Magnetic Visions

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Magnetism
is one of the
fundamental forces
in nature,
but its role and origin
is largely unknown

- Most (visible) cosmic objects are ionized:
  Magnetic fields are easy to generate

- No magnetic monopoles:
  Magnetic fields are hard to destroy

… but they are difficult to observe

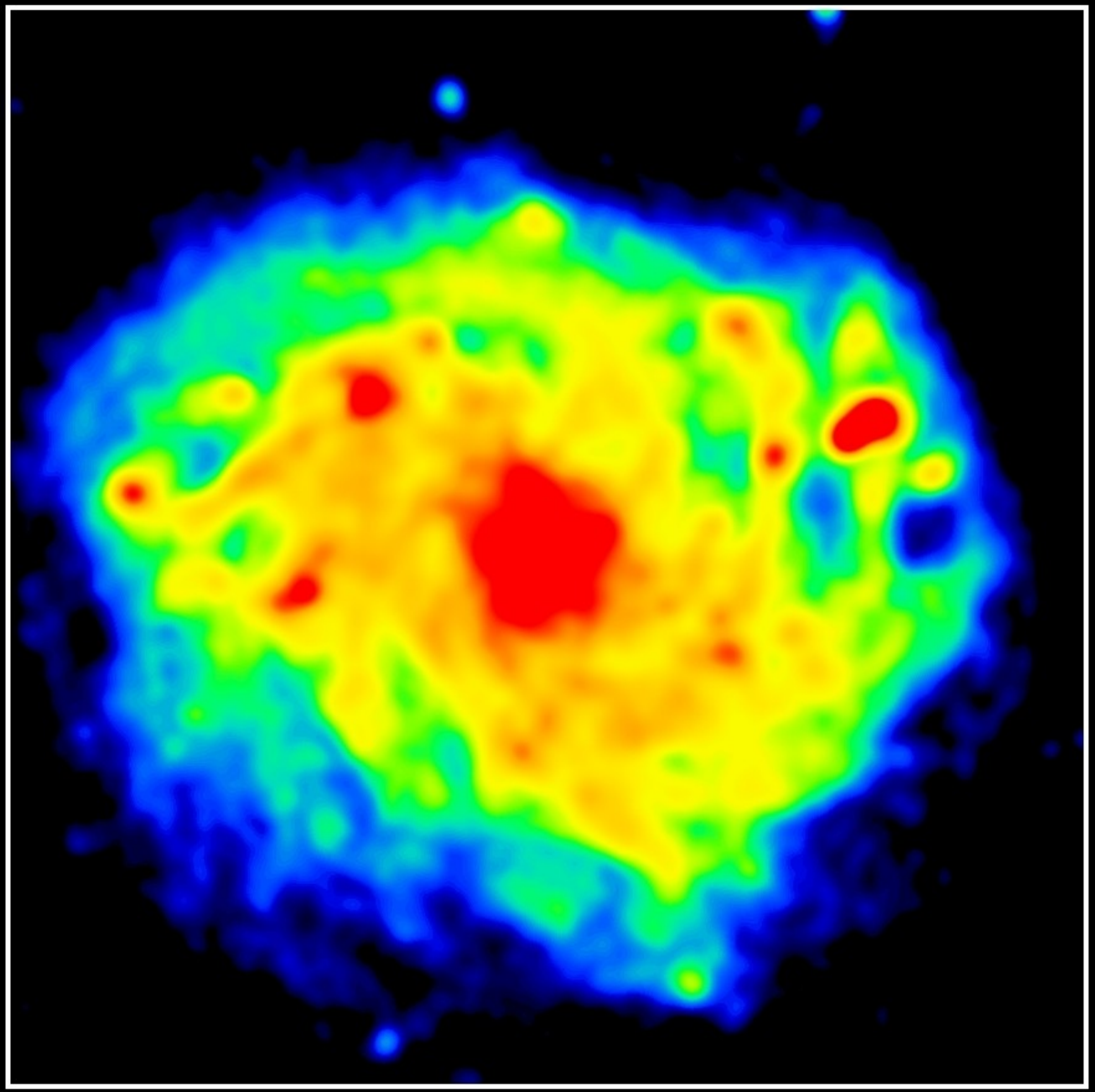
Galactic magnetic fields

- Galactic magnetic fields are possibly more important than believed today
- Surprises and discoveries can be expected
- Observational methods:
  Polarized radio synchrotron, Faraday rotation, Zeeman splitting

Are galactic magnetic fields dynamically important ?

NGC6946

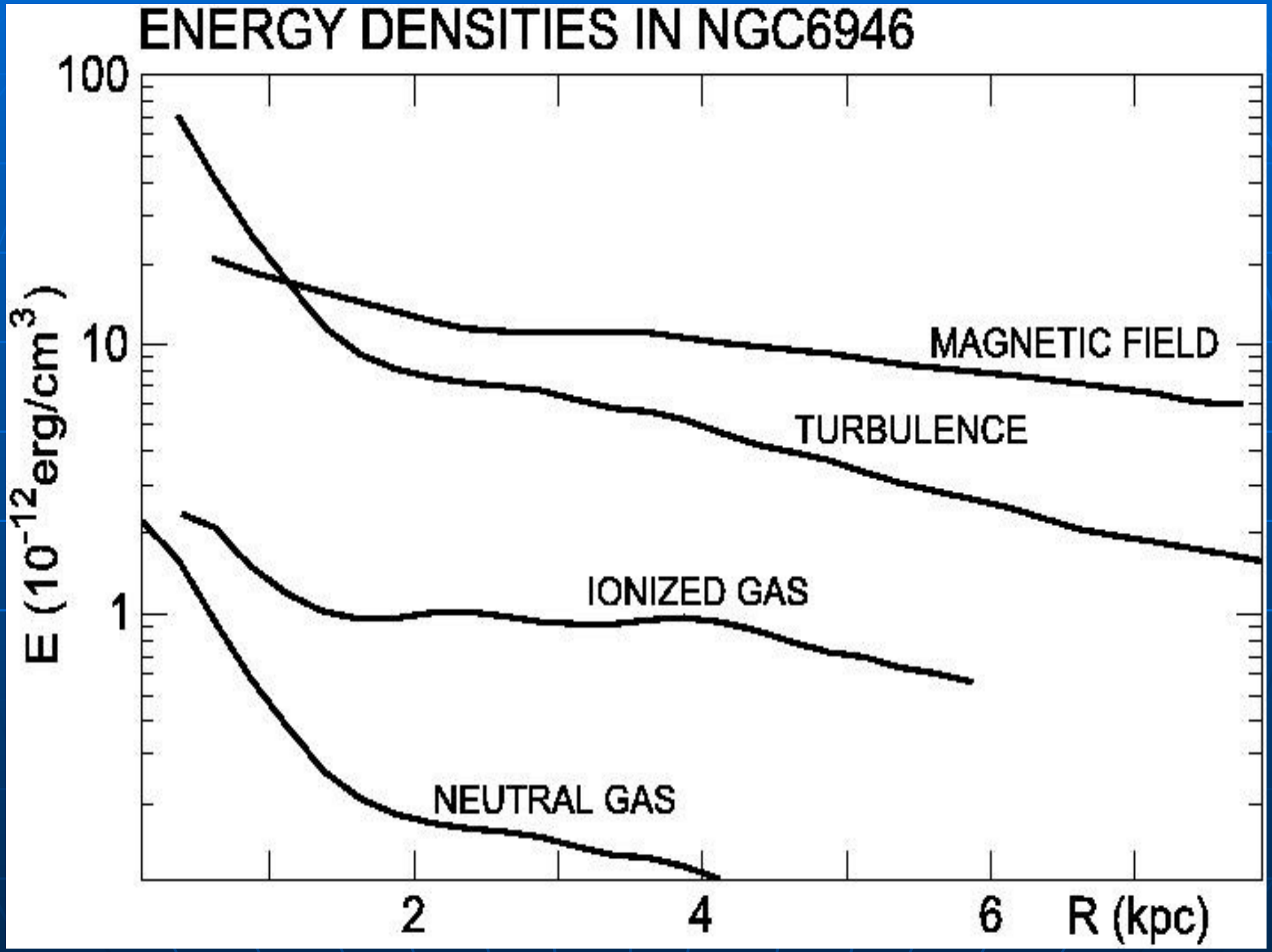
VLA 20cm
Total
synchrotron
(Beck 2007)



Magnetic field strengths in spiral galaxies

(assuming equipartition with cosmic rays)

Average total magnetic field:	5 – 15 G
Total field in spiral arms:	20 - 30 μG
Total field in circum-nuclear rings:	40 – 100 G
Total field in Galactic Centre filaments:	• 1 mG


ENERGY DENSITIES IN NGC6946
100
10
1
E (10^-12 erg/cm^3)
MAGNETIC FIELD
TURBULENCE
IONIZED GAS
NEUTRAL GAS
2
4
6
R (kpc)

- ***Radio polarization*** traces regular magnetic fields in the sky plane

- Regular magnetic fields are generated by compressing, shearing or helical gas flows (dynamo)

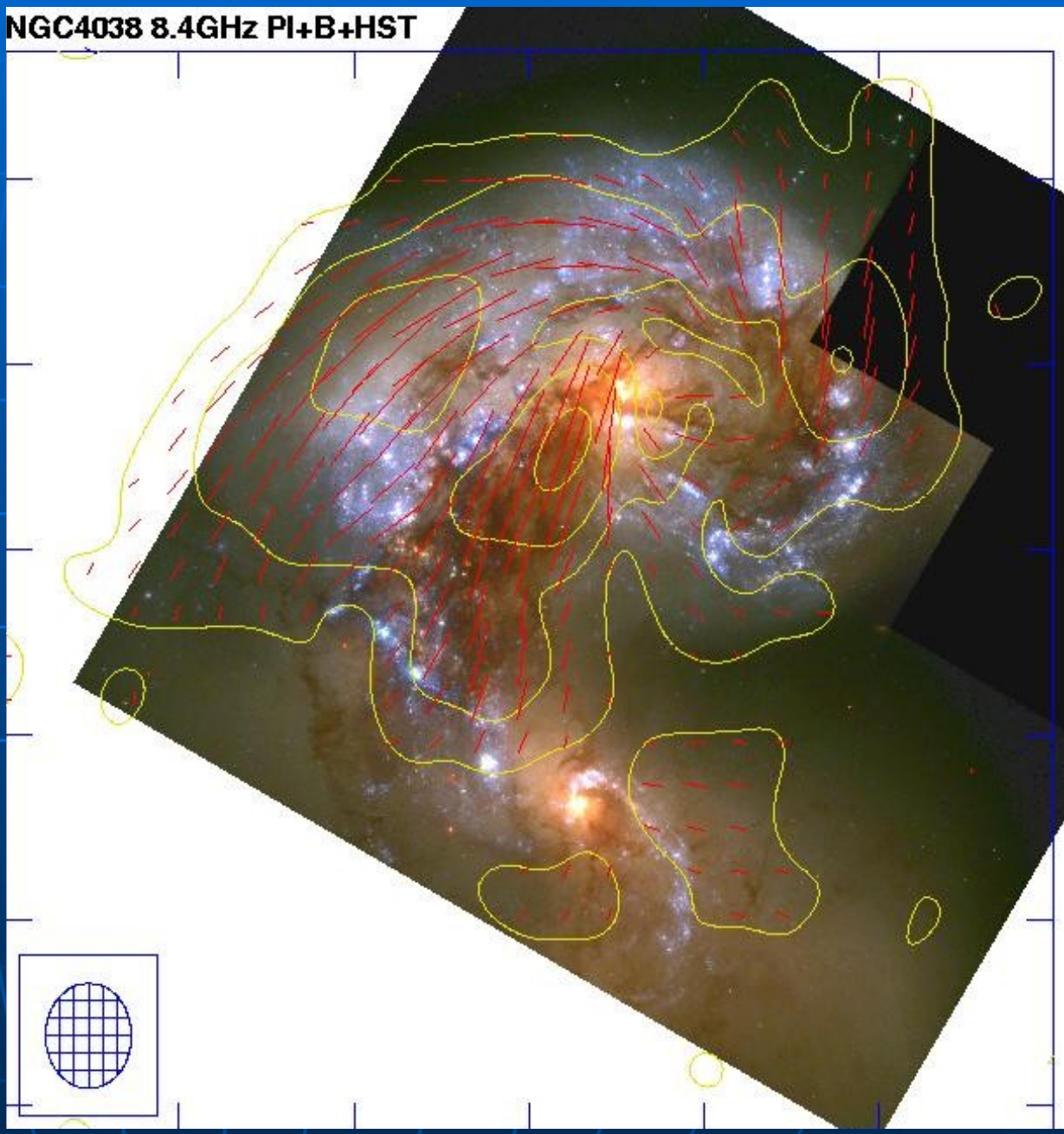
- ⟶ *Polarization traces gas flows*

The Antennae

VLA Polarized Intensity + B

(Chyzy & Beck 2004)

Field amplified by compression

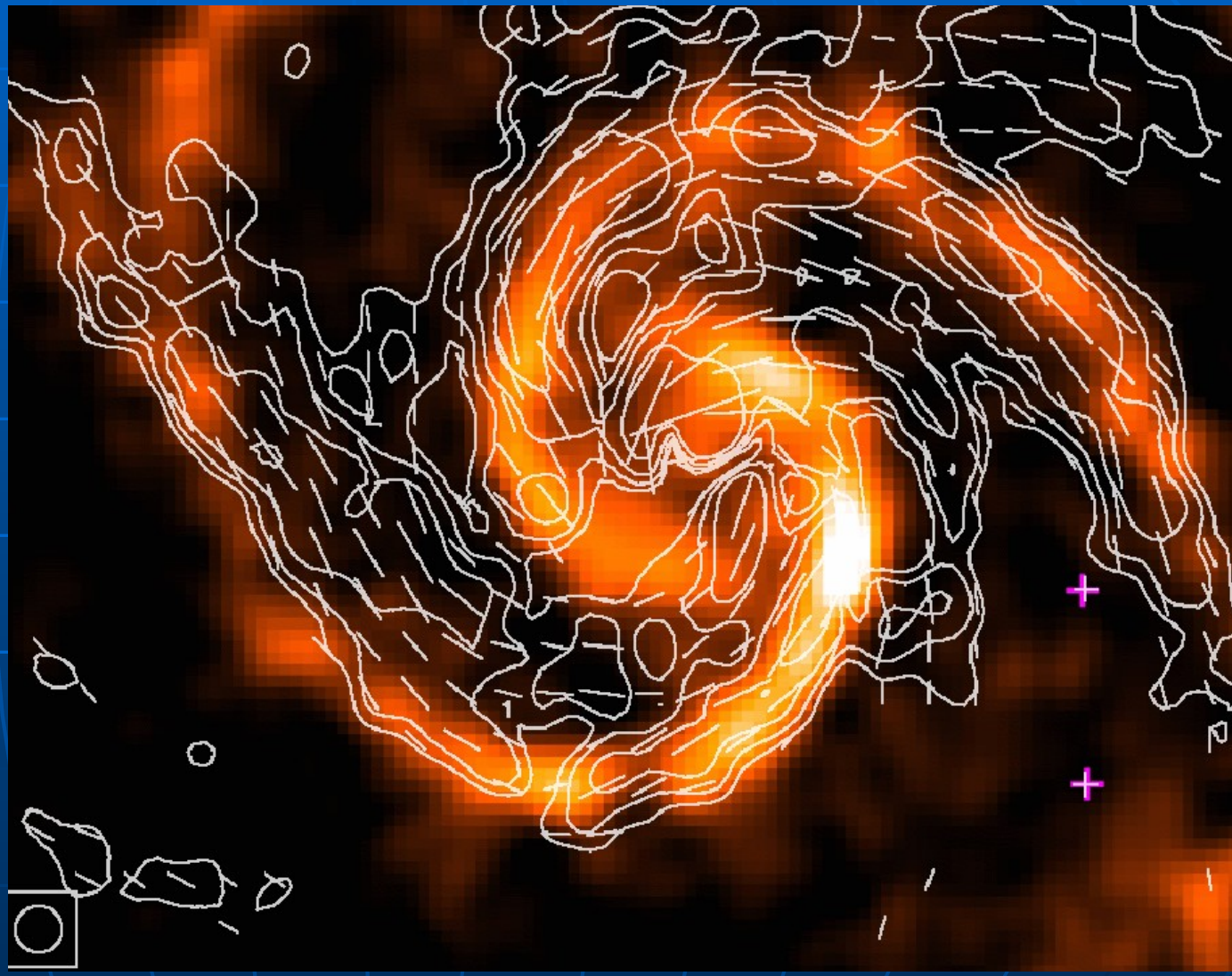


Can magnetic fields affect gas flows ?

M51

Polarized intensity
+ B
(Fletcher et al. 2007)

No shock:
The regular field affects the flow of the warm gas

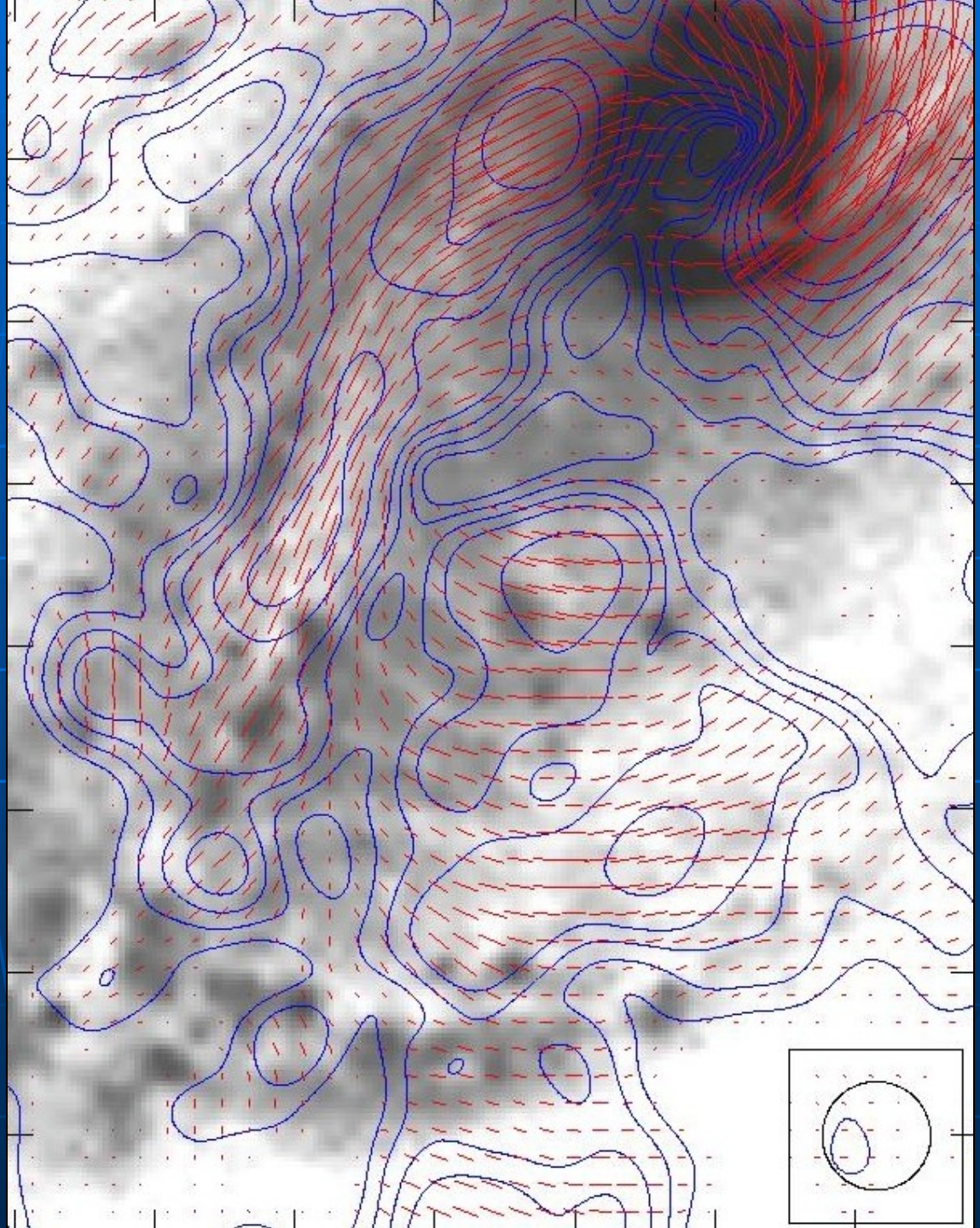


Polarized intensity (Effelsberg+VLA) and BIMA CO data (Regan et al. 2001)

NGC1097

VLA Polarized Intensity + B (Beck et al. 2005)

No shock: The regular field affects the flow of the warm gas

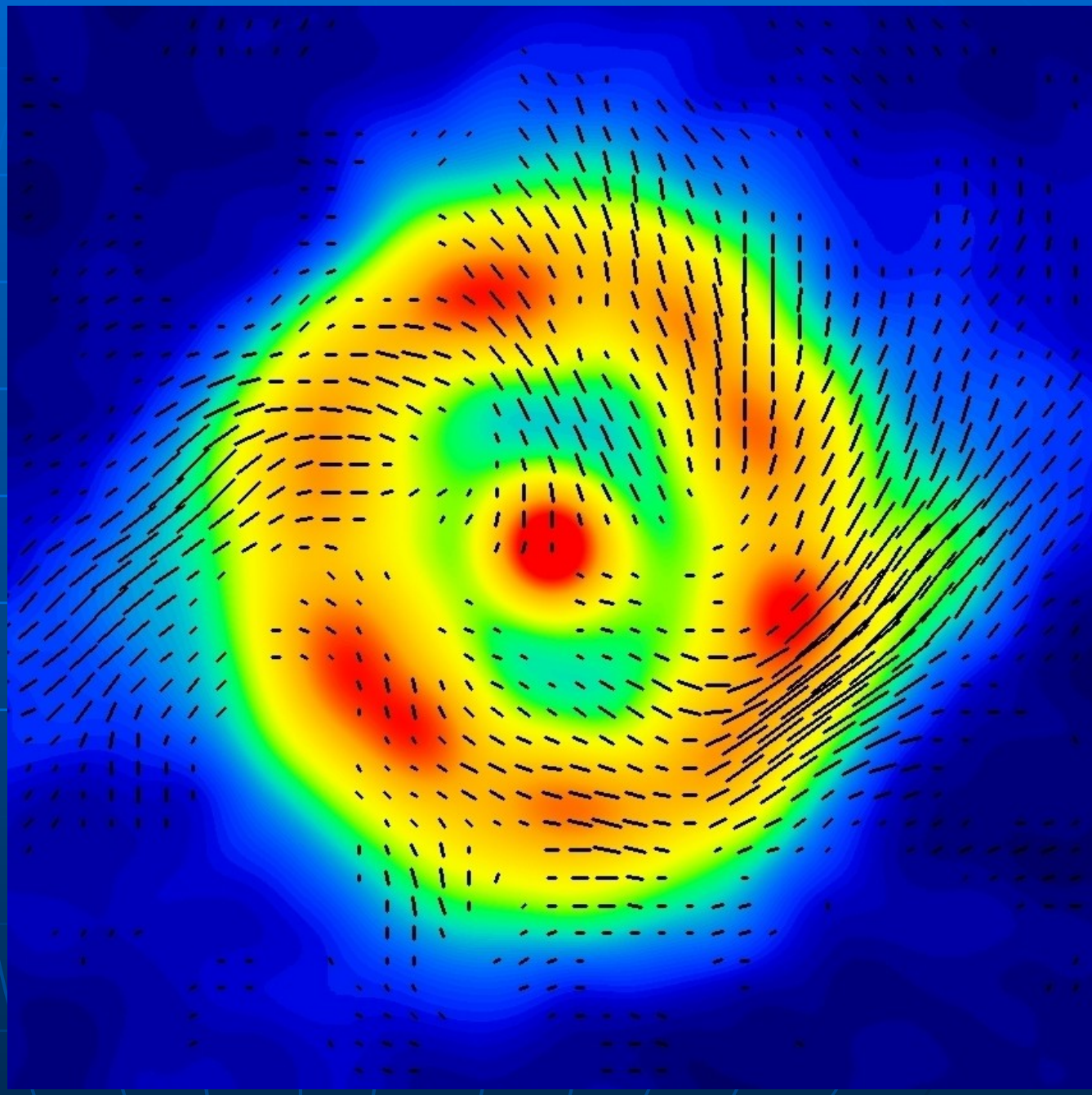


NGC1097

Circumnuclear ring

VLA Total intensity
+ B
(Beck et al. 2005)

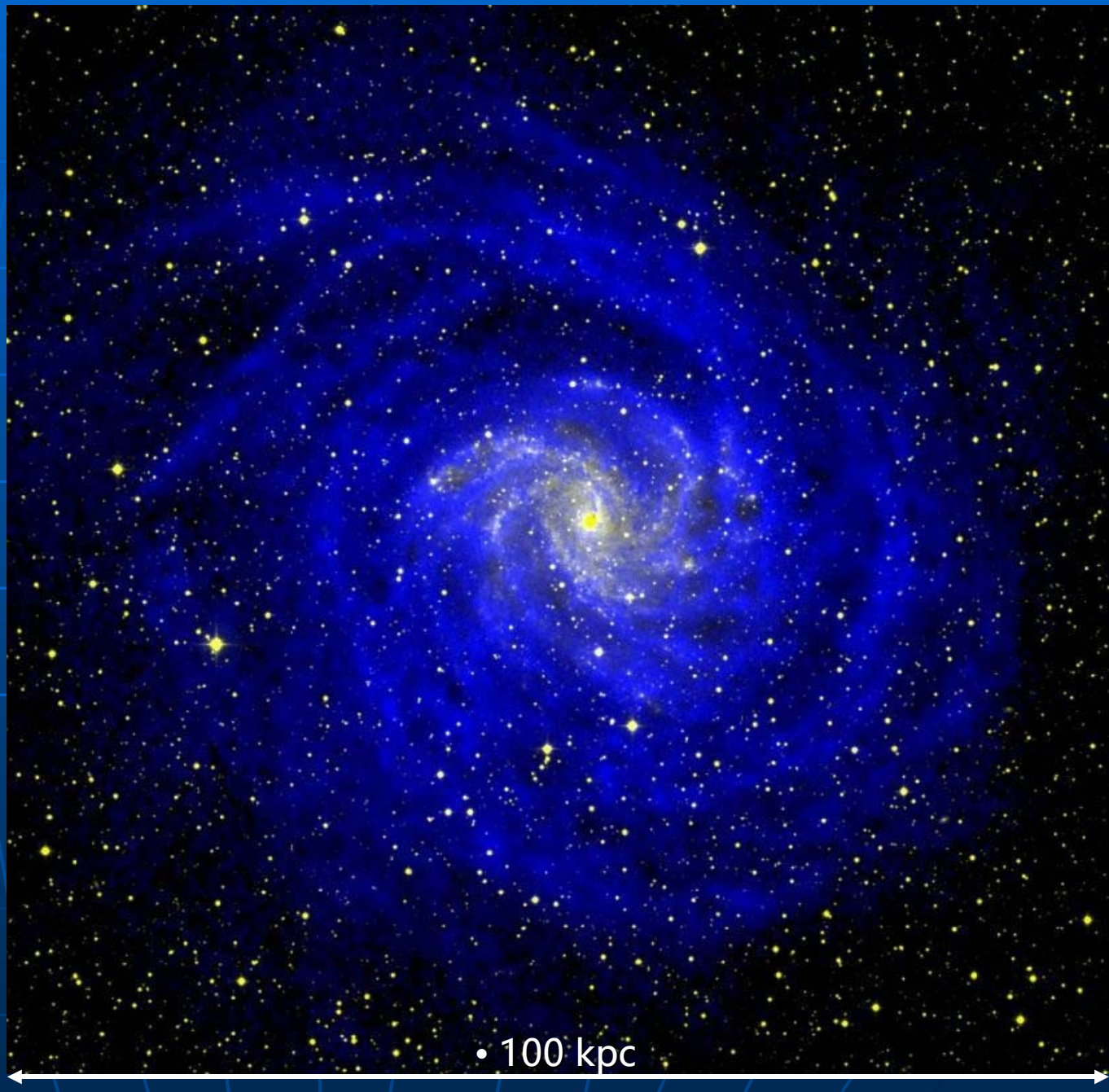
The strong field drives mass inflow to feed the nucleus



How extended are galactic magnetic fields ?

NGC6946

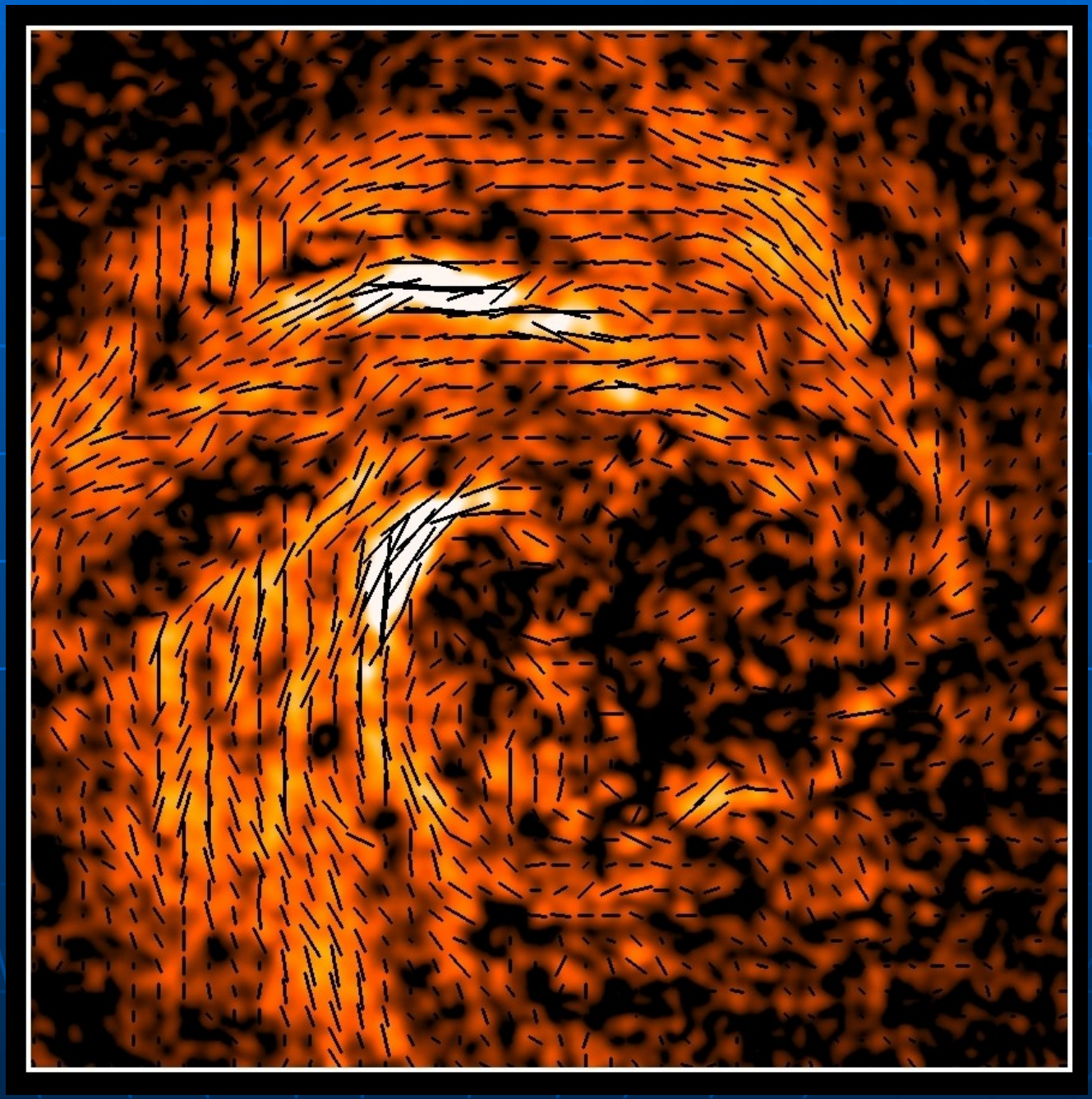
WSRT HI
+ optical
(Braun 2006)



NGC6946

VLA Polarized Intensity + B (Beck 2006)

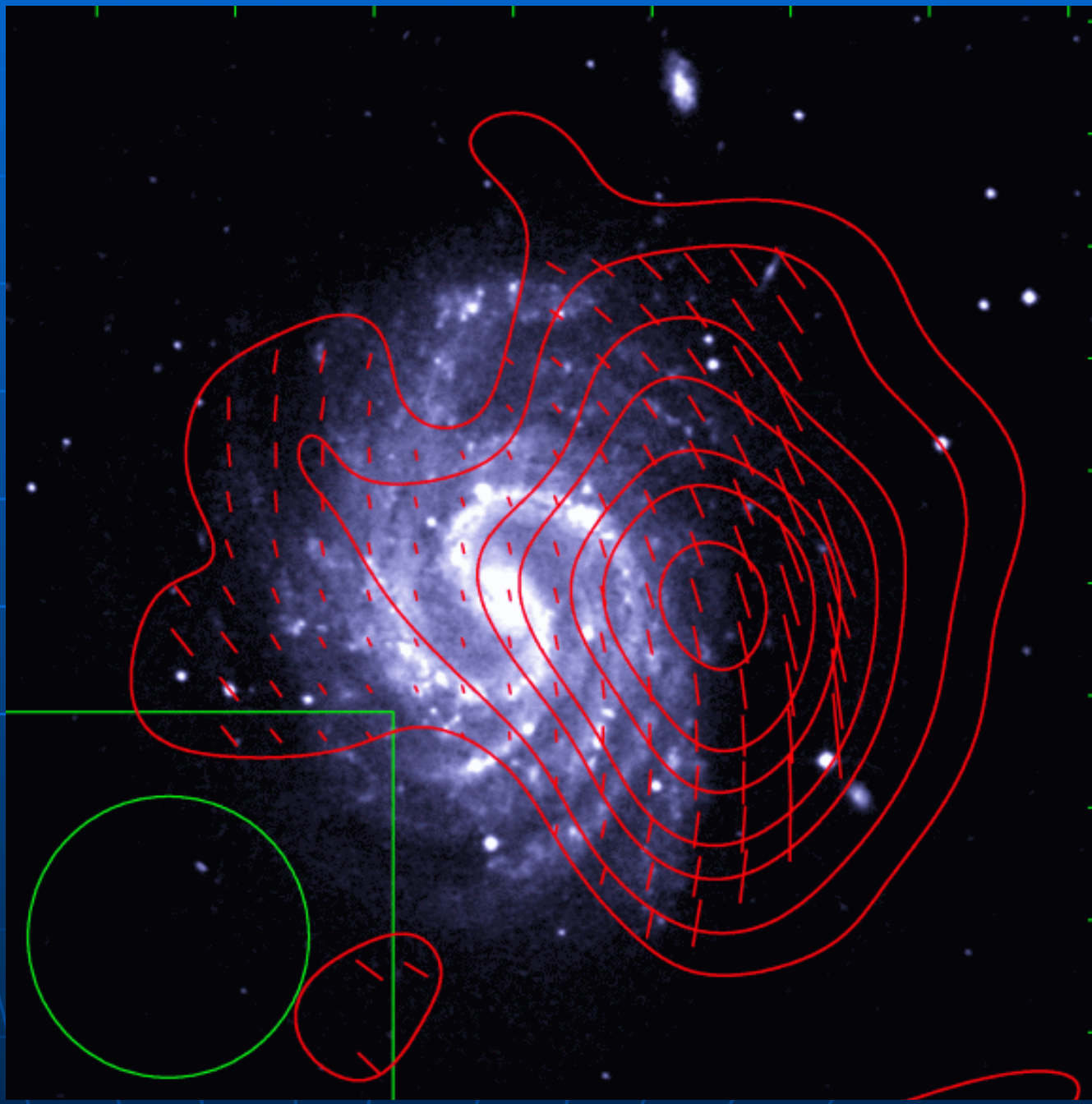
Magnetic spiral arms extending to > 25 kpc



NGC4535

Effelsberg Polarized Intensity + B
(Wezgowiecz et al. 2007)

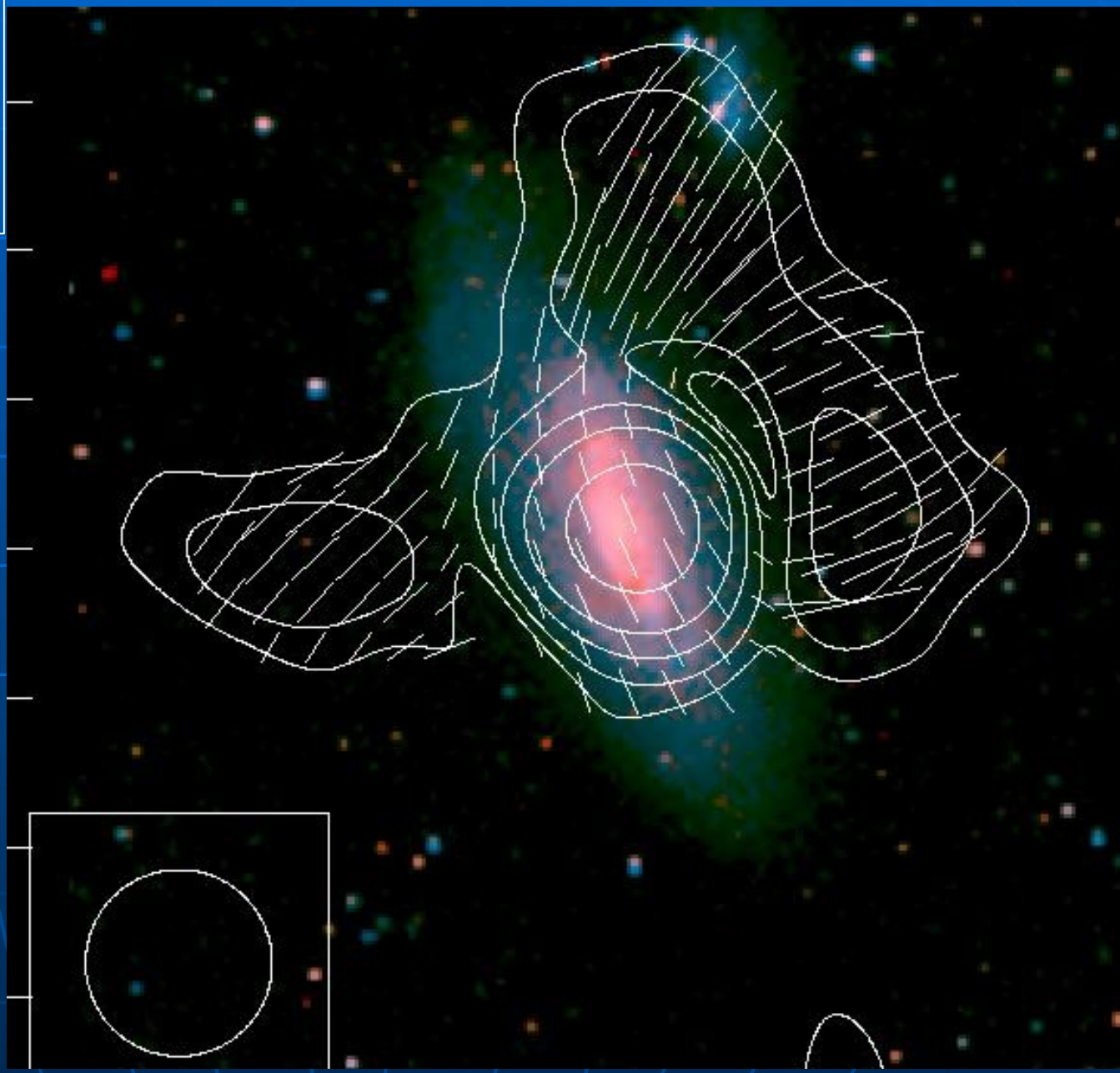
Field compressed by interaction



NGC4569

Effelsberg Polarized Intensity + B
(Chyzy et al. 2006)

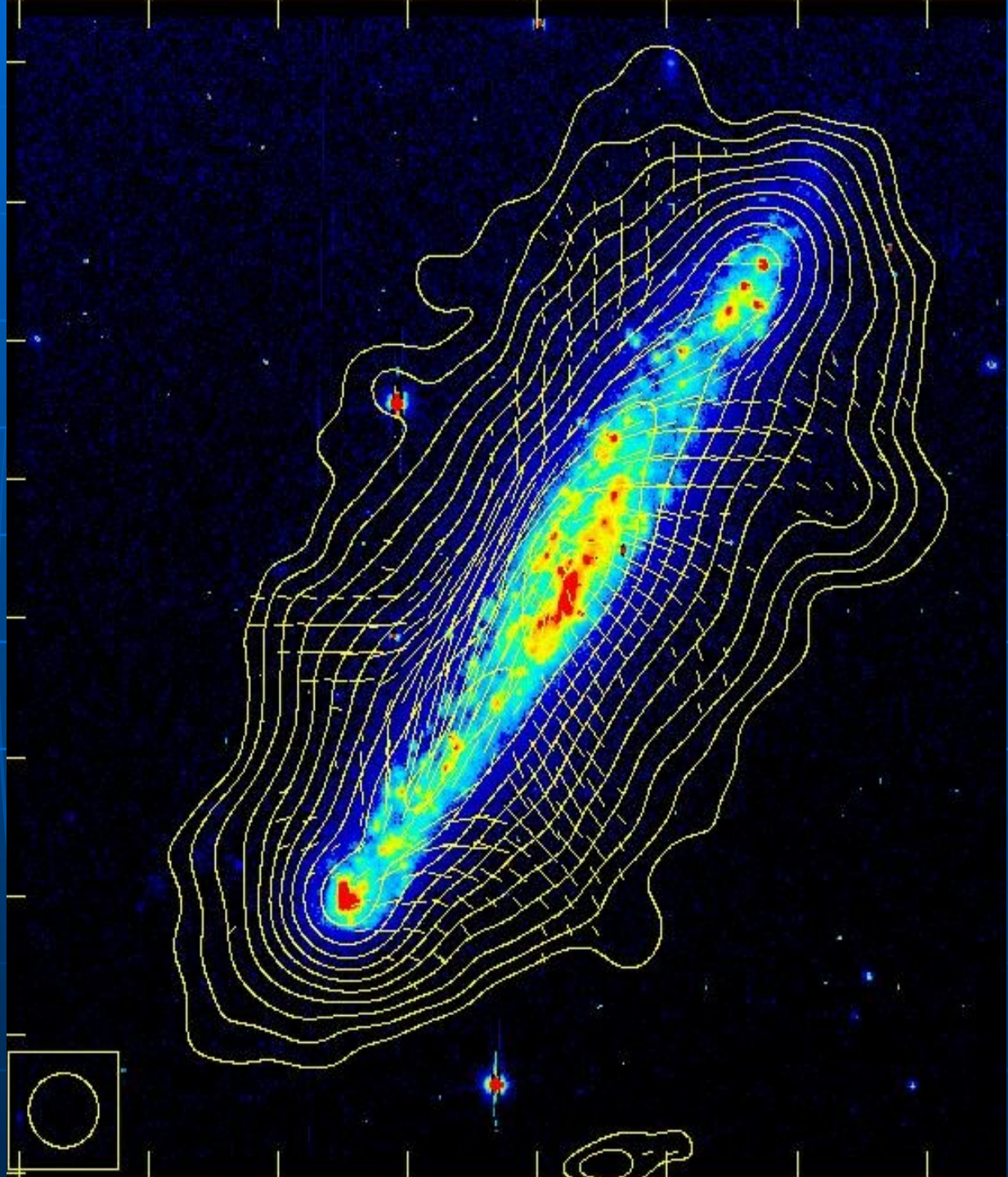
Field pulled out by interaction



NGC5775

VLA Total intensity
+ B
(Tüllmann et al. 2001)

Field pushed out by a galactic wind



Low-frequency radio emission:

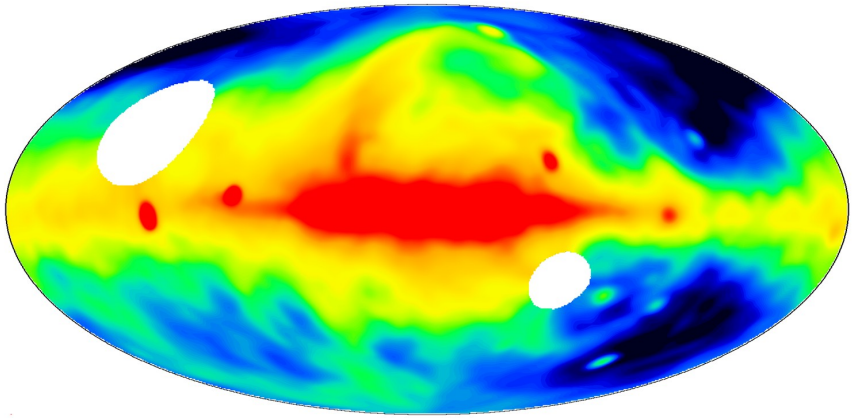
Window to the low-energy nonthermal Universe

LOw Frequency ARray

30-80 MHz
110-240 MHz

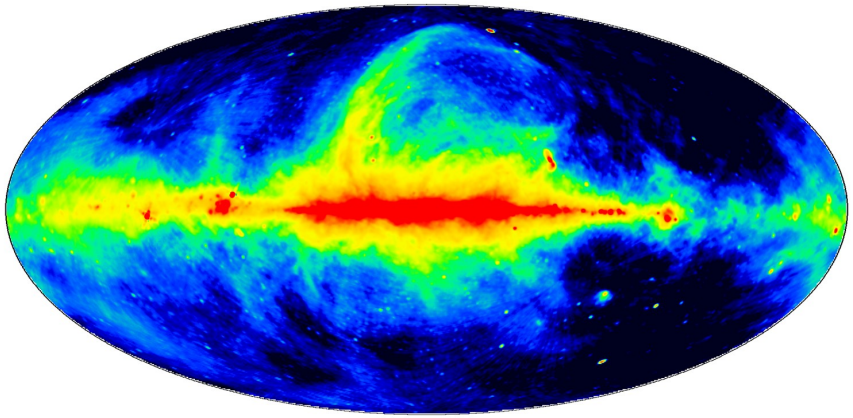
Radio surveys of the Milky Way: Distribution of cosmic-ray electrons

45 MHz



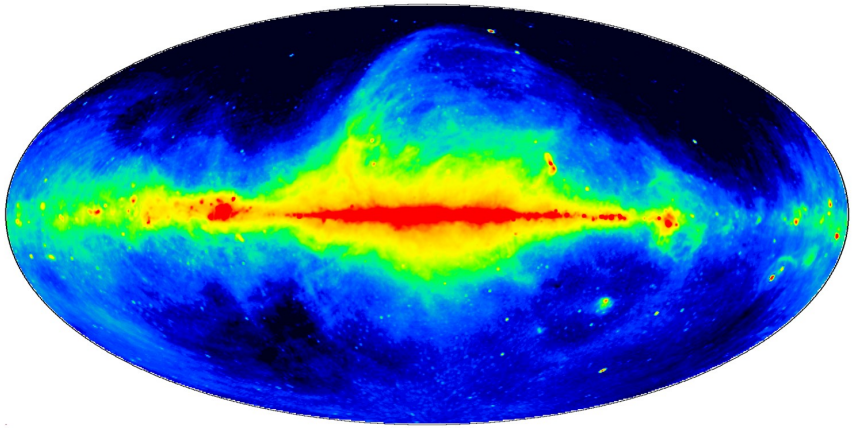
MU-Radar and Maipu Radio Observatory

408 MHz



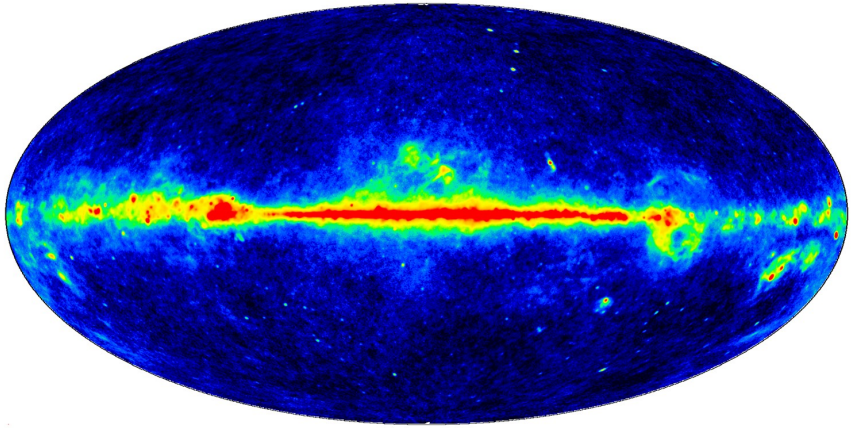
Jodrell-Bank 250-feet + Effelsberg 100-m + Parkes 64-m

1420 MHz



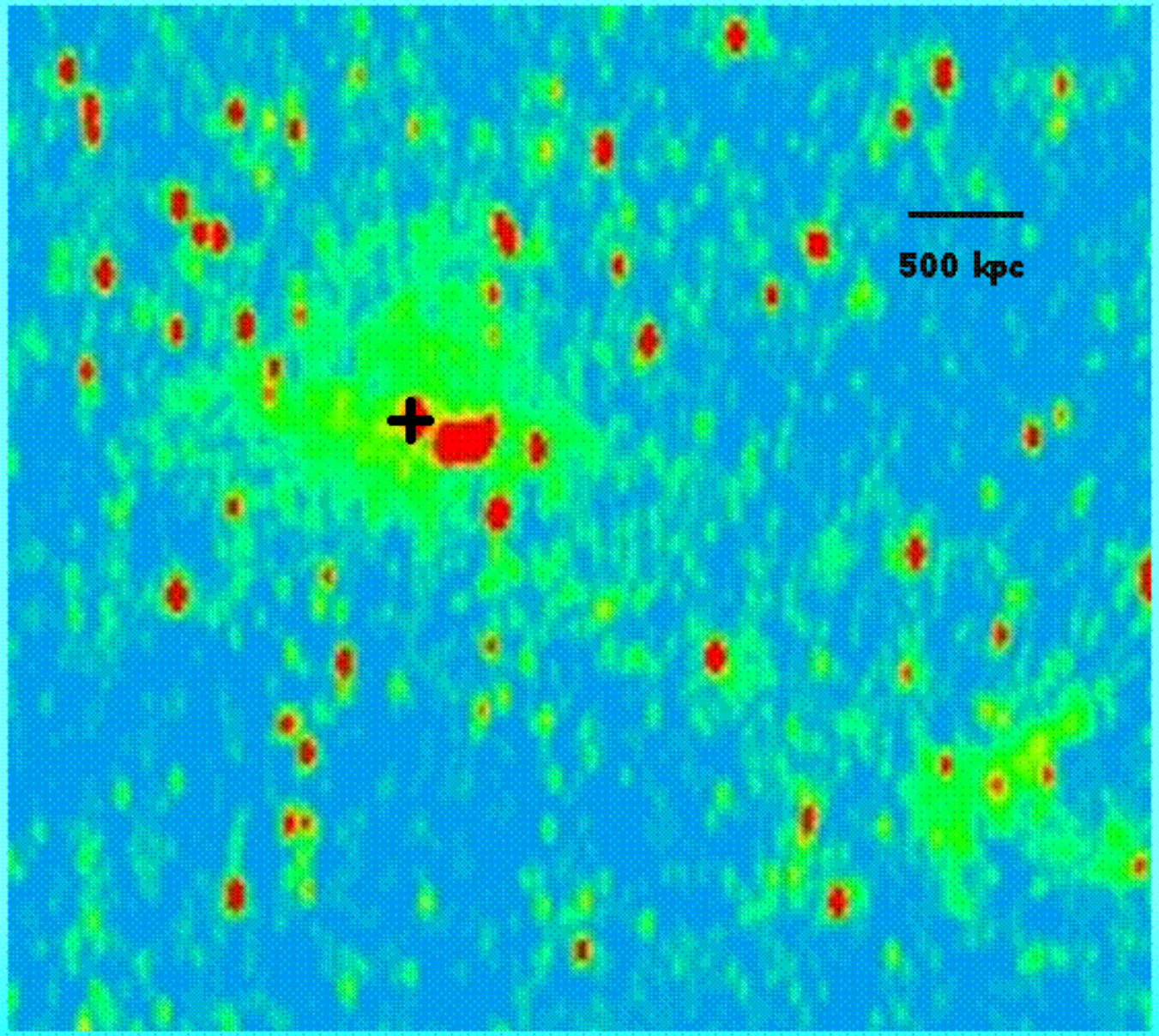
Stockert 25-m and Villa Elisa 30-m

22.8 GHz (K-band)



Wilkinson Microwave Anisotropy Probe (WMAP)

COMA Cluster

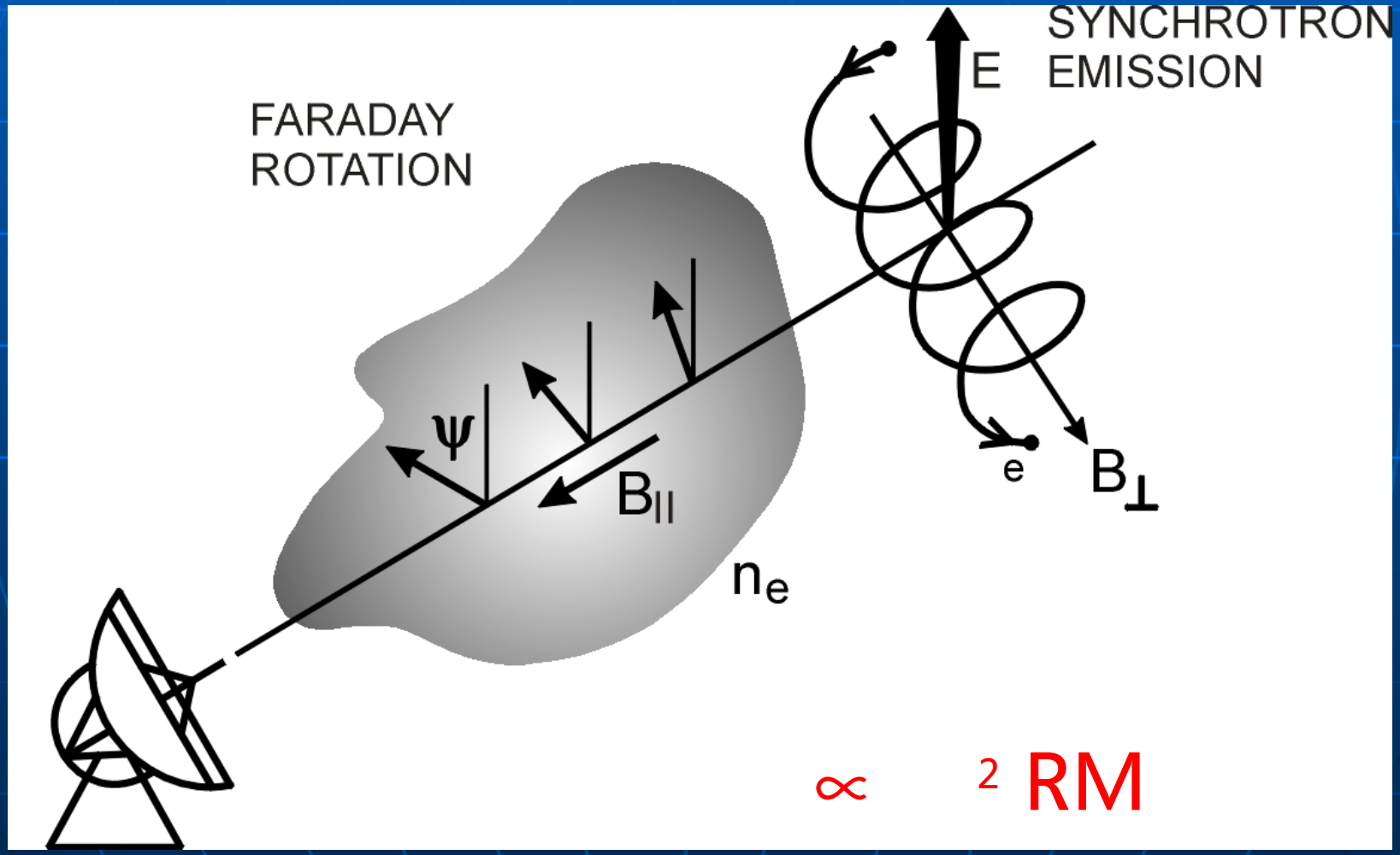


Center

RADIO: WSRT, 90 cm (Feretti et al.1998)

Observing at low frequencies
*traces **old**, low-energy*
cosmic-ray electrons
*in **weak** magnetic fields*

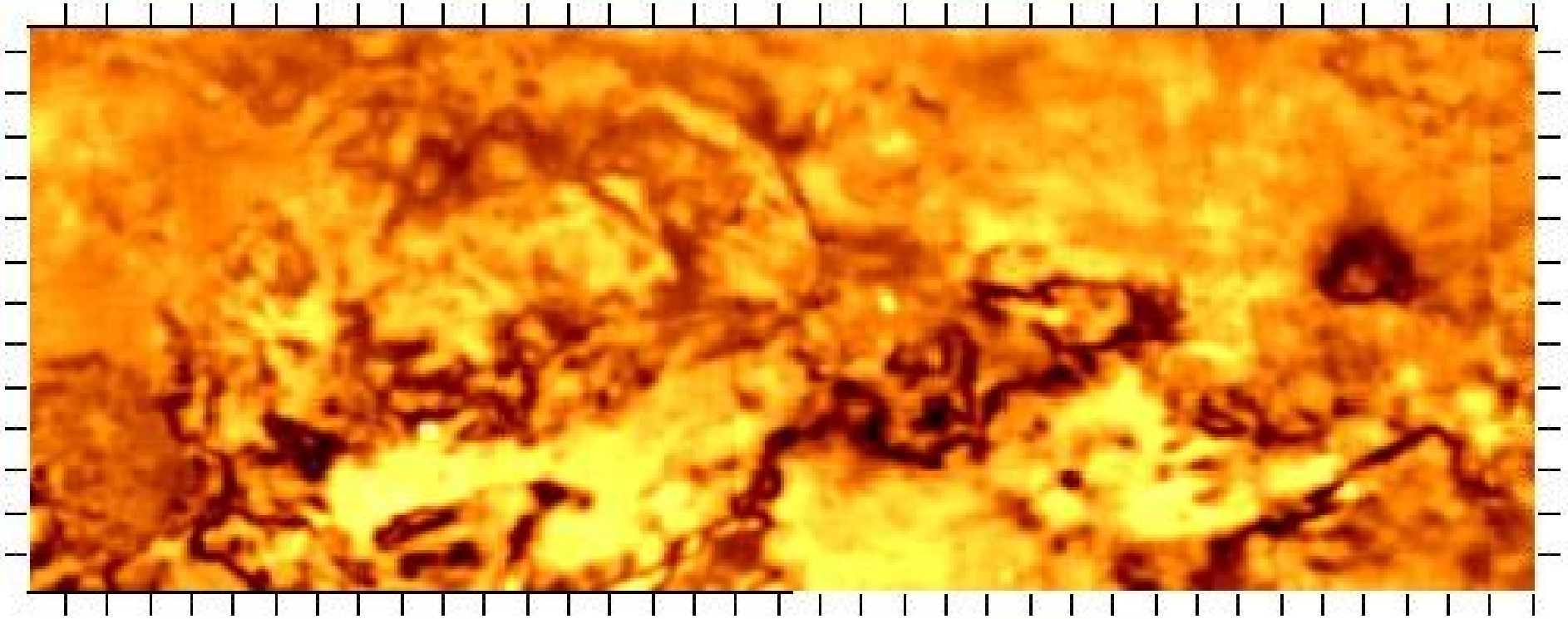
Faraday rotation



$\propto \lambda^2$ RM

Polarization silhouettes / Faraday screens

Modification of polarized background by Faraday rotation: probing weak magnetic fields and thin ionized gas



l=166° l=150°

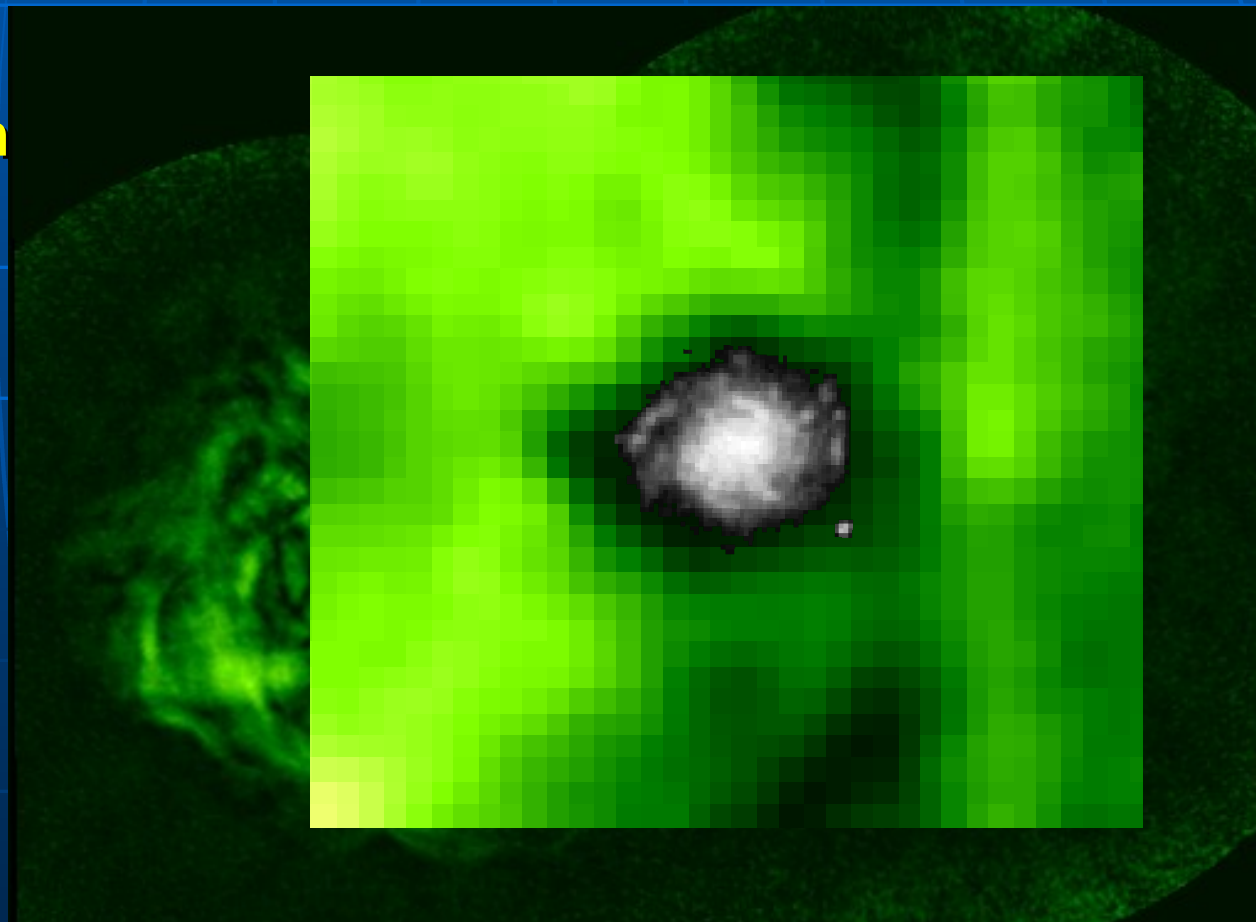
Effelsberg 21cm Galactic plane survey (Reich et al. 2003)

Polarization silhouettes / Faraday screens

Probing galactic magnetism in distant galaxies

Faraday depolarization of Fornax A by NGC 1310 (VLA)

(Fomalont et al. 1989)



Spectro-polarimetry:

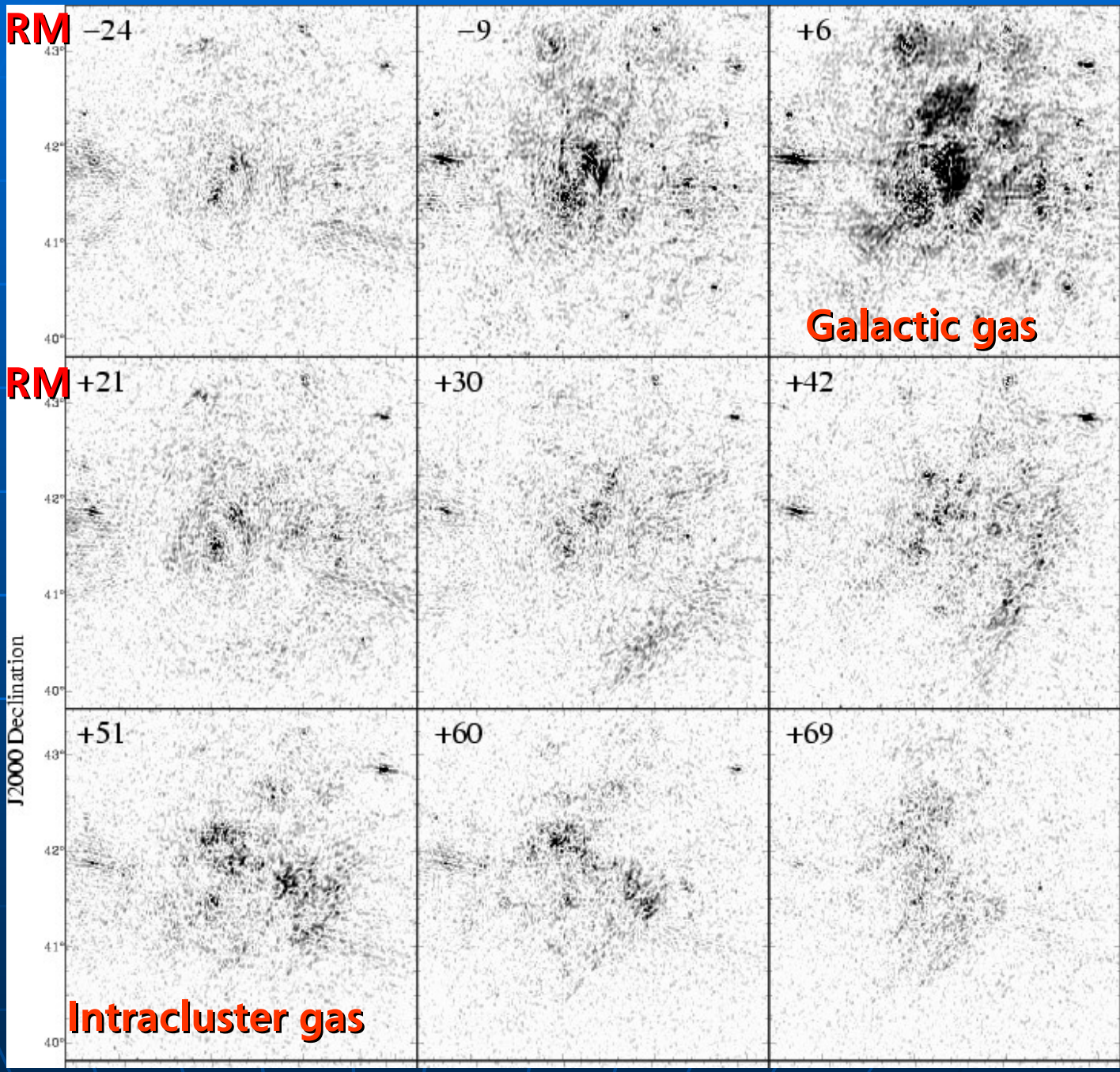
Different RMs trace different layers along the line of sight

→ *RM tomography*

Perseus Cluster

(WSRT)

(de Bruyn & Brentjens 2005)



Is the intergalactic space magnetic ?

LOFAR RM Survey

- LOFAR can in measure very low Faraday rotation measures of polarized background sources and hence detect very weak magnetic fields:

- Galaxy halos, clusters, relics:

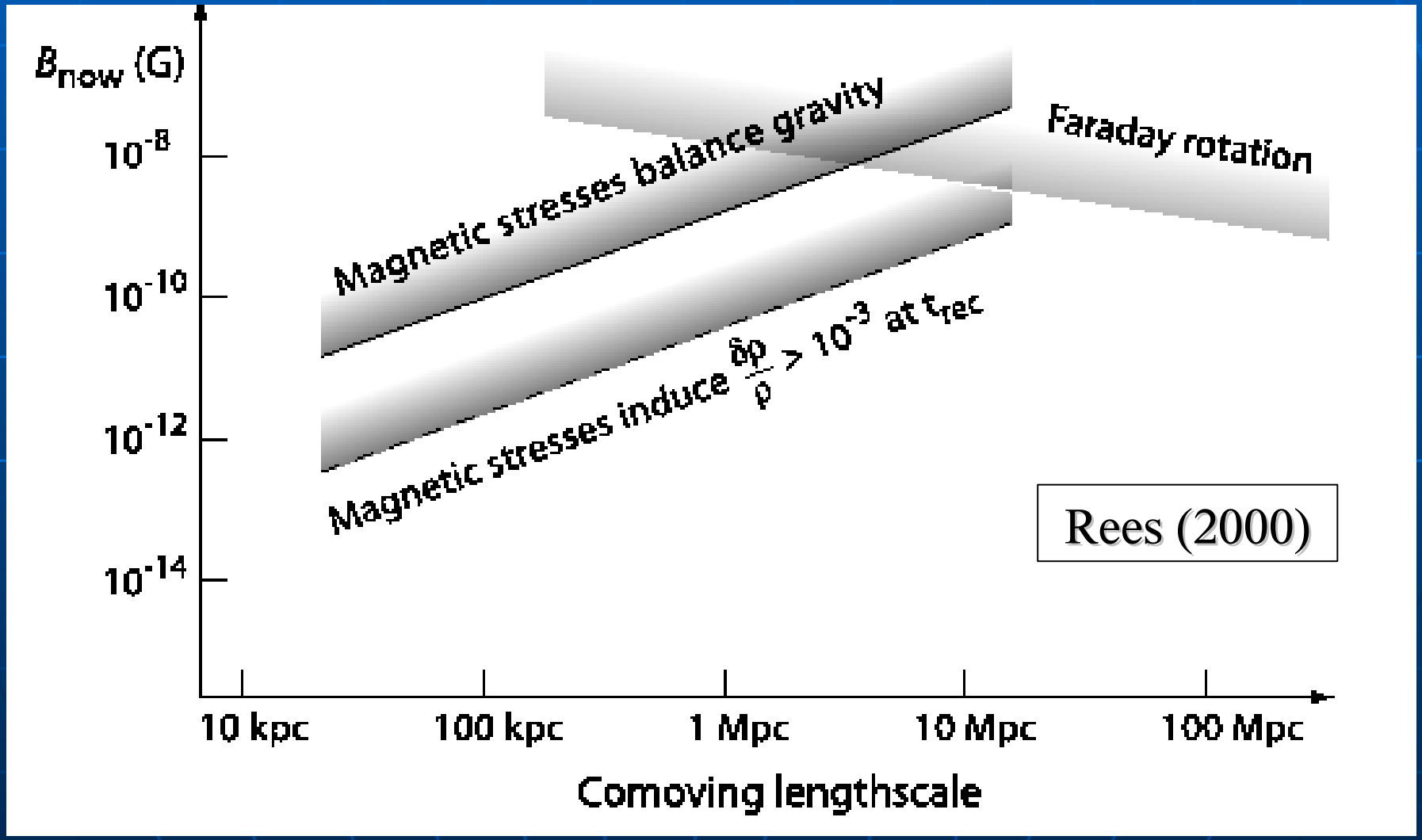
  $n_e=10^{-3}$ cm^{-3}, $B_{||}$ =1 G, L=1 kpc: RM~1 rad m^{-2}

- Intergalactic magnetic fields:

  $n_e=10^{-3}$ cm^{-3}, $B_{||}$ =0.1 G, L=1 kpc: RM~0.1 rad m^{-2}

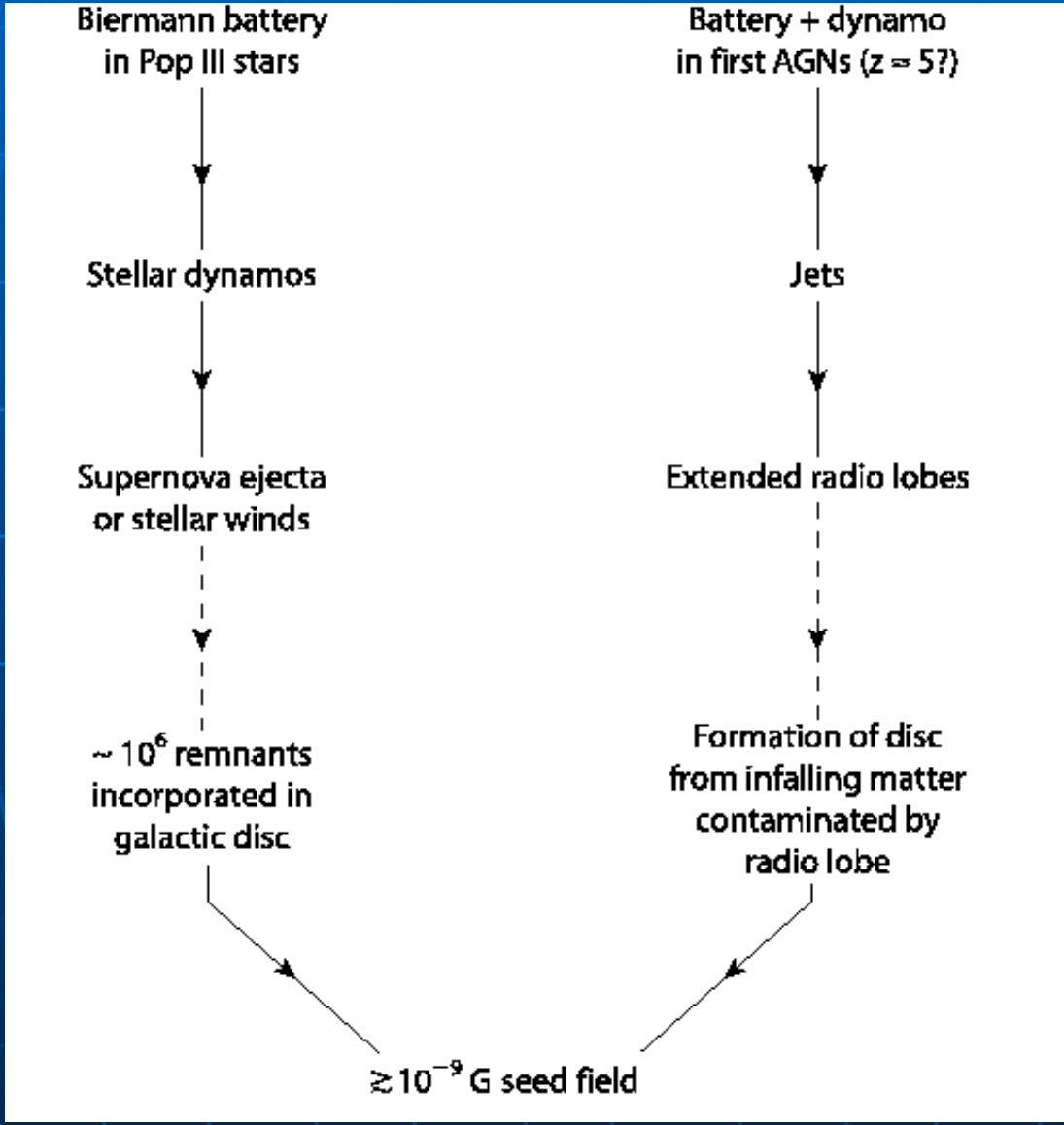
Did magnetic fields affect galaxy formation ?

Dynamical importance of primordial intergalactic fields



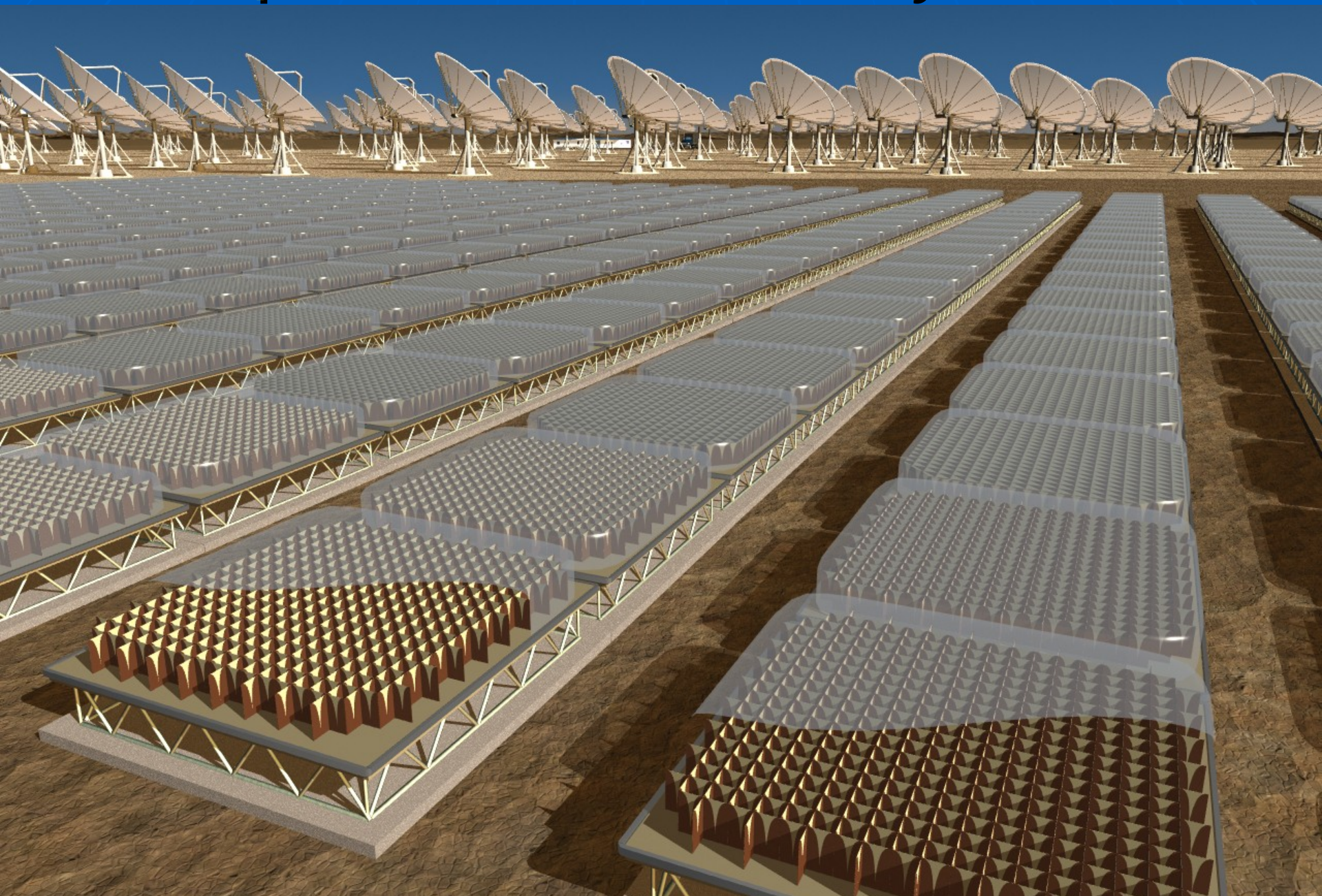
When and how were the first magnetic fields generated ?

Seed fields



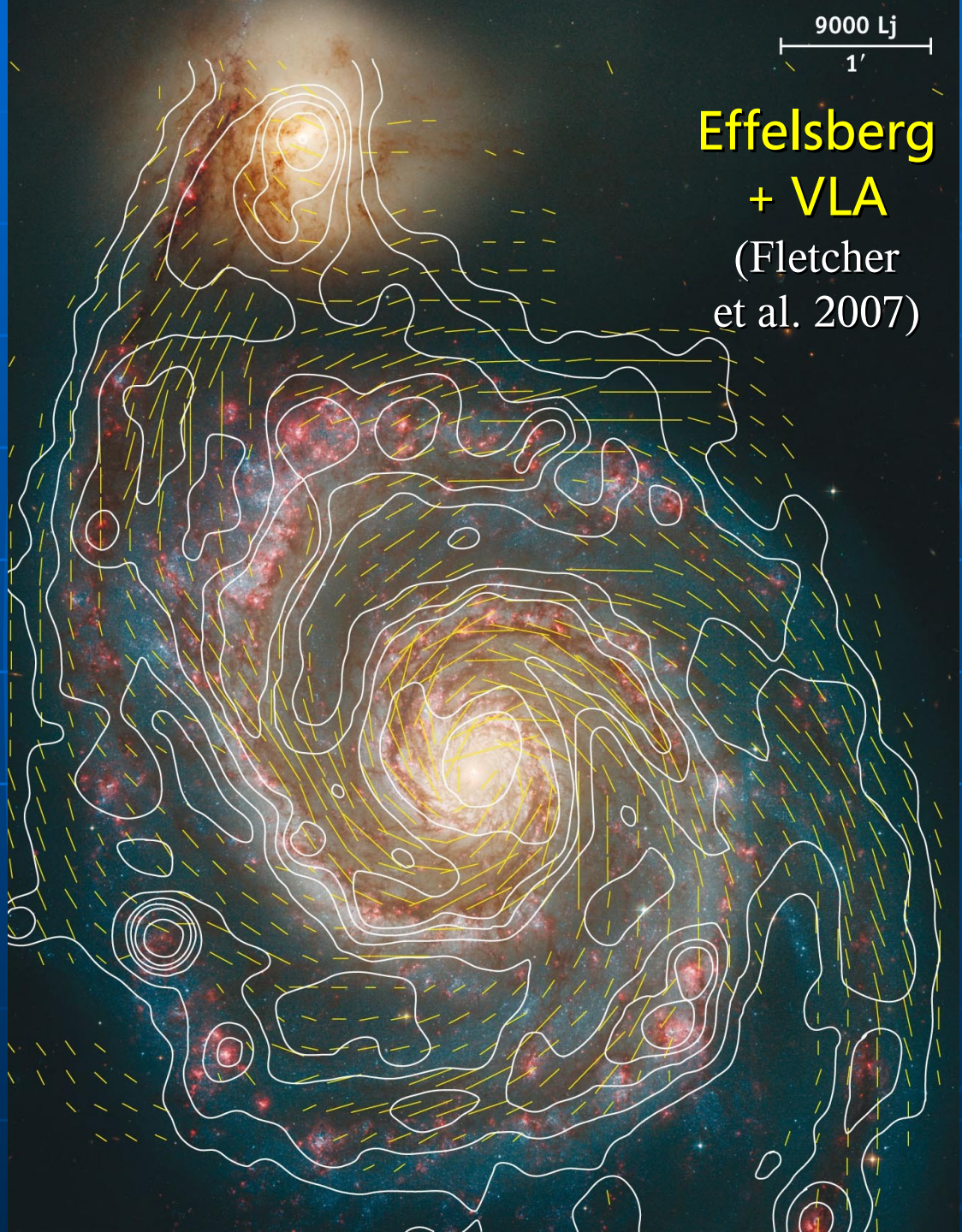
Rees (2004)

Square Kilometre Array (SKA)



SKA Key Science Project:

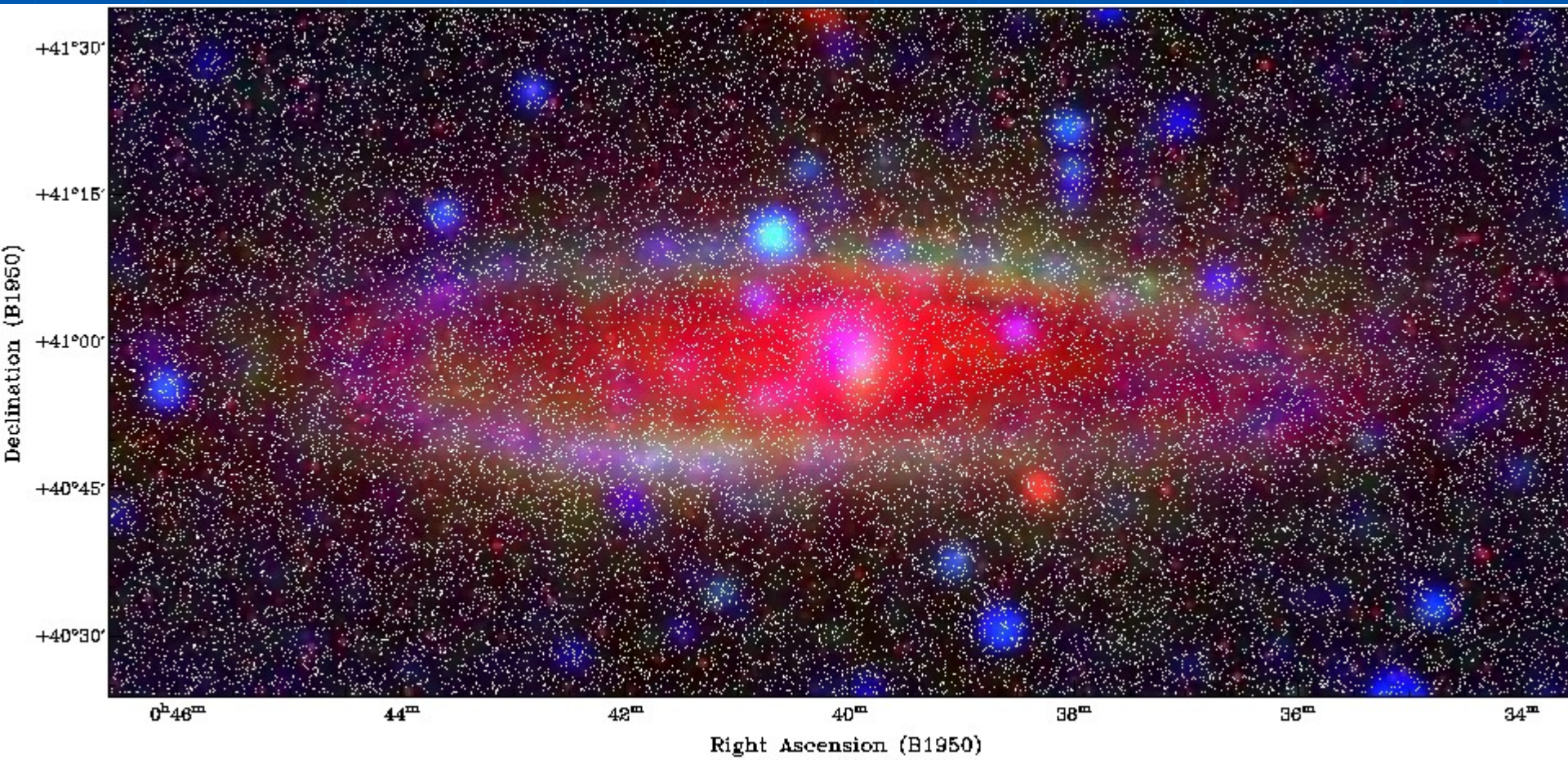
The Origin and Evolution of Cosmic Magnetism



Fundamental questions

- When and how were the first magnetic fields generated ?
- Did magnetic fields affect galaxy formation ?
- How were galactic magnetic fields amplified and maintained ?
- Do magnetic fields fill the whole intergalactic space ?

SKA: Density of RM data from background sources

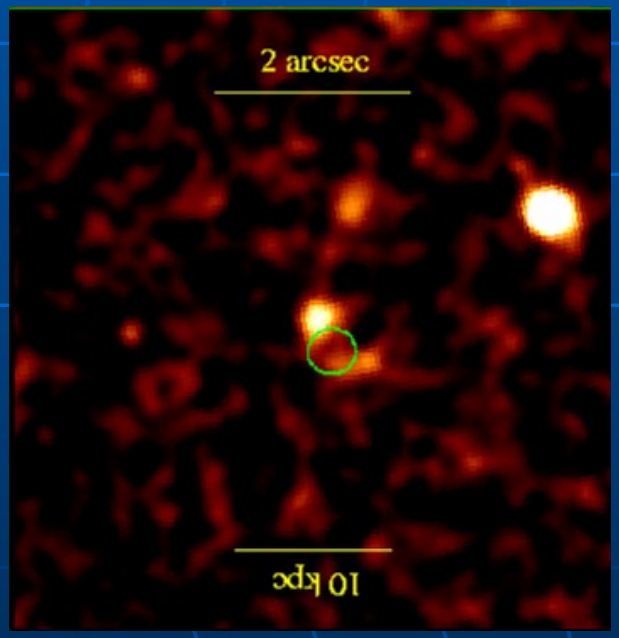


~10000 polarized sources shining through M31

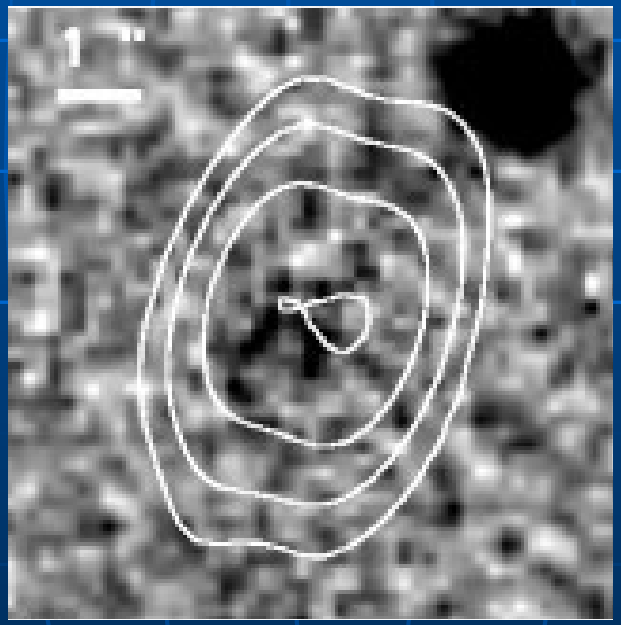
(Gaensler 2006)

SKA Search for primordial fields

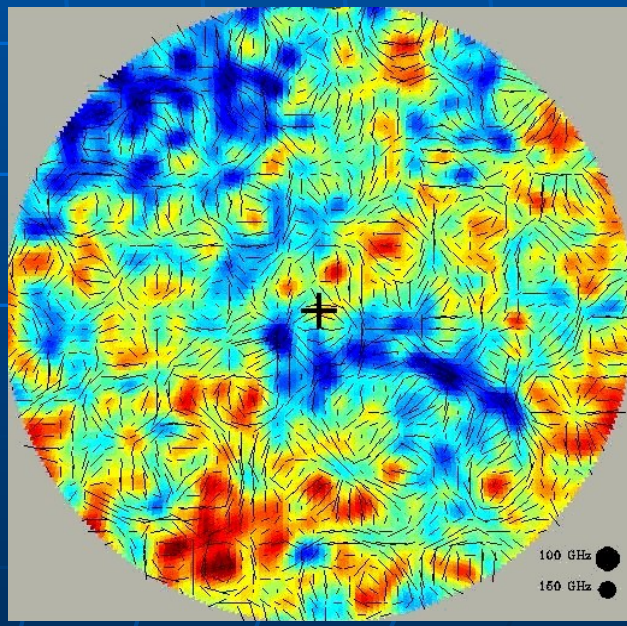
- RMs of high-z starburst galaxies, GRB afterglows, high-z AGNs, high-z (radio) galaxies and of the CMB
- A CMB field of $B_0 \sim 10^{-9}$ G may be detectable via its Faraday rotation (Kosowky & Loeb 1996)



GRB 000131 at z = 4.5
(Bloom et al. 2001)



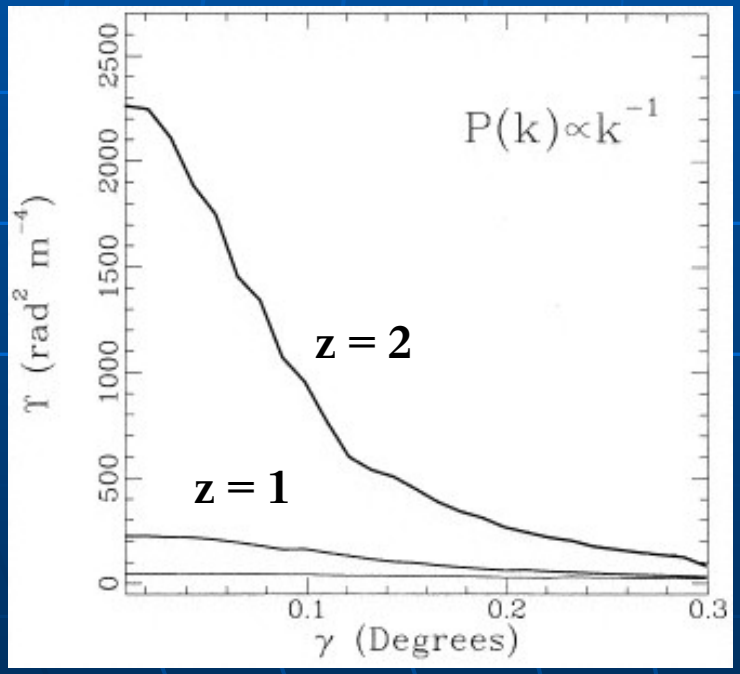
Radio galaxy at z = 5.2
(van Breugel et al. 1999)



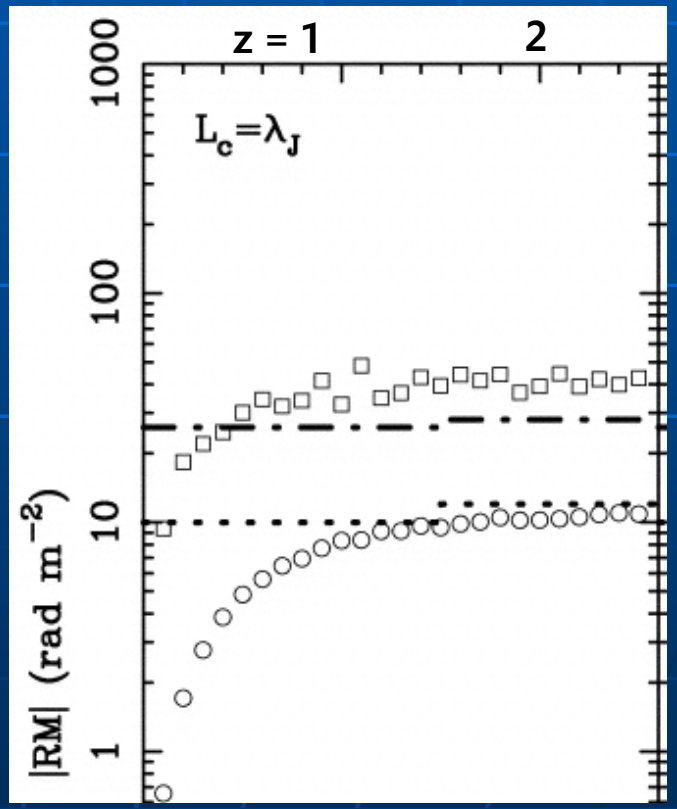
CMB polarization
(BICEP)

SKA Search for primordial fields

- SKA 1.4 GHz all-sky survey: huge sample of RMs
- Expected RMs from a homogeneous IGM field :
  $RM_{IGM} \propto (1+z)^3$
- Statistical analysis :



Two-point RM correlation function for B • 1 nG (Kolatt 1998)



Mean and median RM vs z for B • 6 nG (Blasi et al. 1999)

Conclusions for Science Vision

- Leading role of Europe in observation and theory of galactic magnetic fields, to be strengthened
- More emphasis of magnetic fields in the Science Vision document
- *Principle* facilities: LOFAR (30-240 MHz) ,
  SKA (300 MHz – 3 GHz for Faraday survey & tomography,
  3 – 15 GHz for Faraday-free polarization mapping)
- *Supporting* facilities: Effelsberg, E-VLA,
  PLANCK and beyond