# Low frequency radio observations of the magnetic field in the solar corona

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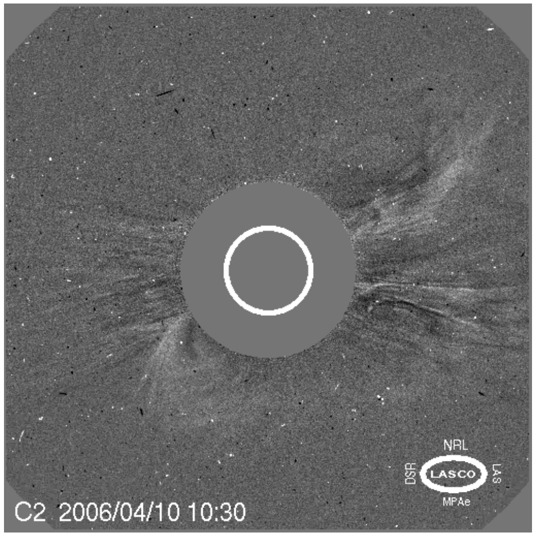
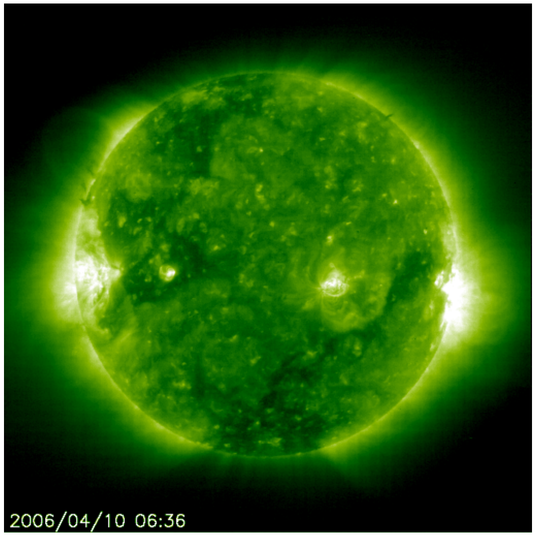
# The Gauribidanur radioheliograph (GRH)

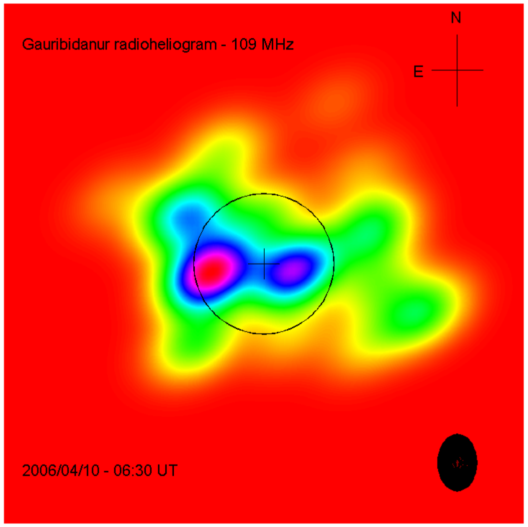
A T-shaped interferometer array

Frequency of operation :
30-110 MHz

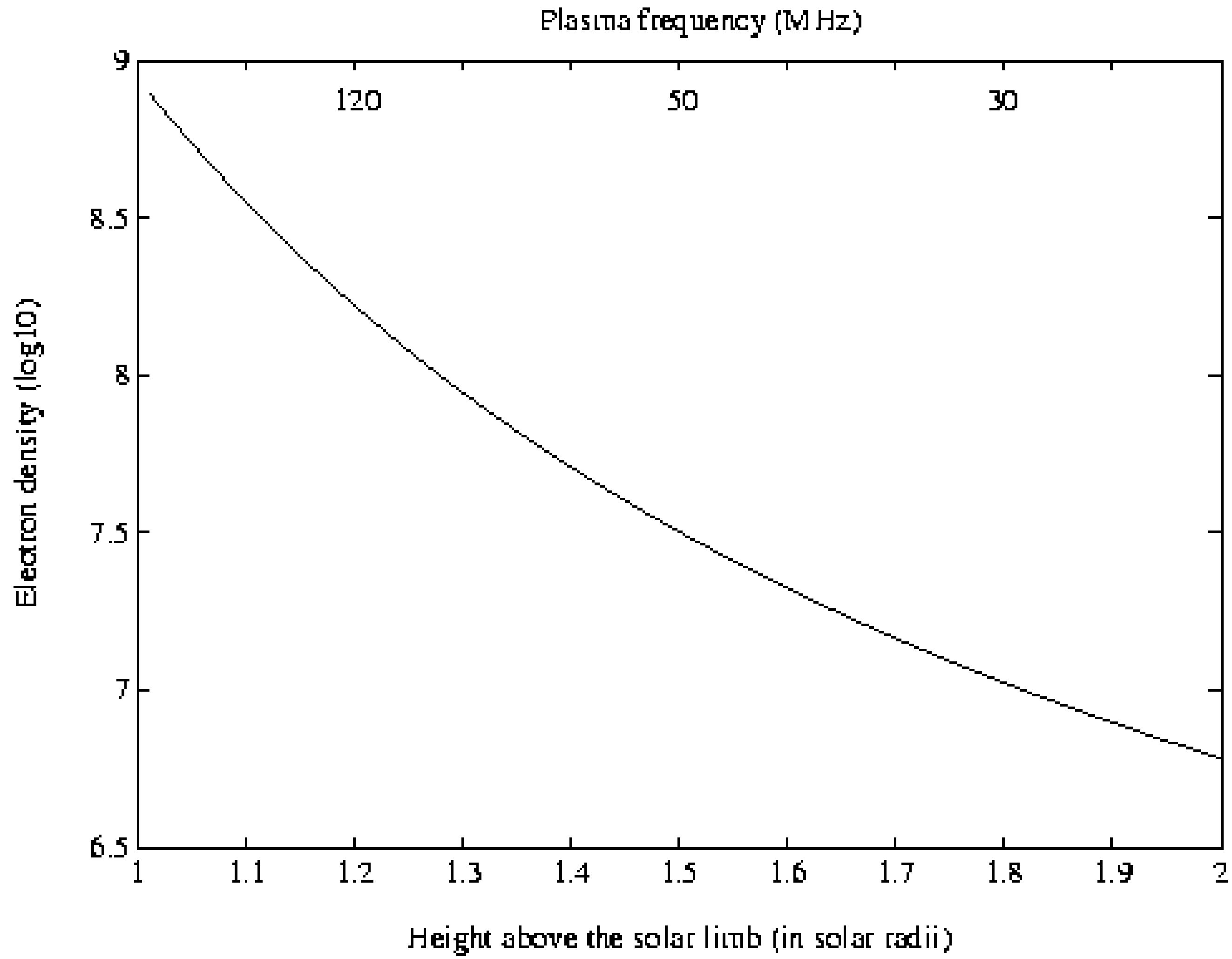
Observing period :
03:00 – 09:00 UT



# Newkirk's electron density model of the solar corona




$$N_e(r) = 42000 * D * 10^{4.32/r} \quad cm^{-3}$$

$$f_p = 9000\ N_e^{1/2} \quad MHz$$

# Observations of the solar coronal magnetic field

- **It is now well recognized that the magnetic field dominates most of the solar corona, playing a crucial role in the formation and evolution of a large variety of structures there.**

- **Despite its fundamental importance, it is difficult to directly measure the coronal magnetic field through optical observations due to a variety of reasons.**

- **In the radio domain, high resolution circular polarization observations in the frequency range 1 - 20 GHz are used to routinely measure the field strengths at heights ~ 0.1 $R_s$ above sunspot regions since the pioneering work of Kakinuma in 1962.**

## Observations of the solar coronal magnetic field

- **Moving to larger heights in the corona, one can obtain information about the magnetic field through ground based observations of circularly polarized radio emission in the range 30 -150 MHz. Note that radio waves from the Sun in the above frequency range originate primarily in its corona.**

- **To determine the complete polarization state of a signal, it is necessary to measure all the four Stokes parameters, i.e. I, Q, U & V.**

- **But Q & U will generally be zero in the above frequency range since Faraday rotation of the plane of linear polarization (both in the solar corona as well as the Earth's ionosphere) is considered to wipe out the latter when the emission is summed over the observing band.**

- **The usual practice in solar radio astronomy (particularly in the above frequency range) is to employ a pair of mutually-orthogonal linearly-polarized antennae in conjunction with a phase switch to obtain I + V & I – V.**

# Observations of the solar coronal magnetic field

- **The other major problem in the study of polarized radio emission from the Sun and other sidereal sources is a knowledge of the instrumental errors and appropriate procedures to minimize them. These include:**

  **(i) cross-talk between the antennas;**

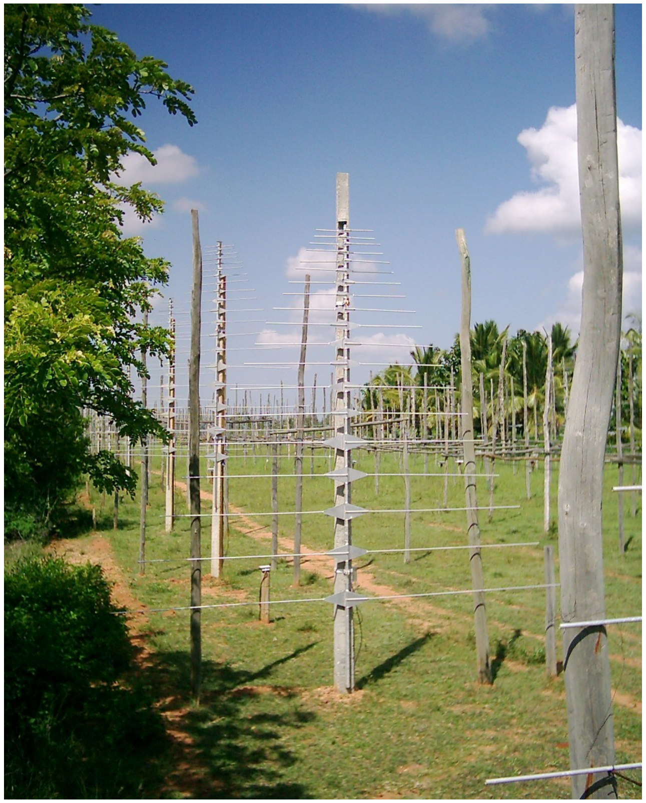
  **(ii) spurious effects due to a combination of the direct radiation from the source and its reflection from the ground;**

  **(iii) off-axis effects.**

# Polarization interferometer at the Gauribidanur radio observatory

- One-dimensional array of 32 antennas in the E-W direction
- Configured as four groups of 8 antennas each
- Orientation of the groups are 0, 45, 90 & 135 degrees
- Time resolution = 100 ms
- Frequency range = 30 – 110 MHz

0 & 45 deg



0 & 135 deg

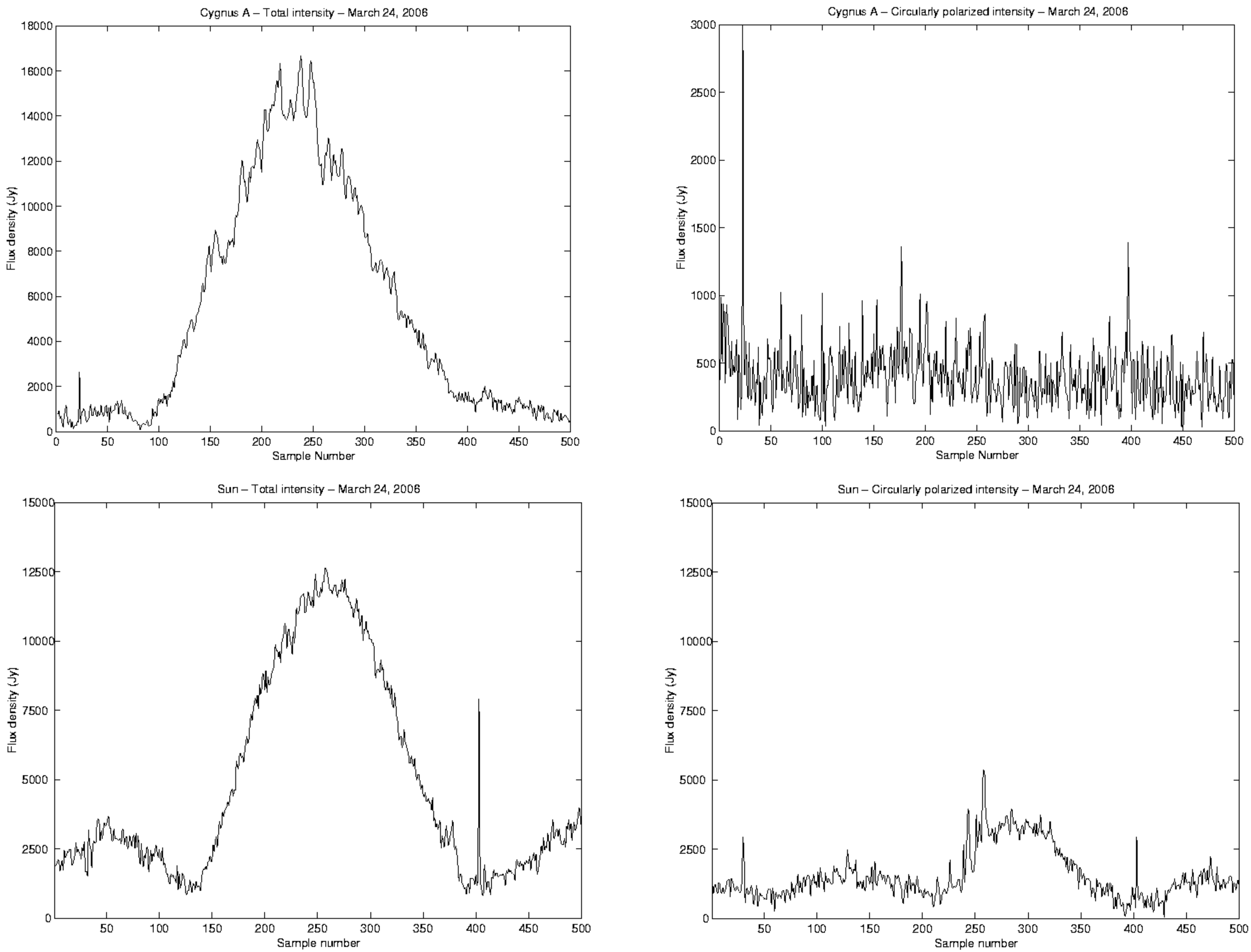
45 & 90 deg

# Observations of the solar coronal magnetic field

- **The collecting area of the Gauribidanur radio polarimeter is large that we make use of observations of unpolarized sidereal radio sources at different declinations in the interval +23 N to -23 S deg (the latitude range over which the Sun moves in a year) to estimate the instrumental errors.**

- **This implies that the errors in circular polarization measurement on the Sun can be effectively removed by choosing an appropriate calibrator in and around the same region of the sky.**

- **The observations →**


Cygnus A – Total intensity – March 24, 2006
Flux density (Jy)
Sample Number
Cygnus A – Circularly polarized intensity – March 24, 2006
Flux density (Jy)
Sample Number
Sun – Total intensity – March 24, 2006
Flux density (Jy)
Sample number
Sun – Circularly polarized intensity – March 24, 2006
Flux density (Jy)
Sample number

**We can estimate the degree of circular polarization from our data.**

**The question is how to get a handle on the value of B from this?**

# On a possible method for measuring magnetic field strength in the outer solar corona

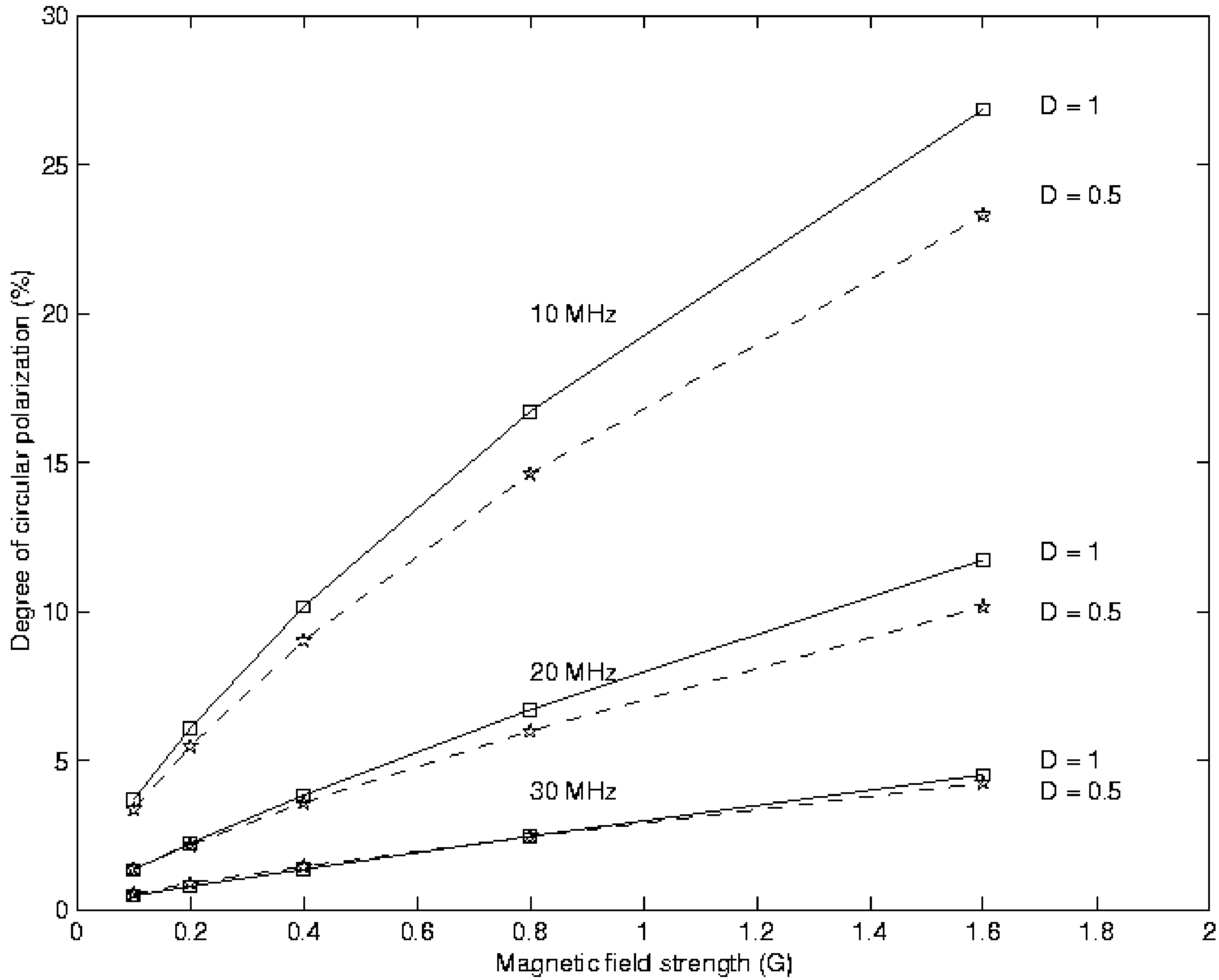
**(Poster P14 by Ch. V. Sastry in this conference)**

- Magnetic field in the solar corona at heights > 0.2 $R_s$ is generally derived indirectly from properties of meter wavelength radio bursts and extrapolation of the optical measurements of the photospheric field using the potential solar surface model.

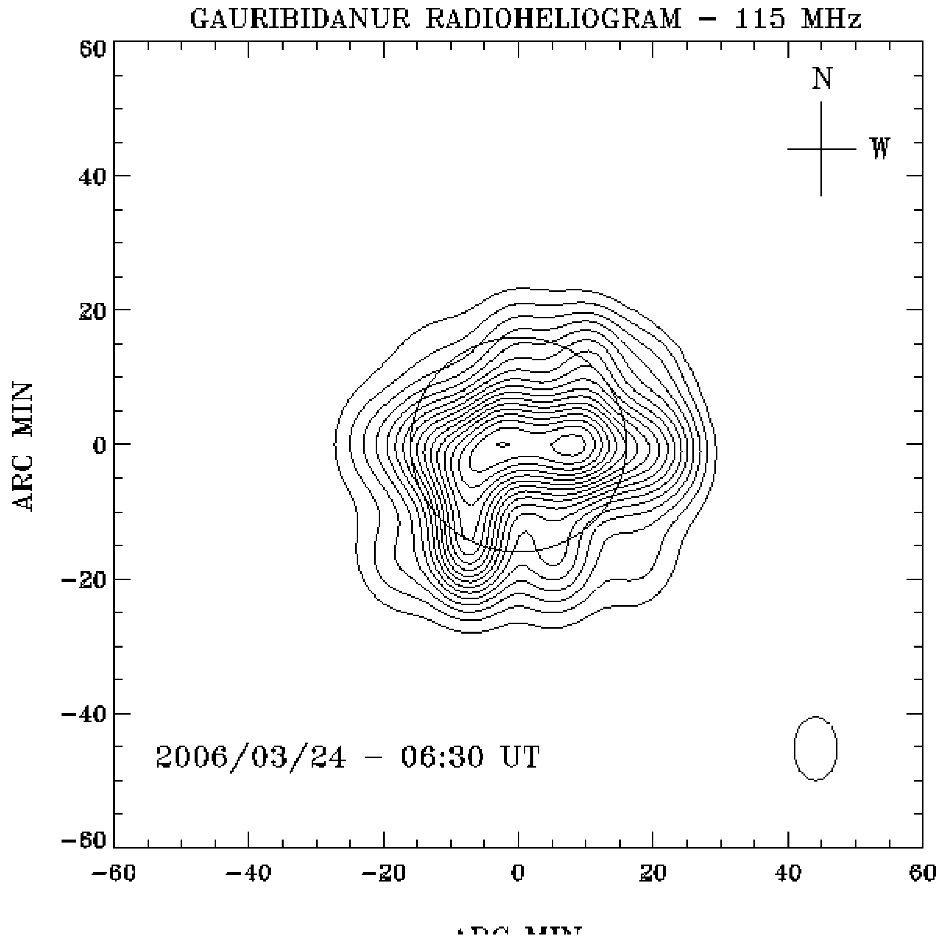
- It is pointed out that thermal radiation from the 'undisturbed' Sun and active regions will be polarized due to the anisotropy arising out due to the existence of magnetic fields in the solar corona.

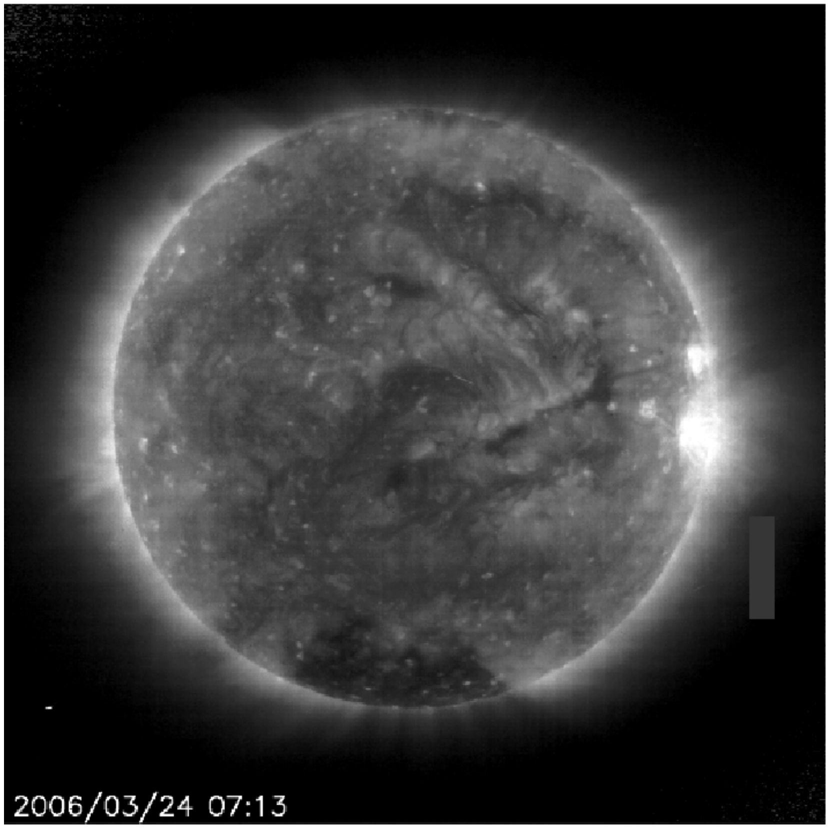
- Circular polarization characteristics of low radio frequency thermal radiation can therefore be used to estimate the magnetic field strength directly.

# Variation of degree of circular polarization with the magnetic field strength of the 'undisturbed' Sun



# Identification of the source region of the observed degree of circular polarization



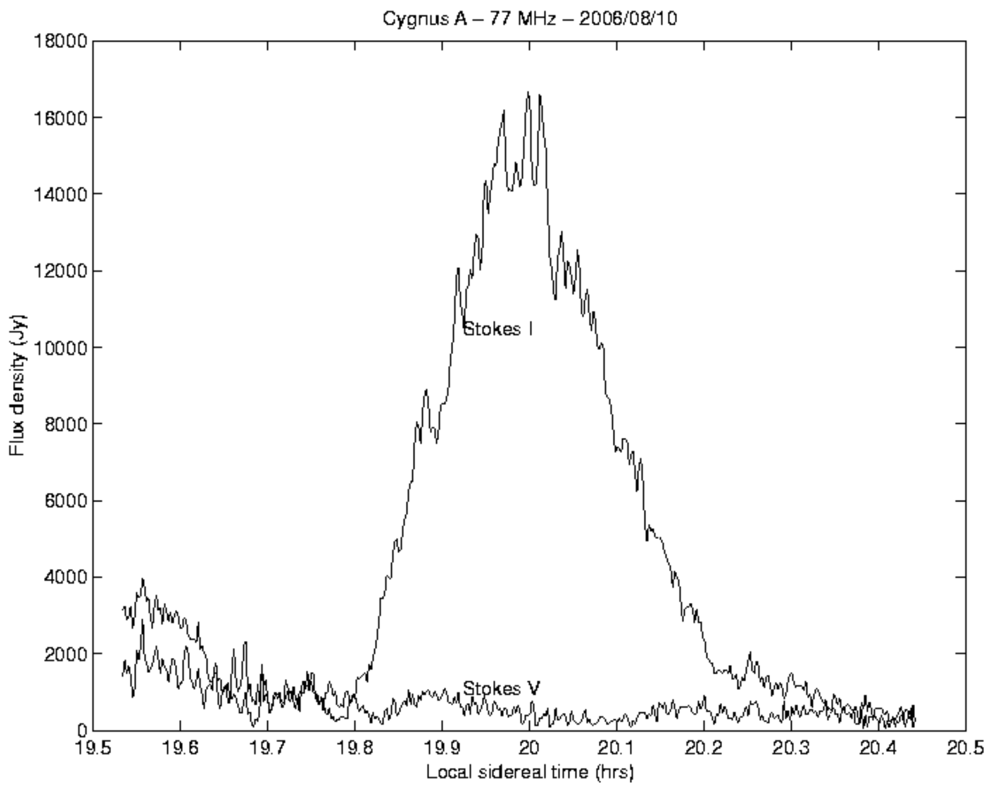
## Observations of the solar coronal magnetic field

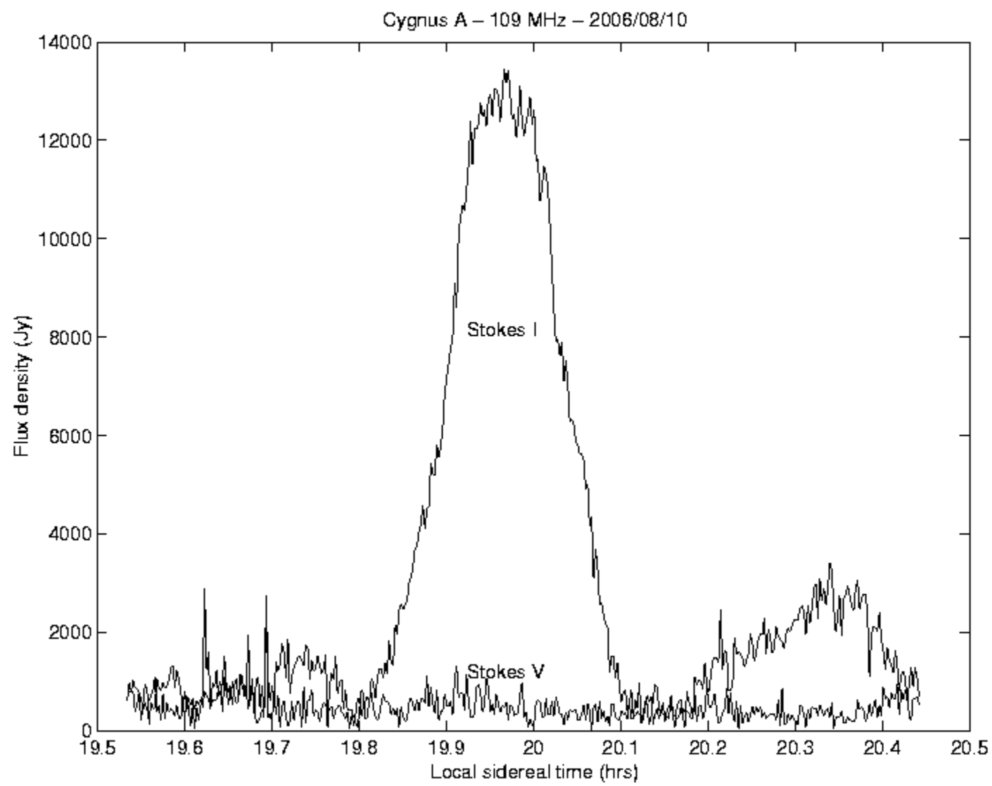
- **The radio noise storms are very useful candidates to measure the coronal magnetic field on a regular basis since they are the most frequently observed solar activity in the above frequency range.**

- **More importantly they are closely associated with the sunspot groups (both old and new) at the photosphere.**

- **Except near the limb, they are usually circularly polarized.**

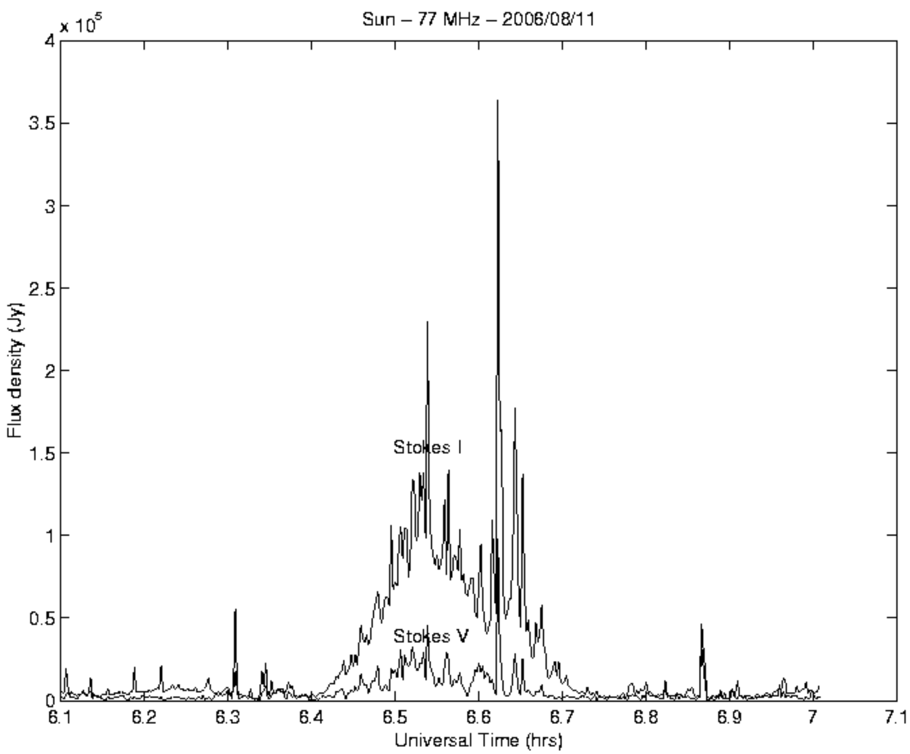
# Gauribidanur radio polarimeter -Observations

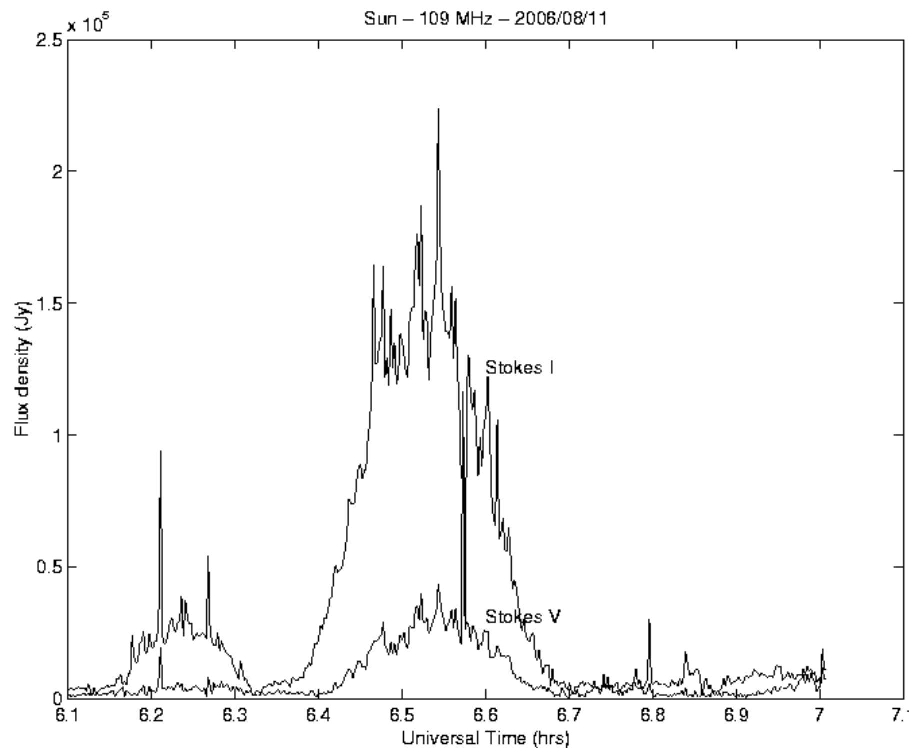



**The figures show the Stokes I & V output from Cygnus A at 77 & 109 MHz, observed on 11 August 2006. The absence of any noticeable deflection in the Stokes V output from Cygnus A at both the frequencies indicates that the instrumental circular polarization, if any, is very minimal.**

# Gauribidanur radio polarimeter -Observations

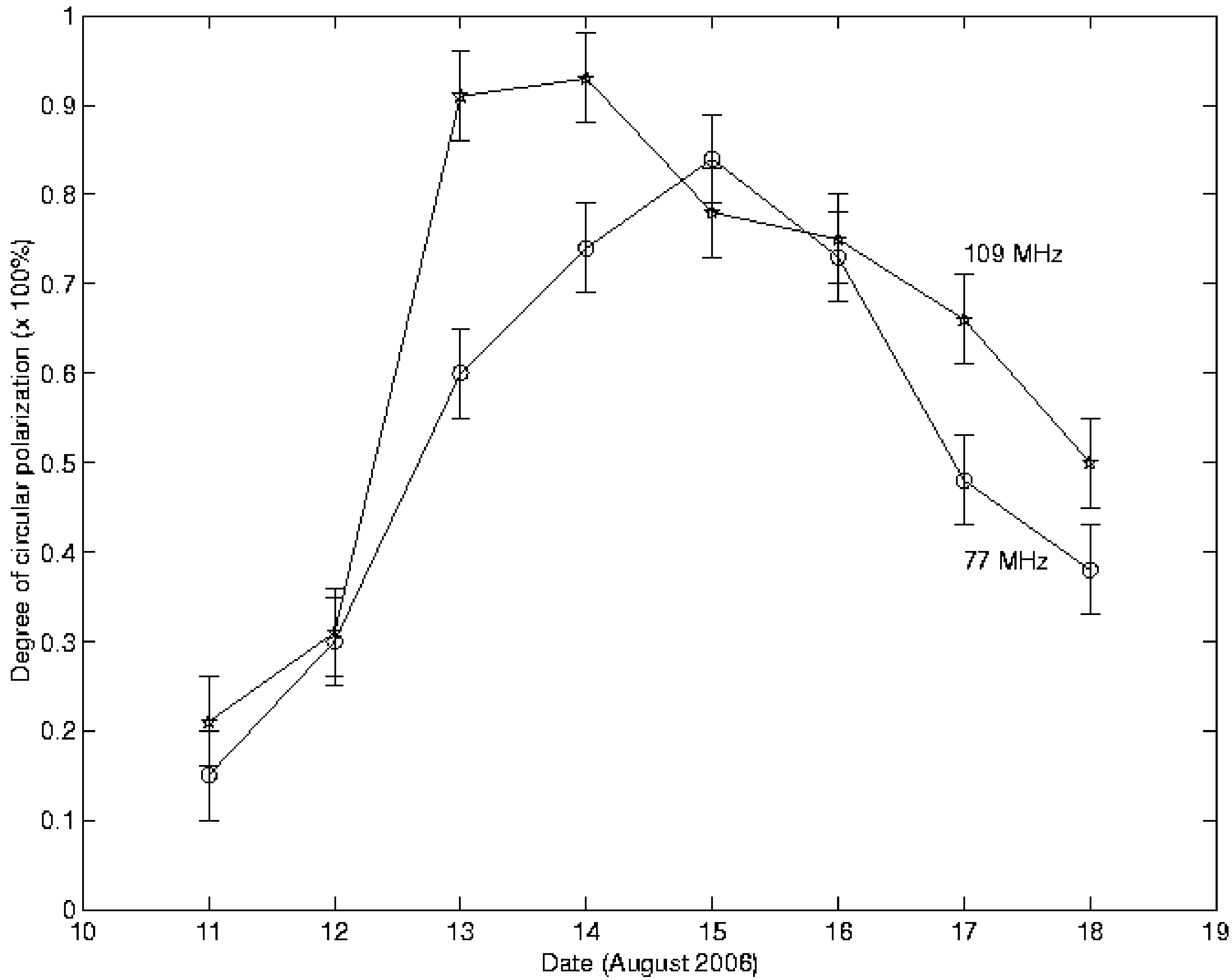



**The figures show the Stokes I & V output from Sun at 77 & 109 MHz, observed on 11 August 2006 – the same day. One can notice the presence of noticeable circular polarized emission from the Sun at both 77 & 109 MHz, compared to Cygnus A.**

**Similar emission from the Sun was observed by us on the following days also, up to 18 August 2006.**

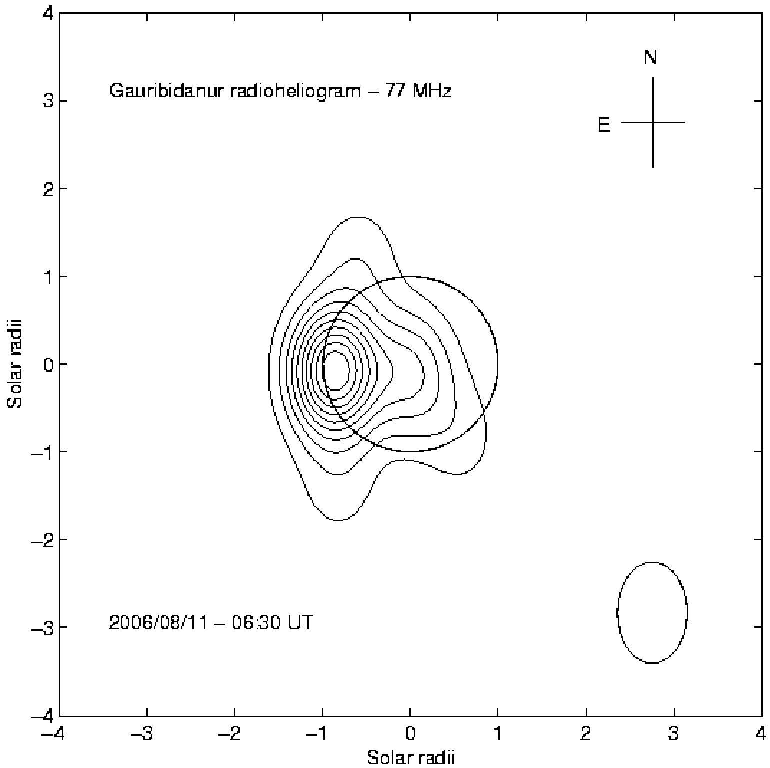
# Day-to-day variation in the observed degree of circular polarization




**Directivity !**

# Gauribidanur radio polarimeter -Observations

- Since one of the above observing frequencies of the polarimeter (i.e. 77 MHz) is common to the Gauribidanur radioheliograph (GRH), we looked at the radioheliogram (in Stokes I) obtained with the GRH around the same time as the polarization observations on 11 August 2006 to infer whether any peculiar emission feature(s) were present in the solar atmosphere on that day.



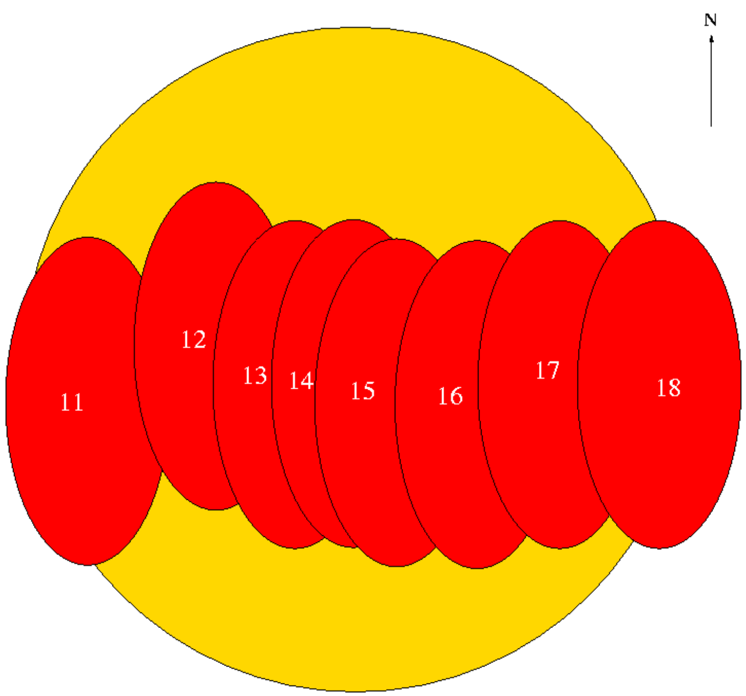

One can notice the presence of an isolated discrete source of intense emission (brightness temperature $T_b \sim 10^9$ K) in the south-east quadrant. Due to issues related to dynamic range, emission from the 'background' corona ($T_b \sim 10^5$ K) is not seen in this image.

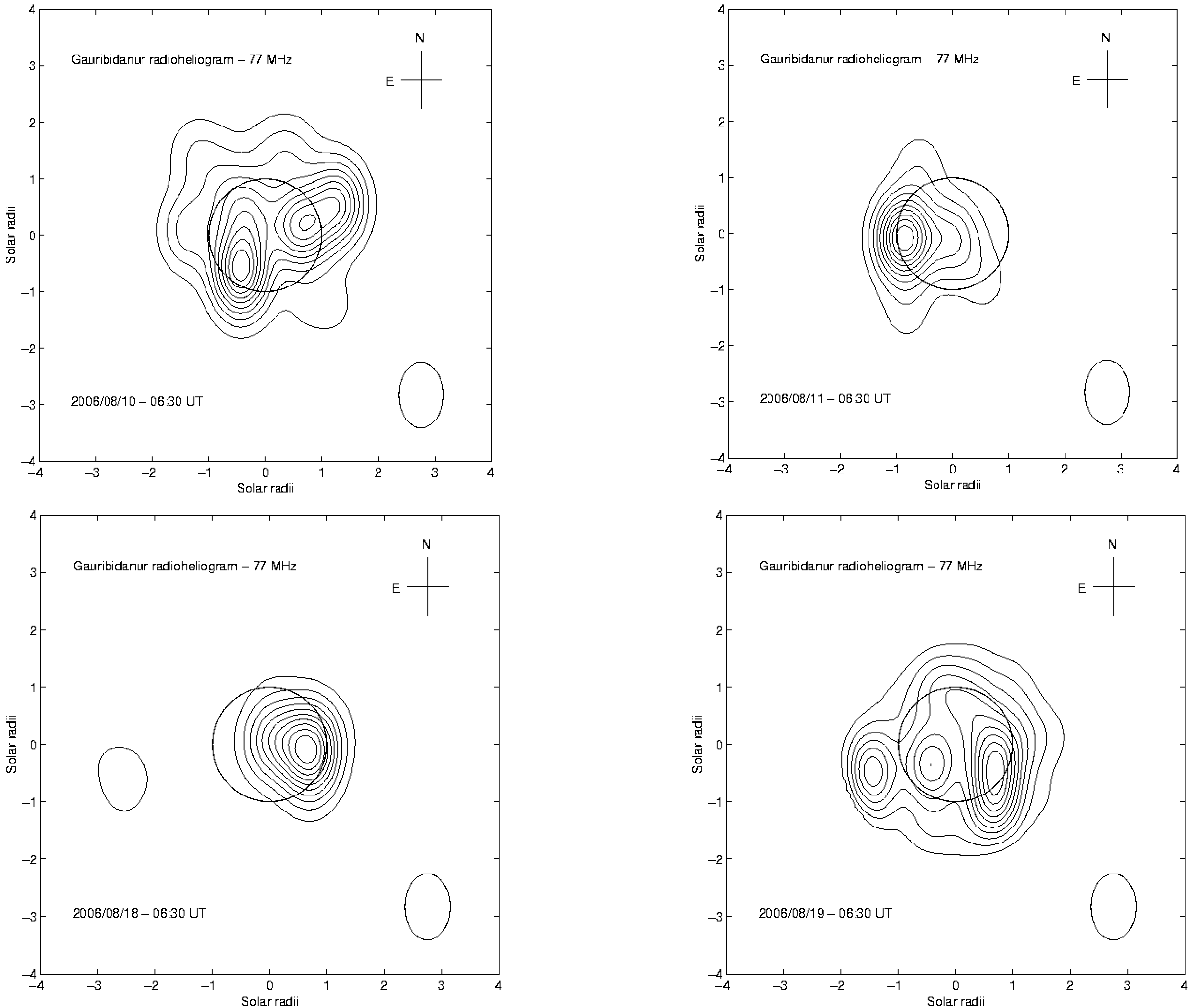
Non-thermal emission. Plasma radiation !

# Gauribidanur radio polarimeter - Observations

- **The above localized emission region persisted for the next few days also and lasted till 18th August 2006. Interestingly, it co-rotated with the Sun and was located in the south-west quadrant on 18th August 2006.**

- **A comparision of the above two radioheliograms observed on 11th & 18th August 2006 with that observed on 10th & 19th August 2006 indicates that the discrete source of intense emission was present only during the interval 11-18 August 2006.**

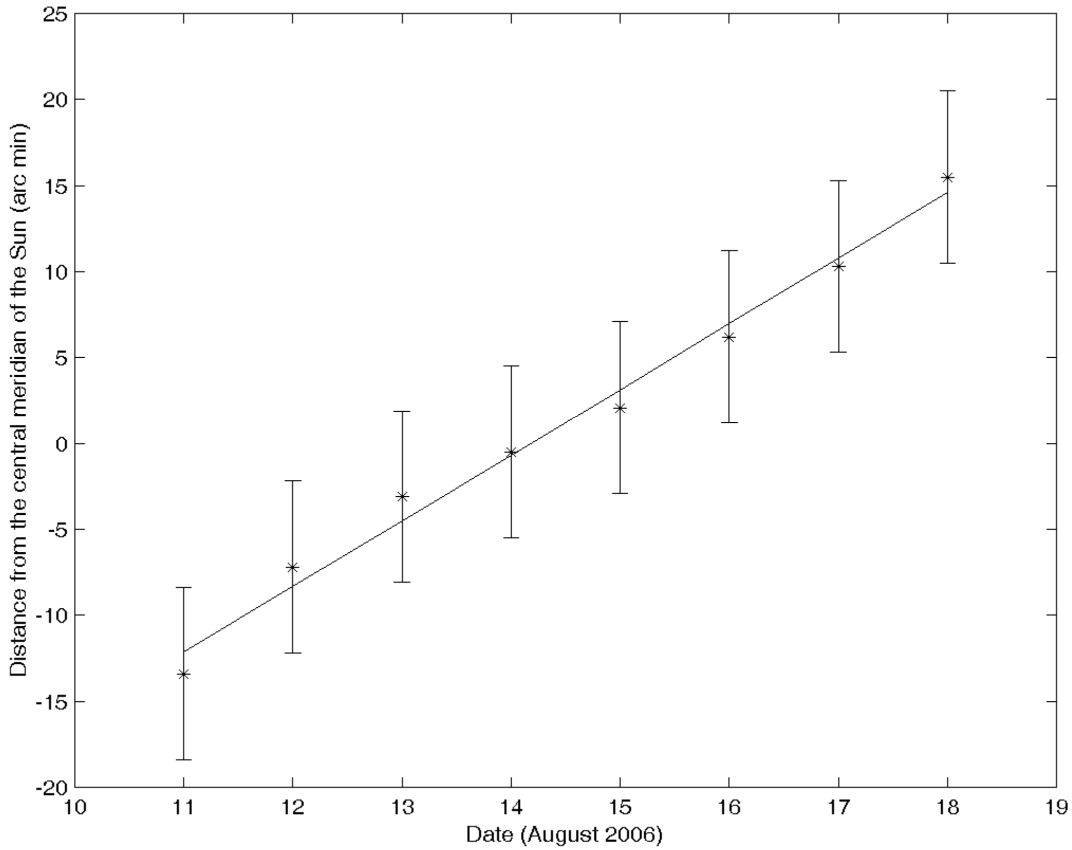



Gauribidanur radioheliogram – 77 MHz
N
E
2006/08/10 – 06:30 UT
Solar radii
Solar radii
Gauribidanur radioheliogram – 77 MHz
N
E
2006/08/11 – 06:30 UT
Solar radii
Solar radii
Gauribidanur radioheliogram – 77 MHz
N
E
2006/08/18 – 06:30 UT
Solar radii
Solar radii
Gauribidanur radioheliogram – 77 MHz
N
E
2006/08/19 – 06:30 UT
Solar radii
Solar radii

# Gauribidanur radio polarimeter - Observations

**We estimated the average daily rotation rate of the discrete source from our radioheliograms and is ~ 4.2 arc min per day.**

**This corresponds to a height of about 1.71 $R_s$ in the solar atmosphere for the emission region.**

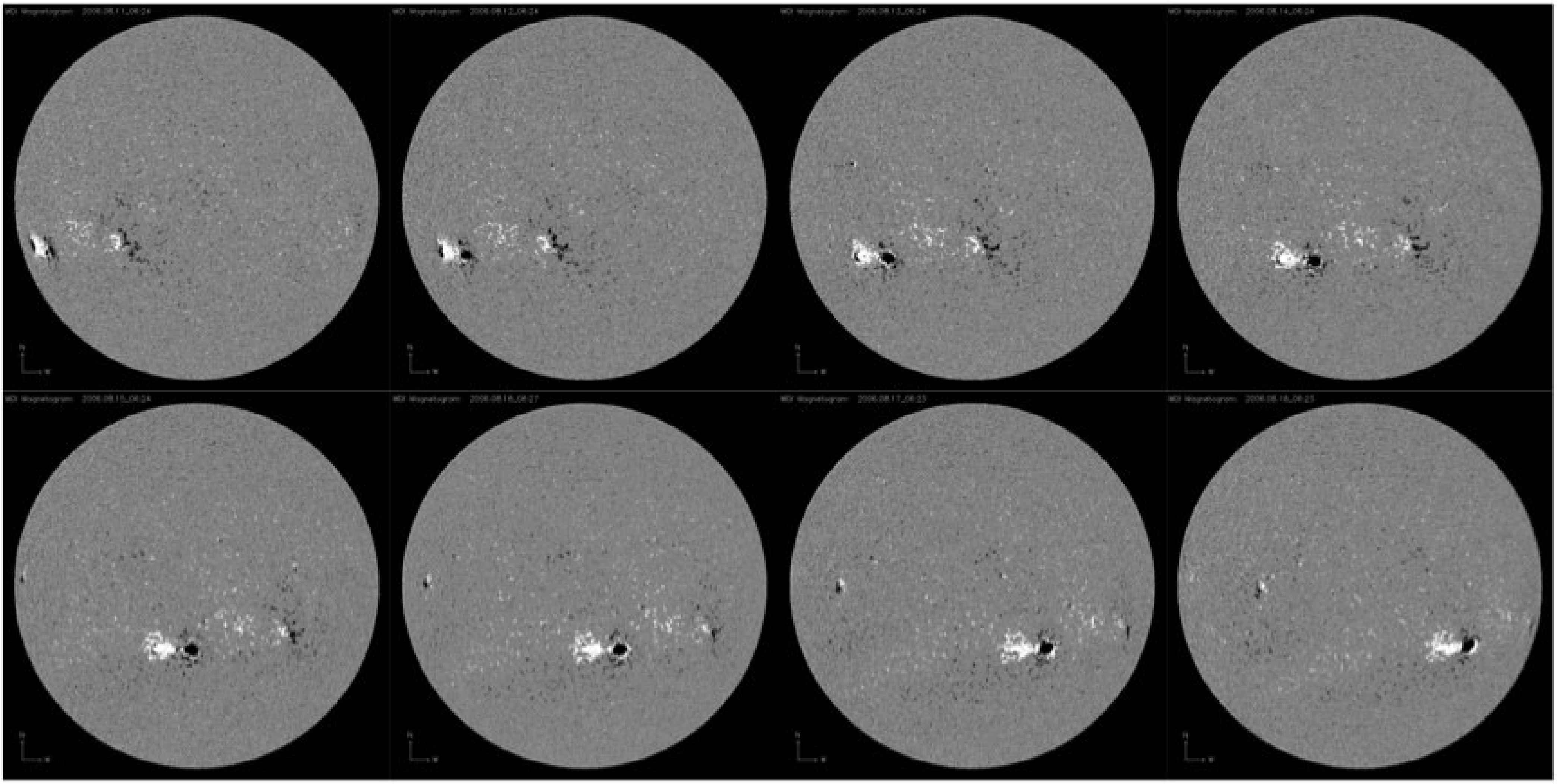


## Gauribidanur radio polarimeter - Observations

- In general, any transient or long duration phenomena observed in the solar corona should have their `origin' in the corresponding activities at the lower layers in the solar atmsophere. This is true particularly in the case of radio noise storms since it is well established that they are closely associated with the sunspot groups at the photosphere.

- So we looked into the magnetogram images of the solar photosphere obtained with the Michelson Doppler Imager (MDI) on board Solar and Heliospheric Observatory (SoHO) to identify the photospheric counterpart of the observed circular polarization at 77 & 109 MHz.

- A comparison indicates that the bright magnetic region AR 10904 (S14 E63) located close to the east limb on 11 August 2006 (CR 2046) must be primarily responsible for the appearance of Stokes V output observed on that day as well as the subsequent days, up to 18 August 2006.


MDI Magnetogram: 2006.08.11_06:24
MDI Magnetogram: 2006.08.12_06:24
MDI Magnetogram: 2006.08.13_06:24
MDI Magnetogram: 2006.08.14_06:24
MDI Magnetogram: 2006.08.15_06:24
MDI Magnetogram: 2006.08.16_06:27
MDI Magnetogram: 2006.08.17_06:23
MDI Magnetogram: 2006.08.18_06:23

## Gauribidanur radio polarimeter - Observations

- **The active region AR 10903 (S12 E26) located to the west of AR 10904 (refer MDI image for 11 August 2006) as the cause for the observed noise storm emission can be ruled out because:**

- **AR 10903 was on the visible hemisphere of solar disk even prior to the appearance of AR 10904 over the east limb, but no detectable noise storm emission/circular polarization was observed by us.**

- **We observed significant circular polarization on 18 August 2006 when AR 10903 was not there on the disk, i.e. the region had crossed over the west limb of the Sun.**

- **Relating the observations at the photosphere and corona by the principle of magnetic flux conservation, we estimated average coronal magnetic field at the above location and is approximately 4.2 G.**

## Gauribidanur radio polarimeter - Observations

- **The estimated B in the present case could be a lower limit since we do not know the `true' noise storm source size.**

- **However, a comparision of our estimate of the magnetic field with that mentioned in the literature from non-type II radio burst observations indicates that the actual value may not be significantly different.**

- **Reiner et al. (2007) recently deduced the magnitude and radial dependance of coronal magnetic field from polarization observations of type III radio storms at frequencies below 1 MHz in the interplanetary medium. The backward extrapolation of their estimate to higher frequencies close to the Sun yield B ~ 10 G at 2 $R_s$. It is to be noted here that the interplanetary type III radio storms are normally associated with type I noise storms observed close to the Sun.**

- **The variation in the size of the noise storm continuum source with frequency and its exponential fit indicates that the former should be ~ 660 arc sec at 77 MHz (Sundaram2004). This is close to the value used in the present calculations.**