Polarisation et champs magnétiques

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Outline

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Introduction

- Cosmic magnetic fields play an important role in the structure, dynamics & energetics of most astrophysical objects.
- The best probes of cosmic magnetic fields are radio waves.
- "The Origin & Evolution of Cosmic Magnetism" (Gaensler, Beck & Feretti 2004)
  ☞ one of the five Key Science Projects of SKA.

Outline

Present radio observations

- Zeeman splitting
  In neutral (molecular & atomic) regions
  $\rightarrow$ regular $B_{\parallel}$ (strength & sign)

- Faraday rotation
  In ionized regions
  $\rightarrow$ regular $B_{\parallel}$ (strength & sign)

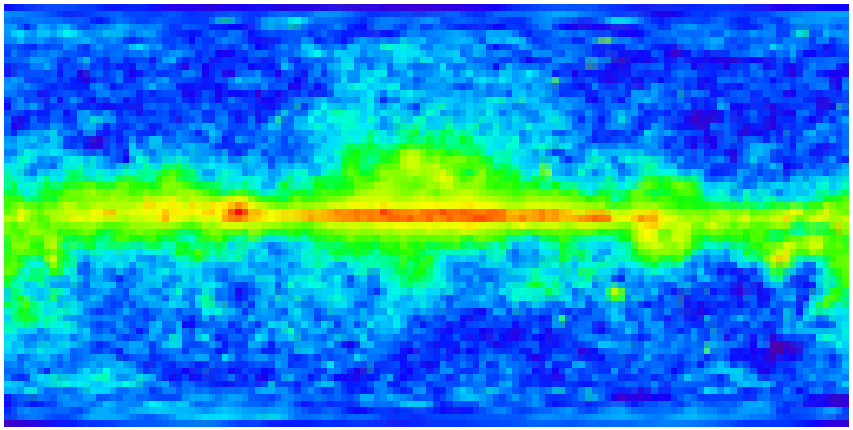
- Synchrotron emission
  In general ISM
  Total intensity $\rightarrow$ total $B_{\perp}$ (strength)
  Polarized intensity $\rightarrow$ ordered $\vec{B}_{\perp}$ (strength & orientation)

Magnetic fields in our Galaxy

- Zeeman splitting
  - ☞ - In atomic clouds : $B \sim$ a few μG
    - In molecular clouds : $B \sim (10 - 3000)\ \mu$G
- Faraday rotation
  - ☞ - Near $\odot$: $B_{\rm reg} \simeq 1.5\ \mu$G & $B_{\rm turb} \sim 5\ \mu$G
    - In GD (away from GC) : $\vec{B}_{\rm reg}$ horizontal & mostly azimuthal
    - In GD : reversals in B_Φ $\Rightarrow$ spiral structure ?
- Synchrotron emission
  - ☞ - Near $\odot$: $B_{\rm ord} \sim 3\ \mu$G & $B_{\rm tot} \sim 5\ \mu$G
    - Global spatial distribution : $L_{\rm B} \sim 12$ kpc & $H_{\rm B} \sim 4.5$ kpc

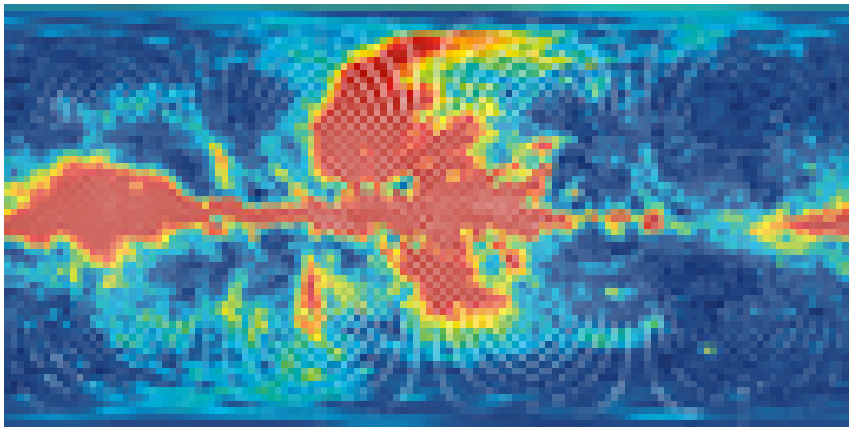
All-sky radio maps

Total intensity



WMAP 23 GHz (WMAP Science Team)

Polarized intensity

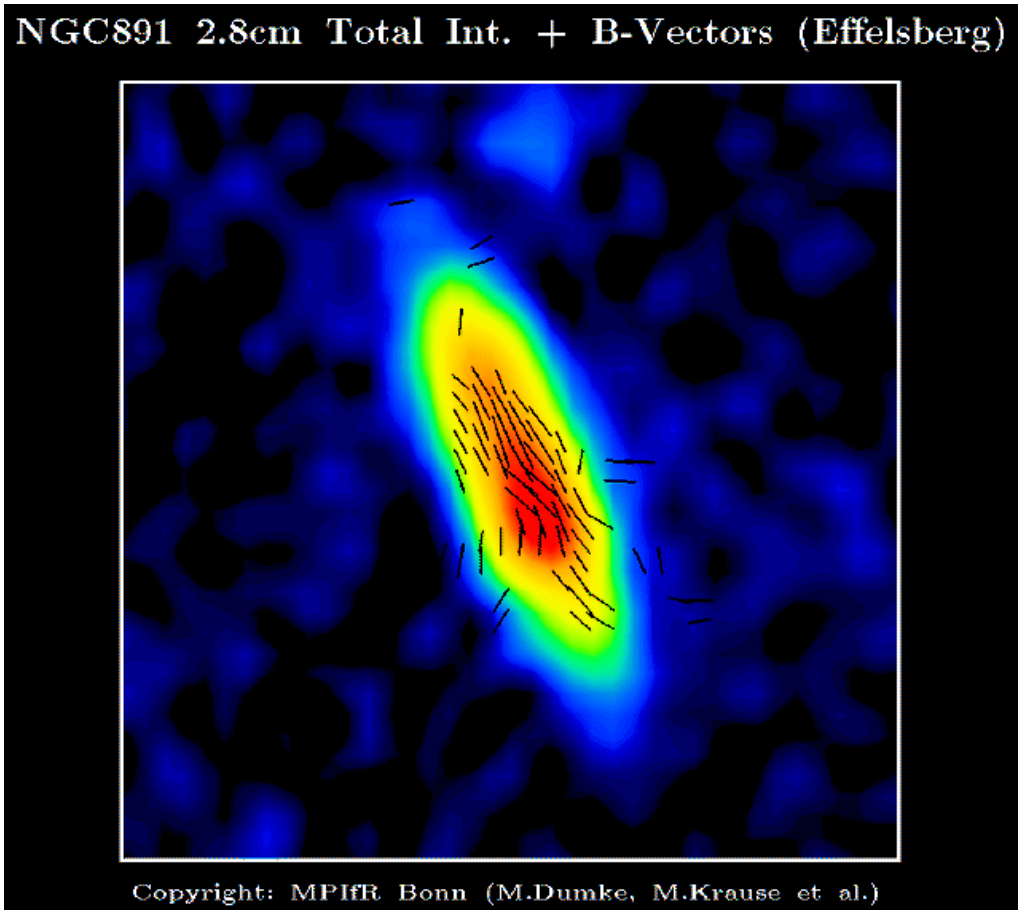


WMAP 23 GHz (WMAP Science Team)

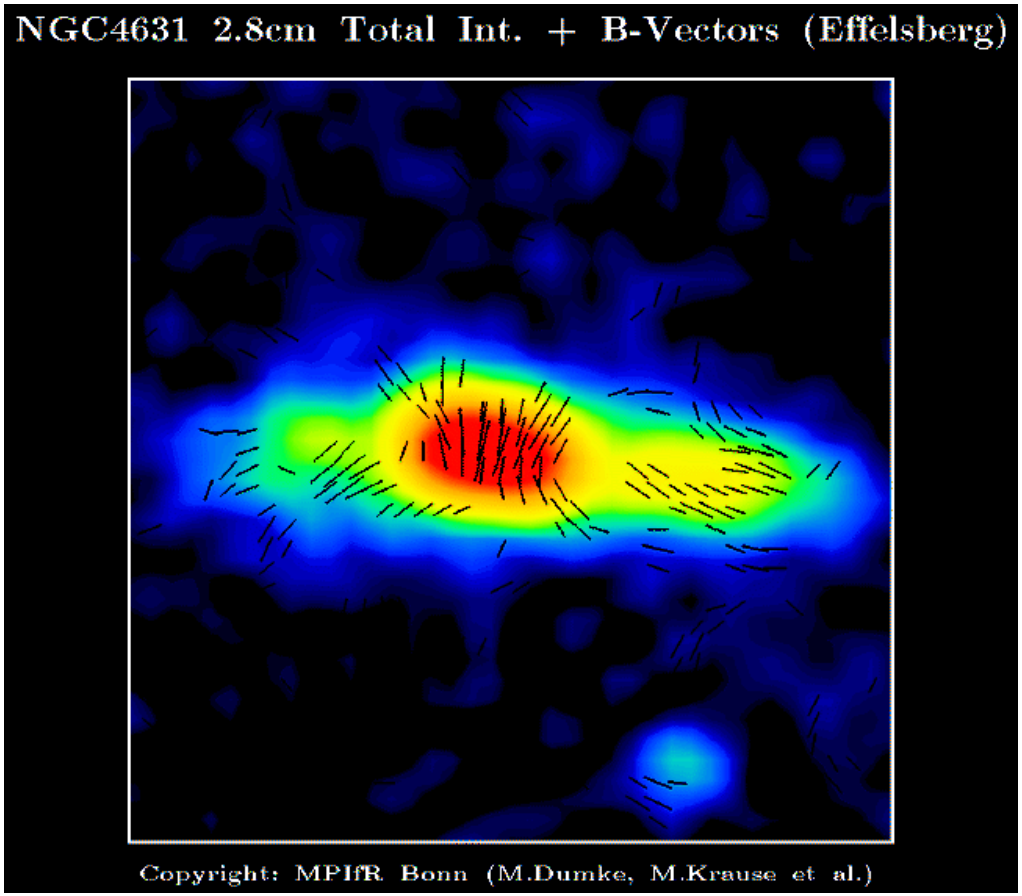
Magnetic fields in external galaxies

- Spiral galaxies
  - All spirals have large-scale, regular $\vec{B}$
  - In disk : $B_{\rm ord} \sim (1-5)\ \mu$G & $B_{\rm tot} \sim (5-15)\ \mu$G
    In halo : $B_{\rm tot} \lesssim 10\ \mu$G
  - Edge-on spirals $\rightarrow$ In disk : $\vec{B}_{\rm reg}$ is horizontal
    In halo : $\vec{B}_{\rm reg}$ has vertical component
    Face-on spirals $\rightarrow$ $\vec{B}_{\rm reg}$ follows spiral arms
- Elliptical galaxies
  - No large-scale, regular $\vec{B}$
    Only small-scale, turbulent $\vec{B}$
  - $B_{\rm tot} \sim$ a few μG

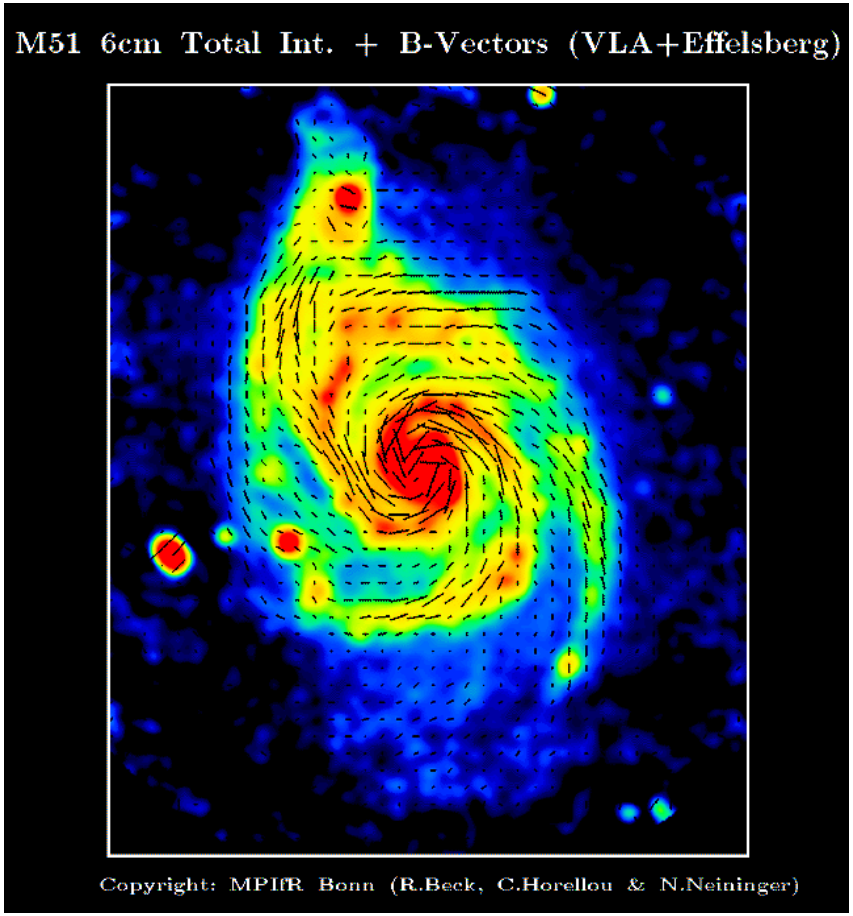
Edge-on spiral galaxy: NGC 891



Edge-on spiral galaxy: NGC 4631



Face-on spiral galaxy: M 51



Magnetic fields in clusters of galaxies

- Faraday rotation
  - ☞ - Clusters have an intergalactic magnetic field
    - $B \sim$ a few μG & $l_{\rm cor} \sim$ a few 10 kpc
- Synchrotron emission
  - ☞ - $\vec{B}$ is completely turbulent
    - $B_{\rm tot} \sim (0.1 - 1)\ \mu$G

Outline

All-sky survey of rotation measures

- Take advantage of the high sensitivity, high resolution & spectro-polarimetric capability of SKA
- Will provide a closely-spaced grid of RMs in all directions
- $\sim 20\,000$ RMs of Galactic pulsars (~ 6 deg^{-2} in GD)
  $\rightarrow$ RMs of all Galactic pulsars beaming towards us
- $\sim 8 \times 10^7$ RMs of extragalactic compact polarized sources ($\sim 2\,000$ deg^{-2}) in 4 years of observing time

☞ Powerful tool to study cosmic magnetic fields at all redshifts

Synchrotron emission and Faraday tomography

- Mapping of total synchrotron emission
- Mapping of polarized synchrotron emission at high ν
  (no Faraday effects)
- Mapping of polarized synchrotron emission at many ν
  $\rightarrow$ Faraday tomography

  When synchrotron emission & Faraday rotation are spatially mixed
  $\rightarrow$ Faraday depolarization (due to differential FR) $\propto \lambda^2$
  $\Rightarrow$ Different λ trace different layers of polarized emission

Our Galaxy

- Grid of pulsar RMs + distance estimates (from parallax or DMs)
  → magnetic field structure in GD on scales $\gtrsim 100$ pc
  - number & location of field reversals
  - magnetic spiral *vs* optical spiral

- Grid of extragalactic source RMs
  → - magnetic field structure in GH & outer GD
  - magnetic fields in SNRs & H II regions
  - power spectrum of magneto-ionic turbulence down to $\lesssim 1'$

- Faraday tomography on diffuse Galactic polarized radio emission
  → high-resolution 3D map of local ($\lesssim 5$ kpc) Galactic magnetic field
  → - small-scale ($\gtrsim 0.1$ pc) magnetic features
  - properties of magneto-ionic turbulence

External galaxies

- Low-z galaxies

  - Deep grid of compact source RMs
  - Mapping of diffuse (total + polarized) synchrotron emission + Faraday tomography (in the nearest galaxies)

  • LMC, SMC, M31
  $\gtrsim 10^5$ RMs + Faraday tomography
  $\rightarrow$ extremely detailed map of magnetic field structure

  • Galaxies out to ~ 10 Mpc (~ 100 galaxies)
  $\gtrsim 50$ RMs + synchrotron mapping
  $\rightarrow$ 3D reconstruction of large-scale magnetic field structure

  • Galaxies out to ~ 100 Mpc ($\sim 60\,000$ galaxies)
  $\gtrsim 10$ RMs
  $\rightarrow$ recognition of simple magnetic patterns (ASS, BSS...)

External galaxies

- Galaxies at $z \gtrsim 0.1$
  - Detailed study of individual galaxies
    - Too small ($\lesssim 1'$) to be probed by grid of *compact* source RMs
    - RMs of background *extended* polarized sources
    $\rightarrow$ maps of magnetic field structure in distant galaxies
    $\rightarrow$ temporal evolution of galactic magnetic fields
  - RM statistics of (unresolved) Lyα absorbers
    $\rightarrow$ trends of $\mathrm{RM}_{\mathrm{source}}$ *vs* z & $\mathrm{RM}_{\mathrm{Ly}\alpha}$ *vs* z separately
    $\rightarrow$ evolution of magnetic fields in galaxies & protogalaxies

Clusters of galaxies

- Grid of compact source RMs
  $\sim 1\,000$ RMs behind typical nearby cluster
  $\rightarrow$ detailed map of magnetic field in individual clusters

- Detection of total synchrotron emission (deep observations)
  $\rightarrow$ estimates of magnetic field strength in clusters