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Radio waves and whistler-mode waves in solar wind and their interactions with energetic electrons

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Abstract

The role of waves in the propagation, scattering and energization of electrons in the solar wind has long been a topic of interest. Conversely, understanding the excitation of waves by energetic electrons can provide us with a diagnostic for the processes that accelerate the electrons. We will discuss two different processes: (1) the interaction of narrowband whistler-mode waves with solar wind electrons, and (2) how periodic Type III radio bursts yield clues to small-scale acceleration of energetic electrons in the solar corona. Waveform captures in the solar wind at 1 AU obtained by the STEREO revealed the existence of narrowband large amplitude whistler mode waves, propagating at highly oblique angles to the magnetic field. Similar waves are less commonly seen inside .2 AU by Parker Solar Probe. The differences provide clues for understanding electron propagation, scattering and energization. Type III radio bursts have long been used as remote probes of electron acceleration in the solar corona. The occurrence of periodic behavior in Type III bursts observed by Parker Solar Probe, Wind and STEREO when there are no observable flares provides a unique opportunity to diagnose small-scale acceleration of electrons in the corona. Periodicities of ˜ 5 minutes in the Solar Dynamics Observatory Atmospheric Imaging Assembly (AIA) Extreme Ultraviolet data in several areas of an active region are well correlated with the repetition rate of the Type III radio bursts. Similar periods occur in the Helioseismic and Magnetic Imager (HMI)data. These results provide evidence for acceleration by wave-modulated reconnection or small-scale size waves, such as kinetic Alfven waves, even during intervals with no observable flares. The possible connections between these two phenomena will be addressed.

Radio waves and whistler-mode waves in solar wind and their interactions with energetic electrons

Motivation

The solar wind includes a number of different electron populations. We focus on evidence solar for p-wave modulation of the acceleration of the energetic electrons (few keV to a few hundred keV) that generate Type III radio bursts, and the interaction of solar wind electrons, including also the lower energy (10s of eV to a few keV) strahl, halo and core populations, with narrowband whistler-mode waes.

Type III radio bursts, due to mode conversion of Langmuir waves, are remote probes of electron acceleration in the corona. 'Storms' of Type III radio bursts must be due to small-scale modulated acceleration.Quasi-periodic variations from seconds to tens of minutes in coronal processes have been studied for ~50 years, but most studies have examined very energetic flares or

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Take Aways

Simultaneous Parker Solar Probe (PSP) and NuSTAR observations provide evidence for ~ 5 minute quasi-periodic acceleration of electrons in the corona when there are no observable flares. Periodic coronal heating and cooling suggests that these small acceleration events (perhaps 'nanoflares') may be important for coronal heating.

Narrowband large amplitude whistler-mode waves are observed in the solar wind both inside .3 AU by PSP and at 1 AU by STEREO. Waves occur in regions with variable magnetic fields and large beta

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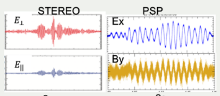
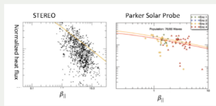
Whistler-mode waves and electrons in the solar wind

Narrowband large amplitude whistler waves are observed in the solar wind both inside 0.3 AU (PSP) and at 1 AU (STEREO) with similar properties .Whistlers are large amplitude, with f~0.2 fce, are often 'close packed,' and occur in regions with varying magnetic field and high beta. The waves at STEREO are highly oblique; highly oblique and parallel waves are intermixed at PSP.



Wave occurrence is constrained by the whistler fan heat flux instability threshold, which has largest growth rates at oblique angles.



The waves are associated with broadened electron pitch angle distributions.

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Wave modulated electron acceleration in a quiescent coronal active region

Serendipitous coordinated NuSTAR and Parker Solar Probe observations, combined with SDO/AIA EUV and HMI, provide evidence for periodic acceleration of electrons when there were no observable flares. Periodicities of ~5-6 minutes in EUV bands in areas of an active region and in the sunspot are well correlated with the repetition rate of the Type III radio bursts on PSP and Wind.

This movie in the 211 A line shows that the active region was quiescent.

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Connections?

1. Whistlers and Langmuir waves are often observed simultaneously by Parker Solar Probe (Bale et al. 2019). Both may be excited by energetic beams, as seen in LAPD experiment (Dorfman et al. SM016-09), or whistlers and Langmuir waves may be connected via a 3-wave decay process
2. Particle tracing shows whistlers can interact strongly with strahl electrons to braoden pitch angls and control heat flux and with energetic electrons, potentially contributing to observed spreading of SEP electrons (Vo et al. SH025-12)

Illuminating Periodicities in the Corona and in Type III radio bursts

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MOTIVATION

The solar wind includes a number of different electron populations. We focus on evidence for solar p-wave mode modulation of the acceleration of energetic electrons (few keV to a few hundred keV) that generate Type III radio bursts, and the interaction of solar wind electrons, including also the lower energy (10s of eV to a few keV) strahl, halo and core populations, with narrowband whistler-mode waes.

Type III radio bursts, due to mode conversion of Langmuir waves, are remote probes of electron acceleration in the corona. 'Storms' of Type III radio bursts must be due to ale modulated small-scale acceleration. Quasi-periodic variations from seconds to tens of minutes in coronal processes have been studied for ~50 years, but most studies have examined very energetic flares or coronal MHD waves.

The evolution of solar wind electrons ranging from strahl energies to solar energetic electron enegies is not understood. It is well known that both radial and longitudinal transport are often very different from predictions of simple models, assuming scatter-free propagation along a Parker spiral magnetic field. Narrowband large amplitude whistler-mode waves can interact with electrons over a wide energy range, potentially contributing to the observed evolution.

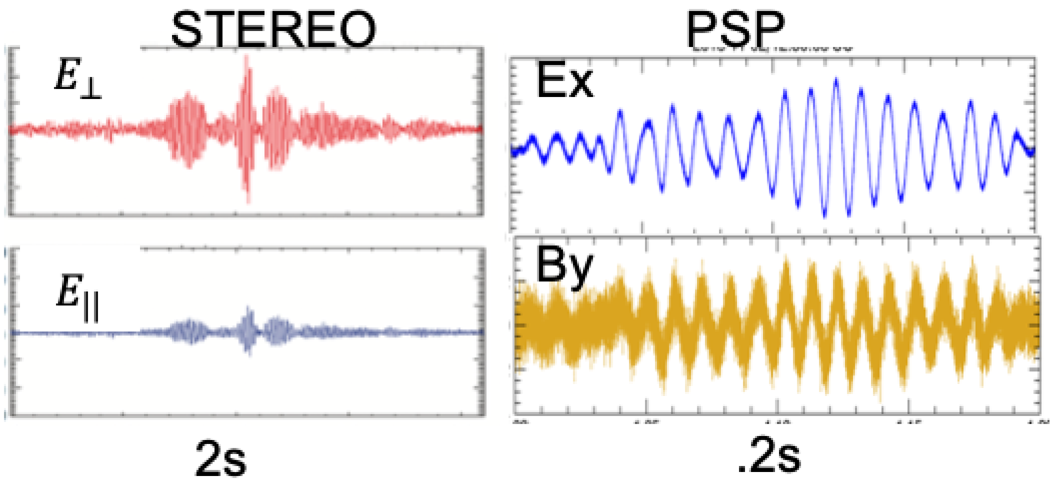
TAKE AWAYS

Simultaneous Parker Solar Probe (PSP) and NuSTAR observations provide evidence for ~ 5 minute quasi-periodic acceleration of electrons in the corona when there are no observable flares. The simultaneous coronal heating and cooling suggests that these small acceleration events (perhaps 'nanoflares') may be important for coronal heating.

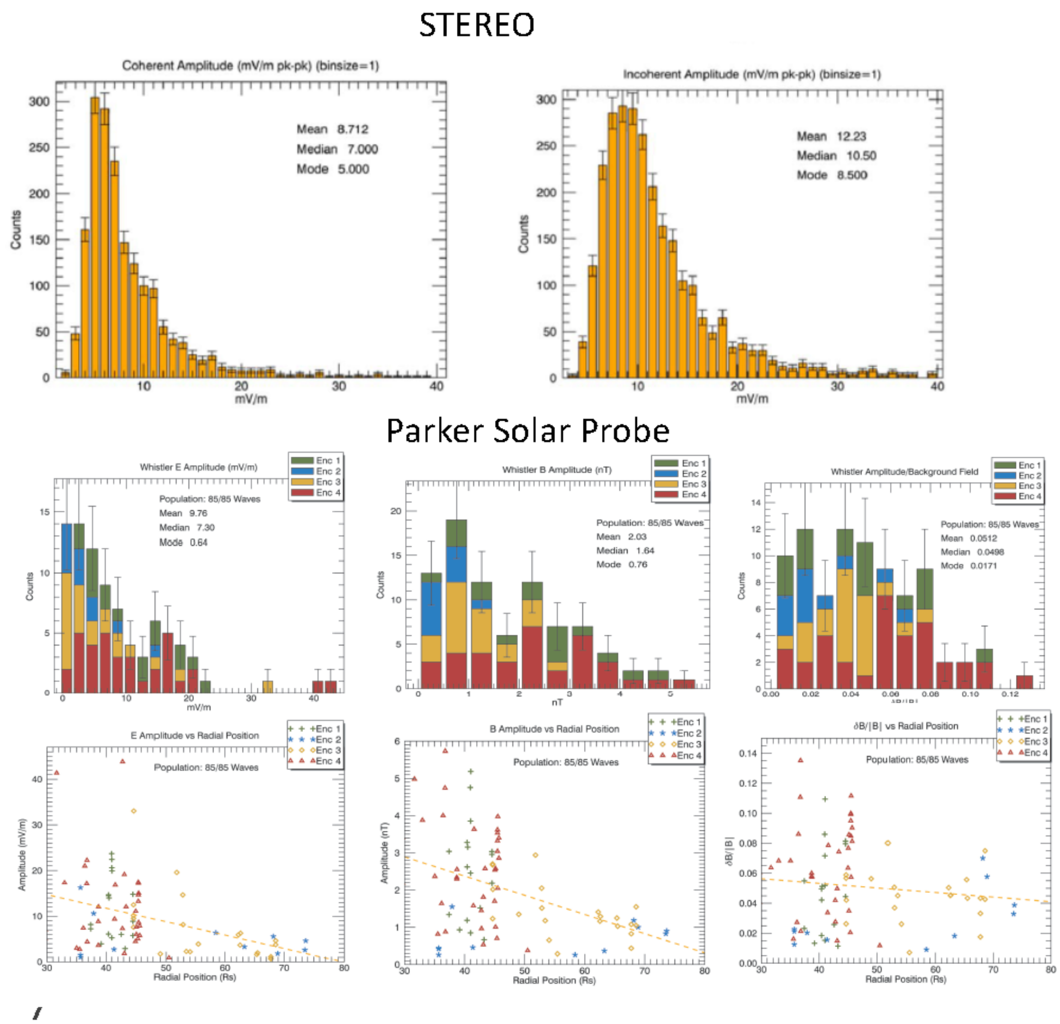
Narrowband large amplitude whistler-mode waves are observed in the solar wind both inside .3 AU by PSP and at 1 AU by STEREO. Waves occur in regions with variable magnetic fields and large beta. Wave occurrence is constrained by whistler fan heat flux instability, consistent with Halekas et al. (2020b), but there may be more than one instability mechanism operating.The waves strongly scatter solar wind electrons.This scattering may explain the observed strahl pitch angle widths and the changes in halo to strahl ratios. It may also contribute to the longitudinal distribution of solar energetic electrons.

WHISTLER-MODE WAVES AND ELECTRONS IN THE SOLAR WIND

Narrowband large amplitude whistler waves are observed in the solar wind both inside 0.3 AU (PSP) and at 1 AU (STEREO) with similar properties. Whistlers are large amplitude, with f~0.2 fce, are often 'close packed,' and occur in regions with varying magnetic field and high beta. The waves at STEREO are highly oblique; highly oblique and parallel waves are intermixed at PSP.

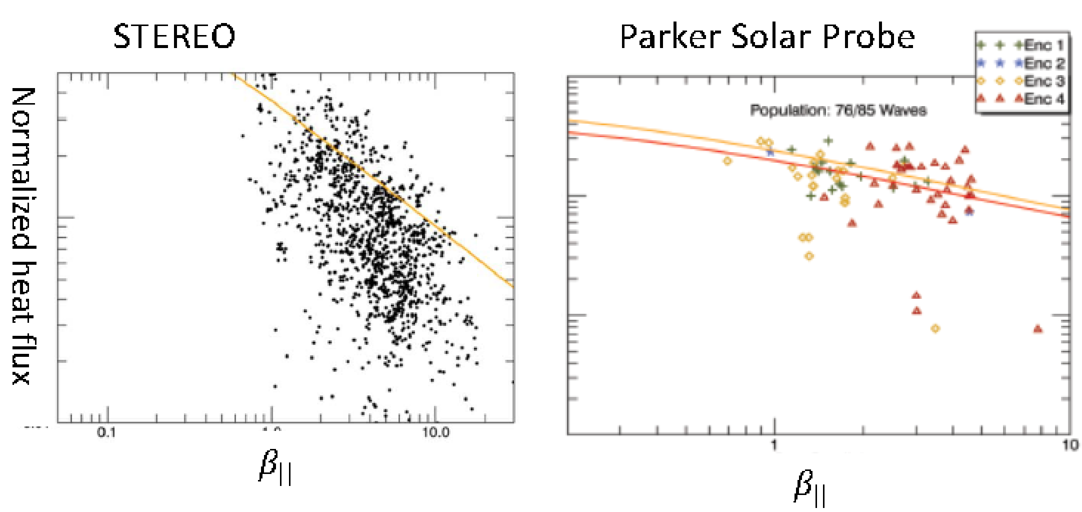


At 1 AU, mean electric field amplitudes are 8-12 mV/m and the largest are >40 mV/m. Inside .35 AU, the mean electric field amplitude is 10 mV/m and the largest are >40 mV/m. The mean dB is 2 nT and dB/B is .05. Amplitudes decrease with radial distance.



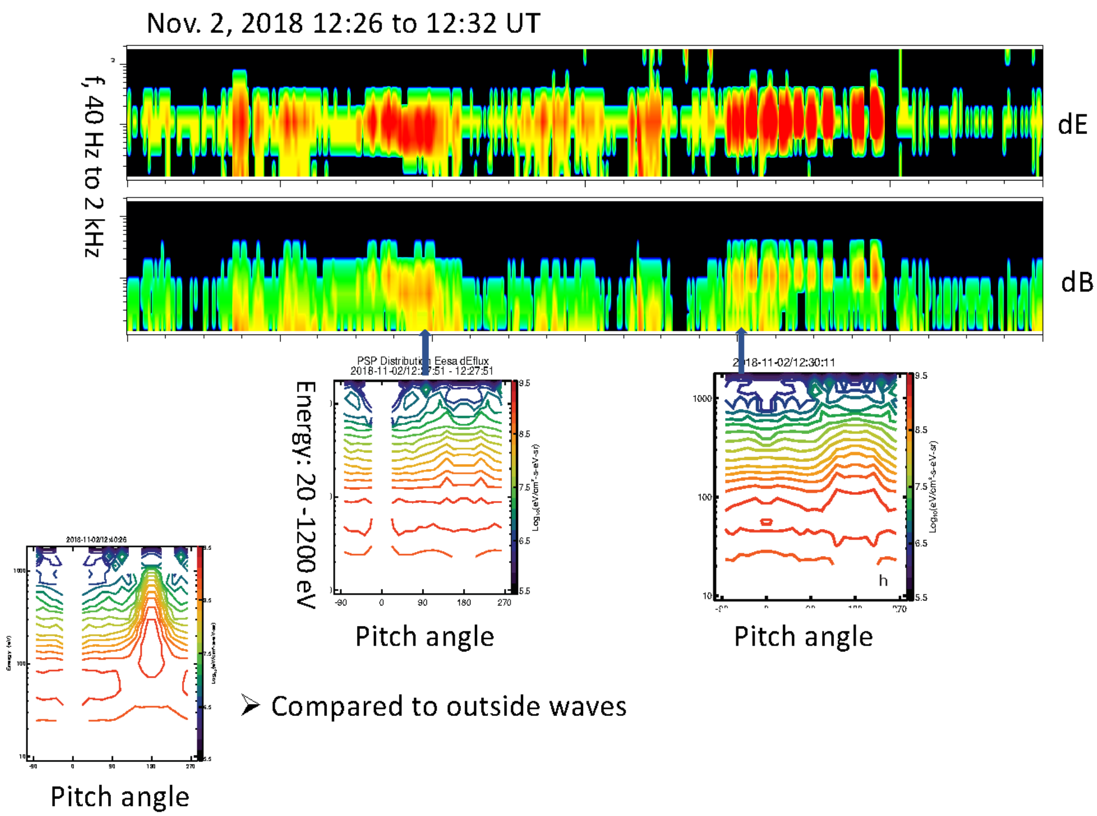
This figure shows the whistler electric field amplitudes at 1 AU (top), and electric field, magnetic field and dB/B at PSP. Bottom panels show radial dependence for PSP amplitudes.

Wave occurrence is constrained by the whistler fan heat flux instability threshold, which has largest growth rates at oblique angles.



This figure shows wave occurrence vs. normalized heat flux and parallel electron beta. The whistler fan instability limit from Vasko et al. (2019) is overplotted.

The waves are associated with broadened electron pitch angle distributions.



The figure plots the electric and magnetic field amplitudes from the bandpass filter data from PSP, showing intense whistlers. Two (28 s) electron distributions (Energy vs pitch angle) show significant broadening compared to distribution obtained where there were no waves.

Cattell et al. (2020a; 2020c; 2020d)

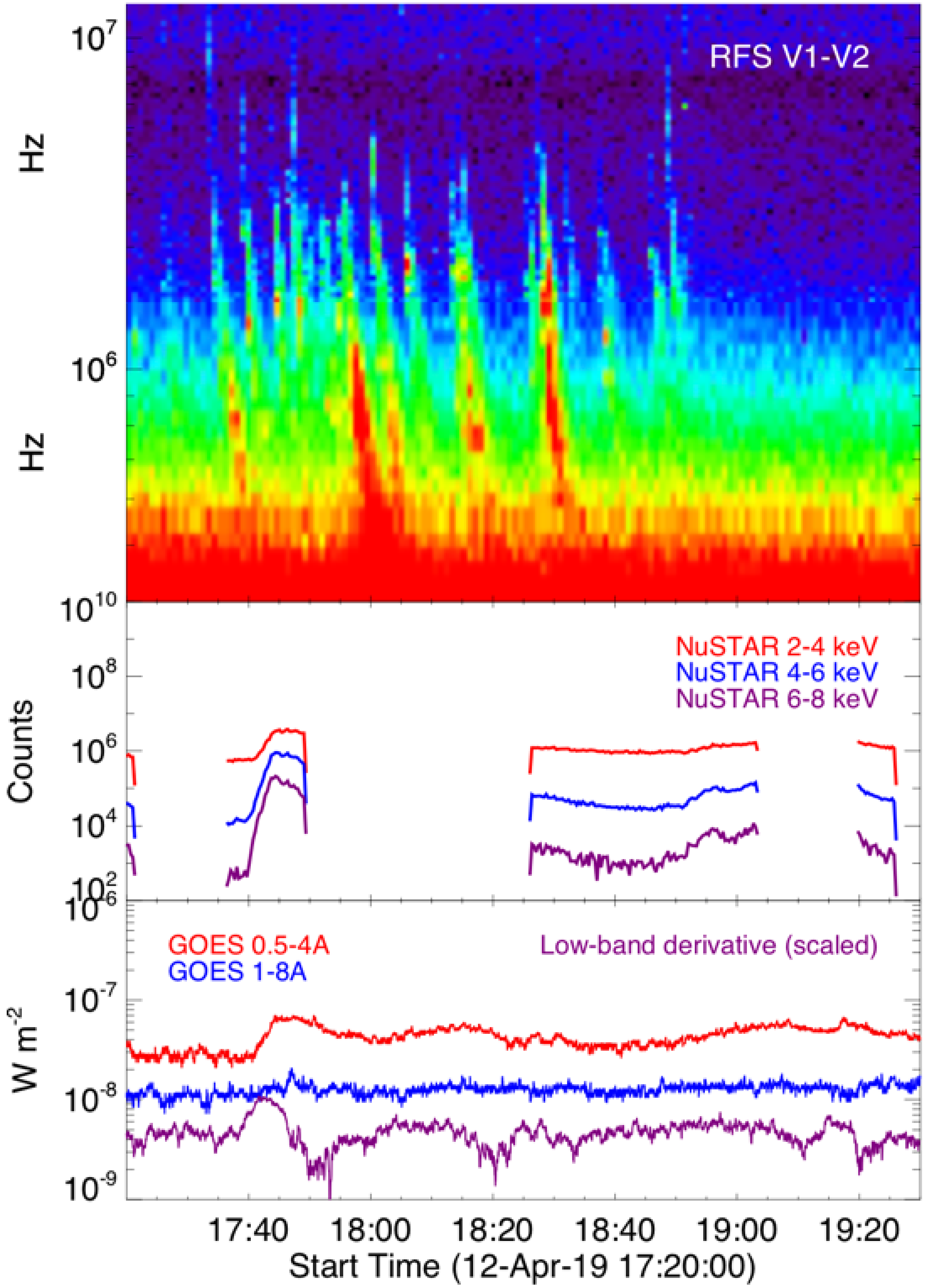
WAVE MODULATED ELECTRON ACCELERATION IN A QUIESCENT CORONAL ACTIVE REGION

Serendipitous coordinated NuSTAR and Parker Solar Probe observations, combined with SDO/AIA EUV and HMI, provide evidence for periodic electron acceleration when there were no observable flares. Periodicities of ~5-6 minutes in EUV bands in areas of an active region and in the sunspot are well correlated with the repetition rate of the Type III radio bursts on PSP and Wind.

This movie in the SDO/AIA 211 A line shows that the active region was quiescent.

[VIDEO] https://www.youtube.com/embed/eBRNCJyjOIw?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

PSP radio data show periodic radio bursts. Here is an example when NuSTAR observed a very tiny microflare. There was no 1-to-1 correspondence with the Type IIIs.



This fIgure plots the interval of interest from 17:20 to 19:30 UT. The top panel shows PSP/FIELDS radio data (V12), with times propagated to 1 AU. The middle panel shows the NuSTAR x-ray data, and the bottom panel shows the GOES x-ray data.

Periodicities of ~5-6 minutes in EUV bands in areas of an active region and in the sunspot are well correlated with the repetition rate of the Type III radio bursts on PSP and Wind.

171 Å peaks lag 211 Å peaks, which lag the radio bursts, suggestive of impulsive heating and then cooling in the lower corona.

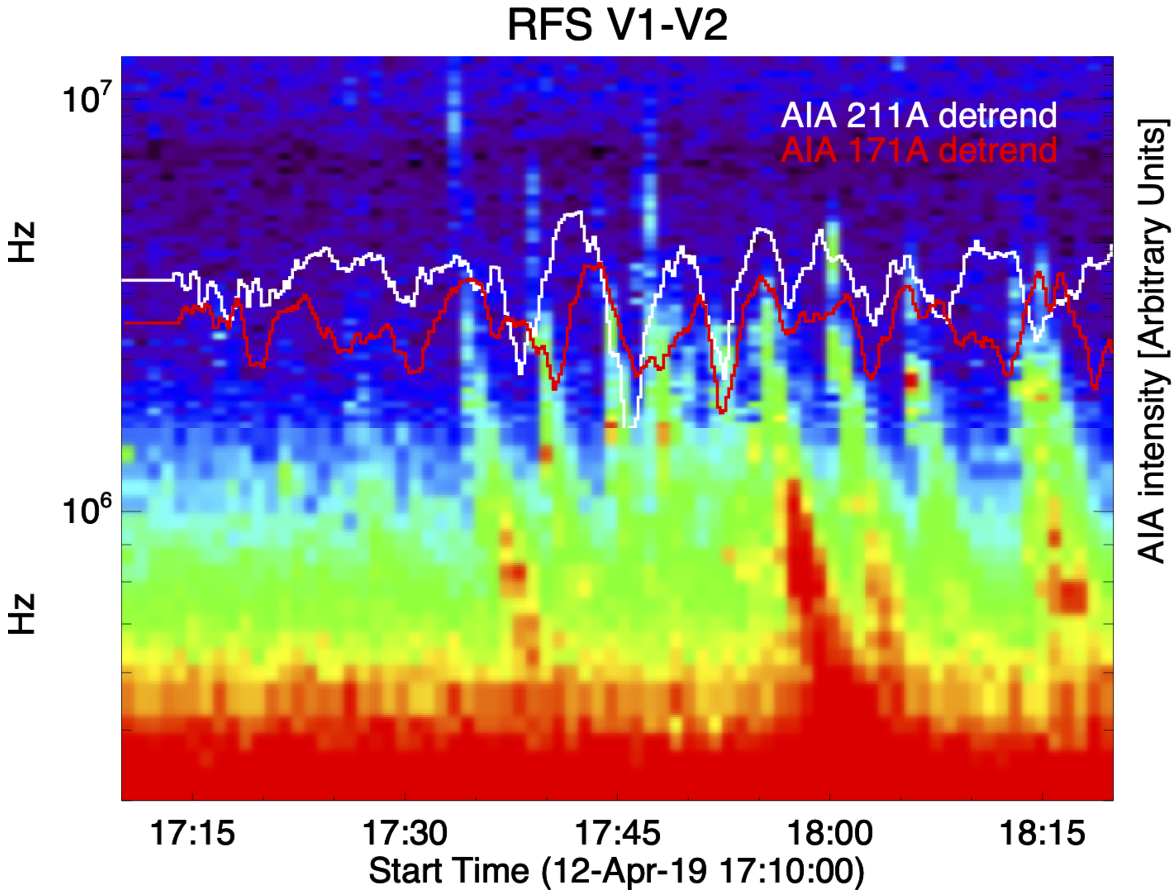


Figure shows time series of PSP radio with detrended AIA 211 (white) and 171 (red) overplotted for Region 2. PSP times have been propagated to 1 AU..

Cattell et al. (2020b)

>>MORE DETAILS IN VIDEO BELOW<<

CONNECTIONS?

1. Whistlers and Langmuir waves are often observed simultaneously by Parker Solar Probe (Bale et al. 2019). Both may be excited by energetic beams, as seen in LAPD experiments (Dorfman et al. SM016-09), some satellite observations (Ergun et al.1998), or whistlers and Langmuir waves may be connected via a 3-wave decay process

2. Particle tracing (Vo et al. SH025-12) shows whistlers can interact strongly with strahl electrons to broaden pitch angles and control heat flux, and with energetic electrons, potentially contributing to observed spreading of SEP electrons.

ILLUMINATING PERIODICITIES IN THE CORONA AND IN TYPE III RADIO BURSTS

[VIDEO] https://www.youtube.com/embed/VS-IoHEWGHU?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Cattell et al., (2020b)

ABSTRACT

The role of waves in the propagation, scattering and energization of electrons in the solar wind has long been a topic of interest. Conversely, understanding the excitation of waves by energetic electrons can provide us with a diagnostic for the processes that accelerate the electrons. We will discuss two different processes: (1) the interaction of narrowband whistler-mode waves with solar wind electrons, and (2) how periodic Type III radio bursts yield clues to small-scale acceleration of energetic electrons in the solar corona. Waveform captures in the solar wind at 1 AU obtained by the STEREO revealed the existence of narrowband large amplitude whistler mode waves, propagating at highly oblique angles to the magnetic field. Similar waves are less commonly seen inside .2 AU by Parker Solar Probe. The differences provide clues for understanding electron propagation, scattering and energization. Type III radio bursts have long been used as remote probes of electron acceleration in the solar corona. The occurrence of periodic behavior in Type III bursts observed by Parker Solar Probe, Wind and STEREO when there are no observable flares provides a unique opportunity to diagnose small-scale acceleration of electrons in the corona. Periodicities of ~ 5 minutes in the Solar Dynamics Observatory Atmospheric Imaging Assembly (AIA) Extreme Ultraviolet data in several areas of an active region are well correlated with the repetition rate of the Type III radio bursts. Similar periods occur in the Helioseismic and Magnetic Imager (HMI)data. These results provide evidence for acceleration by wave-modulated reconnection or small-scale size waves, such as kinetic Alfven waves, even during intervals with no observable flares. The possible connections between these two phenomena will be addressed.

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