Parker (1983) suggested a mechanism for the formation of current sheets (CSs) in the solar atmosphere. His main idea was that tangling of coronal magnetic field lines by photospheric random flows facilitates the continuous formation of CSs in the solar atmosphere. This part of his idea represents one of the many ways by which the turbulent convection zone drives the formation of coherent structures and CSs in the solar atmosphere. Other mechanisms include emerging magnetic flux, interaction of current filaments, and explosive magnetic structures. However, there are two unproven assumptions in the initial idea of Parker for the coronal heating through nanoflares that have to be re-examined. They are related to his suggestion that ALL CSs formed are led to magnetic reconnection and that magnetic reconnection heats the plasma in the solar atmosphere. Let us discuss these two assumptions briefly in this short comment:

1. Are all coherent structures and CSs formed by the turbulent convection
zone reconnecting? Do non-reconnecting CSs play a role in the heating of the corona?

2. Does magnetic reconnection heat the plasma?

We claimed in a recent article (Sioulas et al., 2021) that in a turbulent plasma only a fraction (if any) of the CSs or current filaments formed by the turbulent convection zone, as proposed by Parker, are going to reconnect. The non-reconnecting CSs in the turbulent part of the solar atmosphere play the dominant role in coronal heating. Einaudi et al. (2021) have recently analyzed the formation of non-reconnecting CSs (referring to them as "elementary events" instead of nanoflares). They have performed a careful examination of the coherent structures formed inside the magnetic topology used for their analysis and suggest that the resistive heating ($Q_i = \eta j^2$, where $\eta$ is the resistivity and $j$ the current) due to the filamentation of the current and the formation of non-reconnecting CSs is sufficient to heat the corona. Fig. 7 in their article presents the density distribution of the "elementary events" (non-reconnecting CSs). The question of how the associated distribution of resistive electric fields ($E_{eff} = \eta j$), randomly appearing in non-reconnecting CSs and interacting stochastically with particles, heat the coronal plasma, was not analyzed in the study of Einaudi et al. (2021).

Let us now discuss the second question.

Recent numerical simulations have confirmed the idea that an isolated reconnecting CS systematically accelerates particles (first-order Fermi acceleration), see Figure 3b in Li et al. (2019) and Figure 3b in Arnold et al. (2021), here presented below in Fig. 0.1.

Both studies indicate that isolated reconnecting CSs result in a steady-state kinetic energy distribution that exhibits an extended power-law tail. However, Maxwellian fits to the steady state distribution at low energies indicate that isolated reconnecting CSs cannot heat the plasma on the kinetic level. On the other hand, in a 3D turbulent reconnection environment, where reconnecting CSs, non-reconnecting CSs, and coherent structures (turbulence) co-exist (Comisso & Sironi 2019; Isliker et al. 2019), one observes both, the heating, as well as the acceleration of particles. Consequently, as one moves from small (almost point-like) and isolated reconnecting CS, to 3D large-scale structures filled with reconnecting and non-reconnecting CSs, driven by the turbulent
convection zone, something important is missing, which plays a crucial role in the impulsive heating and the shape of the steady-state distribution.

In Comisso & Sironi (2019), the turbulent reconnection environment was generated by perturbed magnetic fluctuations in a periodic, large simulation box. Isliker et al. (2019) use 3D MHD simulations to study the fragmentation of a large-scale CS generated by emerging magnetic flux and follow test particles inside an open large-scale 3D simulation volume around the fragmented CSs. The results from the PIC simulations and the MHD and test particle simulations are presented in the figure 0.2.

The presence of both, systematic acceleration (first-order Fermi), when particles cross a reconnecting CS, and stochastic heating (second-order Fermi), when particles interact with non-reconnecting CSs (turbulence) is apparent. Non-reconnecting CSs (and thus stochastic acceleration) dominate the heating. As a result, their role in the formation of non-thermal distributions is minimal. On the other hand, reconnecting CSs mostly contribute to the acceleration of particles and the formation of power-law tails, and they have a minimal contribution to the heating of a plasma. These results are analyzed in detail in our recent article Sioulas et al. (2021).

In summary, we can conclude the following:

1. Coronal heating is not due to magnetic reconnection and nano-flares. It is rather due to non-reconnecting CSs formed by the mechanism sug-
Figure 0.2: Examples of particle dynamics inside a turbulent reconnection environment from 3D numerical simulations. (a) Fig. 9a in *Comisso & Sironi (2019)*: The systematic acceleration of the high-energy particles as they cross the reconnecting CSs is the main acceleration mechanism, accompanied by the stochastic interaction with the non-reconnecting CSs. In this study, the authors choose to discuss the role of the non-reconnecting CSs for high-energy particles, and they find that the stochastic interaction is a minor effect for the particles already accelerated by the reconnecting CSs. (b) Fig. 10 in *Isliker et al. (2019)* (and see also Fig. 16 therein): Here we also observe systematic acceleration of the high-energy particles crossing the reconnecting CSs. The high-energy particles escape from the acceleration volume soon after they have encountered the reconnecting CSs. The low energy particles interact with the non-reconnecting CSs and are impulsively heated, as shown in Fig. 11 in the same article.

1. Suggested by *Parker (1983)*. On the other hand, reconnecting current sheets will mostly contribute to the acceleration of particles. Thus, the presence or reconnecting current sheets in a system becomes apparent by the formation of power-law tails in the energy distributions.

2. The recently discovered "campfires" *Chen et al. (2021)* may be a step towards the direction of observing the coexistence of non-reconnecting and reconnecting CSs in the solar corona.

3. In confined and explosive solar flares, the impulsive heating and acceleration of particles are manifest. Thus, the presence of both, turbulent heating and magnetic reconnection, is obvious from current observations.

4. In the solar wind the co-existence of non-reconnecting and reconnecting CSs, which contribute to the stochastic heating and the formation of
the non-thermal tail, respectively, is also well established. We expect that works investigating Parker Solar Probe data will shed light on this point in the near future.

5. The Earth’s magnetotail and the magnetopause are also an example of the coexistence of reconnecting and non-reconnecting CSs, and the heating and acceleration of particles is once again obvious in the data analyzed so far.

6. In the downstream environment of shocks, the coupling of turbulent non-reconnecting CSs and reconnecting CSs is present and contributes to the heating and acceleration of particles.

7. In astrophysical jets, the co-existence of turbulent stochastic heating and particle acceleration through systematic acceleration (reconnecting CSs or shocks) is present in the strongly turbulent plasma flows (Manolakou et al., 1999).

These are only a few examples of astrophysical and space plasmas that illustrate the intensive coupling of turbulence (non-reconnecting CSs), which dominates the stochastic heating, and magnetic reconnection (reconnecting CSs), which dominates the formation of power-law tails in energy distributions.

Let us stress that it is now a well-accepted fact that magnetic reconnection and turbulence are going hand in hand in several astrophysical environments. What we added to this well-accepted fact with our current work in Sioulas et al. (2021) is that stochastic heating by turbulence (non-reconnecting CSs) and systematic acceleration by reconnecting CSs are responsible for the impulsive heating and the acceleration of particles, respectively. We suggest that depending on the large scale magnetic topology, which is responsible for setting up the turbulent reconnection environment, we may have several combinations of heating and acceleration of particles, e.g.:

- Steady or impulsive heating (soft X-Ray dominated flares), when non-reconnecting CSs (turbulence) dominate (Einaudi et al., 2021; Hudson et al., 2021).

- Impulsive heating and particle acceleration when both, non-reconnecting and reconnecting CSs, are present (Lin et al., 2003; Chen et al., 2021).
• Acceleration of high energy particles and no impulsive heating ("cold" flares) when reconnecting current sheets dominate (Lysenko et al. 2018).

There are two approaches active today in the study of magnetic energy dissipation in plasmas. The one uses isolated reconnecting CSs as the basic model, and the other one turbulent reconnection, where non-reconnecting CSs and turbulence co-exist with reconnecting CSs. If we choose the first, we have troubles interpreting the steady or impulsive heating of plasmas. If we choose the second, heating and acceleration of high-energy particles are naturally explained.

After 50 years of active research, the coronal heating problem remains an open problem. Currently, theoretical models proposed to explain the heating of the corona are split into two categories: waves and reconnecting CSs (nano-flares). The purpose of this comment is that of suggesting an alternative heating mechanism, namely non-reconnecting CSs formed by the turbulent convection zone in complex magnetic topologies.

REFERENCES

Arnold, H., Drake, J. F., Swisdak, M., et al. 2021, PRL, 126, 135101

Chen, B., Battaglia, M., Krucker, S., Reeves, K. K., & Glesener, L. 2021, ApJL, 908, L55

Comisso, L. & Sironi, L. 2019, ApJ, 886, 122

Einaudi, G., Dahlburg, R. B., Ugarte-Urra, I., et al. 2021, ApJ, 910, 84

Hudson, H. S., Simões, P. J. A., Fletcher, L., Hayes, L. A., & Hannah, I. G. 2021, MNRAS, 501, 1273

Isliker, H., Archontis, V., & Vlahos, L. 2019, ApJ, 882, 57

Li, X., Guo, F., Li, H., Stanier, A., & Kilian, P. 2019, ApJ, 884, 118

Lin, R. P., Krucker, S., Hurford, G. J., et al. 2003, ApJL, 595, L69

Lysenko, A. L., Altyntsev, A. T., Meshalkina, N. S., Zhdanov, D., & Fleishman, G. D. 2018, ApJ, 856, 111

Manolakou, K., Anastasiadis, A., & Vlahos, L. 1999, AA, 345, 653
Parker, E. N. 1983, ApJ, 264, 635

Sioulas, N., Islier, H., & Vlahos, L. 2021, arXiv e-prints, arXiv:2107.08314