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in arXiv

Solar Wind Proton Behaviour inside Magnetic Field Switchbacks

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Introduction

- The solar wind – a diffuse, collisionless plasma – flows away from the Sun into interplanetary space at ~400km/s. It interacts with the Earth and can, during space weather events, cause severe damage to communication systems. It is therefore important to understand how the solar wind is formed and how it evolves, in order to mitigate the impacts of such events.
- Over the last 50 years many spacecraft have taken in-situ measurements of the solar wind between 1.0 and 0.3AU (1AU is the mean distance between the Sun and the Earth). These measurements have been essential in numerous studies, but to really understand what is happening close to the Sun, we need to take data there.
- To this aim, NASA's Parker Solar Probe [1] (PSP; Fig.1) mission was launched in 2018. During its first perihelion pass, PSP reached 0.16AU, far surpassing the closest distance achieved by previous missions. As such, the data from PSP is novel for studying structures in the early solar wind and predicting how they evolve.

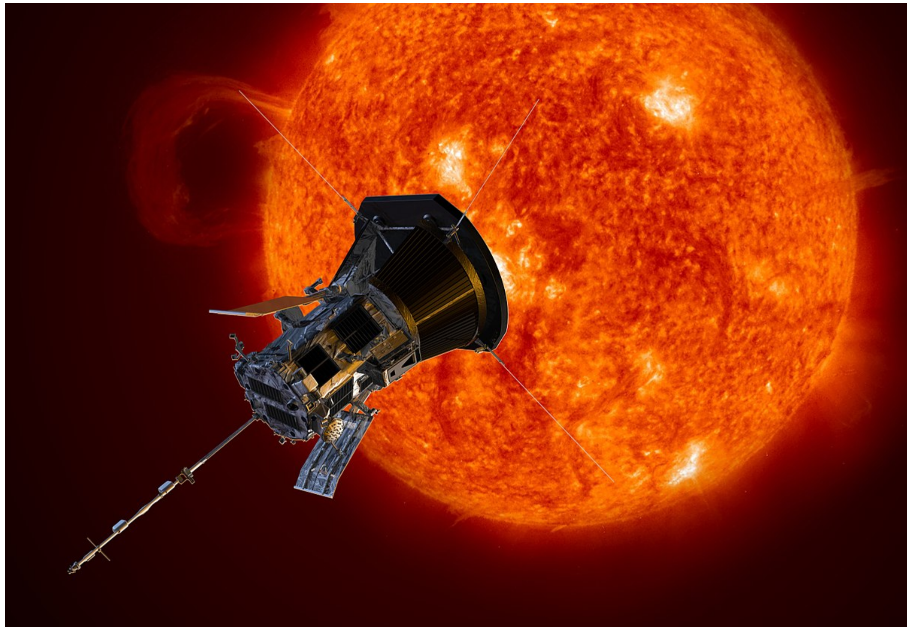

Fig. 1: Artist's impression of Parker Solar Probe orbiting the Sun. Credit: NASA

Background

- One interesting type of structure is magnetic field switchbacks, which are discrete, local folds in the Sun's magnetic field [2] (see Fig. 2). These switchbacks appear as rotations (panel a) in the radial component of the magnetic field (panel c) away from the background orientation with little to no change in the |B| (panel b). Switchbacks are also associated with an increase in the plasma velocity [3] (panel c).
- Switchbacks have previously been observed, with limited resolution, by both the Helios and Ulysses spacecraft, but here we exploit the higher resolution PSP data to investigate the proton core population – the proton population in the solar wind with the largest number density.
- We questioned whether switchbacks exhibit larger proton core temperatures than the background, as they are associated with speed enhancements above the background plasma (i.e. we test if switchbacks show similar temperature-velocity, T-V, relationships to larger scale solar wind structures [e.g. 4,5,6]).
- This work is important for understanding the origins of switchbacks and how they could be linked to the big open questions in the field – how the solar wind is heated and accelerated.

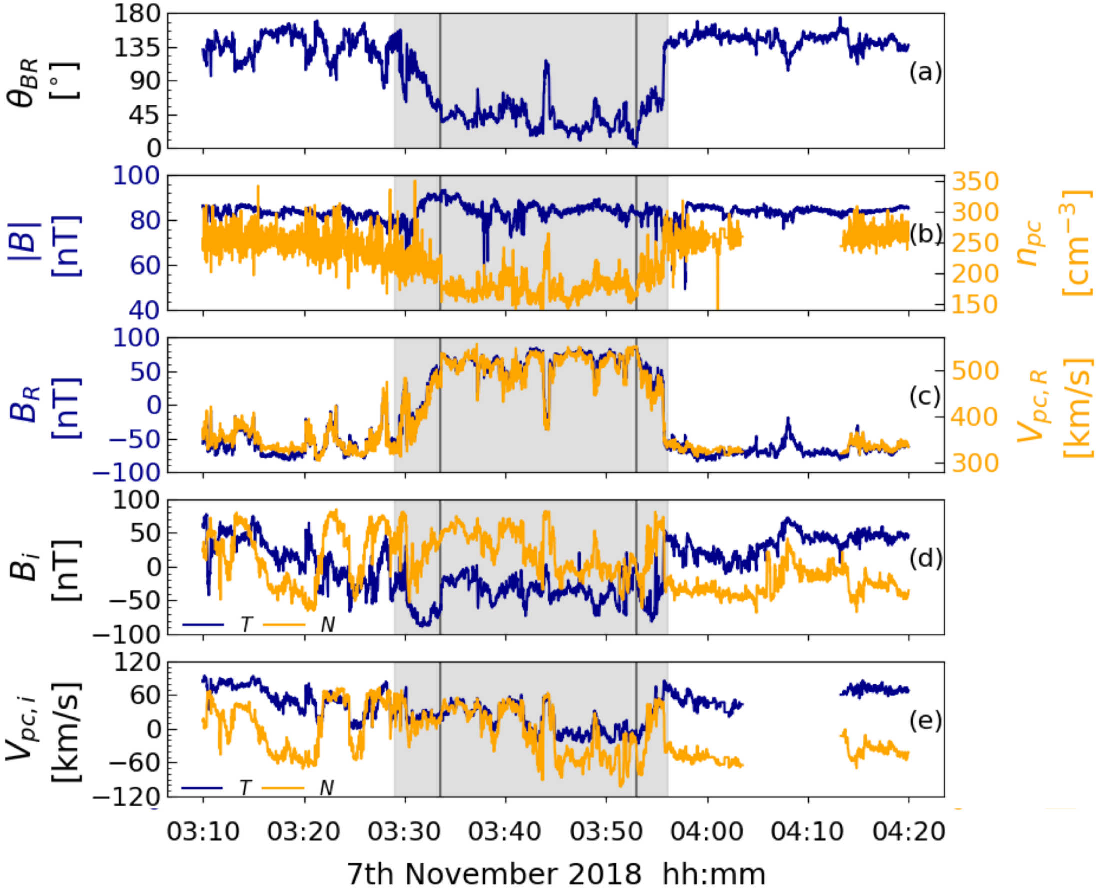

Fig. 2: A selected switchback showing: (a) the magnetic field cone angle – the angle between the magnetic field vector and the radial direction, (b) the magnitude of the magnetic field |B| and the proton core density, (c) the radial components of the magnetic field and the proton core velocity, (d) the tangential and normal components of the magnetic field, (e) the tangential and normal components of the proton core velocity. The grey shaded region highlights the magnetic field switchback and the thin vertical lines indicate the inner region with parallel magnetic field. Credit: [7]

Method

- We used data from Solar Probe Cup [8] (SPC), which is a Sunward facing Faraday Cup on board PSP. In general, Faraday Cups measure the incoming solar wind along one direction (radially towards the Sun for SPC) and this data is processed to produce a one-dimensional distribution function describing the positive ions (protons and fully-ionised helium) at each time.
- We fitted a Gaussian to the peak of each SPC-measured distribution function to extract the proton core population's bulk parameters (i.e. velocity, temperature, density), some of which are plotted in Fig. 2. We focussed mainly on the temperature for this work.
- This study was constrained by the one-dimensional distribution functions and the behaviour of the proton core population during magnetic field rotations (see [7] for more details). As such, when we were considering the proton core temperature, we could only consistently compare the background (anti-radial magnetic field) with switchbacks that underwent a full (~180°) or near-full rotation of magnetic field orientation (radial magnetic field). We therefore limit our discussion to the proton core temperature measured parallel to the magnetic field. The requirement for a full/near-full rotation reduced the number of appropriate switchbacks to five.

Results

- Fig. 3 shows the background parallel temperature vs the switchback parallel temperature for five full/near-full cases (indicated by different colours and symbols). There are two data points for each switchback: one from the SPC measurements (with error bars) and one predicted by assuming switchbacks follow a typical T-V relationship [9] (without error bars).

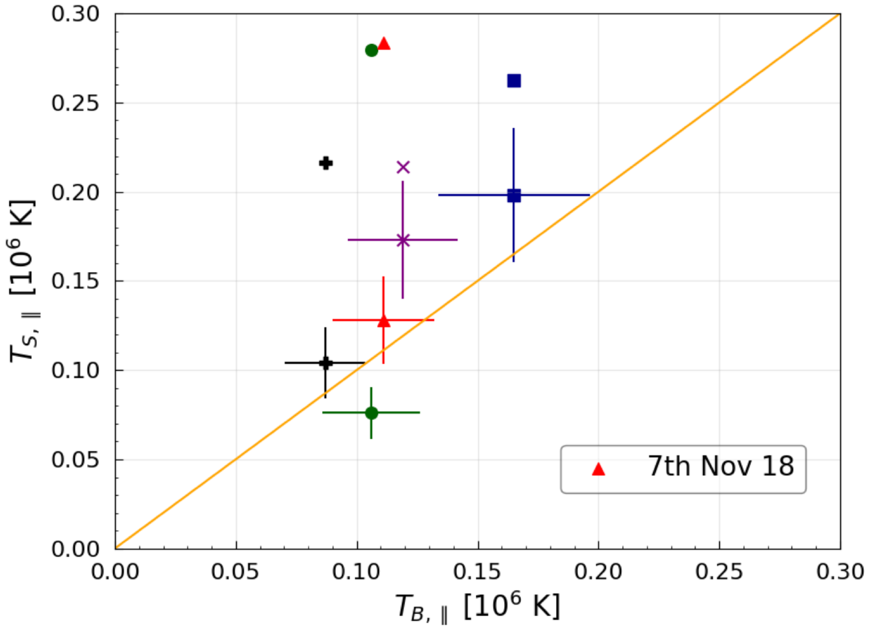

Fig. 3: Proton core parallel temperature in the background plasma vs the switchback plasma. The data points with error bars are the temperatures from the Gaussian fitting. The data points without error bars are temperature predictions based on the velocity. The orange line indicates y=x and the red triangle corresponds to the switchback in Fig. 2. Credit: [7].

Results

- Fig. 3 shows that the proton core parallel temperature inside the full or near-full reversals is not consistent with a T-V relationship (i.e. the T-V predictions lie well above the error bars of the SPC-measured temperatures). Instead the results are much more consistent with no temperature difference between the background and switchback plasma (i.e. the SPC-measured temperatures lie very close to the orange line).

Conclusions

- The proton core parallel temperature inside switchbacks is not consistent with a temperature-velocity relationship
- The proton core parallel temperature is very similar inside and outside of magnetic field switchbacks which suggests that the background and switchback plasmas are the same.
- This is more consistent with switchbacks being caused by Alfven waves – plasma waves with correlated velocity and magnetic field fluctuations - than jets of different plasma from the solar surface.
- The results presented here are part of a paper that has been accepted to MNRAS [7].

Further Work

- Further work will include using the SPAN instrument on board PSP to get a three-dimensional distribution of the positive ions. This will provide an opportunity to investigate the behaviour of the proton core temperature in switchbacks that don't undergo a full reversal of the magnetic field, as the SPAN data is not constrained to one-dimension.
- There is also the possibility of looking at the behaviour of other ion populations inside switchbacks (e.g. fully-ionised helium).

References

[1] Fox N. J., et al., 2016, Space Sci. Rev., 204, 7

[2] Bale S. D., et al., 2019, Nature, 576, 237

[3] Kasper J. C., et al., 2019, Nature, 576, 228

[4] Burlaga L. F., Ogilvie K. W., 1973, J. Geophys. Res., 78, 2028

[5] Lopez R. E., Freeman J. W., 1986, J. Geophys. Res., 91, 1701

[6] Horbury T. S., Matteini L., Stansby D., 2018, Monthly Notices of the Royal Astronomical Society, 478, 1980

[7] Woolley T., et al., 2020, Monthly Notices of the Royal Astronomical Society, accepted [arXiv:2007.10906]

[8] Case A. W., et al., 2020, ApJS, 246, 43

[9] Perrone D., et al., 2019, Monthly Notices of the Royal Astronomical Society, 488