Galactic research with LOFAR

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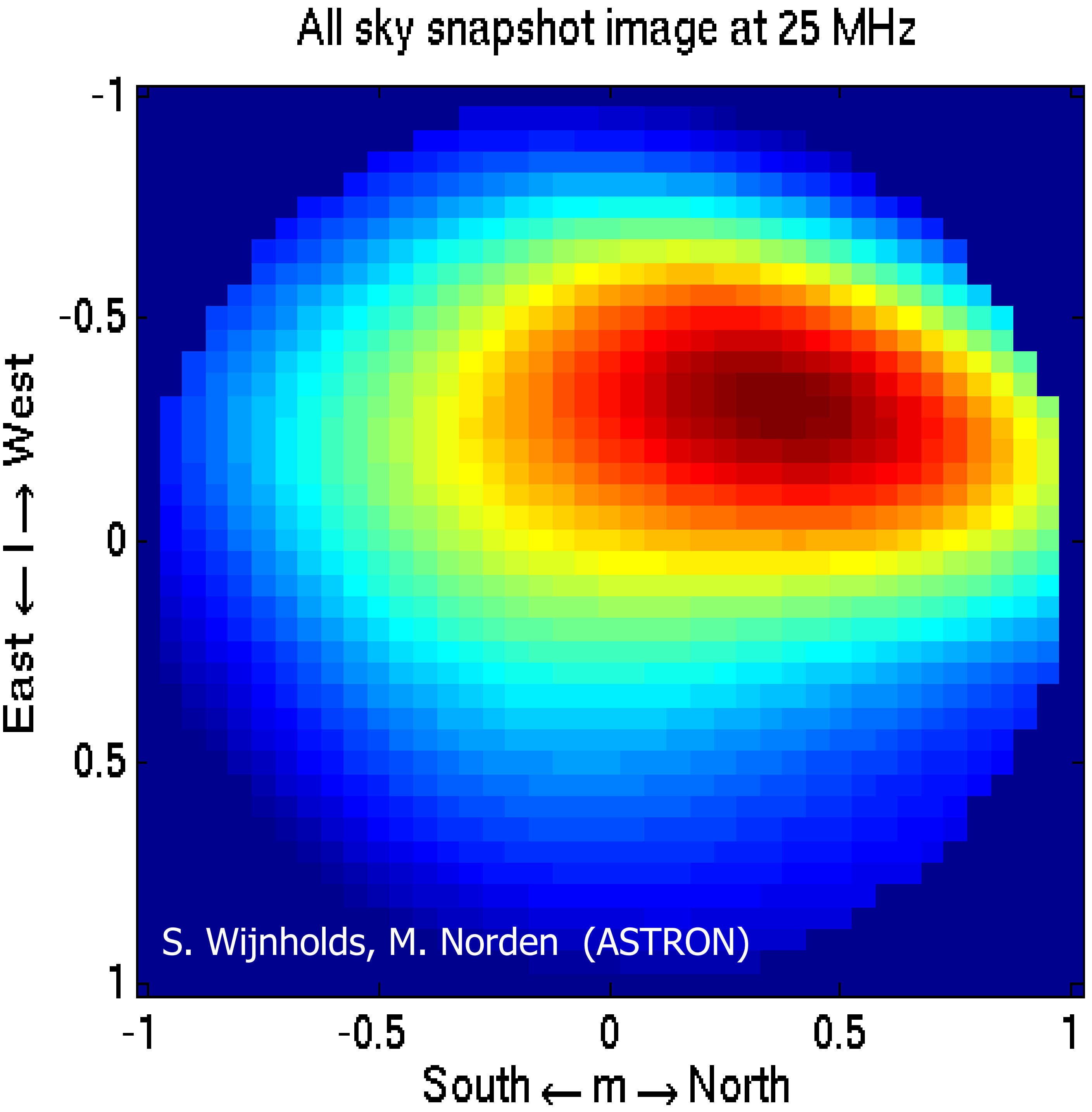
Outline

- „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
21 . 03 . 2007

„First Light“
at
Effelsberg
IS-GE1
20.03.2007

8 dipoles x2 polarizations
τ=4s
512 channels
Δf=156 KHz



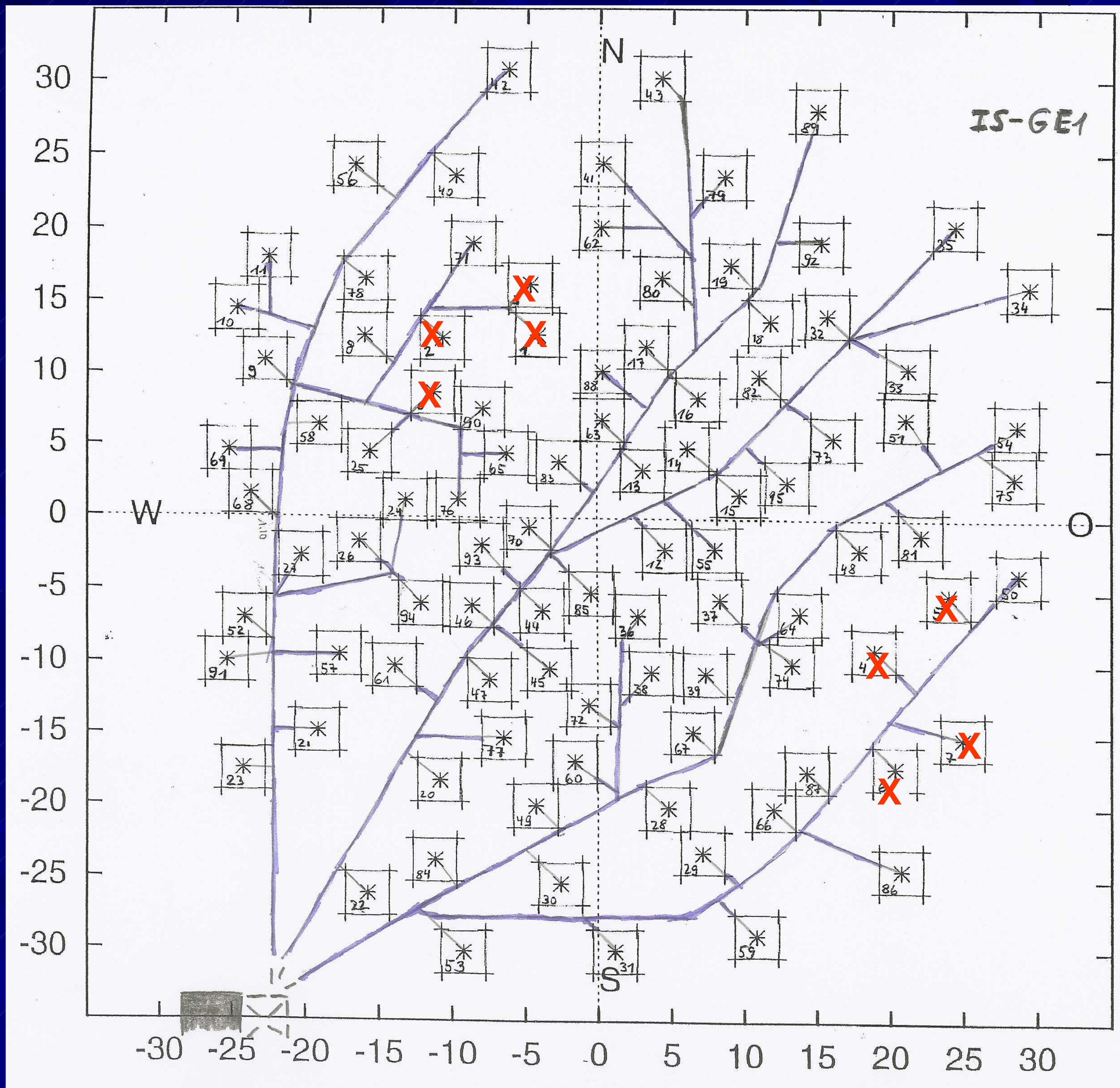
Cable canals

Cable length 110m

total ~22km

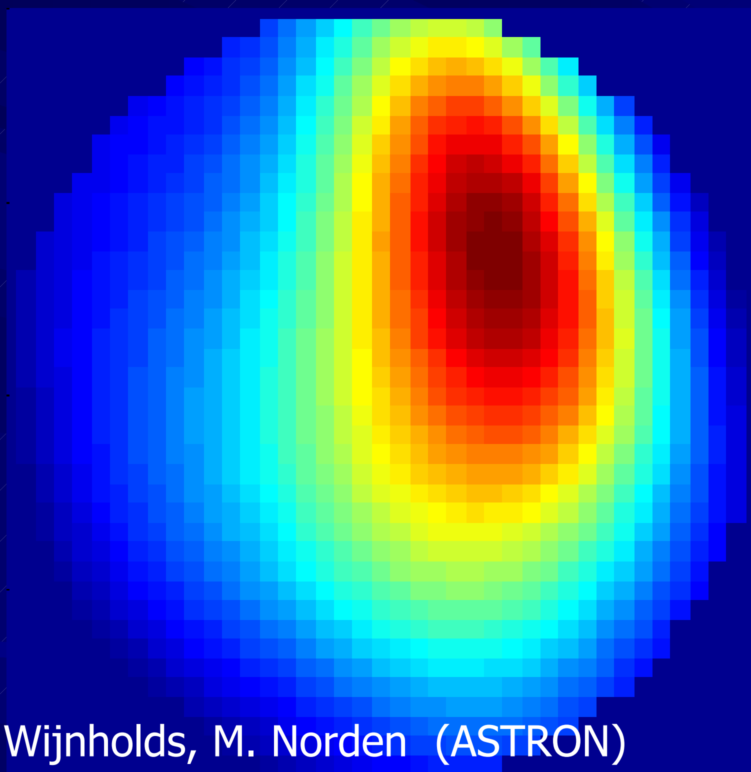
„First Light“

8 dipoles:
HPBW ~22° at 25 MHz

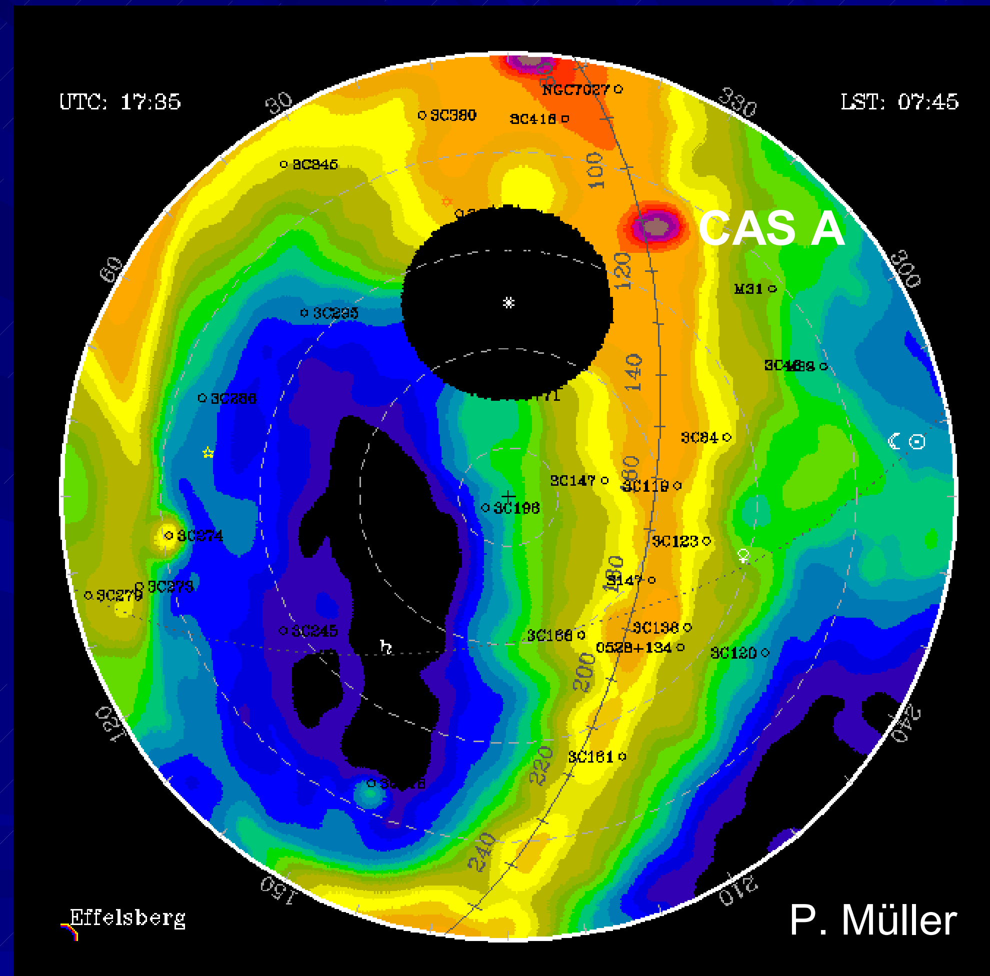


„First Light“ 25 MHz image (HPBW ~22°)

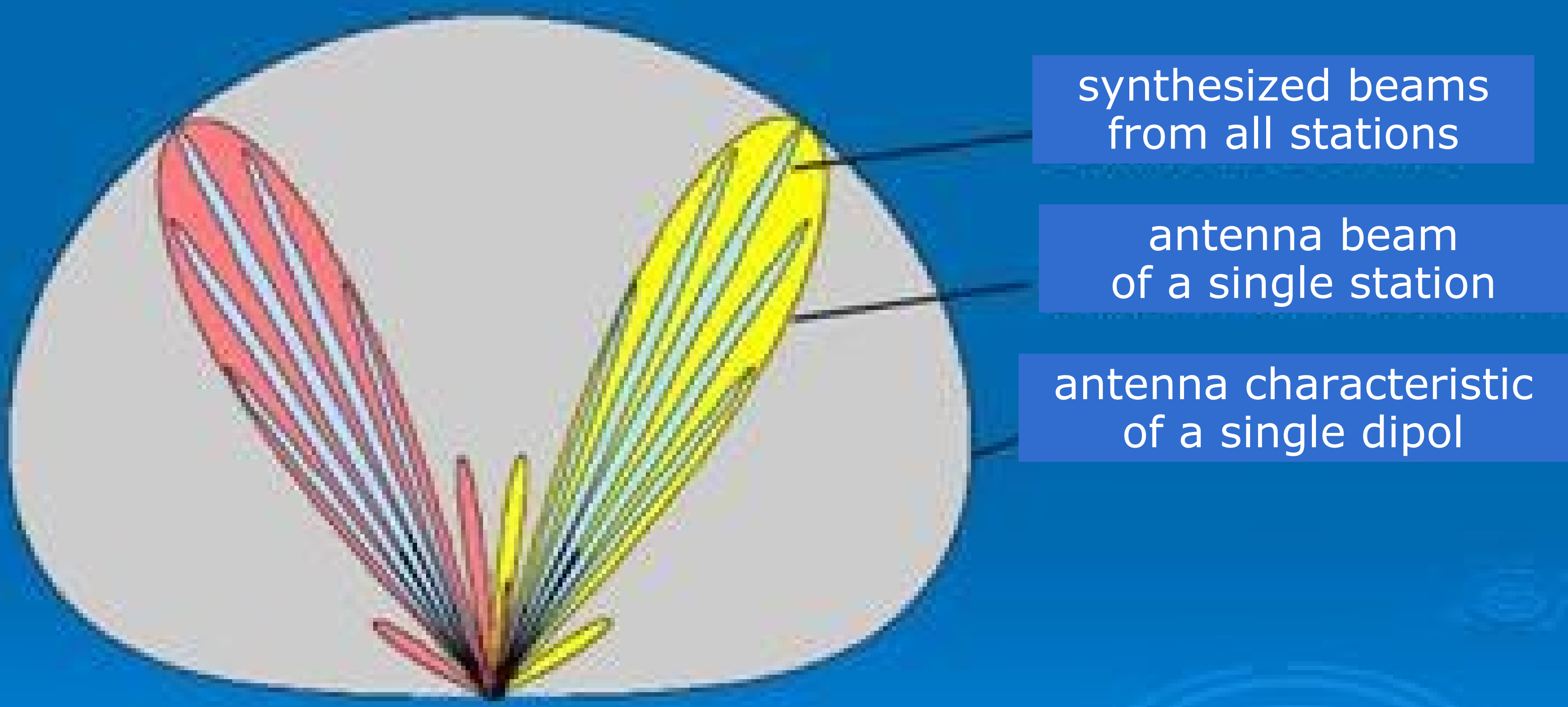
45 MHz survey (HPBW~5°)



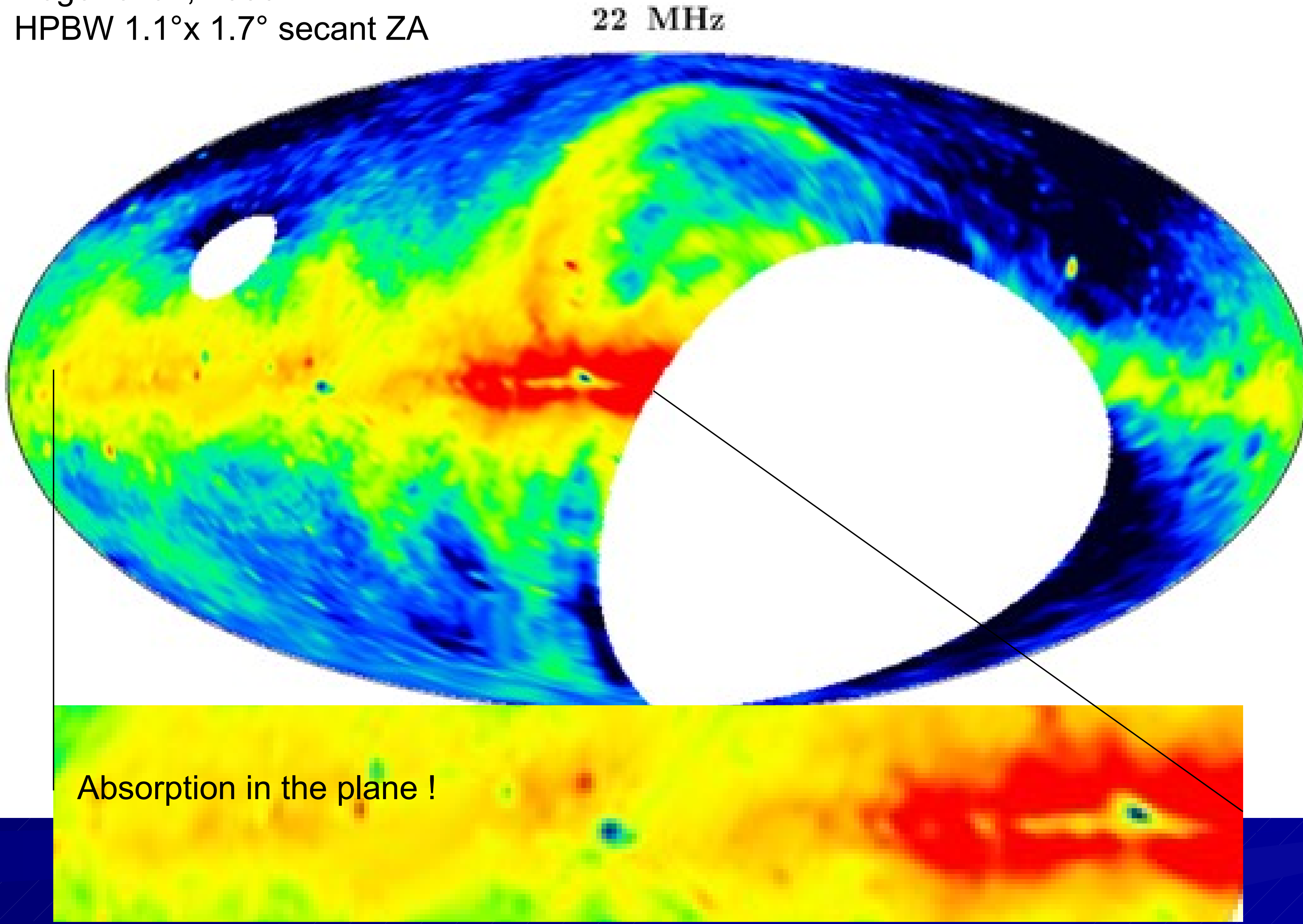
S. Wijnholds, M. Norden (ASTRON)



LOFAR beam(s)

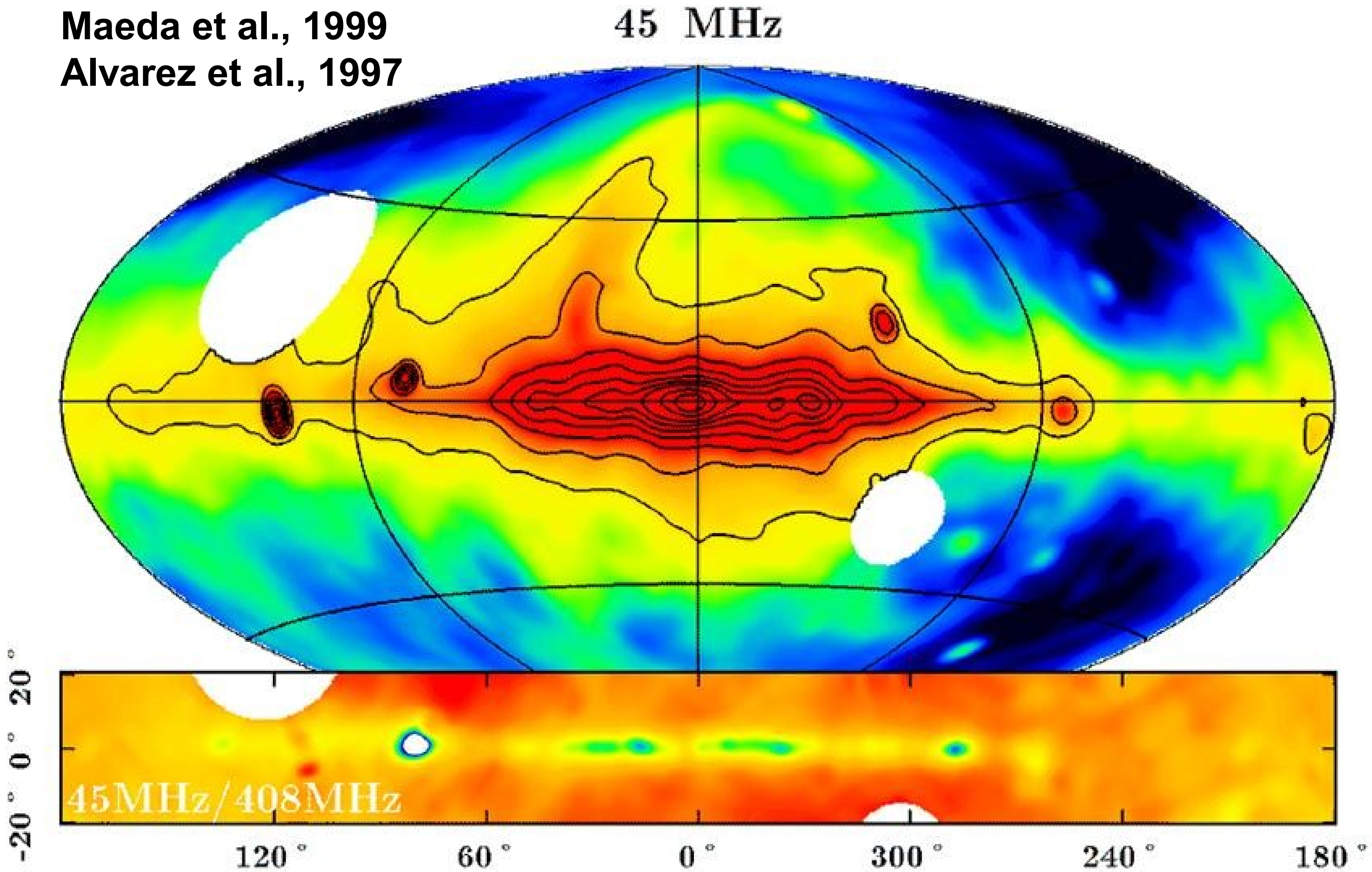

synthesized beams
from all stations
antenna beam
of a single station
antenna characteristic
of a single dipol

Roger et al., 1999
HPBW 1.1°x 1.7° secant ZA

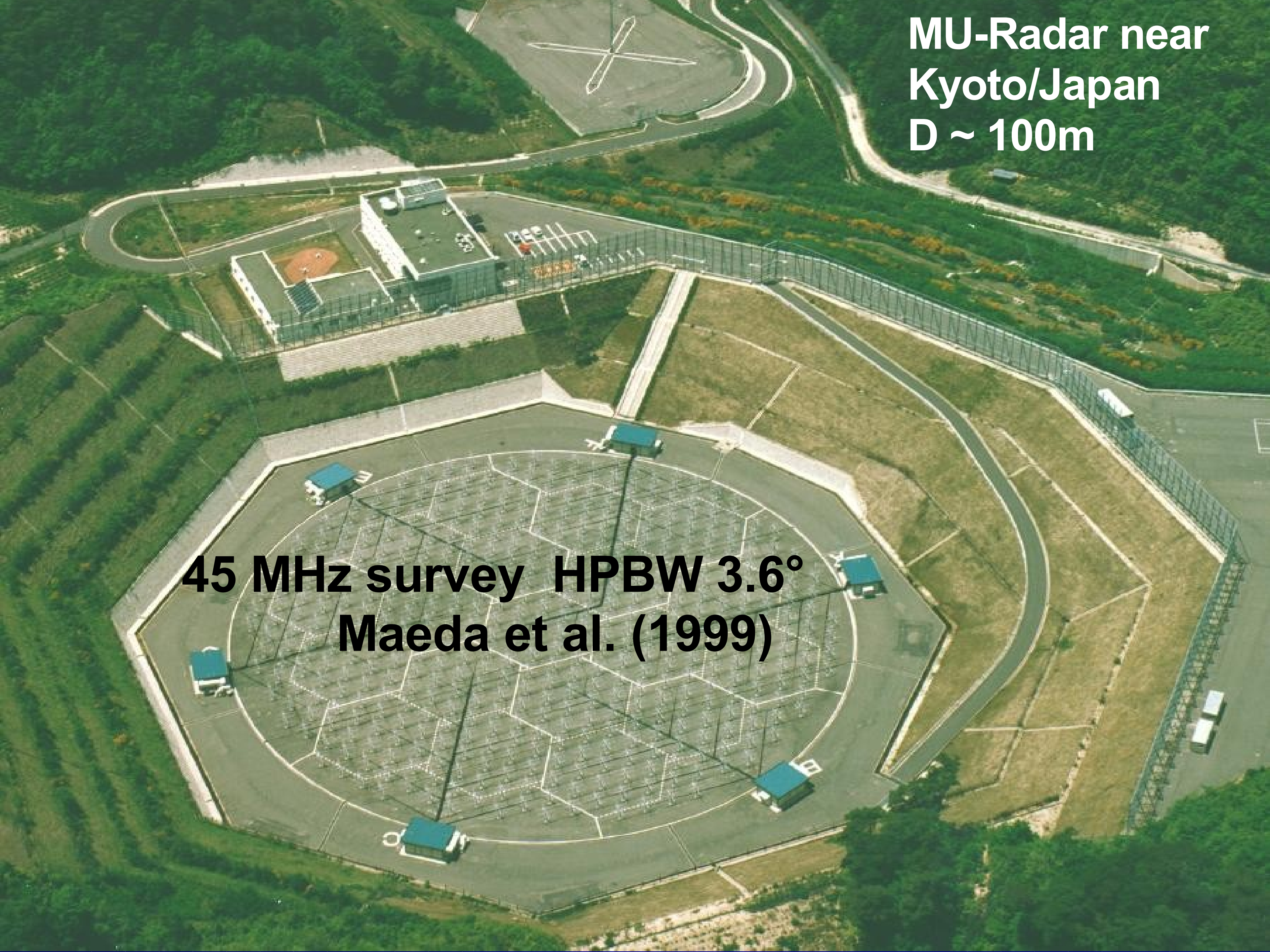


DRAO T-shaped Interferometer
1364m x 443m

Maeda et al., 1999
Alvarez et al., 1997

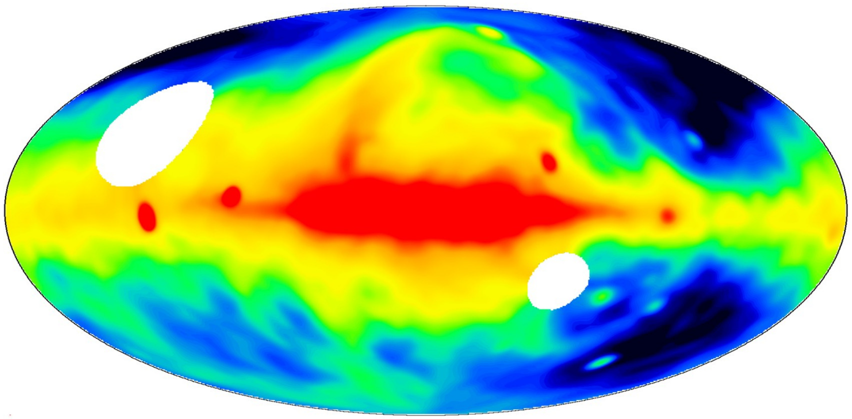


45 MHz all-sky survey at 5° resolution


MU-Radar near
Kyoto/Japan
D ~ 100m
45 MHz survey HPBW 3.6°
Maeda et al. (1999)

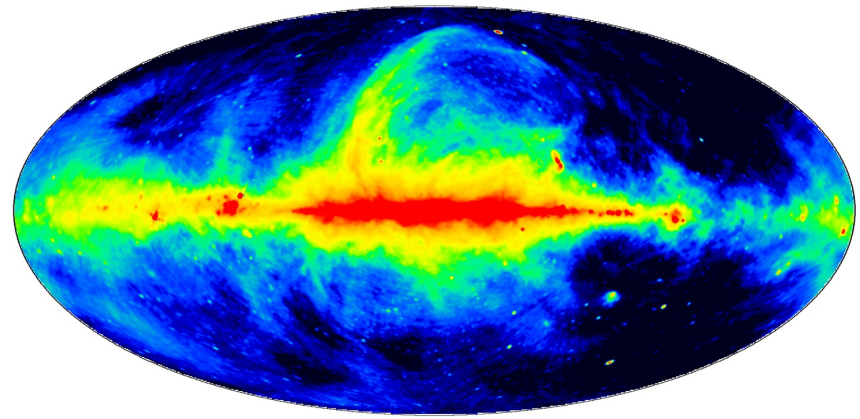
Selected radio continuum surveys

45 MHz



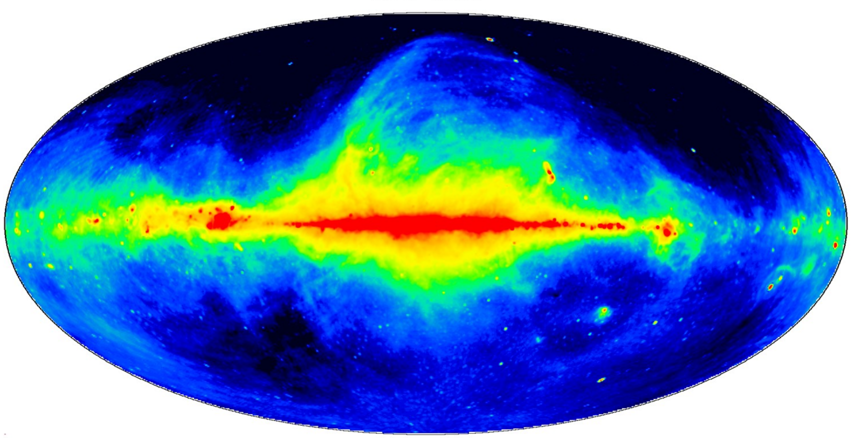
MU-Radar and Maipu Radio Observatory

408 MHz



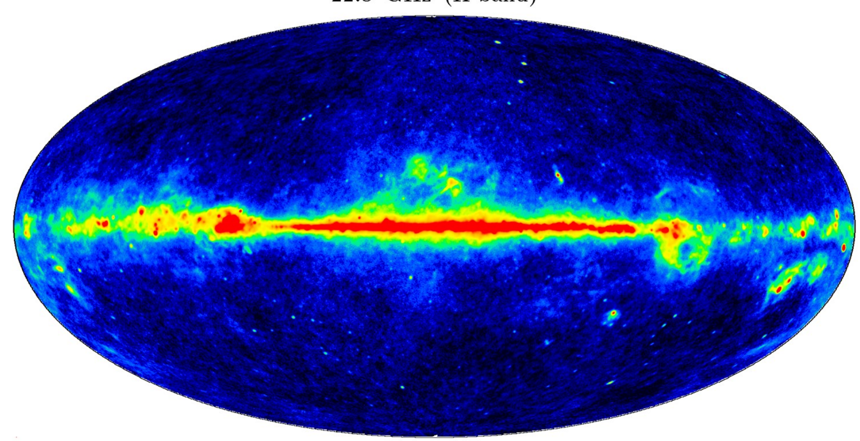
Jodrell-Bank 250-feet + Effelsberg 100-m + Parkes 64-m

1420 MHz



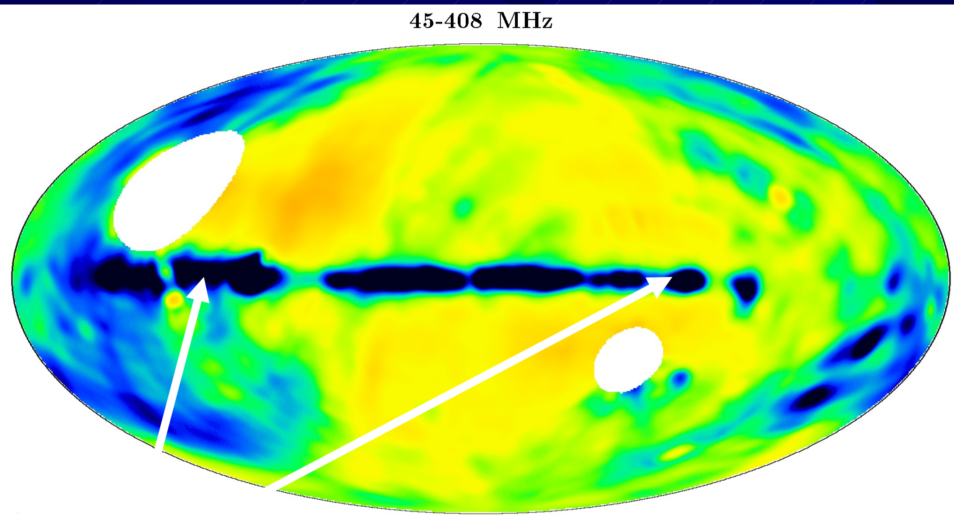
Stockert 25-m and Villa Elisa 30-m

22.8 GHz (K-band)

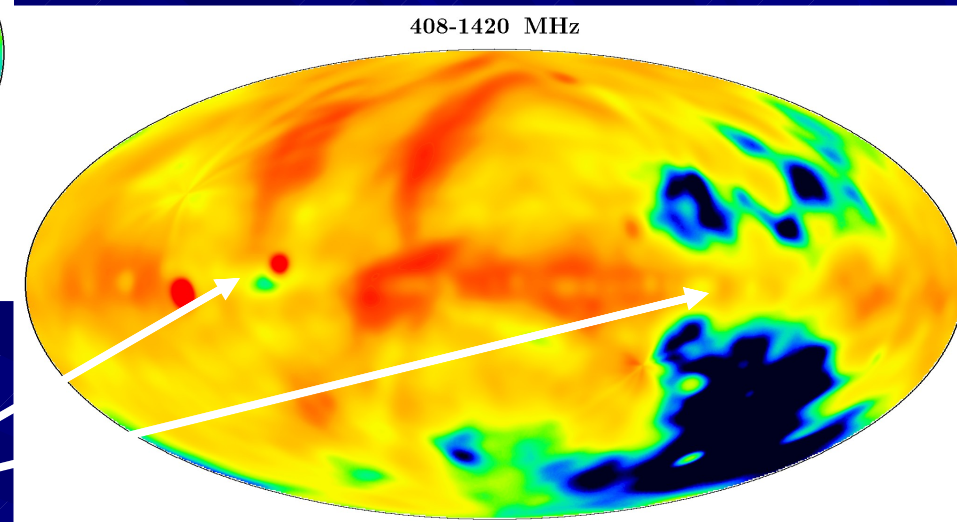


Wilkinson Microwave Anisotropy Probe (WMAP)

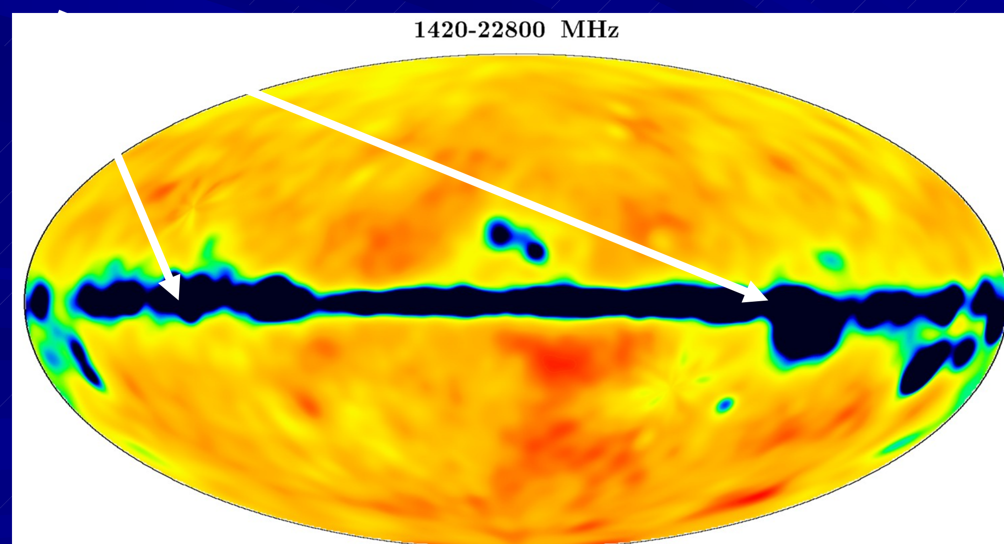
Spectral index distribution



τ large
➔ background absorption



τ small



blue = flat
red = steep

Absorption by thermal gas

18 R.S. Roger et al.: The radio emission from the Galaxy at 22 MHz

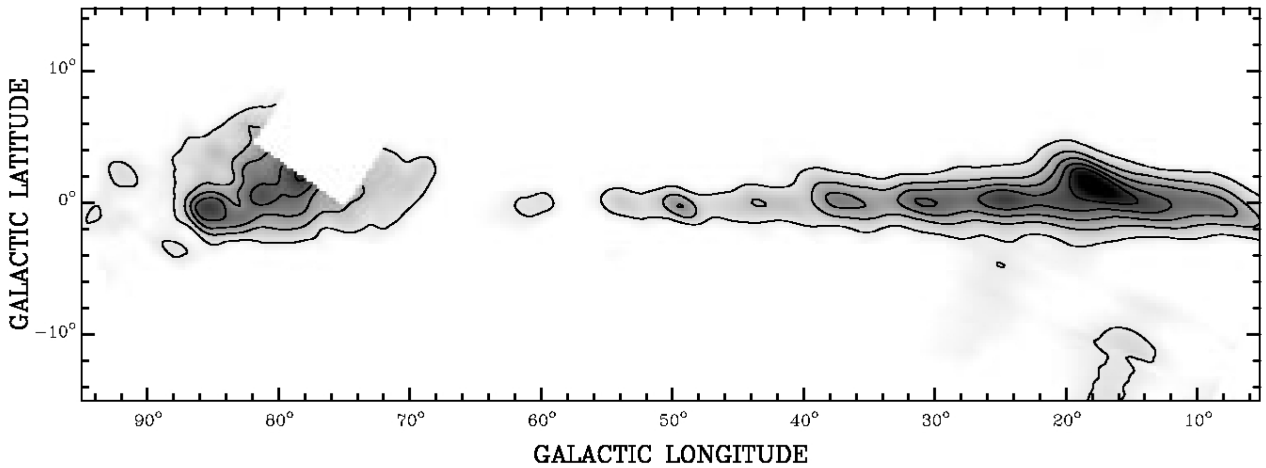
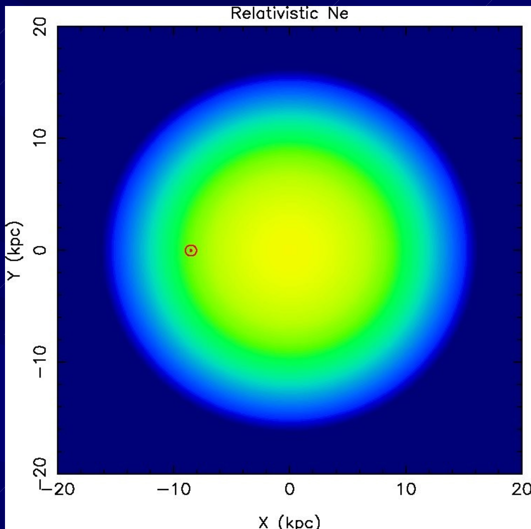


Fig. 6. The "quasi optical depth" at 22 MHz along the Galactic plane in the first quadrant, from a comparison of the 408 MHz and 22 MHz emissions, assuming all absorbing (thermal) gas is on the near side of the background synchrotron emission. Contours are at optical depths of 0.4, 0.8, 1.2, 1.6 and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

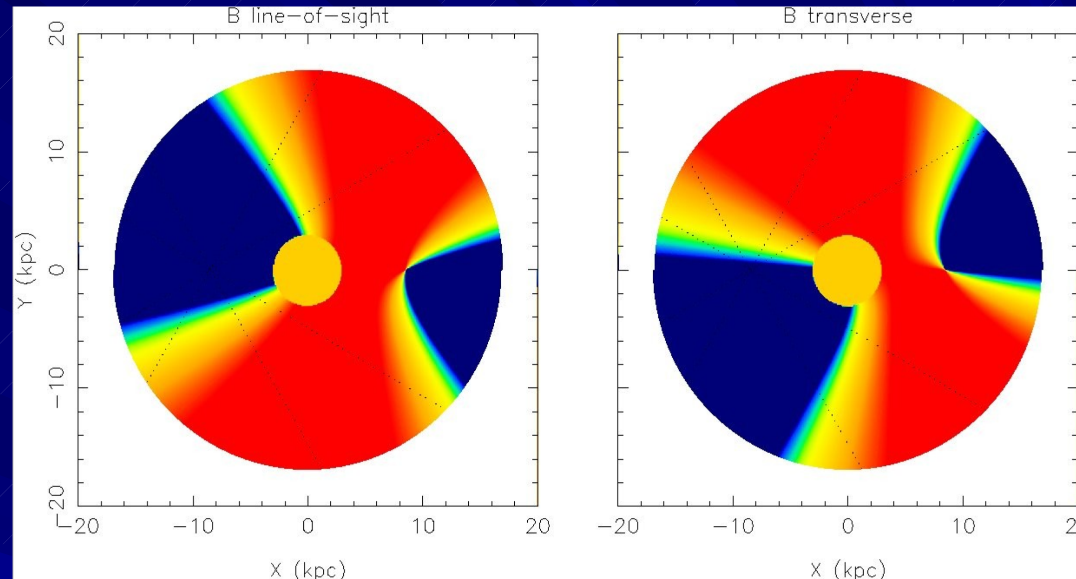
SKADS Galactic polarization simulations (X.H. Sun, W. Reich)

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

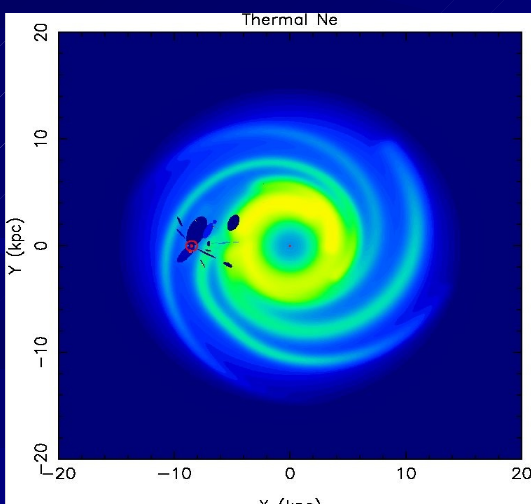


Cosmic ray distribution

+



B-field

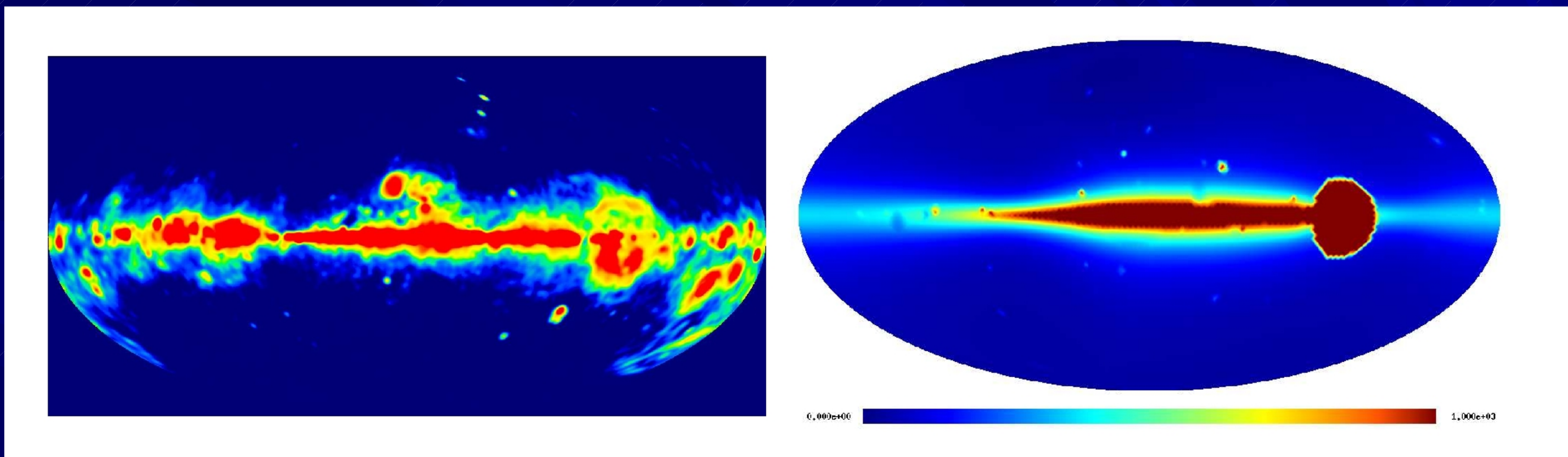


n_e-distribution (NE2001)

All-sky maps :

- Total intensity @ ν
- Polarized intensity @ ν
- Polarization angle @ ν
- Rotation Measure

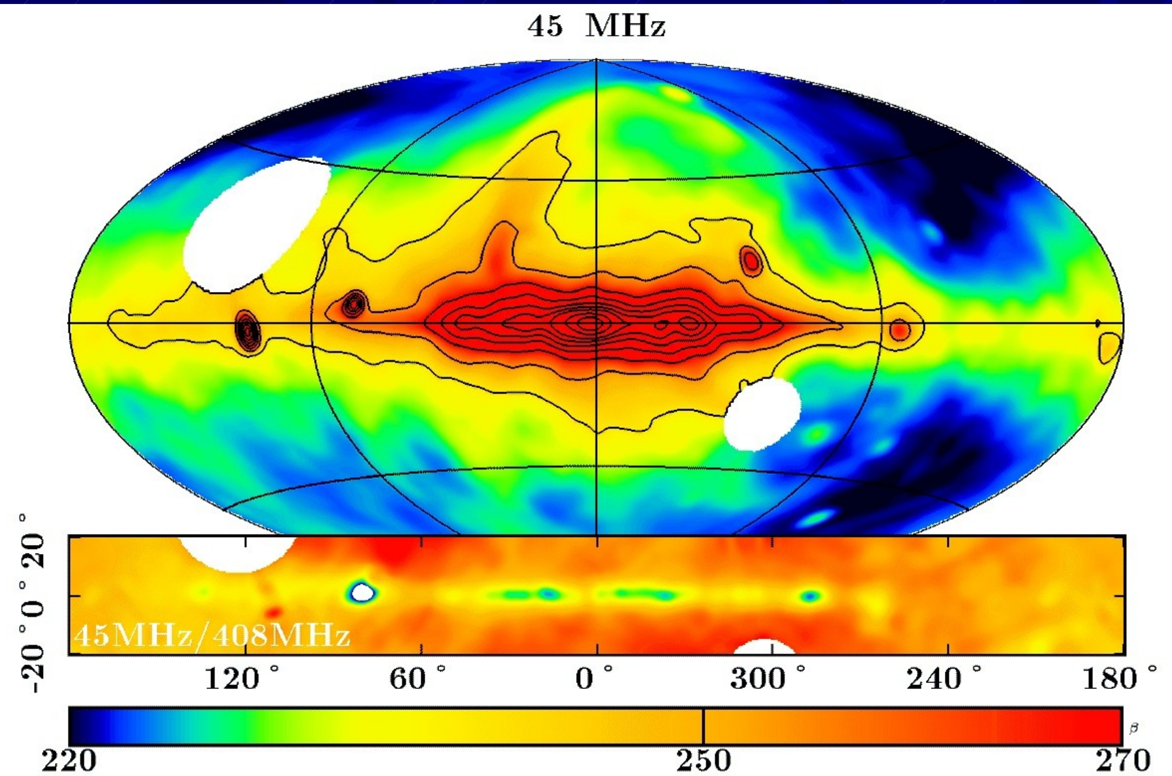
Galactic thermal electron distribution NE2001 (Cordes & Lazio, 2002)



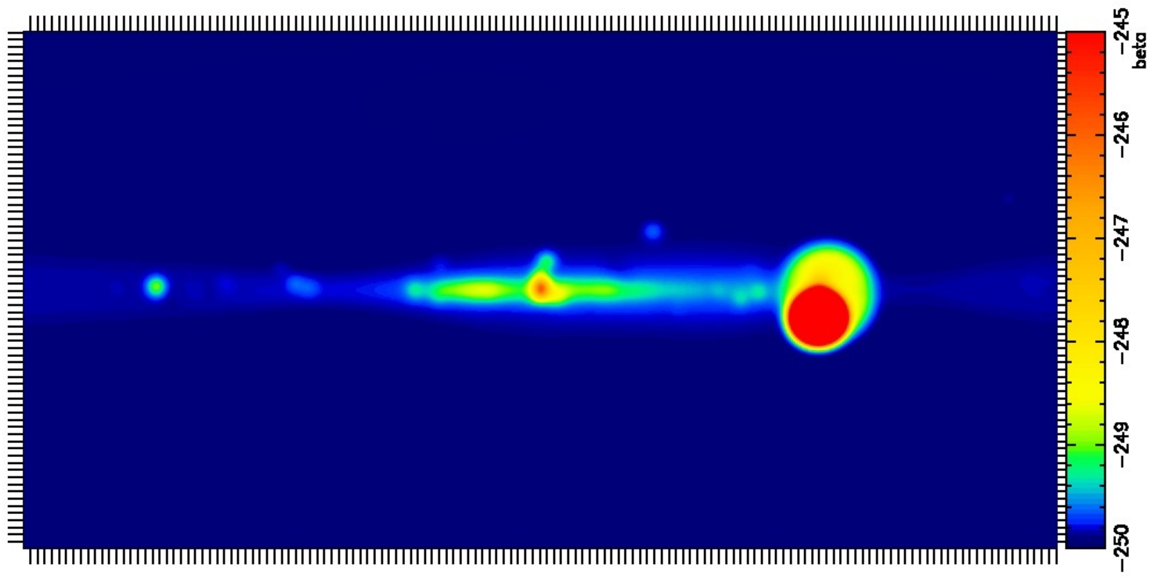
thermal component: WMAP NE2001

- NE2001 unable to reproduce absorption
- diffuse emission not uniform
- In the plane: HII regions + small filling factor

-Δβ (45/408 MHz) ~ 0.3
by thermal absorption



-Δβ (45/408 MHz) ~ 0.03
according to NE2001



NE2001 assumes uniform thermal gas density

Berkhuijsen et al. 2006:

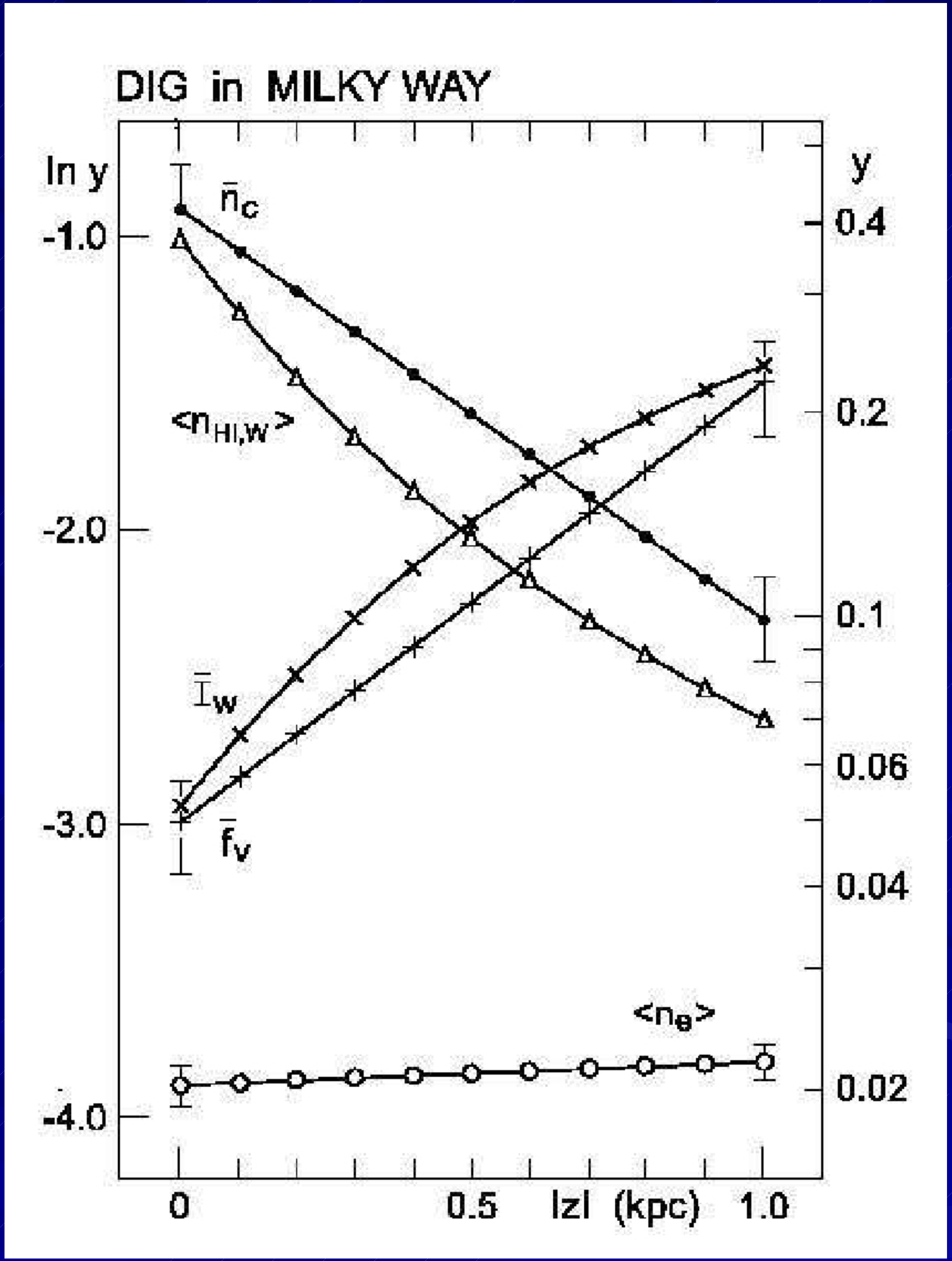
Filling factor f of DIG increases from 6% in the plane to 24% at z =1 kpc

$DM = n_e l = n_c l_c$

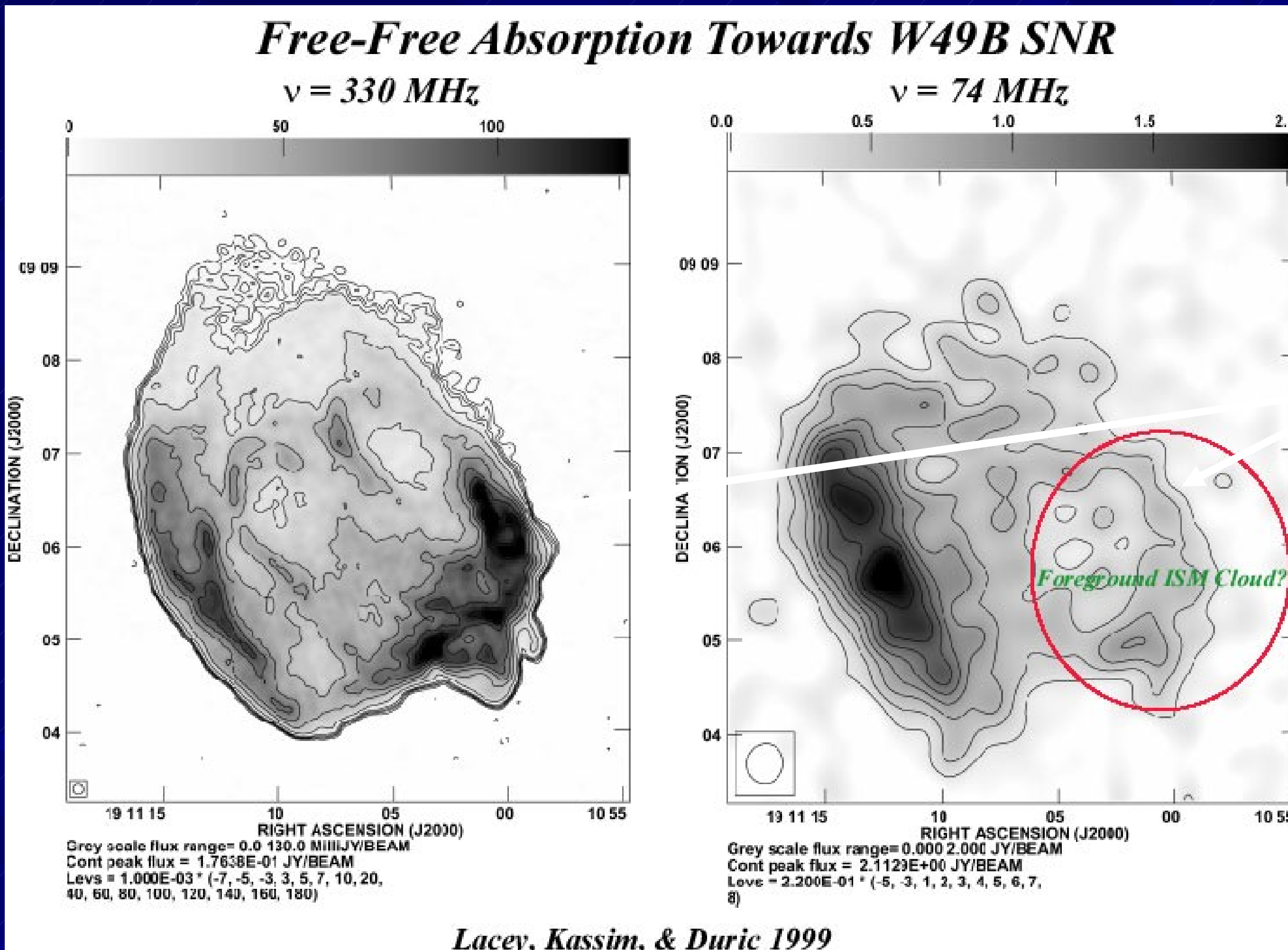
$f = n_e / n_c$

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

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.

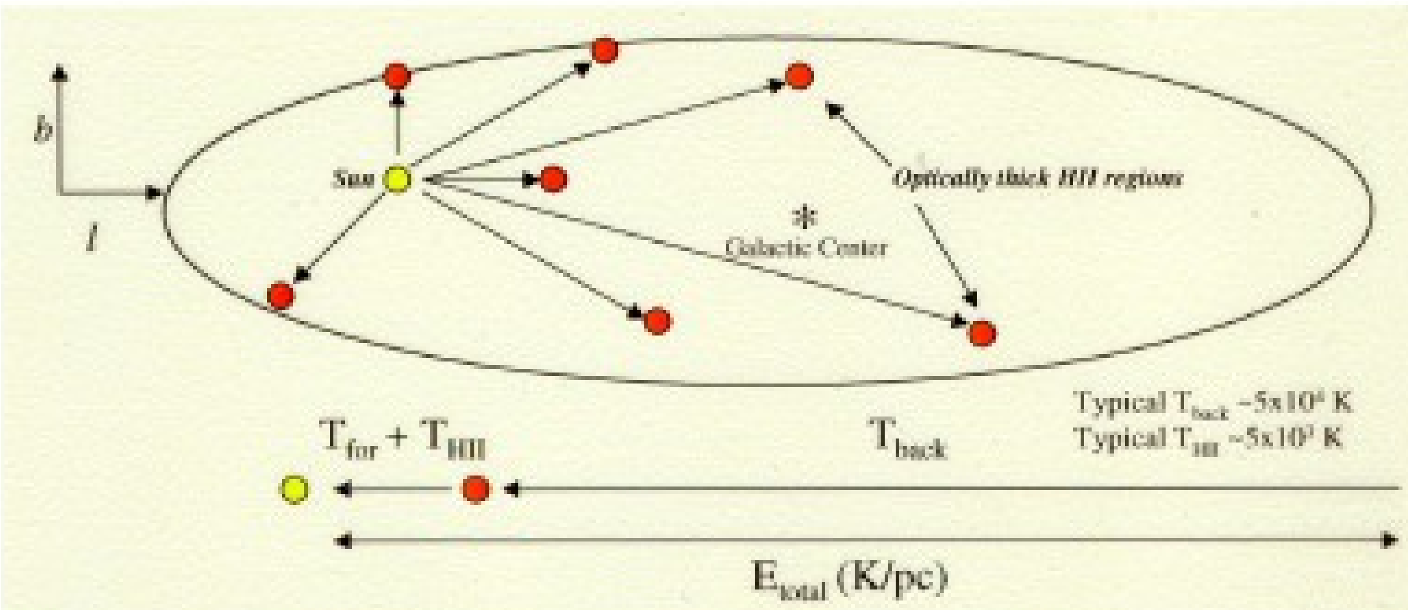
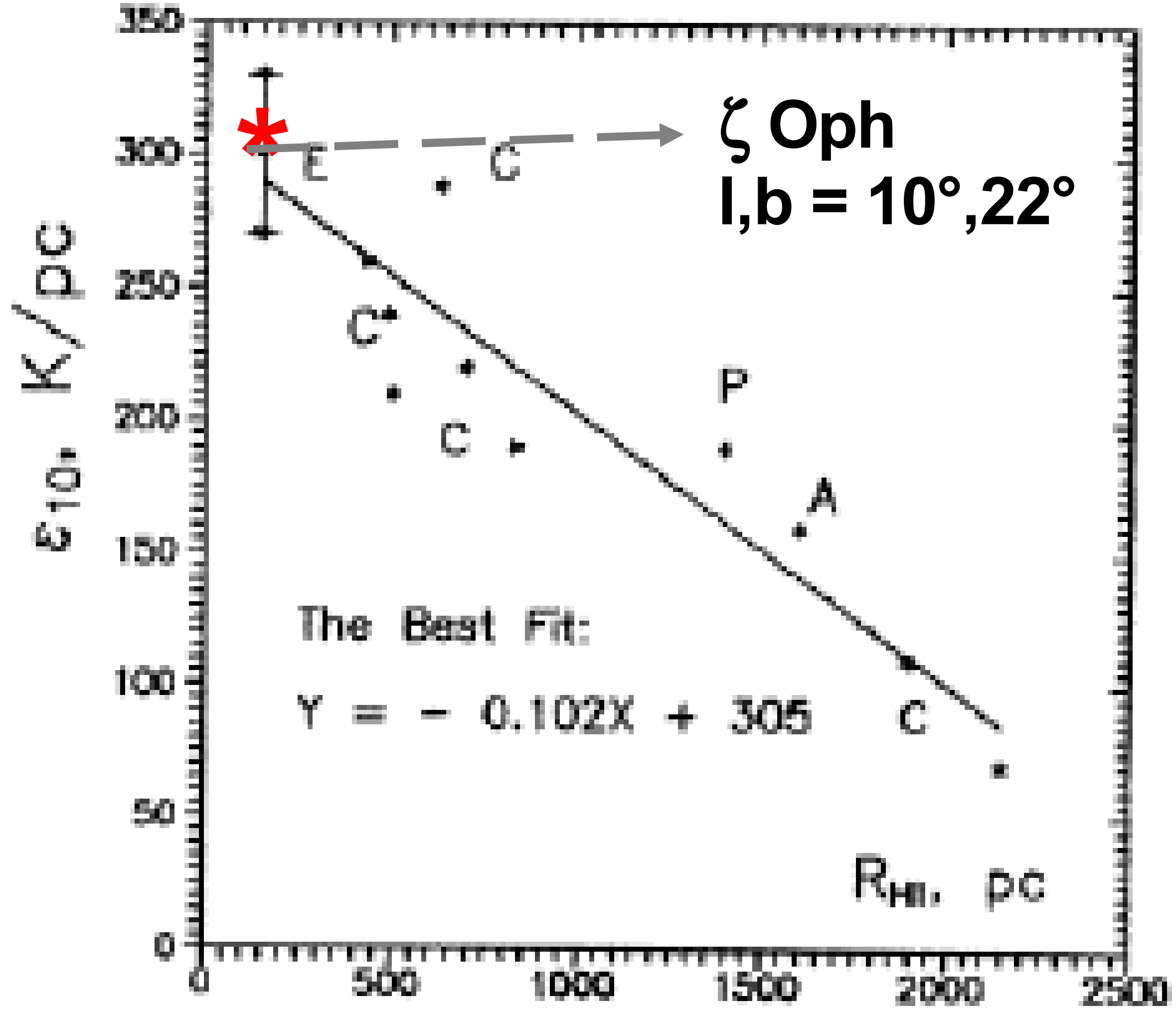


Figure 2.5 Mapping out the cosmic ray electron gas using Galactic HII regions at known distances. This permits decoupling of the foreground and background components of the synchrotron emission along many lines of sight. Absorption hole "flux densities" will range from µJy to mJy and higher depending 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 + soucre scattering near shock fronts
- Optically thick HII-regions: constrains on electron temperature, emission measure, filling factor

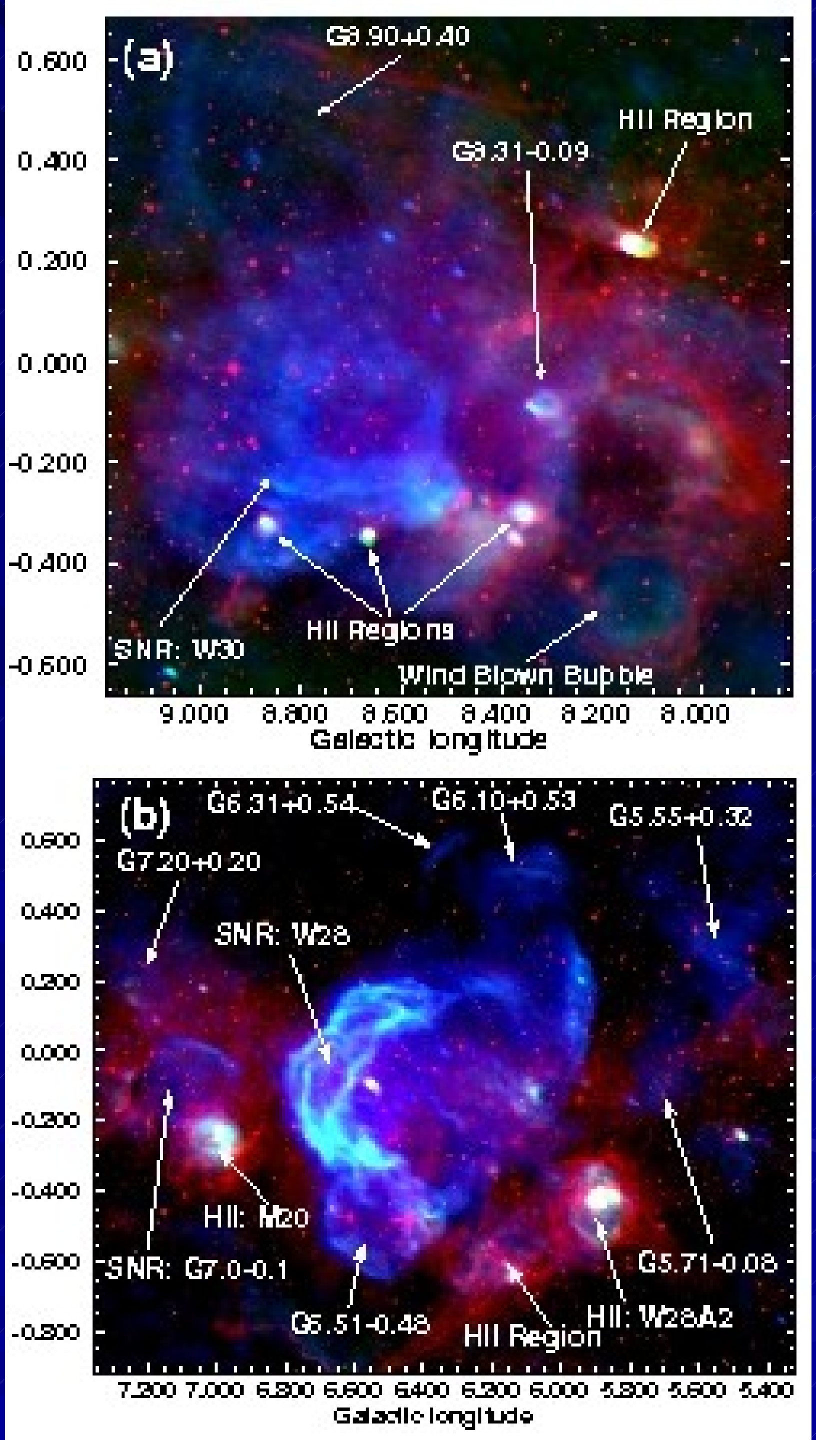
35 new SNRs at 74 MHz

4.5° < L < 22°, IBI < 1.25°

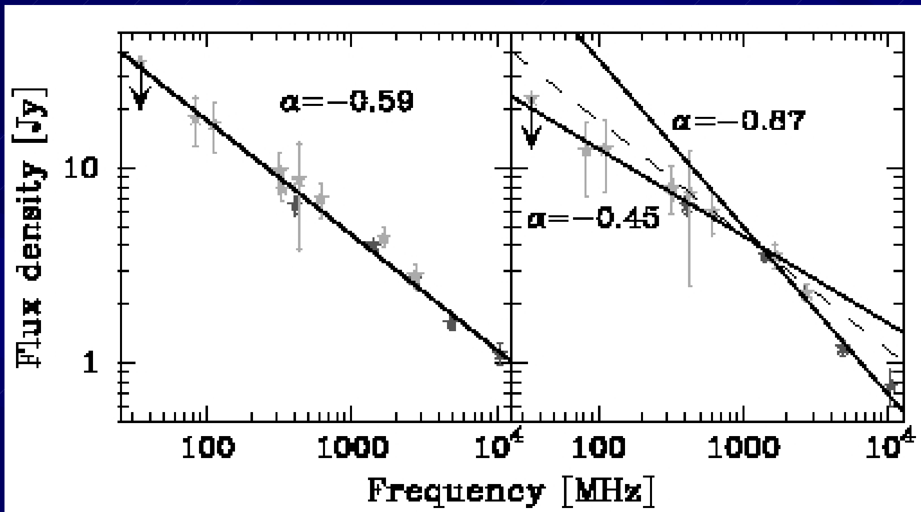
Brogan et al., 2006

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

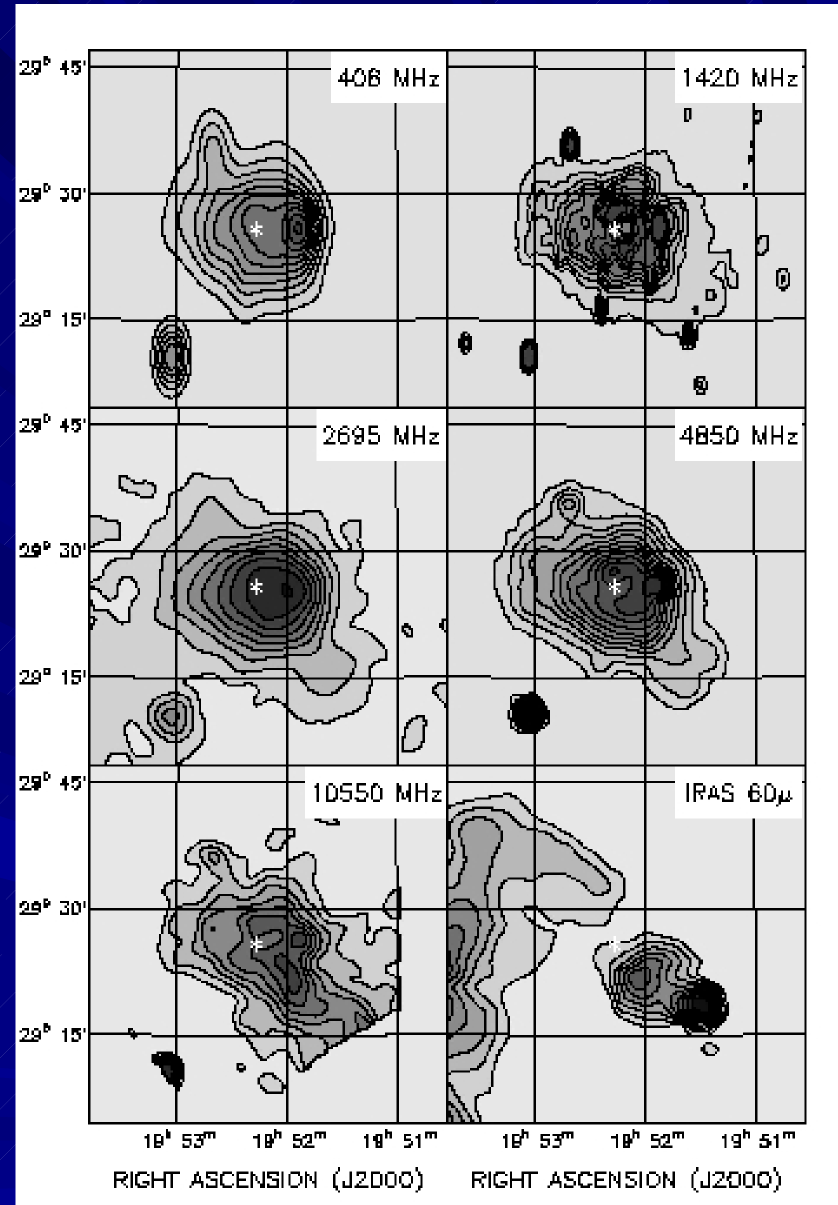


DA495:
evolved Plerionic SNR
Kothes et al., submitted

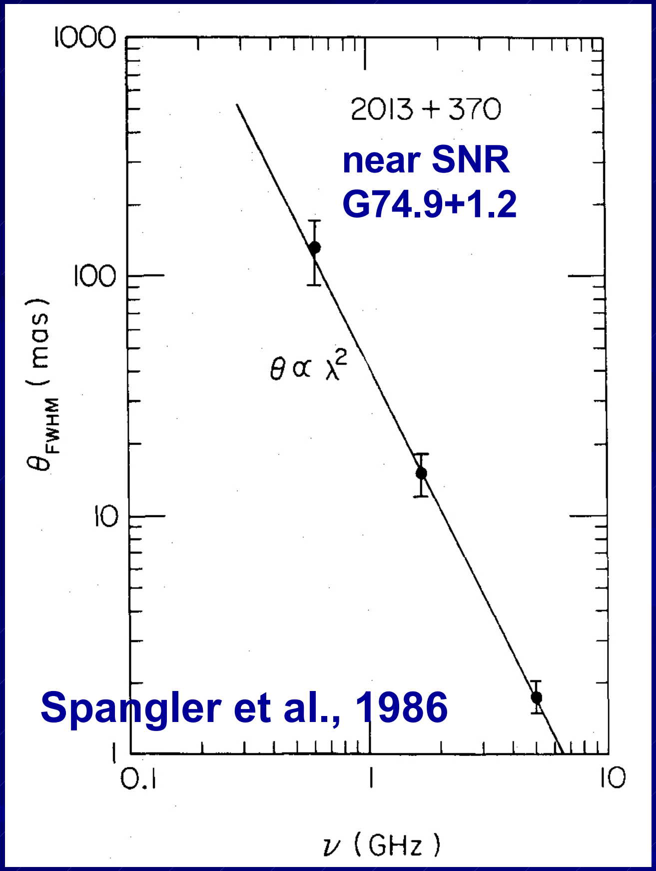


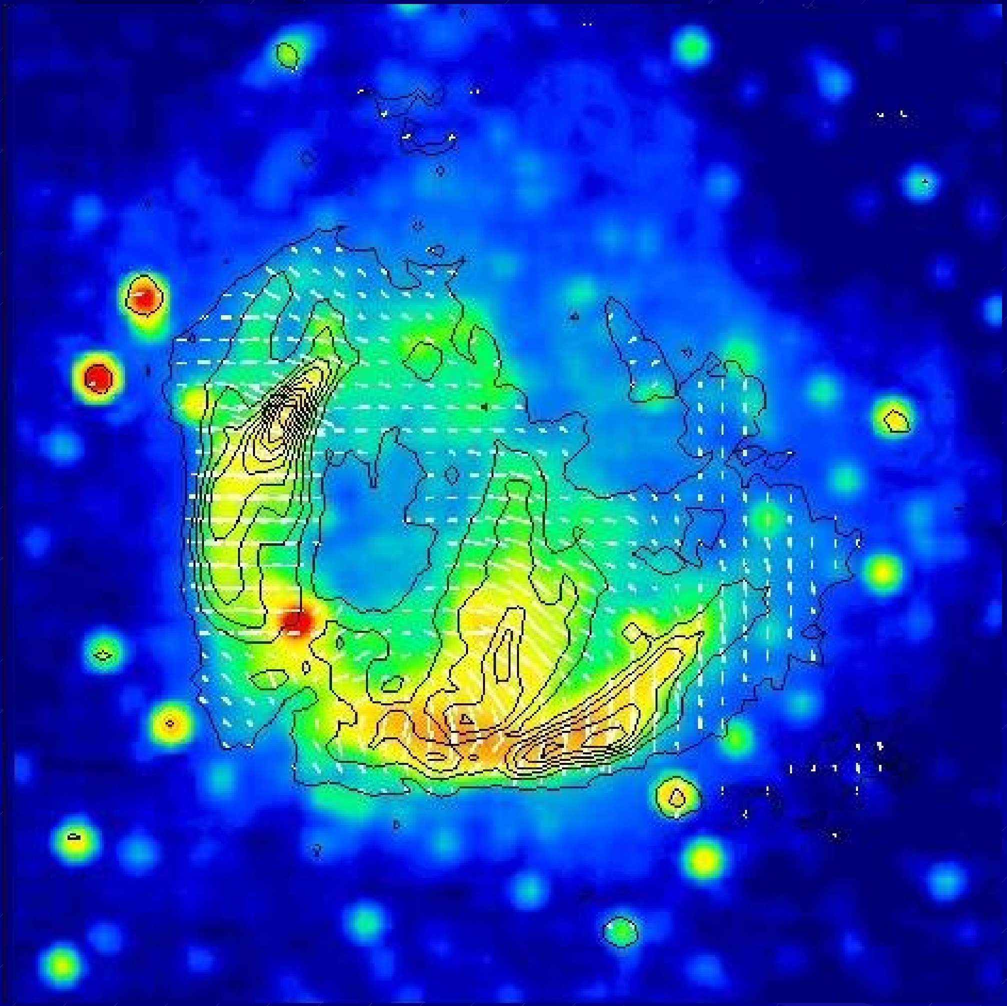
spectrum with (left) and without (right) compact sources
~10% of flux at 1 GHz, ~30% at 100 MHz

spectral break 1.3 GHz, B~1.5 mG,
age ~17 10^3 yr ➔ 50 10^3 yr : break at 150 MHz or 100 10^3 yr : break 38 MHz



CTA1 at 2.64 GHz Effelsberg
fieldsize 3°x3°

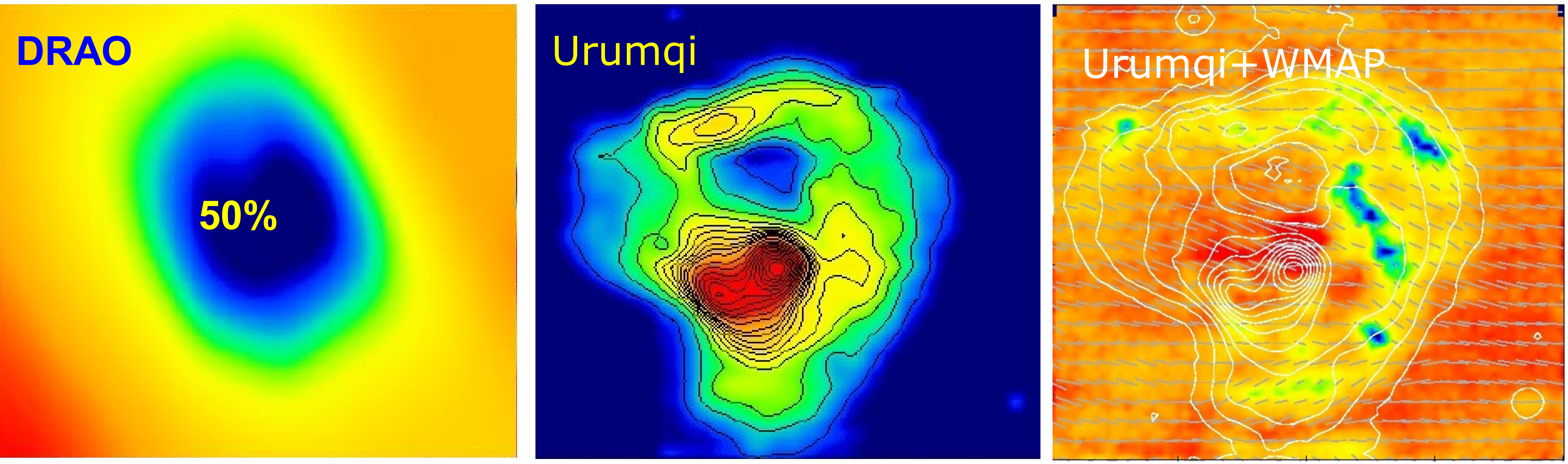




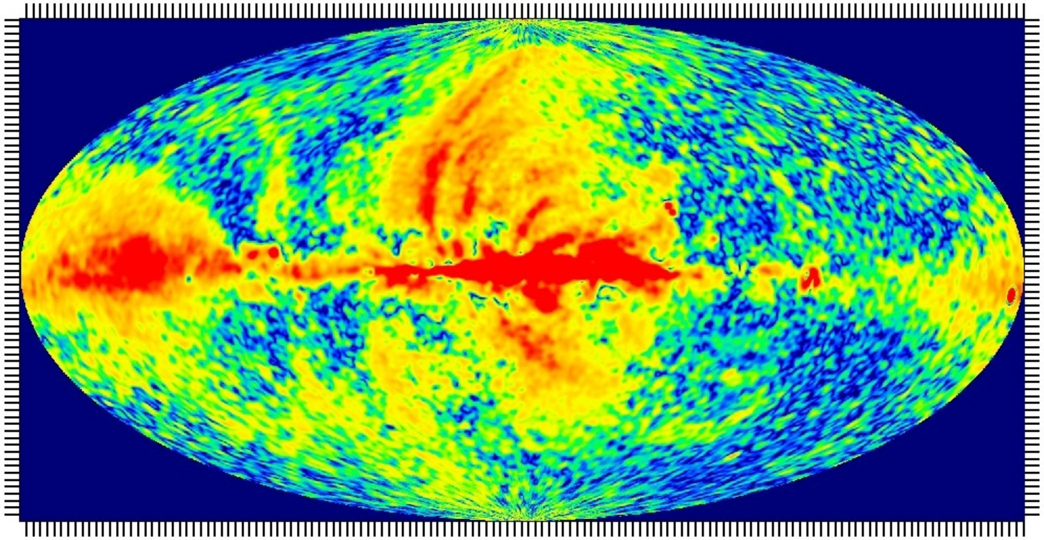
40 mas at 1 GHz ➔ 16“ at 50 MHz

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

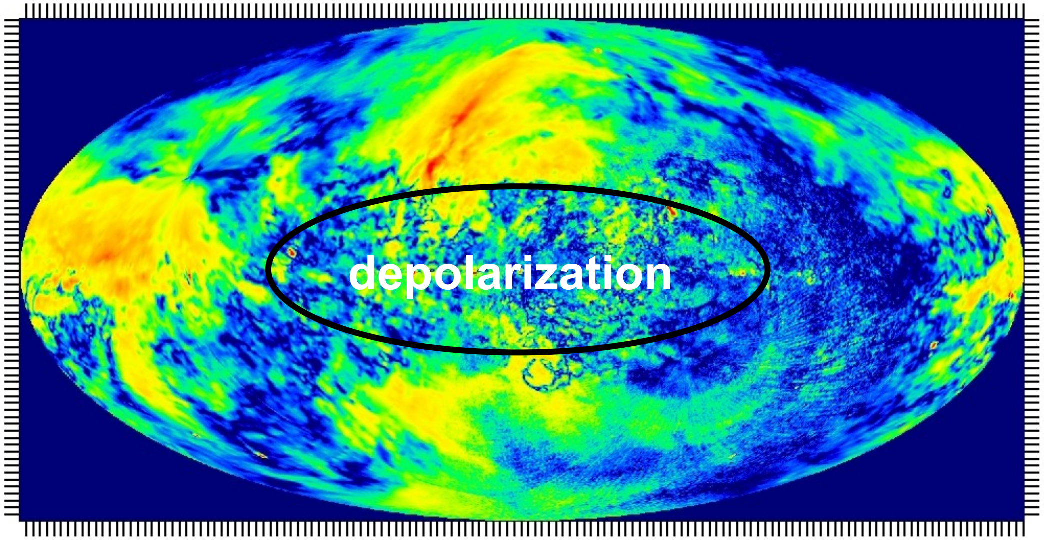
HII Region W1 at 850 pc distance



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



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

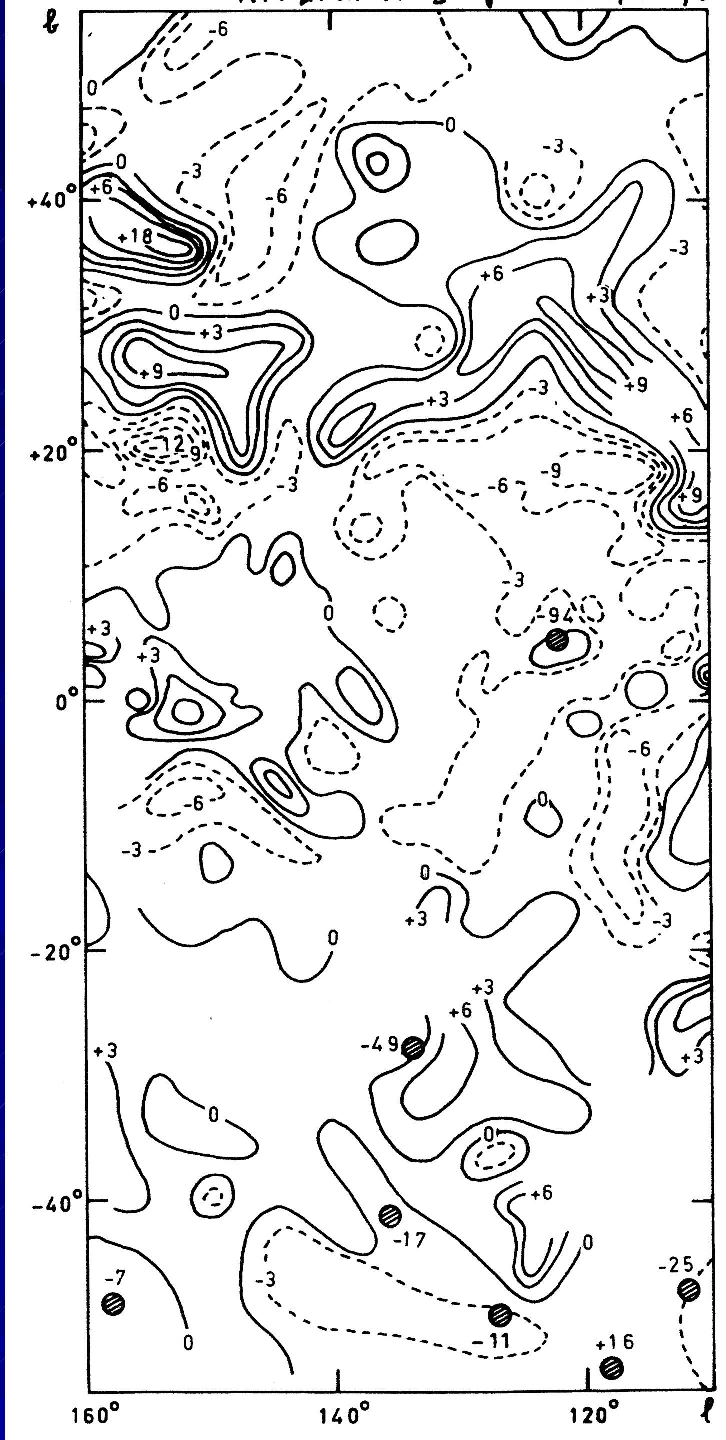


Galactic RM [rad/m²]
Dwingeloo surveys
at
408/465/610/
820/1411 MHz
Observations have different
(and large !) beams

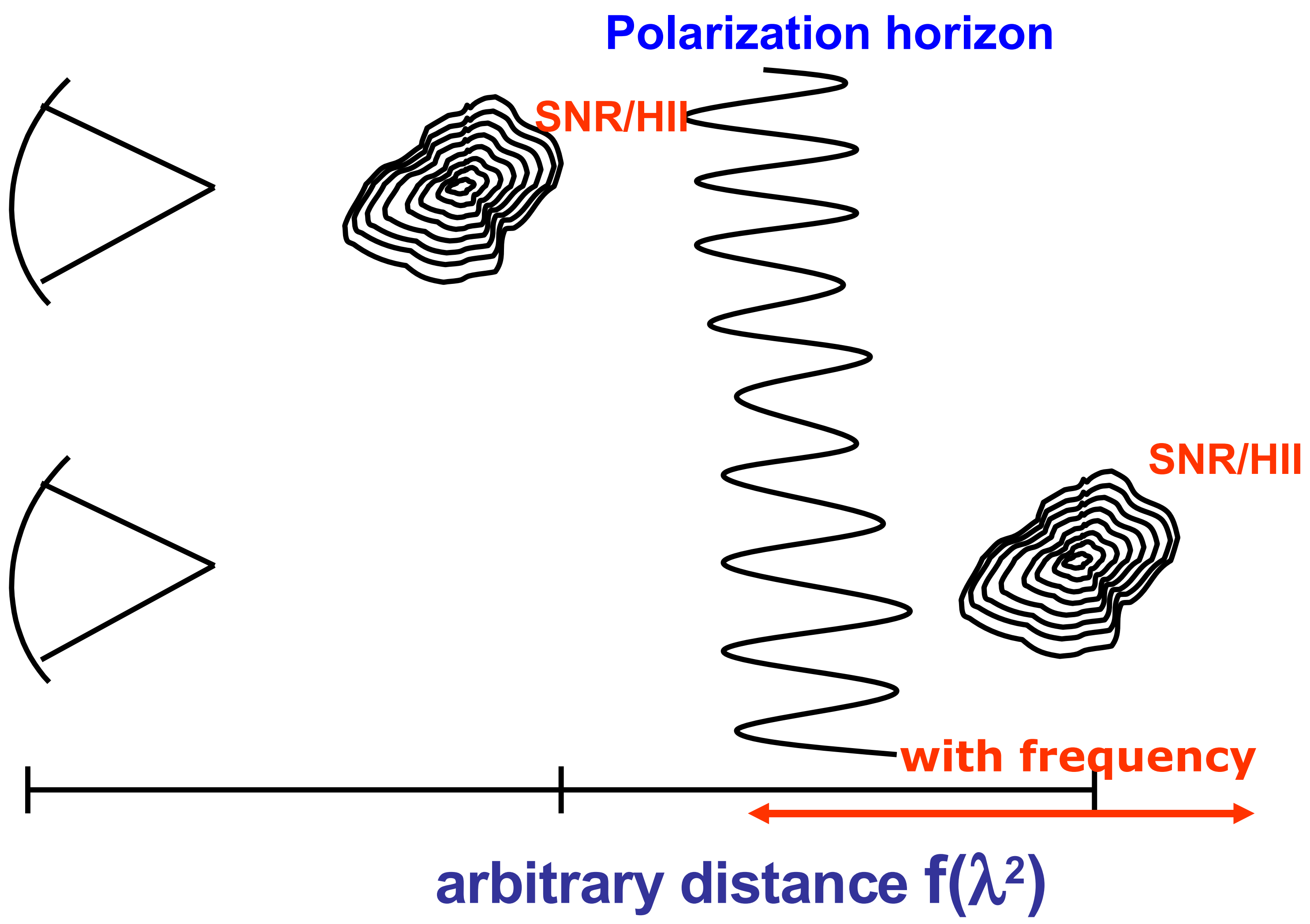
based on λ^2 - Fit

small RM values in general

Spoelstra, 1972, AA, 21, 61



Sketch of the polarization horizon



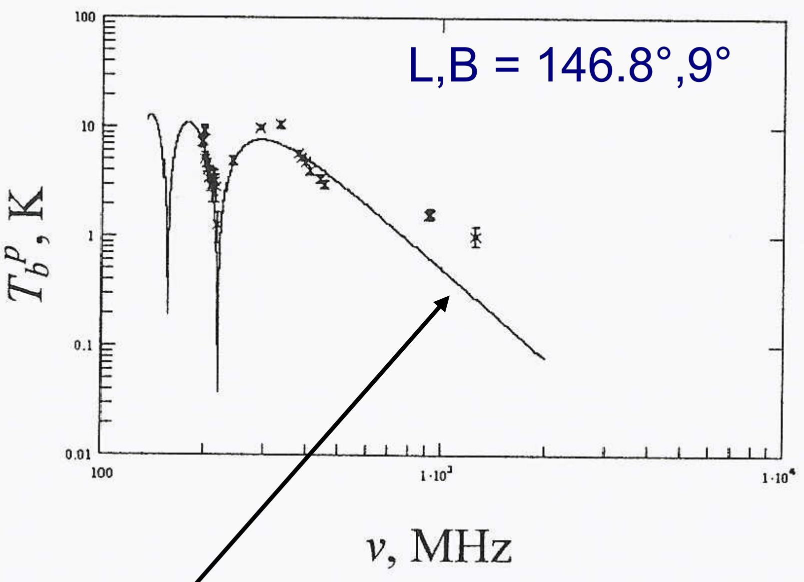
„Polarization Horizon“

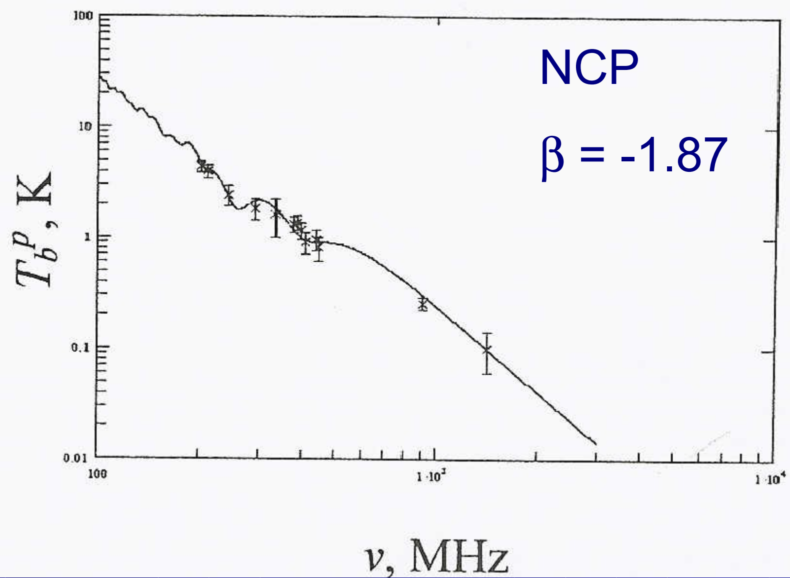
$RM = 0.81\, n_e[\mathrm{cm}^{-3}]\, B_{||}[\mu G]\, L[\mathrm{pc}]$, $\varphi\, [\mathrm{rad}] = RM\, \lambda^2\, [\mathrm{m}]$

for a uniform medium (filling factor = 1)

1.4 GHz for plane (halo) $n_e \sim 0.03(0.01)$, $B_{\|\|} \sim 2(0.2)$	➔RM ~ 35 rad m^{-2} and L ~ 1 (20) kpc
140 MHz	RM ~ 0.35 rad m^{-2} ➔ L ~ 10 (200) pc
45 MHz	RM ~ 0.035 rad m^{-2} ➔ L ~ 1 (20) pc

Vinyajkin & Razin (2002)



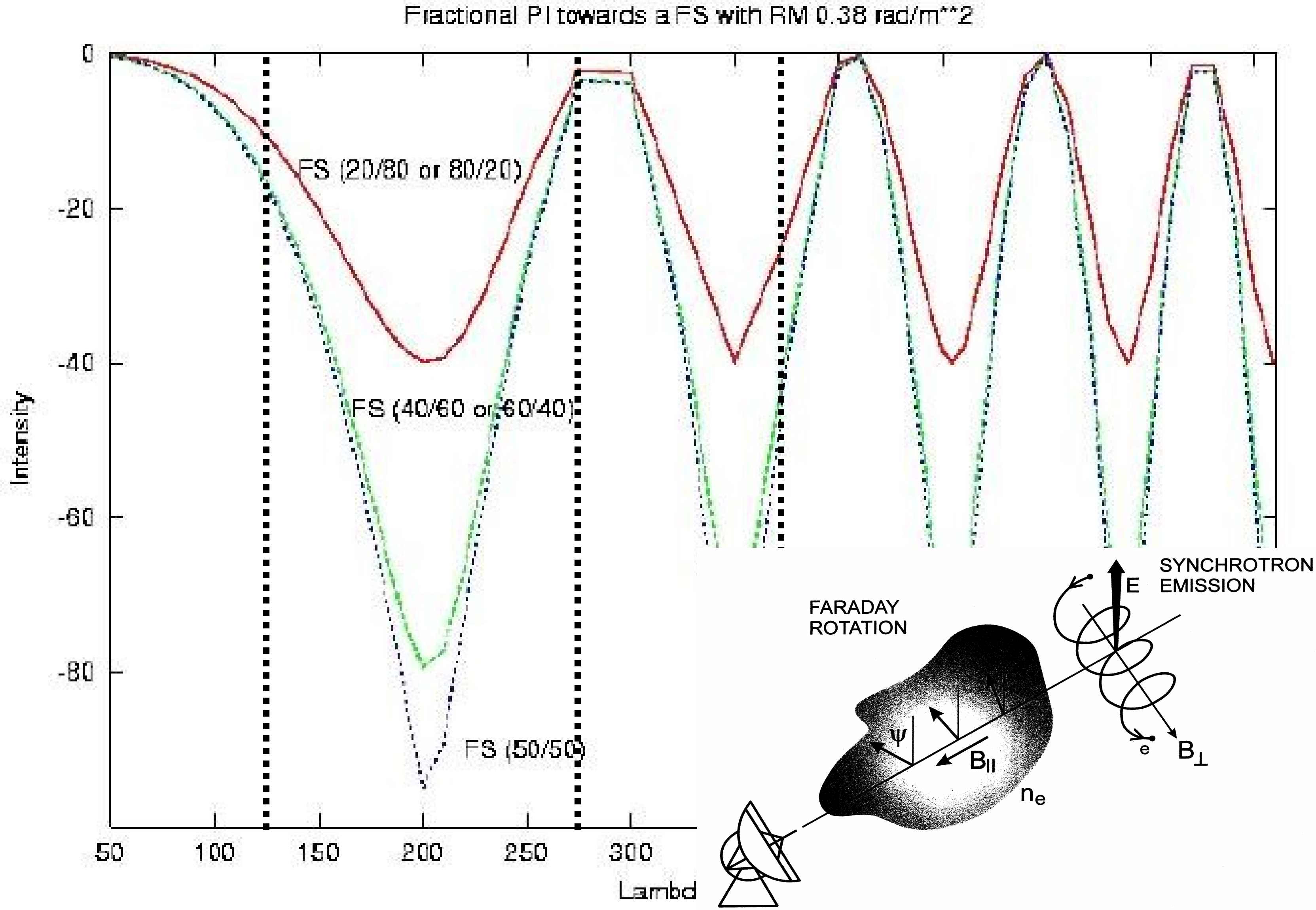


$$T_b{}^p = \frac{A}{2|\psi|}\left(\frac{\nu}{300}\right)^{2-\beta}\left\{\left[\frac{\sin 2\psi\left(\frac{300}{\nu}\right)^2 y}{2\psi\left(\frac{300}{\nu}\right)^2 y}\right]^2 - 2\frac{\sin\left[2\psi\left(\frac{300}{\nu}\right)^2 y\right]}{2\psi\left(\frac{300}{\nu}\right)^2 y}\cos\left[2\psi\left(\frac{300}{\nu}\right)^2\right]+1\right\}^{1/2}$$

Slab model + bandwidth depolarization:

RM = 0.84 rad m^{-2} from $T_b{}^p$ fit

RM = 0.6+/-0.15 from angle fit at high ν



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