Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PEM29-01 Room:503 Time:April 30 09:00-09:25

Spontaneous excitation of Alfven waves and their interactions with high-energy ions in a magnetic mirror configuration

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In laboratory fusion plasmas, high-energy ions are produced with DD and DT fusion reactions and are also created with high-energy neutral beam injection and electromagnetic waves for plasma heating. Special emphasis is given to plasma waves excited by such high-energy ions and their interactions with particles. For example, energetic alpha particles produced with DT fusion process can interact resonantly with shear Alfven waves during slowing-down process, and excite plasma instabilities, that is, so-called Alfven eigenmodes (AEs). Recently, enhancement of energetic ion transport caused by these instabilities has been remarked on its deleterious effects. When a small fraction of alpha particles is transported to the first wall in burning plasma devices, plasma facing materials can be damaged seriously. Many kinds of the experimental observations related to such wave-particle interactions are reported. In this report, spontaneously excited waves in Ion Cyclotron Range of Frequency (ICRF) and their interactions with high-energy ions in a mirror magnetic field configuration are presented.

The ICRF waves are frequently used for the plasma heating in laboratory fusion devices with the mirror magnetic field configuration. When the ICRF power and consequent wave energy levels are increased, it will become important to understand the detailed physics of wave-wave and wave-particle interactions. It is required to consider both linear and nonlinear processes for deposition of ICRF powers. In the ICRF heating experiments on the GAMMA 10 tandem mirror, the maximum ion temperature in the perpendicular direction has reached 10 keV and the temperature anisotropy (which is defined as the temperature ratio of perpendicular to parallel to the magnetic field line) becomes more than 10 in the central cell. Alfven-ion- cyclotron (AIC) waves are spontaneously excited owing to such the strong temperature anisotropy. The excitation of the AIC wave is one of the common physical phenomena in space plasmas with an anisotropic velocity distribution. High energy ions, of which energy is more than 50 keV, have been observed along the magnetic field line at the open end of the mirror magnetic field configuration. The transport of high-energy ions along the magnetic field line owing to the loss processes other than the classical Coulomb scattering has been suggested. The existence of considerable energy transport along the magnetic field line owing to the AIC waves is discussed theoretically. The AIC waves in GAMMA 10, which has several discrete peaks in the frequency spectrum, are excited as eigenmodes. Their spatial structures are measured with a microwave reflectometer inside the plasma and magnetic probes in the peripheral region. Low-frequency fluctuations around 0.1 MHz, which is a differential frequency between discrete peaks of the AIC waves, are observed in the central cell. These fluctuations are also observed in the high-energy ion signal detected by a semiconductor detector installed at the end for measuring ions along the magnetic field line. Pitch angle scattering in the velocity space owing to the spontaneously excited Alfven waves are indicated. The radial transport of high-energy ions owing to the low-frequency MHD instability has been observed, however, the transport across the magnetic field line owing to the AIC waves has not yet been detected.

Observations of spontaneously excited waves in ICRF in the large tokamak experiments are also reported as Ion Cyclotron Emissions (ICE). The fluctuations in ICRF are driven by the presence of non-thermal ion distribution in magnetically confined plasmas and plasmas with the strong anisotropy. Waves owing to fusion products of ^{3}He and T ions are clearly detected in D-plasma and alpha particles in DT-plasma experiments.

Keywords: magnetic mirror configuration, Alfven wave, wave-particle interaction, Alfven Ion Cyclotron wave

PEM29-02 Room:503 Time:April 30 09:25-09:45

Nonlinear wave particle interaction of electromagnetic ion cyclotron wave

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Spacecraft observations and simulations show generation of coherent electromagnetic ion cyclotron (EMIC) triggered emissions with rising-tone frequencies. In the inner magnetosphere, the spontaneously triggered EMIC waves are generated by the energetic protons with large temperature anisotropy. We reproduced EMIC triggered emissions in the Earth's magnetosphere by real scale hybrid simulations with cylindrical magnetic geometry. We perform parametric analyses of electromagnetic ion cyclotron (EMIC) triggered emissions on the gradient of the non-uniform ambient magnetic field using a hybrid simulation. According to nonlinear wave growth theory, as the gradient of the ambient magnetic field becomes larger, the theoretical threshold of the wave amplitude becomes larger although the optimum wave amplitude for nonlinear wave growth does not change. With a larger magnetic field gradient, we obtain coherent rising tone spectra because the triggering process of the EMIC triggered emission takes place only under the limited condition of the wave amplitude. On the other hand, with a smaller magnetic field gradient, triggering of the emissions can be caused with various wave amplitudes, and then the sub-packets are generated at various locations at the same time. The concurrent triggerings of emissions result in incoherent waves, observed as "broadband" EMIC bursts. Broadband emissions induce rapid precipitation of the energetic protons into the loss cone since the scattering by the concurrent triggering takes place faster than that of the coherent emissions. The coherent triggered emission causes efficient proton acceleration around the equator because of the stable particle trapping by the coherent rising tone emission.

Keywords: triggered emission, electromagnetic ion cyclotron wave, wave particle interaction, acceleration, scattering

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PEM29-03 Room:503 Time:April 30 09:45-10:00

Solar energetic particle spectrum at the Sun and the Earth

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It is well accepted that high-energy solar energetic particles are accelerated at reconnection regions in a solar flare and coronal shock waves driven by a coronal mass ejection. The coronal shock waves accelerate particles through the first-order Fermi process. The original Fermi acceleration theory predicts a power law particle distribution in momentum with index depending on shock compression ratio. Solar energetic particle spectra have been well investigated and it is found that the observed spectra are represented by almost power law (with high energy rollover). This looks like natural results at first glance. However, the observed spectrum is the spectrum at the observation location not at the acceleration site, and it is not trivial if the observed spectrum is as same as the source spectrum. There are some evidences that typical observed power law index will be about 6 in ground level enhancement (GLE). If the source spectrum of accelerated particle at a coronal shock is assumed to be as same as observed one, a compression ratio of the coronal shock accelerating particles should be about 1.6 according to the Fermi acceleration theory. This shock strength may not be enough to accelerate particles to GeV energy range in a short time. This implies that the spectrum at the source may not be as same as one at the observation location. While a power law spectrum predicted by Fermi process is a steady state solution, a lot of study show that a shock accelerated particle spectrum is time dependent manner. This fact may also imply a different spectrum between at the Sun and at the Earth. In this study, we investigate an energetic particle spectrum difference between at the source region and at the observation location by the interplanetary particle transport simulations.

Keywords: Solar energetic particles, Spectra

PEM29-04 Room:503 Time:April 30 10:00-10:15

Coupling between ULF waves and high-energy particles in the inner geomagnetosphere based on a drift-kinetic simulation

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Understanding of acceleration mechanisms of electrons to cause drastic variation of the Earth's outer radiation belt is one of outstanding issues of the geospace researches. While the radial diffusion of the electrons driven by ULF waves has been considered as one of the candidate mechanisms, efficiency of the mechanism under realistic ULF characteristics and distribution is far from understood. GEMSIS (Geospace Environment Modeling System for Integrated Studies) of STEL, Nagoya University, is the observation-based modeling project for understanding energy and mass transportation from the Sun to the Earth in the geospace environment. The GEMSIS-Magnetosphere working team has developed a new physics-based model for the global dynamics of the ring current (GEMSIS-RC model). The GEMSIS-RC model is a self-consistent and kinetic numerical simulation code solving the five-dimensional collisionless drift-kinetic equation for the ring-current ions in the inner-magnetosphere coupled with Maxwell equations. In contrast to previous ring current models assuming a force-balanced equilibrium, the new model allows the force-imbalance to exist, which generates induced electric field through the polarization current. The most prominent advantage of the new model is the capability of describing fast time scale phenomena such as injections during substorms and MHD-time scale (ULF) waves.

We applied the GEMSIS-RC model for simulation of global distribution of ULF waves. Comparison between runs with/without ring current ions show that the existence of hot ring current ions can deform and amplify the original sinusoidal waveforms. The deformation causes the energy cascade to higher frequency range (Pc4 and Pc3 ranges). The cascade is more pronounced in the high beta case. It is also shown that the existence of plasmapause strengthens ULFs outside the plasmapause and widens the MLT region where the E_r (toroidal) component is excited from initially-given E_{phi} (poloidal) component. We also report the basic characteristics of the ring current driven ULF waves and its effects on the electron transport in the inner magnetosphere.

Keywords: drift-kinetic approximation, ring current, radiation belt, MHD wave, inner magnetosphere, drift resonance

PEM29-05 Room:503 Time:April 30 10:15-10:30

Radiation spectra from relativistic electrons moving in a Langmuir turbulence

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We examine the radiation spectra from relativistic electrons moving in a Langmuir turbulence expected to exist in high energy astrophysical objects by using numerical method. The spectral shape is characterized by the spatial scale λ, field strength σ, and frequency of the Langmuir waves, and in term of frequency they are represented by {s:0188$_0$ 2πc/λ, ω_{st} = eσ/mc, and ω_p, respectively. We normalize ω_{st} and ω_p by ω_0 as a $\equiv$ ω_{st}/ω_0 and b $\equiv$ ω_p/ω_0, and examine the spectral shape in the a ? b plane. An earlier study based on Diffusive Radiation in Lang- muir turbulence (DRL) theory by Fleishman & Toptygin showed that the typical frequency is $\gamma^2\omega_p$ and that the low frequency spectrum behaves as Fω戸ω^1 for b >1 irrespective of a. Here, we adopt the first principle numerical approach to obtain the radiation spectra in more detail. We generate Langmuir turbulence by superposing Fourier modes, inject monoenergetic electrons, solve the equation of motion, and calculate the radiation spectra using Lienard-Wiechert potential. We find different features from the DRL theory for a >b >1. The peak fre- quency turns out to be $\gamma^2\omega_{st}$ which is higher than $\gamma^2\omega_p$ predicted in the DRL theory, and the spectral index of low frequency region is not 1 but 1/3. It is because the typical deflection angle of electrons is larger than the angle of the beaming cone ≈ 1/γ. We call the radiation for this case " Wiggler Radiation in Langmuir turbulence " (WRL).

Keywords: Radiation mechanism, Relativistic particle, Turbulent electromagnetic field

PEM29-06 Room:503 Time:April 30 10:30-10:45

Fine Spectral Structures and Their Generation Mechanisms for Solar Radio Bursts Observed by AMATERAS

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The solar corona contains many particle acceleration phenomena that are caused by the interactions between the coronal magnetic field and plasma. Non-thermal electrons accelerated in the corona emit radio waves in the metric range. As a result, many types of solar radio bursts are observed. There are many types of complex fine spectral structures in the solar radio bursts. They are thought to be caused by some inhomogeneity of particle acceleration, wave generation, radio emission, and radio propagation processes. Hence, metric solar radio bursts are very important to understand coronal plasma processes such as the particle acceleration and wave-particle interaction.

The fine spectral structures of solar radio type-I bursts were observed by the solar radio telescope AMATERAS. The spectral characteristics, such as the peak flux, duration, and bandwidth, of the individual burst elements were satisfactorily detected by the highly resolved spectral data of AMATEAS with the burst detection algorithm that is improved in this study. The peak flux of the type-I bursts followed a power-law distribution with a spectral index of 2.9?3.3, whereas their duration and bandwidth were distributed more exponentially. There were almost no correlations between the peak flux, duration, and bandwidth. That means there were no similarity shapes in the burst spectral structures. We defined the growth rate of a burst as the ratio between its peak flux and duration. There was a strong correlation between the growth rate and peak flux. These results suggest that the free energy of type-I bursts that is originally generated by non-thermal electrons is modulated in the subsequent stages of the generation of non-thermal electrons, such as plasma wave generation, radio wave emissions, and propagation. The variation of the time scale of the growth rate is significantly larger than that of the coronal environments. These results can be explained by the situation that the source region may have the inhomogeneity of an ambient plasma environment, such as the boundary of open and closed field lines, and the superposition of entire emitted bursts was observed by the spectrometer.

Keywords: Sun, Solar radio burst, corona, wave-particle interaction, radio emission processes

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PEM29-07 Room:503 Time:April 30 11:00-11:15

Co-evolution of upstream waves and accelerated particles around parallel shocks

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We have investigated the co-evolution of upstream waves and the accelerated particles around the parallel shock. Hybrid particle simulations are performed in the exactly parallel shock configuration with Mach number of ˜10. The upstream waves convecting into the shock surface contribute the particles acceleration as reported in Sugiyama et al. (2001). The appropriate wave-length exists for the particle energization, that is, the longer wave-length wave leads the higher energy particles. Simultaneously, the higher energized particles excite the longer wave-length waves in the upstream region. Here we report that the higher energy particles and longer wave-length waves are observed as the time elapses later in the simulation runs. Therefore, the present process is "co-evolution" of the upstream waves and accelerated particles.

Keywords: collisionless shock, particle acceleration, wave-particle interaction

PEM29-08 Room:503 Time:April 30 11:15-11:30

Colliding Two Oblique Shocks: Shock Structures and Particle Acceleration

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Mechanisms of the particle acceleration at a collisionless shock have been intensively studied analytically, numerically, and observationally. Most of the previous studies assume that energetic particles interact with a single shock. However, shock waves are ubiquitous in space, and two shocks frequently come close to or even collide with each other. For instance, it is observed that a CME (coronal mass ejection) driven shock collides with the earth's bow shock [H. Hietala et al., 2011], or interplanetary shocks pass through the heliospheric termination shock [J. Y. Lu et al., 1999]. The detailed structures of such colliding shocks and the accompanied particle heating/acceleration processes have not been understood.

Cargill et al. [1986] performed one dimensional hybrid simulations to discuss the dynamic structure of colliding shocks and the accompanied ion acceleration. They showed that some ions are efficiently accelerated at the time of the collision of two supercritical shocks. However, since electron dynamics are neglected in a hybrid simulation, the microstructures of the colliding shocks, which may affect the early stage processes of particle acceleration, cannot be resolved.

Here, we perform full Particle-in-Cell (PIC) simulations to examine colliding two shocks. In particular, the following three points interacting with two colliding oblique shocks is discussed in detail.

1. Energetic electrons are observed upstream of the two shocks before their collision. These energetic electrons are efficiently accelerated through multiple reflections at the two shocks (Fermi acceleration). Moreover, a part of the accelerated electrons are farther energized by interacting with increasing magnetic field during the collision and/or one of the shocks after the collision.

2. Before two shocks collide, there is a large amplitude wave excited by electrons flowing out to the upstream. We discuss the excitation mechanism and the influence on particle propagation or shock structures.

3. After two shocks collide, we find that a plasma density and pressure in the downstream is lower than the value calculated by MHD. The reason is that energetic electrons run away to the upstream. In addition to this, we discuss kinetic influences by comparing PIC simulation's results with the value after two shocks collide (magnetic fields, the shock velocity and etc.) calculated by MHD.

Keywords: collisionless shock, multi-shock waves, particle acceleration, numerical simulation

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PEM29-09 Room:503 Time:April 30 11:30-11:45

Particle acceleration in high Mach number quasi-parallel shocks

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We study particle acceleration process of electrons and protons in high Mach number (M_A~30) quasi-parallel collisionless shocks by particle-in-cell (PIC) simulation. We found that a fraction of protons which consist of the plasma are injected into acceleration mechanisms and efficiently accelerated around the shock. The energy spectrum of the accelerated protons becomes power-law like distribution. A part of electrons are also accelerated around the shock although they are roughly two orders of magnitude fewer than the accelerated protons. For both protons and electrons, the acceleration processes are often not diffusive and their time-scales are even shorter than the respective gyration times. We also found that protons reflected at the shock generate circularly polarized Alfven waves with very large amplitude in the upstream region of the shock and that, because of the strong perpendicular magnetic field of these waves, the structure of the collisionless shock itself is in fact similar to that of quasi-perpendicular shocks.

Keywords: particle acceleration, plasma, collisionless shocks

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PEM29-10 Room:503 Time:April 30 11:45-12:00

Particle simulations on electron acceleration at Quasi-Perpendicular Shocks

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We found efficient production of non-thermal electrons up to $\gamma\sim20$ in results of three-dimensional full kinetic simulations of quasi-perpendicular shocks. The seed acceleration occurs in large-amplitude electromagnetic wave excited in the most front region of the shock foot. A small portion of electrons keeps staying in the foot region due to the scattering by the large-amplitude electromagnetic wave, and these electrons can get energy from the motional electric field in the shock rest frame. Since the large-amplitude electromagnetic wave is only possible in 3-D simulations, no electron acceleration is observed in previous 1-D and 2-D simulations. After the seed acceleration, these electrons can be further accelerated at the shock lamp region by the shock drift acceleration. The acceleration process occurs during the steepen phase of the self-reformation, and the acceleration efficiency depends on the phase of the shock self-reformation. In contrast to the standard Fermi acceleration at quasi-parallel shocks, the electron acceleration process at quasi-perpendicular shocks is much quicker (order of the ion cyclotron period); however, electrons cannot experience effective acceleration again and again so that there would be an energy limitation of the acceleration. In this presentation, we will discuss the energy limit of electron acceleration at quasi-perpendicular shocks by using simulation results obtained from the K computer.

Keywords: shock acceleration, particle simulation

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PEM29-11 Room:503 Time:April 30 12:00-12:15

The fast acceleration of particles scattered by MHD wave in parallel shock

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The origin of the galactic cosmic ray is believed to be generated around the supernova remnant shocks (SNR), and the first-order Fermi acceleration is widely recognized as the standard theory of cosmic ray acceleration. Yet this acceleration mechanism is not always efficient enough to explain high energy cosmic ray particles extending to the knee. The maximum attainable energy expected by the first-order Fermi acceleration is less than the observations. To overcome this problem, additional acceleration and/or other efficient acceleration processes are needed.

Scattering process is important to investigate diffusive shock acceleration(DSA). In the previous numerical simulations, scattering is often treated as just numerical way like Monte-Carlo methods or electromagnetic perturbation. Among these researches, a special attention is paid to the particle acceleration for the particles scattered by magnetohydrodynamic (MHD) waves around the shock wave front. In the uniform system, when the wave phases are strongly correlated spatially localized traveling wave packets can efficiently large angle scatter charged particles (*Kuramitsu & Hada, 2000*). The scattering process through monochromatic large amplitude MHD waves around the parallel shock (*Sugiyama et al. 2001*) is regarded as a possible pre-acceleration process injecting the thermal particles into the Fermi acceleration process and the subsequent fast Fermi acceleration process.By extending the previous researches, we study a fast particle acceleration process for MHD turbulence around the parallel shock. By using the test particle simulation, we argue about the particle acceleration in the quasi-linear regime and also about the case of strongly coherent waves and large amplitude waves.

Keywords: acceleration of particles, cosmic ray, shock, Alfven wave, coherence, large amplitude

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PEM29-12 Room:503 Time:April 30 12:15-12:30

On statistics of a plasma in a nonuniform flow

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It is well known that energetic particles such as cosmic rays can efficiently be accelerated by scatterers convected by a compressional flow (Fermi acceleration). Scatterers convected by an expanding flow decelerate the particles, but this is not the reverse process of the acceleration. Plasma in space is never uniform, but is rather composed of different plasmas with different propagation speeds. We analyze statistics of energetic particles in such nonuniform plasma flow analytically and numerically. Results will be compared with non-equilibrium plasma distributions in the solar wind.

Keywords: Fermi acceleration, Nonequilibrium distribution

PEM29-13 Room:503 Time:April 30 14:15-14:30

Helicon wave propagation, mode conversion, and plasma heating

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Helicon plasma is a high-density (number density ~10^{19} /m^3) and low-temperature (electron temperature ~a few eV) plasma generated by the helicon wave, i.e., electromagnetic whistler wave in a bounded plasma. Helicon plasma is thought to be useful for various applications including plasma processing and electric thrusters. On the other hand, there remain a number of unsolved fundamental issues regarding how the plasma is generated. Some of the key processes involved are the wave propagation (dispersion relation), mode conversion, collisional and non-collisional damping and resultant plasma heating, ionization and re-combination of neutral particles due to electrons accelerated by the wave, and modification of the dispersion relation due to addition of newly produced plasma.

In this presentation, as a first step to understand the helicon plasma production mechanism, we study the helicon wave propagation, mode conversion, and the plasma heating. According to Shamrai (1996), the helicon wave is linearly mode converted to an electrostatic Trivelpiece-Gould (TG) wave, which can accelerate electrons efficiently. However, the mode conversion and the production of the TG wave strongly depend on the dissipation included in the plasma. Using fluid and particle-in-cell (PIC) simulations, we discuss the mode conversion efficiency, wave damping, and plasma heating due to wave-particle interactions. We show that direct damping of the helicon waves can play major roles in the plasma heating under circumstances relevant to actual laboratory experiments.

Keywords: Helicon plasma, Helicon wave, TG(Trivelpiece-Gould) wave, Mode conversion, PIC simulation

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PEM29-14 Room:503 Time:April 30 14:30-14:45

Hamilton-Jacobi equation based on exterior derivative

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Analytical Mechanics of fields usually singles out the temporal coordinate as an independent parameter and calculates the time evolution regarding fields as dynamical parameters with infinite degree of freedom. Spatial coordinates are treated as infinit number of indexes of dynamical parameters. This approach has a disadvantage when applied to electromagnetism: the resulting equations are not manifestly covariant. Moreover, when applied to gauge fields, the canonical theory with this approach has extra degree of freedom, which need to be eliminated with some constraints. One must fix the gauge at the price of loosing manifest covariance, or introduce some
complicated technique such as Dirac brackets.

The author reported the way to treat four (time 1 + space 3) parameters equally to construct analytical mechanics at the fall SGEPPS meeting. The expression obtained is manifestly covariant, and there is no need for gauge fixing when applied to gauge fields. The present study is to extend it to Hamilton-Jacobi theory. Also, possible application to the fluid dynamics will be discussed at the presentation.

The name of Hamilton-Jacobi equation is well known by name, however, not many researchers try to understand its detail because it is not quite useful to solve actual problems. However, it is conceptually important for the deep understanding of analytical mechanics. Also, it is essential to introduce quantum mechanics based on the knowledge of classical mechanics.

Several attempts have been made to establish classical mechanics of relativistic fluid dynamics, but fully covariant expressions are yet to come. Kambe (2010) has reported the Euler equation can be cast into the form of Maxwell equation with appropriate definitions of variables. The present study has been successfully applied to the analytical mechanics of electromagnetism, therefore, it may be applicable to fluid dynamics based on Hasimoto's representation.

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Keywords: exterior derivative, analytical mechanics, Hamilton-Jacobi Equation, fluid dynamics