R008-01
Zoom meeting D ：11/3 AM2 (10:45-12:30)
10:45〜11:00

Application of CoToCoA to MHD and micro-scale simulations of the magnetosphere

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CoToCoA (Code to Code Adapter) is the cross-reference framework for macro- and micro-scale numerical codes and is developed by MPI library in the current version (1.1.0). CoToCoA framework can make the data generated by the different simulation codes transferred between those simulation codes easily. The main concepts of CoToCoA are that we do not add modifications to the simulation codes as possible without data transfer and we do not need to know the referred simulation code without data format. These concepts allow for many simulation codes to participate in this framework.

In the Solar-Terrestrial and Planetary study, there are many simulation codes due to the differences of physical scales and numerical calculation methods. To couple these simulation codes is hard since the deeply understanding and much knowledge of codes are required. Considering this situation, CoToCoA seems to be the best way to overcome the difficulty.

In this study, we will show the application of CoToCoA framework to couple the MHD simulation code with microsimulation codes. In particular, we focus on coupling MHD simulation with electro-hybrid and test-particle simulations. The implementations of these coupling using CoToCoA are also shown as the easy implementation is the advantage of CoToCoA.

R008-02
Zoom meeting D ：11/3 AM2 (10:45-12:30)
11:00〜11:15

一様及び正規分布の生成方法再考

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Generation of uniform and normal distributions revisited

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Uniformly distributed random numbers are commonly used in particle-in-cell (PIC) simulations of plasma. It is important to a set of random numbers as uniform as possible for reducing initial thermal fluctuations. In the present study, three sets of uniformly distributed integer numbers are generated, which are then shuffled with sets of uniformly distributed random numbers. Conversion of a uniform distribution to a normal distribution with several inverse transform sampling methods is also discussed.

R008-03
Zoom meeting D ：11/3 AM2 (10:45-12:30)
11:15〜11:30

太陽風プラズマによる月面帯電現象の表面形状への依存性

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Effects of Surface Topography on Lunar Surface Charging Processes in the Solar Wind Plasma

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Since the Moon has neither atmosphere nor intrinsic magnetic field, solar wind plasma precipitates directly onto the lunar surface and forms a complex electrostatic environment. The formation of the electrostatic environment is known to be strongly dependent on the topology and sunlight conditions of the lunar surface. The Moon has a wide range of topographic features, from craters and boulders to surface rocks and regolith layers. In recent years, unique topographic features such as vertical holes have been also identified. The investigation of the unique surface charging properties caused by these irregularities is very important to quantitatively understand the lunar surface environment, which will be a critical issue in future lunar explorations. To address this issue, we study the plasma and electrical environments of lunar cavities by performing particle simulations with different solar wind irradiation angles.

We set up a lunar surface with a cavity in the simulation space, and simulated the solar wind plasma flow and the photoelectron emission from the surface. The simulation results show that the surface charging within the cavity can be understood in terms of additive effects of the solar wind plasma and the photoelectron currents. The solar wind electrons collide with the cavity wall at relatively shallow positions due to their greater thermal motions than ions. Therefore, the proportion of solar wind electrons that approach the bottom of the cavity is small, and the deepest part of the cavity surface will be charged positively. This effect will be moderated as the cavity aperture becomes greater, because it leads to the larger number of solar wind electrons approaching the bottom of the cavity. The photoelectron current basically contributes to the positive charging at the photoelectron release point, which is the well-known behavior. On the cavity wall, however, the emitted photoelectrons substantially transported negative charge to the deepest part of the cavity, modifying the current balance condition with solar wind ions inside the cavity. Actual charging properties inside the cavity will be determined by the combination of the solar wind plasma and photoelectron charge transport effects, which are strongly affected by the lunar topology and solar irradiation angle

月にはほとんど大気が存在せず固有の磁場を持たないため、月面には太陽風プラズマが直接降り注ぎ日照の照射により発生する光電子や月面に蓄積された電荷とともに月表面近傍の静電気環境を形成する。形成される静電気環境は月面の日照条件や表面トポロジーに強く依存していることが知られている。月面はクレーターやボルダーなどの地形から、表面の岩石からレゴリス層に至るまで幅広い空間スケールにわたる凹凸が存在する。近年では数 10 m スケールの縦孔などの特異な地形も発見されている。これらの凹凸に起因する特異な表面帯電特性を調査することは、将来の月面探査の成否を左右する月面環境を定量的に理解する上で極めて重要である。本研究では、粒子シミュレーションを用い太陽風の照射角を変化させた場合の各形状の月面の孔やくぼみのプラズマ・電気的環境を比較し、複雑な形状を有する月面の帯電特性を明らかにする。

本研究ではシミュレーション空間に空洞を開けた月面を設置し、それに対し太陽風プラズマフローと日光照射及びそれに付随する表面からの光電子電流を設定し、シミュレーションを行った。太陽風プラズマによる表面帯電では、太陽風電子とイオン間の熱速度差から、電子はイオンより比較的浅い位置で空洞壁面に衝突し吸収されるため深部まで到達する太陽風電子数は少ない。この結果、空洞が深くなるほど空洞内部電位は高電位となることがわかった。この効果は空洞の口径が小さいほど顕著である。なぜなら空洞口径が大きいと、太陽風電子の壁面衝突が壁面に形成されるシース電場により抑制されるためである。光電子による表面帯電では、基本的に光電子は発生した位置に正電荷を蓄積することから正帯電への寄与を示したが、空洞壁面では放出された光電子による空洞深部への実質的な負電荷輸送が行なわれ、空洞内部での太陽風イオンとの電流バランス条件への寄与を示した。実際の空洞内部の帯電状況は、以上の太陽風プラズマと光電子による電荷輸送効果の組み合わせで理解することが可能であり、これらは月面トポロジーや太陽照射角に強く影響される。

R008-04
Zoom meeting D ：11/3 AM2 (10:45-12:30)
11:30〜11:45

あらせ衛星の直方体形状による衛星電位スピン変調と衛星表面帯電モデルとの比較

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Spin-modulated components in the spacecraft potential distorting the electric field measurement of the Arase satellite

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The Arase satellite measures the electric field with the electric field detector (EFD) of the Plasma Wave Experiment (PWE), employing the Wire Probe Antenna (WPT), which consists of the two dipole antennas of 32 m tip-to-tip with a spherical probe (6 cm diameter) attached at each end of the wires (length: 15 m). The potential difference between a pair of the probes provides the electric field vector, while the instrument also records the floating potential of each probe separately (Vu1, Vu2, Vv1, and Vv2). These antennas are extended orthogonal to the spin axis, which is roughly parallel to the sun direction. Normally, E-field measurements are not much affected by fluctuations of the satellite potential because it can be cancelled by differentiating potentials between two probes. However, we found that the satellite potential has significant spin-modulated components that cause serious impact on the E-field measurement. The purpose of this study is to examine the fluctuation of the satellite potential to identify the characteristics and cause of the spin-modulated component. Waveform analyses of the probe potential show that spin-modulated components appear in the spacecraft potential Vsc calculated as the average of Vu1, Vu2, Vv1, and Vv2. A statistical analysis of this modulation reveals that the spacecraft potential Vsc almost always has four fairly-regular peaks per spin; the peaks appear at specific spin phases when the sun illuminates the satellite from the directions of the four corners of its body. To understand how those potential variations are induced, we simulated the Vsc fluctuation associated with the satellite spin, assuming a simple current balance model for the satellite surface. In this model, the net flux of photoelectrons is proportional to the effective emitting area. The result is that the projected area of the spacecraft to sunlight changes by as much as 20% during a satellite spin and this variation play the main role in the Vsc fluctuations. It is also revealed that this spin modulation of the sun-illuminated area arises because of the cuboid body of the Arase satellite. In addition, five particle instruments (LEP-e, LEP-i, MEP-e, MEP-i, and HEP) equipped on two sides of the body make an asymmetry of 12% in the effective emitting area. We discuss that this spin-dependence of the photoelectron emission quantitatively explains the observed modulation of Vsc.

本発表では、ジオスペース探査衛星「あらせ」の衛星電位のスピン変調成分と衛星本体の形状の関係について報告する。あらせ搭載の Plasma Wave Experiment (PWE) では、 4 本のワイヤアンテナ Wire Probe Antenna (WPT, 長さ 15-m, Tip-to-Tip 長 約 32-m) で衛星とプローブ間の電位 Vu1, Vu2, Vv1, Vv2 を常時測定している。アンテナは衛星スピン面内の直交２系統で、ほぼ太陽に対して垂直に張られている。Vu1, Vu2, Vv1, Vv2 の平均値から衛星電位 Vsc を求めることができるが、常時 Vsc に 0.1 V 程度のスピン変調がみられることがわかった。Vsc のスピン変調は毎スピンに 4 つのピークをもち、ピークのタイミングは衛星固定座標系での太陽位置に依存している。衛星表面帯電モデルを用いて、あらせ衛星本体のスピンによる日照面変化を考慮したところ、衛星本体が直方体であること、および２面に取り付けられている粒子観測機の存在が日照面変化に寄与しており、観測されたスピン変調を非常によく説明することがわかった。

R008-05
Zoom meeting D ：11/3 AM2 (10:45-12:30)
11:45〜12:00

Study on Electric Field Sensor Impedance in Magnetized Plasma by PIC Simulation.

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A dipole antenna has been commonly used as electric-field sensors to observe plasma waves in space plasma. To calibrate electric field measurements, we have been using the assumption that wavelengths are much longer than antenna lengths. However, in the next generation of scientific satellite projects, it is possible that the wavelength is comparable to antenna length, and it significantly affects the interpretation of the observation results. Better understanding of electric field sensor responses to short-wavelength plasma waves is required for evaluating intensities and phases of targeted electrostatic waves.

In this research, we simulated the antenna impedances of electric field sensors in magnetized plasmas over electromagnetic waves with short or comparable wavelengths to the antenna. We conducted full Particle-In-Cell (PIC) simulations with electric field sensors as inner boundaries. The results were evaluated considering the linear dispersion relations in magnetized plasmas.

According to the calculation results, when the wave number of the antenna resonance is large enough, it is estimated that the resonances are seen at the frequencies of the electron cyclotron harmonics, which are frequently observed in the magnetized plasmas. The results show in some situations that at near the Upper Hybrid Resonance (UHR) frequency, one or two peaks of the antenna impedance was observed. When the wave number is small enough, the resonances frequencies are shifted to slightly high. The simulation results suggest that the frequencies at where the resonances were seen are determined by the relationship between the length of the antenna and the dispersion relation of the surrounding plasma.

In the present paper, we discuss the characteristics of electric field sensors in plasmas over plasma waves with short wavelengths that are comparable with lengths of electric field sensors.

R008-06
Zoom meeting D ：11/3 AM2 (10:45-12:30)
12:00〜12:15

ヘリコンプラズマ放電における高密度プラズマへの密度ジャンプ遷移機構の解明

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([1] 九大総理工,[2] 東京農工大

Transition mechanism of the density jump to high-density helicon plasma

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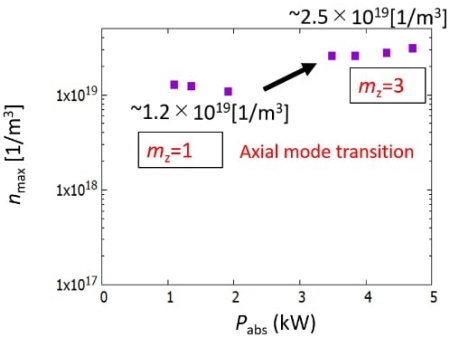
In helicon discharge, abrupt jumps in plasma density, so-called density jumps, are observed as the input power is increased. The transition from a low-density (~10^{16-17} m^{-3}) to high-density (10^{19-20} m^{-3}) plasma is considered to be transition process from Capacitively Coupled Plasma (CCP) to Helicon Plasma (HP) through Inductively Coupled Plasma (ICP). The density jump observed in the ICP production process is known to be the transition from CCP to ICP. However, there is an unclear part in the density jump from the low-density region to the high-density HP. In the low-density region, the electric field consists of the capacitively-coupled component near the antenna, and the inductively-coupled components of the TG (Trivelpiece-Gould) wave which is excited near the antenna and the Helicon wave which penetrates in plasma within its skin depth. The qualitative evaluation of the contributions of these components in the power absorption has not yet be done, and it is unclear whether the low-density plasma is generated by the capacitively coupled component or the inductively coupled component, or the coupling of these components. In practical, it is important to clarify the necessary condition and the trigger for the density jump from the low- to high-density HP by identifying the generation mechanism of the low-density plasma.

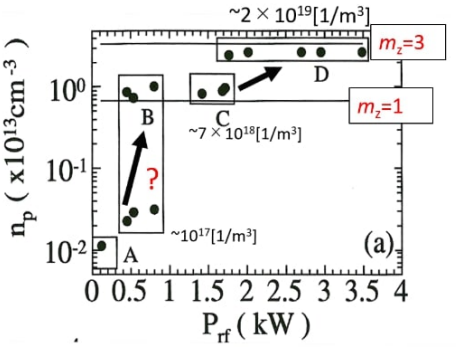
By using 1D model assuming axial uniformity, we have shown previously that the density jump in the high-density region from $1.0*10^{19}$ m^{-3} to $2.5*10^{19}$ m^{-3} is caused by the axial mode transition of helicon wave, which quantitatively explain the experimental results. However, when a low input power is applied, the equilibrium state for the low-density region (~10^{16-17} m^{-3}) is not reproduced by the inductive coupling alone (Fig. 1). Therefore, the process of density jump from the low-density to high-density region (~10^{19-20} m^{-3}) remains unclear. The spatio-temporal evolution and the trigger of the transition process to the high-density HP needs to be clarified for the practical use of HP. In this study, the capacitive coupling component of antenna is included in our model to investigate the density jump from the low- to high-density region. 2D model has also been developed to make comparison with the 1D model.

ヘリコンプラズマ生成において、入力パワーを上げていくと急激に密度が上昇する（密度ジャンプ）現象が観測されている。低密度（~10^{16-17} m^{-3}）から高密度（10^{19-20} m^{-3}）への遷移は、容量性結合プラズマ [Capacitively Coupled Plasma (CCP)] から誘導性結合プラズマ [Inductively Coupled Plasma (ICP)] を経て、ヘリコンプラズマ [Helicon Plasma (HP)] へ遷移する過程であると考えられている。非磁化プラズマ中での ICP 生成過程における入力パワーに依存した密度ジャンプは CCP から ICP への遷移であることがよく知られているが、ヘリコンプラズマ中での低密度領域から高密度 HP への密度ジャンプは未解明な点がある。低密度領域での電場成分としては、アンテナ近傍の容量性結合成分、アンテナ近傍に励起される TG（Trivelpiece-Gould）波とスキン長程度にプラズマ内部に浸透するヘリコン波の誘導性結合成分がある。これらの電場成分のパワー吸収への定量的評価は未だ行われておらず、したがって低密度領域のプラズマ生成が容量結合成分、誘導結合成分どちらによるものなのか、あるいは両者のカップリングによるものなのかは分かっていない。実用上においても、低密度領域におけるプラズマ生成機構を明らかにし、低密度領域から高密度 HP へ遷移するための条件とそのトリガー機構を解明することが求められる。

これまでの我々の軸方向一様性を仮定した 1 次元数値計算では、高密度領域における 1.0×10^{19} m^{-3} から 2.5×10^{19} m^{-3} 程度への密度ジャンプはヘリコン波の軸方向モード遷移により起こっていることが確かめられており、実験結果を定量的に説明できている。しかしながら低い入力パワーを印加した場合、低密度領域（~10^{16-17} m^{-3}）に対する平衡状態は誘導性結合成分のみを考慮したモデルでは得られていない (図 1)。したがって低密度から高密度領域（~10^{19-20} m^{-3}）への密度ジャンプ過程は未解明である。本研究では、低密度領域から高密度領域への密度ジャンプ過程を調べるため、これまで考慮に入れていなかったアンテナの容量性結合成分を含めた計算を行う。さらに 2 次元モデルを構築し、1 次元モデルとの比較も行う。



S. Isayama et al., Phys. Plasmas, **26** 053504 (2019).



M. Nisoa et al., Jpn. J. Appl. Phys. **38**, L777 (1999).

R008-07
Zoom meeting D ：11/4 AM1 (9:00-10:30)
9:00〜9:15

A new global multifluid MHD model with the cubed sphere focusing on Martian ionosphere and magnetosphere

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It is a controversial question how presence of an intrinsic magnetic field affects escape of the ionized atmosphere, i.e., ion escape. In particular, the intrinsic magnetic field of ancient Mars suggested by crustal magnetic fields on the surface might have played a crucial role in atmospheric loss and climate change. Sakata et al. (2020) pointed out that the effects of an intrinsic magnetic field are pronounced in ion escape from the ionosphere which is the main escape process of molecular ions such as O_2^+ and CO_2^+. On the other hand, the effects on O^+ are milder due to the contribution of ion pickup on the neutral oxygen corona. This indicates that different ion species or escape processes have different dependences on the intrinsic magnetic field. However, the study was based on multispecies magnetohydrodynamics (MHD) simulations which assume the same velocity on all ion species and cannot depict behaviors of each ion species sufficiently.

To investigate different dynamics and the intrinsic magnetic field's effects among ion species, we developed a new global multifluid MHD model with semi-discrete central scheme. The multifluid MHD model solves the continuity, momentum, and energy equations of four ion species (H^+, O^+, O_2^+, CO_2^+) and the induction equation of the magnetic field. The electron pressure equation is also solved independently. We adopted the gnomonic cubed sphere grid which has nearly uniform grid and lacks singular points. The simulation domain is set to be from the ionosphere (100 km altitude) to the magnetosphere (several planetary radii) because the presence of an intrinsic magnetic field affects such a wide range of the magnetic configuration. It includes chemical reactions, photoionization, and collisions (ion-ion, ion-electron, ion-neutral, electron-neutral) necessary for the ionosphere. We will show some simulation results for the validation of the model.

References

Sakata, R., et al. (2020). Effects of an intrinsic magnetic field on ion loss from ancient Mars based on multispecies MHD simulations. J. Geophys. Res., 125, e2019JA026945. doi:10.1029/2019JA026945

R008-08
Zoom meeting D ：11/4 AM1 (9:00-10:30)
9:15〜9:30

磁気圏のジャイロ運動論的モデルを用いたフィードバック不安定性の線形安定性解析

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([1] 法政大・理工,[2] 兵庫県立大・情報科学研究科

Linear Stability Analysis of Feedback Instability Using Gyrokinetic Model of Magnetosphere

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The feedback instability occurs in a coupling system of the magnetosphere and the ionosphere and is a theoretical model explaining spontaneous structure formation of the quiet aurora. In this study, we perform a linear simulation of the feedback instability using a gyrokinetic model of the magnetosphere as an initial value problem. In order to properly treats the magnetosphere-ionosphere boundary condition, we develop a new simulation method, where a perturbed distribution function is separated into even and odd components for the parallel velocity. In the simulation results, we observe growth rates and frequencies of the feedback instability almost consistent with those predicted by an analytic dispersion relation of the kinetic Alfven wave in the magnetosphere, however, the growth rate is slightly underestimated. A detailed analysis shows that such discrepancy is due to partial violation of the plane wave assumption of the magnetosphere in the derivation of the dispersion relation. The above comparison is based on the simplest magnetosphere model, i.e., the magnetic field in the magnetosphere is modeled by an isotropic slab magnetic field. In this study, we also try to apply our simulation method to a more realistic magnetosphere model.

フィードバック不安定性は磁気圏と電離圏の結合系において生じるものであり，静穏時オーロラの自発的な構造形成を説明する理論モデルである。本研究においては，初期値問題として，磁気圏のジャイロ運動論的モデルを用いたフィードバック不安定性の線形シミュレーションを行った。磁気圏-電離圏の境界条件を適切に扱うために，摂動を受けた分布関数を平行速度に対して偶関数と奇関数に分離する新しいシミュレーション手法を開発した。シミュレーション結果において，フィードバック不安定性の成長率と周波数が得られたが，それらは磁気圏のアルフベン波の解析的な分散関係によって予測されるものとおおむね一致した。しかし，成長率はわずかに過小評価された。詳細な解析により，そのような不一致は分散関係の導出において磁気圏に対する平面波仮説が部分的に破綻していることに起因することが示された。以上の比較は，最も簡単な磁気圏のモデル，すなわち，磁気圏の磁場は等方的なスラブ磁場によってモデルに基づくものである。本研究においては，より現実的な磁気圏モデルに対して我々のシミュレーション手法を適用することも試みる。

R008-09
Zoom meeting D ：11/4 AM1 (9:00-10:30)
9:30〜9:45

フィードバック不安定性の非線形発展における時空間構造

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[(1] 法政理工,[(2] 日大生産工

Spatiotemporal structure in nonlinear evolution of feedback instability

#Takahiro Teruya[1)],Seiya Nishimura[1)],Makoto Sasaki[2)]
[(1]Hosei Univ.,[(2]Nihon Univ.

The feedback instability occurs in the interaction of the magnetospheric and ionospheric plasma through the kinetic Alfven waves, and is a theoretical model explaining spontaneous development of the quiet aurora. In this study, we perform a nonlinear simulation of the feedback instability adopting a gyrofluid model in the magnetosphere and analyze the spatiotemporal structure in nonlinear evolution in detail. As a preliminary result, a two-dimensional Fourier transform is performed in the temporal and spatial direction for the time evolution of the vortex in the plane perpendicular to the magnetic field. It is observed that the relation between frequency and wavenumber is coherent in the direction of vortex propagation and turbulent in the direction perpendicular to the propagation direction. It is indicated that fold-like structure of the aurora is due to the anisotropy of the vortex behavior.

フィードバック不安定性は，運動論的アルフベン波を介した磁気圏と電離圏のプラズマの相互作用によって発生し，静穏時オーロラの自発的発達を説明する理論モデルである。本研究においては，磁気圏にジャイロ流体モデルを適用したフィードバック不安定性の非線形シミュレーションを行い，非線形発展における時空間構造について詳細に解析した。予備的な結果においては，磁場に垂直な面における渦度の時間発展に対して，時間方向と空間方向に 2 次元フーリエ変換を行った。その結果，周波数と波数の関係が，渦の伝搬する方向にはコヒーレント的に，伝搬方向と垂直な方向には乱流的であることが観察された。オーロラのひだ状の構造は，このような渦のふるまいの異方性に起因することが示唆される。

R008-10
Zoom meeting D ：11/4 AM1 (9:00-10:30)
9:45〜10:00

Fluid modeling of collisionless plasmas and its range of application

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Modeling of collisionless plasmas can be divided into two categories: fluid models and kinetic models. Generally speaking, fluid models require less computational resources than kinetic models, so they are suited for large-scale simulations. However, conventional fluid models such as MHD ignores wave-particle interaction. It has been pointed out that wave-particle interaction affects microscopic and macroscopic dynamics and should not be ignored even in MHD scales. This creates a demand for a fluid model of collisionless plasma that takes into account wave-particle interaction effects.

We have developed a fluid model that incorporates cyclotron resonance effects by applying non-local closure used in Landau-fluid models to the full pressure tensor equation. The model approximately reproduces the linear cyclotron resonance and linear growth of temperature anisotropy instabilities. We

have also shown that a simulation with or model can reproduce quasilinear relaxation of temperature anisotropy via resonant waves.

Another example of a kinetic fluid model is the well-known CGL(Chew-Goldberger-Low) model. The CGL model is used to analyze low-frequency waves in collisionless plasmas. With a proper FLR(finite Larmor radius) correction (and the Hall term), the Hall-CGL-FLR model predicts the growth rate of firehose instability with reasonable accuracy. However, CGL-based models cannot reproduce cyclotron resonance effects such as cyclotron damping and EMIC(electromagnetic ion cyclotron) instability because of the low-frequency assumption.

We will discuss some basic concepts of these kinetic fluid models and their range of application, especially in nonlinear simulation. Our non-local closure model is not limited by frequency (at least up to cyclotron frequency) and can reproduce both EMIC and parallel firehose instabilities but need improvement for quantitative agreement with fully kinetic models. CGL-based models can be very accurate in the low-frequency regime. Still, we found that the fact that CGL-based models do not solve gyro-motion terms in the pressure equation introduces some problems when high-frequency waves inevitably appear in nonlinear simulations. We will see these properties in the simulation of parallel firehose instabilities with different parameters.

R008-11
Zoom meeting D ：11/4 AM1 (9:00-10:30)
10:00〜10:15

非線形ランダウ減衰への等高線力学法の適用

#渡邉 智彦 [1)], 佐藤 大樹 [1)], 前山 伸也 [1)]
[1)] 名大・理・物理

Application of contour dynamics method to the nonlinear Landau damping

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The contour dynamics (CD) method, which originates from the water-bag model for numerical simulation of Vlasov-Poisson system, has developed as a numerical method solving vortex dynamics in two-dimensional ideal fluid with high-accuracy. However, the CD method has rarely been applied to the Vlasov-Poisson system with the charge neutrality condition. We have developed a CD method that can implement the periodic boundary condition, and applied it to simulation of the nonlinear Landau damping. After verification of the energy and particle conservation, we have carried out the CD simulation that can properly trace strong deformation of the distribution function, and found successive creation of electron holes during the nonlinear Landau damping.

Vlasov-Poisson 系の数値解法として考案された water-bag モデルに起源をもつ等高線力学 (CD) 法は、2 次元完全流体の渦力学を高精度で記述する手法として発展した。一方、プラズマのように電荷中性条件を満たす Vlasov-Possion 系への適用はあまりなされてこなかった。我々は、周期境界条件を巧みに適用する CD 法を考案し、非線形ランダウ減衰のシミュレーションに応用した。エネルギーおよび粒子保存性の確認とともに、分布関数の大変形過程を忠実に再現するシミュレーションを行い、非線形ランダウ減衰における電子ホール構造の連鎖的な形成を見出した。

R008-12
Zoom meeting D ：11/4 AM2 (10:45-12:30)
10:45〜11:00

テアリング不安定性の磁気流体力学線形理論における粘性効果の導入

#清水 徹 [1)]
(1RCSCE, 愛媛大

Magnetohydrodynamic linear theory of tearing instability with viscosity effect

#Tohru Shimizu[1)]
(1RCSCE, Ehime Univ.

Tearing instability is the most basic instability of current sheet in resistive Magnetohydrodynamic (MHD). In past 60 years, the linear theory was developed to study the beginning of the instability. Then, my study recently gave a new interpretation of the linear theory, which was shown to be, in fact, applicable for the MHD simulations of the tearing instability. We believe that such linear theory can explain the trigger problem of solar flares and substorms but it does not succeed. One of the fatal problems is that the non-viscous resistive MHD linear theory has no absolute stable condition in which the instability cannot occur in all wave numbers. In other words, the present linear theory predicts that, in the non-viscous resistive MHD, 1D current sheet cannot exist, and hence, always collapses by the instability. Such a theory is not realistic.

This presentation shows how the introduction of viscosity effect in the resistive MHD modifies the linear theory to study the absolute stable condition.

テアリング不安定性は抵抗性磁気流体力学 (resistive MHD) における電流層の最も基本的な不安定性であり、過去 60 年に渡りその線形理論は磁気再結合過程の開始段階を調べるために長く研究されてきた。これに対し、近年の著者の研究により、その線形理論に全く新しい解釈が与えられ、その新しい線形理論は MHD シミュレーションで見られる磁気再結合過程の開始段階をうまく説明できることが示された。そもそも、開始段階の線形理論研究はフレアや磁気嵐のトリガ問題に関連すると期待されるが、未だにうまく関連付けられていない。なぜなら、粘性効果を考慮しない従来の線形理論では、理想 MHD でない限り、テアリング不安定性の絶対安定条件（いかなる波数でも成長率が正にならない条件）が存在しないことが示唆されるからである。言い換えると、わずかでも電気抵抗がある電流層は常にテアリング不安定性が起こることを示唆するが、それは電流層が安定に存在できないことを示唆するので、非現実的である。つまり、宇宙空間では、1 次元的電流層は至るところで観測されおり、それはフレアや磁気嵐がいつも起きているわけではないことを意味する。

これに対し、本研究では、著者が提案する新しい線形理論に、新たに粘性効果を導入することで、絶対安定条件を模索している。本発表では、いくつかの電流層の平衡状態モデルに対する成長率の波数依存性を紹介し、絶対安定条件の存在性について最新の成果を報告する。

R008-13
Zoom meeting D ：11/4 AM2 (10:45-12:30)
11:00〜11:15

密度非対称条件におけるプラズモイド型磁気リコネクションの MHD シミュレーション

#山本 百華 [1)], 銭谷 誠司 [2)]
([1] 神戸大学,[2] 神戸大学

Magnetohydrodynamic simulations of density-asymmetric plasmoid-type magnetic reconnection

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([1]Kobe University,[2]Kobe University

Magnetic reconnection is thought to play an important role in space and solar plasmas. According to magnetohydrodynamic (MHD) simulation studies, it is known that a large number of plasmoids are generated in the magnetic reconnection region and develop turbulently. In previous research, initial conditions were used in which the density and magnetic field of the inflow region were symmetrical, but in actual space, magnetic reconnection often occurs at boundaries with different plasma densities and magnetic fields. Therefore, basic research on plasmoid-type magnetic reconnection under such asymmetric conditions is required.

In this study, we focus on the density asymmetry in plasmoid magnetic reconnection. We carried out large-scale magnetohydrodynamic (MHD) simulations in which the density ratio of the inflow region was changed. Using Cassak & Shay (2007) theory, we predict the reconnection rate as a function of the density ratio. This prediction was verified by simulations. In addition, new properties such as the spiraling of plasmoids were confirmed.

太陽等の宇宙空間のプラズマでは磁気リコネクションが重要な役割を果たすと考えられている。これまでの磁気流体 (MHD) シミュレーション研究の結果、磁気リコネクション領域の中で多数のプラズモイドが生成され、乱流的に発展することが知られている。従来の研究では流入領域の密度・磁場が対称な初期条件を用いていたが、現実の宇宙空間ではプラズマの密度や磁場が異なる境界で磁気リコネクションが発生している。そこで、このような非対称条件下でのプラズモイド型の磁気リコネクションの基礎研究が必要となる。

本研究では密度の非対称条件に着目し、流入領域の密度比を変えた大規模数値シミュレーションを多数実行することでプラズモイド型磁気リコネクションのふるまいに与える影響を調査した。Cassak & Shay(2007) の理論を応用して密度比によるリコネクションレートの推移を予測し、シミュレーションによってその理論予測を検証した。また、プラズモイドが渦状になっているなどの新しい性質が確認できた。今回はこれらの成果について報告する。

R008-14
Zoom meeting D ：11/4 AM2 (10:45-12:30)
11:15～11:30

The impact of oxygen ions on a large scale magnetotail reconnection

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The impact of background oxygen ions on a large scale magnetotail reconnection is investigated. After a pair of quasi-steady proton reconnection jets is generated from the proton diffusion region, the oxygen ions remain approximately demagnetized due to their large mass and exhibit Speiser-type motions outside of the proton diffusion region. The oxygen ion motions act as a spatial loading mechanism of mass, momentum and kinetic energy in the oxygen demagnetized region. That mechanism has an influence on the current carriers and the field structure.

R008-15
Zoom meeting D ：11/4 AM2 (10:45-12:30)
11:30〜11:45

昼側磁気圏境界環境と磁気リコネクション構造

#近藤 光志 [1)]
(1 愛媛大・RCSCE

Relationship between the circumstances of the dayside magnetopause and magnetic reconnection

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(1RCSCE, Ehime Univ.

Magnetic reconnection affects the macro-scale evolution of the surrounding system. On the other hand, the surrounding system also affects the magnetic reconnection. In particular, asymmetric reconnection in the dayside magnetopause is significantly affected by the surrounding system. In this paper, we focus on how these circumstance affect to the magnetic reconnections. Even small asymmetry of the magnetic field strength in the both sides of the current sheet significantly affect to the reconnection structure. For example, the produced plasmoid has also asymmetric structure and high beta plasma flow into the plasmoid in the low beta side, results in the formation of the contact discontinuity in the low beta side plasmoid. These asymmetric reconnection also change the output flow structures. In these asymmetric reconnection, the comparable fast outflow in the low beta side plasmoid with that in the reconnection fan is observed. That is, the fast reconnection jet is not always observed in the reconnection fan in the case of the asymmetric reconnection.

R008-16
Zoom meeting D ：11/4 AM2 (10:45-12:30)
11:45〜12:00

爆発的に成長する非線形無衝突磁気リコネクション

#星野 真弘 [1)]
(1 東大・理

Nonlinear Explosive Magnetic Reconnection in a Collisionless Plasma

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(1University of Tokyo

The debate surrounding onset of the fast magnetic energy dissipation by magnetic reconnection has remained a fundamental topic in the plasma universe, not only in the Earth's magnetosphere but in astrophysical objects such as pulsar magnetospheres and solar flares, for more than half a century. Recently, nonthermal particle acceleration and plasma heating during reconnection have been extensively studied in collisionless plasmas, and it has been argued that rapid energy dissipation can occur for a "thin" current sheet, the thickness of which is of the order of the particle gyro-radius. However, it is an intriguing enigma as to how the fast energy dissipation can occur for a "thick" current sheet with thickness larger than the particle gyro-radius. Here we demonstrate, using a high-resolution particle-in-cell simulation, that an explosive reconnection can emerge with the enhancement of two effects: one is the inertia resistivity due to the magnetization of the meandering particles by the reconnecting magnetic field, and the other is the shrinkage of the current sheet during the early time evolution/linear stage of the plasma sheet. Together with the theoretical approach of the energy principle, we show that, regardless of the initial thickness of the current sheet, the time scale of the nonlinear explosive reconnection is tens of the Alfven transit time.

R008-17
Zoom meeting D ：11/4 AM2 (10:45-12:30)
12:00〜12:15

超並列磁気流体シミュレーションコード OpenMHD の開発

#銭谷 誠司 [1)], 三好 隆博 [2)], 近藤 光志 [3)],Teh Wai-Leong[4)]
(1 神戸大学,(2 広大・理・物理,(3 愛媛大・RCSCE,(4 マレーシア国民大学

Development of a parallel magnetohydrodynamic code: OpenMHD

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(1Kobe U,(2Phys. Sci., Hiroshima Univ.,(3RCSCE, Ehime Univ.,(4Universiti Kebangsaan Malaysia

We have developed a high-performance magnetohydrodynamic simulation code, OpenMHD. It is a second-order finite-volume code with the HLLD-type Riemann solver, written in modern Fortran. The code is parallelized with MPI-3 and OpenMP, and it has been ported to NVIDIA's graphics processing units (GPUs) recently. In this presentation, we will overview technical aspects of OpenMHD, as well as scientific achievements by OpenMHD-users.

我々は超並列磁気流体シミュレーションコード OpenMHD を開発・公開している。OpenMHD は modern fortran で書かれた時間・空間２次精度の有限体積コードで、HLLD タイプの数値流束解法を採用しており、MPI および OpenMP による超並列計算に対応している。さらに最近、NVIDIA 社の CUDA プラットフォームを利用して、OpenMHD は GPU でも動作するようになった。本発表では、OpenMHD の技術的特徴を紹介したうえで、OpenMHD を利用して得られたサイエンス成果を概観する。

R008-18
Zoom meeting D ：11/4 PM1 (13:45-15:30)
13:45〜14:00

Development of a versatile particle-in-cell simulation code for plasma astrophysics

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([1]Chiba University,([2]University of Tokyo,([3]ESST, Kyushu University

Particle-in-cell (PIC) simulations have been used for understanding particle accelerations, particle transport, and magnetic field generation in space and astrophysical phenomena. Using massively parallel supercomputer systems with a parallelized PIC code is a powerful way to elucidate such nonlinear phenomena. We have developed a public PIC code, pCANS (http://www.astro.phys.s.chiba-u.ac.jp/pcans/), for promoting the PIC simulation study in astrophysics as well as in the space plasma physics. pCANS has been used by graduate students and early-career researchers (e.g., Tomita and Ohira, 2019).

A more sophisticated PIC code is necessary for using state-of-the-arts supercomputer systems, such as Fugaku, for efficient computations and parallelization. In this regard, we have used an optimized, hybrid-parallelized code for understanding plasma dynamics at large-scale systems (e.g., Matsumoto et al., 2017; Takamoto et al., 2019,2020; Iwamoto et al., 2019, 2020). We recently started a new project for making this code public for general purposes in computational astrophysics. We have re-organized the code to adapt to different supercomputer systems and data I/O procedures. We have also preconfigured physical problems, such as collision-less shocks and Weibel instability, with proper boundary conditions as a quick start. In this presentation, we report the overview of the code and the current status of the development.

R008-19
Zoom meeting D ：11/4 PM1 (13:45-15:30)
14:00〜14:15

オーロラ加速領域における電界構造の計算機シミュレーション

#池羽 良太 [1,2], 梅田 隆行 [2], 三好 由純 [2]
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Comuputer simulation on the structure of double layer in the auroral acceralation region

#Ryouta Ikeba[1,2],Takayuki Umeda[2],Yoshizumi Miyoshi[2]
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The existence of electric fields in the auroral region was predicted by Alfven (1957). Rocket observations of aurora in 1960's showed the precipitation of high energy electrons, possible due to electric fields in the acceleration region (McIlwain 1960). Evans (1974) reproduced the result of rocket observation by a model calculation, which demonstrated the existence of the auroral acceleration region. Electric fields due to the electric double layers in the auroral acceleration region were first observed by spacecrafts in 1970's (Mozer et al. 1977). The FAST observation showed detailed multi-dimensional structures of the auroral double layer (Ergun et al. 2001). The previous one-dimensional Vlasov-Poisson simulation of a current-carrying plasma showed that a double layer was generated by a strong density depression (Newman et al. 2001). However, multi-dimensional kinetic simulations have not been performed yet due to both computational resources and computational techniques. In the present study, we first perform a two-dimensional particle-in-cell simulation of a current-carrying plasma with a density depression. It is demonstrated that a double layer is driven generated in the two-dimensional system with a weak ambient magnetic field. An electrostatic wave is excited inside the double layer at the frequency around the ion plasma frequency and at the phase velocity around the ion acoustic speed, which propagates in the direction oblique to the ambient magneto field.

オーロラ領域における加速電場の存在は Alfven (1957) によって予言された。1960 年代にはロケットによるオーロラ観測が行われ、加速電場により生成したと思われる高エネルギー粒子の降下を観測した (McIlwain 1960)。Evans (1974) はモデル計算によりロケット観測結果を再現し加速電場の存在を裏付けた。オーロラ領域における電気二重層による加速電場は 1970 年代の科学衛星によりはじめて観測された (Mozer et al. 1977)。また、FAST 衛星観測によってオーロラの電気二重層の詳細な多次元構造が明らかとなった (Ergun et al. 2001)。1 次元 Vlasov-Poisson シミュレーションにより、沿磁力線電流が存在するプラズマ中に強い密度降下を与えることによって電気二重層が成長することを示された (Newman et al. 2001)。しかし、計算資源や計算技術の不足により多次元的な運動論的シミュレーションはこれまで行われてこなかった。本研究では沿磁力線電流中の密度降下による電気二重層形成モデルの 2 次元 Particle-In-Cell シミュレーションを世界に先駆けて行った。その結果、2 次元空間において背景磁場が弱い場合において電気二重層が成長することを確認した。また、周波数がイオンプラズマ周波数、伝搬速度がイオン音速に近くで磁力線に対して斜めに伝搬する静電波動が電気二重層内に励起した。

R008-20
Zoom meeting D ：11/4 PM1 (13:45-15:30)
14:15〜14:30

Parametric dependence of whistler-mode triggered emissions in a homogeneous magnetic field

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We perform an electromagnetic particle simulation of triggered emissions in a uniform magnetic field for understanding of nonlinear wave-particle interaction in the vicinity of the magnetic equator. A finite length of a whistler-mode triggering wave packet with a constant frequency is injected by oscillating an external current at the equator. We find that the first subpacket of rising-tone triggered emissions is generated after termination of the injection of the triggering wave in the homogeneous magnetic field. By analyzing resonant currents and resonant electron dynamics in the simulation, we find that the formation of an electron hole in a velocity phase space forms resonant currents, and the currents cause wave amplification and frequency increase. For further understanding of the characteristics of triggered emissions, we study parametric dependence on the frequency and duration time of the triggering wave. We find that triggered emissions require a certain period of the triggering waves, and the duration time of the injection is determined by the interaction time. For the generation of triggered emissions, the interaction time is more than 1/4 of the nonlinear trapping period in the present simulation.

R008-21
Zoom meeting D ：11/4 PM1 (13:45-15:30)
14:30〜14:45

サイクロトロン共鳴における非相対論的粒子の厳密解

#北原 理弘 [1)], 三好 由純 [1)], 中村 紗都子 [2)], 小路 真史 [1)], 加藤 雄人 [3)], 北村 成寿 [4)]
([1] 名大 ISEE,[2] 京大・理・地球惑星,[3] 東北大・理・地球物理,[4] 東大・理・地惑

The exact analytic solutions of non-relativistic particles in the cyclotron resonance condition

#Masahiro Kitahara[1)],Yoshizumi Miyoshi[1)],Satoko Nakamura[2)],Masafumi Shoji[1)],Yuto Katoh[3)],Naritoshi Kitamura[4)]
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Wave-particle interactions play a crucial role in the dynamics of charged particle such as particle acceleration, pitch angle scattering, wave growth in space plasmas. For quantitative evaluation of wave-particle interactions, it is the most important to estimate the size of a trapping region of charged particles encountering plasma waves in the velocity space (phase space). The trapping region in wave-particle interaction is expressed as a set of closed trajectories in the velocity space with the conserved quantities. In this study, we solve the equation of motion for a non-relativistic charged particle in electromagnetic waves propagating along the uniform ambient magnetic field, and we derived two conserved quantities, which correspond to the diffusion curve in the velocity space and the rescaled Hamiltonian introduced by Albert et al. (2021). Classifying particle trajectories by using the conserved quantities, we derived the exact trapping region in the velocity space. Because the exact trapping region includes trajectories of ”transversal phase bunching” mentioned by Matsumoto et al. (1974), the size of the exact trapping region is larger than that of the trapping region of ”longitudinal phase bunching”. This fact should indicate that the trapping efficiency estimated from the exact trapping region should be higher than that from the longitudinal trapping region. We also found that the parallel velocities of some trapped particles do not always meet the cyclotron resonance condition. These particles can be classified as non-resonance trapping in the sense that the particle velocities do not match the cyclotron resonance velocity, while the particles can also be classified as the resonance trapping in a broad sense that the resonance condition is defined as the temporal-stationary points of the relative phase angles. Our derived exact solution can be applied to the particle data analysis of the high-time-resolution observations and contribute to more quantitative interpretations of wave-particle interactions through the cyclotron resonance.

プラズマ波動による荷電粒子の加速・散乱現象を定量的に評価するためには、速度空間（または位相空間）におけるプラズマ波動による荷電粒子の捕捉領域（以下、捕捉領域）を正確に表現することが重要である。捕捉領域は速度空間中の閉軌道集合として表現され、対応する保存量を定義することができる。我々は一次元かつ一様な背景磁場を平行伝搬する円偏波の電磁波を仮定して、非相対論的荷電粒子の運動方程式を解くことにより、荷電粒子の拡散曲線 (diffusion curve) とリスケールされたハミルトニアンに対応する２つの保存量を導出した。これらの保存量を利用して荷電粒子の軌道を分類することにより、位相空間にける荷電粒子の正確な捕捉領域を表現した。今回導出した捕捉領域は、いわゆる垂直方向捕捉 (transversal phase bunching) を内包し、平行方向捕捉 (longitudinal phase bunching) のみを考慮した捕捉領域よりも面積が大きくなるため、より効率的な粒子捕捉が期待される。また、波動に捕捉される粒子の中には、サイクロトロン共鳴条件 (v_para = V_res) を満たさない粒子も存在することが導かれる。これらの捕捉粒子は、粒子速度と共鳴速度が一致することを共鳴条件とする立場から見れば、「非共鳴捕捉」と呼ぶこともできる。一方で、波動に対する相対位相が停留する点を広義の共鳴条件と考える立場から見た場合には、これらの捕捉粒子を「共鳴捕捉」と捉えることもできる。今後、今回導出した捕捉領域の厳密解を、実際に宇宙空間において観測される粒子データの解析や理論解析に適用することによって、サイクロトロン型の波動粒子相互作用のより定量的な物理解釈が可能となることが期待される。

R008-22
Zoom meeting D ：11/4 PM1 (13:45-15:30)
14:45〜15:00

Simulation Study on Parametric Dependence of Whistler-mode Hiss Generation in the Plasmasphere

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We conduct electromagnetic particle simulations to examine the applicability of nonlinear wave growth theory to the generation process of plasmaspheric hiss. We firstly vary the gradient of background magnetic field from a realistic model to a rather steep gradient model. Under such variation, the threshold amplitude in the nonlinear theory increases quickly and the overlap between threshold and optimum amplitude disappears correspondingly, and the nonlinear process is suppressed. In the simulations, as we enlarge the gradient variation of the background magnatic field, waves generated near the equator do not grow through propagation. By examining extracted typical wave packets from different gradient cases, we find the generation of wave packets is limited to equatorial region when background field is steep, showing a good agreement with what is indicated by critical distance in the theory. We then check the dependence of generation of hiss emissions on different hot electron densities. Since the overlap between threshold and optimum amplitude vanishes, the nonlinear process is weakened when hot electron density becomes smaller. In the simulation results, we find similar wave structures in all density cases, yet with different magnitudes. The existence of suitable values of the inhomogeneity factor S implies that nonlinear process occurs even at a low level of hot electron density. However, by examining JE which is closely related to the wave growth, we find energy conveyed from particles to waves is much limited in small density cases. Therefore, the nonlinear process is suppressed when hot electron density is small, which is in agreement with the theoretical analysis.

R008-23
Zoom meeting D ：11/4 PM1 (13:45-15:30)
15:00〜15:15

ホイッスラーモード・ライジングトーン波の非線形絶対不安定性の必要条件

#大村 善治 [1)], 野儀 武志 [2)]
[(1] 京大・生存圏,[(2] 京大・生存研

Necessary conditions for nonlinear absolute instability of whistler-mode rising-tone emissions

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We have conducted simulations of whistler-mode rising-tone emissions triggered by a wave with a constant frequency transmitted from the equator [1]. Counter streaming resonant electrons interact with the triggering wave, being organized in their gyro-phases forming resonant currents that can modify the wave phase and amplitude resulting in a new wave at higher frequency. An absolute instability should occur to generate the new wave at higher frequencies. With a triggering wave higher than the threshold wave amplitude, a new wave grows as an absolute instability at progressively higher frequencies. The wave grows to a level close to the optimum wave amplitude as an absolute instability near the magnetic equator [2]. We have found that it is necessary for the triggering source point of a rising-tone emissions to move upstream from the equator. The velocity of the source point is given by the sum of the resonance velocity and the group velocity of triggering waves. For the typical energy range of electrons generating chorus emission is about 10 - 30 keV, which gives resonance velocity with its magnitude comparable to that of the group velocity but with the opposite sign. Therefore, the source velocity is can remain relatively small values keeping the source region near the equator. For the wave frequency below half the cyclotron frequency, the source velocity is negative, resulting in the upstream motion of the source point which is favorable for an absolute instability at the equator. When the frequency becomes higher than half the cyclotron frequency, the source point moves to the downstream region, and the absolute instability of a rising tone is terminated in the downstream region.

References
[1] Nogi, T., & Omura, Y., Nonlinear signatures of VLF triggered emissions, submitted to J. Geophys. Res. Space Phys. 2021.
[2] Omura, Y., Nonlinear wave growth theory of whistler-mode chorus and hiss in the magnetosphere, Earth, Planets and Space, (2021) 73:95.
https://doi.org/10.1186/s40623-021-01380-w

R008-24
Zoom meeting D ：11/4 PM2 (15:45-18:15)
15:45〜16:00

大型レーザー実験による磁化プラズマ衝撃波の生成およびその長時間発展

#松清 修一[1)], 諫山 翔伍[1)], 岩本 昌倫[1)], 山崎 了[2)], 森田 太智[1)], 竹崎 太智[3)], 富田 健太郎[4)], 蔵満 康浩[5)], 田中 周大[2)], 佐野 孝好[6)], 羅 皓洋[1)], 東 力也[1)], 高橋 健太[1)], 坂和 洋一[6)]
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Formation and long time evolution of magnetized shocks produced by high power laser experiment

#Shuichi Matsukiyo[1)],SHOGO ISAYAMA[1)],Masanori Iwamoto[1)],Ryo Yamazaki[2)],Taichi Morita[1)],Taichi Takezaki[3)],Kentaro Tomita[4)],Yasuhiro Kuramitsu[5)],J. Shuta Tanaka[2)],Takayoshi Sano[6)],Haoyang Luo[1)],Rikiya Higashi[1)],Kenta Takahashi[1)],Youichi Sakawa[6)]
([1]Kyushu Univ.,[2]Aoyama Gakuin University,[3]University of Toyama,[4]Hokkaido University,[5]Osaka University,[6]ILE, Osaka University

We have developed the method of magnetized collisionless shock formation experiment using high power laser. Long time evolution of the system is investigated by controlling laser power, ambient gas pressure, and target position. To apply an ambient magnetic field in the region of interest, we used a Helmholtz coil driven by a portable pulsed magnetic field generation system. A shock is formed by irradiating an aluminum target surrounded by nitrogen gas. The ablated target plasma pushes the ambient gas which is also immediately ionized right after the main laser shot through photo ionization due to intense radiation emitted by the laser-target interactions. Then, a shock is formed in the gas plasma. We successfully followed long time evolution of the system up to 80ns which is much longer than the previous time (=30-40ns) that we could follow. We will discuss detailed structures of the compressed gas region and the structures are compared with the PIC simulation customized for the experiment.

R008-25
Zoom meeting D ：11/4 PM2 (15:45-18:15)
16:00〜16:15

2つのパルスを用いた高効率な航跡場加速によるGeVプロトン生成

#諫山 翔伍 [1)], 蔵満 康浩 [2)], 福田 祐仁 [3)], 陳 仕宏 [4)], 陳 漢偉 [4)], 耀? 劉 [4)]
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Highly efficient laser wakefiled acceleration to generate GeV energy proton by using dual-laser pulses

#SHOGO ISAYAMA[1)],Yasuhiro Kuramitsu[2)],Yuji Fukuda[3)],Shih-Hung Chen[4)],Han-Wei Chen[4)],Liu Yao-Li[4)]
[(1]IGSES,[(2]GSE, Osaka Univ.,[(3]QST,[(4]NCU

The laser-plasma interaction can generate high acceleration fields, which exceeds those of the conventional accelerators by orders of magnitude. Due to this excellent feature of large acceleration gradient, laser-driven proton acceleration possesses high potential to realize the compact high energy proton sources for various applications, including modern cancer therapies [1]. In space plasma, the model of astrophysical wake acceleration, which is driven by the strong Alfvenic pulses emitted by the magneto-rotational instability in the accretion disk, has been proposed to explain ultra-high energy cosmic rays above 10^{18} eV energy of proton and nucleus [2-4]. It has also been found that wakefield acceleration of particles occurs in a relativistic perpendicular shock, where the precursor waves are excited due to the synchrotron maser instability in the shock front, and the wakefields are generated by the ponderomotive force of the precursor waves [5,6]. In laser produced plasma, numerical attempts to produce GeV proton beams have been made [7-11] for the future experiment to investigate underlying generation process of such high energetic particles.

We propose an efficient hybrid acceleration scheme to generate relativistic (˜GeV) protons with using dual-pulses and solid density (SD) and near critical density (NCD) foils in tandem [12]. The acceleration mechanism is the two-stage acceleration process of radiation pressure acceleration (RPA) and laser wakefield acceleration (LWFA), where the injection of relativistic ions into wakefield is controlled by the parameters of the dual pulses. The energetic protons, which are accelerated by the first laser pulse in the first RPA stage, are injected into the NCD plasma. In the second stage, protons are trapped in front of the second laser pulse and accelerated by the laser induced wakefield. Since the second pulse reaches the NCD plasma through the hole of the SD target made by the first pulse, all amount of second pulse energy is used for the second LWFA, resulting in more efficient acceleration compared to the hybrid RPA-LWFA with a single-pulse, where a large amount of pulse energy is reflected by the SD target, resulting in the reduction of the energy used for the LWFA.

[1] S. V. Bulanov and V. S. Khoroshkov, Plasma Phys. Rep. 28, 453 (2002).
[2] P. Chen et al., PhRvL. 89 161101 (2002).
[3] T. Ebisuzaki and T. Tajima, Astropart. Phys. 128, 102567 (2019).
[4] T. Tajima et al., Rev. Mod. Phys. 4, Number 7 (2020).
[5] M. Hoshino, ApJ. 672, 940 (2008).
[6] M. Iwamoto et al., ApJL. 883, L35 (2019).
[7] B. Qiao, et al., Phys. Rev. Lett. 102, 145002 (2009).
[8] S. S. Bulanov, et al., Phys. Plasmas 17, 043105 (2010).
[9] Z. M. Zhang, X. T. He, Z. M. Sheng, and M. Y. Yu, Phys. Plasmas 17, 043110 (2010).
[10] M. Liu, et al., Phys. Plasmas 25, 063103 (2018).
[11] O. Rahman and Z. M. Sheng, Phys. Plasmas 28, 053106 (2021).
[12] S. Isayama et al., Phys. Plasmas 28, 073101 (2021).

R008-26
Zoom meeting D ：11/4 PM2 (15:45-18:15)
16:15〜16:30

対向伝搬する大振幅アルフベン波による相対論的粒子加速

#高橋 健太 [1)], 諫山 翔伍 [2)], 羽田 亨 [3)], 松清 修一 [4)]
([1] 九大・総理工・大海,([2] 九大総理工,([3] 九大総理工,([4] 九大・総理工

Relativistic particle acceleration by counter-propagating large amplitude Alfven waves

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([1]ESST, IGSES, Kyushu Univ.,([2]IGSES,([3]Kyushu Univ,([4]Kyushu Univ.

Large-amplitude MHD waves are ubiquitous in space, and they are considered to play key roles in particle acceleration. In the solar wind, large amplitude magnetic fluctuations are frequently observed. It is also known that the magnetic field is amplified in the vicinity of collisionless shocks associated with gamma-ray bursts, supernova remnants, and other high energy astrophysical events. Such large amplitude MHD waves may contribute to produce high-energy particles. The interaction between a monochromatic wave and a charged particle, and that between well developed turbulent fields and a particle have been well studied [e.g., Oka et al., ApJ, 2019]. However, there are relatively few studies on particle acceleration through the interaction with developing turbulence. In space, many astrophysical events have long relaxation time so that we often observe developing turbulence and well accelerated particles simultaneously.

In the past we showed that relativistic particle acceleration occurs through the interaction with coherent waves in developing turbulence. In this acceleration process, two counter-propagating Alfven waves are found to play an essential role. Here, in this study, we focus on particle acceleration through the interaction with the counter-propagating two Alfven waves. We investigate the parameter dependence of the acceleration process. By using an analytical theory and test particle simulations, we show that there is a critical wave amplitude above which all particles are accelerated to relativistic energies regardless of their initial energies.

大振幅磁気流体（MHD）波動は宇宙のいたるところで励起され、粒子加速に寄与すると考えられている。太陽風中では背景磁場と同程度の磁場揺らぎが常時観測されており、またガンマ線バーストや超新星残骸等に付随する無衝突衝撃波近傍では、磁場が星間空間に比べてはるかに強く増幅されることが知られている。このような大振幅 MHD 波動は高エネルギー粒子の生成に寄与している可能性がある。従来、単色波と荷電粒子の相互作用や十分発達した乱流場中での粒子加速についてはよく研究されているが、発展途上乱流における粒子加速の研究は比較的少ない。現象の緩和時間の長い宇宙では発展途上乱流がしばしば観測され、コヒーレントな波動とともによく加速された高エネルギー粒子が見られる [e.g., Oka et al., ApJ, 2019]。

我々は過去に、発展途上乱流におけるコヒーレント MHD 波動と粒子の相互作用で相対論的な粒子加速が起こることを示した。この過程では、乱流場の長時間発展（アルフベン波のパラメトリック不安定性）の中で時限的、局所的に現れる２つの対向伝搬するアルフベン波が粒子加速に本質的な役割を果たすことがわかっている。本研究では、対向伝搬する‘２つのアルフベン波’と荷電粒子の相互作用に焦点を当て、粒子加速の特徴、特にパラメータ依存性について精査する。アルフベン波の周波数と位相速度を固定し、振幅を変えていくと、粒子が初期エネルギーによらずすべて相対論的エネルギーにまで加速される臨界振幅が存在することを、理論およびテスト粒子計算によって示す。

R008-27
Zoom meeting D ：11/4 PM2 (15:45-18:15)
16:30〜16:45

相対論的衝撃波上流におけるピックアップ過程による粒子加速

#岩本 昌倫 [1)], 天野 孝伸 [2)], 松本 洋介 [3)], 松清 修一 [1)], 星野 真弘 [2)]
([1] 九大総理工,[2] 東大・理,[3] 千葉大理

Particle Acceleration by Pickup Process Upstream of Relativistic Shocks

#Masanori Iwamoto[1)],Takanobu Amano[2)],Yosuke Matsumoto[3)],Shuichi Matsukiyo[1)],Masahiro Hoshino[2)]
([1]Kyushu University,[2]University of Tokyo,[3]Chiba University

Relativistic shocks are ubiquitous in the Universe as a consequence of interaction between relativistic plasma outflow and interstellar medium and believed to be an efficient particle accelerators. Although particle acceleration at relativistic shocks is often invoked for the generation mechanism of the ultra-high-energy cosmic rays, which is a long-standing in astrophysics, the detailed acceleration mechanism remains unsolved yet.

It is well-known that relativistic shocks emit coherent electromagnetic waves (e.g., Gallant et al. 1992; Hoshino et al. 1992; Iwamoto et al.2017; 2018), which are assumed to originate from the synchrotron maser instability (Hoshino & Arons 1991). 1D particle-in-cell (PIC) simulations of relativistic shocks demonstrated that longitudinal electrostatic waves, which are called wakefields, are induced in the wake of the large-amplitude electromagnetic waves via the stimulated Raman scattering and that nonthermal particles are generated in the upstream (Lyubarsky 2006;Hoshino 2008).Recently, our high-resolution 2D PIC simulation (Iwamoto et al. 2019) confirmed that the particle acceleration associated with the wakefield works even in realistic multidimensional shocks. In this talk, we will discuss the acceleration mechanism in more detail and show that the particles are mainly accelerated by the motional electric field via the pickup process.

R008-28
Zoom meeting D ：11/4 PM2 (15:45-18:15)
16:45〜17:00

Condition for Electron Injection via Stochastic Shock Drift Acceleration

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The acceleration of high-energy particles is commonly seen in heliophysics and astrophysics. The diffusive shock acceleration (DSA) process has been the standard mechanism for particle acceleration at collisionless shock waves. It is, however, well known that DSA cannot explain the acceleration of low-energy electrons because of the lack of efficient scatterers. We have proposed stochastic shock drift acceleration (SSDA) as a plausible mechanism to resolve the problem of electron injection [Katou & Amano, 2019]. The energy gain mechanism of SSDA is essentially the same as the conventional shock drift acceleration (SDA), but the presence of stochastic pitch-angle scattering makes the acceleration more efficient. Good agreements between theoretical predictions based on SSDA and in-situ observations by Magnetospheric MultiScale (MMS) spacecraft have been reported [Amano et al. 2020]. Furthermore, electron acceleration signatures found in fully kinetic Particle-In-Cell (PIC) simulations have also been found [Matsumoto et al. 2017, Kobzar et al. 2021]. Motivated by these previous studies, we will present results of more sophisticated theoretical and numerical analyses.

We use a diffusion-convection equation derived consistently from a fully relativistic pitch-angle diffusion equation. We formulate the problem essentially as a shock acceleration at an oblique shock of finite thickness. This includes the standard DSA as the special case, in which the diffusion length is much longer than the shock thickness. We find that SSDA is understood as the particle acceleration process for which the diffusion length is comparable to the thickness. SSDA, in general, predicts a steeper-than-DSA power-law index. The spectral index is dependent on the diffusion length and becomes steeper as decreasing the ratio between the diffusion length to the shock thickness. The diffusion lengths of low-energy particles accelerated by SSDA may eventually become longer than the shock thickness. As a result, the particles with loner diffusion lengths may be further accelerated by DSA, which is essentially the injection. The present model can describe the continuous transition of acceleration regimes both below and above the injection threshold energy. Using the MMS measurements, we will discuss the condition required for the electron injection at realistic collisionless shocks of various environments.