Galactic research with LOFAR

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Outline

- „First Light“ of IS-GE1
- The low frequency sky
- Emissivity distribution in the Galaxy
- Galactic sources
- Need for high angular resolution
- Galactic polarization
IS-GE1 of MPIFR located south of the Effelsberg 100m telescope

„First Light“ 20.03.2007
„First Light“
at
Effelsberg
IS-GE1
20.03.2007
8 dipoles x2
polarizations
τ=4s
512
channels
Δf=156 KHz

All sky snapshot image at 25 MHz

S. Wijnholds, M. Norden (ASTRON)
Cable canals
Cable length
110m
total ~22km

„First Light“
8 dipoles:
HPBW ~22°
at 25 MHz
„First Light“ 25 MHz image (HPBW ~22°)

45 MHz survey (HPBW~5°)

S. Wijnholds, M. Norden (ASTRON)

P. Müller
LOFAR beam(s)

- Synthesized beams from all stations
- Antenna beam of a single station
- Antenna characteristic of a single dipol
Roger et al., 1999
HPBW 1.1°x 1.7° secant ZA

Absorption in the plane!
45 MHz all-sky survey at 5° resolution

Maeda et al., 1999
Alvarez et al., 1997
MU-Radar near Kyoto/Japan
D ~ 100m

45 MHz survey  HPBW 3.6°
Maeda et al. (1999)
Selected radio continuum surveys

MU-Radar and Maipu Radio Observatory

Jodrell-Bank 250-feet + Effelsberg 100-m + Parkes 64-m

Stockert 25-m and Villa Elisa 30-m

Wilkinson Microwave Anisotropy Probe (WMAP)
Spectral index distribution

\( \tau \) large \( \rightarrow \) background absorption

\( \tau \) small

blue = flat
red = steep
Absorption by thermal gas

Fig. 6. The “quasi optical depth” at 22 MHz along the Galactic plane in the first quadrant, from a comparison of the 408 MHz and 22 MHz emissions, assuming all absorbing (thermal) gas is on the near side of the background synchrotron emission. Contours are at optical depths of 0.4, 0.8, 1.2, 1.6 and 2.0
SKADS Galactic polarization simulations (X.H. Sun, W. Reich)

based on the *Hamurabi-code* (A. Waelkens, T. Enßlin)

Cosmic ray distribution + B-field

All-sky maps:
- Total intensity @ \( \nu \)
- Polarized intensity @ \( \nu \)
- Polarization angle @ \( \nu \)
- Rotation Measure
Galactic thermal electron distribution

NE2001 (Cordes & Lazio, 2002)

NE2001 unable to reproduce absorption
diffuse emission not uniform
In the plane: HII regions + small filling factor
$-\Delta \beta (45/408 \text{ MHz}) \sim 0.3$ by thermal absorption

$-\Delta \beta (45/408 \text{ MHz}) \sim 0.03$ according to NE2001
NE2001 assumes uniform thermal gas density

Berkhuijsen et al. 2006:
Filling factor $f$ of DIG increases from 6% in the plane to 24% at $z = 1$ kpc

$DM = n_e l = n_c l_c$

$f = n_e / n_c$

$EM = DM n_e f^{-1}$

absorption $\tau \sim EM$
Exploitation of Absorption Phenomena

LOFAR enables the unique exploitation of interstellar absorption effects.

For example, the patchiness of the free-free absorption towards the W49B SNR, made apparent by the comparison of 74 and 330 MHz images, provides the first direct evidence of spatial structure in the diffuse ionized component of the interstellar medium.

taken from Lazio (2001)
Figure 2.5 indicates how the hundreds to thousands of H II regions, which could be observed (in absorption) by LOFAR, could be used to map out the 3-D distribution of the cosmic-ray electron gas. High sensitivity, to 0.1 mJy or below is required, as one is utilizing the background emission, with $T_b \sim 10^4$ K, to "shadow" the H II regions. This compares to typical discrete emission sources with $T_b \sim 10^8$ K and higher. Moreover, an array with versatile angular resolution is required, since the ideal measurement is made when the synthesized beam is matched to the size of the H II region. Thus, a versatile array would be able to make use of the wide variety of H II regions throughout the Galaxy for such measurements.

Figure 2.5 Mapping out the cosmic ray electron gas using Galactic HII regions at known distances. This permits decoupling of the foreground and background components of the synchrotron emission along many lines of sight. Absorption hole "flux densities" will range from $\mu$Jy to mJy and higher depending on the size and Galactic coordinates of the target HII region. More sensitive observations will probe a larger volume of the Galaxy and on smaller (<1") scales.
Synchrotron emissivity with distance from sun ➔ more data from LOFAR needed

* Taurus molecular cloud l,b = 170°, -9°
FS 1.4/1.7 GHz polarization analysis
Wolleben & Reich (2004)
High resolution multi-frequency mapping of Galactic emission with LOFAR

- **Tomography**: cosmic rays / magnetic fields / diffuse thermal gas
- **SNRs**: new objects + spectral studies + source scattering near shock fronts
- **Optically thick HII-regions**: constrains on electron temperature, emission measure, filling factor
35 new SNRs at 74 MHz
4.5° < L < 22°, IBI < 1.25°
Brogan et al., 2006

VLA 74 MHz *blue*
SGPS+VLA 1.4 GHz *green*
MSX 8μm *red*

Shell-type SNRs >2.5′
Identified by spectral index and missing IR emission
HPBW ~42″ (restored)
➡ confusion problem:
need for higher resolution and a high dynamic range
DA495: evolved Plerionic SNR
Kothes et al., submitted

spectrum with (left) and without (right) compact sources
~10% of flux at 1 GHz, ~30% at 100 MHz
spectral break 1.3 GHz, $B \sim 1.5$ mG,
age $\sim 17 \times 10^3$ yr $\Rightarrow 50 \times 10^3$ yr: break at 150 MHz or $100 \times 10^3$ yr: break 38 MHz
CTA1 at 2.64 GHz Effelsberg
fieldsize 3°x3°

LOFAR resolution 250 km (Exloo-Eb) ~ 6” at 50 MHz

40 mas at 1 GHz ➞ 16” at 50 MHz

near SNR G74.9+1.2

Spangler et al., 1986
HII Region W1 at 850 pc distance

DRAO

Urumqi

Urumqi + WMAP

50%
PI at 22.8 GHz
WMAP-3yr
(Page et al.)

PI at 1.4 GHz
DRAO+Villa Elisa
(Reich et al.)

depolarization
Galactic RM [rad/m²]
Dwingeloo surveys
at
408/465/610/
820/1411 MHz
Observations have different
(and large !) beams
based on $\lambda^2$ - Fit
small RM values in general
Spoelstra, 1972, AA, 21, 61
Sketch of the polarization horizon

Polarization horizon

SNR/HII

SNR/HII

with frequency

arbitrary distance $f(\lambda^2)$

Landecker et al. 2002

Polarized emission detected from SNR – HII has no effect
RM = 0.81 \( n_e [\text{cm}^{-3}] \) \( B_{||} [\mu \text{G}] \) \( L [\text{pc}] \), \( \varphi [\text{rad}] = RM \lambda^2 [\text{m}] \)

for a uniform medium (filling factor = 1)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Medium Description</th>
<th>RM Value</th>
<th>Length Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4 GHz</td>
<td>plane (halo)</td>
<td>RM ~ 35 rad m(^2)</td>
<td>L ~ 1 (20) kpc</td>
</tr>
<tr>
<td>( n_e \sim 0.03(0.01) ), ( B_{</td>
<td></td>
<td>} \sim 2(0.2) )</td>
<td></td>
</tr>
<tr>
<td>140 MHz</td>
<td></td>
<td>RM ~ 0.35 rad m(^2)</td>
<td>L ~ 10 (200) pc</td>
</tr>
<tr>
<td>45 MHz</td>
<td></td>
<td>RM ~ 0.035 rad m(^2)</td>
<td>L ~ 1 (20) pc</td>
</tr>
</tbody>
</table>
Slab model + bandwidth depolarization:

\[ T_b^p = \frac{A}{2|\psi|} \left( \frac{\nu}{300} \right)^2 \left\{ \frac{\sin 2\psi \left( \frac{300}{\nu} \right)^2 \nu}{2\psi \left( \frac{300}{\nu} \right)^2 \nu} \right\}^{2} \sin \left[ 2\psi \left( \frac{300}{\nu} \right)^2 \nu \right] - 2 \frac{\sin \left[ 2\psi \left( \frac{300}{\nu} \right)^2 \nu \right]}{2\psi \left( \frac{300}{\nu} \right)^2 \nu} \cos \left[ 2\psi \left( \frac{300}{\nu} \right)^2 \nu \right] + 1 \right]^{1/2} \]

RM = 0.84 rad m\(^2\) from \(T_b^p\) fit
RM = 0.6+/-0.15 from angle fit at high \(\nu\)

L,B = 146.8°,9°

NCP

\(\beta = -1.87\)
Faraday screen located in a homogenous synchrotron emitting medium
Galactic research with LOFAR

- high resolution multi-frequency continuum and polarization mapping
- Galactic source studies need the separation from compact sources
- Galactic emissivity distribution and clumpiness of the thermal medium
- local emissivity excess (3D)
- small scale polarization properties of the ISM