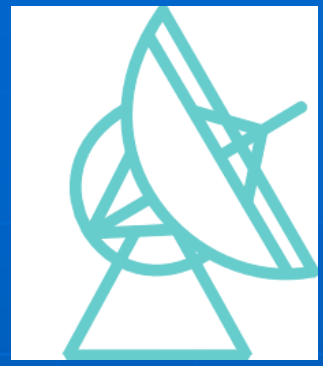

SKA and the Magnetic Universe

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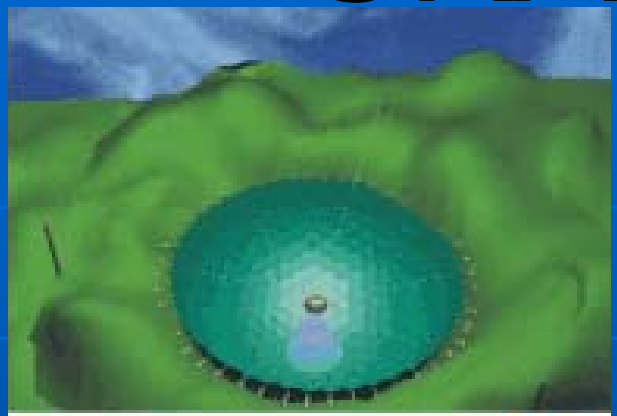
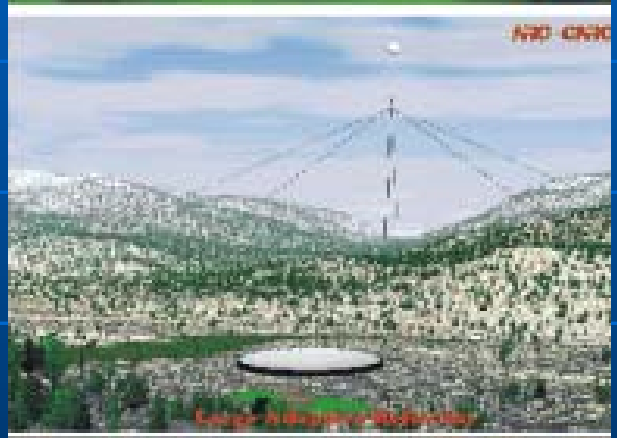
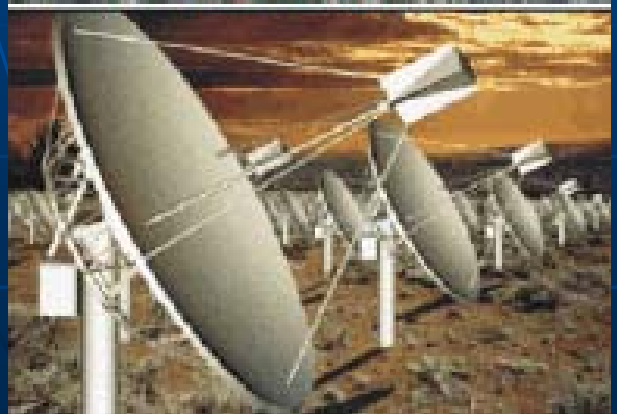
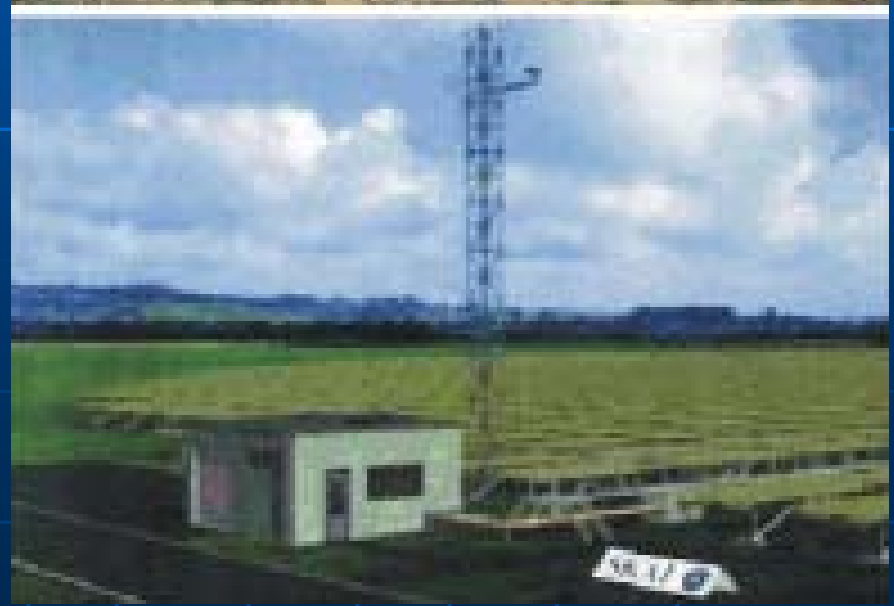
Bryan Gaensler CfA Cambridge
Luigina Feretti CNR / INAF Bologna

SKA Concepts









SKA Key Science

- Testing **Theories of Gravitation** with pulsars

- **The Dark Ages :**
  Epoch of re-ionisation, first black holes

- **The Cradle of Life :**
  Protoplanets, biomolecules, SETI

- **Evolution & Large-scale Structure :**
  Galaxies, Hubble Flow & Dark Energy

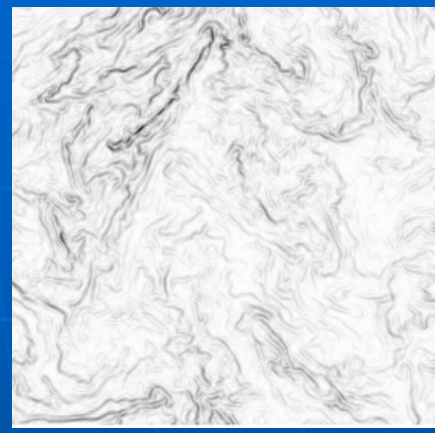
- **Cosmic Magnetism**

Cosmic Magnetism

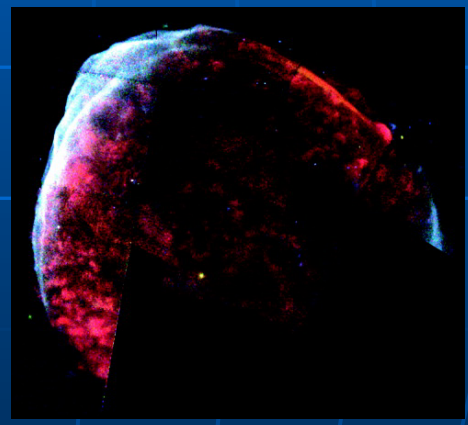
Magnetism is crucial in :

- cloud collapse / star formation
- stellar activity / stellar outflows
- ISM turbulence / gas motions
- supernova remnants
- stability of galactic disks
- acceleration / propagation / confinement of cosmic rays
- heating in galaxy clusters
- AGNs / Jets

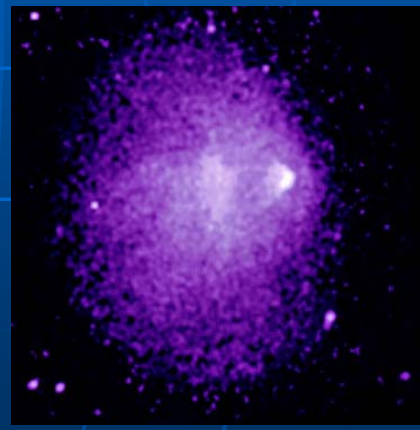
Proplyd in Orion



MHD turbulence



SN 1006



Merger in gal. cluster

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

Fundamental Questions

- ***STRUCTURE***
  - What are the **strength and structure** of the magnetic field in the interstellar, intracluster and intergalactic medium ?
  - What is the **interplay** between the magnetic fields and the gas ?
- ***EVOLUTION***
  - How were the present-day magnetic fields **amplified** and maintained ?
  - How did magnetic fields **evolve** as galaxies evolve ?
- ***ORIGIN***
  - Were the **seed fields** in galaxies and clusters **primordial**, or were they ejected by stars, supernova remnants, or AGNs ?
  - Is there a connection between field formation and **structure formation** in the Early Universe ?
  - *When and how were the **first magnetic fields** generated ?*

Magnetism and Radio Astronomy

Most of what we know about cosmic magnetism is from radio waves !

- Total & polarized synchrotron emission

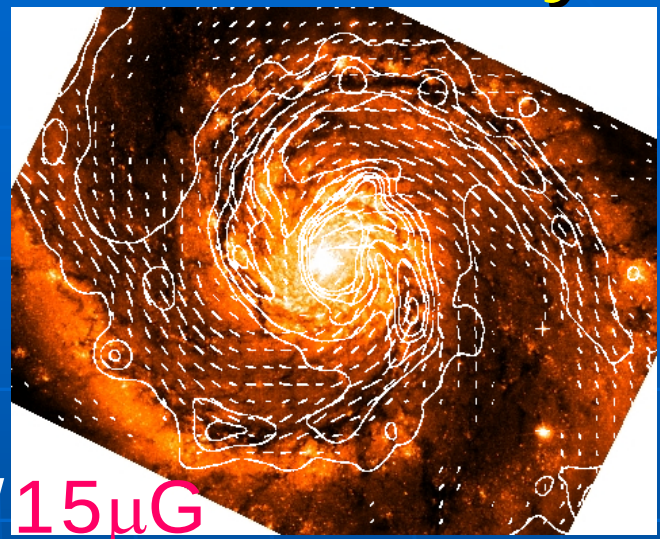
→ strength & orientation of $\langle B_\perp \rangle$ & $B_\perp$

- Faraday rotation

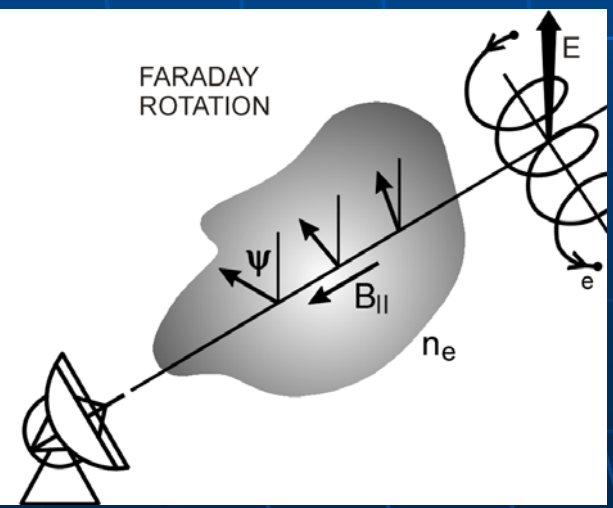
→ strength & sign of $\langle B_\parallel \rangle$

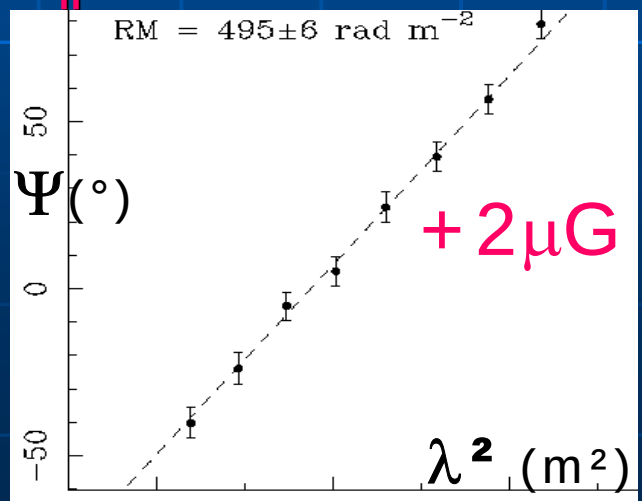
- Zeeman splitting

→ strength & sign of $B_\parallel$

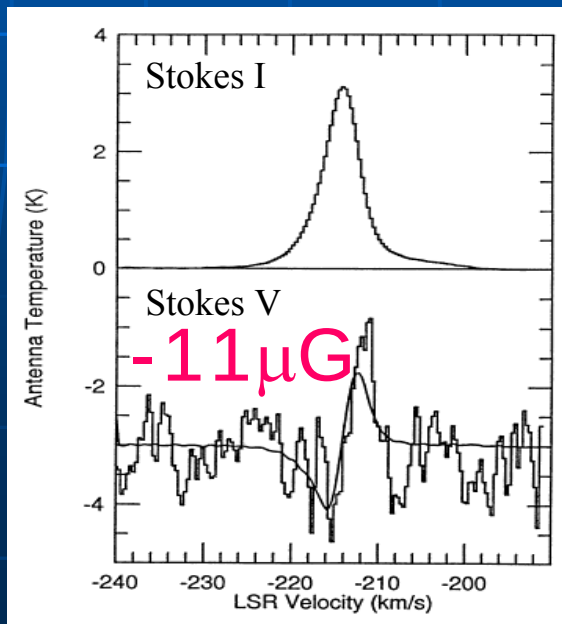


M51 (Fletcher & Beck 2004)



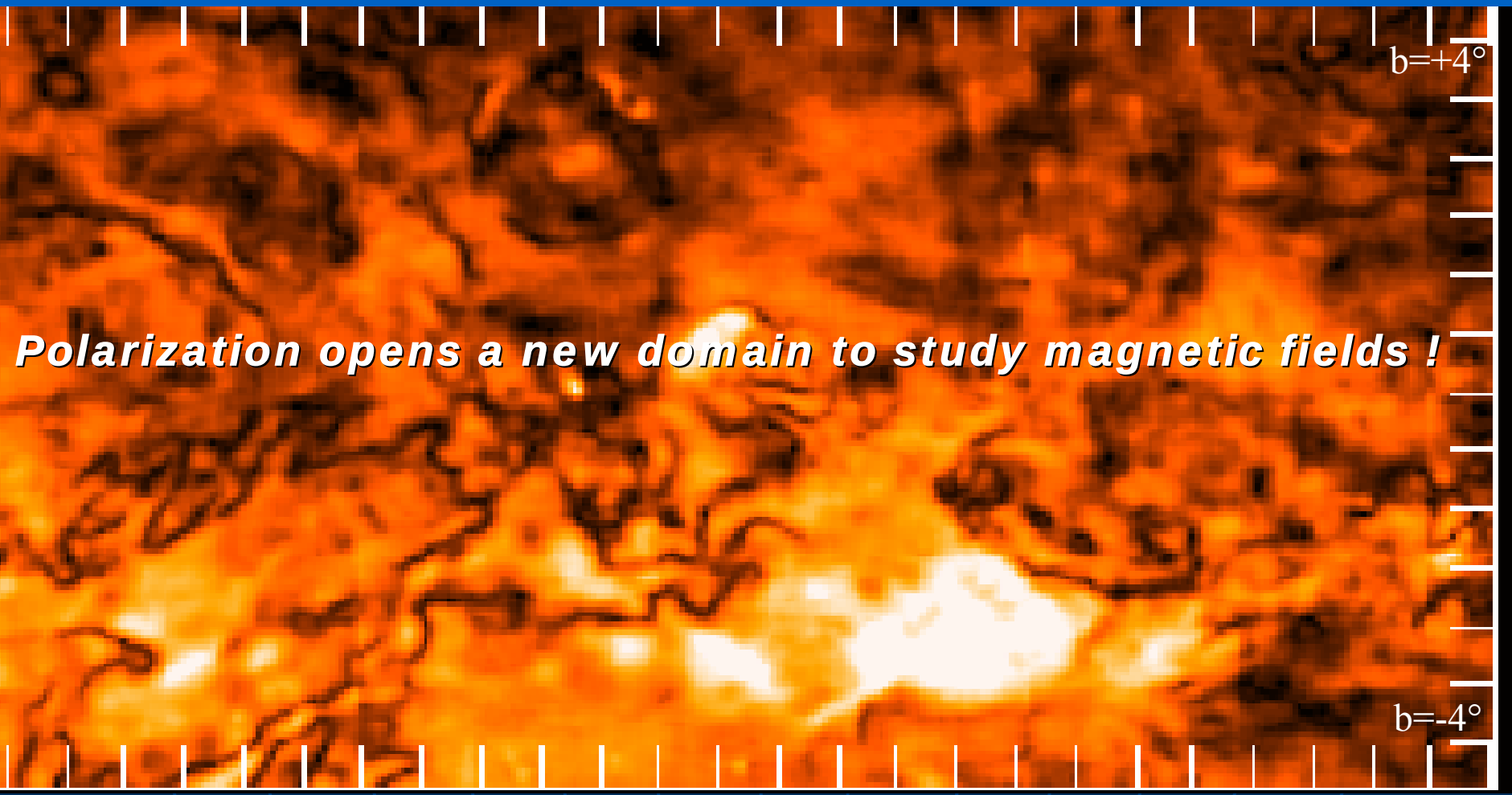


PSR B1154-62 (Gaensler et al 1998)

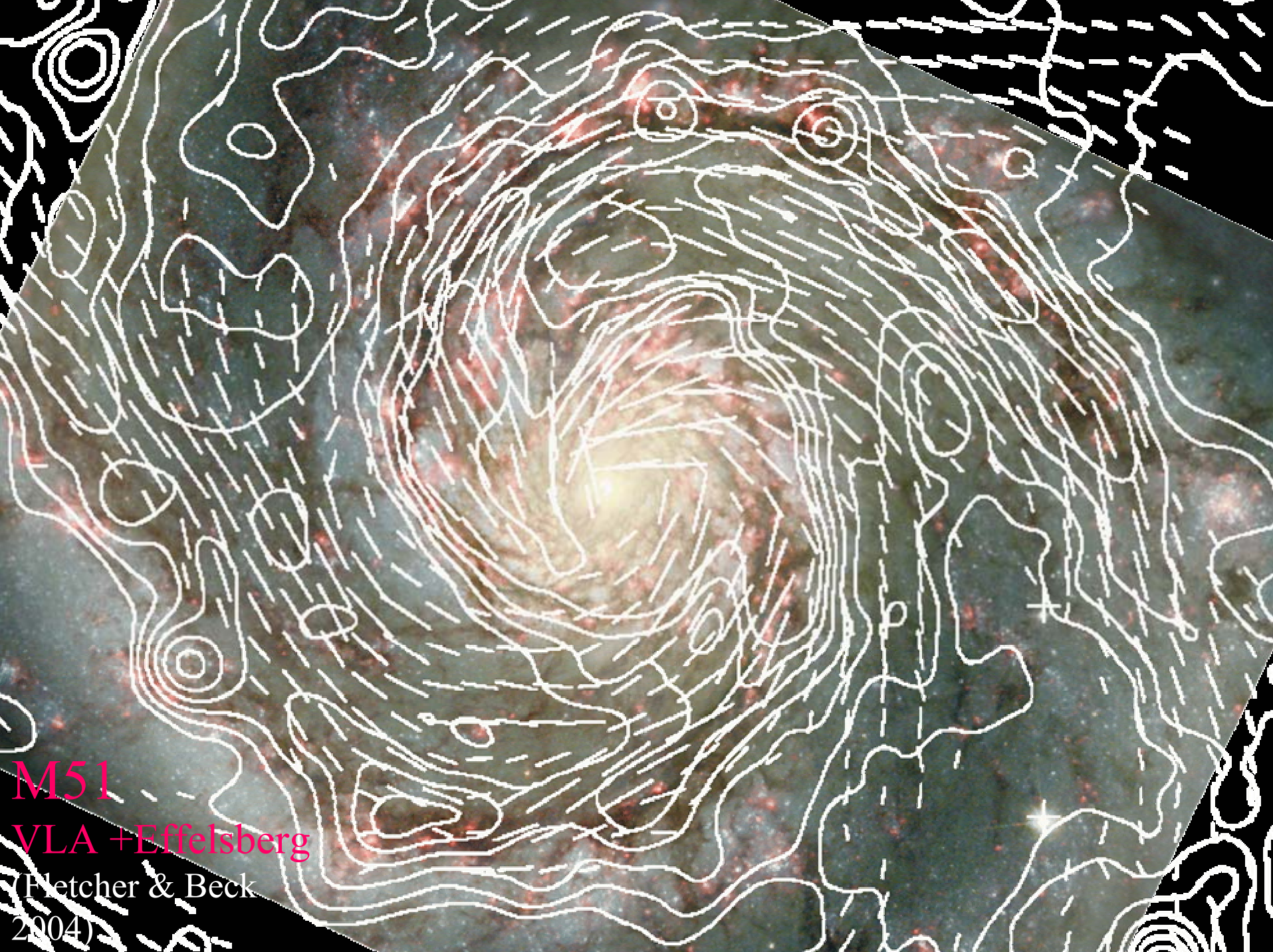


HVC 132+23-212 (Kazès 1991)

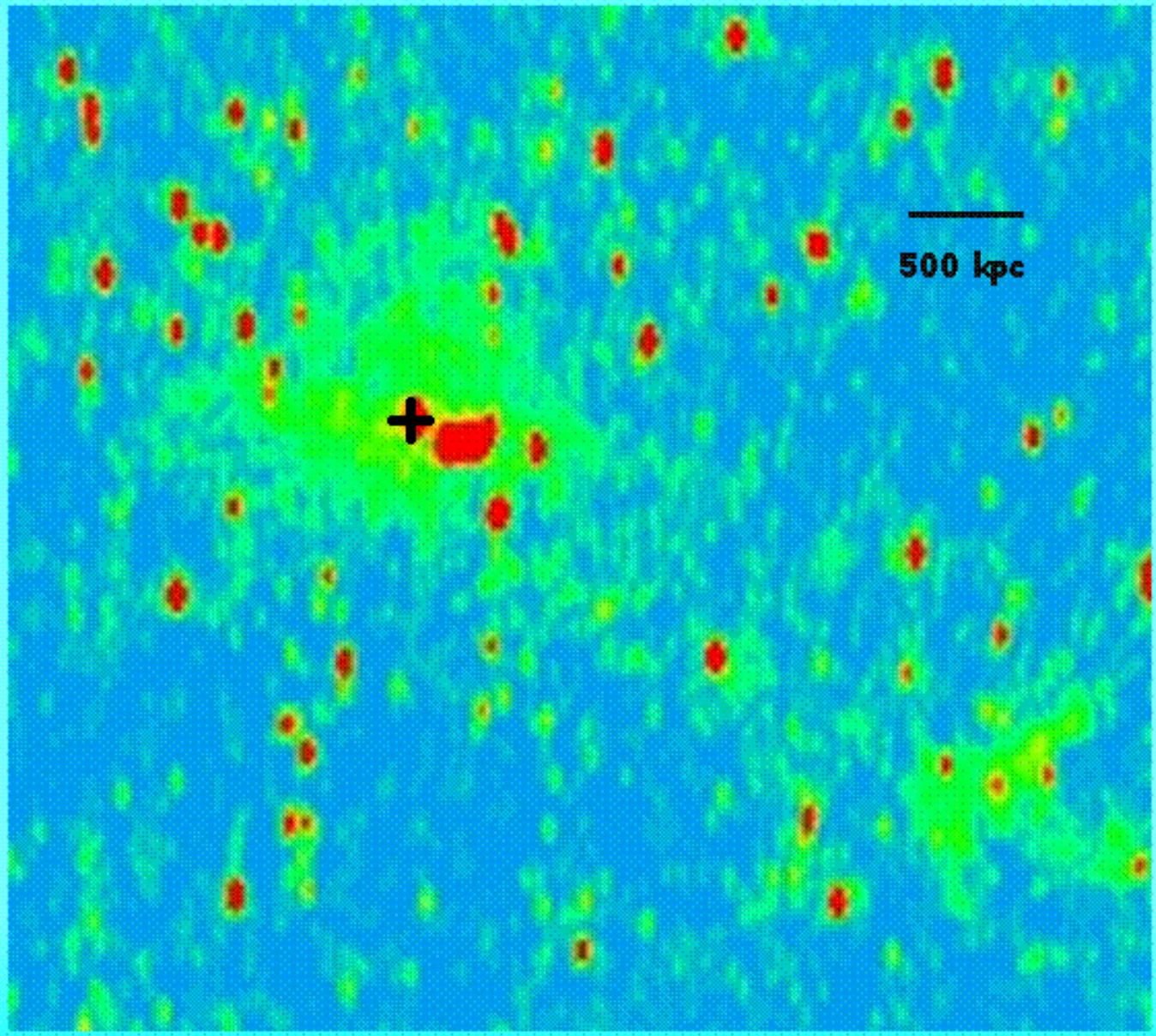
Synchrotron Emission from the Milky Way (Perseus - Auriga)



Polarized emission Total emission Effelsberg 21cm (Reich et al 2003)


M51
VLA +Effelsberg
(Fletcher & Beck
2004)

COMA Cluster

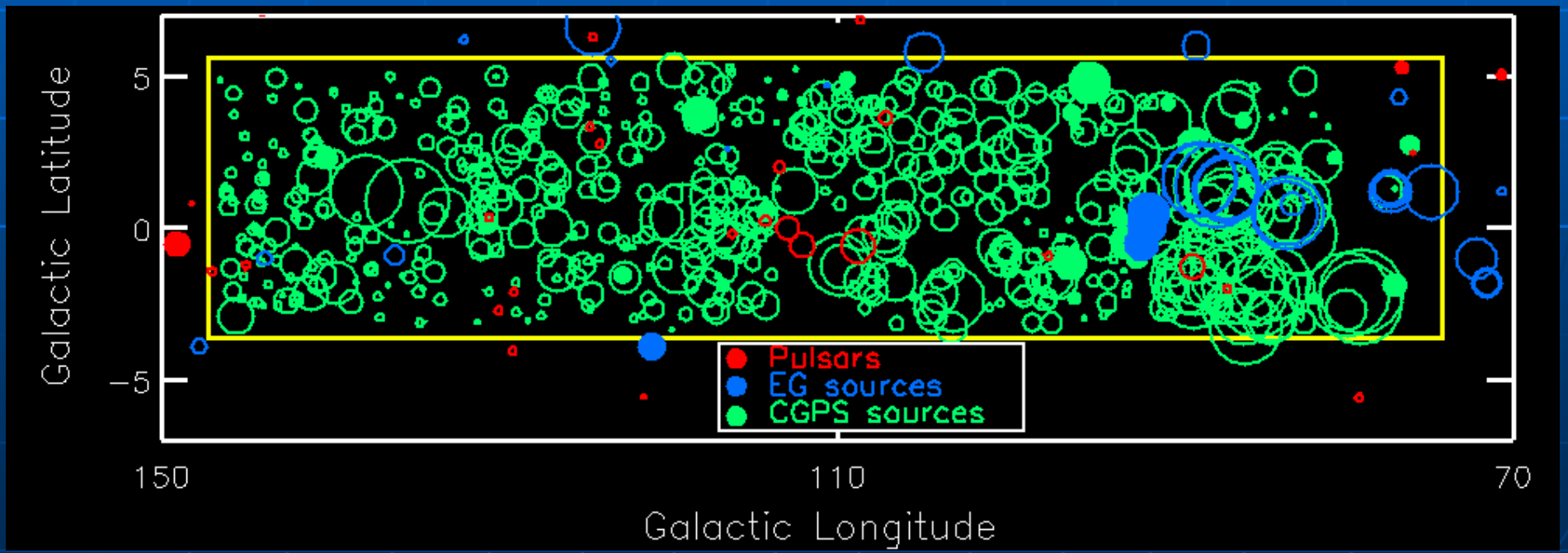


Center

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

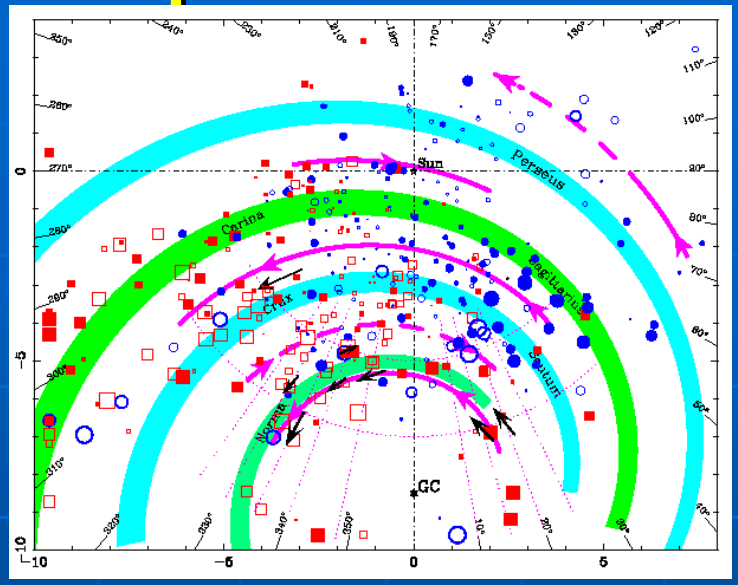
RMs of Background Sources

- Useful probe of *B* in the Milky Way, clusters, Ly-α absorbers, …
- Now: RMs of ~1200 polarized extragalactic sources + ~300 pulsars
- But: Sparse sampling at high |b| : ~0.03 source / deg^2
- Galactic plane surveys with ATCA, DRAO: ~2 src / deg^2
- New Effelsberg survey ($\delta > -20°$) : ~1500 new RMs, ~0.5 src / deg^2

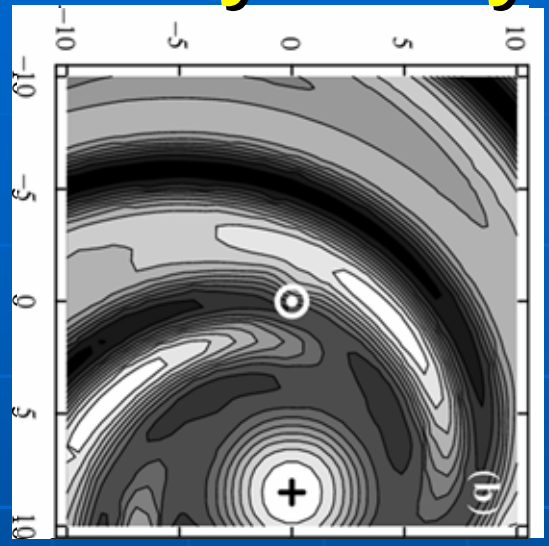


DRAO Canadian Galactic Plane Survey (Brown et al 2003, 2004)

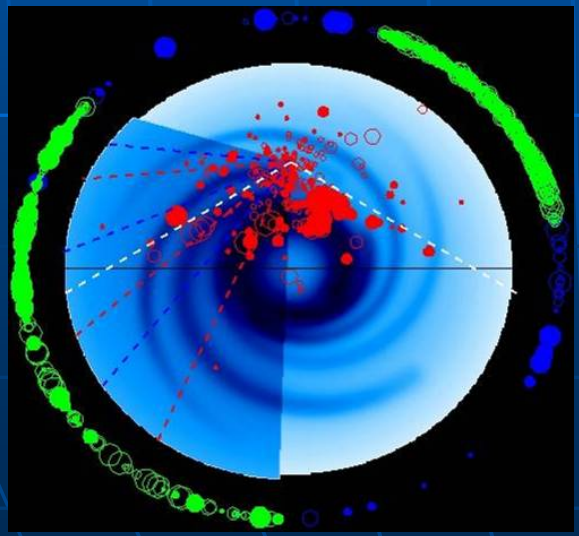
Spiral Arms in the Milky Way



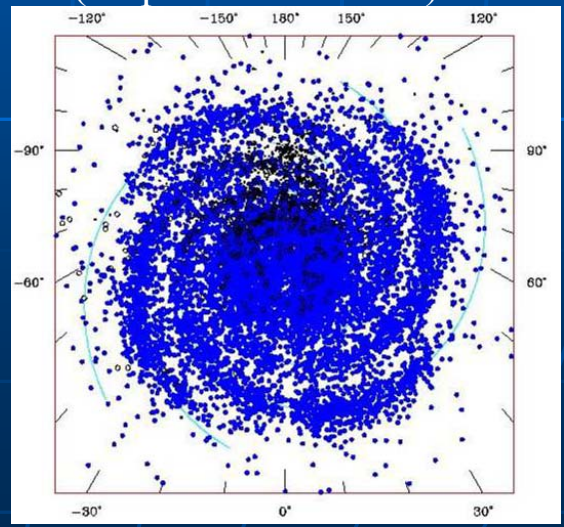
Pulsar RMs + field model (Han et al 2002)



Pulsar RMs + wavelet model (Stepanov et al 2002)

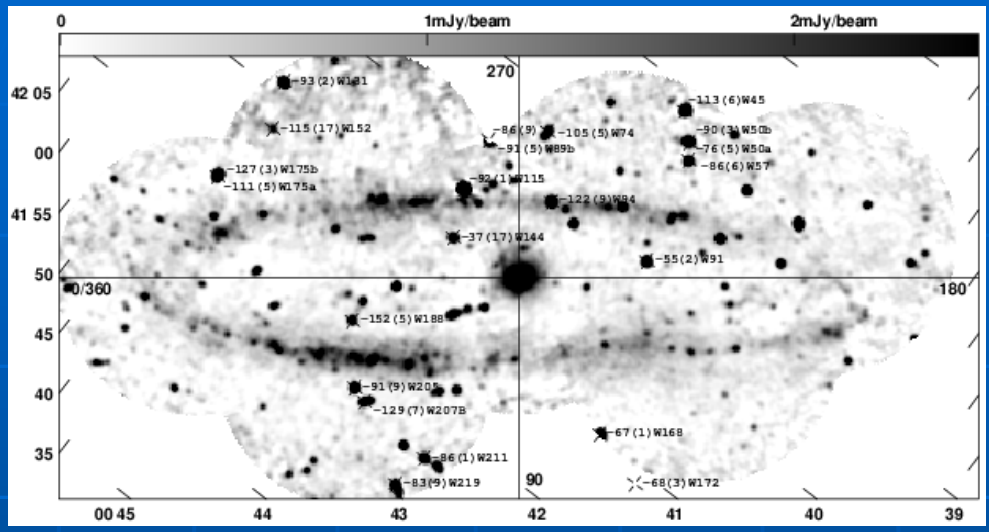


Pulsar + extragalactic RMs (Brown & Gaensler 2004)

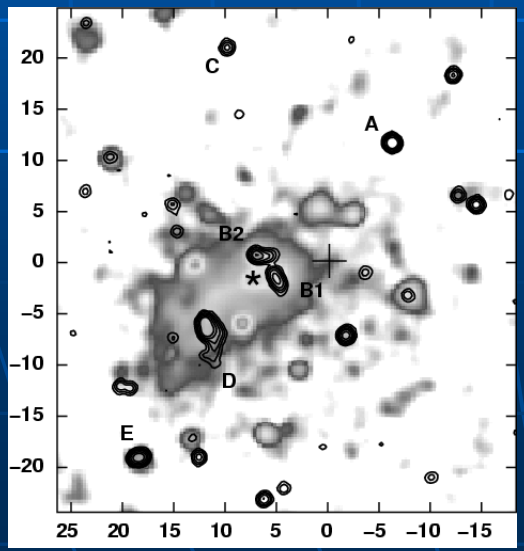


Pulsars to be detected with the SKA (Cordes 2001)

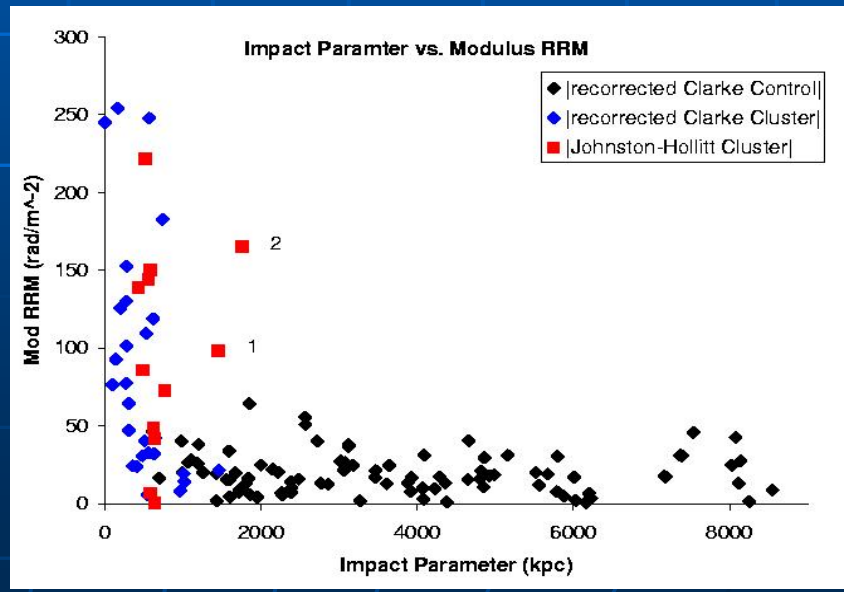
RMs Through Galaxies & Clusters



RMs of 21 polarized sources shining through M31 (Han et al 1998)

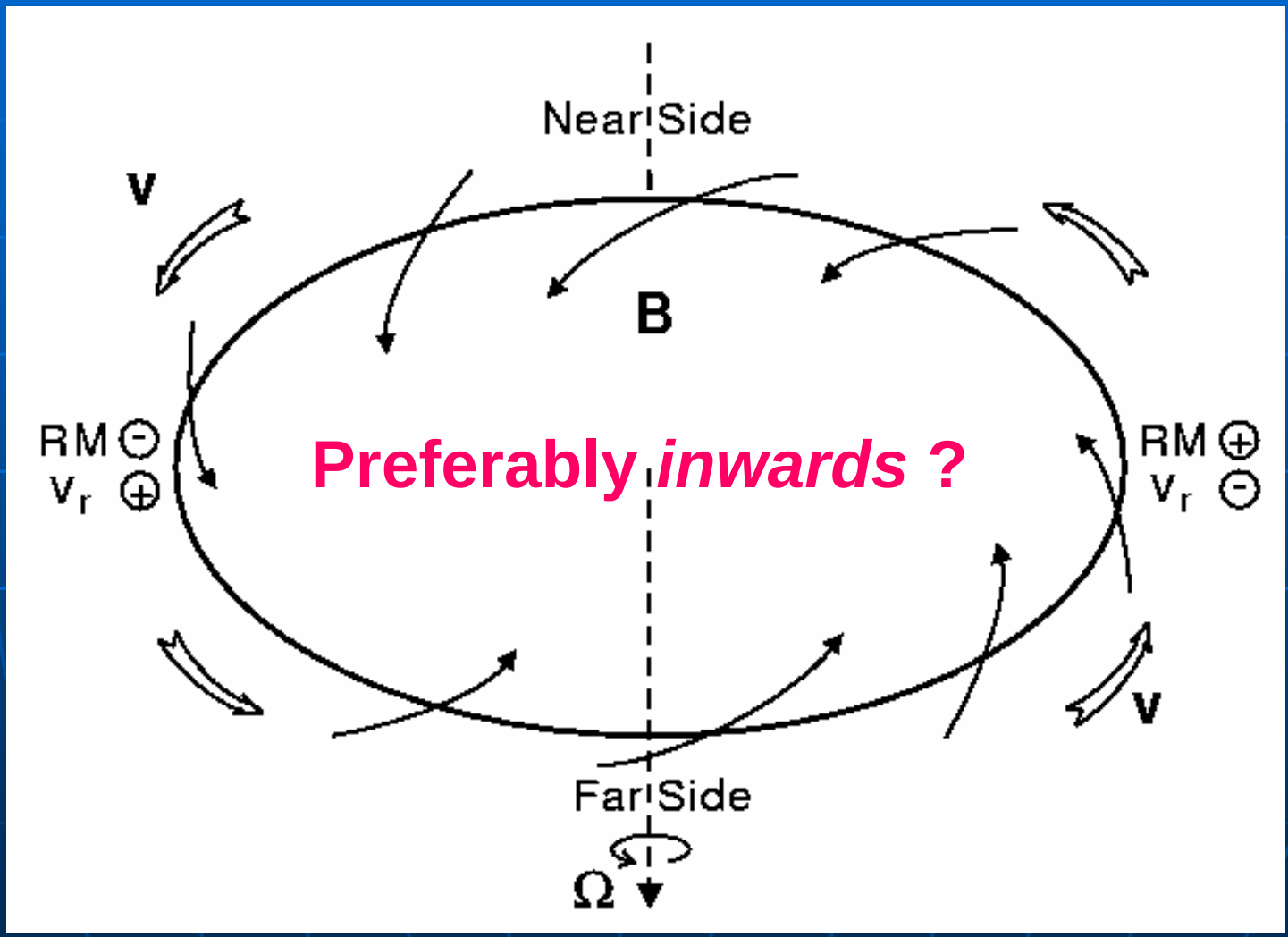


5 RMs through Abell 514 (Govoni et al 2001)



RMs through 30 clusters (Johnston-Hollitt 2003)

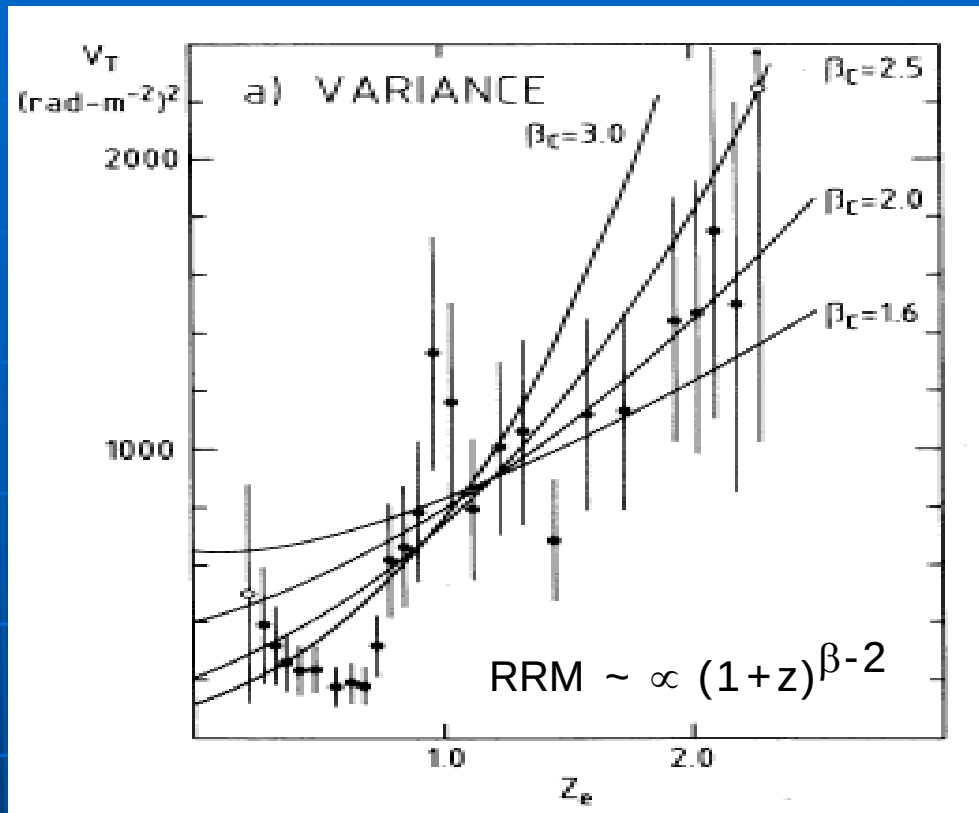
Field Direction in Spiral Galaxies



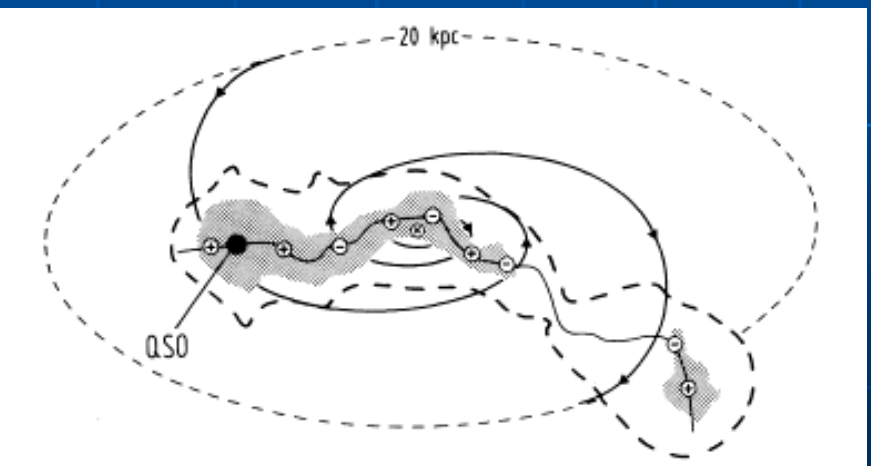
Krause & Beck (1998)

Galaxies at z = 0.1 → ~ 3

Radio emission and B vectors of the QSO PKS 1229-021 at z = 1.0 (Kronberg et al 1992)



Residual RMs of QSOs embedded in intervening clouds (Welter et al 1984)



Field model of the foreground spiral galaxy at z = 0.395 with B ~ 1–4 μG (Kronberg et al 1992)

Poor data !

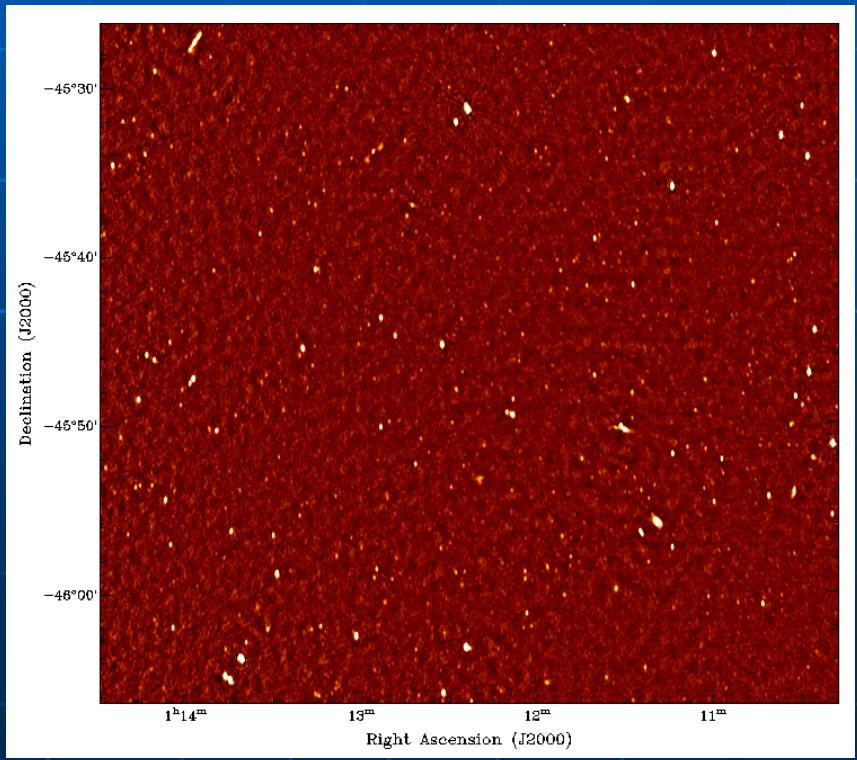
SKA All-Sky RM Survey

- Image the sky to S ≈ 0.1 μJy at 1.4 GHz ("**SKA FIRST**")
- FOV ≈ 1 deg^2 , 1h / pointing (~1 year total), ⟨p⟩ ≈ 5% :

→ RMs for ~ **(1–5) x 10^8** polarized extragalactic sources, spaced by only ~ 30"–50" on the sky!

plus:

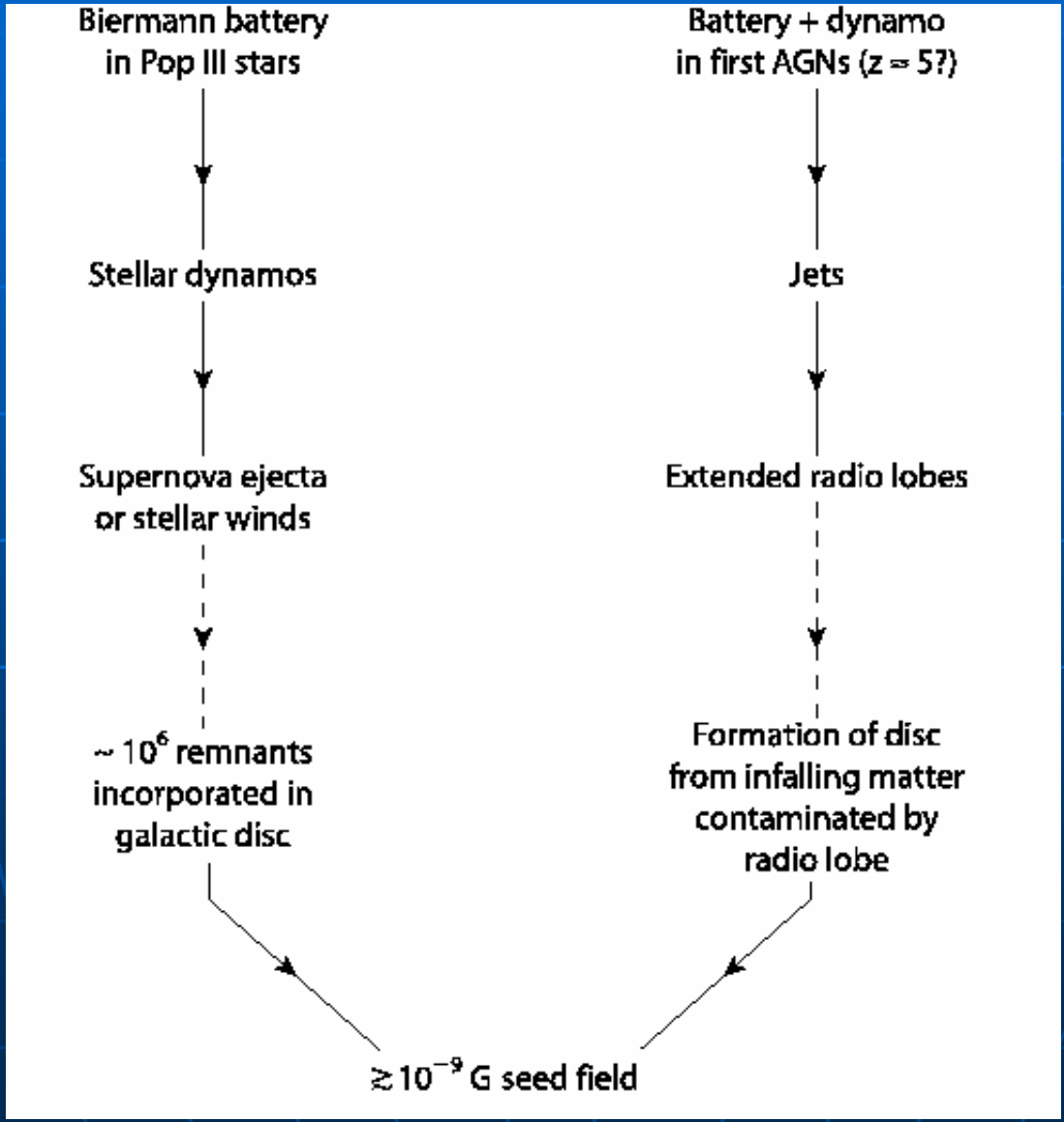
RMs of several 1000 Galactic pulsars and several 100 pulsars in nearby galaxies



Radio sources (total emission) in the ATCA Phoenix Deep Field (Hopkins et al 2003)

When and how were the first magnetic fields generated ?

Seed Fields from Young Galaxies ?

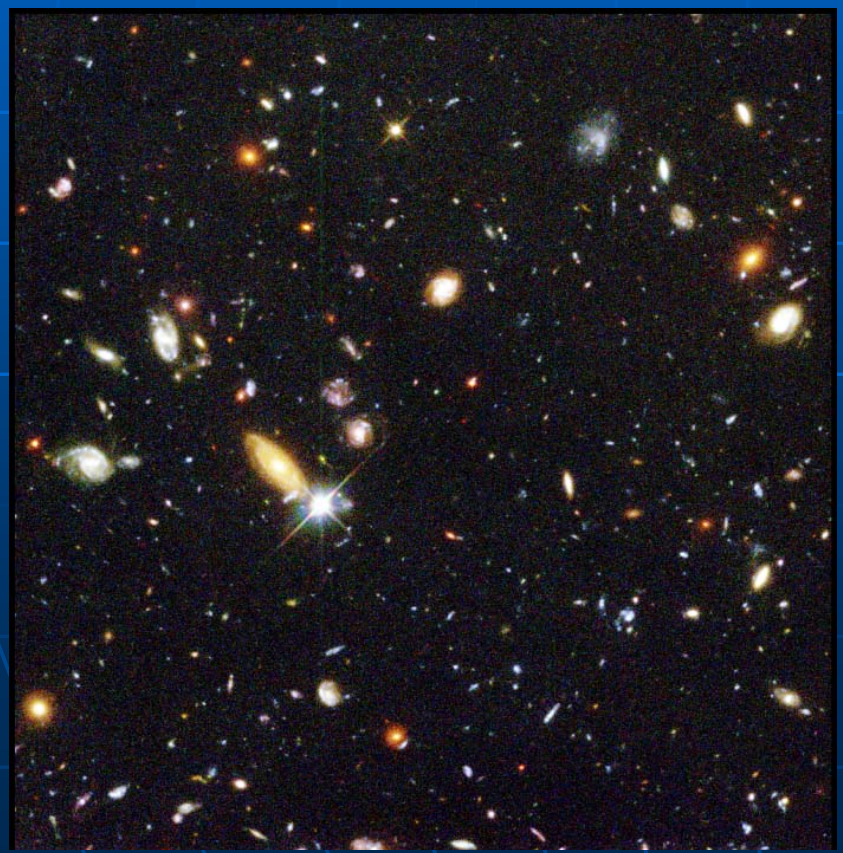


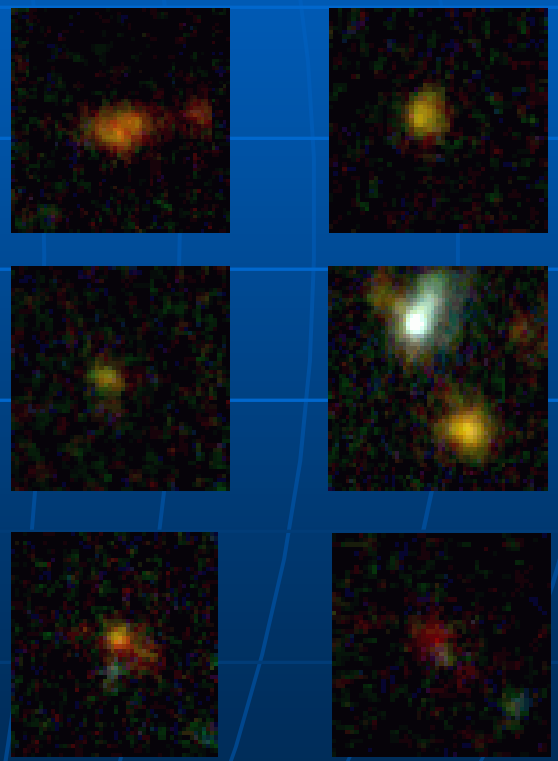
Rees (2004)

Magnetic Fields in Protogalaxies

"**SKA Deep Field**" :

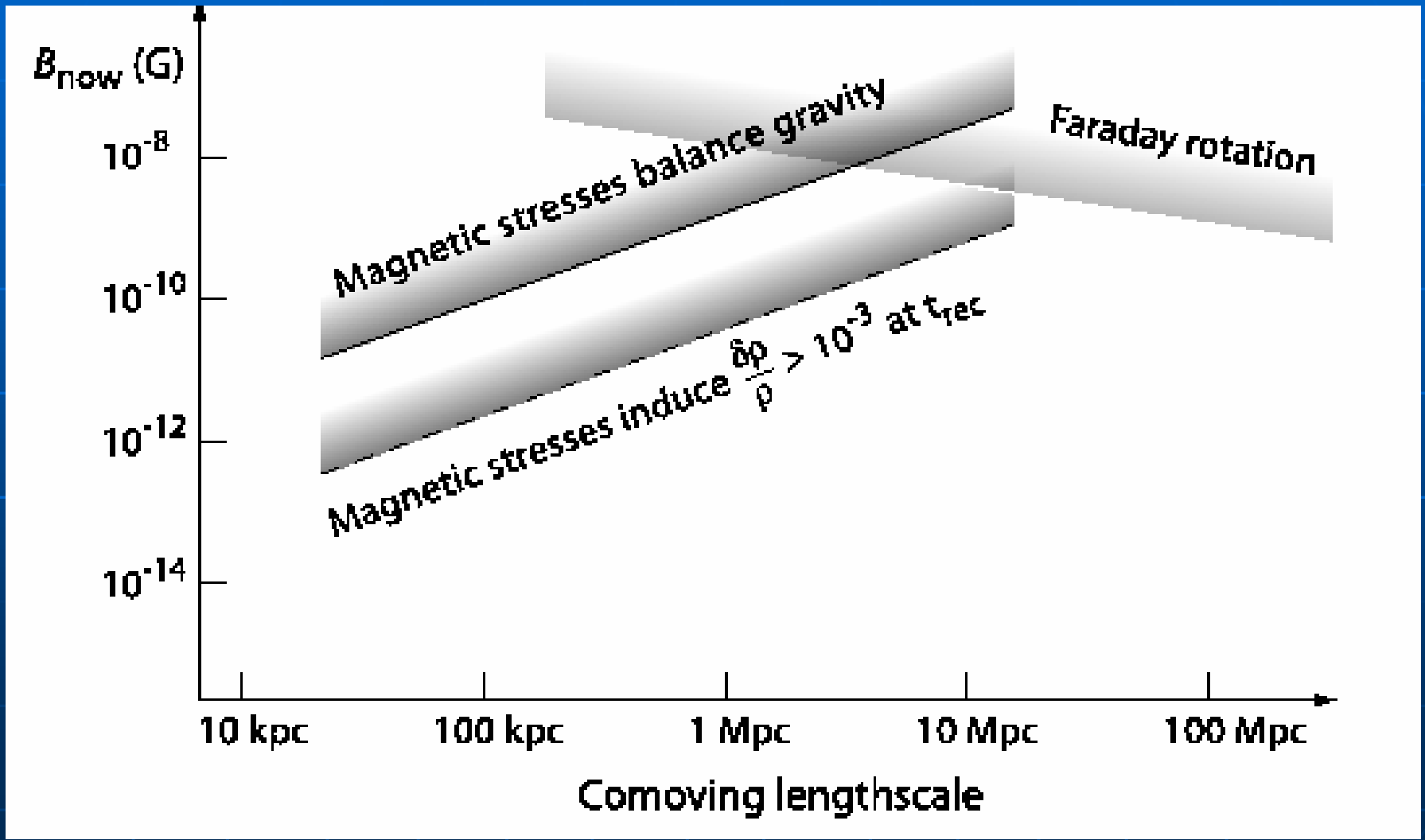
- thousands of "normal" spiral galaxies at z ~ 3 detectable with the SKA (1.4 GHz : size = 1 - 3" , flux ≥ 0.2 μJy)
- their radio flux strongly depends on field strength and on star formation rate (and may be polarized)





HDF galaxies with z > 4 (Driver et al 1998)

Dynamical Importance of Primordial Intergalactic Fields



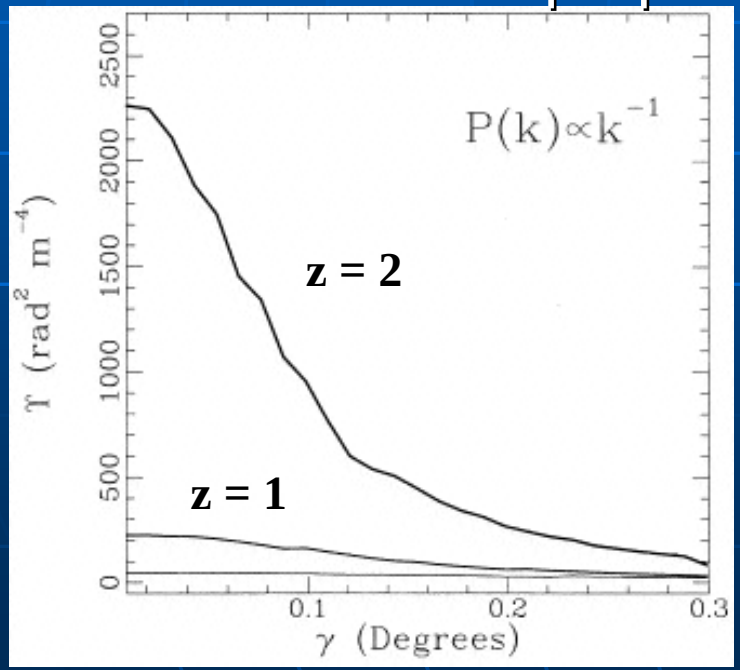
Rees (2000)

Primordial Fields

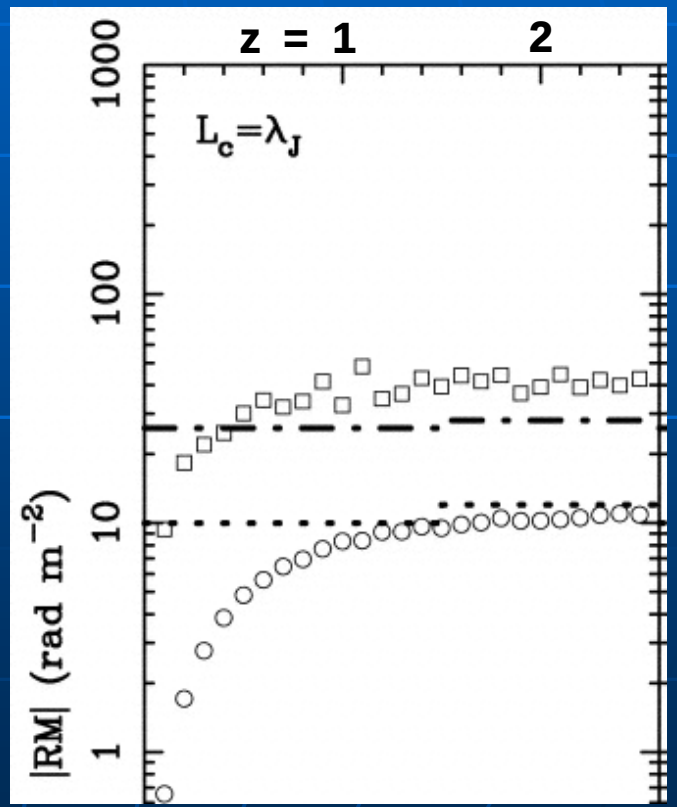
- Early primordial fields could have been generated by battery effects, during inflation or phase transitions
- A primordial intergalactic (IGM) field may have regulated structure formation in the early Universe
- Present-day fields of B ≥ 1 μG could have evolved from $B_0 \sim 10^{-9}$–10^{-10} G primordial seed fields at $z > 5$ by compression and dynamo action
- Upper limits of intergalactic fields from existing studies: $B_{IGM} < 10^{-8...9}$ G (model dependent)

Search for Primordial Fields

- The SKA All-sky Survey will provide a large sample of RMs
- Expected RMs from a homogeneous IGM field :
  $\lambda \propto (1+z)^{-2}$; $n_e \propto (1+z)^3$; $B \propto (1+z)^2 \rightarrow$ $RM_{IGM} \propto (1+z)^3$
- But: IGM fields are probably tangled
- Note: The Galactic foreground has to be subtracted properly



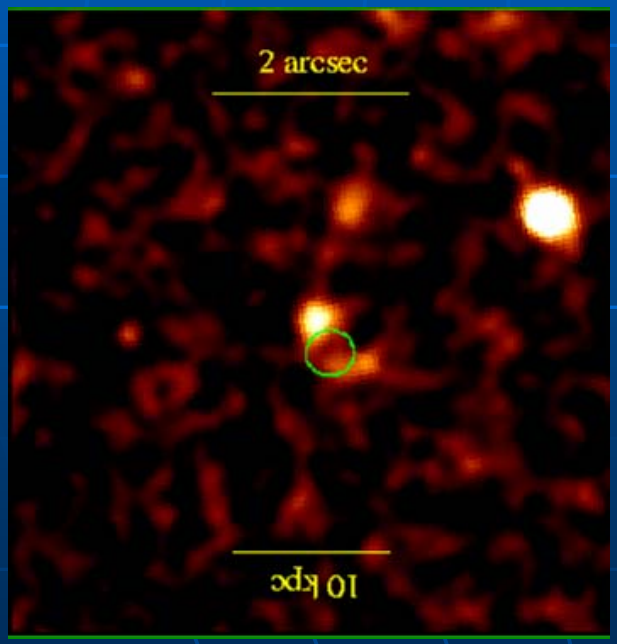
Two-point RM correlation function for B = 1 nG (Kolatt 1998)



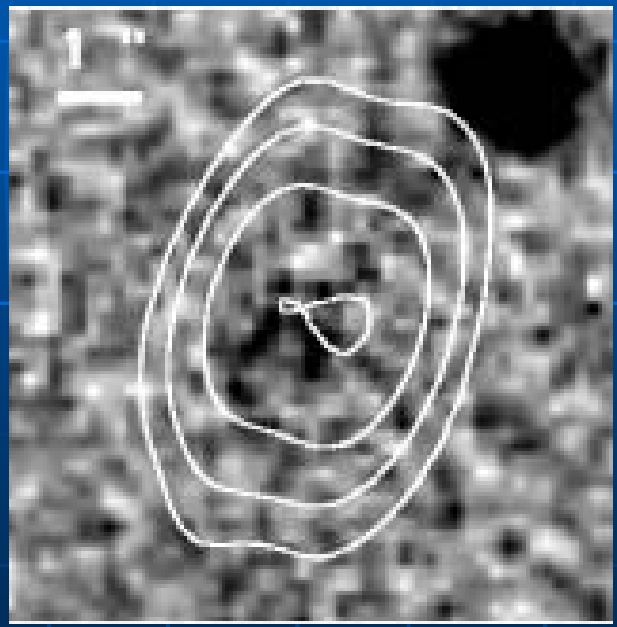
Mean and median RM vs z for B = 6 nG (Blasi et al 1999)

Search for Primordial Fields

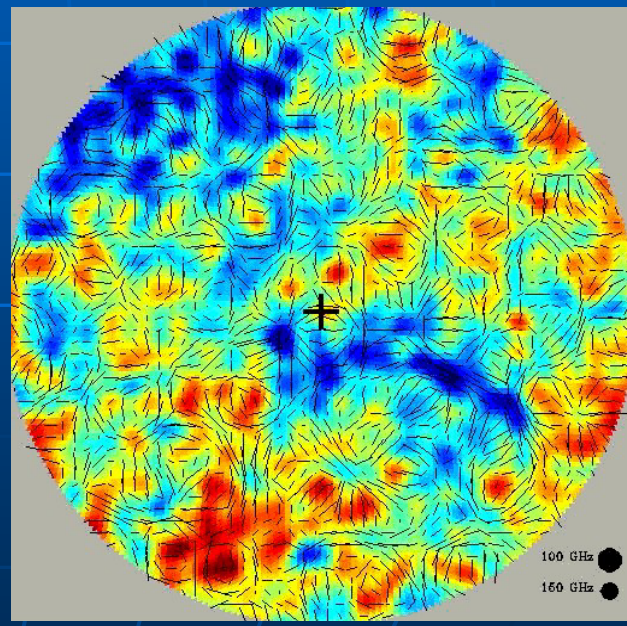
- RMs of GRB afterglows, high-z AGNs, high-z (radio) galaxies, and of the CMB :
- A CMB field of $B_0 \sim 10^{-9}$ G may be detectable as RM_{CMB} (Kosowky & Loeb 1996)



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



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



BICEP CMB
Polarization

SKA Specifications for Polarimetry

- Frequency: at least **1–10 GHz**, 0.3–20 GHz ideal
- Large field of view: **>1 deg^2** at a resolution of <1"
- High sensitivity: **< 0.1 μJy**, confusion limited
- Large bandwidth: **> 400 x 1 MHz** at 1.4 GHz
- Significant concentration (**> 50%**) of antennae in central core (~ 5 km)
- High polarization purity (**–40 dB** at field center, **–30 dB** at field edges)

Conclusions

SKA´s Magnetic Universe …

- **can address *unanswered questions* in fundamental physics & astrophysics**
- **is science which is *unique to the radio band and to the SKA***
- **will almost certainly yield *new and unanticipated results* !**