

# ***Measuring Coronal Magnetic Twist Injected by Photospheric Rotation.***

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## Generalities...

- \* In extreme UV or X-ray, loops are seen in the corona.
- \* The loops are magnetic in nature.
- \* The shape of the loops can give us valuable information.

## What are we trying to study?

- \* The idea is to see how the twist in the magnetic field lines changes with time.
- \* Through the topology of the loops, information about the current within the magnetic field can also be determined.

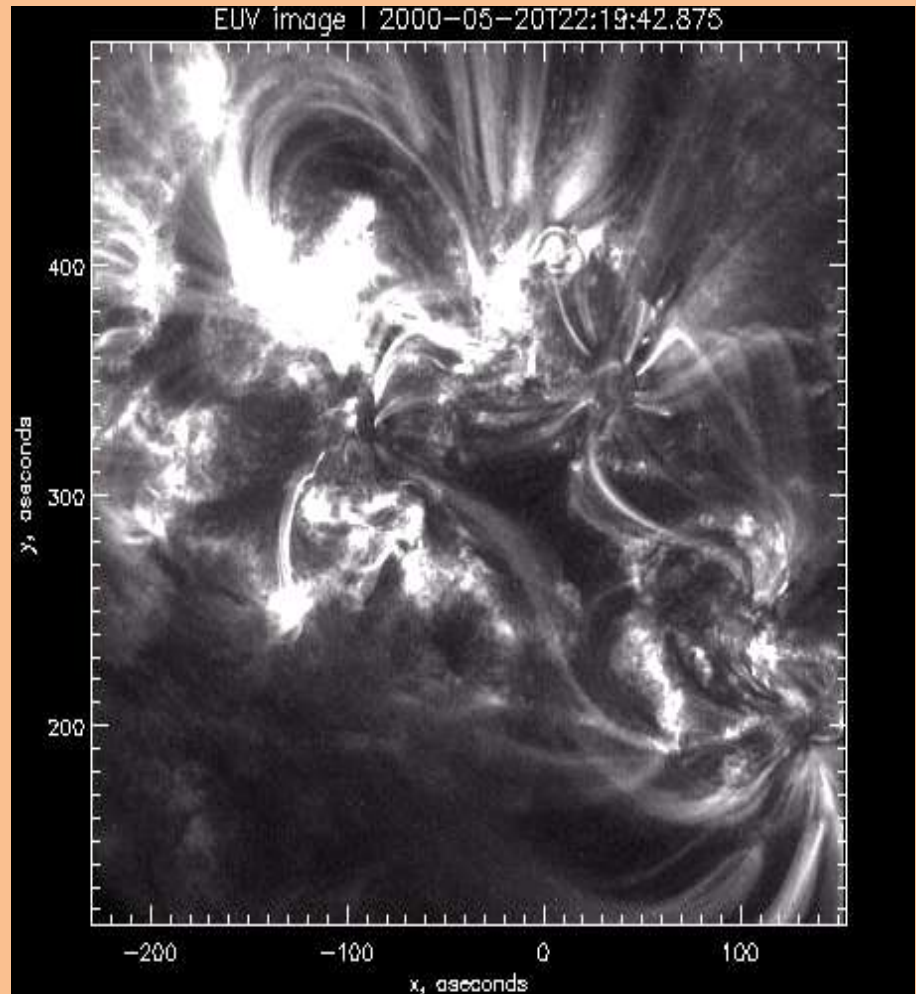


fig.1. TRACE image of the corona in EUV

## Some Background Information



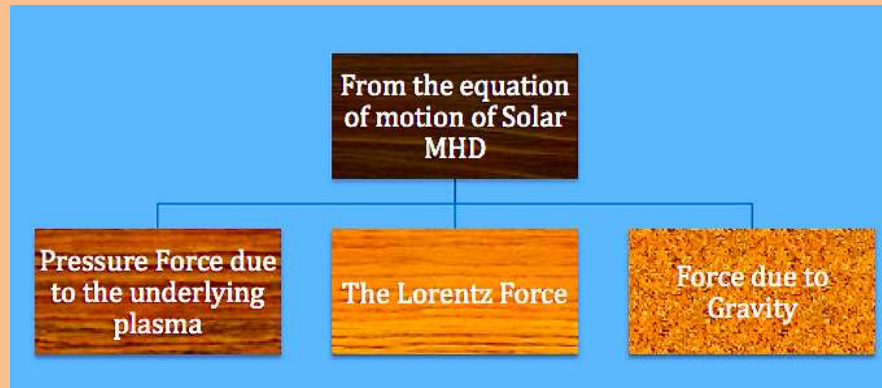
Now the question is...

How to associate the twist of a magnetic loop with its inherent magnetism ?



The answer lies in the primary assumption that the field is **force-free**. By Newton's Second Law, the net force acting on the loop would then be zero.

*What are the forces that are acting on a magnetic loop at a given time?*



## Background Information contd..

- \*  $\nabla \times B = \alpha B$
- \*  $\alpha$  represents the twist for a given field line; it provides a quantitative basis for the topology of a field line.
- \*  $\alpha$  can be written as  $\alpha = 4\pi n$ , where  $n$  is the number of turns per unit length.
- \*  $\alpha$  has units of inverse length.
- \*  $\alpha$  and  $j$  are related.
- \* Hence,  $\alpha$  can also provide information about the current density,  $j$ , in the loops

In Solar MHD, the equation of motion

$$\rho \frac{dv}{dt} = -\nabla p + (j \times B) + \rho g \text{-----(i)}$$

As the magnetic field is in equilibrium, net force is zero

$$-\nabla p + (j \times B) + \rho g = 0 \text{-----(ii)}$$

In most of corona, the Lorentz term,  $(j \times B)$ , dominates

Or, (ii) becomes

$$(j \times B) = 0 \text{-----(iii)}$$

Also, from Ampere's Law,

$$\nabla \times B = \mu_0 j \text{-----(iv)}$$

$$\text{Or, } j = \frac{1}{\mu_0} (\nabla \times B)$$

Substituting for  $j$  in (iii) gives

$$\frac{1}{\mu_0} (\nabla \times B) \times B = 0 \text{-----(v)}$$

Or,

$$(\nabla \times B) = \alpha B \text{-----(vi) [Equation representing the force-free field]}$$

## Procedure

- \* From the loops very little can be known about the actual magnetic field lines.
- \* The idea is to manually draw the loops on a computer screen and comparing these curves with the shape of field lines with a range of different alphas.
- \* The best fitting field line, for a given loop, would give the best estimate of  $\alpha$  for that particular loop.

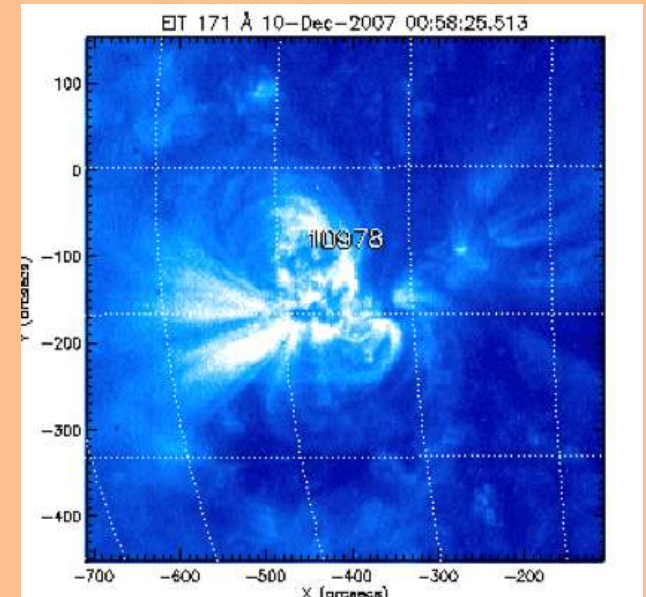


fig.2. Coronal loops in EUV as observed by spacecrafts



fig.3. Procedure in a nut-shell

## Step 1-Computing the Magnetic Field

$$(\nabla \times B) = \alpha B$$

Taking dot product on both sides,

$$\nabla \cdot (\nabla \times B) - \nabla \cdot (\alpha B) = 0$$

$$\rightarrow \alpha \nabla \cdot B + B \cdot \nabla \alpha = 0$$

$$\rightarrow B \cdot \nabla \alpha = 0 \quad [\alpha \text{ is constant along each field line}]$$

Taking cross product on both sides,

$$\nabla \times (\nabla \times B) - \nabla \times (\alpha B)$$

$$\rightarrow \nabla (\nabla \cdot B) - \nabla^2 B = \alpha \nabla \times B$$

$$\rightarrow -\nabla^2 B = \alpha^2 B$$

$$\rightarrow (\nabla^2 + \alpha^2) B = 0$$

$$(\nabla^2 + \alpha^2) B = 0 \quad [\text{The Helmholtz Equation}]$$

$$B(x, y, z) = \frac{1}{2\pi} \int_{-\infty}^{\infty} G(x-x', y-y', z) B_z(x', y', 0) dx' dy'$$

• For constant  $\alpha$  fields,  $\nabla \times B = \alpha B$  ends up becoming the **Helmholtz Equation**.

• For a given  $\alpha$  and a photospheric flux distribution,  $B_z$ , the solution can be obtained using the Green's Function (Chiu and Hilton, 1977).

• The Green's Function is a function of  $\alpha$ ; for different alphas we have different Green's Function.

• Knowing the magnetic field enables the plotting of field lines.

## Step 2 - Tracing the Coronal loops

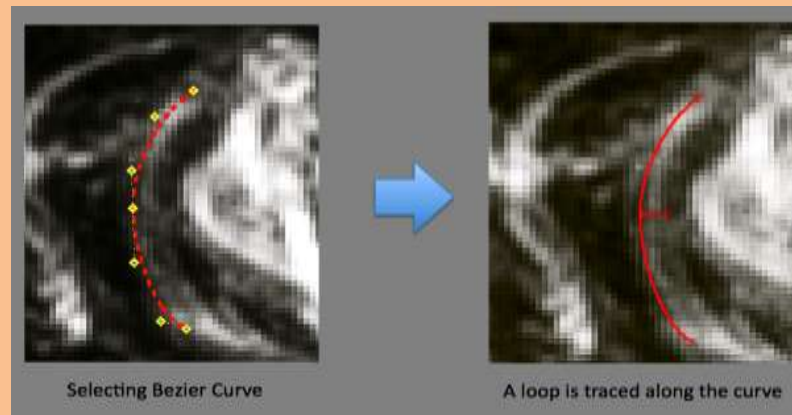


fig.4. Bezier Curve as the foundation for tracing loops on TRACE images

### Step 3 - Doing the auto-fit

- The aim is to minimize the distance between the traced loop and the plotted field lines.
- Distance,  $d(\alpha, h)$ , between the traced loop and the corresponding field lines is a function of both  $\alpha$  and  $h$ .
- Auto-fit computes the parameter space.
- It also gives the global minimum of  $d(\alpha, h)$ .

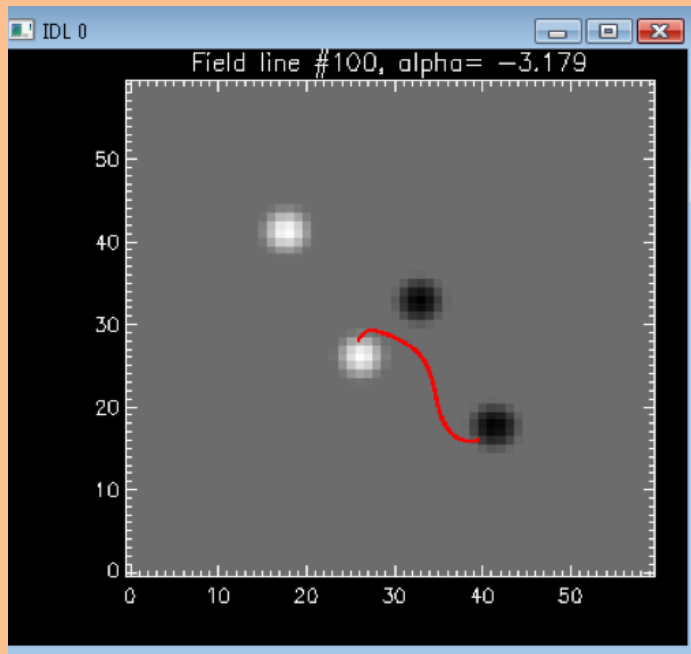


fig.5. One loop

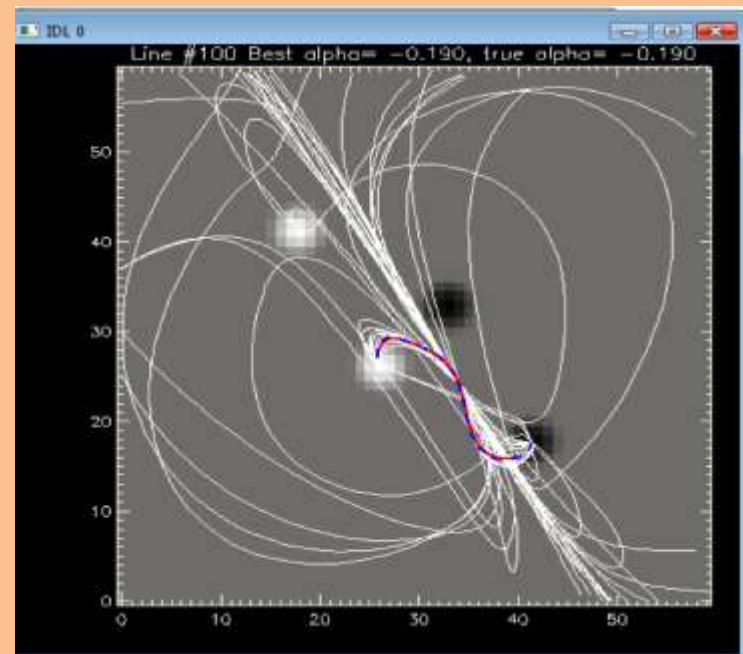


fig.6. Many possible magnetic field lines

## Step 4 - Doing the manual-fit

- The "best-fit" given by the auto-fit gives us a global minimum of  $d(\alpha, h)$ .
- The parameter space computed by the auto-fit gives a range of minima.
- The best minimum has to be hand-picked and the method of selection is still obscure.

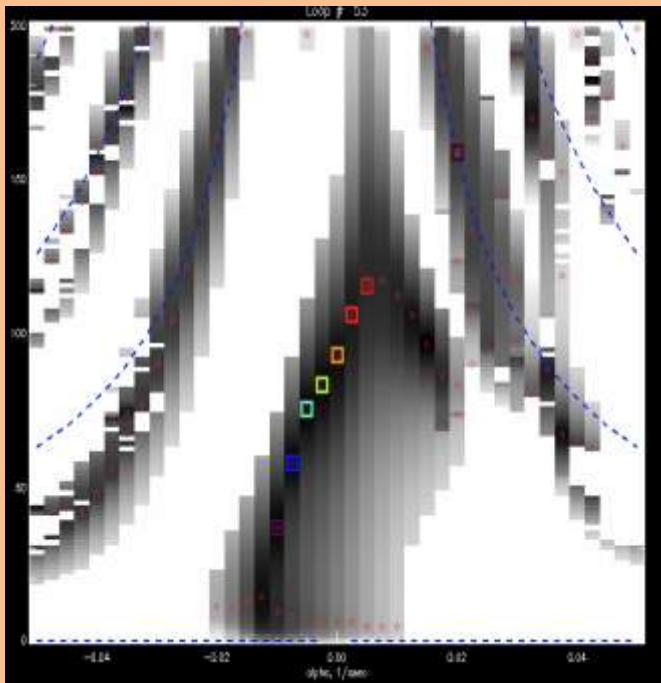


fig.7. The parameter space

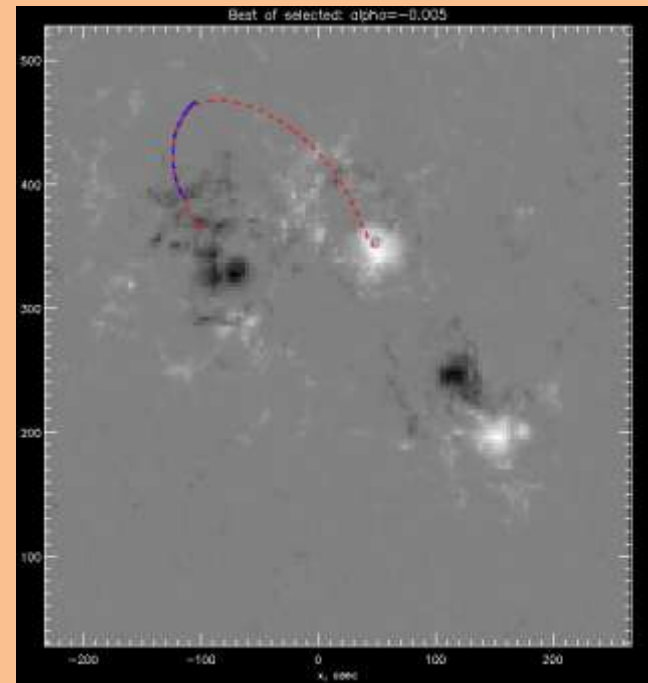


fig.8. The best possible field line

## The region of interest..

- The analysis involved active regions 09002 and 09004.
- The available data were after 2000-05-18.
- We managed to analyze data from 32 hours to 75.25 hours after 2000-05-18.

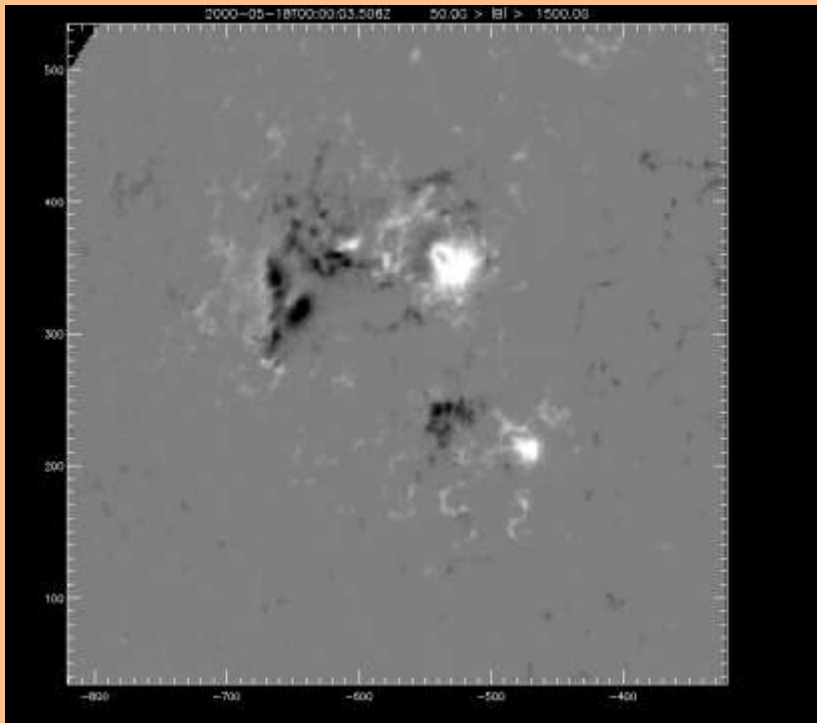


fig.9. Movie showing the active regions 09002 and 09004

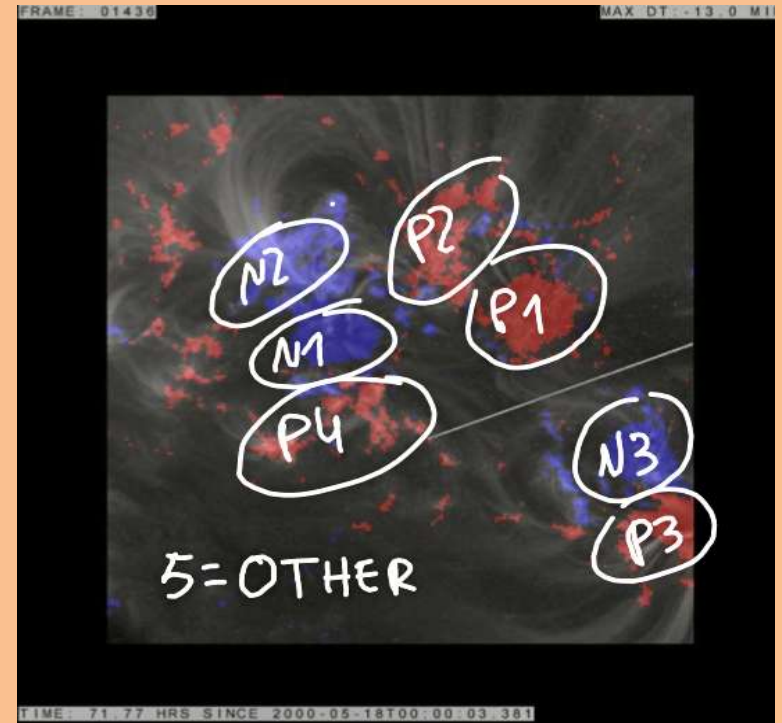


fig.10. The different poles involved

## A sample...

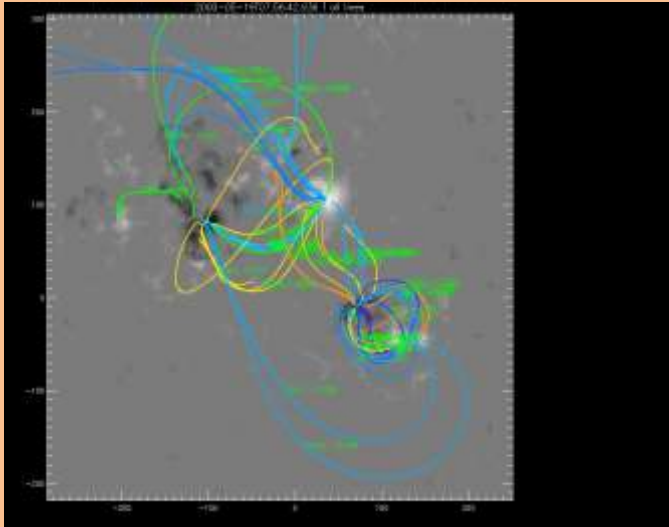


fig.11. Image taken 32 hours after 2000-05-18. Here showing the field lines on the magnetogram.

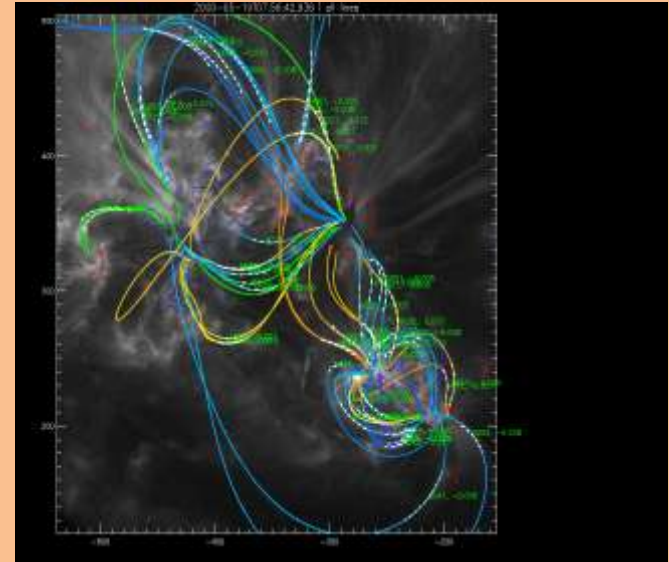


fig.12. Same field lines on the TRACE image.

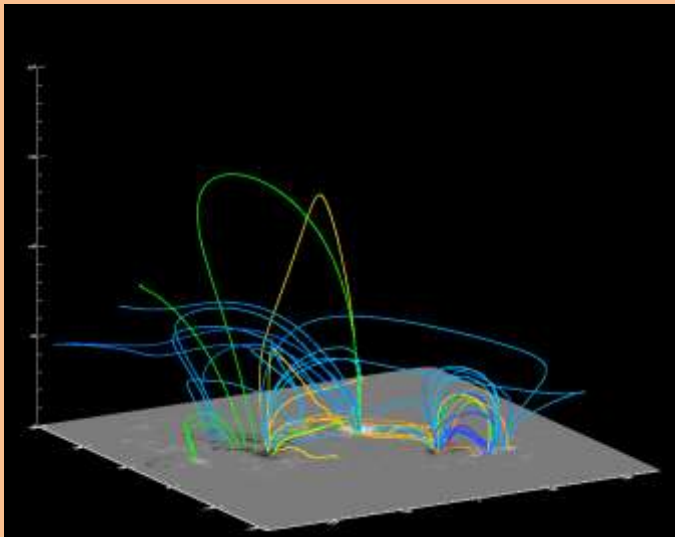


fig. 13. A 3D view

# I. Large Active region (09002)

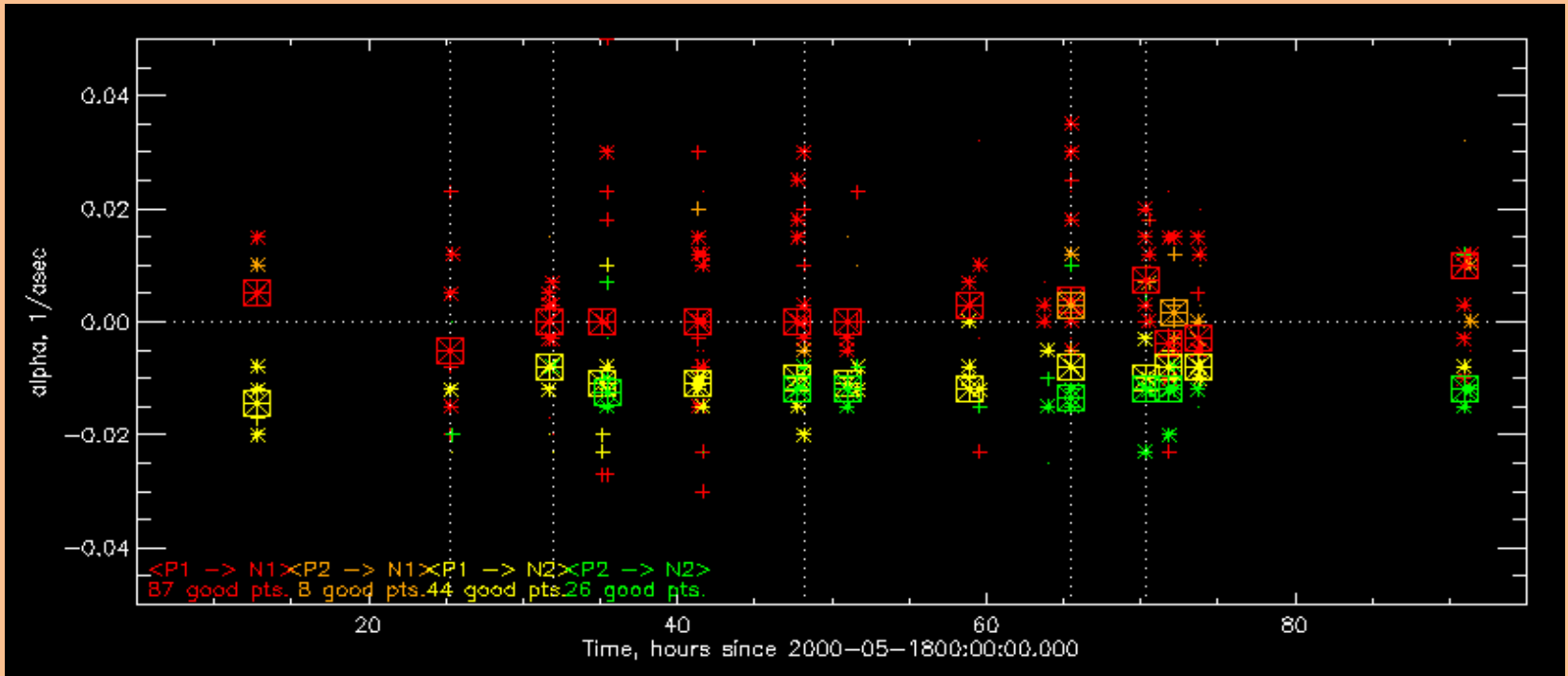


fig.14. Results of the large active region (09002)

Poles	Alpha Change Rate (1/asec*hr)
P1 - N1	7.0328656e-005
P1 - N2	-0.00025554931
P1 - N2	6.8088018e-005
P1 - N2	-5.3386817e-005

## II. Small Active region (09004)

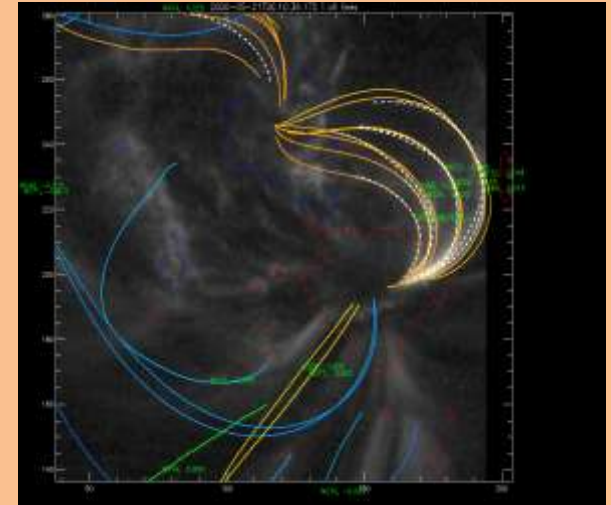
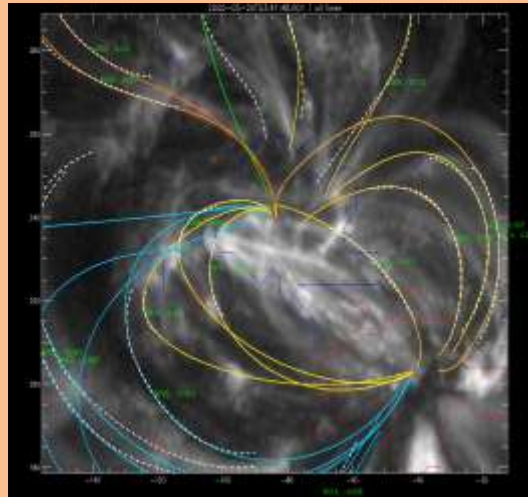
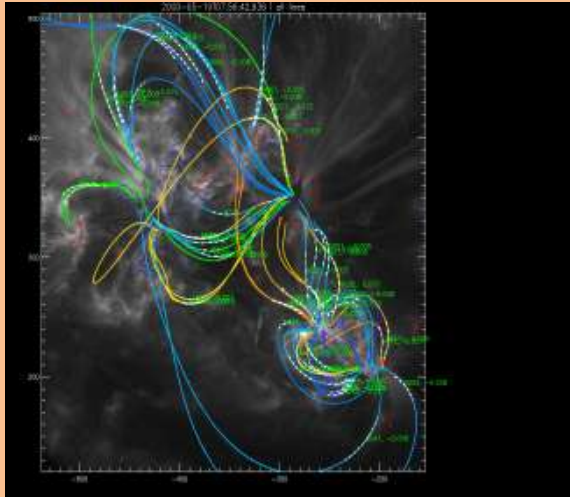
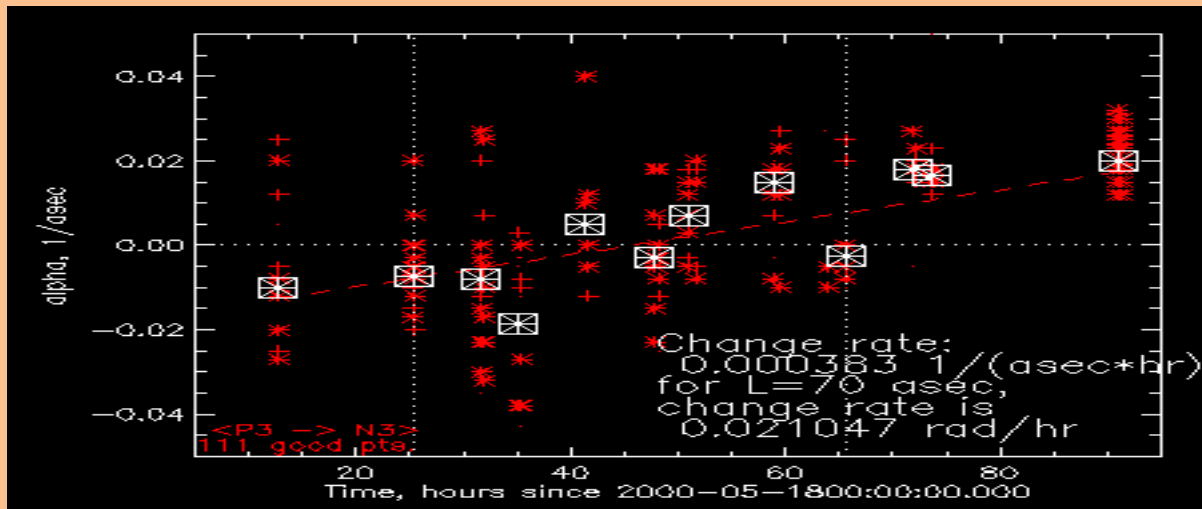


fig.15. Configuration of the field lines in 09004 at times 32 hours, 51.20 hours and 72 hours since 2000-05-18 respectively.



Poles	Alpha Change Rate (1/asec*hr)
P3-N3	0.0003831

fig.16. Results of the small active region (09004). The twist of the field line changes from negative to positive.

## More on the smaller active region 09004...

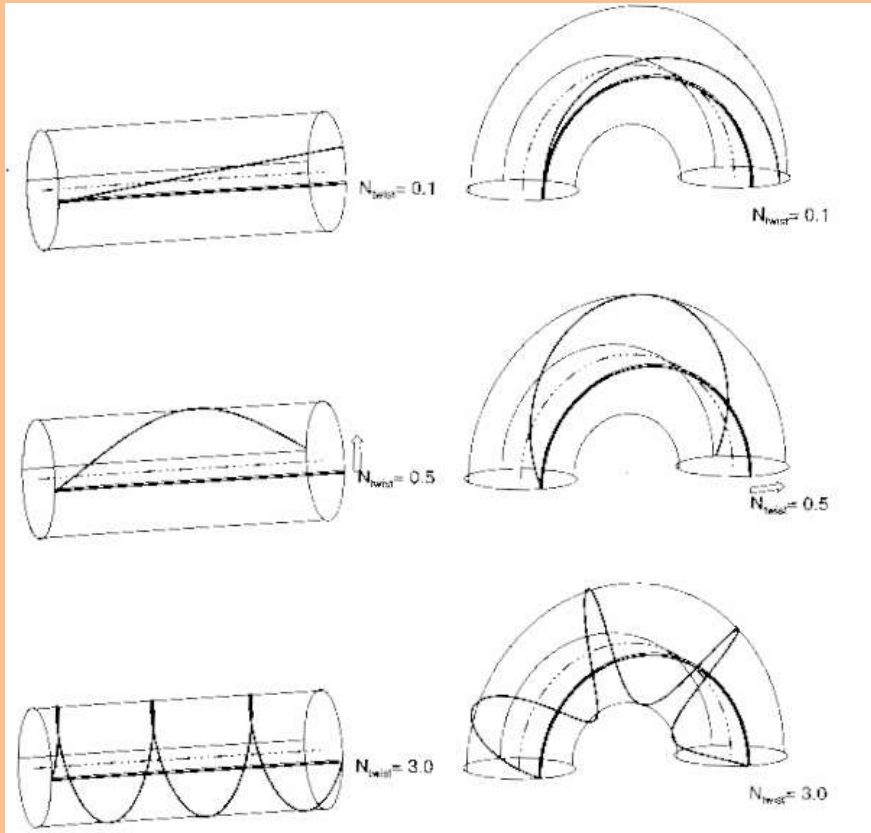


fig.17. Cylindrical and semicircular flux tubes, with the field lines on the surface. The two poles, of the active region 09004 are analogous to the two ends of a semicircular flux tube.

Angle by which the magnetic field lines twist,

$$\theta = \frac{1}{2} * \alpha * L$$

Angle of rotation of the coronal footpoints,

$$\theta_{\text{footpoint } s} = \theta_p + \theta_n - \theta_b$$

- Clockwise rotation of the poles imparts a positive twist.
- The poles P3 and N3 are rotating clockwise.

## More angular analysis of the footpoints and field line twist of 09004...

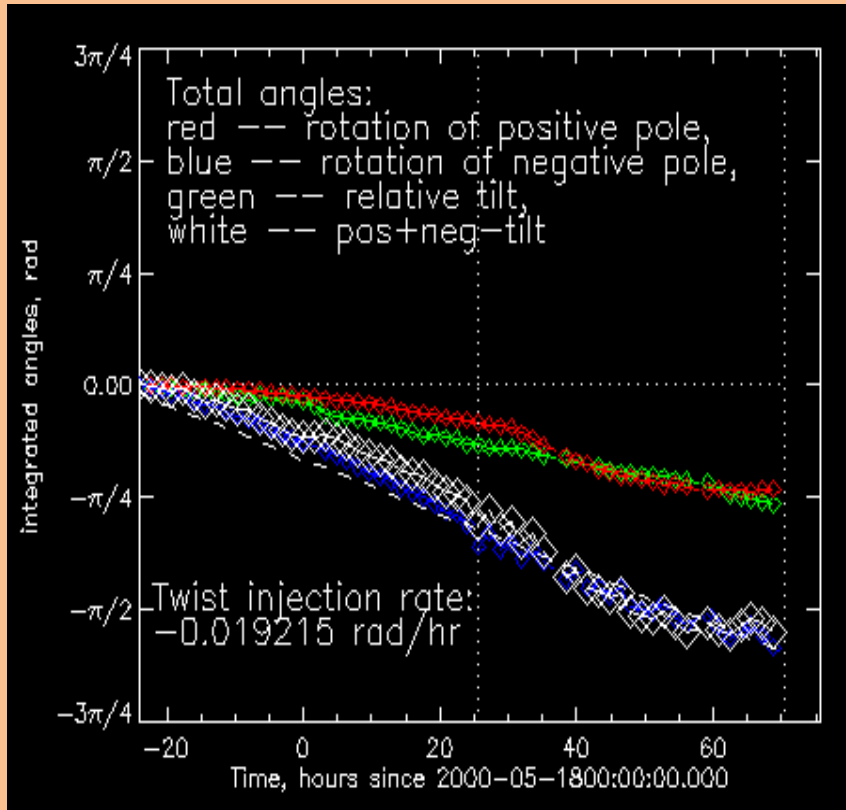


fig.18. The total angular displacement taking place at the poles since 2000-05-18. The rate of change is steep at first and then reaches a plateau. Data from Longcope and Ravindra, 2007.

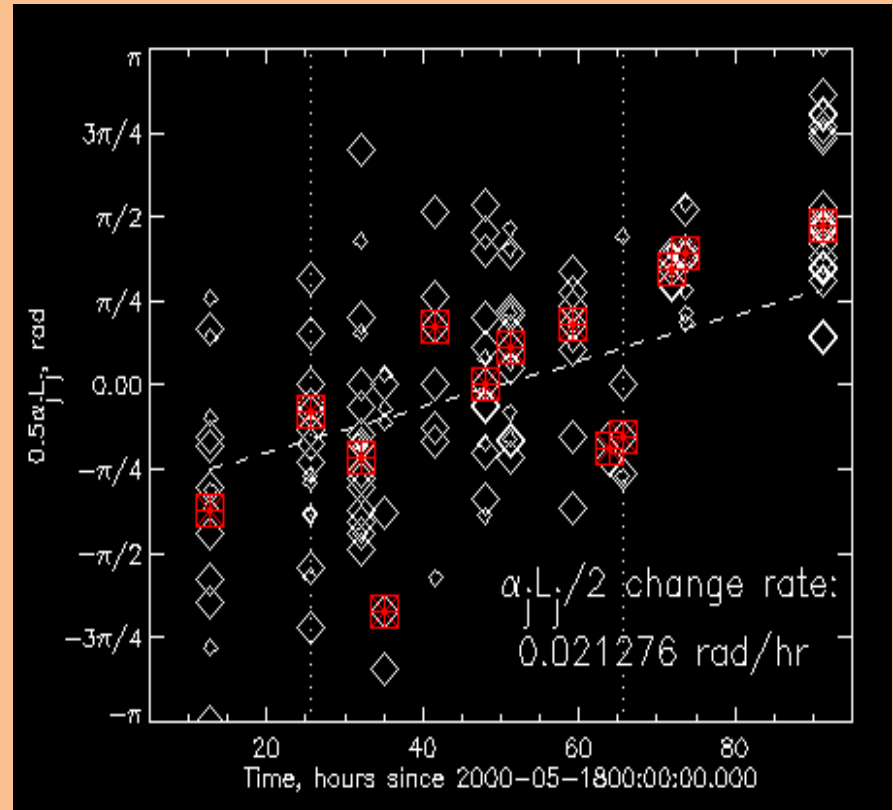


fig.19. The angle of twist of the magnetic field lines with time. Here, a positive twist of the field lines is evident again. The angle of twist of the field lines was computed using the length of each individual field line.

## **Conclusions:**

- There was no significant change in twist of the field lines of the large active region (09002).
- For the small active region (09004), the twist changes from negative to positive.
- The rate of angular twist of the field lines connecting P3 to N3 was quite close to the rate of rotation of the poles.

## **Ideas for future projects:**

- Exploring the regions where reconnections are taking place (P1-N3, P3-N1).
- Finding the magnitude of current passing through the loops.



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