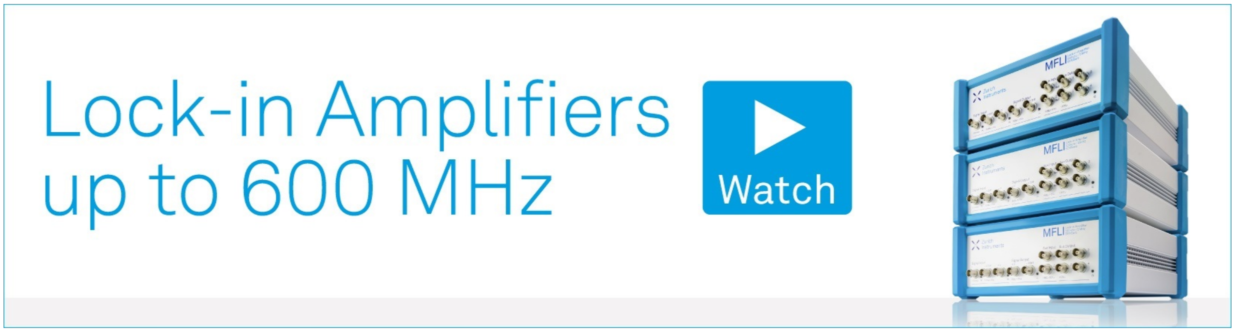
Publication Year	2016
Acceptance in OA	2020-05-22T16:08:06Z
Title	Characterizing the Alfvénic slow wind: A case study
Authors	D'AMICIS, RAFFAELLA, BRUNO, Roberto, Matteini, L.
Publisher's version (DOI)	10.1063/1.4943813
Handle	http://hdl.handle.net/20.500.12386/25106
Serie	AIP CONFERENCE PROCEEDINGS
Volume	1720

Characterizing the Alfvénic slow wind: A case study

Cite as: AIP Conference Proceedings **1720**, 040002 (2016); https://doi.org/10.1063/1.4943813

R. D'Amicis, R. Bruno, and L. Matteini



AIP Conference Proceedings **1720**, 040002 (2016); https://doi.org/10.1063/1.4943813

Characterizing the Alfvénic Slow Wind: a case study

R. D'Amicis[1,a)], R. Bruno[1] and L. Matteini[2]

[1]INAF - IAPS, Rome, Italy
[2]Imperial College, London, UK

[a)]Corresponding author: raffaella.damicis@iaps.inaf.it

Abstract. Alfvénicity is a feature characterizing solar wind fluctuations and is defined by a high correlation between velocity and magnetic field components and in ideal conditions by equipartition between kinetic and magnetic energies. It is a feature characterizing especially the fast wind while slow wind shows usually lower correlation between velocity and magnetic field components. However this is not always the case. Under certain conditions a high degree of Alfvénicity can be found also within slow wind. In the present paper, we show the existence of two kinds of slow solar wind with similar velocities but which display different characteristics. The different degree of Alfvénicity is a feature discrimanating the two types of slow wind. This feature is always linked to a low magnetic field compressibility as shown in the present paper using a case study. It is found that the Alfvénic slow wind is more similar to fast wind rather than to the standard slow wind apart from velocity. This fact can be attributed to a different source region on the solar surface. Actually the standard slow wind comes from coronal streamers or active regions while the Alfvénic slow wind originates from the boundary of coronal holes sharing characteristics typical of fast wind.

INTRODUCTION

Alfvénicity is a feature characterizing solar wind fluctuations at scales between tens of minutes and few hours [1] especially within the trailing edge of fast streams that flow from coronal holes [2]. Alfvénicity is defined by a high correlation between velocity and magnetic field components and in ideal conditions (in particular in the region near the Sun) by equipartition between kinetic and magnetic energies. The slow wind has in general a lower correlation and smaller amplitude of the fluctuations since it is more strongly intermixed with structures of non-Alfvénic nature [2]. Therefore fast and slow solar wind have a different Alfvénic content which depends not only on the type of wind but also on the radial distance from the Sun. Helios in-situ observations showed that Alfvénic fluctuations amplitude is larger close to the Sun and reduces when going away from the Sun. Moreover the degree of Alfvénicity decreases as well [3, 4].

Helios observations have also shown that close to the Sun at 0.29 AU Alfvénic correlations also characterize the slow solar wind [5]. The Alfvénic character can be observed as far as dynamic interactions between fast and slow wind have not yet developed suggesting that compressive phenomena not only velocity shears govern the observed radial decrease of Alfvénicity of solar wind fluctuations [6]. Moreover, [7] found that solar cycle 23 shows a very peculiar behavior. They found that the maximum of solar cycle 23 is largely dominated by slow wind as expected, which, however, shows a high degree of Alfvénicity comparable or even higher than that found in the fast wind during the minimum of the same cycle. These puzzling findings motivated the present analysis.

In this paper we perform a comparative study between fast and slow solar wind showing a case study with the aim to characterize the Alfvénic slow solar wind respect to the typical slow wind. Next sections will be devoted to the different origin of the two slow winds, to the role played by compressibility and to a summary of our findings.

ORIGIN OF THE ALFVÉNIC SLOW WIND

The present analysis is based on a case study corresponding to a time interval of about 50 days of data during maximum of solar cycle 23 from DoY 10 to DoY 60 of 2002, including almost two solar rotations as shown in Figure 1. We use data from the Solar Wind Experiment (SWE) on board WIND [8] at 92 s resolution which also includes magnetic

Solar Wind 14
AIP Conf. Proc. 1720, 040002-1–040002-4; doi: 10.1063/1.4943813

field measurements averaged over plasma measurement and calculated from 3-second Magnetic Field Investigation (MFI) experiment [9].

Alfvénicity is quantified by the correlation coefficient between the z components of magnetic field and velocity ρ_{vb} computed at 1 hr scale, since solar wind fluctuations show a strong Alfvénic character at this scale [3]. From top to bottom the plots display the solar wind speed profile V_{sw}, ρ_{vb}, number density n_p, magnetic field magnitude B and O^{7+}/O^{6+} ratio. The oxygen ratio is taken from the SWICS instrument on board ACE at 1 hr resolution [10].

This time interval is representative since we can identify the three different types of solar wind we are interested in: fast wind (F), typical slow wind (TS) and Alfvénic slow wind (AS) respectively. TS is characterized by compressive structures both in density and magnetic field and no correlations between b and v. AS and F show similar features: the presence of Alfvénic fluctuations with similar correlation coefficients, large amplitude fluctuations and nearly no compression in both density and magnetic field strength. Actually these two quantities are found to keep almost constant during the intervals selected. It must be noted that the opposite sign of the correlation in F and AS is related to the different magnetic polarities detected by the spacecraft. This three events are then found also on the successive solar rotation.

Another important parameter is the O^{7+}/O^{6+} ratio which is an indicator of the different region of origin. It usually has high values within slow wind from coronal streamers and low values within fast wind coming from coronal holes. Higher values of this ratio characterize TS rather than F and AS which have on the other hand similar characteristics. The different values of O^{7+}/O^{6+} ratio found in the different intervals we selected suggest that we are observing plasma coming from different solar regions. We can project back the solar wind measurements on a synoptic chart in order to verify that. Figure 2 shows a model of coronal magnetic field for solar rotation 1985 and 1986. Here blue, light shading shows the positive regions while the red ones negative regions. The neutral line is black. We project back in time on the solar surface using as a rough estimate a constant and radial velocity. We find that F and AS come from the meridional extensions of the polar coronal holes characterized by open field line regions while TS comes from a source region, limited in extension and characterized by a more complex field line topology. Our findings support the results by [11] who found the existence of two kinds of slow solar wind with different origins using UVCS meaurements.

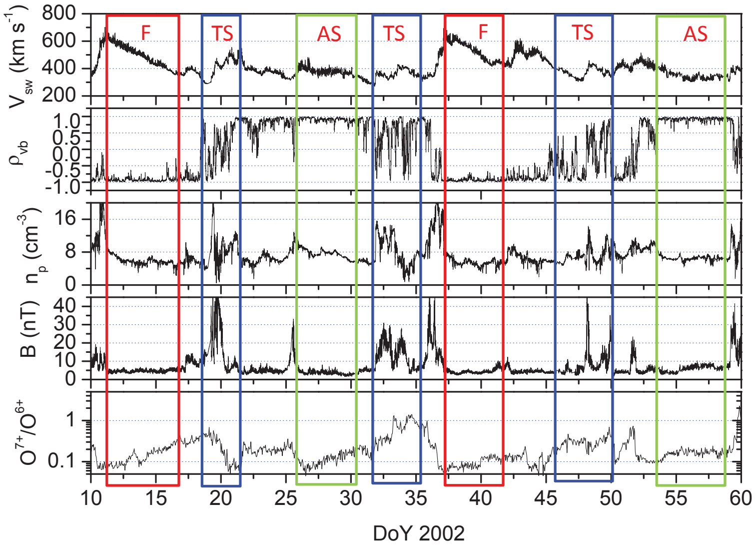


FIGURE 1. From top to bottom: bulk speed V_{sw}, correlation coefficient at 1 hr scale ρ_{vb}, proton number density n_p, magnetic field magnitude B, O^{7+}/O^{6+} for fast ('F', red box), typical slow ('TS', blue box) and Alfvénic slow ('AS', green box) wind.

ROLE OF COMPRESSIBILITY

The different Alfvénic character of these two types of slow wind can be due also to an intrinsic feature of these fluctuations such as fluctuation compressibility as suggested by [12]. This authors showed that compressible phenomena

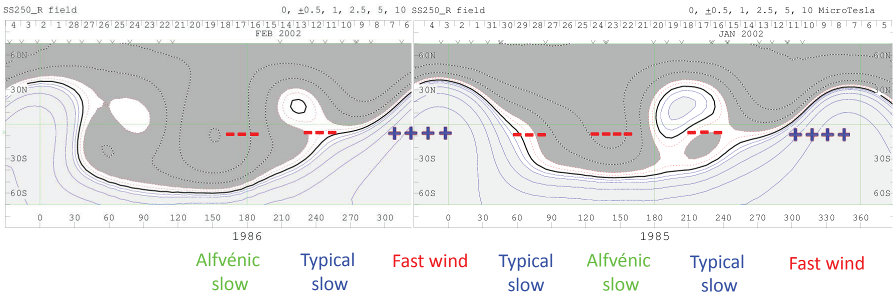


FIGURE 2. Synoptic chart of Carrington rotation 1985 and 1986. Blue and red are positive and negative polarity, respectively. 'Plus' and 'minus' signs indicates the polarity detected by the spacecraft when crossing the different plasma regions.

play an important role in determining the Alfvénic character of solar wind fluctuations. Alfvénicity is studied by means of the normalized cross-helicity, σ_C, which is defined following [3] as $\sigma_C = (e^+ - e^-)/(e^+ + e^-)$. The latter is written in terms of e^+ and e^- which are the energy associated to z^+ and z^- modes (the Elsässer variables), respectively. These quantities were computed at 1 hour scale as solar wind fluctuations show a strong Alfvénic character at this scale [3, 13]. The normalized cross-helicity, studied for the first time in the solar wind framework by [14], depends on the correlation between v and b. The value of σ_C is 1 (-1) when only an outward (inward) mode is present. Absolute values of σ_C below 1 correspond to the presence of non-Alfvénic fluctuations in the solar wind parameters. The v-b correlation coefficient is linked to σ_C by $\sigma_C/\sqrt{1-\sigma_R^2}$ saying that σ_C acts as a correlation coefficient only if σ_R, which is the normalized residual energy, is small or in other words near equipartition of energy. Actually σ_R is defined as $\sigma_R = (e^v - e^b)/(e^v + e^b)$ giving the balance between kinetic and magnetic energy (in Alfvén units), normalized to the total energy. It was first used with solar wind data by [15]. The absence of magnetic (kinetic) fluctuations corresponds to σ_R equal to +1 (-1), while equipartition gives σ_R= 0, as for Alfvénic fluctuations. A thorough explanation on that topic is given in [13].

[16] have found that the decrease of the normalized cross-helicity, σ_C, is sometimes related also to magnetic field and/or density enhancements. Thus, compressibility effects might be able to play a non-negligible role in the evolution of the interplanetary plasma as for example the depletion of Alfvénicity.

In Figure 3 we show from top to bottom the velocity speed profile, σ_C and ρ_{vb} (black and orange line respectively), e^+ and e^- (black and orange line respectively) and we calculate density and magnetic field compression defined, as in [12], as $C_\rho = \sigma_\rho^2 / < \rho^2 >$ with σ_ρ the variance of density normalized to the average value and $C_{bi} = \sigma_B^2/\sigma_{bi}^2$ with σ_B^2 and σ_{bi}^2 the variance of magnetic field magnitude B and that of magnetic field components so that it quantifies the ratio of compressive fluctuations over directional ones.

We find that event F and AS are characterized by higher value of σ_C than the ones characterizing event TS. Regions characterized by a depletion of σ_C corresponds to lower e^+ values rather than higher e^- values as shown for example when comparing event TS and AS. There is not a clear relationship with density compression since it keeps on average the same level throughout the whole time interval even if it is slightly lower in F and AS rather than in TS. On the contrary, magnetic field compression varies more clearly depending on the different solar wind region. On average we observe a lower value of magnetic field compressibility in event F and AS rather than in event TS. The role played by compressive phenomena in destroying Alfvénic correlations was found also on a statistical basis by [6]. They analysed different phases of solar cycle 23 at 1 AU finding a predominance of slow wind and showing the presence of a dominant Alfvénic population at solar maximum as already found by [7]. Thus not only fast streams but also slow streams can be highly Alfvénic.

SUMMARY AND CONCLUSION

This paper focuses on the existence of two kinds of slow solar wind. They have a comparable speed but differ for other features. The first difference is in the different Alfvénic content. In the typical slow wind Alfvénic correlations are poor while in the Alfvénic slow wind v-b correlations are high and comparable to those in the fast wind. This might be linked to the presence of compression in magnetic field fluctuations which acts in destroying v-b correlations. However

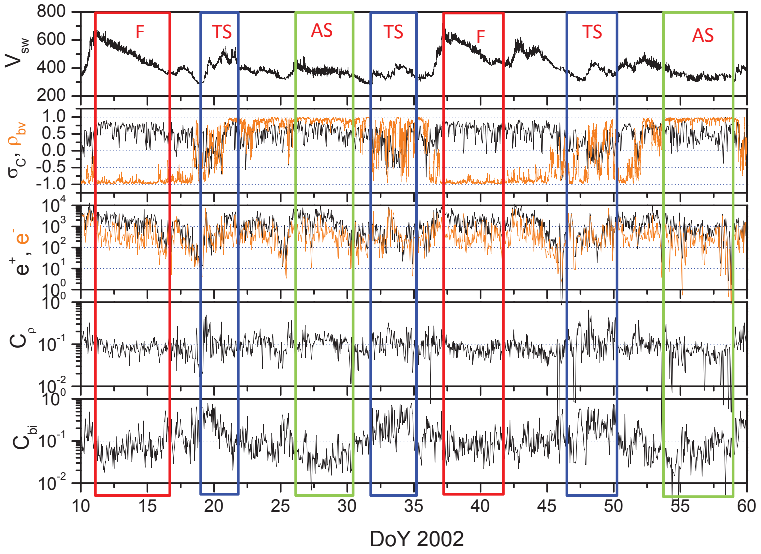


FIGURE 3. From top to bottom: proton bulk speed V_{sw} (in km/s), σ_C and ρ_{vb} (black and orange line respectively), e^+ and e^- in km^2/s^2 (black and orange line respectively), density compression C_ρ and magnetic field compression C_{bi} for fast ('F', red box), typical slow ('TS', blue box) and Alfvénic slow ('AS', green box) wind.

their main difference must be found in the different origin of the two slow winds: one coming from coronal streamers or active regions and the other originating from the boundary of coronal holes. In conclusion Alfvénic slow wind owns characteristics more similar to fast wind rather than to typical slow wind. Another aspect worth investigating is the role played by the microphysics but it will be the topic of a future paper.

ACKNOWLEDGMENTS

The authors are grateful to the following people and organizations for data provision: K. W. Ogilvie and R. P. Lepping (both at NASA/GSFC) for WIND/SWE and WIND/MFI data, respectively. Solar magnetic field maps at the source surface are available from http://wso.stanford.edu/. The present work has been supported by the Italian Space Agency (ASI) under contract I/013/12/0 ASI/INAF.

REFERENCES

[1] R. Bruno, B. Bavassano, U. Villante, 1985, J. Geophys. Res., 90, 4373
[2] J. W. Belcher and L. Davis, 1971, J. Geophys. Res., 76, 3534–3563
[3] Tu, C. Y., and E. Marsch, 1995, Space Sci. Rev., 73, 1
[4] R. Bruno and V. Carbone, Living Rev. Sol. Phys., 10, 2
[5] E. Marsch et al., 1981, J. Geophys. Res., 86, 9199
[6] R. D'Amicis and R. Bruno, 2015, Astrophys. J., 805, 84:1–9
[7] R. D'Amicis, R. Bruno and B. Bavassano, 2011, J. Atm. Sol.-Terr. Phys., 73, 653-657
[8] K. W. Ogilvie et al., 1995, Space Sci. Rev., 71, 55
[9] R. P. Lepping et al., 1995, Spce Sci. Rev., 71, 207
[10] G. Gloeckler, et al., 1998, Space Sci. Rev., 86, 495
[11] E. Antonucci, L. Abbo, and M. A. Dodero, 2005, Astron. and Astrophys., 435, 699
[12] R. Bruno and B. Bavassano, 1991, J. Geophys. Res., 96, 7841–7851
[13] B. Bavassano, E. Pietropaolo, and R. Bruno, 1998, J. Geophys. Res., 103(12), 6521
[14] W. H. Matthaeus, and M. L., Goldstein, 1982, J. Geophys. Res., 87, 6011
[15] D. A. Roberts, L. W. Klein, M. L. Goldstein, and W. H. Matthaeus, 1987, J. Geophys. Res., 92, 11,021
[16] B. Bavassano, and R. Bruno, 1989, J. Geophys. Res., 94, 168