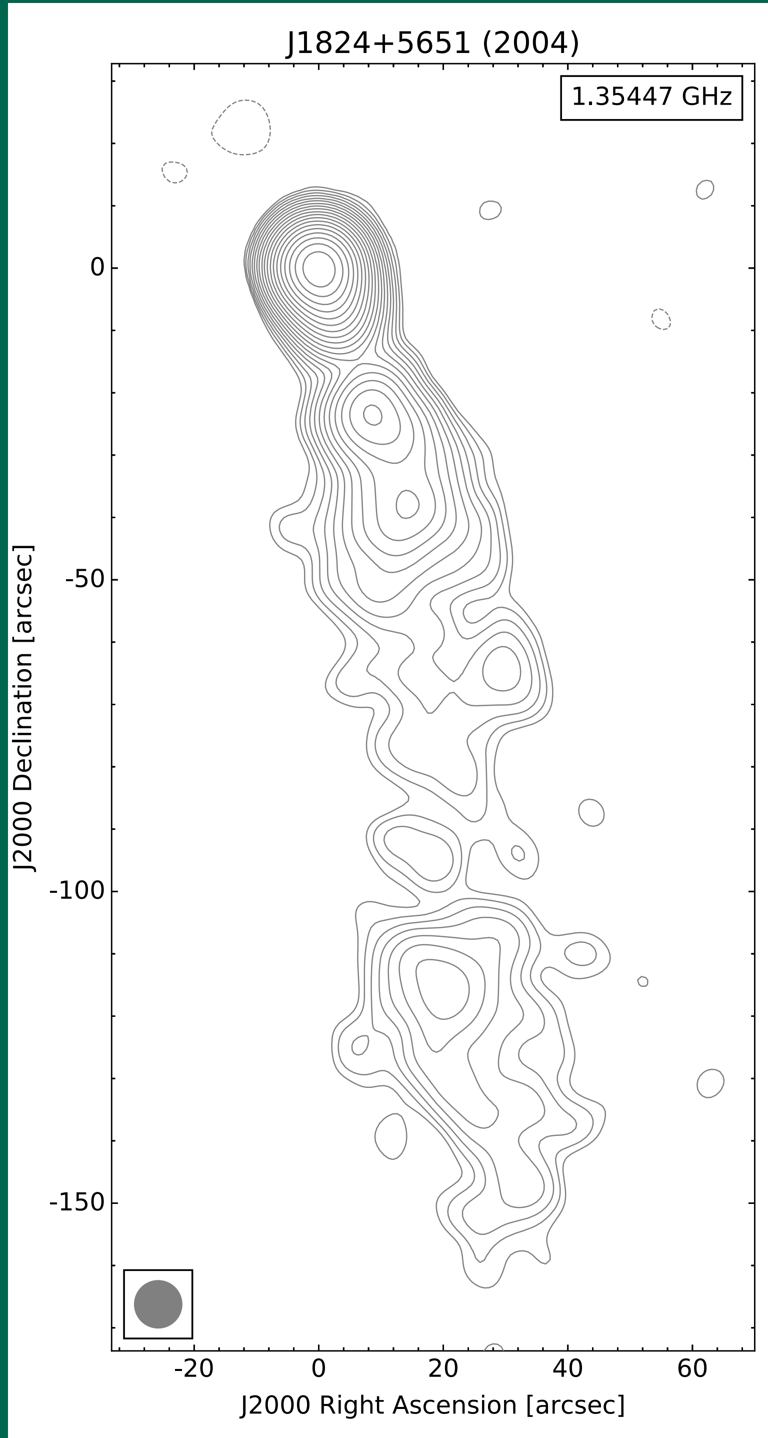
o BG196 – 135 AGNs from the MOJAVE programme (2010 – 2011)

Follow-up VLBA observations at 5, 2.3, 1.7 and 1.4 GHz:

o BG246, BG258 – 191 AGNs from the MOJAVE programme (2017 – 2019)

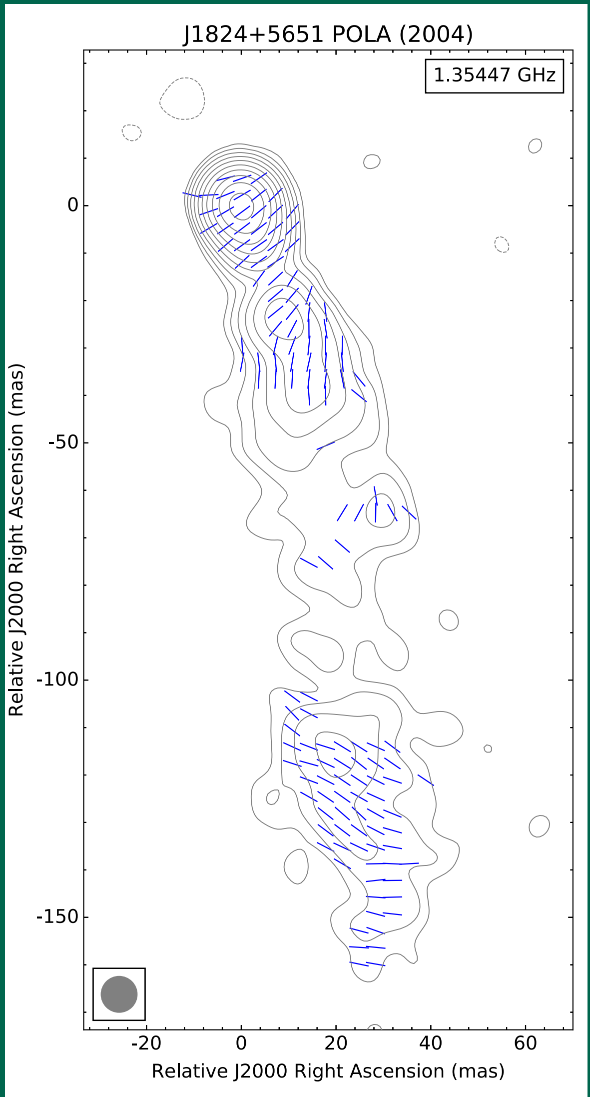
1.358 – 1.665 GHz results – 1823+568 (2004)



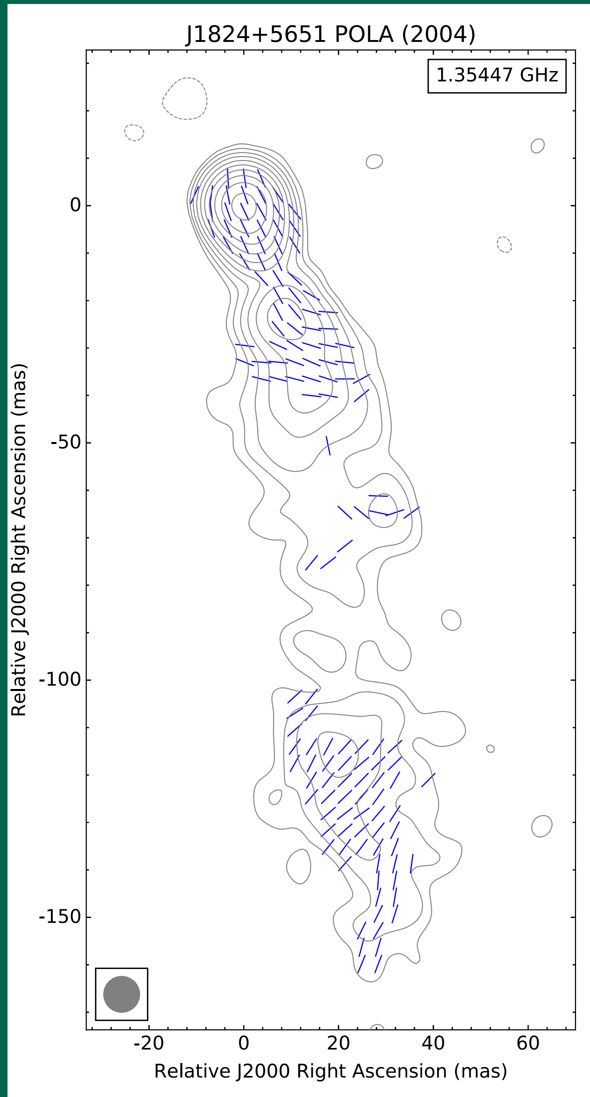


5-1.4 GHz spectral index (2019)

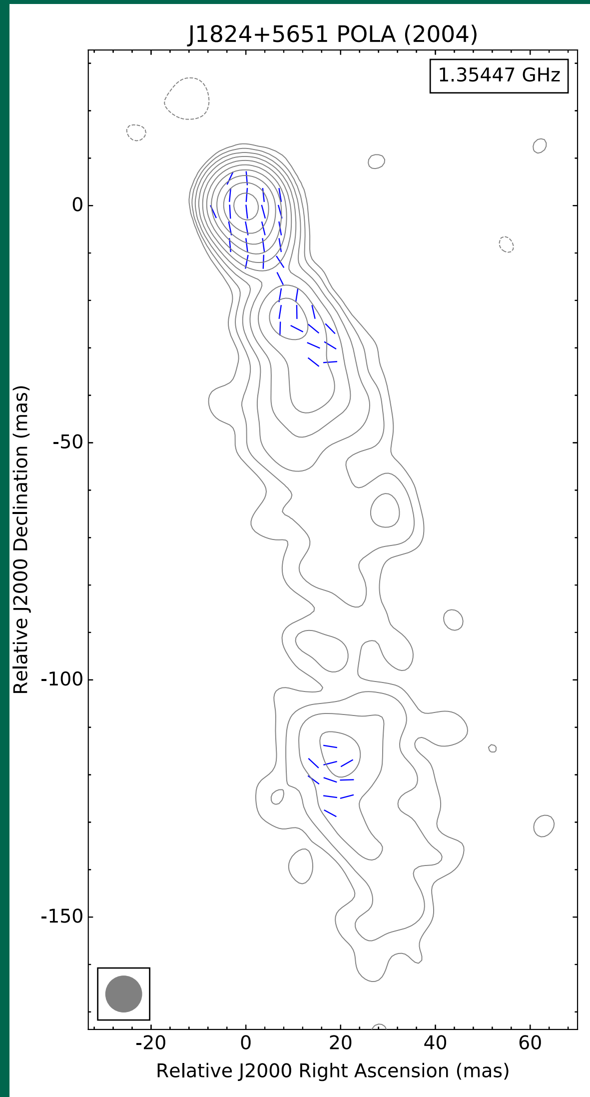
Polarization (B-field) Structure



Uncorrected



Corrected for Galactic RM

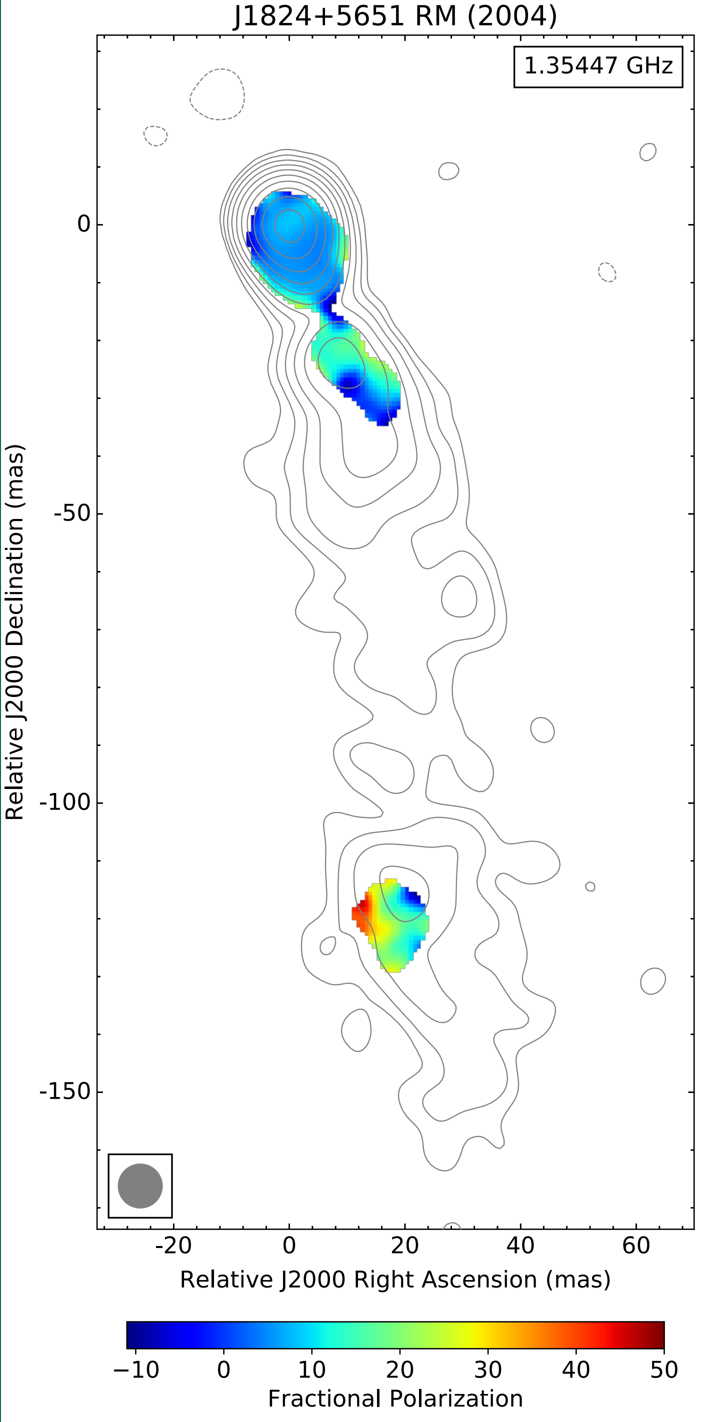


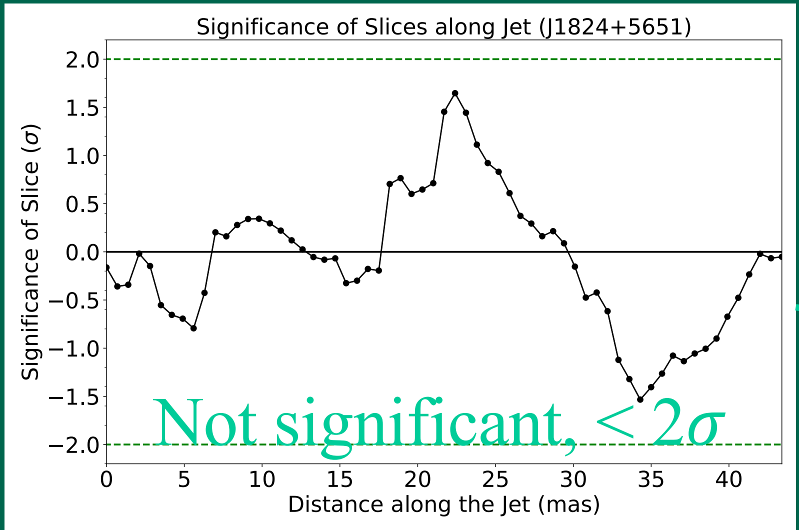
Corrected for Total RM

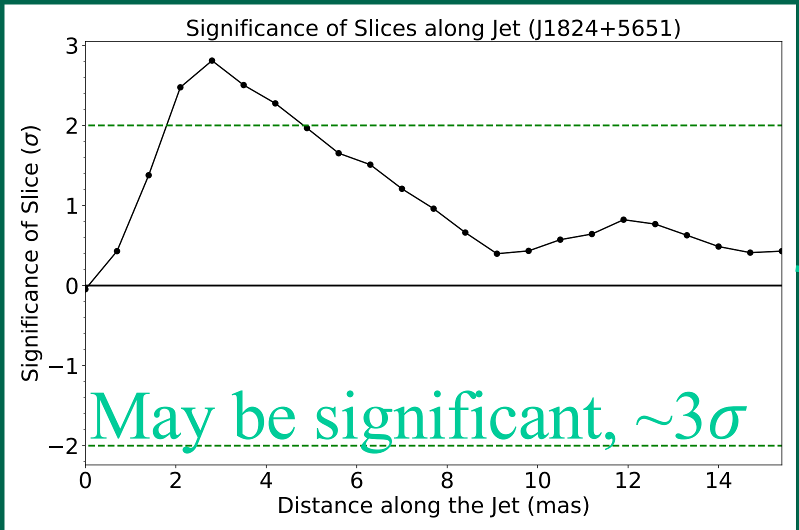
RM Structure (after subtraction of Galactic RM = 36 rad/m^2)

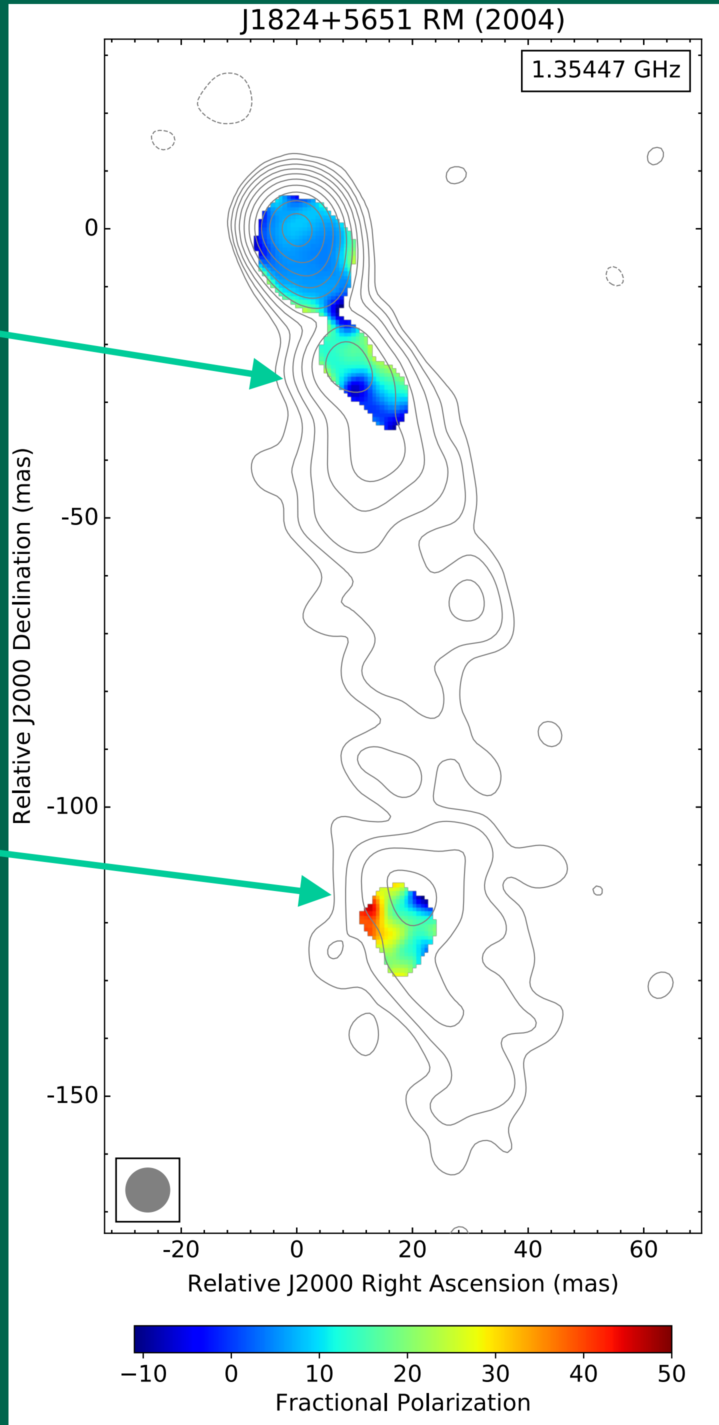
RM values in far fewer pixels than those with 1.35 GHz pol – to derive RM, must have pol detected at all 4 frequencies.

Underlines importance of good sensitivity at all frequencies – want to derive both RM and intrinsic B field in as much of the image as possible





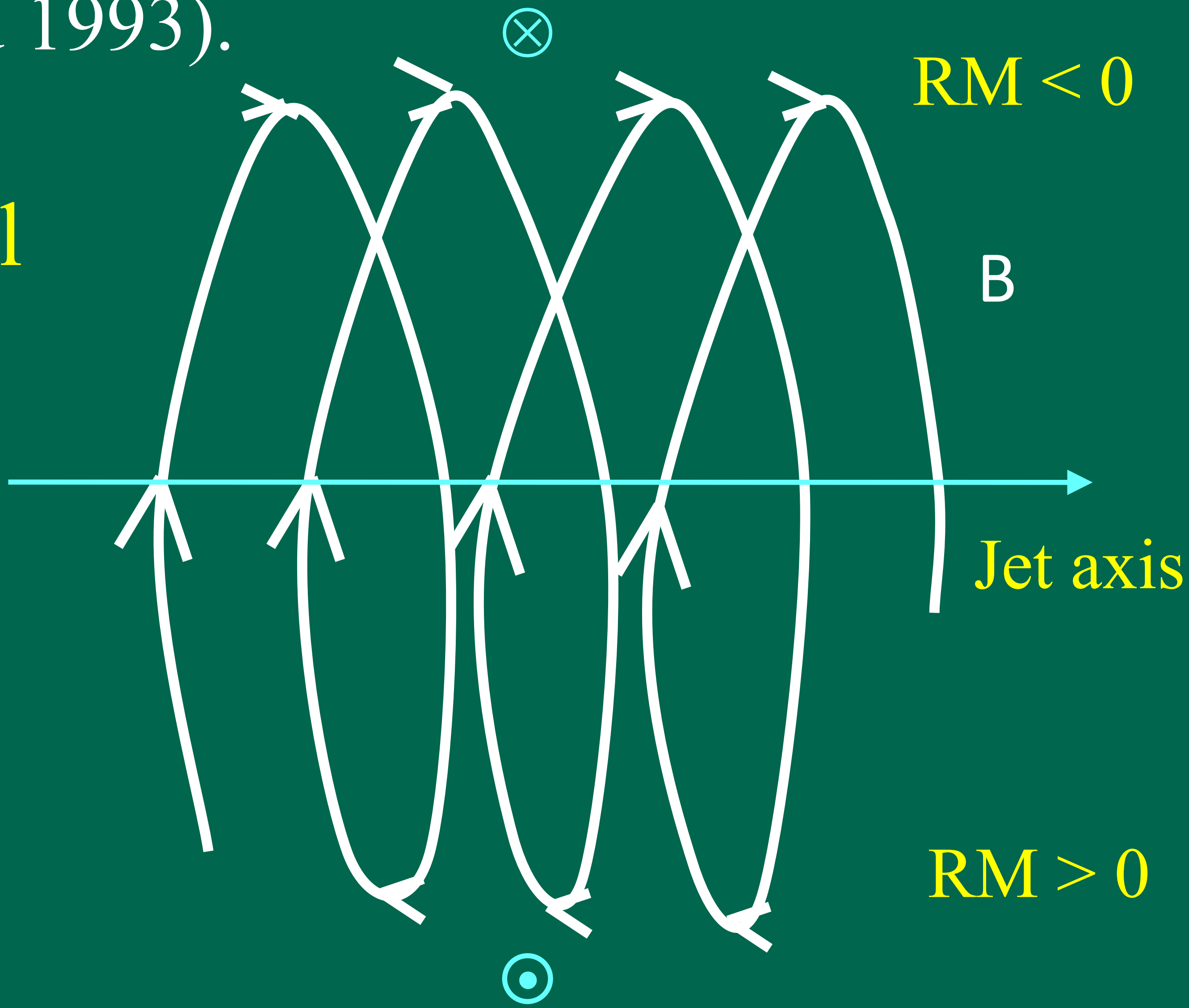




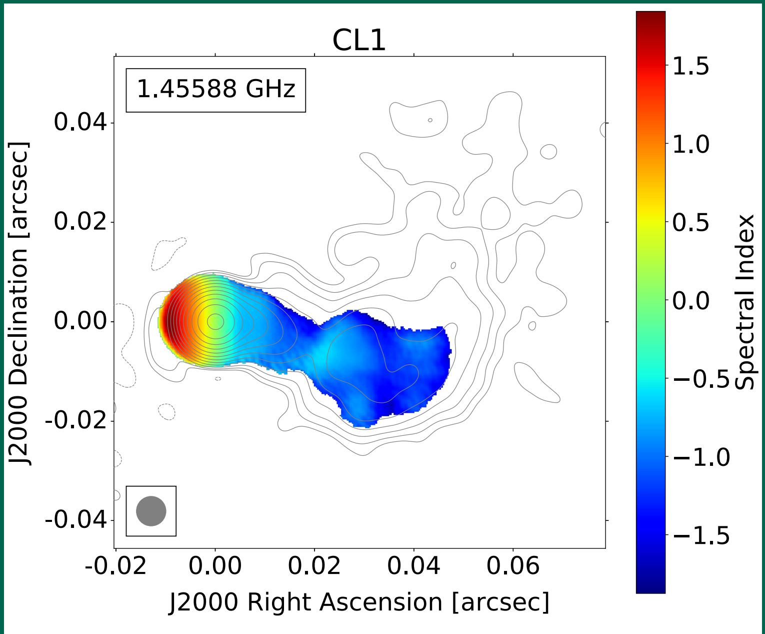
Transverse RM gradients, evidence for toroidal B-field component

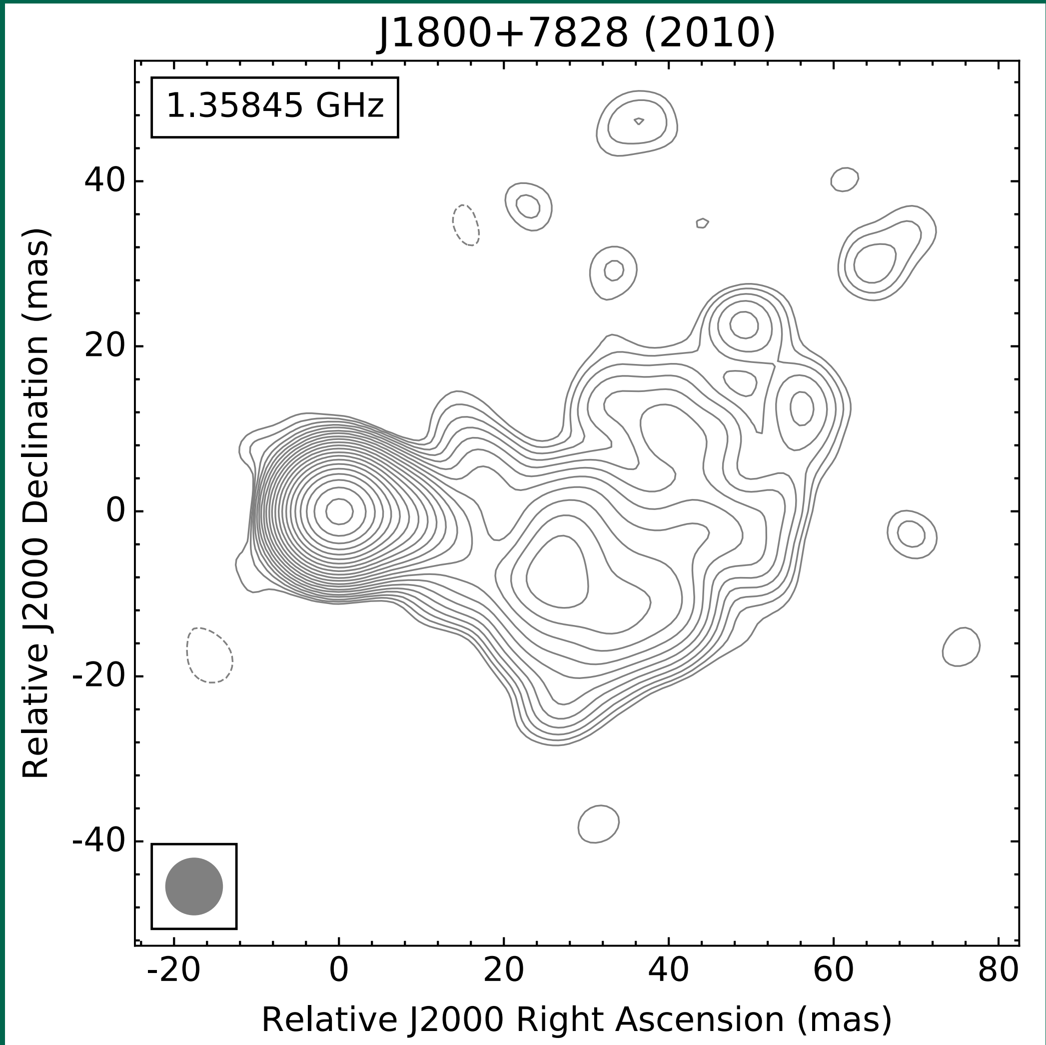
How a toroidal jet B field component can lead to a Faraday-rotation gradient *across* the jet – systematically changing *line-of-sight* B field (Perley et al. 1984, Blandford 1993).

$$RM \sim \int n_e \, B \bullet dl$$

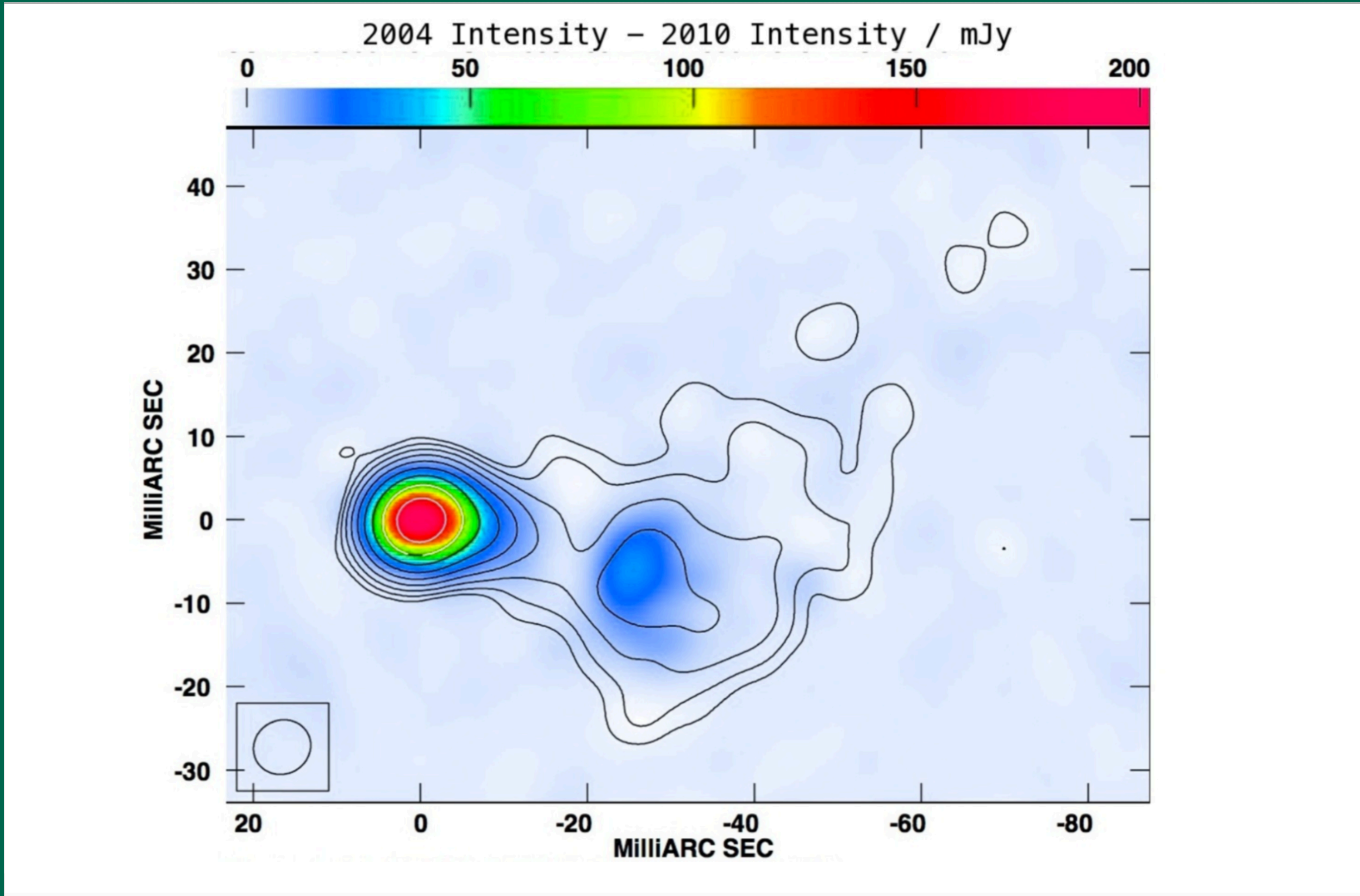


1.358 – 1.665 GHz results – 1803+784 (2004 & 2010)



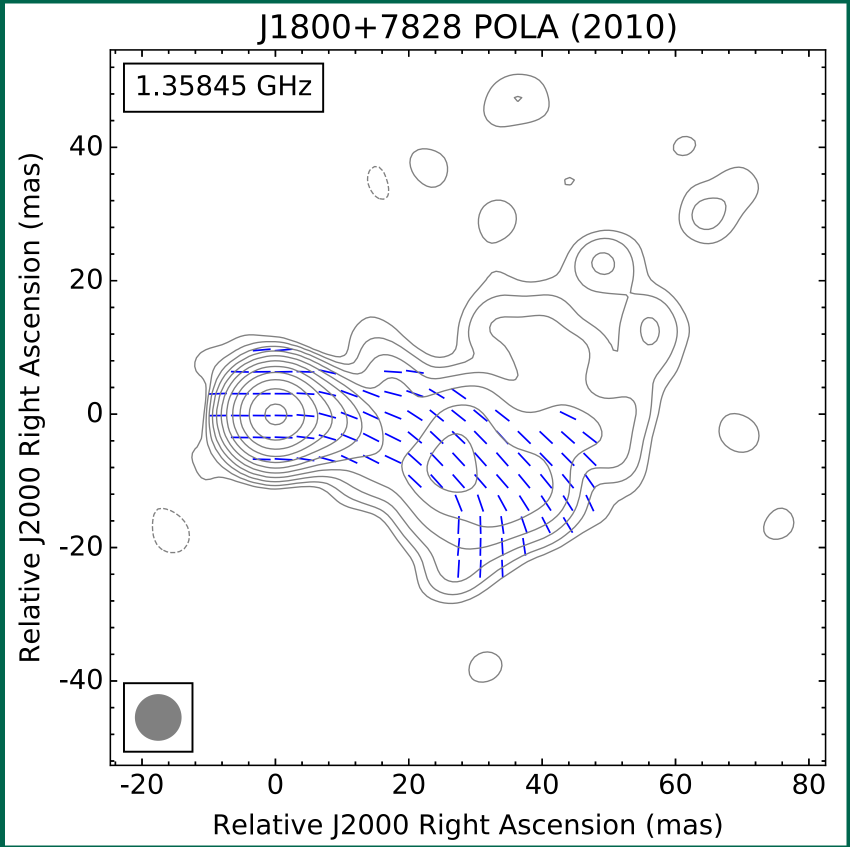


5-1.4 GHz spectral index map (2017)

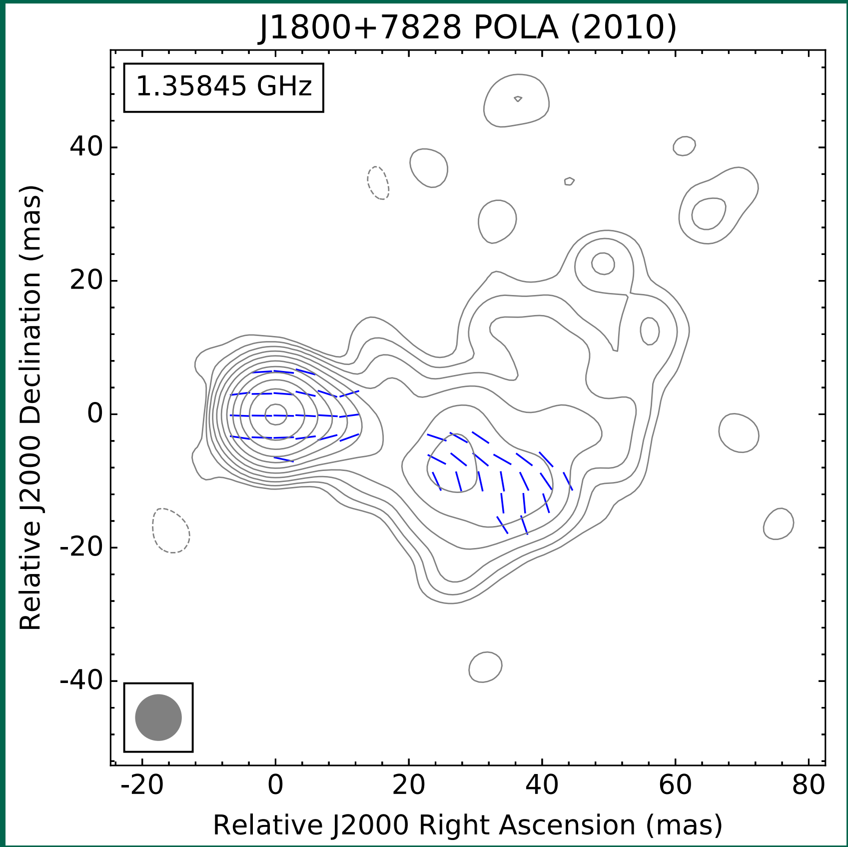


Difference of I maps obtained for 2004 and 2010 data, showing variations in core and fading of a bright jet component

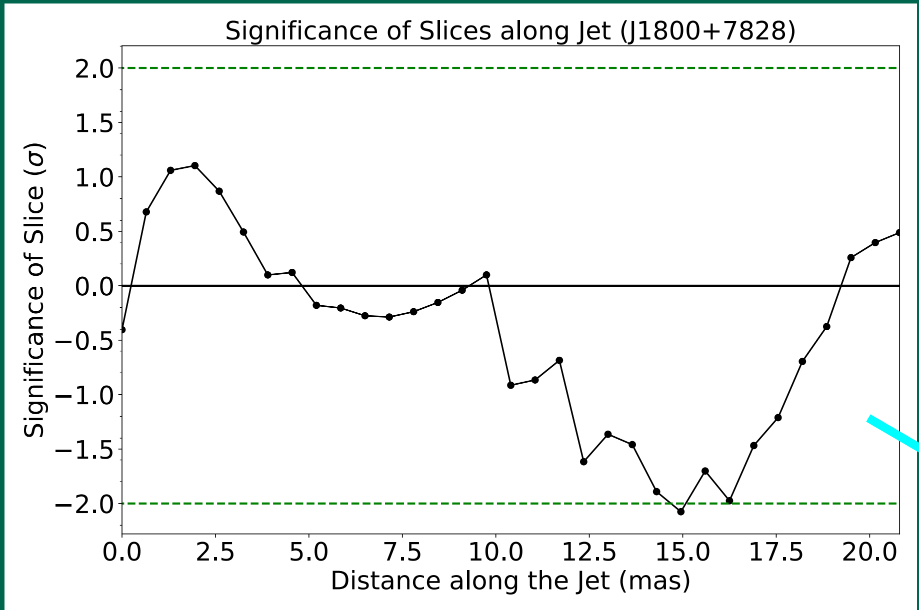
Corrected for Galactic RM

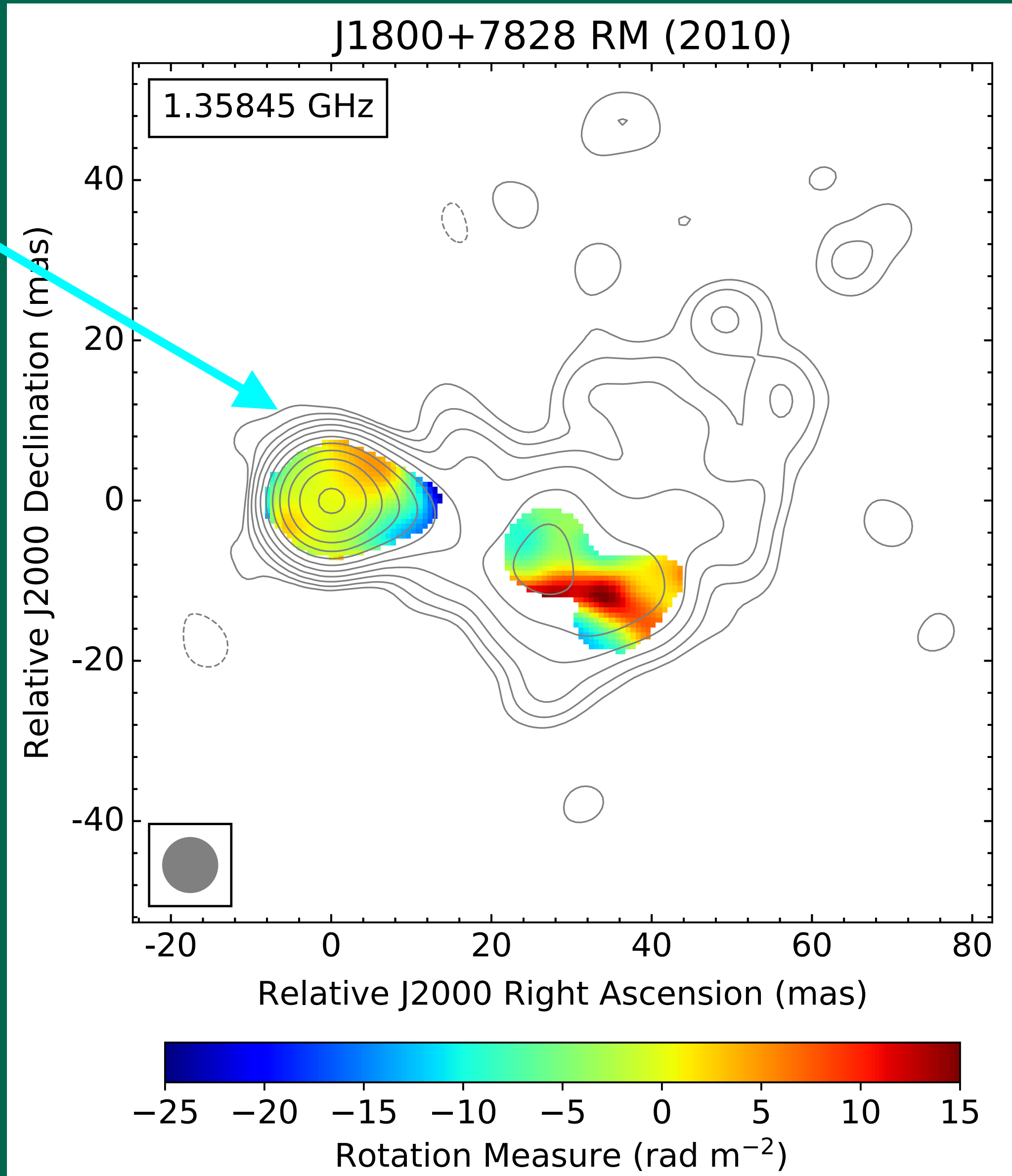


Corrected for Total RM



Considerable information is potentially lost due to polarization not being detected at one or more frequencies at some locations

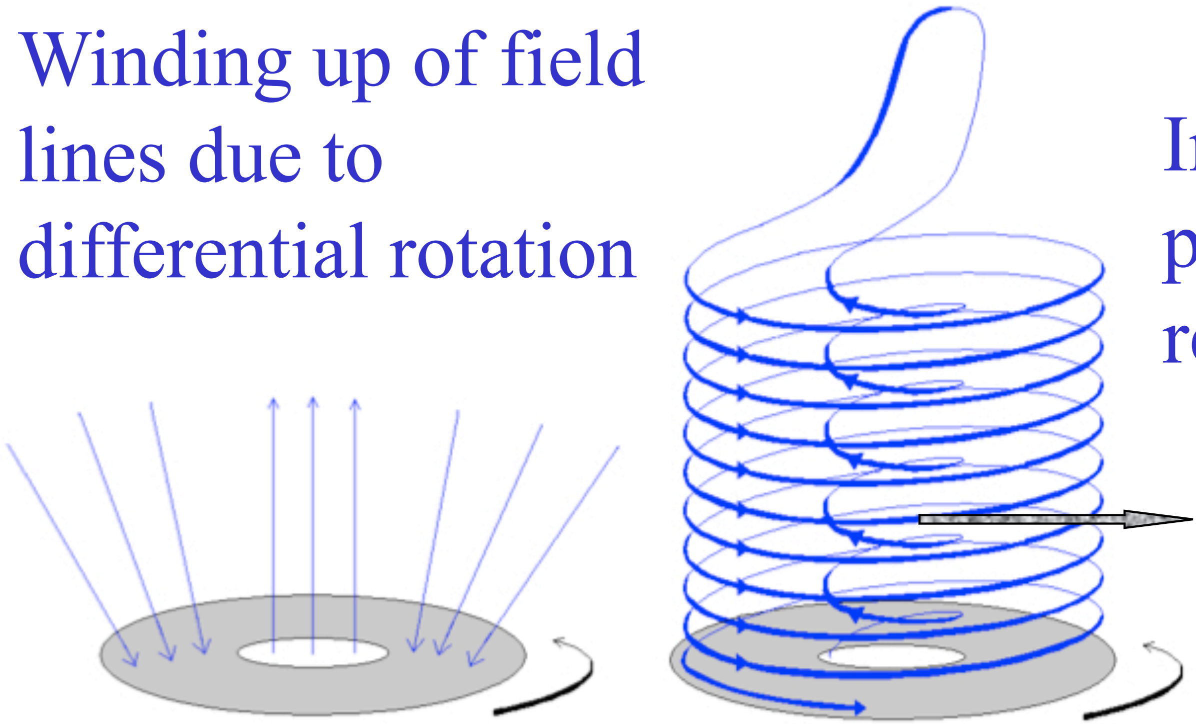




Oppositely directed transverse RM gradients (checkerboard pattern) in core region?

Not convincingly here, but worth checking with other observations!

Possible explanation: "Outgoing" B field in jet/inner accretion disc closes in outer disc

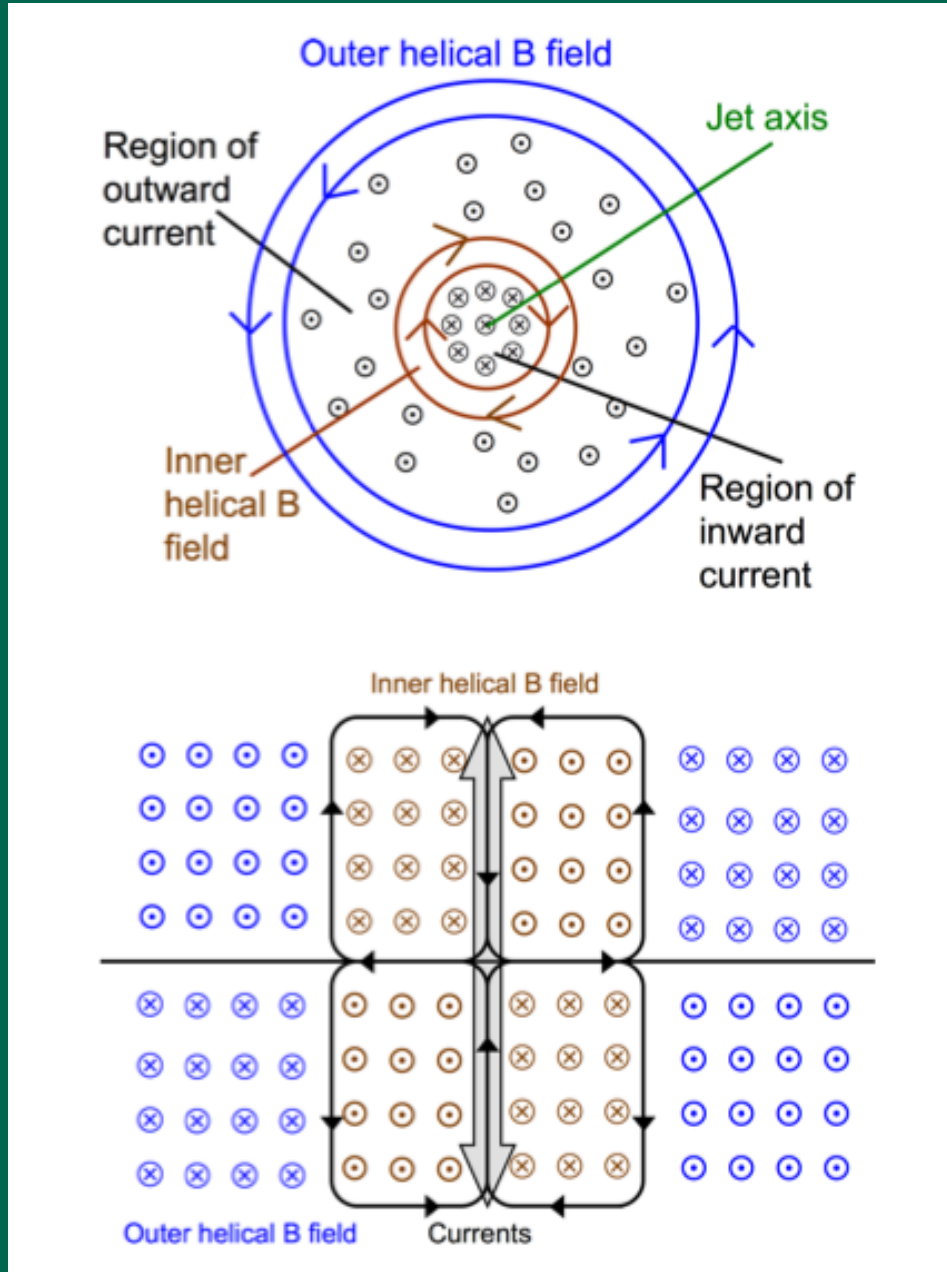


Integration path passes through both regions of helical field

$$\int n_e B \bullet dl$$

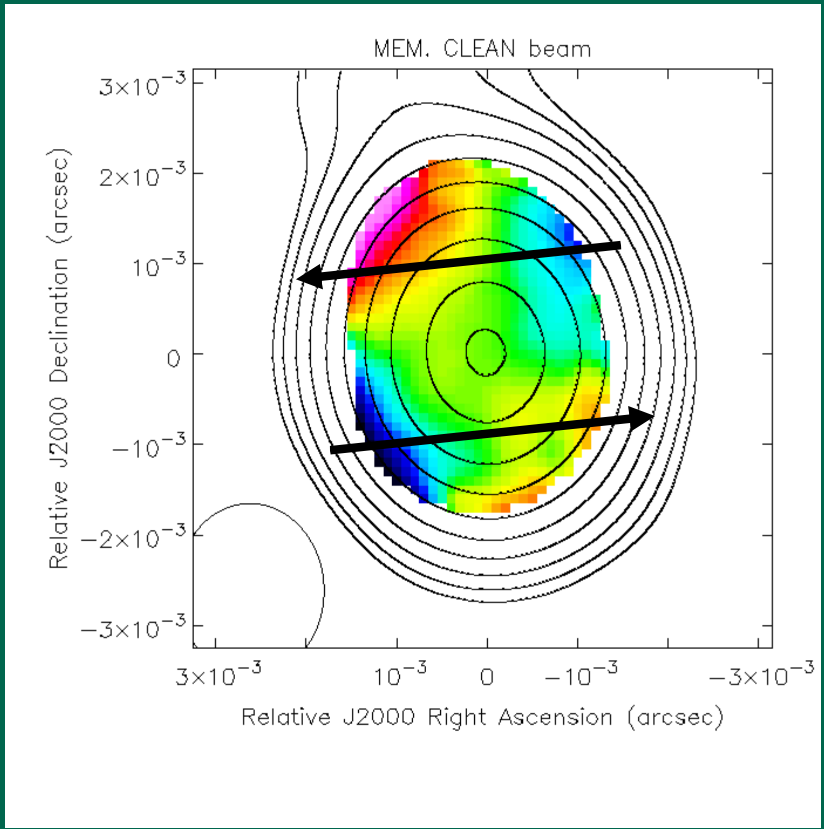
Presence of a "return field" in a more extended region surrounding the jet forms a nested helical-field structure

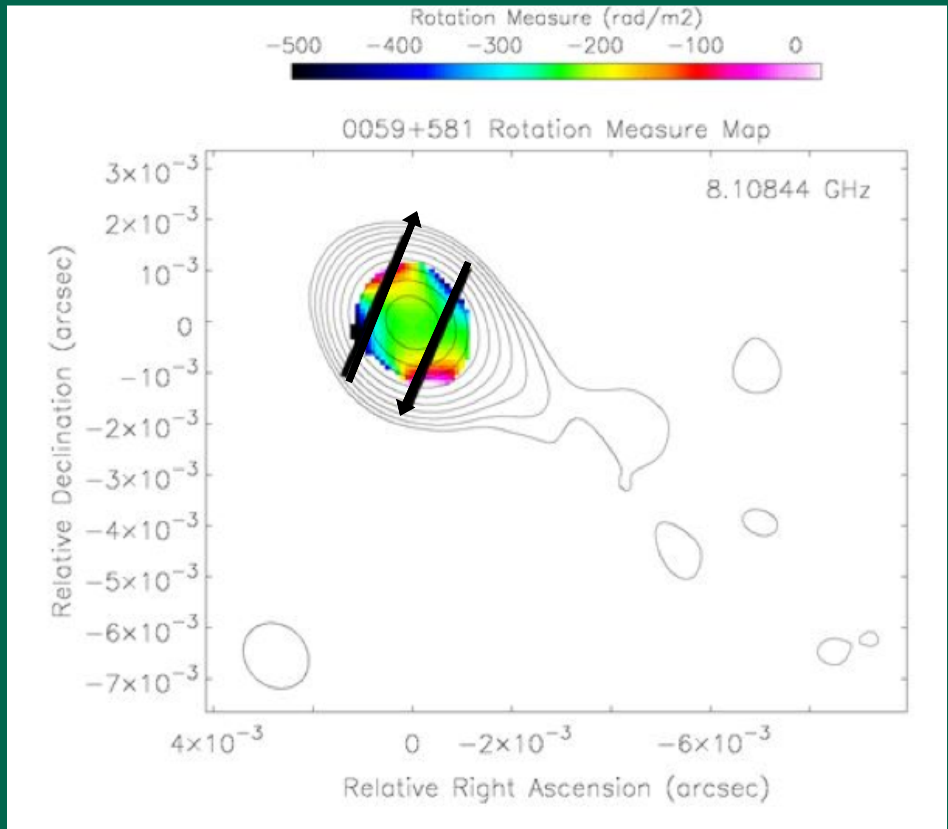
This system of B fields and currents is similar to that of a co-axial cable, with current running inward along the jet axis and outward in a region surrounding the jet.



DG et al. 2018

Reversals of RM gradients have been directly detected in seven AGN, with two more tentative cases (DG et al. 2018):





Mahmud et al. 2013

DG et al. 2018

Summary

- High-sensitivity VLBI polarization observations at multiple frequencies in the L band can provide rich information about I and B-field structures on scales of 10's to 100's of parsec from the core

- Pol angles must be corrected for Faraday rotation, but Faraday rotation distribution can be determined if observations are made with > 2 frequencies

- 1.4-1.7 GHz observations analyzed so far show evidence for toroidal/helical B field components far from the core, rich B-field and RM structure, fading of jet components on time scales of ~ 6 years

Some technical challenges

- Mitigating RFI, reducing thermal noise

- Well-behaved cross-talk, so D-terms can be accurately removed; accurate flux calibration for reliable spectral index maps

- Aiming for roughly equal sensitivities all across the L band, so that lower sensitivity at one L-band frequency doesn’t severely limit RM map

- Ability to make RM maps with 6-8 frequencies, increasing accuracy of resulting RMs and giving redundancy

Parting thought:

The jets are fundamentally electro-magnetic structures, which likely have helical B fields and carry current.

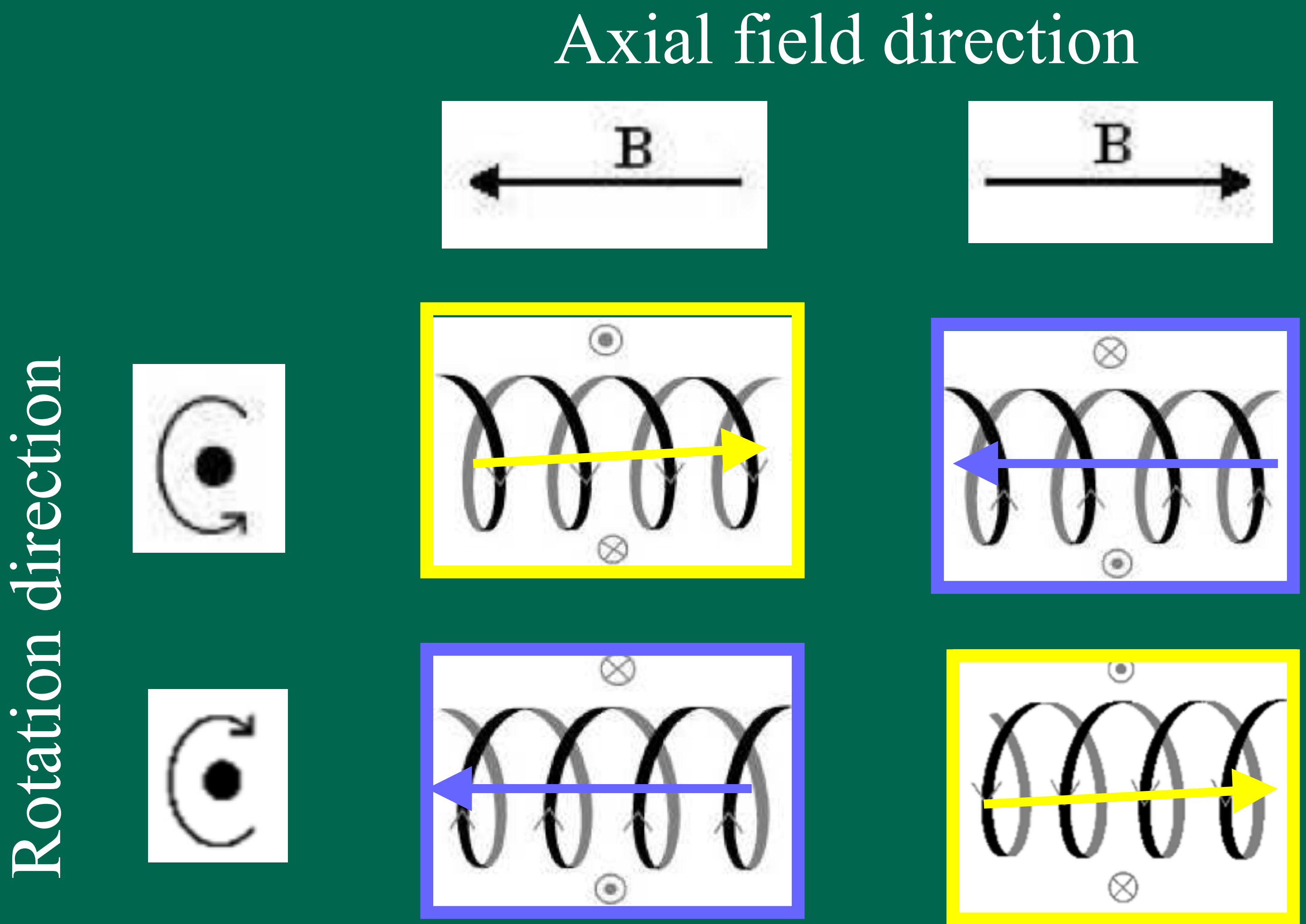
Polarization observations imaging all scales are crucial to enhance our understanding of these objects!

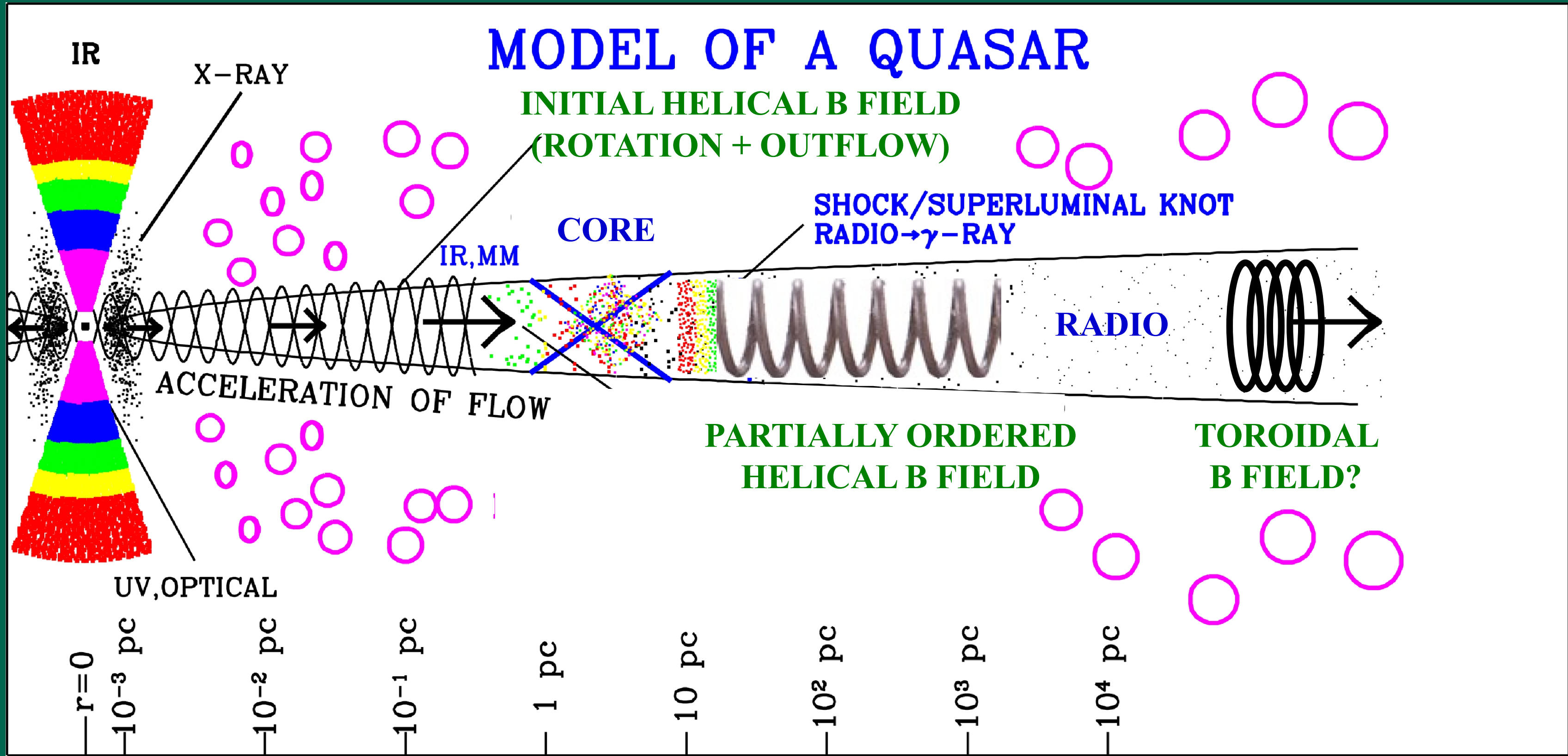
Molly resolved never again to jump into a box of packing chips after rolling on the sitting room carpet.

Extra slides

An observed RM gradient (toroidal B field) will correspond to a particular axial current direction — inward or outward.

Arrows show direction of implied current





Gabuzda 2017

• Observations of transverse RM gradients + modeling of Marscher (2015) suggest a picture with both helical (ordered) + chaotic (turbulent) B components in jet:

Helical B ⇒ RM gradients   Chaotic B ⇒ variability