R008-01
Zoom meeting D ：11/3　AM1　(9:00-10:30)
09:15-09:30

宇宙プラズマ現象予測モデル開発に向けた機械学習・数値シミュレーション・観測による学習データの整備

#深沢　圭一郎[1],木村　智樹[2],徳永　旭将[3],中野　慎也[4]
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Development of training data with collaboration of observation, MHD simulation and machine leaning for space weather forecast

#Keiichiro Fukazawa[1], Tomoki Kimura[2], Terumasa Tokunaga[3], Shin'ya Nakano[4]
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The machine learning has become a powerful tool to find the relation between variables thanks to the deep learning technique. This performs greatly in the classification, regression and recently generative modeling in the engineering and commercial areas. However, due to the satisfaction of physical laws in the scientific research area, the application of machine learning has some difficulties. In particular, the generative modeling is very sensitive to scientific data since the generated data is not guaranteed by the physical laws.

To overcome these problems, we have tried to apply machine learning to space plasma physics. In the observation there are many lacks data in space and time. Using the technique of GAN (Generative Adversarial Networks), we have challenged to represent the lack data of aurora image by ASI (All-Sky Imager) of THEMIS. Now we use the natural training data not only the observation data and we have obtained the smooth represented data, however these data cannot satisfy the physical laws. Then we prepare the training data of only observation.

From this thought the preparing the training data is the most important for machine learning. Then we have prepared the global simulation data of magnetosphere using real solar wind data for the generation and forecast the configuration of the magnetosphere. These data are the very large size and time elapsed data so that the data set cannot be stored in often case and usual machine learning cannot treat these data set. However recently there are 3D CNN (convolutional neural network) and RNN (recurrent neural network) which can be trained by 3D data set and these data set may become very important. In this study, we show the database of this data set data, representation of the auroral image and their status.

R008-02
Zoom meeting D ：11/3　AM1　(9:00-10:30)
09:30-09:45

畳み込みニューラルネットワークによるショックレット識別

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Classification of shocklets using convolutional neural network

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In the foreshock region of the earth's bow shock, various plasma waves are generated due to the interaction between the solar wind plasma and the plasma beam streaming back from the shock. One of the most eminent types of the waves is the so-called shocklet, a large amplitude nonlinearly steepened magnetosonic wave sometimes accompanied by a high-frequency whistler-mode precursor on the steepened wavefront. Despite their importance in the foreshock physics and nonlinear wave theories, there remain a number of unsolved issues on the shocklets, including the fundamental question of their definition.
With this background in mind, we conducted research using the convolutional neural network (CNN) to find how accurately the shocklets and non-shocklets can be correctly identified. We use the derivative nonlinear Schrodinger equation (DNLS), a nonlinear equation that models time evolution of quasi-parallel Alfven waves, to produce a large amount of model-shocklet dataset. Then we phase shuffle these data to create the same amount of non-shocklet dataset. Using them as the training data for the CNN, we check how accurately it can separate the two different datasets. We will present the details of the study and the results and analysis of waveforms that let the CNN misjudge.

地球バウショックの上流域では、衝撃波起源の逆行プラズマと太陽風プラズマとの相互作用により、様々な種類のプラズマ波動が励起される。なかでも、大振幅の磁気音波が急峻化した波形をもち、急峻化した波面に高周波ホイッスラー波動を伴うことのあるショックレットは、宇宙プラズマ中に観測される典型的な非線形波動のひとつとして、恰好の研究対象となってきた。その一方、ショックレットの定義は明確ではなく、シミュレーションによって得られる波形と実際に観測される波形とが同一かどうかの判断には客観性が求められる。
この観点を踏まえて本研究では、磁気流体波動の中から磁力線にほぼ平行に伝播する 2 種類のアルフヴェン波をとりだした DNLS（微分型非線形シュレーディンガー方程式）を用いて多数の（モデル）ショックレット・データを生成し、ショックレットと非ショックレットとの識別精度の検証を行った。まず、様々な初期条件のもとで DNLS の時間発展によりショックレットデータ（SHD）を生成する。次に、これらをフーリエ変換し、振幅情報を保持したまま位相をシャッフルして逆フーリエ変換することにより、位相サロゲートデータ（PSD）を生成する。パターン認識の一つである畳み込みニューラルネットワーク(CNN)に多数の SHD と PSD を学習させ、これらを正しく判別できるかどうかを検証した。また、正しく判断できなかった場合の波形の特徴について検討した。発表では、解析方法と結果の詳細および今後の展望を述べる。

R008-03
Zoom meeting D ：11/3 AM1 (9:00-10:30)
09:45-10:00

Performance measurements of the particle-in-cell code with adaptive load balancing

#Yosuke Matsumoto
Chiba University

In the last meeting at JpGU, we reported current status of development of our particle-in-cell simulation code: We successfully implemented the recursive multi-section algorithm, which have been used in the cosmological N-body simulations (Makino, 2004; Ishiyama et al., 2009), into the PIC simulation code. Benchmark tests of the Weibel instability showed that this technique is capable of maintaining the workload balance in a controllable way. In addition, it also adapts to the moving injector boundary which is a standard technique for examining collision-less shock simulations. Having these successful early results, we are examining its parallel efficiency with larger numbers of MPI processes. Associated data copies and rather complex inter-process data transfers introduce additional costs which in turn hamper efficient parallel scaling. We need to optimize the MPI transfer algorithm and the frequency of triggering this adaptive balancing. In this presentation, we report detailed algorithms of the MPI transfer for this technique and results from performance measurements on supercomputer systems including Fugaku.

R008-04
Zoom meeting D ：11/3 AM1 (9:00-10:30)
10:00-10:15

Multi-step Boris integrator for non-relativistic E-cross-B drift

#Takayuki Umeda
ISEE, Nagoya Univ.

In the present study, we show that the original (two-step) Boris scheme is the unique solution that satisfies the energy conservation law exactly for the non-relativistic E-cross-B drift. We also show that the original Boris scheme does not satisfy the energy conservation law exactly for the relativistic E-cross-B drift. We propose a new multi-step scheme for the non-relativistic E-cross-B drift with higher accuracy.

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

弱磁化宇宙プラズマ中の固体物体周辺の静電構造に関する粒子シミュレーション

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Simulations of Electrostatic Structure near Solid Bodies in a Weakly-Magnetized Space Plasma

#Yohei Miyake[1)], Wojciech J. Miloch[2)], Solveig H. Kjus[2)], Hans L. Pecseli[2)]
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Interactions between space plasma and solar system solid bodies (airless bodies with no global magnetosphere) have been one of outstanding problems in the space science community, in the context of its application for understanding the plasma environment near the terrestrial moon, asteroids, spacecraft, and small dust grains. A solid object immersed in space plasma absorbs most of impacting plasma electrons and ions, and in some occasions it also releases charged particles such as photoelectrons, secondary electrons, and some other minor charged particles. As a result, the object in space will be electrically charged. The solid surfaces and electric potential of the object also alter the dynamics of charged particles in its vicinity, giving rise to a sheath or wake around it, where the plasma quasi-neutrality is locally violated. It is generally believed that the spatial extent of such non-neutral regions is characterized by the Debye length, the shortest characteristic length in the plasma.
Our particular interest is on a magnetized plasma contacting with solid bodies, the dimensions (D) of which are greater than the average electron gyroradius (R_{eg}) of the environment. Attributed to the strong magnetization of electrons, electric disturbances generated at the solid surface will survive in a long distance along magnetic field lines and extend much farther than the local Debye length of the plasma. Such sufficient spatial extent of the disturbance will support wave-associated phenomena generated away from the bodies. The condition ($D>R_{eg}$) in consideration will be satisfied for some sort of solar-system bodies such as the terrestrial moon in the solar wind, as well as manmade spacecraft in the ionospheric plasmas.
In the present study, spacecraft-plasma interaction in a weakly magnetized plasma is studied with numerical plasma particle simulations. The simulations confirm that a negatively charged satellite will repulse incoming electrons, pushing them off to its sides if the spacecraft is traveling fast enough through plasma. The electrons will be directed along magnetic field lines in jet-like flows that resemble wings in our models. This particular feature is confirmed to extend tens or even hundreds of meters to the sides of the spacecraft, which are much longer than local Debye lengths of the ionospheric plasma. We have dubbed this signature as an electron wings, and reported it as another form of spacecraft interference with in-situ measurements.

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

Full PIC simulations of the surface charging on the nightside of Phobos: The effect of surface-plasma interaction

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The solar wind interaction with an airless body generates surface charging. On the dayside, the surface potential is determined by current balance between incoming solar wind and plasma emitted from the surface (e.g., photoelectrons, secondary electrons). On the other hand, charging process on the nightside is more complex due to the wake forming effect. This effect is basically explained by ambipolar diffusion. Previous studies calculated the potential on the nightside of Phobos using an analytical model based on a self-similar solution [e.g., Farrell et al., 2018]. These show that the potential reaches about -200 V or more on the nightside. However, the details of electromagnetic field and density distribution around the body have not been clarified. In order to understand the process of surface charging, we have calculated the plasma environment around Phobos by self-consistent 2-D particle-in-cell (PIC) simulations.
Our calculations show that the difference of results between the analytic model and PIC simulation becomes large near the body on the nightside. This discrepancy is thought to be resulted from a surface-plasma interaction effect. To assess this effect, we then calculated plasma environment under some different types of the shape of the body.
In the assumption of an ellipse-shaped body, two types of charge separation are clearly identified, which is not seen for a sphere-shaped body. One is the separation at the wake flank and the other is at the sheath near the surface. It means that ion-rich plasma exists near the surface while the electron density exceeds ion density at the wake flank.
We have identified a number of key factors for better understanding surface charging processes on the nightside of Phobos. We will discuss the importance of Debye screening effects to interpret the obtained numerical results.

R008-07
Zoom meeting D ：11/3 AM2 （10:45-12:30）
11:15-11:30

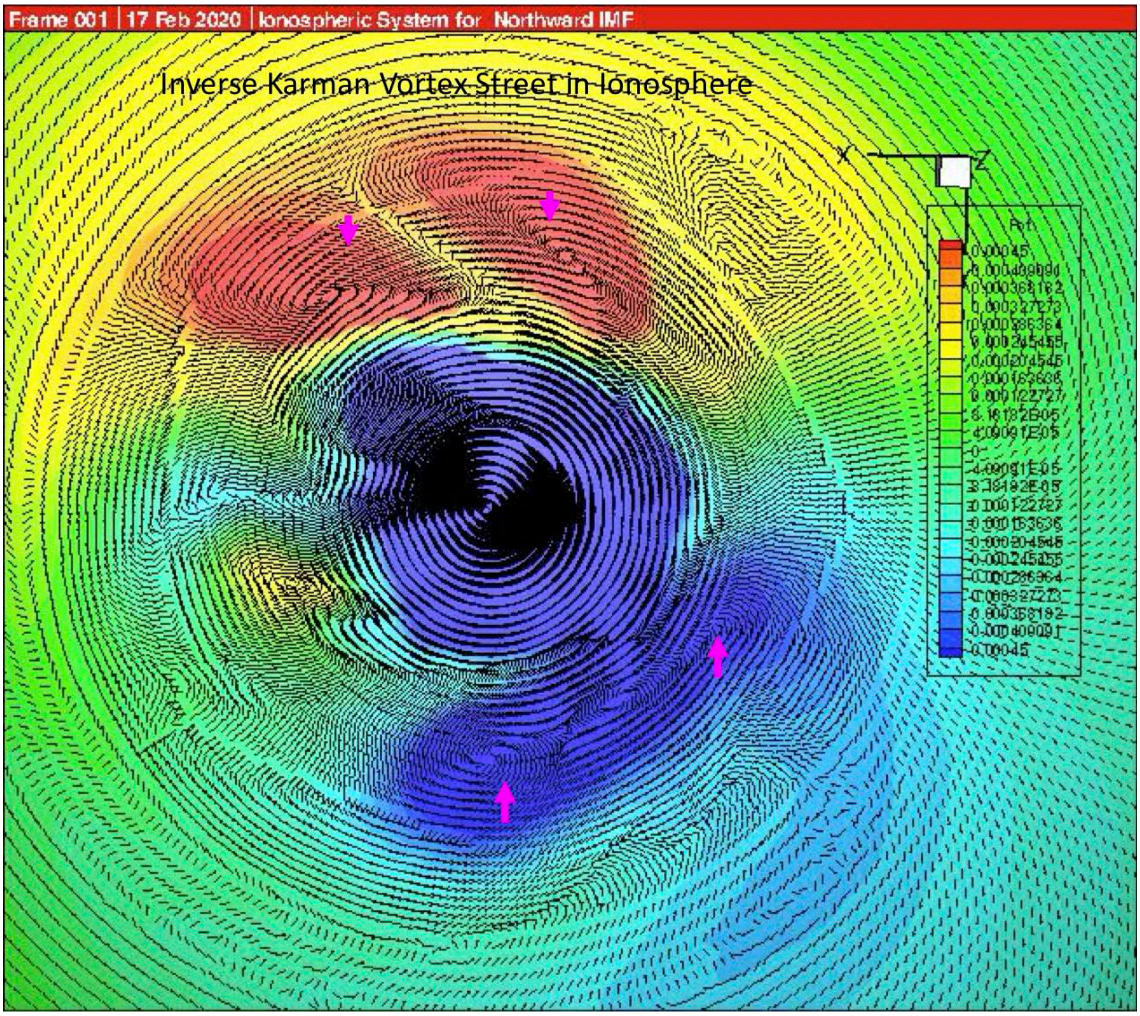
逆と順カルマン渦を介した大域的地球磁気圏のコーヒーレント構造

#蔡 東生
筑波大・シス情

Global Magnetospheric Coherent Structure based on Inverse and Forward Karman Vortex

#DongSheng Cai
ISIS, U Tsukuba

Global magnetospheric coherent structures related to the dynamics of the dayside magnetopause frontier for a northward IMF configuration, are analyzed using global 3D MHD simulations. The main goal is to reach a global synthetic scenario focusing on the formation of 3D unstable/stable structures developed among inside/outside magnetopause and ionosphere in different steps from the dayside to the night side. They are: (i) the transverse Kelvin-Helmholtz (K-H) vortexes are generated along and outside the magnetopause near the dayside region, while other K-H vortexes are generated along and inside the magnetopause; (ii) these vortexes are unstable in one each row, adjust, and evolve into a marginal stable Karman vortex street near the equator; (iii) the inside K-H vortexes extends toward northward/southward to form inverse Karman vortex street in north/south ionosphere; (ii) all rows of vortexes are shed off soon from the magnetopause/ionosphere, respectively; (iv) these forward/inverse Karman vortexes soon are reformed into stable longitudinal (stream-wise) coherent vortexes and survive for long time over large distances x~-130 to 140Re in the magnetotail. All these processes lead to the global and consistent formation of magnetospheric coherent structures.



R008-08
Zoom meeting D ：11/3 AM2 (10:45-12:30)
11:30-11:45

Dynamic profile formation in the high-density helicon plasma

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Helicon plasma is one of the Radio Frequency (RF) plasma sources that can generate high-density (number density 10^{19} m^{-3}) and low-temperature (electron temperature from a few eV to several eV) plasmas by utilizing the helicon wave, i.e., the electromagnetic whistler wave in a bounded geometry [1-3]. The helicon plasma is thought to be useful for various applications including plasma processing, nuclear fusion, and electric thrusters [4].
The helicon plasma production involves various processes such as the wave excitation (the RF antenna - plasma coupling), the wave propagation (dispersion relation), collisional or non-collisional wave damping and plasma heating, ionization of neutral particles, and flux transport of the plasma. Besides these fundamental physical issues, the effects of neutral dynamics on the plasma transport and the maximum plasma density are shown to be significant by experimental as well as theoretical studies.
In our study, we have constructed the self-consistent fluid model including the neutral dynamics. By using this model, we have certified several important temporal behaviors of the power absorption [5], the flux balance [5], density jumps [6] and the neutral dynamics [6] in the high-density helicon plasma, which are consistent with the experimental results [7]. In our presentation, we will discuss the dynamic behaviors of helicon discharge in detail including the effect of the neutral dynamics.
[1] R. W. Boswell, Phys. Lett. 33A, 457 (1970).
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[3] F. F. Chen, J. Vac. Sci. Technol. A 10, 1389 (1991).
[4] S. Shinohara, Adv. Phys.: X 3, 1420424 (2018).
[5] S. Isayama, S. Shinohara, T. Hada and S. H. Chen, Physics of Plasmas, 26, 053504 (2019).
[6] S. Isayama, S. Shinohara, T. Hada and S. H. Chen, Physics of Plasmas, 26, 023517 (2019).
[7] M. Nisoa, Y. Sakawa and T. Shoji, J. Appl. Phys., 40, 5A (2001).

R008-09
Zoom meeting D ：11/3 AM2 （10:45-12:30）
11:45-12:00

デカメータ波電波による天の川銀河中心巨大ブラックホールバイナリー情報の追試

#大家 寛
東北大・理・地物

Tracing Study on the Decameter Radio Wave Codes Suggesting Super Massive Black Hole Binary at the Center of Our Galaxy

#Hiroshi Oya
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1 Introduction
Based on the analyses of the decameter radio wave signals observed in June 2016 and 2017, by the Tohoku University Decameter Radio Wave Long Baseline Interferometer, we have arrived at the conclusion that there are super massive black hole binary that consist of Gaa with mass of 2.27 + - 0.02 million solar mass and Gab with mass of 1.94+ - 0.09 million solar mass; Gaa and Gab are taking binary orbits with period 2200+ - 50 sec with speeds of 18% and 22 % of the light velocity, respectively. To accept the existence of such an extreme binary system we meet the paradigm problem of the generation of the gravitational waves. That is, we should accept that there could be no gravitational wave generation for the case of the super massive black holes. To proceed the study in this direction, it is required to confirm whether the decameter radio wave codes that becomes origin of the super massive black hole hypothesis are correct or not. For this purpose we continue the decameter radio wave observations in 2018 and 2019; by the analyses of data observed in these periods following confirmations are provided.
2. Observation
The observations are made for the two category of modes; that is , one is a category where the Galaxy center is observable and the other is a category where no Galaxy observable. Because of extremely low SN ratio where the signal level is lower than 1 hundredth of the background noise level, we should be extremely careful about elimination of the system noise and modulation of data by artificially generated signal. By applying completely same procedure to the data handling for both categories of observation data we can eliminate such additional disturbances by subtracting result for non Galaxy case (NGA-n) from Galaxy observation case (GA-m,). With the datasets observed in 2016, and in 2017 we prepared 8 data sets 1) 2016 Obs. (GA-1,NGA-1) (GA-2 , NGA-1); 2); 2017 Obs. (GA-3,NGA-2), (GA-4 , NGA-2); 3) 2018 Obs.(GA-5,NGA-3), (GA-6 , NGA-3);4) 2019 Obs. (GA-7,NGA-4), (GA-8 , NGA-4), The data set GA-m and NGA-n consist of 7 night observations with 5 hour observation periods for each night.
3. Results of Analyses
To search for the signal that are buried in large background noise the FFT results are averaged over 864 independent cases for each observation night data. In term of relative value, the average FFT level approach to S+N=2E-2 where S and N are signal and noise level, respectively. When we average over 7nights, the results are given by S+N/(7^0.5)=7E-5 (eq. 1). By adding data in 2018, and 2019, we can take average of 8 cases for the case of (eq.1) as S+N/((7x8)^0.5)=4.2E-5 (eq,2). From (eq.1) and (eq.2) we finally obtain N=1.14E-4 and S=2.66E-5. Before approaching this step FFT results are averaged over 864 times then original S to N ratio becomes 1 to 126.
4. Conclusion
Through the above described procedure we have clearly confirmed the existence of the signal part in FFT results by separating from large background noise. From identical portion of FFT result spectra (GA-m, NGA-n) then we can find the parameter of BH binary system using simulation methods as has been made in the published paper.

１、序 本研究(1)では 2016 年、2017 年いずれも 6 月に、東北大学デカメータ波電波長距離干渉計により、21.86MHz で実施された観測データに基づき特異な電波パルスコードを見出しそのコードが二種のスピン周期 173+ - 1sec,（Gaa と命名） 及び 148+ -1sec （Gab と命名）を示す Kerr ブラックホールに起源をもつこと、その周期がバイナリーの公転周期 2200+ - 50sec で周波数変調を受けていることが明らかにされた。周波数変調率より Gaa は光速度の 18%, Gab 22% (誤差+ - 0.5%)で周回することが判明し、円形ケプラー軌道で軌道面を銀河面と仮定するとき、Gaa 及び Gab の質量は太陽質量単位で、それぞれ(2.27+ - 0.02.2)E6 及び (1.94+ - 0.09)E6 （E6 は 10 の 6 乗） となる。本研究の結果重力波の発生理論に従えば重力波放射量は多く、短時間に消え、存在が否定される。逆に矛盾に対し、超巨大ブラックホールでは重力波は事象限界で進行を停止し、外部への重力波の放射がないこと議論の余地が残されている。従って超巨大ブラックホールバイナリーの提言に至った観測とデータ解析の正しさは追試されねばならない。この目的で本研究ではさらに 2018 年及び 2019 年の 2 期、主に 4 月から 7 月にかけての観測を実施し解析を行った、本論はその成果の報告である。
２．観測
観測は天の川銀河中心の出現時と同銀河中心が天空にない時点での２つのカテゴリーの実施をしている。対象データは超低 SN 比現象（SN 比 1/100 以下）で、多数回平均を必要とし、統計的再現性を高めるために、わずかなシステム雑音および方位決定のための解析上持ち込むフリンジ関数は消去されねばならない。このため全く同じ受

信システムと解析法を、銀河中心が天空にない時点での観測データに適用することが不可欠となる。すでに論文発表を行った 2016 年及び 2017 年観測分を再記すると本研究対象のデータセットは以下の通りとなる。なお、銀河中心出現時の観測分を GA-m、銀河中心の出現していない場合の観測分を NGA- n と表現し、データ解析で用いた差し引きペアーを（GA-m, NGA-n）と表す。

１、2016 年　(GA-1,NGA-1)、及び(GA-2, NGA-1)
２、2017 年　(GA-3,NGA-2)、及び(GA-4,NGA-2)
３、2018 年　(GA-5,NGA-3)、及び(GA-6, NGA-3)
４、2019 年　(GA-7,NGA-4)、及び(GA-8,NGA-2)

GA-m, NGA-n はそれぞれ、データ取得時のサンプリング周期が帯域 100Hz に対し 3kHz とし、各夜 5 時間の観測で７夜分よりなるが、2019 年４月 24 日以降、サンプリング周期が 2.5kH としなるため８夜分をそれぞれ１データセットとしている。

3. データ解析結果

各観測夜 5 時間のデータに対する最長周期 8196sec の FFT 解析は独立データはチャンネル数３、周波数 3、解像度内での方位の掃引数３、各チャンネルでの独立データ数 32 セットから合計 864 平均回数を得ていて、その結果は、相対比で表現する場合、平均の信号 S、雑音 N に対し S+N＝２E-４に達する。それぞれ７夜分相当を平均した場合、S＋N/(7^0.5)＝７E-５（1 式）で　S<<N の場合の１/(7^0.5) に近い。さらに今回新たに加わった４例を加え合計８例で平均化を進めると､S＋N/(56^0.5)＝4.2E-５（2 式)が得られた｡1､2 式より S=2.66E-5 及び N=1.15E-4　となり、この評価の方程式にいたる前に FFT 結果を 864 回平均しているため FFT 解析出発点での S 対 N 比は 1 対 126 となっていることも判明した。

４・結論

銀河中心から到来するデカメータ波は膨大な雑音性の電波であるが、そこに微弱ながら確かに信号コードが恒久的に発せられていることが、2016 年及び 2017 年観測に加え 2018 年及び 2019 年の観測データを加えることで統計的な確かさをもって検証された。天の川銀河系中心にはこのコードの解読結果が示した超巨大ブラックホール・バイナリーの存在が保証される。

(1)Oya, H. (2019)　https://www.terrapub.co.jp/e-library/9784887041714/index.html

R008-10
Zoom meeting D ：11/4 AM1 (9:00-10:30)
09:00-09:15

Simulation study of the energetic electron precipitation in the polar region considering the magnetic mirror force

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It has been widely accepted that whistler-mode chorus emissions play important roles in scattering energetic electrons into the loss cone in the magnetosphere. Recent studies suggest that the periodicities of pulsating aurora can be explained by the characteristic time scale of chorus. For the quantitative study of the relation between chorus and auroral activities, numerical experiments enable us to simulate realistic properties of precipitation and resultant auroral emissions in the polar ionosphere.
In the present study, we developed a simulation code for the motion of energetic electrons with the mirror force acting on the precipitating electrons taken into account, which enables us to solve the variation of the pitch angle of the electrons during their precipitation. We also employ a module computing the altitude distribution of the ionization rate by precipitating energetic electrons in the polar ionosphere. We use the Monte Carlo method to derive the ionization rate by the precipitating electrons, as has been used in previous studies [e.g., Hiraki and Tao, 2008]. By combining the developed modules, we study the time scale and intensity of the ionization rate due to the energetic electron precipitation by chorus emissions. Simulation results show that the influence of the mirror force on the altitude profile of ionization is significant for electrons with high initial pitch angle, corresponding to the pitch angle close to the loss cone. The effect of the mirror force results in the broadening of the altitude profile of the ionization upward due to the reflection of mirroring electrons. Simulation results with energetic electrons whose kinetic energy is larger than 100 keV show that the formation of the secondary peak around the mirror point in the altitude profile of the ionization rate. We discuss the energy dependence and the effect of the mirror foce on the altitude profile of the ionization rate quantitatively.

R008-11
Zoom meeting D ：11/4 AM1 (9:00-10:30)
09:15-09:30

Particle simulation of VLF triggered emissions in a parabolic magnetic field

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We perform one-dimensional electromagnetic particle simulations to study fundamental processes of VLF triggered emissions in the inner magnetosphere. Approximating the dipole magnetic field by a parabolic magnetic field, we assume a cylindrical model to describe particle dynamics along the magnetic field line. We put antennas perpendicular to the background magnetic field at the magnetic equator and oscillate currents with the fixed frequencies for the different duration and the different amplitudes. We observe triggered emissions with frequency variations from the triggering waves with 0.40 of the electron cyclotron frequency. We have analyzed the nonlinear wave-particle interaction in the vicinity of the magnetic equator in detail. In the generation process of triggered emissions, counter-streaming energetic electrons form nonlinear resonant currents causing the frequency variation and growth of triggering wave packets, resulting in the formation of subpackets with slightly higher frequencies. The nonlinear triggering process is repeated many times with gradually increasing frequencies of subpackets, forming a chorus element of large frequency variation. By changing the wave amplitude and frequency of the triggering wave packet, we can control the occurrence of rising tone emissions.

R008-12
Zoom meeting D ：11/4 AM1 （9:00-10:30）
09:30-09:45

一様磁場におけるホイッスラーモード・トリガード放射の電磁粒子シミュレーション

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Electromagnetic particle simulation of whistler mode triggered emissions in a homogeneous magnetic field

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We perform a one-dimensional electromagnetic particle simulation in a uniform magnetic field to study the initial stage of the generation process of whistler-mode triggered emissions at the equatorial magnetosphere. To find the generation of whistler-mode waves by triggering waves in the simulation system, we drive two orthogonally aligned antennas by right-handed polarized external currents oscillating with frequencies below the electron cyclotron frequency. During the propagation of triggering whistler-mode waves, we inject energetic electrons into the simulation system. After the injection, we find the generation of new emissions as the result of the interaction between the triggering waves and the injected energetic electrons. The triggered emissions have both rising-tone and falling-tone structures. We report characteristics of the nonlinear wave growth and its threshold condition in the homogeneous magnetic field, and present analyses of particle dynamics in the velocity phase space based on the nonlinear wave growth theory.

ホイッスラーモード・トリガード放射の初期の生成過程の研究のために 1 次元電磁粒子コードによるシミュレーションを行う。 シミュレーションでは地球磁気圏の赤道部分でおこる物理過程を調べるために一様磁場を設定する。トリガリング波の生成には右旋回する外部電流を利用する。電子のサイクロトロン周波数以下の周波数で励振することによってホイッスラーモードのトリガリング波を実現することができる。このトリガリング波がシステム内を伝搬している際に高エネルギー電子をシステム内に一様に注入する。 このモデルにおいて新しいパケット（トリガード放射）の生成を確認した。トリガード放射のパケットは周波数上昇するパケットと周波数減少するパケットの 2 種類が含まれていた。このトリガード放射のパケットの生成過程を調べるために粒子の速度空間における運動の解析を非線形成長理論に基づいて行う。そして、一様磁場において生成されるトリガード放射のパケットの非線形成長や成長に必要な振幅の閾値の特徴を報告する。

R008-13
Zoom meeting D ：11/4 AM1 (9:00-10:30)
09:45-10:00

Study of the nonlinear scattering of energetic electrons into the loss cone by coherent whistler-mode waves

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Whistler mode chorus emissions play important roles in the pitch angle scattering process of energetic electrons. Previous studies revealed high correlation of the wave amplitude of chorus emissions to both auroral luminosity [Nishimura et al, 2010] and the electron flux in the loss cone [Kasahara et al, 2018]. However, detailed processes scattering electrons into the loss cone are still unclear. Conventionally, the pitch angle scattering of energetic electrons has been considered as a diffusion process based on the quasi-linear theory. On the other hand, Kitahara and Katoh (2019) has theoretically and numerically revealed that coherent whistler-mode waves effectively trap small pitch angle electrons and change their pitch angle away from the loss cone. Further investigation for the detailed process of the pitch angle scattering by chorus emissions has been required.
To clarify the physical process of scattering electrons into the loss cone, we have updated the test particle code of Kitahara and Katoh (2019) in order to compute the motion of a large number of electrons by a massively parallelized supercomputer system. By using the developed code, we compute the motion of energetic electrons moving along a field line under the presence of a packet of monochromatic whistler-mode waves generated at the magnetic equator. We assume both the wave amplitude and frequency of whistler-mode waves; the wave frequency 0.3 times of the electron gyrofrequency at the magnetic equator, and wave amplitude 0.01% ~ 0.1% of the background magnetic field intensity at the equator (B_{0eq}). We also assume that the plasma frequency is equal to 4 times of the electron gyrofrequency at the magnetic equator and is uniform along a field line. We calculate the motion of 17,212,500 energetic electrons, whose initial energies and equatorial pitch angles are assumed to be in the ranges of 10 ~90 keV and 5 ~ 89 degree, respectively.
Our simulation results show that electrons not only near the loss cone but also in the large pitch angle range are scattered into the loss cone and contribute to the loss cone flux. We evaluate the ratio of the number of electrons inside/outside the loss cone quantitatively. We obtained the ratio 0.5 for the wave amplitude 0.1% of the background magnetic field. We also analyzed the trajectories of electrons scattered into the loss cone in order to investigate the physical process responsible for the pitch angle scattering. According to Omura et al. (2008), we estimated the size of the trapping region in the velocity phase space, in other words the θ - ζ phase space, where θ is the difference between the parallel component of the electron velocity and the resonance velocity, and ζ is the relative phase angle between gyrophase and wave phase, which is useful to understand the changes of the pitch angle and kinetic energy of resonant electrons.
Based on the results, we categorize 2 types of the nonlinear pitch angle scattering; resonant scattering and non-resonant scattering. Resonant scattering decreases electrons' pitch angle greatly. The range of pitch angle change is almost corresponding to the electromagnetic electron hole size. This feature is consistent with the report by Hikishima (2010) as "non-linear scattering". Non-resonant scattering makes electrons of a few degrees larger than the loss cone fall into the loss cone. Even if electrons do not satisfy the resonance condition, the pitch angle of electrons is perturbed by the wave electromagnetic field and therefore some of electrons are scattered into the loss cone.
For the case of the wave amplitude 0.1% of the background magnetic field, we further analyzed the origin of electrons scattered into the loss cone. The simulation result revealed that half of electrons inside the loss cone had their initial pitch angle near the loss cone (α_{LC}) and that others had a few to twenty degree away from the loss cone (α_{NS}), indicating the role of the resonant nonlinear scattering. We found that α_{NS} is energy dependent; 15 and 10 degree for 20 and 30 keV electrons, respectively. On the other hand, electrons whose pitch angle between α_{LC} and α_{NS} do not contribute the electron flux inside the loss cone, because of the effect of anomalous trapping of low pitch angle electrons [Kitahara and Katoh, 2019]. Focusing on the influence of the wave amplitude, the number of electrons scattered into the loss cone by non-resonant scattering increases as the wave amplitude increases. We also found the increase of the number of electrons scattered into the loss cone from the larger pitch angle range by resonant scattering. Based on the simulation results, we discuss how the waves amplitude affects loss cone flux and roles of nonlinear effect in the pitch angle scattering of energetic electrons.
References
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[5] Hikishima, M., Y. Omura, and D. Summers (2010), Microburst precipitation of energetic electrons associated with chorus wave generation, Geophys. Res. Lett., 37, L07103, doi:10.1029/2010GL042678.

R008-14
Zoom meeting D ：11/4 AM1 (9:00-10:30)
10:00-10:15

Dependence of Nonlinear Wave Growth of Hiss Emissions on Plasma Simulation Parameters

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A recent particle simulation has successfully reproduced the generation of plasmaspheric hiss emissions with fine structures in accordance with the nonlinear wave growth theory. In this study, we examine the performance of nonlinear growth of hiss emissions under different parameters by running the one-dimensional KEMPO code with a parabolic variation of background magnetic field. We find that as the total number of particles is reduced, the amplitude of hiss emissions increases because of the enhancement of thermal fluctuations. As the density of hot electrons decreases, we find that wave amplitude goes through the nonlinear growth stage with a smaller magnitude. The nonlinear wave growth theory demonstrates that wave only grows when its amplitude is between the threshold magnitude and optimum magnitude. We find that for a lower density of hot electrons, the overlap between the threshold amplitude and optimum amplitude becomes smaller, which leads to no obvious growth of wave amplitude at a specific point. By implementing a bandpass filter, we obtain instantaneous frequencies of hiss emissions with different densities of hot electrons at the same location. We find that the growth of wave amplitude spreads to higher frequency parts for a lower density of hot electrons. As we decrease the gradient of background magnetic field, we find that the threshold amplitude becomes smaller while the optimum amplitude remains unchanged. Based on the various examinations, we obtain a comprehensive understanding of properties of hiss emissions.
Reference:
[1] Hikishima, M., Omura, Y., & Summers, D. (2020). Particle simulation of the generation of plasmaspheric hiss. Journal of Geophysical Research: Space Physics, 125, e2020JA027973. https://doi.org/10.1029/2020JA027973

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

A method for obtaining steady-state solutions to the particle transport equation

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Understanding the transport of energetic charged particles is a crucial problem with numerous applications in space and astrophysical plasma physics. Classical Parker's transport equation describes convection with the background plasma flow and spatial diffusion with respect to it. It has been widely used in modeling, e.g., particle acceleration at collisionless shocks, propagation of energetic particles in the heliosphere and beyond. The diffusion-convection equation is obtained by assuming pitch-angle isotropy from the more fundamental transport equation derived by Skilling (Skilling 1975), often called the focused transport equation. It can be used in a broader range of applications in which finite pitch-angle anisotropy is crucial. On the other hand, it is, in general, difficult to solve the focused transport equation with an analytic approach due to its higher dimensionality, and one often resorts to numerical methods.
In this study, we are only concerned with the steady-state solution of the transport equation under given boundary conditions, which is often the case in practical applications. One of the most straightforward and naive approaches is to integrate the time-dependent transport equation in time for a sufficiently long time such that the numerical solution approaches the steady-state. This approach is, however, clearly not the optimum in terms of numerical efficiency. The required numerical cost increases quite substantially when the system involves multiple, vastly different time scales. The reason for this is that an explicit time-integration scheme needs to resolve the shortest time scale, whereas the steady-state should be obtained well after the longest time scale in the system is reached.
We here present a practical and efficient numerical method to obtain the steady-state solution to the transport equation. Since the equation is linear, the discretized form can, in general, be represented as a matrix equation. The steady-state solution is simply obtained by inverting matrix using routines provided by standard well-optimized numerical libraries. The problem thus essentially reduces to the discretization strategy. We demonstrate that accurate numerical solution can be obtained by using the pseudo-spectral method with an appropriate choice of basis functions. More specifically, we expand the solution with the Chebyshev polynomials for each dimension and represents the matrix using the pseudo-spectral approach. We will discuss the basics of the proposed method, application to the shock acceleration theory, and its possible extensions.

R008-16
Zoom meeting D ：11/4 AM2 (10:45-12:30)
11:00-11:15

A fluid closure in wavenumber space to model cyclotron resonance of hot magnetized plasmas

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Physical models of plasmas can be roughly divided into two types: fluid models and kinetic models. Fluid models such as MHD describe large scale phenomena well and require relatively less computational resources in numerical simulations. However, usual fluid models do not describe wave-particle interactions of collisionless plasmas. Therefore, ad hoc resistivity terms are added in diffusion regions such as the vicinity of neutral sheet in magnetic reconnection. Kinetic simulation models, especially particle-in-cell methods are often used to model small scale phenomena but the slow convergence property and the grid size restriction make it difficult to apply to three-dimensional macroscopic simulations.
A fluid description that contains kinetic effects is not only convenient for numerical simulations but may also make theoretical discussions of the interaction of different scales easier because of the reduced degree of freedom.
A method to take into account Landau damping of electrostatic waves was developed by Hammett & Perkins [1]. They approximated the highest order velocity moment of Vlasov equation (the heat flux term when up to the second-order moment is taken) by a linear combination of lower order terms (number density, fluid velocity, and pressure) in the wavenumber space so that the resulting dispersion relation resembles the dispersion relation given by linear kinetic theory (the description with plasma Z-function). This cannot be achieved by local dissipation terms.
By following the same strategy, we have extended the model to take into account cyclotron resonance effect for electromagnetic waves propagating parallel to the ambient field. We solve the time evolution of the off-diagonal component of the pressure tensor by approximating the relevant component of the heat flux tensor. This model roughly reproduces the kinetic dispersion relation of hot magnetized plasmas. The theory and a couple of applications will be shown.
[1] G. W. Hammett and F. W. Perkins, Phys. Rev. Lett. 64, 3019 (1990).

R008-18
Zoom meeting D ：11/4　AM2　(10:45-12:30)
11:30-11:45

リング状速度分布をもつ高速イオンによる低域混成波不安定性の非線形発展に関する粒子シミュレーション及び高速イオン注入が不安定性に及ぼす影響の評価

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PIC simulation on lower hybrid waves instabilities driven by ring-like energetic ions: role of energetic-ion injection.

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Instabilities driven by energetic ions are important issues both for space and fusion plasma. Lower hybrid waves (LHWs) are excited by energetic ions with a ring-like velocity distribution perpendicular to the magnetic field. LHWs contribute ion and electron acceleration. For example, in the auroral region of the Earth's magnetosphere, LHWs driven by precipitating ions can contribute oxygen ion energization. There are many simulation studies for LHWs solving an initial value problem but studies including an energetic-ion injection effect are rare.
In this study, we focus on non-linear developments of lower hybrid waves instabilities driven by ring-like energetic ions: time evolution of wavenumber, velocity distribution, its gradient, and energy transfer. In the real situation, energetic ions should be continuously injected where LHWs are observed. Therefore, we also investigate and discuss a difference between an initial value problem and energetic-ion injection model.

高速イオンが引き起こす不安定性は宇宙プラズマや核融合プラズマに共通する重要な物理過程である。高速イオンが磁場に対して垂直方向にリング状の速度分布を持つ場合、不安定性が生じ低域混成波が励起されることが知られている。低域混成波はイオン、電子の両方を加速すると考えられており、例えば、地球磁気圏オーロラ帯では降下イオンによって駆動された低域混成波によって酸素イオンが加速されることが観測によって明らかになっている。低域混成波に関するシミュレーション研究は様々な領域でされているが、高速イオンの注入効果を含めたシミュレーションは殆どされていない。
本研究では、核融合プラズマにおける典型的なパラメータを用いて低域混成波不安定性の非線形発展を調べる。特に不安定性の前後におけるエネルギー、速度分布、波数など種々の物理量がどのように変化するかに着目する。また、低域混成波が観測されている場所では、高速イオンは継続的に注入されていると考えられることを踏まえて、高速イオンを注入することで不安定性にどのような影響を与えるかについても考察する。

R008-19
Zoom meeting D ：11/4 AM2 (10:45-12:30)
11:45-12:00

Intermediate shocks: real or imaginary?

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One of the most fundamental yet unsettled issues in magnetohydrodynamics (MHD) is the presence (or absence) of the so-called intermediate shock waves. Just as the fast and slow shocks may be considered as the steepened, finite-amplitude versions of their linear wave counterparts, the intermediate shocks may be realized via steepening of finite amplitude intermediate waves, as first demonstrated by high-precision numerical simulations (Wu, 1987). The intermediate shocks satisfy the Rankine-Hugoniot conditions, upstream and downstream flows are respectively supersonic and subsonic to the intermediate speed, and the entropy increases across the shock. Nevertheless, the intermediate shocks were considered non-existent in reality (Jeffrey and Taniuti, 1964; Kantrowitz and Petschek, 1966) as they do not satisfy the "evolutionary conditions," i.e., infinitesimally small perturbations given to the shock cannot be resolved as a superposition of waves outgoing from the shock, due to the lack of degrees of freedom (=number of waves).

On the other hand, it has been proposed that this entire argument can drastically be altered when dissipation is included in the plasma, no matter how small the dissipation may be (Hada, 1994; Markovskii, 1998; Inoue and Inutsuka, 2007). When dissipative wave modes are included, arbitrary perturbations given to the shock can be expressed as a superposition of outgoing wave modes. Therefore, the intermediate shocks are evolutionary in dissipative MHD, and hence, in a real plasma.

In the presentation, by solving the boundary value problem, we will show that the waves incident to the intermediate shock generate waves in other modes (including the dissipative modes) by a "strong" mode conversion, and the distribution of waves can be uniquely determined across the shock. After making a remark on the uniqueness to the MHD Riemann problem (Wu, 1987; Takahashi, 2013), we will argue that it is worthwhile making an effort to detect the intermediate shocks by spacecraft observations (Chao 1993, Feng and Wang, 2008; ibid, 2009), given the recent development of accurate and fine resolution measurements and data analysis techniques.

R008-20
Zoom meeting D ：11/4 PM1 （13:45-15:30）
13:45-14:00

磁化プラズマ衝撃波の大型レーザー実験と数値実験

#松清 修一
九大・総理工

Gekko XII experiment and numerical simulation on magnetized collisionless shock

#Shuichi Matsukiyo
ESST Kyushu Univ.

Shock reformation is a phenomenon unique to a collisionless system, which is a periodic collapse and formation process of the shock front occurring even when the upstream plasma is completely uniform and steady, and contributes to the generation of large amplitude waves and to produce particle acceleration as well. Related with the gyro motion of the ions reflected at a shock, the structures so-called foot, ramp, and overshoot are cyclically formed and destroyed. It was theoretically predicted in the 1980s by using computer simulation, but has not been proven yet. In this research we aim at the demonstration of shock reformation, which is not realized by the in-situ observation in space, by using the Gekko XII high power laser experiment at Institute of Laser Engineering (ILE), Osaka University. In the experiment in 2019 we could successfully apply 3.8T ambient magnetic field in the experimental system for the first time. The observed shock clearly contains inner structures not seen in our previous experiments without ambient magnetic field. We identified the so-called overshoot and foot in the shock transition region. In addition, a precursor of a shock modified by the ambient magnetic field is also identified in the early stage after the main laser shot. The results are compared with one-dimensional PIC simulation customized for the experiment.

R008-21
Zoom meeting D ：11/4　PM1 （13:45-15:30）
14:00-14:15

無衝突衝撃波の大型レーザー実験に向けた数値シミュレーション:多イオン種の効果

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Numerinal simulation for high power laser experiment of collisionless shock: Effect of multi ion species

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We are conducting collaborative research with the Institute of Laser Engineering (ILE) at Osaka University on collisionless shock experiment. In the experiment, a high-speed target plasma produced by ablating a target plate using a high power laser sweeps a gas plasma to generate a shock wave in the gas plasma. A nitrogen gas is used in the experiment. From the analysis of experimental data, an ionized nitrogen gas plasma contains various nitrogen ions with different valence of ions.
To compare the experimental results with numerical simulation, we have developed full particle-in-cell simulation code. However, our previous simulations treat only single ion species. In this study we perform a shock simulation with taking the effect of multi-ion species (different valence of ions) into account.

我々は、大阪大学レーザー科学研究所(ILE)との共同研究により、無衝突衝撃波の実証的研究を行っている。実験では、平板ターゲットを大型レーザーでアブレーションしてできる高速ターゲットプラズマが、超音速でガスプラズマを掃きためることで、ガスプラズマ中に衝撃波を生成する。実験では窒素ガスを用いるが、これが電離してできる窒素ガスプラズマは様々な価数の窒素イオンを含むことが実験データから示されている。
これまで実験との比較のために行ってきた数値実験(PIC 計算)では 1 種類のイオン種しか含んでおらず、そのためガスプラズマ中を伝搬する衝撃波の振る舞いを正確に再現できていない恐れがある。本研究では、多イオン種(多イオン価数)の効果を検証するため、ガスプラズマとして異なる価数を持つ複数のイオン種を含めた衝撃波の数値実験を行う。

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

無衝突磁化プラズマ衝撃波の大型レーザー実験：外部磁場強度依存性

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High power laser experiment of collisionless magnetized shock: Effect of ambient magnetic field strength

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A collisionless shock in space plays a role of an energy converter. However, the details of structure of its transition region, where energy conversion occurs, have been still poorly understood. Shock reformation is known as an energy conversion process occurring in a collisionless system. A shock front is cyclically formed and destroyed due to the gyro motions of ions reflected at the shock. While it was predicted theoretically in the 1980s, the reformation has not been fully proven through in-situ observations so far. In this study, we aim to demonstrate the shock reformation by using high power laser experiment (Institute of Laser Engineering, Osaka University).
Last year, we successfully applied almost homogeneous ambient magnetic field of 3.8T in the region of interest in a chamber and produced a magnetized shock. Using self-emission streak measurement and Thomson scattering measurement, we observed clearly different plasma density structures between magnetized and unmagnetized cases. On the other hand, a cyclic nature of the shock reformation was not clear probably due to insufficient strength of the applied ambient magnetic field. In the planned experiment this year, we will try to apply 5.6T ambient magnetic field. The results will be compared with those of the last year to discuss the variation of shock structure and the signatures of shock reformation due to the difference of applied magnetic field strength.

無衝突衝撃波は宇宙空間で高効率のエネルギー変換器の役割を担っている。がエネルギー変換が起こる変位層の構造の詳細はいまだによく理解されていない。無衝突系に特有のエネルギー変換過程として、衝撃波リフォーメーションが知られている。衝撃波リフォーメーションとは、衝撃波面で急激に立ち上がる磁場と電場によって反射されるイオンのジャイロ運動に伴って周期的に発現する衝撃波面の崩壊・再形成過程である。1980 年代に理論的に予測されたが、宇宙でのその場観測による実証は未だに実現されていない。本研究では、マルチスケールでの観測が可能で、再現性に優れたレーザー実験（大阪大学レーザー科学研究所）により、衝撃波リフォーメーションの実証を目指す。
我々は昨年、チャンバーの検査領域に 3.8T のほぼ一様な外部磁場を印加し、磁化プラズマ衝撃波の生成実験に成功した。自発光ストリーク計測およびトムソン散乱計測によって、外部磁場を印加した場合としなかった場合で明らかに異なるプラズマの密度構造をとらえた。しかしながら、磁場強度が不十分で、リフォーメーションの周期性をとらえるには至らなかった。本年 10 月に予定している実験では、5.6T の外部磁場の印加を目指す。昨年度の結果と比較し、磁場強度の違いによる衝撃波構造の変化、リフォーメーションの兆候の有無について議論する。

R008-23
Zoom meeting D ：11/4 PM1 （13:45-15:30）
14:30-14:45

交差する 2 衝撃波による宇宙線加速

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The DSA with two crossing shocks

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One of the most widely accepted mechanisms for producing high-energy particles (cosmic rays) is the diffusive shock acceleration (DSA). In this process, cosmic rays are scattered by turbulence upstream and downstream of the shock, repeatedly cross the shock, and gain energy by the effect of adiabatic compression. Although the DSA with a single shock has been studied intensively, that with multiple shocks is not well understood. Recently, the DSA with two parallel shocks was studied by Nakanotani et al. (2018). Here we extend their analysis to the case with two crossing shocks.
By performing test particle simulations in the background of two crossing hydrodynamic shocks, we found that the cosmic rays can be accelerated more efficiently than the case with two parallel shocks. This is because, in a single shock or a series of multiple parallel shocks, the background flow is compressed only along the flow direction, while in a system with two crossing shocks, the flow can be compressed in transverse directions as well. In the presentation, we will discuss details of our simulation method and result.

宇宙線の加速機構の有力候補の一つとして、衝撃波統計加速（フェルミ加速）がある。宇宙線が、衝撃波周辺に存在する大振幅の磁気流体乱流により散乱され、衝撃波の上流域・下流域を行き来することによって結果的に断熱圧縮をうけて加速されるというものである。単一の衝撃波による加速機構は長年研究されてきたが、複数の衝撃波による加速の研究は多くない。近年、Nakanotani et al. (2018) により 2 つの互いに平行な衝撃波による加速の研究が行われた。本研究ではこれをさらに発展させ、2 つの交差する衝撃波による粒子加速現象を明らかにすることを目的とする。背景場として中性流体の衝撃波交差構造を仮定し、テスト粒子計算により粒子の分布関数、特にそのベキ指数について調べた。2 つの衝撃波が交差する構造の中では、単一衝撃波の場合はもちろん、互いに平行な 2 つの衝撃波の場合と比較しても、より高効率な加速が起こる。これは、単一衝撃波や 2 つの互いに平行な衝撃波の場合、圧縮は流れの方向である 1 方向にのみ生じるが、2 つの衝撃波が斜めに交差する場合には、複数方向の圧縮を受けるためである。交差する衝撃波系内での DSA により、よく知られた限界ベキ指数の上限を越えるハードなスペクトルが得られることを示す。

R008-24
Zoom meeting D ：11/4 PM1 (13:45-15:30)
14:45-15:00

Electron scattering and acceleration at quasi-perpendicular shock: Comparison between PIC simulation and MMS observation

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Non-thermal electrons with power-law energy spectra are directly observed at Earth's quasi-perpendicular bow shock. Magnetospheric Multiscale (MMS) spacecraft, with the high time resolution of electron measurements, give us an opportunity to reveal electron scattering and acceleration processes at the Earth's bow shock. In fact, Oka et al. (2017, 2019) reported in-situ evidences of pitch-angle scattering of non-thermal electrons by whistler waves using MMS data.

We have performed a PIC simulation of quasi-perpendicular collisionless shock to apply the Earth's bow shock. Our PIC simulation has reproduced energetic electron features reported by Oka et al., (2017, 2019) as follows: (1) broadening of the upstream pitch-angle distribution toward the shock, (2) power-law energy spectrum in the shock transition region, (3) burst of energetic electron in the foot region, and (4) electron hole in the downstream pitch-angle distribution. To understand these electron features, we analyze the trajectories of scattered/accelerated electrons in detail. We will discuss the electron acceleration related with the shock drift acceleration. Also, we will discuss the electron burst associated with the shock reformation, as previous PIC simulations reported (Lembege and Savoini, 2002; Matsukiyo and Scholer, 2012).

R008-25
Zoom meeting D ：11/4 PM1 (13:45-15:30)
15:00-15:15

Synchrotron Maser Emission and Associated Particle Acceleration in Relativistic Shocks

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Relativistic shocks are ubiquitous in the universe, in which synchrotron maser instability produces ultra-intense electromagnetic waves. Recent 1D simulations show that longitudinal electrostatic waves, which are called wakefields, are induced in the wake of the large-amplitude electromagnetic precursor waves and that nonthermal particles are generated during the nonlinear collapse of the wakefields (Lyubarsky 2006; Hoshino 2008). This particle acceleration may explain the origin of ultra-high-energy cosmic rays (Chen et al. 2002).
Although the synchrotron maser instability in the context of relativistic shocks are important for the cosmic ray acceleration, it has so far been discussed solely with one-dimensional simulations (e.g., Langdon et al. 1988) and it is not well known whether the same mechanism can operate in more realistic multidimensional systems. However, our high-resolution 2D PIC simulations (Iwamoto et al. 2017, 2018) showed that the wave emission continues with substantial amplitude for the first time. We confirmed that the large-amplitude electromagnetic precursor waves continue to persist and that the wakefields are indeed excited by the intense electromagnetic waves (Iwamoto et al. 2019). The wakefields collapse during the nonlinear process of the parametric decay instability in the near-upstream region, where both ions and electrons are accelerated by the motional electric field in the upstream and the particle energy spectra show clear nonthermal tails. In this talk, we discuss this particle acceleration and wave-plasma interaction for more details.

R008-26
Zoom meeting D　：11/4　PM2　(15:45-17:30)
15:45-16:00

Plasmoid-dominated Turbulent Reconnection in a Low-beta Plasma

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In magnetohydrodynamics (MHD), magnetic reconnection has been discussed by Sweet--Parker and Petschek models. It was recently found that a laminar Sweet--Parker reconnection evolves to plasmoid-dominated turbulent reconnection in a large-scale system. It is believed that the reconnection rate during the plasmoid-dominated stage is approximately 0.01.

Plasma beta in the inflow region is a key parameter in the reconnection system. However, even though plasma beta is extremely low around reconnection sites in a solar corona, many aspects of the plasmoid-dominated reconnection in the low beta regime remain unclear.

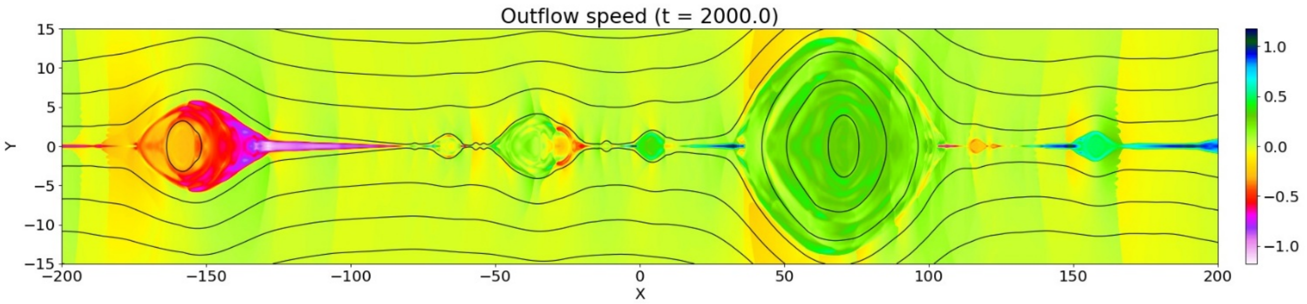
In this contribution, we explore basic properties of plasmoid-dominated reconnection in a low-beta background plasma, by means of resistive MHD simulations. We have found that the system becomes highly complex due to repeated formation of plasmoids and shocks. We have also found that the average rate increases in the beta < 1 regime, in contrast to popular results. We attribute this to compressible effects. We have applied a compressible reconnection theory to this problem. Our key predictions are verified by extensive numerical survey.

We further discuss the relevance to an earlier study. We argue that our results better represent average properties of reconnection after the initial plasmas are ejected.

We will also overview improvements to our simulation code.

Reference:

S. Zenitani and T. Miyoshi, Astrophys. J. Lett., 894, L7 (2020)



R008-27
Zoom meeting D ：11/4 PM2 (15:45-17:30)
16:00-16:15

Transition of dominant ion-scale instabilities and conditions for magnetic reconnection in strong perpendicular shocks

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It is well known that the energy distribution of particles in space is usually not represented by a thermal Maxwellian distribution but has a high energy power-law tail called "non-thermal particles". Collisionless shock waves, generated by supernova remnant shocks and solar flares, are considered to contribute significantly to the generation of such high energy particles. The first order Fermi acceleration is thought to be the primary particle acceleration mechanism, which requires some mechanisms that pre-accelerate from thermal to an intermediate energy. Extensive studies on the pre-acceleration mechanisms have been conducted over the years. In high Alfven Mach number shock waves, ions are partially reflected by the shock front, various instabilities can be excited by the velocity difference between three particle species, i.e. the incoming electrons, ions and reflected ions. Some of these instabilities play a crucial role in electron pre-acceleration.
In this study, we investigate plasma instabilities in the perpendicular shock transition region. We focus on Alfven Ion Cyclotron (AIC) instability and Weibel instability, both of which are excited by an effective temperature anisotropy generated by the reflected ions. The AIC instability via the ion cyclotron resonance generates a rippled shock surface, while the Weibel instability has been shown to generate folded current sheets, which eventually dissipate via magnetic reconnection to accelerate electrons (Matsumoto et al., 2015). Qualitatively, the Weibel instability will be the dominant mode at very high Mach numbers (or weak magnetic field), and otherwise, the AIC instability should dominate. However, the exact relation between the two instabilities has not been fully understood.
In our study, we adopted a local model focusing only on the transition layer and investigated the dependence of instability on upstream physical parameters such as Alfven Mach number, cyclotron frequency/plasma frequency ratio, electron/ion mass ratio. We consider a homogeneous plasma in the upstream rest frame and as the initial distribution, incoming electrons and ions have a Maxwellian distribution, while reflected ions have a ring distribution. We performed linear analysis for the three-component plasma model and found that the AIC and Weibel instabilities both appear from a single dispersion relation in different limiting cases. We found that the maximum growth rate of waves propagating parallel to the ambient field depends largely on Alfven Mach number, ring ion plasma beta and ring ion ratio among the upstream parameters. We also examined Particle-in-cell simulations and confirmed that the growth rates are in agreement with the linear theory. The result of our parameter survey has shown that (1) the transition between the AIC and Weibel instabilities is around where the maximum growth rate reaches about ~7/ion cyclotron frequency, (2) Magnetic reconnection is observed in the ring distribution model, but only for extreme conditions (M_A ? 100, n_r/n_0 ? 0.5), (3) when the reflected ions are represented by a beam distribution, magnetic reconnection is more active than the ring model under similar conditions. In this presentation, we will report linear analysis and simulation results especially focusing on the transition between the AIC and Weibel instabilities, the conditions for the magnetic reconnection and the difference between the ring and beam distribution models.

R008-28
Zoom meeting D ：11/4 PM2 （15:45-17:30）
16:15-16:30

Field structure and plasma momentum transfer in quasi-steady large-scale magnetic reconnection

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In the geomagnetotail, a large scale magnetic reconnection is one of the most important energy release and transport processes. We study the large scale magnetic reconnection in a two-dimensional magnetotail by means of a hybrid model. Around the diffusion region, characteristic electromagnetic field structures, e.g. a quadrupolar out-of-plane Hall magnetic field, and accelerated plasma particles are generated by the local plasma dynamics. The some field structures are phasestanding around the diffusion region and the boundary layer between the reconnection plasma jet and the lobe region. The out-of-plane magnetic field propagates away from the reconnection jet region as a kinetc Alfven wave with super-Alfvenic speed around the boundary layer of the plasma sheet. The wave transfers substantial energy and momentum by Poynting flux together with the accelerated plasma particles. These mechanisms are important for understanding the balanced dynamic structure of the quasi-steady large scale two-dimensional magnetic reconnection.

R008-29
Zoom meeting D ：11/4 PM2 （15:45-17:30）
16:30-16:45

抵抗性テアリング不安定性の磁気流体線形理論における粘性効果

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RCSCE,愛媛大

MHD linear theory of resistive tearing instability with viscosity effect.

#Tohru Shimizu
RCSCE, Ehime Univ.

A new MHD linear theory of resistive tearing instability based on Loureiro theory (Phys.Plasmas,2007) is developed, introducing the viscosity effect. Originally, FKR theory (Furth Killeen Rosenbluth, Phys.Fluids,1963) well-known as a classical theory of resistive tearing instability is inapplicable for high speed, i.e. Alfvenic, tearing instability for uniform resistivity. This problem can be resolved on basis of Loureiro theory, where the perturbation in non-zero equilibrium plasma flow field and uniform resistivity is rigorously studied. In our previous study, it has been reported that the linear growth rate in Loureiro theory can reach a unit of the Alfven time scale as the upper limit. The Loureiro theory assumes the uniform resistivity but to be non-viscous. In this paper, introducing the viscosity effect in the Loureiro theory, it is shown that the growth rate is monotonically reduced as the viscosity increases but it suggests that the growth rate cannot be negative, i.e. stable. It suggests that tearing instability cannot be stable only for resistivity but also for viscosity, at least, in linear MHD theory.

R008-30
Zoom meeting D ：11/4 PM2 （15:45-17:30）
16:45-17:00

非対称磁気リコネクションにおけるプラズモイド成長

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Growth of the crab-hand shaped plasmoid in the asymmetric magnetic reconnection

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Magnetic reconnection structure in the asymmetric magnetic reconnection remarkably different from that in the symmetric reconnection. Studies about the asymmetric reconnection without the shear magnetic field in the initial isothermal equilibrium (Nitta et al. 2016, Nitta & Kondoh 2019) showed a new plasmoid structure shapes like a crab-hand, and suggested that the extension speed of the plasmoid depends on the Alfven speed in each side of the current sheet.
In this study, we reconsidered the essential factor to determine the plasmoid extention speed by the two-dimensional magnetohydrodynamical simulations. Each simulation started from the initial equilibrium state with asymmetrical magnetic distribution and uniform Alfven speed distribution in the entire asymptotic region. As a result, we found in the asymmetric case, the plasmoid extension speed is not symmetric even the Alfven speed distribution is uniform, but depends on the magnitude relationship between the sound speed and the Alfven speed.

電流層をはさんだ両側の磁場強度などの物理量が対称である対称磁気リコネクションと、非対称な場合の非対称磁気リコネクションとでは、プラズモイドやジェットといった磁気リコネクション構造が大きく異なることが分かっている。特に、簡単化した音速一定・シアー磁場無しという条件下における非対称リコネクションの研究(Nitta et al. 2016, Nitta & Kondoh 2019)では、プラズモイドは電流層に分断され蟹の手型を形成することが確かめられ、そのプラズモイドの伸展速度は両領域の Alfv?n 速度で決まることが示唆された。
本研究では、これらの先行研究における音速一定という条件を Alfv?n 速度一定に変更した 2 次元磁気流体シミュレーションによって、プラズモイドの伸展速度の本質的要因について考察した。その結果、初期圧力平衡を仮定した Alfv?n 速度一定という条件下であっても、磁場強度が非対称な場合、プラズモイド伸展速度は対称（両領域で同じ）にならないことが分かった。そして、伸展速度は Alfv?n 速度だけでなく、Alfv?n 速度と音速の大小関係にも依存することが分かってきた。

R008-31
Zoom meeting D ：11/4 PM2 （15:45-17:30）
17:00-17:15

非対称磁気リコネクションにおける高速プラズマ流構造と非対称度依存性

#近藤　光志
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Fast plasma flow in the asymmetric magnetic reconnection and the dependence on the asymmetry

#Koji Kondoh
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Large structure of the fast plasma flow in the asymmetric magnetic reconnection is significantly different from that in the symmetric case. Particuraly, the maximum speed of the fast flow is not always observed in the reconnection fan sandwiched by the pair of slow-shocks. In the symmetric case, the fast plasma flow is deccelerated in the reversed fast shock behind the plasmoid. On the other hand, in the asymmetric case, the fast shock is deformed and field aligned flow structure is formed, so plasma is accelerated also in the low-beta side plasmoid.

非対称磁気リコネクションのプラズマ流構造は対称磁気リコネクションとは大きく異なる。特に異なるのは、その最大速度がスローショックに囲まれたリコネクションファンで観測されるとは限らないことである。対称磁気リコネクションでは、スローショックで加速されたプラズマは、プラズモイド後方のファストショックで大きく減速されるため、最大速度はリコネクションファン内で観測される。一方、非対称磁気リコネクションでは、ファストショックの形状がゆがみ、また、磁力線に沿ったプラズマ流構造が形成されるため、プラズモイド内の圧力勾配で効率的に加速が行われる。その結果、リコネクションファンと低ベータ側プラズモイドの両方で同速程度のプラズマ流が観測される。
ここでいう非対称は、電流層をはさんだ両領域の磁場強度などの物理量の非対称であり、本研究では、初期状態として領域全体の温度を一定、磁場強度を非対称としている。