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ABSTRACTS

OBSERVATIONS OF LARGE AMPLITUDE SOLITARY WAVES IN THE EARTH'S MAGNETOSPHERE AND COMPARISON TO THEORIES

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Solitary waves with large electric fields (up to 100s of mV/m) have been observed throughout the magnetosphere and in the bow shock. We discuss observations by FAST in the low altitude auroral zone, by Polar in the low altitude auroral zone and, at high altitudes ($\sim$ 4-8 R_E), during crossings of the plasma sheet boundary and cusp, and new measurements by Cluster at the bow shock, in the cusp and at the plasma sheet boundary. Electron solitary waves are ubiquitous, and are observed for wide range of f_{ce}/f_{pe}. In contrast, to date, ion solitary waves have only been observed in the auroral zone at low altitudes in the region where $f_{ce}/f_{pe} \gg 1$. We describe some results of statistical studies of ion solitary waves at low altitudes and electron solitary waves at high altitudes. Ion solitary waves, observed in regions of upward field-aligned currents and ion beams, are negative potential structures and have velocities between O^+ and H^+ beam speeds, scale sizes of approximately $10\lambda_D$, and normalized amplitudes, $e\phi/kT_e$, of order 0.1 because the electron temperatures are large (plasma sheet values). In addition, the amplitude increases with both the velocity and the scale size which is inconsistent with the predictions of 1d ion acoustic soliton theory. The observations are well modeled by the simulations of Crumley et al. (2001) which include only the plasma sheet electrons and the beam ions. Both observations and the simulations are consistent with an ion hole mode associated with the ion two stream instability. Electron solitary waves are observed over a wide range of plasma conditions. We will discuss the scale sizes and time variability of the regions where the solitary waves occur, utilizing data from the four Cluster satellites. Statistical studies of characteristics of high altitude electron solitary waves observed by Polar will be described. The waves have velocities from 1000 km/s to > 2500 km/s. Observed scale sizes are on the order of 1-10 λ_D with $e\phi/kT_e$ up to $\mathcal{O}(1)$. For these solitary waves also, the amplitude increases with both the velocity and the scale size, consistent with electron hole modes as was observed at low altitudes. The solitary waves are stable based on the criterion developed by Muschietti et al.(1999). Comparisons with recent 2d and 3d simulations of electron holes will be discussed.

DYNAMICS OF STREAMER FORMATION AND ITS IMPACT ON TRANSPORT IN DRIFT-ROSSBY TURBULENCE

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We present the results of recent investigations of the generation of streamers in drift-Rossby turbulence. A theory of radially extended streamer cell formation and self-regulation is presented within a random phase approximation approach. The role of magnetic curvature, pressure advection nonlinearity and proximity to marginal stability in streamer formation are investigated. We also explore the shearing on the underlying turbulence and Kelvin-Helmholtz type instability as mechanisms for streamer self-regulation. In particular, shearing by radial streamer flows is more effective in quenching streamer growth than the conventionally invoked process of sub-scale Kelvin-Helmholtz instability. Finally aspects of streamer structure and dynamics are used to estimate the variance of the drift-wave induced heat flux, which is shown to be proportional to the streamer intensity level. The variance is found to be of order unity, thus calling the applicability of the quasilinear estimates into question. The implications of streamer formation for the probability density function (pdf) of the transport flux will be discussed. Dynamics of streamer formation will be also presented near threshold as a result of secondary instability of coherent drift waves. In this context, the nonlinear interaction of drift turbulence and large scale flows is addressed within the envelope formalism.

PLASMA RESONANCES, COHERENT STRUCTURES, FSOC, NONLINEAR INTERACTIONS AND INTERMITTENT TURBULENCE

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Most of the observed turbulent space plasma processes are intrinsically intermittent with at least two distinctly different time scales, one time scale associated the intermittency which is very short and an evolutionary time scale which is much longer in duration. This has led Chang [1] to suggest that the behavior for intermittent turbulent plasma processes is related to the phenomenon of forced and/or self-organized criticality [FSOC] based on the concepts of path integrals and the dynamical renormalization-group. Subsequently, Chang [2] constructed physical topological models to describe the basic interactions for such processes in the context of the formation and evolution of the coherent structures generated near plasma resonances and the fast interactions and relaxation diffusion among these structures. We shall apply these ideas to several relevant space plasma phenomena including those related to the substorm dynamics of the magnetotail and the intermittent turbulent electric field fluctuations in the Earth's auroral zone.

1. Chang, T., IEEE Trans. Plasma Sci. 20, 691, 1992.
2. Chang, T., Physics of Plasmas, 6, 4137, 1999.

SELF-ORGANIZATION OF ZONAL FLOW STRUCTURES

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Recently, the formation and dynamics of zonal flows have been the subject of intense investigation, primarily by large-scale simulations. In this talk, I will discuss the physics of zonal flows and endeavor to penetrate behind the pretty color viewgraphs so often shown in connection with this subject. Specifically, I will focus on:

a.) the dynamics of zonal flow generation by drift wave turbulence and the importance of ray chaos in underpinning the validity of stochastic methodology.

b.) the coupled evolution of zonal flows and turbulence. In particular, the existence of a condensate solution and the consequent bifurcation between it and the 'normal' solution will be discussed as a possible cause of cyclic bursts observed in simulations.

c.) the spatial scales typical of zonal flows and how they are determined.

d.) zonal flow saturation. Here, I will discuss both tertiary generalized "Kelvin-Helmholtz" instability, and self-consistent evolution of the wave spectrum induced by zonal flows and non-linear trapping of waves by zonal flows. The coupled 'predator-prey' equations for the zonal flow spectrum and drift wave spectral intensity (including noise) are solved. Drift wave intensity scales linearly with collisionality for weak flow damping, and ala' mixing length theory for strong damping. The cross-over parameter is determined. More interestingly, a condensate solution at low radial wavenumber appears in the case that the zonal flow damping exceeds a (bifurcation) threshold. This condensate or 'jet', spectra may well be relevant to streamer or transport event formation observed in simulations, since the jets long radially wavelength. Interestingly too, jet formation occurs in regimes of large flow damping where zonal flows are weak. The presence of a bifurcation for the appearance of jets also suggests that the 'bursting' phenomenon observed in simulations may be a hysteresis - loop phenomena, symptomatic of transitions between zonal flow and condensate dominated regimes. Finally, we report on novel time-dependent solutions of the predator-prey system, as well. I will also argue that tertiary instability is not robust and that the other mechanisms must be considered carefully, as well.

e.) direct zonal flow effects on transport and the coupled evolution of zonal flows and the mean electric field.

Throughout this review, I will emphasize the connections to general theoretical issues.

LABORATORY EXPERIMENTS ON ALFVÉN WAVES IN INHOMOGENEOUS PLASMAS AND ALFVÉN WAVES WHICH CAUSE INHOMOGENEOUS PLASMAS

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There is a great deal of interest in both the propagation of Alfvén waves in plasmas with density and magnetic field gradients as well as Alfvén waves which can cause plasma inhomogeneities. The FREJA, FAST, and Interball satellites have frequently encountered density striations in the auroral ionosphere. These waves have been studied in great detail in the **La**rge **P**lasma **D**evice (LaPD) at UCLA. The plasma, which is 10m in length and 500 ion Larmor radii in diameter (He ($\lambda_{\|} \approx 2m$), Ar ($\lambda_{\|} \approx 10m$), $1.5kG$, $40cm$ plasma diameter, 2–$4.0 \times 10^{12} cm^{-3}$, fully ionized) supports Alfvén waves. Our initial investigations, involving low amplitude ($\delta B_{wave}/B_0 \geq 10^{-4}$) shear waves, have examined the wave characteristics in the kinetic ($v_A < v_{the}$) and inertial ($v_A > v_{the}$) regimes, as well as in magnetic field gradients. Launching higher power waves ($\delta B_{wave}/B_0 \geq 10^{-3}$) with a variety of antennas has extended these studies. Waves are launched using a helical antenna at frequencies below and above the ion cyclotron frequency. Below f_{ci} the wave fields slowly spread across the background magnetic field and the current associated with them forms a rotating spiral. The higher power wave causes a localized density perturbation when B_{wave}/B_0 exceeds 10^{-3} even when the wave propagates below the cyclotron frequency. The perturbation is measured using Langmuir probes as well as laser induced fluorescence (LIF) signals from Ar II ions. We will present wave propagation data in which the temporal history of the vector magnetic field was acquired at 20,000 spatial locations. The data is used to calculate 3D wave currents, wave phase fronts and energy propagation. In addition we will present detailed laser induced fluorescence (LIF) studies of Argon plasmas in which density perturbations have been observed. The studies show the ion motion in the wave fields as well as their expulsion from localized regions in the plasma. In Helium the wave pattern is more complex than in Argon. There are up to five braided current channels associated with the wave. The wave magnetic field in planes parallel to the background magnetic field forms vortex type structures, which rotate in both the clockwise and counterclockwise directions. Using a field aligned current antenna, field line resonances have been created in the device. In both the shear and compressional Alfvén wave regimes, standing waves at frequencies which correspond to multiples of half-wavelengths along the column are observed. Data from the standing compressional wave radiation patterns, which can produce large fields ($B_{wave}/B_0 \approx 10^{-2}$), and a comparison to theory, will be presented. Finally we present preliminary results of a set of experiments in which large amplitude Alfvén shear waves, as well as compressional waves, are driven by the expansion of a dense, laser produced plasma which is embedded in the background magnetized plasma. Temporal evolution, wave patterns and spectra of these waves along with associated density perturbations will be presented.

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DIRECT OBSERVATION OF PARALLEL ELECTRIC FIELDS IN A SPACE PLASMA

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The purpose of this talk is to put forth direct observations of parallel electric fields and accompanying electron distributions in the downward current region of the aurora. The parallel electric field is found to be consistent with a nearly monotonic potential ramp that extends 10 Debye lengths along the ambient magnetic field. The unaccelerated electron distribution, "upstream" of the parallel electric field, has a dense, cold core, and displays minimal heating. The accelerated distribution, "downstream" of the parallel electric field, shows an energetic peak and substantial modification due to wave-particle interactions. Immediately downstream of the parallel electric field are intense, broadband quasi-electrostatic emissions that are identified as a series of electron phase-space holes previously associated with parallel electric fields in this region. These data suggest a self-consistent treatment of the parallel electric field must include substantial velocity space diffusion in the electron distribution. These data establish a direct association between parallel electric fields and electron phase-space holes.

STABILITY OF PHASE SPACE TUBES AND BIPOLAR STRUCTURES IN THE AURORAL IONOSPHERE

Martin V. Goldman and David L. Newman

Two-dimensional simulation studies of the nonlinear evolution of the two-stream instability have shown that phase holes and bipolar structures acquire coherence over large distances, leading to tubelike structures with axes perpendicular to B. These structures break up after at time on the order of a hundred plasma periods. The breakup is accompanied by the growth of electrostatic whistler waves and the appearance of perpendicular fields of the same magnitude as the parallel bipolar wave fields. Using an idealized BGK model of phase space tubes, we have demonstrated numerically and analytically that the breakup process corresponds to an instability in which whistlers and tube vibrations are coupled. The largest growth occurs when the whistler frequency is matched to the vibration frequency of the tubes. We present a new analysis of the instability focusing both on phase-space processes and on moments of the zero and first-order electron distribution functions. The whistlers emitted during this instability may correspond to VLF "saucers," which are often observed in the presence of bipolar structures in the auroral ionosphere.

FORMATION OF BIPOLAR STRUCTURES BY LOCALIZED PARALLEL ELECTRIC FIELDS

David L. Newman, Martin V. Goldman, and Robert E. Ergun

Localized parallel electric fields have been identified as a source for anti-Earthward propagating bipolar structures in the downward current region of the auroral ionosphere [R. E. Ergun, this meeting]. We present the results of open-boundary Vlasov simulations in the vicinity of such a parallel electric field (i.e., a ramp in the electrostatic potential), which is modeled by imposing an inhomogeneous ion density structure inferred from analytical models of potential ramps. The electrons evolve self-consistently in phase space such that upstream electrons are accelerated by the local parallel E-field, thereby forming an unstable two-stream distribution on the downstream side of the ramp. The two-stream instability results in the generation of a series of electron phase-space holes (supporting bipolar field structures). Among the features of the simulations that can be compared with observations are: the sizes and velocities of the emerging bipolar fields; the relative upstream and downstream electron temperatures; and the imposed ion density profile.

EXPLANATION FOR THE SIMULTANEOUS APPEARANCE OF BIPOLAR STRUCTURES AND WAVES BETWEEN ION CYCLOTRON HARMONICS IN THE AURORAL IONOSPHERE

Martin V. Goldman, David L. Newman, Frank Crary and Robert Ergun

In the downward current region of the auroral ionosphere, the FAST spacecraft has observed bipolar electrostatic structures on Debye length scales and waves at frequencies between ion cyclotron harmonics. Such bipolar structures have been previously identified with the nonlinearly evolved state of a two-stream electron instability. We present the results of long-duration and large-scale particle-in-cell (PIC) simulations which produce, from one set of initial conditions, both bipolar electrostatic structures and, at later times, ion Bernstein waves with peak intensities between multiples of the ion cyclotron frequency. The ion Bernstein waves are driven by a weaker beam instability caused by a residual positive slope in the nonlinearly evolved (nonthermal) electron distribution. Although there are a variety of processes which can produce ion Bernstein modes, we show that a common source (an electron beam) can produce both of these observed phenomena in the downward current region. Comparisons are made between theory and observation.

DETERMINATION OF THE POSITION IN SPACE OF THE HF EXCITED ION ACOUSTIC AND LANGMUIR WAVES WITH THE TROMSØ HEATER/EISCAT COMBINATION

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To better understand the mechanisms which give rise to the enhanced ion acoustic and Langmuir waves in ionospheric HF modification experiments, measurements were made with the EISCAT Tromsø heater and the two incoherent scatter radars to locate the regions of enhancement in space. Simultaneous measurements were made of the enhancements with both the VHF (224 MHz) and the UHF (933 MHz) radars, the latter being scanned in the magnetic meridian plane between vertical and field aligned through the "Spitze" angle. The results show that enhanced both bottom-side and topside ion acoustic and plasma waves at UHF and VHF are a common occurrence in these data. Whereas topside UHF ion acoustic features were common, topside enhanced plasma waves were not observed, possibly due to lack of radar sensitivity. At UHF the enhanced ion waves were strongest in a broad region between the Spitze angle and geomagnetic field aligned pointing directions. The bottom-side plasma wave enhancement appeared to peak in a region close to the field-aligned direction. In this pointing direction the bottomside ion line enhancement occurred at a location significantly lower than the critical height, and apparently also much lower than the height to expect from refraction alone.

The topside features we believe give evidence for the production and propagation of Z mode waves during this experiment. Incoherent scatter observations indicate that the plasma density at the peak of the layer is low enough for Z-mode waves to penetrate. However if the ionosphere were horizontally stratified one would expect the topside excitation to be observed in a spatially limited area corresponding to the efficient coupling of the O-mode and the Z-mode in a narrow region near the Spitze angle, not in a broad region as observed. There is no evidence in these data for a decay of Z mode waves into Bernstein and lower hybrid waves inside the overdense F layer as we believe to have observed previously. Subsequent observations of heater-enhanced airglow by others also show a strong tendency for the airglow to maximize in a direction centered on the magnetic field aligned direction. The cause of a possible relation of these phenomena is unclear. Plans currently under way to observe stimulated electromagnetic emission (SEE) from the heated region to determine whether various spectral features of this emission show similar angular dependence are briefly described.

GYROTROPIC SOLAR WIND

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We present a solar wind fluid model that extends from the chromosphere to the orbit of Earth. The model is based on the gyrotropic (6 moment) approximation to the 16-moment set of transport equations, in which we solve for the density, drift speed, temperature parallel and perpendicular to the magnetic field, as well as transport of both parallel and perpendicular thermal energy along the magnetic field (heat flux). The model does a complete inventory of all the energy supplied, including radiative loss and ionization and recombination in the upper chromosphere and transition region. The solar wind plasma is created dynamically through (photo-) ionization in the chromosphere, and the plasma density in the transition region and corona is computed dynamically, dependent on the type of coronal heating applied, rather than being set arbitrarily. The main improvement over previous models lies in the calculation of the proton energy flux in the transition region, where classical heat conduction is only retrieved in the collision-dominated limit. This transport model can serve as a “test-bed” for any coronal heating mechanism. As a specific example we consider heating of coronal protons by a turbulent cascade of Alfvén waves. The high coronal proton temperatures in this case lead to a downward proton energy flux from the corona which is much smaller than what classical transport theory predicts, resulting in a very low coronal density and an extremely fast solar wind with a small mass flux. Only when some of the Alfvén wave energy is forcibly deposited in the lower transition region can a realistic solar wind be obtained. Because of the poor proton heat transport, in order to produce a realistic solar wind any viable heating mechanism must deposit some energy in the transition region, either directly or via explicit heating of the coronal electrons.

NONSTATIONARITY OF COLLISIONLESS SHOCK WAVES

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Collisionless shocks are commonly found in space. When the ratio of reflected to incoming ions is high, the shock may become nonstationary. We discuss stability of supercritical perpendicular shocks by using a method similar to the hybrid simulation, in which we seek for a self- consistent profile of the ion distribution and the electromagnetic field. We report results of our parametric survey varying the upstream Mach number, the fraction of the reflected ions, and thermal velocities of the upstream and the reflected ions.

STATISTICAL STUDY OF BROADBAND LOW FREQUENCY NOISE CORRELATED WITH TRANSVERSELY ACCELERATED IONS OBSERVED BY AKEBONO

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Akebono was launched in 1989 into a semi-polar orbit with an altitude range between 300 km and 10,000 km, and has been operated successfully for about 12 years. Electrostatic broadband low frequency noise observed by Akebono in the region of ion heating/acceleration transverse to the geomagnetic field line is studied.

Our waveform analysis revealed that the electrostatic broadband noise are classified into two types of noise; one is continuous noise with upper cutoff around a few kHz and the other is intermittent impulsive waveform extended more than 10 kHz. The continuous broadband noise is closely correlated with transversely accelerated ions (TAI) and the wave is the possible main energy source of ion heating/acceleration. Simultaneous precipitating electrons are also usually observed.

The spatial and temporal distribution of the continuous broadband noise and its relationship with precipitating electrons and heated ions are statistically studied using one solar cycle observation datasets of Akebono. The continuous broadband noise and precipitating electrons in the energy range below a few hundreds eV are distributed in the quite narrow invariant latitude range in the dayside cusp, and the region is extended toward the lower latitude range for the other local time. On the other hand, ion heating occurs mainly in the cusp region. We also performed multi-dimensional correlation analyses among wave intensity, frequency, particle density, temperature, etc. quantitatively. These results will be important clues to understand global dynamics in the polar region.

ELECTRON PHASE SPACE HOLES, SOME THOUGHTS AND AN EARLY LOOK AT CLUSTER DATA

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The Polar spacecraft and PWI instrument investigated electron phase-space holes (EPSH) in a region between FAST investigation near 3000 km in the auroral acceleration zone and the Geotail investigation in the distant plasma sheet. Specifically the Polar experiment found EPSH in the near earth plasma sheet and cusp/cleft field lines. The Polar investigation revealed EPSH traveling both upwards and downwards, sometime simultaneously, at a significant fraction of the electron thermal speed consistent with other investigations. Sometime the EPSH observed by the Polar PWI were organized transverse to the magnetic field. In addition the Polar investigation was conducted over an environment where the ratio of the electron gyrofequency to the electron plasma frequency varied from less than one to more than one. The ratio of these two frequencies was shown to be related to the shape of the EPSH with more magnetic EPSH being more spherical and less magnetic EPSH being more pancake-like. The recently commissioned Cluster spacecraft will extend the investigation of EPSH to new regions of the magnetosphere. The analysis of Cluster plasma wave data is at the preliminary phase and we will present a progress report on the first examples of EPSH we have studied using this data.

LABORATORY SIMULATION OF BROADBAND ELF WAVES IN THE AURORAL IONOSPHERE

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The general topic of the acceleration of low-altitude ionospheric ions and the possible operating mechanisms is of interest to the space community [1]. One such mechanism receiving much recent attention involves turbulence generated by inhomogeneity in the perpendicular (to the magnetic field) plasma flow [2]. This mechanism, known as the inhomogeneous energy-density driven instability, is particularly relevant in situations where shear in the perpendicular velocity exists and where magnetic-field-aligned currents may be too small for the current-driven electrostatic ion-cyclotron (CDEIC) instability [3]. These situations are modeled in plasma produced by the WVU Q Machine. These laboratory results on the generation and propagation of ion-cyclotron waves have been invoked in the interpretation of the broadband, extremely-low-frequency electrostatic waves associated with the most intense and most common ion heating in the Earth's ionosphere [1,4,5]. The concepts of the instability mechanism and properties of the waves and ion heating will be presented. Comparisons with SCIFER and Freja data [5] will be discussed.

1. Kintner et al., Phys. Plasmas 7, 2135, 2000; J. Geophys. Res. 105, 21237, 2000.

2. Ganguli and Palmadesso, GRL 15, 103, 1988; Gavrishchaka et al., Phys. Plasmas 3, 3091, 1996; Koepke et al., Phys. Rev. Lett. 72, 3355, 1994; Amatucci et al., Phys. Rev. Lett. 77, 1978, 1996.

3. Drummond and Rosenbluth, Phys. Fluids 5, 1507, 1962; Kindel and Kennel, JGR 76, 3055, 1971.

4. Kintner et al., GRL 23, 1873, 1996; Bonnell et al., GRL 23, 3297, 1996; Lynch et al., GRL 23, 3293; Andr et al., JGR 103, 4199, 1998; Knudsen et al., JGR 103, 4171, 1998; Lund et al., JGR 104, 22801, 1999; JATP 62, 467, 2000.

5. Koepke et al., JGR 104, 14397, 1999; Hamrin et al., Inhomogeneous transverse electric fields and wave generation in the auroral region: A statistical study, to appear in JGR, June 2001.

FINE STRUCTURE OF BOUNDARY LAYER WAVES

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Broadband plasma waves in the ELF/VLF frequency range that have been detected on field lines just adjacent to the polar cap are called the Polar Cap Boundary Layer (PCBL) waves. These waves are spiky, and their frequency dependence and intensities are quite similar to those of Magnetopause Boundary Layer Waves. It is speculated that PCBL waves are on the low latitude boundary layer magnetic field lines, but at lower altitudes. Intense PCBL waves are present at this location essentially all (96%) of the time. The most intense waves are detected coincident with the field-aligned currents. The wave intensities in electric and magnetic components follow power laws approximately. High resolution data show "magnetic noise bursts" and three types of intense electric signals , namely, solitary bipolar pulses, lower hybrid waves, and narrow-band waves near electron plasma frequency. Some theoretical models for the fine structures of the PCBL waves will be discussed.

ON ION-CYCLOTRON RESONANCE HEATING OF CORONAL FUNNELS AND HOLES

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In the past years strong efforts were made to explain the observed (with SOHO) extreme ultraviolet emission-line widths (broadenings or equivalent temperatures) and Doppler shifts (speeds) of heavy ions as the result of heating and acceleration by high-frequency waves in the solar corona. Novel models for coronal funnels and holes were developed to explain these observations on the basis of multi-fluid equations and kinetic equations for the resonance of ions with cyclotron waves. This paper summarizes some of these recent results and addresses key plasma physics issues related to the problem of wave energy absorption and transport, and to the evolution of the distribution functions of the particles and spectra of the waves. Apparently, a key role in the wave-particle kinetics is played by pitch-angle diffusion in the wave frame, in association with plateau formation in the velocity distribution functions, for which evidence is found in old in-situ observations of solar wind protons (from the Helios plasma measurements) as well as in recent numerical simulations of heavy ions (such as from oxygen or iron). The physics of the wave-particle processes is discussed in the light of the existing data and predictions of quasi-linear theory.

MHD-TURBULENCE DRIVEN BY LOW-FREQUENCY WAVES AND REFLECTION FROM INHOMOGENEITIES: THEORY, SIMULATION AND APPLICATION TO CORONAL HEATING

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affiliation?

In a number of space and astrophysical plasmas, turbulence is driven by the supply of wave energy. In the context of incompressible magnetohydrodynamics (MHD) there are basic physical reasons, associated with conservation of cross helicity, why this kind of driving may be ineffective in sustaining turbulence. Here we investigate some basic requirements for sustaining steady turbulence and dissipation in the context of incompressible MHD in a weakly inhomogeneous open field line region, driven by supply of unidirectionally propagating waves supplied at a boundary. While wave driving itself cannot sustain turbulence, the addition of reflection permits sustainment. Another issue is that the nonpropagating or quasi-two dimensional part of the spectrum is particularly important in setting up a steady cascade. Thus, details of the wave boundary conditions also affect the ease of sustaining a cascade. Supply of a broad band spectrum of waves can overcome the latter difficulty but not the former. Implications for coronal heating and other astrophysical applications, as well as simulations, are suggested.

COHERENT POTENTIAL STRUCTURES INDUCED BY BEAM INSTABILITIES IN PLASMAS

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We performed electrostatic particle simulations with beams of electrons and ions. In the presence of beams of electrons and ions with a relative drift velocity, there occurs the Buneman instability. We varied thermal velocities of electrons and ions, and found that nonlinear evolutions of the instability are very different depending on these parameters. A large sinusoidal potential is formed initially by the instability, and it traps the electrons and ions, depending on the magnitude of the potential and the thermal velocities of beam electrons and beam ions. Trapping of electrons and ions leads to formation of isolated potentials called electron holes and ion holes, respectively. Under some conditions both electron and ion holes coexist, and they interfere with each other. We classify the final states of these nonlinear evolutions, and clarify the necessary conditions for them. Next we performed another set of simulation runs assuming two ion beams and one electron beam. The interaction of two streaming ion beams generates large potential structures, which traps the electron beam. In addition to the competing processes between electron and ion holes, we found a case where large potential structures are formed as a result of strong coupling of electron and ion holes. A variety of coherent potential structures can result from these electron / ion beam instabilities in a simple model of one-dimensional electrostatic system with periodic boundaries. Their spatial structures and stability can be different depending on the dimensions and boundaries of the simulation system.

THEORY OF HF-DRIVEN PARAMETRIC DECAY IN THE PRESENCE OF A MAGNETIC-FIELD-ALIGNED DUCT

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In ionospheric HF interaction experiments, when Incoherent Scatter Radars are used for diagnostics, there is an important observability aspect. It is a trade-off between radar-line-of-sight, HF polarization, and angular width of the excited Langmuir turbulence spectrum. Observability has often been better than expected. In order to explain this, it was long ago proposed (Muldrew 1978) that the angular width of the turbulence spectrum is increased by refraction in plasma density irregularities. These are assumed to be magnetic-field-aligned and to be plasma density depressions; they are known to occur as a result of the HF exposure, and are often referred to as "striations". In this work, we shall refer to them as "ducts", associating to their function as wave guides.

We have developed a version of the theory of the parametric decay of an HF wave into a Langmuir wave and an ion-acoustic wave in the presence of a duct. The process becomes decay into discrete duct modes. Our method of analysis is of Galerkin type, using eigenfunctions of the electrostatic eigenvalue problem, which has a somewhat peculiar Hermitian structure. We arrive at a formula for the growth rate depending on the average of the ion-acoustic response function over the spectrum of the corresponding normalized eigenfunction. Several such duct modes are simultaneously excitable in the sense of having positive growth rate.

Emphasis will be on the method of analysis. But, in addition, results of a numerical solution of the damped and driven Zakharov system with inclusion of pre-existing ducts, will be shown. This will show that the excitable modes are excited and co-exist even if they have slightly different growth rates, and that observability will be improved, as expected.

CAVITATION OF LOWER HYBRID WAVES IN THE EARTH'S IONOSPHERE

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Localized electrostatic wave packets in the frequency region of lower hybrid waves have been detected by the instruments on the FREJA satellite and earlier also by instrumented rocket payloads. These waves are often associated with local density depletions, indicating that the structures can be interpreted as wave filled cavities which are strongly elongated along the magnetic field. The basic features of the observations are discussed, providing a survey of the conditions for occurrence and spatial distributions. The basic properties of the individual cavities and associated fluctuating electric fields are discussed, as well and typical densities, widths and other characteristics obtained for selected orbits. Possible physical processes forming the observed cavities are discussed.

A COMPARISON OF SOLITARY STRUCTURES OBSERVED ON THE CLUSTER AND POLAR SPACECRAFT

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The Cluster and Polar spacecraft are polar-orbiting spacecraft that contain Wideband Receivers for detecting plasma waves with high time resolution in the frequency range of about 25 Hz to 580 kHz. There are similar receivers located on all four of the Cluster spacecraft, as well as on the Polar spacecraft. On both spacecraft the data are directly downlinked to the ground at 220 kbits/sec. These data are used to study electric field structures, or electron phase-space holes, that move along earth's magnetic field lines. The electric field structures are identified in the data by a characteristic bipolar or unipolar pulse that occurs over short time periods, characteristically a few hundred microseconds to one millisecond. We compare the structures as observed on Cluster to those observed on Polar in similar regions. In addition we examine measurements of the solitary structures that are obtained simultaneously on up to four Cluster spacecraft to better understand their propagation and spatial characteristics. Where possible, particle data will be examined for any evidence of local heating and acceleration by these structures.

RADIATING ELECTRON HOLES AS THE CAUSE OF AKR FINE STRUCTURE

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We present evidence for the presence of nonlinear electron acoustic waves or electron holes in the Auroral Kilometric Radiation (AKR) source regions. The data recorded by the FAST satellite show that the edges of the downward acceleration region, are characterized by the presence of two electron populations : a dominant hot (keV) component and a minority cold (a few 10 eV) component. At these edges, electron acoustic waves are very strongly excited reaching amplitudes of up to 1 V/m. The nonlinear electron acoustic waves form intense wave packets and are modulated by ion acoustic waves. These structures are electrostatic and propagate along the magnetic field at speeds ranging from several 10 km/s up to a few 100 km/s. They are the ultimate result of a parallel electric field in the upward auroral current region, they may, however , themselves self-consistently contribute to the generation of large scale parallel electric fields.

Using high-resolution wave tracker data of the FAST satellite, we investigate the properties of the frequency and time fine structure of AKR and demonstrate that a considerable fraction of the emission consists of a large number of elementary radiation events which we interpret as the signature of the interaction of localized electron acoustic waves (electron holes) with the horseshoe particle distribution. The elementary radiation events have their source in the spatially localized wave structures which are located at the edges of the auroral upward current density cavity. Observation of fine structure of this kind provides information about the local dynamics of the auroral zone turbulence. In particular, it provides an indication of the existence of layers - with a few kilometers extension along the magnetic field - carrying parallel electric potential drops.

"OSCILLITONS" – A NEW TYPE OF SOLITON IN BI-ION PLASMAS

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It is well established that the addition of a second ion population into a proton-electron plasma gives rise to new low-frequency wave modes. Here we investigate stationary structures streaming with sub-fast speed in such a bi-ion plasma. It is shown that a new type of stationary structure occurs as result of mode splitting effects caused by the second ion population. These so-called oscillitons are characterized by an oscillating spatial structure superimposed on the spatial growth or decay associated with the usual single-ion solitons. Examples of the solution of the full non-linear equations describing stationary bi-ion flows are given which show that oscillitons may contribute to a better understanding of diverse low-frequency phenomena observed in the mass loaded plasma environments of Mars, Jupiter and comets. A similar type of soliton should exist in the high-frequency range on scales of Debye lengths if the plasma contains two electron populations.

SIMULATION OF LANDAU DAMPING OF NONLINEAR ALFVEN WAVES

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Nonlinear Landau damping of the ion-acoustic-like oscillations created due to ponderomotive coupling of Alfven harmonics in finite beta plasma was studied numerically. Two types of nonlinearity were taken into account (i) the weak nonlinear motion of plasma bulk particles that leads to mode coupling and ion-acoustic quasi-mode formation and (ii) strong nonlinearity of resonant particles that are responsible for the Landau dissipation. The dynamics of nonlinear Alfvén wave packet as well as the particle distribution function was studied.

HEAVY ION ACCELERATION AND HEATING IN THE SOLAR CORONA

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The problem of resonant cyclotron wave-particle interaction in the divergent solar wind can be described as having two spatial scales (i) the characteristic scale of wave-particle interaction, that is on the order of several ion gyro radii (microscopic scale) and (ii) the inhomogeneity scale, that is of the order of the solar radius (macroscopic scale), the latter is larger than the former. For more than twenty years the problems of particle heating and acceleration were treated by either application of the homogeneous quasi-linear diffusion or by direct particle simulation. In both cases the obtained solutions were strictly applicable only to small regions, with scales comparable or only slightly exceeding the scales of the homogeneous quasi-linear relaxation, and no large scale solutions were presented. We developed an approach that describes the macroscopic evolution and takes into account macroscopic consequences of fast wave-particle interaction without going into details of a microscale process. Our model is based on a scale separation between the characteristic scales of wave-particle interaction and scales of inhomogeneity. Because of a large difference between the scale of quasi-linear interaction and the inhomogeneity scale, the relaxation process looks like a slow wave on the ion distribution function, that moves along parallel (to the magnetic field) velocity, due to slow change of the solar wind parameters. On the front of this wave, an instant pitch angle diffusion of the solar wind ions takes place at every distance. Using this model, we investigated the acceleration processes in the solar wind that are based on resonant interaction of the solar wind ions with left-hand and right-hand polarized MHD waves propagating along the magnetic field in outward direction. We claim that due to interaction with Alfven waves heavy ions acquire parallel velocity on the order of that explain their preferential acceleration. There is a gap between the maximum ion resonant velocity for left-hand polarized waves and the minimum resonant velocity for right-hand polarized waves, where there are no waves. Ions should overcome the gap to have a complete spherical shell distribution function and to acquire parallel velocity along the magnetic field. We investigated possible mechanisms that can bridge the gap. These include mechanisms that work in the homogeneous solar wind, such as resonance broadening and mirroring on long-wavelength MHD perturbations. An additional mechanism, caused by energy transformation from perpendicular to parallel motion of ions in the inhomogeneous magnetic field of the divergent solar wind, was also studied. Numerical simulations have shown that the average parallel velocity acquired by the heavy ions follows the Alfven velocity as a function of the distance from the sun. We investigated stability of the shell distribution function on macroscopic scales and have shown that the ion shell-like distribution function, created due to interaction with waves with larger phase velocities at small distance, was unstable with respect to interaction with waves with smaller phase velocities at larger distances. We investigated numerically the transformation of the ion distribution as function of the distance from the sun.

THREE-DIMENSIONAL STRUCTURES OF ELECTRON HOLES IN MAGNETIZED PLASMAS

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Satellite observations have indicated differing shapes and sizes of electron holes (e-holes) depending on the magnetization of the electrons in the plasma. We have done a simulation study on the electron hole structure by varying the ratio (R) of the electron cyclotron frequency (f_{ce}) to the electron plasma frequency (f_{pe}). The simulations were performed using a three-dimensional particle-in-cell (PIC) code. In order to simulate a large volume of plasma, the PIC code was parallelized using domain decomposition along the magnetic field direction (z). The plasma was driven by an electron beam. For a relatively small beam velocity, the initially driven high-frequency (HF) waves evolve into electron hole structures. When $R = f_{ce}/f_{pe} < 1$, the electron hole structures are generally elongated in the direction transverse to the magnetic field and they have parallel scale length ($\ell_{\|}$) of a few Debye lengths. If the perpendicular scale length is $\ell_{\perp}$, $\ell_{\perp} \gg \ell_{\|}$ for $R < 1$, making the e-hole structure like a disc. On the other hand, if $R > 1$, and especially when $R > 2$, the initial HF waves evolve into electron holes of a variety of shapes and sizes; i.e., it is possible to have e-holes with $\ell_{\perp} \gg \ell_{\|}$ and $\ell_{\perp} \sim \ell_{\|}$. The e-holes having $\ell_{\perp} \gg \ell_{\|}$ undergo a modulational instability. The modulational instability is associated with radiation of long wavelength electrostatic whistler waves. This instability fragments them into e-holes with $\ell_{\perp} \sim \ell_{\|}$. Such e-holes radiate lower hybrid waves. In the late stage of the simulations, the plasma is dominated by lower hybrid waves with very short perpendicular and long parallel wavelengths.

ELECTRON HOLE AS AN ANTENNA RADIATING PLASMA WAVES

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Electron holes (e-holes) are moving space charge in a magnetized plasma. It is well known that a fast moving charge in a plasma radiates plasma waves if the velocity of the charge satisfies the condition for Cerenkov radiation. This idea is applied to study the waves generated by an electron hole. A linear analysis is performed. It is shown that when the e-hole structure has a long scale length perpendicular to the magnetic field such that $\ell_{\perp} \gg \ell_{\|}$, the parallel scale length of a few Debye lengths, the electron hole radiates plasma waves near the electron plasma frequency (f_{pe}). When $f_{pe} \ll f_{ce}$, the electron cyclotron frequency, such waves are electrostatic whistler waves. They cause modulation in the perpendicular structure of the electron hole as seen in 3-D simulations. On the other hand, when $\ell_{\|} \sim \ell_{\perp}$, the electron hole is seen to be an effective radiator of lower-hybrid waves. These features of an electron hole are the consequence of the Fourier spectrum of the wave number components present in the structure of the e-hole. Radiation resistance of the e-hole structure is calculated. The results of the linear analysis are useful in developing a better understanding of the results from numerical simulations.

DO THE DENSITY CAVITIES ASSOCIATED WITH THE LOWER HYBRID SOLITARY (LHS) STRUCTURE BELONG TO SHORT WAVELENGTH INERTIAL ALFVÉN WAVES?

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Recently Hoymark et al., [2000] reported statistical behavior of lower hybrid solitary (LHS) structures. One of the noteworthy results of the statistical study was on the perpendicular size ($\ell_\perp$) of the density cavities associated with the LHS structures. The typical value of was found to be about 30 m; there was a lower cutoff at about 15 m. On the high side, the $\ell_\perp$ was limited to the collisionless skin depth λ_s; that is, $\ell_\perp \leq \lambda_s$. In addition, it was reported that the LHS structures moved across the Earths magnetic field lines with a velocity km/s. We find that these features of the LHS structures match nicely with the scale lengths and group velocity given by the inertial Alfven wave dispersion relation, especially in the electrostatic limit ($\ell_\perp \leq \lambda_s$) in which the waves have significant density perturbations. The inertial Alfven waves could be driven by the LH waves, as demonstrated in the electrostatic limit by 3-D particle-in-cell simulations of electron beam driven waves [Singh et al., 2001].

1. Hoymark et al., Cavitation of lower hybrid waves in the Earths ionosphere, J. Geophys. Res., 105, 18,519, 2000.

2. Singh, N., et al., Evolution of electron beam generated waves resulting in transverse ion heating and filamentation of the plasma, J. Geophys. Res., in press, June 2001.

CHAOTIC IONS AND ELECTROSTATIC ION WAVES

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It is well known that low-amplitude oblique electrostatic ion waves can produce chaotic ion motion in magnetized plasma. Here we consider the effect that these chaotic ions have on the energy density and dispersion relations of the ion waves that produce chaotic motion. Detailed measurements of the ion distribution function are used to quantify the presence of chaotic ions, the wave dispersion relations, and the wave energy density as well as their interactions. Even a small number of suprathermal ions can produce significant effects on the wave energy densities as well as the dispersion relations. Branches of the electrostatic dispersion relation which are strongly damped for maxwellian velocity distributions, can become weakly damped if there are suprathermal ions. In addition to linear waves, low amplitude BGK waves are also observed.

THE SMALL AMPLITUDE OF DENSITY TURBULENCE IN THE INNER SOLAR WIND

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Measurements of the amplitude of MHD turbulence in the inner solar wind, here defined as the region between the outer corona and the perihelion of the Helios spacecraft ($\simeq 60R_{\odot}$), are important in assessing wave-driven models of the solar wind. Such measurements show the energy density of turbulence available for heating and acceleration, or at least the portion which has survived dissipation in the inner corona. Radio propagation observations provide such information on the amplitude and spatial power spectrum of density fluctuations in the inner solar wind. In this talk, I discuss the interpretation of measurements of fluctuations in the phase of a Very Long Baseline Interferometer due to moving density turbulence in the solar wind. These measurements, made with the interferometer of the Istituto di Radioastronomia of the Italian Centro Nazionale delle Richerche, yield a quantity C_N^2 which is proportional to the variance of the electron density fluctuations. Other observations, primarily radio, yield information on the mean plasma density in this part of space. Comparison of these measurements yields an estimate for the *modulation index* $\epsilon_n^2 \equiv \langle(\delta n)^2\rangle/\bar{n}^2$. These new observations, on two lines of sight through the inner solar wind, indicate that ϵ_n is in the range of 0.077 to 0.167 at heliocentric distances of $22-26R_{\odot}$. This modulation index is lower than encountered in studies of turbulence in the interstellar medium, and indicates that either (1) the turbulence in this part of space is quite weak, or (2) the turbulence is strong, but close to incompressible. I will argue that ϵ_n is likely to be a proxy for a similar variable describing magnetic field fluctuations, ϵ_b, and velocity fluctuations ϵ_v. If this is the case, interpretation (1) above is the correct one. I will discuss the implications for wave-driven models of the solar wind.

BROADBAND LOW-FREQUENCY TURBULENCE AND ITS ROLE IN THE ION AND ELECTRON ACCELERATION

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Broadband low-frequency waves are observed in all active regions in the magnetosphere, and are associated with field-aligned electron acceleration and transverse ion heating. Recent results from FREJA, POLAR and CLUSTER indicate that these broadband waves are composed mainly of Doppler shifted dispersive Alfven waves with perpendicular scales between ion gyroradius and electron inertial length. We shall present observations of turbulent fields in various regions of the magnetosphere (auroral zone, boundary layer, magnetopause) and discuss the particle acceleration mechanisms. The electron acceleration is related to the parallel electric field of thes waves, while the ion energization is most likely produced by orbit randomization on small scale electric field structures which make the broadband turbulence.

DIRECT NUMERICAL EVIDENCE OF ALFVÉN-WAVE FILAMENTATION IN DISPERSIVE MHD

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The three-dimensional dynamics of a small-amplitude monochromatic Alfvén wave propagating along an ambient magnetic field is simulated by direct numerical integration of the Hall-MHD equations. As predicted by the two-dimensional nonlinear Schrödinger equation or by more general amplitude equations retaining the coupling to low-frequency magnetosonic waves, the transverse instability of the pump leads to wave collapse and formation of intense magnetic filaments, in spite of the presence of competing, possibly linearly-dominant, instabilities that in some instances distort the above structures. An important role in a possible early arrest of the collapse is played by quasi-transverse instabilities that drive magnetosonic waves and prescribe the eventual directions of the filaments. As the pump amplitude is increased, the enhancement of the magnetic field intensity is strongly inhibited, but strong gradients nevertheless develop. For moderate amplitudes, helical magnetic filaments form, with a flattened cross section and a pitch equal to the pump wavelength. These structures get fragmented in a more nonlinear regime. When averaged along the longitudinal direction, the transverse flow is almost incompressible and its dynamics governed by the forced reduced-MHD equations.

AURORAL ZONE PLASMA WAVES

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The various wave modes and instabilities will be briefly reviewed with attention placed on wave modes/structures that might be important for ion heating.

INTERPLANETARY NONLINEAR ALFVEN WAVES

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We use Ulysses solar polar magnetic field and plasma data to show that Magnetic Holes (MHs) and Magnetic Decreases (MDs) are the results of the evolution of nonlinear Alfven waves. Alfven waves also exhibit phase steepening. Thus Alfven waves are both dissipative and compressible. If most "rotational" and "tangential" discontinuities are products of such wave evolution, it can now be understood why there are very few "ideal" RDs and TDs. RDs typically have magnetic magnitude changes and TDs typically have some normal field components across them. The idea that RDs and TDs detected in interplanetary space are parts of steepened nonlinear Alfven waves explains why directional discontinuities (DDs) have both rotational and compressional properties.

QUASI-LINEAR THEORY OF CYCLOTRON RESONANCE AND ITS APPLICATION TO SOLAR WIND HEATING AND ACCELERATION

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The quasi-linear theory for the resonance of ions with cyclotron waves was developed three decades ago, and a great effort has been made to use this theory to explain the solar wind heating and acceleration. However, these applications have led also to problems and not been entirely successful. The major problem is how the wave energy of solar origin is transferred and converted to thermal energy of the solar wind protons and heavy ions, especially of the core (in phase space) protons. We have made a systematic study of this issue and indeed some progress. Firstly, we derived from the equation of diffusion in velocity space the total energy conservation law, by a sum of the wave energy over the power spectrum and of the kinetic energy over the resonant particles in velocity phase space, under the condition that the absolute value of the wave growth rate is much smaller than the wave frequency. Secondly, we developed a model based on the quasi-linear theory of cyclotron resonance. The full set of anisotropic multi-fluid equations, including the heating and acceleration rates as determined by cyclotron-wave resonance, is solved self-consistently together with the spectral transfer equation for Alfvn and cyclotron waves. In this way, conservation of the total wave and particle energy is automatically guaranteed. Thirdly, by help of the model calculations we found that, if a yet unknown mechanism can transfer energy to waves at high frequencies in resonance with the core protons, and thereby maintain the rigid slope of a power-law spectrum, then the model results can somehow match the UVCS observations. However, the required amplitude of the wave spectrum is very small, and the damping rate of the waves is very high. It seems not easy to find a real mechanism doing the job required by the unknown one. Fourthly, if the unknown mechanism can transfer the kinetic energy of the resonant particles to the non-resonant ones and keep the distribution function a drifting bi-Maxwellian, then the model shows that the spectrum drops at a frequency much lower than the proton cyclotron frequency, and that the initially large thermal anisotropy (like the temperature anisotropy of the O+5 ions observed by UVCS) creates an instability and decreases abruptly. Finally, we propose a new way for the spectral transfer of wave-energy to the core protons. The initial waves of solar origin resonate with those protons having a large inward speed and thus make them form a plateau with zero pitch-angle gradient. These protons cannot be resonant with the later coming cyclotron waves, which thus survive until they are resonant with the core protons. This scenario seems to solve the problem of how wave energy is transferred to the core protons and explain the observed thermal anisotropy.