地球バウ・ショックにおける電子加速の最高エネルギー

加藤 拓馬 [1]; 天野 孝伸 [1]
[1] 東大・理

Maximum energy of an electron acceleration at the Earth bow shock

Takuma Kato[1]; Takanobu Amano[1]
[1] University of Tokyo

The acceleration of non-thermal particles is an important subject in space physics. The shock accelerated non-thermal electrons have been observed at the Earth bow shocks (Gostling et al. 1989). These electrons are supra-thermal (with energies from 1keV to 100keV), and their distribution is power-law. However, acceleration models proposed in the past could not reproduce such observed spectra. Recent in-situ satellite observations of the Earth bow shock found wave-particle resonances between whistler waves and electrons at the shock transition region (Oka et.al. 2017). These results indicate that whistler waves play an important role for the acceleration of supra-thermal electrons.

We propose a new acceleration mechanism that takes into account the effect of stochastic pitch-angle scatterings by whistler waves during the course of the Shock Drift Accelerations (SDA), which is an adiabatic acceleration process for supra-thermal electrons at the shock transition region (Wu 1984, Leroy and Mangeney 1984). By introducing stochasticity with pitch-angle scatterings, the acceleration efficiency may be improved. We theoretically analyzed the energy spectrum of electrons by using a box model which considers the dependence of an electron distribution only on energy and pitch-angle. We showed that the electron energy spectrum becomes a power-law and its spectral index depends only on the magnetic field gradient in the limit of strong scattering. We also found the maximum energy attainable through the proposed model, and it scales linearly with the pitch-angle scattering coefficient. We have also confirmed these results by performing Monte Carlo simulations. We demonstrated that the proposed model is qualitatively consistent with observations. In this presentation, we quantitatively discuss the consistency between the theory of the proposed model and observations.

非熱的粒子の加速は宇宙空間物理における重要な物理過程の一つである。地球バウ・ショックにおいて非熱的な電子が、稀ではあるが人工衛星によって観測されている (Gostling et al. 1989)。これらの電子は、およそ 1keV から 100keV までのエネルギーを持っていて、またその分布はベキ型であることがわかっている。しかし、この分布を自然に説明するような加速モデルは未だに提唱されていない。また最近の衛星観測によると、非熱的電子が観測されるイベントにおいて、衝撃波遷移層における電子とホイッスラー波の共鳴が検出されている (Oka et.al. 2017)。これは、地球バウ・ショックにおける電子加速にこの共鳴が重要な役割を果たしている可能性を示唆している。

これらの結果を受けて我々は、衝撃波ドリフト加速に、波動粒子相互作用によるピッチ角散乱を取り入れた新しいモデルを提唱する。衝撃波ドリフト加速とは、衝撃波遷移層における断熱的な加速機構である (Wu 1984, Leroy and Mangeney 1984)。このモデルにピッチ角散乱を取り入れることで、電子の加速効率をより向上することができる。我々は、このモデルに関する理論的な解析を行った。議論を簡単にするために、解析を行う際には、電子分布のエネルギー・ピッチ角依存性のみを考慮するボックス近似を用いた。この解析によって電子のエネルギースペクトルは、散乱が強く電子分布が等方的とみなせる場合には観測と整合するベキ型になるという結果が得られた。また、このモデルには加速できる電子の最大エネルギーが存在し、それはピッチ角散乱係数に比例することを示すことができた。これらの結果を確認するために、我々はこのモデルに関してモンテカルロシミュレーションを行った。その結果、シミュレーション結果が理論的な解析の結果と整合した。なおこの加速モデルは衛星観測の結果と比較が可能であり、比較を行った結果、定性的には観測結果に矛盾しないことがわかった。本発表では、主に加速モデルと観測結果の整合性に関してより定量的に議論する。

相対論的衝撃波における航跡場加速

岩本 昌倫 [1]; 天野 孝伸 [1]; 星野 真弘 [1]; 松本 洋介 [2]
[1] 東大・理; [2] 千葉大理

Wakefield acceleration in two-dimensional relativistic shocks

Masanori Iwamoto[1]; Takanobu Amano[1]; Masahiro Hoshino[1]; Yosuke Matsumoto[2]
[1] University of Tokyo; [2] Chiba University

The origin of high energy cosmic rays has not been fully understood, and the acceleration mechanism is still controversial. Recently Chen et al. (2002) proposed the particle acceleration by the large-amplitude Alfven waves at gamma-ray bursts as a model of the generation of ultra-high energy cosmic rays, based on the wakefield acceleration (WFA) mechanism which was initially proposed by Tajima and Dowson (1979) in the context of laser-plasma interactions in the laboratory. The WFA in laboratory is induced by an intense laser pulse (or transverse electromagnetic waves) propagating in a plasma. The mechanism may also operate in relativistic shocks in nature because it is known that large-amplitude electromagnetic precursor waves are excited by synchrotron maser instability (SMI) driven by the particles reflected off the shock-compressed magnetic field in relativistic shocks (Hoshino and Arons, 1991). In fact, Hoshino (2008) demonstrated the generation of the non-thermal electrons by the wakefield induced by the ponderomotive force of the electromagnetic precursor waves in relativistic magnetized shocks by means of 1D PIC simulation.

In multidimensional systems, it is well known that Weibel instability (WI) develops in the transition region of weakly magnetized shocks. Previous PIC simulation studies in multiple dimensions indeed showed that the shock transition is dominated by the WI at low magnetization. Since both WI and SMI are excited from the same free energy source in the same region and the growth rate of the WI is larger than that of the SMI at low magnetization, it was believed that the WI dominates over the SMI and the precursor wave emission could be shut off in multidimensional shocks.

Recently, by using 2D PIC simulations, we have shown that the SMI can coexist with the WI and that the precursor wave emission continues to persist to the Weibel-dominated regime (Iwamoto et al. 2017). We also showed that the wave power is sufficient enough to induce wakefield for a wide range of magnetization parameter. However, the WFA did not operate in our previous simulation in pair plasmas because the finite mass ration between positive and negative charges is essential for the WFA. To investigate the feasibility of the WFA in relativistic shocks, we carried out 2D simulations in ion-electron plasmas. We found that the wakefield is indeed induced in the upstream. In this presentation, we discuss the acceleration mechanism.

Theory and Observation of Nonthermal Electrons at Quasi-perpendicular Bow Shock

Takanobu Amano[1]; Takuma Kato[1]; Naritoshi Kitamura[2]; Yosuke Matsumoto[3]; Masahiro Hoshino[1]
[1] University of Tokyo; [2] University of Tokyo; [3] Chiba University

The acceleration of energetic charged particles has been a topic of great interest both in space physics and astrophysics. In-situ observations of particles in space often find an extended non-thermal tail typically with a power-law in the energy spectrum. One of the most promising mechanisms to produce such non-thermal particles is the first order Fermi acceleration at shock waves. However, it is very well known that shock-associated enhancements of energetic electron fluxes are very rare at traveling interplanetary shocks (Lario et al. 2003, Dresing et al. 2016). On the other hand, relatively strong planetary bow shocks that stand in the solar wind sometimes produce energetic electrons (Gosling et al. 1989, Oka et al. 2006, Masters et al. 2013). Radio and X-ray synchrotron emissions from young supernova remnant shocks suggest that the acceleration of electrons is highly efficient at these shocks. The question is that what controls the shock acceleration efficiency for the non-thermal electrons.

Historically, the energetic electrons associated with shock crossings have been observed as spiky flux enhancements. With the unprecedented temporal resolution of particle measurement made by the MMS (Magnetospheric MultiScale) spacecraft, such a spike is now resolved to be a gradual flux increase from the upstream to downstream within a thin shock transition layer. This signature of supra-thermal electrons may potentially be understood with a recently developed theoretical model for the electron acceleration at quasi-perpendicular shocks.

The theory, which we call stochastic shock drift acceleration (SSDA), is based on the classical shock drift acceleration but takes into account the effect of stochastic pitch-angle scatterings. It assumes that a fraction of particles are trapped within the shock transition region because of strong pitch-angle scatterings. The trapped particles experience a nearly constant fractional energy gain per unit time via the magnetic mirror force (or equivalently, the gradient-B drift in the direction of the motional electric field). The SSDA theory predicts a power-law energy spectrum with its spectral index determined solely by the magnetic field gradient scale length. The energetic particle intensity profile within the shock transition layer should increase gradually toward downstream. These features are qualitatively consistent with some of the shock crossings observed by MMS.

In this study, we conduct quantitative comparisons between the theory and MMS observations of high Mach number quasi-perpendicular shocks. The electron energy spectra at the shock may well be represented by a power law from just above the thermal energy (~0.2keV). We find that the cut-off energies of the power-law component sometimes exceed the upper limit of the FPI instrument (~30 keV). A bursty appearance of high-frequency whistler waves (with frequencies around 0.1-0.5 times electron cyclotron frequency) is a typical signature of such strong shocks, suggesting that pitch-angle scatterings are going on for the accelerated electrons. Assuming the diffusion-convection equation for the energetic electrons, we may estimate the pitch-angle scattering coefficients from the observed profiles of the particle intensity. We will discuss the consistency between the theory of SSDA and MMS observations.

Magnetic Field Saturation of the Ion Weibel Instability in Interpenetrating Relativistic Plasmas

Yosuke Matsumoto[1]
[1] Chiba University

The magnetic field is a fundamental physical quantity found everywhere in the universe. It plays essential roles in galaxy spiral arms, high-energy astrophysical phenomena, star formation, and cyclic dynamos at the interior of stars and planets. Because of its ubiquity, the origin of the magnetic field is of great interest in various research fields.

The Weibel instability arises from anisotropy in the plasma velocity distribution function. Because the instability feeds the free energy of the anisotropy and converts it into magnetic energy, it is one of the promising mechanisms responsible for the origin of the magnetic field. Following early theoretical works, numerical simulations have revealed its wide applicability. The generated magnetic field plays crucial roles in collisionless shock formation, associated particle accelerations, and afterglows of gamma-ray bursts. Recent experiments using high power laser facilities have succeeded in showing detailed images of the nonlinear structure characterized by filaments of the current.

Kato [2005] proposed a theoretical model describing magnetic field evolution in cylindrical currents of the electron Weibel instability, and found that the maximum magnetic field could be obtained when the current reached the so-called Alfven current (Alfven, 1939). This gives an upper limit of the cylindrical current in which the Larmor radius of particles in the self-generated magnetic field is comparable with the filament size, and thus determines the magnetic field saturation.

In this talk, we show the evolution and saturation of the Weibel instability in interpenetrating relativistic ion-electron plasmas by means of three-dimensional (3D) PIC simulations. Large-scale, long-term simulations enabled us to elucidate for the first time the coalescence of ion-scale current filaments and the resulting magnetic field saturation after reaching the ion Alfven current limit.

To explore the nonlinear evolution of the Weibel instability, we used a fully kinetic electromagnetic PIC code (Matsumoto et al., 2017). Simulation runs were initialized by two cold unmagnetized counter flows with a bulk Lorentz factor of gamma=5 in the laboratory frame. The beams were set in the x-direction with the periodic boundary condition in the all directions. The cold counter-streaming condition induced a very large anisotropy of the velocity distribution in the system. Consequently, the relativistic Weibel instability grew rapidly in the whole region of the simulation domain.

We found that the Weibel-generated magnetic fields sustained for long time periods after reaching the ion Alfven current limit in the 3D space; the Weibel filaments are stable during the filament merging process against secondary instabilities such as the Buneman and other electrostatic modes found in 2D in-plane simulation studies. We also found that electron heating processes continue during coalescence of ion-scale filaments in the late nonlinear stage and are crucial for the sustained magnetic field.

無衝突衝撃波の高強度レーザー実験

松清 修一 [1]
[1] 九大・総理工

High power laser experiment on collisionless shock

Shuichi Matsukiyo[1]
[1] ESST Kyushu Univ.

Laboratory experiment on collisionless shocks by using high power laser is performed in collaboration with the Institute of Laser Engineering (ILE) at Osaka university. An aluminum foil target surrounded by nitrogen gas is irradiated by Gekko XII hyper laser. The target foil is ablated to produce expanding aluminum plasma. This target plasma sweeps a surrounding nitrogen gas plasma which is produced as a result of photo ionization due to strong radiation through laser-target interaction. Then, a shock is formed in the gas plasma. The above shock formation process is observed using a number of diagnostics such as the optical imaging based on self-emission, shadowgraphy, and collective Thomson scattering. We will discuss characteristics of the shocks by analyzing the observed data. In particular, upstream of the shock at early time stage is paid attention to focus on local plasma heating due to a microinstability.

帯電する飛翔体で使用可能なラングミューアプローブの開発

田寺 慶樹 [1]; 阿部 琢美 [2]; 三宅 亙 [3]
[1] 東海大; [2] ＪＡＸＡ宇宙科学研究所; [3] 東海大・工

Development of Langmuir Probe for Spacecraft with Charged Potential

Yoshiki Tatera[1]; Takumi Abe[2]; Wataru Miyake[3]
[1] Tokai Univ; [2] ISAS/JAXA; [3] Tokai Univ.

The floating potential of a spacecraft in space varies with the number flux of charged particles incident to and emitting from its surface. A low earth orbit (LEO) satellites is known to be negatively charged due to incidence of thermal electrons, and its potential can be negatively charged up to several volts. In addition, it is known that the ion sheath with a thickness of several centimeters is formed on the spacecraft surface. In the case of spacecraft on which active experiments are carried out, it is possible for the potential to be much larger and then the sheath thickness on the spacecraft surface is possible to be several tens centimeters. Such a situation is unacceptable for measurements by a Langmuir probe because an amplitude of the sweep voltage to obtain the current versus voltage (I-V) relationship in the Langmuir probe measurements is typically a few volts, and therefore the sweep with respect to the floating potential cannot cover the voltage range necessary for the electron temperature and density estimation. Furthermore, undesirable impact may be exerted to the probe measurement because of the ion sheath formed on the spacecraft surface. Therefore, it is important to identify whether or not the probe is stays inside the sheath during its measurement.

We are developing an electric circuit for the Langmuir probe which can be used on spacecraft with large floating potential so as to avoid such unfavorable situation. In the developed circuit, the voltage sweep to get the I-V relationship consists of two steps; 1) coarse sweep for wide voltage range to get the I-V relationship consisting of the three regions of the ion current saturation region, retarding region and electron current saturation region, and 2) fine sweep for narrow voltage range. A voltage from 0 to 100V is applied to the probe to find the space potential on the spacecraft in the first step. In actual measurement, the circuit is designed to find the potential on which the gradient of logarithmic probe current with the voltage becomes maximum in a wide range of the voltage sweep. In the second step, the probe voltage is determined with respect to this space potential so that one can obtain the I-V relationship with a fine step which is necessary for the electron temperature and density estimates. Such a circuit for Langmuir probe measurement was first developed a few years ago. However, the circuit did not work properly because of the significant noise to the probe current.

In this study, we try to modify the logic of the FPGA program in the circuit to overcome the problem. Then, the performance was tested by confirming whether the reference potential with respect to the plasma could be properly determined. It was concluded that the circuit can successfully determine the potential. We try to verify experimentally how ion sheath formed on the spacecraft surface affects the measurement to estimate plasma parameter. A result of the present study is summarized as follows, 1) Inside the ion sheath, the electron temperature and density tend to be estimated higher and lower, respectively, than that outside the sheath. 2) In the measurement inside the ion sheath, the reference potential estimated from the coarse sweep tends to be shifted to higher voltages compared that obtained outside the sheath. 3) The circuit can not properly decide the reference potential for the narrow range sweep voltage when the probe locates deep inside the sheath. We notice important feature in the I-V relationship in the ion saturation and the electron retarding regions when the probe is put deeper inside of the sheath(closer to the conductive body). In the future, we will also study a possibility to distinguish inside and outside of the sheath about the probe position from the I-V relationship by discussing the electric potential distribution around the conductor and the sheath generation process of the probe surface in the ion sheath.

宇宙空間の飛翔体の浮動電位はその表面への荷電粒子の入射と放出の数によって変化する．低高度の人工衛星の場合，電離圏中の熱電子の入射により負に帯電する．その電位はプラズマ空間電位に対して負に数ボルトにまでなることがある．また，人工衛星表面にはその電位に対応した厚さ約数センチの鞘が形成されることが知られている．衛星上で能動的な実験を行う場合は，その電位はより大きくなる可能性があり，鞘の厚さも数十センチにまで広がる可能性がある．衛星上で電子温度や密度の推定を目的としてラングミューアプローブを用いる場合，I-V 特性を得るための掃引電圧振幅は数ボルト程度であるため，大きく帯電した衛星電位を基準にこの程度の掃引を行ってもプラズマパラメーターの推定に必要な情報を得ることは困難である．したがって，このような状況下では一般的なラングミューアプローブを用いてプラズマパラメーターを推定することができない．さらに，飛翔体表面に形成された鞘がラングミューアプローブの設置された位置にまで成長し，プラズマパラメーターの推定に影響を及ぼす可能性があることが考えられる．そのため，飛翔体上でプラズマ測定を行った際にプローブが鞘の内側もしくは外側での測定なのかの判別が重要となっている．

本研究の目的は大きく帯電する飛翔体上で使用可能なラングミューアプローブのための回路の開発である．また，本回路を用いてプラズマ測定を行った際に，衛星表面上に形成される鞘がプラズマパラメーターにどの程度の影響を及ぼすのかについても研究を行う．

この回路ではプローブに二種類の掃引電圧振幅を印加し，最終的にプラズマパラメーターの推定に必要な I-V 特性を取得する．一つ目の掃引では，周囲のプラズマに対する飛翔体の電位を見つけるために広い範囲を粗い電圧ステップ

で測定し，イオン飽和領域，減速電界領域から飽和電子電流領域の三つの領域からなる I-V 特性を得る．そして，得られた I-V 特性の対数を取りその中で傾きが最大となった時の電位を次の電圧掃引のための基準電位とする．二つ目の掃引では，一つ目の電圧掃引で決定した基準電位を基準に狭い電圧幅を細かい電圧ステップで測定し，プラズマパラメーターの推定に必要な電流—電圧特性を取得する．

上記を目的とする当初の研究では，一つ目の電圧掃引の際にプローブ電流に混入したノイズの影響を受け基準電位を適切に決定できないという問題があった．これを解決するために本研究ではノイズの影響を受けずに基準電位を決定できるよう回路内の FPGA プログラムロジックの改修を実行し．基準電位を決定できるかどうかについての実証実験を行った．そして，回路は狭い電圧幅の電圧掃引のための基準電位とプラズマ空間電位を正常に決定することが出来ていることを確認した．

次に，衛星表面上に形成される鞘がプローブ法による電子温度等のプラズマパラメーター推定にどのような影響を及ぼすのかについて実験的に検証を行った．飛翔体の電位が空間電位に対して負の方向に大きく変動した場合の飛翔体表面を模擬した円筒型，平板型の導体を低高度の電離圏プラズマ環境を模擬した真空チャンバー内に設置し，鞘が存在するであろう導体周辺でプローブによる測定を実施した．さらに，帯電した飛翔体上でプローブ法を用いたプラズマ測定を行い得られた I-V 特性から飛翔体表面上に設置されているプローブが鞘の内側もしくは外側なのかの判別が可能か否かについて，検討した．

結果は次のとおりである．１）プローブがイオン鞘の鞘端周辺もしくは内側に位置する場合に推定した電子温度・密度は，この影響を受けていない場合に推定した電子温度・密度と比べ，電子温度は高く，電子密度は低く見積もられる．２）本回路を用いた場合，狭い電圧幅の電圧掃引のための基準電位が鞘の影響を受けていない時のものと比べて高電圧側にシフトする傾向がある．３）プローブがイオン鞘に深く入り込んだ場合，狭い電圧幅の電圧掃引では，プラズマパラメーターの推定に必要な I-V 特性を得られない可能性が高い．４）プローブがイオン鞘にさらに深く入り込んだ場合，I-V 特性にはイオン飽和領域から減速電界領域にかけての領域において特徴的な電流値の変化が見られる．

今後は，得られた I-V 特性からプローブの位置がイオン鞘の内側なのか外側なのかの判別が可能か否かについて，導体周辺の電位分布とイオン鞘内でのプローブ表面の鞘の形成過程とその形に着目し検討する．

On the Boris solver in particle-in-cell simulation

Seiji Zenitani[1]; Takayuki Umeda[2]; Tsunehiko Kato[3]
[1] Kyoto U; [2] ISEE, Nagoya Univ.; [3] CfCA, NAOJ

Particle-in-Cell (PIC) simulation has been extensively used in theoretical plasma physics. In PIC simulation, the Boris method is a de facto standard to advance charged particles. Owing to its accuracy, robustness, and stability, it has been used for nearly 50 years. Meanwhile, there is a growing demand for better particle solvers in PIC simulations in plasma astrophysics.

As a first topic, we will introduce a new form of the Boris integrator to advance particles. The new form takes advantage of two exact solutions for the Coulomb-force part and for the Lorentz-force part, and then it achieves the second-order accuracy. Numerical tests are conducted by test-particle simulations and by PIC simulations, in comparison with the Boris solver. The new solver provides a better accuracy than the Boris solver in most cases, whereas it only requires few extra computation time.

As a second topic, we will present a numerical boost problem in a relativistic magnetized flow. It is found that gyration-based solvers lead to an unphysical boost in the flow direction in the relativistic regime. Our analysis and numerical tests reveal that the numerical boost for cold particles is proportional to the square of the timestep, i.e. (delta t)**2. Our new solver reduces the numerical boost to 1/3 of that of the Boris solver. This fact gives us further confidence to employ the new solver.

Divergence-free shock-capturing schemes for magnetohydrodynamics

Takashi Minoshima[1]; Takahiro Miyoshi[2]; Yosuke Matsumoto[3]
[1] JAMSTEC; [2] Phys. Sci., Hiroshima Univ.; [3] Chiba University

The magnetohydrodynamic (MHD) simulation is an indispensable tool to study various macroscopic dynamics in space-terrestrial plasma environments. A common strategy to build an MHD simulation code for the space plasma would be based on a shock-capturing scheme. The shock-capturing scheme calculates an intermediate state between computational cells through an exact or approximate solution of the Riemann problem, in order to update the hyperbolic conservation laws in a divergence form. Numerous studies have been devoted to develop robust and accurate Riemann solvers for MHD equations, and currently, the HLLD approximate Riemann solver by Miyoshi and Kusano (2005) becomes a de fact standard for MHD simulations of space and astrophysical plasmas.

Many Riemann solvers are designed based on a one-dimensional problem, and they can be extended to multi-dimension by a dimension-by-dimension fashion. However, MHD shock-capturing schemes do not necessary preserve the divergence-free condition of the magnetic field, and its violation may lead to an unphysical solution. Staggered grid spacing for the magnetic field is one of the method to perverse the divergence-free condition, in which the induction equation is discretized to be consistent with the curl form (Evans and Hawley 1988). Developing a proper method to combine the shock-capturing scheme with the divergence-free scheme has been a major concern for computational MHD.

In this paper, we propose two simple methods for the divergence-free shock capturing scheme. The scheme adopts the HLLD Riemann solver and the staggered grid spacing as a building block. The critical issue is the calculation of the electric field (numerical flux of the magnetic field) at the cell corner that should be consistent with the solution of the Riemann problem. The first method is a successive one-dimensional reconstruction of the numerical flux from a cell center to a corner. The second method is a recovery of a proper amount of numerical diffusion in the familiar Flux-CT scheme by Balsara and Spicer (1999). Furthermore, we incorporate a multi-dimensional upwinding in order to obtain a less oscillatory solution in advection-dominated problems. The two methods are consistent with a one-dimensional shock-capturing scheme for one-dimensional problems. Various benchmark tests and physical problems are demonstrated to measure the capability of the proposed methods.

Effects of background heavy ions on magnetic field structure and ion dynamics in a large scale magnetic reconnection

Masao Nakamura[1]
[1] Dept. of Aerospace Eng., Osaka Prefect. Univ.

We investigate effects of background heavy ions on magnetic field structure and ion dynamics in a large scale magnetic reconnection. After the formation of fast reconnection jets away from a diffusion region, the background heavy ions exhibit unmagnetized Speiser-type motions far from the diffusion region, although the protons show various characteristic motions according to the distances from the reconnection line. These motions result in a change of density rate and a momentum exchange between the protons and background heavy ions through the electromagnetic field in the reconnection jets That makes derivations of the ion cross-tail current carriers and distributions and the field structure form the no heavy ion case.

磁気リコネクションでのイオンと電子のエネルギー分配

星野 真弘 [1]
[1] 東大・理

Ion and electron energy partition during magnetic reconnection

Masahiro Hoshino[1]
[1] University of Tokyo

Ion and electron heating and their energy partition during collisionless magnetic reconnection are investigated using particle-in-cell simulations. We analyze the time evolution of the ion and electron temperatures associated with the motion of the reconnecting flux tube, where the plasma temperature is defined as second-order moment of velocity distribution function in the center of the flux tube frame, and we show that the plasma heating during magnetic reconnection can be separated into two stages: the nonadiabatic heating stage, in which the magnetic field lines are just reconnecting in the X-type diffusion region, and the adiabatic heating stage, in which the flux tube is shrinking after two flux tubes merge. During the adiabatic heating stage, the plasma temperature T and the volume of the flux tube V follows the standard fluid-type adiabatic relation. In the nonadiabatic heating stage where the reconnecting flux tube covers not only the X-type diffusion region but also the separatrix boundary of reconnection, we found numerically that the ratio of the increment of the ion temperature to that of the electron temperature can be approximated by Ti/Te = (Mi/Me $)^{1/4}$, where Mi and Me are the ion and electron masses, respectively.

強磁場下の無衝突磁気リコネクションによる運動論的アルヴェン波の不安定化

下村 和也 [1]; 渡邉 智彦 [2]; 前山 伸也 [2]
[1] 名大・理・素粒子宇宙; [2] 名大・理・物理

destabilization of kinetic Alfven wave driven by collisionless magnetic reconnection with strong guide field

Kazuya Shimomura[1]; Tomo-Hiko Watanabe[2]; Shinya Maeyama[2]
[1] Particles and astrophysical, Nagoya Univ.; [2] Dept. Physics, Nagoya Univ.

Magnetic reconnection is a fundamental physical mechanism that leads to conversion of magnetic energy to kinetic energy, topological change of magnetic field lines, and self-organization in space and laboratory plasmas. In collisionless plasmas, it is considered that two fluid or kinetic effects play essential roles in production of the reconnection electric field in the diffusion region. It is also suggested that the electron inertia effect or the anomalous resistivity become more important than particle orbit effects.

We have carried out numerical simulations of the collisionless magnetic reconnection with the strong guide field by use of the gyro kinetic model [1], where we have found that the reconnection electric field forms the beam electrons at the X-point. The liner dispersion relation in a limit of plane waves suggests that the kinetic Alfven wave can be excited by the beam when the beam velocity exceeds the Alfven speed.

To investigate the beam instability in the field configuration via the magnetic reconnection, it is necessary to reveal the structure of a total distribution function during the reconnection. We have developed the full-f reconnection model with the nonlinear term of the electric field acceleration and have carried out a numerical simulation by use of the new model, where the shifted Maxwellian distribution function of electrons is formed at the X-point during the magnetic reconnection. In addition, by use of this simulation result, we have also analyzed the beam instability of the kinetic Alfven wave in the X-point configuration formed during the magnetic reconnection.

[2] A. Ishizawa and T.-H. Watanabe, Physics of Plasmas 20, 102116 (2013)

電離圏不均一性を考慮した磁気圏-電離圏結合系におけるフィードバック不安定性の解析

樋渡 淳也 [1]; 渡邉 智彦 [2]; 前山 伸也 [2]
[1] 名大・理・素粒子宇宙; [2] 名大・理・物理

Analysis of Feedback instability in the magnetosphere-ionosphere coupling system with ionospheric inhomogeneity

Junya Hiwatari[1]; Tomo-Hiko Watanabe[2]; Shinya Maeyama[2]
[1] Particle and Astrophysical Science, Nagoya Univ.; [2] Dept. Physics, Nagoya Univ.

Aurora coloring the polar night sky. The variety of colors and curtain-like shapes and behaviors have continued to attract people. Aurora is a light emission phenomenon when plasma particles emitted from the sun and falling on the earth collide with neutral particles in the atmosphere and particles in the excited state return to the ground state. Neutral particles emit light in the earth's ionosphere, but in order for plasma particles flying from outer space to penetrate into it, a physical mechanism that accelerates that plasma particle is necessary. Moreover, we can not give clear answer to the fluctuating behavior characteristic of aurora even today. Since the aurora is observed even in the quiet time without explosive energy opening phenomenon such as magnetic reconnection, its physical mechanism exists potentially in the terrestrial ionosphere and the magnetosphere surrounding it . However, its details are often unresolved.
The theory considered to give the most influential answer to these problems is the physical mechanism of Feedback instability in the magnetosphere - ionosphere coupled system.

The area where we can observe aurora is the ionosphere E layer (altitude 100 - 120 km), and the degree of ionization in this region is low and it is filled with weakly ionized plasma. Therefore, collision with neutral particles is important. The electron cyclotron frequency is larger than the collision frequency with neutral particles, so that the collision with neutral particles can be ignored. However, in the ion motion, the collision frequency with the neutral particle is larger than the ion cyclotron frequency, so the influence of the magnetic field is small for ions.

Unlike such ionosphere, the magnetosphere (altitude 1,000-100,000 km) is filled with completely ionized plasma, so that collisions between neutral particles and electrons or ions can be ignored.

The outline of Feedback instability is as follows. In the Earth's magnetosphere, there is a magnetic field line extending from the ionosphere to the magnetic equator. The Alfven wave along this magnetic field and the wave of density fluctuation propagating in the vertical direction to the magnetic field existing in the ionosphere resonate with each other. As a result, field aligned current and density fluctuation grow spontaneously. Therefore, it is believed that only waves of frequencies causing resonance grow selectively, resulting in the generation of aurora.

In previous studies, physical quantities in the ionosphere have been treated as uniform with height averaging and not highly dependent (Robert L. Lysak, 1991, T. - H. Watanabe, 2010 etc). This is due to the fact that the thickness of the ionosphere is a very small scale compared with the it of the magnetosphere. However, the physical quantity of the ionosphere actually depends on the altitude, in particular the conductivities are changing drastically. Therefore, in this research, we performed a linear analysis with a model that treats various physical quantities in the ionosphere as heterogeneous with altitude dependence. As a result of the linear analysis, it was found that there were situations that became unstable even in consideration of ionospheric heterogeneity.

極圏の夜空を彩るオーロラ。その多彩な色やカーテン状の形状や挙動は人々を魅了し続けてきた。オーロラとは、太陽から放出され地球に降り注ぐプラズマ粒子が大気中の中性粒子に衝突し、励起状態になった粒子が基底状態に戻る時の発光現象である。中性粒子が発光を起こすのは地球の電離圏だが、そこにまで宇宙空間から飛来したプラズマ粒子が侵入するためには、何かそのプラズマ粒子を加速させるような物理機構が必要である。また、オーロラに特徴的な揺らめく挙動に対しては、今日でも明確な答えを与えることはできていない。磁気リコネクションのような爆発的なエネルギーの開放現象のない静穏時でもオーロラが観測されることから、その物理機構は地球電離圏やそれを取り巻く磁気圏に潜在的に存在しているものであることが分かる。しかし、その詳細は未解決なことが多い。

これらの問題に対して、最も有力な答えを与えると考えられている理論が、磁気圏 - 電離圏結合系におけるフィードバック不安定性という物理機構である。

オーロラの発光が最も観測される領域は電離圏 E 層（高度 100-120km）であり、この領域での電離度は低く弱電離プ

ラズマで満たされている。そのため中性粒子との衝突が重要である。電子の運動では、中性粒子との衝突周波数よりも電子サイクロトロン周波数の方が大きいため中性粒子との衝突は無視することができる。しかしイオンの運動では、中性粒子との衝突周波数がイオンサイクロトロン周波数よりも大きいため磁場の影響は小さい。

　このような電離圏とは異なり、磁気圏（高度 1,000-100,000km）は完全電離プラズマで満たされているため、電子・イオンの双方において中性粒子との衝突は無視することができる。

　フィードバック不安定性の概略は次のとおりである。地球磁気圏には、電離圏から磁気赤道に伸びる磁場が存在しているのだが、この磁場に沿った Alfven 波と電離圏に存在する磁場に垂直方向に伝播する密度揺らぎの波が互いに共鳴しあい、その結果として沿磁力線電流と密度揺らぎが自発的に成長する。したがって、共鳴を引き起こす周波数の波だけが選択的に成長し、オーロラが発生するに至ると考えられている。

　これまでの研究では、電離圏での諸物理量は高さ平均をとって高度に依存しない均一なものとして扱ってきた（Robert L. Lysak, 1991 や T. -H. Watanabe, 2010 など）。これは、電離圏の厚さが磁気圏の厚さに比べて非常に小さいスケールであることに由来している。しかし、実際の電離圏の物理量は高度に依存しており、なかでも伝導度などは激しく変化している。そこで本研究では、電離圏での諸物理量が高度依存性を持つ不均一なものとして扱うモデルで線形解析を行った。線形解析の結果、電離圏の不均一性を考慮に入れた場合でも不安定となる状況が存在することが分かった。

磁気圏-電離圏結合における磁気流体乱流の発生とその特性

渡邉 智彦 [1]; 前山 伸也 [1]; 兼山 将寿 [2]
[1] 名大・理・物理; [2] 名大・理・素宇

Generation of magnetohydrodynamic turbulence and its properties in the magnetosphere-ionosphere coupling

Tomo-Hiko Watanabe[1]; Shinya Maeyama[1]; Masatoshi Kaneyama[2]
[1] Dept. Physics, Nagoya Univ.; [2] Physics, Nagoya Univ.

Magnetosphere-ionosphere (M-I) coupling in the polar region plays an essential role in auroral dynamics. Feedback instability is one of a possible mechanism to explain self-excitation of auroral arcs. In our recent simulations, we observed spontaneous transition from the feedback instability growth phase to a nonlinear turbulence phase. After the saturation of the instability growth, the Alfvenic turbulence is generated in the M-I coupling system where counter-propagating shear Alfven waves interact each other. The turbulent spectrum shows a power law scaling close to $k^{-5/3}$ on a low wavenumber side in consistent to the magnetohydrodynamic turbulence theory by Goldreich and Sridhar (G-S). Scaling for the parallel wavenumber is also investigated to be compared with the G-S theory. Turbulent spectrum on the ionosphere also presents a different property from that in the magnetosphere, which will be useful in comparison with auroral observations.

極域における磁気圏-電離圏結合はオーロラのダイナミクスに重要な役割を演じている。そこに生起するフィードバック不安定性はオーロラアークの自発的な発生を説明する有力な機構である。我々の最近のシミュレーションでは、フィードバック不安定性成長相から非線形乱流相への自発的な遷移が見られた。不安定性成長の飽和後に磁気圏-電離圏結合系においてアルヴェン乱流が作り出され、そこでは逆向きに伝搬するアルヴェン波同士の相互作用が生じる。その乱流スペクトルは、低波数側で $k^{-5/3}$ に近いべき乗則を示しており、Goldreich と Sridhar (G-S) による磁気流体乱流理論と整合している。磁場平行方向波数のスケーリングについても調べ、G-S 理論との比較を行う。また、電離層上での乱流スペクトルは磁気圏中でのものとは異なった性質を示しており、オーロラ観測との比較において有用である。

Impact of the IMF Rotation on the depolarization front and Alfven Transition Layer

DongSheng Cai[1]
[1] ISIS, U Tsukuba

3D three-dimensional global PIC simulations are performed in order to analyze the dynamics of the magnetotail as the interplanetary magnetic field (IMF) rotates from north to south. This IMF rotation has quite different impacts within meridan/equatorial planes which can be analyzed over two successive temporal phases. First, as IMF rotates from North to Dawn-Dusk direction, the X-point (magnetic reconnection) evidenced in the magnetotail (meridian plane) is moving earthward (from x=-35 Re to x=-17.5) distance at which it stabilizes. This motion is associated to the formation of "Crosstail-S" patterns (within the plane perpendicular to the Sun-Earth line) through the neutral sheet in the nearby magnetotail. Second, as IMF rotates from dawn-dusk to South, the minimum B field region is expanding within the equatorial plane and forms a ring. This two-steps scenario is analyzed in strong association with the cross-field magnetotail current Jy, in order to recover the pre-signatures of substorms triggering. The second step dynamics (IMF rotation from Dawn-Dusk to South) is very complex and requires to be classified into two sub-phases (A and B) because the full penetration of the IMF into the magnetotail takes a certain delay. In the first phase A, Jy in the magnetotail disappears. After the dipolarization, IMF penetrates the magnetotail region, Jy appears again in the second phase B, and a thinning of the current sheet occurs. In these two sub-phases, we will investigate how current thinning, recovery of Jy are associated to the dynamics of the dipolarization front by visualizing the so called Alfven transition layer.

月面近傍プラズマ・ダスト環境の粒子モデルシミュレーション

三宅 洋平 [1]; 西野 真木 [2]
[1] 神戸大学; [2] 名大 ISEE

Numerical simulations of plasma/dust environment near lunar surface

Yohei Miyake[1]; Masaki N Nishino[2]
[1] Kobe Univ.; [2] ISEE, Nagoya University

Lunar dust is one of important constituents of the moon exosphere. The dust particles are supplied from a regolith layer covering the moon surface. A number of dust transport mechanisms such as the dynamic fountain model have been proposed to explain the existence of submicron-sized dust particles even at the altitude of 100 km. It is widely believed that an electrostatic effect as a result of interactions with surrounding plasma play an important role in the dust mobilization and transport processes. In the present study, we assess the lunar electric and dust environment near a complex landscape on the moon by means of particle simulations. The particle-in-cell simulation reproduces an electric environment resulting from electrodynamic interactions among a solar wind plasma, a photoelectron cloud, and a solid lunar surface. The obtained environment is utilized for subsequent dust dynamics simulations. The dust dynamics computations are based on the test-particle approach. Although inter-dust direct interactions are excluded under assumption of low dust density, a time-variable charge on each dust grain, due to collection or emission of plasma particles, is taken into consideration based on the Monte-Carlo approach. Our numerical simulations showed that the stochastic charging of small dust grains plays a crucial role in dust levitation as well as dust mobilization across the sunlight-shadow interface.

月の表層および外気圏環境を特徴づける構成要素として、レゴリス層から上空に供給されるダスト（微粒子）の存在がしばしば取り上げられる。高度 100 km において確認されているサブミクロンサイズのダストに関して、「dynamic fountain」モデルなどいくつかの輸送機構が提唱されているが、共通して周囲のプラズマとの相互作用による静電力学効果が重要な役割を持つと考えられている。我々は、複雑な形状を持つ月面上の電気およびダスト環境に着目し、粒子シミュレーション解析を進めている。まず太陽風プラズマ、月表層の光電子シース、月固体表面の間の電気力学相互作用を Particle-in-cell 法により自己無撞着に記述し、月面近傍の静電環境を再現する。続いて、得られた電気環境を背景場として、ダスト挙動のテスト粒子解析を実施する。本研究では、月表層のダスト密度は十分に低いものとし、ダスト同士のクーロン相互作用効果は無視しているが、ダスト表面への荷電粒子流出入の効果をモンテカルロ法により記述し、ダスト電荷の時間変化を考慮している。実際に我々の数値解析では、統計的な帯電過程がダスト浮遊や日向・日陰領域間のダスト移動において重要な役割を果たしていることがわかってきている。本発表では、固体表面近傍の微小ダストに関して考慮すべき物理素過程を整理し、月ダスト環境シミュレータ構築に向けたロードマップを議論する。

Stochastic motion of electrons in the presence of parallel propagating finite amplitude whistler mode waves

Yasuhiro Nariyuki[1]; Shinji Saito[2]; Makoto Sasaki[3]; Tohru Hada[4]
[1] Faculty of Human Development, Univ. Toyama; [2] Nagoya Univ.; [3] RIAM, kyushu Univ.; [4] IGSES, Kyushu Univ

Diffusion processes of electrons have been the main topic to understand radiation belt dynamics. Although the quasi-linear theory for whistler wave modes has been used to model the diffusion processes, a recent test particle simulation pointed out that effects of finite amplitude, which is not incorporated into the quasi-linear theory, can play a significant role in electron diffusion [Saito et al, JGR, 2016]. The purpose of the present study is to model the electron diffusion processes including the effects of finite wave amplitude. By using the Mori projection operator method [Mori, PTP, 1965], we obtain the generalized Langevin equation from the equation of motion of electrons. We discuss to model the dependence of the diffusion coefficients on the wave parameters by using test particle simulation data.

接触不連続における全圧を維持する電子温度の条件: 運動論シミュレーション

辻根 成 [1]; 春木 孝之 [1]; 梅田 隆行 [2]; 成行 泰裕 [3]; 佐藤 雅弘 [1]
[1] 富山大・理工（工学）; [2] 名大 ISEE; [3] 富山大・人間発達

The condition of electron temperatures to maintain total pressure in contact discontinuities: kinetic simulations

Naru Tsujine[1]; Takayuki Haruki[1]; Takayuki Umeda[2]; Yasuhiro Nariyuki[3]; Masahiro Sato[1]
[1] University of Toyama; [2] ISEE, Nagoya Univ.; [3] Faculty of Human Development, Univ. Toyama

Contact discontinuities in Magnetohydrodynamic regimes are boundary layers where, at constant pressure, the particle number density and temperature rapidly change, without a corresponding change in the normal plasma flow and magnetic field. Hybrid and particle-in-cell simulations of contact discontinuities have previously been performed, and its stability has been discussed [Wu *et al*., GRL, 1994, Lapenta & Brackbill, GRL, 1996]. When the total pressure is almost constant on the electron time scale in the absence of an electron heat flux, then the initial pressure and temperature profiles satisfy a pressure relation $(p_{e2}$-$p_{e1})(p_{i2}$-$p_{i1}) <0$ and a temperature relation $(T_{e2}$-$T_{e1})(T_{i2}$-$T_{i1}) <0$ [Tsai *et al*., JGR, 2009]. Here the subscript i indicates an ion, e indicates an electron, and 1 and 2 indicate the regions of low and high particle number densities, respectively.

In this study, we analytically reconsidered the derivation of both pressure and temperature relations. We then performed Vlasov simulations with initial parameters based on observational data [Hsieh *et al*., GRL, 2014], using a 4th-order conservative and non-oscillatory scheme [Umeda *et al*., CPC, 2012]. We investigated the physics of contact discontinuity structure by varying the ratio of ion and electron temperatures between a low and high particle number density region. As a result, we found that the constant total pressure on the electron time scale is not maintained with the initial pressure and temperature relations but is maintained with T_{e1} ~T_{e2}. We also observed that the ion number density structure diffuses even though the total pressure is maintained in all cases. These results show that the condition of total pressure on the electron time scale cannot stabilize the contact discontinuity.

宇宙プラズマ中の非線形ＭＨＤ波動についての諸問題

羽田 亨 [1]
[1] 九大総理工

Outstanding issues on nonlinear MHD waves in space plasmas

Tohru Hada[1]
[1] IGSES, Kyushu Univ

Large amplitude magnetohydrodynamic (MHD) waves are ubiquitous in space, in particular, in the solar wind and regions near collisionless shocks. The existence of these waves is confirmed by in-situ spacecraft experiments, providing us with excellent opportunities to examine various nonlinear physical processes of large amplitude waves in general. There remain numerous issues left unsolved, however, despite the importance of these waves not only in space plasma but also in high-energy astrophysical environment (e.g., as a scatterer of cosmic rays). In this presentation, by limiting our attention only to quasi-parallel propagating Alfven waves, we will first review our current understanding of the subject, and then discuss possible future development of the modeling effort, incorporating the multi-point, high-accuracy spacecraft data. In particular, we will study some of the important assumptions made when various reduced models are derived.

宇宙プラズマ、特に太陽風中や衝撃波近傍域などには大振幅の磁気流体（ＭＨＤ）波動が存在し、非線形発展をおこなっている。これらの波動は人工衛星による「その場」観測により詳細なデータが得られるため、非線形波動現象を研究するための恰好の題材となっている。さらに高エネルギー粒子（宇宙線）の散乱体として、宇宙線輸送や衝撃波加速などの基本物理過程において本質的な役割を果たしている。一方、有限振幅ＭＨＤ波動の非線形発展については種々の理論モデルが存在し、これまでに多くの研究がなされてきたが、未解明かつ重要な課題がまだ多く残されているのが現状である。そこで本講演では、特に準平行伝播アルフヴェン波の非線形発展に対象を絞り、これまでの研究を踏まえて、今後の理論展開の展望と、衛星による多点・高精度観測によりどのような解析が可能になるか考える。具体的には、非線形ＭＨＤ方程式から簡約化された数理モデル（DNLS など）を導く際の妥当性の検証、波動間位相相関の生成と崩壊などについて議論を行う。

プラスマ波動と near-field

中村 匡 [1]
[1] 福井県大

Waves and Near-Fields in Plasmas

Tadas Nakamura[1]
[1] FPU

http:/www.fpu.ac.jp

Solutions to Maxwell's equations consists of two parts: propagating components (electromagnetic waves) and the near-field. Unfortunately, there seems to be considerable confusion on the latter. For example, Coulomb interaction is often explained as the result of interchange of virtual photons, however, the Coulomb field is not a photon but a near-field. Also, little attention is paid to the difference between propagating plasma waves and plasma near-fields in space physics.

The near-field is understood as the off-shell solution to the inhomogeneous linear equations; the term "off-shell" means solutions that do not satisfy the dispersion relation. When the field source is static (Coulomb field or magnetic dipole, for example), it is easy to decompose the field into waves and off-shell near-fields. Here in this talk, the way to do this decomposition for time-dependent field source is explained. When we solve Maxwell's equations, usually we make use of Fourier-Laplace transform to obtain the dispersion relation. The time dependence of the fields is obtained by the inverse Laplace transform using the residue theorem; the wave components are obtained from the residue at the pole of dispersion relation. One can obtain the near-field component by subtracting this residue contribution from the solution of the inhomogeneous equations.

This result can give answers to a variety of questions. Is the earth's magnetic field made of photons? What component of Alfven waves comes from the photons? Why can auroral electrons carry closed currents when their speeds are much faster than the Alfven speed? How can the Jupiter's moon Io carry currents near its body? These examples will be explained in the talk.

マックスウェル方程式の解は，電磁波として伝搬する成分とそれ以外の成分にわけることができる。クーロン場やダイポール磁場は後者の例である。この後者については用語等の混乱がみられるが，ここでは near-field と呼ぼう。この near-field については種々の誤解が散見される。たとえば，クーロン場による荷電粒子の相互作用を「仮想光子の交換」などと表現することがあるが，この相互作用は光子（伝搬成分）によるものではなく，near-field によるものである。プラズマ波動に関しても，near-field の部分をどのようにあつかうかはあまり意識されていないように思われる。

数学的には near-field は非同次線形方程式の特殊解のうち，波動分散関係をみたさない，いわゆる off shell の解に対応する。場がダイポール磁場のように時間変化しない場合はこれは簡単に伝搬成分と分離できるが，時間変化する場合にどう分離するか，というのが本講演の主眼である。通常，マックスウェル方程式を解く場合は，フーリエ・ラプラス変換して，方程式を代数方程式に落としこんで分散関係を得るが，この解をラプラス逆変換して時間の関数にもどすときに，留数定理を使って分散関係の極を拾っている。この極から来る成分を非同次線形方程式の特殊解から除くことによって，near-field 成分を抽出することができる。

講演者は学生のころから「地球磁場は光子なのか？」という疑問をもってきたが，本講演の計算により，それは光子ではなく near-field であると納得することができた。同様に考えると，たとえばアルフベン波は光子か，という疑問にも答えることができる。また，アルフベン速度よりはるかに速いオーロラ粒子が準中性を保ちながら電流を運ぶメカニズムや，木星の衛星イオの運動による電流など，宇宙空間物理的な応用も広く考えられるであろう。講演ではこれらの例についても解説する。

ブラックホールは重力波源となりうるか

大家 寛 [1]
[1] 東北大・理・地物

Becomes the black hole the origin of the gravitational waves?

Hiroshi Oya[1]
[1] Geophysics, Tohoku Univ.

1. INTRODUCTION

As results of a study on the observations and analyses of the decameter radio wave pulses from the center of our Galaxy, it has been concluded that the super massive objects at the center of our Galaxy consist of two black holes which are forming a binary system rotating with common period of 2200sec; two black holes called Gaa and Gab, here, are associated with spin with rotation periods of 176.4+-1.7 sec and 148.6+-1.0 sec with orbiting velocities 18% and 21.4% of the light velocity, respectively. The radius of the orbits of Gaa and Gab are 0.13 AU and 0.15 AU ; applying Newtonian dynamics with assumption of coincidence of the orbital plane surfaces with the observing direction, it has been concluded that Gaa and Gab have masses of (2.27+-0.06)x10ˆ6 SM and 1.94+-0.03)x10ˆ6 SM with unit of solar mass as SM; total mass for the binary BH is then given by (4.22+-0.03)x10ˆ6 SM which is fairly close to (4.35+-0.13)x10ˆ6 SM that is resulted by studies of the group of stellar tracking projects.

2. PROBLEM OF STABILITY OF THE BINARY SYSTEM

Considering the all parameters deduced for the Gaa and Gab binary system, the discussions have been raised from stand points of the stability of the binary system these are 1) symmetry of the shape relating to the tidal disturbances and rotational disturbances, 2) generation of the gravitational waves which make dissipation of the orbiting energy.

3. DISCREPANCY FOR GENERATION OF GRAVITATIONAL WAVES

The symmetry problem 1) can be solved by assuming super symmetric nature of the Kerr BH with the maximum rotation as well as simple state of the objects inside of the event horizon which is described by only two parameters such as mass and angular momentum. The reduction of the radii of the orbits of the binary due to the emissions of gravitational waves is however is inevitable in so far as we follow the traditional theory of the generation of the gravitational wave from the black hole.

4. THE THEORETICAL INVESTIGATION OF THE GRAVITATIONAL WAVE PROPAGATION

In the present studies the propagation of wave general across the event horizon have been theoretically investigated using the space time of Minkowski that is realized in the frame that is making free fall in the black hole space time. The results has indicated, both for Shwartschild and Kerr black holes, that the waves are ceased to propagate at the event horizon. Then we concluded that black hole is not able to be origin of the gravitational wave.

5. DISCUSSION AND CONCLUSION

The LIGO results that reported observations of the gravitational wave from the stellar mass black hole mergers might be separated to the truth of the observation of the gravitational waves and assumption of the origin as to be black hole merger. An alternative interpretation of the possible origin of the merger is the merger of the compact stars which have no event horizon. In 2001 and 2004, Mazure and Mottola presented the possibility of the existence of black hole mimics called gravastar (gravitational vacuum condensation star) that is quite same compactness as stellar black hole but has no event horizon. By the study of our study the existence of the graviton which is currently assumed as origin of gravity force meets problem because the graviton is also a wave in the regime of the quantum mechanics.

１．序論

本研究は銀河中心より到来するデカメータ波電波パルスの分析の結果にもとづき、銀河中心部に確定されつつある超巨大ブラックホールは、単一ブラックホールでなく、自転する Binary ker BH であるとの結論に達している。 Binary を形成する二つの巨大ブラックホールは本論では Gaa および Gab と呼ぶが、それぞれ、スピン周期 176.4+-1.7 sec および 148.6+-1.0 sec を持ち、半径 0.13 AU および、0.15 AU の円軌道を周期 2200 sec で周回している。この場合の視線方向に対する軌道速度は、Gaa および Gab がそれぞれ光速度の 18.0% および 21.4 % を示し、公転面と視線方向が一致する場合を仮定すると、Gaa および Gab の質量を 太陽質量、SM 単位で表すとき、それぞれ (2.27+-0.06)x10ˆ6 SM および (1.94+-0.03)x10ˆ6 SM となる。なお 両者の合計質量は (4.22+-0.03)x10ˆ6 SM となり、銀河中心部の 40 個近い恒星の運動を追跡する研究グループが結論している銀河系中心部の質量 (4.35+-0.13)x10ˆ6 SM に近い。問題は BH Binary、Gaa,Gab が安定系であるか、否かにあり、二重星軌道での潮汐力の非対称性、各天体のスピン対称性が議論対象となるが、角運動量と質量のみが制御パラメターとなるブラックホールでは超対称が仮定できる。しかし、安定性議論で最も大切なのは、重力波放射による軌道収縮と合体である。

２．重力波放射に関する矛盾

中性子星からの重力波放射が確認されて以来、ブラックホールからの重力波放射も中性子星の場合と同じ論法で展開されてきた。2015 年９月に LIGO によって重力波が歴史上初めて観測され、以来４例の重力波は５ SM から 40SM の星質量ブラックホールの合体と報告されている。同じ論法を本研究の結果に適用すると、Gaa-Gab Binary システムは約 10 時間 で合体することになる。

3. Event Horizon と波動伝搬

本研究では、ブラックホール時空を Free Fall する Minkowski 時空にて波動の伝搬を記述する論法で Shwartschild BH および Kerr BH の Event Horizon をよぎる波動は全て位相速度、群速度ともに 0 となることが示された。このことは、光が出てこないという明白な事実と一致するとともに、BH からは重力波も出ないことを示している

4　討論および結論

LIGO の重力波観測は確かであるが、しかし、その源がブラックホールという点で誤解のパラダイムに従っている可能性がある。代案として浮かぶ重力波源は、2001 及び 2004 年に Mazure および Mottola　の提出したブラックホールと同じ質量と近い密度を持ちつつ Event Horizon をもたない天体、Gravitational Vacuum Condensation Star (Gravastar) が提言される。なお、本研究での全ての波動が Event Horizon を通過できないという結論は、従来、重力の源として仮想されてきている Graviton も量子論レベルで波動性をもつことから、重力の源ではありえなくなる。

FKR と Loureiro のテアリング不安定性線形理論の再検証

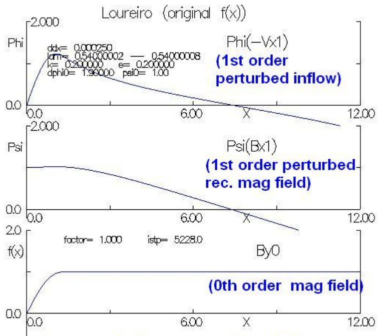
清水 徹 [1]; 近藤 光志 [2]
[1] RCSCE, 愛媛大; [2] 愛媛大・RCSCE

Re-examinations of the FKR and Loureiro's linear theories of tearing instability

Tohru Shimizu[1]; Koji Kondoh[2]
[1] RCSCE, Ehime Univ.; [2] RCSCE, Ehime Univ.

The FKR (PhysFluids1963) and Loureiro(PhysPlamsas2007)'s theories are numerically re-examined as a kind of the initial value problem, which are well-known as the linear theories of the tearing instability in the magnetohydrodynamic magnetic reconnection problem. Modifying the traditional treatments of those theories, a group of new perturbation solutions are found. The new results are completely different from those of the traditional theories and can answer why those theories give some mutually inconsistent results. It is shown that our new perturbation solutions of Phi(x) and Psi(x) shown below are consistent with full-MHD simulations of the plasmoid instability with the uniform resistivity.

磁気流体力学テアリング不安定性に関するよく知られた二つの線形理論の問題点を指摘し、本研究において初期値問題として数値的に得られた正しい摂動解の性質について論じる。ここで対象とする理論は FKR(Fruth,et.al.,PhysFluids1963) と Loureiro(PhysPlasmas2007) の理論である。本発表により、それらに共通に用いられるテアリング不安定特有の伝統的な解析手法の問題点が指摘される。本研究の結果は従来のそれら線形理論の結論とは大きく異なるし、それら理論の相互矛盾の原因が平衡解の設定方法にあることを指摘する。さらに、本研究で見つけられた新しい摂動解のいくつかの性質が従来の一様抵抗 Plasmoid Instability の数値シミュレーション結果と合致することが示される。



An example of zero-crossing solution
based on the Loureiro's perturbed eqs.

非対称磁気リコネクションにおけるプラズマ加速

近藤 光志 [1]
[1] 愛媛大・RCSCE

Plasma acceleration in the asymmetric magnetic reconnection

Koji Kondoh[1]
[1] RCSCE, Ehime Univ.

In the case of the magnetic and/or plasma environment on both sides of current sheet is asymmetric, the structure of the magnetic reconnection is significantly different from that in the symmetry case. In this paper, I report the plasma acceleration in the asymmetric magnetic reconnection.

電流層を挟んだ両側のプラズマ、磁場環境が非対称な場合、その磁気リコネクション構造は、対称な場合と大きく異なることが分かっている。本発表では、このような非対称磁気リコネクションの磁気流体スケールの構造、特に磁気リコネクションに伴うプラズマ流の加速について調べた結果を報告する。対称磁気リコネクションにおいても、スローショック以外での断熱加速が報告されているが、非対称磁気リコネクションにおいては、また異なる加速により、電流層を挟んだ両側の非対称度に対する、プラズマ流の最大速度の関係が単純な線形関係にないことを示す。

Study on the reconnection jet fronts based on fully kinetic simulations

Takuma Nakamura[1]; Takayuki Umeda[2]
[1] IWF, OeAW; [2] ISEE, Nagoya Univ.

We have performed a series of 3-D fully kinetic particle-in-cell simulations of anti-parallel magnetic reconnection to investigate the three-dimensional development of reconnection jet fronts treating three instabilities: the lower hybrid drift instability (LHDI), the ballooning/interchange instability (BICI), and the ion kink instability. Sufficiently large system size and high ion-to-electron mass ratio of the simulations allow us to see the coupling among the three instabilities in the fully kinetic regime for the first time. In this study, we particularly focused on the two cases changing the initial density ratio R between the center of the current sheet and the background region. In Case-A, R is set to be 20, which is large enough to excite the LHDI at the reconnection jet fronts. In this case, as the jet fronts develop, the LHDI and BICI become dominant over the ion kink instability. The rapid growth of the LHDI enhances the BICI growth and the resulting formation of finger-like structures. The small-scale front structures produced by these instabilities are similar to recent high-resolution observations of the dipolarization fronts in the near-Earth magnetotail using the Magnetospheric Multiscale (MMS) mission. On the other hand, in Case-B in which R=3.3, we see neither rapid growth of the LHDI nor turbulent development of the jet fronts. These results indicate the importance of the LHDI in the turbulent development of the reconnection jet fronts and the resulting energy conversion at the jet fronts.

R008-P04 **会場: Poster** **時間: 11 月 25 日**

Electromagnetic linear dispersion relation for plasma with a drift across magnetic field revisited

Takayuki Umeda[1]; Takuma Nakamura[2]
[1] ISEE, Nagoya Univ.; [2] ISAS,JAXA

A current across the magnetic field is formed in various situation in plasma. The relative drift between ions and electrons due to the cross-field current becomes a source of various microscopic instabilities. Fully electromagnetic and kinetic linear dispersion relation for plasma with a drift across magnetic field is derived by assuming an uniform background plasma. The dielectric permittivity tensor for shifted Maxwellian velocity distributions is also presented.

1 次元静電ブラソフシミュレーションを用いた電離圏観測ロケットウェイク近傍の電子速度分布関数に関する考察

遠藤 研 [1]; # 加藤 雄人 [1]; 熊本 篤志 [2]; 臼井 英之 [3]
[1] 東北大・理・地球物理; [2] 東北大・理・地球物理; [3] 神戸大・システム情報

Study of electron distribution functions around the wake of an ionospheric sounding rocket by a 1D Vlasov-Poisson simulation

Ken Endo[1]; # Yuto Katoh[1]; Atsushi Kumamoto[2]; Hideyuki Usui[3]
[1] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [2] Dept. Geophys, Tohoku Univ.; [3] System informatics, Kobe Univ

A sounding rocket moving supersonically in the ionosphere interacts with the surrounding plasma. It leads to the formation of a rarefied plasma region called plasma wake behind the rocket. Through several rocket experiments carried out previously, it has been suggested that plasma waves are excited around the rocket wake [Yamamoto, 2001; Endo et al., 2015]. Endo et al. (2015) classified plasma waves observed in the S-520-26 rocket experiment into three groups as Group A, B, and C. They concluded that Group A waves are electrostatic electron cyclotron harmonic (ESCH, ECH) or/and upper hybrid resonance (UHR) mode waves and that Group B and C waves are whistler mode waves. The intensities of these waves had spin-phase dependence which was different depending on kinds of plasma waves. Considering that the observed waves could be short-wavelength electrostatic modes, the obtained spin-phase dependence should represent the spatial distribution of free-energy sources for plasma wave instabilities. The actual distribution functions around the rocket wake, however, are not well known, and the relation with the wake formation process is unclear.

Singh et al. (1987) carried out a one-dimensional Vlasov-Poisson simulation and showed that two- or multi-stream electrons appear on the wake-axis up to 1.3 % of the near-wake region (ion void or the most diluted region nearest spacecraft). However, the electron distribution function in other part of the plasma wake could not be reported due to the effect from the boundaries [Singh et al., 1987], lack of computational resources, and large numerical errors from particle-in-cell (PIC) like calculation scheme in time development of the electron distribution function [Sakanaka et al., 1971; Singh, 1980].

In this study, we develop a one-dimensional Vlasov-Poisson code and carry out simulations on our own in order to investigate the distribution functions near the wake edges and the region more downstream. We assume a simulation model similar to that adopted by Singh et al. (1987), in which plasma expands into a void region along the magnetic field line. In this simulation, the time variation of plasma distribution was regarded as the spatial variation downstream. In order to suppress numerical errors, we adopted the time-splitting method [Cheng and Knorr, 1976] and the rational CIP method [Xiao et al., 1996] as used in Abe (2006). We perform simulations for two cases of ion-electron mass ratio: $m_i/m_e = 2.9*10^4$ assuming O^+ dominated plasmas in the lower ionosphere and $m_i/m_e = 40$. In the latter case, we achieve calculation up to 43 % of near-wake region, and find six types of charge density disturbances including Langmuir waves propagating from the wake edge to the outside and inside of the wake. The obtained Langmuir waves are triggered by an oscillating electric field around the wake edge. The oscillating electric field generates electron beams associated with the Langmuir waves. The electron beams form non-Maxwellian distribution functions around the wake edge. At the wake center, we obtain two- or multi-stream electrons, which are produced mainly by the negative wake potential. These simulation results indicate that non-Maxwellian electrons are created due to both the inward polarization electric field formed close to the wake axis, and the oscillating electric field appearing more outside.

In this presentation, we will show the simulation results of the charge density disturbances and electron distribution functions, and will discuss their generation process showing the relationship with electric field.

電離圏を超音速で飛翔する観測ロケットは周囲のプラズマと相互作用しながら運動する．そのため，その後方には航跡（ウェイク）と呼ばれる低プラズマ密度領域が形成される．過去のロケット実験により，ロケットのウェイク近傍でプラズマ波動が励起することが指摘されている [Yamamoto, 2001; Endo et al., 2015]．Endo et al. (2015) は，S-520-26 ロケット実験で観測されたプラズマ波動を 3 種類（Group A, B, C）にグループ分けし，Group A を静電的電子サイクロトロン高調波（ESCH，ECH）及び高域混成（UHR）モード波動，Group B と C をホイッスラーモード波動であると結論した．それぞれの波動強度はロケットのスピン位相角に応じて変化し，その変化の仕方はグループごとに異なることも明らかになった．観測されたプラズマ波動が短波長静電波であると考えると，このスピン位相角依存性はプラズマ波動を励起する電子の空間分布に対応していると考えられる．しかし，ロケットウェイク周囲の電子速度分布関数についてはあまりよく分かっておらず，ウェイク形成過程との関係も明らかになっていない．

Singh et al. (1987) は 1 次元の静電ブラソフシミュレーションを行い，near-wake 領域（飛翔体近傍の最も希薄な領域）の約 1.3%までのウェイク軸上で，二流体・多流体型の電子速度分布関数が得られることを示した．しかしながら，シミュレーション境界の影響 [Singh et al., 1987] や計算機資源の制約，粒子法（PIC）に似た計算スキーム [Sakanaka et al., 1971;

Singh, 1980] を用いていたことによる数値拡散のため，他の領域における速度分布関数については調べられなかった．

そこで，本研究ではウェイクのより下流やウェイク端での速度分布関数を調べるため，改めて 1 次元静電ブラソフコードを開発しシミュレーションを行った．モデルの置き方は Singh et al. (1987) を参考にし，一次元空間に設定した低密度領域の両側から背景の高密度プラズマが流れ込む現象を模擬した．シミュレーションで再現される粒子の分布の時間変化は，それらのウェイク下流方向の空間分布とみなした．本シミュレーションでは数値拡散を抑えるため，Abe(2006) を参考にして time-splitting 法 [Cheng and Knorr, 1976] 及び有理関数 CIP 法 [Xiao et al., 1996] を用いた．

シミュレーションは，低高度電離圏でみられる O^+ 主成分のプラズマを仮定した $m_i/m_e = 2.9*10^4$ と，$m_i/m_e = 40$ の，2 パターンのイオン電子質量比で計算を行った．質量比 $m_i/m_e = 40$ の場合は near-wake 領域の 43%にあたる領域まで計算することができ，その結果，ウェイクの内外に向かって伝搬するラングミュア波など 6 種類の電荷密度擾乱が観測された．ラングミュア波はウェイク端で起こる振動電場によって駆動され，その振動電場はラングミュア波の伝搬に関わる電子ビームを生成するものであった．そのため，ウェイク端付近では電子ビームを伴う電子速度分布関数が得られた．一方，ウェイク中心では，主にウェイク中の負のポテンシャルによって作られる二流体・多流体型の電子速度分布関数が見られた．以上のシミュレーション結果は，ウェイク近傍の非マクスウェル型速度分布が，ウェイク内向きの分極電場とより外側にできる振動電場の両方によって生成することを示している．

本発表では，電荷密度擾乱及び電子速度分布関数の空間分布の結果を示し，その成因について電場分布との関係を示しながら議論を行う．

EMIC 波と相互作用する高エネルギープロトンのダイナミクス

関根 友博 [1]; 大村 善治 [2]; Summers Danny[3]
[1] 京大・工・電気; [2] 京大・生存圏; [3] Memorial Univ. Newfoundland

Dynamics of energetic protons interactingwith electromagnetic ion cyclotron waves

Tomohiro Sekine[1]; Yoshiharu Omura[2]; Danny Summers[3]
[1] Electrical Engineering, Kyoto Univ.; [2] RISH, Kyoto Univ.; [3] Memorial Univ. Newfoundland

We perform simulations of non-relativistic protons interacting with EMIC waves in the Earth’s magnetic
eld. We
nd that the non-relativistic protons are trapped and accelerated by waves. We also perform simulations of the motion of relativistic protons in the Juvian magnetic
eld. We
nd highly efficient acceleration of the protons by the EMIC waves. The efficiency is greater than that at the Earth. In this acceleration process, the direction of proton velocity along the magnetic

eld is reversed. We observe that this acceleration process is quite similar to the acceleration process of relativistic electrons by whistler-mode chorus waves, called Relativistic Turning Acceleration(RTA). We modify the nonlinear trapping theory for the relativistic proton case. We con
rm that our results satisfy the theoretical conditions for RTA.

Shear Alfven wave turbulence: Particle-In-Cell simulation

Shinji Saito[1]; Yasuhiro Nariyuki[2]; Takayuki Umeda[3]
[1] Nagoya Univ.; [2] Faculty of Human Development, Univ. Toyama; [3] ISEE, Nagoya Univ.

The solar wind is known to be in highly turbulent state. Turbulent cascade process supplies fluctuation energy at magneto-hydrodynamics (MHD) scales into kinetic scales where ion and electron kinetics have a crucial role for physics of turbulence such as nonlinear cascade to shorter scales and dissipation. In-situ observations in the solar wind at 1 AU have demonstrated that magnetic energy spectrum at the kinetic scales becomes steeper than that at MHD scales, and reaches at electron kinetic scales. It suggests that undamped or weakly dissipated fluctuations cascade into electron kinetic scales. Various kinetic wave modes, such as Alfven-cyclotron mode, kinetic Alfven mode, and whistler mode, are proposed as key constituent modes in kinetic turbulence. These fluctuations are expected to be converted from fluctuations in MHD regime. However, there is an open question for the conversion process from MHD to kinetic fluctuations.

The purpose of this study is to investigate nonlinear cascade process of shear Alfven mode turbulence into electron kinetic scales. In order to demonstrate the conversion process in wave turbulence in fully kinetic regime, two-dimensional fully kinetic particle-in-cell simulation is used, which covers scales well-larger than ion kinetic scales by resolving electron kinetics. The simulation is initialized by a superposition of shear Alfven mode waves with wave length well-longer than ion inertial length. It is expected that the self-consistent development of shear Alfven mode turbulence leads to some undamped/weakly dissipated fluctuations at kinetic scales and finally dissipate at electron kinetic scales. We will show the cascade of shear Alfven wave turbulence into electron kinetic scales and discuss how the fluctuations at electron kinetic scales are dissipated.

Anomalous trapping of low pitch angle electrons by coherent whistler mode waves

Masahiro Kitahara[1]; Yuto Katoh[1]
[1] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.

Chorus emissions that are one of coherent whistler-mode waves observed in the inner magnetosphere scatter energetic electrons in pitch angle, while the pitch angle scattering is closely related to energetic electron precipitation into the atmosphere contributing to diffuse/pulsating aurora. Conventionally, it is considered that energetic electrons satisfying the cyclotron resonance condition in the energy range from a few keV to tens of keV are scattered toward the loss cone by chorus emissions. However, previous studies indicate that low pitch angle electrons tend to be scattered away from the loss cone by coherent whistler-mode waves [e.g. Li et al., 2015]. In this study, we derive the equations of the motion of electrons including the terms neglected in previous studies and theoretically reveal anomalous trapping of low pitch angle electrons scattered away from the loss cone. Furthermore, we carry out a spatially one-dimensional test particle simulation along a dipole magnetic field assuming whistler mode waves propagating along the field line with frequency sweeping. In the simulation results, we reproduce that the large amplitude chorus waves generate a bump in the pitch angle distribution. We find that particles near the loss cone are more effectively scattered away from the loss cone and the bump generated in the pitch angle distribution becomes large for larger wave amplitude.

１次元、２次元および３次元磁場における高エネルギー電子とホイッスラーモードコーラス波の相互作用

高橋 渓太 [1]; 大村 善治 [2]; Summers Danny[3]
[1] 京大生存研; [2] 京大・生存圏; [3] Memorial Univ. Newfoundland

Interaction between energetic electrons and whistler mode chorus waves in 1-D, 2-D and 3-D magnetic fields

Keita Takahashi[1]; Yoshiharu Omura[2]; Danny Summers[3]
[1] RISH; [2] RISH, Kyoto Univ.; [3] Memorial Univ. Newfoundland

To evaluate the validity of a 1-D and 2-D model magnetic fields, we perform test-particle simulations and monitor the resonant trapped electrons in 1-D, 2-D and 3-D models. With respect to the adiabatic motions of electrons, the trajectories of electrons in the 1-D and 2-D motions show agreement with those in the 3-D model in terms of cyclotron and bounce motions. When simulations including the whistler mode waves are performed, we find that cyclotron resonance occurs with similar timing in each models. Though relativistic turning acceleration (RTA) is observed in each models, the energy that electrons acquire in the 1-D and 2-D models is greater than those in the 3-D models. It is confirmed that the 1-D and 2-D model realizes the Earth's dipole magnetic field adequately only near the equator, which suggests that the results of simulations based on the 1-D model at high-latitude positions may be greatly different from those in 3-D model.

1 次元および 2 次元モデル磁場の有効性を評価するために、1 次元、2 次元および 3 次元磁場のもとでテスト粒子シミュレーションを行い、電子を運動を解析した。 断熱運動に関しては、1 次元および 2 次元運動における電子の軌道は、サイクロトロンおよびバウンス運動の観点から 3 次元モデルにおける軌道と一致することが確認された。 ホイッスラーモード波を含むシミュレーションを行った場合、サイクロトロン共鳴が各モデルにおいて同様のタイミングで生じる。Relativistic Turning Acceleration（RTA）は各モデルで確認されたが、電子が 1 次元および 2 次元モデルで得るエネルギーが 3 次元モデルのエネルギーよりも大きくなる。 1 次元及び 2 次元モデルは、赤道付近で地球の双極子磁場を適切に表現できることが確認されたが、高緯度位置における 1 次元、2 次元モデルに基づくシミュレーションの結果は、3 次元モデルと大きく異なる可能性がある。

高強度レーザーを用いた無衝突衝撃波実験のデータ解析

堀江 由実 [1]; 松清 修一 [2]; 羽田 亨 [3]
[1] 九大・総理工・大海; [2] 九大・総理工; [3] 九大総理工

Data analysis of collisionless shock experiment using high power laser

Yumi Horie[1]; Shuichi Matsukiyo[2]; Tohru Hada[3]
[1] ESST,Kyushu,Univ.; [2] ESST Kyushu Univ.; [3] IGSES, Kyushu Univ

Collisionless shocks often play important roles in various high energy phenomena in space. We have performed a collisionless shock experiment using a high power laser at the Institute of laser engineering (ILE) at Osaka University to investigate multiscale structures of the transition region of a collisionless shock. Our goal is to understand non-equilibrium plasma processes occurring in the shock transition region reproduced by the experiment with a number of diagnostics including collective Thomson scattering measurement.

The experimental method is as follows. An aluminum foil target in the nitrogen gas is irradiated by the Gekko No.12 laser (~250 J *3beams, 527nm, Gaussian shape with 1.3ns duration). The target plasma expanding with supersonic flow velocity sweeps the gas plasma which is produced by the strong radiation due to laser-foil interaction. The target is the aluminum foil of 3 mm *3 mm *200 um, the gas pressure is varied as 2.5, 5, 10 Torr. We utilize a number of diagnostics such as shadowgraphy, self-emission streaked optical pyrometer (SOP), collective Thomson scattering (CTS), etc. In particular, the CTS measurement is effective in measuring the local quantities inside the shock transition region. We confirmed that a shock is successfully formed for each gas pressure. In the case of the gas pressure of 5 Torr and 10 Torr, a steep shock surface is seen by the SOP and the CTS measurements. In the case of 2.5 Torr, the transition from upstream to downstream relatively blunt. In this case, the temperature increase of the upstream gas plasma is observed even in the early stage before that a shock is clearly formed. It is found that this temperature increase is caused by the interaction between the target aluminum ions and the gas plasma. We will also estimate the shock parameters for each gas pressure and report the conditions for the upstream temperature increase.

In the forthcoming ILE experiment scheduled in October this year, we will apply an external magnetic field to reproduce a magnetized collisionless shock. The results will also be reported if possible.

宇宙における高エネルギー現象では、しばしば無衝突衝撃波が重要な役割を果たす。宇宙の無衝突衝撃波を実験室に再現して遷移層近傍の多スケール構造を詳細に調べるため、我々は大阪大学レーザー科学研究所 (ILE) との共同実験により、高出力レーザーを用いた無衝突衝撃波生成実験をおこなっている。本研究では、衝撃波遷移層で起こる非平衡プラズマ過程を実験的に再現し、協同トムソン散乱計測をはじめとする各種計測によってその詳細を明らかにすることを目的とする。

実験方法は、以下のとおりである。窒素ガス中のアルミ箔ターゲットに激光 No.12 レーザーを照射し、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。照射レーザーは～250J *3 ビーム、波長は 527nm、ガウス型長パルス (1.3ns) で、照射スポット径は 300um(um=10^{-3}mm) である。ターゲットは 3mm*3mm*200um のアルミ箔で、ガス圧は 2.5,5,10Torr とした。光学計測として、自発光計測、シャドー計測、協同トムソン散乱計測を用いた。特に、遷移層内部の局所量の計測には協同トムソン散乱計測が有効である。各ガス圧に対して衝撃波の生成を確認した。ガス圧 5Torr および 10Torr の場合には、急峻な衝撃波面が自発光計測と協同トムソン散乱計測で確認できた。2.5Torr の場合には、上流から下流への遷移は比較的なだらかになった。この場合、衝撃波が形成される前の早い段階で、上流ガスプラズマの温度上昇が見られた。この温度上昇は、ターゲットのアルミイオンとガスプラズマの相互作用によって起こることが分かった。各ガス圧における衝撃波のパラメータや上流の温度上昇が起こる条件についても報告する。

今年度 10 月に行われる ILE 実験では、磁化プラズマ衝撃波を生成するために、磁場を印加した実験を行う予定である。解析が間に合えばその結果も報告する。

DNLS モデルによるアルフヴェン波動の非線形発展

菅 さおり [1]; 羽田 亨 [2]; 松清 修一 [3]
[1] 九大・総理・大海; [2] 九大総理工; [3] 九大・総理工

Nonlinear evolution of Alfven waves in the DNLS system

Saori Kan[1]; Tohru Hada[2]; Shuichi Matsukiyo[3]
[1] ESST,Kyushu Univ.; [2] IGSES, Kyushu Univ; [3] ESST Kyushu Univ.

Large amplitude magneotohydrodynamic (MHD) waves are ubiquitous in space plasma, in particular, in the solar wind and regions adjacent to collisionless shocks. The existence of these waves is confirmed by spacecraft experiments, providing us with excellent opportunities to examine various nonlinear physical processes of large amplitude waves in general. There remain numerous issues left unsolved, however, despite their importance not only in the field of space plasma but also in nonlinear wave physics. In this presentation, we make a re-visit to the relatively well-known model of the derivative nonlinear Schroedinger equation (DNLS), which describes the nonlinear evolution of nearly degenerate two Alfven waves that propagate quasi-parallel to the background magnetic field. Via theory and numerical simulation employing the CELF scheme (energy conserving, variable time step), we will discuss the Rieman problem within the DNLS and show that a series of solitons are generated, as expected from the inverse scattering analysis.

宇宙プラズマ、特に太陽風中や衝撃波近傍域には大振幅の磁気流体（ＭＨＤ) 波動が存在し、非線形発展をおこなっている。これらの波動は人工衛星観測により確認されており、非線形波動現象を研究するための恰好の題材を提供している。有限振幅ＭＨＤ波動の非線形発展については多くのモデルが存在するが、未解明かつ重要な課題が数多く残されているのが現状である。本研究では、ＭＨＤ波動の中でも特に、磁力線にほぼ平行方向に伝搬する２つのアルフヴェン波を含む簡約数理モデルである微分型非線形シュレーディンガー方程式（DNLS) を用いて、理論および数値シミュレーションにより、このモデルに含まれるソリトン解について議論を行う。数値シミュレーションには CELF 法の計算スキームを用いるが、これはエネルギーが厳密に保存されることと計算ステップ長が可変であることが特徴である。これまでほとんど注目されることのなかった 2-parameter soliton 解や breather 解の性質を示す。また、DNLS 上でのリーマン問題の時間発展としてソリトン列が生成されることを示し、これらと逆散乱法による固有値との対応について議論を行う。

Cross-reference simulations by scalable communication library for the study of wave-particle interactions in magnetospheres

Yuto Katoh[1]; Keiichiro Fukazawa[2]; Takeshi Nanri[3]
[1] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [2] ACCMS, Kyoto Univ.; [3] RIIT, Kyushu Univ.

We carry out a series of electron-hybrid and MHD cross-reference simulations for the study of the generation and propagation of chorus emissions in the planetary magnetosphere. Chorus emissions are electromagnetic plasma waves commonly observed in planetary magnetospheres and are a group of coherent wave elements changing their frequency in time. While the generation process of chorus has been reproduced by numerical experiments [e.g., Katoh and Omura, GRL 2007a] and has been explained by the nonlinear wave growth theory [Omura et al., JGR 2008, 2009], previous studies revealed similarities and differences of the spectral characteristics of chorus in planetary magnetospheres, which has not been understood yet.

In the cross-reference simulations, we use the MHD code for the investigation of the range of variation of the spatial scale of the planetary magnetosphere. The electron hybrid code is used to reproduce the generation process of chorus emissions under the initial conditions provided from the MHD simulations. An electron fluid code [Katoh, 2014] is also used for the study of the propagation of chorus emissions in the meridional plane of the magnetosphere.

We have been developing a cross-reference simulation code by scalable communication library for the study of wave-particle interactions in planetary magnetospheres. We use Advanced Communication Primitives (ACP; http://ace-project.kyushu-u.ac.jp/main/jp/01. library for the communication among the simulation codes, which enables us to carry out 'strong' cross-reference simulations; the data exchange among simulation codes is conducted by direct memory access, instead of file output as has been used in conventional 'weak' cross-reference simulations. In the present study, we describe the simulation models used in the developing code and show their initial results.

不安定条件下での宇宙エレベーターの挙動

辻野 勇樹 [1]; 羽田 亨 [2]; 松清 修一 [3]
[1] 九大・総理工・大海; [2] 九大総理工; [3] 九大・総理工

Dynamics of the space elevator under unstable conditions

Yuki Tsujino[1]; Tohru Hada[2]; Shuichi Matsukiyo[3]
[1] ESST, Kyushu Univ.; [2] IGSES, Kyushu Univ; [3] ESST Kyushu Univ.

The space elevator, which basically is a cable connecting the earth and the outer space (up to ~16 Re), is expected as a new means of transport. If it is realized, it can be a traffic infrastructure that can be used continuously for a long time. Also, by the departure of spacecraft from the satellite on the space elevator, people can advance further into the universe. The technical demands of the space elevator are high, and it was far from realization, but with the discovery and development of new materials typified by carbon nanotubes, the feasibility has increased, and the research is progressing. Recently there appears an increasing number of academic studies about the conceptual design (e.g., Edwards, 2007) and climber and wind influence (e.g., Lang, 2005, Williams, 2009), although, overall, the research is still at the initial stage of examination.

Since there is numerous debris flying near the earth that can collide the space elevator, and since the debris density is greatly influenced by the atmospheric density, one cannot ignore the space weather connection to the stable and long-term operation of the space elevator. In this research, we focused on the dynamics of the cable when a significant impact is given to the space elevator. First, we developed a numerical model to simulate the motion of the cable using the lumped-mass model, i.e., the cable is modeled by a continuous elastic spring-mass point system. The following forces are included in the model: gravitational force due to the Earth, the centrifugal force and the Coriolis force due to the revolution movement around the earth, internal stress and the friction of the cable. We first determined the equilibrium positions of the mass points and then checked small-amplitude oscillations of the system correspond to those obtained by eigenvalue analysis. We will report the simulation results on the cable movement when a finite amplitude impact is given at various locations, directions, and magnitudes, with and without including the effect of cable disconnection.

現在、宇宙（16Re 程度）と地上で物や人のやり取りをする唯一の手段はロケットである。ロケットは、コスト、環境への影響、安全面に課題がある。これらを解決する新たな宇宙への輸送手段として、宇宙エレベーターの概念が提唱されている。宇宙エレベーターは、静止軌道以遠での遠心力と静止軌道以内の重力とによる張力を利用して地上と宇宙をつなぐ建造物（ロープ）である。したがって、ロケットのように使い捨てではなく、長期にわたって継続的に利用できる交通インフラとなる。また、宇宙エレベーター上の衛星から探査機や宇宙船が出発することで人類がさらに遠くの宇宙へ進出することができる。宇宙エレベーターの技術的要求は高く、実現には程遠いものであったが、カーボンナノチューブに代表される新素材の発見や開発をきっかけに実現性が高まり、研究が本格化している。Edwards[2007] による宇宙エレベーターの概念設計に始まり、Lang[2005],Williams[2009] たちのケーブルの展開や、クライマーや風の影響についての学術的研究はあるが、まだ初期的な検討に過ぎない。

地球近傍には多くの宇宙デブリが存在するため、長時間スケールではこれらと宇宙エレベータの衝突事故を考慮する必要がある。また宇宙デブリ密度は高高度における大気密度に影響されるため、宇宙天気との関連も重要である。本研究では宇宙エレベーターに大きな衝撃が与えられた時のケーブルのダイナミクスに注目した。まず、ケーブルの運動をシミュレートするための数値モデルを開発した。ケーブルは Lumped Mass 法により多数の弾性ばね—質点系として近似し、これらの地球による重力、地球の自転に起因する遠心力とコリオリ力、ケーブルの伸縮による内部応力を考慮した。まず力学的平衡位置を求め、固有値問題の解として微小振動スペクトルを求め、シミュレーションの結果と一致することを確認した。ケーブルに微小ではなく有限の力積が加わる場合を想定し、様々な条件下でのケーブル運動を計算した。ケーブルの有限振幅振動と地球への落下について、またケーブルに加わる張力が限界値を超えた場合にケーブルが切断されることをとりいれたモデルを用いて破壊条件を求めた結果を報告する。