Small-scale Magnetic Flux Ropes with Field-aligned Flows via the PSP In-situ Observations

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Magnetic flux rope, formed by the helical magnetic field lines, can sometimes remain its shape while carrying significant plasma flow that is aligned with the local magnetic field. We report the existence of such structures and static flux ropes by applying the Grad-Shafranov-based algorithm to the Parker Solar Probe (PSP) in-situ measurements in the first five encounters. These structures are detected at heliocentric distances, ranging from 0.13 to 0.66 au, in a total of 4-month time period. We find that flux ropes with field-aligned flows have certain properties similar to those of static flux ropes, such as the decaying relations of the magnetic fields within structures with respect to heliocentric distances. Moreover, these events are more likely with magnetic pressure dominating over the thermal pressure and occurring more frequently in the relatively fast-speed solar wind. Taking into account the high Alfvénicity, we also compare these events with switchbacks and present the cross-section maps via the new Grad-Shafranov type reconstruction. Finally, the possible evolution and relaxation of the magnetic flux rope structures are discussed.