Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PEM26-01 会場:102B 時間:5 月 22 日 13:45-14:00

３次元磁気リコネクションにおけるプラズモイド誘導乱流
Plasmoid-induced turbulence in 3D magnetic reconnection

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One of the main issues on magnetic reconnection processes is the mechanism breaking the frozen-in condition around the x-line and providing the electric resistivity in collisionless plasmas. It has been recognized empirically in magnetohydrodynamic simulations that the Petschek-type fast reconnection can be achieved only when an intense resistivity arises locally near the x-line. However, the generation mechanism of the resistive effects in collisionless plasmas is poorly understood in the kinetic framework. In 2D reconnection, it has been demonstrated by kinetic simulations that the momentum transport due to the Speiser-type motion of the electrons around the x-line gives rise to the so-called inertia resisticity which results in the electron viscosity term in the generalized Ohm's law. Although the electron inertia resistivity gives intense dissipation under the thin current layer on the order of the electron inertia length, such a thin current sheet has been observed neither in the laboratory experiments nor in the geomagnetosphere. The observational results have shown that the current sheet width during the fast reconnection is much larger than that in the 2D kinetic simulations and electromagnetic wave activities are usually accompanied. These characteristics infer the existence of the anomalous effects due to wave-particle interactions that are not incorporated in the 2D simulations.

In order to investigate the 3D effects in the dissipation process, the present study has performed large-scale particle-in-cell (PIC) simulations in 3D system. The code employs the adaptive mesh refinement (AMR) and is massively parallelized, which enables us to perform highly efficient simulations on state-of-the-art supercomputers. The 3D simulations revealed that the thin current layer is unstable to a low-frequency electromagnetic mode with $w_{ci} < w < w_{LH}$, where w_{ci} and w_{LH} are the ion cyclotron frequency and the lower hybrid frequency, respectively. The mode propagates in the cross-field direction and produces the turbulent flow around the electron current layer, so that the electron current is impeded by the turbulence on average. The turbulence effect is evaluated by the anomalous terms in the generalized Ohm's law and is found to provide significant contribution to the force balance. In particular, it is very interesting to remark that the turbulence effect is strongly enhanced in association with the plasmoid ejections. Although the present simulations have been carried out for an unrealistic ion-to-electron mass ratio (mi/me = 100), the linear analyses have demonstrated that the mode still survives for the real mass ratio (mi/me = 1836).

In this paper, we show the recent kinetic simulation results in large-scale 3D system, where it is described that the intense turbulence is caused due to the plasmoid ejections. The possible scenario under the real mass ratio will be discussed using the linear analyses based on the two-fluid equations.
Keywords: 3D magnetic reconnection, dissipation mechanism, turbulence, plasmoid, AMR-PIC simulation

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PEM26-02 会場:102B 時間:5 月 22 日 14:00-14:15

希薄な差動回転円盤における磁気回転不安定性の局所ハイブリッドシミュレーション
Local Hybrid Simulation of Magneto Rotational Instability in dilute differentially rotating disks

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Magneto-Rotational Instability (MRI) is a plasma instability which is considered to take place in a magnetized differentially rotating astrophysical disks. It is first proposed by Velikhov in 1959 and later by Chandrasekhar in 1960. Its importance in astrophysical rotating disk was pointed out by Balbus and Hawley in 1991.

This instability can generate MHD turbulence within a few periods of orbit and can generate a strong turbulent viscosity. Thus this instability is considered to play a major role in the context of accretion which requires a strong viscous effect to transport angular momentum in the disk. These nonlinear behaviors of MRI, such as generation of turbulence or accretion due to the strong turbulent viscosity, are mainly studied by numerical simulations under MHD approximation which assumes the plasma as a single component fluid.

However, recent analytical and numerical studies have shown that kinetic effects can be important on the evolution of MRI in dilute accretion disks which are often found around black holes. These studies have mainly focused on the generation of pressure anisotropy during the evolution of MRI, and the plasma which constitutes the accretion disk is treated as a Landau fluid.

In this study, we developed 2-dimensional hybrid code to study local differentially rotating collisionless plasma. We treated ion as a particle and electron as a massless fluid, and included the effect of gravity and tidal force. In this presentation, we would like to discuss the generation and relaxation process of pressure anisotropy during the evolution of MRI.

キーワード: プラズマ不安定, 降着円盤, 磁気回転不安定性, 運動論プラズマ
Keywords: Plasma instabilities, Accretion disks, Magneto Rotational Instability, Kinetic plasma effects

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PEM26-03 会場:102B 時間:5 月 22 日 14:15-14:30

太陽風中のプロトン温度異方性とアルフェン乱流の径方向発展
Evolution of proton temperature anisotropy and Alfvenic turbulence in the radially expanding solar wind

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In the present study, we develop an analytical model of the radially expanding solar wind plasma that includes the proton temperature anisotropy and low-frequency Alfvenic turbulence. The conservation of the ”apparent temperature” in the flux tube is derived as the Bernoulli law in the magnetohydrodynamic (MHD) equations with the pressure anisotropy. Our analytical model shows that the conversion from ”apparent temperature” to ”real temperature” occurs in the radially expanding solar wind.

キーワード: 太陽風, プロトン温度異方性, アルフェン乱流
Keywords: solar wind, proton temperature anisotropy, Alfvenic turbulence

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PEM26-04 会場:102B 時間:5 月 22 日 14:30-14:45

音速抑制法を用いた太陽内部熱対流数値計算
Numerical calculation of solar thermal convection with the Reduced Speed of Sound Technique

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We suggest the new technique to calculate solar internal convection efficiently. It is important to understand the solar internal convection. This issue is deeply related to investigation of the solar global flow and the solar dynamo problem. There is a difficulty to solve the solar internal convection numerically, i.e. the speed of sound. The speed of sound is about 200 km/s, whereas the speed of convection is about 50 m/s at the base of the convection zone. The time step is significantly short with this high speed of sound. The anelastic approximation is often adopted to avoid this difficulty and there are many works with this approximation. This approximation, however, requires the frequent global communication in parallel computing and the efficiency becomes bad with large number of CPUs. A larger resolution with larger number of CPUs is essential to solve the proper angular momentum transport by turbulence. Therefore, we are looking for another way, i.e. RSST(Reduced Sound Speed Technique). The speed of sound is artificially reduced with the transformed equation of continuity and the time step can be took large. This technique does not require the global communication. We investigate the validity of this technique to describe the convection. 3D simulations of the convection shows that the characteristic features does not change with RSST when Mach number is smaller than 0.7.

キーワード: 太陽, 対流, 数値計算
Keywords: sun, convection, numerical calculation

PEM26-05 会場:102B 時間:5 月 22 日 14:45-15:00

太陽表面対流スケールに対する磁場の役割
The role of magnetic field on the scale of solar surface convection

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我々は、太陽表面対流の卓越するスケールである超粒状斑の生成メカニズムを、放射磁気流体数値計算を通して調べている。

太陽表面対流は、粒状斑と超粒状斑という少なくとも 2 つのスケールを持つ。超粒状斑のセル境界付近には磁場が集まり、上層大気の加熱に大きな役割を果たすと考えられている。
超粒状斑は発見から約 50 年たつが、その生成機構については現在も議論が続けられている。古典的には、ヘリウムの再結合が超粒状斑を駆動すると考えられてきた。しかし、近年可能になったヘリウムの部分電離を考慮した流体計算では、超粒状斑が表れなかったという例が報告されている。
一方、Crouch ら（2007）は磁場と熱対流の相互作用による説を提唱している。対流のランダム運動による磁束の移流・合体で磁気ネットワークが形成され、その対流へのフィードバックで超粒状斑が生まれるというシナリオである。

この研究では、Crouch らの主張に基づき、対流層から光球・彩層までを含んだ磁気対流計算により、超粒状斑の生成過程における磁場の役割を明らかにすることを目指した。太陽表面はさまざまな物理プロセスが絡み合っており、結果をなるべく定量的に正しいものにするため、LTE 放射輸送や部分電離を考慮した放射磁気流体コードを開発した。
磁場を入れない計算で対流層の深さを変化させたところ、少なくとも深さ 10Mm までででは、表面に超粒状斑のようなスケールは現れなかった。これは先行研究と整合的である。
講演では、磁場を加えた場合の結果を報告し、超粒状斑の生成過程における磁場の役割を議論する。

キーワード: 太陽, 光球, 対流, 磁場
Keywords: sun, photosphere, convection, magnetic field

PEM26-06 会場:102B 時間:5 月 22 日 15:00-15:15

磁気圏における Region2 沿磁力線電流の生成機構について
Magnetospheric sources and mechanisms of Region 2 field-aligned currents

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Field-aligned currents (FACs) are the electric currents that flow along magnetic field lines between the ionosphere and the magnetosphere. In the ionosphere, large-scale FACs reside in an annulus that encircles the geomagnetic pole. The FACs located on the poleward side are called <region 1>, while those located on the equatorward side are called <region 2>. Of the two FAC systems, the latter Region 2 FACs are thought to be closed on the nightside, driven by the pressure gradient in the ring current region or the inner edge of the plasma sheet. In order to drive FACs constantly, there must be a region where $j*E < 0$ (with j and E being the current density and electric field, respectively). In the past, this basic energetics of the current system has not been seriously considered. To investigate the source mechanisms of region 2 FACs, we performed global MHD simulation and examined the dynamo processes in the magnetosphere. Our new finding is that the region 2 FACs are closed not only on the nightside, but also on the dayside even in a quasi-stationary magnetosphere. Similar to the nightside region 2 system, dayside region 2 FACs are driven by the plasma pressure gradient and their energy source is the thermal energy of the plasma. However, unlike the nightside region 2 system, the dynamo region of the dayside region 2 system is located at high latitudes just equatorward of and adjacent to the dayside cusp. Thus the dayside cusp is essential for the generation of dayside region 2 FACs. We discuss in detail the physical processes associated with the dayside region 2 system.

キーワード: 磁気圏, 沿磁力線電流, MHD シミュレーション
Keywords: Magnetosphere, Field-aligned current, MHD simulation

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PEM26-07 会場:102B 時間:5 月 22 日 15:30-15:45

衛星ウェイクの電界計測への影響に関するプラズマ粒子シミュレーション
Plasma particle simulations on spacecraft wake effects on electric field measurements

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将来磁気圏探査衛星で計画される定常および波動電界の精密測定に向け、宇宙プラズマ環境中における電界センサーの振る舞いをより詳細に把握する必要がある。イオンのドリフト速度が熱速度より大きいプラズマフロー中では、背景プラズマ中に比べてイオン密度が低いウェイク領域が衛星の後方に形成される。特に極風中などでは冷たいイオンフローが高い電位を有する衛星に排斥されることで、ウェイク領域が拡大する [1]。このウェイク領域に片側の電場プローブが侵入すると、ウェイクポテンシャルに起因するスプリアス電界が観測されることが報告されている。このような不要成分を同定もしくは除去するためには、衛星周辺のウェイク構造やその形成過程を詳細に解析する必要がある。こうした解析は、限られたケースを除いては理論や地上実験で取り扱う事が困難であり、数値的手法の確立が急務となっている。

本研究では、電界センサー周辺プラズマ環境、およびその環境下でのセンサー特性評価にプラズマ粒子計算機実験を適用する。粒子モデル計算機実験は個々のプラズマ粒子の運動方程式を解き進めていくため、原理的にはウェイクの形成過程を運動論効果も含めて矛盾なく再現することができる。

本発表では Cluster 衛星周辺のウェイク構造の数値モデリングとプラズマ粒子シミュレーション解析について報告を行う。特に衛星本体に加え、ウェイク形成に一定の影響を及ぼす可能性のあるブームを数値モデルに取り込む。一般にブームの半径（数 mm）は衛星本体のサイズ（数 m）に比べて非常に小さいため、ブーム形状が解像可能なメッシュサイズでシミュレーション領域を区切ることは現実的ではない。そこで本解析ではブーム中心軸の最近傍グリッド点に実際のブーム正電位より低い電位を設定することで、仮想的に細いブーム形状を模擬することとした。このモデルを用い、プロトンと O+イオンを含むプラズマ中でウェイク形成の計算機実験を行った。その結果、衛星のみならずブームの後方にもウェイク構造が認められ、ラム側とウェイク側のプローブ間に電位差が発生することを確認した。これを電界値に換算すると 3〜5 mV/m 程度となり、観測による報告例と近い結果となった。今後はブームとフローの成す角度に対するウェイク構造の依存性を調査し、スピン面内の電場センサーがどのようなスプリアス電界波形を測定するかを調査する。

[1] E. Engwall et al., Wake Formation Behind Positively Charged Spacecraft in Flowing Tenuous Plasmas, Phys. Plasmas, 13, 062904, 2006.

キーワード: 電界センサー, 衛星ウェイク, 粒子シミュレーション
Keywords: Electric field sensor, Spacecraft wake, PIC simulation

PEM26-08 会場:102B 時間:5 月 22 日 15:45-16:00

相対論的衝撃波における電磁場エネルギーの散逸
Dissipation of electromagnetic energy at relativistic shocks

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Poynting-flux dominated relativistic flows are thought to occur in many high-energy astrophysical environments, including pulsar winds, jets in active galactic nuclei and gamma-ray bursts. In the case of a pulsar wind, the relativistic flow is terminated by a standing shock (the termination shock) occurring at the point where the pressure of the flow equals to that exerted by a surrounding medium. Although neither ideal magnetohydrodynamic (MHD) flows nor ordinary MHD shocks do not convert the dominant electromagnetic energy into the kinetic energy of particles, observations do suggest that the kinetic energy is dominant in the downstream of the shock, indicating the presence of an efficient energy conversion mechanism. Magnetic reconnection is often invoked as a mechanism that annihilates the fluctuating component of magnetic fields originating from obliquely rotating central objects. However, it is suggested that magnetic reconnection cannot provide sufficient dissipation, so that the fluctuating component remains until the wind reaches the termination shock.

Motivated by this, the dynamics of a relativistic shock standing in a highly magnetized wind containing a fluctuating component is studied. The fluctuation is modeled by a circularly polarized magnetic shear wave embedded in the flow (i.e., an entropy mode wave.) The frequency of the wave measured in the shock rest frame is boosted by the relativistic Doppler shift, and thus, can be higher than the plasma frequency in a parameter regime relevant to pulsar winds. This opens up a new dissipation channel. The upstream wave can be converted into electromagnetic waves (or photons) by the discontinuity and the dissipation may be triggered through subsequent instabilities. By utilizing a newly developed relativistic two-fluid code for pair plasmas, such a energy conversion mechanism is actually shown to exist. It is demonstrated that the shock is strongly modified by self-consistently generated intense electromagnetic waves. A precursor region is formed ahead of the shock in which significant amount of the electromagnetic energy is dissipated into particles. It is found that an initial highly magnetized wind is converted into a particle-energy-dominated, non-relativistic flow across the shock, as required by the boundary condition imposed by a surrounding medium.

キーワード: 衝撃波, 電磁波, 相対論
Keywords: shock, electromagnetic wave, relativistic

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PEM26-09 会場:102B 時間:5 月 22 日 16:00-16:15

太陽風と局所的磁場を持つ誘電物体との相互作用に関するブラソフシミュレーション
Vlasov simulation of the interaction between the solar wind and a dielectric body with magnetic anomaly

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月のような固有磁場を持たない誘電物体に太陽風が当たると、夜側にウェイクと呼ばれる真空の領域が形成される。これは太陽風速度がイオンの熱速度に比べてはるかに大きく、イオンが月の夜側に侵入することができないためである。ところが、日本の月周回衛星「かぐや」が 2008 年に月面上空 100km よりプラズマ密度と磁場の観測を行ったところ、ウェイク内部においてイオンが観測された。これは月表面の磁気異常と惑星間空間磁場 (IMF) との相互作用により月昼側の太陽風イオンが散乱され、月裏側に侵入したためと考えられている。本研究では、月に見立てた誘電物体に弱いダイポール磁場を配置し、太陽風との相互作用についての 2 次元グローバルブラソフシュレーションを行い、イオン侵入過程に対する磁気異常の影響について調べた。
イオンのウェイク内への侵入には以下の二通りの過程があることが分かった。磁気異常によって物体昼側にショック構造ができ、このショック構造によってイオンは反射され、ジャイロ運動によって月の裏側に回りこむ。一方、電子の熱速度は太陽風速度に対してはるかに大きいために、電子はウェイク内に侵入できる。これにより月の夜側表面では負の電荷を帯び、物体方向へ電場が生じる。この電場と IMF によってExBドリフトによる磁気対流が生じ、ジャイロ運動とは反対方向からウェイク内へイオンが侵入する。
Keywords: Vlasov, Global simulation, magnetic anomaly, full-kinetic