Uncovering magnetic field topology from synchrotron polarization

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Multifrequency surveys

Many existing / upcoming polarization surveys span large wavelength ranges

e.g.: GMIMS

300 MHz – 1.8 GHz

CHIME

400 MHz – 800 MHz

GBT intensity mapping survey

700 MHz – 900 MHz

3D data sets

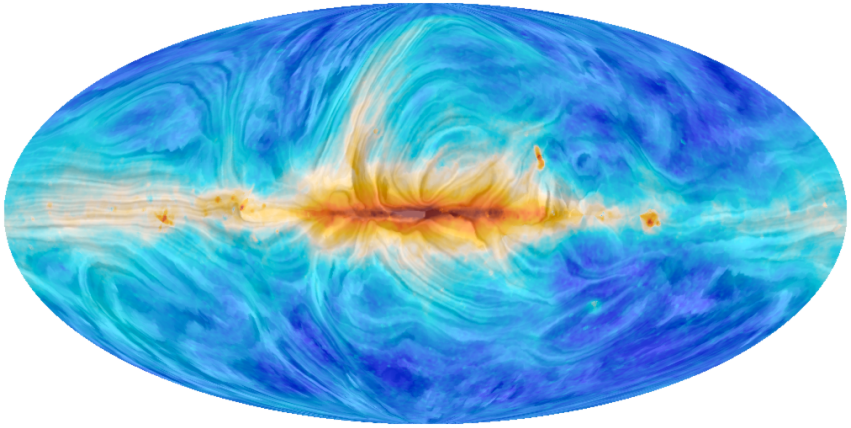
credit: NRC-CNRC

credit: CSIRO

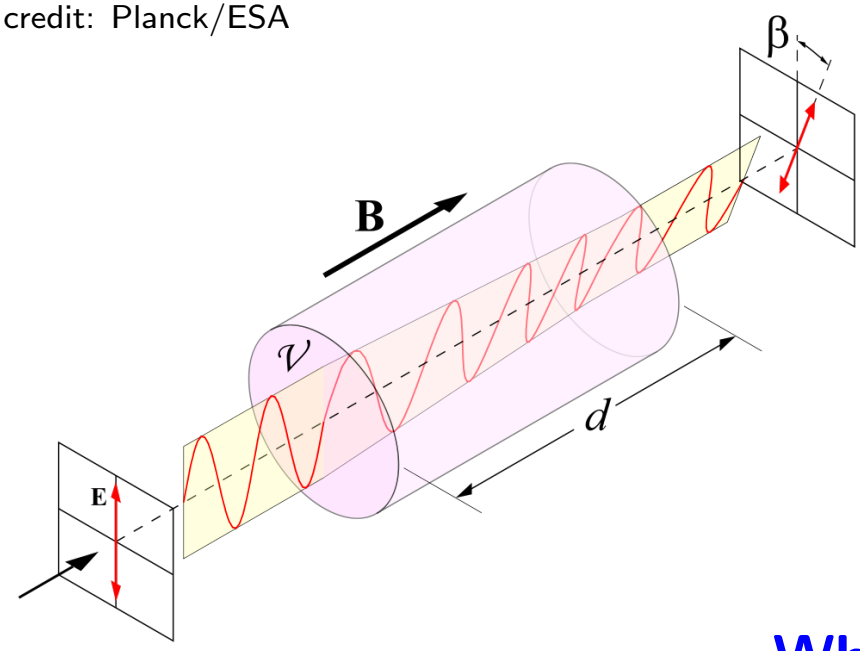
credit: Andre Renard

credit: NRAO

Magnetic vector field



credit: Planck/ESA



credit: Wikimedia Commons

Synchrotron emission is polarized; orientation given by plane-of-sky component of B-field, $B_\perp$

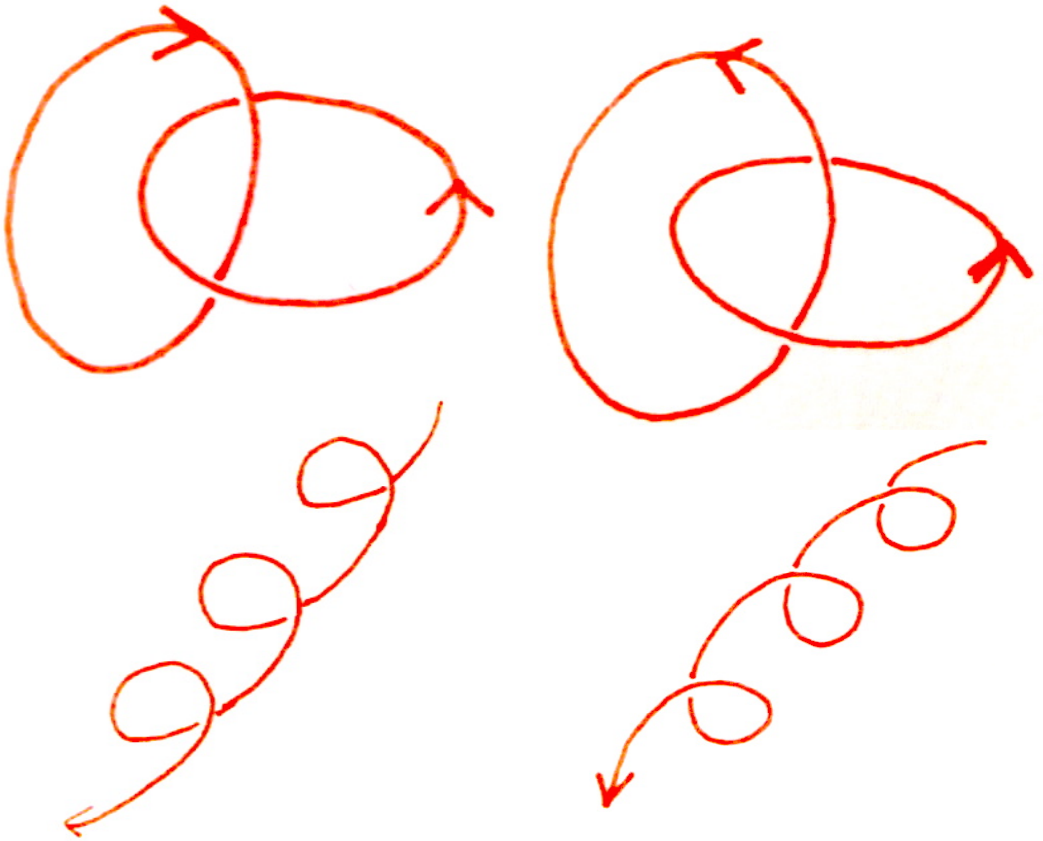
Faraday rotation depends on line-of-sight component of B-field, $B_\parallel$

B-**field**: 3D vector at each 3D position

multifrequency observations: 3D data sets, sensitive to all three vector components, but only in projection

What can('t) we learn?

Magnetic helicity



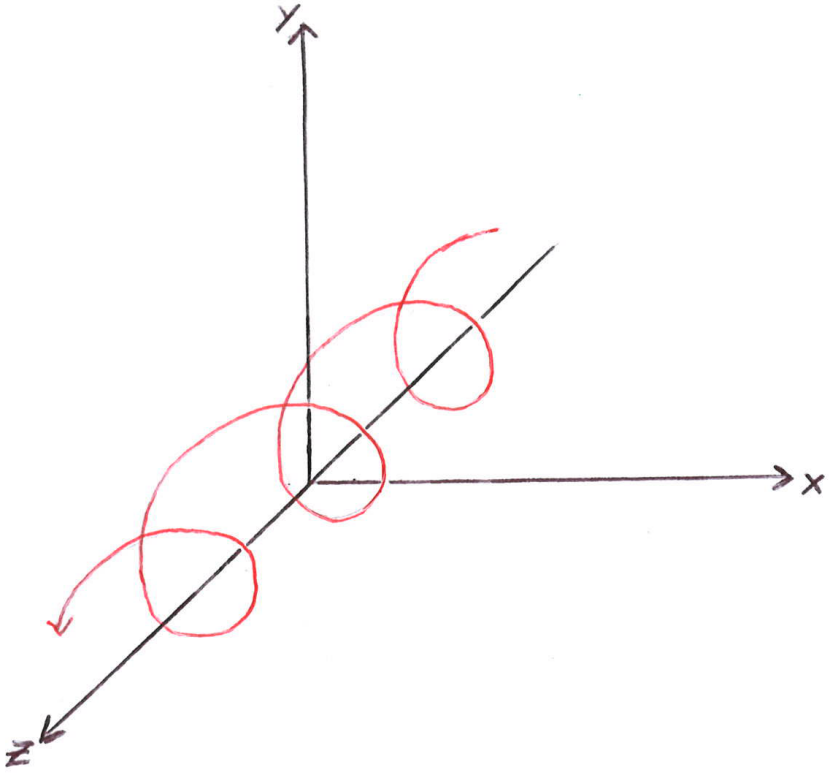
$$H = \int_V \mathrm{d}^3x\, A \cdot B$$

conserved if:

- conductivity high
- nothing happens at the surface of V

Helicity predicted by all mean-field dynamo models, but details (such as sign) differ.

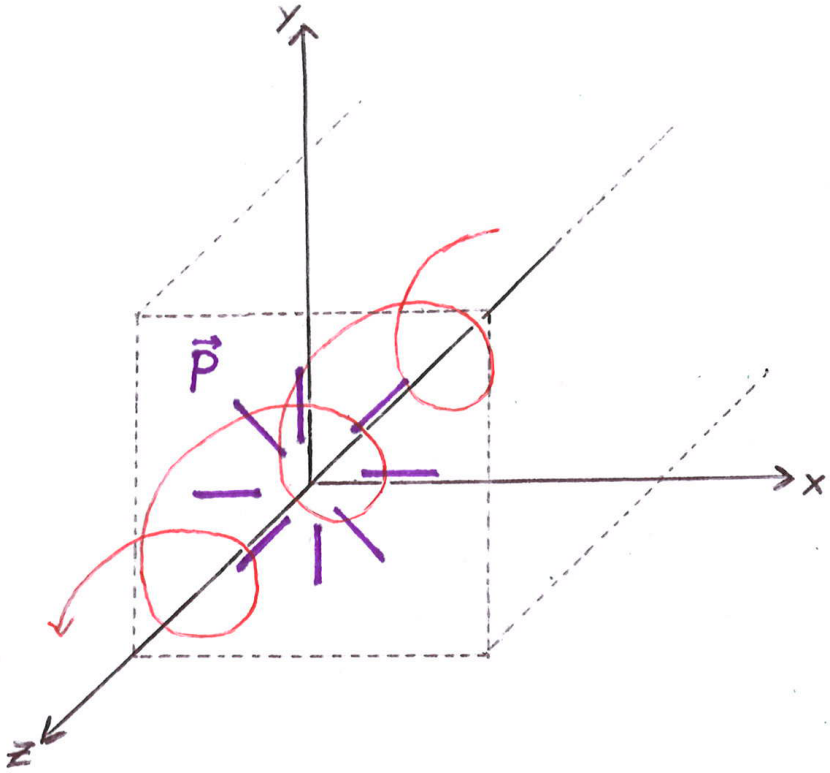
Detecting magnetic helicity I



Helix seen face on:

Junklewitz et al. 2011
Oppermann et al. 2011

Detecting magnetic helicity I



Helix seen face on:

$B_\perp$ appears circular

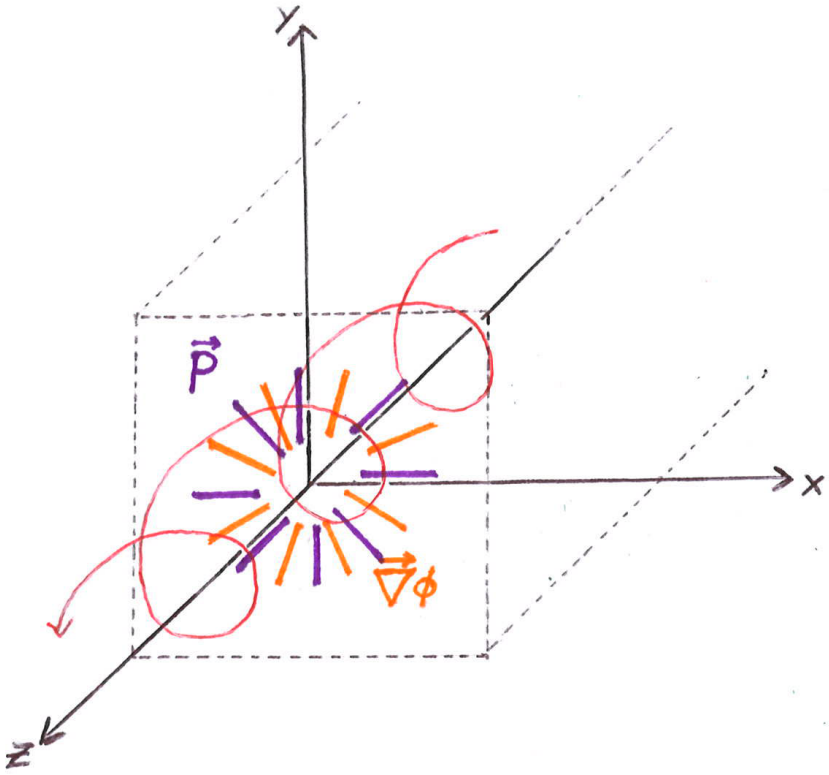
polarization appears radial

(in the absence of Faraday rotation)

Junklewitz et al. 2011

Oppermann et al. 2011

Detecting magnetic helicity I



Helix seen face on:

$B_\perp$ appears circular
polarization appears radial
(in the absence of Faraday rotation)

$B_\parallel$ positive or negative
gradient of Faraday depth radial

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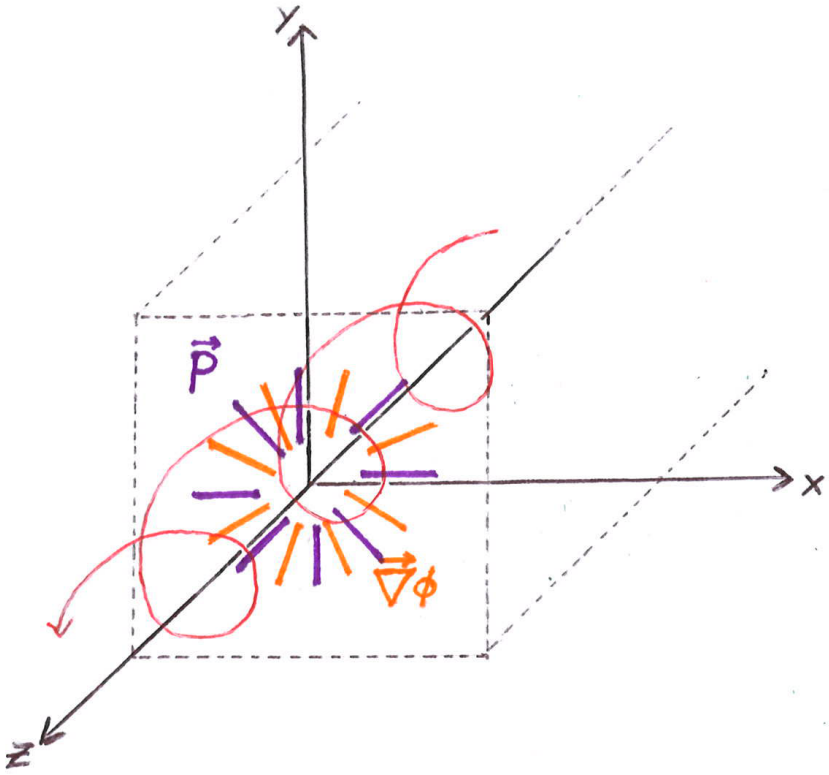
Detecting magnetic helicity I



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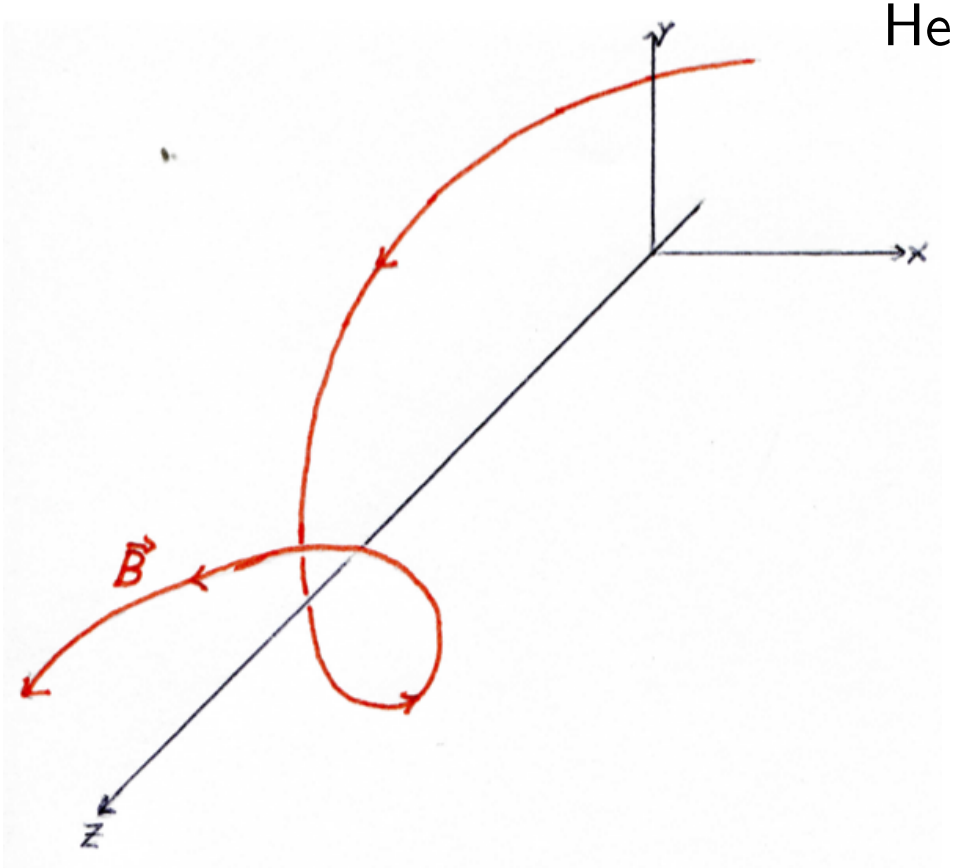
To detect helicity, look for preferred alignment of P and $\nabla\phi$

Junklewitz et al. 2011
Oppermann et al. 2011

Detecting magnetic helicity II



Helix seen face on:

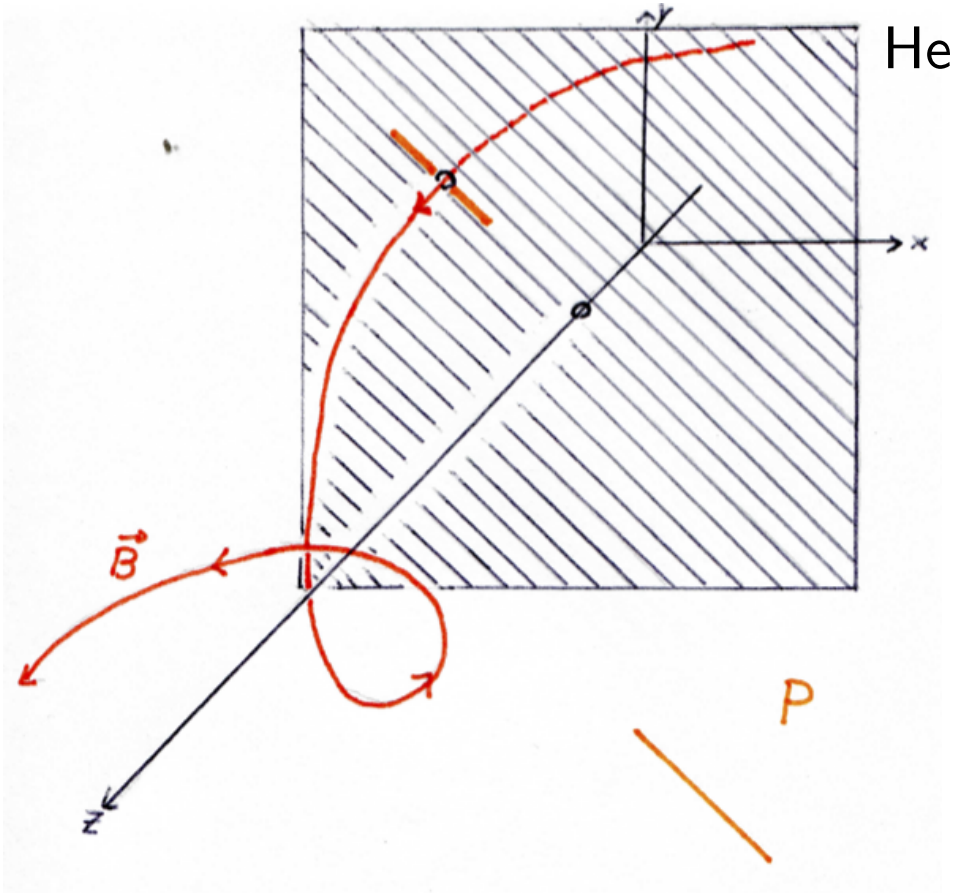
polarization at different distances appears at different angles, thus depolarization

but resonance between scale of helicity and wavelength possible, thus repolarization

depends on sign of helicity

Brandenburg et al. 2014
Horellou et al. 2014
Volegova et al. 2010

Detecting magnetic helicity II



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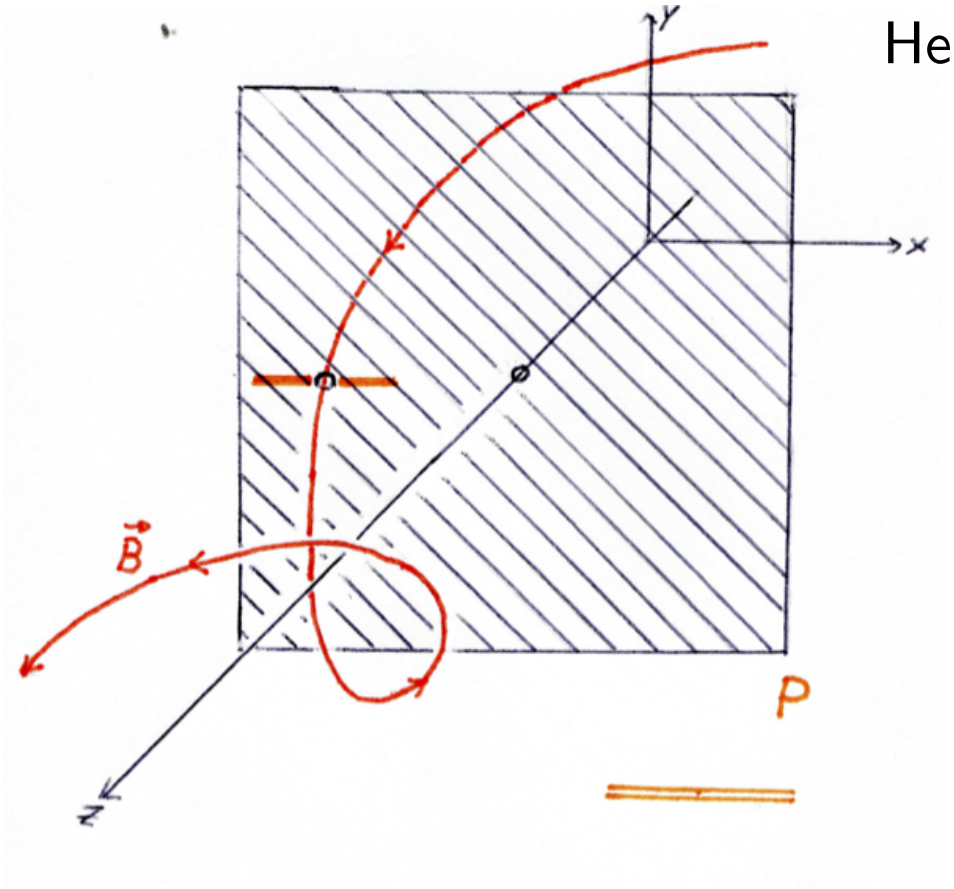

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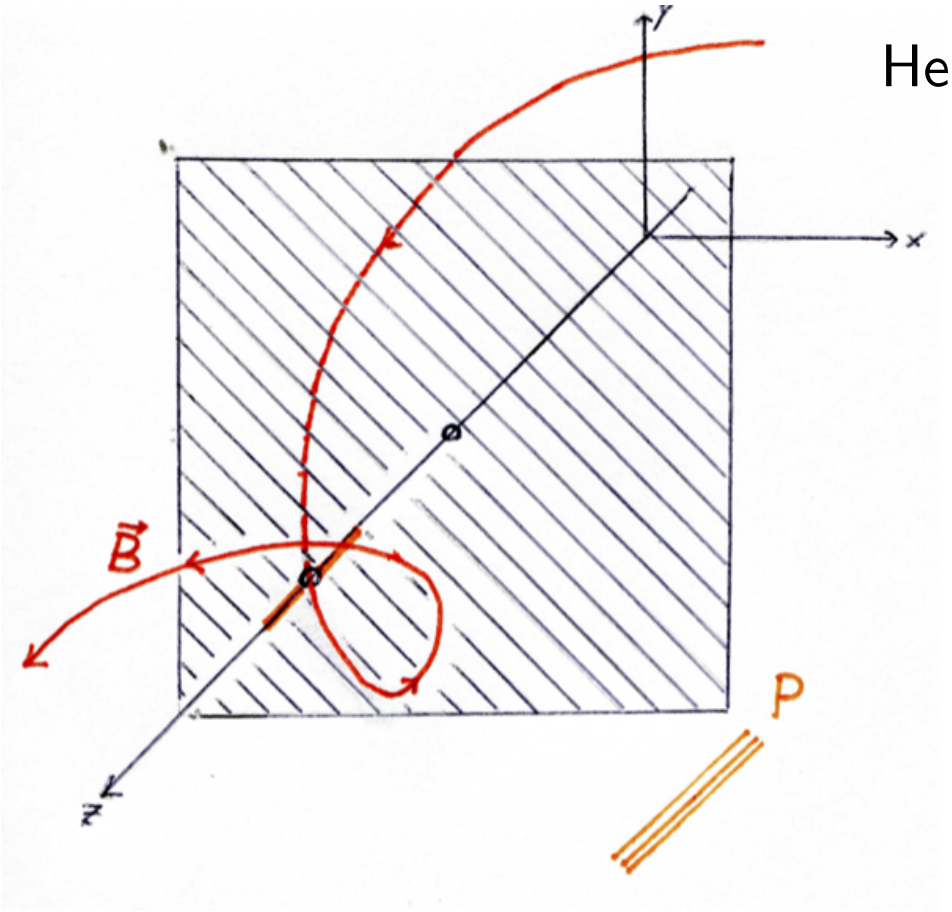

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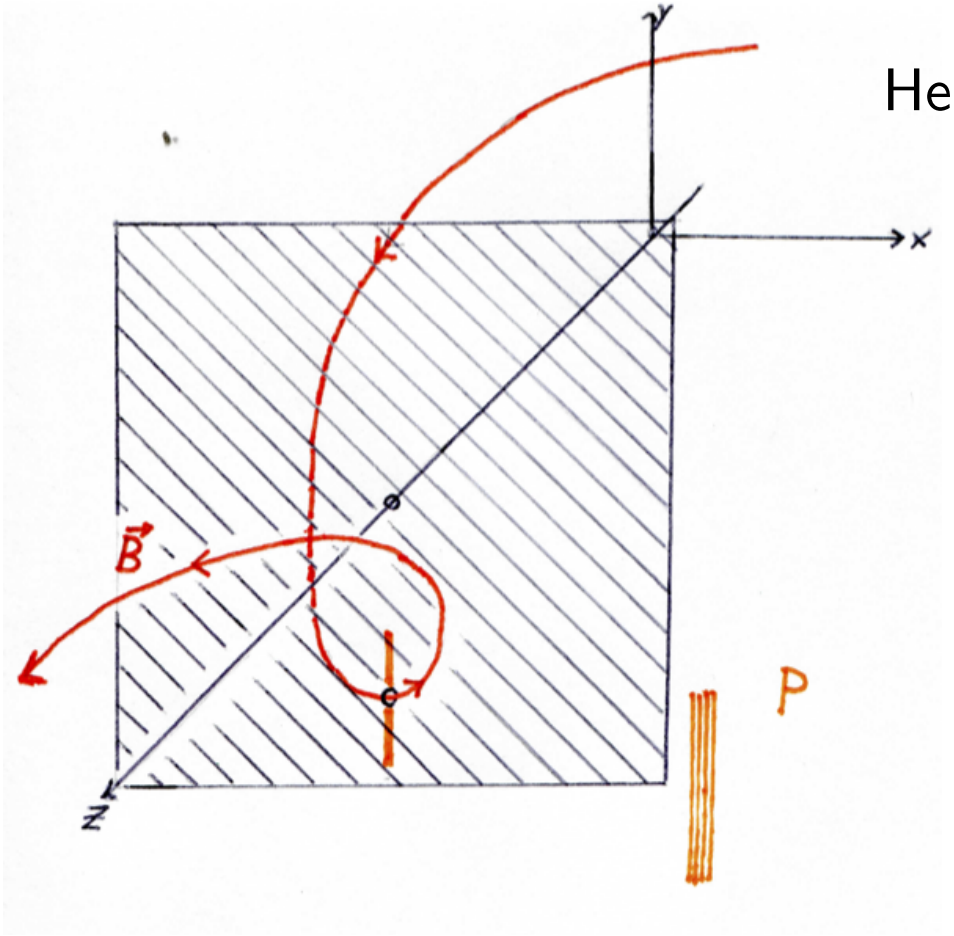

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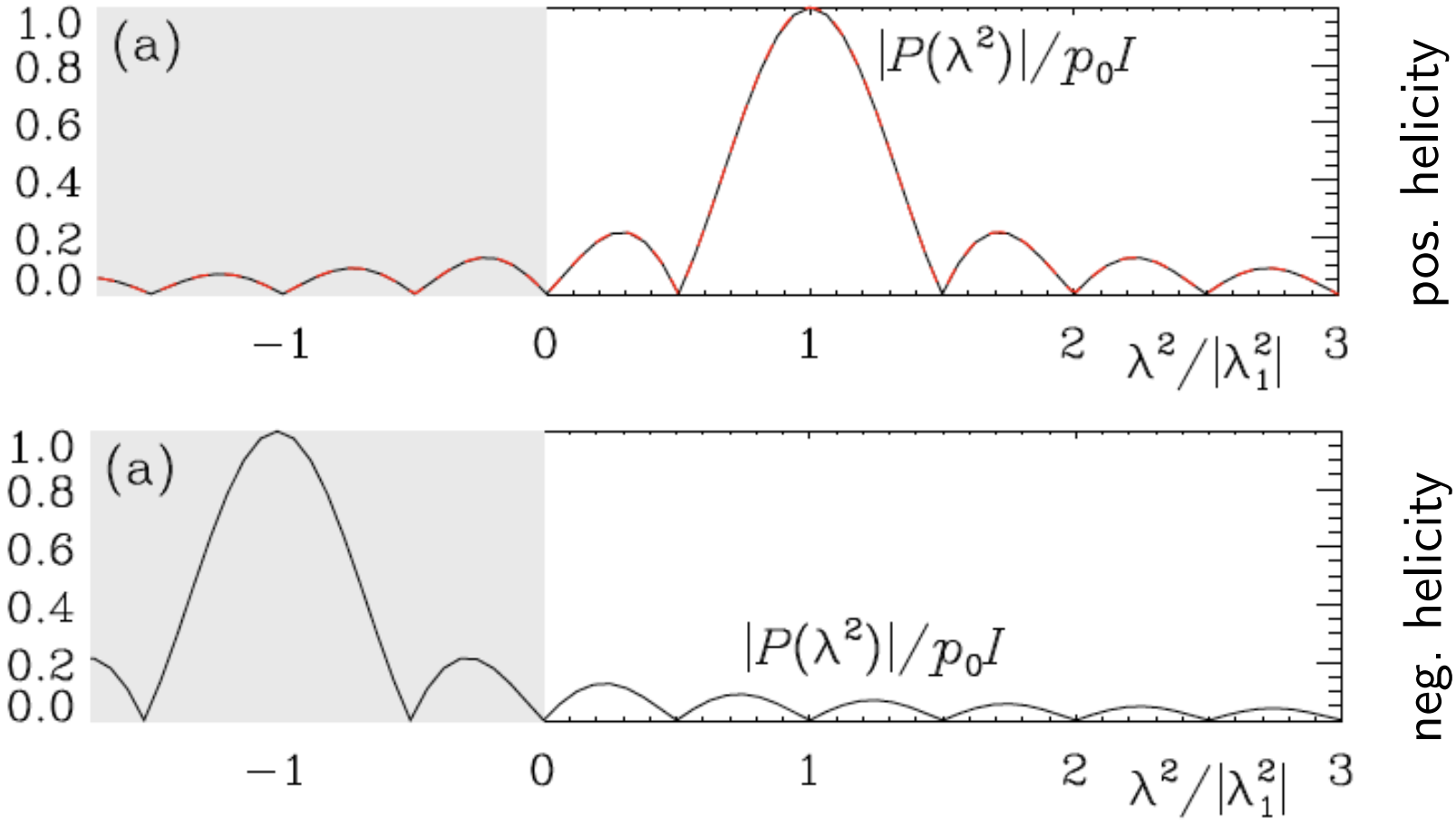


Brandenburg et al. 2014

Detecting magnetic helicity III

What if positive and negative helicity on different scales?

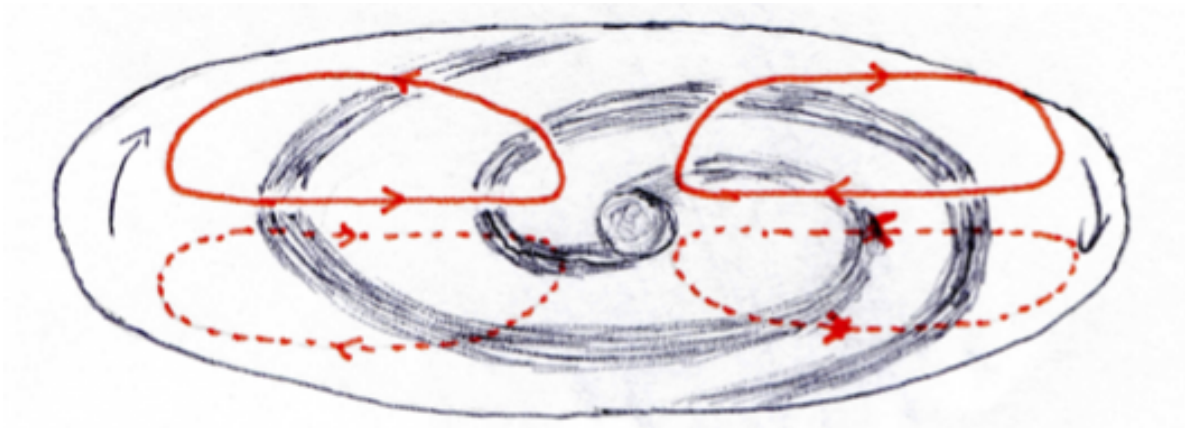
- Estimate power spectrum for positive and negative helical component of the B-field
- Proper estimate (with uncertainty) requires marginalization over B-field realizations
- lots and lots of parameters. . .

Summary

- Inferring exact 3D B-field without strong assumptions impossible
- But statistical quantities may be accessible
- Helicity can teach us about the Galactic dynamo
- Has specific signatures in polarization data
- There is hope, but assessing significance takes care

Bonus slides

The α-Ω dynamo



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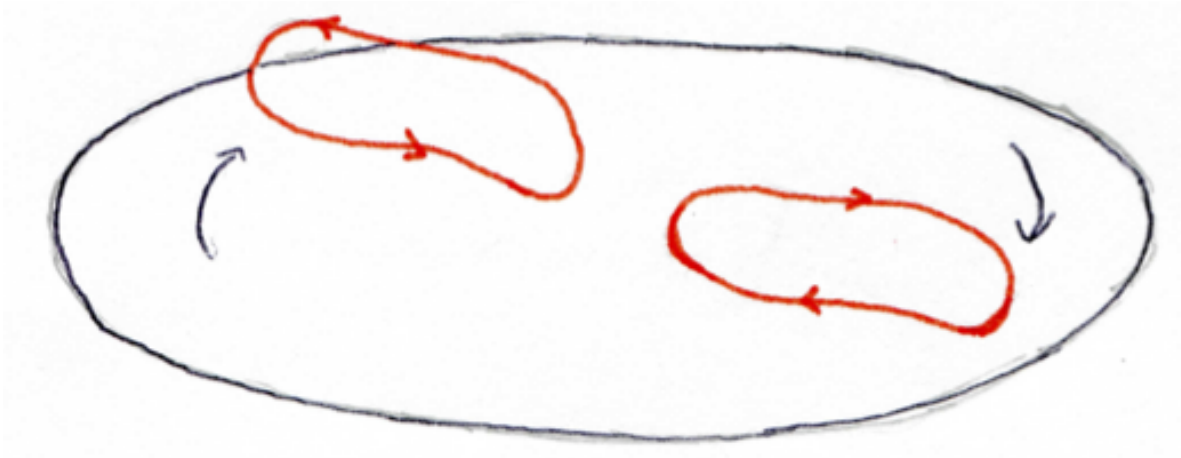

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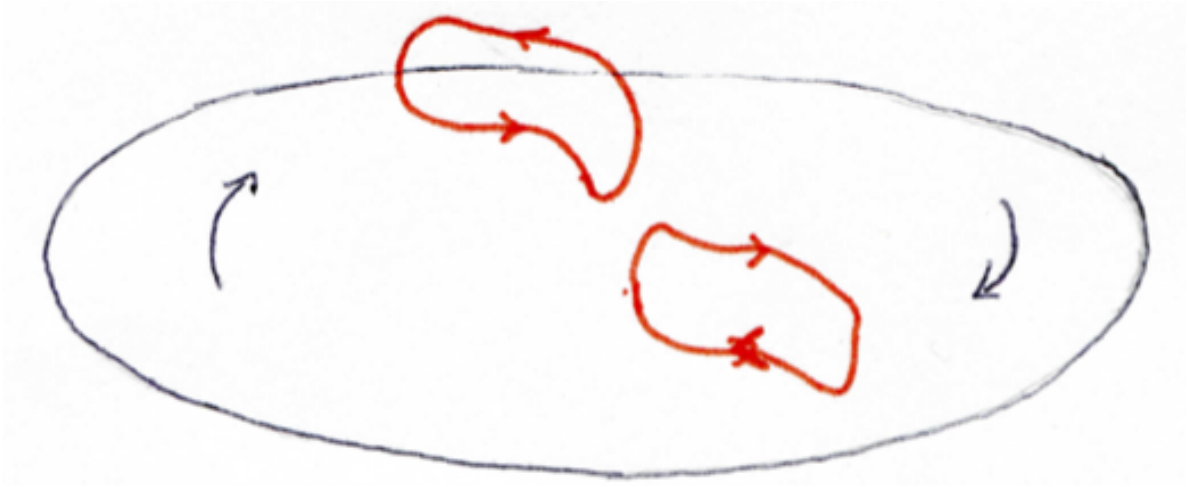

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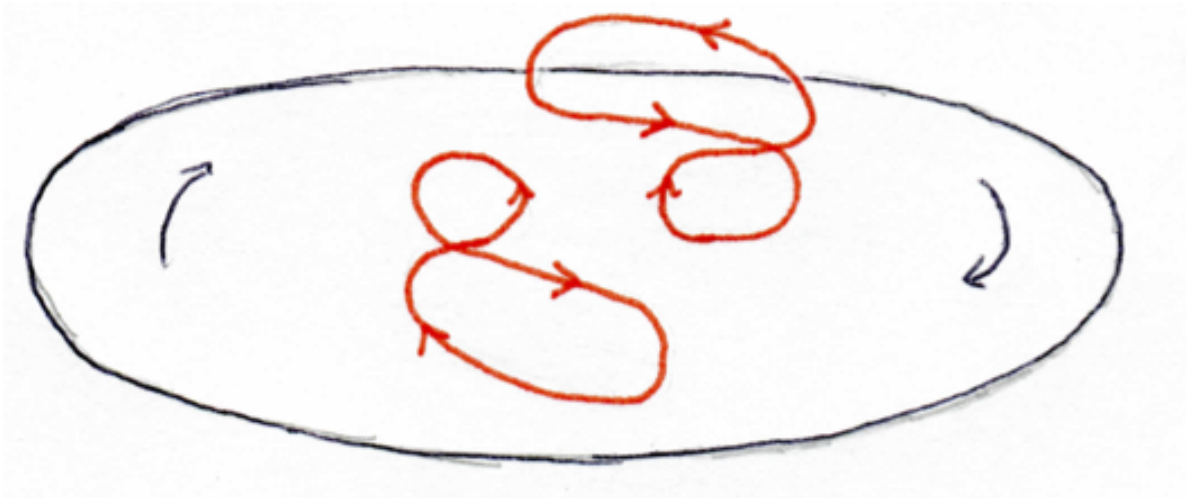

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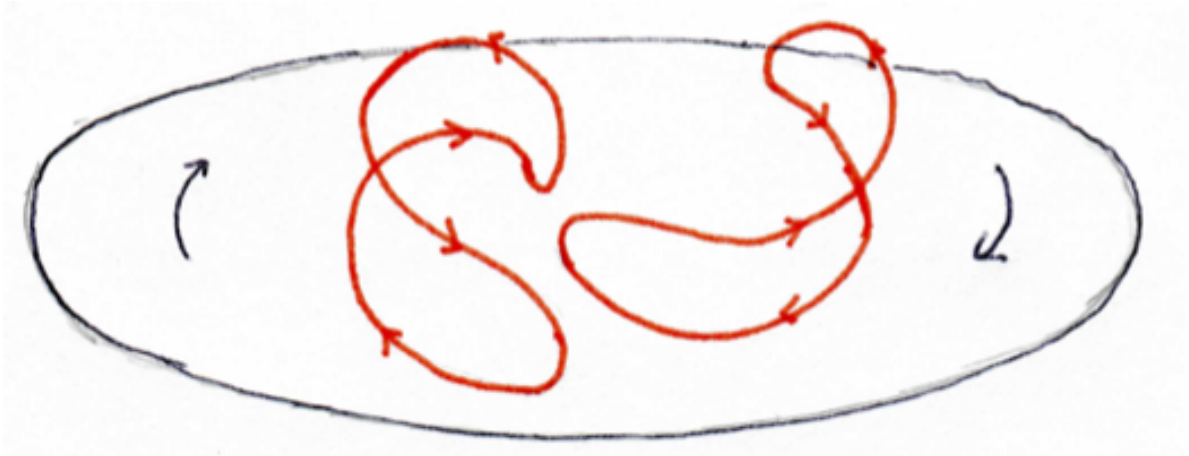

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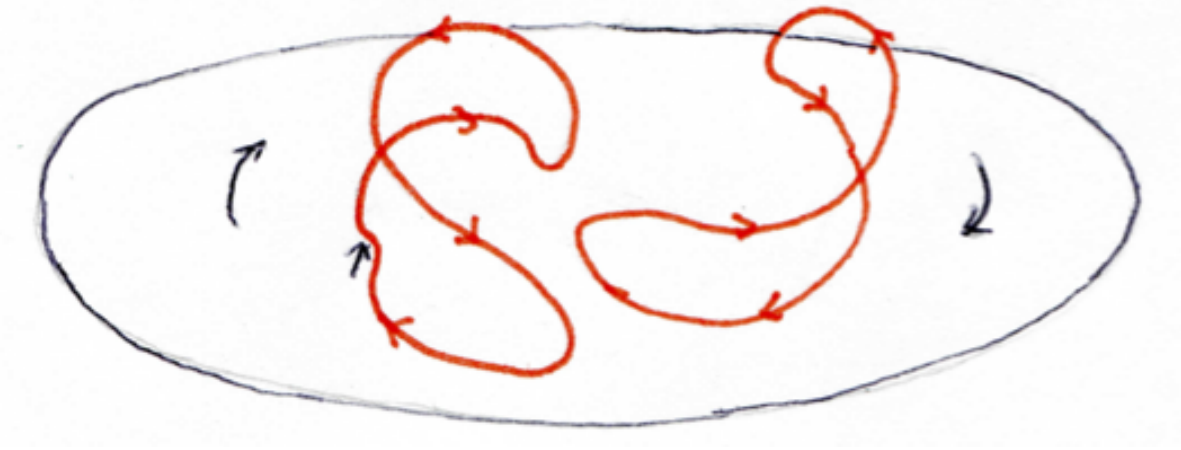

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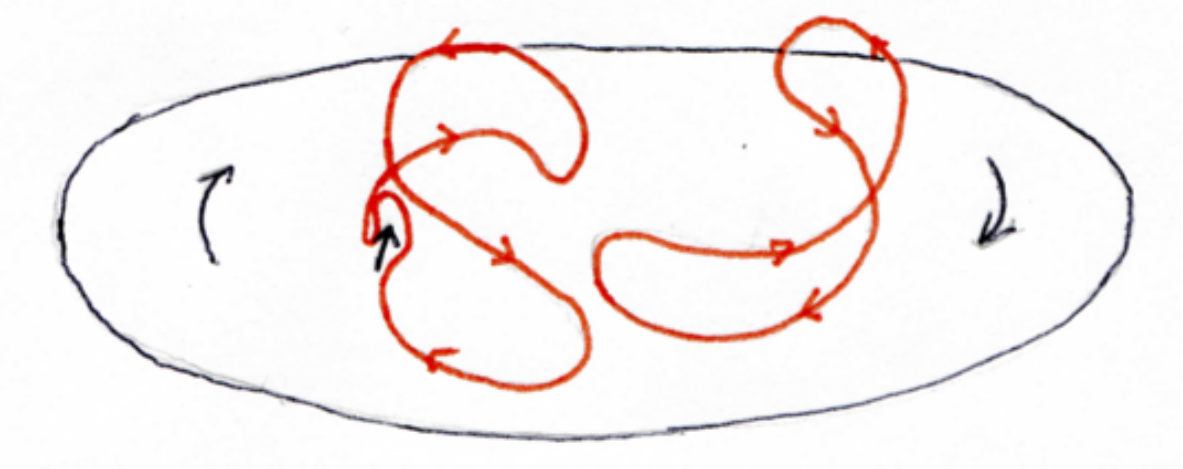

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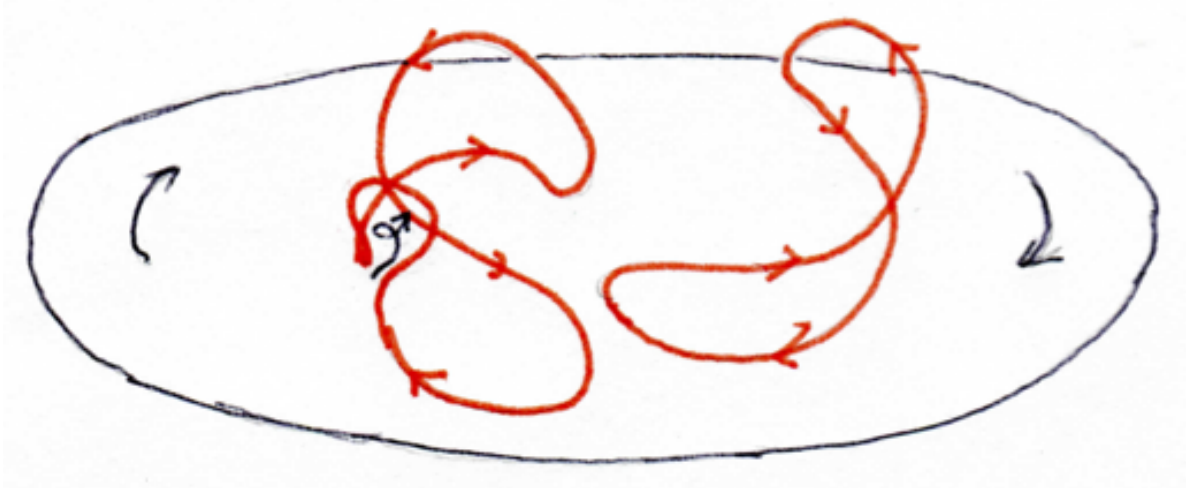

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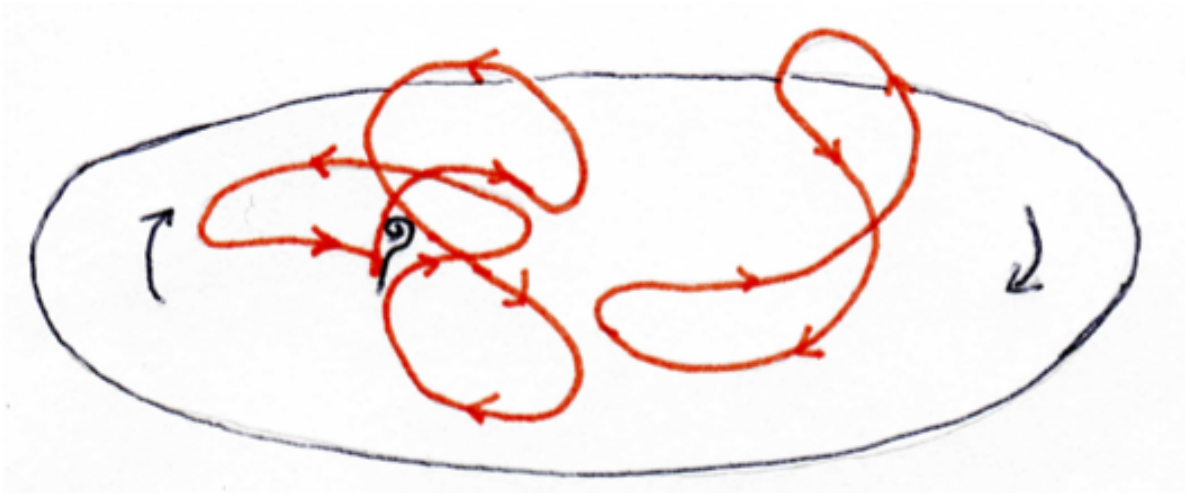
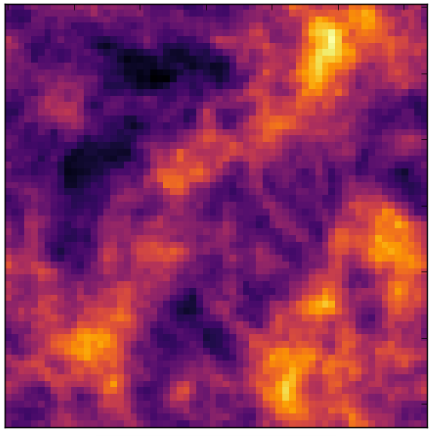


- small-scale kinetic helicity leads to B-field growth, twists B-field
- leads to small-scale helicity, leads to reduced B-field growth
- dynamo gets quenched, unless helicity moved around
- expect opposite signs of helicity either in different regions or on different scales

Detecting magnetic helicity I

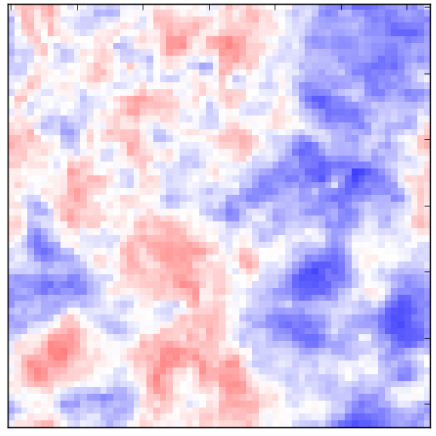
example: **positive helicity** on all scales

Stokes I



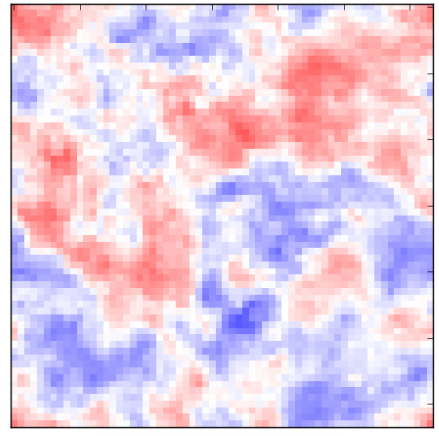
small large

Stokes Q



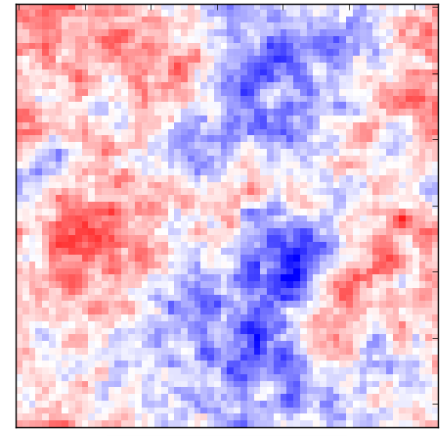
negative positive

Stokes U



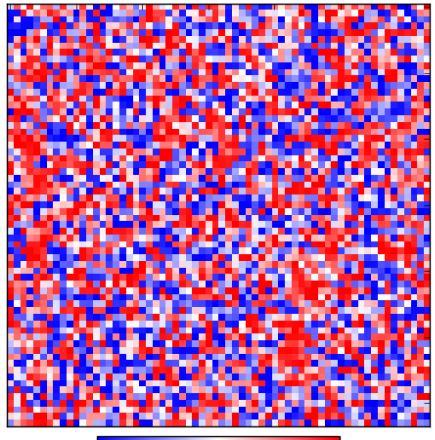
negative positive

Faraday depth



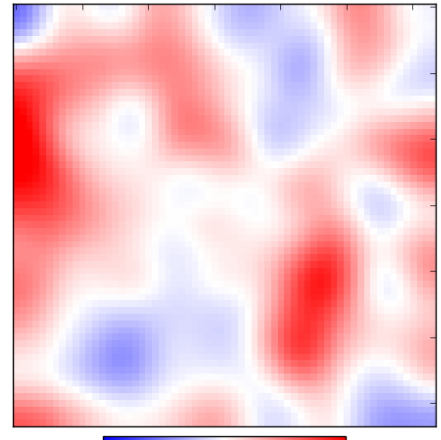
negative positive

alignment



orthogonal parallel

smoothed alignment

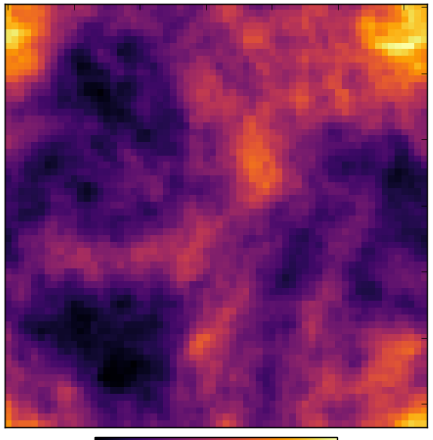


orthogonal parallel

Detecting magnetic helicity I

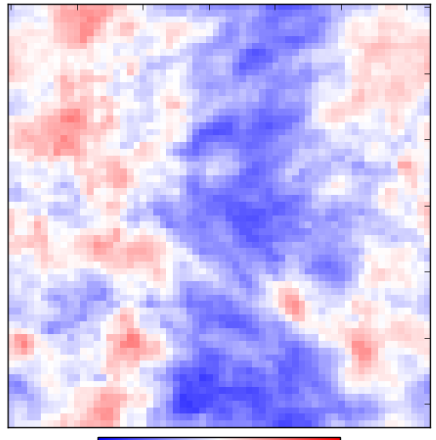
example: **negative helicity** on all scales

Stokes I



small large

Stokes Q



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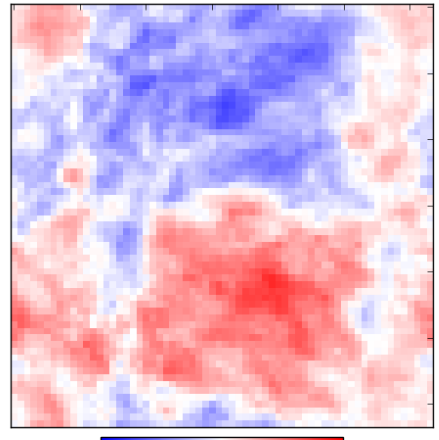
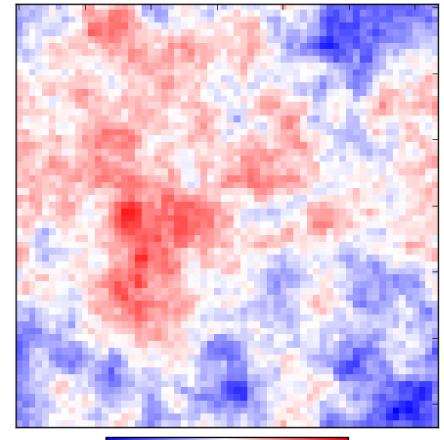


negative positive

Faraday depth



negative positive

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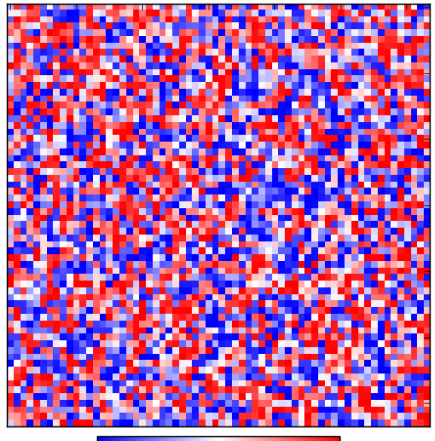
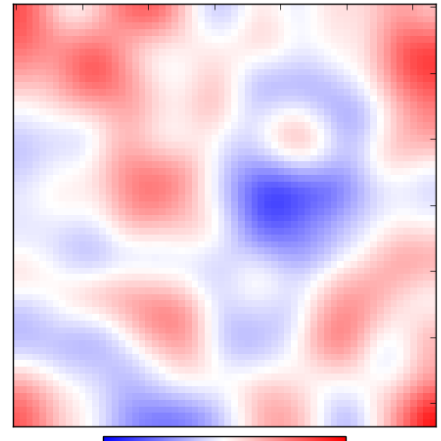


orthogonal parallel

smoothed alignment

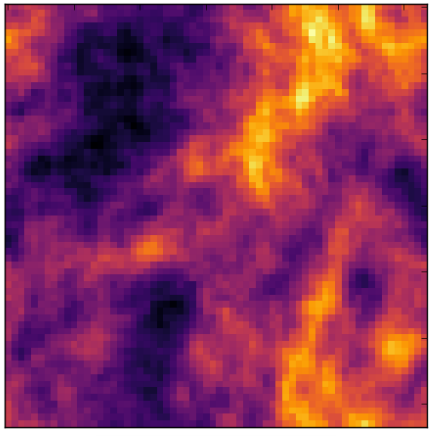


orthogonal parallel

Detecting magnetic helicity I

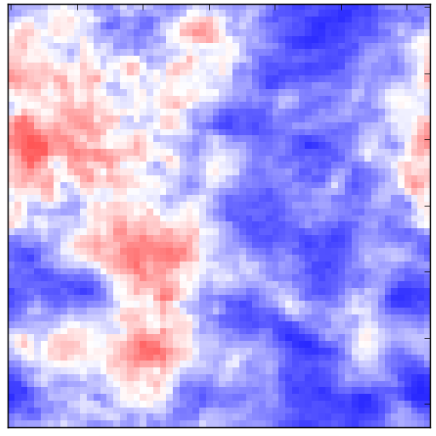
example: **no helicity** on all scales

Stokes I



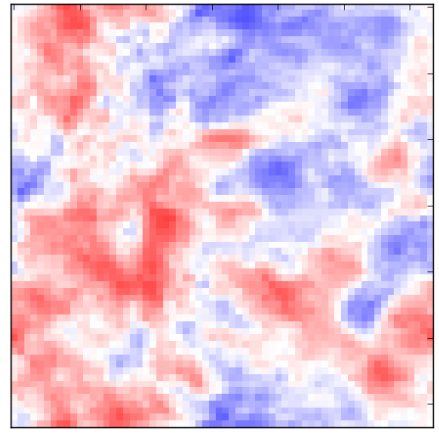
small large

Stokes Q



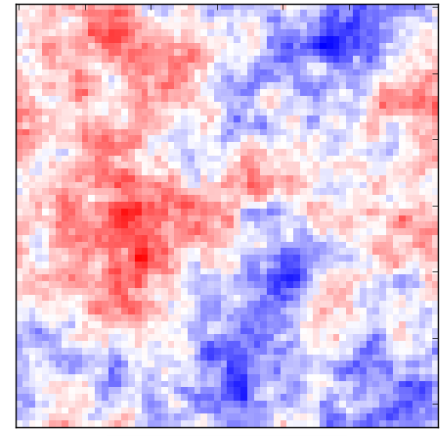
negative positive

Stokes U



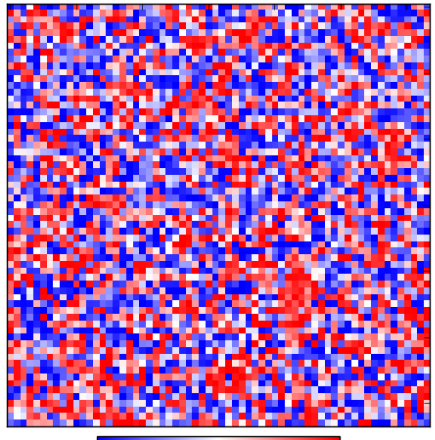
negative positive

Faraday depth



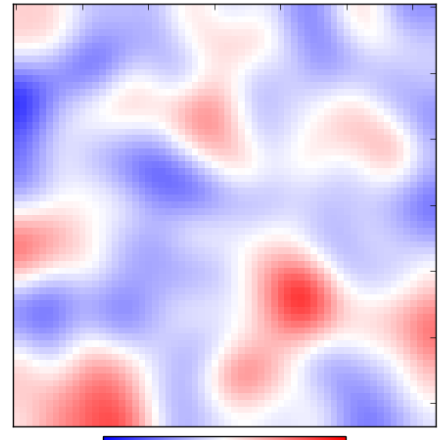
negative positive

alignment



orthogonal parallel

smoothed alignment



orthogonal parallel

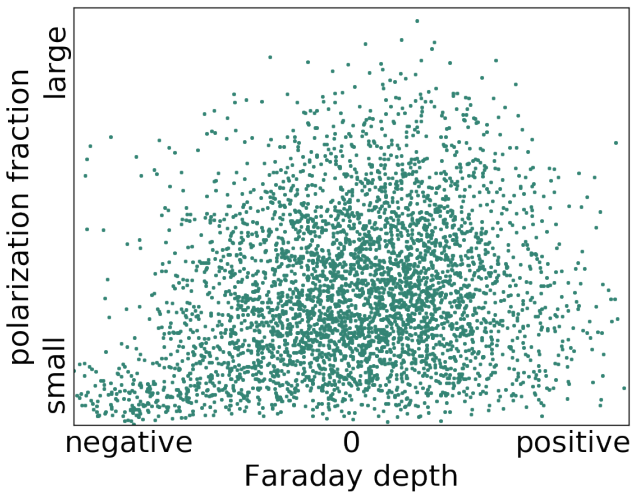
Detecting magnetic helicity II

If mix of scales, not necessarily a clear resonance

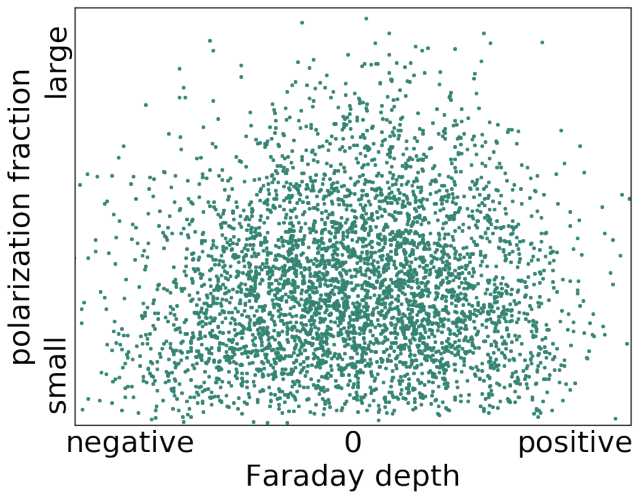
But expect (anti-) correlation between
Faraday depth and polarization degree

Volegova et al. 2010

negative helicity



no helicity



positive helicity