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Comment to the paper "Azimuthal size scales of solar wind periodic density structures" by Di Matteo et al. (2024)

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Introduction

In a recent paper, Di Matteo et al. (2024) proposed a sophisticated analysis of the quasi-periodic variations of the solar wind (*SW*) number density (N_{SW}), referred to as Periodic Density Structures (*PDSs*; $f \approx 0.45$–4.65 mHz), which were observed by two spacecraft (Wind and ARTEMIS-P1) in the interplanetary medium. They obtained results which, in my opinion, are important also in the context of the scientific debate regarding the fluctuations at discrete frequencies observed in the magnetosphere (mostly in range $f \approx$ 1–5 mHz). Indeed, the occurrence, the origin and the characteristics of these fluctuations (which play an important role in the magnetospheric dynamics) have been examined, in the last decades, in a large number of papers, often with controversial results mainly related to their relationships with *SW* fluctuations at similar frequencies and to the possible existence (and stability) of sets of favorite magnetospheric frequencies [review by Di Matteo and Villante (2024) and papers therein referenced]. On the other hand, in recent years, some papers highlighted some critical aspects of the data analysis which might have influenced the conclusions of several investigations. In particular, Di Matteo and Villante (2017) and Di Matteo and Villante (2018) applied two different methods adopted in the scientific literature (the Welch method, *WM*, and the Multitaper method and F-test, *MTM*) to the same data sets and showed that the *WM*/*MTM* agreement in the identification of the wave occurrence and frequency estimate might occur only in ≈50% of cases, both in the *SW* and in the magnetosphere. In addition, an analysis conducted by Villante et al. (2022) revealed different characteristics in the fluctuations of the *SW* dynamic pressure (P_{SW}) when the same *SW* stream was observed by two spacecraft at different places in front of the magnetosphere. All these aspects make ambiguous the analysis of the relationships between the *SW* and the magnetospheric fluctuations; as we discuss in this note, the results proposed by Di Matteo et al. (2024) add other interesting elements in this context.

The comparison between PSDs and magnetospheric fluctuations at discrete frequencies

In their analysis, Di Matteo et al. (2024) examined the characteristics of *PDS* with periods ranging from a few minutes to a few hours (radial length scale of tens to several thousands of megameters). In particular, they conducted a robust estimate of the spectral properties of the N_{SW} fluctuations (they also examined the interplanetary magnetic field's intensity, not considered in the present note) in the frequency range $f \approx$ 0.45–4.65 mHz, that were associated with 68 *PDS*s observed by Wind and ARTEMIS-P1 in front of the magnetosphere over 9 years (2012–2020) and occurring during intervals of high density (maximum values above 15 cm^{-3}), slow *SW* streams (below 450 km/s); they also determined the level of coherence between the events observed by the two spacecraft, obtaining interesting results. Namely,

- 79 out of 158 events of N_{SW} fluctuations identified by Wind occurred in the same frequency range (within ±0.3 mHz) of the corresponding events detected by P1 (P1 identified 166 events). In practice, for the same *SW* parcels, comparable frequencies were estimated at the spacecraft positions for about half of events; meanwhile, the frequency to be attributed to the other half of the events that will impact the magnetosphere is uncertain. In this context it is interesting to remind that Viall et al. (2009), who examined the frequencies of *PDSs* and dayside magnetospheric oscillations in the f = 0.5–5.0 mHz range using 11 years of Wind and GOES observations (1995–2005), reported that in ≈54% of the *SW* segments with a spectral peak, at least one of the same discrete frequencies was statistically significant in the corresponding magnetospheric data segment. Eventually, according to the results of Di Matteo et al. (2024), this percentage of correspondence between the frequencies of *SW* and magnetospheric fluctuations might be related to *SW* events in which the estimated frequencies of fluctuations would have been the same at different places in front of the magnetosphere.
- Considering only the events characterized by high level of coherence (43) between Wind and P1, the percentage of agreement is higher below $f \approx$ 1 mHz (≈59%), progressively decreasing and practically vanishing at higher frequencies. Reinforcing previous arguments, these conclusions are important in this context in that the frequencies below ≈1 mHz have been rarely explored in the magnetosphere; consequently, the analysis of the relationship between *SW* and magnetospheric fluctuations could likely have been investigated mostly in a frequency range ($f \approx$ 1–5 mHz) in which the agreement between the frequencies of *SW* fluctuations observed at two different places might be poor.
- In extreme cases, moreover, Wind and P1 provided, for the same *PDS*, very different results: for example, for a parcel observed on 1 January 2014, Wind identified a single fluctuation event ($f \approx$ 1.8 mHz; **Table 1** in Di Matteo et al., 2024) while four peaks emerged in the power spectra at P1 ($f \approx$ 0.7, ≈1.5, ≈2.2, ≈3.7 mHz). It confirms that the aspects of the *SW* fluctuations often differ significantly between the observations of the same *SW* parcel at different places (Villante et al., 2022; **Figure 2**). All these arguments suggest caution before assuming a definite identification of the characteristics of the compressive fluctuations impinging the magnetosphere when the event is observed by a single spacecraft (Di Matteo and Sivadas, 2022).
- Obviously, the global frequency distributions of events at Wind and P1 are not the same (**Figure 5** in Di Matteo et al., 2024). Nevertheless, in both cases, they manifest the highest occurrence at $f \approx$ 0.5–0.8 mHz (a frequency range rarely explored in magnetospheric investigations, as previously remarked), with some evidence for enhancements around $f \approx$ 1.9 mHz, and, less explicit, around $f \approx$ 2.7–2.9 mHz and $f \approx$ 3.2–3.8 mHz. Interestingly, in the last 30 years, several papers, proposed the possible existence of frequencies more common than others for magnetospheric fluctuations, in particular $f_1 \approx$ 1.3, $f_2 \approx$ 1.9 (most common), $f_3 \approx$ 2.6–2.7, and $f_4 \approx$ 3.2–3.4 mHz (e. g., Samson et al., 1991; Ruohoniemi et al., 1991; Samson et al., 1992; Walker et al., 1992; Francia and Villante, 1997; Villante et al., 2001). In this sense, corroborating the conclusions of several analysis in favor of magnetospheric fluctuations directly driven by compressional *SW* modes approximately at the same frequencies (Kepko et al., 2002; Kepko and Spence, 2003; Villante et al., 2007; Viall et al., 2009; Villante et al., 2013, 2016), the results of Di Matteo et al. (2024) might confirm, at least in a statistical sense, that several magnetospheric fluctuations at discrete frequencies might be associated with the interaction of *PDS*s with the magnetosphere.

Conclusion

As discussed in the previous paragraph, several results obtained for PDS by Di Matteo et al. (2024) might find correspondence in those obtained, over many years, in the analysis of the magnetospheric fluctuations at discrete frequencies (such as the enhancements of the event occurrence at given discrete frequencies, more evident around $f \approx$ 1.9 mHz …; review by Di Matteo and Villante (2024) and papers therein referenced). On the other hand, other aspects such as the general ≈50% of (dis)agreement between the frequencies of fluctuations observed by the two spacecraft (Di Matteo and Villante, 2017, Di Matteo and Villante, 2018) as well as the strong disagreement in the fluctuations content occasionally obtained when the same SW parcel is observed at different places confirm that, as underlined by Di Matteo and Villante (2024), further investigations of the relationship between SW and magnetospheric fluctuations should pay careful attention to several critical aspects which may strongly influence the results of the data analysis (i.e., the method of data processing which may be critical for the identification of events; the unambiguous identification of the characteristics of the SW fluctuations impinging the magnetosphere); in addition, it is useful to remind that the magnetospheric response is expected to be different in different regions (and intermixed with concurring local generation processes) and strongly influenced, at least in terms of the frequency of fluctuations, by the daily, seasonal and solar cycle variation of the local resonant frequency.

Author contributions

UV: Writing–original draft.

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