Filamentary structures in LOFAR observations of the interstellar medium

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*on behalf of the LOFAR-EoR team
**LOFAR: Low Frequency Array**

van Haarlem et al., 2013

- **LOFAR-HBA (6-8h) observations**
  - 115 - 175 MHz, 0.2 MHz resolution
  - 5 deg x 5 deg images, 3 arcmin resolution

- **HBA: 115 - 240 MHz bow-tie dipoles**

- **LBA: 10 - 80 MHz droop dipoles**

LOFAR-CORE, near Exloo, the Netherlands
Faraday rotation $\sim \phi \lambda^2$

- with radio telescope we observe emission in Stokes I,Q,U,V at different frequencies

$$P(\lambda^2) = Q(\lambda^2) + iU(\lambda^2)$$

- perform transformation from $\lambda^2$ to Faraday depth $\phi$ (RM synthesis)
Rotation Measure Spread Function

Resolution $\approx$ Spectral Bandwidth

\[ \delta \Phi \approx 2 \sqrt{3} / \Delta \lambda^2 \]

LOFAR - 150 MHz (4 m²)
WSRT - 350 MHz (0.3 m²)

Max Scale $\approx$ Min Frequency

\[ \Delta \Phi_{\text{scale}} \approx \pi / \lambda_{\text{min}}^2 \]

Faraday Thin Structures

\[ \lambda^2 \Delta \Phi \ll 1 \]

Faraday Thick Structures

\[ \lambda^2 \Delta \Phi \gg 1 \]
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NCP field
from -10 to +13 rad/m²

ELAIS-N1 field
from -10 to +13 rad/m²


3C196 field
from -3 to +8 rad/m²


LOFAR-HBA observations
3C196 field

Jelic et al., 2015, A&A
3C196 field: constrains on $B_{\|}$

**magnetic field reversal(s)**

PULSAR 434 ms; +2.7 rad/m$^2$; 11.3 pc cm$^{-3}$
(J. Hessels & V. Kondratiev)

\[
\langle B_{\|} \rangle = \frac{\text{RM [rad m}^{-2}] }{0.812 \text{ DM [pc cm}^{-3}] }
\]

\[
\langle B_{\|} \rangle = 0.3 \pm 0.1 \mu\text{G}
\]

H alpha map (Finkbeiner 2003)

\[
\sigma \langle B_{\|} \rangle = \sqrt{\left( \frac{\sigma_{(RM)}}{0.81 \langle n_e \rangle L} \right)^2 + \left( \frac{\langle \text{RM} \rangle \sigma_{(n_e)}}{0.81 \langle n_e \rangle^2 L} \right)^2}
\]

\[
\sigma \langle B_{\|} \rangle \approx 0.2 \mu\text{G}
\]
3C196 field: constrains on the filament

- The lack of emission in total intensity, an upper limit to the thermal free-free emission, $T_{ff} < 0.2$ K

- $T_e = 8000$ K and $dl=1$ pc $\rightarrow n_e < 1$ cm$^{-3}$

- Thickness in Faraday depth of 1 rad m$^{-2}$
  \[ B_{||} > 1.2 \text{ microG} \]

- Assuming equipartition between magnetic and thermal energy
  \[ B_{tot} < 6.5 \text{ microG} \]
3C196 field: a possible model

Jelic et al., 2015, A&A
3C196 field

depolarization canals

discovered pulsar

Jelic et al., 2015, A&A
3C196 field: WSRT 350 MHz observations
3C196 field: Planck dust polarization maps

Zaroubi et al., 2015, MNRAS
• rich morphology of polarized emission detected with LOFAR (115 - 175 MHZ), with the brightness temperature of a few K
• each field has different polarization horizon
• probed ISM mostly close by (<200 pc), within the Local Bubble
• discovery of many filamentary structures and linear depolarization canals (thermal instabilities with anisotropic conduction; trails of stars,...)
• the filamentary structure also shows a signature is Planck dust polarization maps, a common underlying physical structure
• LOFAR an excellent instrument to study ISM with an exquisite resolution in Faraday depth (1 rad/m²)

THANK YOU !