The Galactic magnetic field

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Big Questions:

What is the origin of galactic magnetic fields?

How do they evolve and how are they maintained?

- dynamo models: large-scale magnetic fields
- RM Grid + diffuse synchrotron (SKA-Survey)

What is their interaction with other components in galaxies ("Galactic ecology")?

- turbulence and magnetic fields in objects:
  - small-scale magnetic fields
    - (for masers, see Wouter Vlemming's talk)
  - diffuse synchrotron + RM Synthesis (SKA-Low)
Measuring methods at our disposal:

1. Synchrotron emission

Total emissivity:
\[ \varepsilon \propto B_{\perp}^2 \]

Polarized intensity:
\[ p \propto \frac{B_{\text{reg}}}{B_{\text{tot}}} \]
Measuring methods at our disposal:

2. Faraday rotation

2a ‘Classical’:

Polarization angle rotates with observing wavelength $\lambda$: $\theta \propto RM \lambda^2$

where rotation measure $\int n_e B \cdot dl$

RM Grid

current: ~40,000 sources
ASKAP/POSSUM: x 100
WSRT/WODAN:
SKA: x 1000

Taylor et al 2009
Measuring methods at our disposal:

2. Faraday rotation

2a ‘Classical’:

Polarization angle rotates with observing wavelength $\lambda$: $\theta \propto \text{RM} \lambda^2$

where rotation measure $\text{RM} \propto \int_0^L n_e B \cdot dl$

2b Rotation measure synthesis: (Burn 1966, Brentjens & de Bruyn 2005; Heald 2009)

Faraday depth $\phi \propto \int_{l_1}^{l_2} n_e B \cdot dl$

$P_{\text{obs}}(\lambda^2) = W(\lambda^2)P(\lambda^2) = W(\lambda^2) \int \phi e^{2i\phi\lambda^2} d\phi$

$R(\phi) = K \int_{-\infty}^{\infty} W(\lambda^2) e^{-2i\phi\lambda^2} d\lambda^2$

$F_{\text{obs}}(\phi) = F(\phi) * R(\phi) = K \int_{-\infty}^{\infty} P_{\text{obs}}(\lambda^2) e^{-2i\phi\lambda^2} d\lambda^2$

$K = \left( \int_{-\infty}^{\infty} W(\lambda^2) d\lambda^2 \right)^{-1}$
Large-scale magnetic fields in the Milky Way
Large-scale magnetic fields in the Milky Way

SKA-survey RM grid:
- accurate distances
- many more pulsars

: how big is reversal?
: deviations from spiral?

→ how does dynamo work?
Large-scale magnetic fields in the Milky Way

foreground objects make modeling difficult

A quadrupolar field...

Taylor et al 2009

Han 2003
Large-scale magnetic fields in the Milky Way

foreground objects make modeling difficult

A quadrupolar field...

... or the influence of nearby (large-angular-scale) structures?
Large-scale magnetic fields in the Milky Way

foreground objects make modeling difficult

SKA-survey RM grid:
- testing dynamo models

SKA-low RM Synthesis:
- study discrete objects (SNRs, HII regions, SF regions etc)

... or the influence of nearby (large-angular-scale) structures?
Small-scale magnetic fields in the Milky Way

**Outer scales:**
- synchrotron fluctuations
- structure functions

**Mach number:**
- polarization gradients

**Power spectral index:**
- structure functions
Small-scale magnetic fields in the Milky Way
LOFAR synchrotron fluctuations probe turbulence

→ Outer scale ~ 15 pc

→ $B_{\text{ordered}}/B_{\text{random}} > 0.2$

Iacobelli et al 2013
Small-scale magnetic fields in the Milky Way

New diagnostic for these polarization changes in the ISM: the gradient in complex vector $\mathbf{P}$

$$|\nabla \mathbf{P}| = \sqrt{\left( \frac{\partial Q}{\partial x} \right)^2 + \left( \frac{\partial U}{\partial x} \right)^2 + \left( \frac{\partial Q}{\partial y} \right)^2 + \left( \frac{\partial U}{\partial y} \right)^2}.$$
Small-scale magnetic fields in the Milky Way

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Small-scale magnetic fields in the Milky Way
Compare to magnetohydrodynamical simulations

Burkhart et al 2011

subsonic

supersonic
Small-scale magnetic fields in the Milky Way

Compare to magnetohydrodynamical simulations

Compare with observations using the **skewness** (asymmetry) and **kurtosis** (‘peakedness’) of the probability density distribution of $|\nabla P|$:  

The observed interstellar turbulence is subsonic or transsonic
All-sky polarization gradient: mapping out Mach number

* I removed this map from the presentation as it is as yet unpublished *

S-PASS survey: Parkes 2.3 GHz continuum (PI Carretti)
All-sky polarization gradient: mapping out Mach number

* I removed this map from the presentation as it is as yet unpublished *

S-PASS survey: Parkes 2.3 GHz polarization
Turbulence is transonic across the Milky Way (?)
All-sky polarization gradient: mapping out Mach number

SKA-survey:
- high resolution: distinguish between objects and ISM
- high sensitivity: can probe regions in halo

Note: NO missing short spacing problem for polarization gradients!

→ Turbulence is transonic across the Milky Way (?)
Structure functions: work in progress

amplitude

slope

Iacobelli et al 2014

Stil et al 2011
Structure functions: work in progress

amplitude

slope

SKA-survey RM Grid:
- high resolution: distinguish between objects and ISM
- high sensitivity: distinguish higher-order effects (breaks in slope $\rightarrow$ turbulence injection)

Iacobelli et al. 2014
Stil et al. 2011
Rotation Measure Synthesis/Faraday Tomography
Current RM synthesis data of Galactic foreground: FAN region at \((l,b) = (137^\circ, +8^\circ)\)

Proposed model:
- foreground component: Local Bubble wall
- circular feature: HII region expanding in low-density plasma
- discrete, small-scale, synchrotron emitting structures
Current RM synthesis data of Galactic foreground: towards Perseus cluster at \((l,b) = (150^\circ, \pm13^\circ)\)
Current RM synthesis data of Galactic foreground: towards the A2255 cluster at \((l,b) = (94^\circ, +35^\circ)\)
RM Synthesis of Galactic foreground: Big Picture?

- Insensitivity to Faraday thickness?
- Local Bubble?
- Faraday caustics?
- Loop III?
LOFAR RM Synthesis fields:
Galactic foreground around nearby galaxies

* NGC628
* NGC891
* NGC5055
* IC342
* M51
* NGC5907
* M82
* NGC628
* NGC89

PhD thesis Cameron Van Eck
GMIMS: Global Magneto-Ionic Medium Survey
(PI Landecker; Wolleben et al 2009)

Angular resolution 30 – 60 arcmin

Faraday depth resolution of 3.5 rad m$^{-2}$
Maximum detectable Faraday depth $\sim 115$ rad m$^{-2}$

GMIMS + LOFAR: Faraday depth resolution of $< 0.5$ rad m$^{-2}$
Summarizing:

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<th>Galactic magnetic field component</th>
<th>CURRENT</th>
<th>SKA</th>
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<tr>
<td>large-scale</td>
<td>one reversal</td>
<td>mapping of 3D field</td>
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<td>some vertical component</td>
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<td>small-scale</td>
<td>transonic turbulence in</td>
<td>mapping Mach number throughout Galaxy</td>
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<td>outer scale ~10 pc in</td>
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