Density Enhancement Streams in The Solar Wind

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This letter describes a new phenomenon of recurring plasma density enhancements having $\Delta n/n \leq 10\%$ that occur at a repetition rate of ~5 Hz. They were observed sporadically for about five hours between 14 and 15 solar radii on Parker Solar Probe orbit 12 and they are seen in the same radial range on both the inbound and the outbound orbit 11 and other orbits. Their apparently steady-state existence suggests that their pressure gradient is balanced by the radial electric field, which was not measured. However, the electric field components measured in the plane perpendicular to the Sun-satellite line had sharp features like those hypothesized for the radial component, which offers support for the pressure balance requirement. These structures do not correlate with any magnetic field so they are not associated with any electromagnetic wave and they are probably not the result of a three-wave or similar process.

I Introduction

Low frequency turbulence is thought to energize the solar wind plasma through a cascade process that is described by the power spectra of the fields. The magnetic field has generally been the parameter utilized in such studies [Bowen et al, 2020; Chen et al, 2010, 2016, 2020, 2021]. In a few cases, the electric field and/or the plasma density spectra have been shown to have decreasing power in the kinetic range as compared to that in the inertial range [Chen et al, 2013; Mozer et al, 2020; Salem et al, 2012]. The purpose of this letter is to describe events in which the power in the solar wind plasma density and electric field achieved a local maximum in the kinetic range.

The measurements of interest were made on the Parker Solar Probe, whose X-Y plane, perpendicular to the Sun-satellite line, contains a two-component electric field and spacecraft potential measurement by antennas that are not much larger than the spacecraft [Bale et al, 2016]. By fitting the measured spacecraft potential to the low rate density measurements obtained from the SWEAP plasma measurements [Kasper et al, 2016; Whittlesey et al, 2019], higher frequency estimates of the plasma density and density fluctuations [Mozer et al, 2022] have been obtained.

II Data

Examples of power spectra obtained on Parker Solar Probe orbit 12 during a two-minute interval when the spacecraft was located about 15 solar radii from the Sun are given in Figure 1. In both the electric field of panel 1a and the plasma density of panel 1b, the spectra exhibit local maxima at a frequency of about 5 Hz. The reason for the maximum in the plasma density is illustrated in panel 1c as due to spiky pulses of density fluctuations, $\Delta n/n$, occurring at a frequency of several Hz. Six examples of these repetitive density enhancements, as large as 0.1, are shown over a six hour interval in Figure 2, when the spacecraft was located between about 14 and 15 solar radii.

The plasma density is measured by the particle instruments on the Parker Solar Probe at an ~1 Hz rate. To obtain the plasma density at the observed ~5 Hz rate, the spacecraft potential (the average of the four biased antenna voltages), is utilized. It is measured at a much higher rate and it depends on the plasma density, as the plots in figures 3a and 3b show. Figure 3a gives the 30-second-averaged plasma density in cm^{-3} as measured by the plasma instruments and figure 3b gives the spacecraft potential in volts as measured by the electric field instrument. Their obvious correlation is illustrated in figure 3c, which plots the logarithm of the density versus the spacecraft potential. The least squares fit to this data is illustrated by the red dashed line in figure 3c whose equation is

$$\ln(\text{density}) = 0.2841\,\text{SCP} + 8.458 \tag{1}$$

where SCP is the spacecraft potential. The slope of the fit agrees well with all of the density data although the magnitude of the fit changes with changing external parameters in the solar wind. Because $\Delta n/n$ is independent of the magnitude of the density, the slope of the least squares fit is sufficient for obtaining quantitative estimates of the parameter of interest.

The many tens of seconds durations of these density streams suggest that they are stable structures. According to the Generalized Ohm's law, this stability requires an electric field that balances the pressure gradient. This pressure gradient electric field, in the radial Z direction, is computed as shown in figure 4d. It is emphasized that this component of the electric field was not measured on the Parker Solar Probe. However, the two measured electric field components, in the X-Y plane, were measured, as shown in figures 4b and 4c. That they have characteristics similar to those of the hypothesized electric field of panel 4d lends credence to the conclusion that the stable density structures were supported by the largely unmeasured electric field. The periodic electric field structures of figures 4b and 4c produce the bump in the electric field spectrum of figure 1a. Also shown in figures 4e and 4f are the four single-ended potentials of the electric field measurement. Their similarity and reasonableness suggest that the resulting fields and density structures were not associated with a spacecraft wake or similar non-physical perturbation. One component of the magnetic field is illustrated in Figure 4g to show that there was no magnetic field fluctuation associated with the density structures. All data in Figure 4 were high pass filtered at one Hz.

Density and electric field repetitive streams also occurred on other spacecraft orbits at similar distances from the Sun. Examples of such structures on both the inbound and outbound orbit 11 are illustrated in figure 5.

That there is no such activity in the magnetic field provides evidence that no electromagnetic field is associated with these density streams in a three-wave or any other process.

Variations of the proton and electron fluxes and spectra were uncorrelated with the times of the density streams. In addition, beta (0.1), the Alfven speed divided by the solar wind speed (~1), the ion temperature (60 eV), the wind speed (400-600 km/sec), and the Debye length (2 m), all had significant fluctuations but none of them correlated with the off-and-on nature of $\Delta n/n$.

III Conclusions

Stable, repetitive, streams of pulsing electric field and plasma density are observed at about 15 solar radii on the Parker Solar Probe. Their origin and physics may be associated with processes occurring near the solar surface or they may be locally generated. Process occurring near the solar surface that might be associated with such streams are:

- Nano flares
- Bursty, periodic, reconnection
- Other spatial structures on the Sun

Their relative energy content and contribution to solar wind acceleration and heating remain as topics for further investigation.

IV Acknowledgements

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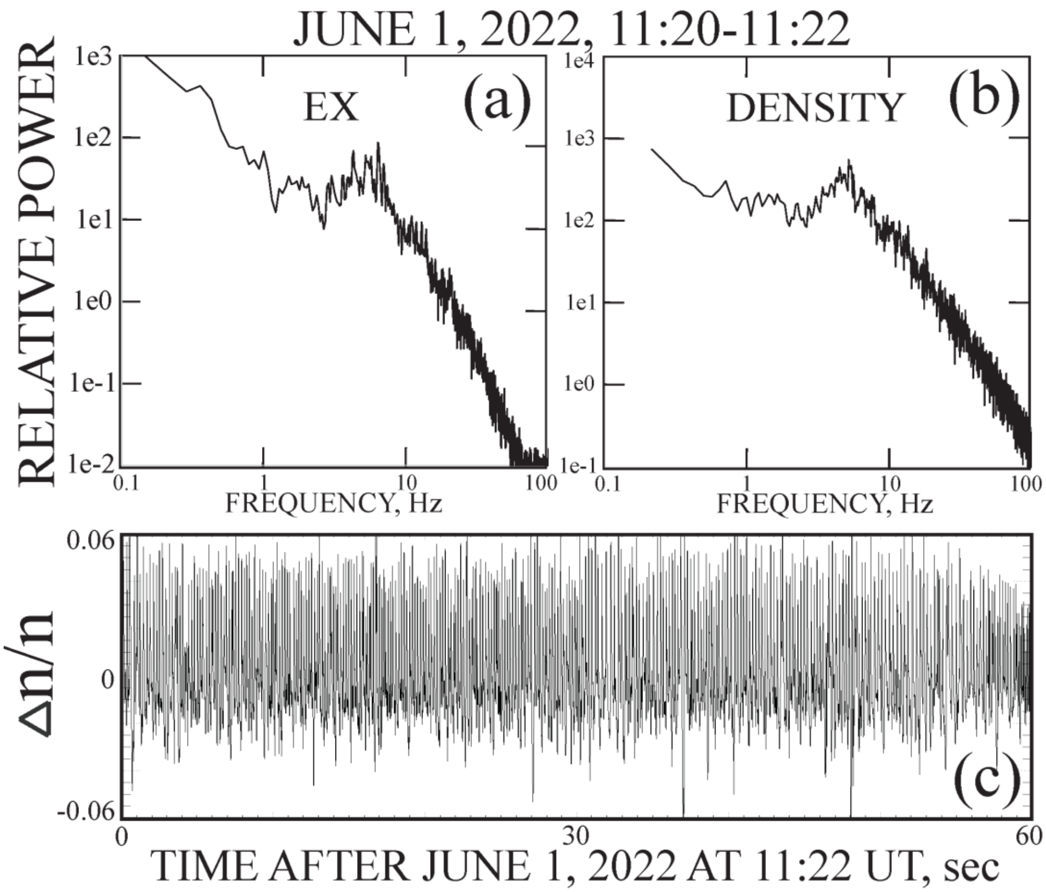

Figure 1. Power spectra of the electric field (panel 1a) and plasma density (panel 1b) during a two-minute interval during Parker Solar Probe orbit 12 at a distance of 15 solar radii from the Sun. The peak in the panel 1b density spectrum in the kinetic regime at ~5 Hz was due to repetitive density pulses illustrated in panel 1c.

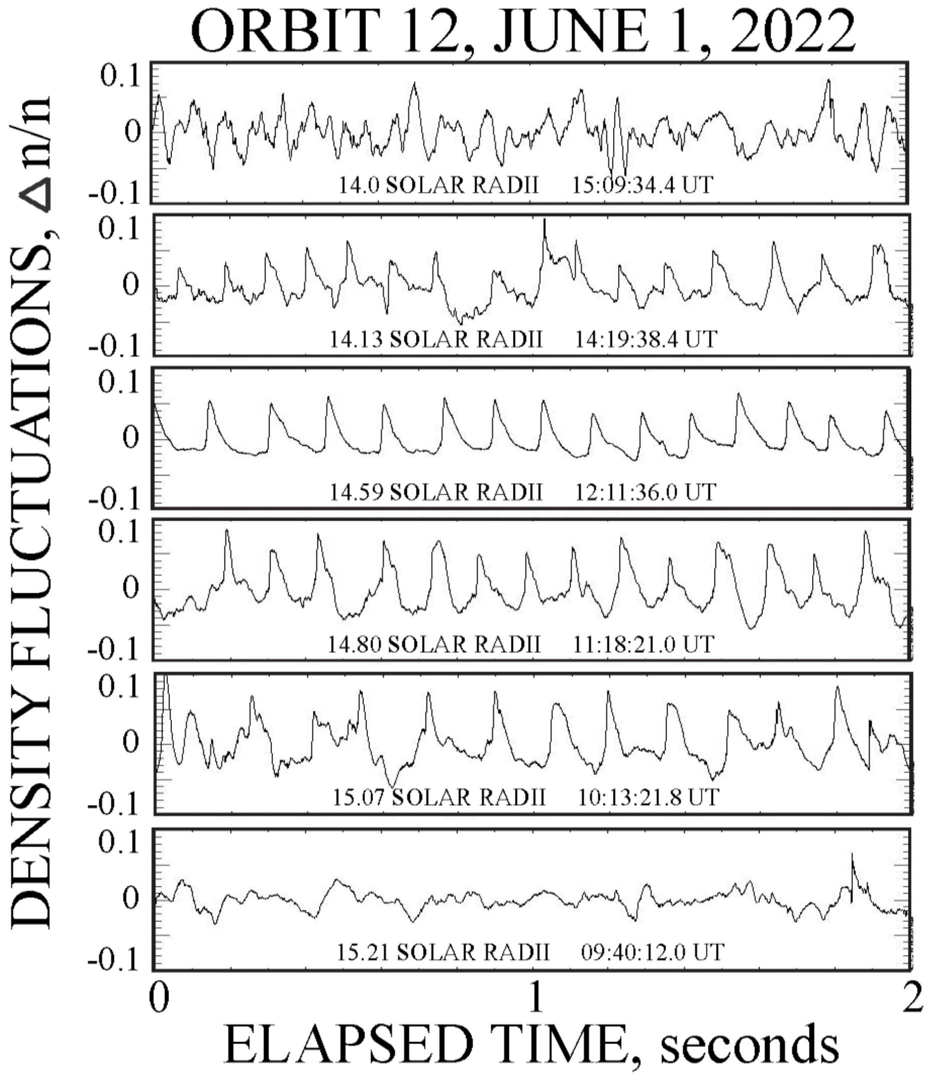

Figure 2. Six examples of two-second repeating plasma density enhancements observed over a six-hour interval at 14 to 15 solar radii.

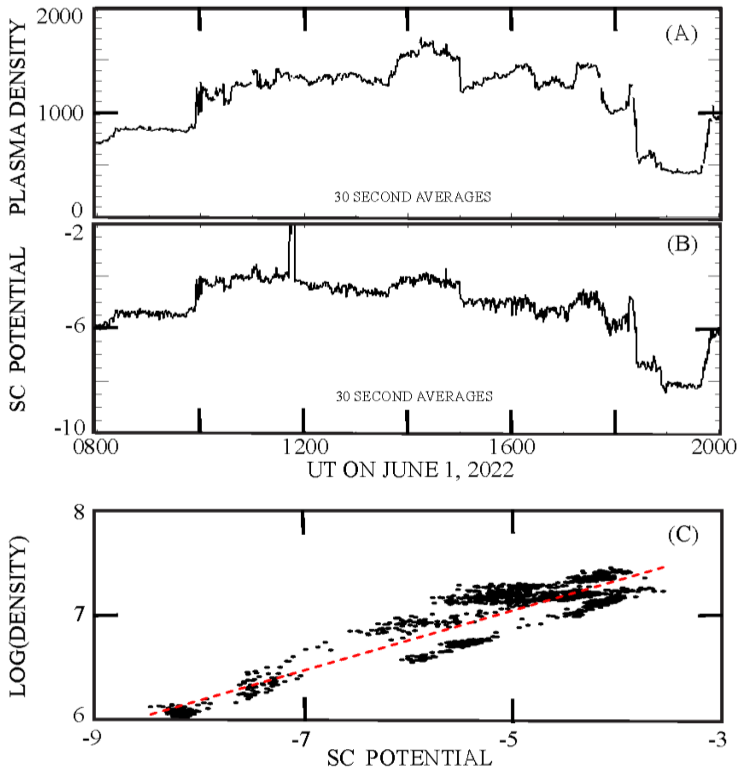

Figure 3. Comparison of the 30-second averaged plasma density (panel 3a) and spacecraft potential (panel 3b) showing their correlation over a 12-hour time interval. Panel 3c compares the log of the density with the spacecraft potential, showing a linear average dependence illustrated by the red dashed line.

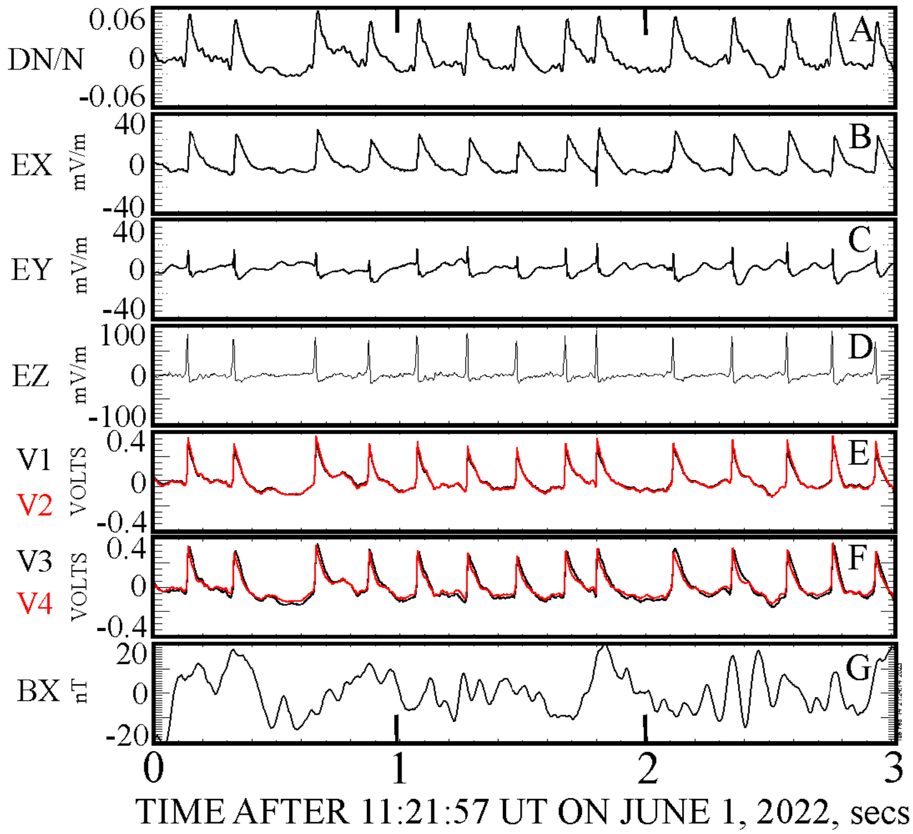

Figure 4. The radial (Z) component of the electric field (panel 4d) computed from the Ohm's law requirement that the pressure gradient due to the density fluctuations of panel 4a is balanced by the electric field (EZ is not measured on the Parker Solar Probe). The measured electric field components (panels 4b and 4c) have characteristics similar to EZ, which provides support for the pressure balance requirement. Also shown (panels 4e and 4f) are the four individual antenna voltages whose average is the spacecraft potential. A magnetic field component is shown in panel 4G to illustrate that the density/electric field periodic structures are not accompanied by a magnetic field signal. All data in this figure are high pass filtered at one Hz.

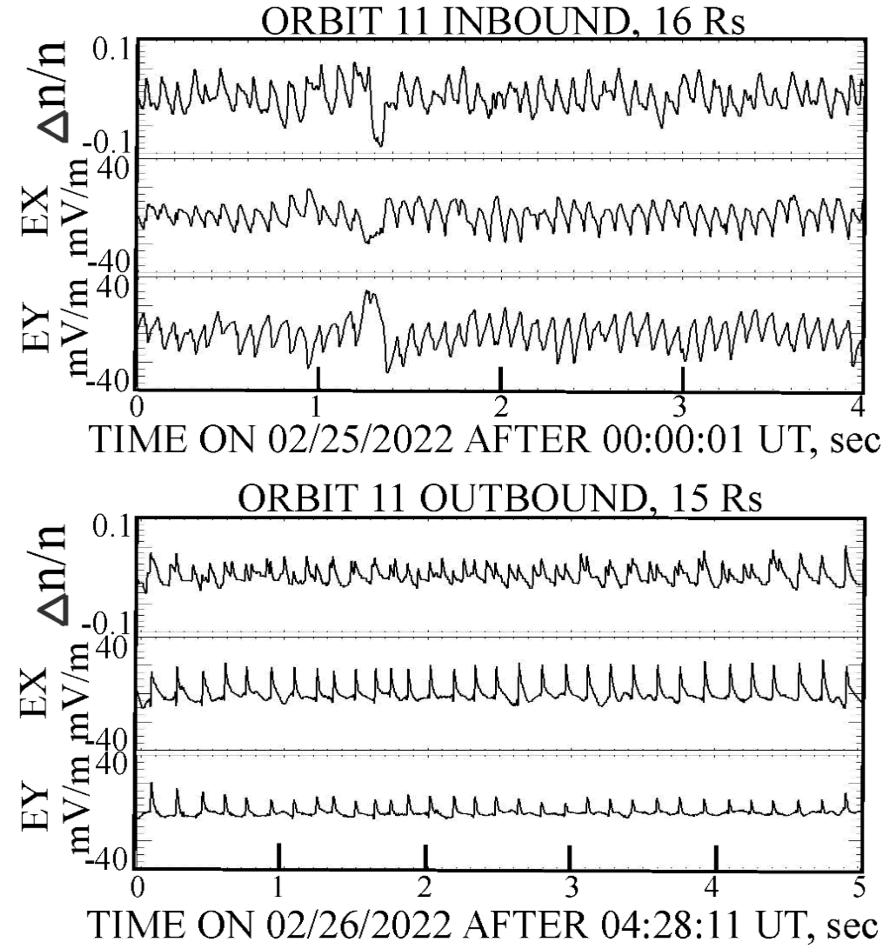

Figure 5. Examples during the inbound and outbound portions of orbit 11 that also had streaming electric field and density enhancements near 15 solar radii.