Multi-step Boris integrator for Lorentz-force equation

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The Buneman-Boris scheme solves the Coulomb-Lorentz force equation by separating it into the acceleration by the Coulomb (electric) force and the rotation by the Lorentz (magnetic) force. The Boris integrator (push) is widely used for solving the Lorentz force equation with the second-order accuracy via two-step computation of the cross product between a velocity vector and a magnetic field vector. However, the Boris integrator itself has a larger numerical error in its gyration angle for a larger time step. The purpose of this study is to decrease the numerical error of the Boris integrator by increasing the number of steps.

経路積分を使った相対論的拡散の計算：δ関数のあつかい

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Delta Function in Propertime Path Integral for Relativistic Diffusion:

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There is an infinite speed component in a solution of a simple diffusion equation with the first order time derivative. Infinite speed means violation of causality in relativistic theory, and it is known the solution of such a equation has pthological solutions of growing modes. Propagation with infinite speed can be viewed as propagation from the future to the past by Lorentz transform, and the damping mode becomes growing mode with this time reversal propagation.

When we treat the diffusion process as a Markovian random walk process, the displacement at one time step must be such that Delta x^2/Delta t = finite. Consequantly the velocity must be infintely large in the limit of infinitely small time step, which means causality violation. Markovian random walk yields diffusion equation with first order time derivertive, therefore, causality violation is unavoidable in the first order equations.

To aviod this difficulty, the author proposed a method to use proper time as a parameter of time evolution; the distribution function is defined over a four dimensional Minkowski space. Then the time evolution of sinle particle distribution function can be solved with the method of path integral. The four velocity in the Minkowski space has a constraint coming from the energy shell. To enforce this constraint, we must insert a delta function in each step of path integral. This is similar to the path interal of gauge fields in quantum field theory. It is known there is an ambiguity in the measure of delta function integration, which causes so called Faddeev-Popov ghost in quantum field theroy. There is similar ambiguity in our proplem here, which will be discussed in detail in the presentation.

前回の学会（2017 年度 JpGU）で相対論的拡散の計算に経路積分を使う手法を紹介した。時間に関して一回微分の拡散方程式の解は，速度が無限大の成分をもっていることが知られているが，相対論の領域ではこれは因果律をやぶることになる。この結果拡散の速度が光速にくらべて無視できない状況になると，物理的にはありえない増大するモードがあらわれるなど，矛盾が生じる。

速度無限大の成分がでてくるのは，マルコフ的酔歩問題では不可避である。これは N ステップの移動距離が，一ステップの距離の$\sqrt{N}$のオーダーでしか増えないため，有限時間で有限の移動距離を確保するためには，一ステップで無限大移動しなければならないからである。したがって，マルコフ的（時間に対して一回微分）な方程式では因果律をやぶることは避けられない。

この問題を克服するため，Israel & Stewart (1970) は時間に関して二階微分の項を含む理論を提唱した。この路線はその後因果的熱力学（Causal Thermodynamics）と呼ばれ，21 世紀に入ってからも多くの論文が書かれている。しかしながら，この手法は無限大の速度をおさえるために技術的に導入されたものであるため，得られた解が物理過程を正しく記述している保証はない。たとえば，Israel & Stewart の手法で熱伝導方程式を導出すると，いわゆる電信型の方程式になり，伝搬速度が大きくなると波動方程式に漸近して速度の上限を保証するが，波動方程式が散逸をあらわしているとは言えない。

前回の学会で発表した手法は，固有時間による経路積分を使い，因果律をやぶらないように拡散を計算するというものであった。固有時間にそっての Minkowski 空間内を移動は 4 元運動量が energy shell の条件を満たしていなくてはならないという制約がある。そこでこの研究では各ステップにδ関数をはさんでこの条件をみたすという手法をつかった。経路積分にこのようなδ関数を導入すると，それを積分する測度の任意性の問題が生じる。これはゲージ場の経路積分で Faddeev-Popov のゴーストと呼ばれる問題である。発表では，この任意性を相対論的拡散の場合はどうあつかうべきかについて論じる。

銀河中心部デカメータ電波パルスの到来方向とそのバイナリー・ブラックホール起源の確認

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Confirmations of Source Direction of the Decameter Radio Wave Pulses from the Binary Black Hole at the Center of Our Galaxy

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1. Introduction The present studies start with observations of the decameter radio wave pulses using Decameter Radio Wave Long Baseline Interferometer, at Tohoku University (DWLBI), which has been improved to have digital data acquisition system since June 2016. After detailed investigations, mainly based on the FFT analyses, the previous results of the current studied on the quest for existence of the black hole binary deduced from the observed decameter radio wave pulses have been largely improved.

2. Observations The observations of the present studies have been made from June 5 to June 30, in 2016 using DWLBI whose data acquisition system improved to digital data sampling method. The Interferometer system consists of three stations at Yoneyama, Zao, and Kawatabi that provide baselines with lengths from 44km to 83km; the detected decameter radio waves at 21.86MHz are converted down to signals, centered around 1kHz with bandwidth of 800Hz, that are transmitted through telemeter channel to main station at Tohoku University at Sendai

3. FFT Analyses For the obtained digital data from each observation station of the

interferometer system, interferometry correlation functions were calculated by digital computer to find interferometry fringe function to which the template fringe to detect the arrival directions of the signal were applied. To these direction correlated data, FFT analyses are carried out so as to pick up the source signals of a few percent level compared with large background noises by averaging 6000 times trial of independent FFT operations.

4, Problem of Generation of Time Varying Data Caused by Fringe Function of Noise Because the time varying data is generated from the detected noise signals associated with the function of interferometer where the data between partner stations are multiplied , the results of FFT analyses include the spectrum components of these noise-fringe origin. To eliminate these artificial disturbance components the observation data of sky noises, without the signals from Galaxy center, to which we have applied the fringe function to search for the direction of Galaxy center, .have been observed.

5. Elimination of Ionosphere Effects For the case of low elevation angle, the ray paths of the decameter radio waves at 21.86 MHz are largely affected by the ionosphere. To resolve the difficulty the method of virtual vacuum setting of the interferometer system is applied; that is, virtual position of interferometer system is set at the position ,in quasi vacuum space, along the average ray paths, where we can search the radio wave source as if there is no ionosphere. The relation between the virtual interferometer and the real interferometer system is related with phase differences, due to the propagation through the ionosphere, that can be eliminated in the present method of fringe correlation.

6. Conclusion Results of FFT analyses have definitely indicated that the purposing spectra are arriving from the center part of our Galaxy with allowance angle range of + - 0.2 degree. The resulted spectra are characterized by two fundamental periods at 178 and 154 sec corresponding respectively to Gaa and Gab. It is verified that current results proposed before 2016 should be corrected; that is, principal BH bodies should be the black hole binary which consists of Gaa and Gab contrary to the previous proposal of 5 sets of black hole binaries. The present results show that the mass of Gaa is 1.86 million solar mass and the mass of Gab is 1.61 million solar mass.

１．序　本研究では主として、東北大学デカメータ電波長距離干渉計システムを用い、我銀河系中心部のデカメータ電波パルス観測を実施してきていて、2016 年からシステムを新たにデジタル方式干渉計へと改良し本格的観測に入り、周期 20sec 以上のパルス電波源と対応する巨大ブラックホール群について精査した。その結果 2010 年以前の提言は大幅に修正されることとなった

2. 観測　　今回、長距離基線デカメータ電波干渉計観測は、2016 年 6 月 5 日から 30 日にわたる銀河中心部の直接観測期間と 2016 年 12 月 05 日から 2017 年 2 月 20 日の銀河中心部の出現しない時期の観測を対比する形で実施した。干渉計の観測点は Yoneyama, Zao、および Kawatabi の 3 局よりなり、最長 83km, 最短 44km の 3 基線が設定されるが、21.860MHz にて全帯域幅 1kH で観測された受信信号は仙台局にテレメータ伝送される。各信号は 900Hz, 1000Hz および 1100Hz において帯域幅 100Hz の狭帯域信号に分割され、各々サンプリングレート 3　 kHz で AD 変換された後干渉データとして処理される。

3.　方位決定におけるフリンジ周期変動の混入問題　　　干渉計による電波の到来方位決定の際、干渉計の各観測局に設置したシステムの絶対位相の校正が困難な状況下で、方位決定する方式としてフリンジ相関法をとった。すなわち、干渉計処理後のデータは到来方位決定のため方位検出用テンプレート・フリンジと相関を取ったのち、パルス周期探索のための FFT 解析を実施する。しかし、この場合、結果に地球回転効果として表れるフリンジの周期が混入するという

重要な障害が明らかとなった。そこで、銀河中心部の出現しない時点での干渉計処理データに銀河中心部の方位探索と同一のテンプレート・フリンジを作用させ、その FFT 結果をレファレンスとし、銀河中心部観測データの干渉計処理信号に対する FFT 結果から差し引く方式をとった。これにより方位決定のため混入してくるフリンジ変動分を除去することが可能となった。

4. 電離層効果の除去　　　21.86 MHz の電波に対する電離層効果は比較的大きく電波源仰角 20 度以下では夜間 F1 層の厚い場合電波の到来方向は 10 度を越して偏向する。従って電離層密度分布を知って Ray Trace を行う等の正攻法では、夜間 F1 層構造の決定精度の限界から、対処不可能と結論され、脱電離層の手法をとった。それは一定の期間の平均電離層で得られる Ray Path にそって電離層の影響のないところまで、干渉計システムの位置を移動させ、ここで真空空間として、電波源方位決定法を適用するもので、この移動させたシステムと実際地上で観測しているシステムとの間の電離層伝搬による位相差を未定位相として消去する方式をとった。

5　FFT 解析結果とシミュレーションによる源パルス波形の導出　　　FFT 解析により方位決定と同時に周期 10sec から 8200sec にわたり、背景雑音の 1/1000 から 1/100 のパルス成分を抽出している。解析結果から対象とするパルス群は銀河系中心部の出現と明確に対応し+ - 0.2 度の精度で我が銀河系中心に源を持つことが確証された。パルス群を示すスペクトルは基底スペクトルの中心が Gaa に対する 178 sec と Gab に対する 154 sec にあり、それぞれ第 4 高調波まで展開していて,

それぞれに 2200sec の周期変調（周波数変調）があり、中心スペクトルの上下にそれぞれ (1/2200) Hz の周波数変調を反映する３～５個の側帯波スペクトルの存在を示して、Gaa と Gab は互いに 2200sec で公転するバイナリーを構成していると示唆される。ここで、本研究では、円軌道を仮定し速度を探査しつつ Gaa および Gab は同レベルの仮定のもと、それぞれの基底スピン周期から、第２、第３、第 4 高調波に至る正弦波群からなり、軌道運動に基づく視線方向の Doppler 効果を考慮したのパルス電波を放射に対するシミュレーション関数に対し FFT 解析を試みた。シミュレーション関数と観測データにたいする FFT 解析結果は良く一致するシミュレーション関数のパラメターがえられた。

6. 結論　　　従来５組以上の存在を言及してきた巨大ブラックホール・バイナリ—のうち最大級の 1 対のみが明確に存在し、その他は中間質量ブラックホールが存在は否定できないという結果と大幅な修正となった。得られたパラメータに Kepler—Brahe の法則を適用すると Gaa, および Gab の公転速度が 0.17c および 0.196c の場合質量はそれぞれ 186 万および 161 万太陽質量となる。

太陽風プラズマ中の見かけの温度の熱力学的性質: ポリトロープモデル

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Thermodynamic property of the apparent temperature in the solar wind plasma: A polytropic model

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It is well known that large amplitude fluctuations exist in the solar wind plasma. The fluctuations have the broadband spectra and often have time period longer than several hours. Magnetohydrodynamic (MHD) systems are widely used to describe the global phenomena in the solar wind plasma. There is no doubt that MHD systems play an important role in solar wind plasma physics, while the systems usually need the cut-off scale (coarse-graining scale) larger than typical ion scales such as the ion inertial length and the ion gyro-radius. It is noteworthy that finite amplitude fluctuations with the wave length smaller than coarse-graining scales often exist. It is believed that these fluctuations heat plasmas and produce thermally non-equilibrium components. In other words, it is not trivial whether energy of the fluctuations is negligible at the coarse-graining scale or not.

In this presentation, a thermodynamic property of the energy of coarse-graining scale fluctuations (apparent temperature) is discussed. We firstly discuss the specific heat ratio of the apparent temperature and the specific heat of systems using the Wentzel-Kramers-Brillouin (WKB) approximation. Then, a physical interpretation of the polytropic indices, which are often used in the solar wind MHD model, is presented.

3次元大域的ＭＨＤシミュレーションにおけるコヒーレントな渦力学と乱流構造

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Coherent Vortex Dynamics and Turbulent Structures in Magnetosphere in 3D Global MHD Simulation-Hairpin and Horseshoe Vortices

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The Kelvin-Helmholtz instability and its vortices generated by the velocity shears have long been considered to be a key to understand the mass, momentum, and energy transfers from the solar wind to the magnetosphere. However, the large Reynolds number of the magnetosphere also suggests that these vortices may be shed-off from the magnetopause boundary sooner or later, and become to be free vortices and align to be the so-called Karman Vortex Street. These Karman vortices sooner or later will breakdown (vortex-breakdown) and, thus, the flow becomes to be turbulent by a nonlinear process. At the same time, these free vortices that are the transverse vortices disappears and the new stream-wise or longitudinal vortices are gradually formed. These stream-wise vortices survive for a long time that is much longer than the periods of vortex rotations and constitute to the coherent structure that recently considered playing an important role in mixing the masses, momentum, energies between the solar wind and the magnetosphere. In the present report, we show these magnetospheric coherent vortex structures and dynamics using 3D large-scale global MHD simulations. These vortices should be able to be observed and identified in the tetrahedrally-configured satellite systems like MMS.

一様抵抗プラズモイド不安定性の MHD 数値研究

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Numerical MHD study for Plasmoid Instability in Uniform Resistivity

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The plasmoid instability (PI) caused in uniform resistivity is numerically studied with a MHD HLLD numerical code. It is shown that the PI observed in numerical studies may often include numerical tearing instability caused by the numerical dissipations. The reconnection rate observed in the numerical tearing instability can be higher than that of the physical tearing instability. In addition, the tearing instability can be classified into symmetric and asymmetric tearing instability. The symmetric tearing instability tends to occur when the thinning of current sheet isstopped by the physical or numerical dissipations, often resulting in the drastic changes of the magnetic field topology in the plasmoid chain. Hence, to correctly explore PI, the numerical and symmteric tearing instability must be rigorously eliminated. In this paper, we could not specify the critical Lundquist number Sc beyond which PI is fully developed. It suggests that Sc dose not exist.

Hall magnetic field structure and plasma dynamics in large-scale magnetic reconnection

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We investigate Hall magnetic field structure and plasma dynamics in large-scale magnetic reconnection. The Hall field is induced by the electrical currents generated by the difference between ion and electron dynamic motions in and around the magnetic diffusion region. The Hall field structure extends away from the diffusion region and stands in the ion reconnection jets and at their boundary layers. Its extending edge propagates as an Alfven wave farther away in the pre-existing plasma sheet boundary layer with the accelerated ions. We discuss the cause-and-effect relationship existing between the Hall magnetic field structures and the plasma dynamics in various conditions of magnetic reconnection.

極域プラズマ観測衛星周辺の非対称電位構造に関する粒子シミュレーション

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Particle Simulations on Near-Spacecraft Electrostatic Structures in Polar Plasma Environment

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This paper reports the international collaborative project on spacecraft-plasma interactions in the Polar Ionospheric environment, which is initiated by Kobe University and University of Oslo. In order to have better understanding of the processes, we utilize the 3-dimensional plasma particle simulations in the project. It is known that asymmetry in near-spacecraft electrostatic environment causes erroneous signals in double-probe electric field measurement data. Such non-natural signals are often referred to as a spurious electric field. In addition to widely-recognized contributions from a spacecraft wake and a photoelectron cloud to such asymmetric environment, our simulations suggest that trajectories of background electrons reflected by a negatively-charged satellite will be guided to a certain direction along a geomagnetic field line. They will be a new source of asymmetric electrostatic field influencing double-probe measurements. We will report preliminary simulation results indicating this effect for a case of the Freja satellite.

神戸大学とノルウェー・オスロ大学の連携により進められている、極域飛翔体ープラズマ相互作用の数値シミュレーション研究活動について報告する。本研究では、衛星プラズマ相互作用の数値解析で実績のある 3 次元のプラズマ粒子シミュレーション手法を活用し、極域飛翔体周辺のプラズマ環境じょう乱の発生メカニズムを解明することを目標とする。科学衛星や観測ロケットで幅広く用いられるダブルプローブ電場計測では、飛翔体から進展した、対を成すプローブ電位の差をとることで飛翔体自体の帯電の影響を除去している。しかし、何らかの理由により、衛星周辺に非対称な電位構造が形成されると、その影響は差動計測では完全に除去されず、不要電場として観測データに混入する。このような非対称電位構造を作る原因として、衛星ウェイクや光電子放出の影響が盛んに議論されてきた。これらの原因に加え、負に帯電した衛星で反射された背景電子が、磁力線方向にガイドされることで、非対称電位構造ひいては不要電場が発生することを示唆する数値結果を得た。Freja 衛星による観測事例を紹介し、計算機シミュレーションによる衛星周辺電位構造の再現とその初期分析結果を報告する。

Effect of the neutral depletion in helicon discharge

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Neutral depletion is a process in which neutral density decreases due to processes other than ionization. In the context of laboratory plasma sources, some experimental and theoretical studies suggest that the neutral depletion plays important roles in determining the plasma transport [1-3] and the maximum plasma density [1,4-6]. The neutral depletion is known to occur when the plasma pressure is comparable to the neutral gas pressure. If this is the case, the neutrals will naturally be cleared away from the region of high plasma pressure so that the net force balance is maintained. At the site of the neutral depletion, the drag force by the neutrals acting on the ions is reduced, letting the ions to escape the plasma readily. The result is an unexpected decrease in the plasma density as the input power is increased. Physical understanding of the neutral depletion may lead to a design of high-density helicon plasma sources not limited by the suppression of the maximum plasma density caused by the neutral depletion.

In our study, we have constructed the self-consistent fluid model to investigate the time evolution of the helicon discharge. Our model includes the wave excitation, the electron heating via collisional dissipation of excited waves, and the diffusion of charged particles. Also, we have included the neutral dynamics in our model and investigated the effect of the neutral depletion in the time evolution of helicon discharge.

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ILE 無衝突衝撃波実験における協同トムソン散乱計測のための数値実験

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Virtual collective Thomson scattering measurement for collisionless shock experiment at ILE

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Recently, collisionless shocks have been successfully reproduced in a laboratory by using high power laser facilities. We have performed the laboratory experiment on collisionless shocks in collaboration with the Institute of Laser Engineering (ILE) at Osaka University. To measure the local plasma quantities in the shock transition region, collective Thomson scattering (CTS) measurement is utilized. The CTS is the elastic scattering of low frequency and long wavelength incident electromagnetic waves by collective oscillations of plasma electrons. The spectrum of the scattered waves enables us to infer the local plasma quantities such as the electron density, electron and ion temperature, the valence of ions, etc, a function of local position along the path of the incident probe laser light. If the plasma is nearly in thermal equilibrium, scattered wave spectrum typically has two double-peaks called electron feature and ion feature. The electron (ion) feature denotes collective electromagnetic waves scattered by Langmuir waves (ion acoustic waves). Because the electron feature is usually too weak to be detected in an equilibrium plasma, we measure only the ion feature and analyze it. The CTS theory in a non-equilibrium plasma has not been established so far. In the foreshock region, a back- streaming plasma is often observed as a beam by which beam instability is easily generated. In such a non-equilibrium plasma near the shock, electron feature may possibly be enhanced by the beam instability and detected in laboratory experiments. Therefore, we have proposed electron feature measurement in the ILE experiment.

In this study we investigate the characteristics of the CTS in a non-equilibrium plasma to detect electron feature at ILE experiment. The CTS in a non-equilibrium plasma is numerically simulated not only to directly make comparison with the experimental results but also to optimize the ILE experimental conditions. First, PIC simulation is performed to reproduce a beam instability occurring in the vicinity of a shock wave. Then, the obtained data of electron density fluctuations is incorporated into the wave equation of scattered waves. In this way, we construct a simulation system of the virtual CTS for multidimensional and realistic parameters in the ILE experiment. Here, we discuss the CTS when the beam velocity is 5 or 10 times the electron thermal velocity. In particular large velocity of the ion beam results in the clear characteristics of higher harmonics in the scattered wave spectrum. In addition, it is found that the probability to detect the electron feature drastically increase by changing geometrical setting of the measurement system. We also report the simulation results for various mass ratios to estimate relative intensity between the ion and electron features.

近年、高強度レーザーを用いて宇宙空間の無衝突衝撃波を実験室に再現できるようになってきた。我々は大阪大学レーザーエネルギー学研究センター（ILE）との共同実験により無衝突衝撃波実験を行っている。実験で再現される衝撃波の遷移層構造を計測するのに、協同トムソン散乱計測を用いている。協同トムソン散乱は自由電子による比較的低周波数（≪ mec^2/h）かつ長波長（＞デバイ長）の光の弾性散乱である。これを計測に利用することで、散乱光の特徴から電子密度、電子およびイオンの温度、イオン価数などの諸量をプローブ光経路に沿った位置の関数として見積もることができる。平衡プラズマの場合、協同トムソン散乱の散乱光スペクトルはイオン音波により散乱されたイオン項とラングミュア波により散乱された電子項の二つのダブルピークが得られることがよく知られている。通常電子項は強度が非常に弱く検出が困難なため、イオン項のみ計測、解析を行う。一方、非平衡プラズマの場合の協同トムソン散乱についてはこれまであまり研究されておらず、その理論的整備は遅れている。無衝突衝撃波の衝撃波上流にはしばしばビームが形成され、ビーム不安定性が起こる。衝撃波近傍の非平衡プラズマではビーム不安定性により電子項が増幅され、検出できる可能性があるため、我々は ILE 実験での電子項計測を提案している。

本研究では、ILE 実験での電子項検出を念頭に置いて、非平衡プラズマにおける協同トムソン散乱の特徴を調べる。最適な ILE 実験条件の検討および ILE 実験結果との直接比較に向けて非平衡プラズマにおける協同トムソン散乱を数値実験により再現する。まず、衝撃波近傍で起こるビーム不安定性を PIC 計算で再現する。その後、PIC 計算により得られた電子密度揺動の時空間データを適宜補間して散乱光の波動方程式に移植し、別途これを解く。このようにして、実パラメータの下で多次元協同トムソン散乱を再現できる数値実験システムを開発した。今回は、電子ビームやイオンビームの速度を電子熱速度の 5 倍、10 倍にした場合の協同トムソン散乱を議論する。多くの場合で、電子項が大きく増幅されることを確認した。とりわけ、イオンビームの場合は速度を大きくすると高調波が現れ、散乱光スペクトルに大きな影響を与えることがわかった。また、計測システムの幾何学的配置を工夫することで、電子項検出の可能性を大きく高められることも示す。イオン項と電子項の強度比較のためイオンと電子の質量比を様々に変えた結果も合わせて報告する。

Intense Electromagnetic Waves Excited in Two-dimensional Relativistic Shocks

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The origin of high energy cosmic rays ($>10^{15.5}$eV) has not been fully understood, and the acceleration mechanism is still controversial. Recently Chen et al. (PRL, 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 ($>10^{18}$eV), based on the wakefield acceleration mechanism which was initially proposed by Tajima and Dowson (PRL, 1979) in the context of laser-plasma interactions in the laboratory. The wakefield acceleration 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 driven by the particles reflected off the shock-compressed magnetic field in relativistic shocks (Hoshino and Arons, PoP, 1991). In fact, Hoshino (ApJ, 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 one-dimensional Particle-In-Cell (PIC) simulation.

The wakefield acceleration has been discussed only in one-dimensional shocks so far. It is not known very well whether or not the same mechanism can operate in more realistic multi-dimensional systems. In multi-dimensional shocks, the inhomogeneity may appear in the transverse direction of the shock, and the waves emitted from different positions at the shock may overlap with each other. Consequently, the wave coherency which is essential for the ponderomotive force may be broken and the wakefield acceleration may not occur. Another possible problem is the competition between the synchrotron maser and Weibel instability. The Weibel instability occurs near the shock front due to effective temperature anisotropy generated by the reflected particles in the shock transition region. Since both the instabilities are excited from the same free energy source, the efficiency of the precursor wave emission may be affected or even completely shut off.

To solve these subjects, we investigated in this study the properties of the precursor wave emission in relativistic shocks by using the two-dimensional PIC simulation. Since the growth rate of the synchrotron maser instability at high harmonics are significantly large, the precursor waves are high-frequency electromagnetic waves and thus may easily be damped. Therefore, our simulations were performed with high spatial resolution to resolve the precursor waves well. We observed that large-amplitude, coherent precursor waves were excited in two-dimensional shocks, and found that the amplitude of the precursor waves was large enough to induce the wakefield acceleration even if the Weibel instability occurs. In addition, the amplitude of the precursor wave remains finite and has reached a quasi-steady state by the end of the simulation. In this presentation, we quantitatively evaluate the efficiency of the precursor wave emission in both one-dimensional and two-dimensional shocks, and then discuss the possibility of the wakefield acceleration model for the production of non-thermal electrons in an astrophysical shock.

Particle simulations of instabilities driven by ring velocity distribution and density gradient

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In this contribution we study generation of electrostatic waves and their conversion to electromagnetic waves in systems where plasma density gradient and ring beam instability are present using 2D-3V electromagnetic code KEMPO2. Ring beam instability is characterized by velocity distribution drift in the direction perpendicular to the external magnetic field. Properties of plasma with such velocity distributions was recently studied [1,2] and it was found that this type of instability can generate strong emission of electrostatic waves in the direction perpendicular to the magnetic field (for example upper hybrid waves or Bernstein modes) [3]. Beside ring beam instability, density gradient can cause gradient drift instability [4]. Electrostatic waves generated by the mentioned instabilities can convert to electromagnetic waves like LO mode, RX mode, or whistler mode chorus emissions. In described system we study the temporal evolution of wave spectra, velocity distributions, Poynting flux, and electric and magnetic energies to identify the wave mode conversion. Such a conversion process might be a source of electromagnetic emissions measured by spaceraft on the plasma-pause density gradient.

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Particle trapping and ponderomotive processes during breaking of ion acoustic waves in plasmas

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The recent fluid simulation revealed that the ponderomotive potentials and ponderomotive frequencies of electrons and ions can be used as proxies to identify the steepening and breaking of the ion acoustic solitary waves (IASWs) in plasma. However, the behavior of these proxies may get modified in the presence of kinetic effects such as particle trapping. In the present study, we performed one-dimensional particle-in-cell (PIC) simulations to examine the effects of the kinetic processes on the behavior of these proxies at the breaking of IASWs in plasma. The electron and ion equilibrium densities were superimposed by long-wavelength Gaussian type perturbation, which initially evolves into two IASW structures. These structures are observed as two phase space vortices due to the trapping of electrons in the ion acoustic (IA) potentials. The IASW structures grow due to the steepening of their trailing edges, and later they break to form a chain of IA phase space vortices. Each of these vortices is associated with bipolar electric field resulting positive potential structure. We estimated the amplitude, width and the phase speed of the IASWs at their breaking process to examine their link with the trapping velocity. In addition, we computed the electron and ion ponderomotive potentials and frequencies from the PIC simulations to verify their applicability in identifying wave breaking limit, under the kinetic regime. The present study shows that the behavior of the ponderomotive potential during the IA wave breaking process is similar to the one which is proposed through fluid simulations. We find that IA wave breaking occurs when the maximum trapping velocity of the electron (Vtrap+Vs) exceeds its thermal velocity. A present simulation study shows that both maximum electron trapping velocity and ponderomotive potential can be used to identify the IA wave breaking processes in plasmas.

MHD乱流中での宇宙線の異常輸送

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Anomalous transport of cosmic rays in MHD turbulence

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The motion of cosmic rays (energetic particles) in the MHD turbulence is complex. Even in the simplest setting of the fossil slab model, in which the turbulence electromagnetic field is given as a superposition of static finite amplitude MHD waves, the cosmic rays can at times be trapped by a large amplitude wave packet and stay there for a long time, or can they make almost ballistic motion without much influenced by the turbulence field. At some large time and spatial scales, their motion may deviate from the classical Brownian motion. If this is the case, the transport of the cosmic rays should be treated using the concept of sub- and super-diffusion for this particular time and the spatial scales.

In our earlier presentations at this conference, we have introduced a natural formalism to model the anomalous transport using the fractional diffusion equation, in which the spatial diffusion term involves a fractional differentiation operator. An essential external parameter in this model is the order of the differentiation, and this has to be determined via inspection of the cosmic ray scattering by a given MHD turbulence field.

In this presentation, we discuss how the properties of the given turbulence are mapped to the statistical properties of motion of the cosmic rays. We will pay particular attention to the influence of the turbulence energy density, turbulence spectrum, and intermittency. By analytic theory and test particle simulations, we will then determine the order of the differentiation of the spatial diffusion term for some realistic turbulence models associated with astrophysical shocks.

磁気流体（ＭＨＤ）乱流中で宇宙線（高エネルギー荷電粒子）は複雑な運動をする。電磁場がＭＨＤ波動の重ね合わせで与えられる簡単な時間定常スラブ乱流の場合でも、宇宙線は波動パケットに捕捉されて長時間を過ごしたり、乱流場の影響をほとんど受けずにバリスティックに運動したりする。ある長い時間・空間スケールで古典的ブラウン運動からのズレが生じる場合、これら宇宙線の集団の輸送を扱う際には準・超拡散の概念を取り入れる必要がある。

これまで本学会にて、このような非ガウス的な統計性質を持つ粒子集団の異常輸送を表現する自然な数理モデルとして、フラクショナル移流拡散方程式を提案した。このモデルの本質的なパラメータとして、空間拡散のフラクショナル微分の階数があるが、これは与えられたＭＨＤ乱流のもとでの宇宙線の散乱によって決める必要がある。

この観点から本講演では、乱流の統計がどのように宇宙線拡散の統計に反映されるかを議論する。特に注目するのは、乱流の総エネルギー密度、スペクトル、間欠性である。解析およびテスト粒子計算により、天体衝撃波近傍に存在し得る典型的なＭＨＤ乱流モデルに対して、宇宙線空間拡散の微分階数の値を決める。

A plasma mixing measure for collisionless magnetic reconnection

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Magnetic reconnection is a fundamental process of (1) change in magnetic topology, (2) energy transport, and (3) plasma mixing. Previous studies have largely focused on the first two aspects, while little attention has been paid to the plasma mixing during magnetic reconnection. In this presentation, partially inspired by a recent diagnosis in geophysical fluid dynamics, we propose a new measure to mark electron mixing sites in the reconnection system. Combining the forward- and backward-time mixing fractions, we introduce a finite-time mixing fraction (FTMF). The FTMF is tested in several cases of symmetric and asymmetric reconnection systems. Surprisingly, if the timestep is appropriately set, the FTMF marks the electron-scale dissipation region very well. For example, it marks the magnetospheric side of the X line in asymmetric reconnection, in agreement with the site of the nonideal energy dissipation. The mixing site is loosely related to the nonideal energy dissipation, which is a driver term of the single-fluid entropy. Implications of these results, current technical issues, and future prospects will be discussed.

非対称リコネクションにおける拡散領域と接触不連続面の磁気流体数値計算

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Diffusion region and contact discontinuity in asymmetric reconnection

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Asymmetric reconnection is not rare phenomena in space plasma, rather frequent phenomena compared with symmetric ones. The separation of the x-point and the s-point in the diffusion region and the entering the contact discontinuity into the low beta side in the asymmetric reconnection have been reported in the previous studies [Nitta et al., 2016]. In this study, the results of the fine MHD simulation about the asymmetric reconnection with different asymmetries are reported.

宇宙プラズマにおいて、非対称な磁場環境における磁気リコネクションは珍しい現象ではなく、むしろ対称磁気リコネクションより頻繁である。非対称磁気リコネクションに関する先行研究では、拡散領域内での X 点と S 点の分離、接触不連続面の低 β プラズマ領域側への浸入が報告されている。本研究では、これらの現象の非対称度依存性などを高解像度の磁気流体計算により詳細に調べた結果を報告する。

高強度レーザー実験における磁化プラズマの協同トムソン散乱の数値実験

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Numerical simulation of collective Thomson scattering in a magnetized plasma in high power laser experiment

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We have been performing collisionless shock experiments in collaboration with the Institute of Laser Engineering at Osaka University. To measure microstructures of the shock transition region, collective Thomson scattering (CTS) measurement has been utilized. The CTS is the scattering of an incident electromagnetic wave through the interaction with collective density fluctuations of plasma electrons. We can estimate local plasma quantities along the path of the incident wave by analyzing the spectrum of the scattered waves. However, theory of the CTS in a magnetized non-equilibrium plasma is not established. Since we plan to perform experiments of collisionless magnetized shocks, we need to construct the theory of the CTS in such a plasma.

Here, we investigate the characteristics of the spectrum of the CTS in a magnetized equilibrium and non-equilibrium plasmas by using one-dimensional full particle-in-cell (PIC) simulation with periodic boundary conditions. We can reproduce the CTS by putting a monochromatic electromagnetic wave as a proxy of the incident wave into the simulation system. It is assumed that all the waves (the incident wave, scattered waves, and plasma waves) propagate perpendicular to the ambient magnetic field. First, the CTS in an equilibrium plasma is reproduced. We found that the scattered wave spectrum shows quite different characteristics from that in an unmagnetized plasma. Electron cyclotron harmonics leads to a number of peaks in the CTS spectrum. In the shock transition region a cross field ion beam is often observed and it strongly amplifies the electron cyclotron harmonics. We will report the characteristics of the scattered wave spectrum in such a case.

我々は、大阪大学レーザーエネルギー学研究センターとの共同研究により、無衝突衝撃波の実験的研究に参画している。衝撃波遷移層におけるプラズマミクロ構造の計測に、協同トムソン散乱計測が用いられる。これは、プラズマ中の電子密度揺動による光の散乱を利用して、散乱光の特徴からプラズマの諸量を推定する計測法である。実験ではこれまで、技術的な理由から外部磁場を印加してこなかったが、今後磁場を印加した実験を想定しているため、磁化プラズマ中の協同トムソン散乱理論の整備が急務となってきた。

ここでは、磁化プラズマ中の協同トムソン散乱による散乱光のスペクトル特性について、1 次元 PIC シミュレーションを用いて研究する。まず、熱平衡状態の磁化プラズマ中に、プローブ光を模した単色の電磁波を磁力線垂直方向に入射して、協同トムソン散乱を自己無撞着に再現した。非磁化プラズマによる協同トムソン散乱では、ラングミュア波による散乱光とイオン音波による散乱光が現れることが知られている。磁化プラズマでは、電子サイクロトロン高調波が励起されるので、これによる散乱光が新たに確認できた。衝撃波遷移層では、磁力線を横切る方向のイオンビームがしばしば存在し、これが不安定性によって電子サイクロトロン高調波を大きく増幅させることが知られている。発表では、この場合に得られる散乱光スペクトルの特性について詳しく報告する。

高マッハ数衝撃波の３次元 PIC シミュレーション：電子加速効率のパラメタ依存性

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3D PIC simulations of high-Mach-number shocks: Parameter dependence of the electron acceleration efficiency

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The diffusive shock acceleration (DSA) theory has provided a solution to observational evidences for efficient accelerations at collision-less shocks, as it predicts a power-law energy spectrum of particles having a spectral index that is close to the values suggested by multi-wavelength observations. As the DSA theory presumes pre-existing mildly energetic particles, pre-acceleration mechanisms are required to provide a seed population for DSA, particularly for electrons. The connection between pre-acceleration and DSA remains a critical issue in shock acceleration theory.

In order to deal with electron acceleration mechanisms in a self-consistent system, we examined 3D PIC simulations of a quasi-perpendicular, high-Mach-number shock. We successfully followed a long-term evolution, in which we found two different acceleration mechanisms coexist in the 3D strong shock structure. The Buneman instability was strongly excited ahead of the shock front in the same manner as have been found in 2D simulations. The shock surfing acceleration was found to be very effective in the present 3D system. In the transition region, the ion-beam Weibel instability generated strong magnetic turbulence in 3D space. Energetic electrons, which initially experienced the surfing acceleration, underwent the shock drift acceleration while being scattered by interacting with the turbulent fields. This pitch-angle scattering allowed the energetic particles stay in the upstream regions much longer than classical estimates from the adiabatic theory.

In this presentation, we discuss the 3D simulation is essentially important for the effective non-thermal electron acceleration by comparing with 2D simulations under the same upstream conditions: The in-plane upstream magnetic field case, in which the Buneman mode was weakly destabilized, resulted a faint heating in the turbulent area. On the other hand, the efficient SSA was realized in the out-of-plane case. The surfing-accelerated electrons, however, cannot undergo the subsequent stochastic SDA because of the weak turbulence level, which is due to limited growth of the ion Weibel instability in the 2D out-of-plane upstream magnetic field condition. We also discuss with 3D simulation runs under different upstream magnetic field obliquity. We found that super-luminal cases resulted limited acceleration efficiency as previously reported for magnetized relativistic shocks.

モンテカルロ法による衝撃波遷移層での非熱的電子加速のモデリング

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Monte-Carlo modeling of nonthermal electron acceleration within the shock transition region

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The acceleration of non-thermal particles is one of the most important problems in space physics and astrophysics. Galactic cosmic rays with energies below 10^{15}eV are believed to be accelerated by the 1st order Fermi acceleration at supernova remnant (SNR) shocks as it naturally reproduces a power law energy spectrum roughly consistent with observations. However, it is well known that the Fermi acceleration is not efficient for non-relativistic electrons. Non-thermal radio and X-ray synchrotron emissions from relativistic electrons at SNR shocks imply that there exists a pre-acceleration mechanism that injects sub-relativistic electrons to the 1st order Fermi acceleration. This is called the injection problem and has been one of the unresolved issues in the shock acceleration theory.

One of the important electron acceleration mechanisms is the shock drift acceleration (SDA) [Wu 1984, Leroy and Mangeney 1984]. SDA occurs when an electron interacts with the shock transition region in an adiabatic manner. During the interaction, the electron travels anti-parallel to the motional electric field due to the gradient-B drift and thus gains energy. However, it is well known that the SDA alone cannot reproduce a power-law type spectrum and also the acceleration efficiency is not necessarily sufficient to explain observations of energetic electrons at the bow shock.

We here propose a new acceleration mechanism that takes into account the effect of pitch-angle scattering via wave-particle interaction during the course of SDA. This means that we essentially abandon the adiabatic approximation and introduce the stochasticity into the acceleration process. To simplify the analysis, we employ a box model in which only the dependence on the energy and pitch-angle of the distribution function is considered. We use the Monte-Carlo method for modeling the pitch-angle scattering. The Monte-Carlo simulations have been performed to investigate the dependence on model parameters such as Mach numbers, shock angles, and pitch-angle scattering coefficients. We find that, for a limiting case where an analytic estimate on the accelerated particle spectra is possible, the simulation results agree with the theoretical prediction. Based on the simulation results, we discuss the properties of the proposed acceleration mechanism in this report.

非熱的粒子の加速は、宇宙空間物理学や天体物理学における重要な問題の一つである。エネルギーが 10^{15}eV 以下の銀河宇宙線については、超新星残骸における Fermi 加速によって生成されていると広く信じられている。実際、この加速過程は、観測で得られるべき型のエネルギースペクトルを自然に再現することができる。しかし、Fermi 加速は非相対論的な電子に関しては非効率であることが分かっている。しかし、超新星残骸における非熱的電子からの電波や X 線領域でのシンクロトロン放射の観測結果から、Fermi 加速の起こる相対論的なエネルギーまで非相対論的な電子を加速する過程が存在することが示唆されている。この過程についてはよくわかっておらず注入問題と呼ばれている。

この問題を考えるうえで重要とされている加速過程の一つに衝撃波ドリフト加速 (SDA) [Wu 1984, Leroy and Mangeney 1984] がある。この加速過程は電子の運動が断熱的な場合に、衝撃波遷移層と電子の相互作用によって起こる過程である。電子は衝撃波の遷移層中で、磁場勾配ドリフトによって対流電場方向に運動することで加速される。しかし、SDA 単独ではべき型のスペクトルや、地球バウ・ショックで観測されているような加速効率を再現できないという問題があった。

本研究では、新しい加速機構として、SDA の途中で波動粒子相互作用によるピッチ角散乱を取り入れた統計的な加速機構を考える。ここでは簡単のために、電子分布関数のエネルギーとピッチ角依存性のみを考慮したボックス・モデルを考えた。さらに、解析関数で表されたピッチ角散乱係数を仮定し、モンテカルロ法を用いて電子分布関数を計算した。これを行うことで、電子のエネルギー分布やピッチ角分布のパラメーター (衝撃波のマッハ数、磁場配位、ピッチ角散乱係数) 依存性を調べた。その結果、解析的な計算が可能な条件では、シミュレーション結果が理論と一致した。本発表では、シミュレーション結果を基にこの加速機構の性質について議論する。

磁気流体乱流中における宇宙線の異常輸送のテスト粒子シミュレーション

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Test particle simulation of Anomalous cosmic ray transport in MHD turbulence

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Diffusion of particles in general is often described as a classical diffusion, in which individual particles undergo the well-known Brownian motion, and the pdf (probability distribution function) of particles evolves according to the classical diffusion equation. Some examples are the motion of pollens in the air, a drop of ink in water, and the motion of a crowd of people in an open space. On the other hand, cosmic rays (energetic charged particles) can behave quite differently as they are scattered by MHD (magnetohydrodynamic) turbulence in space plasma. These particles may sometimes be trapped for a long time by large amplitude MHD wave packets, or they may travel long distance without much changing its velocity and traveling direction when the turbulence is weak. Given a distribution of the MHD turbulence, a typical cosmic ray trajectory may consist of multiple events consisting of trapping and ballistic motions (walk-stick model).

From this perspective, we study the nature of cosmic ray diffusion in the MHD turbulence, in particular, how the macroscopic parameters that describe the turbulence, such as the total energy and the power-law index, are related to the statistical properties of the cosmic ray diffusion. In this poster presentation, we show (1) diffusion of particles within the framework of the walk-stick model, and (2) diffusion of cosmic rays in a given turbulent MHD field.

First we consider the walk-stick model, in which the particles are assumed to alternate walk (velocity v=1 or -1) and stick (v=0) in the one-dimensional space. The time interval for the walk and the stick events (t_{walk} and t_{stick}) are determined by respective probability distribution functions. If we use the normal distribution function to determine t_{walk} and t_{stick}, we obtain the Brownian motion time series. Instead, if we use the power-law distribution (with the power-law index mu and nu for the walk and the stick events, respectively), we can generate the so-called Levy walk time series. For an ensemble of particles we define the diffusion coefficient D(tau) = <delta x^2 >/ tau, where delta x is the traveling distance within time scale, tau. When D(tau) ~tau^{-gamma}, we have normal diffusion (gamma=0), sub-diffusion (-1 <gamma <0), and super-diffusion (0 <gamma <-1).

Then we consider a physical model in which cosmic rays travel in a given MHD turbulence. The turbulence is generated by superposition of many monochromatic MHD waves. The wave amplitude is given so that the wave power spectrum obeys the power-law with a given power-law index, i.e., A=epsilon$*k^{-alpha}$. The wave phases are assumed to be random. Cosmic ray equation of motion is numerically time integrated by Buneman-Boris method. By evaluating ensemble average of cosmic rays we compute the time scale dependent diffusion coefficient. When tau <10^3, D is almost proportional to tau, implying that the cosmic rays are making ballistic motion when the time scale is less than the mirror-reflection time scale. Beyond this time scale, there appear regimes with normal and anomalous diffusion with different characters. Details of the computations will be explained in the presentation.

多くの場合、粒子拡散現象は、個々の粒子はブラウン運動を行い、粒子の集合である確率分布関数の時間発展は古典拡散方程式にしたがって記述される。一方で宇宙線（高エネルギー荷電粒子）の磁気流体乱流中の拡散は、これとは質的に異なる可能性がある。たとえば、大振幅波動に粒子が閉じ込められたり、また乱流の影響が小さい領域では長時間速度がほとんど変化せずに運動を続けたりするからである。このような停滞と歩行との繰り返しによる粒子運動モデル (walk-stick model) を用いて、宇宙線の輸送を考えることができる。

本研究の目的は、磁気流体乱流中における宇宙線の拡散について理解を深めることであり、特に乱流エネルギーやベキ則で与えた乱流スペクトルのベキ指数のような巨視的パラメータが、宇宙線輸送の統計にどのような関係を持つかを調べることである。本発表では、(1) walk-stick model による粒子の拡散、(2) 磁気流体乱流中の宇宙線の拡散の２点について、テスト粒子シミュレーションを行った結果を述べる。

まず初めに、１次元方向に walk (v=1 or -1) と stick (v=0) を繰り返す粒子のモデル (walk-stick model) を考える。それぞれの時間 (t_{walk}, t_{stick}) を対応した確率分布関数から決定する。一般的な粒子の拡散であるブラウン運動の場合は、ガウス分布より t_{walk} と t_{stick} を求め、宇宙線の拡散のモデルとなる levy-walk の場合は、t_{walk} を P ~$x^{-\mu}$、t_{stick} を P ~$x^{-\nu}$ としたベキ乗分布を用いて決定する。また、粒子の統計を議論するために、時間スケール τ を用いた拡散係数 D(τ) = ＜ Δx^2 ＞ / τ を導入する。ここで Δ x は時間スケール τ における粒子の移動距離である。拡散係数を D(τ) ~ $\tau^{-\gamma}$ で表したときの γ の値によってそれぞれの拡散は、通常拡散（normal diffusion、γ =0）, 準拡散（sub-diffusion, -1 ＜ γ ＜ 0）, 超拡散（super-diffusion, 0 ＜ γ ＜ 1）となる。

次に、磁気流体乱流中の宇宙線の運動を考える。乱流は多数の波動関数の重ね合わせによって生成し、単一波の振幅と波数は A= $\varepsilon * k^{-\alpha}$ により与える。位相はランダムとする。Buneman-Boris 法により宇宙線の軌道を計算し、粒子のアンサンブル平均を評価することにより、拡散係数の時間スケール依存性を評価する。ミラー反射時間よりも短い時間スケールでは、拡散係数はほぼ τ に比例し、運動はほぼ ballistic であることがわかるが、これよりも長い時間スケールの領域において、通常拡散、異常拡散の領域が現れる。計算法の詳細および計算結果について、ポスターにて発表する。

Kinetic temperature anisotropy instabilities in inhomogeneous collisionless plasmas

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It is well known that the temperature anisotropy is ubiquitous in collisionless space plasmas. As the particles tend to conserve their first and second adiabatic invariants, a finite temperature anisotropy is naturally generated, for instance, when a plasma flow exists in an inhomogeneous magnetic field. Once the anisotropy grows over a threshold, the system becomes unstable against kinetic instabilities, which then tend to reduce the anisotropy to a marginal stability condition. This makes the evolution of the system closer to the magnetohydrodynamics (MHD) description. Therefore, understanding of temperature anisotropy instabilities is the key for macroscopic modeling of collisionless plasma dynamics.

In the Earth's magnetosphere, the earthward plasma convection from the plasma sheet easily generates a perpendicular anisotropy with the temperature perpendicular to the magnetic field larger than the parallel. In this case, both the electromagnetic-ion-cyclotron (EMIC) instability and the mirror instability may become unstable. Although a lot of theoretical and numerical studies have been reported for these instabilities, most of them treated instabilities in a homogeneous plasma. In application to magnetospheric physics, however, the inhomogeneity of the ambient magnetic field should be important. In addition, in the magnetosphere there often exists a cold plasma population. Such a cold plasma may be negligible in terms of the plasma pressure, whereas it can be dominant in terms of the mass density. The cold plasma density may also have a spatially inhomogeneous distribution. It changes the dispersion relation and thus may have a non-negligible impact on the instability properties. Finally, the distribution of the hot plasma population may also be inhomogeneous. It is well known that the mirror instability in spatially inhomogeneous plasmas acquires a finite real frequency due to diamagnetic drift and is called the drift-mirror instability. Nevertheless, nonlinear properties of this instability and also competition between the EMIC mode have poorly been understood.

In this report, we discuss how the inhomogeneity affects the kinetic instabilities driven by a perpendicular anisotropy. We use a generalized quasi-neutral plasma hybrid simulation model, in which the effect of cold plasma population is taken into account. In this model, the cold plasma dynamics is essentially determined by the MHD equations. The hot plasma population driving the temperature anisotropy instabilities is solved by the Particle-in-Cell (PIC) scheme. The effect of the hot, kinetic species is correctly taken into account in a self-consistent manner.

We discuss both two- and three-dimensional (2D and 3D) nonlinear simulations with spatially inhomogeneous initial conditions with and without a cold plasma population. In particular, how the competition between the EMIC and mirror instabilities is affected by the initial inhomogeneity will be discussed. The results will also be compared with simulations with the homogeneous system.

Parameter tuning of a 5th order Conservative and Non-oscillatory Scheme for Vlasov simulations

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In Vlasov simulations, we treat the distribution function in a position-velocity phase space, resulting in strongly reduced numerical noise. One of the most powerful tools to numerically integrate the distribution function in time is a conservative and non-oscillatory scheme. Here, the limiter function in the scheme has several parameters controlling gradient in the numerical interpolation. The appropriately selected parameter set can suppress both numerical diffusion and oscillations of the profile.Our aim is to construct a conservative and non-oscillatory scheme to sufficiently suppress diffusion using a controlling parameter set and raising the scheme-order much higher. At present, a 5th order conservative and non-oscillatory scheme is proposed, but appropriate parameter set is unknown.So far, we have performed Vlasov simulations of a simple model using a 3rd order conservative and non-oscillatory scheme.As a result, the parameter set affects in the physics of Vlasov simulations.

In this study, we calculated numerical flux varying some parameters at the four points of a Gaussian test profile with the 5th order scheme.To minimize the error between the numerical and analytical solution leads to the construction of the better parameter sets.In particular, we found the parameter sets are sensitive to the error at the tail of the Gaussian profile.By understanding the condition of parameters to be set, we can tune them in the limiter function.