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

Laura Bercic[1], Daniel Verscharen[2], Christopher Owen[3], Lucas Colomban[4], Matthieu Kretzschmar[5], Thomas Chust[6], Milan Maksimovic[7], D Kataria[8], Chandrasekhar Anekallu[8], Etienne Behar[9], Matthieu Berthomier[10], Roberto Bruno[11], Vito Fortunato[12], Christopher Kelly[13], Yuri Khotyaintsev[14], Gethyn Lewis[8], Stefano Livi[15], Philippe Louarn[16], Gennaro Mele[17], Georgios Nicolaou[18], Gillian Watson[8], and Robert Wicks[19]

[1]Mullard Space Science Laboratory, University College London
[2]University of New Hampshire Main Campus
[3]University College London, Mullard Space Science Laboratory
[4]Laboratoire de Physique et Chimie de l'Environnement et de l'Espace
[5]CNRS and University of Orléans
[6]Laboratoire de Physique des Plasmas (UMR7648)
[7]LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université de Paris
[8]University College London
[9]IRF Swedish Institute of Space Physics Kiruna
[10]LPP
[11]INAF-IFSI
[12]Planetek
[13]Mullard Space Science Laboratory
[14]Swedish Institute of Space Physics (IRF)
[15]SwRI
[16]IRAP, CNRS
[17]Leonardo
[18]UTSA
[19]Northumbria University

November 22, 2022

Abstract

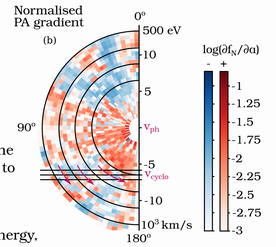
Solar wind electrons play an important role in the energy balance of the solar wind acceleration by carrying energy into interplanetary space in the form of electron heat flux. The heat flux is stored in the complex electron velocity distribution functions (VDFs) shaped by expansion, Coulomb collisions, 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 suprathemal electron deficit in the solar wind

L. Berčič[1], D. Verscharen[1,2], C. J. Owen[1], L. Colomban[3], M. Kretzschmar[3], T. Chust[4], M. Maksimovic[5], D. O.Kataria[1], C. Anekallu[1], E. Behar[6,7], M. Berthomier[4], R. Bruno[8], V. Fortunato[9], C. W. Kelly[1], Y. V. Khotyaintsev[10], G. R. Lewis[1], S. Livi[11], P. Louarn[12], G. Mele[13], G. Nicolaou[11], G. Watson[1], and R. T. Wicks[14]

6 Pitch-angle gradient - example (b)

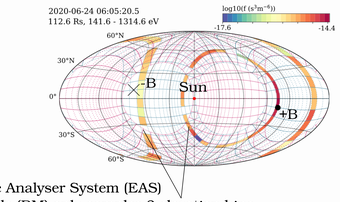


The pitch-angle gradient for the electrons with velocities close to v_{cyclo} is negative (blue)

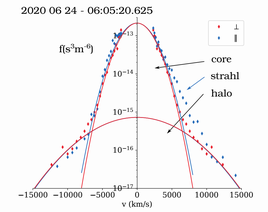
→ Electrons following the diffusion paths loose energy, which corresponds to scenario (b).

Data analysis - electron VDFs 1

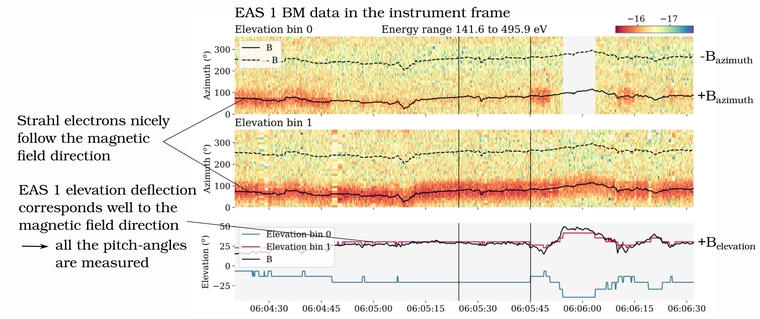
SWA-EAS 1 and 2 field of view in the spacecraft frame



Electrostatic Analyser System (EAS) in burst mode (BM) only samples 2 elevation bins corresponing to mangetic field positive and negative direction.



Bi-Maxwellian fits to the core and the halo



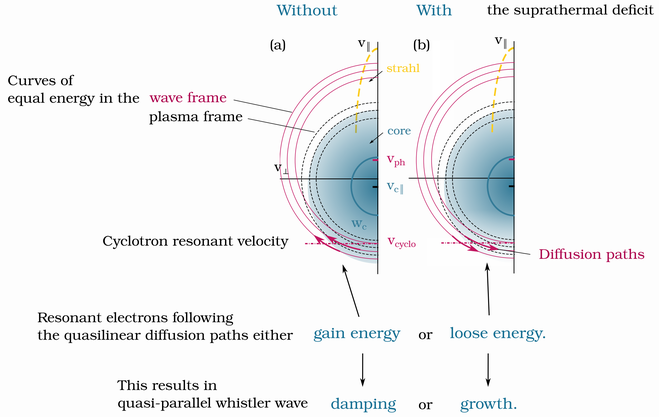
Strahl electrons nicely follow the magnetic field direction

EAS 1 elevation deflection corresponds well to the magnetic field direction

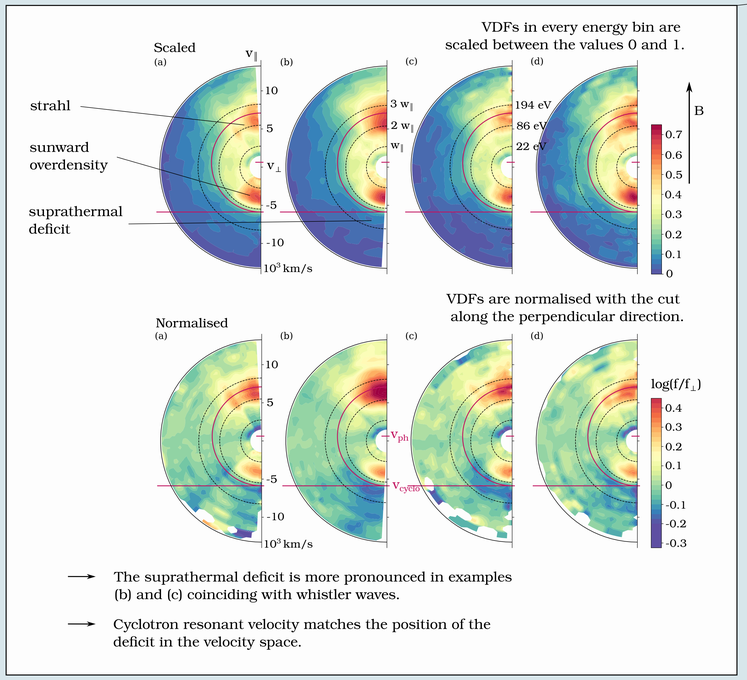
→ all the pitch-angles are measured

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

The instability mechanism



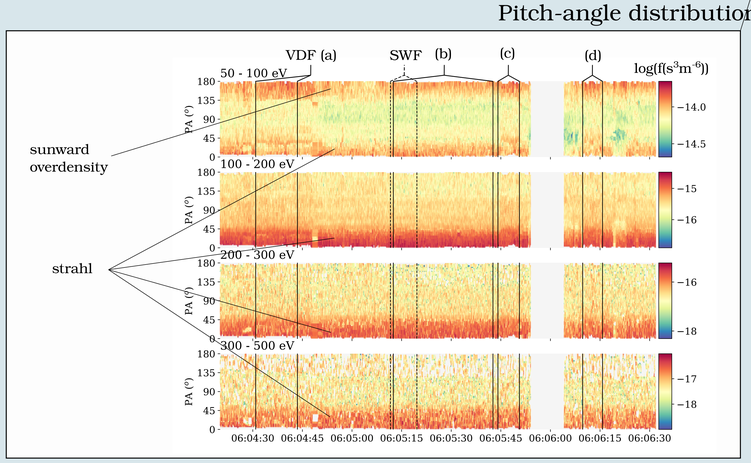
5 VDFs averaged over the selected subintervals



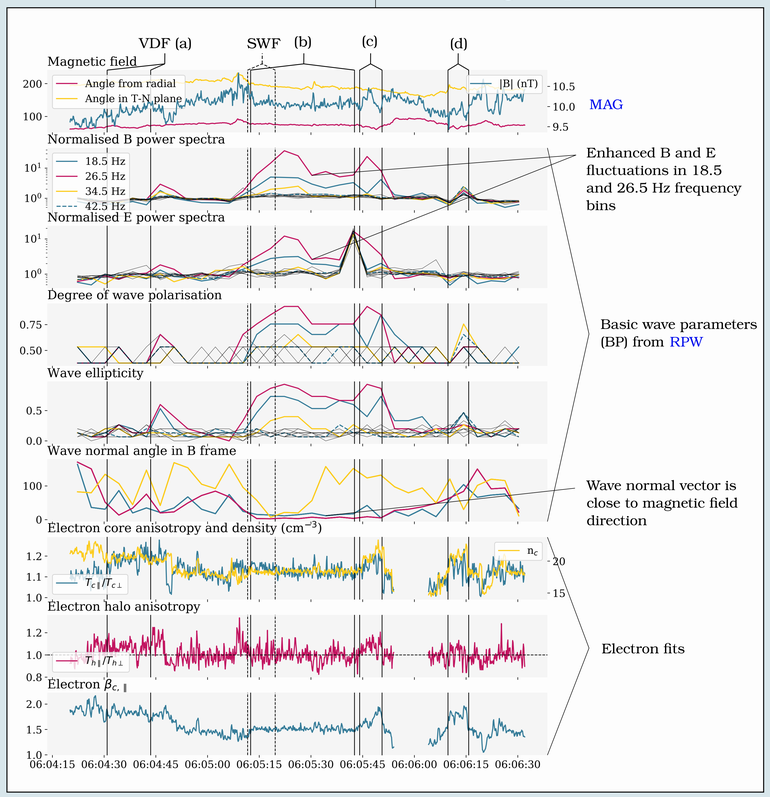
→ The suprathermal deficit is more pronounced in examples (b) and (c) coinciding with whistler waves.

→ Cyclotron resonant velocity matches the position of the deficit in the velocity space.

4 Pitch-angle distributionos

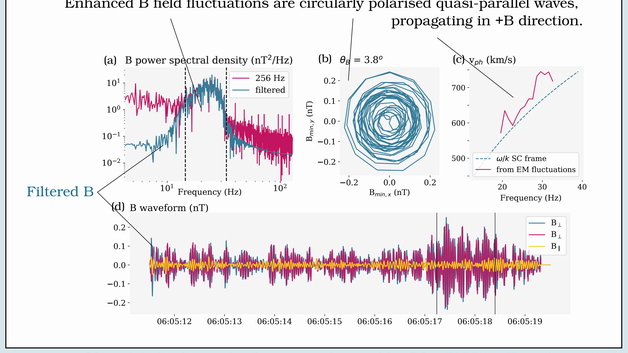


3 Fields and plasma properties during the presented interval



Data analysis - snapshot waveforms (SWF) 2

Enhanced B field fluctuations are circularly polarised quasi-parallel waves, propagating in +B direction.



More details about whistler waves observed by SO: vPICO by Kretschmar el al. vPICO by Colomban et al.

[1]Mullard Space Science Laboratory, University College London, Dorking, RH5 6NT, UK
[2]Space Science Center, University of New Hampshire, 8 College Road, Durham NH 03824, USA
[3]LPC2E/CNRS, 3 Avenue de la Recherche Scientifique, 45071 Orléans Cedex 2, France4LPP, CNRS, Ecole Polytechnique, Sorbonne Université, Observatoire de Paris, Université Paris-Saclay, Palaiseau, Paris, France
[5]LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Univ. Paris Diderot, Sorbonne Paris Cité, 5 place Jules Janssen, 92195 Meudon, France
[6]Swedish Institute of Space Physics (IRF), Kiruna, Sweden
[7]Laboratoire Lagrange, OCA, UCA, CNRS, Nice, France
[8]INAF-IAPS, Via Fosso del Cavaliere 100, 00133 Roma, Italy
[9]Planetek Italia, Italy
[10]Swedish Institute of Space Physics (IRF), Uppsala, Sweden
[11]Southwest Research Institute, San Antonio, Texas, USA
[12]IRAP, Université de Toulouse, CNRS, UPS, CNES, Toulouse, France
[13]Leonardo, Taranto, Italy
[14]Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne, UK

l.bercic@ucl.ac.uk

SWA RPW MAG