Observing nearby galaxies at low frequencies - results from the LOFAR MKSP

Rainer Beck

MKSP observation plan

- Tier 1 survey of ≈60 galaxies (HBA)
  Search for diffuse polarisation, RM grid towards polarised extragalactic sources
- Tier 2 deep survey of ≈10 galaxies (HBA)
  Magnetic field structure in outer disk and halo
- Milky Way fields (piggyback with extragalactic fields)
  Properties of Galactic magnetic fields in the foreground
- Survey of ≈10 giant radio galaxies (HBA)
  Magnetic field structure, RMs from intergalactic space
- Survey of ≈5 stellar jets (HBA)
  Search for polarised emission, magnetic field structure

MKSP proposals

- Cycle 0:
  1 proposal on 14 galaxies, 10 observed
  (HBA, 4 also with LBA)

- Cycle 1:
  8 proposals on 10 galaxies, 8 observed/to be observed
  (HBA only)
  + 2 joint proposals (Virgo cluster/galaxies, extragalactic recombination lines)

- Cycle 2:
  3 proposals on 4 galaxies (2 with HBA, 2 with LBA)
  + 2 joint proposals (ELAIS-N1, extragalactic recombination lines)

MKSP projects on nearby galaxies

Galaxy	Array	Responsible	Observed	Status
NGC891	HBA	D. Mulcahy	Nov. 2012	**Ready**
M81/82	HBA	B. Adebahr	March 2013 / Jan. 2014	Mostly processed
M81/82	**LBA**	B. Adebahr	March 2013	--
IC342	HBA	C. Van Eck / R. Beck	Feb. 2013	Partly processed
IC342	**LBA**	A. Horneffer	Feb. 2013	--
NGC3627/3628	HBA	R. Paladino	March 2013	Partly processed
NGC4631	HBA	R.J. Dettmar	April 2013	-- almost
M51	HBA	D. Mulcahy	April 2013	**Ready, submitted**
M101	HBA	G. Heald / S. Seethapuram- Sridhar	June 2013	Processing started
NGC6946	HBA	W. Jurusik / C. Chyzy	July 2013	Partly processed
IC10	HBA	V. Heesen	Aug. 2013	--
IC10	**LBA**	V. Heesen	Aug. 2013	--
Stephans Quintet	HBA	B. Nikiel-Wroczynski	Sept. 2013	Partly processed
M33	HBA	R. Paladino / M. Iacobelli	Oct. 2013	Processing started
M33	**LBA**	R. Paladino	Oct. 2013	--
NGC628	HBA	D. Mulcahy	Nov. 2013	--
NGC3432	HBA	A. Miskolczi	Nov. 2013	--
NGC4449	HBA	C. Chyzy	Feb. 2014	Processing started
NGC4258	HBA	B. Adebahr	Feb. 2014	Just observed
NGC3079	HBA	E. Varenius	*March 2014*	Just observed
NGC5055	HBA	K. Sendlinger	*April 2014*	*To be observed*
NGC4490	HBA	B. Nikiel-Wroczynski	*April 2014*	*To be observed*
Virgo Cluster	HBA	F. de Gasperin	*April 2014*	*To be observed*
NGC5775	HBA	G. Heald	*May 2014*	*To be observed*

Students and postdocs working with LOFAR MKSP data

Status: 2 April 2014

Institute	Name	Degree	Final year	Topic	LOFAR data
Bochum Univ.	Arpad Miskolczi	PhD	2014	Edge-on galaxies at low ν	useful
	Carlos Sotomayor	PhD	2014	Ionospheric Faraday rotation	important
	Kati Sendlinger	PhD	2016	Galaxy spectra at low ν	crucial
	Stefan Blex	PhD	2017	Edge-on galaxies with LOFAR	crucial
MPIfR Bonn	Andreas Horneffer	Postdoc	2016	Spiral galaxies at low ν	crucial
	Björn Adebahr	Postdoc	2016	M81/M82 at low ν	crucial
	Jana Köhler	PhD	2014	Galactic emission at low ν	crucial
Bonn Univ.	Henrik Junklewitz	Postdoc	2017	Information theory	important
ASTRON	Charlotte Sobey	Postdoc	2017	Pulsars	crucial
ASTRON / Groningen Univ.	Sarrvesh Seethapuram Sridhar	PhD	2017	M101 at low ν	crucial
Krakow Univ.	Robert Drzazga	PhD	2014	M81/M82 at low ν	useful
	Wojciech Jurusik	PhD	2014	Galaxy spectra at low ν	crucial
	Blazej Nikiel-Wroczynski	PhD	2014	Compact galaxy groups	crucial
Leiden Univ.	Marco Iacobelli	PhD	2014	Fan region at low ν	crucial
	Carl Shneider	PhD	2014	Turbulent ISM	useful
Nijmegen Univ.	David Jones	Postdoc	2015	Milky Way, IC342	important
	Cameron Van Eck	PhD	2017	Milky Way, IC342	crucial
Southampton Univ.	Volker Heesen	Postdoc	2015	IC10 at low ν	important
	David Mulcahy	Postdoc	2017	M51, NGC628, NGC891	crucial
	Alex Clarke	PhD	2017	Clusters and superclusters	important

Mostly funded by DFG

Total: 13 students + 7 postdocs

LOFAR data are crucial for 8 students + 4 postdocs

MKSP: progress

- Superb HBA images of extended synchrotron emission
  (see next talk by David Mulcahy)
- Extremely low upper limit for integrated diffuse polarised emission from M51: **<0.01%** (HBA, David Mulcahy)
- Low-frequency HBA spectra of galaxies
  (see talk by Blazej Nikiel-Wroczynski at MSSS workshop)
- Extended polarised emission from the Milky Way foreground in Fan region and the fields around M51 and A2255 (HBA)
- Polarised signals and high-precision RMs from 35+4 pulsars (HBA+LBA)

RMs of pulsars

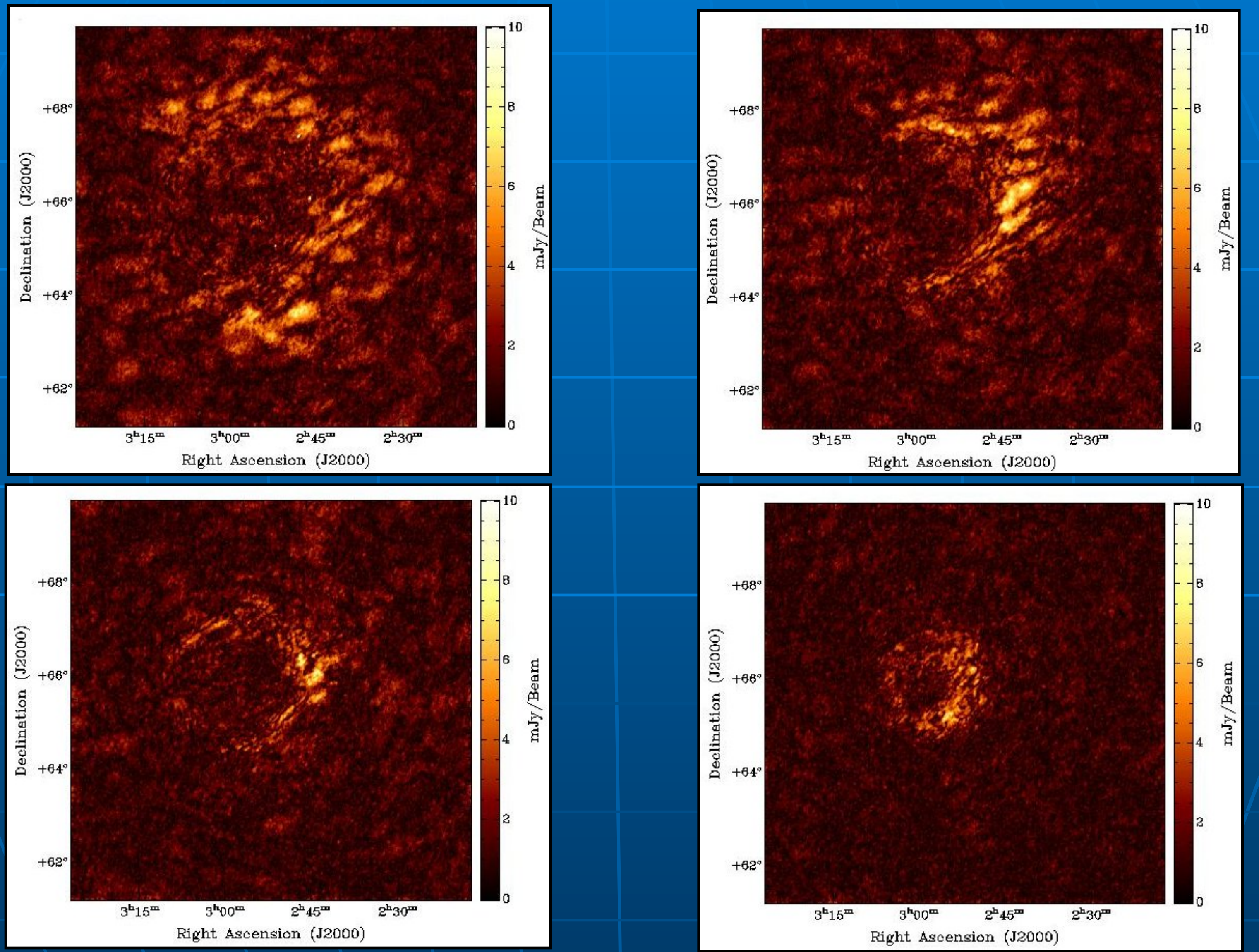
(C. Sobey & A. Noutsos)

PSR	RM (rad m^{-2})	DM (pc cm^{-3})	$B_{\parallel}$ (μG)
B0834+06	25.26 ± 0.05	12.889 ± 0.006	1.960 ± 0.004
B1642-03	16.04 ± 0.18	35.727 ± 0.003	4.49 ± 0.05
B1919+21	-16.92 ± 0.07	12.455 ± 0.006	-1.358 ± 0.006
B2217+47	-35.60 ± 0.11	43.519 ± 0.012	-0.818 ± 0.003

- $B_{\parallel} \sim$ **RM / DM** (if fluctuations in B and n_e are uncorrelated)
- Excellent precision of magnetic field strength measurements
- More precise than measurement of the local ISM field by Voyager 1: 5.62 ± 0.01 μG (Burlaga et al. 2013)

Polarization from the FAN region of the Milky Way

LOFAR HBA 120-180 MHz, Faraday depths φ=-1 … -5 rad/m^2



Iacobelli et al. 2013

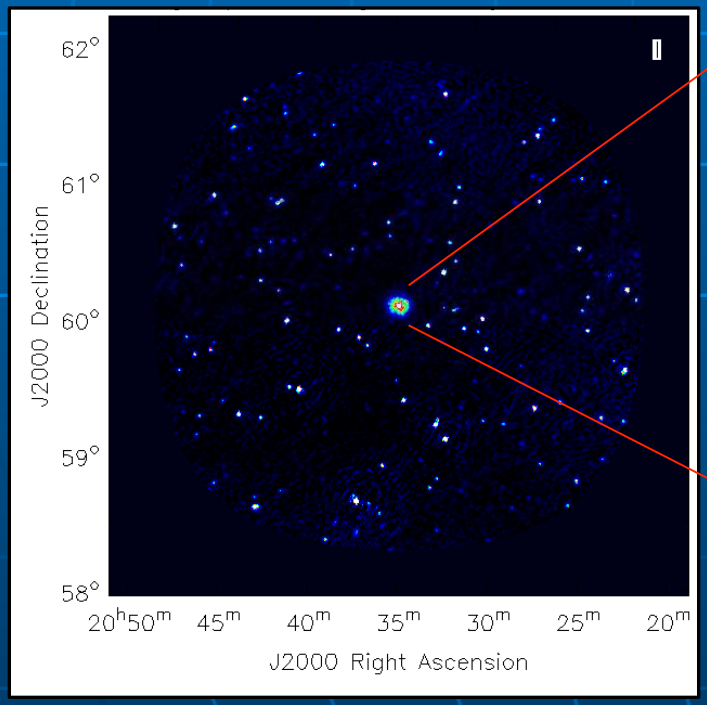
NGC6946 LOFAR HBA

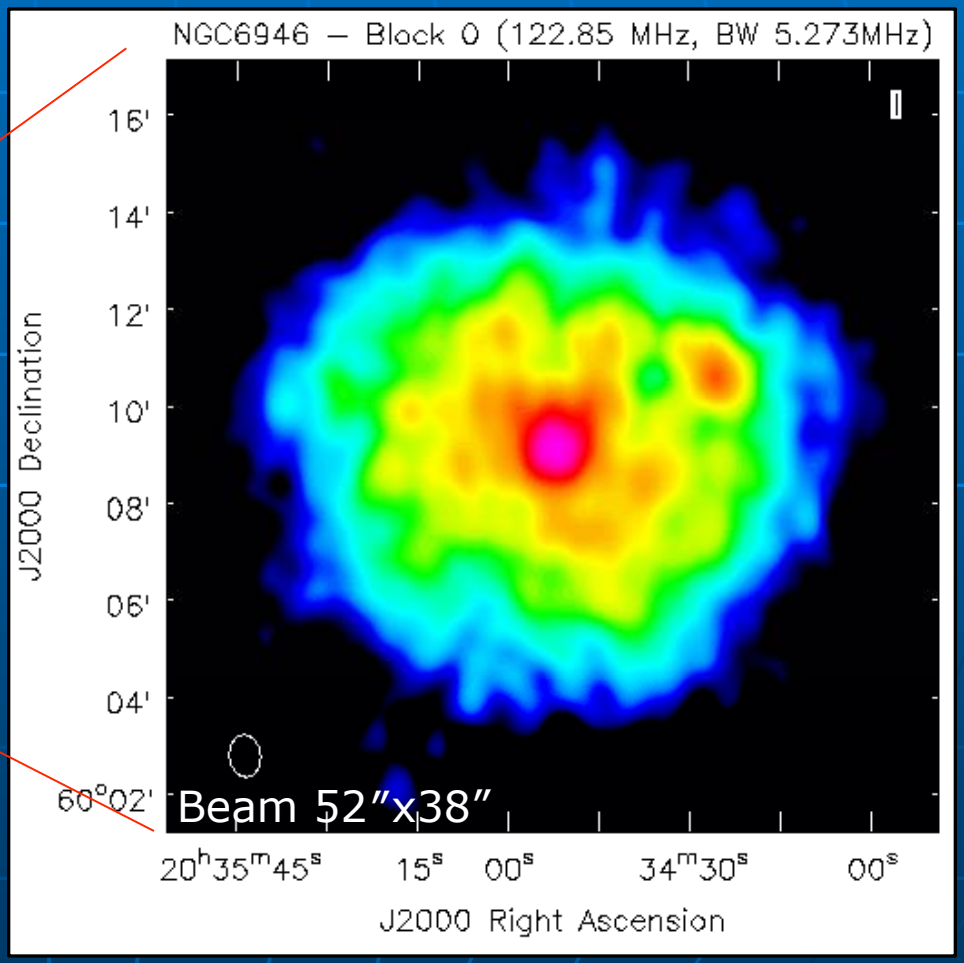
LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

W. Jurusik et al.

Preliminary results
from SB000 – SB026

Full field of view

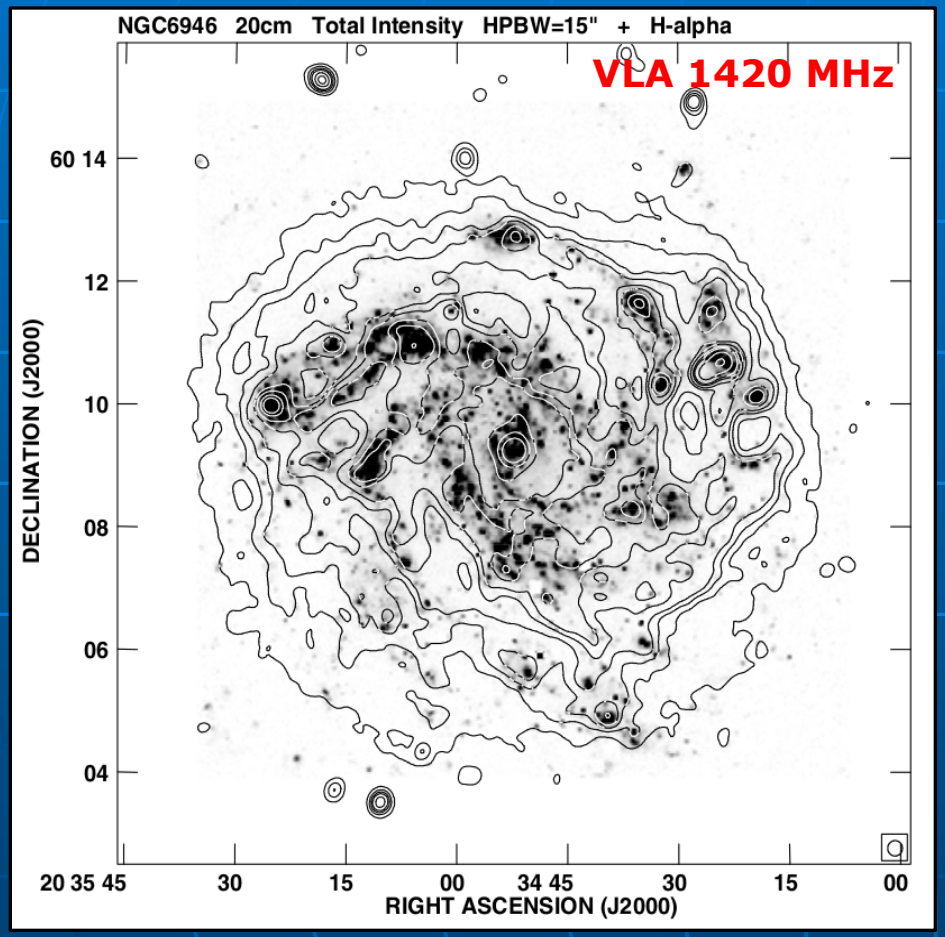




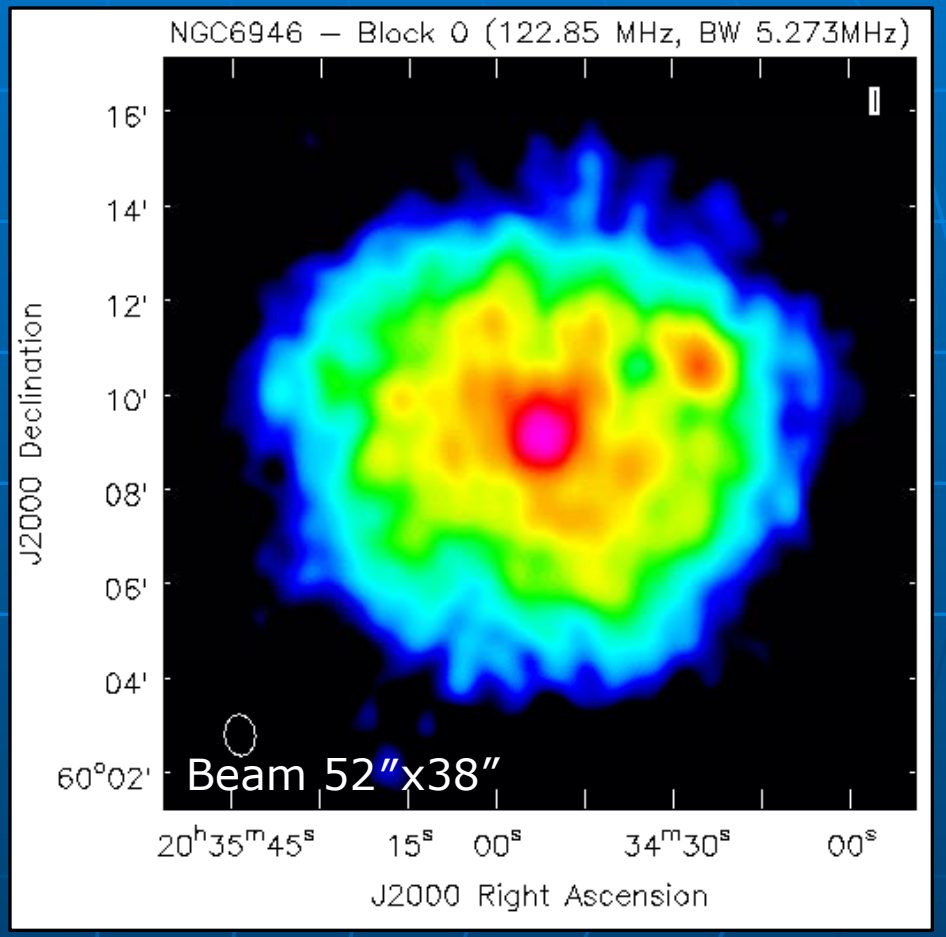
NGC6946 LOFAR HBA

LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

W. Jurusik et al.



R.Beck, A&A 470, 539 (2007)



LOFAR HBA: Radio envelope is more extended than in the VLA image

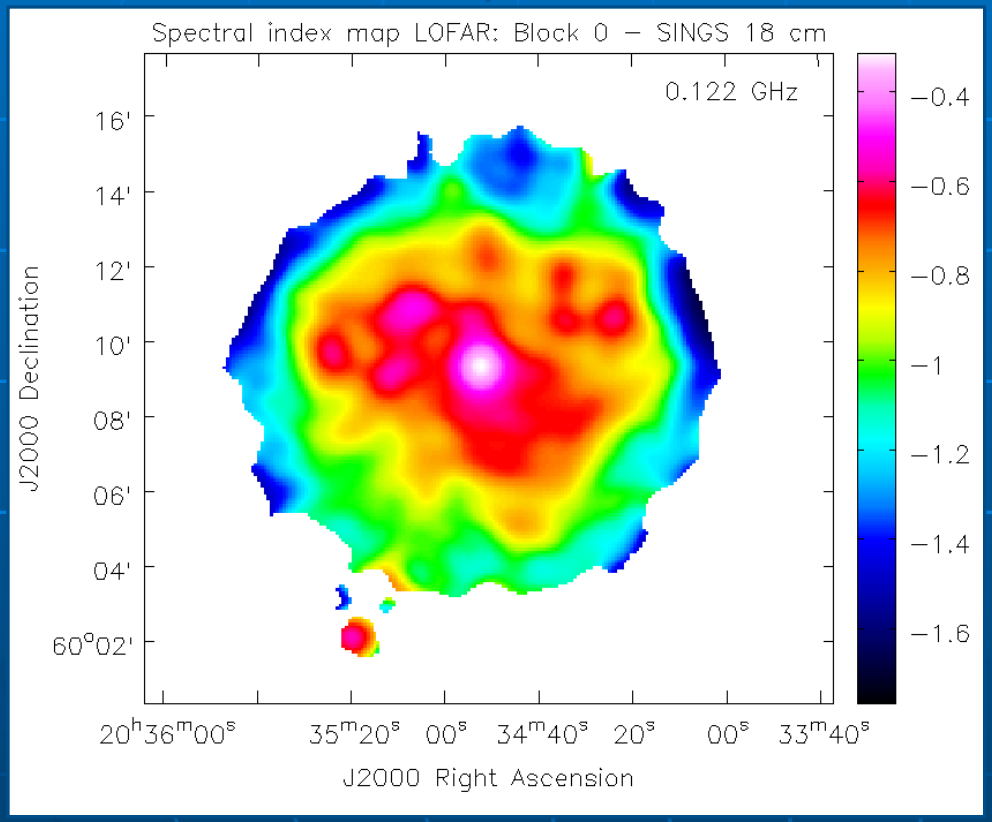
NGC6946 LOFAR HBA

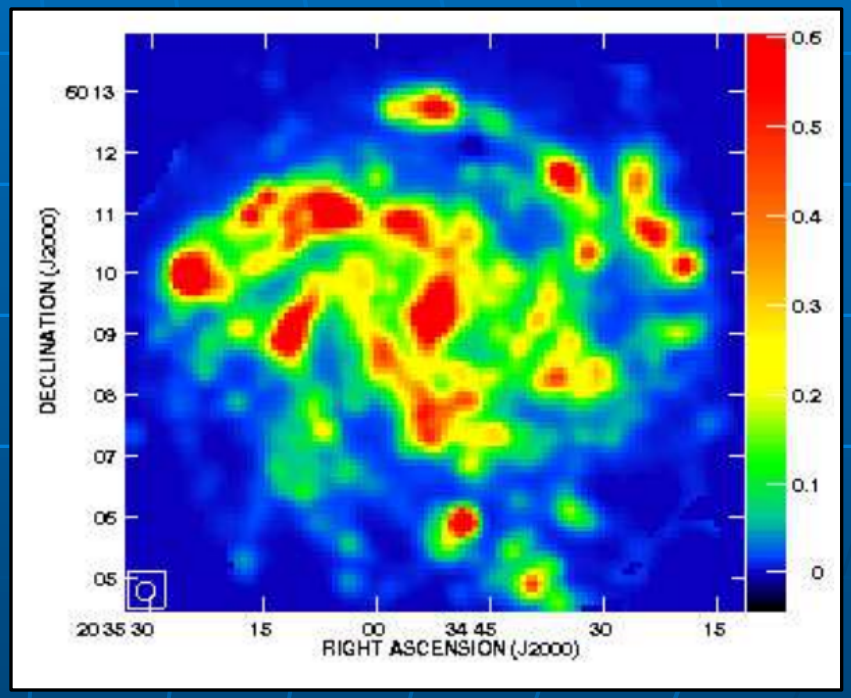
LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

W. Jurusik et al.

Spectral index map

WSRT 1366 MHz / LOFAR 123 MHz





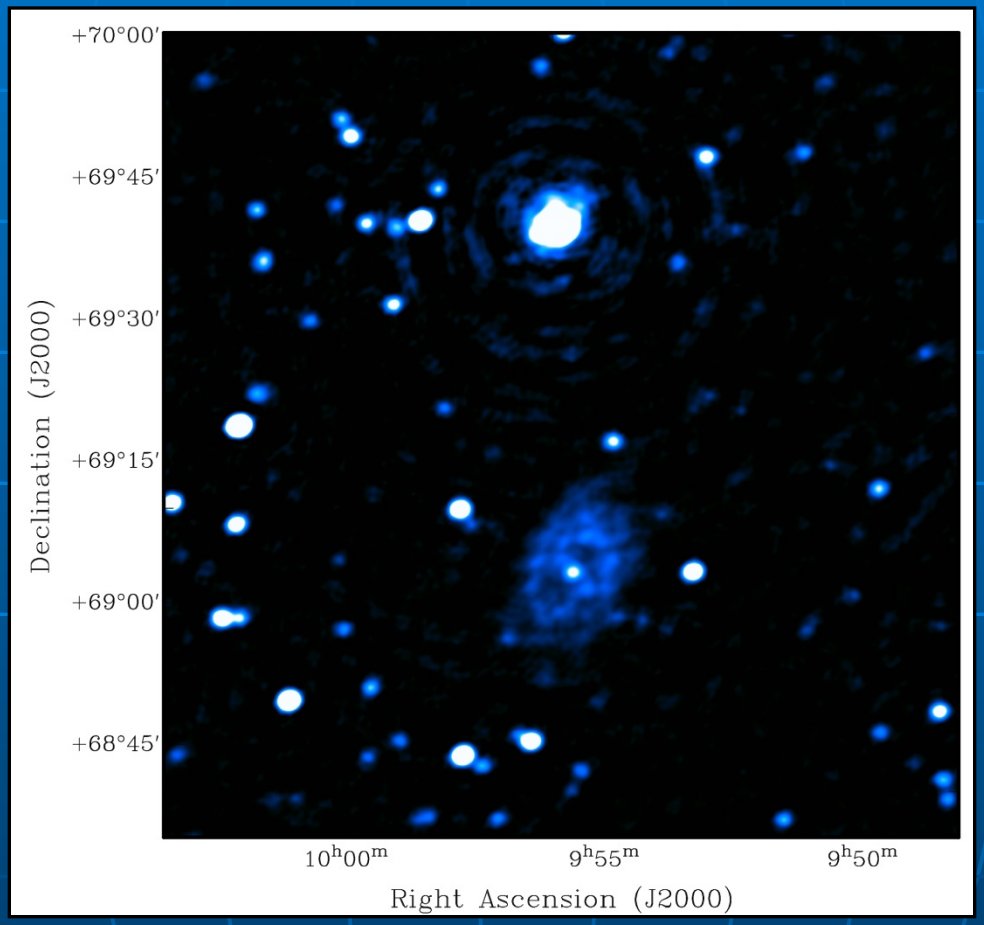
Spectral index is flat at locations of giant HII regions:
Thermal absorption ?

Free-free emission at 3.5 cm (Tabatabaei et al. 2013)

M82/M81 LOFAR HBA

LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

B. Adebahr et al.

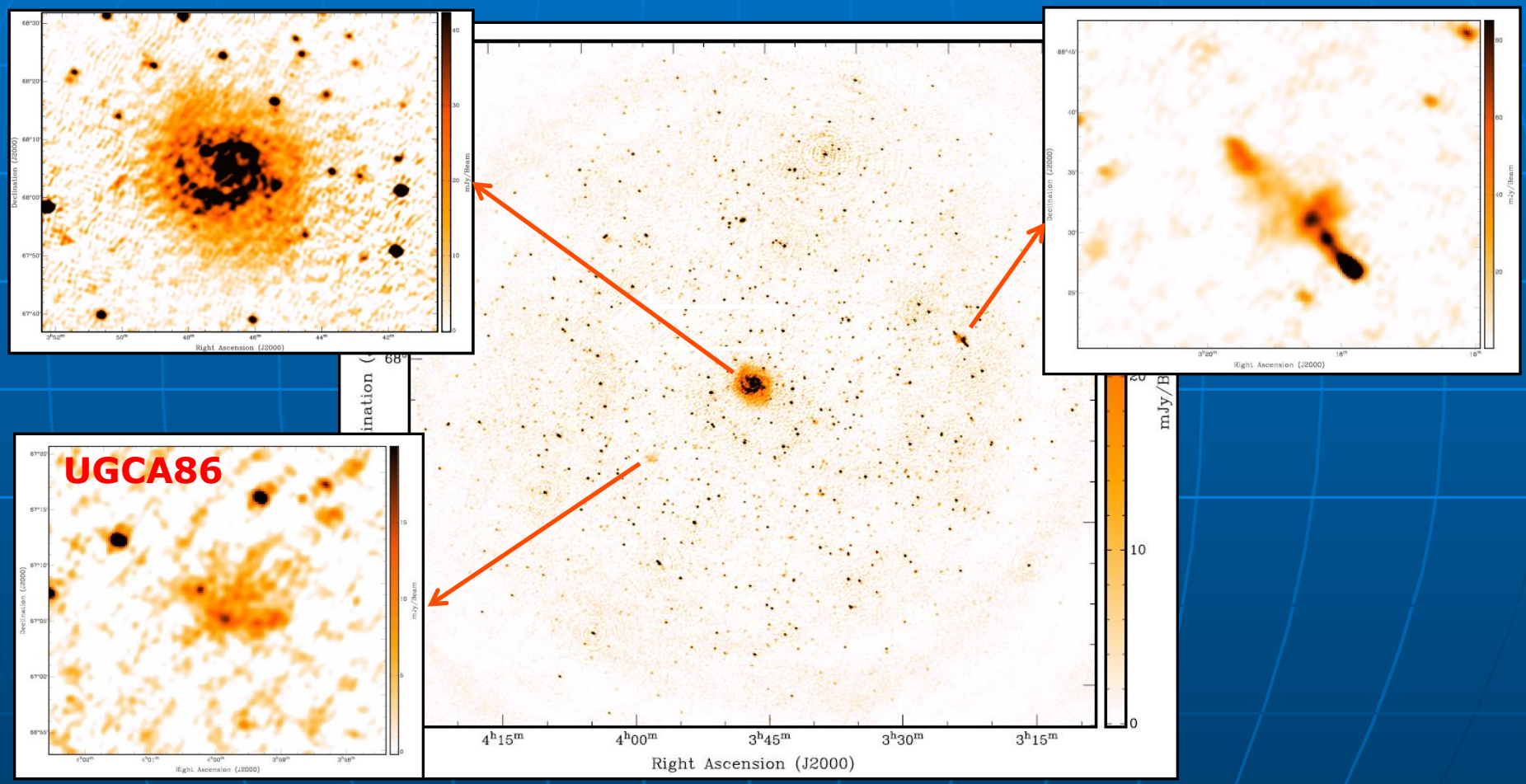


150 MHz, ≈2 MHz bandwidth (9 subbands), 1’ resolution, ≈3 mJy/b noise, 10h of data, processed on JUROPA cluster at FZ Jülich

IC342 LOFAR HBA

LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

C. Van Eck et al.

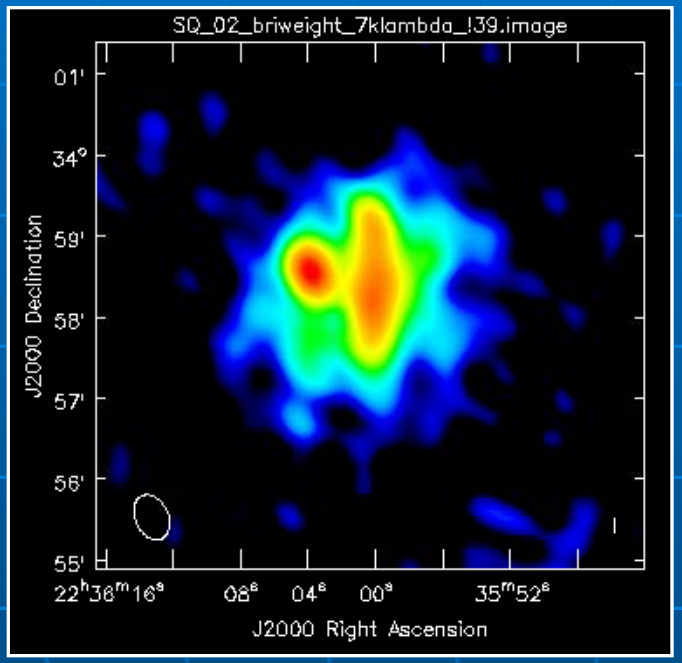


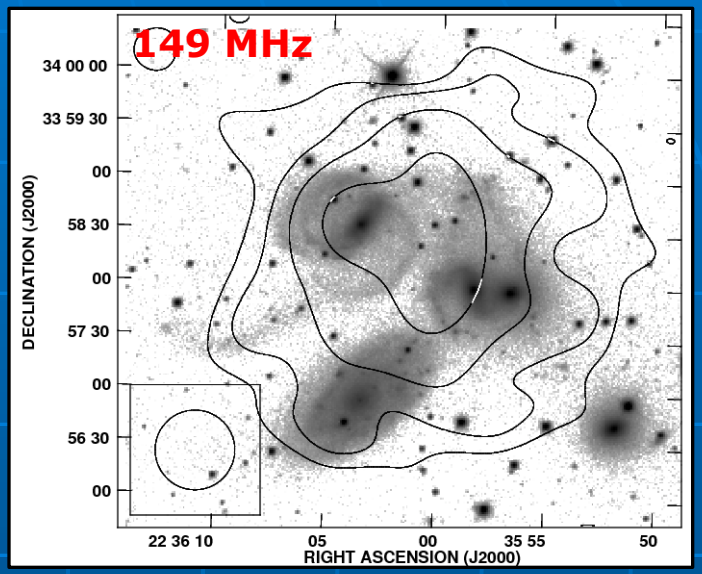
139 MHz, 5 MHz bandwidth (27 subbands), 1’ resolution,
≈2.5 mJy/b noise, 3.8h of data

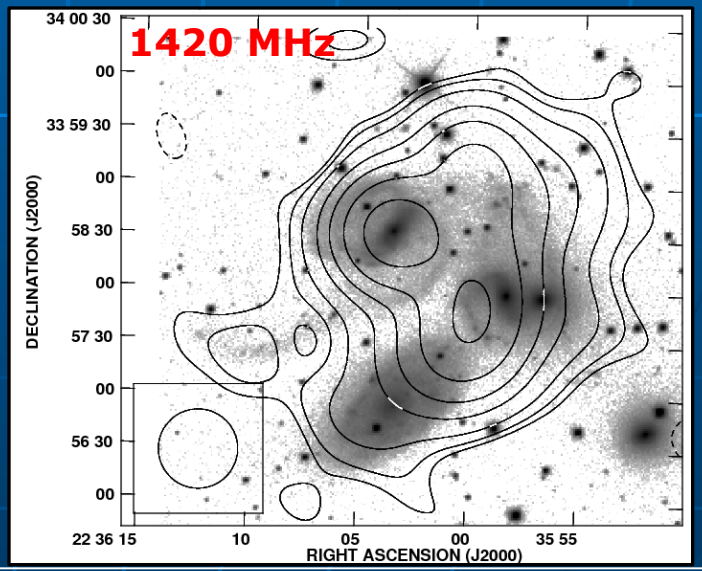
Stephan´s Quintet LOFAR HBA

LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

B. Nikiel-Wroczynski et al.







Preliminary result:

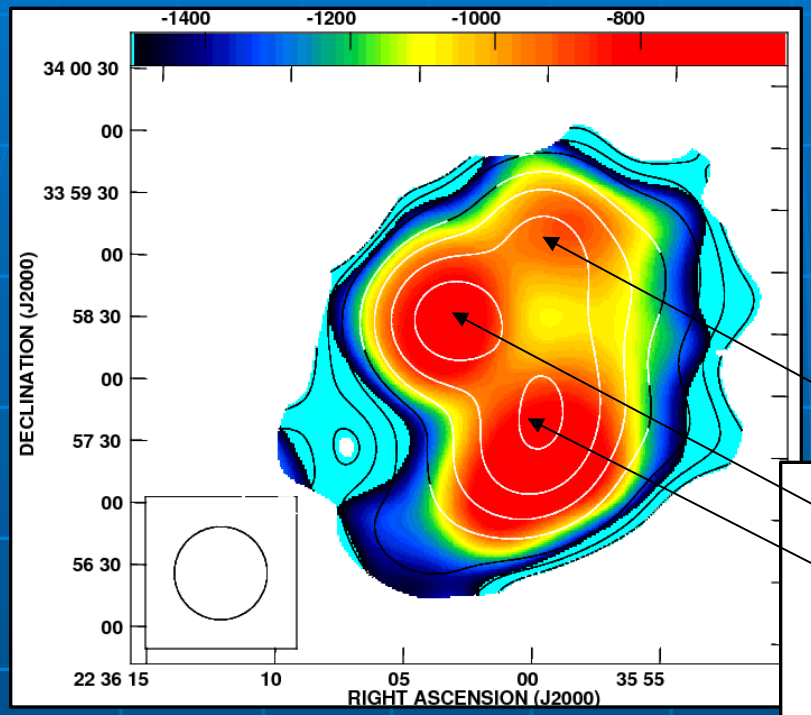
LOFAR map at 170 MHz, convolved to a common beam of 45” (to be compared with the VLA 1420 MHz data)

B. Nikiel-Wroczynski et al., MNRAS 435, 149 (2013)

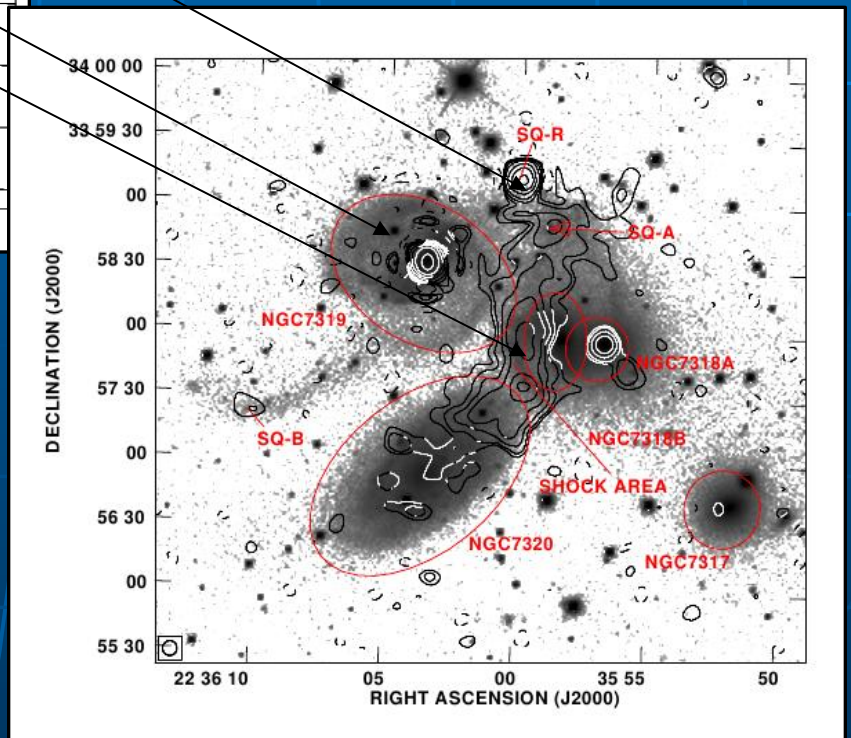
Stephan´s Quintet LOFAR HBA

LOFAR Survey of Nearby Galaxies – LOFAR Cycle 0

B. Nikiel-Wroczynski et al.



Spectral index map is limited by the size of the radio envelope in the VLA image at 1420 MHz



- Preliminary estimate for the magnetic field in the shock area (near the emission maximum):

  $10.0 \pm 1.5\ \mu G$

- MF+CR energy density:

  $\approx 10^{-11}$ erg cm^{-3}

No polarised diffuse emission from nearby galaxies detected so far – why ?

Missing short spacings in λ^2 space

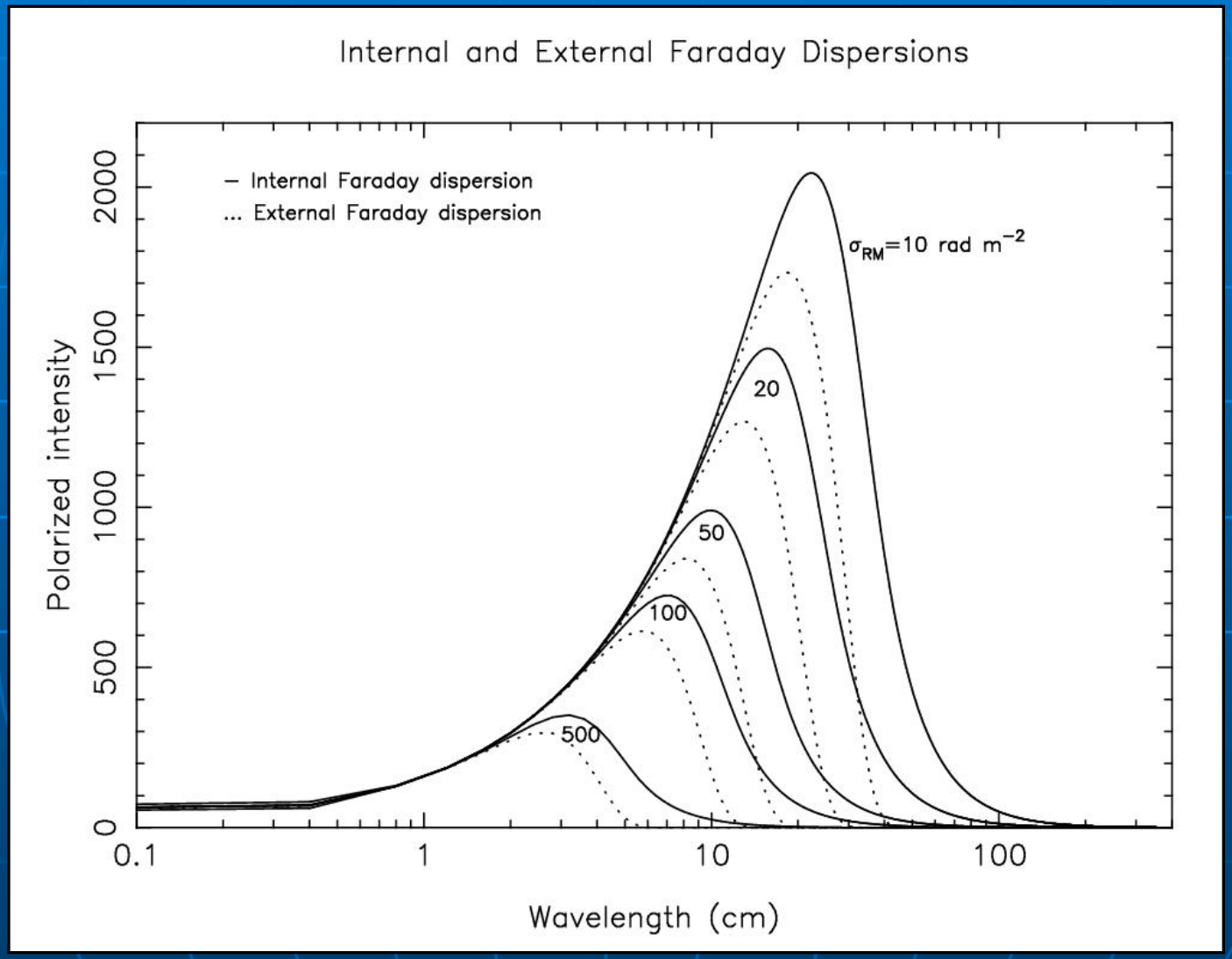
in LOFAR observations:

We cannot detect polarised emission

that is extended in Faraday space

(e.g. from galaxy disks)

Spectrum of polarised intensity



Arshakian & Beck 2011

Faraday depolarisation

- Internal Faraday dispersion (Burn 1966):

  $$p = p_o \, (1 - \exp(-S)) / S$$

- External Faraday dispersion (Burn 1966):

  $$p = p_o \exp(-S)$$

- Short wavelengths (Burn 1966):

  $$S = 2 \, \sigma_{RM}^2 \, \lambda^4$$

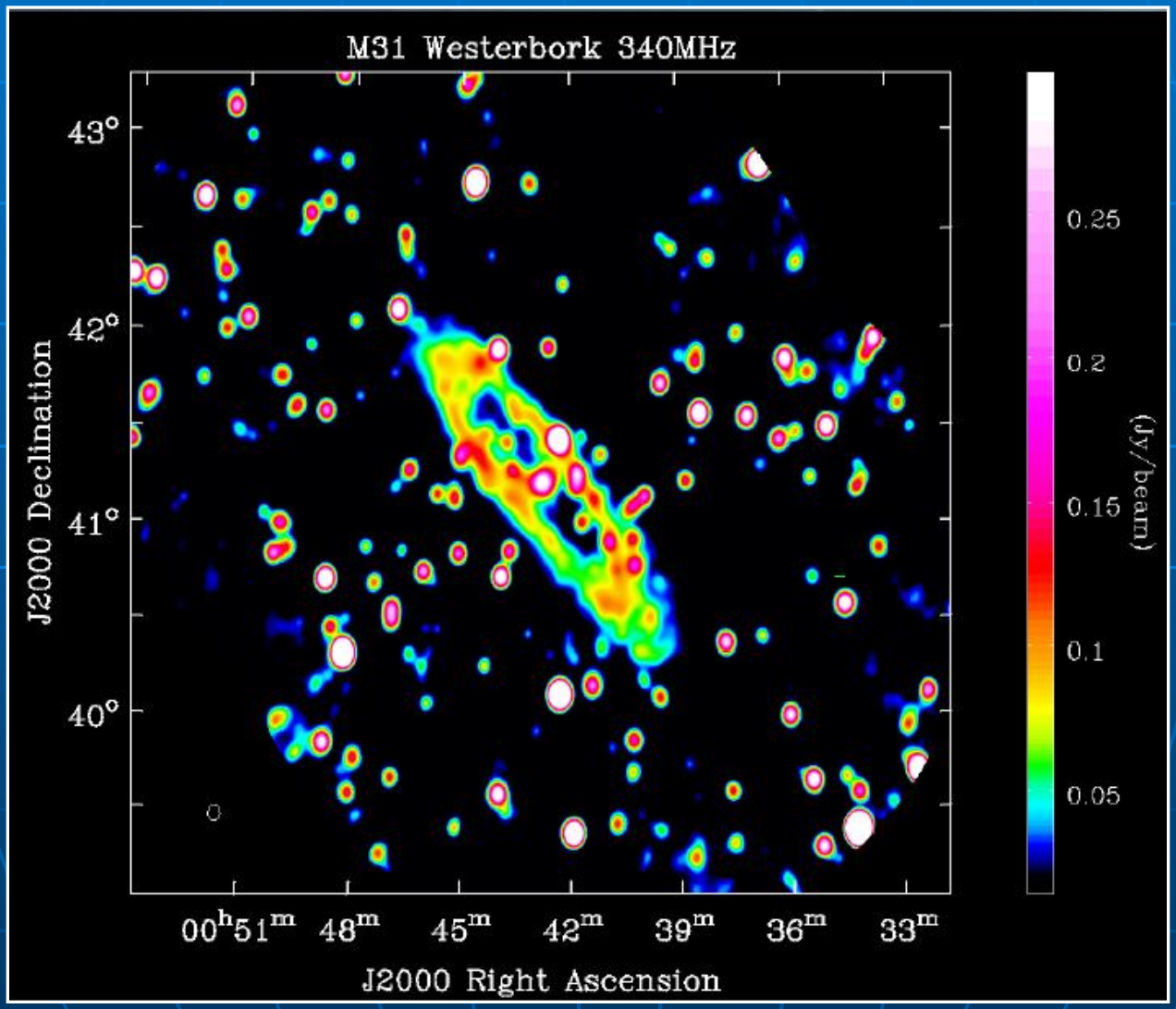
- Long wavelengths (Tribble 1991):

  $$S = 2 \, \sigma_{RM} \, \lambda^2$$

  σ_{RM}: RM dispersion

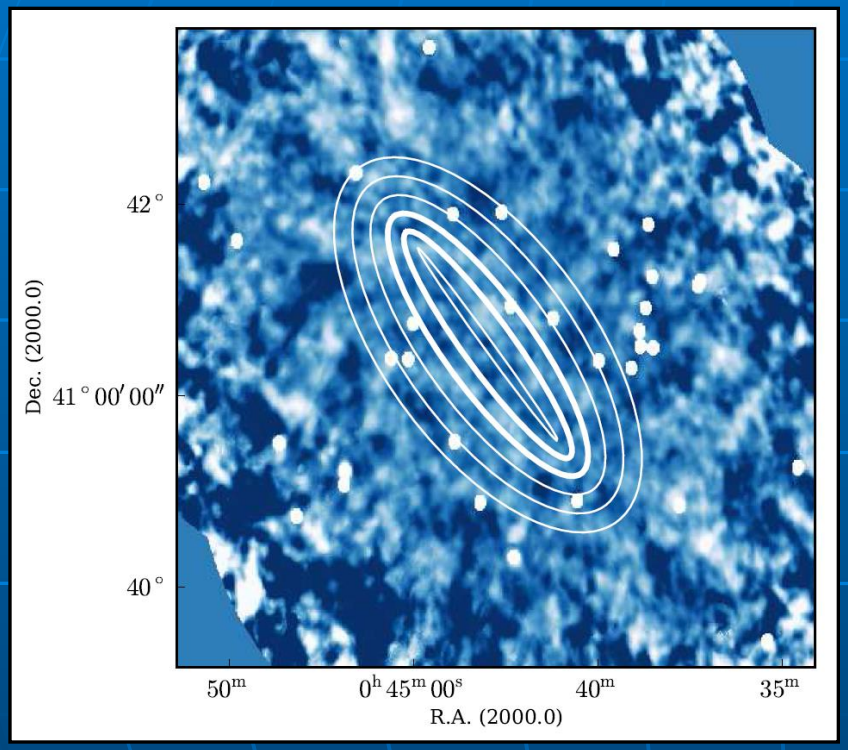
M31 WSRT 310-376 MHz

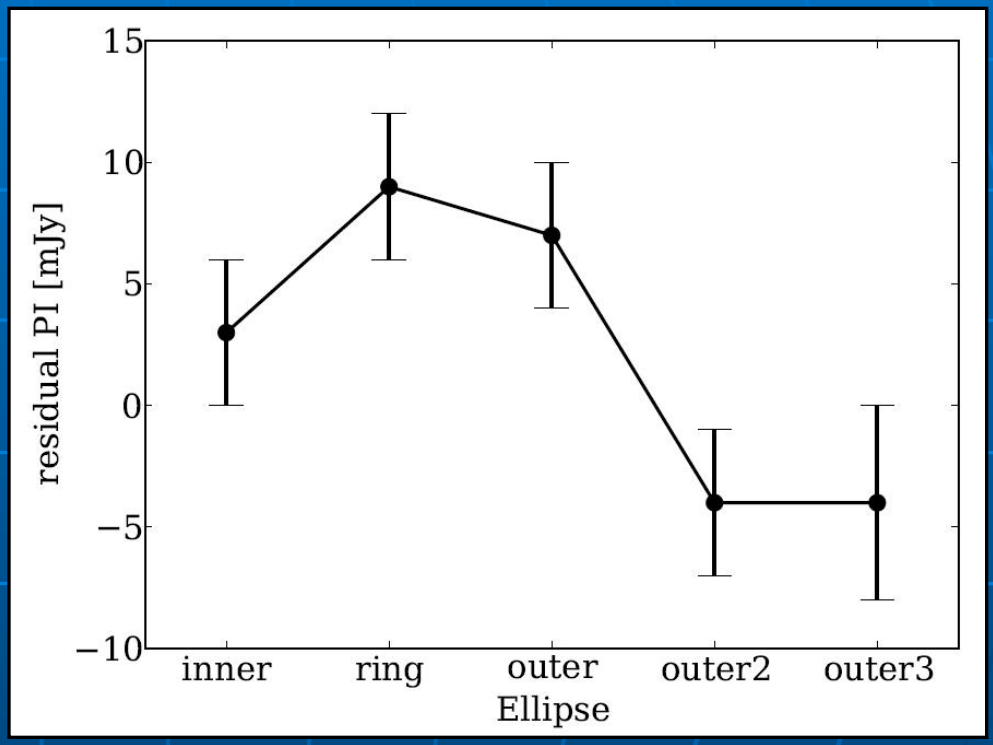
Gießübel et al. 2013



M 31 WSRT 310-376 MHz Polarised intensity

Gießübel et al. 2013





- Detection of very low polarisation (**0.21 ± 0.05%**) by integration of Faraday spectra
- DP (90cm/6cm) = **0.005 ± 0.002**
- Predicted: Burn: DP = 0.0004; Tribble: DP = 0.015

Theoretical LOFAR HBA rms noise

HBA band 120-180 MHz, ≈300 subbands,
effective BW 60 MHz, 38 Dutch stations

- 1h integration: thermal noise ≈ 0.06 mJy
- 10h integration: thermal noise ≈ 0.02 mJy

- Best values so far:
  0.2-0.3 mJy (I), **0.13** mJy (Q,U) in 8h
  (M51: David Mulcahy)

- Detection of diffuse polarisation needs deeper images

Magnetism Science Working Group Membership

Did you know?

Increasing a telescope's collecting area increases its sensitivity. This means that weaker signals can be detected.

Name	Institution
Melanie Johnston-Hollitt – Co-Chair	Victoria Univ Wellington
Federica Govoni – Co-Chair	INAF-OA Cagliari
Tobia Carrozzi	
Lisa Harvey-Smith	CASS
Bryan Gaensler	Univ Sydney
George Heald	ASTRON
M. Haverkorn	ASTRON
Anna Scaife	Univ Southampton
Rainer Beck	MPIfR
Larry Rudnick	U. Minnesota
J. Stil	U. Calgary
K. Takahashi	
Takuya Akahori	Univ Sydney
Russ Taylor	U. Calgary
Dominic Schnitzeler	MPIfR
Luigina Feretti	INAF-IRA
Katia Ferrière	Observatoire Midi-Pyrenées
Annalisa Bonafede	Hamburg
Ann Mao	Madison-Wisconsin/MPIfR
Ivan Agudo	JIVE
Sergio Colafrancesco	Wits University
James Green	SKA Organisation
Tyler Bourke	SKA Organisation

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