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Indicators of solar filament remnants in ICMEs

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Abstract. Coronal mass ejections (CMEs) associated with solar filament eruptions expel huge amount of mass, energy and magnetic helicity in interplanetary medium as part of interplanetary coronal mass ejections (ICMEs). Despite of the fact that around 70% of CMEs are associated with filament eruptions, identification of filament (cold) material are rare in *in-situ* measurements. Only few earlier studies report *in-situ* observations of filament material by the ACE and Wind spacecraft at L1 point. We examined 10 ICMEs with filament remnants during the last solar cycle for which cold filament material was identified as periods of density enhancements, temperature depressions and low ionic charge states with depressed deviations in RMS parameters (magnetic and plasma). We further attempt to determine the threshold magnitudes of relative changes in magnetic, plasma and compositional parameters associated with *in-situ* observations which could serve as indicators for filament plasma.

Keywords : solar wind – filaments – ICMEs – plasma

1. Introduction

The plasma injected into the solar wind during coronal mass ejections (CMEs) at the Sun plays an important role in the interaction of the Sun with the Earth and its magnetosphere (Gosling et al. 1973, Sharma et al. 2013). About 70% of the CME eruptions are associated with solar filaments (Webb & Hundhausen 1987). While the relation between disappearing filaments and magnetic clouds is well established (Bothmer & Schwenn 1994), the observations of filament plasma in *in-situ* spacecraft measurements is rare (Lepri & Zurbuchen 2010, Sharma & Srivastava 2012, Lee & Raymond 2012). The research presented here contains a systematic survey of *in-situ* filament plasma signatures to identify the threshold magnitudes of parameters

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(plasma, magnetic and compositional) for CMEs associated with eruptive filaments during the last solar cycle.

2. Data and analysis

Plasma, magnetic and compositional signatures characteristic of filament material for 10 ICME events associated with eruptive filaments were studied using techniques discussed by Sharma & Srivastava (2012). The events studied were previously reported in literature by Burlaga et al. (1998), Gopalswamy et al. (1998), Skoug et al. (1999), Lepri & Zurbuchen (2010), Lee & Raymond (2012), Sharma et al. (2013). Various magnetic and plasma parameters used to interpret *in-situ* filament remnants (Fig.1) included relatively high magnetic field magnitude, magnetic flux rope structure, high proton and ionic densities, elevated helium density, depressions in thermal velocities and RMS deviations, compositional signatures with low ionic charge states. The *in-situ* properties were investigated through magnetic (MFI/Wind, MAG/ACE) and plasma (3DP/Wind, SWE/Wind, SWEPAM/ACE and SWICS/ACE) instruments onboard ACE and Wind spacecraft. The dataset resolution ranges from 1 minute to 2 hours and is obtained from NASA/GSFC CDAWeb (*www.cdaweb.gsfc.nasa.gov/istp_public/*).

3. Results and conclusions

The study of *in-situ* parameters for 10 CMEs associated with erupting filaments has revealed mean threshold magnitudes which can serve as indicators for filament remnants. These values were acquired by comparison of averaged magnitudes of parameters in filament plasma region with those in ambient medium. Solar wind parameters measured 10 hours ahead of associated shock and 10 hours behind the rear boundary of filament plasma region were used and averaged for the duration equivalent with filament plasma region. The mean magnitudes of drop/rise in these parameters of 10 ICMEs observed over the solar cycle can potentially serve as the threshold values. Key results from study are summarized as follows:

1. Magnetic field strength rises up to $\approx$11 nT in region associated with filament plasma remnants. These remnants are located over magnetic flux rope structures in magnetic clouds and are consistent with the filament models from Martens & Zwaan (2001).
2. Plasma parameters indicate high density and low temperature characteristic of filament material in interplanetary medium. Thermal components viz. proton and electron temperatures, ionic thermal velocities and RMS deviations in proton thermal velocity show a relative drop in magnitudes. Drop in proton temperature is higher than electron temperature, while the thermal velocities of carbon and oxygen ions show a relative drop of nearly 10 km/s. These are

accompanied with rise of about 15 n/cc in proton and ion densities in filament plasma region. Electron as well as alpha particle densities also show a rise in their relative magnitudes.

3. Carbon and oxygen ion charge states show a drop with higher decrease in the relative magnitude of carbon ion. Iron charge states does not show any variation that could be taken as an indicator of filament plasma.

The above results must be carefully interpreted in "relative" aspects with respect to ambient environment. There is a considerable difference in minimum and maximum magnitudes of these indicators as the specific signatures displayed by individual ICMEs observed close to the Earth show considerable variation. This is due to difference in sampling location (ICME cross-section sampled by *in-situ* spacecraft) over different phases of the solar cycle. The magnitude of identification parameters can also be influenced by use of different instruments and data analysis techniques (Sharma & Srivastava 2012).

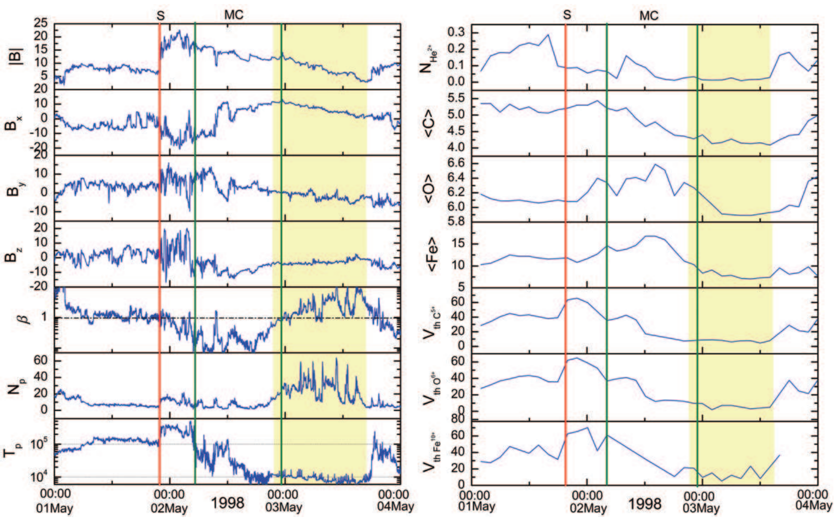

Figure 1. A plot of magnetic and plasma parameters from May 01-04, 1998. Left Panel: (top to bottom) magnetic field strength (|B|), magnetic field components (B_x, B_y, B_z) in nT, plasma beta, proton density (N_p) in n/cc, and proton temperature (T_p) in Kelvin, obtained from Wind spacecraft. Right Panel: (top to bottom) alpha particle density, ionic charge states of carbon (C), oxygen (O) and iron (Fe), thermal velocities of carbon(V_{thC^5}), oxygen (V_{thO^6}) and iron ($V_{thFe^{10}}$) in km/s, from ACE. Shock (S) arrived at 22:00 UT on 1 May precedes the magnetic cloud (MC) during 05:15 UT - 23:00 UT on 2 May, while filament material which arrived during interval from 20:30 UT on 2 May to 16:30 UT on 3 May is highlighted in yellow. Skoug et al. (1999) reported the event with prolonged He^+ enhancement and low ionic charge states.

Table 1. Relative changes in magnetic, plasma and compositional parameters associated with filament remnants to those in ambient solar wind. Negative (-) indicates drop while positive indicates rise in magnitudes of averaged parameters.

Parameters	Mean	Minimum	Median	Maximum
|B| (nT)	10.94	-0.22	8.03	36.33
δB	0.38	-0.93	0.19	3.52
δT	-6040.46	-42980.76	-92.89	-16.62
$V_{\mathrm{th}\alpha}$ (Km/s)	-2.03	-18.60	-3.34	18.02
δV_{thp}	-14.68	-100.29	-4.33	-0.98
V_{thFe} (km/s)	1.68	-11.18	8.1	14.91
$V_{\mathrm{thO^{6+}}}$ (km/s)	-10.04	-30.04	-9.83	4.63
$V_{\mathrm{thC^{5+}}}$ (km/s)	-9.40	-27.01	-7.87	10.16
T_{e} (K)	-2.6×10^4	-1.0×10^5	-1.8×10^4	5.2×10^4
T_{p} (K)	-4.0×10^4	-1.2×10^5	-3.9×10^4	6.1×10^4
N_{e} (n/cc)	6.67	0.36	3.11	26.29
N_{p} (n/cc)	15.99	2.14	16.56	31.77
N_{α} (n/cc)	0.28	-0.26	0.26	1.17
N_{i} (n/cc)	14.63	1.95	13.42	28.37
α/p	0.028	-0.02	0.02	0.08
$< Q_{\mathrm{Fe}} >$	1.76	-1.74	1.72	4.50
$< Q_{\mathrm{O}} >$	-0.04	-0.24	-0.14	0.39
$< Q_{\mathrm{C}} >$	-0.33	-0.74	-0.34	0.08

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