Magnetic Switchbacks as Remnants of Torsional Alfvén Waves

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Magnetic switchbacks (SBs) are sudden magnetic field reversals in the *interplanetary magnetic field* (IMF) embedded in the solar wind (SW). They have been sporadically observed since the 70s (during e.g. the *Helios* and *Ulysses* missions), but have received relatively little attention up until the launch of *Parker Solar Probe* (PSP) in 2018, when close flybys of the Sun revealed unexpected quantities of SBs. Since then, lots of more research has been done relating to this phenomenon.

The vast amount of data available today has enabled us to quantitatively define SBs. One important property of SBs is that they are spherically polarised, with ∼constant magnetic field strength throughout the structure, and can thus be interpreted as local rotations in the IMF. Another property is that the degree of IMF reversal, θ, follows a decreasing power law. The latter implies that the vast majority of SBs are in fact not complete magnetic field reversals, and only a few reach a maximum reversal of $\theta = 180^\circ$ w.r.t. to the ambient IMF.

The processes in which SBs are generated remain uncertain, but some promising theories have been put forward. These theories are for the most part classified as being either *reconnection*- or *Alfvén wave*-based. In reconnection-based theories, SBs are typically generated in what is known as *interchange reconnection*, a process in which magnetic loops reconnect with "open" magnetic field lines and spew out perturbations along the newly formed field lines. This is an *ex-situ* process, meaning that it happens within the Sun's atmosphere as opposed to in the SW. Alfvén wave-based theories explain SBs as Alfvénic fluctuations of different kind. One popular model is the steepening of small amplitude Alfvén waves into large amplitude ones in the *super-radially* expanding SW. This particular process, as opposed to interchange reconnection, takes place *in-situ* in the SW. Statistical studies have shown that the occurrence rate of SBs increases beyond the solar *corona*, which implies that both in-situ and ex-situ processes are needed to explain the collective phenomenon of SBs [Pecora et al. 2022].

Generally, the Alfvén wave-based theories deal with planar, *shear Alfvén waves* emanating from the corona. Below the corona, in the dense *photosphere* and *chromosphere*, Alfvén waves often manifest themselves in tight magnetic concentrations known as *magnetic flux tubes* as *torsional Alfvén waves* (TAWs). TAWs may be excited by e.g. *magnetic swirls* and *tornadoes*, which have been observed to be omnipresent in the lower atmosphere. In my Master's thesis, I aim to explore whether these TAWs can steepen into SBs as they evolve through the layers of the solar atmosphere and eventually into the SW. Similar studies have been done by e.g. [Magyar et al. 2021], but it remains unclear whether TAWs can penetrate the *transition region* (TR) into the corona, and whether they can survive through the corona and all the way out to the SW. If the TAWs can somehow survive the high gradients of the solar atmosphere, then it seems likely that the waves can steepen into SB-like structures with $\theta \geq 90^\circ$, following the general Alfvén wave-based SB formation theory. My study will be conducted numerically using the 3D *magnetohydrodynamic* (MHD) solver *Glow* developed at the Space Physics Research Group here at the UH.

References

[Pecora et al. 2022] Magnetic Switchback Occurrence Rates in the Inner Heliosphere: Parker Solar Probe and 1 au. *The Astrophysical Journal Letters*. DOI: 10.3847/2041-8213/ac62d4

[Magyar et al. 2021] Could Switchbacks Originate in the Lower Solar Atmosphere? I. Formation Mechanisms of Switchbacks. *The Astrophysical Journal*. DOI: 10.3847/1538-4357/abec49