ASTRON

Netherlands Institute for Radio Astronomy

Observations of magnetic fields in the Milky Way disk and halo

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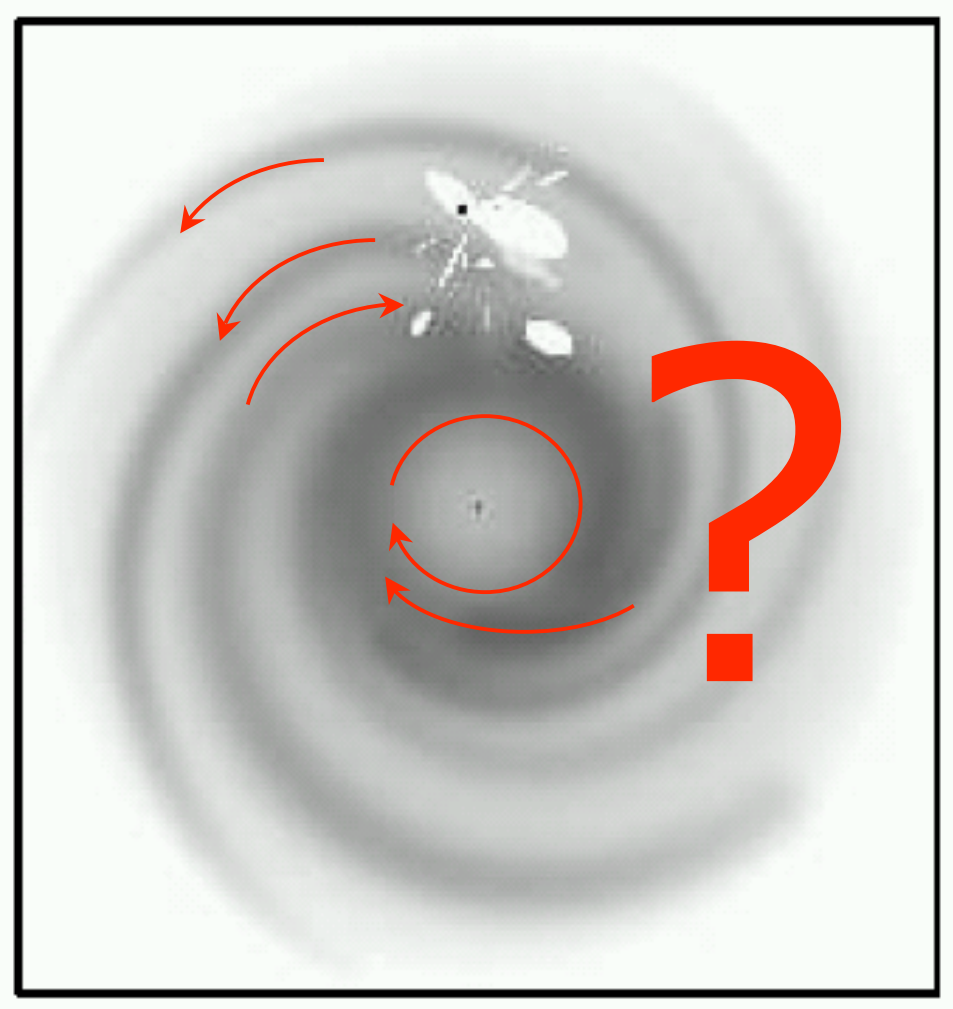
ASTRON/Leiden

Outline

- Magnetic fields in the Galactic disk
- Magnetic fields in the Galactic halo
- New developments (warning: biased!)

Magnetic fields in the Galactic disk



$B_{tot} \approx 6\ \mu G$ at solar circle

$B_{tot} \approx 10\ \mu G$ at R = 3 kpc

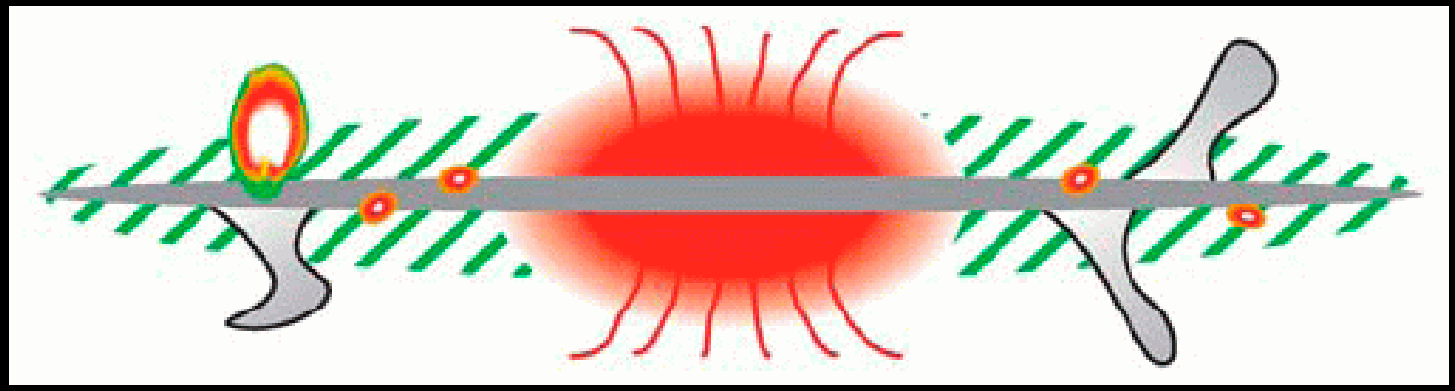
$B_{reg} \approx 2\ \mu G$ at solar circle

B_{ran} higher in spiral arms
B_{reg} higher in interarms

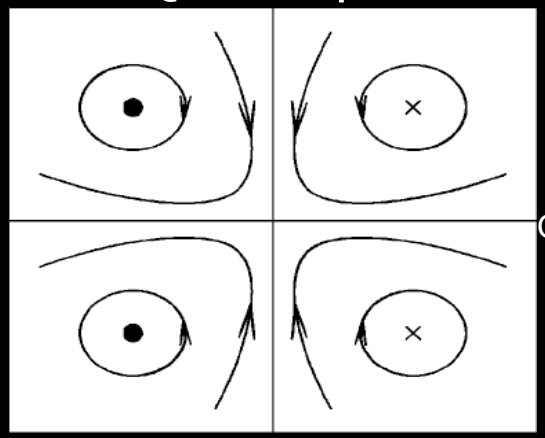
Disk magnetic field models:

AUTHOR	DATA	MODELS	RESULTS
Jansson et al 2009	WMAP 22.8GHz PI 1433 EGS RMs	log spirals, Sun, Brown, ring, Page, exponential	Disk and halo separate Sun model for disk
Sun et al 2008	I at 22.8GHz, 408MHz P at 22.8GHz, 1.4GHz EGS RMs	ASS, BSS, log spirals, ASS+RING, ASS+ARM	ASS + one reversal
Men et al 2008	Pulsar RMs	ASS, BSS, Ring	None of the models fit
Brown et al 2007	Pulsar and EGS RMs in plane; 4th Q.	log spirals	Single reversal best, but all high χ^2
Nota & Katgert 2009	107 Psr and 131 EGS RMs $\|b\| < 3°$; 4th Q.	log spirals, ring	Reversals in every arm and interarm. No ring
Kronberg & Newton-McGee 2009	EGS RMs	symmetry along Gal longitude	indicates ASS
Frick et al 2001	551 EGS RMs	wavelet analysis	Even symmetry of local large-scale field
Han et al 2006	554 Pulsar RMs	l.o.s. dependence of RM	Reversals in every arm and interarm

Magnetic fields in the Galactic halo

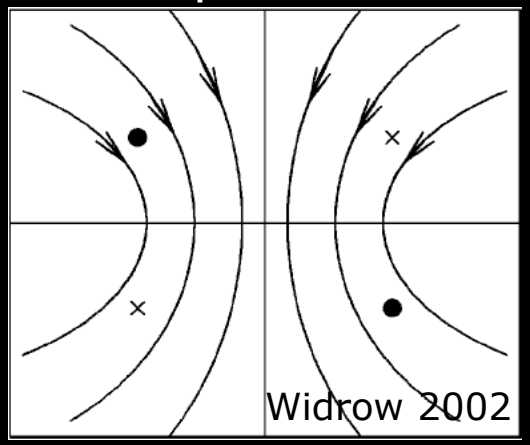


Quadrupolar

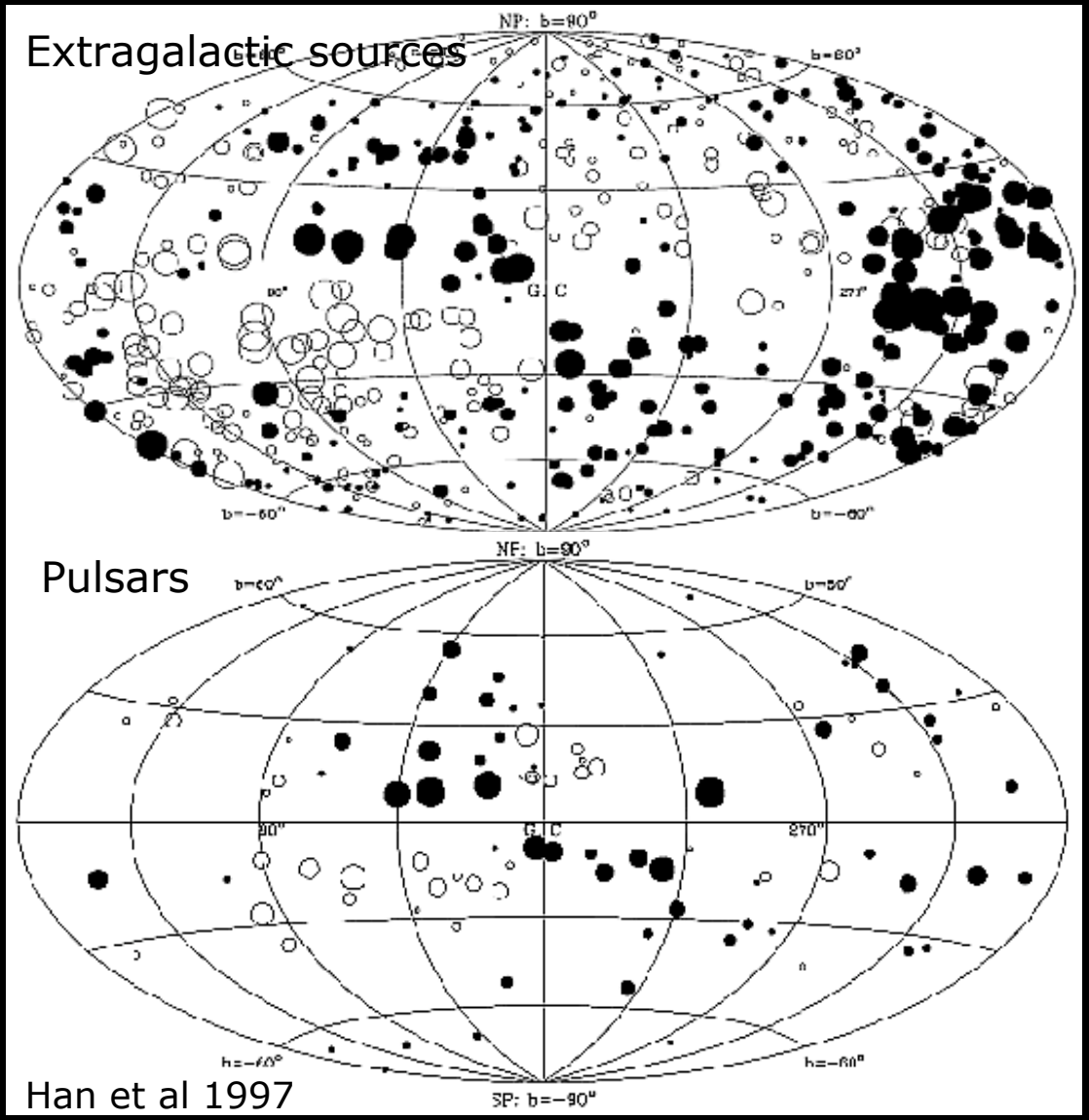


Galactic plane

Dipolar



Large-scale patterns in the rotation measure sky in the Galactic halo (≡ at high absolute Galactic latitudes)

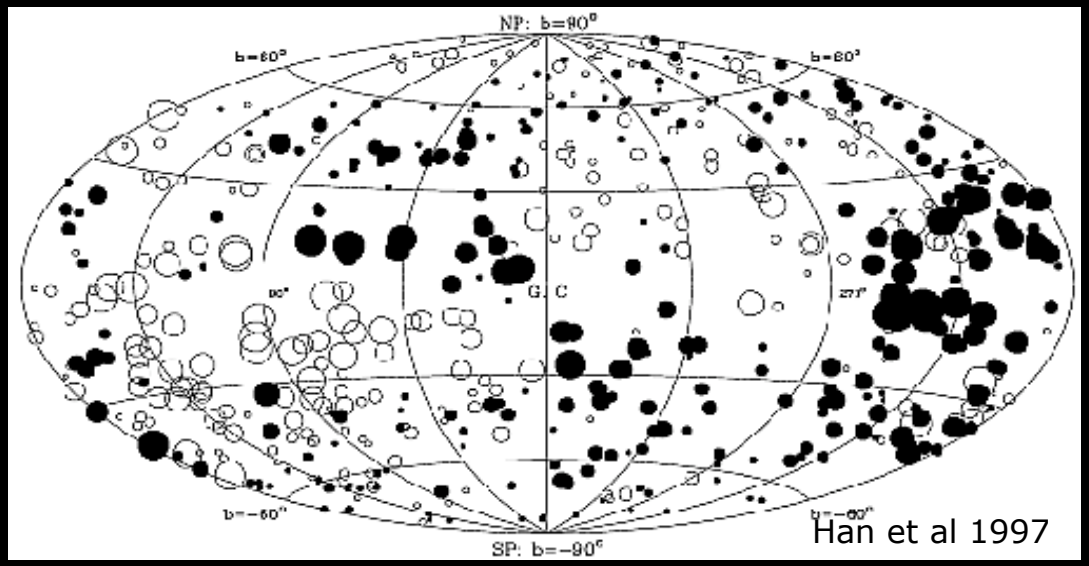


Magnetic scale height:

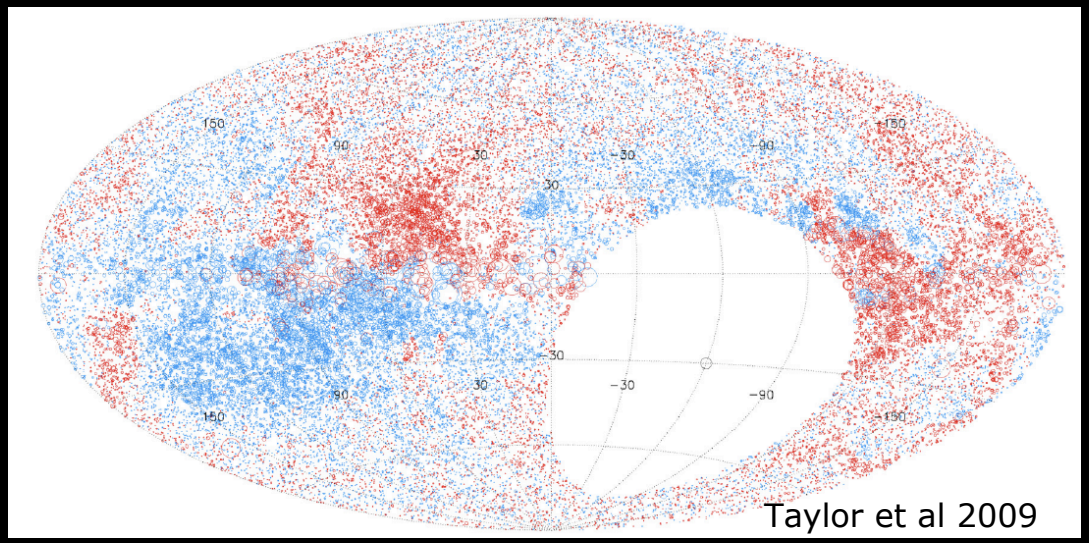
0.7 kpc (Simard-Normandin & Kronberg 1980)

1.2 ± 0.4 kpc (Han & Qiao 1994)

Large-scale patterns in the rotation measure sky in the Galactic halo

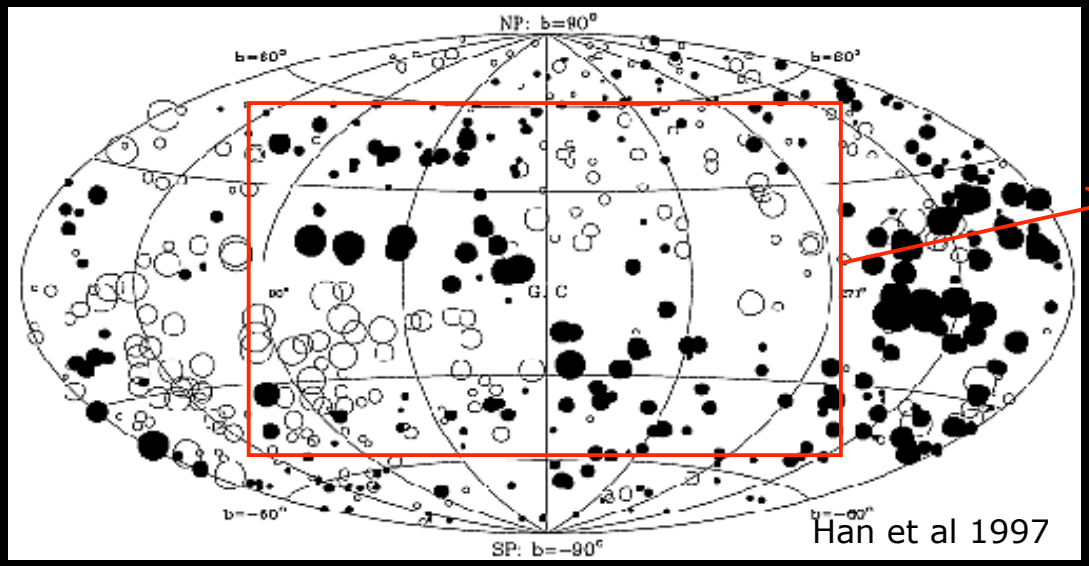


Han et al 1997

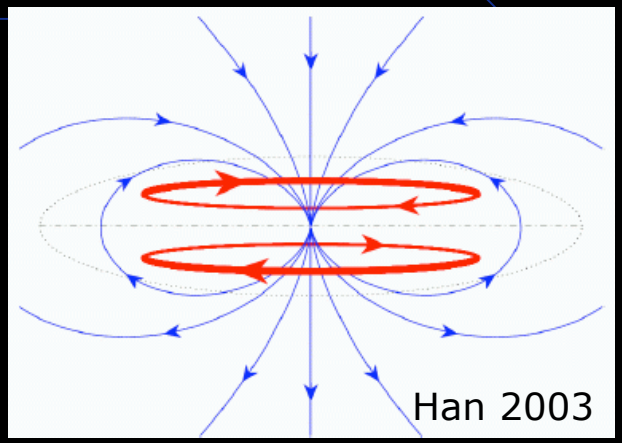


Taylor et al 2009

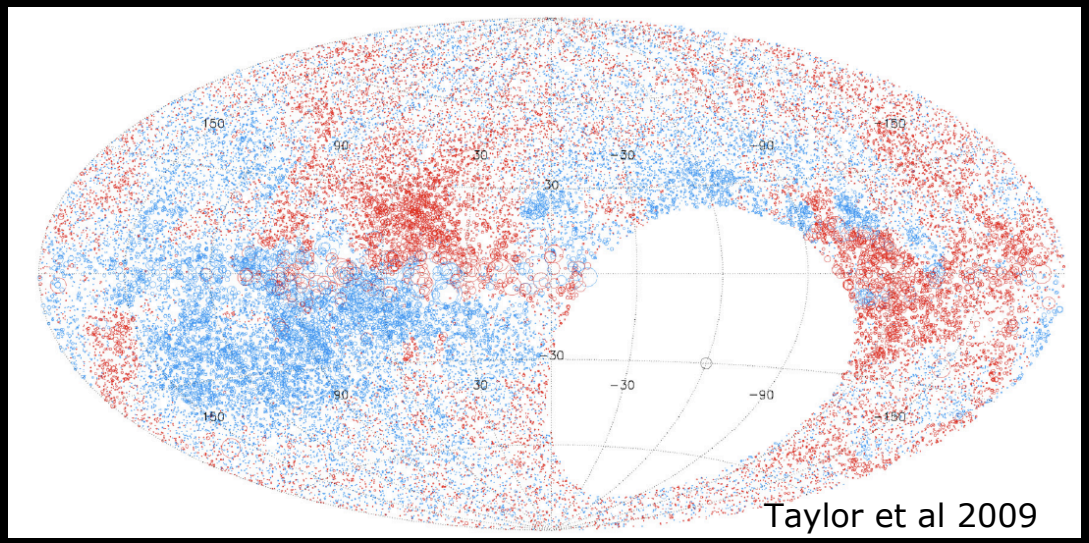
Large-scale patterns in the rotation measure sky in the Galactic halo



Han et al 1997

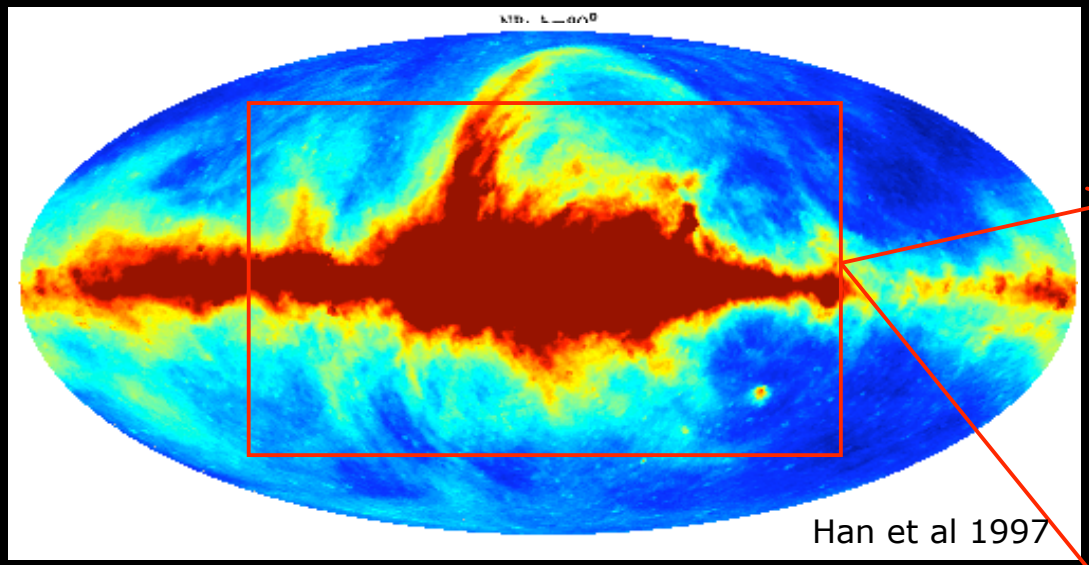

Han 2003

An A0 dynamo…

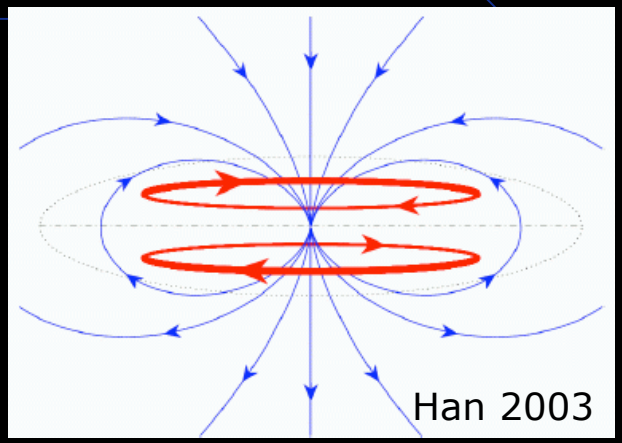


Taylor et al 2009

Large-scale patterns in the rotation measure sky in the Galactic halo



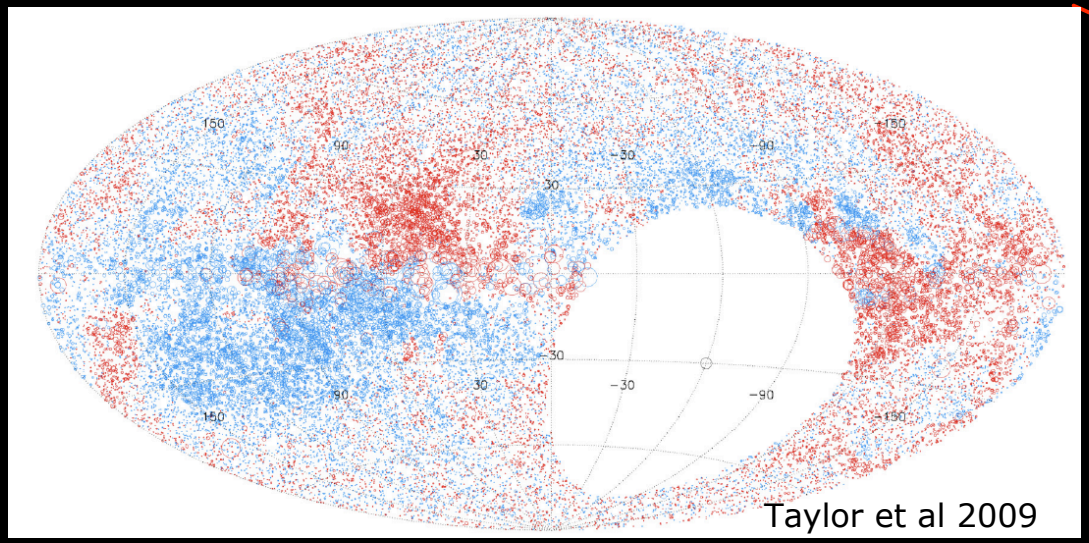
Han et al 1997



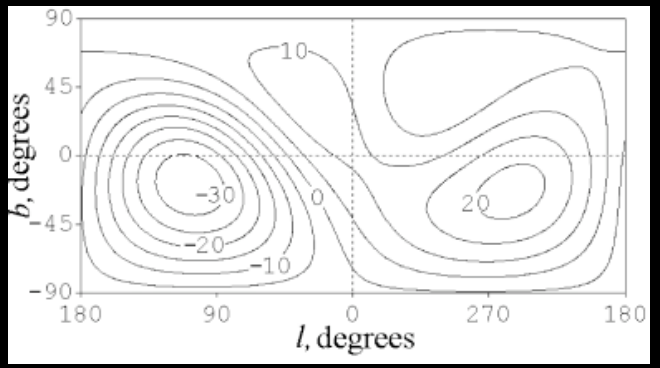
Han 2003

An A0 dynamo…

… influence of the
North Polar Spur
… and a local even field?

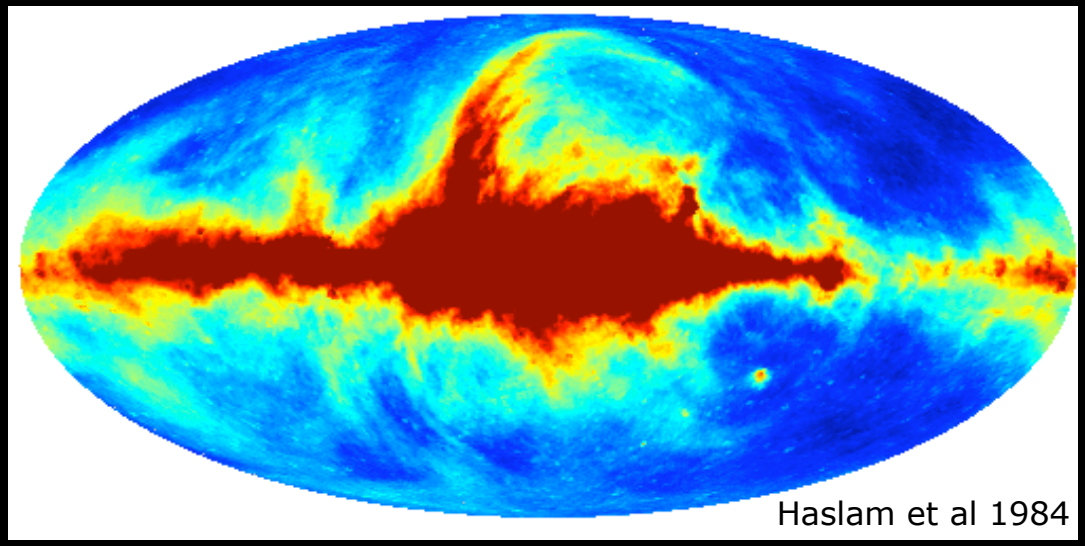


Taylor et al 2009



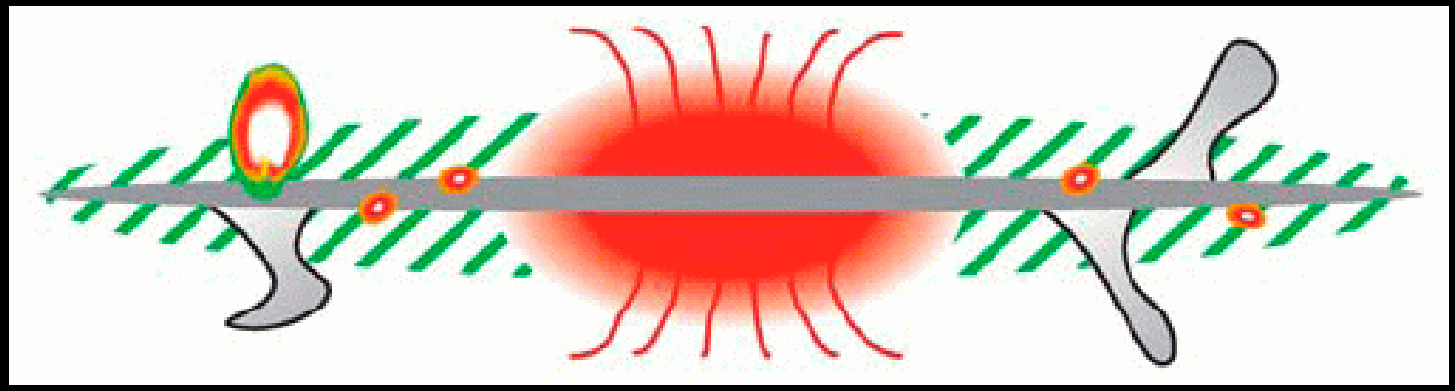
Frick et al 2001

Modeling of the North Polar Spur in progress to estimate the foreground RM contribution from this structure:

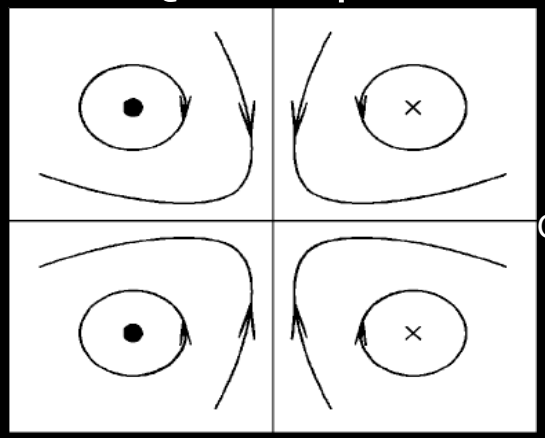


Haslam et al 1984

Magnetic fields in the Galactic halo

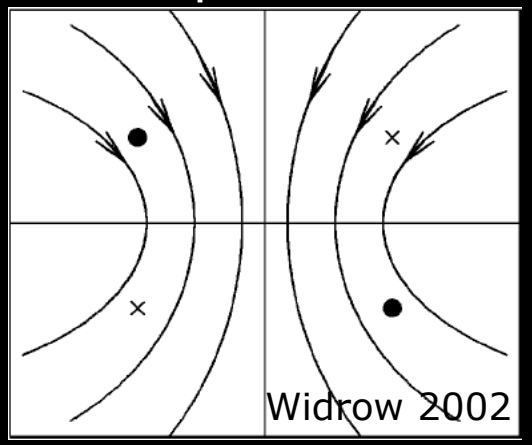


Quadrupolar



Galactic plane

Dipolar

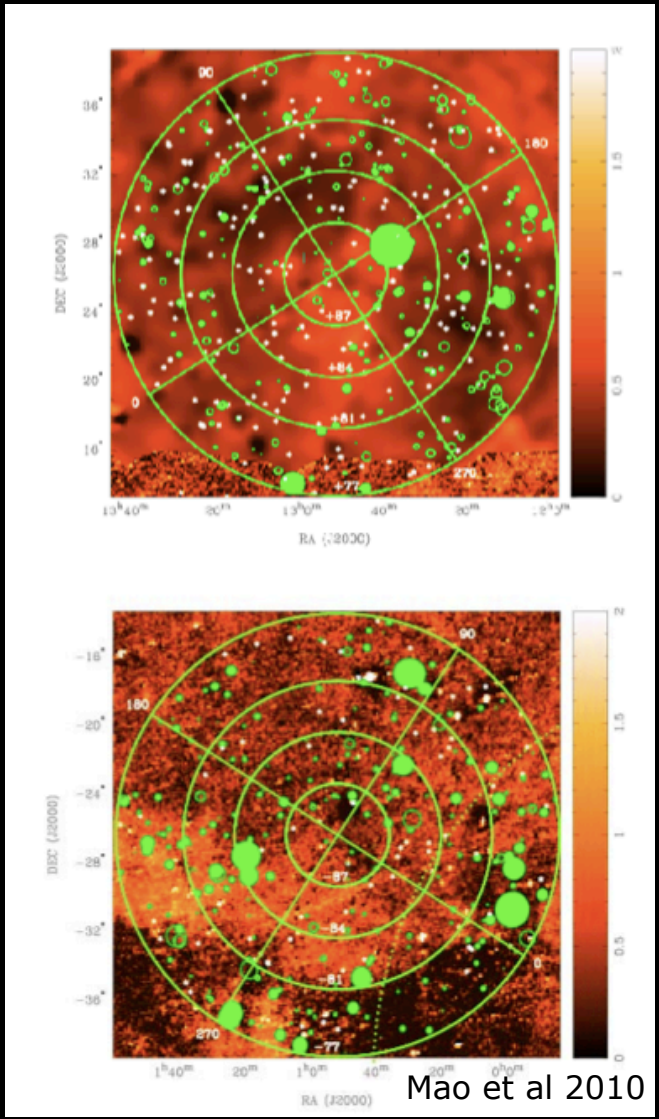


Dynamo

(Zweibel & Heiles 1997)

Weak diff rotation
or primordial field

Large-scale vertical magnetic field in the Galactic halo at the solar radius:



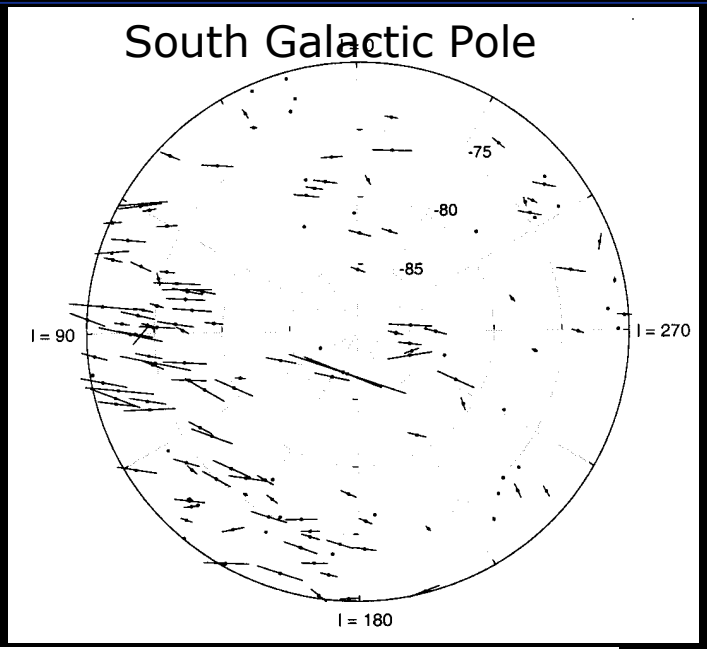
Mao et al 2010

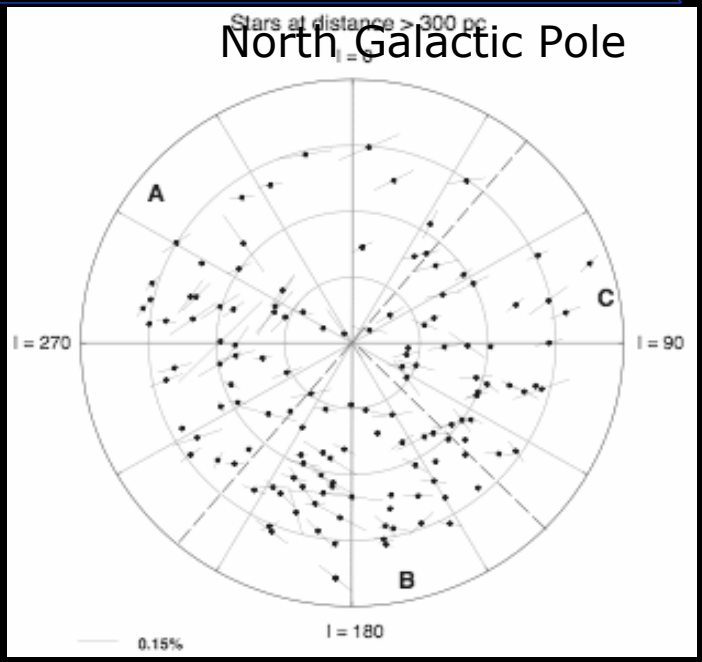
RMs of 472 extragalactic sources in the north, 341 sources in the south at $|b| > 70°$

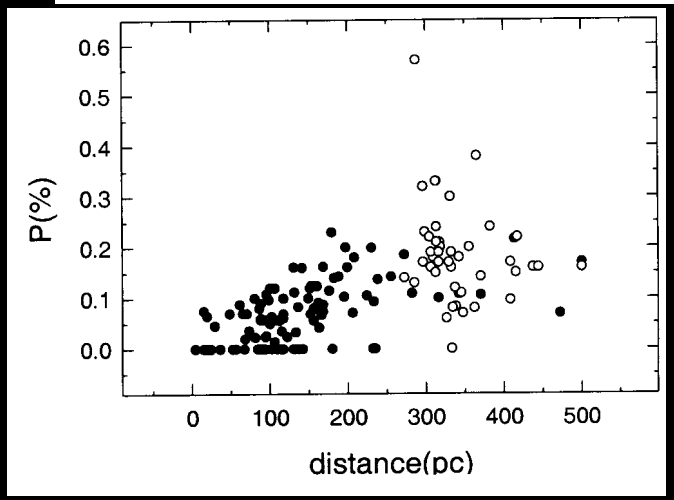
north: $\langle RM \rangle = 0.0 \pm 0.5$ rad m^{-2}

south: $\langle RM \rangle = 6.3 \pm 0.7$ rad m^{-2}

Star-light polarization: large-scale field at b < 0°, smaller-scale structure at b > 0°







Berdyugin & Teerikorpi 2001

Also: disk fields coupled to halo field at least up to 500 pc height

Large-scale vertical magnetic field in the Galactic halo at the solar radius:

Han & Qiao (1994): B_{vert} = 0.3 ± 0.2 μG from S to N

Taylor et al (2009): B_{vert} = 0.14 ± 0.02 μG at b>0° from N to S
B_{vert} = 0.3 ± 0.03 μG at b<0° from S to N;

Mao et al (2010): B_{vert} = 0.0 ± 0.02 μG at b>0°
B_{vert} = 0.31 ± 0.03 μG at b<0° from S to N

New developments:

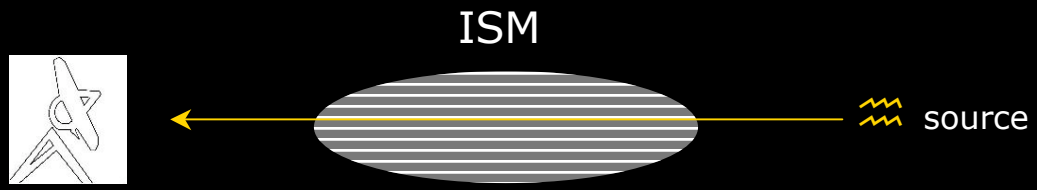
Rotation Measure Synthesis

GMIMS: the all-sky survey from 300 - 1800 MHz

LOFAR: the LOw Frequency ARray

Faraday rotation and rotation measure synthesis

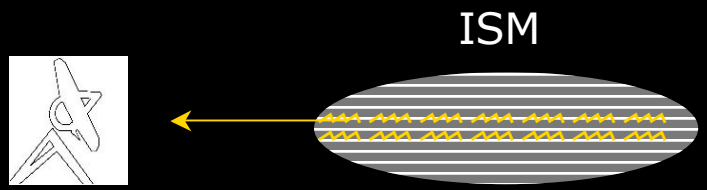
Faraday rotation:



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

where rotation measure $\mathrm{RM} \propto \int n_e\, B_{//}\, dl$

Rotation measure synthesis:



$P(\lambda^2) = W(\lambda^2) \int F(\phi)\, e^{2i\phi\lambda}\, d\phi$

$F(\phi) * R(\phi) = \int P(\lambda^2) e^{-2i\phi\lambda}\, d\lambda^2$

Faraday depth $\phi \propto \int n_e\, \mathbf{B}\cdot\mathbf{dl}$

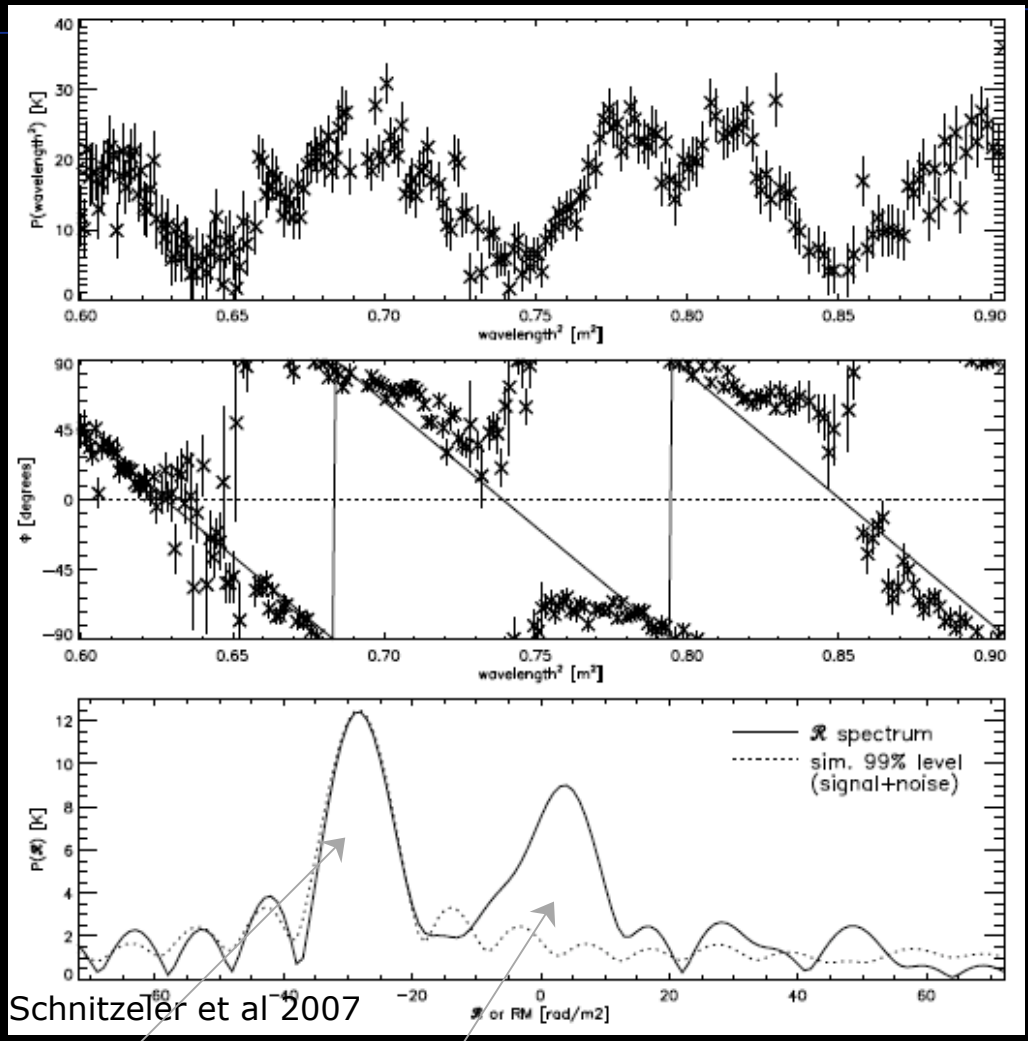
(Burn 1966, Brentjens & de Bruyn 2005)

Faraday rotation and rotation measure synthesis

Linearly polarized intensity

Polarization angle

Faraday depth spectrum

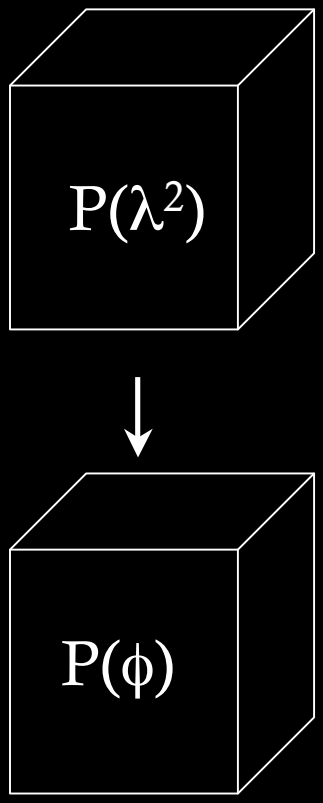


Schnitzeler et al 2007

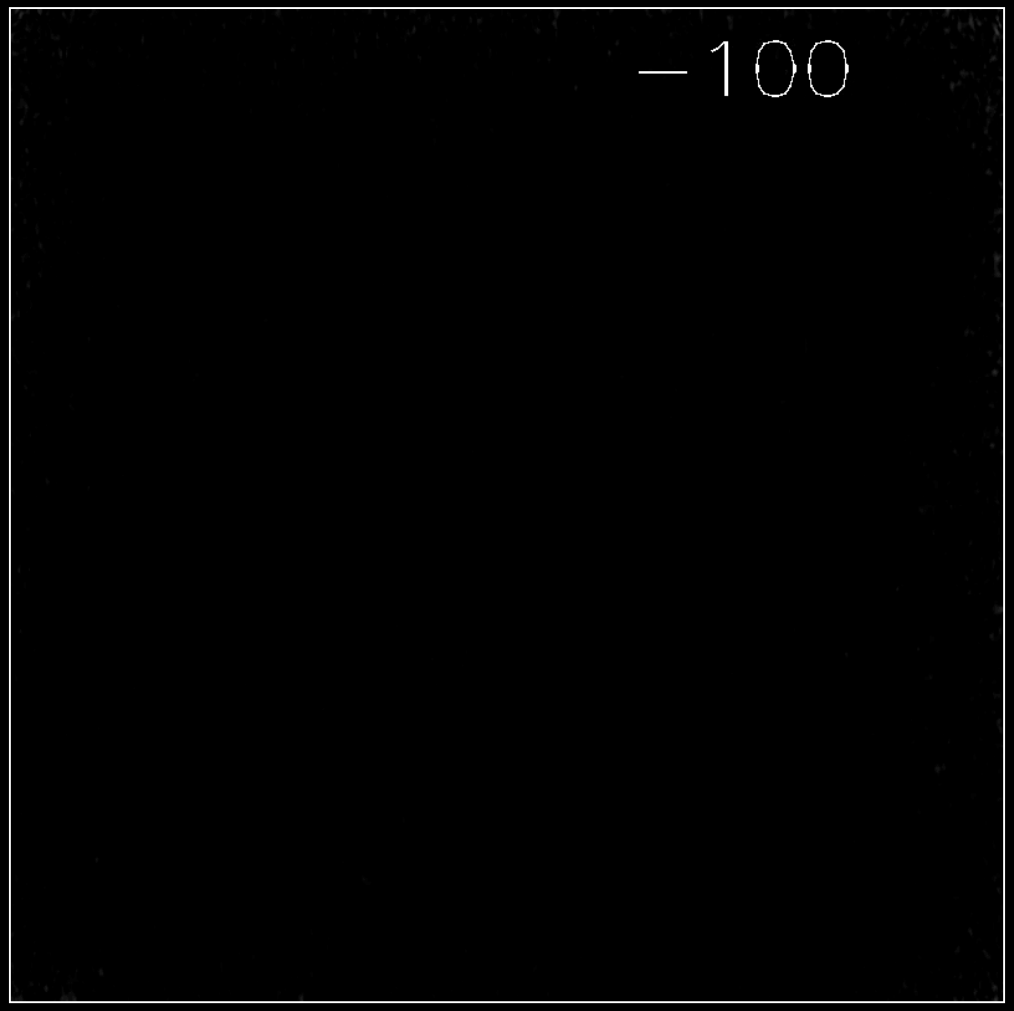
e.g. extragalactic point source

e.g. Galactic interstellar medium

Faraday rotation and rotation measure synthesis

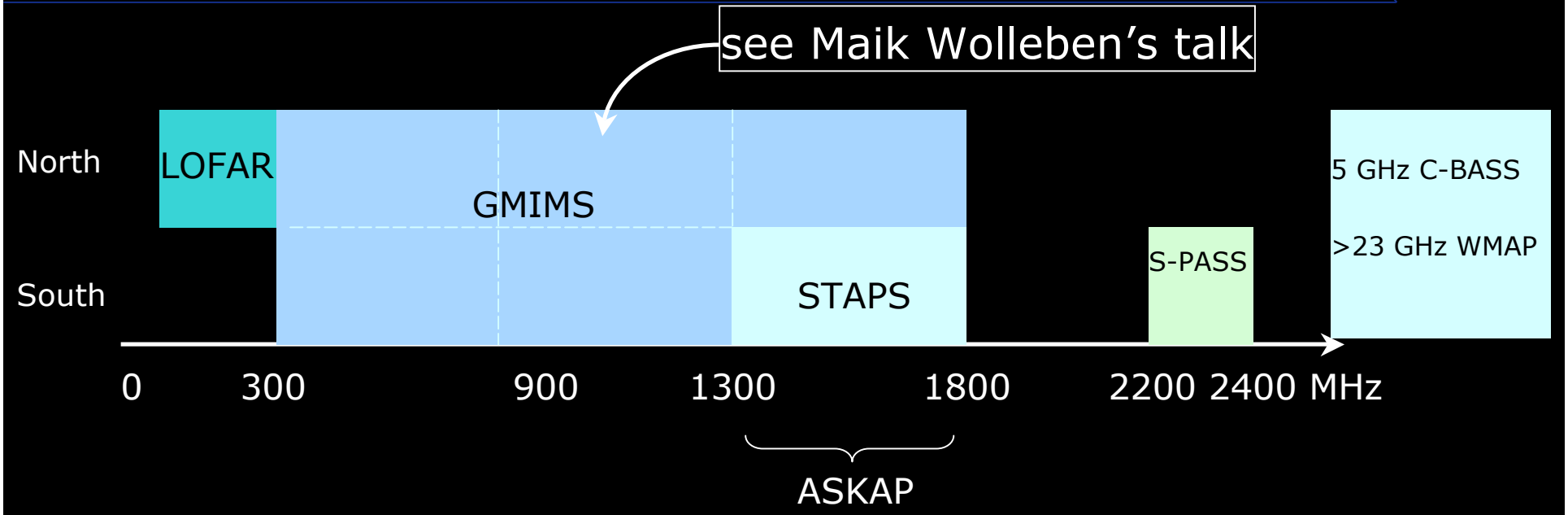


ϕ = Faraday depth
= 0.81∫ n_e **B·dl**



7ºx7º field around (l,b) = (181º,20º)
Schnitzeler et al 2008

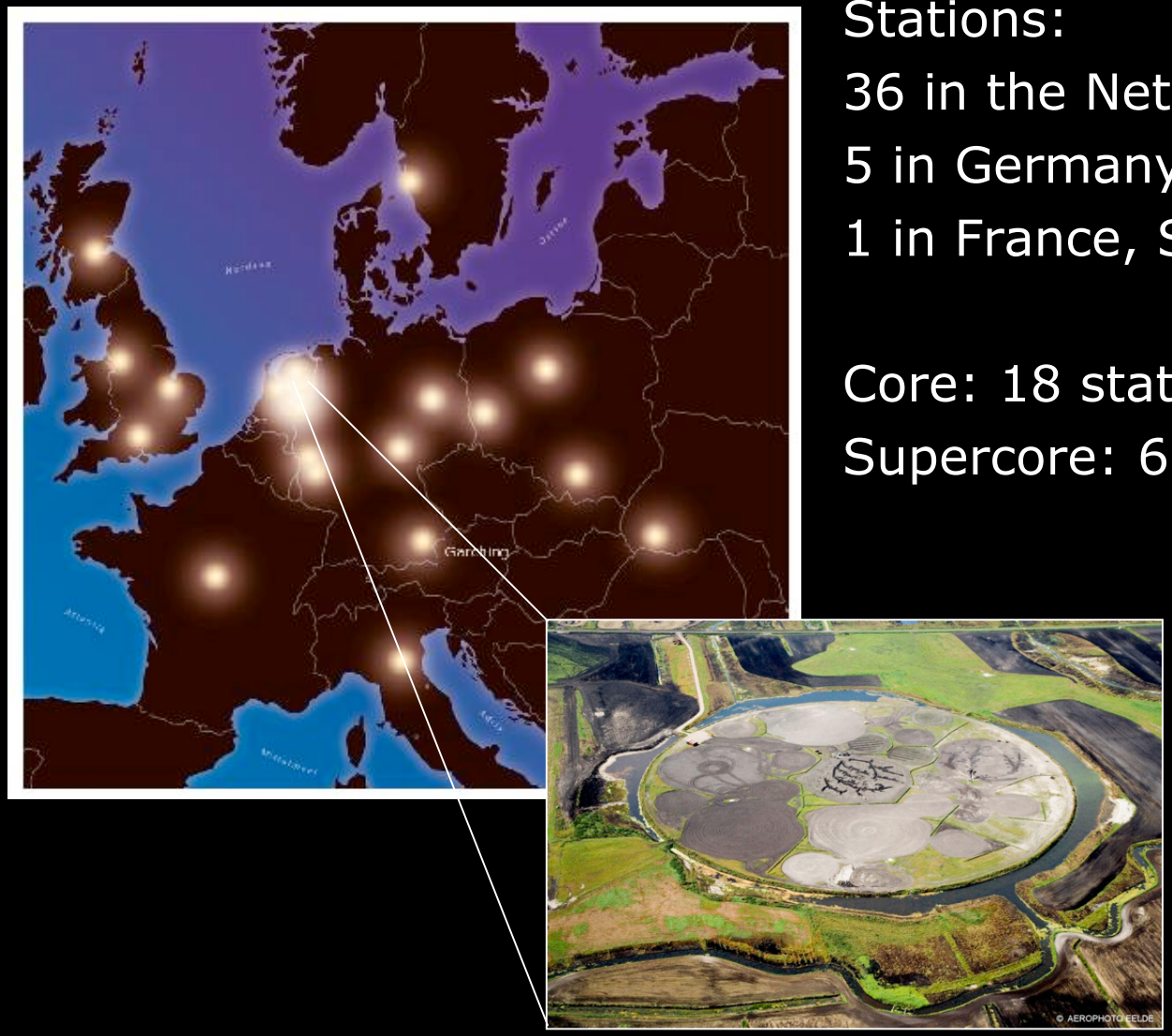
Radio spectro-polarimetric surveys



GMIMS = Global Magneto-Ionic Medium Survey (PI Wolleben)
Faraday depth resolution of 3.5 rad m^{-2}

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

LOFAR: the Low Frequency ARray



Stations:

36 in the Netherlands

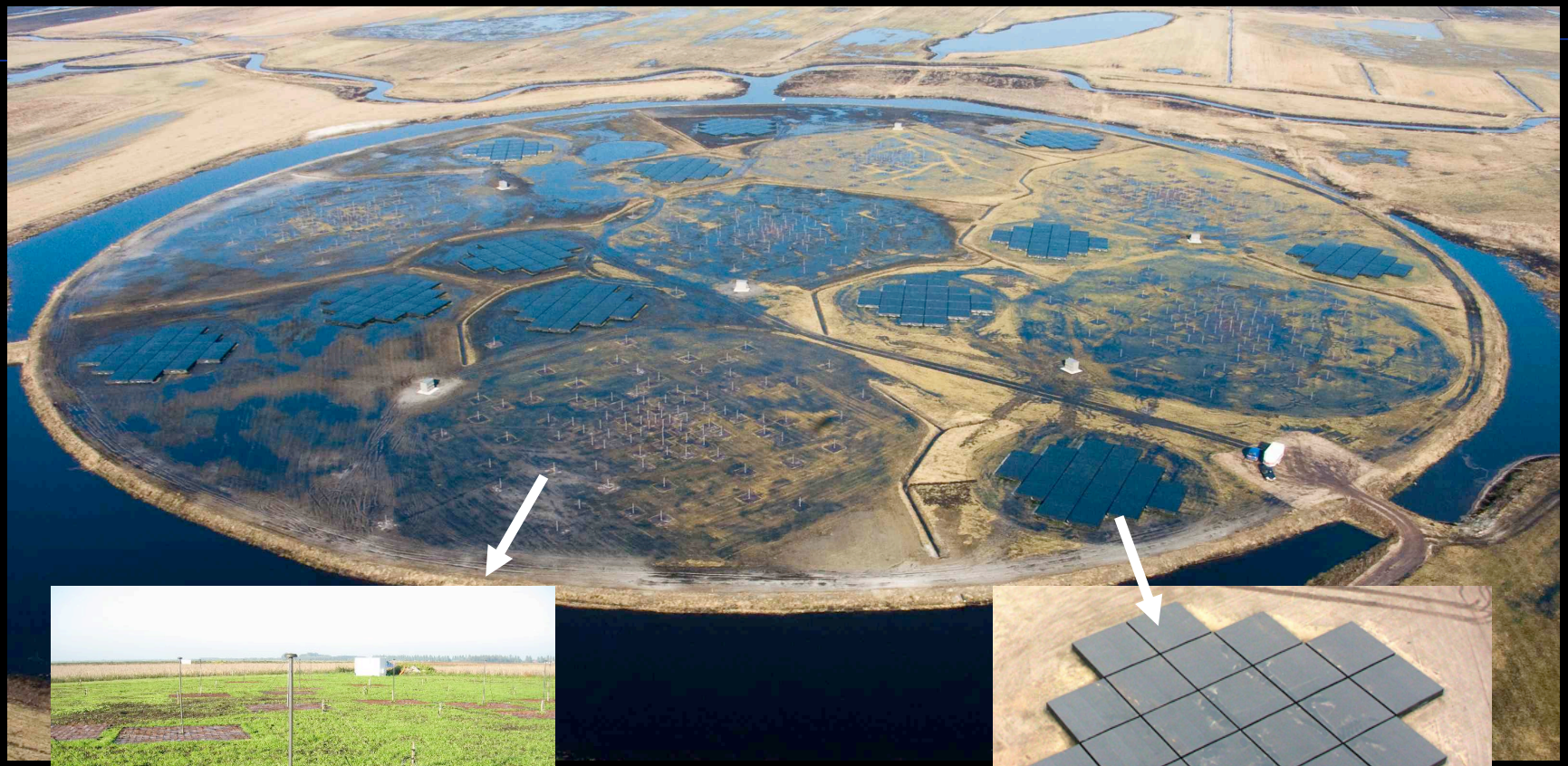
5 in Germany

1 in France, Sweden, UK, …

Core: 18 stations within ~2 km

Supercore: 6 stations within 300m

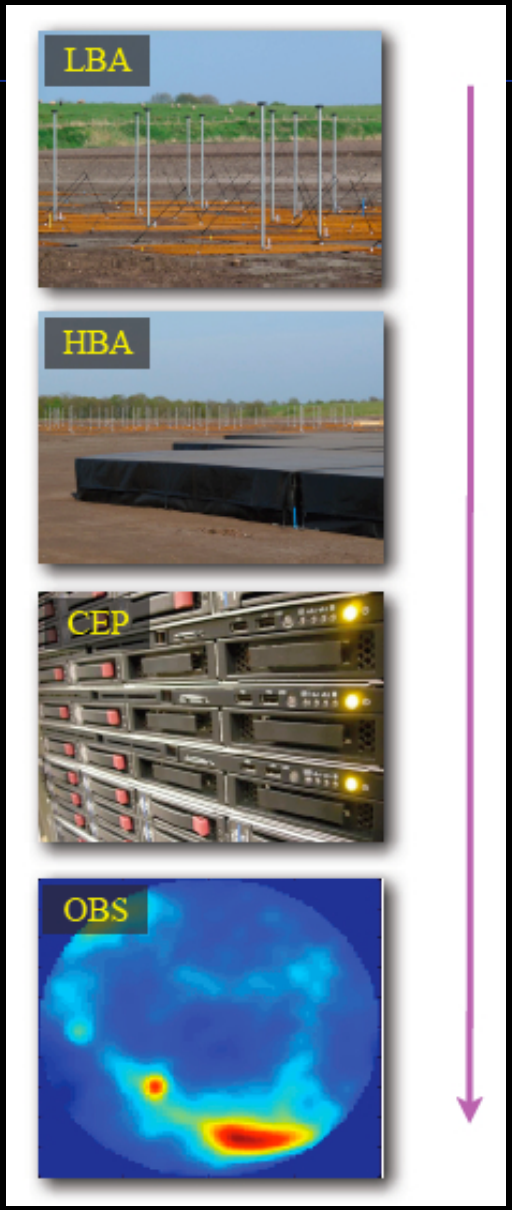
LOFAR: the Low Frequency ARray



Low Band Antennas
(LBA): 10 - 90 MHz

High Band Antennas
(HBA): 110 - 240 MHz

LOFAR: the Low Frequency ARray



Data processed in Blue Gene/P supercomputer at Groningen (CEP)

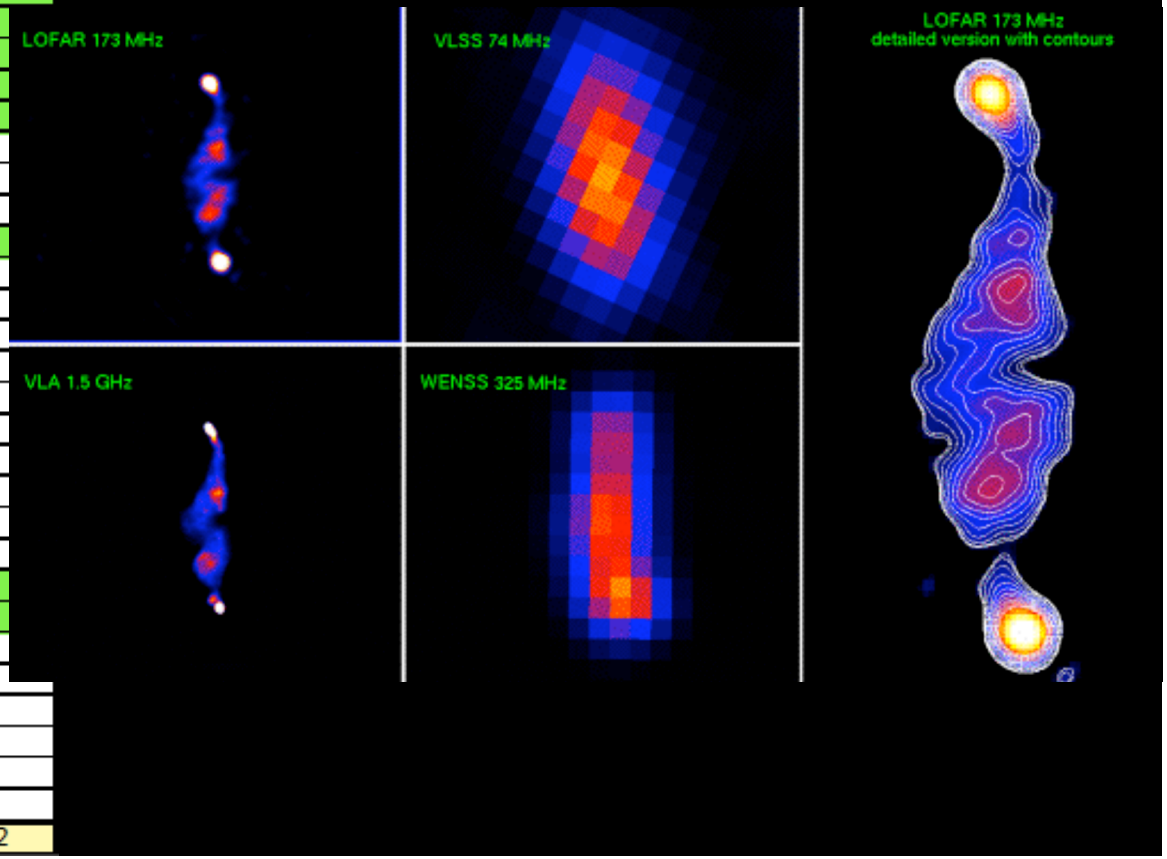
Three data pipelines (for now):

- imaging pipeline
  (including RM synthesis)
- beam-formed data pipeline
  (including pulsars)
- very high energy cosmic ray pipeline

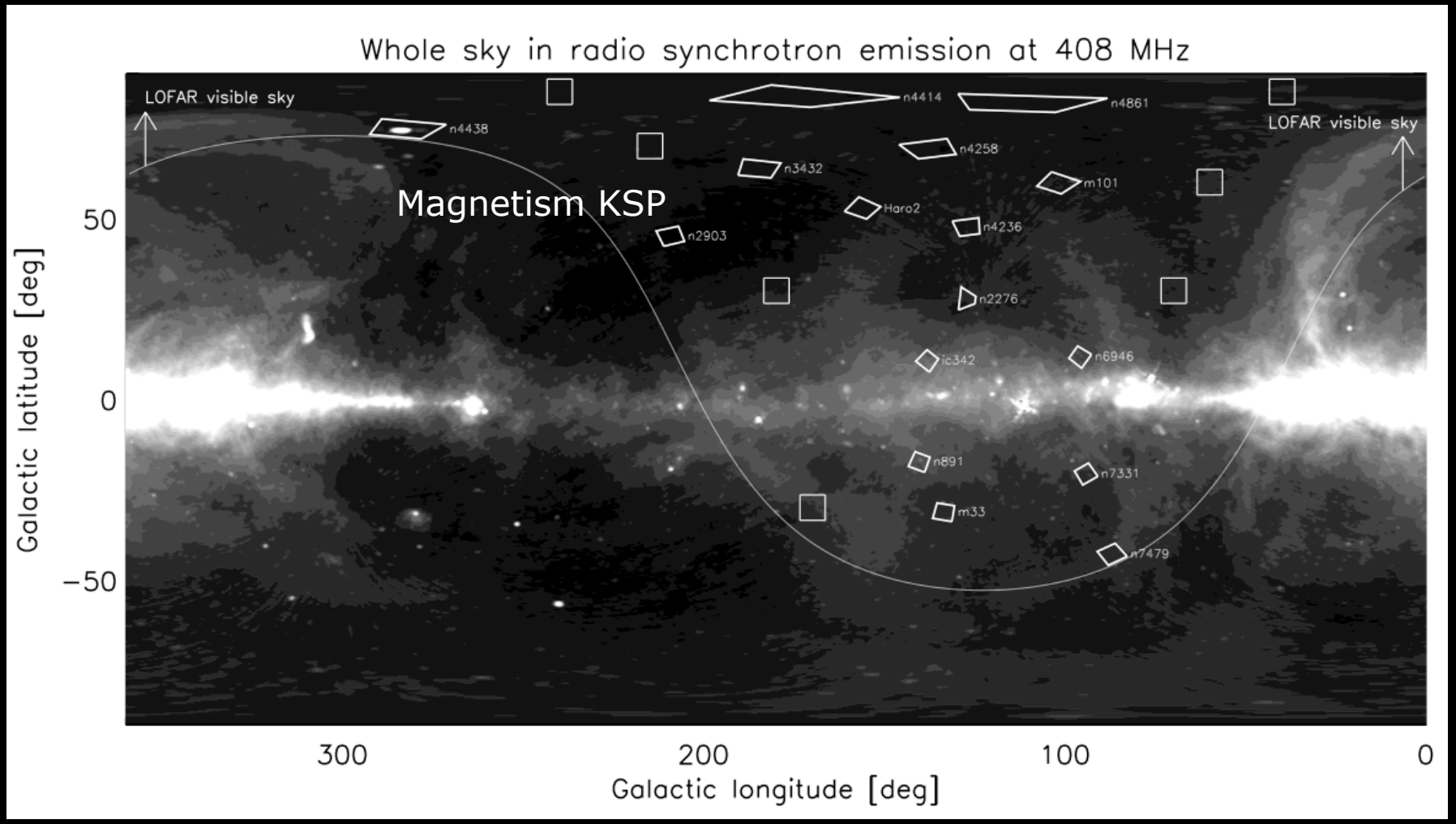
LOFAR status mid-April: 22 validated stations

Station/Item	Cabinet	LBA	HBA	Fibre	CEP connection	Validated
CS302						
RS307						
RS503						
RS106						
RS208						
CS030						
CS401						
CS021						
CS032						
RS306						
CS301						
CS501						
RS509						
CS103						
CS001						
CS002						
CS003						
CS004						
CS005						
CS006						
CS007						
CS024						
CS201						
CS101						
CS026						
RS205						
CS017						
RS104						
RS210						
RS310						
RS404						
RS406						
RS407						
RS409						
RS410						
RS508						
Effelsberg						
Tautenburg						
Garching						
Potsdam						
Juelich						
Nancay						
Onsala						
Chilbolton						
Totals	31	28	25	29	29	22

Early results: high-res (9 arcsec) image of 3C61.1 (van Weeren)



LOFAR shows a first look into the magnetized weak Galactic halo with RM synthesis



Summary

Magnetic fields in the Galactic disk: Strength and direction fairly well-known, but controversy about number of reversals.

Magnetic fields in the Galactic halo:
- Anti-symmetric pattern with respect to plane in inner Galaxy: signature of A0 dynamo or local stucture?
- No vertical field component at solar radius

New developments:
- RM Synthesis
- all-sky, super-broadband survey: GMIMS
- LOFAR opens the low-frequency (= weak magnetic field) sky