The Role of Magnetic Helicity in the Initiation of CMEs from Emerging Active Regions

Alexander Nindos

Section of Astrogeophysics
Physics Department
University of Ioannina
Ioannina GR-45110
Greece

Outline

- Objective
- Data base
- The concept of magnetic helicity
- Computations of the AR’s coronal helicity
- Conclusions

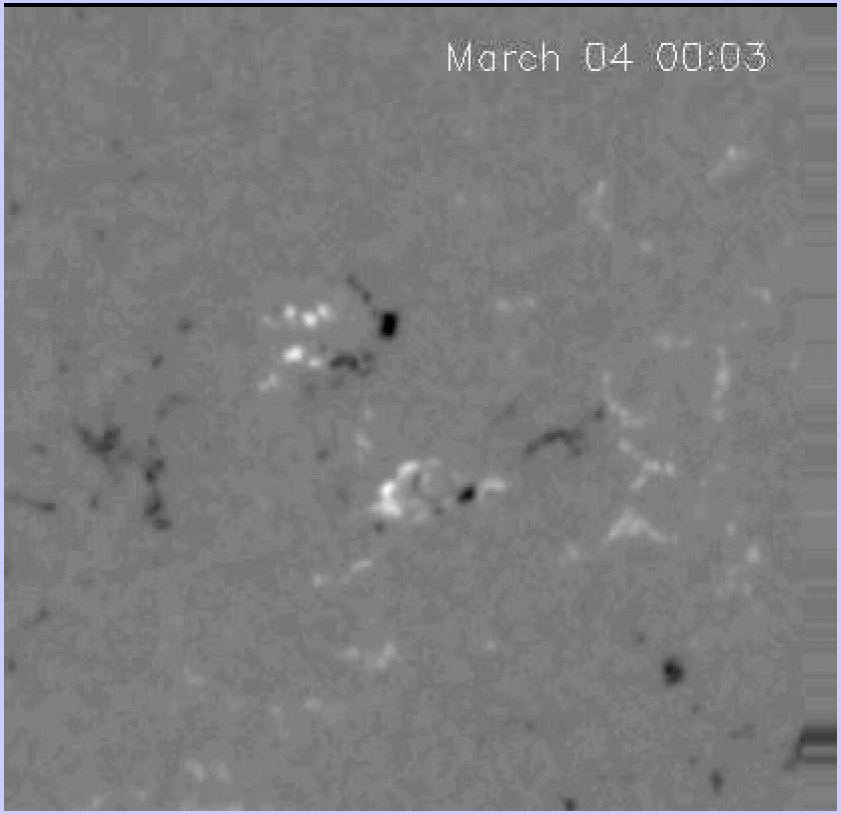
Objective

- Whether CME initiation is controlled by the amount of helicity stored in the corona.
- How to do it? Study A.Rs that emerge on the visible side of the solar disk.
- EFRs sometimes are associated with eruptions of nearby filaments (Bruzek 1952; Feynman & Martin 1995; Wang & Sheeley 1999)
- Here we investigate whether **the AR itself** that forms after the bipole emergence erupts or not.
- At the beginning of emergence most A.Rs's twist is not necessarily zero (e.g. Leka et al. 1996) but usually small (Pevtsov et al. 2003).
- Consequently, monitoring the helicity evolution of such A.Rs becomes less ambiguous.

Database

- Find A.Rs emerging within longitudes E45 and E00.
- Get rid of those that emerge with significant twist.
- Compute the coronal H at the beginning of flux emergence.
- Follow the A.R and compute its coronal H just before its first CME or when it reaches W45 (whichever happens first).
- 18 A.Rs give CME before crossing W45 and 25 do not.

A Typical Example



Magnetic helicity

$$H = \int_V \mathbf{A} \cdot \mathbf{B} dV$$

- H quantifies the amount of magn. field's twist wrt its lowest energy state (potential field).

It is meaningful only when B is fully contained inside V (at any point of the surface S surrounding V, $B_n = 0$). This is because $\mathbf{A}$ is defined through a gauge transformation $\mathbf{A}' = \mathbf{A} + \nabla\Phi \Longrightarrow$ H is gauge-invariant only when $B_n = 0$.

- H is conserved **(even under reconnection)**.

Relative magnetic helicity

For a domain like the corona with boundaries that are not flux surfaces we introduce the relative magnetic helicity wrt to a reference field B_p having the same distribution of B_n on S

$$H_r = \int_V \mathbf{A}\cdot\mathbf{B} dV - \int_V \mathbf{A_p}\cdot\mathbf{B_p} dV$$

- A potential field is a convenient choice for $\mathbf{B_p}$.
- $\mathbf{A_p}$ is the corresponding vector potential satisfying $\nabla\cdot\mathbf{A_p} = 0$ and being horizontal on the photosphere.
- H_r is gauge invariant
- It has all the physical properties of magnetic helicity.

Coronal Helicity: the LFFF approximation

- Coronal field under the linear force-free field assumption (Alissandrakis 1981)

$$\nabla \times \mathbf{B} = \alpha \mathbf{B}$$

- Compute coronal helicity H_c as a function of the derived alpha
- Follow Berger (1985) and Demoulin et al. (2002) and get

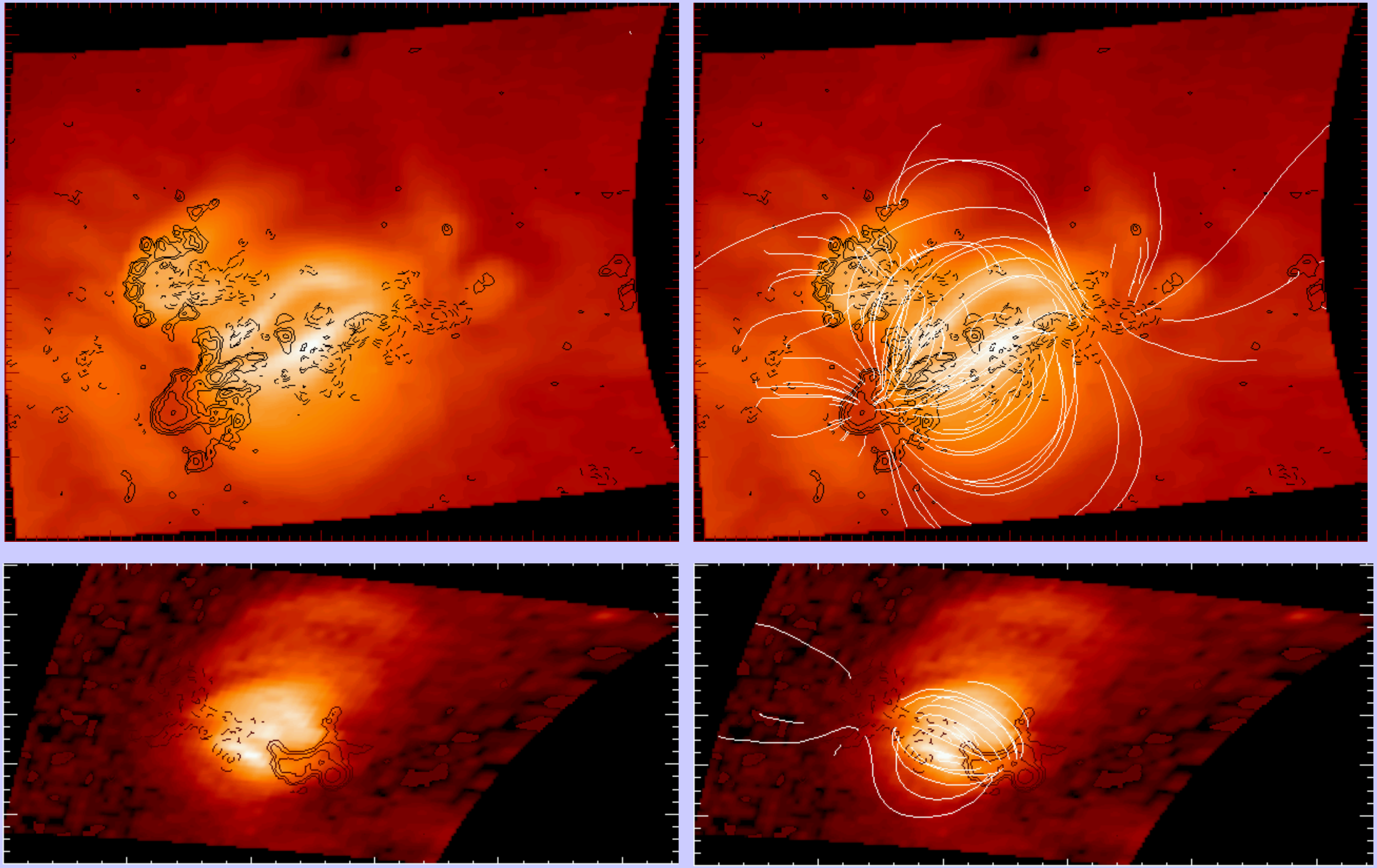
$$H_c = \alpha \sum_{n_x=0}^{N_x} \sum_{n_y=0}^{N_y} \frac{|\widetilde{B}^2_{n_x,n_y}|}{(k_x^2 + k_y^2)^{3/2}}$$

The $alpha_{best}$ Method

- For each AR use MDI magnetograms and compute alpha: (1) at the beginning of flux emergence and (2) just before its first CME or when it reaches W45 (whichever happens first).
- Determine alpha iteratively and as objectively as possible:

1. Compute the coronal field assuming a given alpha.
2. Compute the mean distance d_{mean} btw the coronal loops and the closest computed lines.
3. Through successive steps, select the alpha that gives the best global fit, ie, lowest d_{mean}

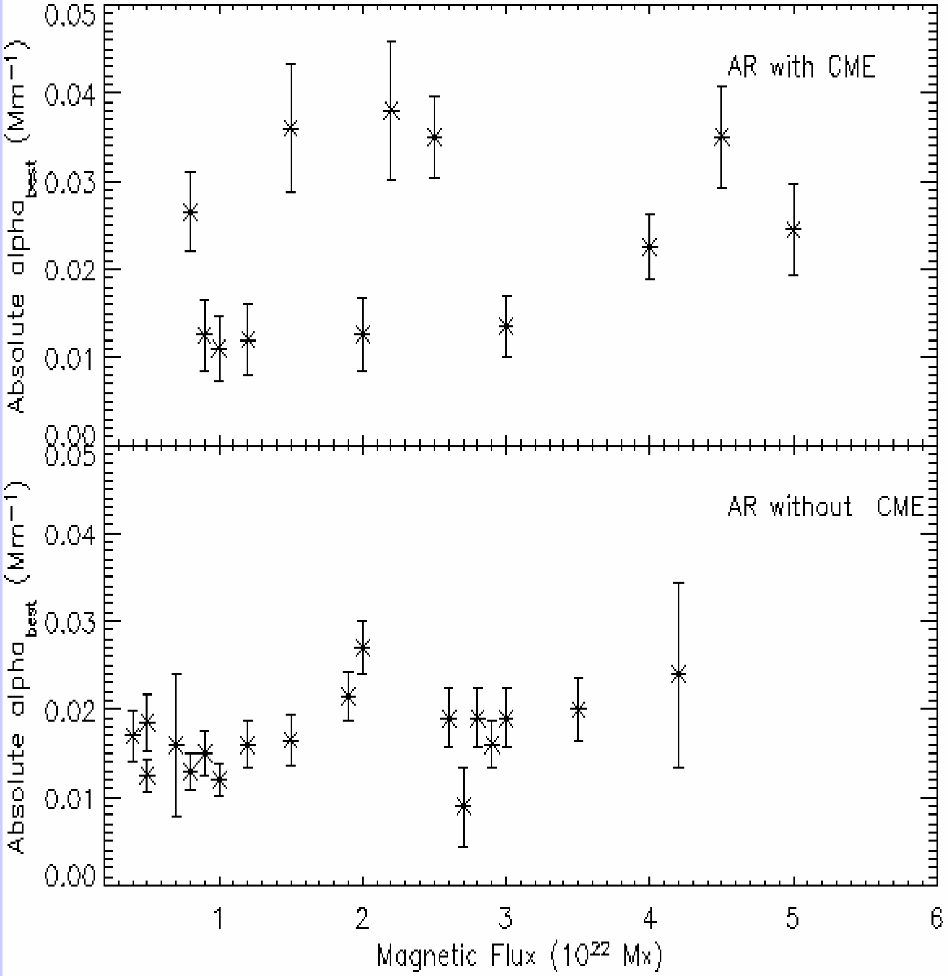
Two Typical Examples

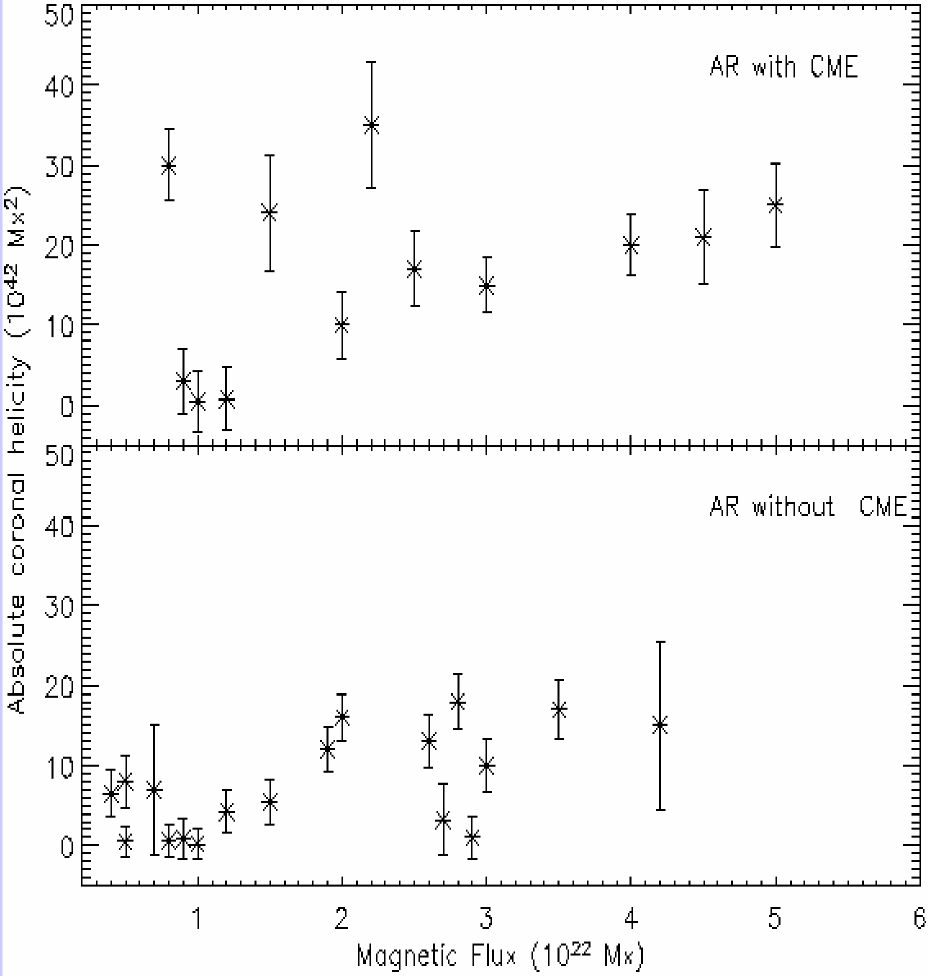


Just before CME

At W45 No CME

ARs for which alpha$_{best}$ method works





Coronal Helicity: a second approach

Compute H_c at the time of the first CME or when the AR reaches W45 using:

$$H_c = H_{c,emerg} + \Delta H_{inj}$$

H_c: the coronal helicity we need to compute

$H_{c,emerg}$: the helicity already stored in the corona at the beginning of flux emergence (use $\text{alpha}_{\text{best}}$ method: it should be almost potential).

ΔH_{inj}: the total accumulated helicity injected into the corona from the time flux emergence begins until the time we are interested in.

Transient Helicity Injection into the Corona

Separate temporal evolution of H_r across the photosphere S_p into a tangential and normal term (Berger 1999):

$$\left.\frac{dH_r}{dt}\right|_t = -2\oint(\mathbf{v_t}\cdot\mathbf{A_p})B_n dS_p$$

$$\left.\frac{dH_r}{dt}\right|_n = 2\oint(\mathbf{B_t}\cdot\mathbf{A_p})v_n dS_p$$

Compute helicity injected into the corona

- Use MDI LOS images
- Remove differential rotation
- Compute horizontal velocities using LCT method
- LCT does NOT detect $\mathbf{v_t}$ but (Demoulin & Berger 2003)

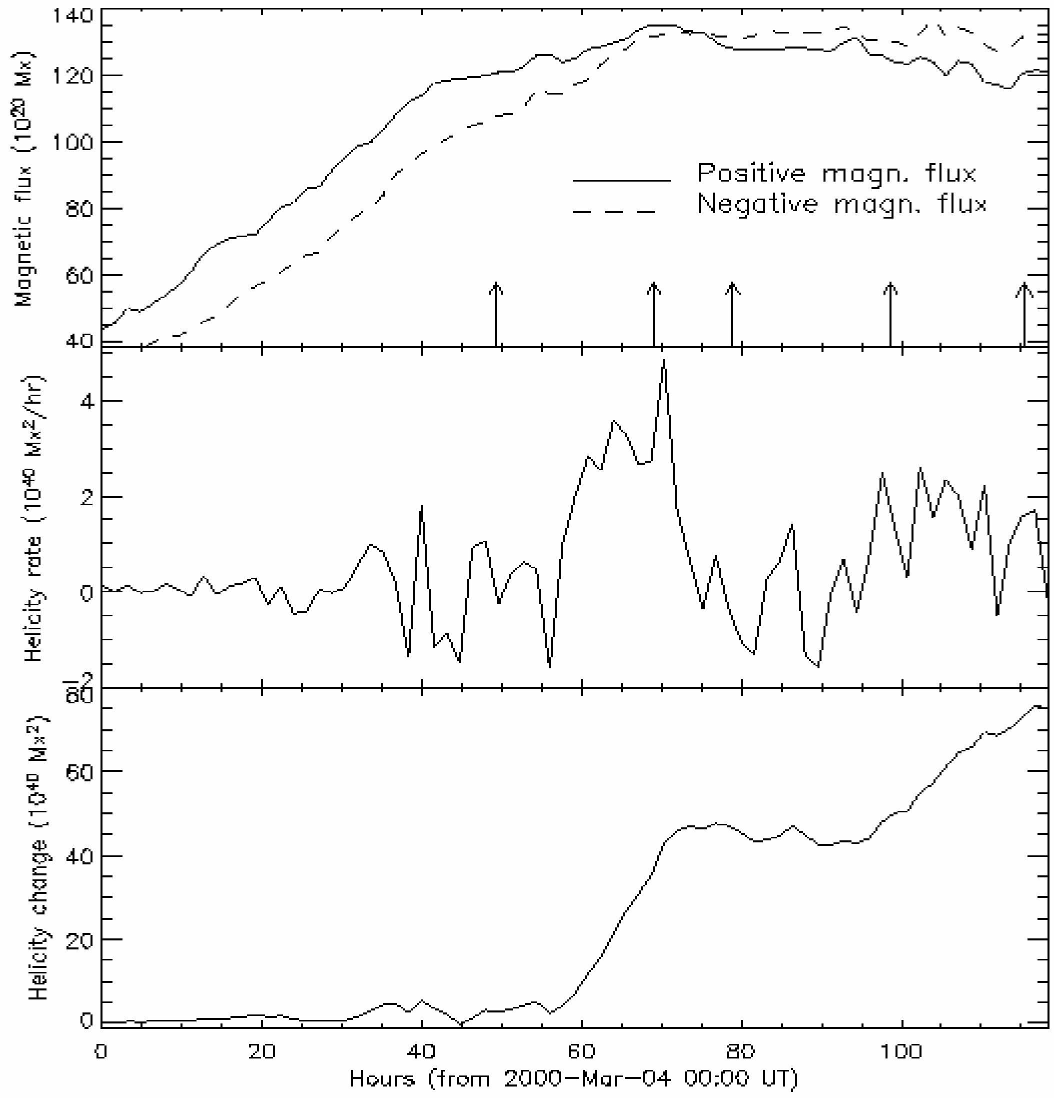
$$\mathbf{v}_{LCT} = \mathbf{v}_t - \frac{v_n}{B_n}\mathbf{B}_t$$

Then either combine it with $dH/dt|_n$ and $dH/dt|_t$ and get the whole helicity flux density $G_A = -2(\mathbf{A_p} \cdot \mathbf{v}_{LCT})\, B_n$

Or even better get LCT results and use as helicity flux density (Pariat et al. 2005)

$$G_\theta(\mathbf{x}) = -\frac{B_n}{2\pi}\int_{S'} \frac{\mathrm{d}\theta(\mathbf{r})}{\mathrm{d}t} B'_n \, dS'$$

A Typical Example

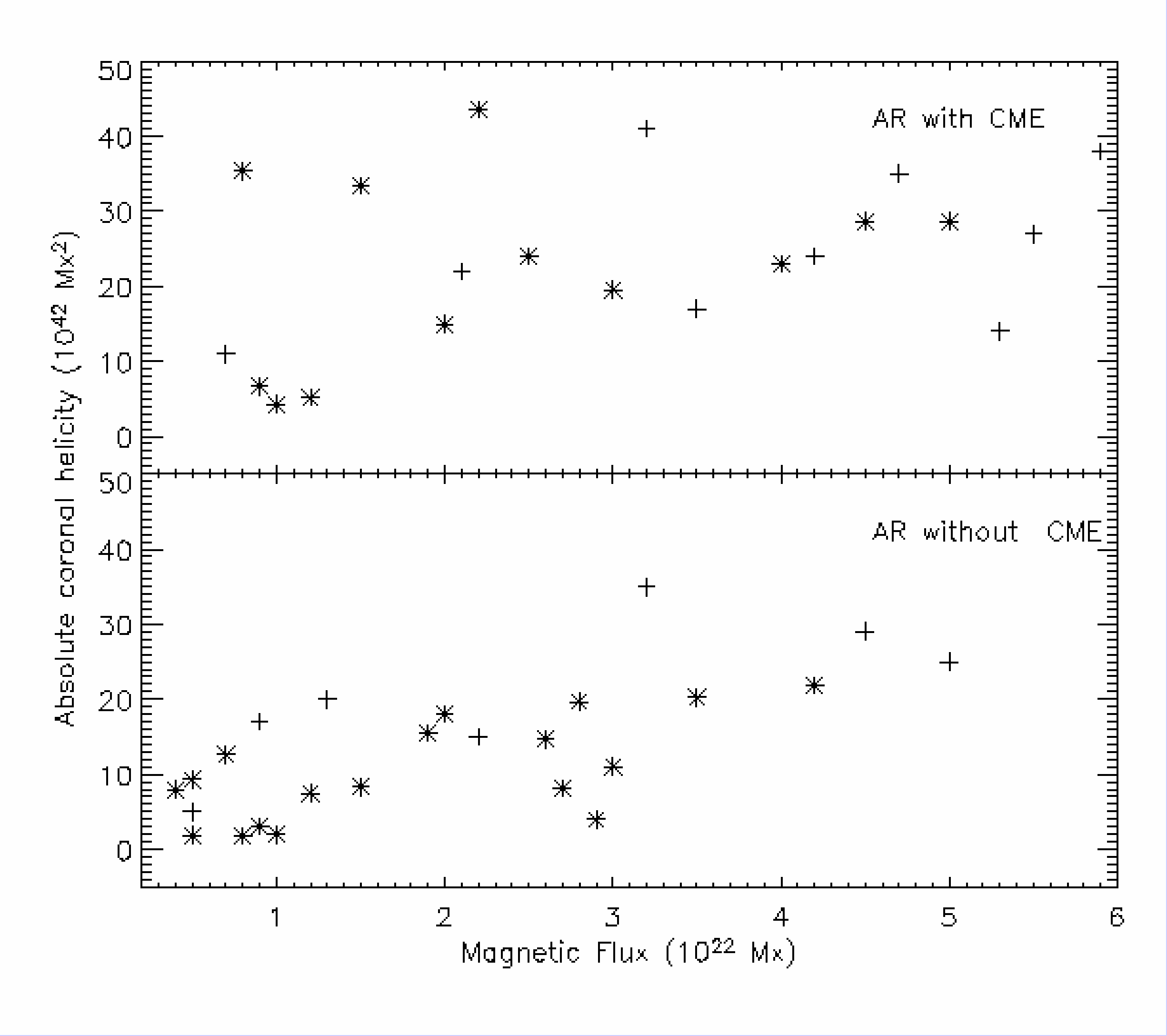


Magnetic flux

Helicity injection rate

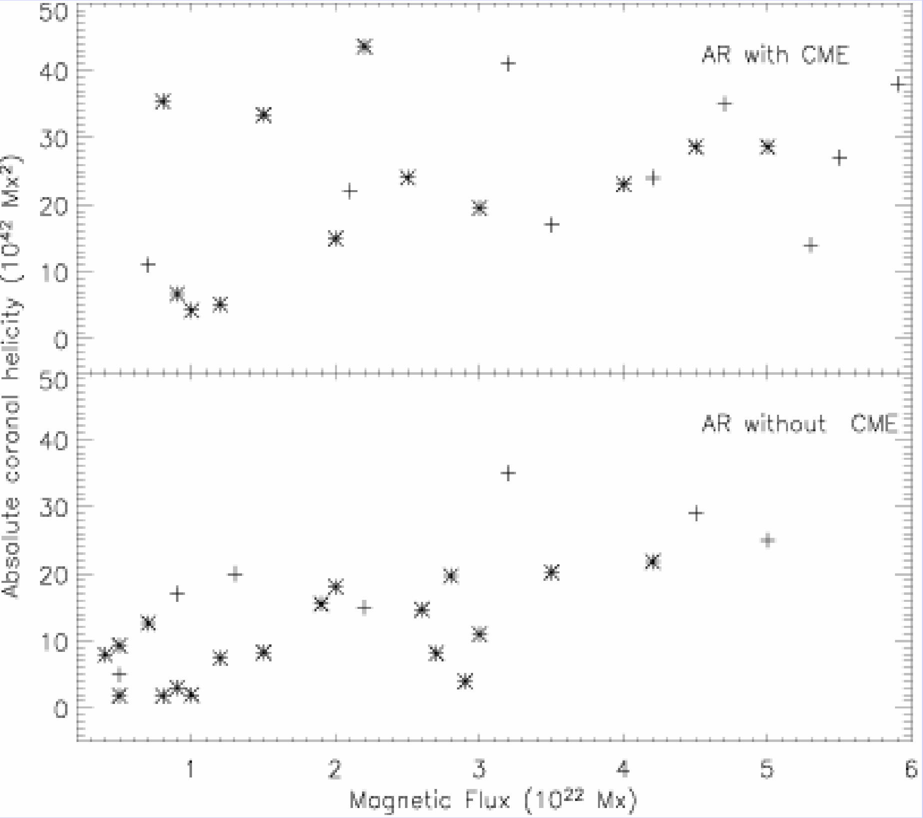
ΔH_{inj}: Accumulated change of helicity

All A.Rs together

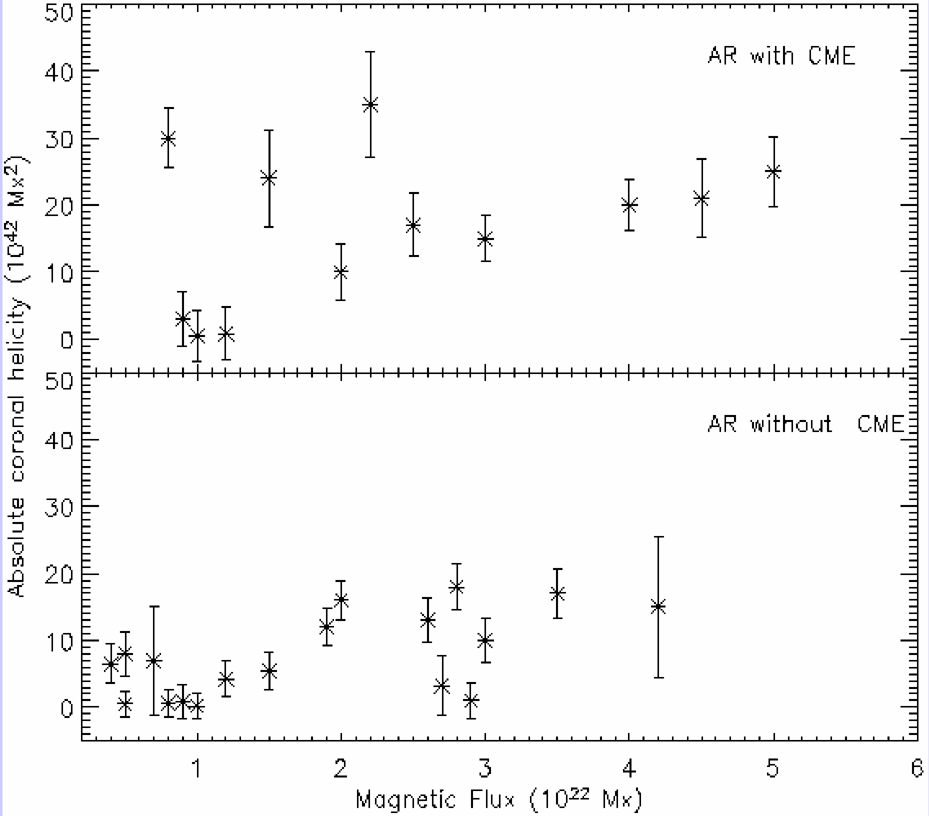


Crosses: A.Rs for which alpha$_{best}$ method did not work satisfactorily

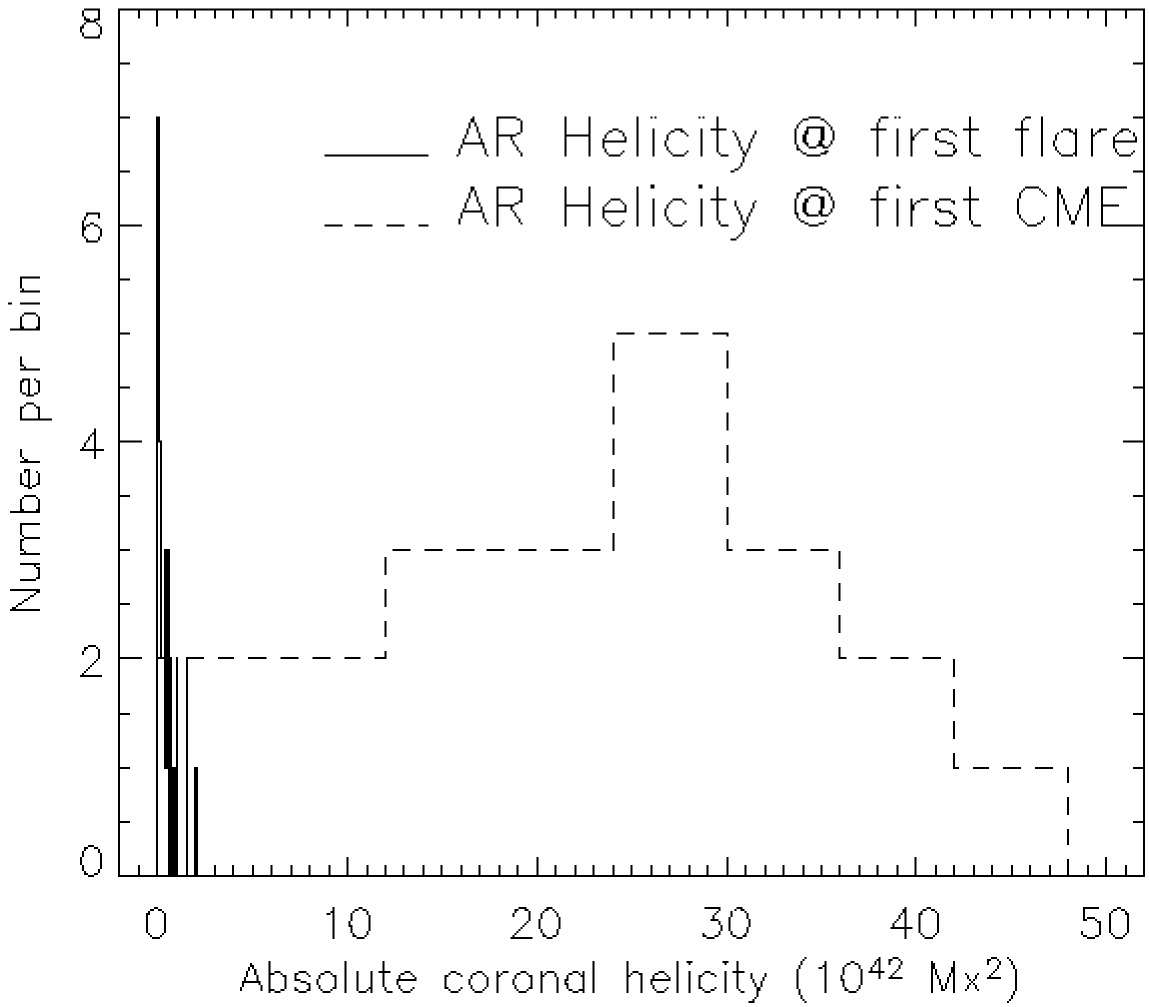
Helicities using ΔH_{inj}



Helicities from $alpha_{best}$ method



- Right panel shows smaller helicities; reflects intrinsic difficulties of lfff and $alpha_{best}$ method.
- **However, the conclusion from both sets is the same: the null hypothesis (ie there is no association btw the CME initiation and whether the AR's *H* is bigger or smaller than the median value of the sample's *H*) is rejected at the >99.9% confidence level.**



Complete segregation!

Conclusions

- This work provides direct observational support for the paradigm that the helicity accumulation is a necessary condition for CME initiation (No significant helicity? No CME!)
- Flares without CME → Reconnection events
- CMEs → Helicity expulsion
- These results are independent from the A.R's magnetic flux or the strength of the flare.
- A by-product of this study: $alpha_{best}$ method under-estimates AR's twist (see also Kliem & Valori 2004; Leka et al. 2005)