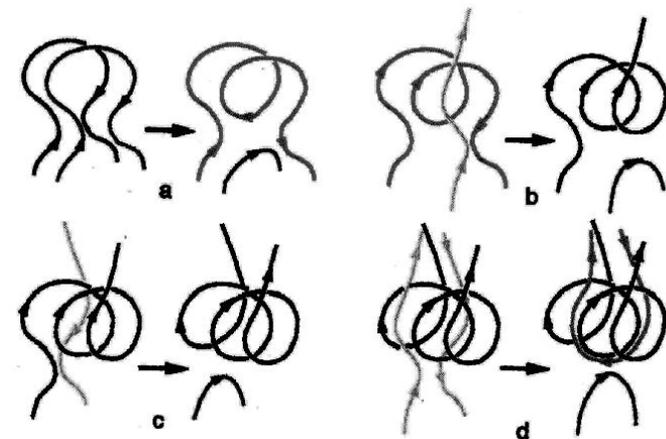
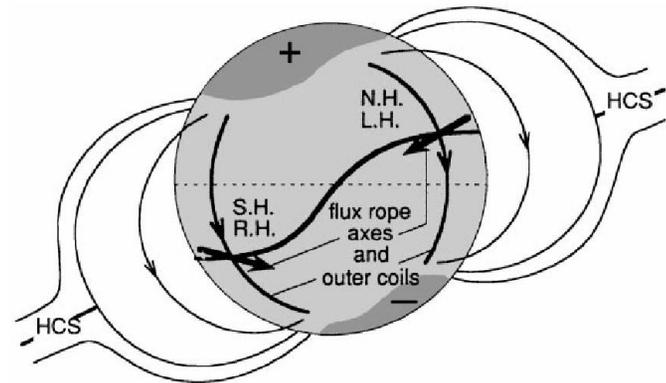


# THE AR-ICME TOPOLOGY CONNECTION

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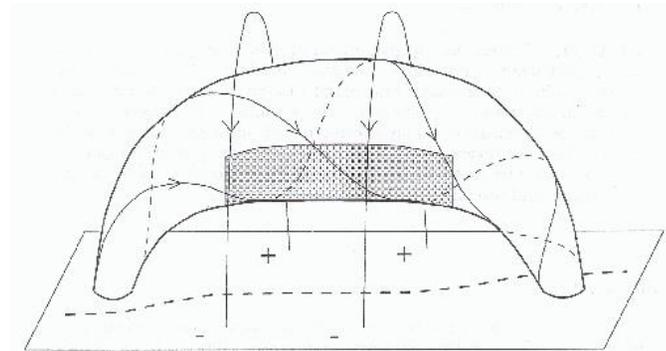
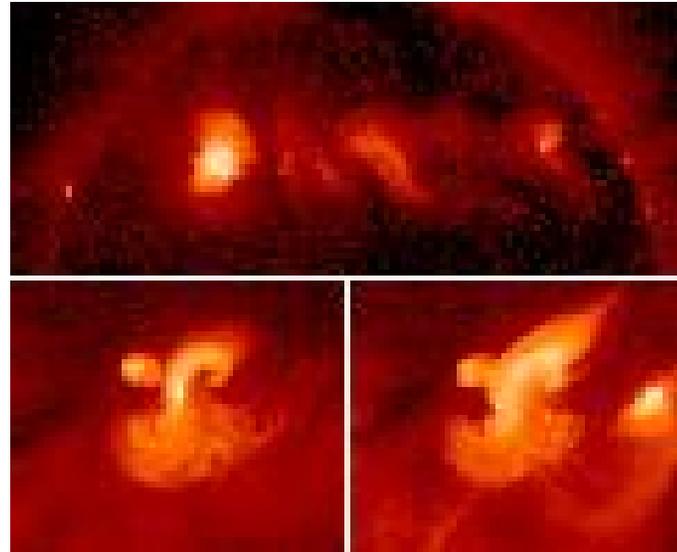
# Magnetic Clouds and Solar Progenitors: Filaments (Crooker 2000 review)

- Left-handed (Right-handed) MCs tend to come from the Northern (Southern) hemisphere
- Tilts of MC axes wrt ecliptic plane are correlated with tilt angles (relative to the heliomagnetic equator) of associated erupting filaments.
- The north-south component of MC fields tends to flip at around cycle maximum.
- The field of MCs is made up of the large-scale dipole fields.
- MCs carry the imprint of the large-scale solar magnetic field out into the heliosphere.



# Magnetic Clouds and Solar Progenitors: Active Regions (Canfield, Pevtsov, Leamon 2000-2004)

- Left-handed (Right-handed) MCs tend to come from the Northern (Southern) hemisphere
- Tilts of MC axes wrt ecliptic plane are NOT correlated with tilt angles (relative to the heliomagnetic equator) of associated active regions.
- The north-south component of MC fields tends to flip at around cycle MINIMUM.
- The field of MCs is made up BOTH active-region and large-scale dipole fields.
- MCs carry the imprint of BOTH active regions and the large-scale solar magnetic field out into the heliosphere.



# Leamon et al. (2004) Results: Solar - Inter-planetary Comparison

No.	Year	Event Times:		AR	$I_{MC}/I_{AR}$	$\Phi_{MC}/\Phi_{AR}$	$(\alpha L)_{AR}$	$(\alpha L)_{MC}$
		Eruption	Magnetogram		$\times 10^{-3}$	%		
1	1995	Feb 04 15:56	Feb 04 01:51	7834	0.15–0.53	20–38	–0.34	–53.2
2	–	Feb 28 08:46	Feb 27 07:17	7846	0.05–0.30	8–18	–0.01	–62.2
–	–	–	Feb 28 19:45	–	0.12–0.28	8–12	–0.91	–
3	–	Dec 11 03:31	Dec 10 17:22	7930	0.13–1.25	115–279	1.94	–25.8
–	–	–	Dec 11 17:15	–	0.58–4.02	122–314	1.30	–
4	1998	Feb 14 02:29	Feb 12 17:33	8156	0.30–0.66	22–30	–0.85	+43.1
5	–	Apr 29 16:58	Apr 28 16:38	8210	0.09–0.83	35–69	1.64	+26.3
–	–	–	Apr 29 16:39	–	0.36–1.19	40–72	1.27	–
6	1999	Feb 14 11:16	Feb 11 19:26	8457	0.36–1.07	43–89	–0.46	–25.0
7	–	Aug 04 04:11	Aug 02 16:36	8651	0.06–0.13	5–7	–1.06	–37.6
8	–	Sep 17 22:28	Sep 20 17:00	8700	0–0.53	0–13	–0.59	–124.8
9	2000	Jul 14 09:27	Jul 11 16:52	9077	0.58–0.71	61–69	–7.79	–33.5
–	–	–	Jul 14 16:39	–	0.55–0.68	52–112	–5.45	–
–	–	–	Jul 17 16:32	–	1.78–6.12	138–274	–1.60	–
10	–	Jul 25 02:48	Jul 21 20:28	9097	0.13–0.14	6.0–6.4	–1.42	–53.9
11	–	Jul 27 22:18	Jul 26 16:33	9097	0.19–0.49	40–106	1.42	–21.6
–	–	–	Jul 28 16:40	–	0.83–4.00	121–317	–1.14	–
12	–	Aug 09 16:30	Aug 08 16:37	9114	0.59–1.35	56–79	–1.70	+35.2
–	–	–	Aug 11 16:58	–	0.60–1.14	46–62	–1.19	–

# Discussion: Solar - Interplanetary Comparison: Active-Region Related Magnetic Clouds

Consider three simple models of the solar genesis of the observed MC flux:

- The active region alone (the AR model);
- The overlying large-scale dipole alone (the LSD model);
- A region of reconnection of the active region and the large-scale dipole (the AR-LSD reconnection model).

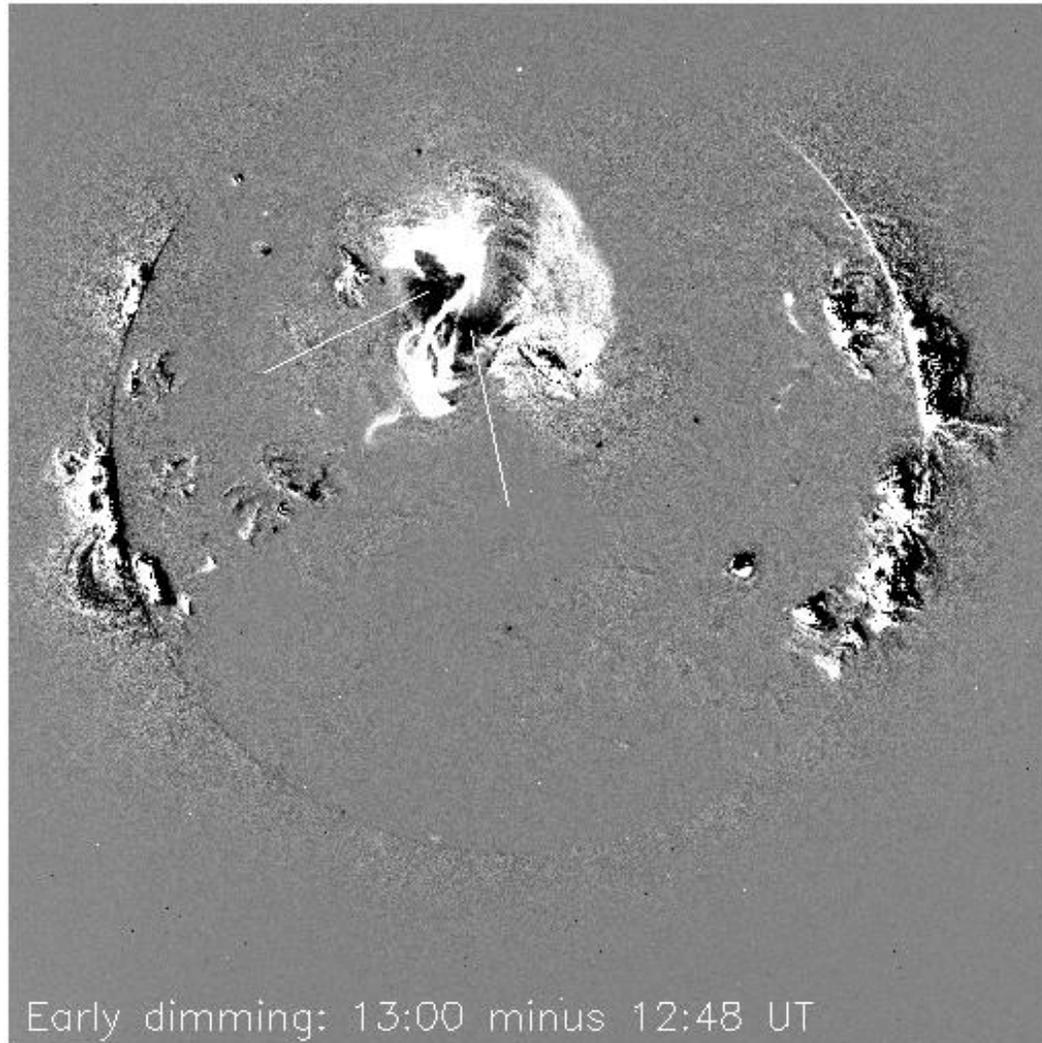
Three basic results (Leamon et al 2004):

- The flux ratios  $\Phi_{MC}/\Phi_{AR}$  tend to be large.
- The current ratios  $I_{MC}/I_{AR}$  tend to be orders of magnitude less than the flux ratios  $\Phi_{MC}/\Phi_{AR}$ .
- There is a statistically significant proportionality between the flux ratios  $\Phi_{MC}/\Phi_{AR}$  and the current ratios  $I_{MC}/I_{AR}$ .

# First Result: Large Flux Ratios

NB: No attempt to ID footpoints of dimming region (e.g., Lepping *et al.* [1997], Webb *et al.* [2000])

- The flux ratios  $\Phi_{MC}/\Phi_{AR}$  tend to be large.
- Inconsistent with the AR model
- Consistent with the LSD model
- Consistent with the AR-LSD reconnection model

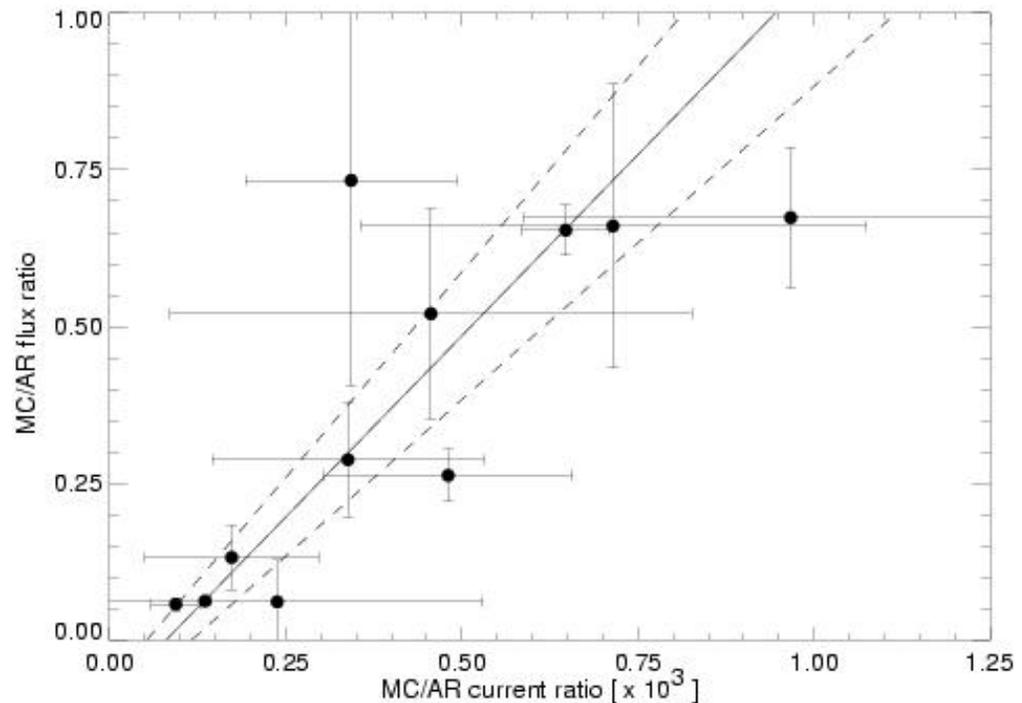


## Second Result: Current Ratios $\ll$ Flux Ratios

- The current ratios  $I_{MC}/I_{AR}$  tend to be orders of magnitude less than the flux ratios  $\Phi_{MC}/\Phi_{AR}$ .
- Makes sense only in the context of the AR and AR-LSD reconnection models, if there is no significant current present outside the cores of active regions.
- Although this view is reasonable, it is hard to defend, since as a practical matter vector magnetographs lack sufficient sensitivity to measure currents beyond the strong-field areas of active regions.
- It remains possible that there exist on the Sun very extended regions outside ARs with current density that is low, but nevertheless not so low that their contribution to the total current of MCs is negligible.

## Third Result: $I_{MC}/I_{AR}$ grows with $\Phi_{MC}/\Phi_{AR}$

- Whether or not the relationship is linear, it is demonstrably real.
- Spearman rank-order correlation coefficient is 0.811, with confidence level 99.8%.
- This trend can most easily be explained in terms of the AR-LSD reconnection model.
- The combination of  $I_{MC} \ll I_{AR}$  and  $\Phi_{MC} \sim \Phi_{AR}$  argues against AR model.



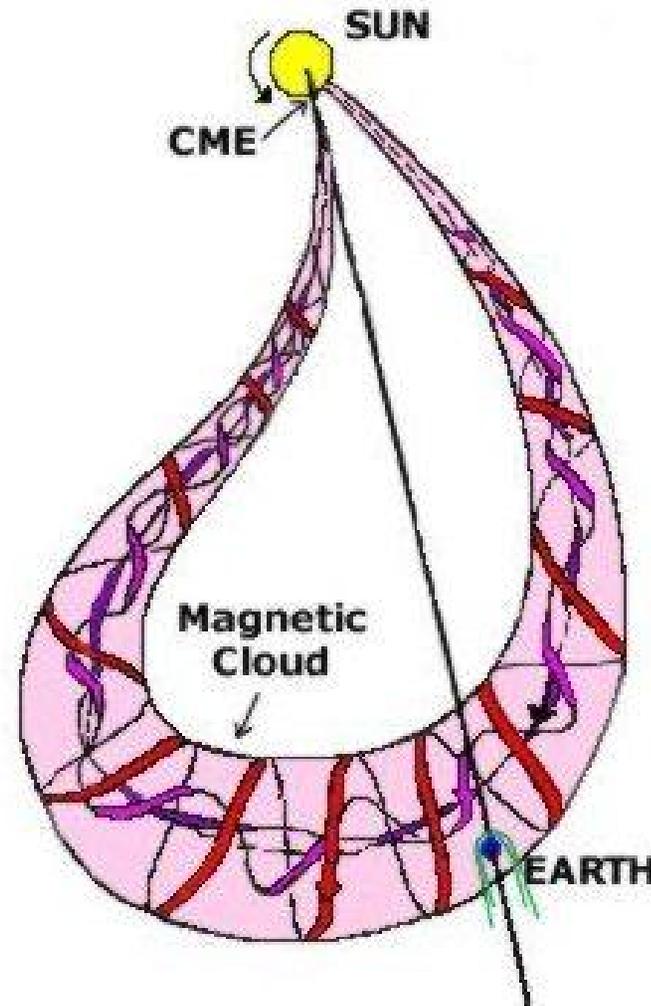
# Twist and Turns

NB:

- $\alpha L \sim$  total twist in length  $L$ .
- ARs:  $L = \pi \ell / 2$  from magnetograms.
- MCs:  $L = 2.5$  AU (Larson *et al.* [1997] case study.)
- $N_{\text{turns}} \equiv \alpha L / (2\pi)$ .

Two basic results:

- $(\alpha L)_{MC} \sim 10 (\alpha L)_{AR}$ .
- No systematic sign or amplitude relationship between  $(\alpha L)_{MC}$  and  $(\alpha L)_{AR}$ .



[After Marubashi]

Not to Scale

# Implications for the Simple Models

- $(\alpha L)_{MC} \gg 1$  rules out AR and LSD models.
- Only the MC-LSD reconnection model can produce so many turns within the resulting magnetic cloud.
- Only the MC-LSD reconnection model can explain the lack of relationship between  $(\alpha L)_{AR}$  and  $(\alpha L)_{MC}$  (Zhang & Low [2003]).

# Summary

Considering three simple models – that the flux of magnetic clouds originates in:

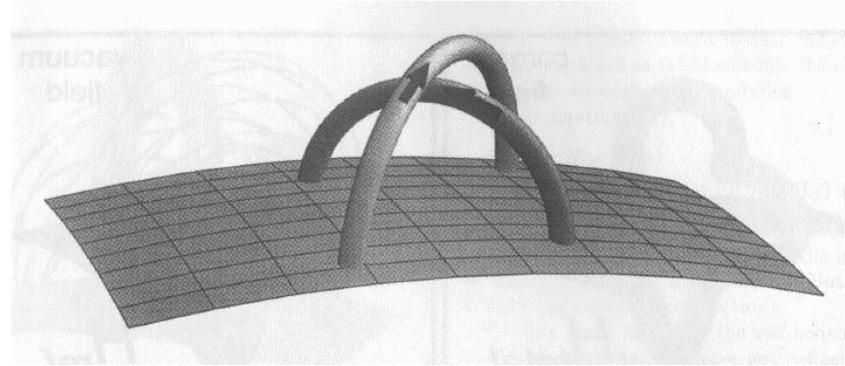
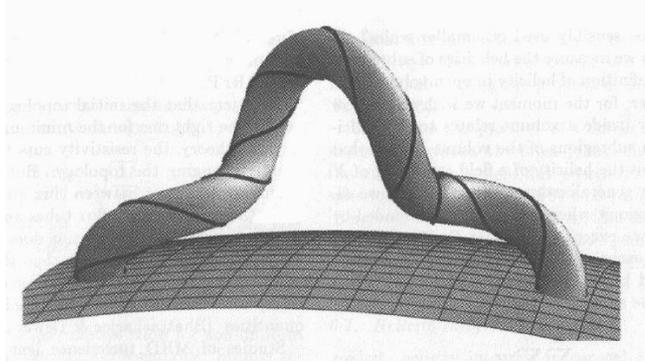
- Active regions alone (AR model);
- The overlying large-scale dipole alone (LSD model);
- A region that has experienced reconnection of the active region and the large-scale dipole (AR-LSD reconnection model).

And the observational results that :

- $\Phi_{MC}/\Phi_{AR}$  values are large
- $\Phi_{MC}/\Phi_{AR} \gg I_{MC}/I_{AR}$
- $I_{MC}/I_{AR}$  is proportional to  $\Phi_{MC}/\Phi_{AR}$
- $(\alpha L)_{MC} \gg 1$
- $(\alpha L)_{MC}$  and  $(\alpha L)_{AR}$  unrelated in sign and amplitude

Only the AR-LSD reconnection model works for AR-related MCs!

## Where to go ... (proposed)



- Relative magnetic helicity (Finn & Antonsen [1985]):

$$H_V = \int_V (\mathbf{A} + \mathbf{A}_P) \cdot (\mathbf{B} - \mathbf{B}_P) d^3x.$$

- Self [AR] and mutual [AR-LSD] helicity (Berger [1999]):

$$H_{AR}^{self} = \int_{AR} \mathbf{A} \cdot \mathbf{B} d^3x, \quad H_{AR-LSD}^{mutual} = 2 \int_{AR-LSD} \mathbf{A}_P \cdot \mathbf{B} d^3x.$$

- Discrete flux tubes with linking number  $L_{ij}$ , twist  $\mathcal{T}$  and writhe  $\mathcal{W}$ :

$$H = \sum_{i=1}^N \sum_{j=1}^N L_{ij} \Phi_i \Phi_j, \quad L = \mathcal{T} + \mathcal{W}.$$

- Magnetic helicity conservation.

# Why not to go there ... (weaknesses from three rejection letters)

First submission (AFOSR):

- No feedback

Second submission (SHINE):

- “Estimation of magnetic flux in cloud may contain large uncertainties.”
- “Because of evolution of current system in the flux rope across the heliosphere, the ratio of current in active region and magnetic cloud may not be proven useful.”
- “It is not clear whether using helicity will further the goals of understanding clouds.”

Third Submission (LWS2003):

- “The Potential Field Source Surface (PFSS) model, which they intend to use, appears to be inappropriate to the purpose because the fields near active regions are not likely to be potential.”

**END**