Whistler instability driven by the sunward electron deficit in the solar wind: High-cadence Solar Orbiter observations

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Abstract

Solar wind electrons play an important role in the energy balance of the solar wind acceleration by carrying energy into interplanetary space in the form of electron heat flux. The heat flux is stored in the complex electron velocity distribution functions (VDFs) shaped by expansion, Coulomb collisions, and field-particle interactions. We investigate how the suprathermal electron deficit in the anti-strahl direction, which was recently discovered in the near-Sun solar wind, drives a kinetic instability and creates whistler waves with wave vectors that are quasi-parallel to the direction of the background magnetic field. We combined high-cadence measurements of electron pitch-angle distribution functions and electromagnetic waves provided by Solar Orbiter during its first orbit. Our case study is based on a burst-mode data interval from the Electrostatic Analyser System (SWA-EAS) at a distance of 112 R_S (0.52 au) from the Sun, during which several whistler wave packets were detected.
by Solar Orbiter’s Radio and Plasma Waves (RPW) instrument. The sunward deficit creates kinetic conditions under which the quasi-parallel whistler wave becomes unstable. We directly test our predictions for the existence of these waves through solar wind observations. We find whistler waves that are quasi-parallel and almost circularly polarised, propagating away from the Sun, coinciding with a pronounced sunward deficit in the electron VDF. The cyclotron-resonance condition is fulfilled for electrons moving in the direction opposite to the direction of wave propagation, with energies corresponding to those associated with the sunward deficit. The quasilinear diffusion of the resonant electrons tends to fill the deficit, leading to a reduction in the total electron heat flux.
Whistler instability driven by the suprathermal electron deficit in the solar wind


The pitch-angle gradient example (b) shows the electron distribution in the velocity space. The pitch-angle gradient for the electrons with velocities close to \(v_{\parallel}\), is negative (blue). Electrons following the diffusion paths lose energy, which corresponds to scenario (b).

The instability mechanism includes:
- Curves of equal energy in the plasma frame.
- Resonant electrons following the quasi-parallel whistler wave.

Fields and plasma properties during the presented interval:
- Enhanced B and E fluctuations in 18.5 and 48.5 Hz frequency bands.
- Basic wave parameters (BP) from SWF.
- Wave normal vectors close to magnetic field direction.
- Enhanced B and E fluctuations in 18.5 and 48.5 Hz frequency bands.

Data analysis - electron VDFs:
- VDFs averaged over the selected subintervals.
- Normalised VDFs averaged over the selected subintervals.
- VDFs are normalised with the cut along the perpendicular direction.
- The suprathermal deficit is more pronounced in examples (b) and (c) coinciding with whistler waves.
- Cyclotron resonant velocity matches the position of the deficit in the velocity space.

Data analysis - electron VDFs:
- Enhanced B and E fluctuations are circularly polarised quasi-parallel waves, propagating in +B direction.

More details about SWA observations by Owen et al.
More details about SWA-EAS observations by Kretzschmar et al.

Electrostatic Anomalous System (EAS) in burst mode (BM) only samples 2 elevation bins corresponding to magnetic field direction and magnetic direction.

Shocks electrons nicely follow the magnetic field direction.

EAS 1 elevation definition corresponds well to the magnetic field direction — all the pitch angles are measured.

Electron halo anisotropy and wave polarization.

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