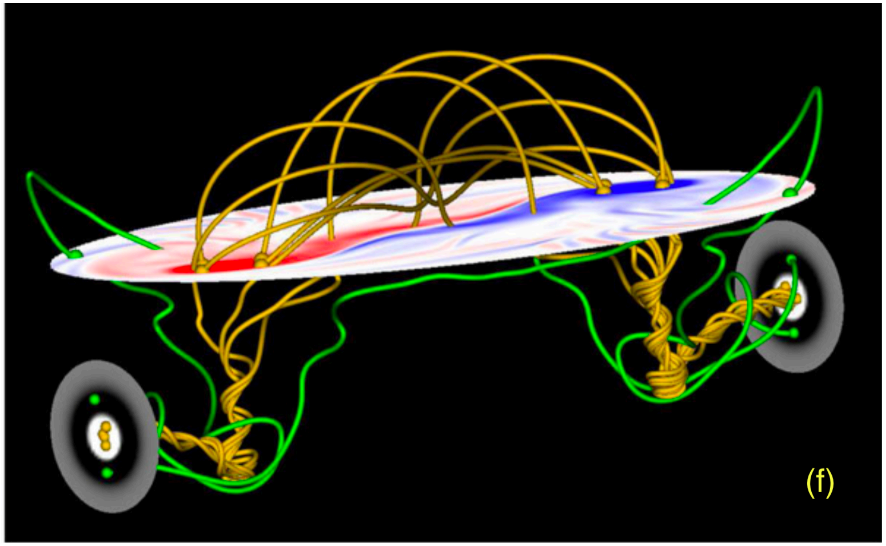
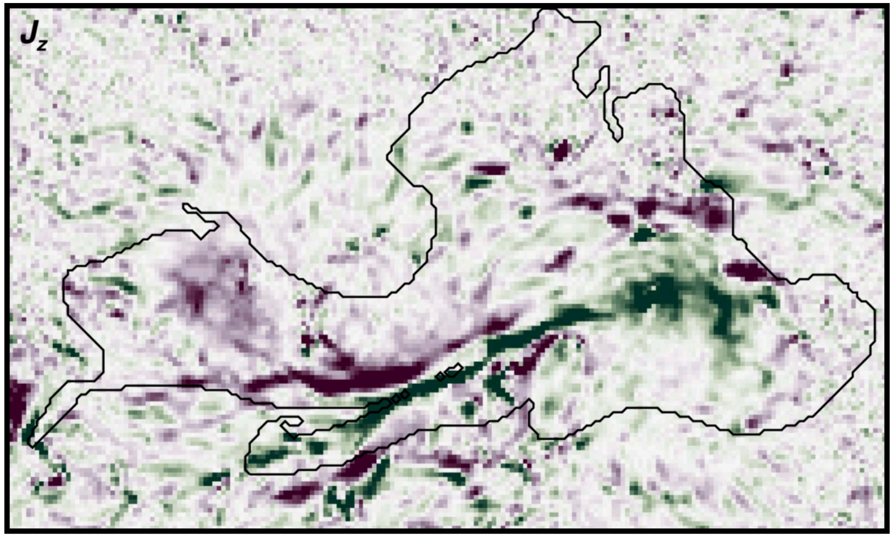
Electric-Current Neutralization and Eruptive Activity





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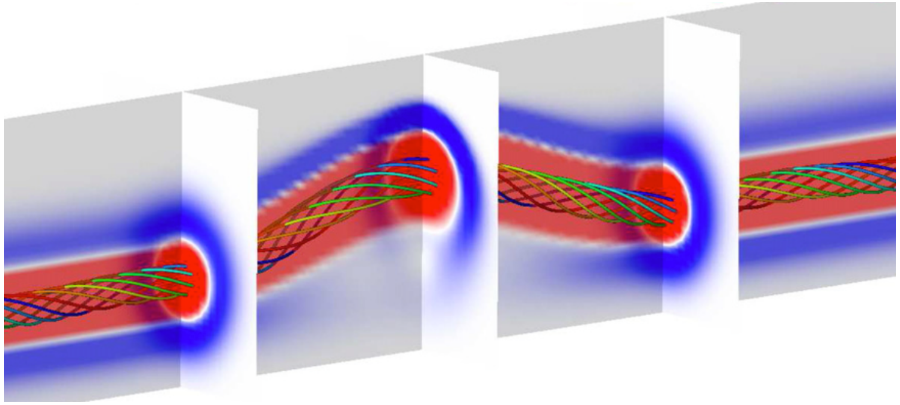
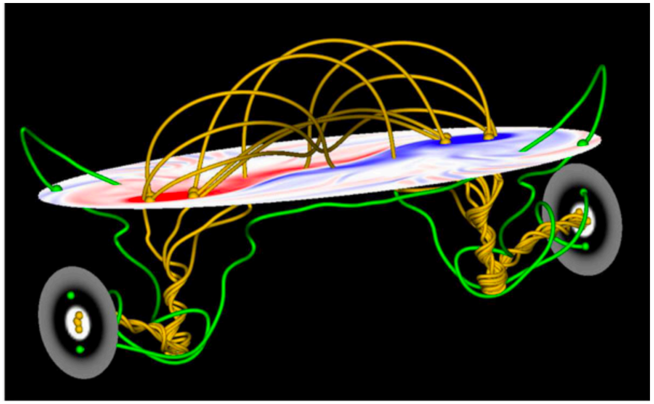
Abstract

The physical conditions that determine the eruptive activity of solar active regions (ARs) are still not well understood. Various proxies for predicting eruptive activity have been suggested, with relatively limited success. Moreover, it is presently unclear under which conditions an eruption will remain confined to the low corona or produce a coronal mass ejection (CME).

Using vector magnetogram data from SDO/HMI, we investigate the association between the degree of electric-current neutralization and eruptive activity for a sample of ARs. We find that the majority of CME-producing ARs are characterized by a strong net current, while the total current in ARs that do not produce CMEs is well neutralized, even if those ARs produce strong (X-class) confined flares. This suggests that the degree of current neutralization can serve as a good proxy for assessing the ability of ARs to produce CMEs.

Introduction



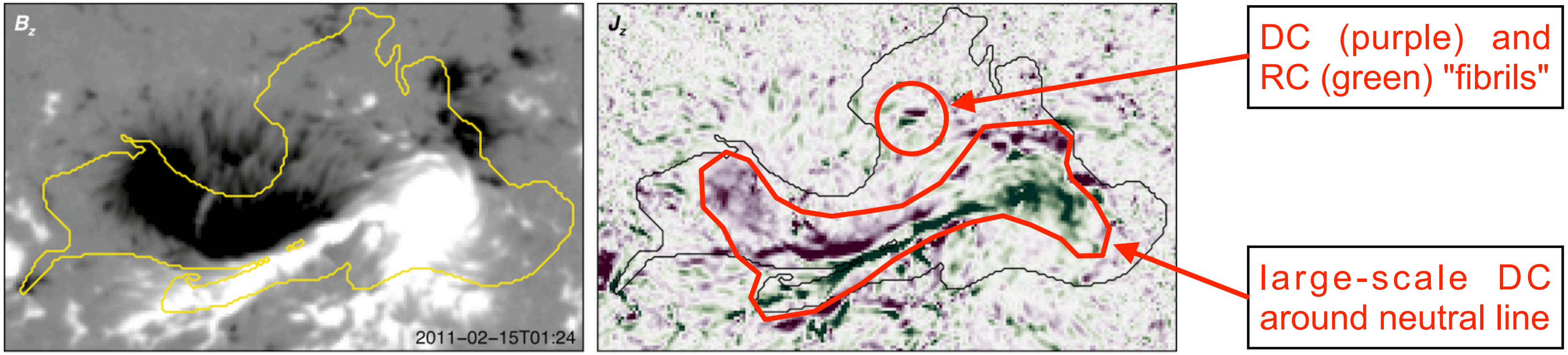


MHD simulation of flux emergence. *Left:* current-neutralized sub-photospheric flux rope (red/blue: direct/return current). *Right:* After emergence into the corona, the flux rope carries mainly direct current (Török et al. 2014).

In an isolated magnetic flux rope (as in the convection zone), electric currents are neutralized: the central **direct current (DC)** is surrounded by an oppositely directed **return current (RC)** of same strength (|DC/RC|=1; top left image). Non-isolated flux ropes (as in the corona), however, can, under certain conditions, carry a substantial **net current** (|DC/RC|>1; top right image).

In (well-isolated) active regions (ARs), the currents are always **balanced,** i.e., all currents that flow into an AR (j_z>0) flow also out of it (j_z<0). However, there has been a long-lasting debate on whether or not AR-currents are **neutralized** (Parker 1996; Melrose 1996), which requires that the sum of all in and out-flowing currents is zero also within <u>each AR polarity.</u> Recent numerical studies (e.g., Török & Kliem 2003; Török et al. 2014; Dalmasse et al. 2015) suggest that current-neutralization breaks down if significant shear has developed at the neutral line of an AR.

Introduction



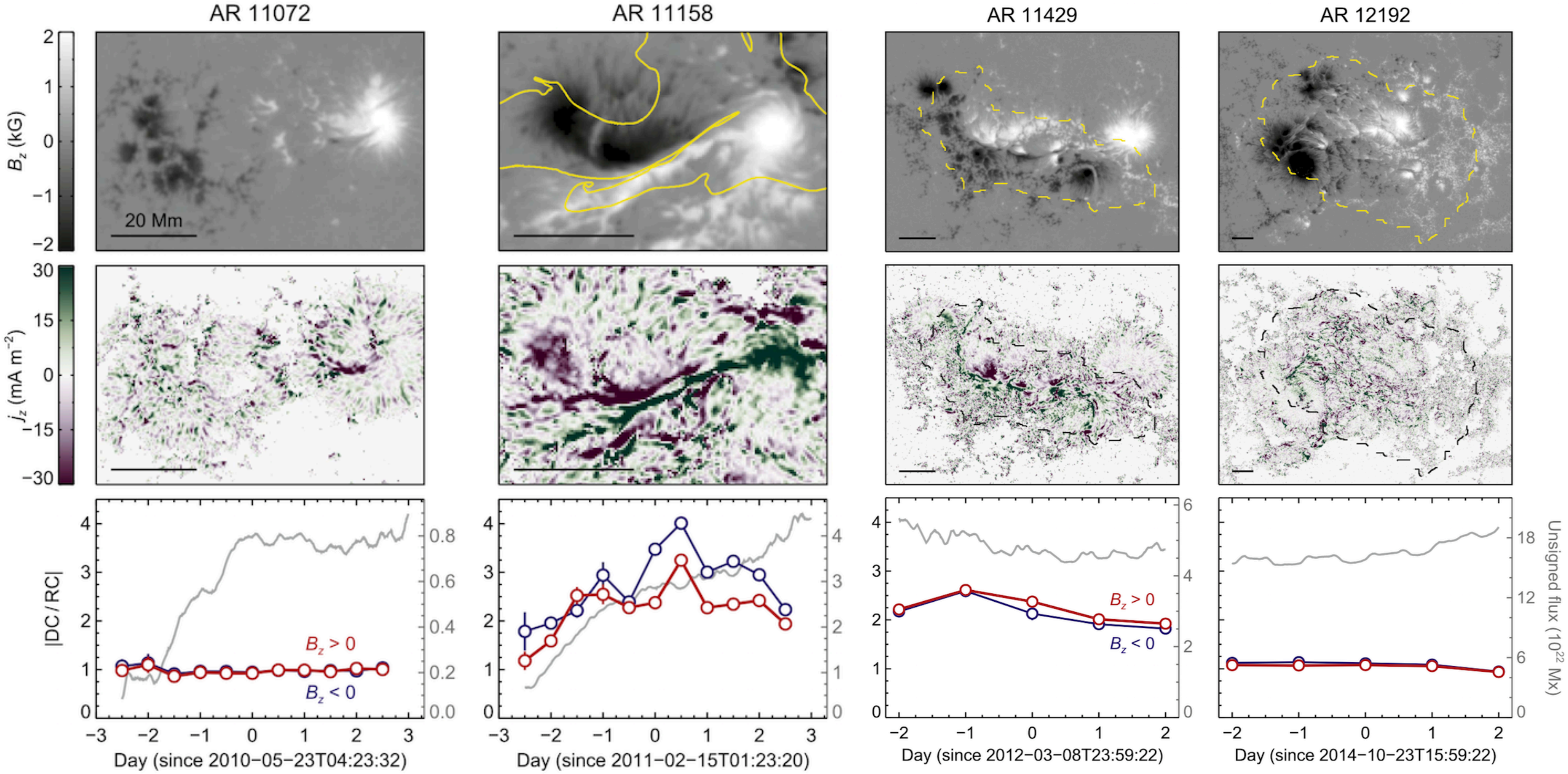
HMI observations of AR 11158 (left: B_z; right: j_z). From Liu et al. 2017.

HMI observations indicate that ARs (unlike single flux ropes) contain many "fibril-like" direct and return currents that seem to cancel out, so that the whole AR is neutralized (as suggested by Parker 1996). However, some ARs additionally show a strong direct current surrounding the neutral line (e.g., Georgoulis et al. 2012), indicative of the presence of a non-neutralized flux rope (or strongly sheared magnetic arcade) in the AR center (supporting the suggestion by Melrose 1996).

Our hypothesis: Since strong net currents indicate the presence of flux ropes, they may serve as a proxy for the capability of an AR to produce a CME.

Our approach: Measure |DC/RC| for a sample of ARs and compare with eruptive activity of AR. |DC/RC| is evaluated in closed-flux-area above eruptive neutral line.

Pilot study with four cases (Liu Y. et al. 2017)



AR	⟨|DC/RC|⟩	⟨Φ⟩	*J*-pattern	Flares	CMEs
AR 11072	0.98 ± 0.01	25°.1 ± 6°.4	No	No	No
AR 12192	1.06 ± 0.01	41°.2 ± 11°.3	No	Yes	No
AR 11429	2.17 ± 0.01	67°.4 ± 8°.5	Yes	Yes	Yes
AR 11158	2.54 ± 0.02	63°.6 ± 6°.9	Yes	Yes	Yes

<Φ>: average shear angle along PIL; *J*-pattern: elongated current around neutral line

Preliminary conclusions from pilot study

(1) CME-producing ARs exhibit a strong, double-J-shaped net current along their neutral line, whereas ARs that are quiet or produce only confined flares do not have such a feature and are almost perfectly current-neutralized.

(2) The differences in neutral-line shear are less pronounced, suggesting that |DC/RC| may serve as a better proxy for an ARs capability to produce CMEs (i.e., eruptive flares) than the shear along the neutral line.

(3) In ARs with a strong net current, we found no indications for a localized return current surrounding the direct current, as it is the case in isolated magnetic flux ropes. Rather, return currents appear only as small, fibril-like patches, which cancel out with similar patches of direct current.

Ongoing study

AR	Date/Time	Flare	CME	Posit.	|DC/RC| (+bz,area)	|DC/RC| (+bz,mask)	|DC/RC| (−bz,area)	|DC/RC| (−bz,mask)	|DC/RC| (ave, mask)
11283	2011.09.06/22:12	X2.1	Yes	N14W18	3.031(0.109)	3.692(0.109)	1.373(0.032)	3.795(0.303)	3.694(0.161)
11515	2012.07.06/23:01	X1.1	Yes	S17W50	1.695(0.032)	5.855(0.284)	2.739(0.100)	4.777(0.268)	5.316(0.195)
11875	2013.10.28/01:41	X1.0	Yes	N07W64	2.238(0.062)	2.336(0.126)	1.991(0.042)	2.072(0.085)	2.204(0.076)
11890	2013.11.05/22:07	X3.3	Yes	S09E36	2.844(0.078)	2.551(0.106)	1.292(0.018)	3.653(0.117)	2.623(0.102)
11944	2014.01.07/18:04	X1.2	Yes	S09W01	1.580(0.026)	3.451(0.146)	2.848(0.108)	4.160(0.226)	3.806(0.135)*
12017	2014.03.29/17:35	X1.0	Yes	N10W32	2.305(0.069)	2.299(0.069)	1.691(0.046)	2.308(0.070)	2.304(0.049)
12205	2014.11.07/16:53	X1.6	Yes	N15E33	2.145(0.041)	3.498(0.091)	1.680(0.028)	2.617(0.057)	3.058(0.054)
12242	2014.12.20/00:11	X1.8	Yes	S18W29	1.647(0.023)	1.784(0.028)	1.589(0.023)	2.223(0.044)	2.004(0.026)
12297	2015.03.11/16:11	X2.1	Yes	S16E13	2.702(0.049)	2.896(0.069)	2.932(0.057)	2.707(0.053)	2.802(0.044)
12673	2017.09.06/11:53	X9.3	Yes	S09W38	2.514(0.032)	3.157(0.055)	2.548(0.033)	2.609(0.060)	2.883(0.041)
11166	2011.03.09/23:13	X1.5	No	N11W15	1.144(0.016)	1.079(0.017)	1.014(0.013)	1.178(0.017)	1.129(0.012)
11302	2011.09.24/09:21	X1.9	No	N13E45	1.114(0.017)	1.270(0.020)	1.292(0.018)	1.225(0.018)	1.248(0.014)
11562	2012.08.31/20:00	C8.4	Yes	S16E40	1.254(0.067)	1.207(0.066)	1.356(0.074)	1.301(0.099)	1.254(0.059)*
11667	2013.02.06/00:24	C8.7	Yes	N22E14	1.481(0.073)	1.802(0.107)	1.218(0.051)	1.400(0.112)	1.601(0.077)
11817	2013.08.11/23:24	C8.4	Yes	S22E22	2.835(0.093)	3.138(0.108)	2.283(0.066)	2.987(0.096)	3.063(0.072)
11817	2013.08.12/12:00	M1.5	Yes	S22E14	2.747(0.089)	2.992(0.104)	2.148(0.058)	2.654(0.081)	2.823(0.066)
11836	2013.08.30/02:04	C8.3	Yes	N11E46	1.583(0.208)	1.873(0.289)	1.017(0.048)	1.495(0.198)	1.684(0.175)
12027	2014.04.04/14:12	C8.3	Yes	N13E23	1.173(0.076)	1.978(0.218)	1.146(0.042)	1.527(0.094)	1.753(0.119)

We are currently investigating a larger sample of flare-producing ARs (see table above). The preliminary results support main conclusions by Liu et al. 2017:

(1) ARs that produce CMEs have strong net currents (|DC/RC|≳1.6), regardless of the strength of the associated flare. (ARs 11562 and 11944 have to be re-evaluated: the wrong neutral line was used for the current-integration in these cases).

(2) ARs that produce X-class flares but no CMEs are well neutralized (|DC/RC|≲1.3)

...see also a similar study by Avallone & Sun 2020, arXiv:2003.02814v1

References

Avallone & Sun 2020, arXiv:2003.02814v1

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