Using Pulsars to study the Magnetic Field in The Milky way

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MPIFR , Bonn (24th April 2003)

To find the magnitude of the magnetic field in galaxies one assumes that the cosmic rays or highly energetic relativistic charged particals are in equipartition with the magnetic field

$$B^2/8\square \quad V \sim E\_syn$$

where $B = B_u + B_t$

The magnetic field usually has a regular uniform component and a turbulent random component

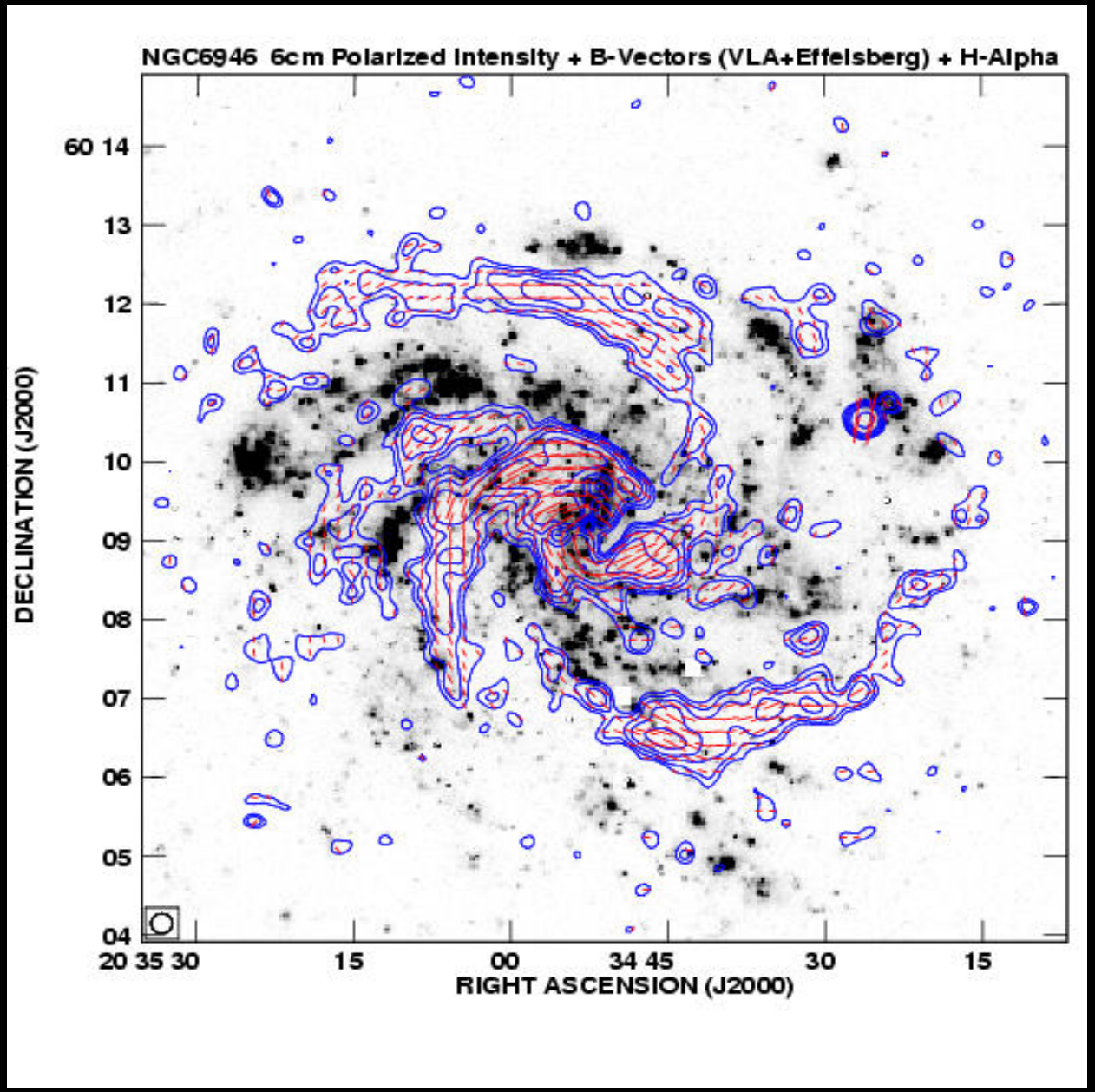
Relativistic particles moving along magnetic fields produces synchrotron emission which results in polarized emission

The regular component of the field can be seen as polarized intensity

The turbulent component tends to reduce the polarized intensity

As an example let us consider a real galaxy!!

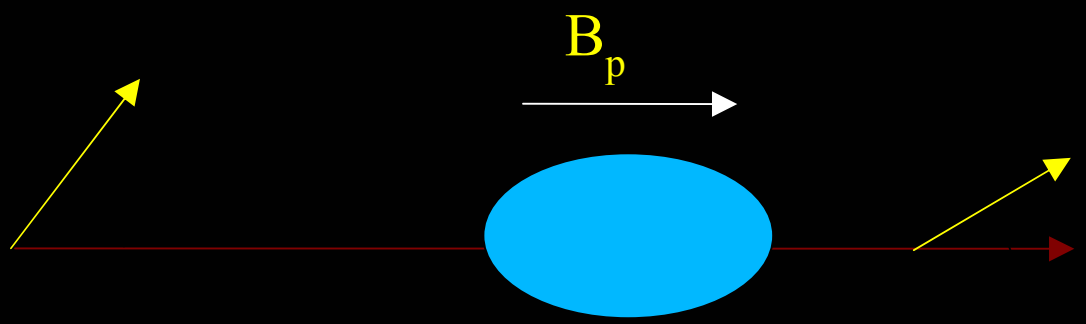
Magnetic Field in NGC 6946



- The optical arm (dark patches) have tangeled or turbulent magnetic field
- The inter-arm magnetic field follows a regular pattern with a magnitude of about 10 μG

(Beck 2001)

The direction of the magnetic field can be found by measuring Faraday rotation (expressed as rotation measure RM)

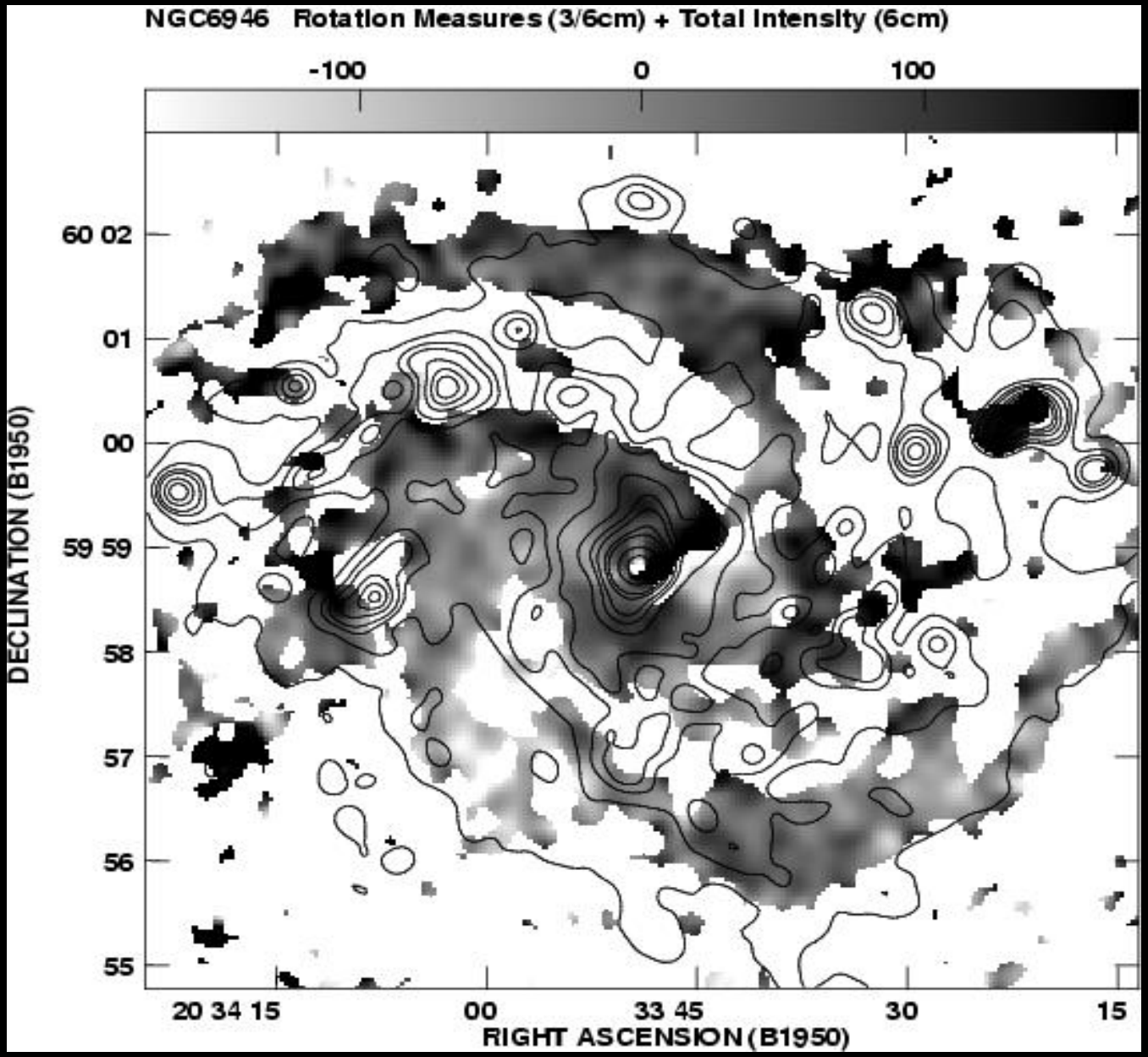


The electric vector rotates by an amount after passing through a magnetoionic plasma. The amount of rotation is given by RM as ,

$$RM = 0.81 \int_0^L n_e B_p \, dl$$

The sign of RM gives the direction of the magnetic field

ROTATION MEASURE MAP



(Beck 2001)

Norther half has +ve RM

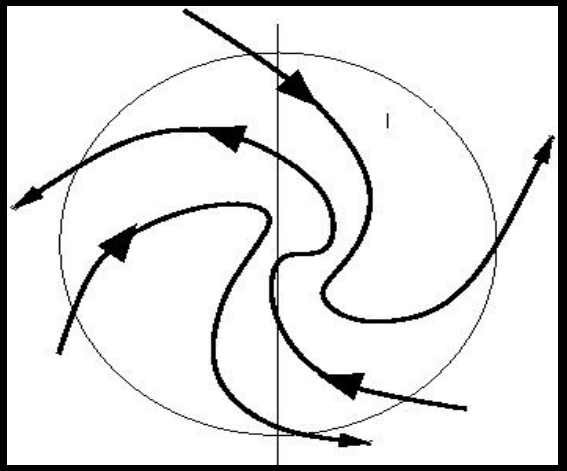
Southern half has -ve RM

This galaxy is thought to have an axisymmetric structure !!

ORIGIN OF MAGNETIC FIELDS:

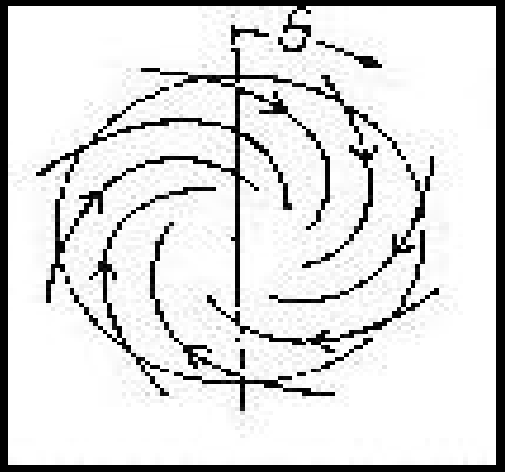
A tremendous potential difference of $\sim 3 \times 10^{12}$ volts is required to build up a field of 10^{-6} G over a 10 kpc scale over a period of 10^{10} years.

Relic or Primodial Field Hypothesis
Cosmological Magnetic Field



Bisymmetric

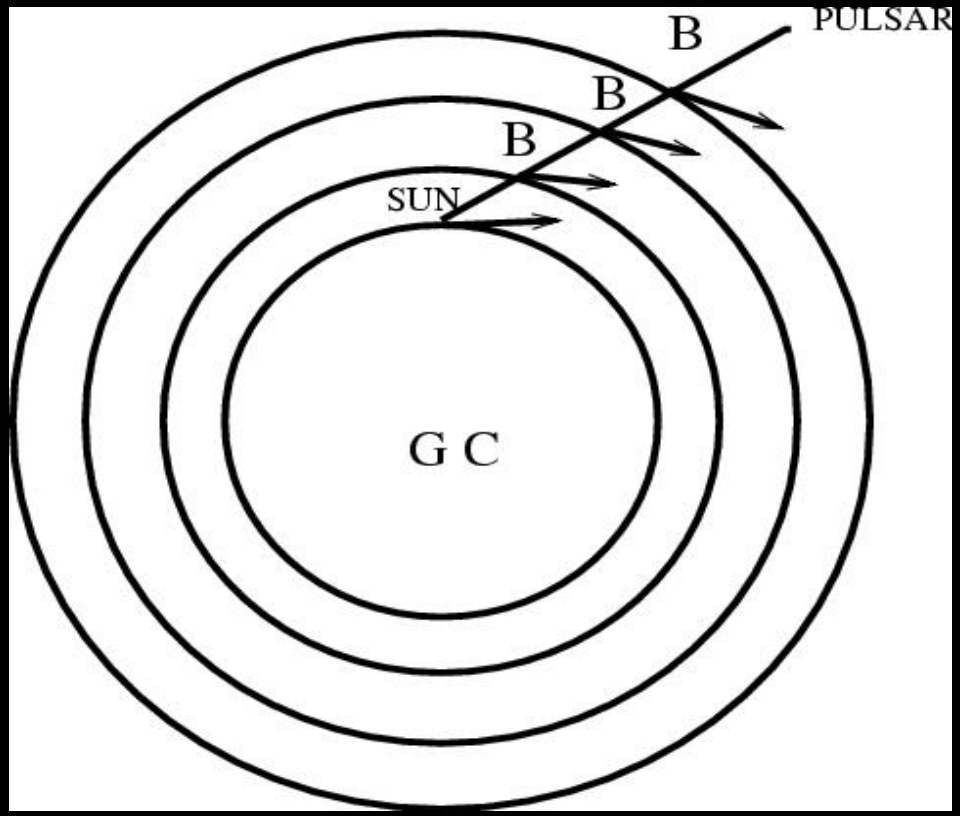
Stellar Ejections
The Dynamo



Axisymmetric

What kind of tools are necessary to study the Galactic magnetic field ?

Objects which are **highly polarized**
distances known
distributed uniformly in the Galaxy



Pulsars which are rotating neutron stars turns out to be the most ideal probe of the Galactic magnetic field as they satisfy all the above criteria.

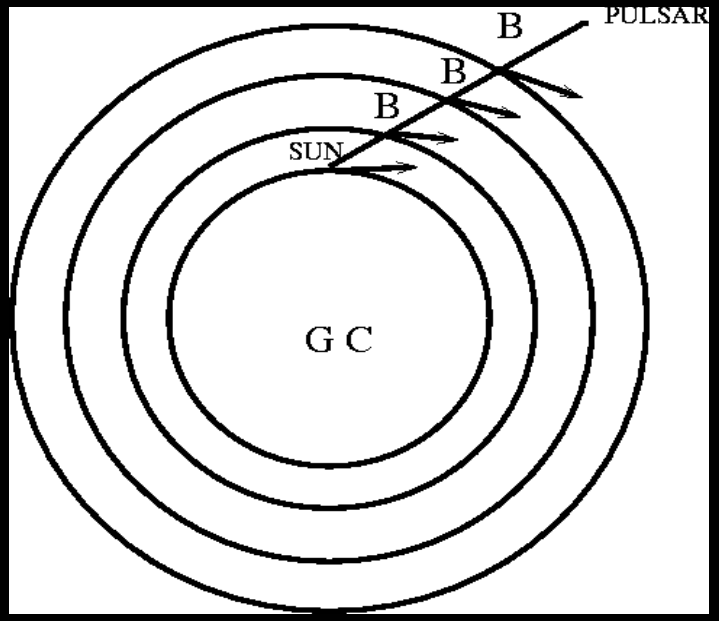
Magnetic Field in the Milky Way using Pulsars as probes

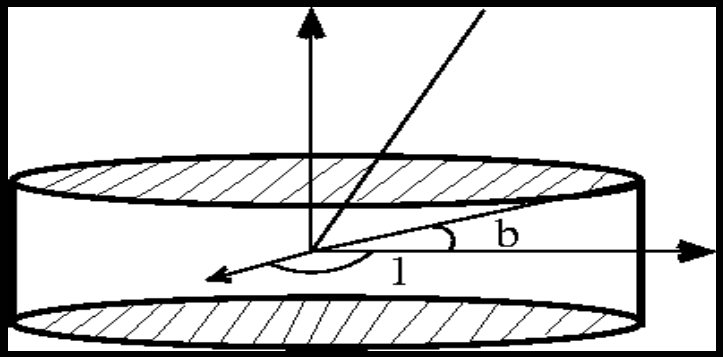
Average Parallel Component
of the Magnetic field

$B_p = 1.232 \quad RM / DM$

$$RM = \int n_e \; B_p \; dl$$

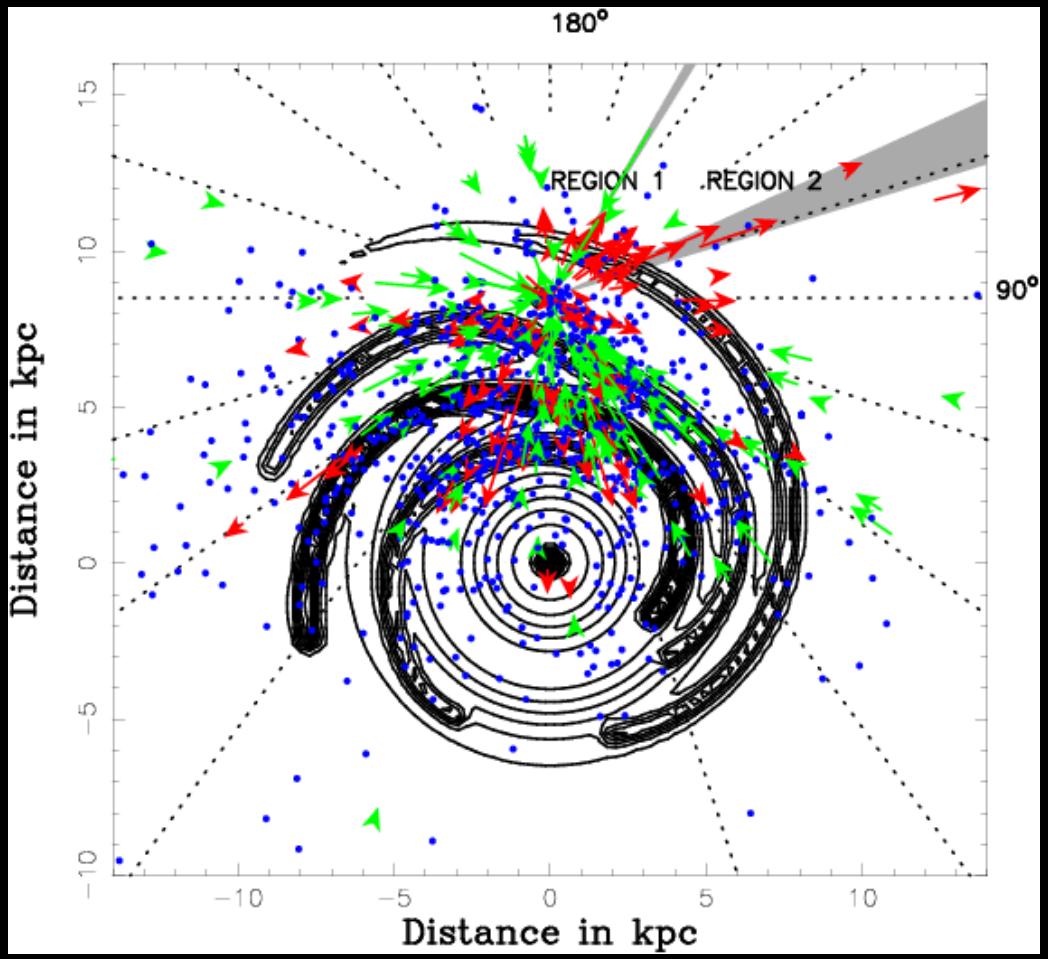
$$DM = \int n_e \; dl$$





Out of 1500 Pulsars Discovered, RM exists for only 350 objects !!!

RM Distribution in the Galactic Disk



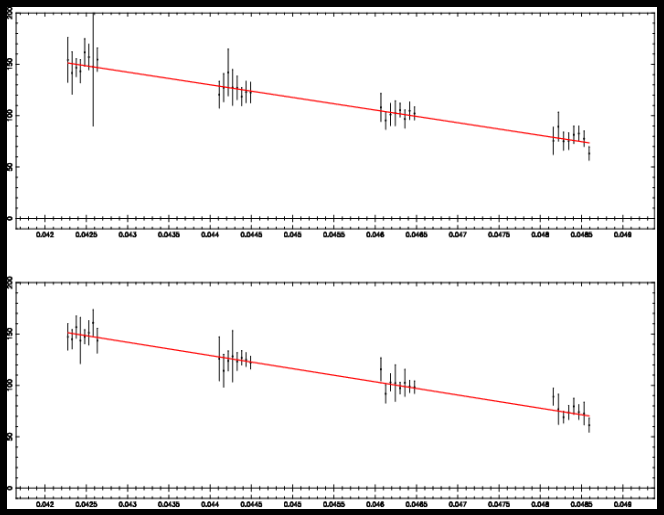
We have obtained new RM for 25 Pulsars using the Effelsberg Radio Telescope !!!

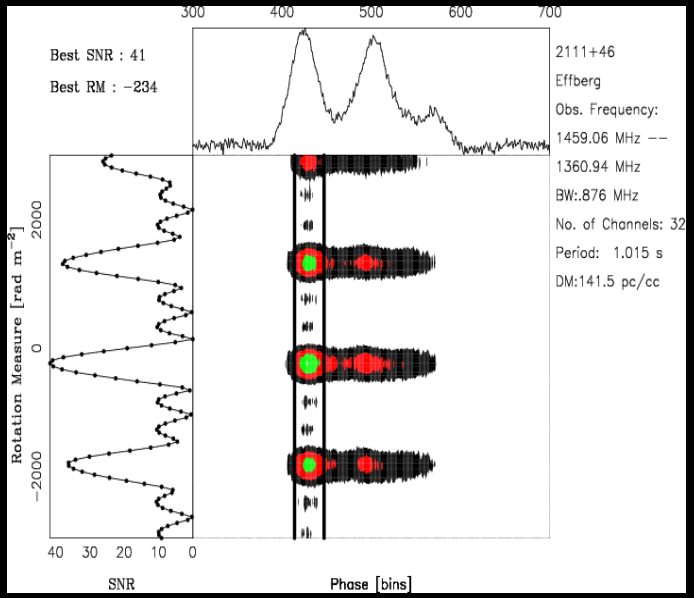
Mitra, Wielebinski, Kramer, Jessner 2003

Measuring pulsar RM's:

$$PA = RM\ \lambda^2 + PA_o$$

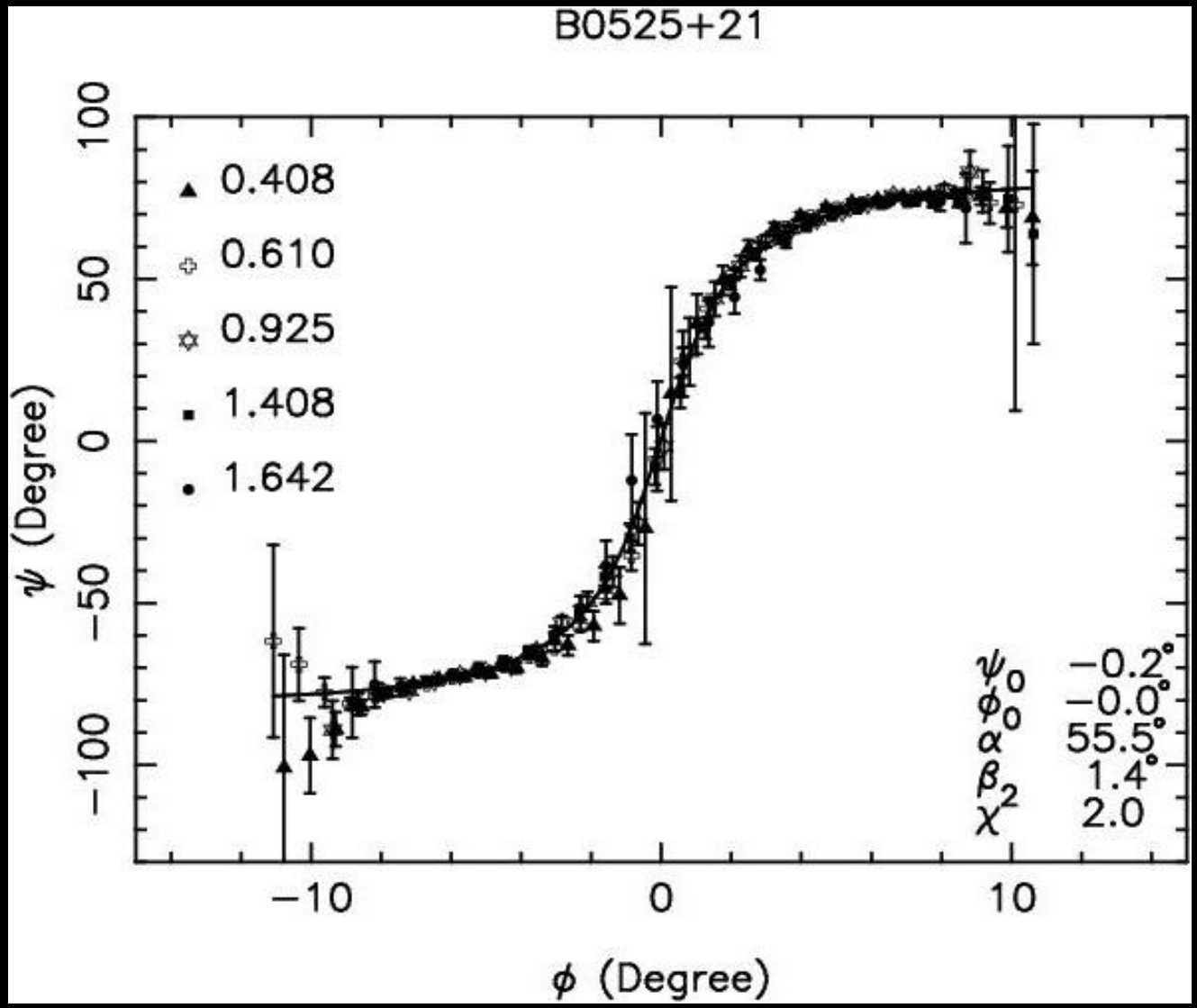
RM obtained by maximizing linear polarization





Many pulsars have almost zero RM suggesting negligible intrinsic contribution.

NO ROTATION MEASURE VARIATION ACROSS THE PULSE PHASE IS OBSERVED



(Li et al 2003)

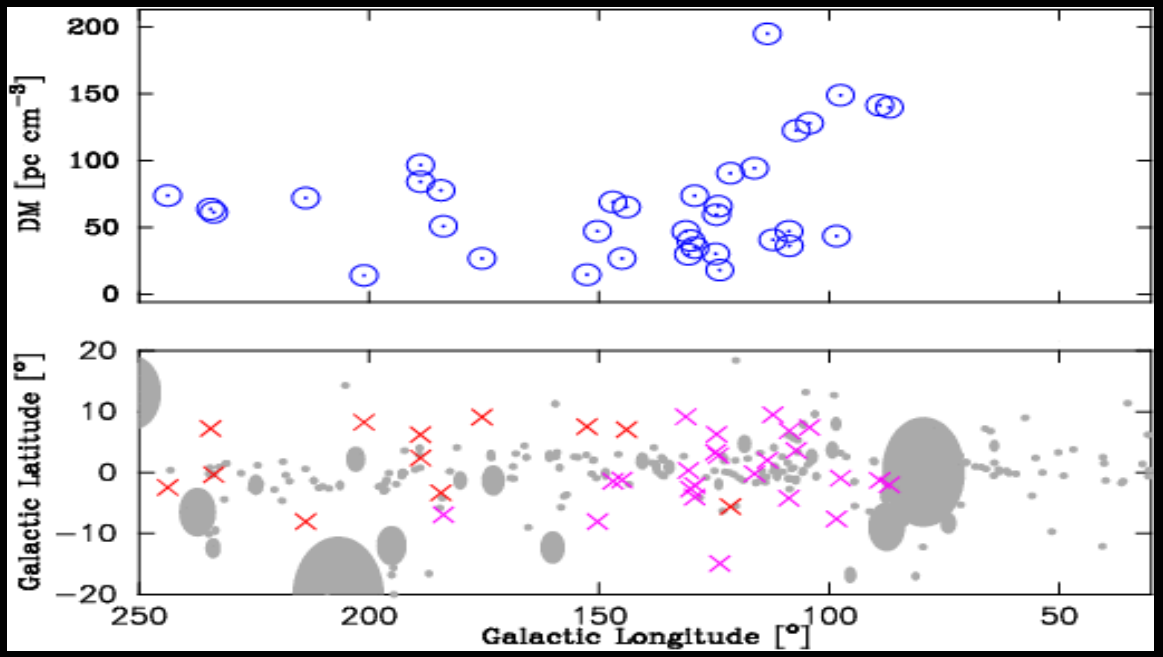
RVM

Radhakrishnan & Cooke (1969)

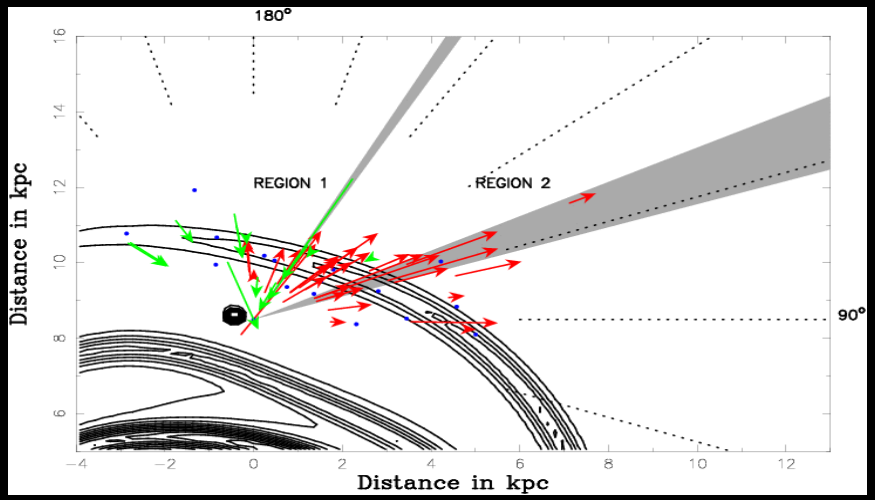
The emission arises from purely dipolar field, and particles are highly rigid, or relativistic!!

The Perseus Arm : $85^o < l < 240^o$

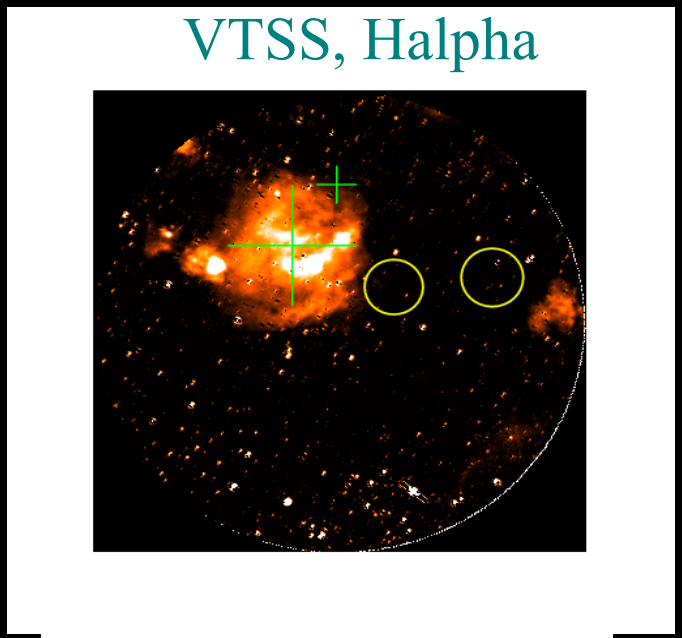
Pulsars & HII regions

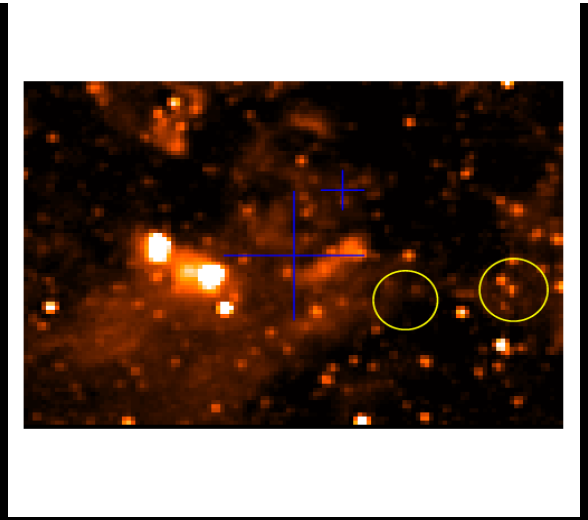


(Sharpless 1959)



Effect of HII Regions on Pulsar RM: (Region 1)





21 cm (Reich et al. 1997)

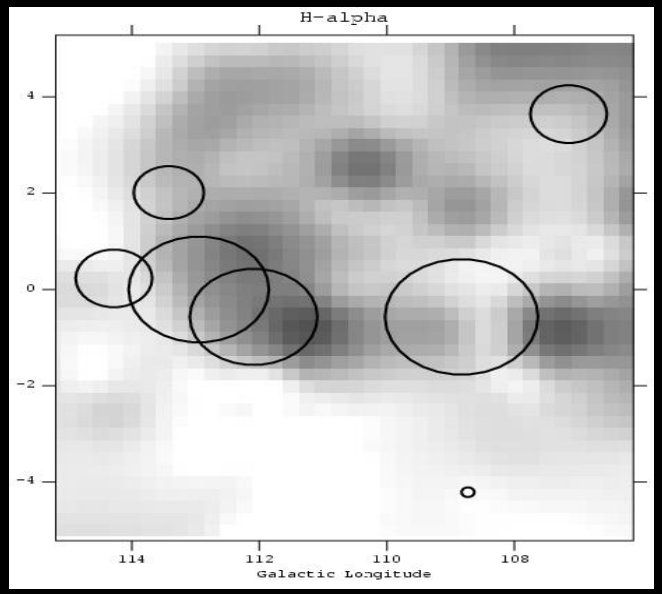
The HII region S205 strongly affects RM of Pulsars located behind it.

For Psr J0357+523 the following properties are observed:

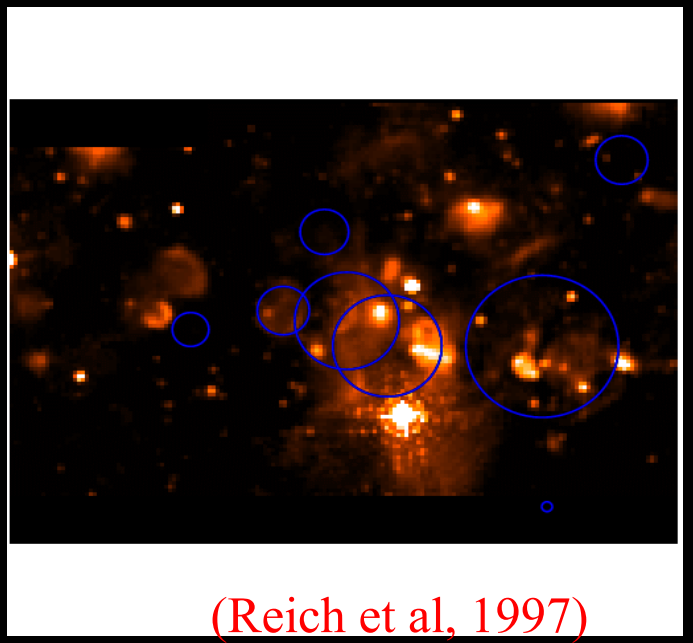
- Sign of RM is reversed
- RM increases by 250 rad m^{-2}
- DM increases by 50 pc/cc
- EM increases by 90 pc cm^{-6}
- Estimated magnetic field 5 μG
- Pulse is scatter broadened

Effects of HII cont....: (Region 2)

Wham , Halpha



21cm



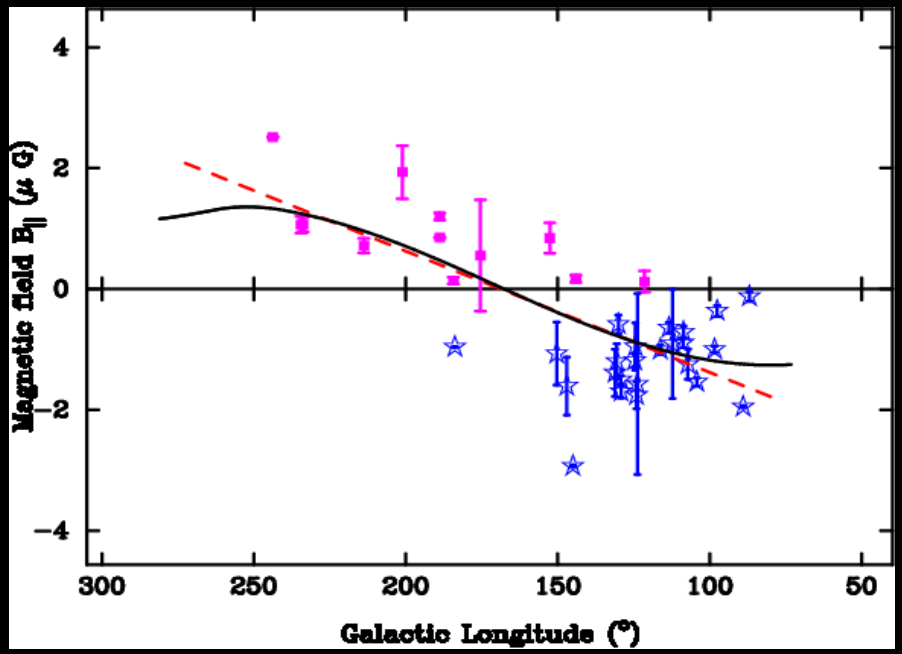
(Reich et al, 1997)

This is a complex of HII regions.
Sudden anomalous increase of RM, DM & EM is observed.

MODEL FOR THE INTER-ARM MAGNETIC FIELD

Consider a model where a constant magnetic field B_o follows the local Perseus arm , with a phase lag θ_o

Note: Pulsars affected by HII regions and supernova remnants are excluded !!



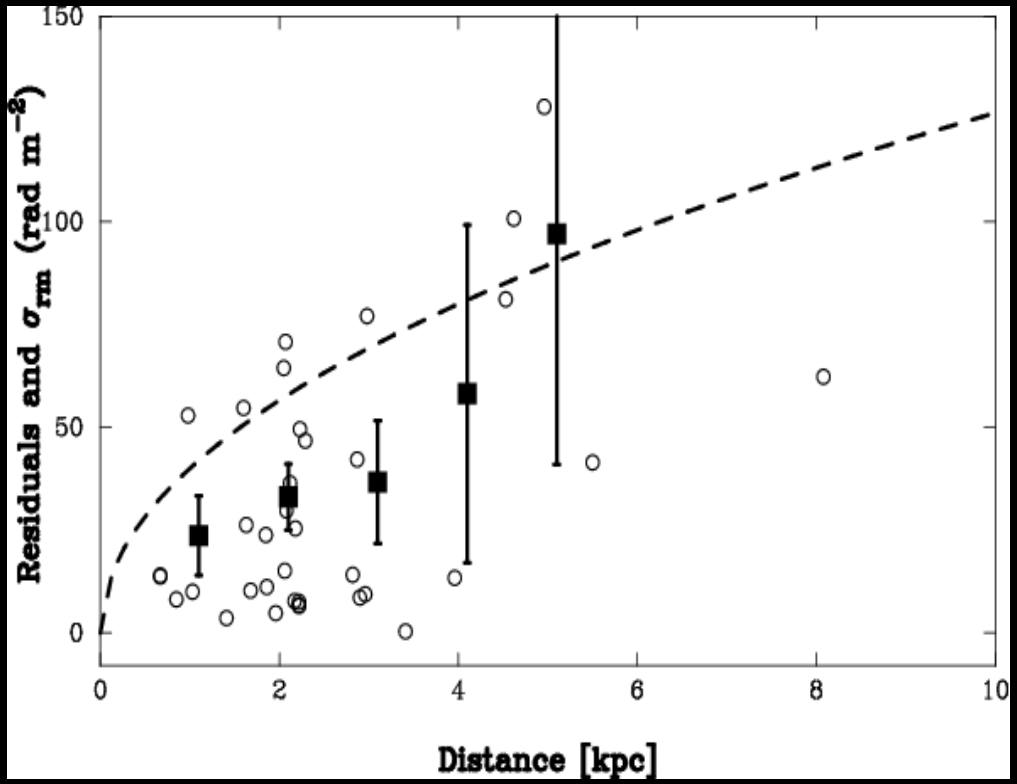
- B^o = 1.7 +/- 1 μG
- Θ^o = 12° +/- 8°

The large scale magnetic field of the Milky way seem to behave in a similar manner as other spiral galaxies: i.e.
the magnetic arm follows the local spiral arm with a slight phase offset.

Effect of fluctuation of magnetic field and electron density on pulsar RM

For a gaussian random fluctuation of B, ne and L

The residual RM is: $\sigma_{rm} = 0.81\ \delta ne\ \delta B\ (L\ D)^{0.5}$



Mean of the distributions

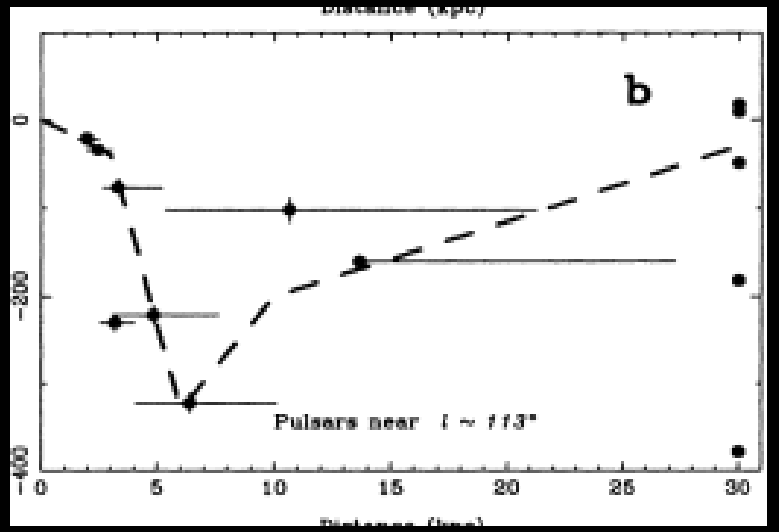
- $\delta n_e \sim 1\text{ -}5\ cm^{-3}$
- $\delta B \sim 1\text{ -}10\ \mu G$
- $L \sim 50\text{ -}100\ pc$

Field Reversals towards the Perseus Arm

- Pulsars gives information of B upto 5 - 6 kpc
- Extragalactic sources are needed to find B in the outer Galaxy

Earlier studies suggests field reversal towards the Perseus arm beyond 6 kpc

(Han et al 1999)

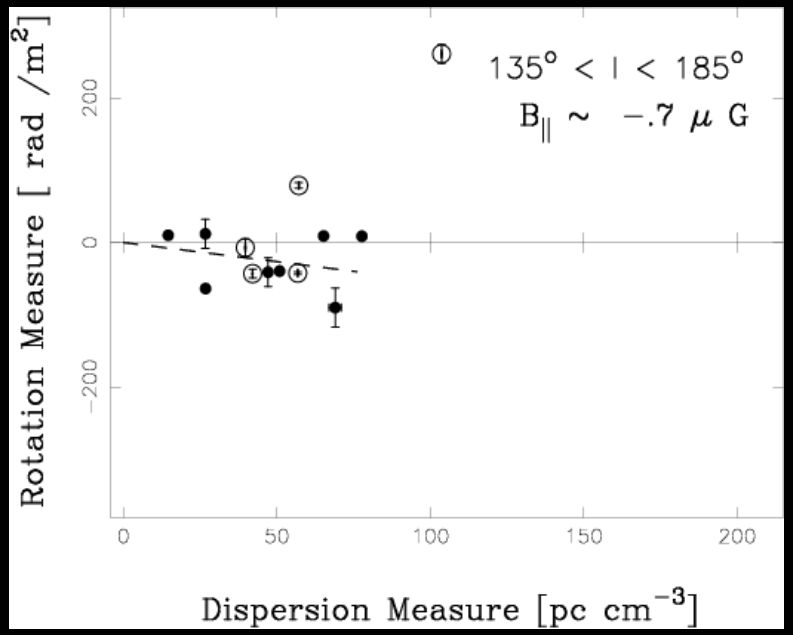


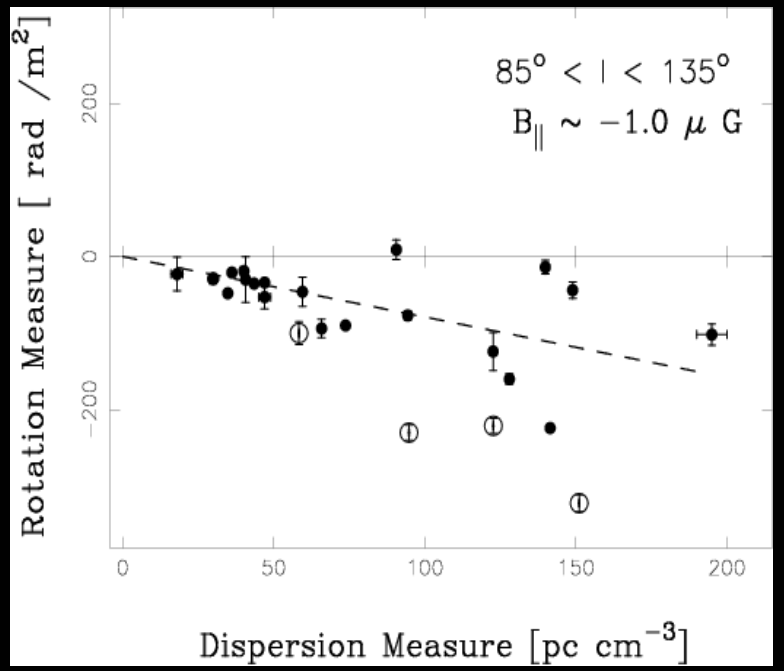
Caveats:

Few EG sources were available within b < | 10º |. (Brown et al 2002)

Effect of HII regions are not taken into account.

Pulsars which were used to claim Galactic reversal lies behind HII regions.



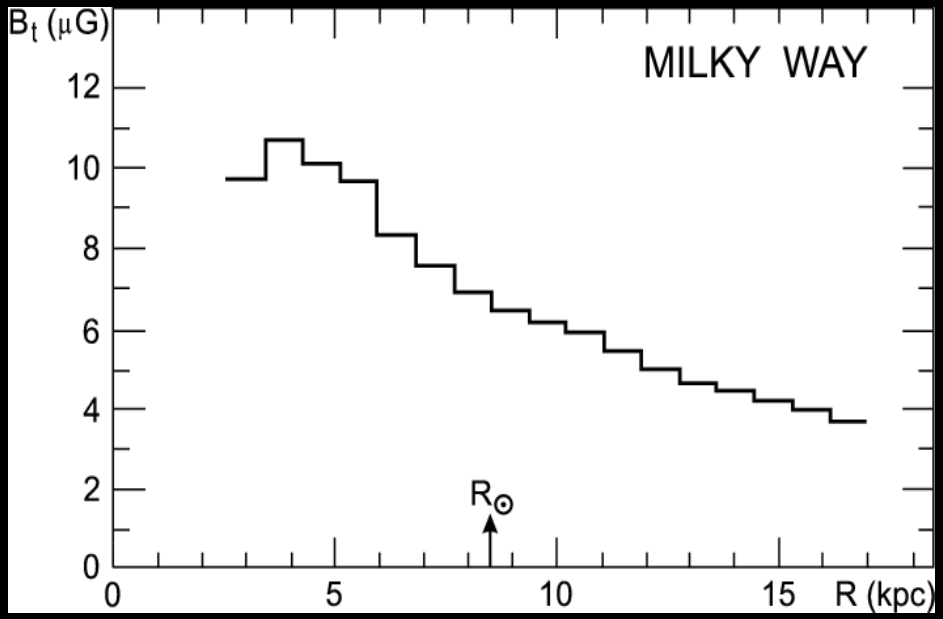


Summary

- HII regions strongly affects RM of pulsars
- The local magnetic field has a strength of 1.7 +/-1 μ G
- The inter-arm magnetic field follows the spiral arm
  with a slight phase offset of 12^{o} +/- 8^{o}
- To study the magnetic field in the disk , sources used
  should be confined to $b < |10^{o}|$
- Combining new and old RM data for pulsars
  no evidence for field reversal is seen in the
  outer Galaxy, within $85^{o} < l < 250^{o}$ at a distance of 6kpc
- Field reversals claimed in other parts of the Galaxy
  MUST be re-examined

Connecting Equipartition and RM values of Magnetic field

The magnetic field obtained from equipartition with cosmic rays is ~2 times higher than that obtained from pulsars !!



(Beck 2001)

(Berkhuijsen 2001)

This suggests:

- Equipartition does not hold in our Galaxy
- RM and DM in pulsars are anticorrelated

(Long term RM & DM monitoring of pulsars are needed)