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Composition of Interplanetary Coronal Mass Ejections

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Coronal mass ejections (CMEs) are large expulsions of plasma and magnetic field from the solar corona and can cause disastrous space weather effects. CMEs result from the eruptions of magnetic flux ropes and are often associated with filaments. Flux ropes are a coherently helical magnetic structure with its field line winding around one central axis more than one turn. Filaments are cold and dense plasmas usually located at the flux rope dips. CMEs and their flux ropes are called interplanetary CMEs (ICMEs) and magnetic clouds (MCs) after leaving the solar corona, respectively. Composition of ICMEs, including elemental abundances and charge states of heavy ions, opens a new avenue to study CMEs[1].

The ratios between different elemental abundances can diagnose the plasma origin of CMEs (e.g., from the corona or chromosphere/photosphere) due to the first ionization potential (FIP) effect, which means elements with different FIPs get fractionated between the photosphere and corona. We find that the filament abundance ratios of elements such as Fe/O, Mg/O, and Si/O are close to their corresponding photospheric values. This does not support that the filament material originates from the condensation of the surrounding coronal plasma due to thermal instability[2].

The ratios between different charge states (or the average charge state) of a specific element can provide the electron temperature of CMEs in the corona due to the freeze-in effect, which can be used to investigate the eruption process of CMEs. Our statistical results based on 96 MCs show that the $<Q_{Fe}>$ (average iron charge state) distributions of 92 (~96%) MCs can be classified into four groups with different characteristics. In group A (11 MCs), the $<Q_{Fe}>$ shows a bimodal distribution with both peaks being higher than 12+. Group B (4 MCs) presents a unimodal distribution of $<Q_{Fe}>$, with its peak being higher than 12+. In groups C (29 MCs) and D (48 MCs), the $<Q_{Fe}>$ remains higher and lower than 12+ throughout spacecraft passage through the MC, respectively. The bimodal distribution implies that the flux ropes have existed prior to CME eruptions[3].

The solar cycle has an average period of ~11 years and is well represented by the sunspot numbers (SSNs). Our statistical studies about the ICME composition show that all the elemental abundances and charge states of heavy ions possess the solar cycle dependence[4]. Figure 1 shows the solar cycle dependence of ICME helium abundance, defined as $A_{He}=n_{He}/n_H \times 100$, along with the abundances of slow solar wind (< 400 km s^{-1}) and fast (> 600 km s^{-1}) solar wind for comparisons[5].

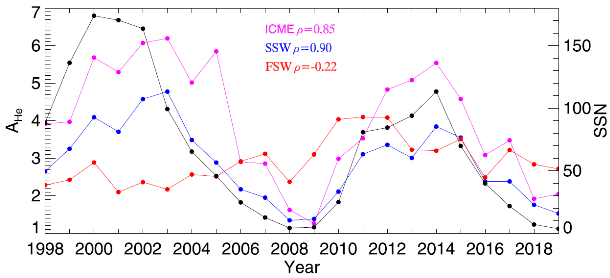

Figure 1. The solar cycle dependence of A_{He} within ICMEs (pink), slow solar wind (SSW; blue), and fast solar wind (FSW; red). The Spearman rank cross-correlation coefficients (ρ) between yearly A_{He} and SSNs (depicted with the black line) are also presented.

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